P2.1 **Mechanisms for a flooding over Korea in August of 2002**

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1. Introduction

Climatologically, the summertime in Korea is characterized by the location and activity of hot and moist maritime air masses (mT) called by Northern Pacific High (NPH, hereafter). Typically, NPH gradually expands to the north and starts to have an influence on Jeju island in mid-June concerning about the northward movement of Changma front, and Korea receives heavy rainfall caused by Changma front from the late June to July. From the late July after Changma period, NPH keeps expanding to the north enough to have its influence upon the most part of Korea, and then NPH begins to shrink about after the mid-August. Therefore, the typical summer over Korea is characterized by heavy rainfall mainly connected with Changma front in June and July (and/or sometimes concerning about occasional activities of Typhoon) and a hot spell for a month from the late July to the mid-August.

However, Korea has experienced abnormal heavy rainfall episodes in recent years. That is, during the last 5 years, record-breaking heavy rainfall events have appeared after the Changma period that can be expressed as a major rainy period, and on the contrary monsoon activities were less active than normal year during the Changma period. There was an abnormal heavy rain period starting after the withdrawal of Changma also in the summer of 2002. Heavy rainfall was recorded mostly over the whole nation during 12 days from 4 to 15 of August (Fig. 1), and the area-mean precipitation amount reached to about 400 mm that is 30% of annual total. For example, the local maximums were 608.0 mm in Bonghwa, 605.1 mm in Geoje, 582.5 mm in Yangpyoung, 569.5 mm in Imsil and 560.0 mm in Jangheung during this period.

There are previous studies to describe mechanisms responsible for anomalous summer rainfall over Korea. Lee (1989) studied that there were clear differences between the two summers (dry summer, 1982 and wet summer, 1985 in Korea) in the lower tropospheric pattern of geopotential height, wind and mixing ratio. Hwang and Park (2000) showed that the combined effect of the unusual strong moisture tongue emanated primarily from the Indian monsoon region and the instability due to the upper level stationary trough was found to be responsible for the record-breaking heavy rainfalls in 1999. Yun et al. (2001) showed that the merging effect between 30-60 days tropical wave train and southward/westward 30-60 days wave produced heavy rain in post-Changma period of 1998 in Korea.

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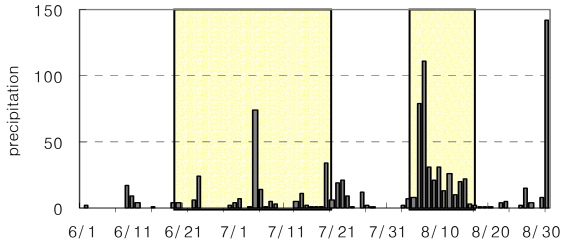

Fig. 1. Daily precipitation (mm) averaged over South Korea for summer of 2002. Shaded areas indicate Changma period (first) and heavy rainfall period (second), respectively.

The purpose of this study is to analyze the mechanisms responsible for a flooding over the Korean peninsula in August of 2002.

2. Data and analysis methods

The NCEP/NCAR reanalysis data (Kalnay et al., 1996) with a horizontal resolution of 2.5° intervals is used in this study for the synoptic analysis and other statistical treatments. A climatology averaged during 30 years from 1971 to 2000 is calculated to get the anomaly fields. Also, daily mean SST (Sea surface temperature) data from NCEP and surface observation data of KMA are used for the analysis of SST and daily precipitation for the summer of 2002, respectively.

In order to investigate the characteristics of heavy rainfall in August of 2002, we define three rainfall periods (Fig. 1). First, pre-heavy rainfall period is defined from 23rd of July to 3rd of August, and mid-heavy rainfall period is during 4~15 August. Finally, post-heavy rainfall period is from 16 to 27, August. Here, heavy rainfall period is defined following the press report of KMA (KMA, 2002).

3. Characteristics of synoptic features

3.1 Upper air pressure system

Figure 2 shows the 500hPa geopotential heights and height anomalies in the pre-, mid- and post-heavy rainfall period. During the pre-heavy rainfall period (Fig. 2a and 2b), NPH stronger slightly than normal year is expanded to the northern part of Korea and it causes the positive anomaly around the Korean peninsular. And in the north Mongolia centered at 50N, the strong positive anomaly is shown connected with development and northeastward shift of Tibetan High in the upper troposphere. A the trough is visible near Okhotsk sea.

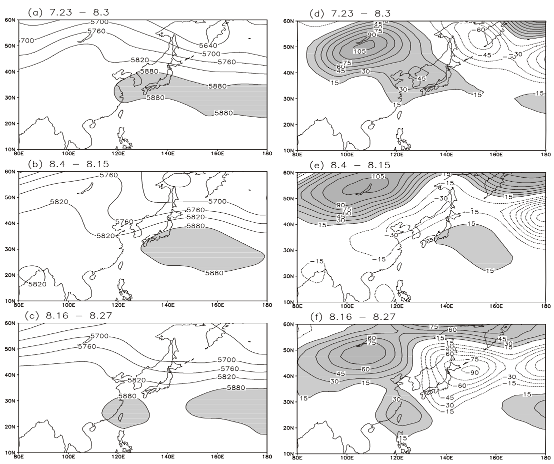

Fig. 2. Geopotential heights (left) and height anomalies (right) at the 500hpa level during (a, d) pre-heavy rainfall, (b, e) mid-heavy rainfall and (c, f) post-heavy rainfall period. Shaded indicate areas greater than 5880 m in the left panel and greater than 15 m in the right panel.

In the mid-heavy rainfall period (Fig. 2b and 2e), the upper ridge around the northern part of Mongolia is developed very strongly and steeply, showing the pattern of blocking. A strong positive anomaly around Okhotsk sea is seen. Consequently, a deep upper trough becomes stagnant between the two highs. The increase of baroclinicity over the Korea peninsular provides a dynamically favorable environment responsible for heavy rainfall over the Korean peninsular. For the post-heavy rainfall period (Fig.2c and 2f), blocking high located at the north-Mongolia was weakened, NPH expanded to the southern part of China, and the strong upper trough is moved eastward.

3.2 Low level moisture flux

Figure 3 shows the moisture flux vector and convergence at the 850hPa level for three periods. During the pre-heavy rainfall period, moisture is transported from the south along the boundary of NPH to the west of Korea.

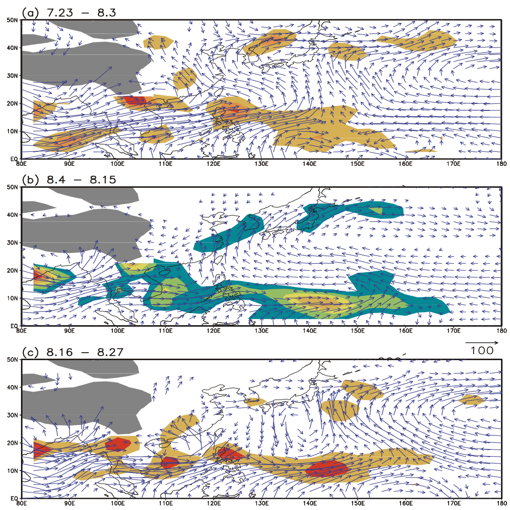

Fig. 3. 850 hpa moisture flux and convergence during (a) pre-heavy rainfall, (b) mid-heavy rainfall and (c) post-heavy rainfall period. A reference vector of 100 gkg^{-1} ms^{-1} is shown. Moisture fluxes less than 15 gkg^{-1} ms^{-1} are not shown. Shaded area represents the moisture convergence zone greater than $1*10^{-5}$ gkg^{-1} s^{-1}.

Although there is a strong westerly flow from Indian ocean, most of the moisture is moved to the east of Japan and to the south China, and consequently there is not much direct flow because the flank of NPH covers most part of Korea. In the mid-heavy rainfall period (Fig. 3b), large amount of the low level moisture is transported from south to north throughout the Korean peninsular as follows along the edge of NPH stepped back slightly. Therefore, this unstable synoptic condition – characterized by transport of the low level moisture along the low level jet and cold advection at the upper level – is primarily responsible for heavy rainfall. On the other hand, in the post-heavy rainfall period (Fig. 3c), dry westerly flow prevails over Korea, reducing moisture transport into the Korean peninsula.

3.3 Sea surface temperature (SST)

During the summer of 2002, warmer SST than normal appears over the equatorial tropical Pacific between 160°E and 110°W (Fig. 4). A positive anomalies appears in the northern Pacific of the mid latitude around 30°N.

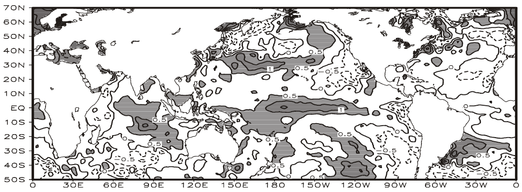

Fig. 4. SST anomaly for 2002 summer. Shading represents positive anomalies greater than 0.5℃, and dotted lines represent the negative values. Contour interval is 0.5℃.

To investigate the impact of warmer SST forcing to the pressure system in summer of 2002, the lag-correlation between the 500hPa geopotential height and SST is calculated. In Fig. 5, time-series of SST is weekly data averaged over two areas showing warmer anomalies. One is the tropical eastern Pacific (10°S -10°N, 180~60°W) and the other is the area of the northern Pacific in the mid-latitude (25-35°N, 150-180°E). Sequence of the geopotential height anomalies is selected at the point of (50°N, 100°E) which is a center of strong positive anomalies.

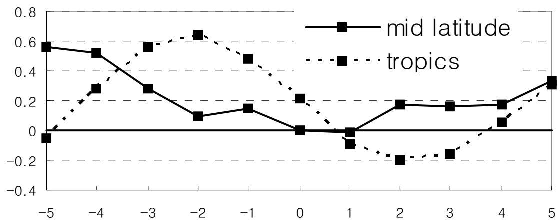

Fig. 5. Lag correlation between the area mean SST anomalies over the mid-latitude Western Pacific and tropics and the 500 hpa height anomalies over the north Mongolian. The abscissa represents the lag between the two weekly time series. Negative lag indicates that height leads SST.

In this figure, both of maximum correlation coefficients have the negative lags. That is, strong positive height anomaly in the north Mongolia leads warm SSTs of the tropics and the mid-latitude. Therefore we feel that SST variations over two areas are not directly responsible for the pressure system around the East Asia.

3.4 Soil moisture (SM)

Another possible mechanism is the feedback between the soil moisture and extratropical climate extreme. There are several studies to describe the relationship between soil moisture and precipitation variability (Hong and Pan, 2000; Douville et al., 2001; Hong and Kalnay, 2002). According to their studies, soil moisture responds to precipitation variability but also affects precipitation through evaporation. This two way interaction has often been referred to as a positive feedback, since the water added to the land surface during a precipitation event leads to increased evaporation, and this in turn can lead to further rainfall. Kang (2003) examined the feedback process between soil moisture and precipitation during the East Asian summer monsoon period. He demonstrated a interaction between monsoon system over East Asia, that is, less (more) precipitation occurred in the wet (dry) soil condition because of the weak (strong) monsoon circulation.

In Fig. 6, SM has decreased steadily until July and then negative anomalies appeared in June and July appear, while SM anomaly of August records the positive value due to heavy rainfall over Korea.

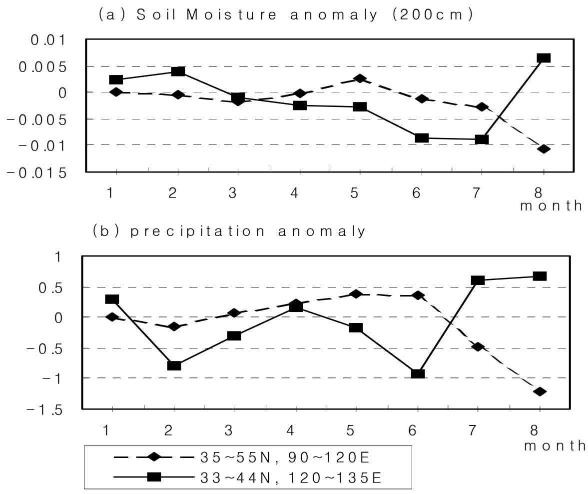

Fig. 6. Monthly anomalies of (a) deep layer soil moisture and precipitation over the north of China (dashed line) and the Korean peninsula (solid line).

However, SM shows near normal conditions from January to July and soil is very dry in August in China. In case of precipitation anomalies, monthly variations over these two areas are very similar to those of SM except April over Korea. However SM anomaly has lagged correlation to precipitation anomaly by about a month. It is interesting to note that anomalies over the two regions exhibit opposite signs.

4. Model simulation

To investigate the dynamic mechanisms and the impact of SM to extreme rainfall over the Korean peninsula, detailed analyses are performed using the NCEP Regional Spectral Model (Juang et al., 1997).

In this study the domain is over East Asia and initial conditions are obtained from the reanalysis (Kalnay et al., 1996). The lateral boundary conditions and base fields are linearly interpolated in time from the 6-h reanalysis data. Two types of runs with different soil moisture over the RSM domain designed are: CTL, with soil moisture taken from the reanalysis soil moisture for 2002; CLM, with climatological soil moisture from the reanalysis for the period 1971-2000. In the CTL experiment only the bottom (deep) soil moisture model layer (10-200cm) is updated from the reanalysis every 6 hour during the model integration period, while the soil moisture in the top (shallow) layer is predicted. This is because the top soil layer (0-10cm) interacts directly with the atmosphere forcing.

Figure 7 shows the precipitation of observation and of CTL experiment in 2002 summer. Generally, the precipitation band in CTL experiment is similar to that in the observed.

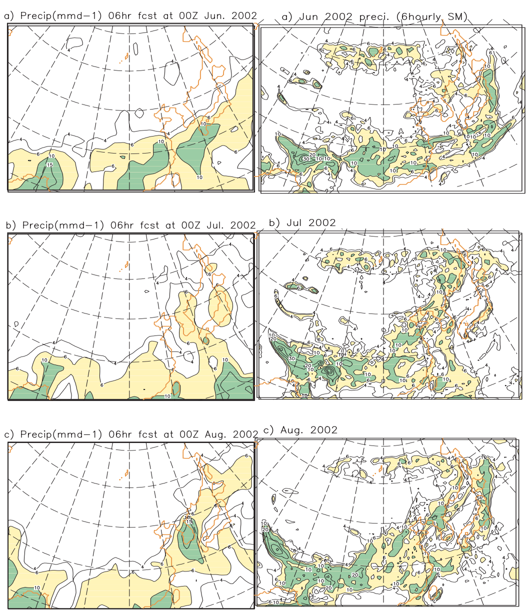

Fig. 7. The precipitation(mm) from observation (left) and from CTL experiment (right) for 2002 summer.

To investigate the mechanism and the impact of SM to extreme rainfall over Korea, more detailed analysis will be performed with the simulater data in the RSM.

Acknowledgments

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