

Dealing with Climate Change: Palaeoclimate Research in Australia

Abstract

Palaeoclimate research relevant to marine systems in Australia includes the collection and analysis of: (a) shallow-water and deep-sea corals, which provide high-resolution archives, (b) deep-sea sediment and ice cores, which span longer time scales, and (c) palaeoclimate modelling, which gives us insights into mechanisms, dynamics and thresholds underlying past climate states. Palaeoclimate research in Australia is mature and well recognized internationally. To further advance Australian palaeoclimate research, we must address major challenges that include insufficient research vessel access, insufficient targeted research funding, as well as the lack of a well-funded national centre to coordinate research efforts (e.g. academic institution or ARC Centre of Excellence for Palaeoclimate Research).

Background

The main palaeoclimate data/proxy group is located at the Australian National University (Research School of Earth Sciences, 15+ researchers and their groups). Smaller groups also exist at the University of Western Australia, the Australian Institute of Marine Science (AIMS), James Cook University, University of Queensland, University of Wollongong, Curtin University, University of Sydney, Macquarie University, Melbourne University, the University of Tasmania, ANSTO Environment, Geoscience Australia and the Australian Antarctic Division. The main palaeoclimate modelling group is located at the University of New South Wales (Climate Change Research Centre) with smaller groups at CSIRO, Monash University and the University of Western Australia.

Australia is a member of the International Ocean Discovery Program (IODP), through the Australian and New Zealand International Ocean Discovery program Consortium (ANZIC), hosted at ANU and with 22 member organisations in Australia and New Zealand. IODP is the world's largest multinational geoscience program and includes almost all OECD countries. IODP carries out deep scientific coring in all of the world's oceans using a variety of platforms, and provides 'ground truthing' of scientific theories that are often based largely on remote sensing techniques. 'Environmental changes, processes and effects' is one of three key research themes within IODP.

ANZIC is funded jointly by Australia and New Zealand, with Australia being the major partner. Australia's funds are provided under an ARC/LIEF grant, with the ARC funds amounting to \$1.8 million p.a. and the 18 Australian partners providing \$855,000 p.a. toward Australian membership of IODP. ANZIC actively supports Australian scientists to participate in IODP palaeoclimate research. Between 2009-2014, 16 Australian scientists participated in palaeoclimate-focused IODP expeditions as members of the Science Party. Through ANZIC, from 2010-2014, 12 Australian

scientists have been granted up to \$40,000 of post-cruise funding, and in 2012 and 2014 ANZIC supported a total of 24 Australian scientists in groups through analytical funding of up to \$25,000 to work on legacy material.

Australian palaeoclimate science is also funded through the Australian Research Council (ARC, Discovery Grants, Future and Laureate fellowships), the ARC Centre of Excellence for Coral Reef Studies, the Australian Institute of Marine Science (AIMS), the Australian Antarctic Division (AAD), university fellowships and joint international programs (e.g. Australian Academy of Science administered programs, French and U.S. science programs). Ship time is supported through the Australian Antarctic Science Program, the Marine National Facility, significantly through international research vessels, and the Integrated Ocean Discovery Program (IODP). Other funding sources include AINSE and ABRS grants.

Australia's palaeoclimate research contributes to several international working groups of IGBP-Past Global Changes (PAGES; e.g. Ocean2k, Aus2k, 2k-Network, Sea-Ice Proxy and IMPRESS), of the International Union for Quaternary Research (INQUA; e.g. SHAPE), PALSEA2 (PALeo constraints on Sea Level rise), PLIOMAX (Pliocene Maximum Sea Level) and PMIP (the Palaeoclimate Modelling Intercomparison Project). It has also contributed to the Intergovernmental Panel for Climate Change (IPCC) assessment reports (e.g. AR5 working group 1, Chapter 14: *Climate Phenomena and their Relevance for Future Regional Climate Change*). Australian palaeoclimatologists are representatives on many international governing, scientific and technical boards related to IODP and international collaborative science programs (e.g. BIOTRACERS, ECORD, IMPRESS, PAGES, SCAR).

The research is mature and rates internationally. Some examples of high-impact contributions by Australian scientists over the past 5 years include (but are not limited to): Climate sensitivity (Rohling et al. 2012, *Nature*), sea-level history (O'Leary et al. 2013, *Nature Geoscience*; Rohling et al. 2014, *Nature*; Zinke et al. 2014, *Nature Communications*), ocean acidification (McCulloch et al., 2012, *Nature Climate Change*), ENSO, Indian Ocean and Southern Hemisphere climate modes (Abram et al. 2008, *Nature Geoscience*; Maina et al. 2013, *Nature Communications*; McGregor et al. 2013, *Nature Geoscience*; Abram et al. 2014, *Nature Climate Change*; Zinke et al. 2014, *Nature Communications*), ocean carbon cycle (Yu et al. 2010, *Science*), Antarctic melting rates (Mulvaney 2012, *Nature*; Abram et al. 2013, *Nature Geoscience*), past behaviour of oceanic currents (De Decker et al., 2013, *Nature Geoscience*).

Relevance

Palaeoclimate reconstructions can be used to estimate the sensitivity of the climate to CO₂ and other boundary conditions (e.g. Rohling et al. 2012), an important parameter needed to understand the possible extent of future warming of the planet. Some periods in the past may provide analogues that can constrain important aspects of the climate system (e.g. the cryosphere) under future scenarios (e.g. Cook et al., 2013). Furthermore, palaeoceanographic data are used to calibrate climate models. Indeed, the most recent assessment by the IPCC (AR5) has for the first time included palaeoclimate information in its evaluation of climate model performance (Braconnot

et al. 2012). Palaeoceanographic data and palaeoclimate modelling provide a benchmark against which to assess current and future changes in climate, the carbon cycle and marine ecosystems, for example in response to ocean acidification (e.g. Moy et al. 2009) and the role of seasonal sea ice (e.g. Houben et al., 2013). High-resolution coral data can give us a better understanding of the characteristics of natural climate variability including societally-relevant interannual to decadal oscillations (such as the ENSO and the IOD; e.g. Abram et al., 2008; McGregor et al. 2013; Zinke et al., 2014) and therefore improve the forecast of such events, including Australian rainfall impacts. Finally, palaeoclimate modelling can provide for additional interpretation of the proxy data (e.g. Huiskamp and Meissner, 2012; Phipps et al., 2013). Examples include the exploration of the dynamical mechanisms underlying past changes (e.g. Brennan et al., 2013), and the formal detection and attribution of anthropogenic influences on the ocean (e.g. Bindoff et al., 2013).

End-users for this research range from state and national governments to environmental and resource agencies in Australia (and internationally) who have to develop long-term planning strategies for 'living in a changing environment' (ARC National Research Priorities) or global research priorities (Kennicutt et al. 2014) over the coming decades and centuries.

Science needs

Key Challenges

The most important challenges our community is facing include insufficient research vessel access, insufficient targeted research funding and the lack of a well-funded national centre to coordinate research efforts. For example, funding for RV *Investigator* has been reduced from the original plan of 300 to just 180 days per year, and university-based research needs to seek, independently, both ship and project support to guarantee the achievement of scientific objectives. Other marine nations (e.g. Japan, Germany, France, US), which have several national research vessels each, support ~300 days ship time and link funding for ship time and research to ensure success. Palaeoclimate research is largely a university-driven research field with heavily restricted opportunities for collaborative support from government research institutions (such as the CSIRO, Geoscience Australia, or the AAD) where this science is no longer specifically supported or a research priority. In contrast, the IODP programme is key to research programmes and should receive longer term funding. Again, Australia is unusual among IODP member countries in having funding for only 2 years (renewal necessary for 2016 and beyond). ARC funding should be targeted for the areas of oceanography, earth sciences and climate modelling. A key challenge is also to retain the necessary scientific expertise and leadership to undertake this research effort within Australia.

Key Science Gaps

- Understanding of the climate history for the Australasian region
 - Sea level: Impact of natural variability (including Antarctic Ice Sheet variability) on sea level and rates of change. Sea level benchmarks from past periods of warming and higher CO₂ (i.e. MIS5e, MIS11, the Pliocene, etc.).
 - Climate sensitivity of the Australasian region: develop a history of wet and dry phases for Australia, and define leads and lags between oceans and land.
 - Develop a history of continental run-off (weathering history).

- Subtropical/tropical marine variability and change
 - History of the East Australian Current and Leeuwin Current, plus the dynamics of the Indo Pacific Warm Pool.
 - Spatially and temporally comprehensive marine climate history for Indo-Pacific waters, decadal climate variability within different background climate states, which are part analogues for future climate (i.e. MIS5e, MIS11, the Pliocene, etc.). The climate of the past 2000 years is of particular interest (international research priority).
 - The role of external forcings (orbital, solar, volcanic, greenhouse gases) in driving past changes.

- Southern Hemisphere ocean modes and linkages
 - Better understanding of the dominant modes of variability in the Southern Hemisphere Oceans, on timescales ranging from annual to orbital.
 - Better constraints on the timing of past changes, particularly during glacial/interglacial transitions.
 - Linkages between the Northern and Southern Hemisphere oceans, including any leads or lags.

- Ocean control of atmospheric carbon dioxide (CO₂) during past warming events
 - Identification of the main sources of CO₂ during past key warming events.
 - Identification of mechanisms, triggers and thresholds involved during these past periods of abrupt warming.
 - Adequate representation of these processes and feedbacks in climate models used for future projections.

- Adaptability of marine organisms to climate variations
 - Better understanding of organism changes through time via fossil assemblages.
 - Better understanding of reef ecosystem responses to past disturbance (climate, ocean acidification, land-derived, etc.) and identification of refugia.
 - Effects of fisheries on deep-sea corals.

- Global climate - carbon cycle - ecological dynamics and feedbacks
 - Ocean-atmosphere-cryosphere linkages and feedbacks
 - The lack of an Australian palaeoclimate model able to simulate long timescales and including prognostic palaeoproxies.

Key Outcomes

- High-resolution reconstruction of past sea levels and understanding of driving mechanisms.
- High-resolution reconstructions of past sea surface temperatures.
- Improved understanding of changes in climate variability in the Australasian region leading to improved forecasts for rainfall and weather extremes.
- The development of an Australian climate model able to simulate long timescales and including prognostic palaeo climate proxies (e.g. oxygen and carbon isotopes), as well as a fully coupled carbon, nitrogen and phosphorus cycle.
- Improved proxies for ecosystem composition and carbon cycle parameters such as productivity, nutrient availability and oxygen, including development and utilisation of chemical composition of fossil organisms as climate proxies.
- Understanding of the climatic events leading to, and resulting from, Antarctic ice sheet deglaciation and collapse and the subsequent impact on oceanic ecosystems (tropical to polar).

Perspective

Specific Science Priorities:

- Establishment of a coordinated palaeoclimate national agenda (defining national priorities in terms of locations, time spans, tools, techniques, supplementary data, and ensuring an appropriate division of resources).
- Establishment of a well-funded national centre to coordinate research efforts. This can be either an academic institution or an ARC Centre of Excellence for Palaeoclimate Research. While Australia's palaeoclimate researchers are international leaders in their respective fields, there is at present insufficient funding to coordinate this world-class research between groups that are scattered all over the continent. Such a centre would also allow for the training and retention of necessary scientific expertise in Australia.
- Strengthen and maintain Australia's capacity as world leaders in developing high-resolution palaeo-environmental reconstructions from the tropical oceans. Need for clear understanding of tropical climate variability influencing the Indo-Australian region over priority and relevant time intervals. Provide a better understanding of the range of climate variability in regional areas across Australia, and understand how the natural environment has responded.
- Need for a systematic effort to develop/maintain palaeoclimate modelling research

capacity. Palaeoclimate modelling requires models that are computationally efficient and that include representations of key elements of the Earth system (such as the carbon cycle, stable isotopes and ice sheets). These requirements are very different to the requirements for modelling 21st century climatic change, where the emphasis is generally on maximising the spatial resolution of the models. As such, palaeoclimate modelling requires dedicated modelling frameworks or, at the very least, dedicated versions of existing models.

- Australian community works towards taking a leading role in the reconstruction of the deglacial history of the poorly constrained (Mackintosh et al. 2014) East Antarctic Ice Sheet (EAIS) using marine-based records proximal to the ice shelf to interpret current changes in the mass of the ice sheet, and potential contribution to sea-level rise. Given the presence of Australian bases in East Antarctica, the existing expertise in the region, and the impact of EAIS melt on Australian sea level, investment in this area is needed. With the new vessel RV *Investigator*, and a new icebreaker coming in the next decade, there is potential to make significant advances. There is also an opportunity for Australian scientists to participate in international efforts in this field, through the IODP and ANDRILL programs.
- Strengthening Australia's involvement in Southern Ocean and Antarctic Circumpolar Current (ACC) palaeoclimate science. Link with ISOLAT (*Integrated Southern Ocean Latitudinal Transects*), an international program to advance Southern Ocean palaeoceanography through a coordinated series of sections through the different regions of the Southern Ocean (Dr Leanne Armand, Macquarie University, is a member). These priorities relating to high latitude palaeoceanography were identified in the recent SCAR Antarctic and Southern Ocean Science Horizon Scan (Kennicutt et al. 2014). Indeed, one of the proposed focus regions is a transect south of Tasmania to the ice-edge, capturing the important transition zone between the western Pacific and eastern Indian oceans. Australian scientists are particularly well-placed to address this transect, as well as the overall sub-goals of reconstructing:
 - Variability of latitudinal sea-ice extents, westerly wind strength and dust deposition, and the biological pump and their implications for air-sea gas exchange and atmospheric chemistry (CO₂);
 - Variability of surface ocean fronts and their relation to ACC activity and changes in westerly winds
- Strengthening Australia's research capacity in sea-level reconstructions to develop critical benchmarks for a warmer, high CO₂ world.

Realisation

- A large (and well-funded) academically based institution that acts as a coordinating centre (comparable to University of Southampton in the UK, or Scripps /Woods Hole in the US).
- An ARC Centre of Excellence for palaeoclimate research (integration of palaeoclimate proxy and modelling communities).
- Longer-term and increased ARC funding options (5 years, 30% success rate).
- Long-term funding of the RV *Investigator* at 300 days per year.
- Two additional small research vessels to carry out work in the coastal zone, and for short-term voyages.
- Australia must remain a member of IODP. Australian scientists will gain through shipboard and post-cruise participation in cutting edge science, by building partnerships with overseas scientists, by having research proponents and co-chief scientists who can steer programs and outputs, and by early access to key samples and data. They will also have the opportunity of science training for postdoctoral and doctoral students in marine science that could not be obtained in any other way. Our region is unique to address various global science problems. Being a member of IODP will help us maintain our leadership in Southern Hemisphere marine geoscience research.
- In order for Australian scientists to put forward strong drilling proposals to IODP, there must be funding mechanisms in place to support pre-drilling geophysical site surveys. For example, the UK supports membership in IODP through a Site Survey Investigations scheme (<http://www.nerc.ac.uk/research/funded/programmes/ukiiodp/news/ao-ssi/>).
- A challenge common to many facets of ship-based marine science is the lack of coordination between funding for ship-time through an application to the MNF and funding for the research (e.g. salary, travel, equipment and analysis costs), which typically comes from applications to the ARC or the AAS. Better coordination of these funding rounds would maximize use of resources and ensure the best science is properly supported.
- National effort in palaeoclimate modelling (development of a palaeo-version of the ACCESS model). We must ensure that Australia maintains access to world-class palaeoclimate modelling capacity – including not just the development of the tools themselves, but also ongoing maintenance, training and investment in personnel.
- The Australian marine geoscience community needs to strengthen their involvement in international efforts in terms of infrastructure and human resources. For example, being proactive about bringing international researchers on the RV *Investigator* (if funding exceeds 180 days per year) and also trying to

attract foreign research vessels in our waters (i.e. have some financial attraction/incentives to do this (e.g. pay ship time, joint scholarships)). Re-institute the MST (Marine Science Technology) grant system or something similar.

- Closer coordination through funding of working groups, for example through renewal of national program of activity (i.e. AUSCORE – Australian Coral Records) to link the Australian palaeoclimate community. This will allow an integration of research expertise/measurement and modelling facilities across organizations, and provide a coordinated coral and sediment core material sharing and sample effort.
- Archiving of physical coral and core material and material exchange to ensure maximum use of material collected to date. AIMS, for example, currently houses the AIMS Coral Core Archive, a national facility which, at present, contains coral material from the Great Barrier Reef and eastern Indian Ocean reefs. There is scope to curate additional material within this archive and thus make it a truly national facility of international significance. There is a sediment core repository at Geoscience Australia but it needs resources to bring it to international standards.
- The development of a national training curriculum for universities and an ability/access to the RV *Investigator* to train future Australian marine palaeoclimate scientists. A small training marine geoscience program has been supported by ANZIC since 2013, and a larger Master's at sea marine training program is under development through a consortium of universities headed by Macquarie University.

Additional comments

The following related and more specific white paper can be downloaded at http://web.maths.unsw.edu.au/~katrinmeissner/white_paper/paleoclimate.html

Zinke, J, McGregor, H, Lough, J, Abram, N, Webster, J, O'Leary, M, Gagan, M, McCulloch, M and I Goodwin, Dealing with climate change through understanding tropical ocean-atmosphere climate interactions and their impacts on marine ecosystems.

List of contributing authors and affiliations

Nerilie Abram, Research School of Earth Sciences, The Australian National University
Leanne Armand, Department of Biological Sciences, Macquarie University
Zanna Chase, Institute for Marine and Antarctic Studies, University of Tasmania
Patrick De Decker, Research School of Earth Sciences, The Australian National University
Michael Ellwood, Research School of Earth Sciences, The Australian National University
Neville Exon, Australian IODP Office, Research School of Earth Sciences, The Australian National University
Michael Gagan, Research School of Earth Sciences, The Australian National University
Ian Goodwin, Marine Climate Risk Group, Macquarie University
Will Howard, School of Earth Sciences, University of Melbourne
Janice Lough, Australian Institute of Marine Science, ARC CoE Coral Reef Studies
Malcolm McCulloch, ARC CoE Coral Reef Studies, University of Western Australia
Helen McGregor, Research School of Earth Sciences, The Australian National University
Katrin Meissner, Climate Change Research Centre, University of New South Wales
Andrew Moy, Australian Antarctic Division, Australian Government
Mick O’Leary, Department of Environment and Agriculture, Curtin University
Steven Phipps, Climate Change Research Centre, University of New South Wales
Greg Skilbeck, University of Technology, Sydney
Jody Webster, Geocoastal Research Group, School of Geosciences, University of Sydney
Kevin Welsh, School of Earth Sciences, University of Queensland
Jens Zinke, University of Western Australia Oceans Institute

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