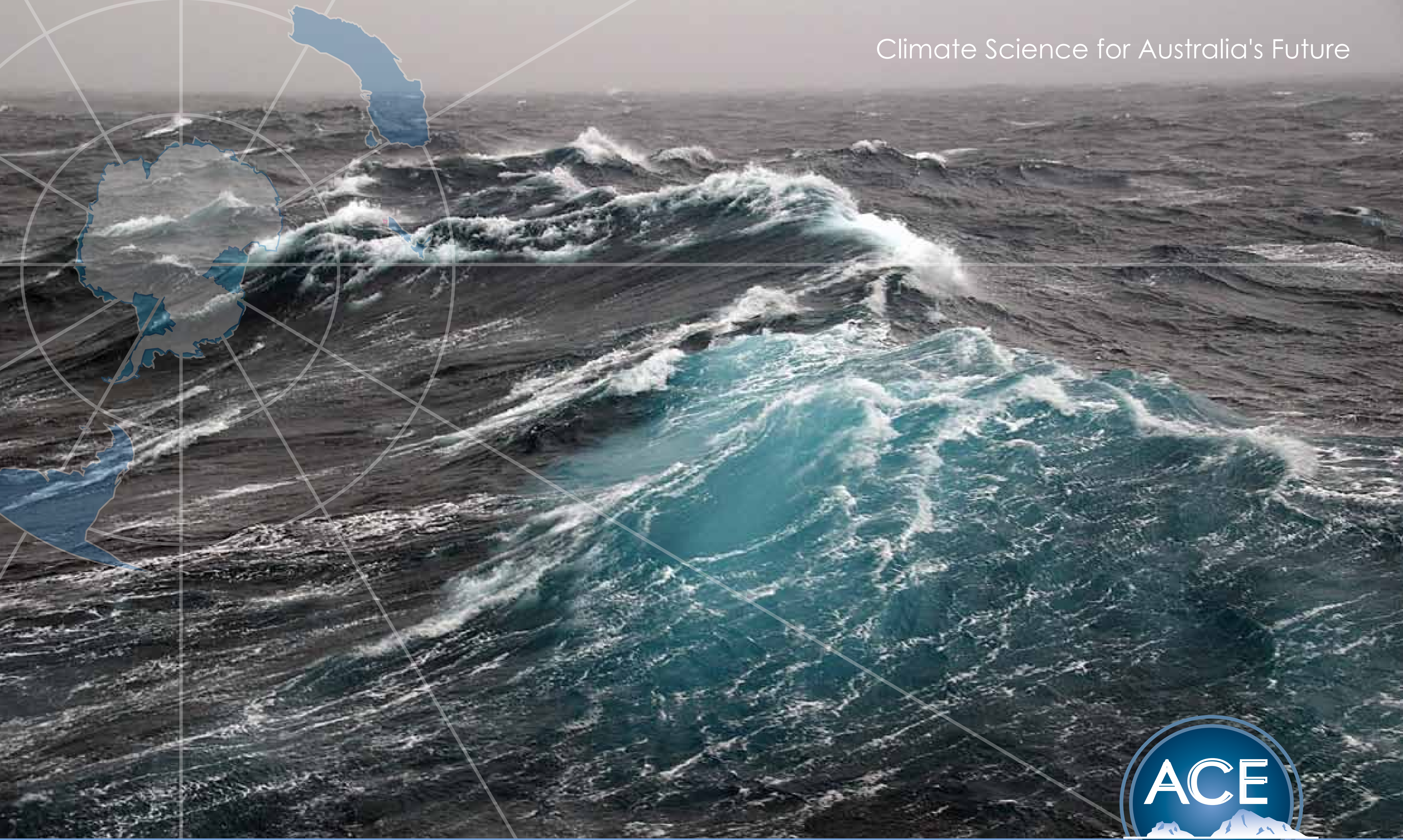
Climate Science for Australia's Future



REPORT CARD
Southern Ocean Acidification

ANTARCTIC CLIMATE & ECOSYSTEMS CRC

PHOTO 2

This cold-water coral reef was recently discovered 800m below the ocean surface on the edge of the Antarctic continental slope. The corals are comprised of aragonite and will be amongst the first organisms to disappear if ocean acidification increases.

ACE CRC Report Card
Southern Ocean Acidification

Introduction

There is now a clear scientific consensus that the increasing volume and rate of our carbon dioxide (CO_2) emissions are causing rapid and unprecedented changes in our oceans. These will have potentially serious impacts within the 21st century, for the sustainability and management of many marine and coastal ecosystems.

Ocean acidification science is rapidly evolving. Since the ACE CRC Position Analysis on ocean acidification was released in 2008[1] significant advances in knowledge have been achieved, including by ACE CRC researchers in the Southern Ocean.

The aims of this document are:

1. To update the Australian Government on the latest developments in ocean acidification scientific research, highlighting the ACE CRC's efforts and niche in this rapidly expanding research arena since the first Position Analysis;

2. To outline the likely impacts of increased carbon dioxide absorption on the Southern Ocean in particular; and

3. To identify issues for Australia's consideration in future policy development.

Ocean acidification 101

Ocean acidification is the name given to the ongoing decrease in the pH of the world's oceans, caused by their uptake of anthropogenic carbon dioxide from the atmosphere.

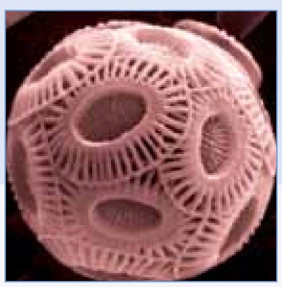
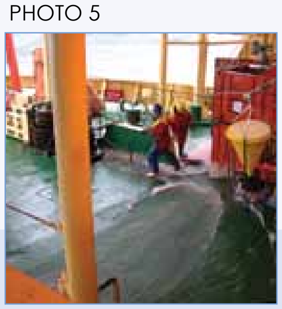
The term pH is short for potentiometric hydrogen ion concentration, ie the concentration of hydrogen ions in a solution. The value assigned is measured on a logarithmic scale which means that a drop in pH of 1 unit eg from 8 to 7, represents ten times the increase in hydrogen ions.

When carbon dioxide dissolves in seawater it forms weak carbonic acid that rapidly releases a hydrogen ion and a bicarbonate ion.

The hydrogen ions generated make the ocean more acidic (ie lower the pH) and some react with carbonate ions to produce more bicarbonate ion.

Thus, the net effect of increasing carbon dioxide in seawater is to increase concentrations of hydrogen ions, carbonic acid and bicarbonate while decreasing concentrations of carbonate ions making it more difficult for marine organisms to produce calcium carbonate shells.

In addition to direct impacts on marine calcifiers, other equally concerning impacts of increasing carbon dioxide in our oceans are emerging, including: the influence of ocean chemistry on trace metal availability to organisms, combined effects of carbon dioxide with temperature and oxygen on zooplankton metabolism, egg and sperm motility and fertilisation success, settlement and recruitment success for fish larvae, pheromone-like communication and behaviour cues for fish, and reduced sound absorption and thus a noisier ocean that may affect mammals and other animals that communicate acoustically.

The Issue	What we know	What we don't know	What we're doing	What's at stake	Online Links
• Ocean acidification  PHOTO 3	• The global ocean currently absorbs one-quarter of the anthropogenic CO_2 added to the atmosphere each year[2,3]. • Of the anthropogenic CO_2 emissions absorbed by the world's oceans, the Southern Ocean absorbs over 40%.	• Whether the Southern Ocean will continue to absorb the same proportion of anthropogenic CO_2 in future. • Where and when new additions of CO_2 will combine with naturally varying distributions of CO_2 in the ocean to regionally amplify acidification (e.g. the Ross Sea may experience delayed impacts)[35].	• Quantifying Southern Ocean processes that influence the uptake of CO_2. • Measuring and monitoring Southern Ocean carbon chemistry and ocean-atmosphere interaction.	• The continued climate mitigation service of the global ocean: - Atmospheric CO_2 levels are tempered by the oceanic uptake of CO_2 i.e. without the ocean current atmospheric CO_2 concentration would be would be ~450 ppm[36] instead of ~387 ppm[37]. - This hidden ocean 'service' has been estimated to represent an annual subsidy to the global economy of US$60 – US$400 billion per year[38].	• Global Carbon Project 2008: www.globalcarbonproject.org
 PHOTO 4	• The uptake of CO_2 into the ocean is driving a change in ocean chemistry: lowering ocean pH[5] and the concentration of carbonate ions[6] available to organisms that build calcium carbonate shells or skeletons (known as calcifiers).	• How Southern Ocean non-calcifiers will respond to changes in CO_2, pH and carbonate ion availability. • How acidification will interact with other ocean variables likely to change in the future (e.g. temperature and oxygen).	• Studying past, present and likely future impacts of ocean acidification on Southern Ocean organisms including: - pteropods and deep-sea corals (aragonite calcifiers) and - foraminifera and coccolithophores (calcite calcifiers).	• The role of Southern Ocean calcifiers in the global carbon cycle.	• Royal Society Report 2005: royalsociety.org/Ocean-acidification-due-to-increasing-atmospheric-carbon-dioxide/
 PHOTO 5	• Some calcifiers are more at risk than others: shells can be made from aragonite or calcite (and aragonite is more easily dissolved than calcite)[7].	• How calcifiers made from aragonite and calcite will respond to changes in pH and carbonate ion availability.		• Fossil fuel CO_2 emissions are currently tracking above all scenarios used by the IPCC[39]. If this trend in emissions continues, organisms would be subject to the lowest ocean pH experienced in the past ~20 million years by 2300 and the rate of fall in pH may possibly be the most rapid ever experienced[40].	• Ocean Acidification 2007: www.abc.net.au/catalyst/stories/s2029333.htm
 PHOTO 6	• Continued acidification will push the ocean towards chemical compositions not seen for a long time[8]: - pre-industrial pH was 8.2[9] - current average pH is 8.1[10] - we expect a drop to 7.8 by 2100 under 'business as usual' CO_2 emissions[11].	• What areas of the Southern Ocean are most at risk of continued ocean acidification.	• Developing comprehensive Southern Ocean ecosystem models to illuminate: - populations at risk, - communities at risk, and - regions at risk.	• The health and function of ocean ecosystems in vastly more acidic waters.	• CO_2 emissions and trends 2008: www.globalcarbonproject.org/carbonbudget/index.htm
 PHOTO 7	• Polar pH is changing at twice the rate of tropical waters[12].	• What the rate of acidification will be in Southern Ocean waters.		• Polar ecosystems are forecast to be among the first to be affected by acidification[41].	• High Latitude Acidification 2009: tos.org/oceanography/issues/issue_archive/issue_pdfs/22_4/22-4_fabry.pdf

Impacts on Southern Ocean organisms

Ocean acidification is expected to impact on micro-organisms such as phytoplankton and zooplankton first. The impacts felt at this level feed up through the food web to higher trophic levels such as fish, birds and mammals. Here we summarise the current state of knowledge on the impact of ocean acidification on all trophic levels in the Southern Ocean in turn for both calcifying and non-calcifying organisms. We currently know most about the likely effects of ocean acidification on calcifying organisms as the bulk of our efforts have been directed to these 'sentinel' organisms. We note, however, that there is increasing concern that ocean acidification could affect the non-calcifying species. Non-calcifying phytoplankton (diatoms and flagellates) and non-calcifiying zooplankton (copepods and krill) dominate the Southern Ocean ecosystem and the mechanisms of impacts of acidification on these and other higher trophic levels, such as fish, remains a serious gap in our knowledge.

Southern Ocean calcifiers	What we know	What we don't know	What we're doing	What's at stake	Online Links
• Calcifying Phytoplankton - coccolithophores  PHOTO 8	• Coccolithophores show both negative and positive responses to ocean acidification in laboratory experiments[13,14]. • The Southern Ocean coccolithophore Emiliania huxleyi appears to be shifting its habitat south due to environmental pressures[15].	• How Southern Ocean coccolithophores respond to changing atmospheric levels of CO_2. • Whether effects measured in laboratory studies differ due to experimental design (e.g. pH can be changed experimentally using CO_2 gas or by introducing acid).	• Studying the natural variability of Southern Ocean coccolithophores since the last glacial maximum. • Following best practice guides for ocean acidification methods that have been recently established.	• *Emiliania huxleyi* is one of the most prominent producers of calcium carbonate in the world's ocean[13]. Increasing CO_2 can stimulate their growth through enhanced photosynthesis or hamper growth through enhancing dissolution of their calcium carbonate shells. As they play a significant role in regulating marine carbon cycling and atmosphere - ocean CO_2 exchange[42] their likely response to future ocean acidification is of the utmost importance.	• Coccolithophores 2010: earthobservatory.nasa.gov/Features/Coccolithophores/ • Guide to Best Practices 2010: epoca-project.eu/
• Calcifying Zooplankton - foraminifera - pteropods	• Some species of modern planktonic foraminifera in the Southern Ocean have 30-35% lighter shell weights than their counterparts from pre-industrial times[16].	• How calcifiers such as pteropods will respond to ocean acidification in the Southern Ocean (as they are made of a more soluble form of calcium carbonate than foraminifera).	• Investigating the impacts of ocean acidification on pteropod shells. • Monitoring plankton and calcifier biodiversity in the Southern Ocean.	• Shelled zooplankton play important roles in the Southern Ocean food web as well as transporting atmospheric carbon to the deep ocean on their death[43]. Models predict the Southern Ocean will become unstable for pteropod shell production as early as 2030[41].	• Southern Ocean Sentinel 2010: www.abc.net.au/catalyst/stories/2886137.htm
• Southern Ocean Corals	• Cold-water corals are likely to experience difficult water chemistry conditions by 2100[10] (some as early as 2020[17]). • Some Mediterranean corals survive in a different form, i.e. adapt, in undersaturated waters[18].	• Whether Southern Ocean corals respond to acidification in the same way and at the same rate as tropical corals. • Whether Southern Ocean corals are able to adapt to undersaturated waters.	• Investigating the distribution of Southern Ocean corals above and below the current aragonite saturation horizon in the Southern Ocean.	• Warm water corals are important fish habitats and have been demonstrated to be very susceptible to ocean acidification[44]. Little is known about the potential impacts of acidification on coldwater coral-associated fish[45].	• Acid Test – can we save our oceans from CO_2? 2009: na.oceana.org/sites/default/files/reports/Acidification_Report1.pdf

Southern Ocean non-calcifiers	What we know	What we don't know	What we're doing	What's at stake	Online Links
• Bacteria	• A substantial fraction of the organic carbon in the oceans depends upon breakdown by heterotrophic bacteria[19].	• Whether ocean acidification will impact bacterial processes and/or role in the marine ecosystem.	• Investigating impacts of ocean acidification on key members of the Southern Ocean community such as: - bacteria, and	• Changes in bacterial activity and growth efficiency can profoundly affect the oceanic net carbon balance.	• Ocean Acidification Effects on Cyanobacteria 2010: www.co2science.org/subject/o/summaries/acidificationcyano.php
• Phytoplankton - diatoms	• Growth of some diatoms are enhanced with increasing CO_2 in lab experiments[20] although other researchers have found CO_2 enhanced productivity to be nutrient dependent[21].	• Whether non-calcifying phytoplankton will have a competitive advantage in a high CO_2 ocean.	- phytoplankton through mini-cosm experiments.	• Diatoms contribute about half of all marine primary production and are known to actively take up CO_2 for photosynthesis[46].	• Ocean Acidification Effects on Diatoms 2010: www.co2science.org/subject/o/summaries/acidificationdiatoms.php
• Zooplankton - krill - copepods  PHOTO 9	• Antarctic krill *Euphausia superba* show impaired embryonic development at high CO_2 levels[22]. It also appears that survival and recruitment of early larval stages would be significantly reduced under elevated CO_2[23]. • In contrast to krill studies, high CO_2 exposure did not significantly affect survival, body size or developmental speed of the copepod Acartia tsuensis [24].	• Whether all life stages of krill respond negatively to high CO_2 concentrations. • Whether copepods will have a competitive advantage in a high CO_2 ocean.	• Investigating the effects of acidification on the survival and development of all life stages of Antarctic krill. • Determining Antarctic krill growth, recruitment and survival.	• Changing krill distribution is expected to impact predators including seals, penguins and whales[34]. • Planktonic copepods compose the bulk of the biomass in most pelagic zooplankton communities and are an important food source for higher trophic organisms including krill and fishes[24].	• The world's most abundant crustacean 2010: www.antarctica.gov.au/science/southern-ocean-ecosystems/krill
• Fish	• Tropical juvenile clownfish olfactory (smell)senses are detrimentally affected as the acidity of seawater increases[25] and larval fish survival to adulthood is dramatically decreased by ocean acidification[26].	• Whether ocean acidification will impact upon Southern Ocean fish behaviour or population structure.	• Determining effects of ocean acidification on lower trophic levels likely to impact fish populations.	• Replenishment of fish stocks requires successful recruitment from larval to adult stage. Additional CO_2 absorbed into the ocean reduces recruitment success and has far-reaching consequences for the sustainability of fish populations.	• Ocean Acidification Effects on Fish 2010: www.co2science.org/subject/o/summaries/acidfish.php
• Birds & Mammals - penguins - seabirds - seals - whales	• We know that seabird and penguin breeding success is diet dependent[27]. • A more acidic ocean will be a noisier place for whales[28,29].	• How impacts on krill, phytoplankton and zooplankton will be felt by higher trophic levels.	• Documenting foraging, population and reproductive success for: - penguins - seabirds - seals and - whales.	• Projected future CO_2 emissions[28,29] imply significant increases in noise within the auditory range critical for environmental, military, and economic interests.	• A noisier ocean at lower pH 2010: www.nature.com/ngeo/journal/v3/n1/full/ngeo719.html

Impacts on Southern Ocean ecosystems

There is increasing concern that ocean acidification could affect the functioning of whole marine ecosystems, and particularly polar ecosystems. However, the mechanisms by which population impacts will occur have not been identified. The majority of our research to date has been laboratory-centric, making it difficult to extrapolate single-species impacts into whole of natural ecosystem settings. The best analogues we have for high-CO_2 ocean environments are natural marine ecosystems near volcanic vents. These ecosystems point the way toward dramatically different ecosystems once pH drops below 7.8.

Southern Ocean ecosystems	What we know	What we don't know	What we're doing	What's at stake	Online Links
• Ecosystem Structure  PHOTO 10	• Naturally high CO_2 marine environments elsewhere in the world exhibit major shifts in marine ecosystem structure as pH drops[30]. • In one study, the tipping point for structural change appears to be at a pH of 7.8[30]. Southern Ocean ecosystems may be more or less sensitive.	• How changes in populations and communities of both calcifying and non-calcifying organisms will impact the greater Southern Ocean ecosystem structure. • What impacts ocean acidification will have on higher trophic levels (e.g. fish). • Whether ocean acidification will act with or against multiple stressors (e.g. temperature).	• Investigating impacts of ocean acidification on key members of the Southern Ocean community (such as phytoplankton) through mini-cosm experiments.	• Decreases in carbonate ion availability are likely to compromise the fitness of calcifiers and could shift the ecological and evolutionary competitive advantage to non-calcifying organisms[45].	• Ocean Acidification Network: www.ocean-acidification.net
• Ecosystem Function  PHOTO 11	• Calcifiers are important components of the Southern Ocean carbon cycle as they transport carbon to the deep ocean[31,32] and contribute to the regulation of marine carbon cycling and the exchange of CO_2 between the ocean and atmosphere[33]. • The organisms at risk of acidification in the Southern Ocean are important components of the food web, as they are prey for higher trophic level species including krill, Antarctic fur seals, Adelie penguins and whales[34].	• Whether ocean acidification will affect processes and functions other than calcification (e.g. reproduction rates). • How impacts on non-calcifying organisms will change the Southern Ocean ecosystem. • How impacts on keystone species such as krill will then impact upon higher trophic levels (e.g. seals, whales and seabirds) and ecosystem services (e.g. fisheries).	• Addressing the Southern Ocean's role in global ocean circulation and ecosystem processes. • Quantifying trophic links in Antarctic marine predators. • Documenting foraging behaviour, population trends and reproductive success for penguins, seabirds, seals and whales.	• The full impact of ocean acidification on organisms is still in its infancy. We are not yet able to predict how impacts may propogate through marine ecosystems to ultimately effect higher trophic levels (e.g. fish) and the climate services the ocean provides us (i.e. continued absorption of a significant proportion of atmospheric CO_2)[45]. • We don't know how impacts will be felt in the natural setting on non-calcifying organisms and as these organisms hold important places in the Southern Ocean food chain (e.g. sea ice diatoms and krill) this of serious concern.	• Guide to Ocean Acidification for Policy Advisers and Decision Makers 2009: epoca-project.eu/index.php/what-do-we-do/outreach/rug/oa-the-facts.html • Ocean Acidification Questions Answered 2010: epoca-project.eu/index.php/what-do-we-do/outreach/rug/oa-questions-answered.html

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ANTARCTIC CLIMATE
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ACE CRC Report Card

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RC01-101123
ISBN: 978-1-921197-12-3

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

The ACE CRC is a unique collaboration between its core partners the Australian Antarctic Division; CSIRO; University of Tasmania; the Australian Government's Department of Climate Change and Energy Efficiency; the Alfred-Wegener Institute for Polar and Marine Research (Germany); and the National Instute of Water and Atmospheric Research Limited (New Zealand) and a consortium of supporting partners.

PHOTOS

FRONT COVER PHOTO Steve Rintoul (CSIRO): The Southern Ocean.
PHOTO 2. Martin Riddle (Australian Antarctic Division): Cold-water coral reef, recently discovered 800m below the ocean surface on the edge of the Antarctic continental slope.
PHOTO 3. ACE CRC: Deploying sediment trap in the Southern Ocean aboard the Aurora Australis.
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