Ocean-Atmosphere Dynamics in the Indo-Pacific Warm Pool Region during the Past 8,500 Years

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Seasonally resolved palaeoclimate data are important for reconstructing dynamic changes in tropical climate systems and for understanding the processes controlling climate change. We are in the process of developing a multi-proxy approach (δ^{18}O, Sr/Ca, U/Ca, δ^{13}C, Δ^{14}C) to coral-based palaeoclimatology that is yielding records of climatic processes over the last 8,500 years. The following mini-abstracts contain recent results pertinent to our understanding of the Hadley Circulation.

Ocean-atmosphere Interactions and Abrupt Cooling in the Tropics 8,000 Years Ago

Establishing the relative timing and magnitude of climate change in the tropics and high latitudes provides a means for evaluating the role of the tropics in global climate change. The largest abrupt climate change in the Holocene occurred between 8,400 and 8,000 calendar years ago, when the temperature dropped by 4-8°C in central Greenland and 1.5-3°C around the North Atlantic region. We collected cores from a sequence of well-preserved *Porites* corals within a rapidly uplifted palaeo-reef in Alor, Indonesia, with ^{230}Th ages spanning 8,400 to 7,600 calendar years before present. Measurements of coral Sr/Ca and δ^{18}O have yielded a semi-continuous record (310 years) showing SSTs essentially the same as today from 8,400 to 7,600 years ago. However, both tracers show that this period of climatic stability is interrupted by an abrupt ~3°C cooling over a period of ~100 years, reaching a minimum 8,000 years ago (Gagan et al., 2002).

The rapid cooling of ~0.3°C per decade in the Warm Pool 8,000 years ago is nearly synchronous with the so-called ‘8.2 ka cold event’ in the North Atlantic region. This finding supports the hypothesis that abrupt climate change at high latitudes can propagate rapidly to the tropics via atmospheric teleconnections. In the case of the 8.2 ka event, initial cooling at high latitudes could serve to enhance the equator-to-pole temperature gradient and strengthen meridional circulation and tradewind velocity in the tropics. Stronger tradewinds would increase near-equatorial upwelling, providing an efficient means for cooling the tropical ocean surface. The results suggest that the tropical ocean-atmosphere could serve to propagate abrupt climate changes between the northern and southern hemispheres without a significant time lag.

Tropical Atmospheric Circulation and the Seasonal Expression of the Holocene ENSO

A central issue limiting our understanding of the palaeo-ENSO is that it has not been possible to determine if the changing intensity of the ENSO precipitation signal is directly related to changes in El Niño temperature anomalies in the tropical Pacific Ocean. Resolving the debate requires palaeoclimate data that are capable of revealing the relative magnitude of the oceanic and atmospheric signals diagnostic of the ENSO phenomenon.

We investigated the relationship between mean climate and ENSO using Holocene *Porites* coral colonies preserved in growth position on palaeo-reefs from Papua New Guinea (equatorial Warm Pool), Sumba in southern Indonesia (edge of Warm Pool), and the Australian Great Barrier Reef (subtropical periphery of Warm Pool). High temporal resolution Sr/Ca and $^{18}O/^{16}O$ ratios in these corals provide a history of off-equator warming of the surface ocean, enhanced evaporation in the austral spring, and reduced interannual variability of monsoon rainfall from 4,800 to 6,200 years ago. Despite this different climate state, the ocean-atmosphere feedbacks diagnostic of the ENSO remain predictably phase-locked to the annual cycle. Yet, compared to ENSO behaviour of recent decades, the response of Australian monsoon precipitation to El Niño temperature anomalies is subdued in the mid-Holocene. The suppressed ENSO-monsoon interaction is best explained by enhanced southeasterly wind-driven divergence in the tropical Pacific, and northward displacement of the Intertropical Convergence Zone. The results suggest that large-scale changes in the tropical atmospheric circulation can play an active role in modulating ENSO-monsoon interactions and the precipitation response to El Niño temperature anomalies.

Records of skeletal $^{18}O/^{16}O$ for massive *Porites* microatolls from Christmas Island in the central equatorial Pacific provide high-resolution proxy records of ENSO variability since 3,800 years ago (Woodroffe et al., in press). The comparative histories indicate that ENSO anomalies were less intense between 3,800 and 2,800 years ago, and more pronounced 1,700 years ago. Amplification of ENSO ~2,000 years ago is consistent with model predictions based on precessional changes in insolation seasonality. However, the non-linear onset of ENSO variability in the late Holocene appears to reflect stronger rainfall teleconnections through abruptly enhanced interaction between the Southern Oscillation and the Intertropical Convergence Zone.

The Role of the Tropics in the Little Ice Age

A recent 420-year history of SST (from coral Sr/Ca and U/Ca) and SSS (from coral $\delta^{18}O$) anomalies for the Great Barrier Reef, Australia, suggests that a dramatic shift in the tropical ocean-atmosphere system occurred at the end of the Little Ice Age (LIA). Although the period from 1565 to 1700 AD is ~0.2-0.3°C cooler than the long-term average, SSTs are consistently as warm as the late 20th century from 1700 to 1850 AD. A striking feature of the 420-year $\delta^{18}O$ record is an abrupt 0.2‰ shift in $\delta^{18}O$ towards lower modern values between 1850 and 1870 AD. The shift in $\delta^{18}O$ in the 1870s marks a significant recent freshening of the southwest Pacific (Hendy et al., 2002).

The higher salinities observed in the southwest Pacific coral record between 1565 and 1870 AD are best explained by a combination of advection and wind-induced evaporation resulting from a strong latitudinal temperature gradient and intensified atmospheric circulation. If warm tropical Pacific SSTs encouraged evaporation and a stronger Hadley circulation dried the subtropics during the LIA, then global average water vapour should have increased. The results imply that the tropical oceans may have played an important role in driving the LIA glacial expansion during the repeated advances between 1600 and 1860 AD.

References

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