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South African Research Infrastructure Roadmap

Research Infrastructure (RI) proposal

South African Polar Research Infrastructure (SAPRI)

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Contents

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

The Southern Hemisphere polar region is a system of interconnected physical and ecological components comprising the Antarctic continent, sub-Antarctic islands, the Southern Ocean and the deep ocean basins surrounding South Africa, along with the overlying atmosphere and the opportunities to observe the universe from this largely uninhabited location. The human dimension gives structure to the research investigation, because Antarctica and the surrounding region outside the countries' exclusive economic zones are regulated by treaties engraved in the principle of science for society. The Antarctic region is hence climatically, ecologically and socio-economically linked to South Africa, and the vast range of disciplines require a holistic approach. The proposed establishment of the South African Polar Research Infrastructure (SAPRI) will ensure coordination of South African marine and Antarctic research as a national *Big Science* programme, providing seamless access to existing and new research infrastructure required to develop and enhance long-term observations of South Africa's polar region.

The SAPRI is designed as a consortium hosted at the South African Environmental Observation Network (SAEON), which has proven experience in managing infrastructures and will fast-track its set up and operations. The ultimate objective of SAPRI is to enable balanced research growth across the polar disciplines, and to maintain and further expand the world-class long-term observational datasets already established. In addition, SAPRI will transform the access to, and perception of, the South African polar regions for technicians, engineers, scientists of all disciplines, learners and students, government, private business and civil society. The establishment of SAPRI will elevate South Africa into a central role within the Antarctic space, with the produced science and international standing directly benefiting the governmental strategies for Antarctica and the sub-Antarctic islands. As the only African player in the polar regions, South Africa will further accelerate the implementation of the pan-African Science, Technology and Innovation agenda, thus achieving the main imperatives of the National System of Innovation.

Impact

The SAPRI founding principle is to ensure that the investment in research infrastructures translates into the generation of science for the benefit of society, retention of capacity and international recognition of expertise. South Africa has a comparative geographical and historical advantage to study the Antarctic region and the polar sciences. As one of the first signatories of the Antarctic Treaty, and through the existence of the South African National Antarctic Programme (SANAP) overseen by the governmental departments DSI and DEFF, which manages one of the world's leading ice breaker research vessels, the country has established itself as a major international player. To build on this and ensure sustainability, the SAPRI represents a strategic step change in the coordination of national infrastructure for the polar sciences, which is based on a redesign of the SANAP structure within DSI according to the principles of economy of scale along with transparent institutional agreements between the SAPRI and its consortium partners. The proposed RI is conceived to improve coherence and budget coordination across the SANAP stakeholders and beyond, as well as international programmes, which is expected to ultimately enable a more favourable environment for innovation, research and development of human capacity in an area that is not traditionally represented by Africa.

Through SAPRI, government and the research community will join forces to: (1) contribute to the national obligations in terms of treaties, international agreements and scientific bodies, by means of sustained long-term observations and a single entry-point for expert consultations; (2) grow the scientific understanding of the incredibly large region of ocean and territories surrounding Southern Africa, through a substantial increase of research outputs and training capacity, and the establishment of physical and digital infrastructures to simulate the polar environment in Africa and increase the diversity of contributions; (3) improve the relationship between polar science and society, by showing the relevance of scientific and operational activities in this region through the Antarctic Legacy and the use of advanced digital technology; (4) unleash the innovation and commercial potential linked to developing instruments and services for operating in extreme and remote environments, such as the design of new sensors, polar vessels and the development of services from digital twin models.

Polar research is built on infrastructures of various sizes, which result from several investment cycles and are custodied by different players. SAPRI will maximize the return on investment by subscribing to the main principle of Antarctic expeditions, thus ensuring that several valuable platforms are exploited at the same time for operational and scientific needs, from large facilities such as ships and field bases, to medium facilities such as land-based laboratories, ship-based container laboratories and supply vehicles, down to individual field gear. The establishment of SAPRI will hence create one of the main pillars for the transition towards a polar institute that would eventually combine the logistics with the strategic scientific agenda.

Scientific excellence

The scientific plan of the SAPRI follows on from extensive engagement with the Marine and Antarctic community, from established teams and newly engaged research teams wanting to develop into this space. The SAPRI will establish scientific excellence in multiple disciplines - from terrestrial science on the sub-Antarctic Islands of Gough and Marion and Antarctica itself, to ocean physics and biogeochemistry, through the full suite of ocean trophic levels to the top predators who make the terrestrial space their breeding grounds, to the deep-seafloor dynamics and ecosystems that exist here, to the cryosphere, sea-ice dynamics, atmosphere and space physics. Throughout the SAPRI this scientific excellence will constantly be viewed and communicated in terms of value to society.

The uniqueness of SAPRI is better represented by the concept of unitedness: the creation of a unified but distributed infrastructure that will coordinate, combine and strengthen the existing fragmented components. SAPRI is novel because it creates a model in which the scientifically established lines of research that rely on the observations of essential variables will be transformed into long-term monitoring structures. This will create new opportunities for research and substantially increase our understanding of the impacts of global climate change on the regions which impact South Africa, but also which South Africa are custodian to.

The SAPRI, as systemic innovation, will enable polar research through its integrated facilities (IFs), which are components combining various kinds of research infrastructures that share common objectives and/or logistical needs. Four IFs will be coordinated and connected through a hub, responsible for polar science logistics, data management and administration. One is dedicated to digital data transformation, product dissemination, training, outreach and societal benefits. Two of the three research-related SAPRI IFs will ensure sustainability of long-term observations (LTO) on land, ocean, seafloor, atmosphere and space, by means of a balanced combination of autonomous devices and dedicated equipment for fieldwork on the Antarctic continent and on the islands. The third is an innovation that will bring new opportunities for ice-related research in Africa by establishing the first sub-zero, temperature-controlled laboratory for the simulation of the Antarctic and sub-Antarctic environment. Thanks to the Polar Lab, more students, scientists and technicians will be exposed to polar science and technology without the need to leave the continent and participate in research cruises to Antarctica. These technologies represent a novel and innovative approach in thinking, which the SAPRI will develop to support new science on the continent of Africa and gain a deeper understanding of our regional interest and to increase our scientific reputation internationally.

Management plan

The SAPRI Lifecycle has been designed as follows:

- Currently: SAPRI proposal development and initial stakeholder engagement, which encompasses the Conceptual and Technical co-design.
- Year 1-3: Setup phase and initial infrastructure procurements. This will begin in April 2021 and infrastructure required for installation during the SA Agulhas II dry-dock will be prioritized for procurement in 2021. This phase also includes continued technical design and establishment of SLA's and MoU's
- Year 4-13: Running phase. Within this phase is the functional running of the SAPRI: all procurements and replacements of infrastructure, data management, engagements, research and takeover cruise work, student development and publications. This phase will also start the consultation towards the establishment of a South African Polar Research Institute
- Year 14-15: Closure or continuation or transition depending on recommendations from reviewers and consortium investors (DSI, DEFF).

The Management Team for SAPRI, and those advisory structures governing them, are detailed in Chapters 3 and 4 extensively. The key to effective governance is of course communication and this will be established and encouraged throughout the SAPRI lifecycle to ensure the effective working relationships. Key to the success of SAPRI will be the alignment of the endorsed scientific projects with the infrastructure availability from different partners before finalizing the evaluation process of SANAP proposals. Access to platforms will hence be maximised through multiple projects' coordination and co-design of the expensive Antarctic expeditions. Given the seasonal nature of polar research, this joint management of resources will also make valuable equipment available to other communities outside the polar space. The management of observational networks and research platforms done by the SAPRI will allow the researchers to focus on the new science that will be enabled by the infrastructure.

All data collected using infrastructure procured through the SAPRI will be made freely available for use. Certain datasets may be embargoed pending student dissertation write-ups or sensitivities, but never indefinitely nor for commercial gain. All international data standards and best practices will be adhered to.

Governance and stakeholder engagement

SAEON, the host institution of the SAPRI, already manages two Research Infrastructures (SMCRI and EFTEON) and thus has extensive management experience in this regard. SAEON follows all of the NRF policies in terms of procurement and financial management, human resources and employment of staff, and legal framework. These policies will be used in the effective governance and management of the SAPRI.

A number of advisory panels will be established to govern the activities within the SAPRI: the DSI-DEFF Steering Committee, the SAPRI Advisory Panel, the SAPRI Scientific Panel, Thematic User Fora and a structure that has been largely requested by the science community, a SANAP Coordination Committee that will be responsible for the alignment between science projects and the infrastructure. This combination of advisory structures will ensure transparent institutional arrangements and continuous scientific inputs for the expansion of the SAPRI.

Through the drafting of this proposal, the SAPRI has already engaged with over 25 South African stakeholders (including government departments, Historically Black and White HEIs, science councils, research institutions and non-government organisations) primarily related to the scientific endeavours of the RI and thus the infrastructure required. The DEFF provided specific comments on the fundamental requirements pertaining to logistical arrangements. Once established, SAPRI will further engage with all stakeholders including national government departments with interests in the marine and Antarctic space to ensure the national priorities are addressed within the RI. In addition, international collaborators and potential funders, private enterprise and philanthropic groups will be engaged to market the RI but also gain traction and support internationally.

Capacity development

The SAPRI will employ 39 staff members annually to manage, procure, maintain, train, operate and process data streams stemming from the infrastructure made available through the RI. These include seven Management Team staff who will manage the relationships, the funders, the Integrated Facility teams, the outreach, the data management and above all, the expectations associated with the SAPRI. Additionally, SAPRI will have a minimum of 11 technicians, four interns, four overwinter team members for top predator research at Marion Island, two administrators and 10 data centre team members. SAEON will provide specialised services such as IT network administration, data curation, HR, financials and supply chain management. These positions will be shared with SMCRI and EFTEON.

No direct funding through the SAPRI will be available for student bursaries or post-doctoral positions owing to the proposal being primarily an enabler of infrastructure and such infrastructure needs to be maintained for optimal use. However, SAPRI will capitalise on the experience of the Antarctic Legacy of South Africa to promote humanities and social sciences research and the STEM disciplines involved in polar sciences. Dedicated training initiatives will enhance the capacity to do science in the polar environment, either by allowing more students to experience Antarctic conditions in the Polar Lab and by consolidating the SANAP project SEAmester, the first South African class afloat. SAPRI will work with the Principal Investigators of the endorsed projects to find and support funding avenues (e.g. NRF/DSI and PDP bursary schemes) to support training from the BTech / Honours level, right through to Post-doctoral fellows. Focus will be driven towards Historically Black HEIs and the progression of Women in STEM fields of study.

SAPRI's goal within capacity development is to encourage the next generation through outreach and engagement to follow STEM pathways of study, make available the required infrastructure and / or data to research projects for students to undertake their field work and support the career pathways as best as possible to retain skills to South Africa.

Monitoring, evaluation and risk management

The SAPRI monitoring is based on a detailed plan of stage-gating, reporting structures and analysis of risks. Overseeing the SAPRI and to ensure it always aligns with National Government Priorities, is a DSI-DEFF Steering Committee which will receive annual reports on SAPRI progress and will be instrumental in the five-yearly reviews of the RI. The SAPRI will report quarterly to the SAEON Managing Director, the NRF Corporate and DSI funders on progress, to raise any fundamental issues and comment on scientific excellence achieved. Annually, the progress of SAPRI will be reported to all stakeholders, any additional funding entities and conservation agencies in terms of permitting restrictions.

The greatest risks are financial in terms of cuts to government funding for the SAPRI and drastically unfavourable exchange rates. Additional high risks associated with the impact of SAPRI include changes in national political priorities, high-level incongruence between government department funders, failure of funders to contribute and changes in international agreements. These are effectively out of the hands of SAPRI Management Team and host institution, but will be closely monitored and mitigation plans developed to support the continuation of SAPRI. The potential failures to recruit excellent leadership and of the host institution to operationalize systems are risks which need to be addressed from the outset of SAPRI to ensure the RI is effective from the start.

Financial plan and budget

The SAPRI budget over its 15-year life-cycle falls just short of R 1.1 billion, while using a staggered incremental approach of inflation given the difficulties in forecasting economic growth, and thus inflation, over the next 15 years. The projected running cost of the SAPRI is less than R 60 million per year, which is exclusive to the current R 130 million annual budget made available for the SA Agulhas II and maintenance of the bases at Marion and Gough Islands and Antarctica. The proposed outlay for capital expenditure, linked to physical infrastructure, amounts to R 386 million. These infrastructures cover the wide range of scientific disciplines engaged within this document, and further augment the large and medium infrastructure already in existence and maintained by the stakeholders of the SAPRI. The balance of the budget relates directly to the human capital, maintenance and support of the infrastructure purchased and the incredible data management capacity required for such a diverse entity. Every single one of the over 25 stakeholders engaged in the drafting of the SAPRI stated that the support required to optimally make use of, maintain, obtain data from and make accessible and useable to the greater community was instrumental to such an enterprise and should be effectively budgeted for at similar levels afforded to other *Big Science* programmes.

From the offset, additional funding avenues for the SAPRI have been identified and in some instances, already engaged. The first of these is to realign the DSI SANAP-Science funding, which is currently made available in three-year competitive call cycles, to support long-term projects in terms of running costs, while making available funding for new and innovative scientific endeavours. SAPRI, through the proposed integration of the SANAP budget, will take a balanced approach of financing the required infrastructure and reallocating funding to science proposals for greater support to research and innovation in the polar space. Secondly, funding to build the proposed Polar Lab, on premises owned by the UCT, has been requested from the DHET under the Infrastructure Funding Category Focus Area "National Academic Priorities" of ~R 50 million. Finally, funding initiatives from national (e.g. student bursaries and internships, science funding, etc), international (multinational partnerships, polar science initiatives, etc), private entities and philanthropic donor grants need to be investigated more robustly once the SAPRI is established to ensure continuity and longevity, while easing the burden on central government support.

In conclusion, the SAPRI was co-designed by the Marine and Antarctic community, including established and newly engaged stakeholders ranging from multi-disciplinary scientists to policy makers and funders, to develop holistically and in support of one another, a comprehensive *Big Science* Research Infrastructure that benefits everyone. If consolidation of the current fragmented components of polar science in South Africa is not undertaken, then postgraduate students, once trained, will leave to work within established research facilities who value their skill sets (often overseas), scientific publications will suffer, multi-disciplinary research and technical innovation will be stifled, the transformation of polar science will be drawn out and the important link to society will remain under prioritised. In order to create the *Big Science* this proposal hopes to achieve, it will require authentic leadership, dynamic management, innovative thinking, out-of-the-box problem solving to deal with, not only the multiple stakeholders involved with SAPRI, but the extreme conditions in which these infrastructural resources will be deployed and used. The outcome of this will be a co-designed, sustainable and responsive Research Infrastructure which services the needs of all whilst enhancing what has already been established.

1 IMPACT

The **South African Polar Research Infrastructure (SAPRI)** forges close collaboration in marine and Antarctic sciences between the key role players from government, higher education, science councils, private business and civil society. The infrastructure and coordination offered through SAPRI will ensure integration of South African marine and Antarctic research, maximising the science production and uptake by facilitating access to existing and new infrastructures. SAPRI is explicitly designed to provide the infrastructure required to develop and enhance long-term observations of South Africa's polar region, with the objective of ensuring continuous research growth, maintaining and building on existing world-class long-term observational datasets and training the next generation of technicians, engineers, natural, humanities and social scientists. It will ultimately contribute to societal benefits and the strengthening of South Africa's Antarctic legacy through science-based advice to policy makers and international treaties and easy access to advanced data products for downstream utilisation.

Given the diversity of contexts, the impact of the proposed Research Infrastructure (RI) should be considered in the national and international framework of Antarctic science and international treaties. This chapter, beyond highlighting the medium and long-term impacts of the RI, introduces the multifaceted political and science background pertaining to the establishment of a *marine and Antarctic research facility* indicated in the South African Research Infrastructure Roadmap (SARIR) published by the Department of Science and Technology (now Department of Science and Innovation, DSI) in 2016.

As a first step, it is necessary to clarify the **terminology and geographical ambit of the RI**, since the terms *marine and Antarctic* may have different interpretations depending on the context. Despite the geographic region designated for Antarctic science being ambiguous (Elzinga, 2017, Figure 1), a definition is nevertheless required to designate the RI operational activities. These boundaries do not however need to be geographical or based on topographical considerations. *Antarctica* in this context is considered the main qualifier, but it is not limited to the Antarctic continent, including for instance the subantarctic islands and the space science that can be conducted on these remote regions. Similarly, *marine* in this context extends the area of interest to the oceanic waters surrounding the Antarctic continent, including the continental shelves[1] of the South African Exclusive Economic Zone (EEZ). It is important to remark that even the Southern Ocean is not an official geographic area identified in the International Hydrographic Organization (latest 1953 edition), even though it is commonly used in many communities of practice and for some UN Members it might be the official geographical name[2]. The current accepted terms in international conventions are *Antarctic area* or *Antarctic waters* and as such are the terms used in the Polar Code (2017)[3] of the International Maritime Organization, indicative of those waters south of 60° South.

The Southern Hemisphere polar region is a system of interconnected physical and ecological components, in which the human dimension is the collating investigative texture; the term **polar science will thus be preferred in this proposal**, as the container of all scientific activities done on the Antarctic continent (including space science), in the sub-Antarctic islands and in the Southern Ocean,

1 Shallow coastal waters are excluded from this definition due to the existence of the Shallow Marine and Coastal Research Infrastructure (SMCRI), also established in the framework of SARIR.
2 https://www.jcomm.info/index.php?option=com_content&view=article&id=376&Itemid=100253
3 http://www.imo.org/en/mediacentre/hottopics/polar/pages/default.aspx

up to and including South Africa's offshore EEZ regions. The use of this term, not just referring to the Antarctic system, would also ensure that the SAPRI can facilitate scientific collaborations with dependent and associated systems in the polar Northern Hemisphere.

For reference, a full list of the acronyms used throughout this document is given in Appendix A.

1.1 STRATEGIC IMPORTANCE

1.1.1 South Africa's comparative geographical advantage

Antarctica is the closest continent to South Africa, at a distance of ~4000 km. Argentina, Chile, New Zealand and Australia can also claim a direct geographical advantage in terms of access to the Antarctic continent. This has led to Cape Town being one of the five gateway cities to Antarctica, along with Ushuaia (Argentina), Punta Arenas (Chile), Christchurch (New Zealand) and Hobart (Australia). These are official ports of entry[4] for travels to and from the Antarctic continent, and in addition provide home ports of departure for most oceanographic expeditions in Antarctic waters.

South Africa is not only geographically close by, but also connected to Antarctica in geological, astronomical and climatic terms. Southern Africa shares a common geological history with Antarctica as part of the reconstructed Gondwana supercontinent. This implies that the genesis and distribution of mineral resources is similar in both continents. This permanently uninhabited large expanse of land is surrounded by the Southern Ocean, the only large basin of the world ocean that runs uninterrupted along a series of parallels circumnavigating the Antarctic continent and linking the Pacific, Indian and Atlantic Oceans. The Southern Ocean and Antarctica constitute the Southern Hemisphere polar system, a region that plays a major role in regulating global climate which is, in addition, particularly sensitive to environmental stresses such as climate change.

The Southern Hemisphere polar region is an important window into geospace, especially for monitoring the geomagnetic field and the variations of the ionosphere and upper atmosphere. Events on the sun can be measured from this vantage point by investigating cosmic ray activity, furthering our understanding of climate variability. Polar regions have a huge climatic relevance in an anthropogenically changed climate due to the so-called polar amplification and ice-albedo feedback. In addition, they regulate mid-latitude weather and modulate climatic trends such as the precipitation-drought cycles, especially in countries bordered by large oceans like South Africa. The Southern Hemisphere polar system has a large buffering capacity due to the wide oceanic area involved, which has been identified as a major storage of heat and carbon of anthropogenic origin. This region covers approximately 20% of the world ocean surface and is responsible for approximately 40% of the oceanic uptake of anthropogenic carbon and 75% of the stored excess heat generated in the lower atmosphere (Gruber et al., 2019 and references therein). The system of currents is therefore of major interest for the redistribution of these stored amounts. The Antarctic continent is also surrounded by the largest expanse of seasonal sea ice on Earth, which is directly connected to the system of continental ice sheets and the protruding ice shelves (the largest reservoir of freshwater in the climate system). After an apparent expansion of sea ice extent persisting since the beginning of satellite-based records, characterised by large annual variations, in the last 5 years Southern

4 https://antarctic-cities.org/the-project/

Hemisphere sea ice has experienced a decline comparable to that observed in the Northern Hemisphere (Parkinson, 2019).

In this context, the geographical advantage of South Africa within the Southern Hemisphere polar system gains a more dominant role, as delineated in the Marine and Antarctic Research Strategy (MARS[5]) and the South African Antarctic and Southern Ocean Research Plan[6] (2014-2024) prepared for the National Research Foundation in 2014 (Skelton et al., 2014). These documents, together with the science plan proposed and successfully executed by the Southern Ocean Carbon and Climate Observatory (SOCCO) funded by the DSI Grand Challenge and an updated vision of Antarctic research proposed by the South African scientific community (Ansorge et al., 2017) have guided the meta-design of this proposal. In addition, the Department of Environment, Forestry and Fisheries (DEFF) has recently submitted for public consultation a draft document for an Antarctic and Southern Ocean Strategy[7] (ASOS) that involves the major governmental entities. The ASOS focuses on the administrative component of Antarctic activities and further highlights the concept of geographical advantage. Through a definition of the South African interests in Antarctica, it recognises the fragmentation of the current structure (see also the next section) and proposes a possible way forward which has been taken into consideration in preparing this proposal.

Beyond the status of an Antarctic gateway and the historical role of South Africa in Antarctic exploration, exploitation and accessibility, it is the configuration of active climatic systems around southern Africa that makes the country's positioning unique. The crossroad of different systems (the Antarctic Circumpolar Current and the Southern Ocean, the Agulhas Current and the Benguela Current) which connect the tropical Indian Ocean to the temperate South Atlantic and the polar frontal zone, makes the region one of the most interesting ecosystems in the world ocean from a scientific and socio-economic viewpoint, with a large abundance and diversity of marine living resources (Rogers et al, 2020). The proximity of the Southern African sub-continent to the Antarctic makes it an advantageous location to study the seasonal distributions of ocean-basin migratory species such as the large baleen whale guild of the Southern Ocean. Sub-Antarctic islands such as the Prince Edward Archipelago interspersed within this distinctive environment provide unique laboratories for the exploration of this globally important system and for studies on its response to climate change.

The most recent perspective on Antarctic research for the 21st century (Kennikutt et al., 2019) gave pressing evidence that the "popular beliefs that Antarctica is pristine, stable, isolated, and reliably frozen" does not hold anymore, if it ever did. The Antarctic region is constrained by a lack of critical observations, which would inform our system understanding and the proper calibration of Earth System models that will allow us to improve the reliability of future projections. The geographical advantage of South Africa is hence of major relevance since access to Antarctica and surrounding oceans is still one of the major challenges in implementing the scientific roadmap.

5 https://www.nrf.ac.za/sites/default/files/Marine%20and%20Antarctic%20Research%20Strategy%20Final.pdf
6 https://www.nrf.ac.za/sites/default/files/Antarctic%20and%20Southern%20Ocean%20Research%20Plan.pdf
7 https://www.environment.gov.za/sites/default/files/docs/draftantarcticasouthern_oceanstrategy_asos.pdf

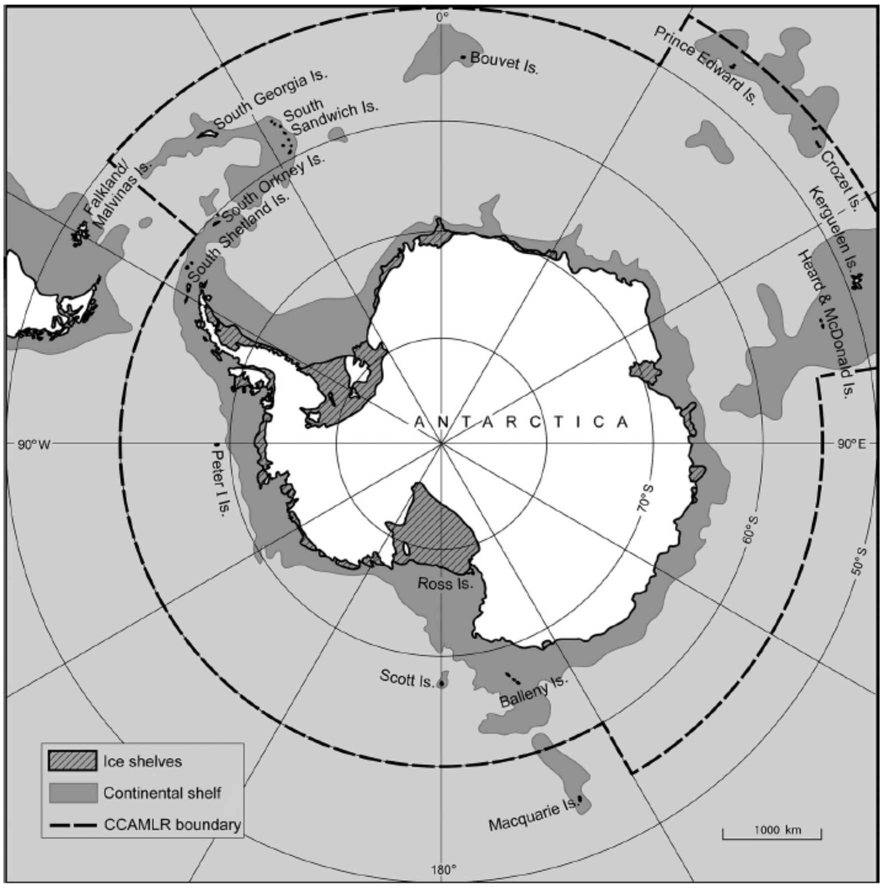


Figure 1 ***Antarctica and the Southern Ocean****, with the boundary established by CCAMLR (from Hennings et al., 2017). The region of interest to this proposal extends further north, to include the deep ocean surrounding South Africa.*

1.1.2 Beneficiaries

To better understand the multiple beneficiaries of the SAPRI (Table 1), it is relevant to illustrate the political and administrative context in which the RI will operate, and the involved stakeholders.

South Africa is one of the 12 original signatories of the Antarctic Treaty[8], which evolved into a system of several components termed the Antarctic Treaty System (ATS). It remains the only country from the African continent to be a part of the ATS, giving it a crucial role in representing the entire region. The ATS ensures *"in the interests of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord."* The Treaty withholds any legitimacy of territorial claims and applies to the area south of 60° South Latitude, including all ice shelves and islands (Figure 1). Military activities are prohibited except in support of science; commercial exploitation of resources on the continent and the ice shelves is precluded (Joyner, 1991). The ATS is an international legal framework by which the parties exert their presence in the Antarctic region through continuative research activities. Therefore, it promotes scientific research, the exchange of data and international cooperation. South Africa is represented in the ATS by the Department of International Relations and Cooperation (DIRCO). According to their website[9] *"scientific research conducted in Antarctica is of benefit to South Africa as it is to the other littoral*

8 https://www.ats.aq/e/antarctictreaty.html
9 http://www.dirco.gov.za/foreign/Multilateral/inter/ats.htm

states of the Southern Hemisphere and indeed to the entire world as results are analysed and utilised internationally." However, the latest framework documents promulgated by DIRCO do not report specific references to a long-term international Antarctic strategy (Sidiropoulos and Wheeler, 2016), which is instead proposed by DEFF in the ASOS document.

Several international bodies have emanated from the ATS. South Africa is a member of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR [10]), which is composed of 26 Members and 10 Acceding States. Based on the best available scientific information, the Commission agrees on a set of conservation measures that determine the use of marine living resources in the Antarctic. The current official boundaries of Antarctic research are the ones defined by CCAMLR (Figure 1), and the working groups in the scientific committee are very active in their work towards the establishment of Antarctic marine protected areas. South Africa is represented by the DEFF (the Chief Directorate - Specialist Monitoring Service sits in the Commission and the Chief Directorate - Oceans and Coasts represents the country on the Scientific Committee). Of interest to this document is also the membership of South Africa within the Council of Managers of National Antarctic Programs (COMNAP [11]). This is the international association that brings together countries of the ATS with a national Antarctic programme. DEFF is the South African representative through its Chief Directorate - Specialist Monitoring Service. Presently, 29 ATS nations operate about 100 facilities through their National Antarctic Programs, both seasonal (summer-only) and year-round. Finally, South Africa is a member of the International Whaling Commission and South African scientists have played an important role in the IWC Scientific Committee, including within the IWC's current Southern Ocean Research Partnership and historic International Decade of Cetacean Research (IDCR) and Southern Ocean Whale Ecosystem Research (SOWER) initiatives.

In response to the ATS obligations, South Africa took responsibility for a Norwegian base on Antarctica in Dronning Maud Land in 1959/60 and made it a permanent base (now SANAE IV). Through a series of programs, the country finalised the current South African National Antarctic Programme (SANAP [12]) in 2003. South Africa has also established a permanent base on Marion Island (Prince Edward Islands) since its annexation in 1948. This is a South African territory included in the Antarctic waters within the CCAMLR boundaries. In addition, the South African Weather Service (a public entity overseen by DEFF) currently leases and manages a weather station on Gough Island (a United Kingdom territory) in the South Atlantic. Since 2003, the SANAP functions have been distributed between the Department of Science and Innovation (DSI) and the DEFF (Figure 2). The latter institution retains responsibility for all logistics, and infrastructure maintenance is operated by the Department of Public Works and Infrastructure (DPWI). DSI retains responsibility for the scientific research component. The DEFF SANAP component (hereafter referred to as **SANAP-Logistics**) has maintained South Africa's research presence in Antarctica and on the Prince Edward Islands, as well as the official representation of South Africa in the international bodies indicated above. The scientific research of SANAP (hereafter referred to as **SANAP-Science**) and the administration of grants on behalf of DSI is operated by the National Research Foundation (NRF). SANAP-Science calls currently follow a three-year cycle including specific consultation with SANAP-Logistics. Access to infrastructure by South African and international scientists currently is linked solely to NRF-funded SANAP-Science projects. To put the level of investment into perspective, before the impact of the COVID-19, the direct research funding for SANAP-Science was ~R18 million per year, while SANAP-Logistics was ~R130 million per year. The

10 https://www.ccamlr.org/
11 https://www.comnap.aq/
12 https://www.sanap.ac.za/

latter comprises the logistics support for the Antarctic and sub-Antarctic presence, which is one of the fundamentals for participation in the ATS and the annexation of the Prince Edward Islands territory. SANAP-Logistics manages the South African icebreaker SA Agulhas II[13] providing 160 days of ship time annually, with one day of ship time currently costing approximately R500,000. An additional 60 days of ship time on the SA Agulhas II have been made available in recent years for dedicated scientific expeditions in the Southern Ocean through DSI/NRF funding. In general, only science projects funded through the NRF SANAP-Science call have had access to the 160 days of ship time closely associated with base logistics administered by DEFF. Since 2015 the additional SANAP-Science ship time has been open to scientific participants outside the SANAP-Science circle of projects. From 2016, the NRF SANAP-Science budget also funds SEAmester, a very successful postgraduate “class afloat” that introduces marine science as an applied and cross-disciplinary field to students on board the SA Agulhas II (Ansorge et al., 2016). One additional component of the SANAP-Science budget is dedicated to the maintenance of the Antarctic Legacy of South Africa

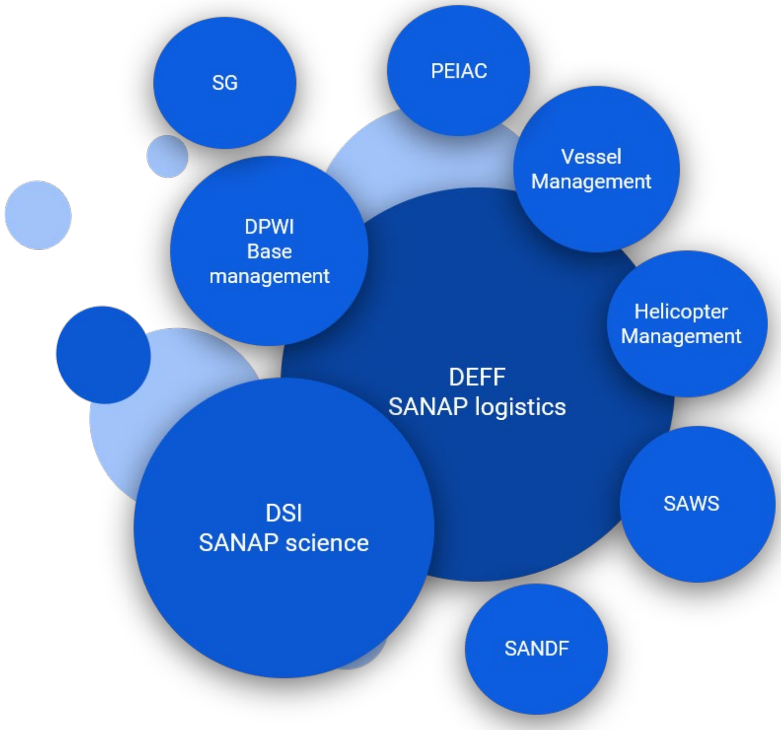


Figure 2 ***Main institutional and logistic components of SANAP.*** *DSI: Dept of Science and Innovation; DEFF: Dept Environment, Fishery and Forestry; DPWI: Dept of Public Works and Infrastructure; PEIAC: Prince Edward Islands Advisory Committee; SG: Surgeon General; SANDF: SA National Defence Force; SAWS: SA Weather Service. Helicopter and vessel management are externally contracted entities through SANAP-Logistics.*

In practice, the South African support and contribution to Antarctic research and associated international obligations are distributed among a large number of institutional and scientific parties, as illustrated in Figure 2. SANAP is therefore an extended network of organisations, which is currently regulated by agreements between individual parties and a loose regulation of the access to national infrastructure. The South African scientific community is involved as an advisory component of the Prince Edward Island Advisory Committee (PEIAC), with executive powers chaired by divisions of DEFF.

13 https://www.sanap.ac.za/explore/vessels

Only scientists from the funded SANAP-Science projects can access the SANAP-Logistics infrastructure. They are invited to the planning sessions of the annual relief voyages to Antarctica, and they are usually reserved 10 berths depending on the conditions. Vessel and helicopter management is operated by DEFF depending on the SANAP-Logistics needs and commissioned to external contractors.

A shortcoming of the current setup is that any additional cost beyond the maintenance of the Antarctic presence guaranteed by DEFF is expected to be covered by the DSI/NRF portion of the SANAP-Science funding. This includes logistics support for scientific research (e.g. helicopter or terrestrial transport for Antarctic field work), as well as procurement and maintenance of specific gear for scientific operations and sampling, and salaries for overwintering science personnel. The latter item does not include additional costs such as insurance, evacuation, medicals, etc. which need to be covered as extra costs by the respective science organisations contracting the personnel.

Antarctic research comprises multiple disciplines and a wide geographical ambit. The scientific and academic boundaries in Antarctic research are often stronger than the political boundaries, and they influence the scope of inquiry (Elzinga, 2017). Much of the planning in the international context has been designed around the Scientific Committee on Antarctic Research[14] (SCAR), an international body operating within the International Council of Science. SCAR was founded on disciplinary bases, through the establishment of permanent Science Groups on Geosciences, Life Sciences, Physical Sciences, and Humanities and Social Sciences. South Africa is the only African country that is a full member of SCAR, with good standing due to its status as original signatory. This gives the country an international visibility, recognised by the participation of South African scientists in SCAR bodies. The South African National Committee for SCAR is currently hosted by the SANAP-Science component without a specific budget item. Individual South African scientists are currently involved in several action groups and high-level standing committees, although their coordination is unstructured. Given SCAR's geopolitical role in the ATS, it is worth capitalizing on this scientific and political advantage, while also contributing to the transformation of global Antarctic science.

In an effort to coordinate this fragmented landscape, the Marine and Antarctic Research Strategy (MARS) was constructed from the bottom-up, and finalised top-down[15] in consultation between DSI and DEFF. The Antarctic and Southern Oceans research plan (Skelton, 2014) was consolidated into a combined strategy including the coastal components of marine science. A major purpose of this strategy was to provide an overarching policy framework for a wide range of pre-existing programme and project-level plans, policies and strategies. In relation to the administrative and policy component, MARS identified horizontal priorities for delivering the strategy. Among them, *Intervention 1: Coordination and Governance* indicated the appointment of a marine and Antarctic research steering committee. The committee was meant to ensure that logistical needs for researchers were aligned with receptive capabilities of the line departments and research entities. As indicated in the document, "[...] coordination will ensure that research grants awarded by the funding agencies are aligned with available logistical support. This has been a major challenge for researchers and government administrators alike, where research and logistics were not seen to be aligned, particularly for Antarctic related research." Indeed, *Intervention 5: Infrastructure and Research Platforms* highlights the existence of a rich suite of platforms for Antarctic research, indicating that the Government has invested heavily in the provision of research infrastructure platforms. According to the MARS document, the coordination of their deployment is considered critical to maximise the

14 https://scar.org/
15 https://pmg.org.za/committee-meeting/20904/

outputs that could be derived from them. At the time of writing of this proposal, a preliminary line of coordination has been established between DSI and DEFF to manage the SA Agulhas II calendar, one of the largest and most expensive infrastructures for Antarctic research.

Table 1: ***Preliminary list of SAPRI beneficiaries.***

Beneficiary Type	Beneficiaries and target groups
Government (incl. subsidiaries and parastatals)	Department of Science and Innovation Department of International Relations and Cooperation Department of Environment, Forestry and Fisheries Department of Water and Sanitation Department of Public Works and Infrastructure South African Weather Service South African National Space Agency South African Institute for Aquatic Biodiversity South African Environmental Observation Network National Research Foundation Council for Scientific and Industrial Research Department of Arts and Culture South African National Biodiversity Institute
International bodies	Antarctic Treaty System (AST) Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Council of Managers of National Antarctic Programs (COMNAP) International Whaling Commission (IWC) International Oceanographic Commission (IOC) of UNESCO Global Ocean Observing SYstem (GOOS) World Meteorological Organisation (WMO) Scientific Committee on Antarctic Research (SCAR) Scientific Committee on Oceanic Research (SCOR) Southern Ocean Observing System (SOOS) International Long-Term Ecological Research (ILTER)
Industry	Small and medium enterprises in the field of ocean technology Vessel management: African Marine Solutions (AMSOL) Commercial fisheries Oil and gas exploration companies and consultancies Antarctic Logistics Centre International Small and medium enterprises in the field of Antarctic tourism Renewable energy companies in support of sustainable base power supply Ship designers, operators and managers
Academia and Research Institutions	Any South African institute of tertiary education involved in the polar science or technology and innovation space. Given the diversity of disciplines in this space, a large number of academic groupings will ultimately benefit from the infrastructure. Those that have shown interest already include: • University of Johannesburg • University of Pretoria

	• University of the Witwatersrand • Rhodes University • Nelson Mandela University • University of South Africa • University of Fort Hare • University of Cape Town • Stellenbosch University • Cape Peninsula University of Technology International Universities and research institutions already collaborating with the SA community from their countries are listed in Figure 5 and Figure 6.
Society	Secondary education teachers, for content and improved literacy e.g. in traditional fields such as geography, life sciences, maths, chemistry and physics (STEM), but also business innovation, technology, computer skills and coding Tertiary education lecturers, for content for all disciplines represented in the SAPRI, including natural and social sciences, as well as data, law, history, arts, and business schools Law and policy makers The general public interested in global change and the Blue-Economy as well as the exceptional ecosystems of the polar oceans Human health studies in extreme environments Arts and culture organisations Museums and galleries International Association of Antarctic Tour Operators Cape Town City Council as a Gateway City

1.1.3 Business justification

1.1.3.1 *Value proposition*

SAPRI proposes a step change in the coordination of national infrastructure for the polar sciences, which is based on a redesign of the SANAP structure according to the principles of economy of scale. The proposed RI is conceived **to integrate the NRF-based SANAP-science budget items into the SAPRI, favouring the alignment between the science plans and the infrastructure for polar research**. This proposal follows the successful management model of the multi-disciplinary African Coelacanth Ecosystem Programme (ACEP)[16] funded primarily by DSI through the NRF-SAIAB national facility, but using research infrastructures from numerous governmental agencies and partners. Given the much larger context of polar research, the SAPRI proposes to further expand this model towards the creation of a **common coordination space where scientific projects from different sources can access infrastructural resources and benefit from a co-design approach to research**. This concept moves away from the simple model of a centralised hub holding infrastructures and making it available to competitive users, in recognition of the complexity of designing polar expeditions and the need to create equitable access to resources. Through SAPRI, the scientific productivity of core research infrastructures managed by SANAP-Logistics will be further valorised as also envisaged in the ASOS document. The polar research capabilities will be enhanced by applying a phased approach to: 1) establish coordination relationships with existing infrastructure and their stakeholders; 2) maintain and further expand the network of polar long-term observations; 3) align the infrastructure availability

16 https://www.saiab.ac.za/acep.htm

with the independently evaluated research projects run by the RI users and 4) continuously incorporate new infrastructure based on innovative technologies, improved scientific understanding and new users. The long-term datasets resulting from SAPRI will be discoverable, accessible, reliable, extendable, usable, reusable, integratable and downloadable for further use in research, modelling, education and decision making.

The proposed coordination and rationalisation effort detailed in Chapter 3 aligns entirely with the strategic guidelines indicated in the white paper on Science, Technology and Innovation [17]. In particular, the SAPRI is designed to improve coherence and budget coordination across the SANAP stakeholders (SANAP-Science, SANAP-Logistics and the national and international scientific community), which is expected to ultimately enable a more favourable environment for innovation, research and development of human capacity in an area that is traditionally represented by Northern Hemisphere countries. The establishment of SAPRI will thrust South Africa into a central role for accelerating the implementation of the pan-African Science, Technology and Innovation (STI) agenda, thus achieving the main imperatives of the National System of Innovation.

Research and innovation infrastructures are recognised drivers of knowledge generation (see footnote 17). In addition, an infrastructure that coordinates world-class, system-wide research in Antarctica would strengthen perceptions among its citizens that South Africa is an innovative country acting as a global citizen with a clear commitment to ocean, ecosystem and climate stewardship. The innovation drive is an essential ingredient for remote and autonomous data collection, particularly in the context of Antarctic science where direct collection of data through human activities is either challenging or impossible. This innovative approach to data collection is embedded in the UN Decade of Ocean Science [18] project of The Digital Ocean. The SAPRI would therefore represent a grand contribution of South Africa to this decade-long international endeavour to create *the science we need for the ocean we want*. This concept provides the foundation for polar science in the SAPRI design. Whenever possible, observational platforms will be turned into the **modern concept of digital twins**, which are virtual models of real physical systems, items or processes that are achieved through real-time communications and Internet of Things [19]. Digital twin technology will bring polar infrastructures and the data they collect to the hand of researchers and the wider public. A digital model of the SA Agulhas II and the stations will allow training and familiarisation of new team members and field assistants with the environment. This feature will also be used in museums and online virtual experiences. The societal benefits are further illustrated in Chapter 2.

1.1.3.2 ***Public good***

Antarctica is a public good by definition. Antarctic science is framed in the **principle of science for society**, due to the special connotation of the Antarctic continent and polar spaces in general. There is no direct commercial exploitation of Antarctic resources, but Antarctic presence and the knowledge and understanding generated by science have always been considered as an indicator of the scientific, political and societal standing of any country participating in the ATS. As such, the proposed RI is by definition conducive to public good enhancement and preservation, as it would consolidate the South African presence in this space by enlarging its local and international support base in the scientific

17 https://www.gov.za/sites/default/files/gcis_document/201912/white-paper-science-technology-and-innovation.pdf
18 https://www.oceandecade.org/
19 For a popular introduction to digital twin technology see
https://www.forbes.com/sites/bernardmarr/2017/03/06/what-is-digital-twin-technology-and-why-is-it-so-important/?sh=3b4141552e2a

community and civil society. This has been fully detailed in the extended list of beneficiaries in Table 1 and in the related section.

Understanding polar landscapes has an ultimate bearing on the public good of South Africa. This includes the common ancestry of the continental landmasses, its importance and still not well understood role in global and regional climate through carbon - climate feedbacks, its growing contribution to sea level rise, its own sensitivity to climate change through changes to circulation, sea-ice, storm characteristics, ocean acidification and the unique biodiversity of the sub-Antarctic Islands and the Antarctic continent itself. The historical, legal and cultural frameworks through which all these concepts are understood is also relevant to the public good. Africa is widely predicted to be the continent worst affected by climate change, an effect of both continental characteristics and politico-economic vulnerability, which is in turn the result of racialised histories (Hulme, Doherty, Ngara, New, & Lister, 2001; van Sittert, 2015). Antarctica is hence becoming more central to the earth's and particularly South Africa's future in a time of planetary change (Kennicutt et al., 2019).

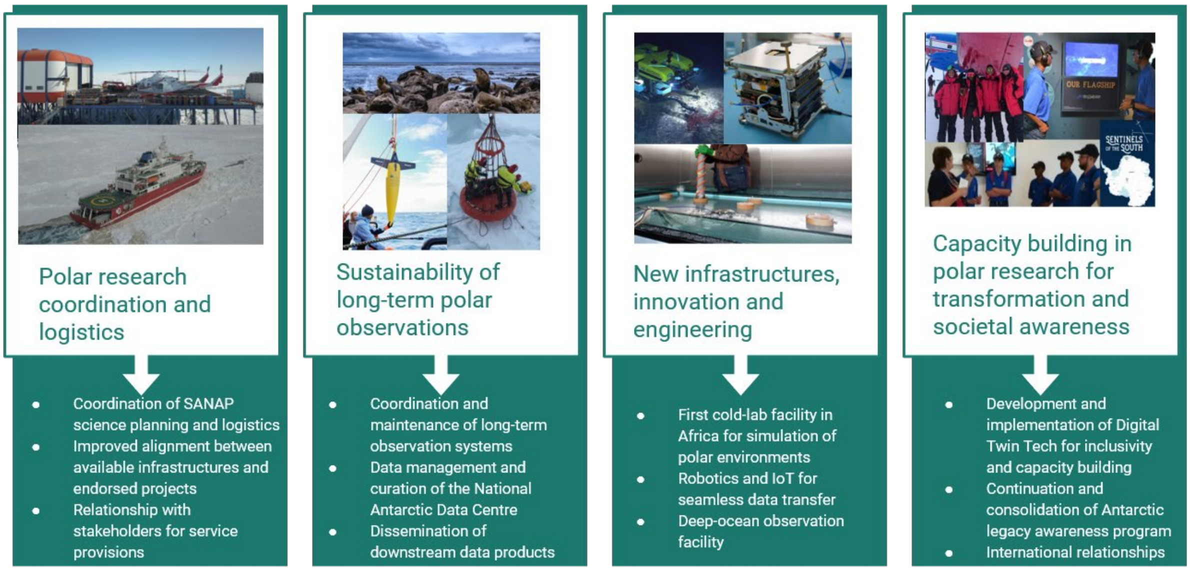


Figure 3 ***The 4 main pillars of SAPRI.*** *They illustrate the conceptual context that has been considered in the design of the RI and the proposed components.*

Even without climate change, understanding Antarctic processes is crucial for the South African public good. The Southern Ocean is critical to the planetary heat and carbon cycles. Meteorological systems which build over the Southern Ocean and South Atlantic for example, directly influence the mid-latitude cyclones and thus rainfall over the Western Cape and into the interior. Also, the study of space physics over the poles directly influences safe passage of passenger planes as they travel across the earth. The study of the geology and geomorphology of Antarctica directly impacts our understanding of how our Earth formed, influencing shared knowledge of our common ancestry, recognising that in geological supercontinent studies, Antarctica is a near white "jigsaw piece" with only cryptic exposed clues as to where it fits in. The study of marine top predators helps us understand their feeding habits, impacts of historic exploitation and associated recovery, and areas of ecological significance (Hindell et al. 2020), which in turn informs us of planktonic blooms driving production in the vast Southern Ocean and the draw-down or re-fertilisation of iron and other co-limiting trace nutrients related to these blooms. The study of biogeochemistry and carbonate chemistry informs us of the anthropogenic impact in the Southern Ocean, which ultimately affects global ecosystems. We are also directly responsible for the conservation and longevity of plants and animals residing in those areas that South

Africa has been entrusted to safeguard. Antarctica serves as a test case, as the only continent currently not owned by any country and previously uninhabited, for historical, legal and philosophical studies of colonisation and ownership in the Humanities.

1.1.3.3 ***Services offered***

The SAPRI is meant to become the collating agent between SANAP-Science and SANAP-Logistics. The main services are framed in 4 main pillars of operations as depicted in Figure 3:

1. Polar research coordination and logistics
2. Sustainability of long-term polar observations
3. New infrastructures, innovation and engineering
4. Capacity building in polar research for societal benefits.

These services will be embedded in a series of integrated facilities that are fully described in Chapter 2. We highlight here some illustrative examples of the type of services for each pillar.

Polar science coordination and logistics

This set of services is currently distributed between SANAP-Science and SANAP-Logistics. The SAPRI aims at restructuring the SANAP-Science component and supporting the joint coordination office with SANAP-Logistics. This is summarised in the following points:

- Endorsement of national and international scientific projects that align with the SANAP science plan, currently defined by the MARS document;
- Dedicated office to coordinate the infrastructural needs of SANAP-endorsed projects (expedition planning, access to large infrastructure, equipment clearance, etc.), in close collaboration and agreement with the mandate of the SANAP-Logistics component and the ASOS proposal. This will include the support of a science Logistics Coordinating Officer, who has been a vital missing link over the past years;
- Access to facilities managed by the SAPRI and facilitating the access to other national and international RIs. This component will ensure equal distribution of SAPRI facilities among the endorsed projects beyond SANAP, as well as making instrumentation that is not deployed during the seasonal polar activities available for other existing research programmes in South Africa;
- Availability of specialised polar garments and gear for field expeditions in addition to the SANAP-Logistics stocks. This will complement the current service offered by SANAP-Logistics and will ensure the appropriateness of gear for scientific work.

Management of long-term observation networks and product dissemination

- Integration of science-driven existing polar observational networks of recognised scientific value and/or national interest into a coordinated workflow that will ensure their long-term, economically viable sustainability
- Management of designated long-term observational systems in terms of instrumentation, data communication, overwintering personnel and coordination between other institutional stakeholders (e.g. SAWS, SANSA, DEFF, SMCRI, SOCCO)
- Preservation of metadata, data, multimedia data and, where applicable, digital links to physical samples (stored in external, organised collections facilities) through the SAPRI data facilities

- Dissemination of downstream data products (observational and model-based level 3 and 4 products, see Chapter 3) that have been proven scientifically effective and can be incorporated in the SAPRI data processing
- Technical service that will support polar equipment with regard to ensuring that they are well maintained, calibrated, have established standard operating procedures and technician(s) to assist in deployment during the endorsed projects
- Provision of equipment and technical support for the observation of remote environments, the deep-sea and the geology/glaciology of the Antarctic region.

New infrastructures, innovation and engineering

- Creation of the first laboratory on the continent for the simulation of polar environments, the training of polar scientists and the design and testing of instruments and material for extreme conditions;
- Calibration and testing of instrumentation for extreme environmental conditions within the temperature-controlled facility. This service will be offered at minimal cost for the consortium partners and commercially charged to external customers (other international institutions and private companies);
- Preservation and storage of ice and geological samples at the temperature-controlled facility. This is free of charge or at minimal cost for the projects endorsed by SAPRI, and it will be offered to external customers at commercial rates;
- Establishment of an interdisciplinary team of engineers that will support the development of new equipment and infrastructure for collecting data in polar regions and remote environments in general. This will include the design of new instruments and sensors for multidisciplinary research;
- Expertise in polar navigation and improved methods for designing polar vessels in maritime engineering – especially with regard to ice-going operations;
- Establishment of dedicated data scientist(s) to enable the remote transfer and archival of data by means of digital twin technology and Internet of Things communication;
- Coordination with the South African network of nano-satellites for the cost-effective transmission of real time and near-real time data to the national facilities;
- Coordination with the South African National Space Agency (SANSA), in support of space weather monitoring and forecast services to national and international partners. Space weather observations have been conducted within the SANAP for the past 15 years and will be continued within SAPRI.

In addition to the infrastructure which will be made available to support the National System of Innovation and contribute to a knowledge society, services that will be offered to its stakeholders and the public by the SAPRI include:

- Training of highly skilled post-graduate students (scientific and technical) and interns in association with innovative research platforms and sea-going experiences that will add knowledge and expertise in support of the South African scientific community and Blue Economy initiative;
- The SAPRI will have an enhanced, coordinated and informed voice, supporting government commitments and participating in international polar and marine programs. This will also include research in Areas Beyond National Jurisdiction, which is relevant for continental shelf

claims and will assist other governmental departments such as Mineral Resources and Energy in monitoring issues related to sea-floor mining and resource exploitation;

- A dedicated Antarctic legacy and Antarctic humanities program, enhancing society's understanding of the country's polar and marine science achievements, as well as preserving and communicating the ongoing science activities.

1.1.3.4 ***Products offered***

Several products will be developed under the umbrella of the SAPRI, particularly in collaboration with small, micro and medium enterprises (SMME). SAPRI would also encourage the patenting process of said products should this be a possibility, though will not directly fund this. Based on the current capacity of South African partners, the following list gives an example of the products that can be made available in the near future:

1. User-specific sensors designed for use onboard autonomous profilers such as Argo floats, buoyancy gliders and wave gliders;
2. Drifting autonomous buoys to track sea ice movement and properties;
3. Subsurface mooring designs developed for fast-flowing currents, sea-ice movement and ocean acoustics;
4. Filtration systems for seawater used onboard ships and within laboratories to isolate either planktonic size classes or specific dissolved materials;
5. Advanced animal tracking and monitoring technologies;
6. Semi-continuous long-term observation platforms;
7. Digital models for material response to wave and ice interactions and applications to maritime engineering;
8. Long-term science-based data and value-added data products to support policy and outreach to society.

The research produced by the infrastructure will foster new blue-sky research, which will lead to an expansion of the set of products.

1.1.3.5 ***Classical research products***

The number of scientific publications on Antarctic science (including the Southern Ocean) is increasing worldwide. Indicators suggest that Antarctic studies are characterised by stable growth and dynamic international collaboration (Ji et al., 2014), with an increasing number of articles and citation counts since 1995. The more productive disciplines are geology, ecology, oceanography and meteorological sciences. South Africa is 17th in the world in terms of publications with almost 1800 publications, which correspond to 2.4% of the total (source: Web of Knowledge, search terms: Antarctic* OR “Southern Ocean”, retrieved in January 2021). The US has 33% of the publications, followed by the UK, Germany and Australia, all between 10 and 15%. South African bibliometric indicators have increased, from 30 publications a year in 1995 to more than 90 per year since 2015. South Africa’s scientific production in Antarctic research is thus growing at the same pace as the other countries (2019 showed a peak of 119 publications).

It is interesting to note that the installation of research stations and large infrastructures do not necessarily increase national research productivity in a quantitative manner (Kim and Jung, 2016). International collaborations seem to supplement the lack of large infrastructures in generating international recognition and prowess in Antarctic research, as it has been shown for Belgium, the Netherlands and Malaysia. However, in the case of India and China, infrastructural investments have had a direct return since these countries are now within the 20 most productive countries, with India recently surpassing South Africa despite its much later involvement in the ATS. The steady increase in publications is also not homogeneously distributed among the disciplines. An analysis of the distribution in South Africa compared to the world indicates that ecology, geology and conservation biology are the leading disciplines, with ecology being twice more productive than the others. Oceanography follows in the line, since it has been growing consistently since 2015. Life sciences show the more stable production of scientific outputs over time, largely represented by the work done on the unique habitat of the Prince Edward Islands.

There are thus different paces in the South African contribution to polar sciences, and SAPRI will ensure an open, responsive and diverse access to the polar knowledge system and infrastructures. Urgent measures are needed to prevent losses of unique expertise in fundamental polar fields such as geology and geomorphology of the Antarctic continent, mostly due to the erratic and limited logistical support for field observations. Scientific funding to these disciplines has not been maintained continuously with some cycles having no field-based programs, further exacerbated by the limitation of basic infrastructure to support such fieldwork.

While retaining existing expertise, the SAPRI strategy of open and distributed access to infrastructures in partnership with training institutions will increase the focus on inclusivity, transformation and linkages as addressed in the NSI. This will lead to an optimisation of the various branches of polar science and the consolidation/promotion of innovative developments such as those done in marine robotics and sea ice science. There is no Antarctic science without knowledge of cryospheric processes, and this lack of expertise in the country has prevented South Africa from being able to realise its potential to be the gamechanger in transforming the polar research system.

Polar science is influenced by scientific curiosity and classic research, but these activities reverberates in the science diplomacy field. Research in the major part of the geographical region underlying this proposal is only allowed due to scientific interest and relevance and not as a function of mineral or product exploitation, sovereign dominance of land or oceanic regions, or similar. Thus, the more classical research products will naturally be a large part of the output of the SAPRI.

These will include, but are not limited to:

1. Through the long-term observations of essential variables, new knowledge will be generated in terrestrial, ocean, marine, cryosphere, space science and technology, contributing to a diverse array of products evidenced by the multiple scientific disciplines listed in the Introduction. This will include but is not limited to inventories of biogeochemical elements of anthropogenic origin, seafloor and geological maps, species identification and distribution, climate change impacts on sea ice, marine and terrestrial habitats as well as the influence of some variables on climate change. These will be stand-alone products in their own right, serving societal knowledge, or contributing key input into policy and international polar agreements.
2. Peer-reviewed research papers will be published in journals promoting science understanding in the multiple scientific disciplines supported by SAPRI. This understanding will be particularly impactful given the global significance of the region (highlighted in the Introduction). Publications will be aimed at both regional and international audiences but will also promote well-established South African journals where possible. In addition, information around scientific publications will be made accessible to the wider public in appropriate formats such

as popular science publications, news articles and websites. The SAPRI and DSI will be suitably acknowledged in all such publications.

3. Observational and modelling based products (machine learning, re-analysis etc) that support both the research and societal climate assessment, prediction and ecosystem management policy needs.
4. Standards and Best Practices, new methodologies and technical aspects of the work undertaken in the various disciplines will be published, in line with the IODE Ocean Best Practices System[20] to promote quality data products and continuity.
5. Human Capital Development through training of highly skilled interns, post-graduate students at Honours and master's level, as well as Doctoral and Postdoctoral researchers in support of socio-economic development. The Introduction lists ten South African universities already engaged with the SAPRI and this will be enhanced through the SAPRI capacity development plan. This also excludes the large number of international universities already or likely to become involved with key investigators within SAPRI including African institutions e.g. Mozambique, Namibia, Kenya. Given the multidisciplinary nature of the SAPRI, the active participation of female students and young researchers, as well as those from disadvantaged communities will be fostered from the very beginning of SAPRI.

1.1.3.6 ***Collaborative space***

SAPRI will encompass several stakeholders, partners and entities, who are situated geographically across South Africa. Most notably in terms of physical space where infrastructure will reside and be worked with, the following spaces apply:

1. East Pier warehouse - in collaboration with DEFF, a number of pieces of infrastructure will be stored here, prepared for deployment and maintained thereafter. Infrastructure to be housed here includes the container labs (if enough space available), mooring equipment and Argo floats. The exact space to be made available still needs to be negotiated with DEFF. Should the improved logistical capacity needed for terrestrial research in Antarctica, be unable to be housed at East Pier, when not in use in Antarctica, warehousing could be provided at the DSI/NRF SA Astronomical Observatory facility in Cape Town.
2. The SOCCO - South African Robotics Ocean Technology Innovation Centre (SA-RobOTIC) - this facility, which was set up by SOCCO with DSI infrastructure funding is managed by Sea Technology Services under a collaborative agreement with CSIR, is based at East Pier and houses the current robotics procured under the Southern Ocean Carbon - and Climate Observatory (SOCCO), along with a number of other instruments owned by other entities such as specialised Argo floats, Ski-Monkey camera systems and CTDs. It also conducts innovative engineering R&D in response to research needs such as high precision sensors, which open commercialisation opportunities.
3. SOCCO Experimental Observational Facilities - SOCCO also comprises four experimental infrastructure facilities that provide ship and land-based observational capabilities: Ocean CO2; Ocean bio-optics; Ocean Iron and GEOTRACES.
4. Drifter cage - this small cage storage area houses SVP drifters received by NOAA and is also based at East Pier. The cage is maintained by the SAWS.

20 https://www.oceanbestpractices.org/

5. Polar Lab - this innovative laboratory, once built, will be located on UCT grounds and will become a shared space for recreating polar (ice) environments and temperature-controlled instrumentation work.
6. BIOGRIP facility - with reference here to the recently established biogeochemistry infrastructure BIOGRIP, which will be a shared collaborative space for nutrients, isotopes and general biogeochemistry analyses.
7. Council for Geosciences - for the storage and curation of geological samples, as well as the GIS facilities and expertise.
8. Seafloor facility - this facility will be based at SAIAB in Makhanda. The team will develop and assemble the seafloor instruments in this lab and ship to Cape Town where loading will take place onto the vessel. Some storage for instrumentation to and from the vessel may be needed at East Pier for this, thus the facility in (1) will also act as a transient facility prior to and after voyages.
9. Digital Antarctic facility – this facility is initially focused on the SA Agulhas II and will be expanded to the other platforms. All digital assets (detail data, raw models, reduced order models) will be housed at Stellenbosch University, including her data and models. This laboratory will further function to calibrate all sensors related to the SA Agulhas II full-scale instrumentation and her scale models.
10. SMCRI Laboratory - as a partner to the SAPRI, the Shallow Marine and Coastal Research Infrastructure (SMCRI) facility, hosted by SAEON on the Ocean Sciences Campus of the Nelson Mandela University, may be considered a collaborative space. There will be a sharing of instruments, particularly for the Prince Edward Island work, but also of technicians, sample analysis (nutrients, salinities, microplastics, heavy metals, plankton), etc.
11. SAEON Offices - SAEON will provide office space for the SAPRI hub, initially within the DEFF building with the Egagasini Node and then in the NRF Cape Town campus when it is finalised.
12. MRI Isotope laboratory - the Mammal Research Institute isotope laboratory at the University of Pretoria could be seen as a collaborative space to integrate isotopic research from various SAPRI projects.
13. Facility for Symposiums, workshops and conferences (ex SANAP biannual symposium and international events such as SCAR and its biannual standing committees and scientific groups and forums).

1.1.4 Education and Training

South Africa has a unique opportunity to transform the national and international research system, including the cliché of what an Antarctic scientist should look like. International science bodies like SCAR are currently focused on increasing the diversity of researchers involved in the far South, including through programmes like SCAR WIAS https://www.scar.org/antarctic-women but there is more to be done in terms of race and nationality. South Africa could be a leader in the wider call to imagine a postcolonial Antarctic, or to decolonise Antarctic science, history and art (Dodds, 2006; Dodds & Collis, 2017; Howkins, 2010; Scott, 2017). South Africa has a key role to play as the only country in Africa involved heavily in Antarctic research, both acting as a platform for wider African Antarctic science and changing the perception of the "whiteness of the white continent".

1.1.4.1 *Research*

Given the multidisciplinary nature of the SAPRI, the possibility of training technicians, interns, post-graduate students and employing postdoctoral researchers is substantial (see Chapter 5 for the detailed plan). Students from Honours and BTech level, through to PhD and DTech level will be encouraged with every stakeholder and partner to the project. The SANAP programme has provided an average of 70 student bursaries per year since 2004. As observed in the varying number of research outputs in Antarctic research produced annually by South Africa (Section 1.1.3.5), there has been a similar variability in student numbers linked to the projects that had access to funding. The SAPRI will ensure continuity of these results, and thus stabilise and further increase the number of students by allowing a wider community to access polar platforms.

The SAPRI will also encourage stakeholders or PIs to involve postdoctoral researchers in promising and growing projects to facilitate expansion and maximum impact in achieving research and HCD objectives. Students and interns will be trained from the development and creation of instruments through project management, observations and modelling, *in situ* training (at sea or on the Islands/continent) all the way through to data quality, processing, archiving and interpretation. The SAPRI will also support students and interns being trained through DEFF and will continue to foster and grow the strong co-supervision model that is currently in place. Providing instrument platforms through SAPRI as well as a coordinated approach to the SA Agulhas II and hence the Prince Edward Islands and Antarctica will open access to polar research throughout the country. Peer to peer collaborations between early career scientists will be enhanced through active involvement in the Association of Polar Early Career Scientists of South Africa (APECSSA), which will be an integral component of capacity development and communication through the societal pillar of SAPRI.

In addition, the SAPRI has a strong equity and redress agenda and will actively commit to recruiting female students and students who have come from disadvantaged backgrounds by utilizing programs such as SEAmester [21] and supporting black academics at HBUs to access the SAPRI platforms. In alignment with the proposed ACEP model, the SAPRI will engage with the Phuhlisa program [22] to design training in polar science. This approach will be co-generated from the inception of SAPRI to ensure that the most effective method of engagement is utilised to grow and support a transformed, diverse polar community.

The SAPRI will also encourage an applied nature to the research projects undertaken, so that students making use of the SAPRI facilities will be able to put this knowledge into practice once they are employed. The SAPRI will actively encourage skills development of young technicians, engineers and scientists with regard to new technologies and industry-endorsed techniques and methods. These skills will provide an excellent complement to Operation Phakisa Ocean, a major Blue Economy initiative, that will increase the demand for skills in marine observations and highly numerate marine science applications to service developing operational capabilities such as the DEFF-led Ocean and Coastal Information Management System (OCIMS). In addition, such a skill set will ensure that graduates are eligible to be employed seamlessly anywhere in the world.

The Prince Edward Islands historical monitoring is an outstanding example of how individual scientists and small teams can make a profound collective impact on our knowledge of sub-Antarctic environments. As a nation, we cannot rely on single individuals but on a system, because this can reproduce itself and provide continuity. The existing and new observational platforms identified in SAPRI will be utilised to train post-graduate students, continuing and enhancing the model proposed by the SEAmester program (see Chapter 5), hence reaching across all the South African Universities to inspire and contribute to a knowledge society. The *in-situ* training and experience gained by

21 https://seamester.co.za/
22 https://www.saiab.ac.za/acep-phuhlisa-programme.htm

overwintering personnel is truly life-changing for many aspiring researchers and contracted personnel. Field experience in experimental design, data collection and contextualisation of science in the environment (and not just in front of a computer) is becoming increasingly rare globally. The continued support (through SAPRI and HEI) of overwintering personnel at Antarctic and sub-Antarctic bases constitutes a vital aspect of skills development, life experience and research progress. To date, and due to these varied and intense experiences, such returning overwinterers have become influential contributors in various sectors of South Africa and the world, including to public understanding of science. Not every South African student will, however, have the privilege to visit Antarctica but there will be many other experiential opportunities offered through the SAPRI, especially through the Polar Lab, which is a simulator of Antarctic and sub-Antarctic environments.

1.1.4.2 ***Public understanding of science***

Humanities disciplines such as literature, history, archaeology, architecture and the arts, and social sciences disciplines like development studies, economics, philosophy, anthropology and psychology, can all contribute directly to Antarctic knowledge production as well as to the public understanding of polar science in South Africa and further afield. Psychological studies of isolation in overwintering teams have produced significant results elsewhere but have not yet been conducted on South African teams. Indigenous knowledge systems about Antarctic-derived weather patterns are the subject of on-going anthropological research in Chile, Argentina and Australia and will be promoted in South Africa through the SAPRI communication pillar. There are long histories of, for instance, sailors from African shores engaged in sealing activities on sub-Antarctic islands, which have yet to be excavated, analysed and the resulting knowledge disseminated. These could contribute to a broad sense of national ownership of the region, increasing the motivation to steward and explore.

The Public Humanities programmes of interdisciplinary projects such as the Oceanic Humanities for the Global South project (www.oceanichumanities.com) have experience in drawing together diverse knowledge and promoting awareness of science and history, in ways that will contribute to the SAPRI work. Wider public understanding of Antarctica’s place in South Africa (and South Africa's place in Antarctica) can also be promoted through a South African Antarctic Artists and Writers Programme, based on the model of most other countries with Antarctic research programmes (USA, Australia, New Zealand and UK[23]). This is something that the SAPRI communication pillar will initiate by inviting artists, writers, journalists, and documentary film teams to join research expeditions (with minor additional expense) substantially enhancing the impact and visibility reaching public audiences nationally and internationally. As such, the SAPRI would play a key role in facilitating access to Antarctic research and coordinating the public relations and arts-and-culture-based promotion. This contributes to raising awareness of Antarctic territories, national pride, scientific curiosity, and South Africa’s international standing and commitment to environmental stewardship.

According to the World Economic Forum, South Africa is rated last out of 148 countries in terms of the quality of education for maths and science. Yet, the world is moving through the fourth industrial revolution, which is heavily reliant on data science, technology and out-of-the-box thinking. Thus, as a country, we need to address the negative perception of maths and science by providing inspirational role models and curriculum-based programs which support the teaching of maths and science. The

23 https://www.nsf.gov/geo/opp/aawr.jsp; https://www.antarctica.gov.au/about-us/antarctic-arts-fellowship/; https://www.antarcticanz.govt.nz/media/community-engagement; https://www.bas.ac.uk/media-post/british-antarctic-survey-and-arts-council-england-fellowships-3/

charismatic nature of polar science can be used to attract students to scientific, research, conservation and maritime careers more generally.

The best approach to this is to showcase these subjects in a way that is engaging, relevant and attainable. This role in the Antarctic space has been undertaken by the Antarctic Legacy of South Africa[24] (ALSA), which is currently an initiative of Stellenbosch University within the 3-year funding cycle of SANAP. As part of the wider integration of the SANAP components, SAPRI will make ALSA a founding pillar of the outreach and science communication activity within the RI, as further detailed in Chapter 2. The ALSA model will be expanded to incorporate all the polar science disciplines represented in South Africa.

Science communication is the key factor, as the public understanding of polar science needs to be well communicated. The ALSA experience in communicating remote places and the research involved in their exploration will ensure a coherent approach to the public understanding of polar research. It will be a focus of the SAPRI through its dedicated component to engage the scientists and technicians from all the disciplines it represents, along with creative arts teams to create content for secondary education use. The content should be in the form of documentary-style videos, online engagements with scientists that involve Q&A sessions, visits to schools that cannot easily visit research vessels, internships and job-shadow opportunities, demonstration days, etc. A breakthrough in communication will come from the elaboration of digital twins of the ship, the bases, the Polar Lab and other platforms, which will allow learners and the wider public to immerse themselves in the science environment.

Marine and Antarctic science has long been a key component of the SAEON Egagasini's node education program and has been integrated into efforts to support curriculum-based outreach and inform communities. Hundreds of learners and educators have been inspired through visits to the Agulhas I and II and a select few have had the opportunity to go to sea on both SEAmester and other research cruises. The broader SAEON education program team (across the marine and terrestrial nodes) will work with SAPRI to support science integration into schools and communities.

1.1.5 Employment creation

The SAPRI will directly employ 39 staff over a 15-year life cycle. In the development of the SAPRI, most institutions interviewed noted the lack of technical resources to assist with data acquisition, sample analysis, data processing, at-sea work, as well as the terrestrial environments, etc. This would be a vital area that requires the creation of employment, whether internal to the SAPRI or external. Given the sporadic need for e.g. sea-going technicians, depending on logistics, it is essential that SAPRI technicians are multi-disciplinary, able to go to sea and work on a variety of instruments, as well as process data on land and carry out procurement and asset control. To ensure for this a dedicated employment plan, which will inherently include training, has been designed to support this component that is a founding pillar of long-term observations.

In addition to the 11 technical staff, 10 data team members, 2 administration, 4 annual overwinter team members and 7 Management Team members will be employed. Staff already in place in the host organisation, SAEON, will contribute and support the SAPRI.

24 https://blogs.sun.ac.za/antarcticlegacy/

External employment opportunities will be facilitated through SAPRI due to the increased contracting of SMEs to support the growing needs of the innovative and highly technical nature of the research supported by the SAPRI, including the development and maintenance of instrumentation. SAPRI will play a large role in both seeding and potentially supporting the growth of MEs and start-ups outside (but connected to) SAPRI.

1.1.6 Commercialisation

Science and research in the polar and marine space are usually undertaken over long periods of time to better understand our planet. Yet, nearly all of our modern-day inventions stem from curious minds who were able to commercialise their thinking. The two primary commercial outputs envisaged from the SAPRI would be the development of new sensors, infrastructure or technologies, and the provision of services to a community greater than those involved with the SAPRI. SOCCO has already demonstrated the success of basic-science as a platform for technology innovation and commercialisation. It has started the national and international commercialisation of its in-house CO2 sensors, innovation originally designed and built to address the needs of its robotics observations. Examples of potential commercial outputs are given below:

- Development of cost-effective new sensors, infrastructures and technologies: there is a niche in the market with new technologies being developed, but most are typically very expensive and not all are robust enough for the extreme cold and long deployments the SAPRI would be undertaking:
    - Biogeochemical and physical sensors as payloads on autonomous instruments, moorings or overside instrumentation
    - Deep seafloor landers, camera technologies and ecosystem samplers
    - Diverse mooring technologies and deployment techniques
    - Sea-ice surface drifters
    - Animal biologging and monitoring technology.
- Services and future marketable products:
    - Calibration of sensors and infrastructure in temperature-controlled environments within the Polar Lab
    - Storage of temperature-sensitive samples within the Polar Lab
    - Marine natural products from seafloor biota
    - Data science: maximising the value chain from data collection, quality control, processing and archiving to data products for uptake by commercial / government / academic and public enterprises
    - Development of digital services from digital twin models is a major opportunity-maker in current business. The implementation of these technologies is not yet commonplace as most technical activity, especially in the marine sector, revolves around the creation of efficient real-time digital twins. It is foreseen that digital twins, packaged to deliver specific digital services, will evolve as marketable products of the future.

1.1.7 Outputs, outcomes and impacts

Table 2 ***Outputs, outcomes and impacts***

Outputs	Outcomes	Impact	Macro-economic environment
Educational and public Outreach	Learners encouraged to take maths and science at school and to study science at a tertiary level. Enhanced public awareness of South Africa's work in the polar regions.	Higher uptake of maths and sciences at school. Improved pass rates and University exemptions. Improved public buy-in for polar activities.	Better qualified learners for the job market. Improved pass rates at HEI's. Awareness and appreciation of the environment.
Education and training through research in polar region	Number of students graduated through the infrastructure, number of interns and technicians trained, publications, presentations, but also statistics on their career-track (including future academics, science council and government lab employees).	Knowledge base for global understanding of the Polar region and the life it supports and changes to the planet. Enhanced representation of South Africa in the international polar research. A transformed and diverse polar research community.	Furtherance of South African interest, skills and knowledge development for application in the Polar region. A base for leveraging science-tourism benefits from Antarctica.
Data	Multi-disciplinary datasets will become available at improved spatial and temporal resolution. Ongoing Essential variables will be measured and number of variables increased. Data will be high quality, open access by researchers, government, industry and citizen scientists.	Informed Antarctic regional policies and public support for promoting SA's Antarctic interest. Improved understanding of the ocean environment around South Africa and Antarctica, as well as the terrestrial, biological and space environment. Understanding of the impact and	New business creation and entrepreneurship, to exploit the opportunities created by the growing demand for services in the polar region. Long-term observations to detect climate change in the Southern Ocean and Antarctic environment. Improved use of data and generation of new

		consequences of global change. Released specifically for innovation and improved government. Knowledge of linkages between the Polar disciplines (ocean, atmosphere and biosphere)	products and services and faster R&D. Data products and information for Phakisa and information to ensure environmental planning in the growth of polar science. Informed macroeconomic polar policies for government and improved marine and terrestrial governance
New knowledge, science and technology	Intellectual property protection. Continued innovation. Increased publications. Increased presentations in the international arena. Improved governance.	Competitiveness in the Polar region supply markets. Increased publications in high impact factor journals. Increased collaboration with international partners.	Export income growth. Increased knowledge economy. Improved management of resources, MPAs and biologically sensitive regions.
New analytical services, and services to partners	Increased use of collaboration and partnerships to develop mutually advantageous trade with respect to servicing different national interests in the Polar region. Transform big data sets into actionable information. Broader user base of analysed datasets.	Positioning the SAPRI as a competitive force in international frameworks of polar science. Increased data-driven decision making.	Partnerships with African and international collaborators in a world-wide excellent science network. Improved decision-making and increased innovation. Technology transfer.

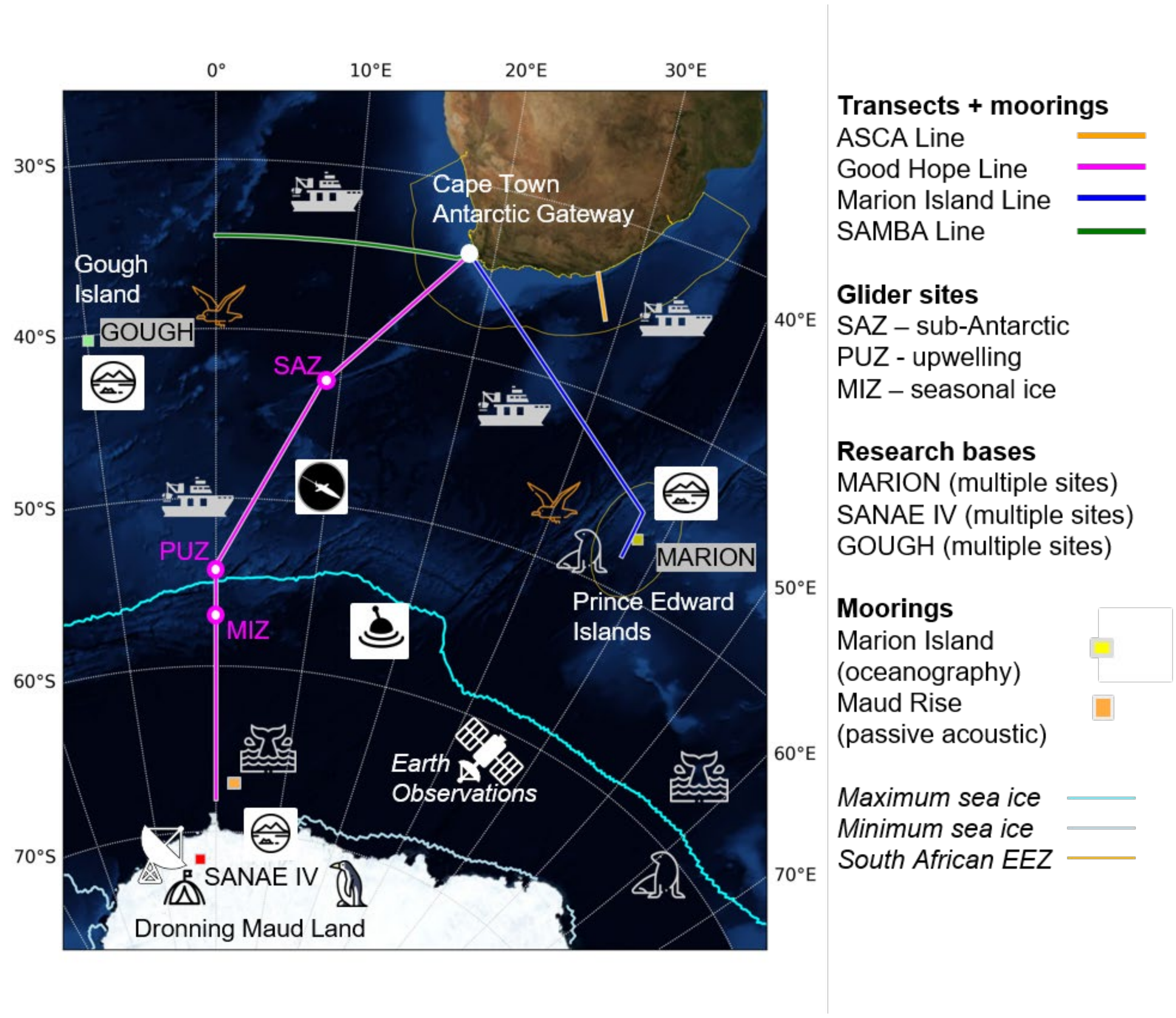


Figure 4 ***Map of the South African scientific presence in polar research****. The map shows the location of the research bases within the region subject to the ATS, the main transects and mooring sites of the oceanographic programmes and the locations of the glider long term and experimental observing sites (LTEOS). The extent of seasonal sea ice and the South Africa's (SA) exclusive economic zone (EEZ) around mainland Africa (SA EEZ) and around Prince Edward Island are also shown. [This image has been designed using resources from Flaticon.com]*

1.2 Scientific

South Africa has a recognised capacity in undertaking long-term observations of the polar environment as illustrated by the map of its presence in polar research (Figure 4). South African science and vision within SANAP is summarised in the MARS research themes:

- Oceans and marine ecosystems under global change
- Earth system observations
- Ecosystems, biodiversity and biodiscovery
- Innovation and development
- Human enterprise

Box 1, found at the end of the next section, presents an overview of the current and future South African and international research interests, which will be served and facilitated by the proposed RI. Chapter 2 will further expand on the excellence and uniqueness of the multiple RI components.

1.2.1 South Africa in the polar scientific context

Over the past 50 years, multiple measurements of land, ocean, atmosphere and space variables have been made. In this context, and in the activities presented in Figure 4, we focus on the observations collected in the framework of SANAP projects since 2003 and on the datasets that have been coordinated as part of international long-term initiatives. Figure 5 and Figure 6 present a schematic showing the breadth and extent of long-term datasets that have been, or are being, observed by South Africa's SANAP community in the region and sites illustrated in Figure 4. The full details are given in Appendix B. This is the science universe that the SAPRI intends to integrate, support and grow. These schematics are not meant to be an exhaustive inventory of all the existing data collected by South African scientists in polar expeditions. In particular, oceanographic cruises have occupied some of the transects shown in Figure 4 earlier than shown in Figure 5, but those data have been mostly used within the teams that originated them. We highlight here the set of data that have been specifically funded by SANAP and the related earlier programs, and that have contributed to the creation of a continuous database of national and international interest.

Globally valued long-term climatological and ecological datasets have been generated and maintained by the South African science community, specifically at Marion - and Gough islands (top panel of Figure 5). They meet South Africa's (in the case of Marion island) and the United Kingdom's (in the case of Gough Island) obligations under the Agreement on the Conservation of Albatrosses and Petrels (ACAP) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the World Meteorological Organization. Phenological investigation of vegetation at Marion Island commenced in the mid-1960s alongside the first detailed invertebrate research. Vegetation and invertebrate research here has progressed through aspects of physiological investigation related to climatic changes and tolerance, invasion biology, etc. Top marine predator research (seabirds and marine mammals) commenced in earnest in the late-1970s/early-1980s. Demographic research on several of these species have continued uninterrupted to date, providing amongst the worlds' most intensive long-term investigations of vertebrate life-histories. Concomitant efforts to better understand population sensitivities to global change (including climate change) have seen much focus on foraging ecology and species interactions at the local and regional scales over recent decades. A broad footprint of international partnerships and collaborations resulting in high impact research outputs have been heavily dependent on these long-term top predator datasets.

As shown in the bottom panel of Figure 5, since the first decade of this century, a new set of oceanographic observations has been implemented through national funding linked to the Grand Challenge and SANAP. Since 2012, the country has operated the SA Agulhas II, a world-class polar research vessel equipped with full-depth CTD capabilities, multiple winch systems for over-side operations of nets and equipment with extensive wet and dry laboratory space. The ship transects and mooring programs maintained by South Africa, with international collaborators, provide data and information which serve the global community and have been recognised through international panels as being essential. This dataset has recently been expanded by the addition of dedicated sea ice research. All polar institutions in the world run research on ice properties, which represent about half of the scientific production in Antarctic science. South Africa has primarily relied on external collaborations for ice-related research. In the past few years, a line of research led to the development of expertise in cryospheric processes and the deployment of dedicated container laboratories to be loaded on the vessel and autonomous ice-tethered devices to observe sea-ice drift. The South African science community have also developed capacity and infrastructures to analyse key ocean variables that have the potential to develop into longer-term datasets on nutrients, carbonate chemistry, trace metals, phytoplankton abundance and primary and secondary production.

SOCCO science aims to understand and predict the changing role of the Southern Ocean in the regional and global carbon - climate system as well as contribute to closing the observational gaps in time and space in the Southern Ocean. To support this goal, it has undertaken 2 major long-term observational initiatives: The ship-based (SA- Agulhas I and II) underway CO_2 and physical surface ocean observations, which has been carried out in almost all the relief voyages since 2008. These data are integrated as the South African contribution to a globally coordinated gridded data product (SOCAT). From this SOCCO has developed a machine learning product CSIR-ML6 and has reconstructed the temporal and spatial variability of ocean CO_2 since 1985. It is now used globally for ocean science and to constrain the trends in the global carbon budget and IPCC. The second SOCCO long term observational effort is based on the deployment of coupled ocean robots (gliders) capable of providing long-term high-resolution observations of the seasonal variability in the physics, the CO_2 and biogeochemistry in the upper 1000m and across the air-sea interface. These high-resolution observations have been undertaken in both the SAZ and the Polar upwelling zone since 2012. In addition to robotics and CO_2, SOCCO has developed an infrastructure capacity for GEOTRACES, bio-optics and experimental biogeochemistry that serves as a national asset allowing cost-effective research and development for powerful multi-ecosystem observations. SOCCO is growing into a global leader in integrating high resolution observations into machine learning models to reduce the existing biases and uncertainties in the reconstruction of air-sea fluxes. These reconstructions are fundamental to understanding and predicting, through improved ocean and Earth System models, the sensitivity of the Southern Ocean to climate change.

Space physics observations in the southern high latitudes are rare compared to northern latitude coverage and as such the suite of instruments at the SANAE IV base, Marion Island, and Gough Island provide unique and valuable data sets (Figure 6). Most of this data is contributed to international observation networks that cover a variety of topics, e.g. the World-wide lightning location network (WWLLN; www.wwlln.net), Automatic Whistler Detection and Analysis Network (AWDAnet) for plasmaspheric modelling, and the SuperDARN radar network, among others. These are all global data sets dealing with phenomena in both hemispheres. South Africa operates the longest continuously operational Antarctic neutron monitor in the world; this data is used for heliospheric physics and modelling related to radiation dose rates pertaining to commercial flight operations. Fundamental space physics research questions operate on various time scales -- from real time measurements, now-casting and forecasting of space weather, to monitoring the 22-year solar cycle -- high quality, high cadence and long-term observational data sets are valuable assets.

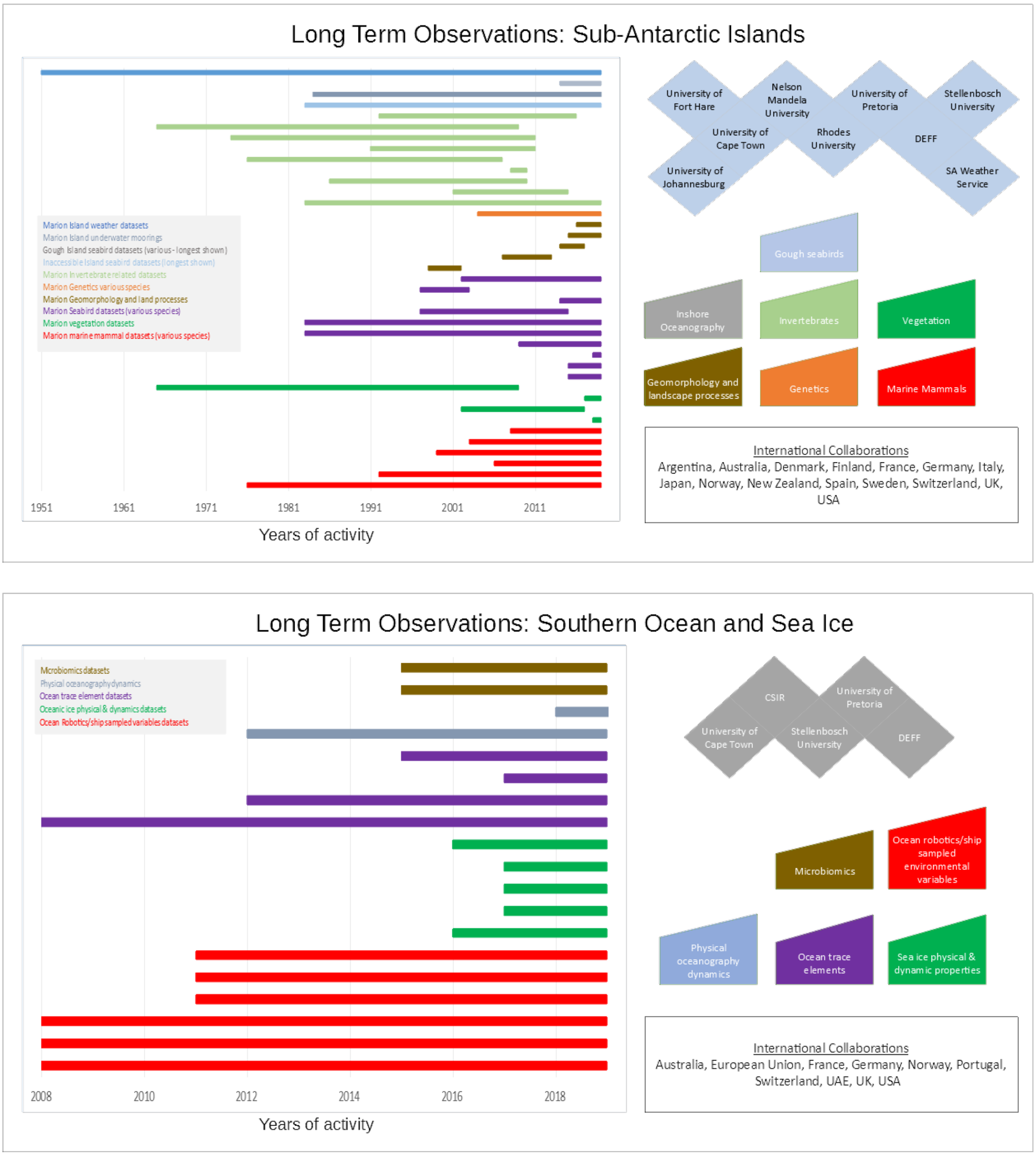
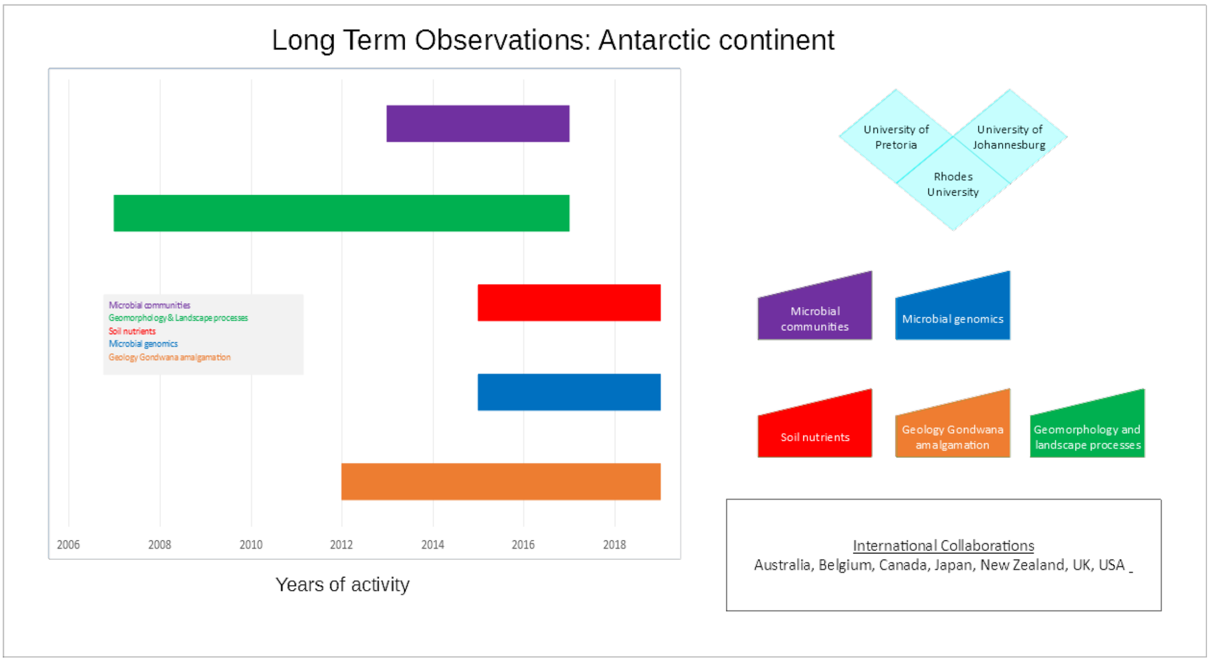


Figure 5 ***Historical long-term observations in the sub-Antarctic islands and Southern Ocean***. *The historical and ongoing observations are colour-coded according to the general themes in the legend on the right, which also shows the national stakeholders. Time series ending on the right margin of the graph were supported within the 2018-20 SANAP funding cycle. The list of international countries collaborating with the national partners is also indicated. Each bar represents a different dataset that is specifically listed in Appendix B. (Source: N. de Bruyn)*



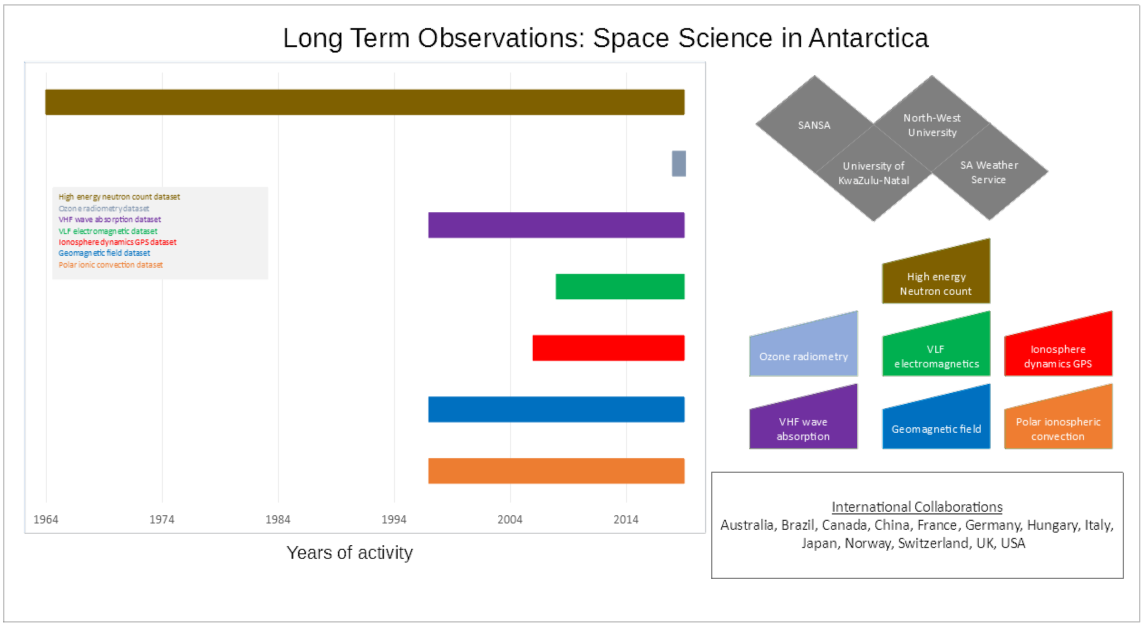


Figure 6 ***Historical long-term observations in Antarctica.*** *See caption to Figure 5 for details.*

1.2.2 Scientific impacts of SAPRI on long-term observations

As demonstrated by the successful international repositories (see Chapter 2 and Table D1), the observational value chain is established only if data are sustainable and integrated into international observational networks. SAPRI will enhance the value of past and future data, making them more readily available for creating knowledge.

The SAPRI will create an environment conducive to science by consolidating the following aspects of long-term observational systems:

- Establishment of a multi-disciplinary network of polar monitoring sites which make use of a seamless integration of manpower and advanced autonomous observations, information and communication technologies. The consolidation of existing observational networks will lead to the development of a durable model for incorporating new observations and data streams according to a research-to-operation protocol.
- More efficient research expeditions, for increased scientific production and capacity development through the implementation of dedicated science logistics management. A large portion of human and capital resources is currently employed by scientists to organise and maintain these expeditions and the observational networks. Precious resources will then be redirected towards scientific products and training.
- Provision and maintenance of advanced vehicles and instrumentation for the exploration and characterisation of the Antarctic environment through a combination of human-operated and autonomous devices. Improved efficiency and redundancy of existing and new equipment by establishing dedicated warehouses for their booking, management and maintenance. This will alleviate some pressure on the SANAP-Logistics component and ensure harmony and alignment between the requirements of scientific projects and the infrastructural components.
- Modernisation of existing Antarctic large RIs (ship and bases) will allow remote control of operations, continuous near real-time data streams and archival thereof.
- Establishment of dedicated facilities to perform science and train personnel to operate in cold environments. This will allow personnel to collect, measure and store ice samples, conduct temperature-controlled experiments on biological specimens from the polar environment and to recreate the harsh ice-ocean-atmosphere dynamics for the design/calibration of instruments and the impact on structures and materials.
- Creation of a deep-sea thematic study area, which represents new capacity for South Africa in the deep polar ocean (200 - 6000 m) but also in the shallower environment of the Sub Antarctic islands and the Antarctic continental shelf and slope. Deep ocean geomorphology and benthic ecosystem research in South Africa is in its infancy. A dedicated facility will develop research projects to explore and quantify diversity in our deep oceans and, due to the seasonality of access to Antarctica, support complementary research within South Africa's mainland EEZ and other areas.

Box 1: *Polar science research framed into the South African MARS science themes (adapted and expanded from MARS, Skelton et al., 2014 and Ansorge et al., 2017)*

MARS Theme 1: Oceans and marine ecosystems under global change

Large-scale ocean circulation and global climate. The Southern Ocean is a unique part of the global coupled ocean - climate system in that it "closes" the ocean circulation on a horizontal scale by linking all the ocean basins. Vertically, it closes the meridional overturning circulation (MOC), a global system of surface and deep ocean currents. It is the primary mechanism for the ventilation, transport and storage of heat, fresh water and carbon throughout the global oceans, and connects the ocean surface and atmosphere with the deep oceanic reservoir of heat, nutrients and carbon. The most dynamic region of the Southern Ocean–MOC circuit lies south of Africa. The weather generated in this area regulates water supply to the Cape winter rainfall regions and winter snow melt from the Drakensberg mountains to Gauteng. Similarly, changes in oceanic circulation patterns within the region of the Prince Edward Island group is impacting the islands' climate and diversity/abundance of species that it supports. To identify the potential drivers of climate change in this region, we need to improve understanding of the interplay between the Southern Ocean and the Greater Agulhas Current systems which borders the South African coastlines.

Southern Ocean in the coupled ocean-atmosphere-biosphere-sea-ice system. Understanding the links between ocean-atmospheric physics at the synoptic-seasonal scales coupled to mesoscale and sub-mesoscale dynamics are critical to understand and model the evolution of carbon-climate feedbacks, ocean, the biological carbon pump, iron availability, macronutrient and trace element biogeochemistry, ocean ecosystem functioning. Extensive multiscale and seasonal investigations into the sensitivity of large-scale trends in the Southern Ocean are necessary. About 85% of all ocean productivity is supported by nutrients derived from the Southern Ocean. These nutrients are seldom limiting south of 50°S, yet phytoplankton biomass remains low as a result of trace- or micro-nutrients and light limitation. Through combined observations, experimentations and empirical models, we can constrain the exchange fluxes of carbon and other climate-relevant biogeochemical elements and help assess the risks associated with changing oceanic biogeochemical cycles.

Antarctic ice shelves and sea ice and their role in the global environment. The seasonal advance and retreat of the Antarctic's 15 million square kilometres of sea ice is a phenomenon that remains under-appreciated, particularly during winter when access is limited. The use of remote sensing observations allows capture of the large-scale and longer-term variations, but this information needs to be ground-truthed by appropriate observations. Much of climate science is dedicated to the study of ice shelves, and their role in sea level rise. East Antarctica is undergoing a major decline in ice volume, which is likely due to ocean warming. Ice shelves may also be further exposed to the action of waves in case of sea-ice reduction. In-situ measurement and long-term monitoring of Antarctic sea is in its infancy, especially the way it is affected by the storminess of the Southern Ocean. Sea ice also acts as a habitat for microorganisms and a buffer for micronutrients, CO_2 and trace elements. There is a clear need for further research to better understand how these processes influence the Antarctic cryosphere and its link to the climate system.

MARS Theme 2: Earth systems

A window into geospace. Fundamental questions for space physics include the mechanisms of coupling between the solar wind - magnetosphere - ionosphere systems and the energy transfer between the different layers in the upper atmosphere. Space weather affects critical infrastructure such as power grids, navigation and communication networks and commercial air traffic. Important research questions include how helio-climate variability may impact long-term terrestrial climate, or how best to forecast the severity of impacts on our atmosphere and technologies from sporadic solar storms. For example, space weather observations within the South Atlantic Magnetic Anomaly where the earth's magnetic field is weakest, are critical for understanding the impact of particle precipitation on ionospheric scintillation and its impact on satellite navigation. Space weather modelling and prediction efforts rely on data from the southern high latitudes and it is important for South Africa to establish and enhance its independent research and development capability in this field.

A window into earth's history. By driving the global carbon cycle, the Southern Ocean has played a key role in earth's climate over millennia. To understand both the magnitude and rate of current change, the scientific community needs to delve into the past. Some of the best-known proxies for past climate are derived from microbial organic compounds and metals and their isotope signatures recorded in microfossils, which serve as a palaeo-thermometer and record of ice volume, as well as an archive of past nutrient utilisation. Similarly, gases trapped in continental ice-cores provide a CO_2 and temperature record.

Multiple proxies in sediment or ice cores as well as dating of these archives, along with eroded surfaces and deposits allow reconstruction of past climate evolution, sea ice extent and

In the shorter term, the terrestrial landscape of continental Antarctica, most visible in the areas of exposed ground called nunataks, is key to understanding the earth system's responses to global change. Ground temperature measurements in the region show that the active layer and permafrost temperatures continue to increase. Such information has important implications for understanding Antarctic geomorphology, permafrost, the active layer and water availability in soils, as well as how these are changing in a warming climate. Recognising that progressive ice sheet instability, arising from global warming is receiving increasing attention, related to this is the recognition that the heat flux from the rock substrate underlying the ice-sheet is not uniform. Consequently, studies on the heat input from the rock adjacent to and beneath the ice-sheet base will contribute to understanding the Antarctic ice-sheet evolution and stability.

In addition to research on earths' history informing on climate change scenarios, there remains a need to obtain better data and an improved understanding on the common ancestry of the continental landmasses. Although the configuration of Gondwana is fairly well constrained prior to its fragmentation, the geological processes and distribution of the continental blocks which led to its amalgamation are still poorly understood. In this context, Dronning Maud Land, where SANAE IV is located, lies in the broad area of the intersection of two orogenic mountain belts of similar age – the East African and Kuunga Orogenies. The timing of the breakup of Gondwana is not well constrained with new data limited to Dronning Maud Land suggesting an earlier breakup initiation by ca. 30 Million years at ca 210 My with onshore paleomagnetic data suggesting that Antarctica had drifted significantly by ca. 180My. This has implications for the age of formation of the

environmental consequences over geological time-scales of millions of years.	Southern Ocean, ocean floor sediments and magnetic anomaly patterns.
MARS Theme 3: Living systems	
Ecosystem functioning and the response to global change. The terrestrial ecosystems in the sub-Antarctic provide valuable opportunities to study ecosystem responses to global change. The Prince Edward Islands, in particular, have experienced warming at double the global average rate and a decrease in precipitation of 30% since the 1960s. Some biotic (e.g. rapid upslope expansion of flora) and abiotic (e.g. loss of ice plateau) consequences of these climatic changes have already been documented, with severe impacts on ecosystem functioning predicted. Furthermore, the study of seabirds and seals at their terrestrial breeding grounds provide valuable information on the state of the surrounding marine environment. Tight interactions across the food web impact a wide range of trophic levels, from bacteria and viruses to apex marine predators. Global warming is likely to drive important changes in biological interactions between the components of the pelagic food webs. Currently, abilities to reproduce the seasonal cycle of primary producers with numerical models are limited, which impacts on the reliability of projected responses to changes. At the same time, the microbial community and predators (from krill to whales) have complex, little-understood feedbacks that affect productivity and therefore biogeochemical cycles that are of global importance. Sub-Antarctic islands typically have simple ecosystems, which have been affected by the variable histories of these islands (continental or volcanic origin, glaciation, volcanism) linked to global change. For Marion Island, genetic diversity is unexpectedly high and notably structured across the island, while at local scales,	Invasive species on Marion and Gough Islands are of growing concern as a consequence of the changes which they effect on native species (with documented impacts on seabirds, invertebrates and plants) and the resulting impacts on primary productivity, nutrient dynamics and community composition. In contrast to several new species becoming established on sub-Antarctic islands, few alien species have to date established themselves on continental Antarctica, although the potential for the establishment of human-transported species (and the associated environmental impacts) may increase strongly under warming conditions. As a result, these ecosystems are also particularly well suited for studying the interplay between climate change and biological invasions. *Biodiscovery and biotechnology.* Recent advances in metagenomics have focused attention on mining genomes for enzymes, biocatalytic pathways and bioactive secondary metabolites with industrial and pharmaceutical potential, as well as on the potential for gene discovery in the largely unexplored novel marine viral genomes. While the sub-Antarctic and Antarctic regions, including the Southern Ocean and the sea ice, are thought to be regions of relatively low higher organisms species diversity, but high microbial diversity, high levels of endemism and high levels of functional genomic adaptation to these extreme environments. There is scope and capacity within South Africa to explore the potential of this field. Modern metagenomic bioprospecting methods have the

dispersal is influenced by prevailing winds and local topography. Understanding the exact drivers of such high diversity and spatial complexity, as well as the role of local adaptations, will be important in ensuring the long-term conservation of biota. Given their extreme isolation, both Antarctica and the sub-Antarctic islands also form an ideal system for understanding invasion trajectories and for examining the impacts of species introductions (and subsequent eradication; e.g. rodents and feral cats) on ecosystem functioning.	advantage that they have almost zero environmental impact – just a few grams of soil or milliliters of water can generate gigabases of nucleic acid sequences that can advance our understanding of polar biodiversity, bio-economy, and climate change.
MARS Theme 4: Innovation and technology	
Technology and engineering. The infrastructure and logistics supporting polar research are constantly in need of redesign, maintenance and improvement. The harsh conditions of the Antarctic provide an opportunity to evaluate the most recent designs and adaptation of technologies and construction materials. Over and above being infrastructure platforms, research vessels such as the SA Agulhas II allow for multiple opportunities for parallel and non-exclusive research. Ships can be equipped with measurement probes which contribute to all the fields of research listed in Theme 1 and 3, to the near-real time transmission of data for weather and climate models, while at the same time fostering the blue economy and maritime transport. Today, the SA Agulhas II (SAAII) is equipped with +200 engineering sensors. She boasts an unparalleled full-scale data history which has proven its crucial utility to validate the POLARIS Risk Index for the International Maritime Organization and has led to internationally published research on ice-induced propeller moments, wave slamming and human task performance. This research area offers unique opportunities for innovative and	Next frontiers of research aim to fully leverage the unique advantage of scarce operational full-scale ship data towards novel research contributions in shipping. New engineering models for ships require validation against real data. The SAAII, her working environment, her sensors and her access culminates to data and matchless practical traction. Furthermore, the challenging field conditions for research promote creativity in the development of novel technologies that can be applied more broadly and are already generating commercial opportunities. *Robotics and autonomous observation devices.* Modern technologies are delivering significant advances in automation and unmanned platforms that can address our lack of scientific ability or continued presence through year-round observations. Such activities in engineering and robotics have multiple auxiliary benefits to society by spurring scarce skills in engineering and innovation that provide positive spin-offs for the greater South African economy. It is important that South Africa remains a global

leading engineering studies; within the South African context this field is largely unexplored.	leader in the rapidly growing area of specialised marine technology and robotics.
MARS Theme 5: Human enterprise	
Geopolitics and legal aspects. South Africa has enacted a number of statutes that are directly or indirectly relevant to this region. It is therefore essential to monitor and ensure that the South African domestic legislative and regulatory framework remains in line with developments in international law. *Arts, architecture and literature.* South African activities within the humanities in Antarctica and the Southern Ocean remain insignificant and the few that have been undertaken remain poorly recorded. The challenge is to engage with non-scientists, creating opportunities for artists (such as writers, poets and musicians) and social scientists to partake in SANAP voyages to see for themselves the region and to be involved with South Africa's activities within it. This area has been addressed successfully by other programmes and South African expeditions are only recently starting to incorporate these aspects that will largely enhance the awareness of Antarctica.	*Human history and archaeology.* Although relatively recent, there is a rich history of human enterprise in the Antarctic and Southern Ocean. The Antarctic Legacy of South Africa archival database is an online, open-access tool for supporting historical, archaeological, sociological and other research. This research sub-theme intends to encourage usage of the resource and to develop and refine this important asset. *Social adaptation and human impact.* The Antarctic and Southern Ocean is a harsh inhospitable region in which any human activity can be extremely stressful and unforgiving. As such, the region provides a natural laboratory for studying the human condition under stress (prolonged lack of daylight, close confinement, etc.). Also, tourism to the polar region is increasing and already makes use of South African infrastructure. The effects of tourism in these highly sensitive regions of the world need to be closely studied.

1.3 Socio-economic

South Africa has an interest in ensuring that the ATS continues to be recognised as the only appropriate mechanism for the management, environmental stewardship and governance of the region. Hence, Antarctic research takes on a political dimension: if a country's researchers produce and disseminate good science that is recognised by the international partnership, this achievement bears well to the government's standing (Elzinga, 2016). To this end, the South African government has indicated its ongoing commitment to continued research through major financial investments in polar infrastructures, which have generated an impulse in attracting the general public to the understanding and conservation of Antarctica and the oceans. The STEM disciplines, science, technology, innovation, engineering, biology, geography, etc., are firmly entrenched within Antarctic science.

Some of the ways in which the SAPRI intends to undertake this work includes:

- Promoting awareness through Humanities and Social Sciences research as well as the incorporation of the successful ALSA initiative, with knowledge dissemination to promote the STEM disciplines involved in polar sciences
- Foster innovation in communication technology and development of extreme environment materials/technology with possible commercialisation potential
- Advanced data management and the use of digital twin technology to ensure rapid data analysis, availability of climate-relevant time series and products for their integration in decision-support systems
- Establishment and retention of a cohort of African polar scientists with interdisciplinary skills and exposure to state-of-the-art RIs
- Data arising from the SAPRI will directly contribute to Operation Phakisa and OCIMS, supporting the development of a Blue Economy within South Africa
- Due to the increasing dependence of modern society on technological systems (e.g. satellite navigation), which are electrical systems that can be disturbed by external currents and magnetic field variations, it has become critical to understand the effects of space weather disturbances on industrial technologies such as aviation, communications, power distribution and space flight. SAPRI, in collaboration with SANSA, will contribute to the maintenance of these necessary long-term observations.

1.3.1 Economic contribution

Polar science relies heavily on instrumentation coming from international suppliers and facilities, such as those for calibration of sensors, based overseas. Through the SAPRI, the aim is to build and retain capacity in South Africa to create sensitive equipment within temperature controlled environments and fit for the use in extreme conditions, develop technologies for satellite communication, biogeochemical sensors for use on autonomous instrumentation, terrestrial photography automation for ecological studies, and other novel and unique ideas. The community at large has always had to "make a plan"; a spirit which echoes through the various scientific disciplines. If SAPRI is able to transform this landscape as envisaged, the benefit in the long term will be a spin-off of small and medium enterprises that could retain skill and development within South Africa, and attract international investment.

The remoteness of polar and open ocean operations is a precursor to risk and hence economic losses. South African Search And Rescue[25] coordinates measures to search for, assist or effect rescue operations in the case of maritime accidents or incidents in one of the most expansive search and rescue regions in the world. The navigation of vessels in ice and stormy waves demands some of the harshest and most contradicting ship design requirements. Vessel operations in ice are not reserved for polar research, oil exploration and cargo transfer. In Antarctica, tourist activities are growing rapidly owing to increased traffic from cruise ships under the International Association of Antarctica Tour Operators[26]. From 1998 to 2007 the number of tourist vessels in Antarctica grew from 15 to 55. In 2018, the same number of vessels delivered 13% more trips, bringing 40% more visitors to visit the Antarctic continent - that is ~46 000 people. Likewise, enterprise has seen an increased demand for polar expedition vessels including orders for 14 Polar Class 6, ice-strengthened cruise vessels for

[25] https://www.transport.gov.za/web/search-and-rescue/about-us
[26] https://iaato.org/

Compagnie du Ponant, two Hapag-Lloyd expedition ships and luxury yachts such as the Scenic Eclipse and Crystal Endeavour. Some of these vessels are aiming to operate in Antarctica. The expertise and knowledge generated by the SAPRI, especially with the digital twin project of the SA Agulhas II, will contribute to polar shipping and improved design methods. Her ice loading data has already served to validate the POLARIS Risk Index[27], instituted by the International Maritime Organization to improve polar safety, and can become an international reference for this industry.

On a broader scale, the data arising from SAPRI will help provide knowledge about weather and climate patterns, leading to improved forecasting and the information collected from the terrestrial and marine observations will assist in understanding the impact of climate change on our lands, coasts and the ecosystems they support, facilitating improved management and sustainable exploitation.

1.3.2 Community engagement

It is imperative to foster a nation-wide sense of ownership of polar spaces and resources, to promote stewardship and encourage innovation and exploration. To achieve this, it is important to address any remaining sense of exclusion of particular groups, through research and engagement. Firstly, it is important to know more about attitudes to polar science among ordinary citizens and where these come from, which can be achieved through social sciences research. Secondly, we need to create new narratives of inclusivity and entitlement through the arts and humanities. For instance, women were not allowed on any Antarctic bases before the middle of the twentieth century, and early South African Antarctic science did not allow Black participation. Better understanding these histories is important for finding ways to address them, particularly given South Africa's current role as representative of the African continent in Antarctic science and management.

As ALSA recognised when expanding its portfolio from the heritage collection and archival to engagement and communication issues, polar and marine science, including issues such as ecology on the sub-Antarctic islands, space physics or seafloor characteristics are abstract concepts when communities are faced with abject poverty. Yet, SAPRI will almost directly influence all South African communities. For example, observations of the ocean and land inform our impact on climatic systems and in the long-term allow the issue of extreme weather warnings and planned mitigation measures that disaster management teams need to employ. Also, understanding the ecosystems around the world, regardless of how far away or how extreme, allows scientists to analyse changing global systems and the impacts on the food web, and inform fishing activities in the long run. The top-down cascade through the food web trophic feeding level is as important as the bottom-up influence, and this is not yet very well understood globally especially in pristine environments like the Antarctic region.

Thus, the engagement of the community, from the poverty-stricken to the policy-maker, is critical and needs to be addressed at these various levels. As recognised by the recent inclusion of a Marine Science curriculum in high schools, children should be educated about the ocean and the Antarctic region, its benefits and its vulnerabilities. Following the successful model developed by ALSA and through the integration within SAPRI, public awareness will be strengthened through news articles and documentary film-making, but also with engagements using out-of-the-box thinking - informative question and answer sessions at local parent-teacher, neighbourhood council or social meetings,

27 https://arcticshipping370project.wordpress.com/data-sources/polaris-system/

engagement with political parties to include science-based public awareness into party manifestos, science fairs and exhibitions at shopping centres, etc.

1.3.3 Collateral benefits

Cape Town is already considered an Antarctic Gateway City which is part of an expansion plan advocated by DEFF. Many vessels already pass through the port to access Antarctica during the austral summer. However, with the increased capacity development that would come from an enhanced marine and polar infrastructure setup, and in alignment with the Antarctic strategy proposed by DEFF, the international attention on Cape Town is anticipated to increase substantially. This will mean more ships, scientists and teams visiting South Africa which would increase the demand on the marine industry (ship chandling, repairs and maintenance), the services industry, and tourism.

1.3.4 Well-being

South Africa still has a very long way to go to address the numerous political, race and gender inequalities and frustrations that prevail. Through the SAPRI, young scientists, technicians and engineers from all backgrounds and ethnicities, regardless of sex, religion or class, will be encouraged, taught and nurtured. SAPRI will actively enforce a policy of inclusivity of all to ensure it meets the ideals of the nation, in a safe environment. The SAPRI will encourage passion and excellence by engaging with those who are keen to create a legacy of world-class, proudly South African, science. This ethos will be encouraged from the start and become a cornerstone of the SAPRI.

1.4 Return on Investment

The SAPRI founding principle is to ensure that the investment in infrastructures translates into the generation of science for the benefit of society, retention of capacity and international recognition of expertise. Polar research is built on infrastructures of various sizes, which result from several investment cycles and are custodied by different players. Given the nature of Antarctic expeditions, the return on investment is maximised if several platforms are exploited at the same time for operational and scientific needs, from large facilities such as ships and bases, to medium facilities such as land-based laboratories, ship-based container laboratories and supply vehicles, down to individual field gear. The following specific returns are envisaged:

1. SAPRI will be an implementer of the governmental strategic initiatives (MARS and ASOS) and will provide a channel to coordinate SANAP-Logistics and SANAP-Science, harmonizing infrastructure management. This will contribute to rationalizing the distribution of costs between public entities and their relative lines of funding for the benefit of the South African investment to maintain the presence in Antarctica.
2. The investment in a focused set of RI platforms for polar research will release the infrastructural cost from the academic funding cycle and individual science-related projects. The main benefits include:
    a. the possibility to share platforms among various partners beyond the duration of each project, following a successful model already implemented within NRF with the ACEP programme;
    b. the rationalisation of infrastructural maintenance costs through a centralised system;
    c. the related redirection of core academic funding from infrastructural costs towards research-based applications;

    d. the enhanced investments that would stem from historical investments in marine and Antarctic research infrastructure.
3. SAPRI will represent a durable infrastructural pillar towards the constitution of a national research institute. The proposed two-pronged approach will reduce the amount of a further marginal investment and will ensure a more rapid integration of the science components on the backbone of a functioning research infrastructure.
4. SAPRI will represent a local incubator of small, micro and medium enterprises (SMME), specifically in remote technologies. SMMEs can access services, equipment and support in product/technology commercialisation. SAPRI will support the transformation of the demographic ownership profile of technology-based firms (and in particular SMMEs).
5. SAPRI will represent a hub for international communities with the possibility to generate return on investment through renting of infrastructures and equipment. The cohesive approach will unlock other potential funding sources from international bodies.

1.4.1 Business justification outputs

SAPRI, once established and running, will contribute significantly to classic research outputs such as qualified post-graduates and research papers, but has the capacity to generate vast amounts of new knowledge leading to new ventures. These may be in the form of user-specific services such as sample analysis and sensor calibration and validation, but also in new products for the research community and for commercialisation ventures. These have been explored in Sections 1.1.1.2 - 1.1.1.4.

1.4.2 Beneficiaries

Briefly described in Section 1.2 on Socio-economics, and touched on in various other sections, the beneficiaries of this RI are numerous. These range from:

1. Academic institutions, their staff and students,
2. Government departments working in this marine and polar space (DEFF, DSI, DPWI and more) and their public entities (NRF, SAEON, SAWS, CSIR, SANSA, CGS and more),
3. Specifically, the City of Cape Town as a Gateway to Antarctica, but also the other cities and towns that will host parts of the SAPRI (e.g. the seafloor entity in Makanda),
4. Established SMMEs and those that may be spun-off through the life-cycle of the SAPRI,
5. Secondary learners and the teachers engaging with the capacity development and educations awareness material,
6. The general public engaging with the public awareness material.

1.4.3 Education and training

This has been discussed in various sections above. However, it cannot be emphasised enough how important it is to engage with the next generation of technicians and scientists on the beauty and awe of studying marine and polar science. Structures like the SAPRI can be mobilised to enthuse the younger generation to engage with the sciences, for example, to strengthen the need to understand climate change and development of mitigation measures, or to understand food-webs and consequences of their disruption. In addition, it will be critical to establish an informed cohort of policymakers, legislators and officials through the development of local research in the Humanities and Social Sciences, particularly on the legal, historical (including archaeological), geopolitical and aesthetic frameworks that are relevant to the South African context.

1.4.4 Research capacity development

The SAPRI has already attracted interest from over 20 institutions in South Africa including historically disadvantaged tertiary education facilities. Polar and marine science has been led in South Africa historically by the affluent and more well to do institutions. But this has changed over time, with institutions from various backgrounds playing a role in the future of this multidisciplinary initiative. Research expeditions in themselves are valuable for capacity building of overwintering expedition personnel. As highlighted, APECSSA is already an established portal for early career South African polar scientists, with international links that can encourage their development and it will form a strong component of SAPRI.

1.4.5 Commercialisation

This has been discussed extensively and already shown in reality with groupings such as Sea Technology Services who have developed technologies used within the SAPRI such as glider sensors, the deep-sea camera and the Ski-Monkey. Many more initiatives like this are envisaged through the massive amount of new development and skill acquisition planned within the SAPRI. These include such things as the Polar Lab, new biogeochemical sensor capabilities, new laboratory sample processing techniques, new laboratory equipment and specialised on-board underway measurement devices, automated camera traps on the sub-Antarctic islands with satellite communications to South Africa, and satellite communication technology itself. There have been many ideas suggested through the proposal phase and development of this SAPRI initiative and many more will likely develop as the life-cycle of the SAPRI progresses.

2 SCIENTIFIC EXCELLENCE

The massive undertaking of this national RI, in the context of its geographic extent, multi-institutional and multi-disciplinary nature, makes a long-term observing-based approach to procuring, deploying and maintaining relevant and necessary infrastructure of paramount importance. The best (and most logical) method to determine these long-term observations is that of essential variables[28] (Figure 7). This allows for avoidance of duplication of efforts and an adoption of internationally verified standards and best practices, thus allowing for easy dissemination and maximum utilisation of data. A number of international organisations[29] have assembled and verified the value of essential variables for the climate, ocean, biogeochemistry within the ocean, biology and ecosystems within the ocean, terrestrial science (including the hydrosphere, cryosphere and biosphere) and the atmosphere (including surface, upper-air and composition). Listed in addition to the above are variables related to space physics and space weather. The essential variables most critical to the SAPRI are listed in Appendix C. Not all polar scientific research and endeavours fit within this long-term observation of essential variables approach and while this approach is recommended, it is not prescriptive.

The final decision around the science being carried out utilizing the SAPRI will be agreed upon by the science advisory panel. The approach of essential variables will however assist the panel by providing guidance particularly in the initial procurement stages of infrastructure investment.

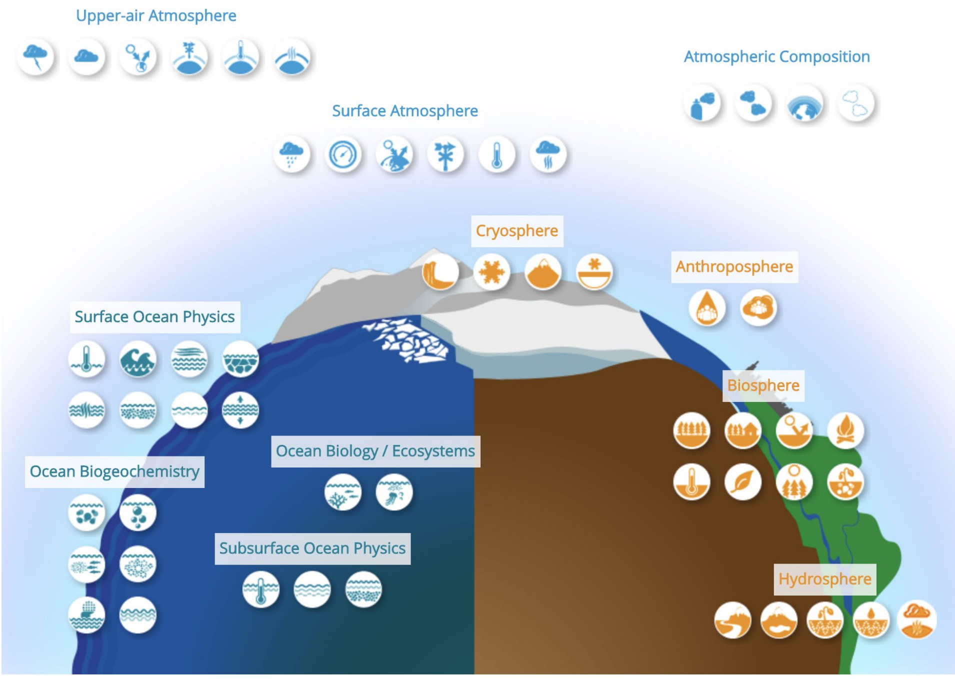


Figure 7 ***A schematic description of the Essential Variable****s as defined by the Global Climate Observing System (GCOS), and focused on the atmosphere, cryosphere, lithosphere (not shown), oceans, anthroposphere, biosphere, and the hydrosphere.*

28 https://www.goosocean.org/index.php?option=com_content&view=article&id=170&Itemid=101; https://gcos.wmo.int/en/essential-climate-variables;
29 https://gcos.wmo.int/en/essential-climate-variables/table

2.1 UNIQUENESS AND NOVELTY

The scientific uniqueness and value associated with the SAPRI is its multidisciplinary approach to the broadly defined polar sciences from a South African perspective. Over 20 universities and institutions have shown a keen interest in being associated with this work and easily cover most of the essential variables herein listed. This places the long-term observation approach to developing the research infrastructure in a position of strength.

The SAPRI is designed to facilitate the MARS science components detailed in Box 1. The relatively small community associated with marine and Antarctic research in South Africa, as opposed to larger countries with well-established programs, allows for easy sharing of scientific ideas leading to inter-disciplinary and trans-disciplinary research. Furthermore, given the historically limited funding available to research teams, many projects have long benefitted from this 'shared resource' way of undertaking research, allowing for a greater collaborative effort. On the other hand, this small community is endangered by the risk of losing expertise and the lack of support for turning scientific achievements into durable observational systems for long-term societal benefits.

In this context, uniqueness is better represented by the concept of unitedness: the creation of a unified but distributed infrastructure that will coordinate, combine and strengthen the existing fragmented components of SANAP under the MARS umbrella. SAPRI is novel because it will create a model in which the scientifically established lines of research that rely on the observations of essential variables will be transformed into long-term monitoring structures and will create new opportunities for research that have not been done before in South Africa and in none of the developing countries operating in the Antarctic region.

This will be achieved through the participation of the consortium partners in integrated facilities coordinated by the RI host (Figure 8), as detailed in Chapter 3 and 4. The term **"integrated facility" (IF)** is introduced here to define a component of the SAPRI that combines various kinds of research infrastructures sharing common objectives or logistics needs. Two components are responsible for the coordination of polar logistics, data management and communication. One component is dedicated to outreach, training and societal benefits. The three research-related components of SAPRI, which are shown in the centre of Figure 8, directly enable polar research and are framed in two of the pillars shown in Figure 2, namely sustainability of long-term observations and new infrastructures and innovation.

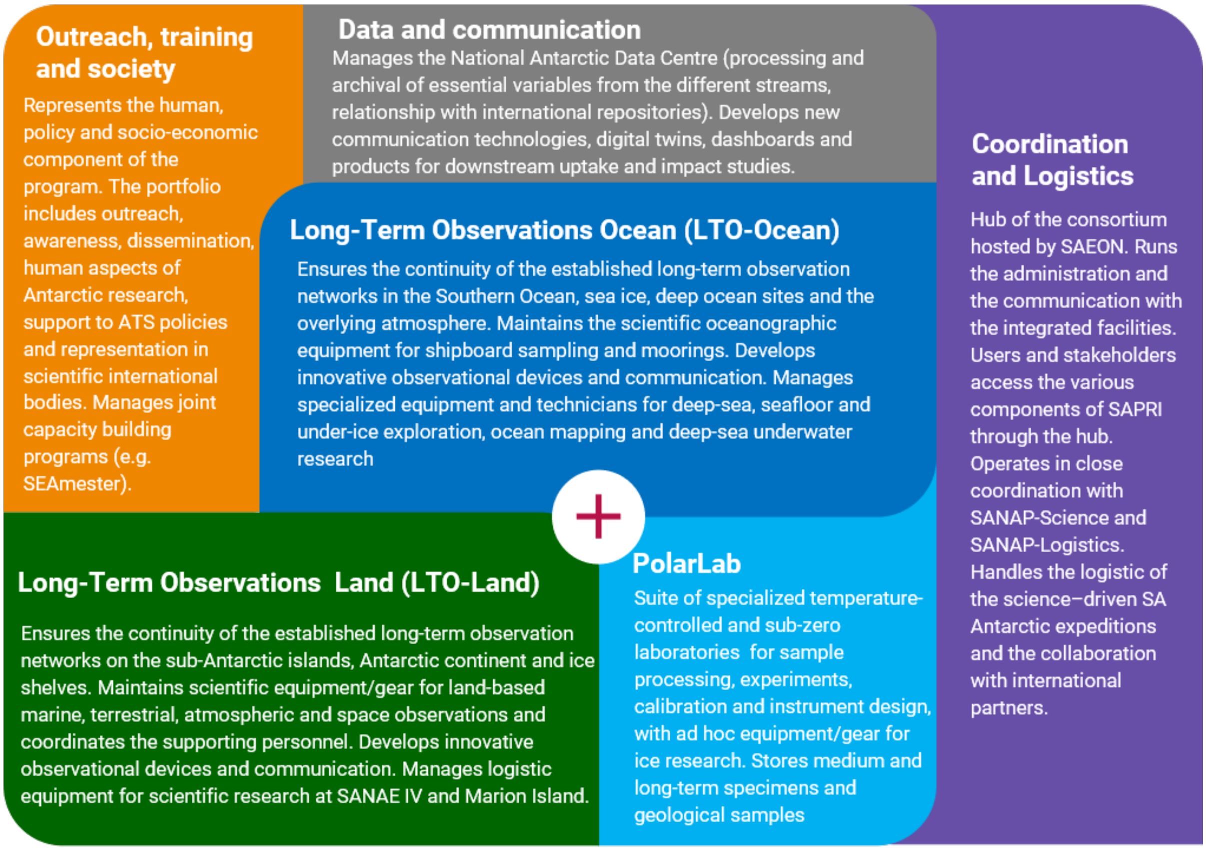


Figure 8 ***Schematic of the SAPRI Integrated Facilities*** (IF). The IFs directly linked to research and field activities are connected by the plus sign, which also shares engineering and technical capacity. Chapter 3 gives a complete overview of each IF and their organisational structures.

SAPRI will assist the consortium partners to turn the existing science-funded observational networks of essential variables that have been identified as needing infrastructural support (Appendix C) into durable and sustainable data streams and products. These variables fall under five thematic study areas:

1. The land - geomorphology and the underlying geology, cryosphere, ecological studies, plant and marine mammals, birds;
2. The atmosphere - covering surface, upper air and atmospheric composition;
3. Space physics - most notably that of space weather;
4. The ocean and sea ice - from physics through to biogeochemistry and from microbiome through to the upper trophic levels;
5. The seafloor and sediment - including geology, geophysics and geochemistry as well as biology (e.g. benthic organisms).

These study areas have been operationally distributed in the three IFs (Figure 8 and Chapters 3, 4), according to the infrastructural needs to support the observational networks and the research. LTO-Land will incorporate and develop the research infrastructures in areas 1-3 which require access to land-based infrastructures, while LTO-Ocean will combine 4, 5 and 2, the latter in recognition that atmospheric measurements are linked to different operational platforms both on land and ocean. In the first phase of SAPRI, these IFs will mostly operate on existing infrastructures (that are currently hosted by the members of the consortium) with new infrastructures being added in the setup and running phases (see also Chapters 3 and 4). The Polar Lab is a new infrastructure that will commence in Phase 1 and supports all thematic areas, unified by the multi-disciplinary requirements of conducting research in cold and sub-zero environments.

The value chain of long-term observations cannot be considered finalised without a proper integration with the data workflow, archival, distribution and innovation in real-time or near-real-time data and data product availability and accessibility. This function is undertaken by the integrated facility Data, Products and Societal benefits (Figure 8 and Figure 12). This facility also integrates the final pillar of SAPRI, capacity building and awareness, as shown in Figure 2. The capacity building will be centrally organised but distributed to the various science-driven platforms, while the societal and awareness component will be ensured through the integration within SAPRI of the Antarctic Legacy of South Africa, currently funded through dedicated SANAP resources.

Antarctic scientists have a great responsibility to popularise and to communicate their research to the lay public as the public has no or limited opportunities to access the Antarctic region. For this reason, Antarctic science needs to be simplified and communicated in such a way that it is understandable to the public through science communication and made interesting and attractive through the arts. Another novel aspect of SAPRI will be a unified communication role for Antarctic science, and a promotion of cultural engagement, which is lacking in South Africa. It is acknowledged that the role of science outreach and awareness is part of SAASTA's (South African Agency of Science and Technology Advancement) mandate, however it is still believed that the role of Antarctic science outreach and awareness in the form of science communication needs to be tightly linked to the research infrastructures, a role perfectly fulfilled by the SAPRI concept.

In addition to all these factors, the uniqueness of South Africa's three oceans could and should be used to develop capacity and transform the science landscape. This is further elaborated in Chapter 5.

2.2 EXCELLENCE

The consortium approach of the SAPRI allows for the research infrastructure to take advantage of the scientific excellence acquired by the consortium partners. The following sections give an overview of the excellence and novelty of the proposed IFs.

2.2.1 LTO-Land

This integrated facility focuses on the coordination and management of the land-based observational networks and the support for research activities needing access to the polar and sub-Antarctic terrestrial infrastructures. LTO-Land comprises a large variety of research areas with existing capacity. The IF will enhance the existing capacity, strengthen existing research themes, and allow for the development of new themes with a focus on local human capacity development and international collaboration. Each sub-theme within the IF offers its own unique advantages, whereas common benefits are also visible across themes. As illustrated in the Introduction, South Africa has been collecting several essential variables from the ones listed in Appendix C and additional ones can be added that cannot be currently sustained by research-based activities alone. This list also includes variables that belong to the atmospheric, space and marine realms but that operationally are best served through land-based infrastructures. A typical example is the study of some marine mammals and seabirds, which requires sampling operations to occur mostly from land.

Geographically, LTO-Land operates in three different regions (Figure 4): the Prince Edward Island system owned by South Africa, Gough Island which is owned by the United Kingdom of which South Africa leases the land to undertake observations, and the Dronning Maud Land (DML) section of Antarctica where SANAE IV is located. For this reason, the logistical needs for accessing the research vessel should also be considered in coordination with LTO-Ocean and the main SAPRI logistics hub.

The LTO IF will enable the continuation of the observational networks of essential variables, fulfilling their logistics and accessibility needs. Due to their reliance on general research funding lines within SANAP, some of these networks are at risk of interruption or have already been interrupted, with the additional impact of the COVID-19 pandemic.

Given the variety of sites and platforms that have been implemented during the years of the time series acquisition (Figure 5), the specific decision on the selected sites and equipment investment will be subjected to a dedicated process within the consortium as detailed in Chapter 3.

2.2.1.1 ***Dronning Maud Land (DML)***

- *Geology, Geophysics, Geomorphology, Paleoclimates.* Antarctica is the most unexplored continent and the limited occupation of the summer bases can barely provide sufficient information. Given the geological relevance of DML explained in Chapter 1, these areas are in need of systematic mapping. In Gondwana reconstruction, three countries share the longest coastline in contact with Antarctica from ~20°W to ~35°E - southern Africa, India and Australia. To date SANAP has operated only between ~9°W and ~5°E. **Earth science research will contribute to an improved understanding of the continental geological evolution of DML**. Aspects of the studies will improve our knowledge of correlations between Antarctica and southern Africa whereas the primary mapping in central DML will produce more detailed information of the geology of the understudied areas. Systematic mapping will also improve access to these areas and the overall safety of the national Antarctic program. Three significant magnetic anomalies have been recognised in western DML, although the nature of the structures related to each other is unclear. Data collected will contribute to the SCAR CGG (Geology and geophysics) and AntMAP (digital geological database) programs. The Antarctic ice sheet is a major driver in global environmental- and sea-level change. **Yet virtually no onshore or offshore paleoclimate research has been conducted in the area around SANAE IV, and consequently research on paleoclimatic reconstruction will be novel and will contribute to similar studies conducted elsewhere on the Antarctic continent on modern climate evolution**. SAPRI LTO-Land will enable this research by integrating the observational networks established through SANAP-funded projects to ensure sustainability and field equipment support for collecting the identified essential variables. Major limiting factors are the short duration of the fieldwork season, which could be extended by using aircraft transportation, and the lack of appropriate vehicles (e.g. polar tractors like the Pisten Bully 300 and lighter sledges) for transporting scientists and equipment in the field without resorting to expensive helicopter trips that are not often guaranteed. The experience of consortium partners UJ, UP and RU in establishing long-term observation stations will guide the choice of the selected sites and equipment.
- *Permafrost and Ice Sheet Dynamics.* There is presently a lack of permafrost studies, ice sheet dynamics research, and glacial and periglacial geomorphological research for western DML. Cryosphere research is of international significance. **Increasing temperatures have led to a worldwide decrease in permafrost and reduction in ice sheet coverage with melting contributing to sea-level rise. Research conducted within the area of Antarctica accessible**

from SANAE IV, currently with few observation sites in DML and none (currently) for western DML, will contribute to our understanding on climate change and permafrost linkages, as well as bi-polar (southern-northern hemisphere) dynamics and connections. Datasets on permafrost-active layer dynamics contributed by South Africa until the funding interruption in 2018 represent the only such datasets for the larger region of western DML. LTO-Land will re-establish the long-term monitoring permafrost sites and the necessary equipment/logistics, to ensure continued monitoring of permafrost dynamics in a changing climate. An additional avenue of potential research includes monitoring ice sheet fluctuations using sensitive gravity stations which can measure annual ice sheet accumulation/loss. Ice-specific equipment will be maintained in collaboration with the Polar Lab. Research in these areas will be guaranteed by the consortium partners from UJ, UP, RU, CGS and UCT.

- *Terrestrial ecology, Microbiology and Genomics.* Research on Antarctic ecology is mostly directed to the microbial components. The current research focuses on **elucidating the effects of extreme environmental conditions on shaping microbial communities and the nutrient cycles they mediate**, as well as seeking to understand their possible feedback mechanisms. Microbial ecology research for the poorly characterised western DML region of Antarctica will focus on sampling ice-free habitat to correlate this with abiotic factors (*e.g.* soil nutrients, altitude, temperature, distance from the coast, katabatic wind regimes). The research generated from this set of essential biological variables will contribute to the SCAR groups Ant-ERA (Antarctic Thresholds – Ecosystem Resilience and Adaptation) and AntECO (State of the Antarctic Ecosystem). This component shares the same resources of other terrestrial research activities, and LTO-Land will ensure maximum integration, maintenance and sharing of field equipment that is now fragmented between the various participants of the SANAP research program. Research in these areas will be guaranteed by the consortium partners from UJ, UP and RU.
- *Space physics.* Essential variables are not internationally available for this discipline. However, the South African National Space Agency (SANSA) has guided this discussion and provided the five variables listed in Annexure A. Polar research on the space environment contributes to space weather forecasting. Space physics research, concerned with the dynamics between electromagnetic and particle emissions from the sun and the magnetic field of the earth, requires measurements of the high latitude regions in order to monitor and understand global space weather phenomena. The polar regions are (geographically) ideally suited to studying the ionosphere. Due to the lack of infrastructure focusing on such research in the southern high latitudes, **the current installation at SANAE IV is critical to space weather forecasting and data product generation**. Furthermore, solar activity occurs in approximately 11-year cycles, with the solar magnetic field reversing every 22 years, and as such there is great importance in observing the relevant parameters over the long-term. SAPRI will collaborate with SANSA for the maintenance and expansion of the suite of research infrastructure which is currently sustained by the SANAP science program and will be integrated in LTO-Land. The consortium partner SANSA has the capacity to further support LTO-Land through technical expertise. Its technicians can maintain a variety of interdisciplinary instruments, as well as research and develop new and existing instrumentation.
- *Meteorology and atmospheric sciences.* Robust knowledge of meteorology, long-term climate variability and trends is sparse for the Antarctic region, mainly due to the scarcity of observational platforms and reliance on numerical weather prediction and reanalysis products. The international community through the World Meteorological Organization has

emphasised the importance of polar predictions[30]. The consortium partner SAWS is the leading authority for meteorological information in South Africa. Its automated weather station network conducts regular, WMO-compliant meteorological observations, contributing data into the Global Telecommunication System (GTS) for numerical weather models. Furthermore, SAWS hosts a Global Atmosphere Watch (GAW) station, which forms part of the WMO long term climate monitoring program. **Polar weather and climate are key components of the Earth system and their predictability is largely connected to the real-time availability of data.** Maintenance and expansion of currently installed atmospheric, cryospheric and GAW instrumentation will be addressed. Data from such stations will also greatly enhance peripheral research themes that require geophysical information to correlate with specific observation in the field, such as micro-climate investigations, weather drivers of biological changes, and climate/weather impacts on abiotic environments.

2.2.1.2 ***Prince Edward Islands (PEI) and Gough Island***

This area of polar research will be coordinated closely with the Shallow Marine and Coastal Research Infrastructure (SMCRI), and the various research entities that are part of the consortium. SMCRI has planned to establish a Sentinel Site on Marion Island with a suite of observatories in the coastal zone including atmospheric monitoring to study environmental drivers, ecological processes and long-term changes. Building on this existing infrastructure, SAPRI will add the relevant logistics and equipment for the open ocean and terrestrial counterparts.

- *Marine Predators (Mammals and Seabirds).* Long-term observations of marine mammal and seabird populations are done from Marion and Gough Islands. Seabirds and seals, as marine top predators, provide unique insights into the health of the Southern Ocean, because they forage at sea, but must return to land to breed/moult. This collection of essential variables seeks to understand the sensitivity of marine mammal and seabird populations to environmental and anthropogenic drivers. The assessment of individual heterogeneity helps to disentangle these population processes, intra- and interspecific interactions. **Existing long-term data series from Marion Island, maintained annually for more than 38 years, provide some of the best population monitoring studies in the region and in the world**. SAPRI will ensure the maintenance of continued monitoring (human capacity, tags, field equipment) of these populations to sustain the research and further the insights into ocean health in a changing environment. The internationally recognised consortium partners UP, NMU, UCT and the close collaboration with DEFF will guarantee the excellence of the scientific approach and a rapid integration of the essential variables' datastream for distribution to other researchers in South Africa and in the international context.
- *Geomorphology, terrestrial ecology, microbiology and genomics.* A dedicated infrastructure for supporting the terrestrial component will complement the SMCRI Sentinel Site, which focuses on the coastal environment. **The essential variables collected on the island provide valuable data on the island ecosystem response to changes in the surrounding sub-Antarctic environment, giving insights into global change impacts on the region**. Through the establishment of science-driven logistical support, personnel and equipment for the long-term monitoring of coastal seeps/wetlands and streams, micro-climate monitoring, climate observations and the re-establishment of valuable past monitoring activities such as vegetation transects), SAPRI will ensure continuity in the collection of essential variables and

30 https://www.polarprediction.net/

their use for research and society. The scientific background and initial backbone on the specific platforms and protocols to be used will be ensured by the participation of the leading partners UP, RU, NMU, FH, SUN and UniSA as direct consortium partners or participants through the user forum (see Chapter 5).

- *Space physics.* SANSA operates an **observational station at Marion Island base collecting long-term observations of the identified essential variables** (Appendix C). The same considerations indicated for the SANAE IV long-term observations and activities apply here, and they will be implemented according to the specific logistics required for accessing the infrastructure on the island.
- *Meteorology and atmospheric sciences.* SAWS operates observational meteorological stations at Marion and Gough Islands, collecting long-term observations of the meteorological and climate essential variables (Appendix C). The research enabled by this infrastructure is similar to what was described for DML. The importance of PEI and Gough installations is further magnified due to the rapid spatial change which weather conditions exhibit at these dynamic remote sites and the relevance of having continuous datastream that would improve the forecasting on land. LTO-Land will work closely with SMCRI on PEI to ensure that data collected in this way will have short-term, tactical utility (e.g. navigation and planning), as well as long-term, hind-cast utility for climate research.

2.2.2 LTO-Ocean

LTO-Ocean includes essential variables listed under ocean, ice physics and biogeochemistry, as well as the microbe, phytoplankton and zooplankton biomass, fish abundance and distribution and genomics listed under the biology, biodiversity and ecosystems essential variables.

In contrast to LTO-Land, where the geographic regions define the access to infrastructures and observational networks, LTO-Ocean will **facilitate access to and further develop a number of dedicated ocean platforms** in order to obtain the best scope of identified essential variables. As described earlier for LTO-Land, due to the variety of sites and platforms that have been implemented during the various historical projects (Figure 5), the specific decision on selected sites and equipment investment will be subjected to a dedicated process within the consortium as detailed in Chapter 4. Given the complex nature of the oceans and the facilities and logistics associated with research vessels, the technical-intellectual home of the observing systems will also be decided when the advisory board has confirmed the essential variables to be measured and the final equipment to be purchased. This will ensure that these observational systems are placed with the correctly skilled research groups and will ensure the quality of the observation and data products.

2.2.2.1 ***Research vessels***

Traditionally, ocean related research has taken place on large, **well-equipped research vessels** such as the SA Agulhas II. Even with all the advances in ocean robotics, research vessels remain a much-required platform for ocean related research with **routine observational cruises contributing to internationally recognised programmes such as GO-SHIP[31] and GEOTRACES[32] that provide essential information for monitoring and understanding changes in the ocean**. The ship itself is a device to

31 https://www.go-ship.org/
32 https://www.geotraces.org/

collect data, and the SA Agulhas II is an international model for multi-scale measurements of engineering data that can inform the design of polar vessels. Chapter 1 illustrated the complexity of large infrastructure management within the broad SANAP space. Science delivery and excellence is tightly linked to ease of access to these infrastructures and to proper logistics management. Over-the-side sampling operations, along with detailed sample analysis and extensive multi-faceted underway data acquisition, is only possible from a research vessel. In addition, the ship can host specialised container laboratories for sampling essential variables such as the micronutrient iron and sea ice features. Finally, nothing can replace a research vessel for training and inspiring early career scientists.

Where necessary and agreed on through the governing bodies, underway equipment will be combined and updated, and human resources will be provided through SAPRI. In addition, SAPRI will foster multi-disciplinary inclusion of teams and scientists, allowing for additional parameters to be collected during underway and over-the-side operations. This is a description of how the SAPRI will enhance the science activities on the vessel based on the existing infrastructure:

- Over-the-side operations, commonly identified as Conductivity, Temperature and Depth (CTD) operations. These can host multiple physics and optics instruments, seated on a frame called a rosette which holds specialised bottles for sample collection (Niskin). These samples are not limited to physics or biogeochemistry, but can be used for phytoplankton, microbe and microzooplankton sampling as well. A dedicated metal-free rosette for sampling trace metals is also available, with specialised GoFLO bottles. The DEFF and SOCCO already own these large CTD instruments acquired through national funding. In addition, SOCCO and UCT own an underway CTD which can be deployed from the aft of the vessel whilst steaming, providing relatively high-resolution profiles of Temperature and Salinity. Through this proposal, actions will be taken to combine the existing sparse national infrastructures and funding will be earmarked for additional Niskin/GoFLO bottles, sensor calibration and replacement/redundancy, as well as technical human resources required to operate these instruments at sea, process and archive data and maintain the instrumentation itself.
- Underway equipment that continuously collects water samples during navigation. The SA Agulhas II is equipped with a series of sensors that are permanently installed such as the thermosalinograph (TSG) which is maintained by DEFF as one of the ship's assets, and a fluorometer and CO_2 flux sensor (an underway General Oceanics pCO_2 instrument) and pH, which is managed by SOCCO. In addition to this, there are a series of optical instruments that are not permanent features but can be installed on the vessel during specific scientific expeditions to measure optical characteristics of the phytoplankton community (backscatter, attenuation, absorption, multiple fluorescence). The instruments currently managed by SOCCO form part of the DSI infrastructural funding. The SAPRI set-up and design phase (Chapter 3) will establish a dedicated task team to assess the best options for managing the infrastructure.
- Specialised container laboratories that are loaded onto the ship prior to the science voyages. Four container labs are currently maintained and operated by CSIR as part of the SOCCO national infrastructure: two certified trace metal-clean containers following GEOTRACES[33] best practices, one radiotracer container laboratory certified for ^{14}C and ^{55}Fe and one general chemistry container with fume hood. Similar to the previous point, these instruments will be

33 https://www.geotraces.org/

considered for integration within SAPRI during the set-up phase and maintained/upgraded for longer term availability to the scientific community.

- Various types and sizes of phyto- and zooplankton net systems. These are towed from a particular depth to the surface either vertically or obliquely. Similarly, surface tows are undertaken for microplastic and surface plankton research. The equipment needed for polar research of plankton is the same as that used for coastal research by SMCRI and DEFF. SAPRI will enhance the availability and efficient use of existing netting and frames for plankton acquisition, flow-meters and technical human resources for sample collection and analysis (using sample analysis techniques and imaging technology such as Zooscan and Underwater Vision Profiler (UVP)), data archiving and maintenance.
- A number of monitoring lines are undertaken each year (Figure 4): The Good Hope Line , the SAMBA and ASCA CTD lines (all of which augment data along these transects for additional parameter sampling), CTD monitoring lines between and around the Prince Edward Islands and the Crossroads CTD and XBT line which extends across the Agulhas Return and Agulhas Currents from Marion Island back to the South African coast each year. These monitoring lines are established but not guaranteed. SAPRI will foster multi-disciplinary inclusion of teams and scientists, allowing for additional parameters to be collected during underway and over-the-side CTD operation work and tows with phyto- and zooplankton nets. Moorings in association with these lines need addressing.
- The ship herself is a measuring platform, which is already used to provide real-time data on her performances. The Digital Antarctic facility in SAPRI will contribute to make the ship a full-scale monitoring system and create the digital twin DIGSAAII for downstream exploitation. This will happen thanks to existing and additional platforms mounted to the vessel, such as automatic weather stations, underway PAR, wave radar, automatic cameras for real-time ocean state acquisition (sea ice and surface roughness), echosounders used for plankton and fish density descriptions, and multibeam echosounders for seafloor characterisation. Critically, the SA Agulhas II is not equipped with a multibeam echosounder, side-scan sonar technology or a wave radar to estimate wave conditions. These should be key instruments for acquisition for the vessel through SAPRI. Prior agreements and coordination with DEFF will be essential due to them being permanently installed on the vessel. Ship-based personnel will require training in running these systems. Marine geophysical data can be processed and archived at the CGS.
- The ship is equipped with facilities for deep-sea sediment coring and its crew have demonstrated capability of deploying coring equipment during science voyages with international teams. However, the existing coring equipment available in the country is not usable and needs replacement. Sediment cores and samples provide fundamental data on seabed character, sedimentation, benthic community composition and ecosystem functioning. Southern Ocean sediment cores are highly sought-after because of the potential for reconstructing the Southern Ocean's role in past climate. SAPRI will make available funding to procure the proper coring equipment as decided during the technical design phase and maintain it as part of the seafloor observation platforms (Section 2.2.2.4).

2.2.2.2 *Autonomous platforms*

Research vessels cannot be maintained at sea indefinitely. **Autonomous platforms** have been developed over the last 30-40 years with major developments in the field over the last decade specifically. **The DSI-funded programme SOCCO hosted at CSIR pioneered ocean robotics in South Africa by investing in a fleet of ocean and wave gliders and engineering capacity building and**

creating the South African Robotics Ocean Technology Innovation Centre (SA-RobOTIC), currently hosted at the DEFF premises in Cape Town. **South African oceanography is now recognised as a global leader in ocean robotics**, particularly with respect to long term deployments that reduce the cost and sparseness of ship-based observations and observe ocean physics and biogeochemical dynamics scales that cannot be done using ships. SAPRI will expand on the infrastructure model successfully developed at SOCCO to provide the necessary set of operational technological services as well as expand its HCD and R&D roles in ocean robotics. Since SOCCO is a parallel national infrastructure funded through DSI, the details on the infrastructure development will be agreed during the implementation phase (Section 3.1.2.2). Local engineering developments have also indicated the opportunity for developing innovative biogeochemical instrumentation such as sensors for measuring carbon in the water. The proposed infrastructure will focus on the following ocean robotics and Lagrangian instrumentation in general, as well as the related technical capacity:

- Wave and buoyancy gliders, capable of undertaking very high-resolution scientific expeditions. These are ideal for process studies and seasonal studies as they need to be retrieved and maintained periodically. Gliders can also be maintained in pseudo-mooring mode as demonstrated by several SANAP science projects and have contributed to critical high-frequency time series of essential variables.
- Argo floats, capable of standard operations (2000 m profiles), biogeochemical studies (such as the Southern Ocean Carbon and Climate Observations and Modeling - SOCCOM - project) and deep Argo profilers capable of 4000-6000 m profiles (instrument dependent) contribute to a larger global program and can be effective in ultimately providing long term information over large areas of the ocean.
- Satellite tracked ocean and sea ice drifters can be used to track surface water movement and when deployed on ice floes, their movement within the Marginal Ice Zone (MIZ) and related ice features. SAPRI will coordinate with SAWS for the routine deployment of ocean drifters and by joint coordination between LTO-Ocean and the Polar Lab will work to consolidate the prototype array of low-cost expendable buoys for long-term sea ice monitoring.
- Animal tracking devices that allow measurement of ocean properties are logistically included in LTO-Land, but their technology is related to the engineering development done in the ocean space.

2.2.2.3 ***Moorings***

The existing long-term observations funded by national research programs have also been maintained by means of **subsurface moorings** deployed to the sea floor.

- South Africa plays host to three subsurface mooring systems: the South Atlantic Meridional Overturning Circulation Basin-scale Array (SAMBA) out into the South Atlantic Ocean (along 34.5° S), the Agulhas System Climate Array (ASCA) across the Agulhas Current (currently not deployed) and the Marion Island moorings. These three mooring systems, all endorsed by international bodies, share similar instrumentation which allows for sharing of instrumentation and consumables, technical skills, communication costs, data processing techniques and interpretation methods. SAPRI will facilitate the harmonisation of existing infrastructures and the sharing of equipment and personnel through LTO-Ocean.
- The high source levels of baleen whale vocalisations make the acoustic monitoring of populations possible over a wider area and with greater efficiency than visual detection. Passive Acoustic Monitoring (PAM) is now widely used to monitor seasonal abundance by latitude and therefore seasonal migration patterns. South Africa has carried out PAM within

SANAP, during which deep-water automated acoustic recorder moorings were deployed on the Maud Rise (65°00'S; 2°30'E) and off the west coast of South Africa providing significant information on seasonal migration patterns of Antarctic blue and fin whales. PAM is more efficient than ship-based visual monitoring and can provide significant understandings of stock structure, distributions, and migration patterns required for stock status assessments. The mooring equipment with the array of acoustic hydrophones was initially developed by the University of Pretoria's Mammal Research Institute Whale Unit and the equipment has been transferred to CPUT. SAPRI will promote the use of acousting moorings in combination with the cost-effective mooring deployment of oceanographic instrumentation from other disciplines. Ship-time is minimal in relation to long-term data that can be collected over the mooring soak period. These data will contribute to the International Whaling Commission Southern Ocean Research Partnership and their international Southern Ocean Hydrophone Network (as was carried out with previous data) to contribute to a global array of Southern Ocean PAM of baleen whale migrations.

These infrastructures are in some cases already existing at partner institutions. For instance, mooring equipment is owned by DEFF and by SAEON, and PAM devices are available at CPUT. The details of the sharing, continued maintenance and additional acquisitions are further given in Section 3.1.2.

2.2.2.4 ***Land based Laboratories***

Most of the biogeochemical, nutrient, trace metal, and sensor validation samples collected at sea are not processed at sea due to time and space constraints. Thus, effective and efficient **state-of-the-art laboratories** and **sample analysis instrumentation** are required to ensure these data are accurately acquired. A major national breakthrough has been achieved with the establishment of a dedicated RI for biogeochemistry (BIOGRIP). Through the new Water and Soil Biogeochemistry Node that will be established at SUN, BIOGRIP will provide a range of high-quality water analyses, as well as facilities for experimental work that will be of great support for oceanic polar research. This will be especially relevant for the measurement of macronutrients in the ocean and within sea ice. SAPRI will undertake an agreement with BIOGRIP management to ensure that samples from the designated LTO-Ocean sites and cruises will be processed through the BIOGRIP facility at convenient costs and will contribute with expertise to make certain that the most appropriate techniques are used. SAPRI will likewise partner with SMCRI and DEFF for the processing and analysis of phytoplankton and zooplankton samples collected by LTO-Ocean. This will be detailed in dedicated agreements that will provide the necessary complementary resources, both in terms of consumables or technical personnel.

Not all the essential variables required for polar research are however considered within the BIOGRIP implementation plan. Two main laboratories have been established as part of previous national initiatives funded by DSI. The SOCCO infrastructure holds a dedicated laboratory for measuring oceanic carbon variables. This laboratory is fully functional and equipped, and currently located at the CSIR Stellenbosch premises. SAPRI will integrate this laboratory in the LTO IF to expand their accessibility to a wider community and improve the exchange with other facilities. The Centre for Trace and Experimental Biogeochemistry (TracEx) is a virtual centre located in Stellenbosch and brings in researchers from SUN and other local and international institutions together with an aim to gain an improved understanding on biogeochemical cycling of bioactive trace elements in marine environments. The Centre promotes the mandate of international GEOTRACES program and runs the laboratory on trace metal analyses[34], which is an international excellence due to the paucity of these specialised metal-clean facilities. This facility is considered a crucial component of the long-term monitoring of the Southern Ocean, given the role played by trace nutrients in the functioning of the planktonic system.

2.2.2.5 ***Seafloor observation platforms***

Much of our existing knowledge of the structure and functioning of benthic ecosystems comes from data collected in tropical and temperate environments and from depths shallower than 100 m. Relatively little benthic research has been conducted in high latitudes (>40° N or S) and in the deep-sea. Within South Africa's territories, the shelves shallower than 250 m only cover 16.6 % and 1.4 % of the exclusive economic zones around South Africa and the PEI, respectively (Figure 4). As such, we have a very limited understanding of the structure, functioning and services provided by the deep-sea system.

The SAPRI seafloor is a novel structure within LTO-Ocean that will spin-off from the recognised experience of both SAEON and SAIAB in benthic research. These platforms will **permit research that directly addresses the knowledge gap on deep-sea systems, enhancing our ability to manage resources and providing globally standardised data to report against national and global development and biodiversity targets**. This thematic study area would directly address the following biology and geology essential ocean variables (Appendix C):

- seabed mapping, sampling geomorphology and benthic habitat delineation;
- fish abundance and distribution;
- hard coral cover and composition;
- invertebrate abundance and distribution.

The consortium partner SAEON has established baseline data and imagery in the PEI from which indices can be developed to detect future changes. To continue and advance this monitoring programme, it would be best placed as a component within a larger, more formally supported research platform, through which the seabed biodiversity can continue to be observed.

The seafloor thematic study area in LTO-Ocean will do this through three embedded infrastructure units focussed on mapping, biodiversity monitoring (with the primary method being underwater imaging systems) and biogeochemistry (the latter in collaboration with the SMCRI and BIOGRIP RIs). The first two will build on three existing infrastructure platforms funded through the National System of Innovation; namely the Marine Remote Imagery Platform, the Geophysics and Mapping Platform both based at SAIAB, and the Offshore Invertebrate Observing Program from SAEON. Through SAPRI, these partners' facilities that now operate in the shallow ocean will be integrated with LTO-Ocean in phase 1 and further expanded to enable research in the shallow and deep sea of polar environments. This equipment will provide fundamental data on seabed character, sedimentation, benthic community composition and ecosystem functioning, and enable research into climate change and the role of benthic organisms in carbon cycling and other biological processes. The sampling techniques and data they provide will align with the GEBCO Seabed2030 project[35], Global Ocean Observing System (GOOS), Scientific Community for Oceanographic Research (SCOR) and the Intergovernmental

34 https://tracexsite.wordpress.com/laboratory-facilities/
35 https://seabed2030.gebco.net/southern_ocean/

Oceanographic Commission (IOC) for the reporting against Sustainable Development Goals and Aichi targets.

2.2.3 Polar Lab

This IF will represent **the first laboratory of its kind for conducting experiments in a temperature-controlled polar environment in Africa**. More students, scientists and technicians will be exposed to polar science and technology without the need to leave the continent and participate in a research cruise to Antarctica. The Polar Lab will simulate the polar environment conditions by means of dedicated cold rooms and an ice-wave tank for seawater experiments, which would be one of the few in the world. The experiments will be monitored from other locations in the country thanks to the concept of Digital Twin Technology illustrated in the next section. The Polar Lab enables the researchers to experiment with the polar environment at any time of year under controlled sub-zero temperatures – regardless of how warm it is outside. It will combine the experience garnered at other international cold laboratories to allow the reproduction of polar physical conditions, such as ice growth, sea ice-water-wave interactions, and biological habitats to conduct assays and incubations. The Polar Lab is a medium-sized infrastructure that requires building works and a phased approach, as further detailed in Chapter 3 and 4. Phase 1 will build technical capacity by implementing mobile labs and the necessary equipment that can be used both in South Africa and in the field. The construction planning will require an initial consultation between the DSI and the involved partners to ensure sufficient funding availability for the building in Phase 2. The University of Cape Town has indicated the intention to host the Polar Lab on their premises through various options, as further detailed in Section 3.1.2. The proposed outcome of Phase 2 will be the construction/refurbishment of the Polar Lab building and the equipment of the various labs according to the priority list. The IF is designed to host gear and equipment for measuring the physical, biological and chemical properties of ice in the field and for preserving ice and temperature-sensitive samples. It will finally represent an essential platform for designing innovative instruments or sensors for the polar regions as well as to test and to calibrate equipment used in the other SAPRI facilities.

SAPRI-coldlab will support a whole host of polar research activities across science and engineering disciplines which require temperature-controlled conditions down to extreme sub-zero values. This will allow personnel to undertake the following research that is currently not possible in the country and the continent:

- Artificial sea ice creation in a wave tank;
- Study of wave-ice interactions and damping of pancake ice and interstitial frazil ice;
- Study of biological uptake, production and gas exchanges in natural and artificially created sea ice;
- Study of atmosphere-ice-ocean interaction in artificially created sea ice;
- Sub-zero testing and analysis of physical, mechanical and biogeochemical properties of Antarctic and artificial sea ice samples;
- Sub-zero testing and analysis of physical and mechanical properties of Antarctic geological samples;
- Near-zero and sub-zero experiments with biological specimens from the polar ocean, sub-Antarctic islands and the Antarctic continent.

The Polar Lab will also fill a gap in the preservation of temperature-sensitive samples and will foster the design and possible commercialisation of innovative sensors for the polar environment. This will allow the following activity to take place:

- Cold storage capacity of ice samples, biological cultures and geological samples for full exploitation of research potential;
- Sub-zero testing of newly developed observation platforms (terrestrial, atmospheric, oceanic, sea ice and space-related) for their suitability in extreme environments;
- Calibration of some acquired commercial instruments, including gliders, with considerable savings in maintenance costs.

This IF will enable the development of equipment for the collection of sea ice and environmental observations and samples via shipboard, *in situ*, custom designed ice-tethered instruments and remote sensing satellite data in collaboration with the engineering components of LTO-Land, LTO-Ocean and the data workflow illustrated in the next section. Cost-effective ice-tethered prototype instruments already have been designed to be deployed on pancake and consolidated pack ice under Antarctic winter conditions and are equipped with GPS sensors to measure ice drift, inertial measurement units for waves-in-ice monitoring (significant wave height and period, wave direction, power spectrum) and environmental sensors (temperature, humidity, pressure, wind speed, wind direction). These ice-tethered observation and measurement platforms will be further developed to facilitate efficient data acquisition and transmission to land-based researchers at various institutions in the country, to allow for a larger spread of the knowledge-base and the validation and calibration of numerical models.

2.2.4 Data, Products and Societal benefits (DPS)

This IF is planned to bring together the SAPRI Data Centre, the various types of generated data and downstream products, including modelling and the societal outreach program. This latter term should be intended in the broader sense, inclusive of research in humanities, digital-human interfaces, awareness and coordination of the public and stakeholder relationships with the RI. Data products are now key to LTO systems - so, apart from data management skills in machine learning, methods and analysis are needed. Just like the other IFs, DPS is built on a phased integrating approach, with the aim of combining different components that are already operating in the polar science field under the SANAP funding cycles or expanding existing facilities within the consortium partners.

2.2.4.1 ***Data management***

The SAEON Data Centre will be expanded to host SAPRI data and hence will host the designated National Antarctic Data Centre (NADC) for South Africa. The SAEON Data Centre, together with the SAEON administration, will thus have a cross-cutting function throughout the SAPRI IFs (see Chapter 4). A representative from the SAPRI DC will sit on the Scientific Commission on Antarctic Research - Standing Committee on Antarctic Data Management[36] (SCAR-SCADM).

The SAPRI Data Centre, guided by the expertise already in place at SAEON, will maintain current best practice in relation to its repository management functions and related systems, and best international practises will be adopted for data management. The SAPRI Data Centre will provide integrated and secure access to the RI's data by applying the Open Archival Information System (OAIS) model and following the FAIR (Findable, Accessible, Interoperable, and Reusable) principles.

Much of the data generated by the existing research activities shown in Chapter 1 have been handled directly by the principal investigators generating the data. SANAP, unlike the other international

36 https://www.scar.org/resources/scadm/overview/

Antarctic programs, does not have a unified repository with a dedicated Data Management Plan (DMP). The collective return on investment and the international exposure as an Antarctic-research country are thus diminished. All SANAP-generated data need to be made publicly available according to the SARIR and NRF principles, but there is no dedicated national effort. Antarctic research data generated in South Africa are therefore either kept internally or linked to publications, or distributed through international repositories, depending on the resources of each individual research team.

SAPRI will homogenise these data streams, thus reducing the strain on research teams and ensuring proper timeliness and metadata generation that aligns with international repositories. Full details on how existing facilities and expertise at SAEON will be integrated in this IF to support this operation are given in Chapter 4 and in Appendix D. A few examples of the international repositories that will be included in the SAPRI DMP are given in Table D1 and Appendix D.

For all these cases, the SAPRI Data Centre can help principal investigators to create specific DMPs to ensure a seamless workflow to translate the data. For example, the Council for Geosciences has the capacity to update and publish geological and geophysical maps and is also the final custodian of rock samples collected in SANAP. In addition, given the lack of international standards in the case of sea ice observations, SAPRI has the opportunity to become a leader in the definition of essential metadata for ice-related variables.

2.2.4.2 ***Data products***

The DPS will be the host of two main components of the SAPRI, the **Digital Antarctic** and the **Communication Technology** team, which will be distributed assets (see Section 3.1.2 and Figure 18). Many of the key essential variables for polar science are currently available through the use of Earth Observations (EO) or geospatial information systems, which rely on the use of satellites and specialised algorithms to retrieve proxy information at spatial and temporal scales that are unthinkable with the more traditional sampling methodologies. Examples are land vegetation cover maps, ice sheet thickness, sea surface data for temperature, salinity, sea state, ocean colour and sea ice. Model output data are also a source of EO data, especially in the case of atmospheric and ocean reanalyses. Due to the process of blending observations with dynamical models, reanalyses can be used to reconstruct past conditions over the Antarctic region and models can be used to predict future states.

EO and model data are produced and distributed internationally by large national agencies or consortia[37]. Most downstream products are freely available for scientific use. However, the global scale products need specific adjustment for the Southern Hemisphere and the regions around South Africa and Antarctica. In addition to this, their processing is left to individual investigators, who may not necessarily have the resources to tailor the products to the region of interest and create workflow automation for continuative use. <u>DPS will develop dedicated tools and dashboards to facilitate research activities that need EO products. There is a major capacity building outcome linked to this effort, since EO and geospatial information skills are scarce in the country, especially for ocean and ice products, which cover the largest portion of the Antarctic region.</u> The use of remote sensing applications in monitoring the cryosphere has potential in terms of enhanced skills transfer and capacity development of South African graduates with reference to remote sensing techniques and

37 A few examples are: https://earthdata.nasa.gov/, https://earth.esa.int/, https://www.copernicus.eu/

image interpretation. Such research also offers increased and more informed management in terms of ice charting and safety for personnel in the Antarctic field through, *e.g.* crevasse identification.

Raw EO data or more specialised data products such as Synthetic Aperture Radar (SAR) imageries, are distributed only to selected partners and are distributed upon request to national contact points. Individual researchers can hardly gain access to these data, unless they collaborate with other international contact points, which automatically creates a dependence relationship with external contributors. SANSA is the national contact point for EO data, and DPS will strengthen the relationship with the polar science community by ensuring that necessary data are stored and made available to scientists, including the necessary training component for working with raw data. SANSA has capacity in terms of data management, including data processing, storage and dissemination.

2.2.4.3 ***Communication***

Satellites are also used to communicate data from human-based and autonomous sampling in the remote Antarctic regions through commercial channels. This is a major expenditure that principal investigators have to bear on their science budgets, with little margin for savings or data aggregation since it is done on a per-platform basis. The DPS facility will conceptualise this component in Phase 1 and will seek for further inclusion in Phase 2 by interacting with the CPUT's satellite programme, which was established in 2009 and has been funded by DSI for the past 10 years. The Africa Space Innovation Centre was established within the programme to build CPUT's satellites and develop and commercialise CubeSat radio communications products for the international market. The M2MSat and the new generation MDASat are focused on developing payload capability to eventually support the complete VHF Data Exchange System (VDES) standard.

This new constellation will represent a testbed for machine-to-machine and Internet-of-Things communications applications within SAPRI, as the software-defined radio payload provides the capability to upload new functionality through software updates once the satellite is in orbit. The VDES provides a capability of data exchange between ships and shore users by terrestrial or satellite link. The use of the VDES spectrum is also free. The system provides a communications platform for users anywhere around the world, and it is suited for the Antarctic and Southern Ocean regions, where commercial communication methods are expensive. VDES can be used for any sensor or other device deployed by LTO-Land and LTO-Ocean that collects data that must be transferred to a central location. A VDES payload on a polar orbiting satellite provides a further advantage in that it covers the entire globe. At mid-latitudes the same location on the Earth is revisited four times per day, and the Antarctic region would be revisited every orbit, up to 15 times per day.

DPS will work with the consortium partners to co-develop a payload and sharing of the M2MSat and MDASat-2 platforms. These missions are currently defined to mainly service the South African Exclusive Economic Zone (EEZ). To operate the satellite at a higher duty cycle to also cover other areas, the satellite bus design must be revisited with a dedicated line of development to include the additional power generation, computational and communications capacity needed to effectively support SAPRI.

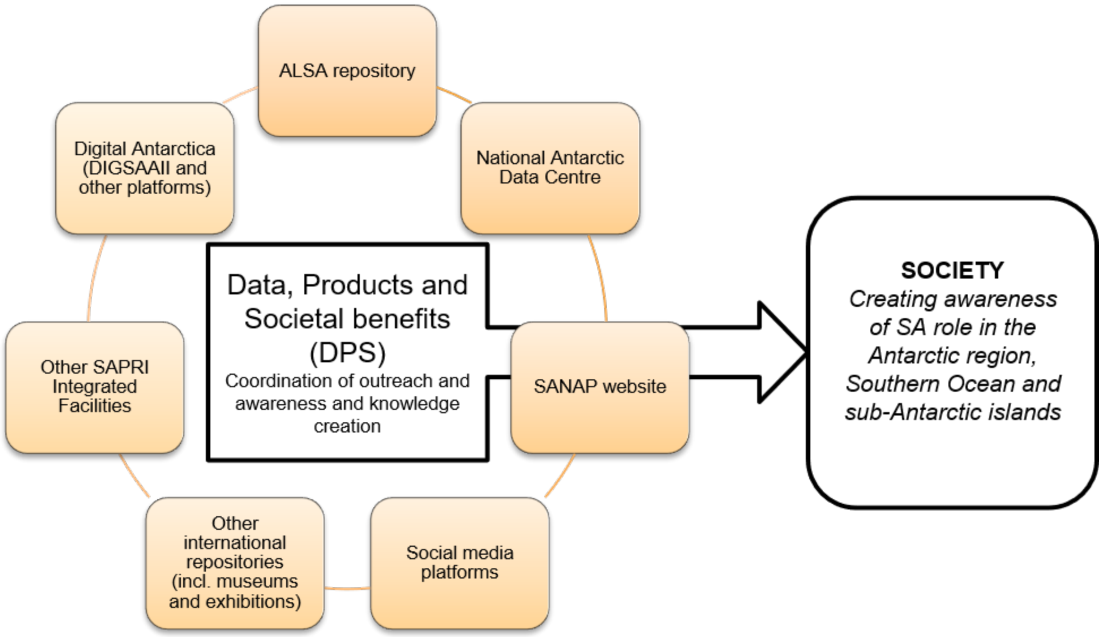


Figure 9 ***Schematic model of the integrated platform within the DPS*** *that will lead to outreach, communication, awareness and transformation.*

2.2.4.4 *Transforming the perception of polar science through innovation, outreach and awareness*

Despite the long history of South African endeavours in the Antarctic region, little of this history has been preserved up until 2009 and even less research has involved the social sciences, law and humanities. The role South Africans have played in scientific, biological, meteorological, engineering and other research in the polar sciences has never been fully recognised, and the changing societal context of the programme remains poorly understood even though there are considerable insights that can be gained from understanding this context and its change over the past 70 years.

SCAR recognised the importance of Humanities and Social Science research as critical to Antarctic research through the establishment of a Standing Committee on Humanities and Social Science. While historical, legal and humanities research is a growing field in South Africa, these areas are sorely underrepresented in relation to other Antarctic nations. SAPRI will provide a coordinating hub to identify areas for further research, issue calls and encourage interdisciplinary collaboration, driving growth in these important fields. This can be achieved in collaboration with existing interdisciplinary bodies such as Environmental Humanities South (UCT, http://www.envhumsouth.uct.ac.za/) and Oceanic Humanities for the Global South (Wits, www.oceanichumanities.com).

Historians and other researchers will be able to draw on the ALSA archive. ALSA has become the digital repository (archive) focused on the history of Antarctic research, including primary resources and material that can be used for outreach and awareness purposes. ALSA contributes to creating a community ethos, partly via the creation and administration of the SANAP website. The potential for this initiative to become a reference for the South African "polar society" at large is enormous, and it is at the core of the DPS facility. Building on the ALSA experience, and through a complete integration of ALSA within the SAPRI, we will bring the infrastructure closer to research/training institutions and stakeholders that have historically been less involved with polar science, and ultimately into the homes of the general public in South Africa.

The concept is illustrated in Figure 9, which highlights the cross-cutting role of DPS and how it will engage with the other SAPRI components to transform the perception of the polar environment in society. The outreach component of SAPRI will funnel the various activities done within the integrated facilities to create Antarctic awareness. This will align South Africa with the objectives of the international community of the SCAR capacity building strategy, which is “to make best use of Antarctic science to illustrate key scientific principles in schools and universities”. As one of the Gateway Countries to Antarctica, we have a moral obligation to capacity building activities and to be role models for the preservation of the Antarctic region. SAPRI, and particularly the component Digital Antarctica, will contribute towards educational platforms and a “museum in a suitcase”, by means of engaging digital visualisations that exploit augmented reality. SAPRI will strengthen the ALSA initiatives, currently a project with a 3-year cycle, through the enhancement of the Antarctic digital museum and the creation of advanced 360° footage of the major polar infrastructures, to create effective digital twins which can be accessed by the scientific community and the general public.

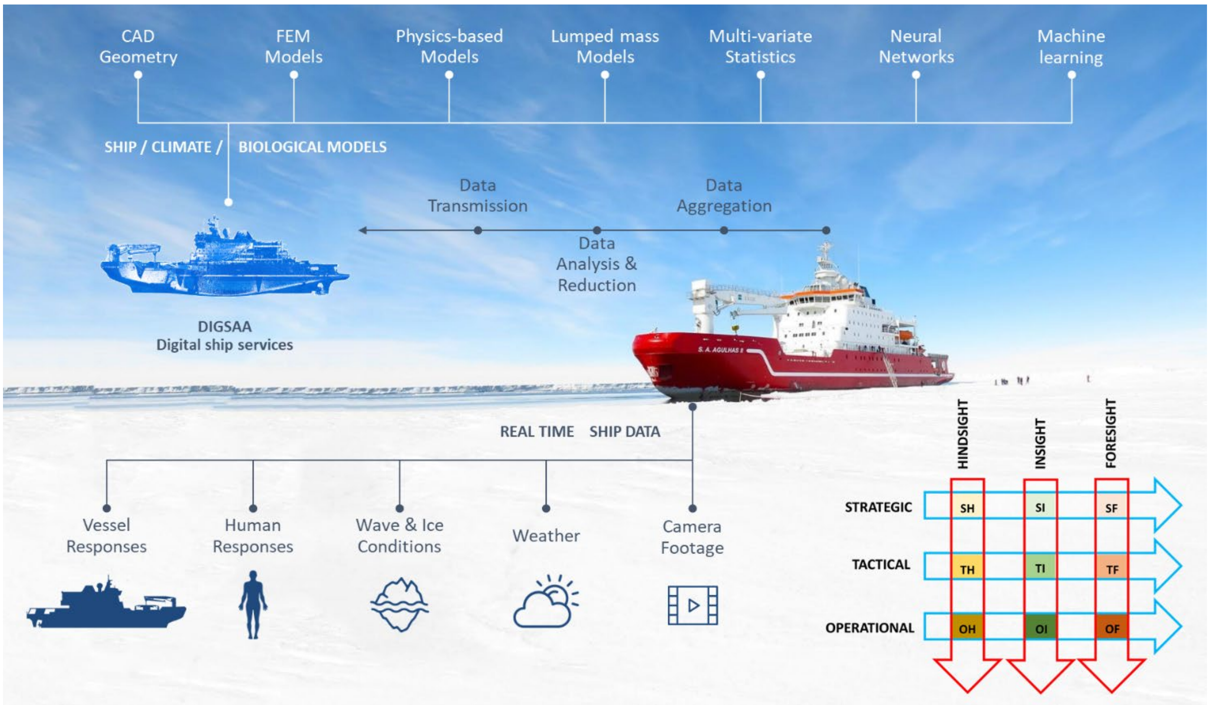


Figure 10 ***A diagram summarizing available ship data and potential model resources*** *which could be combined in differen*t design patterns to create digital services for the SA Agulhas II (DIGSAAII). (Source A. Bekker)

Digital twins are a definitive trend in the 4th industrial revolution and are being embraced more and more by science. The UN Ocean Science Decade has indicated the concept of a “Digital Ocean” as central to the development of more inclusive science. These powerful platforms promise to advance education, research, innovation and industrial development related to shipping, oceans and polar research. The potential open access of versatile, real-time data between research vessels and land-based stations reaches beyond the ambit of engineering to support the research community in their investigations of the environment, climate system impacts and more energy-efficient ship operations. Further, digital twin technologies are central for driving resource intensive economies with technology development in other sectors.

The versatility of digital twin solutions is by nature interdisciplinary, in that their establishment requires the connection of solutions from several fields of engineering, including data science, physics models, measurements, sensor analytics of diverse data streams for engineering, climatological, oceanographic and societal use. The fruitful contribution of digital twin technology further requires a thorough understanding of stakeholder interests as well as an understanding of user needs and adoption protocols. Benefits to the community include the advancement of scientific level and internationalisation of the immediate research environment, the cross-pollination of complementary expertise. Digital twins also have a major transformational role since they would allow scientists with other commitments to participate in traditionally long polar expeditions, or to supervise students from remote. Thanks to the digital technologies they can be placed in prominent roles in the fields of polar engineering and virtual research lab/virtual museum demonstrations.

<u>The main model of a digital twin chosen by SAPRI is the SA Agulhas II (SAAII)</u>, and this will be further expanded to other platforms during Phase 2, when additional funding will be made available for the Digital Antarctic component. The SAAII is already equipped with +200 engineering sensors, as well as other observational devices that are not yet interconnected. As illustrated in Figure 10, it is proposed to fully leverage the unique advantage of scarce operational full-scale data towards new research contributions in environmental observations and shipping. The SAPRI plans to push the SAAII to yet another frontier by completing her evolution as a digital asset, hinging off Maritime 4.0 (Sullivan et al., 2020). New engineering models for ships require validation against real data. The SAAII, her working environment, her sensors and her access culminates in data and matchless practical traction. Research ideologies should thus be driven by the "school of practice" and first-hand experience of the needs of ship owners, officers, crew and passengers.

The consortium partner SUN, in collaboration with international institutions and the other teams running real-time observations on the ship like SAWS and UCT, are at the forefront of this endeavour to develop and implement innovative digital services for the SAAII. The scientific excellence, stakeholder benefits and commercial potential are summarised in Figure 11, in a series of sub-projects that will engage with the various components of the SAPRI, from the Data Centre to the LTO-Ocean and the engineering teams working on communication and autonomous systems. Data transmission is now a major cost for the ship's custodian DEFF, which not only reduces operational capabilities, but also limits the scientific production of the deployed instrumentation. As an example, gliders deployed from the ship are currently piloted from land through a series of workarounds since the ship bandwidth is insufficient. The integrated design of the DIGSAAII network will thus have multiple benefits that will translate into scientific excellence.

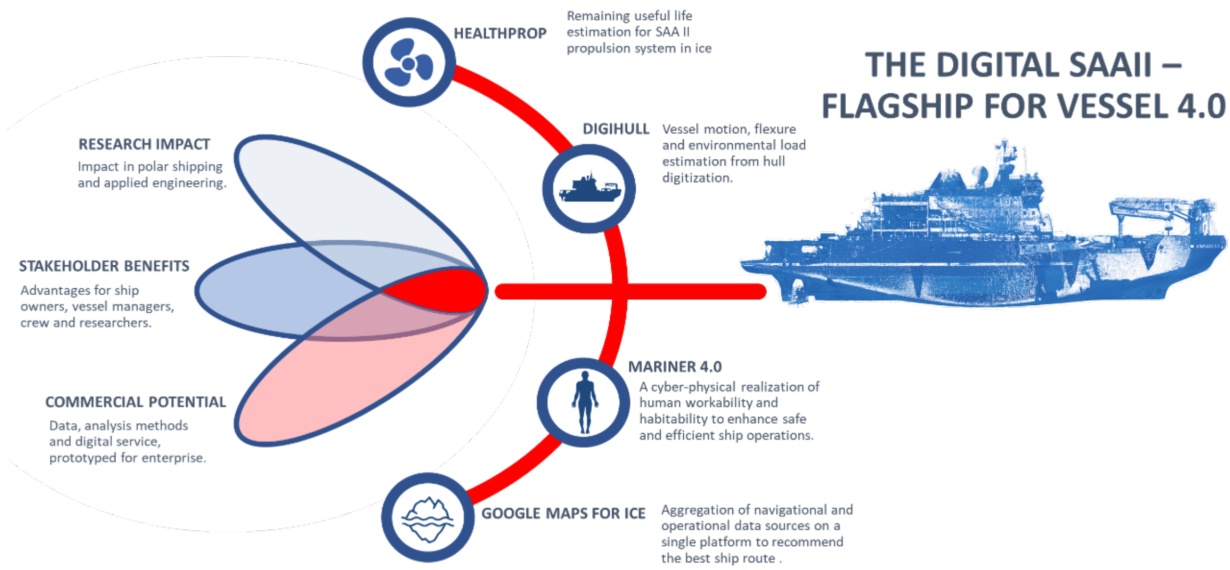


Figure 11 ***Scientific excellence and potential impacts of the DIGSAAII within SAPRI***. *They include: a novel method for the inverse calculation of ice-induced propeller moment and estimation of ship's useful life; analysis methods leading to insights of the structurally most damaging ship operations, such as wave slamming pressure and ice loads; delivery of increased crew safety and awareness through information on human task performance and habitability; a novel aggregation of multiple environmental data to improve routing options and minimise ice loading on the hull, fuel consumption or transit time.*

2.3 APPROPRIATENESS OF THE RI FOR THE REQUIRED RESEARCH

Oceanographic and ecosystem research transformed and expanded from a strongly ship-based or land-based characterisation of mean properties of variables studied, to a stronger focus on variability of variables. The driver of this shift is within the need to predict large-scale climate sensitivities and climate trends and continues to stimulate innovation through improved methods, technology and approaches. Ultimately Antarctica and the southern oceans surrounding South Africa are some of the last frontiers of observing systems, yet this region has such a vital role in climate change. There is a growing recognition within Africa and globally of the need to ensure a Blue Economy, something which can only be truly realised through sustained and broad-based environmental observations, FAIR data and knowledge products, precisely SAPRI's mandate. In addition, the SAPRI is being launched at the beginning of the UN Ocean Decade for Sustainable Development and midway through the African Union's Decade of African Seas and Oceans which will promote SAPRI in both regional and global collaboration.

As highlighted in Section 1.1.3, the proposed reorganisation of marine and Antarctic research infrastructure management through the SAPRI initiative is inherently promoting organisational transformation and innovation. The infrastructure that will be required exists not only as available platforms and sensors from third party manufacturers and suppliers, but also will need to come from a new cohort of engineers and scientists producing and adopting niche platforms and sensors to obtain the information required, along with the requisite support to maximise their value.

In the past, instruments and infrastructure were strongly linked to individual groups and institutional briefs. The new climate and ecosystem research challenges can only be addressed by inter-disciplinary consortia that require not only greater advanced planning and coordination, but also cross-cutting back-up around data quality and management. Similarly, in terrestrial research, new autonomous sensor technology and communications have enabled great strides to be made in on-going observations ranging from biological cellular function to animal behaviour, and continuous automated observations of the physics and chemistry of the lower and upper atmosphere. The capital outlay for the infrastructure required to sustain this globally competitive research is high; so too are its maintenance costs. It will be more effective to support such research by taking a national infrastructure model approach through SAPRI instead of the single user historical model.

A national infrastructure model also has the advantage of being a mechanism that facilitates regional and global infrastructure partnerships. One of the key benefits for SAPRI is the regional and global visibility, strengthening the case to make South Africa a global destination for Southern Hemisphere Polar Research. A key aspect for this kind of infrastructure is delivering information and innovating products required by society and policy-makers at the national, regional and international scale. The SAPRI thus becomes a mechanism to deliver strong support to research and HCD, technological innovation while creating societal benefits.

While most future needs for the research supported by the SAPRI cannot be predicted at this stage, an important outcome beyond the improved coordination and planning is continuing the demographic diversification and development of capabilities that will make it possible for the South African polar research community to create innovative responses to address those needs holistically and successfully.

2.4 INTER-DISCIPLINARY RESEARCH ENABLED BY THE RI

As it should be clear at this stage, polar science in South Africa is spread across a number of disciplines and thematic study areas, which are not just restricted to the already loose definition of polar sciences given in the Introduction. This creates skills which may be useful to adjacent science initiatives, but also creates needs which require a consolidated approach to overcome. The interdisciplinary research space enabled by the SAPRI is defined by the 4 main MARS themes (Section 1.2 and Box 1). This research strategy was largely formulated by the scientific community. SAPRI will allow further expansion of this polar research space to incorporate emerging needs that support economic opportunities for South Africa. SAPRI will thus facilitate the science that is needed to inform new challenges such as

- Antarctic Tourism (excluding the Prince Edward Islands)
- Gateway Country and City to Antarctica
- Non-exploitative renewable energy
- Biotechnology
- Geo-engineering (excluding prospecting).

All the SAPRI IFs inform the larger domain of Earth System Science (ESS). ESS is part of a dedicated funding support by NRF in South Africa through the Earth System Science Research Program. It embraces a tier of layered dynamics, each requiring its own set of investigative instrumentation and skills set. While in the past, much of the effort has gone into the processes and components of these ESS domains, the emphasis in this strategy is across the boundaries in order to advance the understanding and consequences of interactions across the layers. The whole cannot be studied by a single entity and collaboration and interaction between component teams is essential. The strategic approach is to focus on the major sub-themes independently, starting with space science – upper – lower atmosphere dynamics, proceeding to atmospheric-sea ice-ocean interactions and atmosphere–landscape interactions. SAPRI provides infrastructural support to all these disciplines by means of the dedicated facilities LTO-Land, LTO-Ocean and Polar Lab, as well as access to data and products through the integrated facility DPS.

The physical environment greatly influences biotic components of ecosystems, especially at high latitudes, where strong seasonality and extreme conditions tend to dominate biotic interactions. The Antarctic and Southern Ocean regions are subject to observable climate and other global change due to activities outside the region, e.g. increases in atmospheric CO_2 and other greenhouse gases causing regional warming, salinity changes and ocean acidification as well as poleward shifts on westerly winds. These effects lead to feedback, which in turn influence global biogeochemical cycles. The Southern Ocean, one major research theme facilitated by the proposed LTO-Ocean infrastructures, plays a central role in both global and regional climate. The Southern Ocean is also one region where deep-ocean CO_2 reservoirs exchange directly with the 50 times smaller atmospheric reservoir, thus potentially altering the presently balanced fluxes of natural CO_2. An understanding of these ocean dynamics is essential to ensure that global CO_2 mitigation efforts in the coming century are effective.

The impact of human presence on sensitive dynamics in the Antarctic region is not well studied or understood. Thanks to the seamless coordination envisaged by SAPRI, South Africa can take advantage of its presence and participation in the ATS by developing an interdisciplinary active programme of research, which can inform and advise on the non-exploitative use of Antarctic resources and the human impacts on the ocean and island systems.

Humanities research is inherently synthetic, connecting across a wide range of disciplines and producing key coordinating insights. The Environmental Humanities, Science and Technology Studies, and Critical Ocean Studies are growing disciplines worldwide with world-leading researchers also based in South Africa. Within the MARS theme Human Enterprise, research aims to explore international relations, law, the humanities, as well as the historical, sociological and political dimensions of South African activities within Antarctica, the Southern Ocean and its sub-Antarctic islands. The Humanities and Social Sciences will be further promoted by SAPRI in order to properly understand the history of Apartheid and post-Apartheid involvement in the Antarctic region, to contextualise future-oriented research, and to decolonise Antarctic science globally. Through the dedicated infrastructure on Outreach and Society, SAPRI will serve as an enabler to broaden South African research capacity on human activity in this region, both in terms of the disciplinary base, as well as the researcher communities and individuals who are actively engaged. This capacity building will also be achieved through the South African Association of Polar Early Career Scientists (APECS-SA).

The public and stakeholder awareness of the research and its implications for resilience planning, mitigation and adaptation is critical and the RI community has the responsibility to show societal value for the significant investments that make this RI possible. The integration of Humanities and Social Sciences research projects as well as ALSA into the SAPRI through the DPS facility will support this communications function. The collaboration with Digital Humanities of South Africa (DHASA) and the RI SADiLAr will create the possibility of making polar research available in all South African Indigenous languages.

The innovation and technological component promoted by the DSI White Paper introduced in Chapter 1 will be greatly facilitated by the SAPRI design and will foster interdisciplinary and transdisciplinary research. One of the primary purposes of engineering in SAPRI is to establish, maintain and expand a safe, efficient and cost-effective platform for research in the Antarctic and Southern Ocean. Due to the harsh conditions of Antarctica and the surrounding oceans, survival and research is possible only through superior hardware, as people have to be capable of working under strenuous conditions. This will create several lines of interface with various types of interdisciplinary research. Some examples include the following:

- Design and build facilities for living and working
- Develop, install, maintain and improve infrastructure (communication systems, electricity generation, heating, ventilation and air conditioning systems, water supply and sanitation, harbours, runways, etc.)
- Design, build, maintain, and improve transportation systems and logistics management systems
- Satellite Communications
- Energy management and generation
- Polar vessel design, research and evaluation
- Supplies, waste and materials handling
- Security of infrastructure and natural resources.

2.4.1 Significance of linkages with other RI

SAPRI will collaborate directly with two already established research infrastructures, namely the Shallow Marine and Coastal Infrastructure (SMCRI) and the Biogeochemistry Research Infrastructure Platform (BIOGRIP) (Table 3).

SAPRI, within the context of its long-term observations and science, may develop collaborative relationships in the future with:

1. The Expanded National Terrestrial Environmental Observation Network (EFTEON), specifically as regards terrestrial ecosystems on the sub-Antarctic Islands and Antarctic base,
2. Biobanks and DIPLOMICS with regard to terrestrial research,
3. The Natural Sciences Collection Facility (NSCF) to archive unique and newly identified specimens of fauna and flora,
4. The Solar Research Facility with particular reference to generating energy at the three bases and reducing the carbon footprint of research in these regions.

Table 3 ***SAPRI collaborations****. Planned (P) and envisaged (future - F) linkages with the other SARIR initiatives.*

Thematic area	**Identified RI**	**Linkage**
Humans and Society	The South African Network of Health and Demographic Surveillance Sites	
	National Centre for Digital Language Resources (SADiLAR)	

Health, Biological and Food Security	Distributed Platform for "Omics" Research (DIPLOMICS)	F
	Biobanks	F
	Nuclear Medicine	
Earth and Environment	A South African Marine and Antarctic Research Facility	this proposal
	Biogeochemistry Research Infrastructure Platform (BIOGRIP)	P
	An Expanded National Terrestrial Environmental Observation Network (EFTEON)	F
	Shallow Marine and Coastal Research Infrastructure (SMCRI)	P
	The Natural Sciences Collection Facility	F
Materials and Manufacturing	Nano-manufacturing Facility	
	Materials Characterisation Facility	
Energy	Solar Research Facility	F

2.4.2 Alignment with international RIs

In the polar sciences context, international RIs are identified with the national Antarctic programs contributing to the ATS, SCAR, ILTER and GERI. There are two main models throughout the countries running national Antarctic programs: the centralised infrastructure approach (U.S.), which separates the infrastructure availability from the research component; and the polar institute approach (the majority of the other Antarctic countries), which co-manages the Antarctic operations and scientific research under a unified organisation. China combines both approaches by establishing a Polar Research Institute of China and the National Arctic and Antarctic Data Centre under the National Science and Technology Infrastructure. Other hybrid approaches can be found in Russia and Brazil, in which several institutions are responsible for different components of the Antarctic program.

The U.S. NSF Office of Polar Programs promotes creative and innovative scientific research, engineering, and education in and about the polar regions, catalysing fundamental discovery and understanding of polar systems and their global interactions to inform the nation and advance the welfare of all people. The U.S. National Science Foundation is the federal agency responsible for funding and managing U.S. activities in Antarctica, but the Foundation does not directly hire individuals for this work. Most are selected by participating organisations and institutions by means of a concerted science plan and periodic calls for proposals.

A few examples of “polar institutes” are the Australian Antarctic Division, the Norwegian Polar Institute, the Alfred Wegener Institute in Germany and the Indian National Centre for Polar and Ocean Research.

The Australian Antarctic Division, based in Hobart, Tasmania, is part of the Australian Government’s Department of Agriculture, Water and the Environment. The Division is responsible for Australia’s presence and activities in the Australian Antarctic Territory and the Southern Ocean. The Division leads Australia’s Antarctic Program and the Australian Government’s scientific program in Antarctica. Australia’s national interests and research are set out in the Australian Antarctic Strategy and 20 Year Action Plan. The Plan recognises Australia’s strong strategic and scientific interests in Antarctica and the Southern Ocean and aims to build Australia’s role as a leader in Antarctica.

The Norwegian Polar Institute (NPI) is a directorate under the Ministry of the Climate and Environment. The Institute’s activities are focused on environmental management needs in the polar regions. In addition to collaboration on environmental protection in the Barents region, the Institute dedicates much effort to research on climate, long-range transport of pollutants and their impact on the environment, and biodiversity. The institute is the environmental authority for Bouvet Island and for Norwegian activities in Antarctica. It administers the national Antarctic program and its research plan by means of one research department and four service departments, Operations and Logistics, Environment and Mapping, Communications, and Administration.

The Alfred Wegener Institute is primarily active in the cold and temperate regions of the world. As an internationally respected centre of expertise on polar and marine research, the Alfred Wegener Institute is one of the very few scientific institutions in the world that are equally active in the Arctic and Antarctic. It coordinates German polar research efforts, while also conducting research in the North Sea and adjacent coastal regions in Germany. The research programme "Marine, Coastal and Polar Systems” pools the scientific expertise of the AWI in regard to all geo-scientific, biological and climatological research themes in the Polar Regions, the Arctic Ocean and the Coastal and Shelf Sea Regions of the North Sea. AWI is composed of three scientific divisions and one division dedicated to administration and infrastructure management.

The National Centre for Polar and Ocean Research (NCPOR) is India’s premier R&D institution responsible for the country’s research activities in the polar and Southern Ocean realms. The Centre represents the centralised organisation for the coordination and implementation of the Indian Antarctic Programme, including the maintenance of India’s permanent station in Antarctica. It facilitates the scientific research activities being undertaken by other national institutions and organisations in Antarctica, the Arctic and in the Indian Ocean sector of the Southern Ocean. It is composed of six departments, three dedicated to the science components, one for deep-sea exploration and mapping, and two dedicated to expeditions, operations and management.

SAPRI is currently aligned with the U.S. approach, since it focuses on infrastructure administration and management. However, it does not include the strategic science planning component, which is instead a mandate of the NSF Polar Office. The proposed Phase 3 would lead to the transition towards the approach that is most commonly found in the other Antarctic countries. NPI and NCPOR are the models more akin to the proposed development, although the SAPRI would further expand the research opportunities with the establishment of the Polar Lab, which is not present at the other institutions.

3 MANAGEMENT PLAN

In highlighting the history of the science undertaken south of South Africa, the SAPRI also highlights the clear silo-like nature of the current status of polar research in our country. Many groups working within the same disciplines are not always aware of what equipment they may have available to them. Discussions around SANAP take-over voyages and logistics versus the necessary science needing to be undertaken to support our very presence as a country in the polar regions is often fraught with misunderstandings. Given the marine and Polar community in South Africa is, by its nature, very small, this silo-like approach to conducting the National Antarctic Programme can be inefficient and limiting to both research projects and logistics operations alike.

This is one of the objectives of the SAPRI - to build a polar community that works synergistically with DEFF's logistical components of sub-Antarctic and Antarctic base management as well as vessel and helicopter management. SAPRI will not be a successful venture if there is no clear and mutual agreement between the science and the logistics of polar research, with these relationships being consistently nurtured and mutually developed. Such coordination is envisaged to lead to the eventual establishment of a national polar institute, which would allow the logistics and science plans to be aligned, as happens in the majority of international polar programmes. A good level of integrated management will be required to operate SAPRI sustainably and economically. Such integrated management will promote complementarity and avoid duplication as well as drive the overall costs of polar research down to improve the return on investment. This obviously emphasises the importance of a common understanding and regular meetings, not only between the SAPRI and SANAP-logistics operational staff, but also between SAPRI's principal investors, the DSI and DEFF.

Given the distributed nature of SANAP and the need to engage with multiple research partners and institutions, **the proposed management structure hinges on the consortium approach**, in which the consortium manager will act as the main coordination hub and provider of administrative services to the various SAPRI components. Consortium partners will be involved through dedicated agreements that will specify the nature of the collaboration. The main principles are delineated in this chapter; the details will need to be fully defined by the governance bodies and the consortium manager once the proposal is approved and funded. Existing infrastructures currently funded through science programs and maintained by consortium partners will need to be harmonised within the SAPRI integrated facilities (IFs), and this process requires the existence of a legal entity representing SAPRI. Figure 12 presents a diagram of the proposed IFs introduced in the previous chapter, whereas full details on the governance plan will be illustrated in Chapter 4.

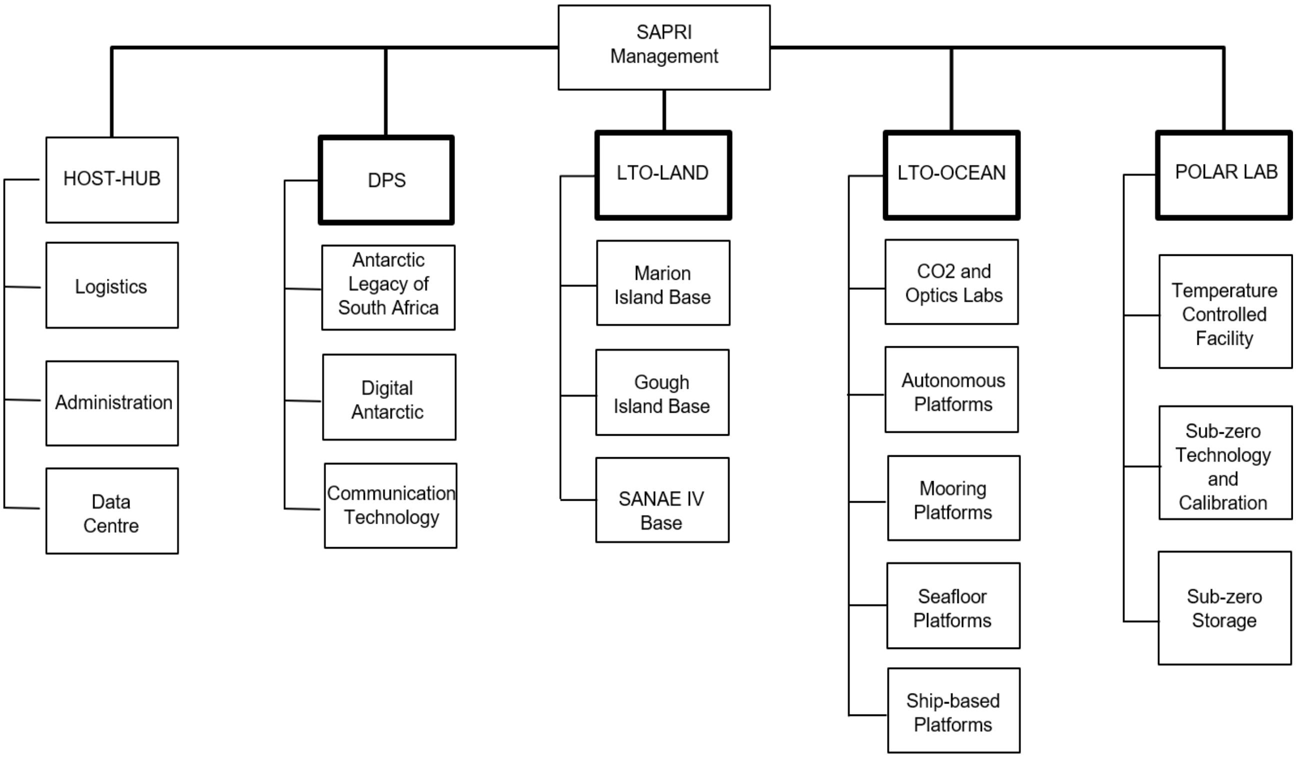


Figure 12 ***Layout of the SAPRI Integrated Facilities (IF) and their components***. *This diagram highlights the thematic relationship within the consortium and the scientific ambits that will guide the management organisation. The hierarchical organigram and the related dependencies among the consortium partners are presented in Chapter 4.*

3.1 THE RI LIFE CYCLE

Following the SARIR life cycle template for research infrastructures, the life cycle of the SAPRI is described in multiple phases (Figure 13 and Table 4):

1) The SAPRI is currently in the proposal phase to be presented to the SARIR panel for approval
2) Proposals have been requested and received from the larger scientific community covering the disciplines as broadly as possible that are involved in Marine and Polar science in January 2020. The presented Conceptual and Technical Design of the SAPRI stems from these proposals but takes into account the contingent situation, the need to share resources (human and infrastructure) where possible across SAPRI and the necessity to operate in conditions of reduced funding availability. A few high-priority components have been built into the proposal in Section 3.1.2; the other components proposed in the consultation phase will be briefly illustrated and further detailed through dedicated working groups for eventual fund-raising actions. It is important to note that the range of components should not be considered exclusive. Should other disciplines be keen to join the SAPRI initiative, this will be considered within the appropriate governance structures.
3) After approval and the allocation of a budget to the consortium host, **PHASE 1** will start (Figure 13). The setting-up phase will involve a number of key activities: establishment of the governance, negotiations with consortium partners and other key stakeholders; development of SLAs, MoUs and MoAs; identification of critical infrastructure requirements, linked to either

long-term monitoring maintenance or other requirements such as the SA Agulhas II dry-dock schedule. This phase will also include the redesign of SANAP-Science procedures for project endorsement and their alignment with infrastructure availability.

4) The running phase (**PHASE 2**, Figure 13) will see the operational establishment of all the planned IFs, the flow of infrastructure procurement, rolling out of projects within the SANAP framework, research and take-over cruise work plans, capacity development and skills transfer.
5) In the context of SAPRI's long-term environmental research a complete shut-down phase cannot be premeditated at this stage and it is not envisaged. Given the impacts of global climate and environmental change, the growing economic and international importance of the Antarctic region, and the need for science plans to be coordinated with the infrastructural development, the scientific community expressed the potential to evolve SAPRI into a national polar institute (**PHASE 3**, Figure 13). Within the estimated 15 years life cycle and at least after 2 or more years of a successful running phase, a consultation should be started between the SAPRI community and the governmental stakeholders to consider the transition to a South African Polar Research Institute. This consultation phase will consider the various governance options and how to maximise the infrastructural investment of the SAPRI. If the consultation would not recommend the transition, SAPRI will continue Phase 2 indefinitely, unless a shutdown would be necessary for contingency reasons. Phase 2 will also contribute to the training of the necessary scientific workforce that would be absorbed by the new entity if continuing into Phase 3.

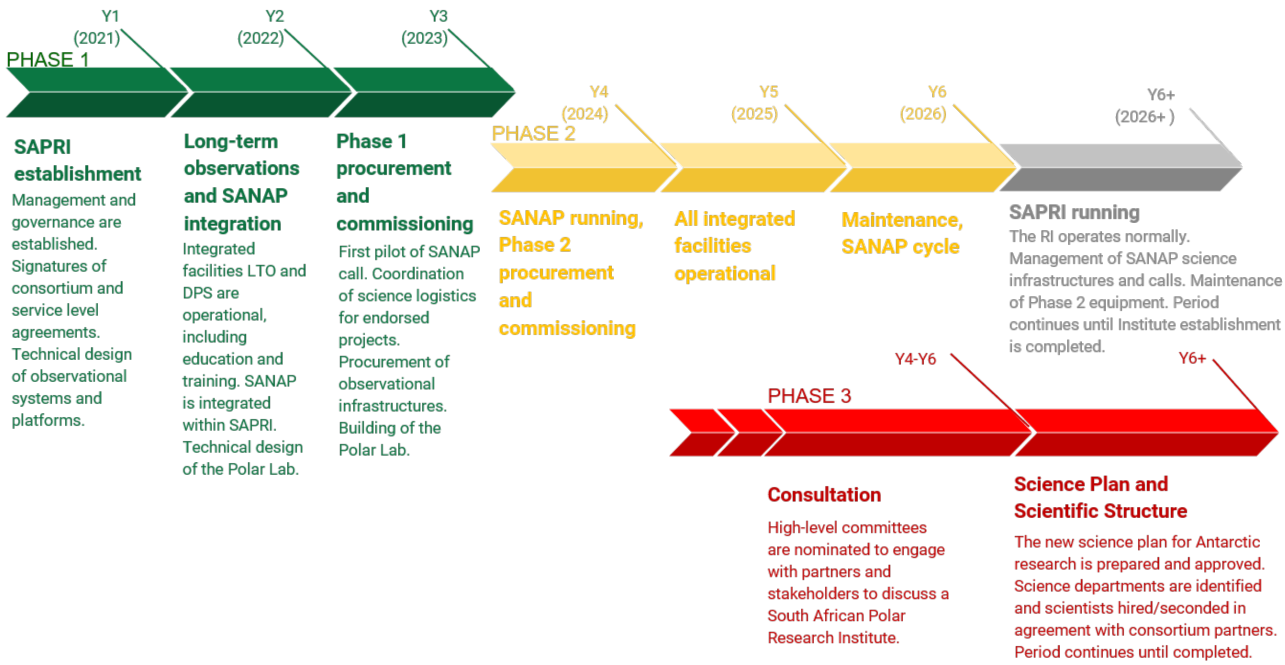


Figure 13 ***Diagram of the proposed phases in the SAPRI life cycle***. *Further details are given in Sections 3.1.5 and 6.2.*

3.1.1 Position of this RI on the Life Cycle

Table 4 ***Main phases of the SAPRI life cycle***. *The exact starting period of Phase 3 cannot be determined, and it will depend on the consultation phase in periods 4 to 6.*

	Years of Implementation														
Life Cycle Phase	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Set-up (PHASE1)	X	X	X												
Running (PHASE 2)				X	X	X	X	X	X	X	X	X	X	X	X
Transition (PHASE 3)							X	X	X	X	X	X	X	X	X
Shut-down*															

3.1.2 Setting up the RI

3.1.2.1 *Conceptual Design*

This proposal is the result of a series of consultations and previous proposals that involved stakeholders at various levels.

The following institutions and stakeholders have been consulted:

1. Cape Peninsula University of Technology (CPUT)
2. Council for Geoscience (CGS)
3. Council for Scientific and Industrial Research (CSIR)
4. Department of Environment, Forestry and Fisheries (DEFF), specifically the Oceans and Coasts and Antarctica and Islands branches
5. Department of Science and Innovation (DSI)
6. National Research Foundation (NRF)
7. Nelson Mandela University (NMU)
8. Rhodes University (RU)
9. Sea Technology Services (STS)
10. Stellenbosch University (SUN)
11. South African Environmental Observation Network (SAEON)
12. South African Institute for Aquatic Biodiversity (SAIAB)
13. South African Space Agency (SANSA)
14. South African Weather Service (SAWS)
15. University of Cape Town (UCT)
16. University of Fort Hare (UFH)
17. University of Johannesburg (UJ)
18. University of KwaZulu-Natal (UKZN)
19. University of Pretoria (UP)

20. University of South Africa (UNISA)
21. University of the Witwatersrand (WITS)

This document also includes components that were previously submitted to the SARIR panel by the champions Dr Pedro M.S. Monteiro and Prof Stephen Hoskins. Notably, the previous iterations of this RI proposal indicated the need for extended consultation with the wide spectrum of stakeholders involved in research within the polar region, which was meticulously done. The stakeholders' management teams of the listed entities (Managing Directors, Research Vice-Chancellors, Directors and or Executive) were contacted to determine whether their institution should be involved within the stakeholder engagement process, which departments within their institution and the key individuals the champions of the SAPRI should engage with to realise the full potential of the RI. The promotion of key individuals to the process of building the SAPRI proposal was thus taken as willingness by the institution to be involved with the SAPRI going forward. The champions met with the representatives between November 2019 and January 2020, and had a consultative meeting in February 2020, in which the consortium model was proposed to DSI and considered favourably. The consortium manager was decided upon by the DSI through evaluation of proposals submitted by those institutions keen to host. Proposals were submitted to the SAPRI champions by SAEON, UCT and NMU. The DSI chose to place the SAPRI hosting within SAEON given their already successful hosting of two Research Infrastructures (SMCRI and EFTEON), their finance, procurement and human resource procedures following those set forward by the NRF and thus the DSI, and their long relationship with the DEFF. In doing so, the DSI has created the opportunity for South Africa to integrate a unique, continuous and intercontinental mega-environmental research infrastructure spanning from the Limpopo over 6000 km to the SANAE IV base in Antarctica.

The COVID-19 pandemic has since then affected the process and substantially delayed the work on the proposal. Financial implications have been raised and have contributed to a reshaping of the initial conceptual design. Continual online meetings between the champions and the SAEON representatives, the Managing Director Johan Pauw and the Manager of the Egagasini node Juliet Hermes, brought to fruition the development of a draft proposal submitted for comments in September 2020 to the identified representatives of the interested parties, and separately to the DSI and DEFF. The current version incorporates those comments. It has to be acknowledged that, while every attempt was made to contact as many stakeholders who have been involved (or are currently) in the polar research space, more groups likely exist that would want to become involved as SAPRI is initiated. Thus, further stakeholder engagement is envisaged for input to the conceptual design of the SAPRI. Where possible, collaborative multidisciplinary and trans-disciplinary projects will be encouraged from the outset of SAPRI. Following on from this will be the establishment of the SLAs, MoUs and MoAs with the stakeholders and integrated facilities to ensure clear objectives, infrastructure procurement, access and usage, data management guidelines and personnel requirements. Given the large number of stakeholders at the outset, this process is likely to take time and inform an adaptive organisational management process.

The overall conceptual design presented in Chapter 2 has been delineated by taking into account the submitted documents from the scientific community and the need to proceed with the harmonisation of the existing and fragmented polar research infrastructures. The governance structure detailed in Chapter 4 has been designed to assist and advise in this process. In terms of management priorities, the following *integrative projects* have been considered, and they have been grouped within the IFs shown in Figure 12 (see also Figure 14 for details on the periods of planning).

HOST-HUB

- Establishment of a joint task team SAPRI-DSI-DEFF to work towards the harmonisation of the ASOS and MARS strategic initiatives with the SAPRI implementation and create a joint technical coordinating body (the SANAP Coordination Committee, see Chapter 4). This task will be overseen by the logistics Coordinating Officer.
- Establishment of a joint task team SAPRI-NRF for drafting the procedures for technical evaluation and endorsement of SANAP and international projects, and the provision of the requested infrastructures.

DPS

- Integration of ALSA within the DPS. This task will be led by the DPS coordinating officer.
- Establishment of the Digital Antarctic task team and relationship with the SAEON Data Center.
- Engagement with the ACEP Phuhlisa transformation program to design the training program in polar science.

LTO (Land and Ocean)

- Integration of the marine mammals, bird and space observation networks. This task will be led by the LTO-Land Coordinating Officer and will include the review of the appointment procedures for overwintering teams.
- Establishment of a task team to drive the integration of the SOCCO infrastructure within LTO-Ocean. The task team will be co-led by SOCCO management and by the LTO-Ocean Coordinating Officer. The subsequent technical design of the components of this IF will consider the various options in terms of maintenance of the current glider fleet, hand-over or co-management of the existing sampling infrastructures (GEOTRACES, container labs, CO_2 and bio-optics labs, etc).
- Transfer of the maintenance of the ASCA mooring array facility (DSI-funded project currently based at SAEON, but should be handed-over from Egagasini to SAPRI).
- Identification and eventual hand-over of existing terrestrial equipment acquired through SANAP-Science funding from consortium partners to SAPRI. This work will be a task of the LTO-Land coordinating manager.
- Initial set-up of the deep-sea observatory with the procurement and installation of the multibeam echo-sounder and/or side-scan sonar on SA Agulhas II (depending on funding availability and technical suitability), as well as other equipment for DIGSAA2. This conceptual design task is led by the LTO-Ocean Coordinating Officer in consultation with the DPS Coordinating Officer for integration with the data network.

Polar Lab

- Coordination with UCT, DSI and DHET to plan the building of the Polar Lab and establish the IF. A funding proposal has been submitted by UCT to DHET in the Infrastructure Funding Category, under the Focus Area “National Academic Priorities”. This task will be coordinated by the SAPRI Management Team through an appointed part-time technical project manager, who will liaise with the UCT Planning & Design department. The Polar Lab coordinating manager appointment is planned after the completion of the building phase and before the commissioning.

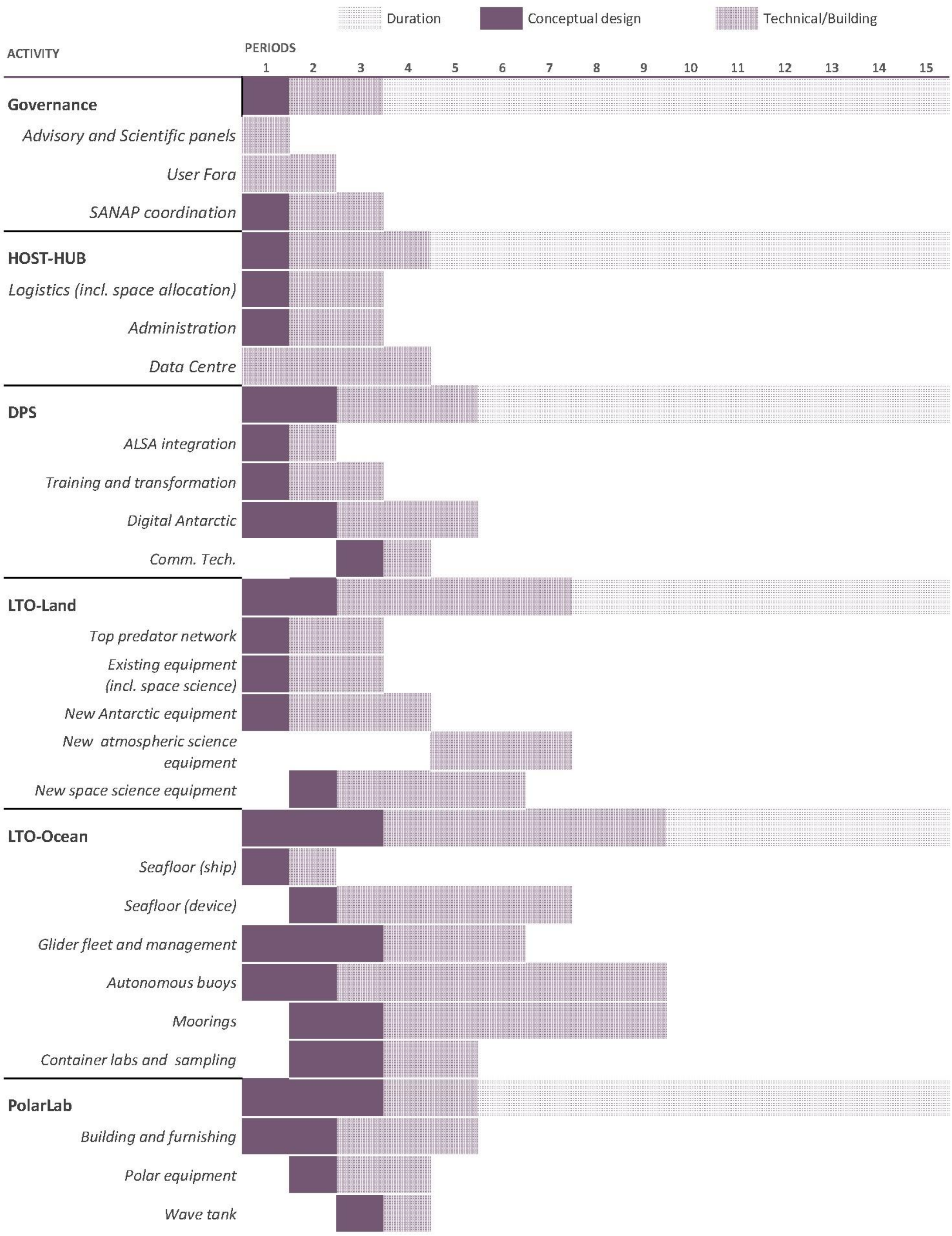


Figure 14 ***Planning of the anticipated conceptual, technical or building periods during the SAPRI life cycle.*** The main bar for each component shows the overall distribution of planning periods, which in some cases are longer than Phase 1 (Y1-Y3). The technical and building periods imply dedicated budget lines for construction and procurement of new equipment. The conceptual design phase involves the establishment of dedicated task teams or further consultations with the consortium partners.

3.1.2.2 *Technical Design*

As with the conceptual design of the SAPRI, Phase 1 will include a series of technical discussions that will shape the main features of the proposed IFs. The integrative projects identified in the previous section will start as soon as the Management Team and the governance are established and operational. The scientific community has indicated the main infrastructural requirements summarised in Chapter 2. Due to the many uncertainties in terms of currency fluctuations, availability of specialised equipment on the market and need for extended consultations, it was not possible at this stage of the proposal to delineate a fully detailed technical planning of the single components in each IF. The budget Illustrated in Chapter 7 for Phase 1 gives a preliminary distribution of the planned purchases and expenditures, including running costs. It is important to realise that this budget is far from ideal, and that given the broad multidisciplinary nature of this infrastructure, it would be dysfunctional and counterproductive to establish a prescriptive top-down list of priorities. For this reason, this proposal gives indicative technical guidelines that will be confirmed by the Management Team in coordination with the User Fora (see Chapter 4). New investments will be carefully considered via proposals submitted to the User Fora for evaluation. An adaptive management approach will thus be followed, in accordance with the planned Antarctic and Southern Ocean expeditions and the existing and future funded projects.

The durations of the conceptual and technical design and building periods are presented in Figure 14, matching the periods of the budget distribution. The initial integrative projects identified in the previous sections will have a round of conceptual design during the first year and are expected to complete their technical design and procurement process within Phase 1. Dedicated task teams will be established to discuss the procedures for accessing infrastructures already existing in SAPRI partner institutes. This does not include the large infrastructures of SANAP-logistics, which will be discussed at a higher level in the relevant governance bodies. Infrastructures developed and purchased through previous SANAP and DSI funding will be as much as possible integrated within SAPRI, according to details decided by the task teams and finalised in the individual partner SLAs. This is the case for Antarctic equipment located at universities, the infrastructure for biogeochemistry and trace metals currently housed in SOCCO and the mooring components hosted at SAEON and CPUT, all acquired through DSI and/or SANAP funding. For more complex equipment such as the glider fleet, the CO_2 and bio-optics lab, an example of the model to be implemented is the so-called "grafting", in which there is a 2-4 year transition period during which equipment and human capacity are built within the SAPRI. During the consultation phase, such a model has been proposed for the CO_2 and bio-optics labs developed within SOCCO, which can take advantage of the current infrastructure maintained by DEFF Oceans and Coasts for their monitoring purposes. The SAPRI will work towards these solutions, to rationalise the procurement and deployment of equipment, and the appointment and deployment of technical expertise thus building economies of scale to increase the national return on investment.

The typical procedure for technical design and procurement of long-term observations is illustrated in the following points:

- In consultation with the advisory structures (Chapter 4), decisions on prioritisation of infrastructure to be procured will be made by SAPRI Management Team. This will take into account the long-term monitoring projects listed above, the large-scale infrastructure calendar determined by DEFF, the SA Agulhas II dry dock schedule (where infrastructure needs to be installed on the vessel), amongst other considerations.
- A service level agreement (SLA) or MoU will be drawn up between the SAPRI and the involved consortium partners. Each SLA will be unique to the institution involved, and will include resolution on arrangements of existing staff and infrastructure, the procurement process for new equipment, commissioning, the access policy and the maintenance/replacement.

- Once the infrastructure has been procured, either the IF or the SAPRI hub will maintain the infrastructure, dependent on the nature of the instrument and the SLA.

Technical design related to data management is fully described in Section 3.3 and the Appendix D.

3.1.2.3 *Establishment and Construction*

In terms of the SAPRI hosting hub, negotiations with DEFF around office space and facilities will need to be finalised as, although SAEON will be the host, their offices are currently hosted by DEFF. The SAPRI will require office space for seven individuals at minimum (see Section 3.2), preferably with space for an additional seven individuals as visiting scientists, students or interns. The SAPRI Management Team will also need access to boardroom facilities with telecommunication technology for virtual meetings, kitchen and bathroom facilities, storage facilities for infrastructure being readied for take-over or research cruises and ideally workshop space for instrumentation maintenance or pre-cruise preparation. The ideal space would be at East Pier alongside the DEFF Antarctica and Islands facilities to allow for easy communications with the logistics team and access to the SA Agulhas II and adjacent loading facilities. This technical phase will be carried out during the first year of the project (Figure 14). Expanded LTO infrastructure will require storage facilities preferably at East Pier. However, if space at East Pier is inadequate, capacity could potentially be developed at other institutions in the Cape Town area, but this would require additional funding.

The major construction work will be the building of the Polar Lab, which UCT has submitted a request for funding to DHET in the Infrastructure Funding Category, under the Focus Area “National Academic Priorities”. The SAPRI will commit the funding to equip the Polar Laboratory. Once again, equipment and furnishing procurement and usage, maintenance, consumable usage, utilities, personnel, etc will be clearly articulated within the SLA with UCT.

Being novel in Africa, the conceptual design of the Polar Lab will be based on existing polar research facilities outside of South Africa, such as at the Dartmouth Thayer School of Engineering, USA, the University of East Anglia[38], UK, and the University of Tasmania, AUS. An important difference to these facilities will be the establishment of a wave tank for sea water operated at sub-zero temperature conditions. The only such installation to our knowledge is currently operated at the Hamburgische Schiffbau-Versuchsanstalt GmbH (HSVA) focusing on ice-ship engineering studies. A schematic of the Polar Lab is shown in Figure 15, to illustrate the various chambers and laboratories to carry out the science proposed in Chapter 2. The facility is planned to be integrated in a newly constructed double-storey building on Upper Campus, UCT. The construction of the Polar Lab will be managed by a specialised project manager in collaboration with the UCT Planning & Design department. The establishment and construction will comprise the following main phases: 1) pre-tender; 2) demolition of old workshop buildings; 3) Building works; 4) Installation of interior fittings and equipment, including:

- Plumbing installation incl. specialised plumbing required for the wave tank and the smaller ice freezing tanks, as well as the saltwater disposal.
- Electrics installation incl. specialised video cameras and sensors for remote control and monitoring of experiments (DTT).

38 https://www.uea.ac.uk/about/school-of-environmental-sciences/research/atmosphere-ocean-and-climate-sciences/roland-von-glasow-air-sea-ice-chamber

- Installation of floors, walls and ceiling insulation as well as air locks, water treatment and recycling and access control.
- Installation of the main and smaller tanks.
- Installation of temperature and humidity control units and control room
- Installation of stainless-steel laboratory furniture.
- Setup of office space for visiting students and scientists.

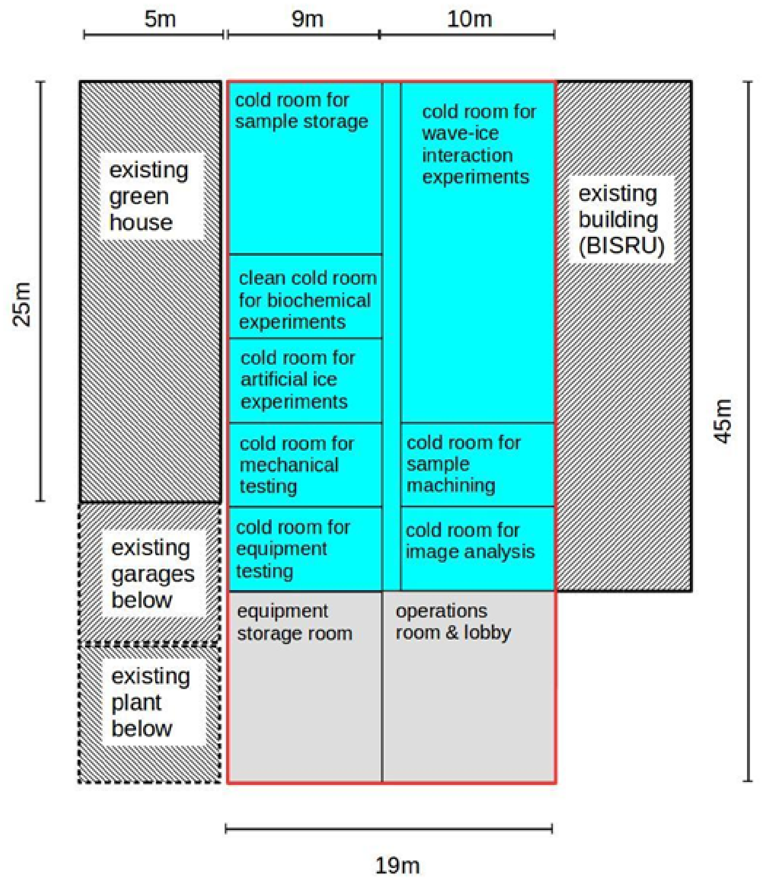


Figure 15 ***Schematic of the Polar Lab and its components***, with a total surface of 855 m^2. The new building envelope is in red and the specialised cold rooms are in light blue.

3.1.2.4 *Commissioning*

Commissioning the Polar Lab will entail the furnishing and installation of the major equipment for ice growth and clean laboratories for biological/biogeochemical experiments. The commissioning phase will continue into Phase 2 (Figure 14), with a series of procurement processes that will be proposed by the Coordinating Officer in agreement with the SAPRI Management Team and the dedicated User Forum.

The new specialised equipment will need to be commissioned as they are procured: autonomous platforms, newly developed deep-sea landers and ROV systems, specialised laboratory equipment used for sample analysis, the multi-beam echo-sounder to be installed on the SA Agulhas II, etc. The infrastructure commissioning will be led by the IF Coordinating Officer in collaboration with the consortium partner that will host the infrastructure, if not directly managed by SAPRI. However, it will remain the responsibility of the SAPRI to ensure the correct protocols are followed and all documentation is properly archived in case of faults further down the line. The approval of the commissioning phase will be done by the Management Team. As part of Phase 1, the IF Coordinating Officers will need to receive additional training in SHE-Q and facilities management (if they do not have this already).

3.1.3 Running the RI

3.1.3.1 *Operation*

The main functions that are proposed to become operational in Phase 2 are summarised per IF in Table 5.

Table 5 ***Planned operational functions of the SAPRI IFs.***

Integrated facility	**Operations**
SAPRI Management Hub	❑ Day-to-day management of SAPRI and communication with the IFs ❑ NRF-compliant administration, record keeping, HR processes and procurement procedures ❑ Secretariat for the governance bodies, reporting and liaising with stakeholders ❑ Central hub for access to IFs and alignment between infrastructure availability and science projects/plans (SANAP and other programmes) ❑ Allocation of funding to IFs and overall financial management of the platform ❑ Coordination of the logistics for science–driven SA and international expeditions, in close collaboration with DEFF
LTO-Land	❑ Management of the SAPRI long-term observation networks on the sub-Antarctic islands, Antarctic continent and ice shelves ❑ Management of overwintering scientific personnel and technicians linked to the observational networks and the endorsed scientific projects ❑ Maintenance of scientific equipment/gear for land-based observations and coordinates the supporting personnel ❑ Management of specialised vehicles and logistic equipment for scientific research at SANAE IV and Marion Island in coordination with DEFF ❑ Coordination between multi-site warehouses and provision of services as required by the HOST-HUB

	❑ Development of innovative observational devices and communication.
LTO-Ocean	❑ Planning and management of the SAPRI long-term observation networks in the Southern Ocean, sea ice, deep ocean sites and the overlying atmosphere ❑ Management of sea-going technicians and maintenance of equipment for ocean (shipboard and mooring) sampling and under-ice exploration, ocean mapping and deep-sea underwater research ❑ Management and maintenance of autonomous devices as agreed upon in Phase 1 ❑ Coordination between multi-site warehouses and provision of services as required by the HOST-HUB ❑ Provision of expert guidance and training on ocean sampling and instrument calibration ❑ Development of the oceanic component of new observational devices and communication, in collaboration with the other IFs and other partners
DPS (including SAPRI Data Centre)	❑ Coordination of the human aspects of Antarctic research ❑ Promotion and marketing of SAPRI ❑ Dissemination of research findings to the broader scientific community and general public. ❑ Stakeholder support and consultation for ATS policies and international programme, including the coordination of the scientific representation in international bodies ❑ Coordination, management and organisational support of the joint capacity building programs between the IFs (e.g. SEAmester, summer schools, etc.) ❑ Management of the training assistance for students, technicians and scientists accessing the IFs ❑ Maintenance of the SAPRI Data Centre ❑ Consolidation of historical data ❑ Retrieval, processing and archival of data according to the management protocols (see details in Appendix D) ❑ Update and provision of data management protocols
Polar Lab	❑ Day-to-day management and maintenance of the laboratory facility ❑ Access control and booking in coordination with the HOST-HUB

	❑ Provision of expert guidance and training on ice sampling and storage ❑ Technical assistance for science projects and design of new instruments ❑ Maintenance of scientific equipment and gear for ice sampling and fieldwork ❑ Storage and archiving of samples as necessary and in accordance with the data management protocols

3.1.3.2 ***Maintenance***

Maintenance of the SAPRI equipment is distributed between the various IFs Table 5. It will be ongoing to ensure continuous operations and quality control of the generated data before transmission to the data centre. As part of the SLAs and MoUs with stakeholders and IFs, a detailed maintenance schedule will be established for each piece of infrastructure procured by or shared with the SAPRI. Detailed Standard Operating Procedures (SOP) will be established from the start, so that any change-over of staff may successfully continue the maintenance of SAPRI-procured and shared infrastructure over the life cycle of the SAPRI.

Certain maintenance will be linked to the ship's schedule and planned according to take over cruises. The maintenance of largescale polar infrastructures is the responsibility of DEFF, which will communicate periods of extended maintenance and/or limited availability. For instance, dry dock periods of the SA Agulhas II will be noted in SAPRI plans in order to carry out any equipment additions in agreement with DEFF.

The SAPRI data centre will undergo regular maintenance as laid out in Appendix D

3.1.3.3 ***Building Community***

The SAPRI will begin its life-cycle with over 20 national stakeholders keenly involved with its inception and success going forwards. The SAPRI also builds on extensive regional and international collaborations, both scientific and in terms of treaties which look to the safe-guarding of the Antarctic continent and key species inhabiting these marine and polar regions. These will mostly consist of scientists directly using the SAPRI platforms for research and student training

The SAPRI will build on the existing skills within the South African community of researchers while working to transform successive generations of technicians, engineers, scientists, humanitarians and decision-makers. The SAPRI will link to other research infrastructures working in both the marine, atmospheric and terrestrial spaces, such as SMCRI, BIOGRIP and EFTEON. In accordance with the strategic planning delineated in the ASOP by DEFF, the SAPRI should be developed into a uniquely African Gateway to the marine and Antarctic region south of Africa and use the opportunity to engage researchers from neighbouring African countries. Given the diverse array of disciplines involved in the SAPRI there will be many users interested in the data products from different disciplines to enhance their own work or international scientists.

Further to this are users such as government departments who require higher-level value-added data products to inform policy for example. This group will expand rapidly as SAPRI is able to create products from historic and present data and make them more widely available. In addition, there will be a community of interested and affected parties (public) and citizen scientists who will be engaged in the SAPRI through the DPS and other outreach activities.

3.1.3.4 ***Capacity Development through Education and Training***

As noted earlier and further elaborated on in Chapter 5, one of the key successes of the SAPRI will be the engagement of early career professionals (exemplified by APECSSA) to continue and extend the work undertaken within the marine and polar space encompassed by the SAPRI thus far. Much of the vigour of the older generation of researchers has gone out of marine and polar science due to a lack of funding, infrastructure and logistical constraints. Through the SAPRI, a new generation of researchers will receive the critical mix of skills necessary to extend long-term observation records and undertake strategic research which has been put on hold for years due to the above mentioned constraints Experience, regardless of whether it is technical or scientific in nature, cannot be taught in a classroom. It is a hands-on, taught, and sometimes re-taught process, requiring many hours of dedicated teamwork in the field. The use of digital twin technologies and the possibility to partly supplement some field experiences in a virtual or simulated laboratory way will further increase the capacity.

Whereas some disciplines can benefit and use extensive robotic automated data logging equipment on land and offshore, other disciplines require trained people on the ground (geology, geophysics, geomorphology, biology) for data observation and sample collection. In this context it is important to maintain continuity of personnel in safe operation in the field, recognizing the subtle but inherent dangers in field operations from tented camps and overland travel. Experienced field personnel are also required in the event of search and rescue operations. This training is currently done within the SANAP-Logistics component, and it will be further enhanced within the LTO-Land IF to ensure that the new generation of polar scientists and technicians will operate safely in the field.

In addition to this are the metrics of any scientific endeavour - postgraduate student theses and peer-reviewed scientific publications. In support of these more traditional aspects should be those of instrument patents, methodological papers including those constituting standards and best practices, data downloads and citations, policy input, teaching resources that can be used for secondary and tertiary education, blogs and vlogs from the ocean or laboratories and other less-traditional training and educational materials. As highlighted in Section 6, SAPRI will keep track of all students using infrastructure and of all outputs produced for reporting purposes and to ensure SAPRI is meeting the needs of and being responsive to its stakeholders. We anticipate that the postgraduate student numbers will increase with time as the national and international collaborators and infrastructure users grow.

Education will be further enhanced through the well-established SAEON science engagement program to reach secondary learners and educators from all over South Africa and to use polar science to support the curriculum in schools and involve them in SAPRI-led annual camps, schoolyard LTER, workshops, Expos, internships etc. In addition to this, education of society is vital, and this will be supported through both the SAEON science engagement program and the DPS IF.

3.1.3.5 ***Upgrading, Replacement and Extension***

In addition to the maintenance schedules and SOPs mentioned in Section 3.1.3.2, which is required for each piece of SAPRI-procured infrastructure, there should be an equipment upgrading, replacement and extension schedule <u>under standard conditions</u>. The proposed equipment and the related budget cover a period of 15 years and were driven by the proposals presented by the science community during the meta-design phase. Availability of commercial instruments will change over the years, as well as the currency fluctuations will affect the priorities indicated in this proposal document. All the upgrades, replacements and extensions will be discussed within the Management Team in consultation with the advisory structures (Chapter 4). Given the vast array of equipment within the SAPRI the replacement of equipment lifespan will vary: *in situ* marine instrumentation will need to be replaced every 5-8 years, however there will be a certain amount of redundancy so this can be set to a 5 year rolling period. Gear and fieldwork equipment for terrestrial and ice activities may require shorter replacement times. This task and the relative replacement plans will be undertaken by the respective IF Coordinating Officers. The current fleet of gliders that has been procured and maintained by CSIR-SOCCO is obsolete and its replacement has been distributed over the first 15 years of the SAPRI life cycle. Larger equipment such as the deep-sea rovers, the Antarctic supply vehicles or the wave-ice tank will likely be replaced only once during the SAPRI lifespan. This will include IT upgrades for the SAPRI data centres, as highlighted in Appendix D.

3.1.4 Shutting down

3.1.4.1 ***Phase-out***

Given that the initiation of the SAPRI revolves around security of long-term observations, the re-establishment of critical observations required over a long period of time to gauge environmental health (e.g. climate change science) and the development of new observations and techniques which will be required for operations related to our EEZ and Operation Phakisa (e.g. seafloor observations), it is not envisaged that projects or components of the SAPRI will automatically phase-out. This will be subject to periodic assessment (Table 14) and a well-managed infrastructure procurement system, an efficient and properly adhered to infrastructure maintenance schedule and funding for running costs and personnel related to the SAPRI infrastructure.

3.1.4.2 ***Decommissioning***

Depending on the life-span of certain infrastructure (e.g. the longevity of a buoyancy glider), which will be detailed for each piece of infrastructure as per Section 3.1.3.5, certain items of high-value infrastructure may require decommissioning.

3.1.4.3 ***Closure or transition to new entity***

The SAPRI Advisory Panel will periodically review the success of SAPRI in the context of the political, institutional, scientific and funding landscapes before making recommendations to the DSI, DEFF and NRF on the extension, transformation or termination of the SAPRI. Pertinent considerations will include national policies and strategies, the infrastructure still functional at the end of the life-cycle and the redeployment of skilled staff.

3.1.5 Stage gate decision making

The main stage gate points or milestones are illustrated in Figure 16. A more detailed table with deliverables and milestones is given in Section 6.2. The design components of Phase 1, which expands on the activities leading to the decision-making stages 1 to 3 are detailed in Figure 14.

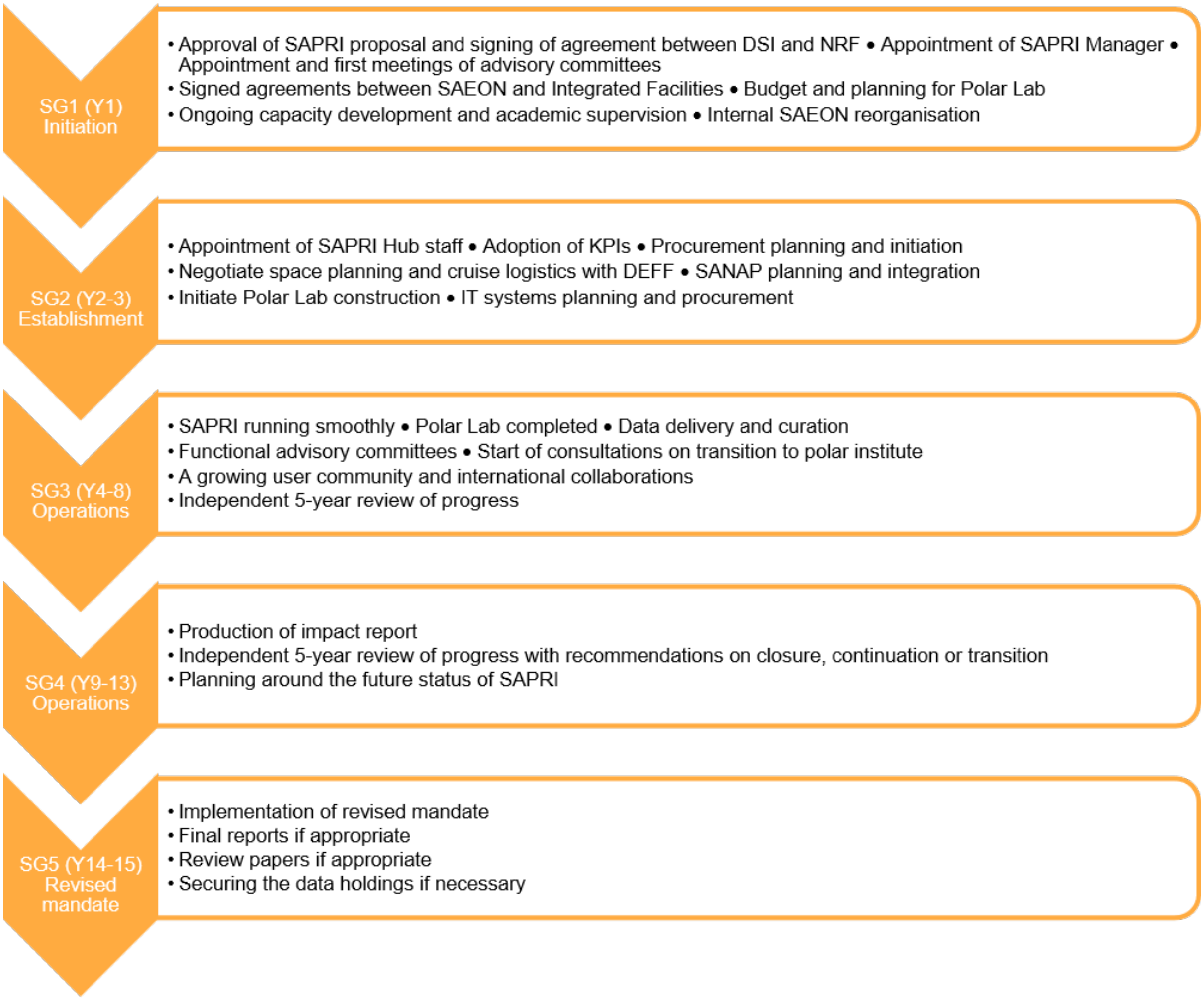


Figure 16 ***Decision making during the RI life cycle***. The green text refers to the continuation of the infrastructure according to Phase 3, while the text in orange highlights the indefinite continuation of Phase 2.

3.2 Technical capacity to operate and maintain the RI

The hierarchical layout of the SAPRI detailing the management plan is presented in Figure 12 and described section by section.

3.2.1 Project leadership

The project leadership of SAPRI will be undertaken by the SAPRI Management Team guided by the NRF policies and SAEON Management. The SAEON organisational structure prescribes the leadership roles, which are based on management positions that are advised by dedicated advisory and scientific panels as fully detailed in Chapter 4. The appointment of the SAPRI Manager and Management Team will follow the NRF recruitment policies, according to a procedure proposed for the BIOGRIP infrastructure and illustrated in the diagram in Figure 17. Should the recruitment process take long, SAEON will appoint an acting SAPRI Manager.

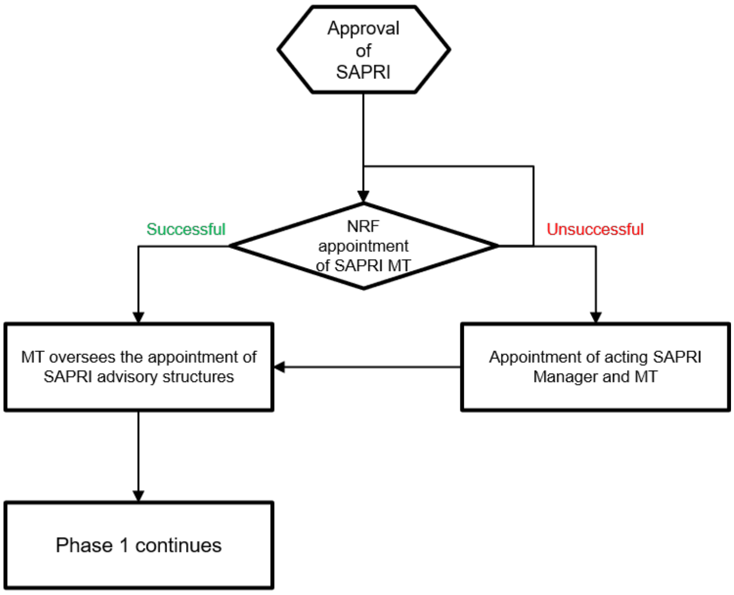


Figure 17 ***Flow diagram for the appointment of the SAPRI Management Team*** (MT).

3.2.2 Management skills

The SAPRI will make use of the following management skills during the life-cycle of the RI.

Table 6 ***Required management skills***

	RI Life Cycle Phase			
Management Skill	**Planning and Specification**	**Set-up**	**Running**	**Shutting Down**
Strategic management	X	X	X	X
Planning and design management	X	X		
Commissioning management		X		
Handover management				X
Operational management		X	X	X
Change management				
Research management		X	X	X
Services management			X	
Product management			X	
IP management			X	X

Knowledge management			X	X
Technology management			X	X
Innovation management			X	
Monitoring and evaluation management		X	X	X
Human resources management		X	X	X
Technical management		X	X	X
Marketing management			X	
Quality control management		X	X	X
Communication management		X	X	X
Financial management	X	X	X	X
Environmental management	X	X	X	X
Social impact management	X	X	X	X
Community engagement management		X	X	X
Stakeholder relationship management	X	X	X	X
SHEQ management		X	X	X

3.2.3 RI Management

3.2.3.1 *General management*

Management of the SAPRI, including the Coordinating Officers for each of the IFs, the hub-hosting team and oversight of the administrative functions, will be undertaken by the SAPRI Manager who will report to SAEON Management and be guided by the high-level SAPRI advisory structure.

3.2.3.1.1 Organisational leadership

The SAPRI Manager will require a suite of skills to effectively implement and manage the RI. This will include a scientific background in marine and polar science but equally important is experience in managing a diverse team of both staff and stakeholders and the ability to manage a geographically dispersed team. In addition to the ability to manage research infrastructure, they will need experience in HR and finance management ideally within an NRF context.

Within the SAPRI, an additional key position will be a dedicated Logistics Coordinating Officer who will need to work side-by-side with the DEFF logistics team for Antarctica and Islands to ensure clear and consistent communication regarding all take-over and research cruises. This work will include involvement with the planning and execution of take-over cruises and equipment management while serving as an intermediary for various science teams where needs be. This position will ensure consistent and effective handling and communication between the teams.

The other Coordinating Officers will facilitate the work of the relevant IFs and research communities.

3.2.3.1.2 Human resources management

Human resource management will remain an undertaking of the HR team at SAEON who report directly to the SAEON Managing Director, based in Pretoria. With SMCRI, EFTEON and SAPRI additional HR support staff will be required. All permanent and contract positions will be advertised, short-listed and managed through this system as per NRF policies.

3.2.3.1.3 Financial management

All procurement for the SAPRI as well as the hubs will be undertaken through a central channel within the SAEON National Office and the SAPRI Manager and Logistics Coordinating Officer. In addition, SAPRI will have a dedicated, high level administration officer to support finance and logistics. Standard NRF procedures will apply, including the annual performance and procurement plans and supply chain management policy (in accordance with the Public Finance Management Act and Treasury regulations). Audits will occur through the NRF 's internal auditor with external financial audits done through the Auditor-General. Additional financial support staff will be added to the current SAEON capacity, in collaboration with EFTEON and SMCRI.

Where considerable procurement is required through one of the IFs managed by another consortium partner, a Service Level Agreement may be drawn up between SAEON and the institution to allow for a transfer of funds. However, a reconciliation of funds and reporting thereof will be required monthly from the institution back to SAEON. Thus, the institution will need the appropriate financial administration structure in place to deal with this, along with effective asset management, insurance of infrastructure and accounting of where all infrastructure resides.

3.2.3.1.4 Communication and Marketing management

Although marketing is a critical activity it is not seen as one that requires a full-time position from the beginning. Marketing will be run through the DPS component of SAPRI, which will integrate the successful communication and outreach activities done by ALSA, and where necessary will be outsourced. SAPRI will have its dedicated website, linked to SAEON and may also incorporate the current SANAP website component depending on the choice made during the design phase described above. A newsletter for communication will be initiated with regular updates from all the different components as well as progress. It will feature on the platforms (website, social media) already established by ALSA. The newsletter will be a prominent feature on the SAPRI website that will link all the different endorsed and affiliated science projects and the SANAP platforms.

Initially SAPRI will work with an outside consultant to produce videos, brochures and displays that can then be updated. These will be aimed at the public, policy makers and the research community (primarily South African, but also regional and international). As the Digital Antarctica component grows, their products will become more central. It is anticipated that all collaborators of SAPRI will be able to provide content for marketing and the SAEON science engagement team will also assist in ensuring that there is appropriate content.

Any direct business marketing needed for products developed will be on an *ad hoc* basis and will be run past the advisory board and the NRF's intellectual property office.

3.2.3.1.5 Operations management

The operations of the SAPRI (Table 5) will be overseen by the Coordinating Officers of the Integrated Facilities, in conjunction with the Logistics Coordinating Officer and the SANAP-Logistics teams. The relationship of this distributed management is detailed below in Section 3.2.3.2.

The SAPRI operations management will be characterised by the concept of adaptive management, in the sense that technical personnel may be redistributed across the IFs depending on the stage of the RI life cycle. A greater emphasis and operational support will be dedicated to establishing data management infrastructure and systems for the first 3-5 years, following which human resources will be shifted towards technical operations of research equipment and oversight of data workflows. The SAPRI advisory system will play a key role in determining the timing and specific details for the adaptive management to maximise the research potential and benefits of the research infrastructure.

3.2.3.1.6 Relationship management

In collaboration with consortium partners, the SAPRI Management Team will be responsible for maintaining and building national and international relationships and contributing to the Antarctic Treaty System (amongst other international relationships). The DPS facility conceptualised in Chapter 2 will progressively grow to incorporate the coordination of international relationships. The work needs to involve the DIRCO, and the national representatives that are part of DEFF. Table 7 shows the major bi-directional relationships with stakeholders and an example of specific management actions (see also Table 1 for a detailed list of the beneficiaries).

Table 7 ***Management of relationships.***

Stakeholder	Management required
Government	Communication: quarterly and annual reporting to funders as per NRF policy and RI requirements; annual impact report; newsletters etc Advisory: Government representation on SAPRI advisory committee; scientific representation in international working groups and other bodies of the Antarctic Treaty System; dedicated DEFF/DSI/SAPRI working committee around ships time and large infrastructures
Industry	Communication: popular articles, industry conferences etc. The South African Marine Resources Exploration Forum (SAMREF) hosted by SAEON will play a role here Advisory: SAPRI to be represented in maritime cluster meetings and other industry related forums. SAPRI to seek engagement of small and medium enterprises for fostering innovation and technological development
Academia	Communication: the integration of ALSA into SAPRI will ensure continuity of the current communication with academia through the SANAP website, which will

	become a component of the SAPRI website. Participation in disciplinary fora and the SANAP bi-annual forum, which will be grown into the SAPRI forum MoU/MoA: annual steering committee meetings with HEIs, specifically with UCT as the Polar Lab host. The DPS IF will put dedicated effort into engaging HEIs which haven't had a strong role in Antarctic science, in particular historically disadvantaged HEIs Advisory: representation of academia in SAPRI Scientific Steering Committee and User Fora
Society	There will be a strong thrust of managing relationships with society through the DPS to ensure South Africans embrace the importance of our Antarctic involvement Communication: popular articles, news articles, videos, blogs, websites, radio and television

3.2.3.1.7 Quality management

This task will fall to the SAPRI Management Team, and with input from SAEON Management, the NRF, DEFF and DSI. All best practices will be followed in terms of the entire observation life cycle and value chain, as laid out by the international best practices documented for collecting essential variables and the FAIR and TRUST data principles (Section 3.6.1 for Data Quality Management and Data Quality Assurance Systems). As highlighted, all sensors will be regularly calibrated by certified laboratories.

3.2.3.2 ***Distributed management***

SAPRI Management Hub

The SAPRI Management Hub will be physically hosted at SAEON in Cape Town, to be closer to the DEFF administration that oversees the Antarctic large research infrastructures. Its administrative role will be fast-tracked taking advantage of the existing administrative and technical capacity that is available at the SAEON central administration in Pretoria and at the Egagasini and uLwazi nodes in Cape Town. Initially there will be support for SAPRI through the current SAEON Egagasini team (Egagasini manager, admin officer, education officer and technician) until all roles are filled. The hub will host the Management Team, which is composed of the SAPRI Manager, the Coordinating Officers of Logistics, LTO-Ocean and LTO-Land and the technicians in charge of the Cape Town facilities and warehouses. The specific tasks of these technicians will be agreed upon through concerted actions with DEFF, given the need to maximise the efficiency of existing and new facilities. The personnel overseeing the National Antarctic Data Centre will also be hosted at the SAEON premises in Cape Town, depending on their specific roles. Additional administrative personnel are planned to be hosted in the hub as the volume of HR and procurement activities grows. A more detailed description of the management organogram and support of the existing SAEON administrative and technical facilities is shown in Figure 18 in Chapter 4.

Integrated facilities management

Each IF will have a Coordinating Officer, who will be a member of the SAPRI Management Team and will report to the SAPRI Manager. These positions will be filled by senior professionals with proven scientific and technical experience in one or more of the disciplines pertaining to the respective IF scope.

Although some IFs are physically administered from the hub, they are composed of external facilities, such as warehouses and equipment, housed at the consortium partners' premises. This is currently the case for the LTO-Ocean glider fleet, some LTO-land equipment and the planned deep-sea facility that will be conveniently hosted at SAIAB premises due to the presence of existing technical and scientific skills. Technicians and supporting personnel may be directly hired by other consortium partners through funding from SAPRI under specific Service Level Agreements (SLA).

In the case of the LTO-Land and LTO Oceans, the Coordinating Officers will work closely with the various institutions and stakeholders involved with long-term observations, as well as with the Logistics Coordinating Officer to ensure continued communication around take-over and research team science. Where required, the officers may also work with international teams within international projects endorsed by the SAPRI governing bodies.

The DPS and Polar Lab IFs will be hosted outside of SAEON, at Stellenbosch University and University Cape Town, respectively. This is due to the already existing capacity determined by the presence of ALSA and the UCT sea-ice science and engineering teams. The supporting staff will be employed by the respective institution and funded through the SAPRI via specific SLAs, inclusive of HR and procurement to be done through the consortium partners' administrations.

3.2.3.3 ***Cyber infrastructure management***

The cyber infrastructure will be managed under the auspices of the SAEON cyber infrastructure. SAEON is part of the SANReN infrastructure and hence the SAPRI Data Centre will be directly embedded into the system. Backups, including tape backup, will be automated and at two geographically distributed servers (outside of the SAEON central server) which will provide security in case of system breakdowns.

3.2.3.4 ***R&D management***

The SAPRI has been modelled on the NRF-SAIAB ACEP programme, which aligns the NRF funding opportunities with infrastructure availability from different partners. The R&D management of the SAPRI will thus be hinged on the reshaping of the existing SANAP-Science system to accommodate this model. As introduced in Section 1.2.1, much of the budget allocated for funding the SANAP scientific components is used to maintain long-term observations, thus reducing the R&D potential and the possibility to transform the historical range of users. The management of observational networks and research platforms done by the SAPRI will allow the researchers to focus on the new science that will be enabled by the infrastructure. The peer-reviewed evaluation of the SANAP science proposals will still be done according to the NRF procedures, hence completely independent of the SAPRI. The proposals recommended for funding, as well as other projects of national interest funded outside the SANAP framework, will be endorsed by the SAPRI and considered for logistics planning (see also Section 3.3 for more details on the access to platforms). The SAPRI contribution to and management of R&D will thus be done through the research partners involved in the endorsed projects.

In the first two phases, the SAPRI will not specify the research agenda, which will be based on the national research interest in the polar space. The research design of the SAPRI, and thus the use of the infrastructure, will be advised by the Scientific Steering Committee who will be informed by the individual thematic User Fora. These fora will advise on priorities for infrastructure in current use, planned usage, standardisation, maintenance and calibration schedules, etc. Critically, these fora will also advise where new technologies needed for the SAPRI are being developed or where focus needs to be placed in achieving research goals set forth by the community. SAPRI will foster interdisciplinary fora with various skills to find solutions with out-of-the-box thinking.

3.2.3.5 *Access and work scheduling management*

A comprehensive infrastructure register and booking system will be established for and across the IFs. The main management operations are organised as follows:

- An exhaustive list of assets will be maintained by the SAPRI Management Team. Given the sheer size of the SAPRI, this is considered a critical practice and the specific procedures will have to be reviewed periodically by the advisory structures as the assets grow with time.
- A centralised electronic booking system will be initiated and maintained by the hub. It will show the infrastructures available for each IF and their planned usage. The updating of this list is ultimately the responsibility of the Coordinating Officers.
- Any requests to use or access infrastructures will be placed through the online system to check maintenance schedules of that instrument, what projects it is currently booked for and when the instrument will be available for use. Regular meetings will be held within the Management Team to ensure a smooth functioning of the booking system, to resolve requests by two or more users at the same time, with emergency meetings called when needed.

3.3 ACCESS POLICY

As illustrated in Chapter 1, polar research is built on infrastructures of various sizes, from large facilities such as ships and bases, to medium facilities such as land-based laboratories, ship-based container laboratories and supply vehicles, down to individual field gear. In most instances, due to the seasonal nature of this research, all the equipment may need to be used at the same time and distributed among different users. The SAPRI is designed to work with the whole range of infrastructures and facilitate their usage for scientific purposes, but it is not meant to regulate the direct access to the SANAP-Logistics infrastructures (namely, the SA Agulhas II and the bases). This role is mandated to DEFF through the Cabinet's decree (see Section 1.1.2). During the conceptual and design phase described in Section 3.1.2, the SAPRI and DEFF will undertake a joint process to specify the detailed procedures.

The next sections and Table 8 thus describe access policies for the infrastructures, data and products that are directly controlled or curated by the SAPRI.

3.3.1 Data

Data collected and curated through SAPRI will follow the FAIR (Findable, accessible, interoperable and reproducible) and TRUST (Transparency, Responsibility, User focus, Sustainability and Technology) policies and, where possible, be connected to international repositories. In particular, the SCAR data policy applies, which is binding on all nations and researchers collecting data south of 60°S. The data access policy and access management ultimately follow the NRF and government policies for publicly funded research. Standard Operating Procedures for data acquisition and data requests will be compiled by the SAPRI Data Centre. A fully detailed preliminary Data Management Plan is given in Appendix D.

Unless specifically requested, the SAPRI Data Centre will issue deposited datasets by default with a Creative Commons License that allows sharealike and commercial use while conserving rights of intellectual property owners across multiple jurisdictions. Users of the data, distinguished according to the Table 8, must give appropriate credit, provide a link to the license, indicate if changes were made and distribute their contributions under the same license as the original.

Data are broadly described in terms of five classes, which determine their accessibility:

- Level 0: Unprocessed instrument and/or field data at full resolution in any digital format. These data are not quality assured but have all communication artefacts removed (e.g. duplicated data, unreadable formats, etc.)
- Level 1: Calibrated data at full resolution, spatially-corrected and geo-referenced, time-referenced, annotated and quality controlled with ancillary information.
- Level 2: Derived chemical, physical and biological variables converted to standard units and data stored in standard digital formats. International protocols and metadata descriptors available.
- Level 3: Mapped and/or published (with DOI) variables or derived aggregates, with metadata and standard digital formats. Distributed to international datasets.
- Level 4: Model output or results from analyses of lower-level data (e.g. variables derived from multiple measurements, data products from machine learning analytics, etc.).

Approved metadata will always be accessible independently of restrictions, and they will indicate:

1. Whether use is limited to non-commercial applications;
2. Whether a publication embargo is applicable;
3. Whether the data refers to species that are endangered or otherwise sensitive;
4. Whether the data is private to an individual;
5. Whether there are ethics considerations attached to the data;
6. Whether end users should be identifiable.

Accessibility will depend on the restriction level, and conditions 3 and onwards render the Creative Commons license suite unsuitable and an alternative one will be provided. The general guidelines for the maximum embargo period will be agreed between the Management Team and the advisory structures, taking into account the criteria for distribution of publicly funded data.

3.3.2 Differentiated access to the SAPRI infrastructures

Given the complex, multi-disciplinary, multi-institutional nature of SAPRI, differentiated access to data, equipment and human resources will be inherent. The access to the SAPRI research platforms by users and research partners will be through a fair and competitive manner by means of the concept of *endorsed projects*. The endorsement request is submitted to the Management Team through the dedicated online portal. It contains the description of the project, the infrastructure requirement and a preliminary indication of the time and duration.

Only scientific proposals that have received full peer-reviewed scrutiny and recommended for funding can be considered for endorsement. Projects that are eligible for endorsement can be large integrated scientific projects that have been designed through the SAPRI, international projects, or smaller team or individual projects. In the case of individual student projects for theses, they will have to be submitted by a reference supervisor, with indications of the current funding conditions (see also Chapter 5 for further information on training support).

The Management Team will consult with the scientific advisory structures and will continuously update the list of endorsed projects. During the endorsement phase, the Management Team will contact the Principal Investigator to discuss adjustments and changes based on fair principles of resource sharing. This will be a transparent process, in the spirit of maximising the return on investments. Independently of the funding state of each project, the actual use of the SAPRI infrastructures will be the result of a joint process and may require adjustment of the science plans. Whenever possible, priority will be given to SANAP projects and projects of national strategic interest. Projects that have been successfully evaluated through the SANAP science calls are automatically endorsed. The proposed revision of the current SANAP call documents will include dedicated forms for the SAPRI infrastructures, in such a way that the proposals will contain the necessary details for endorsement. Endorsed projects that pertain to Antarctic expeditions and research cruises will be assessed jointly by the SANAP Coordination Committee, to ensure a proper alignment with the availability of large-scale infrastructures.

Endorsed projects will receive a unique identification number and information on how to access the requested platform. The project PI will sign a hire, loan or access agreement depending on the nature of the infrastructure and will maintain an updated list of people requiring access or using the platform. The agreement will detail the maintenance as well as other ancillary procedures, including the possibility that the SAPRI personnel may inspect the platform. Access to the platform may require further insurance, induction and/or training, whose details and arrangements will also be indicated in the agreement. Some of the infrastructure will only be operated by qualified technicians and the technicians will operate the equipment to achieve the agreed research objectives, but within the SOP limits. The agreement will finally specify the type of reporting required during and at the end of the period of usage.

Table 8 ***Summary of the SAPRI access policies.***

User	Access policy	Access management
Local researchers (including Government researchers)	● Open access to all research platforms for endorsed projects after signature of the agreement ● Open access to all data products not under embargo via the product portal	● Access to platforms and data up to level 2 will be available to the indicated members of the endorsed project for the agreed duration ● Access to data products (>level2) will occur after registration via the data portal ● A unique identifier will facilitate access management and reporting for the endorsed projects
International researchers	● Open access to all research platforms for endorsed projects after signature of the agreement or dedicated MoU ● Open access data will be made available through international shared repositories ● Open access to all data products not under embargo via the product portal	● All management rules defined for local researchers apply for the endorsed international projects ● Extended access or joint management will be regulated through dedicated MoUs or MoAs depending on the nature of the project and the financial implications
Consortium partners	● Same policy as Local researchers for endorsed projects ● Same policy as Own staff when the partner manages an IF or any of its components	● Same access management as Local researchers for endorsed projects ● Same access management as Own Staff when the partner manages an IF or any of its components
Society	● Access to value added products on the website, including videos and virtual products ● Learners and educators will have regulated	● Access to data products (>level2) will occur after registration via the data portal ● Access to infrastructure as part of educational outreach will be

	physical access to research infrastructure as part of the educational outreach activity	managed to ensure proper research activities
Citizens	● Open access to all data products not under embargo via the product portal ● Regulated access to platforms during dedicated open days	● Access to data products (>level2) will occur after registration via the data portal ● Access to infrastructure as part of educational outreach will be managed to ensure proper research activities
Own staff	● Regulated access to platforms for maintenance, inspection and extension ● Access to the data infrastructure depending on roles	● The SAPRI Management Team will decide access management

3.4 DATA MANAGEMENT

The fully detailed preliminary data management plan for the SAPRI Data Centre is found in Appendix D and briefly summarised here.

Data emanating from long-term monitoring projects, and from projects supported by SAPRI infrastructure going forward, will be submitted to the SAPRI Data Centre, and made freely available to all data users according to the policies described in the previous section. All SAPRI data must be archived in the SAPRI Data Centre but may also be stored in a trusted repository where acknowledgement of SAPRI will be through referencing the original DOI. In cases where projects submit data to other local or international repositories, the SAPRI Data Centre will need to be able to harvest this data or metadata for inclusion in the SAPRI data archives.

Historical data which have been obtained using infrastructure provided by individual research grants or institutions or as part of earlier and ongoing SANAP projects will need to be negotiated by the SAPRI Management for open and free access to all data users (where not already available through other local and international repositories). All SAPRI consortium partners will be encouraged to make their historical data freely available to all users through the SAPRI Data Centre. The role of the SAPRI Data Centre will not just be to preserve data but will also need to make it discoverable and available for reuse. For discoverability, metadata and an Open Data Platform (ODP) will be put in place.

The SAPRI Data Centre will be part of the SAEON national data infrastructure. This will reduce the infrastructural costs for the maintenance of the Antarctic Data Centre and will ensure integration with the national data policies. The following are common to infrastructure in support of multi-institutional research programmes and networks such as SAPRI, e.g. SMCRI and EFTEON:

1. **Distributed 'Ecosystem' or System of Systems**: Looking externally, SAPRI will be part of an emerging global system of systems, which is distributed rather than highly centralised. Distributed systems that interoperate based on widely adopted standards are the norm. Looking internally, SAPRI will be more centralised, but not completely, in a hub-and-spokes design. A set of standards will be imposed by the Management Team in consultation with the advisory structures, and the subsystems operated at the IFs. They will operate independently, but periodically upload standard datasets to the centre, where the portal and archive facilities will reside.
2. **Multiple Data Providers and Custodians**: Any infrastructure needs to recognise the fact that many providers will contribute data, and that there may be a significant variation in size and data stewardship maturity of the providers.
3. **Implementation Flexibility**: The concept of a single portal to serve all needs is outdated and impractical. The SAPRI data facility will need to develop a suite of products and services that allow options - ranging from traditional single portal access to services that allow interaction with the data infrastructure from any system of choice. Such an open, flexible approach is strongly advocated.
4. **Stratified Roles and Responsibilities**: Research data is subject to a life cycle, and as such require inputs and effort from a variety of role players during its lifetime. In general, it moves from the care of scientists and technicians to data librarians and custodians for publication and description, and then to data centre management for long-term preservation. Emphasis should be placed on developing appropriate multi-party contracts for data management, even if no funds change hands.

The research infrastructure design principles for SAPRI will be based on the following guidelines:

- Data and services are described properly, preserved properly, discoverable, and cited properly;
- Once discovered, its utility, quality, and scope can be understood, even if the data sets are large;
- Once understood; it can be accessed freely and openly;
- Once accessed, it can be included into distributed processes, and collated - preferably automatically, and on large scales;
- Once processed, the knowledge gathered can be reused.

This forms the basis of current SAEON infrastructure, and the SAEON hosted RIs and will serve as a blueprint for SAPRI systems integration into this system of systems.

3.5 SAFETY, SECURITY, INSURANCE AND UTILITIES

Safety

The SAPRI will adhere to all SHE-Q practices and will request all integrated facilities working within the SAPRI to adhere to the same procedures. Furthermore, all participants undertaking field research on the Islands and Antarctic bases, and working onboard the research vessels, will undertake the necessary safety courses and adhere to all safety procedures. This will be facilitated through SAPRI and all costs covered by SAPRI.

Security

All consortium partners will be responsible for security to mitigate loss of infrastructure. All members will have to adhere to security practices established by the SAPRI should they be hosting infrastructure procured by the SAPRI.

Insurance

Infrastructure procured through the SAPRI will be covered under the appropriate insurance policies as suggested by the NRF through SAEON. In particular equipment left in the field for months (moorings, autonomous measuring stations, etc.) or traveling autonomous devices, or equipment used during research expeditions (put over the side of the ship, on sea ice, ice sheets and on the Antarctic continent) is highly risky given the impact of extreme environmental conditions, vandalism, loss of communication, etc. This equipment needs to be correctly insured by the consortium member on whose asset register the equipment is listed.

Utilities

This needs to be laid out in the Service Level Agreements and where applicable will be paid by the SAPRI to the consortium member.

3.6 QUALITY ASSURANCE SYSTEMS

The development and operations of the SAPRI will comply with all national and international regulations and international best management practices. SAPRI has an ethical responsibility and commitment to the Antarctic Treaty System to not harm the environment. Strict ethical guidelines will be followed in any research using animals. Environmental impact assessment will be submitted for approval to DEFF, which is the relevant authority regarding the Madrid Protocol. Research cruises are regulated by the South African Maritime Safety Association (SAMSA) as well as through DEFF policies.

The SAPRI Science is based on the long-term observations of Essential Variables (Chapter 2 and Appendix C). The SAPRI should thus follow internationally accepted standards and best practices in terms of all stages of the observation life cycle - deployment and sampling/SOP/operations, pre-mission preparation (e.g., calibration and validation), data retrieval and formatting, primary quality control and secondary quality control, with all data stored on local and international repositories. Many of the long-term projects already follow very stringent practices and these will be maintained where existing and bolstered in places where gaps exist.

The development and operations of the SAPRI Data Centre will comply with all national and international regulations and international best management practices. More details are given in the Appendix D.

3.7 READINESS FOR ROLL-OUT AND OPERATION

Management

SAEON currently hosts two Research Infrastructures, the SMCRI and EFTEON. SAEON is thus ideally situated to begin work on a third Research Infrastructure, building on lessons learned and requirements from the first two. In addition, the SAEON Egagasini Node for marine-offshore systems is established in long-term ocean observing and has been based at DEFF since 2007. SAEON has an established human resource and procurement system which abides by the PFMA and National Government rules and regulations and are thus able to begin work on setting up the SAPRI as soon as the proposal is approved.

Experience has taught that new research infrastructures typically follow a S-growth curve. SAPRI thus proposes an establishment phase over 3 years assessment (Table 14). The management/logistics staff will be employed first to work under the guidance of the SAPRI Advisory Committee to ensure that the links between the science and logistics are resolved and to provide logistical support to the current SANAP projects. During this time SAEON will reorganise in preparation to fully support SAPRI with a Data Centre, HR administration, financial administration, procurement, SOPs, reporting, and office and storage facilities.

Science

Much of the science described within the SAPRI consists of existing long-term monitoring projects. Some of these have been halted due to funding or vessel access constraints, while others are ongoing. The SAPRI would thus need to prioritise the re-establishment of as many of the long-term monitoring projects as possible to show initial advancement of the Research Infrastructure. Thereafter, the newer entities (e.g. Polar Lab and Seafloor operations) would need to gather momentum while dedicated research cruises are being put in place. The SAPRI will thus likely focus on the take-over voyages and long-term monitoring science within Phase 1, thereafter looking to continue with the proposed integration of SANAP and a new round of science projects.

Data

Components for information management and storage capability (the data structures, bandwidths, servers, portals and archives) partially exist at SAEON with links to SANReN and CHPC, and SAEON's data repositories, as well as SAIAB storage infrastructure and data management system/protocols for biodiversity data, but will need to be upgraded to handle the rising supply and demand associated with SAPRI. This will be done collectively, over the three-year start-up phase, aiming at full operational status by year four; and subsequent upgrades after that to keep pace with evolving user needs. Human capacity in order to carry this out will also need to be increased. The Digital Antarctic component will work towards upgrading data storage and transmission on the SA Agulhas II as part of the DIGSAAII (Section 2.2.4). Prototypes have already been developed by the consortium partners and will need to be integrated. This will be a first step, continued in Phase 2, to enhance the capacity of the ship to perform its operational tasks required by DEFF, as well as the near real-time transfer of valuable scientific data for research.

3.8 Feasibility of the project plan

After the earlier experiences in building the proposal and the extended consultation phase, the feasibility of SAPRI is strong and expected to be successful. The entities that expressed their interest in participating in the consortium represent the main players in polar sciences, and they have been running related infrastructural projects. Despite the reduced budget availability at this stage, the conceptual design will guide the planning for the next 15 years and possibly lead to the creation of a polar institute that would unify the infrastructural and scientific components. However, this prospect is beyond current project planning as its actual feasibility hinges on a few critical inter-organisational relationships to be encapsulated in future national policies and strategies. First and foremost, the shared collaborative understanding and political will of the two government departments who are the principal investors in polar science, namely DSI and DEFF. The SAPRI business model will be maximised by formal agreements between the departments.

The second key relationship is between SAPRI and DEFF. The operations of SAPRI rely on these crucial interdependencies. The existence of joint agreements for the planning, budgeting, capacity development, integration, coordination and decision-making related to the shared use of the large infrastructures that are not components of this proposal will optimise the feasibility of the SAPRI and lead to efficient and fruitful expenditure of the SARIR investment.

A third key relationship is between SAEON, the consortium partners and the scientific community, which ultimately retain the highest expertise in polar sciences. As host organisation and consortium manager, SAEON will have fiduciary responsibilities for many crucial aspects of the SAPRI organisation. The articulated governance of the SAPRI detailed in the next chapter has been designed to ensure smooth relationships and proper measures for operational functioning and, when necessary, to advise on producing an evolving business model.

A complete feasibility plan with milestones and deliverables is given in Section 6.2.

3.9 LEADERSHIP

The distributed nature of SAPRI and the wide range of disciplines and hence platforms that will be maintained, both in continuation or establishment, along with the complex logistics and intergovernmental relationships, require leadership at various levels to promote a common vision and commensurate strategies and business models. The leadership style from the top should be an authentic but dynamic combination of transactional, transformational and servant leadership. SAPRI, being a research infrastructure and not a research institute, does not only require academic credentials from its leadership but also a proven ability in general science management and interorganisational negotiations to balance the tension between science, logistics, stakeholders and governance in the public service domain.

SAPRI leadership needs to facilitate both adherences to fixed standards as well as creativity and innovation in a complex and rapidly-changing multi-institutional and multi-disciplinary organisation. There is no one best leadership style that will generate the ideal organisational ambidexterity. This calls for a combination of transformational and transactional leadership. However, the SAPRI Manager will have to demonstrate emotional intelligence in understanding the employees' and stakeholders' perceptions and the organisational climate to continuously adapt to the best possible approach for the most positive impact. The leadership style displayed by the SAPRI Manager would thus play a significant part in SAPRI's success, provided that contextual factors (logistics, environment, resources, legislation, complexity, externalities) and employee/stakeholder perceptions are considered.

Nonetheless, SAPRI leadership will be a collective at various levels, as constituted by its structural model. Members of the advisory panel will be expected to offer sound advice to the SAPRI Management Team. Consortium partners will be responsible for appropriate leadership within their respective organisations. As is the norm, government entities and the NRF Board are expected to perform their statutory roles duly in support of SAPRI and ensure their decisions are based on accurate information.

4 GOVERNANCE AND STAKEHOLDER ENGAGEMENT

4.1 LEGAL ENTITY

SAEON is the identified consortium manager and NRF is the legal entity.

4.1.1 Legal agreements in consortia

The proposed entity is the result of an extensive consultation with the stakeholders (detailed in Section 3.1.2.1). Previous attempts indicated the contingent variety of stakeholders, and the complexity of creating a unified view that would integrate the diversified needs of the polar research community. SAPRI is organised as a consortium hosted by SAEON, acting as the consortium manager. Based on the considerations expressed in the earlier chapters, the proposed IFs will be incubated in a distributed fashion among the members of the consortium as illustrated in Figure 18. SAEON is an environmental research infrastructure programme of the National Research Foundation (NRF), itself an entity of the Department of Science and Innovation (DSI). As such, SAEON functions under NRF policies and regulations in terms of management, reporting structures, procurement and human resource procedures. SAEON also successfully hosts both the SMCRI RI and the EFTEON RI.

A basket of legal agreements will apply to the consortium. Memoranda of Agreement (MoA) will be signed with all consortium partners, including DEFF, service providers and external sponsors when financial transacting is concerned, and these will include service level agreements and technical specifications and will be subject to the Public Finance Management Act. Memoranda of Understanding (MoU) will be signed with partners, collaborators and users who will not require financial transacting with SAPRI. Research grants and scholarships will be subject to the signing of project and bursary agreements that will specify the conditions of granting. All legal arrangements will be subject to approval by the NRF Legal Department.

4.1.2 Branding and hosting

SAPRI is the proposed branding name of the **S**outh **A**frican **P**olar **R**esearch **I**nfrastructure. Importantly, SAPRI will be distinctly branded as a SARIR-funded research infrastructure to underpin research as opposed to a research institute to perform research. It will be hosted at SAEON, and subject to the NRF governance policies, including those for branding and communications. The SAPRI will not be required to establish its own administrative policies and processes and instead will be fast-tracked by SAEON within the administration of the NRF. The existing SAEON administration and nodes will contribute to integrating the SAPRI into the NRF structure. This is shown in Figure 18 by separating the SAEON contribution into two components (horizontal and vertical): one that represents the cross-cutting and existing SAEON central administration and data centre that will be expanded to support the RI needs; and the other that is the dedicated infrastructural component created within SAPRI.

Due to the consortium approach and the distributed nature, SAPRI is designed as a separate RI within SAEON. The management and logistics hub will be based in Cape Town in close proximity to the DEFF units, the SA Agulhas II and other related teams (e.g. the Department of Public Works and Infrastructure and the SOCCO infrastructures). Office space, workshop and storage of infrastructure space will be negotiated further with DEFF and other consortium partners. Initial discussions around this have already been had between SAEON and the DEFF management teams. In the start-up phase, the SAPRI Management team will be hosted in the DEFF Foretrust Building where the SAEON Egagasini node is also located. Other components of the IFs, such as the fleet of autonomous vehicles, the seafloor observatory or the container laboratories will be hosted within the premises of the relevant consortium partners, and properly formalised by means of the service level agreements (Section 4.1.1). During the meta-design phase, the University of Cape Town has indicated availability to host the Polar Lab on its premises, in recognition of the already existing capabilities for treating ice samples. A similar expression of interest has been expressed by Stellenbosch University, in order to host the outreach and Digital Antarctica components of the DPS integrated facility where the ALSA and the Sound and Vibration unit operating the sensors on the SA Agulhas II are located.

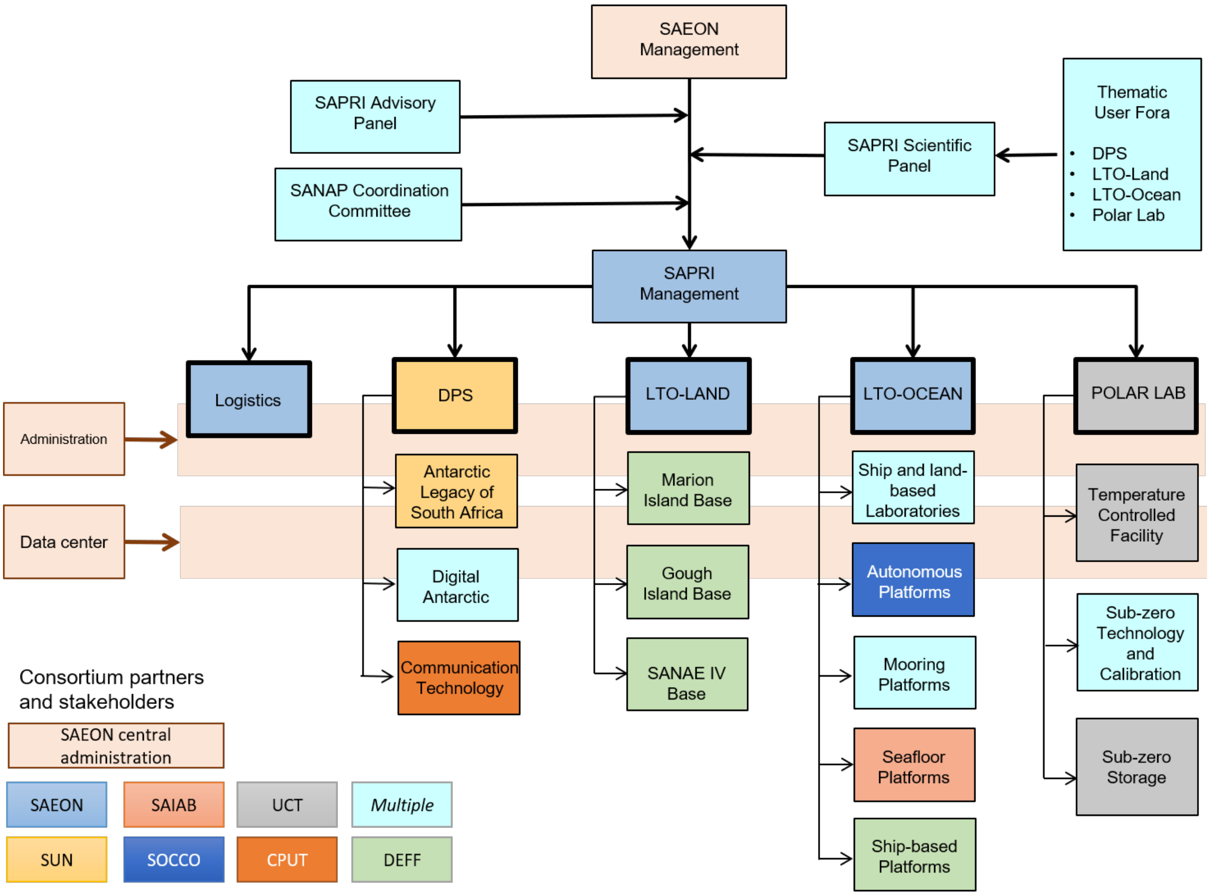


Figure 18 ***Schematic of the distributed nature of the SAPRI***, *based on Figure 12. The components flagged as "Multiple" include all the consortium partners that are not explicitly listed in the legend.*

4.2 ADVISORY STRUCTURES

The SAPRI will be advised by already existing and newly proposed high-level committees and some more technical panels, as illustrated in Figure 19 and detailed in the following sections.

Joint DSI-DEFF Steering Committee

This committee represents the custodian departments of the SAPRI, namely DEFF and DSI. The two departments will be using this committee to give expression to their respective high-level strategies, ASOS and MARS (Section 1.1.2).

SAPRI Advisory Panel (SAP)

While the working structure of the SAPRI will be shaped by NRF guidelines, the high-level priorities of the SAPRI need to be advised upon by an advisory panel of organisational stakeholders. The SAPRI Advisory Panel (SAP) will be officially appointed by SAEON Management. During the setup phase, this operation will be done in consultation with the initial team that developed the approved SAPRI proposal. The SAP is responsible for developing a common understanding among the consortium partners and for advising the SAEON MD and the SAPRI Manager on strategic directions for the development of the RI and the ongoing refinement of the SAPRI business model, inclusive of the SAPRI's Key Performance Areas and Indicators. The SAP will provide comment and recommendations on the business plans, annual reports and budgets. The SAP will ensure alignment with the national strategies and will advise on the implementation of the scientific strategic directions proposed by the Scientific Panel. It is composed of an independent chair (the exact method of election still to be decided), the SAPRI Manager, the chairperson of the SAPRI Scientific Panel, one senior representative from every consortium partner, chairperson of the SANAP coordination committee, chair of the users forum, and one senior representative for each of DSI, DEFF and DIRCO. The SAP will meet twice a year, following the reports from the Management Team and the Scientific Panel; a first meeting to receive and approve the annual reports and a second meeting to approve the business plans for the new year. During Phase 1 of SAPRI, more frequent meetings may be organised to provide timely advice to the SAEON MD and the SAPRI Management Team.

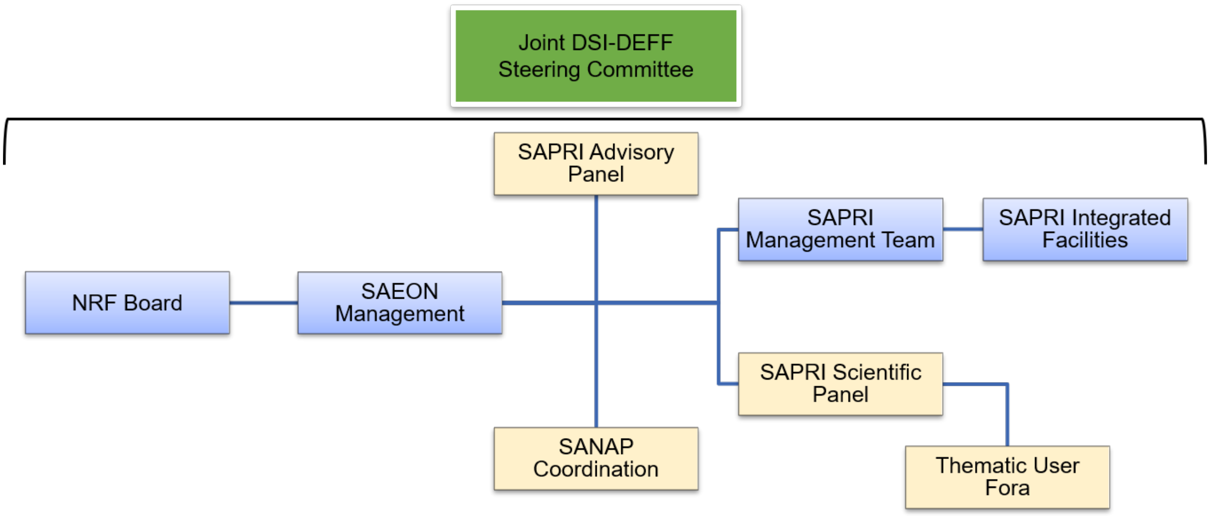


Figure 19 ***Schematic of the advisory structure***. *Yellow boxes indicate the proposed advisory bodies and their relationship with the other structures.*

SAPRI Scientific Panel (SSP)

A continuous alignment with international scientific research is of paramount importance in polar sciences. A SAPRI Scientific Panel (SSP) will be established to advise on the long-term scientific directions and their integration with the research plans proposed by SCAR and the other international bodies illustrated in the Introduction. The SSP will prepare recommendations to be submitted to the SAP, which will advise on their implementation to the SAEON management and NRF Board. The members of the SSP will be scientists of high international standing, also including international scientists from an array of disciplines. The chair of the SSP will be elected by majority.

Given that the SMCRI and BIOGRIP Research Infrastructures are involved with the SAPRI, they should have representation on the SAPRI Scientific Panel.

One of the initial tasks of the SAPRI management is to develop the terms of reference and identify possible candidates for this panel and to send out formal invitations. The members of the SSP are envisaged to be the South African representatives in the major international science committees and research groupings, such as CCAMLR, SCAR, SCOR, IWC and others. The SSP will advise the technical design of the observational platforms and inform the procurement process in consultation with the Management Team.

Thematic User Fora

The SSP is assisted by four thematic User Fora, one for each of the SAPRI scientific pillars namely LTO Land, LTO Ocean, Polar Lab and DPS. This apparent separation of the community of practice is implemented in recognition of the specific requirements of the multiple disciplines involved in polar sciences and served by the RI. This division is however not prescribed and joint meetings of the Fora are encouraged to enhance interdisciplinarity and shared use of resources. The Fora will have at least one annual meeting, with the addition of ad hoc meetings that will be advertised on the RI web site and mailing list. Participation will be open to all current and prospective users. The SAPRI Coordinating Officers will each chair their respective user forum.

The User Fora will be able to advise SAPRI management on availability and feasibility of additional infrastructures for take-over or research cruises, or whether SAPRI own infrastructures may be used for other EEZ related endeavours or on international polar expeditions, should requests arise.

SANAP Coordination Committee

The proposed integration of the SANAP-science component will require a dedicated advisory structure that is parallel to the management of SAPRI, with the aims to advance the implementation and coordination of the SANAP related activities. The Committee revises plans for expeditions based on the scientific and operational requirements of SAPRI partners and users as submitted by the PI of the funded SANAP projects and other endorsed projects. Following the scientific recommendation from the independent NRF science review panel or other international review process, the Committee will ensure the alignment between the logistics requirements and the scientific aims. It will deliberate and negotiate the logistical priorities and schedules among the partners. It is co-chaired by a nominee from DEFF and the SAPRI Manager and it will include the NRF representative of the SANAP competitive research funding programme to ensure continuity and alignment. The other members consist of the South African representative of COMNAP and the SAPRI Coordinating Officers (Logistics, DPS, LTO Land, LTO Ocean, Polar Lab). In addition to this, the chair of the Prince Edward Island Advisory Committee (PEIAC) should be included. This panel will also invite the Principal Investigators of the endorsed scientific and long-term projects to aid the decision-making process on the logistics related to the science to be undertaken.

Members will not sit on this committee for fixed terms because the terms will be dictated by the incumbent in the respective position. The Committee may consult with the Scientific Panel and the specific User Fora if deemed necessary and it would benefit with input from several technical figures, such as but not exclusive to: the DEFF fleet managers and helicopter teams and senior technicians, the vessel operators and the vessel Captains, the technical teams overseeing the maintenance of scientific systems onboard the vessel, Chief Engineers and communications experts. The terms of reference and identification of members to serve on this committee will be one of the initial tasks of the SAPRI Management.

4.2.1 Fiduciary control

The NRF is a science council established under Act 23 of 1999 within the domain of the DSI. It has a governing board appointed by the Minister of Higher Education Science and Innovation. As with the other two RIs hosted by SAEON, there is no room within the NRF structure for control through a governing board dedicated to SAPRI. Instead the NRF Executive will be responsible for implementing the fiduciary controls over SAEON and thus over SAPRI. The SAP will be accountable for offering sound advice and SAEON Management will be accountable for implementing that advice within the constraints and context of the larger organisation.

4.2.2 Ethical conduct

University ethics committees or funding bodies for research projects are responsible for ensuring that legal and ethical standards are met during the execution of research projects. Therefore, while ethics pre-approval will not be a SSP and/or SAPRI Data Centre related activity, by the time SAPRI data are submitted to the SAPRI Data Centre repository for archiving, SAPRI Data Centre staff will verify that legal and ethical guidelines have been followed.

Data will be stored on secure servers. The SAPRI Data Centre will be compliant with the Protection of Personal Information Act 4 of 2013 (POPI) and Promotion of Access to Information Act 2 of 2000 (PAIA). The POPI Act is designed to protect personal information processed by both private and public bodies, whereas the PAIA Act is legislation which allows access to any information held by the State, and information held by private bodies that is required for the exercise and protection of any rights. Metadata records will not contain personal information for scientists or data owners, but work contact details will be used. These details are typically provided by the users themselves with the understanding that they will be made available in the metadata record.

4.3 MANAGEMENT MODEL

The day-to-day management of the SAPRI will fall to the SAPRI Management Team, which is designed in accordance with the NRF-SAEON corporate structure. The Management Team will coordinate the IFs as shown in Figure 18 and Figure 20. The team will comprise:

- The SAPRI Manager, who will be responsible for the implementation of the RI in accordance with approved annual performance plans and budgets, compliant with NRF-SAEON policies and processes, and aligned with the guidance received from advisory structures and stakeholder departments.
- A logistics Coordinating Officer whose role will be to interact with SANAP-Logistics coordinated by the Antarctica and Islands teams and support overarching logistics of all IFs
- Four Coordinating Officers, one for each integrated facility (DPS, LTO-Land, LTO-Ocean and Polar Lab). They will be responsible for the integration of the IFs and their components within the SAPRI structure, science liaison, science communications, science outreach and engagement activities, and research administration.

- SAEON National Office will provide HR, SCM and Finance support in a shared services arrangement.
- The SAPRI Data Centre (SAPRI DC) will be hosted by SAEON and will therefore be incorporated into the governance structure of SAEON. The SAPRI DC will receive finance, business and HR support from the SAEON National Office. SAEON uLwazi Node will provide IT network, ICT development, data curation and data science support in a shared services arrangement.
- Two instrument operators, one each for the LTO Land and LTO Ocean teams will report to the respective Coordinating Officers.
- Two research technicians, one each for the LTO Land and LTO Ocean teams will report to the respective Coordinating Officers.
- The Polar Lab will be managed by an MoU with UCT given the building will be located there. A project manager for overseeing the building and commissioning of the Polar Lab will be employed at UCT through funding from SAPRI. The research technician will be appointed before the commissioning starts.

4.3.1 Organisational structure

The organisational structure of the Management Team and the Integrated Facilities is detailed in Figure 20. The figure also shows the role of the users, in particular the Principal Investigators, post-doctoral fellows and students who will participate in the RI functioning, for instance in the development of new technologies, training, laboratory experiments, etc. They will not be funded by the SAPRI running costs, but by SANAP or other projects endorsed by SAPRI.

4.3.2 Management line functions

The relationship between the consortium partners will be managed through MoAs and specific SLAs. The consortium partners that host an IF (or one of its components) with the associated personnel, will have their internal line management functions as per conditions of employment. Additional line management functions will be established via service level agreements that govern how each component will relate to the consortium manager and what services the consortium partner will provide as part of SAPRI.

4.3.3 Reporting lines

The reporting lines within the SAPRI will depend on the respective IF and/or components and the relative MOAs and SLAs. In general, the staff employed at each IF will report to the Coordinating Officer, who will report to the SAPRI Manager within the Management Team (see Figure 20). All relationships between the consortium partners will be governed by service level agreements that set out the KPIs for each component. A list of the main reporting periods and the respective recipients is given in Section 6.3.

SAPRI data will be hosted by the SAEON Data Centre and will therefore be incorporated into the governance structure of SAEON. The SAPRI Data Centre will receive finance, business and HR support from the SAEON National Office. Reporting lines will be in the first instance to SAEON in its context as a Business Unit within the NRF, and to the SAPRI Management Team.

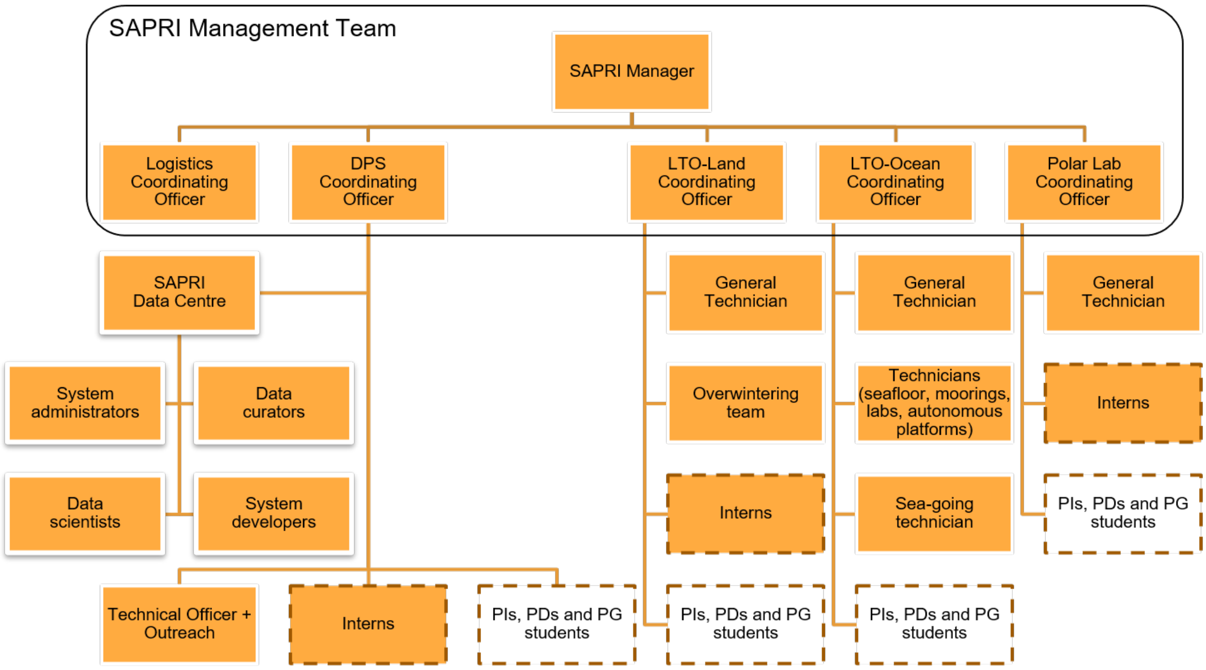


Figure 20 ***Organisational structure of the SAPRI Management Team and Integrated Facilities***. *Filled boxes are funded by SAPRI. The SAPRI Data Centre is highlighted as a cross-cutting auxiliary component of the DPS since it will be embedded in the SAEON Data Centre to host the National Antarctic Data Centre. Dashed frames indicate external funding or co-funding. The white boxes indicate the users (Principal Investigators, Post-Doctoral fellows and PostGraduate students) that will be "co-generated" by the RI.*

4.3.4 Dependencies

Given the distributed nature, SAPRI is characterised by several dependencies between the consortium partners. The main ones are illustrated in Figure 18, which comprise the key role played for instance by the DEFF SANAP-Logistics infrastructure, the SOCCO and the Polar Lab hosted on UCT premises.

4.3.5 Networks, relationships and alliances

The SAPRI will contribute to the South African presence in the Antarctic Treaty by playing a consulting role for the governmental departments that are the official representatives in the international networks (DEFF and DIRCO). Through this relationship, SAPRI will participate in the international networks and alliances listed in Table 1, namely COMNAP and CCAMLR. The DPS facility, in agreement with the Management Team, will coordinate and assist the South African representatives in the SCAR scientific committees and the IWC, WMO and SOOS working groups.

4.4 Stakeholder Engagement Plan

Stakeholder engagement is essential to gain agreement on the SAPRI's value proposition, and in doing so, gain support and the commitment for the success of SAPRI, whilst also addressing the concerns of the stakeholders as best possible. For SAPRI, it is especially important that stakeholders are engaged appropriately, in particular that we achieve a joint committee between the DEFF and the DSI and strong buy-in from the key institutes involved in polar research and the SANAP projects. In addition are the key international stakeholders with whom South Africa holds certain responsibilities within the polar space, such as the other signatories of the Antarctic Treaty. Finally, as South Africa's National Antarctic Data Centre, the SAPRI Data Centre would need to observe the requirements of SCAR-

SCADM for Antarctic data management, specifically about the inclusion of metadata in the Antarctic Master Directory. The SAPRI Data centre will align with all such international data bodies. More detail is given in Appendix D.

The points below illustrate the steps taken for the initial stakeholder identification and involvement during the meta-design phase and proposal preparation:

1. Initial involvement of the community done by DSI via a consultative meeting in August 2019, with successive nomination of champions. Identification of contacted stakeholders based on SANAP records and past scientific publications in polar research (academic and non-academic).
2. Formal invitation to the management (cc to the scientists who participated in the first consultative meeting) to express interest in the initiative and to nominate two contact persons. The institutions were also informed of the nomination of any of their members in the drafting groups during the first consultative meeting.
3. Organisation of meetings with the nominated contact points or with the scientists who expressed interest (Champion's visit or teleconference).
4. Request to submit a proposal for research platforms through a template, indicating existing infrastructures and requirements for the new ones. Received a total of 23 proposals from 13 leading institutions (other institutions were involved in each proposal).
5. Invitation to submit a bid for hosting the administrative hub and the distributed research facilities of the RI. Received three nominations. DSI was involved in the decision process. Having considered the proposals and the emerging framework for SAPRI, the alignment with the goal of creating the SARIR projects as national institutions, DSI indicated SAEON to be in a position to drive such an agenda. SAEON has the advantage of being institutionally modular and hence the administrative superstructures for managing the complexity of the proposed consortium arrangement of SAPRI exists.

4.4.1 Stakeholder types

Table 9 ***Stakeholder types.***

Stakeholder Type	Stakeholder Role	Specific Stakeholders
Facilitators	Those who make it possible/easy to do business – government, policy makers, regulators, licensing agencies, standards authorities, RI staff	Departments of Science and Innovation, Environment Forestry and Fisheries, international Relations and Cooperation, Public Works, Basic Education, Higher Education, South African Weather Service, SAMSA, the Presidency, SAEON staff, IF staff and host organisations, SAPRI staff, NRF Corporate Executive, Customs
Influencers	Those that make life easier or harder – politicians, activists, lobbyists, industry associations,	National Business Initiative, business chambers, SMME, parliamentary portfolio committees, political parties,

	the media, environmentalists, trade unions, citizens	WWF, WESSA, conservation agencies, mining and forestry multi-nationals, energy companies, Treasury, International policy makers
Suppliers	Those who provide whatever is needed to function – finance, services, components, utilities, capital goods, operational supplies, knowledge, real estate, building infrastructure	Department of Science and Innovation, DEFF, NRF, SAWS, ESKOM, Public Works, Telkom, scientific instrument manufacturing companies, transport companies, international research programmes, universities, science institutions, conservation agencies
Competitors	Those in the same business (such as other RIs), or those competing for the customer's wallet (other projects, priorities)	SAPRI is publicly funded and will be competing for a share thereof with all other public entities. Platforms and data will be open and freely available thereby reducing competition. All National RIs (NRF and others) can simultaneously be both competitors and collaborators.
Collaborators	Those that work with the RI to enhance its impact	Science councils and SoEs (especially CSIR, ARC, SANBI, SANSA and SAWS), HEI's, government departments, conservation agencies, civil society, international polar research programmes, treaties and donors, National Business Initiative, SAASTA
Clients or users	Those who buy products or services or the user community (research-based or industry-based), the scientific community, citizens	International donors, HEIs, research programmes and researchers, basic education, civil organisations, local governments, fisheries, tourism

4.4.2 Stakeholder engagement plan

Table 10 ***Stakeholder engagement plan***

Stakeholder Type	**Engagement plan**
Facilitators	Regular public communication as described in the marketing plan will ensure general awareness among facilitators. Facilitators will be visited every second year to be informed first hand of the RI's activities and results. IF will be visited twice a year (MoU steering Committee meetings) although these may be held virtually if the situation requires. NRF corporate will be regularly updated on special projects and will also receive the required quarterly reports on the SAPRI
Influencers	Regular public communication as described in the marketing plan will ensure general awareness and endorsement among facilitators. Care will be taken to maintain good relations with influencers. Extensive use will be made of social and multimedia (newsletters, popular press, websites, videos, blogs) to keep the influencers informed.
Suppliers	Suppliers will be individually targeted as and when required. Commercial suppliers would be assisted to comply with SCM requirements. Donors will be rewarded with public recognition if acceptable to them. HEIs will provide a supply of students, interns and services, and good relations with their respective research offices will be sought.
Competitors	It is not foreseen that head-on competition will be experienced within the country and internationally. Offering of collaborative opportunities and reliable accessible data would ensure good relations within the larger research community.
Collaborators	Collaborators will be treated fairly and respectfully. Their contributions will be publicly acknowledged. Where appropriate, such collaborations will be regulated by MoU's/MoA's. Resources and data will be freely shared with collaborators. SAPRI and SAEON staff will offer supervision to students. Staff will provide news articles and communication materials to SAASTA and other science communication and engagement specialists.

Clients or users	It is not expected that SAPRI will generate much income from clients and users besides the research community. The administration of such commercialised activities is also often prohibitive. The general principle would be that the data, equipment and standard information products have already been paid for by the government. However, there might be areas of innovation that can be commercialised, or services, such as sensors, devices, digital technologies, as well as use of the Polar Lab for material and instrument testing at sub-zero conditions. There might also be opportunities for offering low-cost monitoring and regular data services to clients if there is spare capacity available. If spare capacity is not available, fair pricing for cost recovery would be pursued.

5 CAPACITY DEVELOPMENT

5.1 STAFFING

5.1.1 Staff evolution

5.1.1.1 *Life cycle*

A total of 39 staff (by Year 4) is envisaged for SAPRI, and with, *ceteris paribus,* a continued 38 staff members to the end of the SAPRI life cycle. The first three years will see an increase in staff from 18 in Year 1, 25 in Year 2 and 31 in Year 3 (Figure 21). Staff for SAPRI are divided as follows:

1) Management staff:

SAPRI Manager, Coordinating Officers for each of the IFs (LTO-Land, LTO-Ocean, DPS, Polar Lab), a Coordinating Officer for Logistics who will work closely with SANAP and DEFF Antarctica and Islands, and a Project Manager (part-time) for the Polar Lab building phase.

2) Overwinterers for Marion Island:

Four overwinter team members will be supported every year for the SAPRI life cycle specifically for top predator work on Marion Island.

3) Technicians:

A total of 11 technicians will be employed through the SAPRI, the specifics of their tasks still to be defined through further technical discussions with the IFs. However, it is envisaged that dedicated instrument technicians be employed for LTO-Land, LTO-Ocean and a dedicated at-sea technician (likely with training in computer data systems and electronics). The Outreach component of DPS should have a dedicated technician working with them as well. The remaining six technicians will likely be spread between the Seafloor team, a mooring technician, a biogeochemical analysis technician, an autonomous platforms technician, a CO2 laboratory technician, a terrestrial field technician and a Polar Lab technician.

4) Administrative staff:

Two administrative staff are planned to assist with HR related issues, finance, procurement, meeting and travel administration, etc. These posts will begin in Year 4. SAPRI will rely on SAEON National Office staff for the first three years.

5) Interns:

Four interns have been budgeted for to work with technicians and Coordinating Officers from Year 2.

6) Data Centre staff:

The largest component of the staffing for the SAPRI will be employed within the Data Centre given the large task of collating all historical data, and archiving, processing and disseminating all the new data acquired. Staff will consist of three data curators, three system developers, two system administrators and two data scientists.

As stated in Section 3.2.3.1.5, the SAPRI operations management will be characterised by the concept of adaptive management, in the sense that technical personnel may be redistributed across the IFs depending on the stage of the RI life cycle. A greater emphasis and operational support will be dedicated on establishing data management infrastructure and systems for the first 3-5 years, following which human resources will be shifted towards technical operations of research equipment and oversight of data workflows.

SAPRI management staff are allocated to administer the infrastructural unit, build relationships locally, regionally and internationally to work with other polar and marine teams and actively pursue funding initiatives. The team of technicians is structured to maintain and optimise the infrastructure procured through the SAPRI and also assist consortium partners in maintaining existing infrastructure where possible. The Data Centre team will look at all data work across the SAPRI and make the best use of data acquired in an open and freely accessible manner. The Top Predator overwinter team takes the strain off the SANAP Science budget to have to fund these positions and continue the long-term observations made in this field over the past 30+ years. Finally, without substantial administrative support, given the diversity of the consortium and the considerable administrative belabouring from operating with public funds, the SAPRI will not meet its objectives to enhance the current system, and even worse, might just upset the system.

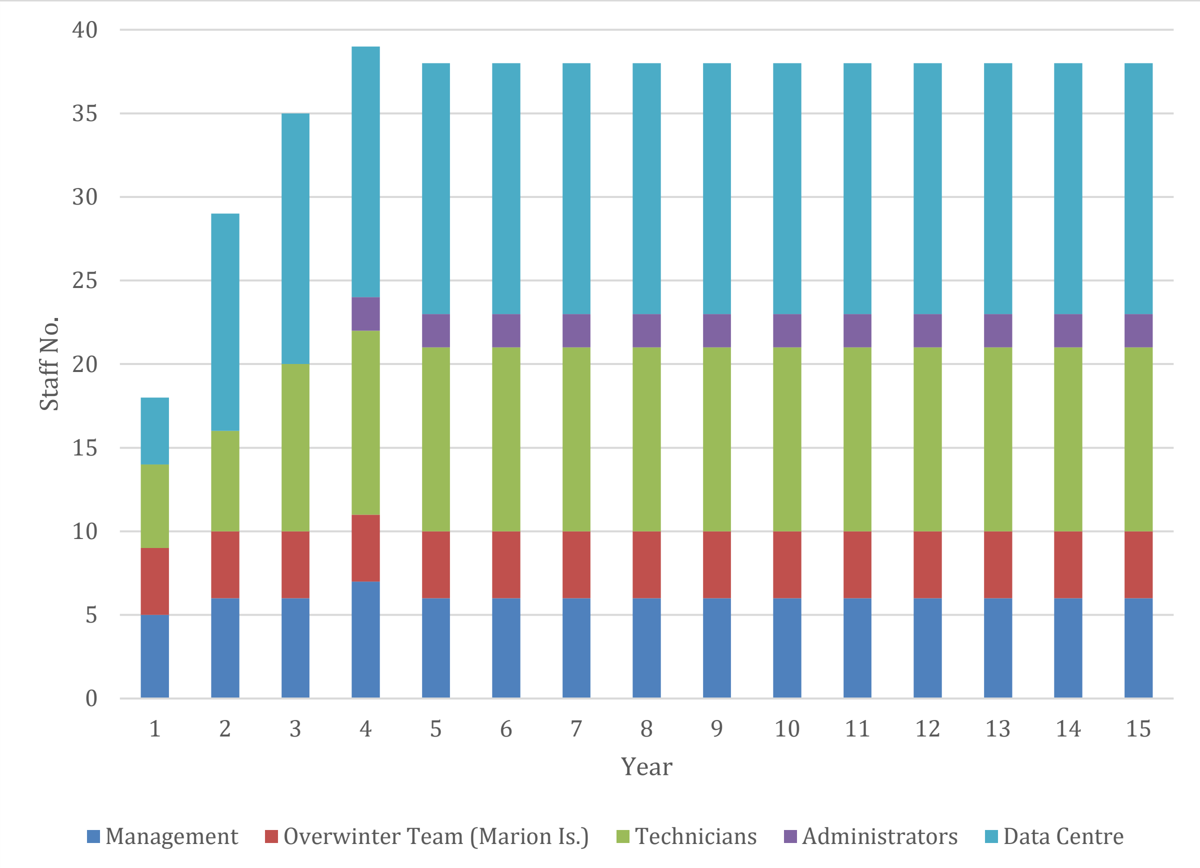


Figure 21 ***Distribution of staff over the SAPRI life cycle***.

5.1.1.2 *Extended community*

The SAPRI will have a large and diverse extended community that will interface with SAPRI staff at strategic, scientific, technical and policy levels. The wide range of platforms made available and the distributed nature of the LTO IFs will enhance the multi-disciplinary efforts and the large community that collaborates with the SAPRI. The researchers and staff of the LTO IFs will work closely with the SAPRI staff, interlinked with the outreach/citizen science activities and communication. Users interested in data and data products will liaise with the data management platform. The international community will also collaborate with SAPRI staff on science and logistics activities which will include training and research visits.

Managing the data along a data pipeline requires cooperation with data producers to ensure data are deposited in accessible formats with the appropriate metadata. Accessibility of data to a range of data users with different levels of technical skills and resources for managing data needs to be ensured. Hence, data systems along the data lifecycle need to be developed in consultation with data producers and users.

5.1.1.3 *Shift from national to international focus*

SAPRI will inherently be part of the international polar community, as well as part of an international network of Antarctic programmes and LTERs, contributing to GCOS and GOOS observing aims and will be of significant international relevance. SAPRI will contribute not only to national policy but also to international policies and treaties described throughout this document. As the only African country with an Antarctic base, SAPRI will also support the development of polar science on the African continent. It is anticipated that from the onset of SAPRI there will be strong collaborations with other polar institutes.

5.1.1.4 *Deployment of new technology*

New internationally developed research technologies will almost certainly become available during the lifetime of the SAPRI, perhaps some even driven through SAPRI. Some innovative local customisation for cost-savings, local circumstances or environmental robustness may well be implemented. However, this will have limited influence on the staff evolution except for any additional training which may be required. In particular, data management is evolving in many of its subcomponents as technologies improve and global efforts at harmonizing data management approaches improve. As such this is a field where staff expect to engage in developing their skills to remain current.

5.1.1.5 *Entering new markets*

It is highly likely new fields of study or skill sets will evolve over the next 10 years. If and when new markets become apparent, it will be prudent to assess the implications and possibilities by firstly analysing the external environment and the internal capabilities. Should it be possible to service the market with existing staff, they will be appropriately motivated and skilled for the additional service. Alternatively, new staff will be added to the SAPRI.

5.1.1.6 *Summary of staff evolution*

Table 11 ***Summary of staff evolution over the RI lifecycle.***

Life Cycle Stage	Activity	Type of staff required
Setting up	Conceptual design	SAPRI co-champions and SAEON Management Team (pre-SAPRI approval by SARIR panel)
	Technical design (includes set up of SLAs)	SAPRI Management, IF stakeholders, general technicians of the IFs
	Establishment and construction	SAPRI Management, Overwinterers, Data Centre, Technicians
	Commissioning	SAPRI Management, Overwinterers, Data Centre, Technicians
Running	Operation	SAPRI Management, Overwinterers, Data Centre, Technicians, Administration
	Maintenance	SAPRI Management, Overwinterers, Data Centre, Technicians, Administration
	Building community	SAPRI Management, Overwinterers, Data Centre, Technicians, Administration
	Education and Training	SAPRI Management, Overwinterers, Data Centre, Technicians, Administration
	Upgrading, replacement and Extension	SAPRI Management, Overwinterers, Data Centre, Technicians, Administration

Shutting down	Phase out	SAPRI Management, Overwinterers, Data Centre, Technicians, Administration
	Decommissioning	SAPRI Management, Overwinterers, Data Centre, Technicians, Administration
	Closure	SAPRI Management, Overwinterers, Data Centre, Technicians, Administration

5.1.2 RI relationship with staff

5.1.2.1 ***Permanent staff***

The following types of staff will be permanently employed over the lifecycle of SAPRI:

- Management staff
- Technicians
- Data Centre staff (administrators, curators, developers)
- Overwinter team members for long-term observations
- Administration staff

Together they will be the core team ensuring data delivery from the RI's sites and instruments. These types of positions and a distributed operational structure are not new to SAEON and existing conditions of employment, business processes and policies, and the NRF's performance management system will therefore be applicable to the permanent staff.

A situation may arise where a member of SAPRI staff is better employed by a consortium member organisation rather than by SAEON. If this transpires, an MoA will be signed and the funding transferred to the consortium member. KPIs of said staff will be jointly established between the consortium member and SAPRI Management and regular meetings will be held. Any issues of poor performance or misguided application of resources with respect to SAPRI as the umbrella organisation will be raised in the advisory structure. It is essential that the MoAs should include criteria and processes for withdrawal of SAPRI membership in such cases.

5.1.2.2 ***Temporary staff***

Temporary staff will likely only be necessary to fill temporary vacancies in the permanent staff structure, or through the DST-NRF internship program and the NRF's Professional Development Programme (PDP) as well as postdoc opportunities, or will be no-cost staff exchanges with collaborating international networks. However, it may be necessary from time to time to have specialised research, engineering, capacity development and other organisational tasks performed by specialists in which case they will be appointed on a temporary basis as independent contractors with specific milestones for payment, with no organisational support from SAEON. In cases where organisational support is necessary, such specialists will be employed as temporary staff earning a monthly salary without benefits, but working part-time or full-time from a SAPRI location offering office support.

5.1.2.3 *Seconded staff*

It is not envisaged that SAPRI will make use of seconded staff.

5.1.3 Location of staff

5.1.3.1 *Single sited*

N/A

5.1.3.2 *Distributed*

SAPRI Management, along with LTO Oceans and the SAPRI Data Centre will be located at the SAEON Egagasini / DEFF offices in Cape Town. The rest of the IFs will be distributed. This aspect requires more than a holistic management regime – it requires strategic leadership (3.9) and ongoing efforts to ensure that the distributed team does not feel removed from SAPRI. The joint leadership of the RI (SAPRI Advisory Panel and SAEON), along with the partnership with DEFF will translate and regularly communicate the SAPRI strategy internally and externally, and ensure that management practices and policies are conducive to performing on the strategy. The cost of coordinating a distributed organisation is significantly higher than a single site organisation and will be budgeted for annually. Workshops to address technical or workplace problems, and new or change management issues, will be held across the IFs. Cost savings on communication requirements will be achieved by videoconferencing where appropriate. The NRF and SAEON electronic systems will facilitate administrative, communication and networking issues. Staff at the National Office will be required to have a service delivery orientation in order to facilitate the staff and the work of the IFs.

SAPRI's proposed advisory structure (Figure 19) attempts to drive cohesion throughout the distributed RI. It is designed to provide consultative forums at the main levels of the organisation i.e. government, the research community and the RI administration.

5.1.4 HR Responsibilities

5.1.4.1 *Skills planning*

There will be limited skills planning required for the SAPRI as much of the envisaged work is building onto current long-term observing programs, ensuring their sustainability, and the skills needed for this are well known between SAPRI, DEFF and the other key collaborators. There may be a need to expand on management skills given the diverse (both in discipline and space) nature of the SAPRI. There is standard skills training prescribed by South African Maritime Safety Authority (SAMSA) which is necessary for any at-sea work and this is part of the SAPRI planning (safety at sea, etc).

5.1.4.2 *Recruitment*

An open recruitment policy will be applied taking into consideration technical qualifications, experience and transformation policies, and favouring SA residents over international candidates where the former meet the job requirements. Transformation of the polar research and technical community will be a key consideration in recruitment.

5.1.4.3 ***Conditions of employment***

Employment will be in accordance with the NRF Conditions of Employment, the NRF Financial Policies and NRF HR policies, as amended from time to time. This means permanent staff will receive standard benefits plus those they elected from the Cost-to-Company offering. Temporary staff will be employed on short-term contracts, or as independent contractors, or as interns/PDPs and will receive fewer or no benefits.

5.1.4.4 ***Staff integration***

New staff will undergo a 3-day induction hosted by the SAEON National Office where they will also meet with key support staff members. Additionally, they will have an integration day at their particular IF or main hub involving information about the host organisation. This will introduce them to the SAPRI and its strategic role within the science landscape, as well as how their employment fits into the NRF. Scientific and technical staff will attend joint SAPRI workshops and other activities. Given the distributed nature of SAPRI it is essential to foster a sense of belonging. There will be regular virtual meetings between SAPRI staff, especially at the beginning of their employment and in the lead up to any cruises.

5.1.4.5 ***Policies and rules***

It is a legal requirement to treat all staff the same. The same staff policies and NRF rules will therefore apply to all SAPRI staff. Even if staff are hosted by different organisations the NRF rules apply rather than that of the host. This may lead to confusion but is a preferable approach and one that needs to be continuously managed. There may be additions required to these rules and the SAPRI manager will be responsible for developing such rules and obtaining broad support for those, and for ensuring that the new rules are applied.

5.1.1.1 Equity

It is well established that workplace diversity offers resilience and enables innovation. The appointment of SAPRI personnel will be subject to NRF’s prescribed equity policies and senior personnel will receive training during NRF’s diversity management workshops. Should the available pool of applicants from designated groups fall short of expectations, capacity development positions will be considered.

5.1.1.2 Conflict resolution

A culture of respect, integrity and appreciation of diversity in the workplace will be cultivated as per the organisational values of NRF. Such a culture would allow the expected diversity of staff to differ with respect and to have an open debate about such differences. Should conflicts not be resolved, the issue will be dealt with in accordance with the NRF’s grievance procedures.

5.1.1.3 Unions

The NRF recognises one union at present and has effective processes through which it negotiates with the union. Due to the size of the NRF, it is unlikely that any new unions will be recognised by NRF but in case of dispute, a member may be represented by his/her union of choice.

5.1.1.4 Performance agreements

The permanent and temporary staff of SAPRI will use NRF performance agreement guidelines and templates, which will be discussed and agreed with the line manager at the start of the position and every 6 months following.

5.2 HUMAN CAPACITY DEVELOPMENT

South Africa is in dire need of transformation and capacity development within the marine science community. A key aspect of the uniqueness of South African Antarctic science is that it is the only African country involved on the Antarctic continent, and therefore has a leadership role to play in promoting African Antarctic science. Coordinated outreach and awareness activities that are integrated in the RI can assist in this matter. By creating *Antarctic awareness* on different educational and cultural levels, SAPRI will increase the consciousness of citizens around the role of the Southern Hemisphere in the Earth system. This will likely lead to more interest in the STEM disciplines and attract younger generations to scientific studies in the Antarctic region, and the broader marine science community. Whereas SAPRI represents the transformation of an existing system and a new way of doing, the issue of transformation along demographic criteria is pertinent for SAPRI. The SAPRI needs to develop young black and / or female scientists, technicians and engineers. Antarctic research should not only be a workspace for those who study environmental science, but also attainable to those who study engineering, social sciences, the creative arts, journalism, law, finance and management. SAPRI will promote the multidisciplinary nature of research possibilities in the Antarctic sphere, expanding our reach, our research footprint and the diversity of our community.

A key component of the SAPRI outreach to students is the successful SEAmester (www.seamester.co.za) cruises run collaboratively between UCT and SAEON and funded by DSI through SANAP. The objective of the SEAMester cruise is to encourage interaction between young South African scientists, lecturers and field specialists in a hands-on, practical environment on board the SA Agulhas II. Every University in South Africa is represented by the student cohort, many of whom continue to study within the marine field. SEAmester is currently run along the ASCA line, enabling students to be a part of a long-term observing program. SEAmester will become an integral part of SAPRI and will continue either on the ASCA line or wherever the science and long term observing fit in with the timeframe.

5.2.1 Career path development

Given the integration of SAPRI into SAEON and the close partnerships with many other institutes, it is envisaged that there will be a wide array of career opportunities for staff, both internally and within partner organisations. It is unlikely there will be a high staff turnover, allowing significant training of staff, in particular in the technical aspect of SAPRI. Staff will be offered every opportunity to enhance their careers through training. In particular, given the sporadic nature of the cruises, technicians will be upskilled in a variety of disciplines from deploying observing equipment at sea through data manipulation and science communication.

5.2.2 Reskilling

Given the long-term nature of the infrastructure within SAPRI it is unlikely there will be replacement infrastructure that needs reskilling of designated staff. However, given the nature of research cruises there may be a need to train staff in different aspects but this will be evident in advance and can be prepared through workshops or national or international travel and will not impact the running of

SAPRI. SAPRI will equip staff with marketable skills hence it is unlikely they will need to be reskilled in the event of the shutdown of SAPRI.

5.2.3 Continuous education, training and staff development

Apart from support for short courses and staff development through group exercises, the NRF offers support for staff who want to enroll for additional academic education. The NRF has also contracted the University of Stellenbosch Business School to offer a range of management development courses to selected staff. All of these opportunities will be available to those SAPRI staff in NRF's employment. Similarly, consortium partners will be contracted to advance the career development of their SAPRI-funded staff.

5.3 POST-GRADUATE STUDENT AND POST-DOC DEVELOPMENT

5.3.1 Post-graduate students

A key factor that will be addressed by SAPRI is the involvement of historically Black universities within polar science. The SANAP program, in the period 2004-2019 (before the transition to the new funding system for students), provided more than a 1100 grant-holder linked bursaries, of which 40% were for Black students. However, the majority of these students are only marginally involved in fieldwork operations and mostly on terrestrial environments on the PEI. Fewer Black students are involved in Southern Ocean, Antarctic and ice-related studies. In order to be successful, a co-generative approach is needed between SAPRI and the universities. An example of a very successful program is the ACEP Phuhlisa transformation program. SAPRI will engage with Phuhlisa in Phase 1 and meetings will be held with key stakeholders at the historically Black HEIs. Although these universities are involved in SEAmester, SAPRI aims to develop and support polar research being carried out by the research staff. This could be in the way of small research grants or targeted interactions. The proposed meetings will help to develop the best way possible for sustainable involvement.

As an infrastructure, the SAPRI does not fund students directly through bursaries. The redesign of the SANAP science funding will make available a larger portion of funding to support student training and their access to infrastructure. Based on the past SANAP bursaries data, we expect that a minimum of 80 post-graduate students per year will directly benefit from the SAPRI infrastructure. In addition to this the SAPRI has involvement and buy-in from all South African universities that carry out polar science, as well as international institutions. They will directly and indirectly support further PhD, MSc, MTech, Hons and BTech students in an array of disciplines, which should rapidly increase this number to the target of 100 per year. The access procedures to the platforms will allow us to keep track of the students' involvement, and the DPS IF will collect the research outputs produced and the graduation numbers as part of its reporting and outreach. Following on from and expanding the SANAP symposium, there will be a bi-annual postgraduate science symposium to present results and foster interdisciplinary research that will be communicated to the greater public through various channels.

5.3.2 Post-docs

Postdocs are an integral part of the science culture in South Africa and a good way to attract scarce skills to the SAPRI, as they are the backbone of research and development. The aim of SAPRI is to provide essential infrastructure and technical support to carry out world-class science, but not to fund the science itself. For this reason, no postdoc bursaries are allocated within the budget. However, SAPRI staff and collaborators will support postdocs in applying for NRF bursaries and also through the PDP program.

5.3.3 Interns

SAPRI will make full use of the NRF/DSI internship program to support interns within SAPRI. Given the program is now two years long, it will enable the interns to develop the skills needed to carry out the work. In many cases interns continue to postgraduate studies and the SAPRI will continue to support the interns and encourage them to apply through the NRF granting mechanism. There is also dedicated funding to support interns within the SAPRI Data Centre and given the cross-cutting nature of this the interns will likely work across the IFs. There is a possibility for internships through the training funding if the need arises.

5.4 RESEARCH CAPACITY AND CAPABILITY DEVELOPMENT

5.4.1 Access and distribution

The SAPRI nodes are distributed and the network of collaborators and partners is across the whole country. However, given the logistics of the large infrastructure, the research cruises and the location of the SA Agulhas II dock in Cape Town, the majority of the fixed assets and the Management Team will be based in Cape Town's harbour. Use will be made of other large harbours, such as Port Elizabeth and Durban, as is needed. However, the operational research equipment will be open access based on project endorsement to all HEIs and research communities (see Section 3.3 for details).

5.4.2 Cyber infrastructure

5.4.2.1 *Data*

SAPRI will be a data intensive RI, particularly as data acquisition from instruments such as gliders is a requirement. South African Antarctic and sub-Antarctic research is multi and interdisciplinary, covering the biological, oceanographic, atmospheric, geological and space sciences, as well as engineering and the humanities. Most research groups store their data in-house, either on internal databases or simply stored on hard drives, but some do deposit data in repositories (Table D1 in Appendix D). Data will be submitted by the users of SAPRI to the SAPRI Data Centre for archiving. Archiving the continuous data streaming of real-time data from oceanographic instruments and observation platforms is a requirement for SAPRI.

5.4.2.2 *Data characteristics (volume, velocity, variety, veracity, value)*

Data for SAPRI can be characterised as Big Data (Figure 22), covering both structured and unstructured data types, sourced from machines (sensors/instruments/satellites), as well as human generated sources. This vast amount of data will need to be gathered, stored, managed, and manipulated at the right speed, at the right time, to gain the right insights. Furthermore, this initiative will need to ensure collection/creation of scalable data (Volume), of different types (Variety), under controllable generation rates (Velocity), whilst maintaining the fundamental characteristics of the raw data (Veracity).

In addition, data requirements can be described in terms of four classes of data:

1. Level 0 Data: Raw, unprocessed, not quality assured
2. Level 1 Data: Calibrated, quality assured, and verified
3. Level 2 Data: Published, meta-data descriptions available, and possible derivations (aggregates, etc.) are available
4. Level 3 Data: Modelled values derived from / calibrated against any of the other levels

Data from all identified initiatives in the SAPRI will need to be assessed during the initial stages of the envisaged project/programme in order to assess precise data characteristics.

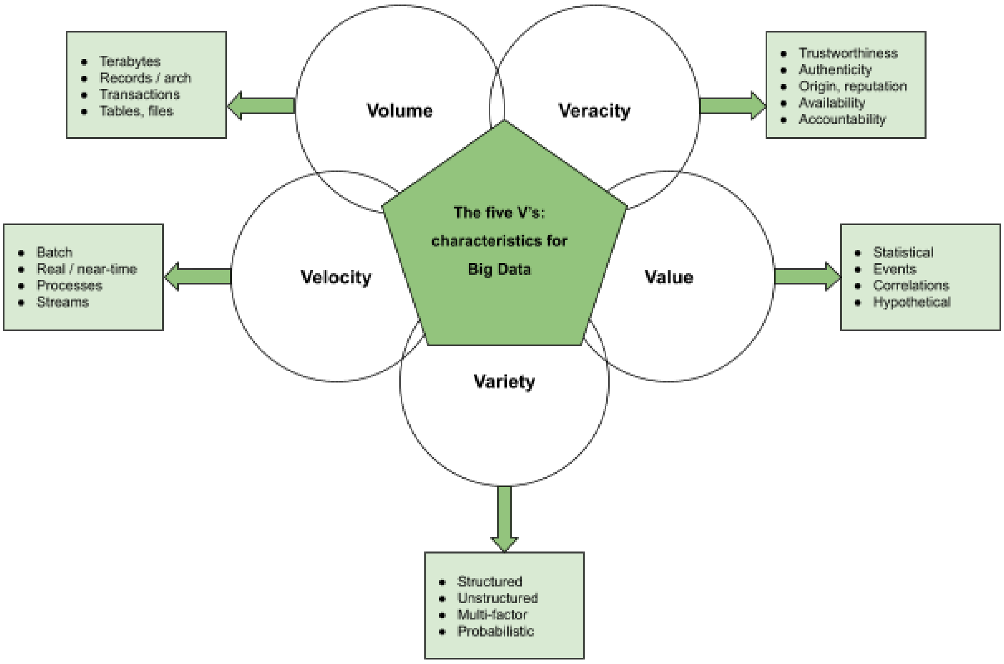


Figure 22 ***Big data characteristics*** *(adapted from Hiba et al. 2015)*

5.4.2.3 ***Data storage***

The estimate in the table below is for the initial three years of operation. The storage requirements will increase during the operational phase and additional storage will need to be budgeted for every three years. Furthermore, systems will be designed to allow data storage and accessibility beyond the lifetime of the project (see Section 3.1.4).

All four levels of storage (Levels 0-3 described above) will be required.

Table 12 ***Aggregated storage requirements***

Location of data	Data storage volume estimated (Petabyte)
On-site (Hub)	2 PB
Distributed (Nodes)	minimal
National (DIRISA)	2PB

5.4.2.4 ***Data transport***

Data transport will be required to connect the myriad of data producers (machine and human), as well as consumers (systems and services, human). This should include, as a minimum:

- data transport for the uplinking of data from scientific cruise ships (e.g. SA Agulhas II), terrestrial stations (e.g. Marion Island, SANAE), possible via available or future satellite-based telecommunications (see Section 2.2.4).
- data transport for the downlinking of data to terrestrial base stations and downstream research facilities and infrastructure, possibly via a combination of satellite and fixed line (e.g. fibre) telecommunications.

Lastly, the chosen data transport mechanisms will need to support uplink and downlinking of both continuous data streams (e.g. as captured from oceanographic instruments such as ocean gliders) and bulk data.

5.4.2.5 ***Data mining***

Data mining will be key in order to aid in automated methods of organising the vast amount of data to be collected in line with SAPRI.

5.4.2.6 ***Accreditation of data repositories***

See Section 3.3.1 for information on data access policies and licenses.

Trusted Digital Repository accreditation is not required; however, SAEON is looking into this for the SAEON Open Data Platform and the SAPRI repository will be integrated.

5.4.2.7 ***Data stewardship and management***

Data collection and management protocols will be adopted from international partner programmes and be imposed and regularly audited by the SAPRI Management Team and the SAPRI Data Centre. SAEON's data curators will review the life cycle of data sets and manage the associated metadata and publication requirements. In the medium term (3 years), procedures will be implemented to maintain the digital integrity of archived data and to ensure its continued readability with contemporary visualisation and query applications.

5.4.2.7.1 Aggregated storage requirements

Refer above to Section 5.4.2.3 for information on data storage.

5.4.2.7.2 Interoperability and linkages with other facilities

A key aim of the SAPRI Data Centre will be to increase the usability and re-use of the data by improving their interoperability. The SAPRI Data Centre will therefore focus on development and interoperability of various public data portals. Globally, linkages need to be nurtured with many infrastructures and networks. Locally, the SAPRI Data Centre will need to maintain close linkages with MIMS / OCIMS (at DEFF), SMCRI, SAEON Egagasini (as South Africa's contributor to the international Argo Float array facility), the Ocean Biodiversity Information System (OBIS), the South African node of the Global Biodiversity Information Facility (SABIF), Natural Science Collections Facility (NSCF), SAIAB, and Iziko.

5.4.2.8 *Computing*

SAPRI will be computing-intensive. Data for SAPRI can be characterised as Big Data, covering both structured and unstructured data types, sourced from machines (sensors/instruments/satellites), as well as human generated sources. This vast amount of data will need to be gathered, stored, managed, and manipulated at the right speed, at the right time, to gain the right insights. Level 3 data generation (model data derived from observations) is likely to play an increasingly significant role after the three-year Phase 1.

5.4.2.8.1 Local computing (take computing to where the data is)

Local computing will largely be the responsibility of the stakeholders. The specification of local computing shall be guided by data production, consumption and data transport needs, as described above. This will include considerations for handling continuous streams of data, as well as bulk data.

5.4.2.8.2 National computing resources

As detailed in a previous section, SAPRI Data can be characterised as Big Data, covering both structured and unstructured data types, sourced from machines (sensors/instruments/satellites), as well as human generated sources. This vast amount of data will need to be gathered, stored, managed, and manipulated at the right speed, at the right time, to gain the right insights. Furthermore, this initiative will need to ensure collection/creation of scalable data (Volume), of different types (Variety), under controllable generation rates (Velocity), whilst maintaining the fundamental characteristics of the raw data (Veracity).

In addition, as described earlier in Section 3.3.1 data requirements can be described in terms of four classes of data:

- Level 0 Data: Raw, unprocessed, not quality assured
- Level 1 Data: Calibrated, quality assured, and verified
- Level 2 Data: Published, meta-data descriptions available, and possible derivations (aggregates, etc.) are available
- Level 3 Data: Modelled values derived from / calibrated against any of the other levels

High performance computing resources may be required to process data up from level 0 to level 2. High performance computing resources will definitely be required to generate models that process input data and generate forecasts/hindcasts.

5.4.2.8.3 Distributed Computing: viz Cloud computing and/or Grid computing

The requirements for cloud and grid computing are likely to increase in time for Level 3 data requirements. The need for high performance computing has been detailed in the previous section. Cloud and/or grid computing from NICIS must be considered as a possible provider of computer resources.

5.4.2.8.4 Computational architectures

The specification of computational architecture will be guided by the Big Data characteristics as discussed above.

5.4.2.8.5 Compute intensity (high performance computing)

Computing capabilities provided by the SAPRI Data Centre server infrastructure will generally need to be adequate for data processing. Computing-intensive modelling will be required, and the services of the CHPC will be needed for this.

5.4.2.9 ***Connectivity***

The SAEON National Office and SAPRI Data Centre are near an existing SANReN PoP. Bandwidth needs to be appropriate to facilitate data transfer from stakeholder institutes to the SAPRI Data Centre. SANReN PoP is preferable, but some institutes / stakeholders will be ADSL connected. Data from oceanographic instruments and observation platforms will be transmitted via satellite to downlink operators (SAPRI stakeholders responsible for these connections). Downlink operators will need to be connected to SANReN in order for the SAPRI Data Centre to then obtain the data.

5.4.2.9.1 Local interfaces to networks

Both the RI environment and Disaster recovery environment have SANReN equipment onsite. Local networking and security equipment will be required to connect the RI to the SANReN network.

5.4.2.9.2 SANReN

Figure 23 below proposes an arrangement for the SAPRI Data Centre, Tier 2, and Tier 1 infrastructure. Links between Tier 2 and Tier 1 infrastructures should be at least 10 Gbps. ADSL connections between SAPRI stakeholders and SANReN must be addressed.

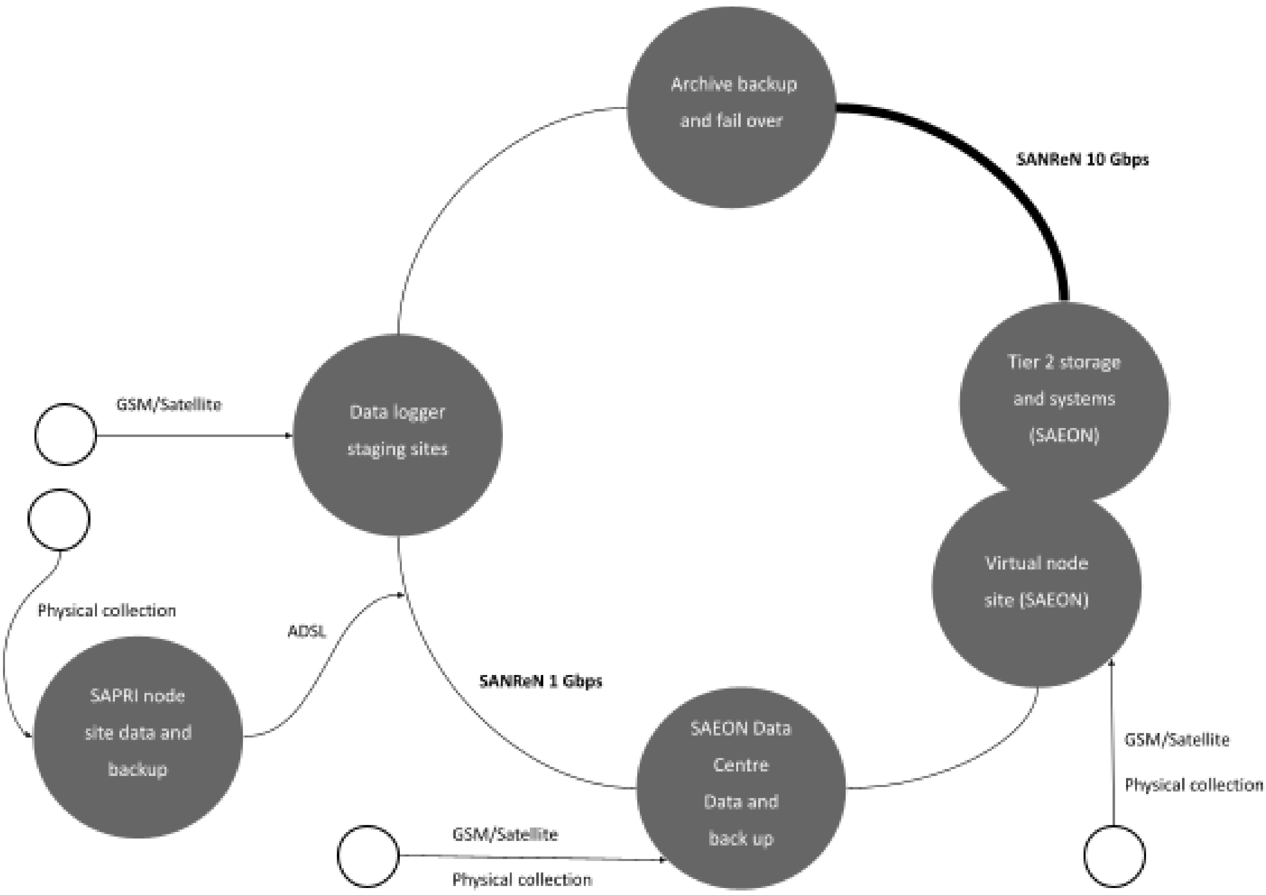


Figure 23 ***SAPRI cyber infrastructure arrangement***.

5.4.2.9.3 International bandwidth

At this stage it is not foreseen that SAPRI will have an impact on international bandwidth, except for typical traffic associated with data downloads. The impact of this on international bandwidth is difficult to estimate.

5.4.2.9.4 Light paths
A dedicated Layer 2 network connection might be needed for frequent, high-volume backup and restore operations.

5.4.2.9.5 Software and middleware
A mixture of open source and proprietary software will be used. High-end security software will be particularly important. Specialised middleware and operational database technology for management of data and metadata will be needed, including refinements and extensions in respect of model data, video and image processing and automated annotation software, and management of very large datasets.

5.4.2.10 *Added Value Services*

5.4.2.10.1 Federated identity management
Federated identity management is the ideal access arrangement for SAPRI.

5.4.2.10.2 Multi-media communication
A requirement for multimedia communication between the SAPRI Administration Hub, the SAPRI Data Centre, the SAPRI nodes (Polar Lab, LTO Land, LTO Ocean, Society), and with stakeholders is an axiom. Through the dedicated components in the DPS integrated facility, SAPRI will also contribute funding and technology to the enhancement of communication between the SA Agulhas II, the bases and their DEFF managers on land.

5.4.2.10.3 Security
CyberSecurity will be a major concern at all levels. Data repository security is handled by Content Management System provisions in current middleware and given that the vast majority of data sets will be in the public domain, is deemed to be adequate. Network security is the most important concern since public access to web-based systems and services is a prerequisite, requiring proper firewall, malware, virus, and infrastructure abuse precautions.

The following considerations apply:

1. Physical security:
    a. Access control - physical access control should be in place for server facilities, with a log of entry to the server room as a norm.
    b. Emergency capabilities should include fire-fighting equipment, preferably automated, and standby power for controlled shutdown and extended operation during load-shedding and power outages - generally up to 4 hours.
    c. Backups should be automated, and backup, disaster recovery, and archiving facilities should be distributed to at least two physically separate sites to provide security in case of systems breakdowns.
2. Logical Security
    a. Access control, policies in respect of fair use, and monitoring of user behaviour are all required to detect anomalous behaviour and protect digital assets;
    b. External threat mitigation via proper firewall configuration, separation of networks into logical clusters, centrally managed malware and anti-virus protection, and user education and policies will be required;

c. Backup plans and fail-over mechanisms should allow stratified backups and fairly rapid recovery, management software for this have been included into the capital and operating cost budget;
d. Software license management should be implemented centrally;
e. Management of data through a life cycle includes user education and standard procedures or policies to ensure adequate copies, backup, and archiving is in place.

3. Insurance and Support
   a. All physical hardware should be adequately insured and appropriate support plans must be included in the purchase;
   b. All critical systems software should be provided with a support license.
4. Availability: Network, device, IT services, server, application, and sensor monitoring can be automated using enterprise monitoring software.
5. Due diligence and audit compliance: A schedule of risks and provisioning or mitigation measures, including a business continuity plan, should be available. The measures identified should be managed by way of periodic assessment of effectiveness and reporting. Automated assessment of provisions is possible and should be implemented as far as possible.

5.4.2.11 *Consolidated view of cyber infrastructure requirements*

Table 13 ***View of cyber infrastructure requirements***

Cyber Infrastructure Component	Location	Requirement	Budget Capital Items (Rand)	Yearly Running Expense (Rand)
Data	Local to RI	Will start with 1 Peta Byte storage and expand storage over 5-year period	R3 000 000.00	R1 000 000.00
	National (DIRISA)	1 Peta Byte Storage that will be expanded as backup requirements expand year on year.	R3 000 000.00	R1 000 000.00
Computing	Local on RI sites	6 data processing node 4 backup Nodes	R4 000 000.00	
	National (CHPC)	We will incrementally	Unknown	Unknown

		integrate into the national integrated cyber infrastructure system		
Connectivity	Local on site	Local network will run at 10Gbps & 40Gbps depending on connection type	R1 600 000.00	
	National (SANReN) and international (NREN)	20Mbps international + 10Gbps backend connection	R384 000.00	R384 000.00
Security	Firewalls, Monitoring and other security measures.	Firewalls at RI and National (Dirisa) sites. Infrastructure and service monitoring. Ai infrastructure to monitor and adapt to security needs.	R1 500 000.00	R500 000.00
Software	Virtualisation and Backups software.	Vmware Virtualisation Veeam Backup and replication	R 2 500 000.00	
Hosting	Hosting hardware	Hosting costs at RI and national (Dirisa)	R120 000.00	R120 000.00

6 MONITORING, EVALUATION AND RISK MANAGEMENT

6.1 MONITORING AND EVALUATION

Formal consolidated reports are compiled annually by the SAPRI Manager for comment by the SAPRI Advisory Panel through to the DSI-DEFF Steering Committee, who report any persistent problems to the NRF for resolving. Every five years a formal independent review is commissioned by the SAPRI Advisory Panel, of every IF and the system as a whole, and reported to the DSI-DEFF Steering Committee.

The Coordinating Officers of SAPRI will prepare quarterly progress reports for the SAPRI Manager and the SAEON Managing Director, which will be used to produce the compulsory quarterly reporting to NRF and DSI. A SAPRI Advisory Panel meeting will be held every year when the annual progress of SAPRI will be presented and discussed. There will also be bi-annual meetings of the DSI-SARIR Management Forum at which the SAPRI Manager will report. An annual glossy Impact Report will also be developed for all stakeholders. The detail of SAPRI's reporting cycles is given in Table 15.

In addition to the standard scientific parameters for evaluation of research activities, a 5-year independent review will consider typical strategic performance metrics, e.g. mission-effectiveness, cost reduction, efficiency, accountability, best management practices, economies of scale and the application of technology.

The stage gate cycling proposed in Table 14 provides detail about the periodic assessment of SAPRI's progress and the criteria for decision making. The monitoring variables and performance indicators are broadly listed in Section 6.3, in terms of the input, output, outcome and impact framework. Assessment of SAPRI's financial management will include two inter-annum projections of expenditure, NRF internal audits, year-end financial reports, annual external financial audits by the Auditor General and ongoing assessment of procurement against procurement plans.

Internal monitoring and evaluation of the performance and impact of the SAPRI Data Centre will be automated from the CCU data management centre (DMC). Figure 24 below shows how such an automated information management system may function. The SAPRI Data Centre will ingest data from a large number of stakeholders, as well as very large datasets from a variety of sensors and platforms over a wide geographical area. To make sense of all the data and metadata streams and where the samples / data are located in the process will require a workflow and data tracking system. The data can then be tracked from where it is collected / downloaded in the field all the way through to where the DOI is cited in a manuscript. Such an information management system is essential for a data intensive RI such as SAPRI and will also aid in the monitoring and internal evaluation of staff performance.

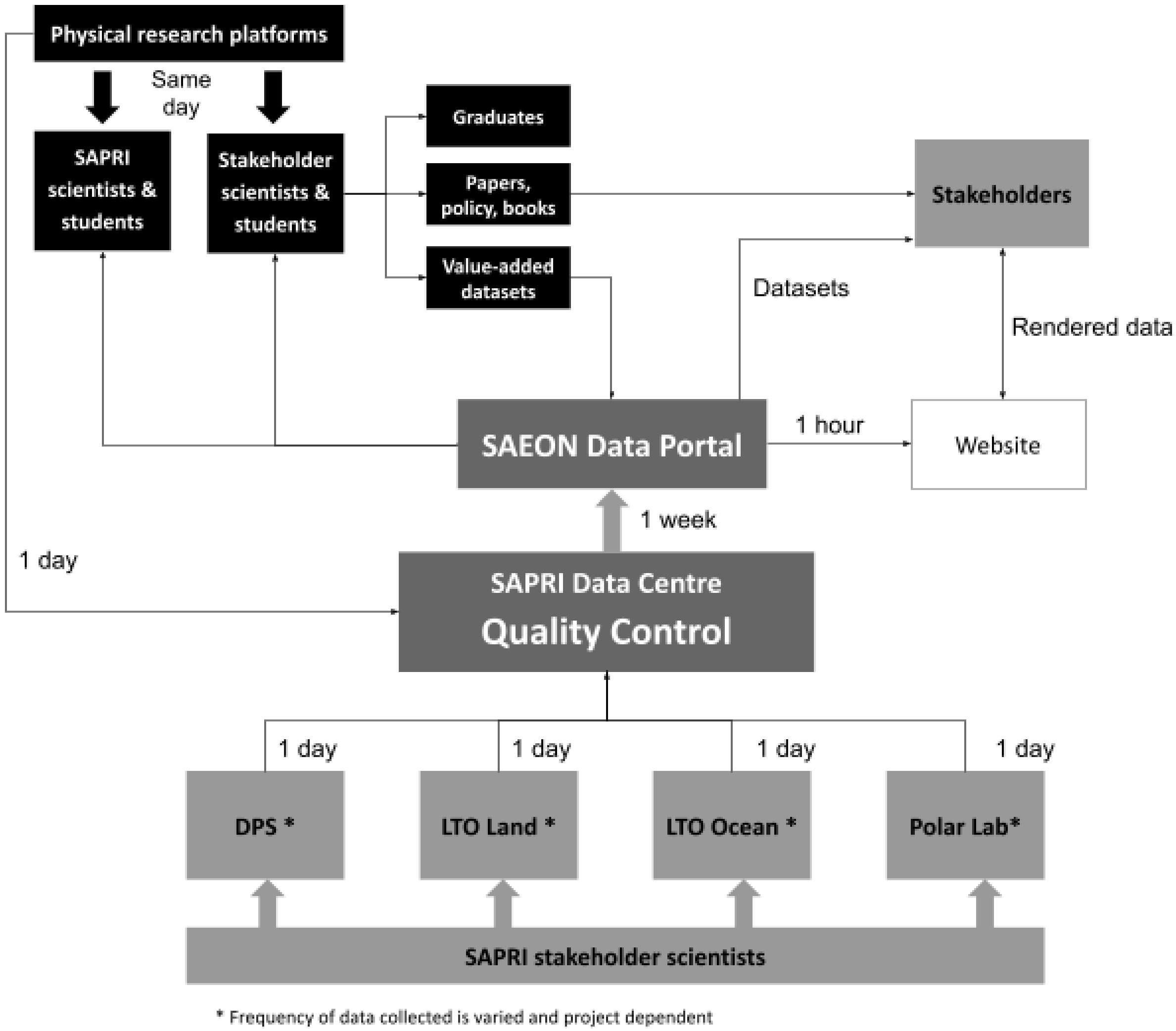


Figure 24 ***Proposed automated monitoring and evaluation system for SAPRI data.***

6.2 Stage gate process for implementation

The SAPRI life cycle (Figure 13) describes three main phases each with deliverables, criteria and outputs. The transition from one phase component to another on the Life Cycle is shown in Table 14.

Table 14 ***Outline of stage gate programme management for SAPRI over a 15-year life cycle***. *The stage gate numbers (SG) refer to the diagram in Figure 16. The table continues in the next 3 pages.*

Stage Gate	Deliverable	Criteria for success and decision making	Actions and Outputs
SG1. Initiation of SAPRI	SAPRI proposal approved for funding by SARIR Evaluation Panel. Appointment of an Acting SAPRI Manager until the appointment and induction of a permanent SAPRI Manager Signed agreements between SAEON and integrated facilities Capacity development, student training, education and communication plan finalised Scientific requirements	3-year foundational Phase 1 budget committed by DSI Signing of contract between DSI and NRF by July 2021 Agreement on institutional arrangements between DSI, DEFF, NRF, integrated facilities and SAEON Co-developed approach for capacity development and student training with HBHEIs Communication policy implemented List of minimal key requirements for scientific case established	Revision of proposal and business plan if the budget awarded does not correspond with the proposed budget or DSI-DEFF agreement on institutional arrangements necessitates adjustment. Clear strategy about how to gather necessary commitments at institutional and governmental level Internal reorganisation by SAEON to accommodate SAPRI requirements Recruitment of permanent SAPRI Manager Appointment of members of advisory committees and first meetings held Budget for Polar Lab approved and start of construction planning phase Transformed polar science landscape Societal interest and take up of polar science

Stage Gate	Deliverable	Criteria for success and decision making	Actions and Outputs
SG2. End of Year 3	Hub staff appointed, mandated and operational Measurable and satisfactory Key Performance Indicators identified Initiate planning and procurement of instrumentation Space requirements met by DEFF and/or consortium facilities Cruise logistics agreed and undertaken Planning, procurement and installation of IT infrastructure Finalised plans for Polar Lab and construction proceeding SANAP-science reorientated to exploit SAPRI infrastructure better and become integrated with SAPRI logistics	Advice and endorsements obtained from advisory structure Availability of resources (within budget and enough staff) Quality of staff and training requirements Limited restraints on operations from Covid-19 regulations Stable exchange rates Agreement on standardisation of equipment and Essential Variables measurements	Potential cruises undertaken Potential instruments deployed Staff complement fully functional Advisory structure offering sound advice IT infrastructure functional Polar Lab under construction

Stage Gate	**Deliverable**	**Criteria for success and decision making**	**Actions and Outputs**
SG3 (years 4-8)	SAPRI running smoothly and seamlessly with strong international collaborations, appropriate equipment and infrastructure, data flows, a user community that is transforming and growing, a sound advisory structure, effective and impactful outreach programmes and sustained support from government. Achieving research results, delivering relevant services to scientific community 5-year critical review of progress and deliverables	Availability of resources Quality analyses (Instrument review and data quality check) Risk analyses (on budget, on time, within business and science plan) Within capital and running budgets Stakeholder satisfaction Utilisation of RI monitored and reported. Milestones, deliverables and KPIs met or exceeded Recommendations from 5-year review endorsed by SAPRI advisory structure	If equipment deployed successfully then continue to operating phase If some instruments are not in due to technical issues or there are queries wrt data quality then finalise set-up first (resource, risk and business implications) Agreement on business plan towards a prioritised implementation of the recommendations Polar Lab construction effectively completed
SG4 (years 9-13)	10-year critical review of progress and deliverables Produce an impact report and apply for additional funding to continue RI for another cycle. Pending mandate from government to continue, to transform or to wind down	Measured stakeholder satisfaction and achievement of milestones, deliverables and KPIs Recommendations from 10-year review endorsed by SAPRI advisory structure Risk analyses per mode of future business model	Agreement on business plan towards a prioritised implementation of the recommendations within availability of capital and running budgets and identified risks If funding application was successful, continue with operations If transformation is imperative, enter hand-over phase = Run

Stage Gate	Deliverable	Criteria for success and decision making	Actions and Outputs
	If required plan the distribution and transfer of assets and redeployment of staff Implement special instructions and legal obligations for dissolution or transformation	Funding application successful and adequate resources available National stakeholders agree on revised business plan	full operations with other entity for another two years If required enter shut-down phase = Wrapping up of student projects, papers and data archiving and action the dissolution plans.
SG5 (years 14-15)	Final progress report and review papers. Implement transfer of data holdings for responsible data archiving	Institutional, political and Financial commitment on major upgrade / decommission / merger obtained	

6.3 Reporting

Indicators, as per Table **15** will be collected on a continuous basis by the SAPRI Hub, Data Centre, DEFF, SAEON and integrated facilities, for scheduled reporting periods to the NRF and DSI.

Other potential indicators are the number of unique visits to the public website, number of papers in accredited journals, citation index, number of presentations, number of active MoUs and MoA's, instrument uptime percentage, meeting of EV standards, percentage of compliance with policies and maintenance schedules, staff turnover, number of international activities, number of postgraduates associated with SAPRI, qualitative assessment of capacity development and transformation, and number of contributions to government policies and strategies.

Table 15 ***The SAPRI reporting schedule***

Report	Frequency	Content	Recipient(s)
Integrated Facility Progress	Quarterly	Reports by consortium partners will detail the no. of instruments serviced, field trips completed, datasets uploaded to SAPRI Data Centre, stakeholders engaged with, educational outreach activities, number of users of the respective platforms, challenges, risks, etc.	SAPRI Manager
SAPRI Progress	Quarterly	Same as above plus narrative on KPIs e.g. staff demographics, user demographics, involvement of historically black universities, no. datasets archived, data downloads from portal, visits to website, papers published, meetings and conferences attended, samples analysed, stakeholders reached, learners and educators reached, and all other KPIs required by NRF, etc.	SAEON MD NRF Corporate DSI
SAPRI Progress	Annual	KPIs including narrative on milestones, deliverables, targets, budget, HR, risks and challenges	DSI-DEFF Steering Committee for endorsement, addressing systemic obstructions and recommendations towards advancing socio-economic meaning SARIR Management Committee SAPRI Advisory Structure for comment SAEON MD for submission to Steering Committee

Report	Frequency	Content	Recipient(s)
Impact Report	Annual	Glossy review of activities, output and impact	All stakeholders
Permit reports	Annual	Progress on projects that required a sampling / research permit	DEFF, Conservation Agencies
Project grant annual progress report	Annual	Progress on projects funded by NRF, SANAP, international funding agencies, etc.	Funding agency
SAPRI Review	Every 5 years	Analyses of scientific, public and policy-relevant datasets	All stakeholders

6.4 RISK MANAGEMENT

Due to the breadth of the scope of operations of SAPRI and the diversity of organisations involved, several risks are relevant and require appropriate organisational responses in order to address and mitigate those risks. These have been identified and analysed in Table 16.

Table 16 ***Analysis of the risk management matters and interventions to be considered by SAPRI***. *Legend: H=High, M=Medium, L=Low. Analysis of the risk management matters and interventions to be considered by SAPRI. Legend: H=High, M=Medium, L=Low.*

Risk Category	Specific Risk	Likelihood	Impact	Rating of Risk	Mitigation Intervention
Strategic	Changes in national political priorities	L	H	M	Communication of SAPRI impact
	High-level incongruence between DEFF, DSI and NRF	L	H	M	Annual meetings of DSI-DEFF Steering Committee and substantive agreements towards conflict resolution

	Poor advice from the advisory structure	L	M	L	Appropriate members. Avoid political agendas
Set-up	Failure to recruit excellent leadership	L	H	M	Sound recruitment processes.
	Failure by the host to operationalise the SAPRI systems	L	H	M	Appointment of excellent staff. Maintain excellent stakeholder relations.
	Failure by the main stakeholders to come to the party	M	H	M	Maintain excellent stakeholder relations. Excellent internal communications and regular meetings
Operational	Breakdown or loss of Agulhas II and/or SANAE / Marion bases	L	L	M	Adherence to maintenance schedules Excellent technical staffing
	Incongruence and/or inefficiencies between SAPRI and DEFF logistic teams and the Integrated Facilities	M	M	M	Establish a shared vision and open relationship supported by unambiguous processes and sound procedures.
	Poor performance by staff and Integrated Facilities	M	M	L	Establish a shared vision and open relationship supported by unambiguous processes and sound procedures
Financial	Cuts in revenue from government	H	H	H	Deliver the expected return on investment and demonstrate impact and value
	Drastically unfavourable exchange rates	M	H	H	If alternatives are not available, a budget increase will need to be requested.

Environmental	Harsh atmospheric conditions related to Climate Change delaying or prohibiting research	M	M	M	This is an uncontrollable wild card However mitigatiHowever, be in place to ensure safety at sea and on land training is adhered to.
Legislative	Restrictions on procurement processes	M	M	M	Secure a special dispensation with Treasury if necessary
	Changes to international agreements	L	H	L	Appropriate representation on behalf of South Africa in committees and meetings
	Changes in government structures	M	M	M	This is an uncontrollable wild card
Ethical	Biological sampling and marine mammal research do not meet ethical standards	L	L	L	All activities will be reviewed by the ethics committee

7 FINANCIAL PLAN AND BUDGET

7.1 THE FINANCIAL REFERENCE PERIOD

The financial reference period for SAPRI is:

Year 1 – 3: Setting up of the SAPRI along with initial infrastructural procurements (Phase 1). The setup phase includes the provision of SLAs and MoUs establishment.

Year 4 – 13: A ten-year running phase for SAPRI (Phase 2). Within this phase, a parallel process will assess the SAPRI and science plan and prepare for the potential transition to an institution (Phase 3).

Year 14 – 15: Ideally the SAPRI will phase into an institution at this stage.

For comparison purposes, the budget is given over a 15-year period, with a clear indication of the phases.

7.2 TYPES AND SOURCES OF FUNDING

Two types of funding for the RI are considered:

- Capital Funding
- Revenue generated during operation

7.2.1 Capital funders

Table 17 ***List of capital funders***

Type of funder	Characteristic of funder	Name of funder for this RI
National Government Capital Grant	This is typically grant funding that may arise from a single department, or multiple departments, working in isolation, or through some form of centralised capital fund for RI.	Department of Science and Innovation (DSI) through the South African Research Infrastructure Roadmap (SARIR)
International Government Capital Grant (Framework Grants and Structural Funds)	This is capital funding made available as part of research framework programmes where South African RIs partner with international RIs, such as Horizon 2020 funds. Having partnerships with international RIs may	At this stage, there are no International Government Capital Grants secured for SAPRI. Once the SAPRI is established, this avenue of funding could be explored further.

	lead to access to structural funds such as the European Development Fund, the African Development Bank, the Development Bank of Southern Africa, etc.	
Philanthropic Organisations/Donors Grants	These organisations are known to invest in research and research infrastructure and include entities such as the Wellcome Trust, the Bill and Melinda Gates Foundation, the Rockefeller Foundation, Howard Hughes Foundation, etc.	Not a viable option for SAPRI. However, once the SAPRI is established, these possibilities linked to the UN Decade of the Ocean could be explored.
Industry and Multi-nationals	Industry and multi-nationals may fund specific components of a RI that are either dedicated to their needs or open, but placed at the RI to develop certain capabilities, capacity and skills.	At this stage, no funding has been requested from the private industry. However, this may be an option to explore once the SAPRI has been established.
Loans/Debt Funding	With the restriction on government funds, more and more RIs will have to be funded on loan capital, especially those that can show a good surplus that can be used to service the loan	Not a viable option for the SAPRI.
In-kind Contributors	An in-kind contribution can consist either of the direct provision of a tangible asset to the infrastructure or of expenditure incurred directly by the contributor, which benefits the RI.	Through the detailed and extensive engagement which has taken place with institutions to establish the SAPRI proposal, much in-kind infrastructures have been discussed in service of the SAPRI. These include, but are not limited to, SMCRI

		(PEI Infrastructure), DEFF, SOCCO, UCT, UJ, etc. Additionally, UCT has submitted a request for funding to the DHET for building the Polar Lab under the Infrastructure Funding Category Focus Area "National Academic Priorities"

7.2.2 Revenue generated during operation

Table 18 ***Revenue generated during SAPRI operations***

Type of operational revenue	Characteristics of this revenue	Indicate how this RI will earn this type of revenue
Government Baseline Funding Grant	A baseline funding grant is planned as part of the RI sustainability and kicks in once the RI has been commissioned. It will also cover further concept design and technical design activities in the early set-up phase. Where more than one government department has an interest in the RI more than one baseline grant may be possible.	This proposal is a detailed motivation for continuous baseline funding over a 15yr period from the Department of Science and Innovation (DSI) through the South African Research Infrastructure Roadmap (SARIR)
Services Rendered	The services that the RI will be offering have been discussed under the business justification. These services have revenue potential and can be charged for with various price options over the user base as described in the stakeholder analysis and in the access governance.	SAPRI is not designed to be a commercial entity. However, through the Polar Lab and lab analysis of samples, services may be rendered for commercial benefit to the consortium partners of SAPRI.
Direct Sales of Products	The products that RI will be offering have been discussed	SAPRI is not designed to be a commercial entity. However,

	under the business justification. These products have revenue potential and can be charged for with various price options over the user base as described in the stakeholder analysis and in the access governance.	the development of in situ sensors may result in a commercial benefit to the consortium partners of SAPRI.
Memberships	In some cases, income from memberships is possible. These memberships normally include certain benefits such as a limited number of services or products or free access to research outcomes. Membership fees are good to boost cash flow since payment is upfront.	Not a viable option for the SAPRI.
Partnerships	Partnerships refer to contributions made by long-term research partners that contribute to the running of the RI.	These include the provision of already existing infrastructure for use in the SAPRI, consumables, laboratory space, container labs, personnel able to transfer skills, and other various types of in-kind contributions.
Project Grants	Project Grant income is a major source of income during operation. This covers a broad field of grants, including research grants, framework grants, etc.	PI’s in their various disciplines will apply for research grants supporting their science undertaken through the SAPRI. This is an indirect income as it supports the PI and research costs (consumables, services, etc.), and may thus support the SAPRI.
Other	NRF SANAP-Science and SANAP Ships time budgets	Many of the current long-term monitoring and research projects within the polar science landscape are funded through the NRF SANAP-Science and ship time budgets.

		Some of these funding will benefit the SAPRI running costs into the future and the exact portion year on year will depend on the projects supported. Ship time covered by NRF SANAP is related to research cruises - again dependent year on year. The funding for the DPS IF, which integrates ALSA and the SEAmester program, will also come from this source.

7.3 Cost structure

The cost structure is divided into:

- Capital cost
- Running cost

7.3.1 Capital cost

Table 19 ***Capital cost***

Capital Cost Item	**Characteristics of this capital cost**	**Indicate how these cost items will apply to this RI**
Civil Engineering Works	This includes site preparation, earth works, filling, levelling, paving, etc.	Not directly included in this proposal but required for building the Polar Lab.
Buildings	This may include new buildings or refurbishment of old buildings that will house the RI or parts thereof	The Polar Lab building costs are requested in the funding request to DHET.
Specialised Scientific Equipment	This is a large component of capital expenditure and includes research equipment, facilities and laboratories	A list of specialised equipment is summarised in Appendix E.

Supporting Facilities	This may include standby power, water purification, air conditioning, clean laboratory spaces, extraction fans, security, etc.	The Polar Lab and the specialised container labs will be equipped with clean laboratory spaces, air-conditioning and extraction fans. A major temperature-control system is required for the Polar Lab to simulate Antarctic conditions, as well as a system to recycle water and treat brines and flumes. Green building solutions will be prioritised.
Auxiliary Infrastructure	This includes infrastructure supporting the main RI such as access roads, overnight facilities for researchers, transport under special circumstances, such as ships, aeroplanes, etc.	Auxiliary infrastructures also include the vehicles (polar tractors, skidoos, for transporting scientists and equipment in Antarctica and the equipment/gear for fieldwork and overnight stay. Not included in the set-up phase of SAPRI, but aircraft transportation may sensibly reduce logistics costs if properly organised. The main logistics service provider in the Dronning Maud Land Air Network (DROMLAN) is the Antarctic Logistics Centre International (ALCI). The ALCI facilitates the activities of Antarctic operators using Cape Town as their gateway to Antarctica. Engagement with these operators and auxiliary infrastructures will be considered in Phase 2 and beyond.
Data	Hardware for data storage, data security, data verification and curation and data mining which may be on-site or centrally hosted, or cloud based, etc. It includes redundant systems. Refresh technology must be in budget.	The SAPRI Data Centre will be established within the SAEON Data Centre and a considerable amount of infrastructure is required for this. These are summarised in Appendix E.
Computing	This may refer to hardware and software for in-house as well as national resources for high performance computing, grid computing,	For SAPRI this relates specifically to staff employed by the SAPRI in terms of laptops, screens, office infrastructure, etc.

	cloud computing, etc. Refresh technology must be in budget.	
Connectivity	RIs will have to be connected to the national grid and to the Internet. SANReN connectivity may require upgrading of systems on the RI site as well as upgrading of existing national infrastructure. Refresh technology must be in budget.	These costs are included within the Data section. A dedicated capital cost item has been included to develop new satellite communication systems between the continent and the observational platforms. The Digital Antarctic component of the DPS IF will also deploy computing and monitoring devices to implement the digital twin technology at the bases, the ship and the Polar Lab.
Equipment Replacements	Research and other equipment have varying lifetimes, many of which are much shorter than the RI life cycle. Replacement has to be planned into the business case as capital injections from time to time after the operations have started.	Replacement costs have been included in the proposed business plan. They range from the replacement of the glider fleet and mooring equipment, as well as gear for terrestrial and oceanic fieldwork. The capital cost has been distributed evenly over the life cycle, since polar equipment is subjected to extreme conditions that makes its lifetime more unpredictable. Autonomous devices such as drifters need to be continuously replaced since they are lost at sea and cannot be retrieved.
Equipment Upgrades	Research and other equipment need upgrades from time to time. These should appear as capital cost spread over the life cycle of the RI.	Upgrade costs for the SAPRI Data Centre have been included
New Equipment Expansions	New generations of research and other equipment emerge on a continuous basis and the RI should plan the acquisition of these new generations of equipment to remain competitive and to ensure sustainability.	The major capital costs related to new equipment are linked to the devices for the new deep-sea observatory, the seawater wave tank for sea-ice/ocean interactions and the new equipment installed on future moorings.

5.1.2 Running cost

Table 20 ***Running cost***

Running Cost Item	**Characteristics of this running cost**	**Indicate how these cost items will apply to this RI**
Utilities	Utilities include electricity, water, gas supply, waste treatment, etc.	These costs are included in the overheads of the IFs and as such are not detailed here.
Data	The running costs aspects of data includes external service fees and levies for data management, curation, security, backup and storage.	These costs are included within the DPS, specifically the SAPRI Data Centre.
Computing	The running costs aspects of HPC includes external service fees and levies for access to HPC CPUs.	These costs are included within the DPS, specifically the SAPRI Data Centre.
Connectivity	The running costs aspects of connectivity includes external service fees and levies.	These costs are included in the overheads of the IFs and as such are not detailed here.
Consumables	Consumables include all specialised gases, chemicals, glassware, packaging, protective clothing, disposable materials, etc., that are related to experiments done in the RI. This cost is usually recovered from user fees or project grant income	Costs are detailed for each of the IF's requiring consumable costs. These are linked to computing, data, gases, chemicals, glassware, etc. Included here is the running costs of the autonomous platforms and moorings unit in terms of batteries, engineering, design and data management.
Security	Running cost for security includes monthly levies for security companies, secure laboratory space, personal and physical security measures, etc.	These costs are included in the overheads of the IFs and as such are not detailed here.
Rental/Levies	This running cost includes monthly/annual rental of land and premises	These costs are included in the overheads of the IFs and as such are not detailed here.

Staff	Staff cost is usually a major running cost item for a RI. The staff requirements have been indicated in the Staffing Model. Staff cost is made up of salaries, benefits, training and travel costs.	SAPRI will employ 39 people by Year 4. These include 7 Management team members (Manager, Coordinating Officers and 3-year Project Manager for the Polar Lab), 2 Admin staff, 11 technicians across the IFs, 4 annual overwinter team members for Marion Island and 15 Data Centre staff.
Maintenance	Maintenance costs start kicking in once the RI is operational. Preventative maintenance and emergency maintenance make up these costs. It is an important cost item for sustainability of the RI.	These costs are included within the running costs for the IF's.
Shut-down costs	Shut-down costs include phasing out costs, decommissioning costs and costs of closure and may include disassembly, waste, recycling, storage, reskilling and relocation costs.	No costs have been specified here.
Other overheads	Other overheads may include taxes, levies, interest, insurance, and other costs not mentioned above	These costs are included in the overheads of the IFs and as such are not detailed here.
Contingencies	Contingencies arise from unforeseen events, fault margins on planning, unexpected increases in exchange rate and interest rate, inflation, etc.	These costs have been taken into account within the ICRR.
Other (Specify)		Line items included here are related to ad interim management costs, travel and admin of the advisory panels, general travel and catering for SAPRI activities, a capacity development training budget and costs associated with report writing.

7.4 Financial indicators

Given the uncertainties at the time of compiling the SAPRI proposal linked to the global health pandemic and financial stability of South Africa in a double recession, a very conservative inflation rate was adopted for the high-level budget. This was also staggered with the projection available to

2023 (http://www.tradingeconomics.com/south-africa/forecast), and thereafter increased to allow for robustness within the budget.

From Year 1 into Year 2, an inflation of **4.5%** was adopted.

From Year 2 into Year 3, 4 and 5, an inflation of **5.5%** was used.

From Year 5 into subsequent years to Year 13, an inflation of **6.5%** was used.

For the final two years, an inflation of **7%** was used.

This inflation calculation was applied to all Running Costs, inclusive of salaries, and the ICRR inflation year on year.

7.5 A HIGH LEVEL BUDGET

A high-level budget for this RI according to the standardised financial plan is provided in the table below. The full budget, the focused first five-year budget and summaries of both these budget layouts are provided in the spreadsheet appended to the proposal for further details.

Projected for the full 15 years, the budget for SAPRI is summarised as follows:

Total Capital Costs:	R 385 712 497.00
Total Running Costs:	R 594 650 159.00
ICRR	R 116 022 937.00
Total Project Cost:	R 1 096 385 593.00

The final amount proposed for the SAPRI by SARIR has not yet been stated. This budget thus represents the most accurate estimate of what a Research Infrastructure focusing on the incredibly large region of oceans around South Africa, its responsibilities on Antarctica and sub-Antarctic Islands, would need to look like.

		etting Up and Infrastructure Procurements (initial							Running						Shutting Down		
Year per life cycle phase		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
AVAILABLE DST GRANT		**R61 784 444**	**R65 290 346**	**R90 497 660**	**R119 910 186**	**R95 659 244**	**R91 992 723**	**R70 408 464**	**R61 037 068**	**R54 422 532**	**R77 464 163**	**R52 896 140**	**R56 342 306**	**R59 982 889**	**R63 596 771**	**R68 006 903**	**R1 089 291 840**
DSI SARIR Grant																	
REVENUE																	
Capital Finance Type	***DESCRIPTION***																
National Government Capital Grant		R39 251 000	R37 192 336	R54 158 169	R76 782 775	R53 655 410	R48 247 077	R26 575 730	R15 750 000	R7 250 000	R25 275 000	R275 000	R300 000	R300 000	R350 000	R350 000	**R385 712 497**
In-Kind	Polar Laboratory Building (land from UCT, funding through DHET)		R50 000 000														**R50 000 000**
	East Pier Stores (to be negotiated), etc																**R0**
Sub-total		R39 251 000	R37 192 336	R54 158 169	R76 782 775	R53 655 410	R48 247 077	R26 575 730	R15 750 000	R7 250 000	R25 275 000	R275 000	R300 000	R300 000	R350 000	R350 000	**R385 712 497**
Running Revenue																	
Government Baseline Funding Grant		R16 355 000	R21 568 975	R27 289 725	R31 136 392	R32 437 910	R34 546 374	R36 791 888	R39 183 361	R41 730 279	R44 442 747	R47 331 526	R50 408 075	R53 684 600	R56 887 094	R60 856 213	**R594 650 159**
Other (in-kind)	SANAP Funding (NRF) - 3 yearly cycle (estimate only)	R18 000 000	R18 000 000	R18 000 000	R20 000 000	R20 000 000	R20 000 000	R22 000 000	R22 000 000	R22 000 000	R24 000 000	R24 000 000	R24 000 000	R26 000 000	R26 000 000	R26 000 000	**R330 000 000**
	SANAP Ships time (annual - estimated costs only)	R38 000 000	R39 000 000	R40 000 000	R41 000 000	R42 000 000	R43 000 000	R44 000 000	R45 000 000	R46 000 000	R47 000 000	R48 000 000	R49 000 000	R50 000 000	R51 000 000	-	**R623 000 000**
	LTO-Land: SAEON-PEI (In-kind from SMCRI)																
Sub-total		R16 355 000	R21 568 975	R27 289 725	R31 136 392	R32 437 910	R34 546 374	R36 791 888	R39 183 361	R41 730 279	R44 442 747	R47 331 526	R50 408 075	R53 684 600	R56 887 094	R60 856 213	**R594 650 159**
EXPENDITURE																	
Capital costs																	
Specialised Scientific Equipment																	
	DPO	R1 200 000	R0	R0	R8 000 000	R300 000	R0	R0	R0	R0	R0	R0	R0	R0	R0	R0	**R9 500 000**
	LTO-Land	R15 000 000	R17 366 926	R17 366 926	R5 000 000	R9 000 000	R9 000 000	R4 000 000	R4 000 000	R4 000 000	R0	R0	R0	R0	R0	R0	**R84 733 852**
	LTO-Ocean	R5 000 000	R16 465 410	R28 388 743	R55 643 275	R42 205 410	R39 072 077	R22 375 730	R11 500 000	R3 000 000	R0	R0	R0	R0	R0	R0	**R223 650 645**
	Polar Lab	R250 000	-	R5 200 000	R5 000 000	R2 000 000	-	-	-	-	-	-	-	-	-	-	**R12 450 000**
Supporting Facilities																	
Data	*DPO: Data Management (Additional infrastructure, etc)*	R17 333 000	R3 000 000	R3 000 000	R3 000 000	-	-	-	-	-	R25 000 000	-	-	-	-	-	**R51 333 000**
Computing	*Computers, office equipment and furniture, incidentals, sundries*	R468 000	R360 000	R202 500	R139 500	R150 000	R175 000	R200 000	R250 000	R250 000	R275 000	R275 000	R300 000	R300 000	R350 000	R350 000	**R4 045 000**
Subtotal		R39 251 000	R37 192 336	R54 158 169	R76 782 775	R53 655 410	R48 247 077	R26 575 730	R15 750 000	R7 250 000	R25 275 000	R275 000	R300 000	R300 000	R350 000	R350 000	**R385 712 497**
Running Costs																	
Consumables																	
	DPO	R1 050 000	R1 097 250	R1 157 599	R1 221 266	R1 288 436	R1 372 185	R1 461 376	R1 556 366	R1 657 530	R1 765 270	R1 880 012	R2 002 213	R2 132 356	R2 281 622	R2 441 335	**R24 364 816**
	LTO-Land	R200 000	R209 000	R320 495	R338 122	R356 719	R379 906	R404 599	R430 899	R458 907	R488 736	R520 504	R554 337	R590 368	R631 695	R675 912	**R6 560 199**
	LTO-Ocean	R4 000 000	R4 180 000	R5 559 900	R5 965 695	R6 293 808	R6 702 905	R7 138 593	R7 602 605	R8 096 771	R8 623 061	R9 183 559	R9 780 492	R10 416 224	R11 145 361	R11 925 535	**R116 614 509**
	Polar Lab	-	-	-	R250 000	R263 750	R280 894	R299 152	R318 597	R339 305	R361 360	R384 849	R409 864	R436 505	R467 060	R499 755	**R4 311 091**
Staff		R10 005 000	R14 746 725	R18 842 252	R21 874 304	R22 666 411	R24 139 723	R25 708 809	R27 379 877	R29 159 574	R31 054 947	R33 073 516	R35 223 298	R37 512 811	R40 126 523	R42 922 401	**R414 436 171**
Additional administrative costs		R1 100 000	R1 336 000	R1 409 482	R1 487 001	R1 568 786	R1 670 758	R1 779 357	R1 895 014	R2 018 191	R2 149 374	R2 289 085	R2 437 873	R2 596 335	R2 234 835	R2 391 273	**R28 363 364**
Subtotal		R16 355 000	R21 568 975	R27 289 725	R31 136 392	R32 437 910	R34 546 374	R36 791 888	R39 183 361	R41 730 279	R44 442 747	R47 331 526	R50 408 075	R53 684 600	R56 887 094	R60 856 213	**R594 650 159**
ICRR		R5 000 000	R5 225 000	R5 512 375	R5 815 556	R6 135 411	R6 534 213	R6 958 937	R7 411 268	R7 893 000	R8 406 045	R8 952 438	R9 534 346	R10 154 079	R10 864 864	R11 625 405	**R116 022 937**
PROJECT TOTAL		**R60 606 000**	**R63 986 311**	**R86 960 269**	**R113 734 723**	**R92 228 731**	**R89 327 664**	**R70 326 555**	**R62 344 629**	**R56 873 279**	**R78 123 792**	**R56 558 964**	**R60 242 421**	**R64 138 679**	**R68 101 958**	**R72 831 618**	**R1 096 385 593**

7.6 VISUALISATION OF THIS HIGH-LEVEL BUDGET

The following aspects of the Financial Plan are now visualised in the form of Line graphs, Pie Charts and Bar Graphs.

7.6.1 Project View

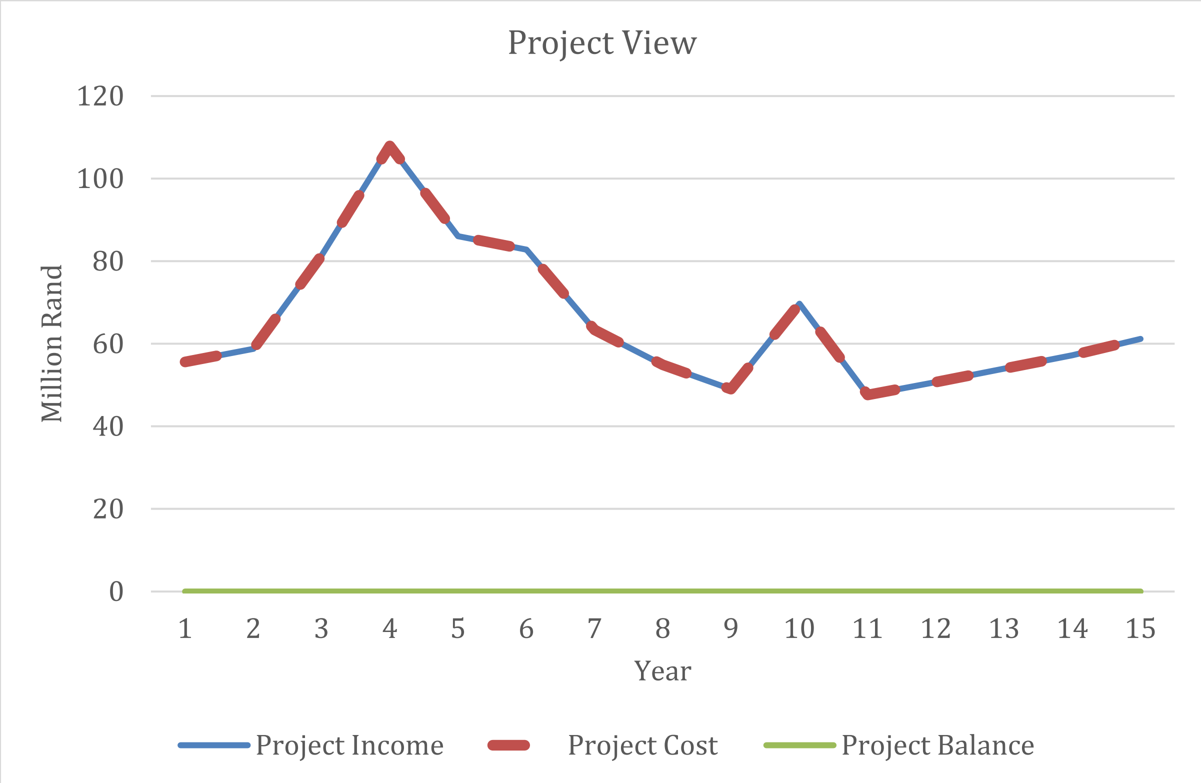


Figure 25 ***High-level budget: project view.***

BREAKEVEN AND CASH FLOW

The final approved amount available to SAPRI by the SARIR has not been given. Thus, a budget of a zero profit or loss is used to show the trend of project costs over the 15-year budget period. The first peak of increased costs occurs in Year 4, a little more than R 107 million, with a second peak at Year 10 of just less than R 70 million. These are directly proportional to the capital investment costs noted in the following graph. Note, these amounts do not include the 10% ICRR amounts.

7.6.2 Capital View

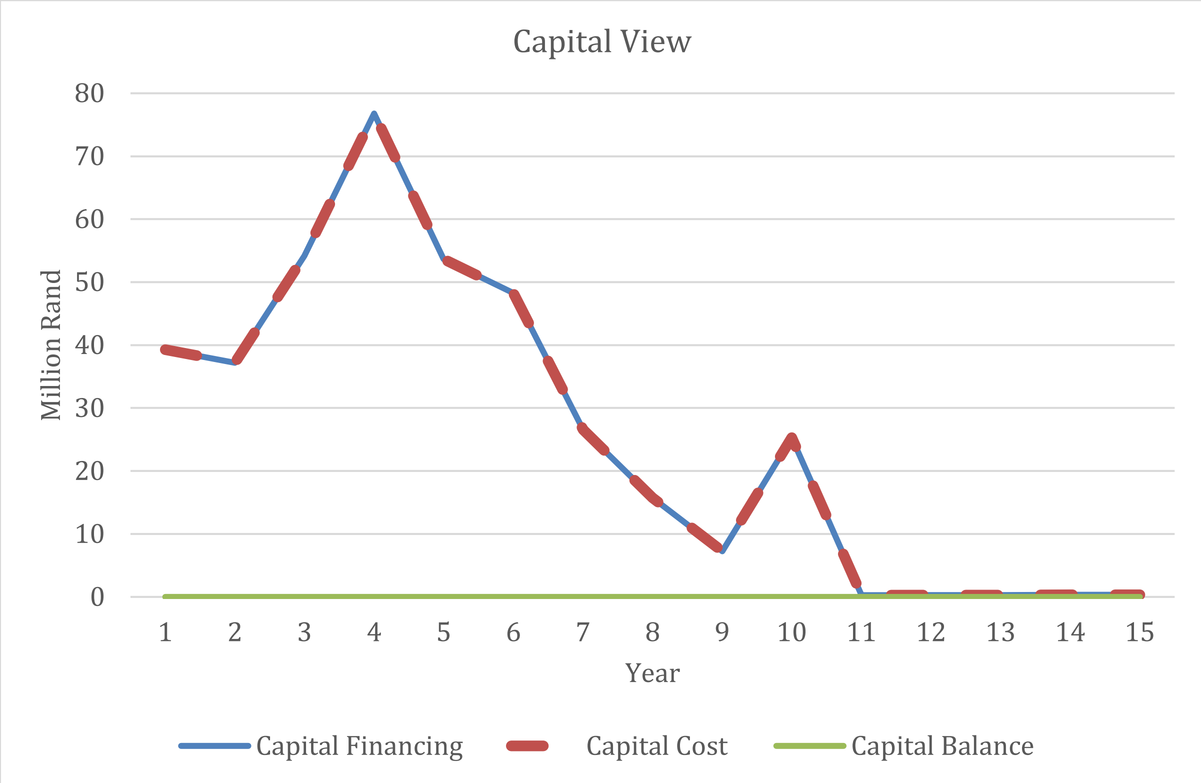


Figure 26 ***High-level budget: capital view***

BREAKEVEN AND CASH FLOW

The trend of two peaks in Year 4 and Year 10 in the Project View diagram is similar to that of the Capital View above. The initial procurement of specialised equipment in Year 1 will focus on those required for installation during the projected SA Agulhas II dry-dock in October 2021. These costs will ramp up over Year 2 and 3, peaking in Year 4, when the bulk of equipment listed in Appendix E will be procured. The peak in Year 10 is related to the replacement and upgrade of infrastructure required for the Data Centre.

7.6.3 Operational view

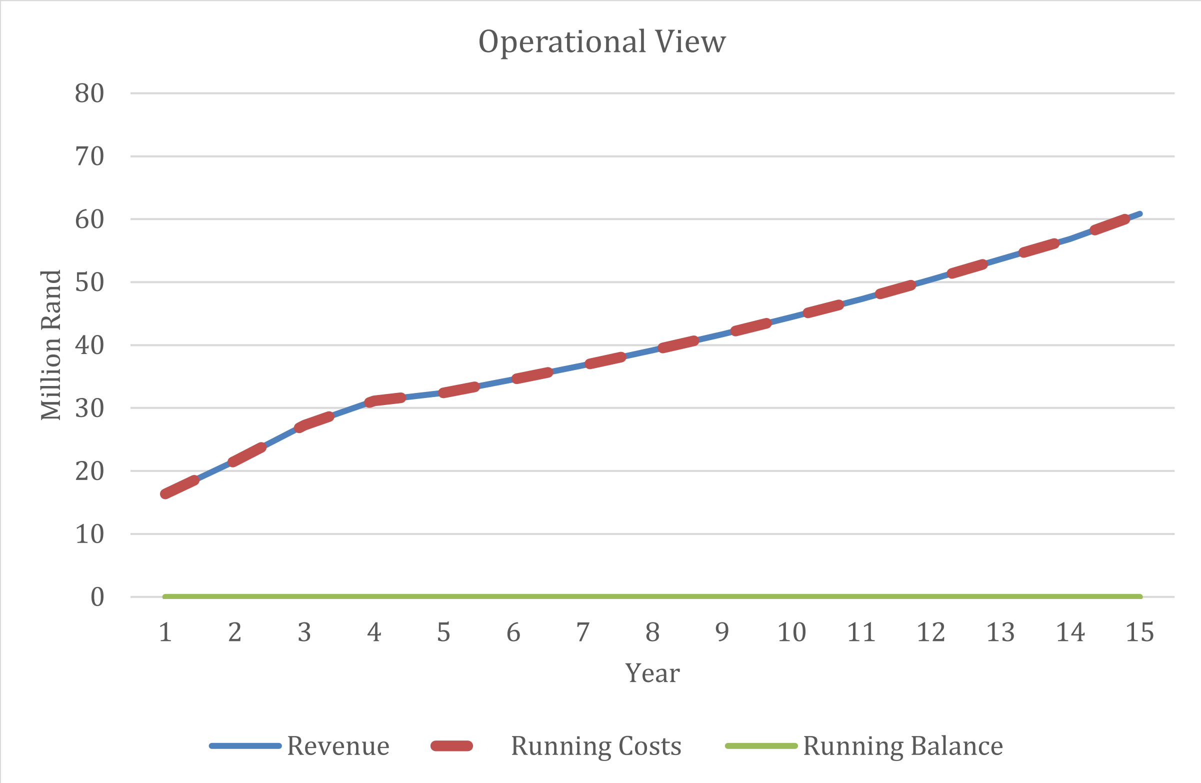


Figure 27 ***High-level budget: operational view***

BREAKEVEN AND CASH FLOW

The Operational View relates directly to the running costs and salaries the SAPRI will require for its operations. These are additionally related to the staggered inflation values given in the Financial Indicators section above. Running costs and salaries are not projected to peter off as the SAPRI is planned to remain operational through its lifespan, either as an infrastructure, or transitioning to an institute as proposed in Phase 3. The SAPRI, along with its Operational budget in particular, will be assessed between Year 4 and possibly before Year 7 to determine the feasibility of converting the SAPRI into a polar institute.

7.6.4 Capital Finance Type

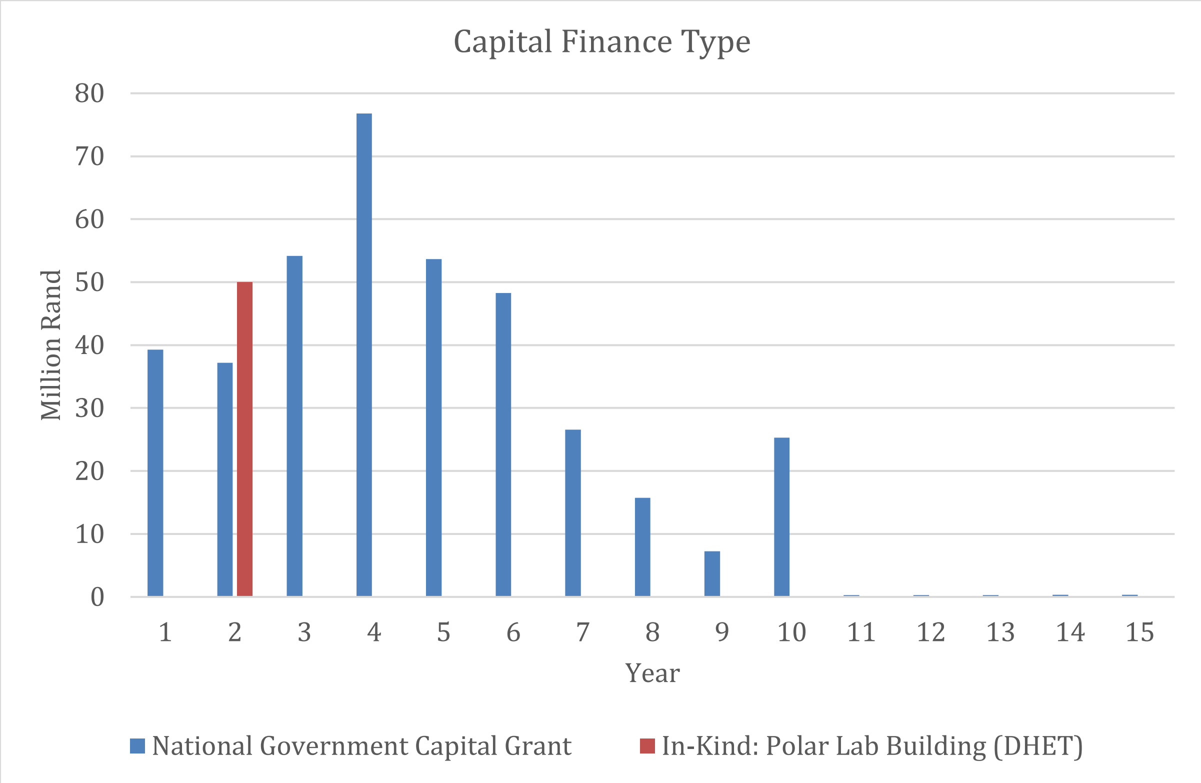


Figure 28 ***High-level budget: operational view***

DISCUSSION

The primary Capital Finance for the SAPRI will come from the National Government Capital Grant (DSI, through the SARIR programme). An in-kind contribution in Year 2, pending a submitted proposal to DHET, will be used to build the Polar Lab. Critically, these fundings do not include the infrastructure already procured and available through various IFs already for use within the SAPRI. As specified in the types of Capital Funders above, there exist opportunities, once the SAPRI has been established, to explore options for capital investment from other sources. These however are not guaranteed and are thus not included here.

7.6.5 Capital Finance Breakdown

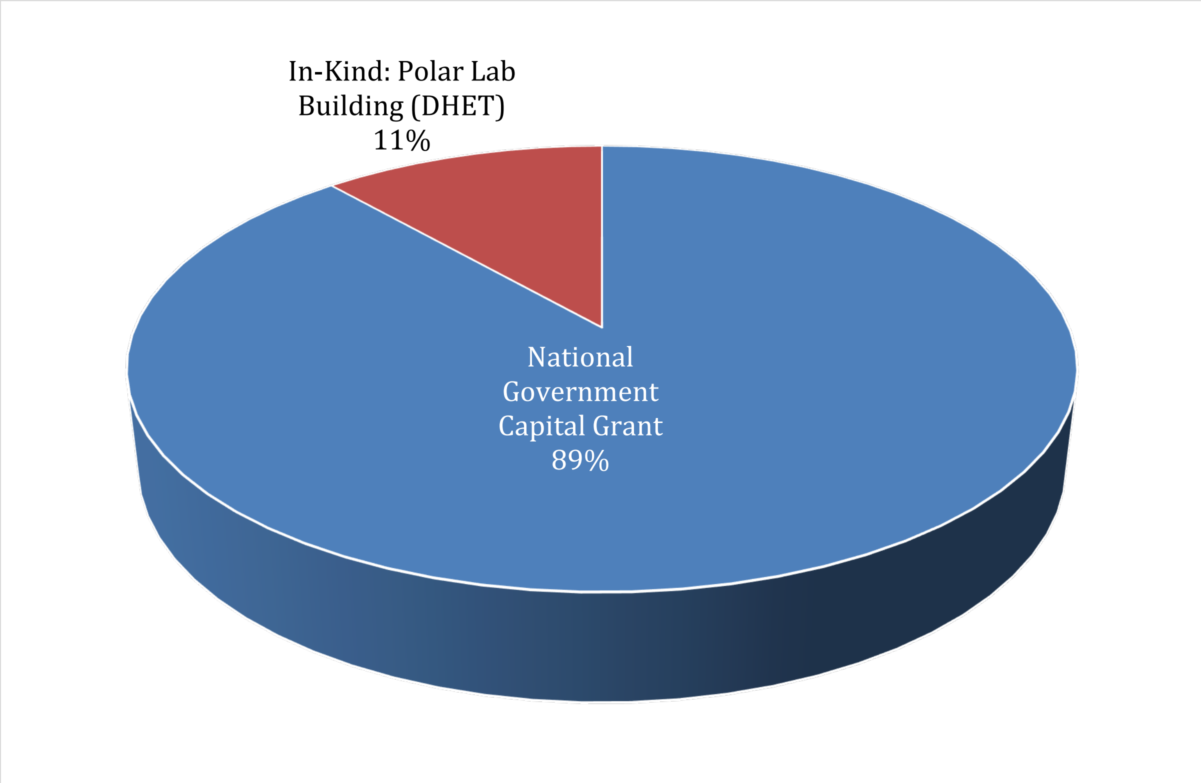


Figure 29 ***High-level budget: capital finance breakdown***

DISCUSSION

As per the Capital Finance Type section, only two sources of Capital funding for the SAPRI exist currently - the National Government Capital Grant (DSI, SARIR) with 89% of the total, and the in-kind building proposal for the Polar Lab (DHET) with 11% of the total. Notably, both sources of Capital Funding are from Governmental sources. Critically, this funding does not include the infrastructure already procured and available through various IFs already for use within the SAPRI. As specified in the types of Capital Funders above, there exist opportunities, once the SAPRI has been established, to explore options for capital investment from other sources. These however are not guaranteed and are thus not included here.

7.6.6 Running Revenue

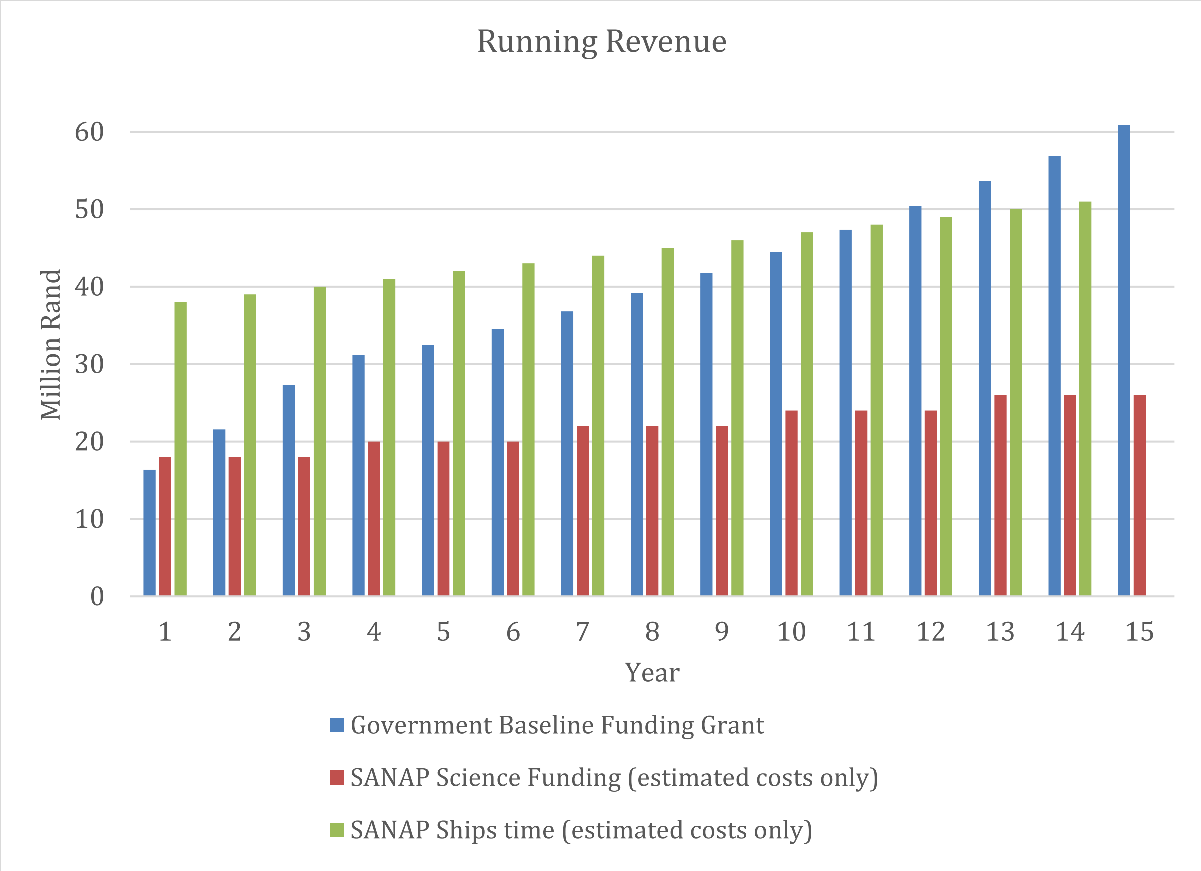


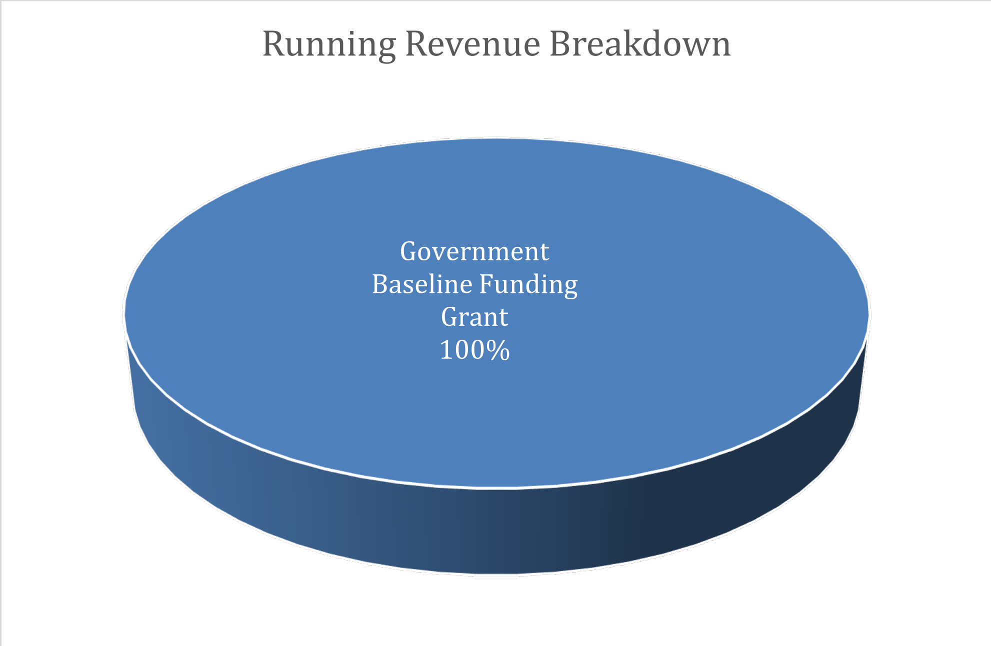
Figure 30 ***High-level budget: running revenue***

DISCUSSION

Currently, a number of long-term monitoring projects and science initiatives are supported through the NRF SANAP-Science funding described in Section 1.1. These include the SEAmester program and the Antarctic Legacy of South Africa (ALSA), which are proposed to be integrated within the SAPRI. With the establishment of SAPRI and the proposed redesign of SANAP-Science in coordination with DSI and NRF, these sources will be turned into additional running revenues. They will be redistributed and balanced, in order to maximise the portion dedicated to new science proposals (the SANAP call, see Section 3.2.3.4), and to minimise the infrastructural and running costs for maintaining the long-term observations. The 21% of the total would then be fully dedicated to the science funding, following the NRF-SAIAB ACEP model. Ship time will be used to fund research cruises based on the endorsed projects and to offset some of the running costs associated with the SEAmester and the other training projects dedicated to the transformation of the polar science community.

In blue, the Government Baseline Funding Grant required to operate the SAPRI over 15 years. The additional columns in dark red and green show the NRF SANAP-Science estimated yearly costs which will contribute to running costs and the ship time costs required for SEAmester training cruises and polar research year on year.

7.6.7 Running Revenue Breakdown



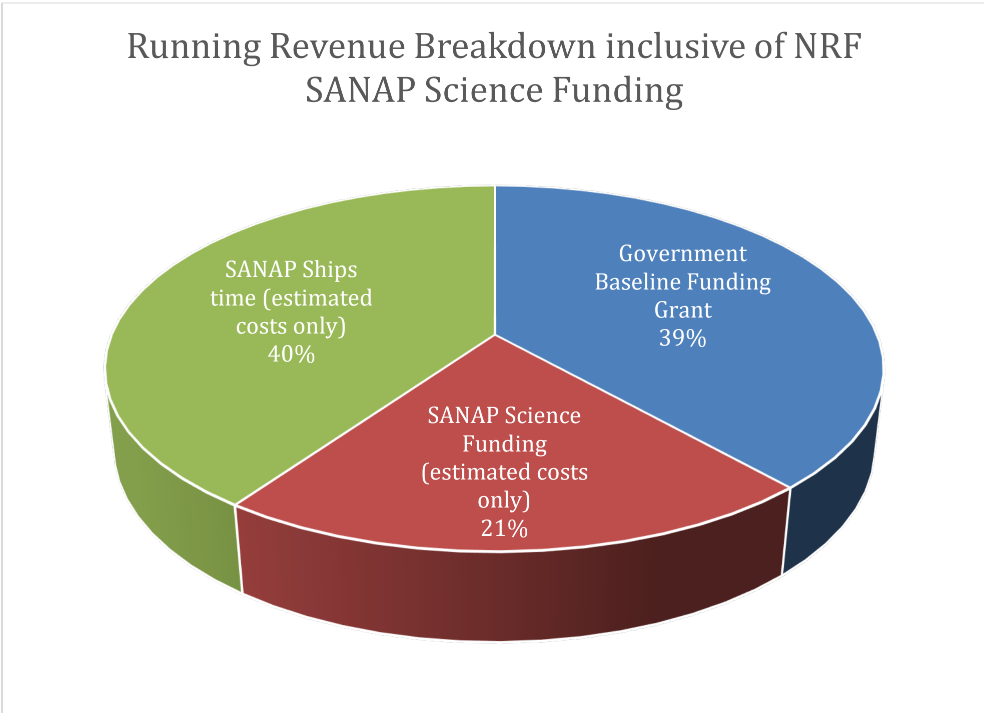


Figure 31 ***High-level budget: running revenue breakdown***

DISCUSSION

Two pie charts are shown for the Running Revenue Breakdown - exclusive and inclusive of the NRF SANAP Science and Ships costs funding which contributes in some degree currently to the long-term monitoring taking place. The NRF SANAP Science and Ships time costs are estimates only.

7.6.8 Capital Costs

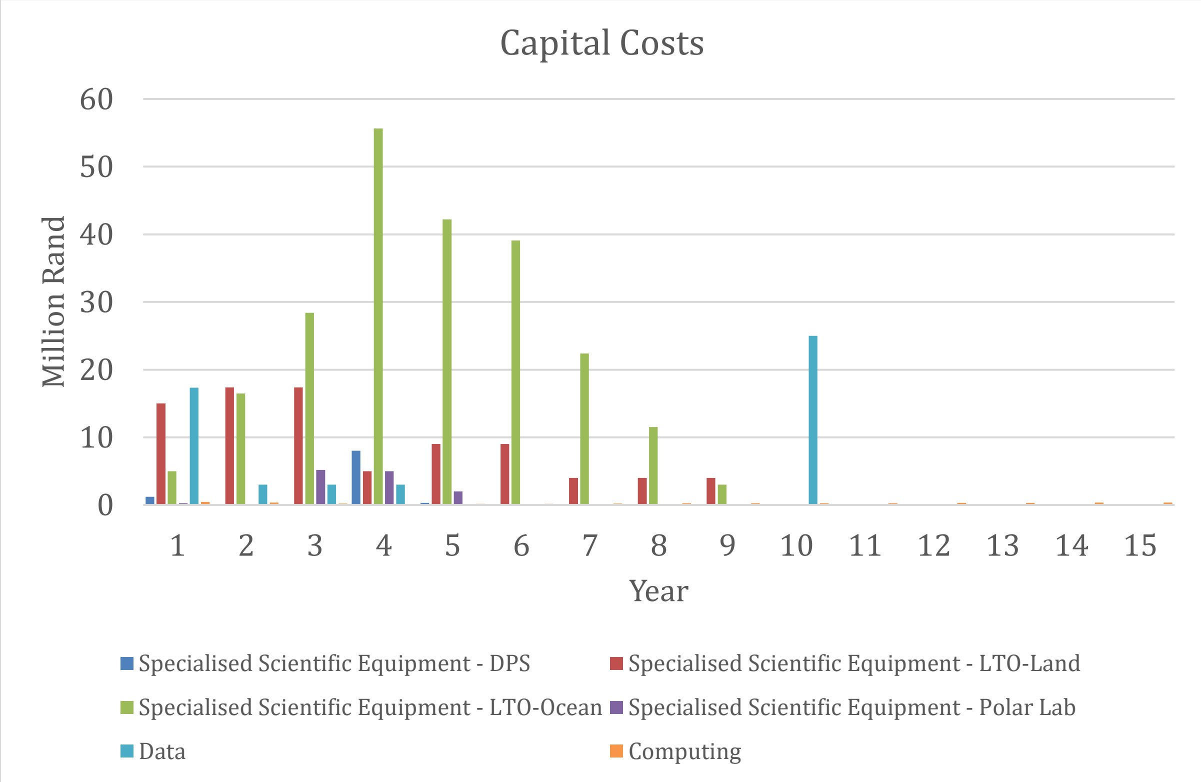


Figure 32 ***High-level budget: capital costs***

DISCUSSION

A breakdown of the Capital Costs associated with SAPRI are given. The costs are associated with Specialised Equipment for the various groupings (DPS, LTO-Land, LTO-Ocean and Polar Lab), the Data Centre and Computing for SAPRI personnel. These infrastructures and equipment are summarised in Appendix E.

7.6.9 Capital cost breakdown

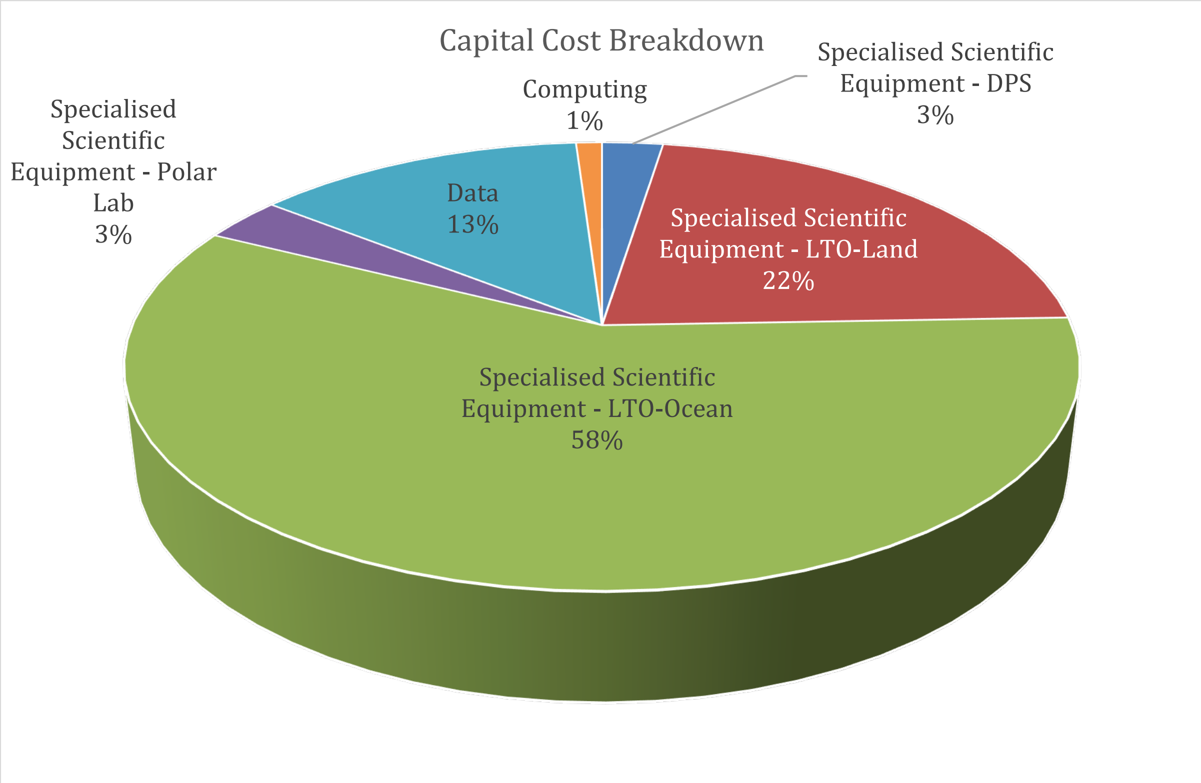


Figure 33 ***High-level budget: capital cost breakdown***

DISCUSSION

The breakdown of Capital Costs is given in the above pie chart. More than half the budget is for LTO-Ocean infrastructure (58%), with 22% for LTO-Land, 13% for the Data Centre, 3% each for the Polar Lab and other DPS infrastructure (other than Data Centre costs), with 1% remaining for general computing needs for SAPRI staff. These infrastructures and equipment are summarised in Appendix E.

7.6.10 Running Costs

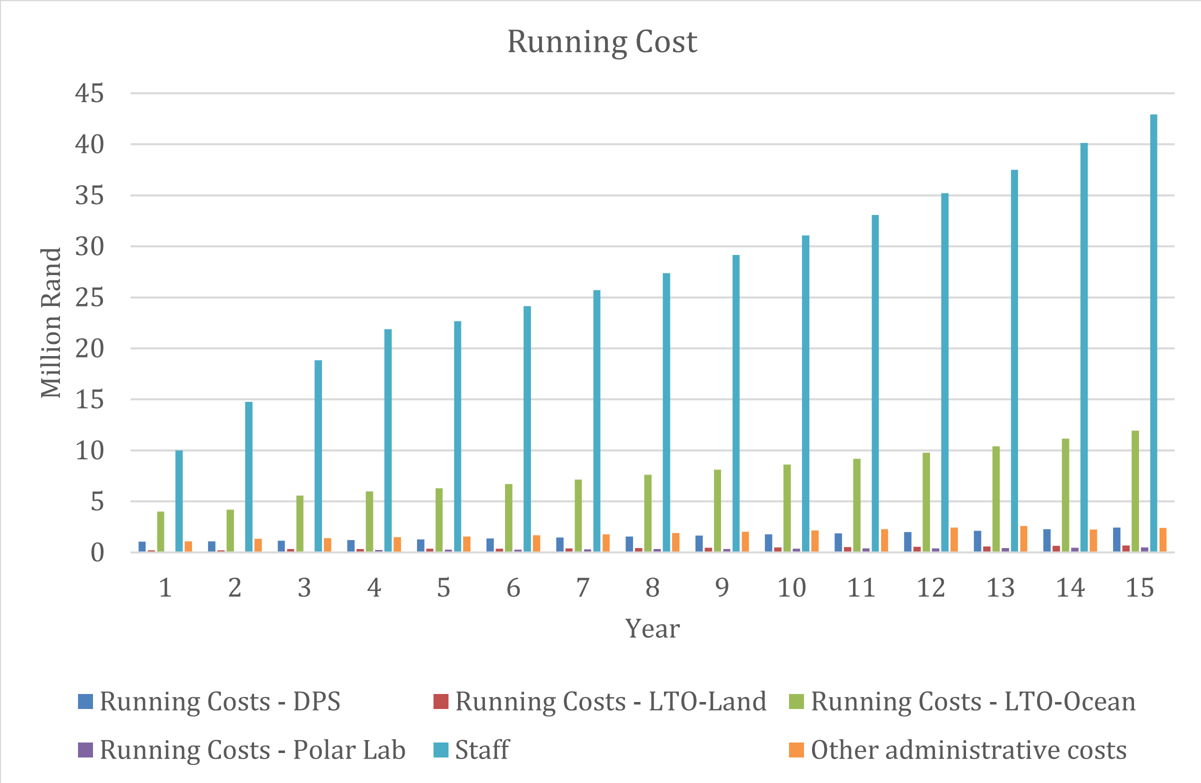


Figure 34 ***High-level budget: running cost***

DISCUSSION

Running costs for the SAPRI inclusive of staff salaries. Please refer to the Section 7.4 on the year-to-year inflation costs used to project the budget to 15 years.

7.6.11 Running costs breakdown

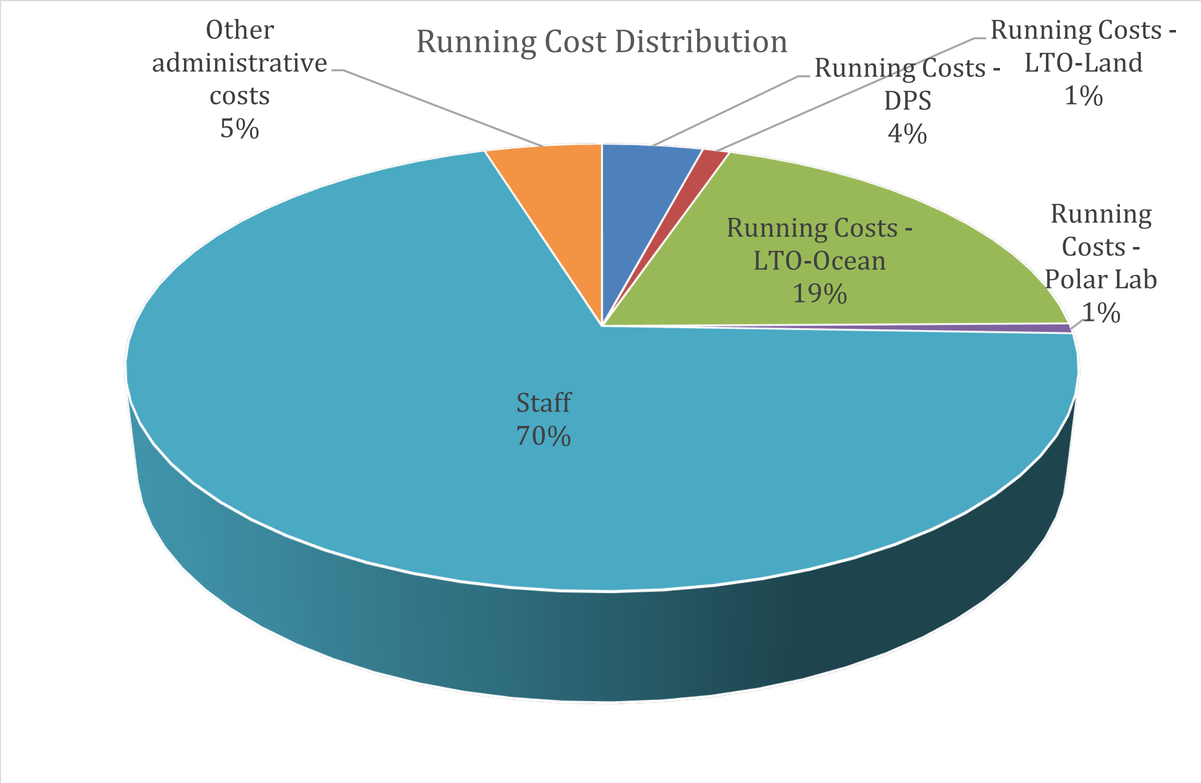


Figure 35 *High-level budget: running cost breakdown*

DISCUSSION

In terms of distribution of the Running Costs, staffing is the majority of the costs with 70% (divided further below). Followed by Consumables for LTO-Ocean (19%), Other administrative costs further detailed below (5%), Consumables for DPS (4%), Consumables for LTO-Land and Polar Lab at 1% each.

The staffing portion can be further divided as follows (totalled to 100% of the 70% Running Cost):

1. Management (SAPRI Manager and Coordinating Officers for each of Logistics, LTO-Land, LTO-Ocean, DPS and the Polar Lab) - **18 %**
2. Administration dedicated to SAPRI - **2 %**
3. LTO-Land (exclusive of Coordinating Officer) - **15 %**
4. LTO-Ocean (exclusive of Coordinating Officer) - **15 %**
5. DPS (exclusive of Coordinating Officer) - **42 %**
6. Polar Lab (exclusive of Coordinating Officer) - **5 %**

Other administrative costs which are available to the whole of SAPRI on an application basis are as follows:

1. A training budget. The SAPRI, once established, should investigate additional avenues of funding for training from various SETAs, Universities, the NRF and through the DEFF overwinterer training initiatives for each takeover.
2. Travel, organisation and administration for Advisory Panel meetings (where virtual meetings will not suffice)

3. Travel, meeting and administration for general use of the SAPRI Management and IFs for meetings (where virtual meetings will not suffice).

Given the complexity of this infrastructure, adaptive management will be applied during the various phases, and these percentages will be adjusted according to the needs, the national strategies and high-level advisory.

7.6.12 Government Contribution

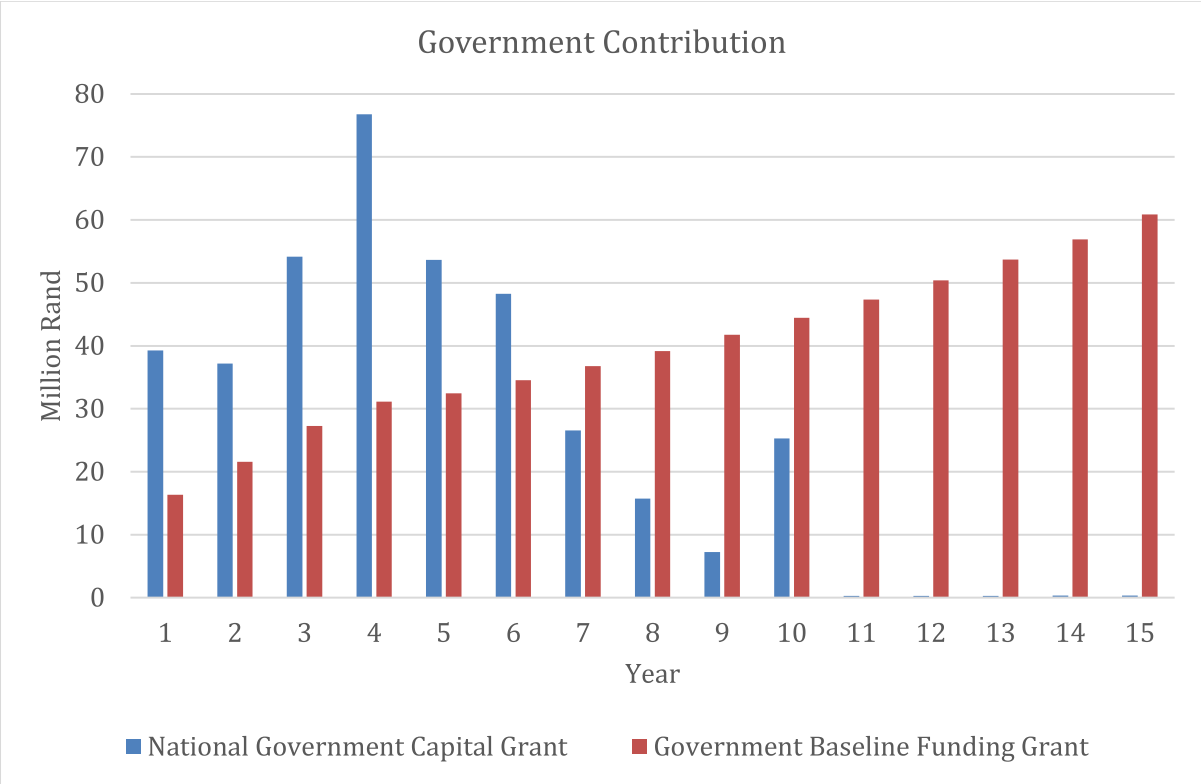


Figure 36 *High-level budget: government contribution*

DISCUSSION

The National Government Capital Grant peaks in Year 4 and Year 10 again, with only maintenance of computing infrastructure from Year 11 onwards. The Government Baseline Funding Grant increases over the years to peak in Year 15 when salaries and running costs should be at their highest. Please refer to Section 7.4 on how the year-on-year cost inflation for the latter was calculated.

7.7 SUMMARY OF THE FINANCIAL PLAN AND BUDGET

The SAPRI is requesting, for the full 15 years, a budget as follows:

Total Capital Costs:	R 385 712 497.00
Total Running Costs:	R 594 650 159.00
ICRR	R 116 022 937.00
Total Project Cost:	R 1 096 385 593.00

The Capital Costs budget is requested in full from the DSI: R 385 712 497.00. An amount of R 50 million in Year 2 has been requested from the DHET for the building of the Polar Lab on premises owned by consortium partner UCT. While no International Government Capital Grants or Industry / Multi-national Grants have been secured yet, the SAPRI represents an infrastructure of critical interest for the national obligations in the Antarctic Treaty System as well as the global climate and socio-economic challenges. Thus, once SAPRI has been established, these avenues of funding should be actively pursued to augment the work already being done by SAPRI by that stage.

The Operational (or Running) Costs budget is also requested in full from the DSI: R 594 650 159.00. It is noted that the NRF SANAP Science budget currently funds some of the operations included under the SAPRI initiative (e.g. long-term monitoring of seal and bird populations on Marion Island). As such, discussions between DSI and NRF on how these costs may be offset by the SANAP Science allocated budget must be held once the SAPRI is established. In addition, no ship-days related costs were included in the SAPRI as this is a current line item under the NRF SANAP budget. Ideally, the DSI-based SANAP-Science and SANAP vessel costs are to be included into the SAPRI as additional forms of funding to the project. This will allow adaptive management of that budget, which will favour all disciplines. For instance, improved budgets for flying personnel to Antarctica earlier in the season and extracting later as done by most Antarctic programmes, could accommodate for more scientists in Antarctic field work. This would facilitate a more productive use of limited infrastructure as well as any new infrastructure procured, also relieving pressure on ship berths that would allow additional operations at the base and science on the ship.

The budget detailed here and within the spreadsheet supplied is a true reflection of the numerous engagements with the science communities contributing to the SAPRI proposal. While comparisons may be made to previous iterations of this Research Infrastructure and the skewed weighting of costs towards ocean science initiatives, a comprehensive suite of integrated facilities representing many more research disciplines has been included within the SAPRI proposal. This funding should be considered complementary to the national line of funding managed by DEFF for the SANAP-Logistics component, which is ~ R 130 million annually (Section 1.1.2). In order to put this investment into an international perspective, the annual budget for the Australian Antarctic Division is currently around 100 million AUD per year (~R 1 billion), with about 60% of it dedicated to the provision of operations and services and the reminder to science projects. The British Antarctic Survey annual budget is GBP 50 million (also ~ R 1 billion), while the Alfred Wegener Institute has a total budget of EUR 85 million, to sustain both Arctic and Antarctic research and expeditions. A smaller institution such as the Norwegian Polar Institute has a total annual budget of NOK 250 million (~ R 435 million) with approximately 40% dedicated to Antarctic operations, of which 80% is dedicated to operations and infrastructure costs.

As a final consideration and being mindful of the vision to expand the SAPRI into a comprehensive polar institute during the planned life cycle, it is important to include in this period the motivation and planning for building a new ship. This infrastructure goes beyond the current SARIR scope. Ships' lives are typically 30 years – the SA Agulhas II was motivated through SA Agulhas I being 30 years old and no longer insurable. At the end of the SAPRI cycle delineated in this proposal, the polar community will be much more consolidated, so that a commission of inquiry into SANAP will not be necessary as when funding for the SA Agulhas II was sought. The SAPRI will be the natural place to develop the concept for such a novel polar infrastructure, especially given the knowledge that it will accumulate in polar maritime engineering over the next 15 years.

8 CONCLUSION

Given the very diverse nature of the polar science community, both in discipline and stakeholder, the process of finalising this proposal has taken many years and much stakeholder input. South African polar science has many strengths; excellence in scholarship, highly productive and high graduate throughput, and it is held in high regards internationally. However, it remains a fragmented and sub-critical community, with less than optimal less technology and skills resourcing for 21st century climate and ecosystems science, particularly with regards observations and the under-utilization of large-scale infrastructure such as ships and bases. It is in the latter that the South African Polar Research Infrastructure (SAPRI) aims to transform, consolidate and further strengthen South African polar science and in doing so, to strengthen international partnerships, the impact of its science and a new generation of scientists.

- The concept of SAPRI has broad support since its development is based on an integrative transdisciplinary design as a community-driven initiative in response to the opportunity created by the SARIR. As a national programme aligned to addressing national objectives and imperatives flowing from various government strategies, SAPRI enjoys the support of its two government sponsors, namely the DEFF and the DSI.

- The distinctive competency of SAPRI is that it will transform the way South Africa is approaching polar research by way of systemic innovation through the reorganisation of marine and Antarctic research infrastructure management. The SAPRI thus becomes a mechanism to deliver strong support to the polar research enterprise to precipitate in HCD, economies of scale and technological innovation while creating societal benefits. The Polar Lab is being considered for funding by the DHET and will form part of SAPRI's key infrastructure as an example of a new national research platform with inherent possibilities for innovation and service delivery in a previously unexplored field.

- Importantly, the new SAPRI leadership, inclusive of the staff, consortium partners and advisory structure, will have to both facilitate clockwork-like adherence to fixed standards as well as creativity and innovation in a complex and rapidly-changing multi-institutional and multi-disciplinary organisation. In addition to standard scientific parameters, a 5-year independent review will consider typical strategic performance metrics, e.g. mission-effectiveness, cost reduction, efficiency, accountability, best management practices, economies of scale and the application of technology.

- Moving away from the current silo-like nature of South African polar science to a more integrated approach will be a sure way of becoming a legitimate "Big Science" operation. If SAPRI is not established, the status quo of fragmented communications between the logistics and science endeavours will continue and South Africa runs the risk of establishing a mediocre scientific reputation with sub-optimal return on national investment in marine and Antarctic science resources. This will sustain national underachievement in the potential rates and quality of innovation, capacity development, publications and postgraduate output.

- DEFF and its internal SANAP will greatly benefit from SAPRI's enhanced contributions to both international agreements and treaties, as will SAPRI also improve delivery in terms of the respective and shared national government mandates held by DEFF and DSI (among others developing the knowledge economy, the data-driven economy, and the Blue Economy). These contributions will be guided by and reported to the DSI-DEFF Steering Committee.

- Finally, the establishment of SAPRI will provide South Africans with cost-effective and efficiently run shared research platforms to lead and participate in emerging fields of marine and Antarctic research. New research agendas will be opened up by a well-funded and managed SAPRI, South African students will be trained to achieve international competency, South Africa will retain ownership of the research deliverables, the profile of the South African marine and Antarctic research community will rapidly transform to reflect the demography of its population, South African citizens' appreciation of the Antarctic region and science will be further enhanced, better information for policy making will be generated and data curation will be significantly upgraded.

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APPENDIX A: LIST OF ACRONYMS

AARDVARK	Antarctic-Arctic Radiation-belt Dynamic Deposition VLF Atmospheric Research Konsortium
ADCP	Acoustic Doppler Current Profiler
ASCA	Agulhas System Climate Array
ATS	Antarctic Treaty System
ATNS	Air Traffic and Navigation Service
BIOGRIP	Biogeochemistry Research Infrastructure Platform
CBD	Convention for Biological Diversity
CPUT	Cape Peninsula University of Technology
CSIR	Council for Scientific and Industrial Research
CTD	Conductivity, Temperature and Depth instrument
DFFE	Department of Forestry, Fisheries and Environment
DIRCO	Department of International Relations and Cooperation
DPWI	Department of Public Works and Infrastructure
DSI	Department of Science and Innovation
DML	Dronning Maud Land
ECMWF	European Center for Medium-Range Weather Forecasts
EFTEON	Expanded Freshwater and Terrestrial Environmental Observation Network
EEZ	Exclusive Economic Zone
EV	Essential Variable
GAW	Global Atmospheric Watch
GCOS	Global Climate Observing System
GEBCO	General Bathymetric Charts of the Oceans
GeMaP	Geophysics and Mapping Platform
GOOS	Global Ocean Observing System
GTS	Global Telecommunication System
HF	High-frequency
ICAO	International Civil Aviation Organisation
ISES	International Space Environment Service
LTO	Long-Term Observations
MARIP	Marine Remote Imagery Platform
MARS	Marine and Antarctic Strategy
MBES	Multibeam Echosounders
MIZ	Marginal Ice Zone
NMU	Nelson Mandela University
NSI	National System of Innovation
NWP	Numerical Weather Prediction
NWU	North-West University
OBBiT	Offshore Benthic Biodiversity Team
PEI	Prince Edward Islands
PEIAC	Prince Edward Island Advisory Committee
RI	Research Infrastructure(s)
RSA	Republic of South Africa
RU	Rhodes University
SAIAB	South African Institute for Aquatic Biodiversity
SAEON	South African Environmental Observation Network
SAMBA	South Atlantic MOC Basin-scale Array
SANAE	South African National Antarctic Expedition
SANAP	South African National Antarctic Programme

SANDF	South African National Defense Force
SANSA	South African National Space Agency
SAPRI	South African Polar Research Institute
SAR	Synthetic Aperture Radar
SARIR	South African Research Infrastructure Roadmap
SAWS	South African Weather Service
SCAR	Scientific Committee on Antarctic Research
SG	Surgeon General
SLA	Service Level Agreement
SMCRI	Shallow Marine and Coastal Research Infrastructure
SMME	Small Medium and Micro Enterprises
SOCCO	Southern Ocean Carbon and Climate Observatory
SOCCOM	Southern Ocean Carbon and Climate Observations and Modeling project
SUN	Stellenbosch University
UAE	United Arab Emirates
UCT	University of Cape Town
UFH	University of Fort Hare
UJ	University of Johannesburg
UK	United Kingdom
UKZN	University of KwaZulu-Natal
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNISA	University of South Africa
UP	University of Pretoria
USA	United States of America
UWC	University of the Western Cape
WMO	World Meteorological Organisation
WWLLN	World-Wide Lightning Locating Network
XBT	eXpendable BathyThermograph

APPENDIX B: LONG-TERM OBSERVATIONS FUNDED THROUGH SANAP

These projects have been funded by SANAP (cycle 2018-20 included).

They are classified according to the following domain:

- sub-Antarctic islands
- Southern Ocean and sea ice
- atmosphere and geospace
- Antarctica

Sub-Antarctic islands

Domain	Programme	PI	Institution	Long-term obs	Year start	Year end	Existing facility	Int collaboration	Nat collaboration	Database
Marion Is LTER (terrestrial, ocean and atmosphere)	Marion Island Marine Mammal Programme (MIMMP)	de Bruyn	UP	elephant seal demography	1983	ongoing	Marion base and huts, ship	Australia, France, Argentina, USA	NMU, UCT	MIMMP in-house
				elephant seal foraging ecology	1999	ongoing	Marion base and huts, ship, isotope lab	Australia, Germany, UK, Norway, Denmark, USA	NMU, UCT, Stell	MIMMP in-house, Movebank, MEOP, Pangea, RAATD
				fur seal demography	1992	ongoing	Marion base and huts, ship	Australia,	NMU	MIMMP in-house
				fur seal foraging ecology	2003	ongoing	Marion base and huts, ship, isotope lab	Australia, UK, France, Norway	NMU, UCT, UniVen	MIMMP in-house, Movebank
				killer whale demography	2006	ongoing	Marion base and huts, ship	France, UK		MIMMP in-house
				killer whale foraging ecology	2008	ongoing	Marion base and huts, ship, isotope lab	USA, UK, France, Australia	NMU, UCT, DEA	MIMMP in-house, RAATD
Marion Is LTER (terrestrial, ocean and atmosphere)		Makhado	DEA							
Marion Is LTER (terrestrial, ocean and atmosphere)		Greve	UP	Vegetation composition	2018	ongoing	Marion base and huts, ship	Australia	UCT, RU	
Marion Is LTER (terrestrial, ocean and atmosphere)		le Roux	UP	*Azorella selago* (cushion plant) demography	2002	ongoing	Marion base and huts, ship	Australia, Switzerland		In-house
				Vascular plant composition (at fine scales)	2017	ongoing	Marion base and huts, ship	Finland		In-house
				Vascular plant distributional limits	1965 (Huntley); 2006 (le Roux & McGeoch)	ongoing	Marion base and huts, ship			In-house
Marion Is LTER (terrestrial, ocean and atmosphere)		Pistorius	NMU	Seabird (11 species) at-sea foraging distribution	2015	ongoing	Marion base and huts, ship	France, Australia, New Zealand	DEA, UCT, UP	In-house, seabird tracking databases
				Seabird (11 species) trophic ecology	2015	ongoing	Marion base and huts, ship	France, Australia	DEA, UCT, UP	In-house
Marion Is LTER (terrestrial, ocean and atmosphere)	Seabirds	Connan, Ryan	NMU, UCT	Mostly burrowing seabirds (trophic ecology, pollutants)	2018	ongoing	Marion base and huts, ship	France, UK, Japan, Italy		
		Connan, McQuaid	Rhodes	Trophic ecology (sooty, light-mantled, grey-headed albatrosses)	2009	2010	Marion base and huts, ship	France		In-house
Marion Is LTER (terrestrial, ocean and atmosphere)		Meiklejohn	UP	Surface and subsurface temperatures polar desert	1998	2001	Marion base and huts, ship	Sweden		In-house Rhodes and UFH
Marion Is LTER (terrestrial, ocean and atmosphere)		Meiklejohn	Rhodes	Surface and subsurface temperatures feldmark habitat	2007	2012	Marion base and huts, ship	Sweden	Rhodes, UFH	In-house Rhodes and UFH
Marion Is LTER (terrestrial, ocean and atmosphere)		Nel	UFH	Surface and subsurface temperatures polar desert	2014	2017	Marion base and huts, ship	Sweden	UP, Rhodes	In-house Rhodes and UFH
Marion Is LTER (terrestrial, ocean and atmosphere)		Nel	UFH	Micro-climate parameters and surface and subsurface temperatures Mesrug	2015	ongoing	Marion base and huts, ship		UNISA	In-house UFH and UNISA
Marion Is LTER (terrestrial, ocean and atmosphere)		Nel	UFH	Surface and subsurface temperatures mires	2016	ongoing	Marion base and huts, ship		UNISA	In-house UFH and UNISA
Marion Is LTER (terrestrial, ocean and atmosphere)		Nel	UFH	Micro-climatic parameters (numerous sites around the island)	2015	ongoing	Marion base and huts, ship		UP, UNISA	In-house UFH and UNISA
Marion Is LTER (terrestrial, ocean and atmosphere)		Jansen van Vuuren	UJ	Genetic diversity, but changes here are typically over hundreds to thousands of years	2004	ongoing for different species	Marion base and huts, ship	Australia,	UP, Unisa	In-house UJ as well as public repositories such as GenBank
Marion Is LTER (terrestrial, ocean and atmosphere)	Seabirds	Ryan	UCT	Wandering Albatross demography	1983	ongoing	Marion base and huts, ship	UK, France	DEA, NMU	FitzPatrick in-house
	Seabirds	Ryan	UCT	Northern Giant Petrel demography	1983	ongoing	Marion base and huts, ship	UK, France	DEA, NMU	FitzPatrick in-house
	Seabirds	Ryan	UCT	Grey-headed Albatross demography	1997	ongoing	Marion base and huts, ship	UK, USA	DEA, NMU	FitzPatrick in-house
	Seabirds	Ryan	UCT	Sooty Albatross demography	2014	ongoing	Marion base and huts, ship	UK, France	DEA, NMU	FitzPatrick in-house
	Seabirds	Ryan	UCT	Lightmantled Albatross demography	2014	ongoing	Marion base and huts, ship	UK, France	DEA, NMU	FitzPatrick in-house
	Seabirds	Ryan	UCT	White-chinned Petrel demography	1997	2002	Marion base and huts, ship	UK, France	DEA, NMU	FitzPatrick in-house
	Seabirds	Ryan	UCT	Wandering Albatross foraging	1997	ongoing	Marion base and huts, ship	UK, France	DEA, NMU	FitzPatrick in-house, Seabird Tracking Database
	Seabirds	Ryan	UCT	Other seabird foraging (10 species, but mostly one-off investigations)	2002	ongoing	Marion base and huts, ship	UK, France, Spain	DEA, NMU	FitzPatrick in-house, Seabird Tracking Database

Sub-Antarctic islands

Domain	Programme	PI	Institution	Long-term obs	Year start	Year end	Existing facility	Int collaboration	Nat collaboration	Database
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown (via Greve)	Monash Univ (via UP)	Microhabitat temperature, soil temperature (ibutton) loggers	2002	2013	Marion base and huts, ship	Australia		Raw data: Monash University, in-house; U. Stellenbosch Centre for Invasion Biology Data repository; Procesed data: Leihy, R. I., Duffy, G. A., Nortje, E. & Chown, S. L. Figshare. http://dx.doi. org/10. 4225/03/5a3999b9e3215 (2018).
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown (via Greve)	Monash Univ (via UP)	Surface temperature, Satellite Observations	2001	2015	Marion base and huts, ship	Australia, USA		Raw data: MODIS. Processed:Leihy, R. I., Duffy, G. A., Nortje, E. & Chown, S. L. Figshare. http://dx.doi.org/10. 4225/03/5a3999b9e3215 (2018).
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown, Treasure (via Greve)	Stellenbosch/Monash/Pretoria	Weevil body size	1986	2010	Marion base and huts, ship	Australia		Raw data: U Stellenbosch Centre for Invasion Biology Data repository; SL Chown; AM Treasure; Treasure, A.M. & Chown, S.L. 2014. Antagonistic effects of biological invasion and temperature change on body size of island ectotherms. Diversity and Distributions 20, 202-213.
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown, Treasure (via Greve)	Stellenbosch/Monash/Pretoria	Springtail abundance	2008	2009	Marion base and huts, ship	Australia		Raw data: U Stellenbosch Centre for Invasion Biology Data repository; SL Chown; AM Treasure; Treasure, A.M. & Chown, S.L. 2013. Contingent absences account for range limits but not the local abundance structure of an invasive springtail. Ecography 36, 146-156; Treasure, A.M., le Roux, P.C., Mashau, M.H. & Chown, S.L. Species-energy relationships of indigenous and invasive species may arise in different ways – a demonstration using springtails. Scientific Reports, in review.
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown, McClelland (via Greve)	Stellenbosch/Monash/Pretoria	Soil Invertebrate abundance and biomass, Commenced with Alan Burger's surveys	1976	2007	Marion base and huts, ship	Australia		Raw data: U Stellenbosch Centre for Invasion Biology Data repository; SL Chown; GTW McClelland, McClelland, G.T.W., Altwegg, R., van Aarde, R.J., Ferreira, S., Burger, A.E. & Chown, S. L. 2018. Climate change leads to increasing population density and impacts of a key island invader. Ecological Applications 28, 212-224.
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown, McClelland (via Greve)	Stellenbosch/Monash/Pretoria	Mouse abundance, size, demographics	1991	2011	Marion base and huts, ship	Australia		Raw data: U Stellenbosch Centre for Invasion Biology Data repository; SL Chown; GTW McClelland, McClelland, G.T.W., Altwegg, R., van Aarde, R.J., Ferreira, S., Burger, A.E. & Chown, S. L. 2018. Climate change leads to increasing population density and impacts of a key island invader. Ecological Applications 28, 212-224.
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown, McClelland (via Greve)	Stellenbosch/Monash/Pretoria	Black-faced (Lesser) Sheathbill demography	1974	2011	Marion base and huts, ship	Australia		Raw data: U Stellenbosch Centre for Invasion Biology Data repository; GTW McClelland,
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown, Terauds (via Greve)	Monash Univ (via UP)	Rephotography from Brian Huntley's 1965/66 images	1965	2010	Marion base and huts, ship	Australia		Raw data: Monash University (and now UP)
Marion Is LTER (terrestrial, ocean and atmosphere)	Invertebrates	Chown	Monash University	Invertebrate genomics and physiology, multiple data sets	1992	2016	Marion base and huts, ship	Australia, France, New Zealand, UK, Switzerland, Norway		Raw data: Monash University, in-house SL Chown; Some archived by U. Stellenbosch CIB Data repository (esp. T. Haupt thesis data)
Gough Is	Seabirds	Ryan	UCT	Tristan Albatross demography	1983	ongoing	Gough base, ship	UK		FitzPatrick in-house, RSPB
	Seabirds	Ryan	UCT	Atlantic Yellow-nosed Albatross demography	1983	ongoing	Gough base, ship	UK		FitzPatrick in-house, RSPB
	Seabirds	Ryan	UCT	Sooty Albatross demography	2014	ongoing	Gough base, ship	UK		FitzPatrick in-house, RSPB
	Seabirds	Ryan	UCT	Southern Giant Petrel demography	2009	ongoing	Gough base, ship	UK		FitzPatrick in-house, RSPB
Inaccessible Is	Seabirds	Ryan	UCT	plastic ingestion by petrels	1987	ongoing	Inaccessible hut, ship	UK	NMU	FitzPatrick in-house

Sub-Antarctic islands

Domain	Programme	PI	Institution	Long-term obs	Year start	Year end	Existing facility	Int collaboration	Nat collaboration	Database
	Seabirds	Ryan	UCT	beach debris	1984	ongoing	Inaccessible hut, ship	UK	NMU	FitzPatrick in-house
	Seabirds	Ryan	UCT	alien species distributions	1989	ongoing	Inaccessible hut, ship	UK		FitzPatrick in-house
	Seabirds	Ryan	UCT	Nesospiza bunting morphology	1989	ongoing	Inaccessible hut, ship	UK		FitzPatrick in-house
Marion LTER	Oceanography	Ansorge and Lamont	UCT and DEA	Moorings	2014	ongoing	Two moorings between Marion and PEI	-	DEA	DEA
Marion Isl LTER	Vegetation	smith, gremmen	U.S.	Vegetation community change on eastern coastal plain	1971	ongoing	Marion Isand base	Netherlands		Valdon Smith, Niek Gremmen,. Data Analyse Ecologie

Southern Ocean and sea ice

Domain	Programme	PI	Institution	Long-term obs	Year start	Year end	Existing facility	Desired Facility	Int collaboration	Nat collaboration	Database
Southern Ocean and sea ice	SOCCO	Monteiro, Nicholson, Mtshali, Thomalla	CSIR	carbon	2008	ongoing	Ship, CO2 lab		EU, USA, France	UCT, SU, SAWS	SOCCO server, Rosebank
Southern Ocean and sea ice				chlorophyll	2008	ongoing	Ship		EU, USA, France	UCT, SU, SAWS	SOCCO server, Rosebank
Southern Ocean and sea ice				nutrients	2008	ongoing	Ship, BGC lab		EU, USA, France	UCT, SU, SAWS	SOCCO server, Rosebank
Southern Ocean and sea ice				carbon	2011	ongoing	Glider, robotics lab, CO2 lab		EU, USA, France	UCT, SU, SAWS	SOCCO server, Rosebank
Southern Ocean and sea ice				chlorophyll and bio-optics	2011	ongoing	Glider, robotics lab, bio-optics lab		EU, USA, France	UCT, SU, SAWS	SOCCO server, Rosebank
Southern Ocean and sea ice				temperature	2011	ongoing	Glider, robotics lab		EU, USA, France	UCT, SU, SAWS	SOCCO server, Rosebank
Southern Ocean and sea ice				salinity	2011	ongoing	Glider, robotics lab		EU, USA, France	UCT, SU, SAWS	SOCCO server, Rosebank
Southern Ocean and sea ice				oxygen	2011	ongoing	Glider, robotics lab		EU, USA, France	UCT, SU, SAWS	SOCCO server, Rosebank
Southern Ocean and sea ice	Marginal Ice Zone	Vichi, Skatulla, Rampai, MacHutchon, Mishra	UCT	sea-ice concentration	2016	ongoing	Ship, sea-ice cameras		Australia	SAWS, SU	PANGEA and UCT private
Southern Ocean and sea ice				sea-ice drift	2017	ongoing	Ship, buoys		Australia, UAE	SAWS	UCT private
Southern Ocean and sea ice				sea-ice waves	2017	ongoing	Ship, buoys		Australia, UAE	SAWS	UCT private
Southern Ocean and sea ice				sea-ice floe size	2017	ongoing	Ship, sea-ice cameras		Australia		UCT private
Southern Ocean and sea ice				sea-ice physics (including material props)	2016	ongoing	Ship, buoys, polar lab		Australia, Germany		UCT private
Southern Ocean and sea ice	TracEx/GEOTRACES	Roychoudhury	SU	Bioactive trace metals	2015	ongoing	Ship, container lab, clean laboratory, ICP-MS, CTD	Dedicated extended ship time, MC-ICPMS, Technician, Sediment corer	France, Germany, Norway		GEOTRACES
Southern Ocean and sea ice				Iron	2008	ongoing	Ship, container lab, clean laboratory, ICP-MS, CTD, FIA	Dedicated extended ship time, MC-ICPMS	France, Norway	CSIR	GEOTRACES
Southern Ocean and sea ice				Al and REEs	2015	ongoing	Ship, container lab, clean laboratory, ICP-MS, CTD, FIA	MC-ICPMS			GEOTRACES
Southern Ocean and sea ice				Nano-particles	2012	ongoing	Ship, McLane Pumps, HVAC- particle collector		USA, Australia		PRIVATE
Southern Ocean and sea ice				Isotopes (oxygen, hydrogen, carbon, Nitrogen)	2017	ongoing	Ship, Picarro Isotope analyzer	Technician	Norway, USA	UCT	GEOTRACES
Southern Ocean and sea ice				Sea-ice trace metal biogeochemistry	2017	ongoing	Ship, clean laboratory, ICP-MS, CTD	Trace-clean ice corer, Ice core repository	Norway, Germany, Australia	UCT	PRIVATE
Southern Ocean and sea ice				Ocean acidification	2018	ongoing	Ship, BGC lab	Extended ship time in regions beyond the existing lines	Norway	SAWS, CSIR	PRIVATE
Southern Ocean and sea ice				Whales and Ocean Biogeochemistry	2019	ongoing	Ship, BGC lab, Clean laboratory and container, CTD	Extended ship time in regions beyond the existing lines	Australia	UCT, CPUT	PRIVATE
Southern Ocean and sea ice				Anthropogenic pollutants and their isotopes	2018	ongoing	Ship, BGC lab, Clean laboratory and container, CTD	MC-ICPMS, Technician	Switzerland, Netherlands		PRIVATE
Southern Ocean and sea ice	TracEx/GEOTRACES	Fietz	SU	Dust	2015	ongoing	Ship, dust sampler, CTD, BGC, clean laboratory, ICP-MS, SEM, QEMSCAN	buoys, sediment corer, trace-clean ice corer, extended ship time in regions beyond GHL		UCT	PRIVATE
Southern Ocean and sea ice	TracEx/GEOTRACES	Fietz/Roy	SU	Bioactive trace metals	2015	ongoing	Ship, container lab, clean laboratory, ICP-MS, CTD	autonomous observing systems, e.g. in situ chemical analyzers, electrochemical sensors, passive preconcentration samplers			GEOTRACES
Southern Ocean and sea ice	TracEx	Fietz	SU	Macronutrients (N, P, Si, bSi)	2015	ongoing	Ship, container lab, clean laboratory, CTD, spectrophotometer	autoanalyser		UCT	PRIVATE
Southern Ocean and sea ice	TracEx	Fietz	SU	Phytoplankton community composition (pigments and genomics)	2015	ongoing	Ship, BGC, CTD	HPLC	Norway	UCT, CPUT	PRIVATE
Southern Ocean and sea ice	TracEx/BioGEOT	Fietz/Lloyd/Makhalanyane		Prokaryotic community composition (genomics)	2018	ongoing	Ship, BGC, CTD			UP	PRIVATE, UP
Southern Ocean and sea ice	TracEx/BioGEOT	Fietz		Community composition changes driven by external forces	2015	ongoing	Ship, BGC, CTD, incubators, polar lab	HPLC		UCT	PRIVATE
Southern Ocean and sea ice		Bekker	SU								
Southern Ocean and sea ice	Atmospheric Biogeochemistry	Altieri	UCT	Surface ocean ammonium, chl, PP, aerosol composition	2017	ongoing	Ship, underway		USA	SAWS, CSIR	Private
Southern Ocean and sea ice		Fawcett	UCT								
Southern Ocean and sea ice	SAMOC	Ansorge and Lamont	UCT	Ocean monitoring of key physical variables	2012	ongoing	Ship and Moorings	Ship	France, USA, ARgentina, Brazil, UK	UCT DEA	DEA, IFREMER, NOAA
Southern Ocean and sea ice	Climate variability and change	Reason	UCT	Winds, MSLP, GPH, temperatures, rainfall, heat fluxes	2018	ongoing	Modelling		UK, Portugal, Germany		
Southern Ocean and sea ice	Microbiomics	Makhalanyane	UP	Microbial community data	2015	ongoing	Ship, spectrophotometer, CTD,				CMEG Server/Pretoria
Southern Ocean and sea ice				Soil nutrients	2015	ongoing	Ship, spectrophotometer, CTD,				

Atmosphere and Geospace

Domain	Programme	PI	Institution	Long-term obs	Year start	Year end	Existing facility	Int collaboration	Nat collaboration	Database
Lower atmosphere and Geospace		Sievers	KZN							
Lower atmosphere and Geospace	Space Weather HF radar	Kosch	SANSA	Polar ionospheric convection	1997	Ongoing	HF radar	USA, UK, Japan, Canada, Norway Australia, Italy, France, China	UKZN	SANDIMS in-house
Lower atmosphere and Geospace	Polar Space Weather Studies	Lotz	SANSA	Geomagnetic field	1997	Ongoing	Magnetometer su	Germany	NWU	SANDIMS (SANSA in-house database)
Lower atmosphere and Geospace	Polar Space Weather Studies	Lotz	SANSA	GPS for ionospheric dynamics	2006	Ongoing	GPS antenna sui	Italy, Brazil, Fran	SARAO	SANDIMS, DemoGrape, DORIS
Lower atmosphere and Geospace	Polar Space Weather Studies	Lotz	SANSA	Very low frequency (VLF) electro	2008	Ongoing	VLF antenna suit	Hungary, USA, U	UCT, UKZN	SANDIMS, WWLLN, AWDAnet
Lower atmosphere and Geospace	Polar Space Weather Studies	Lotz	SANSA	VHF wave absorption in the iono	1997	Ongoing	Riometer (SANA	Japan	NWU	SANDIMS
Lower atmosphere and Geospace	Polar Space Weather Studies	Lotz	SANSA	Ozone radiometer	2018	Ongoing	Ozone radiomete	Japan		SANDIMS
Lower atmosphere and Geospace	Polar Space Weather Studies	Lotz / Strauss	SANSA / NWU	High energy neutron count	1964	Ongoing	Neutron Monitor	Germany	NWU	NWU, SANDIMS

Antarctica

Domain	Programme	PI	Institution	Long-term obs	Year start	Year end	Existing facility	Desired Facility	Int collaboration	Nat collaboration	Database
Antarctica and cryosphere	Gondwana Amalgamation and Correlation Research Project GAACRP	Grantham	UJ	No long term observation procedures as Geology is fundamentally a historical science largely based on the axiom The Past is the Key to the Present attributed to Charles Lyell (viewed as the father of geology) and "You have to know the past to understand the present." Carl Sagan	2012	ongoing	Utilises logistical support to access field areas using SHIP, DROMLAN, NPI, SANAE, TROLL and potentially Maitri/Novolarevskaya, Princess Elizabeth, Syowa.	Containerised field logistics equipment to facilitate field operations along Dronning Maud Land Coast combined with formal collaboration agreements with AWI, NPI, Indian program, Belgian and Japanese programs.	NIPR Japan, ANU Canberra, SCAR GEOMAP, CGG geophysics	UCT	GIS geological map database produced in 1996 within SANAP and constantly updated with new data collected on rock age and chemistry.
Antarctica and cryosphere		Makhalanyane, Cowan	UP	Microbial community data	2015	ongoing	Ship, NZ base, spectrophotometer,		NZ, USA, Canada, UK, Belgium,		
Antarctica and cryosphere				Soil nutrients	2015	ongoing	Ship, spectrophotometer,				
Antarctica and cryosphere	Landscape Processes in Antarctic Ecosystems	Meiklejohn	RU	Ground temperatures, air temperatures & soil moisture, plus landform inventory	2007	2017	SANAE & Troll		ANTPAS (Antarctic Permafrost and Soils, SCAR and IPA)	FH, UP	RU in-house and GTPN-P (Global Terrestrial Permafrost Network)
Antarctica and cryosphere		Matcher	RU	Microbial community data	2013	2017	SANAE & Troll				

APPENDIX C: ESSENTIAL VARIABLES

Ocean Physics Essential Variables (surface and subsurface):

- Sea surface temperature
- Sea surface salinity
- Sea surface height
- Sea state
- Sea ice
- Ocean surface stress
- Ocean colour
- Surface currents
- Surface heat flux
- Subsurface currents
- Subsurface temperature
- Subsurface salinity
- Ocean sound

Ocean Biogeochemistry Essential Variables:

- Oxygen
- Dissolved organic carbon
- Dissolved Inorganic carbon
- Nitrous oxide
- Nutrients
- Micronutrients
- Particulate organic matter
- Stable carbon and nitrogen isotopes
- Transient tracers and their isotopes

Biology and Ecosystems within the ocean Essential Variables:

- Fish abundance and distribution
- Bird and mammal demography, abundance and distribution
- Phytoplankton biomass and diversity
- Zooplankton biomass and diversity
- Hard coral cover and composition
- Microbe biomass and diversity
- Invertebrate abundance and distribution

Terrestrial Essential Variables (lithosphere, hydrosphere, cryosphere and biosphere):

- Groundwater
- Glaciers
- Ice sheets and ice shelves
- Permafrost
- Snow
- Above-ground biomass

- Albedo
- Evaporation from land
- Fraction of absorbed photosynthetically active radiation
- Land cover
- Land surface temperature
- Leaf area index
- Soil carbon
- Soil moisture
- Rocks

Atmospheric Essential Variables (Surface, Upper-air, Composition)

- Precipitation
- Pressure
- Radiation budget
- Temperature
- Water vapour
- Wind speed and direction
- Earth radiation budget
- Upper-air temperature
- Upper-air water vapour
- Upper-air wind speed and direction
- Aerosols
- Carbon dioxide, methane and other greenhouse gases
- Clouds
- Ozone
- Precursor for aerosols and ozone

Space Weather Essential Variables:

- Geomagnetic field
- Neutron count
- Very low frequency signal strength and phase
- Ionospheric total electron count
- Ionospheric convection
- Ionospheric absorption
- Ionospheric scintillation

APPENDIX D: DATA MANAGEMENT PLAN

Data management, data products and data communication

A preliminary SAPRI Data Management Plan

1. INTRODUCTION

The SAEON Data Centre will be expanded to include the SAPRI Data Centre (SAPRI DC) and will host the designated National Antarctic Data Centre (NADC) for South Africa. A representative from the SAPRI DC will sit on the Scientific Commission on Antarctic Research - Standing Committee on Antarctic Data Management (SCAR-SCADM). As South Africa's National Antarctic Data Centre, the SAPRI DC will observe the requirements of SCADM for Antarctic data management, specifically with regards to inclusion of metadata in the Antarctic Master Directory. As a member of SCADM, the SAPRI DC will also be able to receive expert guidance and advice from other Antarctic data centres.

1.1. UNIQUENESS AND NOVELTY

The SAEON Data Centre has an existing capability to establish best practice open data management solutions that are enabled by state-of-the-art technology. Technology transfer of existing know-how will be key in the establishment for SAPRI data. This will be complemented by SAEON's capability to innovate and develop novel solutions where required for SAPRI. The technology transfer and innovation process will be driven by the following aspects

- Infrastructure (hardware and software) to handle the myriad of data sources (in-situ, remote sensed, model generated, etc)
- Harmonising and characterising data from the above sources into specific data families (spatial, multi-dimensional, time-series, unstructured/object stores)
- Applying and adapting metadata standards to all data sources
- Applying or implementing interoperable or standards-based metadata and data access services for all data sources
- Applying or implementing data visualisation mechanisms and applications for all data sources

1.2. EXCELLENCE

The SAPRI Data Centre will maintain current best practice in relation to its repository management functions and related systems, and best international practises will be adopted for data management. The SAPRI Data Centre will provide integrated and secure access to the RIs data by applying the Open Archival Information System (OAIS) model and following the principles of FAIR (Findable, Accessible, Interoperable, and Reusable).

Much of the data generated by the existing research activities shown in the proposal have been handled directly by the principal investigators generating the data. SANAP, unlike the other international Antarctic programs, does not have a unified repository with a dedicated Data Management Plan (DMP). The collective return on investment and the international exposure as an Antarctic country are thus diminished. All SANAP-generated data need to be made publicly available according to the SARIR and NRF principles, but there is no dedicated national effort. Antarctic research data generated in South Africa are therefore either kept internally or linked to publications, or distributed through international repositories, depending on the resources of each individual research team.

SAPRI will homogenise these data streams, thus reducing the strain on research teams and ensuring proper timeliness and metadata generation that aligns with international repositories. Full details on how existing facilities and expertise at SAEON will be integrated in this IF to support this operation are given in Chapter 4. A non-exhaustive list of the international repositories that will be included in the SAPRI DMP are given in Table D1.

For all these cases, the SAPRI Data Centre can help Project Investigators (PIs) to create specific DMPs to ensure a seamless workflow to translate the data. For example, the Council for Geosciences have the capacity to update and publish geological and geophysical maps and are also the final custodian of rock samples collected in SANAP. In addition, given the lack of international standards in the case of sea ice observations, SAPRI has the opportunity to become a leader in the definition of essential metadata for ice-related variables.

Table D1*. List of the international repositories accessed by SANAP science programs and that will be integrated in the DPO IF.*

IF and theme	Description of repositories
LTO-Land: marine mammal research	The multi-national Southern Oceans Research Partnership[39] (IWC-SORP, part of the International Whaling Commission), Retrospective Analysis of Antarctic Tracking Data (RAATD, a SCAR project), and Marine Mammals Exploring the Oceans Pole to Pole[40] (MEOP) consortiums provide platforms for combined data for large scale (spatial and temporal) research efforts. Access to the PANGAEA[41] data management concept and MOVEBANK allows the reconciliation of marine mammal tracking data with oceanographic data.
LTO-Land: terrestrial ecology, microbiology and genomics	In the case of terrestrial ecology, plant functional traits are submitted to the TRY database[42] and the Tundra Trait Team database. Soil and near-surface temperature data are submitted to the global initiative SOILTEMP[43] and research on climate change and alien invasive effects on biodiversity is increasingly being done in collaboration with colleagues working on Australian and French sub-Antarctic islands, thus distributed through their national data servers. Metabarcoding data generated on microbial diversity studies conducted within SANAP are submitted to the publicly accessible GenBank[44] database hosted by the National Center for Biotechnology Information (USA).
LTO-Land: geology, geomorphology and geophysics	Data produced under the SANAP geology and geophysics projects typically comprise spatial data related to (geology) rock types, whole rock major and trace elements, radiogenic isotopes, geochronology (age dates) and metamorphic studies and (geophysics) magnetic and gravity variations. Such data from pre-2006 have been compiled in a GIS database, which has been made available to two external agencies for incorporation into larger geological databases on Antarctic geology. These agencies include (1) the Quantarctica database developed in QGIS by the Norsk Polar Institute and (2) a SCAR project that compiled a geological database over Antarctica in ArcGIS format. An initiative has commenced at CGS, to catalogue

39 https://iwc.int/sorp
40 http://www.meop.net/
41 https://www.pangaea.de/
42 https://www.try-db.org/
43 https://soiltemp.weebly.com/
44 https://www.ncbi.nlm.nih.gov/genbank/

IF and theme	Description of repositories
	samples from Antarctica currently hosted at the National Core Library at Donkerhoek. Cryosphere data distribution in western DML will maintain existing links to regional projects, ensuring South African recognition and contribution to cryosphere research. Permafrost data will adhere to standards as set out by the Global Terrestrial Network on Permafrost [45] (GTN-P), an international repository of permafrost related data and metadata, and continue to contribute to this database.
LTO-Ocean: cruise data and autonomous devices	Oceanographic data are rather sparsely distributed, depending on the type of cruise and platform. Data collected during the SANAP relief voyages are included in the Marine Information Management System [46] (MIMS) maintained by DEFF in collaboration with SAEON, which is an official IODE National Oceanographic Data Centre. Scientific cruises funded by the SANAP DSI component are instead submitted to international repositories through the IOC GOOS [47] observation programmes. Although all SANAP groups use international standards, the interoperability is not guaranteed until all the data are published by the various international repositories, which creates delay in the data sharing within South Africa. The majority of data is ultimately redistributed through the Southern Ocean Observing System [48] (SOOS), where the tool SOOSmap provides a unified searchable system.
LTO-Ocean and Polar Lab: sea ice	PANGAEA has also been used by the South African researchers to disseminate sea ice observations data, to complement the submission to the ASPEcT [49] expert group (also endorsed by SCAR), but which does not generate a DOI. There is currently a lack of unified international repositories for sea ice data, and SAPRI would be in the position to take advantage of this gap.
LTO-Ocean: Seafloor mapping and benthic ecosystem	Biodiversity data will be published to OBIS and GBIF and fish data will also be linked to the Global Archive data repository.

45 https://gtnp.arcticportal.org/
46 http://data.ocean.gov.za/
47 https://www.jcomm.info/
48 http://www.soos.aq/
49 http://aspect.antarctica.gov.au/

IF and theme	Description of repositories
	Best practice guidelines for the management of seafloor geology data will need to be finalised to ensure that all data collected are stored in a central repository for long-term management. Bathymetry data will be published on the GEBCO dataportal and the IHO data centre. This will be done in consultation with CGS.
DPS: Antarctic legacy	The Antarctic Legacy of South Africa (ALSA) Digital Repository, which is an open access repository within the policy of the NRF of 2015 and the SCAR data policy no 39.

1.3. INTER-DISCIPLINARY RESEARCH ENABLED BY THE RI

Data holdings will include the full range of science described in the SAPRI proposal. Potential institutional participation or users of the data will include all the stakeholders listed in the SAPRI proposal as well as:

- Municipalities
- Provincial government
- Private sector
- Public
- Students
- International research institutions/organisations

2. DATA MANAGEMENT PLAN

2.1. DATA MANAGEMENT DURING THE RI LIFE CYCLE

2.1.1. Operations

Table D2: ***The major operational aspects of the SAPRI Data Centre***

Platforms	Operations
Data management	The data management team will be based in the SAPRI Data Centre (15.5 FTE staff by year 3). Operations by the SAPRI Data Centre staff include: ● System development and setting up infrastructure for SAPRI data ● Data quality assurance, curation, archiving of data ● Protocols for quality assurance, curation and archiving of data written and regularly updated ● Data processing and product generation protocols written and regularly updated ● Daily maintenance of servers ● Development and regular maintenance of databases, data portals and websites ● Uploading raw and processed data onto the SAPRI Data Centre portal ● Data backed-up, archived and persistent identifier numbers assigned to datasets ● Attend to stakeholder queries
	KPIs (data management): protocols in place; data from stakeholders uploaded to the portal within a week (with metadata); stakeholder satisfaction. KPIs (data systems): protocols in place; limited downtime of servers and satellite links; real-time data uploaded onto the portal within a day; no data loss due to infrequent back-ups; stakeholder satisfaction.

2.1.2. Maintenance

Table D3 below shows the maintenance schedule for the SAPRI Data Centre.

Table D3: ***Maintenance schedules envisaged for the SAPRI Data Centre***

	Maintenance Type	Level	Frequency
Hardware infrastructure	Routine, preventive & corrective	Operational	Weekly
Software systems	Routine, preventive & corrective	Operational	Weekly

2.1.3. Upgrading, Replacement and Extension

Table D4*: Envisaged upgrading schedule for the SAPRI Data Centre*

	Upgrade frequency	**Extension frequency**	**Replacement frequency**
Hardware infrastructure	Every 12 - 24 months	Every 6 months * dependent on need to scale service up due to additional demand	Every 5 - 10 years
Software systems	Every 6 - 12 months	Every 3 - 6 months * dependent on need to scale service up due to additional demand	Every 3 - 5 Years

** above dictated by service-oriented-architecture model, vs shrink-wrap product model

2.1.4. Closure or transition to new entity

In the case of closure, SAEON will assume responsibility for ensuring that SAPRI data can be preserved in the long term irrespective of the institutional status of SAPRI, and it will manage this function in a planned and documented way. Data shall be stored on SAPRI Data Centre servers, or if impractical, stored at approved external repositories (which should be detailed in the data management plans for each project). Data held by the SAEON Data Centre servers will be maintained in suitable formats as far as is possible - preferably in long-lived formats as opposed to proprietary formats.

SAPRI Data Centre metadata and data holdings are proposed to be secured through the following means:

1. The metadata catalogue would be preserved at the Global Change Master Directory (which maintains a master copy of the metadata records in the Antarctic Master Directory coordinated by SCADM).
2. Ocean related data would be transferred to the Marine Information Management System (MIMS) at the Department of Environment, Forestry and Fisheries (DEFF).

3. The SAPRI Data Centre would transfer non-marine related data to the SAEON Open Data Platform, or other suitable data repositories.
4. Some of the data holdings would also already be available through other institutions and repositories (see Table D1).

2.1.5. Data centre management

The SAPRI Integrated Facilities are connected to the internet and will be connected to the data portal of the SAPRI Data Centre. SAEON National Office and the SAPRI Data Centre will be serviced by SANReN. Backups will be automated and two geographically distributed servers will provide security in case of system breakdowns. A SAPRI Data Centre Coordinator will be responsible for the overall coordination of SAPRI data within the SAPRI Data Centre; Data Curators (x3) will be principally responsible for the cataloguing and archival of SAPRI data; Systems Administrators (x2) will be responsible for user support, and the daily management, upkeep and configuration of the computer systems; Developers (x3) will maintain and develop SAPRI Data Centre systems and tools; Data Scientists (x2) will be responsible for producing tools, dashboards and data products; and, an Office Administrator will be responsible for the general administration of the office. In addition, four interns in various capacities will ensure capacity development in these scarce skills fields and for succession planning purposes.

The SAPRI Data Centre Coordinator will oversee the data management pipeline up to publication on the internet. To this end, SAEON has developed an observations database which is suitable for further customisation by the SAPRI. The SAEON Chief Data and Information Officer is responsible for the development and interoperability of various public data portals and will continue doing so for the SAPRI. These data portals allow for computation and visualisation of own and external data, and are connected to global Earth and environmental data systems. All of these existing organisational arrangements in SAEON will require expansion in order to cope with the increased production of data and the possibilities of computation and visualisation given the wide range of data that will be generated. SAPRI nodes hosted by external organisations will start off by relying on the connectivity and services provided by the host, until a different perspective is obtained.

2.2. ACCESS POLICY AND INTELLECTUAL PROPERTY RIGHTS

Unless specifically requested, the SAPRI Data Centre will issue deposited datasets by default with a Creative Commons License that allows sharealike and commercial use while conserving rights of IP owners across multiple jurisdictions. The ShareAlike 4.0 International (CC By-SA 4.0) allows users to copy and redistribute the material in any medium or format as well as adapt and build upon the material for any purpose, even commercially. Users of the data must give appropriate credit, provide a link to the license, indicate if changes were made and distribute their contributions under the same license as the original (see unabridged terms of license here).

Upon submission, data providers must indicate

1. Whether use is limited to non-commercial applications;
2. Whether a publication embargo is applicable (a letter required to motivate the embargoing of data);
3. Whether the data refers to species that are endangered or otherwise sensitive;
4. Whether the data is private to an individual;
5. Whether there are ethics considerations attached to the data;
6. Whether end users should be identifiable.

Conditions 3 above and onwards render the Creative Commons license suite unsuitable, and data providers must provide an alternate user license (with associated terms and conditions) or disallow public access to the data.

2.3. DATA MANAGEMENT

2.3.1. SAPRI Data Centre mission statement for SAPRI data

To provide integrated and secure access to the RIs data following the principles of FAIR (Findable, Accessible, Interoperable, and Reusable).

2.3.2. SAPRI Data Centre goals and objectives for SAPRI data

The main outcomes that will be delivered through our approach to data and information are those that result in[50]:

- efficient, interoperable and internationally networked data infrastructure delivered through collaboration
- enhanced public and researcher access to data
- minimisation of restrictions on data exploitation
- preservation of source data in a manner that permits long-term re-usability
- increased reliance on open source technologies and methodologies
- improved capacity to integrate multidisciplinary data to help derive innovative products and/or drive new scientific discovery

The SAPRI Data Centre should ensure that:

- a wide range of Antarctic scientific data are managed for the long term and made available in an easily accessible form,
- metadata records are managed for all South African Antarctic scientific research data and are made available for public searching in an effective form,
- South African Antarctic data are included in The Scientific Commission on Antarctic Research (SCAR) and other international data systems,
- it maintains current best practice in relation to its repository management functions and related systems,
- it maintains confidentiality of data during embargo periods,
- it facilitates the custodian's right to be cited as the source of published data,
- information is provided to scientists on the resources that are available to support their work and advice is available on the design of data collection programs and effective data management strategies through assistance with developing Data Management Plans.

2.3.3. Digital object life cycles

Digital data curation and preservation models are often envisioned as life cycles[51]. Such a life cycle describes the journey of data from its inception and funding through to its creation and on to storage and reuse via a trusted repository. Life cycles are useful for identifying the points at which information needs to be exchanged, and the responsibilities inherent for both data providers and data repositories. The SAPRI Data Centre will use a range of curation levels depending on the quality of the data received, and will provide basic tools to users in order to manage their data (such as a metadata authoring tool, and a data submission tool).

50 Australian Antarctic Data Centre (20 November 2018). Core Trust Seal Assessment Information - Australian Antarctic Data Centre. Retrieved from https://www.coretrustseal.org/wp-content/uploads/2018/11/Australian-Antarctic-Data-Centre-AADC.pdf.

51 http://www.dcc.ac.uk/resources/curation-lifecycle-model

Data Management Plans (DMPs): Project implementers should have Data Management Plans in place so that they address data management from the start of their research projects. DMPs are often a requirement of grant funding bodies. The SAPRI Data Centre will advise and help researchers complete DMPs.

2.3.4. Data formats and data families

The long-term preservation likelihood of data varies depending on the format. To maximise this likelihood, file formats submitted to the SAPRI Data Centre should whenever possible have the following attributes:

- open documentation
- platform-independence
- non-proprietary (vendor-independent)
- no "lossy" or proprietary compression
- no embedded files, programs or scripts
- no full or partial encryption
- no password protection

Based on these attributes, the file formats that achieve 'high' preservation likelihood (and are therefore desirable formats for data submission) are preferred. While it is a data provider's choice as to the format of submission, it is strongly advisable to submit data in formats that have a high long-term preservation potential. The SAPRI Data Centre will not guarantee format migration should the existing format become obsolete.

Data typically belongs in data family categories (Table D5); the data from the SAPRI research programmes fall into one or more of these data family categories. The SAPRI Data Centre will have the capability to accept all of these data families.

Table D5: ***Data Families***

Data Family	Typical Metadata Standards	Typical Data Services	Typical Operational Environment
Traditional Spatial Data	ISO 19115 FGDC	OGC WMS	Spatial Database, File System
Multidimensional Data	ISO 19115	OpenDAP ErDDAP	NetCDF Array Database
Physico-Chemical Observations Data	ISO 19115 SensorML	SensorThings SOS/ O&M	RDBMS Text Files

Ecosystem Observation Data	EML DwC +	DwC + Object Download	MetaCAT RDBMS Spreadsheets Text Files Images Video Audio
Genetic Data		FTP ASN.1	GenBank

Example generic data families and interoperability requirements[52]. The abbreviations are: OGC: Open Geospatial Consortium web services, WMS: Web Map Service; SOS: OGC Sensor Observation Service; O&M: OGC Observations and Measurements model; EML: Ecological Markup Language, DwC: Darwin Core, and DwC+ - with extensions, RDBMS - relational databases.

2.3.5. Metadata

Metadata is the primary mechanism for documenting data and in relevant cases, the instruments, sensors and procedures involved in data collection. Metadata standards support unlimited links to other documents, particularly in the form of Web pages. This enables the fundamental metadata parameters (who, when, where, what) to be augmented with detailed descriptions and parameters that the custodian considers necessary for other scientists to make effective use of their data. All datasets that are archived in the SAPRI Data Centre must be accompanied by metadata. All metadata will be publicly accessible, to allow potential users to locate datasets of interest to them.

Metadata will ideally be applied in an automated way, either by:

1. Using web service APIs provided for this purpose (i.e. metadata records will be submitted by the user using an online tool developed by the SAPRI Data Centre), or
2. Allowing the SAPRI Data Centre to harvest and synchronise metadata associated with an institutional or domain repository. Many SAPRI stakeholders already make use of various repositories (Table D1) - the possibility of aligning these with the SAPRI Data Centre will need to be investigated (dependent on supported metadata standards).

A basic metadata scheme required for data submission to the SAPRI Data Centre will be compiled, with mandatory attributes (that must all be completed regardless of data type or conditions) and optional attributes, the completion of which depends on conditions.

Minimum metadata for the SAPRI Data Centre will be determined using DataCite and ISO 19115 / SANS-1978. The DataCite Metadata Schema is a list of core metadata properties, chosen for accurate and consistent identification of a

52 Based on http://dx.doi.org/10.1007/978-3-319-27288-7_11

resource for citation, discovery and re-usability purposes. The schema can be used to describe any digital object, meaning it can be used for any data family.

The SAPRI Data Centre, as the South African Antarctic Data Centre, will submit validated metadata records to the Global Change Master Directory (GCMD) to have them included in the Antarctic Master Directory, as stipulated by SCADM (the Standing Committee on Antarctic Data Management) (http://www.scar.org/scadm/the-amd-metadata). The GCMD uses the DIF (Directory Interchange Format) (DIF-10) metadata standard, as well as ISO 19115, or possibly schema.org. Therefore, all SAPRI Data Centre metadata will need to be stored in one of these standards. The DIF standard is compliant with the ISO 19115 metadata standard, and all SAPRI Data Centre metadata records will automatically be converted to 19115 format (and also into various profiles of the 19115 standard). The NASA DIF standard is regularly reviewed and updated by NASA. The SAPRI Data Centre should always use the latest version of the DIF standard.

2.3.6. Data integrity and authenticity

Data submissions will be checked for authenticity of records. The SAPRI Data Centre will have a versioning system for datasets and metadata records.

2.3.7. Data discovery and identification

The SAPRI Data Centre metadata catalogue will be searchable via a comprehensive tool on the SAPRI Data Centre website. The search tool will need to operate on the SAPRI Data Centre collection of DIF metadata (the Global Change Master Directory standard used by the international Antarctic community). The SAPRI Data Centre metadata catalogue will need to be available for harvesting by other organisations, and will also include proper citations for authors.

2.3.7.1. Data reuse

The role of the SAPRI Data Centre will not just be to preserve data, but will also need to make it discoverable and available for reuse. For discoverability, metadata and an open data platform needs to be in place. Appropriate metadata will be completed, which will be updated should this be necessary. Additionally, where possible, data will be converted to “long-lived” formats (e.g. .xls to .csv).

2.3.7.2. Persistent Identifiers for Data Sets

Persistent and unique identification of datasets are considered best practice for data management globally. Persistent Identifiers are globally unique numeric and/or character strings that unambiguously reference a specific digital object. Assigning such an identifier to a data set allows its use and citation to be tracked, preserving the acknowledgement of the data creator. The SAPRI Data Centre will have the capability to issue Digital Object Identifiers (DOIs), through for example becoming a registered member of DataCite. If the data set is already registered with a persistent identification number from another scheme, the data provider must inform the SAPRI Data Centre curation team.

2.3.8. Confidentiality / ethics

The SAPRI Data Centre will maintain different levels of “release status” for datasets, including:

- Public (the data are publicly available according to the conditions of the CC-BY licence)
- Embargoed (the data are not publicly available, but will become so within a set period of time, typically used to give scientists time to publish findings or for a student to complete a thesis)
- Confidential (the data are not publicly available and it is unlikely that they ever will be)
- In review (the data are available via a specific link and password (intended for use by journal reviewers before publication)

University ethics committees or funding bodies for research projects are responsible for ensuring that legal and ethical standards are met. Therefore, while ethics approval will not be a SAPRI Data Centre related activity, by the time data are submitted to the SAPRI Data Centre repository for archiving, SAPRI Data Centre staff will verify that legal and ethical guidelines have been followed.

Data will be stored on secure servers. The SAPRI Data Centre will be compliant with the Protection of Personal Information Act 4 of 2013 (POPI) and Promotion of Access to Information Act 2 of 2000 (PAIA). The POPI Act is designed to protect personal information processed by both private and public bodies, whereas the PAIA Act is legislation which allows access to any information held by the State, and information held by private bodies that is required for the exercise and protection of any rights. Metadata records will not contain personal information for scientists or data owners, but work contact details will be used. These details are typically provided by the users themselves with the understanding that they will be made available in the metadata record.

2.3.9. Physical samples

Several SAPRI research groups collect physical samples, which are either preserved and stored until analysis (and the processing step destroys the sample), or preserved for future potential analysis or for collections / reference purposes. For the latter, some groups deposit samples in organised collections within for example the Council for Geoscience (e.g. SAPRI-LTO Land: terrestrial Antarctica), SAIAB (e.g. SAPRI-LTO Ocean: seafloor), and Iziko to name a few. There is currently no capacity in the country to store polar samples that need to be preserved at sub-zero conditions, and this gap will be fulfilled by the SAPRI Polar Lab. The SAPRI Data Centre in conjunction with the respective IF coordinators will need to incorporate a process for aligning with the collections management software of these collections facilities (such as Specify) to use persistent identifiers to link any physical samples that are associated to datasets in the SAPRI Data Centre repository.

Assessing the possibility of integrating systems with the National Science Collections Facility (NSCF), a SARIR RI coordinated by the South African National Biodiversity Institute (SANBI), will also be important for strengthening networks of natural science collections.

2.4. QUALITY ASSURANCE SYSTEMS

2.4.1. Quality management

The SAPRI Data Centre will adopt best international practices in the collection, quality control, archiving and dissemination of data to ensure the data is reproducible and comparable to other international datasets. The SAPRI Data Centre will provide integrated and secure access to the RIs data following the principles of FAIR (Findable, Accessible, Interoperable, and Reusable). The SAPRI Data Centre will develop in-house maturity models for quality metrics as an important benchmark for quality and continuous improvement.[53]

Raw data (pre quality control) will be retained and archived for future reference.

Upon receiving a dataset, SAPRI Data Centre staff will manually perform a series of checks on the files (including file format, suitable and accurate metadata, etc.). Metadata records will be submitted by the user using an online tool developed by the SAPRI Data Centre. This tool will have some automatic validation processes, e.g. ensuring that all mandatory elements have been created, dates are in the correct format, etc. Users will be unable to submit a metadata record without all the mandatory elements. After submission, SAPRI Data Centre staff will then check the metadata record for completeness to ensure that it adequately describes its associated dataset.

53 https://www.rd-alliance.org/group/fair-data-maturity-model-wg/case-statement/fair-data-maturity-model-wg-case-statement

All metadata records undergo another validation process at the Global Change Master Directory (GCMD) for SCAR-SCADM's Antarctic Master Directory. This process is performed by GCMD validation tools and GCMD staff.

The SAPRI Data Centre will have an online support page. Users or members of the general scientific community will be able to use this page to contact the SAPRI Data Centre about a particular dataset, for more information about a dataset or if they feel the metadata record is lacking. These requests will be documented for tracking and resolution.

2.4.2. Quality assurance flagging

Quality assurance and quality control measures prevent errors from entering or remaining in a data set. These activities ensure data quality before it is collected, entered, or analyzed, and monitor and maintain the quality of the data throughout the study's data life cycle[54]. Methodology of quality assurance and control vary widely, and there will possibly be no standard practice for submissions to the SAPRI Data Centre. However, data providers who have performed some form of quality assurance or control must indicate this upon submission, and provide a quality assurance methodology to accompany the quality assurance flag.

2.4.3. Workflows

The SAPRI Data Centre will develop data workflows to describe the flow of data from submission to the data centre to public data access. The primary goals of these workflows will be to:

- improve data flow and data handoff, making tracking of data status easy and preventing data loss,
- improve transparency for end users by providing more details to populate metadata records (i.e. limitations and processing methods applied to datasets).

In addition, tools will be developed to provide clear data management workflows, including a metadata authoring tool and a data submission tool. SAPRI Data Centre staff will also advise users on best practises for Data Management Plans (DMPs).

A final quality assurance check is used by a wide range of users. There will be a mechanism for reporting questionable data back to the system, and an obligatory follow-up procedure.

2.4.3.1. Continuous data flows

Automated workflows will potentially be implemented for the processing of continuous data from some oceanographic instruments to help ensure data quality. These workflows will be documented in detail, and old versions of the software archived. When software is changed, a test dataset must be processed by both the old and new workflows to check for any systematic differences. Many of the workflows will have internal data validity checks built in: for instance, pre-assigned permissible data ranges, or mass and energy balance checks.

2.4.3.2. Documented storage procedures

The SAPRI Data Centre will apply documented processes and procedures in managing archival storage of data. The google drive as well as an internal wiki should be used to provide documentation on processes and procedures, which will be particularly useful in the event of staff changes. Regular back-ups of all servers will be made. Minimum standards will be abided by in terms of server maintenance, server security (physical and online), virus protection, data storage, backup and recovery.

54 DataOne - Quality Control

3. INTERNATIONAL REPOSITORIES AND STAKEHOLDER ENGAGEMENT

3.1. STAKEHOLDER ENGAGEMENT PLAN

3.1.1. SAPRI Data Centre: International responsibilities

3.1.1.1. Alignment with SCAR - SCADM

The Scientific Committee on Antarctic Research (SCAR) is an inter-disciplinary committee of the International Science Council. SCAR recognises the critical importance of data management within national and international polar programmes and the necessity of ensuring data accessibility to all. SCAR's Standing Committee on Antarctic Data Management (SCADM) helps to facilitate the cooperation between scientists and nations with regard to scientific data and advises on the development of Antarctic data management. SCAR has adopted a Data and Information Management Strategy, developed by SCADM, to ensure that the scientific user community has adequate access to data and information. SCADM coordinates the Antarctic Data Management System, which is composed of:

- The Antarctic Master Directory (AMD)
- The National Antarctic Data Centres (NADCs)

As a signatory to the Antarctic Treaty and party to the Delegation of SCAR, South Africa has a responsibility to align with the requirements of SCAR and its policies on data management.

3.1.1.2. The Antarctic Master Directory (AMD)

The Antarctic Master Directory is hosted by NASA's Global Change Master Directory. The Global Change Master Directory provides metadata support to the international Antarctic community, provides national Antarctic portals for each country, and amalgamates all Antarctic metadata into the Antarctic Master Directory. The AMD is a directory of data descriptions and is not a central database containing the actual data. Data custodians (e.g. research institutions) are responsible for determining conditions of access to the data.

3.1.1.3. The National Antarctic Data Centres

A National Antarctic Data Centre (NADC) is a focal point for Antarctic data and recruitment of NADCs is a key responsibility of SCADM. Countries may establish their own NADCs, or designate an existing institution as their NADC. South Africa does not currently have a NADC in place - the SAPRI Data Centre should take on that role.

In summary, NADCs, and therefore the SAPRI Data Centre should[55]:

- Provide the national focal point for the Antarctic Data Management System
- Assist national scientists in the production and maintenance of metadata records
- Validate the metadata records
- Forward periodically validated metadata records to the Antarctic Master Directory host
- Provide advice on Antarctic data management issues

As South Africa's National Antarctic Data Centre, the SAPRI Data Centre would need to observe the requirements of SCADM for Antarctic data management, specifically with regards to the inclusion of metadata in the Antarctic Master Directory.

55 https://www.scar.org/data-products/adms/

A representative from the SAPRI Data Centre needs to sit on the SCADM. The SAPRI budgeting also needs to include funds for this person to attend annual SCADM meetings, and the SCAR polar conference every second year, where SCADM meetings are held.

3.1.1.4. *SCAR - SCAGI*

The SCAR Standing Committee on Antarctic Geographic Information (SCAGI) manages and works to improve the geographic framework not only for Antarctic research, but also for activities including operations, environmental management and tourism. SCAGI actively develops a range of Geographic Information products through its various projects, including: the SCAR Composite Gazetteer of Antarctica, the SCAR Antarctic Digital Database, and the SCAR Map Catalogue. These are active products that are used and valued by the Antarctic community. The SAPRI Data Centre will ensure involvement with SCAGI; this will benefit all stakeholders, particularly the SAPRI-LTO Land node including terrestrial Antarctica.

4. CAPACITY DEVELOPMENT

4.1. STAFFING REQUIREMENTS

Table D6: ***SAEON Data Centre staffing requirements***

1 x SAPRI data coordinator / programme officer (included as part of Management Team)
1 x FTE IT Systems administrator - senior
1 x FTE IT Systems administrator - mid level (from year 2)
2 x FTE Data curators - senior (1 from year 1, 2 from year 2)
1 x FTE Data curator - mid level (from year 2)
1 x FTE Systems developer - senior
2 x FTE Systems developer - mid level (2 from year 2)
1 x FTE Data scientist - senior (from year 3)
1 x FTE Data scientist - junior (from year 3)

- Coordinator / programme officer: responsible for the overall coordination of SAPRI data within the SAEON Data Centre
- System administrators and user support: responsible for the daily management, upkeep and configuration of the computer systems
- Data curators: principally responsible for the cataloguing and archival of data
- Developers: to maintain and develop SAEON Data Centre systems and tools, as well as to work on specialist databases for disseminating particular scientific data
- Data scientists: responsible for tools and dashboards and data product development as required
- Office administration: responsible for general administration for the office
- Interns in various capacities to ensure capacity development in these scarce skills fields and for succession planning purposes

The SAEON Data Centre staff will receive finance, business and Human Resources support from the SAEON National Office.

4.2. SUMMARY OF DATA STAFF EVOLUTION:

Table D7: ***Summary of data staff evolution for the SAPRI Data Centre***

Life Cycle Stage	Activity	Type of staff required
Setting up	Conceptual design	Coordinator / programme officer
	Technical design	Systems developer, systems administrator, data curator
	Establishment and construction	As above
	Commissioning	As above with office administrator
Running	Operation	Additional systems developers and data curators
	Maintenance	Additional systems administrator
	Building community	Coordinator / programme officer
	Tools and data product development	Data scientists
	Education and Training	Staff act as mentors to 4 interns
	Upgrading, replacement and Extension	Systems developer, systems administrator,
Shutting down	Phase out	Coordinator / programme officer, data curators, systems administrators
	Decommissioning	As above. Migrating data to permanent archive
	Closure	

APPENDIX E: SUMMARISED LIST OF SPECIALISED EQUIPMENT REQUIRED BY THE SAPRI

These lists are not exhaustive or conclusive. Further technical iterations will take place between the Management Team and IFs once SAPRI is funded and established.

1) Management Team
    - Computing and office infrastructure related to day-to-day operations
2) DPS
    - Data Centre computing infrastructure: Servers, computers, large storage infrastructure, website hosting, and refurbishment over time.
    - Outreach infrastructure such as digital projectors, banners, teaching materials and models.
    - Digital twin of Antarctic science including data storage onboard SA Agulhas II.
    - Nanosatellite technology development
3) LTO-Land
    - Antarctic terrestrial sampling gear: Piston bullies, sleds, tents, camping gear, safety gear, climbing gear, containers.
    - Marion Island terrestrial sampling gear: Tents, camping gear, safety gear.
    - Marine mammal and sea-bird tagging and field instruments
    - Weather station instruments
    - GAW station instruments
    - Space science instruments (radars) for Antarctica
4) LTO-Ocean
    - Multi-beam / side scan sonar installation on SA Agulhas II
    - Autonomous instruments: Glider, wave gliders, Argo floats, SVP drifters, Wave drifters, Ice drifters
    - Over-side vessel instrumentation: CTD sensors, Niskin bottles, Zooplankton nets, Phytoplankton nets.
    - Mooring instrumentation: ADCPs, Microcats, Acoustic Release, location beacons, buoys, passive acoustic listening stations.
    - Onboard and land-based biogeochemistry, chemistry and physics laboratory equipment.
    - Deep-sea benthic observing systems: ROV, deep-sea landers, camera-based systems
5) Polar Lab
    - Ice tanks
    - Wave tank
    - Calibration and sensor equipment
    - Ice corers and augers
    - Clean laboratory facilities
    - Polar gear