The Asian Monsoon

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Preface

The Asian monsoon is a spectacular occurrence in the Earth's climate system. During summer, the monsoon engine pumps moisture transported across thousands of miles from the Indian and Pacific Oceans, producing heavy rains over south and east Asia and adjacent marginal seas; meanwhile, it dumps sinking, dry air to the north and west of Asia's monsoon area, forming the World's largest desert zone, which stretches from the Sahara and the Middle East to Mongolia. During winter, the Siberian cold wave pushes airflow across the equator, causing heavy rains over Indonesia, northern Australia, and the southern Pacific convergence zones.

What makes the Asian monsoon so powerful is the combination of thermal contrast between the World's largest landmass (Eurasian continent) and ocean basin (the Indo-Pacific Ocean) and the presence of the World's largest ridge, the Tibetan Plateau. This unique tectonic setting responds to seasonal progression of the solar radiation and Earth's rotation, producing the *monsoon climate* with its seasonal reversals in both the prevailing winds and associated precipitation, characterized by "wet" summers and "dry" winters. Positive feedback with hydrological processes amplifies the monsoon circulation. The accompanying desert and the Mediterranean climate over the subtropics are "twin" to the monsoon climate, as both are produced by the Asian monsoon system.

The giant Asian monsoon system (often called the Asian–Australian monsoon system) dominates the entire eastern hemisphere tropics and subtropics. It interacts with the El Nino/Southern Oscillation (ENSO) and extratropical circulations and has far-reaching impacts for the global climate and the environment. The Asian monsoon exemplifies the most complex interactions among Earth's surface, ocean, atmosphere, hydrosphere, and biosphere. The scientific importance of the Asian monsoon cannot be overemphasized.

The Asian monsoon is also of enormous importance to humans. About 60% of humanity inhabits the region of the Asian monsoon – a region where torrential rains,

storms, droughts, heat waves, and cold-air surges are a part of the economy, culture, and rhythms of life. The vegetation, biogeochemistry, economy, and society across the Asian monsoon regions are all critically influenced by the evolution and variability of the Asian monsoon.

The science pertaining to the monsoon has advanced enormously in the last two decades due to an increased wealth of new data from satellite observations and field experiments, and the advances in computing power and mathematical representations of coupled climate systems. My intent in compiling this book is to offer a timely summary of recent progress and also the remaining gaps in our knowledge and to provide a full and current account of scientists ever-improving, expanding understanding of the physics associated with monsoon weather and climate. Particular attention is given to the rapid progress made in monsoon predictions, some possible directions for future change, and the monsoon's impacts on economies.

In view of the topic's complexity and scientific diversity, leading scientists at the forefront of monsoon research were invited to contribute to this book. Most chapters contain an authoritative review of the subject and highlight conceptual breakthroughs as well as frontier research issues.

This volume begins with an overview of the Asian monsoon (Part One: Chapters 1–3). Chapter 1 describes the Asian monsoon as a multiscale, coupled atmosphere–ocean–land dynamic system that interacts with other components of the Earth's climate system. Chapter 2 provides a global perspective of the monsoon. Chapter 3, complementing other chapters, focuses on the most powerful boreal winter monsoon and Austral summer monsoon over the Maritime Continent and Australia; providing a comprehensive overview of the monsoon in general and the Asian–Australian monsoon in particular.

The character of the monsoon system is highly variable on many temporal and spatial scales. Part Two (Chapters 4–7) describes the monsoon variability over a broad range of timescales, from days to decades, and on various spatial scales, from the smallest mesoscale to continental and global scales. The great variety of monsoon weather is described in Chapter 4, with a detailed account of both south Asian and east Asia. Chapter 5 provides a comprehensive review of the current knowledge and issues of the monsoon's intraseasonal variations. In Chapter 6 is summarized the main features of interannual variability and possible causes. Variability on the decadal to interdecadal timescale is addressed in Chapter 7.

Understanding of the monsoon climate and its changes represents one of the most difficult challenges to climate science because of the complexity of its interactions over a wide range of atmospheric processes, as well as associated interactions between the atmosphere, ocean, and land. Part Three of this book (Chapters 8–13) is devoted to better improving the understanding of the monsoon system's physical processes and its roles associated with the Earth's climate system. This part looks at the atmospheric internal dynamical processes on a mesoscale (Chapter 8) and on large and planetary-scales (Chapter 9). Hydrological processes are also discussed (Chapter 10). Also included in this part are the interactions of the monsoon system with land surface processes (Chapter 11), and ENSO–Asian monsoon interactions (Chapter 12), and as well the roles of the Tibetan Plateau (Chapter 13). These

chapters, along with the discussions on the atmosphere–ocean interaction discussed in Chapter 1, lay out a firm basis for understanding the complex monsoon physics.

Seasonal prediction of monsoon activity is vitally important for society and remains a foremost challenge to climate prediction in the 21st century. Part Four (Chapters 14–15) deals with the numerical modeling and prediction of the monsoon activity. The governing dynamical controls and physical representations that determine the potential predictability of monsoons are explored in Chapters 14 and 15. Although the dynamical models of the coupled ocean–atmosphere–land system still have considerable difficulty in capturing the predictability, the discussions in this part of the book offer new ideas that are expected to contribute to noticeable improvements in the monsoon climate predictions in the coming decades.

Part Five of the book (Chapters 16–18) enhances the understanding of the monsoon environment and its societal influences. Evidence from paleorecord studies shows that the Asian monsoon system has undergone remarkable changes on geological timescales. Chapter 16 gives a detailed account of the past monsoon cycles according to geological, orbital, and millennial and centennial timescales. In the future, anthropogenic influences, including landuse/cover changes and atmospheric composition changes on regional and global scales, may considerably affect the future of the Asian monsoon. Possible human influences on the Asian monsoon are discussed in Chapter 17. The focus of Chapter 18 is on the monsoon's impacts on agriculture and the economy. Of note is the fact that the monsoon's influences on humanity reach far beyond agriculture – these aspects are dealt with more specifically elsewhere.

This book can be used as a comprehensive interdisciplinary text for college students, both undergraduate and graduate. It can also serve as a professional reference for research scientists and professionals in the fields of meteorology, oceanography, climate dynamics, environmental science, geography and geology, hydrology, paleoclimatology, agriculture, and the social sciences. Its informative content is such that most material in this book can also be of great value to non-specialists.

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Abbreviations

ABL	atmospheric boundary layer
AGCM	atmospheric general circulation model
AIMR	all-India monsoon rainfall
AIR	all-India rainfall
AIRI	all-Indian rainfall index
AIRS	Atmospheric Infrared Sounder
AMIP	Atmospheric Model Intercomparison Project
AMTEX	Air Mass Transformation Experiment
ANOVA	analysis of variance
AO	Arctic Oscillation
APCN	APCE Climate Network
APEC	Asia–Pacific Economic Cooperation
ARMEX	Arabian Sea Monsoon Experiment
ARPS	Advanced Regional Prediction System
ASCII	Air–sea Convective Intraseasonal Interaction
ASR	absorbed solar radiation
AUS	northern Australian region
AV	absolute vorticity
AWMI	Asian winter monsoon index
BATS	biosphere–atmosphere transfer scheme
BMRC	Bureau of Meteorology Research Centre
BOB	Bay of Bengal
BOBMEX	Bay of Bengal Monsoon Experiment
C-POL	C-Band Polarimetric Radar
CAPE	convective available potential energy
CCA	canonical correlation analysis
CCCMA	Canadian Centre for Climate Modeling and Analysis
CCM	Climate Community Model

CCSR	Center for Climate System Research
CEOF	complex empirical orthogonal function
CGCM	coupled general circulation model
CHI	southern China and East China Sea region
CI	convection index
CID	convective interaction with dynamics
CINE	convective inhibition negative energy
CISK	conditional instability of the second kind
CISO	climatological ISO
CLIVAR	Climate Variability and Predictability Programme
CMAP	Climate Prediction Center Merged Analysis of Precipitation
CMIP	Coupled Model Intercomparison Project
CNRM	Centre National de Recherches Meteorologiques
CO_2	carbon dioxide
COADS	Comprehensive Ocean–Atmosphere Data Set
COARE	Coupled Ocean–Atmosphere Response Experiment
CODAS	comprehensive ocean–atmosphere data set
COLA	Center for Ocean–Land–Atmosphere Studies
CPC	Climate Prediction Center
CRIEPI	Central Research Institute of Electric Power Industry
CRU	Climatic Research Unit
CSE	continental-scale experiment
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSM	Climate System Model
CTRL	control experiment
CZ	Cane–Zebiak model
DEMETER	Development of a European Multimodel Ensemble system for
DERFs	Dynamical Extended Range Forecasts
DJF	December–January–February
DO	Dansgaard–Oeschger
DOE	Department of Energy
DTEP	deep tropical eastern/central Pacific
EAH	East African Highlands
EAM	east Asian monsoon
EASM	east Asian summer monsoon
EAWM	east Asian winter monsoon
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño/Southern Oscillation
EOF	empirical orthogonal function
EQIO	equatorial Indian Ocean
EQUINOO	Equatorial Indian Ocean Oscillation
ERBE	Earth Radiation Budget Experiment
FCL	free convection level
FFT	fast Fourier transform
FGGE	First GARP Global Experiment

FRCGC	Frontier Research Center for Global Change
FSU	Florida State University
FSULAM	Florida State University Limited Area Model
GAME	GEWEX Asian Monsoon Experiment
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCM	general circulation model
GDP	Gross Domestic Product
GEWEX	Global Energy and Water Cycle Experiment
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	greenhouse gas
GISP2	Greenland Ice Sheet Project 2
GISS	Goddard Institute for Space Studies
GLA	Goddard Laboratory for Atmospheres
GLACE	Global Land Atmosphere Coupling Experiment
GMS	geostationary meteorological satellite
GOALS	Global–Ocean–Atmosphere–Land–System
GOOS	Global Ocean Observing System
GP	genesis potential
GPCP	Global Precipitation Climatology Project
HadAM3	Hadley Centre Atmospheric Model version 3
HFP	Historical Forecast Project
HMR	homogeneous region monsoon rainfall
HUBEX	GAME–Huaihe Basin Experiment
HyARC	Hydrospheric Atmospheric Research Center
HYCOM	HYbrid Coordinate Ocean Model
IAP	Institute of Atmospheric Physics
IAV	interannual variability
IIOE	International Indian Ocean Expedition
IMD	India Meteorological Department
IND	India/Arabian Sea region
INDOEX	Indian Ocean Experiment
INSAT	Indian National Satellite
IO	Indian Ocean
IOD	Indian Ocean Dipole
IOP	Indian Ocean Panel; Intense Observing Period (Chapter 8)
IOZM	Indian Ocean Zonal Mode
IPCC	Intergovernmental Panel on Climate Change
IR	infrared
ISBA	interactions soil–biosphere–atmosphere
ISM	Indian summer monsoon
ISMR	Indian summer monsoon rainfall
ISO	intraseasonal oscillation
ISOV	ISO variability
ISV	intraseasonal variability

ITCZ	intertropical convergence zone
JAMSTEC	Japan Marine Science and Techonology Center
JASMINE	Joint Air–Sea Monsoon Interaction Experiment
JJA	June–July–August
JJAS	June–July–August–September
JMA	Japan Meteorological Agency
KMA	Korea Meteorological Agency
L–AI	land–atmosphere interaction
LAI	land–atmosphere interaction
LAI	leaf area index
LASG	Laboratory of Atmospheric Sciences and Geophysical Fluid Dynamics
LBC	lower boundary condition
LF	low frequency
LH	latent heat
LIM	Linear Inverse Model
LLJ	low-level jet
LPS	low-pressure systems
LPSD	low-pass standard deviation
LS	leading stratiform
LSM	land surface model
LSS	land surface schemes
LST	local solar time
LT	local time
MAM	March–April–May
MCC	mesoscale convective complex
MCS	mesoscale convective systems
MCV	mesoscale convective vortex
MEM	maximum entropy method
MH	monsoon Hadley
MIS	marine isotopic stage
MISO	monsoon ISO
MISR	multiangle imaging spectroradiometer
MJJA	May–June–July–August
MJO	Madden–Julian Oscillation
MLD	mixed layer depth
MLM	mixed layer model
MM5	Fifth-Generation NCAR/Penn State Mesoscale Model
MME	multimodel ensemble
MODIS	moderate resolution imaging Spectroradiometer
MONEX	Summer Monsoon Experiment
MONTBLEX	Monsoon Trough Boundary Layer Experiment
MPI	Max Planck Institute for Meteorology
MRF	medium-range forecast
MRG	mixed Rossby–gravity

MRI	Meteorological Research Institute
MSU	Microwave Sounding Unit
MT	monsoon trough
MTC	mid-tropospheric cyclone
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCMRWF	National Centre for Medium-Range Weather Forecasting
NCSU	North Carolina State University
NDJF	November–December–January–February
NH	northern hemisphere
NHET	northern hemisphere near-equatorial trough
NIES	National Institute for Environmental Studies
NINO3.4	5°S–5°N, 170°–120°W
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRL	Naval Research Laboratory
NWP	numerical weather prediction
OAI	ocean–atmosphere interaction
OI	optimal interpolation
OLR	outgoing long-wave radiation
OLRA	outgoing long-wave radiation anomaly
OSSE	Observing System Simulation Experiment
OSU	Oregon State University
PBL	planetary boundary layer
PC	principal component
PDF	probability distribution function
PDO	Pacific decadal oscillation
PDS	point-wise downscaling
PENR	Penninsular Indian Rainfall
PHI	Philippine Sea region
PILPS	Project for Intercomparison of Land Surface Parameterization Schemes
PMP	Possible Maximum Precipitation
POP	Principal Oscillation Pattern
PR	precipitation radar
PS	parallel stratiform
PSAC	Philippine Sea anticyclone
PSU	Penn State University
PV	potential vorticity
PWC	precipitable water content
QBM	quasibiweekly mode
QBO	quasibiennial oscillation

QuikSCAT	Quick Scatterometer
QXPMEX	Qinghai–Xizang Plateau Meteorology Experiment
RAM	Regional Atmospheric Model
RegCM	Regional Climate Model
RHC	reverse Hadley circulation
RMM	real time multivariate MJO
RWS	Rossby wave source
SACZ	South Atlantic convergence zone
SAH	south Asian High
SAM	south Asian monsoon
SAS	Simplified Arakawa–Schubert Scheme
SCS	South China Sea
SCSMEX	South China Sea Monsoon Experiment
SEAM	southeast Asian monsoon
SECHIBA	Schématisation des Echanges Hydriques à l'Interface entre la Biosphère et l'Atmosphère
SH	southern hemisphere
SHAP	sensible heat driven air-pump
SiB	simple biosphere
SLP	sea level pressure
SMH	Siberian–Mongolian High
SMIP	Seasonal Model Intercomparison Prediction
SMP	Sumatra and Malay Peninsula
SNU	Seoul National University
SOI	Southern Oscillation Index
SON	September–October–November
SPCZ	South Pacific convergence zone
SRES	Special Report on Emission Scenarios
SSA	singular spectrum analysis
SSH	sea surface height
SSiB	simplified SiB
SSM/I	Special Sensor Microwave Imager
SST	sea surface temperature
STA	seasonal transitional axis
STJ	subtropical jet stream
SVD	singular value decomposition
TAMEX	Taiwan Area Mesoscale Experiment
TAO	Tropical Atmosphere–Ocean
TBO	tropospheric biennial oscillation
TC	tropical cyclones
TCZ	tropical convergence zone
TEJ	tropical easterly jet stream
TH	Tibetan High
TKE	Turbulent Kinetic Energy
TMI	TRMM Microwave Imager

TOA	top-of-atmosphere
TOGA	Tropical Ocean–Global Atmosphere
TOPEX	Topography Eeperiment for Ocean Circulation
TRMM	Tropical Rainfall Measuring Mission
TS	trailing stratiform
TSI	total solar irradiance
U200	200-mb zonal wind
UKMO	United Kingdom Meteorological Office
UTC	universal coordinated time
VP200	velocity potential at 200 hPa
WCR	west central Indian rainfall
WCRP	World Climate Research Programme
WEB	westerlies and easterlies boundary
WGSIP	CLIVAR Working Group on Seasonal to Interannual Prediction
WISHE	wind-induced surface heat exchange
WMO	World Meteorological Organization
WMONEX	winter MONEX
WNP	western North Pacific
WNPSM	western North Pacific summer monsoon
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch

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