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RELATIONSHIP BETWEEN SOVIET SNOW AND KOREAN RAINFALL

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ABSTRACT

In this study the statistical relationship between winter–spring Soviet snow depth and summer monsoon rainfall over South Korea has been investigated by lag correlation coefficients and composite analysis. Data for the 1966–95 period are used. Results reveal that the winter/springtime snow depth over western Eurasia (over Kazakhstan) is negatively related, whereas the snow depth over eastern Eurasia (over Manchuria–eastern Siberia) is positively related with Korean monsoon rainfall. The dipole correlation pattern suggests that heavy snow over eastern Eurasia and light snow over western Eurasia is favourable, whereas the reverse situation is unfavourable for monsoon activity over South Korea. The NCEP–NCAR re-analyses data reveal that the dipole correlation configuration is indicative of a mid-latitude long-wave pattern with an anomalous ridge over north Asia during the winter prior to a weak Korean monsoon and an anomalous trough prior to a strong monsoon. The re-analyses data further suggest that the position, shape, and strength of the summertime North Pacific subtropical high and the low-level jet over the East Asian sector could be considerably influenced by the snow distribution over Eurasia. Copyright © 2002 Royal Meteorological Society.

KEY WORDS: Soviet snow depth; Korean monsoon rainfall; mid-latitude circulation; East Asian monsoon circulation

1. INTRODUCTION

The prolonged influence of Eurasian–Himalayan snow on the climate conditions over India is well documented. Blanford (1884) was apparently the first to correlate some measure of Himalayan snow with Indian rainfall. With the advent of satellite technology, several studies have examined the relationship between satellite-derived snow cover estimates and monsoon variability over India (e.g. Hahn and Shukla, 1976; Rao *et al*., 1996; Bamzai and Shukla, 1999). All these studies have shown a negative relationship between the Eurasian snow cover and the Indian monsoon rainfall (IMR), implying that extensive (little) Eurasian snow cover in winter–spring was followed by deficient (excess) IMR. Several groups have reproduced the observed relationships by means of numerical experiments based on general circulation models (e.g. Barnett *et al*., 1989; Vernekar *et al*., 1995).

In an empirical study, Kripalani and Kulkarni (1999) related the observed Soviet snow depth with IMR. They found that the snow depth variations over western Eurasia surrounding Moscow are negatively related with IMR, whereas the snow variations over eastern Eurasia in central Siberia are positively related, depicting a dipole-type correlation configuration. The primary result of that study was a strong positive relationship of snow depth over central Siberia with IMR. Another important result of that study and earlier studies (Kripalani *et al*., 1996, 1997) was the identification of localized regions where snow variations–mid-latitude circulation anomalies have an impact on monsoon variability.

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Most of the studies have emphasized the linkage between Eurasian snow and South Asian rainfall (in particular India). Studies have also related monsoon rainfall variability over East Asia (in particular China) with snow cover over the Qinghai–Xizang (i.e. Tibetan) Plateau. The relationships are found to be complicated (Yang and Xu, 1994; Dong and Yu, 1998), probably since monsoon variability over East Asia is of a tropical and sub-tropical nature. Yang and Xu (1994) found that rainfall over some regions of China was related negatively with Eurasian snow cover and some was positively related. When they considered China as a whole they found a very weak relationship, thus suggesting that the relationship over East Asia has to be considered over smaller spatial domains. Studies on the relationship between Eurasian snow and the rainfall over Korea have been limited.

The most significant weather phenomenon during the summer season in Korea is the quasi-stationary front extending from south China to southern Japan. This front is called 'Changma' in Korea, 'Mei-yu' in China and 'Baiu' in Japan. This front is located along the northern and northwest periphery of the subtropical anticyclone, and is characterized by a convergence zone between the tropical maritime airmass to the south and a continental or polar airmass to the north. The Changma season has a large portion of the annual rainfall, and is associated with droughts and floods over the Korean peninsula (Tao and Chen, 1987; Oh *et al.*, 1997). Besides the intraseasonal variabilities due to the internal dynamics, land surface processes also play an important role in the interannual variations of summer monsoon rainfall over Korea. Keeping the above in mind, the purpose of the present study is to examine the relationship between winter–springtime Soviet snow depth and summer rainfall over South Korea and to compare these results with Soviet snow–IMR relationships (Kripalani and Kulkarni, 1999).

2. DATA

(i) The historical Soviet snow depth data product has been developed at the National Snow and Ice Data Center, Boulder, CO, USA, under the bilateral data exchange agreement with the State Hydrometeorological Service Obninsk, Russia. The data are for 284 stations with data periods varying from 1881 to 1984 (version 1), updated till 1995 (version 2). This study uses the monthly product only, i.e. the mean of the snow depth values for a given month.

For computations, the data for the 284 stations have been converted into 70 uniform blocks of 5° latitude by 10° longitude (Kripalani and Kulkarni, 1999). Continuous data for all the blocks are available since 1966. The results presented here are based on the snow depth over these uniformly spaced blocks. More details on this data product and the number of stations falling in each of the 70 blocks are given by Kripalani and Kulkarni (1999).

(ii) Summer rainfall over South Korea accounts for 50–60% of the annual precipitation; hence, seasonal monsoon (June through August) rainfall data for 12 stations uniformly spread over South Korea (obtained from the Korea Meteorological Administration) have been used to prepare a time series of Korean monsoon rainfall (KMR) for the period 1966–95 by simple arithmetic averages for the 12 stations.

The most dominant empirical orthogonal function (variance explained: 58%) of the seasonal rainfall for these 12 stations shows loadings of the same sign (positive) for all the stations — justifying the average of the 12 stations as representative of Korean rainfall. The correlation coefficients between the KMR series and rainfall series for each of the 12 stations vary from 0.50 to 0.87, further confirming that KMR represents rainfall variations over the whole of South Korea. The mean KMR is 626 mm, with a standard deviation of 164 mm.

(iii) Gridded 2.5° × 2.5°, latitude × longitude, monthly geopotential heights at the 500 hPa level and vector winds at the 850 hPa level for the period 1966–84 over the Northern Hemisphere have been extracted from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) re-analyses data set (Kalnay *et al.*, 1996).

(iv) The monsoon rainfall for India for the period 1966–95 has been downloaded from the website of the Indian Institute of Tropical Meteorology (http://www.tropmet.res.in), and is designated as IMR.

To facilitate comparison with Soviet snow–IMR results (Kripalani and Kulkarni, 1999), the Soviet snow–KMR results computed here are also based on the same data period, i.e. 1966–84. Data for the 1985–95 period have been kept as an independent set to examine their application to forecasting.

3. CONNECTIONS BETWEEN SOVIET SNOW AND KMR

To examine the relationship of wintertime snow depth over the former Soviet Union and summer monsoon rainfall over Korea, correlation coefficients (CCs) are computed between KMR and snow depth at each of the 70 blocks for the months of October through to April preceding the Korean summer monsoon period. The most significant feature of this analysis is that, in general, the correlations are negative west of 100 °E and positive to the east of this meridian. The smoothed correlation pattern for the month of February, showing maximum contrast between the positive and negative correlations, is shown in Figure 1. Thus the spatial pattern depicts a dipole structure similar to the one observed for IMR. The separation line between the negative and positive regions for the IMR–snow connections was 70 °E. Though the pattern has been maintained, it has shifted east by about 30–40° longitude for KMR (see Figure 2). This shift of correlation pattern towards the east may be due to the troughs and ridges occurring with the passage of Rossby waves in the mid-latitude westerlies.

To examine the correlation structure further, two time series of monthly snow depth at key locations were prepared. These series are based on the blocks where the snow variations show a significant relationship with most of the months (i.e. October through to April). The series for the negative relationship is based on the average snow over the region 45–55 °N, 60–80 °E (region KN in Figure 2, hereafter referred to as western Eurasia), while the series for the area of positive relationship is based over the region 55–65 °N, 120–140 °E (region KP in Figure 2, hereafter referred to as eastern Eurasia). Region KN lies over Kazakhstan, northeast of the Caspian Sea, and region KP lies over Manchuria (eastern Siberia), northwest of the Okhotsk Sea.

A large-scale circulation feature can be represented by information at one or two locations. For example, the El Niño–southern oscillation phenomenon over the Pacific is represented by information at two locations (sea-level pressure difference at Tahiti and Darwin) or at one location (Darwin pressure tendency). In a similar

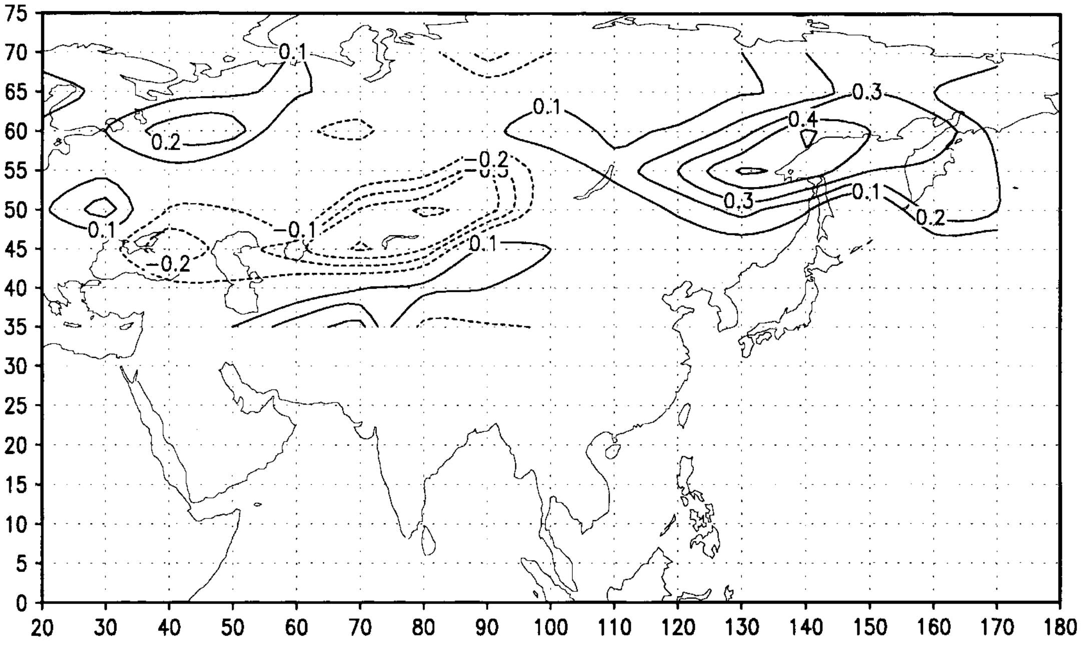

Figure 1. Monthly spatial distribution of the correlation coefficients of February snow depth with the subsequent summer monsoon rainfall over Korea

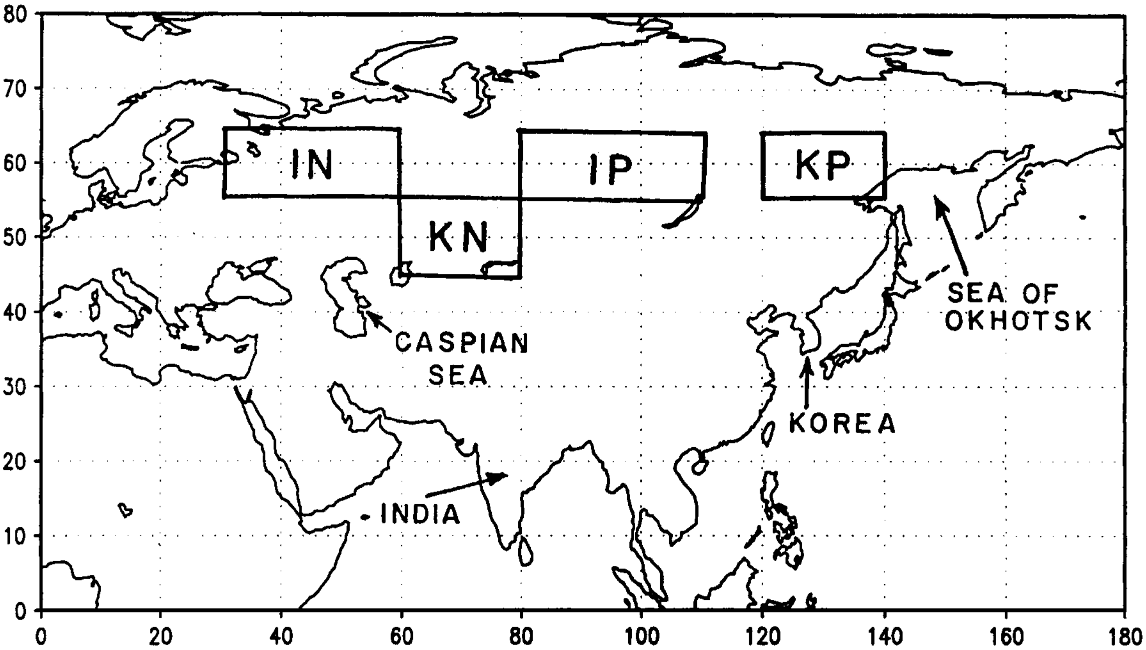

Figure 2. Map showing the regions where snow variations are significantly related with IMR and KMR. IN: region where snow is negatively related with IMR; IP: positively related with IMR; KN: negatively related with KMR; KP: positively related with KMR

way, the snow variations over the locations identified above can be considered to represent a large-scale phenomenon over the Eurasian sector.

Before we examine the relation of KMR with snow depth over these key locations, the monthly climatology and variability, i.e. the annual cycle of snow depth over the regions of western and eastern Eurasia, identified above is shown in Figure 3. Over the course of the annual cycle the average monthly snow depth increases from 1 cm in October to more than 20 cm in February over western Eurasia (Figure 3, upper panel), whereas it increases from 8 cm in October to more than 40 cm in March over eastern Eurasia (Figure 3, lower panel). The annual cycle is characterized by a relative gradual establishment of continental snow from October to February–March, and a rapid ablation of the snow pack during the spring and the summer months. The variation (standard deviation) of snow depth increases with increasing depth for each month over western Eurasia (Figure 3, upper panel), whereas for eastern Eurasia it remains practically the same (Figure 3, lower panel.)

Once again, lag CCs between the monthly snow time series and the KMR are computed based on the same 19 year period. The absolute value of significant CC (t test) for this sample is about 0.42 (0.54) at the 5% (1%) level. This figure (Figure 4) clearly illustrates that the winter–spring snow depth over western (eastern) Eurasia is negatively (positively) related to subsequent KMR. Snow over western Eurasia shows a significant (at the 5% level) relationship during November, February, and March only. However, the pattern for eastern Eurasia shows a monotonic increase from October through to February, with CCs significant at the 1% level from December through to April. The correlation maximum occurs in November (−0.47) for western Eurasia and February (+0.62) for eastern Eurasia. Choi *et al.* (1998) also found that the maximum negative correlation between satellite-derived Eurasian snow and KMR occurs during November.

Thus, snow anomalies over the above key regions (in particular over eastern Eurasia) are closely associated with KMR; hence, snow anomalies over small-scale regions, rather than the whole of Eurasia, may be considered a more useful predictor of KMR. Further, as noted above, the pattern of the correlation structure has shifted east by about 30–40° longitude for KMR compared with that for IMR, implying that the localized regions over which snow variations are related to the monsoon variability are different for South and East Asia.

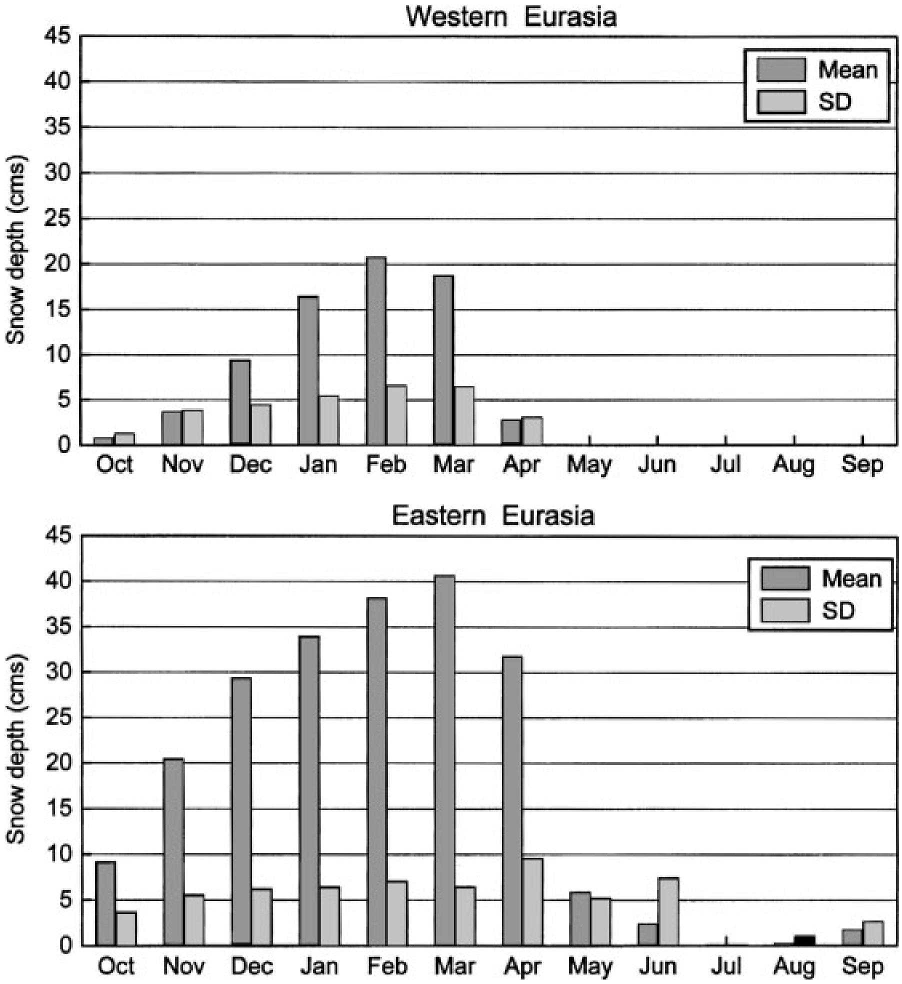

Figure 3. Annual cycle of snow depth and standard deviation over western Eurasia (upper panel) and eastern Eurasia (lower panel)

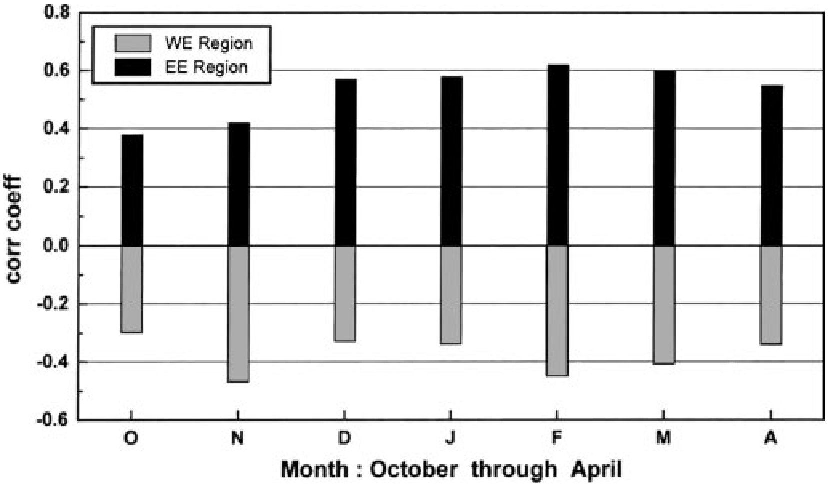

Figure 4. Monthly lag correlation coefficients of KMR with snow depth over western Eurasia (WE) and eastern Eurasia (EE)

3.1. *Application in forecasting*

To explore the possible utility of snow anomalies for local regions for predicting KMR, a multiple linear regression equation of the form $y = a + bx_1 + cx_2$ is developed for the period 1966–84, where y is the KMR, x_1 is the snow depth over western Eurasia during the preceding November, and x_2 is the snow depth over eastern Eurasia for February. The values of the constant a and the two regression coefficients b and c are 229.36, −14.01, and 11.21 respectively. Based on this equation, KMR is estimated on the independent data set 1985–95. Except for the years 1987 and 1993, the interannual variations in KMR are reasonably well estimated (Figure 5). The CC between the observed and estimated KMR for the period 1985–95 is only 0.20; however, when the years 1987 and 1993 are eliminated the CC increases sharply to 0.62. Both 1987 and 1993 happen to be El Niño years.

Yang (1996) found that more (less) Eurasian winter snow cover occurs during El Niño (La Niña) events and that the usual snow–monsoon links break down during the El Niño episodes. Climate simulations using general circulation models have shown that negative sea-surface temperature (SST) anomalies in the western Pacific and positive SST anomalies over the eastern and central Pacific (i.e. El Niño state) are favourable to heavy snowfall over Eurasia (Dong and Valdes, 1998). Rao *et al.* (1996) also suggested that the snow–monsoon rainfall relationship becomes stronger when partial correlation is used to exclude the El Niño years. All these studies suggest that an El Niño episode has a strong influence on the snow distribution over Eurasia. This may be a possible reason that KMR is not well estimated during the El Niño years of 1987 and 1993.

3.2. *Circulation features associated with the dipole correlation structure*

The land–sea temperature contrast is the basic forcing mechanism of the Asian monsoon circulation. Shukla (1987) hypothesized that excessive snowfall during the previous winter and spring seasons can delay the build up of the monsoonal temperature gradient because part of the solar energy will be reflected and part will be utilized for melting the snow or for evaporating the soil moisture. Some of the resulting melt water is stored in the form of soil moisture, and this water continues to inhibit the surface sensible heating through absorption of the latent heat of vaporization. Thus, it is hypothesized that snow mass influences the strength of the Asian summer monsoon by delaying the time at which significant surface sensible heating can occur and by constraining the amount of heating that can take place.

Thus the lingering of deep snow in winter–spring could be an important factor for the slower build up of the summer season continental heat sources affecting the development of the following monsoon, whereas light snow could be conducive to good monsoon activity. In view of this hypothesis, the relation between snow

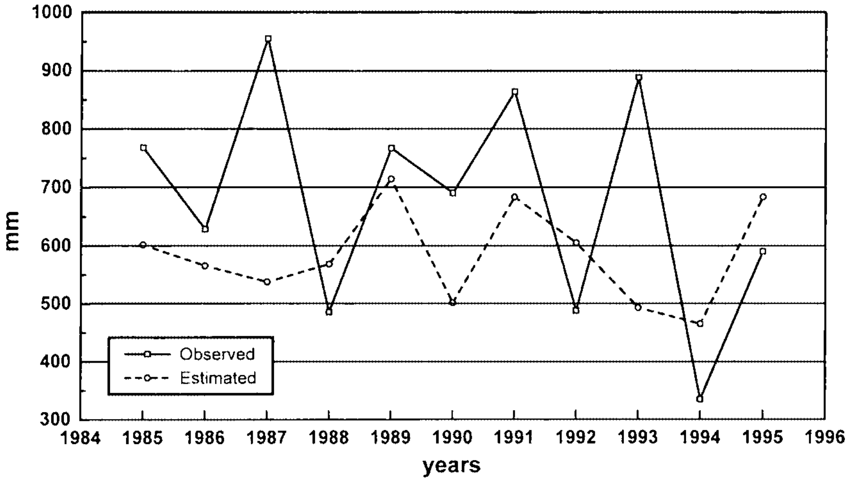

Figure 5. Observed and estimated KMR (mm) based on a multiple linear regression equation

and monsoon rainfall should be negative. In our analysis, the region over western Eurasia shows a significant negative relationship consistent with the above physical mechanism; however, the snow over eastern Eurasia shows a stronger and significant positive relationship. Why is the relationship of snow over the above two regions the reverse of that with KMR?

Meehl (1994, 1997) has noted a well-organized large-scale pattern at the 500 hPa level over the Northern Hemisphere during the winter prior to a strong South Asian monsoon. This pattern shows negative height differences over the Middle East, positive differences over North Asia, and negative differences over Northeast Asia. This is indicative of a mid-latitude long-wave pattern, such that there is anomalous ridging over Asia. The associated 500 hPa height anomalies for winter prior to a weak monsoon show almost the opposite pattern, with an anomalous trough over Asia. These circulation features fitted very well with the dipole correlation pattern obtained for the IMR–snow connections (Kripalani and Kulkarni, 1999).

Further, Corti *et al.* (2000) suggest that the same large-scale long-lasting anomalous circulation system may determine both winter and early spring snow depth anomalies over Eurasia, due to persistence, and also the large-scale anomalous monsoon circulation over South Asia. Ferranti and Molteni (1999) also suggest that the interannual variability of Eurasian snow depth in early spring is dependent upon the atmospheric circulation during the preceding winter. In view of this, the standardized snow depth values over western and eastern Eurasia were prepared for the January to April period. The time series of these standardized values, along with the standardized KMR, depicting interannual variability are shown in Figure 6. Hence, to investigate whether mid-tropospheric circulation features as seen by Kripalani and Kulkarni (1999) are also observed during winter prior to the summer monsoon over Korea, monthly re-analyses data sets have been used.

To start with, years were identified where the January to April snow depth was heavy (standardized value >1.0) over the western Eurasian region; at the same time, during these years the snow depth over eastern Eurasia should be on the negative side (years 1973, 1976, 1977). Similarly, years are identified where snow depth has been heavy over the eastern Eurasian sector, but negative over western Eurasia (years 1970, 1971, 1978). Three sets of years for each category are identified with the above criteria during the 1966–84 period (a mere coincidence that all years fall in the 1970s). These can be inferred from Figure 6.

Based on these two sets of years, composite monthly anomaly charts for January to August of 500 hPa geopotential heights were prepared; anomaly composites were prepared by removing the 19 year climatology. Maps for January, April, and July (representing winter, spring, and summer respectively) only are presented in Figure 7. The left (right) panels are composites for heavy snow over western (eastern) Eurasia.

Figure 7(a) shows negative height differences over the Middle East, positive differences over North Asia, and negative over Northeast Asia and beyond for heavy snow over the western sector. The associated 500 hPa height anomalies show an opposite pattern for heavy snow over the eastern sector (Figure 7(b)). These results imply that an anomalous trough over North Asia during winter could favour good monsoon activity over South Korea, whereas an anomalous ridge could be unfavourable. Interestingly, these figures resemble the negative (Figure 7(a)) and positive (Figure 7(b)) extremes of the Eurasian Type 1 pattern (Clark *et al.*, 1999) and the covariance patterns between the time series of snow depth principal component 1 and 500 hPa height anomalies (Corti *et al.*, 2000). The composite anomaly patterns during April and July also reveal contrasting circulation features for the two sets of years (Figure 7(c) and (d); Figure 7(e) and (f)).

Kim *et al.* (1998) composited wintertime 500 hPa geopotential height anomalies for dry and wet summers over Korea. For dry summers they found a pattern having some resemblance to Figure 7(a). They attributed this pattern to the prevalent zonal wind circulation over the mid–high latitudes over the Eurasian continent, which may shift the west Pacific subtropical high northward during dry summers. On the other hand, for wet summers they found a pattern having some resemblance to Figure 7(b). They suggested that the ridge over the Okhotsk Sea and East Asian continent is much stronger during a wet summer than a dry summer.

For India, a ridge (trough) over North Asia leads to excess (deficient) monsoon rainfall (Kripalani and Kulkarni, 1999). Thus the wintertime flow patterns over North Asia are remarkably reversed for similar extreme monsoon situations over India and South Korea. This may be due to the passage of troughs and ridges in the mid-latitude westerlies. This may also imply that monsoon activity over India and South Korea is negatively related. Such a negative relationship between Indian and South Korean monsoon rainfall has been noted (Kim, 1998; Kripalani and Kulkarni, 2001; Kim *et al.*, 2002b). The CC between IMR and KMR is

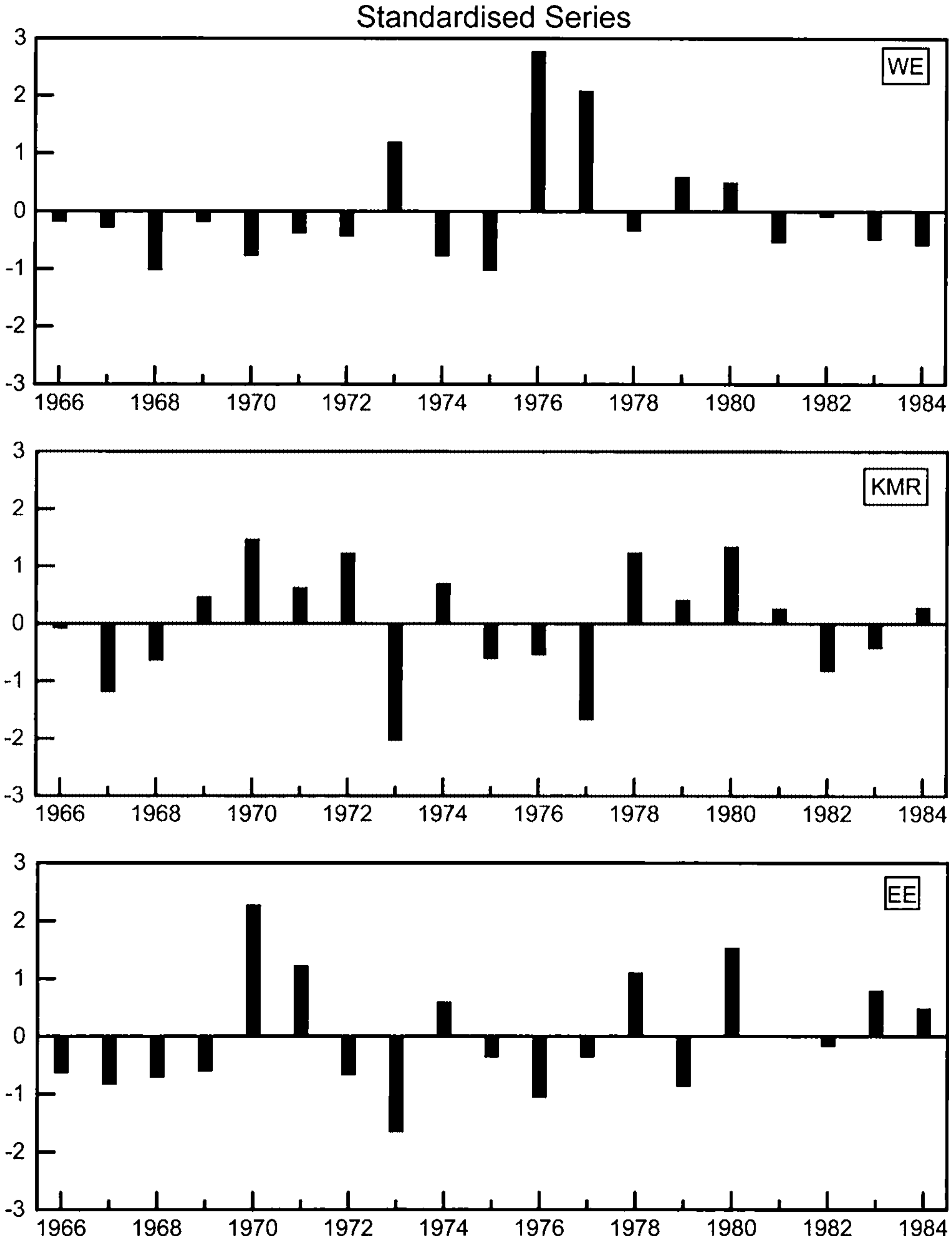

Figure 6. Standardized series of January to April snow depth over western Eurasia (upper panel), eastern Eurasia (lower panel) and June to August KMR (central panel) depicting interannual variability

−0.30 for the 1966–95 period. To examine the relationship on a decadal basis, 11-year sliding CCs between IMR and KMR for the period 1966–95 were computed (Figure 8). Figure 8 shows a negative relationship throughout the period of analysis.

The low-level jet and moisture transport are more important for the monsoons. The North Pacific subtropical high greatly influences the climate over East Asia. The low-level jet at the northwestern edge of this anticyclone transports large amounts of water vapour into East Asia (e.g. Tao and Chen, 1987; Kim *et al.*, 2002a). At the southern edge of this high is the western Pacific warm pool. The influence of the anomalous heating

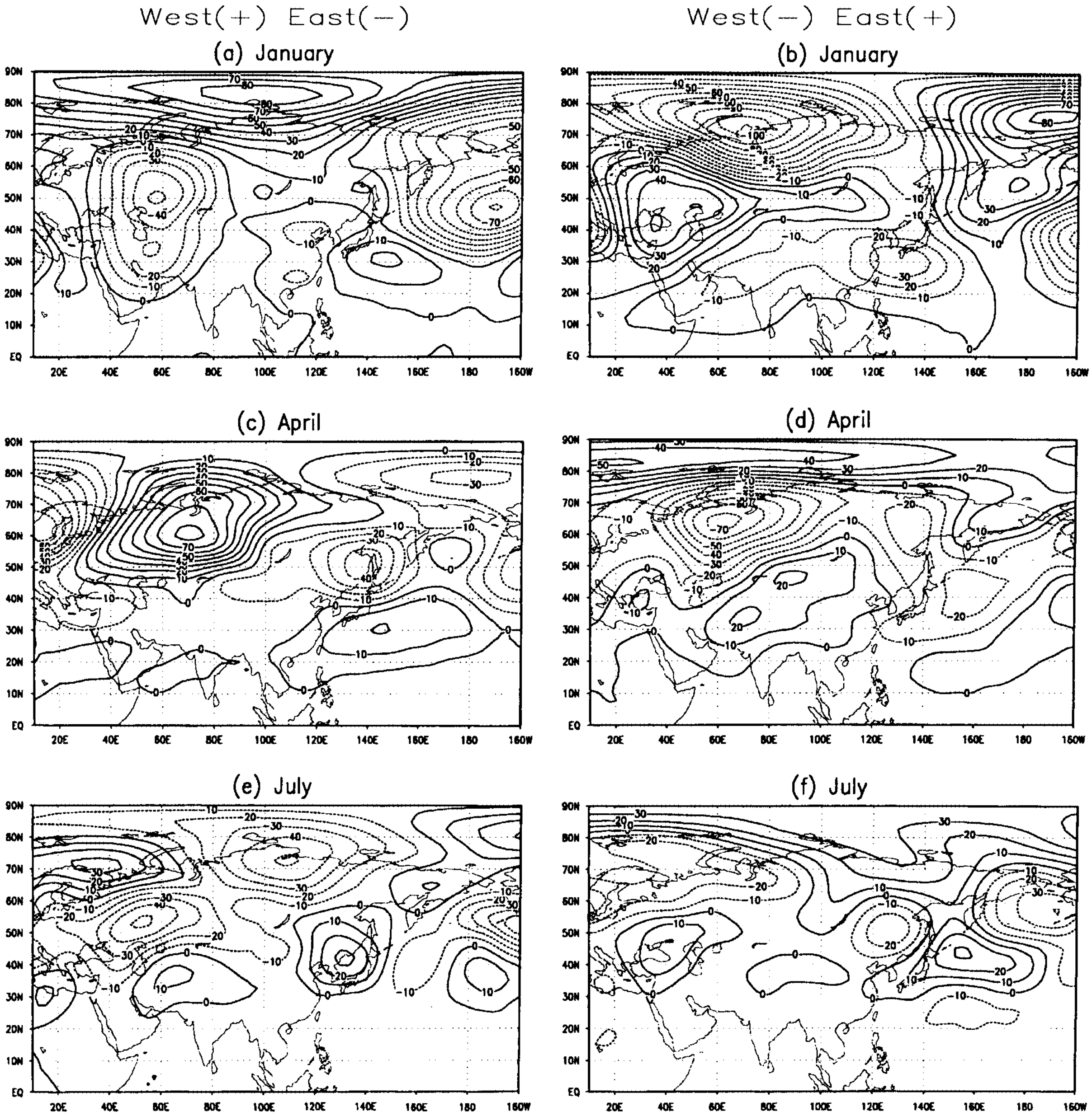

Figure 7. Monthly composite anomalies for the 500 hPa geopotential heights for heavy (light) snow over western (eastern) Eurasia (left panels) and for heavy (light) snow over eastern (western) Eurasia (right panels)

over the warm pool on the atmospheric circulation and precipitation over East Asia is also well documented (e.g. Huang and Sun, 1992). Gong and Wang (1999; also see the IPCC report Houghton *et al.* (2001: 152), showed that summer (June–August (JJA)) precipitation over central and eastern China near 30 °N is positively correlated with the intensity of this high, with negative correlations to the north and south. A location of the subtropical high further south than normal is conducive to heavy summer rainfall in this region.

To examine the above aspects, a composite analysis of the wind anomaly in the lower troposphere, i.e. 850 hPa level, during summer (JJA) was prepared for the same two sets of years mentioned above. These features are presented in Figure 9.

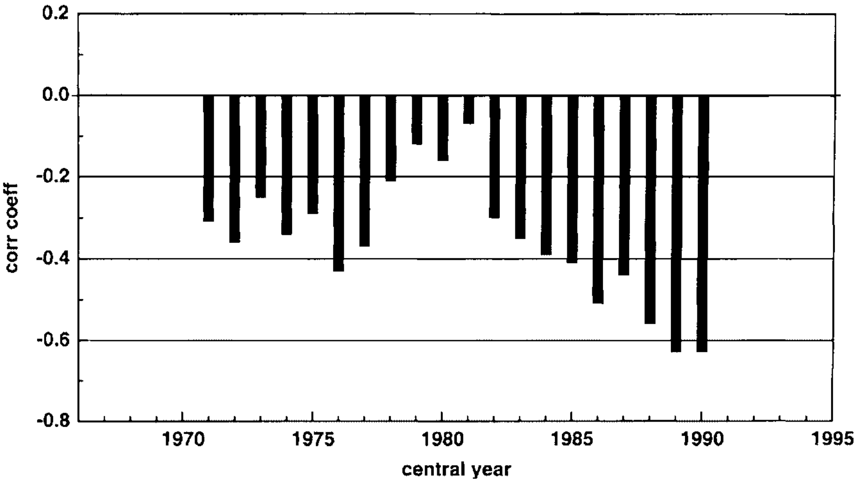

Figure 8. The 11-year sliding correlation coefficients between KMR and IMR. Values are plotted at the centre of the 11 year period

A careful examination of the JJA 850 hPa wind vector anomaly pattern over East Asia for heavy snow over western Eurasia and light snow over eastern Eurasia (Figure 9, upper panel) reveals the following:

(i) weakening and southward shift of the subtropical high, as seen over the region 20–40 °N, 165 °E–170 °W;
(ii) weakening of the low-level jet, as revealed by northwesterlies in the region of Korean peninsula 25–40 °N, 120–150 °E; this flow will reduce moisture supply over the Korean peninsula, as dry continental air may prevail;
(iii) southwesterlies/easterlies are seen to approach central and eastern China around 30 °N, 120 °E which may bring a moisture supply from the Pacific as suggested by Gong and Wang (1999).

On the other hand the wind vector anomaly for light snow over western Eurasia and heavy snow over eastern Eurasia (Figure 9, lower panel) shows the following:

(i) intensification of the North Pacific subtropical high seen over the region 30–50 °N, 160 °E–160 °W;
(ii) intensification of the low-level jet, as revealed by the anomalous easterly flow towards southern China, southerly flow over central China, and southwesterly flow over the Korean peninsula (20–40 °N, 110–130 °E); this intensified low-level jet transports large amounts of water vapour from the Pacific into the East Asian sector, leading to good monsoon activity over the Korean peninsula.

Thus the position, shape, and strength of the North Pacific subtropical high and the low-level jet play a dominant role in the distribution of monsoon rainfall over South Korea. The analysis here reveals that these summer features over the East Asian sector could be considerably influenced by the winter–spring snow distribution over Eurasia and affect the rainfall distribution.

Thus the winter circulation patterns over North Asia, for the extreme monsoon activity over South and East Asia, support the issues raised by Meehl (1994, 1997), that the snow depth changes may be indicative of changes in the large-scale mid-latitude circulation, which affect land temperatures, land–sea temperature contrast, monsoon flow, and subsequent monsoon strength.

4. SUMMARY

An analysis of the statistical connections between Soviet snow depth and KMR was carried out. Results revealed that the wintertime snow depth over western (eastern) Eurasia was negatively (positively) related

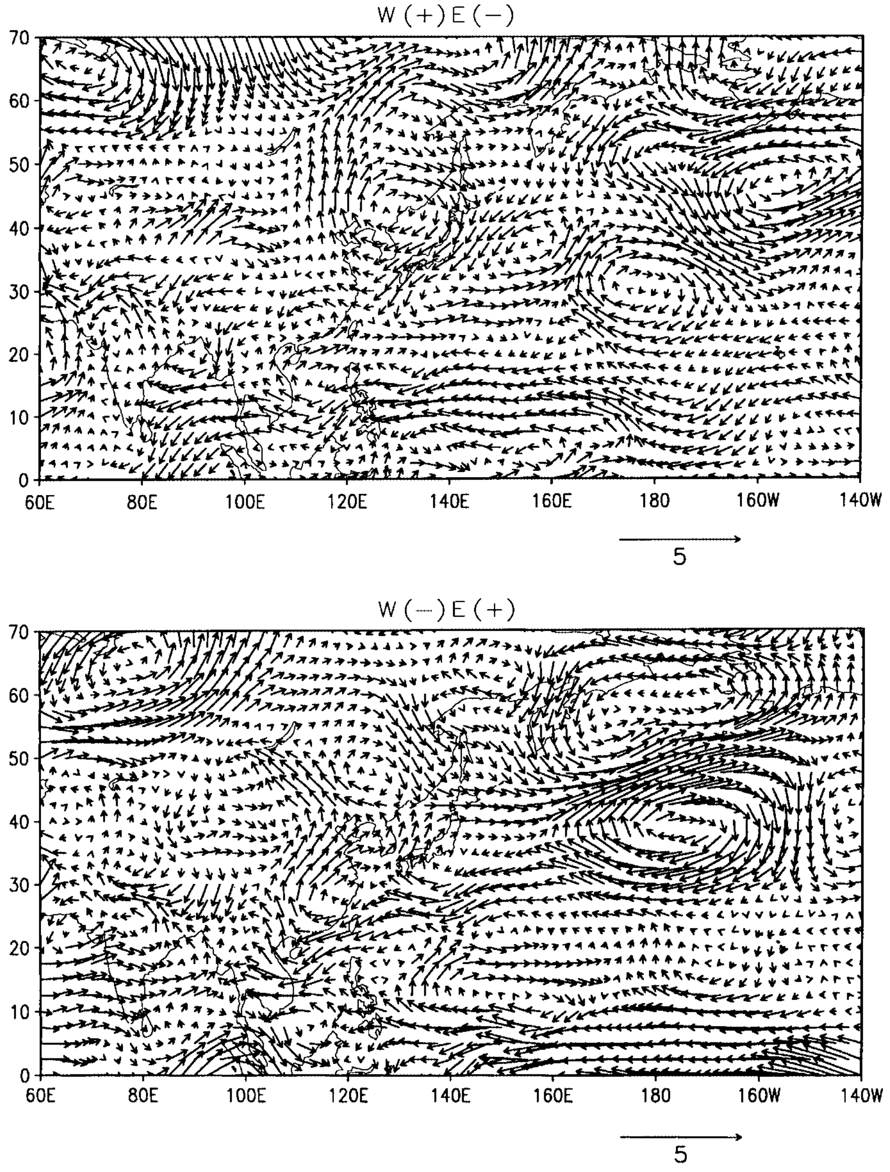

Figure 9. Composite anomalies for the summer monsoon period (JJA) for 850 hPa wind vectors for heavy (light) snow over western (eastern) Eurasia [W (+), E (−): upper panel] and for heavy (light) snow over eastern (western) Eurasia [W (−), E (+): lower panel]

with subsequent monsoon rainfall over South Korea. Composite anomaly maps for the mid-tropospheric level showed an anomalous ridge during winter over North Asia for the heavy (light) snow depth over western (eastern) Eurasia, whereas an anomalous trough was noticed for heavy (light) snow over eastern (western) Eurasia. The winter anomalous trough (ridge) over North Asia is favourable (unfavourable) for monsoon activity over South Korea. Further, a composite wind vector analysis over the lower tropospheric level reveals that light snow over western Eurasia and heavy snow over eastern Eurasia may intensify the North Pacific subtropical high and the low-level jet, resulting in good monsoon activity over South Korea, whereas heavy snow over western Eurasia and light snow over eastern Eurasia may weaken these features. These results imply that monsoon rainfall over Korea has some connections with snow variations over the former Soviet Union, but not all of the interannual variability of the KMR is necessarily caused by snow. For the period of analysis, about 30% variance in KMR can be explained by the snow variations; hence, these results have some forecast potential. The above analysis also revealed that the localized regions over which snow variations are related to subsequent monsoon are different for South and East Asia. Finally, monsoon activity over India and South Korea is negatively related.

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REFERENCES

Bamzai AS, Shukla J. 1999. Relation between Eurasian snow cover, snow depth and the Indian summer monsoon: an observational study. *Journal of Climate* **12**: 3117–3132.

Barnett TP, Dumenil L, Schlese U, Roeckner E, Latif M. 1989. Effects of Eurasian snow cover on regional and global climate variations. *Journal of the Atmospheric Sciences* **46**: 661–685.

Blanford HF. 1884. On the connexion of Himalayan snowfall and seasons of drought in India. *Proceedings of the Royal Society of London* **37**: 3–22.

Choi BC, Davies TD, Osborn TJ, Lee SH. 1998. On the relationship between Eurasian snow cover and summer rainfall in South Korea. Part I: statistical analysis. *Journal of the Korean Meteorological Society* **34**: 478–485.

Clark MP, Serreze MC, Robinson DA. 1999. Atmospheric controls on Eurasian snow extent. *International Journal of Climatology* **19**: 27–40.

Corti S, Molteni F, Brankovic C. 2000. Predictability of snow depth anomalies over Eurasia and associated circulation patterns. *Quarterly Journal of the Royal Meteorological Society* **126**: 241–262.

Dong B, Valdes PJ. 1998. Modelling the Asian summer monsoon rainfall and Eurasia winter/spring snow mass. *Quarterly Journal of the Royal Meteorological Society* **124**: 2567–2596.

Dong M, Yu J. 1998. A study of the Tibetan snow cover on the general circulation in East Asia monsoon area. In *Proceedings of the International Conference on Monsoon and Hydrologic Cycle*, Kyongju, Korea, 22–25 April; 57–61.

Ferranti L, Molteni F. 1999. Ensemble simulations of Eurasian snow-depth anomalies and their influence on the summer Asian monsoon. *Quarterly Journal of the Royal Meteorological Society* **125**: 2597–2610.

Gong DY, Wang SW. 1999. Experiments on the reconstruction of historical monthly mean northern hemisphere 500 hPa heights from surface data. *Report of the Department of Geophysics*, Peking University.

Hahn DG, Shukla J. 1976. An apparent relationship between Eurasian snow cover and Indian monsoon rainfall. *Journal of the Atmospheric Sciences* **33**: 2461–2462.

Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds). 2001. *Climate Change 2001. The Scientific Basis. Contribution of the Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press: Cambridge, UK and New York, USA; 881pp.

Huang RH, Sun FY. 1992. Impacts of the tropical western Pacific on the East Asian summer monsoon. *Journal of the Meteorological Society of Japan* **70**: 243–256.

Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Iredell M, Saha S, White G, Wollen J, Zhu Y, Chelliah M, Ebisuzaki W, Higgins W, Janowiak J, Mo KC, Ropelewski C, Wang J, Leetmaa A, Reynolds R, Jenne R, Joseph D. 1996. The NCEP/NCAR 40-year reanalysis project. *Bulletin of the American Meteorological Society* **77**: 437–471.

Kim BJ. 1998. Interannual variation of summer rainfall in Korea and its association with Asian monsoon circulation. PhD thesis, Pusan National University, Korea.

Kim BJ, Moon SE, Huang R, Lu RY. 1998. Relationship between the winter time atmospheric circulation over the northern hemisphere and the summer monsoon rainfall in Korea. In *Proceedings of the International Conference on Monsoon and Hydrologic Cycle*, Kyongju, Korea, 22–25 April; 247–251.

Kim BJ, Kripalani RH, Oh JH, Moon SE. 2002a. Summer monsoon rainfall patterns over South Korea and associated circulation features. *Theoretical and Applied Climatology* **72**: 65–71.

Kim BJ, Moon SE, Lu R, Kripalani RH. 2002b. Teleconnections: Summer monsoon over Korea and India. *Advances in Atmospheric Sciences* **19**: 665–676.

Kripalani RH, Kulkarni A. 1999. Climatology and variability of historical Soviet snow depth data: some new perspectives in snow–Indian monsoon teleconnections. *Climate Dynamics* **15**: 475–489.

Kripalani RH, Kulkarni A. 2001. Monsoon rainfall variations and teleconnections over South and East Asia. *International Journal of Climatology* **21**: 603–616.

Kripalani RH, Singh SV, Vernekar AD, Thapliyal V. 1996. Empirical study on Nimbus-7 snow mass and Indian summer monsoon rainfall. *International Journal of Climatology* **16**: 23–34.

Kripalani RH, Kulkarni A, Singh SV. 1997. Association of the Indian summer monsoon with the northern hemisphere mid-latitude circulation. *International Journal of Climatology* **17**: 1055–1067.

Meehl GA. 1994. Coupled land–ocean–atmosphere processes and south Asian monsoon variability. *Science* **266**: 263–267.

Meehl GA. 1997. The south Asian monsoon and the tropospheric biennial oscillation. *Journal of Climate* **10**: 1921–1943.

Oh JH, Kwon WT, Ryoo SB. 1997. Review of the researches on Changma and future observational study (KORMEX). *Advances in Atmospheric Sciences* **14**: 207–222.

Rao MS, Lau KM, Yang S. 1996. On the relationship between Eurasian snow cover and the Asian summer monsoon. *International Journal of Climatology* **16**: 605–616.

Shukla J. 1987. Interannual variability of monsoons. In *Monsoons*, Fein J, Stephens PL (eds). Wiley and Sons: New York; 399–463.

Tao S, Chen L. 1987. A review of recent research on the east Asian summer monsoon in China. In *Monsoon Meteorology*, Chang CP, Krishnamurti TN (eds). Oxford University Press: 60–92.

Vernekar AD, Zhou J, Shukla J. 1995. The effect of Eurasian snow cover on the Indian monsoon. *Journal of Climate* **8**: 248–266.

Yang S. 1996. ENSO–snow–monsoon associations and seasonal–interannual predictions. *International Journal of Climatology* **16**: 125–134.

Yang S, Xu L. 1994. Linkage between Eurasian winter snow cover and regional Chinese summer rainfall. *International Journal of Climatology* **14**: 739–750.