Intraseasonal oscillations and interannual variability of surface winds over the Indian monsoon region

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The role of intraseasonal oscillations (ISOs) in modulating synoptic and interannual variations of surface winds over the Indian monsoon region is studied using daily averaged National Centers for Environmental Prediction/National Centre for Atmospheric Research (NCEP/NCAR) reanalyses for the period 1987–1996. Two dominant ISOs are found in all years, with a period between 30–60 days and 10–20 days respectively. Although the ISOs themselves explain only about 10–25% of the daily variance, the spatial structure of variance of the ISOs is found to be nearly identical to that of high frequency activity (synoptic disturbances), indicating a significant control by the ISOs in determining the synoptic variations. Zonal and meridional propagation characteristics of the two modes and their interannual variability are studied in detail.

The synoptic structure of the 30–60 day mode is similar in all years and is shown to be intimately related to the strong ('active') or weak ('break') phases of the Indian summer monsoon circulation. The peak (trough) phase of the mode in the north Bay of Bengal corresponds to the 'active' ('break') phase of monsoon strengthening (weakening) the entire large scale monsoon circulation. The ISOs modulate synoptic activity through the intensification or weakening of the large scale monsoon flow (monsoon trough). The peak wind anomalies associated with these ISOs could be as large as 30% of the seasonal mean winds in many regions. The vorticity pattern associated with the 30–60 day mode has a bi-modal meridional structure similar to the one associated with the seasonal mean winds but with a smaller meridional scale. The spatial structure of the 30–60 day mode is consistent with fluctuations of the tropical convergence zone (TCZ) between one continental and an equatorial Indian Ocean position. The 10–20 day mode has maximum amplitude in the north Bay of Bengal, where it is comparable to that of the 30–60 day mode. Elsewhere in the Indian Ocean, this mode is almost always weaker than the 30–60 day mode. In the Bay of Bengal region, the wind curl anomalies associated with the peak phases of the ISOs could be as large as 50% of the seasonal mean wind curl. Hence, ISOs in this region could drive significant ISOs in the ocean and might influence the seasonal mean currents in the Bay.

On the interannual time scale, the NCEP/NCAR reanalysed wind stress is compared with the Florida State University monthly mean stress. The seasonal mean stress as well as interannual standard deviation of monthly stress from the two analyses agree well, indicating absence of any serious systematic bias in the NCEP/NCAR reanalysed winds. It is also found that the composite structure of the 30–60 day mode is strikingly similar to the dominant mode of interannual variability of the seasonal mean winds indicating a strong link between the ISOs and the seasonal mean. The ISO influences the seasonal mean and its interannual variability either through increased/decreased residence time of the TCZ in the continental position or through occurrence of stronger/weaker active/break spells. Thus, the ISOs seem to modulate all variability in this region from synoptic to interannual scales.

Keywords. Surface winds; intraseasonal oscillations; interannual variability.
1. Introduction

The Indian summer monsoon is known to have intra-seasonal fluctuations that are manifested in the form of active and weak (or break) spells of monsoon rainfall. These active and break spells of the monsoon are associated with fluctuations of the tropical convergence zone (TCZ) (Yasunari 1979, 1980, 1981; Sikka and Gadgil 1980; Gadgil 1988). The TCZ over the Indian monsoon region represents the ascending limb of the regional Hadley circulation. Thus the intraseasonal oscillations (ISO) of the monsoon are essentially a manifestation of fluctuations of the regional Hadley circulation. Therefore, these oscillations should be seen in other circulation features (e.g. wind) and precipitation as well. These fluctuations initially noted in Indian station data (Keshavamurthy 1973; Dakshinamurti and Keshavamurthy 1976) were later shown to be related to coherent fluctuations of the regional Hadley circulation (Krishnamurti and Subramaniam 1982; Murakami et al 1984; Mehta and Krishnamurti 1988; Hartman and Mitchellson 1989). The intraseasonal oscillation of the monsoon, though not periodic, has two dominant bands in the spectrum (Krishnamurti and Bhalme 1976; Krishnamurti and Ardunay 1980; Yasunari 1980). One band contains the period between 10 and 20 days while the other contains period between 30 and 50 days. The 10–20 day oscillation has a clear westward propagation and a weak northward propagation in the northern hemisphere (NH). The 30–50 day oscillation has a northward and eastward propagation over the monsoon region.

Most studies so far on ISOs of the monsoon have been limited to upper air data, outgoing long wave radiation (OLR) or precipitation. No careful documentation of the ISOs of surface wind is available. This is because reliable daily surface wind data covering the large Indian Ocean region was not readily available. With the availability of the NCEP/NCAR reanalyses products (see section 2), we are now in a position to examine the ISOs of the surface wind. As the surface winds drive oceanic circulation, it is possible that ISOs of the surface wind are responsible for driving intraseasonal variability in the Indian Ocean. Recently, direct measurements by Schott et al (1994) using three moorings and shipboard profiling during January 1991 to February 1992 show a clear oscillation with a period of about one month in the upper ocean zonal transport off Sri Lanka. These intraseasonal oscillations in the ocean transport (or currents) are most vigorous during the south-west monsoon season, when the monsoonal ISOs are also most vigorous.

The Indian summer monsoon is a unique phenomenon in the global tropics. The seasonal mean monsoon (precipitation as well as circulation) is determined by seasonal migration of the mean position of the zonal TCZ in this region from south of the equator during the northern winter to about 25°N in northern summer. It is also known that the TCZ does not remain stationary during the summer season but fluctuates intermittently between two favoured positions (Sikka and Gadgil 1980). One such region is over the Indian continent along the ‘monsoon trough’ extending from north Bay of Bengal to north-western India. The other favoured position is over the warm waters in the equatorial Indian Ocean. The fluctuations of the TCZ within the season are intimately linked to ISOs of the monsoon. The relative residence time of the TCZ in the two favoured locations is expected to determine the seasonal mean precipitation and circulation. During an average northern summer the residence time over the continental position is higher resulting in higher seasonal precipitation over the continent during this season. Changes in the relative residence time in the two favoured locations could change the seasonal mean. Therefore, the statistics of the ISOs are expected to be related to the seasonal mean and its interannual variability. Moreover, the synoptic disturbances (lows and depressions) in this region generally form in the shear zone of the TCZ. Since the ISOs are linked to fluctuations of the TCZ, it is logical to expect that the ISOs modulate synoptic activity too.

A conceptual model of how the ISOs can influence the interannual variability of the monsoon was proposed by Goswami (1994). The relationship between the intraseasonal variability and interannual variability (IAV) of the Indian monsoon, however, has not been clearly documented from observations. Not many studies have actually addressed the question. Mehta and Krishnamurti (1988) examined the interannual variability of the 30–50 day mode in the winds, at 850 and 200 mb levels for the period 1980 to 1984 using European Centre for Medium Range Weather Forecasts (ECMWF) operational analysis. They examined mainly the variations in the northward propagation characteristics and did not attempt to relate these to variations of the seasonal mean. Moreover, the ECMWF operational analysis was deficient in representing tropical divergent circulation in that period (Trenberth and Olson 1988). Therefore, the results of Mehta and Krishnamurti (1988) could have been influenced by this bias in the analysis. Singh and Kripalani (1990) and Singh et al (1992) used long records of daily rainfall data over the Indian continent and examined the 30–50 day oscillation of the precipitation. They could not come to a clear conclusion regarding the relationship between ISOs and IAV of the monsoon rainfall. Ahlquist et al (1990) studied radiosonde observations at 12 Indian stations between 1951 and 1978. They examined ISOs with period longer than 10 days but did not try to relate the ISOs with IAV of the monsoon. Recently, Ferranti et al (1997) studied the relationship between intraseasonal