A New Monsoon Index and the Geographical Distribution of the Global Monsoons

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(Received August 27, 2002; revised January 29, 2003)

ABSTRACT

A new monsoon index, the dynamical normalized seasonality (DNS), is introduced to study the issue of monsoons. This DNS index can describe both seasonal variation and interannual variability of different monsoon regions. It can also be used to delimit the geographical distribution of the global monsoon systems. Furthermore, it is pointed out that the index is very useful for understanding deeply the monsoons to study the difference, relationship, and interactions among the classical monsoon, ordinary monsoon and monsoon-like system.

Key words: dynamical normalized seasonality, monsoon index, global monsoon system

Since the monsoon is a key component of the earth's climate system affecting the livelihood of more than 60% of the world population, it is extremely significant to investigate and forecast the monsoon. To objectively delineate the extent of the monsoon and describe its variability, the first task is simply to define the monsoon and then to propose a rational monsoon index. As is known, the word "monsoon" is an ancient term and derives from the Arabic word "mausim" meaning season. Although the definition of the monsoon is debatable, all agree that the monsoon is a seasonal shift of wind direction from winter to summer and from summer to winter (Pedelaborde, 1963; Ramage, 1971; Khromov, 1978; Krishnamurti, 1996). Zeng et al. (1994) and Zeng and Zhang (1998) presented a new concept of normalized seasonality and then the (general) monsoon was defined as the significant seasonality of the atmospheric circulation, especially for the wind field. Furthermore, Li and Zeng (2000) discussed the significance of the normalized seasonality of the wind field and its rationality for characterizing the monsoon. A disadvantage of this index given by them, however, is that it is a static index; that is, it may only outline the domains of the monsoons and can represent neither the seasonal variation of the monsoons nor their interannual variability. Some monsoon indices, e.g. the All Indian Rainfall Index (AIRI) (Shukla and Paolino, 1983), Webster and Yang Index (WYI) (Webster and Yang, 1992), Monsoon Hadley Circulation Index (MHI) (Goswami et al., 1999), convection index (CI) (Wang and Fan, 1999), and others (He et al., 2001; Zhu et al., 2000), are used to characterize monsoon variability, but a unified monsoon index suitable for all known monsoon regions has not yet been found. Recently the authors have proposed a unified dynamical index of the monsoon, the dynamical normalized seasonality (DNS) (Li and Zeng, 2002).

The basic idea of the DNS index is based on the intensity of the normalized seasonality of the wind field. The monsoons possess very strong seasonal variation; it is therefore rational that strong and weak monsoons may be measured by use of the magnitude of seasonality of the wind field. Such a DNS index is given by

$$\delta_{m,n} = \frac{||\overline{\boldsymbol{V}}_1 - \boldsymbol{V}_{m,n}||}{||\overline{\boldsymbol{V}}||} - 2, \qquad (1)$$

where $\overline{\boldsymbol{V}}_1$ and $\overline{\boldsymbol{V}}$ are the January climatological wind vector and the mean of January and July climatological wind vectors, respectively, and $\boldsymbol{V}_{m,n}$ is the monthly wind vector for year n and month m. The norm $||A||$ is defined as $||A|| = \left(\int\int_S |A|^2 dS\right)^{1/2}$ where S denotes the domain of integration. (In calculations at a point

$$(i,j), ||A_{i,j}|| \approx \Delta s[(|A^2_{i-1,j}| + 4|A^2_{i,j}|$$

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$$+|A^2_{i+1,j}|)\cos\varphi_j + |A^2_{i,j-1}|\cos\varphi_{j-1}$$
$$+|A^2_{i,j+1}|\cos\varphi_{j+1}]^{1/2}$$

where φ_j is the latitude at the point (i, j), $\Delta s = a\Delta\varphi\Delta\lambda/4$, a is the mean radius of the earth, and $\Delta\varphi$ and $\Delta\lambda$ in radians are resolutions in the meridional and zonal directions, respectively). It is evident that the DNS index is an extension of the static normalized seasonality (SNS) index first presented by Zeng et al. (1994) (see also Zeng and Zhang, 1998). In the DNS index, the value 2 is subtracted in the right hand side of formula (1) because the critical value of significance of the quantity $||\overline{\boldsymbol{V}}_1 - \boldsymbol{V}_{m,n}||/||\overline{\boldsymbol{V}}||$ is 2 (Li and Zeng, 2000; 2002). In this manner, in the Northern (Southern) Hemisphere, $\delta < 0$ represents the winter (summer) monsoon, and $\delta > 0$ the summer (winter) monsoon. Taking the climatology value $\overline{\boldsymbol{V}}_m$ in place of $\boldsymbol{V}_{m,n}$ in (1), then one has

$$\delta_m = \frac{||\overline{\boldsymbol{V}}_1 - \overline{\boldsymbol{V}}_m||}{||\overline{\boldsymbol{V}}||} - 2, \qquad (2)$$

where $m\,(m = 1, \cdots, 12)$ denotes the calendar month. It can show the seasonal variation of the monsoon. Further, when $\overline{\boldsymbol{V}}_m$ in (2) equals the July climatological wind vector $\overline{\boldsymbol{V}}_7$, the DNS becomes the SNS index as follows

$$\delta = \frac{||\overline{\boldsymbol{V}}_1 - \overline{\boldsymbol{V}}_7||}{||\overline{\boldsymbol{V}}||} - 2. \qquad (3)$$

By this we can outline the geographical distribution of the global monsoon systems. The above analysis suggests that the DNS index can be used to delimit the monsoon, and some works have also indicated that it could represent the annual cycle and interannual variability of different monsoons as well (Li and Zeng, 2000; 2002).

Figure 1 shows the extent of the global monsoon systems from the SNS index, based on the NCEP/NCAR reanalysis data (1958–1999) (Kalnay et al., 1996). Clearly, all the classical monsoons such as the Asian-Australian monsoon (Webster et al., 1998; Lau et al., 2000) and West African monsoon (Ramage, 1971; Khromov, 1978) are indicated in Fig. 1, and the American monsoon system is also shown. Moreover, it is obvious that the global monsoon systems can be divided into three categories: the tropical monsoon, subtropical monsoon, and the monsoon in the temperate zone and frigid zone (Fig. 1). The tropical monsoons consist of a broadly connected region extending from western Africa to Indonesia and the Solomon Islands with southward protrusions to Madagascar and northern Australia, and of other isolated monsoon areas such as the South American monsoon (Zhou and Lau, 1998). Another broadly connected region includes the South Asian monsoon (Ramage, 1971), Indonesian monsoon (Ramage, 1971), South China Sea monsoon (Lau et al., 2000), Australian monsoon (Webster et al., 1998), western North Pacific monsoon (Murakami and Matsumoto, 1994; Wu and Wang, 2000), West African monsoon (Webster et al., 1998), Somalia-western Indian Ocean monsoon (Krishnamurti, 1996), and so on. The subtropical monsoons are encountered over East Asia (Zhu et al., 1986; Tao and Chen, 1987), North America (Douglas et al., 1993), northern Africa and part of the Mediterranean (Pedelaborde, 1963), central Asia along the northern edge of the Iranian and Tibetan Plateau, southern Australia (Khromov, 1978),

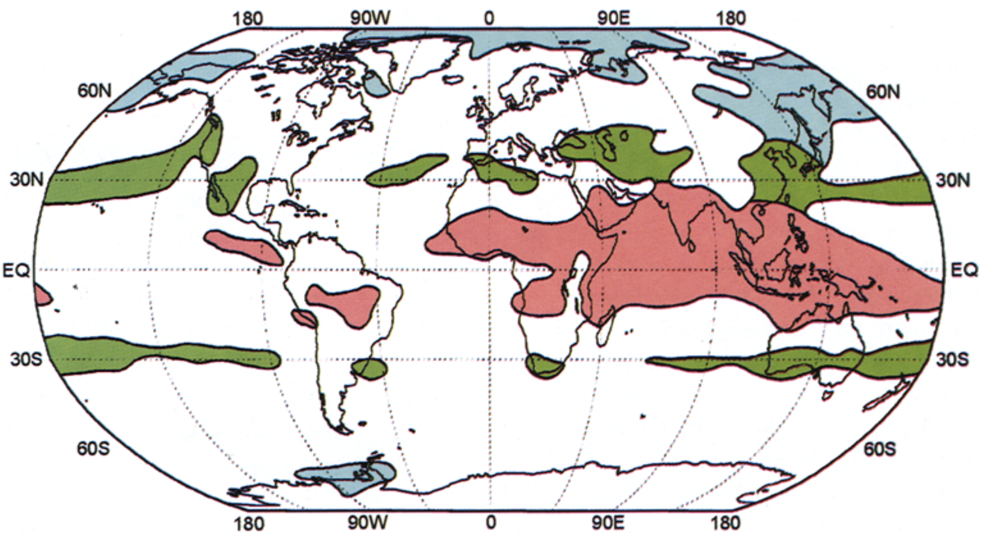

Fig. 1. Geographical extent of the global surface monsoons. The red, green, and blue areas indicate the tropical, subtropical, and temperate-frigid monsoons, respectively.

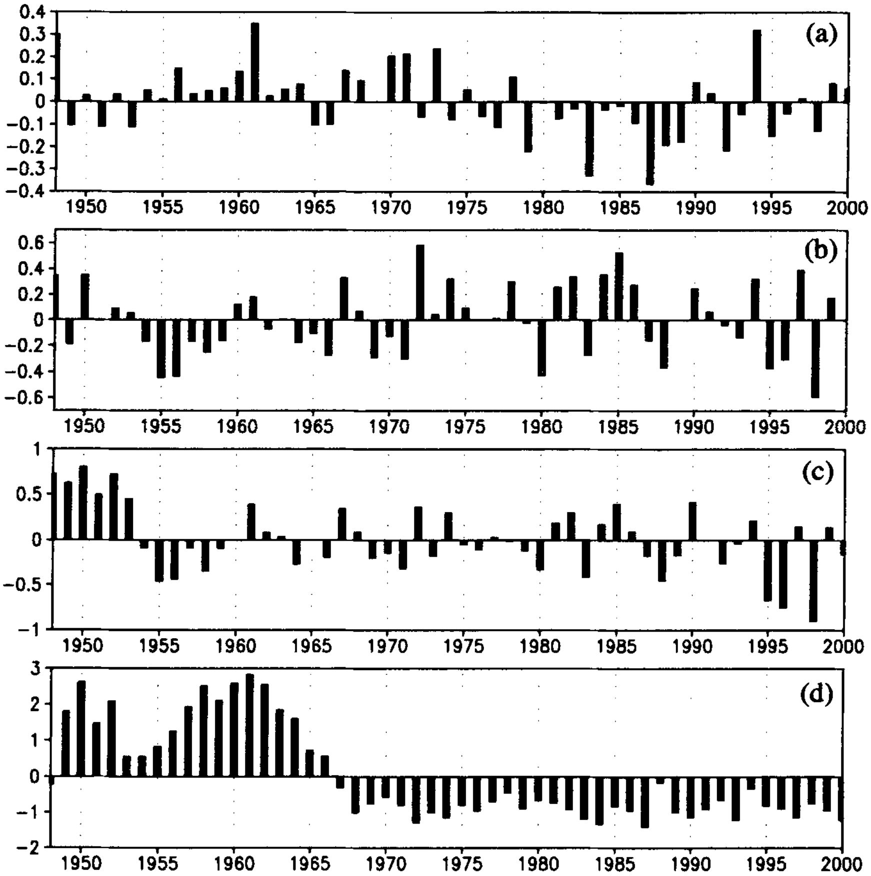

Fig. 2. Anomaly series of the DNS indices of the summer (JJA mean) monsoons of (a) the South Asian (5°–22.5°N, 35°–97.5°E), (b) the East Asian (10°–40°N, 110°–140°E), (c) the South China Sea (0°–25°N, 100°–125°E), and (d) the West African (5°–17.5°N, 20°W–40°E). All series are calculated by use of the data of the wind field at 850 hPa, except for the South China Sea summer monsoon at 925 hPa.

South Africa (Khromov, 1978), and some long zones along 30° in the oceans in the Northern and Southern Hemispheres. The monsoons in the temperate-frigid zones appear in the Far East (Khromov, 1978), northern Alaska, and the Arctic. Figure 2 shows the interannual variability of the DNS indices of four traditional summer monsoons, which include the South Asian summer monsoon, East Asian summer monsoon, South China Sea summer monsoon, and West African summer monsoon.

According to the delineation of the global monsoon systems, three concepts should be clarified: classical monsoon, ordinary monsoon, and monsoon-like. For the classical monsoon, both the wind field and its weather are monsoonal, i.e. remarkably seasonal. The tropical monsoons, East Asian monsoon, and North American monsoon belong to this category. For the ordinary monsoon, its weather is not monsoonal even though its wind field is so, i.e., it does not bring any remarkable change in rainfall. The subtropical monsoons over the oceans affected by the normal annual march of the subtropical high ridges (Ramage, 1971) and some monsoons in temperate-frigid zones may just be ordinary monsoons. For those that are monsoon-like, the weather is monsoonal, whereas the winds are not so. The above classifications are very useful for understanding deeply the monsoons, and it is essential to study the differences and relationship among the three kinds of monsoon and their interactions. This awaits further work.

Acknowledgments. This work was supported jointly by the National Natural Science Foundation of China under Grant Nos. 40233027 and 40275025, and ZKCX2-SW-210.

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一个新的季风指数和全球季风的地理分布

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摘　要

一个新的季风指数即动态标准化季节变率被提出用来研究有关季风的问题。这个动态标准化季节变率指数能够很好地描述不同季风区的季节变化和年际变率，而且它还可以用来划分全球季风系统的地理分布。进一步，本文指出它对于深入理解季风来研究经典季风、庸季风和类季风系统的区别、联系及相互作用是非常有用的。

关键词: 动态标准化季节变率，季风指数，全球季风系统