

ABSTRACT

ENSO dynamics and the Earth's climate : from decades to Ice Ages.

JULIEN EMILE-GEAY

There is now acute recognition of the central role of tropical Pacific sea-surface temperatures in orchestrating climate variability on timescales longer than a few years : it is the familiar El Niño - Southern Oscillation (ENSO) phenomenon and its low-frequency modulation. There is, moreover, considerable interest in extending this notion to longer periods : decades, centuries, millennia, and glacial cycles. In this thesis, we explore a subset of mechanisms whereby low-frequency variability is produced within the tropical Pacific, and exported to other parts of the globe.

The first chapter focuses on the origins of Pacific decadal variability. Using linear equatorial wave theory, we compute the Green's function response of a shallow-water model of the tropical Pacific ocean, assessing the spectral characteristics of the ocean's response to a variety of endogenous and exogenous wind forcings : this shows that the Tropics remain the best place to force the equatorial thermocline, and we conclude that the variability is most likely to arise spontaneously via air-sea interactions, rather than midlatitude stochastic forcing.

The second chapter focuses on the past millennium and natural climate forcings : solar and volcanic perturbations to the radiative budget. In particular, we explore the impacts of the massive 1258 volcanic eruption, using an intermediate complexity model of ENSO (Cane-Zebiak) forced by estimated aerosol loading and solar irradiance anomalies. Compiling paleoclimate data from a wide array of sources, we show that the eruption is very likely to have triggered an El Niño event in the midst of an otherwise cold period - most likely forced by low solar irradiance - with important consequences for neighboring areas. We also draw a diagram ENSO likelihood as a function of volcanic forcing, and identify a threshold of about 4 W m^{-2} (slightly above that of Krakatau, 1883), where volcanic forcing starts to noticeably increase the likelihood of an El Niño event in the model.

Thirdly, we address similar questions for the Holocene, and explore how solar and orbital forcing could have produced centennial- to millennial-scale variability in the ENSO system. Using the same model, forced by our best estimates of solar irradiance, we conduct ensemble simulations perturbed by realistic amounts of stochastic wind. We show that solar irradiance can plausibly generate millennial-scale ENSO variance above the model's level of internal variability, in spite of the noise. We then explore teleconnections to the North Atlantic and North Pacific, Southeast Asia and Central Andes regions, and offer a mechanism explaining the major paleoclimate records of solar-induced variability over the Holocene.

Lastly, we investigate how ENSO teleconnections might have differed during the Last Glacial Maximum (LGM). Starting from various GCM reconstructions of the mean state of the LGM atmosphere, we use a linear and nonlinear baroclinic model to simulate the stationary wave response to idealized tropical SST anomalies. The structure of the glacial ENSO changes little in these models, and we show that it is the altered mean state of the LGM atmosphere that profoundly modifies ENSO teleconnection patterns. No consensus is found between the two GCMs at LGM, and the simplified models suggest that it is due to different wave/mean-flow interactions in the northern midlatitudes.

Overall, this work supports the notion that ENSO dynamics, whether externally forced or not, play a fundamental role in generating global climate change on all timescales.