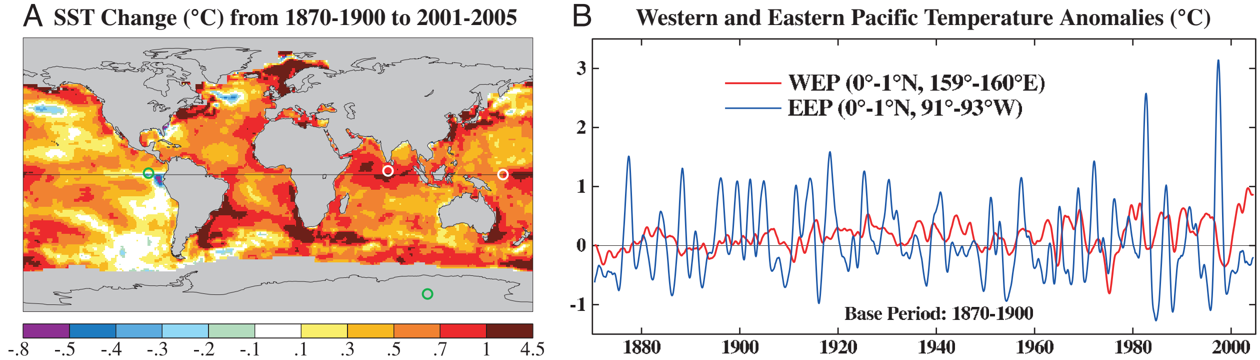

Fig. 3. Comparison of SST in West and East Equatorial Pacific Ocean. (*A*) SST in 2001–2005 relative to 1870–1900, from concatenation of two data sets (5, 6), as described in the text. (*B*) SSTs (12-month running means) in WEP and EEP relative to 1870–1900 means.

cover longer periods. Nevertheless, it is apparent that the first transient climate simulations (12) proved to be quite accurate, certainly not "wrong by 300%" (14). The assertion of 300% error may have been based on an earlier arbitrary comparison of 1988–1997 observed temperature change with only scenario A (18). Observed warming was slight in that 9-year period, which is too brief for meaningful comparison.

Super El Niños. The 1983 and 1998 El Niños were successively labeled "El Niño of the century," because the warming in the Eastern Equatorial Pacific (EEP) was unprecedented in 100 years (Fig. 3). We suggest that warming of the Western Equatorial Pacific (WEP), and the absence of comparable warming in the EEP, has increased the likelihood of such "super El Niños."

In the "normal" (La Niña) phase of El Niño Southern Oscillation the east-to-west trade winds push warm equatorial surface water to the west such that the warmest SSTs are located in the WEP near Indonesia. In this normal state, the thermocline is shallow in the EEP, where upwelling of cold deep water occurs, and deep in the WEP (figure 2 of ref. 20). Associated with this tropical SST gradient is a longitudinal circulation pattern in the atmosphere, the Walker cell, with rising air and heavy rainfall in the WEP and sinking air and drier conditions in the EEP. The Walker circulation enhances upwelling of cold water in the East Pacific, causing a powerful positive feedback, the Bjerknes (21) feedback, which tends to maintain the La Niña phase, as the SST gradient and resulting higher pressure in the EEP support east-to-west trade winds.

This normal state is occasionally upset when, by chance, the east-to-west trade winds slacken, allowing warm water piled up in the west to slosh back toward South America. If the fluctuation is large enough, the Walker circulation breaks down and the Bjerknes feedback loses power. As the east-to-west winds weaken, the Bjerknes feedback works in reverse, and warm waters move more strongly toward South America, reducing the thermocline tilt and cutting off upwelling of cold water along the South American coast. In this way, a classical El Niño is born.

Theory does not provide a clear answer about the effect of global warming on El Niños (19, 20). Most climate models yield either a tendency toward a more El Niño-like state or no clear change (22). It has been hypothesized that, during the early Pliocene, when the Earth was 3°C warmer than today, a permanent El Niño condition existed (23).

We suggest, on empirical grounds, that a near-term global warming effect is an increased likelihood of strong El Niños. Fig. 1*B* shows an absence of warming in recent years relative to 1951–1980 in the equatorial upwelling region off the coast of South America. This is also true relative to the earliest period of SST data, 1870–1900 (Fig. 3*A*). Fig. 7, which is published as supporting information on the PNAS web site, finds a similar result for linear trends of SSTs. The trend of temperature minima in the East Pacific, more relevant for our purpose, also shows no equatorial warming in the East Pacific.

The absence of warming in the EEP suggests that upwelling water there is not yet affected much by global warming. Warming in the WEP, on the other hand, is 0.5–1°C (Fig. 3). We suggest that increased temperature difference between the near-equatorial WEP and EEP allows the possibility of increased temperature swing from a La Niña phase to El Niño, and that this is a consequence of global warming affecting the WEP surface sooner than it affects the deeper ocean.

Fig. 3*B* compares SST anomalies (12-month running means) in the WEP and EEP at sites (marked by circles in Fig. 3*A*) of paleoclimate data discussed below. Absolute temperatures at these sites are provided in Fig. 8, which is published as supporting information on the PNAS web site. Even though these sites do not have the largest warming in the WEP or largest cooling in the EEP, Fig. 3*B* reveals warming of the WEP relative to the EEP [135-year changes, based on linear trends, are +0.27°C (WEP) and −0.01°C (EEP)].

The 1983 and 1998 El Niños in Fig. 3*B* are notably stronger than earlier El Niños. This may be partly an artifact of sparse early data or the location of data sites, e.g., the late 1870s El Niño is relatively stronger if averages are taken over Niño 3 or a 5° × 10° box. Nevertheless, "super El Niños" clearly were more abundant in the last quarter of the 20th century than earlier in the century.

Global warming is expected to slow the mean tropical circulation (24–26), including the Walker cell. Sea level pressure data suggest a slowdown of the longitudinal wind by ≈3.5% in the past century (26). A relaxed longitudinal wind should reduce the WEP–EEP temperature difference on the broad latitudinal scale (≈10°N to 15°S) of the atmospheric Walker cell. Observed SST anomalies are consistent with this expectation, because the cooling in the EEP relative to WEP decreases at latitudes away from the narrower region strongly affected by upwelling off the coast of Peru (Fig. 3*A*). Averaged over 10°N to 15°S, observed warming is as great in the EEP as in the WEP (see also Fig. 7).

We make no suggestion about changes of El Niño frequency, and we note that an abnormally warm WEP does not assure a strong El Niño. The origin and nature of El Niños is affected by chaotic ocean and atmosphere variations, the season of the driving anomaly, the state of the thermocline, and other factors, assuring that there will always be great variability of strength among El Niños.

Will increased contrast between near-equatorial WEP and EEP SSTs be maintained or even increase with more global warming? The WEP should respond relatively rapidly to increasing GHGs. In the EEP, to the extent that upwelling water has not been exposed to the surface in recent decades, little warming is expected, and the