A.P. Dimri · Amulya Chevuturi

Western Disturbances - An Indian Meteorological Perspective

Springer

Western Disturbances - An Indian Meteorological Perspective

A.P. Dimri • Amulya Chevuturi

Western Disturbances - An Indian Meteorological Perspective

Springer

A.P. Dimri
School of Environmental Sciences
Jawaharlal Nehru University
New Delhi, India

Amulya Chevuturi
School of Environmental Sciences
Jawaharlal Nehru University
New Delhi, India

ISBN 978-3-319-26735-7 ISBN 978-3-319-26737-1 (eBook)
DOI 10.1007/978-3-319-26737-1

Library of Congress Control Number: 2016930300

Printed on acid-free paper

This Springer imprint is published by SpringerNature
The registered company is Springer International Publishing AG Switzerland.

Foreword

The Indian subcontinent experiences mainly four seasons. Among them, the Southwest monsoon season (June to September) is the most important season as it contributes 70–90 % of the annual rainfall over the country. However, the northern parts of the country and neighboring Pakistan also experience a wet season during the winter, due to the passage of western disturbances, winter weather systems moving eastwards across the region. This season is very important as it plays an major role in the winter crop (Rabi) production and hydrology over the region. This region has a complex topography due to the Himalayas. The weather systems moving across this region interact with this complex topography and lead to more complexity to the dynamics and predictability of weather systems. The synoptic features and dynamics of these weather systems were not explored in the past due to lack of adequate observations and modeling efforts. Over the years, our understanding of these winter weather systems has improved substantially due to improvement of observational networks over the region and systematic modeling efforts. Better understanding of these systems has also helped to improve weather prediction skills over the region, which is reflected in the operational weather forecasts issued by the India Meteorological Department.

In concert with these developments, this book *Western Disturbances, An Indian Meteorological Perspective* by Prof A.P. Dimri and Dr. Chevuturi will prove to bridge an indispensable knowledge gap for earth scientists at all stages of their careers, from undergraduate students to the professionals. Western disturbances in the context of Indian meteorology are an important weather phenomenon which in the current context of climate change has gained importance due to its influence on the Himalayan snow cover, glaciers, northern Indian river feed, agriculture, etc. This book will provide readers with a broad perspective on development and interpretation of physical, dynamical, and thermodynamical processes associated with winter weather systems over the Indian subcontinent. The description accompanied by numerous illustrations sufficiently provides concise deliberations for established researchers and also policy makers. The book provides most adequate composite integration of available references right from the last decade to the latest.

In the first chapter of the book, updated understanding on structure and evolution of western disturbances is provided. This chapter provides more comprehension than many other treatments on the subject. With the advent of computational facilities, observational reanalysis, and numerical methods, constructing the natural environment became much easier. Simulations of the atmospheric flows/interactions are better understood and explained with such efforts. Chapter 2 dwells into those details and synthesizes efforts carried on this direction with the latest positioning. In the recent decade it is observed that midlatitude westerlies have strengthened their interactions with other seasonal weather systems. Chapter 3 deliberates on factors leading to such interaction and their effect. It is one of the important aspects in the context of recent global changes. In Chap. 4, discussion on western disturbances embedded within large-scale westerlies is provided. In the context of global change, this is one of the most important aspects providing understanding of large-scale flows affecting the life cycle of weather systems. In the fifth chapter, the western disturbances and their impacts and climate change issues are discussed. Prof. Dimri and Dr. Chevuturi have provided here an excellent summary on the Indian winter weather systems at different spatial and temporal scales. I believe this book will be an excellent reference for students, professionals, and policy makers on the winter weather systems over India.

Indian Institute of Tropical Meteorology M. Rajeevan
Pune, India

Preface

Meteorology, climatology, and atmospheric sciences have been extensively studied over India. But sometimes, a unified compilation of such an extensive knowledge resource base is lacking, which may result in gaps in the information flow. With India having a vast and heterogeneous geography, it is imperative to have detailed understanding of its intricacies. This book comprehensively reviews a weather phenomenon impacting the Indian subcontinent. Western disturbances (WDs), the wintertime precipitating events, are the focus of this book. This book can be used as a reference by students, professors, and other research scholars to achieve a detailed understanding on the subject. Other than its importance in terms of a meteorological phenomenon, WDs as precipitating events have significant consequences on the ecology and the socioeconomy of the region. Overall this book answers the questions of what/when/why/how about the WDs. This book defines WDs and details the physical and dynamical understanding of their structure and migration. It also includes the causes and impacts with detailed illustrations and various case studies for a clear understanding of the subject.

The book's visualization and conception came about during our research tenure that focused on the Himalayan climate. Wintertime precipitation over the Himalayas and northern India is a very interesting topic and has not been comprehensively researched. So many research questions on the topic are still unanswered. Further, most of the research is available in older formats that are not easily accessible. Without a review or a textbook understanding of the topic, intensive research on the topic is challenging. Thus, we came to believe that such a book would be a requirement in this field of research, especially from the point of view of young researchers. All of these reasons compelled us as researchers to write this book. During the course of writing, we grew as authors and researchers. Despite our previous experience on the topic, while doing the researching behind this book, our knowledge grew as new information was uncovered. It was a uniquely interesting learning experience for us.

We would like to express gratitude for the scholastic support of the various experts whose peer-reviewed papers and other research work has been used and referred to in this book. Acknowledgment is indeed due to the different sources of observational datasets that have been properly cited within the book. We would also like to thank our editor at Springer Petra van Steenbergen and our publisher Springer for making this book possible. We convey our appreciation for the reviewers for their suggestions and comments that helped us in improving the book. Last but not the least, we would also like to thank our colleagues, friends, and family who supported us in our endeavor and helped us during our journey.

New Delhi, India

A.P. Dimri
Amulya Chevuturi

Contents

1 Western Disturbances – Structure 1
1.1 Introduction 3
1.2 Origin and Migration of Western Disturbances 5
1.3 Western Disturbances at a Synoptic Scale 10
1.4 Structure of Western Disturbances 14
1.5 Western Disturbances and Linkages with Large-Scale Forcing 19
References 21

2 Western Disturbances – Dynamics and Thermodynamics 27
2.1 Dynamics of Western Disturbances 29
2.2 Modelling Studies Related to Western Disturbances 32
2.3 Interplay With Himalayan Orography and Land-use – Land-Cover Interactions 45
References 55

3 Western Disturbances – Indian Seasons 61
3.1 Winter 63
3.2 Pre-Monsoon 65
3.3 Monsoon 67
3.4 Post-Monsoon 77
References 79

4 Western Disturbances – Indian Winter Monsoon 83
4.1 Introduction 84
4.2 Interannual Variability of the Indian Winter Monsoon 86

4.3 Sub-seasonal Oscillation Associated with the Indian Winter Monsoon 92
4.3.1 Wet and Dry Winters over the WH and Its Associated Circulation 93
4.3.2 Large-Scale Global and Local Forcings 99
4.4 Intraseasonal Oscillation Associated with the Indian Winter Monsoon 101
References 109

5 Western Disturbances – Impacts and Climate Change 113
5.1 Winter Precipitation and Its Impacts 113
5.2 Severe Weather 116
5.3 Western Disturbances in the Changing Climate 120
5.4 Western Disturbances and Future Research 124
References 125

Index 129

List of Figures

Fig. 1.1 Map of Indian Subcontinent 2
Fig. 1.2 Meteosat satellite image (Channel 2) for a WD travelling towards India. Satellite images of (**a**–**j**) are from 06 January 2009 to 15 January 2009 each at 0000 UTC. *Red circle* marks the migrating WD 8
Fig. 1.3 An asymmetric upper-air trough with closer packing in the rear 11
Fig. 1.4 500h Pa geopotential ($\times 10^{-2}$ m; *shaded*) and wind (m/s; *arrow*) for 05 February 2002 to 09 February 2002 with WRF model simulation (Dimri and Chevuturi 2014) 16
Fig. 1.5 Vertical distribution of geopotential height anomaly averaged over latitude (25°N–40°N) for WD in February 2002 17
Fig. 1.6 Same as Fig. 1.5 but averaged over longitude (65°E–85°E) 18
Fig. 1.7 Conceptual model of WDs (*MI:* Moisture incursion, *PRECIP:* Precipitation, *SL:* Surface low, *STWJ:* Sub-tropical westerly jet, *TA:* Westward tilted axis in vertical, *WD:* Upper air western disturbance) 20

Fig. 2.1 (**a**) Schematic representation of cascading Himalayan mountain ranges (Pir Panjal- Great Himalaya-Zanskar-Ladhak-Karakoram) and western-central–eastern Himalayan region (**b**) Topographic ($\times 10^{3}$ m) overview of the Himalayas 28
Fig. 2.2 Reanalysis of sea level pressure at 0000 UTC on (**a**) 19 Jan 1997 and (**b**) corresponding 24 h forecast of sea level pressure in 08 difference model experiments 37

Fig. 2.3 500 hPa Geopotential height (m) after 48 h model forecast valid at 0000 UTC on 23 Jan 1999 over flat (**a**, **b** and **c**) and normal topography (**d**, **e** and **f**) with different model horizontal resolutions 39
Fig. 2.4 Precipitation (cm/24 h) after 48 h model forecast valid at 0000 UTC on 23 Jan 1999 over flat (**a**, **b** and **c**) and normal topography (**d**, **e** and **f**) with different model horizontal resolutions 40
Fig. 2.5 500 hPa wind (m/s; *arrow*); geopotential height (m; *red contour*) and wind speed above 22 m/s (*grey shed*) in (**a**) model, (**b**) MERRA and (**c**) NCEP-NNRPII on 07 Feb 2002 0000 UTC 41
Fig. 2.6 Spatial distribution of model simulated maximum (**a**) CAPE (J/kg) and (**b**) CIN (J/kg) on 07 Feb 2002 0000 UTC.. 42
Fig. 2.7 Longitude-pressure cross section (at the line across preak precipitation spatial distribution of the storm) at 1700 UTC 17 Jan 2013 for geopotential height anomaly (*shaded*) and perturbation geopotential height (m; *contour*)........................ 43
Fig. 2.8 Time-pressure cross section (area averaged over the grid around NCR) for CAPE (J/kg; *shaded*), temperature (°C; *black contours*) and specific humidity (g/kg; *blue contours*) 44
Fig. 2.9 Vertical cross section of vorticity ($\times 10^5$ s^{-1}, *shaded*), model precipitation (cm/day; *green line*) and observed precipitation (cm/day; *purple line*) along 33°N for the WD case studied.. 48
Fig. 2.10 Lon-pressure cross section vertical distribution at 34°N latitude of model simulated meridional wind (ms^{-1}) (continuous *black contour*) and air specific humidity (×1e-3) (broken *red contour*) at 0000 UTC during active WD (a) 21 Jan 1999 (**b**) 22 Jan 1999 (**c**) 23 Jan 1999 (*Left hand side* vertical axis corresponds to the pressure distribution and *right hand side* vertical axis corresponds to the topography $\times 10^2$ m) 50
Fig. 2.11 Twenty-four hour cumulative precipitation on 22 December 2006 in (**a**) observational data (APHRODITE) and (**b**) the corresponding REMO simulated field, and geopotential height (m; *shade*) and vector wind (m/s; *arrow*) in the REMO simulation at (**c**) 850 hPa on 20 December 2006, (**d**) 500 hPa on 20 December 2006, and (**e**) 500 hPa on 20 December 2006... 51

Fig. 2.12 Lon-pressure cross section vertical distribution at 34°N latitude of model simulated geopotential height (m; *continuous black contour*) and air specific humidity (×1e-3; *shaded*) at 0000 UTC during active WD (**a**) 20 Dec 2006 (**b**) 21 Dec 2006 (**c**) 22 Dec 2006 (*Left hand side* vertical axis corresponds to the pressure distribution and right hand side vertical axis corresponds to the topography $\times 10^2$ m) 53
Fig. 2.13 Lon–pressure distribution of vorticity (×1e-5/s; *shade*), relative humidity (%, *broken contour*), and topography ($\times 10^3$ m; shaded bar) on (**a**) 19 December 2006, (**b**) 20 December 2006, (**c**) 21 December 2006, (**d**) 22 December 2006, (**e**) 23 December 2006, and (**f**) 24 December 2006 at 35°N Lat in the REMO simulation 54

Fig. 3.1 Kalpana satellite images for (**a**) 15 June 2013 (0600 UTC), (**b**) 16 June 2013 (0600 UTC) and (**c**) 17 June 2013 (0600 UTC). (**d**–**f**) is same as (**a**–**b**) but with INSAT-3A with thermal infrared band 71
Fig. 3.2 Geopotential height anomaly (*shaded*) and perturbation geopotential height ($\times 10^2$ m/s; *contour*) over the axis normal to the formation of TCS for different time periods 73
Fig. 3.3 Conceptual model of the PEM towards Himalayas 75

Fig. 4.1 (**a**) Topography (×1e–3 m; *shaded*) and ratio of 0.05° grids for stations (%; *contour*) over the western Himalayas. The area of 30°N, 72°E to 37°N, 82°E is considered in the present chapter; (**b**) winter season precipitation climatology (mm/DJF) based on APHRODITE precipitation observed data reanalysis 85
Fig. 4.2 (**a**) The monthly (Dec, Jan, and Feb) and seasonal (DJF) precipitation (mm/d) anomaly in APHRODITE observational reanalysis and (**b**) difference in 3-month (Dec, Jan, and Feb) average wet- and dry-year composites precipitation (*shaded*) and region with 99 % confidence level (within *contour*) 87
Fig. 4.3 Difference between 03 (DJF) month average wet and dry composites of wind (m/s; *contour*; winds above 99 % significant level are *plotted*) and geopotential height (m; *shaded*; region within contour corresponds to 99 % significant level) at (**a**) 200 hPa (**b**) 500 hPa and (**c**) 850 hPa 88

Fig. 4.4 Seasonal anomalous velocity potential (×1e–6 m^2/s; *contour*) with corresponding anomalous divergent wind (m/s; *arrow*) at $\sigma = 0.1682$ and anomalous outgoing longwave radiation (W/m^2; *shade*) for (**a**) wet and (**b**) dry year composites and seasonal anomalous stream function (×1e–6 m^2/s; *contour*) with corresponding anomalous rotational wind (m/s; *arrow*) at $\sigma = 0.1682$ and anomalous outgoing longwave radiation (W/m^2; *shade*) for (**c**) wet and (**d**) dry year composites 90
Fig. 4.5 Correlation between 28 years (1980–2007) area averaged winter precipitation –D(-1)JF(0) – (mm/d) with sea surface temperature (°C) during (**a**) D(-2)JF(-1) (**b**) MAM(-1) (**c**) JJA(-1) (**d**) SON(-1) and (**e**) D(-1)JF(0). (Figures in bracket correspond to sea surface temperature with previous and corresponding seasons). Region within *contour* corresponds to 99 % significant level 91
Fig. 4.6 Correlation between seasonal (DJF) and monthly (Dec, Jan, and Feb) interannual precipitation variability based on APHRODITE 92
Fig. 4.7 Cumulative average monthly anomalous precipitation (mm/month) during wet composites of (**a**) Dec, (**b**) Jan, and (**c**) Feb and for dry composites of (**d**) Dec, (**e**) Jan, and (**f**) Feb. Masking with 10 mm/month was employed 94
Fig. 4.8 Monthly difference in (wet–dry) anomaly for 200 hPa geopotential height (hPa, *contour*) and wind vector (ms^{-1}, *arrow*) for (**a**) Dec, (**b**) Jan, and (**c**) Feb. The hatched region corresponds to ≥95 %. Similarly, only winds with 95 % significance and above are shown 95
Fig. 4.9 Same as Fig. 4.8, but for outgoing longwave radiation (W/m^2; *shaded*) 97
Fig. 4.10 Longitude–pressure vertical cross section at 30°N of the anomalous meridional moisture flux (kg/m/s) during wet ((**a**), (**b**), and (**c**)) and dry ((**d**), (**e**), and (f)) composites of Dec, Jan, and Feb, respectively 98
Fig. 4.11 Area-averaged (30°N 72°E to 37°N 82°E) vertical cross-sectional distribution of anomalous air temperature (°C) in (**a**) wet and (**b**) dry composites for Dec (*black line*), Jan (*red line*), and Feb (*green line*) and area-averaged (30°N 72°E to 37°N 82°E) anomalous 2-m surface-air temperature (*black line*; °C) and anomalous precipitation (mm/d) during (**c**) wet and (**d**) dry year composites of Dec, Jan, and Feb............................... 100