ANTARCTIC CLIMATE & ECOSYSTEMS
COOPERATIVE RESEARCH CENTRE

2010-2011 Annual Report

Australian Government
Department of Sustainability, Environment, Water, Population and Communities
Australian Antarctic Division

CSIRO

UTAS

Australian Government
Department of Climate Change and Energy Efficiency

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

NIWA
Taihoro Nukurangi

Established and supported under the Australian Government's Cooperative Research Centres Program

Contents

Table of Contents

Annual Report 2010-2011

© Antarctic Climate and Ecosystems Cooperative Research Centre 2011
This work is copyright. It may be reproduced in whole or in part for study or training purposes subject to the inclusion of an acknowledgement of the source but not for commercial sale or usage. Reproduction for purposes other than those listed above requires the written permission of the Antarctic Climate and Ecosystems Cooperative Research Centre.
Requests and enquires concerning reproduction rights should be addressed to:

Antarctic Climate and Ecosystems Cooperative Research Centre
Private Bag 80
Hobart Tasmania 7001
Tel: +61 3 6226 7888
Fax: +61 3 6226 2440
Email: enquires@acecrc.org.au
www.acecrc.org.au

Executive Summary

During the reporting period the ACE CRC became fully established, with new staff recruited and research programs well underway.

By the end of the reporting period, the ACE CRC had hosted members of the CRC Program and successfully completed the 'Six Month' and 'First Year' reviews. The ACE CRC had also led and participated in its first major voyage and key scientists began the process of contributing to the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5). A number of important scientific papers were published during the period.

1.1 Achievements

A number of major research achievements occurred over the reporting period. Oceans Program leader Dr Stephen Rintoul led a multidisciplinary team of 40 Australian and international scientists to the Mertz polynya in Antarctica to investigate changes from the sea surface to the sea floor following the calving of the Mertz glacier tongue in February 2010. This event allowed a great natural experiment to unfold, giving scientists an opportunity to study how the environment in this region will change following the loss of the 3,200km^2 tongue, and what implications this will have for regional and global ocean circulation (see page 30).

The Austral summer also saw the successful completion of the ICECAP survey of the bedrock of part of East Antarctica. This major international collaboration is revealing what lies beneath the East Antarctic ice sheet and has profound implications for understanding how this region will respond to climate change and for projections of sea-level rise. Scientists from the Cryosphere Program were part of the international team, which published a paper in *Nature* on the results of this work (see page 33).

The ACE CRC's contribution to the Southern Ocean component of the global Surface Ocean Carbon Atlas (SOCAT) has been completed, with online publication of the atlas planned for late 2011. Development of regional estimates of carbon fluxes has commenced in the lead-up to the next IPCC AR5 assessment process, with participation in the **RE**gional **C**arbon **C**ycle **A**ssessment and **P**rocesses project (RECCAP – a component of the Global Carbon Project, www.globalcarbonproject.org).

The Ecosystems Program began the next phase of building a second-generation marine ecosystem model for the Southern Ocean. Efforts were centred on the ACE CRC collaborations with Old Dominion University in the United States of America (USA) and CSIRO Marine and Atmospheric Research (CMAR).

A highlight for the year was the development of a new 'Report Card' format for delivering updates on the latest ACE science. The first in the series, *Report Card: Southern Ocean Acidification,* was launched in April 2011 and received very positive acclaim from policymakers and scientists. A new *Report Card: Sea-Level Rise* is in preparation.

The ACE CRC and the Bureau of Meteorology (BoM) co-hosted the very successful *2010 Southern Exposure: Australia-New Zealand Climate Forum* in Hobart in October 2010. The program consisted of

three days of presentations, workshops and interactions on climate science. More than 170 presentations were given to the capacity audience of 220 scientists from Australia, New Zealand, the United Kingdom, South Africa, the United States of America and Taiwan.

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change is now being prepared. The ACE CRC is making important contributions: Dr Stephen Rintoul is Coordinating Lead Author on the 'Observations: Oceans' chapter, and Dr Shigeru Aoki (Japan) is a Lead Author; Prof Nathan Bindoff is a Coordinating Lead Author for the chapter on 'Detection and Attribution of Climate Change'; and Dr John Church (formerly ACE CRC Program Leader, now an ACE CRC Honorary Research Fellow) is a Coordinating Lead Author for 'Sea Level Change'. Prof Ian Allison (formerly ACE CRC Program Leader, now an ACE CRC Honorary Research Fellow) is a Lead Author for the 'Observations: Cryosphere' chapter; and Prof Kurt Lambeck (formerly ACE CRC) is a lead author for the chapter on 'Information from Paleoclimate Archives'. This list does not take into account the considerable contributions that ACE scientists will make through the peer review literature, and as contributing authors.

The ACE CRC published 3 books, 10 book chapters, 74 articles in scholarly refereed journals, and 9 full written conference papers in refereed proceedings during the reporting period (see Appendix 1).

Honours and awards

ACE staff members have been presented with Honours and Awards during the reporting period. In August 2010, Dr Stephen Rintoul received the Inaugural Antarctic Science Lecturer Award from the Scientific Committee on Antarctic Research (SCAR) for his research achievements in Southern Ocean research. In addition, in October 2010 Dr Rintoul received the 16th W.S. Jardetzky Lecturer award from the Lamont-Doherty Earth Observatory.

Dr Andrew Bowie received a 2011-2013 University of Tasmania 'Rising Star' award in January 2011. Dr Bowie also received the Royal Society – Australian Academy of Science 'Exceptional Young Researcher' award in October 2010.

Staff appointments

During the reporting period, ACE successfully recruited a full complement of research and administration staff, enabling it to kick-start its research and utilisation programs.

Name	Position	Start Date	Program
Dr Ben Galton-Fenzi	Ice Shelf-Ocean Modeller	6/07/2010	Cryosphere
Dr Adam Treverrow	Ice Sheet Modelling Scientist	2/08/2010	Cryosphere
Dr Pier van der Merwe	Trace Element Marine Analytical Chemist	2/08/2010	Carbon
Dr Laura Herraiz-Borreguero	Ice Shelf Oceanographer	16/08/2010	Cryosphere

Name	Position	Start Date	Program
Ms Miranda Harman	Communications Manager	26/09/2010	Executive
Dr Alex Fraser	Remote Sensing Specialist	4/10/2010	Cryosphere
Dr Steven George	Sea-level Rise Specialist	25/10/2010	Oceans
Dr Beatriz Pena-Molino	Physical Oceanographer - Observer	9/12/2010	Oceans
Dr Stuart Corney	Ecological Modeller	1/01/2011	Ecosystems
Dr Guy Williams	Sea Ice / AUV Specialist	4/01/2011	Cryosphere
Dr Elizabeth Shadwick	Carbon Post-doc	15/02/2011	Carbon
Dr Jessica Melbourne-Thomas	Ecological Statistician/Modeller	21/03/2011	Ecosystems
Dr Catia Domingues	Physical Oceanography - Modeller	26/04/2011	Oceans

Major purchases for the year

Major capital costs for the year were for a new computer server ($53K) to support ACE CRC multi-disciplinary modelling efforts, Iridium floats ($57K) and Argo floats ($332K) for oceanographic observations.

External reviews

The ACE CRC had its 'Six Month Review' on 20 August 2010 with no significant actions or issues arising.

The 'First Year Review' took place on 11 March 2011 with ACE hosting the CRC Review panel. Issues arising from this review were to fill the vacant independent Board member position, and the appointment of a Board member with accounting experience to the Budget, Finance and Risk Board sub-committee. Both of these matters have been subsequently resolved. Mr Tony Coleman has been appointed to the Budget, Finance and Risk sub-committee, and Mr Howard Bamsey has filled the independent Board member position.

During the reporting period the ACE CRC Board further developed its transition planning for post-2014. The ACE CRC has subsequently begun structured engagement with key stakeholders. To date no clear future funding mechanism has been identified to enable the current ACE collaboration to transition to a new entity after June 2014.

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.

Financial risk is identified as a 'medium' risk. This risk rating resulted from the actual funding received from the CRC Program being 20% less than requested in the ACE CRC application. The risk that, despite the Board's best intentions, ACE will not be able to successfully deliver *all* the contracted outputs with this diminished funding is mitigated by a suite of actions. These include seeking complementary funding and careful management of costs. The result of these management actions is that the projected cash position for the end of the ACE CRC's current funding period has improved from a forecasted deficit of $262K to a forecasted surplus of $41K.

Logistic risk continues 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. The SIPEX-2 voyage foreshadowed for 2011-2012 was rescheduled for 2012-2013. This has resulted in some delays in field work for the Cryosphere and the Ecosystems Programs. These delays are not anticipated to be material over the life of the ACE CRC.
Fixed-wing aircraft capability continues to be problematic due to operational difficulties. As a work-around, the aerial sea ice work during the year was completed using helicopter-based observations. While the Australian Antarctic Division (AAD) assesses its future fixed-wing aircraft capability, helicopter-based sea ice operations will continue.

Staffing, collaboration and usage are all identified as 'low' risk. The potential loss of staff towards the end of the life of the ACE CRC still needs to be carefully managed. This risk is being managed through the development of the transition plan and close collaboration with core participants.

The planned collaboration with Memorial University (MUN) in Canada, which was to provide an Autonomous Underwater Vehicle (AUV) for the SIPEX-2 field campaign in 2012, ceased after discovering that this specific vehicle would be difficult to operate from the *Aurora Australis* given limited deck space and the acoustically noisy operating environment. The ACE CRC has commenced a new collaboration with Woods Hole Oceanographic Institution (WHOI), which owns and operates a smaller AUV. The new vehicle has a different mapping range to the proposed original AUV, and the sea ice research project within the Cryosphere Program had to be adjusted accordingly.

1.3 End-user Environment

The major changes in the end-user environment relate to the political and policy arena. The ACE CRC built its Impact Tool (IT) on the assumption that a global mechanism for setting a price on carbon would be established around the time of the Copenhagen climate change negotiations in December 2010. The passage of the recent suite of legislation through the Australian Parliament provides a more concrete framework to cost the economic impacts of the ACE CRC's research.

ACE CRC research provides critical input to government and industry end-users, enabling them to more accurately project future changes in climate and to plan accordingly, whether by way of mitigation or through adaptation.

The ACE CRC is providing important input into the IPCC AR5. Two ACE scientists attended the Lead Author meetings held in Kunming China from 8 November to 11 November 2010.

The *Climate Futures for Tasmania* project highlighted the value of producing climate change projections at local scales, developing the outputs in close collaboration with end-user groups, and delivering the outputs in formats that are meaningful to various sectors of the community. The *Climate Futures for Tasmania* model has received recognition from end-users in Tasmania and opportunities are arising to deploy this model in other regions of Australia.

The ACE CRC is also exploring multidisciplinary research projects with its commercial partners and with the University of Tasmania (UTAS).

1.4 Impacts

The modelling used in the ACE CRC Impact Tool (IT) for the ACE CRC application was built on the premise that ACE research will deliver cost savings to governments, industry and society by providing more timely and accurate science, climate information, models and sea-level rise projections than would otherwise be available. Cost savings would be derived by governments being able to more effectively model the economics of the timing and scope of mitigation and adaptation policies. The savings would be realised by not over mitigating (i.e. causing unnecessarily large economic impacts) or by under responding (causing avoidable impacts of climate change). The modelling used in the IT was developed in consultation with the Australian Government Treasury Climate Change Unit. The ACE CRC IT estimated that the net present value of savings to governments in using the first year's outputs of the ACE CRC was in the order of $66m; and $216m over the life of the ACE CRC.

The 0.15% savings attributed for the results of ACE research is extremely conservative. A recent report by the DCCEE[1] valued coastal infrastructure likely to be affected by a 1.1m rise in sea level at $226b. $216m represents only 0.1% of coastal infrastructure value, and much more is at risk from climate change than coastal infrastructure.

Since the IT was conducted for the ACE CRC application, a 'worst-case' revised estimate of the value of ACE research was undertaken assuming a pessimistic economic outlook for the next 13 years. Estimates of savings from accurate and timely climate modelling were halved from 4% of Gross Domestic Product (GDP) to 2% of GDP, and the GDP annual growth rate reduced from 2.8% to 1% out until 2015. In addition, for the Ecosystems Program, the value placed on ecosystems protection was reduced by a half from $50 to $25 per household. Even with these radical changes in anticipated impacts, the expected benefits of ACE research equates to the expected costs of ACE research (i.e. a 1:1 return). Given this is an extremely negative long term view of the economy, and the fact that ACE

[1] DCCEE (2011) Climate Change Risks to Coastal Buildings and Infrastructure: A Supplement to the First Pass National Assessment

is only claiming a tiny percentage (0.15%) of the savings in GDP achieved from timely and accurate climate science, this is still a significant return on investment.

2 Governance and Management

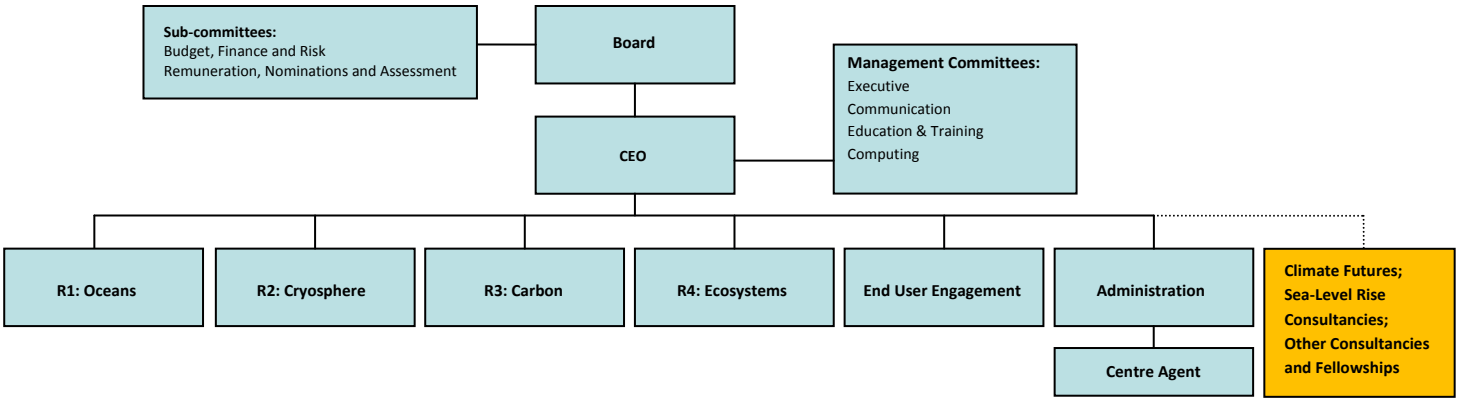
The ACE CRC is an unincorporated joint venture comprising 6 essential and 17 other participants. The University of Tasmania (UTAS) continues to provide Centre Agent services such as human resource and financial services as in-kind contributions. UTAS signed the Commonwealth Agreement on behalf of all 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 17 parties.

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

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

The ACE CRC's transition plan has been developed to consider the ACE CRC's future beyond the life of current CRC Program funding. At this juncture there are no obvious direct funding vehicles that will assist ACE to transition in its current form. Other options are being explored which may support components of the existing ACE CRC. Regular updates to the IT and transition plan will ensure rigorous management going forward.

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



2.1 Governance – Board, Committees and Key Staff

The Board

The Board is constituted with a balance of skills, experience and independence and operates in accordance with the provisions of the Participants' Agreement. It comprises an independent chairperson, representatives of ACE CRC six Essential Participants, two representatives from Other Participants (including one commercial participant), two independent members and two ex-officio members (without voting rights). During the reporting period one independent Board position

remained vacant (it has subsequently been filled by Mr Howard Bamsey). An ACE CRC Code of Conduct for Board members has been developed and approved by the Board.

Board meetings are held every quarter. During this reporting period Board meetings were held on 17 September 2010, 1 December 2010, 28 February 2011, and 4 May 2011.

End-user organisations, Pitt & Sherry Pty Ltd and the Department of Climate Change and Energy Efficiency (DCCEE), were represented on the Board by Mr John Pitt and Dr Ian Carruthers/Mr Geoff Leeper/Ms Harinder Sidhu respectively. Mr Ian Carruthers (DCCEE) resigned during the reporting period and was replaced by Mr Geoff Leeper. Mr Geoff Leeper subsequently resigned and was replaced by Ms Harinder Sidhu. UTAS representative, Prof Alan Canty, resigned and was replaced by Prof Paddy Nixon.

Name	Role	Key Skills	Independent/ Organisation	Number of meetings	% as Board member
Prof Ulrich Bathmann	Board Member	- Leadership in international scientific programs - High level administrative experience - Strong international standing as a scientist	Alfred Wegener Institute (Essential Participant)	0/4	0% Granted leave of absence by Board
Mr Ian Carruthers	Board Member	- High level executive experience in government - Leadership on strategies to deliver science capability for national needs - Broad and extensive experience on climate change, environment and natural resources management	Department of Climate Change & Energy Efficiency (Essential Participant)	1/1 (resigned after 33rd meeting)	100%
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	75%

Name	Role	Key Skills	Independent/ Organisation	Number of meetings	% as Board member
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 COAG on climate change policy, legislation and regulation	Tasmanian Government (Other Participant)	2/4	50%
Mr John Gunn	Ex-Officio	- High level executive management experience in research agencies and government - Strategic planning of national and international research programs - Marine and climate science leadership	Australian Antarctic Division (Essential Participant)	3/4	75%
Mr Geoff Leeper	Board Member	- High level executive experience in government - Leadership on strategies to deliver science capability for national needs (Australian Climate Change Regulatory Authority) - Broad and extensive experience in government and policy; Corporate Services Branch, Department of Families, Housing, Community Services and Indigenous Affairs, and Medicare Australia	Department of Climate Change & Energy Efficiency (Essential Participant)	1/1	100%

Name	Role	Key Skills	Independent/ Organisation	Number of meetings	% as Board member
Ms Lyn Maddock	Board Member and Acting Chair 17 Sep 2010	- High level executive management experience in government - Extensive policy experience - Board experience in a number of NGO's	Australian Antarctic Division (Essential Participant)	3/4	75%
Dr Bruce Mapstone	Board Member	- Extensive experience in research leadership and management at senior & institutional levels - Established experience with CRC establishment, leadership, and governance, including the previous ACE CRC - Broad relevant domain expertise in climate and marine science	CSIRO (Essential Participant)	3/4	75%
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	NIWA (Essential Participant)	0/4	0% Granted leave of absence by Board
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)	2/4	50%

Name	Role	Key Skills	Independent/ Organisation	Number of meetings	% as Board member
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)	2/4	50%
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	100%
Ms Harinder Sidhu	Board Member	- High level executive experience in government - Broad and extensive experience in policy, communications and public affairs activities	Department of Climate Change & Energy Efficiency (Essential Participant)	1/2	50%
Dr Katherine Woodthorpe	Chair	- High level management skills - CEO of 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	3/4	75%

The Board has established sub-committees. The Budget, Finance and Risk sub-committee includes Mr John Gunn (AAD), Dr Bruce Mapstone (CMAR), Prof Paddy Nixon (UTAS, previously Prof Alan Canty) and Mr Tony Coleman as members. They met on 19 November 2010 and also considered matters 'out of session'.

The Remuneration, Nominations and Assessment sub-committee consists of Dr Katherine Woodthorpe, Ms Lyn Maddock and Mr Greg Johannes. They met on 24 November 2010.

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. The ACE CRC Executive Committee convenes quarterly. These meetings occurred on 21 July 2010, 16 November 2010, 22 February 2011, and 12 April 2011.

Name	Role	Key Skills	Organisation
Prof Nathan Bindoff	Leader, Climate Futures; Director TPAC	Computing/research	ACE CRC/TPAC
Ms Carrie Bloomfield/Ms Wenneke ten Hout	Administration Manager	Administration	ACE CRC
Dr Andrew Constable	Leader, Ecosystems Program	Research	ACE CRC/AAD
Ms Miranda Harman	Communications Manager	Communications/Media	ACE CRC
Assoc Prof Marcus Haward	School of Government, UTAS	Research/policy/end-user engagement	ACE CRC/UTAS
Dr Julia Jabour	IMAS Representative	Education	IMAS
Ms Tessa Jakszewicz	Deputy CEO, Business Development	Business Development/end-user engagement	ACE CRC
Ms Kate Maloney	Business Management	Finance, administration, governance	ACE CRC
Prof Andrew McMinn	IMAS Representative	Education	IMAS
Dr Kelvin Michael	IMAS Representative	Education	IMAS

Name	Role	Key Skills	Organisation
Dr Tas van Ommen	Program Leader, Cryosphere Program	Research	ACE CRC/AAD
Dr Tony Press	CEO	Management, governance	ACE CRC
Mr Tomas Remenyi	Student	Education	IMAS/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

Communications Coordination Committee

A new ACE CRC Communications and Media Manager was appointed on 26 September 2010. The communications coordinating committee met once during the reporting period on 16 February 2011. There was regular liaison between the ACE CRC Communications and Media Manager and partner Communications Managers during the reporting period.

Name	Role	Organisation
Ms Sally Chambers	General Manager, Corporate Communications	AAD
Mr Peter Cochrane (1 February 2011- 30 June 2010)	Coordinator, Communications and Media Office	UTAS
Ms Moya Fyfe (1 July 2010-31 January 2011)	Communications and Media Manager	UTAS
Ms Miranda Harman (26 September 2010-30 June 2011)	Communications and Media Manager	ACE CRC
Ms Tessa Jakszewicz (1 July 2010-28 September 2010)	acting Communications and Media Manager	ACE CRC
Mr Craig Macaulay	Communications Officer	CSIRO

Education and Training Committee

An Education and Training committee has been formed between the Institute of Antarctic and Marine Studies (based at UTAS) and the ACE CRC to discuss a range of matters relating to education and training. Discussions during this reporting period have centred on recruitment of PhD students and improving the visibility of ACE CRC and IMAS research projects. The Education and Training committee met 7 times informally throughout the reporting period.

Name	Role	Organisation
Prof Mike Coffin	Executive Director IMAS (from 1 January 2011)	IMAS
Dr Julia Jabour	IMAS Representative	IMAS
Prof Gustaaf Hallegraeff	IMAS Representative	IMAS
Prof Andrew McMinn	IMAS Representative	IMAS
Dr Tony Press	CEO	ACE CRC
Prof Michael Stoddart	Interim Executive Director IMAS (until 31 December 2010)	IMAS

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 met twice during the reporting period on 30 July 2010 (pre-meeting) and 9 August 2010. The Computing Committee also provided advice on the ACE CRC's server requirements resulting in the selection and purchase of the new computer server.

Member	Role	Organisation
Ms Carrie Bloomfield/Ms Wenneke ten Hout	Administration Manager	ACE CRC
Mr Colin Broadbent	Information Technology Resources	UTAS
Ms Margie Cole	Executive Officer	IMAS
Mr James Culverhouse	Information Technology Resources	UTAS
Mr James Harrison	Information Technology Resources	UTAS
Dr Klaas Hartmann	Researcher	IMAS
Mr Ben Joseph	Information Technology Resources	UTAS

Member	Role	Organisation
Dr Jan Lieser	Researcher	ACE CRC
Ms Kate Maloney	Business Management	ACE CRC
Dr Tony Press	Chief Executive Officer	ACE CRC
Dr Jason Roberts (Chair)	Researcher	AAD
Mr Peter Walsh	Data Manager	IMAS
Dr Roland Warner	Researcher	AAD

Key Staff

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

2.2 Participants

No changes to participants have occurred for the reporting period.

Type of Participant	Participant
Essential	Alfred Wegener Institute of Polar and Marine Research (AWI), Germany
Essential	Australian Antarctic Division (AAD)
Essential	CSIRO Division of Marine and Atmospheric Research (CMAR)
Essential	Department of Climate Change and Energy Efficiency (DCCEE)
Essential	National Institute of Water and Atmospheric Research Ltd (NIWA), New Zealand
Essential	University of Tasmania (UTAS)
Other	Centre for Polar Oceanography and Modelling (CPOM), University College London, UK

Type of Participant	Participant
Other	Chinese Academy of Meteorological Science (CAMS)
Other	Department of Sustainability, Environment, Water, Population and Communities (SEWPAC)
Other	First Institute of Oceanography (FIO), China
Other	GHD Pty Ltd
Other	Institute of Low Temperature Science (ILTS), Hokkaido University, Japan
Other	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS), France
Other	Memorial University of Newfoundland (MUN), Canada
Other	Myriax Software Pty Ltd
Other	National Institute of Polar Research (NIPR), Japan
Other	Pitt & Sherry
Other	RPS MetOcean Pty Ltd
Other	SGS Economics and Planning Pty Ltd
Other	Tasmanian Government
Other	University of Texas at Austin, USA
Other	University of Texas at San Antonio, USA
Other	Vrije Universiteit Brussel, Belgium

2.3 Financial Management

The ACE CRC made considerable efforts to ensure that its budget would be balanced following the shortfall in funding from the CRC Program. The result of these management efforts was that the projected cash position for end of the ACE CRC's current funding period changed from a forecasted deficit of $262K to a forecasted surplus of $41K.

Staff appointments were made based on three-year contracts with most appointments due to expire (subject to review) at the end of 2013. This was done to manage costs and to reduce the projected end of contract deficit. Staffing is kept under constant review and adjustments to contracts will be made, taking into account priorities and finances, towards the end of the life of the ACE CRC.

Other factors that assisted in rebalancing the budget included:

- Two participants provided additional cash contributions to cover the cost of staff positions, sea-level rise tool costs, and ocean acidification research costs. The additional cash contributions of $97K from the AAD and $75K from DCCEE were received during the reporting period. Confirmation of an additional cash contribution of $385K from DCCEE was received prior to year end for additional sea-level rise research and web tool development.
- Interest of $206,396 was earned on the ACE CRC account during this reporting period (shown as 'Other Firm Cash' in the ACE CRC financial tables).

In terms of in-kind contributions, there was an unfavourable difference of 21% to the agreement budget in the current reporting year. This resulted from a number of factors:

- The AAD's contribution for the current year was 29% lower than budgeted. This was due in part to the early completion of the AAD Mill Island core drilling in the prior year. Therefore, to date the AAD contribution is 7% under budget. The remainder of this difference is due to the SIPEX-2 rescheduling. It is expected over the life of the ACE CRC that this contribution from the AAD will run to budget.
- The other major factor to the lower than expected in-kind contributions was the University of Texas ICECAP project logistics costs. This difference arose due to the foreign exchange rate changing for USD to AUD from 0.67 (at the time of the application in 2009) to 1.02 (as at 30th June 2011). Thus the contribution of survey costs for ICECAP was substantially less on exchange into AUD than budgeted ($387K) representing a reduction of 35%. As all work was completed, it is expected that this variance will remain for the life of the ACE CRC.

The online 'Expenses' table for the ACE CRC over the year shows major variances to the agreement.

As reported in last year's annual report the calculation of variances needs to be amended in the agreement column for the carried forward cash. The expected use of these additional funds and the years in which the expenditure was budgeted was advised to the CRC Program in June 2010.

Table 1 Excerpt from the online 'Expenses' table 3

	Actual	Agr'mt	Diff	%Diff
Employee Expenses	2,579	2,952	-373	-13
Supplier Expenses	1,318	2,159	-841	-39
Capital	451	340	111	33
Other Expenses	-	-	-	-
TOTAL EXPENSES	4,348	5,451	-1,103	-20

Table 2 The online 'Expenses' table 3 adjusted for carried forward cash

	Actual	Agr'mt	Diff	%Diff
Employee Expenses	2,579	2,952	-373	-13%
Supplier Expenses	1,318	3,139	-1,821	-58%
Capital	451	1,229	-778	-63%
Other Expenses	-	-	-	-
TOTAL EXPENSES	4,348	7,320	-2,972	-41%

In the current year, the differences in employee expenses relate to the timing of staff appointments. The final of 13 new appointees commenced in April 2011. It is expected that this variance will be a timing difference and it is expected that over the life of the ACE CRC this expenditure will run to budget.

The difference in supplier expense arose due to a number of factors:

- The timing of logistics payments for ship use were deferred into future financial years (deferral amount $1.27M);
- With the final staff member commencing April 2011, this delayed the start of some programs and consequently showed a positive variance for supplier expenses in the reporting year. These are timing differences and are expected to run to budget over the remaining life of the ACE CRC; and,
- The change of the timing of the SIPEX-2 cruise (now scheduled for September 2012), means that the preparation costs for this cruise and capital purchases will be expended in next financial year, resulting in an underspend in this reporting year.

2.4 Communications

The ACE CRC endeavours to measure, and ensure the effectiveness of its communications, by actively seeking input from end-users through face-to-face meetings, end-user representation on the Board and end-user surveys.

ACE CRC conducted a number of internal and external communications activities during the reporting period.

Internal communications activities

Activity	Description	Date
ACE CRC Annual General Meeting	Held for all ACE participants to discuss ACE and collaborations	18 Aug 2010
ACE CRC Symposium	Staff and students share research achievements and results	19 and 20 Aug 2010
ACE CRC Executive	Planning forum for ACE Program Managers and members of administration team	21 Jul 2010; 16 Nov 2010; 22 Feb 2011; 12 April 2011;
ACE CRC e-newsletter	Newsletter includes CEO message and several topical research articles	Sep 2010; Dec 2010; June 2011
ACE CRC Website	A new version of the website www.acecrc.org.au was launched in Q4 and includes a staff intranet section	June 2011

External communications activities

The ACE CRC has undertaken a number of activities to communicate its successes and to transfer knowledge to end-users. Highlights during the reporting period included a presentation booth at the International Climate Change Adaptation Conference on the Gold Coast and Greenhouse 2011 in Cairns and the co-hosting of the Australian and New Zealand Climate Forum in Hobart. The ACE CRC also hosted the National Storm Tide Modelling workshop in Melbourne on 27 July 2010.

A briefing of the then Tasmanian Climate Change Minister, the Hon Nick McKim, was held in December 2010 and the ACE CRC presented 'Towards IPCC 5 – Tasmania's contribution to climate change science' to Tasmanian Federal and State members of Parliament in February 2011.

ACE CRC glaciologists initiated the *Climate Conversations* outreach program, a series of community forums designed to encourage conversations between scientists and the public about climate change. During the reporting year, several *Climate Conversations* events were held along the NSW mid-north coast and around Tasmania.

At a national level, one-on-one discussions were held regularly with government and industry representatives. Meetings were held with representatives from DCCEE, DAFF, DIISR, SEWPAC, Telstra, Geosciences Australia, Insurance Council of Australia, Westpac, QANTAS, Origin Energy, Kathmandu, Visy, Bendigo Bank, mecu, GE and The Climate Institute.

The ACE CRC developed and implemented a new Report Card format for delivering updates on its science. The first in the series, *Report Card: Southern Ocean Acidification* was launched in April 2011 and received very positive feedback.

ACE CRC Position Analyses - which are summary publications updating the latest science - have been well received. The *Southern Ocean Circulation and Climate Change* Position Analysis was progressed extensively during the reporting period and is due to be published late 2011.

An external online survey of users of the ACE CRC sea-level rise web tool (www.sealevelrise.info) was developed to gauge effectiveness of the web tool and to guide priorities for future development. The survey identified that 67% of survey respondents were actively using the sea-level rise web tool.

Other external communications activities included:

Activity	Description	Date
Media Releases	8 ACE CRC media releases were issued. 'New Observations of Coastal Erosion with Climate Change'; 'The Science is in and it's Time to Move On'; 'Climate Conversations'; 'Australian First in Climate Projections'; 'Minister launches Climate Futures for Tasmania Water and Catchments research results'; 'Minister launches Climate Futures for Tasmania Impacts on Agriculture research results'; New insights into the formation of the East Antarctic ice sheet'; 'ACE CRC launches Southern Ocean Acidification Report Card'	Throughout the reporting period
Southern Ocean Acidification Report Card	The first Report Card was produced by the ACE CRC, providing an update of the scientific understanding of ocean acidification and its impacts in the Southern Ocean	April 2011
Technical Report	Shoreline Change at Roches Beach 1957-2010, South-Eastern Tasmania. This report outlines coastal erosion at Roches Beach due to sea-level rise	August 2010
Face-to-face briefings	Tasmanian State Government; DCCEE; DAFF; DIISR; SEWPAC; Telstra; Geosciences Australia; Insurance Council of Australia; Westpac; QANTAS; Origin Energy; Kathmandu; Visy; Bendigo Bank; mecu; GE; The Climate Institute	Throughout the reporting period
ACE Vodcasts	A series of short video clips interviewing ACE CRC scientists about their research were created and uploaded on to You-Tube; Vimeo and the ACE CRC website	June 2011
ACE CRC e-newsletter	Newsletter includes CEO message and several topical research articles. Distributed to over 400 research participants and government and industry end-users	Sep 2010; Dec 2010; June 2011
ACE website www.acecrc.org.au	Regular updates including ACE news and events and news clippings on relevant research topics	Several times per month

Overall strategy to ensure communications effectiveness

The ACE CRC continues to seek and develop mechanisms to measure its effectiveness. ACE CRC's major end-users are represented on the Board and have the opportunity to directly influence ACE CRC communications. Given the strong representation of end-users on the Board, it was deemed unnecessary to establish a standalone 'end-user' committee. Strategies to ensure the ACE CRC's effectiveness include one-on-one meetings with end-users, to seek feedback on current research and guide future development. End-user forums are also held from time to time, but none were held during the reporting period. The ACE CRC measures and monitors its media profile.
The ACE CRC website and e-newsletter seek to gather feedback from users and readers. The ACE CRC is adopting Google Analytics to measure its website effectiveness.

2.5 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 Australian Antarctic Division (AAD), the Integrated Marine Observing System (IMOS) and the Tasmanian Partnership in Advanced Computing (TPAC).

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

The ACE CRC does not hold any patents in Australia nor overseas.

3 Performance against Activities

3.1 Progress against the Key Challenge/Outcomes

1. Oceans: The Southern Ocean and Sea-Level Rise (SLR)

How is the Southern Ocean changing, and the implications that this will have for Australian and global climate now and in the future?

The ACE CRC is exploiting the revolution in ocean observation technology to increase its capacity to study the role of Antarctica and the Southern Ocean in global and regional climate. The ACE CRC is using profiling floats that drift with the ocean currents and periodically rise to the surface to transmit temperature and salinity measurements. Miniaturised oceanographic sensors attached to seals are providing information on seal biology and also the oceanic environment in which they live. Seals travel far through the ocean and even beneath the winter sea ice. Fixed moorings, ships and

satellites are also being used to measure the physical and chemical properties of the Southern Ocean.

ACE CRC researchers are repeating tests previously carried out to calibrate changes in ocean characteristics; using satellite altimetry to determine how the Antarctic Circumpolar Current (ACC) distributes surface chlorophyll and sea ice; and monitoring regional variations in sea surface height in the Southern Ocean. This research allows IPCC-class models to be tested against observations in order to improve the models and deliver more reliable climate projections.

The ACE CRC collaborates with United States of America, French, German, Chinese, New Zealand and Japanese partners in the Antarctic to increase our understanding of current and future changes in the Southern Ocean and further improve global climate models.

One of the most significant impacts of climate change will be caused by a rise in sea level. Recent research has shown that sea levels are rising at rates near the higher end of previous projections, and that the rate of sea-level rise is accelerating. The ACE CRC's Sea-Level Rise (SLR) 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 recession of the coastline with rising sea levels.

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 decision support tool (www.sealevelrise.info). The decision support tool provides key 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.

2. Cryosphere: Impacts of Changing Snow and Ice Cover

How will sea ice and the Antarctic ice sheet respond to changes in climate and what impact will changes in the cryosphere have on climate and sea level?

The ACE CRC's Cryosphere Program is split into three main research projects: the dynamic role of polar ice sheets in future sea level; the role of Antarctic sea ice in the climate system; and past and present climate - records and dynamics.

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 great ice sheets is increasing, and that this is due to increasing discharge of ice by glaciers, rather than simply by increased melt. Current computer models which 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 major uncertainty in sea-level predictions over century and longer time scales.

The ACE CRC's 'dynamic role of polar ice sheets in future sea level' project aims to improve computer models of ice flow dynamics, basal processes and interactions with atmosphere and ocean. The ACE CRC is collaborating with international efforts in model development, particularly building on our expertise in ice flow properties and ice-shelf-ocean interactions. The developing models will

include stresses to the ice, presently neglected in ice sheet models, treatment of basal conditions, including sliding ice and sediments, basal hydrology and subglacial lakes. The transition of glaciers from grounded ice flow to floating ice shelves is being refined, so that changes at the ocean margins are correctly propagated to the flow in the ice sheet interior.

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 the Cryospheric Evolution of the Central Antarctic Plate' (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 have real-world boundary data as inputs. The ICECAP survey targets deep subglacial basins and major outlet glaciers which hold the greatest potential for dynamic ice sheet changes, and consequently to potential sea-level rise (see page 33).

The ACE CRC's second Cryosphere project, 'The role of Antarctic sea ice in the climate system', revolves around the fact that sea ice is a key component of Earth's climate system – the annual change from the Antarctic winter maximum sea ice extent to the summer minimum is one of the largest natural physical changes on the planet. Through a variety of feedback mechanisms, sea ice acts as an agent and indicator of climate change. Sea ice also plays a structuring role in marine ecosystem function. Over the last decades, the extent of sea ice and its thickness have decreased in the Arctic, and a reduction in extent has also occurred in the Antarctic Peninsula region. However, it is not known how the thickness of Antarctic sea ice is changing.

The ACE CRC is conducting field research including the future deployment of an Autonomous Underwater Vehicle, instrumented with upward-looking sonar to measure sea ice drift. In situ observations to validate/calibrate satellite remote sensing including airborne laser altimetry will also be conducted, as well as remote sensing and deployment of sea ice mass balance stations, equipped with biological sensors, and sea ice drifting buoy arrays.

The last 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, process studies and to test models. The project is producing additional high-resolution climate records for the Antarctic. The project 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, the ACE CRC is expanding the spatial extent, and extending the temporal length 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 instrumental period. Finally, the ACE CRC is investigating longer-term fundamental climate processes related to forcing changes due to isolation and greenhouse gas variations over the last glacial cycle, and exploring hemispheric climate coupling and abrupt climate change events.

3. Carbon: Southern Ocean Uptake

Will the Southern Ocean continue to remove CO_2 from the atmosphere and how rapidly will this increase the acidity of the ocean?

Currently one third of humankind's annual emissions of the fossil-fuel derived greenhouse gas, Carbon Dioxide (CO_2), are absorbed by the oceans. The Southern Ocean presently absorbs 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.

The absorption of CO_2, however, comes with a cost – a decrease in the alkalinity of the ocean (often called ocean acidification). This change will have potentially serious impacts, within the 21st century, for the sustainability and management of many marine and coastal ecosystems and fisheries. Acidification is occurring first in polar seas, and for this reason examining ecosystem responses in the Southern Ocean offers a bellwether for probable impacts around Australia.

The ACE CRC collaborates with many organisations and countries around the world to understand the ability of the Southern Ocean to draw down atmospheric carbon, and whether or not the ocean carbon sink has a saturation point. Understanding the Southern Ocean's ability to sequester carbon is vital for understanding our environmental future and, as emphasised by the IPCC, is of crucial importance for the setting of efficient emissions reductions 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. It focuses on three key projects.

The first of these projects involves measuring the magnitude of 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 overturning oceanic circulation and therefore hampers the effectiveness of the ocean's physical pump. Changes in sea ice cover, ocean warming and stratification, and lack of supply of the limiting trace nutrient iron all potentially have negative effects on the effectiveness of the biological pump 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 anthropogenic 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 impacted by ocean acidification.

The final Carbon project examines the potential and ecological risks of increasing Southern Ocean uptake of CO_2 via ocean iron fertilisation. The ACE CRC aims to study natural iron fertilisation to investigate the associated extent of carbon uptake and ecosystem health and compare these results to deliberate fertilisations. The ACE CRC then will assess the efficacy and risks of ocean fertilisation using field observations, synthesis, and numerical simulations. The ACE CRC collaborates with DCCEE, SEWPAC, ACCESS, the Australian Climate Change Science program, CSIRO, AAD and other international agencies (IOCCP, CO2/CLIVAR, GEOTRACES, and IPCC). Impacts of ACE CRC's research

include cost savings by governments and industry derived from more accurate carbon cycle models and more informed carbon management strategies.

4. Ecosystems: Impacts of Climate Change on Antarctic Marine Life

What will be the impact of Southern Ocean and sea ice changes on Antarctic ecosystems and fisheries?

The Ecosystems Program addresses the challenge of what will be the impact of Southern Ocean and sea ice changes on Antarctic ecosystems and fisheries. The current expectation is that the 'keystone' nature of krill will remain the same but that the productivity of the ecosystem will generally decline with the loss of sea ice. However, emerging science is showing that the productivity of the system is uncertain and that the development of a pelagic system without sea ice may result in the structure of the food web shifting from a krill-based food web to a fish-based food web, such as that seen on the Kerguelen Plateau of the Southern Ocean. Such a change could seriously affect fisheries in the region, and the conservation of whales and other higher predators. The ACE CRC is using a combination of field studies along with qualitative and quantitative modelling to evaluate different scenarios for the Antarctic marine ecosystem based on prognoses of change from the IPCC AR5 analyses.

The Ecosystems Program is researching the impact of Southern Ocean and sea ice changes on Antarctic ecosystems and fisheries by focussing on four key projects. The first of these is assessing the risks to key species of Southern Ocean marine ecosystems from climate change impacts, such as temperature and ocean acidification.

Literature and expert opinion is being used in a risk assessment framework to assess species' responses to climate change scenarios, including the development of conceptual models of the impacts of change in the physical environment and food webs. Spatial modelling will ascertain key environment drivers for species. IPCC AR5 results will be used to ascertain change in those drivers and the likely consequences to species distributions and dynamics.

The second project in the Ecosystems Program aims to contribute to determining the ecosystem impacts of predicted changes in Antarctic sea ice by evaluating the linkages between ocean productivity and the spatial and temporal dynamics of the sea ice zone, including sea ice physical and biological parameters.

A realistic model of sea ice algal productivity is being developed which requires a model of algae attached to the underside of the sea ice as well as algae entrapped in the brine channels throughout the entire ice thickness. Further, the Ecosystems Program is collating historical datasets from the Southern Ocean. An international dataset is being developed of sea ice biological and biogeochemical parameters from ice cores. The number of ice cores to be included in this database is likely to increase as more scientists become involved and release their unpublished data.

The third aspect of this project is to conduct in situ studies, including field programs. In situ measurements of ice algal biomass and production and an understanding of how they relate to the physical attributes of sea ice and the water column are essential for developing the spatial models and the dynamic simulation models.

Identification of key food web processes that could be impacted by changes in the physical and biogeochemical environments in eastern Antarctica is the third project involved in the Ecosystems Program. This project has been split into two parts.

Part 1 includes regular sampling on the 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 is the development of a ship- and land-based integrated ecosystem study to evaluate the primary food web linkages from phytoplankton to top predators in eastern Antarctica. This project is a multidisciplinary food web study, which includes the integration of land-based and sea-based activities in collaboration with other relevant projects in the Australian Marine Mammal Centre at the AAD.

The last project in this program focuses on drawing on the results of the other ACE CRC Ecosystems projects to create a second generation marine ecosystem model which will be used to assess historical and future climate change impacts on Antarctic marine ecosystems, as well as to evaluate the types of objectives that could be appropriate for the conservation of Southern Ocean species.

Models currently under development include the Ecosystem Productivity Ocean Climate (EPOC) modelling framework, a Regional Ocean Modeling System (ROMS) model of eastern Antarctica and the Kerguelen Plateau and the Australian Earth-system model through ACCESS. Development of a further ecosystem model using 'Atlantis' is also being undertaken to model effects on biodiversity and to support other modelling efforts in the program. This project aims to synthesise and integrate knowledge on food webs and ecosystems to build a second-generation model that couples food web models (EPOC and Atlantis) with the ROMS model. This work is using reviews of different components of the ecosystem and is developing an appropriate representation of those components in the modelling environment. Comprehensive testing will be undertaken with EPOC and Atlantis to develop the most efficient representations possible of each module while still preserving their sensitivity to climate change impacts.

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 can be undertaken based on plausible scenarios for climate change impacts, as developed in the other three projects in the ACE CRC Ecosystems Program.

An important component of this early work is the development of user-friendly interfaces for building and managing these models in order to enable greater participation of ecologists and modellers alike from partner laboratories in Australia and overseas.

3.2 Research

The ACE CRC is on target to achieve its research outputs. A detailed summary of ACE research activities at the program level (Oceans; Cryosphere; Carbon; and Ecosystems) can be found below.

The level of end-user involvement, and evidence that the research is meeting end-user needs, is outlined in section 3.3.

In total, ACE CRC researchers have published 3 books, 10 book chapters, 74 articles in scholarly refereed journals, and 9 full written conference papers in refereed proceedings. In addition, 25 articles in scholarly refereed journals are 'in press'. These publications show that the ACE CRC is well on track to deliver its research outputs.

1. Oceans

The ACE CRC's Oceans Program is on target to achieve its research outputs.

All new staff commenced in this reporting period. Dr Catia Domingues (Physical Oceanographer – Modeller) started on 26 April 2011 and is working with Prof Nathan Bindoff. Dr Beatriz Pena-Molino (Physical Oceanographer – Observer) started on 9 December 2010 and is working with Dr Stephen Rintoul. Dr Steven George commenced on 25 October 2010 as the Sea-Level Rise Specialist working with Dr John Hunter.

In addition, the Southern Ocean Observing System (SOOS) executive position has been filled and will commence in August 2011. The SOOS International Project Office (IPO) is co-located with the Integrated Marine Observing System (IMOS) based at the University of Tasmania. The ACE CRC's Oceans Program will be collaborating closely with the SOOS IPO (see page 41).

The process for developing the next IPCC report is well underway with both Dr Stephen Rintoul and Prof Nathan Bindoff providing input into the deliberations of Working Group 1 for the Fifth Assessment Report (AR5). Prof Bindoff and Dr Rintoul attended the first lead author meeting of the IPCC WG1 in China in November 2010.

Dr Stephen Rintoul led the multi-disciplinary Mertz Glacier voyage in January and February 2011. The aim of this voyage was to measure changes in temperature, salinity, oxygen, carbon and nutrients from the sea surface to the sea floor, following the calving of the Mertz glacier tongue in February 2010 (see page 30). Three scientific moorings were deployed in the region to measure the outflow of Antarctic Bottom Water (ABW) from the Mertz polynya. These moorings will collect data on current speed and direction, temperature, salinity and oxygen, and will be retrieved in two years' time. The team also measured water properties using a CTD (conductivity, temperature and depth) profiler instrument. The CTD profiler was lowered at 149 stations during the month-long expedition and almost 100 profiles were collected over the continental shelf and slope in the Mertz polynya region. A preliminary analysis of the CTD results suggests that the calving of the glacier tongue has had an impact on the salinity of dense water on the continental shelf in the region.

The *Climate Change and the Southern Ocean* Position Analysis took longer in development than anticipated; however, it will be released by December 2011.

A National Storm Tide Modelling Workshop was organised by the ACE CRC and the DCCEE and held on 27 July 2010 in Melbourne. Dr John Hunter and Ms Tessa Jakszewicz from the ACE CRC attended the workshop. The workshop discussed the need for a national storm-tide model and the best approach for its development. A strategy for modelling storm tides induced by tropical cyclones was

also considered. Modelling of storm tides driven by synoptic weather patterns around the Australian coastline has since been completed through collaboration between the ACE CRC and the University of Western Australia (UWA).

Online training for the sea-level rise decision-support tool (www.sealevelrise.info) was developed. Additional funding from DCCEE was also secured to further develop the sea-level rise web tool. Plans for the 2011-2012 reporting period include securing expertise from UWA and the Water Research Laboratory at the University of New South Wales (UNSW) to enable tropical cyclone and beach erosion modelling to be incorporated into the web-based decision-support tool. The website at sealevelrise.info will be redeveloped, providing the statistics of projected flooding events at high-resolution around the whole of the Australian coastline.

The ACE CRC's Oceans Program team published 16 articles in scholarly refereed journals and 4 are in press. They also published 1 book, 3 book sections and 5 full written conference papers in refereed proceedings.

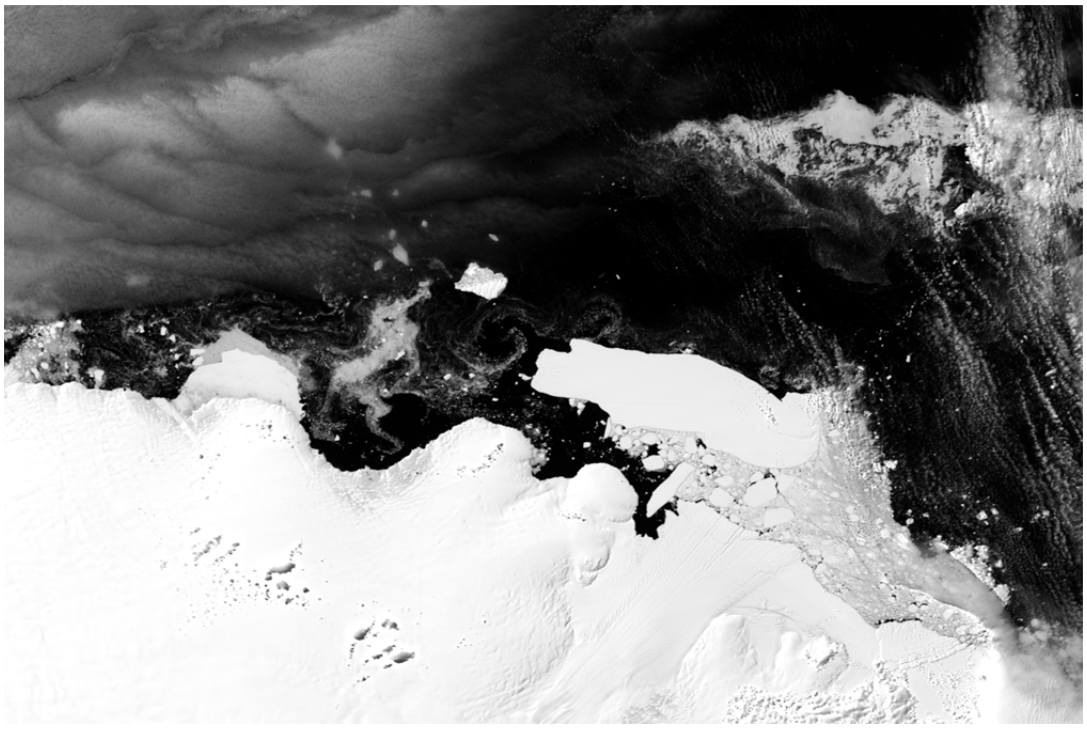
Calving of Mertz Glacier and its impacts

In mid-February 2010, a massive iceberg labelled B09B collided with the Mertz Glacier Tongue, which at that time protruded out about 100km from the Antarctic coastline at about 145°E. The collision precipitated the calving of another massive iceberg from the tongue, C28, which had a length of 78km and width between 33 and 39km. This calving event removed 80% of the tongue, leaving only a 20km long stub. The calving had been anticipated, as rifts cutting across the tongue have been developing over many years, but the precise timing of the event was not predicted.

The Mertz Glacier region plays an important role in the formation of Antarctic Bottom Water (ABW), which is a key driver of global ocean circulation.

The calving of the glacier tongue and the shift of the icebergs changed the geography adjacent to the glacier. Satellite images show that the high rate of sea ice production in the large body of water near the glacier (the Mertz Glacier polynya), which controls bottom water production, is still occurring. Further changes can be expected when iceberg B09B once again begins to move.

The Mertz polynya and glacier are the focus of research programs at the ACE CRC. ACE CRC partners at the Laboratoire d'Etudes en Géophysique et Océanographie Spatiales in France have GPS beacons on the glacier and iceberg C28 for a study of the glacier calving and iceberg evolution. Moorings have been deployed in the polynyas, and a voyage at the beginning of 2011 has undertaken oceanographic surveys. The body of work already undertaken and planned allows us to use the area as a natural laboratory - to observe and monitor the impacts of changes in the glacier system and its surrounds on the ocean and climate system as well as the regional biology. Satellite remote sensing will continue to play a key role in this monitoring.



The Mertz Glacier tongue as at 30 December 2010. MODIS image courtesy of NASA

2. Cryosphere

The ACE CRC's Cryosphere Program is on target to achieve its research outputs with its entire new staff in place in this reporting period. Dr Alex Fraser (Remote Sensing Specialist) commenced on 4 October 2010, Dr Ben Galton-Fenzi (Ice Shelf-Ocean Modeller) started on 6 July 2010, Dr Laura Herraiz-Borreguero (Ice Shelf Oceanographer) commenced on 16 August 2010, Dr Adam Treverrow (Ice Sheet Modelling Scientist) commenced on 2 August 2010, and Dr Guy Williams (Sea Ice / AUV Specialist) started on 4 January 2011.

A major achievement during this reporting period was the publication in *Nature* of the paper 'A dynamic early East Antarctic Ice Sheet suggested by ice-covered fjord landscapes'. The authors of the paper include several members of the Cryosphere Program. The article was published on 2 June 2011 and illuminates a 20-million-year period of repeated growth and retreat of the ice sheet following initial Antarctic glaciation around 34 million years ago. It shows a geological connection with past climate changes, helps the understanding of how climate and the ice sheet interact and connects the ice with changes in past and perhaps future sea level. This paper was a product of the ICECAP project (Investigating the Cryospheric Evolution of the Central Antarctic Plate), an international collaboration, which has now provided the first detailed understanding of the early development of the ice sheet that now fills the Aurora Subglacial Basin in Antarctica. This basin extends more than 1000 kilometres inland from Australia's Casey Station and is covered by some of the thickest and oldest ice in Antarctica. From December 2010 to January 2011, the ICECAP project completed a total of 47,000km aerial line surveys from Casey Station (see page 33).

The ICECAP project has already delivered against the 2012 milestone for 'analysis and interpretation of the ICECAP data'. In the 2011-2012 reporting period the ICECAP team will hold a workshop in August in Hobart, and additional ICECAP airborne radar surveys will provide further data to the already completed ACE CRC survey work.

The SIPEX-2 sea ice voyage is scheduled for 2012/2013, a year later than envisaged when milestone 2.2.5 was written. A SIPEX-2 workshop was held at the Australian Antarctic Division in early 2011 to plan the voyage. Further meetings and/or workshops will be held to finalise the activities and preparation for this voyage.

The analysis of ice bore holes at Mill Island showed an approximate 0.75 degree Celsius warming of surface temperature over the last 60 years. Dr Jason Roberts is analysing these data. The new ice-core PhD student (Ms Mana Inoue) will continue ice core analysis of the Mill Island core recovered in the last reporting period as part of her project 'Glaciochemical Study of Mill Island Ice Core Records'.

Together with ANSTO, further Beryllium analyses were done from ice cores recovered from Law Dome. PhD student Mr Joel Pedro is working closely with ANSTO on this project and has published two papers during this reporting period.

The December 2010-January 2011 ICECAP Basler flights were very successful, completing a total of 47,000km line surveys from Casey Station. The aerial sea ice work was completed from *Aurora Australis* during October to December 2010 using helicopter-based observations. Fixed-wing aircraft capability continues to be delayed due to operational uncertainties. In May 2011, the ACE CRC sea

ice team published *Deep Sea Research Part II: Topical Studies in Oceanography* volume (58, 9-10), 'Antarctic Sea Ice Research during the International Polar Year 2007-2009'. A total of 21 papers were published in this volume, of which 15 had ACE CRC authorship. The volume was edited by ACE CRC staff Dr Tony Worby, Dr Klaus Meiners and Dr Petra Heil.

Preparation for the Autonomous Underwater Vehicle (AUV) mission is progressing well, after delay in appointment of staff. The planned collaboration with Memorial University in Canada, which was to provide an AUV for the SIPEX-2 field campaign in 2012, ceased after two seasons of trial voyages aboard *Aurora Australis* (in 2009 and 2010). It became apparent that the large Explorer class vehicle would be difficult to operate from *Aurora Australis* given limited deck space and the acoustically noisy operating environment. The ACE CRC has commenced a new collaboration with Woods Hole Oceanographic Institution (WHOI) in the USA, which owns and operates a smaller AUV. The new vehicle has the advantage that it can be operated much closer to the under-side of the ice, but the disadvantage of having a shorter operating range.

The scientific focus of the AUV work has thus shifted to conducting higher-resolution swath mapping of ridge structures on a single floe, or an area up to 1km², rather that the longer transects originally proposed. However, the focus on a smaller area will increase the ability to match airborne and AUV data (from above and below the ice respectively) and thus provide a more comprehensive suite of complementary data for determining the ice and snow characteristics of the sea ice.

Dr Guy Williams attended a meeting at WHOI in April 2011 for discussions about the AUV for the 2012 experiment to collect critical sea ice mass data.

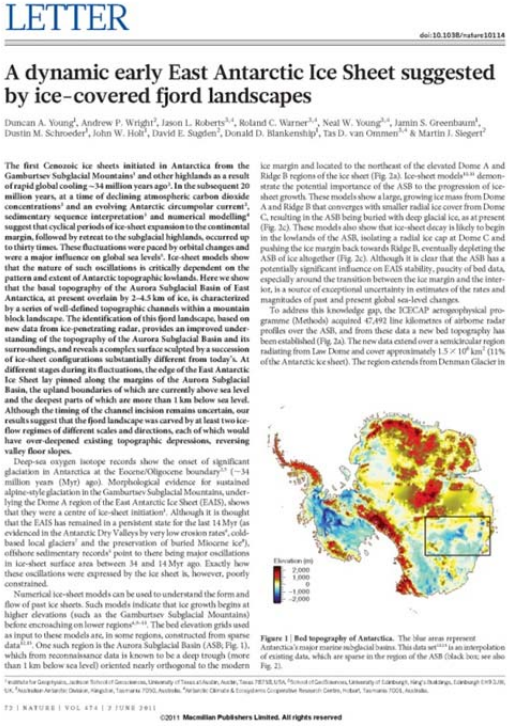
The ACE CRC's Cryosphere Program team published over 35 articles in scholarly refereed journals. They also published 2 books and 6 book sections.

New insights into the formation of the East Antarctic ice sheet

An international team including scientists from the ACE CRC and the Australian Antarctic Division has shed new light on what lies beneath a large slice of the East Antarctic ice sheet.

The research reveals a vast, smooth and deep bedrock basin, reaching more than a kilometre below sea level, bordered by rugged mountain ranges, which are cut by broad valleys. Interpreting this buried landscape has brought new insights into the early development of the Antarctic ice sheet.

The research was published in June 2011 in the journal *Nature*. This important scientific paper illuminates a 20-million-year period of repeated growth and retreat of the ice sheet following initial Antarctic glaciation around 34 million years ago. It shows a geological connection with past climate changes, helps us understand how climate and the ice sheet interact, and connects the ice with changes in past and perhaps future sea level.



LETTER

doi:10.1038/nature10114

A dynamic early East Antarctic Ice Sheet suggested by ice-covered fjord landscapes

Duncan A. Young[1], Andrew P. Wright[2], Jason L. Roberts[3,4], Roland C. Warner[3,4], Neal W. Young[3,4], Jamin S. Greenbaum[1], Dustin M. Schroeder[1], John W. Holt[1], David E. Sugden[5], Donald D. Blankenship[1], Tas D. van Ommen[3,4] & Martin J. Siegert[2]

The first Cenozoic ice sheets initiated in Antarctica from the Gamburtsev Subglacial Mountains[1] and other highlands as a result of rapid global cooling ~34 million years ago[2]. In the subsequent 20 million years, at a time of declining atmospheric carbon dioxide concentrations[3] and an evolving Antarctic circumpolar current[4], sedimentary sequence interpretation[5] and numerical modelling[6] suggest that cyclical periods of ice-sheet expansion to the continental margin, followed by retreat to the subglacial highlands, occurred up to thirty times. These fluctuations were paced by orbital changes and were a major influence on global sea levels[7]. Ice-sheet models show that the nature of such oscillations is critically dependent on the pattern and extent of Antarctic topographic lowlands. Here we show that the basal topography of the Aurora Subglacial Basin of East Antarctica, at present overlain by 2–4.5 km of ice, is characterized by a series of well-defined topographic channels within a mountain block landscape. The identification of this fjord landscape, based on new data from ice-penetrating radar, provides an improved understanding of the topography of the Aurora Subglacial Basin and its surroundings, and reveals a complex surface sculpted by a succession of ice-sheet configurations substantially different from today's. At different stages during its fluctuations, the edge of the East Antarctic Ice Sheet lay pinned along the margins of the Aurora Subglacial Basin, the upland boundaries of which are currently above sea level and the deepest parts of which are more than 1 km below sea level. Although the timing of the channel incision remains uncertain, our results suggest that the fjord landscape was carved by at least two ice-flow regimes of different scales and directions, each of which would have over-deepened existing topographic depressions, reversing valley floor slopes.

Deep-sea oxygen isotope records show the onset of significant glaciation in Antarctica at the Eocene/Oligocene boundary[2,3] (~34 million years (Myr) ago). Morphological evidence for sustained alpine-style glaciation in the Gamburtsev Subglacial Mountains, underlying the Dome A region of the East Antarctic Ice Sheet (EAIS), shows that they were a centre of ice-sheet initiation[1]. Although it is thought that the EAIS has remained in a persistent state for the last 14 Myr (as evidenced in the Antarctic Dry Valleys by very low erosion rates[8], cold-based local glaciers[9] and the preservation of buried Miocene ice[10]), offshore sedimentary records[4] point to there being major oscillations in ice-sheet surface area between 34 and 14 Myr ago. Exactly how these oscillations were expressed by the ice sheet is, however, poorly constrained.

Numerical ice-sheet models can be used to understand the form and flow of past ice sheets. Such models indicate that ice growth begins at higher elevations (such as the Gamburtsev Subglacial Mountains) before encroaching on lower regions[6,11]. The bed elevation grids used as input to these models are, in some regions, constructed from sparse data[12,13]. One such region is the Aurora Subglacial Basin (ASB, Fig. 1), which from reconnaissance data is known to be a deep trough (more than 1 km below sea level) oriented nearly orthogonal to the modern ice margin and located to the northeast of the elevated Dome A and Ridge B regions of the ice sheet (Fig. 2a). Ice-sheet models[11,14] demonstrate the potential importance of the ASB to the progression of ice-sheet growth. These models show a large, growing ice mass from Dome A and Ridge B that converges with smaller radial ice cover from Dome C, resulting in the ASB being buried with deep glacial ice, as at present (Fig. 2c). These models also show that ice-sheet decay is likely to begin in the lowlands of the ASB, isolating a radial ice cap at Dome C and pushing the ice margin back towards Ridge B, eventually depleting the ASB of ice altogether (Fig. 2c). Although it is clear that the ASB has a potentially significant influence on EAIS stability, paucity of bed data, especially around the transition between the ice margin and the interior, is a source of exceptional uncertainty in estimates of the rates and magnitudes of past and present global sea-level changes.

To address this knowledge gap, the ICECAP aerogeophysical programme (Methods) acquired 47,492 line kilometres of airborne radar profiles over the ASB, and from these data a new bed topography has been established (Fig. 2a). The new data extend over a semicircular region radiating from Law Dome and cover approximately 1.5 × 10⁶ km² (11% of the Antarctic ice sheet). The region extends from Denman Glacier in

Elevation (m)
2,000
1,000
0
−1,000
−2,000

Figure 1 | Bed topography of Antarctica. The blue areas represent Antarctica's major marine subglacial basins. This data set[14,15] is an interpolation of existing data, which are sparse in the region of the ASB (black box; see also Fig. 2).

[1]Institute for Geophysics, John A. Jones Building, University of Texas at Austin, 10100 Burnet Road, Austin, Texas 78758, USA, [2]School of GeoSciences, University of Edinburgh, Crew Building, King's Buildings, West Mains Road, Edinburgh EH9 3JW, UK, [3]Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia, [4]Antarctic Climate & Ecosystems Cooperative Research Centre, Private Bag 80, Hobart, Tasmania 7001, Australia.

©2011 Macmillan Publishers Limited. All rights reserved

The paper is focused on a key geological feature in East Antarctica, the Aurora Subglacial Basin (ASB). This extends more than 1,000 kilometres inland from Australia's Casey Station and is overlain by some of the thickest ice in Antarctica. While scientists knew of its existence from Australian ground survey work in the 1970s, this project, called ICECAP, has provided the first detailed understanding of the early development of the ice sheet that now fills the basin.

Accurate maps of regions like the ASB where the ice sheet rests on bedrock below sea level are important for computer models predicting ice sheet changes and future sea-level rise. The bedrock of this area had been poorly known until now.

The new research shows the full extent of the basin, bounded on the East and West by sharp mountain ranges. The mountains are cut through by very wide, deep, smooth fjords sculpted by ice. It is likely that these massive fjords were excavated by several episodes as the ice sheets advanced through the basin to the continental margins and retreated to the high central subglacial mountains of East Antarctica.

The paper, with authors from Australia, the United Kingdom and the United States of America, is the first major product from the ICECAP project – a collaboration that began in 2007. In the Antarctic field seasons of 2008-9 and 2009-10 scientists flew 47,000 kilometres of survey lines from Casey. The area surveyed corresponds to a semicircle centred on Sydney and stretching from Hobart, out beyond Broken Hill and up to Brisbane. High-resolution ice-penetrating radar was used to capture the rock surface under the ice sheet and layers within the ice up to 4.5km thick, providing insight into bedrock conditions and past ice flow.

ICECAP stands for *Investigating the Cryospheric Evolution of the Central Antarctic Plate*. The ACE CRC authors on the *Nature* paper are glaciologists Dr Jason Roberts, Dr Roland Warner, Dr Neal Young and Dr Tas van Ommen, all from the ACE CRC Cryosphere Program.

3. Carbon

The ACE CRC's Carbon Program is on target to achieve its research outputs. All new staff commenced in this reporting period. Dr Pier van der Merwe (Trace Element Marine Analytical Chemist) started on 2 August 2010 and Dr Elizabeth Shadwick (Carbon Post-doctoral researcher) started on 15 February 2011.

Compilation of information on the controls on Southern Ocean CO_2 uptake and resulting ocean acidification is well advanced, and a presentation on 'Carbon Uptake in Polar Continental Shelf Regions', will be given in September 2011 at the LOICZ (Land-Ocean Interactions in the Coastal Zone) Open Science Conference in China with the publication expected to be submitted in December 2011.

Additional observations of ocean carbon contents were achieved during the repeat of the SR3 transect aboard *Aurora Australis* research vessel in January 2011 and from multiple transits of *l'Astrolabe*, the French Antarctic resupply vessel.

The final papers were submitted in April 2011 to the editors for *Deep Sea Research Part II: Topical Studies in Oceanography* special issue on the SAZ Sense Process Study. A total of 21 papers will be published in this special issue in November 2011.

Carbon flux moorings were deployed on *Southern Surveyor* in September 2010 and were recovered in April 2011. The moorings determine seasonal controls on air-sea CO_2 exchange and carbon transport to the ocean interior.

In May 2011, an ACE CRC team led a joint Australian - New Zealand expedition in the Tasman Sea, to study the role of trace elements and isotopes as micronutrients and their importance for marine fertility in the open ocean around Australia, as part of a larger global effort under the GEOTRACES program. Results from a time-series biogeochemistry experiment at Casey Station, East Antarctica, showed that fast-ice has an iron fertilisation potential for over 400m^3 of iron-limited surface Southern Ocean seawater, per m^2 of fast ice.

Reflecting the overall expertise of the Carbon Program in examining the role of micro-nutrients in the control of carbon cycling in the Southern Ocean, program leader Prof Tom Trull was an invited plenary speaker on Ocean Fertilisation at the International Union of Geodesy and Geophysics (IUGG) Conference in Melbourne 28 June – 7 July 2011.

The ACE CRC's contribution to the Southern Ocean component of the global Surface Ocean Carbon Atlas (SOCAT) has been completed, with online publication of the atlas planned for September 2011. Development of regional estimates of carbon fluxes has commenced in the lead-up to the next IPCC AR5 assessment process, with participation in the **RE**gional **C**arbon **C**ycle **A**ssessment and **P**rocesses project (RECCAP – a component of the Global Carbon Project, www.globalcarbonproject.org).

Plans for the 2011-2012 reporting period include carrying out KEOPS-2 (**KE**rguelen : compared study of the **O**cean and the **P**lateau in **S**urface water). This project studies the effect of natural iron fertilisation of the ocean by the Kerguelen plateau on the biological pump of CO_2 and on the cycles of other chemical compounds relevant for climate. This research will be carried out on-board the

French research vessel *Marion Dufresne* during October and November 2011 and will include participation by two new PhD students (Mr Fabien Queroue and Mr Emmanuel Laurenceau).

The IMOS Southern Ocean Time Series Moorings was redeployed in August 2011 to complete a full year of automated observing of the seasonal controls on air-sea CO_2 exchange and carbon transport to the ocean interior. New PhD student (Mr Nick Roden) will undertake underway observations expanded to include microbial carbonate forming organisms in the open Southern Ocean (milestone 3.2.3) on-board *Aurora Australis* in January 2012. This will complete this milestone, which was delayed owing to withdrawal of a previous student from the project. Completion of associated analysis is expected in mid-2012.

The ACE CRC's Carbon Program team published 9 articles in scholarly refereed journals and has submitted several articles to the special issue in *Deep Sea Research Part II: Topical Studies in Oceanography* (as mentioned above). They also co-authored 1 book section and presented 2 papers at the OCEANS '10 IEEE Sydney Conference, which were published in refereed proceedings.

4. Ecosystems

The ACE CRC's Ecosystems Program is on target to achieve its research outputs.

The modelling group is well underway following late commencement of new staff in the reporting period. Dr Stuart Corney (Ecological Modeller) started on 1 January 2011. Dr Corney has collaborated with ROMS experts at the Old Dominion University in the USA from April 2011 to June 2011. Dr Jessica Melbourne-Thomas (Ecological Statistician/Modeller) commenced work on 21 March 2011. Dr Melbourne-Thomas is collaborating closely with scientists from the CSIRO Marine and Atmospheric Research on her 'Atlantis' model.

The compilation of data into a long term circum-Antarctic database of biomass associated with sea ice is progressing well. Travel to the USA and partners in Germany in March and May 2011 resulted in the collation of data sets on sea ice biological properties from 21 German, USA and Australian voyages (1983 – 2007). The data is being prepared for inclusion into the ASPeCt sea ice database held at the AAD. Quality control review and compilation into this database of data sets is now planned for completion by December 2011.

The SIPEX-2 voyage is scheduled for 2012/2013, which is a year later than envisaged when milestone 4.2.3 was written. Planning for this voyage has commenced. A hyperspectral sensor has been tested under East Antarctica and Weddell sea ice and contact with UK collaborators for the laser-based system has been established.

The Australia-Japan workshop 'Establishing a benchmark to assess climate change impact in the eastern Antarctic Marine System' was held during 21-24 February 2011 at the CCAMLR headquarters in Hobart. This workshop consolidated collaboration on marine ecosystems change in eastern Antarctica. The workshop also discussed publication of papers on the results arising from the project, to be published next year. This special issue is expected in the PLoS One Collection (an online journal published by Public Library of Science, http://www.plosone.org).

There has been substantial progress on risk assessments of climate change impacts on Antarctic marine ecosystems. The compilation of data and statistical analytical methods are ready for analysis next year.

During the reporting period, the Ecosystems Program contributed to the Working Group 2 of the IPCC Fifth Assessment Report (AR5). Their research on impacts of climate change in Polar Regions will contribute to chapter 28 of the report.

In the reporting period, the ACE CRC developed a *Report Card: Southern Ocean Acidification*. This was launched in April 2011. Dr Donna Roberts attended an Ocean Acidification Reference User Group conference in Monaco convened by Prince Albert II. This group launched a new guide called 'Ocean Acidification: Questions Answered' in which the ACE CRC is referenced.

The Department of Climate Change and Energy Efficiency (DCCEE) has contributed additional funds in 2011-2012 to enable research to compare the shell weights of pteropods collected south of the polar front (54°S) to those analysed and collected from waters north of the polar front (47°S).

The Ecosystems Program contributed papers to the special volume of *Deep Sea Research Part II: Topical Studies in Oceanography*, 'Antarctic Sea Ice Research during the International Polar Year 2007-2009', published in May 2011.

A second international workshop of the Southern Ocean Sentinel Program (Sentinel-2) will be held in May 2012 with the aim of summarising the state of knowledge on observed and potential climate change impacts on Southern Ocean marine biodiversity. A series of papers will be submitted on ecosystem changes and risk assessments in the next reporting period. Further planning and ROV development will be done for the SIPEX-2 research voyage. The ROV and associated instruments will undergo sea trials in March 2012.

The ACE CRC's Ecosystems Program team published over 17 articles in scholarly refereed journals and 7 articles and 1 book section are in press.

3.3 Utilisation and Commercialisation

The ACE CRC continues to seek innovative ways of communicating research outcomes to maximise uptake of ACE CRC science. The section below provides a summary of the major utilisation/commercialisation activities on a program level.

Oceans

ACE Position Analyses, which are summary publications updating the latest science, have proven to be an effective mechanism to transfer knowledge to encourage utilisation of research outputs. The *Southern Ocean Circulation and Climate Change* Position Analysis was progressed extensively during the reporting period and will be published in late 2011.

Oceans Program researchers, Dr Stephen Rintoul and Prof Nathan Bindoff are coordinating lead authors for the IPCC Fifth Assessment Report (AR5) process. Oceans Program research outputs form

important inputs into IPCC science chapters and also provide significant parameters for the global climate models, which provide projections of future climate.

The Oceans Program has important links to international scientific collaborations, such as the Southern Ocean Observing System (SOOS) and the Global Ocean Observing System (GOOS) (see page 41). Through these collaborations, the Oceans Program research outputs are utilised by the global scientific community.

The sea-level rise impacts component of the program is widely used by coastal planners and coastal infrastructure owners who are able to access estimates of the future likelihood of flooding due to sea-level rise via the ACE CRC sealevelrise.info webtool. The ACE CRC also collaborates with its commercial participants to provide consultancy services.

Cryosphere

The Cryosphere Program continued to map changes to the east Antarctic ice sheet. Results from the first two field seasons have already shown that the area may be more vulnerable in the long term to climate change than previously thought. Changes in the ice sheets have the potential to significantly affect global sea levels and this important information feeds into IPCC models used to project future sea-level rise.

Dr Ian Allison is a lead author of Working Group 1 of the IPCC Fifth Assessment Report (AR5). Cryosphere Program outputs form important inputs to the IPCC AR5 science chapters.

Carbon

The Carbon Program participated in the production of the *Report Card: Southern Ocean Acidification*. The *Report Card: Southern Ocean Acidification* clearly communicates recent developments in the potential impacts of ocean acidification on whole marine ecosystems.

An important component of the Carbon Program's research is assessing the likely impact of artificial fertilisation of the ocean with iron. The program provided draft assessment guidelines for the International Maritime Organisation Convention on the Prevention of Pollution by the Dumping of Wastes in the Ocean (London Convention).

Ecosystems

The Ecosystems Program produced the *Report Card: Southern Ocean Acidification*. As mentioned above, the Report Card clearly communicates recent developments in the potential impacts of ocean acidification on whole marine ecosystems. This Report Card received wide acclaim from the research and government communities, in particular for the accessibility of the information it contained.

During February 2011, the Ecosystems Program participated in the Australia-Japan workshop 'Establishing a benchmark to assess climate change impact in the eastern Antarctic Marine System' which was held at the CCAMLR Headquarters in Hobart. This workshop consolidated collaboration on marine ecosystems change in eastern Antarctica.

The Ecosystems Program also worked with the IPCC AR5 committee to ensure that the Antarctic region would be adequately included in the deliberations of Working Group 2. ACE CRC research on impacts of climate change on marine ecosystems in Antarctica will be included in chapter 28.

Planning has started for the next Southern Ocean Sentinel workshop, which will be held in May 2012.

3.4 Education and Training

Education

The Institute for Marine and Antarctic Studies (IMAS) at the University of Tasmania continues to support the education program.

ACE CRC and IMAS staff teach into undergraduate science degrees, and graduate diploma, honours, coursework masters, research masters and PhD programs. Students study a range of topics relevant to Antarctica and the Southern Ocean.

In the reporting period 8 PhD students commenced, 11 completed and 34 PhD students continued their studies on ACE CRC related research. Of the 11 completions, 2 are now employed at the ACE CRC, 1 found employment with CSIRO Division of Marine and Atmospheric Research (CMAR), 1 is employed by IMAS, 4 were successful in securing post-doctoral positions overseas, and 3 found employment in other areas. During the reporting period, 12 PhD students submitted their theses for examination. Of these, 5 students were successful in securing postdoctoral positions: 1 at ACE, 1 at AAD, 1 at UTAS, 1 interstate and 1 overseas.

During the reporting period, 1 Masters student completed and 2.5 EFTSL continued their studies. Four new Honours students commenced and 2 part-time Honours students continued their studies. A total of 5 Honours students graduated in the reporting period, of whom 2 enrolled in PhDs, 2 are now employed by UTAS, and 1 found work elsewhere.

These higher degree by research students were supervised by 21 University of Tasmania staff and 18 non-university staff members. A total of 20 current higher degree by research students are being supervised by staff from the AAD, 13 by staff of CSIRO and 10 by staff funded directly by the ACE CRC.

A total of 174 students were enrolled in undergraduate education courses during the reporting period, of whom 29 students were enrolled in a Bachelor of Antarctic Science.

Eleven students were enrolled in the Masters of Antarctic Science by coursework at the end of reporting period. The course is designed to produce expertly trained scientists with international experience and research skills in the area of Antarctic marine science.

New enrolments in Honours and Masters degrees are not strong, despite multiple projects available. The issue is the lack of students applying. The ACE CRC is working with IMAS and the CSIRO-UTAS QMS program to improve visibility of projects and enhance recruitment. However, Honours and Masters students are not as valuable to research outputs as PhD students, and the ACE CRC will continue its focus on PhD students.

In addition, ACE CRC provided travel support for conferences to 5 PhD candidates during the reporting period.

Training courses for end-users/professional development

During the reporting period, the ACE CRC hosted one forum, one symposium followed by workshops and a separate workshop attended by a total of 258 end-users. The events are outlined below.

The ACE CRC hosted the Australia-New Zealand Climate Forum 2010 (ANZCF2010) from 13 to 15 October 2010 in Hobart. The guiding theme for the forum was *Southern Hemisphere Climate: features – findings – futures*, with particular focus on the role of Antarctica and the Southern Ocean in the climate of Australia and New Zealand. This multi-organisational event was attended by 220 end-users.

The ACE CRC symposium was held from 18 to 20 August 2010. The 2010 Symposium commenced with an annual general meeting on 18 August. This was followed by a day of presentations and a poster session, which was attended by 29 end-users from AAD, CSIRO, IMOS, Pitt&Sherry, DPIPWE, DCCEE, Hydro Tasmania, ABARE, DPAC and WWF. Several workshops were held on 20 August and were well attended by end-users.

The ACE CRC also hosted the National Storm Tide Modelling Workshop in Melbourne on 27 July 2010, which was attended by 9 end-users from DCCEE, Geoscience Australia, CSIRO, CRC for Spatial Information, UWA, SEA Pty Ltd, GHD Pty Ltd and UTAS.

3.5 SME Engagement

There was active engagement with the four SME participants in the ACE CRC Program. Pitt&Sherry Managing Director, Mr John Pitt, holds an ACE Board position as the representative of the commercial and SME participants.

In conjunction with SMEs, Pitt&Sherry and SGS Economics and Planning, ACE participated in a number of tenders for climate change related consulting projects and completed a number of collaborative consulting projects for Government. These collaborations have assisted in knowledge sharing between the ACE CRC and the SMEs, and with governments.

Myriax, a SME Software Company, is collaborating closely with the Ecosystems Program to develop and utilise their 4D-visualisation software for the presentation of ecosystems modelling and risk assessment results.

The ACE CRC has interacted with other SMEs during the reporting period, particularly in the sea-level rise impacts component of the Oceans Program. The ACE sea-level rise impacts team has developed a web-based tool to assist in coastal planning and infrastructure maintenance. During the reporting period, an online vocational training course was implemented to assist in the use of the web tool. This has increased the accessibility of the web tool to a broader market, including SME environmental and engineering consulting firms. The ACE CRC continues to focus on interacting with SMEs through peak industry bodies such as the Association of Australian Ports and Marine Authorities, the Australian Local Government Association, Engineers Australia and the Planning

Institute of Australia. The primary topic of interest is the sea-level rise web tool. The ACE CRC will intensify its interaction in 2011-2012 as it will re-launch the web tool and upgrade its functionality.

3.6 Collaboration

Currently, the ACE CRC collaborates with 85 organisations. Of these, 30 are Australian, 2 New Zealanders, 7 Asian, 21 North American, 1 South American, and the remaining 24 are scattered throughout Europe.

Of the 30 domestic collaborations, 6 are industry/private sector, 8 Australian Government Institutions, 3 State Government Institutions, 10 Universities and 3 others.

Of the 55 international collaborations, 30 are Universities, 23 research institutions, 1 industry/private sector, and 1 other.

During the reporting period, the ACE CRC had 10 overseas visitors from 5 different countries, including 4 visitors from Participants.

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

A Demonstration of International Collaboration

ACE CRC's Oceans Program plays a major role in the Southern Ocean Observing System (SOOS) and the Global Ocean Observing System (GOOS).

SOOS observes the Southern Ocean because it provides the principal connection between the Earth's ocean basins and between the upper and lower layers of the global ocean circulation. Any changes in the Southern Ocean will therefore have global ramifications. The ACE CRC Oceans Program provides significant observations to SOOS using ships, satellites, floats and moorings. With these outputs, SOOS can present a draft plan for an integrated multi-disciplinary observing system for the Southern Ocean.

GOOS, on the other hand, is a permanent global system for observations, modelling and analysis of marine and ocean variables. The ACE CRC Oceans Program aids in the provision of sustained observations of the oceans to help identify observational gaps and to ultimately improve the efficiency and effectiveness of the GOOS. This international collaboration is important to get a better view of the global ocean system.

Through these international collaborations, the ACE CRC Oceans Program research outputs are utilised by the global scientific community to better detect and interpret future change.

An illustration of the components of the Global Observing System. Image courtesy of the Global Ocean Observing System (GOOS)

4 Other activities

ACE CRC continued to undertake a number of externally funded research and consultancy activities, primarily in the areas of fine-scale climate modelling and analysis (Climate Futures for Tasmania and NDRP) and sea-level rise impact assessments.

Climate Futures for Tasmania was an externally funded, collaborative research project that has generated improved climate change information for Tasmania over the 21st century. During the reporting period, there was an intense focus on the production of the final technical reports and end-user engagement activities. These reports have been distilled into a series of end-user documents. These are available from the Tasmanian Department of Premier and Cabinet website: www.climatechange.tas.gov.au. Apart from the five core component technical reports, the project held 14 workshops, 5 exhibitions at science conferences, 54 briefings to Australian, Tasmanian and Local Government, published 5 research papers with 14 research papers in preparation, and informed over 65 different stakeholders during its 230-plus meetings and briefings. In excess of 75 organisations are now using and presenting results based on Climate Futures for Tasmania project outputs without any further input from the project.

Natural Disaster Resilience Program (NDRP): The work already undertaken in the Climate Futures for Tasmania project will be extended to examine changes to severe weather events likely to cause significant damage (and cost) to Tasmania in the NDRP. 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 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), severe storms and flash flooding. Further work will examine changes in summer fuel loading in identified high-risk regions of Tasmania using established pasture models.

National Environmental Research Program (NERP): Project 3 – Climate Futures – is a project within the Landscapes and Policy (LAP) hub funded through the National Environmental Research Program (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.

ClimateAsyst®: The ACE CRC has a commercial agreement with SME consulting firm Pitt&Sherry in relation to the development and commercialisation of ClimateAsyst®. The project received funding from the Tasmanian and Local governments. ClimateAsyst® is a software tool that assists infrastructure asset owners to understand the potential impacts of climate change on their infrastructure. ClimateAsyst® outputs help end-users to determine whether current design codes for planned infrastructure will be adequate. ClimateAsyst® has been promoted within Tasmania, mainly in local councils and the Tasmanian State Government, with a view to marketing it nationally and internationally.

Tasmanian Planning Commission SLR Project: This project is a collaborative project with UTAS. It combines GIS mapping, storm-tide modelling and sea-level rise probability of flooding data. It will be

able to determine and map the probability of flooding from the sea for all parts of the Tasmanian coastline where there is LiDAR (Light Detecting and Ranging equipment) data.

QANTAS/Great Barrier Reef Foundation partnership: This project tracks changes in seal movements in the Southern Ocean to see if they are altering their movements due to changes in the ocean currents. The project also helps to track oceanic changes, which can be used to research climate change.

AECOM first pass sea-level rise risk assessment for Department of Defence: AECOM environmental and engineering consulting firm was contracted by the Department of Defence to do a first-pass risk assessment of sea-level rise for key defence sites around Australia. AECOM engaged the ACE CRC to complete a scientific technical review of the sea-level rise science components of their report. The ACE CRC provided a technical consulting report, which commented on sea-level rise aspects of the AECOM draft report.

Effluent Dispersal from Davis Station: This consultancy, completed by ACE CRC researchers Dr John Hunter and Dr Ben Galton-Fenzi for the Australian Antarctic Division, describes a brief investigation of the impacts of the effluent outfall at Davis Station, East Antarctica. The two elements were an analysis of the mean and variability of the longshore component of the current, using observations from four current meters; and simple modelling of the effluent outfall, using a model originally developed for shoreline discharges from the oil industry.

Australian Mapping of Antarctica: This project for the Australian Antarctic Division scoped out possibilities for a book on the topic of Australian Mapping of Antarctica.

5 Glossary of Terms

Abbreviation	Organisation Name
A	
ABARE	Australian Bureau of Agricultural and Resource Economics
AAD	Australian Antarctic Division
ABW	Antarctic Bottom Water
ACC	Antarctic Circumpolar Current
ACCESS	Australian Computational Earth Systems Simulator
ACE CRC	Antarctic Climate & Ecosystems Cooperative Research Centre
ANSTO	Australian Nuclear Science and Technology Organisation
ANZCF2010	Australia-New Zealand Climate Forum 2010
ASB	Aurora Subglacial Basin
ASPeCt	Antarctic Sea Ice Processes & Climate
AUV	Autonomous Underwater Vehicle
AVCAL	Australian Private Equity & Venture Capital Association Ltd
AWI	Alfred Wegener Institute for Polar Research (Germany)
B	
BoM	Bureau of Meteorology
C	
CAMS	Chinese Academy of Meteorological Science (China)
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CLIVAR	Climate Variability and Predictability Program
CMAR	CSIRO Marine & Atmospheric Research
CO_2	Carbon Dioxide
COAG	Council of Australian Governments
CPOM	Centre for Polar Oceanography and Modelling (United Kingdom)
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTD	Conductivity, Temperature and Depth
D	
DAFF	Department of Agriculture, Fisheries and Forestry
DCCEE	Department of Climate Change and Energy Efficiency
DIISR	Department of Innovation, Industry, Science & Research
DPAC	Tasmanian Department of Premier & Cabinet
DPIPWE	Tasmanian Department of Primary Industries, Parks, Water and Environment
E	
EPOC	Ecosystem Productivity Ocean Climate
F	
FIO	First Institute of Oceanography (China)
G	
GDP	Gross Domestic Product
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	International Climate and Environmental Change Assessment Project
ILTS	Institute of Low Temperature Science, Hokkaido University (Japan)
IMAS	Institute of Marine and Antarctic Studies, University of Tasmania
IMOS	Integrated Marine Observing System
IOCCP	International Ocean Carbon Coordination Project
IP	Intellectual Property
IPCC AR5	Intergovernmental Panel on Climate Change Fifth Assessment Report
IT	Impact Tool
IUGG	International Union of Geodesy and Geophysics
K	
KEOPS	Kerguelen compared study of Ocean and Plateau in Surface waters
L	
LAP	Landscapes and Policy
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (France)
LiDAR	Light Detecting and Ranging equipment
LOICZ	Land-Ocean Interactions in the Coastal Zone
M	
MUN	Memorial University (Canada)
N	
NASA	National Aeronautics and Space Administration (USA)
NDRP	Natural Disaster Resilience Program
NERP	National Environmental Research Program
NGO	Non-Government Organisation
NIPR	National Institute of Polar Research (Japan)
NIWA	National Institute for Water and Atmospheric Research (New Zealand)
Q	
QMS	Quantitative Marine Science Program
R	
RECCAP	Regional Carbon Cycle Assessment and Processes
ROMS	Regional Ocean Modeling System
ROV	Remotely Operated Vehicle
S	
SAZ	Sub-Antarctic Zone
SAZ-SENSE	Sensitivity of Sub-Antarctic Zone waters project
SCAR	Scientific Committee on Antarctic Research
SEWPAC	Department of Sustainability, Environment, Water, Population and Communities
SIPEX	Sea-ice Physics & Ecosystem Experiment
SLR	Sea-Level Rise
SME	Small and Medium Enterprises
SOCAT	Surface Ocean Carbon Atlas
SOOS IPO	Southern Ocean Observing System International Project Office
T	
TPAC	Tasmanian Partnership for Advanced Computing

U	
UNSW	University of New South Wales
USA	United States of America
UTAS	University of Tasmania
UWA	University of Western Australia
W	
WHOI	Woods Hole Oceanographic Institute (USA)
WWF	World Wildlife Fund

Appendix 1– list of publications

Books – Authorised Research (unweighted)

Allison, I., Bindoff, N.L., Bindschadler, R.A., Cox, P.M., de Noblet, N., England, M.H., Francis, J.E., Gruber, N., Haywood, A.M., Karoly, D.J., Kaser, G., Le Quéré, C., Lenton, T.M., Mann, M.E., McNeil, B.I., Pitman, A.J., Rahmstorf, S., Rignot, E., Schellnhuber, H.J., Schneider, S.H., Sherwood, S.C., Somerville, R.C.J., Steffen, K., Steig, E.J., Visbeck, M. and Weaver, A.J. (2011). The Copenhagen Diagnosis: Updating the World on the Latest Climate Science. Oxford, Elsevier.

Gifford, R.M., Steffen, W., Finnigan, J.J., Lynch, A., van Ommen, T., Karoly, D., Manton, M., Mapstone, B., McDougall, T., Pitman, A., Smith, N. and Wijffels, S. (2010). To live within Earth's limits: An Australian plan to develop a science of the whole earth system. Canberra, Australia, Australian Academy of Science.

Krupnik, I., Allison, I., Bell, R., Cutler, P., Hik, D., López-Martínez, J., Rachold, V., Sarukhanian, E. and Summerhayes, C. (2011). Understanding Earth's polar challenges: International Polar Year 2007-2008. Edmonton, Alberta, Canadian Circumpolar Institute and the University of the Arctic.

Book Chapters

Allison, I. (2011). International Polar Year 2007-2008. Encyclopedia of Snow, Ice and Glaciers, Encyclopedia of Earth Sciences Series. Singh, V.P., Singh. P. and Haritashya, U.K. (eds). Netherlands, Springer**:** 647-648.

Allison, I. (2011). Papua. Encyclopedia of Snow, Ice and Glaciers, Encyclopedia of Earth Sciences Series. Singh, V.P., Singh. P. and Haritashya, U.K. (eds). Netherlands, Springer**:** 815-816.

Allison, I., Ananicheva, M., Burgess, D., Gogineni, P., Hagen, J.-O., Rachold, V., Sharp, M. and Thing, H. (2011). Chapter 2.4: Greenland Ice Sheet and Arctic Glaciers. Understanding Earth's polar challenges: International Polar Year 2007-2008. Krupnik, I. et al (eds). Edmonton, Alberta, Canadian Circumpolar Institute and the University of the Arctic**:** 215-232.

Allison, I., Carlson, D., Ellis-Evans, C. and Munro, N. (2011). Chapter 1.6: The IPY International Programme Office (IPO), 2005-2010. Understanding Earth's polar challenges: International Polar Year 2007-2008. Krupnik, I. et al (eds). Edmonton, Alberta, Canadian Circumpolar Institute and the University of the Arctic**:** 115-126.

Allison, I., Krupnik, I., Cutler, P., Danell, K., Ellis-Evans, C., López-Martinez, J., Munro, N., Sarukhanian, E. and Summerhayes, C. (2011). Chapter 1.5: Organization and implementation of IPY, 2005–2009. Understanding Earth's polar challenges: International Polar Year 2007-2008. Krupnik, I. et al (eds). Edmonton, Alberta, Canadian Circumpolar Institute and the University of the Arctic**:** 87-114.

Bell, R., Allison, I., Alverson, K., Danell, K., Fahrbach, E., Krupnik, I., López-Martínez, J., Sarukhanian, E. and Summerhayes, C. (2011). Chapter 5.1: Early Science Outcomes of IPY 2007-2008. Understanding Earth's polar challenges: International Polar Year 2007-2008. Krupnik, I. et al (eds). Edmonton, Alberta, Canadian Circumpolar Institute and the University of the Arctic**:** 529-544.

Lowe, J.A., Woodworth, P.L., Knutson, T., McDonald, R.E., McInnes, K.L., Woth, K., von Storch, H., Wolf, J., Swail, V., Bernier, N.B., Gulev, S., Horsburgh, K.J., Unnikrishnan, A.S., Hunter, J.R. and Weisse, R. (2010). Past and Future Changes in Extreme Sea Levels and Waves. Understanding Sea-Level Rise and Variability, Wiley-Blackwell**:** 326-375.

Orheim, O., Press, A. and Gilbert , N. (2011). Managing the Antarctic environment – the evolving role of the Committee for Environmental Protection. Science diplomacy: Antarctica, science, and the governance of international spaces. Berkman, P.A., Lang, M.A., Walton, D.W.H. and Young, O.R. (eds). Washington, DC, Smithsonian Institution Scholarly Press**:** 209 -221.

Rintoul, S., Fahrbach, E., Abele, D., Ackley, S., Allison, I., Bowie, A., Brandt, A., Brussaard, C., Cavanagh, R., Danis, B., De Baar, H., De Broyer, C., Evans, C., Heywood, K., Hofmann, E., Hoppema, M., Iversen, S., Johnston, N., Klepikov, A., Murphy, E., Segers, H., Strass, V., Summerhayes, C., Tancell, C., Wadley, V., Woodworth, P. and Worby, A.P. (2011). Chapter 2.3: Southern Ocean. Understanding Earth's polar challenges: International Polar Year 2007-2008. Krupnik, I. et al (eds). Edmonton, Alberta, Canadian Circumpolar Institute and the University of the Arctic**:** 187-214.

Rintoul, S.R. and Fahrbach, E. (2010). The Southern Ocean Observing System. Understanding Earth's polar challenges: International Polar Year 2007-2008. Sarukhanian, E. and Summerhayes, C. (eds). Smithsonian Institution, USA**:** 385-390.

Articles in Scholarly Refereed Journals

Bengtson Nash, S.R., Rintoul, S., Kawaguchi, S., Staniland, I., Van den Hoff, J., Tierney, M. and Bossi, R. (2010). "Perfluorinated compounds in the Antarctic region: Ocean circulation provides prolonged protection from distant sources." Environmental Pollution **158** (9): 2985-2991.

Bowie, A.R., Townsend, A.T., Lannuzel, D., Remenyi, T.A. and van der Merwe, P. (2010). "Modern sampling and analytical methods for the determination of trace elements in marine particulate material using magnetic sector inductively coupled plasma-mass spectrometry." Analytica Chimica Acta **676** (1-2): 15-27. *(reported as accepted/in press in previous annual report, now published)*

Brown, M., Kawaguchi, S., King, R., Virtue, P. and Nicol, S. (2011). "Flexible adaptation of the seasonal krill maturity cycle in the laboratory." Journal of Plankton Research **33** (5): 821-826.

Burn-Nunes, L.J., Vallelonga, P., Loss, R.D., Burton, G.R., Moy, A., Curran, M., Hong, S., Smith, A.M., Edwards, R., Morgan, V.I. and Rosman, K.J.R. (2011). "Seasonal variability in the input of lead, barium and indium to Law Dome, Antarctica." Geochimica et Cosmochimica Acta **75** (1): 1-20.

Cassar, N., Difiore, P.J., Barnett, B.A., Bender, M.L., Bowie, A.R., Tilbrook, B., Petrou, K., Westwood, K.J., Wright, S.W. and Lefevre, D. (2011). "The influence of iron and light on net community production in the Subantarctic and Polar Frontal Zones." Biogeosciences **8** (2): 227-237. *(reported as accepted/in press in previous annual report, now published)*

Constable, A.J. (2011). "Lessons from CCAMLR on the implementation of the ecosystem approach to managing fisheries." Fish and Fisheries **12** (2): 138-151.

Cook, S.S., Whittock, L., Wright, S.W. and Hallegraeff, G.M. (2011). "Photosynthtic Pigment and Genetic Differences between two Southern Ocean Morphotypes of Emiliania Huxleyi (Haptophyta) 1." Journal of Phycology **47** (3): 615-626. *(reported as accepted/in press in previous annual report, now published)*

DeLiberty, T.L., Geiger, C.A., Ackley, S.F., Worby, A.P. and Van Woert, M.L. (2011). "Estimating the annual cycle of sea-ice thickness and volume in the Ross Sea." Deep-Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1250-1260. *(reported as accepted/in press in previous annual report, now published)*

Difiore, P.J., Sigman, D.M., Karsh, K.L., Trull, T.W., Dunbar, R.B. and Robinson, R.S. (2010). "Poleward decrease in the isotope effect of nitrate assimilation across the Southern Ocean." Geophysical Research Letters **37** (L17601).

Downes, S.M., Bindoff, N.L. and Rintoul, S.R. (2010). "Changes in the subduction of Southern Ocean water masses at the end of the twenty-first century in eight IPCC models." Journal of Climate **23** (24): 6526-6541.

Durack, P.J., Wijffels, S. and Bindoff, N.L. (2011). "[Global Oceans] Oceans salinity: a water cycle diagnostic?" In: Blunden, J., D. S. Arndt, and M. O. Baringer (eds), State of The Climate in 2010. Bulletin of the American Meteorological Society **92** (6): S91-S93.

Fischer, U.H., Mair, D., Kavanaugh, J.L., Willis, I., Nienow, P. and Hubbard, B. (2011). "Modelling ice-bed coupling during a glacier speed-up event: Haut Glacier d'Arolla, Switzerland." Hydrological Processes **25** (9): 1361-1372.

Fraser, A.D., Massom, R.A. and Michael, K.J. (2010). "Generation of high-resolution East Antarctic landfast sea-ice maps from cloud-free MODIS satellite composite imagery." Remote Sensing of Environment **114** (12): 2888-2896.

Gaebler-Schwarz, S., Davidson, A.T., Assmy, P., Chem, J., Henjes, J., Noethig, E., Lunau, M. and Medlin, L.A. (2010). "A new cell stage in the haploid-diploid life cycle of the colony-forming haptophyte Phaeocystis antarctica and its ecological implications." Journal of Phycology **46** (5): 1006-1016. *(reported as accepted/in press in previous annual report, now published)*

Giles, A.B., Massom, R.A., Heil, P. and Hyland, G. (2011). "Semi-automated feature-tracking of East Antarctic sea ice from Envisat ASAE imagery." Remote Sensing of Environment **115** (9): 2267-2276.

Heil, P., Massom, R.A., Allison, I. and Worby, A.P. (2011). "Physical attributes of sea-ice kinematics during spring 2007 off East Antarctica." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1158-1171.

Helm, K.P., Bindoff, N.L. and Church, J.A. (2010). "Changes in the global hydrological-cycle inferred from ocean salinity." Geophysical Research Letters **37** (L18701).

Hemer, M.A., Church, J.A. and Hunter, J.R. (2010). "Variability and trends in the directional wave climate of the Southern Hemisphere." International Journal of Climatology **30** (4): 475-491.

Herraiz-Borreguero, L., Mottram, R. and Cvijanovic, I. (2010). "Discussing progress in understanding ice sheet-ocean interactions." Eos: Transactions, American Geophysical Union **91** (45): 419.

Herraiz-Borreguero, L. and Rintoul, S.R. (2010). "Subantarctic mode water variability influenced by mesoscale eddies south of Tasmania." Journal of Geophysical Research: Oceans **115** (C4): C04004.

Herraiz-Borreguero, L. and Rintoul, S.R. (2011). "Subantarctic mode water: Distribution and circulation." Ocean Dynamics **61** (1): 103-126.

Hill, K.L., Rintoul, S.R., Oke, P.R. and Ridgway, K. (2010). "Rapid response of the East Australian Current to remote wind forcing: The role of barotropic-baroclinic interactions." Journal of Marine Research **68** (3-4): 413-431.

Hill, K.L., Rintoul, S.R., Ridgway, K.R. and Oke, P.R. (2011). "Decadal changes in the South Pacific western boundary current system revealed in observations and ocean state estimates." Journal of Geophysical Research: Oceans **116** (C01009).

Holbrook, N.J., Goodwin, I.D., McGregor, S., Molina, E. and Power, S.B. (2011). "ENSO to multi-decadal time scale changes in East Australian Current transports and Fort Denison sea level: Oceanic Rossby waves as the connecting mechanism." Deep Sea Research Part II: Topical Studies in Oceanography **58** (5): 547-558.

Johnson, C.R., Banks, S.C., Barrett, N.S., Cazassus, F., Dunstan, P.K., Edgar, G.J., Frusher, S.D., Gardner, C., Haddon, M., Helidoniotis, F., Hill, K.L., Holbrook, N.J., Hosie, G.W., Last, P.R., Ling, S.D., Melbourne-Thomas, J., Miller, K., Pecl, G.T., Richardson, A.J., Ridgway, K.R., Rintoul, S.R., Ritz, D.A., Ross, D.J., Sanderson, J.C., Shepherd, S.A., Slotwinski, A., Swadling, K.M. and Taw, N. (2011). "Climate change cascades: Shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania." Journal of Experimental Marine Biology and Ecology **400** (1-2): 17-32.

Jouandet, M.-P., Trull, T.W., Guidi, G., Picheral, M., Ebersbach, F., Stemmann, L. and Blain, S. (2011). "Optical imaging of mesopelagic particles indicates deep carbon flux beneath a natural iron-fertilized bloom in the Southern Ocean." Limnology and Oceanography **56** (3): 1130-1140.

Kawaguchi, S., Kurihara, H., King, R., Hale, L., Berli, T., Robinson, J.P., Ishida, A., Wakita, M., Virtue, P., Nicol, S. and Ishimatsu, A. (2011). "Will krill fare well under Southern Ocean acidification?" Biology Letters **7** (2): 288-291.

Koubbi, P., Ozouf-Costaz, C., Goarant, A., Moteki, M., Hulley, P.A., Causse, R., Dettai, A., Duhamel, G., Pruvost, P., Tavernier, E., Post, A.L., Beaman, R.J., Rintoul, S.R., Hirawake, T., Hirano, D., Ishimaru, T., Riddle, M. and Hosie, G. (2010). "Estimating the biodiversity of the East Antarctic shelf and oceanic zone for ecoregionalisation: Example of the ichthyofauna of the

CEAMARC (Collaborative East Antarctic Marine Census) CAML surveys." Polar Science **4** (2): 115-133. *(reported as accepted/in press in previous annual report, now published)*

Kramer, M., Swadling, K.M., Meiners, K.M., Kiko, R., Scheltz, A., Nicolaus, M. and Werner, I. (2011). "Antarctic sympagic meiofauna in winter: Comparing diversity, abundance and biomass between perennially and seasonally ice-covered regions." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1062-1074. *(reported as accepted/in press in previous annual report, now published)*

Kruetzmann, N.C., Rack, W., McDonald, A.J. and George, S.E. (2011). "Snow accumulation and compaction derived from GPR data near Ross Island, Antarctica." The Cryosphere **5** (2): 391-404.

Kusahara, K., Hasumi, H. and Tamura, T. (2010). "Modeling sea ice production and dense shelf water formation in coastal polynyas around East Antarctica." Journal of Geophysical Research C: Oceans **115** (10).

Lacarra, M., Houssais, M.N., Sultan, E., Rintoul, S.R. and Herbaut, C. (2011). "Summer hydrography on the shelf off Terre Adélie/George V Land based on the ALBION and CEAMARC observations during the IPY." Polar Science **5** (2): 88-103.

Lambeck, K., Antonioli, F., Anzidei, M., Ferranti, L., Leoni, G., Scicchitano, G. and Silenzi, S. (2011). "Sea level change along the Italian coast during the Holocene and projections for the future." Quaternary International **232** (1-2): 250-257.

Lannuzel, D., Bowie, A.R., van der Merwe, P.C., Townsend, A.T. and Schoemann, V. (2011). "Distribution of dissolved and particulate metals in Antarctic sea ice." Marine Chemistry **124** (1-4): 134-146.

Leane, E. and Nicol, S. (2010). "Charismatic krill? Size and conservation in the ocean." Anthrozoos **24** (2): 135-146.

Mahowald, N.M., Kloster, S., Engelstaedter, S., Moore, J.K., Mukhopadhyay, S., McConnell, J.R., Albani, S., Doney, S.C., Bhattacharya, A., Curran, M.A.J., Flanner, M.G., Hoffman, F.M., Lawrence, D.M., Lindsay, K., Mayewski, P.A., Neff, J., Rothenberg, D., Thomas, E., Thornton, P.E. and Zender, C.S. (2010). "Observed 20th century desert dust variability: Impact on climate and biogeochemistry." Atmospheric Chemistry and Physics **10** (22): 10875-10893.

Markus, T., Massom, R.A., Worby, A.P., Lytle, V., Kutz, N. and Maksym, T. (2010). "Freeboard, snow depth and sea ice roughness in East Antarctica from in situ and multiple satellite data." Annals of Glaciology **52** (57): 242-248(247). *(reported as accepted/in press in previous annual report, now published)*

Massom, R.A., Giles, A.B., Fricker, H.A., Warner, R.C., Legresy, B., Hyland, G., Young, N. and Fraser, A.D. (2010). "Examining the interaction between multi-year landfast sea ice and the Mertz Glacier Tongue, East Antarctica: Another factor in ice sheet stability?" Journal of Geophysical Research: Oceans **115** (C12027).

Massom, R.A., Reid, P., Stammerjohn, S.E. and Barreira, S. (2010). "[Antarctica] Sea ice extent and concentration". In: Arndt, D. S., M. O. Baringer, M. R. Johnson (eds), State of The Climate in 2009. Bulletin of the American Meteorological Society **91** (7): S131-S133.

Massom, R.A. and Stammerjohn, S.E. (2010). "Antarctic sea ice change and variability - Physical and ecological implications." Polar Science **4** (2): 149-186.

McDougall, T.J. and Klocker, A. (2010). "An approximate geostrophic streamfunction for use in density surfaces." Ocean Modelling **32** (3-4): 105-117.

Meijers, A.J.S., Bindoff, N.L. and Rintoul, S.R. (2011). "Estimating the Four-dimensional structure of the Southern Ocean using satellite altimetry." Journal of Atmospheric and Oceanic Technology **28**: 548–568.

Meiners, K.M., Norman, L., Granskog, M.A., Krell, A., Heil, P. and Thomas, D.N. (2011). "Physico-ecobiogeochemistry of East Antarctic pack ice during the winter-spring transition." Deep-Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1172-1181. *(reported as accepted/in press in previous annual report, now published)*

Norman, L., Thomas, D.N., Stedmon, C.A., Granskog, M.A., Papadimitriou, S., Krapp, R.H., Meiners, K.M., Lannuzel, D., van der Merwe, P. and Dieckmann, G.S. (2011). "The characteristics of dissolved organic matter (DOM) and chromophoric dissolved organic matter (CDOM) in Antarctic sea ice." Deep-Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1075-1091. *(reported as accepted/in press in previous annual report, now published)*

O'Brien, C., Virtue, P., Kawaguchi, S. and Nichols, P.D. (2011). "Aspects of krill growth and condition during late winter-early spring off East Antarctica (110-130°E)." Deep-Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1211-1221.

Osterblom, H., Sumaila, U.R., Bodin, O., Hentati Sundberg, J. and Press, A.J. (2010). "Adapting to Regional Enforcement: Fishing Down the Governance Index." PLoS ONE **5** (9: e12832).

Ozsoy-Cicek, B., Ackley, S.F., Worby, A.P, Xie, H. and Lieser, J.L. (2011). "Antarctic sea-ice extents and concentrations: comparison of satellite and ship measurements from International Polar Year cruises." Annals of Glaciology **52** (57): 318-326(319).

Pedro, J.B., Smith, A.M., Simon, K.J., Van Ommen, T.D. and Curran, M.A.J. (2011). "High-resolution records of the beryllium-10 solar activity proxy in ice from Law Dome, East Antarctica: Measurement, reproducibility and principal trends." Climate of the Past Discussions **7** (1): 677-713.

Pedro, J.B., Van Ommen, T.D., Rasmussen, S.O., Morgan, V.I., Chappellaz, J., Moy, A.D., Masson-Delmotte, V. and Delmotte, M. (2011). "The last deglaciation: Timing the bipolar seesaw." Climate of the Past Discussions **7** (1): 397-430.

Peloquin, J., Hall, J., Safi, K., Smith, W.O., Wright, S. and van den Enden, R. (2011). "The response of phytoplankton to iron enrichment in Sub-Antarctic HNLCLSi waters: Results from the SAGE experiment." Deep-Sea Research Part II: Topical Studies in Oceanography **58** (6): 808-823.

Petronio, L., Lipizer, M., Santis, L.D., Rintoul, S. and Wardell, N. (2010). "Offshore seismic reflection data: an oceanographic perspective." Bolletino di Geofisica Teorica ed Applicata **51** (2-3): 89-98.

Petrou, K., Hill, R., Doblin, M.A., McMinn, A., Johnson, R., Wright, S.W. and Ralph, P.J. (2011). "Photoprotection of sea-ice microalgal communities from the east antarctic pack ice." Journal of Phycology **47** (1): 77-86. *(reported as accepted/in press in previous annual report, now published)*

Phipps, S.J., Rotstayn, L.D., Gordon, H.B., Roberts, J.L., Hirst, A.C. and Budd, W.F. (2011). "The CSIRO Mk3L climate system model version 1.0 – Part 1: Description and evaluation." Geosci. Model Dev. **4** (2): 483-509.

Raymond, B., Marshall, M., Nevitt, G., Gillies, C., Van Den Hoff, J., Stark, J., Losekoot, M., Woehler, E.J. and Constable, A.J. (2011). "A Southern Ocean dietary database." Ecology **92** (5): 1188.

Roberts, D., Howard, W., Moy, A., Roberts, J., Trull, T., Bray, S. and Hopcroft, R. (2011). "Interannual pteropod variability in sediment traps deployed above and below the aragonite saturation horizon in the Sub-Antarctic Southern Ocean." Polar Biology (online): 1-12.

Sampson, C., Golden, K., Gully, A. and Worby, A.P. (2010). "Surface impedence tomography for Antarctic sea ice." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1149-1157. *(reported as accepted/in press in previous annual report, now published)*

Stammerjohn, S.E., Maksym, T., Heil, P., Massom, R.A., Vancoppenolle, M. and Leonard, K.C. (2011). "The influence of winds, sea surface temperature and precipitation anomalies on Antarctic regional sea ice conditions during IPY 2007." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 999-1018. *(reported as accepted/in press in previous annual report, now published)*

Stevens, R.P. and Heil, P. (2011). "The interplay of dynamic and thermodynamic processes in driving the ice-edge location in the Southern Ocean." Annals of Glaciology **52** (57): 27-34(28). *(reported as accepted/in press in previous annual report, now published)*

Tamura, T., Ohshima, K.I., Nihashi, S. and Hasumi, H. (2011). "Estimation of surface heat/salt fluxes associated with sea ice growth/ melt in the Southern Ocean." Scientific Online Letter on the

Atmosphere **7**: 17-20.
Timmermann, R., Le Brocq, A., Deen, T., Domack, E., Dutrieux, P., Galton-Fenzi, B., Hellmer, H., Humbert, A., Jansen, D., Jenkins, A., Lambrecht, A., Makinson, K., Niederjasper, F., Nitsche, F., Nøst, O.A., Smedsrud, L.H. and Smith, W.H.F. (2010). "A consistent dataset of Antarctic ice sheet topography, cavity geometry, and global bathymetry." Earth Syst. Sci. Data Discuss. **3** (2): 231-257.
Toyota, T., Haas, C. and Tamura, T. (2011). "Size distribution and shape properties of relatively small sea-ice floes in the Antarctic marginal ice zone in late winter." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1182-1193.
Toyota, T., Massom, R., Tateyama, K., Tamura, T. and Fraser, A. (2011). "Properties of snow overlying the sea ice off East Antarctica in late winter, 2007." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1137-1148.
Treverrow, A., Warner, R.C., Budd, W.F. and Craven, M. (2011). "Meteoric and marine ice crystal orientation fabrics from the Amery Ice Shelf, East Antarctica." Journal of Glaciology **56** (199): 877-890.
van der Merwe, P., Lannuzel, D., Bowie, A.R., Mancuso Nichols, C.A. and Meiners, K.M. (2011). "Iron fractionation in pack and fast ice in East Antarctica: Temporal decoupling between the release of dissolved and particulate iron during spring melt." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1222-1236. *(reported as accepted/in press in previous annual report, now published)*
Vancoppenolle, M., Timmermann, R., Ackley, S.F., Fichefet, T., Goosse, H., Heil, P., Lieser, J., Leonard, K.C., Nicolaus, M., Papakyriakou, T., and Tison, J.-L. (2011). "Assessment of radiation forcing data sets for large-scale sea ice models in the Southern Ocean." Deep-Sea Research II **58** (9-10): 1237-1249. *(reported as accepted/in press in previous annual report, now published)*
Verleyen, E., Hodgson, D.A., Sabbe, K., Cremer, H., Emslie, S.D., Gibson, J., Hall, B., Imura, S., Kudoh, S., Marshall, G.J., McMinn, A., Melles, M., Newman, L., Roberts, D., Roberts, S.J., Singh, S.M., Sterken, M., Tavernier, I., Verkulich, S., de Vyver, E.V., Van Nieuwenhuyze, W., Wagner, B. and Vyverman, W. (2011). "Post-glacial regional climate variability along the East Antarctic coastal margin-Evidence from shallow marine and coastal terrestrial records." Earth-Science Reviews **104** (4): 199-212.
Watson, C., Burgette, R., Tregoning, P., White, N., Hunter, J., Coleman, R., Handsworth, R. and Brolsma, H. (2010). "Twentieth century constraints on sea level change and earthquake deformation at Macquarie Island." Geophysical Journal International **182** (2): 781-796.
Williams, G.D., Hindell, M., Houssais, M.-N., Tamura, T. and Field, I.C. (2011). "Upper ocean stratification and sea ice growth rates during the summer-fall transition, as revealed by Elephant seal foraging in the Adelie Depression, East Antarctica." Ocean Science **7** (2:Special Issue: Synoptic Antarctic Shelf-Slope Interactions): 185-202.
Williams, G.D., Meijers, A.J.S., Poole, A., Mathiot, P., Tamura, T. and Klocker, A. (2011). "Late winter oceanography off the Sabrina and BANZARE coast (117-128°E), East Antarctica." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1194-1210.
Worby, A.P., Meiners, K.M. and Ackley, S.F. (2011). "Antarctic sea-ice zone research during the International Polar Year, 2007-2009." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 993-998.
Worby, A.P., Steer, A., Lieser, J.L., Heil, P., Yi, D., Markus, T., Allison, I., Massom, R.A., Galin, N. and Zwally, J. (2011). "Regional-scale sea-ice and snow thickness distributions from in situ and satellite measurements over East Antarctica during SIPEX 2007." Deep Sea Research Part II: Topical Studies in Oceanography **58** (9-10): 1125-1136. *(reported as accepted/in press in previous annual report, now published)*
Young, D.A., Wright, A.P., Roberts, J.L., Warner, R.C., Young, N.W., Greenbaum, J.S., Schroeder, D.M., Holt, J.W., Sugden, D.E., Blankenship, D.D., van Ommen, T.D. and Siegert, M.J. (2011). "A dynamic early East Antarctic Ice Sheet suggested by ice-covered fjord landscapes." Nature

474 (7349): 72-75.
Yu, J., Liu, H., Jezek, K.C., Warner, R.C. and Wen, J. (2010). "Analysis of velocity field, mass balance, and basal melt of the Lambert glacier-amery ice shelf system by incorporating Radarsat SAR interferometry and ICESat laser altimetry measurements." Journal of Geophysical Research B: Solid Earth **115** (B11): 1-16.

Full Written Conference Paper – Refereed Proceedings

Bindoff, N.L., Stammer, D., Le Traon, P.Y., Trenberth, K., Mauritzen, C., Church, J.A., Smith, N., Malone, T., Suga, T., Tintore, J. and Wilson, S. (2010). Capabilities of global ocean programmes to inform climate services. Procedia Environmental Sciences, Geneva.
Blankenship, D.D., Young, D.A., Siegert, M.J., van Ommen, T.D., Roberts, J.L., Wright, A., Warner, R.C., Holt, J.W., Young, N.W., Le Meur, E., Legresy, B., Cavitte, M. and IcecapTeam (2010). New constraints on the structure and dynamics of the East Antarctic Ice Sheet from the joint IPY/Ice Bridge ICECAP aerogeophysical project. American Geophysical Union, San Francisco, California.
Kaser, G. and Allison, I. (2011). Highlights of International Polar Year (IPY) Results: Ice Changes in Antarctica, the Himalayas and Other Mountain Glacier Regions. Subsidiary Body for Scientific and Technological Advice (SBSTA) 34th Workshop on research of the UNFCCC.
King, P., Lewis, R., Walker, D., Alexander, P., Bose, N. and Worby, A.P. (2010). The memorial explorer: Developing the role of AUVs in under-ice research. OCEANS'10 IEEE Sydney, OCEANSSYD 2010, Sydney, NSW.
MacKinnon, J., Alford, M., Bouruet-Aubertot, P., Bindoff, N., Elipot, S., Gille, S., Girton, J., Gregg, M., Hallberg, R., Kunze, E., Garabato, A., Phillips, H., Pinkel, R., Polzin, K., Sanford, T., Simmons, H. and Speer, K. (2010). Using Global Arrays to Investigate Internal-Waves and Mixing. In Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society OceanObs'09, Venice, Italy, 21-25 September 2009, ESA Publication WPP-306.
Palmer, M.D., Antonov, J., Barker, P., Bindoff, N., Boyer, T., Carson, M., Domingues, C.M., Gille, S., Gleckler, P., Good, S., Gouretski, V., Guinehut, S., Haines, K., Harrison, D.E., Ishii, M., Johnson, G.C., Levitus, S., Lozier, M.S., Lyman, J.M., Meijers, A., von Schuckmann, K., Smith, D., Wijffels, S. and Willis, J. (2010). Future Observations for Monitoring Global Ocean Heat Content. In Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society. OceanObs'09, Venice, Italy, 21-25 September 2009, ESA Publication WPP-306.
Pender, L., Trull, T.W., Mclaughlan, D. and Lynch, T. (2010). Pulse - A Mooring for Mixed Layer Measurements in the Open Ocean and Extreme Weather. OCEANS '10 IEEE Sydney Conference and Exhibition, Sydney, Australia.
Trenberth, K.E., Balmaseda, M., Bindoff, N.L., Church, J., Freeland, H.J., Lagerloef, G., Nerem, R.S., Palmer, M., Rintoul, S., Roemmich, D., Sabine, C.L., Stammer, D. and Stott, P. (2010). Intergovernmental Panel for Climate Change (IPCC) and Attribution and Prediction of Climate: Progress since the Fourth Assessment. In Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society OceanObs'09, Venice, Italy, 21-25 September 2009, ESA Publication WPP-306.
Trull, T.W., Schulz, E., Bray, S.G., Pender, L., McLaughlan, D., Tilbrook, B., Rosenberg, M. and Lynch, T. (2010). The Australian Integrated Marine Observing System Southern Ocean Time Series facility. OCEANS'10 IEEE Sydney, OCEANSSYD 2010, Sydney, NSW.