ANTARCTIC CLIMATE & ECOSYSTEMS
COOPERATIVE RESEARCH CENTRE

2013-2014 Annual Report

Australian Government
Department of the Environment
Australian Antarctic Division

CSIRO

UTAS

AWI
Alfred Wegener Institute
for Polar and Marine Research
in the Helmholtz Association

NIWA
Taihoro Nukurangi

An Australian Government Initiative

CRC
AUSTRALIA

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1 Executive Summary

The Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC) had a particularly successful year in 2013-2014, delivering on the vast majority of its milestones at the conclusion of round 4 funding.

The CRC welcomed the announcement by Government early in the year of $25M funding to extend the CRC to 30 June 2019. The application for funds and the scope of the CRC's research program for this period were approved by Government on 20 May 2013. We are very grateful for the Government's ongoing support of the ACE CRC and thank our many supporters for their support in the re-bid process.

Particular acknowledgement must go to Dr Tony Press who stepped down as CEO at the end of June 2014 after 5.5 years at the helm. Dr Press was instrumental in securing the additional resources for the ACE CRC and leaves a strong legacy for us to build on over the next five years. We all thank him for his commitment to the ACE CRC and look forward to an ongoing association with him as he pursues his many and varied Antarctic interests.

In December 2013, ACE CRC staff physically relocated to the University of Tasmania's new Waterfront Building at Salamanca Place in Hobart. The ACE CRC now occupies the top floor of the new building in a combination of office and open plan workstations, with world-class laboratory facilities and a world-class view of the Hobart city and port. It is a terrific workplace and brings together under one roof the ACE CRC, the University of Tasmania's Institute of Marine and Antarctic Research (IMAS), the Integrated Marine Observing System (IMOS), and Southern Ocean Observing System (SOOS) secretariat.

Within this reporting period, Dr Tony Press was commissioned by the Federal Government to lead a "20 year strategic plan for Australia's Antarctic program", and at the time of writing (October 2014) the report has just been publicly released. The landmark *20 Year Australian Antarctic Strategic Plan* presents a widely consulted set of recommendations for supporting Australia's long-term scientific and strategic interests in the Antarctic. The report has been welcomed by the research community and Government as an important step in addressing the steady decline in funding experienced by the Antarctic program in recent years. The report also calls for better coordination of funding for Australia's Antarctic research activities, and a sustainable funding model for the ACE CRC beyond 2019.

The incoming Federal Government also made two other significant announcements relevant to the ACE CRC, namely an additional $24M for the Antarctic Gateway project, to drive new collaboration between the University of Tasmania, CSIRO and AAD, and a review of the CRC Programme which will be conducted in the 2014/15 financial year.

ACE CRC staff continued to receive national and international recognition for their work. These are outlined in detail in the body of the report, but I will highlight here the achievements of two people at opposite ends of their careers – Professor Ian Allison who received an Order of Australia for his distinguished service to climate science, and David Gwyther, an ACE CRC PhD student, who received a prestigious Fulbright Postgraduate Scholarship to study in the USA for a year.

1.1 Achievements

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) was released in September 2013 and has delivered a clear, up-to-date view of the current state of scientific knowledge on climate change. The ACE CRC is very proud to have 18 staff contributing as Coordinating Lead Authors, Lead Authors or Contributing Authors. At the time of the release of the Working Group 1 Report, the ACE CRC held a highly successful media briefing that raised awareness of the report and provided local media with an opportunity to ask detailed questions to ACE CRC scientists involved in its preparation.

A major highlight of our field program this year was the extremely successful Aurora Basin ice coring project. This work took place approximately 550 km inland from Casey and was made possible through a major collaboration with the French Antarctic program and partners from 15 institutions from around the world. A 300 m long ice core is now being analysed to recreate the (approximate) 2,000 year climate history of the region.

Other major field work undertaken in the past year includes a joint US-Australian voyage on the US vessel *Nathaniel B. Palmer* which deployed six moorings funded equally by the ACE CRC and IMOS. The moorings were deployed adjacent to the Mertz and Totten Glaciers, both regions where large changes are currently being observed, and are scheduled for recovery by the *RSV Aurora Australis* in late 2014. The ACE CRC sea ice group had major collaborations with the German Antarctic program on three voyages of the RV Polarstern, including the deployment of ACE CRC drifting buoys to track ice motion, and a multi-disciplinary study to explore the under-ice habitat of krill using an ACE CRC remotely-operated vehicle. Scientists in the ACE CRC Carbon program carried out two voyages to the Southern Ocean Time Series Facility, a site that continues to build a long-term record of carbon uptake in the Southern Ocean, and played a lead role in the development of a new release of the Surface Ocean Carbon Atlas.

In March 2014, the ACE CRC was the major sponsor, in conjunction with the International Glaciological Society, of the International Sea ice Conference. This conference was held in Hobart over 5 days, involving 205 delegates from 13 countries. The conference highlighted the strength of the ACE CRC in building international partnerships, with much of the focus dedicated to the presentation and discussion of results from the ACE CRC's Sea Ice Physics and Ecosystem Experiment (SIPEX II) – a major Antarctic field program in the current term of the CRC.

The conference highlighted how the ACE CRC, together with its partners, is one of the few institutions internationally with the capability to organise and deliver on multi-disciplinary, integrated and innovative field programs of this magnitude. The economic benefits of the conference underline the value of the research sector to the Tasmanian economy.

In conjunction with the International Sea Ice Conference, the ACE CRC launched its latest Position Analysis titled *'Antarctic Sea ice and Climate Change'*. The report deals with the apparent paradox of Antarctica's annual sea ice extent increasing by approximately +1.5% per decade, in contrast with the decline in Arctic sea ice extent and the projections of a decline in Antarctic sea ice extent by global climate models. The launch of the Position Analysis was widely reported in the local and national media and supported by articles in *The Conversation* written by ACE CRC scientists.

In June 2014, the ACE CRC held a highly successful Symposium "ACE CRC – Looking Back, Looking Forward". Opening presentations by ACE CRC senior scientists Dr Steve Rintoul and Prof Nathan Bindoff set the scene for the symposium with presentations on the ACE CRC's considerable achievements since 1991, and the scientific challenges still ahead. Many of the presentations were made by ACE CRC students and we were pleased to welcome representatives from many of the ACE CRC partners, including the Department of Industry, the Department of Environment and the Tasmanian Department of State Growth.

The ACE CRC continued to publish world-class research, including 23 book chapters and 85 scholarly articles in refereed journals during the reporting period.

The ACE CRC also continued to play an important role in capacity building, with 47.5 (FTE) students working on PhD projects directly related to the ACE CRC.

Honours and awards

This year ACE CRC staff and honorary staff have received a number of prestigious honours and awards.

On 1 June 2014, Prof Ian Allison received the Order of Australia for his distinguished service to the environment as a glaciologist, to furthering international understanding of the science of the Antarctic region, and to climate research. The Order of Australia recognises, by national honour, those who have made outstanding contributions that benefit their communities. Prof Ian Allison also received adjunct professorship at the University of Tasmania in June 2014.

Dr Steve Rintoul received the Society for Underwater Technology (London, UK) Award in recognition of his contribution to the field of oceanography. The Society notes that Dr Rintoul's leadership in oceanography has been critical to advancing coordinated international investigation of the Southern Ocean and to promoting long term Southern Ocean observing systems.

Dr Rob Massom and Dr Steve Rintoul and Prof Ian Allison were appointed members of the Scientific Committee on Antarctic Research (SCAR) Horizon Scan 'Future Directions in Antarctic Science'.

In addition, Dr Rob Massom was awarded a Visiting Professorship at the Institute of Low Temperature Science at Hokkaido University, Japan, from July to November 2013. Dr Rob Massom also was appointed co-Chair of the International Glaciological Society (IGS) International Sea Ice Symposium on 'Sea Ice in a Changing Environment', Hobart, Australia.

Drs Andrew Bowie, Catia Domingues and Guy Williams received Australian Research Council Future Fellowships. Future Fellowships provide four-year fellowships to outstanding Australian mid-career researchers and preference is given to researchers who can demonstrate a capacity to build collaboration across industry and/or research organisations and/or with other disciplines. Drs Bowie, Domingues and Williams will continue to provide their in-kind expertise to the ACE CRC.

Dr Catia Domingues was elected co-Chair of the WCRP 'sea level grand challenge' and elected co-Chair of the International Quality-Controlled Ocean Database (IQuOD) initiative. Dr Domingues was also appointed a member of the CLIVAR Research Foci on 'Consistency between planetary heat balance and ocean heat storage'.

Dr John Hunter, ACE CRC honorary fellow, received honorary fellowship of the Planning Institute of Australia for the contribution of his sea-level rise research to urban planning.

Dr Bronte Tilbrook was elected member of the Global Ocean Acidification Observing Network and elected member of the GOOS panel for establishing essential ocean variables for biogeochemistry for future ocean observing.

Throughout the reporting period, as Australia's invited observer, Dr Donna Roberts was a member of the International Ocean Acidification Reference User Group and Australia's elected expert member of the United Nations Environment Programme's Conservation of Biological Diversity Ocean Acidification Expert Committee.

Staff appointments

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

Name	Position	Start Date	Program
Sam Poynter	Ice Core Laboratory Assistant	7 April 2014	Cryosphere

Major purchases for the year
Major capital costs for this reporting period were:

Item	Amount $	Program
SATLANTIC in-situ FIRe fluorometer system	$18,000	Carbon
seaFAST S2 System	$19,900	Carbon
Autosamplers 1360 Dionex Chromatography	$32,156	Cryosphere
TOTAL	**$70,056**	

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

1.2 Risks and Impediments

The risk register, established at the beginning of this funding period, was updated and discussed at Board meetings during the reporting period. The purpose of the register is to ensure careful management of risks throughout the life of the ACE CRC.

The announcement that the ACE CRC would be refunded for five years from 1 July 2014 to 30 June 2019, downgraded the financial risk to 'low'. All staff members were extended to the end of June 2014.

Logistic risks continue to be identified as 'medium'. This is because conducting field work in Antarctica and the Southern Ocean is inherently risky due to ocean, ice and weather conditions. The environment is very hard on equipment, and aircraft and shipping delays and rescheduling are not uncommon. Within the reporting period field work to the Amery Ice Shelf was not possible, nor were additional flights over inland Antarctica for the ICECAP project.

Collaboration and usage are all identified as 'low' risk. Staffing has been revised to a low risk due to renewed funding.

The ability of the ACE CRC to meet its milestones because of funding pressures on ACE CRC's core partners remains a risk. Budget cuts to Government agencies have reduced their ability to carry out some functions. The ACE CRC has identified this as a risk and has taken steps to minimise the impact of this risk on ACE CRC activities.

1.3 End-user Environment

The web tool *Canute* (funded by the Department of Industry, previously called Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education) is used to predict sea-level changes around the coast of

Australia. It has 416 active users and a further 412 people who have signed up to the website but as yet have not completed all the training.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) was released in late 2013. The contributions of ACE CRC staff over several years to the preparation of the report represent a major commitment to end-users nationally and globally. The IPCC is the international body responsible for providing governments with the largest and most comprehensive summary of the latest scientific information on climate change. This work depends on voluntary input from scientists around the world and ACE CRC researchers have been involved as coordinating lead authors, lead authors, contributing authors and as reviewing editors or reviewers of the first, second and final drafts of chapters, both as scientific expert reviewers and on behalf of the Australian Government. The Synthesis Report, which integrates and synthesises material in the Working Group reports for policymakers, will be finalised in Denmark, Copenhagen on 31 October 2014. The IPCC projections are a major source of information for policy makers.

The fiscal environment remained tight with the Government budget decisions affecting partners in the ACE CRC and the general economic climate affecting the private sector and ACE CRC end-users. This has presented a continuinally challenging environment for engaging end-users in long term planning for climate change.

The ACE CRC Board includes representatives from its core partners, key government stakeholders and Small to Medium Enterprise (SME) representatives, as well as an independent Chair and independent members. The representation of these key stakeholders on the ACE CRC Board ensures that our strategic direction is in alignment with our end-users. During the reporting period, the ACE CRC worked closely with our core end-users to develop the research plan for the new round of funding from 2014 to 2019.

1.4 Outcomes (round 10 CRCs only)

Not applicable to Round 10 CRCs.

1.5 Impacts (round 11 CRCs only)

No significant change has occurred during the year to require adjustment to the Impact Tool. The ACE CRC has submitted a new Impact Tool with its application for the 2014 – 2019 funding round.

2 Research

The ACE CRC has delivered on the vast majority of its research goals. A detailed summary of the research activities at the program level – Oceans, Cryosphere, Carbon and Ecosystems – is given below. Information on involvement with end-users and evidence that the research is meeting their needs is also provided below.

In 2013-2014, our researchers published a total of 23 book chapters, 85 articles in scholarly refereed journals, and 1 full written conference paper in refereed proceedings. A further 15 articles were submitted to scholarly refereed journals or are in press at the time of reporting. This shows the ACE CRC continues to deliver its intended research outputs. The publications are listed in Appendix 1.

2.1 Performance against activities

2.1.1. Oceans: the Southern Ocean and Sea-level Rise

Project Summary

Southern Ocean processes influence climate and biogeochemical cycles on global scales. The Southern Ocean connects the ocean basins and links the shallow and deep limbs of the overturning circulation, a global-scale system of ocean currents that determines how much heat and carbon the ocean can store. The upwelling of deep waters releases carbon and returns nutrients that support biological productivity in the surface ocean; the compensating sinking of surface waters into the ocean interior sequesters carbon and heat and renews oxygen levels. The capacity of the ocean to moderate the pace of climate change is therefore controlled strongly by the circulation of the Southern Ocean. The future of the Antarctic ice sheet, and hence sea level rise, is increasingly understood to be determined by the rate at which the relatively warm ocean can melt floating glacial ice around the margin of Antarctica. Given the significance of the Southern Ocean to the Earth system, any change in the region would have impacts that extend well beyond the high southern latitudes.

The ACE CRC Oceans program has continued to make significant progress in understanding the nature, causes and consequences of change in the Southern Ocean. The Southern Ocean is warming more rapidly and to greater depth than the ocean average, reflecting the vigorous overturning circulation there. The deep-reaching nature of Southern Ocean warming means the region makes a significant contribution to the overall increase in ocean heat content and sea level rise. Changes in salinity have been documented throughout the full depth of the Southern Ocean. The addition of freshwater from glacial melt and from an increase in precipitation have both contributed to the observed changes in salinity. ACE CRC scientists have also documented widespread decreases in oxygen content, in particular decreases that are consistent with human influence and potentially a weakening of the overturning circulation in the oceans.

To determine the causes of Southern Ocean change, observations are compared with models run with and without the effect of human activities on climate. This technique allows quantitative assessment of how much change has occurred (detection) and how much can be related to human drivers (attribution). These studies have provided clear evidence of a human influence on global climate.

Among the most significant impacts of climate change will be a rise in sea level. Recent research has shown that sea levels are rising at rates near the highest of previous predictions, and that the Antarctic ice-sheet contributes more to this than was understood less than a decade ago. The recent IPCC Fifth Assessment Report (AR5) predicts higher future sea levels (than AR4), with increased confidence (see Figure 1).

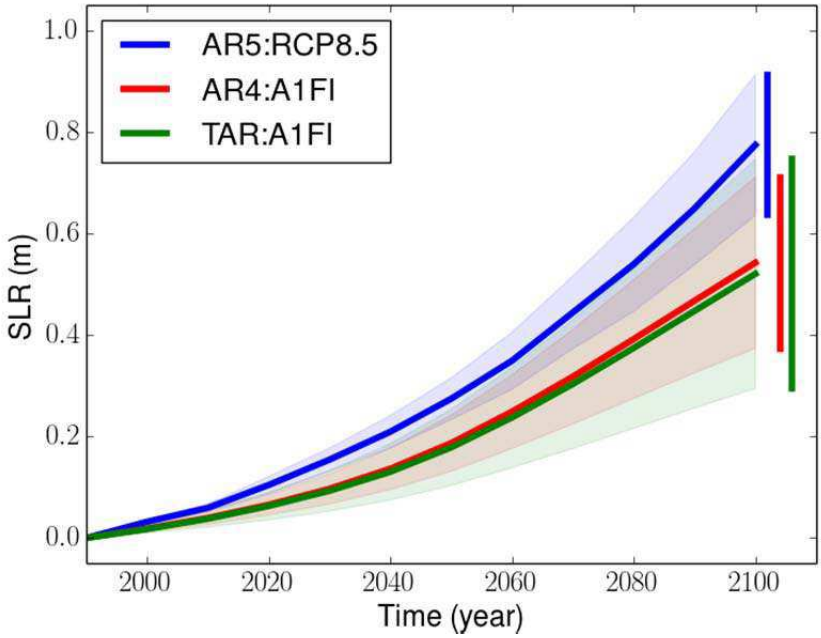


Figure 1: Predictions of future sea level from the three most recent IPCC reports (high emission scenarios). The range represents +/- 1 standard deviation of the model ensemble spread.

The ACE CRC's Sea-Level Rise Impacts project focuses on providing decision-makers with targeted assessments of the risks of sea-level rise. This work is incorporating the effects of storm surges and the recession of the coastline as sea levels rise. The ACE CRC is helping Australia plan and prepare for future sea-level changes by providing specialised technical consulting, specialised vocational training for governments and industry, and a sea-level rise calculator tool called *Canute* (www.sealevelrise.info). *Canute* provides a wide range of stakeholders with an understanding of how to assess risks to existing assets, plan adaptation, and set appropriate design codes and planning strategies for future development. While the new round of ACE CRC funding does not include a Sea Level Rise Program, we are exploring options to maintain the *Canute* sea level rise tool online as a service to the Australian community. It will most likely be hosted and supported by the Tasmanian Partnership for Advanced Computing (TPAC), based in Hobart.

Research Activities 2013-2014

The IPCC AR5 report was released in late 2013. Dr Steve Rintoul was a Coordinating Lead Author for the Oceans chapter, which assessed the observational evidence for change in the oceans. Prof Nathan Bindoff was a Coordinating Lead Author for the *Detection and Attribution* chapter and also contributed to the Technical Summary

and Summary for Policymakers. ACE CRC scientists also contributed to several other chapters as lead and contributing authors, including chapters on sea level rise, the cryosphere, and future projections (see Section 3.1 for more detail).

The *Oceans* chapter of AR5 (Rhein et al., 2013) shows that the oceans have stored about 93% of the extra heat energy accumulated by the planet over the past 50 years. This indicates the importance of ocean observations for tracking the evolution of climate change. The oceans also act as a rain gauge: basin-scale changes in ocean salinity provide the strongest evidence to support the hypothesis that greenhouse warming leads to an enhancement of the global water cycle, with more precipitation in rainfall-dominated areas, and more evaporation in areas where evaporation dominates precipitation. Observations from tide gauges and satellites show that the rate of sea level rise since 1993 is substantially higher than the average over the past century.

The IPCC AR5 *Detection and Attribution* chapter (Bindoff et al., 2013) concluded that human influence on the climate system is clear and it was *very likely* that human activities had a substantial contribution to the warming of the oceans. Ocean observations played a key part in supporting the conclusions of change in the climate system including those related water cycle changes that could be attributed to human influences.

Dr Catia Domingues and colleagues have published a series of papers investigating changes in ocean heat content and the planetary energy balance (Church et al., 2013; Johnson et al., 2013; Abraham et al., 2013). These studies are fundamental to understanding the evolution of earth's climate over recent decades. Griffies et al. (2014) provide an in depth assessment of global and regional sea level changes between 1993 and 2007.

A joint US-Australian voyage on the US research icebreaker *Nathaniel B. Palmer* took place in January 2014. The voyage collected the first oceanographic data in the vicinity of the Totten Glacier. The Totten Glacier is the most rapidly thinning glacier in East Antarctica but it is not yet clear whether the thinning reflects ice dynamics or melting by warming ocean temperatures. Moorings deployed in the 2013-2014 season will be recovered by the RSV *Aurora Australis* in December 2014. The ship will also collect a comprehensive set of ocean observations from ship-based profilers, ice-capable profiling floats, acoustically-navigated gliders, and tracer measurements. The combined data set will allow us to test the hypothesis that ocean warming is driving increased mass loss from this part of East Antarctica.

A paper published in *Geophysical Research Letters* (van Wijk and Rintoul, 2014) provided the most detailed assessment to date of changes in Antarctic Bottom Water (ABW). Observations by the ACE CRC and international colleagues have documented rapid warming and freshening of this dense water. However, the cause of these changes is not clear. The new study extended the record to forty years and

considered changes in oxygen as well as temperature and salinity. The paper shows the volume of the dense bottom water layer has decreased by 50% since the early 1970s but oxygen concentrations have remained high. The authors conclude that freshening of the source waters, due to a change in precipitation or melting of Antarctic ice shelves, is the primary cause of the changes in the bottom water layer.

Other scientific highlights of the Oceans program in 2013-2014 included the first continuous underway measurements of oxygen isotopes near Antarctica (Bass et al., 2014); a review paper assessing how changes in the physical environment affect the habitats of marine biota, with contributions from the Oceans and Ecosystems programs (Constable et al., 2014); evidence for widespread freshening in the sea ice zone (Aoki et al., 2013); a comprehensive review of Southern Ocean dynamics (Rintoul and Naveira Garabato, 2013); a study using the trajectory of Argo floats to quantify the westward flow south of Tasmania for the first time (Fieschi et al., 2013); a study using virtual particle trajectories in a numerical model to identify and quantify outflow pathways for ABW (van Sebille et al., 2013); a joint paper with the Carbon program explaining how physical and biological processes control oxygen and carbon dioxide concentrations in the Southern Ocean (Shadwick et al., 2014); and a metagenomic study published in *Nature Communications* showing how ocean currents shape the distribution and diversity of micro-organisms (Wilkins et al., 2013).

The Sea-level Rise Impacts team continue to develop the *Canute* web-based decision support tool. The tool provides estimates of the likelihood of present and future flooding at approximately 12,000 simulated-tide-gauge locations, with an effective resolution of 2.5 km along the entire length of the Australian coastline. This allows a prospective developer, for example, to make an initial estimate of the expected future storm-surge characteristics of a particular region before proceeding to a site-specific survey. Similarly, assessments can be made of the exposure of existing assets to the possible increased risk of flooding. Users now have the ability to assess the impact of the latest IPCC AR5 sea level predictions (whilst still being able to access the TAR and AR4 datasets).

An alternative method of asset exposure assessment has been developed (Hunter, 2011), which considers the predicted sea level induced change in the number of flooding events at a particular site. New code has been developed to implement the technique, and is being ported onto the *Canute* website as an additional user feature. This will be further complemented by an ability to calculate a location specific 'allowance' (i.e., the amount by which the height of coastal infrastructure needs to be altered to cope with climate change).

We are still working closely with the Spatial CRC (CRCSI) to translate the output from the calculator into high-resolution maps of predicted flood inundation. CRCSI has built a subset of our data into their new, web-based GIS, which is presently in testing mode. When their system is in production mode, the ACE CRC will be able to link into their server to create flood maps on-the-fly from within the *Canute* website.

The original concept of combining inundation probability integrated with second pass geomorphology was not realistic. The main reason for this was that the two datasets are working on different spatial scales and the concept of *Canute* is initial pass assessment. The spatial geomorphology data is more akin to a specific site study and thus this milestone has not been achieved.

The website has a tool to calculate the additional effect waves have on sea-level, for example, to show how far they will run up the beach. Previously, this required a user to have some knowledge of the offshore wave climatology. A new version of the tool has been developed which employs the output of the NOAA WAVEWATCH III model to provide offshore wave data for the whole Australian coastline. The new configuration allows arbitrary wave data to be easily integrated into the back-end. The test system can presently use both CSIRO and ECMWF model wave data, and it is planned that this data will migrate onto the production system.

We have been working closely with our partners to popularise the tool. This has taken the form of industry conferences, and grey literature publications. Planning for the project's end phase has involved the production of code documentation, and coherent versioning schemes. A 'bare-bones' configuration of the site has also been developed, which has removed any dependence on the present financially supported server. Plans are underway to transfer hosting of the *Canute* tool to the Tasmanian Partnership for Advanced Computing.

The tool is steadily acquiring new users, and it is envisaged that these users will continue to have basic access to *Canute* beyond the project's end phase.

2.1.2 Cryosphere: Impacts of Changing Snow and Ice Cover

Project Summary

The ACE CRC's Cryosphere Program is made up of three main research projects: the dynamic role polar ice sheets play in determining future sea levels; the role of Antarctic sea ice in the climate system; and the records and dynamics of past and present climate.

The great ice sheets of Antarctica and Greenland hold the largest potential for substantial and prolonged contributions to sea-level rise in a warming climate, but our present ability to predict these changes is limited. Recent observations suggest that the contribution to sea-level rise from both these great ice sheets is increasing, and that this is due to increasing discharge of ice by glaciers, rather than simply to more melt. Current computer models that simulate ice sheet dynamics and their links within the climate system are inadequate for quantifying the nature, rapidity and extent of the response of the ice sheets to climate change, and this gives rise to the principal uncertainty in sea-level predictions over time scales of a century and longer.

The project, 'The dynamic role of polar ice sheets in future sea level,' aims to improve the computer models of ice-flow dynamics, basal processes (occurring underneath ice sheets, where they interact with land) and interactions with the atmosphere and ocean. The ACE CRC is collaborating with international efforts in model development, in particular though building on our expertise in the properties of ice flow and the interactions between ice shelves and the ocean. The models now take account of stresses to the ice that were previously neglected, and the ACE CRC's contributions include improved treatment of basal conditions, particularly the melting under ice shelves, and a better understanding of conditions at the surface of and beneath ice sheets. Modelling of the transition of glaciers from grounded ice flow to floating ice shelves is also being refined, so that the effects of changes occurring at the ocean margins on the flow in the ice-sheet interior are also taken in to account.

The ACE CRC is involved in a major collaboration with international partners in the aerogeophysical survey of unexplored sectors of East Antarctica. This project is called 'Investigating Cryospheric Evolution through Collaborative Aerogeophysical Profiling' (ICECAP). The suite of instruments used in these surveys is producing vital knowledge of bedrock topography, basal rock, sediment and water conditions. These data will ensure that ice-sheet models are enhanced by real-world boundary data. The ICECAP survey targets deep sub-glacial basins and major outlet glaciers, which hold the greatest potential for dynamic ice sheet changes, and consequently for potential sea-level rise.

The Cryosphere program's second project, 'The role of Antarctic sea ice in the climate system,' seeks to understand the key roles sea ice plays in the earth's climate system: the annual change in Antarctica from the maximum extent of sea ice in winter to the minimum in summer is one of the largest natural physical changes on the planet. Through a variety of feedback mechanisms, sea ice acts as both an agent and an indicator of climate change. It is also an important structure with respect to marine ecosystems. Over recent decades, the extent of sea ice and its thickness have decreased in the Arctic; a very significant reduction in extent has also occurred in the Antarctic Peninsula region, but overall there is a slight positive increase in sea ice extent of +1.5% per decade for the period 1979 to the present. It is not known how the thickness of Antarctic sea ice is changing as this cannot yet be determined accurately from satellites.

The ACE CRC is conducting field research, including the deployment of an Autonomous Underwater Vehicle (AUV), equipped with upward-looking sonar, to measure the drift of sea ice; a Remotely Operated Vehicle (ROV), equipped with a hyperspectral radiometer, to measure biomass production; and deployment of drifting buoys to measure sea-ice kinematics. To validate and calibrate satellite remote sensing, in situ observations and airborne laser altimetry are being further developed. This work supports ACE CRC involvement and leadership in the International Space Science Initiative to improve derivation of Antarctic sea ice

thickness and volume from satellite remote sensing. ACE CRC scientists continue to lead the development of an Antarctic fast ice network in Antarctica, which now has six active international collaborators.

The third project in the Cryosphere Program is 'Past and present climate: records and dynamics'. Climate records from the Antarctic region, Southern Hemisphere and even Australia are relatively sparse and of short duration. The previous IPCC reports have underscored the need for more palaeoclimate records from the Southern Hemisphere. These records are needed to support climate reconstructions and process studies and to test models. The project is producing additional high-resolution climate records for the Antarctic. The team is developing existing records and using these to investigate regional and hemispheric climate processes, with emphasis on connections to Australian climate.

In order to do this, we are expanding the spatial extent and the timespan of the network of high-resolution ice-core records from East Antarctica. ACE CRC researchers are calibrating high-resolution ice-core records against modern meteorological data, and using these to probe climate dynamics over timescales beyond the period of human records. Finally, we are investigating longer-term processes related to natural climate forcing variations over the last glacial cycle, and the manner in which these influence the progression of global climate change and abrupt climate events.

Research Activities 2013-2014

The Cryosphere program continued to be very productive this year, with significant field activities and emerging results from recent fieldwork. Important publications resulting from this work are referred to below.

Work in understanding the dynamic role of ice sheets in sea level progressed with associated modelling and ICECAP aerogeophysics research results. In July 2013, the group was joined by British Marie Curie Fellow, Dr Rupert Gladstone, who will be hosted at the ACE CRC for approximately 2 years. Dr Gladstone is assisting in further development of approaches to coupling ice-shelf ocean models. Logistical constraints in the 13/14 season prevented ICECAP and Amery ice shelf fieldwork, however, researchers drew on data from the Amery ice shelf to publish a range of papers, including a description of seasonal variability of ice-ocean interactions (Herraiz-Borreguero et al., 2013); basal marine ice formation (Craven et al., 2014; McDougall et al., 2014); and on life-forms beneath the ice shelf (Post et al., 2014). Research in understanding the physical mechanisms that control the past and present rates of Antarctic ice discharge, needed to assess future sea level rise, and changes to ocean circulation adjacent to Antarctica will continue in the renewed ACE CRC.

The ice-ocean modelling has advanced our understanding of the coastal ocean processes that control the melting of Antarctic ice shelves. This includes the first study

showing the influence of coastal polynya activity on the basal melting of ice shelves, using the Mertz Glacier tongue (Cougnon et al., 2013). Another study examined basal melting under the Totten Glacier (Gwyther et al., 2014), which is a focus of East Antarctic ice mass balance studies (and ongoing ACE CRC research) due to its large regional rate of ice loss.

ICECAP research led to major improvements in our understanding of the underlying geology beneath the East Antarctic ice sheet (Aitken et al., 2014), with implications for both ice sheet flow and the search for ice over a million years old (Fischer et al., 2013) that might be recovered by future coring.

Sea ice research continued in this year, progressing work arising from the 2012 Sea Ice Physics and Ecosystem eXperiment (SIPEX-II) voyage reported last year. This was facilitated by a major sea-ice symposium held in Hobart in March 2014 under the auspices of the International Glaciological Society (IGS) (see Section 3.1). This meeting also included several workshops, including one specifically on SIPEX-II. SIPEX-II data are being used to validate on a regional scale and this work is being pursued in the renewed ACE CRC. ACE CRC sea ice research was strongly reflected in relevant sections within the IPCC AR5, in particular on East Antarctic sea ice and change. The following Cryosphere Program researchers provided their expertise to the IPCC AR5:

- Dr Ian Allison, Honorary Research Professor, (Lead Author, Working Group 1, Chapter 4 - Observations: Cryosphere)
- Dr Rob Massom and Dr Tony Worby (Contributing Author, Working Group 1, Chapter 4 - Observations: Cryosphere)
- Prof Peter Lemke, AWI, Germany (Reviewing Editor, Working Group 1, Chapter 4 - Observations: Cryosphere)

A peer-reviewed report on the state of Antarctic sea ice extent and concentration was produced for the *State of the Climate* series published by the American Meteorological Society (Massom et al., 2013).

Fieldwork continued, with collaborative involvement in three voyages (AntXXIX-6, -7 and -9) conducted by Alfred Wegner Insitute on the *RV Polarstern*. This included joint work on sea ice dynamics and deployment of ACE drifting buoys, and a multi-disciplinary ice and krill study which successfully used an ACE CRC remotely-operated vehicle (ROV).

This was a big year for the ice core research group, with a major expedition to Aurora Basin. This deep field activity was highly successful, recovering three ice cores and conducting associated work at the site, approximately 550 km inland of Casey Station. The main core, 303 metres in length will provide a record covering around 2,000 years of climate and environmental information from a region previously devoid of such information (the nearest ice core being Law Dome, roughly 500 km to the north). The project is a large collaboration, with 15 participating institutions,

and analysis has commenced, with core material already under analysis in the US (Desert Research Institute, Nevada) and Germany (AWI). These early analyses show a very well resolved ice core chronology with clear volcanic ties established already for the past 800 years. Two shallower cores, reaching just over 100 metres deep provide additional ice for analyses that have large ice demand. The borehole for one of these shallower cores was used to provide access to the porous firn, from which large volumes of air were pumped. These large volume samples allow for exotic trace gases to be detected and changes in recent decades to be assessed.

High profile research results continue to emerge from the large collaborative efforts around dating and combining high resolution cores from across Antarctica. These results have a strong reliance on the very accurate Law Dome ice core chronology, which is now synchronised with the new West Antarctic Ice Sheet (WAIS) core. This work includes a reconstruction of Southern Hemisphere climate over the last millennium (Neukom et al., 2014) and a volcanic forcing record for the past 2,000 years (Sigl et al., 2014).

2.1.3. Carbon: Southern Ocean Uptake

Project Summary

Currently one quarter of humankind's annual emissions of the fossil-fuel derived greenhouse gas, CO_2, are absorbed by the oceans. The Southern Ocean accounts for about 40% of that total. The oceans act as a reservoir for carbon, called a carbon sink, which accumulates and stores carbon via the ocean's physiochemical and biological processes.

Increased absorption of CO_2, however, comes at a cost – a decrease in the alkalinity of the ocean (often called ocean acidification). In the 21st century this change will have potentially serious impacts on the sustainability and management of many marine and coastal ecosystems and fisheries. Upwelling of sea water rich in CO_2 occurs more strongly in polar seas, and it is there that acidification will cross geochemical thresholds first, producing, for example, an undersaturation of the carbonate minerals that form the skeletons or shells of many marine organisms. This is a clear reason for giving the Southern Ocean special attention.

ACE CRC collaborates with many organisations and countries around the world to understand the ability of the Southern Ocean to draw down atmospheric carbon. This understanding is vital for our environmental future and, as emphasised by the IPCC, is crucial for the setting of efficient emissions reductions in order to limit climate warming. The ACE CRC Carbon Program has the overall goal of quantifying the role of the Southern Ocean in the global carbon cycle via three main projects.

The first of these projects involves measuring the magnitude of the uptake of atmospheric CO_2, the processes that control this uptake, and their propensity for change. The Southern Ocean's ability to take up CO_2 will not continue at current

rates if global climate change reduces the rate of the ocean's normal mixing processes and therefore hampers their effectiveness. Changes in sea-ice cover, ocean warming and stratification, and a lack of supply of the limiting trace nutrient iron all potentially have negative effects on the effectiveness of the 'biological pump' (those biologically-mediated processes, viewed as a whole, which transfer carbon from the surface region of the ocean to its interior) to lock CO_2 in the Southern Ocean carbon sink.

Determining the extent of ocean acidification caused by the uptake of CO_2, and its biogeochemical ramifications, is the second project in the Carbon Program. The overall goal is to determine how the progress of acidification depends on both the uptake of human-produced CO_2 and its interaction with naturally varying processes that control the distributions of alkalinity, dissolved inorganic carbon, and nutrients. Using samples from Antarctic voyages, the Carbon Program is mapping the progress of acidification and measuring the abundance of carbonate-forming organisms that may be affected by ocean acidification.

The final Carbon project examines potential carbon sequestration benefits and associated ecological risks of increasing the Southern Ocean's uptake of CO_2 by iron fertilisation of the ocean. The CRC focuses its efforts on the study of natural iron fertilisation – most of which is wind-borne iron from rocks and soils – in order to investigate the associated extent of carbon uptake and ecosystem health and to compare these results to artificial fertilisations.

The ACE CRC Carbon Program collaborates with national and international bodies including the Department of Industry, Department of Environment, the Australian Computational Earth Systems Simulator (ACCESS), the Australian Climate Change Science program, CSIRO, the AAD, International Ocean Carbon Coordination Project (IOCCP), CO_2/Climate Variability and Predictability Program (CLIVAR), GEOTRACES, the Global Carbon Project and the IPCC. Impacts of the ACE CRC's research include cost savings by governments and industry as a result of more accurate carbon-cycle models and more informed carbon-management strategies.

Research Activities 2013-2014

This year the Carbon Program's focus was on assembling data and synthesizing results in the final year of the current term of the ACE CRC. In addition, the Carbon program carried out two voyages to service the Integrated Marine Observing System (IMOS) Southern Ocean Time Series facility, to recover and deploy new air-sea flux data, to measure surface biogeochemistry, and to recover deep sediment trap moorings each time. Important results this year from the three Carbon Projects are discussed below.

Ocean Uptake

This project had several successes in the development of automated observations of Southern Ocean surface ocean processes that influence climate and carbon cycling. Combining oxygen and total gas tension sensor outputs from the Southern Ocean Time Series (SOTS) moorings this project was able to provide the first full seasonal record of net community production, which revealed unexpectedly strong production in early spring when the surface mixed layer was still very deep and cold (Weeding and Trull, 2014). We were able to determine the relative influences of physics and biology on the total annual uptake of carbon dioxide by combining wind, mixed layer depth, temperature, salinity and carbon dioxide partial pressure sensor results (Shadwick et al., submitted). In addition, the project launched three new "Bio-floats", which are autonomous profiling floats that form part of the ongoing collaboration with French researchers to study the influences of iron inputs on productivity over the Kerguelen Plateau. These floats have sensors for dissolved oxygen, phytoplankton (measured as chlorophyll fluorescence), and suspended particles (measured as red-light backscatter). Analysis of the telemetered sensor data is ongoing, with early results revealing a mosaic of different biological responses to the natural input of the limiting trace nutrient iron from the Kerguelen Plateau.

The ACE CRC carbon program members had a lead role in the development of a new release of the Surface Ocean Carbon Atlas (SOCAT; Bakker et al 2014), including chairing the group responsible for all Southern Ocean waters south of 30°S. SOCAT is a major international effort to deliver a uniformly quality controlled data product of underway surface CO_2 observations for use by researchers in the detection of changes in ocean carbon uptake and for testing ocean carbon cycle models. Ocean sink estimates for a new global carbon budget (LeQuere et al 2014) were dependent on the latest release of SOCAT.

Ocean Acidification

Research progressed on determining the controls and magnitude of CO_2 uptake and acidification in the Southern Ocean. Shadwick et al (2014) described how the removal of the Mertz Glacier tongue in 2010 resulted in dramatic changes in CO_2 uptake and ocean acidification. The study showed enhanced biological production and CO_2 uptake by surface waters since 2010 that are opposite to the expected ocean acidification changes from CO_2 uptake alone. The changes in the Mertz Polynya region may be an indicator of future regime shifts for the coastal waters undergoing rapid loss of ice and is a natural laboratory to study how high latitude shelf waters might respond to future change. The results contrast with a study from the previous year off Davis Station (Roden et al., 2013) that showed CO_2 uptake and ocean acidification change exceeded the values predicted from increasing atmospheric CO_2 alone. The combined results point to the importance of understanding shelf-offshore interactions and localised feedback associated with physical and biological processes that can significantly alter the exposure of

Antarctic shelf ecosystems to ocean acidification. Research also proceeded on determining ocean interior changes in carbon (Sloyan et al., 2013) and oxygen using new sensor technology on profiling floats (Takeshita et al., 2013).

Ocean Fertilisation

The ACE CRC Carbon team submitted several papers for the special issue of *Biogeosciences* dedicated to the French-Australian Kerguelen Ocean Plateau compared Study (KEOPS-2). This major effort demonstrated that natural iron fertilisation from the Kerguelen plateau produces a mosaic of phytoplankton blooms extending downstream over hundreds of thousands of square kilometers, which also exhibits large variations in local values of carbon production and export. This research significantly advanced our understanding of the role of natural iron fertilisation on Southern Ocean biogeochemical cycles and ecosystem functioning, particularly how the strong seasonal decoupling between iron supply and carbon export can largely explain the different fertilisation efficiencies reported previously. When the results of process studies such as KEOPS-2 are extrapolated over the whole Southern Ocean, a small change in the estimate of the carbon sequestration efficiency (defined as unit of carbon exported per unit of iron added above background conditions) could result in different conclusions as to the capacity, for instance, of artificial iron fertilisation as a means of mitigating rising atmospheric concentrations of anthropogenic CO_2.

New information on the physical speciation of trace elements in Antarctic coastal sea ice (fast ice collected near Casey station) revealed lithogenic (i.e., terrestrial) origin and low iron solubility (Lannuzel et al., 2014). This result is in contrast with data obtained in pack ice during the SIPEX-II voyage, where the majority of the iron was biogenic (i.e., derived from plants or animals) in composition. The new measurements and calculated fluxes indicate that a large fraction of the iron pool within sea ice may be bioavailable, and therefore effective in promoting primary productivity in the marginal ice zone.

The Carbon team also addressed for the first time the organic complexation of iron in the sea ice environment, showing that more than 99% of iron is bound to organic ligands. The exact nature of these ligands is unknown, but the ubiquitous presence of exopolysaccharides typically observed in sea ice and their binding characteristics make high molecular weight polysaccharides a good candidate. The linear relationship observed between the concentration of dissolved organic ligands and the concentration of dissolved iron in sea ice clearly demonstrates that organic ligands control the distribution of iron in this environment. The organic complexation of iron may therefore hold the explanation for the retention of iron in sea ice at levels up to two orders of magnitude higher than Antarctic surface waters, and contribute to the subsequent fertilisation of the marginal ice zone during spring melt.

ACE CRC researchers also took a lead role in the international program GEOTRACES, a global study of the marine biogeochemistry of trace elements and their isotopes in

the oceans. This included participation in the Scientific Steering Committee and chairing of the Data Management Committee in the year of the release of the first Intermediate Data Product (IDP). The IDP shares hydrographic and marine geochemical data acquired during the first 3 years of the GEOTRACES program to strengthen and intensify the collaboration within the broader ocean research community. The IDP 2014 consists of two parts: (1) the digital data and (2) the e-GEOTRACES Electronic Atlas. The data product includes contributions from many laboratories around the world that form part of the GEOTRACES program. The GEOTRACES data are of value to many fields of oceanography. The release of the quality-controlled data, in a timely manner, is of great benefit to ocean research. Further details can be found at www.egeotraces.org.

These evolving perspectives on the interactions of iron fertilisation with the characteristics and health of ecosystems informed collaborations with the Department of the Environment (previously called the Department of Sustainability, Environment, Water, Heritage and the Arts) that led to an amendment to the International Maritime Organisations London Protocol in October 2013 to improve the regulation of ocean fertilisation.

2.1.4 Ecosystems: Impacts of Climate Change on Antarctic Marine Life

Project Summary

The Ecosystems program addresses the challenging question of the impact of changes in the Southern Ocean and sea ice on Antarctic ecosystems and fisheries. The current expectation is that krill will remain a keystone species in the future but that the productivity of the ecosystem will generally decline if future projections of less extensive sea ice are realised (noting that some areas such as the Bellingshausen Sea already have a much shorter sea ice season than several decades ago). However, emerging science is showing that the productivity of the system is uncertain and that a long-term reduction in sea ice may give rise to a pelagic system, with the food web structure in high latitudes shifting from being krill centric to one centred on fish, such as that seen on the Kerguelen Plateau of the Southern Ocean. Such a change could greatly affect the region's fisheries and the conservation of whales and other higher predators who rely on krill as a primary food source. The ACE CRC is using a combination of field and analytical studies, along with qualitative and quantitative modelling, to determine what may happen to the Antarctic marine ecosystem based on the prognoses of change from the IPCC AR5 analyses.

The Ecosystems program has four projects researching possible changes to Antarctic ecosystems and the consequences for fisheries. The first of these is identifying the risks to key species of Southern Ocean marine ecosystems from the effects of climate change, such as temperature changes and ocean acidification. Literature and expert opinion are being used in a risk-assessment framework to evaluate the responses of species to climate-change scenarios. This work includes the development of conceptual models of the impacts on the physical environment

and on food webs. Spatial modelling will identify major environmental drivers for species, and IPCC AR5 results will be used to ascertain changes in those drivers and the likely consequences to species distributions and dynamics.

The second project aims to help determine the impacts on ecosystems of predicted changes in Antarctic sea ice through evaluating the linkages between ocean productivity and the spatial and temporal dynamics of the sea-ice zone, including physical and biological parameters of sea ice. A sea-ice 'emulator' is being developed to improve models of the productivity of algae in sea ice until a full physical model for sea ice is completed. The international dataset of the biological and biogeochemical parameters of sea ice from ice cores is being further developed. In situ measurements of the biomass and production of ice algae and an understanding of how these relate to the physical attributes of sea ice and the water column are essential for developing the spatial models and the dynamic simulation models. Field programs in winter and spring will help identify these relationships.

The third project in the Ecosystems program is made up of two parts, and focuses on identification of food-web processes that might be impacted by changes in the physical and biogeochemical environments in eastern Antarctica. Part 1 includes regular sampling on the Southern Repeat (SR3) oceanographic transect, combined with spatial statistical analyses of available data to evaluate the types of changes in phytoplankton and zooplankton assemblages that could arise as a result of a changing climate, and the mechanisms that could cause those changes. Part 2 of this project is to develop the foundations for an integrated ship- and land-based program to evaluate the primary food-web linkages from phytoplankton to top predators in eastern Antarctica. A multidisciplinary approach, which involves collaboration among agencies in Australia and overseas, is being adopted to sustain this program in the long term.

The fourth project draws on the results of the other ACE CRC Ecosystems projects to create a second-generation model of marine ecosystems, which will be used to assess historical and future climate change impacts on Antarctic marine ecosystems, and to evaluate the types of objectives appropriate for the conservation of Southern Ocean species. Models currently in development include the Ecosystem Productivity Ocean Climate (EPOC) modelling framework centred on the krill-based ecosystem, a regional ocean model (using the Regional Ocean Modelling System - ROMS) of eastern Antarctica and the Kerguelen Plateau, the Australian Earth-system model through ACCESS, and an end-to-end ecosystem model using 'Atlantis'. A NetLogo representation of key components of the ecosystem has also been developed to help validate approaches to modelling the different penguins, seals and whales to be used in the Atlantis model. This work is employing the latest cross-program knowledge of different components of the ecosystems in order to represent them appropriately in the modelling environment. These enhanced ecosystem models will be coupled to an ocean-ice-atmosphere model through the

ROMS, in partnership with the modelling group at Old Dominion University, USA. Once developed, experiments will be undertaken based on plausible scenarios for climate change impacts, as developed in the other three projects in the ACE CRC Ecosystems program.

Research Activities 2013-2014

The Ecosystems Program has contributed significantly to assessments of climate change impacts on Southern Ocean ecosystems during this reporting period. It coordinated a scientific community assessment of how changes in physical habitats directly affect marine biota in the Southern Ocean that was published in the journal *Global Change Biology* (Constable et al, 2014). The Program Leader, Dr Constable, supported by others in the program, was a lead author of the Polar Regions Chapter of the IPCC AR5 by the IPCC Working Group II published in March 2014.

The peer-reviewed, web-based Southern Ocean Knowledge and Information (SOKI) Wiki has been released into the public domain at www.soki.aq. The site provides up-to-date information used by the scientific community in modelling and assessments of the Southern Ocean as well as a means of communicating information to the wider public on the status of knowledge on Southern Ocean ecosystems. SOKI is also now being used by the ICED and SOOS communities as a vehicle for coordination of their research groups, developing and publishing standard field, modelling and analytical methods and for communicating initiatives and plans by the scientific community. The Ecosystems Program has also finalised a position analysis on observing Southern Ocean ecosystems and contributed to the position analysis on Antarctic Sea Ice and Climate Change 2014. The Ecosystems Program's modelling group has developed end-to-end modelling approaches linking ocean, sea ice, biogeochemistry and upper trophic levels representing two energy pathways – one through Antarctic krill and the other through copepods and small myctophid fish (Kawaguchi et al., 2013; Melbourne-Thomas et al., 2013; Bedford et al., in review; Mori et al., in review). A cartoon model of key components has been developed in 'NetLogo' to better explore the approaches to modelling seals, whales and penguins that will be finalised in the Atlantis model. These models are nearing publication. A sea-ice habitat 'emulator' has been further advanced for inclusion in the ecosystem models by testing approaches for modelling larval krill habitat (sea ice, light, algae) using the simulation sea ice model, C-ICE. A basic emulator has been included in 'NetLogo' and 'Atlantis'. In conjunction with ICED, the group has participated in developing scenarios of change in Southern Ocean habitats from now until 2100 based on IPCC CMIP5 model outputs. The Ecosystems Program's modelling group also coordinated a session on modelling approaches to test scenarios at the Integrated Marine and Biogeochemistry Ecosystem Research (IMBER) Open Science Conference 2014 in Bergen, Norway. Model descriptions and parameter inputs are available in SOKI. Testing of the end-to-end ecosystem models is now underway. This slight delay in the development of models has delayed the

publication of the ecosystem observing change position analysis. The final draft is ready for publication and will be delivered in the renewed ACE CRC.

Results of the Australian-led SIPEX-II voyage and also the winter-spring voyage on the AWI vessel *Polarstern* in the Weddell Sea and the South Atlantic are being finalised and prepared for publication, including new data on sea ice habitats and their importance to larval and juvenile krill. Importantly, a relationship has been established between sea-ice thickness and ice algal distribution. These results and other work on the role of sea ice in Southern Ocean ecosystems and the effects of changing sea ice on the ecosystems was presented at an ACE CRC-led International Symposium on Sea Ice in a Changing Environment in Hobart in March 2014.

Further progress has been made in the international coordination of a circumpolar program to measure change in Southern Ocean ecosystems. The Ecosystems Program has contributed to workshops and planning in ICED and the Southern Ocean Observing System. It provided the central planning and leadership of a workshop on ecosystem Essential Ocean Variables (eEOVs) hosted by Rutgers University in March 2014 (http://www.soos.aq/products/soos-products?view=product&pid=25) from which a proposal was submitted for a SCOR Working Group to further develop eEOVs for Southern Ocean and global observing of marine ecosystems. These results were considered a highlight at the SCAR Open Science Conference in New Zealand in August 2014.

2.2 Education and Training

Education

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

ACE CRC staff teach PhD, Masters by Research and Masters by Coursework students. They also teach Honours programs and units in undergraduate courses, mostly to students taking science degrees, although a few undergraduates from other backgrounds (e.g., Arts) do enrol in first-year Antarctic studies units taught by IMAS.

During the reporting period, 47.5 (FTE) students were involved in PhD studies related to the ACE CRC, including 8 commencing students. There were also 4 completions and 1 withdrawal during the reporting period. Out of the 4 PhD students that graduated during the reporting period, 3 are in post-doctoral positions overseas and 1 is currently in a data manager role at the University of Tasmania. In total, 39 UTAS staff and 52 non-university staff were involved in PhD supervision.

PhD student, David Gwyther, was a 2013 Fulbright Postgraduate Scholar. David spent his scholarship year (July 2013 – June 2014) at the University of Texas at Austin,

USA – and institution which is an ACE CRC participant. For the full report and student profile see page 29.

Also in the reporting period, 1 Masters by Research student completed their studies. This student's supervision involved 2 UTAS staff and 2 non-UTAS staff.

A total of 313 students were enrolled in IMAS undergraduate units during 2013-2014. Of these, 40 were enrolled in the Bachelor of Antarctic Science and 38 in the Bachelor of Marine Science. IMAS also enrolled 32 students in the new Bachelor of Marine and Antarctic Science (introduced in February 2014), which will supersede both of the existing undergraduate courses. Total undergraduate numbers have also showed a 11% increase on the last reporting period which remains encouraging. We expect a signficant number of these undergraduate students to go on to higher degrees at UTAS, with good potential for the ACE CRC to attract them into research projects relevant to Antarctica and the Southern Ocean.

At fourth-year undergraduate level, there were 16 students enrolled in Science Honours programs (6 of these students completed during the reporting period), and 28 students enrolled in Professional Honours (which articulates to the Master of Marine and Antarctic Science coursework masters). Six non-university staff members were involved in the formal teaching of the postgraduate units within the Professional Honours program. There were 29 (FTE) students enrolled in the Master of Marine and Antarctic Science, including 11 commencements and 18 completions.

These figures indicate a resurgence in interest in Honours / Masters coursework programs, which augurs well for future recruitment into PhD programs within the ACE CRC. There have been strong employment outcomes for this year's PhD graduates, who continue to develop outstanding professional careers. Out of the 4 PhD students that graduated during the reporting period, 3 are in post-doctoral positions overseas and 1 is currently in a data manager role at the University of Tasmania.

The ACE CRC will continue to work closely with IMAS to improve visibility of projects and enhance student recruitment.

Furthermore, IMAS has developed a free online marine and Antarctic science course which is run through the Open2Study program of Open Universities Australia. The month-long course consists of 37 short videos and there are four modules. Subject material covers the full spectrum of activity undertaken by IMAS. Prof Craig Johnson (IMAS) and Dr Jessica Melbourne-Thomas (AAD and ACE CRC) present the course. As of 18 September 2014, 3,673 students have taken the course; 15,125 videos have been watched; and 1,132 classroom posts have been made.

The ACE CRC has 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 are held weekly 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. Moreover, DaSH (Data Science Hobart) weekly sessions have been organised by ACE CRC students and researchers to build a community of researchers to discuss data, concepts, tools, methods and to solve problems. The weekly IMAS seminars also allow for students and researchers to have discussions and improve collaborations.

Furthermore, the career resilience workshop for early career researchers and postgraduates on 6 June 2014 was well attended by ACE CRC PhD students. This career resilience workshop involved working out strategies for developing sustainable career pathways and examples of career pathways from a panel of marine/Antarctic scientists were featured.

The ACE CRC 2014 Symposium – *Looking Back: Looking Forward – Antarctic Science for the 21st Century* provided a scientific context for future research in the Antarctic and Southern Ocean; highlighted the big questions for the future; and showcased the work of emerging Antarctic scientists. A call for student abstracts resulted in 8 student abstracts being presented and 5 students presenting posters. The best oral presentation award went to Lavenia Ratnarajah and the best poster award went to Indiah Hodgson-Johnston.

A list of all ACE CRC PhD students, including commencement date, research program, project title, research organisation, country and expected completion date, is provided in Appendix 2.

Training courses for end-users/professional development

During the reporting period, the ACE CRC hosted 1 symposium and several workshops for end-users, attended by a total of 207 end-users.

ACE CRC Symposium 2014

The ACE CRC held another highly successful Symposium on the 4th and 5th of June 2014. The Symposium, *Looking Back: Looking Forward – Antarctic Science for the 21st Century*, focused on providing a scientific context for future research in the Antarctic and Southern Ocean; highlighted the big questions for the future; and showcased the work of emerging Antarctic scientists. Registrations for the Symposium exceeded expectations, with more than 130 people attending. The following organisations attended the Symposium: AAD, Antarctic Tasmania, Bureau of Meteorology (BoM), CCAMLR, CSIRO, Department of Environment, IMAS, IMOS, Australian Maritime College, Curtin University, Victoria University of Wellington, and the Chinese Academy of Sciences.

Southern Ocean Modelling Workshop

The ACE CRC and the AAD hosted the Southern Ocean Modelling Workshop on 21 February 2014 to discuss progress and directions for Southern Ocean ecosystem modelling work amongst the Hobart community. The workshop helped identify

synergies and informed future strategies for modelling work. Approximately 40 people, including end-users, attended.

Sea ice view tool training

The Sea Ice View Tool is a software package that provides satellite data products to vessels operating in the Antarctic sea ice zone, to assist with navigation. Dr Lieser trained 6 employees from P&O Maritime on 23 September 2013 in the use of the software. Emphasis was placed on interpretation of the data products that were available for the season, and their origin. A manual for the tool as well as a printed copy of Sea Ice Reports for reference were given to participants. This training will be done annually, on request, before the commencement of the Antarctic shipping season.

Canute

Canute, the publically available sea level calculator, provides estimates of the likelihood of future flooding from the sea. By combining two uncertainties (the frequency of present storm surges and the uncertainty of future sea-level rise) into a single likelihood, a statistically robust prediction is generated. To use *Canute*, people need to register and complete the online training. There are currently 416 active users and a further 412 people who have signed up to the website but not yet completed all the online training.

ACE CRC Student Profile

David Gwyther

Fulbright Scholarship Recipient

PhD student David Gwyther has returned from a 12-month research scholarship in the United States, where he has been modelling the impact of ocean warming and circulation changes on East Antarctic ice shelves.

The opportunity to join ACE CRC's partners in the international ICECAP program at the University of Texas came when David received a prestigious Fulbright Postgraduate Scholarship worth $40,000.

David's research is focused on improving ocean modelling of the Totten Glacier region by incorporating ice thickness and ocean depth observations gathered by the world-leading Institute for Geophysics based in Austin.

Using these data David has built a high-resolution model of the interaction between the ocean and the ice in the cavity beneath Antarctic ice shelves. His simulations – run on supercomputing resources provided by the Tasmanian Partnership for Advanced Computing (TPAC) – indicate a strong link between the rate of ice shelf melting and the presence of polynyas. Polynyas are areas of wind-swept ocean that produce large quantities of sea ice and drive the formation of cold, salty and dense water.

"The models indicate that polynyas have the potential to limit melting by driving cold water under the ice shelf. This raises implications for how future changes to polynya strength and persistence will affect ice shelf melting," he said.

Ice shelves are important because they restrict the flow of ice from the continent into the ocean, and are thus a key factor in controlling the rate of sea level contribution from the Antarctic Ice Sheet. As one of the fastest-thinning glaciers in East Antarctica, the area around the Totten Glacier is of particular interest to the ACE CRC and to the ICECAP program.

David Gwyther aboard RV Nathaniel B. Palmer (Jan 2014)

One of the key goals of David's scholarship has been to exchange knowledge, data and modelling experience within the ICECAP group. The outputs from this collaboration, including an article published in the journal *Ocean Sciences*, highlights the success of the ACE CRC's international research partnerships.

"The Texans do a lot of amazing observations using aircraft, but they don't do any ocean modelling of their own. We specialise in the modelling, but we need the aerial observations to ensure the models are as accurate as possible. That's one of the reasons the partnership is so valuable to both parties," he said.

A rare opportunity to see the East Antarctic region up close came in January 2014, when David joined scientists for a six week research trip aboard the American research icebreaker, RV *Nathaniel B. Palmer*. The trip was an important opportunity for David to get hands-on experience taking oceanographic measurements and gain the valuable real-life insight that computer modellers often lack.

As a former Queenslander who was "somewhere on the Texas spectrum already," David said the experience had been transformational. "That's really what Fulbright is all about," he said. "It has a really strong ethos of cultural exchange in the name of peace and learning."

2.3 SME Engagement

There was active engagement with the three SME participants in the ACE CRC program. pitt&sherry Managing Director, Mr John Pitt continued to hold an ACE CRC Board position as the representative of the commercial and SME participants.

The Sea-level Rise Impacts project continued developing *Canute* including datasets from RPS MetOcean.

New products and services

During the reporting period, services were provided utilising the Sea Ice View tool for an expedition cruise company in the Ross Sea. This service included providing the software, its installation, provision of images suitable for use with the software (MODIS images and sea ice concentration maps)and other training/support as required.

In addition, weekly sea ice reports (with sub-weekly updates where requested) were provided to AAD Operations which was further distributed to the Australian Maritime Safety Authority, the Russian *RV Akademik Shokalskiy*, the Chinese *RV Xue Long*, and the French *RV l'Astrolabe*. Additionally, this service was provided to the US *RV Nathaniel B Palmer* for a cruise to the Mertz and Totten glaciers. A collation of these reports is available in the third edition of the Season's Sea Ice Report edited by Dr Jan Lieser and produced in June this year.

3 Results

3.1 Utilisation and Commercialisation

The ACE CRC continues to seek innovative ways of communicating its research outcomes to maximise the uptake of our scientific work. This section begins by outlining important activities that have involved staff from across the ACE CRC. Additional details are then provided for individual programs.

IPCC

The contributions of ACE CRC staff over several years to the release of the IPCC AR5 represent a major commitment to end-users nationally and globally. The IPCC is the international body responsible for providing governments with the largest and most comprehensive summary of the latest scientific information on climate change. This work depends on voluntary input from scientists around the world and ACE CRC researchers have been involved as coordinating lead authors, lead authors, contributing authors and as reviewing editors or reviewers of the first, second and final drafts of chapters, both as scientific expert reviewers and on behalf of the Australian Government. The IPCC AR5 was released late 2013.

Eight ACE CRC staff have held senior roles during the IPCC AR5's preparation:

- Prof Nathan Bindoff (Coordinating Lead Author, Working Group 1, Chapter 10 - Detection and attribution of climate change: from global to regional; Contributing Author, Summary for Policy Makers; Technical Summary)
- Dr Steve Rintoul (Coordinating Lead Author, Working Group 1, Chapter 3 - Observations: Oceans; Contributing Author, Summary for Policy Makers; Technical Summary)
- Dr Andrew Constable (Lead Author, Working Group 2, Chapter 28: Polar Regions)
- Dr Ian Allison, Honorary Research Professor, (Lead Author, Working Group 1, Chapter 4 - Observations: Cryosphere)
- Dr John Church, Honorary ACE CRC Fellow, (Coordinating Lead Author, Working Group 1, Chapter 13 - Sea Level Change; Contributing Author, Summary for Policy Makers; Technical Summary)
- Dr Shigeru Aoki, ILTS, Japan (Lead Author, Working Group 1, Chapter 3 - Observations: Oceans)
- Prof Phil Boyd (Lead Author, Working Group 2, Chapter 6 – Ocean systems)
- Prof Kurt Lambeck, formerly ACE CRC (Lead Author, Working Group 1, Chapter 5 - Information from Paleoclimate Archives)

In addition, the following ACE CRC personnel were Contributing Authors, Reviewers or both:

- Dr John Hunter (Contributing Author and Reviewer, Working Group 1, Chapter 13 - Sea Level Change; Contributing Author, Working Group 2, Chapter 5 – Coastal Systems and Low-Lying Areas; Contributing Author, Technical Summary)
- Dr Catia Domingues (Contributing Author, Working Group 1, Chapter 3 – Observations: Oceans; Chapter 10 - Detection and attribution of climate change. Reviewer, Working Group 1, Chapter 3 – Observations: Oceans Oceans; Chapter 13 - Sea Level Change)
- Dr Tas van Ommen (Reviewer, Working Group 1, Chapter 2 - Observations: atmosphere and surface; Chapter 4 - Observations: Cryosphere; Chapter 5 - Information from Paleoclimate Archives. Government Reviewer, Working Group 1, Chapter 4 - Observations: Cryosphere)
- Dr Rob Massom and Dr Tony Worby (Contributing Author, Working Group 1, Chapter 4 - Observations: Cryosphere)
- Dr Roland Warner (Government Reviewer, Working Group 1, Chapter 4 - Observations: Cryosphere)
- Dr Stuart Corney (Reviewer, Working Group 1, Chapter 10 – Detection and Attribution of climate change: from global to regional; Working Group 2, Chapter 28: Polar Regions)
- Prof Richard Coleman (Reviewer – Working Group 1, Chapter 4 - Observations: Cryosphere; Chapter 13 – Sea Level Change)

- Prof Peter Lemke, AWI, Germany (Reviewing Editor, Working Group 1, Chapter 4 - Observations: Cryosphere)
- Dr Xiao Cunde, CAMS, China (Reviewing Editor, Working Group 1, Chapter 13 - Sea Level Change)

1st Antarctic and Southern Ocean Science Horizon Scan

ACE CRC scientists were invited to play a prominent role in the "First Antarctic and Southern Ocean Science Horizon Scan" carried out by the Scientific Committee on Antarctic Research (SCAR). The Horizon Scan identified 80 of the most significant questions for Antarctic and Southern Ocean science for the next two decades (Kennicutt et al., Nature, 2014a; Kennicutt et al., Antarctic Science, 2014b). A critical element of the Horizon Scan was a retreat where selected representatives of the community gathered in Queenstown, New Zealand, from April 20 to 23, 2014. Dr Rob Massom, Prof Ian Allison and Dr Steve Rintoul attended this retreat.

A wide range of outreach activities have taken place with politicians, policy makers and the public, as well as within the science community. These are listed below:

- Briefings provided to government, industry and the community on IPCC AR5 results. This was achieved through presentations at major meetings like the ACE CRC Symposium 2014 and Greenhouse 2013, a large number of media appearances, targeted briefings, and talks at schools and community fora.
- Briefings to politicians and representatives across all levels of government.
- Public lectures and school visits.
- Regular review with key government departments such as Department of Environment and Department of Industry, commercial participants, and ACE CRC's essential and other research participants.
- The Annual General meeting was held on 18 November 2013 with a Department of Industry representative, research partners (ILTS, LEGOS) and commercial participants (pitt&sherry and SGS).

Oceans

As detailed above, the IPCC AR5 was a major focus of both our science and outreach work during the year. The IPCC AR5 has had a large influence on national and international responses to climate change. Researchers from the ACE CRC have been very active in communicating the conclusions of the IPCC AR5 to stakeholders in government, industry and the community. This was achieved through presentations at major meetings like Greenhouse 2013, a large number of media appearances, targeted briefings, and talks at schools and community fora.

The ACE CRC continues to play a lead role in shaping international Antarctic and Southern Ocean science. Working groups and panels with ACE CRC leadership or membership include numerous panels of the World Climate Research Program (including the Climate Variability and Predictability (CLIVAR) Science Steering Group and the Sea Level Grand Challenge), the Southern Ocean Observing System (SOOS),

and the Bluewater and Climate Node of Australia's Integrated Marine Observing System (IMOS).

The Oceans Program also maintained important links with the international scientific community via collaborations, such as the SOOS and WCRP. Several researchers played a prominent role in the First Antarctic and Southern Ocean Science Horizon Scan as highlighted above.

Sea-level Rise

With regard to sea level rise, we record uptake of the *Canute* sea level rise tool by the number of new registrations and active users of the website. There are currently 416 active users and a further 412 people who have signed up to the website but have not yet completed all the online training. Regular reviews were held with key commercial participants, and we are have worked to expand the tool's functionality. Help and feedback are provided frequently to the *Canute* user base. This also extends to general public enquiries on sea level issues.

Cryosphere

The Cryosphere Program has had strong external engagement with end users and media through the year. Highlights include having Dr Rob Massom selected as one of a high-level group to conduct the 'First Antarctic and Southern Ocean Science Horizon Scan' for the Scientific Committee on Antarctic Research (SCAR).

The International Glaciological Society (IGS) Sea Ice Symposium in March 2014 was a major vehicle for outreach, including a number of science workshops and a very popular Polar Open Science Day. The Open Science Day was held at the new waterfront premise and included lectures and demonstrations for all ages. It attracted around 2,000 visitors.

The IGS Sea Ice Symposium also saw the launch of the ACE CRC *Antarctic Sea Ice and Climate Change* Position Analysis.

Both the IGS Sea Ice Symposium and the Aurora Basin ice core expedition attracted wide and thorough media coverage, with interviews, website and blog presence. In addition, scientists within the program provided interviews around major publications, including the palaeo-volcanic publication, and expert commentary on cryospheric issues including sea-ice extent and ice sheet melt/sea-level rise.

Carbon

The Carbon Program communicates directly with the Department of Environment on policy matters such as providing a scientific basis for the evaluation of the potential risks of proposed marine geo-engineering activities, including ocean fertilisation. Research uptake is also reflected by incorporation of outputs into IPCC reports as highlighted above.

Ecosystems

The peer-reviewed web-based Southern Ocean Knowledge and Information (SOKI) Wiki has now been released into the public domain on the internet (www.soki.aq), providing up-to-date information used by the scientific community in modelling and assessments of the Southern Ocean as well as a means of communicating information to the wider public on the status of knowledge on Southern Ocean ecosystems.

During the reporting period the Ecosystems Program contributed to Working Group 2 of the IPCC AR5. The Program's research on impacts of climate change in Polar Regions contributed to Chapter 28 of the report released in March 2014. The Ecosystems team also provided input and leadership to international working groups, such as SCOR-WG140 Biogeochemical Exchange Processes at the Sea-Ice Interfaces. Members of the Ecosystems Program attended the IMBER (Integrated Marine Biogeochemistry and Ecosystem Research) Open Science Conference in June 2014 in Bergen, Norway. This interdisciplinary global environmental change research initiative focuses on understanding the sensitivity of marine biogeochemical cycles and ecosystems to global change and predicting ocean responses to global change and the effects on the Earth System and human society.

Strategies for ensuring uptake by end-users include:

- Regular reviews with end-users to understand needs and transfer knowledge
- Production of Position Analyses, Report Cards and Technical Reports, including mail-out to an established database of users.
- An ACE CRC Position Analysis on Antarctic Sea Ice and Climate Change 2014 was released in March 2014, following a briefing with end-users at a workshop in Canberra on 29 August 2013.
- E-newsletters and Twitter to keep users updated on the latest science
- Attendance and presentations at conferences and symposiums
- Direct involvement in IPCC reporting process (as a major conduit to policymakers nationally and internationally)
- Media releases and briefings to journalists
- Implementing strategies to measure uptake (for example downloads of reports)

3.2 Intellectual Property Management

The Intellectual Property (IP) management arrangements are outlined in the ACE CRC IP Assignment Deed and the Participants Agreement. The IP clauses within the Agreement were established in accordance with the National Principles of IP Management.

As a 'public good' CRC, the ACE CRC aims to make its research outputs widely and freely available. It does this by publishing its results in formal journals, public-ready documents, via its website and by providing data via means such as the sea-level

rise webtool (www.sealevelrise.info). Much of the scientific data collected is available through the Australian Antarctic Data Centre at the AAD, the Integrated Marine Observing System (IMOS) and the TPAC.

If ACE CRC licenses use of its Centre IP to a third party that party can only use the IP on the basis that it does not prejudice ACE CRC's ability to maximise the commercial return from the Centre IP. This ensures that benefits are maximised for Australia.

ACE CRC does not hold any patents in Australia or overseas.

3.3 Communications

The ACE CRC is committed to effective communication within the organisation, among its partners, with external users and the wider community, and to provide up-to-date information on its research results and their implications for the future. This section provides details of the various means by which this is achieved. Further information about communication with end-users is given in section 3.1.

Communication with ACE CRC partners

The ACE CRC Board is made up of independent and partner representatives. All partners are invited to the Annual General meetings and their organisations are provided with copies of all newsletters, annual reports and other ACE CRC publications. Regular one-on-one meetings occur between partner staff in Australia and overseas.

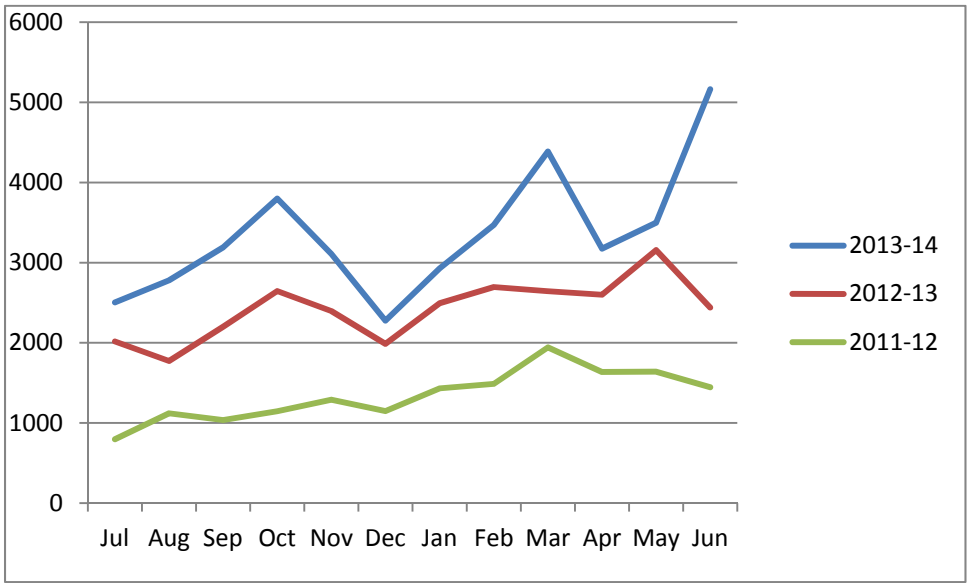
Internal communication

- **Staff forum** - a staff forum was held on 12 September 2013, which focused predominately on the move of the ACE CRC to the new UTAS Waterfront Building.
- **Staff Intranet** is provided through acecrc.org.au
- **Internal email:** Several lists are maintained and used to disseminate information on a day-to-day basis.
- **ACE CRC executive meetings** were held in October 2013, February 2014 and May 2014.
- **ACE Chit Chat and DaSH** – weekly 'ACE Chit Chat' and DaSH sessions are held to discuss research amongst staff and students, for more detail see section 2.2.

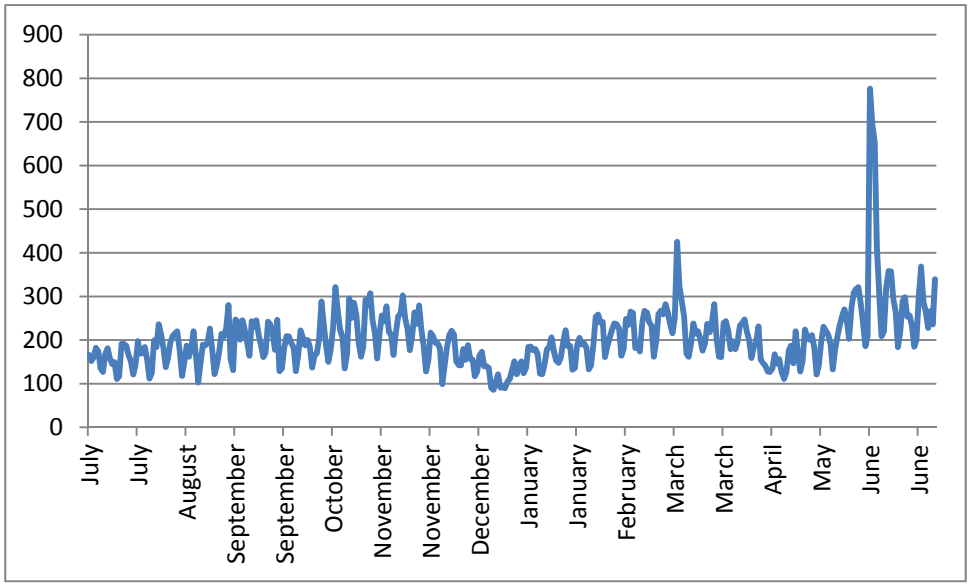
External communication

- **ACE CRC website** (www.acecrc.org.au): The website has continued to serve as a key communications platform for the ACE CRC. It was regularly updated during the reporting period with news updates, media releases, publications and job advertisements. Metrics gathered using a website traffic tool indicate that overall traffic to the site is continuing to grow – recording 74,143 unique

visits during the reporting period compared with 54,290 in the preceding period.



Traffic spiked during the reporting period at 776 unique visitors on June 20 (coinciding with the posting of new job advertisements on the ACE CRC website) and at 425 unique visitors on March 11 (coinciding with the IGS Sea Ice Symposium in Hobart).



- ***Canute***, the Sea Level Calculator (www.sealevelrise.info) is a free online support tool for calculating sea level rise allowance.
- **E-Newsletter:** ACE News (available online) was produced and distributed in September 2013 to 739 subscribers including members of the Australian climate change research community, policy makers, advisors, the media, staff and the general public. The newsletter contains details of recent

research breakthroughs from across ACE CRC's research programs, upcoming symposia and staff achievements. The message returned an overall read rate of 36.4% and a click-through rate of 8.9%.

- **Media**: Eighteen news updates were issued by the ACE CRC during the period, and an additional one media release was issued jointly with the Australian Antarctic Division. The Meltwater Media Monitoring service recorded 966 online mentions of the ACE CRC on Australian media sites and 13 on international online sites. Note: these statistics are indicative and only include media stories that were published online.
- **Documentary:** ACE CRC pteropod biologist Dr Donna Roberts appeared in the documentary Acid Ocean produced by 360 Degrees Films during the reporting period.
- **Social media**: The ACE CRC has a Facebook page and Twitter account (@acecrcscience). There were roughly 200 Twitter followers during the reporting period, an increase of about 70 on the preceding period. There were 51 tweets posted during the period.
- **Position Analyses:** These publications provide plain English summaries of the latest research in their particular fields. Their aim is to inform Government policy makers and planners and the wider community about our current state of knowledge and what this suggests for the future. The *Antarctic Sea Ice and Climate Change 2014* Position Analysis was launched on 11 March 2014.
- **Technical Reports**: The following technical reports were released during the reporting period: 'Sea Ice Reports Volume 3 for the Season 2013-14'; 'Near-Field Jet/Plume Modelling of an Outfall at Bridport, Tasmania'; 'Sea-Level Rise Allowances in the PACCSAP Region of the Pacific Ocean'; 'Estimating Sea-level Allowances for Atlantic Canada under Conditions of Uncertain Sea-Level Rise'; and 'Derivation of Revised Victorian Sea-Level Planning Allowances Using the Projections of the Fifth Assessment Report of the IPCC'.
- **Face-to-face meetings/briefings:** A Roundtable briefing summarising the latest work in all programs was held in Canberra on 29 August 2013 for approximately 30 end-users. The Position Analysis on *Antarctic Sea Ice and Climate Change 2014* and a draft of the Paleo Position Analysis were presented. Various meetings were held with Ministers and other individual MPs from across the political spectrum. Moreover, Dr Guy Williams and the ACE CRC Chair of the Board attended the CRC Showcase in December 2013. Furthermore, senior staff and the CEO, Dr Tony Press, hosted a free public talk on 11 February 2014 reviewing the science of climate change, including regional impacts in Australia, resulting from the release of the IPCC AR5 at the end of 2013.
- **Sponsorship:** The ACE CRC was the major sponsor for the International Glaciological Society (IGS) Symposium on Sea Ice in a Changing Climate held in Hobart, Tasmania from 10-14 March 2014. The symposium aimed to assess the current state of the marine cryosphere, which is one of the most sensitive components of the earth system. The conference was attended by more than 200 delegates. The ACE CRC also sponsored the Australian

Meteorological and Oceanographic Society (AMOS) National Conference 2014 'Southern Investigations' held in Hobart, Tasmania from 12-14 February 2014. This conference presented unique opportunities for Australian scientists to present cutting edge research in weather, climate and ocean sciences, with a strong focus on southern hemisphere research. This conference was attended by more than 350 delegates.

- **Polar Open Science Day and other community briefings:** The ACE CRC opened its doors on Sunday 9 March 2014 for the public to meet our polar scientists, listen to their unique experiences and play polar science games to understand the science that the ACE CRC does and why it is important. The event was aimed primarily at primary and high school students. The event was attended by over 2,000 people. Furthermore, the Young Antarctic Science Program (YAS) run by ACE CRC staff and students visited Windermere Primary School, Friends School, St Michaels Collegiate and Lenah Valley Primary during the reporting period, and presented ACE CRC science in a fun and engaging way. Moreover, several other ACE CRC staff presented their research to schools around Tasmania, including Friends' School, Guildford Young College, and Hobart College.

4 Resources

4.1 Governance – board, committees and key staff

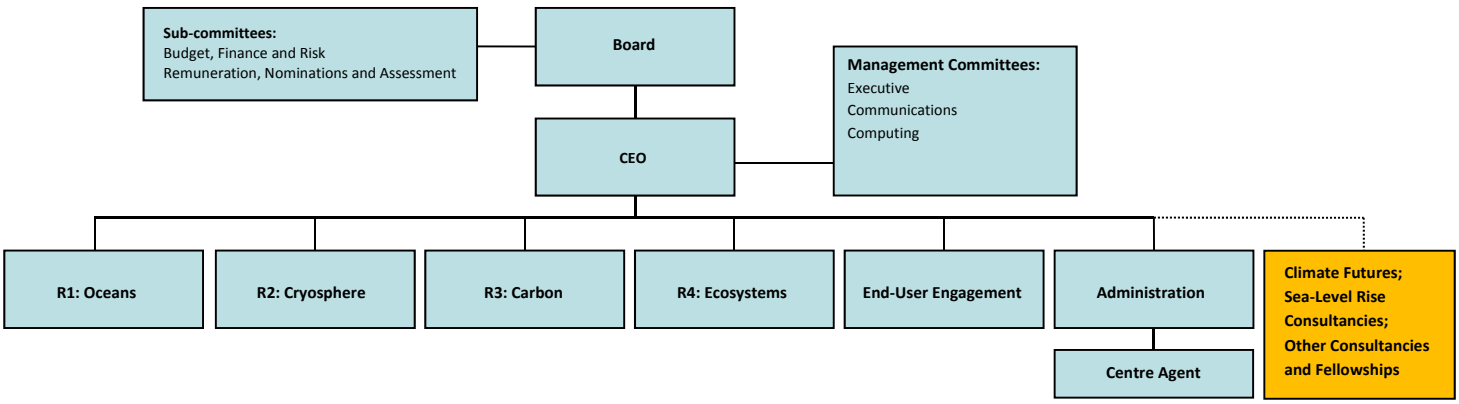
The ACE CRC is an unincorporated joint venture comprising 6 essential and 15 other participants. UTAS continues to provide Centre Agent services such as human resource support and financial services as in-kind contributions. UTAS signed the Commonwealth Agreement on behalf of all participants. The six Essential Participants are bound by the Participants Agreement, and the Other Participants Agreements set out the duties and commitments of the remaining 15 parties.

There were no changes in the participants during the reporting period.

ACE CRC is registered for GST and classified as a government partnership for taxation purposes.

The Impact Tool (IT) forms the basis of the risk register against which ACE CRC manages its risks. The IT is also used to manage ACE CRC activities and track performances against contracted milestones.

The governance and management structure of ACE CRC has been established as follows:



The Board

The Board is constituted with a view to balancing the skills and experience of its members, and operates in accordance with the provisions of the Participants' Agreement. During the reporting period it comprised of an independent Chair, representatives of the ACE CRC's six Essential Participants, two representatives from Other Participants (including one commercial participant), two independent members and two ex-officio members. Board members are governed by an ACE CRC Code of Conduct developed in previous years. There were no changes to the Board membership this year.

Board meetings are held every quarter. During this reporting period meetings were held on 4 September 2013, 18 November 2013 (including AGM), 5 February 2014 and 6 June 2014.

End-user organisations, pitt&sherry Pty Ltd and the Department of Environment, were represented on the Board by Mr John Pitt and Ms Jo Mummery respectively.

Board Members

Name	Role	Key Skills	Independent/ Organisation	Number of meetings
Prof Howard Bamsey	Board Member	- High level national and international policy and diplomacy expertise - Federal departmental and university executive managerial expertise - Specialist in climate change, energy security, climate economics and sustainable development	Independent	1/4 (6 June 2014)
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 (4 September 2013- by phone; 18 November 2013- Chair; 6 June 2014)
Dr Tony Fleming	Board Member	- Broad and extensive experience in development of environmental policy and program delivery - Extensive Federal and State public service experience - Experience with not-for-profit sector - High level policy experience	Australian Antarctic Division (Essential Participant)	3/4 (4 September 2013; 5 February 2014; 6 June 2014)

Name	Role	Key Skills	Independent/ Organisation	Number of meetings
Dr Nick Gales	Ex-Officio	- High level national and international experience in science and policy - High level science expertise in applied marine mammal conservation science - Australian Marine Mammal Centre leadership	Australian Antarctic Division (Essential Participant)	4/4 (4 September 2013; 18 November 2013; 5 February 2014; 6 June 2014)
Mr Greg Johannes	Board Member	- High level executive management experience in both policy and operational roles in the public and private sector - Substantial and wide ranging Board experience in both the research and community sector - Lead State Government representative in national negotiations under Council of Australian Governments (COAG) on climate change policy, legislation and regulation	Tasmanian Government (Other Participant)	4/4 (4 September 2013; 18 November 2013; 5 February 2014; 6 June 2014)
Dr Bruce Mapstone	Board Member	- Extensive experience in research leadership and management at senior & institutional levels - Experience with CRC establishment, leadership, and governance, including the previous ACE CRC - Broad relevant domain expertise in climate and marine science	Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Essential Participant)	4/4 (4 September 2013; 18 November 2013; 5 February 2014; 6 June 2014)

Name	Role	Key Skills	Independent/ Organisation	Number of meetings
Dr Bettina Meyer	Board Member	- High level Antarctic science expertise - Strong international standing as a scientist - High level administrative experience	Alfred Wegener Institute (Essential Participant)	0/4 Exempt
Ms Jo Mummery	Board Member	- High level executive management experience - Specialist in national and international climate change policy, climate change science policy, assessing climate change impacts and adaptation, Australian biodiversity	Department of Environment,	1/4 (4 September 2013- by phone)
Dr Rob Murdoch	Board Member	- High level executive management experience - Broad experience in the operation of research vessels - Extensive Board experience - High level science expertise in biological oceanography and marine ecology	National Institute for Water and Atmospheric Research, New Zealand (NIWA) (Essential Participant)	0/4 Exempt
Prof Paddy Nixon	Board Member	- Extensive experience in research leadership and management at senior & institutional levels - High level industrial and commercial executive management experience - Broad and extensive expertise in computer science and technology	University of Tasmania (Essential Participant)	3/4 (4 September 2013; 18 November 2013; 5 February 2014)

Name	Role	Key Skills	Independent/ Organisation	Number of meetings
Mr John Pitt	Board Member	- Experienced company director including broad network across private and public sectors - High level private sector executive management (including technology commercialization) experience - Strategic planning expertise in relation to the adaptation of infrastructure assets to climate change	pitt&sherry (Other Participant)	4/4 (4 September 2013; 18 November 2013; 5 February 2014; 6 June 2014)
Dr Tony Press	Ex-Officio	- High level leadership and administrative experience - Extensive experience in government and public policy - High level international experience in science and policy	ACE CRC	4/4 (4 September 2013; 18 November 2013; 5 February 2014; 6 June 2014)
Dr Katherine Woodthorpe	Chair	- High level management skills – Chief Executive Officer (CEO) of Australian Private Equity & Venture Capital Association Ltd (AVCAL) - 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 (4 September 2013, 18 November 2013 – by phone, 5 February 2014, 6 June 2014)

The Board has two sub-committees. The Budget, Finance and Risk sub-committee includes Dr Bruce Mapstone (CSIRO), Prof Paddy Nixon (UTAS) and Mr Tony Coleman as members. This committee met October 2013 to sign off on the accounts for the year ending 30 June 2013 and a series of email exchanges occurred between members of this sub-committee during the reporting period.

The Remuneration, Nominations and Assessment sub-committee consists of Dr Katherine Woodthorpe, Dr Tony Fleming and Mr Greg Johannes. This committee met several times during October and November 2013 to discuss the recruitment of a new CEO. They met again early 2014 for these interviews.

The Executive Committee

The ACE CRC Executive Committee advises the CEO and Board on a range of matters relating to management of resources, research coordination and research utilisation across the ACE CRC portfolio. Due to the move to our new premises and planning for the 2014-2019 funding period, the ACE CRC Executive Committee only met three times during the reporting period. The ACE CRC Executive Committee convened on 16 October 2013, 20 February 2014 and 14 May 2014.

Name	Role	Key Skills	Organisation
Prof Nathan Bindoff	Leader, Climate Futures; Director Tasmanian Partnership for Advanced Computing (TPAC)	Computing/research	ACE CRC/TPAC
Ms Wenneke ten Hout	Administration Manager (on leave until September 2013)	Administration	ACE CRC
Dr Andrew Constable	Leader, Ecosystems Program	Research	ACE CRC/AAD
Ms Miranda Harman	Communications Manager (until March 2014)	Communications/Media	ACE CRC
Ms Kate Maloney	Business Manager	Finance, administration, governance	ACE CRC
Dr Kelvin Michael	IMAS Representative	Education	IMAS
Dr Tas van Ommen	Program Leader, Cryosphere Program	Research	ACE CRC/AAD

Name	Role	Key Skills	Organisation
Dr Tony Press	CEO	Management, governance	ACE CRC
Dr Stephen Rintoul	Program Leader, Oceans Program	Researcher	ACE CRC/CSIRO
Dr Jason Roberts	Researcher, Chair ACE CRC Computing Committee	Research/computing	ACE CRC/AAD
Prof Thomas Trull	Program Leader, Carbon Program	Researcher	ACE CRC/UTAS/CSIRO
Ms Margaret White	Administrative Assistant/Executive Secretary (July-September 2013)	Administration	ACE CRC

Communications Coordination Committee

The Communications Coordinating Committee met informally during the reporting period and regular liaison between the ACE CRC Communications and Media Manager and partner Communications Managers were made during the reporting period.

Name	Role	Organisation
Ms Sally Chambers	General Manager, Corporate Communications	AAD
Mr Peter Cochrane	Media Manager, Communications and Media Office	UTAS
Ms Miranda Harman (until March 2014)	Communications and Media Manager	ACE CRC
Mr Craig Macaulay	Communications Officer	CSIRO
Ms Sam East (until October 2013)	Communications, Outreach and Marketing Officer	IMAS

Education and Training Committee

The Education and Training committee, composed of representatives from the Institute for Marine and Antarctic Studies (IMAS, based at UTAS) and the ACE CRC, is available to discuss a range of matters relating to education and training. The committee met informally during the reporting period and provided the necessary information through the Executive Committee.

Name	Role	Organisation
Prof Mike Coffin	Executive Director IMAS	IMAS
Dr Julia Jabour	IMAS Representative	IMAS
Prof Gustaaf Hallegraeff	IMAS Representative	IMAS
Dr Kelvin Michael	IMAS Representative	IMAS
Dr Tony Press	CEO	ACE CRC

Computing Committee

The ACE CRC Computing Committee supports the science, education and policy programs of the ACE CRC by providing advice on information technology, infrastructure and management. The ACE CRC Computing Committee advises the ACE CRC Executive Committee and CEO. The ACE CRC Computing Committee did not formally meet during the reporting period.

Member	Role	Organisation
Ms Wenneke ten Hout	Administration Manager	ACE CRC
Mr Antony Cave	Information Technology Resources	UTAS
Mr James Harrison	Information Technology Resources	UTAS
Mr Iain Sheppard	Information Technology Resources	UTAS
Dr Jan Lieser	Researcher	ACE CRC
Ms Kate Maloney	Business Manager	ACE CRC
Dr Tony Press	Chief Executive Officer	ACE CRC
Dr Jason Roberts (Chair)	Researcher	AAD
Dr Roland Warner	Researcher	AAD

Key Staff

Staff Member	Role	Organisation	% Time
Dr Tony Press	CEO	ACE CRC	100%
Dr Stephen Rintoul	Program Leader - Oceans	ACE CRC/CSIRO	50%
Dr Tas van Ommen	Program Leader - Cryosphere	ACE CRC/AAD	80%
Prof Tom Trull	Program Leader - Carbon	ACE CRC/CSIRO	75%
Dr Andrew Constable	Program Leader - Ecosystems	ACE CRC/AAD	60%

Staff Member	Role	Organisation	% Time
Prof Nathan Bindoff	IPCC AR5 – coordinating lead author and Deputy Program Leader – Oceans	ACE CRC/IMAS	50%
Prof Ian Allison*	IPCC AR5 – lead author	ACE CRC	50%
Ms Kate Maloney	Business Manager	ACE CRC	100%
Ms Miranda Harman (until March 2014)	Communications Manager	ACE CRC	60%
Ms Wenneke ten Hout	Administration Manager	ACE CRC	50%
*Prof Ian Allison is an Honorary Research Professor			

4.2 Participants

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
Australian Antarctic Division (AAD)	Essential	56 428 630 676	Government
CSIRO Division of Marine and Atmospheric Research (CMAR)	Essential	41 687 119 230	Government

Participant's name	Participant type	ABN or ACN	Organisation type
Department of Industry (previously called the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education)	Essential	74 599 608 295	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

Participant's name	Participant type	ABN or ACN	Organisation type
Department of Environment (previously called the Department of Sustainability, Environment, Water, Population and Communities)	Other	34 190 894 983	Government
First Institute of Oceanography (FIO), China	Other	NA	Government research institute
Institute of Low Temperature Science (ILTS), Hokkaido University, Japan	Other	NA	Research institute
Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), France	Other	NA	Research institute
Myriax Software Pty Ltd	Other	95 009 587 848	Industry
National Institute of Polar Research (NIPR), Japan	Other	NA	Government research institute
pitt&sherry	Other	88 234 540 094	Industry
RPS MetOcean Pty Ltd	Other	42 107 962 872	Industry
SGS Economics and Planning Pty Ltd	Other	25 007 437 729	Industry
Tasmanian Government	Other	84 531 577 304	Government

Participant's name	Participant type	ABN or ACN	Organisation type
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 in the reporting period.

4.3 Collaboration

Currently, the ACE CRC collaborates with 81 domestic and international organisations. Of these, there are 24 Australian, 3 New Zealand, 9 Asian, 19 North American, 1 South American, and 25 European.

Of the 24 domestic collaborations, there are 7 Australian Government Institutions, 1 State Government Institution, 11 Universities, 4 industry/private sector, and 1 other.

Of the 57 international collaborators, there are 32 universities, 2 from industry/private sector, and 23 research institutions/organisations.

The research vessel *RV Umitaka-Maru* from Tokyo University of Marine Science and Technology arrived in Hobart on 7 February 2014. The event was celebrated with a combined ACE CRC and AAD workshop at the ACE CRC. The workshop's main focus was on the Australia-Japan collaboration in Antarctic Science, and highlighted recent research outcomes, and future planning opportunities.

The Sea-level Rise Impacts team is still working closely with the Spatial CRC (CRCSI) to translate the output from the sea-level rise calculator into high-resolution maps of predicted flood inundation. The CRCSI has built a subset of our data into their new, web-based GIS, which is presently in testing mode. When their system is in production mode, we will be able to link into their server to create flood maps on-the-fly from within the *Canute* website. This collaboration is vital to achieve this milestone.

During the reporting period, the ACE CRC had several overseas visitors, including visitors from participants (NIWA, University of Texas - Austin and LEGOS).

In July 2013, the Cryosphere Program was joined by British Marie Curie Fellow, Dr Rupert Gladstone who will be hosted at the ACE CRC for approximately 2 years. Dr Gladstone is assisting with the further development of coupled ice-shelf ocean models. This collaboration is vital to achieve Cryosphere Program milestones.

Dr Liu Yaping from the 'State Key Laboratory of Cryospheric Sciences' at the Cold and Arid Regions Environmental and Engineering Research Institute Chinese Academy of Sciences (CAREEI). Dr Yaping will be working with the Ice Core Group at the ACE CRC for the next 12 months on a 'Visiting Scholar Program' funded by the China Scholarship Council's Postdoctoral Program.

For further discussions on end-user collaborations, see section 3.3 of this report.

4.4 Financial Management

The ACE CRC completed the 2013-14 financial year with a cash balance of $2,359K. Of this, $1,864K was associated with trade and other payables and recognised as expenses in the 2013-14 financial year. The remaining $495K represented deferred grant funds, which were carried forward to the new extension term of the ACE CRC to cover transition costs to, and contingent liability provisions in, the continuing entity.

The online 'Expenses' Table 3 for the ACE CRC over the year shows the major variances to the agreement:

	Totals to 2013-14				Totals for 5 years			
	Actual	Agr'mt	Diff	%Diff	Actual	Agr'mt	Diff	%Diff
Employee Expenses	3,274	2,113	1,161	55	14,247	12,273	1,974	16
Supplier Expenses	2,466	576	1,890	328	7,662	5,798	1,864	32
Capital	0	0	0	0	1,347	807	540	67
Other Expenses	255	612	-357	-58	255	612	-357	-58
TOTAL EXPENSES	5,995	3,301	2,694	82	23,511	19,490	4,021	21

Expenses for the 2013-14 year were above agreement levels due to two main factors:

- As outlined last year, logistics payments associated with SIPEX-II were deferred into the 2013-14 financial year. This accounted for $1,740K of the supplier expenses variation.
- Originally, staff appointments were made based on three-year contracts with most appointments due to expire at the end of 2013. This was done to manage costs and to reduce the projected end-of-contract deficit. With the extension of the ACE CRC for a new term, contracts for staff were extended, with costs for these covered from savings in other expenses and additional revenue from interest income.

Expenses for the five years were $4,021K higher than the agreement level. These costs covered the delivery of the carried forward program into the 2009-14 agreement period, as well as additional shipping costs required to deliver the SIPEX-II

voyage in a tightened AAD budgetary environment, compounded by impacts of this voyage being stuck in sea-ice for 10 days in the 2012-13 season.

The higher expense level was funded from the following main sources :

- Brought forward cash from the prior agreement period of $2,797K
- Additional participant income achieved over the five year period of $797K
- Other income (mainly interest) of $814K
- Less deferred grant funds carried forward of $495K

5 Other activities

The ACE CRC continued to undertake a number of externally funded research and consultancy activities, primarily in the area of fine-scale climate modelling and analysis (NDRP and NERP).

Natural Disaster Resilience Program (NDRP): The work already undertaken in the Climate Futures for Tasmania project is being extended to examine changes to severe weather events likely to cause significant damage (and cost) to Tasmania. This program aims to identify and address disaster risk priorities throughout the State. The ACE CRC has secured 2.5 years of funding from the Program, administered by Tasmanian State Emergency Services, to investigate these weather events using a combination of established and new techniques and indices. These events include increased bushfire risk (encompassing both bushfire meteorology and hazard), and severe storms.

National Environmental Research Program (NERP): Project 3 – Climate Futures – is a project within the Landscapes and Policy (LAP) hub funded through the NERP. This project extends and builds upon the successful Climate Futures for Tasmania project. This project coordinates with seven national projects within the LAP hub to provide climate change information and datasets for research into ecosystems and landscapes in a changing climate.

During the reporting period, the Climate Futures Project, encompassing both NDRP and NERP projects, have published 9 articles in scholarly refereed journals and 1 technical report (see below).

Articles in scholarly refereed journals

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International Journal of Wildland Fire **23**(3): 309-321.
Grose, M., Fox-Hughes, P., et al. (2014). "Changes to the drivers of fire weather with a warming climate – a case study of southeast Tasmania." Climatic Change **124**(1-2): 255-269.
Harris, R., Grose, M., et al. (2014). "Climate projections for ecologists." Wiley Interdisciplinary Reviews: Climate Change **5**(5): 621-637.
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Harris, R., Porfirio, L., et al. (2013). "To Be Or Not to Be? Variable selection can change the projected fate of a threatened species under future climate." Ecological Management and Restoration.
White, C. and Fox-Hughes, P. (2013). "Seasonal climate summary southern hemisphere (summer 2012-13): Australia's hottest summer on record and extreme east coast rainfall." Australian Meteorological and Oceanographic Journal **63**: 443–456.
Williamson, G., Prior, L., et al. (2014). "Projecting canopy cover change in Tasmanian eucalypt forests using dynamically downscaled regional climate models." Regional Environmental Change **14**(4): 1373-1386.

Technical Report

Fox-Hughes, P., Harris R.M.B., et al. (2014). *Climate Futures for Tasmania: future fire danger technical report*, Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania.

6 Additional requirements

6.1 Performance review

Strategies to implement all the recommendations resulting from the May 2012 performance review were reported as implemented in previous years: those referring to transition are no longer applicable and any which are ongoing have been incorporated into the new funding period 2014-2019.

7 Glossary of Terms & Acronyms

A	
ABW	Antarctic Bottom Water
AAD	Australian Antarctic Division
ACCESS	Australian Computational Earth Systems Simulator
ACECRC	Antarctic Climate & Ecosystems Cooperative Research Centre
AGM	Annual General Meeting
AMC	Australian Maritime College
AUV	Autonomous Underwater Vehicle
AWI	Alfred Wegener Institute for Polar Research (Germany)
B	
BoM	Bureau of Meteorology
C	
CAMS	Chinese Academy of Meteorological Science (China)
CAREERI	Cold and Arid Regions Environmental and Engineering Research Institute (Chineses Academy of Sciences)
CCAMLR	Convention for the Conservaton of Antarctic Marine Living Resources
CEO	Chief Executive Officer
C-ICE	Simulation sea ice model
CLIVAR	Climate Variability and Predictability Program
CMAR	CSIRO Division of Marine & Atmospheric Research
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon Dioxide
CPOM	Centre for Polar Oceanography and Modelling (United Kingdom)
CRC	Cooperative Research Centre
CRCSI	Cooperative Research Centre for Spatial Information
CSIRO	Commonwealth Scientific and Industrial Research Organisation
D	
DIICCSRTE	Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (now called the Department of Industry)
E	

ECMWF	European Centre for Medium-Range Weather Forecasts
eEOVs	Essential Ocean Variables
EPOC	Ecosystem Productivity Ocean Climate
F	
FIO	First Institute of Oceanography (China)
G	
GEOTRACES	An international study of the biogeochemical cycles of Trace Elements and Isotopes in the Arctic and Southern Oceans
GOOS	Global Ocean Observing System
I	
ICECAP	Investigating Cryospheric Evolution through Collaborative Aerogeophysical Profiling
ICED	Integrating Climate and Ecosystem Dynamics
IDP	Intermediate Data Product
IGS	International Glaciological Society
ILTS	Institute of Low Temperature Science, Hokkaido University (Japan)
IMAS	Institute for Marine and Antarctic Studies, University of Tasmania
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research project
IMOS	Integrated Marine Observing System
IOCCP	International Ocean Carbon Coordination Project
IP	Intellectual Property
IPCC AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
IPCC AR5	Intergovernmental Panel on Climate Change Fifth Assessment Report
IQuOD	International Quality-Controlled Ocean Database
IT	Impact Tool
ITR	Information Technology Resources
K	
KEOPS-2	Kerguelen compared study of Ocean and Plateau in Surface waters (2nd study)
L	
LAP	Landscapes and Policy

LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (France)
M	
N	
NDRP	Natural Disaster Resilience Program
NERP	National Environmental Research Program
NIPR	National Institute of Polar Research (Japan)
NIWA	National Institute for Water and Atmospheric Research (New Zealand)
NOAA	National Oceanic and Atmospheric Administration
R	
ROMS	Regional Ocean Modelling System
ROV	Remotely Operated Vehicle
S	
SCAR	Scientific Committee on Antarctic Research
SCOR	Scientific Committee on Oceanic Research
SGS	SGS Economics & Planning Pty Ltd
SIPEX-II	Sea-ice Physics & Ecosystem Experiment
SME	Small and Medium Enterprises
SOCAT	Surface Ocean Carbon Atlas
SOKI	Southern Ocean Knowledge and Information wiki
SOOS	Southern Ocean Observing System
SOTS	Southern Ocean Time Series
T	
TAR	Third Assessment Report (IPCC)
TPAC	Tasmanian Partnership for Advanced Computing
U	
UTAS	University of Tasmania
W	
WAIS	West Antarctic Ice Sheet
WCRP	World Climate Research Programme

Appendix 1– list of publications

Book Chapters

Alexander., L., Allen., S., et al. (2014). Summary for Policymakers Climate Change 2013: The Physical Science Basis. T. Stocker., D. Qin., G.-K. Plattner.et al. Cambridge, United Kingdom, Cambridge University Press: 3-29.

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Wynn-Edwards, C., King, R., et al. (2014). "Development of a Continuous Phytoplankton Culture System for Ocean Acidification Experiments." Water **6**: 1860-1872.
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Jabour, J. (2011). The Utility of Official Antarctic Inspections: Symbolism without Sanction? Exploring Linkages between Environmental Management and Value Systems: The Case of Antarctica, Christchurch, New Zealand.

Appendix 2– list of ACECRC PhD students

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
1. Arthur, Benjamin	31/10/11	FT	鍌 cosystems	Winter Habitat Usage and Trophic Links for Antarctic Fur Seal Populations in the Southern Ocean	UTAS	Australia	October 2015
2. Baird-Bower, Debbie	8/04/13	FT	Ecosystems	Demographic Responses of Antarctic Fur Seals to Environmental Variability	UTAS	Australia	April 2017
3. Baker, Barry	31/07/02	PT	Ecosystems	Demography and Conservation of Shy Albatross (Thalassarche cauta)	UTAS	Australia	July 2015
4. Bedford, Merel	1/03/14	FT	Ecosystems	Representing Southern Ocean predators in end-to-end ecosystem models using individual-based modelling	UTAS	Australia	March 2018
5. Black, James	28/08/14	FT	Carbon	Measuring impacts of ocean acidification on biological communities in Antarctica: an in-situ experiment and laboratory exploration of	UTAS	Australia	August 2018

***Total enrolment is 50 PhD students (head count) which includes commenced, continued and graduated during the reporting period**

****FT– full-time internal; FX – full-time external; PT– part-time internal; PX – part-time external**

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
				the mechanisms of community			
6. Cleeland, Jaimie	20/05/13	FT	Ecosystems	Macquarie Island's Albatrosses: A comprehensive assessment of population and demographic status and trends and the environmental and anthropogenic	UTAS	Australia	May 2017
7. Cougnon, Eva	8/10/12	FT	Cryo/ Oceans	Quantifying the Impact of Glacial Melt Water on Antarctic Bottom Water	UTAS	Australia	October 2016
8. Cubillos Castillo, Joana	23/08/07	FT	Ecosystems	Calcification Patterns of The Coccolithophore Coccolithus Braarudii From the Late Quaternary to the Southern Ocean	UTAS	Australia	December 2013
9. Della Penna, Alice	19/11/12	FX	Ecosystems	Living in a fluid dynamical system: how do marine predator respond to turbulence?	UTAS	Australia	November 2016
10. Deppeler, Stacy	15/10/13	FT	Ecosystems	Effects of Elevated pCO2 on the Productivity of Marine Microbes and the	UTAS	Australia	October 2017

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
				Remineralisation of Nutrients in Coastal Antarctic Waters			
11. Durand, Axel	3/04/13	FT	Carbon	Ocean Deoxygenation, a Paleo Proxy Perspective	UTAS	Australia	April 2017
12. Graham, Felicity	18/07/11	FT	Oceans	Understanding the Dynamics of ENSO and How They Might Change with Global Warming	UTAS	Australia	July 2015
13. Groeskamp, Sjoerd	27/06/11	FT	Oceans	Estimating Diffusion Coefficients from Ocean Hydrography	UTAS	Australia	June 2015
14. Gwyther, David	5/03/12	FT	Cryo	Investigating the Impact of Ocean Warming on Antarctic Ice Shelves	UTAS	Australia	March 2016
15. Hamilton, Vicki	24/07/12	FT	Ecosystems	Energetic Variability in Sperm Whales and Relationships with the Marine Environment	UTAS	Australia	July 2016
16. Hodgson-Johnston, Indiah	21/10/13	FT	Ecosystems	Beyond the Bases? Applying Contemporary Principles of International Law to Australian Sovereignty in Antarctica	UTAS	Australia	October 2017
17. Holmes,	1/04/14	FT	Carbon	Tracing the source of iron	UTAS	Australia	April 2018

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
Thomas				inputs to the Southern Ocean using radiogenic isotopes			
18. Inoue, Mana	4/04/11	FT	Cryo	Glaciochemical Study of Mill Island Ice Core Records	UTAS	Australia	April 2015
19. Jackson, Christine	15/01/06	PX	Ecosystems	Determining Cetacean - Cephalopod Trophic Interactions - A Qualitative and Quantitative Approach	UTAS	Australia	January 2015
20. Janssens, Julie	6/09/12	FT	Carbon/ Cryo	Incorporation Mechanisms of Organic Matter and Iron into Sea Ice	UTAS	Australia	September 2016
21. Jia, Zhongnan	2/05/11	FT	Ecosystems	Diet and Energy Budget of Antarctic Krill (Euphausia superba) - Relationship between Krill and Winter Sea Ice	UTAS	Australia	May 2015
22. Johnson, Rob	7/02/11	FT	Ecosystems	Effects of Climate Change on Phytoplankton Primary Production and Chemotaxonomy in Southern Ocean and Antarctic Ecosystems	UTAS	Australia	February 2015

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
23. Karsh, Kristen	1/07/05	PT	Carbon	Environmental controls on nitrogen isotopic fractionation by subantarctic and Antarctic phytoplankton	UTAS	Australia	August 2014
24. Lago, Veronique	6/04/11	FT	Oceans	Testing of climate models and sea level rise projections using observations of ocean heat uptake	UTAS	Australia	April 2015
25. Laurenceau, Emmanuel	1/10/11	FT	Carbon	Controls on Organic Carbon Sequestration from the Naturally Iron-fertilised Phytoplankton Bloom over the Kerguelen Plateau	UTAS	Australia	October 2015
26. Lee, Shi Hong	15/12/12	FT	Ecosystems	Impact of Climate Change on Physiological and Behavioural Responses of Coastal Microphytobenthos	UTAS	Australia	December 2016
27. McInnes, Julie	20/11/13	FT	Ecosystems	Using Non Invasive Faecal DNA Methodologies to Investigate Albatross Diet	UTAS	Australia	November 2017
28. Meyer,	22/09/08	PT	Oceans	On the Role of Diapycnal	UTAS	Australia	August 2014

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
Amelie				Mixing in the Antarctic Circumpolar Current on the Meridional Overturning Circulation			
29. Michael, Pam	4/02/13	FT	Ecosystems	Potential impacts of climate change on the dynamics and distribution of tuna, major industrial pelagic longline fleets and consequent interactions with threatened albatrosses: a first application to the Indian Ocean	UTAS	Australia	February 2017
30. Moore, Kirrily	1/04/09	FT	Ecosystems	Biodiversity of the Southern Ocean: An Assessment of Morphological and Molecular Diversity in Key Octocorallia Groups	UTAS	Australia	December 2014
31. O'Toole, Malcolm	7/11/11	FT	Ecosystems	Top Marine Predator Foraging Behaviour in Relation to Primary Productivity in the Southern Ocean	UTAS	Australia	November 2015
32. Pittard, Mark	30/04/12	FT	Cryo	Ice Sheet Response to	UTAS	Australia	April 2016

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
				Enhanced Ice Shelf Basal Melt			
33. Plummer, Christopher	1/05/10	FT	Cryo	Holocene Climate and Environmental Indicators from Trace Chemistry of Law Dome Ice Core, Antarctica	UTAS	Australia	December 2014
34. Polanowski, Andrea	3/10/11	PT	Ecosystems	Mechanisms for Sex Determination in Antarctic Krill	UTAS	Australia	October 2015
35. Queroue, Fabien	1/10/10	FT	Carbon	Manganese Distributions in the Southern Ocean and the Co-impact Mn-Fe-Cu on Phytoplankton	UTAS	Australia	December 2014
36. Quiroz Espinosa, Juan	1/03/14	FT	Ecosystems	A consistent approach to the estimation of sustainable harvests of Patagonian Toothfish in Chilean, France and Australian Jurisdictions	UTAS	Australia	March 2018
37. Ratnarajah, Lavenia	1/12/13	FT	Carbon	Effect of natural iron fertilisation by krill and whales on the Southern Ocean carbon cycle	UTAS	Australia	December 2017
38. Remenyi,	22/07/08	FT	Carbon	Quantifying Dust	UTAS	Australia	August 2013

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
Tomas				Deposition into the Southern Ocean Using Dissolved Aluminium Concentrations as a Tracer			
39. Roach, Christopher	8/03/10	FT	Oceans	Ekamn Currents in the Antarctic Circumpolar Current	UTAS	Australia	December 2014
40. Roden, Nick	14/03/11	FT	Carbon	Acidification and Carbonate Chemistry of Shelf Waters in the Australian Antarctic Territory	UTAS	Australia	March 2015
41. Sinoir, Marie	1/06/09	FT	Carbon	Zinc as a Co-limiting Micronutrient: Its Distribution and Modelling Regarding Climate Change (change in pCO2) in the Tasman Sea	UTAS	Australia	August 2013
42. Steer, Adam	1/10/09	FT	Cryo	Optimising Airborne LiDAR Positioning for Remote Area Geophysical Surveys	UTAS	Australia	December 2014
43. Stevens, Roger	15/05/08	FT	Cryo	Investigation of Ice Edge Controls	UTAS	Australia	December 2013
44. Turner,	7/05/12	FT	Ecosystems	Adaptive Management	UTAS	Australia	May 2016

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
Jacquelyn				Responses: The Impact of Climate Change on Commercial Fisheries			
45. Ugalde, Sarah	15/02/10	FT	Ecosystems	Primary Production and Fate of Antarctic Sea Ice Algae	UTAS	Australia	February 2015
46. Vargas-Hernandez, Jose Mauro	22/03/10	FT	Oceans	The Signature of Global Warming in the Indo-Pacific Ocean: Investigation of the Subsurface Dynamics	UTAS	Australia	August 2014
47. Vasconcellos de Menezes, Viviane	20/02/12	FT	Oceans	Remarkable Near-surface Eastward Flows in the South Indian Ocean: Understanding the Dynamical Links between the Indian Ocean Subtropical Gyre, Indonesian	UTAS	Australia	February 2016
48. Walters, Andrea	1/12/07	FT	Ecosystems	Marine Mammal Biology in Tasmanian Waters/Southern Ocean	UTAS	Australia	August 2014
49. Wynn Edwards, Cathryn	1/03/09	FT	Ecosystems	Impacts of Ocean Acidification on the Bottom of the Antarctic	UTAS	Australia	December 2014

Name*	Commencement Date	Status **	Research Program	Project Title	Research Organisation	Country	Expected Completion Date
				Food Web: Quantification of Changes in Nutritional Quality of Phytoplankton and Bottom Sea Ice Algae and the Effect on Juvenile Krill			
50. Younger, Jane	6/06/11	FT	Ecosystems	Glacial Refugia of Antarctic Ice Breeding Species	UTAS	Australia	June 2015