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Land–sea correlations in the Australian region: post-glacial onset of the monsoon in northwestern Western Australia

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ABSTRACT

Deep-sea core Fr10/95-GC17, collected offshore North West Cape at the western tip of Western Australia, is located beneath the path of the Leeuwin Current. This shallow, warm and low salinity current is an offshoot of the Indonesian Throughflow that transfers water and heat from the West Pacific Ocean into the Indian Ocean. The location is at the edge of the Indo Pacific Warm Pool, the source of large-scale transfer of moisture and heat from the ocean to the atmosphere. For this core, we combine previously published data with new research and use a revised chronology to re-examine the timing of climate change during the last 34,000 years in the tropics of northern Australia. The age model for the core is based on 15 radiocarbon dates complemented by luminescence ages and an oxygen isotope record. This study draws on an extensive range of analyses that have been performed on the core, including micropalaeontology of planktic and benthic foraminifera and coccoliths, stable isotopes analysis of foraminifera and their faunal composition, clay content, sediment composition and pollen analyses. Sea-surface and land temperatures are estimated from the foraminifer faunal analyses and from pollen spectra, respectively. The clay fraction and sediment composition and radiogenic isotopes of that fraction helped identify changes both on land and at sea: changes such as rainfall as shown by river discharge, and oceanic current tracing by neodymium, strontium and lead isotopes obtained from sediments.

The most significant finding is that a major threshold was crossed at 13 ka BP. Prior to that time, rainfall over NW Western Australia was low as was sea-surface temperature (SST); river discharge to the ocean was also low as a result of the lack of monsoonal activity and finally, ocean alkalinity would have been lower than at present due to the uptake of atmospheric CO_2. By 13 ka BP, the entire system moved away from glacial period conditions. The Indo-Australian monsoon commenced in and offshore northwestern Western Australia. SST and land temperature increased dramatically and ocean alkalinity changed due to the formation of a "barrier layer" (a low salinity cap), over the Indo Pacific Warm Pool. During the Holocene, river discharge and the land and ocean temperatures did not covary, for example, the highest rainfall did not coincide with the highest SST. Finally, the last 5 ka saw a strengthening of ENSO in the region.

1. Introduction

Northern Australia borders the Indo Pacific Warm Pool [IPWP] which is characterised by persistently high (>28 °C) sea-surface temperature [SST] (Yan et al., 1992). The IPWP is an important region for the transfer of heat and moisture to the atmosphere. Due to its extensive surface area, the IPWP is often described as the "heat engine" of the world where high convective clouds form and carry moisture to altitudes well over 10 km (Fig. 1), releasing much latent heat in the process (Webster, 1994). It is also a region where, unlike the subtropics, there is little seasonal change in SST (Fig. 2, supplementary Figs. 1–2). The landmasses located within the IPWP or bordering it are referred to as the "Maritime Continent" (Ramage, 1968). This is justified by the fact that the oceans indirectly control, to a great extent, terrestrial processes, such as massive river discharges at times of monsoonal rains and the associated cyclonic activity, vegetation growth and weathering. Heat exchange also occurs during the transfer of water from the Pacific Ocean to the Indian Ocean (Fig. 3).

An important question is "Was the configuration/stability of the IPWP the same as today during the last glacial maximum (LGM), a time when sea level was much lower [~125 m] and today's

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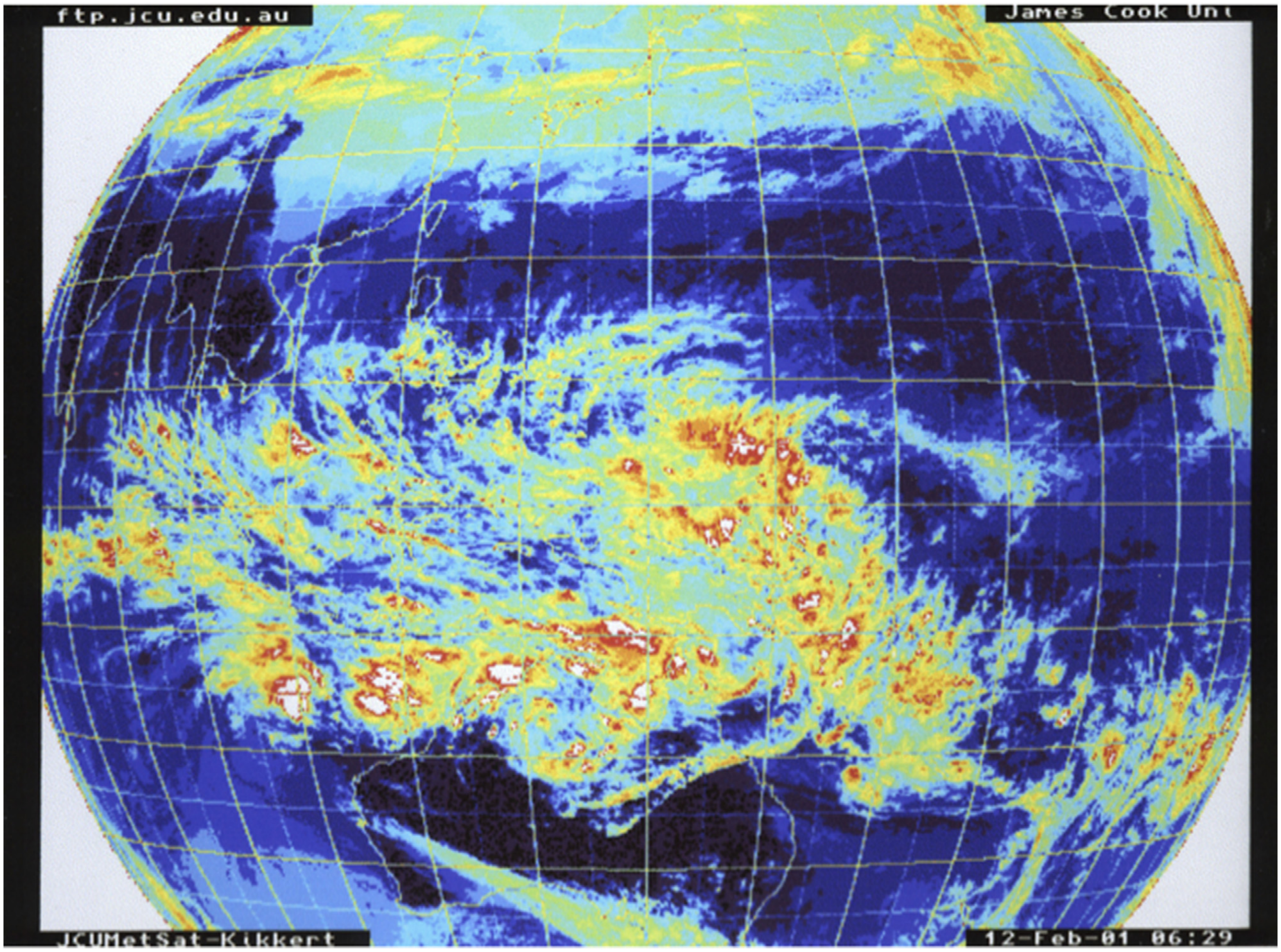

Fig. 1. Satellite image taken on 12–2–2001 showing the presence of high convective clouds covering almost the entire surface area of the Indo Pacific Warm Pool. For more details, refer to De Deckker et al. (2003). Image taken from James Cook University satellite image compendium, courtesy of Professor Kippert.

continental shelves were exposed?". A corollary question would be: "Was northern Australia also under a monsoonal system at the LGM?" At that time, there would have been less oceanic surface to generate high convective clouds and the ensuing high seasonal rainfall and cyclonic activity. This question was partly addressed by De Deckker et al. (2003) through the study of the $\delta^{18}O$ record of numerous marine cores and through regional SST reconstruction (Barrows and Juggins, 2005). Until recently, it was considered that SST in the centre of the IPWP was, like today, of the order of 28 °C or slightly less (Linsley, 1996; Brijker et al., 2007; Levi et al., 2007, and more recently by DiNezio and Tierney (2013), mostly through modelling of the IPWP for the LGM). However, this contrasts with the recent study of Tripati et al. (2014) which indicated that SST could have been 4–5 °C lower at the LGM offshore New Guinea, a finding which explains more easily the advance of glaciers on that island (Barrows et al., 2011). What we already know is that the subtropical convergence zone, which today sits over parts of northern Australia during the austral summer, must have been located north of the equator (De Deckker et al., 2003). Cyclonic activity was either significantly reduced at the LGM, or even possibly completely absent, at least for the region adjacent to northern Australia.

Other questions worth considering are: at what stage were the features of the modern Warm Pool in place, and what were the responses on land and in the oceans once seasonal monsoonal activity became established over the southern fringe of the IPWP? Another relevant question to attempt to answer is whether oceanic processes changed through time with respect to oceanic circulation, such as CO_2 exchange between the atmosphere and the oceans, and with respect to oceanic productivity.

Here we present multidisciplinary studies on deep-sea core Fr10/95/GC17, taken offshore North West Cape where it is judiciously located at the edge of the IPWP. We aim to use this core to answer the questions raised above, and also because, being at the fringe of today's IPWP, we can investigate waxing and waning of the IPWP through time, and more importantly the role of the IPWP on the entire region through time. In addition, the location of such a core adjacent to Australia enables us to investigate the terrestrial signals which would be mixed with the pelagic sediments and the remains of planktic and benthic organisms simultaneously. As a result, it is possible to identify both marine and terrestrial signals of climate change registered within samples from such a core. This is rather important as there are few high resolution records of environmental change on land from northern Australia. Such a multidisciplinary study of a marine core detailing changes both on land and at sea contrasts with most palaeoceanographic studies that rely on only one or two environmental proxies, such as stable oxygen isotope analyses of planktic foraminifers, trace element ratios, or compounds secreted by coccoliths or other microscopic algae. In order to interpret environmental changes on both land and sea, we have here not only dated samples from a deep-sea core with two different absolute dating techniques (radiocarbon and OSL), but