IWM-7

Abstracts of Papers for the Seventh WMO International Workshop on Monsoons (IWM-7)

(New Delhi, India, 22-26 March, 2022)

India Meteorological Department
Ministry of Earth Sciences

Compiled and Edited by

Dr. D. R. Pattanaik

Coordinator, IWM-7

India Meteorological Department (IMD)

सत्यमेव जयते
Ministry of Earth Sciences
Government of India

Formal Inauguration programme
of the
Seventh WMO International Workshop on Monsoons (IWM-7)
22-26 March 2022
Host : India Meteorological Department (IMD),
Ministry of Earth Sciences (MoES)
New Delhi, India

PROGRAMME

Date: 23rd March 2022; Mode : Online; Time : 1800-1915 IST (1230-1345 UTC)

1800 IST *1230 UTC*	Welcome	**Arrival of Guests**
1800-1810 IST *1230-1240 UTC*	Welcome Address By	**Dr. M. Mohapatra** *DGM, IMD, PR of India with WMO & President IMS*
1810-1820 IST *1240-1250 UTC*	Brief Report about IWM-7	**Prof. C. P. Chang** **Dr. Ajit Tyagi** *(Co-Chairs, International Scientific Committee, IWM-7)*
1820-1825 IST *1250-1255 UTC*	Address By	**Dr. Estelle De Coning** *Head, WWRP Division, WMO*
1825-1830 IST *1255-1300 UTC*	Address By	**Dr. Michael Sparrow** *Head, WCRP Division, WMO*
1830-1835 IST *1300-1305 UTC*	Announcement of IMS's Sir Gilbert Walker Gold Medal Award	**Indian Meteorological Society, National Council** *Secretary, IMS*
1835-1840 IST *1305-1310 UTC*	Release of Abstract Volume : IWM-7	**Dr. M. Ravichandran** *Secretary, MoES*
1840-1850 IST *1310-1320 UTC*	Address By Guest of Honour	**Dr. M. Ravichandran** *Secretary, MoES and Chairman, NOC & IOC, IWM-7*
1850-1900 IST *1320-1330 UTC*	Address (Pre recorded video message)	**Prof. Petteri Taalas** *Secretary General, WMO*
1900-1910 IST *1330-1340 UTC*	Inaugural Address (Pre recorded video message)	**Dr. Jitendra Singh** *Hon'ble Minister of Earth Sciences, Govt. of India*
1910-1915 IST *1340-1345 UTC*	Vote of Thanks By	**Dr. D. R. Pattanaik** *Coordinator, NOC/LOC, IWM-7 and Secretary, IMS*

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Seventh WMO International Workshop on Monsoons (IWM-7)

22-26 March 2022, New Delhi

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Message from SG, WMO

WEATHER CLIMATE WATER
TEMPS CLIMAT EAU

WMO OMM
World Meteorological Organization
Organisation météorologique mondiale
Organización Meteorológica Mundial
Всемирная метеорологическая организация
المنظمة العالمية للأرصاد الجوية
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Ref.: 0691Z/2022-L1 SG

Subject: Online "Seventh WMO International Workshop on Monsoons" in New Delhi, India 23-26 March 2022, hosted by India Meteorological Department of Ministry of Earth Sciences, and India Meteorological Society.

WMO Message:

Prof. Petteri Taalas, Secretary-General of WMO, addresses in the opening of the online "Seventh WMO International Workshop on Monsoons" through video recording on 23 March 2022.

WMO appreciates and congratulates India Meteorological Department of Ministry of Earth Sciences and the Indian Meteorological Society for organizing this online workshop on monsoons.

WMO informs that the International Workshop on Monsoons (IWM) is a major quadrennial symposia/workshops series under the World Weather Research Programme (WWRP) of WMO and is WMO's effort to provide a forum for researchers and forecasters to discuss recent advances and current issues involving monsoons as key features of earth-system phenomena covering weather-to-climate time scales affecting more than two-thirds of populations around the world.

WMO expresses appreciation to the Indian Institute of Tropical Meteorology and Indian Meteorological Society to host International Monsoon Project Office (IMPO) to contribute to global monsoon research coordination under the auspices of WMO and to support WMO's dedication on the advancement of monsoon science.

WMO emphasizes the importance of the monsoon systems in the circulation of the atmosphere, and their vital and diversified roles in and effects on evolution of weather and climate systems, like tropical cyclones.

WMO recognizes that global warming and urbanization over the past century had already caused a significant rise in the intensity and frequency of extreme rainfall events and their variabilities in all monsoon regions, and thus had increased difficulties in prediction of monsoon weather and climate.

WMO further recognizes that while there has been an overall improvement in the skill of monsoon forecasts during the recent years, the increasingly erratic monsoon weather patterns in the backdrop of climate change are making forecasts more unpredictable at

Ref.: 0691Z/2022-LL SG

local/regional scales. As a result, monsoon prediction at regional scales is becoming more challenging and at the same time more imperative. Thus, strengthening of monsoon research to better support operations and services is a priority for both India and global monsoon services.

WMO reaffirms that WMO, as the specialized agency of the United Nations System in weather, climate, and water, and through Members' NMHSs, ensures the delivery of timely and reliable and authoritative warnings information to support national mandates and global SDGs.

WMO re-iterates WMO's leading roles and initiatives in adopting earth system approach combined with unified date policy to understanding and predicting weather, climate, water and environment related phenomena with impacts, including monsoons to meet evolving challenges in sciences and technologies and emerging requirements for better services to societies.

WMO encourages the monsoon scientific and operational communities to explore and fully utilize WMO regional structure and governance through WMO new regional concept and approaches: a) to most fit regional diversity and characteristics in developing monsoon forecasting skills and competencies, b) to meet evolving regional and national requirements, c) to enhance skills and competencies of Members' NMHSs through a global network of monsoon forecasting, and 4) finally to enable regional structure and governance to serve as reliable vehicles and platforms for WMO Members to provide monsoon weather and climate forecasting services with unified international quality and standard.

Prof. Petteri Taalas
Secretary-General

Message from Secretary, MoES

सचिव
भारत सरकार
पृथ्वी विज्ञान मंत्रालय
पृथ्वी भवन, लोधी रोड, नई दिल्ली–110003

सत्यमेव जयते
डॉ. एम. रविचंद्रन
Dr. M. Ravichandran

SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
PRITHVI BHAWAN, LODHI ROAD, NEW DELHI-110003

MESSAGE

I am glad to learn that India Meteorological Department (IMD), Ministry of Earth Sciences (MoES), Government of India is hosting the Seventh WMO International Workshop on Monsoons (IWM-7), using virtual platform during 22-26 March, 2022. The IWM-7 is being organized jointly by the IMD-MoES and the WWRP Working Group on Tropical Meteorology Research (WGTMR), in cooperation with the CLIVAR/GEWEX Monsoons Panel of the World Climate Research Programme (WCRP) and the International Monsoons Project Office (IMPO) hosted by the Indian Institute of Tropical Meteorology (IITM), and Indian Meteorological Society (IMS).

India is blessed with two monsoons in a year, the Southwest monsoon during June to September and the Northeast monsoon during October-December. Monsoons affect the Indian people in every aspect of their lives. From ancient history to modern times, it has controlled their everyday existence. Monsoon variability has a direct link with the country's economy and a severe monsoon drought can pull down India's GDP even up to 2%.

Recognizing the urgent need for improving monsoon prediction capabilities in the country in a systematic and timely manner, the Government of India launched an ambitious and well-resourced research programme on Mission mode, called the Monsoon Mission. The first phase of the mission was implemented during 2012-2017, and the second phase which started in 2017 is underway. Through this mission, MoES also augmented its capability of High-Performance Computing (HPC), which is close to 10 petaflops now, and able to generate high-resolution forecasts with 3 km resolution using meso-scale model, 12 km resolution using global forecast system model, and about 38 km using ocean-atmosphere coupled model. These continuous efforts by MoES has enabled IMD to (i) provide forecast at block level which has immensely benefited the agricultural sector, and (ii) improved the predictions of extreme events, like cyclones and heavy rainfall in recent period.

I am confident that the IWM-7 will provide a platform to the academicians, scientists, numerical modeling, communities and operational forecaster from leading international and national organizations to deliberate and understand the complexities of monsoon processes and its prediction in the backdrop of challenges faced by climate change.

I convey my best wishes for the success of this conference.

(M. Ravichandran)

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Message from DG, IMD

डॉ. मृत्युंजय महापात्र
मौसम विज्ञान विभाग के महानिदेशक,
विश्व मौसम विज्ञान संगठन में भारत के स्थाई प्रतिनिधि
एवं कार्यकारी परिषद के सदस्य

Dr. Mrutyunjay Mohapatra
Director General of Meteorology,
Permanent Representative of India with WMO,
Member of Executive Council, WMO

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम भवन, लोदी रोड़
नई दिल्ली–110003
Government of India
Ministry of Earth Sciences
India Meteorological Department
Mausam Bhawan, Lodi Road
New Delhi - 110003

Message

It gives me immense pleasure to convey that the **Seventh WMO International Workshop on Monsoons (IWM-7)** is hosted by India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) and jointly coordinated by World Weather Research Programme (WWRP) and World Climate Research Programme (WCRP) of World Meteorological organization (WMO) during 22-26 March 2022, New Delhi, India.

Monsoon circulation is observed over many parts of the globe including North America, North Africa, Indian, East Asia, Western North Pacific, South America, South Africa and the Australia with varied regional characteristics. The Indian/South Asian monsoon is predominant among the regional monsoons with strong land-sea contracts. Southwest monsoon during June to September affects the people in the region every aspect of their lives. Timely arrival of monsoon rains is very crucial for providing farming operations, drinking water, water resources (reservoir) management, generation of hydro power etc.

Recently, IMD in collaboration with Sister Organisations of MoES has taken major steps in improving the weather, climate and hazards warning services capabilities in the country including the forecast of monsoon in different timescales. With the improvement in observational and forecasting tools including augmentation of NWP Models, Radar network and satellite products, forecasting/warning services in respect of monsoon and associated severe weather including tropical cyclones, heavy rainfall, thunderstorms, flash/urban floods etc have shown significant improvement in the skill & lead time in the short/medium range (up to 7 days), extended range (up to 3 to 4 weeks) and seasonal forecasts. However, the increasingly erratic monsoon weather patterns in the backdrop of climate change are posing major challenges to the prediction of severe weather and its risk reduction at local/regional scales. Considering this, IMD has introduced impact based forecasts and risk based warning in recent years.

The scientists from across the globe will present their new findings with about 38 invited talks, 72 Oral talks and another 70 short Oral presentation during the IWM-7 event. I am optimistic that the IWM-7 symposium will provide an excellent opportunity for interaction among scientists, academician, numerical weather modeling communities and operational forecasters. It will strengthen the capabilities of National Meteorological and Hydrological Services (NMHSs) to improve the monsoon monitoring, forecasting and warning services.

I wish the event a grand success.

(Mrutyunjay Mohapatra)

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PREFACE

The International Workshop on Monsoons (IWM) is a major quadrennial symposia/workshops series under the World Weather Research Programme (WWRP) of the World Meteorological Organization (WMO). IWM is organized by the WWRP Working Group on Tropical Meteorological Research (WGTMR) with co-sponsorship across WWRP and the World Climate Program (WCRP) CLIVAR/GEWEX Monsoon Panel and the WWRP/WCRP Sub-seasonal 2 Seasonal (S2S) Project. IWMs are conducted to address monsoon variability and impacts as a part of the societal challenges prioritized by the WWRP : High Impact Weather, Water, Agriculture, Urbanisation and new Technologies in monsoon regions around the world. The previous IWMs from IWM-1 to IWM-6 were organized in different parts of the world, viz., (i) IWM-1, 24-28 Feb 1997 : Denspasar, Bali, Indonesia; (ii) IWM-2, 23-26 Mar 2000: New Delhi, India ; (iii) IWM-3, 2-6 Nov 2004: Hangzhou, China; (iv) IWM-4, 20-25 October 2008: Beijing, China; (v) IWM-5 : Macau, China, 27-31 Oct 2013 : Hong Kong, China, 01 Nov 2013 and (vi) IWM-6 : Singapore, 13-17 Nov 2017.

The seventh workshop in the series, IWM-7, is being jointly organized by India Meteorological Department, Ministry of Earth Sciences, Government of India and WGTMR, in cooperation with the WCRP CLIVAR/GEWEX Monsoons Panel, the International Monsoons Project Office (IMPO) hosted by the Indian Institute of Tropical Meteorology (IITM) and Indian Meteorological Society (IMS) at New Delhi, India during 22-26 March 2022. The workshop was initially planned for March 2021, but due to the pandemic at global level, it was rescheduledand is finally being organizedin virtual model during 22-26 March 2022.

Monsoon rainfall is the lifeline for more than half the world's population, for whom agriculture is the main source of livelihood. The traditional way of defining "monsoon" has been in terms of an apparent seasonal shift of the prevailing winds between winter and summer. Monsoons cover many parts of the globe including all tropical continents, and the tropical oceans. Regional monsoons are delineated in terms of the North American monsoon (NAM), North African monsoon (NAF), Indian monsoon (IND), East Asian monsoon (EAS), Western North Pacific monsoon (WNP), South American monsoon (SAM), South African monsoon (SAF) and the Australian monsoon (AUS).

Extensive research is being conducted since the beginning of the 20th century by scientists across the globe to improve our understanding of monsoon predictability, improve the accuracy of predictions, and refine projections of the impact of man-made climate change on monsoonal systems worldwide. This has the potential to bringsignificant socio-economic returns by maximizing the benefits of monsoon rainfall and reducing the impact of extreme events. The IWM-7 will provide a forum to discuss the recent developments on monsoon modelling, its prediction, new technologies and tools used for prediction of extreme rainfall events, field experiments and finally the benefits of monsoon prediction to the society. The prediction of monsoon will cover all spatial and temporal scales, from weather and sub-seasonal to seasonal and decadal, as well as for long-term climate projections.

The scientists from across the globe will present their new findings during the 5-day workshop with about 38 invited talks, 72 Oral talks and another 70 short Oral presentations during the IWM-7 sessions, on different themes viz., 1. Regional Monsoons, 2. Sub-seasonal to Seasonal (S2S) Predictions, 3. Modelling monsoon processes, 4. Climate Change and Monsoons, 5. High Impact Monsoon Weather, 6. Field Experiments and Observational Campaigns, 7. Monsoon Information and Prediction for Societal Benefit and 8. New Technologies and Tools. We are optimistic that the IWM-7 will provide an excellent opportunity for interaction among scientists, academicians, numerical weather prediction modeling communities and operational forecasters. It will strengthen the capabilities of National Meteorological and Hydrological Services (NMHSs) of monsoon affected countries to improve the monsoon monitoring, forecasting and warning services. A key highlight of the IWM-7 outcomes is to bring out a special issue of the peer-reviewed journal ***MAUSAM: Quarterly Journal of Meteorology, Hydrology & Geophysics***, published quarterly by IMD, consisting of papers based on invited as well as contributed presentations to be delivered by participants across the globe, after the due peer review process.

As in the previous IWM sessions, a training workshop was also organized in conjunction with IWM-7, to offer short refresher courses to NMHS forecasters, focused on the sub-seasonal to seasonal (S2S) prediction of monsoons. However, this time the training workshop was organized in advance of IWM-7 and delivered online, during 01-12 November 2021 on ‘‘Sub-seasonal to Seasonal (S2S) Prediction of Monsoons’’. More details about the training workshop along with the recordings of the talks by resource persons are available at https://impo.tropmet.res.in/iwm7training.php.

This booklet **“Abstracts Volume : IWM-7”** is the compilation of all the abstracts that will be presented during IWM-7. We take this opportunity to thank all the contributors of IWM-7 for sharing their research results. We are also thankful to Director General of Meteorology, IMD for agreeing to bring out the proceedings of IWM-7 as a special issue of MAUSAM. We also would like to express our gratitude to all the collaborative institutes/organizations, particularly MoES-IMD, WMO, WWRP, WCRP, IMPO-IITM and IMS for providing valuable support in making this event successful.

C. P. Chang
Ajit Tyagi
D. R. Pattanaik
Rupa Kumar Kolli
Yukari Takayabu

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1.	M. Ravichandran, Secretary, Ministry of Earth Sciences (MoES), India, Chair
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15.	M. N. Rajeevan, Former Secretary, MoES and Member, WMO Research Board, India
16.	Rupa Kumar Kolli, Former Executive Director, International Monsoon Project Office, IITM, Pune, India
17.	Sulochana Gadgil, Indian Institute of Sciences (IISc), India
18.	Yuhei Takaya, WWRP/WCRP S2S Project, Japan
19.	Yukari Takayabu, WWRP WGTMR; WCRP CLIVAR/GEWEX Monsoons Panel, Japan
20.	Zhuo Wang, WWRP WGTMR, USA

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42.	Yuhei Takaya (S2S core project representative, Japan)
43.	Yukari Takayabu (WWRP WGTMR & WCRP CLIVAR/GEWEX Monsoons Panel, University of Tokyo, Japan)
44.	Zhiyong Meng (Peking University, China)
45.	Zhuo Wang (WWRP WGTMR, USA)

National Organising Committee (NOC)

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6.	R. Krishnan, Exec. Director, CCCR, IITM, Pune
7.	E.N. Rajagopal, Former Head, NCMRWF, New Delhi
8.	Ajit Tyagi, Ex DGM, IMD, New Delhi
9.	Rupa Kumar Kolli (Former Executive Director, IMPO, IITM, Pune, India)
10.	M. Mohapatra, DGM, IMD & President, IMS, New Delhi
11.	A. K. Mitra, Head, NCMRWF, New Delhi
12.	D. S. Pai, Head CRS, IMD, Pune (Convenor)
13.	D. R. Pattanaik, Head NWP, IMD, New Delhi (Coordinator)

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Dr. D. R. Pattanaik, IMD New Delhi, Coordinator

Curriculum Vitae of Cochairs, ISC, Session's Chair and Invited Speakers

Co- chairs International Scientific Committee – IWM7

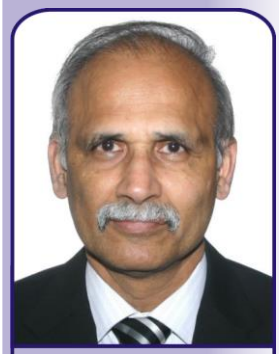
Chih-Pei Chang

Prof. Chih-Pei Chang at present working as the Distinguished Professor Emeritus, Department of Meteorology, Naval Postgraduate School.
B. S., National Taiwan University, 1966
Ph. D., University of Washington, 1972 (advisor: Prof. James R. Holton)
Menneken Research Award, Sigma Xi Society, 1980; Fellow, American Meteorological Society, elected 1981; Clarence Meisinger Award, American Meteorological Society, 1983; Best Paper Award, Papers in Meteorological Research, 1989; Distinguished Professor Medal, Naval Postgraduate School, 2003; Hong Kong Observatory 120th Anniversary Distinguished Meteorologist, 2003; Fellow, Meteorological Society of the Republic of China, elected 2007; U.S. Navy Superior Civilian Service Award, 2013; Honorary Member, Hong Kong Meteorological Society, 2013; World Meteorological Administration Certificate of Appreciation, 2017
Chair of IWM-1,3,4,5,6; Chair of WMO WGTMR Monsoon Panel 2010-2017; Chief Editor, Editorial Board, World Scientific Series on Asia-Pacific Weather and Climate.

Ajit Tyagi

Dr. Ajit Tyagi is currently Senior Advisor at Integrated Research and Action for Development, New Delhi and Member of WMO/WWRP Working Group on Tropical Meteorology. He has served as Koteswaram Chair Professor with Ministry of Earth Sciences, Director General of Meteorology, India Meteorological Department and Assistant Chief of Air Staff (Meteorology), Indian Air Force. He was Permanent Representative of India (2009-2013) with WMO and member of its Executive Council. He has served on the Governing Councils of SAARC Meteorological Research Centre and IITM Pune. He as Director General of Meteorology carried out modernisation of India Meteorological Department and brought significant improvements in weather forecasting and warning of high impact weather events in the country. Under his leadership Agro Advisory Services were extended to 640 districts. He played important role in organizing South Asian Climate Outlook Forum (SASCOF) and developing Global Framework of Climate Services (GFCS).

Chairs – Invited talk Session



Rupa Kumar Kolli

Dr. Rupa Kumar Kolli received his Ph.D. (1981) and M.Sc. (1976) degrees in Meteorology from Andhra University. Currently he is an Honorary Scientist at the International Monsoons Project Office (IMPO) located at IITM, and helps coordinate monsoon research under WWRP and WCRP. He had served earlier as the Executive Director of IMPO (2019-21).
Dr. Kolli had served as the Chief of World Climate Applications and Services Division at WMO Secretariatin Geneva for 13 years (2006-19) and made significant contributions to the development of Regional Climate Centres and Regional and National Climate Outlook Forums, which are recognized to be key operational elements of the Global Framework for Climate Services (GFCS). Dr. Kolli also holds important positions in several international bodies: (i) Vice-Chair, WMO Standing Committee on Climate Services; (ii) Member, Vulnerability, Impacts, Adaptation and Climate Services (VIACS) Advisory Board for CMIP etc.
Dr. Kolli has earlier worked at IITM from 1982 to 2006 and was the Head of its Climatology and Hydrometeorology Division. He co-authored a book with the late Prof. G.B. Pant on "Climates of South Asia" published by John Wiley in 1997, published several research papers on climate prediction, climate change and climate services. He was a Lead Author for IPCC Fourth Assessment Report published in 2007. He Dr Kolli is a Life Member and Fellow of IMS.

Kunio Yoneyama

Dr. Kunio Yoneyama is the Director of the Dynamic Coupling Ocean-Atmosphere-Land Research Program of JAMSTEC. His research interests focus on *tropical meteorology including the Madden-Julian Oscillation and water vapor variability, and on* tropical-extra tropical interactions. He joined JAMSTEC in 1990 and has acted as an ocean-going scientist and led several international field campaigns. Currently, he takes a role of co-chair of scientific steering committee for the international program called Years of the Maritime Continent (YMC), which aims at improving our understanding and prediction skill of weather-climate system over the MC and its global impact. Dr. Yoneyama received his PhD in Science from Nagoya University in 2003.

Yali Luo

Dr. Yali Luo is currently a senior scientist at the State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, China. Her research mainly focuses on convective storms and extreme weather. She received her Ph.D. degree at University of Utah, United States in 2003. She was the chief scientist of the Southern China Monsoon Rainfall Experiment (SCMREX), a WMO/WWRP Research & Development Project (2014-2021).

Paul E. Roundy

Prof. Paul E. Roundy is a Professor in the Department of Atmospheric and Environmental Sciences at the University at Albany in Albany New York. He holds a PhD in Meteorology from Penn State University from 2003, and a Bachelor of Science in Physics. He enjoys studying the dynamics of the tropical atmosphere and its connections to the global atmosphere and ocean, specializing in analysis of large datasets in the context of the equations of motion.

Sushil Kumar Dash

Prof. Sushil Kumar Dash entered Met. Science in 1975 as a PhD student in the PRL, Ahmedabad after an illustrious academic career in Physics. Prof. Dash superannuated from IIT Delhi as Professor and Head in the Centre for Atmospheric Sciences and is currently associated with the CoE in Climate Modelling as Visiting Scientist. In his 47 years of experience in teaching and research, Prof. Dash has successfully supervised 20 Ph.D., 16 M.Tech/M.Phil./M.Sc./MCA students. Prof. Dash is actively involved in R&D activities, including 35+ sponsored projects His main areas of interest are Inter-annual Variability of Indian Monsoon, Climate Modelling, Climate Change Studies and HPC in Environmental Sciences. Prof Dash has published 140+ refereed papers in journals of repute. He has been deputed to many reputed institutions across the world as Visiting Scientist. Prof Dash has been the Fellow and President of IMS, Fellow of Royal Meteorological Society, UK and the Member, The National Academy of Sciences, India.

Kyung-Ja Ha

Prof. Kyung-Ja Ha received Ph. D from Yonsei University in 1992. Her main fields of study are monsoon climate, climate dynamics, and global hydroclimate change. She is currently a professor of atmospheric sciences department since 1994 at Pusan National University and Center for Climate Physics, Institute for Basic Sciences (ICCP) since 2017. She was principal investigator for the Global Research Laboratory project for Global Monsoon Climate Change. She serves as president of Korean Meteorological Society (2022-2023), Executive Editor of Climate Dynamics, Editor of Nature Scientific Report, and advisor, Presidential Advisory Council on Science and Technology. She has been a fellow of the Korean Academy of Science and Technology.

Ajit Tyagi

Dr. Ajit Tyagi is currently Senior Advisor at Integrated Research and Action for Development, New Delhi and Member of WMO/WWRP Working Group on Tropical Meteorology. He has served as Koteswaram Chair Prof. with MoES, Director General of Meteorology, India Meteorological Department and Assistant Chief of Air Staff (Meteorology), Indian Air Force. He was Permanent Representative of India (2009-2013) with WMO and member of its Executive Council. He has served on the Governing Councils of SAARC Meteorological Research Centre and IITM Pune. He as Director General of Meteorology carried out modernisation of India Meteorological Department and brought significant improvements in weather forecasting and warning of high impact weather events in the country. Under his leadership Agro Advisory Services were extended to 640 districts. He played important role in organizing South Asian Climate Outlook Forum (SASCOF) and developing Global Framework of Climate Services (GFCS).

Yukari N. Takayabu

Dr. Yukari N. Takayabu, obtained M.Sc degree in 1985 and PhD in 1993 from the University of Tokyo, Japan. The topic of her PhD was "Organized cumulus convective systems over the tropical Pacific Ocean." Dr. Yukari's research topics are primarily in Tropical Meteorology, Tropical Convection and Global Climate Global Precipitation. She has received many awards such as : 1998 The Japan Meteorological Society's Award; 2007 Saruhashi Award (Distinguished Women Scientists' Award); 2021 American Meteorological Society Fellow.

Professional career

2019-present : Vice Director, Atmosphere and Ocean Research Institute, The University of Tokyo
2017-present : Member of the Science Council of Japan
2007-present : Professor, The University of Tokyo
2000-2007 : Associate Professor, The University of Tokyo
1994-1995 : Visiting Researcher, NASA/GSFC (hosted by Dr. K.-M. Lau)
1987-2000 : Researcher, Senior researcher, The National Institute for Environmental Studies

Mrutyunjay Mohapatra

Dr. Mrutyunjay Mohapatra is the Director General of Meteorology, India Meteorological Department and Permanent Representative of India with WMO & Member of Executive Council, WMO. With a Ph. D in Physics and 28 years of experience in meteorology, he has made significant contributions in improvement of early warning services of IMD. He brought laurels to the country from international agencies for effective cyclone warning. He is popularly known as "The Cyclone Man of India". He is the author of more than 105 research papers in peer reviewed national/international journals. He edited 18 books and 7 Journals. He received awards/recognitions from different agencies including Fellow, Indian Meteorological Society (IMS), Certificate of Merit for Young Scientist by Ministry of Earth Sciences and 25th Biennial Mausam Award. He is (i) President, IMS (ii) Chairman, Regional Sub-project Management Team of Severe Weather Forecast Programme for South Asia, and was Chairman of (iii) WMO/ESCAP Panel on Tropical Cyclones for 2017-18, (iv) Technical Evaluation Committee for Consultancy on National Cyclone Risk Mitigation Project.

Invited Speakers

Richard H. Johnson

Dr. Richard H. Johnson is professor emeritus in the Department of Atmospheric Science at Colorado State University, where he has been a faculty member since 1980. He served as Department Head from 2007 to 2011. His research interests are in atmospheric convection, tropical and monsoon dynamics, mesoscale processes, and the atmospheric boundary layer. He has over 165 publications in the refereed literature and is editor of four books in atmospheric science. Johnson was elected AMS Fellow in 1994, received the AMS Verner E. Suomi Award in 2013, was elected AAAS Fellow in 2017, and an AMS named symposium was held in his honor in January 2022.

Alice M. Grimm

Prof. Alice M. Grimm is Graduated in Physics, PhD in Atm. Sci. Full Professor, Department of Physics, Federal University of Parana, Brazil. Was Visiting Research Scientist at IRI-Columbia University. Is Researcher of the Brazilian National Council of Scientific and Technological Development, was member of its Advisory Committees on Atm. Sci. and on Env. Sci. Principal Investigator of 23 research projects, participated in 5 others. She was member of the AMS STAC Committees on Climate Variations and on Southern Hemisphere Meteorology/Oceanography, WMO/WWRP/TMR Monsoon Panel Executive Committee, WMO Commission for Atm. Sci. Management Group, WCRP/CLIVAR/GEWEX Monsoons Panel, and of the Urban Climate Change Research Network Steering Committee (Columbia University). Presently, Co-Chair of the CLIVAR/GEWEX Working Group on American Monsoons.

Received the University of Sao Paulo Award for best Doctoral Theses (1993); 16th IITM Silver Jubilee Award (2003); Women of Science Award, DST of the State of Parana, Brazil (2010); Outstanding Scholar, Federal University of Parana (2010), and Journal of Climate Editor´s Award (2013). Her research interests : climate variability and change, predictability, teleconnections, extreme events. Dr. Alice has published 62 articles, 16 book chapters, and 210 conference papers in proceedings.

Leila Carvalho

Prof. Leila Carvalho is a Professor in the Department of Geography, UCSB (2009-present). She obtained her PhD in Atmospheric Sciences at the University of Sao Paulo, Brazil, in 1998 where she was also Assistant Professor (1998-2008). Most of her career has been dedicated to examine and explain mechanisms associated with climate variations and changes in geographic locations dominated by monsoon systems. The main focus of this research has been on mechanisms causing extreme precipitation (and dry conditions) on a wide range of spatiotemporal scales and how climate change has modified trends of these events. She is also interested in mountain weather and climate, including atmospheric rivers, downslope windstorms and wildfires. She coordinates the Climate Variability and Change group http://clivac.eri.ucsb.edu/. She is currently serving as a Co-Chair of the WCRP CLIVAR/GEWEX Monsoons Panel.

B. N. Goswami

Prof. B. N. Goswami made path breaking contributions in understanding the variability and predictability of the South Asian monsoon on intra-seasonal to multi-decadal time scales using observations, theoretical and modeling tools. His discovery of the Indian Ocean Dipole Mode highlighted the importance of ocean-atmosphere interactions over the Indian Ocean on climate variability. Conceptualizing and leading the MoES Monsoon Mission Phase-I he built capacity in coupled modeling, he helped develop the first Earth System Model of the country and elevated the country's short, Extended and Seasonal prediction systems to the world's best level. With 190 publications in high impact journals Prof. Goswami's work is widely recognized with total citations ~ 22500. His contributions are recognized nationally with the Shanti Swaroop Bhatnagar Prize (1995), Fellowship of all three leading Science Academies of India and internationally by Fellowship of the World Academy of Science, Italy.

Sanjay K. Srivastava

Dr. Sanjay K. Srivastava, Ph D (Applied Physics), is presently Chief of Disaster Risk Reduction at UN Economic and Social Commission for Asia and the Pacific (ESCAP). He was ESCAP Regional Adviser on Disaster Risk Reduction from Oct 2009 to June 2014; Head of Hydro-met disasters at SAAARC Disaster Management Centre – New Delhi from 2007-2008; Deputy Project Director of Disaster Management Support Programme at Indian Space Research Organisation (ISRO); Scientist/Engineer at ISRO HQ Bangalore since 1991. He is the recipient ofISRO's Team excellence award in 2008-09 for his contributions towards harnessing space technology applications for the benefits of rural poor. He has been a lead author of ESCAP's flagship publication – Asia-Pacific Disaster Report since its inception in 2010.

Mrutyunjay Mohapatra

Dr. Mrutyunjay Mohapatra is the Director General of Meteorology, India Meteorological Department and Permanent Representative of India with WMO & Member of Executive Council, WMO. With a Ph. D in Physics and 28 years of experience in meteorology, he has made significant contributions in improvement of early warning services of IMD. He brought laurels to the country from international agencies for effective cyclone warning. He is popularly known as "The Cyclone Man of India". He is the author of more than 105 research papers in peer reviewed national/international journals. He edited 18 books and 7 Journals. He received awards/recognitions from different agencies including Fellow, Indian Meteorological Society (IMS), Certificate of Merit for Young Scientist by Ministry of Earth Sciences and 25th Biennial Mausam Award. He is (i) President, IMS (ii) Chairman, Regional Sub-project Management Team of Severe Weather Forecast Programme for South Asia, and was Chairman of (iii) WMO/ESCAP Panel on Tropical Cyclones for 2017-18, (iv) Technical Evaluation Committee for Consultancy on National Cyclone Risk Mitigation Project.

Michael Bell

Prof. Michael Bell obtained a B.A. degree from the University of Florida and completed his M.S. thesis at Colorado State University (CSU) on tropical cyclone intensity theory and Ph.D. dissertation at Naval Postgraduate School in Monterey, California on air-sea interaction at high wind speeds. He worked at the National Center for Atmospheric Research as a research scientist before becoming an Assistant Professor at the University of Hawaii in 2012. He joined the faculty at CSU in 2016 where he currently teaches and conducts research as a Professor of Atmospheric Science. He is the recipient of the NSF CAREER, ONR Young Investigator, and White House PECASE Awards for his research in tropical weather and climate, tropical cyclones, field experiments, radar observations, and numerical modeling.

Kunio Yoneyama

Dr. Kunio Yoneyama is the Director of the Dynamic Coupling Ocean-Atmosphere-Land Research Program of JAMSTEC. His research interests focus on *tropical meteorology including the Madden-Julian Oscillation and water vapor variability, and on* tropical-extra tropical interactions. He joined JAMSTEC in 1990 and has acted as an ocean-going scientist and led several international field campaigns. Currently, he takes a role of co-chair of scientific steering committee for the international program called Years of the Maritime Continent (YMC), which aims at improving our understanding and prediction skill of weather-climate system over the MC and its global impact. Dr. Yoneyama received his PhD in Science from Nagoya University in 2003.

Kazuhisa Tsuboki

Dr. Kazuhisa Tsuboki, obtained his master degree M.Sc. in 1987 and D.Sc. in 1990 from Department of Geophysics, Hokkaido University, Japan. Dr. Tsuboki at present working as a Professor of Institute for Space-Earth Environmental Research, Nagoya University and Typhoon Science and Technology Research Center, Yokohama National University, Japan. His field of research include Tropical cyclone, Extreme weather, Numerical simulation etc.

Research and work experience:

- 2015/10-present: Professor, Institute for Space-Earth Environmental Research, Nagoya University and Yokohama National University (since 2021/10)
- 2012/04-2015/9: Professor, Hydrospheric Atmospheric Research Center, Nagoya University
- 2001/04-2012/03: Associate Professor, Hydrospheric Atmospheric Research Center, Nagoya University
- 1997/04-2001/03: Associate Professor, Institute of Hydrospheric-Atm. Sci., Nagoya University

Toru Terao

Dr. Toru Terao is Graduated from the Graduate School of Science, Kyoto University in 1998, and is awarded a Ph. D. His major research topics are on Asian monsoon dynamics, precipitation mechanisms in Northeastern Indian subcontinent, and validation of rainfall estimated by satellites. Associated with his research and educational expertise, in 2019, he awarded Minister of Education, Culture, Sports, Science and Technology Commendation. Now, leading an Asian hydroclimatological research project, Asian Precipitation Experiment (AsiaPEX), under the Global Energy and Water Exchanges (GEWEX) framework. Currently, he is affiliated to Kagawa University, Japan as a Professor and the Director of the International Consortium of Earth and Development Sciences (ICEDS).

Yali Luo

Dr. Yali Luo is currently a senior scientist at the State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, China. Her research mainly focuses on convective storms and extreme weather. She received her Ph.D. degree at University of Utah, United States in 2003. She was the chief scientist of the Southern China Monsoon Rainfall Experiment (SCMREX), a WMO/WWRP Research & Development Project (2014-2021).

Atul Kumar Sahai

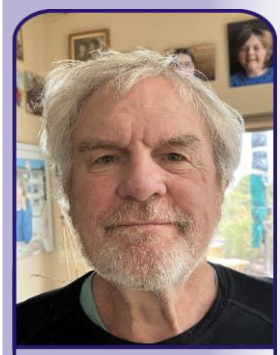
Dr. Atul Kumar Sahai superannuated as scientist-G from Indian Institute of Tropical Meteorology (IITM). He led to the development and operationalisation of a dynamical ensemble system for predicting heat and cold wave, onset and active-break cycles of monsoon, cyclogenesis etc. 2-3 weeks in advance. As the Head, Climate Research and Services, IMD, Pune he has implemented Global Framework for Climate Services and established the Regional Climate Centre. In recognition of his expertise, Dr. Sahai had been appointed as SSC member, WWRP, WMO for providing scientific guidance in S2S project. Dr. Sahai had about 150 scientific publications in scientific journals. In recognition to his scientific contributions, he has been awarded with many awards like Certificate of Merit Award of MoES; 30th Biennial MAUSAM Award; Golden Jubilee Award, IITM, Pune; Two times IITM Silver Jubilee award; IMS award for research paper on Weather and Climate Services etc.

Ming-Jen Yang

Prof. Ming-Jen Yang received his PhD from the University of Washington at Seattle, USA, in 1995. After one-year postdoctoral training at the University of Washington, he returned to Taiwan in September 1996, and he is now a Full Professor at National Taiwan University. He studied severe weather systems including thunderstorms, squall lines, mesoscale convective systems, Mei-Yu fronts, and typhoons. His research interests involve simulating and analyzing a variety of severe convective systems; examining the convective (1-10 km) and mesoscale (10-100 km) structures of storms; investigating the evolution and mechanism(s) whereby they develop; testing theories, hypotheses and various physical representations; and finally interpreting the observed behaviours of these rainfall systems. His research interests also include the improvement of cloud-process (microphysics and cumulus parameterization) representations in numerical models, and the further understanding of convection and precipitation phenomena.

Brian Golding

Prof. Brian Golding is Fellow in Weather Impacts at the Met Office, visiting professor at Bristol University and co-chair of the World Meteorological Organisation's 10-year High Impact Weather project (HI Weather). In a 49-year career at the Met Office, Brian's research has spanned numerical modelling, data assimilation, nowcasting, flood and ocean wave prediction, interactive forecaster graphics, and weather impacts in aviation, defence, winter road maintenance and health amongst others. From 1990-1992 he was on sabbatical at the Australian Bureau of Meteorology, applying mesoscale NWP to Australian weather systems. From 2005-2012 he was Director of Weather Science at the Met Office. Following his retirement from this role, he was awarded the OBE for services to weather forecasting and the prediction of hazardous weather. Since 2015 he has co-chaired HI Weather, leading research into best practice in weather-related warning systems.



Peter John Webster

Prof. Peter John Webster is currently Emeritus Professor of Earth and Atmospheric Sciences at Georgia Institute of Technology, USA. His main interests and in the physics of low-frequency atmospheric and ocean dynamics and a special interest in the structure and variability of the monsoon. His interest in monsoons stems from his involvement the Monsoon Experiment in 1979-80 following his graduation from MIT, and subsequent tropical field investigations EMEX, TOGA TOGA COARE and JASMINE that he helped design, organize and take part in the analysis of data.

Webster's overriding interest has been in the advancement of science with the purpose of applying research results for the betterment of society, especially in the developing world. During the last decade, he has led efforts for the extended forecast on floods in the Ganges, Brahmaputra and Indus river systems and heat wave forecasts in Gujarat India. These forecasts, aimed at extreme events were constructed in probabilistic form to allow users to make informed decisions and to take mitigatory actions if necessary. More recently he has concentrated creating probabilistic forecasts for agricultural societies especially in rain-fed areas of the planet in the belief that useful forecasts delivered in understandable form will improve sustainability.

Webster has written many papers on the themes listed above and has recently published a book on the Dynamics of the Tropical Atmosphere and Oceans. He has been recognized by a number of national and international prizes and awards.

Paul E. Roundy

Prof. Paul E. Roundy is a Professor in the Department of Atmospheric and Environmental Sciences at the University at Albany in Albany New York. He holds a PhD in Meteorology from Penn State University from 2003, and a Bachelor of Science in Physics. He enjoys studying the dynamics of the tropical atmosphere and its connections to the global atmosphere and ocean, specializing in analysisz of large datasets in the context of the equations of motion.

Suryachandra Rao

Dr. Suryachandra Rao is a senior-scientist at Indian Institute of Tropical Meteorology, and is leading "Monsoon Mission" program of India as Associate Mission Director.

"Monsoon Mission" is an ambitious mission mode program to improve the skill of Indian Summer Monsoon weather and climate. As a result of this program India's dynamical model are now one of the better models among models from other leading centers. His works on Indian Ocean Dipole, zIndian Ocean Warming and Indian Monsoon variability and prediction were highly cited by peers. Dr. Rao has published around 100 research papers (with high citations ~7000) in leading international journals and received several awards nationally and internationally. At present he is also serving as a member of Clivar/GEWEX Monsoons Panel. His efforts, as project director of High Performance Computer, also responsible for establishing India's first multi-petaflops High Performance Computer.

D. S. Pai

Dr. D. Sivananda Pai worked in IMD during 1992-2022 in different capacities. Presently, Dr. Pai is Director of the Climate Institute of Climate Change (ICCS), Kerala on deputation from IMD. He has published 65 research papers in various National and International journals and 25 research reports. zHis current fields of interest are climate change, variability and prediction. Dr. Pai has served as a member of the WMO CBS Expert Team on Extended and Long-Range Forecasting, co-leader of the WMO Task Team on Regional Climate Outlook Forums (TT-RCOFs) during 2014-16 & leader of TT-RCOFs from 2017-2018. During 2018-2019, he was the co-lead of WMO Inter-Programme Expert Team on Regional Climate Activities (IPET-RCA**).** From 2020 Dr. Pai is working as one of co-lead of working group on Basic Instructional Package for Climate Services (BIP-CS) of WMO Expert Team (ET) Capacity Development and Communication (CDC). Since 2010, he has also contributed significantly in the preparation of the seasonal consensus forecast outlook for south Asia region under South Asian Climate Outlook Forum (SASCOF). Dr. Pai is the recipient of Certificate of merit in Atm. Sci. for the year 2010 by MoES, Indian Meteorological Society (IMS) Award for the best paper published on Weather and Climate Services (2011-2012), IMS Award for best paper published on Monsoon Research (2015-16).

M. Rajeevan

Dr. M. Rajeevan is presently working as the MoES Distinguished Scientist has more than 35 years of experience in operational forecasting and research on Tropical Meteorology. He had served the India Meteorological Department, Indian Institute of Tropical Meteorology, Department of Space and Ministry of Earth Science. Rajeevan was the Secretary to the Government of India, Ministry of Earth Sciences during December 2015 to July 2021.

Dr. Rajeevan made significant contribution in research on Monsoon variability, Seasonal Forecasting, Climate Change and Extreme Weather Events, Prediction of Mesoscale systems and development of climate data sets like gridded rainfall and temperature for India. Dr. Rajeevan was a member of WCRP/CLIVAR Asian-Australian Monsoon Panel and presently a member in the Research Board of WMO. He has more than 140 research papers with a h-index of 50 and more than 11,000 citations.

Qing Bao

Dr. Qing Bao obtained B. Sc in Meteorology, Nanjing Institute of Meteorology in 2002 and Ph.D in Meteorology, Institute of Atmospheric Physics, Chinese Academy of Sciences, China. Dr. Bao at present working as Prof. at State Key Laboratory of Numerical Modelling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, China since 2018. His research topics are primarily in Climate system modeling, subseasonal to seasonal prediction and Seamless prediction.

Professional Experience

Dr. Bao is the recipients of many prestigious awards viz. 2011 XIE Yibing Young Scientist Award; 2012 IAP Science innovation Award 2012; 2014 Tsinghua University-Inspur Group Computational Earth Science Talent Award 2014; 2015 AAS Esteemed Paper Prize; 2015 IAP Science innovation Award; 2016 TIANHE Star Awards for Excellence Application.

Shigeo Yoden

Prof. Shigeo Yoden (Professor Emeritus, and Vice Director of the Institute for Liberal Arts and Sciences, of Kyoto University) had been the Professor of Meteorology of Kyoto University from 2002 to 2020. His major areas of research and education are Atmospheric Dynamics, Geophysical Fluid Dynamics, and Climate Dynamics. He won the 1992 Award of Meteorological Society of Japan for the study on the general circulation of the atmosphere with idealized nonlinear models. He had been a member of the WCRP/SPARC Scientific Steering Group from 1999 to 2005, and co-theme leader on Stratosphere-Troposphere Dynamical Coupling in SPARC SSG from 2005 to 2015, and currently an activity leader on Stratospheric And Tropospheric Influences On Tropical Convective Systems (SATIO-TCS) from 2016. He also served as the President of the IUGG/IAMAS International Commission on the Middle Atmosphere from 2007 to 2011.

Yuhei Takaya

Dr. Yuhei Takaya is Senior Researcher in Meteorological Research Institute, Japan Meteorological Agency, 1-1 Nagamine, Tsukuba, Ibaraki 305-0052, Japan.

Email: yuhei.takaya@mri-jma.go.jp

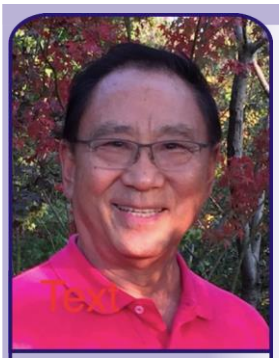
Dr. Takaya is Expertise in Climate dynamics, Climate modeling, Sub-seasonal to seasonal prediction.

Members:

WWRP/WCRP Sub-seasonal to Seasonal (S2S) Project Steering Group member

WCRP Working Group on Subseasonal to Interdecadal Prediction (WGSIP) member

Scientific Online Letters on the Atmosphere (SOLA) Editor



Bin Wang

Dr. Bin Wang is a Professor of the Atmospheric Sciences at the University of Hawaii and Director of the Earth System Modeling Center at the Nanjing University of Information Science and Technology. His research fields involve Climate Dynamics, Atmospheric Dynamics, Tropical Meteorology, and Geophysical Fluid Dynamics. Specific research interest areas include Global and regional monsoons, Tropical Intraseasonal Oscillation, El Nino-Southern Oscillation, Climate variability, predictability and prediction, climate changes, tropical cyclones, atmosphere-ocean interaction, atmospheric waves and instability. He was an elected Fellow of the American Geophysical Union and the American Meteorological Society. He received the Carl-Gustaf Rossby Research Medal bestowed by the American Meteorological Society in 2015 "for creative insights leading to important advances in the understanding of tropical and monsoonal processes and their predictability."

Kyung-Ja Ha

Prof. Kyung-Ja Ha received Ph. D from Yonsei University in 1992. Her main fields of study are monsoon climate, climate dynamics, and global hydroclimate change. She is currently a professor of atmospheric sciences department since 1994 at Pusan National University and Center for Climate Physics, Institute for Basic Sciences (ICCP) since 2017. She was principal investigator for the Global Research Laboratory project for Global Monsoon Climate Change. She serves as president of Korean Meteorological Society (2022-2023), Executive Editor of Climate Dynamics, Editor of Nature Scientific Report, and advisor, Presidential Advisory Council on Science and Technology. She has been a fellow of the Korean Academy of Science and Technology.

Andrew Turner

Prof. Andrew Turner is a Professor in Monsoon Systems funded jointly by the University of Reading's Academic Investment Programme and National Centre for Atmospheric Science (NCAS), based in the Department of Meteorology. His general interests are in monsoon variability, predictability and prediction including the interaction between monsoon systems and other elements of the climate system. Prof. Turner led the INCOMPASS field campaign to India in 2016, including aircraft measurements and installation of new eddy covariance flux towers. This work has resulted in the recent INCOMPASS Special Collection in Quarterly Journal of the Royal Meteorological Society, where he is also an Associate Editor. He is a former Co-Chair of the GEWEX/CLIVAR Monsoons Panel and a Lead Author of the recent Working Group I Contribution to the Sixth Assessment Report of the IPCC.

Tim Li

Dr. Tim Li is Professor at Department of Atmospheric Sciences and International Pacific Research Center, University of Hawaii. He got his BS degree in Meteorology at Peking University in 1983, and his PhD in Meteorology at University of Hawaii in 1993. His research topics are primarily in tropical climate dynamics including MJO and ENSO dynamics, variability of the monsoon and typhoon, sub-seasonal-to-seasonal (S2S) prediction, and global climate change under global warming. He has published 400 professionally referred papers, with a citation number of 20000 based on Google Scholar and H-index of 75. He served as an editor for Journal of Climate and Earth Science Review. He was awarded University of Hawaii Board of Regents Medal for Excellence in Research in 2019. His detailed CV including publication list may be viewed at

http://www.soest.hawaii.edu/MET/CVs/CV_Tim_LI_Jan_2022.pdf

Raghavendra Krishnan

Dr. Raghavendra Krishnan specializes in climate modelling to understand various aspects of climate variability and change, with special emphasis on the Indian / South Asian Monsoon. Currently, he is the acting Director of the prestigious institute Indian Institute of Tropical Meteorology, Pune. He also leads the Centre for Climate Change Research at IITM, Pune which has developed the first Earth System Model (ESM) from India and is contributing to the CMIP6 experiments and IPCC Sixth Assessment Report (AR6). He has published over 100 scientific articles, supervised 12 PhDs and is recipient of various awards and honours, notably Fellow of the Indian Academy of Sciences, Indian National Science Academy and Indian Meteorological Society. He is a member Joint Scientific Committee (JSC) of the World Climate Research Programme (WCRP) and a Coordinating Lead Author for the IPCC AR6 WG1 report.

Shigeo Yoden

Dr. Heidi Kreibich is Head of the working group "Flood risk and climate adaptation" at the German Research Centre for Geosciences. She is chair of the Panta Rhei initiative of the International Association of Hydrological Sciences (IAHS) and president elect of the EGU Division on Natural Hazards. She is contributing author for the IPCC Working Group 2 Assessment Report 6 (AR6) and executive Editor of the ISI-Journal NHESS. Her research is focused on flood risk modelling, vulnerability analysis and loss modelling, climate adaptation and risk management, including impact-based forecasting and emergency management. Among her outstanding contributions are: the first quantification of the loss reducing effects of private precautionary measures. The development of the research avenue of probabilistic, multi-variable loss modelling and the concept of the cost assessment cycle for continuous, integrated cost assessment in risk management.

Narendra Kumar Tuteja

Dr. Narendra Tuteja has over thirty years of scientific and engineering experience in industry, applied research and academia in hydrology, water resources and natural resource management across Australia, Europe and South Asia. Narendra has supported development of policies and decision making in the water sector. He has guided development and delivery of operational water quantity and quality forecasting services at short-, medium- and extended-range time scales in Australia. In his current role, he guides rural water supply and flood modelling work of Water NSW,which is a State-Owned Corporation andbulk water supplier in New South Wales, Australia. He has collaborated nationally and overseas and published peer reviewed literature on wide ranging topics in water and environment domains. He is a member of the Hydrology Coordination Panel of the World Meteorological Organisation, WMO Hydrology Coordinator - Earth System Modelling and Prediction, and author of WMO Seasonal Hydrological Prediction Guidelines to be published in 2022.

D. R. Pattanaik

Dr. D. R. Pattanaik joined the India Meteorological Department (IMD) in June 1998 as a Meteorologist while doing his Ph.D at the IITM, Pune. At present, Dr. Pattanaik is working as Sc-F and Head, Numerical Weather Prediction (NWP) Division of IMD. Dr. Pattanaik has worked in IMD as operational forecaster, researcher, NWP modeller and also as instructor. He has been engaged in research work in the areas of monsoon variability, monsoon forecasting, extended range forecasting and extreme weather events (heavy rainfall, heat wave/cold wave, cyclones etc.), climate variability, climate change etc. He has published about 80 research papers in peer reviewed international/national journals. He has been delivering talks and also contributed as resource person for various training activities that are being conducted by WMO. Dr. Pattanaik's is the recipient of the award 'the Certificate of Merit for outstanding contribution in the field of Atmospheric Science & Technology by the Ministry of Earth Sciences, Government of India in 2011, the Young Scientist Award for the best research paper published in Tropical Meteorology for the years 2014 by Indian Meteorological Society (IMS) and 30th MAUSAM award for the best paper published the journal "MAUSAM' during the year 2018-2019. Dr. Pattanaik has been the Secretary of IMS during last two terms.

Dev Niyogi

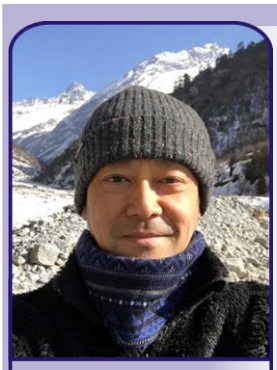
Dr. Dev Niyogi, is John E. "Brick" Elliot Centennial Endowed Professor at the University of Texas at Austin, in the Jackson School of Geosciences, and Department of Civil, Architectural and Environmental Engineering. He is a graduate faculty at Oden Institute of Computational Engineering and Science, and University of Texas Center for Space Research. He is also Professor Emeritus, Purdue University, Department of Agronomy and Department of Earth, Atmospheric, and Planetary Sciences, and former Indiana State Climatologist (2005- 2018).
Prof. Niyogi's research seeks to significantly contribute to our understanding of the Earth system, particularly the urban and agricultural landscapes, and the dynamic role of coupled land surface processes on weather and regional meteorological extremes. An important ongoing and emerging focus of his research is to translate the scientific work undertaken into decision tools and portals with a particular focus on hydroclimatology and sustainable climate-ready/resilient cities.

Yukari N. Takayabu

Dr. Yukari N. Takayabu, obtained M.Sc degree in 1985 and PhD in 1993 from the University of Tokyo, Japan. The topic of her PhD was "Organized cumulus convective systems over the tropical Pacific Ocean." Dr. Yukari's research topics are primarily in Tropical Meteorology, Tropical Convection and Global Climate Global Precipitation. She has received many awards such as : 1998 The Japan Meteorological Society's Award; 2007 Saruhashi Award (Distinguished Women Scientists' Award); 2021 American Meteorological Society Fellow.

Professional career

2019-present : Vice Director, Atmosphere and Ocean Research Institute, The University of Tokyo
2017-present : Member of the Science Council of Japan
2007-present : Professor, The University of Tokyo
2000-2007 : Associate Professor, The University of Tokyo
1994-1995 : Visiting Researcher, NASA/GSFC (hosted by Dr. K.-M. Lau)
1987-2000 : Researcher, Senior researcher, The National Institute for Environmental Studies



Hatsuki Fujinami

Dr. Hatsuki Fujinami is a Lecturer of the Institute for Space-Earth Environmental Research (ISEE), Nagoya University, Japan and a member of Asian-Australian monsoon working group of GEWEX/CLIVAR Monsoons Panel. His research interests include understanding the processes responsible for precipitation variations in monsoon Asia over a broad range of time scales from diurnal cycle to climate change. He has worked extensively in diurnal precipitation cycle, low pressure systems and intraseasonal oscillations and the interplay among them around South Asia, helping to improve understanding of these process that provide water resources and to contribute S2S prediction. He uses in-situ observational data, atmospheric reanalysis and satellite remote sensing data to uncover important processes. He has recently studied the mechanism of nocturnal precipitation in the Meghalaya Plateau and the Himalayas including glacierized area.

Chidong Zhang

Dr. Chidong Zhang leads the Ocean Climate Research Division of theNOAA Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington. He joined NOAA in 2016 after his 20-year academic career in University of Miami. He received PhD in Meteorology from the Penn State University, MS in Meteorology from University of Utah, and BS in Meteorology from Peking University. His research interests include tropical large-scale air-sea interaction and intraseasonal variability, especially the Madden-Julian Oscillation (MJO), weather-climate interface, field observations of weather-climate processes, and new observing technologies.

Sulochana Gadgil

Dr. (Mrs.) Sulochana Gadgil was trained at Harvard University, with a PhD. in Applied Mathematics, a post-doctoral fellow at MIT, and after two years as a CSIR pool officer as IITM, joined the Indian Institute of Science in 1973.She has made significant contributions to our understanding of the Indian monsoon and its variability, its links with atmospheric convection over tropical oceans and the relationship of such convection with the sea surface temperature. She played a key role in the establishment and nurturing of the Centre for Atmospheric and Oceanic Sciences at the Indian Institute of Science and spearheaded the efforts to formulate the Indian Climate Research Program (ICRP). She has served on many committees in atmospheric sciences and is a recipient of several awards including Lifetime excellence award in Earth Sciences of 2016 from the Ministry of Earth Science.

Rohinton Emmanuel

Prof. Rohinton Emmanuel is Professor of Sustainable Design and Construction and Director, Research Centre for Built Environment Asset Management (BEAM) at Glasgow Caledonian University. He has long worked on urban heat island studies in warm regions and has taught and consulted on climate and environment sensitive design, building and urban sustainability and its assessment, building energy efficiency, thermal comfort and carbon in the built environment. Rohinton was the Secretary of the largest group of urban climate researchers, the *International Association for Urban Climate* (2010-2013) and was a member of the Expert Team on *Urban and Building Climatology* (ET 4.4) of the World Meteorological Organization (WMO) as well as the CIB Working Group (W108) on "*Buildings and Climate Change*." He is currently the Coordinator of an Erasmus Mundus Joint Master's Degree Programme on urban climate and sustainability (MUrCS – www.murcs.eu).

Uma Charan Mohanty

Prof. Uma Charan Mohanty specializes in Numerical Weather Prediction (NWP) in tropics, with special emphasis on extreme weather systems over India. After superannuated from Indian Institute of Technology (IIT) Delhi, currently serving as Visiting Prof. in School of Earth, Ocean and Climate Sciences (SEOCS), IIT Bhubaneswar. He has developed/adapted/utilized short-, medium- and extended- (monthly to seasonal) range prediction systems with meso-scale, regional, global as well as Multi-Model Ensemble models in academic research environment and transferred for operational use. Prof. Mohanty spearheaded the efforts to implement Severe Thunderstorms Observations and Regional Modelling (STORM) program of India and its extension to SAARC STORM program involving all the eight countries of this region for joint field experiments, data assimilation and meso-scale modelling work. For his pioneering contribution to Asian summer monsoon studies and NWP in tropics he received several awards including prestigious Santi Swarup Bhatnagar Prize and Sir Gilbert Walker Gold Medal. He has published over 300 scientific papers in peer reviewed journals, supervised 43 PhDs and several M.Tech and M.Sc dissertations. For his overall contributions in Atmospheric Sciences, he has been elected Fellow of all the four National Academies of Sciences and Engineering of India.

Nachiketa Acharya

Dr. Nachiketa Acharya is a statistical climatologist with specialties in statistical and machine learning modeling in climate science, especially sub-seasonal to seasonal climate forecasting. He is currently serving as an Assistant Research Professor at the Department of Meteorology and Atmospheric Science, Pennsylvania State University. He has also held influential positions at the International Research Institute for Climate and Society at Columbia University, the Institute for Sustainable Cities at the City University of New York, the National Centre for Medium-Range Weather Forecasting in India, the Indian Institute of Technology Delhi, and Bhubaneswar. He received his Ph.D. in Statistics from Utkal University, India in 2014 which focused on statistical techniques for extended range prediction of the Indian monsoon. He is actively engaged in several Regional Climate Outlook Forum and co-leading the Building Block-3 of Regional Information for Society, WCRP.


Invited
Oral
Short oral

Invited

	Co- chairs ISC	
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2.	Ajit Tyagi	Introduction to IWM-7

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INVITED

Indian Monsoon Mission : Operational Advances in Short to Medium Range Forecasts in India

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Abstract : Monsoon prediction on all time scales is very vital for socio-economic applications for India. Despite many scientific and technological advances, understanding its variability across a wide range of time and space scales and providing reliable predictions remains a challenge even today. Recognizing the urgent need for improving monsoon prediction capabilities in the country in a systematic and timely manner, the Government of India had launched an ambitious and well-resourced research programme on Mission mode, called the Monsoon Mission. The first phase of the mission was implemented during 2012-2017 and the second phase during 2017-2021. The most important milestone under the Monsoon Mission was implementing the state-of-the-art dynamical prediction systems on all time scales, from short range to seasonal. India is now proud of having one of the best weather and climate prediction systems for generating real time forecasts and warnings.

In this lecture, I would be discussing the operational advances realized in short to medium range weather forecasts over the Indian region and the contribution of the Monsoon Mission. Technical details of the operational forecasting systems and examples on prediction of tropical cyclones, mesoscale convective systems, heavy rainfall spells and floods, and major air pollution outbreaks will be discussed.

In addition, salient results from the Indo-US and Indo-UK joint observational campaigns conducted under the Monsoon Mission will be discussed along with the immediate plans to improve short to medium range forecasts further in near future.

Short to Medium Range Impact Based Forecasting of Monsoon in India : Progress and Plans

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Abstract : There have been major advances in the last few decades in our understanding of the Indian monsoon and its variability. Substantial progress has been made on both observational and numerical modelling of monsoon. All these have resulted in more accurate monsoon and associated severe weather forecast in different spatio-temporal scales. The extended range forecast, is followed by short to medium range forecast and warnings at district levels daily valid up to next five days. It is followed by 3 hourly nowcast valid upto next three hours at district & station levels. There has been improvement in accuracy of prediction of various severe weather phenomena in short to medium range (upto five days) by about 40% in recent five years as compared to previous five years. However, improvement of forecast and warning skill of any severe weather alone is not sufficient to minimize damage to lives and property. It is essential to extend severe weather standalone forecast and warning system, to hazard forecast systems (hazard models) and then to impact estimation (risk based models) with proper stake holder interaction for risk based warning (RBW) and response action to protect lives and livelihoods.

Considering all these, India Meteorological Department (IMD) was providing impacted based forecast (IBF) and RBW upto coastal district level for landfalling cyclones using its historical data on associated Hazard, exposure and vulnerability. IMD introduced the IBF on heavy rainfall, thunderstorm, heat wave and strong wind since August 2019 at district and city scale in its short to medium range forecasts and nowcasts indicating the likely impact of the weather in different sectors and required response actions relying on the threshold based severity of weather determined from its past data and associated hazards & impacts. In monsoon 2020, such IBF and RBW services were made available operationally at 25 major capital cities. In the monsoon, 2021, scope of IBF & RBW was further expanded for districts with collections and layering of exposure, hazard, vulnerability, and impact data and hence development of risk matrix. The urban flood model, flash flood guidance system, susceptibility zonation maps for landslide, a web-based Dynamic Composite Risk Atlas (WEB-DCRA) for cyclone hazards and heat action plan for heat wave are introduced. Thus the IBF under implementation by IMD includes all the four components, viz., meteorological hazards, (ii) geophysical hazards, (iii) geospatial applications and (iv) socio-economic attributes. Present paper reviews various approaches and stages of Development of IBF for monsoon. The success of IBF for monsoon weather will enhance the management of critical resources like agriculture, water & power and support urban and disaster management sectors among others.

Interannual and intraseasonal variability of the South American monsoonand its combination in the MJO modulation by ENSO

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Abstract : The interannual precipitation variability in South America (SA) is mostly associated with ENSO. In all seasons but summer the first variability mode is connected to ENSO. In summer, ENSO commands the second mode. The first mode features highest precipitation variability in Central-East SA (CESA), which includes the South Atlantic Convergence Zone (SACZ). In this region, summer surface–atmosphere interactions triggered by spring soil moisture anomalies seem to be more important than remote forcing on interannual time scale. The first variability modes in summer and spring are dipole-like, with centers in CESA and southeast SA (SESA) that tend to reverse polarity from spring to summer, suggesting that spring conditions in CESA influence the anomalies in summer. In spring this mode is associated with ENSO; in summer this connection is not evident.

The intraseasonal monsoon precipitation variability over SA happens in several time scales. The most important modes feature spectral peaks around 12 days, 24 days and 42 days. The two first modes in all frequency bands feature dipole patterns between CESA and SESA, but with the main centers a little displaced to the north or to the south of the climatological SACZ. Similar periods were found in the intraseasonal variability of the southern Africa monsoon, and teleconnections between them are evident.

The intraseasonal variability is modulated by the interannual and longer period variability. An example is the MJO modulation by ENSO. The background ENSO-related anomalies influence several aspects of MJO: propagation, frequency of its phases, anomalous convection and teleconnections. Therefore the MJO impacts on SA are modified, as the spatial distribution of anomalous precipitation and frequency of extreme events and their temporal distribution throughout the MJO cycle. Although linear combination of impacts is evident, there are also important non-linear effects regarding the teleconnections between subtropical South Pacific and South America.

The effects of climate change on the global and regional monsoons

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Abstract : Monsoons supply the majority of annual rainfall to large regions of the tropics and affect the lives of billions of the global population through their reliance on monsoons to supply water for agriculture, industry and human health. This review talk summarises the latest expert assessments of monsoon climate change, including from the recent IPCC 6th Assessment Report, and examines progress over generations of climate models. Observed 20th-century rainfall trends in the major monsoon regions as well as in the global monsoon are discussed, along with modelling studies that attempt to attribute these trends to anthropogenic factors. The latest future projections are presented, including from the most recent CMIP6 models which feature larger climate sensitivities, under the various shared socioeconomic pathways (SSPs), than their CMIP5 counterparts. The major uncertainties in near-term future projections of monsoon rainfall are also discussed, including the roles of coupled modes of internal variability and aerosol emissions patterns.

Teleconnection between North Atlantic summer SST and Indian summer monsoon rainfall (ISMR) on sub-seasonal to multi-decadal time scales

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Abstract : While associations with the ENSO falls far short of explaining the potential predictability of the Indian monsoon rainfall (ISMR) and even in the backdrop of weakening the ENSO-ISMR relationship in recent decades, the ENSO is still considered the most prominent predictable driver of the ISMR. On the other hand, there is rather compelling evidence of association between the North-Atlantic sea surface temperature (SST) modulated by the Atlantic Multi-decadal Oscillation (AMO) and ISMR on multi-decadal and interannual time scales. However, two concerns have prevented the AMO from being accepted as a predictable driver of the ISMR so far. First, how does the extratropical NA SST produce the atmospheric response to create the Teleconnection Bridge to ISMR? Second, the linear associations between the AMO and ISMR do not mean causality. Here, based on earlier work, we advance a hypothesis of teleconnection between the NA SST and ISMR and establish the causality between the two using two different nonlinear causal inference techniques. In the heart of the teleconnection is a wave number four stationary Rossby wave train seen on multi-decadal, interannual as well as on sub-sesaonal time scales. We unravel that the Atlantic Multi-decadal Oscillation (AMO) and the El Nino and Southern Oscillation (ENSO) are two independent drivers of ISMR with the former contributing as much to ISMR variability as does the latter. Observations and climate model simulations support the AMO-ISMR causality through a Rossby wave train driven by NA-SST that modulates the seasonal mean by forcing long active (break) spells of ISMR.

Global Monsoon: Concept and Dynamic Response to Anthropogenic Warming

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Abstract : This talk discusses the current understanding of the projection of global and regional monsoons under climate change, focusing on land monsoon rainfall (LMR) that provides water resources for about 70% of the world population. Monsoon has been progressively studied since the 17th century, yet only recently have regional monsoons been recognized as a global system. The talk will begin with a discussion of the concept of Global Monsoon and related debating issues. The climate sensitivity of global and regional LMR to anthropogenic warming projected by CMIP 6 models will be reviewed, emphasizing the critical physical processes responsible for the projected changes. In theory, regional mean LMP changes can be approximated by the changes in the product of the mid-tropospheric ascent and 850-hPa specific humidityplus moderate contribution from evaporation. The spatially uniform increase of humidity cannot explain markedly different regional LMR changes. The greenhouse gas (GHG) forcing increases moisture content but stabilizes the atmosphere. The two thermodynamic effects offset each other, resulting in a moderate thermodynamic impact on LMR. The Inter-model spread analysis suggests that the GHG-induced circulation changes (dynamic effects) are primarily responsible for the regional differences.The last part of the talk will discuss models' common biases, missing and poorly resolved physical processes, sources of projected uncertainties, and conceivable ways forward.

Reducing the impact of high impact weather

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Abstract :A priority of weather services is to protect lives and property from hazardous weather. Research on how to achieve that most effectively is the mission of the World Weather Research Programme's High Impact Weather (HIWeather) project. HIWeather brings together physical and social scientists from a wide variety of disciplines and from across the world to study each step of the process from monitoring the weather to making effective protective responses. HIWeather uses a simple model of the warning production and communication chain that highlights the roles of key actors and organisations involved in forecasting the weather, the resulting hazard and its socio-economic impacts, in formulating the warning and communicating it to the end-user. In my talk I shall summarise the results of that research in the context of severe weather associated with monsoons, identifying key principles for the design of weather-related warning systems. In doing so, I shall connect this work with ideas from the design of community-based warning systems, with developments in social media communication, with research on impact-based forecasting, and with progress in convection-permitting and higher resolution NWP models. A key result is that the communication of knowledge is at least as important as its content, and that the creation and nurturing of partnerships between organisations is critical to that.

Air-Sea Transition Zone in the Context of Monsoons

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Abstract : Air-sea interaction has long been recognized a critical process of monsoons. It has been traditionally treated as a synonym of air-sea fluxes in a sense that estimating air-sea fluxes has dominated the study of air-sea interaction. Meanwhile, it also has long been recognized that air-sea fluxes are influenced by the structures and fluctuations of the upper ocean and marine atmospheric boundary layer. The upper ocean, air-sea interface, and marine atmospheric boundary layer as a single identity, instead of a combination of the three, constitutes the air-sea transition zone. This presentation proposes that it is the time to expand the definition of air-sea interaction from processes at the air-sea interface to those in the entire air-sea transition zone, especially in the context of monsoons. Discussions also cover challenges of studying air-sea interaction in its new definition, particularly observing the air-sea transition zone. Examples are given to recent and current attempts to meet the challenges. A vision of possible future capabilities of observing the air-sea transition zone is offered.

Seasonal Prediction of Indian Monsoons

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Abstract : The monsoons (both Southwest and northeast) dominate the annual cycle of rainfall in India, which has strong influence on the agricultural practices in the country. Among the two monsoons, the southwest monsoon experienced from June to September is the principal rainy season for most parts of the country with a contribution of more than 75% of the annual rainfall. The NE monsoon rainfall is experienced during October to December period provides rainfall mainly over south Peninsula. An important feature of the southwest monsoon is its stability and regularity with all India southwest monsoon season rainfall (ISMR) being within ±30% of its long period average (LPA) during almost all years and within ±10% of LPA in about 70% of the years. In the regional scale, the variability of the rainfall can be much more than this. Therefore, any significant changes in the temporal and spatial distribution of the rainfall had noticeable impact on the country's agriculture production. Therefore, since the establishment of India Meteorological Department (IMD), in 1875, the seasonal forecasting of the monsoon rainfall has been one of its important operational responsibilities. The first operational LRF of Indian summer monsoon rainfall for the region covering whole India and Burma was issued on June 4th, 1886 using empirical method by Blandford who was the first Head of the IMD. Efforts for better forecasts started after that milestone provided improved understanding of the monsoon seasonal variability and predictability.

Early approach towards the seasonal prediction of Indian summer monsoon rainfall was based on the empirical/statistical prediction models which used ENSO related parameters along with other slowly-varying climate drivers as predictors for the forecasting of large-scale rainfall and precipitation anomalies over India. The statistical models also provide benchmarks for skill assessment of the now commonly used state of the art global general circulation models (GCMs) for the seasonal forecasting of Indian monsoon. Use of first generation atmospheric GCMs for seasonal forecasting was started in the mid 1990's. However, noticeable improvement in the skill of seasonal forecasting Indian summer monsoon by dynamical was observed only in the recent one decade or so with the advent of the coupled atmospheric-Ocean GCMs along with the advancement in both the estimate of the atmospheric & oceanic initial conditions as well as the model physics. This was helped by the improved understanding of the climate variability at different scales, significant improvement in the super computing power and advent of modern observation systems like satellite & radars.

Compared to the southwest monsoon, very little efforts have been made to predict the northeast monsoon rainfall mainly due to its very low seasonal predictability caused by strong intraseasonal variability in the rainfall observed during the season.In this review, historical development of seasonal forecasting of Indian southwest monsoon will be presented with emphasis on present status of the seasonal forecasting skill of Indian monsoon based on various approaches such as statistical models, dynamical models (single and multimodal), hybrid statistical cum dynamical models etc. Limitations and advantages of each of these approaches will also be discussed. Discussion will also be made about factors limiting the seasonal predictability of the Indian monsoons and future prospects for the further improvement in the skill of forecasting Indian Monsoons.

High-Resolution Simulations of Heavy-Rain-Producing MesoscaleConvective Systems Using Cloud-Resolving Models

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Abstract : In East Asia, most disaster-producing heavy rainfalls are caused by mesoscale convective systems (MCSs) composed of intense cumulonimbus clouds. A stationary line-shaped MCSs are the most dangerous precipitation system and often cause a heavy rainfall which results in severe floods and landslides. To study and to forecast heavy-rain-producing MCSs, a cloud-resolving model (CRM) is indispensable. A definition of CRM may be given by the non-hydrostatic buoyancy term which is composed of deviations of temperature, pressure and water vapor mixing ratio as well as hydrometeor mixing ratios. CRMs are defined as a numerical model which explicitly calculates time-dependent equations of all these terms. Recently, CRMs have been developed in different countries and used for researches and operational forecasts of MCSs. Tsuboki and Luo (2020) reviewed recent studies of high-resolution simulations of heavy rainfall systems using CRMs and also showed two simulation experiments of heavy rainfall in association with Baiu front and a typhoon. The purpose of the present paper is to update the review of the recent development of CRMs and their applications to simulate heavy-rain-producing MCSs.

As shown in Tsuboki and Luo (2020), horizontal resolutions of 1-4 km have been used for simulations of real weather systems including MCSs. Some heavy rainfalls were successfully simulated using high-resolution CRMs. On the other hand, other heavy rainfall systems are difficult to be simulated by CRMs. There may be some factors for the difficulty of quantitative simulation. To solve this problem, a promising method is an assimilation of radar data. Recently, a phased array weather radar (PAWR) has been developed, which can make a very rapid three-dimensional scan. Moreover, a polarimetric PAWR has been developed and used for an experimental observation. This paper also reports the advantage of these PAWRs and suggests a possibility to improve simulations of heavy-rain-producing MCSs by the PAWR data assimilation to a CRM.

Reference: Tsuboki, K. and Y. Luo, 2020: High-resolution simulations of heavy rainfalls in association with monsoon systems and typhoons using cloud-resolving models. World Scientific Series on Asia-Pacific Weather and Climate-The Multiscale Global Monsoon System.**11**, 113-131.

A brief review of JAMSTEC YMC Activities

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Abstract : An international field program called the Years of the Maritime Continent (YMC) has been conducted. YMC offers coordination opportunities for field campaign with the MC local agencies, and many intensive observations have been done since 2017. Since several field campaigns have been postponed due to COVID-19 pandemic, its field campaign phase is expected to continue until early 2023. We at JAMSTEC conducted several field campaigns with many local agencies and universities from Indonesia, Philippines, Palau, and the Federated States of Micronesia. During the early years of YMC we conducted two campaigns off the west coast of Sumatra focusing on the relationship between local circulation such as diurnal cycle of rain and large-scale circulation of the Madden-Julian Oscillation (MJO) in 2015 as a pilot study and in 2017. On the one hand, we conducted field campaigns targeting the boreal summer intraseasonal oscillation (BSISO) in 2018, 2020, and 2021 in the western Pacific deploying our research vessel and/or unmanned autonomous surface vehicles (ASVs) as well as radiosonde soundings at land-based sites. In this talk, we briefly mention about the results obtained through those campaigns from the two aspects. First one is some scientific knowledge mainly about the behaviour of diurnal cycle of rain along the coast of Sumatra, and the second one is an introduction of our trial to study air-sea interaction focusing on atmospheric meso-scale convection using ASVs in conjunction with the ship.

Climate Extremes in The Hydroclimate Change

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Abstract : We live in a monsoon country. Approximately 62% of the world's population living in global land monsoon rely on freshwater resources from monsoon rainfall, controlled by the global hydrological cycle. During the last several years, we realized increasing trends in the frequency and intensity of extreme rainfall in different monsoon regions. Also, we found there are clear distinctions in the context of extreme rainfall intensity and size. This point is an important motivational factor.

Moreover, CESM2-Large ensemble 50 MME shows substantial changes in the monsoon rainfall variability, not only its amplitude but also its duration. Both changes can affect various social-ecological fields.

So the outline of my talk will be about recent advances and findings on hydroclimate, including monsoon duration, intensity, rainfall extremes changes, its mechanism, and evaporative demand from the warming climate. We tried to provide how dynamic and thermodynamic factors control rainfall extremes over East Asia in late summer, heatwaves based on dry conditions, and stationary waves, wildfire, and ENSO-rainfall variability. Lastly, I want to introduce new projects plans.

North and Central South American Low Level Jets: mechanisms and association with active and break phases of the South American Monsoon System

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Abstract : The South American Monsoon System (SAMS) has unique features comparatively with other monsoons. Among them is the South America Low-level Jet (SALLJ). The SALLJ is a climatological feature that plays a critical role in the spatiotemporal distribution of precipitation in South America. While previous studies have focused on the mechanisms and variability of the SALLJ in the central Andes (i.e., southeast Peru, Bolivia, and Paraguay), the occurrence of the low-level jet in the eastern slopes of the northern Andes (i.e., northeast Peru, Colombia, and Venezuela) and its linkages to the central region have not been previously explored. This study shows that the SALLJ in the northern branch exceeds 10 m s−1 during September-February and the frequency can be as high as in the central region. When the Central jet is active, moisture is transported to the subtropics and SAMS experience periods of less rainfall. However, when the Northern jet is active, moisture is transported towards eastern South America, invigorating the SAMS. Here we use Self Organized maps to characterize the behavior of the SALLJ along eastern Andes. This method is capable of characterizing both jets. With this methodology we investigate mechanisms explaining both jets, focusing on the relationships with tropical and midlatitudeforcings. We show that the frequency and intensity of the SALLJ in the northern Andes has substantially increased in the last 39 years.

Interactions between Tropical Cyclones and Vertical Wind Shear

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Abstract : It has been known for several decades that vertical wind shear (VWS) generally inhibits tropical cyclone (TC) genesis and intensification, but the interactions between these two weather phenomena can be very complex and difficult to forecast. The scientific and forecast challenges of TC and VWS interactions are due in part to the involvement of multiple spatial and temporal scales. On seasonal time scales, basin-wide TC activity is largely affected by VWS associated with the El Nino Southern Oscillation, but recent work has shown that extratropical sources of shear are important contributors. VWS associated with the global monsoon system also plays an important role, with the seasonal contributions dependent on the regional characteristics and climatology of the monsoonal flow. On synoptic scales, recent studies have shown that moderate amounts of VWS interacting with weak TCs can promote substantial uncertainty in intensity change, with some TCs succumbing to the shear and weakening while others can withstand or even modify the shear locally and then intensify. Environmental moisture provides an important modulating effect to these shear interactions, with drier conditions often leading to increased ventilation of the storm core by VWS. On the mesoscale, VWS impacts convective organization within a TC, leading to asymmetries in vertical motion that can either enhance or inhibit TC genesis and intensification, and also can lead to extreme precipitation impacts. VWS can also influence eyewall replacement cycles, leading to further uncertainty in structure and intensity forecasts. This talk will review recent studies and progress on our understanding of VWS and TC interactions, including the role of the global monsoon system in creating the conditions that lead to these interactions across multiple scales. Future directions for research on this topic will also be discussed.

Evolution of Water Budget and Precipitation Efficiency of Mesoscale Convective Systems associated with Southwesterly Monsoon Flows over the South China Sea

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Abstract : In this study, the evolution of precipitation efficiency (PE) and water budget of mesoscale convective systems (MCSs), which produced heavy rainfall over the South China Sea and southern Taiwan on 25–28 August 2015, are investigated using satellite observations and model simulations. The MCS is embedded within the southwesterly monsoon flow from Indo China with abundant moisture. The evolution of PE and water budget is first examined in a semi-Lagrangian frame work following the movement of targeted MCS, and is confirmed in an Eulerian framework over the broad-scale area enclosing the MCS. The sensitivity of water budget and moisture fluxes to low-level moisture amount and horizontal wind speed is investigated. Water budget in the semi-Lagrangian framework shows that if the low-level large-scale moisture is increased (decreased) by 10%, the total condensation and deposition will be increased (decreased) by 10% (30–40 %); moisture flux convergence will be significantly enhanced within the MCS to generate more precipitation, and evaporation will be more pronounced over the region of weak convection. Similar results are found in an Eulerian framework. For the strong convective cells(radar reflectivity of greater than 35 dBZ) within the MCS, the calculated large-scale PE is 20–25% and the microphysical PE is 35–40%. The surface precipitation is highly sensitive to the large-scale moisture change, and less sensitive to wind-speed change. In particular, 10% decrease of low-level (below 700 hPa) relative humidity results in 10–20% decrease of moisture flux and 10–40% reduction of surface precipitation.

Key words : Water budget, Precipitation efficiency, Atmospheric rivers.

Equatorial Rossby Waves, the Madden Julian Oscillation, and their Impacts on Monsoons

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Abstract : Convectively coupled equatorial Rossby waves and the Madden Julian oscillation (MJO) organize synoptic to subseasonal variability in winds and rainfall across the tropics. This presentation reviews research on how these features interact with monsoon rainfall patterns, especially near the seasonal initiation and termination points of monsoons and during their break and active rainfall periods. How the spatial structures of subseasonal monsoon rainfall events evolve with these disturbances in the context of the global atmospheric circulation will be shown at different stages of the monsoon seasonal cycle.

Monsoon Prediction Across Scales

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Abstract : Variability of the monsoon occurs across all space and time scales moving fromperiods of abundant rainfall to intervals of drought. Precipitation may varydecadally, seasonally (overall strong and weak monsoons), intra-seasonally (activeand break intervals) and on shorter time scales, extra-synoptic (15-day), synoptic(monsoon depressions, tropical cyclones), mid-latitude incursions and diurnally.

All of these components of a monsoon system have been well described butpredicting their occurrence with sufficient lead-time to be useful, both inmitigating adverse effects (e.g., floods and drought) or in taking advantage ofperiods of anticipated rainfall has been, and remains, difficult.

Based on the basic physics of the couple ocean-atmosphere monsoon wecommence by showing the interdependence of these various components.. Usingthis knowledge, we seek to extend general monsoon predictability across allscales. We utilize extended ensemble predictions from global models aimed atestablishing the probability of regular occurrences of monsoon phenomena bethey be benign and extreme. Predictive skill at various lags that exist today will bediscussed together with an assessment of where there is hope for improvement.

We will discuss a new idea of the development of a hybrid Bayesian model forintra-seasonal variability that uses statistics to improve ensemble predictions.Finally, we briefly discuss monsoon predictability in a changing climate. Whereasthere are still questions about the changing frequency of extreme events, thebasic dynamics and thermodynamics of the monsoon will remain the same so thatmonsoon ensemble forecasts with current global models will remain useful. Yet,the possibility of more abundant and intense events within the monsoon place aheavier burden on communicating and disseminating predictions to user groupsand potentially affected populations.

Implications of Volcanic Aerosols for Seasonal Forecasting of the Indian Monsoon in A Changing Climate

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Abstract : There is unequivocal evidence that human-induced climate change, in particular greenhouse gas (GHG) emissions, has been the main driver of the observed intensification of heavy precipitation over the land regions across the globe, and has also contributed to increases in agricultural droughts in some regions, which are further projected to enhance with additional warming during the 21st century (IPCC AR6 WG1, 2021). In addition to GHG forcing, anthropogenic aerosol emissions from the Northern Hemisphere (NH) are recognized to have influenced monsoon precipitation changes over the West African, South Asian and East Asian monsoon regions, since the second half of the 20th century (IPCC AR6 WG1, 2021). In particular, the expected enhancement of the South Asian monsoon precipitation by GHG forcing since 1950s has been offset by precipitation reduction caused by the NH anthropogenic aerosols (IPCC AR6 WG1, 2021).

Near-term climate projections for the period 2021-2040 indicate that the South Asian monsoon will be dominated by the effects of internal variability, but will increase in the long-term (IPCC AR6 WG1, 2021). In this context, it must be highlighted that uncertainties due to unpredictable natural forcings such as large volcanic eruptions can lower the degree of confidence in projecting near-term monsoonal changes. This talk is aimed to provide some insights into the role of large volcanic eruptions on the tropical atmosphere-ocean coupled system and the Indian monsoon, with implications for monsoon seasonal forecasting.

Potential Vorticity Generation by West African Squall Lines

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Abstract : Using sounding data from the 2006 African Monsoon Multidisciplinary Analyses (AMMA) field campaign over West Africa, a composite of squall lines that tracked on the cyclonic shear side of the African Easterly Jet (AEJ) has been created. Latent heating within the trailing stratiform regions of the squall lines produced a mid-tropospheric positive potential vorticity (PV) anomaly centered at the melting level, as commonly observed in such systems. However, a unique aspect of these PV anomalies is that they combined with a 400-500 hPa positive PV anomaly extending southward from the Sahara. The latter feature is a consequence of the deep convective boundary layer over the hot Saharan desert. The results provide evidence of a coupling and merging of two PV sources, one associated with the Saharan heat low and another with latent heating, that ends up creating a prominent mid-tropospheric positive PV maximum to the rear of West African squall lines. This superposition of PV anomalies makes mesoscale convective systems associated with West African easterly waves particularly potent incipient disturbances for tropical cyclogenesis over the eastern Atlantic Ocean.

The increasing overheating problem in urban South Asia : mitigation options

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Abstract : In the face of global climate change as well as rapid urbanisation, cities in the global South experience double jeopardy of overheating due to both global and urban warming. The IPCC – AR6 report highlighted that in South Asia, rapid urbanisation, especially in the hot, humid belt leads to greater exposure to heat risk, both due to increasing urban populations as well as overheating due to global/urban warming. However, a city-focused exploration of thermal comfort trends, especially in the hot, humid tropics, remain relatively unexplored. In this talks we will explore the recent historical trends (1991-2020) in outdoor thermal comfort across the entire island of Sri Lanka and evaluate the likely effects of known urban climate mitigation strategies – shade, vegetative cover, wind flow, and high albedo materials. We find that 'very strong heat stress' approaching 'extreme heat stress' that was barely registered in 1990s is now common across two-thirds of the landmass of Sri Lanka in the hottest month (April). Even in the coolest month (January), 'moderate heat stress' unknown as recently as in the 1990s is now commonplace in the most densely populated parts of the country. High shading and vegetation could reduce heat stress, even in the hottest month, but this would be increasingly difficult to achieve as the warming continues. As such, policies to reduce global warming needs to be urgently pursued while simultaneously addressing urban warming in Sri Lanka. Implications for other rapidly growing South Asian cities will be explored.

Modulation of global monsoon systems by the equatorial Quasi-Biennial Oscillation

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Abstract : There are some observational pieces of evidence that the equatorial quasi-biennial oscillation (QBO) in the stratosphere influences tropospheric variations in the form of moist convection and its large-scale organization into meso-to-planetary-scale systems. The organized moist convective systems include the Madden-Julian Oscillation (MJO) and the El-Nino Southern Oscillation (ENSO) in sub-seasonal and inter-annual time scales, respectively, as reviewed recently by Hitchman et al. (2021) and Haynes et al. (2021). In addition, there could be QBO modulation of monsoon circulation, which is a periodic response of a large-scale circulation system in low- and mid-latitudes, driven by a continental-scale contrast between lands and oceans, to the annual cycle of solar forcing due to the revolution of the Earth around the Sun. We apply the composite difference analysis introduced by Kumar et al. (2021) by using the QBO-phase angles based on the EOF method of Wallace et al. (1993). After describing the climatology of global monsoon systems for neutral ENSO periods in 40 years (1979-2018) with monthly mean ERA-Interim reanalysis dataset, eight QBO phases (45 degree each) were introduced to investigate the statistical significance of the difference of composite means of opposite QBO phases in the tropospheric quantities, in boreal summer (JJA) and austral summer (DJF) separately. Precipitation, its proxy data, and circulation fields show statistically significant composite differences between specific opposite QBO phases. Some typical examples for QBO modulation of global monsoon systems are obtained in the equatorial Western Pacific and Central Pacific for Phase 1 - Phase 5 in austral summer, characterized by zonal shifts (eastward or westward) of the Walker circulation. Also, in the northern subtropics in boreal summer with an intensification of the west side of Ogasawara high in Western Pacific in Phase 8, and in austral summer with an intensification of Atlantic high in North Atlantic in Phase 4.

Economic and societal impacts of the Indian summer monsoon

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Abstract : In the colonial times it was said that the Indian economy is 'a gamble on the monsoon' because of the large impact of the monsoon variability on agricultural production and hence the economy of India. With the large investment in development by the government since independence in 1947 and the substantial decrease in the contribution of agriculture to the gross domestic product (GDP), it was expected that the impact of the monsoon would decrease and the economy would evolve to become drought proof. However, the first quantitative assessment of the impact of the Indian summer monsoon rainfall (ISMR) on the food-grain production (FGP) and GDPby analysis of the variation during 1951-2003 (Gadgil and Gadgil 2006)showed that the impact of severe droughts has remained 2 to 5% of GDP throughout this period. The adverse impact on the agriculture has such a large impact on GDP in years of deficit rains because 60% of the population is still part of the agricultural work force.

Most meteorologists believe that the major cause of famines is the food shortage due to droughts, so a famines is the most adverse impact of monsoon variability. The impact of droughts prior to and early in the colonial era, was minimized by traditional social institutions and collective use of farm revenues. The major famines of 1876-1878, 1896-1897, 1899-1900 in which millions died in the colonial era were associated with droughts.However, after independence in 1947, despite severe crop failures in association with the droughts of 1968,73,79 and 1987, there were no famines. The last famine, one of the largest was the Bengal famine of 1943 (in which 2-3 million people died) occurred when the monsoon rainfall over Bengal as well as ISMR was above the average and hence the monsoon could not have been responsible for it.. The Nobel Laureate AmartyaSenattributes the total absence of famines in India since independence to the installation of multiparty democratic system. The contrasting case is China, which has been more successful than India in economic progress, which had the largest recorded famine in history during 1958-61 in which 30 million perished. This demonstrates the role of social institutions and governance in determining the social impact of the monsoon.

Derivation of strategies to enhance production in the face of monsoon variability and the appropriate strategy for the predicted monsoon regime, on the basis of harnessing of the knowledge of monsoon variability, monsoon predictions and crop models and with appropriate emphasis on the socio-economic dimension will also be discussed in the lecture. Gadgil, Sulochana and Siddhartha Gadgil, The Indian Monsoon, GDP and Agriculture. Economic and Political Weekly, 2006, XLI (47), 4887-4889.

SST Fronts/Gradients in the Bay of Bengal and their Impact on Indian Summer Monsoon Rainfall at Different time scales

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Abstract : It is well-established that warm ocean currents play an essential role in the systematic development of extratropical cyclones. Since the Indian Ocean is landlocked on its northern side, one expects no such strong air-sea interaction. However, in this talk, I show how the SST fronts in the Bay of Bengal modulate Indian summer monsoon rainfall over India at different temporal scales. We have investigated how the SST fronts and gradients in the Bay of Bengal modulate the monsoon rainfall at different time scales by conducting well-designed model experiments. A narrow coastal Bay of Bengal SST front is essential to sustain rain over central India. The SST front promotes intense convection in its vicinity to source the monsoon-low pressure systems. Basin-wide meridional SST gradients support intraseasonal monsoon rainfall over India. Small scale SST eddies in the Bay of Bengal also appears to be modulating monsoon rainfall at a seasonal time scale.

GEWEX AsiaPEX: Collaboration toward Understanding of Multiscale Variability of the Asian Hydroclimatological System

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Abstract : We have launched the Asian Precipitation Experiment (AsiaPEX) in 2019 to understand Asian land precipitation over diverse hydroclimatological conditions and multiple time scales for better prediction, disaster reduction, and sustainable development. AsiaPEX is a prospective Regional Hydroclimatorogical Project (RHP) under the Global Hydroclimate Panel (GHP). It is a successor of the GEXEX Asia Monsoon Experiment (GAME) and the Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative (MAHASRI). One of our key questions of our project is to elucidate the future projection of the Asian monsoon system, which emerges as a crucial mission under the climate change. We defined our project strategy in our six approaches: 1) observation and estimation of variation and extremes in Asian land precipitation and important variables, 2) process studies of Asian land precipitation focusing on diverse land-atmosphere coupling, 3) understanding and prediction of the variability of Asian monsoon from subseasonal to interdecadal time scales, 4) high-resolution land surface hydrological modeling and monitoring incorporatingimpacts of human water withdrawal, agriculture, vegetation and cryosphere, 5) coordinated observation and modeling initiatives, 6) detection and projection of the climate change impact on regional precipitation in Asia. We had a Kick-off Conference in 2019 and develop research activities from above approaches. One of our main activities will be conducting an observational and modeling initiatives. We will propose Asia Monsoon Year-II as a coordinated observational and modeling initiative toward the understanding of the systematic view of Asian hydroclimatological system in summer and winter. Coupling of the land surface and the atmospheric processes including the convection would be a focus of the project, with a special focus on the diurnal variation. An improvement of the predictability in sub-seasonal to seasonal (S2S) time scales will be a benchmark of our understanding of the system. The intensive observation period will be around 2025/26-2026/27 monsoon seasons.

Distinctive South and East Asian Monsoon circulation responses to global warming

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Abstract : The Asian summer monsoon (ASM) is the most energetic circulation system. Projecting its future change is critical for the mitigation and adaptation of billions of people living in the region. There are two important components within the ASM: South Asian summer monsoon (SASM) and East Asian summer monsoon (EASM). Although current state-of-the-art climate models projected increased precipitation in both SASM and EASM due to the increase of atmospheric moisture, their circulation changes differ markedly - A robust strengthening (weakening) of EASM (SASM) circulation was projected. By separating fast and slow processes in response to increased CO_2radiative forcing, we demonstrate that EASM circulation strengthening is attributed to the fast land warming and associated Tibetan Plateau thermal forcing. In contrast, SASM circulation weakening is primarily attributed to an El Niño-like oceanic warming pattern in the tropical Pacific and associated suppressed precipitation over the Maritime Continent.

Convective and Microphysical Characteristics of Extreme Precipitation Revealed by Multisource Observations over the Pearl River Delta at Monsoon Coast

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Abstract : Extreme precipitation is an issue of worldwide concern, but its microphysics remain elusive. The convective and microphysical characteristics of extreme precipitation features (EPFs) in a monsoon coastal area (South China) are investigated mainly using two-year observations from a dual-polarization radar and distrometers. The EPFs are accompanied by a broad range of convective intensity, and categorized into the “intense”, “moderate”, and “weak” convection accounting for 17.3%, 48.6% and 34.1% of the total population, respectively. The EPFs with weaker convection show weakened size sorting and less breakup of large raindrops, but a larger ratio of liquid water path to ice water path and more prominent coalescence warm-rain process. All the three categories are dominated by the coalescence in the liquid-phase processes, and have much more populous raindrops than the “continental” with a mean size larger than the “maritime” regime. These results improve our understanding of extreme precipitation from the microphysical perspective.

Warm Season Heavy Precipitation Observed From Satellite Earth Observations

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Abstract : In recent years, frequency of heavy rainfalls causing disastrous floods is increasing in Japan and in East Asia. We utilize a huge amount of three-dimensional precipitation radar data observed from the Tropical Rainfall Measuring Mission satellite, and the Global Precipitation Measurements (GPM) core satellite, to analyze how precipitation characteristics are affected by the environment in the warm season. There are two different types of warm-season severe precipitation. One is a thunder-storm type with smaller areas and with relatively shorter durations, associated with severe convection. Another is a wide-area extreme precipitation with long durations, which causes wide-area disastrous floods. Between these two types of heavy rainfalls, large-scale environments and mechanisms of heavy rainfall systems are very different. The former is associated with the Convective Available Potential Energy (CAPE)-type atmospheric instability, while the latter is with the Moist Adiabatic Unstable Layer (MAUL)-type instability. We would like to discuss why the global warming can cause the increase of disastrous heavy rainfalls.

Role of Land Surface Processes on Indian Summer Monsoon Rainfall: Understanding and Impact Assessment

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Abstract : The earth's surface is intimately connected to the overlying atmosphere through exchange of energy, moisture and momentum. Through these exchanges the surface of earth influences the atmospheric boundary layer, convection, precipitation and thereby affects weather and climate systems. The Indian Monsoon Region (IMR) is critical for the land atmosphere feedback due to the underlying land surface characteristics such as soil, vegetation, topography and rainfall distribution. The region also has been identified as soil moisture-rainfall coupling hotspots. Moreover, the surface heterogeneity over the IMR makes the land surface processes more complex and therefore understanding and representing these feedback processes associated with Indian Summer Monsoon becomes crucial for the rainfall predictions. The region lacks land surface observations which constraint the representation of spatiotemporal surface variability and the associated predictability of weather and climate models. To this end, a high-resolution (4km and 3hourly) soil moisture and soil temperature (SMST) data at surface and subsurface soil layers (0-10cm, 10-40cm, 40-100cm) are generated over the IMR for the 37 years (1981-2017) using Land Data Assimilation System (LDAS) forced with various local observations and analysis. The validation of these SMST data with available station observations and satellite estimates shows credibility of the developed data over the coarser global reanalysis SMST data products. The developed dataset also replicated the seasonal and inter-annual variation of SMST and diurnal variability of ST.

The high-resolution SMST are further initialized in a mesoscale NWP model (WRF) for the simulation of monsoonal disturbances. The utilization of high-resolution SMST in the NWP model shows consistent improvement in simulating surface meteorological parameters, rainfall and its spatiotemporal distribution associated with monsoon depression. The MD track forecast error is improved by ~15% when initialized with high-resolution SMST. In the other set of experiments that carried out by initializing soil moistures from various sources having notable discrepancy in the magnitude and distribution of SM in the regional climate model (RegCM) to simulate the excess, deficit and normal summer monsoons, it is found that SM tends to have a positive relationship with precipitation and evapotranspiration and a negative relation with sensible heat flux. The better representation of SM in the model initial conditions significantly enhancing the model skill (of an about 0.1 in correlation) in simulating the summer monsoon. The land surface representation and evapotranspiration due to the high-resolution SMST initialization played a dominant role leading to improved rainfall simulations.

Key words : Soil moisture, Land atmosphere feedback, Monsoon, Precipitation.

Sub-Seasonal To Seasonal (S2S) Predictions of theAsian Summer Monsoon: Current Status and Future Directions

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Abstract : This presentation provides an update on the sub-seasonal to seasonal (S2S) prediction capability of the Asian summer monsoon. The prediction skill of the S2S monsoon prediction has been considered to rely on the predictability originating the initial states (initial value problem) and boundary forcing of slowly-varying components such as the ocean and land (boundary value problems). However, because coupled models now represent relevant interaction processes, the S2S monsoon prediction is a initial value problem of the coupled system with multi-time-scale variability and their interactions. By leveraging the advantages of the coupled model predictions, in this presentation, a special focus is put on the interannual modulation of the Asian summer monsoon by the dominant climate variability including the boreal summer intraseasonal oscillation, ENSO, Indian Ocean basin-wide variability, Indian Ocean Dipole and the interactuions between these modes. Sub-seasonal and seasonal monsoon variability has two-way time-scale interactions, thus better representing and predicting the interaction is a key for accurate predictions both at sub-seasonal and seasonal time-scales.

In a newly launched initiative of the Working Group on Subseasonal to Interdecadal Prediction (WGSIP), “Prediction Capabilities” revisits the S2S monsoon prediction in its sub-theme. Some results are presented to highlight the current predictive capability. In the last decade, several new data archives of the S2S predictions have offered unprecedented opportunities for S2S monsoon prediction studies, which include the data archives of the WWRP/WCRP Sub-seasonal to Seasonal Prediction Projects (S2S), the WCRP Climate-system Historical Forecast Project (CHFP), the Copernicus Climate Change Service (C3S), the North American Multi-Model Ensemble (NMME), the theSubseasonal Experiment (SubX). These data archives can be used for exploring the potential of S2S predictions and are expected to create synergy between modeling and observationally based studies in Asia and to further advance S2S monsoon prediction.

FGOALS-f2 Seamless prediction system of IAP-CAS and application in the Asian Monsoon

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Abstract : Seamless Prediction of weather and climate is an important way to promote services, and is characterized by the multi-time scale forecasting, usually from sub-seasonal to decadal prediction (S2D), which is considered to fill the gaps between weather and climate, near-term and long-term climate prediction. The improvement of prediction skills for extreme weather and climate disasters will undoubtedly contribute to disaster risk reduction and the sustainable development of the monsoon regions. The latest FGOALS-f2 ensemble prediction system is a seamless predictions established in 2019. There are 4 fully coupled components of FGOALS-f2, including atmospheric, oceanic, land, and sea ice modules. The dynamic core of atmospheric component is FV3, and the key process of the physical processes in atmospheric component of FGOALS-f2 is a resolved convection precipitation scheme. FGOALS-f2 prediction system not only achieved 30-year reforecasts, but also began operational prediction in 2020. Recently, the FGOALS-f2 outputs of the subseasonal to seasonal (S2S) prediction have been submitted to WWRP/WCRP S2S Phase 2 Project. The prediction products cover both the global and regional areas, such as ENSO, MJO, TC, Arctic Sea Ice, Tibet Plateau and surrounding Asian monsoon regions. Some typical applications of the seamless system in the monsoon region will be introduced, such as the seasonal prediction in China and Nepal, the latest decadal prediction for China, and support for Tanker Rescue in Sri Lanka.

Precipitation and Its Variability in the High Elevation Area of the Nepal Himalayas

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Abstract : The hydrological cycle in the Himalayas is characterized by large amounts of precipitation over slopes and the existence of glaciers in high-elevation areas. The cycle maintains the headwaters of major rivers such as the Indus, the Ganges, and the Brahmaputra, and provides water resources for South Asia's large population. In the central-eastern Himalayas, most of the total annual precipitation falls in summer (June-September), which makes summer precipitation a crucial part of the high-elevation hydroclimate in the Nepal Himalayas. Meteorological observations at elevations of >4,000 m asl over the Himalayas are still extremely scarce. Therefore, in situ observations with high temporal resolution remain essential. In order to better understand summer precipitation in such area and mechanisms of its variability, international collaborative research on precipitation in the Himalayas (HiPRECS: Himalaya precipitation study) has been carried out since 2019. HiPRECS performs a comprehensive research based on in-situ observations including glacier sites, satellite remote sensing (e.g., TRMM, GPM and Meteosat-IODC), large-scale and regional-scale data analyses (e.g., ERA5) and numerical simulation using cloud-resolving models (e.g, WRF and CReSS). We established a raingauge network in the Rolwaling valley in the eastern Nepal Himalayas, which has eight rain-gauge stations covering from ~1,000 m to ~5,500 m asl. The two of them are located close to Trakarding-Trambau glacier system. Here, based on the results from the ongoing research project, we will present the features of diurnal precipitation cycle at the glacier site and its driving mechanism. We also show extreme rainfall events observed in the raingauge network, which is induced by the multi-scale interaction among topography, synoptic-scale low pressure systems and intraseasonal oscillations such as BSISO and QBW.

A Machine Learning Approach for Probabilistic Multi-Model Ensemble Predictions of Indian Summer Monsoon Rainfall

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Abstract : A single deterministic rainfall forecast is not sufficient for effectively predicting seasonal Indian Summer Monsoon Rainfall (ISMR), which is characterized by high variability. The user community should be given probabilistic forecasts that convey the inherent uncertainty of the predictions. While such probabilistic seasonal forecasts can be produced from general circulation model (GCM) output, one single model generally does not represent all sources of error. The probabilistic multi model ensemble (PMME) is a well-accepted way to improve on the skill of probabilistic forecasts by individual GCMs. PMME can be made with one of two approaches: non-parametric, or parametric with respect to the occurrence of three categories of seasonal total rainfall-below, near, and above normal as defined by the climatological base period. Both the methods have their limitations. Non-parametric PMME use a smaller ensemble size which results in overconfident forecasts, and parametric PMME make the inaccurate assumption that total rainfall follows a Gaussian distribution. To avoid these problems, we propose the use of Extreme Learning Machine (ELM), a novel machine learning approach, to construct PMME for ISMR forecasting. ELM is a state-of-the-art generalized form of single-hidden-layer feed-forward neural network. However, since the traditional ELM network only produces a deterministic outcome, we use a modified version of ELM called Probabilistic Output Extreme Learning Machine (PO-ELM). PO-ELM uses sigmoid additive neurons and slightly different linear programming to make probabilistic predictions. In this talk, the skill and interpretability of the proposed method for seasonal ISMR forecasts will be presented.

Medium and extended range forecast of monsoon over India : Application in Agricultural Sectors

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Abstract : For the vast agro-economic country like India the forecast of southwest monsoon rainfall on short to medium range (5 days) to extended range time scale up to about 3 to 4 weeks (prediction of active-break cycle of monsoon) is vital for issuing reliable advisories to the farming communitiesof the country. As the Agriculture production is directly influenced by monsoon performance over the rain fed portion of India, the reliable forecast of monsoon in medium to extended range forecast can be very beneficial to the farming communities of the country. Recognizing the urgent need for improving the monsoon prediction capabilities in the country in a systematic and timely manner, India Meteorological Department (IMD) through the concerted efforts of the Ministry of Earth Sciences (MoES) and collaborative work with IITM and NCMRWF has augmented its NWP modelling capability and is now able to generate forecasts at very high resolutions; 3 km using meso-scale model, 12 km using Global Forecast System (GFS) & Global Ensemble Forecast System (GEFS) models and about 38 km using ocean-atmosphere coupled Climate Forecast System (CFS) model. These continuous efforts by MoEShave enabled IMD to provide forecast at district/block level at short to medium range time scales and met-subdivision/district at extended range time scale.

In addition to the forecast products from GFS and GEFS models at 12 km resolution in the medium range time scale (Day 1 to Day 5 forecasts), IMD is also preparing Multi-Model Ensemble (MME) forecasts at district level by using the outputs from other three global models viz., the Unified Model from NCMRWF, GFS model from NCEP and Global Spectral Model (GSM) from JMA. Based on the evaluation of district level MME forecast for the 2021 monsoon season it is found that MME has a potential of predicting weather events in medium range. The correlation coefficient between observed rainfall and day 1, day 2, day 3, day 4 and day 5 forecast during July to October 2021 for Indian districts are 0.65, 0.61, 0.56, 0.51 and 0.47 respectively.

Like in the medium range IMD has also implemented CFSv2 based Extended Range Forecasts (ERFs) for application in Agricultures. The performance of operational ERF issued by IMD is evaluated for the southwest monsoons 2020 and 2021 at all India level, four homogeneous regions, 36 met-subdivisions and 676 districts spreading over India. Based on the analysis of various verification scores it is observed that for all three categories (Above Normal, Normal and Below Normal) ERF forecast of 2021 shows better accuracy than the 2020 forecast. Overall it is seen that the model performance is reasonable for week 1 and week 2, whereas it shows slightly larger deviation in week 3 and week 4 forecasts. Thus, considering the complex nature of extended range monsoon forecasting at smaller spatial scales, the present results show encouraging signals for applications in Agricultural sectors.

Advances in the Development and Application of Forecasts in Water Sector

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Abstract : The exponential rise in demand for water to grow food, supply industries and sustain urban and rural populations has led to a growing scarcity of freshwater in many parts of the world. A number of major river basins around the world supporting large populations experience moderate to severe water scarcity up to 6 to 12 months, at varying inter-annual to inter-decadal time scales. The talk will cover developments in streamflow forecasting in Australia over a decade following the Millennium Drought (1997–2009) in south-eastern Australia which decimated production in Australia's most important agricultural regions, and significantly impacted the ecological health of Australian rivers, particularly in the Murray-Darling Basin. Example use cases of forecasts in the water and environment sectors will be discussed together with an overview of developments underway within the auspices of WMO Global Hydrological Status and Outlook System (HydroSOS).

Land Processes and Feedbacks within NWP and Earth System Models: Humandominated landscapes, and the role of AI/ML, Digital Twins, for Sensing the Unsensed

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Abstract : The last decade has witnessed remarkable progress on observing and modeling land surface processes (LSPs) and land use land cover (LULC) feedbacks on weather and climate extremes. Examples include: the role of antecedent dry conditions and cities compounding heat waves, antecedent wet soil state intensifying landfalling tropical cyclone rainfall, vegetation green cover and irrigation providing moisture and dynamic feedback on seasonal and subseasonal forecast improvements, urbanization affecting heavy rainfall especially over and around cities, impact on improved air pollution and heat mapping for public health applications, amongst other. The IPCC assessments also consider land feedback and landuselandcover processes in the analysis. Thus, over the past decade, the highlight is a clear and conclusive affirmation about the critical impact of landstate on regional and global weather and climate and, in particular, on the extremes. The question is no longer whether land surface features such as urbanization agriculture impact the regional meteorology, hydroclimatology, and environmental systems- and has been answered as an emphatic 'yes'.

The questions now, looking forward to the next five-ten years, are: (i) How is the land state affecting the regional weather and climate This is in the context of improved process-scale and explainable understanding. (ii) How should the land state, especially agriculture and urbanization- two of the most human-influenced landscapes- be represented within weather and EaSMs. (iii) What is the role of AI/ML approaches in developing future land models and associated datasets? The last question is especially pertinent for the data-driven approaches set to dominate the global applications in coming years. We have improved our understanding of developing the models and the model physics, but the availability of input data that can help with improved predictions continues to be the bottleneck.

These three core questions will be discussed in the context of prior achievements; and the work underway with causal models linking physics-based analysis with data-driven approaches taking the case of urban rainfall changes, agricultural irrigation effects, and human well-being. The discussion also focuses on efforts underway over India, in particular for the DST climate change network program on Urban Climate and the National Supercomputing Mission Urban Modeling project. Within the US/international context, an update on the development of the World Urban Data Analysis and Portal Tools (WUDAPT) and urban datasets that are needed to represent the different processes will be provided. Also, the emergence of AI/ML approaches for downscaling/upscaling data and forecasts, developing input products/data needed for running the models and the emerging world of regional Digital Twins within the EaSM perspective will be discussed to incorporate the multiscale processes and human decision/societal aspects that have not been adequately considered in land models is particularly interesting. The need for defining a metric as to the value of the forecast beyond the quantitative estimates is becoming even more urgent as more localized decision drive models are being designed. The next decade will see a more critical role of land efforts to create datasets that can localize NWP and climate models, provide information aboutsensing the unsensed, and deal with the information across different scales, with applications to extremes predictions and more seamless spatiotemporal changes. Amidst all these exciting technology-driven developments, there is a clear need for more process-scale understanding to be continuously supported and developed as we look to benefit from physics-based intelligent models.

Monsoon Outlook to Impact Forecasting

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Abstract : Impact-based forecasting signals an evolution from "what the weather will be" to "what the weather will do" and thus bridges the gaps between national weather services and the end users such as disaster risk management and development sector communities. It is a user-friendly way of communicating the climate risk information to support risk-informed and strategic decision-making for enhanced preparedness and in-season policy interventions. Recognizing its value for risk reduction, resilience building and prevention, the member States requested ESCAP to strengthen impact-based forecasting capacities in the region.

The presentation will introduce a methodological concept that translates the pre-monsoon seasonal outlook to multi-sector impact-based forecasting. Building on the seasonal forecasts for precipitation available from South Asia Climate Outlook Forums (SASCOFs) and risk profiles of the region from the Asia-Pacific Disaster Report 2019/2021, it provides customized risk scenarios and impact-based forecasting for disaster risk management and for addressing climate risks in key development sectors such as agriculture, energy, health and water management. It sets an example of operationalizing the WMO global framework of climate services; identifies and narrows down the areas of potential impacts that may emanate from the climate events on the people, economy, and their livelihood for strategic policy interventions and enhanced preparedness. It also highlights the scope for improvement in impact-based forecasting with additional and more precise information on hazards, risk profiles and socio-economic exposure and vulnerability.

Extended Range Monsoon Prediction

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Abstract : Extended range forecast (ERF) implies an outlook with a lead-time of 2-3weeks and is in between the short-medium and seasonal scale of weather prediction. Thus, the ERF of monsoon in sub seasonal time scale is a challenging gap area in research and operational forecast domain. Several efforts have been undertaken to improve the ERF in the past decade or so at IITM for operational implementation at IMD. The research and development that lead to the development of ERF are summarized at first. It describes the efforts that were undertaken to establish the statistical properties of monsoon intra-seasonal oscillations, establish the predictability horizon, represent the oscillations in state-of-art climate models and finally develop the latest state-of-art forecast technique. This technique is now operationally implemented at IMD.

The study then summarizes potential applications of ERF in meteorological perspective. The primaryuse of this forecast system is the development of an operational country-wide forecast product in the extended range time scale. The application of this forecast can be made in several allied fields like agro-meteorology, hydrometeorology, health sector etc. A brief discussion is made relating the potential use of this forecast to these fields. The performance of ERF for southwest monsoon and northeast monsoon during the recent years have been discussed along with its prospects of its application in different sectors like, agriculture and hydrology. The performance of ERFs for the southwest monsoon seasons clearly captured the intra-seasonal variability of monsoon including delay/early onset of monsoon, active/break spells of monsoon and also withdrawal of monsoon in the real time in providing guidance for various applications. For applications in agriculture sector meteorological subdivision level forecasts are prepared for two weeks for the purpose of issuing agro advisory.

In addition to the regular ERF products for application in agriculture and hydrology, additional products are being prepared like, Standarised Precipitation Index (SPI), land-surface hydrology products like soil moisture and runoff change, transmission windows products for vector borne diseases, heatwave/coldwave, cyclogenesis probability etc for applications in agriculture, hydrology, health sector, power and disaster management.

Impact Based Forecasting of Urban Flooding

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Abstract : Pluvial floods in urban areas are caused by local, fast storm events with very high rainfall rates, which lead to inundation of streets and buildings before the storm water reaches a watercourse. An increase in frequency and intensity of heavy rainfall events due to climate change and an ongoing urbanization may further increase the risk of pluvial flooding in many urban areas. Currently, warnings of pluvial flooding are mostly limited to information on the intensity and duration of rainfall in large areas, which is often not detailed enough for authorities or affected people to take effective emergency measures, like preventing water from entering buildings or moving belongings to higher stories. To demonstrate the feasibility and advantages of impact-based forecasting of urban flooding, we present a proof-of-concept for an impact-based forecasting system for pluvial floods in an urban area in Germany (Rözer et al. 2021). Using a model chain consisting of a rainfall forecast, an inundation, a contaminant transport and a damage model, we are able to provide predictions for the expected rainfall, the inundated areas, spreading of potential contamination and the expected damage to residential buildings. A neural network-based inundation model is used, which significantly reduces the computation time of the model chain (Berkhahn et al. 2019). The output of the damage model is a map showing the spatial distribution of the estimated damage to residential buildings and the certainty of the estimate in shape of a probabilistic damage distribution (Rözer et al. 2019). To demonstrate the feasibility, a hindcast of a recent pluvial flood event is performed in an urban area in Germany. The required spatio-temporal accuracy of rainfall forecasts is still a major challenge, but the results show that reliable impact-based warnings can be available up to 5 min before the peak of an extreme rainfall event. It will be discussed how the outputs of an impact-based forecasting can be used to disseminate impact-based early warnings and the benefits this could have.

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THEME : CLIMATE CHANGE AND MONSOONS

Indian summer monsoon onset - Role of upper air circulations

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Abstract : Indian summer monsoon onset over Kerala is one of the prominent features in the regional monsoon circulation and its early/late onset leads to vigor/fatigue in the Kharif crop yield. The present study investigated the physical mechanisms of early and late-onset composites with special emphasis on mid-latitude wave interaction. The dates of the monsoon onset were considered based on the IMD criteria and categorized into nineteen early, twenty one late onset and thirty three normal onset years during the study period (1948-2020) based on meteorological and oceanographic parameter changes. Anomalous OLR in early-onset composites indicates enhanced cloudiness over the Bay of Bengal and Western Pacific Ocean, while in the late-onset, an enhanced convection was observed off the coast of Somali and Central Pacific Ocean. Significant changes like Eurasia warming and cooling over north India, upper level strong westerlies from the East Caspian Sea and cyclonic circulation over northwest region to north India inhibit the convection in early onset years. Vertically Integrated moisture transport also shows high (weak) moisture transport from central Indian Ocean (Arabian Sea) to north of 15°N in early (late) onset years. Wave activity flux showed stationary Rossby wave shove upper level circulations and tropospheric temperatures to east in early onset, whereas these features were decreased in late onset years. Strong coupling of SST and convection were observed in early May/mid June for early/late onset years. Finally this study portrayed significant changes in the early and late onset years, which will be helpful for prediction of monsoon onset in advance.

Relationship between Azores High and Indian summer monsoon

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Abstract : The interannual variation of Indian summer monsoon (ISM) not only affects millions of people in India, but also the global weather and climate. The teleconnections of this variation are not stable. A dominant mode of the recent four decades ISM rainfall shows west-east dipole pattern with above normal rainfall towards west and central India and subdued rainfall towards the east and northeast India, and is related to the vigorous Azores High. The vigorous Azores High is accompanied by enhanced subsidence resulting in well-built widespread upper-troposphere convergence. This forms the meridionalvorticity dipole consisting of anomalous cyclonic and anti-cyclonic circulation at 30ºN and 50ºN, respectively. The meridionalvorticity dipole increases the Asian jet at its entrance. In addition, the widespread North Atlantic convergence boosts the Rossby wave source. The cascading down Rossby wave train imposes successive negative, positive and negative Geopotential height (GPH) anomalies over north Mediterranean, northwest of India and northeast of India, respectively. The negative GPH anomaly at the north Mediterranean further increases the Asian jet towards the Caspian Sea. The increased Asian jet strengthens the monsoon circulation through the 'silk-road' pattern. While, the dipole GPH anomalies north of India shift the core of the Tibetan High westward triggering monsoon activity towards the west and central India and subdued monsoon over east and northeast India, forming an anomalous west-east dipole rainfall pattern and vice-versa. Future work should examine the extent to which these teleconnections are represented in the climate forecast models to aid the seasonal prediction of ISM rainfall.

Key words : Indian summer monsoon, India Landmass, Asian jet-stream, vorticity, Rossby wave activity flux, Empirical Orthogonal Function, Principal Component.

Decline in Indian summer monsoon synoptic activity in response to the Arctic and Antarctic sea ice melt

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Abstract : The Arctic sea ice is melting rapidly in response to global warming. The future projections based on high emission scenarios by climate models suggest that we will have ice free summers in the poles by the middle of 21stcentury. The effect of polar sea ice melt on low latitudes is poorly understood. Recent research suggests that the melting of Arctic and Antarctic sea ice can affect deep tropics through ocean dynamics. The shut down of oceanic meridional overturning circulation would result in excessive heat accumulation in the tropical oceans. Such a response to the polar sea ice melt can affect tropical weather systems, including the Indian summer monsoon (ISM). Here, we investigate the effect of polar sea ice melt on mean and synoptic scale features of ISM using a suite of experiments using coupled and uncoupled climate models. A control (CTRL) run using coarse resolution (20x20) coupled Community Earth System Model (CESM1.2.2) has been performed for 350 years. Another experiment in which the albedo of the sea ice is lowered is performed for 50 years by branching off the CTRL simulation at 300thyear. The increased absorption of solar radiation in this experiment would lead to a melting of sea ice. This experiment is designated as sea ice melt experiment (SIME). As the coarse resolution simulations are unable to resolve the synoptic scale weather systems, we have run an ensemble of high-resolution Community Atmospheric Model (CAM5) by using the sea surface temperature and sea ice concentration annual cycles from the coupled model simulations. Our results show that in SIME simulations, the LPS genesis frequency declines by 40%. The weakening of the LPS genesis in the SIME runs is linked to a weakening and equatorward shift of the inter-tropical convergence zone.

How extreme could trends in Indian Summer Monsoon Rainfall be over the next decades?

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Abstract : We estimate possible extreme changes in the Indian summer monsoon rainfall for the coming decades using a large ensemble of summer monsoon realizations from multiple seasonal predictions systems. Our estimates show that for the next decade there is a ~60% chance of wetting trends, whereas the chance of drying is ~40%. We find that wetting trends are systematically more favoured than drying with the increasing length of the period. We also quantify the likelihood of extreme trends and show that there is at least a 1% chance that monsoon rainfall could increase or decrease by one fifth over the next decade. Monsoon rainfall trends are found to be influenced by trends in sea-surface temperatures over the Nino3.4 region and tropical Indian Ocean, hence rainfall change over the next decades is conditional on the timing of future El Niño Southern Oscillation phases and Indian Ocean warming under climate change. We demonstrate how internal variability can exacerbate or alleviate the influence of forced climate change on Indian summer monsoon rainfall and find that it is unlikely that the climate change signal for increased rainfall will emerge from the underlying internal variability in monsoon rainfall by the year 2050. The estimates of extreme rainfall change provided here could be useful for disaster preparedness and aid the development of successful adaption policies on decadal to multidecadal time-scale.

Different future changes between early and late summer monsoon precipitation in East Asia

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Abstract : This study investigates future changes in East Asian summer monsoon (EASM) precipitation and the associated atmospheric circulation changes based on ensemble projections with a 60-km mesh atmospheric general circulation model developed at the Meteorological Research Institute (MRI-AGCM60). The projections at the end of the twenty-first century under the Representative Concentration Pathway 8.5 (RCP8.5) scenario indicate an overall increase in EASM precipitation but with large sub-seasonal and regional variations. In June, the Meiyu-Baiurainband is projected to strengthen, with its eastern part (i.e., the Baiurainband) shifted southward relative to its present-day position. This result is robust within the ensemble simulations. In July and August, the simulations consistently project a significant increase in precipitation over the northern East Asian continent and neighboring seas; however, there is a lack of consensus on the projection of the Meiyu–Baiurainband in July. A small change in precipitation over the Pacific is another feature in August.

Results of sensitivity experiments with the MRI-AGCM60 reveal that the precipitation changes in early summer are dominated by the effects of sea surface temperature (SST) warming (i.e., uniform warming and the tropical pattern change), inducing an increase in atmospheric moisture and a strengthening and southward shift of the upper-level East Asian westerly jet (EAJ), especially over the Pacific. On the other hand, the influence of land warming and successive large SST warming in the extratropics is apparent in the precipitation changes in late summer. These late summer effects oppose and exceed the early summer effects through changes in the EAJ and low-level monsoon winds. These results suggest that the competition between the opposing factors makes the signal of the Meiyu-Baiurainband response smaller in July than in June. Therefore, there tends to be a larger spread among simulations regarding the future tendency of the rainband in July.

Changing characteristics of Monsoon Intraseasonal Oscillations in a Warming Climate

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Abstract : In the backdrop of increasing temperatures related to global warming, the Monsoon Intraseasonal Oscillations (MISOs), which define a significant proportion of intraseasonal variability of the Indian summer monsoon, are expected to exhibit more spatio-temporal variability, prompting an increased frequency of extreme events. An investigation of the observed changes in the characteristics of long (>=7 days) and short (<7 days) active and break spells in the early twenty-first century (2001-2019) in comparison with the late twentieth century (1982-2000) has been carried out. It is found that in the recent period, a decreased (increased) frequency of the short (long) active/break spells along with a strengthening of short spells have been noticed. An east-west asymmetry in the spatial distribution of rainfall is further noted with western India experiencing intensified (weakened) active (break) spells. Contrariwise, the central and eastern parts of the country witness weakening (intensification) of active (break) spell in the early twenty-first century. A comprehensive composite investigation of various dynamical and thermodynamical parameters reveals an increase in the strength of low-level winds in the Arabian Sea, thereby increasing the moisture convergence and instability over the western Indian region and the nearby oceanic regions, resulting in the observed east-west asymmetry in the rainfall spatial distribution. Increased intensity of the equatorial Madden Julian Oscillation and its coupling with the northward propagating MISO spells seems to play a pivotal role in lengthening the active/break spells. It is speculated that such changes are triggered by the amplified temperatures over the global oceans in the recent period.

Evaluation of Indian Summer Monsoon in Simulation of CMIPs Experiment

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Abstract : The Indian Summer Monsoon Season (ISMS) during June-July-August-September (JJAS) prevails mainly due to land–sea heating contrast between Indian Ocean and India land mass as well as controlled by semi permanent features such as the low level westerly jet over the Arabian Sea at 850 hPa, and the tropical easterly jet at 200 hPa over the Indian Ocean. The variability of Indian Summer Monsoon Rainfall (ISMR) during ISMS on intra seasonal to inter annual scale is manifestation of changes in wind circulation (at 850 and 200hPa) and Relative Humidity (RH). Therefore, for the reliable future projection of ISMR in Climate Models simulation, the correct representation of monsoon circulation and rainfall in simulation is very important. For this purpose, the wind, RH and rainfall simulated in the historical experiment of climate models Climate Model Intercomparision Project (CMIP) phase 3, 5 and 6 are considered. Over the homogeneous monsoon regions of the North West, India (NWI), Central Northeast India (CNI), North East India (NEI), West Central India (WCI), Peninsular India (PI) and Hilly Regions (HR), a number of climate models in CMIP3, CMIP5 and CMIP6 are evaluated on wind, rainfall and RH against the reanalyzed data of ECMWF reanalysis (2.5°×25°), NCEP/NCAR grided data set (2.5× 2.5), ERA5 of ECMWF, observed rainfall (2.5 × 2.5) of GPCP and IMD (1°×1° and 0.25° × 0.25°) observed data are taken. A very few models could represent wind, rainfall and RH on inraseasonal and intrannual time scales.

Key words : Indian Summer Monsoon Season (ISMS), Wind circulation, Rainfall, Relative Humidity, CMIPs.

Indian Summer Monsoon Variability: El Niño-Teleconnections and Beyond

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Abstract : Understanding the Spatio-temporal variations of the Indian Summer monsoon (ISM) is an important, and challenging problem. Low-frequency variations (on interannual or longer scales) of ISM are highly influenced by various drivers such as El Niño-Southern Oscillation (ENSO), Indian Ocean climate variability, Eurasian snow cover changes, the Pacific Decadal Oscillation, the Atlantic Multidecadal Oscillation. On the other hand, the long-term variations are dominated by anthropogenic climate change influence. It is known that the variability of ISM is strongly tied to forcing from ENSO, and such external forcing in the form of teleconnections is key for seasonal monsoon prediction. Improving seasonal prediction of ISM requires fundamental knowledge built on vigorous research focused on remote and internal forcing's. Not just ENSO from Pacific, other modes of variability from tropical to subtropical Indian Ocean, Atlantic Ocean and mid-latitudes to extra-tropical region could potentially alters the strength of ISM at various time scales. Thus, an improved understanding of these drivers and their teleconnective effects on ISM variability is the way forward for further improvements in monsoon prediction. This book/work highlights the recent advances in understanding various teleconnections that influence and drive ISM variability and change. In particular, physical mechanisms that link various global drivers to ISM variability are emphasized using a wide range of datasets, modern techniques and models.

A Climate Change Perspective of evolution of Northeast Monsoon and Its Global Teleconnections over the South Peninsular India Region

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Abstract : With the livelihood of about 250 million people dependent on the seasonal rains over South Peninsular India (SPI), which occur during the October to December period, the termed Northeast monsoon (NEM) is of a huge economic and societal importance as the region does not receive significant rainfall during the Southwest monsoon. The present study focuses on performing a detailed study on the effects of global warming on the behavior and patterns of NEM rainfall events and its associated rainfall over the SPI region. This study involves the investigation of long-term climatology, variability, trends, and global teleconnections of various categorical rainfall events as defined by the India Meteorological Department (IMD) and its associated rainfall over SPI using a high-resolution (0.25° × 0.25°) data from IMD for the period from 1901 to 2016. Based on the aAnalysis, it was found that the overall variability in the rainfall has significantly increased in the second half of the 20th century. The rainfall over Tamil Nadu, Rayalaseema, and SPI as well has increased in the recent period due to the increase in of high- intensity rainfall events, the rainfall in other districts had however decreased. The percentage contribution of moderate- intensity rainfall events to the seasonal rainfall is more compared to the others. A few districts that have never seen an extremely heavy rainfall event have experienced a few in the recent period, posing a higher risks to floods. The existing relationships of NEM rainfall over SPI with the global/local teleconnections such as with ENSO, IOD, and ISMR have weakened in the recent decades after 1988. This study is very useful in determining the effects on various sectors due to the variability of heavy rainfall events over SPI during this season and assists the risk management sectors in adapting advanced technologies for a sustainable future in the present global warming era.

Key words : Global warming, Northeast monsoon, Teleconnections, South Peninsular India.

South Asian Monsoon Response to Weakening of Atlantic Meridional Overturning Circulation in a Warming Climate

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Abstract : Observational records and climate model projections reveal a considerable decline in the Atlantic Meridional Overturning Circulation (AMOC). Changes in the AMOC can have a significant impact on the global climate. Sustained warming due to increased greenhouse gas emissions is projected to weaken the AMOC, which in turn can lead to changes in the location of Inter-tropical convergence zone (ITCZ), oceanic and atmospheric large-scale circulation, tropical precipitation and regional monsoons. Using proxy records, observations and CMIP6 simulations of IITM Earth System Model (IITM-ESM), we investigate the changes in the AMOC and associated changes in the large-scale circulation and precipitation patterns over the South Asian monsoon region. Transient CO2 simulation and additional model sensitivity experiments with realistic surface heat and freshwater perturbation anomalies under the experimental protocol of Flux Anomaly Forcing Model Intercomparison Project (FAFMIP) performed with IITM-ESM reveal a decline in the strength of AMOC. The weakening of AMOC is associated with enhanced heat and freshwater forcing in the North Atlantic resulting in the reduction of northward oceanic heat transport and an enhanced northward atmospheric heat transport. Changes in AMOC lead to weakening of large-scale north-south temperature gradient and regional land-sea thermal gradient, which in turn weaken the regional Hadley circulation and, monsoon circulation over the South Asian region. Both the FAFMIP and transient CO2 experiments reveal consistent results of weakening South Asian Monsoon circulation with a decline of AMOC, while precipitation exhibits contrasting responses as precipitation changes are dominated by the thermodynamic response. The suite of observational and numerical analysis provides a mechanistic hypothesis for the weakening of South Asian monsoon circulation concomitant with a weakening of AMOC in a warming climate.

Climate Extremes in the Hydroclimate Change

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Abstract : We live in a monsoon country. Approximately 62% of the world's population living in global land monsoon rely on freshwater resources from monsoon rainfall, controlled by the global hydrological cycle. During the last several years, we realized increasing trends in the frequency and intensity of extreme rainfall in different monsoon regions. Also, we found there are clear distinctions in the context of extreme rainfall intensity and size. This point is an important motivational factor.

Moreover, CESM2-Large ensemble 50 MME shows substantial changes in the monsoon rainfall variability, not only its amplitude but also its duration. Both changes can affect various social-ecological fields.

So the outline of my talk will be about recent advances and findings on hydroclimate, including monsoon duration, intensity, rainfall extremes changes, its mechanism, and evaporative demand from the warming climate. We tried to provide how dynamic and thermodynamic factors control rainfall extremes over East Asia in late summer, heatwaves based on dry conditions, and stationary waves, wildfire, and ENSO rainfall variability. Lastly, I want to introduce new projects plans.

THEME : FIELD EXPERIMENTS AND OBSERVATIONAL CAMPAIGNS

The Interplay between Monsoons and Greenhouse Gases Variability in India

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Abstract : Indian monsoons play an important role in and influence the transport and variability of greenhouse gases over India and adjacent regions. Various studies demonstrated this fact and showed that monsoon signatures are observed in the observations. Also, it showed strong spatial variations across the plume. All these studies are either based on model simulations or mid-tropospheric satellite observations over India. There was no study available based on in-situ observations over this region. Therefore, using surface-based, and aircraft-based greenhouse gases observations we report the influence of monsoons on greenhouse variability over the Indian region.

Identify Cloud Cover Zones in Indonesia

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Abstract : Climate zoning information will be used for planning in various sectors in Indonesia. Normalization was carried out for cloud cover hourly elements for 7 years starting 2014 to 2020 from 106 meteorological stations of the BMKG in Indonesia. Hierarchical cluster analysis using the ward method was carried out to determine 4 areas of cloud cover zoning in Indonesia. Spatial zoning mapping with a contour map is carried out using the IDW method which is modified based on the cluster output of the point analysis. The diurnal and the annual pattern are interpreted by heatmap analysis in each zoning. The results of the analysis show that areas with little cloud cover areas can be clearly distinguished in the islands of Nusa Tenggara, Southeast Sulawesi, and Madura Island which are included in the cloud cover zone 4. Cloud cover zone 2 is located in Bogor, Jambi, South Sumatra, Sumatra. West Kalimantan, West Sulawesi, and Papua are the areas with the most cloud cover, this is because most of these areas are highland areas and are areas with a moderately humid atmosphere and areas with lots of convective clouds that affect cloud cover variability. on the diurnal cycle. The dominant cloud cover zone area including monsoon areas with seasonal variability of cloud cover in Indonesia is generally caused by ITCZ movements and monsoon variability involving annual variations. However, there are slight differences in cloud cover zone 3, such as in northern Sumatra, which is located near the ocean area, so that local factors such as land and ocean wind circulations also affect cloud cover variability in this region.

Interaction of Convective Organisation with Monsoon Precipitation, Atmosphere, Surface and Sea: The 2016 INCOMPASS Field Campaign in India

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Abstract : The INCOMPASS field campaign combined airborne and ground measurements of the 2016 Indian monsoon. The monsoon supplies the majority of water in South Asia but forecasting from days to the season ahead is limited by large, rapidly developing errors in model parametrizations. The lack of detailed observations prevents thorough understanding of the interaction between monsoon circulation and the land surface: a process governed by boundary-layer and convective-cloud dynamics.

INCOMPASS used the UK Facility for Airborne Atmospheric Measurements (FAAM) BAe-146 aircraft for the first project of this scale in India, to accrue almost 100 hours of observations in June and July 2016. Flights from Lucknow in the northern plains sampled the contrast in surface and boundary layer structures between dry desert air in the west and the humid environment over the northern Bay of Bengal, during pre-monsoon and monsoon conditions. Flights from Bengaluru in southern India measured contrasts from the Arabian Sea, over the Western Ghats mountains, the rain shadow of southeast India and the southern Bay of Bengal. Flight planning was aided by forecasts from bespoke convection-permitting models at the Met Office and India's NCMRWF. On the ground, INCOMPASS installed eddy-covariance flux towers to provide detailed measurements of surface fluxes and their modulation by diurnal and seasonal cycles. These data will be used to better quantify the coupling between the atmosphere and land surface.

Here we describe emerging results from INCOMPASS and implications for monsoon prediction. This includes the emergence of regimes of onshore and offshore convection over the Western Ghats, themselves controlled by the boreal summer intraseasonal oscillation. In northern India, we reveal the importance of mesoscale gradients in soil moisture in causing the initiation of deep convection later in the day. We conclude with an outlook to future efforts needed to improve model biases and monsoon prediction.

Analysis of Convective Organization over the Monsoon Zone using Radar Observations

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Abstract : The monsoon trough over Central India, which mostly comprises the monsoon zone, is an important component of the regional climate system. The rainfall over the monsoon zone during the summer monsoon is associated with intense convergence in the boundary layer, cyclonic vorticity above the boundary layer, and organized deep moist convection. Deep convection can be scattered across an area at times, but it can also be spatially clustered in one place. This varying spatial distribution of convection can be referred to as the organization and it correlates well with severe weather. Hence, the quantification of convective organization becomes important.

With their high spatio-temporal resolution (1-2 km, 5-10 minutes), ground-based radars are the best observational tool for studying convective organization/clustring and its evolution. In this context, we examined 3D volumetric data collected by the IMD S-band radar at Bhopal and the IITM C-Pol radar at Silkheda in the monsoon core zone during the monsoon 2021. We first identify areas of convective and other types of echoes from radar reflectivity maps using the rain-type classification technique to characterize the nature of precipitating clouds. Following that, scalar clustering metrics are applied to the radar-identified convective echoes/objects in order to objectively quantify the degree of convective organization during the observed rain episodes. These metrics are based on the specific parameters of the clouds present within the radar domain viz. number, size and propinquity of different convective objects and describe the strength of organization with a numerical quantity. The temporal changes in the morphological characteristics of observed convective elements (number, size, and proximity) during the rain episodes are examined from the perspective of convective clustering. This type of radar-based convective clustering (at the scale of a GCM grid box) can serve as an observational basis for quantitative comparison to the convective organization in convection schemes.

Role of orography on the cloud and precipitation properties over the Western Ghats

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Abstract : The spatial and temporal variations of cloud and precipitation properties over the Western Ghats (WG) are investigated using high-resolution observations of ground-based X-band and Ka-band weather radars. The X-band and Ka-band radars are installed at Mandhardev, a remote hilly location in the WG and are also known as precipitation radar and cloud radar, respectively by virtue of their capability. The spatial structure of rainfall intensity (RI), rainfall amount (RA) and rainfall frequency (RF) are obtained to understand the gradients in precipitation properties over the complex terrain of the WG. The maxima of RA and RF are seen on the slopes away from summit whereas the maximum of RI is observed in offshore and lee side region. The 18-dBZ echo top heights show shallow clouds in upslope areas and deep clouds in offshore/coastal and lee side of the Ghats. The tropical rainfall measuring mission (TRMM) data (2A25 product) is also used to complement the radar observations with the large-scale features of summer monsoon precipitating clouds. Further, the effects of orographic features (slope, elevation, terrain, etc.) on the precipitation features are investigated. The zone of maxima of RF and RI are observed to be correlated with the elevation of mountains. For a closer examination, the precipitation features across the WG are investigated along the line of Range Height Indicator (RHI) scan which is able to provide the gradients in cloud and precipitation properties at the scale of the complex terrain of the Ghats. The RHI data analysis shows frequent occurrence of shallow clouds on the low-lying slopes and the peak of mountains. A trimodal distribution of cloud systems is seen from 18-dBZ echo tops heights, around 2 km, 5 km and 7 km. Besides orographic factors, the associated dynamics and microphysics are also examined in order to understand the causative factors.

Cloud Radar Monitored Cloud Vertical Structure Measurements for Better Predictability of ISM Vigor

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Abstract : The vertical structure of cloud (VSC) and associated dynamical information are mainly utilized to decipherer the wet and dry Indian Summer Monsoon (ISM) spells. The first Indian ground-based 35-GHz cloud radar measurements of equivalent radar reflectivity (dBZe) and spectral width profiles over a Western Ghats region during the two ISM spells clearly show contrasting cloud vertical structure differences. These observed VSC changes are closely associated with the large-scale circulation associated with the monsoon intra-seasonal oscillation signature over the observational site. Moreover, a conspicuous characteristic role associated with the low-level warm cloud and the pertinent rain processes is well brought with the three lower-order moments of cloud radar spectra. Further, the role of convection and the dynamical process can be explained with the VSC that inherently connects both the macro-and micro-physical aspects of cloud and large-scale dynamics from the reanalysis data. The secondary ice production process associated with mid-level mixed-phase clouds plays a vital role in understanding the change of ISM vigour. The high-level ice-phase cloud's principal function during ISM wet spell becomes one-third or less during ISM dry spell, which is the main reason for surface rainfall yield differences during the wet and dry spell. Our aim is also to cross-check this observed VSC with the currently using cloud parameterization schemes used in the models, for mainly unravelling the macrophysical compose and dynamically controlled microphysical process. This study can be a scientific observational basis for testing the ISM cloud parameterization schemes for a better atmospheric circulation model.

Study of atmospheric electrical conductivity during monsoon season at a tropical station of Northern India

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Abstract : This paper presents analysis of atmospheric electrical conductivity during monsoon season at a highly polluted site of Northern India. Continuous measurements of unipolar atmospheric electrical conductivity along with some meteorological parameters were made from June to August' 2020 at Noida adjoining Yamuna Express highway of India. It was investigated that the atmospheric electrical conductivity was positively correlated with wind speed, relative humidity, and rain fall while negatively correlated with average temperature in the monsoon season of the study period. Different possible causes for the variation of atmospheric electrical conductivity in the light of meteorological parameters were discussed in the present study. In the short term range of monsoon season, wind was found to be an important factor that modifies the behaviour of electrical conductivity. Further, the findings were expected to be valid for all the sub-tropical regions also. Therefore, the results of present study demonstrate the short range variations in surface atmospheric electrical parameters with due consideration of the meteorological parameters.

Key words : Monsoon, Conductivity, Climate, Meteorological parameters.

Variability of Convective Activity Over North Indian Ocean and Neighbourhood in Modulating Onset, Withdrawal and Break Features of Monsoon

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Abstract : The variability of convective activity over the north Indian Ocean (Bay of Bengal and Arabian Sea) during the monsoon season from June to September (JJAS) has been investigated on inter-annual and longer time scales by using 40-year (1980–2019) monthly mean outgoing long-wave radiation (OLR) data. The association of variability of convective activity with the onset, withdrawal, break and seasonal rainfall over India during the monsoon season has also been discussed. The 40-year period has been divided into two groups of 20 years with the first 20 years from 1980 to 1999 (hereafter called F8099) and second 20 years from 2000 to 2019 (hereafter called L2019).

It is seen that the mean sea surface temperature (SST) over the north Indian Ocean shows higher values during period L2019 compared to that in period F8099. The inter-annual variability of SST shows a significant increasing trend both over the Arabian Sea and the Bay of Bengal with a comparatively higher rate of increase of SST over the Arabian Sea. There is also increasing tendency of degree of moist convective instability and associated convective rainfall during the period L2019 compared to the period F8099 with a magnitude of difference is higher over the Arabian Sea compared to the Bay of Bengal. On inter-annual time scale, a significant decreasing trend of OLR anomaly is also noticed mainly over the Arabian Sea indicating an increasing trend of convective activity. The analysis also indicated that there is a rapid progress of monsoon to the north after its onset over the southern tip of India leading to early onset over northern India. Similarly there is a delayed withdrawal phase of monsoon from northwest India in period L2019 compared to period F8099 is basically due to the increasing convective activity over the north Arabian Sea and neighbourhood during the onset and withdrawal phase of monsoon, respectively. During the peak monsoon phase of July-August, convective activity over the North Bay of Bengal (NBAY) is correlated positively with the break frequency, whereas the convective activity over the North Arabian Sea (NARA), South Arabian Sea (SARA) and South Bay of Bengal (SBAY) regions are related inversely with the frequency of monsoon break.

Key words : Outgoing long wave radiation, North Indian ocean, Indian monsoon, Break monsoon, onset & withdrawal

Investigating the Atmosphere-Biosphere Carbon Exchange Processes in Northeast India Using the Eddy-Covariance Technique

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Abstract : Tropical forest ecosystems play a significant role in controlling the global carbon cycle. Several bio-meteorological parameters control the carbon dynamics of a forest ecosystem. We have studied the bio-meteorological processes of a tropical semi-deciduous forest in northeast India to understand the dynamics of the net ecosystem exchange (NEE). It is observed that on a monthly scale, mostly the leaf area index, incoming radiation, vapor pressure deficit, and air temperature control the carbon transfer processes. Furthermore, the diurnal patterns of rainfall and associated cloudiness during the monsoon season indirectly control the carbon uptake by modulating the incoming radiation. The pre-monsoon season is the most preferred, while the winter season is the least favourite time for carbon uptake by this forest. The respiration component of the studied forest ecosystem is found to be higher compared to the other similar ecosystems in India. The estimated annual NEE of the forest was +177 and -31 gC m-2 yr-1 for 2016 and 2018, respectively. The annual gross primary productivity (GPP) of the forest for 2016 and 2018 was estimated as 2693 and 2564 gC m-2 yr-1, respectively.

THEME : HIGH IMPACT MONSOON WEATHER

Hydraulic Jump : The Cause of Heavy Rainfall on the Immediate Lee Side of the Western Ghats in the Maharashtra State of India

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Abstract : North-South mountains (known as "The Western Ghats or WG") running parallel to the west coast of peninsular India, separate the Maharashtra state (lying on the northwest of peninsular India), into two meteorological subdivisions, 1) Konkan lying on the windward side of WG receiving high monsoon rainfall (2390 mm) and 2) Madhya Maharashtra (MM) lying on the leeward side receiving low monsoon rainfall (600 mm). The state of Maharashtra has two more subdivisions on the leeward side of WG viz. Marathwada and Vidarbha, however, do not lie on the immediate leeward side of WG. In this study, a subdivision of MM is further subdivided into 1) north-south strip of 80 km width on the immediate lee side (ILS) from the crest of WG and 2) Area extending eastwards from ILS to 280 km, referred to as "distant lee side (DLS)". DLS contains some parts of the Marathwada subdivision also. The study indicates that the ILS region receives higher mean monsoon rainfalls than monsoon rainfalls over DLS region. Higher rainfalls over ILS region have been shown due to the occurrence of the "Hydraulic Jump (HJ)". The dynamics of HJ are explained using Froude number and vertical velocities. The climatological high rainfall over ILS remained an unnoticed feature in the spatial monsoon variability over peninsular India. The study claims, "Phenomenological Discovery" of a new feature of spatial monsoon variability and attributes it to HJ. The incorporation of HJ has the potential to impact on forecasting of monsoon rainfall over the region by numerical models.

How Interactions between Tropical Depressions and Western Disturbances Cause Heavy Precipitation

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Abstract : It is now well understood that the devastating 2013 floods of north India were caused by the interaction of an extra tropical western disturbance and a tropical depression. Previous authors have debated how common such interactions are, whether they often have significant impacts, and if they manifest in different ways. In this study, we use existing databases of western disturbances and tropical depressions and parse them to identify potential interactions between 1979 and 2015. These are filtered according to proximity and mean system intensity, leaving 60 cases which are studied in detail using synoptic charts, vorticity and moisture budgets, and moisture tracking.

It is found that two broad families of interaction exist: dynamical coupling of the WD and TD, and moisture exchange between the TD and WD. These are subdivided into five distinct interaction types: (i) vortex merging; (ii) excitation of the TD through interaction with a WD-triggered jet streak entrance region; (iii) TD pushing moisture towards a WD; (iv) WD pulling moisture from a TD; and (v) WD contributing moisture to the TD. Of these, it is found that the jet streak excitation type is associated with the heaviest precipitation and greatest fatalities. Interactions are most common in the pre- (May and June) and post- (September and October) monsoon seasons, with vortex mergers, the most common interaction type, being particularly prevalent in October.

SEEPS and SEDI Metrics for Verification of Model Predicted Extreme Rain over India during Recent Monsoons

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Abstract : Stable Equitable Error in Probability Space (SEEPS) and the Symmetric Extremal Dependence Index (SEDI) are two advanced verification metrics which are complementary scores of forecast performance. While SEEPS quantifies general performance in the prediction of dry/wet spells, the SEDI focuses on higher threshold events. Both scores assess the locally important aspects of the forecast. They make use of the climatological distribution of precipitation at each location to define thresholds. Thus it is possible to aggregate the scores over climatologically diverse regions and an index can be computed.

High resolution rainfall forecasts over India based on NCUM-G, UKMO and GFS models is assessed during four recent monsoons (2018-2021) using SEEPS and SEDI metrics. The verification is carried out against (i) 0.25 × 0.25 grid IMD-NCMRWF merged rainfall analysis and (ii) 0.1 ×0.1 deg grid IMERG rainfall data to assess the sensitivity of verification to grid resolution. The results indicate (i) the high grid resolution of the models is effective in producing the improved skill in prediction of rainfall exceeding 90^{th}percentile rainfall threshold as indicated by SEDI.(ii) models predict excessive number of light and moderate rain and underestimate the heavy rains over India.

The Interaction of Tropical and Extra Tropical Air Masses Controlling East Asian Summer Monsoon Progression

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Abstract : The East Asian summer monsoon (EASM) is a complex phenomenon, influenced by both tropical and mid-latitude dynamics and by the presence of the Tibetan Plateau. The EASM front (EASMF) separates tropical and extratropical air masses as the monsoon marches northwards. In this study, we apply Eulerian and Lagrangian methods to reanalysis data, focusing on the seasonal evolution and variability of the EASM and highlighting the dynamics of the air masses converging at its front.

A frontal detection algorithm is used to perform a front-centred analysis of EASM evolution. This highlights the primary control role of the sub-tropical westerly jet (STWJ) on strength and poleward progression of the EASMF, in particular during the Mei Yu stage. The upper-level mid-latitude forcing acts in conjunction with the southerly advection of low-level tropical air, modulated by the seasonal cycle of the South Asian monsoon and the location of the Western North Pacific subtropical high. Mei Yu is distinguished by an especially clear tropical-mid-latitude interaction, with air masses converging at the EASMF. Composite analysis based on EASMF latitude during Mei Yu reveals the influence of the STWJ on the strength of mid-latitude flow impacting on the northern side of the EASMF. In turn, this affects the extent of the warm moist advection on its southern side and the distribution and intensity of resultant rainfall over China.

This study shows the validity of an analysis of EASM evolution focused on its front and on the related low-level airstreams, at least in the Mei Yu stage. The framework highlighted shows how the upper-level flow drives the low-level airstreams converging at the EASMF, thus controlling the shape of EASM progression. This framework provides a basis for studies of model evaluation, climate variability and for analysis of extreme events, such as the 2020 floods in the Yangtze River Basin.

Indian Summer Monsoon and Tropical Cyclones

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Abstract : Formation of tropical cyclones (TCs) during Indian summer monsoon (June-September) is considered to be rare. Recent years experienced many intense tropical cyclones (TCs) during the arrival (15 May- 15 June) and withdrawal (15 September - 15 October) phase of the monsoon. In year 2021, TC Tauktae over the Arabian Sea during 14-19 May reached the stage of extremely severe cyclonic storm followed by a very severe cyclonic storm Yaas over the Bay of Bengal during 23-27 May. In the same year cyclonic storm Gulab occurred over the Bay of Bengal during 24-28 September followed by severe cyclonic storm Shaheen over the Arabian Sea during 30 September - 4 October. In 2020 also super cyclonic storm Amphan existed over the Bay of Bengal during 16-21 May and Severe Cyclonic Storm Nisarga occurred during 1-4 June over the Arabian Sea. All these systems occurred during the monsoon transition (arrival and withdrawal) period and appeared to be rare. So, in the recent years does the tropical cyclone activity changed during the monsoon transition phase? Is there any change in the monsoon circulation? These are the questions we are addressing in this paper.

The initial analysis based on 38 years (1982-2020) dataset confirms that the TC activity during the monsoon transition phase has increased over the Arabian Sea, but the change over the Bay of Bengal is not significant. Compared to past years, thermodynamic conditions are becoming favourable for the genesis and intensification of tropical cyclones during the monsoon transition period in recent years. Indian summer monsoon arrival and departure is accompanied by the distinct changes in the large-scale circulation over the Indian landmass and surrounding oceanic regions. Later part of the study deals with the analysis of the changes in the monsoon circulation during the transition phase.

Urban Modification of Heavy Rainfall : A Model Case Study for Bhubaneswar Urban Region

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Abstract : An increase in urbanization has been witnessed from 1980 to 2019 over Bhubaneswar, the capital city of Odisha state. The impact of this increase in urban areas on rainfall such as shifts in rainfall pattern and intensity has been assessed in this study. To evaluate these changes, four heavy rainfall events such as 06th March 2017, 23rd May 2017, 20 – 22 July 2018, and 04 – 08 August 2018 have been simulated with 1980 and 2019 land use land cover (LULC) obtained from United States Geological Survey imageries. With these two LULC sensitivity, urban canopy model (UCM) experiments also been carried out. The results from these experiments suggest that the incorporation of correct LULC is necessary for the high-resolution Weather Research and Forecasting (WRF) model to simulate rainfall events. Expansion in urban area increases the rainfall intensity and also the spatial shift was more pronounced along the peripheral region of the city. The analysis of vertically integrated moisture flux suggests more amount of moisture present over the region received intense rainfall. An increase in urbanization increases the temperature at the lower level of the atmosphere, which increases planetary boundary height, local convection, and rainfall over the region. Contiguous Rain Area method analysis suggests that the 2019 LULC with single layer UCM predicts better spatial representation of rainfall and the intensity error is also less compared to other experiments.

Key words : Urban area, Heavy Rainfall, UCM, WRF model, Bhubaneswar.

Simulation of Extreme Drought Features of Indian Summer Monsoon: Performance with Two Land Surface Schemes

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Abstract : In this study, the land surface schemes of Biosphere-Atmosphere Transfer (BAT) and Community Land Model (CLM4.5) are coupled with Regional Climate Model (RegCM4.7) for the simulation of severe drought during Indian Summer Monsoon (ISM). For this purpose, nested simulations are performed using non-hydrostatic RegCM4.7, with the outer domain of 45km covering CORDEX region of South Asia and nested run with 15km covering Indian subcontinent. Both experiments, model was initialized on 1stMay and integrated upto 1stOctober with initial and lateral boundary condition forced with ERA interim reanalysis. Weekly OISST data from NOAA has been used throughout simulation period. The University of Washington (UW) PBL of boundary layer scheme, mixed convection scheme, i.e., Emanuel over land and Grell over Ocean and the SUBEX-Pal explicit moisture scheme are used for the entire simulation. Two severe drought period of 2002 and 2009 during ISM are investigated on monthly to seasonal scale precipitation, temperature and circulation features. The simulated rainfall and temperature are evaluated with IMD and CRU data sets. The circulation feature is compared with the reanalysis of ERA interim. The results show that both the schemes are well represented deficit monsoon features, however, BAT scheme simulates temperature reasonably well whereas CLM is better in rainfall simulation in both the domains which are in close agreement with CRU and IMD observation.

Key words : South Asia CORDEX, Indian summer monsoon. Regional climate model, land surface scheme, ERA-Interim reanalysis.

THEME : MODELLING MONSOON PROCESSES

Seasonal Prediction of ISMR Using WRF : A Dynamical Downscaling Perspective

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Abstract : The seasonal prediction of the Indian summer monsoon by dynamically downscaling the CFSv2 output using a high resolution WRF model over the hindcast period of 1982-2008 has been performed in this study. The April IC ensembles of the CFSv2 have been averaged to provide the initial and lateral boundary conditions for driving the WRF. The WRF model is integrated from 1st of May to 1st of October for each monsoon season over the period of study. The WRF models improves the rainfall skill and minimizes the errors as compared to the parent CFSv2 model. The rainfall pattern is simulated quite closer to the observation in the WRF model over CFSv2. Comprehensive statistical rainfall verification scores also support the improvement of rainfall forecasts using WRF. The improvement in the skill of the rainfall can be attributed to the improved in the simulation of low level winds, tropical easterly jet stream, mean sea level pressure and the surface temperatures. The relative humidity and the diabatic heating profiles along the vertical column of the atmosphere are simulated better in the WRF model. Along with the upper air parameters, the surface heat fluxes are realistically simulated in the WRF model. The dynamical downscaling method helps in improving the forecast of the significant meteorological parameters. The dynamically downscaled forecasts are further improved by the methods of linear and quantile mapping bias correction techniques and the results show that the dynamically downscaled forecasts can be further improved and the skill can be increased by the hybrid dynamical-statistical downscaling methods.

Interaction of Rivers with the Indian Summer Monsoon :Modeling, Impact on Variability and Implications for Predictability

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Abstract : Rivers form an essential component of the earth system, with 36000 km3 riverine-freshwater being dumped into the global oceans every year. The role of rivers in controlling the sea-surface salinity and the ensuing air-sea interactions is well known from observational studies; however, there have been limited attempts to include rivers into coupled models used for seasonal prediction. We quantify the impact of the riverine freshwater forcing on the Indian Summer Monsoon (ISM) variability by employing a routing model coupled to an ocean-atmosphere-land general circulation model (GCM). 37 years long seasonal hindcasts were carried out using this model setup. Daily varying freshwater discharge into the northern Bay of Bengal (BoB) causes enhanced mixed layer temperature gradients in the Bay. This causes frequent genesis of monsoon low-pressure systems, which have a longer lifetime and travel much more inland. Significant upper-ocean variability is noted at intra-seasonal time scales which leads to enhanced air-sea interactions. Stronger vorticity and specific humidity to the north of the northward propagating intra-seasonal convection band results in greater rainfall amplitude associated with monsoon active phase. Riverine freshwater interacts with the coupled monsoon system by modulating the upper ocean stratification and the associated air-sea interactions at synoptic to intra-seasonal time scales. Inclusion of rivers causes a significant improvement in the rainfall-runoff coupled feedback, the inter-annual variability of the mixed layer heat budget terms, and modulates the remote teleconnections. Improved seasonal mean temperature and salinity profiles in the BoB lead to the formation of thicker barrier layers, which is closely tied to the freshwater from rivers. The improvements in oceanic processes result in an overall improvement in the seasonal rainfall prediction skill. These results bear important implications for Indian Summer Monsoon Rainfall (ISMR) forecasting.

Improvements in the Tropical Diurnal Cycle by Incorporating COARE Flux Algorithm in CFSV2

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Abstract : The variability at diurnal to seasonal scale in coupled models is primarily governed by surface boundary conditions (sea surface temperature (SST), turbulent heat, and momentum fluxes) between the ocean and atmosphere. Although efforts have been made to achieve the accuracy in surface fluxes and SST in observation and reanalysis products, less attention has been paid towards achieving similar accuracy in coupled model simulations. Improper diurnal phase and amplitude in intra-daily SST and precipitation are among the well-known problems in most global coupled general circulation models, including the Climate Forecast System v2(CFSv2) model. The present study attempts to improve the representation of ocean-atmosphere surface boundary conditions in CFSv2, primarily used for India's operational forecasts at different temporal/spatial scales. In this direction, the diurnal warm layer and cool skin temperature correction scheme is implemented along with the surface flux parameterization scheme following Coupled Ocean-Atmosphere Response Experiment (COARE) v 3.0. The coupled model re-forecasts with a revised flux scheme resulted in improved characteristics in various ocean-atmosphere parameters and processes at diurnal and seasonal time scales. At the diurnal scale, the phase and amplitude of intra-daily SST and mixed layer depth variabilities are improved over most tropical Oceans. Improved diurnal SSTs helped in enhancing the diurnal range of precipitation by triggering stronger intra-daily convection. The improved diurnal ocean-atmospheric boundary state translated into a reduction in seasonal mean dry bias over Indian landmass and the wet bias over global oceans. Better simulation of El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) related non-linearity, ENSO-Indian Summer Monsoon Rainfall (ISMR), and IOD-ISMR relation is among the most critical improvements achieved by revising the turbulent flux parameterization. The revised flux scheme also improved prediction skills for tropical SST indices and ISMR. The revised flux parameterization can significantly enhance India's prediction capability at short and extended range predictions for features like diurnal extreme rainfall events, monsoon intraseasonal oscillations, Madden-Julian Oscillation, etc.

Spatial verification of probabilistic rainfall forecast over Indian Land Region

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Abstract : Rainfall forecasting during the monsoon season over Indian land region is not only extremely important but challenging as well. This challenge is further enhanced due to the uncertainty associated with the models used for weather forecasting. This inherent uncertainty can be handled efficiently by using an Ensemble prediction system (EPS). In order to build confidence in using probabilistic forecasts verification of these forecasts is a necessity. This study deals with the verification of the probabilistic rainfall forecast obtained from the National Centre for Medium Range Weather Forecasting (NCMRWF) EPS (NEPS) for three monsoon seasons, i.e., JJAS 2019, 2020 and 2021. Verification is done based on the Brier Score (BS) and its components (reliability, resolution and uncertainty), Brier Skill Score (BSS), reliability diagram, relative operating characteristic (ROC) curve, area under the ROC (AROC) curve and Ranked Probability Score (RPS). The observation dataset used for this verification is the IMERG rainfall (0.1x0.1 degree). Spatial verification is also carried out for some heavy rainfall cases using CRA method. Verification of rainfall forecasts is carried out for rainfall exceeding 5, 10, 15, 20 and 50 mm/d thresholds. Analysis of the BS and reliability and resolution components and BSS shows that the model is able to perform predict rainfall in excess of 20 mm/d with a low BS and a high BSS.

The analysis of displacement, volume and pattern errors to the total error shows that the volume contributes the least. For heavy rainfall, pattern is better matched. Spread-skill relationship shows that the uncertainties in NEPS system are better represented for the rainfall area and volume. These results indicate that rainfall area and volume demonstrate higher reliability and skill in the forecasts as compared to intensity.

Key words : Forecast Verification, Monsoon Rainfall, Spatial CRA verification.

Implementation of a Seamless Modelling System at NCMRWF: Ensemble Monsoon Prediction from Hours-to-Season

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Abstract : In last one decade due to availability of enhanced computing resources, atmosphere/ocean observed data and improved assimilation-forecast system, the skill of tropical wind and rainfall forecasts have improved in medium range time scale. High capacity computers are aiding ensemble forecasting systems at high resolutions and enhanced ensemble manners. This has helped us in dealing with uncertainties in monsoon rainfall forecasting by issuing probabilistic forecasting from global and regional ensemble prediction systems. By inclusion of exclusive Ocean, Land-Surface, Sea-Ice and Bio-Geo-Chemistry into the prediction model, a complete Earth System Model is now possible for going beyond medium range to a season and even climate projects. Particularly for India where the monsoon rainfall information is the lifeline of people the water forecasted at short, medium and sub-seasonal to seasonal scale is very important for agriculture and water management. Due to improved model skill, services at short-term climate scales (up to a season) have become possible. AT NCMRWF a seamless modelling system is implemented for providing weather/climate information across scales from hours to a season. The advantage of such seamless modelling systems is its fast model development cycle. The field campaign data collected at local scales can be experimented with meso-scale and large-scale process studies in model to improve the model. While the models are gradually improving, there is enhanced demand of rainfall forecast from various sectors of economy for a variety of applications. Keeping pace with the demand, developing and demonstrating applications for water sector is a challenge for weather/climate modelling community. A state-of-art global/regional atmosphere/ocean data assimilation system has been implemented at NCMRWF for daily real-time use for initializing the global/regional models. The model based forecast guidance at time scales from hours-to-season is used by IMD as one of the input for operational forecasting for monsoon and other seasons. The skill of the deterministic and ensemble forecasts during monsoon period for different time scales will be presented in the workshop.

Atmospheric Kinetic Energy Spectra from Global and Regional NCMRWF Unified Models

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Abstract : The horizontal resolution of numerical weather prediction (NWP) models has been steadily increasing in the recent past decades. Accordingly, it is quite essential for rigorous evaluation of models' kinetic energy (KE) at different scales specifically at mesoscales. It is known from observations that the atmospheric KE spectrum, plotted as a function of wavenumber(k), in the free troposphere and lower stratosphere indicates a canonical structure characterized by a slope roughly follows a power law of k^(-3) at synoptic range of scales and then transitions to shallower k^(-5/3)-law in mesoscale regions. The -3 slope is in general thought to be resulting from an enstrophy cascade while there is still no clear consensus on the -5/3 slope at mesoscales and is still in continuous debate. Nevertheless, the canonical KE spectrum is often shown as evidence of the correctness of the NWP model's performance. Therefore, in this study, we examine the KE spectra produced by the two operational models running at National Centre for Medium Range Weather Forecasting (NCMRWF) based on Unified Model (UM) referred to as NCUM-Global (NCUMG) and NCUM-Regional (NCUMR). The NCUMG and NCUMR deliver daily 10-day and 3-day weather forecasts with a spatial resolution of ~12km and ~4km, respectively. Here we discuss the implications of these KE spectra on questions concerning atmospheric spectra and model capabilities. The evaluation of KE spectra follows the Helmholtz decomposition where the horizontal flow fields will be decomposed into rotational and divergent components through which we also assess high-resolution NCUMR capability in resolving mesoscales relative to NCUMG. Therefore, this study has strong implications for future high-resolution model development at NCMRWF.

Revealing sources of Model error in Indian Summer Monsoon Forecasts

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Abstract : Previous work has shown that Met Office weather forecasts during the Indian summer monsoon (ISM) initially have too much precipitation over India, but that this decreases throughout a 7-day forecast so that there is too little precipitation by the end. The precipitation decrease has been shown to vary with the observed phase of the Boreal Summer Intra-Seasonal Oscillation (BSISO), with a smaller reduction during active to break transitions and generally a smaller reduction for active phases than for break phases. We have also shown that the major systematic errors in the ISM in Met Office models are established within the first few days of simulation and can then persist to climate timescales. The current work extends this analysis to seasonal hindcasts from the Met Office (GloSea5-GC2) and IITM (CFSv2) coupled forecasting systems.

In both systems, the main pattern of errors is established during the first ~10 days and then persists throughout the remainder of the forecast. However, there are differences in how the precipitation varies with forecast lead time, depending on time of year (within June-August), the BSISO phase, and also between the two modelling systems. The reduction in precipitation for GloSea5-GC2 hindcasts is much greater earlier in the season, leading to a large negative bias with respect to observations. However, later in the season there is a much smaller reduction leading to a smaller negative bias. This is consistent with previous results for Met Office coupled climate simulations but contrasts with CFSv2, for which the opposite behaviour is seen. When the forecast begins in an active BSISO phase there is a larger decrease in precipitation than when the forecast is initialised during a break phase. We find that it takes roughly 50 days for the seasonal forecast to become independent of the initial observed BSISO phase.

On the simulation of northeast monsoon rainfall over southern peninsular India in CMIP5 models

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Abstract : The skill of 34 CMIP5 models to simulate the mean state and interannual variability of Northeast Monsoon Rainfall (NEMR) is studied here. The mean (1979-2005) NEMR over southern Peninsular India (SPIRF), Indian Ocean and Maritime continents (10°S-30°N,40°E-120°E) is simulated reasonably well by CMIP5 models with pattern correlation ranges from 0.6 to 0.93. Diverse behaviour in the simulation of Indian and Pacific Ocean SST is observed in the CMIP5 models. A set of models (high skill models: HSM), which shows an NIOD like mean (1979-2005) SST bias in Indian Ocean and strong La Nina like mean SST bias in the Pacific Ocean, are able to simulate the mean NEMR more realistically. Another set of models (low skill models: LSM) which shows a Positive IOD (PIOD) like mean SST bias in the Indian Ocean and weak La Nina like mean SST bias in the Pacific Ocean are not able to simulate the observed equatorial Indian Ocean westerlies, which leads to an abnormal ascending motion and unrealistic wet bias over the western Indian Ocean and dry bias over the southern Peninsular India, southeast Asia and southeast Indian Ocean. The observation analysis reveals that the establishment of South China Sea anticyclone and Bay of Bengal anticyclone during El Nino and PIOD are strongly related with the ascending motion over south peninsular India and enhances the south Peninsular Indian rainfall during NEM season. Around 70% of the CMIP5 models were not able to capture the observed positive correlation that exist between SPIRF and Nino3.4 SST as well as SPIRF and DMI. Unrealistic westward extension of South China Sea anticyclone and Bay of Bengal anticyclone (up to 70°E) is also observed in the LSM-IAV model ensemble. This is manifested as the abnormal descending anomalies and unrealistic dry bias over the southern Peninsular India and negative CC between SPIRF and Nino 3.4 SST as well as SPIRF and Dipole Mode Index. The descending anomalies over South China Sea and ascending anomalies over the western Indian Ocean and southern Peninsular India (50°E-80°E) is well captured but with lower intensity in HSM-IAV model ensemble and hence it captures the observed positive CC between SPIRF and Nino3.4 SST as well as SPIRF and DMI.

Key words : NEMR, El Nino, PIOD.

Predicting Onset and Withdrawal of Indian Summer Monsoon : Recent Advance and Regional Extension

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Abstract : Facing climate change and developing adaptation strategies, we desperately need predictions. However, the limitations of current models prevent further progress. The limits of the predictability of modeling forecasts are partly due to the primary intention of numerical simulation: mirroring the local nature of direct interactions in the physical world faithfully. However, the models are not perfect mimicries of nature. In particular, teleconnections may be absent within numerical models [1]. A new strategy is urgently needed in weather and climate sciences. Here I show that a new understanding of essential physical mechanisms of monsoon arrival and withdrawal allows more than a month in advance to predict monsoon timing [2]. The approach is fundamentally different from the numerical weather and climate models; it is based on statistical physics principles and newly discovered spatial-temporal regularities (or teleconnections between Tipping Elements) in a monsoon system. The forecasting relies on the re-analysis data-set: temperature and relative humidity (1000hPa). Such a strategy opens possibilities for long-term predictions in meteorology and climate science. It applies to cases when the numerical models fail, particularly the monsoon timing prediction.

I present solid evidence of the reliability of forecast: the five years tests show successful results. The results are documented on PIK-monsoon-web-page [3], in Indian newspapers, and internationally. The approach provides a long-term forecast: 40 days in advance for the onset and 70 days for the withdrawal date. Applicability of the methodology is not limited by specific location; it works for different parts of India: Central India (Eastern Ghats), Telangana, Delhi.

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The role of mid-tropospheric moistening and land surface wetting in the progression of the 2016 Indian monsoon

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Abstract : Accurately predicting the spatial and temporal variability of the Indian monsoon precipitation is limited by inadequate understanding of the underlying processes, which feeds into systematic model biases. In this study, we aim to understand the dynamic and thermodynamic features associated with the progression of the monsoon, using 2016 as a representative year, with the help of convection-permitting simulations of the Met Office Unified Model. Simulations are carried out in a 4 km-resolution limited area model, nested within a coarser global model. Two major processes thought to influence the north-westward progression of the monsoon are: (1) the interaction between the low-level monsoon flow and a mid-tropospheric dry-air intrusion from the northwest and (2) land surface wetting from pre-monsoon showers. We find that the 4-km limited area model simulates the mid-tropospheric moistening that erodes the north-westerly dry intrusion, pushing the northern limit of moist convection north-westwards. The surface soil moisture also plays a major role at the leading edge of the monsoon progression. The heavy rains associated with the local onset saturate the soil, leading to an energy-limited regime that does not contribute further to the progression of monsoon rains. The 4 km model is tested with an alternative land surface configuration to explore its sensitivity to land surface processes. We find that the choice of soil and vegetation ancillaries affects the time scales of soil moisture-precipitation feedback and the timing of diurnal convection, thereby affecting the local onset. We further compare these simulations with a parameterised convection run at 17 km resolution to isolate the effects of convective parameterisation and resolution. The model with explicit convection better simulates the dynamic and thermodynamic features associated with the progression of the monsoon.

Mechanisms of Rainfall Biases in Two CORDEX-CORE Regional Climate Models at Rainfall Peaks over Central Equatorial Africa

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Abstract : Two regional climate models (RCMs) participating in the CORDEX Coordinated Output for Regional Evaluations (CORDEX-CORE) project feature a dipole-type rainfall bias during March-May (MAM) and Septembe-November (SON) over central equatorial Africa (CEA), consisting of positive bias in west central equatorial Africa (WCEA) and negative bias in east central equatorial Africa (ECEA). One is the Regional Model version 2015 (REMO2015) and the other is the fourth version of the Regional Climate Model (RegCM4-v7). RCMs are nested in three Earth system models (ESMs) from phase 5 of the Coupled Model Intercomparison Project (CMIP5), and in the reanalysis ERA-Interim, at ~25-km spacing grid resolution. This study highlights misrepresented underlying physical processes associated with these rainfall biases through a process-based evaluation. Both RCMs produce a weaker Congo basin cell, associated with a weaker landâ€“ocean zonal surface pressure gradient. Consequently, less water vapor enters the region, and little is transported from WCEA to ECEA, resulting in higher moisture availability in the west than in the east. This leads to an unevenly distributed moisture across the region, favoring a stronger atmospheric instability in WCEA where the moist static energy (MSE) anomalously increases through an enhanced latent static energy (LSE). Moisture arrives at a slower pace in ECEA, associated with the weak cell's strength. The intensity of ascent motions in response to the orographic constraint is weak to destabilize atmospheric stability in the lower layers, necessary for initiating deep convection. Therefore, the convection is shallow in ECEA related to underestimating the MSE due to the reduced LSE.

Indian Summer Monsoon intercomparison in CORDEX-CORE and CORDEX-SA

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Abstract : Monsoon dynamics intercomparison in modelling suites of Coordinated Regional Climate Downscaling Experiment-South Asia (CORDEX-SA) and Coordinated Regional Climate Downscaling Experiment-Coordinated Output for Regional Evaluation (CORDEX-CORE) is attempted. CORDEX-CORE consists suites of regional climate models (RCMs) but at higher model horizontal resolution (~25km) than CORDEX-SA (~50km). Otherwise, in principle, CORDEX-CORE experiment evolved based on experiences from CORDEX-SA. In the present study, firstly, historical period of 1979-2005 is considered. The performances are evaluated against the corresponding observations. Temporal, spatial and intra-seasonal variability is considered and compared. The spatial distribution of precipitation is better represented in CORDEX-CORE than CORDEX-SA. The probability distribution shows the CORDEX-CORE ICHEC member simulates closed precipitation with the corresponding IMD gridded observation over Indian landmass as compared with the other model members. Comparison of active and break spells from simulated suites and corresponding IMD gridded observations shows better evolution in CORDEX-CORE suites. Model uncertainty evaluation shows that CORDEX-CORE ensemble has less variability than the corresponding similar model suites from CORDEX-SA. This is the preliminary finding so far and more analysis are under way.

NCMRWF Reanalysis Products for Monsoon Studies.

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Abstract : National Centre for Medium Range Weather Forecasting (NCMRWF) produced first of its global and regional data reanalysis recently. The global reanalysis is for the period twenty year from 1999 to 2018, using its GFS based system (NGFS) at T574L64 (~23km in horizontal) resolution. The regional one is carried out in collaboration with Met Office (MO), U.K, and the India Meteorological Department (IMD) as a project, called Indian Monsoon Data Assimilation and Analysis (IMDAA), under the aegis of National Monsoon mission. IMDAA is carried out at 12 km horizontal resolution for a 42 year period from 1979 to 2020, involving mesoscale version of Met Office Unified mode and 4D-Var data assimilation system. The main objectives of these efforts are to produce, high-resolution analysis fields to study the Indian monsoon and to provide short-term mean fields for its seasonal/long-term forecasts. The key features of Indian Summer monsoon as seen in these re-analysis data sets will be discussed in this presentation.

Assessment and Bias Decomposition of Isotope Enabled General Circulation Models for Indian Summer Monsoon and their Implication to Paleoclimate Modelling

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Abstract : Past climate reconstruction based on isotope studies of various natural proxies (tree rings, speleothems, soil carbonates, sediments, etc.) largely depends on the isotope values of the pristine rainwater with which these proxies isotopically equilibrate. Isotope-enabled General Circulation Models (GCMs) simulate precipitation stable isotope ratios 18O/16O and D/H (expressed as □□□O and □D) considering various physical processes operating in the hydrologic cycle. For the same reason, these GCMs are an integral part of various paleoclimate models. In the present study, performances of seven such GCMs are evaluated near/over various Indian proxy locations for the Indian Summer Monsoon (June-September). Apart from this, a systematic bias decomposition (during various processes) for the models is provided for the first time over the Indian sub-continent.

Analysis shows that models underestimate the mean isotope values over west (WI) and eastern India (EI) but has a mixed response over north India (NI). Overall, the IsoGSM model (free and nudged versions) better simulates isotopes and physical fields. Observed isotope data show a minor dependence on the rainfall (amount effect) in WI and EI, but a strong effect in the NI. In contrast, most of the models show a significant amount effect (with a rate of -1‰/ 100mm/month to -6‰/ 100mm/month for □□□O). The rainfall amount overestimated in the Arabian Sea and the monsoon trough impart a sizable bias in the isotope values of WI and NI respectively. The bias decomposition suggests that the skill of the models over the WI depends on how proficiently the models (1) simulate mid-tropospheric vapour isotope values and (2) evaluate raindrop evaporation. Our study suggests how these models can be further improved by tuning appropriate parameters to achieve a realistic simulation of isotope ratios by GCMs in the Asian monsoon region.

Study of Dynamical and Morphological Characteristics of Meso-Scale Convective Systems to Develop 'Thunderstorms Numerical Prediction Model (TNPM)'Over Tropics

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Abstract : The large scale kinematic and thermodynamic behaviour, evolutionary features & 3D structure of selected mesoscale Convective Systems, e.g., intense Cloud Clusters, and Severe Thunderstorms, NHCZ & SHCZ, SSTs would be investigated by using Aircraft, Doppler Weather Radar, conventional, and Satellite data fitted with Lightning sensors &CubeSats carrying high-frequency passive microwave sensors, over the domain.

High resolution Satellite imageries (Geostationary) with emphasis on the large scale kinematic and thermodynamic behaviour of selected mesoscale Convective Systems (e.g. intense Cloud Clusters, NHET, SHET, NHCZ, SHCZ, ITCZ, Monsoon Depressions/Thunderstorms) initially, over Bay of Bengal during (i.e., 15 – 25° N and 85 – 95° E), and their values of characteristics, e.g., lifetime, distribution, trajectories, size and vertical extent of these systems would be investigated first by making use of aircraft and conventional data over the domain followed by the process of Initialization, Computation, Parameterization in order to develop Thunderstorm Numerical Prediction Model (TNPM) over the Tropics and later extending over mid-latitude regions.

The digital images from the Geostationary Satellite fitted with Lightning sensors & future constellation of CubeSats (TROPICS) carrying high-frequency passive microwave sensors. would be analysed as a "Movie Loop" sequence on a computer-controlled image storage display and processing device called Mc IDAS(Man-Computer-Interaction-Data-Access-System).

Three to six hours Sounding (Surface) and Drop-Sounding, would be analysed in time section of temperature anomaly, relative humidity and equivalent potential temperature. The integration of Satellite and Surface Sounding data would be accomplished through plausible model in which the section strips are treated as space sections.

Later, the kinematic features of the Disturbed Phases be correlated with the extracted Sea Surface Temperature (SSTs) over the grid box & the Time Series plot of 0300 UTC Surface Pressure Gradient; between a few selected stations falling at almost the same latitude and longitude, to bring out the few optimum values of these parameters would be used to develop 'Thunderstorm Numerical Prediction Model (TNPM)'.

THEME : MONSOON INFORMATION AND PREDICTION FOR SOCIETAL BENEFIT

How Well Do Seasonal Forecast Models Simulate South Asian Monsoon Precipitation?

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Abstract : Skilful seasonal monsoon forecasts can provide information on whether the coming season will be wetter or drier than average. This has the potential to benefit long-term planning decisions and provide advanced warning of drought and flood conditions. Climatic conditions in South Asia are predicted to become more extreme and unpredictable due to climate change, threatening food security and water availability and thus accurate seasonal forecasts will become even more imperative in the future. The South Asian Seasonal Climate Outlook Forum has been selected by the World Meteorological Association as a pilot to demonstrate good Operation Seasonal Forecast practices, which include creating a more objective seasonal forecast using appropriately calibrated dynamical models. As part of the Asia Regional Resilience to a Changing Climate (ARRCC) programme, we will present work which we have conducted alongside regional partners to assess the skill of 12 dynamical seasonal prediction systems in predicting seasonal precipitation during two key monsoon seasons; southwest (June to September), and northeast (October to November). Based on verification metrics computed for the period 1993-2016, we show that most of the models assessed demonstrate positive skill in predicting South Asian precipitation variability, with large spatial differences between the models. We also show that models are more skilful in locations where precipitation variability is driven by the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). We conclude that large range in skill between models highlights the importance of using a Multi-Model Ensemble as a basis for the SASCOF regional forecast, and the spatial differences between models demonstrate the benefits of tailoring model skill assessments to individual country domains.

Influence of Asian-Australian Monsoon and Indo-Pacific Sea Surface Temperature Variability on Urban Climate in Major Cities of Indonesia for Low-carbon Building Design

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Abstract : In order to implement the nationwide climate change mitigation plan in the housing and settlement sector, it is important to develop Typical Meteorological Year (TMY) for building energy simulations. Recently, a new climate classification in Indonesia has been proposed for passive cooling potential in building design based on the diurnal and monthly variational characteristics of weather elements. In this study, the impact of regional climate variability such as Asian-Australian Monsoon and Indo-Pacific Sea Surface Temperatures (SSTs) over the Indo-Pacific Ocean on the urban climate of 22 major cities in Indonesia was investigated for each climate classification. Observed daily average temperature, average relative humidity, and precipitation were obtained from Indonesian National Met Service (BMKG). The lag-correlations analysis method was applied to examine lead-lag relationships to identify the temporal coherence between the major city climate with Asian-Australian Monsoon indices and SST anomalies along the Indo-Pacific Ocean region. In general, precipitation was strongly correlated with Indo-Pacific SSTs, with the low precipitation in Jambi and Bengkulu due to IOD + phase in dry season. Meanwhile, in Medan, Bogor, and Sorong the low precipitation is associated with the ENSO + phase. The relative humidity was strongly correlated with the monsoon, which affects the seasonal changes of relative humidity during dry season (low) and wet season (high) in Palembang, Bogor, and Wamena. Then, average temperature was strongly correlated with a combination of the monsoon and SSTs, which affects the seasonal changes of temperature during dry season (high) clearly in Jambi and Semarang associated with IODM and ENSO in + phase. Meanwhile, in Sumbawa Besar and Sumba Timur, the seasonal changes of temperature strongly affected by Asian Monsoon (during wet season) and Australian Monsoon (during dry season). The physical factors were also discussed, for the remaining cities where the correlation is low.

Key words : Monsoon, Sea Surface Temperature, Lag-Correlations Analysis, Urban Climate.

Decadal Prediction of the Indian Ocean Dipole - Links from the Southern Ocean

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Abstract : Decadal prediction is the prediction of climate for the next 5-20 years. Decadal Prediction has gained great importance as it tries to bridge the gap between seasonal and Centennial (50-100 year) predictions creating a balance between initial conditions and boundary conditions. We analysed the model output from CMIP5 decadal runs and found that two of the models, i.e., CanCM4 and MIROC5 show prediction skills of significance for the Indian Ocean Dipole for up to a decade. The Indian Ocean Dipole is one of the leading modes of climate variability in the tropics, which affects global climate. As earlier established, the models also show year-long lead predictability of the El Niño Southern Oscillation. We show that the source of the lead predictability of the Indian Ocean Dipole is signals emerging from the Southern Ocean. These decadal prediction skills and predictability for a climate driver like the Indian Ocean Dipole have immense benefits for climate science and society in general.

THEME : NEW TECHNOLOGIES AND TOOLS

A machine learning approach to improve tropical cyclone intensity prediction of NCMRWF ensemble prediction system

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Abstract : Global NWP models, including ensemble prediction systems (EPS), have considerable ability to predict tropical cyclone tracks, intensity, and structure. However, due to coarse resolution, the prediction of tropical cyclone (TC) intensity is relatively poor. The bias in the model predicted maximum sustained winds (MSW) and central pressure (CP) is large when TCs are of more intensity. This paper describes the suitability of machine learning (ML) techniques to reduce this limitation by bias correcting TCs in the NCMRWF Ensemble Prediction System (NEPS) over the North Indian Ocean (NIO). A bias-corrected intensity of the TC system will help minimize losses of property and livelihoods and better preparedness for offshore activities. Different machine learning techniques have been tried for the bias correction of mean MSW and CP while the spread of ensemble members has been retained. The study based on seventeen TC cases during 2018-2020 shows that Random Forest and Support Vector Regression techniques are superior to multivariate regression methods. The model was trained on best track data received from India Meteorological Department. The reduction in bias of mean MWS and CP are reasonably good and the distribution of bias-corrected intensities are in better agreement with the best track parameters.

Key words : NWP model, Tropical Cyclone, Intensity, Machine Learning

Improved Ocean analysis with upgraded model in the Global Ocean Data Assimilation System

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Abstract : The National Centers for Environmental Prediction (NCEP) and the Indian National Centre for Ocean Information Services (INCOIS) produce global ocean analyses based on the Global Ocean Data Assimilation System (GODAS). This system uses a state-of-the-art ocean general circulation model named modular ocean model (MOM) and the 3D-Variational (3DVar) data assimilation technique. NCEP routinely provides a real-time ocean analysis based on MOM3 in GODAS. INCOIS operational analysis is based on MOM4p0d. Indian Institute of Tropical Meteorology (IITM) currently uses INCOIS operational analysis to initialize the coupled model CFSv2 for the seasonal Indian Summer Monsoon Rainfall (ISMR) prediction. In this study, we will show how upgrades to the forward model simulations from MOM4p0d to MOM4p1 impact ocean analyses over the tropical Indian Ocean in GODAS. Observed temperature and salinity profiles in the global ocean were assimilated in both experiments. We will also show the impact of assimilating actual salinity profiles as compared to synthetic salinity.

THEME : REGIONAL MONSOONS

Influence of Eurasian snow, Atlantic SST and Arctic Oscillation on summer monsoon rainfall variability over the North East regions of India

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Abstract : The North East Indian Summer Monsoon Rainfall (NEISMR) over the eastern-most part of the country has been exhibiting a declining trend in the summer monsoon rainfall since the last 4-5 decades. Hence, it becomes imperative to examine the possible drivers of this variability. The contemporary India Meteorological Department's high-resolution gridded rainfall dataset is extensively used in this study to evaluate the regional aspects of snow-monsoon link over India.This observational study evaluates the potential role of Eurasian snow in the recent decades towards modulating the NEISMR with a lead time of almost 6 months. The proposed relationship is manifested by the changes in the high-latitude atmospheric winter snow variability over Eurasia having an implicit connection with Arctic Oscillation (AO). Excessive wintertime Eurasian snow leads to an anomalous cooling of the overlying atmosphere and is associated with the negative mode of AO, inducing a large scale atmospheric meridional circulation descending over the tropical north Atlantic, which is linked with cooling of this region. Once the cold anomalies are established over the tropical Atlantic, it persists up to the following summer leading to an anomalous atmospheric large scale zonal circulation further inducing a descending branch over NE-India resulting in weak summer monsoon rainfall.

Key words : North East India Summer Monsoon, Eurasian Snow, Atlantic SST, Arctic Oscillation

Decadal changes of the early summer Asian monsoon and the South China Sea tropical cyclones during the years 2001 through 2020

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Abstract : An interdecadal increase in the western North Pacific (WNP) tropical cyclone (TC) genesis frequency in May has recently been reported (Xu and Wang 2014, Huangfu et al. 2017a; Chen et al. 2017). The advanced monsoon onset over the Asian Summer Monsoon region, particularly over the South China Sea (SCS), was proposed as the major cause for the interdecadal increase. An unique feature of this decadal scale phenomenon is that the increase was observed only in May but not in other months. In the present study, we used 60 years (1961-2020) of TC data and 40 years (1981-2020) of the global reanalysis data to investigate the changes of the SCS TC activity during May and the associated large-scale environment. We found that the increasing trend was weakened during the most resent decade (2011-2020), and meanwhile the advanced monsoon onset was not discernable. The period of 2011-2020 was identified as a decade of the minimum TC genesis frequency over the SCS in May since 1961. The extremely inactive TC genesis was attributed to the weak low-level cross equatorial monsoonal flow over the Indian Ocean and the strong easterlies from the western Pacific penetrating through the Philippine Sea and the SCS to the Bay of Bengal and beyond in the tropics, and the enhanced springtime cyclonic circulation over the land area of East Asia. The weakened tropical easterlies and strengthened subtropical westerlies resulted in the abnormally strong anticyclonic circulation over the SCS that inhibited TC genesis during the resent decade.

Investigation of Dry Air Intrusion over India during Break Phases of Summer Monsoon

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Abstract : It has been suggested that the dry air intrusion from the Middle East over the Indian region during boreal summer results in more prolonged dry spells over India. In order to quantify the effects of dry air intrusion, an index is developed in terms of standardized moisture deficit transport anomalies. The moisture deficit is defined as the difference between saturation specific humidity and the actual specific humidity. Using this index, we identified the break spells of the Indian summer monsoon (ISM) that coincided with and without dry air intrusion events during July and August for 1981-2014. It was found that 34 (04) events of dry spells coincide with intrusion (no intrusion) events. We noted that during core summer monsoon months (July and August), a vast reservoir of moisture deficit air at 850-hPa exists over the northern and western Arabian Sea, which eventually acts as the primary source of dry air during this period. Further, we have identified that during dry air intrusion activity, monsoon low level jet (LLJ) acts as a primary carrier in transporting the dry air to continental India during break phases of the ISM. A composite analysis of all dry air intrusion events reveals that LLJ undergoes a broadening followed by weakening before the monsoon break phase in response to an enhancedbarotropic instability. It results in strengthening of zonal flow towards poleward flanks, followed by weakening at the core. Dry air intrusion activity enhances the static stability of the atmosphere over continental India during the break phase and ultimately strengthens the prevailing dry atmospheric conditions.

Key words : Low level jet; Dry air intrusion.

Modes of Coastal Precipitation over Southwest India and Their Relationship to Intraseasonal Variability

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Abstract : The west coast of India, dominated by the Western Ghats mountain range, is among the rainiest places in the tropics. The interaction between the land-sea contrast of the coast, the monsoonal westerlies, and the oblique orientation of the mountains is subject to complex intraseasonal variability which has not previously been explored in depth. This study investigates that variability from the perspective of the land-sea contrast, using EOF analysis to discern regimes of onshore and offshore rainfall over southwest India and the eastern Indian Ocean. Locally, it is found that the rainfall is most sensitive to mid-tropospheric humidity: when this is anomalously high, deep convection is encouraged; when this is anomalously low, it is suppressed. A moisture tracking algorithm is employed to determine the primary sources of the anomalously wet and dry mid-tropospheric air. There are important secondary contributions from low-level vorticity and cross-shore moisture flux. The dominant control on intraseasonal variability in coastal precipitation is found to be the BSISO: over 75% of the strongest offshore events occur during phases 3 and 4, and about 40% of the strongest onshore events occur during phases 5 and 6. The location of monsoon low-pressure systems, and, to a lesser extent, the active-break cycle of the monsoon is also shown to be important in determining the magnitude and location of coastal rainfall. Spectral analysis reveals a broad peak at 8-20 days in the variability of the onshore-offshore mode.

Spatial and temporal variability of monsoon rainfall and its trends on the Southern slopes of Central Himalayas

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Abstracts : The study was conducted using 107 stations rainfall time-series data for the last four decades from 1977 to 2018. The reliability of the time series data were checked using robust statistical tools. During the study period, extreme monsoon events were investigated. The climate extremes were associated with El Niño and La Niña episodes. Drought years 1992, 2009, and 2015 were consisted on El Niño episodes and flood years 1998, 2000 and 2007 associated with La Niña years. In the regional prospective, there was diverse monsoon dynamics over the western, central, and eastern regions of Nepal lies on the southern slopes of the Central Himalayas. The central region of Nepal recorded more rainfall during the monsoon season than the eastern and western regions. This region was more vulnerable than any other regions. The central region has recorded large spatial variability of summer rainfall ranging from less than 200 mm/months in lesser Himalayas to more than 3500 mm/months in mid-mountainous. There was strong correlation between the Nepal Summer Monsoon Rainfall (NSMR) and Southern Oscillation Index (SOI).Generally, large negative/positive magnitude of SOI on Indian and Pacific Ocean influence weakening/strengthening NSMR.

Key words : Monsoon Extremes, El Niño, Man-Kendall test, SOI, Nepal.

Southern African Monsoon :Intraseasonal Variability and Monsoon Indices

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Abstract : Southern African (SAF) summer monsoon rainfall varies over a range of timescales. Here the emphasis is placed on its intraseasonal variability (ISV), which is of great importance for rain dependent activities and subseasonal prediction. Rotated ISV modes are determined based on daily rainfall gauge data (1979–2005) in eastern SAF. One of the leading modes exhibits strongest factor loadings over the core monsoon region, and is associated with variations in the monsoon circulation. This mode exists in the 10–20, 20–30 and 30–90 day bands of ISV. Spectral analysis, as well as lead-lag composite anomalies keyed to its positive and negative phases in each band confirm oscillations with periods of 12, 24 and 40 days, also present in ISV of South America (SA) monsoon. The 12-day oscillation is associated with the quasi-biweekly oscillation originated from Rossby waves in the extratropical westerly belt. The 24 and 40 day oscillations are linked to tropical convection and involve tropical and extratropical teleconnections between SA and SAF, with related convection anomalies over tropical SA/Atlantic Ocean playing a role in the eastward propagation of anomalies towards SAF. In the 30–90 day band, the oscillation is clearly associated with the MJO, with the positive phase more concentrated in MJO phases 1 and 2. A monsoon precipitation index (MPI) is proposed to help characterize, monitor and predict active and break monsoon spells. It is based on the average standardized precipitation anomaly over a selected area with the strongest precipitation variability in the core monsoon region over land, and represents well the monsoon core variability. Monsoon circulation indices associated with the MPI are also defined, since prediction skills are better for circulation than precipitation. Besides, these indices indicate the monsoon circulation features that most affect rainfall variability in different parts of SAF.

Orographic Rainfall Processes in India - Results from the IMPROVE Project

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Abstract : Regional orography around India exerts a profound control on weather and climate, both in summer and winter as part of the diurnal cycle of convection, as well as in extreme events. This presentation summarizes the key results of the Indo-UK IMPROVE project (Indian Monsoon Precipitation over Orography: Verification and Enhancement of understanding). IMPROVE considers two focal regions. The Western Ghats intercept the monsoon flow across the Arabian Sea and receive some of the most frequent and heaviest summer rainfall, including being subject to extremes such as the 2018 Kerala floods. Meanwhile, the Himalayas play a vital role in separating dry midlatitude flows from tropical airmasses in summer, while suffering extremes in winter due to western disturbances - cyclonic storms propagating on the subtropical westerly jet.

We examine the impact of orography on the observed convective diurnal cycle and assess its simulation in models at a range of resolutions including convection-permitting scales. MetUM and WRF model experiments, in addition to DWR retrievals, are used to identify key mechanisms between forcing at the large scale from the BSISO and newly identified regimes of on- and offshore convection near the Western Ghats. An additional aspect to this work is consideration of a novel Froude number approach for understanding the convective regimes. Secondly, the role of orography in extreme events is considered, incluing its interactions between passing tropical depressions or western disturbances. Finally, land-atmosphere interactions occurring during the diurnal cycle of precipitation in the Western Ghats and Himalayas regions are discussed. IMPROVE works towards a deeper understanding of orographic rainfall and its extremes over India and uncovering why such mechanisms may be poorly represented in models.

The Influence of Monsoon Low-Level Jet on the Heavy Rainfall over the Western Ghats

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Abstract : The Low-Level Jet (LLJ) across the Arabian Sea during the Indian summer monsoon season plays very crucial role in the evolution of monsoon rainfall activities across the sub-continent more specifically over the Western Ghats along the west coast of India. The heavy rainfall occurrences are very frequent over the Western Ghats due to orographic lifting of the south-westerly monsoonal flow throughout the season. The variation in number and locations of rainfall maxima is strongly controlled by the characteristics of the LLJ. The IMDAA high spatial resolution (12km, 1-hourly) regional reanalysis data of National Centre for Medium-Range Weather Forecasting (NCMRWF), from 1979 to 2020 and India Meteorological Department (IMD) gridded rainfall data for the same period were utilized for the study of LLJ characteristics such as core speed, westerly wind depth, zonal extent, meridional extent along with branching over the Arabian Sea and leading cyclonic vorticity in the lower tropospheric levels. It is found that the heavy rainfall phenomena over the western Ghats and their specified attributes were showing profound relationships with each characteristic attribute of LLJ. The increase in the number of daily maxima along west coast region is related to the core strength and meridional extent of LLJ whereas zonal extent played a role over the intensity and occurrence of heavy rainfall episodes. Although, the maxima of heavy rainfall show location specific persistent features but north-south undulation of the heavy rainfall zones along the west coast displays a significant dependency on the strength and zonal extent of the LLJ.

Key words : Indian Monsoon Data Assimilation and Analysis (IMDAA)

Evaluation of Multiple Gridded Precipitation Datasets Using Gauge Observations over Indonesia during Asian-Australian Monsoons Period

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Abstract : Gridded precipitation datasets are widely available from satellites observations and reanalysis model outputs. However, its performance at specific region in the world may vary and depends on several factors, such as grid data spatial resolution, rainfall estimation algorithms, geographical location, elevation and regional climate conditions. This study aims reporting on 13 gridded precipitation datasets performance over Indonesia through direct comparisons with rain gauges measurement at the daily and monthly time scales over a 12 years period (2001–2012). The results show that, in general, the CPC and MERRA2 have the highest coefficient correlations and the lowest RMSEs compared to the other datasets in Indonesia, followed by GPCC, at daily timescales. At montly timescale, GPM also showed high correlation with surface observations. The similar analysis also has been done for Asian Monsoon period (December – January – February) and Australian Monsoon Period (June-July-August).

Key words : Precipitation Datasets, Asian-Australian Monsoons, Surface Observations, Satellite Observations, Indonesia.

Radar-derived properties of the convection during the passage of low pressure systems

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Abstract : The synoptic-scale low-pressure systems (LPSs) undergo different intensity named as lows, depression, and deep depression. The role of LPS in producing rain over the core monsoon zone (central India) is well documented, however, the convective structure of LPSs categories, and the role of large-scale dynamics/thermodynamics on their genesis and phase progression remains unexplored. In this work, the climatological composite mesoscale convective features over core monsoon zone associated with different LPSs categories are investigated using TRMM-PR measurements (JJAS; 1998-2013) along with the ERA5 reanalysis products.

Monsoon lows in the Bay of Bengal (BoB) are accompanied with a significant amount of convective rains and are unaffected by total LPSs rains over the central Indian region. The convective centre lies at the north BoB during monsoon depression, and there are broad stratiformrain bands in the south and southwest sector over the central Indian landmass. The distribution of convective and stratiform rain for deep depression have a resemblance of depressions with slight change like higher convective rain over Central Indian and a southward movement in the stratiform rain bands. During monsoon LPSs, the diurnal cycle of convection is unique. Although there is a bimodal distribution in general (except in the land depression, when it is monomodal), the peak time occurrence varies. The proportion of convective and stratiform rain in total rain fluctuates during the day.

Further, we examine the mesoscale convective characteristics associated with monsoon LPSs in terms of deep convective cores (DCC), wide convective cores (WCC), deep-wide convective cores (DWC) and broad stratiform regions (BSR). The spatial distribution of DCC, WCC, DWC and BSR shows heterogeneity during different monsoon LPS.
Details will be presented in the upcoming conference.

Quantifying the Role of Antecedent Southwestern Indian Ocean Capacitance on the Variability of Summer Monsoon Rainfall over Homogeneous Regions of India

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Abstract : Recent rapid changes in the global climate and warming temperatures increase the demand for local and regional weather forecasting and analysis to improve the accuracy of seasonal forecasting of extreme events such as droughts and floods. On the other hand, the role of ocean variability is at a focal point in improving the forecasting at different time scales. Here we study the effect of Indian Ocean mean sea level anomaly (MSLA) and sea surface temperature anomalies (SSTA) on Indian summer monsoon rainfall during 1993-2019. While SSTA and MSLA have been increasing in the southwestern Indian Ocean (SWIO), these parameters' large-scale variability and pre-monsoon winds could impact the inter-annual Indian monsoon rainfall variability over homogeneous regions. Similarly, antecedent heat capacitance over SWIO on an inter-annual time scale has been the key to the extreme monsoon rainfall variability from an oceanic perspective. Though both SSTA and MSLA over SWIO have been influenced by El Niño-southern oscillation (ENSO), the impact of SWIO variability was low on rainfall variability over several homogeneous regions. However, rainfall over northeast (NE) and North India (NI) has been moulded by ENSO, thus changing the annual rainfall magnitude. Nevertheless, the impact of ENSO on monsoon rainfall through SWIO variability during the antecedent months is moderate. Thus, the ENSO influence on the atmosphere could be dominating the ocean part in modulating the inter-annual variability of the summer monsoon. Analysis shows that the cooler (warmer) anomaly over the western Indian Ocean affects rainfall variability adversely (favourably) due to the reversal of the wind pattern during the pre-monsoon period.

Regional rainfall analysis of Haryana in relation to monsoon teleconnections and agriculture

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Abstract : This study examined the long-term (1980-2019) spatio-temporal trends, variability, and teleconnections of Indian summer monsoon (ISM) rainfall of all districts of Haryana, India and their impact on agricultural productivity. The innovation behind this was to study the teleconnections with ISMR in a state which is agriculturally important because it comprises only 1.53% of country total area yet it is the second largest contributor to national central pool of food grains, so impact of rainfall on agricultural production and productivity may have national level repercussions. Around 86% of the area of Haryana is arable out of which 96% is cultivated. So studying the effect of teleconnections at regional level monsoon rainfall may be helpful in sustaining the farm productivity by taking decisions such as crop selection for the Kharif season, mid-season irrigation scheduling based on rainfall etc. The gridded datasets of India Meteorological Department (IMD) was used to statistically analyze the rainfall climatology, trend, coefficient of variation and intensity of rainfall. The gridded datasets of European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis V5 (ERA5) were examined for lower and upper tropospheric wind circulation (850hPa & 200hpa), vertically integrated moisture transport (VIMT), and surface moisture flux (SMF). The datasets of National Oceanic and Atmospheric Administration were correlated with ISM rainfall and composite deviation of rainfall and rainfall intensity during El Niño and La Niña from Neutral years was examined at district level. Our analysis revealed that districts lying in eastern agroclimatic zone (EAZ) of Haryana received more Indian summer monsoon rainfall (ISMR) during each month of ISM as compared to the ones situated in western agroclimatic zone (WAZ), whereas most of the districts showed an overall decreasing trend in ISMR behaviour in recent times. During the El Niño years, most of the locations in the state received deficient to large deficient category as per ISMR, whereas during the La Niña episodes, most of the locations received excess to large excess category as per ISMR, which is indicative of the influence of El Niño-Southern Oscillation (ENSO) on the regional scale. The influence of ISMR on bajra productivity for the districts lying in WAZ and rice productivity for the districts lying in EAZ was undertaken. We have revealed to relate the qualitative and quantitative aspects of ISMR dynamics with teleconnections, viz: ENSO at districts level in Haryana state. This study is beneficial to understanding the impact of climate change and climate variability on ISMR dynamics in Haryana which may further guide the policy-makers and beneficiaries for optimizing the use of hydrological resources.

Influence of Aircraft Observations in Simulating the Indian Monsoon Features in the IMDAA Reanalysis

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Abstract : Indian Monsoon Data Assimilation and Analysis (IMDAA) produced a long-term, high-resolution (12 km) satellite era retrospective reanalysis over India and the surrounding monsoon region initially for 40 years from 1979 to 2018, and extended to 2020. There are plans to disseminate IMDAA equivalent products from NCMRWF Unified Model (NCUM) operational global analysis at the same horizontal resolution from 2021 onwards. IMDAA system assimilated a wide variety of conventional and satellite observations after proper quality control. Aircraft based observations (ABO) is one such type that witnessed a tremendous increase from the first to fourth decade of IMDAA reanalysis period, with more automated observations such as AMDAR apart from the manual AIREPS. The outbreak of the Covid-19 global pandemic and the associated grounding of commercial aircrafts generated a huge gap in the ABO globally and over the IMDAA domain. This study analyses the influence of ABOs in the simulation of Indian monsoon features under the framework of IMDAA. The impact of ABOs in simulating the monsoon features is analyzed through a data denial experiment, and by comparing the results with the control which assimilates the ABOs for nine months from March-November 2019. Results suggest that the ABOs have the largest impact on the representation of upper troposphere and lower stratosphere features. Weakening of monsoon circulations is noticed in the data denial experiment, with pronounced changes in the Tropical Easterly Jet (TEJ) during the Indian summer monsoon season. Another interesting feature noticed in this study is the better representation of the monsoon convective regions over the Bay of Bengal and the Arabian Sea with the assimilation of ABOs.

THEME :
SUB-SEASONAL TO SEASONAL (S2S) PREDICTIONS

Subseasonalto Seasonal Prediction System at NCMRWF : Rainfall Predictability and Associated Teleconnections

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Abstract : Weather prediction at timescales of less-than-a-week benefits from the developments in model physics, resolutions, dynamical-core as well as better observations and data assimilations techniques. On the other hand, the seasonal prediction has benefited from the identification of sources of predictability and dynamical representation of lower-boundary. National Centre for Medium-Range Weather Forecasting (NCMRWF) has adopted the Unified Model for developing a seamless prediction system. In this endeavor a coarse resolution coupled model was implemented in March 2017, followed by an Extended Range Prediction (ERP) system in monsoon 2018 and seasonal forecasting system in 2021. Here, we analyze the skill of the NCMRWF modeling system in simulating the weather across the time scales. Sample forecast products from NCMRWF S2S prediction system are demonstrated. An objective evaluation of skill of NCMRWF hindcasts runs shows skillful forecasts up to two weeks from analysis of a large number of samples. Also the forecasts initialized in May are shown to accurately predict the sign of JJAS rainfall anomaly 80% of the times with correlation coefficient of over 0.5. This shows promising prospect of using the model as one of the component in the multimodel prediction system of ISMR.

Areas of improvement in the model are identified by analyzing the mean state of ocean-atmosphere and representation of teleconnections. An equatorial wet bias present in the model is thought to be responsible for the dry bias over the Indian mainland. While El-Nino and its associated teleconnections are correctly simulated by the model, model suffers in simulating the mean state in the Indian Ocean both at subseasonal and seasonal time scales. The implications of these findings on the predictability of the ocean-atmosphere state in the Indian Ocean are discussed.

Prediction and Predictability of the Seasonal Indian Summer Monsoon Rainfall

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Abstract : Large socio-economic impact of the Indian summer monsoon rainfall (ISMR) extremes motivated numerous attempts at its long range prediction over the past century. However, actual prediction skill remained low and that is attributed to the inherent chaotic nature of the summer monsoon. In other words, all previous studies have estimated a rather low potential predictability (PP) of the seasonal ISMR, attributing primarily to the chaotic nature of the sub-seasonal variability (synoptic + intraseasonal; e.g., Webster et al., 1998). Nevertheless, here we show that Indian summer monsoon is a highly predictable system based on the findings that sub-seasonal fluctuations are partly predictable as they are tied to slowly varying global predictors (e.g., El Niño and Southern Oscillation). Moreover, the synoptic systems have a maximum predictable contribution to the seasonal ISMR anomaly. The observed strong association between sub-seasonal components with the global predictors provides a scientific basis for predictability of the ISMR beyond the conventional estimates of PP.

The complex association of sub-seasonal modes with the global predictors, which vary on interannual to the multi-decadal time scale, shapes the predictability of the ISMR. As a result, the prediction of seasonal ISMR is more accurate in some decades than the others. Based on observations it is estimated that an average of about 76% ($R \sim 0.87$) of the interannual ISMR variance was predictable around the 1960s and that has now decreased to about 64% ($R \sim 0.79$) in the past four decades (Saha et al., 2020;GRL). We have also used coupled global model (CFSv2) to estimate the prediction skill and predictability of the ISMR. Using extensive re-forecast experiments (1920 years) by CFSv2, it is shown that the ISMR prediction skill and PP at three-month lead are 0.71 and ~0.82 respectively, which are much higher than earlier estimates. A new method of estimating PP is also proposed (Saha et al., 2019, 2020;JGR).

Novel Comparison of Ensemble Forecast Precipitation (Pattern) Skill during the 2019 Indian Monsoon Season

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Abstract : Precipitation is a diagnosed cumulative by-product of many atmospheric physics processes, and is often used to assess the skill of a modelling system due to its relative importance on human activity. Too much precipitation can have a devastating impact on daily life. The 2019 Indian monsoon season (JJAS) precipitation total was 110 % of its long period average (LPA) of 880mm. We have compared the 2019 season forecast skill in two global ensemble forecast systems: (1) a fully coupled lagged ensemble used for sub-seasonal to seasonal (S2S) time scales, and (2) an atmosphere-only Numerical Weather Prediction (NWP) with forecasts out to 8 days. Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG-GPM) are used to verify the ensemble forecasts across a seamless range of time scales spanning the short- and medium-range. To do this, forecast and observed precipitation fields are summed over a sequence of increasing accumulation windows for increasing lead time horizons from 2 to 8 days to reflect the increased influence of forecast errors. The actual skill and potential pattern skill of the ensemble forecasts were computed for these different lead time/accumulation combinations. Our results show large rainfall biases across all lead time/accumulation combinations when compared to GPM. We also found that the results are sensitive to the number of ensemble members and the method of ensemble generation. Moreover, the actual skill of the coupled ensemble is higher than the atmosphere-only ensemble over the five pre-defined Indian homogeneous climatological regions.

Key words : ensemble forecast verification, Indian monsoon, short- and medium-range Numerical Weather Prediction, Extreme weather.

A Novel Way of Correcting For the Between-Ensemble Member Bias in a Lagged S2S Ensemble

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Abstract : The GloSea5-GC2 S2S 40-member lagged ensemble consists of members that are up to 10 days different in age, with four members initialised every day. For quantitative downstream applications absolute values of precipitation are needed and simple cheap means of achieving a within-ensemble bias adjustment (without hindcasts) could be considered highly desirable. As an initial test case, within-sample daily parametric distributions are derived using the JJAS 2019 monsoon season accumulations in a "location non-specific" way, which shows considerable changes with forecast lead time. The model distribution is also markedly different to the Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG-GPM) distribution, which is used as the observation base line.

The concept of using parametric quantile mapping (PQM) is not new. What is novel is the manner in which the PQM is derived and applied. The derivation of model distributions as a function of forecast lead day horizons establishes which model distributions to use as the reference for adjusting the rainfall accumulations as a function of lead day horizon, i.e. not attempting to correct the members to a vastly different (observed) distribution shape, but a more subtle shift towards the model's best guess of reality, rather than reality itself. PQM is applied through the use of pre-computed lookup tables, which makes it computationally efficient.

The approach is only worthwhile if it can be shown that the within-ensemble-bias (or internal bias) can be mitigated against. A series of initial results using weather-style verification metrics are presented which show the evolution of skill as a function of ensemble forecast age up to 30 days. The results demonstrate that this very simple initial set-up has promise, but there is need for refinement, e.g.: datasets used for the parametric distribution fitting, regionalisation, and time slicing.

MISVA – Monitoring and Forecast of Intra Seasonal Variability over Africa: a jointresearch/operationalcollaborativeactionbetweenMeteo-FranceandseveralWestAfricanNMHSs.

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Abstract : MISVA- Monitoring and Forecast of Intra Seasonal Variability over Africa - is a joint research /operational collaborative action between Meteo-France and the West African weather forecastingservices: ANACIM (Senegal), Mali Meteo, ANAM Burkina Faso, DMN Niger, ANAM Chad and DMNTogo,plus ACMADand AGRHYMETin2021.
Thisactionaimsat:

(i) At synoptic scale : a better understanding and better forecasting of rains, especially extreme rains.

(ii) At subseasonalrange : setup a methodology for S2S prediction based on the human expertise of several ensembles.

(iii) Build capacities of West African NMHSs in delivering useful information to their stakeholders.

In recent years, CREWS-Burkina Fasopilote project benefited from this structure, followed by CREWS-Togo and CREWS-Chad in 2021.

To this end, a series of product so fnumerical forecast models, satellite products and insitu observations are developed at the state of the art by the CNRM and updated daily on a webpage.

A daily summary of the most effective synoptic products is created automatically, as well as a weekly briefing for the subseasonal range. A weekly video-discussion takes place every Tuesday from June to October. Common French language is a serious asset for this project.

The new version of the MISVA website will be presented, as well as some innovative products.

Despite a limited skill of rain forecast in the deterministic and ensemble forecast systems as well as alimited influence on the mjo over west Africa, we show that the comprehension of regional driversof variability, combined with the analysis of relevant parameters other than precipitation, can lead to a very useful S2S predictions.

Boreal Summer Intraseasonal Oscillation Convective Initiations in S2S Reforecasts

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Abstract : Boreal summer Intraseasonal Oscillation(BSISO) with a 20-90 day periodicity is closely tied to the active and break phases of Indian Summer Monsoon(ISM) and is a major source of predictability on the intraseasonal timescale. Predicting the initiation of BSISO over equatorial Indian Ocean is of vital importance in the prediction of BSISO northward advancement over the ISM domain. This study tries to quantify the skill of BSISO convective initiation and propagation in models which are part of the Sub-seasonal to Seasonal (S2S) prediction project. The BSISO convective initiations over the Equatorial Indian Ocean are identified using a BSISO index and skills of S2S models are assessed. The models show a wide range of skills ranging from 10 to 26 days in predicting the BSISO initiations. The convective initiation prediction skill is relatively less compared to the strong BSISO propagation skill in majority of the models. The convective strength and propagation speeds (both eastward and northward) are better represented in the ECMWF and UKMO reforecasts as compared to the other models. Previous studies show that mean moisture distribution in the lower troposphere is an important factor in deciding the ability of the model in simulating the BSISO characteristics. The relationship of the mean moisture gradient over the ISM domain and its relationship with BSISO initiation and propagation prediction skill is also examined in the S2S models and a moderate positive relation is found.

Case Study : Subseasonal Prediction for Disaster Risk Reduction - May 2018 Extreme Rainfall Event in Sri Lanka

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Abstract : Predicting extreme rainfall events well in advance can significantly reduce the impact of climate-related disasters. The Madden-Julian Oscillation (MJO) is considered as the dominant mode of subseasonalvariability in the tropics. Especially in the Indian Ocean and particularly Sri Lanka, the MJO strongly modulates the probability of wet periods during phase 2 and 3. As MJO can be predicted with considerable skill at lead times up to 2–3 weeks at present, S2S prediction of heavy rainfall events can be used to help protect life and property by disaster preparedness and humanitarian planning.

During 19-27 May 2018, heavy torrential rains led to severe flooding in northwestern Sri Lanka , as well as flooding and landslides in southwestern parts.

A major driver of this event can be shown to be the passage of an active pulse of the MJO, that coincided with the climatological date of the monsoon onset.

This pulse was predicted up to 30 days in advance by the European Centre for Medium Range Weather Forecasts (ECMWF)- Ensemble System.

It facilitated to carry out preparedness activities, response planning and humanitarian planning to reduce impact of disaster. Compare with floods and landslide events that occurred in May 2016 and May 2017, preparedness measures helped to significantly reduce the death toll in May 2018.

Northward Propagation of Convection during Boreal Summer over Arabian Sea and Bay of Bengal

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Abstract : Indian summer monsoon exhibits a dominant mode of variability in intraseasonal timescale (20-70 days), which is associated with northward propagation of convection from the equatorial region to the foothills of the Himalayas. We aim to understand the governing dynamics behind this northward propagation of convection over the Arabian Sea (AS) and Bay of Bengal (BoB) using the vorticity budget equation. Many previous theories have suggested that the generation of vorticity to the north of an existing convection center in the presence of mean easterly shear is essential for the convection to move northward. Using observational analysis, we found that the tilting term in the vorticity equation leads the rainfall maxima by about 6-8 days over BoB and 2-3 days over AS. Moreover, the tilting term exhibits stronger nature over BoB as compared to AS.

Further investigation shows that the component of the tilting term associated with the meridional gradients in vertical velocity in intraseasonal timescale acts to the vertical gradient of the zonal mean flow to generate positive anomalies in tilting. It is also found that convective updrafts are generally stronger and more vertically stretched over BoB, which could be responsible for the enhanced tilting. The beta effect is found to be essential for northward propagation over BoB. Beta effect induces an asymmetry in the meridional winds around the convection maxima, which drives dry air into the convectioncenter and helps develop a new convection center to the north. This mechanism is relatively much weak in the AS. However, a component of the tilting term associated with vertical shear of mean meridional winds modulate ISO propagation over AS and helps explain the higher phase speed over AS compared to BoB.

Preliminary results on implementing these diagnostics on a 15-year long multi-physics multi-model ensemble (MPMME) data developed using coupled model CFSv2 will also be discussed. This study underlines the role of convection in northward propagation and provides a pathway to improve model performance for simulating intraseasonal variability and summer monsoon.

Predictability of Summer Monsoon Monthly Rainfall and Associated Extreme events over Taiwan by using NCEP GEFSv12 Model

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Abstract : The skillful prediction of monthly scale rainfall at small regions like Taiwan is one of the challenges of the meteorological scientific community. As far as seasonal rainfall prediction is concerned, existing forecast systems across the world can simulate the year-to-year variation. However, the month-to-month variability during a year is still challenging due to the large uncertainty associated with aberrant internal low-frequency fluctuations. Taiwan is one of the sub-tropical islands in Asia and it is one of the world's most mountainous islands where landslides and flash floods in/near the mountains and flooding over low-lying plains and urban areas are the main hazards and regularly experiences rainfall extremes, particularly during summer monsoon season (June through September; JJAS). In September 2020, NOAA NCEP implemented Global Ensemble Forecast System version 12 (GEFSv12) to support stakeholders for sub-seasonal forecasts, hydrological applications, and consistent reforecast data for 2000-2019 has been generated. In this study, the GEFSv12 rainfall reforecast products on a monthly scale rainfall and associated extremes have been evaluated against CMORPH data. For further prediction skill improvement, the GEFSv12 rainfall raw products have been calibrated with a quantile-quantile (QQ) mapping technique against CMORPH. The results suggest a remarkable improvement in the prediction skill of GEFSv12 in representing the East Asian summer monsoon circulation dynamics and its influence on summer monsoon rainfall over Taiwan compared to GEFS-SubX. The spatial patterns of climatological features of monthly rainfall over Taiwan during JJAS from Raw and QQ-GEFSv12 are similar to CMORPH. However, Raw-GEFSv12 has a large wet bias and overestimated wet days, while QQ-GEFSv12 is close to realistic. The rainfall prediction skill of GEFSv12 is significantly high (>0.5) in most parts of Taiwan and particularly more during peak monsoon months. The calibration method significantly improved the prediction skill of deterministic and ensemble probabilistic forecasts of summer monsoon monthly rainfall and associated extreme rainfall events (> 50mm/day) over Taiwan.

Key words : Summer monsoon, Post-processing, GEFSv12, Extreme events, Prediction skill, Taiwan.

The Roles of Extra Tropical Atmospheric Circulations in the Madden Julian Oscillation

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Abstract : The Madden Julian oscillation (MJO) of tropical convection couples to the global atmospheric circulation. It drives Rossby waves into the global atmospheric circulation, and these Rossby waves interact with the momentum budget of the tropics, thereby influencing the characteristics of the tropical MJO signals in convection and circulation. This review summarizes the nature of this coupling between the tropics and the global atmosphere and suggests how this coupling influences the spectral and structural characteristics of the organized tropical convection and its associated atmospheric circulation.


SHORT ORAL
CUM
E-POSTER

THEME : CLIMATE CHANGE AND MONSOONS

Role of Aerosols in Modulating Clouds and Precipitation over Central Highland Region of India

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Abstract : Aerosols have important role in modulating the cloud properties and consequently precipitation over a region. Aerosols concentration and size have impacts on precipitation, i.e. either supress or enhance precipitation by modulating cloud properties. The association of aerosol and precipitation is studied over Central highland region of India and therefore to understand the long-term impact of aerosols on the precipitation, the eighteen year (18) years (2003-20) observational datasets of Aerosols Optical Depth (AOD), clouds, and meteorological parameters are considered. It is found that, the presence of fine-mode aerosols during the summer monsoon season (June-July-August-September) may enhance monsoon precipitation. In addition, the fine-mode aerosol is associated with high cloud fraction containing both liquid water and ice. Such findings certainly help to understand long-term impacts of aerosol on clouds and precipitation.

Key words : Aerosol Optical Depth, Precipitation, Cloud properties, Fine mode aerosol, MODIS.

Modeling of the Malaria Transmission Dynamics over Four regions in India

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Abstract : Over the course of history Malaria has taken a enormous toll on both human life and development in malaria endemic countries (Hay et al. 2010). Several countries in the temperate climate managed to eliminate it (Killen et al. 2002). In Indian region, out of twelve Anopheles species nine Anopheles vectors are intricate in malaria transmitting in diverse geo-ecological paradigms. Around 2 million confirmed malaria cases and 1,000 deaths are reported annually, according to the WHO South East Asia Regional Office estimates 15 million cases and 20,000 deaths. In Southeast Asia India contributes 77% of the total malaria cases and mortality. Multi-organ involvement/dysfunction is reported in both parasite Plasmodium falciparum and P. vivax malaria cases.Likewise 80 per cent of country's total malaria cases were reported from 10 states, viz., Jharkhand, Chhattisgarh, Odisha, West Bengal, Maharashtra, Gujarat, Madhya Pradesh, Assam, and Rajasthan. Uttar Pradesh.

Revisiting the Indian Summer Monsoon Variability over the Eastern Coast of India

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Abstract : The Indian Summer Monsoon (ISM) is one of the most studied meteorological component of the hydrologic cycle due to the complexity of multi atmospheric processes involved besides its great importance in the economy and environment. The ISM (June-July-August-September) has the most contribution in the annual rainfall regime of India and displays a heterogeneous distribution. Further the behaviour of Indian Summer Monsoon Rainfall (ISMR) as strong and weak ISM is moreover impacted by the large-scale coupled interactions of ocean, land and atmosphere in the equatorial Indian as well as Pacific Ocean. This study investigates the ISMR and its spatiotemporal variability over the eastern coast of India (ECI) which are generally designated as the coastal plains of India. For the study, we have acquired precipitation observations from Monsoon-Asia APHRODITE (horizontal resolution 0.25° × 0.25°; 1951-2005) and Hadley-OISST (horizontal resolution 1° × 1°) from NCAR-UCAR. It shows that the ECI has decreasing monsoon rainfall distribution spatially moving towards the south (coastal West Bengal to southern coastal Tamil Nadu). The El Niño–Southern Oscillation (ENSO) impacts the ISMR as the eastern coast of India receives less rainfall in the warming phase of ENSO in comparison to the cold phase. In addition, the southern coastal regions as South Andhra Pradesh, and Tamil Nadu have relatively higher ISMR (in comparison to northern coastal regions) in cold phased years with respect to warm and neutral phases of ENSO. The impacts of Indian Ocean Dipole (IOD) on the ISM is assessed showing mixed signals over the eastern coast of India besides more rainfall during the negative IOD in some of the coastal regions with respect to IOD categorization. The ENSO-IOD connection is examined besides the seasonality and regime shift in the rainfall over the eastern coast of India. With the ISM being impacted by the decadal oscillations, possible teleconnections are discussed.

Key words : ISMR, ENSO, IOD.

Does El-Nino amplify the Arabian Sea Aerosol and Indian monsoon relationship?

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Abstract : Recent studies have shown a positive relationship between Arabian Sea (AS) aerosols and Indian monsoon rainfall at short time scales. However, not much is known about what factors control this relationship. This study investigates the role of El-Nino Southern Oscillation(ENSO) in modifying this Arabian Sea Aerosols and Indian Monsoon (ASAM) relationship. The ASAM relationship was explored using 33 years of long-term aerosol and rainfall datasets. Irrespective of the phase of ENSO, the correlations were found to be positive and significant. The highest dust loading over AS was found to be during El-Nino, followed by Normal and La-Nina. The ASAM correlations follow the overall dust loading over the AS, with the highest values during El-Nino, followed by Normal and La-Nina. During high dust aerosol loading conditions irrespective of the phase of ENSO, the moisture carrying south-west winds over AS is intensified and shifted northeastward towards the Indian mainland, increasing the overall moisture convergence and rainfall over India. The surprising finding is the highest dust-induced rainfall enhancement during El-Nino when the large-scale seasonal rainfall is the least over India. This has implications for rainfall projections into the future as both El-Nino characteristics and dust emissions in the adjacent deserts change.

Long-Term Trend in Rainfall during Various Seasons : A Case Study over India

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Abstract : Many studies attempted in the past to address the question of long-term trends in the Indian Monsoon rainfall and extreme rainfall during the monsoon season. But there are very few attempts made till now to investigate the same aspects for rainfall during various seasons over the Indian region. While the rainfall during the pre-monsoon and post monsoon are smaller than the monsoon precipitation, it still comprises up to 30% of monsoon rainfall and is considered important because of its role in agricultural practices in the country. Although rainfall is an important aspect of agriculture, increased frequency of extreme rainfall is creating huge damages to life and economy. Studies show an increase in extreme rainfall events over India in the recent past. In the present study, an effort is made to investigate the long term trends in the mean rainfall and extremes during various season over the Indian region using 41 years of daily gridded rainfall data from Indian Meteorological Department (IMD). In this study the regions which showing an increasing trend in both mean and extreme rainfall is identified for various seasons over India.

Study On Long Term Trends in Atmospheric Moisture and Its Teleconnections with Monsoon Rainfall

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Abstract : India receives a major share of rain during the southwest monsoon, which serves rain-fed irrigation for agriculture and hence it is important for the economy of the nation. The moisture transported from adjacent water bodies and land areas regulate the intensity and duration of the rainfall. It is reported that the monsoon is getting weaker alongside an increasing trend in extreme events. In the present study, we are discussing some of the long time trends in atmospheric moisture over the Indian subcontinent and adjoining water bodies. Also, the impact of the moisture trend affects the overall monsoon rainfall. For this study, we have used daily rainfall data from IMD and temperature and humidity data from NCEP. We focus the study on extreme rainfall. We have analyzed the moisture and rainfall patterns from 1951 to 2020, together with some of the derived moisture parameters such as total column precipitable water and moist static energy. After 1985, it has been observed that the trend in the lower atmospheric moisture was significantly increasing. The last two decades recorded a significant increase than the previous decades. These positive trends were recorded mainly over the northeastern sector of the African continent, the southern Indian Ocean extending till the Arabian Sea and northern India. The increasing trend in moisture was observed to be high in the lower layers of the atmosphere up to 700 hPa. The increase in extreme rainfall events is concentrated in the last decade. The increase in the temperature causes the atmosphere to hold more moisture. This recent increase indicated by the above parameters gives rise to the formation of tall cumuliform clouds with the capability of forming catastrophic extreme rainfall events in the warm environment.

Some characteristics of monsoon disturbances over the north Indian Ocean in recent years

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Abstract : The large scale monsoon circulation over the south Asian region is highly influenced by the monsoon disturbances (depression (maximum sustained wind (MSW) speed (17-33 knots)) and cyclones (MSW speed ≥ 34 knots). Considering the impact of climate change on inter annual variability of characteristics of these disturbances and the monsoon rainfall, a study has been undertaken to analyse the trends in charateristics of monsoon disturbances during summer monsoon season (June - September) in terms of their genesis, life period, track & translational speed, accumulated cyclone energy and power dissipation index over the Bay of Bengal (BOB) and Arabian Sea (AS) based on the best track data of India Meteorological Department during the period of last 30 years (1991-2020) as compared to previous 30 years period of 1961-90.

There has been about two and 0.9 cyclonic disturbances (CDs) (MSW ≥ 17 knots) per year over the BOB and AS respectively during 1991-2020 against 4.7 and 0.8 CDs per year during 1961-1990. Thus there is significant decrease by about 57% in average number of CDs over the BOB in recent 30 years as compared to previous 30 years. However, the study indicates that there is no significant trend in the genesis frequency of CDs over the BOB and an increasing trend in genesis frequency over the AS during 1991-2020. There is a decreasing trend in the duration of CDs over the BOB during 1991-2020 (3.5 hrs per year) du to limited westward propagation of these CDs. The 12 hourly translational speed of CDs do not show any trend over the BOB and AS. The accumulated cyclone energy (ACE) and power dissipation index(PDI) shows decreasing trend over the BOB and increasing trend over the AS which could be attributed to decreasing duration of the CDs over the BOB and increasing trend in the frequency & intensity of the CDS over the AS respectively.

Key words : Monsoon, Cyclonic disturbance, Bay of Bengal, Arabian Sea.

Estimating the Trend of Climatic Parameters over the Helmand River Basin, Afghanistan from 1981-2019

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Abstract : This study presents an overview of the trend of climatic parameters over the Helmand River Basin, a large, closed, arid basin in southern of Afghanistan. The objective is to investigate the trend of climatic parameters over the Helmand River Basin, to understand this objective, first of all, the observed data arranged to generate climatic parameters datasets include Temperature, (Tmax, Tmin), Precipitation, for the period from 1981-2019. Then regression equation and correlation coefficient analysis were applied between climatic parameters and time span to determine the trend of climatic parameters.

The study found that in the upper Helmand river basin which is locate in high elevation, annual temperature decreased and precipitation, increased but in the lower Helmand river basin which situated in low elevation, temperature increased and precipitation decreased.

There is considerable uncertainty due to the data scarcity, but all results indicate a strong tendency towards drier conditions. Warming trend, partly above 0.5°C since the 1981s in combination with a dramatic precipitation decrease by varied rate in lower part. The Helmand river basin, about 40 percent of Afghanistan receives most of its moisture from melting snow and spring storms. Similar to many desert streams, the Helmand river and its main tributary, the Arghandab River, are characterized by large fluctuations in monthly and annual temperature and precipitation.

Based on the results of the study, change in the climatic parameters is already perceived in the study regions. As it was expected from climate trend analysis, most of the people agreed on increasing temperature, and decreasing precipitation. This study recommends that due to climate change, temperature and precipitation are highly uncertain in Afghanistan and policy makers should considers this issue while making strategies. This study can be used as an outline for another river basin in Afghanistan.

Counter-Clockwise Shift of the Indian Monsoon Sparse Zone in context of Climate Change

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Abstract : The spatio-temporal variability of the Indian summer monsoon is an interesting topic for climatologists. However, the spatio-temporal variability of drought prone areas of India in the context of climate change gets less attention. In recent decades, Indian monsoonal rainfall has gotten weaker, and India has not experienced any excess monsoon years in the last two decades, while a number of deficit monsoon years have occurred in the recent past (2002, 2004, 2009, 2013). In the present study, a zone with less seasonal rainfall compared to the long-term average climatology (116 years) is considered the Monsoon Sparse Zone (MSZ). It is found that, the region experiences more drought events where MSZ persists, which confirms that the MSZ is one of the primitive conditions for the formation of the drought. Various datasets were used to study the MSZ and its epochal shifts during the past century in India. The MSZ locales follow the counter-clockwise transition from west to north-central India through the peninsular region from one epoch to another (each of 29 years). Detailed analysis suggests that MSZ shifting is insensitive to epochal time selection. The large-scale fields that have a physical relationship with the monsoonal rainfall are commensurate with the MSZ shift. Furthermore, in the process of identifying the future location of MSZ, Coordinated Regional Climate Downscaling Experiment-South Asia (CORDEX-SA) regional climate models simulation outputs are used. The profound statistical analysis indicates that the MSZ will continue to counter-clockwise shift over India. In the future, it will be shifted over to north-west India through central India. This is of great concern in a region that is seeing continued growth in the population and a need for increased agricultural intensification. The study findings will be useful for climatologists, drought monitoring, water resource planning, agriculture, as well as different socioeconomic sectors in India.

Key words : Indian summer monsoon variability, monsoon sparse zone, drought.

Active-break cycles of Indian summer monsoon and their variability during cold and warm Phases

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Abstract : Characteristics feature of Indian monsoon rainfall is the prolonged spells of wet and dry condition often lasting for some weeks. During these wet and dry spells, precipitation over Indian landmass is characterized by periods of enhanced and reduced rainfall, which are commonly referred to as 'active' and 'break' phases of the monsoon respectively (Ramamurthy 1969; Raghavan 1973). Here we use high resolution (0.250 x 0.250) gridded daily rainfall dataset for the period 1901-2020 to identify the active and break spells based on standardized daily rainfall anomaly averaged over core monsoon zone(650E-880E,180N-280N) following Rajeevan et al., (2010). Because Indian Summer Monsoon rainfall (ISMR) shows a significant correlation with rainfall over core monsoon zone. We find 193 active spells and 142 break spells of different duration during 1901 to 2020, out of which more(less) no active (break) spells are observed during cold phase (1901-1960) while the reverse trend is observed during warm phase (1960-2020). Active spells of 3-4 days followed by 5-6 days are more as compared to longer spells(>6days). However, for longer spells (>11 days) break spells are more than the active spells irrespective of warm and cold phase. During both cold and warm phase an increasing trend is found in active days while break days show a decreasing (increasing) trend in cold(warm) phase. Considering decadal variability, active (break) days are more during 1941-1950 (1991-2000). During monsoon season maximum number of active (break) days are observed during 21-31 July (21-31 August) and thereafter active(break) days show decreasing(increasing) trend. In the present study we also examine the composite rainfall anomaly over Indian landmass, composite SST, OLR, surface pressure and wind anomalies over Indian region. This study also examines the evolution of active and break phases with 5, 10, 15 and 20 days lag of rainfall, SST, OLR, wind, latent and sensible heat flux. This study clearly depicts the distinct characteristics of different surface field including rainfall during active and break phases and their evolution.

Decadal variability of Monsoon Core Zone rainfall

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Abstract : The present study examined the variability of summer monsoon rainfall over the Monsoon Core Zone (MCZ) using century-long observed rainfall data. Spectrum and wavelet analysis of rainfall observation reveal significant decadal variability in MCZ rainfall. Wavelet analysis also revealed that, from 1930 to 2005, the amplitude of decadal variability is amplified compared to the prior half-century. Correlation analysis with dominant sea surface temperature (SST) indices of the global ocean confirms that MCZ rainfall decadal variability undergoes temporal modulations. Interdecadal Pacific Oscillation (IPO) and Niño3.4 region SST variability displayed a significant negative correlation during 1901-1948, whereas, during 1949–1980, Topical Indian Ocean shows positive correlation, and during 1981–2010, IPO, Pacific Decadal Oscillation (PDO) and Niño3.4 SST variability display positive and Tropical Indian Ocean (TIO) basin-wide SST, Atlantic Multi-decadal Oscillation (AMO) displays negative significant correlation with MCZ rainfall variability. Detailed study of dynamical and moist thermodynamical processes associated with decadal rainfall variability is studied, which adds value in developing decadal prediction system and contribute towards understanding the hydrological, ecological and socioeconomic aspect of MCZ as well as neighbouring regions.

Key words : Monsoon Core Zone, Decadal Variability, Rainfall, Monsoon, Dynamics, Thermodynamics.

Projection of Indian Monsoon Sparse Zone shift under Climate Change

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Abstract : The spatiotemporal variability of the Indian summer monsoon (ISM) is of interest both from a societal perspective as well as a scientific endeavor. Recent studies indicate the potential for weakened Indian monsoonal rainfall. The Indian region has yet to experience an "excess monsoon" year in the 21st century. On the other hand, several "deficit monsoon" years have been witnessed (e.g., 2002, 2004, 2009, and 2013). Thus, understanding how the monsoon variability interplays with drought potential is of growing relevance. For such an assessment, this study defines a zone with less seasonal rainfall than the long-term average (116 years) as a 'Monsoon Sparse Zone (MSZ)'. Various datasets were used to study the MSZ and its epochal shifts during the past century in India. It is found that the region experiences more drought events where MSZ persists thus highlighting that the MSZ is one of the preconditions for the initiation and persistence of the drought. The MSZ hotspots show a counter-clockwise transition from west to north-central India through the peninsular region from one epoch to another. The epochs considered equalsubperiods of 29 years each for the 116 years. The results were tested for the duration of the epochs considered, and it is found that the MSZ shifting is insensitive to epochal time selection. The large-scale meteorological features related to the monsoonal rainfall also commensurate with the MSZ shift. In the context of identifying the projected future location of MSZ, Coordinated Regional Climate Downscaling Experiment-South Asia (CORDEX-SA) regional climate models simulation outputs are analyzed. The statistical analysis of the CORDEX data indicates that the MSZ will continue the counter-clockwise march over India. The MSZ location is likely to be shifted over to northwest India through central India in the future. This shift is of concern as it indicates that the region that is seeing continued growth in the population and has increased agricultural intensification could lead to cascading impacts. This finding related to the potential shift in MSZ would need to be considered for food and water security across India and indeed the wider monsoon region.

Key words : Indian summer monsoon variability, monsoon sparse zone, drought.

Identification of Temperature and heat wave zones over India

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Abstract : Heat waves are studied to understand their regional vulnerability, causation over the Indian subcontinent in the context of the current global warming scenario. An updated, high resolution gridded surface air temperature data sourced from the India Meteorological Department (IMD) for the recent 70-year period (1951-2020) is used to ascertain the regions of maximum temperatures and heat wave vulnerability during the hottest months of March to May. Results reveal three distinct regions of maximum temperatures, over West Rajasthan in Northwest, North Madhya Pradesh and Southwest Uttar Pradesh in North-central, and East Maharashtra in South-central parts of India based on both the magnitude and frequency days of maximum temperatures. Contrastingly, three localised regions of heat wave vulnerability were identified in the north, northeast and southeast parts of India incontrovertibly different from the three maximum temperature zones. The causation of heat waves was identified as the advection of heat by anomalous southwest, west and northwest wind flow from the three maximum temperature zones. Heat waves over southeast India, manifesting since 1970 denote the impact of global warming in recent decades. Climate model simulations of the current climate conform with the observed maximum temperature zones indicating the role of radiative heating. This study discerns the regions of maximum temperatures and heat wave vulnerability and identifies the causation to be triggered by wind flow from the maximum temperature zones under favourable atmospheric circulations. Results from this study would find wide application not only in the prediction, but also in the risk and vulnerability assessment.

Key words : Maximum temperatures, Heat Waves, atmospheric flow patterns, Model simulation.

Evaluation of Indian Summer Monsoon System under the influence of Climate Change

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Abstract : This study is aimed at evaluating response of the Indian Summer Monsoon (ISM) to the climate change scenarios based on various coupled climate models. The monthly averaged datasets of twelve coupled climate models are considered from the Coupled Model Intercomparison Project phase 6 (CMIP6) outputs for the study period of 1980-2014 and 2065-2100 for the investigation of the Indian Summer Monsoon. The evaluation of the historical simulation of the models is done by comparing the model outputs with the various ground based observations, satellite, and reanalysis datasets. Further, the robust climatic models were selected to visualize the behaviour of ISM under variable warming scenarios. The analysis between the historical simulation of the models with the observational/reanalysis datasets show differences but few models like CESM2, CESM2-WACCM, and MRI ESM2 well captured the pattern of ISM. Significant Inter model differences are also noted in this study. The statistical tests conducted for examining the differences in the historical and the future warming scenarios infer that there is a significant change in the pattern of ISM due to climate change. Thus, it can be concluded that with the help of CMIP6 models that there is a significant alteration in the Indian Summer Monsoon in the future when compared with the historical simulations and observations. Detailed results will be presented during the conference.

Key words : Coupled Climate Models, Indian Summer Monsoon, CMIP6, Statistical Tests, Historical simulations.

THEME : FIELD EXPERIMENTS AND OBSERVATIONAL CAMPAIGNS

Thermodynamic Structure of Atmospheric Boundary Layer over the West Coast of India during Active and Weak Phases of Indian Summer Monsoon

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Abstract : Atmospheric boundary layer (ABL) is the layer very close to the Earth's surface where significant interaction of mass, momentum and energy take place between the Earth's surface and the atmosphere. Earlier studies indicated considerable difference between the thermodynamic structure of the ABL over the southern and northern Arabian Sea due to the unique dynamic structure over the region. Increasing influence of thermodynamics on the rainfall towards future is also reported elsewhere. However, the ABL thermodynamics is rarely reported due to the lack of continuous and quality data with high vertical resolution. Current study investigates the thermodynamic structure of the west coast of India during active and weak monsoon situations using high resolution radiosonde data (~ 5 m height interval) of Thiruvananthapuram (TVM), Mangalore (MNG) and Mumbai (MUM) obtained from India Meteorological Department (IMD). Daily station rainfall from IMD over these stations and OLR data from NOAA are also used for the study. The active and weak monsoon are classified based on the OLR values over the region. The atmosphere is near neutral or absolutely stable during active monsoon conditions and conditionally unstable during weak monsoon situations over Thiruvananthapuram and conditionally unstable during both active and weak conditions over MNG and MUM. The ABL over MUM show well defined mixed layer up to about 800 m during weak monsoon. Further, the conditional instability over MUM is stronger than that over MNG. Rainfall is found to be more associated with the stations with unstable ABL. ABL height is more during the weak monsoon conditions in all the stations, and the variation is more (> 1 km) over MUM. The different thermodynamic structure over the stations is attributed to the unique wind profile over the stations.

Characteristics of Tropical warm clouds and its role on the summer monsoon rainfall

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Abstract : This study investigates the role of warm clouds associated with monsoon rainfall and the warm rain onset process. Due to the high sensitivity to cloud droplets, ground-based cloud radar measurements are instrumental for characteristics of warm clouds and studying smaller cloud droplets' growth into a giant raindrop. Quality controlled, and high-resolution vertical-looking Ka-band radar measurements, during July-August 2015, are utilized. Along with the cloud radar, the co-located surface-based and space-based measurements extracted specifically for warm clouds are also used which make this a unique and robust multi-instrument-based observational study on warm clouds over India. An indigenously developed cloud classification algorithm is used over a data sample of 1.8 million profiles to extract the vertical profiles of equivalent reflectivity factor (Ze) when cloud height is confined to 0° isotherm (5.3 km AMSL). Rain and microphysical parameters are examined during the occurrence of warm clouds from the Disdrometer, rain gauge, and CloudSat respectively. Two modes of warm clouds have been detected; boundary layer shallow clouds whose cloud top is limited below 4 km and cumulus congestus having cloud top between 4.0 and 5.5 km. Temperature lapse rate well explained the generation of shallow cloud at trade inversion layer at 3 km which later weaken and rise to 5 km increasing cloud top height. Low-level updraft and subsidence above the warm clouds are also evident from the vertical velocity. Non-precipitating characteristics of the majority (75%) of the warm clouds are prominent from the Ze (and velocity) peaks at -20 dBZe and -40 dBZe (-1 m/s) in the CFAD analysis. Both Disdrometer and CloudSat observations confirm the superiority of smaller cloud drops and hence weak inherent nature of warm clouds. Maximum Ze below 20 dBZe with 25% frequency limits the possibility of heavy warm rain. It further leads to a poor amount (13%) of rain accumulation due to warm clouds to the total rain accumulation.

Observational atmospheric vertical structure of Core monsoon zone in Central India

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Abstract : During the monsoon season, the Indian Summer Monsoon (ISM) core zone is characterized by the establishment Tropical Convergence Zone during onset and it fluctuates in this region for the peak monsoon months. The rainfall in core zone aids in the identification of active and break spells by average rainfall throughout the region. Observation from Bhopal, in Central India, a crucial core monsoon zone, has the potential to provide new insights on ISM knowledge and predictability. The study uses 11 years of GPS-Radiosonde measurements obtained from Indian Meteorological Department (IMD) during 2011-2020. Seasonal wind reversal, higher humidity content, elevated levels of freezing layer, cold point tropopause and boundary layer, increase of convective available potential energy (CAPE) and active presence of all levels of clouds characterise the monsoon at the study site. To study the turbulence characteristic over the region, turbulence structure parameter of refractive index; C_n^2 has been determined using the temperature, humidity and pressure profile. Atmospheric vertical structure shows a layered structure of turbulence with higher values in the boundary layer. Monsoon signature is evident in the vertical structure of turbulence with a local minimum band of C_n^2 observed clearly around 10–15 km. The presence of such minimum in C_n^2 persists throughout the annual cycle; however, its presence is much prominent during monsoon season. The monsoon is further characterized by the interaction of three level cloud systems (low, mid and high) which are present only during monsoon. Fractional cloud cover at all pressure levels from ERA5 reanalysis has been used to study the cloud vertical structure. Investigation of turbulence and cloud features help in better understanding of ISM.

Wet scavenging of heavy metals during monsoon season in Delhi

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Abstract : Metropolitan cities of India are facing multitude of problems such as widespread urbanization, hazardous air pollution levels, overpopulation, water scarcity, water contamination, etc. Rain water is a major source of fresh water on earth but in heavily polluted regions it is contaminated with air pollutants such as SO2, NO2, particulate matter, heavy metals etc. In this study, assessment of heavy metals was carried out in atmospheric precipitation events in the months of July and August during 2021 at JNU site in Delhi. Among the investigated species, lithogenic metals such as Al ranged between 0-5180 µg/l whereas trace elements such as Pb, Ni and Cd which are largely contributed by anthropogenic sources ranged between 0-870 µg/l, 0-610 µg/l and 40-120 µg/l, respectively. Levels of various heavy metal species in rain water are influenced by factors such as proximity of sources, direction of air masses and the amount of precipitation, thereby, making precipitation chemistry an important marker of atmospheric pollution. Higher relative abundance of metals such as Pb and Cd which are potentially toxic to living organisms, results from contamination due to anthropogenic sources in Delhi. These metals are scavenged during rainfall and get deposited onto different surfaces. Hence, the atmospheric deposition of the metal aerosols needs to be studied in a more comprehensive manner. Rain water harvesting is considered as a popular measure for mitigation of water scarcity to meet human needs, therefore, studies related to heavy metal composition of rain water are significant from human health point of view also.

THEME : HIGH IMPACT MONSOON WEATHER

Extreme rainfall events prediction during Indian Summer Monsoon using Convective-scale Ensemble Prediction System

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Abstract : In order to explore atmospheric predictability of high-impact monsoon weather under more realistic framework, it is necessary that models have sufficient resolution to explicitly resolve mesoscale processes and moist convections.The efforts to tackle the uncertainty at shorter time scale have led to the ensemble approach applied at convective scale resolution.The regional ensemble prediction system at National Centre for Medium Range Weather Forecasting (NCMRWF) (NEPS-R) is used in this study for predicting extremely heavy (≥200 mm/day) and very heavy (120-200 mm/day) rainfall events during Indian summer monsoon season in year 2019. NEPS-R is based on the regional version of Met Office Global and Regional Ensemble Prediction System (MOGREPS) with 12 ensemble members (1 control + 11 perturbed). The horizontal resolution of NEPS-R is ~4 km and there are 80 vertical levels extending up to a height of 38.5 km. The initial and boundary conditions generated from the NCMRWF Global Ensemble Prediction System (NEPS-G) are downscaled to run NEPS-R. The initial condition perturbations in NEPS-G are generated by Ensemble Transform Kalman filter (ETKF) method. The model uncertainties in NEPS-R are addressed by Random Parameters (RP2b) scheme. The probabilistic precipitation forecasts from NEPS-R are verified with respect to NCMRWF satellite gauge merged rainfall observations. The probabilistic skill of the regional model forecasts is quantified with reference to long term climatology from the Indian Monsoon Data Assimilation and Analysis (IMDAA) reanalysis between 1979 and 2018. This convective scale NEPS-R is able to capture the extremely heavy and very heavy rainfall events with significant predictive skill at short range prediction scale.

Did the first paper in meteorology published by an Indian decode tornado dynamics 154 years ago?

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Abstract : Meteorological research was started in India since 18thcentury in the era of British colonialism mostly by the British people. Then, who was the first native Indian published a paper in meteorology? A paper entitled, 'A note on whirlwind at Pundooah' by BabuChunderSikurChatterjee documented in the 'Proceedings of Asiatic Society of Bengal' on 1865 (page no. 124, 125 and a plate) was probably the first paper published by a native Indian in an Indian journal implying that the meteorology, as a subject, was how much deep rooted in India. The paper was in the form of note reporting a tornado to the Surveyor General office of India occurred at Pundooah. The uniqueness of the note was that it was supported by a plate which depicted meticulously a mind-blowing sketch of the tornado invoking its locus, direction of rotation and horizontal scale of suction vortex and tornado cyclone retrieved from the trail of devastation. The spatial and temporal scales of tornado were exactly matched with the papers published more than hundred years later by Orlansky and Fujita. With all probability, the note may be the first paper which evaluated the horizontal scale of tornado and its suction spot accurately in the history of meteorology. This article has paved a way to rewrite the history of meteorology contributed by native Indian predating India Meteorological Department, constituted on 1875.

Key words : First paper in meteorology, Indian, tornado, Horizontal scale.

Simulation of Cloudburst Event Over Kerala during the 2019 Monsoon Season

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Abstract : The Cloudburst is an extreme weather event capable of producing torrential rainfall in a small area in a short time. A heavy rainfall event where the rainfall rate exceeds 100 mm/h is termed a classical Cloudburst. Cloudburst generally occurs during the monsoon season due to strong convection associated with orographic forcing over the western Ghats and Himalayan regionwhich causes widespread damage to property and loss of lives. So it is crucial to predict such events to help authorities to take preventive measures. We use the numerical mesoscale model Weather Research Forecast model (WRF) to simulate the cloudburst of Kerala on 8th August 2019, to capture and understand the underlying dynamical andthermodynamical characteristics of this event. The WRF model was initialized with NCEP GDAS and GFS data with two domains, the outer domain spans from 10°S to 30°N latitude, 55°E to 95°E longitude. The inner domain spans from 5°N to 15°N latitude, 70°E to 80°E longitude. We ran simulation with two sets of resolutions 15km, 5km and 9 km, 3km. Two cloud microphysics parameterizations namely Ferrier and WSM6 and two cumulus parameterizations namely Kain-Fritsch and New Tiedtke have been used for sensitivity study and examine the performance of the schemes. We conducted a sensitivity study on initializing data, resolution, and lead time. The results show that the best scheme to simulate the cloudburst was New Tiedtke and Ferrier with 9km and 3km two way nested configuration. The simulated hydrometeor structure of the cloud system from the best experiment is comapred with cloud hydrometeros derived from ERA-5 data sets. The result also showed that the 2-day lead simulation better captured the cloudburst characteristics and the simulation initialized with GDAS data performed marginally better than the simulation initialized with GFS data.

Key words : Cloudburst, Extreme Weather Event, WRF.

Comparing the interaction of dry air incursion with monsoon depression using ERA-5 and IMDAA reanalysis datasets

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Abstract : Monsoon depressions (MDs) that originate over the Bay of Bengal travel northwest and bring substantial rainfall over northern and central India during the summer monsoon. These events often interact with mid-level (700–400 hPa) dry air masses that significantly modify the rainfall pattern and intensity. Previous studies on MDs using global reanalysis data have often emphasized the need for higher resolution to understand the dynamics of such interactions better. The present study intercompares the composite structure and the mesoscale dynamics of MDs and their interaction with dry air masses using the ERA5 and the high resolution Indian Monsoon Data Assimilation and Analysis (IMDAA) reanalysis products. The study was conducted explicitly on monsoon depressions consolidated from the IMD cyclone track database for 1982–2012. Overall, the monsoon features are more realistically represented in IMDAA, whereas ERA-5 exaggerates the characteristics associated with vigorous monsoon circulation. In terms of accumulated precipitation, ERA5 fails to capture the intensity related to depressions when they interact with a dry air intrusion (D-with-DI). In contrast, IMDAA compares well with the observed IMD rainfall over all cases. The drop in magnitude of rainfall over the Western Ghats during D-with-DI events is also well captured by IMDAA as verified using IMD observations. The interaction with the dry air incursion is further explored using various thermodynamical parameters that effectively bring out the small-scale features that are not resolved in the ERA5 analysis. Thus, in summary, the high resolution of IMDAA enables us to capture the more refined mesoscale structure embedded within the MD, thus having a potential use for applications such as wind resource assessment over India.

Extreme Rainfall Events over India during Monsoons and its relation to the Madden Julian Oscillation: Probabilistic Predictability by the Medium-Range Multi-Model Ensembles

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Abstract : The Extreme Rainfall Events (ERE) have a large spatio-temporal variability and are often influenced by the large-scale oceanic and atmospheric coupled phenomena. One such dominant feature in the Tropics is the Madden–Julian Oscillation (MJO), which affects the weather and climate across the globe at an intraseasonal timescale, and it influences on the ERE is prominent south of 20°N, and the tropical weather by 55% across the various meteorological scales. A recent study by P.C.Anandh, and NareshKrishnaVissa (2020), examined that the occurrences and characterization of the ERE were more pronounced during the active phases of the MJO. In 2021, India recorded 125 extremely heavy rainfall events during September and October, the highest in five years, owing to late withdrawal of the southwest monsoon (SWM) and formation of higher-than-normal low-pressure systems. The highest rainfall departure of +1,538% was recorded in the Saurashtra and Kutch subdivisions of Gujarat state on 14-September. The Himalayan state received 203.2mm rainfall against the normal of 35.3mm in October. The SWM withdrew from the entire country on 25-October against the normal date of 15-October, making it the seventh-most delayed retreat since 1975. The Chennai city of Tamil Nadu state recorded 79% excess rainfall having received a total of 1097.6mm from 1-October to 28-November, during Northeast Monsoon season. These extreme rainfall episodes during recent monsoons including this year, gives necessity to focus, and study not only the rainfall prediction capability of the Numerical Weather Prediction Ensemble models, but also to derive the forecast relationship between MJO phases and amplitude along with ERE. This study focuses on the development of a grand multi-model ensemble probability approach for the prediction of extreme rainfall events along with probabilistic influence by the MJO active, suppress conditions in the medium range timescale (3-5 days) over Indian subcontinents.

References:
P. C. Anandh, and Naresh Krishna Vissa (2020), “On the linkage between extreme rainfall and the Madden–Julian Oscillation over the Indian region”, Meteorological Applications, DOI: 10.1002/met.1901

Key words : Extreme Rainfall Events, MJO, India, Monsoons, Ensemble Probabilistic Forecast.

Investigation of Rainfall and lightning inter-relationship during the South West Monsoon seasons over lightning hotspots of India

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Abstract : The country like India is associated with frequent occurrence of severe weather events like heavy rainfall, thunderstorm, lightning etc during summer monsoon season from June to September. The understanding of association of rainfall and lightning activity in various aspects is an important research footsteps. The relationship of lightning activity and rainfall over India is investigated during the summer monsoon seasons of last 5 years from 2017 to 2021. The gridded rainfall of India Meteorological Department available at the spatial resolution of 0.25° × 0.25° is used for this purpose. Further, the lightning data are collected from Indian Institute of Tropical Meteorology (IITM) and Earth Networks ground-based sensors which are capable of segregating cloud to ground and intra cloud lightning along with its polarity. Based on the rainfall category (light, moderate and heavy/very heavy), the clustering (k-means) is performed for the lightning data along with its spatial and temporal occurrences. The correlation of different categories of rainfall with lightning flash counts is examined at various time intervals, in time lags and effective radii. The correlation of flash count and rainfall intensity with different categories have also been examined over the lighting hotspot of India and surroundings. The findings of this study not only improve the understanding of lightning rainfall relationship over India during the southwest monsoon season from June to September and could also provide staple information for the improvement of forecasting of extreme events like thunderstorm/lightning.

Key words : Lightning, Rainfall, Clustering.

HRRR : Nowcast guidance to predict extreme weather events during monsoon season

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Abstract : Extreme rainfall events occurring on a nowcast scale have become a new reality of monsoon and they are one of the most devastating weather phenomenon over India. The High Resolution Rapid Refresh (HRRR) model became operational (experimental mode) at India Meteorological Department in January 2021. HRRR model operationalized in IMD is the first dedicated dynamical numerical weather prediction model specifically designed to improve nowcast and very short-range forecast services of the IMD. In the HRRR setup, the high resolution non-hydrostatic WRF model is configured with cycling data assimilation strategy using 3DVAR-FGAT technique. The model provides the forecast at very high temporal and spatial resolutions for next 12 hours with an update at 2 hours interval. The model is run simultaneously in three domains over Indian mainland covering Northwest India, East & Northeast India and South Peninsular India.

In this study evaluation of HRRR simulated near surface meteorological fields is carried out for 10 days between 1st August to 10th August 2021 against the different available observations such as conventional observations along with quality controlled multiple radar observations collected continuously at 10 minutes interval are considered for this study. The validation is done for all the three domains for which HRRR is run. During the period of study, there was a good agreement between the model predicted and the observed precipitation on an hourly basis. However, there are instances where the displacement is observed with respect to the region of precipitation. Standard verification metrics like RMSE, POD etc were also calculated for HRRR models for all three domains. With respect to synoptic observations, HRRR model run for Northwest India gave more Root Mean Square Errors for wind, temperature, pressure and humidity as compared to other two regions where errors were less. GPS based precipitable water also showed more bias for northwest India when compared to other two regions. With respect to radial winds also, comparatively northwest domain had more bias as compared to other two regions. The model is able to predict convection 6-10 hours in advance. Overall, HRRR products provided relatively reliable forecasts on all the three domains.

Key words : HRRR, WRF, 3DVAR, FGAT, RADAR.

Climatology of Thermodynamic indices and background synoptic conditions responsible for severe convection during pre to post monsoon seasons over Indian Region

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Abstract : Accurate forecasting of severe convective systems requires the knowledge of complex, non-linear interaction between the local thermodynamics and background synoptic conditions. In order to investigate the mechanisms responsible for severe convection associated with variety of mesoscale and synoptic systems in different seasons over the Indian region, a preliminary analysis is conducted to understand both the local thermodynamic and background conditions responsible for the severe convection. Using the monthly normals of India Meteorological Department (IMD) Radiosonde and Radiowind network of observations (1971-2000) available for 35 stations, various thermodynamic indices are computed. Monthly thermodynamic diagrams are prepared to understand the atmospheric instability along with the annual variation of basic parameters over the respective stations. Background conditions during the same period are also analyzed using the ERA5 reanalysis products. Particularly, the varying large-scale conditions and characteristic features during the Premonsoon, different phases (onset, active and withdrawal) of Southwest monsoon and Post monsoon seasons conducive for the severe convective systems will be discussed in the conference. Monthly Climatology of lightning flashes (TRMM LIS data) is also utilized. Investigating the monthly thresholds of various thermodynamic indices along with background large scale features over different regions can provide a helpful proxy to forecast the severe convective systems over the Indian subcontinent which have great socio-economic importance.

Monsoon over Mumbai - the contrasting behaviour of the clouds and precipitation during the inter-seasonal, intra-seasonal and heavy rainfall phases of south-west monsoon

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Abstract : The urban megacity of Mumbai which is situated on the western coast of Indian subcontinent experiences heavy rainfall spells during the pre-monsoon and monsoon periods from the cloud systems originating from the eastern and western part of the region respectively. The present study highlights the vertical structure of clouds and microphysical characteristics of precipitation during the inter-seasonal and intra-seasonal phases of monsoon over Mumbai for a continuous period of 4 years (2018-2021). The study will also portray the cause and the impact of the severe rainfall events of Mumbai which cause severe flooding at the city quite frequent during the monsoon times.

The study has been accomplished by using a Joss-WaldvogelDisdrometer data set up at IMD campus in Santacruz (Central Mumbai) along with the radar reflectivity data from S-band Doppler Weather Radar placed at Colaba in southern Mumbai. The wind direction and corresponding rainfall observation over Santacruz shows that Mumbai receives rain primarily from easterly winds during the pre-monsoon time which then shifts to the south-westerly winds during the monsoon period. A distinct diurnal variation with three rainfall peaks was noted for the pre-monsoon period. The dominance of urban convective environment in the pre-monsoon period and the impact of moisture supply from the marine sources over the city during the monsoon months are considered to be contributing factors for the contrasting diurnal pattern of rainfall for these inter-seasonal phases of monsoon. The corresponding vertical profile of radar reflectivity also shows that the rainfall peaks are complimented with clouds and hydrometeors yielding higher reflectivity during pre-monsoon season. The microphysical characteristics of rainfall shows, larger diameter raindrops dominate the pre-monsoon months compared to the monsoon period. The strong updraft generated during the pre-monsoon period is strongly related to these microphysical features of rainfall.

Monsoon intra seasonal Rainfall oscillation over Gujarat state 2021

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Abstract : Indian summer monsoon which exhibits a wide spectrum of variability on Diurnal, Daily, Seasonal, Inter annual and Decadal time scales over different region/state of the country. A study has been taken to analyse the intra seasonal variability of monsoon rainfall and associated characteristics for Indian Summer Monsoon 2021 over Gujarat state for Month of September has been carried out.

Gujarat state has two meteorological subdivisions Gujarat region and Saurashtra-Kutch. During monsoon season 2021, the subdivision Gujarat Regionreceivednormal rainfall of about 80cm (-12% departure), subdivision Saurashtra-Kutch received excess rainfall of about 62 cm (24% departure) and Gujarat state as a whole received normal rainfall of about 70 cm rainfall (2% departure).Though Gujarat state received normal rainfall during monsoon 2021 but there is large variation in monthly rainfall over the state. The state received 88 percent rainfall during June(-12 % departures), 60 percent during July(-40% departure), 30 percent during August(-70% departure) and 368 percent during September(268 %departures).

Due to a few spells of rain during September 2021 the seasonal rainfall of the state became normal .Author tries to study the variation of intra seasonal rainfall and associated dynamical parameters for the month of September 2021. The data sets used for the study are u and v wind data from ERA5reanalysis data set with 0.25*0.25 .deg horizontal resolution with vertical levels 1000 to 500 hpa standard levels for the month September 2021 with daily time steps (00UTC, 06UTC, 12UTC and 18UTC) and for area 68 .deg E to 72 .deg E and 20 .deg N to 24 .deg N; daily area averaged rainfall data from Rain gauges, AWS over Gujarat state for the period September 2021.

Due to interaction of Low Pressure Area over southwest Madhya Pradesh & neighbourhood up to 7.6 km above mean sea level and the shear zone along Latitude 20°N between 3.1 km & 5.8 km above mean sea level, the state received heavy rain over Gujarat region and heavy to very heavy rain with isolated extremely heavy rain over Saurashtra-Kutch 2nd week of September .The highest rainfall recorded on 9th September was 25 cm in GirSomnath District. During 13th to 15th September 2021Gujarat state received an active wet spell due to the oscillation of monsoon trough up to Saurashtra coast andinteraction with cyclonic circulation over Gujarat region. During the period heavy to very heavy rainfall with extremely heavy rainfall occurred over the state with highest rainfall recoded 52 cm recorded at Rajkot,47 cm at Junagadh and 41 cm at Jamnagar on 14th September 2021. On 24th September Gujarat state received a good spell of monsoon rainfall with highest daily rainfall of 19 cm in Jamnagar district due to the cyclonic circulation over West Rajasthan. Last rainfall spell for the month was from 28th to 30th September 2021 due to intensification of Well-Marked Low Pressure Area into a Depression over northeast Arabian Sea & adjoining Kutch due to which highest rainfall recorded was 29 cm in Junagadh district on 30th September 2021.

The ERA5 data is used to compute relative vorticity and hovumuller plot is prepared for lower level(1000-850mb) and higher level(700-500) vorticity for the month September 2021 are shown in the figure 1a. During the extremely heavy rainfall events, positivevorticityadvectionis observed at higher level also. Thus vertical advection of positive vorticity up to higher level can be considered as a tool for extremely heavy rainfall forecast.

Impact based forecast of flash floods over South Asia

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Abstract : Flash floods are one of the major natural disasters of short duration occurring from varied factors prevalent in South Asian countries and greatly affect the environment. They occur with torrential rainfall within a few minutes to a couple of hours depending upon the region's land surface, geomorphological and hydrological factors. As a consequence of climate change, frequency of flash floods events is increasing mainly due to increase in the extreme rainfall events and their intensity. Any change in weather pattern leads to major impact on the hydrological cycle which plays a vital role in occurrence of flash floods under favourable land surfaces.

Flash floods are particularly small-time scale events with short occurrence time. They are one of the most powerful, high impact and the most challenging phenomena, which make its forecasting quite a challenge for the meteorological community with the reasonable lead time. It poses a great threat and loss to life, livestock & infrastructure facilities and its timely and accurate guidance is significant for the disaster management authorities and other stakeholders.

Recognizing the need for South Asia and considering its monsoon rainfall variability and topography features which is highly prone for occurrence of flash flood events, World Meteorological Organization (WMO) has taken up a project for developing the capabilities of NHMSs for enhancing the flash flood early warning system. These enhancements assist by empowering the mandated national authorities to follow the correct procedure to protect the communities at risk from the adverse impacts of flash floods. As a regional center of the South Asia Flash flood guidance System (SAsiaFFGS), India Meteorological Department (IMD) has started monitoring and providing guidance of flash floods events associated with extreme rainfall. The SAsiaFFGS is a tool necessary to provide operational forecasters and disaster management agencies with near real-time informational impact-based guidance products with a lead time of 3 to 6 hours. The current study evaluates the performance of the SAsiaFFGS over the South Asian region.

Key words : Flash flood, Impact, FFGS, Threat, Risk, South Asia.

Analysis of Heavy Rainfall Over India in August 2019 and the performance of Global Numerical Model Forecasts

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Abstract : Heavy rainfall is very common in central India during southwest monsoon season. It brings a lot of misery to the people of this region. Monson season 2019 witnessed massive flood during August over many parts of India.

Rain related incidents reportedly claimed more than 260 lives from different parts from the country during the month. Kerala, Maharashtra, Gujarat, Odisha, Uttarakhand, Karnataka, Bihar etc. The month of August witnessed one monsoon depression, which started as a low pressure area over North Bay of Bengal and adjoining coastal areas of Bangladesh and west Bengal on 6th, it became well marked over the same region on same date. It concentrated into depression over northwest Bay of Bengal off north Odisha west Bengal coast on same date. It crossed north Odisha-West Bengal coasts close to Balasore during afternoon of 7thAugust. Thus, in the present study the two heavy rainfall spells from 4-11 August and 14-18 August 2019 along with the performance of Global Forecast System (GFS) model at a horizontal resolution of 12 km have been discussed.

The GFS model forecast could capture most of the heavy rainfall episodes with the lead time of 2 to 3 days. However, the extremely heavy rainfall episodes are underestimated in the model forecast.

THEME : MODELLING MONSOON PROCESSES

Does increasing horizontal resolution improve seasonal prediction of Indian summer monsoon? : A climate forecast system model perspective

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Abstract : The state of the art in respect of the prediction of Indian summer monsoon (ISMR) is the use of coupled climate models. Models in general have a hard time in producing accurate forecast of seasonal mean monsoon. Serious effort is being put globally to improve the quality of forecast. One of the simple and easy to comprehend approaches among the scientific community, is to increase the horizontal resolution of the model to improve the accuracy of the predictions. The seasonal prediction skill of CFSv2 with two different resolutions, namely T126 and T382 is studied using hindcast data. Using novel diagnostic tools such as total variation distance and two-state Markov Chain analysis, it is shown that increasing the horizontal resolution of the model has minimal impact on the quality of seasonal prediction. The underlying rain distribution and associated transition probabilities are very similar in both the versions of the model. The Markov chain analysis also provides critical clues about the issues associated with convective processes in the model. Both the models produce longer (shorter) wet (dry) spells compared to the observations. Although the conventional error metrics are useful to assess the prediction skills, the new metrics used in the study provide further insights on possible pathways to improve model physics. Machine learning based methods can be potential tools for seasonal prediction of monsoons.

Downstream and In Situ Genesis of Monsoon Low-Pressure Systems in Coupled Models

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Abstract : The low-pressure systems (LPS) are cyclonic vortices of ~1000 km diameter embedded in the large-scale monsoon circulation. A dozen of such synoptic-scale precipitating vortices originate over the Bay of Bengal (BoB) and adjacent land region and then propagate north-westward across continental India and produce as much as 60% of the total rainfall over Central India. Despite its importance in the water security of the country, the fundamental genesis mechanisms of LPS are still not fully understood. Further, the current generation general circulation models also lack skill in simulating the LPS. Using an automated algorithm, we tracked the LPS activity in 11 models from the Coupled Model Intercomparison Project Phase 5 (CMIP5) and broadly classified their genesis mechanisms into in situ (due to the local processes) and downstream amplification (in which the westward propagating atmospheric disturbances from the Pacific amplify over the BoB). In the CMIP5 models, we observed a westward propagation of LPS rather than the classical north-westward due to the weaker potential vorticity advection. We also find that the in situ genesis dominates in all models with an average of 56%, while 63% of systems are in situ in observations. The percentage of downstream genesis in the models (32%) is close to that of observations (30%). Although bulk statistics of both the genesis mechanisms are comparable, significant inter-model variability is observed. The temporal distribution of downstream LPS in models is different from the observations. Models tend to simulate a higher frequency of downstream LPS genesis in June and July contradicting the observed peak in August and September. This might be due to the stronger Rossby wave activity in the models in June.

Representation of process-oriented diagnostics in IMDAA reanalysis during monsoon

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Abstract : The study aims to understand the crucial physical processes responsible for tropical precipitation variability at sub seasonal timescales during boreal summer monsoon season over Indian region. For this purpose, we have used newly generated long term (1979-2020) Indian Monsoon Data Assimilation and Analysis (IMDAA) reanalysis product. In this work, process-oriented diagnostics (example: vertical integrated column water vapor (CWV) and moist static energy budget (MSE)) are employed onto the reanalysis data to examine the role of vertical structure of large-scale vertical motion. Further, examined the convection transition statistics in the reanalysis data to study the sensitivity of moisture structure in precipitation evolution. Results are validated using the ERA5 reanalysis and the relative roles are quantified.

Our examination suggests that despite having systematic biases in key variables responsible for monsoon convection, several aspects (mean state, vertical structure, poleward propagation etc) of the sub-seasonal variability are captured well in the reanalysis data, which is encouraging. Further, budget analysis reveals that horizontal advection term acts as a coherent signal during active and break monsoon episodes over Indian region. Nevertheless, diagnostics also reveal that moisture-convection feedback mechanism is relatively weaker in IMDAA reanalysis compared to ERA5. Our study not only highlights the need for process based diagnostics in checking the fidelity of IMDAA reanalysis but also indicate the merit and demerits of IMDAA reanalysis for better understanding of the monsoon processes.

Improved PQPF in the NEPS-G using Ensemble BMA technique over India

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Abstract : Extreme rainfall events are becoming frequent in different parts of the world under the warming climate. Improved forecasting is crucial for the better management of disasters caused by extremes. Numerical weather prediction (NWP) has improved substantially in recent decades but still lacks accuracy in predicting extreme rainfall events. Probabilistic forecasting using ensemble models can be used for the better prediction of extremes. However, the raw ensemble forecasts are generally hard to rely upon. This could be due to insufficient model resolution, less-than-optimal initial conditions, sub-optimal treatment of model uncertainty and sampling errors. Statistical post-processing is inevitable for realizing the full potential of ensembles by elimination of biases and reconstruction of proper ensemble spread. Bayesian model averaging (BMA) developed by (Raftery et al, 2005) is a promising method for statistical post-processing of probabilistic forecasts to create predictive probability density functions (pdfs) for weather quantities. The key feature of the BMA method is that it does not depend on long term climatology. It is useful in combining forecasts from multiple ensemble members based on their performance over a training period. National Centre for Medium Range Weather Forecasting (NCMRWF) runs the NCMRWF ensemble prediction system (NEPS) constituted by 22 members and having a resolution of 12 km for operational weather forecasting up to 10 days. In the present study, the impact of post-processing the rainfall forecasts from the NEPS using Ensemble BMA over Kerala is assessed during the recent three monsoon seasons (2019-2021). Improvement in the PQPF of extremes is quantified using over CRPS, Brier Score and Mean absolute error (MEA).

Assessing land surface variability during summer-monsoon period with IMDAA reanalysis data

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Abstract : The Indian summer monsoon period is from June to September. The summer starts in April and the weather is hot and dry. Sunlight heats the land and ocean surfaces, but land temperatures rises more quickly due to lower heat capacity. As the land's surface becomes warmer, the air above it expands and an area of low pressure develops. Ocean remains at low temperature (high pressure), due to this pressure difference, moist air blow from ocean to land and cause rainfall over the Indian continent. Land surface processes play a vital role during summer monsoon. IMDAA reanalysis data over India is presently the highest resolution atmospheric reanalysis carried out for the Indian monsoon region. The Joint UK Land Environment System (JULES) is a land surface model that has evolved from the Met Office Surface Exchange Scheme (MOSES). JULES can be easily operated within the Unified Model and offline (standalone), the impact of land surface on weather prediction and climate can be readily assessed. JULES standalone uses IMDAA Met forcing for this study of summer monsoon period for Indian region. This study demonstrates the variability of land surface variables and energy fluxes for the summer monsoon period.

Structure and dynamics of a case-study monsoon depression in high-resolution numerical simulations using the Met Office Unified Model

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Abstract : Monsoon depressions (MD) are synoptic-scale cyclonic vortices that form over the Bay of Bengal and propagate north-westward onto the Indian subcontinent. Despite their importance, key questions on the mechanisms driving their generation and development are still open. In this study, we inspect the structure and dynamics of a case study MD (1-10 July 2016) using a set of high-resolution simulations performed within the INCOMPASS project. The simulations are performed at a grid spacing of 17 km, 4.4 km and 1.5 km (with parametrised convection for the former experiment and explicit convection for the latter two). Initial results of this study show that the two higher-resolution simulations are more effective in resolving intense rainfall caused by deep convection, convergence lines and orographic enhancement. The evolution of the case-study MD can be divided into two stages: an early stage during which the MD is completely embedded in a close-to-saturated environment up to the mid-troposphere and a later stage that shows a well-defined depression structure and an intrusion of low-potential-temperature dry air at low- and mid-levels interacting with the MD. During this latter stage, the dry-air intrusion brings in low PV-air towards the centre of the depression. Further analysis of the case study takes advantage of a system-relative framework to have a detailed understanding of the time evolution of the dynamic and thermodynamic parameters around the storm centre and at its small- and meso-scale structure. For example, the 1.5 km-spacing simulation enables us to highlight the presence of individual vorticity towers embedded within the MD. During the early stage of evolution, we see a wave-like pattern in the total potential vorticity (PV) at higher levels of the troposphere. Once the depression is well-defined, the vorticity towers extend throughout the troposphere with relatively positive PV towards the east of the depression and negative PV towards the west. In summary, using a suite of high-resolution numerical simulations of a case-study MD, we are able to achieve a detailed understanding of its structure and dynamics, highlighting the processes driving its evolution.

Role of Cloud Processes behind the Indian Summer Monsoon Rainfall and its prediction

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Abstract : Cloud microphysical processes and rainfall over the Indian summer monsoon (ISM) region are unique because of strong interaction among clouds, thermodynamics and dynamics. The heating and presence of water vapor during ISM help for the formation of cloud particles in stratiform clouds and convective cumulus. We have analyzed the role of detailed cloud microphysical processes in controlling the ISM rainfall (ISMR) in inter-annual and sub-seasonal time scales from the Goddard Earth Observing System (GEOS) model (i.e., MERRA 2). The microphysical process rates (e.g., auto-conversion, freezing, accretion of rain and snow) are found to be well associated with the seasonal mean rainfall. Besides, they also play a significant role in the interannual variability of the monsoon. During excess (deficient) monsoon years the microphysical process rates increases (decreases) significantly. The microphysical processes are also found to be linked with large scale phenomena, i.e., ENSO. The reduction of these processes is even more in El-Nino deficient years as compared to Non-El-Nino deficient years. It is revealed that these microphysical processes are strengthened during active spell than break spell and have significant sub-seasonal variability. The variance is more in synoptic scale as compared to super-synoptic and monsoon intraseasonal oscillation (MISO). Further these subseasonal variances are well correlated with the mean rainfall. The understanding of detailed microphysical processes during ISM clouds will pinpoint the development of climate model for depicting mean monsoon and further skill of seasonal prediction.

Key words : Indian Summer Monsoon, Cloud Microphysical processes, MISO, ENSO, Teleconnection.

Evaluation of short range forecasts from Global and Regional Ensemble Prediction Systems of NCMRWF

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Abstract : Information of uncertainty associated with weather prediction helps significantly in decision making particularly if forecast is area specific. Uncertainty that occurs in the area specific forecasts on both temporal and spatial scales can be quantified by Ensemble Prediction Systems (EPS) at regional scale. In recent years, some weather services across the globe are providing the weather forecasting by running regional convection-permitting (CP) ensemble at 4 km and less grid space. A short-range (0-75h) regional EPS is running operationally in the NCMRWF at convective scale (~4km) with 11 ensemble members at 00 UTC. The model sub-grid scale uncertainties are handled by the Random Parameters scheme.

The area specific forecast is evaluated with respect to those obtained from 12 km global EPS operational in the NCMRWF. We analyzed different cases including verification of summer monsoon months over a domain centering over India and its neighborhood. The focus of the study is to verify surface weather variables, particularly precipitation, over the Indian region during monsoon. Some weather extremes such as depressions and heavy rainfall event associated with Indian summer monsoon are also considered.

Role of PBL and Microphysical Parameterizations during WRF Simulated Monsoonal Heavy Rainfall Episodes over Mumbai

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Abstract : Monsoon circulation and associated rainfall add complexities in the boundary layer features over the Indian subcontinents. The characteristics of boundary layer and microphysical variables and their variations at differing spatial and temporal scale is investigated during monsoonal heavy rainfall scenarios. During the summer monsoon months (June to September) of 2014–2018, 16 heavy rainfall cases are considered for this study. High-resolution simulation is conducted with three nested domains having a horizontal resolution of 18, 6, and 2 km with the 35 vertical levels in the advanced research WRF (WRF-ARW) model. The sensitivity experiment is performed with seven planetary boundary layer (PBL) schemes; non-local first-order closure [Yonsei University (YSU), Asymmetric convective model, version 2 (ACM2), and Shin-Hong], local one-and-a-half order [Mellor-Yamada-Janjic (MYJ), quasi-normal scale elimination (QNSE), Bougeault-Lacarre´re (BouLac), and Grenier-Bretherton-McCaa (GBM)] and five microphysics (MP) schemes [WSM6, Goddard, WDM6, Thompson, and Lin et al.]. PBL parameterization in combination with the Lin et al. scheme shows a significant impact on rainfall and dynamical and thermodynamical parameters at the surface and the upper levels. QNSE showed a relatively deeper and warmer atmospheric boundary layer compared to others to support strong upper-level divergence and high moisture content within the lower levels. Based on the results, QNSE is found to have a relatively better skill for representing the conducive environment, and Lin et al. microphysics could accommodate the same for the occurrence of the intense monsoonal rainfall events over Mumbai. The said combination is possibly effective for other coastal areas of India for better prediction of intense monsoonal rainfall episodes as well.

THEME : MONSOON INFORMATION AND PREDICTION FOR SOCIETAL BENEFIT

Comparative Study of Intraseasonal Variability of Summer Monsoon Rainfall over North and South Bihar, India

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Abstract : The state of Bihar, India is situated in the Gangatic plain in east of the Uttar Pradesh, North of the Jharkhand and west of the West Bengal while its north boundary touches the Nepal (foothills of Himalayan). The intraseasonal variability of summer monsoon rainfall over this state is responsible for drought and flood condition. For the current study, the Bihar has been divided into two parts namely, North Bihar and South Bihar in which North Bihar comprises of a number of rivers flowing from the Himalaya while south of the river Ganga has a very few rivers. The monsoon observed rainfall variability is studied by using the Indian Meteorological Department (IMD) gridded data at spatial resolution 0.25*0.25 for the period of 1961-2020. It is found that the excess of rainfall occur in North Bihar while in South Bihar, deficit rainfall commonly found. The active phase more pronounced in North Bihar while break phase is more in South Bihar. That result that sharp difference between these two regions in rainfall variability occurs and need to make policies according to this so that the agricultural activity can be improved in terms of drought and flood.

Key words : Intraseasonal Variability, Monsoon rainfall, Summer Monsoon Season, Active and Break phase.

Role of Machine Learning for Indian Monsoon Prediction

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Abstract : Climate change has tremendous impacts on the socioeconomic prospects of the world. The unprecedented potential of climate change includes extreme weather events, heatwaves, etc. The Indian monsoon is one of the most prominent monsoon systems in the world and in particular is more susceptible to the growing impacts of climate change. Rainfall in India has remarkable influences upon agriculture, health, hydro-power generation, and many other sectors. Keeping this in mind, the scientific community has made significant efforts for comprehending the fundamentals of monsoon, finding the evolution and trend of monsoon, making reliable predictions, assessing the economic impact, formulating policy, and making decisions regarding climate change and its impacts on livelihood. Accurate prediction of the Indian monsoon rainfall remains a daunting task, which is a product of numerous complex atmospheric and oceanic processes. The difficulty in predicting the Indian monsoon arises due to the presence of nonlinearity and instability of the climate. While physically based numerical modeling has progressed considerably over the last half-century, due to the inherent complexities of the underlying physical processes, alternative approaches are explored to make the predictions accurate, and in this endeavour, machine learning techniques have emerged as the most proficient and potential methods of prediction. The importance of machine learning techniques lies in their wider applicability and the incredible efficacy to solve a complex problem effectively with the help of newer and faster algorithms. The machine learning models once learned and identified the specific patterns in data can able to produce automated decisions without human intervention. Presently, machine learning techniques are gaining popularity in other contexts and their lack of application from a climate prediction perspective is a need of concern. Thus, there is a dire need for extensive research to find out efficient machine learning techniques for improving the predictability of the Indian monsoon.

Bias-Corrected Extended Range Forecast of Rainfall in Operational Framework of IMD

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Abstract : The operational extended-range forecast (ERF) system of IMD based on the Climate Forecast System Version-2 (CFSv2) coupled model during the southwest monsoon seasons (June to September) of 2020 and 2021 is evaluated at river basin scales for managing reservoir operations. The model's output rainfall is validated for different nine river basins situated in various meteorological subdivisions of India. For this purpose, models' simulated rainfall in the ERF period is considered in CFSv2. The Week1 (day 2-8), Week2 (day 9-15), Week3 (day 16-22) and Week4 (day 23-29) accumulated rainfall is assessed for each initial condition during the summer monsoon months of India. The validation is carried against the IMD observed gridded rainfall, available at comparable grid resolution. The statistical metrics, correlation coefficients (CC), root mean square error (RMSE), mean bias error (MBE), mean absolute error (MAE) and normalised RMSE (NRME) was calculated for individual river basins and the skill of models' forecast is evaluated. The raw forecast is further corrected for bias using the normal correction ratio method. The ERF forecasts show skilful results up to the Week2 period for most river basins. However, the CC is highest for relatively larger river basins like Hirakud and Tapi compared to other river basins. An improvement in RMSE and NRMSE was also noticed for the bias-corrected forecast as compared to the raw forecast. The model performance indicates that the ERF may be utilised for various hydrological applications in the lead time of two to three weeks. The ERF may provide a valuable indication to look for the accumulated rainfall forecast in an extended period to gaze close observation for hydrological activity.

Key words : CFSv2; Extended Range; River Basin; Indian Summer Monsoon.

Analysis of GFS and GEFS model forecasts at IMD during South west monsoon 2021

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Abstract : India Meteorological Department (IMD) gives forecasts in medium range scale using the deterministic model GFS and ensemble model Global ensemble forecast system (GEFS) at T-1534 resolution. GFS model operational at IMD employs spectral dynamic core in NOAA Environmental Modelling System (NEMS) configuration with semi-Lagrangian dynamics in linear reduced Gaussian grid. Model uses hybrid 4D Ensemble Variational assimilation system for creating model initial condition and assimilating more number of observations over the Indian region. GEFS model at IMD has 21 members comprising one control run from GFS (deterministic) and 20 perturbed members. This work is carried out over the Indian south west monsoon period of 2021. Model performance is evaluated over different spatial domains over India and different rainfall categories. It is found that both GFS and GEFS models are able to capture the general characteristics of rainfall over the region although rainfall bias is observed in some regions. In the prediction of extremely heavy rainfall events, there is an under estimation of rainfall in both the models. Usefulness of probabilistic forecast in prediction of rainfall during monsoon period is examined.

Wind power potential assessment over India using IMDAA and ERA5 reanalysis data

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Abstract : Renewable energy does not emit pollutants and GHGs, unlike fossil fuel-based power plants. The total share of renewable energy from the renewable energy sector in India is 25.24 %. In the current analysis, the wind power potential over India is calculated and compared using IMDAA and ERA5 reanalyses data at 1000 and 975 hPa levels from 1985 to 2019. Firstly, the seasonal pattern of wind speed between IMDAA and ERA5 datasets are compared. The maximum wind speeds are observed in the monsoon months. In the post-monsoon season, the eastern coast shows higher winds because of the dominant winds from the North-East. The Wind Power Density (WPD) also shows a similar seasonal behaviour like wind speed with higher order of magnitude for WPD. The diurnal pattern indicates that the western Indian region in Gujarat and Rajasthan has peak power potential in the afternoon and late-night hours while Eastern coast, in the afternoon hours. The seasonal bias of wind speed between IMDAA and ERA5 shows that the IMDAA overestimates the wind speed throughout the Indian region except for Jammu and Kashmir, NE states, central Rajasthan, South Odisha, and the Western Maharashtra region. The area-averaged time series of wind speed for western states and southern states exhibit higher winds in pre-monsoon season for western states compare to southern states. The comparison of IITM extended range forecast models with IMDAA and ERA5 is also done to evaluate the performance of IITM extended range forecast models.

Extended Range Forecast of Onset and Withdrawal of Southwest Monsoon over India Using Coupled Model

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Abstract : The onset of Indian Summer Monsoon (ISM) over the southern coast of India (Kerala) coinciding with the beginning of monsoon rain occurs in early June. It further advances northward and covers most part of the county by middle of July. The withdrawal of monsoon commences from northwest India around 3rd week of September. There are, however significant variations is seen in its onset and withdrawal of monsoon. Prediction of monsoon onset (beginning of rainy season) and also the withdrawal of monsoon are crucial in India since it is connected to water-resource management and agricultural planning.

This study discussed the operational capability of real-time forecast of onset and withdrawal of ISM in extended range period using an objective method. The operational ERF system of IMD is based on the CFSv2 coupled model, run once in a week based on every Wednesday initial condition. The forecast with 16 ensemble members is run for 32 days based on each initial condition. In the present study the onset of monsoon over Kerala and the withdrawal of monsoon from the northwest India as predicted in the operational extended range forecast (ERF) modeling system of IMD is analyzed for last 5 years from 2017 to 2021. Here, we analyzed the rainfall over Kerala and the strength of Low-Level Jet (LLJ) associated with the monsoon current from ensemble members of ERF for the onset date and the rainfall and circulation features over northwest India for the withdrawal of monsoon.

The onset of monsoon over Kerala was close to normal date of 1st June during 2017 (30 May), 2020 (1st June) & 2021 (3rd June), whereas it was early onset during 2018 (25th May) and late onset during 2019 (08th June). With regard to the commencement of withdrawal date from northwest India last 5 years from 2017 to 2021 witnessed delayed withdrawal of monsoon (30 Sep, 29 Sep, 09 Oct, 28 Sep and 06 Oct respectively) against the normal date of 17th September. The results indicated that the real-time ERFs have demonstrated the variability of onset and withdrawal dates during last 5 years very well.

Key words : Indian Summer Monsoon; Extended Range Forecast; Onset and withdrawal of monsoon.

Monsoon Rains and Flow Predictions – A Case Study of Upper Krishna

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Abstract : Now a day's water sharing between is leading to lot of litigations especially in river basins flowing through different states in India. There are tribunals which fixed share of water to each riparian states. But river flow is not fixed due to vagaries of monsoon in different years. The fixed quantum formula is not an optimum solution for river water sharing because of quantity of flow varies from year on year. The formula entitles upper riparian states to hold water when lower riparian states suffer from drought. The water is released at once when there are floods but by that time crops are withered in drought affected areas.

The solution lies in prediction and flows in real time. IMD, CWC and other agencies have network to calculate and predict flows. The IOT is lacking to integrate data generated on different parameters. An exercise on upper Krishna is done taking into account basin wide rainfall daily from public domain of IMD daily and river flows given by CWC and other state agencies. We found there is a match between cumulative rainfall and surplus resulting from Almatti reservoir. Linking rainfall and river flows helps in predicting and managing water in space and time.

In our college (BIET) a study is initiated in machine learning to predict flows from antecedent precipitation and for short term rainfall forecast. This will help Governments on upper and lower side to share river water in a more logical manner instead of utilizing their share of water until last minute before a flood occurs. Machine learning through historical and real time goes a long way in addressing present river water distribution leading to many disputes.

Block level weather forecast based Agro-Advisory and its impact for Bihar, India

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Abstract : Location specific early information of upcoming weather event and their translation into advisory found as helpful decision making tool for farmers. These advisories contains location specific weather forecast coupled with their interpretation in terms of measures to be taken up by the farmers at field. The present study is carried out to investigate the verification of block level weather forecast provided to the farmers and the uptake of advisory by decision makers for East Champaran, Supaul and Nalanda districts of Bihar. Verification of GFST-1534 model rainfall forecast with block level observation was performed for Monsoon 2020 and Monsoon 2021. Verification was performed as per the contingency table verification method recommended by WWRP/WGNE (World Weather Research Programme/Working Group of Numerical Experimentation). Obtained results shows high Ratio score >75%, positive Hansen and Kuipers score (HK) (>80% of blocks), False Alarm Rate (low for 77 to 83% of blocks) and high POD. Overall, skill scores support the use of the model forecast in preparation of forecast based advisory. Acceptance of the advisory and their impact was further analysed by collecting end of season and dynamic feedback from the farmers. Feedback analysis indicates that advisories are highly useful for the farmers and they follow advisory particularly for sowing, irrigation, fertilizer application and harvesting operations. Prior information of rainfall and extreme event emerges as significant requirement of the farmer.

Key words : GFST-1534 Model forecast, Skill Scores, Location specific forecast.

Indian Summer Monsoon Variability with Geostationary Satellite OLR

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Abstract : Scanning radiometers on-board the meteorological satellites measure the radiance in narrow windows within the visible and infra-red spectra. For example, in the case of the INSAT VHRR these windows are 0.55-0.75μ and 10.5-12.5μ respectively. The broad-band outgoing longwave radiation and the planetary albedo are derived indirectly from such window measurements by applying physical and/or statistical algorithms. Geostationary satellite (INSAT-3D/3R) narrowband based OLR observations offer the significant advantage of an instantaneous response to surface temperature changes and played an important role in Indian Monsoon activity.

It has been shown that Indian Summer Monsoon (ISM) phases starting from onset, active and withdrawal are associated with the development of a Maximum Cloud Zone (MCZ) near equatorial belt and its northward propagation. The alterations or oscillations between onset, active, break periods of the ISM can easily be monitored through meridionally propagating cloud bands as 30 to 50 days periodicity. Localized weather events also affect the periodicity of these MCZ every year differently. These variabilties of ISM with INSAT OLR field is discussed in detail in this work.

Key words : Indian Summer Monsoon, OLR, Meridional propagation, active and break period.

THEME : NEW TECHNOLOGIES AND TOOLS

Multi-model Spatial verification of rainfall forecast during recent monsoons using a state-of-art technique

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Abstract : In this is study we have used a state-of-art technique for spatial verification of rainfall forecast for mult-models. Here we have study five global models viz. NCUM, UKMO, GFS(IMD), GFS(NCEP) and ECMWF, this technique provides an information which is not possible to obtain using traditional grid-point based verification methods. It objectively identifies simple objects in rainfall fields at different thresholds, which would mimic what humans call as "regions of interest". This process is a multistep one which is called the convolution thresholdingtechinique. It basically involves application of a simple circular filter which in terms is a function of convolution radius (CR), here we have used 2 grid squares (1 grid size ~25 km). Once the filter is applied, the convolved field is thresholded using a convolution threshold (CT) to generate a mask field, in this study we have used CT's as 20, 40, 60,80,100, and 120 mm for CR=2 grid squares. These simple objects are the connected regions of "1" in the mask field. Finally, the actual data is restored inside the mask regions of object interiors to obtain the object field. Thus the objects are the function of CR and CT.

From this spatial verification of high intensity rainfall in the cluster pair table shows interesting results for the NCUM at higher thresholds (60 and 80mm). The angle difference is the lowest for the NCUM and highest for the GFS (IMD) for day 1 to day 5 lead time for 80mm of rainfall intensity. The area ratio is the highest for the NCUM and lowest for the GFS (NCEP) for day 1 to day 5 lead time for 60mm of rainfall, which shows a very good areal extent of forecast 5 days in advance , which is very well supported by the total interest.

A machine learning framework for the detection of builtup changes in : use of multi-spectral satellite images

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Abstract : In the last decade, ESA (European Space Agency) and NASA (National Aeronautical Space Agency) were successfully able to launch Sentinel-2 and Landsat-8 satellite. The high spatial resolution and multi-spectral images generated by these satellites are available in open domain and empower researchers to identify the changes in built-up areas over time. The significant improvement has been noticed in remote sensing research using the index based approaches to extract the builtup region from single time point imagery. In this study, an automated framework has been proposed using builtup change detection index and machine learning-based thresholding algorithm to detect the builtup changes using multi-temporal dataset. The new proposed framework has been implemented on Landsat-8 multi-temporal images to detect the overall built-up growth in the Indian capital city Delhi and its surrounding region for a period of 8 years. The derived framework generates the builtup changes within a short span of time, compare to conventional post classification change detection algorithms. The utility of derived information of builtup changes has been found in numerical weather prediction modeling, impact based weather forecasting, urban growth and planning, and disaster management.

Pyscancf - the python library for single sweep datasets of IMD weather radars

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Abstract : PyScanCf is a Python library that generates Cf-Radial (Polar) and Gridded (Cartesian) data from Indian Meteorological Department (IMD) weather radar single sweeps. This library aims to simplify data handling for scientists and researchers. It can be used extensively in Python to work with weather radar data. The tool kit is developed by using top python packages, such as NumPy, Py-ART, NetCDF4, Matplotlib, Pandas, and Cartopy, in order to merge the data into a single file in two formats (cf-radial and grid), and to plot Max-CAPPI Products such as Max-Z, Max-V, and so on. This library's source code is available on GitHub and is licensed under the MIT license. Thank the IMD for providing basic radar dataset. The Python programming language and the dependent library packages are entirely free and open source. Scientists and researchers can use PyScanCf for over 28 IMD radars, professionals working on radar data, or weather enthusiasts anyone who wishes to undertake extensive analysis on radar data can use to generate polar and gridded data well as to plot Max-CAPPI. The detailed example notebooks have been uploaded to the PyScanCfGitHub repository in which every function has been demonstrated. Further, a tutorial video is also uploaded on YouTube (https://youtu.be/OUrdhe5virA) link is provided in the readme section of the GitHub repository. This library will be expanded to incorporate other approaches such as clutter removal, attenuation correction, and rain retrieval algorithms. Our main objective is to create tools to automate the data analysis process, which will reduce the time necessary to prepare output and deliver quick and well-formatted findings for weather data interpretation in support of reproducible science.

THEME : REGIONAL MONSOONS

Changes in the relationship between El Niño Southern Oscillation and Indian summer monsoon rainfall from early to recent decades during different phases of monsoon

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Abstract : The El Niño Southern Oscillation (ENSO) is an important coupled ocean-atmosphere phenomenon in the tropical Pacific Ocean and an important driver of the Indian summer monsoon rainfall (ISMR) variability. Here, we explore the impact of ENSO on the onset (June), peak (July-August) and withdrawal (September) phases of Indian summer monsoon by studying the changes in the ENSO-ISMR relationship from early decades (1951-1980) to recent decades (1986-2015). Significant weakening of the ENSO-ISMR relationship is observed in recent decades during all the three phases. During El Niño events, the rainfall over most Indian regions is increased in recent decades during onset phase, but decreased during peak and withdrawal phases. On the other hand, the rainfall during La Niña events is decreased during onset and withdrawal phases and increased during peak phase. A significant increase (decrease) in sea surface temperature (SST) is observed over the central equatorial Pacific and Indian Ocean during El Niño (La Niña) events in recent decades. These changes in SST together with the changes in the low level winds and Walker circulation over the Indo-Pacific domain are significantly linked to the changes in ISMR during the El Niño and La Niña events during all the three phases. However, most robust relationship is observed during the onset phase.

Characteristics of monsoon rainfall in last four decades over an urban area of the Gangetic plains

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Abstract : Unplanned expansion of urban areas has a bigger role in changing weather and climate patterns of their surroundings. Fast urbanisation is often linked with diminishing greenery, changes in land use, land cover, increase in air pollution levels and formation of urban heat islands. Moreover, some of the existing research has already linked the changes in precipitation regimes with urban areas. In the present research it is attempted to analyse the characteristics of Indian Summer Monsoon Rainfall (ISMR) over the urban areas of Patna in the months of June, July, August, and September (hereafter JJAS). For this purpose, the urban areas are delineated using very high-resolution Copernicus CGLS-LC 100 (v. 3.0.1) land cover data from Proba-V satellite. The high resolution (0.05°×0.05°) daily gridded rainfall data from CHIRPS dataset is considered for the present study for the period of 1981-2021. Every month of JJAS is individually analysed to envisage the trend of low to moderate rainfall events (0 - 35.6mm/ day) and rather heavy to extremely heavy rainfall (>35.6mm) events during the last four decades. A distinct trend exists for each of the months, and it may be concluded that the rainfall regime has been well modified in recent decades for the urban area of Patna.

Key words : Urbanisation, ISMR, Gangetic Plains, CHIRPS.

Trends and variabilities of Indian summer monsoon rainfall in different intensity bins over west coast and monsoon core zone

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Abstract : Summer Monsoon Rainfall (SMR) accounts for 75-80% of India's annual rainfall, and its fluctuation has far-reaching implications. Hence research on variability of SMR has important socio-economic relevance. In this study, features of SMR are studied for the two regions, viz. West Coast (WC) and Monsoon Core Zone (MCZ) in the Indian subcontinent utilising gridded rainfall data from IMD and sea surface temperature (SST) data from Met Office Hadley Centre for 1901-2020. We classified rain events into different intensity bins viz. dry, low, moderate, high, very high, extreme rainfall events. Statistical analysis was carried out to understand the rainfall variabilities. A significant decreasing trend in SMR is seen in MCZ. A significant increasing trend in low and a significant decreasing trend in very high intensity bins are also noticed in MCZ. In WC, significant trend is shown only for extreme intensity bin, which is an increasing trend. From the correlation analysis between two regions, moderate intensity bin correlation has increased significantly from 1961-2020. For extreme intensity bin from 1901-1990 the correlation between two regions were negative and from 1991-2020 the correlation became significantly positive. Analysis on relationship of rainfall with global SST brings out that the correlation of SMR in WC with Arabian Sea (AS) and Bay of Bengal (BoB) SST has changed from 1950s; the correlation was positive earlier and became a significant negative correlation after 2000. WC-SMR and Niño 3 SST correlation has changed from 1980. MCZ-SMR has significant positive correlation with South West Pacific Ocean SST before1960. But after 1960, the correlation became negative and from 1980, it became significantly negative. Extreme intensity bin correlation with Niño 3 region has changed from 1960s in both regions. The recent changes in rainfall pattern and its relationship with SST clearly indicates the climate shift.

Meridional gradient of sea surface temperature over the Bay of Bengal and its association with summer monsoon rainfall in the Indian subcontinent

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Abstract : Active and break cycles of Indian summer monsoon predominantly associated with 30-60 day mode of intraseasonal oscillation. The genesis of active break cycles is marked by the convection developed over the equatorial Indian Ocean followed by its northward propagation through the Bay of Bengal. Based on the meridional temperature gradient between east equatorial Indian Ocean (EEIO) and the northern Bay of Bengal (NBB), we developed a novel SST index and can be named 'Monsoon SST Index (MSI)'. The influence of MSI on the rainfall pattern over the Indian subcontinent during the Indian summer monsoon (ISM) period from 1982 to 2019 were analysed to identify the linkage between the MSI and ISM rainfall. The correlation between MSI and rainfall in the central Indian region manifests in two phases, and they are proceeding and receding phases with the correlation of 0.85 and 0.92, respectively. High gradient days (HGD) and Low gradient days (LGD) are defined based on the +1 standard deviation and -1 standard deviation of MSI at least for three consecutive days, respectively. HGD and LGD explicitly mimic the active and break periods of ISM rainfall. Rainfall in the central Indian region shows an anomalous increase(decrease) during HGD(LGD). The SST over the NBB exhibits anomalous cooling during the HGD and an anomalous warming of the north Bay of Bengal during the LGD. Low level westerlies show an anomalous acceleration during the HGD, whereas a significant weakening of westerlies is evident during the LGD. An anomalous convergence is apparent during the HGD, whereas anomalous subsidence is dominated during the LGD. Thus it can be concluded that the HGD (LGD) is associated with the active (break) monsoon period and thereby it governs the intraseasonal oscillation of ISM.

Revisiting climatological Diurnal cycle of precipitation over Indian subcontinent using latest IMERG data

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Abstract : Diurnal oscillation in precipitation is one of the most fundamental modes which are multidimensional and highly influenced by regional characteristic. The simulation of diurnal cycle of rainfall is a generic problem in most of the climate models. The detailed understanding of the diurnal cycle of rainfall from observations is limited. Very high-resolution multiyear satellite data globally, is best suited to study its intricacies. TRMM provided 3-hourly 25 km horizontal resolution data, which stimulated many researchers to study diurnal on a global scale, which due to scarcity of data was earlier limited to local scale. Recently, the constellation of satellites along with complete network of rain-gauge/radar is available under Global Precipitation Mission. It provides IMERG, a superior quality data at 10 km resolution at half-hourly time interval thus providing a good opportunity to revisit the climatological diurnal cycle.

Harmonics corresponding to diurnal and semi-diurnal is calculated in terms of amplitude and phase using 21 years of IMERG data. It shows the region dominated by significant diurnal oscillation. Over the land almost entire central India, the Western and Eastern Ghats, the Himalayan region, and the north-east region and similarly over Ocean, North Bay of Bengal has significant diurnal amplitude with varied time of peaking. These individual diurnal components, in a whole describes the whole monsoon process. However, when seen as a mean rain, it disguises these elementary components. This study brings out another way to look precipitation by dissociating it to the smallest temporal and spatial scale, thus giving one more avenue to improve monsoon simulation by climate models.

Dynamic and thermodynamic structure of atmosphere associated with extreme rainfall events over Kerala during August 2019

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Abstract : Extreme rainfall events occur frequently during the summer monsoon season over India and these extreme events are catastrophic especially in the hilly regions of Western Ghats and Uttarakhand. Study on extreme rainfall events is necessary for a better understanding of favourable situation and mechanism responsible for formation of the extreme rainfall events. This helps the authority to issue proper warning and hence to take abatement steps to minimise the damage. Further, locations that are vulnerable for landslides can be identified on the basis of terrain features to relocate the people to safe areas. Hence an attempt is made for a better understanding of the mechanism responsible for the extreme rainfall events occurred over Kerala during August 2019, based on dynamic and thermodynamic structure of the atmosphere. The analysis is carried out utilising NCMRWF IMDAA / ERA5 reanalysis wind, temperature and humidity data sets, hourly IMDAA rainfall and daily IMD rainfall and 3 hourly TRMM rainfall. Vorticity, divergence, vertical velocity, CAPE, CIN, LFC, moist static energy, precipitable water, etc. were studied for the extreme rainfall events. It is found that low level convergence and upper level divergence increase from 05 August and vorticity increases from 07 August. These circulation features are responsible for high ascending motion over the area. We examined thermodynamic structure based on the temperature and humidity profiles. Abrupt increase of CAPE was noticed during the extreme rainfall events. Very low CIN values are observed during these events indicating shallow stable layer near the surface. This indicates presence of convective instability in the atmosphere just before these extreme rainfall events. Moist Static Energy also indicates an increase associated with the extreme events. Specific humidity in the lower atmosphere and precipitable water in three different layers also showed strikingly high values during the extreme rainfall events.

Secular Trends in the Length of the Seasons of India and its teleconnections

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Abstract : The southwest monsoon during the boreal summer and India winter monsoon during boreal winter season are characteristically defined as fixed length sequence of the calendar months. This study examines the interannual variability of seasonal temperature and rainfall in the Indian subcontinent during the boreal winter and summer seasons, taking into account the varied lengths of the seasons. We utilize latest 50 years of India Meteorological Department observed rainfall data of spatial resolution 0.25° × 0.25° and temperature gridded data of spatial resolution 0.5° × 0.5° to compute onset, demise and seasonal length using the objective definition proposed by Misra and Bhardwaj (2019). The teleconnections between seasonal anomalies of surface temperature and rainfall over India and corresponding SST anomalies of the tropical Oceans, especially over the northern Indian and equatorial Pacific Oceans, are stronger in case of the varied seasonal length compared to fixed length of the season. It is also noteworthy that the variations of these teleconnections are significant with spatially diverse sub-zones across the Indian subcontinent.

Comparative Analysis of 2013 & 2021 Southwest Monsoon Advance over India

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Abstract : Southwest Monsoon (SWM) advance in the year 2013 was the rapidest during the period 1941-2021, as it took only 15 days to cover the entire India after its onset over Kerala on 1st June. In the year 2013, SWM covered the entire country on 16th June, about a month earlier than its normal date of 15th July.

In the year 2021, SWM advanced into most parts of the country except Northwest India till 14th June within just 11 days of its onset over Kerala on 03rd June without any hiatus due to active monsoon circulations and formation of low pressure areas. At this pace the SWM Advance would have been even faster than that in 2013. But further progress of monsoon over remaining parts of northwest India became slow only to cover the entire country by 13th July against the normal date of 08th July. To diagnose the underlying causes behind this unique meteorological phenomenon, we have analysed all the 6 semi-permanent systems associated with both the monsoon years and also the associated global parameters like MJO and ENSO using IMD bulletins, NCEP Reanalysis, IMD GFS and CIMSS data.

Unfavorable Madden Julian Oscillation, Mascarene High and Cross equatorial flow and the Mid-Latitude Westerlies resulted in weaker westerlies over eastern and central parts of Arabian Sea and weaker winds of the order of 10-20 knots along the west coast of India. As a consequence, no Low Pressure Systems formed over the north Bay of Bengal and weak lower levels easterlies prevailed over the Bay delaying the monsoon progress over Northwest India delaying the progress of SWM by almost a month.

AMO-Eurasian teleconnection and its relationship with Indian summer monsoon

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Abstract : The Atlantic multi-decadal oscillation (AMO) is considered as a major driver for the multidecadal variability of Indian summer monsoon (ISM). In this study we explore a new pathway to better understand this teleconnection. The AMO induced diabatic heating is known to give rise to an upper-tropospheric teleconnection pattern consisting of an arching wave train from the north Atlantic to the west central Asia (WCA) across Eurasia. Geopotential height anomalies over WCA is known to have a strong bearing on the ISM strength on inter-annual time scale, and the ISM is also known to modulate the height anomalies over WCA through the 'monsoon-desert' mechanism. In this study we revisit the AMO-ISM relationship in the context of how the AMO modulates the geopotential height anomalies over WCA. Probability distribution of the WCA geopotential height anomalies during positive and negative AMO phases reveal that the cold AMO phase favours more negative height anomalies over WCA as compared to the warm AMO phase. The anomalous anti-cyclone over WCA would strengthen the mid-tropospheric cyclonic circulation over north-west India and in turn strengthen the monsoon circulation. Hence this study offers an alternate viewpoint of AMO-ISM relationship compared to the prevalent understanding which argues that the AMO modulates the ISM by altering the tropospheric temperature gradient over the region.

Teleconnection between Atlantic Multidecadal Oscillation and Indian Summer Monsoon Rainfall

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Abstract : This study provides a relevant ground for attaining deeper perception about the teleconnection between the Atlantic multidecadal oscillation (AMO) and the Indian summer monsoon rainfall (ISMR) in observations and state-of-the-art climate models that participated in Coupled Model Intercomparison Project Phase 5 (CMIP5). Approximately 73% of models reproduce the internal natural variability associated with AMO, but amongst these, very few replicate the explicit comma-shaped AMO sea surface temperature (SST) pattern. The observational analysis bestows compelling evidence that the AMO influences ISMR through two physical processes: firstly, by modulating the El Niño related anomalous Walker and regional Hadley circulations asymmetrically and secondly, through the tropospheric response allied with the Rossby wave train. The models that fail to reproduce the AMO-ISMR teleconnection are incompetent in capturing the first physical mechanism correctly. In contrast, in general, all models show limitations in simulating the second physical mechanism. The models, which show the observed rainfall response over India, also simulate the large-scale features allied with AMO.

Characteristics features of Low-Level Jet (LLJ) in ERA5 and IMDAA during Indian Summer Monsoon in satellite era

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Abstract : The Indian summer monsoon (ISM) is the most cardinal phenomenon retains the Low-Level Jet (LLJ) at 850 hPa have strong horizontal shear and transporting moisture from the Indian ocean to land which makes it important for convective rainfall over the Indian region. Changes in LLJ affect the moisture transport which triggers the changes in the rainfall patterns over Indian region. We attempt to inspect the low-level circulation features linked with the ISM for 40 years from 1981 to 2020. Seasonal characteristics features of LLJ and associated rainfall variability investigated in this study using ERA5 and IMDAA data sets. In the month of May the feeble wind is observed whereas, for the seasonal mean (JJAS) the robust wind is observed in both data sets for the given time period. Both data sets are able to characteristics captures of LJJ well however magnitude of wind is less in IMDAA compared to the ERA5. Moreover, rainfall over the Central eastern India overestimated in IMDAA. The aspects of LLJ and other meteorological parameters are rationally analyzed during normal, excess and deficient years of the ISM rainfall season. The result gives the useful understandings for the compassion of two data sets to create suitable standards for Indian region and the forthcoming use of the ERA5 and IMDAA data.

Key words : LLJ, Indian summer monsoon, ERA5, IMDAA, Excess monsoon, Deficit monsoon.

Investigation of extremely heavy rainfall episodes over Tamilnadu during northeast monsoons of 2015 and 2021

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Abstract : Tamilnadu receives about 48% of its annual rainfall during the northeast monsoon season. The northeast monsoon season also serves as the chief cyclone season for the North Indian Ocean and the subsequent movement of cyclonic systems has a significant impact on the monsoon's performance. In this paper, study has been carried out to investigate the extreme rainfall deluge over Coastal Tamilnadu districts during Nov-Dec 2015. The intense rainfall and its associated weather systems are investigated by utilizing NWP model and satellite data information. The extremely heavy rainfall hotspots and rainfall persistence in and around the urban areas of Chennai city is also investigated. Along with the 2015 episode, this paper also tries to study the extremely heavy floods over Chennai and adjoining Coastal districts of Tamilnadu during Nov 2021. The weather signatures, the intense rainfall epochs are investigated from various observational platforms. The intra-seasonal fluctuations are also explored to observe the existence of relationship, if any, between the two flood events of 2015 and 2021.

Key words : Northeast Monsoon, Heavy Rainfall, Urban Areas, NWP model, Intra-seasonal Fluctuations.

Characteristics Features of hourly Rainfall over plains and complex terrain regions

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Abstract : Recently NCMRWF released unique high-resolution Indian Monsoon Data Assimilation and Analysis (IMDAA) data sets. The 40 years of reanalysis to span the era of modern space-based observations are complimentary to ground-based conventional observations for the different region of India. This study demonstrates the potential use of the IMDAA data for the study related with the diurnal cycle of rainfall.

The salient features of this study are presented here: During summer monsoon season the areas (i) windward side of the north south oriented hill ranges - Western Ghats (ii) the extreme north-eastern part of the country (iii) foothills of Himalaya receives large amounts of seasonal rainfall due to the barrier effect of orography. The reanalysis showed that time of occurrence of maximum rainfall is earlier than observed, which suggest the early release of convective instability and precipitation in the model short-range forecast. The study is aimed at improving our understanding of the major sources of variation and uncertainty in rainfall over mountains and plains. An important characteristic is the relationship between precipitation amount and elevation. Information on the variation of precipitation with elevation helps in providing a realistic assessment of water resources, estimation of maximum precipitation, and hydrological modelling of mountainous regions. The phase of the diurnal cycle over inland complex terrain orography is significantly different from coastal orography. The diagnostics study is conducted for core monsoon regions, Gangetic plains, equatorial Indian Ocean, etc

The frequency of hourly rain increases toward the east in the windward side of the Khasi and Jaintia hills and the east-west-oriented hills separating Bangladesh from the north-eastern parts of India. The results are presented for different geographical regions.

Verification of Extended Range Model Rainfall Forecasts during Post Monsoon season over South Peninsular India

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Abstract : There is increase in demand for the reliable Numerical weather Prediction system for agricultural sector in the south Peninsular India. Unprecedent excess rainfall and deficient rainfall can cause havoc which may result in the floods or drought in this region, with a direct impact on the nation economy. With the advancement of computational technologies, accuracy of prediction system is increasing. The objective of this paper is to evaluate the prediction of Extended range Forecast model (ERF) currently operational at India Meteorological Department (IMD) for the cluster of districts, comprising of 11 sub-regions of south peninsular met-subdivision from 2003 to 2020 during Northeast Monsoon season. The ERF forecast is based on multi-model ensemble (MME) prediction system having 16 different ensemble members from Climate Forecast System 2 (CFS.v2) coupled model and the hindcasts run is from 2003-2020. The rainfall is categorized based on the departure from the normal and are categorized into five categories viz., the large excess (≥ 60%), excess (20 to 59%), normal (-19 to 19%), deficient (-20 to 59%) and large deficient (≤ - 60%) based on the departures from the mean rainfall. The skill scores are obtained by comparison of accumulated rainfall from ERF model against the observed rainfall IMD gridded data provided by National Data Center(NDC), IMD Pune for the same 11 sub- regions. The onset, active phase condition of Northeast Monsoon is captured well in ERF model.

Key words : Extended range Forecast model, northeast monsoon, rainfall.

THEME :
SUB-SEASONAL TO SEASONAL (S2S) PREDICTIONS

Prediction of Rainfall over Kerala Using Deep NeuralNetwork

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Abstract : Precipitation is one of the key elements which support all life on Earth. From ancient times the prediction of precipitation has always been a tough grind for the weather forecasters. As precipitation is influenced by a plethora of variables giving precipitation a non linear characteristic, this unique nature makes the variable difficult to analytically model. To bridge the gap we are presenting the framework of a deep neural network which can improve the accuracy of precipitation forecasts a few days ahead over the Kerala region. The prime focus of our study is to reduce the forecast errors and false alarms in precipitation forecasts. For this, we have developed a deep neural network model which feeds on relevant meteorological parameters and learns the features from it. The efficiency of the trained model is determined by validating the model against data which are not used for training the network. The results revealed that the neural network model can be used for predicting the daily accumulated rainfall over the Kerala region with minimal amount of error and false predictions.

Key words : Weather Prediction, Deep Neural Network.

Extended Range Prediction of Madden-Julian Oscillation (MJO) using IITM CFS v2 and the role of initial error on the prediction skill

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Abstract : Various studies have shown the impact of initial error, initial phase and amplitude of MJO on the skill of models in predicting MJO, which varies for each model. Here we have analyzed the role of initial error in the skillful prediction of MJO beyond one week. From the strong events during May- September two sets of events are considered on the basis of error in the initial day forecast. The 25% of strong events each with least initial day error (LIDE) and highest initial day error (HIDE) were used for the study. The initial errors of MJO are defined and categorized using the multivariate MJO index introduced by Wheeler and Hendon (2004)

It was noted that the major contribution to error was from events with the initial phase lying over Western Pacific and Indian Ocean regions. While the poor simulation of enhanced convection over the Indian Ocean was immensely contributing to error in LIDE cases, it was the suppressed convection over the Indian Ocean, which was poorly captured in HIDE cases. The higher error in the simulation of MJO characteristics of the Indian Ocean is causing the HIDE cases to fail from initial lead days. After ~7-10 days lead, both the sets of events were having similar error growth. This result shows that the memory of initial day error is not carried beyond 10 days lead time. The study advocates that reducing the biases in model dynamics and physics could possibly improve MJO simulation over IO, rather than by improving initial conditions while considering the 2-3 weeks lead-time forecasts.

Verification of five Global model's Precipitation during summer monsoon season 2020

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Abstract : The rainfall prediction accuracy of five state-of-the-art operational models during summer monsoon season 2020 was assessed. Precipitation forecasts from global numerical weather prediction (NWP) models are verified against rain gauge in medium range. The National Center for Medium Range Weather Forecasting (NCMRWF) Unified Model (NCUM), the UK Meteorological Office (UKMO), the Global Forecasting System (GFS), the National Center for Environment Prediction (NCEP) and the European Centre for Medium-range Weather Forecasts (ECMWF) are considered for this study. The skill of the models was analysed using different statistical scores like spatial as well as traditional scores. The skill of these five models were also analysed in predicting the heavy rain events during the monsoon period. Among these models, ECMWF is much closer to the observations followed by unified and GFS models. However, the skill of NCUM followed by UKMO is better in predicting the number of rainy days in all rain/no rain, moderate rainfall (>15.6mm/day) and heavy rainfall (>64.5 mm/day) categories. The spatial correlation of all models suggests that the skill of the models is decreasing with forecast lead time. However, ECMWF have best skill among the models followed by unified models. The lowest false alarms with highest POD are noticed in ECMWF while opposite skill is noticed in GFS. The average rainfall over five selected regions suggests that all models are over predicting the rainfall over North East and Central India.

Impact of spectral nudging in the simulation of summer monsoon rainfall over India

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Abstract : The accurate simulation of the Indian summer monsoon rainfall (ISMR) using dynamical models at high spatial and temporal resolution is a challenging task. A regional (Weather Research and Forecasting) model with a 15-km horizontal resolution is employed to dynamical downscale the ERA5 reanalysis data over the Indian summer monsoon (ISM) region for the period 1982-2018. In this study, the effectiveness of spectral nudging (SN) in dynamical downscaling of ISM is evaluated and compared to the control simulation (NSN). Horizontal wind components and temperature fields are nudged in this study to keep the model simulated fields from drifting away from large-scale reference circulations. The IMD 0.25° x 0.25° gridded rainfall products are used to evaluate the model simulated rainfall. This study focuses on the model's ability in estimating monsoon rainfall at seasonal, sub-seasonal, and daily scales over India and its monsoon homogeneous regions. In comparison to the NSN, the SN exhibited a more realistic simulation of ISM features, as evidenced by the spatial distribution of rainfall and area-averaged accumulated rainfall over monsoon homogenous regions. The SN simulations also improve the interannual variability of monsoon rainfall over the monsoon core region. Overall, SN demonstrates the ability to simulate spatial and temporal variations in monsoon rainfall, whereas NSN shows underestimation. Verification metrics computed for extreme monsoon events (i.e., excess and deficit years) show that the SN simulation outperforms the NSN simulation. The following improvement is noticed with SN against observation: (1) The simulated biases, RMSE is less and high CC is identified. (2) The usage of SN in WRF helps the simulation of the seasonal extremes (such as Excess, Deficit).

Key words : Spectral nudging, ISM, dynamical downscaling.

The skill of Subseasonal to Seasonal Forecast Models in predicting the eddy forcing associated with Extratropical-Tropical Interaction

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Abstract : Numerous studies have pointed out that the mean flow modulation due to eddy forcing is a significant part of the atmospheric general circulation over the extratropics and the tropics. The atmospheric transient eddies redistribute heat and momentum. A bidirectional teleconnection process exists between the tropical to extratropical (T2E) and extratropical to tropical (E2T), in which migrating transient eddies cause a significant variation of weather and climate in both regions. The diagnostics of the E2T interaction based on eddy transport indices described in Kalshetti et al. 2020 suggest that an E-vector-based approach is useful in diagnosing extratropical-tropical interactions. The present study tests the skill of sub-seasonal to seasonal (S2S) scale operational forecast by isolating days with such strong interaction by using the previously developed eddy indices. Results from our analysis show that mostly dynamical models fail to forecast whenever E2T indices show prominent transport events with longer lead times beyond a week. Rainfall skill over monsoon core zone is better predictable as compared to the north Indian rainfall. On a daily scale, extratropical transients intruding over the North Indian region are one of the key influencers for extended range prediction as compared to the monsoon core region. This lack of skill could be attributed to the inappropriate eddy forcing (or eddy divergence) in the present S2S models.

Key words : S2S prediction, extreme event, transient eddy, extratropical-tropical interaction.

Role of land surface feedback processes on the prediction skill in the S2S scale during monsoon onset in a coupled model framework

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Abstract : Monsoon onset over Kerala (MOK) marks the beginning of the rainy season in India. The normal date of MOK is 1 June; however, it varies with a standard deviation of 8–9 days from year to year. Prediction and outlooks of monsoon onset are crucial for agriculture planning. The timing of MOK can have a significant impact on agricultural productivity. So, the exact date of prediction of MOK is very important. The MOK is associated with changes in the large-scale dynamical parameters as well as local moisture parameters. The differential heating of land and sea is the primary cause that drives the ISM. However, several studies show the sensitivity of onset to different meteorological and climatic factors. It is not well known how the land surface initial states impact the forecast of the onset in the operational forecast models. In this study, we compare the spatiotemporal characteristics of different surface meteorological parameters during MOK from Met Office GLOSEA5-GC2 model hindcast and IITM CFS model. Following Joseph et al. (2015) we compare the skill of the coupled models in the s2s scale. For the observation, IMD and ERA5 reanalysis datasets have been used during the period of study (2003-2015). We compare biases from the observation and differences between the models themselves. To see that how strongly land surface fluxes affect the near surface variables we have calculated the Coupling Strength (CS)during the monsoon onset days for the period (2003-2015). Our study indicates that the error in surface fluxes is responsible for bias in rainfall patterns. Also it affect the prediction skill on S2S scale during monsoon onset (2003-2015).

Long-Lead Prediction and Predictability of the Indian Summer Monsoon Rainfall

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Abstract : The Indian Summer Monsoon Rainfall (ISMR) defined as the accumulated rainfall from June to September over the Indian subcontinent is strongly linked with the socio-economic conditions of the South Asian region. Small swings in its variability can result in catastrophic climate conditions in the region (Gadgil&Gadgil, 2006, Parthasarathy et al., 1988). With recent success in understanding the monsoon mechanism (Goswami&Chakravorty, 2017, Charney&Shukla, 1981, Walker, 1923) and predicting the seasonal variation of ISMR up to 4-month in advance (Capua et al. 2019), very little attention has been given to the potential predictable skill of ISMR at longer lead time. Here, we present that a global scale recharge-discharge mode controls the potential predictability of ISMR and discover a predictor based on the depth of 20^{o} isotherm (D20) that is least affected by atmospheric noises. We found that the potential predictable skill of ISMR remains ~0.8 at 18-24 month lead when simultaneous contribution from all the three tropical basins are taken in account. Smaller initial errors phase-locked with the annual cycle with relatively slower growth rates make the long-lead ISMR forecasts more predictable. However, independent realization of the long-lead potential predictability is a challenging task due to the small scale non-linear D20 anomalies. Therefore, we believe that with the advent of non-linear deep learning models, our findings provide optimism for long-lead skilful prediction of ISMR in coming years.

Changes in Asian jet meridional displacement and its influence on Indian summer monsoon rainfall in observations and CFSv2 hindcast

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Abstract : Studies have analyzed the meridional displacement of Asian jet (MDAJ) and its influence on East Asian rainfall; however, the relation with Indian summer monsoon rainfall (ISMR) is not fully explored, limiting the prediction skill of ISMR. In this study the impact of MDAJ on the ISMR in observations and Climate Forecast System version 2 hindcast is examined, for the period of 1985 to 2019 boreal summer (JJAS). Empirical Orthogonal Function, correlation and regression analysis etc has been used for the study. The leading mode of variability in the upper-tropospheric zonal wind anomalies along the Asian jet exhibits a north–south seesaw pattern in both observation and model. The strength of the meridional displacement/loading of the summer Asian jet is robust over the East Asian region in the observations, whereas in the case of CFSv2 the signals are strong both over the West and East Asian regions. The southward displacement of the Asian jet (SWDAJ) provokes reduced precipitation over the central and northern India regions in observation which is well captured by the model but with slight overestimation of its strength. Physical mechanisms that link the SWDAJ and monsoon rainfall are unravelled in this study. Observed precipitation enhancement in the Meiyu-Baiu rain band is the characteristics of SWDAJ over East Asia (EA), linked with divergence over India, which is completely absent in the model. During June and July, the dominant meridional displacement of the Asian jet is located over both West and EA regions. These dominant anomalies migrated eastward to the EA region by September in the observations, whereas persisted over both regions in the model. This study suggests that the teleconnections of the Asian jet variability and ISM rainfall are over dependent on ENSO in the model, specifically in late monsoon season, limiting ISMR prediction skill.

Key words : Asian Jet variability, Indian Summer Monsoon, Meridional Displacement

Sub-seasonal variability of the Indian summer monsoon rainfall 2020 in observation and CFSv2 hindcasts

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Abstract : All India summer monsoon (ISM) rainfall during 2020 is above normal with 109% of its long-period average and exhibited a prominent month-to-month variability with unexpected low precipitation in July over Indian subcontinent. The possible factors determining the unusually reduced rainfall in July 2020 are investigated in the observations. We have also examined the predictability of 2020 ISM rainfall using the National Centers for Environmental Prediction (NCEP) Climate Forecast System version-2 (CFSv2) hindcasts. Regardless of weak La Niña conditions in the Pacific and Tropical Indian Ocean (TIO) warming throughout the season, the westward extension of anomalous Western North Pacific (WNP) anticyclone modulated the monthly variations of ISM 2020 in the observations. Strong low-level moisture divergence corroborated with westward propagating atmospheric cold Rossby wave as a response to suppressed WNP convection linked to a low-level anticyclone mainly contributed to the reduced rainfall over the monsoon trough region in July 2020. The TIO warming-induced atmospheric Kelvin waves and strong low-level convergence over the Meiyu-Baiurainband region due to mid-latitudinal circulation adjustments are accountable for the southwestward shift of intense WNP anticyclone. In contrast, CFSv2 model showed strong positive rainfall anomalies over India in July 2020. Though the model is able to predict the TIO warming, it failed to represent the westward extension of the WNP anticyclone, which adversely impacted the prediction of rainfall pattern in July 2020 over India.

THEME : HYDROLOGICAL APPLICATION

Performance of Flash Flood Guidance System over West Coast of India during Tropical Cyclone TAUKTAE

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Abstract : Flash floods are typically associated with high-intensity rainstorms with short response time. They have the potential to severely impact and damage communities at different climatic settings especially in a densely populated region of South Asia. Recent years witnessed an increased effort to understand the dynamics of Flash floods with the availability of high-resolution hydro-meteorological and topographical data. Despite their scientific significance and social impacts, the fundamental processes triggering a flash-flood response are yet not fully understood.

Operational flash flood warnings over small watersheds with high spatial and temporal resolution have become feasible with (a) the development of new approaches for the extraction of useful information from radar and satellite remotely sensed data and rain gauge sensors, (b) the availability of high resolution digital spatial data and the ability to derive useful hydrologic information through geographic information systems applications, (c) advances in computer technology for fast processing of data over large areas with high resolution by inclusion of uncertainty propagation computations [2]. In this context, the operationalisation of South Asia Flash Flood Guidance Services is one such attempt to integrate the hydrological mechanisms causing saturation runoff in response to intense rainfall causing flash floods over the watersheds of Indian region. The purpose and objective is to provide location specific flash flood guidance up to watershed level on pluvial flash floods in the form of risks with 24 hour lead time based on numerical weather forecasts and threats with 6 hour of lead time based on near real-time observations based on 00,06,12 and 18 UTC observations.

Though still evolving, the efficacy of South Asia Flash Flood Guidance System at operational level is validated by many accurately forecasted Threat and Risk potentials of various Flash Flood events in the South Asia region. This article presents the novel concept and efforts adapted in India, in assessing the capability of this state of art Flash Flood Guidance System developed to provide effective operational guidance on flash floods at watershed level. This work enhances the utility of this system along with NOWCAST by the operational meteorologists and hydrologists by bridging the gap for better predictability of hydro-meteorological events like Flash Floods at local level.

Key words : Flash Flood, Watersheds, Threshold runoff, FFG, Soil moisture, Bankful.

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