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SHORT CONTRIBUTION

Kinetic energy spectra of divergent wind in the atmosphere

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ABSTRACT

Spectral analysis of kinetic energy of the divergent wind in the zonal wave number domain has been performed using the National Meteorological Center wind field of January 1979. It is shown that the kinetic energy spectrum of the divergent wind in the high wavenumber regime ($8 \leq l \leq 18$) follows a -2 power law.

1. Introduction

The diagnostic analysis of kinetic energy spectra of the atmosphere, e.g., Wiin-Nielsen (1967), exhibits a -3 power law in the high wavenumber regime ($8 \leq l \leq 15$). From theoretical studies of two-dimensional turbulence, Kraichnan (1967) and Leith (1968) suggest that an inertial subrange corresponding to a -3 power law may exist. Numerous efforts have been made to search for the possible existence of an inertial subrange in the large-scale turbulent motion of the atmosphere.

The two-dimensional turbulence theory is concerned with the nondivergent flow, which is a reasonable first approximation to the atmosphere because of the dominance of the rotational component of the wind. Although the divergent component of atmospheric flow may be neglected in calculating the magnitude of kinetic energy, the atmospheric energetics, particularly the generation of atmospheric kinetic energy, depend crucially upon the divergent flow (Chen and Wiin-Nielsen, 1976). Furthermore, the proper treatment of divergent wind is an important aspect of the initialization of numerical forecast models. Thus, it would appear to be of some importance to explore the kinetic energy spectrum of the divergent flow in the atmosphere.

Chen (1980) recently analyzed the kinetic energy spectrum of the divergent wind in the tropics at 200 mb. This result indicates that the kinetic energy spectrum of the divergent wind follows a power law which has a slope of about -2 in the high wavenumber regime. This note presents a more extensive spectral analysis of the divergent wind using the multi-level data of middle latitudes.

2. Data and computation

Since the divergent component of wind field is vital in this study, care should be exercised in the analysis of the wind observations. It has been shown in a previous study (e.g., Chen et al., 1978) that the multivariate analysis of the wind using optimum interpolation at NCAR (National Center for Atmospheric Research) (Schlatter, 1975) yields divergence values of 10^{-5} to 10^{-6} s^{-1}, typical of synoptical-scale disturbances. A variation of this scheme of observational wind analysis has been operational at the National Meteorological Center (NMC) (Bergman, 1979) since late 1978. Therefore, the wind field used in this study was the twice daily (0000 and 1200 GMT) global NMC analysis

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for the month of January 1979 on mandatory pressure surfaces (1000, 850, 700, 500, 400, 300, 250, 200, 150, 100 mb).

The horizontal wind vector is separated into its divergent and rotational components by means of an iterative method proposed by Endlich (1967) and modified by Chen (1975) to a spherical domain. The wind separation is performed over the Northern Hemisphere. In order to compare with some previous spectral analyses of atmospheric kinetic energy, the domain considered in this study is between 15° N and 85° N.

3. Results and discussion

It was mentioned in the introduction that the total wind may be replaced by the rotational wind in calculating the magnitude of the kinetic energy, but, the generation of atmospheric energy depends crucially upon the divergent wind. Table 1 provides an overview of the atmospheric kinetic energy in the Northern Hemisphere north of 15° N during the month of January 1979. K, K_R and K_D are the kinetic energy of the total, rotational and divergent wind, respectively. The subscripts Z and E are zonal and eddy components respectively. K_Z and K_E in January 1979 are somewhat larger than in previous studies, e.g. Wiin-Nielsen (1967). Notice that K_D is only a very small percentage of K. It is also interesting to note that K_{DE} is several times larger than K_{DZ}.

Kinetic energy spectra of the rotational and divergent wind, K_R and K_D, are displayed, respectively, in Fig. 1. Since the rotational wind explains most of atmospheric kinetic energy, the K_R spectrum should represent well the K spectrum. In fact, the K_R spectrum shown in Fig. 1 is similar to the K spectrum of other studies, e.g. Wiin-Nielsen (1967). The salient features of the K_R spectrum are as follows: the ultralong waves, i.e. wavenumbers (l) 1 and 2, have the largest kinetic energy, K_R decreases gradually from $l = 3$ to 7, and a drastic declination of K_R occurs at $l > 7$. The K_R spectrum follows a power law of -3.2 in $8 \leq l \leq 18$. The K_D spectrum decreases gradually as the wavenumber increases in the low wavenumber regime $1 \leq l \leq 7$. A sharp decrease of K_D occurs at $l = 7$. A power law of -2 is obeyed by the K_D spectrum in $8 \leq l \leq 18$. In other words, the reduction of the K_D spectrum is less sharp

Table 1. *Mean values of zonal and eddy kinetic energies of total wind* (K), *rotational wind* (K_R) *and divergent wind* (K_D). *Subscript* Z *and* E *denote zonal and eddy component, respectively. Unit of various kinetic energies is* 10^5 Jm^{-2}

(a) Zonal Component				
K_Z	K_{RZ}	K_{DZ}	K_{RZ}/K_Z	K_{DZ}/K_Z
10.01	9.84	0.17	98.3%	1.7%

(b) Eddy Component				
K_E	K_{RE}	K_{DE}	K_{RE}/K_E	K_{DE}/K_E
11.23	10.49	0.52	93.4%	4.6%

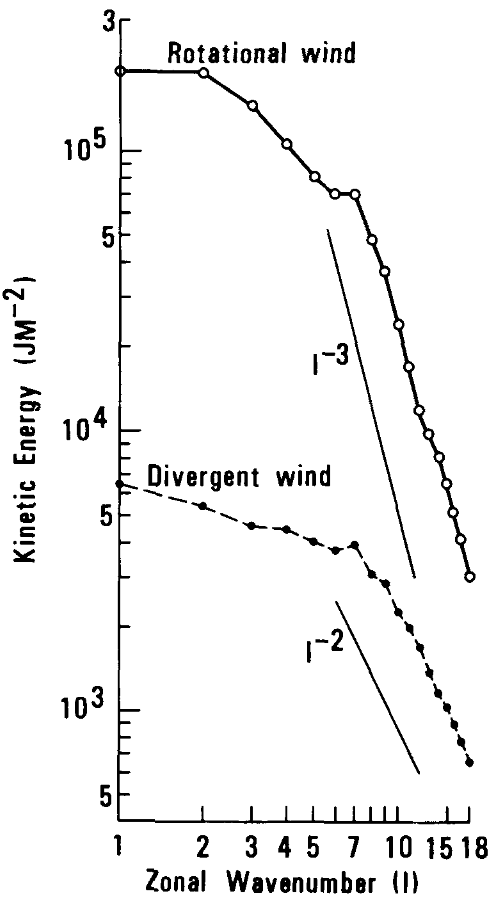

Fig. 1. Kinetic energy spectra of rotational and divergent wind of the atmosphere.

Table 2. *Values of slope as function of pressure*

Pressure (mb)	1000	850	700	500	400	300	250	200	150	100	Vertical Average
K_R	−2.9	−3.1	−3.2	−3.3	−3.4	−2.8	−3.8	−3.8	−3.6	−2.5	−3.2
K_D	−2.4	−2.4	−2.1	−1.7	−1.9	−2.0	−2.1	−2.2	−2.0	−1.6	−2.0

than that of the K_R spectrum when $l > 7$. This alternatively indicates that the ratio between K_D and K_R becomes larger in the high wavenumber regime.

The slope of the K_R and K_D spectra in the high wavenumber range $8 \leq l \leq 18$ are determined by linear regression. The values of slopes at various pressure levels are displayed in Table 2. Comparison between Wiin-Nielsen's (1967) result and Table 2 shows that the slope of K_R in the present study is slightly steeper, but is not unrealistic. The slope of K_D shows a bimodal distribution vertically which is similar to the vertical distribution of K_D in some previous studies (Chen and Wiin-Nielsen, 1976; Chen et al., 1978).

The -3 power law in the high wavenumber regime has been recognized as a necessary condition for the existence of an inertial subrange in two-dimensional turbulence theory. Although the divergent wind is important in atmospheric energetics, we are generally satisfied that K_D is negligible compared with K_R. Therefore, no attempt has been made in the past to explore the K_D spectrum.

It should be noted that a portion of the divergent kinetic energy shown here is probably induced through nonlinear interactions of the rotational wind itself, while the remainder is due to the transient gravity-inertial mode energy. Thus, the geostrophic mode may be indirectly the major contributor to K_D spectrum. A study to investigate this possibility is being undertaken.

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