INTRASEASONAL OSCILLATION

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Contents

Summary

The tropical intraseasonal oscillation resides on special timescales between the traditional definitions of weather and climate. Its role of bridging weather and climate and its broad impact on different components of the Earth system, especially by its dominant component, the Madden-Julian Oscillation (MJO), make it an extremely interesting and important subject for research. In this article, the fundamental properties of the MJO is summarized, its connections to other weather and climate variability described, and its impact on various components of the Earth system illustrated. The main purpose of this article is to provide basic materials on the tropical intraseasonal oscillation for people from different disciplines to appreciate this fascinating phenomenon and to relate it to seemly independent observations in their own fields,

however remote they might be from tropical meteorology. It is the hope of the author that the MJO serves as a drop of catalyst in the rising tide of inter- and multi-disciplinary collaborations in science and humanity.

1. Introduction

The intraseasonal oscillation refers to variability on timescales of 20-100 days. This range of timescale is in between the typical timescales for weather (up to 15 days) and climate (from a season and beyond). The importance of the tropical intraseasonal oscillation to bridge weather and climate has been increasingly recognized. It has also become more evident recently that the tropical intraseasonal perturbations in the atmosphere are closely connected to variability in other components of the Earth system, such as the ocean circulation, marine biology, atmospheric chemistry, and geodynamics. This article provides descriptions of the most fundamental observed features of the tropical intraseasonal oscillation and its broad impact on the Earth system.

Different terminologies have been used in the literatures to describe tropical atmospheric variability on the intraseasonal timescales, for example, "tropical intraseasonal oscillation "(TIO) or simply "intraseasonal oscillation" (ISO), "tropical intraseasonal variability" (TIV), "30-60 day oscillation", and the "Madden-Julian Oscillation" (MJO). Slightly different definitions for the intraseasonal timescale have also been used (e.g., 30 – 60 days, 30 – 90 days). While distinctions among these specific definitions might exist, it is of little doubt that there are two dominant components in the intraseasonal timescale range, however it is defined. One is an eastward propagating component, which is commonly referred to as the MJO, the other is a northward propagating component associated with the Asian summer monsoon. Arguably, these two components are related to a certain extent and independent of each other in other aspects. In this article, both will be discussed but the broad impact on the Earth system will be emphasized for the MJO.

The rest of the article is arranged in the following way. A brief history of the study on the tropical intraseasonal oscillation is given first (Section 2). The observed nature of the MJO and intraseasonal oscillation of the Asian monsoon is then respectively described (Section 3). The broad impact of the MJO is illustrated in terms of its role of bridging weather and climate and connecting other components of the Earth system (Section 4). Challenges posed by the tropical intraseasonal oscillation to our understanding of its dynamics, our ability of reproducing its salient features in our state-of-art numerical models, and our ability of predicting its evolution are then discussed (Section 5). Finally, a summary and conclusion are given (Section 6).

This article can be viewed as an excerpt from two recent more comprehensive reviews on the subject by Lau and Waliser (2005) and by Zhang (2005), augmented with fresh materials since their publication and additional materials not covered by them. There is a broad range of intraseasonal fluctuations in the tropical atmosphere and ocean that are associated to neither the MJO nor the intraseasonal oscillation of the Asian summer monsoon. Their information, too fragmental to be included in this article, can be found in Lau and Waliser (2005). The two reviews in combination provided a nearly complete list of the huge amount of bibliography on the subject up to the time of their publication. This allows literature references in this article to be limited to mostly those not in the two reviews, so massive redundancy is avoided. These two reviews are recommended to interested readers for more detailed discussions on topics related to the tropical intraseasonal variability in general and the MJO in particular.

2. Brief History

The first documentation of the tropical intraseasonal oscillation based on modern instrumental data was given by Madden and Julian in their pioneering studies (Madden and Julian 1971, 1972), and hence the Madden-Julian Oscillation (MJO). Their observations were based on atmospheric rawindsonde data of about 10 years collected from a broad tropical Indian and Pacific region. As many precedents in the history of science, they found signals of the intraseasonal oscillation completely by accident when they analyzed their data for something else. Their observation of the gross structure and evolutionary behavior of the tropical intraseasonal oscillation (Fig. 1, more details in Section 3.1) still serves as the classic, text-book standard description of this phenomenon. Subsequent observations up to date using more advanced technology have only added details to theirs. Madden and Julian (2005) provided a more detailed historical perspective of their and other observational work on the MJO.

Observations of the intraseasonal oscillation since Madden and Julian’s groundbreaking work have experienced two major advancements. One is the use of global data. Satellite data, initially from polar-orbiting and geostationary weather satellites, and now also from a constellation of satellites for monitoring the Earth system, have allowed us first to gain a global view of the phenomenon and now to peer into details in its multi-scale four-dimensional structure and evolution, and its interaction with non-traditional meteorological quantities, such as ozone and ocean biology. In conjunction with this is the development of numerical assimilation technology for atmospheric observations, which transfigures observational data at randomly distributed data-collecting sites into global regular grids and provides four-dimensional data for all standard quantities for weather prediction climate diagnostics (wind, temperature, humidity, pressure, etc.). The combination of satellite data and numerical data assimilation products (especially global reanalyses) has proven irreplaceable to the furtherance of our knowledge on the intraseasonal oscillation.

The second major advancement in observations of the tropical intraseasonal oscillation is the use of oceanic observations collected from moored buoys, especially from an array of such buoys over the equatorial Pacific, and from ships. These data have allowed us to truly appreciate the air-sea interaction nature of the intraseasonal oscillation. Observational evidence supporting the contention that the MJO can be instrumental to El Niño – Southern Oscillation (ENSO) could not have been gained without such oceanic observations (see Section 4.7).

The methodology for the study of the MJO has also undergone substantial development. Band-pass filtering, often through the fast Fourier transform, has been the most basic tool to isolate intraseasonal signals from those of lower and higher frequencies. To further extract the MJO from the total intraseasonal signals, it is common to use the empirical orthogonal function (EOF) analysis or its likes (e.g., extended or combined EOF, singular vector decomposition (SVD) or Hilbert-transfer SVD). The leading modes from these analyses, if in pair with one mode in quadrature to the other and if well separated from the neighboring modes (North et al 1982), are taken as a representation of the MJO. MJO amplitude and phases (i.e., longitudinal locations) can then be derived from the two leading modes. The most recently developed diagnostic tool for the MJO is an EOF analysis combining near-equatorial low- and upper-level zonal wind and a convective variable (cloudiness or precipitation). It takes the advantage of the coherent pattern in the circulation and convection unique to the MJO (see Section 3) and thereby is able to extract MJO signals without the traditional band-pass filtering. The superiority of this method over others is that it can be used in real time applications (monitoring and forecasting) where band-pass filtering is impractical if ever possible. A product of the method is a time series labeled as "Real-time Multivariate (RMM)" MJO index (Wheeler and Hendon 2004). Based on this index, MJO behavior in both boreal and austral summers can be consistently derived (Section 3).

In addition to observations, progress has also been made in our theoretical understanding of the dynamics of the tropical intraseasonal oscillation and in our ability of numerically simulating and forecasting it. But, the challenge they present to us is much more substantial than their progress. This will be discussed in Section 6.

Of course, the most important advancement in the study of the tropical intraseasonal oscillation has been in our understanding of this phenomenon and our appreciation of its broad impact. This article strives to cover the most updated knowledge on this subject that might be most relevant to a broad range of disciplines.

3. Observed Large-Scale Characteristics

In this section, observed characteristics of the tropical intraseasonal oscillation are discussed respectively for the eastward propagating MJO (Section 3.1) and northward propagating intraseasonal oscillation associated with the Asian summer monsoon (Section 3.2).

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Biographical Sketch

Chidong Zhang was born and raised in Beijing, China. After high school, he worked in a farm for two years, which offered him an irreplaceable experience. He then enrolled in Peking University and gained a BS in geophysics majoring in meteorology in 1982. He subsequently worked in then Satellite Center of the Chinese Meteorological Administration for a year before continued his education in University of Utah, where he received an MS in meteorology in 1985. He then entered the graduate school in The Pennsylvania State University and earned his PhD in meteorology in 1989. His PhD research topic was the dynamics of equatorial waves in the atmosphere. After a short experience as a Research Associate at Penn State, he was awarded with a NOAA Global Climate and Change Fellowship, which supported him as a postdoctoral visitor in the University of Washington for 1991 – 1992. He then stayed at the University of Washington as a Research Assistant Professor until 1997 when he moved to the University of Miami. He was a Research Associate Professor (1997 – 2000), Associate Professor (2000 – 2004), and Professor (2004 – present) in meteorology and physical oceanography at the University of Miami.

Tropical meteorology and climate have been the main research interests of Chidong Zhang since graduate school. Topics related to the MJO, especially its interaction with the ocean and its influence on ENSO, have been his main research foci for years. His other research interests have been water vapor variability in the tropical troposphere, and the intertropical convergence zone (ITCZ) and its associated shallow meridional circulation. Recently, his research repertoire has expanded to the dynamics of the West African monsoon, aerosol effects on tropical precipitation, and vertical diabatic heating profiles in the tropics.

Dr. Zhang is a member of the American Meteorological Society and the American Geophysical Union.