The Effect of Eurasian Snow Cover on the Monsoon Rainfall of Pakistan

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Abstract

The Eurasian winter and spring snow cover anomalies along with spring snowmelt have been considered as the important factors affecting the Indian summer monsoon rainfall in particular and the Asian summer monsoon rainfall in general. No previous study has been found in which the effects of Eurasian snow cover on the monsoon of Pakistan would have been analyzed. In this study authors tried to examine the snow cover effects on summer monsoon rainfall of Pakistan (PSMR). Surprisingly, our findings appear as contrary to the findings of previous studies for Asian summer monsoon rainfall (ASMR) and Indian summer monsoon rainfall (ISMR) and no significant negative correlation is found between these above mentioned parameters and PSMR. Only monsoon rainfall of Punjab (may be due to its homogeneity with Indian monsoon dominated regions and smooth arrival of monsoon system from Bay of Bengal) appears to be negative for both winter snow cover and spring snowmelt and not for spring snow cover. Rainfall of NWFP in summer holds better negative correlation as compared to rest of the provinces only for spring snowmelt. Negative correlation is also found between spring snow cover and spring snowmelt. Summer snow cover shows good positive correlation with PSMR in general and with rainfall of Punjab in particular. As far as El Nino is concerned, area of winter snow cover is found above normal and below normal monsoon rainfall is observed while for La Nina, the areas of winter snow cover and spring snow cover are found below normal resulting into above normal rainfall in monsoon. Two snow cover data sets are obtained from two different sources for verifying the correlation. Spring snowmelt area has been calculated as a difference between snow cover of February and that of May.

Key Words: Eurasian snow cover; Spring snow cover; Spring snowmelt; Summer monsoon rainfall of Pakistan; Correlation; El Nino; La Nina

Introduction

Monsoon of South Asia is a jugular vein for the lives of flora and fauna of this unique region of the world. It is a major phenomenon affecting the lives of one-fifth of the world population who live in this sub-continent. This phenomenon has been a hot issue for more than 100 years due to its inter-annual variability. This variability affects the socio-economic condition of the people by affecting agriculture, drinking water, hydro-power and the other needs of the inhabitants of this region. Therefore, near-to-correct prediction of rainfall amount attracted the meteorologists from all over the world to address the complications lie in this phenomenon. This summer monsoon is a coupled atmosphere-land-ocean phenomenon in which both the largest water mass on earth, the Indian and Pacific Oceans, and the largest land mass on earth, the Eurasian continent, play significant roles (Bamzai and Shukla, 1999). Due to this land-ocean interaction, the monsoon rainfall is majorly correlated with sea surface temperature (SST) and Eurasian snow cover (ESC). According to them, among all other varying surface conditions, snow cover experiences the largest spatiotemporal fluctuations. They observed that delayed or weakened monsoon circulation is due to the delay or reduction in the normal warming of the landmass as it is steered by the combination of land-sea temperature

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contrast and latent heat release. The snow cover extent over Eurasia forms over 60% of the Northern Hemisphere snow cover (Bhanukumar, 1988). Infact, snow cover is one of the important climatic elements which interact with the global atmosphere by changing the energy regime as a result of the large albedo and net radiation deficit (Matson & Wiesnet, 1981). Generally, the snow cover of the previous season may be related to the present synoptic flow pattern. This feedback mechanism can be used as a forecasting tool.

Several research papers (Hahn & Shukla, 1976; Dey & Bhanukumar 1982; Ropelewski et al. 1984) have been published in pursuation of the snow-monsoon relationship. The relationship between Eurasian-Himalayan snow cover and the large scale Chinese rainfall has also been a topic for a few research papers like Yang & Xu (1994). Yasunari (1990, 1991) and Yanai & Li (1994) suggested the possible influence of the Eurasian snow on the general circulation of the atmosphere. In the study of Vernekar et al. (1994), it was found that the excessive snow cover is associated with a weak monsoon characterized by higher sea level pressure over India, a weaker Somali jet, weaker lower tropospheric westerlies, and weaker upper tropospheric easterlies. They elaborated that energy used in melting excessive snow reduces the surface temperature over a broad region centered around the Tibetan Plateau. Furthermore, reduced surface sensible heat flux reduces the midtropospheric temperature over the Tibetan Plateau resulting into the reduction of the midtropospheric meridional temperature gradient over the Indian peninsula, which weakens the monsoon circulation. Bamzai & Shukla (1999) found that Western Eurasia was the only geographical region for which a significant inverse correlation exists between winter snow cover and subsequent summer monsoon rainfall. The inverse snow-monsoon relationship, according to them, held especially in those years when snow was anomalously high or low for both the winter as well as the consecutive spring season. Contrary to previous findings, no significant relation was found between the Himalayan seasonal snow cover and subsequent monsoon rainfall. Region for western Eurasia was defined by 40°-60° N, 10° W-30° E; southern Eurasia is the region of Eurasia south of 50° N. In their findings, the largest correlation for the period 1973-94 for DJFM snow cover with Indian Monsoon rainfall (JJAS) was found with the western Eurasian Snow cover (-0.63), followed by Eurasia (-0.34). The correlation between Eurasian snow cover anomalies and the Indian monsoon rainfall anomalies for spring season (AM) was -0.28. The study of Liu & Yanai (2002) was unique with other previous studies as it used long time series (1922-98) of the Eurasian spring snow cover and it considered other parts of Asian continent for summer rainfall. While previous studies (except Sankar-Rao et al., 1996) were mostly concerned with the relation of the winter/spring snow anomaly to the Indian or Chinese monsoon rainfall. They found that the statistical relation between All India Monsoon Rainfall (AIMR) and Eurasian Spring Snow Cover (ESSC) changes over a multi-decadal time scale. The negative correlation between them has increased markedly since the 1970s. The region where the summer rainfall has the strongest and most stable negative correlation with the preceding ESSC is located in northern Mongolia, south of Lake Baikal.

All these studies focused on India, China and other parts of Asia (except Liu & Yanai, 2002 who considered entire Asia including Pakistan) but none of them directly addressed the impact of Eurasian snow cover on the summer monsoon rainfall of Pakistan (PSMR). In this paper an attempt has been made to diagnose the possible

impact of Eurasian snow cover on the rainfall of Pakistan. Topography of Pakistan is somewhat different with India due to its different orographic features. Northern Pakistan is a unique junction of Hindukush, Karakorum and Himalaya (HKH) ranges. Monsoon rain has no access to the extreme northern and north-western parts of Pakistan. Similarly, vast area of Balochistan beyond the Koh-e-Suleman ranges is exempted from the monsoon rain. But due to close association of Arabian Sea, Sindh and Punjab receive rain from both monsoon systems: that is systems originated from Arabian Sea and Bay of Bengal. These interesting orographic features of Pakistan initiated us to redress the impact of Eurasian snow cover on PSMR. As previous studies showed a consistent inverse correlation between the amount of Eurasian snow cover especially in winter/spring and the coming summer monsoon rainfall, that is, the snow cover of the previous season may be related to the current synoptic flow patterns through time-lag mechanisms for seasonal prediction, so as a continuation of previous studies, this study addresses the usage of Eurasian snow cover extent in different seasons with PSMR. In this study condition of Eurasian summer snow cover during the monsoon season with the PSMR has also been included for discussion, state of which has never been addressed especially for Pakistan.

Data and Methodology

Two different types of Eurasian snow cover data are used here. Rutgers university data from 1972-2007 is obtained from their website http://climate.rutgers.edu/snowcover. Robinson, D.A. & A. Frei (2000) defined Eurasian region as areas including the entire European and Asian continents from the North Pole to 20° north latitude. The grid cells are based on a polar stereographic projection so although they vary in size, the average resolution is approximately 190 km. The second Eurasian snow cover data from 1974-2007 is achieved from their website http://www.cpc.noaa.gov/data/snow/ or ftp server (ftp://ftp.cpc.ncep.noaa.gov/wd52dg/snow/snw_cvr_area/EU_AREA). This operational snow cover product is output as an 89X89 grid that has been overlaid on a polar stereographic projection. These experimental weekly snow cover products produced after May 31, 1999. Data of Area weighted rainfall (AWR) for the months of July, August and September prepared at Climatological Data Processing Centre (CDPC), Karachi, Pakistan is used in this study for the period 1972-2007. In the whole study, anomalies of snow cover area have been correlated with the anomalies of area weighted rainfall (AWR) of monsoon season (JAS). In this paper two different time series (of the same period 1974-2007) based upon the two different Eurasian snow cover data sources are used for comparative study of the impact of Eurasian snow cover on the PSMR. Secondly, time series based upon the Rutgers University data is extended for two years (1972-2007) and again its correlation is generated with PSMR. Trend line behaviors (moving average for 5 years) are also analyzed to observe the trends of snow cover and AWR (Figure 4 & 5). As contrary to India, normally onset of monsoon rainfall starts from 1st July, therefore, monsoon months are considered from July-September. Different parameters of Eurasian snow cover are correlated with PSMR to study their validity as predictors for PSMR. Areas covered by winter snow cover (DJF), spring snow cover (MAM) and spring snowmelt (difference between February and following May) are tested as predictors for the seasonal prediction of PSMR. Summer snow cover area has also been analyzed for the three months of monsoon (JAS). Due to the versatile

topography of Pakistan different regions receive different amount of rainfall, so, province vise analysis is also done along with combined AWR of the whole Pakistan.

Results and Discussion

In the study of Bhanukumar (1988), the detected correlation was stronger (0.6) between spring snowmelt and the previous winter snow cover than between the winter snow cover and the monsoon rainfall (-0.4). There was an obvious negative correlation between Eurasian spring snowmelt and monsoon rainfall (-0.44) along with five out of 13 cases which showed a positive relationship. It is not strange as Walker (1910) also found 13 out of 34 cases without any relationship. Our findings also testify the findings of Bhanukumar (1988) according to which winter snow cover is very strongly correlated with spring snowmelt over Eurasia. In our findings correlation found is 0.58 (Table 4). For the whole Pakistan correlations of winter snow cover and spring snowmelt with rainfall are 0.027 and -0.005 respectively (Table 1).

Table 1: Correlation between Eurasian Snow Cover and AWR from 1974-2007 by using Rutgers University data

Region	Winter Snow Cover	Spring Snow Cover	Spring snowmelt	Summer Snow Cover
Pakistan	0.027	0.067	-0.005	0.177
Punjab	-0.12	0.091	-0.093	0.316
NWFP	0.011	0.061	-0.111	0.109
Sindh	0.163	0.014	0.072	0.006
Balochistan	0.077	-0.008	0.109	0.104

While for the Punjab, which is strongly affected from the monsoon system, correlations of winter snow cover and spring snowmelt with AWR are -0.12 and -0.1 respectively. Time series in Figure 1 & 2 are also showing this trend. These values for PSMR clearly appear as contrary to previous findings for Indian rainfall where strong significant negative correlations have been found. Correlation coefficient between the winter Eurasian snow cover and the monsoon rainfall was (-0.54) in the study of Hahn & Shukla (1976) who used 1967-76 data. Dickson (1983, 1984) used 1967-80 data (-0.59), Bhanukumar (1987) used 1966-1985 data (-0.38), Sankar-Rao et al. (1996) used 1973-90 data (-0.41) and Bamzai & Shukla (1999) considered 1973-1996 data and cc was (-0.34). According to the study of latter, the low cc values compared to Hahn and Shukla, and to Dickson were mainly because of not including the 1967-72 data. They mentioned that the values of correlation between Eurasian snow cover anomalies and JJAS Indian rainfall showed that studies that have included the 1967-71 data report higher correlation. Furthermore, correlations between Eurasian summer snow cover and the AWR of Pakistan & Punjab are found 0.2 & 0.34 respectively (Table 2).

Table 2: Correlation between Eurasian Snow Cover and AWR from 1974-2007 by using NCEP data

Region	Winter Snow Cover	Spring Snow Cover	Spring Snowmelt	Summer Snow Cover
Pakistan	0.034	0.057	0.002	0.2
Punjab	-0.117	0.098	-0.105	0.338
NWFP	0.035	0.057	-0.131	0.165
Sindh	0.164	-0.012	0.116	0.019
Balochistan	0.079	-0.02	0.093	0.122

Table 3: Correlation between Eurasian Snow Cover and AWR from 1972-2007 by using Rutgers University data

Region	Winter Snow Cover	Spring Snow Cover	Spring snowmelt	Summer Snow Cover
Pakistan	-0.005	0.08	-0.092	0.137
Punjab	-0.09	0.122	-0.154	0.25
NWFP	-0.014	0.077	-0.1792	0.077
Sindh	0.114	0.007	0.003	-0.029
Balochistan	0.030	-0.007	0.018	0.062

Table 4: Correlation values between different snow covers from 1974-2007 by using Rutgers University data

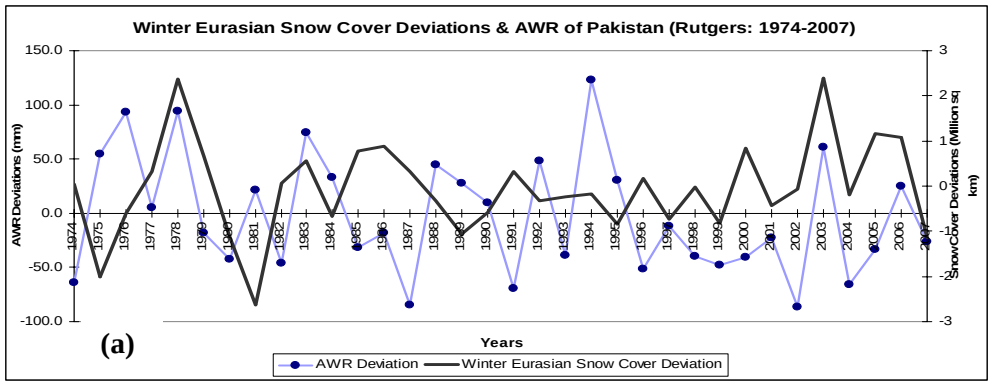
	Winter Snow Cover	Spring Snow Cover	Spring Snowmelt	Summer snow Cover
Winter Snow Cover	1			
Spring Snow Cover	0.109	1		
Spring Snowmelt	0.583	-0.269	1	
Summer snow Cover	-0.043	0.415	-0.375	1

It indicates that PSMR is more correlated positively with summer Eurasian snow cover as compared to other Eurasian snow covers. It is interesting to note that when duration of years is extended from tail end (1972-2007) positive correlation values between spring & summer snow cover and AWR decrease slightly while non-significant negative correlation values between winter snow cover and AWR increases as pointed out by Bamzai & Shukla (1999). According to them low cc was due to the exclusion of 1967-72 period. It is found that spring snowmelt appears to be negatively correlated (-0.4) with summer snow cover (Table 5). It means that more snowmelt is followed by the decrease in summer snow cover (Figure 3). Spring snow cover is found with strong positive correlation with summer snow cover (0.41). Negative correlation is also found between spring snow cover and spring snowmelt. This result reveals that more spring snow cover causes reduction in melting of snow cover. This is due to high albedo and cooling of the surrounding air. This cooling affects the tropospheric heating and thus causes slow melting of snow. This slow melting of spring snow cover directs the increase in summer snow extent (Table 3) which may be testified by considering the negative correlation between spring snowmelt and summer snow cover (-0.38). For spring snow cover, the maximum positive correlation is found with Punjab as compared to rest of the provinces (Table 1, 2 & 3). It shows that when range of years is extended this correlation becomes more positive. Trend line behaviors although ascertain inverse correlation between winter, spring and spring snowmelt snow cover areas with AWR of Pakistan and positive correlation between summer snow cover and AWR at some extent although correlation coefficients are not supporting this relation. Similarly, unlike whole Pakistan, Punjab and NWFP, winter snow cover appears to be more positively correlated with Sindh (Table 2).

Table 5: Correlation values between different snow covers from 1974-2007 by using NCEP data

	Winter Snow Cover	**Spring Snow Cover**	**Spring Snowmelt**	**Summer snow Cover**
Winter Snow Cover	1			
Spring Snow Cover	0.116	1		
Spring Snowmelt	0.541	-0.243	1	
Summer snow Cover	-0.016	0.399	-0.402	1

It is interesting to note that the winter snow cover area was on increasing trend (Figure 4) in the years of persistent drought (1999-2003). These years are observed in some studies (Waple & Lawrimore, 2003; Levinson and Waple, 2004) that a severe drought hit much of southwest Asia between 1999 and 2003, including Afghanistan, Kyrgyzstan, Iran, Iraq, Pakistan, Tajikistan, Turkmenistan, Uzbekistan and parts of Kazakhstan. Years of 1978 and 2003 are the two years where contrasting results are observed (Figure 1 & 2). In these years rain was above mean not only for Pakistan but also in the province wise analysis and astonishingly winter snow cover, spring snow cover and spring snowmelt are also representing very high above mean values (Figure 1,2,3 & 4), while summer snow cover is representing negative correlation instead of positive correlation.



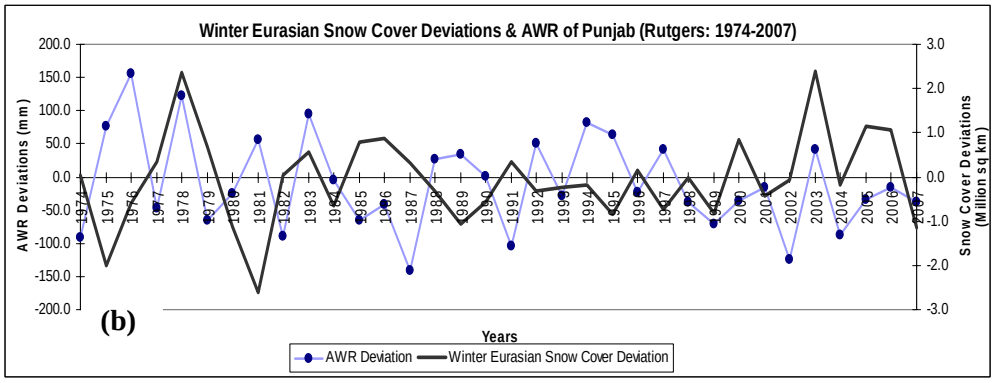
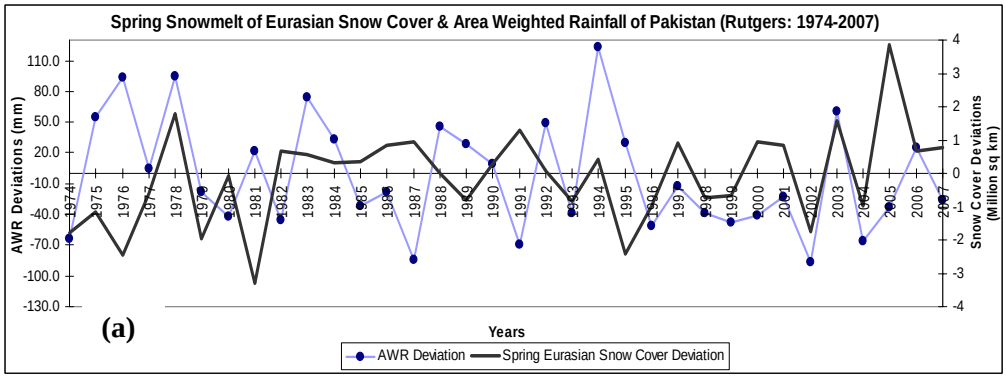


Figure 1



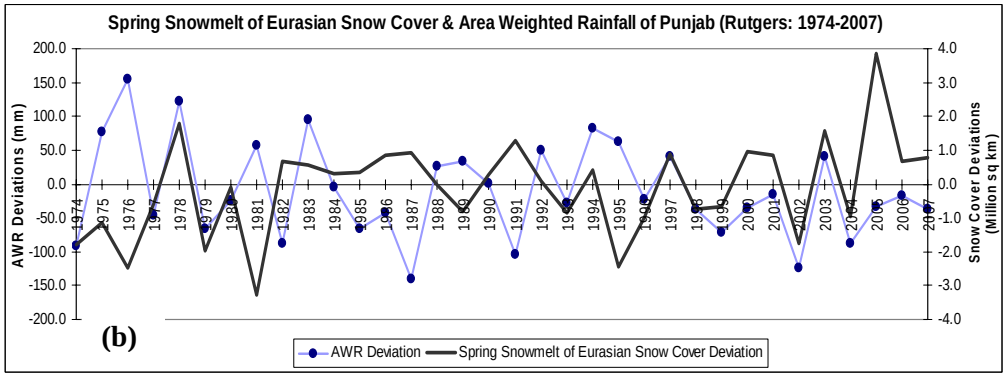


Figure 2

Rain of 1972, 1982, 1987, 1991 and 2002 was so much below normal as these years are declared unanimously strong El Nino years. Conspicuously, in all above mentioned persistent drought years (except 2002), winter snow cover was above the normal. During the period of strong La Nina years (http://ggweather.com/enso/years.htm) like 1976, 1988 and 1989 the values of AWR were above normal while values of winter and spring snow cover were below the yearly normal. 1973 was also characterized as strong La Nina year but value of winter snow cover was above normal.1972, 1987 and 2002 were three El Nino years and the values of winter, spring, spring snowmelt and summer snow cover was above the mean incase of 1972 & 1987, while incase of 2002, all were below normal.

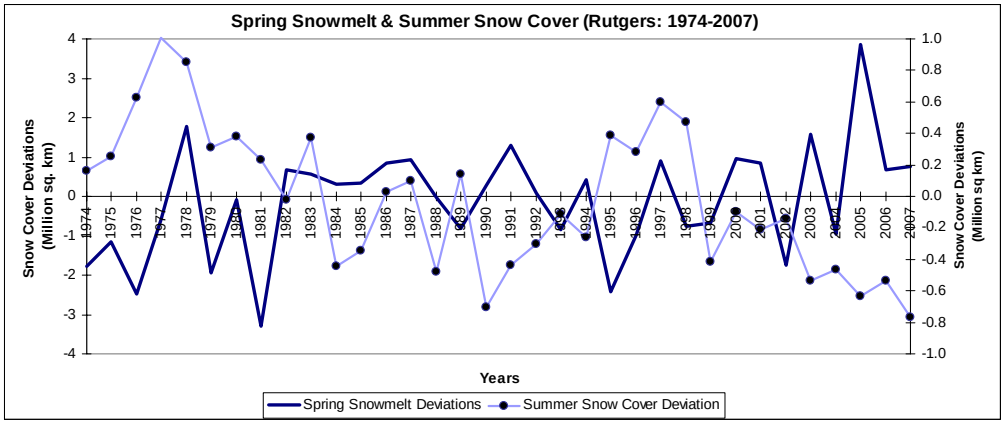


Figure 3

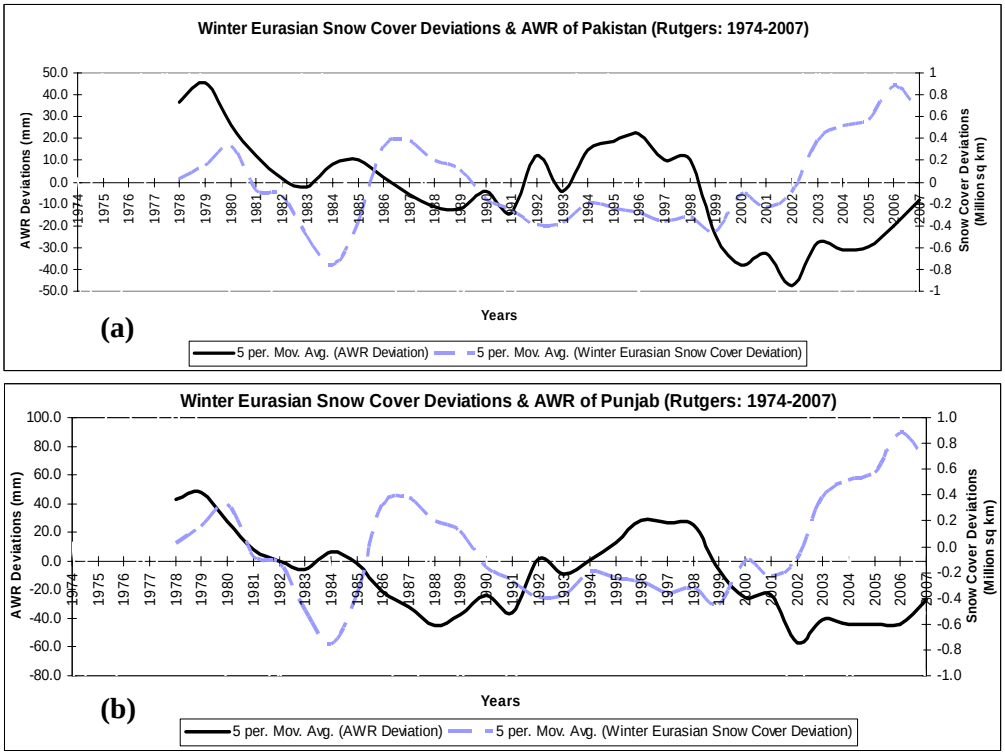


Figure 4: Trend Line behaviours averaged for 5 years for Winter Eurasian snow cover

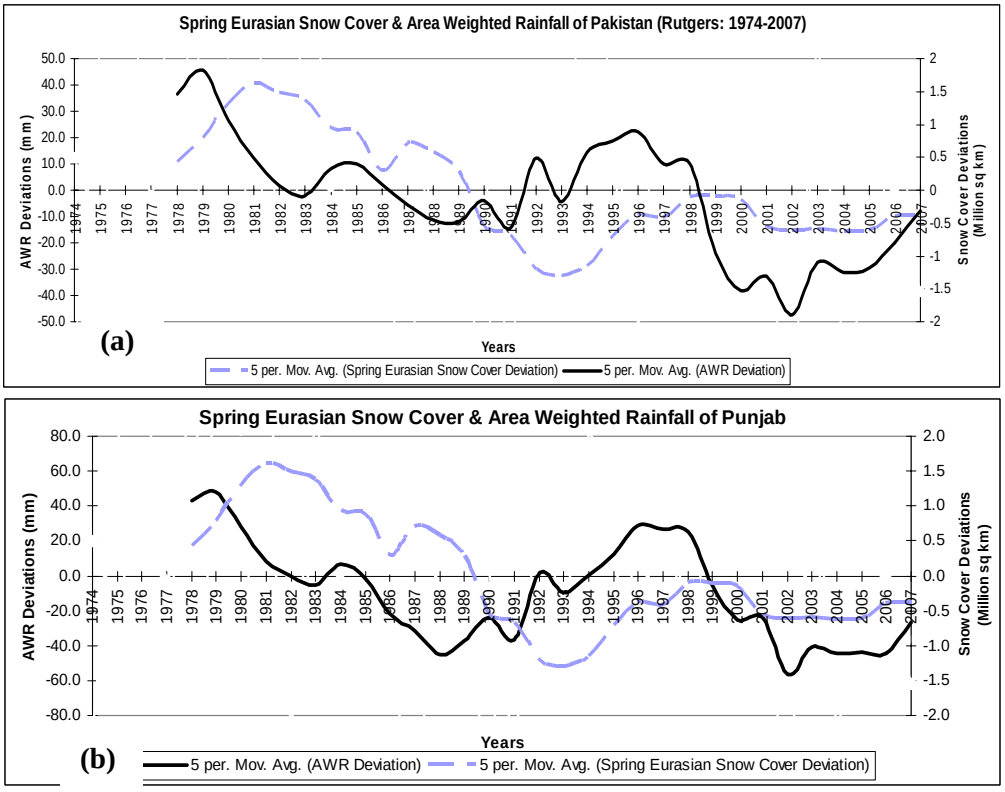


Figure 5: Trend Line behaviours averaged for 5 years for Spring Eurasian snow cover

Conclusions and Recommendations

After the discussion of above mentioned results, it is found that winter, spring, spring snowmelt and summer Eurasian snow covers are not negatively correlated with the PSMR unlike Indian summer monsoon rainfall (ISMR). These almost zero or very low negative correlated values for PSMR clearly appear as contrary to previous findings for Indian rainfall where strong significant negative correlations have been found. Previous studies hold good results of negative correlation for monsoon of India may be due to its vast plain area. But as far as monsoon rainfall of Pakistan is concerned, snow cover appears to be non-significant. Punjab is the only province for which correlation values of both winter snow cover and spring snowmelt with rainfall are found to be negative while for NWFP, values of only spring snowmelt is found to be more negative than Punjab (Table 1 & 2). But when period of 1972-2007 is considered, increase in negative correlation is found between spring snowmelt and rainfall along with very low negative correlation between winter snow cover and rainfall. Negative correlation is also found between spring snow cover and spring snowmelt. The maximum positive correlation of spring snow cover with Punjab as compared to rest of the provinces also opposes the findings of previous studies for India where negative correlation was found. Similarly, unlike whole Pakistan, Punjab and NWFP, winter snow cover appears to be more positively correlated with Sindh also invites extensive research. Winter snow cover is found to be very strongly correlated with spring snowmelt over Eurasia (-0.58) like

previous studies. As summer snow cover is representing the permanent snow of Eurasia, so, although its statistical correlation comes out to be good for the Punjab especially and for the whole Pakistan generally, but its detailed study is necessary for analyzing its meteorological effects upon the PSMR. During El Nino years, trend of winter snow cover was found above normal and during La Nina years, winter and spring snow cover areas are found below normal. This study also realizes the selection of small domain instead of vast area of Eurasia like snow cover of Tibetan Plateau and increase in period of study. Extensive snow cover of 1978 and 2003 followed by extensive rainfall which is found in time series is also addressable.

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