Teleconnections: Summer Monsoon over Korea and India

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ABSTRACT

This study investigates the relationship between the summer monsoon rainfall over Korea and India, by using correlation analysis and Singular Value Decomposition (SVD).

Results reveal that summer monsoon rainfall over Korea is negatively (significant at the 99% level) correlated with the rainfall over the northwest and central parts of India. In addition, coupled spatial modes between the rainfall over Korea and India have been identified by the SVD analysis. The squared covariance fraction explained by the first mode is 70% and the correlation coefficient between the time coefficients of the two fields is significant at the 99% level, indicating that the coupled mode reflects a large part of the interaction between the summer monsoon rainfall over Korea and India. The first mode clearly demonstrates the existence of a significant negative correlation between the rainfall over the northwest and central parts of India and the rainfall over Korea.

Possible mechanisms of this correlation are investigated by analyzing the variation of upper–level atmospheric circulation associated with the Tibetan high using NCEP / NCAR Reanalysis data.

Key words: summer monsoon rainfall, tibetan high, singular value decomposition (SVD)

1. Introduction

The summer rainfall in Korea, which accounts for more than 50% of the annual rainfall, is largely affected by the Asian monsoon circulation associated with the global circulation (e.g., Yoshino 1982; Lee 1989).

Some authors (e.g. He et al. 1987; Yatagai and Yasunari 1995; Park and Schubert 1997; Tao and Zhu 1964) have stressed the importance of the Tibetan high in the Asian summer monsoon circulation. Tao and Zhu (1964) found that when the Tibetan high migrates eastward (westward), the western Pacific high at 500 hPa advances toward (retreats from) East Asia. Yatagai and Yasunari (1995) showed that the Taklimakan desert experiences a wet (dry) summer when the Tibetan high shifts eastward (westward). Park and Schubert (1997) indicated that the East Asian summer drought in 1994 was caused by the unusually early development of the climatological upper–level anticyclone flow east of the Tibetan Plateau.

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On the other hand, He et al. (1987) showed that from spring to summer 1979, the upper–level southern Asian anticyclone underwent two distinct stages of abrupt transitions, resulting in the successive onsets of the early summer rains over Southeast Asia and the Indian summer monsoon. Thus, it is fully suggested that the variation of upper–level atmospheric circulation associated with the Tibetan high should play a significant role in influencing the summer climate in East Asia.

One of the most important problems for monsoon meteorologists is the relationship between the East Asian and Indian summer monsoons. Krishnamurti and Subrahmanyam (1982) suggested that the circulation anomalies at 850 hPa over India are coupled with those over East Asia through the western Pacific via the zonally–oriented anomaly trough or ridge line which is moving northward. Yasunari (1986) and Kripalani et al. (1997) investigated the relationship between the mid–latitude circulation and the summer rainfall over India on an intraseasonal timescale. They showed that there is a strong correlation between the 500–hPa height and the summer rainfall over Northeastern China. Kripalani and Singh (1993) also showed that the rainfall in North China is highly related to the rainfall in India. However, a meaningful but unresolved question is whether the summer rainfall in Korea is associated with the summer monsoon circulation and related with the rainfall over India. Thus, it becomes necessary to examine the possible relationship between the summer rainfall in Korea and the Indian summer monsoon rainfall on the interannual timescale. In this study, we investigate the relationship between the summer rainfall in Korea and the Indian subdivisional summer monsoon rainfall, and suggest a possible mechanism responsible for this relationship by analyzing the variation of upper–level atmospheric circulation associated with the Tibetan high.

2. Data and method of analysis

2.1 *Data*

The following rainfall data are used: (i) summer (June to August) mean rainfall in Korea and (ii) summer monsoon (June to September) rainfall of each of the 33 contiguous meteorological subdivisions of India during the period from 1953 to 1994. The Indian summer monsoon rainfall data are prepared by properly area–weighting the monthly rainfall recorded at 306 rain gauge stations distributed fairly uniformly over the plains of India. These cover about 90% of the total area of India, and are available on the website of the Indian Institute of Tropical Meteorology (http: // www.tropmet.ernet.in).

Monthly mean geopotential height data at 200 hPa on a 2.5° by 2.5° latitude–longitude grid are employed to examine the variation of upper–level atmospheric circulation associated with the Tibetan high. These data are obtained from the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP / NCAR).

2.2 *Method of analysis*

Singular Value Decomposition (SVD) analysis is used to investigate the possible link between Indian summer monsoon rainfall and the summer rainfall in Korea. SVD analysis is a powerful tool to identify sets of linear relationships between different fields and requires no user–supplied parameters (Bretherton et al. 1992; Von Storch and Navarra 1995; Wallace et al. 1992). In addition, SVD analysis yields some statistics which can be used as measures of the strength of the relationship between the two fields. In the present study, we use the Squared Covariance Fraction ($A_{SCF,k}$, where k indicates the mode number). $A_{SCF,k}$ indicates the percentage of the total squared covariance explained by the k–th SVD mode, and is defined as:

$$A_{\mathrm{SCF},k} \equiv \frac{\pi_k^2}{\sum_{l=1}^{n} \pi_l^2} \times 100\%,$$

where π_k is the singular value of the k–th SVD mode, and n is the number of modes. Because SVD analysis decomposes the covariance matrix into singular values and sets of orthogonal patterns, the sum of the squared singular values is equal to the total squared covariance of the two fields. Thus, $A_{\mathrm{SCF},k}$ is a measure of the relative importance of that particular SVD mode in the relationship between the two fields.

3. Results

3.1 *Relationship between the summer rainfall in Korea and the Indian summer monsoon rainfall*

Figure 1 shows the distribution of correlation coefficients between the summer rainfall in

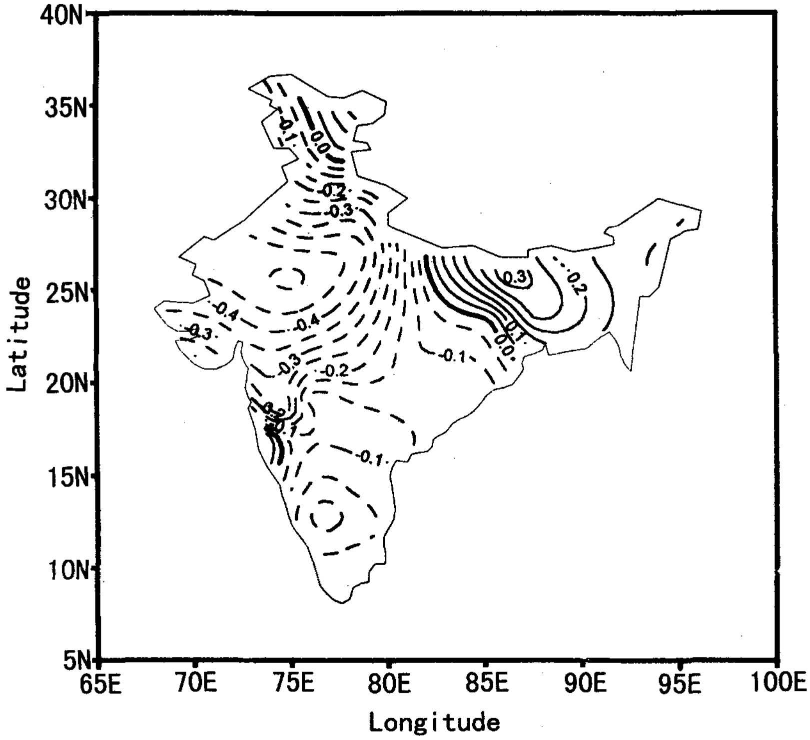

Fig. 1. Distribution of correlation coefficients between the summer rainfall in Korea (SRK) and 33 meteorological subdivisional summer monsoon rainfalls over India (ISMR).

Korea and the Indian summer monsoon rainfall during the period from 1953 to 1992. Significant negative correlations appear over the northwestern and central parts of India where the rainfall is affected by the southwesterly monsoon flow from the Arabian Sea. Weak and positive correlations appear over northeastern India. Parthasarathy et al. (1993) indicated that the northwestern and central parts of India (about 55% of the total area of the country) have similar rainfall characteristics and associations with regional / global circulation parameters. The correlation coefficient between the summer rainfall in Korea and the summer monsoon rainfall over the northwestern and central parts of India during the period of 1961 to 1992 is −0.49, significant at the 99% level (Fig. 2). Thus, it can be said that the summer rainfall in Korea is negatively and significantly correlated with the summer monsoon rainfall over the northwestern and central parts of India.

According to Kripalani et al. (1997), the Indian summer monsoon rainfall is positively correlated with the 500−hPa geopotential heights over three mid−latitude regions, that is, Northeastern China, the Algerian region and the Caspian sea region. On the other hand, Park et al. (1989) showed that the wet summer in Korea is closely related to the deepening trough associated with the cold vortex over Northeastern China. The relation of summer rainfall to 500−hPa height also implies that the summer rainfall in Korea is inversely related with the Indian summer monsoon rainfall.

In order to identify the important coupled modes between the summer rainfall in Korea and the Indian summer monsoon rainfall, singular value decomposition (SVD) is employed. The first singular mode is shown in Fig. 3 using heterogeneous correlation maps. The heterogeneous correlation illustrates the spatial pattern of Indian summer monsoon rainfall that is coupled to the time fluctuation of the summer rainfall in Korea (and vice versa). The squared covariance fraction (SCF) explained by the first mode is 70.3% and the correlation coefficient between the time coefficient of the two fields is 0.52. The large SCF value indicates that this coupled mode reflects a large part of the linear interaction between the summer rainfall in

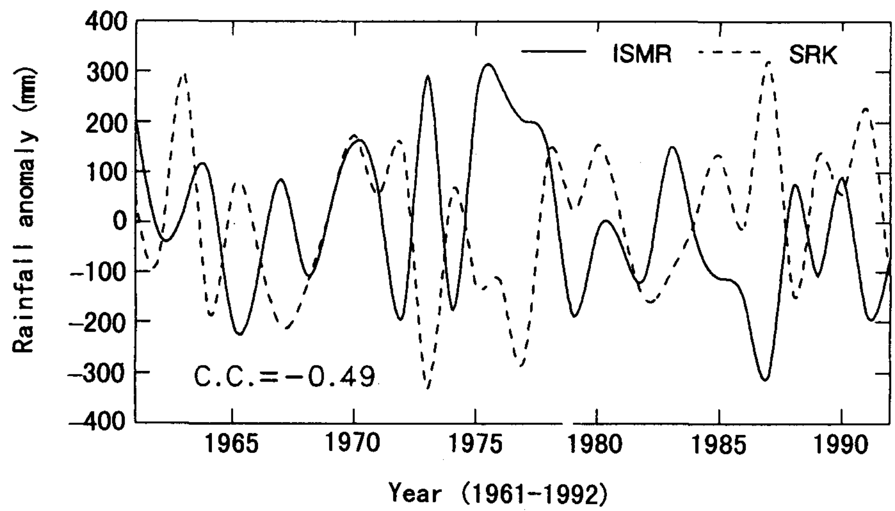

Fig. 2. Interannual variations of the summer rainfall in Korea (SRK) and the summer monsoon rainfall (ISMR) over the northwestern and central parts of India.

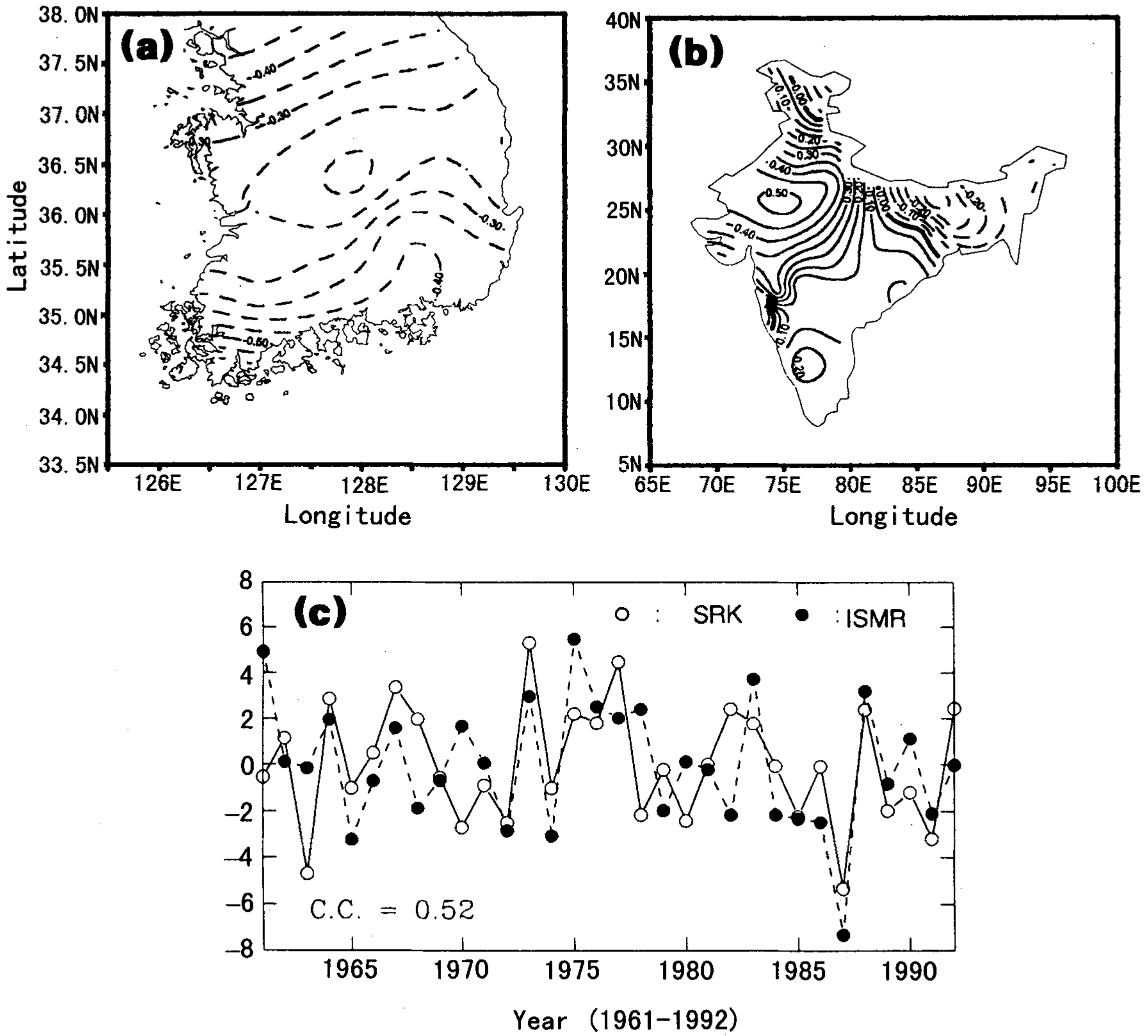

Fig. 3. Heterogeneous correlation patterns for (a) SRK and (b) ISMR and (c) their corresponding time coefficients for the first SVD mode.

Korea and that in India. The first mode clearly demonstrates above–normal summer rainfall over the northwestern and central parts of India and the associated below–normal summer rainfall over the whole of Korea.

The second SVD mode is shown in Fig. 4. SCF2 is 13.8% and the correlation coefficient is 0.61. The existence of this mode indicates that the summer rainfall over the southern part of Korea is positively correlated with the summer monsoon rainfall over the northeastern and southern parts of India.

3.2 *Variation of the upper–level atmospheric circulation associated with this relationship*

The Tibetan high might be a medium between the summer rainfall in Korea and the Indian summer monsoon rainfall (Wu and Ni 1997). In this study, the correlations between the SVD time coefficients of Indian summer monsoon rainfall and geopotential heights at 200 hPa over the Northern Hemisphere are calculated for understanding the upper–level

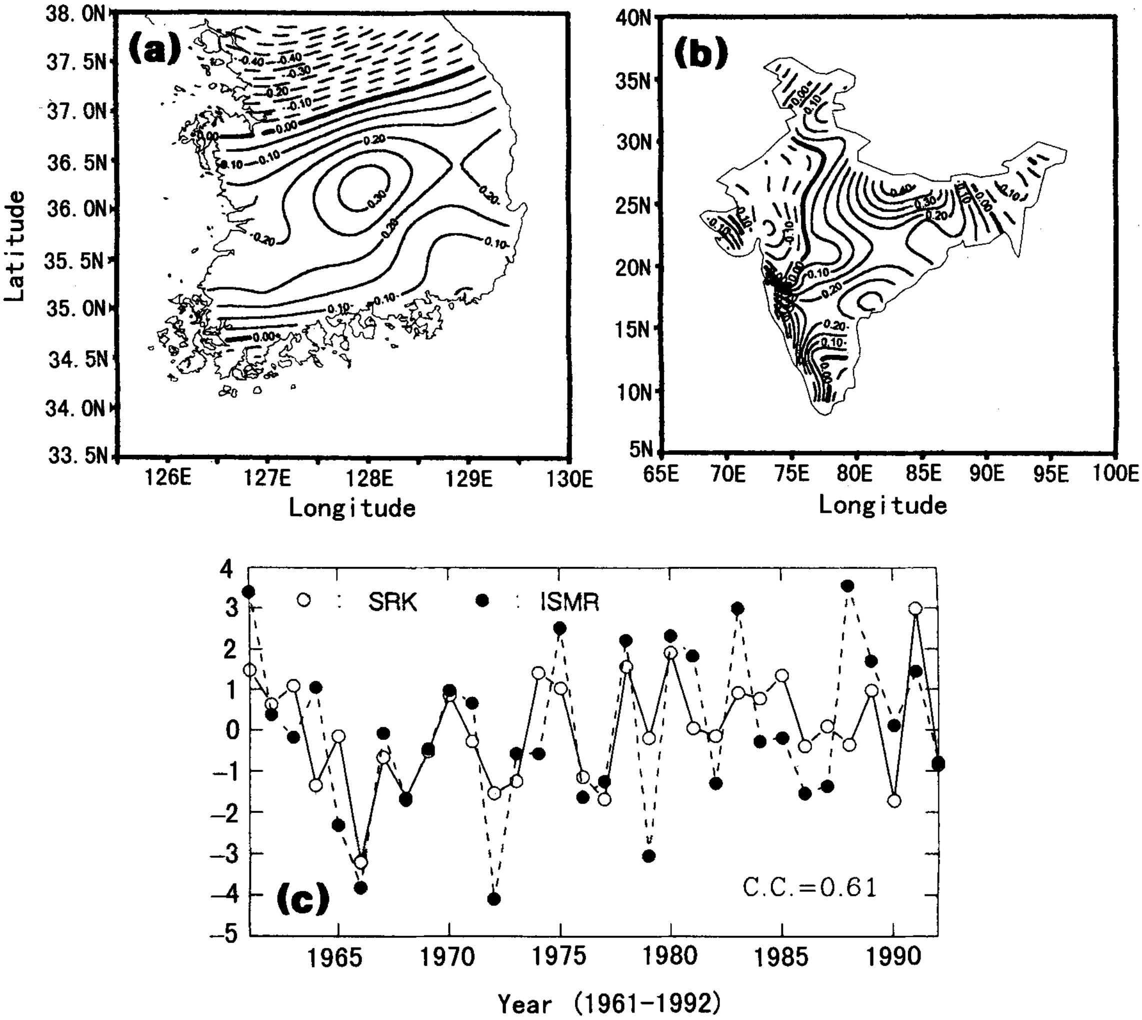

Fig. 4. The same as Fig. 3 but for the second SVD mode.

atmospheric circulation responsible for the negative correlation between the summer rainfall in Korea and India.

Correlation maps for July (a) and August (b) between the 200–hPa geopotential height and the time series of the first SVD mode of Indian summer monsoon rainfall are shown in Fig. 5. Positive centers in July are found over East Asia, the northern part of Africa, and Southwest Asia. Among the above three areas, the largest positive center is located over East Asia. The positive correlation over this region is stronger in July than in August. The summer rainfall variation in Korea is mainly affected by a similar pattern of geopotential height anomaly over East Asia at 200 hPa.

The correlation of the 200–hPa height with the second SVD mode is somewhat different from that of the first mode. In both July and August, positive correlations over the northern part of Africa and Southwest Asia are stronger than in the first mode, whereas it is weaker over East Asia (Fig. 6). It is illustrated that the second mode corresponds to the formation of

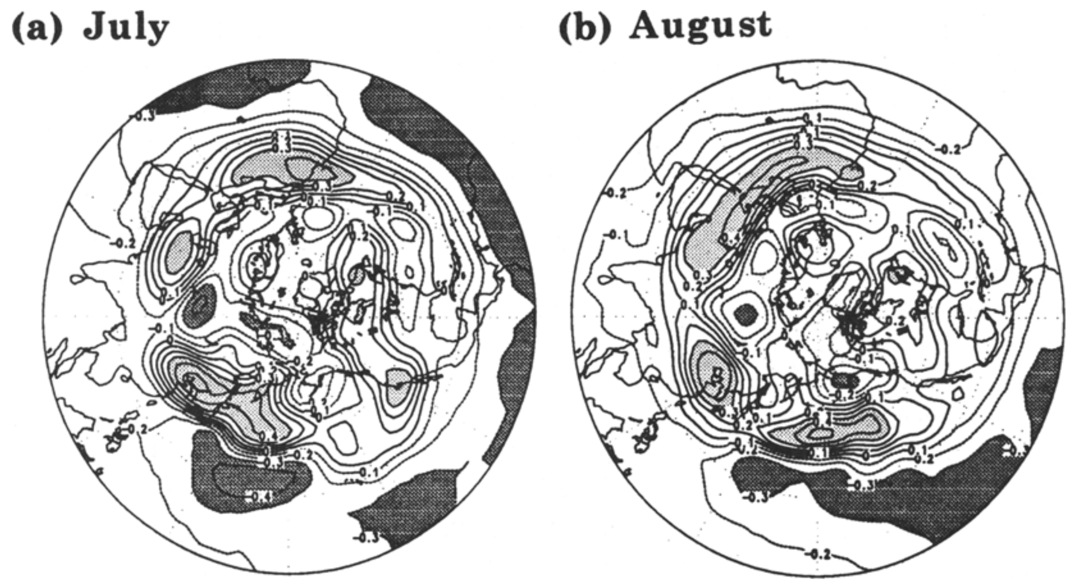

Fig. 5. Correlations between mode 1 SVD ISMR time series and geopotential height for (a) July and (b) August at 200 hPa over the Northern Hemisphere. Shading represents a correlation coefficient greater than +0.3 for positive values or less than –0.3 for negative values.

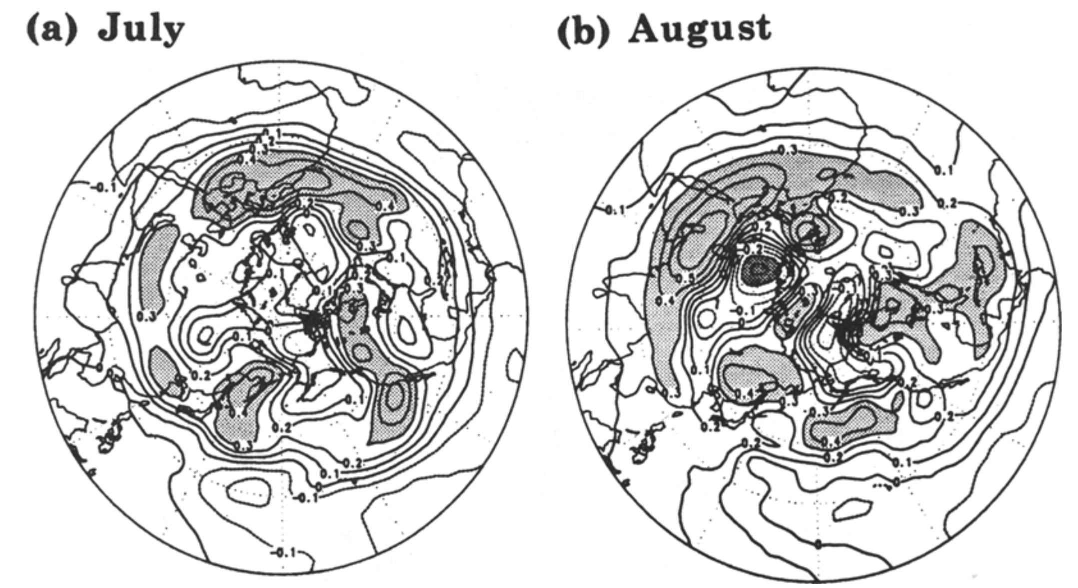

Fig. 6. The same as Fig. 5, but for mode 2 SVD IMSR time series.

another center of upper–level Tibetan high associated with its abrupt northwestward jump in summer. Thus, when compared with a dry summer in Korea, above–normal summer monsoon rainfall appears over the northwestern and central parts of India due to the advance of the monsoon from southeast to northwest. In addition, it is suggested that below–normal summer rainfall in Korea is related to the northeastward extension of the Tibetan high at 200 hPa in association with above–normal rainfall over the northwestern and central parts of India. The examination of the relationship between the summer rainfall in Korea and that in India in both these years, and its association with the 200–hPa atmospheric circulation characterized by the Tibetan high, may become an additional support for the negative correlation between them. When the strengthened Tibetan high extends northeastward, an intense increase of geopotential height in the upper troposphere over the eastern Tibetan Plateau and South China results in the formation of a new upper–level anticyclone. This anticyclone in the present study is referred to as " the eastern Tibetan anticyclone" for the sake of convenience in explaining the variation of the Tibetan high and its relation to the summer climate in East Asia.

The variation of the eastern Tibetan anticyclone over the East Asian monsoon region is investigated by applying empirical orthogonal function (EOF) analysis to the summer mean 200–hPa height data from 1980 to 1997. The first eigenvector (Fig. 7) explains 36.2% of the

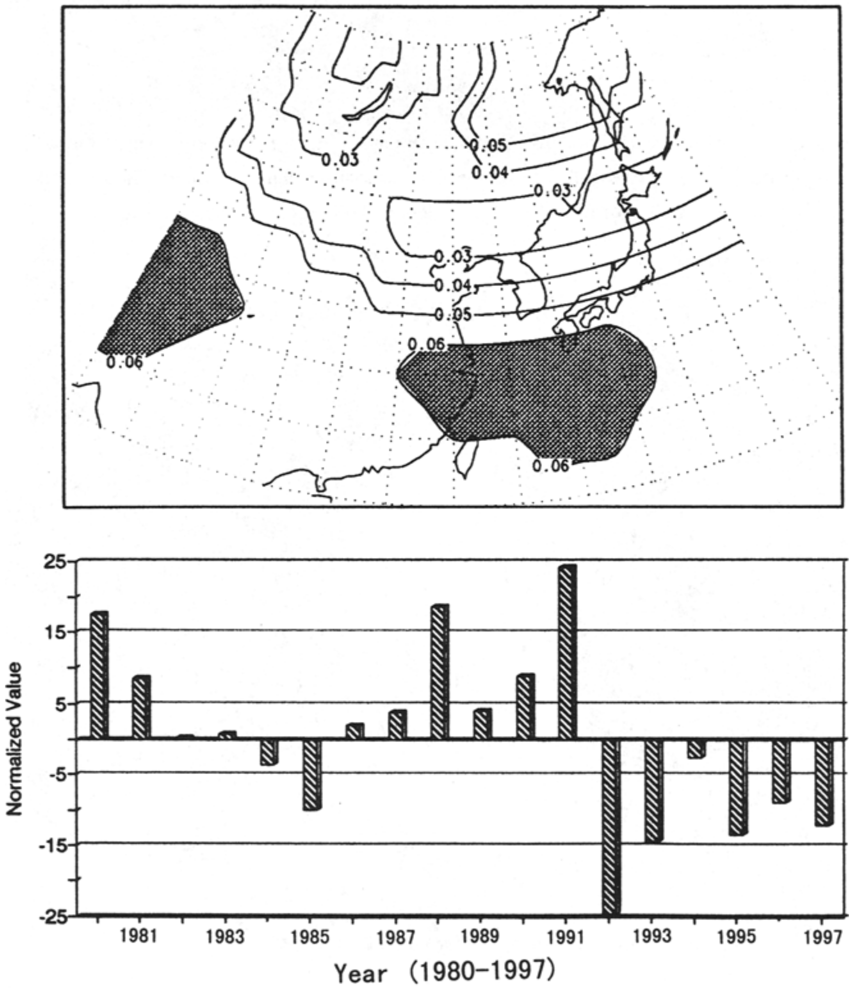

Fig. 7. The first EOF mode of normalized height at 200 hPa based on data from 18 summer seasons (June to August).

total variance over the domain. It is characterized by relatively large positive values over the Tibetan Plateau and the East China Sea. The associated time series, with an abrupt change in 1992, is positively correlated (+0.20) with the summer rainfall series in Korea. The second eigenvector (Fig. 8) explains 22.0% of the total variance. Its spatial pattern is characterized by positive values over Northeast China and negative values over a zonal band crossing South China. This mode is related to the further northward extension of the eastern Tibetan anticyclone. The time series associated with this mode has a negative correlation (−0.40) with the summer rainfall series in Korea. In particular, there is a negative and significant correlation (−0.67) between the time series of this mode and that of the first EOF mode for outgoing longwave radiation (OLR) over the Indian Ocean including the Indian subcontinent, the spatial pattern of which shows excessive summer monsoon rainfall over the northwestern and central parts of India (not shown). The above–mentioned results suggest the plausible mechanism responsible for the relationship between the summer rainfall in Korea and the Indian summer monsoon rainfall as follows, as shown in Fig. 9. Excessive summer monsoon rainfall

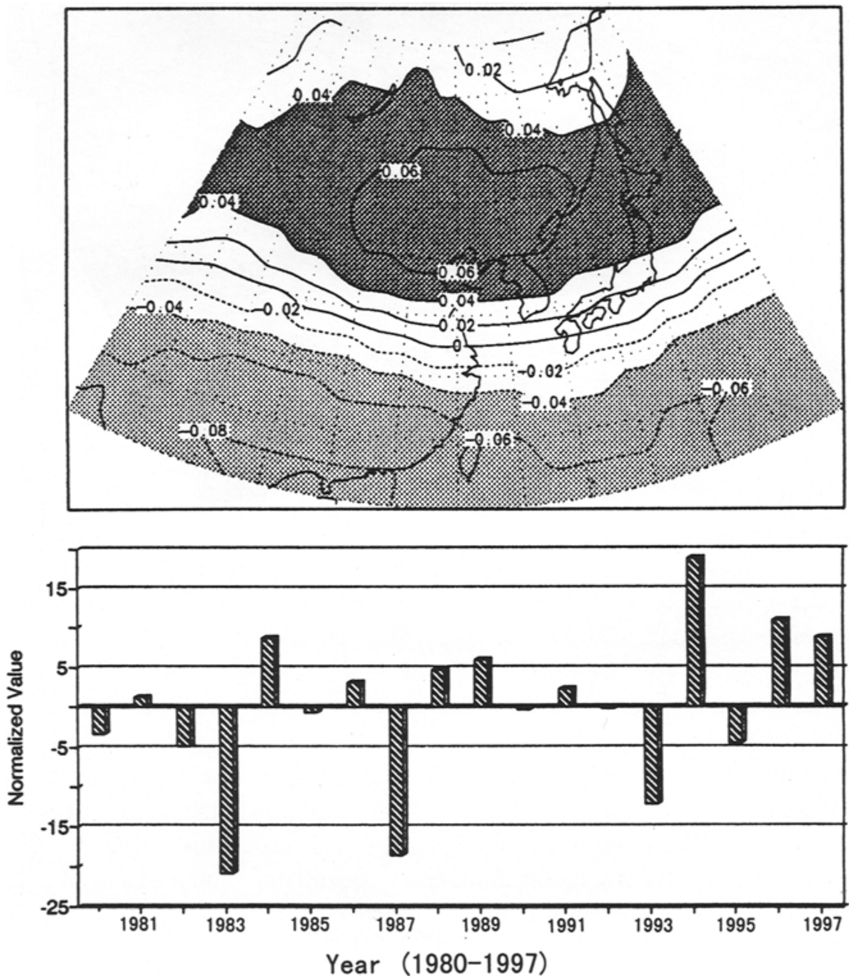

Fig. 8. The same as Fig. 7, but for the second EOF mode.

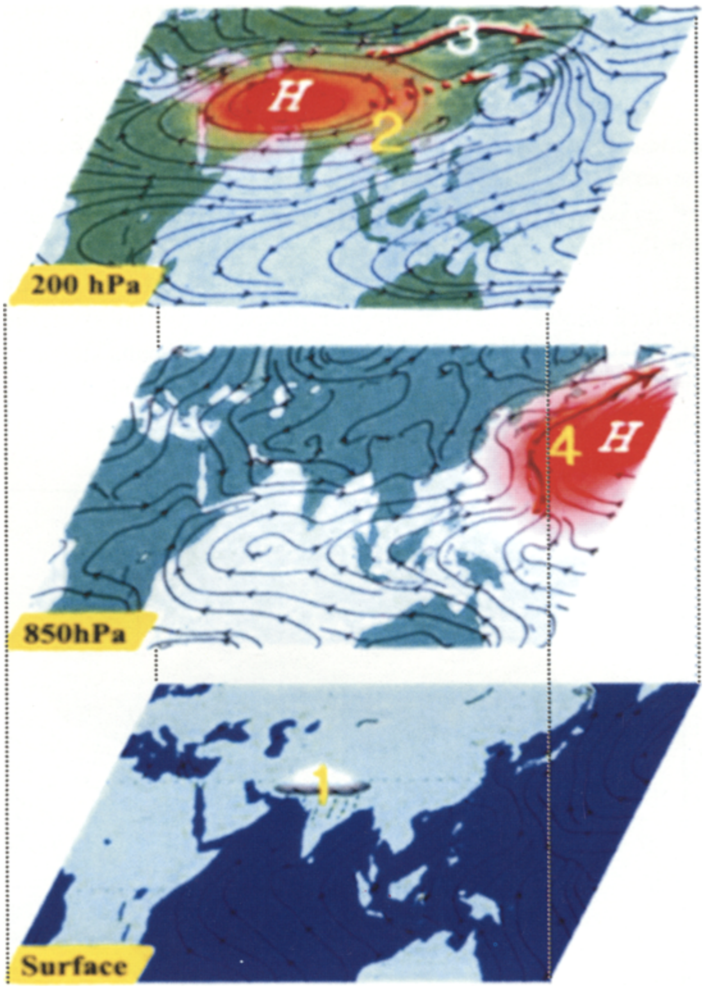

Fig. 9. Schematic maps of the relationship between excessive rainfall over the northwestern and central parts of India at the surface (Stage 1), the abrupt northwestward extension of the Tibetan high accompanied by the northward jump of the jet stream at 200 hPa (Stages 2 and 3), and the northwestward shift of the western Pacific high at 850 hPa (Stage 4).

over the northwestern and central parts of India, in association with the southwesterly at the surface being stronger than normal, may intensify the Tibetan high at 200 hPa. The intensified Tibetan high tends to extend northeastward, leading to the formation of the eastern Tibetan anticyclone over the eastern Tibetan Plateau and South China. This eastern Tibetan anticyclone may be accompanied with the abrupt northward jump of the subtropical jet at 200 hPa and the northwestward extension of the western Pacific high at 850 hPa, resulting in a dry summer over the Korean peninsula.

4. Summary and discussions

A study of the relationship between summer monsoon rainfall variability over Korea and India on the interannual timescale is carried out in this study. Ryoo et al. (1993) tried to examine a possible link between the summer rainfall in Korea and all–Indian summer monsoon rainfall and but they failed to obtain good results due to the considerable spatial variability of the Indian summer monsoon rainfall. Thus, subdivisional summer monsoon rainfall data over India is used in this study. Results from a correlation analysis and a Singular Value Decomposition (SVD) analysis show the existence of an inverse relationship (a correlation coefficient of −0.49, significant at the 99% level) between the summer rainfall in Korea and the summer monsoon rainfall over the northwestern and central parts of India.

Recently, Krishnan and Sugi (2001) have suggested an out–of–phase variability relationship between the Baiu rainfall over Japan and the monsoon rainfall over India during the early summer season (June and July). They found that composite wind differences at 200 hPa between wet and dry Baiu events are characterized by a mid–latitude cyclonic anomaly located to the east of the Caspian and Aral Seas, an anticyclonic anomaly near 100°E around Mongolia, and an anomalous cyclone further eastward over northeast Asia, which is called the Asian Continental Pattern. Many studies (e.g., Krishnan et al. 2000; Wang and Yasunari 1994) have reported that anomalous lows in the middle and upper troposphere around the Caspian Sea region are associated with weak Indian monsoon activity, and blocking highs over the Mongol plateau and the Okhotsk region are associated with enhanced Baiu rainfall. All of these studies suggested that the Indian monsoon rainfall and the East Asian summer rainfall may be related to a similar atmospheric circulation.

The analyses on the 200–hPa heights in this study suggest that the Tibetan high and the related northward shift of the subtropical upper–level jet may be responsible for the negative correlation between the summer monsoon rainfall over Korea and that over India, as shown in Fig. 9. Most recently, Lu et al. (2002) found the existence of a teleconnection pattern in upper–level meridional wind related to the meridional displacement of the upper–level jet stream over East Asia, Iran and Northwest Africa, which is a possible linkage of the East Asian summer monsoon to the Indian monsoon. These regions are in line with three positive centers in correlation maps between the 200–hPa geopotential height and the time series of the first SVD mode of Indian summer monsoon rainfall.

Although the Tibetan high is stressed in this study as a possible mechanism for the negative correlation between the summer monsoon rainfall over Korea and that over India, the Indian and East Asian monsoons may be affected by many global and regional atmospheric circulation and oceanic factors. In addition, Khandekar (1998) summarized that the Indian summer monsoon rainfall is closely related to the ENSO event in the equatorial eastern and central Pacific, the Eurasian winter snow cover, and the phase of the quasi–biennial oscillation (QBO) during and before the monsoon season. For further study, it may be required to examine the mechanism of this relationship by analyzing these factors in detail through dynamical and statistical methods. Chen et al. (1992) pointed out that only the rainfall in northern China shows a positive correlation with the summer monsoon rainfall over central India. Accordingly, one should be careful when mentioning in general the existence of the Indian–East Asian monsoon relationship.

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