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Exploring South Africa's southern frontier: A 20-year vision for polar research through the South African National Antarctic Programme

Antarctica, the sub-Antarctic islands and surrounding Southern Ocean are regarded as one of the planet's last remaining wildernesses, 'insulated from threat by [their] remoteness and protection under the Antarctic Treaty System'¹. Antarctica encompasses some of the coldest, windiest and driest habitats on earth. Within the Southern Ocean, sub-Antarctic islands are found between the Sub-Antarctic Front to the north and the Polar Front to the south. Lying in a transition zone between warmer subtropical and cooler Antarctic waters, these islands are important sentinels from which to study climate change.² A growing body of evidence^{3,4} now suggests that climatically driven changes in the latitudinal boundaries of these two fronts define the islands' short- and long-term atmospheric and oceanic circulation patterns. Consequently, sub-Antarctic islands and their associated terrestrial and marine ecosystems offer ideal natural laboratories for studying ecosystem response to change.⁵ For example, a recent study⁶ indicates that the shift in the geographical position of the oceanic fronts has disrupted inshore marine ecosystems, with a possible impact on top predators. Importantly, biotic responses are variable as indicated by different population trends of these top predators.^{7,8} When studied collectively, these variations in species' demographic patterns point to complex spatial and temporal changes within the broader sub-Antarctic ecosystem, and invite further examination of the interplay between extrinsic and intrinsic drivers.

Further south, beyond the Polar Front, the Southern Ocean and Antarctica provide a unique platform from which to investigate questions of past, present and future change. For example, continental ice cores provide a record of earth's climatic history over the last 800 000 years^{9,10} and the isotopic composition of the fossil shells of benthic foraminifera provides a proxy measure of past sea temperatures and ice volume¹¹. The region's varied pelagic and benthic ecosystems are already showing responses to current environmental change – including declining primary production, changes in circulation and mixed layer depth – as well as impacts on keystone species in Antarctic food webs. Sea ice around the Antarctic Peninsula is rapidly disappearing, potentially driving a decrease in krill biomass as a result of reduced recruitment.¹² By comparison, sea ice extent around the rest of Antarctica is increasing and while West Antarctica is warming, East Antarctica is cooling. Even advanced climate models cannot adequately capture these opposing trends, reducing our ability to predict future changes and impacts in the region. The complex interplay between these positive and negative melting trends has highlighted the vulnerability of Antarctic Bottom Water formation, which may be compromised by increased fresh water input through increased melt run-off in a warming climate.¹³ Measures of global sea level rise are currently 3 mm per year, but these levels could increase rapidly if the unstable West Antarctic ice sheet melts, including the ongoing collapse of the Larsen B and C Ice Shelves.

The Southern Ocean is also a crucial sink for anthropogenic CO₂¹⁴, but may become a future source¹⁵. In addition, this ocean is a major reservoir of unused macronutrients, particularly nitrate and phosphate, primarily because of iron and light limitation of phytoplankton growth.¹⁶ Consequently, this region exports essential nutrients to the lower latitude oceans via intermediate and bottom water circulation. How changes in Antarctic Bottom Water formation will alter such nutrient fluxes remains unexplored. Moreover, changes in macronutrient utilisation by phytoplankton in Southern Ocean surface waters will control the ocean's ability to regulate atmospheric CO₂ in future.¹⁷

In addition to the importance of the Southern Ocean in oceanographic, climate and ecological research, other opportunities for research exist – notably in space science, exploration and earth's geological history. The dry, stable atmosphere over Antarctica and the convergence of the earth's magnetic field lines provide ideal conditions for studying the near earth space environment, the solar system, and the universe beyond. Related to this, the varied continental ecosystems hold secrets to life in extreme environments. As Antarctica was once part of the supercontinent Gondwana, an understanding of its evolution is key to understanding the broader evolution of the neighbouring continental blocks of Africa, India and Australia.¹⁸

Taken together, Antarctica and the Southern Ocean form a critical natural laboratory where international scientific investigation can infer the fundamental drivers of the entire earth system and of the near-earth space environment. Advancing our understanding is critical to better comprehend the region's role in global ocean-atmospheric circulation, ecosystem adaptation and its impact on earth's radiation balance. Research emanating from this region already offers conclusive and alarming evidence that the world's climate is changing rapidly. The need to continue monitoring is critical.

A pivotal role for South Africa in the Antarctic and Southern Ocean

South Africa has a strong geographical advantage for conducting and directing research in the Antarctic and Southern Ocean (Figure 1). Logistically, it is the closest African point to the South Pole and is a well-established gateway to Antarctica – acting as a summer springboard for many international expeditions. The distance to Antarctica is the greatest of all southern continents, allowing for a unique configuration of ocean circulation. A transect between Cape Town and Antarctica crosses one of the world's most oceanographically and biologically dynamic regions, encompassing three ocean basins, two major boundary currents and the circumpolar current. The Southern Ocean south of Africa also marks the intersection of deep and bottom water masses (Figure 1), which modulate both heat and CO₂ exchange with the atmosphere.

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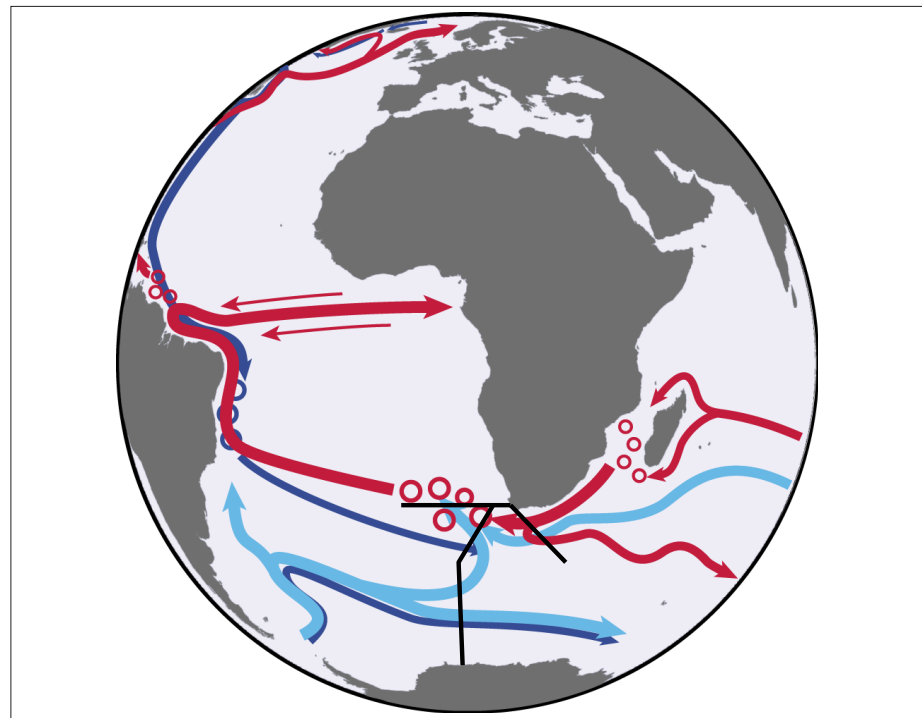


Image courtesy of Jonathan Durgadoo, GEOMAR, Kiel.

Figure 1: Schematic of the ocean circulation south of Africa. Colours indicate surface (0–1000 m, red), intermediate (1000–1500 m, light blue) and deep (1500–4000 m, dark blue) pathways and their interconnectivity. In the South Atlantic, two northward flowing routes exist: the cold-water route which is the direct inflow from the Drake Passage, and the warm-water route southwest of South Africa. The three black lines highlight the main transects occupied by the SA *Agulhas II* during its annual relief voyages to the Prince Edward and Gough Islands and SANAE on the Antarctic continent. Measurement of the ionospheric dynamics by means of the ionospheric scintillation monitor on the SA *Agulhas II* provides a unique data set for studying the impact of the South Atlantic Magnetic Anomaly on ionospheric dynamics.

Indeed, the South African Weather Service already capitalises on this geographical advantage through an established long-term observation programme at its Cape Point Global Atmosphere Watch Station. From a biological perspective, South Africa has had a research presence on the Prince Edward Islands since 1951^{19,20}, which, together with annual visits to Gough Island in the South Atlantic, has allowed for time-series observations and monitoring at both sites. In contrast, Dronning Maud Land in Antarctica is a distinct biogeographical region that remains poorly studied.²¹ The South African National Antarctic Expedition bases (SANAE I–IV) have been located in the region since the 1960s. The current SANAE IV base is ideally situated to address the gaps in terrestrial earth and biological research.

South Africa was a founding member of the Antarctic Treaty System which, over the past 50 years, has proven to be an effective governance regime for Antarctica and the adjacent Southern Ocean. South Africa is currently the only African signatory to this treaty and the only African nation with an Antarctic research programme. The country therefore bears a regional responsibility to serve the broader African community. The Antarctic Treaty System advances a philosophy of peace and security based on principles of mutual cooperation, excellence in scientific research and high standards of environmental protection. As an active participant, South Africa has a long-standing track record and long-term commitment to undertaking research in the region.

South Africa has an interest in ensuring that the Treaty continues to be recognised as the *only* appropriate mechanism for the management, environmental stewardship and governance of the region. To this end, the South African government has indicated its ongoing commitment to continued research through major financial investments in new state-of-the-art platforms – including new and refurbished bases on Marion Island and at SANAE IV; a new polar research and supply vessel, the SA *Agulhas II*; and a new ocean robotics facility at the Council for Scientific and Industrial Research (CSIR). In addition, the establishment of a nationwide South African Environmental Observation Network (SAEON) and DST/NRF Centres of Excellence has further facilitated outstanding academic research, helping to ensure that South African marine and terrestrial science remains at the forefront of international recognition.

Notwithstanding the obvious importance of multidisciplinary and multinational research in this region, there is an increasing fear that these priorities will be neglected in the face of growing economic and human challenges. This fear has been widely recognised in various discussion forums, most notably in the recently released 20 Year Australian Antarctic Strategic Plan which states that 'leadership is fast eroding as logistic and scientific capabilities rapidly stagnate'.

In parallel to national research investments, South Africa remains a party member to various international Southern Ocean and Antarctic initiatives and these continue to guide its research mandate and interests. South Africa is represented on the Scientific Committee on Antarctic Research (SCAR) and within the Council of Managers of National Antarctic Programmes. South African researchers are also leaders and key participants in several SCAR Scientific Research Programmes and Expert/Action Groups across the broad fields of biology, geology and physical sciences.

In the sub-Antarctic belt, the Prince Edward Islands are globally important breeding sites for several marine top predators, including albatrosses and petrels, which South Africa, through its membership of the Agreement on the Conservation of Albatrosses and Petrels, has agreed to conserve. The islands were declared a Special Nature Reserve in 2013 under the *NEMA: Protected Areas Act 57 of 2003* and currently enjoy the highest level of protection of any South African natural area. The large South African exclusive economic zone around these islands exceeds that of mainland South Africa in coverage and likely supports important marine resources.²² Through the declarations outlined above, South Africa is responsible for all research, monitoring and conservation activities in the region.

Since the inception of the Antarctic Treaty System, South Africa has been at the forefront of a number of major international oceanographic, astrophysical, biological and biophysical projects in which international partnerships are well embedded. These projects seek to develop not only the infrastructure for global research, but also to train and develop human capacity in these scientific fields including, most recently, space research through the establishment of the South African National Space Agency (SANSA).

Antarctic and Southern Ocean research for South Africa and Africa

In a country such as South Africa – with its complex socio-political history, structures and a large population, many of whose lives are determined by day-to-day necessities of food security, water resources, health and education – it is imperative that the scientific community interrogate the need for continued South African involvement in Antarctica and the Southern Ocean. The recently established national Marine Antarctic Research Strategy (MARS) plan achieves just that.

MARS aims to consolidate Antarctic and Southern Ocean research efforts by the Department of Environmental Affairs (DEA), Department of Agriculture, Forestry and Fisheries (DAFF) and Department of Science and Technology (DST), while remaining central to the expectations and deliverables emerging from the Operation Phakisa Oceans Economy initiative. For South Africa to conduct world-class science, there is a clear need to strengthen Antarctic and Southern Ocean research and its capacity through strong leadership, coordination and consolidation. To achieve these goals, MARS prioritised five thematic areas, which are listed below. It is expected that MARS will soon be implemented through DST and DEA channels and that existing South African National Antarctic Programme (SANAP) activities will be reviewed to align with this multifaceted strategy. Continued financial investment in promoting a broad portfolio of multidisciplinary research under MARS, and its implementation through national research programme calls such as SANAP, are essential if South Africa wishes to remain globally competitive in this key geopolitical region.

Of importance now is aligning ongoing and well-established national and international projects with the MARS themes, while allowing for growth and a re-evaluation of priorities.

MARS Theme 1: Oceans and marine ecosystems under global change

Large-scale ocean circulation and global climate

The Meridional Overturning Circulation (MOC) is 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. Central to the MOC is the Southern Ocean, which provides a link between the upper and lower ocean layers, and across all ocean basins. The most dynamic region of the Southern Ocean–MOC circuit lies south of Africa. 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.

Southern Ocean in the coupled ocean-atmosphere-biosphere system

The Southern Ocean is an important component in the global carbon cycle and is responsible for 40–50% of the ocean's anthropogenic CO₂ uptake.^{14,23} Understanding the links between ocean-atmospheric physics, light and iron availability, macronutrient and trace element biogeochemistry, ocean ecosystem functioning and productivity are crucial to reliable modelling of carbon–climate feedbacks. Extensive multiscale and seasonal investigations into the sensitivity of large-scale trends in the Southern Ocean are necessary. Through combined observations and empirical models, we can derive low-uncertainty CO₂ exchange fluxes and help assess the risks associated with a changing oceanic carbon cycle.

Antarctic sea ice and its role in the environment

The seasonal growth and decay 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. Sea ice also acts as a habitat for microorganisms and a buffer for nutrients, CO₂ and trace elements. Earth system models have a coarse parameterisation of sea ice processes, mostly designed to modulate the transfer of heat and CO₂ fluxes across the sea surface. There is a clear need for further research to better understand how these processes influence the Antarctic cryosphere.

MARS Theme 2: Earth systems

A window into geospace

Fundamental questions for space physics include the mechanisms of energy transfer between the different layers in the upper atmosphere and the impact of space weather on the middle atmosphere and modern electrical technologies (e.g. radio communications) on the ground. We have a limited understanding of the generation and impacts of space weather; important 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.

SANSA operates an extensive array of ground-based instruments to monitor space weather from southern Africa, Gough and Marion Islands, SANAE IV and the SA *Agulhas II*. 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.

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 isotope ratios recorded in microfossils such as foraminifera and diatoms, which serve as a palaeo-thermometer and record of ice volume¹¹, as well as an archive of past nutrient utilisation²⁴. Similarly, gases trapped in continental ice-cores provide a CO₂ and temperature record exceeding 800 000 years.^{9,10} Combining multiple proxies in sediment or ice cores and cosmogenic nuclide dating of eroded surfaces and deposits allows reconstruction of past climate evolution, sea ice extent and environmental consequences.

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 and are the focus of continuing research. This research is focusing on obtaining better data and an improved understanding from the recent magnetic and gravity aerial surveys of the sub-glacial rock basement and will contribute to the recognition and definition of sub-glacial continental blocks, which comprised pre-Gondwana supercontinents like Rodinia. In this context, Dronning Maud Land lies in the broad area of the intersection of two orogenic mountain belts of similar age – the East African and Kuunga Orogenies – both of which also transect southern Africa and northern Mozambique.

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.

MARS Theme 3: Living systems

Ecosystem functioning and the response to global change

How resilient are Antarctic and Southern Ocean ecosystems 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.^{25,26} Furthermore, the study of seabirds and seals at their terrestrial breeding grounds can also provide valuable information on the state of the surrounding marine environment.

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 iron and light limitation.²⁷ Tight interactions across the food web also 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 the reliability of projected responses to changes. At the same time, the microbial community and predators (from krill to killer whales) have complex, little-understood feedbacks that affect phytoplankton 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 island²⁸⁻³⁰, while at local scales, dispersal is influenced by prevailing winds and local topography³¹. 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. feral cats) on ecosystem functioning.³² 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 species diversity, high levels of endemism reflect 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 advantage that they have almost zero environmental impact – just a few grams of soil or water can generate gigabases of nucleic acid sequences.

MARS Theme 4: Innovation and technology

Technology and engineering

The infrastructure and logistics supporting research are constantly in need of re-design, 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 act as high-resolution measurement probes which contribute to the validation of satellite data and climate models. This research area offers unique opportunities for innovative and leading engineering studies; within the South African context this field is largely unexplored. Furthermore, the challenging field conditions for biological research also promote creativity and ingenuity in the use and development of novel technologies³³ that can be applied more broadly³⁴.

Robotics

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.³⁵ Such vested 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 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.

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.

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, for example by Australian researchers through an initiative called 'Antarctica: A new musical'.

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. 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.

Taking South African Southern Ocean and Antarctic Science forward

Are we able to align with the SCAR Antarctic and Southern Ocean Horizon Scan priorities? In October 2016, South Africa's leading polar researchers convened a 2-day workshop in Cape Town. The aim of this workshop was to build on past policy efforts under the MARS and Operation Phakisa Ocean Economy Initiatives and to review the 2014 National Research Plan for South Africa in Antarctica and the Southern Ocean.³⁶ The workshop aimed to formulate a renewed vision at retaining world-class research, technology and innovation within the SANAP framework. The workshop created a forum to debate identified priorities and challenges for research and to discuss how best to align these priorities to the societal needs outlined by MARS. This Commentary summarises the outcome of the workshop; it presents specific priorities for research investment while identifying challenges and infrastructural needs critical to ensure that South Africa retains its international edge in polar research. Furthermore, we identify steps that both academic researchers and government departments must follow if (1) this vision is to become a reality, (2) South Africa is to retain its geographical and historical advantage in the region, and (3) the country's polar research programme is to remain a proud and sustainable national contributor to Antarctic research in the future.

The need for development of a comprehensive research theme for South African science in Antarctica and the Southern Ocean has been the concern of the scientific community for over a decade. Following the transfer of the research management role of SANAP from the then Department of Environmental Affairs and Tourism (DEAT) to the DST in 2003, DST produced an Antarctic Research Strategy for South Africa (ARESSA) to guide SANAP research. The ARESSA vision was to establish a national research programme that will (1) develop human capital innovation and economic growth, (2) increase the programme's international profile and influence, and (3) create a coordinated interactive effort towards public visibility. The implementation of the national research effort unfortunately remains to this day fragmented, with strategic priorities defined across several key stakeholders in a largely uncoordinated manner.

The recent National Research Plan for South Africa in Antarctica and the Southern Ocean and MARS reports both plan to seek a clearer vision by aligning extensive and targeted research within the Antarctic and oceanic domains while meeting key challenges identified by the 2014 SCAR Horizon Scan.³⁷

How can SANAP make a global impact?

While the themes above clearly identify with those of the international community, the question unique to South Africa is what approach should be taken to achieve the success of this vision against the context of South Africa's increasing societal needs? The ongoing societal challenges that South Africa faces are in stark contrast to the escalating costs and logistics of accessing such remote regions. Yet the past few decades have seen a growing appreciation by government of the major importance of Antarctica and the Southern Ocean in governing global climate. With climate change predicted to severely impact on resources and future agricultural productivity in South Africa, understanding the mechanisms that drive change is of fundamental importance. What is

critical is for South African polar science to move away from single researcher or institution projects to multidisciplinary (multinational) and integrated projects, with collaborators from a number of fields who address broad and internationally relevant questions. To do so, increased research time across all disciplines is critical to allow more comprehensive and in-depth research questions to be addressed.

The bulk of oceanographic research continues to be restricted to the three logistic relief operations, with only an additional 30 dedicated sea days available each year. For land-based research, the relief voyages provide a major limitation by their time-constrained access to Antarctica and the islands (logistical requirements dictate research access). Although there is comparable long-term data series, seasonal data are lacking and are crucial to understand biotic responses to changes in climate. The number of participants per voyage is also limited by space; large numbers of berths are reserved for logistical and maintenance personnel.

There is an increasing trend to link pure or basic research with applied research. One such opportunity can come from closer ties between SANAP-orientated research and commercial enterprises, notably fisheries. From a fisheries perspective, there is a growing world food security concern and the need to increase fisheries yields in this region is well recognised. As fishing technology continues to improve, large-scale krill fishing will become economically viable, and within a decade South Africa could find itself well placed geographically to benefit in terms of economics and job development from a krill fishery. This will require concurrent advances in single and multispecies models to provide the basis to maintain and regulate a sustainable fishery; this field is one in which South Africa continues to make valuable contributions.^{38,39}

Bridging together operations with often competing interests is critical for the success of any polar research programme.⁴⁰ It is now critical that these activities be facilitated through a single polar research entity, which provides a platform for multinational and multidisciplinary collaborations. In doing so, the scientific community is able to obtain a critical mass and direct its efforts and limited resources towards key research goals – a strategy adopted by many international partners.

A clear message from the recent workshop for the long-term visibility and sustainability of SANAP is to ensure research outcomes are of global relevance. Such excellence can be attained through high-impact publications, continued leadership in Antarctic and Southern Ocean affairs and high-level and close coordination between science and logistical activities. Most importantly, South Africa's role as both a regional and international leader is linked to the development of high-quality human capital in sciences and numeracy. Furthermore, the associated study fields have to be competitive in terms of bursaries and travel grants, to attract the most talented people within the country. A blueprint outlining future opportunities for early career researchers working in this region is critical for the interaction and strengthening of both international and national networks. The Antarctic and Southern Ocean region provides excellent opportunities for raising public awareness and engaging with the future generation of polar scientists. Not only are the conditions and environment spectacular, but the scope of science from space research to deep sea exploration is extreme. South Africa's ability to enthuse the next generation of scientists can be enhanced by the use of modern day social media and more conventional channels – the recent success of SEAmester, South Africa's Class Afloat programme⁴¹, is an example.

It is critical that, in future years, SANAP continues to remain well positioned to respond to new breakthroughs and new environmental challenges and, at the same time, remains effective in its ability to foster innovation and discovery. Workshops such as the one reported on here are essential to allow scientists to align Antarctic research priorities to national priorities, thereby ensuring a cohesive vision for future research priorities. At a time of tightening budgets and unforeseen cuts in research and logistical support and limited access outside of logistical voyages, the need to prioritise the scientific and societal demands of South Africa remains our greatest challenge. Notwithstanding, Antarctic and Southern Ocean research has made, and will continue to make, pivotal contributions to South Africa's international research standing and our global research footprint.

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