P1.1 MOUNTAIN UPLIFT AND ENSO

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1. INTRODUCTION

How climate changes will modify the behavior of El Niño/Southern Oscillation (ENSO) is one of important questions in future climate projections. Paleoclimate studies show an evidence of past changes in ENSO variability. An investigation of ENSO with general circulation models (GCM) under different climate forcing gives us a good insight on mechanism of ENSO variability and its changes. Mountain uplift can cause a change in SST and ocean general circulation (Kitoh 1997, 2002a). As the new MRI coupled GCM (MRI-CGCM2: Yukimoto et al. 2001) has shown an ability to reproduce a reasonable climate without flux adjustments (Kitoh 2002b), we use this MRI-CGCM2 to study the sensitivity on ENSO by progressive mountain uplift.

2. MODEL AND EXPERIMENT

We used the new Meteorological Research Institute global atmosphere-ocean coupled GCM (MRI CGCM2, Yukimoto et al. 2001). The model consists of a T42 L30 AGCM and a global 0.5-2.0° by 2.5° L23 OGCM.

We used eight different mountain heights: 0% (no mountain), 20%, 40%, 60%, 80%, 100% (control run), 120%, and 140%. Land-sea distribution is the same for all experiments and all mountains in the world are uniformly varied. Each run is integrated without flux adjustments for 50 years, for which the last 40 years' data are analyzed.

3. RESULTS

3.1 ENSO in the control run

The model reproduces a reasonable El Niño and associated precipitation and atmospheric circulation changes. Figure 1 shows the leading EOF mode of the near global (50°S–50°N) SST. This explains 18.5% of the total variance and corresponds to the model El Niño. There are positive SST anomalies over the equatorial central and eastern Pacific, the Indian Ocean and the Atlantic Ocean. Negative SST anomalies are found over the western tropical Pacific. The eastern equatorial Indian Ocean is also covered by negative SST anomalies. Figure 1 also shows the associated regression fields of the wind vector at 850 hPa and the precipitation. Westerly wind anomalies prevail over the entire equatorial Pacific, while the Indian Ocean is covered by easterly wind anomalies. Large precipitation anomalies are associated with the SST anomalies in the tropical Pacific and the Indian Ocean, implying an eastward displacement of the rainfall center. These features are in agreement with the observations.

3.2 ENSO in the mountain runs

Figure 2 shows the annual mean SST for experiments M0 through M14. Over the tropical region in M0, the local SST maximum above 29°C is centered around the date line, while SST below 26°C is found in the eastern Indian Ocean and the eastern Pacific Ocean. Over the equatorial Indian Ocean, the SST gradient is reversed between the lower mountain runs and higher mountain runs. A zonal SST gradient in the tropical Indian Ocean increases with mountain uplift from M0 to M14 with a decreasing SST along the eastern coast of Africa and an increasing SST in the equatorial eastern Indian Ocean. This change is mainly associated with an intensifying southwesterly summer monsoon flow in the Arabian Sea and a weakened wind strength in the eastern Indian Ocean. The location of warm pool shifts westward with progressive mountain uplift, and after M8, the maritime continent becomes the region of the maximum SST. Although the maximum SST value increases with mountain uplift, regions with SST above 29°C rather shrink in M12 and M14. A cold tongue in the equatorial eastern Pacific is most clear in M0, becomes weaker with mountain uplift until M10, but again shows some development in M12 and M14. Both the air-sea heat fluxes and ocean dynamical changes are responsible for these SST changes. For the changes in air-sea heat fluxes, those in latent heat flux and net shortwave radiation are dominant, with the former being larger than the latter in the experiments. The mountain uplift causes stronger trade winds and would make the western Pacific SST cooler. Ocean dynamics works to make the warm pool SST warmer from M0 to M8. In M0, a zonal SST gradient in the central and western tropical

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Pacific is very small. Strengthened trade winds with mountain uplift make the zonal SST gradient larger and warm the western Pacific, making a La Niña-like mean state. This background situation still holds with further mountain uplift from M8 to M14, but at these stages, increasing evaporation with stronger winds surpasses the dynamical effect and cools the western Pacific.

Figure 3 shows the leading EOF of near-global SST for each run and Fig. 4 shows the power spectra. In M0, the SST anomaly pattern is nearly symmetric about the equator. The maritime continent and the tropical Indian Ocean have an opposite polarity with the eastern equatorial Pacific. Negative SST anomalies shrink with mountain uplift and the M14 has almost same polarity in the entire tropical oceans. It is also seen from Fig. 3 that the location of maximum SST variability shifts westward by mountain uplift. Variance explained by the leading EOF is largest in M0 and also is its total power. They decrease toward M14. The frequency also changes by mountain uplift. The M0 has a spectral peak at longer than 6 years, while M2 and M4 have a peak between 4 and 6 years. The highest mountain cases (M12 and M14) have a power peak around 3 years. In summary, with mountain uplift, the variability of model El Niño becomes smaller and its frequency becomes higher.

In order to clarify the reason of systematic changes of model El Niño with mountain uplift, Figs. 5–8 show the annual mean SST, standard deviation of monthly mean SST, annual mean zonal wind stress, and zonal distributions of the leading EOF of SST at the equator, respectively. As was already seen in Fig. 2, M0 has a clear cold tongue and a large zonal SST gradient. The SST gradient becomes weaker and M12 and M14 have a very weak gradient in the central equatorial Pacific. The interannual standard deviation of equatorial SST (Fig. 6) is largest in M0, and smallest in M14. The change in easterly winds is very distinct in the central and western equatorial Pacific. It is weak with lower mountain cases, while it is stronger and extends more westward with higher mountain cases. This is associated with increasing strength of the subtropical anticyclones with mountain uplift (Kitoh 2002b). Figure 8 shows that the longitude of maximum correlation of the leading EOF lies around 150°W in lower mountain cases, but it shifts toward the date line in cases M10, M12 and M14. It also demonstrates a big change of the SST polarity over the equatorial Indian Ocean.

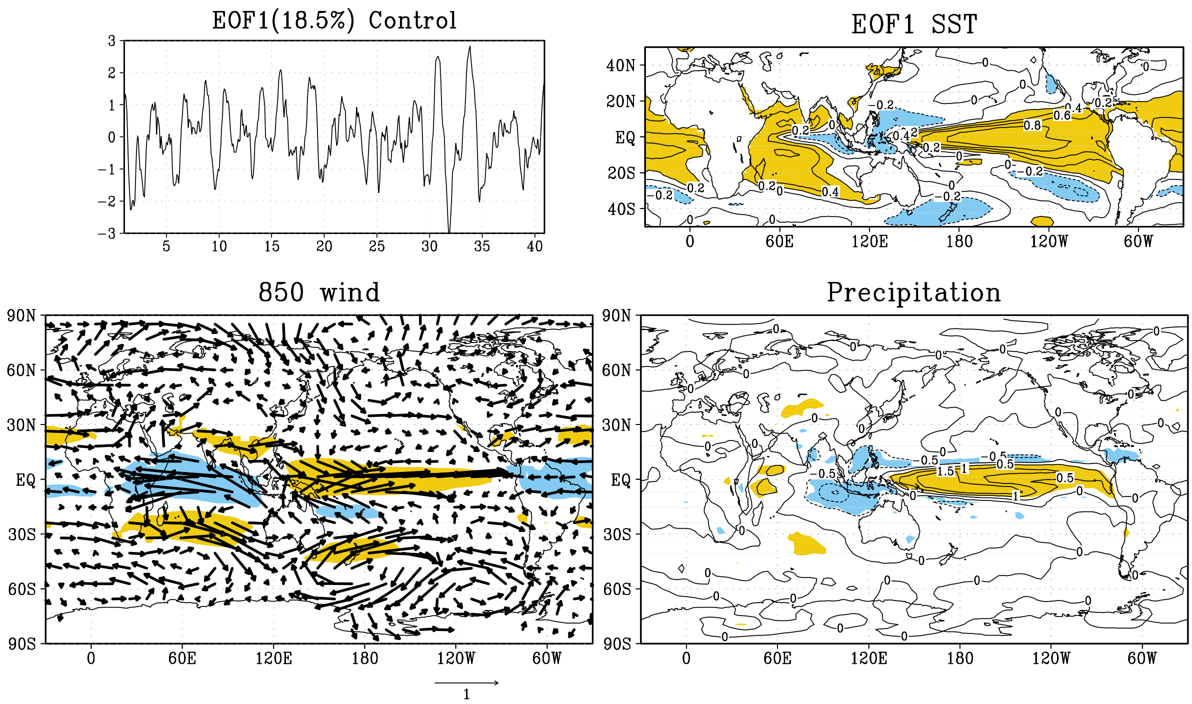

Figure 1. (Upper) The first EOF of the near global (50°S–50°N) SST of the control run. (Below) Associated regression fields of the wind vector at 850 hPa and the precipitation. Regions with correlation coefficients larger than +0.2 or less than –0.2 (statistically significant at approximately 95% level) are shaded.

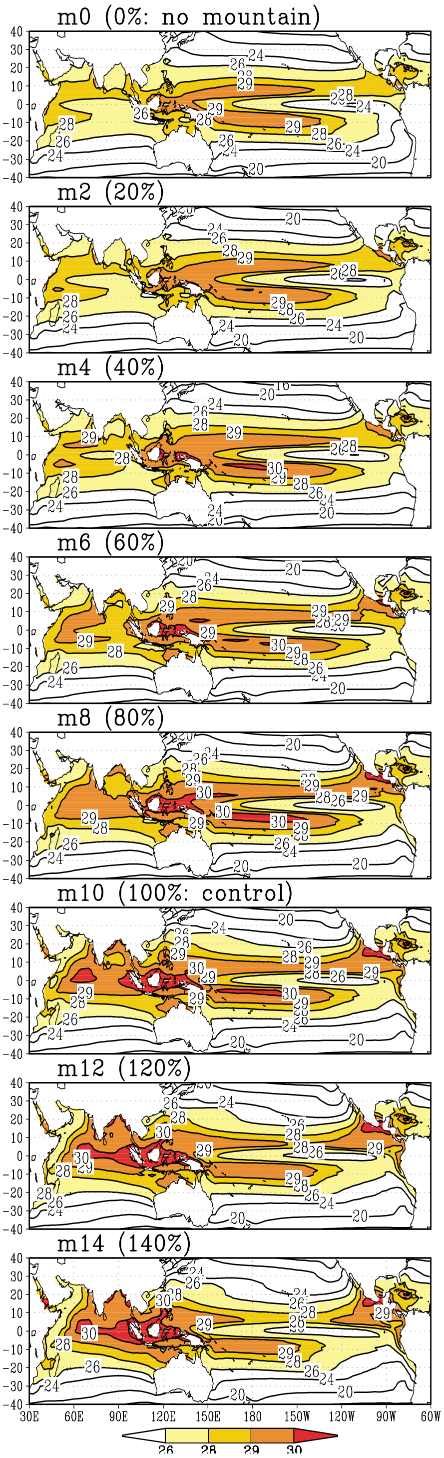

Figure 2. Horizontal distributions of the annual mean SST for all experiments (M0, M2, M4, M6, M8, M10, M12 and M14).

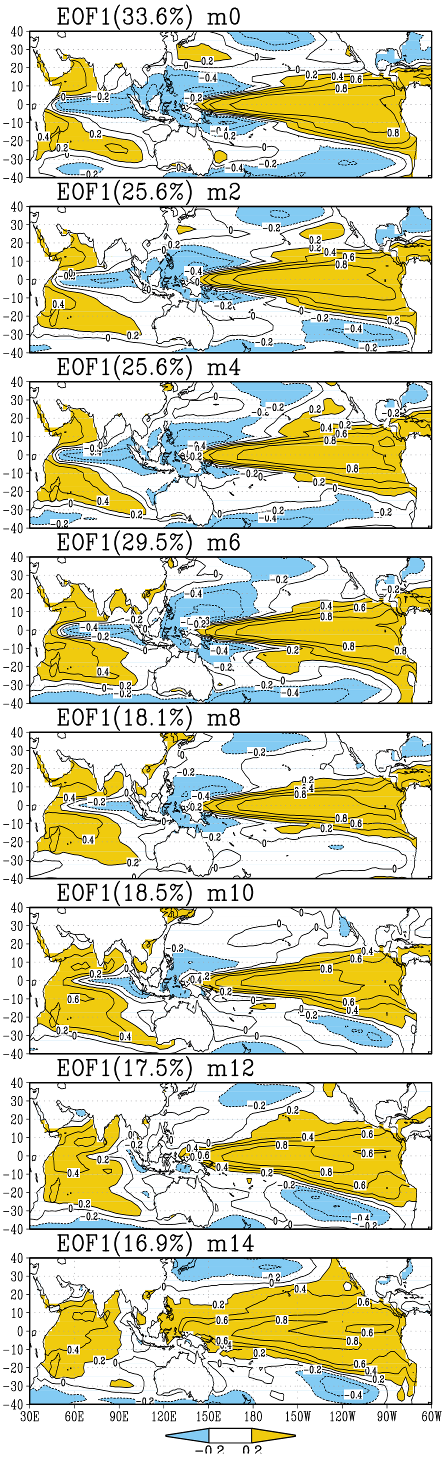

Figure 3. The leading mode of EOF of the near global SST for each experiment (M0, M2, M4, M6, M8, M10, M12 and M14).

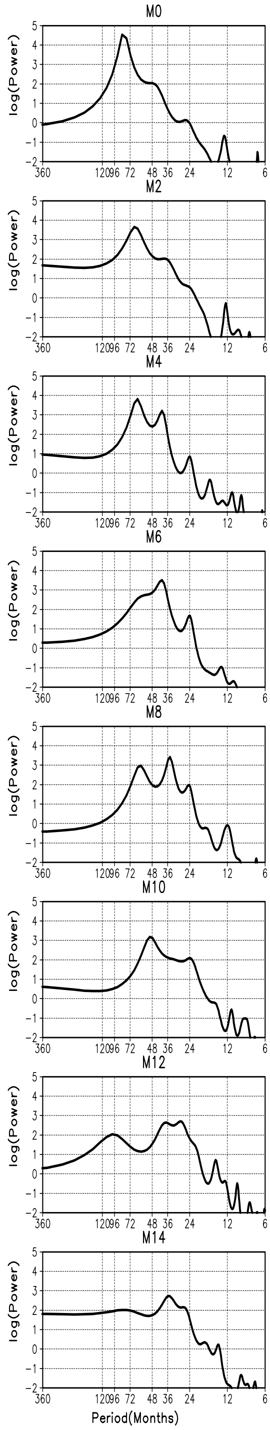

Figure 4. Power spectra of each leading mode of SST EOF.

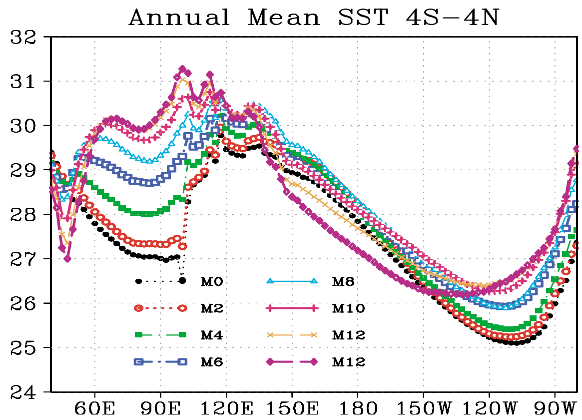

Figure 5. Annual mean SST averaged for 4°S-4°N.

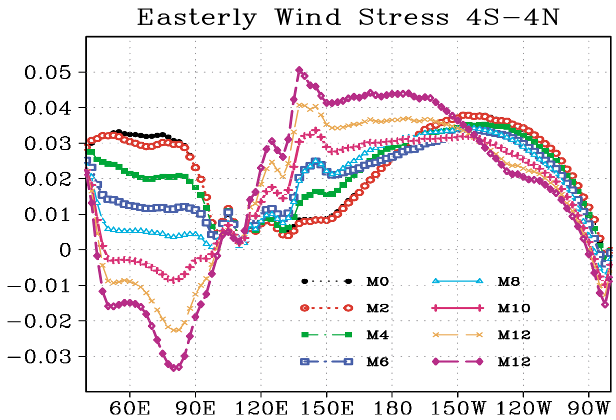

Figure 7. Annual mean zonal wind stress for 4°S-4°N. Positive means easterly wind stress.

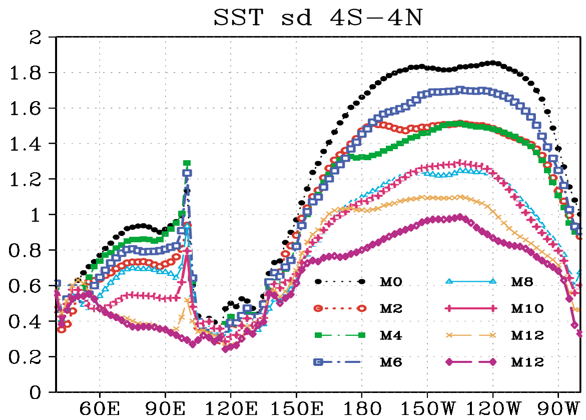

Figure 6. Standard deviations of equatorial monthly mean SST.

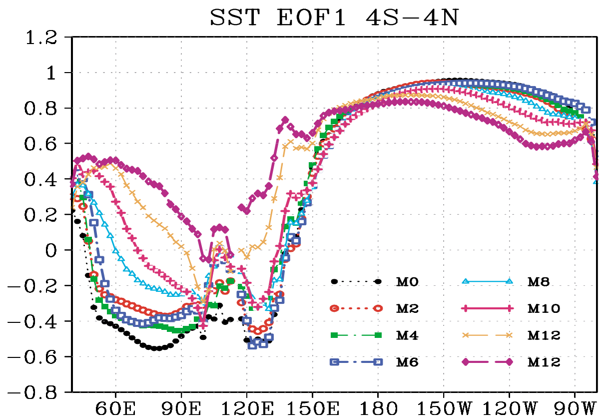

Figure 8. Zonal distributions of the leading EOF of SST at the equator.

4. CONCLUDING REMARKS

The intensity of the Pacific subtropical anticyclone and associated trade winds became stronger with mountain height. The western Pacific warm pool and ENSO systematically changed by mountain height. When the mountain height is low, a warm pool is located over the central Pacific due to weak trade winds in the Pacific. The model El Niño is the strongest, frequency is long and most periodic in the 0% run. They become weaker, shorter and less periodic when the mountain height increases.

As mountain height increases, the trade winds intensify and the location of the maximum SST variability shifts westward. This would shorten the length to the western Pacific where the Rossby wave reflects, reducing the period of El Niño variability. Smaller amplitude of El Niño with higher mountain cases may be related with smaller SST gradient in the central Pacific. A shorter return period may also contribute to a smaller amount of warm water pile up, and less variability.

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