Australian Government
Department of the Environment
Bureau of Meteorology

CSIRO

Australian Climate Change Science Programme

Ocean acidification coordination meeting: summary report

18 February 2014, CSIRO Marine Laboratories, Hobart

The Australian Climate Change Science Programme (ACCSP) convened a meeting of Hobart-based ocean acidification (OA) researchers to with a view to sharing information, taking stock of research activities, encouraging collaboration and identifying important future research objectives.

The **context** for the meeting was set by Anthony Swirepik from the Department of the Environment and Libby Jewett, Director of the Ocean Acidification Program at the National Oceanic and Atmospheric Administration (NOAA) in the US.

Meeting attendees gave a series of presentations on work being carried out by CSIRO, the Antarctic Climate & Ecosystems Cooperative Research Centre (ACECRC), the Australian Antarctic Division (AAD) and University of Tasmania (UTAS). These presentations addressed two broad areas of OA research: **understanding the physical and chemical systems** and **understanding impacts on ecosystems**.

The meeting highlighted the fact that the Australian OA research community is maximising its limited resources and funding through collaboration and leverage from other programs and international partners.

The key challenges in OA research identified at the meeting were the highly variable nature of the systems being investigated and the difficulties associated with the complexities of multi-stressor impacts.

A brief summary of each presentation and the concluding discussion follows. More detailed information is available from each of the presenters.

Meeting participants: Mark Baird (CSIRO); Phil Boyd (UTAS); Ian Cresswell (CSIRO); Paul Holper (CSIRO); Catriona Hurd (UTAS); So Kawaguchi (AAD); Libby Jewett (NOAA); Andrew Lenton (CSIRO); Richard Matear (CSIRO); Karen Pearce (Bloom Communication); Donna Roberts (ACECRC/UTAS); Elizabeth Shadwick (UTAS/ACECRC); Andy Steven (CSIRO); Anthony Swirepik (Department of the Environment); Ron Thresher (CSIRO); Bronte Tilbrook (CSIRO/ACECRC); Tom Trull (UTAS); Karen Westwood (AAD).

CONTEXT

Australian policy context | Anthony Swirepik, Department of the Environment

The Australian Government, through the Department of the Environment, funds research into a range of climate change science priorities in line with the national framework for climate change science. In implementing this framework, a high level coordination group for climate change science in Australia was established to:

- develop a single integrated program to address national climate change science priorities
- coordinate the delivery of climate change research across agencies and research domains in a funding-restricted environment.

In this context, the Australian Government is keen to develop an ocean acidification research community to leverage resources and funding. It is envisaged that initially the focus of the collaboration will be on Hobart-based ocean acidification research teams within CSIRO, ACECRC and AAD to ensure:

- efficient and effective use of resources in an environment of restricted funding
- research is targeted on agreed science priorities.

In the future, this collaboration will be extended to connect Hobart-based ocean acidification researchers to other research teams around Australia to develop a consistent and coherent story across the community.

Key ocean acidification policy questions

- How will changing ocean carbon chemistry affect key marine species?
- Will the Southern Ocean continue to act as a sink and absorb carbon dioxide?
    - What impact will this have on the physical system and on ecosystems?

Global OA community context | Libby Jewett, NOAA

NOAA OA Program

NOAA established its Ocean Acidification Program (OAP) in 2011, as a result of legislation passed by US Congress. The legislation offers the program funding security, but it is only a small program and it relies on leverage partnerships with other programs in NOAA. The OAP funds approximately 50 different projects being undertaken by researchers from NOAA and universities. The projects range from monitoring efforts and assessing biological impacts through to bio-socioeconomic modelling, and are delivered through six themes:

1. Monitoring – receives half the program’s funds; network of dedicated OA research cruises, ships of opportunity equipped with autonomous underway OA sensors and 12 fixed OA moorings around the continental US, Hawaii and Alaska.
2. Biological and ecosystem response – research conducted at NOAA’s fisheries laboratories and in coordination with universities and other research institutes.
3. Data management
4. Modelling – this work includes development and use of models to improve understanding of OA impact on coastal fisheries, food-web models, and economic forecast models to analyse the economic impacts of changes to fisheries.
5. Adaptation strategies

6. Education and outreach – vitally important to increase public awareness and understanding of OA; among other avenues, the program works with aquaria, NGOs, etc to ensure they have the latest science in the most useful format for their audiences/uses.

The Wendy Schmidt Ocean Health XPrize is a potential source of new instrumentation for OA research. The US Government has shown some interest in the prize format as a model for developing new technology and getting networks talking about major issues.

OA International Coordination Centre

The Ocean Acidification International Coordination Centre (OA-ICC) has been established at the International Atomic Energy Agency (IAEA). Based at the IAEA environmental laboratories in Monaco, the OA-ICC works to works to 'promote, facilitate and communicate global activities on ocean acidification. One role of the OA-ICC is to work on protocols for experimental data'. Other roles are still being determined, but it is likely that the OA-ICC will be around for the next couple of years.

Global OA Observing Network

The Global Ocean Acidification Observing Network (GOA-ON) has been established to coordinate and expand OA-related observing worldwide, not only in international waters but also in national waters/along coastlines.

The goals of GOA-ON are to provide:

1. An understanding of global OA conditions
2. An understanding of ecosystem responses to OA
3. The data necessary to model OA

GOA-ON also aims to broaden global knowledge of the OA threat.

The network has a nested system design, with pursuit of the three goals being across the open ocean, coasts and shelf seas, and coral reefs occurring at three levels:

- *Level 1:* critical minimum measurements (operational measurements applied to *document* OA dynamics).
- *Level 2:* an enhanced suite of measurements that further promote understanding of the primary mechanisms (including biologically mediated mechanisms) governing control of ocean acidification dynamics (operational measurements applied towards *understanding* OA dynamics).
- *Level 3:* Opportunistic or experimental measurements that may offer enhanced insights into OA dynamics and impacts (non-operational measurements under *development* that may be later adapted to Level 2).

GOA-ON is using various platforms, including ship-based surveys and volunteer observing ships; moorings and piers; and gliders and floats.

Next on the agenda for GOA-ON is:

- Reviewing the GOA-ON plan
- Recruiting new members and providing capacity building
- Checking platforms to see if data is meeting requirements
- Planning the next GOA-ON workshop to be held in 2015 – possibly in Australia.

UNDERSTANDING THE PHYSICAL AND CHEMICAL SYSTEMS

Seawater carbonate chemistry and ocean acidification | Bronte Tilbrook, CSIRO/ACECRC

This research focuses on detecting the change in the state of the carbonate chemistry for Australian regional seas and the Southern Ocean, and the influence this has on OA. The data contributes to many impacts groups and to international programs to document change in the ocean. It is also used for the development of data products and synthesis efforts (maps, etc.). For instance, ACCSP-funded carbonate chemistry research in Bass Strait is feeding into carbon capture and storage investigations in the Gippsland basin. The project is also a contributor to international efforts to develop observing system networks, taking a lead role in the Australian region.

Observations are made through ships of opportunity, deep ocean sections, IMOS reference sites, and moorings at sites all around Australia. The Southern Ocean effort includes sampling in high latitude shelf waters, underway measurements and deep ocean sections that are the baseline for detecting broad scale in ocean acidification. (Key aspects of the Southern Ocean work are covered in the presentation by Elizabeth Shadwick.)

Another focus area is the Great Barrier Reef (GBR), a region considered particularly at risk to OA. To understand the exposure and vulnerability of the GBR to OA we need to:

- determine the regional variability in the carbonate chemistry for the GBR and drivers.
- detect acidification change and establish ways to detect the response of ecosystems at reef to whole-of-GBR scales.

In particular we need to understand the influence of:

- source waters (Coral Sea)
- coastal inputs (e.g. sediments, estuaries)
- GBR shelf (reef and inter-reef regions)

Coral Sea studies are being assisted by observations from *Trans Future 5,* which sails through the region every six weeks from Japan. The carbonate chemistry of the shelf and insights into the role of coastal inputs is being investigated using a Rio Tinto ship, *RTM Wakmatha*, which collects data on its regular voyages each month between Weipa and Gladstone. Detailed sampling is also occurring at an IMOS national reference site in the central GBR (Yongala) and at Heron Island in the south GBR.

Modelling and observational work being undertaken on Heron Island is crucial to understand reef functioning. This work is aimed at:

- representing the circulation and biogeochemistry in and around Heron Island
- integrating modelling and observational approaches to determine calcification and production at whole-of-reef scales
- developing parameterisations of production and calcification of the various benthic communities in reef environments
- providing a foundation to simulate future change in OA and the range of responses likely in the reef ecosystem under changed environmental conditions
- developing tools to refine observations and modelling approaches to detect how calcification and production apply the same approaches and apply to the whole GBR (e.g. see the presentation by Mark Baird).

Comparison of Arctic and Antarctic vulnerability to ocean acidification and new perspectives from the Southern Ocean | Elizabeth Shadwick, UTAS/ ACECRC

Research comparing coastal regions of the Western Arctic and Arctic Archipelago with coastal conditions around Antarctica (excluding the Antarctic Peninsula) found major differences between the two systems. The Arctic showed lower salinity and alkalinity, larger seasonal warming, larger biological production and smaller seasonal increases in pH and Ω.

Natural variability is very large in these (undersampled) systems, so there needs to be caution about attributing changes to anthropogenic forcing.

These observations were made in summer, the least vulnerable season, and changes detected are only over a season/short-term event. For year round observations we need to move to autonomous systems. There is an opportunity for Australian/US leadership in West and East Antarctica – where the longest historical records of carbon dioxide system observations exist.

Marine and Coastal Carbon Biogeochemistry Cluster | Andy Steven, CSIRO

Australia's coasts are biodiverse, highly productive, a significant store of carbon, undergoing significant change and largely un-quantified and unaccounted for. The Marine and Coastal Carbon Biogeochemistry Cluster (Coastal Carbon Cluster) brings together CSIRO, seven Australian universities and the Australian Institute of Marine Science to better parameterise this biogeochemistry.

CSIRO's interest is developing improved marine carbon modelling, by:

1. Developing accurate, daily national-scale marine productivity services
2. Developing climate and biogeochemical marine models that can accurately represent changes in carbon dioxide emissions on carbon cycling, including the potential for ocean acidification.
3. Developing ecological models to evaluate how changes in carbon cycling may affect ecosystem services.
4. Evaluating the use of natural- based carbon storage mechanisms, including blue carbon.

The strategy for linking observations and modelling is:

1. More efficient and effective observations
2. Data model assimilation
3. Model coupling and orchestration
4. Ecosystem models
5. Management strategy evaluation
6. Data access and effective communication.

There are four work programs in the Cluster:

1. Carbon sequestration, stoichiometry and stores potential of Australian coastal ecosystems
2. Benthic community metabolism and benthic-pelagic coupling
3. Pelagic community metabolism in Australian coastal waters
4. Scaling up to regional inventories and data assimilation and parameter and model uncertainties.

Carbon chemistry research in the CSIRO coastal environmental modelling team | Mark Baird, CSIRO

The CSIRO coastal environmental modelling suite consists of:

- a hydrodynamic model
- spectrally-resolved optics
- benthic ecology (multiple seagrass types, macroalgae, benthic microalgae and corals)
- OCMIP carbon chemistry routines
- gas exchange calculations.

Modelling is being used to understand how carbon chemistry relates to circulation on the Great Barrier Reef (Heron Island). Work on model parameterisation is still underway, but the modelling is helping resolve a lot of processes that we can't see, and provides the opportunity to make measurements without having to go and do transects.

OA research on Heron Island shows that when the water has spent a long time on the reef, the carbon chemistry has been changed further from ocean conditions.

Modelling carbon chemistry in the boundary layer surrounding photosynthesising, respiring and calcifying organisms has showed that microalgae experience a different pH to bulk pH, and that the difference depends on both the size of the plankton (larger being greater), and the pH in the bulk medium. This effect has been experimentally shown to be more pronounced for benthic plants. Using a future scenario with more acidic bulk sea water pH, there is a greater increase in pH. Decreased buffering of seawater in another consequence of ocean acidification.

Large scale modelling of ocean acidification | Andrew Lenton, CSIRO

Historical changes in ocean acidification around Australia

A reconstruction of the data set of observed changes in ocean acidification around Australia since the re-industrial (1870: 288 ppm) to present day (2011) suggests that GLODAP data overestimate aragonite saturation state to the north of Australia. This is important because all CMIP5 products use GLODAP, so the mean state is biased (although trends are comparable).

Quantifying the impacts of ocean acidification on our future climate

ACCSP funded work using Earth system modelling to investigate how the features of the carbon chemistry system act together has found that direct carbon impacts are very small in response to OA but there are large biogeochemical changes such as carbon export in the north Pacific and Southern Oceans, with impacts on oxygen and trophic levels. Direct carbon feedback isn't large but consequences will be when carbon changes seawater chemistry. Consequences of OA will be felt not through climate change, but through the flow of energy in the marine ecosystem affecting productivity, composition and diversity.

Projected impacts of ocean acidification and warming on corals

Work through the Pacific-Australia Climate Change Science and Adaptation Planning program (PACCSAP) has developed a new model linking OA and coral bleaching through calcification rates. This has not been done before. The work focuses on Earth system models' (CMIP5) projections of future changes (monthly scale, 1˚´ 1˚) and hasn't accounted for depth profiles or different species (this is to come), but found SST is the big factor in harming corals in the short to medium term. While there is little evidence for coral dissolution due to OA by the end of the century, OA impacts the resilience of coral to other environmental stressors.

UNDERSTANDING IMPACTS ON ECOSYSTEMS

Ocean acidification and other environmental stressors on marine systems | Phil Boyd, UTAS

OA research has been at the vanguard of examining environmental stressors on marine systems. It is important to be aware of increasing complexity of biological and environmental responses when we're looking at OA – it is not the only factor that influences marine systems. There are dangers of misattribution of responses, with some features acting independently while others have very complex effects and interactions. Investigations of multiple stressors on marine systems need to adopt a slow and sure approach that takes in the system complexity and doesn't assume linear/causative relationships.

Effects of ocean acidification on Antarctic marine protists | Karen Westwood, AAD

There is an increased risk of OA in Antarctic waters due to higher carbon dioxide solubility in colder water. There are also large annual variations in carbon dioxide in Antarctica, ranging from <100 ppm in spring/summer to >450 ppm below the sea ice in winter. Given this wide range we might expect some resilience in response to OA in Antarctic waters.

The effect of OA on Antarctic marine protists is being examined. Protists are single-celled organisms that account for the majority of biomass in the Southern Ocean. They form the marine microbial loop and are the driver of carbon and energy flow to the entire Antarctic food web, determining the quantity and quality of food available to higher trophic levels. The marine microbial loop is also important because it mediates the draw-down of carbon dioxide from the atmosphere and export to the deep ocean.

Studies using minicosms showed that there was a clear response of protists to carbon dioxide, with a decrease in gross primary production (GPP) and a change in community composition. (The response only occurred at concentrations more than twice the present day concentrations, which might be expected given the large fluctuations in carbon dioxide in Antarctic coastal waters.)

Under high carbon dioxide there was a significant growth of a small weed species rather than the large diatoms which were seen under low carbon dioxide. This has implications for krill (which find it difficult to eat such small cells), carbon export (larger cells sink more rapidly) and carbon dioxide uptake (a reduction in GPP means that less carbon dioxide will be drawn down under a high carbon dioxide scenario). The cause of these changes is the basis of ongoing work.

Ocean acidification impacts on Antarctic krill | So Kawaguchi, AAD

Krill is a key species in the Antarctic ecosystem. It has enormous biomass as a single species (several hundred millions to billions of tonnes) and is the major food for whales, seals, fish, sea birds and squid. It is also the target species for the biggest, most rapidly growing fishery in the Southern Ocean. Krill live for 5-7 years and grows to a maximum of 7 cm. Their long life span reduces opportunities to adapt to environmental changes.

Examination of the effect of carbon dioxide on krill embryonic development showed no effects at 1000 ppm but at 2000 ppm krill can't hatch. The first three days matters to egg hatch rate (during this time the krill have no organs, i.e. no system for self regulation). During this time the krill embryos are at 0-500 m below the ocean surface, so the sub-surface carbon dioxide level is important. Hatch rates vary between different egg batches. Could this be a natural selection process? Examining hatch rates is just a starting point because krill has a long and multi-stage life cycle. However the development period (eggs) is still important.

Work with the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has produced hatch rate maps using pCO_2 data. These maps show a great deal of spatial heterogeneity. The maps are a useful product.

Next steps are to examine gene expression under different carbon dioxide levels in an effort to understand the actual mechanisms of carbon dioxide on krill. A priority for 2014 is investigation of the combined effects of carbon dioxide and temperature on embryonic development, as well as carbon dioxide effects on krill larvae behaviour. Collaboration with modellers is needed for ongoing work.

Ocean acidification in temperate coastal systems | Catriona Hurd, UTAS

The biological modification of a bethnic seabed by seaweed was examined using fluctuating pH to reflect the conditions in a natural coastal system. pH in a kelp bed is higher than in 'bulk' water. While fluctuating pH had an effect on the growth of the seaweed, it had no effect on recruitment/spore release.

The diffusion boundary layer is a microscopic layer between the seaweed surface and the bulk water. In this layer carbon dioxide, pH and oxygen vary substantially due to seaweed metabolism, while in the overlying bulk water these variables are approximately constant. In slow flowing environments the diffusion boundary layer is thick, while in fast flowing environments it is thin. There are fewer OA effects in slow flow environments, while in mixing environments the effect is exacerbated. Wave exposed sites are likely to be more vulnerable to OA effects (for all calcifiers).

Ocean acidification impacts in high latitudes | Donna Roberts, ACECRC/UTAS

Investigations of OA in high latitudes are important because polar regions are acidifying at twice the rate of tropical regions; the Antarctic fishing industry is valued at US$250 million/year; calcifiers (coccolithophores, foraminifera and pteropods) are vital to the way the oceans draw down carbon dioxide from the atmosphere and play profound roles in the transfer of carbon dioxide to the deep ocean store; and biological responses to OA in the region to date are cause for concern. We're already seeing modern forams that are lighter than pre-industrial forams, and pteropod shells getting softer and more fragile (but maintaining their elasticity).

A Free Ocean CO_2 Enrichment (FOCE) experiment – antFOCE – will take place this year to examine the effects of high carbon dioxide waters on an entire polar sea-floor community. This is the first FOCE experiment to take place in a polar region. The four-month experiment at Casey station will contribute community-scale policy relevant research to the global research network from a region especially at risk from OA.

Developing management options for deep-sea ecosystems | Ron Thresher, CSIRO

Huon Marine Reserve, south of Tasmania, contains seamounts that are home to long-lived, slow-growing corals. The Reserve has been investigated to assess the scale of OA risk to a deep-sea ecosystem, and to determine what the threats are (and what can be done about them).

The corals are sitting in Antarctic intermediate water, and their distribution appears to be determined by temperature and carbonate saturation state. Projections suggest that these corals are doomed, as there will be no viable habitat for them by 2100.

The corals are living in varying aragonite saturation states, so there's scope for adaptation. However, the reef building species (there's only one there) is more sensitive to OA.

Available management options include protecting habitat, identifying and protecting possible refugia, reducing other stressors, translocating corals, and providing alternative substrates.

DISCUSSION: OPPORTUNITIES FOR COLLABORATION AND DEVELOPING OCEAN ACIDIFICATION RESEARCH IN THE AUSTRALIAN REGION AND SOUTHERN OCEAN

Collaboration

- The Australian OA research community is well connected, with many links between programs, institutions and international researchers and agencies. There is scope for collaboration with NOAA on hydrodynamic/biogeochemical modelling.
- There is great value in the OA work Australia does in Antarctica; it is important to keep international colleagues informed about this work.

Understanding the physical and chemical systems

- A lot of the multi stressor observations are made concurrently. There is a wealth of data, but variability is not defined.
- The aim is to use remotely sensed data and models to work out what's going on, then use observations to test the results. To this end it is important to know about next generation satellites: what they are doing, what data they are generating and the opportunities for OA research.

Understanding impacts on ecosystems

- Measurements need to be made for biological systems. It might be worth turning to tried and tested case studies to find out what measurements these are.
- We need to better understand biological responses (genotype/phenotype) and ecosystem responses. In doing so we need to try and incorporate the complexity of these systems. We need to better couple observations/models/experimental findings.
- We can begin to interrogate historical fisheries data.

Australian Climate Change Science Programme

Ocean Acidification Coordination Meeting

Tuesday 18 February 2014

CSIRO Marine Labs, Castray Esplanade, Hobart

Shearwater room

Participating agencies

ACE CRC

Australian Antarctic Division

CSIRO

Department of the Environment

NOAA

University of Tasmania

Meeting objectives

- Enhance awareness of current projects and products
- Encourage collaboration
- Identify future research directions
- Compilation of inventory of current and future research and interactions

Notes

1. This meeting will focus on ocean acidification research undertaken primarily by Tasmanian agencies.
2. Researchers from outside CSIRO need to sign in at reception. The Shearwater Room is upstairs from reception.
3. There will be a meeting Rapporteur who will prepare a brief report and subsequently distribute it to participants.

APPENDIX

Program

Time	Session	Presenter
08.30	Arrival, sign in at front desk	
08.45	Welcome and description of meeting objectives	Paul Holper (CSIRO)
08.55	Introductory comments	Anthony Swirepik (DoE)
09.05	Ocean acidification networks	Libby Jewett (NOAA Ocean Acidification Program)
	Presentations on current and future research, interactions, outputs & products (10 + 5 min discussion each)	
09.20	Australian region and Southern Ocean acidification	Bronte Tilbrook (CSIRO/ACECRC)
09.35	Comparison of Arctic and Antarctic vulnerability to ocean acidification and new perspectives from the Southern Ocean	Elizabeth Shadwick (UTAS/ ACECRC)
09.50	CSIRO collaboration cluster for coastal carbon	Andy Steven (CSIRO)
10.05	Modelling ocean acidification in coastal and shelf ecosystems	Mark Baird (CSIRO)
10.20	Large scale modelling of ocean acidification	Andrew Lenton (CSIRO)
10.35	Morning tea	
	Presentations continued (10 + 5 min discussion each)	
11.00	Ocean acidification and other environmental stressors on marine systems	Phil Boyd (UTAS)
11.15	Effects of ocean acidification on Antarctic marine protists	Karen Westwood (AAD)
11.30	Ocean acidification impacts on Antarctic krill	So Kawaguchi (AAD)
11.45	Ocean acidification in temperate coastal systems	Catriona Hurd (UTAS)
12.00	Ocean acidification impacts in high latitudes/Antarctic Free Ocean CO2	Donna Roberts (UTAS)
12.15	Developing management options for deep-sea ecosystems	Ron Thresher (CSIRO)
12.30	Discussion on opportunities for collaboration and developing ocean acidification research in the Australian region and Southern Ocean	
13.00	Lunch (canteen)	