

Meteorology *of* Tropical West Africa

The Forecasters' Handbook

Edited by **Douglas J. Parker and Mariane Diop-Kane**



World
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Foreword

This book represents the first effort to document modern weather forecasting science for a specific region of the world. As the Secretary-General of the World Meteorological Organization (WMO), I am particularly pleased to have seen this book evolve as a collaboration between operational forecasters, numerical modelling agencies and the academic community. This partnership, which has its roots in the African Monsoon Multidisciplinary Analyses (AMMA) international programme, has led to a fusion of material and ideas in the book, bringing together theory and practice.

The book documents scientific knowledge about the West African weather systems and summarizes the principles and practice of operational prediction. The material has been organized in such a way to take the reader seamlessly from the regional climate, through a study of the synoptic and mesoscale weather systems, to practical forecasting methods on timescales of hours, days, weeks and a whole season. Modern weather forecasters need to take into account all these timescales when delivering their prediction services. New tools including kilometre-scale prediction models and new satellite products have the potential to assist forecasters in their delivery of forecast information to address user requirements.

WMO was one of the partners in the preparation of this book, through its Education and Training Office, the Data-processing and Forecasting System Division of the Weather and Disaster Risk Reduction Services Department and the World Weather Research Programme within the Atmospheric Research and Environment Branch. In addressing the needs of the meteorological community in West Africa, the book makes a significant contribution to the WMO Capacity Development Programme.

Moreover, natural disasters have been well documented in West Africa, and it is expected that this book

will improve the ability of the National Meteorological and Hydrological Services (NMHSs) to deliver accurate hazard information for risk assessments, prevention, response and recovery. The publication of this book is also timely, as in 2017 WMO initiates the implementation of the well-known Severe Weather Forecasting Demonstration Project (SWFDP) in the West African region. I expect this book to be the primary scientific reference for training in severe weather forecasting associated with this project and a key source for academic training of students and professionals in meteorology in West Africa, a critical region for weather forecasting. This is a zone in which the population is particularly vulnerable to weather and climate events, where the science of meteorology has a strong track record, including the Global Atmospheric Research Programme (GARP) Atlantic Tropical Experiment (GATE) experiment of the 1970s, and where there has been a recently renewed research impetus through the AMMA programme.

I look forward to this book making a significant contribution to the quality of weather forecasts and warnings in West Africa in the coming years. I also hope that it will stimulate new research and operational activities, in particular, in the use of numerical weather prediction (NWP) systems and, in return, through feedback, increase the quality of NWP evaluation activities. Furthermore, the emphasis on the use of in situ and remotely sensed measurements in forecasts should provide additional motivation for the implementation and exploitation of measurement systems in West African countries.

Petteri Taalas
Secretary-General,
World Meteorological Organization

Preface

This book aims to synthesise the latest knowledge of West African meteorology with operational tools and methods for weather forecasting in the region. We hope that it will be valuable for the training of weather forecasters in West Africa, for weather forecasters around the world having an interest in tropical predictions, and for students of meteorology. It is our intention that the material should appeal to students who have an interest both in tropical dynamics and operational forecasting, and the book is targeted at both the undergraduate and postgraduate levels. A basic meteorological knowledge is assumed.

The book is particularly demanded by national meteorological services, whose general forecasting services are still in their early stages. For many years, focus has been on forecasting for aviation, but with climate change and its associated hazards and impacts, there is increasing demand for specific meteorological forecasts at a wider range of time and space scales. The main users need predictions for agriculture and food security, water resources, civil protection and disaster risk reduction, and health. Although the book does not address these issues directly, the phenomena needed to issue such forecasts at the required timescales have been covered throughout the book, with the aim of giving the forecaster enough materials to extrapolate and deliver such weather and climate services. The book also gives some insight for further research needed.

The book emerged from discussions between the two editors and Chris Thorncroft about West African forecasting for the JET2000 experiment in 2000. For that campaign, we were flight-planning for the UK research aircraft and trying to use modern numerical weather prediction (NWP) products alongside the conceptual models known to operational forecasters in the region. It was clear that there has been a lack of documentation of the basic meteorology of West Africa, a lack of documentation of forecasting methods (a more widespread problem for the tropics), and a lack of communication between the research and forecasting communities (again, not a problem unique to West Africa).

The African Monsoon Multidisciplinary Analysis (AMMA, 2002 onwards) offered an opportunity to deal

with some of these problems, and a forecasting programme was integrated with the intensive AMMA field campaigns of 2006. The AMMA Operational Centre (AOC) included a team of forecasters selected from different national meteorological services in West Africa, and hosted by the African Centre of Meteorological Applications for Development (ACMAD) in Niamey. This group worked on the production of systematic, standardised daily forecasts and analyses for presentation in the daily briefings at the AOC. The AOC forecasting programme was led by Jean Philippe Lafore and Zilore Mumba, and achieved some significant successes: a network of forecasters and researchers was created, important dialogues were initiated, and the standardisation of diagnostic plots, in the form of the West African Synthetic Analysis/Forecast (WASA/F), was put in place. However, the AOC forecasting also highlighted (at least for the academics involved) the massive challenge of developing reliable daily forecasts in the region, especially of convective systems.

Following the AOC forecasting, further development of WASA/F was conducted by ACMAD and the Centre National de Recherches Météorologiques, Météo-France (CNRM) over the next couple of years. We regard this framework for consistent plotting of weather features to be an essential part of the scientific development of forecasting in this region. There are a number of important conceptual models of weather systems in West Africa (African easterly waves (AEWs) and so on), and it is necessary to analyse, monitor, track and predict the behaviour of such features. By demarking relatively simple structures, such as an AEW trough, other aspects of the same phenomenon can be implied, if the user knows the typical configuration of such features: in the case of an AEW, the user can infer likely areas of rainfall, and rainfall type, relative to the trough location. In order for this conceptual framework to be useful it is necessary that there is scientific rigour to the process, and a great deal of the effort undertaken in creating this book has gone into the consideration of these principles. Features to be drawn schematically should correspond to agreed measures and thresholds in observational or model data, so that in principle those measures could be inferred within quantitative limits from the schematic features.

The plots should also be 'repeatable', in the sense that another forecaster making the same chart would produce the same result. Considerable effort has been put into the achievement of these goals; a summary of the rules for plotting of weather features on the WASA/F maps is provided in Chapter 11.

Preparation and writing of the book began formally in October 2009 at a workshop hosted by the International Centre for Theoretical Physics (ICTP) and co-funded by the World Meteorological Organization's (WMO's) World Weather Research Programme (WWRP) in association with THORPEX-Africa. A one-day workshop was used to explore some processes of interaction between researchers and forecasters, and the outcome was a structured plan of chapters and their content (including, importantly, the list of lead authors). This workshop also formalised the Editorial Committee for the project, and led to the agreement of the basic modus operandi of the preparation of the book.

Given that the important results to be documented are universal, and mainly are not country dependent, it was agreed that we could work with a small core group of forecasters alongside the various academics who were participating. Some other principles were at this point agreed:

- The Handbook will always describe the state of the art, assuming the availability of a full set of tools. This will give forecasters at the main centres the best information on the current state of knowledge, and will serve to drive demand for such tools.
- The Handbook will also describe pragmatic approaches to forecasting, including for example the plotting of synoptic charts from regional observations and the computation of stability indices from upper air data.
- Methods that are untested may be included in the Handbook, if there is good reason to do so, such as demonstrated success of the method in another part of the world. This approach will allow forecasters to perform the necessary testing for their region.
- Most chapters are separated into two parts: background scientific knowledge and operational methods.

Each chapter has one or two lead authors, plus a group of contributing authors. All chapters were peer reviewed by one or more people. In one or two cases the reviewer made substantial and specific contributions to the material and was invited to join the list of contributing authors.

An extended workshop was held in Leeds in the period October to December 2012. A forecaster core group worked together for 8 weeks with various European and African academics and forecasters visiting for shorter periods. This activity was the main opportunity to make progress on intensive collaboration over scientific details.

A final workshop co-funded by WMO, Met Office and ACMAD was hosted by Mariane Diop-Kane at Agence

Nationale de l'Aviation Civile et de la Météorologie du Sénégal (ANACIM) in Dakar in March 2013, with the aim of allowing the whole West African forecasting community (with representatives from eight national forecasting agencies, Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar (ASECNA) and West African Universities) to scrutinise and review the handbook material in order that we could move to completion of the book within a short time after this. In fact, completion of the book took another 2 years, due to iterations needed in resolving some of the ideas raised at that workshop.

Given that West African meteorology involves many interacting processes and spatio-temporal scales, while prior knowledge has hitherto been dispersed among many sources, organisation of the material has been quite complicated, and we have had to make a few choices. In particular, we have made deliberate decisions regarding the terminology of some of the main climatological features. We decided against using the term ITCZ (intertropical convergence zone) over land, because the convergence structure varies significantly with height and this causes confusion in the literature. While we retain 'ITCZ' over the ocean, over the continent we refer, when needed, to specific observable features such as the zone of maximum precipitation. At the same time, we have chosen to retain both of the terms ITD and ITF (intertropical discontinuity and intertropical front). These terms are interchangeable and are each used very widely in the literature and in operational centres. Similarly, we use both tephigrams and skew-*T* diagrams in the presentation of thermodynamic profiles, since both are in common use and the student should be prepared for this.

The main challenges in the preparation of this work have been the limited contributor time available, the need for scientific discourse in order to agree and approve the material to be presented, and the effort needed in ensuring cross-consistency between chapters. We are very grateful to the funding agencies that have supported us, and the time contributed by many scientists.

Chapter 1 presents an overview of the West African climate, without a specific consideration of forecasting methods. The following chapters build from synoptic meteorology through specific weather phenomena to nowcasting. Chapters 7 and 8 move to longer, subseasonal and seasonal timescales. The book then covers methods of remote sensing, numerical weather prediction and finally plotting conventions and standards in Chapter 11.*

*Douglas J. Parker
Mariane Diop-Kane
February 2017*

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The Steering Committee for the project represents the major stakeholders in the book and its impacts, and comprises Aida Diongue-Niang, Mariane Diop-Kane, Ibrahima Hamza, Abdoulaye Harou, Jean Philippe Lafore, Benjamin Lamptey, Ifeanyi Nnodu, Douglas Parker, Patrick Parrish and Leon Guy Razafindrakoto. The Editorial Committee has been responsible for the selection of chapter authors, and has provided strategic guidance on the project throughout. Its members have been Douglas Parker, Ernest Afiesimama, Jim Caughey, Rosalind Cornforth, Mariane Diop-Kane, Aida Diongue-

Niang, Andreas Fink, Ibrahima Hamza, Jean Philippe Lafore, Arlene Laing, Peter Lamb, Benjamin Lamptey, Zilore Mumba, Ifeanyi Nnodu, Jerome Omotosho, Steve Palmer, Wassila Thiaw, Chris Thorncroft and Adrian Tompkins.

In addition to those already named, and the chapter lead authors, we are particularly grateful for contributions made by a very wide group of operational forecasters, and other specialists in West African forecasting, namely Abdou Kassimou, Abébé Abdoulaziz, Garba Adamou, Raphael Agbabu, Leonard Amekudzi, Aboubacar Angoua, Nicole Asencio, Alpha Boubacar Barry, Florent Beucher, Cathryn Birch, Nicolas Chapelon, Fleur Couvreur, Okoloye Cyprian, Diakaria Kone, Abdou Aziz Diop, Marie-Christine Dufresne, Florence Favot, Jim Galvin, Adamou Garba, Amadou Tidiane Gaye, Françoise Guichard, Hama Hamidou, Alioune Kamara, André Kamga, Cheikh Kane, Yassin Khan, Diakaria Kone, Touré Koure, Gnatoulouma Kpabeba, Laurent Labbe, Yerima Ladan, Sidi Ould Mohamed Lemine, Serge Lepape, Ousmane Ndiaye, Justin Noukpozoukou, Mathieu Nuret, Bernard Orji, Deve Orkuma, David Perry Osika, Dazangwendé Emmanuel Poan, Felix Randrianaivalona, Romain Roehrig, Diori Saley, Maré Dominique Sangare, Abdoulaye Sarr, Massamba Seck, Tinni Seydou, Muller Tsatsu Siameh, George Emmanuel Stafford, Abdoulaye Taye, Augustin Tchouanwo, Moussa Yoro Thiam, Madiagne Thiaw, Mamadou Bassando Traore, Henk Verschuur, Patrick Vidal, Jean-Christoph Vincendon, Charles Yorke and Jingmay Yu.

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Acronyms

AAI	absorbing aerosol index
ACARS	Aircraft Communications Addressing and Reporting System
ACMAD	African Center of Meteorological Applications for Development
AEJ	African easterly jet
AERONET	AERosol ROBotic NETwork
AEW	African easterly wave
AI	aerosol index
AIRS	Atmospheric Infrared Sounder
ALMIP	AMMA Land Surface Model Intercomparison Project
AMDARS	Aircraft Meteorological Data Relay
AMJO	African Madden–Julian oscillation
AMMA	African Monsoon Multidisciplinary Analysis
AMMA	Analyse Multidisciplinaire de la Mousson Africaine
AMSU	Advanced Microwave Sounding Unit
ANACIM	Agence Nationale de l'Aviation Civile et de la Météorologie du Sénégal
ANASYG	Graphic SYnoptic ANALysis
AOT	Aerosol Optical Thickness
ARM	Atmospheric Radiation Measurement
ARPEGE	Operational forecasting global model of Météo-France
ASCAT	Advance SCATterometer
ASDAR	Aircraft to Satellite Data Relay
ASECNA	Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar
ATOVS	Advanced TIROS Television and Infrared Observational Satellite Operational Vertical Sounder
AVHRR	Advanced Very High Resolution Radiometer
BoDEx	Bodélé Dust Experiment
BRN	bulk Richardson number
BTD	brightness temperature difference
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAPE	convective available potential energy
CAT	clear air turbulence
CATCH	Couplage de l'Atmosphère Tropicale et du Cycle Hydrologique
CBL	convective boundary layer
CCA	canonical correlation analysis
CCEW	convectively coupled equatorial wave
CDAS	Climate Data Assimilation System
CFS	Climate Forecast System
CIN	convection/convective inhibition
CLAUS	Cloud Archive User Service
CLIVAR	Climate and Ocean: Variability, Predictability and Change
CMC	Canadian Meteorological Centre
CNRM	Centre National de Recherches Météorologiques, Météo-France
CPC	Climate Prediction Center

CRM	Cloud Resolving Model
DCAPE	downdraught CAPE
DMCPAs	Disaster Management and Civil Protection Authorities
ECMWF	European Centre for Medium-Range Weather Forecasts
EJ	easterly jet
ENSO	El Niño Southern Oscillation
EOF	empirical orthogonal function
EPS	ensemble prediction system
ER	equatorial Rossby
ERA-Interim	European Centre for Mid-Range Weather Forecast ReAnalysis Interim
ET	actual evapotranspiration
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites
GARP	Global Atmospheric Research Programme
GATE	GARP Atlantic Tropical Experiment
GCM	general circulation model
GEFS	Global Ensemble Forecast System
GEO	geostationary or geosynchronous Earth orbit
GEWEX	Global Energy and Water Exchanges Project
GFS	Global Forecast System
GIMMS	Global Inventory Modeling and Mapping Studies
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System
GOME-2	Global Ozone Monitoring Experiment-2
GPCP	Global Prediction Climatology Project
GPM	Global Precipitation Mission
GPS	Global Positioning System
GRAS	GNSS Receiver for Atmospheric Sounding
GTS	Global Telecommunications System
GWD	gravity wave drag
HAPEX-Sahel	Hydrology-Atmosphere Pilot Experiment in the Sahel, 1990–1992
HDH	Harmattan dust haze
HI	heat index
HIRS	High-Resolution Infrared Radiation Sounder
HL	heat low
HOAPS	Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data
HRV	high-resolution visible
HSS	Heidke skill score
IASI	Infrared Atmospheric Sounding Interferometer
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IGRA	Integrated Global Radiosonde Archive
IHC	interhemispheric thermal contrast
IR	infrared
IRD	Institute de Recherche pour le Développement
IRI	International Research Institute for Climate and Society
ISCCP	International Satellite Cloud Climatology Project
ISD	integrated surface daily data set
ITB	intertropical boundary
ITCZ	intertropical convergence zone
ITD	intertropical discontinuity
ITF	intertropical front
JAS	July–August–September
JMA	Japan Meteorological Agency
LAM	limited-area model
LCL	lifted/lifting condensation level
LEO	low Earth orbit

LFC	level of free convection
LLJ	low-level jet
LLWAS	Low-Level Wind-Shear Alert System
LLWJ	low-level westerly jet
LST	local solar time
MCA	maximum covariance analysis
MCGE	multi-centre grand ensemble
MCS	mesoscale convective system
MCV	mesoscale convective vortex
MD	monsoon depth
METAR	meteorological aviation routine weather report
METAR	aerodrome routine meteorological report
METAR	meteorological aviation report
MetUM	Met Office Unified Model
MFC	moisture flux convergence
MFD	moisture flux divergence
MIDAS	Met Office Integrated Data Archive System
MISR	Multi-angle Imaging Spectroradiometer
MISVA	Monitoring and Forecasting of Intraseasonal Variability over Africa
MJO	Madden–Julian oscillation
ML	monsoon layer
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	model output statistics
MPE	Multisensor Precipitation Estimate
MRG	mixed Rossby–gravity
MSE	moist static energy
MSG	Meteosat Second Generation
MSL	mean sea level
MSLP	mean sea-level pressure
MT	monsoon trough
MTG	Meteosat Third Generation
MVIRI	Meteosat Visible and Infra-Red Imager radiometer
NBL	night-time, or nocturnal, planetary boundary layer
NCEP	National Centers for Environmental Prediction
NDVI	normalized differential vegetation index
NLLJ	night-time low-level jet
NMHSS	national meteorological and hydrological services
NMS	National Met Services
NOAA	National Oceanic and Atmospheric Administration
NOAA/WPC	National Oceanographic and Atmospheric Administration Weather Prediction Center
NPP	National Polar-orbiting Partnership
NWP	numerical weather prediction
OI	optimum interpolation
OLR	outgoing longwave radiation
OMI	Ozone Monitoring Instrument
OMP	Observatoire Midi-Pyrénées
<i>P</i>	Precipitation
PBL	planetary boundary layer
PC	principal component
PJ	polar jet
POES	Polar-orbiting Environmental Satellites
PPI	plan position indicator
PRESAO	PREvision Saisonairre des pluies en Afrique del l'Ouest
PRESYG	Graphic Synoptic Prediction
PSANAF	Potential dust source areas in northern hemispheric Africa

PV	potential vorticity
PVU	potential vorticity unit
PW	precipitable water
PW*	precipitable water anomaly
PWAT	precipitable water
PWV	precipitable water vapour
QBZD	quasi-biweekly zonal dipole
RCOF	Regional Climate Outlook Forum
RDT	Rapid Development Thunderstorm
RFE2	Rainfall Estimate Version 2
RGB	red, green, blue
RGB	red, green and blue (primary colours combined for image visualisation)
RHI	range–height indicator
RIPIECSA	Recherches Interdisciplinaires et Participatives sur les Interactions entre les Ecosystèmes, le Climat et les Sociétés en Afrique de l’ouest
RMDCN	Regional Meteorological Data Communications Network in Europe
RMM	Real-time Multivariate MJO series
ROC	relative operating characteristic
RTTOV	Radiative Transfer for TOVS
S4CAST	Sea Surface Temperature-based Statistical Seasonal Forecast Model
SAFNWC	Satellite Application Facility on Support to Nowcasting and Very Short Range Forecasting
SAL	Saharan air layer
SAMUM	Saharan Mineral Dust Experiment
SAWS	South Africa Weather Service
SDS-WAS	Sand and Dust Storm Warning Advisory and Assessment System
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEDOO	Service de DONnée
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
SHL	Saharan heat low
SMAP	NASA’s Soil Moisture Active Passive mission, January 2015
SMOS	ESA’s current Soil Moisture and Ocean Salinity mission launched on 2 November 2009
SOLAS 74	International Convention for the Safety of Life at Sea 1974
SOP	Specific Observation Period
SOP-1, SOP-2	Special Observing Periods of AMMA
SPECI	aerodrome special meteorological report
SSM/I	Special Sensor Microwave/Imager
SST	sea surface temperature
STJ	subtropical jet
SVD	singular value decomposition
SWFDP	WMO Severe Weather Forecast Demonstration Project
SYNOP	surface synoptic observation
SYNOP	synoptic observation
TAF	terminal aerodrome forecast
TB	brightness temperature
TCW	total column water
TD	tropical disturbance
TDWR	terminal Doppler weather radars
TEJ	tropical easterly jet
THORPEX	The Observing-System Research and Predictability Experiment
TIGGE	THORPEX Interactive Grand Global Ensemble
TIROS	Television and Infrared Observational Satellite
TOA	top-of-atmosphere
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
UTC	Universal Time Coordinated

UTT	upper tropospheric trough
UV	ultraviolet
VIIRS	Visible Infrared Imaging Radiometer Suite
VIS	visible
VP	velocity potential
WAHL	West African heat low
WAM	West African monsoon
WASA/F	West African Synthetic Analysis/and Forecast
WAWJ	West Africa westerly jet
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WV	water vapour
WWRP	World Weather Research Programme
YOTC	Year of Tropical Convection
ZDR	differential reflectivity

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