Japan Geoscience Union Meeting 2010
(May 23-28 2010 at Makuhari, Chiba, Japan)

APE025-P06 Room: Convention Hall Time: May 27 17:15-18:45

Weakening of tropical atmospheric circulation in the Middle Pliocene

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The Middle Pliocene (ca. 3 Ma BP), the short interval in the long-term cooling trend through the Cenozoic, is the most recent period when the global climate was warmer than present day (e.g. Jansen et al. 2007). The Paleoclimate Modeling Intercomparison Project phase 3 (PMIP3) focuses on this interval as one of the new targets (e.g. Otto-Bliesner et al. 2009). The United States Geological Survey (USGS) Pliocene Research, Intercomparison and Synoptic Mapping (PRISM) Project (e.g. Dowsett et al. 1999) has documented the characteristics of paleoenvironmental conditions in the Middle Pliocene (3.29-2.97 Ma) on a global scale by use of various types of proxy records.
The atmospheric general circulation and the water cycle in the Middle Pliocene were simulated in this work with the boundary conditions reconstructed by PRISM. The model used in this study is the atmospheric component of the Meteorological Research Institute Coupled General Circulation Model, version 2.3.2 (MRI-CGCM2.3.2), the air-sea coupled model (Yukimoto et al. 2001, 2006). The experiments were performed with the boundary conditions derived from the latest version of the PRISM digital data sets (PRISM3), i.e., sea surface temperature and sea ice cover (Dowsett et al. 2009), land ice and vegetation (Salzmann et al. 2008), and topography (Sohl et al. 2009). The concentration of atmospheric CO2 was set to 405 ppmv (Haywood et al. 2009b).
The atmospheric overturning circulation in the Middle Pliocene was decelerated significantly compared to the present day, particularly in the Northern summer. The cell of the Hadley circulation shifted northward and the upward motion was weakened greatly over the Intertropical Convergence Zone (ITCZ), while the downward motion over the Southern subtropical divergence zone was strengthened. In other words, the Hadley circulation was generally weakened and expanded northward and southward in the Middle Pliocene. The Walker circulation was also weakened generally. The horizontal and meridional gradients of sea surface temperature, which define the intensity of the Hadley and the Walker circulation, were reduced significantly in the Middle Pliocene (Brierley et al. 2009). Then we evaluated the contributions of the changes in the sea surface temperature, sea ice distribution, land condition (topography and vegetation), and atmospheric composition to the modulation of the atmospheric circulation by sensitivity experiments. As a result, the sea surface temperature and the land contition contributed mainly for the expansion of the Hadley circulation and the weakening of the zonally asymmetric circulation in general. In contrast, the slowdown of the upward motion over the ITCZ and the weakening of the Walker cell over the equatorial central / eastern Pacific were almost derived from the change in the distribution of sea surface temperature.
The global energy budget of the atmosphere and the hydrological cycle changed with the drastic modulation of the atmospheric circulation. The precipitation over the western tropical Pacific and eastern Indian Ocean warm pool decreased greatly and increased around the region. This represented the expansion of the high precipitation region over the tropics and the subtropics. This pattern corresponded with the change of the atmospheric circulation, the expansion of Hadley circulation to the subtropics and weakening of the Hadley and the Walker circulation. The precipitation over the equatorial central and eastern Pacific increased significantly. This pattern was similar to the El Nino phase of annual variation in the present day climate. From the results of

the sensitivity experiments, the main cause of this anomalous precipitation pattern was documented to the change in the sea surface temperature. The change in the land condition also contributed to the expansion of high precipitation area and the El Nino like pattern, significantly.

Keywords: paleoclimate, Middle Pliocene, PRISM, climate change, Hadley circulation, Walker circulation