ENSO and changes in the mean state in Holocene simulations

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Simulations suggest that Pacific interannual changes in sea surface temperature (SST) are smaller than SST seasonality, whereas the opposite is modeled for precipitation. Nonstationarity in ENSO patterns may affect the interpretation of past variability changes from climate records.

High-resolution paleoclimate indicators provide a unique opportunity to reconstruct and understand how seasonal climate variability and the El Niño-Southern Oscillation (ENSO) have evolved in the past. However, most climate interpretations of paleorecords assume stationarity, i.e. that the modern relationship between a given climate sensor and ENSO was the same in the past, which might not be true. Therefore, one of the difficulties is to infer how changes in mean state and variability have shaped the evolution of SST and other environmental factors, such as precipitation and wind, in the past. Using a suite of simulations performed with the climate model of the Institut Pierre Simon LaPlace (IPSL-CM4; Marti et al. 2010), we discuss the relative effects of different Holocene forcings on seasonality and interannual variability between the early Holocene and the pre-industrial period.

Sensitivity experiments

Previous simulations and model data comparison have established that long-term changes in insolation affected ENSO variability in the Holocene (Clement et al. 2000; Moy et al. 2002). However, the presence of melting remnant ice sheets in the northern hemisphere during the Early Holocene, may have partially offset the impact of the insolation forcing. In this study, simulations of the Early Holocene and the Mid-Holocene are used to infer how the slow variation of the Earth's orbital parameters affected ENSO variability (Luan et al. 2012). We also conducted a set of sensitivity experiments to examine how meltwater release and the presence of remnant northern hemisphere ice sheets may have impacted ENSO characteristics (Braconnot et al. 2012; Marzin et al. in press). The different model years in the simulations were classified either as El Niño, La Niña, or normal years based on the December-January-February SST anomalies in the Niño3 region (150°W-90°W, 5°S-5°N). Anomalies were only classified as El Niño or La Niña events when they crossed a SST threshold of 1.2 times the standard deviation derived from the pre-industrial SST time series.

ENSO is the dominant mode of SST and precipitation variability in all of the simulations. However, both the pre-industrial and past El Niño event simulations are affected by biases common to most climate models (Zheng et al. 2008). For example, the cold tongue (i.e. the equatorial region in the Pacific with cold SSTs) of normal years penetrates too far west along the equator (not shown), as does the equatorial warming associated with El Niño events (Fig. 1a,c). As a result the horseshoe structure of El Niño's SST and precipitation patterns seen today in the western Pacific is not well pronounced. This discrepancy can lead to misinterpretation when comparing simulated changes with high-resolution coral records from the central equatorial Pacific region (Brown et al. 2008). In addition, simulations of ENSO variability are also damped in the eastern Pacific when compared with modern observations.

Spatial variability of ENSO patterns

Our simulations indicate that over time changes in forcing influence the location and intensity of the maximum SST and precipitation anomalies. In the Early Holocene for example, insolation forcing slightly damps the strength of the peak of the event (Fig. 1) compared with pre-industrial control simulations. In these Early Holocene examples a major reduction is simulated west of the maximum

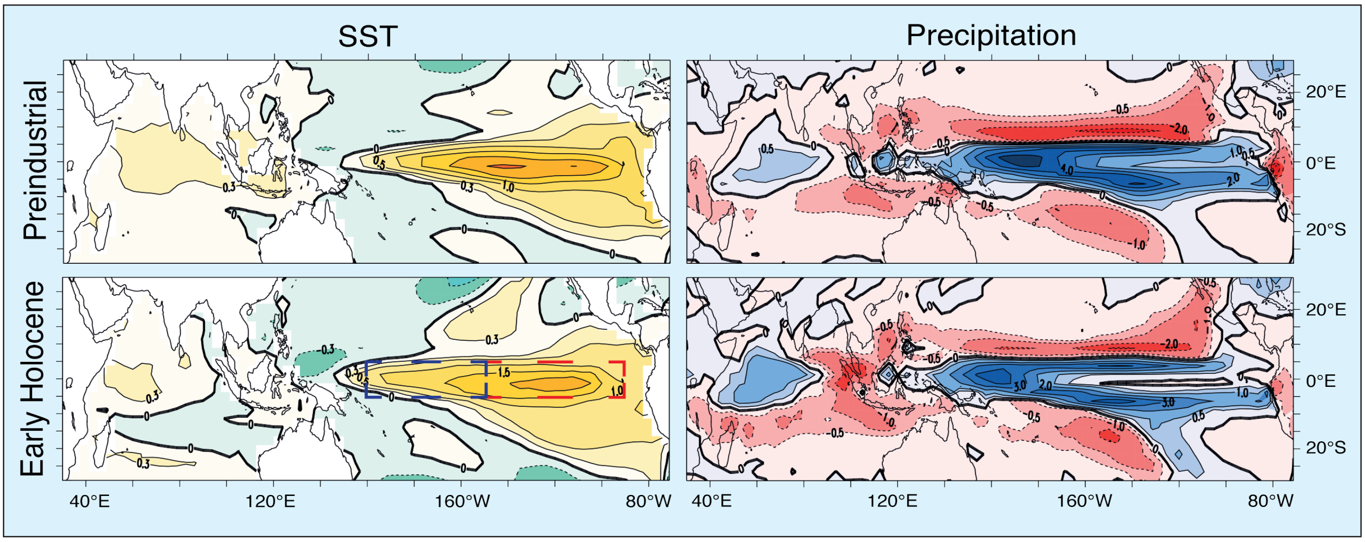

Figure 1: Composite sea surface temperature (SST) anomaly and precipitation anomaly maps during El Niño events as simulated by the IPSL-CM4 climate model for pre-industrial and Early Holocene (9.5 ka BP) climates. The anomalies describe the departures from normal years in each simulation at the peak of the event in December-January. Isolines are plotted every 0.5°C for SST with a refinement of 0.25°C around the 0 line, and every 1 mm d^{-1} *for precipitation with a refinement of 0.5 mm d*$^{-1}$ *around the 0 line. The red and blue dashed boxes in the lower left panel show the Niño3 and Niño4 regions, respectively.*

SST anomaly found in the pre-industrial control simulation, and another important reduction occurs on the South-American coast. Figure 1 therefore illustrates that the teleconnections between the different parts of the Pacific basin, as well as between the Pacific and the Indian Ocean, vary depending on the mean climate state. This further suggests that the climatic relationships between regions today are not stationary in time.

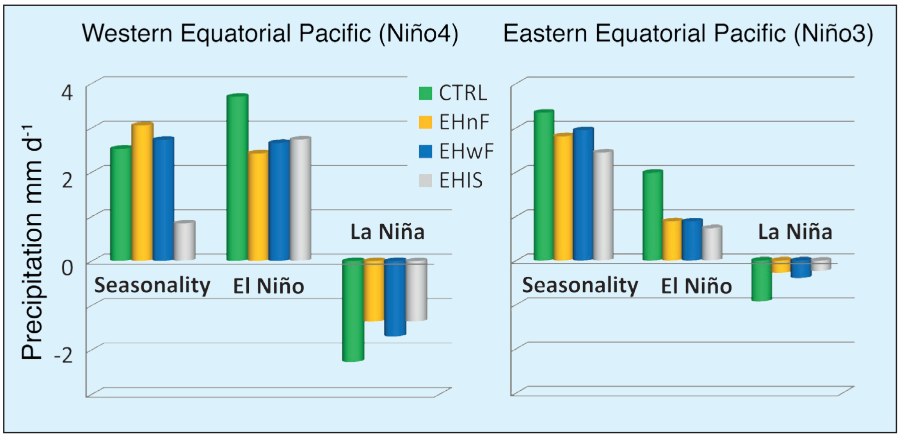

Figure 2: Sensitivity experiments: Diagrams of precipitation (mm d^{-1}) averaged over the Niño3 and Niño4 regions in the Pacific Ocean. Groups of columns show the magnitude of the seasonal cycle and the peak (December) magnitude of El Niño and La Niña events for each of the simulations discussed in the text: pre-industrial (CTRL), Early Holocene (9.5 ka BP, EHnF), Early Holocene with a fresh water flux mimicking ice sheet melting in the North Atlantic (EHwF) and Early Holocene with the presence of remnant Laurentide and Fennoscandian ice sheets (EHIS). See Braconnot et al. (2012) for details on the methodology and statistical significance. The magnitude of the seasonal cycle is computed as the difference between maximum and minimum monthly values at the annual time scale. El Niño and La Niña anomalies correspond to the value at the peak of the event in December.

Changing seasonality and interannual variability accross time

Insolation forcing also affects the seasonality of SST and precipitation. Changes in the magnitude of the seasonal cycle of precipitation mirror the changes in the seasonal cycle of SSTs.

Figure 2 shows the Early Holocene insolation only simulations (EHnF), and pre-industrial control runs (CTRL) for two regions; the West (Niño4 region; 160°E-150°W, 5°S-5°N), and East (Niño3 region; 150°W-90°W, 5°S-5°N). Compared with the pre-industrial control run, the seasonal cycle of precipitation ("seas" in Fig. 2) was increased in the West (Niño4 region) and decreased in the East (Niño3 region) in the Early Holocene. These precipitation changes follow SST changes (not shown). It indicates that the seasonal variability in insolation was in phase with the SST seasonal cycle in the West and out of phase, in the East. The SST seasonal cycle is further amplified by the east-west asymmetry of cloud feedback and the dynamic response of SST to anomalous westerly winds in the eastern equatorial Pacific (Luan et al. 2012). As a consequence, seasonality had a larger effect on SSTs than do changes in interannual ENSO variability, even in the east Pacific (Braconnot et al. 2012).

With regards to precipitation, we note a reduction of larger absolute magnitude associated with El Niño and La Niña events in both the Niño3 and Niño4 regions when compared with the pre-industrial control runs (Fig. 2). Thus, both seasonality and interannual variability damp the SST and precipitation variations in the eastern Pacific, whereas seasonality enhance and variability damp precipitation in the central Pacific.

Our analyses have implications when interpreting records of past ENSO variability across different regions. In the eastern Pacific, Early Holocene seasonality and interannual SST and precipitation variability are reduced compared with SST and precipitation variability in the pre-industrial run. Therefore climate reconstructions, which are primarily determined by the relative sensitivity of climate sensors to seasonality and interannual variability, must take this into account in their calibrations in order to derive robust reconstructions.

In the central to western part of the basin, changes in seasonality and interannual variability act in opposite directions, and our results suggest that only the natural archives that are sensitive to precipitation would register large ENSO changes in the Early Holocene.

Role of additional forcings

The addition of a fresh water flux in the North Atlantic in the Early Holocene simulations leads to increased interannual variability and a slight increase in seasonality (Fig. 2; EHwF) compared with the simulation in which only insolation is changed (Fig. 2; EHnF). This suggests the fresh water flux partially offsets the changes due to insolation compared with the pre-industrial simulation (Fig. 2). This result is similar to the results of fresh water flux experiments under modern (Timmermann et al. 2007) or glacial (Merkel et al. 2010; see also Merkel et al., this issue) conditions. The presence of ice sheets (Fig. 2; EHIS) in the simulations, leads to a strong reduction in seasonality and a further damping of interannual precipitation variability compared with the insolation-only simulation. Particularly in the western Pacific, the results suggest that the remnant ice-sheets in the Early Holocene may have offset the amplification of precipitation seasonality.

Towards a better understanding

Our results show that the pattern of ENSO anomalies between the east and west Pacific is affected differently by forcings, but that SST variations during the Holocene were predominantly influenced by changes in seasonality driven by the Earth's orbital parameters such as insolation.

Linking the development of an El Niño event with changes in the seasonal evolution of the thermocline depth is a key factor explaining the damping of the simulated ENSO in the IPSL models (Luan et al. 2012). Our sensitivity experiments show that fresh water fluxes partially counteract the insolation-driven seasonal phasing and the melting remnant ice sheets strongly affect the mean thermocline depth and east-west gradient in SSTs (Luan et al. submitted). However, it seems that precipitation and SSTs do not necessarily vary with the same relative strength on seasonal and interannual timescales when subject to the same sensitivity experiments. These findings suggest that a better understanding of the controls and timescales of variability is necessary to interpret paleo-records of past ENSO variability correctly, and that paleo-records should be used with caution to test how well models reproduce changes in ENSO variability.

Selected references

Full reference list online under:
http://www.pages-igbp.org/products/newsletters/ref2013_2.pdf

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