

Relationship between lower stratospheric circulation and Indian summer monsoon rainfall : Implication for long range forecasts

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(Received 6 January 2006, Modified 28 September 2007)

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सार — इस शोध-पत्र में सहसंबंध विश्लेषण से उत्तरी गोलार्द्ध के निम्न समताप मंडलीय भूविभवों (100, 50, 30 हैक्टा पास्कल) की मासिक ऊँचाइयों तथा भारतीय ग्रीष्मकालीन मानसून वर्षा (आई. एस. एम. आर.) के मध्य दूरसंबंधों का पता लगाया गया है। विशेष दूरसंबंधों से मानसून के अपने निर्धारित समय के बाद में आने से स्थिर और अविचल पूर्ववर्ती संकेतों का पता लगाया गया है। सरल बहुरैखिकीय समाश्रयण निदर्श का उपयोग करते हुए आई. एस. एम. आर. के पूर्वानुमान के लिए पूर्ववर्ती संकेतों की उपयोगिता की भी जाँच की गई है। इन पूर्ववर्ती संकेतों से भारतीय ग्रीष्मकालीन मानसून वर्षा की दीर्घ अवधि पूर्वानुमान स्कीम में अच्छी संभावना का पता चलता है।

ABSTRACT. In this study teleconnections between monthly northern hemisphere lower stratospheric geopotential heights (100, 50, 30 hPa) and seasonal Indian Summer Monsoon Rainfall (ISMR) have been established through the correlation analysis. Stable and consistent precursory signals for the ensuing monsoon were identified from the significant teleconnections. The usefulness of the precursory signals for the prediction of ISMR was also tested using a simple multiple linear regression model. These precursory signals show a good potential in the long range prediction scheme of Indian Summer Monsoon Rainfall.

Key words – Monsoon, Teleconnections, Stratosphere, Multiple regression, long range forecasting.

1. Introduction

Observational and modeling studies during the past several years have indicated the absence of any individual mechanism or factor that can be projected as the one, which is solely responsible for the interannual variability of Indian summer monsoon rainfall. The primary factor that governs the interannual variability of Indian Summer Monsoon Rainfall (ISMR) is the slowly varying surface boundary conditions (*e.g.*, sea surface temperature, snow cover, soil moisture etc.). The interannual variability of the ISMR is also associated with circulation features of troposphere and lower stratosphere. There are large number of studies, which examined the association between tropospheric circulation features and ISMR (Koteswaram, 1960, Rao, 1962, Joseph, 1978; Joseph *et al.*, 1981, Banerjee *et al.* 1978, Keshavamurty *et al.* 1980, Mooley *et al.*, 1986; Singh, 1986; Sikka, 1980, Shukla and Mooley, 1987; Mooley and Munot, 1997; Parthasarathy and Sontakke, 1988; Bhalme and Jadhav, 1984; Bhalme *et al.*, 1990; Rajeevan, 1991, 1993 & 2002; Pai, 2003). However, there are not many studies that examined the association of stratospheric circulation features with the interannual variability of ISMR.

Most of the studies that examined the relationship of ISMR with the stratosphere circulation features (Thapliyal 1984, Mukherjee *et al.*, 1985; Bhalme, *et al.*, 1987; Mukhopadhyay and Sarkar, 1990; De, *et al.*, 1998) dealt with the association between stratospheric zonal winds at various levels and ISMR. By examining the mean monthly winds at 50 hPa level for the period 1965-80. Thapliyal (1984) observed that the 50 hPa wind pattern of the winter months (January and February) during excess ISMR years was totally contrasting to that during deficient ISMR years. During the excess monsoon years, he observed a ridge in the winter 50 hPa wind pattern over the northern hemisphere located about 20° N. On the other hand during the deficient years, this ridge was found to be broken and replaced by a trough-ridge pattern nearly parallel to the equator. Mukherjee *et al.*, (1985) and Bhalme *et al.*, (1987) observed a positive correlation between lower stratospheric zonal wind anomalies at Balboa (Argentina) and ISMR. Mukhopadhyay and Sarkar, (1990) using rocketsonde data observed a strong semi-annual wave over tropical region (Balasore) during a good monsoon year. The amplitude of this semi-annual wave was also found to be significantly higher over the equatorial Indian region (Thumba). De *et al.*, (1998)

observed that a prognostic value between easterly/westerly phases of Quasi-Biennial Oscillation (QBO) over Thumba exists during antecedent months of January to May and performance of summer monsoon rainfall over India with strong easterlies favouring decreased rainfall and westerlies or light easterlies favouring increased rainfall over the country as a whole.

Bansod *et al.*, (2000) observed that the 10 hPa zonal wind for Balboa and Ascension during January and the 30 hPa zonal wind for Balboa during April are found to be positively correlated with the subsequent Indian summer monsoon rainfall, whereas the temperature at 10 hPa for ascension during May is negatively correlated with Indian summer monsoon rainfall. Kripalani and Kulkarni, (1997) identify all possible links between the stratosphere and Indian monsoon rainfall. Kripalani *et al.*, (1999) examined monsoon teleconnections in the monthly mean geopotential heights (gph) at 50 hPa. For this purpose, they used Free University of Berlin geopotential data over the northern hemisphere (10° N to 80° N) distributed at spatial grid of boxes of 10° × 10° for the period of 1958-1990. They observed positive correlation between seasonal (June-September) monsoon rainfall and geopotential heights over large areas along the latitudinal belt of 10° N - 20° N during January and February. However, they observed that the relationship was stronger during March with positive correlations over Canadian sector and negative correlations over the east Asian sector. Further they concluded that the observed patterns were linked to the ENSO cycle.

At present, a better version of the Berlin monthly stratospheric data over the Northern Hemisphere (0° N – 90° N) is available at 5° × 5° Latitude Longitude resolution. The main aim of this study is to reexamine the monsoon teleconnections identified by Kripalani *et al.* (1999) using this new version of Berlin stratospheric data. We have further examined the monsoon teleconnections at 100 hPa and 30 hPa in addition to 50 hPa. Significant predictive signals were identified and discussed. A simple long range forecasting model for the seasonal (June-September) rainfall using the identified stratospheric predictors has also been proposed.

In the section 2, we discuss the data and methodology used for this study and in the section 3 we discuss the results. Section 4 discusses the potential predictors for ISMR. Section 5 discusses the development of a simple multiple regression model and finally, conclusions are presented in section 6.

2. Data and methodology

The new version of the Berlin stratospheric data set used for this study was obtained from the website of

Meteorological Institute, Free University Berlin (<http://badc.nerc.ac.uk/>). K. Labitzke and Collaborators, 2002, made this data set. These data at different stratospheric pressure levels were interpolated on a horizontal resolution of 5° × 5° (Latitude × Longitude) using geopotential data derived from radiosonde and rocket observations. The data cover the northern hemisphere from 0° N (equator) to 90° N. There is only one value for the north pole (*i.e.*, 90° N). We used the grid point stratospheric data at pressure levels of 100 hPa, 50 hPa and 30 hPa. The data for 100 hPa were available for the period from July 1964 to December 2001 and for other two levels the data were available only from July 1974 to June 2001. (More details of this data set can be seen in the web site).

The Indian summer monsoon rainfall (ISMR) series for the period 1964-2001 used in this study was based on the seasonal (June-September) monsoon rainfall data of all the 36 meteorological sub-divisions in India. The seasonal summer monsoon rainfall over the country as whole was calculated as the area weighted average of seasonal rainfall of all 36 sub-divisions. The ISMR was expressed as the percentage departure from the long period average (LPA) of seasonal summer monsoon rainfall over the country as a whole, which is equal to 88 cm.

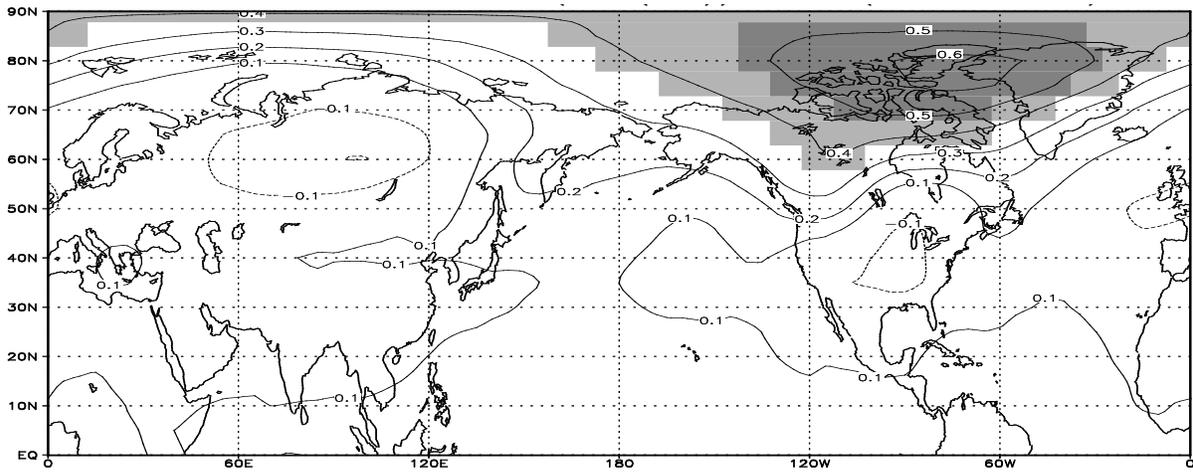
In order to examine the monsoon teleconnections in the geopotential heights, spatial maps of Correlation Coefficient (C.C.) between ISMR and monthly geopotential heights were prepared. For this analysis data for the period 1975-2001 were used. In order to identify the potential predictors for the ensuing summer monsoon rainfall, areas of significant C.C. were identified in the monthly C.C. maps. Over each of the geographical region, the geopotential heights within the rectangular box drawn to enclose maximum areas of most significant C.C. were averaged to form the time series of the corresponding predictive signal (predictor). Moving 21 years C.C. between ISMR and the predictor series was then computed to examine the stability of the relationship between ISMR and the predictors. When the 21 years moving C.C. of predictor with ISMR is above the 5% significant level during most part of the period, the predictor can be assumed to have stable relationship with ISMR. All predictors those having stable relationship with ISMR were then used to develop a simple prediction model for the ISMR. For the model development Multiple Linear Regression analysis (MRA) was used.

3. Results

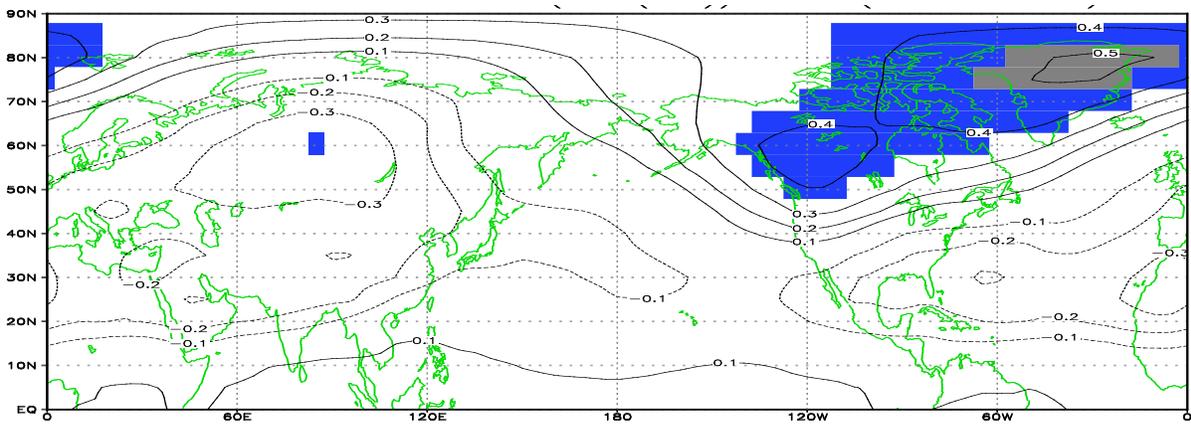
3.1. Spatial patterns of correlation

Monthly spatial patterns of correlation between ISMR and geopotential heights (gph) at 30 hPa, 50 hPa

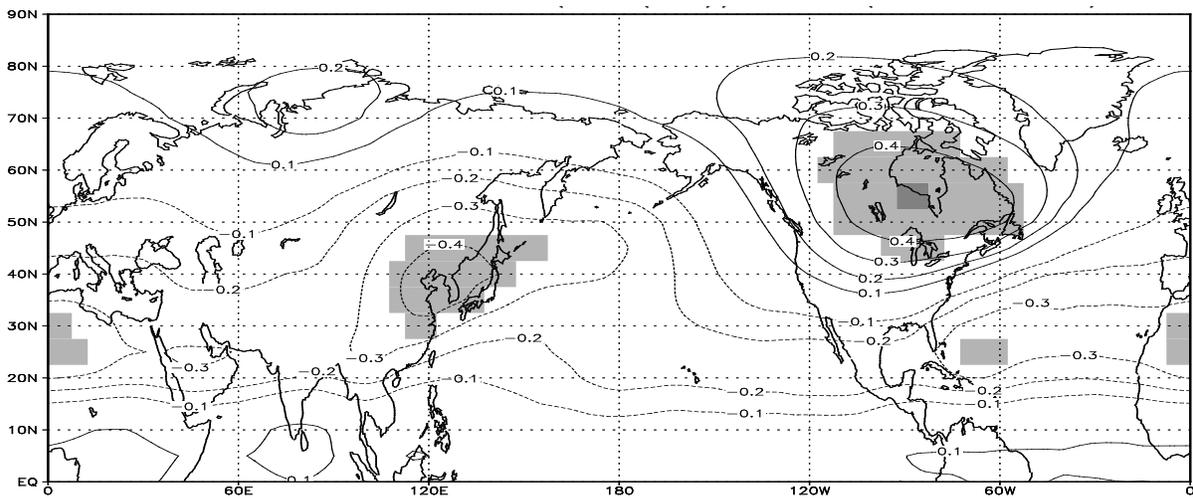
(a) ISMR Vs 30 hPa GPH [Oct (-1)] : C.C. (1975-2001)



(b) ISMR Vs 30 hPa GPH [Nov (-1)] : C.C. (1975-2001)

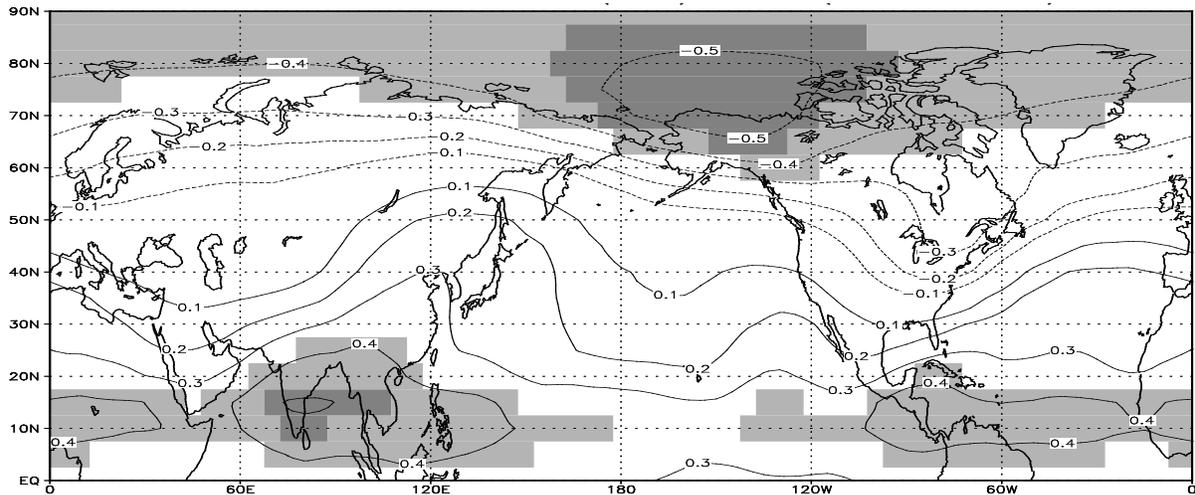


(c) ISMR Vs 30 hPa GPH [Dec (-1)] : C.C. (1975-2001)

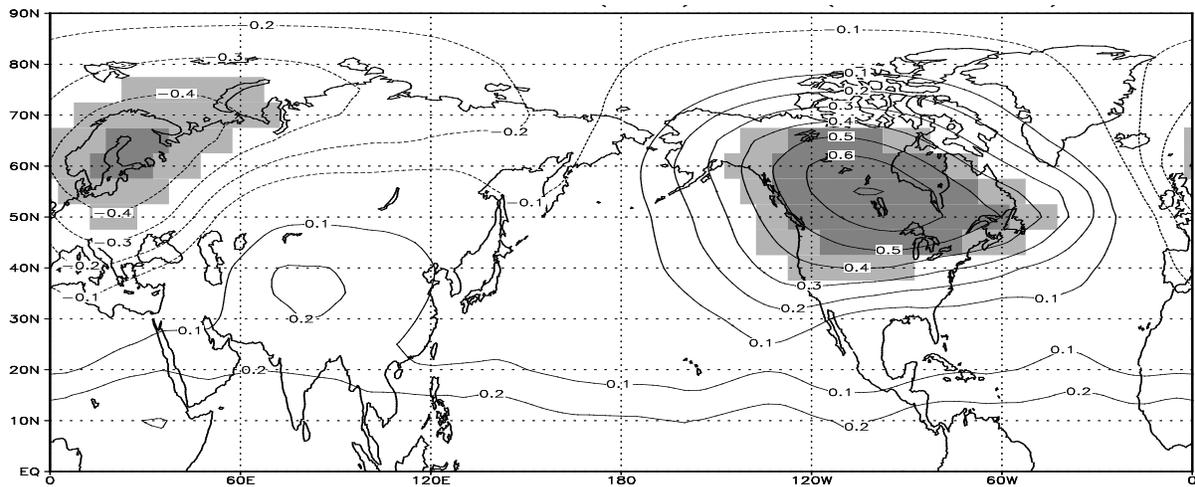


Figs. 1(a-c). Spatial pattern of correlation coefficient between (a) Oct (-1), (b) Nov (-1) and (c) Dec (-1) (30 hPa) geopotential height and Indian summer monsoon rainfall. Period: 1975-2001. Statistical significant 1% (5%) correlation is shaded dark (light). Contour interval : 0.1

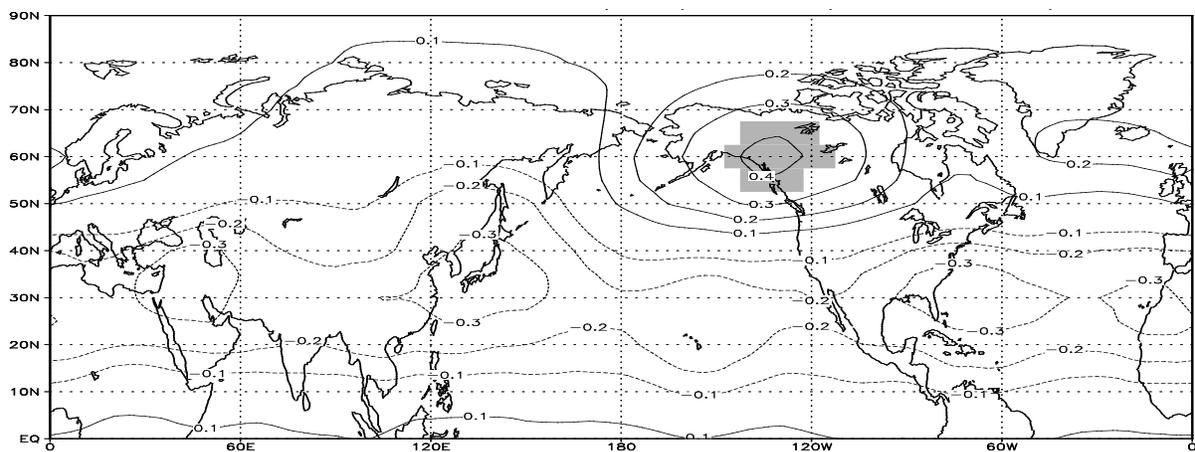
(d) ISMR Vs 30 hPa GPH (Feb): C.C. (1975-2001)



(e) ISMR Vs 30 hPa GPH (Mar) : C.C. (1975-2001)

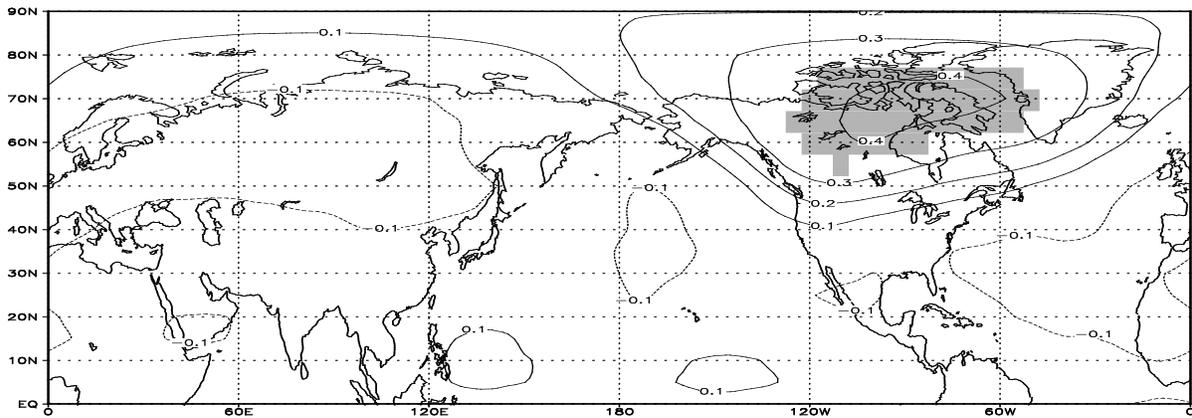


(f) ISMR Vs 30 hPa GPH (Apr) : C.C. (1975-2001)

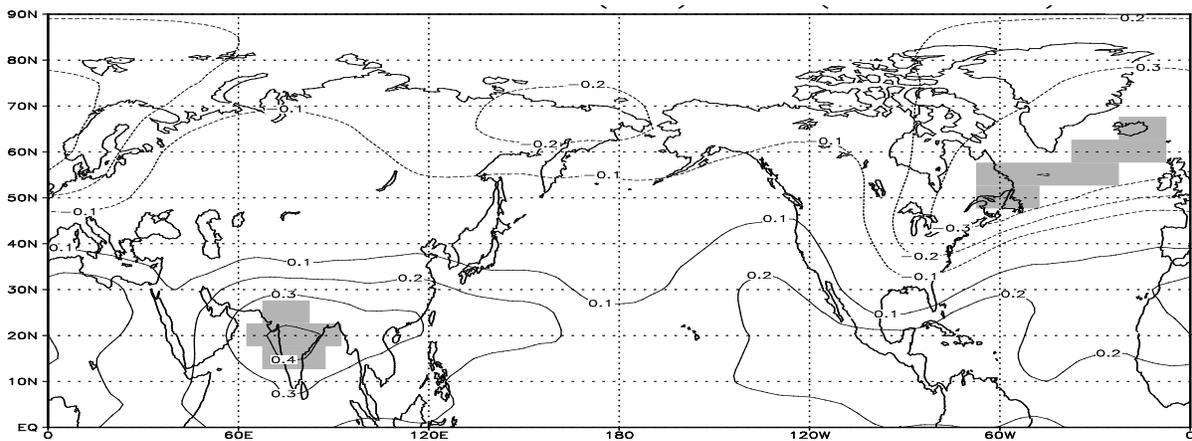


Figs. 1(d-f). Spatial pattern of correlation coefficient between (d) Feb, (e) Mar and (f) Apr (30 hPa) geopotential height and Indian summer monsoon rainfall. Period: 1975-2001. Statistical significant 1% (5%) correlation is shaded dark (light). Contour interval : 0.1

(a) ISMR Vs 30 hPa GPH [Nov (-1)] : C.C. (1975-2001)



(b) ISMR Vs 30 hPa GPH (Feb) : C.C. (1975-2001)



Figs. 2(a & b). Spatial pattern of correlation coefficient between (a) Nov. (-1) & (b) Feb, 50 hPa geopotential height and Indian summer monsoon rainfall. Period: 1975-2001. Statistical significant 1% (5%) correlation is shaded dark (light). Contour interval: 0.1

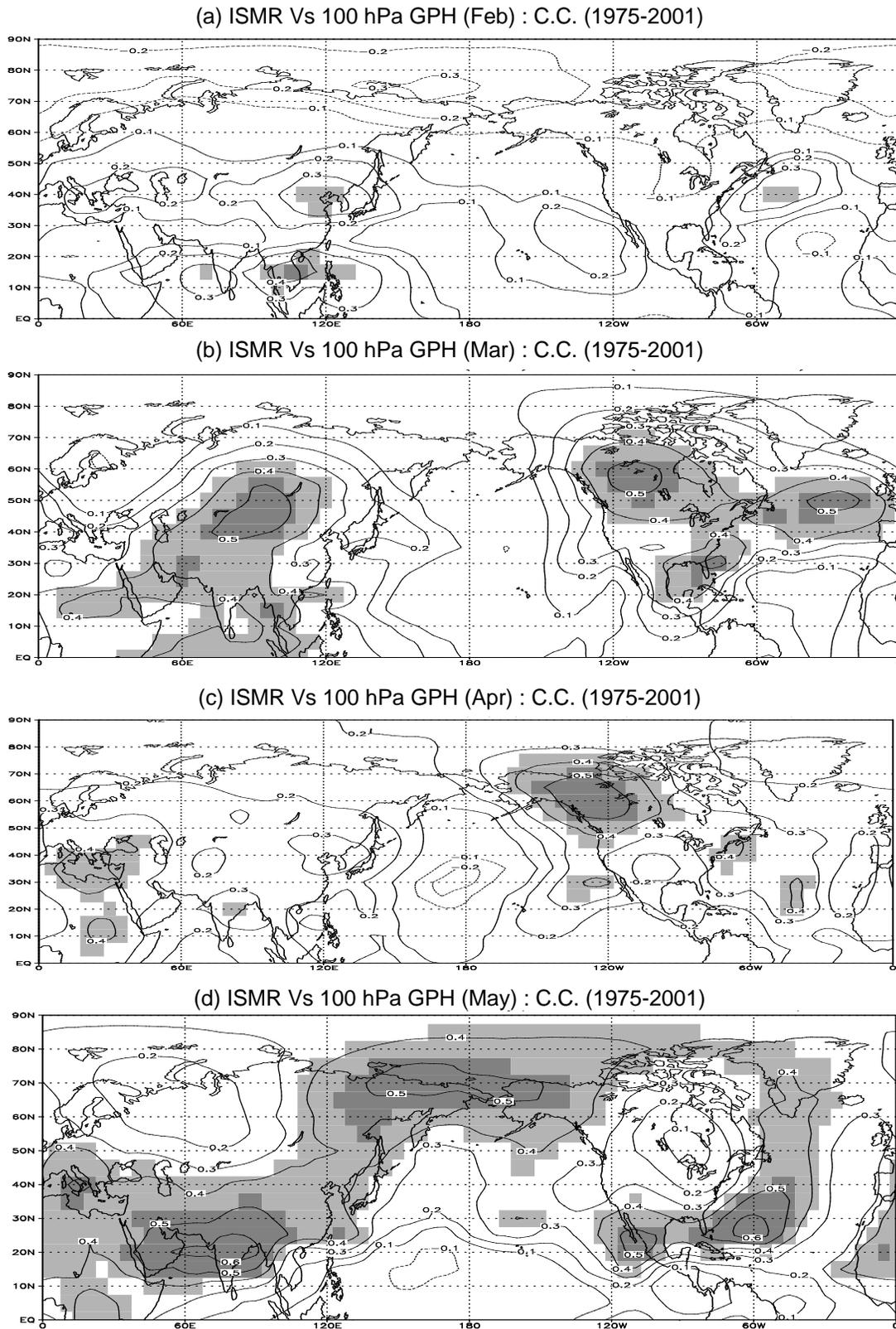
and 100 hPa levels were prepared for the all months from October of previous year to May of the reference monsoon year. Only those monthly correlation patterns that showing significant monsoon teleconnections are presented and discussed here.

3.1.1. Relationship between 30 hPa geopotential height and ISMR

Figs. 1(a-f) shows the monthly spatial distribution of the correlation coefficient between ISMR and 30 hPa geopotential heights during the months of October (-1), November (-1), December (-1), February, March and April. The '-1' within the bracket indicates year prior to the reference monsoon year. The grid boxes with C.C. significant at 1% (5%) level are shaded dark (light).

As seen in Figs. 1(a-f), during October (-1) to December (-1) a positive Correlation Coefficient (C.C.) areas are seen over higher latitudes and negative C.C. area in the middle and lower latitudes with a significant C.C. area over North America and Canada region. During February and March this pattern get reversed with a general negative (-ve) C.C. areas over higher latitudes and positive (+ve) C.C. areas south of it.

Climatologically in the atmosphere at 30 hPa level a zonal oriented gph pattern is observed over northern hemisphere with higher gph values over the tropics and low gph values over higher latitudes indicating a climatological temperature gradient directed from equator to polewards. The waves in the mid latitude westerlies carry the temperature from lower latitudes to higher



Figs. 3 (a-d). Spatial pattern of correlation coefficient between (a) February, (b) March, (c) April and (d) May (100 hPa) geopotential height and Indian summer monsoon rainfall. Period : 1975-2001. Statistical significant 1% (5%) correlation is shaded dark (light). Contour interval : 0.1

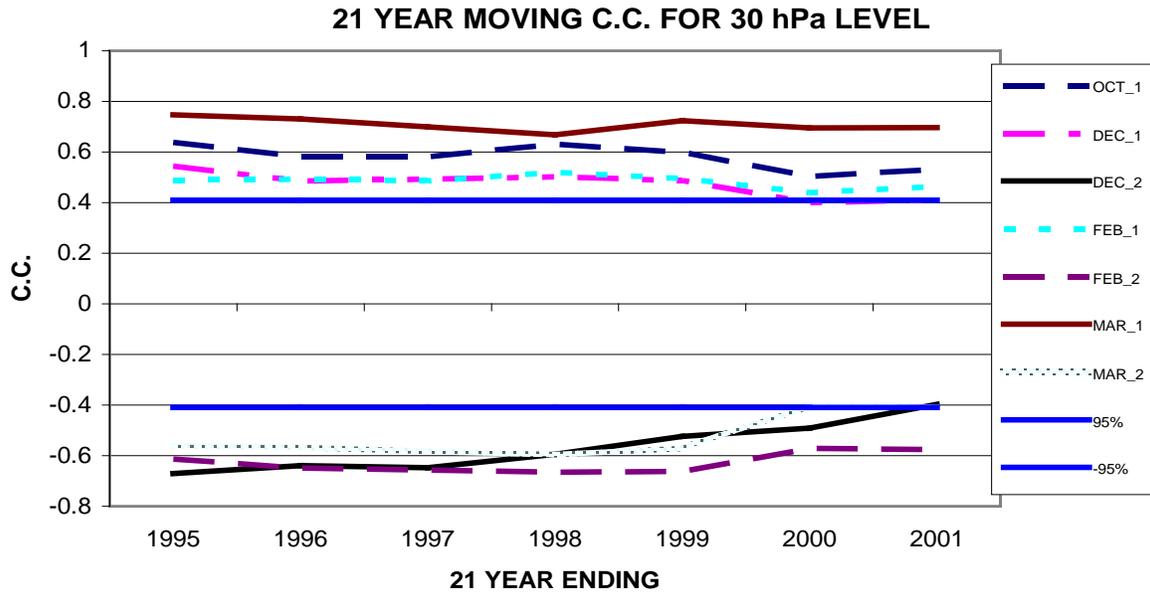


Fig. 4. The 21-year sliding correlation between 30 hPa geopotential heights and ISMR. The 5% and 1% significance level is shown as a horizontal line

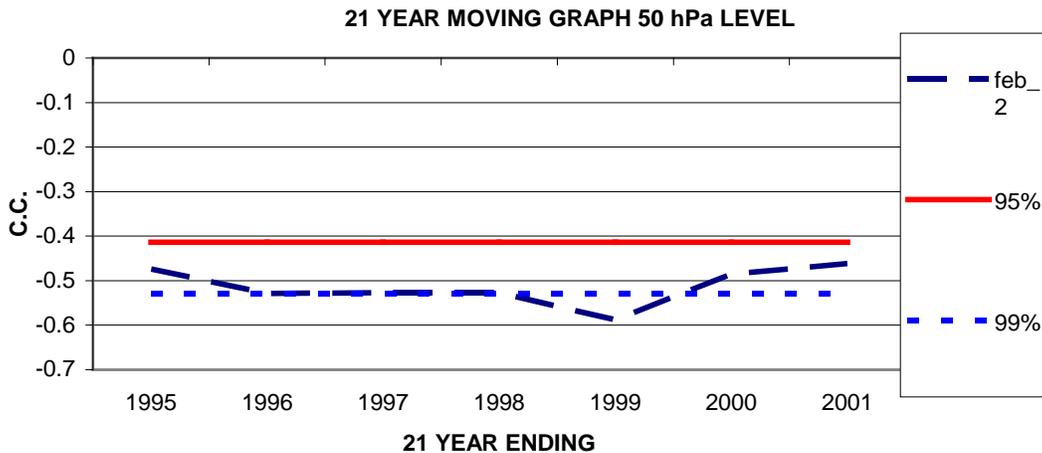


Fig. 5. The 21-year sliding correlation between 50 hPa geopotential heights and ISMR. The 5% and 1% significance level is shown as a horizontal line

latitudes as a part of large scale general circulations system. The positive C.C. areas in the higher latitudes and negative C.C. areas in lower latitudes during October (-1) to December (-1) indicates that prior to a excess (deficient) monsoon. The equator to poleward directed temperature gradient is lower (stronger) than normal. On the other hand during the month of February and March prior to a excess (deficient) monsoon the equator to poleward directed temperature gradient is stronger (weaker) than normal. Stronger (weaker) than normal temperature gradient indicates stronger (weaker) than

normal mid latitudes westerlies and reduced (increased) wave activities. Rajeevan *et al.*, (1998) had proposed similar mechanism using surface temperature anomalies. The persistence of increased wave activities over Eurasian region cause incursion of dry and cold westerly in to the monsoon region it weakens the easterly jet and hence the monsoon. The interesting thing is that such signal is visible even in the lower stratosphere. During the month of February [Fig. 1(d)] positive correlation is seen over most part of tropics (0° - 20° N) but most significant area of positive relationship is seen over Indian region. The

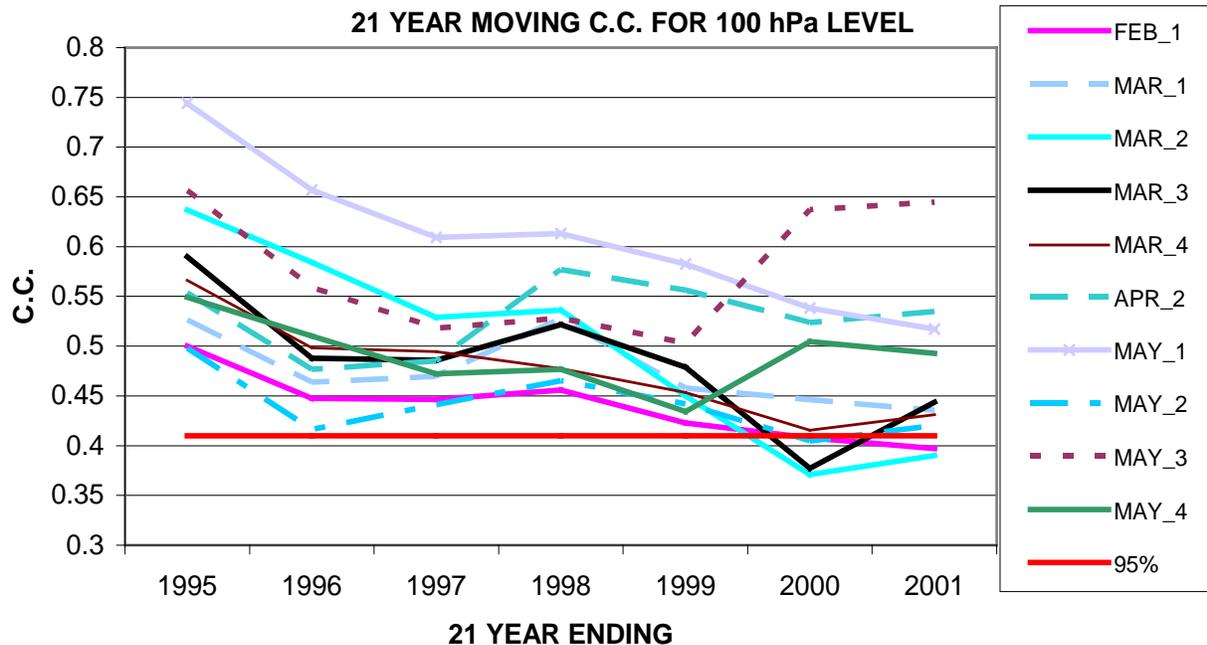


Fig. 6. The 21-year sliding correlation between 100 hPa geopotential heights and ISMR. 5 % significance level is shown as horizontal line

positive correlation imply that ridge along the 10° - 20° N over tropical regions is conducive for good monsoon (Thapliyal, 1984).

3.1.2. Relationship between 50 hPa geopotential height and ISMR

Figs. 2(a&b) shows the monthly spatial distribution of the correlation coefficient between ISMR and 50 hPa geopotential heights during the months of November (-1) and February. The '-1' within the bracket indicates year prior to the reference monsoon year. In all other months there were not any significant C.C. observed over any region of world. Grid boxes with C.C. significant at 5% level are shaded light.

As seen in Figs. 2(a&b), during November (-1) a positive Correlation Coefficient (C.C.) areas are seen over higher latitudes and negative C.C. area in the middle and lower latitudes with a significant C.C. area over North America region. During February this pattern get reversed with a general negative (-ve) C.C. areas over higher latitudes and positive (+ve) C.C. areas south of it with a significant positive C.C. area over Indian region.

A zonal oriented gph pattern is observed at 50 hPa using climatology during the month of November (-1) and during the month of February with lower gph values are

observed in higher latitudes and higher gph values are observed in tropics as in the case of 30 hPa. It indicates a climatological temperature gradient directed from equator to poleward. The negative C.C. areas in the lower latitudes and positive C.C. areas in higher latitudes during November (-1) indicates that prior to a excess (deficit) monsoon. The equator to poleward directed temperature gradient is lower (stronger) than normal. During the month of February this situation get reversed and prior to a deficient (excess) monsoon the equator to poleward directed temperature gradient is weaker (stronger) than normal as in the case for 30 hPa level. Weaker (stronger) than normal temperature gradient indicates weaker (stronger) than normal mid latitudes westerlies and increased (reduced) wave activities, the persistence of weakening (strengthening) of the monsoon is associated with weakening (strengthening) of the monsoon (Rajeevan *et al.*, 1998). Similar features were observed at 50 hPa level also. Positive C.C. over tropics during the month of February [Fig. 2(b)] and significant C.C. over Indian region imply that ridge along 10° - 20° N over tropical region is conducive for good monsoon (Thapliyal, 1984).

3.1.3. Relationship between 100 hPa geopotential height and ISMR

Figs. 3(a-d) shows the monthly spatial distribution of the correlation coefficient between ISMR and 100 hPa

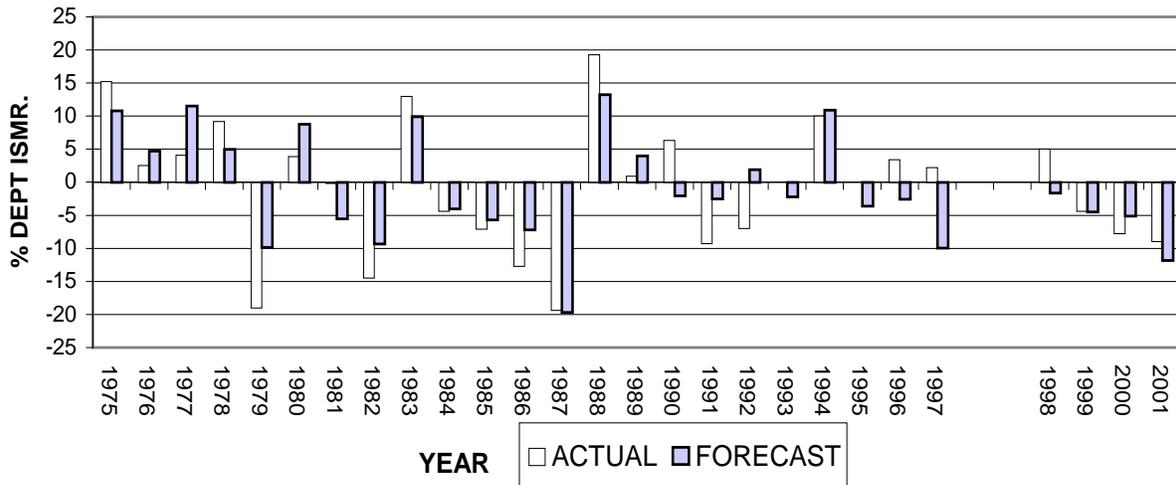


Fig. 7. Performance of simple multiple regression model which used one predictor from each level

geopotential heights during the months of February, March, April and May. The grid boxes significant at 1% (5%) level are shaded dark (light).

Positive C.C. is observed over lower latitudes and negative C.C. (less positive) C.C. is observed over higher latitudes with a significant positive C.C. over southeast Asia, Asia, North America, Saudi Arabia and over Indian region during the months of February, March, April and May [Figs. 3(a-d)]. Less positive (negative) C.C. are observed over Eurasian region during the month of February, March, April and May Figs. 3(a-d).

Climatologically in the atmosphere at 100 hPa level a zonal oriented gph pattern is observed over northern hemisphere with higher gph values over the tropics and low gph values over higher latitudes indicating a climatological temperature gradient directed from equator to polewards as in the case of 50 and 30 hPa levels. The waves in the mid latitude westerlies carry the temperature from lower latitudes to higher latitudes as a part of large scale general circulations system. The positive C.C. areas in the lower latitudes and negative (less positive) C.C. areas over Eurasian region indicate that prior to a good (bad) monsoon the equator to Eurasian directed temperature gradient is stronger (weaker) than normal. Stronger (weaker) than normal temperature gradient indicates stronger (weaker) than normal mid latitude westerlies and reduced (increased) wave activities. The persistence of increased wave activities over Eurasian region cause incursion of dry and cold westerly in to the monsoon region it weakens the easterly jet and hence the monsoon (Rajeevan *et al.*, 1998). Same feature is

observed at 100 hPa level also. During the month of February [Fig. 3(a)] a ridge along 10° - 20° N is conducive for good monsoon (Thapliyal, 1984). This ridge was also visible on higher levels (50 hPa and 30 hPa) during the month of February [Fig. 2(b) and Fig. 1(d)]. During the month of April and May Figs. 3(c-d) negative (or less positive) C.C. is observed over Pacific Ocean and positive C.C. is observed north of it. It indicates that prior to a good (bad) monsoon temperature gradient is weaker (stronger) than normal over this region and it leads to increased wave activity over this region.

4. Potential precursors of Indian summer monsoon rainfall

In section 3, it is observed that the stratosphere geopotential heights at 30, 50, 100 hPa level at certain critical geographical areas have significant teleconnections with Indian Summer Monsoon Rainfall (ISMR). To identify the useful precursory signals for ISMR, predictors were derived as the simple arithmetic average of monthly gph values over the respective geographical regions, which are having significant C.C. at all the three levels (30, 50, 100 hPa). The geographical regions and time period were listed in second and third column of respective tables. An index name is given to each predictor in the last column of each Table. The 21-year moving correlation coefficient (C.C.) between these selected indices and ISMR were calculated for examine stability of the relationship. Figs. 4, 5 & 6 shows the 21 year sliding correlation between 30, 50, 100 hPa and ISMR respectively. From the Figs. 4-6 it is clear that

TABLE 1

Details of the predictors from 30 hPa level

S. No.	Spatial domain	Period	C.C. with ISMR 1974-2001 (significant level)	Index name
1.	70° N - 80° N 90° W - 50° W	Oct	0.61(99%)	Oct1_30
2.	50° N - 65° N 115° W - 80° W	Dec	0.44(95%)	Dec1_30
3.	35° N - 45° N 115° E - 135° E	Dec	-0.43(95%)	Dec2_30
4.	10° N - 15° N 79° E - 90° E	Feb	0.49(99%)	Feb1_30
5.	70° N - 85° N 180° W - 120° W	Feb	-0.52(99%)	Feb2_30
6.	45° N - 60° N 120° W - 80° W	Mar	0.68(99%)	Mar1_30
7.	55° N - 65° N 20° E - 40° E	Mar	-0.48(95%)	Mar2_30

TABLE 2

Details of the predictor from 50 hPa level

S. No.	Spatial domain	Period	C.C. with ISMR 1974-2001(significant level)	Index name
1.	50° N - 60° N 60° W - 30° W	Feb	-0.4151(95%)	Feb1_50

TABLE 3

Details of the predictors from 100 hPa level

S. No.	Spatial domain	Period	C.C. with ISMR 1975-2001(significant level)	Index name
1.	45° N - 55° N 55° W - 40° W	Jan	-0.47 (95%)	Jan1_100
2.	15° N - 20° N 100° E - 125° E	Feb	0.46 (95%)	Feb1_100
3.	40° N - 55° N 75° E - 100° E	Mar	0.53 (99%)	Mar1_100
4.	50° N - 65° N 120° W - 95° W	Mar	0.51 (99%)	Mar2_100
5.	45° N - 55° N 40° W - 20° W	Mar	0.54 (99%)	Mar3_100
6.	55° N - 65° N 140° W - 110° W	Apr	0.55 (99%)	Apr1_100
7.	15° N - 30° N 55° E - 90° E	May	0.65 (99%)	May1_100
8.	25° N - 35° N 70° W - 50° W	May	0.60 (99%)	May2_100
9.	25° N - 35° N 120° W - 100° W	May	0.52 (99%)	May3_100
10.	65° N - 75° N 140° E - 160° W	May	0.50 (99%)	May4_100

Predictor set consist of

- (i) May4_100 (X1)
- (ii) Feb1_50 (X2)
- (iii) Dec2_30 (X3)

Model equation is

$$Y = -2573.0213 + X1* 0.039156 + (X 2*-0.257) + (0.13127*X3)$$

Where Y is response (ISMR). Model development period was chosen from year 1975 to 1997 and verification period from year 1998 to 2001.

Fig. 7 shows the graph between observed and predicted ISMR. From the Fig. 7, it is clear that this model is explaining sign of the ISMR in the independent year except the year 1998. This model does not explain all the years. But this model is explaining about 70% of variance of ISMR. C.C. between actual and predicted ISMR for independent year is 0.78 and during model development period C.C. is 0.82. Root Mean Square Error (RMSE) of the model is 5.45, which is less than the model based on pure climatology. From this model it is clear that these predictors are having some predictive skill for long range

21-year sliding C.C. is statistically significant and stable. Some of the regions are having sliding C.C. significant even at 99 % significant level, so these predictors can be used for prediction of ISMR. Only those indices were listed in tables, which are having significant C.C. with ISMR and 21 year moving C.C. with ISMR is stable. By this process we got 7 gph indices from 30 hPa, 1 gph indices from 50 hPa and 10 gph indices from 100 hPa level as shown in Tables 1, 2 & 3 respectively.

5. Application in forecasting Indian summer monsoon rainfall

In section 4 it is found that certain region at 30, 50, 100 hPa geopotential heights are linked with ISMR and their sliding correlation with ISMR is stable. Keeping in this view a simple multiple linear regression equation is developed between these predictors and ISMR. Different models are developed for predicting ISMR using different predictors. A simple model for predicting ISMR using predictor from 30, 50, 100 hPa levels is explained below.

Following Predictors were chosen for the model as listed in Tables 1, 2 and 3. This model is having one predictor from every 100, 50, 30 hPa level.

forecasting of ISMR. So these predictors can be used with other predictors for long range forecasting of Indian summer monsoon rainfall.

6. Conclusions

On examining the relationship between monthly geopotential heights at 30, 50, 100 hPa level and Indian summer monsoon rainfall for the months October of previous year [Oct (-1)] to May of the reference monsoon year, the following conclusions can be drawn.

(i) The lagged correlations shows that ISMR variability is significantly correlated with geopotential heights at all the three stratospheric levels.

(ii) During the months of October (-1), November (-1) and December (-1) in all the stratospheric levels significant positive C.C. were observed over higher latitudes and significant negative C.C. were observed over lower latitudes, this indicates weaker (stronger) than normal meridional temperature gradient during the excess (deficient) monsoon year.

(iii) During the months of February, March, April and May significant positive C.C. are observed over lower latitudes and significant negative C.C. are observed over higher latitudes indicating stronger (weaker) than meridional temperature gradient during the excess (deficient) monsoon year, *i.e.*, from December (-1) to February the meridional temperature gradient get reversed.

(iv) From the significant teleconnection patterns at the stratospheric levels, around 17 indices of gph were identified that were having significant and stable relationship with ISMR. Among the various predictive signals derived from various geographical areas, one that derived from North America showed highest persistency as reflected in the monthly C.C. patterns of gph. A significant positive teleconnection can be identified over North America that showed movement to lower levels during successive months prior to the monsoon season. This teleconnection was found to move to lower levels from October (-1) at 30 hPa to March at 100 hPa level.

(v) Usefulness of these predictors for forecasting ISMR was tested by developing a simple multiple regression model using the predictors from all the three levels. The model was able to explain the sign of ISMR in most of the years. RMSE of the model was less than the model based on pure climatology. This indicates usefulness of these predictors from stratosphere for the long range forecast of ISMR.

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