P4.13 A STUDY OF DYNAMICAL CHARACTERISTICS ASSOCIATED WITH ABNORMAL WET SUMMER OVER THE KOREAN PENINSULA IN 2003

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1. INTRODUCTION

Bordered by the Tibetan Plateau to the west, the Eurasian land mass to the northwest, and the vast Pacific Ocean to the south and east, East Asia has experienced one of the most pronounced monsoon climates of the globe for centuries. The monsoon, by definition, is a reversal of wind with the season. During the summer, eastern Asia is under the influence of southwest surface winds accompanied by heavy rain, hot climate. During the winter, the prevailing surface wind over the same area is northeasterly, originating from a huge anticyclonic circulation over Siberia. Although an annual event, the monsoon of East Asia has large intraseasonal as well as interannual variabilities associated with its transition, maintenance, and extent of remote influence or teleconnections.

Not surprisingly, the El Nino-Southern Oscillation (ENSO) phenomenon is an important, if not the most important, factor affecting the interannual variability of the global climate and the East Asian climate. Numerous studies have linked ENSO to the temperature and precipitation anomalies in East Asia. However, it is now understood that the impact of ENSO on the climate in East Asia is only moderate (Lau et al. 2000; Chang et al. 2001; Yang et al. 2002). The effect of tropical western Pacific SST has been studied extensively since the 1980s. It has been widely accepted that the warm SST in the tropical western Pacific causes significant changes in the atmospheric heating over the Philippine Sea and in the subtropical western Pacific high (Chang et al. 2000a). These changes are in turn associated with variations in the meridional structure of the local atmosphere (Chang et al. 2000b) and anomalies in precipitation and surface temperature.

Other factors affecting the summer climate include the Tibetan Plateau. The importance of the Tibetan Plateau as an elevated heat source during the northern summer has been noted by many authors. It is known that the onset of the Asian summer monsoon is closely related to the concurrence of a reversal of meridional temperature gradient in the upper troposphere south of the Tibetan Plateau and a warming over the Tibetan Plateau (Wu and Zhang 1998). The relationship between the Eurasian-Tibetan Plateau snow cover and the East Asian summer monsoon has also been studied. Wu and Qian (2003) classified the spatial distribution of Tibetan winter snow anomalies into three typical patterns and reported that a more (less) Tibetan snow anomaly linked to the formation of negative (positive) tropospheric atmospheric temperature anomaly over the Tibetan Plateau, the weak (strong) land-sea thermal contrast over south Asia, and the weak (strong) south Asian summer monsoon circulation. The observation analysis by Zhnag and Wang (2004) supported that increased snow depth could enhance the WPSH and result in wetter summer rainfall over Yangtze River valley, including the effect of the SST warming in the Indian Ocean and Maritime Content. But the associated physical processes have not been clarified.

Above-normal rainfall and below normal temperature over China, Korea and Japan appear in 2003 summer. This study investigates the dynamical characteristics associated with abnormal wet summer monsoon over the Korean peninsula in 2003. We conduct a number of ensemble experiments using National Centers for Environmental Prediction (NCEP) global spectral model (GSM) to confirm the postulation.

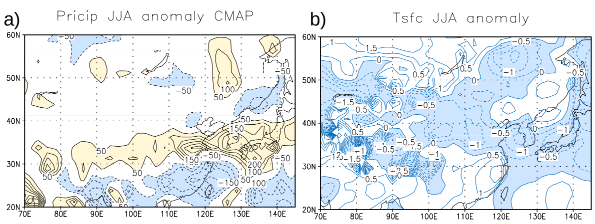

Fig. 1. JJA anomalies of (a) precipitation (CMAP) and (b) surface temperature. Contour interval in (a) is 50 mm day^{-1} and in (b) K. In (a) and (b), solid line denotes positive value, dotted line negative value. Shading in (b) denotes negative value.

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2. THE EAST ASIAN SUMMER MONSOON IN 2003

In 2003, Korea has experienced abnormal wet summer. Figure 1 shows the anomalies of precipitation and temperature during summer. The rainfall amount averaged over the Korean peninsula for summer increases by 114% over the climatology and the area-mean temperature decreases by the 1.1℃. The duration of sunshine decreases by 74.4% and the days of rainfall particularly is the most during the 30 years. August is climatologically a hot spell after the monsoon, but the Korean peninsula experienced a record-breaking wet and cold month.

2.1 Large scale mean circulation

The longitude-pressure sections of the eddy height anomalies in 2003 summer at 40°N in Fig. 2 illustrate the middle latitude stationary waves. The most pronounced feature is the development of the upper-level trough near the 120°E throughout the summer. The trough is deepened and extended to the east of Japan in July. In August, the trough due to a weakened Tibetan high (TH) still exists but weakened. The weakening of the TH results in the slow northward movement of the upper-level jet and consequently intensification of the zonal wind and deeper trough over the East-Asia. Regions of positive anomalies of surface pressure are distinct over the western Pacific (Fig. 3a). The strengthened western pacific subtropical high (WPSH) supplies more moisture to the Korean peninsula and results in record breaking rainy period (Fig. 3b).

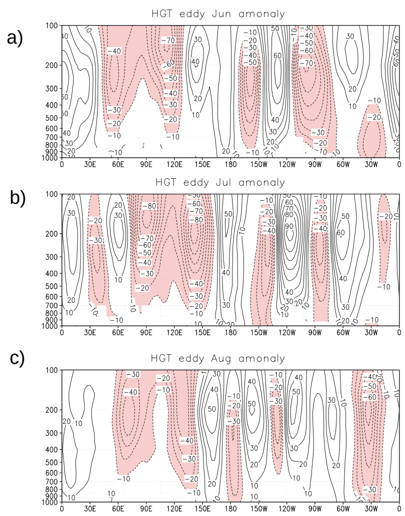

Fig. 2. Longitude-pressure section of the eddy height anomalies at 40°N for (a) Jun, (b) July and (c) August. Contour interval is 10 m. Shading denotes negative value.

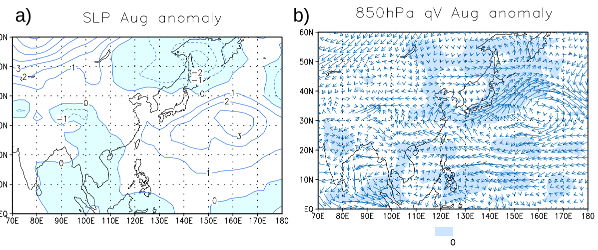

Fig. 3 Anomalies of (a) sea level pressure, (b) moisture advection (vector) and convergence (shaded) at 850hPa in August 2003. Contour interval is 1hPa in (a). Shading denotes negative values in (a).

2.2. Possible forcing mechanisms

In relation to the weakening of the TH, the snow over the Tibetan Plateau in winter of 2002-2003 is remarkably reduced compared to its climatology (Fig. 4a). This leads to the reduction of the surface albedo and increase of the solar radiation absorbed by surface. Subsequently, surface temperature is warmer (Fig. 4b). As a result, melting and sublimation of snow increases after March, causing a reduction of temperature throughout the summer (Figs. 4c and 4d). Due to colder surface temperature, sensible heat is reduced (Fig. 4e). Latent heat flux, on the other hand, is reduced during summer (Fig. 4f).

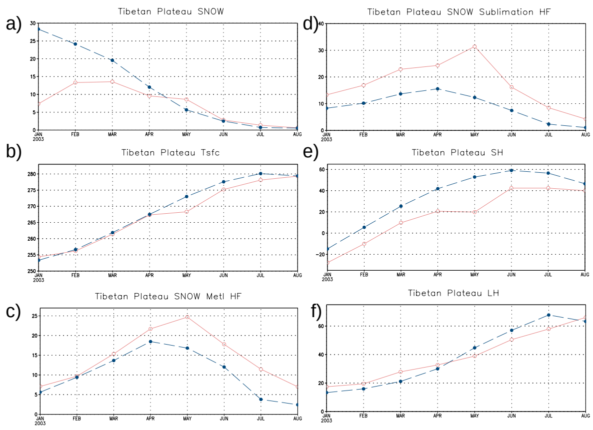

Fig. 4. Monthly time series of (a) snow depth (cm), (b) surface temperature (K), (c) snow sublimation heat flux (W m^{-2}) and (d) latent heat flux (W m^{-2}), averaged over the Tibetan Plateau, for 2003 (solid line) and climatology (dashed line).

In relation to the intensification of the WPSH in August, the warm SST anomalies appear in the tropical western Pacific Ocean (Fig. 5). From the analysis of outgoing longwave radiation (OLR), the tropical convective maximum (TCM) around the Indonesia is similar to the location of the warm SST anomalies. This may imply that the warm SST anomalies lead to the stronger ascending motion and results in the intensification of the WPSH through enhanced descending motion.

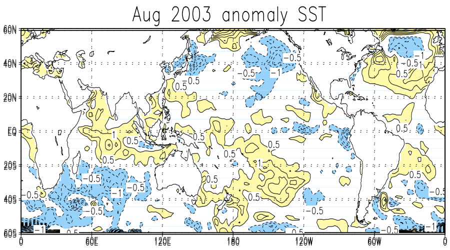

Fig. 5. SST anomaly in August 2003. Contour interval is 0.5°C.

3. THE MODEL AND EXPERIMENT DESIGN

The model used in this study is a GSM, a version of the NCEP MRF model employing a resolution of T62L28. To avoid introducing uncertainties with the initial data, 5-member ensemble runs for each experiment are performed, starting from 0000UTC 1 May to 0000UTC 5 May with 24-hr interval. Model precipitation is compared with the Climate Prediction Center (CPC) Merged Analysis Monthly Precipitation data (CMAP) (Xie and Arkin 1997) with 1.875°×1.875° spatial resolution.

To improve the simulation of EASM, recently developed physical parameterization methods are applied, as summarized in Table 1. The control experiment (CTL) employs the physics package used in the NCEP/DOE reanalysis data (Kanamitsu et al. 2002). In the CTL run, homogeneous land use properties are used, the vegetation type as a meadow and shrub land, the vegetation fraction as 70% and the soil type to sandy-clay-loam. The Medium-Range Forecast (MRF) planetary boundary layer (PBL) (Hong and Pan 1996) scheme for vertical diffusion of momentum and mass, and Fels and Schwarzkopf (1975) scheme for long wave radiation scheme are

Table 1. A summary of physics sensitivity experiments

	Land (Chen and Dudhia 2001)	PBL (Hong et al. 2003)	Radiation (Chou 1999)	Cumulus (Byun and Hong 2005)
CTL	x	x	x	x
LSM	o	x	x	x
PBL	x	o	x	x
RAD	x	x	o	x
CPS	x	x	x	o
ALL	o	o	o	o

Table 2. A summary of external forcing experiments. “o” and “c” means the observed data in 2003 and climatology respectively.

	snow depth	sst	soil moisture
CN03	o	o	o
SNOW	c	o	o
SST	o	c	o
SOIL	o	o	c
CLIM	c	c	c

employed. The cumulus parameterization scheme for deep convection uses the simplified Arakawa-Schubert (SAS) scheme.

Each of the following physics sensitivity experiments changes an option from the CTL experiment. The LSM experiment uses more realistic distribution of land use properties and topography (Chen and Dudhia 2001). More realistic thermal roughness length and velocity scale (Beljaars 1995) are also included in the LSM experiment. The PBL experiment uses the revised PBL scheme (Hong et al. 2003) and the RAD experiment uses the Chou (1999) scheme for long wave radiation scheme. The CPS experiment uses the revised cumulus parameterization scheme of the SAS scheme (Byun and Hong 2005). The ALL experiment uses above four physics schemes.

To confirm the postulation, additional five external forcing experiments are designed in Table 2. The control experiment (CN03) includes revised physics package used in the ALL experiment in Table 1. The observed or climatological boundary values are forced during the simulation period. In CN03 run, observed SST, snow and soil moisture from the reanalysis are forced. The SNOW experiment uses climatological value for snow depth and the SST experiment replaces the observed SST by a climatological SST during 1982-2003. The SOIL experiment uses climatological value for soil moisture and the CLIM experiment uses climatological values for snow depth, soil moisture and SST. The climatological values for snow depth and soil moisture are derived from R2 monthly data during 1979-2003.

4. RESULTS

The ALL experiment simulates well the trough from the south China and Korea to the central Pacific (Fig. 6a). The correlation coefficient over the globe shows as high as 0.65. Other experiments also simulates the large-scale pattern fairly well with the correlation coefficient ranging from 0.54 to 0.65, but less skillful than the results from the ALL experiment.

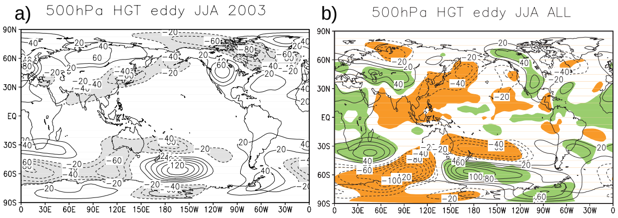

Fig. 6. JJA 500hPa eddy height for (a) reanalysis data, (b) the ALL experiment. Zonal mean is removed. Shading denotes negative values. Significant at the 90% level are shaded in (b).

Thus, the revised physics package used in the ALL experiment is employed for external forcing experiments below. One the other hand, the height anomalies at 500hPa are not simulated well irrespective of physics options.

We now discuss the results of external forcing experiments (Fig. 7). In June (cf. Figs. 2a and 7a), snow did not play a weakening of the TH. However, it is evident that below normal snow amount induces a reduction of the TH in July and August, but their intensities are strong enough (cf., Figs. 2bc, and Figs. 7bc). This results in the positive anomalies of precipitation in south China, Korea, and Japan in summer (Fig. 8a). The location of rain band during the summer slightly shifts southward compared to the observation (see Fig. 1a).

On the other hand, it is found that SST does not affect the abnormal wet summer over East Asia. The weakening of the TH is not seen by the SST experiment (Figs. 7def). Precipitation anomalies are negative over Korea (Fig. 8b), and related low-level flow is weakened (Fig. 9).

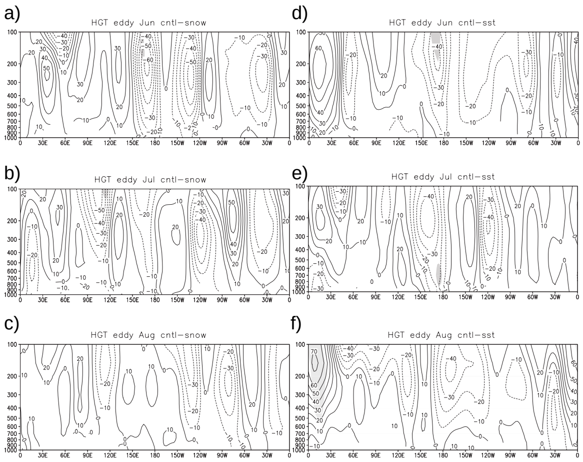

Fig. 7. Eddy height difference between the CN03 and SNOW (left panel) and SST (right panel) experiment. (a), (d) are in June and (b), (e) are in July, (c), (f) are in August. Contour interval is 10m. Significant at the 90% level are shaded.

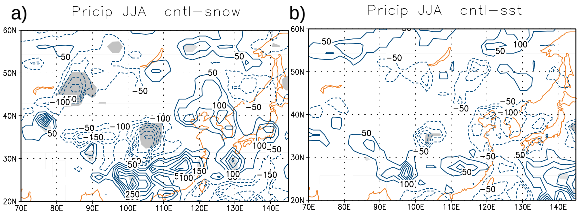

Fig. 8. JJA difference in precipitation of (a) SNOW and (b) SST experiments from the CN03 experiment. Significant at the 90% level are shaded.

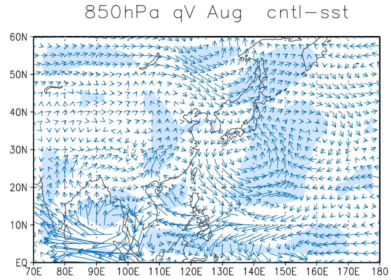

Fig. 9. Difference of moisture advection (vector) and convergence (shaded) between the CN03 and SST experiment in August.

5. SUMMARY AND CONCLUDING REMARKS

In this study, we investigate the dynamical characteristics associated with abnormal wet summer monsoon in 2003 by the analysis of observed features and by conducting the model experiments. From the analysis of observed data, it is found that the reduction of snow depth during the previous winter results in the reduction of the surface albedo, increasing the surface temperature with enhanced melting and sublimation of snow in spring. This leads to cooling over the Tibetan Plateau in April and May in turn and weakening of the TH during the summer of 2003. The resulting weakened TH induces the deeper trough over the Korean peninsula than normal, which allows the intrusion of upper level cold air into the monsoon area. Connected with the strengthened WPSH in the lower level in August, the moisture convergence occurs and stationary front exists over the Korean peninsula. This results in abnormal wet summer in 2003.

From the sensitivity experiments with observed and climatological variation of snow, it is concluded that reduced snow depth over the Tibetan Plateau before May 2003 plays an important role in weakening the TH in July and August, leading to abnormal wet summer over East Asia in 2003.

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