South Africa in the Antarctic Circumnavigation Expedition: A multi-institutional and interdisciplinary scientific project

AUTHORS:
Issufo Halo[1]
Rosemary Dorrington[2]
Thomas Bornman[3,4]
Stephanie de Villiers[5,6]
Sarah Fawcett[7]

AFFILIATIONS:
[1]Department of Conservation and Marine Sciences, Cape Peninsula University of Technology, Cape Town, South Africa
[2]Department of Biochemistry and Microbiology, Rhodes University, Grahamstown, South Africa
[3]South African Environmental Observation Network, Elwandle Coastal Node, Port Elizabeth, South Africa
[4]Department of Botany, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa
[5]Oceans and Coasts Research, Department of Environmental Affairs, Cape Town, South Africa
[6]Department of Chemistry, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa
[7]Department of Oceanography, University of Cape Town, Cape Town, South Africa

CORRESPONDENCE TO:
Sarah Fawcett

EMAIL:
sarah.fawcett@uct.ac.za

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The polar regions are more critically affected by climate change than any other region on our planet.[1,2] On the Antarctic continent and in its surrounding oceans, the effects of climate change are likely to be dramatic,[3] and include large-scale catastrophic ice melt, loss of habitat and biodiversity, and global sea level rise. The 'Southern Ocean' refers to the region where Atlantic, Indian and Pacific Ocean waters come together to encircle Antarctica. These waters connect the different ocean basins by linking the shallow and deep limbs of the global ocean current system ('overturning circulation') and play a critical role in storing and distributing heat and carbon dioxide (CO_2). The Southern Ocean thus regulates not only the climate of the Antarctic, but of the entire earth system.[1,4] By extension, the capacity of the global ocean to ameliorate earth's changing climate is strongly controlled by the Southern Ocean.

Marine phytoplankton (microscopic plants inhabiting the sunlit upper ocean) convert CO_2 (an inorganic form of carbon) dissolved in surface waters into organic carbon through photosynthesis. This organic carbon fuels upper trophic levels such as fish, mammals and birds, and a portion sinks into the deep ocean where it remains stored for hundreds to thousands of years. This mechanism, which lowers the atmospheric concentration of CO_2, is termed the 'biological pump'.[5] The efficiency of the global ocean's biological pump is currently limited by the Southern Ocean, where the macronutrients (nitrate and phosphate) required for photosynthesis are never fully consumed in surface waters. In theory, increased consumption of these nutrients could drive higher organic carbon removal to the deep ocean, enhancing the oceanic uptake of atmospheric CO_2. Indeed, more complete consumption of Southern Ocean nutrients is a leading hypothesis for the decrease in atmospheric CO_2 that characterised the ice ages.[6]

Despite the global importance of the Southern Ocean, knowledge of the controls on and interactions among the physical, chemical and biological processes operating in Antarctic ecosystems is limited, largely because of a scarcity of in-situ observational data, compounded by the challenge of integrating siloed scientific fields. Given predictions that diverse aspects of Southern Ocean physics and carbon biogeochemistry are likely to change in the coming decades, a transdisciplinary approach to studying Antarctic systems is critical.

The ACE project

Driven by the urgent need to improve our understanding of the Southern Ocean and its ecosystems, an international, competitive open call was announced in 2015 for research proposals to participate in an oceanographic voyage around Antarctica (Figure 1). This project – the Antarctic Circumnavigation Expedition (ACE) – plans to follow the path of the largest oceanographic feature of the Southern Ocean, the eastward propagating, wind-driven Antarctic Circumpolar Current (ACC), which mixes oceanic properties across ocean basins and connects numerous Subantarctic island systems. The waters surrounding these islands experience high primary productivity fuelled by nutrients supplied through island run-off and seal and bird activity.[7] The islands also play an important role in the creation and behaviour of eddies[8], which can trap oceanic properties and transport them long distances[9,10], enhancing the role of the ACC as a 'conveyor belt' that connects ocean basins and biological systems (Figure 2).

The goal of ACE, stated in the ACE Project Call for Proposals, is 'to offer international teams of distinguished scientists an outstanding and unique opportunity to study the marine and terrestrial environment of the Subantarctic ecosystem', in a single summer cruise that will start and end in Cape Town (20 December 2016 to 18 March 2017). Over 100 project proposals were submitted to the call, from which 22 were selected by an international panel of experts convened to evaluate them according to criteria based on scientific excellence. Committee members included representatives from polar research institutes in Australia, France, Norway, the Russian Federation, South Africa, Switzerland and the United Kingdom. The 22 selected ACE research projects involve 55 marine and terrestrial researchers from 30 countries working in atmospheric science, biogeochemistry, climatology, glaciology, marine and terrestrial ecology, ocean engineering, oceanography and palaeoclimatology.

The ACE expedition is supported by Ferring Pharmaceuticals and is the maiden project of the newly created Swiss Polar Institute located at the École Polytechnique Fédérale de Lausanne (EPFL), the Swiss Institute of Forest, Snow and Landscape Research WSL, the Swiss Federal Institute of Technology in Zurich (ETHZ), the University of Bern, and Editions Paulsen. ACE will be conducted on board the Russian polar research vessel, *Akademik Treshnikov*, and will consist of three legs: Leg 1 is from Cape Town to Hobart, Leg 2 is from Hobart to Punta Arenas and Leg 3 is from Punta Arenas to Cape Town (Figure 1). During each cruise leg, the ship will stop at numerous Subantarctic islands located in the path of the ACC, allowing for terrestrial and coastal research in addition to the open ocean investigations that will be the focus of the ship's transects.

ACE major objectives and collaborators

Beyond the specific aims of the 22 scientific projects, the objectives of ACE, outlined in the Call for Proposals, are twofold: firstly, 'to enhance international relations and collaborations between countries', and secondly, 'to promote the interest of a new generation of young explorers in polar research'. To achieve these objectives, the implementation of the ACE project is being facilitated by the following partners in addition to the Swiss Polar Institute and EPFL: The Australian Antarctic Division, Institut Paul Émile Victor (France), the Norwegian Polar Institute, the Arctic and Antarctic Research Institute (the Russia Federation), the British Antarctic Survey (BAS), and South Africa's University of Cape Town (UCT), National Antarctic Programme (SANAP), National Research Foundation (NRF) and Department of Science and Technology (DST).

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Figure 1: Proposed route for the Antarctic Circumnavigation Expedition (ACE), on board the R/V *Akademik Treshnikov*. The three legs of ACE are Cape Town to Hobart (Leg 1), Hobart to Punta Arenas (Leg 2) and Punta Arenas to Cape Town (Leg 3). The expected timeline for the cruise is 20 December 2016 to 18 March 2017.

South African contribution: ACE Project XII

South Africa is the only African country to have submitted a successful application to ACE, ACE Project XII: 'A multi-disciplinary, multi-resolution approach to understanding nutrient cycling and microbial diversity in changing Subantarctic ecosystems'. The principal investigator (PI) of this project is Dr Sarah Fawcett from the Department of Oceanography, UCT, with Prof. Rosemary Dorrington from the Department of Biochemistry and Microbiology, Rhodes University, as co-PI. The project involves an additional three South African co-PIs and their collaborators: Dr Thomas Bornman, Elwandle Coastal Node, South African Environmental Observation Network (SAEON) and Nelson Mandela Metropolitan University (NMMU); Dr Stephanie de Villiers, Oceans and Coasts Research, Department of Environmental Affairs (DEA) and NMMU; and Dr Issufo Halo, Department of Conservation and Marine Sciences, Cape Peninsula University of Technology (CPUT). International collaborators from the Department of Geosciences, Princeton University, USA, are also involved.

The broad goal of ACE Project XII is to use microbial diversity (where 'microbial' refers to phytoplankton, bacteria and zooplankton) and metabolic activity in conjunction with measured chemical and physical parameters to develop an integrated model of the Subantarctic island systems in order to better understand their role in Southern Ocean productivity. Investigations of microbe–nutrient interactions will focus on the nitrogen (N) cycle because N exists in marine systems in numerous forms, is linked in a roughly constant ratio to carbon, and is primarily transformed by biology.[11] N is supplied to phytoplankton in different ways. For example, the ocean interior is filled with nitrate (NO_3^-), which is delivered to the sunlit surface ocean by the upward mixing of deep waters. Ammonium (NH_4^+) is produced in surface waters as a by-product of bacterial and zooplankton metabolic activity, and urea (an organic N form) is generated by birds and seals inhabiting the Subantarctic islands and washed into the open ocean by rain or snow-melt. Annually, the amount of phytoplankton growth fuelled by N sources supplied from outside the surface ocean ('new N', the phytoplankton growth upon which is termed 'new production') is balanced by a flux of organic N (and carbon) to the deep ocean ('export production').[12,13] The source and form of N consumed by phytoplankton is thus directly related to the capacity of an ecosystem to absorb CO_2.

To identify the N sources fuelling the island systems and open ACC, the N and oxygen (O) isotope ratios of nitrate and N isotopes of phytoplankton biomass will be measured and interpreted in the context of nitrate, ammonium and organic N concentration data. The N isotopes provide an indication of N source[14-17] and, when combined with measurements of nitrate O isotopes, enable the separation of co-occurring processes (such as nitrification by bacteria and nitrate assimilation by phytoplankton – two processes with very different implications for CO_2 cycling)[18-21]. Microbial community composition will be assessed through a combination of methods selected to maximise spatial coverage and resolution. These methods include: phytoplankton and zooplankton taxonomy; phytoplankton DNA/RNA microarrays that evaluate phytoplankton diversity and gene expression related to N- and carbon cycle processes[22-24]; phenotypic arrays that characterise the metabolic activity of bacterial communities[25,26]; Next Generation Sequencing for microbial diversity[27], and rRNA and cDNA for the identification of metabolically active microbial taxa. Finally, the physical, chemical, and biological data will be incorporated into ongoing high-resolution numerical modelling efforts to produce an integrated view of the Subantarctic systems.

In sum, ACE Project XII will use a multidisciplinary approach to address the following questions regarding Subantarctic microbes and their interactions with their physico-chemical environment: Who is there? What are they doing? Why are they doing it? What are the implications for Subantarctic nutrient cycling, ecosystem function, and CO_2 removal, today and in a warming world?

In addition to ACE Project XII, there is South African participation in seven other ACE projects (led by collaborator countries). South African co-PIs on these projects include: Prof. Ken Findlay, CPUT; Dr Sandy Thomalla, Council for Scientific and Industrial Research; Prof. Peter Ryan, UCT; Prof. Bettine Jansen van Vuuren and Dr Peter le Roux, University of Johannesburg; Prof. Marthaan Bester and Dr Nico de Bruyn, University of Pretoria; Dr Gwynneth Matcher, Rhodes University; and Dr Keith MacHutchon, Coastal Marine Technology Ltd.

Capacity development through ACE

The ACE project offers numerous opportunities for capacity development. Firstly, ACE is funding a Maritime University under the auspices of the Russian Geographical Society. This is an opportunity for postgraduate students from all over the world to participate in a ~25-day transit cruise from Bremerhaven (Germany) to Cape Town during which they will be introduced to the interdisciplinary field of applied marine science. Secondly, ACE Project XII will involve at least four MSc/PhD students and a postdoctoral researcher, to be based at any of the four affiliated South African universities; all co-PIs will contribute to student supervision, thus exposing students to scientific career possibilities within both government and academia. These students will participate in a 3-month multidisciplinary rotation programme between the Dorrington (biology), Fawcett (biogeochemistry), Halo (physics) and DEA/SAEON (marine ecosystem sampling for phytoplankton and zooplankton) groups, the goal of which is to equip them with a range of analytical skills and a broad view of marine systems. Thirdly, ACE Project XII brings together numerous sophisticated and novel analytical techniques, which, when coupled with research visits to international collaborator laboratories, will upskill the students involved and facilitate the transfer of scarce skills that can be applied far beyond this project. Fourthly, to increase the visibility of polar research in general and of the ACE expedition in particular, the ACE management team, together with local and national partners (UCT, DST, SANAP), are planning a series of public events in Cape Town to coincide with the December 2016 departure and March 2017 arrival of the *Akademik Treshnikov.* In addition, ACE Project XII plans to enhance public engagement in science and research through (1) educational efforts facilitated by SAEON's outreach network, which currently includes 13 schools and (2) activities that directly engage the public such as a cruise blog, public lectures, popular articles, media events and participation in national focus events such as National Science Week, National Marine Week and SciFest Africa.

Conclusion

It is anticipated that ACE Project XII (and South African participation in ACE in general) will have a nationwide impact. In addition to developing human capacity, ACE Project XII will yield a deeper fundamental understanding of nutrient cycling and microbial dynamics in the Antarctic, and provide information on ecosystem function in response to environmental drivers. The results will assist decision-makers in formulating appropriate environmental policies to lessen the vulnerability of Subantarctic systems; an example is the Prince Edward Islands, a South African Marine Protected Area (Figure 2).

The research proposed in ACE Project XII is fully aligned with the SANAP mission to 'increase understanding of the natural environment and life in the Antarctic [through] science'[28]. South Africa is also a member of the Commission for the Conservation of Antarctic Marine Living Resources, responsible for contributing to the global effort to conserve Southern Ocean living resources through monitoring and research. This contribution includes research aimed at better understanding the controls on primary productivity, and changes in productivity and carbon cycling related to emerging threats such as ocean warming and acidification. Such fundamental knowledge is key to managing the long-term impacts of global change on the feeding and population dynamics of marine species higher up the food chain, such as fish and top predators. Finally, given that Southern Ocean waters currently support globally significant fisheries, ACE is also relevant to the South African government's ongoing development initiative through Operation Phakisa to 'unlock the potential of South Africa's oceans'[29].

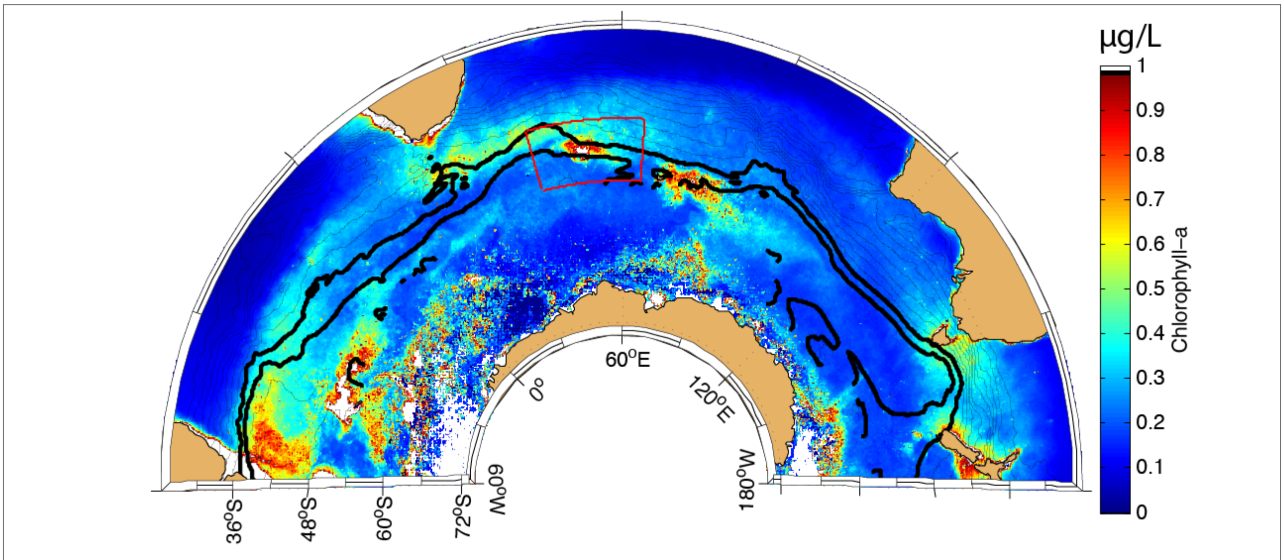

Figure 2: Chlorophyll-a concentrations (μg/L) in the Atlantic and Indian sectors of the Southern Ocean for the austral summer, derived from SeaWifs satellite data averaged for 1997–2004 (spatial grid resolution of 1 degree, nominal temporal resolution of 8 days). Chlorophyll-a is a green pigment used by all phytoplankton for light absorption during oxygenic photosynthesis; the distribution of surface ocean chlorophyll-a can thus be used as a proxy for phytoplankton productivity. The black contours represent streamlines of the mean dynamic topography, computed from the Rio-09 New CNES-CLS09 product and used as a proxy for large-scale geostrophic currents. Bold contours show the core of the Antarctic Circumpolar Current (ACC). The red box indicates the location of the remote South African Prince Edward Islands, where land–ocean interactions will be investigated as part of ACE Project XII. High microbial primary productivity can be inferred from the high chlorophyll-a concentrations around the islands and shallow banks and along the subtropical front.

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