# Influence of North Atlantic Oscillations and Southern Oscillations on Winter Precipitation of Northern Pakistan

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***Abstract***

*With the changing global climate, study has been carried out to uncover the influence of recent trend of tropical and extra tropical weather systems for northern highlands of Pakistan. In this connection North Atlantic Oscillations (NAO) and El Nino Sothern Oscillation (ENSO) have been taken under discussion by means of statistical relationship. Annual temporal correlation in spatial format between precipitation of the study area to global meteorological parameters show that ENSO is more influential than NAO. Observed data for 14 meteorological stations is employed. Precipitation remained above normal in general with positive phase of NAO and negative phase of Southern Oscillations (SO).This shows that strong westerly and El Nino conditions are apposite for better snowfall over Hindukush, Karakorum and Himalaya (HKH). The logical results of this research are the encouraging clue in formulation of climatic and weather models for the development of seasonal predictions based on statistical configuration for winter precipitation over northern Pakistan.*

## Introduction

Pakistan is situated between about 23°N to 37°N and 60°E to 76°E, on the western confines of the SW Monsoon (SWM) over subcontinent. Its climate is mainly arid to semiarid with a small area with sub humid climate. Pakistan being an agricultural state depends on water resources like rainfall glacial ice-melt. Precipitation is received in both summer and winter seasons. Western disturbances approach the upper parts of the country throughout the year while Easterlies are dominant in summer. In summer heavy falls are mainly due to superposition of easterly and westerly. So westerly is the main source of massive rainfall extraction from the easterly and westerly cloud mass.

Irrigation in Pakistan is mainly reliant on the river waters which supply the life line whole year. So the glacial melt is the continuous major water supply to the Indus basin agricultural region. Very complex terrains, great glaciers and sandy/dry hills are the features of the northern highlands of the country. The above mean sea level height of the study region varies from 700 to 8600 meter. Over highlands of northern Pakistan the climate variability are dependent on two major factors; local topographic impact and the global circulation variation (Awan, 2002).

There are two major global circulation oscillations; NAO and ENSO, affecting weather phenomena regionally and locally. The NAO is a foremost mode of global circulation variability in the Northern Hemisphere, mainly in winter season. The name North Atlantic Oscillation (NAO) was instigated by Sir Gilbert Walker in the early nineties (Walker, 1924).

In this mode this study is being carried out to perceive the precipitation anomalies in northern areas of Pakistan caused by North Atlantic Oscillations (NAO) and Southern Oscillations (SO).

There are two phases of NAO, during a positive NAO there is a strengthening of the Icelandic low and Azores high. This strengthening results in an increased pressure gradient over the North Atlantic, which results in strengthened westerly flow of air mass. By the action of strong westerly winds cold air advected to north instead of south-East. So relatively warm and moist ocean water air penetrates into Europe causing augmented temperatures and amplified precipitation (V. Slonosky and P. Yiou, 2002, Hurrell, 1995). According to (Syed et al., 2006) A Positive precipitation anomaly is found in response to the positive NAO phase over central southwest Asia, including northern half of Pakistan.

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The NAO phase intensification and orientation have been modified 'shifted northeastward by 10° to 20° in latitude and 30° to 40° in longitude' under changing climate of the globe particularly with the warming of different regions of the planet (Z.-Z. Hu et al., 2004). In their study regarding northwest India winter precipitation anomalies, Yadav et al (2009) revealed that the impact of ENSO has increased as compared to NAO/AO during the recent decades. This calls for fresh studies to be carried out for the recent influences of the NAO on different regions of the globe.

The second major contributor to the weather fluctuations over the globe is Elnino Southern Oscillations which occurred sporadically in the eastern and central tropical Pacific Ocean (Bell et al., 2012).

A lot of studies are available regarding influence of variation in ENSO on different weather parameters for different regions. Latent heat released during ENSO affect the global weather circulation through wave dynamics (Hoskins and Karoly 1983, Shukla and Wallace 1983, Neelin et al., 2003). Yulihastin et al (2010) showed that western part of Indonesia (Kalimantan region) received much suppressed rainfall during El Nino episodes in central tropical pacific.

Rashid (2004) studied the impact of El Nino and declared that El Nino has negative effect on winter rainfall over Pakistan. The results of comparing bi-monthly multivariate ENSO index to monsoon monthly rainfall showed suppressed rainfall for whole Pakistan (Arif Mahmood et al., 2004). Khan, A. H (2004) discovered that rainfall in winter over Pakistan shows below normal behavior under the influence of OND La Nina conditions. The new study is expected to be supportive for the forecasters along with other inputs for the medium to long range forecast of the winter precipitation.

## Data

Each winter is defined as the period beginning on 1st December of certain year and ending on end of March of the following year. Observed precipitation data is collected from Climatological Data Processing (CDPC) Karachi consisting of 14 stations of northern Pakistan. The winter data of the region has been formulated by averaging out the individual station data. Gridded data from Climate Research Unit (CRU) is also investigated to validate the observed data. Both data series show same increasing trend but the CRU is under estimating the area average precipitation.

There are two commonly used NAO indexes; Rogers (1985) used sea level pressure data from Akureyri, Iceland and Ponta Delgada, Azores and Hurrell (1995), calculated it by using pressure anomalies at Stykkisholmur, Iceland and Lisbon, Portugal.

The NAO index calculated based on the difference between the normalized sea level pressures over Gibraltar (or Portugal, or the Azores) (subtropical high) and Southwest Iceland (polar low) has been used in this study. NAO indices are taken from http://climatedataguide.ucar.edu/guidance/hurrell-north-atlantic-oscillation-nao-index-station-based.

Southern Oscillation (SO) data is acquired from Earth System Research Laboratory, National Oceanic & Atmospheric Administration (NOAA) http://www.esrl.noaa.gov/psd/data/correlation/soi.data. SO index is the representation of the walker circulation in terms of pressure over the tropical Pacific Ocean and is calculated as the difference of the pressure anomaly over Darwin (12°S, 131°E) from that of Tahiti (17° S, 150°E). There are different methods to calculate the SOI (Masud Rana et al., 2007). The SOI used in this study has been formulated in the following way:

$$\text{SOI} = \frac{(\text{Actual Tahiti - Standardized Drawin})}{\text{Monthly Standard Deviation}}$$

Where

$$\text{Standardized Tahiti} = \frac{(\text{Actual Tahiti SLP - Mean Tahiti SLP})}{\text{Standard Deviation Tahiti}}$$

Japan Reanalysis Data (1.25°x1.25°) is acquired by JRA-25 Project to find out the climate variability in last three decades. The data used in the study is mean monthly gridded data from Jan. 1979 to Dec. 2010.

## Methodology

On the basis of snow line extension up to the month of March the area selected for study of winter precipitation is stretched out between 71.5°E-76.5°E longitude and 34°N-37°N Latitude.

The study area comprises of 14 Pakistan Meteorological (PMD) observing stations (Astore, Balakot, Bunji, Cherat, Chilas, Chitral, Dir, Drosh, Garhi Dupatta, Gilgit, Gupis, muzaffarabad, Saisu Sharif and Skardu) situated in Khyber Pakhtunkhwa, Gilgit-Baltistan and Azad Jammu & Kashmir.

Observed Monthly precipitation is averaged out to find the overall climatic picture of the region for winter (December to March) season. Hence 49 winter seasons, from December 1961 to March 2010 are available for analysis. More (Less) than 10% precipitation than normal is considered as positive anomaly for the study period.

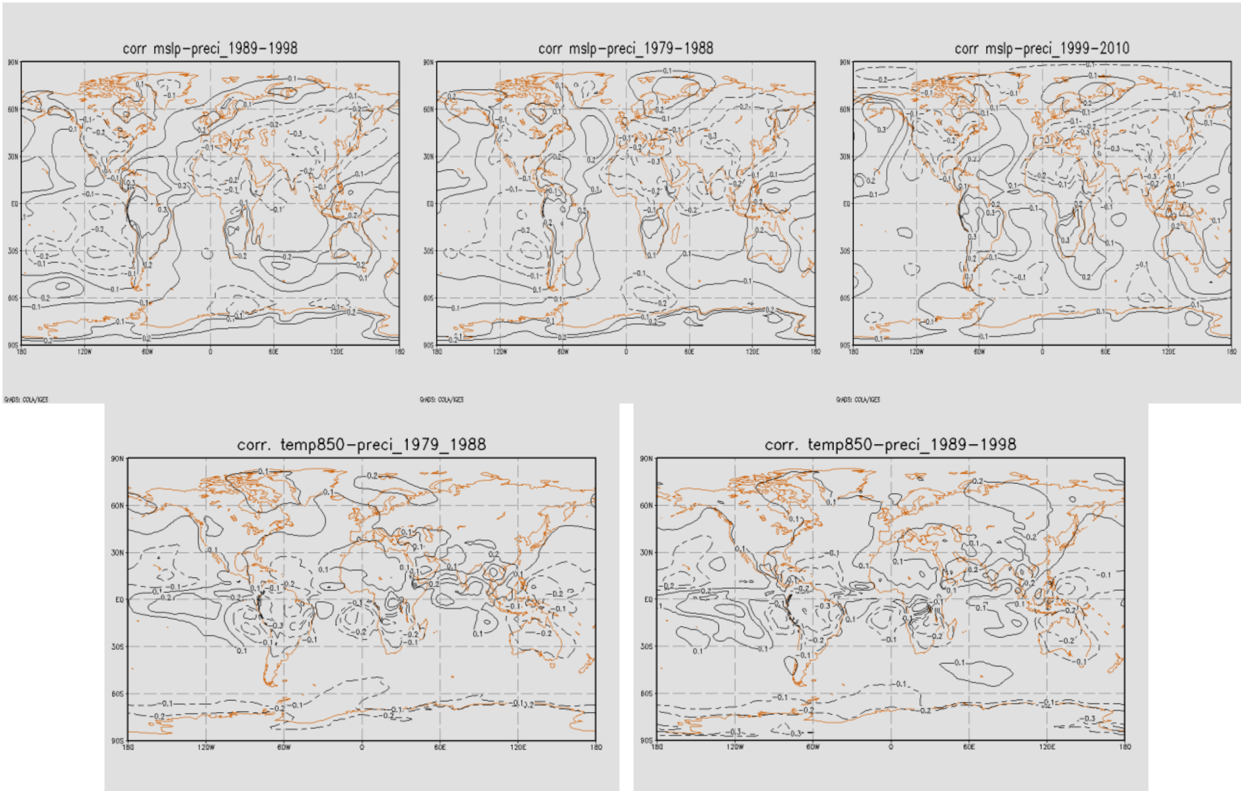
By using SSPS20 software for statistical analysis to find which month NAO index is relatively more influential for the precipitation variability. A positive (Negative) phase of NAO is taken when the index value falls above (below) than one standard deviation from the average of the climatological mean. The logical formulae then deployed for the year to year comparison of the observed data and the index.

A Positive anomaly of SOI is considered when the pressure over Tahiti is greater than that of Darwin (La Nina; a cold phase), whereas negative anomaly represents the greater pressure at Darwin (El Nino).


**Figure 1:** The Study Area

## Results and Discussion

First of all the recent variability of global Sea Level Pressure and low level heating have been investigated by means of statistical analysis. For this purpose decadal temporal correlations have been described on spatial basis. The observed precipitation of the region has been correlated to the JRA-25 gridded data by means of GrADS. The decadal sea level pressure correlation depicts the increasing influence of the variability of Pacific Ocean surface. In all three decades the high pressure at North West Australia (Darwin) has been an indicator of enhanced weather activity over northern Pakistan. Also the low pressure over eastern pacific indicates good relation to the rainfall over the study area. More over the relation to the shifting NAO centers from southwest to northeast can also be observed over the Atlantic Ocean during past three decades.




Low level (850hPa) temperature correlations analysis shows that cooling over Darwin and warming over eastern pacific have influence over the precipitation of northern Pakistan.

In second step of the analysis, observed winter precipitation for the northern highlands comprising of 14 meteorological stations has been analyzed in response to NAO and ENSO. Statistical two sigma tail test has been applied to find out the direct relation of the precipitation to the winter (DJFM) NAO index. It shows insignificant results with only 13% correlations.

Then to reveal the lag correlation, monthly indices have been treated against the observed precipitation. Best correlation remained between precipitation to the previous monthly Index is with December being 30%. The relation in March-April remained 28% and 29 % respectively. The results are calculated at 95% confidence level.

**Table 1:** Statistical relation between Winter Precipitation of northern Pakistan to the NAO index

| NAO Index | Pearson Correlation | Sig. (2-tailed) | N |
|---|---|---|---|
| DJFM | 0.13 | 0.38 | 49 |
| Jan | 0.00 | 1.00 | 49 |
| Feb | -0.05 | 0.71 | 49 |
| Mar | .284* | 0.05 | 49 |
| Apr | .299* | 0.04 | 49 |
| May | -0.14 | 0.33 | 49 |
| Jun | -0.10 | 0.51 | 49 |
| Jul | -0.03 | 0.83 | 49 |
| Aug | 0.05 | 0.76 | 49 |
| Sep | 0.00 | 0.98 | 49 |
| Oct | -0.25 | 0.08 | 49 |
| Nov | 0.03 | 0.82 | 49 |
| Dec | .303* | 0.03 | 49 |

*Correlation is significant at 95% level

The results with positive swing of NAO (for the months of December) reflect an expectation exists for good snowfall over northern highlands of Pakistan. This is an endorsement to the previous studies (Yadav, 2009 and Syed, 2006) as well. This shows that the fluctuation; filling and intensification of Icelandic low and Azores high causes the western disturbances to penetrate into the northern Pakistan with more moisture.

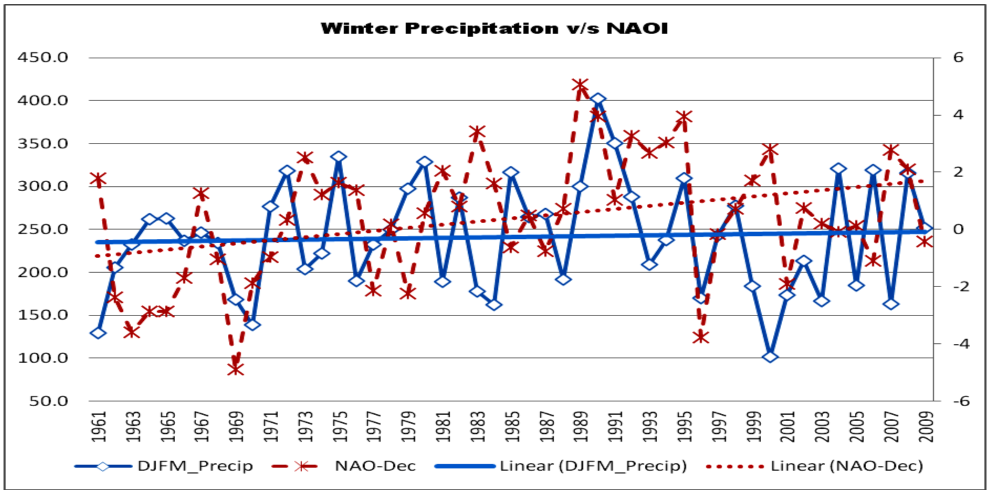



**Figure 2**: Winter Precipitation. and NAO index; NAO showing more positive trend

More over the statistical analysis have been made comparing year to year winter precipitation level to the preceding December index. The physical comparison shows that during Negative phase of NAO (Dec.) the precipitation remained well below normal except in 1989 and 1995. So in 12 years the ratio of the reliance of precipitation on NAO remains more than 80%. By looking the percentage departures which attains minima in ear 2000 indicates the drought period of 1999-2001 in the region. The affecting factor may be numerous but one is clear that NAO added more to the intensity of the drought already prevailed over the region (table 2).

**Table 2:** Negative NAO (Dec.) relation to Precipitation

| Year | DJFM_Precip | % Dep_Precip | Dec_NAO |
|---|---|---|---|
| 1961 | 129.1 | -46 | -4.5 |
| 1963 | 232.3 | -4 | -2.5 |
| 1976 | 190.3 | -21 | -2.6 |
| 1978 | 249.9 | 4 | -3.1 |
| 1987 | 267.8 | 11 | -2.3 |
| 1989 | 300.2 | 25 | -3.4 |
| 1995 | 309.5 | 28 | -3.8 |
| 1996 | 169.6 | -30 | -3.6 |
| 2000 | 101.5 | -58 | -2.2 |
| 2001 | 173.3 | -28 | -4.1 |
| 2002 | 213.2 | -12 | -2.4 |
| 2009 | 252.0 | 5 | -4.4 |

Results show that during negative phase of SOI, winter precipitation in northern region of Pakistan is nearly 40% correlated during the months of November and December. Also the relation of seasonal downpour to the seasonal index is also better correlated. SOI has relatively better correlations to the precipitation than NAO. So the grip of easterly seems to be more effective on the weather phenomena over northern highlands.

**Table 3:** Statistical relations of SO index to the precipitation

| SO Index | Pearson Correlation | Sig. (2-tailed) | N |
|---|---|---|---|
| DJFM | -.387** | 0.01 | 49 |
| Jan | 0.03 | 0.86 | 49 |
| Feb | 0.07 | 0.62 | 49 |
| Mar | 0.06 | 0.71 | 49 |
| Apr | -0.06 | 0.69 | 49 |
| May | -0.02 | 0.88 | 49 |
| Jun | -0.10 | 0.49 | 49 |
| Jul | 0.04 | 0.77 | 49 |
| Aug | -0.08 | 0.60 | 49 |
| Sep | -0.20 | 0.17 | 49 |
| Oct | -0.17 | 0.24 | 49 |
| Nov | -.373** | 0.01 | 49 |
| Dec | -.385** | 0.01 | 49 |

**Significant at 99% level

Many studies have been conducted to find out the relation of ENSO on weather over Pakistan. In general Pakistan receives less rainfall in summer during the El Nino event (Rashid 2004, Ashoke 2004), but interestingly the effect in winter is contrary. A time series is shown between Southern Oscillations and the winter precipitation of the study region. Both the parameters remained out of phase in general, so the warm phase of ENSO is much supportive for the northern areas to be more wet during northern hemisphere winter.

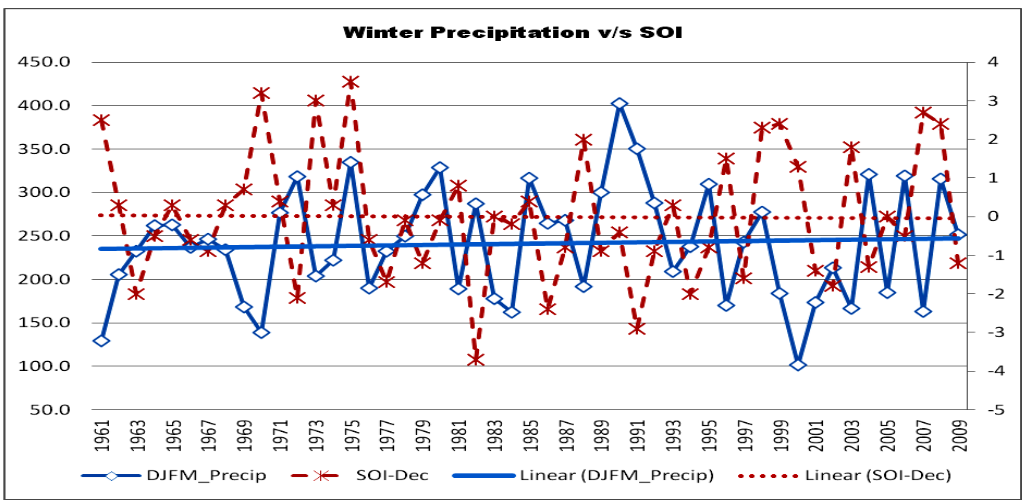



**Figure 3:** Winter precipitation. and Dec. SO index; both showing opposite relation to each other

In connection to the above carried out correlations the SOI for December is opted and treated with winter precipitation on yearly basis. The results thus found are as under:

**Table 4:** Negative SOI (Dec.) relation to the Winter Precipitation of North Pakistan

| Year | DJFM_Precip | % Dep_Precip | SOI-Dec |
|---|---|---|---|
| 1963 | 232.3 | -4 | -2 |
| 1972 | 318.8 | 32 | -2.1 |
| 1977 | 232.8 | -3 | -1.7 |
| 1982 | 286.9 | 19 | -3.7 |
| 1986 | 264.3 | 10 | -2.4 |
| 1991 | 350.4 | 45 | -2.9 |
| 1994 | 237.9 | -1 | -2 |
| 2002 | 213.2 | -12 | -1.8 |

Precipitation over northern mountainous region of Pakistan remained normal or above normal during the negative phase of Southern Oscillations. The exception lies only in 2002 with only 12% below normal precipitation. So this verifies the concept that the ElNino the northern areas of Pakistan receives above normal precipitation (snowfall).

During negative SO Index phase, El Nino helps large-scale anomalies in the zonal winds across the tropical Pacific, in the lower/upper atmosphere. These conditions reflect weaker Walker Circulation (Khan, A. H.2004). Hence the wind drifts eastward along the equator and the low pressure system settles over east pacific. This condition provides a room for the westerly to approach the HKH region even NAO would show weaker gradient over the north Atlantic.

## Conclusion

Lower level temperature and SLP analysis indicate the climatic variability with respect to shifting of NAO centers and fluctuations in the ocean pressures over pacific. These anomalies in connection with global circulation and affect the winter weather activities of HKH region. Positive NAO episode has shown good relation to the precipitation enhancement, whereas during weak pressure gradient over north Atlantic there are more chances of suppressed precipitation activity over northern Pakistan.

Negative phase of Southern Oscillation is directly responsible for above normal precipitation activity over northern highlands whereas the cooling ocean surface over central pacific causes suppressed winter precipitation.

Statistical correlations depicts that SOI remained better contributor for precipitation activity over HKH region as compared to NAOI in the recent decades.

The results of this study give encouraging indications towards the use of NAO and SO as the indicators for the development of regional climate modeling system to study the climate of the region.More over the study indicates a critical look on the global parameters during the weather forecast of during winter season.

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