Intra-seasonal variations of kinetic energy of lower tropospheric zonal waves during northern summer monsoon

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Space spectral analysis of zonal (u) and meridional (v) components of wind and time spectral analysis of kinetic energy of zonal waves at 850 hPa during monsoon 1991 (1st June 1991 to 31st August 1991) for the global belt between equator and 40°N are investigated. Space spectral analysis shows that long waves (wavenumbers 1 and 2) dominate the energetics of Region 1 (equator to 20°N) while over Region 2 (20°N to 40°N) the kinetic energy of short waves (wavenumbers 3 to 10) is more than kinetic energy of long waves. It has been found that kinetic energy of long waves is dominated by zonal component while both (zonal and meridional) the components of wind have almost equal contribution in the kinetic energy of short waves.

Temporal variations of kinetic energy of wavenumber 2 over Region 1 and Region 2 are almost identical. The correlation matrix of different time series shows that (i) wavenumber 2 over Regions 1 and 2 might have the same energy source and (ii) there is a possibility of an exchange of kinetic energy between wavenumber 1 over Region 1 and short waves over Region 2. Wave to wave interactions indicate that short waves over Region 2 are the common source of kinetic energy to wavenumber 2 over Regions 1 and 2 and wavenumber 1 over Region 1. Time spectral analysis of kinetic energy of zonal waves indicates that wavenumber 1 is dominated by 30-45 day and bi-weekly oscillations while short waves are dominated by weekly and bi-weekly oscillations.

The correlation matrix, wave to wave interaction and time spectral analysis together suggest that short period oscillations of kinetic energy of wavenumber 1 might be one of the factors causing dominant weekly (5-9 day) and bi-weekly (10-18 day) oscillations in the kinetic energy of short waves.

1. Introduction

The Fourier technique is widely used to study the spectral characteristics of various atmospheric parameters in both space and time domain. The advantage of the Fourier technique is that the observed field gets decomposed into independent components. These components are called harmonics. Space harmonics are called zonal waves while time harmonics are called frequencies. Through space spectral analysis one can study the energetics of zonal waves and energy exchange among them. Time spectral analysis gives information regarding the variability (periodicity) of atmospheric parameters.

There are a number of studies where the Fourier technique has been used either for space or time domain. For example, works of Saltzman (1970); Krishnamurti and Kanamitsu (1981); Murakami (1981); Awade and Bawiskar (1982); Bawiskar et al (1989); Bawiskar and Singh (1992) are related to space spectral analysis while studies of Krishnamurti and Bhalme (1976); Lau and Chan (1988); Leite and Peixoto (1995) refer to time spectral analysis.

Shapiro and Fred (1960) examined the time-space spectrum of kinetic energy of the geostrophic meridional wind. Kao (1968) presented two dimensional (space and time) Fourier transform method. Dapradine (1978) has examined space-time spectra of the 200 mb motion field. Hayasi (1979b) presented a method of computing wavenumber frequency cross spectra.

In the present study, we propose to address the following points:

Keywords. Space spectral analysis; time spectral analysis.
How the kinetic energy of long waves and short waves varies during the northern summer monsoon?

Are the temporal variations of kinetic energy of long waves and short waves inter-related?

To study these aspects, first we have decomposed the observed \( u \) and \( v \) field at 850 hPa into a spectrum of zonal waves (space spectral analysis) and computed the kinetic energy. The time series of kinetic energy of long waves (wavenumbers 1st and 2) and short waves (wavenumbers 3-10) for 92 days (1st June 1991 to 31st August 1991) are prepared, intercompared and correlated. These time series are further decomposed into a spectrum of frequencies (time spectral analysis) so as to single out dominant oscillations during the northern summer monsoon.

2. Data

Daily \( u \) and \( v \) data at 850 hPa for the period from 1st June to 31st August 1991 were utilized for this study. The data were provided by the National Center for Medium Range Weather Forecasting (NCMRWF), New Delhi. The NCMRWF has a very sophisticated objective analysis and data assimilation system. The data contain objectively analysed gridded field cast 2.5° x 2.5° latitude/longitude grid. We have considered the global area between the equator and 40°N.

The northern summer monsoon of 1991 has been selected because it is one of the normal monsoons of recent years and nearly 75% of Indian land mass received excess or normal rainfall. The broad circulation features of monsoon 1991 at 850 hPa are given in figure 1 which presents the stream function (\( \Psi \)) field. The \( \Psi \) values are computed at each grid point using time averaged (1st June to 31st August 1991) winds. The seasonal monsoon trough over India, south-westerlies over the Indian Ocean and seasonal high pressure cells over the Atlantic and Pacific Oceans are very well depicted (see figure 1) by the data set used for this study.

3. Methodology

Harmonic analysis technique for both space and time domain has been used. Bawiskar and Singh (1992)

Harmonic analysis technique for the computation of kinetic energy of zonal waves in the space. In this study, we have considered the first ten waves. Wavenumbers 1 and 2 represent long waves and wavenumbers 3 to 10 represent short waves. The harmonic analysis technique for time domain has been used by many workers (e.g., Chapman and Lindzen 1970; Haurwitz and Cowley 1973; and Ananthakrishnan et al 1984). The harmonic analysis technique for time domain is briefly discussed below:

Let \( K(t) \) represent kinetic energy of a zonal wave. Here, \( t \) is time. \( K(t) \) is expressed as:

\[
K(t) = \sum_{\omega=0}^{T/2} a_\omega \cos \left( \frac{2\pi \omega t}{T} \right) + b_\omega \sin \left( \frac{2\pi \omega t}{T} \right),
\]

where \( T \) is total number of days. Although we have computed kinetic energy for 92 days (1st June to 31st August 1991), for convenience, we have considered the total period (\( T \)) of 90 days by omitting the first and last day of the time series. \( \omega \) is harmonic number. \( \omega/90 \) gives the number of cycles per day. For example, \( \omega \) equals to 3 represents 3/90 cycles per day, in other words, \( \omega = 3 \) means 30 day period.

Variance explained by an individual harmonic is given by

\[
\sigma_\omega^2 = \frac{1}{T} R_\omega
\]

where,

\[
R_\omega = (a_\omega^2 + b_\omega^2)^{1/2}
\]

\[
\%\sigma_\omega^2 = \frac{(1/2 R_\omega^2)}{(1/2 \sum_{\omega=1}^{T/2} R_\omega^2)} \times 100.
\]

Equation (4) gives the percentage variance explained by an individual harmonic \( \omega \). Since there is one observation in a day, the shortest period for which the spectrum can be estimated is two days.

4. Results and discussion

4.1 Space spectral analysis (wave number domain)

Figure 2 gives latitudinal variation of time averaged (1st June to 31st August 1991) kinetic energy for long waves (wavenumbers 1 and 2) and short waves (wavenumbers 3 to 10). The kinetic energy of long waves increases sharply from the equator to 12.5°N and then decreases northwards, whereas the kinetic energy of short waves gradually increases northwards. In the belt between the equator and 20°N, the kinetic energy of long waves dominates over short waves and in the belt between 20°N and 40°N, the kinetic energy of short waves is more as compared to the kinetic energy of long waves. Considering the above spatial variation of kinetic energy of long waves and short waves, we have