PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 12(2): 1-11
https://doi.org/10.14719/pst.6407

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REVIEW ARTICLE

Historical advancements in Indian monsoon forecasting: A review

Pugazenthi K[1], Jeevanand KP[2], Geethalakshmi V[3], Jagannathan R[4], Dheebakaran Ga[1], Boomiraj K[5] & Pazhanivelan S[6]

[1]Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[2]Central Research Institute for Dryland Agriculture, Hyderabad 500 059, India
[3]Office of Vice Chancellor, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[4]Office of Vice Chancellor, Periyar University, Salem 636 011, India
[5]Department of Environmental Sciences, Tamil Nadu Agricultural University, Coimbatore 641 003, India
[6]Centre for Water and Geospatial Studies, Tamil Nadu Agricultural University, Coimbatore 641003, India

*Email: geetha@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 25 May 2024
Accepted: 27 October 2024
Available online
Version 1.0 : 24 March 2025
Version 2.0 : 01 April 2025

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Pugazenthi K, Jeevanand K P, Geethalakshmi V, Jagannathan R, Dheebakaran G, Boomiraj K, Pazhanivelan S. Historical advancements in Indian monsoon forecasting: A review. Plant Plant Science Today. 2025; 12(2): 1-11. https://doi.org/10.14719/pst.6407

Abstract

The seasonal forecast is an important type of forecast in the agriculture sector particularly in India where the vast population relies on agriculture. Monsoon trade winds contribute to vast portion of Indian rainfall. Owing to its importance, the research activities on the prediction of the Indian monsoon started in ancient times and are carried over for the development of a perfect forecast system. India has bimodal rainfall with two major monsoons. The southwest monsoon contributes more with widespread rainfall over India and the northeast monsoon is the returning monsoon which brings dry wind to northern India and provides huge rain in southern India, particularly Tamil Nadu. Most of the work regarding monsoon has been concentrated on southwest monsoon and less on northeast monsoon based on its importance. Over the years, several projects have been undertaken to enhance seasonal forecasting, with the Monsoon Mission being one of the most recent and significant initiatives aimed at improving prediction accuracy. Additionally, Agromet Advisory Services Bulletins have been developed using seasonal outlooks to provide tailored recommendations to farmers, helping them optimize agricultural practices based on forecasted conditions. This review highlights the advancements in seasonal forecasting, the regional focus on monsoons, and the role of these forecasts in supporting India's agricultural sector.

Keywords

agriculture; Indian monsoon; seasonal forecast

Introduction

Weather forecasting is a common well-known topic familiar to a wide range of communities. With advancements in technologies and improved techniques in weather forecasting, high accuracy forecasts are being disseminated to the people. Agriculture in India is majorly influenced by the monsoon especially southern peninsular region which receives rainfall from both the southwest and northeast monsoon. Further, the strength and severity of monsoon is determined by various global circulation phenomena, particularly by El-Nino Southern Oscillation (ENSO). Several types of weather forecasts are being disseminated to people like nowcast, medium range, extended range, seasonal forecasts and even more special forecasts for specific purposes or communities. Several sectors depend on seasonal forecasts which directly and indirectly affect the livelihood and economics of people through unstable agricultural production, natural disasters and failure in the forewarning system. Among that agriculture sector which holds the livelihood of a major portion of India seems to be the most significant. Crop selection, resource management, yield prediction, pest and disease outbreaks, and price forecasts are major components that depend on seasonal forecasts in the agriculture sector. With climate change creating further unpredictability in weather *viz*., erratic monsoons, prolonged droughts and extreme events, the role of seasonal forecasting becomes even more vital. Over the period of time, several improvements have been made in seasonal forecasting system through different projects focusing on high resolution and long lead time forecasts. At the same time, these improvements alter the schema of India's seasonal forecast also. India was pioneer in seasonal forecasting in earlier days, since the attempts of Blankford and Walker for seasonal forecasting were most pronounced milestones in the field of forecasting weather in early modern era. Due to some constrains, advancements take slow lane for nearly half century in Indian country. Again that, blooming started with huge, funded projects like monsoon mission for achieving state of art in the Indian monsoon prediction. This paper is concentrated on milestones of developments on seasonal forecast so far achieved and its application towards agricultural aspects.

Process and importance of monsoon

One of the important global *circulation* phenomena, monsoon wind provides ample water to the people of India with some fluctuations over some period. An important basic driver of global circulation is solar radiation, which causes wind movement due to uneven heating of land and sea surfaces. Wind direction may be horizontal or vertical, depending on the pressure difference created, and is studied widely as a global circulation system. As mentioned, there are some significant circulations which decide the majority of global wind circulation and dependent parameters such as precipitation, evaporation and humidity (1, 2). During the summer season in the northern hemisphere, intense heating of Indian land masses creates a low-pressure system which makes the Inter Tropical Convergence Zone (ITCZ) shift towards the northern hemisphere. It makes a diversion in the direction of equatorial westerlies towards Indian peninsular as southwest monsoon (3,4). Along with these basics, Simpson (5) added that strong high pressure over the south Indian ocean was also a major determining factor in strengthening these trade winds. Huge moisture-laden trade produces tremendous rainfall by orographic lifting of western ghats in south India. Then it sweeps the entire Deccan plateau with a contribution of 70% annual rainfall of India over the period of June to September (6,7). After August, a reversal of this phenomenon happens which is the normal circulation characterized by north easterly winds heading towards the equatorial region. The magnitude of this trade wind is determined by a strong Siberian winter high-pressure system, low-pressure region over east pacific and north Indian Ocean. Southeastern peninsular part of India, being a rain shadow region during south-west monsoon receives heavy rainfall by dry northeastern trade wind after passing through the Bay of Bengal Sea (8,9). Variability of rainfall during both the monsoon season is reported in various studies and its association with several other global phenomena. Gadgil (10) made some hypotheses regarding driving factors of monsoon and gathered scientific works to check the hypothesis. Some of those hypotheses failed and new aspects of driving factors have been proposed. Chowdary (11) explained interactions of global weather phenomena like ENSO, Madden–Julian Oscillation (MJO), Indian Ocean Dipole (IOD), and snow cover of the Eurasian region with the origin development of Indian monsoon. Relation among the monsoon seasons also studied for Tamil Nadu, peculiar region receiving rainfall from both monsoons significantly higher in north east monsoon (12). Indian food grain production highly depends on monsoon rainfall as around 53% of agricultural lands are rainfed (13). A study reveals the importance of northeast monsoon rainfall on agricultural production of Tamil Nadu and Andhra Pradesh (14). Seasonal forecasting is increasingly used for decision-making in most sectors which are highly dependent on weather conditions. Farmers are major among the sectors, and they use forecasting products at high level for various operations starting from crop planning until crop harvesting and marketing. Along with them, other sectors utilizing forecast products are transport, tourism, marine, aviation, disaster management *etc*. (15).

History and breakthrough of seasonal forecast in India

Indian meteorological works have several benchmarks during the development of meteorological history. A study related to understanding the relationship between South Asia rainfall season and Indian Ocean wind pattern by Halley (16) was considered to be a primitive scientific investigation on seasonal rainfall. These investigations steeped to next level with the installation of meteorological observational stations in Calcutta during 1796 followed by Madras in 1785 and in several locations through which well -structured and informal observations were made. After these installations two major achievements were made, one that mainly focused on cyclones by Harry Piddington and the next one was the discovery of diurnal pressure variation over south Asian land masses which reasoned for origin of two monsoon systems in India. Even studies regarding the monsoon and cyclones were undergone, accurate forecasting and forewarning failed during 1864 Calcutta cyclone and monsoon failures in 1866 and 1871. During 1875, India Meteorological Department (IMD) was established with H.F. Blanford as chief reporter.

Severe drought in 1877 made India to investigate monsoon arrival and rainfall occurrence chances as soon as possible, which was headed by Blanford. He provided forecast from the year 1882 to 1885, considering snow in Himalayan region particularly relationship between North-Western Himalayan snow cover and drought over western Indian regions (3). The attempt of drought prediction provided him greater confidence to predict monsoon rainfall which was disseminated on 4th June 1886 and continued every year till now.

Further, Sir John Eliot was appointed as Director General of Observations, and overcame Blankford with better ideological and observational concepts. During the period of 1889 to 1903, Eliot made huge observations over the Indian ocean and land masses which lead to Indian Monsoon Area synoptic charts preparation which could be called as first Monsoon experiment. He made clear conclusions about the pressure and wind anomalies during monsoon period as abrupt strong wind formation over North Indian Ocean and it strengthens over Arabian sea during southwest to southeast flow. Long Range Forecast of Indian Monsoon was also carried over during Eliot period by utilizing subjective techniques like analogue and simple linear equations. Eliot is the first person to prepare Climatological Atlas of India and published it.

In 1904, Sir Gilbert T. Walker was appointed as next in charge of IMD who dedicated himself in long range forecasting of southwest monsoon. He believed that monsoon trade wind in India region should be influenced by several other factors occurring around the globe. He utilized statistical correlation between Indian Monsoon and various other factors around the globe with reconstructed global meteorological telecommunications. He has developed linear multiple statistical correlation methodology for long range forecast of Indian monsoon. The First World War (1914–1918) made IMD run with a deficit of scientists which made way for Indian scientists to join and serve in IMD. With walker suggestion IMD has been shifted to Pune and then now it is operating in New Delhi during 1926 and 1945 respectively. Walkers' system of monsoon forecast was followed until 1987 with several minor modifications based on studies concerning monsoon physics done by eminent scientist appointed in IMD. During 1988, IMD has adopted 16 parameter power regression model for southwest monsoon rainfall for Indian subcontinent which has failed in 2002 (17). Then from 2003 to 2007, IMD adopted two stage forecast with modified power regression model and Linear Discrimination Analysis (LDA) model (18).

Dynamical forecast development

While the above-mentioned system of forecast is followed for monsoon prediction and forewarning in India, other major research works on dynamical simulation of monsoon were carried over. In spite of Empirical method of forecasting having advantages of less computation power and having higher skill with less complications it has also disadvantages like failure in predicting extreme monsoon conditions and varying relationship between predictand and predictors of monsoon.

Worldwide several studies have been carried over to develop global circulation models after advancement of computation power. Numeric studies were carried over to develop dynamic simulation models and further evaluations were done for optimizing models. In 1965, tropical and sub-tropical precipitation were simulated which fairly showed a realistic distribution of monsoon (19). Hahn and Manabe (20) again simulated Asian monsoon with two criteria with the effect of mountains and without the mountains. They concluded that monsoon is well simulated in mountain conditions and showed the unique characteristic developed because of presence of mountains in Indian region. However significant work of Charney and Shukla (21) on Indian monsoon prediction through dynamic modelling suggested that low prediction skill of monsoon in lower latitudes can be improved by understanding fluctuations in variables such as sea-surface temperature, vegetative cover, albedo and ground moisture. With the advancements in parameterization studies like Sato et al. (22), Moorthi and Suarez (23), and Hack (24), dynamic models were well built to simulate better realistic conditions.

Monsoon Experiment (MONEX)

The monsoon Experiment program was initiated as a subprogram of the Global Atmospheric Research Programme (GARP) which operated in two phases Winter and Summer indicating the two monsoon seasons during the period of 1978 and 1979. It has four objectives focusing on observation and understanding the phenomena happening during monsoon and final objectives as numerical simulation and prediction. In that programme, several findings regarding monsoon and its implication in modelling were performed. In the summer monsoon which has more impact on the Indian region and for winter monsoon the programme was concentrated on China. However, winter monsoon also had gradual impacts on Sri Lanka and South Indian region particularly Tamil Nadu which was neglected in those study periods. Das (25) has discussed clearly about the history and development of the Monsoon Experiment along with possible outcomes. Krishnamurti (26) gave short summary of MONEX programme regarding the observational results, characteristics of boundary layer, and prediction of onset of monsoon.

Tropical Ocean – Global Atmosphere (TOGA)

The significant identification of major global circulation between eastern and western Pacific Ocean (Southern Oscillation) (27) in 1924 paved the key for several researchers. In 1985, World Climate Research Programme (WCRP) initiated TOGA to co-ordinate global scientific community for concentrated and structured work on ocean and atmospheric variability in tropical ocean basins with goals of observation, transmission of data, understanding the mechanisms and modelling the ocean-atmosphere systems for timescales ranging from months to years. Several findings were made by various scientists in understanding the mechanisms and data acquisition techniques (satellite data derivation) that strengthened the modelling aspects (28, 29) which is further compared in the following programme.

Atmospheric Model Intercomparison Project (AMIP)

Intercomparison studies made by the Intergovernmental Panel on Climate Change (IPCC) on the performance of atmospheric models revealed that disagreement of models with observation was much wider. Bourke et al. (30) found that eight models utilized had common similar errors of colder lower air in the troposphere and in upper troposphere of higher latitudes. Considering these performance studies of GCM's, AMIP was suggested in 1989 and formulated in 1991 with background of intercomparison and validation of the GCMs on seasonal and interannual scales with common simulation periods and evaluation metrices (31,32). Detailed information regarding the models and research institutes was described in publication of Phillips (33). Analysis of model outputs of AMIP indicated that summer monsoon wind shear was better predicted than all-India rainfall and some models were able to represent with good brier score (34). Gates (35) report summarizes the important results of the project in concise manner. AMIP results revealed that ensembled mean error indicates most of the simulated parameters like pressure, temperature and wind circulation of seasonal prediction were considerably near to observed data. Ensemble mean of precipitation and ocean surface heat flux showed better agreement with observed with large intermodal differences in lower latitudes. Subseted simulation of original AMIP model's upgraded versions also showed systematic errors in cloudiness with slightly reduced errors in other simulated variables. However, interpretation of AMIP model runs indicated that monsoon precipitation simulated by eleven models was reasonable which were in the category of class I and skill for simulation of excess/deficit monsoon rainfall for the Indian region were marked higher in class I type of models than class II (36).

Along with these, the performance of European seasonal forecasting projects DEMETER and ENSEMBLES over Indian monsoon variability were evaluated (37). In that ENSEMBLES project models have better prediction over previous project models DEMETER. As per the request from WMO Commission of Atmosphere Sciences (CAS), WCRP, WWRP and THORPEX formed a collaborative project on sub-seasonal forecast named "Subseasonal-to-Seasonal S2S" Project in 2009 with objectives of improving forecast skill of sub-seasonal to seasonal weather events (38). S2S projected started with 11 models from different countries' meteorological centres and is currently supported by 13 as listed in Table 1. The skill of S2S models was analyzed and utilized for the prediction of wet and dry extremes during ISM (39).

South Asian Climate Outlook Forum (SASCOF)

South Asia countries are experiencing severe loss and damage due to monsoons over long period of time. The World Meteorological Organization (WMO) supported South Asian countries in organizing and developing South Asian countries forum in 2009 (53). Further from 2010, several forum discussions were made for producing a better South Asian Climate Outlook every year on regional scale. It focuses on community of people engaged in the Water, Agriculture, Disaster Risk Reduction and Health sector for their specific need of seasonal outlooks. Stacey (54) evaluated the skill of 12 operational seasonal forecasting dynamic models available overall forecasting centres for predicting South Asian monsoon and studied the impact of ENSO and IOD on monsoon. All models resulted to have less prediction skill while averaged over the regional level. However positive skills were pronounced for certain regions where the highest correlation occurs with ENSO. Southwest monsoon has less telecommunication with IOD and northeast monsoon has resemblance with ENSO. They also suggested multi-model ensembles for improving skill over region level and selected model ensembles for specific nations.

Monsoon Mission (MM)

As mentioned in above historical section, several intensive works had been carried over to improve the prediction of Indian summer monsoon rainfall. However, there was no significant reflex in the skill score of predicted rainfall (55–57). The skill of a fully coupled ocean land-atmosphere model was demonstrated for Indian monsoon prediction, until that it was not demonstrated but strongly described (58). Assessing the performance of standalone atmospheric models under Seasonal Prediction of the Indian Monsoon (SPIM) project was carried out with five models utilized in AMIP and noticed that only one model had better skill than others which was attributed to high sensitivity of models toward ENSO. These models were configured and all runs were made on PARAM HPC facility of CDAC (59). This demonstration of coupled model and utilization of

Table 1. List of global seasonal prediction models contributed in S2S project

S. No	Model name	Meteorological Centres	Reference
1	Predictive Ocean Atmosphere Model for Australia (POAMA- P24)	Bureau of Meteorology, Australia (BoM)	(40)
2	Beijing Climate Center (BCC) Climate Prediction System version 2 (BCC -CPS-S2Sv2)	China Meteorological Administration.	(41)
3	Grid point, hydrostatic, atmospheric general circulation model GLOBO	National Council of Research of Italy	(42)
4	Centre National deRecherches Météorologiques (CNRM-CM 6.1)	National Centre for Meteorological Research, France	(43)
5	Brazilian Global Atmospheric Model version 1.2 (BAM-1.2)	Centre for Weather Forecast and Climate Studies (CPTEC), Brazil	(44)
6	Global ensemble prediction system (GEPS) version 8.0	Canadian Meteorological Centre (CMC)	(45)
7	Integrated Forecast System (IFS)	European Centre for Medium-Range Weather Forecasts	(46)
8	Regional Unified Model System (RUMS)	Hydrometeorological Centre of Russia (HMCR)	(47)
9	Coupled Prediction System version 3	Japan Meteorological Agency	(48)
10	Global seasonal prediction system GloSea6-GC3.2	Korean Meteorological Society	(49)
11	Climate Forecast System Version 2 CFSv2	National Centers for Environmental Prediction	(50)
12	Chinese Academy of Sciences (CAS) Flexible Global Ocean-Atmosphere -Land system version f2-V1.3 (FGOALS-f2-V1.3)	Institute of Atmospheric Physics (IAP), CAS	(51)
13	GloSea6 (HadGEM3 GC3.2)	UK Met Office	(52)

HPCs paved the way for further investigations of Coupled model integration in HPC which put forth the first mission operated by the Ministry of Earth Science (MoES) named “Monsoon Mission” initiated in 2012. Monsoon mission cleared the gap between research institutes around national and international levels by collaborating and funding project proposals. It has the main objectives of a state-of-the-art dynamical seasonal prediction system extended range prediction, and ensemble short-range weather forecast which had come up with diverse projects (around 40) and MoES between various countries (around 51) (60).

Coupled Atmospheric and ocean model’s better prediction skills than standalone Atmospheric Global Circulation Models (AGCM) and empirical models were proven from the investigations (61, 62). Further, among AGCM Portable Unified Model (PUM) from Hadley Centre, UK as a standalone model (59) and the NCEP CFSv1.0 coupled model performed better than others (63).

The CFSv2 had been developed from integrating four independent systems of integration system and models namely, global ocean data assimilation system (GODAS) operational at NCEP in 2003 (64), NCEP–Department of Energy (DOE) Global Reanalysis 2 (65) that provided the atmospheric and land surface initial conditions NCEP’s Global Forecast System (GFS), the Modular Ocean Model, version 3 (MOM3), from the Geophysical Fluid Dynamics Laboratory (GFDL), all these components are coupled in the Earth System Modelling Framework. Therefore, Indian Institute of Tropical Meteorology Earth System Model (IITM-ESM2.0) evolved from CFS has been utilized as base model for all further works to improve the skill in monsoon prediction and significant advancements are consolidated in Table 2.

Another two objectives of Monsoon Mission related results were not discussed here as this paper concentrates on the seasonal forecast and the major achievements in this project as described in Suryachandra (66) are discussed here.

The mission started its research work analogous to Blankford forecast based on Himalayan snow cover in 1882, Saha et al. (67) attempted to predict Indian Summer Monsoon (ISM) in coupled model CFSv2 and found the relationship of snow cover and summer monsoon rainfall. Experiment results indicated that performance of CFSv2 (T126) has increased performance over CFSv1 and it had been adopted in IITM models (50). However, CFSv2 has a dry basis over the Indian region and was overcome by increasing the resolution as T382 which has reduced dryness but slighter dryness in tropical ocean in the studies of Ramu et al. (68).

Among all studies bias correction for input dataset of model and reduction in error is considered to be significant even though utilized for extended range forecast. Abilash (69) found that utilization of bias corrected SST for extended range forecast development with Global Forecast System (GFSv2) had given better skill improvement. Sahai et al. (70) developed bias correction and downscaling the coarse resolution model output through self-organizing map algorithm. Lead time selection and optimization are also a significant factor in better forecast skill which was identified for ISMR forecast as the initial condition of February rather than May (71–74). An advanced method of data assimilation, which was found to have robust reduction in forecast error was detailed (75). As vast findings were made most of them were left and major work are discussed.

Achievements in Northeast monsoon

Investigating on historical development t of ISMR prediction over Indian region shows that enormous number of works have been done and being going on. Indian being a country having bimodal rainfall from both monsoon but composition of share is almost 90 percent supported by southwest monsoon and least from the northeast monsoon. However, while concentrating on northeast monsoon which found to be crucial for southern peninsular India, particularly Tamil Nadu (48 %) and Kerala (17 %) studies are limited (76). IMD daily weather reports failed to describe about northeast monsoon over long period of time since its first mention in 1923 up to 1977.Then it is published and refined after defining set of criteria to declare northeast monsoon onset by IMD. Meanwhile research on process and interaction of northeast monsoon also started in 1973 which can be noticed in IMD forecast manuals. Studies of Geethalakshmi et al. (77,78) regarding interaction of ENSO and IOD on northeast monsoon

Table 2. Consolidated research activities performed in monsoon mission

Phase	Year	Number of publications	Research areas
I	2012-13	3	Status and utilization of CFS
	2013-14	10	Basic simulation of ISM by utilizing and adjusting the base model under various initial conditions
	2014-15	23	Improvement CFSv2 through input refinement, optimizing parametrization for models and ensembling various condition for better forecast
	2015-16	28	Error analysis in ensemble members, concentration on parametrization
	2016-17	31	Schemes, extreme events and cyclones
II	2017-18	33	Schemes- radiation and cloud, ocean studies, comparison of models
	2018-19	42	Understanding controlling factors, Tropical cyclones, Drought indices
	2020-21	64	Drought studies, trend, microphysics, CMIP5 model utilization, interactions and allied (Rain drop speed, machine

(Source: https://www.tropmet.res.in/monsoon/monsoon2/publications.php).

reveals positive El-Nino years had strong northeast monsoon which was further analysed by Kokilavani et al. (79). Interaction of easterly wave on northeast monsoon was analysed by Geetha and Raj (9) and revealed that good rainfall during northeast monsoon. Yadav (80) studies on ENSO influence on northeast monsoon revealed detailed explanation on El-Nino and La Nina years impacts and proposed physical mechanism regarding that. The importance of ENSO on hydrological status and its influence on rice productivity were analysed by Bhuvaneshwari et al. (81) and revealed El-Nino has direct impact on rice production in the form northeast monsoon rainfall.

Considering the importance and need of northeast monsoon rainfall, forecasting this monsoon rainfall was started from Duraisamy Iyer (82). The distribution and relationship of northeast monsoon among Tamil Nadu districts was studied and it was stated that Tamil Nadu has fairly homogeneous regions of rainfall distribution (83). A significant negative correlation between southwest monsoon and northeast monsoon was found which was suggested to consider as factor for northeast monsoon forecasting (12), which was also supported by Raj (84). Raj had done extensive research work on northeast monsoon starting from 1989 by predicting the onset dates and continued on the line of forecasting northeast monsoon onset dates on Raj (85). Identifying the optimum parameters predictands for northeast monsoon rainfall was started in 1989 then continued by Raj et al. (86) and further refined as six major predictors (Table 3) with prediction error of 13 -18 % (87). Developing a statistical technique for determination of withdrawal dates was done by Raj (88) and further upgraded in the research works of Raj (89). Raj et al. (90) studied the movement of clouds zone from south Bay to Bengal to Peninsular region and explained the mechanism behind movements.

Table 3. Six major predictors of northeast monsoon

S.No	Northeast monsoon Predictor	Percentage explaining
1.	August – September wind speed 850 hPa Thiruvananthapuram	
2.	August zonal wind 150 hPa Thiruvananthapuram	40.9
3.	September zonal wind 300 hPa Thiruvananthapuram	
4.	June -September 150 hPa temperatures of Port Blair	
5.	June -September 150 hPa temperatures of Hyderabad	64.3
6.	April 200 hPa zonal wind	7.4

In the recent years studies on northeast monsoon notably increased. Criteria for prediction of Onset of northeast monsoon was restructure based on studies of Sathyanarayana et al. (91). Raj and Amutha (92) also studied diurnal variation of northeast monsoon rainfall over Tamil Nadu, stated that rainfall maximum at early morning and minimum at afternoons and explained the process behind diurnal variations. Moreover, the investigations on utilization of numerical models for northeast monsoon forecast and characterization also proceeded. Maharana et al. (93) attempted to simulate northeast monsoon with three types of land-surface schemes and proved that Community Land Model version 4.5 (CLM) performs better than other two schemes. Prasanna et al. (94) utilized Asia-Pacific Economic Cooperation (APEC) Climate Center (APCC) models for analysing interannual variability and shift in northeast monsoon and revealed that most of the models failed to represent the purpose. Furthermore detailed description of all the works related to northeast monsoon can be found in monsoon monograph published in 2022.

Seasonal forecast – Agricultural aspect

Indian geographical factor makes the country suitable for cultivation of wide range of crops ranging from cereals, millets, pulses, sugar crops, vegetable crops and cash crops. The unique topography of Himalayans at northern region, southern peninsular plateau with Bay of Bengal at east, Arabian sea at west and Indian ocean at southern region makes it one of the peculiar countries receiving monsoon rainfall. Southwest monsoon provides around 868 mm which contributes around 80-90% of annual rainfall whereas northeast monsoon contributes minimal percentage of share in countrywide. However, northeast monsoon contribution in southern peninsular region is in huge percentages as 450mm for Tamil Nadu and 490mm for Kerala report. Indian agriculture is highly dependent on monsoon as 53 percent of Gross Cropped area is rainfed. Even irrigation sourced from canals, tanks, watersheds and underground water also got affected by the monsoon rainfall. Ramprasad (95) had also pointed these composition farming peoples vulnerability to debt and adaptations. Parthasarathy et al. (96), Gadgil (97), Kumar (98) and Bowden (99) findings discussed regarding the relationship of Indian monsoon and agricultural production (Cropped area, production and productivity) are clearly indicating the importance of monsoon rainfall. Swami et al. (100) analysed agricultural susceptibility towards monsoon utilizing Wet-Dry spell, intensity of rainfall events, long period deviations which contributed for policy makes and farming community. Rao et al. (101) explained clearly the relationship of monsoon and Indian agriculture and indicated the flaws to be filled in the aspects of northeast monsoon and location specific extreme event prediction to reduce crop loss.

Owing to importance of monsoon, seasonal forecasting of ISMR finds crucial position in benefits of farming community. Forecast goodness can be divided into three types according to Murphy (102), (a.) consistency of forecast, (b.) quality of forecast and (c.) value of the forecast. These three are interrelated to each other, as value of forecast is determined by quality of forecast. Value of forecast is assessed in scale of the extent the forecast is utilized especially in economic manner. Jones et al. (103) demonstrated the economic importance of high-quality seasonal forecast on agricultural production. Comparing two types of forecasts utilized for the yield prediction and on comparing with actual observation shows that, prediction was good with the one which utilized data from high skill forecast.

Seasonal forecasting for agricultural aspects was dated from the period of Blankford during severe drought period 1877 and started providing Farmers Weather Bulletin from the year 1945. During 1932, The Agricultural Meteorology Division was established at Pune and initiated various multi-disciplinary activities. It has development over time through prediction method, disseminating ways, usability which is significantly bloomed after Monsoon Mission.

IMD has started Agrometeorological Advisory Service (AAS) at state level in collaboration with State Departments of Agriculture in 1976 and the service has been started at agroclimatic zonal level with the establishment of Agromet Field Units (AMFUs) at State Agricultural Universities, ICAR and IITs since 1991. From 2008 onwards, District level agrometeorological advisory service (AAS) in collaboration with ICAR and State Agricultural Universities under Garmin Krishi Mausam Seva (GKMS) Project has been started. The forecast provided by IMD has various scales in spatial and temporal range so that AAS bulletins are provided at district, state and national level.

IMD provides various types of forecasts at different temporal and spatial scale while concentrating about seasonal forecast, it provides both southwest monsoon forecast and northeast monsoon forecast along with SST, ENSO, IOD. While discussing about temporal scale, IMD provides short, medium and extended range forecast to the farming community. However operational AAS were bounded to disseminating National Agromet Advisory Services Bulletin based on Extended Range Weather Forecast (ERFS) with detailed view about individual state. From 2018 onwards, centralized website for monsoon forecast dissemination has been imitated and published (https://mol.tropmet.res.in). Various sources of seasonal forecast are maintained on that site in graphical representation which would provide an outlook over the season.

The utilization of extended range and seasonal weather forecast for agriculture planning strategy has been explained (104). The case study regarding pest attack, sowing of rice based on ERWF depicted importance and practical utilization of forecast. In case of Seasonal forecast advisories were not given in respect to crop and being disseminated as percent deviation from the normal rainfall. They provided suggestions as, seasonal forecasting can be value added along with region specific crop conditions advisories like crop planning, resource allocation and distribution.

Conclusion

Considering the importance of monsoon on Indian country, MoES has taken several steps to develop state-of-art in seasonal forecasting of Indian monsoon. With huge funding umbrella scheme Atmosphere & Climate Research-Modelling Observing Systems & Services (ACROSS), activities like Monsoon Mission, High Performance Computing Systems, Monsoon Convection, Clouds and Climate Change, Atmospheric Observational Network, Upgradation of Forecast System and Exploring Doppler Weather Radars have been done so far and it also approved to extend next Indian economic year with huge budget. Some of value-added work that can considered are as follows, several vital works have been progressed on southwest monsoon to improve the forecast of monsoon, however studies on extreme events regarding flash flood, drought must be concentrated nowadays, as the number of events are higher. While keeping eye on development activities on both monsoons, northeast monsoon must be given much more importance, even though its contribution to Indian rainfall is less it has significant impact on agriculture of south India particularly Tamil Nadu. Weather observation must be supplemented more for high accuracy of forecast verification and development. In 2019, Data supply portal has been developed and seamlessly involved in data maintenance. However, more integration of weather data available in various institute in state wise to attain centralized weather data access which improves observational network. Recent techniques like artificial neural network, machine learning can also be added up in the line of action along with numerical models. Adaptation and development of bias correction techniques has been observed over studies should be made available to academic and research institutes. Most of the research has been concentrated on investigating and improvement of forecast. Value of the forecast is determined by its significant usage which is followed as disseminating forecast into value added products to public communities.

In agricultural aspect of seasonal forecasting, extended range forecast provided has better performance. However, seasonal forecast in relation to agricultural purpose may also be provided at high resolution special scale with existing disseminating system. More research on extension works regarding the final refined products of forecast has to be done to deliver the developed products to end point users. These can also be achieved by collaborating with State Agricultural Universities. Concentrating more on branched sectors of meteorology like Agricultural meteorology, Aviation meteorology, Urban meteorology could add value to the forecast developed in various sectors. In this paper, forecasting and development activities from the start is discussed and highlighted most of the major works and some left for simplicity of paper. However, Authors sincerely admit all the researchers, academic persons, meteorologists, government behind this developmental bloom. The development path laid over by these research works will enlighten the future research community.

Acknowledgements

The authors greatly thank Agro Climate Research Centre, for their technical assistance and guidance in writing this review and to all researchers who worked on the seasonal forecast of the Indian monsoon.

Authors' contributions

KP and KPJ have formulated the structure, article collection and draft writing. VG, RJ, GD, KB and SP gave scientific inputs and corrected the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None.

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