GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L11809, doi:10.1029/2009GL038207, 2009

Pre-monsoon zonal wind Index over Tibetan Plateau and sub-seasonal Indian summer monsoon rainfall variability

S. S. Dugam,[1] S. D. Bansod,[1] and S. B. Kakade[1]

Received 16 March 2009; revised 30 April 2009; accepted 11 May 2009; published 5 June 2009.

[1] In this paper, by using the Principal Component Analysis (PCA) technique monthly zonal wind indices over Tibetan Plateau (25°N–45°N, 75–105°E) (TP) at 200 hPa have been constructed for the period 1948–2006. These indices are referred as Tibetan Zonal Wind Index (TZWI). The relationship between the TZWI and Indian summer monsoon rainfall on monthly basis has been studied by the correlation analysis. From the analysis, it is observed that pre-monsoon months (April and May) of TZWI show the significant inverse relationship with June and July rainfall over India respectively. The study may be useful for forecasting rainfall activity in June and July months, which are crucial months from the agricultural point of view.
Citation: Dugam, S. S., S. D. Bansod, and S. B. Kakade (2009), Pre-monsoon zonal wind Index over Tibetan Plateau and sub-seasonal Indian summer monsoon rainfall variability, *Geophys. Res. Lett.*, *36*, L11809, doi:10.1029/2009GL038207.

1. Introduction

[2] The June and July rainfall activity over the Indian region is very important from the agriculture point of view. In the recent years of 2002 and 2004, July rainfall was largely deficient, rainfall departure being −49% and −19% respectively. However, no dynamical and statistical models have estimated such a large deficient rainfall anomaly. Therefore, it is necessary to search the atmospheric signal to give some idea about the sub-seasonal rainfall activity well in advance.

[3] Owing to the sparse nature of the data availability on TP prior to the 1980s, studies relating the Indian summer monsoon rainfall and any meteorological field over the TP are scarce. The availability of good-quality of data over the TP during the recent period provides an opportunity to explore various aspects of the effects of the TP and its relationship with the Indian summer monsoon circulation.

[4] The Tibetan Plateau has been mentioned as one of the most important factor for the generation and maintenance of summer monsoon circulation over India. It has been recognized as the heat source/sink in summer/winter for the monsoon circulation over India. During NH summer, the TP due to its high elevation receives a large amount of solar radiation, which effectively heats up the mountain surface and creates a strong heat contrast at the mid-troposphere level. This causes a heat low near the surface and anticyclone (Tibetan High) above. The sensible heat as well as latent heat flux released over the TP drives the Asian monsoon circulation and strongly influence global circulation patterns. The importance of the TP in Asian monsoon rainfall variability is studied by large number of scientists, e.g., *Flohn* [1965, 1968], *Krishnamurti* [1971], *Chang* [1981], *Luo and Yanai* [1983], *Fu and Fletcher* [1985], *Li and Song* [1992], *Yasunai* [1998], *Lin and Zhao* [2000], *Yin et al.* [2000], *Liu and Chen* [2000], and many more. The thermal effects of TP on the planetary-scale summer monsoon circulation have been studied by *Gao et al.* [1981], *Nitta* [1983], *Luo and Yanai* [1984], *Shi and Smith* [1992], *Yanai et al.* [1992], etc. The role of circulation over TP in pre-monsoon also plays an important role as evident by number of studies. Results of General Circulation Model (GCM) experiments, *Ose* [1996] showed that the anomalous cooling due to positive snow mass anomalies in early spring over Tibet tends to produce a weak Asian monsoon. *Kripalani et al.* [2003] have suggested that the spring snowmelt in the western Himalayas may be related to rainfall over India in the following summer. Recent studies have shown that the heating and cooling over the TP have significant effects on the South and East Asian monsoons [*Ueda and Yasunai*, 1998]. *Luo and Yanai* [1983] described the eastern plateau as a huge chimney funneling water vapour from the lower to the upper troposphere. Consequently, monthly mean rainfall in the eastern plateau is observed to be more than that of the western plateau. *Murakami* [1987] showed that the sensible heat flux is extremely large over arid western Tibetan Plateau during June as compared to the eastern side. Therefore, there is a sharp contrast between the western and eastern plateau in terms of precipitation and moisture distribution.

2. Data and Method

[5] The daily grid point zonal wind data(u) over the Tibetan Plateau (25–45°N, 75–105°E) at 200 hPa for the period 1948–2006 have been taken from CDAS-NCEP/

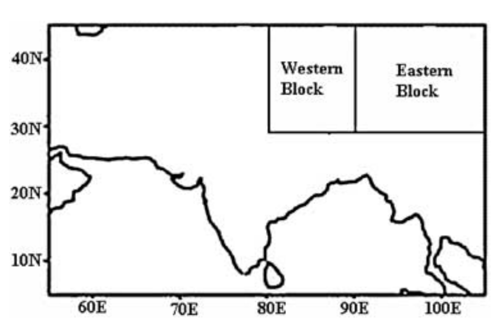

Figure 1. The region for the development of Tibetan zonal wind Index.

[1]Indian Institute of Tropical Meteorology, Pune, India.

0094-8276/09/2009GL038207

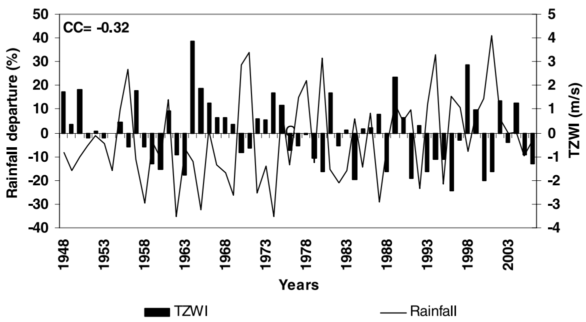

Figure 2a. Relationship between Tibetan zonal wind index in April and June Rainfall departure in (%) over India for 1948–2006.

NCAR reanalysis data from the website nomad3.ncep.noaa.gov.

[6] For the development of zonal wind indices over the TP the entire plateau has been divided in to two blocks (Figure 1), one is western block (30–45°N, 80–90°E) and another is eastern block (30–45°N, 90–105°E). PCA method has been applied to daily grid point u component (at 200hPa) over two blocks mentioned above. The monthly u component time series (combining the PC1+PC2) have been constructed for both the blocks. The variance explained by PC1 plus PC2 over the two blocks are 92 % and 88 % respectively. The monthly gradient between western and eastern blocks have been computed by taking the difference between (PC1+PC2) of respective block and referred as TZWI.

[7] The monthly Indian summer monsoon rainfall data have been taken from the website http://www.tropmet.res.in.

3. Discussions

[8] The correlation coefficients between pre-monsoon months TZWI and summer monsoon rainfall over India have been computed for all four monsoon months from June to September. From the analysis it is observed that April and May TZWI show significant (5% level) inverse relationship with the June and July rainfall respectively as depicted in Figures 2a and 2b. The stability of relationship is tested using the 30 years running window technique and results are presented in Figures 3a and 3b. From Figures 3a and 3b it is seen that after 1970 the relationship is quite significant

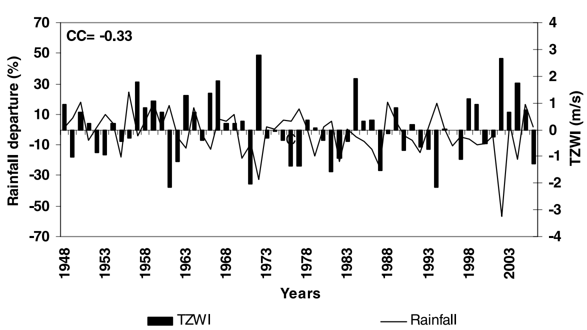

Figure 2b. Relationship between Tibetan zonal wind index in May and July Rainfall departure in (%) over India for 1948–2006.

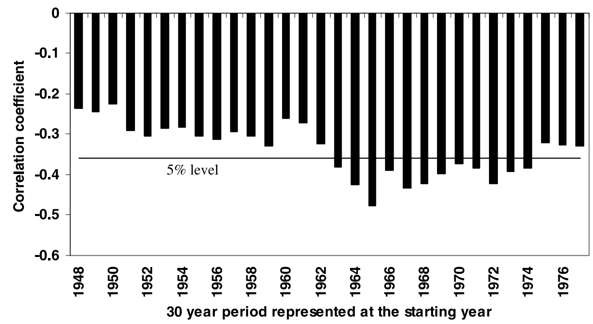

Figure 3a. 30 year running CC between Tibetan zonal wind index in April and rainfall departure in (%) over India in June.

for July and stable. However, significance of the relationship (Figure 3a) between April TZWI and June rainfall somewhat declines in recent period.

[9] There is no significant relationship between pre-monsoon months TZWI and August and September rainfall. It is difficult to explain why there is no significant relationship between pre-monsoon TZWI and August and September rainfall. The probable reason may be that after established phase of monsoon other components of monsoon play a crucial role.

4. Development of a Regression Model

[10] In this section, an attempt has been made to develop a simple linear regression model for the summer monsoon rainfall of June and July with April and May TZWI respectively as predictor for the period 1948–2006. The performance of a regression model is shown in Figures 4a and 4b. It is seen that the observed and estimated rainfall shows close resemblance after 1972. Also the performance of model is tested by using Jackknife method [*Shao and Tu*, 1995]. The model is tested for July rainfall. A model is developed repeatedly using 39 (1968–2006: a stable and significant period) years of data, leaving each time 1 year, randomly selected, for testing the model. The relationship developed has the form:

$$R_i = a_0 + a_i x_i + e;$$
$$i = 1, 2, \ldots, n (\text{where } n \text{ is the number of years})$$

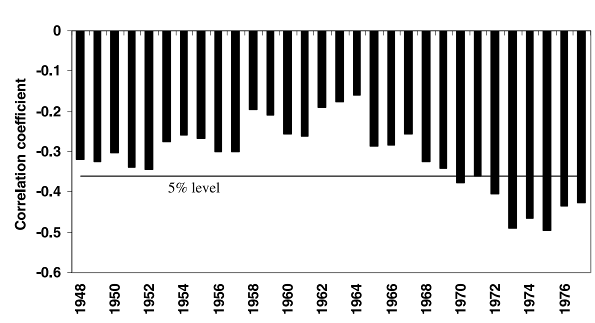

Figure 3b. 30 year running CC between Tibetan zonal wind index in May and rainfall departure in (%) over India in July.

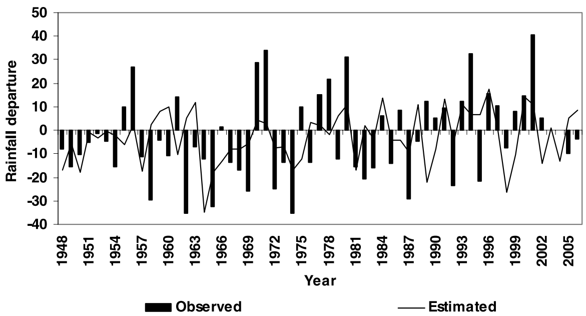

Figure 4a. The actual and estimated rainfall departure in (%) for June.

where, R_i is the predictant (i.e., standardized monsoon rainfall of July), a_0, is the constant term, a_i is the coefficients of the model, x_i is the predictors (i.e., TZWI) considered and e is the error associated with the predictant R_i. The performance of the model has been determined, based on these 39 independent cases of forecast. The root mean square error (RMSE), absolute error (ABSE), and bias used by *Nicholls* [1984] have been computed as measures of the forecast performance. The RMSE = 0.91, BIAS = 0.05 and ABSE = 0.69 of the model is found to be very low. The performance of the model for July is shown in Figure 5.

[11] The physical cause of such a relationship can be quite complex, since the impact of the TP is twofold. First, it acts as a major mechanical blocking barrier that influences both the zonal and the meridional flows. A number of studies, by various scientists show the below-normal temperatures, snow depth and snowmelt during winter and early spring changes circulation patterns over Eurasia and hence affects the strength of the subsequent Indian monsoon [*Barnett et al.*, 1989; *Yasunari et al.*, 1991; *Yanai et al.*, 1992; *Vernekar et al.*, 1995; *Douville and Royer*, 1996; *Kripalani and Kulkarni*, 1999; *Bansod et al.*, 2003; *Kripalani et al.*, 2003]. Recently *Liu and Yin* [2001] have shown that during the years of high North Atlantic Oscillation (NAO, which is a climatic phenomenon of fluctuations in sea level pressure of Icelandic Low and Azores High in the North Atlantic Ocean) index, there is more precipitation anomalies on western TP, which is more as compared to eastern TP and vice versa in low NAO index cycle. This will change the temperature gradient in western and eastern blocks and may change the zonal wind strength. Positive TZWI indicates that strength of westerly is more in western block as compared to eastern block, which may alter the position

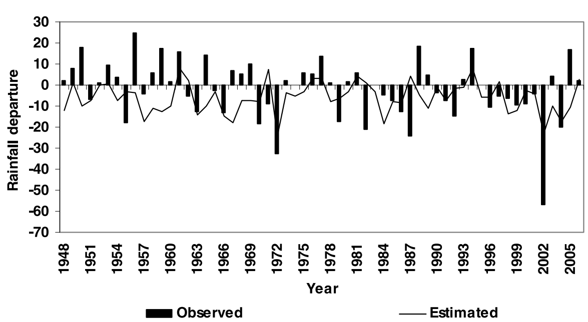

Figure 4b. The actual and estimated rainfall departure in (%) for July.

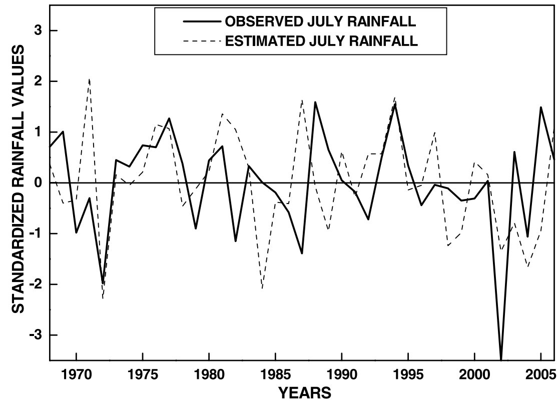

Figure 5. Actual and estimated standardized rainfall for July by Jackknife method.

of Tibetan anticyclone in subsequent June and July. Hence, there may be a change in rainfall activity over Indian region.

5. Conclusions

[12] In this study the monthly variability of TZWI and sub-seasonal rainfall over India has been examined. Based on this the following conclusion are drawn.

[13] The pre-monsoon month's zonal wind index gradient over the Tibetan Plateau in April and May are useful parameter for forecasting the monsoon rainfall variability in June and July months, which are crucial months for agricultural activity and planning.

[14] **Acknowledgments.** Authors are grateful to B. N. Goswami, Director, IITM, P. N. Mahajan, Head, Forecasting Research Division for encouragement and guidance and Department of Science and Technology (DST), Government of India for providing necessary facilities.

References

Bansod, S. D., Z.-Y. Yin, Z. Lin, and X. Zhang (2003), Thermal field over Tibetan Plateau and Indian summer monsoon rainfall, *Int. J. Climatol.*, *23*, 1589–1605.

Barnett, T. P., L. Dumenil, U. Schlese, E. Roeckner, and J. M. Latif (1989), The effect of Eurasian snow cover on regional and global climate variations, *J. Atmos. Sci.*, *46*, 661–685.

Chang, C. C. (1981), A contrasting study of the rainfall anomalies between central Tibet and central India during the summer monsoon season 1979, *Bull. Am. Meteorol. Soc.*, *62*, 20–22.

Douville, H., and J. P. Royer (1996), Sensitivity of the Asian summer monsoon to an anomalous Eurasian snow cover within the Météo-France GCM, *Clim. Dyn.*, *12*, 449–466.

Flohn, H. (1965), Thermal effects of the Tibetan Plateau during the Asian monsoon season, *Aust. Meteorol. Mag.*, *13*, 55–57.

Flohn, H. (1968), Contribution to a meteorology of the Tibetan Highland, *Atmos. Sci. Pap. 130*, Colo. Univ., Fort Collins.

Fu, C., and J. Fletcher (1985), The relationship between Tibet-tropical ocean thermal contrast and interannual variability of Indian monsoon rainfall, *J. Clim. Appl. Meteorol.*, *24*, 841–847.

Gao, Y. X., M. C. Tang, S. W. Luo, Z. B. Shen, and C. Li (1981), Some aspects of recent research on the Qinghai-Xizang Plateau meteorology, *Bull. Am. Meteorol. Soc.*, *62*, 31–35.

Kripalani, R. H., and A. A. Kulkarni (1999), Climatology and variability of historical Soviet snow depth data: Some new perspectives in snow-Indian monsoon teleconnections, *Clim. Dym.*, *15*, 475–489.

Kripalani, R. H., A. A. Kulkarni, and S. S. Sabade (2003), Western Himalayan snow cover and Indian monsoon rainfall: A re-examination with INSAT and NCEP/NCAR data, *Theor. Appl. Climatol.*, *74*, 1–18.

Krishnamurti, T. N. (1971), Tropical east-west circulations during northern summer, *J. Atmos. Sci.*, *28*, 1342–1347.

Li, C., and Z. Song (1992), Seasonal heating of the Tibetan Plateau and its effects on the evolution of the Asian summer monsoon, *J. Meteorol. Soc. Jpn.*, *70*, 319–351.

Lin, Z., and X. Zhao (2000), Temperature anomalies in central and eastern Tibetan Plateau in relation to general circulation patterns 1951–1993, *Int. J. Climatol.*, *20*, 1431–1449.

Liu, X., and B. Chen (2000), Climate warming in the Tibetan plateau during recent decades, *Int. J. Climatol.*, *20*, 1729–1742.

Liu, X., and Z.-Y. Yin (2001), Spatial and temporal variation of summer precipitation over the eastern Tibetan Plateau and the North Atlantic Oscillation, *J. Clim.*, *14*, 2896–2909.

Luo, H., and M. Yanai (1983), The large-scale circulation and heat sources over the Tibetan Plateau and surrounding areas during the early, summer of 1979. Part I: Precipitation and kinematic analysis, *Mon. Weather Rev.*, *111*, 922–944.

Luo, H., and M. Yanai (1984), The large-scale circulation and heat source over the Tibetan Plateau and surrounding areas during the early summer of 1979. II. Heat and moisture budgets, *Mon. Weather Rev.*, *112*, 966–989.

Murakami, T. (1987), Effects of the Tibetan Plateau, in *Monsoon Meteorology*, pp. 235–270, Oxford Univ. Press, New York.

Nicholls, N. (1984), The stability of empirical long-range forecast technique: A case study, *J. Clim. Appl. Meteorol.*, *23*, 143–147.

Nitta, T. (1983), Observational study of heat sources over the eastern Tibetan Plateau during the summer monsoon, *J. Meteorol. Soc. Jpn.*, *61*, 590–605.

Ose, T. (1996), The comparison of the simulated response to the regional snow mass anomalies over Tibet, eastern Europe and Siberia, *J. Meteorol. Soc. Jpn.*, *74*, 845–866.

Shao, J., and D. Tu (1995), *The Jackknife and Bootstrap*, Springer, New York.

Shi, L., and E. A. Smith (1992), Surface forcing of the infrared cooling profile over the Tibetan Plateau. II. cooling-rate variation over large-scale plateau domain during summer monsoon transition, *J. Atmos. Sci.*, *49*, 823–844.

Ueda, H. K., and T. Yasunai (1998), Role of warming over the Tibetan Plateau in early onset of the summer monsoon over the Bay of Bengal and the South China Sea, *J. Meteorol. Soc. Jpn.*, *76*, 1–12.

Vernekar, A. D., J. Zhou, and J. Shukla (1995), The effect of Eurasian snow cover on the Indian monsoon, *J. Clim.*, *8*, 248–266.

Yanai, M., C. Li, and Z. Song (1992), Seasonal heating of the Tibetan Plateau and its effects on the evolution of the Asian summer monsoon, *J. Meteorol. Soc. Jpn.*, *70*, 319–351.

Yasunai, T. (1998), Role of warming over the Tibetan Plateau in early onset of the summer monsoon over the Bay of Bengal South China Sea, *J. Meteorol. Soc. Jpn.*, *76*, 1–12.

Yasunari, T., A. Kitoh, and T. Tokioka (1991), Local and remote responses to excessive snow mass over Eurasia appearing in the northern spring and summer climate—A study with the MRIH-GCM, *J. Meteorol. Soc. Jpn.*, *69*, 473–487.

Yin, Z.-Y., Z. Lin, and X. Zhao (2000), Temperature anomalies in central and eastern Tibetan Plateau in relation to general circulation patterns during 1951–1993, *Int. J. Climatol.*, *20*, 1431–1449.

S. D. Bansod, S. S. Dugam, and S. B. Kakade, Indian Institute of Tropical Meteorology, Dr. Homi Bhabha Road, Pashan, Pune, Maharashtra 411008, India. (dugam@tropmet.res.in)