11.4 THE OBSERVED RELATIONSHIP BETWEEN SNOW COVER, SOIL MOISTURE, AND THE ASIAN MONSOON

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1. Introduction

Using observations of snow cover, soil moisture, surface air temperature, atmospheric circulation, and Indian summer monsoon precipitation, we examine the relationship between interannual variations of the strength of the monsoon and land surface conditions over Eurasia. The basic driver of monsoon circulation is the land-ocean temperature contrast. The simultaneous relationship between ocean temperature and summer monsoon strength cannot be used for prediction, but here we investigate preceding land and atmospheric conditions that can.

Blanford (1884) suggested more than 100 years ago that winter snow cover over the Himalayas may be an important predictor of subsequent summer precipitation over India. In addition to a local influence that involved dry winds sweeping down from the mountains following each precipitation event that would evaporate the fallen rain at the lower levels, reducing the subsequent local source of moisture for precipitation, he also pointed out that remote influences on the large-scale pressure pattern over India are important. If there were high pressure over India, he concluded that these continental scale pressure anomalies would be produced by continental scale land surface conditions. Here we use observations to examine the relationship between preceding land surface conditions and the amount of summer monsoon precipitation in India, making use of a newly-extended data set of snow cover extent (Robinson 2000), the new extended National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis of atmospheric observations (Kistler et al. 2001), tropical sea surface temperatures (Parker et al. 1995), and the Global Soil Moisture Data Bank (Robock et al. 2000).

2. Results

We find that strong Indian summer monsoon precipitation is preceded by warmer than normal temperatures over Europe and North America in the previous winter and over western Asia in the previous spring, but colder temperatures over Tibet. The European temperature anomalies are related to the positive phase of the North Atlantic Oscillation (NAO). Related negative snow cover anomalies in Europe in winter and central Asia in spring (Fig. 1) are produced by circulation and temperature anomalies. The snow-albedo feedback is always operating and prolongs the winter temperature anomalies into the spring and summer when they influence the monsoon, but the snow by itself does not physically control the monsoon. Anomalous snow cover impacts on temperature are not prolonged by soil moisture feedbacks, and there is no obvious relationship between soil moisture and the monsoon (Fig. 1). A regression using previous winter NAO and quasi-biennial oscillation, and simultaneous ocean temperature anomalies, explains most of the variance of interannual Indian monsoon rainfall variations. Figure 2 shows all the time series used in the regression and the results of the regression compared to the Indian monsoon summer precipitation observations.

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3. References

Blanford, H. F., 1884: On the connexion of the Himalaya snowfall with dry winds and seasons of drought in India. *Proc. Roy. Soc. London*, **37**, 3-22.

Kistler, R., et al., 2001: The NCEP-NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation, *Bull. Amer. Met. Soc.*, **82**, 247-268.

Parker, D. E., Folland, C. K. and Jackson, M., 1995: Marine surface temperature: observed variations and data requirements. *Climatic Change*, **31**, 559-600. [We use a common El Niño index, the seasonal standardized anomaly of SST in the Niño 3.4 region (5°N-5°S, 120°-170°W), calculated using this HadCRUT data set, available at http://www.cru.uea.ac.uk/cru/data/temperature/ .]

Robinson, D. A., 2000: Weekly Northern Hemisphere snow maps: 1966-1999. *Proc. 12th Conference Applied Climatology, Asheville, NC*, (American Meteorological Society, Boston), 12-15.

Robock, Alan, Konstantin Y. Vinnikov, Govindarajalu Srinivasan, Jared K. Entin, Steven E. Hollinger, Nina A. Speranskaya, Suxia Liu, and A. Namkhai, 2000: The Global Soil Moisture Data Bank. *Bull. Amer. Met. Soc.*, **81**, 1281-1299.

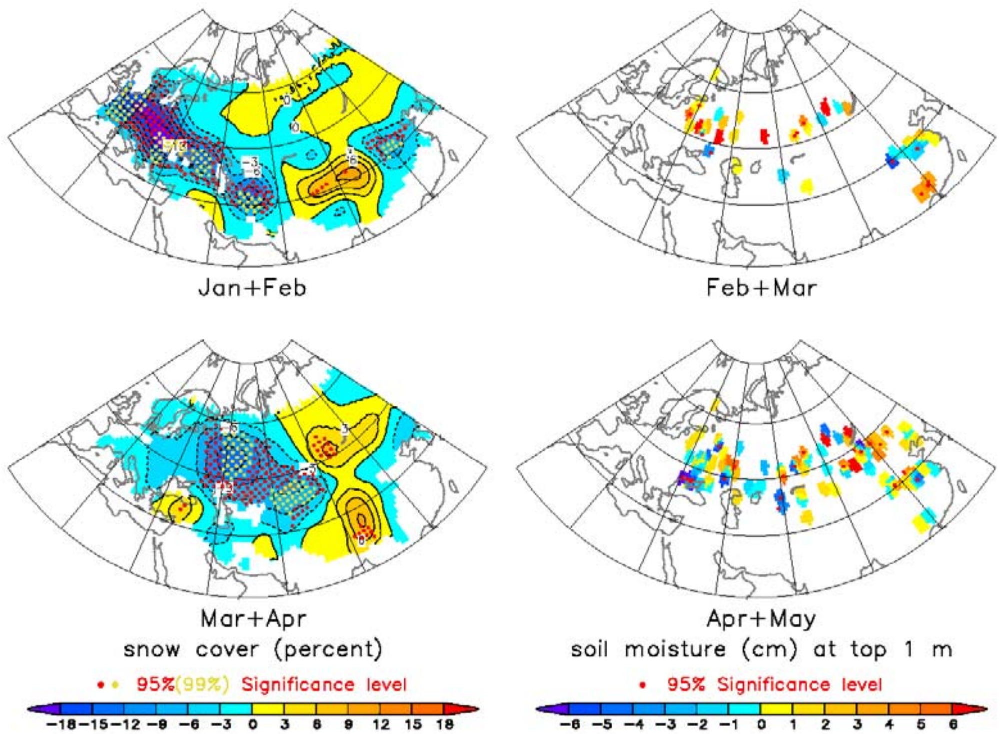

Figure 1. Composite of snow cover and soil moisture patterns for winter and spring preceding summers of high All-India rainfall minus those of low All-India rainfall for the period 1967-2000. Grid points where the signal is significant at the 95% level using a Monte Carlo test are labeled with red dots (•) and those at the 99% level have yellow dots (•).

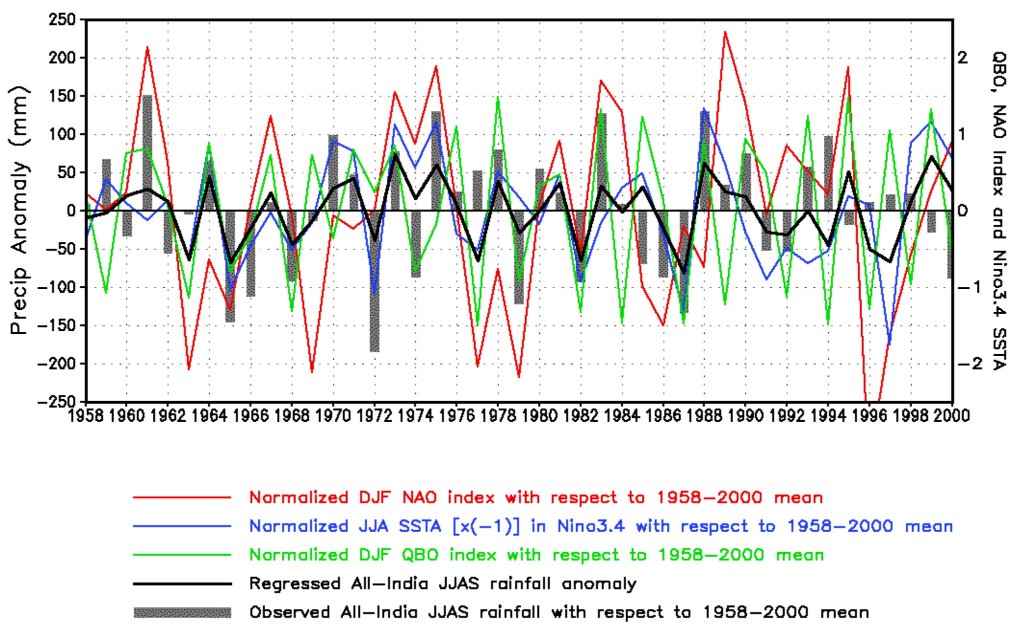

Figure 2. All India rainfall (AIR) anomalies, NAO index, Pacific sea surface temperature anomalies (SSTA) from the Niño 3.4 region, and QBO index. All indices are plotted so that if their anomalies are the same sign as the AIR anomalies, they are positively correlated. The NAO, SSTA, and QBO are normalized by dividing by their standard deviation. The standard deviation for AIR is 83 mm. Also shown is a curve of the multiple linear regression of the AIR based on the three predictors shown. This regression explains 51% of the variance of the observed AIR.