Intraseasonal Variability in the Atmosphere-Ocean Climate System

William K. M. Lau
Duane E. Waliser

Second Edition

Springer

PRAXIS

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About the cover

Madden–Julian Oscillation index phase plot [see Wheeler and Hendon (2004) and Chapter 5 for more information and the reference] for an example forecast from the U.S. National Oceanographic and Atmospheric Administration's (NOAA's) National Weather Service (NWS) Global Ensemble Forecast System (GEFS). The RMM1 (x-axis) and RMM2 (y-axis) values for the most recent 40 days prior to the forecast are given along with the forecast values for the subsequent 15 days. The green line is the mean of the 21-member ensemble forecast (forecast days 1–7: thick line, forecast days 8–15: thin line) along with all 21 individual ensemble forecast members (yellow lines). The light gray shading represents the area in which 90% of forecast members reside and the dark gray shading represents the area in which 50% of forecast members reside.

Courtesy Jon Gottschalck—Climate Prediction Center/NWS/NOAA
(see also Gottschalck et al. 2010 reference in Chapter 12)

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Preface to the Second Edition

In the Preface to the First Edition of this book, we wrote about the goal to provide a one-stop reference text on intraseasonal variability (10–90 days) to bridge the gap between weather forecasts (a few days to a week), and climate predictions (seasonal, yearly, and longer timescales). We seek to further this goal in the Second Edition. The years since the publication of the First Edition have seen significant advances in our understanding of the physical processes, multiscale interactions, and predictability associated with intraseasonal variability in the tropical ocean–atmosphere system. These advances have been achieved by the scientific community at large through (a) increased capabilities in high-resolution global modeling and data assimilation, (b) in-depth theoretical studies, and (c) improved diagnostics mostly from new global satellite observations and improved reanalysis products.

At present, a realistic simulation of the Madden and Julian Oscillation (MJO) is considered a prerequisite for climate models to produce reliable predictions of interannual variability and longer term projections of regional impacts and extreme events from climate change. Common metrics for MJO prediction and diagnostics have been developed and adopted by the scientific community so that model validations and empirical forecasts of the MJO can be compared and evaluated. Operational forecast centers such as the U.S. National Oceanic and Atmospheric Administration Climate Prediction Center, the U.K. Meteorological Office, and the European Center for Medium-range Weather Forecasts, among many others, are producing routine forecasts of the MJO. Predictions of onsets and breaks in major monsoon regions around the world are now focused on the propagation and evolution of regional intraseasonal oscillations (ISOs). International and national organizations such as the World Climate Research Programme and the World Weather Research Programme have joined to sponsor working groups and task forces to organize international projects and workshops to facilitate and coordinate research on the MJO and ISOs. The science community has now coined the term ‘‘seamless prediction’’ to address the continuum of temporal and spatial scales linking weather and climate. Indeed, the MJO and associated regional ISOs represent critical linkages between global weather forecasts and regional climate predictions. Another critical factor spurring the recent rapid advance in our understanding of the MJO and ISO phenomena was the advent of a series of NASA Earth-observing satellites launched between the early 2000s and the present. As a result, the scientific community has access to unprecedented information regarding propagation, horizontal and vertical structures of rainfall, clouds, moisture, and temperature. Such information is essential to define the characteristics of the MJO and associated regional ISOs and their far-field impacts. Other derived quantities such as latent heating profiles and cloud microphysics derived from satellite data and field campaigns are setting the stage for the next level of understanding and improved model fidelity associated with the MJO and ISOs. Studies documenting the influence of the MJO on ozone, aerosols, and carbon dioxide fluctuations in the atmosphere and in ocean productivity are emerging, further demonstrating the far-reaching importance of the MJO and ISOs not only in the physical domain but also in the biogeochemical component of the climate system. Given these momentous recent developments, the Second Edition of the book seems opportune.

The organization of the Second Edition is as follows. The first 12 chapters are either original chapters (Chapters 1, 8, 9), or original chapters with updates (Chapters 2, 3, 4, 5, 6, 7, 10, 11, 12). Chapters 13-18 are new shorter chapters that cover new topics or significant recent advances. In some cases, the latter can also serve as updates or complements to the original chapters. Specifically, the new chapters are: Chapter 13 on "Africa and West Asia" by M. Barlow; Chapter 14 on "Tropical and extratropical interactions" by P. Roundy; Chapter 15 on "Oceans and air–sea interaction" by J.-P. Duvel; Chapter 16 on "Vertical structure from recent observations" by C. Zhang; Chapter 17 on "Multiscale theories" by A. Majda and S. Stechmann; and Chapter 18 on "Chemical and biological impacts" by B. Tian and D. Waliser.

The Second Edition of this book would not have been possible without the support and dedicated efforts of the contribution authors, both old and new. Special thanks are due to Xiouhua Fu, George Kiladis, Tim Li, Jiaylin Lin, Adrian Matthews, Mitch Moncrieff, Benjamin Pohl, David Strauss, Chung-Hsiung Sui, Mike Wallace, Sun Wong, and Klaus Weickmann who have provided constructive comments in reviewing the new chapters. The co-Chief Editors also thank the Earth Science Division of the National Aeronautics and Space Administration, the Office of Global Programs of the National Oceanic and Atmospheric Administration, the Large-scale Dynamics Programs of the Atmospheric Science Division of the National Science Foundation, and the Atmospheric Radiation Measurement and Climate Research Program of the Department of Energy for providing support for years of research of observations and modeling of the MJO and related phenomena. We would also like to express our thanks to the World Climate Research Programme and the World Weather Research Programme for their programmatic sponsorship of a number of panels, working groups, and task forces that have greatly facilitated research on intraseasonal variability and its transition to operational utility.

William K. M. Lau and Duane E. Waliser
June, 2011.

Preface to the First Edition

On the subject of extended range weather forecasts, one of the pioneers of numerical weather forecasts, John von Neumann (1955) wrote:

> “The approach is to try first short-range forecasts, then long-range forecasts of those properties of the circulation that can perpetuate themselves over arbitrarily long periods of time . . . and only *finally* to attempt forecast for medium–long time periods which are too long to treat by simple hydrodynamic theory and too short to treat by the general principle of equilibrium theory.”

In modern phraseology, von Neuman’s short-range forecasts would mean weather forecasts extending out to about 5 days, long-range forecasts would be equivalent to climate predictions extending out to a season or longer, and medium to long-range forecast would refer to intraseasonal predictions having lead times of the order of 2 to 8 weeks. Numerical weather forecasting has seen tremendous improvement since its inception in the 1950s. Today, human activities are often so dependent on skillful short-term weather forecasts, that many have come to the unrealistic hope, and even expectation, that weather forecasts should be accurate all the time. However, any basic textbook on weather forecasting will point out that there exists a natural limit on *deterministic* weather forecasts of about 2 weeks, which is strongly dependent on initial conditions and atmospheric flow regimes.

Recently, the public has been made aware of high-impact climate phenomena such as El Niño and La Niña, which can affect weather patterns all over the world. Thanks in large part to the international climate research program, Tropical Ocean Global Atmosphere (TOGA), scientists now have the observational resources, the knowledge, and the models to make useful (deterministic) predictions of El Niño and La Niña with lead times up to 9–12 months. These predictions in turn have been helpful in making *probabilistic* seasonal-to-interannual forecasts of weather patterns (not deterministic forecasts of individual weather events) more skillful over certain spacetime domains (e.g., wintertime temperature over North America and summer rainfall over the Asian monsoon region and South America). Because the lead time for climate prediction is typically a season or longer—a time long enough for the atmosphere to lose memory of its initial state—the skill of prediction is no longer dependent on the initial conditions of the atmosphere. In contrast to weather forecasts, seasonal-to-interannual climate predictions owe their skill to a dependence on slowly changing boundary conditions at the Earth's surface, such as sea surface temperature, snow cover, and soil moisture, and the considerable impact these boundary conditions have on determining the statistics of observed weather patterns. In the forecasting community, it is often said that weather forecasting is an initial value problem and climate prediction is more akin to a boundary value problem. What about the timescales in between (e.g., lead times between about 2 weeks and 2 months)? Are there atmosphere–ocean phenomena with these timescales that are predictable, and how do these phenomena and their predictability respond to the changing boundary conditions at the Earth's surface? These are among some of the issues to be addressed in this book.

Given the progress in weather forecasting and seasonal-to-interannual climate prediction, it is apparent that we are ready to more formally and thoroughly address forecasting of, in von Neuman's words, the "medium–long time periods". Improving extended range (i.e., intraseasonal) forecasts requires fundamental knowledge built on sound research, realistic models of the atmosphere, ocean, and land components of the climate system, and the training of a new generation of scientists and forecasters. Today, we have many textbooks and research reference books on weather and climate variability, and prediction, but there has been none focused specifically on intraseasonal variability (ISV). There has been a large body of scientific studies showing that ISV is far from a simple interpolation between weather and climate scales/processes, and is not just a red-noise extension of weather variability. Indeed, there are specific and unique modes of ISV that are ubiquitous and can be found in the atmosphere, the ocean, and the solid Earth, as well as in the tropics and the extratropics.

To improve prediction in the intermediary timescale (2 weeks to less than a season) of the atmosphere–ocean, it is vital to improve our understanding of the phenomena that are inherently intraseasonal and the manner in which they interact with both shorter (weather) and longer (climate) timescales. Thus one of the overarching goals of this book is to summarize our current understanding of IV and its interactions with other weather and climate processes. However, in developing the framework for this book, we found that including all aspects of ISV would require too much material for one book. Thus, in order to limit the scope of this book, we have chosen to focus primarily on ISV in the tropical ocean and atmosphere, including its interactions with the extratropics whenever appropriate. Using this guideline, topics directly related to midlatitude atmospheric blocking or extratropic annular modes, for example, will not be treated in their own right in this book, but rather discussed in the context of their interaction with tropical ISV (TISV).

Central to TISV is the Madden–Julian Oscillation (MJO) phenomenon, known also as the 40 to 50-day or 30 to 60-day oscillation. However, TISV in general refers to a broad spectrum of phenomena: some quasi-periodic, some non-periodic, some with global reach, and others with regional manifestations. To avoid possible confusion in this book with the various terminologies used in the literature, we refer throughout this book to all variability longer than synoptic timescales (~2 weeks) and shorter than a season (90 days) as ISV. The MJO is specifically referred to as the atmosphere–ocean entity that exhibits a coherent eastward propagation along the equator with quasi-periodicity of 30 to 60 days. In the general case, when a quasi-periodic oscillation can be identified, the term intraseasonal oscillation (ISO) will be used. When specially referring to ISV or ISO in the tropics, the acronyms TISV or TISO will be used as appropriate. In this nomenclature, MJO is a special case of a TISO.

This book is intended to be a one-stop reference book for researchers interested in ISV as well as a textbook for senior undergraduate and graduate students in Earth science disciplines. The book contains 12 chapters, each with a comprehensive bibliography. Chapter 1 provides a historical account of the detection of the MJO by R. Madden and P. Julian, who discovered the phenomena. The regional characteristics of TISV on South Asia, East Asia, the Americas, and Australia/Indonesia are covered in Chapters 2–5, respectively. Air–sea interactions and oceanic ISV are discussed in Chapters 6 and 7. Chapter 8 discusses atmospheric and solid Earth angular momentum and Earth rotation associated with ISV. Chapter 9 is on El Niño Southern Oscillation (ENSO) connections to ISV. Chapters 10, 11, and 12 are devoted to the theory, numerical modeling, and predictability of ISV, respectively. The chapters are written with self-contained material and frequent cross-referencing to other chapters, so that they need not be read in sequence. Readers are encouraged to jump to their chapters of interest if they so desire. However, we strongly recommend everyone to read the Preface and Chapter 1 first to obtain the proper perspective of the subject matter and objectives of the book.

This book could not have been possible without the support and the dedicated efforts of the contributing authors, who provided excellent write-ups for the chapters in a timely manner. Everyone we contacted regarding this book was very enthusiastic and supportive. In addition, we thank Drs. H. Annamalai, Charles Jones, Huug van den Dool, T. C. (Mike) Chen, Klaus Weickmann, Chidong Zhang, Ragu Murtugudde, William Stern, George Kiladis, and Steve Marcus, and one anonymous reviewer for providing very constructive comments in reviewing various chapters of this book. The co-chief editors will also like to thank the Earth Science Enterprise of the National Aeronautics and Space Administration, the Office of Global Programs of the National Oceanographic and Atmospheric Administration, and the Climate Dynamics and Large-Scale Dynamic Meteorology Programs of the Atmospheric Sciences Division of the National Science Foundation for providing support over the years for research on ISV.

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William K. M. Lau and Duane E. Waliser
Goddard Space Flight Center, Greenbelt, Maryland
October, 2004

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Abbreviations

AAM	Atmospheric Angular Momentum
ACC	Antarctic Circumpolar Current
ADCP	Acoustic Doppler Current Profiler
AGCM	Atmospheric General Circulation Model
AI	Aerosol Index
AMIP	Atmospheric Model Intercomparison Project
AMY	Asian Monsoon Year
ARGO	Array for Real-time Geostrophic Oceanography
AS	Arabian Sea
AVHRR	Advanced Very High Resolution Radiometer
BAC	Bivariate Anomaly Correlation
BFA	Break Followed by Active
BISO	Boreal IntraSeasonal Oscillation
BLEP	Boundary Layer Ekman Pumping
BNFA	Break Not Followed by Active
BoB	Bay of Bengal
BOBMEX	Bay Of Bengal Monsoon EXperiment
BSISO	Boreal Summer ISO
BSISV	Boreal Summer IntraSeasonal Variability
CAM	Community Atmospheric Model
CAPE	Convective Available Potential Energy
CCA	Canonical Correlation Analysis
CCM	Community Climate Model
CCW	Convectively Coupled Wave
CFS	Coupled Forecast System
CG	Chatterjee and Goswami
CGCM	Coupled GCM
CID	Convective Interaction with Dynamics