

Dealing with climate change through understanding past tropical ocean-atmosphere climate interactions and their impacts on marine ecosystems

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PREFACE:

“Dealing with Climate Change through understanding past tropical ocean-atmosphere climate interactions and their impacts on marine ecosystems” was written as a contribution to the National Marine Science Plan White Paper “Dealing with Climate Variability and Climate Change”. The White Paper was compiled from multiple submissions from the community and was presented at the National Marine Science Symposium, held in Canberra from 25-26 November 2014. This contribution highlights Australia’s strong history in tropical coral reef-based paleoclimate research and identifies science and funding priorities for the next decade and beyond. It goes into more detail on tropical paleoclimate than the paleoclimate White Paper and is reproduced here for the benefit of the broader community.

ABSTRACT

Australian scientists are world leaders in developing robust palaeo-environmental reconstructions from coral archives, relevant for understanding Australian climate extremes. The key issues for advancing this field are the need for high-resolution marine paleoclimate records to place the present in the context of past natural climate and sea level change, and to understand the impact of those changes on marine ecosystems. We call for sustained investment in paleoclimate science, infrastructure, and personnel to advance these critical areas of research.

INTRODUCTION

The tropical Indo-Pacific is crucial for global climate. This area comprises the warmest body of surface ocean water on the planet, and the deep atmospheric convection over this warm water acts as the heat engine of the global climate system. Many of the most significant sources of climate variability are generated in the Indo-Pacific; climate modes such as the El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Indian Ocean Basin Mode (IOBM) and the Pacific Decadal Oscillation (PDO), impact global temperatures and cause rainfall extremes over Australia and beyond (England *et al.*, 2014). Observational records are too short to provide perspectives on the natural range of marine climate variability and long-term change, but this information is critical since recent climate simulations suggest that the impacts of ENSO and IOD variability may intensify over the coming century (Cai *et al.*, 2014a, b).

Tropical corals and other carbonate secreting organisms contain annual growth bands (similar to tree rings) that provide high-fidelity reconstructions

of past marine climate and environments with valuable information on climates prior to historical observations (Figure 1). Additionally, the annual density bands give long histories of coral growth, from which to assess the impacts of climate on the backbone of coral reef ecosystems, sustained calcification. Reef and sediment cores from extensive fringing and barrier reef or continental slope environments provide invaluable insights into long-term (thousands of years) reef ecosystem responses and sea level histories.

Australian scientists are world leaders in developing robust climate and coral growth reconstructions from massive coral skeletons in Indo-Pacific coral reefs. Primary research activities are undertaken at The Australian National University (Abram, Fallon, Gagan, McGregor*, Mallela), University of Western Australia (McCulloch, D’Olivo), Australian Institute of Marine Science (Cantin, Lough, Zinke), James Cook University (Lewis, Smithers), University of Queensland (Zhao, Pandolfi, Rodrigues), University of Wollongong (Woodroffe), Curtin University (O’Leary, Zinke), Sydney University (Webster), ANSTO (Hua) and Macquarie University (Goodwin). The work to date has been funded through the Australian Research Council (ARC), Australian Institute of Marine Science (AIMS), the ARC Centre of Excellence for Coral Reef Studies, university fellowships and international research agencies including the Integrated Ocean Discovery Program (IODP). High-impact contributions by Australian scientists to the field over the past 10 years include (but are not limited to) those shown in Table 1.

This field of research actively contributes to the Past Global Changes Ocean2k and Australasia2k initiatives reconstructing natural climate variations of the past 2000 years (e.g. PAGES Consortium 2013 *Nature Geoscience*; Neukom *et al.* 2014 *Nature Climate Change*), and 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*).

RELEVANCE

Much of Australia’s climate is influenced by interannual to decadal oscillations that originate in the tropical Indian and Pacific Oceans. Well-known oscillatory events such as the ENSO and the IOD are now forecast with some degree of certainty once events begin, allowing the Bureau of Meteorology to give around 6-months’ warning of the likely Australian rainfall impacts. Longer-term projections remain elusive, however recent climate simulations suggest frequency of extreme El Niño and positive IOD events may double or triple over the coming century.

Robust, highly resolved climate reconstructions place current marine environmental and climatic variability in a longer context than possible with observational records. Such records contribute to understanding the nature and causes of tropical climate variability and hence, ultimately, help refine the global climate models used to project future climates in a rapidly warming world. Importantly, massive coral records provide the high-resolution (annual to seasonal) link for the past several centuries between recent, short observational records and longer-term, but much lower resolution, paleoclimate records (e.g. marine sediment records) for the region. In addition, fossil corals allow us to generate climate histories for well-dated windows further back in time, and are one of the only ways of reconstructing interannual climate behaviour (such as ENSO and the IOD) in different background climate states of Earth’s past.

End-users for this research, therefore, range from state and national governments and environmental and resource agencies in Australia (and beyond) who develop long-term planning strategies for “living in a changing environment” (an ARC National Research Priority) over the coming decades and centuries. Australian scientists also play a lead international role in this field, where their work has far-reaching impacts for the international science community (see Table 1). Coral palaeoclimate record development is a cost-effective tool for generating solid environmental baselines that add significant value to the often short-term and high-cost instrumented monitoring activities in remote marine locations.

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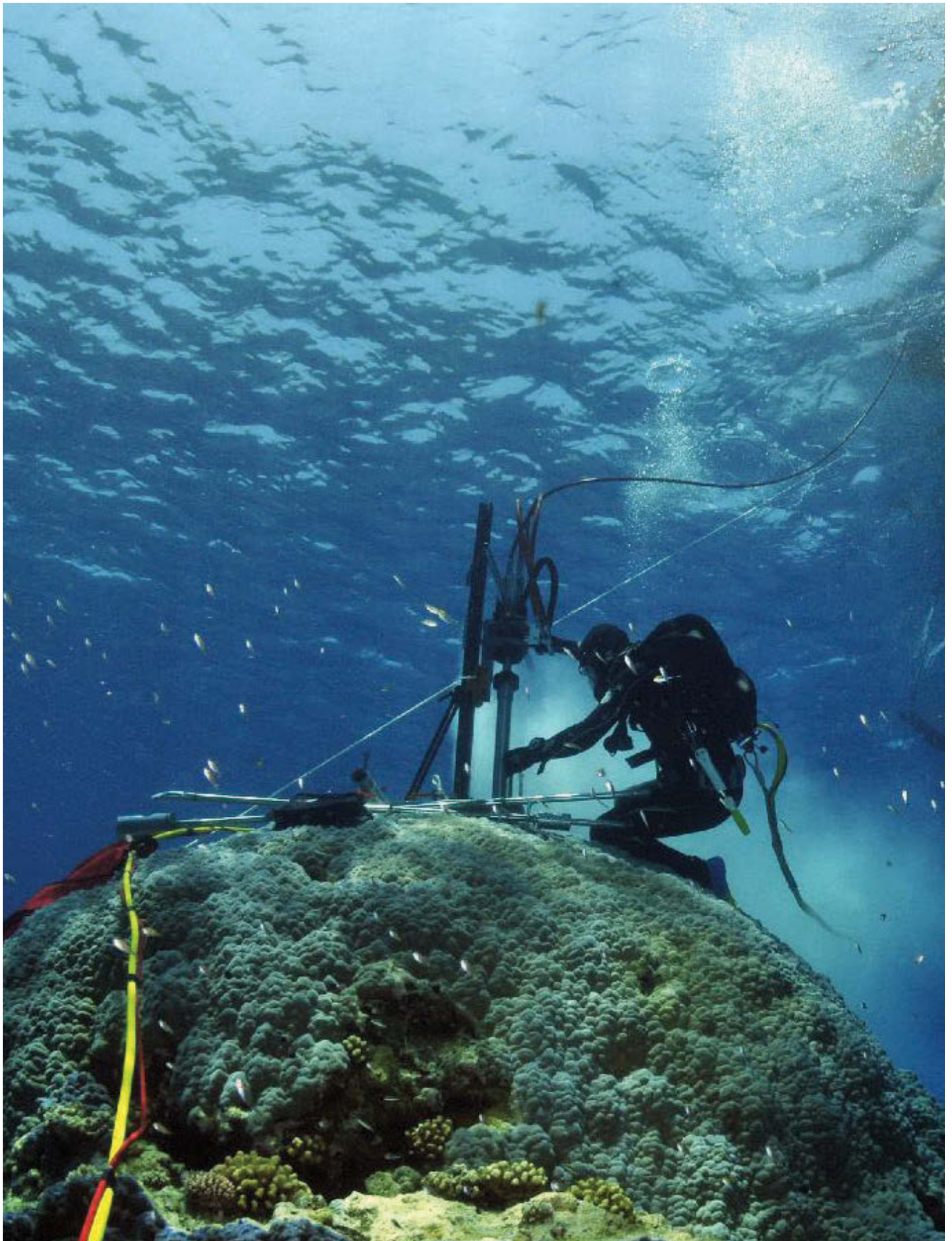


Figure 1: AIMS scientist coring large Porites bommie at Rowley Shoals, northwestern Australian shelf in 2009. Photo credit: Eric Matson, Australian Institute of Marine Science.

Table 1. Research themes, some of the Australian scientists involved, and key publications addressing each theme. For an extended list of references on tropical palaeoclimatology see References.

RESEARCH THEME	AUSTRALIAN SCIENTISTS	KEY PUBLICATIONS
El Niño-Southern Oscillation	McGregor, Gagan, Lough, Zinke	<i>McGregor et al., 2013 Nature Geoscience;</i> <i>Lough et al., 2014 Paleoceanography</i>
Indo-Pacific Warm Pool interactions; Indian Ocean climate modes	Gagan, McGregor, Abram, Zinke, McCulloch, Fallon	<i>Abram et al., 2008 Nature Geoscience;</i> <i>Abram et al. 2009 Quaternary Science Reviews;</i> <i>Zinke et al., 2014 Nature Communications;</i> <i>Zinke et al., 2014 Scientific Reports;</i> <i>Zinke et al., 2008 Geophysical Research Letters;</i>
North Queensland rainfall & Great Barrier Reef teleconnections	Lough, Gagan, Lewis, McGregor, Webster, Fallon	<i>Felis et al., 2014 Nature Communications;</i> <i>Lough et al., 2014 Paleoceanography;</i> <i>Rodrigues et al., 2014 PLoS One</i>
Coral reef environmental health and calcification	Lough, Cantin, McCulloch, Mallela, D'Olivo, Lewis	<i>Mallela et al., 2013, PLoS One;</i> <i>Cooper et al., 2012 Science;</i> <i>Cantin and Lough, 2014, PLoS One;</i> <i>Lough & Cantin, 2014 Biological Bulletin;</i> <i>D'Olivo et al., 2013 Coral Reefs</i>
Sedimentation and river runoff history	Lough, McCulloch, Zinke, D'Olivo, Cantin, Lewis, Fallon	<i>Lough 2011 Coral Reefs;</i> <i>D'Olivo et al., 2013 Coral Reefs;</i> <i>Grove et al., 2013 Climate of the Past;</i> <i>Grove et al., 2012 Biogeosciences;</i> <i>Maina et al., 2013 Nature Communications</i>
Sea-level history	Woodroffe, Smithers, Webster, O'Leary, Zinke, Goodwin	<i>Woodroffe et al., 2012 Geology;</i> <i>Zinke et al., 2014 Nature Communications;</i> <i>O'Leary et al., 2013 Nature Geoscience</i>
Ocean acidification	McCulloch, Trotter, Holcomb, D'Olivo, Fabricius, Lough, Fallon	<i>McCulloch et al., 2012 Nature Climate Change;</i> <i>Holcomb et al., 2014 Scientific Reports</i>
Reef response	Woodroffe, Webster, Smithers, Pandolfi, Zhao	<i>Woodroffe & Webster 2014 Marine Geology;</i> <i>Abbey et al. 2014 Palaeogeography, Palaeoclimatology, Palaeoecology;</i> <i>Carnoin et al., 2012 Geology;</i> <i>Perry et al. 2012 Geology</i>

SCIENCE NEEDS

Key science gaps are:

- The need is for spatially and temporally comprehensive marine climate history for Indo-Pacific waters. This includes well dated windows of societally-relevant interannual and decadal climate variability within different background climate states, which are part analogues for future climate (i.e. MIS_{5e}, MIS₁₁, the Pliocene etc). Climate of the past 2000 years is of particular interest (international research priority).
- The need for a better understanding of reef ecosystem responses to past disturbance (climate, ocean acidification, land-derived etc.) and identification of refugia.
- The need for sea level benchmarks from past periods of warming and higher CO₂ (i.e. MIS_{5e}, MIS₁₁ the Pliocene etc).

Key challenges/needs for addressing the science gaps:

- Funding support for existing key infrastructures in Australia's high resolution paleoclimate centres of Australia (e.g. ARC Discovery; ARC Centre of Excellence for Paleoclimate Research).
- Closer coordination through working group meetings, for example through renewal of the national program of activity (i.e. AUSCORE – Australian Coral Records) to link the Australian coral paleoclimate community. This will allow an integration of research expertise/ measurement facilities across organizations, and provide a coordinated coral core material sharing and sample effort (expensive component of research).
- Archiving of physical coral 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.
- Research vessels access through ARC LIEF funding to collect modern tropical coral material, older coral or reef cores, deep sea corals and sediment cores from ocean drilling campaigns (link with IODP, for instance IODP Exp. 325) from remote locations and to collect a wealth of site survey data needed to stimulate new IODP expeditions.

CONCLUSIONS

There is no doubt that the Australian coral palaeoclimate and palaeoenvironment community have made globally significant contributions to understanding the tropical ocean-atmosphere interactions and impacts that directly mediate Australian climate and rainfall and ecosystems. Australian scientists are world leaders in this field, but the time is ripe to provide a more focussed and integrated approach that capitalises on our location, our significant coral reef ecosystems and Australia's scientific expertise. Outputs are relevant both nationally and internationally.

There is a dire need to develop new records that cover past several centuries and well dated windows of the more distant past from key locations of tropical Indo-Pacific climate variability. This will provide an integrated, high-resolution Indo-Pacific climate history allowing current environmental changes and their impacts to be placed in an historical context. The research links to international efforts to provide critical baseline data (e.g. PAGES2k) to constrain climate model uncertainty (e.g. PMIP3).

To support these scientific priorities there is a need for a national, well-funded initiative to close the huge gap in the number of high-resolution marine paleoclimate records in Australian and Commonwealth waters and for the wider Indo-Pacific. Infrastructure and analytical facilities are already in place. The key challenge over the next 5 to 20 years is to focus the research effort and obtain the necessary funding for the essential sample collection, geochemical analyses and maintenance of facilities needed to produce ground-breaking past climate, sea-level, ocean acidification and environmental change information that is required to understand the context and impacts of future changes in Australia's marine environment. A key challenge is also to retain within Australia the necessary scientific expertise and leadership to undertake this research effort.

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