Feeling the heat: What corals and computers tell us about the past, present and future of the tropics

Steven J. Phipps[1] and Helen V. McGregor[2]

[1]Climate Change Research Centre, University of New South Wales, Australia [2]School of Earth and Environmental Sciences, University of Wollongong, Australia

1. Severe droughts or flooding rains?

El Niño is the dominant mode of natural variability within the climate system, and influences climate extremes across the globe. El Niño events occur every two to seven years, and are characterised by changes in ocean temperatures and atmospheric circulation in the tropical Pacific (Figure 1).

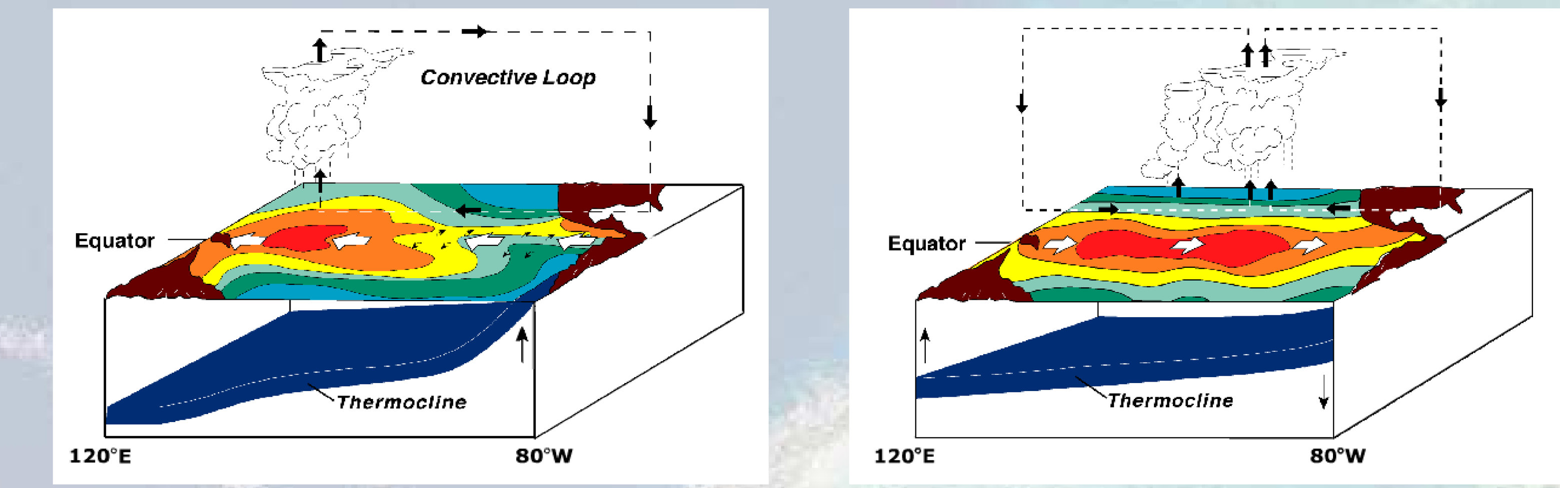

Figure 1. The state of the tropical Pacific during normal years (left) and El Niño events (right).

In a normal year, ocean temperatures are warm in the western Pacific. This drives a convective overturning cell in the atmosphere, creating wet conditions in the west and dry conditions in the east. An El Niño event arises when this overturning falters and the surface trade winds weaken. The warm surface waters in the west flow eastwards, taking the rain with them. A La Niña event is the opposite of an El Niño event, and is characterised by increased rainfall in the western Pacific.

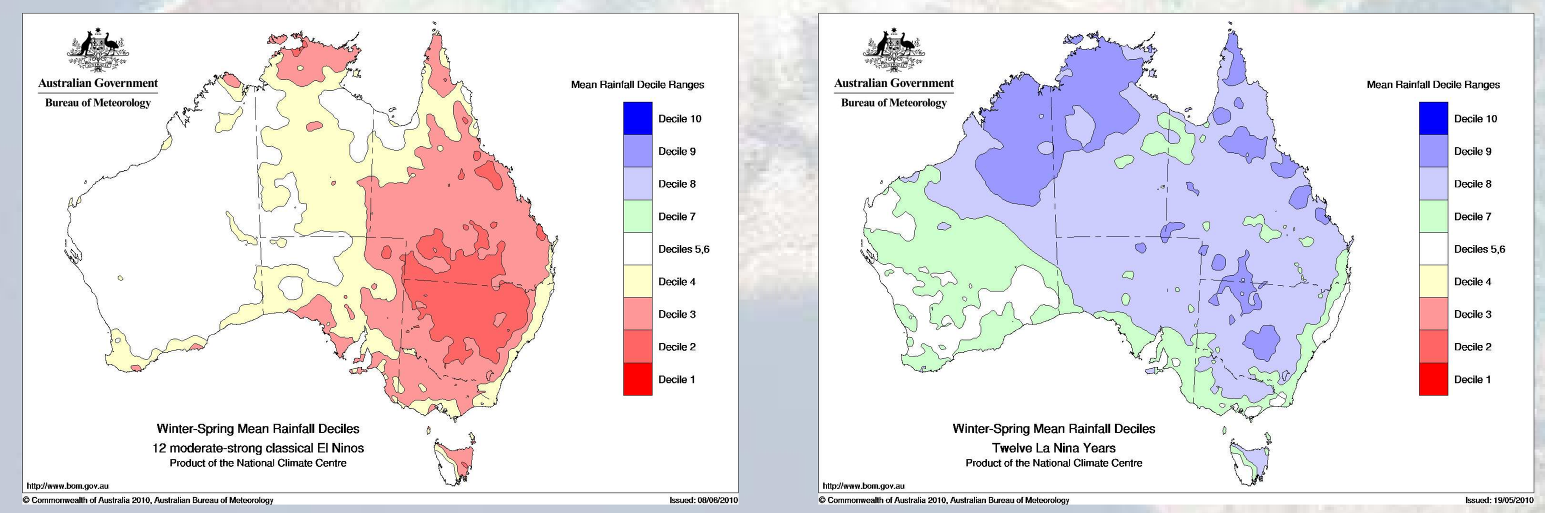

Figure 2. Rainfall over Australia during El Niño events (left) and La Niña events (right).

El Niño has a strong influence on the climate of Australia, as can be seen from Figure 2. El Niño events can cause severe droughts, while La Niña events can bring flooding rains. It is therefore of critical importance to Australian society to be able to predict how El Niño might evolve under future climate change. However, as shown in Figure 3, current predictions are highly uncertain.

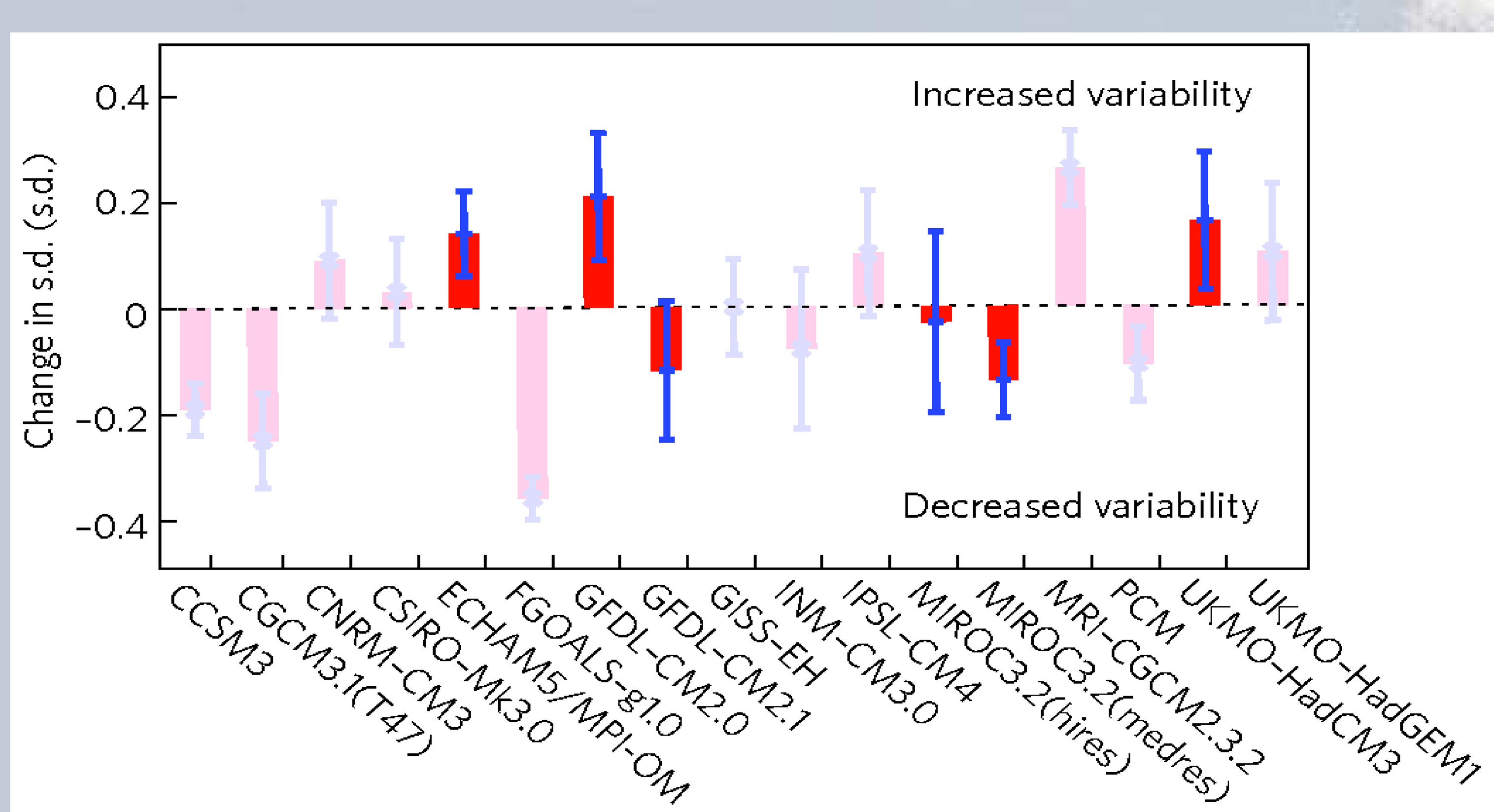

Figure 3. Projected changes in the amplitude of El Niño variability in response to global warming, according to 17 different climate models (Collins et al., 2010).

2. The coral time machine

Past climatic changes provide an opportunity to learn more about the dynamics of El Niño, and to explore the physical mechanisms that can drive changes in its behaviour. In the tropical Pacific Ocean, the annual growth rings of corals capture the history of El Niño. Fossil corals show that El Niño events have become stronger and more frequent over recent millennia (Figure 4). There is also strong variability on decadal timescales, accompanied by rapid switches between modes.

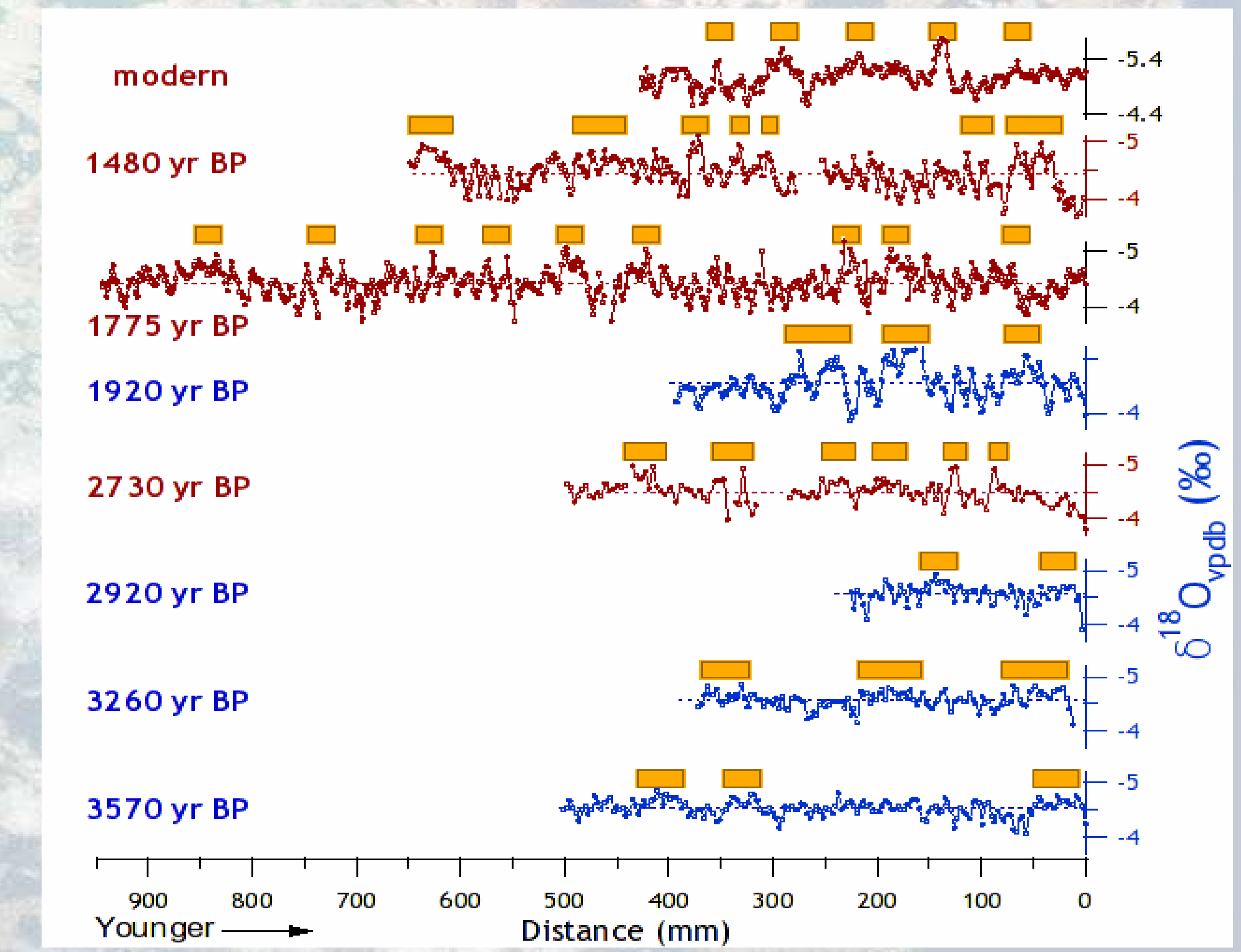

Figure 4. Climate variability in the central Pacific Ocean, recorded by fossil microatolls from Kiritimati (Woodroffe et al., 2003; updated version of Figure 3). Changes in the amount of ^{18}O are strongly correlated with changes in sea surface temperature. Yellow bars indicate El Niño events.

3. El Niño and global climate change

To learn from the coral record, the CSIRO Mk3L climate system model (Phipps, 2010) is used to simulate the evolution of the global climate over the past 8,000 years. The simulations provide a dynamical framework within which physical links can be explored. They reveal that, on millennial timescales, cyclical changes in the Earth's orbit around the sun are the dominant influence on El Niño. Warmer northern summers in the past resulted in stronger easterly trade winds in the tropical Pacific, suppressing the development of El Niño events (Figure 5).

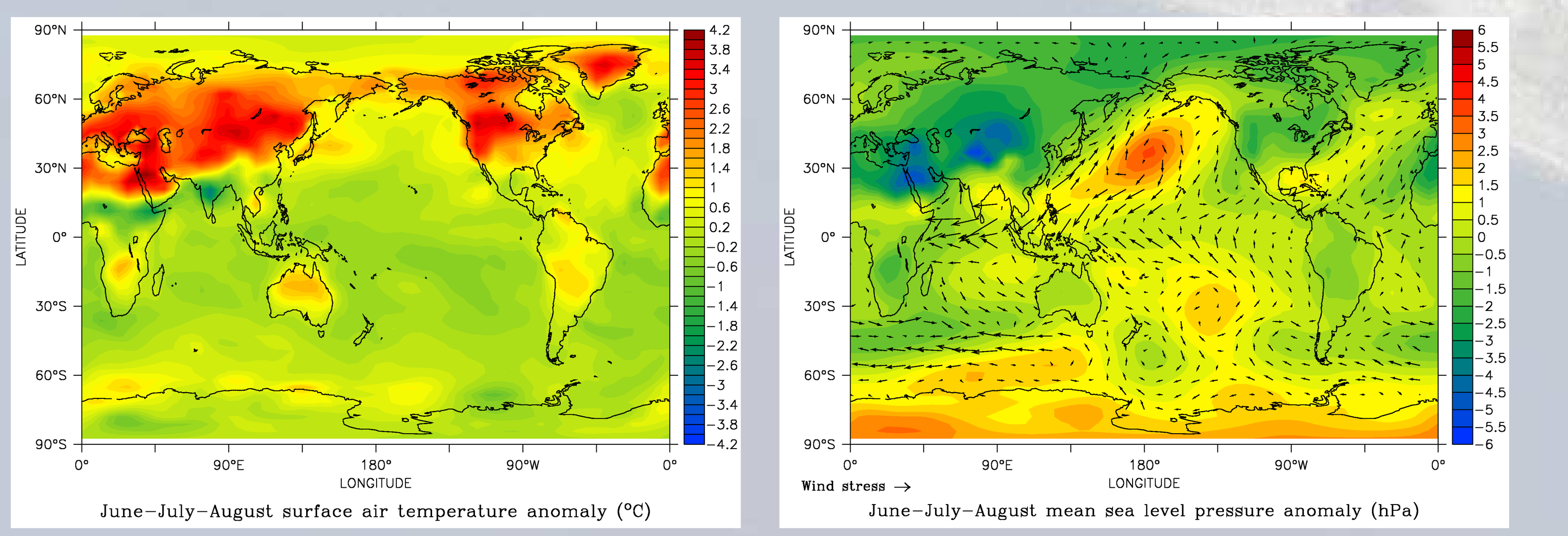

Figure 5. The simulated global climate 8,000 years ago, expressed as anomalies relative to the modern climate: surface temperature (left), and sea level pressure and winds (right).

On shorter timescales, random variability within the climate system becomes increasingly important. Figure 6 shows the evolution of El Niño over the past 8,000 years, according to three independent simulations conducted using the same climate model. Strong stochastic variability on centennial timescales is superimposed upon the overall upward trend in variability.

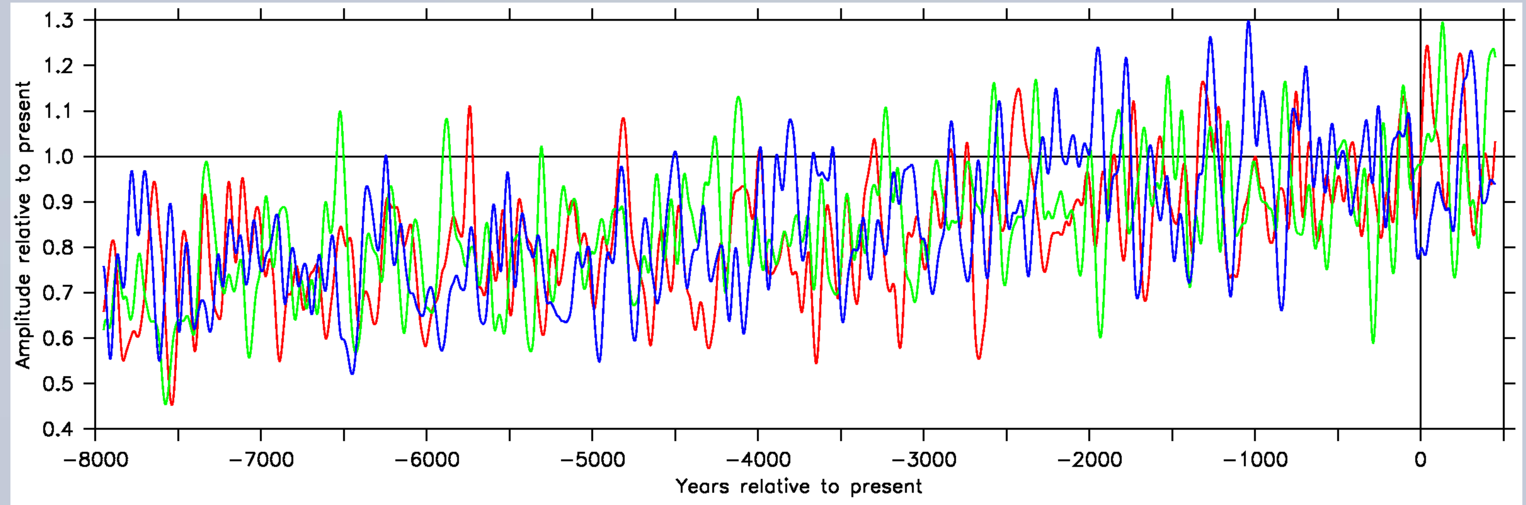

Figure 6. The change in the amplitude of El Niño variability over the past 8,000 years, according to three independent climate model simulations. A 100-year smoother has been applied.

On annual timescales, volcanic emissions can also become important. Figure 7 shows the evolution of sea surface temperature in the central Pacific during the 13th century, according to three independent climate model simulations. A massive volcanic eruption in 1258 CE – the largest to occur during the past millennium – causes sudden and dramatic cooling, initiating a La Niña event. Strong random variability on decadal timescales is also apparent, as in the coral record.

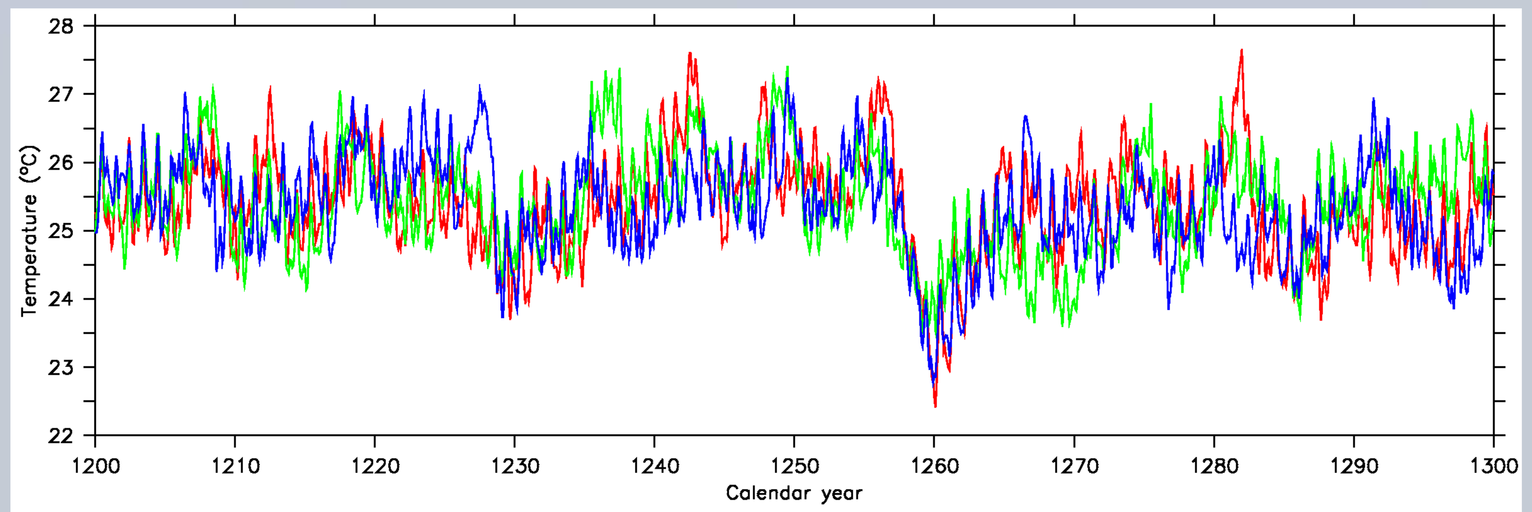

Figure 7. The change in sea surface temperature in the central Pacific Ocean during the 13th century, according to three independent climate model simulations.

4. Conclusions

Coral reefs and computer models tell us that the tropics experience strong natural variability on timescales that range from years to millennia. The work presented here suggests that there are fundamental limits to our ability to predict changes in El Niño during the 21st century. On decadal to centennial timescales, the amplitude of unpredictable random variability is so great that it may swamp any underlying trend arising from increasing concentrations of greenhouse gases.

References

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