ANTARCTIC CLIMATE & ECOSYSTEMS COOPERATIVE RESEARCH CENTRE

2018/19 Annual Report

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Australian Antarctic Division

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Annual Report 2018-19
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1 Executive Summary

As in previous epochs of the ACE CRC, our work in the ACE CRC benefitted tremendously from international and national partnerships and collaborations, across the disciplines. A summary of our achievements is provided below.

2 Achievements

Research and Collaboration

This final annual report presents the culmination of this incarnation of the ACE CRC in terms of research outcomes. This last year of the five year research program delivered on all the research objectives for the organisation in this funding period.

The objectives of the two reseach programs were to:

- Target key gaps in our understanding of ocean, atmosphere and cryosphere processes in the Southern Ocean and Antarctica, with the aim of informing an effective national response to the challenges of climate change, and to enhance the reliability and utility of climate models.
- Assess the impact of changes in the Southern Ocean and Antarctic cryosphere on atmospheric CO_2 concentrations, ocean acidification, ocean productivity and marine ecosystems.

In respect of Research Program 1 (Oceans and Cryosphere):

- Project R1.1 has completed the assessment of changes in temperature and salinity in the Southern Ocean, and major drivers have been identified for the changes.
- Project R1.2 has examined the sensitivity of the Antarctic ice sheet and ice shelves to changes in the ocean heat flux, and hence the potential contribution to sea level rise.
- Project R1.3 has delivered a significant lift in understanding of the processes of sea ice growth and retreat and potential impact on climate, biogeochemical cycling and marine ecosystems.
- Project R1.4 used ice core records to reconstruct climate changes in the Antarctic region over recent millennia in order to characterise natural variability and extend the instrumental records of recent change.

In respect of Research Program 2 (Carbon and Ecosystems):

- Project R2.1 examined whether the Southern Ocean will continue to moderate climate change via the uptake of atmospheric CO_2, quantified regional and seasonal variations in the extent of ocean acidification, and examined iron supply as a limiting nutrient underpinning Southern Ocean productivity.
- Project R2.2 investigated how key Southern Ocean biota respond to multiple physical and chemical changes, such as warming, acidification and changes in sea ice.
- Project R2.3 assessed the current status and trends of physical habitat, individual species, and Southern Ocean ecosystems as a whole, and the likelihood of future states.

Commercialisation and Utilisation

ACE CRC researchers made a significant contribution to the sixth cycle of the IPCC Reports (IPCC AR6) and the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC).

- Working Group 1 IPCC AR6
    - Dr Catia Domingues (Lead author – Chapter 2: Changing state of the climate system)
- Working Group 2 IPCC AR6
    - Prof Philip Boyd (Lead author – Chapter 3: Ocean and coastal ecosystems and their services; and review editor – Cross-chapter paper: Polar regions)
    - Dr Rebecca Harris (Lead author – Chapter 2: Terrestrial and freshwater ecosystems and their services; and author – Cross-chapter paper: Deserts, semi-arid areas, and desertification)
    - Dr Andrew Constable (Lead author – Chapter 17: Decision-making options for managing risk; and lead author – Cross-chapter paper: Polar regions)
- SROCC
    - Prof Nathan Bindoff (Coordinating lead author - Chapter 5: Changing Ocean, Marine Ecosystems, and Dependent Communities)
    - Dr Jessica Melbourne-Thomas (Lead author - Chapter 3: Polar Regions)

During the reporting period, the ACE CRC undertook a wide variety of activities to communicate our research outcomes to maximise awareness and uptake of our scientific work. This included our final Symposium in Hobart, and a final Research User Forum in Canberra, which presented consultation drafts of two Position Analyses and one Report Card.

Education and Training

During the reporting period more than fifty students were involved in PhD studies relating to ACE CRC actvities, with eleven completions during the year. ACE CRC provided financial support to 10 PhD students.

Awards and Special Commendations

PhD graduand, Chen Zhao, received the highly prestigious and competitive 2018 Chinese Government Award for Outstanding Students Abroad.

Staff appointments

During the reporting period, the ACE CRC recruited the following people:

Mainak Mondal	Ocean Modeller
Chelsea Long	Ice Core Technician

There were no major capital costs for this reporting period.

There were no internal or external reviews of the organisation during the reporting period.

3 Risks and Impediments

During the reporting period, the ACE CRC maintained its organisational risk register to capture the different risks to the ACE CRC to the delivery of the ACE CRC milestones. The ACE CRC identified the inherent risks associated with business continuity, finances, reputation, governance, people and safety, environment and community, and project delivery, as well as mitigation measures and specific actions to reduce our risk profile.

The risk register was regularly updated and discussed at Board meetings during the reporting period, with more detailed consideration and tracking of risks undertaken by the Budget, Audit and Risk Committee. The purpose of the register was to ensure careful management of risks throughout the life of the ACE CRC.

4 Impacts

No significant change occurred during the reporting period that would require adjustment to the Impact Tool.

5 Performance against activities

The ACE CRC completed all its milestones, including some carried over from 2016/17 and 2017/18, by the wind up date of 31 October 2019.

The ACE CRC project portfolio was managed at the level of seven discrete projects within two programs: 'Oceans and Cryosphere' and 'Carbon and Ecosystems'. The overall 'Oceans and Cryosphere' program targeted key gaps in our understanding of ocean and cryosphere processes in the Southern Ocean and Antarctica, with the aim of informing an effective national response to the challenges of climate change. The overall 'Carbon and Ecosystems' program delivered knowledge of drivers and changes in the Southern Ocean carbon cycle and ocean chemistry (iron and acidification), the critical responses of biota to environmental change (primary producers, krill, seabirds, Antarctic seals, whales), and assessments of current status, and future trends and impacts on key species and the ecosystem as a whole. As many of the critical knowledge gaps are found at the interface between domains (atmosphere, ocean, cryosphere, biogeochemical cycles and biosphere), all seven projects were designed to be well-integrated with each other. A detailed summary of the research activities at the project level is provided below with a publications list provided in Appendix 1.

Research Project 1.1 The Southern Ocean in a Changing Climate

Research Project 1.1 examined how and why physical and biogeochemical properties of the Southern Ocean are changing, as well as assessing the human contribution to the change.

The project completed its milestones with a number of notable new achievements including the completion of a new collaborative voyage in the Antarctic Circumpolar Current and new research on the rate of uptake of heat in the Southern Ocean and its contribution from humans.

An ACE CRC supported voyage was carried out in November 2018 in the Antarctic Circumpolar Current looking at the momentum and heat balance of the Polar Front.

This was part of a collaboration with groups from the USA to specifically understand "How does interaction of the ACC with topography slow the current and enable the cross-stream heat fluxes that maintain a global overturning circulation". This research aims to improve how dynamical processes are represented in ocean models with the goal of improving ocean current simulations and climate change projections.

An international Deep Argo pilot experiment in the Australian Antarctic Basin was enhanced in 2018-2019. This was the first deployment of floats capable of profiling the full ocean depth in the high latitude Southern Ocean. The project was led by the ACE CRC and includes contributions from the USA, France and Japan. Three ACE CRC Deep Argo floats were deployed from a Japanese vessel in January 2019. The float data are providing unprecedented spatial and temporal resolution of pathways of Antarctic Bottom Water and, in conjunction with repeat hydrography data, are being used to quantify and understand a recent "rebound" in the salinity and density of this water mass.

The joint US-Australian float experiment in the Ross Sea also continued, with additional float deployments and several voyages to the region by other nations. The floats and ship-based data are allowing the structure and transport of the poorly-observed Ross Gyre to be quantified for the first time.

As was noted in the 2017-2018 report, the assessment of changes in temperature and salinity for the global ocean has been completed with major drivers of the changes identified. The assessment was completed through a sequence of papers and special reports on ocean heat content and salinity change in the Southern Ocean and world ocean. These assessments have featured as part of the annual state of the environment reports published by the Bulletin of American Meteorological Society. The drivers of long-term trends in ocean heat content and salinity change have been assessed using the ACCESS ocean model to isolate and quantify the contribution of changes in wind and of surface temperature and salinity. New products have been created using a 4-D variational approach to quantify changes in the ocean inventory of heat, freshwater and oxygen and extend the record to 2016. The IQUoD compilation of quality controlled data has been released and is an important data product for the AR6 IPCC assessments. Curiously, new research has shown that the observed rapid heat uptake in the Southern Ocean in the last decade has been identified as a combination of an "asymmetric" climate mode and human driven climate change (Rathore et al. submitted). The asymetric mode is a climate mode that has a preferential warming/cooling pattern in the northern hemisphere/southern hemisphere. The last decade has strong cooling in the northern hemisphere and anomalously rapid warming in the southern hemisphere and is also readily identified in coupled ocean atmosphere models. This work thus accounts for the hemispheric pattern as an internal or natural variation superimposed with climate change in the last decade.

ACE CRC has made a significant contribution to the sixth cycle of the IPCC reports. These reports feature ACE CRC related work including contributions from ACE CRC staff to the IPCC assessments. The reports are peer reviewed four times, typically more transparent in their review than traditional research papers and the final summary for policy makers and chapters are agreed to in a plenary session of the 195 participating UN countries. These reports represent an important pathway for the communication of climate change science to governments. Prof Nathan Bindoff led the development of the Oceans Chapter in the IPCC Special Report on Oceans and Cryosphere in a Changing Climate (SROCC). Dr Hobbs and Dr Catia

Domingues were contributors to the Polar, Ocean Sea Level Chapters along with postgraduate student Saurabh Rathore. Dr Catia Domingues is lead author in the AR6 report Climate Change 2021: The Physical Science Basis. The final assessment from SROCC will be published in September 2019. The AR6 report will be published in 2021 and the work will feature in an official session at the Ocean Sciences meeting in February 2020.

The project published a number of important research papers during the reporting period. Downes et al. (2019) used helium data and estimates of ocean mixing in the deep ocean to show that buoyant hydrothermal plumes enhance abyssal mixing where the Antarctic Circumpolar Current interacts with sea floor topography. Silvano et al. (2019) used profiling floats "parked" on the sea floor between profiles to obtain the first measurements of the complete annual cycle underneath sea ice on the continental shelf near the Totten Glacier. The measurements showed that warm water was widespread and persistent on the continental shelf and capable of driving rapid rates of basal melt of the floating ice shelf. The inflow of warm water was shown to depend on seasonal variations in currents near the shelf break. A paper including scientists from several ACE CRC themes demonstrated that differences in sea ice and supply of Circumpolar Deep Water could explain variations in biological productivity of three Antarctic coastal polynyas (Moreau et al., 2019).

Research Project 1.2 Ocean Forced Evolution of the Antarctic Ice Sheet

Research Project 1.2 determined the sensitivity of the Antarctic ice sheet and ice shelves to changes in ocean heat flux and the potential contribution to sea level rise.

The project has reported a productive year of research and completed all research outputs. Notable achievements include a successful summer field season on the Totten Glacier downloading data and retrieving instruments from the grounding zone. Simultaneous active seismic mapping of the glacier bed confirmed directly the presence of large subglacial lakes with a water thickness of up to 70 m, a key discovery for understanding the dynamics of the glacier. The Totten has been a key focus of research throughout the last five years, and two important papers were published this year examining the variability of basal melt underneath the ice shelf – a key component of its mass balance (Gwyther et al. 2018, Greene et al. 2018).

At the Sørsdal Glacier, near Australia's Davis research station, geophysical instrumentation was also retrieved. These data are under analysis for publication, and show for the first time the daily and seasonal cycle of water flow over the glacier's surface. This provides the first direct measurements of how surface ponds can form and discharge, which can influence both the flow and calving of ice shelves, which are expected to increase as air temperature around Antarctica warms.

Progress was made in ice-sheet modelling activities, with a particular focus on subglacial processes. Papers from the research team examined the effect of basal sliding on the future theoretical retreat of West Antarctica, as well as the already observed retreat of the Fleming Glacier, Antarctic Peninsula (Jong et al. 2018, Zhao et al. 2018a, 2018b). These studies give a key insight into the behaviour of the ice

sheet under changing conditions, allowing us to better predict the speed of future retreat events.

This year also saw publication of the first numerical analysis of how rifts develop and drive iceberg calving on the Totten Glacier (Cook et al. 2018). This international collaboration applied innovative engineering fracture mechanics methods to modelling an ice shelf, demonstrating the complex range of processes driving iceberg formation. The project is now progressing to a more numerically efficient method, developed for ice sheet simulations in collaboration with engineers from Dalian University of Technology, and three visits between ACE CRC and DUT staff have already been undertaken to develop the code required.

Research Project 1.3 Sea Ice Processes and Change

Research Project 1.3 was aimed at improving understanding of the processes of sea ice growth and retreat to assess future changes in sea ice volume and extent and their impact on climate, biogeochemical cycling and marine ecosystems.

The project completed all milestones, including those outstanding from previous years. We also produced a Position Analysis on Antarctic Sea Ice and Climate Change. And in the case of one piece of work – the high-profile *Nature* article by Massom et al. (2018) –a new research direction was created, namely the effect of sea-ice loss on ice shelf stability and disintegration.

In respect of Milestone 1.3.3, satellite fast ice mapping and analysis produced the first-ever mapping of complete circumpolar fast ice coverage at high spatial (1 km) and temporal (15-day repeat) resolution as well as quantifying its change/variability over the period 2000-2014. This major ground-breaking achievement and new dataset addresses a key knowledge gap identified in the IPCC 5th Assessment Report. It was launched internationally when Dr Fraser who gave an invited keynote address at the International Glaciological Society International Sea Ice Symposium in Canada in August 2019.

The project also produced the first quantification and analysis of circum-Antarctic coastal complexity. This shows that the Antarctic coastline comprises 3 dominant classes i.e. complex at both short and long length scales and low complexity**,** and highlights contrasts between East and West Antarctica and regional variations.

Substantial new insights into the drivers and nature of sea-ice change and variability included:

- Model sensitivity experiments investigating the main drivers of observed recent trends in Antarctic sea ice and Southern Ocean sea-surface temperature or SST (Kusahara et al., Climate Dynamics, 2019). These suggest that the observed trend of overall (net) sea-ice expansion (since 1979) is mostly explained by trends in the thermodynamic surface forcing, notably cooling and drying and a reduction in longwave radiation.
- Publication of a model study of the record Antarctic sea-ice minimum in 2016 (Kusahara et al., 2018, Environmental Research Letters) which suggested that this unanticipated event is largely attributable to thermodynamic surface forcing (53%), while wind stress (as it affects sea-ice dynamics and

deformation) and the sea-ice and oceanic conditions from the previous summer (January 2016) explain the remaining 34% and 13%, respectively

For milestone 1.3.4, the project achieved major outcomes and outputs by deriving important new MIZ information from a number of sources. Remote sensing enabled an extension of aspects of this milestone so instead of only characterising MIZ during maximum extent, we have been able to map and quantify the MIZ for the majority of the year (April to November). This enabled a first physically-based quantification of MIZ extent and its change/variability (since 2007), validated by in situ observations. Key statistics from this work (being finalised in a paper) are:

- Maximum circum-Antarctic MIZ extent: 6.0 million km^2;
- MIZ trend overall: +3,733 km^2/year; and
- MIZ trends per region/sector (2007 – 2017): Ross Sea: +3,181 km^2/year; Bellingshausen and Amundsen seas: +1,996 km^2/year; Weddell Sea: -6,310 km^2/year; Indian Ocean: -2,496 km^2/year; and Western Pacific Ocean: +7,363 km^2/year.

Milestone (R1.3.4) to estimate East Antarctic sea ice volume at maximum extent was successfully completed with the publication of a model analysis of change and variability in Antarctic sea-ice volume (1979-2014), and its seasonal and regional patterns (together with the factors responsible), in *Climate Dynamics* (Kusahara et al., 2019). For East Antarctica (20°E-160°E), the mean volume (unit = $x10^3$ km^3) at maximum extent is: 3.45 ±0.247, ranging from 2.959 (in 1986) to 4.049 (in 2013).

We are also pleased to report the successful completion of milestone R1.3.5 relating to satellite remote sensing and numerical modelling. Major advances were made in terms of validating our ability to derive gap-filling new sea-ice datasets from satellite data, our understanding of key sea-ice parameters and processes, and key aspects of sea-ice numerical modelling.

The following outcomes regarding improvements to sea-ice modelling and process understanding were also achieved:

- Improvement of high-resolution models through inclusion of accurate project-derived information on fast-ice distribution e.g., Kusahara et al. (2017), leading to key insights into sea-ice-ocean-ice sheet interaction processes around the Antarctic coastal margin. This has also led to more accurate assessment of sea-ice production rates and associated brine rejection rates (water-mass modification) e.g., in and around the globally-important Mertz Glacier Polynya, in joint work with ACE CRC Japanese partners.
- The new high-resolution information on fast ice distribution has enabled detailed analysis of the effect of fast-ice change and variability on the stability of the Wilkins Ice Shelf. This includes in a high-profile Nature article (Massom et al., 2018) and a follow-on paper (Massom et al., in prep.) on the role of regional fast ice and pack ice loss in triggering catastrophic ice shelf disintegrations on the Antarctic Peninsula.

Research Project 1.4 Antarctic Climate Variability of the Past 2,000 Years

Research Project 1.4 used ice core records to reconstruct climate changes in the

Antarctic region over recent millennia in order to characterise natural variability and extend the instrumental records of recent change.

During the reporting period, the project continued to work with the international PAGES2k initiative, which is studying past global changes of the last 2,000 years. The Australian group continues to play an important role in the PAGES Ant2k and CLIVASH2k (Climate variability in Antarctica and Southern Hemisphere in the past 2,000 years) that aims improve our understanding of large-scale modes of climate variability and the mechanisms and drivers of climate change in Antarctica, the sub-Antarctic and the wider Southern Hemisphere during the past 2,000 years. We also played a role in submission to the PAGES Iso2k working group to develop a global database of paleo-water isotopes covering the past two millennia. Our dating and synthesis have now been completed for Law Dome 2,000 years, PAGES 2k, CLIVASH and Iso2k community products expect to be published as ACE CRC legacy contribution to the new AAPP.

Engagement with Dr Anthony Kiem from the University of Newcastle regarding hydrology work continued during the period. Dr Anthony Kiem, Dr Tessa Vance and Dr Jason Roberts have been working on the ARC Discovery project to investigate 'Flooding in Australia - are we properly prepared for how bad it can get?'. Work continued with Dr Chris Plummer and Dr Lenneke Jong to provide the numerical quality control on extending the 1,000-year Australian rainfall reconstruction to the full 2,000 years before present and up to present day (2017). This has now been completed and will be written up as part of the new AAPP initiative.

A major activity during the reporting period was the continued analysis of the important Mount Brown South (MBS) ice core. This experienced some delays including core processing delays (from ice cores broken during transit from the field), chemistry analysis delays (from an unknown contaminant in the freezer laboratory which interfered with analysis) and isotope analysis delays (from system break down time, sample backlog due to sampling at considerable finer resolution than originally planned, and staff resourcing due to leave and absences). Despite these issues, it is expected that full records of the primary parameters will be completed with some additional work as part of post-ACE CRC initiatives, principally by the AAPP. The shallow MBS ice cores have been dated back to 1971 and the data quality from this site is excellent, providing us with a very high degree of confidence that this will prove to be an important site for climate reconstructions. Work is continuing on interpretation of this important period of instrumental overlap (1971-2017) and will further enhance and contribute the value of ice core proxies for exploring climate processes and forcing, which is a key research priority identified to characterise natural variability and extend the instrumental records of recent change.

The majority of analysis of key analytes for this milestone was completed by the ACE CRC wind up, including additional ice core sample processing and analysis of the 295m deep ice core. Further quality control, dating and interpretation will form an important legacy project from ACE CRC into the new AAPP initiative. On completion of all laboratory analysis, including data quality control of raw data, dating and subsequent interpretation, the project team will produce and publish the MBS ice core age model and accumulation record, as well as a temperature record using water isotope data. Exploratory analyses of instrumental overlap data and corresponding atmospheric modelling will be completed. Interpretation and synthesis papers will be published, including PAGES key data inputs of temperature,

sea ice extent proxies and volcanic fluxes. Atmospheric modelling work identifying key climatic drivers, and initial interpretation of climate mode proxies and Southern Hemisphere (including Australian) climate teleconnections will also be produced. Additionally, this project will provide records of 1,000 years of climate information for many future research initiatives post-ACE CRC.

The Aurora Basin North ice core dating age scale has been finalised and distributed to collaborators. Dr Mark Curran recently visited LSCE and IGE in France to work on two papers namely high-resolution stable isotope and snow accumulation from the shallow cores and a continuous carbon monoxide emissions record. This completed ABN dating scale and ABN data will be a valuable product from the ACE CRC to support post ACE CRC initiatives. ABN sample analysis and processing has continued, and samples have been provided to national (CSIRO/ANSTO) and international (LSCE/CIC/AWI) partners for further measurements.

The appointment of Dr Joel Pedro brought enhanced scientific input to the group and Dr Pedro investigated a detailed covariance study of EPICA Dome C temperature gradient and Law Dome sea salts spanning 19,000 to 6,000 years BP, and a reconstruction of westerlies over this period. Additionally, a Pedro et al. paper on abrupt climate changes with international collaborators is in final stages of preparation and soon ready for submission. Dr Pedro has also contributed to work submitted on sub-Antarctic ice core expedition papers (with Drs Thomas, Markle and Vallelonga) exploring new sea ice proxies (King et al, submitted). This added to our understanding of sea ice reconstruction from ice cores already delivered during the ACE CRC and will be a key focus moving into the AAPP initiative.

An opportunity arose during the reporting period for Dr Lenneke Jong to join a joint CSIRO (Dr David Etheridge) and Uni Rochester, USA (Dr Vasilii Petrenko) led ice core drilling project which obtained a 100m ice core from a high accumulation site East of DSS, called DE08. This adds significantly to our three existing Law Dome ice cores of varying snow accumulation rates (namely DSS, W10k and W19k) which have all been collected during the ACE CRC term. The combined records will be used to study the influence of different snow accumulation rates on the preservation of the chemical signals and how they are interpreted (e.g. volcanic activity). This new high snow accumulation rate site will be used to test our hypothesis that chemicals across Law Dome are primarily wet deposited; that is, they are dissolved and deposited in snowfall events rather than settling directly from the atmosphere (dry deposited). This process impacts the way the basic chemical measurements must be translated into intensity of production, for example sulphate deposition from volcanoes. This work from the ACE CRC will underpin high priority research in the new AAPP. All ice core processing, analysis and interpretation will be achieved as part of the AAPP.

Another important activity during the reporting period was the opportunity to borrow a line scanning instrument from Dr Criscitiello (University of Alberta, Canada). This work involves Dr Nerilie Abram (ANU), Dr Tessa Vance, Dr Alison Criscitiello (University of Alberta) and Dr Adam Treverrow. This resulted in a visit by Dr's Abram and Criscitiello and hiring a number of assistants to assist with the ice core scanning. This was a unique opportunity to get extra scientific information from the MBS ice core through non-destructive methods. This non-destructive imaging of the MBS ice core will characterise the visible layers within the ice core and assess the environmental information that they represent (e.g. melt layers and wind crusts) and to provide an independent measure of snow accumulation rate. The line scanning was completed

in August 2019, with interpretation to occur as part of the new AAPP and lead to a publication expected in 2020.

Research Project 2.1 Carbon Uptake and Chemical Change

Research Project 2.1 determined whether the Southern Ocean will continue to moderate climate change via uptake of atmospheric CO_2, quantifying regional and seasonal variations in the extent of ocean acidification, and examining iron supply as the limiting nutrient underpinning Southern Ocean productivity.

The project performed well in the reporting period with all milestones completed. As a result of rescheduling and vessel change for the main part of the SR3 section (research milestone R2.1.3) this fieldwork was completed in the 2017-18 reporting period (with all objectives either achieved or exceeded). Associated research publications include papers on observed decadal changes in ocean CO_2 contents along the SR3 section (Conde Pardo et al., 2017), and international synthesis of decadal changes for the South Pacific Ocean (Carter et al., 2019). SR3 hydrographic section CO_2 data are available through the portal of the Global Ocean Data Analysis Project (GLODAP), and underway surface ocean CO_2 measurements via the portal of the Surface Ocean CO_2 Atlas (SOCAT). These papers have been used in local, regional, and global syntheses to determine large scale inter-annual change in ocean carbon uptake for the Southern Ocean (Landschutzer et al., 2015; Conde-Pardo et al, 2017, LeQuere et al., 2018; Carter et al., 2019) and also in projections of future extents of ocean acidification (Sutton et a., 2019; Conde-Pardo et al., 2019). Data and research outputs from the iron component of SR3 will be synthesised, published and submitted to the GEOTRACES Data Assembly Centre in late 2019. Process studies in coastal Antarctic polynyas suggest that the high productivity is driven by iron-rich sea-ice meltwater as well as the inflow of iron-rich modified Circumpolar Deep Water onto the shelf (Moreau et al., 2019).

New perspectives on carbon cycling built by synthesising high frequency automated observations using the Southern Ocean Times Series moorings have been completed with several papers published and several others in review. These new insights are summarised below:

- Despite the very deep mixed layers (~500 m) that occur in winter, net community production (NCP) is significant during this period and into early spring, accounting for ~30% of the annual NCP prior to the onset of stratification which starts about October 1 based on the heat flux changing sign from out to into the ocean (Weeding and Trull, 2014). The winter time production is also revealed by bio-optical sensor records (Schallenberg et al, in review) and may result from reduction of grazing in winter owing to the dilution of the zooplankton to phytoplankton ratio and/or ephemeral stratification events (Trull et al., 2019, in review). These results suggest that future changes in CO_2 uptake in the SAZ are likely to be controlled as much by winter as summer conditions.
- While the pCO_2 seasonal cycle in the SAZ south of Australia as observed at SOTS has much lower amplitude than the strong drawdown that occurs in the iconic North Atlantic bloom at similar latitudes in the northern hemisphere, it also has much greater duration leading to a larger transfer of CO_2 into the ocean over the annual cycle (Shadwick et al., 2015). This result further emphasizes the importance of the Southern Ocean to carbon sequestration of both

anthropogenic and pre-anthropogenic CO_2. This seasonal cycle may now be evolving in response to changing seasonal frontal movements and circulation, processes that also affect ocean acidification in south eastern Australian coastal waters (Conde-Pardo et al, 2019).

- The SAZ phytoplankton community is numerically dominated by very small cells, especially Phaeocystis species, with bio-volume approximately equally partitioned across diatoms, dinoflagellates, and ciliates. The system fully depletes silica seasonally yet manages to export organic carbon to depth (~1.1 g C m^{-2} yr^{-1}) at levels similar to the global median (Eriksen et al, 2018). Thus, lack of silica does not appear to strongly limit export production. This suggests that projected possible increases in Fe fertilisation from strengthening boundary currents and winds would be able to drive increase carbon sequestration by the biological pump, even if silica inputs do not increase in parallel.

Scientific findings have been transferred into outcomes for stakeholders, notably through the preparation of Position Analysis papers and delivery at Research Users Fora in Canberra to Government departments and agencies, as well as outreach activities for local communities and schools. Project RP2.1 research findings are also relevant to the recent intergovernmental agreements establishing ocean acidity as one of seven targets for the United Nations Sustainable Development Goal for the oceans, and as a headline climate indicator for the United Nations Framework Convention on Climate Change.

Research Project 2.2 Biological Responses to Environmental Change

Research Project 2.2 investigated how key Southern Ocean biota respond to multiple physical and chemical changes, such as warming, acidification and changes in sea ice. One of the fundamental questions addressed by the project is how climate change will affect the growth of key phytoplankton species. To understand this question, ACE CRC researchers employed novel experimental methods for understanding the environmental conditions that influence the growth of phytoplankton, and how they might change during the coming decades.

The project team completed experiments on the growth response of key diatom species under projected ocean conditions for the year 2,100. Where past experiments on phytoplankton have tended to focus on the effect of changes in individual properties such as acidity or temperature, this study combined multiple drivers, including light, nutrients, carbon dioxide, temperature and iron, in order to get an understanding of how these drivers interact and of their combined effects on phytoplankton. Preliminary data analyses indicate that phytoplankton activity is likely to increase significantly, with phytoplankton in the sub-Antarctic Southern Ocean to grow at almost twice their current rate by 2,100. However, while some species are likely to benefit significantly, others are likely to suffer declines in productivity. Thus, it is still too early to make conclusions how phytoplankton communities (i.e. other diatom species, polar diatoms; other functional groups such as ubiquitous pico-eukaryotes) will change and how this will affect the broader structure of the ocean ecosystem. The experimental work has been complemented with a ship-based survey onboard *RV Investigator*. During the 2018 voyage, RP2.2 personnel measured phytoplankton iron-uptake and carbon export rates in the vicinity of the Southern Ocean Time Series (SOTS) site.

Experiments on Antarctic krill tested the response of adult krill to ocean acidification

(Ericson et al., 2018). This research showed that adult krill were able to survive, grow and mature when exposed to near-future ocean acidification (1,000 – 2,000 µatm pCO_2) for one year. The ability to of the body fluid seems to be the key to the resilience of adult krill to ocean acidification, however, endogenous rhythms controlling metabolic rate, combined with food availability in the wild, may influence the vulnerability of krill to high pCO_2 in winter. In contrast, krill embryos appear to be unable to maintain this acid-base balance and therefore more vulnerable to ocean acidification. Krill embryo hatch rates rapidly declined beyond 1000 ppm, and none of the embryos in the experimental tank survived when concentrations reached 2,000 ppm. This effect could be further exacerbated by other stressors such as ocean warming.

Work on sea-ice ecosystems included publication of a meta-analysis of historical sea-ice algal biomass data from Antarctic coastal locations resulting in a first constructed annual cycle of Antarctic fast-ice algal biomass and identifying key physical drivers in ice algal seasonal development (Meiners et al., 2018). In addition, RP2.2 personnel participated in a German-led expedition (Dec 2018 – Feb 2019) that improved understanding of the association of juvenile krill with under-ice habitats in the Antarctic marginal ice zone during summer. In summary, all project milestones are now completed.

Research Project 2.3 Status and Trends in Ecosystems

Research Project 2.3 assessed the current status and trends of physical habitat, individual species, and Southern Ocean ecosystems as a whole, and the likelihood of future states.

During the reporting period, the project substantially progressed a marine ecosystem assessment for the Southern Ocean (MEASO) through two international workshops on the topic in the UK and France to finalise the outcomes of MEASO, including assessments of habitats, status and trends of biota, and assessment of food web models. Results will be published in a special issue of *Frontiers in Ecology and Evolution* (co-listed in *Frontiers in Marine Systems*). Results were also presented to the Scientific Committee for the Conservation of Antarctic Marine Living Resources in October 2019 and deliver into the IPCC's sixth assessment report. A paper on the status of data and models for MEASO has been published in the *Journal of Marine Systems* as part of a special issue on Australian Coastal and Ocean Modelling and Observation in Australia's Integrated Marine Observing System (Brasier et al. 2019). Research Project 2.3 also delivered foodweb models for East Antarctica, and the first circumpolar assessment of marine foodweb structure for the Southern Ocean.

The special issue in *Deep Sea Research II* arising from the Kerguelen Axis Marine Science voyage in 2016 is almost completed with most papers now accepted for publication. The design of a circumpolar observing system has continued with ACE CRC making a substantial contribution to a publication on advances to the Southern Ocean Observing System and its priorities for the next five years (Newman et al. 2019). Further progress on biological variables was made in this regard at the annual Science Steering Committee meeting of the Southern Ocean Observing System (SOOS) in May 2019 with a publication due for submission later in 2019 on the priority variables. This will be part of the MEASO special issue.

R2.3 scientists were highly engaged in science communication and delivery of science to stakeholders during the reporting period, including presentations to 1,700 school students at the World Science Festival in Brisbane (March 2019), delivering a workshop on science communication using infographics at the international IMBeR Open Science Conference (June 2019) and contributing as Lead Authors to IPCC reports.

6 Education and Training

Education

The ACE CRC education program continued to be supported by, and provided through, the University of Tasmania's Institute for Marine and Antarctic Studies (IMAS) where students study a range of topics relevant to Antarctica and the Southern Ocean.

During the reporting period, 53.5 (FTE) students were involved in PhD studies related to ACE CRC activities. There were 11 completions during the reporting period. Of the 11 PhD students that graduated during the reporting period, 4 are in post-doctoral positions at partner institutions. A further 5 graduated PhD students are in post-doctoral positions overseas with 2 graduants employed in non-academic positions. There have been strong employment outcomes for this year's PhD graduates, who continue to develop outstanding careers.

The ACE CRC provided financial support to 10 PhD students through top-up scholarships, which were awarded through a competitive process.

In total, 44 UTAS staff and 22 non-university staff including in-kind contributed staff were involved in PhD supervision.

Two Honours students graduated during the reporting period. One of the graduated Honours students is awaiting outcome of a PhD scholarship for a project within IMAS.

Arrangements have been made with IMAS to ensure student supervision for the continuing students completing their course is guaranteed.

A list of PhD students, including commencement date, research program, project title, host research institution, student's country of origin and expected completion date, is provided in Appendix 2.

PhD graduant, Chen Zhao received the highly prestigious and competitive 2018 Chinese Government Award for Outstanding Students Abroad. This award was established by China Scholarship Council in 2003 and it is considered to be the highest award given by the Chinese government to graduate students studying aboard and do not receive any financial support from Chinese Government.

Twenty-eight PhD students, Honours students and early career scientists from 5 different Universities in Australia and New Zealand participated in the Advanced Ocean Modelling Summer School in Tasmania early May. The Summer School was organised by PhD students and co-funded by the ACE CRC to hold the workshop and bring lecturers to Tasmania. Participants learned vital skills to develop and improve ocean models and in the process strenghtened the ocean modelling community across institutes.

The ACE CRC had several structures in place for interaction with and between students. The 'ACE Chit Chat' series has been up and running since 7 June 2012 and has been managed by ACE CRC PhD students since September 2013. The 'ACE Chit Chat' sessions were held fortnightly and update staff and students on what other colleagues or students are currently working on, promote discussion, feedback and collaboration, and faciliate interaction with colleagues and students from different organisations. The weekly IMAS, CSIRO and AAD seminars also allowed for students and researchers to have discussions and improve collaborations.

7 Engagement with Small and Medium Enterprises (SME)

In collaboration with SGS Economics and Planning, an SME as well as a formal ACE CRC 'Other Participant', the ACE CRC successfully completed several projects by providing domain specific expertise both in a procedural or organisational context (such as understanding the scientific research sector and appropriate contacts, information or data sources), and in an academic context (reviewing existing literature; providing expert analysis or advice on climate change and its impacts).

The ACE CRC was an active contributor to the Tasmanian Polar Network, a group of businesses and scientific organisations based in Tasmania, that all have a common focus on supporting commercial and scientific activity in the Antarctic, sub-Antarctic and the Southern Ocean.

8 Commercialisation, Utilisation and Communication

The nature of ACE CRC research was the creation and utilisation via creative commons and open sourcing, and in general, consistent with the Antarctic Treaty, the approach is one of full sharing of research within the Antarctic research community.

The ACE CRC undertook a wide variety of activities to communicate our research outcomes to maximise awareness and uptake of our scientific work. Most day to day communication activities were managed jointly with its partner organisations.

Outreach activities took place with elected representative, policy makers and the public, as well as within the science community. These included briefings to politicians and representatives across all level of government; public lectures, school visits and science festivals; and regular review with key government departments such as the Department of Environment and Energy, and the Department of Industry, Innovation and Science, commercial participants, and ACE CRC's essential and other research participants.

During the reporting period, the ACE CRC hosted two key events and several small workshops, attended by 133 delegates in total.

The ACE CRC managed its communications jointly with its partner organisations.

ACE CRC Symposium

The ACE CRC held its final Symposium on August 1, 2018. The ACE CRC Symposium was attended by over 160 delegates, including from key Government departments. A 32-page booklet covering highlights from the past three decades of ACE CRC research was produced for the event and is available online.

Canberra Research User Forum

The ACE CRC hosted a one-day Research User Forum on 7 March 2019 at the Shine Dome in Canberra. Researchers from the projects R1.1 and R2.2 as well as the Climate Futures group presented consultation drafts of two new Position Analysis publications and a Report Card.

- Position Analysis: Causes and Consequences of Southern Ocean Change
- Position Analysis: Australian Climate Futures
- Report Card: Potential Tipping Points in the Southern Ocean

Feedback and input from the event helped shape the content of the final documents. All Position Analysis publications are available online.

Other

The following small workshops were hosted by the ACE CRC during the reporting period:

- Deglacial carbon cycle workshop – 7 March 2019
- Sea-ice modelling workshop – 19 February 2019
- Microbiomes workshop – 29 October 2018

Beer Aquatic was a monthly public discussion series supported by the ACE CRC and organised by two ACE CRC researchers on the last Thursday of every month. The series allowed for informal and accessible oceanic and Antarctic science discussions in the pub.

9 Intellectual property management

The ACE CRC was a public-good research centre focussed on the important role of Antarctica and the Southern Ocean in the global climate system, and on climate change and its impacts in the Antarctic, Australia and the world.

The value of the ACE CRC's IP can be measured by its social and environmental impact. As a public good CRC, the ACE CRC aimed to make its research outputs widely and freely available consistent with the terms of the Antarctic Treaty System to which Australian is a signatory and with the conditions of participation within the Australian Antarctic Program. As such the ACE CRC did not seek commercial returns from its IP.

The ACE CRC IP comprised research outputs documented and published in peer-reviewed journals and public-ready documents such as position analyses and report cards. Data sets include those collected as part of Antarctic fieldwork as well as the outputs of climate models, such as sea-ice and ice-sheet models (and the sea-ice web-tool now with TPAC). These are all publicly available through repositories such as the Australian Antarctic Data Centre, Tasmanian Partnership for Advanced Computing, and the Integrated Marine Observing System. These data sets provide invaluable public-good assets for researchers now and in the future. A list of data and other research outputs is available on the ACE CRC legacy website.

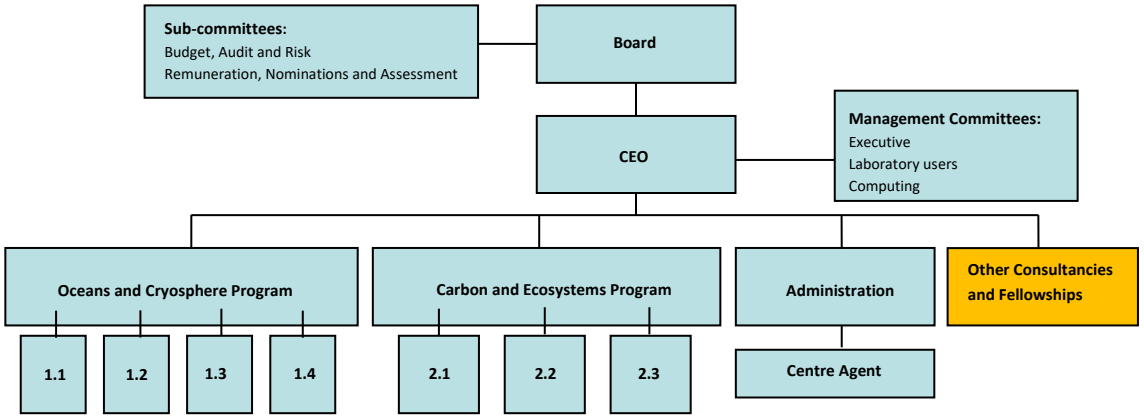
The ACE CRC archived its data and meta data with the Australian Antarctic Data Centre. This is a requirement of any Australian Antarctic research project to comply with Antarctic Treaty obligations.

The ACE CRC did not hold any patents in Australia or overseas.

10 Governance – board, committee and key staff

The ACE CRC was an unincorporated joint venture comprising of 7 core and 14 supporting partners, or 'other participants'. The participating organisations had a Centre Agent agreement with UTAS which provided that UTAS acted as the legal entity for the ACE CRC in respect of such matters as contracts, financial transactions and taxation. The seven Essential Participants were bound by the Participants Agreement, and the Other Participants Agreements set out the duties and commitments of the remaining 14 parties.

The governance and management structure of ACE CRC was as follows (as at 30 June 2019):



BOARD #

Katherine Woodthorpe – Chair
Tony Coleman – Independent
Gordon Hagart – Independent
Nick Gales/Kim Ellis – AAD
Sue Barrell/Peter May – BoM
Tony Worby – CSIRO
Brigid Heywood/Anthony Koutoulis – UTAS
Matt Cahill – Dept. of Environment & Energy
Karen Rees – Tas Government
Mark Kelleher – Ex officio
Gwen Fenton – Ex officio
Wenneke ten Hout – Board

MANAGEMENT TEAM ~

Mark Kelleher – CEO
Wenneke ten Hout (0.8) – Business Manager
David Reilly – Public Affairs Manager (until Sep 2018)
Claire Rutherford (0.4) – Admin

EXECUTIVE COMMITTEE #

Mark Kelleher – CEO (Chair)
David Reilly – Public Affairs Manager (until Sep 2018)
Wenneke ten Hout – Exec Secretary/Education
Steve Rintoul – Program Leader
Tas van Ommen – Program Leader
Tom Trull – Program Leader
Andrew Constable – Program Leader
Nathan Bindoff – University liaison/Climate Futures
Ben Galton-Fenzi – Co-chair, Computing Committee

LAB USERS COMMITTEE #

Pamela Quayle – ACE Lab Manager (Chair)
Zanna Chase – Lab 304
Pier v/d Merwe – Lab 306
Cathryn Wynn-Edwards – Lab 308
Adam Treverrow – Lab 310
Andrew Moy – Lab 312D
Meredith Nation – Lab 312
Toby Bolton – IMAS Lab Manager

COMPUTING COMMITTEE #

Jason Roberts – Co-Chair
Ben Galton-Fenzi – Co-Chair
Alex Fraser - Secretary
Brendon Davey – TPAC
Chen Zhao – Student rep
UTAS IT representative

~ Met weekly
^ Met monthly
# Met quarterly

The Board

The Board was constituted with a view to balancing the skills and experience of its members, and operated in accordance with the provisions of the Participants' Agreement.

The Board comprised of (i) an independent Chair, (ii) one representative from each Australian Essential Participant, (iii) one representative of the Tasmanian Government, (iv) one representative of the Commonwealth Department of Environment and Energy, (v) two persons independent of the Participants and (iv) the CEO and the AAD Chief Scientist who are ex-officio members.

During the reporting period, Dr Peter May commenced on the Board after the Bureau of Meteorology representative seat was vacated by Dr Sue Barrell late 2018. Dr Brigid Heywood from UTAS was replaced on the ACE CRC Board by Prof Anthony Koutoulis late 2018. Mr Kim Ellis commenced on the Board after the AAD representative seat was vacated by Dr Nick Gales late 2018. In the second half of the reporting period, the Tasmanian Government representative was elected, Ms Karen Rees.

Board meetings are held every quarter. During this reporting period, meetings were held on 6 August 2018, 6 November 2018 (including Annual General Meeting), 12 February 2019 and 14 May 2019.

Board Members (in alphabetical order)

Name	Role	Key Skills	Independent/ Organisation	Number of meetings
Dr Sue Barrell	Board Member	- High level national and international experience in science and policy - Science expertise in satellite meteorology, cold front dynamics and cloud band climatology	Bureau of Meteorology	1/1 (replaced by Peter May late 2018)
Mr Matt Cahill	Board Member	- High level management skills - Extensive experience in government and public policy	Department of Environment and Energy (Essential Participant)	2/4

Name	Role	Key Skills	Independent/ Organisation	Number of meetings
Mr Tony Coleman	Board Member	- High level executive management experience in private enterprise - Financial audit, actuarial and risk management expertise - Commercial objectivity and independence from CRC participants	Independent	3/4
Mr Kim Ellis	Board Member	- High level national and international experience in policy - Extensive experience in large-scale transformational change	Australian Antarctic Division (Essential Participant)	2/3
Dr Gwen Fenton	Ex-Officio	- High level science planning and coordination experience - High level national and international experience in science and policy - Science expertise in stable isotope analysis of marine food webs	Australian Antarctic Division (Essential Participant)	4/4
Dr Nick Gales	Board Member	- High level national and international experience in science and policy - Science expertise in applied marine mammal conservation science	Australian Antarctic Division (Essential Participant)	1/1 (replaced by Kim Ellis late 2018)
Mr Gordon Hagart	Board Member	- Extensive experience in financial services including investment - Extensive experience in leadership and management at senior levels	Independent	4/4

Name	Role	Key Skills	Independent/ Organisation	Number of meetings
Prof Brigid Heywood	Board Member	- Extensive experience in research leadership and management at senior and institutional levels - Broad and extensive expertise in biological sciences	University of Tasmania (Essential Participant)	1/1
Mr Mark Kelleher	Ex-officio	- High level executive management experience in both policy and operational roles in the public and private sector - Extensive experience in international business, investment and trade, tourism, and corporate governance and stakeholder management	ACE CRC	4/4
Prof Anthony Koutoulis	Board Member	- Extensive experience in research leadership and management at senior and institutional levels - Broad and extensive expertise in plant sciences	University of Tasmania (Essential Participant)	2/3
Dr Peter May	Board Member	- Extensive experience in research leadership and management at senior and institutional levels - Broad relevant domain expertise in climate and atmospheric science	Bureau of Meteorology (Essential Participant)	3/4
Ms Karen Rees	Board Member	- High level executive management experience in both policy and operational roles in the public sector	Tasmanian Government (Other Participant)	2/2

Name	Role	Key Skills	Independent/ Organisation	Number of meetings
Mr Mark Sayer	Board Member	- High level executive management experience in both policy and operational roles in the public sector	Tasmanian Government (Other Participant)	1/2 (replaced by Karen Rees late 2018)
Dr Tony Worby	Board Member	- High level leadership and administrative experience - Extensive experience in government and public policy - High relevant domain expertise in climate and marine science and policy	CSIRO	4/4
Dr Katherine Woodthorpe	Chair	- High level management skills - High level Board skills - Broad experience on audit committees - Ventracor, Agenix and chaired the Audit Committee of Australian Cancer Technologies Ltd and Insearch	Independent	4/4

The Board had two sub-committees. The Budget, Audit and Risk (BAR) sub-committee included 2 Board directors and an independent director as Chair of the committee. The primary objective of the Budget Audit and Risk committee was to monitor and provide effective supervision of management's financial and risk reporting processes, and review the adequacy of internal control systems to ensure accurate, timely and proper financial and risk reporting. The BAR committee met on 16 October 2018, 8 April 2019 and 14 October 2019. The committee reported to the Board as appropriate, through its Chair.

The Nominations, Remuneration and Assessment committee included four members. It was Chaired by the ACE CRC Board Chair, and had a majority of independent members. The primary objective of the Nomination, Remuneration and Assessment Committee was to assist the Board in fulfilling its responsibilities by reviewing, advising and making recommendations to the Board on the matters pertaining to CEO and Board member remuneration, recruitment, performance appraisal, and succession planning. This committee did not meeting during the reporting period.

Key Staff

Staff Member	Role	Organisation	% Time
Prof Nathan Bindoff	Project Leader – R1.1	ACE CRC/IMAS	50%
Dr Phillip Boyd	Project Leader – R2.2	ACE CRC/IMAS	20%
A/Prof Andrew Bowie	Project Leader – R2.1	ACE CRC/IMAS	50%
Prof Richard Coleman	Project Leader – R1.2	ACE CRC/IMAS	20%
Dr Andrew Constable	Program Leader – Carbon and Ecosystems	ACE CRC/AAD	65%
Dr Mark Curran	Project Leader – R1.4	ACE CRC/AAD	80%
Dr Ben Galton-Fenzi	Project Leader – R1.2	ACE CRC/AAD	80%
Dr So Kawaguchi	Project Leader – R2.2	ACE CRC/AAD	60%
Mr Mark Kelleher	CEO	ACE CRC	100%
Dr Rob Massom	Project Leader – R1.3	ACE CRC/AAD	80%
Dr Jessica Melbourne-Thomas	Project Leader – R2.3	ACE CRC/AAD	70%
Dr Klaus Meiners	Project Leader – R2.2	ACE CRC/AAD	80%
Mr David Reilly (until Sep 2018)	Public Affairs Manager	ACE CRC	100%
Dr Stephen Rintoul	Program Leader – Oceans and Cryosphere	ACE CRC/CSIRO	50%
Ms Wenneke ten Hout	Business Manager	ACE CRC	80%
Prof Tom Trull	Program Leader – Carbon and Ecosystems	ACE CRC/CSIRO	50%
Dr Tas van Ommen	Program Leader – Oceans and Cryosphere	ACE CRC/AAD	60%

11 Participants

The commitment of the seven core partners to the ACE CRC remained strong during the reporting period. Our two international core partners, NIWA and AWI, were closely engaged.

ACE CRC participants during the reporting period

Participant's name	Participant type	ABN or ACN	Organisation type
Alfred Wegener Institute of Polar and Marine Research (AWI), Germany	Essential	NA	Government research institute

Participant's name	Participant type	ABN or ACN	Organisation type
Australian Antarctic Division (AAD)	Essential	56 428 630 676	Government
Bureau of Meteorology (BoM)	Essential	92 637 533 532	Government
CSIRO Oceans and Atmosphere Flagship (O&A)	Essential	41 687 119 230	Government
Department of Environment and Energy	Essential	34 190 894 983	Government
National Institute of Water and Atmospheric Research Ltd (NIWA), New Zealand	Essential	NA	Government research institute
University of Tasmania (UTAS)	Essential	30 764 374 782	University
Centre for Polar Oceanography and Modelling (CPOM), University College London, UK	Other	NA	Research institute
Chinese Academy of Meteorological Science (CAMS)	Other	NA	Government research institute
Curtin University	Other	99 143 842 569	University
First Institute of Oceanography (FIO), China	Other	NA	Government research institute
Institute of Low Temperature Science (ILTS), Hokkaido University, Japan	Other	NA	Research institute

Participant's name	Participant type	ABN or ACN	Organisation type
Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), France	Other	NA	Research institute
National Institute of Polar Research (NIPR), Japan	Other	NA	Government research institute
Old Dominion University	Other	NA	University
SGS Economics and Planning Pty Ltd	Other	25 007 437 729	Industry
Tokyo University of Marine Science and Technology (TUMSAT)	Other	NA	University
Tasmanian Government	Other	84 531 577 304	Government
Vrije Universiteit Brussels (VUB)	Other	NA	University
University of Texas at Austin, USA	Other	NA	University
University of Texas at San Antonio, USA	Other	NA	University

Changes to participants

There were no changes to participants during the reporting period.

12 Collaboration

ACE CRC was a collaborative joint venture of 21 national and international institutions. But beyond this formal organisational level partnership, collaboration was the basic model for all our research activities. In total, across its research program, the ACE CRC collaborated with 91 domestic and international organisations. Of these, there are 24 Australian, 4 New Zealand, 11 Asian, 18 North American, 1 South American, and 33 European.

Of the 24 domestic collaborations, there are 7 Australian Government Institutions, 5 State Government Institutions, 2 Local Government Institutions, 7 universities, 1 industry/private sector, and 2 other.

Of the 67 international collaborators, there are 39 universities, 1 from industry/private sector, 24 research institutions/organisations, and 3 others.

13 Financial Management

The ACE CRC completed the final year of its funding term with a cash balance of $687K. This reflects a cash underspend of $361K ($206K Expenses plus $155K accruals) against the Agreement budget together with the impact of $326K of other income mainly interest and use of retained external income).

These remaining funds were utilised during the wind-up period (to 31 October 2019) to extend and maximise research program milestone delivery, to ensure the ACE CRC research legacy will be fully taken up, and to enable completion of wind up activities including payment of remaining annual leave and staff severance entitlements.

Table 1

	Totals for 2018-19				Totals for 5 years			
	Actual	**Agr'mt**	**Diff**	**%Diff**	**Actual**	**Agr'mt**	**Diff**	**%Diff**
Employee Expenses	4,359	3,760	599	16	18,574	16,642	1,932	12
Supplier Expenses	1,136	990	146	15	5,564	7,680	-2,116	-28
Capital	453	50	403	806	1,704	973	731	75
Other Expenses	0	200	-200	-100	0	753	-753	-100
TOTAL EXPENSES	5,948	5,000	948	19	25,842	26,048	-206	-1

The variations in expenses in 2018-19 were due mainly to delivery of capital equipment (Argo floats) deferred from the originally schedule in prior years in order to secure the most recent software update. Variations in employee and supplier expenses reflect the profiling of the research program being more heavily weighted to the latter years of the ACE CRC term than was outlined in the original budget. The variation in other expenses is due to payments associated with staff contract terminations for annual leave balances and severance entitlements being included in employee expenses.

The 5 year totals reflect that additional external and interest income totalling $879k, along with $1,361k in net savings in supplier/capital expenses, enabled a number of contract extensions for research staff, resulting in the employee expenses variance of $1,708k, and supporting improved outcomes for program milestones.

Apart from the impact of the above-mentioned change in categorisation of final annual leave and severance payments, the cumulative underspend in other expenses is due to an offset by the same amount in income associated with there being no need to utilise the overdraft facility ($553K) to cover previously forecast deficits in the middle years of this term. Also note that the capital variation is mainly due to all Argo float equipment being classified as capital compared to the original budget categorised some purchases as supplier expenses.

The balance of funds as at 30 June 2019 ($687K) was budgeted to cover the following:

- Payment of accrued employee expenses as at 30th June 2019 $155K
- Contract extensions for research staff associated with extending milestone research activity $200K
- Supplier expenses associated with milestone research activity $161K including analysis, computing resources, publication costs
- Administrative staff expenses to undertake wind up activities $109K including oversight of final cash flow, data archiving, and the legacy website.
- Cost of final annual leave and severance entitlements $62K

All Commonwealth Funds provided were fully expended by the wind up date of 31st October 2019.

Staff and non-staff contributions from participants matched the amount committed in the budget for 2018-19, apart from the following:

Participants	***Table 1(a) Number (FTE) of Staff in-kind Contributions***	
	Amount Contributed (FTE)	***Amount Committed (FTE)***
Australian Antarctic Division	20.8	28.6
Bureau of Meteorology	0.7	0.5
CSIRO	6.6	3.5
University of Tasmania	5.7	5.9
CAMS	0.8	0.7
FIO	3.3	3.0
SGS Economics and Planning Pty Ltd	0.0	0.2
Vrije Universiteit Brussel (VUB)	1.2	0.0

Participants	***Table 1(b) Non-staff in-kind Contributions***	
	Amount Contributed ($'000)	***Amount Committed ($'000)***
CSIRO	7,831	200
First Institute of Oceanography (FIO)	3,100	2,750
Tokyo University of Marine Science and Technology	8	120

Shortfalls in staff in-kind contributions were relatively minor and did not impact the program or objectives of the ACE CRC. Shortfalls in AAD were partly offset by additional CSIRO and VUB contributions.

The large CSIRO variance in non-staff contributions reflects an additional voyage provided by the *RV Investigator*, effectively offsetting a voyage originally scheduled but not undertaken in a previous year on the *RV Aurora Australis*.

The following table summarises the overall impact of the above variations in 2018-19 on the Research Programs.

Research Program	***Total Expenditure ($'000)***	***Amount Budgeted ($'000)***
Research Program 1:		
Cash	3,150	2,925
Non-Staff in-kind	12,396	4,341
In-kind Staff (FTE)	30.00	32.90
Research Program 2:		
Cash	2,798	2,075
Non-Staff in-kind	989	1,128
In-kind Staff	20.91	21.00

The Summary for the five years is as follows:

Research Program	***Total Expenditure ($'000)***	***Amount Budgeted ($'000)***
Research Program 1:		
Cash	14,427	14,518
Non-Staff in-kind	63,869	57,719
In-kind Staff (FTE)	151.24	168.90
Research Program 2:		
Cash	11,615	11,530
Non-Staff in-kind	12,875	12,976
In-kind Staff	109.43	113.80

Overall variances were very minor, apart from the impact of AAD budget constraints resulting in a reduction in staff in-kind contributions (partially offset by additional staff contributions from CSIRO) and overall additional ship-time contributions from two of our international participants (ILTS and FIO).

14 Additional Requirements

CRC future plans and transition arrangements

Funding for the ACE CRC concluded on 30 June 2019. Recent changes in CRC guidelines precluded a rebid for funding under this mechanism.

The Department of Environment and Energy commissioned a review of the Australian Government's Antarctic Science governance in 2017. The Commonwealth Government response to the review was released in June 2018 and included an announcement of new Antarctic science funding in the May 2018 budget of $13M per year. This funding is being applied in two components:

- The Australian Research Council's Special Research Initiative in Excellence in Antarctic Science will fund a total of $56M over 7 years; and
- The Department of Industry, Innovation and Science Antarctic Science Collaboration Initiative (ASCI) will fund a total of $50M over 10 years.

The ASCI funding has been applied to the new Australian Antarctic Program Partnership, which will build on the research legacy of the ACE CRC and its previous incarnations.

Other activities

Externally Funded Research

The ACE CRC continued to undertake a number of externally funded research projects in its final year of operation, primarily in the area of fine-scale climate modelling and analysis.

Wine Australia – Australia's wine future: Adapting to short-term climate variability and long-term climate change: This project was funded by the Australian Grape and Wine Authority; commencing 1 July 2016 and to complete by November 2019. The project provided short-term climate variability, as well as trends in climate indices for the near and mid-term scales, in an accessible and usable form to grape growers and wine makers across Australia. The industry now has access to fine-scaled climate information required to identify the most appropriate adaptation response within each region to maintain grape yield, value and wine quality into the future.

High Resolution Reanalysis for Tasmania project: This project was funded through the Tasmanian Department of Police and Emergency Management and generated a reanalysis dataset for Tasmania at 1.5km grid spacing with hourly time steps for a 25-year period, producing a high-resolution meteorological and climatological dataset to inform emergency management and disaster risk activities in Tasmania. The Bureau of Meteorology (BoM) agreed to produce the reanalysis for Tasmania for ACE CRC, forming part of a wider project that will generate a nationwide Australian reanalysis product at a lower 12 km resolution. In the first phase of the project (Stage 1), the Bureau of Meteorology provided a 5-year high-resolution NWP climatology for Tasmania at a spatial resolution of about 5 km and at an hourly time step. The second stage of the project produced a 25-year high-resolution reanalysis at 1.5 km resolution. Phase 3 delivered the remainder of the full 25 year high-resolution reanalysis dataset and completed reporting and stakeholder engagement.

An assesment of the viability of prescribed burning as a management tool under a changing climate project: This project is also funded through the Tasmanian Department of Police and Emergency Management State Emergency Services and will provide a greater understanding of changing fuel loads and ability to plan for changing vegetation patterns in the future. The project commenced in March 2018 and concluded in early 2019.

Climate Analysis and Forecast Ensemble System (CAFE) – creating terciles of CSIRO CAFE model outputs: This project was funded through the CSIRO between February 2018 and June 2019. This project involved downloading forecasts from the CSIRO CAFE system and perform calculations of rainfall terciles in each of those forecasts to enable improved risk management of Hydro Tasmania's physical and financial position through better alignment of its contact position, future generation capability and financial rainfall hedge portfolio.

Modelling coincident extreme weather events under Tasmania's future climate project: This project was funded through the Tasmanian State Government Climate Change Office from March 2018 to February 2019. The project had three objectives: to increase our understanding and awareness of the current likelihood and impact of the highest priority coincident extreme events in Tasmania; to better understand how the frequency and impact of coincident extreme events may change in the future; and to inform state and local government, industries and communities so as to enable them to build their capacity to prepare for and respond to coincident extreme events.

Mesopelagic Southern Ocean Prey and Predators (MESOPP) project: The MESOPP project is a collaboration between AAD, UTAS and various other international collaborators. The underlying concept of MESOPP is the creation of the collaborative

network and associated e-infrastructure (marine ecosystem information system) between European and Australian research teams/institutes sharing similar interests in the Southern Ocean and Antarctica, its marine ecosystem functioning and the rapid changes occurring with the climate warming and the exploitation of marine resources. The project is funded through the European Union and was completed in mid-2019.

Flooding in Australia: are we properly prepared for how bad it can get? project: Together with the University of Newcastle, this project will use novel insights from 2,000 years of climate reconstructions to generate new knowledge about: (i) how bad flooding can get and (ii) what causes flood frequency to change over time. A decision making framework that allows for all the uncertainties associated with managing floods will also be developed. This innovative and multidisciplinary approach will provide a critical evaluation of the accuracy of existing flood estimates – and also the reliability of infrastructure and policy based on those estimates.

During the reporting period, these projects and other related concluded projects published 11 articles in scholarly refereed journals and 5 reports (see below).

Articles in scholarly refereed journals

Allen, K. J., K. J. Anchukaitis, M. G. Grose, G. Lee, E. R. Cook, J. S. Risbey, T. J. O'Kane, D. Monselesan, A. O'Grady, S. Larsen and P. J. Baker (2019). "Tree-ring reconstructions of cool season temperature for far southeastern Australia, 1731–2007." Climate Dynamics.

Campbell, S., T. A. Remenyi, C. J. White and F. H. Johnston (2018). "Heatwave and health impact research: A global review." Health and Place 53: 210-218.

Campbell, S. L., P. D. F. Hughes, P. J. Jones, T. A. Remenyi, K. Chappell, C. J. White and F. H. Johnston (2019). "Evaluating the risk of epidemic thunderstorm asthma: Lessons from Australia." International Journal of Environmental Research and Public Health 16(5).

Campbell, S. L., T. A. Remenyi, G. J. Williamson, C. J. White and F. H. Johnston (2019). "The Value of Local Heatwave Impact Assessment: A Case-Crossover Analysis of Hospital Emergency Department Presentations in Tasmania, Australia." International Journal of Environmental Research and Public Health 16(19): 3715.

Cottrell, R. S., K. L. Nash, B. S. Halpern, T. A. Remenyi, S. P. Corney, A. Fleming, E. A. Fulton, S. Hornborg, A. Johne, R. A. Watson and J. L. Blanchard (2019). "Food production shocks across land and sea." Nature Sustainability 2(2): 130-137.

Earl, N. and I. Simmonds (2019). "Sub synoptic scale features of the South Australia Storm of September 2016 – Part II: analysis of mechanisms driving the gusts." Weather 74(9): 301-307.

Earl, N., I. Simmonds and I. Rudeva (2019). "Sub-synoptic scale features associated with extreme surface gusts during the South Australia Storm of September 2016 – Part I: characteristics of the event." Weather 74(8): 278-285.

Grose, M. R., J. Syktus, M. Thatcher, J. P. Evans, F. Ji, T. Rafter and T. Remenyi (2019). "The role of topography on projected rainfall change in mid-latitude mountain regions." Climate Dynamics.

Harris, R. M. B., L. J. Beaumont, T. R. Vance, C. R. Tozer, T. A. Remenyi, S. E. Perkins-Kirkpatrick, P. J. Mitchell, A. B. Nicotra, S. McGregor, N. R. Andrew, M. Letnic, M. R. Kearney, T. Wernberg, L. B. Hutley, L. E. Chambers, M. S. Fletcher, M. R. Keatley, C. A. Woodward, G. Williamson, N. C. Duke and D. M. J. S. Bowman (2018). "Biological responses to the press and pulse of climate trends and extreme events." Nature Climate Change 8(7): 579-587.

Su, C. H., N. Eizenberg, P. Steinle, D. Jakob, P. Fox-Hughes, C. J. White, S. Rennie, C. Franklin, I. Dharssi and H. Zhu (2019). "BARRA v1.0: The Bureau of Meteorology Atmospheric high-

resolution Regional Reanalysis for Australia." Geoscientific Model Development 12(5): 2049-2068.
Yadav, S., A. J. Stow, R. M. B. Harris and R. Y. Dudaniec (2018). "Morphological Variation Tracks Environmental Gradients in an Agricultural Pest, Phaulacridium vittatum (Orthoptera: Acrididae)." Journal of insect science (Online) 18(6).

Reports

Bindoff N.L., Remenyi, T.A., Love P.T., Harris R.M.B. (2019). "Making climate science impacts clear through end user engagement: Technical report." Antarctic Climate & Ecosystems Cooperative Research Centre, Hobart, Australia.
Love, P. T., Remenyi, T. A., Harris, R. M. B., Bindoff N. L. (2019). "Tasmanian Wilderness World Heritage Area Climate Change and Bushfire Research Initiative, Technical Report." Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania.
Love, P., Remenyi, T. A., Fox-Hughes, P., Harris, R. M. B. and Bindoff, N. L. (2019). "Impact of climate change on weather-related fire risk factors in the TWWHA - Part 2." Antarctic Climate & Ecosystems Cooperative Research Centre, Hobart Australia.
Remenyi T. A., Rollins, D., Love, P., Earl, N., Bindoff, N. Harris R.M.B. (2019). "Australia's Wine Future - A Climate Atlas." Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania.
Harris, R.M.B., Remenyi, T., P. Fox-Hughes, Peter Love, Bindoff, N.L. (2019). "An assessment of the viability of prescribed burning as a management tool under a changing climate. A Report for the National Bushfire Mitigation – Tasmanian Grants Program (NBMP)." Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania.

Sea-Ice Services

The ACE CRC also provided sea ice reporting and analytical services to Antarctica-bound vessels during the 2018/19 year, including *RSV Aurora Australis*, *RV l'Astrolabe*, *RV Investigator*, *HMNZS Otago* (New Zealand) and a commercial fishing operator. This service included providing software, data and images (MODIS images and sea ice concentration maps) and associated training/support.

In addition to data provision, weekly Sea Ice Reports (with sub-weekly updates where requested) were provided to AAD Operations, as well as to the New Zealand Defence Force (*HMNZS Otaga*), the Australian Marine National Facility (*RV Investigator*) and a commercial fishing operator.

The Bureau of Meteorology agreed to take on the delivery of sea ice services following the ceasing of the ACE CRC.

15 Wind-Up Plan

Ceasing Operations

The ACE CRC wound up following the end of the current funding which covered the period 1 July 2014 to 30 June 2019.

The actual wind-up date was 31 October 2019, in order to allow for time to complete the necessary wind-up activities, including maximising milestone outputs, and meeting the Commonwealth Department's reporting and acquittal requirements.

Governance and Management

The Board was required to ensure that:

- All participants were aware of their roles and responsibilities.
- Appropriate management resources were in place to complete all obligations under the Funding Agreement.
- Appropriate arrangements were in place to ensure all contractual obligations to staff were met, together with providing HR assistance to staff as needed to find new employment opportunities.
- The appropriate storage and archiving of documentation with relevant parties, particularly contract material, so that it is accessible by the Commonwealth for a period of at least seven years.

Final Payments

Most ACE CRC funded staff who ceased employment (with UTAS) were entitled to receive applicable severance payments and payout of annual and long service leave balances. ACE CRC was responsible for payment of all annual leave balances and the first four weeks of any applicable severance payments. UTAS was responsible for any remaining severance costs and all long service leave entitlements.

The majority of staff had contracts that ceased on or before 31 May 2019. This date was selected to allow coverage for four weeks' severance payments at the end of contract period to be included the 2018-19 operational budgetary budgets. A small number of staff had contracts extended beyond 30 June 2019 to enable the completion of enhanced milestone deliverables. This was accompanied by provision for applicable annual leave balance and severance entitlements in the wind-up budget.

Student Supervision

Appropriate transition arrangements were made for students with ACE CRC supervisors, with IMAS agreeing to ensure that continued supervisory resources will be in place for the remainder of the student's candidature.

Student Scholarships

Continued funding of residual student scholarship top-up commitments for the period 2019-20/21 will be managed by IMAS, and associated funds (these totalled just over $10,000) were transferred to IMAS.

Data archiving, storage management and access

All ACE CRC Antarctic and Southern Ocean research data is managed by the Australian Antarctic Division as a matter of course to ensure data availability for the future.

Climate Futures project research data has been managed by UTAS' TPAC organisation unit, and with the Climate Futures team and projects being transferred to UTAS, this arrangement will now continue into the future as an ongoing responsibility.

All "corporate" data, including contracts, payroll and human resources has been archived as a matter of course within UTAS as it has been the Centre Agent since inception. This was a straightforward matter given that UTAS is the legal party to all

ACE CRC contracts, the formal employer of all staff and students, and provided all corporate IT systems.

The contents of the ACE CRC website over the life of the organisation has been archived using the PANDORA web archive project administered by the National Library of Australia and state libraries. The final list of publications has been included on the legacy website, along with a brief summary of the scope and achievements of the organisation over its life, and contact details for any queries that may arise. The domain name will remain active for a period of at least seven years.

The remainder of ACE CRC documentation, in the form of hard copy records, publications, and books were handed over to the AAD and UTAS libraries.

Contact Details

The ACE CRC was required to include contact details of at least one ACE CRC staff member responsible for managing the ceasing operations process and who can be contacted after the agreement period to assist the department with any outstanding reporting requirements or information requests. The ACE CRC Business Manager agreed to undertake this role, as she has been employed by UTAS and has a continuing similar role with the AAPP.

Activities Status

The ACE CRC activities comprised mainly the "core" Commonwealth grant-funded research program, but there were also some externally funded complementary activities; these being mainly the Climate Futures research team activity and the sea-ice operation service.

All core program outputs were completed by the wind-up date of 31 October 2019. In many cases the AAPP research program will continue to build on the ACE CRC research legacy.

In relation to the Climate Futures team activities, all cash balances, rights and obligations for relevant projects and accounts have been transferred to the UTAS GSS Department. UTAS, in its role as the Centre Agent, was in any case the legal party to these contracts.

Folowing delivery of the final season of sea-ice services by the ACE CRC over the 2018/19 summer, the Bureau of Meteorology are now the responsible organisation going forward.

Funds management

The balance of Commonwealth funds at 30 June 2019 (end of the funding period) was $687K. This included $155K of accruals for payments to be made early in July, other committed funds $352K (e.g. salaries, leave and severance entitlements for staff with extended contracts), and other funds $180K applied to maximising milestone delivery outcomes (third party analytical services and computing resources, and publication costs).

There were no unspent Commonwealth funds as at 31st October.

Management of intellectual property (IP)

Due to the nature of the ACE CRC intellectual property being creative commons and open source, it was not appropriate to adopt a conventional "IP audit" forma. Rather the focus was on data archiving, storage, maintenance and access. The wind-up approach in relation to data management is outlined above.

Assets

The ACE CRC did not own any assets. Major capital equipment purchases using the Commonwealth Grant funds were transferred to the relevant partner (in most cases Argo floats to CSIRO) as part of the partnership agreement arrangements.

The ACE CRC minor assets (e.g. computers, laboratory equipment) were owned by UTAS with an amortisation charge to the ACE CRC. Upon wind-up, all of these assets remained UTAS property.

Taxation

There were no tax liabilities beyond the normal payroll and GST matters handled by the ACE CRC Centre Agent (UTAS).

Post June 2019 Wind up Activities

The main post 30 June 2019 wind up activities were:

- Final Annual Report, including Exit Report and final financial statements
- Final CRC Online reporting including financial reports, tables, management data questionnaire and online milestone reporting
- Ensuring any residual invoices were paid
- Application of residual funds as at 30 June 2019 consistent with relevant Department and/or Board approvals
- Arranging the handling of any outstanding liabilities (e.g. remaining scholarship obligations)
- Finalise and implement data archiving and management arrangements
- Website modified to advise of ACE CRC closure and contact details
- Director resignation notices
- Appropriate physical transfer of equipment, furniture and photos/artworks to UTAS
- Closure of office and any associated support services (printer maintenance, newspaper supplies, subscriptions)
- Management of final cash balances
- Formal wind-up of the organisation by the ACE CRC Board.

16 Exit Report

Summary of the ACE CRC

Overview

The ACE CRC has been a strong, long-standing and productive collaboration between seven core partners and fourteen supporting partners. The core partners are the Australian Antarctic Division, CSIRO, the University of Tasmania, the Bureau of Meteorology, the Commonwealth Government's Department of the Environment and Energy (under numerous formal names over the life time of the Centre), plus the

Alfred Wegener Institute for Polar and Marine Research (Germany) and the National Institute of Water and Atmospheric Research (New Zealand).

Originally established in 1991, the ACE CRC was successful in five selection rounds:

- 1991 CRC for the Antarctic and Southern Ocean Environment;
- 1996 CRC for Antarctica and the Southern Ocean;
- 2002 CRC for Antarctic Climate and Ecosystems;
- 2009 CRC for Antarctic Climate and Ecosystems; and
- 2014 CRC for Antarctic Climate and Ecosystems

The ACE CRC's latest incarnation was funded through the Australian Government's Cooperative Research Centres Program under a Commonwealth Agreement covering the period from 1 July 2014 to 30 June 2019. The supporting partners include research and academic institutions based in Australia and abroad, as well as one commercial consulting business.

Following the introduction of new CRC program funding guidelines in 2015 the ACE CRC was no longer eligible to apply for any further extensions and will be wound up following completion of its current funding term.

Over its life, the ACE CRC was able to attract over $700 million in Australian and international funds in in-kind support. During this five-year funding term alone, it attracted over $120 million in in-kind support.

This collaboration and in-kind support has been vital in enabling the ACE CRC to act as the primary mechanism by which Australia's Antarctic research sector can assemble multi-disciplinary teams of experts to address strategic science questions, particularly those relating to Climate Change, which cannot be tackled by one institution alone. These collaborations have enabled the ACE CRC and its partners to define the agenda for Southern Ocean and Antarctic research globally and helped in establishing Tasmania as a global centre for Antarctic innovation.

Major Achievements

The ACE CRC delivered significant impact by providing relevant, timely and actionable scientific advice to policy makers, industry stakeholders and the broader public. During the life of the ACE CRC, the Centre continuously sought new and innovative ways to communicate its research outcomes to maximise the uptake of its scientific work. The ACE CRC established a reputation for providing the clear and actionable scientific insights necessary to ensure Australia can successfully meet the challenges of a changing climate.

The Centre's plain-English *Position Analysis* and *Report Card* publications summarised the latest developments in sea level rise, climate change, ocean acidification, sea ice distribution, ocean fertilisation and ocean ecology. To ensure uptake at the policy level, the Centre proactively engaged with relevant departmental offices and parliamentary offices on a regular basis. The Centre's scientists issued regular public statements and made numerous appearances in the media to provide an informed perspective on often-contentious issues relating to climate change. The Centre also conducted regular reviews with end-users to understand their needs and continually improve outputs, and also held bi-annual symposiums attended by a wide range of end-users, stakeholders and the broader community.

Research

The ACE CRC's science has been world leading. As a key driver of research and innovation, the ACE CRC has nurtured the scientific expertise, institutional links and industry innovation that has helped establish Australia's reputation for leadership and stewardship in the Antarctic.

During the current funding period, ACE CRC researchers have published over 600 peer-reviewed scientific papers, including 45 in the prestigious family of *Nature* and *Science* journals. This body of knowledge constitutes a major contribution to global scientific understanding of climate change and its local, regional and global impacts.

The ACE CRC's scientists have led Australian contributions to major deliberations by international governance bodies including the Intergovernmental Panel on Climate Change (IPCC), the Commission for the Conservation of Marine Living Resources (CCAMLR) and the International Maritime Organisation (IMO).

Through a long running ocean-sampling program, the ACE CRC has enabled the development of a vastly improved understanding of the Southern Ocean's fundamental role in regulating and driving ocean circulation.

Our research has also shown that the Southern Ocean is acting as a powerful handbrake on the rate of global climate change, but at the cost of increasing warming and acidification.

Furthermore, we found that the great Antarctic ice sheet, holding around 70 percent of the planet's fresh water, is melting at an accelerating rate under the effects of the changing ocean and atmosphere.

Our ecologists have shed new light on the impacts of these changes on fundamental ecological processes including krill reproduction and phytoplankton distribution, with major implications for fisheries and marine park management.

And of major significant nationally, are findings that demonstrate the intimate connection between our continent's weather systems, including droughts and floods, emerge largely from powerful atmospheric processes over the Southern Ocean and Antarctica.

Commercialisation and utilisation

The ACE CRC has been a public-good research centre focussed on the important role of Antarctica and the Southern Ocean in the global climate system, and on climate change and its impacts in the Antarctic, Australia and the world.

The value of the ACE CRC's intellectual property can be measured by its social and environmental impact. As a public good CRC, and also consistent with the approach implicit in the Antarctic Treaty, the ACE CRC made its research outputs widely and freely available.

The nature of ACE CRC research being created and utilised via creative commons and open sourcing, and in general the approach to full sharing of research within the Antarctic research community has delivered substantial economic benefits but has precluded the building of commercial outcomes.

The ACE CRC has undertaken a wide variety of activities to communicate our research outcomes to maximise awareness and uptake of our scientific work. Outreach activities have taken place with elected representatives, policy makers and the public, as well as within the science community. During this funding term, bi-annual ACE CRC Symposiums (approximately 150-200 attendees) and regular End-user Research Forums (held twice yearly and with approximately 60 attendees) have been key means to communicate research findings to end-users, key stakeholders and the broader community. These events also promoted a sense of community and common purpose among researchers associated with the ACE CRC, strengthened staff and student commitment to the ACE CRC and fostered collaboration among participants. The symposia have been attended by ACE CRC end users from government and industry, and have been an outstanding success.

During the funding period, the ACE CRC held two Symposia (August 2016 and August 2018) and four research user forums in Canberra where the following Position Analysis were presented:

- The Antarctic Ice Sheet and Sea Level
- Managing Southern Ocean Ecosystems
- Ice Cores and Climate
- Ocean Fertilisation
- The Antarctic Sea Ice and Climate Change
- Causes and Consequences of Southern Ocean Change
- Potential Tipping points for Life in the Southern Ocean
- Making climate science impacts clear through end user engagement

SME Engagement

Earlier funding terms of the CRC have included small business enterprises within the partnership structure, and this continued in the 2014-19 term, with SGS remaining as an 'Other' Participant within the partnership structure. The ACE CRC and SGS undertook a number of collaborative projects during this period, mainly involving assessments of climate change implications for end-user organisations.

Education and training

The ACE CRC's education program has been provided through the Institute for Marine and Antarctic Studies (IMAS), which is part of the University of Tasmania. Students studying at IMAS are part of an exciting, world class program focusing on some of the most important scientific questions of our age which include a range of topics relevant to Antarctica and the Southern Ocean.

The relationship between the research programs and students has been symbiotic. While the students gained much from their exposure to theoretical and practical science – including fieldwork in the Antarctic and Southern Ocean – so too has the CRC's research gained much from the students' contributions.

Throughout its life, the ACE CRC gave high priority to training, each year providing postgraduate opportunities for 50 or more students in a wide array of disciplines. While centred on Antarctica, the education of students addressed the needs of specific disciplines such as oceanography, glaciology and atmospheric science. Aside from postgraduate teaching, ACE CRC staff also taught Masters and Honours

students and units in undergraduate courses, mostly to students taking science degrees, although a few undergraduates from other backgrounds (e.g., Arts) did enrol in first-year Antarctic studies units.

A total of 48 PhD students graduated in the 2014-19 term with the ACE CRC supporting close to 300 PhD students over its lifetime, many of whom have gone on to prominent appointments locally and around the world.

International engagement

The ACE CRC engaged on the international stage in a number of different ways. Firstly, we had 21 institutional partners with whom we collaborated on significant scientific research projects. Antarctic and Southern Ocean research is complex and expensive, and takes many years to plan and undertake, so there is great benefit in collaborating across organisations, disciplines and national boundaries. ACE provided a unique mechanism to collaborate with international partners, giving Australian researchers an opportunity to engage internationally, and leveraging Australian Government investment in research many times over. A good example of this included the ICECAP project, where ACE CRC scientists leveraged the resources and infrastructure of the US and Australian Antarctic programs to survey large areas of East Antarctica.

ACE CRC scientists also engaged directly, and at very senior levels, with major international research programs and coordinating bodies, such as the Scientific Committee on Antarctic Research (SCAR), Intergovernmental Panel on Climate Change (IPCC), Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), and the International Whaling Commission (IWC).

Case Study - Intergovernmental Panel on Climate Change
The Intergovernmental Panel on Climate Change (IPCC) is the international body responsible for providing governments with the largest and most comprehensive summary of the latest scientific information on climate change. The contributions of ACE CRC staff over several years to the release of the IPCC's Fifth Assessment Report (AR5) in 2013 represented a major commitment to end-users nationally and globally.

The ACE CRC is again playing a leading role in preparing the IPCC Sixth Assessment Report (AR6), with four ACE CRC researchers being among those selected to contribute as either lead authors, contributing authors, reviewers or editors. The report constitutes the most comprehensive and definitive body of scientific evidence demonstrating anthropogenic factors driving climate change. Another two ACE CRC researchers were selected to contribute as coordinating lead author or lead author for the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC).

Economic Benefits

As a public good CRC engaged in the fundamental science of climate change, the economic impacts of the Centre's research should be measured against the impact of mitigating likely future productivity losses resulting from climate change. This is not an easy task.

In the past broad assessments have been undertaken by the ACE CRC but in in this past year another approach involving a more targeted assessment of the impact of

a particular output from the CRC was adopted. In October 2017, the ACE CRC contracted Agtrans Research to conduct an Impact Assessment of investment in the Climate Futures Tasmania ("CFT") Initiative. The impact assessment was funded to demonstrate the impact of a significant RD&E investment by the ACE CRC and partners.

The investment in the CFT Initiative for the period 2008-2017, based on the best bet assumptions made and sensitivity analyses of key variables, has been estimated to produce a present value of benefits of between $21.5 million and $86.5 million (present value terms) from total investment costs of approximately $16.4 million (present value terms). This produced a net present value of between $5.1 million and $70.0 million and a benefit-cost ratio of between 1.3 and 5.3 to 1. The best estimate of a net present value of $26.6 million, and a benefit-cost ratio of approximately 2.6 to 1, was considered to be an outstanding result and is within the range of benefit-cost ratios for other CRCs and other climate RD&E programs that have been estimated over the past ten years by Agtrans Research.

Case Study - Climate Futures for Tasmania

In 2010 the Tasmanian Government launched Climate Futures for Tasmania, a project developed by the ACE CRC to model projected changes to Tasmania's climate during this century, and its impact on communities, industries and government agencies. The project provided the first fine-scale climate information for Tasmania by downscaling six global climate models with two emission scenarios to generate climate information from 1961 to 2100. The project interprets climate projections at a local scale, so that communities, industries and individuals can use information in their local planning and adaptation actions.

The project also looked at the impacts in the applied areas of water and catchments, assessing how water will flow through various Tasmanian water catchments and into storage reservoirs under different climate scenarios. The project also provided specific climate indicators relevant to productivity in key areas of Tasmanian agricultural production. Finally, working with emergency service agencies, the project identified the climate variables of greatest concern to emergency managers.

Following the release of the report, many flow on research projects have been, and continue to be, undertaken to significantly leverage this core research. These projects undertaken by the ACE CRC's Climate Futures Unit over the current CRC term, and funded by end-users, included future rainfall patterns for Hydro Tasmania's infrastructure planning purposes, several future fire and flood predictions used by State Emergency Services to improve natural disaster preparedness planning and mitigation, and various agricultural sector analyses to guide decisions on future investment in the context of future climate change risk and opportunities

The Tasmanian Government describes the project as its "most important source of climate change projections at a local scale… [and] an essential part of Tasmania's climate change strategy." The project was made possible through the support of a consortium of government and private sector partners.

With the ceasing of the ACE CRC, the University of Tasmania agreed to take on the ACE CRC's Climate Futures team and look to build this capability into the future.

Collaboration

Overview

Collaboration has been the driving force behind all of the ACE CRC's scientific projects, and the key to its success as a research organisation.

Unincorporated Joint Venture Partners

The Centre was an unincorporated joint venture comprising 7 essential and 14 other participants. The seven Essential Participants were bound by the Participants Agreement, and the Other Participants Agreements set out the duties and commitments of the remaining parties.

Type of Participant	Participant
Essential	Alfred Wegener Institute of Polar and Marine Research (AWI), Germany
Essential	Australian Antarctic Division (AAD)
Essential	Australian Bureau of Meteorology (BOM)
Essential	CSIRO Division of Oceans and Atmosphere (CSIRO)
Essential	Department of the Environment and Energy
Essential	National Institute of Water and Atmospheric Research Ltd (NIWA), New Zealand
Essential	University of Tasmania (UTAS)
Other	Centre for Polar Oceanography and Modelling (CPOM), University College London, UK
Other	Chinese Academy of Meteorological Science (CAMS)
Other	Curtin University
Other	First Institute of Oceanography (FIO), China
Other	Institute of Low Temperature Science (ILTS), Hokkaido University, Japan
Other	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), France
Other	National Institute of Polar Research (NIPR), Japan
Other	Old Dominion University (ODU), USA
Other	SGS Economics and Planning Pty Ltd
Other	Tasmanian Government
Other	Tokyo University of Marine Science and Technology
Other	University of Texas at Austin, USA
Other	University of Texas at San Antonio, USA
Other	Vrije Universiteit Brussel (VUB), Belgium

Research Project Partnerships

The ACE CRC operated on the principle that much more can be achieved through collaboration than by working alone. Antarctica is an extreme environment, and the climate systems we study there are indifferent to national and institutional boundaries. To produce high quality science demands a high level of co-operation. At a project level, the ACE CRC maintained over 110 domestic and international collaborations. One example of a collaborative project both domestically and internationally is the ICECAP project which is further detailed below.

Case Study – Collaboration – ICECAP (International Collaboration for Exploration of the Cryosphere through Aerogeophysical Profiling)

The ACE CRC's participation in the international ICECAP project has enabled a major detailed airborne geophysical survey covering large areas of East Antarctica, filling in a vast blank on the map of Australia's Antarctic territory. Using airborne laser and ice penetrating radar instruments, magnetometers and gravimeters, huge areas of the East Antarctic have been surveyed in high resolution for the first time. The data will enable ACE CRC scientists to understand how ice flows from the continent into the ocean and, ultimately, how much this process might contribute to sea level rise.

The ICECAP collaboration involves the ACE CRC and partner institutions: the Australian Antarctic Division; the University of Texas at Austin; the Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS); and non-partner Universities of Edinburgh, Bristol and Exeter. The project has been a highly successful mechanism for international collaboration, leveraging 'in-kind' contributions from national and international partners and funding from peak agencies such as NASA and UK's NERC, in excess of five times the ACE CRC's cash investment. The benefits of the partnership include access to scientific expertise, sharing of highly specialised sensing technology and logistics, and integration of Australian scientists into a world-class research team.

The data collected from hundreds of thousands of kilometres of flight-lines has enormously enhanced our understanding of the East Antarctic ice sheet, including revealing that much more of it rests on bedrock well below sea level than previously thought and therefore may be more vulnerable to a warming ocean and contribute more to future sea level rise than previously thought. The measurements of magnetic properties of the hidden bedrock have also provided recently published insights connecting the geology of East Antarctica and Australia associated with the break-up of past supercontinents.

As a component of NASA's Operation IceBridge, ICECAP flights along tracks previously surveyed by ICESat have extended and improved the precision mapping of the ice sheet elevation, demonstrating the power of advanced scanning laser systems, and gaining valuable insights into the current changes in East Antarctica.

Publications

Since 2014 ACE CRC researchers have published well over 600 peer-reviewed scientific papers, including 45 in Nature and Science journals.

It should also be noted that over the 28-year life of the CRC, ACE CRC researchers have published well over 2,000 peer-reviewed scientific papers. These peer-reviewed scientific papers have had over 60,000 citations with 95 scientific papers published in high profile journals such as *Nature* and *Science*.

Value for Participants

The ACE CRC has been a highly cost-effective mechanism for driving collaboration, leveraging 'in kind' contributions from our national and international partners in excess of five times the cash investment. The ACE CRC has been the primary mechanism by which teams of experts are assembled from across our partners to address strategic, multi-disciplinary science questions that cannot be tackled by one institution alone.

Impact of education programs on industry, the sector in general and on skills development

Key educational outputs

From 1 July 2014 to June 2019, 48 students were awarded PhD degrees with 54 continuing PhD students.

More than 500 students have completed their honours and research higher degrees (PhD and Masters) with the CRC since its establishment in September 1991. The centre has produced students with skills applicable to a wide variety of environmental and policy fields such as oceanography, meteorology, biology, international law, etc.

The impact of education and training programs in areas of skill shortages

The ACE CRC has been an impressive incubator of Australian science innovation, with close to 200 PhD completions during its lifetime. One of the objectives of the ACE CRC's education program during the reporting period was to address the long-term unmet national demand for highly-trained personnel with quantitative skills in oceanography and marine ecology. Significant progress was made towards this objective during the life of the Centre, with many graduates progressing to high-profile professional careers with partner institutions, governments and industry world-wide.

Through partnership with IMAS, the ACE CRC has contributed to the production of the highly popular online course Marine and Antarctic Science. This free online course consists of 37 short videos across four modules, each with a range of quizzes and assessment tasks. Subject material includes how life evolved in the sea, the role of the ocean in climate and the impacts of climate change for ocean processes and marine biota.

Appendix 1– list of publications

Book Chapters

Bindoff, NL, Cheung WWL, and Kairo, JG, 'Chapter 5 - Changing Ocean, Marine Ecosystems, and Dependent Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate', Intergovernmental Panel on Climate Change, IPCC, WMO, UNEP, H-O Portner, DC Roberts, V Masson-Delmotte, P Zhai, M Tignor, E Poloczanska, K Mintenbeck (ed), pp. 1-198.

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Articles in Scholarly Refereed Journals

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*Non-core research publications are those with authors affiliated with the ACE CRC but not address core ACE CRC research

Appendix 2– ACE CRC PhD students 2018-2019

Completed

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Completion Date
1. Baird-Bower, Debbie	08/04/2013	FT	Carbon & Ecosystems	Demographic Responses of Antarctic Fur Seals to Environmental Variability	UTAS	United Kingdom	December 2018
2. Buchanan, Pearse	01/11/2014	FT	Oceans & Cryosphere	Ocean Deoxygenation: A paleo-modelling perspective	UTAS	Australia	December 2018
3. Cleeland, Jaimie	20/05/2013	FT	Carbon & Ecosystems	Macquarie Island's Albatrosses: A comprehensive assessment of population and demographic status and trends and the environmental and anthropogenic	UTAS	Australia	December 2018
4. Deppeler, Stacy	15/10/2013	FT	Carbon & Ecosystems	Effects of Elevated pCO2 on the Productivity of Marine Microbes and the Remineralisation of Nutrients in Coastal Antarctic Waters	UTAS	Australia	December 2018
5. Goedegebuure, Merel (previously Bedford, Merel)	01/03/2014	FT	Carbon & Ecosystems	Representing Southern Ocean predators in end-to-end ecosystem models using individual-based modelling	UTAS	The Netherlands	December 2018
6. Hodgson-Johnston, Indiah	21/10/2013	FT	Carbon & Ecosystems	Beyond the Bases? Applying Contemporary Principles of International Law to Australian Sovereignty in Antarctica	UTAS	Australia	August 2018
7. Mori, Mao	01/12/2014	FT	Carbon & Ecosystems	Modelling ocean transport of key species in the Indian sector of the Southern Ocean	UTAS	Japan	December 2018
8. Plummer, Christopher	01/05/2010	FT	Oceans & Cryosphere	Holocene Climate and Environmental Indicators from	UTAS	Australia	August 2018

FT – full time; PT – part time

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Completion Date
				Trace Chemistry of Law Dome Ice Core, Antarctica			
9. Semolini Pilo, Gabriela	15/12/2013	FT	Oceans & Cryosphere	Eddies Tridimensional Structure and their Role in Oceanic Mass and Heat Distribution	UTAS	Brazil	August 2018
10. Tonnard, Manon	01/10/2014	FT	Carbon & Ecosystems	The biogeochemical cycles of trace metals: distributions and speciation in the ocean and co-impact on the phytoplankton (GEOVIDE)	UTAS/University of Bretagne - cotutelle	France	December 2018
11. Zhao, Chen	13/10/2014	FT	Oceans & Cryosphere	Ice mass unloading and bedrock response in the southern Antarctic Peninsula	UTAS	China	December 2018

Withdrawn

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Withdrawn Date
1. Blanche, Bella	08/02/2016	FT	Oceans & Cryosphere	Detecting human influence in global ocean salinity patterns	UTAS	France	February 2019

Continuing*

* Processes have been put into place with IMAS to ensure supervision is provided for continuing students to complete their PhD

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Expected Completion Date
1. Abdul Salam, Syed	9/06/2017	FT	Oceans & Cryosphere	The temperature distribution within the East Antarctic Ice Sheet	UTAS	Pakistan	December 2020
2. Abhishek Savita, Abhishek	5/06/2017	FT	Oceans & Cryosphere	Global and regional sea level sensitivity to changing ocean water mass properties and circulation processes	UTAS	India	December 2020
3. Aflenzer, Helene	18/04/2016	FT	Carbon & Ecosystems	Impact of ocean acidification on the availability and toxicity of trace elements and nutrients	UTAS	Austria	October 2019
4. Arena, Enrico	27/11/2017	FT	Oceans & Cryosphere	Fingerprinting the Southern Hemisphere's Ocean Contribution to Global Changes in Steric Sea Level	UTAS	Italy	November 2021
5. Black, James	28/08/2014	PT	Carbon & Ecosystems	Measuring impacts of ocean acidification on biological communities in Antarctica: an in-situ experiment and laboratory exploration of the mechanisms of community	UTAS	Australia	October 2019
6. Campbell, Sharon	1/03/2017	FT	Climate Futures	Understanding current and future impacts of extreme heat events on the health of vulnerable Tasmanians	UTAS	Australian	September 2020
7. Cimoli, Emiliano	31/03/2016	FT	Oceans & Cryosphere	Hyperspectral remote sensing of Antarctic sea ice algae and benthos using AUV	UTAS	Italy	October 2019

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Expected Completion Date
8. Cranenburgh, Andrea	01/03/2016	FT	Oceans & Cryosphere	How do standing meanders break the ACC?	UTAS	Australia	October 2019
9. Cyriac, Ajitha	18/11/2015	FT	Oceans & Cryosphere	Eastward flows, ocean mixing and air-sea interaction in the Southeast Indian Ocean	UTAS	India	October 2019
10. Dias, Fabio	24/08/2015	FT	Oceans & Cryosphere	Testing of Climate Models and Sea Level Rise Projections using Observations of Ocean Heat Uptake	UTAS	Brazil	October 2019
11. Duprat, Luis	1/08/2016	FT	Carbon & Ecosystems	Role of sea ice as a source of bio-available iron to Antarctic surface waters	UTAS	Brazil	March 2020
12. Ericson, Jessica	15/10/2015	FT	Carbon & Ecosystems	Using Signature Lipid Analysis to Understand the Biology and Ecology of Antarctic Krill (*Euphausia superba*)	UTAS	New Zealand	October 2019
13. Evans, Eleri	08/07/2015	FT	Oceans & Cryosphere	Processes Controlling Iceberg Calving Rates Around Antarctic Margins	UTAS	Australia	October 2019
14. Gamble Rosevear, Madeleine	01/02/2016	FT	Oceans & Cryosphere	Fine scale ocean processes driving the basal melting of ice shelves	UTAS	Australia	October 2019
15. Genovese, Cristina	29/11/2016	FT	Carbon & Ecosystems	Role of organic ligands in the distribution of iron in polar waters	UTAS	Italy	June 2020
16. Glor, Cheryl	15/09/2017	FT	Oceans & Cryosphere	Investigation of Sea Salt Variability and Volcanic Deposition at Aurora Basin North, East Antarctica – Impacts and Influence on Climate Variability over the Past 2000 Years	UTAS	United States of America	September 2021

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Expected Completion Date
17. Halfter, Svenja	29/11/2017	FT	Carbon & Ecosystems	The Ocean's Biological Pump: Mesozooplankton controls on particle export	UTAS	Germany	November 2021
18. Hancock, Alice	1/1/2016	FT	Carbon & Ecosystems	Effects of ocean acidification on associations among Antarctica and SO marine microbes	UTAS	Australia	October 2019
19. Hamilton, Vicki	24/07/2012	PT	Carbon & Ecosystems	Energetic Variability in Sperm Whales and Relationships with the Marine Environment	UTAS	Australia	October 2019
20. Hellessey, Nicole	01/11/2015	FT	Carbon & Ecosystems	Seasonal lipid changes in Antarctic krill in relation to Climate Change	UTAS	Australia	October 2019
21. Hollman, Hannes	1/03/2017	FT	Oceans & Cryosphere	A geophysical investigation of the subglacial environment and its role in the evolution of ice dynamics	UTAS	Germany	September 2020
22. Holmes, Thomas	01/04/2014	FT	Carbon & Ecosystems	The impact of hydrothermal vents on trace metal biogeochemistry in the Southern Ocean	UTAS	Australia	October 2019
23. Huneke, Wilma	19/10/2015	FT	Oceans & Cryosphere	Quantifying Key Physical Processes Responsible for Ocean Warming under Antarctic Ice Shelves	UTAS	Germany	October 2019
24. Jackson, Andrew	01/03/2015	FT	Carbon & Ecosystems	Who Saved Antarctica?	UTAS	Australia	October 2019
25. Jansen, Jan	01/10/2014	FT	Carbon & Ecosystems	Modelling biodiversity in the Southern Ocean and Antarctica using sparse data	UTAS	Germany	October 2019
26. Kelly, Paige	01/08/2015	FT	Carbon & Ecosystems	Climate Change and Sea Ice Habitats: Modelling effects from plankton to penguins	UTAS	Australia	October 2019

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Expected Completion Date
27. Kennedy, Fraser	18/08/2015	FT	Carbon & Ecosystems	Using experimental sea ice tanks and micro sensors to investigate sea ice microbial ecology	UTAS	New Zealand	October 2019
28. Latour, Pauline	27/04/2018	FT	Carbon & Ecosystems	The Biogeochemistry of Trace Elements in the Australian Sector of the Southern Ocean: GEOTRACES-SR3 repeat section from Tasmania to Antarctica	UTAS	France	April 2022
29. Lee, Shi Hong	15/12/2012	FT	Carbon & Ecosystems	Impact of Climate Change on Physiological and Behavioural Responses of Coastal Microphytobenthos	UTAS	Malaysia	October 2019
30. Libaros, Damien	28/08/2015	FT	Oceans & Cryosphere	Determining changes in sea level around Antarctica	UTAS	France	October 2019
31. McCormack, Stacey	22/07/2015	FT	Carbon & Ecosystems	Energy Flow in Southern Ocean Ecosystems: Comparing mass balance and size-based approaches	UTAS	Australia	October 2019
32. Meijer, Jan Jaap	01/08/2017	FT	Oceans & Cryosphere	An Observational Study of the Role of Standing Meanders in Slowing the ACC and Transporting Heat to Antarctica	UTAS	The Netherlands	August 2021
33. Melvin, Jessica	01/03/2018	FT	Carbon & Ecosystems	Effect of Ocean Acidification on Physiology and Growth of Antarctic Krill	UTAS	Australia	March 2022
34. Patel, Ramkrushnbhai	02/03/2016	FT	Oceans & Cryosphere	The physical and bio-optical structure of Southern Ocean eddies in observations and models	UTAS	India	October 2019

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Expected Completion Date
35. Pavez, Cassandra	10/04/2017	FT	Carbon & Ecosystems	Understanding distribution behaviour and morphology of Antarctic krill by using the data collected by scientific observers on krill fishing vessels	UTAS	Australia	October 2020
36. Peel, Samantha	27/01/2015	FT	Carbon & Ecosystems	Statistical Issues for Mapping Biodiversity in the Southern Ocean	UTAS	Australia	October 2019
37. Perez-Tribouillier, Habacuc	07/10/2015	FT	Carbon & Ecosystems	Quantifying Protactinium, Thorium and Neodymium Isotopes in Southwest Pacific Waters: Elucidating the Oceanographic Controls on these Tracers of Circulation, Productivity and Dust Input	UTAS	Mexico	October 2019
38. Perron, Morgane	02/05/2016	FT	Carbon & Ecosystems	Natural iron fertilisation of oceans around Australian linking terrestrial aerosols to marine biogeochemistry	UTAS	France	November 2019
39. Rathore, Saurabh	31/10/2016	FT	Oceans & Cryosphere	The impact of recent Indian Ocean warming on the circulation, watermass distribution and air-sea interaction	UTAS	India	May 2020
40. Richter, Ole	02/05/2016	FT	Oceans & Cryosphere	Tidal melting of Antarctic Ice Shelves since last glacial maximum	UTAS	Germany	November 2019
41. Schroeter, Ben	01/02/2016	FT	Oceans & Cryosphere	Towards improved modelling of the high southern latitudes	UTAS	Australia	October 2019
42. Schroeter, Serena	30/03/2015	FT	Oceans & Cryosphere	The response of Antarctic sea ice to anthropogenic climate change, from model and satellite observations	UTAS	Australia	October 2019

Name	Commencement Date	Status	Research Program	Project Title	Research Organisation	Country of Origin	Expected Completion Date
43. Sellers, Ben	31/07/2015	PT	Carbon & Ecosystems	Determining Predator Prey Relationships of Killer Whales Within Distinct Areas of the Southern Ocean Using Biochemical Analytical Tools (Signature Fatty Acids and Stable Isotopes)	UTAS	Australia	October 2019
44. Silvano, Alessandro	05/05/2015	FT	Oceans & Cryosphere	Observations of Ocean - Ice Shelf Interaction at the Totten Glacier	UTAS	Italy	October 2019
45. Smith, Abigail	01/06/2018	FT	Carbon & Ecosystems	Influence of Marine Animals on the Biological Carbon Pump in the Southern Ocean	UTAS	Australia	June 2022
46. Sow, Swan	20/09/2015	FT	Carbon & Ecosystems	Microbial Oceanography of the Different Water Masses of the Southern Ocean	UTAS	Malaysia	October 2019
47. Strezelec, Michal	31/05/2016	FT	Carbon & Ecosystems	Source characterisation of atmospheric trace metal deposition around Australia	UTAS	Poland	October 2019
48. Subramaniam, Roshni	11/07/2016	FT	Carbon & Ecosystems	Food web modelling for the Indian sector of the Southern Ocean	UTAS	New Zealand	December 2020
49. Udy, Danielle	04/06/2018	FT	Oceans & Cryosphere	Extending the Palaeohydroclimatology Record of Eastern Australia to Underpin Efficient Water Management by Understanding Long Term Climate Variability	UTAS	Australia	June 2022
50. Ward, Delphine	01/10/2014	FT	Carbon & Ecosystems	Evaluating the likelihood of critical transitions in Southern Ocean ecosystems	UTAS	Australia	October 2019

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51. Wallis, Jake	31/03/2016	FT	Carbon & Ecosystems	Impacts of ocean acidification on Southern Ocean lower-thropic food pathways	UTAS	Australia	October 2019
52. Wariji, Doreen	1/1/2016	FT	Oceans & Cryosphere	High resolution modelling of the retreat of the East Antarctic ice sheet since last glacial maximum	UTAS	India	October 2019
53. Weldrick, Christine	1/12/2015	FT	Carbon & Ecosystems	Mapping Planktonic Trophic Pathways Through the Sea Ice Zone	UTAS	Canada	October 2019
54. Woods, Bree	30/11/2017	FT	Carbon & Ecosystems	Understanding the Energy Pathways through Southern Ocean Mesopelagic Communities	UTAS	Australia	November 2021
55. Yang, Luwei	14/10/2015	FT	Oceans & Cryosphere	Internal Waves and Mixing in the Southern Ocean	UTAS	China	October 2019