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A SYSTEMIC ANALYSIS OF MULTISCALE CONVECTIVE VARIABILITY IN THE TROPICS

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1. INTRODUCTION

Precipitating cumulus convection that extends throughout the troposphere prevails in most regions in the tropics. It has been known to exhibit various spatial and temporal scales tied to tropical waves and disturbances (e.g., Chang 1970). Information of cloud-top temperature deduced from satellite imagery, such as OLR, has been used as an index of deep convective activity in the tropics. Salby and Hendon (1994) had found spectral broadening in the OLR power spectra in the frequency domain over the Indian Ocean–western Pacific sector (i.e., the warm pool), and commented that the background variance cannot be accounted for by simple white noise or first-order red noise processes.

Fractal and multifractal concepts provide a systemic description of complex dynamic phenomena. For instance, they have been developed to understand turbulence phenomena (Frisch 1995). Convection is one type of turbulent motion in the atmosphere. It differs from classical turbulence because of the effects of latent heating, whereas the latter is dominated by dissipative processes. Many quantities related to convective processes have fractal or multifractal characteristics. The goals of this work are to examine and describe the multiscale temporal variability of deep convective systems in the tropics using the multifractal approach. It is noted that the nature of this study is different from that concerning the multifractal aspects of conventional turbulence or the study of single storm systems. It involves the collective behavior and interaction of many multiscale convective systems coupled by dynamics field in the tropical environment.

2. DATA AND ANALYSES

The datasets used are the hourly $0.1° \times 0.1°$ deep convection index, I_{TBB}, during the TOGA-COARE IOP (Nov. 1992–Feb. 1993) and daily $2.5° \times 2.5°$ NOAA OLR from 1979–2003. The index I_{TBB} is derived from the GMS IR irradiance, following the method in Nakazawa (1995). Large values of I_{TBB} are positively correlated with high rainfall rates in the tropics (e.g., Tung and Yanai 2002). Therefore, if I_{TBB} time series is found to be multifractal, it is likely that rainfall has a similar behavior.

Two common methods used to extract multifractal characteristics from a field are utilized. The first one, as demonstrated through the I_{TBB} dataset, is often called the singular measure technique (Tung et al. 2004); the other, applied to the OLR time series, is the structure function technique (Tung and Yanai 2002). Take the structure function for example, it examines the statistical moments of the absolute increments of the time series. If the moments depend on temporal scales in a power-law manner over a large range of scales, i.e., the scaling region, then the time series is said to be a multifractal. The scaling exponents quantitatively characterize the nonstationarity and intermittency of the complex data set. In other words, we seek the following scaling relation:

$$D(t) = \langle |x(i+t) - x(i)|^q \rangle \sim t^{\zeta(q)}, \qquad (1)$$

where $x(t)$ is the OLR time series, $\zeta(q)$ is a function of real value q, and the mean operator $\langle \ \rangle$ is taken over all possible couples of $(x(i+t), x(i))$. A negative q value emphasizes small absolute increments of $x(t)$, while a positive q value emphasizes large absolute increments of $x(t)$. Large absolute increments of $x(t)$ can be thought of as bursts. Hence, large positive q value focuses on the intermittency of the time series.

3. RESULTS

As in Tung et al. (2004), through the I_{TBB}, convective activities over the western Pacific with lifetime ranging from ~1 hour to ~20 days may have interdependence across scales that can be described by a series of power laws, hence a spectrum of so-called "generalized dimensions". That is, the deep convective variability over the western Pacific has multifractal characteristics. The spatio-temporal features of I_{TBB} time series is preliminarily examined by changing the spatial domain for averaging. The multifractal features are weakened with increasing strength of spatial averaging but can not be eliminated.

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The long record of OLR time series confirms the aforementioned scaling region and helps further refine the upper bound of the scaling region to $\sim$ 16 days. Moreover, it suggests that a second scaling region beyond the $\sim$ 16-day scaling break exists over the western Pacific. Similar scaling behaviors are found in other locations in the tropics. For example, in Fig. 1, the second-order structure functions (i.e., $q = 2$ in (1)) derived from OLR over selected locations in the Indian Ocean (IO), the western Pacific (WP), the Eastern Pacific (EP), south America (SA), and Africa (AF) are shown. Among these locations, IO, WP, SA, and AF are chosen to be close to the maximum OLR variance in the intraseasonal time scale identified by Salby and Hendon (1994). EP is a convection-suppressed location; however, it is chosen to examine the scaling behavior associated with the intraseasonal variability, particularly the eastward-propagating Madden-Julian oscillation (MJO). The scaling regions are over-plotted with straight lines in the log-log diagram. The slopes of these lines (i.e., the power-law exponents) are shown in the upper-left corner.

Figure 1 also shows that the occurrence of scaling breaks varies from one location to another. Second scaling regions beyond 16 days are found in IO, WP, and EP, ranging from 16–$\sim$40 days in IO and WP, to 16–64 days in EP. The third scaling regions follow immediately after the second scaling breaks. It is suspected that the second and third scaling regions are associated with the MJO. The second scaling breaks may occur around the dominant periods of MJO in these three locations. Convective variability in SA and AF exhibits a lack of dominant periodicity in the intraseasonal time scale, which is very different from the other three locations. However, none of the scaling regions in these five locations extend to 1 year, setting large-scale tropical climate systems such as the inter-annual variability apart from the sometimes random processes-looking phenomena with time scales shorter than 1 year.

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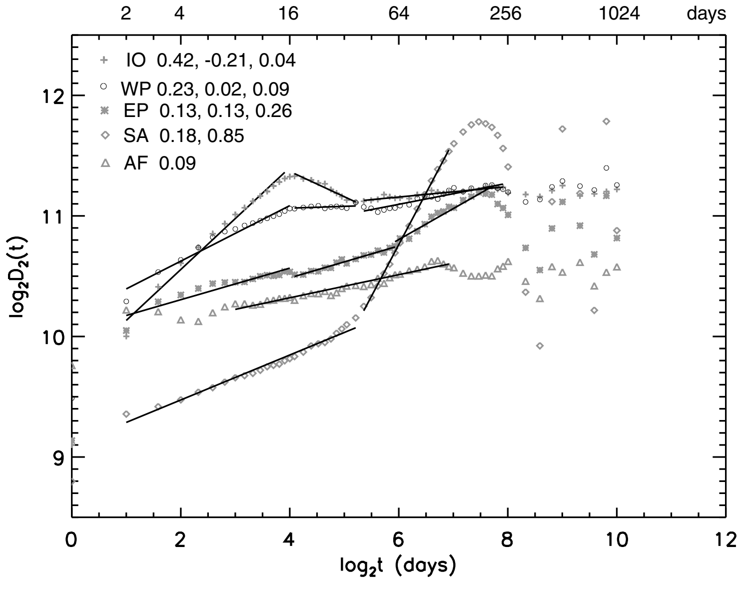

Figure 1. Log-log plot of the second-order structure functions derived from OLR time series over the Indian Ocean (IO, 82.5-87.5° E, 2.5° S-2.5° N), the western Pacific (WP, 165-170° E, 7.5-2.5° S), the eastern Pacific (EP, 115-110° W, 7.5-12.5° N), south America (SA, 55-60° W, 10-5° S), and Africa (AF, 17.5-22.5° E, 0-5° N). Power-law scaling regions are emphasized with solid lines. Power-law exponents are shown on the upper left corner, in the order from left to right.