Evolution of the Asian monsoon and the coupled atmosphere-ocean system in the tropics associated with the uplift of the Tibetan Plateau – A simulation with the MRI coupled atmosphere-ocean GCM

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Large-scale orographies, such as the Tibetan Plateau and the Rocky mountains, play an important role to form the present global climate system (Kutzbach et al. 1993). The large-scale orography has dynamical and thermodynamical effects to the atmosphere, which in turn influences the ocean circulation through the atmosphere-ocean interaction.

Many previous studies investigated the effect of mountains on the Asian summer monsoon using atmospheric general circulation models (AGCMs), by comparing the equilibrium climate states with and without mountains (Tibetan Plateau) and that without mountains (e.g., Hahn and Manabe 1974). However, these studies could not reveal to what degree the change of mountain height affects a climate and monsoon. It can also be postulated that the effect of mountains does not necessarily change linearly with increasing mountain heights. In addition, the Asian summer monsoon has been noted to have an active role of the interannual variability of the coupled atmosphere-ocean system in the tropical Pacific through the east-west circulation (e.g., Yasunari 1990, Yasunari and Seki 1992). The coupling of the Asian summer monsoon with the tropical Pacific Ocean system may, therefore, be crucial for the formation and variability of the tropical climate. An essential issue may be to investigate to what extent and how the tropical climate system, which is a coupled system of the Pacific/Indian Oceans and the Asian monsoon, is regulated by the uplift of the Tibetan plateau and other large-scale orographies.

Thus, to understand changes of the atmosphere/ocean coupled system associated with gradual uplift of the orography, a numerical experiment was conducted using the Meteorological Research Institute (MRI) coupled atmosphere–ocean general circulation model I (CGCM-I) (Abe et al. 2003). The MRI CGCM-I is the global grid model. Horizontal resolution of atmospheric part of the CGCM is 5° in longitude and 4° in latitude, and the vertical is 15 layers. The oceanic part has nonuniform meridional resolution ranging from 0.5° to 2.0°, with a finer grid in the tropics, fixed zonal resolution of 2.5°, and 21 layers vertically.

In this experiment six runs were performed, with six different elevations of the global mountains. That is, 0, 20, 40, 60, 80, and 100% of the present standard mountain height, were set for each run, which is called M0, M2, M4, M6, M8, and M, respectively. The continent-ocean distribution is the same in all runs. All the runs were integrated for 50 years, separately, and the data for the last 30 years (year 21 to 50) were used in our analyses.

An active convection region extends with mountain uplift to form a moist climate in South and East Asia. Monsoon circulation such as low-level westerly, and upper-level anticyclonic circulation, is also enhanced with uplift of the Tibetan Plateau. The increase in precipitation, and the enhancement of southwesterly, in the later stages of the uplift of the Tibetan Plateau, appear only over India and the south and southeastern slope of the Tibetan Plateau. Over the coastal region of Southeast and East Asia, where the maximum precipitation appears in M0, precipitation decreases gradually with uplift of the Tibetan Plateau, and the southwesterly in the later stages becomes weaker. The intensity of the Indian, Southeast Asian, and East Asian monsoon was investigated with indices, which are defined by area mean precipitation. The Indian monsoon becomes strong gradually with mountain uplift; particularly, in the later stages, the remarkable enhancement is found. The intensity of the South Asian monsoon is the strongest in M4. Thus, in the later stages of uplift the Tibetan Plateau, it becomes weaker in association with the northwestward migration of the convective activity. Although the East Asian monsoon is enhanced gradually with uplift of the Tibetan plateau, the enhancement in the earlier stages is larger than that in the later stages. In the equatorial Indian Ocean, sea surface temperature (SST) also increases with uplift of the Tibetan plateau, resulting in the increase in precipitation.

A pool of warm SSTs appears in the western Pacific as the Tibetan Plateau grows up, although SSTs in the tropical Pacific decrease as a whole. In addition, easterly winds at low levels over the equatorial Pacific strengthen as the Tibetan plateau rise. The enhanced easterlies alter surface heat flux and ocean dynamics, changing the water temperature field in the upper Pacific Ocean. Water temperatures between the surface and 300 m in the western Pacific increase because upwelling is suppressed and the thermocline deepens. Water temperatures in the eastern Pacific decrease and the thermocline rises. Therefore, the east-west gradient of water temperature in the Pacific is enhanced for cases with mountain heights of 80% and 100% of the standard mountain height. An increase in diabatic heating over South Asia, as height of the Tibetan Plateau increases, causes sea level pressure (SLP) to decline over the Indian Ocean, and enhances upper atmospheric divergence over the eastern hemisphere. Consequently, the east-west circulation over the Indian and Pacific Oceans strengthens as the Tibetan plateau become taller. Probably, the east-west circulation is also enhanced by changes in convective activity associated with SST changes. The coupled general circulation model (GCM) results show that uplift of the Tibetan Plateau significantly affects the tropical atmospheric and oceanic climate, changing the east-west circulation and altering the evolution of the Asian summer monsoon (Abe et al. 2004).

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