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ORIGINAL ARTICLE

A Study of Teleconnection between the South Asian and East Asian Monsoons: Comparison of Summer Monsoon Precipitation of Nepal and South Korea

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Abstract

This study is carried out in order to bridge the gap to understand the relationships between South Asian and East Asian monsoon systems by comparing the summer (June-September) precipitation of Nepal and South Korea. Summer monsoon precipitation data from Nepal and South Korea during 30 years (1981-2010) are used in this research to investigate the association. NCEP/NCAR reanalysis data are also used to see the nature of large scale phenomena. Statistical applications are used to analyze these data. The analyzed results show that summer monsoon precipitation is higher over Nepal (1513.98 ± 159.29 mm y^{-1}) than that of South Korea (907.80 ± 204.71 mm y^{-1}) and the wettest period in both the countries is July. However, the coefficient of variation shows that amplitude of interannual variation of summer monsoon over South Korea (22.55%) is larger in comparison to that of Nepal (10.52%). Summer monsoon precipitation of Nepal is found to be significantly correlated to that of South Korea with a correlation coefficient of 0.52 (99% confidence level). Large-scale circulations are studied to further investigate the relationship between the two countries. wind and specific humidity at 850 hPa show a strong westerly from Arabian Sea to BOB and from BOB, wind moves towards Nepal in a northwestward direction during the positive rainfall years. In case of East Asia, strong northward displacement of wind can be observed from Pacific to South Korea and strong anticyclone over the northwestern Pacific Ocean. However, during the negative rainfall years, in the South Asian region we can find weak westerly from the Arabian Sea to BOB, wind is blowing in a southerly direction from Nepal and Bangladesh to BOB.

Key words : Summer monsoon precipitation, South Asian and East Asian monsoon, Western North Pacific subtropical high, Tibetan high, Teleconnection.

1. Introduction

The Asian monsoon is a major phenomenon of global climate system and it is seasonal in nature, in which, summer monsoon holds a great importance in relation to fresh water supply, agriculture, and energy production. The Asian monsoon is broadly composed of subsystems; the South Asian monsoon (also known as Indian monsoon), the East Asian monsoon (EASM), and the western North Pacific monsoon

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(WNPM) (Wang et al. 2003). These subsystems are composed of different circulation systems, which at times strongly affect each other, and conversely tend to vary differently at other times (Qian and Zhu, 2002). Teleconnection studies have been carried out to find relations between these far-off located sub-systems.

Teleconnection have been explored in previous studies, especially based on the South Asian (in particular India) and East Asian (in particular China) monsoon subsystems. Kripalani and Kulkarni (2001) studied monsoon precipitation variations and teleconnection between the South and East Asian monsoons. They suggested that the precipitation variations over North China are in phase with monsoon precipitation over India, but out-of-phase when compared to Southern Japan. Another study about summer monsoon precipitation over Korea and India by Kim et al. (2002) suggested that an inverse relationship exists between the summer precipitation of Korea and northwestern and central India; whereas, a weak and positive relation with northeastern India. However, there are some gaps in understanding the connection between the South Asian and East Asian monsoon, especially the monsoon over Nepal that holds a great value in South Asia due to the presence of the Himalayas, which is a major source of water to the South Asian countries. No studies have been carried out to analyze the relation of Nepal's summer monsoon with other East Asian countries.

Nepal represents the central Himalayan region and lies in the southern periphery of the Tibetan Plateau (TP). Its main latitude and longitude is 28ºN and 84ºE, respectively. Nepal extends 885 km east-west and 145-248 km north-south. Within this small area, the altitude rises ranges from just 60 m above sea level (a.s.l). in south to the world's highest peak Mount Everest at 8848 m a.s.l. in north. Nepal is dominated by summer monsoon, which is from June to September that contributes to about 80% of its annual precipitation. It is affected by southeasterly flow from the Bay of Bengal (BOB). Summer precipitation is unequally distributed in Nepal; where central-eastern Nepal receives greater precipitation than northwestern part of Nepal (Sigdel and Ikeda, 2012). In the past, studies related to Nepal as a separate entity has been very limited, however, a study done by Ichiyanagi et al. (2007) suggests that All Indian Rainfall (AIR) index is positively correlated with precipitation in western Nepal, while it is negatively correlated to precipitation in eastern Nepal. In addition, monsoon precipitation over Nepal shows strong in-phase relationship with Southern Oscillation Index (SOI), with correlation coefficient of 0.58 during the period from 1957 to 1988, significant at 99.9% (Shrestha, 2000).

South Korea lies in the southern part of Korean peninsula and its main latitude and longitude is 37ºN and 127ºE. It extends 300 km in longitude and 450 km in latitude. Within its area, the altitude rises from sea level to 1950 m. Summer monsoon over Korea is associated with northward advance of the monsoon trough known as Changma. This subtropical rain band brings majority of summer precipitation to China, South Korea and Japan. The East Asian monsoon begins as a monsoon trough forming over the South China Sea in mid-May. As it accompanies heavy precipitation over the South China Sea, the monsoon trough moves northward along the East Asian coastline in concert with an expansion of the North Pacific High in the northwestern Pacific Ocean (Ho et al., 2003). The summer precipitation in Korea accounts for more than 50% of the total annual precipitation (Kim et al., 2002).

The main objective of this study is to bridge the existing gap and examine the relation of summer monsoon precipitation between Nepal and South Korea during 1981-2010, using summer monsoon precipitation data from both the countries and NCEP/NCAR reanalysis data.

2. Data and Method

This study primarily uses precipitation data collected from 57 stations in South Korea operated by the Korea Meteorological Administration (KMA) and 25 stations in Nepal operated by the Nepal Government's Department of Hydrology and Meteorology (DHM) (Fig.1). Inside these data, typhoon-related precipitation was not removed. The dataset includes summer monsoon months, i.e., June to September (JJAS) covering 30-year period from 1981 to 2010. Monthly mean atmospheric reanalysis dataset archived at National Centers for Environmental Prediction/National Center for Atmospheric Research (Kalnay et al., 1996) is also included in the study. From the various reanalysis dataset, we have used geopotential height (1000, 500 and 200 hPa); wind and specific humidity at 850 hPa; and zonal and meridional wind at 200 hPa, at 2.5º × 2.5º resolution. Southern Oscillation Index (SOI) data was extracted from National Oceanic and Atmospheric Administration (NOAA). The study includes statistical methods like mean, standard deviation, coefficient of variation, moving average, standardization, trend analysis, correlation analysis and scatter plot to analyze the summer monsoon precipitation over Nepal and South Korea.

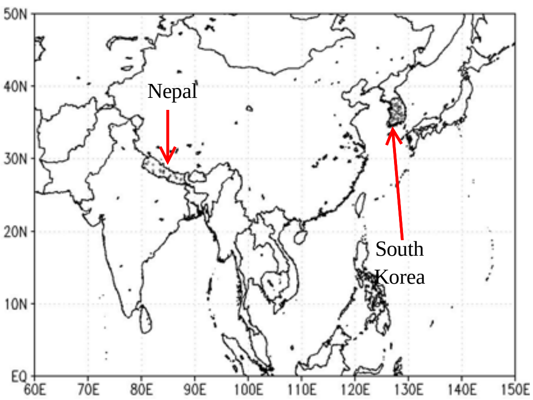

Fig. 1. Map of Asia showing Nepal and South Korea.

3. Results

In this section, teleconnection between the South Asian and East Asian monsoons are examined by comparing the summer (June to September, JJAS) monsoon precipitation of Nepal to South Korea. Firstly, we examine the variability of the summertime precipitation over Nepal and South Korea to investigate their characteristics. Next, we analyze the variation of the geopotential height at different pressure levels (1000, 500, 200 hPa), specific humidity and wind at 850 hPa, and 200 hPa zonal and meridional wind.

In order to examine the climatic variability of summer (JJAS) monsoon precipitation over Nepal and South Korea, the time series graph of the summertime precipitation for the period of 1981-2010 is shown in Fig.2. This time series graph indicates that the precipitation over Nepal is higher than over South Korea. The 30-year average of the summer monsoon precipitation of Nepal and South Korea are calculated as 1513.98 ± 159.29 mm y^{-1} and 907.80 ± 204.71 mm y^{-1}, respectively. The coefficient of variation (CV) of South Korea (22.55%) is higher than that of Nepal (10.52%), which suggests that the amplitude of interannual variation of summer monsoon precipitation is larger over South Korea than over Nepal. The

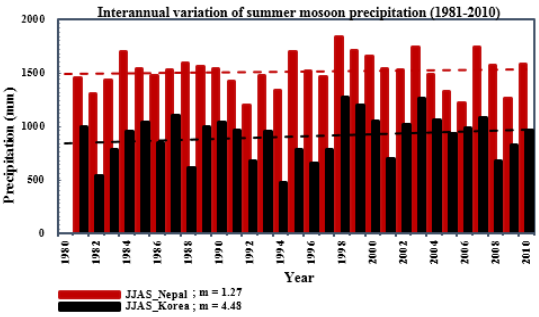

Fig. 2. Interannual variation of summer (JJAS) monsoon precipitation over Nepal (red) and South Korea (black) during 1981 to 2010 along with their respective linear trend line (dashed).

estimated linear trend (dashed line) presented in the same figure indicates that there is an increase in precipitation in both the countries, but the escalation is more apparent for South Korea with a higher slope (m = 4.48) in comparison to that of Nepal (m = 1.27).

Figure 3 shows the time series of average of daily variation of precipitation from July to September during the period of 1981-2010 over both Nepal and South Korea. July is found to be the wettest month in both the countries with their average as 499.81 ± 84.78 mm y^{-1} and 294.77 ± 105.92 mm y^{-1} over Nepal and South Korea, respectively. This is followed closely by August where Nepal receives precipitation of about 441.44 ± 76.90 mm y^{-1} and South Korea receives 278.79 ± 117.91 mm y^{-1}. Also shown is the 10-day moving average (dashed line) to depict the trend of daily precipitation by smoothing the high-frequency noise. Overall, the 10-day moving average indicates high precipitation in July and August through two peaks visible for both the countries, however it is more definite for South Korea. In case of South Korea, primary peak and secondary peak can be associated with Changma and Post-Changma period.

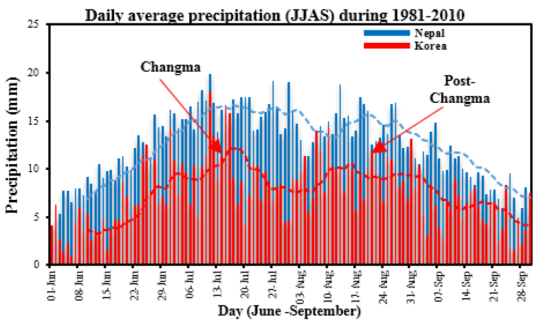

Fig. 3. Average of daily variation of summer (JJAS) monsoon precipitation during 1981-2010 of Nepal (blue) and South Korea (red).

Figure 4 shows the year-to-year standardized precipitation over Nepal and South Korea during 1981-2010, depicting interannual variability for summer monsoon precipitation along with the correlation coefficient (CC) in between them. In this figure, we can see that standardized precipitations of Nepal and South Korea quite well relate to each other i.e., precipitation increases or decreases over the two countries almost at the matching years. It can be further explained with an aid of CC of 0.52 between the summer precipitations over Nepal and South Korea, which is significant at 99% confidence level.

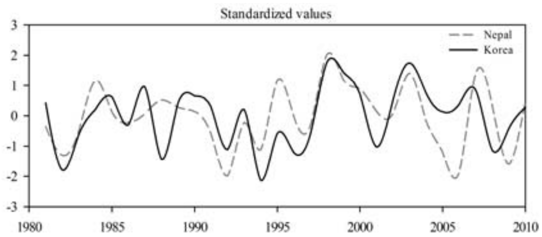

Fig. 4. Year-to-year standardized summer (JJAS) monsoon precipitation over Nepal and South Korea during 1981-2010.

The relation between the summer monsoon precipitation over Nepal and southern oscillation index (SOI) is presented in Fig.5. The CC between them is calculated to be 0.46 and it is above the 99-percent confidence level. Out of the 30 years precipitation data in this study, 21 years are in-phase with SOI. Thus, we can say that southern oscillation is effective in influencing the precipitation pattern over Nepal. This result agrees with the previous studies by Shrestha (2000) and Sigdel and Ikeda (2012). However, the relation between precipitation over South Korea and SOI (not shown here) is found to be low and statistically insignificant.

To further investigate the teleconnection, we present anomaly maps of the positively correlated rainfall years of Nepal and South Korea using base period as 1981-2010. Figure 6 shows the scatter plot that presents the years that are in-phase with respect to each other, i.e. summer monsoon precipitation

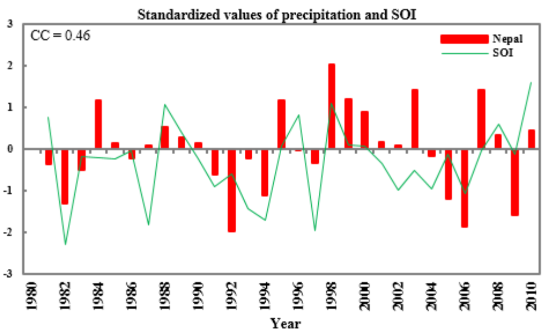

Fig. 5. Relationship of summer (JJAS) monsoon precipitation of Nepal with southern oscillation index during 1981-2010.

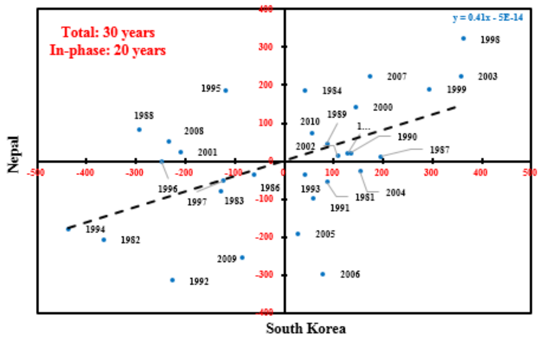

Fig. 6. Scatter diagram showing relation of summer (JJAS) monsoon precipitation of Nepal with South Korea during 1981-2010.

over Nepal and South Korea. From the figure, we can see that there are 20 years of positively related years and 10 years are negatively related. Among the years that are in-phase, there are 12 positive rainfall years and 8 negative rainfall, as shown in Table 1. Using these positive rainfall years and negative rainfall years, we have studied the characteristics of large-scale circulations that could lead to the connection between the two countries.

Figure 7 presents the geopotential height at 1000 hPa of (a) positive rainfall years minus mean, and (b) negative rainfall years minus mean. The main features of the Asian monsoon are higher geopotential height over the northwestern Pacific Ocean, which is an important component of East Asian monsoon (Lu, 2001); and monsoon low over the Indian sub-continent and Bay of Bengal, which is important component of South Asian monsoon system. In Fig.7(a), higher than normal geopotential height can be observed over the northwestern Pacific Ocean close to Japan, from which we can suggest that the northwestern Pacific subtropical high (WNPSH) is evident and very strong during the positive rainfall years. On the contrary, in Fig. 7(b), approximately opposite variation of geopotential height with respect to Fig. 7(a) can be identified. The region with higher geopotential height in Fig. 7(a) has lower geopotential height in Fig. 7(b). Over the northwestern Pacific Ocean, lower than normal geopotential height can be observed in negative rainfall years. Likewise, relatively higher geopotential height can be observed over the Indian sub-continent.

Similarly, Fig. 8(a) shows the 500-hPa geopotential height of the positive rainfall years minus mean. A higher geopotential height is evident over East Asia, with its center over Japan and extending to the Korean peninsula. This suggests that in the positive rainfall years, WNPSH was stronger over these areas. Similar to Fig 7(a), lower geopotential height can be observed over the Indian subcontinent. In contrast,

Table 1. The 20 years of positively associated years in between Nepal and South Korea. The positive rainfall years and negative rainfall years are shown separately

Positive rainfall years	Negative rainfall years
1984, 1985, 1987, 1989, 1990, 1998, 1999, 2000, 2002, 2003, 2007, 2010	1982, 1983, 1986, 1992, 1994, 1996, 1997, 2009

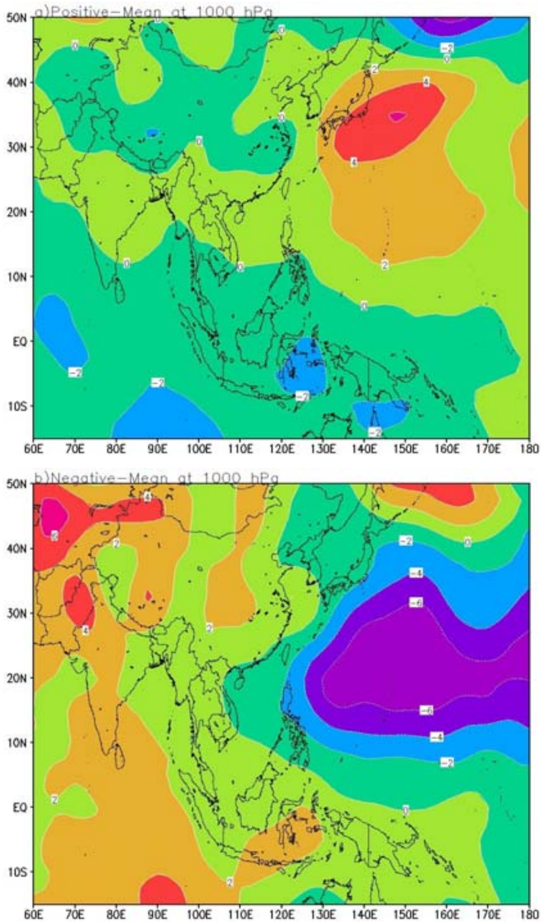

Fig. 7. Geopotential height (contour interval of 2 m) at 1000 hPa. Results are shown for (a) positive rainfall years minus mean, and (b) negative rainfall years minus mean.

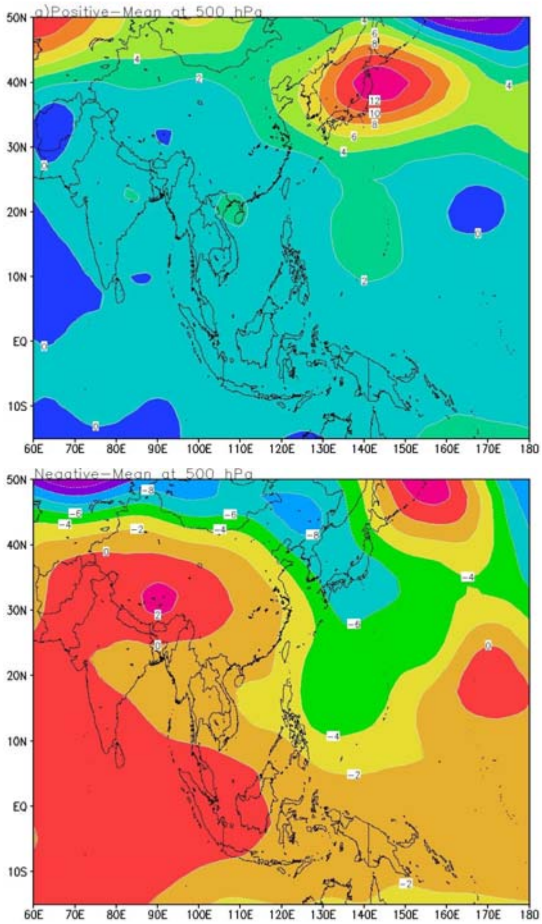

Fig. 8. Same as Fig.7 but at 500 hPa.

Fig. 8(b) shows the 500-hPa geopotential height of negative rainfall years minus mean. Reverse in sign, i.e., lower geopotential height could be observed over Japan and Korean peninsula in the same figure. Then again, slightly higher geopotential height can be observed over Indian sub-continent. From the information through geopotential height at 1000 and 500 hPa, we can say that higher geopotential height can be observed over the western North Pacific Ocean and monsoon low over the Indian subcontinent during the positive rainfall years, whereas the geopotential height seems to be in reverse order during the negative rainfall years. Hence, western North Pacific subtropical high is stronger and monsoon low over Indian sub-continent is lower during the positive rainfall years, and vice versa.

Now we examine the geopotential height at 200 hPa (upper level). The arrangement of low and high geopotential height differs at upper level. Higher geopotential height is observed over South Asia in

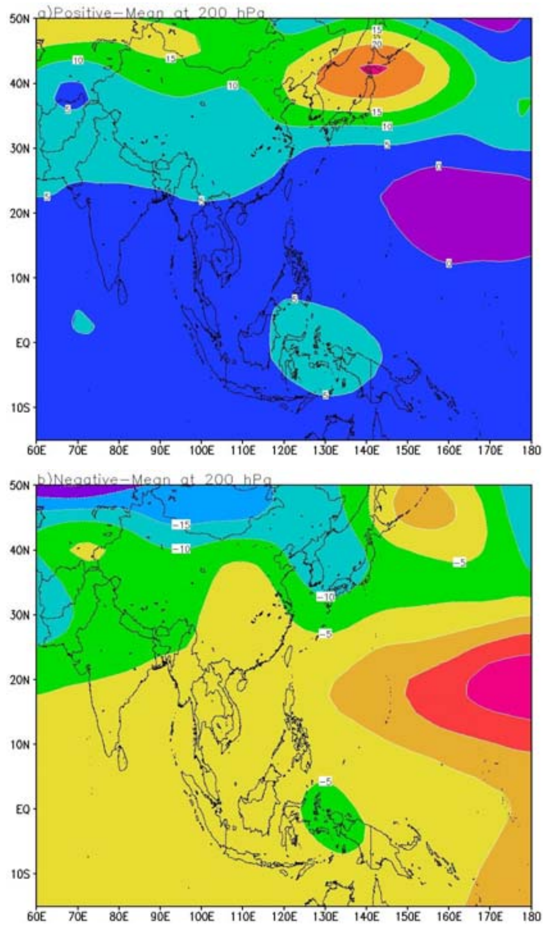

Fig. 9. Same as Fig.7 but at 200 hPa. Contour interval is set at 5 m.

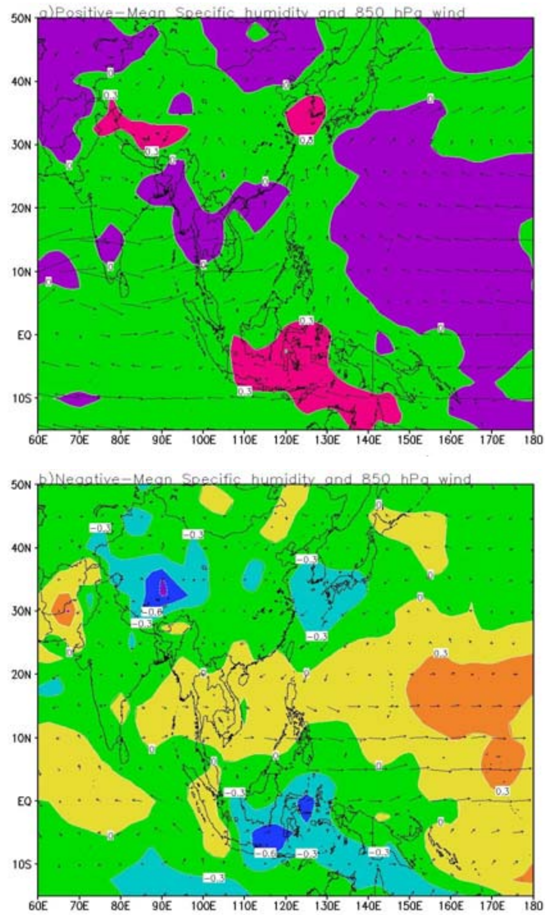

Fig. 10. Same as Fig. 7 but for wind along with specific humidity at 850 hPa. Contour interval is set at 0.3 g kg^{-1}.

between 20-30ºN, known as Tibetan high (TH). The elevated surface and atmospheric heating over Tibetan Plateau (TP) plays a fundamental role in establishment and maintenance of the Asian summer monsoon circulation. The TH, a large-scale upper-tropospheric anticyclonic circulation over the subtropical Northern hemisphere, is an integral element of the Asian summer monsoon systems, with its center sitting over the southern edge of the TP (Li and Yanai, 1996, Zhao et al., 2009). Similarly, in Figs. 9(a) and 9(b), we present plots of geopotential height at 200 hPa of high rainfall years minus the mean and negative rainfall years minus the mean, respectively. In the positive rainfall years, a higher geopotential height can be observed over South Asia, which represents TH. However, negative rainfall years chart depict lower geopotential height in the Indian sub-continent. From the geopotential height charts, we can conclude that in positive rainfall years, TH as well as WNPSH is stronger than normal, whereas it is just the opposite during the negative rainfall years. From this we suggest that WNPSH and TH have

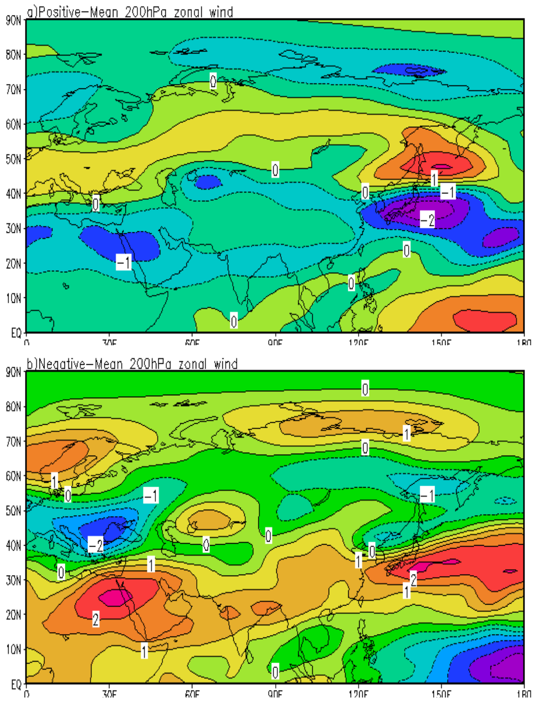

Fig. 11. Same as Fig. 7 but for 200-hPa zonal wind. Contour interval is set at 1 m s^{-1}.

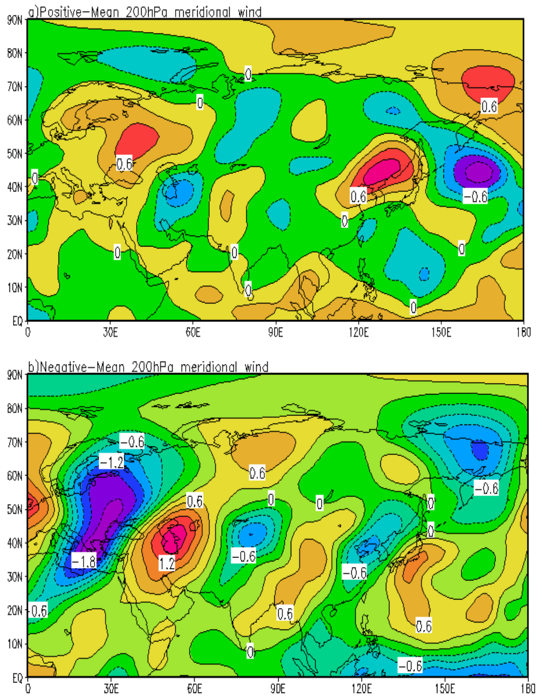

Fig. 12. Same as Fig. 7 but for 200-hPa meridional wind. Contour interval is set at 0.3 m s^{-1}.

significant role in the teleconnection in between the monsoon precipitation of Nepal and South Korea.

The anomaly of wind pattern of summer (JJAS) along with specific humidity at 850 hPa is presented in Fig.10. In Fig. 10(a), during the positive rainfall years, stronger than normal westerly from the Arabian Sea to BOB and an anticyclone over North Pacific Ocean are evident. From BOB, wind moves towards Nepal in a northwestward direction bringing heavy precipitation along with it. In the case of South Korea, the flow of strong moisture-laden wind is in northward direction. A strong anticyclone can be observed over the North Pacific Ocean which relates to WNPSH. On the contrary, spatial pattern of negative rainfall years also illustrate westerly from the Arabian Sea to BOB, but its strength is weaker than that of positive rainfall years. In particular, we can observe the difference in wind direction over Pacific Ocean. From the previous discussion about geopotential height, we learn that lower geopotentail height exists over the North Pacific Ocean during the negative rainfall years, and accordingly in these years we cannot observe anticyclone, but rather a cyclonic motion of wind. Likewise, in East Asia, we can find the southward flow of wind more definite during these negative rainfall years. Figure 10 also shows specific humidity along with wind direction. Specific humidity gives us information related to spatial distribution of available moisture content. In the positive rainfall years, we can see greater value of specific humidity over north-west part of India, TP and South Korea. Lower than normal precipitable water could be seen over the Pacific Ocean. In case of low rainfall years, decreased specific humidity can be observed over TP, South Korea and some parts of Japan, whereas higher specific humidity is found over the Pacific Ocean and South-East Asia.

In Fig. 11, composite anomalies of 200-hPa zonal wind (u) for positive rainfall years (a), and negative rainfall years (b) are presented. The composite anomalies of positive rainfall years show that the intensification of the zonal wind in between 40-50ºN and it is accompanied by reduction of westerly component over the 20-35ºN. While in the composite of negative rainfall years, the intensification of zonal wind is in between 10-35ºN. This can be interpreted as a shift of the East Asian jet stream (EAJS) northwards during positive rainfall years and it shifts southward during the negative rainfall years. Previous studies have found that EAJS is one of the most important components of East Asian summer monsoon and plays a crucial role in the weather and climate over East Asia (Lau et al., 1988). Nepal and South Korea are under the effects of reduced westerly wind during the positive rainfall years, and influenced by intensified zonal wind during the negative rainfall years.

Figure 12 shows the anomalies of 200-hPa meridional wind (v) for the positive rainfall years (a), and negative rainfall years (b). The figures reveal a wave-train like pattern that propagate southeastwards. During the positive rainfall years as well as negative rainfall years, meridional wind present over South Asia and East Asia show out-of-phase relation. Northerly anomalies are seen over East Asia during the positive rainfall years. During the negative rainfall years, the signal is clearer as we can find definite northerly anomalies over Nepal and southerly anomalies over South Korea.

4. Conclusion

In the present study, summer (June-September) monsoon precipitation data of Nepal and South Korea, along with NCEP/NCAR reanalysis data, during the 30 years of 1981-2010, were used to examine the association of summer monsoon precipitation of Nepal and South Korea. The 30-year mean of summer monsoon precipitation over Nepal and South Korea shows higher precipitation over Nepal (1513.98 ± 159.29 mm y^{-1}) in comparison to South Korea (907.80 ± 204.71 mm y^{-1}). Along with it, their liner trend shows that precipitation is increasing over both the countries, but the increase is larger over South Korea with a slope of 4.48, whereas the slope for Nepal is 1.27. The coefficient of variation (CV) of South Korea (22.55%) higher than that of Nepal (10.52%), which suggests that the amplitude of interannual variability of summer monsoon precipitation is larger over South Korea than over Nepal. The daily average precipitation over Nepal and South Korea during this 30 years show two peaks around mid-July and mid-August. The primary and secondary peak over South Korea can be linked to Changma and Post-Changma period. We can find statistically significant positive association between the summer monsoon precipitation over Nepal and South Korea with a correlation coefficient of 0.52. The correlation coefficient between the summer monsoon precipitation over Nepal and southern oscillation index (SOI) is calculated to be 0.46. Out of the selected 30 years, 21 years are in-phase with SOI. On the other hand, the relation of summer monsoon precipitation over South Korea and SOI is low and insignificant.

Out of these 30 selected years, we can find 20 positively related rainfall years. There are 12 years of positive rainfall years, whereas 8 were found to have negative rainfall years. For the positive rainfall years, the geopotential height at 1000 hPa and 500 hPa shows monsoon low over Indian subcontinent and strong western North Pacific subtropical high over the North Pacific Ocean. Likewise, the geopotential height at 200 hPa shows higher geopotential height over the Indian subcontinent representing Tibetan high and low over the Pacific Ocean. This relation is opposite in the negative rainfall years.

Likewise, wind and specific humidity at 850 hPa show a strong westerly from Arabian Sea to BOB and from BOB, wind moves towards Nepal in a northwestward direction during the positive rainfall years. In these years, we can find high moisture content over the TP. In case of East Asia, strong northward displacement of wind can be observed from Pacific to South Korea and strong anticyclone over the northwestern Pacific Ocean. Along with it high precipitable amount of moisture can be observed over South Korea. However, during the negative rainfall years, in the South Asian region we can find weak westerly from the Arabian Sea to BOB, wind is blowing in a southerly direction from Nepal and Bangladesh to BOB. Low moisture content is observed over the TP during this negative rainfall years. In the case of East Asian region, southward flow of wind is observed from South Korea to Pacific and cyclonic movement can be observed over the northwestern Pacific Ocean. Likewise, low moisture content can be observed over South Korea. We can observe opposite distribution of wind direction and specific humidity during the positive and negative rainfall years.

The composite of 200-hPa zonal wind during the positive rainfall years reveal the northward shift of EAJS and during the negative rainfall years, EAJS moves southward. The composite of 200-hPa meridional wind reveal wave-train like structure which spreads in a southeastward direction extending in the Asian monsoon region. An opposite relation is seen in the meridional wind, during the positive rainfall years when northerly flow over South Korea is evident, opposite flow can be observed over Nepal. Likewise during the negative rainfall years when southerly flow is evident over South Korea, northerly flow can be observed over Nepal.

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