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THE RELATIONSHIP BETWEEN SNOW MASS DISTRIBUTION OVER THE EURASIAN CONTINENT AND THE INDIAN MONSOON RAINFALL IN SUMMER

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ABSTRACT

In this study, the empirical orthogonal function (EOF) analysis is applied to the observed snow depth data from January to April of 215 hydrometeorological stations in the former Soviet Union, in order to investigate the time-space characteristics of the interannual variation of snow depth over the Eurasian continent. The eigenvector pattern of the first component shows the seesaw pattern between Europe-Russia/Central Asia and West Siberia. In addition, the linear correlation is found between this component and the Indian monsoon rainfall in summer.This result suggests that the snow-hydrological effect over Central Asia in winter and spring is important for the successive Indian monsoon in summer.

INTRODUCTION

The effect of the interannual variation of winter and spring snow cover over the Eurasian continent on the Asian summer monsoon circulation has been noted by many observational studies ,by using NOAA/NESDIS northern hemisphere snow and ice cover data set . Hahn and Shukla(1976) discussed an apparent inverse relationship between Eurasian mean winter (December-March) snow cover extent and the following summer (June-September) Indian monsoon rainfall for the 1967-75 period. Dey and Bhanu Kumar(1982) also showed an apparent relationship between Eurasian spring snow cover extent and the advance period of the Indian summer monsoon. Mooley et al.(1986) and Bhanu Kumar(1988) related this snow cover extent to the location of the ridge at the 500hPa level along 75°E.

On the other hand, some numerical model experiments have suggested the possible physical processes concerned with these observational studies. Yeh et al.(1983) first examined the effect of the snow cover on the atmospheric circulation using the simplified model. Barnett et al.(1989) and Yasunari et al.(1991), using the General Circulation Model (GCM), also examined the effect of spring snow cover on the atmosphere in the later seasons. These studies emphasized that as well as the albedo effect of snow cover the snow-hydrological effect, i.e. the effect of snow consuming the solar energy during snowmelt and also reducing the heating of the ground after the snowmelt by increased soil moisture supplied by snow melt water, is important.

To verify the snow-hydrological effect, it is necessary to take the information of snow mass into account for the climate - snow cover issue. Although NOAA/NESDIS snow cover data set available since 1966 has been proved to be efficient for this issue, it give us only the information of snow cover extent.

The purpose of this study is to investigate the interannual variation of the Eurasian snow mass distribution and attempt to discuss the relationship between the hydrological process of snow mass and Indian monsoon activity in summer.

DATA AND METHOD OF ANALYSIS

The observed snow depth data of 215 hydrometeorological stations in the former Soviet Union is used, which covers the most part of snow cover area over the Eurasian Continent. This data set was compiled in the USSR State Committee for Hydrometeorology, All Union Research Institute of Hydrometeorological Information - World Data Centre. We made monthly data for the period of 1966 through 1983 from the original daily data. The data from January to April was used for the present study.

In order to investigate the time-space characteristics of the interannual variation of snow depth over the Eurasian continent, the empirical orthogonal function (EOF) analysis is applied to the snow depth data. The all India summer monsoon rainfall data (Parthasarathy et al., 1987) is used as a index of monsoon activity, to correlate with the interannual variation of the Eurasian snow mass.

CLIMATOLOGY OF SNOW DEPTH

Before discussing the interannual variation, it may be necessary to make clear the climatology of the Eurasian snow depth. Fig.1(a)-(d) show the distribution of the mean snow depth in December, February, March, and April. In these figures, it is noted that topography, as well as latitudes, greatly influences the spatial distribution of the snow depth. In February(Fig.1b) and March(Fig.2b), most of the stations show the maximum snow depth, the two maximum areas of snow depth are found; one in the western part of the Ural Mountains, and the other in the marginal region between the West Siberia plain and Central Siberian plateau. In addition, snow depth of more than 100 cm is observed at some stations along the coast of Bering Sea, which may be partly influenced by cyclone activity over the north-eastern Pacific Ocean. In contrast, Eastern Siberia shows the minimum snow depth with the value of less than 40 cm. In the large plain area of Central Asia through Europe-Russia, the snow depth generally increases in proportion to the latitude.

The seasonal cycle of the snow depth distribution over Eurasia is described as follows: In December(Fig.1a), snow depth is generally thin over the whole area, but most of the stations are already covered by snow. In the course of seasonal march, snow depth gradually increases and reaches the maximum in February (Fig.1b). In March (Fig.1c), snow depth still increases to the north of 60°N, but starts to decrease in the southern part and the snow line starts to move northward. This contrast in the seasonal tendency of snow depth clearly results the spatial pattern in April (Fig.1d), where the steep latitudinal gradient of snow depth is apparent along about 60° N line. Nevertheless, the overall spatial pattern of snow depth from month to month seems to be similar to each other, though the snow depth itself considerably changes seasonally.

INTERANNUAL VARIABILITIES OF SNOW DEPTH

The persistency of snow depth anomaly from month to month is examined as a basis for discussions on the interannual variability of snow depth. Fig.2 shows the spatial pattern of correlation coefficients between the snow depth anomaly in January and that in February for each station. The high persistency between these two month is noticeable over the most of the area, that is , when the snow depth in one January is larger (smaller) than its mean value, it tend to be larger (smaller) in successive February. This correlation holds in January through April (i.e., between February and March, March and April). Therefore, we may conclude that over this region snow depth anomalies in late winter through spring seem to represent the characteristic nature of interannual variability of snow depth for each year.

Based upon these characteristics of snow depth anomaly, the EOF analysis is applied to the snow depth anomalies for January through April to investigate time - space characteristics of interannual variability of snow mass during the maximum snow depth season. Fig.3 shows the eigenvector pattern of the first component of the EOFs. The variance of this component to the total variance is 10.4%. It is obvious that there is a seesaw pattern between Central Asia/Europe-Russia and Central/West Siberia, which implies that snow depth is more (less) than normal over the Europe-Russia when it is less (more) over the Central Siberia.

CORRELATION WITH INDIAN MONSOON RAINFALL

The scores of the first component of EOF are correlated to the interannual variation of the following Indian summer monsoon rainfall. Fig.4 shows the scatter diagram of these two data. The score value of the first component here is averaged for the months of January through April for each year. The number in each plot shows that of calendar year. Although the correlation coefficient (-0.358) is not significant, Indian summer monsoon is generally related to the EOF 1. The actual anomaly distribution of snow depth for each year (not shown) is found to be very similar to fig.3, particularly in 1967,68,69,76 and the inverse pattern in 1973,75,78,81,83. However, the pattern in 1966,72,79,82 seem to be quite differed to Fig.3. Excluding these 4 years, we have got the correlation coefficient of -0.578 with a 2% significant level. This result suggests that positive snow depth anomaly over Central Asia and Europe-Russia with negative anomaly over Central and West Siberia is responsible for the weaker than normal Indian monsoon rainfall in successive summer.

CONCLUDING REMARKS

The results deduced here suggests that the snow-hydrological effect over Central Asia and Europe-Russia in winter and spring (January to April) is important for the successive Indian monsoon activity in summer. The importance of the snow cover in this area is already emphasized by Morinaga and Yasunari(1987), Kodera and Chiba(1989), and so on. In future, it is necessary to examine the real physical process related to the interannual variation of snow mass in this area. Furthermore, more investigation should be needed for the cases when the seesaw pattern mentioned above do not appear clearly.

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Figure Caption

Fig. 1 The distribution of the mean snow depth (1966-1983) in December(a), February(b), March(c), and April(d).

Fig. 2 The spatial pattern of correlation coefficients between the snow depth anomaly in January and that in February for each station.

Fig. 3 The eigenvector pattern of the first component of the EOFs. The hatched areas signify the positive value.

Fig. 4 The scatter diagram between the scores of the first component of EOFs and the following Indian summer monsoon rainfall (anomaly). The number in each plot shows that of calendar year.

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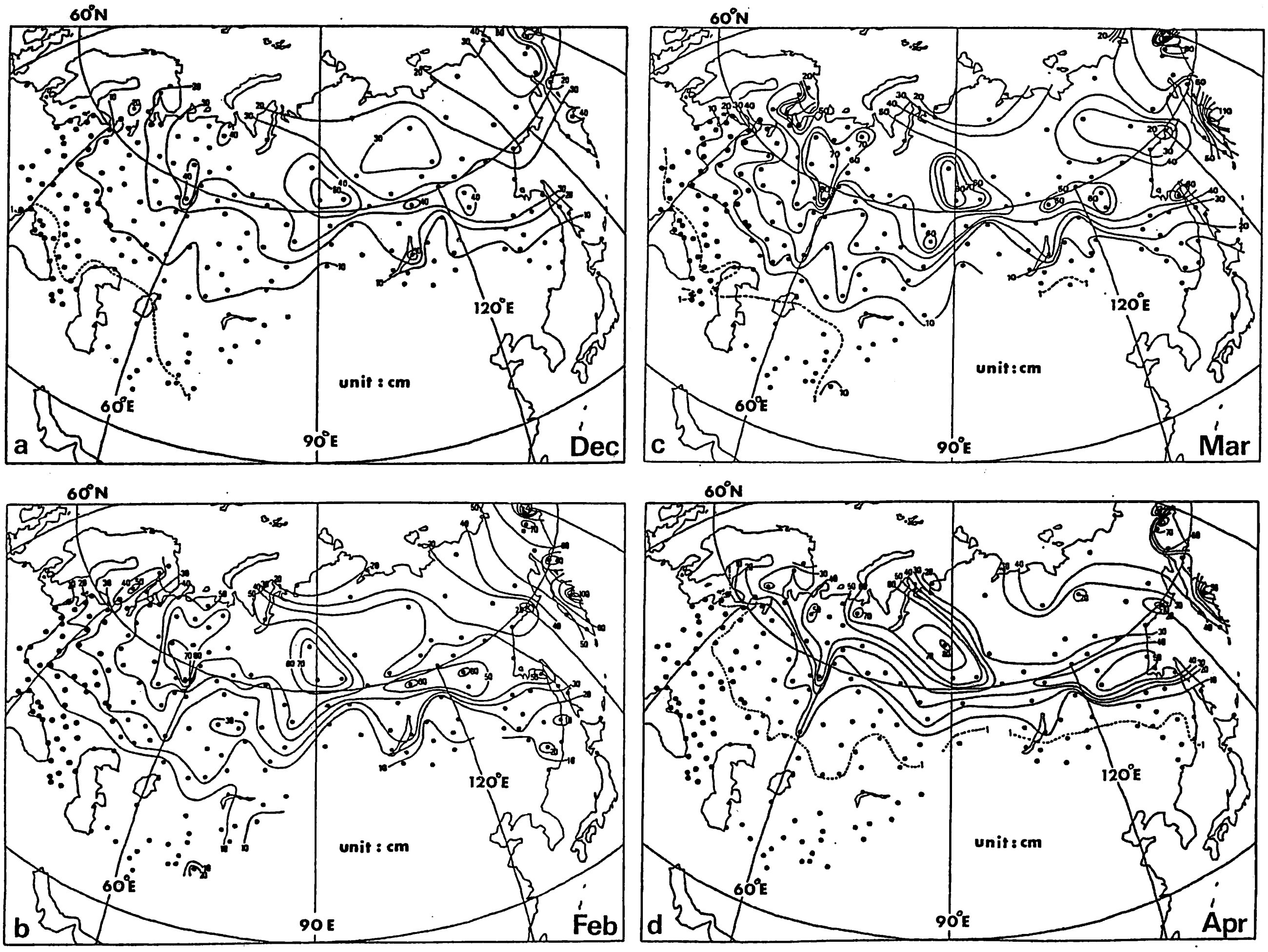
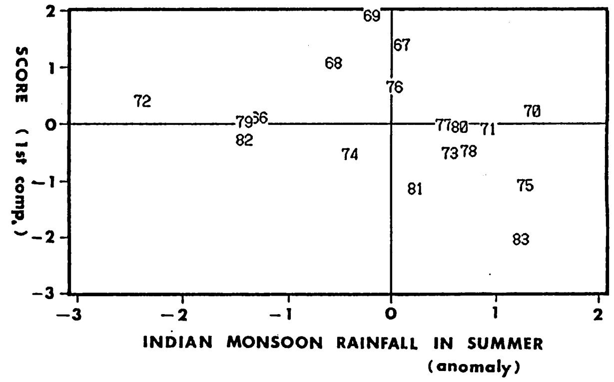
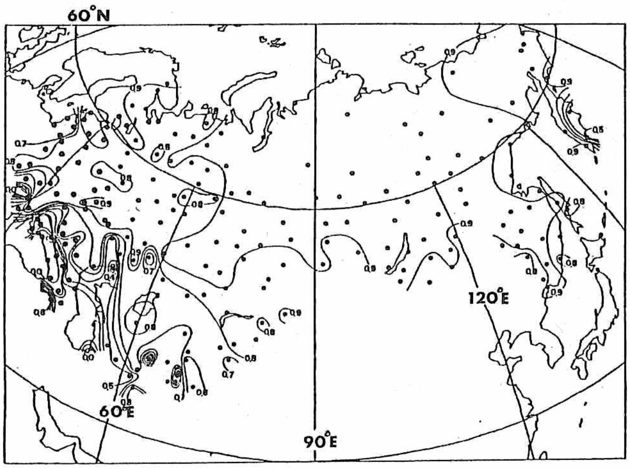
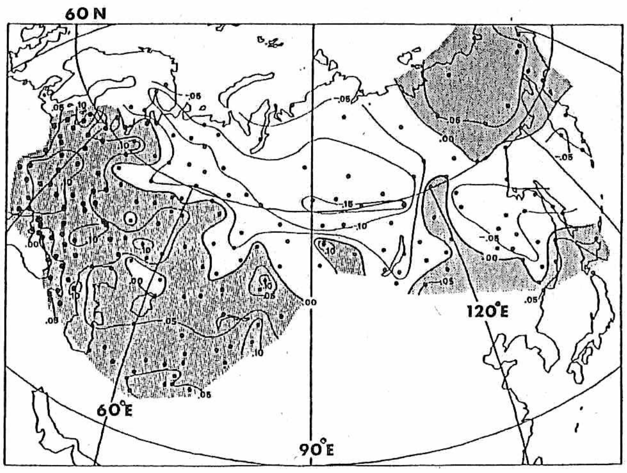


60°N
60°E
90°E
120°E
unit : cm
a
Dec
b
Feb
c
Mar
d
Apr



SCORE (1st comp.)
INDIAN MONSOON RAINFALL IN SUMMER
(anomaly)
69
67
68
76
72
79
66
82
74
77
80
71
70
73
78
81
75
83


60°N
120°E
60°E
90°E


60 N
120°E
60°E
90°E