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Relationships between Eurasian snow cover and the Indian summer monsoon rainfall

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ABSTRACT

Correlation and composite analyses were conducted of snow cover extent, 500hPa geopotential height, and all India monsoon rainfall (AIMR) for 1973-1998. The strongest correlation was found with January European snow cover and AIMR, while such snow cover key region moved southwestward to Central Eurasia in April. In January, European snow cover and NAO are closely related, and both show significant correlations with the subsequent AIMR.

Key Words: Indian summer monsoon rainfall, Eurasian snow cover, NAO, EU1

1. INTRODUCTION

A well-known interaction between snow cover and the atmosphere is the inverse relationships between winter to spring Eurasian snow cover and the following Indian summer monsoon rainfall that was first pointed out by Blanford in 1884. Hahn and Shukla(1976) re-examined the similar relationship such as Eurasian winter snow cover and the following Indian summer monsoon rainfall using satellite derived snow cover extent data edited by National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information Service (NOAA/NESDIS). Since then, the examination of snow-monsoon relation had been updated using different regions over Eurasian continent and different time period. Sankar-Rao et al.(1996) showed that during the summer following the winter with more snow cover over Eurasia, the lower atmosphere is colder over especially north of India suppressing the monsoon circulation. On the other hand, Morinaga et al., (1997) noted that April Central Eurasian snow cover showed the higher correlation coefficient than winter mean Eurasian snow cover. Spring snow cover over this region is related with delay of seasonal march through surface cooling. Either as an indicator and/or an actor, the importance of continental snow cover have been emphasized.

Though its physical mechanism is still far from complete understanding, careful look at various aspects such as regionality and seasonality of snow cover-atmospheric relations give some insights on the problem. The purpose of the study is to examine the circulation modes, and Eurasian snow cover variation that may have an important influence on subsequent Indian summer monsoon rainfall.

2. DATA AND METHODS

A rotated principal component analysis was applied to monthly geopotential height data at the 500hPa level for 1973-1998 that is derived from the NCEP (National Centers for Environmental Prediction) / NCAR (National Center for Atmospheric Research) reanalysis. The teleconnection patterns identified in this analysis were termed according to Barnston and Livezey (1987). The method of the analysis is similar to that used in Nishimori & Kawamura (1993), except for the data analyzed.

For snow cover analysis, NOAA/NESDIS Snow and Ice Chart was used. Weekly snow extent data was averaged to make monthly dataset, 1973 Jan.-1998 Sep.

All-Indian monsoon rainfall dataset for 1973-1998 was downloaded from http://ingrid.ldgo.columbia.edu, IRI/LDEO (International Research Institution for climate prediction/ Lamont- Doherty Earth Observatory) Climate Data Library. The reference of the dataset is Sontakke et al.(1992), and the dataset is updated until 1998.

Eurasian continent is widely covered with snow from autumn to spring. Therefore the continent north of about 35N is divided into 5 regions to detect the regional characteristics of snow cover (Fig. 1). Though the importance of Tibetan region is pointed out by previous studies, this region was excluded from the present study due to the lack of accuracy in data (Ropelewski et al., 1984). Lag correlations were calculated among the three factors (circulation, snow, rainfall) for 26 years (1973-98). (Significance value:0.388, 5%, 0.496, 1%).

3. RESULTS AND DISCUSSIONS

3.1 Snow cover and the subsequent all Indian monsoon rainfall (AIMR)

Correlation coefficients between snow cover of 5 regions and the subsequent AIMR is shown in Table 1. The highest correlation is found between January snow cover extent over Europe (EUP sc Jan) and AIMR(r= -0.59,significant at 1% level, Fig.2 a and c). It is much higher than the Eurasian winter mean snow cover and AIMR (r= -0. 32) which previous studies have pointed out (Hahn and Shukla, 1976, among others). This may indicate that it is EUP sc Jan which is most closely related with AIMR among winter mean All-Eurasian snow cover. The second highest correlation coefficient is between April snow cover extent over Central Europe (CE sc April) and AIMR (r= -0.52, 1%, Fig. 2 a and b).

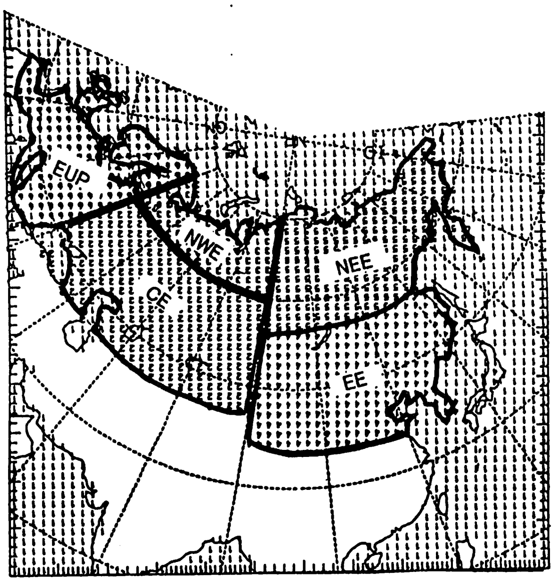

Figure 1 : Snow cover regions.
(NEE: Northeast Eurasia NWE: Northwest Eurasia
EE: East Eurasia CE: Central Eurasia EUP: Europe
ALL means All- Eurasia: NEE+NWE+EE+CE+EUP)

Table 1. Correlation coefficients between snow cover regions and AIMR (1973-98, significance level 0.388: 5% bold, 0.496: 1% underlined) ALL* is sum of 5 regions. Tibetan Plateau is excluded.

	oct	nov	dec	jan	feb	mar	apr	may
NEE	0.25	-0.10	-0.08	-0.05	-0.28	-0.06	-0.18	-0.33
NWE	0.29	0.04	0.36	-0.02	-0.24	-0.32	-0.31	0.04
EE	0.14	0.00	-0.21	0.17	0.19	-0.18	-0.14	0.03
CE	0.16	0.07	-0.12	-0.04	-0.02	-0.33	-0.52	-0.07
EUP	0.14	0.12	-0.14	-0.59	-0.30	-0.32	-0.17	-0.03
ALL*	0.24	0.06	-0.20	-0.37	-0.10	-0.33	**-0.41**	-0.17

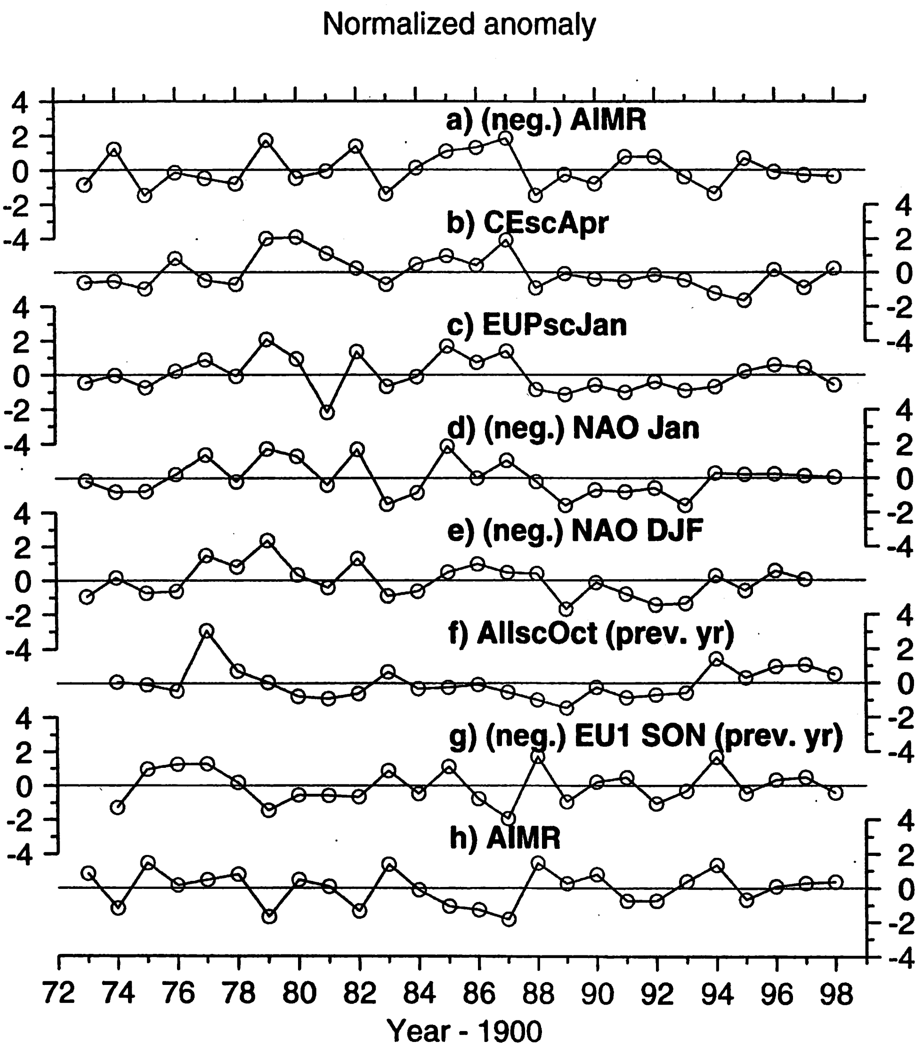

Figure 2: 1973-98 Normalized anomaly of AIMR, key snow cover regions, R-EOF score of related atmospheric patterns.

a) AIMR: all India monsoon rainfall (h) negative)

b) CE sc Apr: Apr snow cover extent over Central Eurasia region

c) EUP sc Jan: Jan snow cover extent over European region

d) NAO Jan : Jan NAO pattern

e) NAO DJF: Dec-Feb mean NAO pattern

f) ALL sc Oct (prev.yr): Oct (-1 year) All Eurasian snow cover extent

g) EU1 SON(prev.yr): Sep-Nov mean (-1 year) EU1 pattern

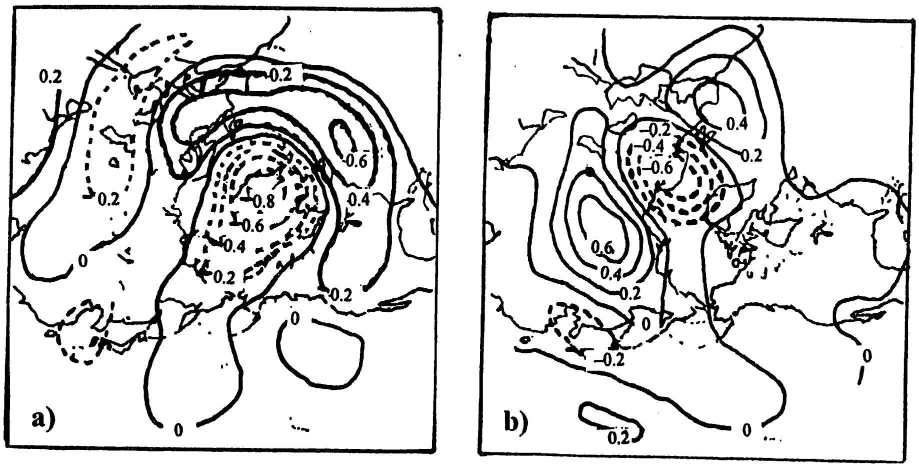

Figure 3 : a) NAO (PCA2, 5.7%) b) EU1 (PCA7, 4.0%)

Contour interval 0.2. Positive values are shown in solid line.

Negative values are shown in dashed line.

3.2 The atmospheric circulation patterns associated with snow and AIMR

Correlation coefficient between EUP sc Jan, CE sc Apr, AIMR and the scores of 12 PCA modes from Jun to May, a year prior to AIMR were calculated. Among 12 PCA patterns, it is notable that NAO (PCA2;5.7%) and EU1 (PCA3; 4.0%) show high correlation with AIMR (Fig.3). Figure 2 shows AIMR, key snow cover regions and the atmospheric patterns which may be related to AIMR from 1973-98.

3.2.1 April circulation

Correlation between CE sc Apr and AIMR are partly explained as follows (Morinaga et al.1997). Though CE sc Apr shows strong relation with AIMR, no typical teleconnection pattern is found in April circulation over Eurasia. However, when composite map of 500hPa gph are made for less snow years (Fig.4, 1973,75,78,83,88) and more snow years (Fig.5, 1979,80,81,85,87), distinct difference is found between the two set of years. When CE sc Apr is small (large), positive (negative) height anomaly dominates over CE region and the stationery ridge (zonal flow) is found over CE. This may be related to the advanced (delayed) northward shift of the subtropical high over India, and then is followed by subsequent more (less) AIMR. During May and the ISM season, the circulation remains zonal in small CE sc Apr years, while a ridge over the Caspian Sea occurs in large CE sc Apr years, leading to the less AIMR (not shown).

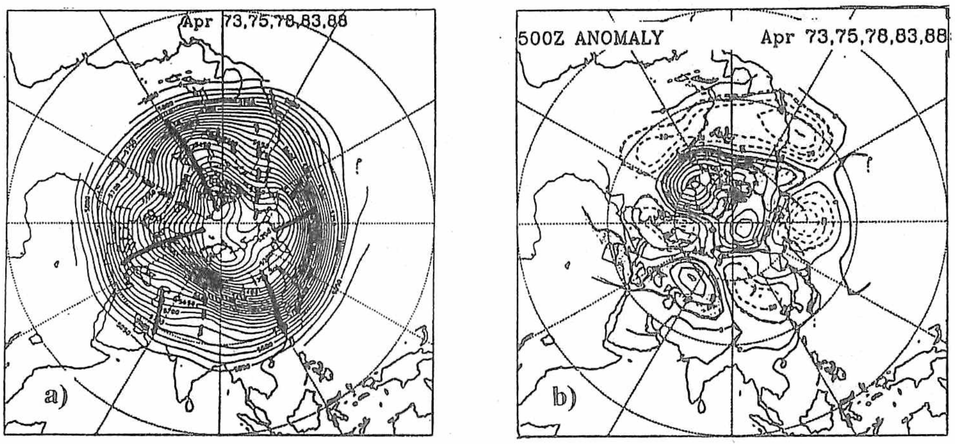

Figure 4: Composit map of less CE sc Apr years a) 500hPa gph and b) anomaly (Contour interval 10m.)

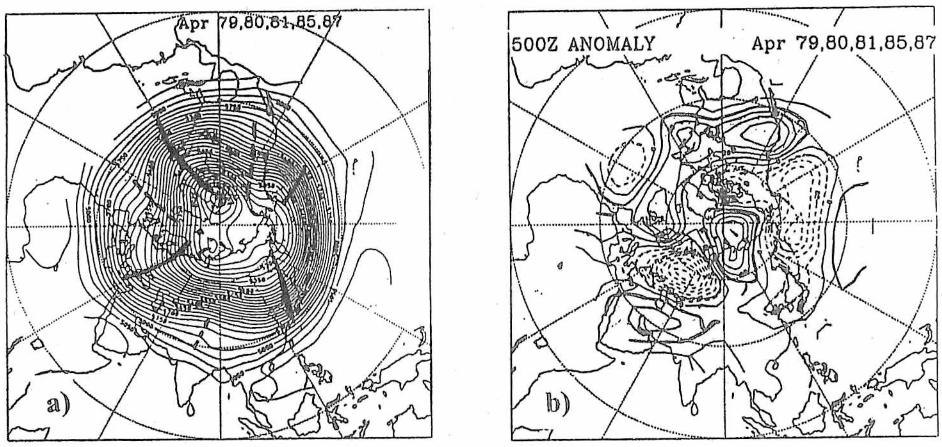

Figure 5: Same as in Fig.4 except for more CE sc Apr years.

3.2.2 January NAO pattern

NAO of January is significantly correlated with EUP sc Jan (r= -0.81, 1%), CE sc Apr (r= -0.50, 1%), and AIMR(r=0.43, 5%) (Fig.2 a-d). Especially, NAO significantly correlated with EUP sc Jan remains from January until February though the signal of NAO does not often last for months. This indicates that when NAO is positive (negative) which means that negative (positive) center is in Iceland, and positive (negative) center in Azores, EUP sc Jan and CE sc Apr is more (less) than average, and AIMR becomes weak (strong). When NAO is positive, westerlies across the North Atlantic is intensified and shifts toward north. Then warm advection from southwest intrudes and warm winters are observed in Europe region and thus EUP sc Jan is small, and vice versa. This is consistent with Gutzler & Rosen (1992) which pointed out that the significant correlations are found between NAO-like pattern and snow cover over western Europe in January and February; thus excessive snow cover is associated with anomalously high pressure west of Scandinavia.

Furthermore, EUP sc Jan is highly correlated with AIMR, and correlation between NAO Jan and AIMR is also significant. This means that EUP sc Jan which is strongly determined by NAO Jan,(in turn, is a good indicator of NAO), would be a good predictor of AIMR. It is possible to suppose that winter NAO plays an important role on Eurasian winter snow cover-AIMR relations.

As shown in Tab.1, both EUP sc Jan and CE sc Apr are significantly correlated with AIMR. Though All-Eurasia sc DJF and CE sc Apr show no correlation (not shown), EUP sc Jan and CE sc Apr are significantly correlated (r=0.48, 5%) , and as NAO Jan is also significantly correlated with CE sc Apr, those three factors (NAO Jan, EUP sc Jan and CE sc Apr) may be a part of a large phenomenon dominant through winter to spring and have important influence on AIMR.

3.2.3 October EU pattern

Sep-Nov mean EU1 (EU1 SON(-1)) is highly correlated with AIMR (r=-0.69) (Fig.2 g and h). The negative correlation indicates that when the circulation pattern has positive centers in western Mongolia, and Spain and adjacent Atlantic, and negative center in Scandinavia, the subsequent AIMR becomes weak, and vice versa. This is consistent with Harzallah & Sadourny (1997) that investigated lagged relationships between AIMR and 500hPa geopotential height, and found a centre of negative correlations over Siberia pronounced during Sep-Nov. Among autumn Eurasian snow cover, All-Eurasia sc Oct (-1) is significantly correlated with EU1 SON(-1) (Fig.2 f and g). That is, when negative anomaly is found over Siberia and Europe, and positive anomaly over Central Eurasia, All-Eurasia sc in Oct (-1) is positive. This could be because snow cover over Eurasia starts to appear from northeast to southwest, and during October, average snow boundary is north of 60N and east of Ob' River (Masuda et al., 1993). Cohen and Entekhabi(1999) showed that autumn snow cover is correlated with winter NAO and the significance is higher than concurrent (winter) snow cover. Cooling associated with snow cover and the extension of Siberian High to west and north are the dominant forces for producing NAO positive patterns. To examine their result, autumn snow and winter NAO were correlated, and significant correlation was found between All-Eurasia sc Oct (-1) and December-February mean (DJF) NAO. This indicates that negative October EU1 accompanying more snow cover over Siberian region leads NAO negative (Iceland positive, Azores negative) in winter. No correlation was found between autumn EU1 and winter NAO.

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