Connection of Winter Time Precipitation System in and around Nepal with Pacific and Indian Ocean Indices

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Abstract
In wintertime (December-March), Nepal receives less amount of precipitation compared to summer. The winter precipitation system in Nepal is linked to the atmospheric variables associated with western disturbances. Additionally, this study covers larger-scale atmospheric circulation over the Indian and Pacific Oceans. The winter precipitation variability was found to be inflated by the westerly circulation passing through western Asia and moist air from the Arabian Sea. The winter precipitation (dryness) was related with positive (negative) Dipole Mode Index (DMI) and negative (positive) Southern Oscillation Index (SOI) with comparable correlations of about 0.4. Both DMI and Sea Surface Temperature (SST) of Indian Ocean revealed that they are in agreement with excess and deficit wintertime precipitation over Nepal.

Key Words: Wintertime, precipitation, DMI, SOI

Introduction
Most of the studies related to climate of South Asia have been concentrated on summer season. Although the winter season has less amount of precipitation (6-12% of the annual amount for Nepal), it has a significant role in the annual cycle of precipitation and hence in water resources and agricultural sectors of Nepal. In addition, winter precipitation in Himalayan region at higher altitude falls in the form of snowfall which is an important source of river discharge particularly during dry periods. Precipitation during winter is generally believed to be associated with the extra-tropical weather systems in the mid-latitude region. The winter precipitation system over Nepal is mainly influenced by the westerly disturbances, which is a low pressure system in the lower troposphere over sub-arctic region that is originated from the Mediterranean Sea. Although westerly disturbances significantly affect weather over the countries such as Iran, Afghanistan, and Pakistan during October to March, Nepal also receives its influences particularly in winter.

The role of large-scale atmospheric phenomenon in winter precipitation systems should be understood in order to make precise climate projections and weather forecasting. Additionally, the moisture associated with the westerlies is a major player behind the winter precipitation in and around Nepal (WPN). The forcing of ocean-atmosphere interactions such as El Nino - Southern Oscillation (ENSO) could play important roles on controlling the circulation of moisture around the region. Ashok et al. (2001) proposed that the event of no drought over India, despite of the strongest El Niño influence, is explained by the positive dipole phase in the Indian Ocean. This observed climate index, Dipole Mode Index (DMI), is defined as the normalized difference in sea surface temperature (SST) anomalies between the western (50°E-70°E and 10° S-10°N) and the eastern (90°E-110°E and 10° S-0°N) equatorial Indian Ocean, and has a high correlation with precipitation in the equatorial Indian Ocean but a low correlation over central and northern Indian latitude regions.

A majority of literatures analyzing the role of ENSO and other teleconnections in South Asia are focused on summer precipitation (Krishnamurthy and Goswami, 2000; Singh, 2001; De and Mukhopadhyay, 1999). However, Rao (1999) examined the winter precipitation in India with SOI and found significant negative correlations in some meteorological subdivisions. Yadav et al. (2007) studied relations between Indian Ocean SST and northwestern winter precipitation. Lang and Barros (2004) studied the winter storms in Himalayas during the year 1999-2000 establishing their own station. Compared with the studies

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focusing on summer monsoon precipitation over Nepal (e.g. Shrestha, 2000; Sigdel and Ikeda, 2012),
studies on wintertime precipitation connecting with atmospheric indices are very limited and has not been examined in detail. This study tries to understand the atmospheric variables in winter and relate them with circulations yielding precipitation. In addition, the study perceives if there any relationship exists in between winter time precipitation over Nepal and atmospheric indices over the Indian and Pacific Oceans.

**Data and Methods**

In this study, 26 rain-gauge monthly data from 1971 January to 2003 December, covering different physiographic regions (Mountains, Hills and flat land) of Nepal were utilized. The stations were selected on the basis that the data series have no missing values. These data were examined carefully so that the removal of a couple of stations may not change the result in inter-annual variability of the series. Similarly Global precipitation Climatology Project (GPCP) data was also used. Japanese Re-analysis (JRA-25) products from 1979 to 2003 were used at 1.25 x 1.25 degree resolution which includes daily and monthly averaged data of zonal and meridional winds, specific humidity and geopotential height. SST data were provided by Global sea ice and sea surface temperature (GISST) analyses. Southern Oscillation Index data were taken from NOOA (www.cdc.noaa.gov) and DMI data from JAMSTEC (www.jamstec.go.jp).

In this study, moisture budget was estimated with the equation;

\[ \langle \partial w/ \partial t \rangle + \langle \nabla Q \rangle = \langle E - P \rangle \]

Where, \( E \) is evaporation, \( P \) is precipitation, \( Q \) is vertically integrated moisture, \( w \) is precipitable water content.

Similarly, vertical integrated moisture flux (\( Q \)) was computed by;

\[ Q = \frac{1}{g} \int_{P_s}^{P_t} qvdp \]

Where, \( q \) is the specific humidity, \( v \) is horizontal wind vector; \( P_s \) and \( P_t \) are the pressure at surface and top of the atmosphere respectively.

**Winter Climatology**

Spatial distribution of December to March averaged winter precipitation over Nepal is depicted in Figure 1a, which shows higher precipitation over western Nepal than other parts with the averaged value of

![Figure 1: Spatial map of (a) WPN (contours unit: mm) with open circle denoting the precipitation stations and (b) correlation map of GPCP Vs. WPN (1979-2003).](image)
about 100 mm. Such distribution is inconsistent with the GPCP distribution, which shows regionally, higher precipitation over west Asian regions such as Pakistan and Afghanistan than over Nepal. The rain gauge data and GPCP data are also found significantly correlated within Nepal (Figure 1b).

The winter climatology of 850 hPa zonal and meridional winds and moisture flux around the region are shown respectively in Figures 2a & 2b, which indicate that the easterly and westerly components of winds dominate over Nepal in winter. Similarly, the westerly moisture flux is observed from northern high lands towards Bay of Bengal, which has increased magnitude over southern side of Nepal and adjoining Ocean.

Figure 2: Winter climatology of 850 hPa (a) zonal wind (contour, unit: m/s) & meridional wind (shaded, unit: m/s) (b) moisture flux around the region (unit: kg/ms).

Association with Atmospheric Variables

Moisture Budget

To observe the moisture flows during winter, a control box was constructed in and around Nepal which extended in between 80°-88.5°E and 26.5°-30°N. The existence of complex topography over the domain makes the estimation of the vertically integrated total moisture flux complicated. Inflow and outflow along four sides were estimated with vertical integration from the lowest surface level to 500 hPa for the southern edge of the box. However, the northern edge at around 30°N stretch out between the pressure levels 500 and 600 hPa, moisture flux values were averaged with reference to 600 hPa and then integrated up to 500 hPa level.

Figure 3: Moisture budget in the control box (unit: kg/season) around Nepal during wintertime.
In addition, surface pressure $P_s$ is used to remove the impact of topography, i.e., the water vapor was set to zero at pressure levels below the $P_s$. Figure 3 shows values of moisture budget in the control box, suggesting existence of moisture divergence in winter over Nepal, as the outflow from southern edge of control box is higher compared to remaining sides.

**Correlations and Regressions**

Relationship between winter precipitation over Nepal (WPN) and various climate indices, (such as SOI, DMI and North Atlantic Oscillation (NAO) from the Pacific Ocean, the Indian Ocean and the Atlantic Ocean) were computed and the results are depicted in Figure 4. Initially, the correlation coefficients among the standardized anomalies of the indices were determined. The WPN has correlation coefficient of -0.39 and 0.42 respectively with SOI and DMI. Both indices are significantly correlated with WPN at 95% confidence level. However, the WPN is not significantly correlated with NAO Index at 0.18.

![Figure 4](image_url)

**Figure 4:** Interannual association of standardized anomalies of DJFM WPN, SOI and DMI.

The geopotential height anomaly at 850 hPa regressed on the WPN is shown in Figure 5, which shows the low pressure over west Asia near Iran and Afghanistan along with the high over the BOB. The steep gradient is found extended from west Nepal to the Arabian Sea, transporting moisture from the sea. The regression map of GPCP anomaly on DMI shows a positive region extended over almost all parts of central India and Nepal (Figure 6a). The core of significant correlation can be seen in the

![Figure 5](image_url)

**Figure 5:** Seasonal geopotential (850 hPa) anomalies (unit: gpm) regressed on WPN.
western Indian Ocean near 5°N. The GPCP anomaly regressed on SOI has nearly a weak negative anomaly around Nepal but a positive correlation observed in south BOB (Figure 6b).

![Figure 6: GPCP anomaly regressed (unit: mm) on (a) DMI and (b) SOI. Shaded area represents significant at 95% confidence level.](image)

Similarly, the horizontal wind regressed on DMI shows a strong cyclonic circulation centered over the Arabian Sea at about 20°N, from which winds are directed towards northwest as well as north (Figure 7). Such circulation pattern can push the moisture from the Arabian Sea to Northern Indian latitudes including Nepal. However, the wind regressed on SOI shows weak circulation towards Tibet plateau, Nepal as well as north India.

![Figure 7: Wind vector (850 hPa) anomaly (unit: m/s) regressed on (a) DMI and (b) SOI.](image)

**Composite Patterns**

The excess as well as deficient phases of WPN, DMI and SOI were selected and similarly the positive and negative phases were obtained by applying the criteria of the standardized anomalies exceeding ±1σ. There were four excess years and three deficient years in WPN, five positive phases and five negative phases in DMI, three positive phases and seven negative phases in SOI in 24-year period (1980-2003). The excess and deficient composite anomalies from the seasonal mean climatology are presented in Figure 8 and 9 respectively. In the excess phase of WPN, GPCP precipitation has a
positive anomaly around Nepal with a stronger value to the west. Similarly in the positive phase of DMI, most part of central India and Nepal are under a positive anomaly of GPCP. In the positive phase of SOI, weak anomaly around Nepal and India and strong anomaly near Pakistan and Afghanistan (Figure 8) can be seen. Reversed patterns for the deficit WPN and negative DMI as well as SOI years (Figure 9) are observed.
Finally, SST anomaly pattern were examined in the excess years of WPN (Figure 10). The western Indian Ocean and some region of the Arabian Sea have a higher positive anomaly, which is found opposite in the deficit years. Equatorial easterly winds during the positive and equatorial westerly winds during negative phases of WPN are seen, which result in downwelling and upwelling respectively over African coast. Furthermore, positive and negative anomaly over western Mediterranean Sea are observed during excess and deficit years of WPN, which indicate mid-latitude disturbances as one of the sources of wintertime precipitation over Hindu Kush Himalayan region. Such disturbances generally form over the western Mediterranean Sea and then pass through western Asia to reach North Indian regions including Nepal.

**Summary**

In the present study, connection between wintertime precipitation and Indian and Pacific Ocean indices has been examined. Winter precipitation over Nepal is dominated by western disturbances. Particularly, the western Indian Ocean and the Arabian Sea served as moisture source regions for Nepal. However, the divergence of moisture is stronger in winter in and around Nepal. Although the correlations suggest similar influences between SOI and DMI, the role of SOI is weak on the winter circulation, while the role
of DMI is strongly influential. Both the regressed patterns and the composite analysis clearly indicate a positive anomaly in precipitation which is stronger in west Nepal than rest of the region. DMI and Sea surface temperature of Indian Ocean both imply that they are in agreement with excess and deficit wintertime precipitation over Nepal. This result agrees with Yadav et al (2007) who suggested that during the excess years of precipitation, the SST was above normal over the equatorial Indian Ocean. The winter precipitation (drought) was related with positive (negative) DMI and negative (positive) SOI at comparable correlations around 0.4. The Equatorial wind systems seem to relate SST anomalies of African coast with moisture flux from the Arabian Sea to Indian continental region including Nepal.

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References


