# ENSO record in mid-late Holocene fossil corals from Line Islands – Forced response or internal variability?

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A major unresolved issue in climate dynamics is the extent to which the El Niño/Southern Oscillation (ENSO) phenomenon responds to external forcing or is sensitive to global mean climate state. The Holocene represents a natural case study for this issue, given the orbitally-induced changes in radiation and the changes in global climate. Records from the tropical Pacific provide hints that ENSO characteristics may have evolved over the Holocene, but definitive evidence has been lacking.

Here we present fossil coral (genus *Porites*) derived high resolution oxygen isotopic ($\delta^{18}O$) records spanning the mid-late Holocene. The coral cores were recovered from the Line Island chain near centre of ENSO activity in the central tropical Pacific. These annually banded fossil corals preserve multidecadal windows on climate variability (each segment 50 to 70 years long), and U/Th dates show that the ages of these corals are relatively evenly distributed throughout the last 7ka. The mean growth rates of the corals allow monthly resolution records with 10 to 15 samples/a. El Niño (La Niña) events in the study area are accompanied with positive (negative) sea surface temperature and rainfall anomalies, which in turn are expressed in negative (positive) anomalies in coral $\delta^{18}O$ records. We address the question of whether there were systematic changes in ENSO characteristics, including the possible evidence for a 'turn on' after 6 ka .

# FROST – FReezing Of duST

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Ice particles occur in the atmosphere in cirrus and in mixed phase clouds and have an influence on e.g. cloud albedo and precipitation. The generation of ice particles can occur via homogeneous or via heterogeneous freezing. For the latter, i.e. the interaction of an ice nuclei (IN) with a water droplet, several different mechanisms (immersion, contact, deposition, and condensation freezing) and their atmospheric relevance are discussed in the scientific community.

During the measurement campaign FROST (FReezing Of coated and uncoated duST particles), LACIS (Leipzig Aerosol Cloud Interaction Simulator) was used to examine the freezing behaviour of coated and uncoated ATD (Arizona Test Dust) particles of a quasi-monodisperse size of 300 nm. A suite of additional instrumentation was used in parallel to characterize the particles with respect to shape, chemical composition, hygroscopic growth and activation to cloud droplets. The coatings on the ATD particles were either succinic acid, $H_2SO_4$ (2 different thicknesses), or $(NH_4)_2SO_4$.

The ATD particles were found to contain small amounts of water soluble material in addition to insoluble materials. By means of online aerosol mass spectrometry, it was possible to distinguish between thin and thick $H_2SO_4$ coatings. For the thin coatings, the $H_2SO_4$ was found to have reacted with material contained in the ATD, so that almost no free $H_2SO_4$ was found. For the thick coatings, $H_2SO_4$ was detected. In general, uncoated particles and those coated with thin coatings of $H_2SO_4$ or of succinic acid, showed almost no hygroscopic growth. Particles coated with thicker coatings of $H_2SO_4$ and of ammonium sulphate grew noticeably above 95% RH. Both, coated and uncoated ATD particles, were found to activate droplets at atmospherically relevant water vapor super-saturations.

Uncoated ATD particles and particles coated with succinic acid or thin coatings of $H_2SO_4$ nucleated ice at higher temperatures, i.e. were more efficient IN, than particles with thick $H_2SO_4$ or ammonium sulphate coatings. Although the latter two were similar in hygroscopic growth and activation behaviour, they differed in their ability to act as IN, with ATD particles coated with ammonium sulphate being the most ineffective IN. This finding suggests that the investigated particle's ability to act as IN might not be related to water activity for the immersion freezing processes investigated in this study.