Antarctic Climate & Ecosystems

Cooperative Research Centre

ANTARCTIC CLIMATE
& ECOSYSTEMS
COOPERATIVE RESEARCH CENTRE

EXIT REPORT 2003-2009

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

Frequently Used Acronyms

AABW	Antarctic Bottom Water
AAD	Australia Antarctic Division
AADC	Australia Antarctic Data Centre
ACE CRC	Antarctic Climate and Ecosystems Cooperative Research Centre
AUV	Autonomous Underwater Vehicle
BROKE-West	the Baseline Research on Krill, Oceanography and the Environment – West voyage
CCAMLR	the Conservation of Antarctic Marine Living Resources
CSIRO	the Commonwealth Scientific and Industrial Research Organisation
DIISR	Department of Innovation, Industry, Science and Research
GEOTRACES	an International Study of Marine Biogeochemical Cycles of Trace Elements and their Isotopes
IMOS	Integrated Marine Observing System
IPCC AR4	the Intergovernmental Panel on Climate Change Fourth Assessment Report
IPCC AR5	the Intergovernmental Panel on Climate Change Fifth Assessment Report
IWC	International Whaling Commission
MIT	Melbourne Institute of Technology
NIWA	National Institute of Water and Atmospheric Research (New Zealand)
QMS	Quantitative Marine Science
ROV	Remotely Operated Underwater Vehicle
SCAR	the Scientific Committee on Antarctic Research
SEWPAC	the Department of Sustainability, Environment, Water, Population and Communities
SIPEX	Sea-ice Physics and Ecosystems eXperiment voyage
TPAC	Tasmanian Partnership for Advanced Computing
WWF-Australia	World Wildlife Fund Australia

Contents

1 Performance Against the Commonwealth Agreement

1.1 The overall achievement of milestones and outputs during the grant period.

In its Round 8 application in 2002, the ACE CRC foreshadowed its potential benefits to Australia in economic, environmental and social terms.

The ACE CRC will contribute economic value: more reliable climate predictions will allow Australia to benefit from the opportunities and better adapt to an evolving climate. Fundamental climate science research by the ACE CRC has contributed significantly to the world's understanding of the extent and pace of climate change. The ACE CRC has developed specific models and tools to allow Australian planners, engineers and policy makers take account of sea-level rise in a risk assessment framework in planning and constructing coastal infrastructure. The Climate Futures for Tasmania project developed climate predictions for all of Tasmania and related these to primary and industrial sectors of the Tasmanian economy.

ACE CRC research will provide data that can underpin improved sustainability of the Southern Ocean krill fishery. The krill fishery in the Southern Ocean continues to grow steadily. The results of the BROKE-West voyage (Jan-Mar 2006), a major marine science collaboration of the ACE CRC, have provided fundamental information on the status of krill stocks in the East Antarctic and has been used to set krill fishing limits. ACE CRC research on ocean acidification highlights the crucial relationship between the ocean's role in sequestering atmospheric CO_2 and its impacts on the marine food chain.

ACE CRC research will enable efficient adaptation to sea-level rise. ACE CRC research has helped resolve the fundamental contribution of ocean expansion to sea-level rise, and highlighted the potential contribution of the Antarctic ice sheets to further sea-level rise. Researchers at the ACE CRC have developed an 'on-line' tool (www.sealevelrise.info) to assist decision makers assess the extent of sea-level rise in coastal Australia. In collaboration with the Australian Government's Department of Climate Change, the ACE CRC has run sea-level rise seminars and workshops around Australia demonstrating the use of this on line tool.

ACE CRC research will attract and focus international efforts on the sector south of Australia... with significant economic benefits to Tasmania... and contribute to the national identity. Hobart continues to grow as a significant global centre for Antarctic and marine science. The ACE CRC, as a focus for much of this research, especially on climate change, has attracted researchers and collaborations from around the world. The Antarctic and marine science sector is a major component of the Tasmanian economy and Australia is recognised as a significant contributor to Antarctic and Southern Ocean research, climate change science and to Antarctic and Southern Ocean affairs.

ACE CRC research has contributed significantly to our understanding of the role of Antarctica and the Southern Ocean in the global climate system, and our work has been central to establishing base lines for detection of climate change signals in the Southern Ocean. For example, evidence of rapid and widespread changes in Antarctic bottom water (AABW) is crucial to understanding how the Southern Ocean may be responding to climate change. The findings that AABW had become less salty and less dense since the 1970s were highlighted in the IPCC's fourth assessment report (AR4) resulting in increased international research because of the significant role that AABW plays in global thermohaline circulation.

The ACE CRC will enable Australia to fulfil major environmental goals. The ACE CRC has contributed significantly to the Australian Government's National Research Priority of a *Sustainable Australia* and the goal for Australia's Antarctic program of *Understanding the role of Antarctica in the global climate system*.

The ACE CRC achieved almost all it set out to achieve. It has delivered fundamental climate change science into the science community nationally and internationally, and to the broader community and policy environment. It successfully introduced a marine ecosystems program and, in responding to its 3rd year review, the ACE CRC built a strong program of work in translating its science into the policy environment through its Position Analyses, research user workshops and short courses. A Deputy CEO (Business Development) was appointed to build the business profile of the ACE CRC and develop new pathways to delivery of ACE CRC science outputs. Despite difficulties in recruiting modelling expertise and some setbacks in achieving minor milestones, the ACE CRC established strong foundations in understanding and modelling sea-ice and in marine ecosystems and the impacts of climate change on Antarctic marine life.

The ACE CRC was successful in its application for refunding through Round 11 of the CRC Program.

1.2 The financial performance of the CRC, including any major problems encountered.

The financial performance of the ACE CRC against the Commonwealth Agreement is represented in the following table based on the audited CRC financial tables lodged with the Department of Innovation, Industry, Science and Research (DIISR) on 1st June 2010:

	Actual ($'000)	Agreement ($'000)	Variance ($'000)	Var %
In kind Contributions				
Salaries	26,435	26,955	-520	(2%)
Other	81,522	66,626	14,896	22%
Grand total in-kind	**107,957**	**93,581**	**14,376**	15%
Cash Contributions				
Core participants	2,545	1,940	605	31%
Supporting participants	357	80	277	346%
Other cash	9,497	0	9,497	
CRC grant	22,364	22,365	0	0%
Grand total cash	**34,763**	**24,385**	**10,378**	43%
Cash Expenditure				
Salaries	15,001	11,078	3,923	(35%)
Capital	2,917	3,343	-426	13%
Other	12,085	9,964	2,121	(21%)
Total Cash Expenditure	**30,003**	**24,385**	**5,618**	(23%)

For the period 1st July 2003 to 31st December 2009, the ACE CRC showed an overall positive variance in its financial performance. The positive in-kind contributions variance ($14.376M) was in a large part due to contributed ship time being more expensive than originally budgeted in the Agreement

due to higher costs, including fuel. Half of the small unfavourable in-kind salaries variance was offset by the favourable cash contribution variance from supporting participants ($277K) as the Tasmanian Government transferred cash to support the recruitment of the commercialisation manager rather than providing an in-kind resource.

Other cash contributions ($9.497M), net of GST ($2.007M), generated during the contract period, amounted to $7.49M. The major inflows were from funding from other Commonwealth and State Government programs ($3.791M), interest received ($1.16M), contract research ($601K) and cash carried over from the previous CRC ($963K).

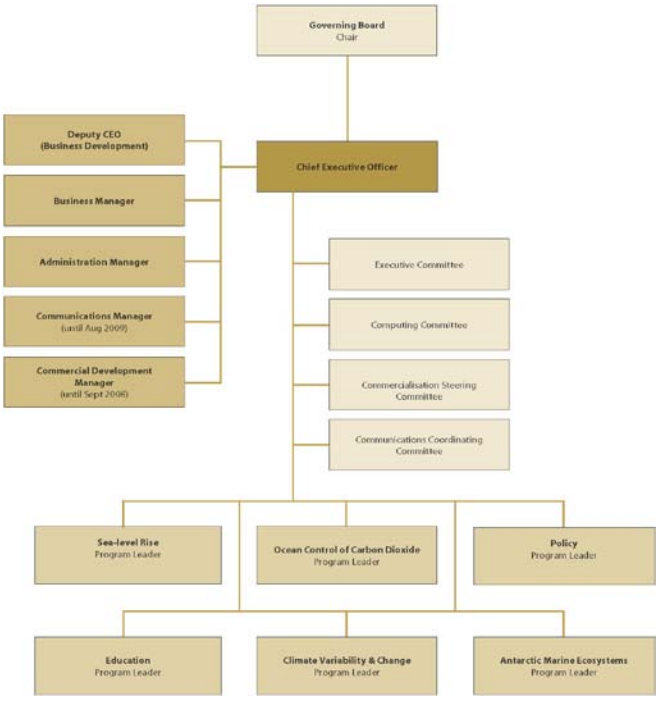
On commencement, the ACE CRC took the financially prudent decision of offering staff positions for only the first five years of the contract period. This was done to mitigate the impact on the salary budget of the lack of indexation of the grant over the granting period. Financial control over expenditure was stringent in an effort to ensure that key staff contracts could be extended into the sixth and seventh year of the grant period, and allow ACE to meet its contracted obligations. These efforts were successful as the tight financial management in the first years of the CRC's operation ensured key personnel were retained to the end of the contract period and into the new ACE CRC (2010-2014).

The unfavourable variance in the cash expenditure section is partly the result of the non-indexation of the grant as discussed above. The other major factor contributing to this variance was the success of the ACE CRC in applying for other funding. Successful bids resulted in additional staff being recruited and applicable expenses being incurred for these projects/grants that were not envisaged at the time of the original agreement.

Overall the financial management of the CRC for the funding period resulted in cash being available to carry forward into the new CRC of $2.797M and a further $1.963M being held for other funded research activities of the ACE CRC.

1.3 The governance and management performance of the CRC

The governance and management of the ACE CRC is shown in the below figure.



Governing Board

The ACE CRC Governing Board had an independent Chair and members from the core partners and key research users. The Australian Antarctic Division held an additional ex-officio seat in recognition of the magnitude of its contribution to the ACE CRC. The Board met 30 times over the grant period of the ACE CRC (2003-2009).

Executive Committee

The ACE CRC Executive Committee was created to support implementation of the ACE CRC through the provision of leadership and advice on a wide range of matters relating to the management of resources, including human resources, and coordination of research across the ACE CRC portfolio. The ACE CRC Executive Committee advised the CEO and Board of the ACE CRC. It comprised all Program Leaders and ACE administration, together with representatives from Tasmanian Partnership in Advanced Computing (TPAC) and the research student body. It also held a seat for a participant from the Australian Bureau of Meteorology. The executive committee met 24 times over the life of the CRC.

Computing Committee

The ACE CRC Computing Committee was created to support the science, education and policy programs of the ACE CRC through advice on Information Technology infrastructure and management. This support focussed primarily on those components of the ACE CRC based on the University of Tasmania's Hobart Campus. The ACE CRC Computing Committee advised the ACE Executive Committee and CEO. This committee met as required.

Commercialisation Steering Committee

The ACE CRC Commercialisation Steering Committee was created to support implementation of commercialisation opportunities arising from ACE CRC activities. The ACE CRC Commercialisation Steering Committee advised the CEO, Executive Committee and Board until the 3rd year review when a Deputy CEO (business development) was appointed. This position was created to replace the commercialisation steering committee and to pursue and develop business opportunities.

Communications Advisory Committee

The ACE CRC Communication Advisory Committee was created to support implementation of the ACE CRC through the coordination of public communication and reporting strategies by the ACE CRC and its partner organisations to maximise awareness of the ACE CRC and its contributions to Australian and international science and policy. The ACE CRC Communication Advisory Committee advised the CEO, Executive Committee and Board of the ACE CRC. This committee met as required.

Third year review

The third year review of the ACE CRC noted that "...the overall performance of the CRC was excellent" and commented very positively on the governance of the ACE CRC and the relationships between the administration, the Board and the partners. The ACE CRC implemented the major recommendations of the third year review.

2 Outputs of the CRC

The key outputs of the ACE CRC (2003- 2009) relate to the production of scientific knowledge about climate change in Antarctica and the Southern Ocean and its impact on Australia. Metrics for the evaluation of the success of the ACE CRC include a comparison of achievement of outputs as defined within the Commonwealth Agreement; the number of refereed scientific journal papers; and use of ACE CRC's intellectual property (i.e. to develop processes that use these scientific outputs and apply them to practical purposes, for example the Sea-level Rise Tool).

2.1 The key outputs of the CRC (including IP, new processes etc.).

Outcome/Outputs

Outcome/Output	Description	Achieved	Details of Achievement
Outcome 1: Reliable climate forecasts			
Output 1.1	Assessment of the variability of Southern Ocean currents and sea–ice	7 out of 8 milestones	ACE CRC research has contributed significantly to a better understanding of the Southern Ocean and its physical variability. Greatly expanded ship-based, satellite, and Argo float observations, complemented by numerical models and simulations have led to greatly enhanced understanding of the role of the Southern Ocean in regional and global climate. ACE research on Antarctic sea-ice in East Antarctica has also greatly improved global understanding of sea-ice dynamics and the role of sea-ice in thermohaline circulation.
Output 1.2	Climate change scenarios for the Southern Ocean circulation and sea-ice	4 out of 4 milestones	ACE CRC research has improved the capability for detection and attribution of contemporary climate change; allowed a better understanding of uncertainties in climate change assessment; and provided greater capacity for verification of climate models. ACE CRC research has provided new data sets and interpretations that put current climate conditions in the context of long-term patterns in past climate.

Outcome/Output	Description	Achieved	Details of Achievement
Outcome 2: Efficient, safe and sustainable operations in Antarctic waters			
Output 2.1	Forecasts of ocean currents and sea-ice	2 out of 3 milestones	ACE developed the *SeaIceViewTool* which is a flexible, intelligent, aid to viewing satellite imagery of sea-ice, enabling more efficient navigation, voyage management and science planning with potential application in both the Antarctic and Arctic regions. The tool is currently being used by Australian and European vessels to chart safe courses through Antarctic sea-ice and to select areas for collection of scientific data.
Outcome 3: Sustainable management of Antarctic marine living resources			
Output 3.1	Incorporation of physical and biological information into an Antarctic ecosystems model	3 out of 6 milestones fully achieved	ACE CRC research contributed significantly to developing a descriptive and predictive Antarctic ecosystem model. The available data for statistical and dynamic modelling were reviewed by a joint workshop of the Scientific Committees of CCAMLR and IWC co-convened by Dr Andrew Constable in 2008; and a successful international workshop on Southern Ocean ecosystems (the Sentinel Workshop) was convened in Hobart in 2009. A sea-ice community model has been developed to be coupled to a physical sea-ice model. These developments are fundamental to the future ecological sustainability of fisheries and conservation strategies in the Southern Ocean, and for understanding the impacts of climate change on the ecology of the Southern Ocean.
Outcome 4: Recognition of oceanic carbon sinks and their impacts, to examine the justification for and permit the effective management of carbon dioxide emissions7			
Output 4.1	An estimate of the current inventory of anthropogenic CO_2 in the Southern Ocean south of Australia	3 out of 3 milestones	The first estimate of the inventory of anthropogenic CO_2 in the Southern Ocean was released as part of a global compilation in 2004 (Sabine et al, 2004) and the second estimate was summarised in a paper by Takahashi et al (2009). ACE CRC research was crucial to the production of these inventories.

Outcome/Output	Description	Achieved	Details of Achievement
Output 4.2	Determination of the role of stratification in biological carbon export to the deep sea, to inform estimates of future carbon export in an increasingly stratified ocean	3 out of 3 milestones	A combination of observations using ACE CRC moorings and deep sediment traps, and the use of these observations in models, has greatly enhanced our understanding of the role of the Southern Ocean's 'biological pump' in regulating atmospheric CO_2. This research is critical to the development and verification of reliable carbon cycle models to simulate future atmospheric CO_2 levels and the path of climate change.
Output 4.3	Determination of the role of iron limitation in biological carbon export to the deep sea	2 out of 2 milestones	ACE CRC research in the Southern Ocean has been important in understanding the role of iron in influencing primary productivity, and the consequential export of carbon to the deep ocean. Research on 'natural' sources of iron (e.g. from the volcanic sources on the Kerguelen plateau) have been conducted and the 'export' of iron compared to ocean iron fertilisation experiments. ACE research has elucidated ecosystem response as a function of the location and season in of ocean fertilisation, and provided vital information on incorporating trace elements into biogeochemical and ecosystem models for the region. These results have allowed prediction of the role of Southern Ocean biology in past and future regulation of atmospheric CO_2 through ecosystem control of carbon transfer to the deep ocean. The ACE CRC published the groundbreaking "Ocean Fertilisation: science and policy issues" Position Analysis in 2008.
Output 4.4	Determination of the role of elevated CO_2 levels on phytoplankton communities	1 out of 1 milestones	ACE CRC researchers aboard *Aurora Australis*, *Southern Surveyor*, and *l'Astrolabe* have measured chemical distributions (including CO_2, alkalinity, biogenic minerals and trace metals) across the Southern Ocean. These experiments have used ultra-clean seawater sampling systems provided by ACE partner, NIWA, as part of the international GEOTRACES project. These observations have been vital in providing a baseline for assessing the magnitude of ocean uptake of CO_2, its impacts, and the role of trace elements in controlling phytoplankton growth.

Outcome/Output	Description	Achieved	Details of Achievement
Outcome 5: Estimates of sea-level change resulting from anthropogenic climate change used as one of the bases for intergovernmental climate change negotiations			
Output 5.1	Review of 20th century sea-level change	2 out of 3 milestones	The landmark publication "Understanding Sea-level Rise and Variability" (2010, ed. Church et al), co-sponsored by the ACE CRC and with significant contributions from ACE researchers, provides an up to date assessment of global knowledge of sea-level rise. The outstanding portion of this milestone will be completed outside the extension CRC.
Output 5.2	Revised projections for future sea-level change during the 21st century and on longer time-scales	3 out of 3 milestones (part)	ACE CRC research has reduced the uncertainty range for estimates of global averaged sea-level rise and produced estimates of ocean thermal expansion. This research formed a vital component of the IPCC's Fourth Assessment Report. Revised model estimates were not completed before the end of the 2009 and will form be part of future contributions to the IPCC Fifth Assessment Report. The outstanding portion of this milestone will be completed in the Cryosphere program of the extension CRC.
Outcome 6: Estimates of sea-level change as an essential input to coastal zone management and other planning considerations in Australia and in neighbouring nations in the South Pacific			
Output 6.1	Estimates of the historical impacts of sea-level change at key locations	1 out of 1 milestones	An analysis of historical tide gauge records at 29 sites around the coast of Australia was completed by assessing and verifying actual tide gauge records of at least 30-years in duration. These form important inputs in developing future estimates of likelihood of flooding events under future sea-level rise.

Outcome/Output	Description	Achieved	Details of Achievement
Output 6.2	Estimates of the expected impacts of sea-level change at key locations	1 out of 2 milestones	The ACE CRC has developed a statistical technique which combines historical tide gauge records with future IPCC projections of sea-level rise to provide an estimate of the likelihood of flooding at a given height above sea-level at some point in the future. The results are delivered via a web-based decision support tool and are currently available for 29 sites around Australia. This information is useful for planners seeking to build new infrastructure along the coastal line or for existing infrastructure managers wishing to define maintenance and upgrade programs in response to sea-level rise.
Outcome 7: Delivery of science outputs to research users			
Output 7.1	Annual forum for research users	2 out of 2 milestones	A total of eight Research Users Forums and Roundtables were held during the grant period. These forums engaged key policy makers from across government in key portfolios including Climate Change and Energy Efficiency; Environment (in its various manifestations); Industry, Innovation, Science and Research; Prime Minister and Cabinet; Office of National Assessments; Agriculture Forests and Fisheries and Defence.
Outcome 8: Improving responses to emergent issues			
Output 8.1	Identify and, with science programs, provide policy users with details on emergent issues and likely impacts on Southern Ocean management regimes	4 out of 4 milestones	A total of 6 ACE CRC Position Analyses were produced which provided policy makers with up to date information on emerging scientific issues in Antarctic and Southern Ocean research and climate change. The Position Analyses covered sea-level rise; ice sheets; sea-ice; CO_2 and oceans; and ocean fertilisation (see section 2.2 below)

Outcome/Output	Description	Achieved	Details of Achievement
Outcome 9: Improved Australian influence in and effectiveness of Southern Ocean management regimes			
Output 9.1	Establish criteria for assessment of Australian influence in, and the effectiveness of, Southern Ocean management regimes	3 out of 3 milestones	Early in the funding period the ACE CRC Policy Program held a number of workshops and meetings to provide a benchmark of Australia's engagement in Antarctic and Southern Ocean governance. This work provided essential background to the development of ACE CRC's successful policy engagement through its End User Forums and Roundtables and the product of its Position Analyses.
Outcome 10: Increase awareness of the climate system and our role/influence within it			
Output 10.1	Train the climate specialists of tomorrow	1 out of 1 milestones	The program has attracted high calibre students and delivered well trained specialists and researchers. From 2003 to end 2009, 62 higher degree students associated with the ACE CRC were conferred their degrees.
Outcome 11: Raise public awareness of Antarctica and Southern Ocean science			
Output 11.1.	Communication liaison with the general public	1 out of 1 milestones	ACE CRC researchers have been actively engaged with the general public through lectures and public events; and by working with partners and with museums, high schools, and other community groups to raise awareness of Antarctic and Southern Ocean science and climate change.

*While the majority of these outputs have been accomplished, several were incomplete upon close of the CRC. Details of these activities are outlined in section 7.1 below.

Publications

Publications output	03/04	04/05	05/06	06/07	07/08	08/09	TOTAL
Refereed papers	65	47	63	81	95	83	434
Books			3		1	1	5
Book chapters	7	2	10	20	15	5	59
Conference papers/abstracts	44	29	33	53	39	46	244
Technical reports		9	2	8	12	17	48
Other	24	4	14	10	23	12	87

To sum up, the ACE CRC has published more than 400 articles in scholarly referred journals since 2003, including 17 in *Nature* and *Science*.

Intellectual Property (IP)

During the grant period, the ACE CRC did not sell, transfer or license its IP for commercialisation. The ACE CRC implemented all core policies and procedures for IP management before the end of the 2005–2006 year. The Third Year Review confirmed that this approach was appropriate for the organisation and the activities that the ACE CRC undertook. The ACE CRC, under the new Commonwealth Agreement, will continue to work closely with our partners to ensure a common understanding and approach in the application of these policies and procedures.

The ACE CRC had as one of its core objectives the development of new approaches to the forecasting of ocean and sea-ice conditions which could be implemented for operational use by partner and other agencies. To that end, ACE developed the *SeaIceViewTool* which is a flexible, intelligent, aid to viewing satellite imagery of sea-ice, enabling more efficient navigation, voyage management and science planning with potential application in both the Antarctic and Arctic regions. In November 2007 we executed a collaboration agreement with a European consortium to field-test the product in the 2007–2008 Arctic summer season. A collaboration agreement with a European consortium to field-test this product in the Arctic region was extended for another year in November 2008. Although there was a very limited specialist market for the product, it was determined that Australia's Antarctic Program would most benefit from using the tool. The tool is currently being used by Australian and European vessels to chart safe courses through Antarctic sea-ice and to select areas for collection of scientific data.

Another of ACE CRC's objectives was to increase the reliability of projections of sea-level rise for Australia and neighbouring nations for use in coastal zone management and other risk assessments. The project '*Estimating Sea-Level Extremes in an Uncertain Future'* developed a web-based decision-support tool to provide projections of the risk of inundation of coastal infrastructure. This project was co-funded by the Australian Government Department of Climate Change and Energy Efficiency. It utilised the ACE CRC's unique method of statistically combining recorded variations in present sea-level (from tides, storms and other meteorological events) with internationally accepted projections of future sea-level to provide a basis for coastal infrastructure planning and maintenance decisions in the 21st century. This tool (www.sealevelrise.info) allows managers and planners to determine

future maintenance regimes and to design new infrastructure at appropriate levels. The ACE CRC, under the new Commonwealth Agreement, will continue to work closely with our partners to refine and develop this tool.

Working in partnership with SME, Pitt&Sherry, a tool which assists infrastructure owners make climate change adaptation decisions for new and existing infrastructure was developed (Climate*Asyst*), This tool is currently being piloted by state and local governments in Tasmania with a view to expand it nationally.

2.2 The level of uptake by end-users of the outputs

The 'public good' nature of the research conducted through the ACE CRC meant that its major end-users were Australian Government Departments and Agencies, local government, international bodies, the broader research community and the general public. There was significant interest from some commercial end users, and some of these became partners in the new ACE CRC.

Australian Government

Position Analyses

Several outputs from the CRC were delivered to end-users in the form of Position Analyses. These position analyses are outlined in the table below.

Date	Position Analysis/Briefing:
3 June 2008	"CO_2 emissions and climate change: ocean impacts and adaption issues"
24 September 2008	Briefing: "A post-IPCC AR4 update on sea-level rise"
24 September 2008	"Climate change, sea-level rise and extreme events: impacts and adaption issues"
12 December 2008	"Ocean Fertilisation: science and policy issues"
11 June 2009	"Changes to Antarctic sea-ice: impacts"
11 June 2009	"Polar ice sheets and climate change: global impacts"

The ACE CRC position analyses aimed to:

- inform the Australian Government about recent developments in scientific research within our programs;
- outline the likely impacts of these developments on Antarctica and the Southern Ocean, on Australia, and globally; and
- identify issues for consideration in policy development.

The Position Analysis *'A post-IPCC AR4 update on sea-level rise'* was commissioned by the Department of Climate Change to provide up to date briefing on sea-level rise for The Hon. Penny Wong, Minister for Climate Change.

Policy and Science 'Forums' and 'Roundtables'

A total of eight Research Users Forums and Roundtables were held during the funding period. These involved presenting ACE CRC research to key government research users. These forums and roundtables were attended by policy makers from a wide range of government departments and agencies including Climate Change and Energy Efficiency; Environment (in its various manifestations); Industry, Innovation, Science and Research; Prime Minister and Cabinet; Agriculture Forests and Fisheries; and Defence. The forums and roundtables were well attended and often oversubscribed.

Following the third year review the roundtables were used also to assist the development of ACE's Positional Analyses by presenting ACE research and seeking input and comment from policy makers on the importance and relevance of that research to their policy requirements. ACE roundtables were also structured to provide knowledge transfer of ACE CRC research and its use in policy development to graduates and new employees in government agencies.

Local Government and Commercial end-users

A sea-level rise consultancy unit was developed to provide coastal industries and government entities with information on sea-level rise and infrastructure risk assessment. Sea-level rise scientific/technical expertise was delivered to port, airport and water authorities and to a number of coastal councils.

In a significant national initiative co-funded by the Australian Government's Department of Climate Change and Energy Efficiency, the Sea-Level Rise program delivered its research into the broader community by providing seminars and workshops on sea-level rise and the use of the risk assessment tool developed by the ACE CRC (www.sealevelrise.info). By the end of 2009 ACE had presented seminars and user workshops to almost 1000 participants across Australia.

The *Climate Futures for Tasmania* project, funded through the Commonwealth Environmental Research Facilities program and Tasmanian Government and business entities, had over 1000 interactions with end users. The results from this project have been delivered to government agencies, businesses, industry and community organisations. A complementary project was to be developed in collaboration with SME partner, Pitt&Sherry, which produced a climate change adaptation planning tool for infrastructure owners (Climate*Asyst*).

International

The importance and impact of ACE research was reflected in the release of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) in 2007. The ACE CRC and its partners provided four Lead and Contributing Authors and five scientific reviewers to Working Group 1 of AR4. The results reported in areas such as sea-level rise, ice sheet mass balance, ocean thermohaline circulation and the ocean's role in global carbon sequestration, all reflected significant contributions from research by the ACE CRC.

In 2007, Al Gore and the Intergovernmental Panel on Climate Change (IPCC) received the Nobel Peace Prize:

"...for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change."

The prize recognised the contribution by a large team of Australian climate scientists to the various IPCC assessment reports – many from the ACE CRC – and it highlighted the important work by Australia in identifying the critical role of the Antarctic and Southern Ocean in global climate.

ACE science continued to contribute to informing policy in the period following the IPCC Fourth Assessment Report (AR4). ACE researchers (Prof Nathaniel Bindoff and Prof Ian Allison were contributing authors) featured in the "The Copenhagen Diagnosis: *Updating the World on the Latest Climate Science*" (2009). The Copenhagen Diagnosis served as a handbook of science updates, to supplement the IPCC's Fourth Assessment Report, for the Copenhagen Climate Conference which was held in December 2009.

The ACE CRC co-sponsored the Southern Ocean Sentinel conference in April 2009 which resulted in the publication of "Southern Ocean Sentinel: an international program to assess climate change impacts on marine ecosystems" (Drs Andrew Constable and Susan Doust 2009). This workshop and report synthesised the current knowledge of Antarctic and Southern Ocean ecosystems and the impacts of climate change, and proposed a research framework for assessing ecosystem responses to climate change in the future. A companion workshop will be held during the ACE extension (2010-2014).

The success of the ACE CRC research was also reflected in the ACE CRC (Drs Donna Roberts and Will Howard) being asked to contribute to the European Project on Ocean Acidification's publication "Ocean Acidification: the facts" in 2009.

ACE CRC research was provided to the Scientific Committee on Antarctic Research (SCAR) for its major synthesis report "Antarctic Climate Change and the Environment: A contribution to the International Polar Year 2007-2008" (2009). Outputs from all four research programs were included within the report and several ACE CRC researchers were chapter authors as described in the table below.

Chapters	**ACE CRC Authors**
Chapter 2: Observations, data accuracy and tools	Dr Steve Rintoul and Dr Tony Worby
Chapter 3: Antarctic climate and environment history in the pre-instrumental period	Dr Mark Curran and Dr Tas van Ommen
Chapter 4: The instrumental period	Dr Steve Rintoul and Dr Tony Worby
Chapter 5: The next 100 years	Dr Siobhan O'Farrell

The high standing of ACE CRC research in the international arena is reflected in the selection of present and former ACE CRC researchers in the IPCC Fifth Assessment report process: Dr Stephen Rintoul (coordinating lead author "Observations: Oceans"), Prof Nathaniel Bindoff (coordinating lead author "Detection and Attribution of Climate Change"), Dr John Church (coordinating lead author the "Sea-level Change"), Prof Kurt Lambeck (lead author "Information from Paleoclimate Archives") and Prof Ian Allison (lead author "Observations: Cryosphere").

Research Community

During the grant period, ACE CRC researchers served on 126 national and 266 international committees, editorial boards or advisory boards related to Antarctic and Southern Ocean research and management, and climate change prediction and analysis. Several ACE CRC researchers served in international leadership roles as chair, co-chair, or workshop convenor or co-convenor.

Some specific examples of outputs from ACE CRC's research program that are utilised by the wider research community include:

- Observations of Southern Ocean surface ocean pCO_2 and full ocean depth CO_2 inventories have been used to assemble the global view of the ocean's role in absorbing anthropogenic CO_2 emissions. This information is used by the climate modelling community for assessments of, and projections for future, climate change.
- Automated ocean moorings developed by the ACE CRC to quantify the transfer of carbon into the deep sea by the biological pump have become a core facility of the Australian Integrated Marine Observing System (IMOS) and these data are freely available to the wider climate community.
- Evidence of rapid and widespread changes in the Antarctic bottom water (AABW) was a significant development in the understanding of climate impacts and changes in the Southern Ocean. These findings were used in IPCC AR4 and have subsequently resulted in increased international research because of the significant role that AABW plays a key role in the global thermohaline circulation. ACE CRC work was central to establishing base lines for detection of climate change signals in the Southern Ocean.

2.3 Key educational outputs

Sixty-two Higher Degrees were awarded to ACE CRC-related students from 2003 to 2009. The third year review of the ACE CRC noted "…that the standard of research training, supervision and student management within this CRC is exemplary".

Sea-level Rise Workshops: courses to demonstrate the on-line tool

Researchers at the ACE CRC have developed an on-line tool (www.sealevelrise.info) to assist decision-makers assess the impacts of potential sea-level rise on coastal Australia. In collaboration with the Australian Government's Department of Climate Change and Energy Efficiency, the ACE CRC has run sea-level rise seminars and workshops around Australia demonstrating the use of this on-line tool. Approximately 1000 individuals from federal, state and local government, and from industry, have been trained in the use of the web tool through a national series of seminars and workshops. A total of 15 seminars and 15 workshops were held nationally.

Short Course: Antarctica and the Southern Ocean – implications for Australian and global climate change

A short course "Antarctica and the Southern Ocean: implications for Australian and global climate change" was developed and presented to Australian Government officials (see government agencies listed below) in May 2009 and March 2010 (oversubscribed - 130 attendees). ACE also briefed Australian Government officials on the policy and legal implications of oceans acidification, climate change and impacts on Southern Ocean shipping.

Australian Government Departments attending the Short Course (May 2009 and March 2010)
Australian Bureau of Agricultural and Resource Economics
Australian National University
Australian Quarantine and Inspection Service NSW
Biosecurity Australia
Bureau of Rural Sciences
Department of Agriculture, Fisheries and Forestry
Department of Climate Change and Energy Efficiency
Department of Foreign Affairs and Trade
Department of Innovation, Industry, Science and Research
Department of the Prime Minister and Cabinet
Embassy of Belgium
European Commission
Natural Resources Management
Office of National Assessments
Royal Australian Navy
Sydney University

3 Impacts to Date

The 'public good' nature of the research conducted through the ACE CRC meant that its major end-users were Australian Government Departments and Agencies, local government, international bodies, the broader research community and the general public. There was significant interest from some commercial end users, and some of these became partners in the new ACE CRC.

The impacts of ACE CRC research is substantially covered in section 2.2 and 2.3 (above). Our research has provided Australia and the world with increased knowledge of the role of Antarctica and the Southern Ocean in the global climate system and climate change, and improved information with which to react to and meet the challenges of a changing climate.

For example, planners, engineers and policy makers can use sea-level rise data in a risk assessment framework in planning and constructing coastal infrastructure. This could then result in making cost effective decisions about the appropriate height above sea level to build future coastal assets.

3.1 The economic benefit to end-users

One of the ACE CRC's missions was to 'contribute key observations and insights on the role of the Southern Ocean and Antarctica in climate in order to produce more reliable projections of variability and change, allowing Australia to benefit from opportunities and minimise risks'.

The *Climate Futures for Tasmania* project used the expertise developed through the ACE CRC to develop climate projections to the end of the 21st Century, and to deliver these to a broad range of stakeholders across all sectors of the Tasmanian economy. *Climate Futures for Tasmania* used an ensemble of six global climate models, run under both high and low greenhouse gas emissions scenarios. The six models show a range of temperature rise from 2.6˚C to 3.3˚C with the rate of change increasing towards the end of the century. From its conception, *Climate Futures for Tasmania* was designed to deliver information in a way that is useful for end users. *Climate Futures for Tasmania* covers the impacts of climate change on Tasmania's weather, water catchments, agriculture and climate extremes, including aspects of sea-level rise, floods and wind damage. New

assessments were made of the impacts of climate change on coastal erosion, biosecurity, and energy production.

The *Climate Futures for Tasmania* project was unique in providing state of the art climate projections at a detailed regional scale. This information is being used in the business models of Tasmania's power generators, and is being taken up across the Tasmanian economy to inform decision making.

An associated project, *Climate Futures for Tasmania – Infrastructure*, with Pitt&Sherry as partners, led to the development of Climate*Asyst* which delivers climate change information to infrastructure asset managers and local government to allow them to take into account climate change (e.g. soil moisture) in making planning, maintenance and construction decisions.

3.2 Other economic benefits to date such as risk mitigation, growth in employment, reduction in costs, and capability enhancement

Risk mitigation

A continuing rise in sea-level will be one of the most obvious and major impacts of climate change. More than 80 per cent of Australians currently live in the coastal fringes of the continent. Around a quarter of Australia's population growth is occurring within three kilometres of the coast, and billions of dollars of crucial infrastructure is vulnerable to sea-level rise, flooding and storm surge. A significant proportion of Australia's population will experience the impacts of a changing climate through rising sea-levels, increased coastal erosion and extreme flooding events. Infrastructure owners and planners need to be able to assess the likely risk to existing assets and to plan appropriately when building new coastal assets.

The ACE CRC responded to this need by developing a method of determining the likely impact of future sea-level rise on coastal assets. The technique statistically combines recorded variations in today's sea-level (through tides, storms, and other meteorological events) with internationally-accepted projections of future sea-level rise.

The analyses provide estimates of the probability that a given asset will be flooded by the sea during its lifetime under different climate projections. This information will help planners, engineers and policymakers to make more informed decisions about maintenance and planning of infrastructure around Australia's coastline, enabling coastal communities to develop appropriate strategies for adapting to the impacts of sea-level rise.

Other economic benefits

The ACE CRC partnership and its research focused international attention on Hobart as a global centre for Antarctic and Southern Ocean science and policy, with significant economic benefits to Tasmania. The ACE CRC, as a focus for much of this research, has attracted researchers and collaborations from around the world. The Antarctic and marine science sector is a major and growing component of the Tasmanian economy, and Australia is recognised as a significant contributor to Antarctic and Southern Ocean research, climate change science and to Antarctic and Southern Ocean affairs.

In the 2003-2004 financial year the Tasmanian 'Antarctic' sector was worth approximately $113.1 million to the economy. The Antarctic Expenditure Survey conducted by the Tasmanian Government revealed that the Tasmanian Antarctic sector was worth approximately $147.7 million by the 2006-07 financial year. The annual growth rate in this part of the Tasmanian economy has been averaged around 6.1% per annum since the mid 1990s.

3.3 The number and value of commercial arrangements involving the CRC's IP or other assets

During the grant period the ACE CRC did not sell, transfer or license its IP for commercialisation.

3.4 The operational status and current valuations of spin-off companies established to commercialise the CRC's research.

The ACE CRC has not created any spin-off companies.

3.5 Case studies of successful commercialisation or utilisation of the CRC's research.

Estimating Sea-Level Extremes in an Uncertain Future

This project was co-funded by the Australian Government Department of Climate Change and Energy Efficiency. It utilised the ACE CRC's unique method of statistically combining recorded variations in present sea-level (from tides, storms and other meteorological events) with internationally accepted projections of future sea-level to provide a basis for coastal infrastructure planning and maintenance decisions in the 21st century. A web-based decision-support tool (www.sealevelrise.info) has been developed to provide projections of the risk of inundation of coastal infrastructure. It will allow managers and planners to determine future maintenance regimes and to design new infrastructure at appropriate levels. A national series of seminars and workshops was delivered to support the use of the web tool. Approximately 1000 individuals from federal, state and local government, and from industry, have been trained in the use of the web tool and a total of 15 seminars and 15 workshops were held nationally.

Climate*Asyst*

The climate change projections made in the *Climate Futures for Tasmania* project were used by Pitt&Sherry to develop Climate*Asyst*. Climate*Asyst* delivers climate change information on a geographical information system to infrastructure asset managers and local government to allow them to take into account climate change (e.g. soil moisture) in making planning, maintenance and construction decisions.

Other commercial utilisation

The ACE CRC has assessed future risk of sea-level rise for a number of industry, local government and not-for-profit organisations, including a large metropolitan airport, a capital city port and coastal councils.

3.6 The environmental and social benefits to end-users through utilisation of the research outputs.

The work of the ACE CRC has contributed significantly to our understanding of global climate change and its impacts regionally and in Australia, and to fulfilling one of the goals of Australia's Antarctic Program, *Understanding the role of Antarctica in the global climate system*, and to the Australian Government's National Research Priority of a *Sustainable Australia.*

Case study: A sustainable krill fishery in the Southern Ocean

ACE CRC research has provided data that underpin improved sustainability of the Southern Ocean krill fishery.

In 2000 the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) suggested the need for a survey to produce data on the krill fishery. In 2001, the scientific planning began which involved submissions of survey plans to CCAMLR in 2004, and proposal approval through the Australian Antarctic Division in 2005. The Baseline Research on Krill, Oceanography and the Environment - West (BROKE-West) voyage, a major marine science collaboration of the ACE CRC, set sail from Fremantle, Western Australia, in January 2006, and returned in April 2006 having surveyed 1.5 million km² of the southern Ocean. The survey of the region from 30˚ to 80˚E, involved an acoustic biomass survey for krill to produce data for a revised catch limit for the krill fishery.

In July 2006, the results of the BROKE-West survey were submitted to CCAMLR resulting in CCAMLR using the survey's biomass estimate to set new precautionary catch limits for the krill fishery (in November 2007).

Case study: Understanding past climate

The Ice Core Climate Research project is one of the ACE CRC's research highlights. Using an ice core drilled 1.2 kilometre deep from the Law Dome in eastern Antarctica, ACE scientists and collaborators were able to describe the Antarctic climate back 90,000 years. The high rate of snowfall in the Law Dome area provides a very detailed record of the climate since the last ice age. As snow is compressed to solid glacial ice, it traps air which becomes sealed as bubbles in the ice. In collaboration with CSIRO, ACE scientists have analysed the ancient air from these bubbles to learn about past atmospheric composition.

Understanding past changes in greenhouse gas concentrations allows better understanding of natural and human drivers of the climate system. Aside from the air bubbles, traces of dust and chemical variations in the ice itself carry information about changes in atmospheric circulation, temperature, and volcanic and biological activity across large areas of the globe. This is a valuable source of information to understand the role of Antarctica in the global climate system.

ACE CRC research on ocean chemistry and acidification highlighted the crucial relationship between the ocean's role in sequestering atmospheric CO_2 and its impacts on marine organisms. Ocean acidification has implications for marine organisms and ecosystems, fisheries and aquaculture.

3.7 Uptake of new knowledge, products or processes developed by the CRC that have reduced the call on the government budget in areas such as health, social security or defence spending.

The scientific information produced through ACE CRC research contributes to the global understanding of climate change and its implications over the 21st century and beyond. This science forms a significant part of the foundation on which decisions about mitigation and adaptation will be made.

While use of the results of this research may not have immediate commercial return, improved understanding of climate change and future climate has direct economic impacts because it better enables governments, industry and society to make decisions about the future (for example the work of both Stern (2006) and Garnaut (2008)). Being able to avoid or mitigate the costs associated with climate and weather (sea-level rise, fires, floods, droughts and extreme weather events; changes in the distribution of pests; climate change impacts on species or natural assets such as the Great Barrier Reef) has direct implications for governments.

The *Climate Futures for Tasmania* project was designed specifically to use this knowledge to provide climate change information directly to governments and industry to guide their investment and policy decisions.

3.8 Case studies which outline knowledge, products or processes developed by the CRC that have a direct non-monetary benefit for end-users.

Case study: Ocean fertilisation

Ocean iron fertilisation is the adding of nutrients or elements (e.g. iron) to the ocean to increase the growth of microscopic marine plants (phytoplankton). Increasing the productivity of oceans, and hence the growth of phytoplankton and the consumption of atmospheric CO_2 during photosynthesis, has been proposed as a form of geo-engineering to mitigate greenhouse gas emissions.

The Department of Sustainability, Environment, Water, Population and Communities (SEWPAC) has used ACE CRC expertise and knowledge of the potential impacts of ocean iron fertilisation to help determine a national approach to this carbon capture and storage technology. ACE CRC staff have participated as scientific advisors on ocean fertilisation to Australian delegations to the International Maritime Organisation and the United Nations Convention on Biodiversity.

3.9 A comparison of the current economic, environmental and social benefits to any predictions contained in the original funding application or Commonwealth Agreement.

The following table contains information from the ACE CRC 2002 funding application and its subsequent business plan.

Predictions in original application	**Achievement of economic, environmental and social benefits**
ACE CRC research will contribute key observations and insights to the global effort to predict climate variability and change. More reliable climate predictions will allow Australia to benefit from the opportunities and better adapt to an evolving climate. The annual value of climate-sensitive sectors of the Australian economy (e.g. agriculture, forestry, water resources, and coastal infrastructure) amounts to several tens of billions of dollars. Even a 0.1% improvement in the outcomes of these sectors in a single year would exceed the cost of the Centre over the full 7-year term.	The ACE CRC provided important science for the Fourth Assessment report of the Intergovernmental Panel on climate change, including on sea level rise; ocean circulation; ocean chemistry and marine species. The AR4 Report is the most authoritative assessment of climate change to date. The sea-level rise tool (www.sealevelrise.info) and Climate*Asyst* allow planners and owners of infrastructure to assess the potential impacts of climate change on infrastructure and infrastructure development. *Climate Futures for Tasmania* provides detailed climate projections to 2100 across all sections of the Tasmanian economy allowing long term impacts of climate change to be factored into economic decisions.

Predictions in original application	Achievement of economic, environmental and social benefits
ACE CRC research will provide data that can underpin improved sustainability of the Southern Ocean krill fishery. The fishery is currently worth A$100 million per annum but is forecast to grow in the future as the need for protein from the sea increases (e.g. as aquaculture feed). If catches rise to the present precautionary catch limit the fishery would be worth a minimum of A$5 billion per annum. The Centre will provide the information necessary to exploit this resource while ensuring sustainable management of the ecosystem.	The Baseline Research on Krill, Oceanography and the Environment - West (BROKE-West) voyage (2006-07), a major marine science collaboration of the ACE CRC surveyed 1.5 million km² of the southern Ocean for krill to produce data for a revised catch limit for the krill fishery. In July 2006, the results of the BROKE-West survey were submitted to CCAMLR resulting in CCAMLR using the survey's biomass estimate to set new precautionary catch limits for the krill fishery (November 2007).
ACE CRC research will enable efficient adaptation to sea-level rise. Sea-level rise at the mid to upper range of current projections, particularly when combined with continued coastal development, is likely to have severe impacts, with millions of people affected by increases in the frequency and severity of extreme flooding events and billions of dollars of coastal development at risk. This is a particular concern for Australia's island neighbours. Narrowing the range of estimates of future sea-level rise will allow Australia and other nations to adapt to rising sea-levels in a manner that minimizes the economic and social cost.	Research conducted in the ACE CRC provided a major contribution to global understanding of sea-level rise, helping to establish the contribution of thermal expansion of oceans to sea-level rise, and highlighting the uncertainties in the projected contribution of Antarctic ice sheets. The sea-level rise tool (www.sealevelrise.info) provides a framework for making risk assessment decisions for coastal infrastructure. For example, ACE CRC sea-level rise research has shown that a 1cm rise in sea-level can result in a $1 million cost of making an airport runway higher. Costs not spend on over-design may be spent on more appropriate adaptation or mitigation.
ACE CRC research will provide for the development of timely ocean and sea-ice extent and thickness forecasts and analyses that will permit more efficient Antarctic shipping operations, and will improve risk management for Antarctic tourism, fisheries industries and scientific operations. A single day delayed in ice costs upwards of $50,000; and more than 10 days were lost in this way in each of the past 2 years of the Australian Antarctic Program.	The ACE CRC developed the *SeaIceViewTool* which is a flexible, intelligent, aid to viewing satellite imagery of sea-ice, enabling more efficient navigation, voyage management and science planning with potential application in both the Antarctic and Arctic regions. In November 2007, we executed a collaboration agreement with a European consortium to field-test the product in the 2007–2008 Arctic summer season. A collaboration agreement with a European consortium to field-test this product in the Arctic region was extended for another year in November 2008. Although there was a very limited specialist market for the product, it was determined that Australia's Antarctic Program would most benefit from using the tool. The tool is currently being used by Australian and European vessels to chart safe courses through Antarctic sea-ice and to select areas for collection of scientific data.

Predictions in original application	Achievement of economic, environmental and social benefits
ACE CRC research will attract and focus international efforts on the sector south of Australia, with the benefits from that research flowing to Australia. This will also result in increased operational activities, research ship visits, visiting scientists, and international conferences, with significant economic benefits to Tasmania.	At the onset of the ACE CRC, there were 11 national and 27 international collaborations on ACE CRC research. From 2003 to 2009 these have increased measurably to 27 national and 52 international collaborations. This equates to a 59% increase in national collaborations and a 48% increase in international collaborations. In the 2003-2004 financial year the Tasmanian 'Antarctic' sector was worth approximately $113.1 million to the economy. The Antarctic Expenditure Survey conducted by the Tasmanian Government revealed that the Tasmanian Antarctic sector was worth approximately $147.7M by the 2006-07 financial year. The annual growth rate in this part of the Tasmanian economy has been averaged around 6.1% per annum since the mid 1990s.
The ACE CRC will be a major centre for research on climate impacts on marine ecosystem health and it will provide the knowledge required to develop "whole-of-ecosystem" sustainable management of Antarctic marine living resources within the context of climate change and variability. This will contribute to Australian leadership as a signatory of the Convention of the Conservation of Antarctic Marine Living Resources (CCAMLR).	ACE CRC research has contributed significantly to the sustainable management of Southern Ocean fisheries. In November 2007, the results of the ACE's BROKE-West survey were used by CCAMLR to set new precautionary catch limits for the krill fishery. The ACE CRC co-sponsored the Southern Ocean Sentinel conference in April 2009 which resulted in the publication of "Southern Ocean Sentinel: an international program to assess climate change impacts on marine ecosystems" (Constable and Doust 2009). This workshop and report synthesised the current knowledge of Antarctic and Southern Ocean ecosystems and the impacts of climate change, and proposed a research framework for assessing ecosystem responses to climate change in the future. A companion workshop will be held during the ACE extension (2010-2014).

Predictions in original application	Achievement of economic, environmental and social benefits
The ACE CRC will provide leverage to ensure that an appropriate portion of international climate research efforts are focused on the Southern Ocean, and thus that Southern Hemisphere climate issues are addressed. It will provide the mechanism for Australia's Antarctic program to achieve the Government goal "to understand the role of Antarctica in the global climate system".	ACE CRC science has played an important role in highlighting the importance of Antarctica and the Southern Ocean to the global climate system. This contribution is reflected in the number of ACE scientists involved in IPCC processes (see section 2.2). The expansion of international collaborations (see above) and the expansion of international partners in the 'new' ACE CRC is a reflection of the leverage provided by ACE for Antarctic and Southern Ocean research.
The ACE CRC will promote engagement in Antarctica and the Southern Ocean as an Australian strength. The value of expanding the national social identity has been emphasized in many contexts, and this specific expansion was the subject of the year 2001 Australian Academy of Technological Sciences and Engineering Conference entitled *Looking South*. Australia has long played a strong leadership role in Antarctic affairs. For example, Australia has led the debate on mineral exploration within the Antarctic Treaty System, and whale sanctuaries within the IWC. It has championed the environmental annex to the Antarctic Treaty and has made major contributions to the precautionary approach adopted by CCAMLR. This leadership position is underpinned by Australia's reputation for high-quality science. The ACE CRC will further enhance this position by making Australia a world leader in research on the interactions and impacts of Antarctic climate and ecosystems.	The enhancement of ACE's (and Australia's) leadership and reputation for high quality science is reflected in the number of ACE CRC scientists involved in the IPCC's Fourth Assessment report (9 authors and reviewers) and invitations to participate in the 5th Assessment Report (5 lead and contributing authors).

4 Impact of Education Programs to Date

4.1 The total number of graduates and the number taking up employment in the industry/end-user sector.

From the beginning of the CRC in 2003 to its completion in December 2009, 62 students were awarded PhD or Masters degrees. The peak student numbers was 06/07 financial year when 80 students were enrolled in higher degrees.

Year	Commenced	Awarded	Total Enrolled
03/04	8	11	57
04/05	11	6	45
05/06	12	7	61
06/07	17	11	80
07/08	4	3	64
08/09	6	11	68
09	2	13	57

To the end of 2009, 44 of the 62 Higher Degree awarded students (71%) took up employment in the industry/end-user sector.

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

One of the objectives of the ACE CRC's education program was to address the long-term un-met national demand for highly-trained personnel with quantitative skills in oceanography and marine ecology.

Significant progress was made towards this objective during the life of the CRC. Two of the main ACE CRC partners (CSIRO and the University of Tasmania) combined to create a specific postgraduate training program in Quantitative Marine Science. The QMS program involved the creation and delivery of formal courses in oceanography, fisheries science and mathematics. Funds were set aside to provide scholarships for research higher degree students wishing to enter the QMS program. The program has now operated for several years and is widely considered to be successful both in attracting and training students.

The ACE CRC is closely aligned with the QMS program, through co-funding and supervision of postgraduate students and in the creation and delivery of post-graduate course work. The ACE CRC Education Program worked closely with the QMS program, with many of the projects available to QMS students supported by ACE CRC scientists.

4.3 A case study which outlines how education programs offered by the CRC have influenced the uptake of new knowledge, products or processes.

Students who have graduated from ACE CRC education programs have taken up positions far and wide, in Australia and overseas. Some of these have taken up cross-disciplinary positions which their unique ACE CRC background has well equipped them for (e.g. with the Office of National Assessments in Canberra). Graduate also work in a broad range of agencies in both State and Federal governments, in other universities, and in post-doctoral positions in institutions around the world. Of the 10 QMS students that the ACE CRC has had through the past 6 years; 6 have gained employment at various institutions in the Hobart area, specifically CSIRO Marine and Atmospheric

Research, the office of Integrated Marine Observing System at the University of Tasmania and in-house at the ACE CRC.

Of the remaining 4 QMS graduates, 3 have gained employment internationally at Princeton University and the Massachusetts Institute of Technology (MIT) in the USA, and Oxford University in the UK while the remaining student now works at the West Australian Marine Science Institute.

The ACE CRC has itself benefitted from its support of the QMS program with 2 graduates being employed in the new ACE CRC (2010-2014).

Case study: Estimating Sea-Level Extremes in an Uncertain Future

This case study, described at 3.5 above, provides a unique example of how ACE CRC research was used to define probabilistic estimates of sea-level rise. With additional funding from the Department of Climate Change and Energy Efficiency, a course in how to use the Sea-level Rise Tool was created, and the use of the tool demonstrated to over 1000 participants around Australia. CRC, ACE In the extension is considering providing on-line training in the use of the sea-level rise tool in the extension CRC.

5 Impact on Collaboration

5.1 Evidence of increased collaboration with the sector/industry, particularly between researchers and end-users.

In 2003 the ACE CRC had 11 national and 27 international collaborations. By 2009, ACE 27 national and 52 international collaborations. This equates to a 59% increase in national collaborations and a 48% increase in international collaborations.

The 'new' ACE CRC (2010-2014) attracted 23 participants, including participants from Japan, China, Germany, the United Kingdom, Belgium, Canada and the United States of America. There are also 5 commercial participants collaborating in the new ACE CRC (2010-2014).

The annual 2-day ACE CRC Symposium

The annual 2-day ACE CRC Symposium was launched in 2004 to promote a sense of community and common purpose among researchers associated with the ACE CRC, to strengthen staff and student commitment to ACE and to foster collaboration among participants. These symposia have been an outstanding success.

Table: Attendance at the annual 2-day ACE CRC Symposium

Year	**2005**	**2006**	**2007**	**2008**	**2009**
Number of people	80	94	92	86	112

The symposia are also attended by ACE CRC end users from government and industry.

Experts' Workshop on Bioregionalisation; and the Southern Ocean Sentinel

The ACE Antarctic Marine Ecosystems Program, together with the WWF-Australia, hosted an Experts' Workshop on Bioregionalisation of the Southern Ocean in 2006-2007. Information gathered from the workshop is being used to improve large-scale ecosystem modelling, ecosystem management and the development of an ecologically sound system of marine protected areas.

The ACE CRC, WWF and the Australian Antarctic Division sponsored the Southern Ocean Sentinel conference in April 2009 which resulted in the publication of "Southern Ocean Sentinel: an international program to assess climate change impacts on marine ecosystems" (Drs Andrew Constable and Susan Doust 2009). This workshop and report synthesised the current knowledge of Antarctic and Southern Ocean ecosystems and the impacts of climate change, and proposed a research framework for assessing ecosystem responses to climate change in the future. A companion workshop will be held during the ACE extension (2010-2014).

5.2 The value participants place on being part of the CRC.

The ACE CRC has provided a unique environment for sustained collaboration on research which is squarely in the national interest: Antarctica and the Southern Ocean; climate change and its impacts regionally, globally and on Australia; and the ecologically sustainability of the Antarctic region.

The value of ACE's research and the worth of its collaboration is reflected in the commitment of its core participants and the expansion of ACE's reach.

The ACE CRC third year review reflected the strong commitment of participants to the ACE collaboration concluding, *inter alia*:

- *The overall performance of the CRC is excellent.*
- *Its research is world class and consistent with international best practice.*
- *Effective collaboration across partners and disciplines is evident.*
- *Important research outcomes have already been achieved that would not have occurred without the existence of the ACE CRC.*
- *All partners are actively contributing to and committed to the ACE CRC as an organisation, and no evidence of disunity was detected.*

The core Australian research partners, the AAD, University of Tasmania and CSIRO were joined by NIWA (NZ) and the Alfred Wegener Institute (Germany) as international core partners in the new ACE CRC (2010-2014). The Department of Climate Change and Energy Efficiency became an end user essential participant and also contributes cash to the CRC. Seventeen other participants from Australia and around the globe are also participating in the ACE CRC (2010-2014).

5.3 A case study which outlines how participants working together led to an impact that would not have been achievable without the collaboration.

Case study: the SIPEX voyage

The 2007 Sea-ice Physics and Ecosystems eXperiment (SIPEX), involving 45 scientists from 12 countries, was a major collaborative, multi-disciplinary project. Led by the ACE CRC and the Australian Antarctic Division, SIPEX was a 55-day multi-disciplinary sea-ice voyage, carried out at the time of maximum sea-ice extent in East Antarctica with the aim of improving our understanding of

the relationship between sea-ice physical processes and the biological environment within and under the ice. SIPEX was conducted as part of a larger International Polar Year project titled 'Antarctic Sea-ice in the IPY' which drew together research programs across many countries. SIPEX contributed a significant amount of information from East Antarctica to this effort.

The SIPEX voyage was a major and demonstrable cross-disciplinary project which integrated physical and biological studies across major research programs in the ACE CRC, as well as providing a focus for international collaboration far broader than the ACE partnerships.

During SIPEX, scientists took a series of measurements at 15 'ice stations' in East Antarctica to describe and characterise the sea-ice environment. Each ice station took between 12-24 hours, with up to 50 scientists working on the ice floes at once. The work ranged from oceanographic measurements of the temperature, salinity and currents under the ice, to detailed electromagnetic measurements of the conductivity of the ice. Field measurements were taken of snow properties as well as sled-based radar measurements. These measurements allowed scientists to identify the snow layers that most affect the reflection of a radar signal, and to estimate snow thickness. Coupled with airborne radar and laser altimetry measurements, this information is being used to interpret satellite altimetry data and develop global ice and snow thickness information.

To understand linked physical-biological sea-ice processes, detailed measurements were made of ice properties, including ice structure, inorganic nutrient concentrations, trace elements (such as iron), and biological parameters such as ice algal biomass and species composition. In addition, Antarctic krill was sampled using trawls and camera systems under the ice.

A number of new technologies were used during SIPEX including the Surface and Under Ice Trawl, used to sample krill immediately under the ice; airborne laser and radar altimetry for measuring sea-ice 'freeboard' (height of ice above the water) and snow cover over tens to hundreds of kilometres; and instrumentation on a Remotely Operated Vehicle for exploring the presence of algae and krill immediately under the ice.

A great deal of airborne data was collected during SIPEX, including aerial photographs over sea-ice, which are archived with images from other field campaigns at the Australian Antarctic Data Centre (AADC). The laser and radar altimetry provide a reference to regional sea-ice and snow thickness in the study region. Biological data from the voyage have also been submitted to the AADC.

Twelve PhD students participated in SIPEX, working with other scientists and students in related disciplines. The *Teachers Experiencing Antarctica* program enabled two teachers to participate in the SIPEX program, and provided a direct link between scientific research in Antarctica and classrooms in Australia and around the world. A website, which was updated daily from the ship, enabled students and the general public to follow the progress of the voyage and to learn about Antarctic research first hand.

A workshop was held in Italy in March 2009 at which the results of SIPEX and all other Antarctic sea-ice research during the IPY were presented. The results of SIPEX will be published in a special volume of *Deep Sea Research II*.

The legacy of the SIPEX voyage is the enhancement of Australia’s international leadership in sea-ice research, and an increase emphasis on multi-disciplinary and collaborative research in the Antarctic sea-ice zone - a major driver of the global climate system.

6 Relationship to the new Commonwealth Agreement

6.1 Future arrangements and prospects for Activities that are uncompleted at the end of the funding period and are not being continued in the extension CRC.

The ACE CRC's uncompleted milestones are listed in the two tables below. The first table outlines milestones that are incomplete at the end of the funding period but will be continued into the extension CRC. The second table outlines the milestones which are uncompleted at the end of the funding period and their future arrangements.

Table: Output/Milestone continued into the extension CRC

Output/Milestone	Description	Details for not achieving in grant period	Extension ACE CRC Output/Milestone/Utilisation
Outcome 1: Reliable climate forecasts			
Output 1.1	Assessment of the variability of Southern Ocean currents and sea–ice	Completed sea-ice variability assessment in 2009. Analysis of 2003 data completed and published. 2007 data is currently being analysed for publication in the extension CRC's Cryosphere program.	Output 2.2: Development of improved sea-ice thickness mapping capability; validation of global satellite sea-ice mass data providing improved assessment of changes to sea-ice thickness and extent and hence total volumes.

Output/Milestone	Description	Details for not achieving in grant period	Extension ACE CRC Output/Milestone/Utilisation
Milestone 1.1.7	Assessment of variability and change of the sea-ice mass budget in the Indian Ocean sector of the Southern Ocean	Unsuitable weather during the SIPEX voyage prevented direct satellite calibration against *in situ* ice thickness measurements. This means that we cannot account for changes in the actual/*in situ* snow cover; however total thickness on tens of km-scales is expected to be comparable and provides substantial progress towards this milestone. This is a substantial contribution to our knowledge of sea-ice and its role in climate and climate change. This milestone will be completed in the Cryosphere program of the extension CRC, by developing new approaches to combine ship based and remote sensing data to derive maps of sea-ice thickness.	Milestone 2.2.10: Validated satellite and historic ship-based data used to extrapolate sea-ice thickness and its seasonal variability for all Antarctica.

Outcome 3: Sustainable management of Antarctic marine living resources			
Milestone 3.1.1	Development of under-ice remote sensing instrumentation for AUV	Project submitted through the AAD's assessment process and was highly rated and received approval. Joint proposal with UK colleagues to the UK NERC to use Autosub failed on technical grounds. Research plan was modified to proceed with other technology. Optical sensor package was purchased and tested in under-ice conditions during fieldwork (Polarstern cruise, Aug-Oct 2006). Modified research program successfully implemented in SIPEX voyage utilizing ROV replacement and optical sensors. In addition, an under-ice trawl was built by AAD to assist with under-ice sampling of krill and environmental conditions. This work will be completed in the Ecosystems Program of the extension CRC.	Milestone 2.2.4: Instrument development and filed planning completed for Autonomous Underwater Vehicle (AUV) mission. Milestone 4.2.3: Bio-optical sea-ice algal sensor and instrumental of Remotely Operated Underwater Vehicles (ROV) developed. Milestone 4.2.4: Spring field program (AUV) East Antarctica sea-ice zone conducted.
Milestone 3.1.2	Testing of the hypothesis that there has been a major change in sea-ice extent in the 1950s and 1960s using data from ice cores, sediment cores, penguin rookeries and operational data	Available data has been assembled and a workshop held in September 2005 (the East Antarctic Workshop) to begin analyses. Biological data for eastern Antarctica was more sparse than anticipated. Data available for statistical and dynamic modelling were reviewed by a joint workshop of the Scientific Committees of CCAMLR and IWC co-convened by Dr Constable in 2008. These data will be available for analyses of potential changes in eastern Antarctica. This work will be completed in the Ecosystems Program of the extension CRC	Output 4.2: Using field studies and spatial statistical analyses, evaluate the linkages between sea-ice spatial and temporal dynamics and ocean primary productivity.

Milestone 3.1.6	Development of a region-based predictive model that integrates existing climate models with higher trophic level ecosystem models	Spatially structured models have been successfully developed. A sea-ice community model has been developed and awaits coupling to a physical sea-ice model. The CCAMLR-IWC workshop on data inputs as well as the Sentinel workshop have contributed to the conceptual development of these models. The Sentinel and CCAMLR-IWC workshop reports have been published. This work will be completed and expanded in the Ecosystems Program of the extension CRC.	Output 4.1: Impact assessment of climate change and acidification on structure and function of Southern Ocean marine ecosystem. Second generation model of Southern Ocean ecosystems coupled with sea-ice, ocean and carbon models.
Outcome 5: Estimates of sea-level change resulting from anthropogenic climate change used as one of the bases for intergovernmental climate change negotiations			
Output 5.2	Revised projections for future sea-level change during the 21st century and on longer time-scales	In 2006, revised estimates for a number of the contribution to the rate of sea-level rise were completed and these were incorporated in revised projections published in IPCC AR4. The 2010 output was not completed by initial ACE CRC term. The outstanding portion of this output will be completed in the Cryosphere program of the extension CRC and will be part of future contributions to the IPCC AR5.	Output 2.1: A high resolution 3-dimensional dynamical ice sheet and ice shelf model for improved assessment of future response of the Antarctic and Greenland ice sheets to climate change. Note: as mentioned in section 2.2, Dr John Church, program leader of the ACE CRC Sea-level Rise Program, was announced as a coordinating lead author of the "Sea-level Change" chapter in the Fifth IPCC assessment report (AR5) *'Climate Change 2013: The Physical Science Basis'.*

Milestone 5.2.2	Estimate of the future contribution of the Antarctic and Greenland ice sheets to sea-level change using an improved high-resolution ice sheet-system model (including ice stream-ice shelf interaction, full thermodynamics and flow anisotropy) and changes in meteorological forcing	Model development was not completed by initial ACE CRC term. Within the 2010-2014 ACE CRC extension we will collaborate with other groups internationally who are also still working on development of the next generation of ice sheet models. The outstanding portion of this milestone will be completed in the Cryosphere program of the extension CRC.	Output 2.1: A high resolution 3-dimensional dynamical ice sheet and ice shelf model for improved assessment of future response of the Antarctic and Greenland ice sheets to climate change.
Milestone 5.2.3	Estimates of the response of ice shelves to global warming from improved models of ice shelf-ocean interaction (validated against field observations and remote sensing data from the Amery Ice Shelf); prediction, from improved models of ice stream-ice shelf boundaries, of the consequence of ice shelf collapse on the discharge of grounded ice	Definitive predictions of the response of the grounded ice sheet to changes in ice shelves was not completed by December 2009. Simulations of response of the Amery ice shelf ocean cavity to global warming have been completed, using a three dimensional ocean model. It is anticipated that offline coupling with an ice shelf model will be undertaken within the ACE CRC extension. There is international consensus that major development is required, to improve ice sheet system models to enable reliable predictions of ice sheet dynamic change. During the 2010-14 extension, the ACE CRC will increase participation in international collaborations focused on model improvement. The outstanding portion of this milestone will be completed in the Cryosphere program of the extension CRC.	Milestone 2.1.10: Model completed and run to provide ice sheet contributions to sea-level rise to 2100+ for different warming scenarios.

Outcome 6: Estimates of sea-level change as an essential input to coastal zone management and other planning considerations in Australia and in neighbouring nations in the South Pacific			
Milestone 6.2.2	Estimates of the changes in frequency of extreme events from numerical modelling studies	A method for integrating sea-level rise and storm surges into coastal risk assessment was documented in a journal article for *Natural Hazards* that appeared as a special edition on storm surge modelling. This combines hydrodynamically modelled historical storm surges with tides to estimate return periods. This was applied to the Victorian coast and studies for Tasmania will be completed by June 2010. Results for eastern Victoria considered by VCAT in relation to a planning application. Future exceedance probabilities of flooding under increased sea-level have been estimated for 29 key Australian coastal sites. The outstanding portion of this milestone will be completed in the Oceans program of the extension CRC.	Output 1.2: Probability assessment tool to assess the risk to existing or proposed coastal infrastructure from sea-level rise and extreme events and implementation of revised planning codes.
Outcome 8: Improving responses to emergent issues			
Milestone 8.1.5	Completion of project; recommendations to government	The ACE CRC will continue to provide recommendations to government in the extension CRC in forms of position analysis papers, consultation and staff briefings as vehicles to transfer scientific findings into language accessible to policy makers.	Utilisation 1.1, 2.1, 3.1, and 4.1: Position Analyses papers, consultation and staff briefings as vehicles to transfer scientific findings in language accessible to policy makers.

Outcome 9: Improved Australian influence in and effectiveness of Southern Ocean management regimes			
Milestone 9.1.4	Completion of project; recommendations to government	The ACE CRC will continue to provide recommendations to government in the extension CRC in forms of position analysis papers, consultation and staff briefings as vehicles to transfer scientific findings into language accessible to policy makers.	Utilisation 1.1, 2.1, 3.1, and 4.1: Position Analyses papers, consultation and staff briefings as vehicles to transfer scientific findings in language accessible to policy makers.

Table: Output/Milestone progressed outside the extension CRC

Output/Milestone	Description	Details for not achieving in grant period	Future arrangements
Outcome 2: Efficient, safe and sustainable operations in Antarctic waters			
Milestone 2.1.3	Operational, coupled, ocean - sea-ice analysis and forecast system	Resourcing constraints and technical issues mean full operability was not possible by end 2009. Progress on necessary components has been made and full operability is still expected post-ACE CRC. This milestone will be progressed outside the extension CRC.	This milestone will be progressed outside the extension CRC.
Outcome 5: Estimates of sea-level change resulting from anthropogenic climate change used as one of the bases for intergovernmental climate change negotiations			
Milestone 5.1.2	Revised estimates of ocean thermal expansion from observations and models (both the CSIRO and AWI models)	Revised observational estimates have been published in Nature and at various international conferences. Revised model estimates will not be completed before the end of the ACE CRC but will be part of future contributions to the IPCC AR5. The outstanding portion of this milestone will be completed outside the extension CRC.	Dr John Church, previously the program leader of the ACE CRC Sea-level Rise Program, was announced as a coordinating lead author of the "Sea-level Change" chapter in the Fifth IPCC assessment report (AR5) *'Climate Change 2013: The Physical Science Basis'.*
Milestone 5.2.1	Revised estimates of future ocean thermal expansion	Revised model estimates have not been completed before the end of the ACE CRC but will be part of future contributions to the IPCC AR5. This output will be completed outside of the extension CRC.	Dr John Church, previously the program leader of the ACE CRC Sea-level Rise Program, was announced as a coordinating lead author of the "Sea-level Change" chapter in the Fifth IPCC assessment report (AR5) *'Climate Change 2013: The Physical Science Basis'.*

6.2 Details of any additional work that may be undertaken to further develop or commercialise the completed outputs of the CRC that are not being further pursued in the extension CRC.

There is no additional commercial development of completed outputs outside the extension CRC.

6.3 The level of expected future economic, environmental and social benefits from any Activities that have been completed and are not being further pursued in the extension CRC.

The 'public good' nature of the research conducted through the ACE CRC means that its major end-users were Australian Government Departments and Agencies, local government, international bodies, the broader research community and the general public. Much of the benefit of ACE research, including from activities that have been completed and not pursued in the extension CRC will derive from enhanced understanding of the course of climate change in Antarctica and the Southern Ocean, for Australia, and globally.

7 Concluding remarks

The ACE CRC performed very strongly from 2003 to 2009. The value that the partners placed on the CRC is reflected in the membership of the extension CRC and the commitment of its partners to the extension. That the extension CRC was able to bring in new partners, including new commercial participants, is testimony to both the importance of the work done by this largely public good CRC, and the engagement of ACE with the commercial sector following the third year review.

The CRC has delivered critical climate science into Australian governments and internationally and ACE leadership in science is evident by the high standing of its researchers. The primary economic benefit of ACE's research is derived from the cost savings to governments, industry and society as a result of timely and accurate climate projections, including, for example, for sea-level rise.

The Economic Impact Prediction Tool used for the ACE CRC extension application (2010 -2014) clearly demonstrated the economic, environmental and social benefits of ACE research and the substantial contribution this research has to future decision making. The benefits were quantified conservatively at around $219 million based on net present value at 2009, for a funding period of 5 years. This figure is equally applicable to the work of the ACE CRC from 2003-2009.

The challenges that climate change brings to the environment and to national and global economies are enormous. The science that the ACE CRC is engaged in is critical to charting the path and pace of climate change. It is only with improved understanding of the underlying science that rational mitigation and adaptation decision can be made. ACE research has provided fundamental building blocks of that understanding.