Natural variability of the central Pacific El Niño event on multi-centennial timescales

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[1] There is an evidence of the increasing intensity as well as occurrence frequency of the so-called central Pacific (CP) El Niño events since the 1990s. We examine whether such an increase in the frequency of CP El Niño may be a manifestation of natural climate variability. A control simulation of the Kiel Climate Model, run for 4200 years with the present values of greenhouse gases, exhibit large variations of the occurrence frequency of the CP El Niño versus the eastern Pacific (EP) El Niño. A model simulates to some extent changes in the occurrence ratio of CP and EP El Niño in comparison with the observations. Therefore, we can not exclude the possibility that an increasing of occurrence frequency of CP El Niño during recent decades in the observation could be a part of natural variability in the tropical climate system. **Citation:** Yeh, S.-W., B. P. Kirtman, J.-S. Kug, W. Park, and M. Latif (2011), Natural variability of the central Pacific El Niño event on multi-centennial timescales, *Geophys. Res. Lett.*, *38*, L02704, doi:10.1029/2010GL045886.

1. Introduction

[2] The El Niño-Southern Oscillation (ENSO) is a coupled ocean-atmosphere tropical Pacific phenomenon on subdecadal timescales, extending its influence beyond the tropical Pacific through atmospheric teleconnections [*Lau*, 1997; *Alexander et al.*, 2002; *McPhaden et al.*, 2006]. In addition, there is the expectation that ENSO statistics would change under global warming although the details remain uncertain because of the large spread of model projections for the 21st century [*Guilyardi et al.*, 2009]. The impact of global warming on changes in ENSO statistics remains an area of active research [*Collins et al.*, 2010].

[3] Studies have reported that recent El Niño events during the 1990s and the 2000s have somewhat different characteristics in terms of the location of the maximum anomalous sea surface temperature (SST) compared to the conventional El Niño which typically exhibits warming in the cold tongue region of the eastern equatorial Pacific [*Kao and Yu*, 2009; *McPhaden*, 2004; *Ashok et al.*, 2007; *Kug et al.*, 2009]. This phenomenon has been viewed as a different type of El Niño and has been named differently. It should be mentioned that, because there is no consensus in what terminology should be used to refer to the non-conventional type of El Niño, we choose to use the term 'Central Pacific (CP) El Niño' and refer to the conventional El Niño as the term 'Eastern Pacific (EP) El Niño' for the sake of its simplicity in contrasting the centers of SST anomaly between the conventional and non-conventional ENSO types.

[4] The atmospheric diabatic forcing over the tropics differs in the CP El Niño and EP El Niño, therefore, the tropical-midlatitude teleconnections to the two types of El Niño is significantly different [*Wang and Hendon*, 2007; *Weng et al.*, 2007]. For instance, the position of the principal atmospheric centers of action at 500 hPa is strikingly different between the two types of El Niño. *Yeh et al.* [2009] further argued that the increasing frequency of the CP El Niño during recent decades could be due to global warming and such a CP El Niño will occur more frequently as anthropogenic global warming is enhanced. Satellite observations suggest that the intensity of CP El Niño has almost doubled during the past three decades, which is related to the increasing intensity as well as occurrence frequency of CP El Niño events since the 1990s [*Lee and McPhaden*, 2010]. However, addition work is needed to understand the increase in the frequency of occurrence of CP El Niño during recent decades. One critical issue is whether the modal shift in El Niño is just a manifestation of natural climate variability on decadal to centennial timescales [*Ashok and Yamagata*, 2009]. One approach to examine this question is to study ENSO modulation in a coupled general circulation model (CGCM) since these model simulations are sufficiently long (order a few millenia) to allow for robust statistical analysis.

[5] Here we present a multimillenial CGCM simulation that exhibits long modulation time scales for the CP El Niño and the EP El Niño. Our purpose is to assess whether the natural changes in the frequency of CP El Niño occurrence simulated by the model are comparable to the observed changes over the last few decades. If the changes are similar then we cannot rule out the possibility that the recent changes are simply natural variability. On the other hand, if the observed changes are much larger that the natural variability predicted by the model, then we argue that the potential importance of a changing climate cannot be neglected.

2. Model and Methodology

[6] The Kiel Climate Model (KCM) is a fully coupled atmosphere-ocean-sea ice model without flux corrections. It consists of the ECHAM5 atmosphere general circulation model [*Roeckner et al.*, 2003], and the NEMO ocean-sea ice general circulation model [*Madec*, 2008], and both components are coupled with the OASIS3 coupler [*Valcke*, 2003]. Detailed is described by *Park et al.* [2009]. KCM is integrated 5000 years in total that was started from the Levitus climatology with the present values of greenhouse gases. KCM

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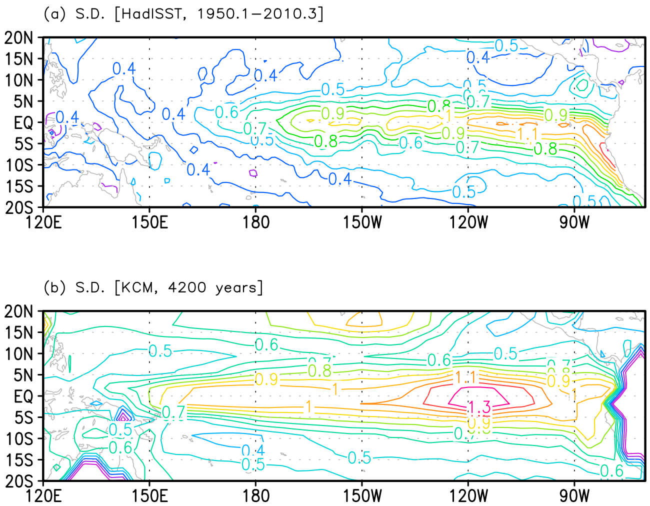

Figure 1. The standard deviation of monthly sea surface temperature (SST) anomaly for the observation for the period of (a) January 1950 to March 2010 and (b) the KCM for the simulation period of 4200 years. Contour interval is 0.1°C. The climatological seasonal cycle is removed in both the observation (1950–2010) and the KCM (4200 years).

simulated realistically the annual and semiannual cycles in the eastern and western equatorial Pacific, respectively. The KCM's dominant spectral peak is found at a period of 4 years and it produces stronger equatorial SST variability than observed, specifically over the western and central equatorial Pacific [*Park et al.*, 2009]. We analyze 4200 years after skipping the spin-up phase. We also used the SST taken from the Hadley Centre SST dataset (HadISST) [*Rayner et al.*, 2003] for the period of 1950–2010. The HadISST is based on data contained within the recently created Comprehensive Ocean and Atmosphere Data Set with a relatively high spatial resolution of 1° × 1° and so is superior in geographical coverage to previous datasets and has smaller uncertainties [*Rayner et al.*, 2003].

3. Result

3.1. CP and EP El Niño Events

[7] Figures 1a and 1b show the standard deviation of monthly SST anomaly for the observation for the period of January 1950 to March 2010 and the KCM for the simulation period of 4200 years, respectively. The maximum of the standard deviation is in the eastern tropical Pacific in both the observational estimates and the KCM simulation, however, large SST variability is also found in the western equatorial Pacific in the KCM compared to the observations. In addition, the KCM fails to adequately simulate the amplitude of SST variability along the coast of the South American coastal line.

[8] In order to define the CP and EP El Niño, we follow a similar methodology used by *Yeh et al.* [2009]. While the climatological amplitude of NINO3 (5°N–5°S, 150°W–90°W) SST index is large at January–February–March (hereafter, 3-month periods are denoted by the first letter of each respective month, JFM) in the KCM, that in the observation is at November–December–January (NDJ). We first collect years in which the JFM NINO3 SST index or the JFM NINO4 (5°N–5°S, 160°E–150°W) SST index is above 0.66°C in the KCM. Note that 0.66°C corresponds to 0.7 standard deviation of JFM NINO3 SST index. Among those years, the EP El Niño is defined as the years in which the JFM NINO3 SST index is greater than the JFM NINO4 SST index. The CP El Niño is defined as the years in which the JFM NINO4 SST index is greater than the JFM NINO3 SST index. The seasonal mean (JFM) SST anomaly is defined as seasonal mean deviations from a climatological (4200 years) seasonal mean SST. Similar to the KCM, we use the NDJ NINO3 SST index and the NDJ NINO4 SST index to define the CP and EP El Niño in the observation. It is noteworthy that the overall results in this paper are not much changed when we use the same seasonal NINO indices in the KCM as in the observation and slightly different criteria to define the CP and EP El Nino in the KCM.

3.2. Statistics

[9] Table 1 provides the number of CP El Niño and EP El Niño simulated in the KCM for the period of 4200 years and that in the observational estimates for the period of 60 years (1950–2010). The total number of CP El Niño is 509 and that of EP El Niño is 709 in the KCM. The occurrence ratio of the CP and EP El Niño is 0.12/year and 0.16/year, respectively. The ratio of CP to EP El Niño occurrence is 0.71, indicating that the EP El Niño is simulated more frequently than the CP El Niño in the KCM. In the observational estimates, the total number of CP El Niño is 4 and that of EP El Niño is 14 and the ratio of CP to EP El Niño occurrence is 0.28, which is considerably smaller than the KCM. This may partly be induced by model's error to represent the ratio, but on the other can be attributed by the short length of the observation.

[10] To identify the difference of the spatial structure between the CP El Niño and the EP El Niño we carry out a composite analysis of the SST anomaly in KCM (Figures 2a and 2b). The EP El Niño (Figure 2a) is characterized by the maximum anomalous mean SST in the eastern equatorial Pacific, on the other hand, the center of maximum SST in the CP El Niño (Figure 2b) is located near the date line in the central equatorial Pacific significantly shifted westward from the EP El Niño. The KCM reasonably captures the spatial structures of EP and CP El Nino in comparison with the observations (Figures 2c and 2d). However, the center of both EP and CP El Nino simulated in the KCM is shifted to the west and the amplitude of anomalous SST in the EP El Nino is weak along the coast of South America, which might be due to the model bias as shown in Figure 1.

[11] It is useful to examine how the statistics of CP and EP El Niño occurrence varies in the KCM. To examine this, we calculate the ratio of the CP to EP El Niño occurrence for each 60 year in the entire simulation period of 4200 years. We purposely choose the time interval of 60 years in order to directly compare with the observation. The open circles in Figure 3a indicate the ratio for the time chunk of 60 years. The ratio significantly varies on each period of 60 year. The mean ratio for each time chunk of 60 years is 0.76. This indicates

Table 1. Number of CP El Niño and EP El Niño Simulated in the KCM and the Observation and Their Ratios

	CP El Nino	EP El Nino	Occurrence Ratio: CP/EP El Nino
KCM	509	709	0.71
Observation	4	14	0.28

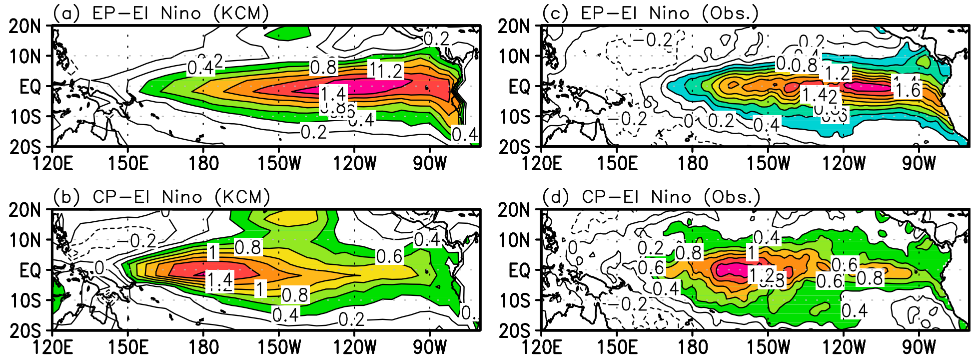

Figure 2. Composite average SST anomaly of EP El Niño and CP El Niño in the KCM. Contour interval is 0.2°C and shading is above 0.4°C.

that the periods when the CP El Niño event occurs less frequently than the EP El Niño are more dominant than the periods when the CP El Niño event occurs more frequently than the EP El Niño. One may also find that there are periods when the ratio is around 0.3 in the KCM, which is similar to the observation, 0.28. The minimum ratio is 0.0, indicating that there is no CP El Niño event during those periods. In contrast, the maximum ratio is 2.0, indicating that the CP El Niño occurs twice as often as EP El Niño events. One standard deviation of the ratio is 0.35, therefore, the ratio in the observation is beyond one standard deviation of ratio in the KCM. Large variations of the ratio, from 0.0 to 2.0, indicates that the natural variability of the CP to EP El Niño occurrence ratio is quite large and that this sub-sampling of the simulation brackets the observational estimate provided above.

[12] We further calculate the ratio for each 30 year in the entire simulation period of 4200 years (Figure 3b). The variations in the ratio become large, for example, the maximum and minimum ratio is 3.0 and 0.0, respectively. The mean ratio for each time chunk of 30 years is 0.82 and one standard

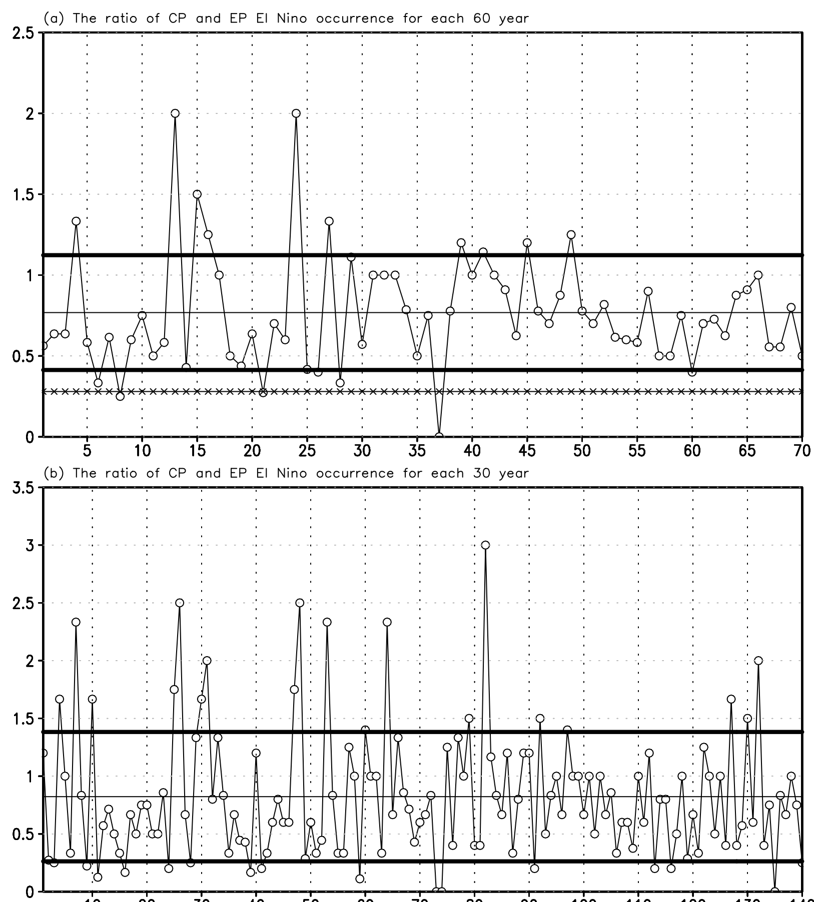

Figure 3. (a) The ratio of the CP and EP El Niño occurrence for each 60 years in the entire simulation period of 4200 years. Thin solid straight line is the mean and thick solid lines indicate plus and minus one standard deviation. Cross straight line is the mean ratio of the observation, 0.28. The number of x-axis represents for each 60 years. (b) Same as Figure 3a except for each 30 years.

Table 2. Ten Periods When the Ratio of CP and EP El Niño Occurrence Is High and Low in the KCM

High Periods		Low Periods	
Model Simulation Period	Ratio of CP and EP El Niño occurrence	Model Simulation Period	Ratio of CP and EP El Niño occurrence
2680–2739	1.33	2800–2859	0.33
3220–3279	2.00	2920–2979	0.25
3340–3399	1.50	3280–3339	0.42
3400–3459	1.25	3580–3639	0.43
3880–3939	2.00	3700–3759	0.27
4060–4119	1.33	3940–3999	0.41
4780–4839	1.20	4000–4059	0.40
4900–4959	1.14	4120–4179	0.33
5140–5199	1.20	4660–4719	0.00
5380–5439	1.25	6040–6099	0.40
Mean ratio of CP and EP El Niño occurrence	1.42	Mean ratio of CP and EP El Niño occurrence	0.32

deviation is 0.56 in Figure 3b, therefore, one may consider that the variation of the ratio between 0.26 and 1.38 is in the range of plus and minus one standard deviation (thick lines in Figure 3b). This indicates that five times increase of the ratio from one period of 30 years to other period of 30 years could be considered as a natural variability. In the observation, the ratio increases three times from the first 30 years (0.14, 1950–1979) to the second 30 years (0.42, 1980–2009). Therefore, we can not exclude the possibility that an increasing of CP El Niño during recent decades in the observation could be a part of natural variability in the tropical climate system. It is noteworthy that *Yeh et al.* [2009] reported that the ensemble mean ratio of CP and EP El Niño in the climate change run of six CGCMs increases as much as five times compared to the present climate run, therefore, one may argue that the magnitude of natural variability in terms of the ratio of CP and EP El Nino can be comparable with that due to the global warming.

3.3. Mean State Change

[13] The mechanism for the frequency changes of CP El Niño occurrence is unknown and is beyond the scope of this paper; however, we conjecture a possible link between the mean state changes and the change of frequency in the CP El Niño occurrence. To show this, we compare the mean state in the Pacific Ocean between the two distinct periods when the ratio of CP and EP El Nino occurrence is significantly different. Based on Figure 3a we select the ten periods when the ratio is high and low, respectively (Table 2). The mean ratio in the high ratio periods (600 years) is 1.42, which is four times larger than that in the low ratio periods (600 years), 0.32. Table 2 indicates detailed statistics of CP and EP El Niño events in the ten high and low ratio periods, respectively.

[14] Figure 4 shows the mean SST difference between the high and low periods. A striking difference of the mean SST exists in both the North Pacific and the eastern subtropical Pacific. Note that shading indicates the region where the difference is a statistical significant at the 99% confidence level. When the ratio is high, the mean SST in the North Pacific is cooler and that in the eastern subtropical Pacific is warmer than the period when the ratio is low. This is consistent to some extent with recent study argued that the SST variability associated with the CP El Niño exhibits a strong connection to the subtropics in the Northern Hemisphere [*Yu et al.*, 2010]. That is, the changes in the mean SST in the extratropics may influence the frequency of CP El Niño occurrence in the tropical Pacific in the KCM via atmospheric teleconnections. We also could find a structure of subsurface temperature extending from the subtropics to the equator between the two periods (not shown). On the other hand, *Yeh et al.* [2009] argued that the increasing occurrence frequency of CP El Niño under global warming scenario was associated with the change in the thermocline structure along the equator. We compare the mean 20°C isothermal depth between the high and low periods (not shown) and it is found that there are little differences, which is in contrast with *Yeh et al.* [2009]. These indicate a possibility that changes in the CP El Niño frequency can occur with changes in the extratropical mean state and without changes in the tropical mean state.

4. Concluding Remarks

[15] In this study, we investigated whether changes in the frequency of CP El Niño occurrence is a part of natural climate variability using a multimillenial CGCM simulation. Based on the statistical analysis in the KCM, we can not exclude the possibility that an increase of CP El Niño during recent decades in the observational estimates could be a part of natural variability in the tropical climate system. In addition, we suggested that the mean SST changes in particular, in the North and subtropical Pacific may be associated with

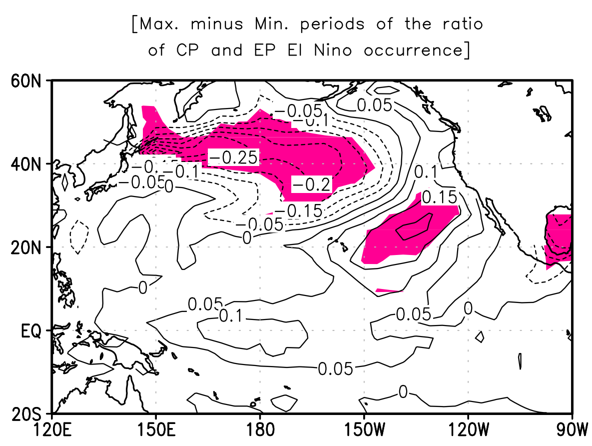

Figure 4. The mean SST difference between the high and low periods of CP and EP El Niño occurrence ratio. See the text for detailed explanation for the high and low periods. Contour interval is 0.05°C and shading indicates the region where the difference is a statistical significant at the 99% confidence level.

the changes in the ratio of CP and EP El Niño occurrence. In spite of a long simulation of period, our results are limited to a single CGCM, therefore, further investigation is necessary to better understand these issues using multiple CGCM simulations. For instance, *Kug et al.* [2010] argued that the occurrence frequency of CP El Niño is closely associated with changes in the western tropical Pacific mean SST based on an analysis of a long simulation (500 years) of the GFDL CGCM. We also found a warmer state in the tropical Pacific in the high frequency of CP El Niño occurrence but it is not statistically significant (Figure 4).

[16] In spite of that, however, there exists a possibility that the changes in the tropical Pacific, which is due to the high frequency of CP El Niño occurrence, may be able to induce the mean SST difference in the extratropics. Therefore, it is also needed to investigate other CGCMs to identify detailed relationship between the mean state and the frequency of CP El Niño event. Finally, it should be also noted that the KCM has a larger variance of SST in the western and central equatorial Pacific than observation, therefore, such a model bias may influence the variability of CP and EP El Niño occurrence. Furthermore, it is needed to examine the detailed criteria of western and central Pacific SST variability (i.e., NINO4 SST index) to define the CP El Niño event in the CGCM.

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