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Evolution of agromet advisory services in India

L.S. RATHORE, KRIPAN GHOSH* and K. K. SINGH**

Former Director General, India Meteorological Department, MoES, New Delhi

**India Meteorological Department, MoES, Pune*

***Former Head, Agromet Advisory Service Division, IMD, MoES, New Delhi*

e mail : lrathore@gmail.com

सार – 1920 के दशक में कृषि रॉयल आयोग द्वारा भारत में कृषि और मौसम विज्ञान के बीच घनिष्ठ सहयोग की आवश्यकता महसूस की गई, ताकि मौसम और फसलों के संबंधों को बेहतर ढंग से समझा जा सके, ताकि सूखे आदि जैसे मौसम संबंधी खतरों से कृषि, अर्थव्यवस्था और मानव जीवन को होने वाले व्यवधान और क्षति को कम या सीमित किया जा सके और उसे अकाल में बदलने से रोका जा सके। इसके परिणामस्वरूप 1932 में पुणे में कृषि मौसम विज्ञान प्रभाग की स्थापना हुई। प्रारंभिक वर्षों के दौरान, प्रतिबल और संबंधित उपचारात्मक उपायों को समझने के लिए विभिन्न संगठनों के सहयोग से प्रेक्षणात्मक व्यवस्था स्थापित करने और अनुसंधान गतिविधियों का संचालन करने के लिए "समन्वित फसल मौसम योजना" के कार्यान्वयन की पहल की गई। किसानों को मौसम सेवाएं प्रदान करने की यात्रा भारत मौसम विज्ञान विभाग (आईएमडी) द्वारा 1945 में "किसान मौसम बुलेटिन" के साथ शुरू की गई, जो विशेष रूप से उनके लिए दिन में दो बार जिलावार मौसम पूर्वानुमान प्रदान करता था। राष्ट्रीय कृषि आयोग (1971) की सिफारिशों के अनुसार, मौसम पूर्वानुमान के साथ-साथ दिन-प्रतिदिन के मौसम आधारित कृषि कार्यों के बारे में जानकारी प्रदान करने के लिए, आईएमडी ने जुलाई, 1977 में तत्कालीन मद्रास (वर्तमान में आरएमसी, चेन्नई) से राज्य स्तर पर कृषि मौसम परामर्श सेवाएं (AAS) शुरू कीं और सभी राज्यों में सेवाएं प्रदान की गई। किसानों को संख्यात्मक मौसम पूर्वानुमान (NWP) मॉडल पूर्वानुमान आधारित सेवाएं राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केंद्र (NCMRWF) द्वारा 1991 में भारतीय कृषि अनुसंधान परिषद (ICAR) और राज्य कृषि विश्वविद्यालयों के सहयोग से कृषि-जलवायु क्षेत्र (ACZ) स्तर पर शुरू की गई। दो संगठनों द्वारा प्रदान किए गए AAS को सिंगल विंडो सिस्टम में एकीकृत किया गया और 1 जून 2008 से जिला स्तर पर IMD में ग्यारहवीं पंचवर्षीय योजना में "एकीकृत कृषि मौसम परामर्श सेवाएं (IAAS)" योजना के रूप में कार्य करना शुरू किया, जिसे बारहवीं पंचवर्षीय योजना में "ग्रामीण कृषि मौसम सेवा (GKMS)" के रूप में आगे बढ़ाया गया और IMD ने ICAR के साथ मिलकर कृषि विज्ञान केंद्रों पर जिला कृषि-मौसम इकाइयों का नेटवर्क स्थापित करके 2018 से ब्लॉक स्तर पर केटरिंग सेवा शुरू कीं। सरकार और निजी संगठनों द्वारा समर्थित सार्वजनिक निजी भागीदारी (PPP) मोड के तहत SMS सहित प्रिंट और इलेक्ट्रॉनिक मीडिया, दूरदर्शन, रेडियो, इंटरनेट आदि जैसे बहुचैनल प्रसार प्रणालियों के माध्यम से किसानों को कृषि मौसम संबंधी सलाह दी जा रही है।

कृषि मौसम निर्णय सहायता प्रणाली के विकास, कृषि मौसम डेटा की प्राप्ति और प्रसारण के लिए ऑनलाइन प्रणाली, विभिन्न भूमि और उपग्रह अवलोकन आधारित कृषि मौसम उत्पादों के निर्माण के साथ-साथ प्रतिकूल मौसम की स्थिति से फसलों को बचाने के लिए उचित उपचारात्मक उपायों की पहचान के लिए वर्तमान में अत्याधुनिक तकनीकों का उपयोग किया जा रहा है। देश के विभिन्न अग्रणी संगठन जैसे- IMD, NCMRWF, IITM, ICAR, ISRO, IITs, NIC, SAUs, SDAs आदि ने लंबी अवधि के लिए सेवाओं और अधिक सूक्ष्म स्थानिक पैमाने पर विस्तारित करने के लिए सार्थक अनुसंधान गतिविधियों और प्रचालनात्मक समर्थन के लिए मिलजुल कर कार्य किया।

ABSTRACT: The need for a close collaboration between the Departments of Agriculture and Meteorology in India was felt by the Royal Commission on Agriculture during 1920s to better understand the relationship between weather and crops, so that disruption and damage caused to agriculture, economy and human life by weather hazards like drought etc. which could be reduced, marginalized or even controlled from turning into famine. This resulted in the establishment of Agricultural Meteorology Division at Pune in 1932. During the formative years, initiative was taken for implementation of the "Co-ordinated Crop Weather Scheme", to establish observational set up and conduct research activities in collaboration with various organizations to understand crop stresses and related remedial measures. Journey of weather services to the farmers commenced in India Meteorological Department (IMD) with "Farmers' Weather Bulletin" in 1945 to provide district wise weather forecast twice a day exclusively for them. In order to provide information on day-to-day weather based farm operations along with weather forecast, as per recommendations of the National Commission on Agriculture (1976), IMD started Agromet Advisory Services (AAS) at state level in July, 1977 from the then Madras (presently RMC, Chennai) and covered all the states. Numerical Weather Prediction (NWP) model forecast based services to the farmers were started by National Centre for Medium Range Weather Forecasting (NCMRWF) at agro-climatic zone (ACZ) level in 1991 in collaboration with Indian Council of Agriculture Research (ICAR) and State Agriculture Universities. AAS provided by two organizations were integrated into a single window system and started functioning as "Integrated Agromet Advisory Services (IAAS)" scheme in IMD, in XI[th] plan, at district level from 1 June 2008, which was further extended as "Gramin Krishi Mausam Sewa (GKMS)" in XII[th] plan and IMD jointly with ICAR started catering services at block level from 2018 by establishing network of District Agro-Met Units at Krishi Vigyan Kendras. Agromet Advisories are being disseminated to the farmers through multichannel dissemination systems like print and electronic media, Door Darshan, radio, internet etc. including SMS under Public Private Partnership (PPP) mode supported by govt. and private organizations.

State of art technologies are presently being used for development of Agromet Decision Support System, online system for receipt and transmission of Agromet data, generation of various land and satellite observation based Agromet products as well as for identification of appropriate remedial measures to save the crops from adverse weather situation. Various leading organizations of the country like, IMD, NCMRWF, IITM, ICAR, ISRO, IITs, NIC, SAUs, SDAs etc. joined hands for meaningful research activities and operational supports to extend the services to further finer spatial scales for longer duration.

Key words - Agromet advisory services, Weather based advisories, Gramin krishi mausam sewa, Climatic risk, Numerical weather prediction.

1. Introduction

Agricultural activities started with domestication of plants and animals, which was necessary for the evolution of agriculture leading to spatial expansion of human civilization and enabling to feed increasing population. The earliest archaeological evidences suggest rapid and large-scale domestication of plants and animals and adoption of agriculture throughout the tropical and subtropical areas of southwestern and southern Asia, northern and central Africa and Central America during 10000 - 7000 cal years BP. Agriculture allowed people to establish permanent villages and towns and develop classified societies which included various segments such as farmers, soldiers, teachers, governors and religious leaders etc. and thus to become sedentary (Gupta, 2004).

Climate has played a pivotal role in the evolution of fauna and flora. Climatic conditions were more conducive throughout the Asian-African region (deMenocal *et al.*, 2000; Goodbred and Kuehl, 2000; Gupta *et al.*, 2003; Fleitmann *et al.*, 2003) during the early Holocene in view of availability of enough rain and river water which might be the cause of origination and expansion of agriculture over the region including Indian subcontinents. This region, characterized by one of the most important climatic features of the Earth – the South Asian or Indian Ocean monsoon system, influences the agricultural activities and consequently the socio-economic life of people of the region (deMenocal *et al.*, 2000; Lal *et al.*, 2001). As the human's awareness and understanding improved towards utilization of natural resources, it resulted in cultivation of diversified crops along the rivers utilizing the abundance of water resources. One of the earliest pieces of evidence of cultivation was noticed along the river Indus in ancient India.

According to Gupta (2004), the summer monsoons might have contained moisture in excess for the crops than required for normal food production during ancient period. In India, both crops wheat and barley, being gown during *Rabi* (winter) season, largely depended on this excess moisture as well as winter rainfall before the irrigation system started. There is report of well-developed irrigation and drainage systems in India, even as early as during the period of Indus Valley Civilization.

There is also historical evidence of occurrence of wide spread repeated, abrupt climate changes throughout the geological record (Alley *et al.*, 2003) which might have altered ecological landscape, leading to floral and faunal adaptation and subsequently improved the ability of the human being to cope with the aberrant weather situations. The knowledge acquired through the process of understanding application of weather and natural resources in cultivation of crops has been linked with the associated Nakshatra System based on the changing rainfall pattern in the annual cycle and transferred generation after generation by means of folklore as well as other methods of communication.

Since ancient times, Indian economy is largely dependent on agriculture and weather plays major role in crop growth and production. Irregular monsoon activities, such as late arrival, break and vigorous condition, early withdrawal etc. led to droughts and floods bringing down agricultural productivity. Till the earlier part of twentieth century, farmers were largely dependent on the traditional knowledge of utilization of natural resources including weather and climate. Situation started changing slowly with the establishment of India Meteorological Department (IMD) during later part of Nineteenth Century. The scientists of IMD understood the usefulness of adopting farm operations based on weather information and weather services were started for the farming community during mid-forties of last century, which is continued till date with enormous improvement keeping pace with fast technological advancement. The journey of the Agrometeorological Advisory Services (AAS) in India during the period has been presented in this paper.

2. Establishment of agricultural meteorology division

As, during the pre-independence era, agriculture was mainly rainfed, the need of intimate scientific knowledge on the relation between weather and crops was felt by the Government, as early as 1920s, for improvement of growth and production of crops in a land of uncertain monsoon rainfall over vast tracts of the country. During the visit of Royal Commission on Agriculture in 1926, IMD presented the proposal for possible coordination between Meteorology and Agriculture with a view to agricultural improvement and advocated an immediate start of research in Agricultural Meteorology (Agricultural Meteorology Division, IMD Pune, 1976). According to the recommendation of the Royal Commission on Agriculture, the Division of Agricultural Meteorology started functioning in 1932 under the umbrella of IMD at Pune and actual work was commenced on 22 August 1932 under the leadership of Dr. L. A. Ramdas (Agricultural Meteorology Division, IMD Pune, 2007). It was one of the earliest Divisions of its kind anywhere in the World.

3. Organization of agrometeorological activities during formative stage

The Agricultural Meteorology Division at Pune served as a temporary unit in IMD till 1939 with the financial support from Imperial Council of Agricultural Research and later it became part of IMD in 1943 (Agricultural Meteorology Division, IMD Pune, 1976, 2007).

As a part of developmental activities, a Central Agricultural Meteorological Observatory (CAgMO) was founded in the farm of the Agricultural College, Pune, in 1933, in close proximity to growing crops. A considerable portion of the initial experimental works in Agricultural Meteorology helped this observatory to grow into a centre for intensive research and a training ground in Agricultural Meteorology for a large number of Agrometeorologists from different parts of India and abroad. The Observatory was equipped with a full of routine and special meteorological instruments, including many new instruments devised by the workers at Pune, to take observations of special interest to agriculture like soil temperature and moisture, radiation, evaporation, percolation *etc*. in addition to the usual meteorological elements.

In these formative years of the Agricultural Meteorology Division, apart from research on microclimate, under the leadership of Dr. Ramdas, initiatives were taken for setting up of agrometeorological observatories in a farm environment, commencement of weather services to farmers, preparation of Crop Weather Calendars, development of observational systems for measurement of evapotranspiration, commencement of All India Coordinated Crop Weather Schemes, designing of sampling procedure for recording observations on crop attributes and phases *etc*. (Agricultural Meteorology Division, IMD Pune, 2007).

3.1. *The co-ordinated crop-weather scheme*

The reports revealed that the preliminary research works conducted at the CAgMO Pune on weather and crops helped to recognize the vital role played by weather as a major control over crop growth and yield. Based on these results, the Agricultural Meteorology Division in Pune with support from the Indian Council of Agricultural Research (ICAR) implemented the "Co-ordinated Crop Weather Scheme" in 1945. This scheme envisaged setting up of a network for recording of systematic crop and weather observations from selected experimental farms in India to ensure that, in future, all the relevant biological and environmental factors might continue to be recorded on one standard plan. Such data, collected for a sufficiently long period, would provide a proper basis for working out reliable crop-weather relationships. Initially, The ICAR sanctioned the scheme for three major food crops, *viz.* rice, wheat and jowar. Soon the Indian Central Sugarcane and Cotton Committees followed the initiative of ICAR and sanctioned schemes on similar lines for Sugarcane and Cotton crops, respectively in 1946 and 1947. The introduction of the Crop-Weather Scheme and its satisfactory working can rightly be regarded as a pioneering step for notable achievement in the field of Agricultural Meteorology in India. The Crop-Weather Scheme for rice, wheat and jowar was taken over by Government in 1950, while that of sugarcane has been extended up to 1961 (Agricultural Meteorology Division, IMD Pune, 2007).

3.2. *Establishment of agrometeorological observational system*

The next major step taken in 1940s was to set up specialized meteorological observatories in crop environment, as opposed to the then system of recording observations only in cities and aerodromes. Inception of Co-ordinated Crop Weather Scheme resulted in steady growth of such observatories across the country. These Agrometeorological observatories were run by the manpower and financial supports provided by the agricultural institutions of the states and centre. The assistance rendered by Agricultural Meteorology Division for these observatories was installation, periodic inspection and maintenance of meteorological instruments, training of observers, collection, scrutiny, and interpretation of data *etc*. Dr. Ramdas played significant role in establishing the system for recording observations of interest to agriculture manually at 0700

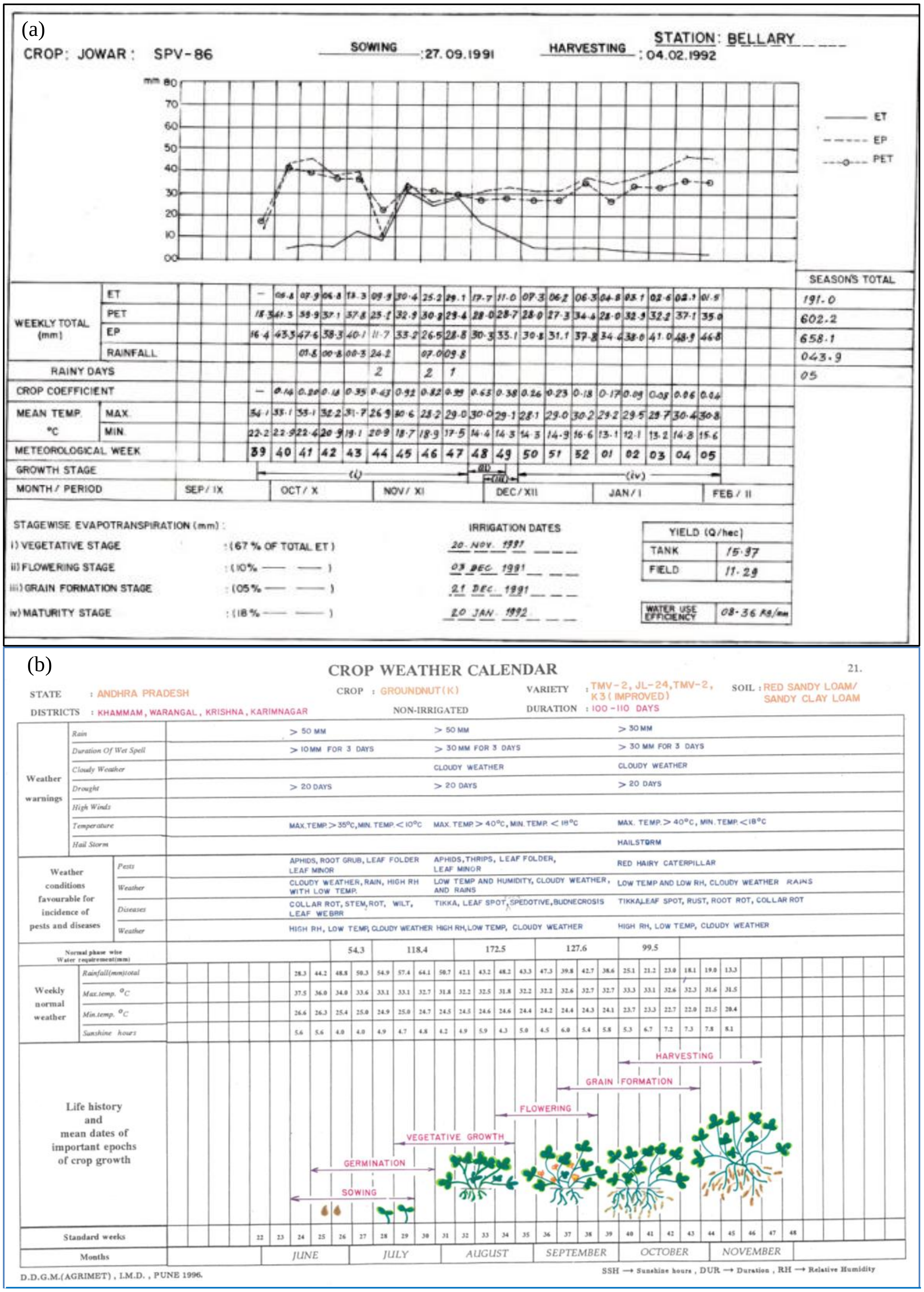


Fig. 1. (a) Crop Weather Diagram and **(b)** Crop Weather Calendar for groundnut in Andhra Pradesh

and 1400 Local Mean Time (LMT) for obtaining profiles of maximum and minimum values of temperature and relative humidity in and outside crops, adoption of the "Standard Week" as the time-unit for agrometeorological work in India and designing of sampling procedure for weekly recording observations on crop attributes and phases (Agricultural Meteorology Division, IMD Pune, 2007).

The aim of establishment of Agrometeorological observational system was to develop underlying crop weather relationships and estimate crop yields. Data on some crops from selected experimental farm observatories had been collected for periods ranging from 5 to 25 years. Some tentative crop weather relationships had been developed using statistical methods with respect to the crops at different crop weather stations. Some studies on climatic parameters like potential evapotranspiration, solar and net radiation, etc. have also been completed with the data (Agricultural Meteorology Division, IMD Pune, 1976).

3.3. *Crop weather diagram and crop weather calendar*

The crop and meteorological data collected from farms and observatories had initially been published in the form of crop weather diagrams (Fig. 1 (a)). The crop weather diagram was a factual summary of the week-by-week progress of the crop growth and the weather conditions experienced by it.

The information depicted in Crop weather diagram was insufficient for the agriculturists and planners. Hence, these diagrams were modified later with the inclusion of all relevant weather parameters along with weather warnings at different growth stages of crops, known as Crop Weather Calendar. Farmers, require knowledge in advance of the weather elements influencing crops for planning agricultural operations and taking precautionary measures. Based on the information received from various agricultural authorities and the knowledge of the normal weather conditions over different parts of the country, the crop weather calendars (Fig.1b) were prepared portraying information of optimum and detrimental weather conditions during various crop growth phases. This provide information on crop growth stages, normal weather for crop growth, warnings to be issued based on prevailing weather conditions, water requirement of crops during their various phenophases, meteorological conditions favorable for development of crop pests and diseases *etc*. These calendars had been supplied to the department's weather forecasting centres to serve as a guide for issuing warnings on agricultural activities (Agricultural Meteorology Division, IMD Pune, 1976, 2007).

Periodical revision of these calendars has been undertaken with inclusion of new crop varieties, soil types and changing cropping and weather patterns. Presently crop weather calendars are available for 12 States of the country. These calendars proved incredibly useful to the planners, agricultural administrators, plant breeders and the farmers in formulating policy matters regarding plant breeding, crop adoption, drought proofing, strategic planning supplemental irrigation, maximizing the yield *etc*. and are of high demand by various Central and State Government as well as private organizations.

3.4. *Evaporation, evapotranspiration and soil moisture measurement*

The investigation of the moisture balance at the ground surface is as important as that of the heat balance for a proper understanding of the physical processing going on in the air layers near the ground. A full appreciation of the problems connected with the reliable measurement of the factors involved, particularly evaporation and evapotranspiration (ET), is highly essential. Accordingly, a network of evaporation stations for evaporation measurements with different kinds of evaporimeters, especially US open pan evaporimeter, had been established in the departmental stations of IMD as well as large number of non-departmental stations. Subsequent to evaporation measurements, under a scheme sanctioned by ICAR, research on ET of different crops, including the development of experimental techniques for measuring this element had been started in 1953. A volumetric method, which was an adaptation of the one developed by Thornthwaite, as well as a gravimetric method developed in the Division were being used for measuring ET. Contribution of Dr. Ramdas in development of gravimetric (Fig. 2 (a)) and volumetric lysimeters for daily measurement of ET losses of both aerobic and anaerobic crops is noteworthy. Such measurements had been made initially on some varieties of wheat, jowar and sugarcane (Agricultural Meteorology Division, IMD Pune, 2007).

Knowledge of water requirement of crops at their various stages of growth and development is crucial factor for scheduling water management.This needs an understanding of water relation in soil plant atmosphere continuum, especially the water transport as ET. Consequently, Agricultural Meteorology Division had established a network of 42 ET stations (35 weighing type and 7 volumetric type lysimeters) (Fig. 2 (b)) for measuring water loss from crops in each major soil-climatic regime since early seventies.

Based on the observations, the march of ET losses has been studied in the context of the growth and

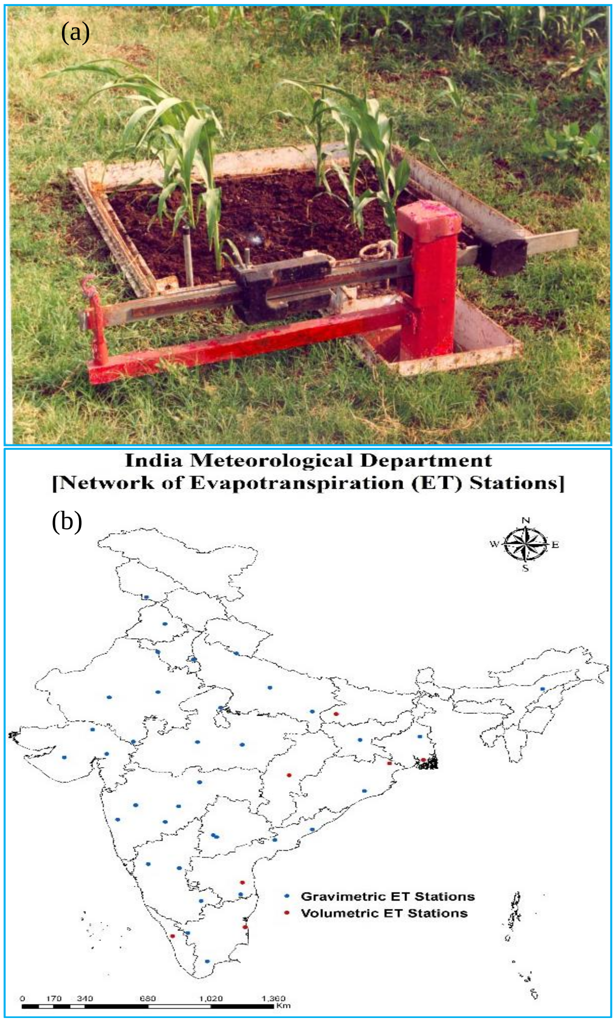


Fig. 2. (a) Gravimetric Lysimeter in the crop field and **(b)** Network of Evapotranspiration observatories under ET scheme

development of the crops to arrive at water requirement at various crop growth stages. Studies carried out on the relationship of ET and other weather parameters also brought out several useful information, which help in better planning in crop sequences and deciding appropriate irrigation strategies.

Using these data, the publications were made containing information on weekly evapotranspiration (ET) losses for different crops at various locations along with important relevant parameters *viz.*, weekly averages of maximum temperature, minimum temperature, relative humidity, mean wind speed, bright sunshine hours, weekly totals in mm of evaporation, rainfall and total rainy days. These publications are found to be useful for planners, scientists, and Agrometeorologist to identify peak consumption and critical periods of crop cycle to meet water need by studying week wise, season wise and crop wise water losses due to evapotranspiration. The ET

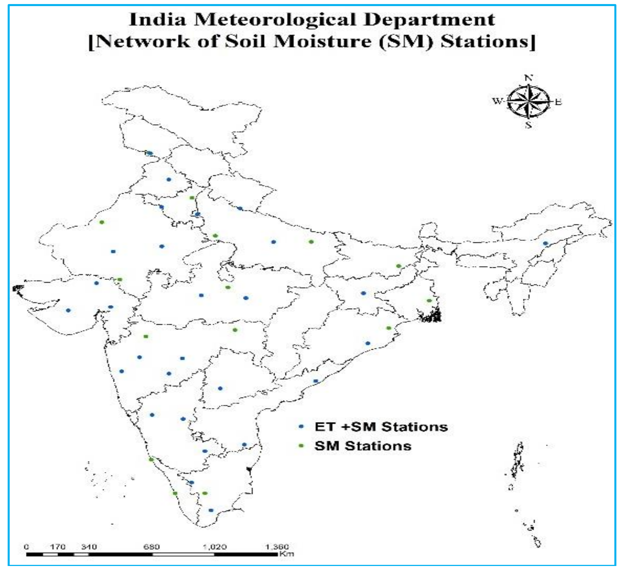


Fig. 3. Network of Gravimetric soil moisture Observatories, as in 2008, in India

scheme existed up to middle of last decade and discontinued in view of development of indirect method of measurement of ET using Remote Sensing technique.

Similar to information on ET, information on available soil moisture is highly essential for the scientists to understand the status of crop growth under various soil and weather conditions. As soil moisture is generally a highly variable parameter, both temporally and spatially, being affected by the soil texture, topography, land cover and climate, a network has been established during last quarter of 20th century for recording soil moisture observations, using gravimetric method, from different regions, with varying climatic conditions and cropping patterns, across the country. There were 43 soil moisture recording stations (Fig. 3), out of which 15 stations were recording only soil moisture, whereas 25 ET stations were also reporting soil moisture along with other meteorological parameters and ET. However, in view of development of systems for estimation of soil moisture using various models as well as Remote Sensing techniques and establishment of recent network of Agro-AWS with the facilities of measuring soil moisture observations, regular recording of gravimetric soil moisture observations has been discontinued.

4. Commencement of weather service to the farmers

One of the most important events took place from agricultural point of view soon after World War II, when IMD, switching over from war work to its peace-time activities, launched specialized services for the farmers. While all the actual forecasts were issued by the Forecasting Units of the IMD, the Division of Agricultural

Meteorology, played an important liaison role by bringing, on the one hand, the problems of the agriculturists and the actual warning requirements of the crops to the notice of the weather forecasters and, on the other hand, telling the agricultural workers in the country the ways in which Meteorology could come to their aid.

4.1. *Farmers' weather bulletin (FWB)*

In addition to rendering advice from time to time to the agriculturists on demand, IMD began to render a regular weather service to farmers, which is familiarly known as "Farmers' Weather Bulletin" (FWB), in 1945 (Agricultural Meteorology Division, IMD Pune, 1976, 2007; Bal *et al.*, 2021). The Regional and State Meteorological Centers of IMD started issuing District wise weather forecast twice a day exclusively for the farming community. These forecasts were valid for the next 48 hours with an outlook of weather for the subsequent two days. Whenever, any detrimental weather with respect to crops in the fields were expected, those features, in the form of adverse weather warnings affecting agricultural operations and crops, were specially mentioned in the bulletins. These bulletins also included the features like first onset of rain at sowing time, probable rainfall intensities and duration, breaks in the rains and their probable duration, untimely rains, frost, hail, squalls *etc*. Later, these bulletins also included district-wise short-term forecast of weather and heavy rainfall or low/high temperature warnings and cyclonic weather warnings to fisherman (Report of Expert Committee on Agrometeorology, 2001).

The FWBs were broadcasted by the regional stations of All India Radio (AIR) in their daily rural programmes, so that the farmers in the remote villages could get the information through village or community radio sets.

4.2. *Agrometeorological advisory services (AAS) in IMD*

As the FWBs contained neither any information on the effect of weather parameters on crops nor any management advisories regarding field operations, they might not be meaningful towards weather based agricultural management. National Commission on Agriculture (NCA), set up by the Government of India in 1971, evaluated the services provided through FWBs and submitted the report and recommendations in 1976. As the weather warning requirements vary amongst regions and crops, it was felt that active collaboration between IMD and State Department of Agriculture (SDA) was a prime requisite. On the recommendation of the NCA (NCA, 1976), it was decided to interpret weather information and issue Agrometeorological Advisory Services (AAS) bulletin under the AAS scheme to fulfill the needs of farming community regarding weather-based farm operations.

In the meantime, during the Satellite Instructional & Television Experiment (SITE) carried out during the year 1975-76, as a joint effort involving IMD, ICAR, Indian Space Research Organization (ISRO) and other agricultural agencies, weather information and related weather based crop specific advisories on the best period for sowing operations, application of insecticides, caution regarding flooding etc. were telecast to about 2000 villages in selected districts of the states of Andhra Pradesh, Bihar, Karnataka, Madhya Pradesh, Odisha and Rajasthan. Experience gathered from the SITE model, issuance of AAS bulletins started initially from the then Madras (presently RMC, Chennai) in July, 1977, followed by the then Calcutta (presently RMC, Kolkata) in October, 1980. Slowly it extended to other states and started functioning through a network of 23 State Agrometeorological Centres (SAMCs) distributed throughout India covering most of its parts at the beginning of 21st century.

During this initial phase, State Agrometeorological Centres of IMD issued AAS bulletins at state level twice a week (Monday & Thursday) on operational basis in consultation with the Director of Agriculture of the respective States. The components of AAS Bulletins (Kashyapi, 1998) were weather summary for the past three or four days including chief amounts of rainfall, forecasts valid for next 48 hours, outlook for another two days and agromet crop conditions and Agrometeorological advisories. The bulletins were disseminated in local languages as well as in English through AIR, Doordarshan, Newspaper *etc*. Apart from these, the extension wing of the State Departments of Agriculture along with other communication system was also utilized to disseminate the bulletins to the farmers for proper management of weather sensitive operations and also save the crops at appropriate time from the adverse weather conditions.

Apart from AAS Bulletins for different states, preparation of National Agrometeorological Advisory Services Bulletins has been started since July 2004 at Division of Agricultural Meteorology, Pune, being the nodal centre and Head Quarter of State Agromet Centres of IMD, for issuing the same to the Ministry of Agriculture, Ministry of Earth Sciences and to the members of Crop Weather Watch Group, who meet every Friday at Krishi Bhavan, Department of Agriculture & Cooperation, Ministry of Agriculture, New Delhi.

4.3. *Pioneering step for setting up numerical weather prediction (NWP) system to the service of agriculture in India*

The drought of 1982 adversely impacting the *Kharif* crops and the destruction of *Rabi* food crops in the fields of Haryana and Punjab during April-May 1983 made the Government concerned about the abnormalities in weather and climate over India, thus caught the attention to focus the need for strengthening short and medium range weather forecasts and studies on short period weather effects on infield agricultural activities. This led to establishment of National Centre for Medium Range Weather Forecasting (NCMRWF) with the specific mandates to –

(*i*) Develop operational medium-range (3 to 10 days in advance) weather forecasting capabilities using global dynamical models along with establishment of necessary infrastructural facilities (supercomputing facility and satellite based communications system), primarily for catering to the needs of farming operations besides other applications, and

(*ii*) Establish Agrometeorological Advisory Services (AAS) with multi-disciplinary activities including setting up of agro-meteorological field units (AMFUs), establishing communication links with AMFUs, involving the agricultural scientists for receiving the downscaled forecast for an AMFU and using it for preparing specific agricultural advisories for the area of the AMFU keeping in view the conditions of the crops on the fields, validation of the forecasts for each AMFU, adoption of agro-meteorological models for area-specific agro-met advisories.

Setting up AMFUs, one in each of the 127 agro-meteorological zones (ACZ) of the country, as determined by the National Commission of Agriculture (1971) and Planning Commission at the National Agriculture Research Project Centres (State Agricultural Universities) was a herculean task and was completed progressively with the tireless efforts made by joint team of officers from Department of Science & Technology (DST), NCMRWF, IMD and ICAR.

The NCMRWF started running dynamical global spectral model R40 provided by the Centre for Ocean-Land-Atmosphere (COLA), USA with complete analysis and forecast system in 1989 to produce weather forecast for next seven days. The horizontal resolution of weather forecast was ~250 km. The weather parameters significant for agriculture included rainfall (mm), cloud cover (okta), maximum and minimum temperature (degree C), wind speed (km/h) and direction (degrees), morning and evening relative humidity, which were produced every day for next 7 days. Subsequently, it switched to NMC/NCEP global NWP system to generate forecast guidance for each of the 127 ACZs consisting of a cluster of districts representing homogeneous agro-meteorological conditions for agriculture planning and operations and its dimension almost matched with horizontal resolution of the weather forecast. The accuracy of the direct model output (DMO) for different weather parameters for next 3 days was improved by subjecting it to statistical and synoptic interpretation of Numerical Weather Prediction (NWP) products using current weather observations of ACZ to prepare final forecast. Local weather observations were regularly received from AMFUs at NCMRWF. Subsequently, the NWP system at NCMRWF was improved periodically through inhouse R&D efforts and international cooperations.

4.3.1. *Statistical and synoptic interpretation of model output*

The method of statistical interpretation (SI) was used for application on a particular AMFU. Man-machine mix, based on model output statistics (MOS) and experience over a particular AMFU, was the strategy adopted for the preparation of the forecast for AMFU. Meteograms of important sites were also prepared. For the purpose of preparing location-specific weather forecast for AAS, the methodology of DMO forecast was adopted. As forecasts based on global circulation models do not represent local conditions very well, statistical relationship was developed between upper air circulation features around the specific area and values of surface weather variables at that location. In the formative years of NCMRWF, SI forecasts were based on the Perfect Program Method (PPM). To begin with, by 1990, predictive relations were developed for maximum and minimum temperatures and in 1991, the scheme was also extended to precipitation forecasts for the summer monsoon season. Since then, the extensive work has been done on the development of forecast techniques and their verifications, and area specific operational forecasts were prepared based on man machine mixed approach. It was a challenging task that was followed twice a week by experienced meteorologists of the Application Group at the NCMRWF.

On 23 March 1991, the Centre started providing experimental forecast on eight weather parameters for next 3 days to five AMFUs co-located with State Agriculture Universities (SAUs) and ICAR institute situated in Ludhiana, Hisar, Delhi, Anand and Trissur. These data were disseminated through telephone in the beginning and later on specific communication channels Very Small Aperture Terminal (VSAT) was established for exchange of data and information with AMFUs, who prepared Agrometeorological advisories for their specific area keeping in view the status of the crops on the fields.

4.3.2. *Preparation and dissemination of agrometeorological advisory bulletins*

The NCMRWF's Application Group generated weather forecasts for eight specific weather elements over specific areas. A panel of agricultural scientists working at each AMFU meet to prepare Agrometeorological advisories using their knowledge and information on crop growing in the fields in their area while keeping in view the local agro-operations corresponding to the crop-cycle. On receiving the weather forecasts from NCMRWF, the agricultural experts discussed the options and decided on advisories which were issued to the area-specific farmers. Thus, the forecasters, agro-experts and local farmers, all remained involved in the process. The AAS advisories in real-time were disseminated to progressive farmers in nearby villages, through different media. These bulletins were pasted on the board at common place in the village or written down on the board by lead farmer. In addition to farmers, AAS bulletins were provided to authorities of concerned departments like agriculture, horticulture, irrigation and animal husbandry *etc*. Feedback from the farmers and agencies were received, and user surveys were also conducted. Annual meetings of the AAS were organized by the NCMRWF to discuss the performance of the AAS. Farmers kept demanding to improve the resolution, accuracy, and lead time of the weather forecast.

Besides above development, DST supported the research proposals from various agriculture universities to work on development of agrometeorological models for area-specific Agrometeorological advisories and establish agrometeorological data base system integrated with All India Coordinated Research Project on Agrometeorology (AICRPAM) at ICAR- Central Research Institute for Dryland Agriculture (CRIDA) Hyderabad. This helped in developing new Agrometeorological products / models for use in AAS to improve quality of Agrometeorological advisory bulletin.

NCMRWF was constantly working on improving the resolution of medium range forecast and made T80L18 model (horizontal resolution of 150 Km) operational in 1993 with support of NCEP. Since 1994, T80 model output was used as basis for forecast preparation for agriculture. Till the beginning of 1994, when the formative phase of the NCMRWF was over, 22 AMFUs had been established which were spread over different parts of the country. Twice a week, weather forecasts also began to be issued on experimental basis from 1991. AAS network kept increasing with the establishment of AMFUs progressively with time.

Global T170 model with the resolution of 75 Km was employed in the year 1999 to generate the forecast in addition to existing one for agriculture. Around this time, based on the consistent improvement in the accuracy and reliability of the model forecast, period of operational forecast for agriculture was extended from 3 days to 4 days. Further in the year 2006, temporal resolution of forecast was extended to 5 days at ACZ level and AAS network extended to 107.

The NCMRWF organized the Annual Review Meeting (ARM) every year involving all the AMFUs, IMD and ICAR to review the progress of AAS, farmers response and decide the future steps to make it more effective. This helped in developing a series of training modules for AMFU scientists on weather observations and monitoring, data analysis, crop production system, weather forecasting, agrometeorological modeling, crop weather calendar *etc*. to improve their skills and expertise.

During the period, AMFUs regularly organized the farmer awareness programmes to interact with farmers on weather, climate, forecast accuracy etc. With such efforts, number of farmers covered under AAS kept increasing exponentially.

5. Integration of agrometeorological advisory services of IMD and NCMRWF

At the end of Xth five year plan, though Agrometeorological advisory services were being regularly provided for many years by both the organizations, *i.e*. by IMD at State level in collaboration with SDAs and by NCMRWF at ACZ level in collaboration with SAUs and ICAR institutes, the demand of the farming community could not be fulfilled due to certain gaps in the system, such as non-availability of skillful weather forecast in appropriate spatial and temporal ranges as per the interest to a farmer. Besides this, non-availability of real-time crop data, lack of decision support system for interpretation of weather forecast into advisories, lack of strong outreach / extension mechanism was some of the other major weaknesses in the systems. In order to meet the farmers' needs in real-time and to have a state-of-art AAS system, Ministry of Earth Sciences (MoES), Government of India constituted a committee in 2006 to suggest setting up of an Integrated Agrometeorological Advisory Service (IAAS) in the country involving all the concerned organizations like IMD, NCMRWF, ICAR, SAUs, Ministry of Agriculture etc., under the Chairmanship of Dr. L. S. Rathore. The committee recommended the integration of existing services making the service more farmers centric with near accurate weather forecast, improved Agrometeorological information and widespread outreach (Recommendation of the Committee on Integrated Agrometeorological Advisory Services in India, 2007).

5.1. *Integrated agrometeorological advisory services (IAAS)*

Being multi-disciplinary in nature, agro-meteorological advisory services had to be essentially a multi-institutional program. Hence, in view of generating agrometeorological information related to various fields of Agriculture to address the issues on day-to-day weather related farm operations, the committee felt that there was need to establish coordination among (*i*) agencies involved in research & development, education and extension activities like SAUs and Institutions of ICAR, (*ii*) institutions involved in generating remotely sensed data, (*iii*) extension organizations involved in dissemination of the advisories to the farming community like Krishi Vigyan Kendras (KVKs), Agriculture Departments (Union as well as States), mass media such as AIR, television, print media, Non-Governmental Organization (NGOs) *etc*.

As per the recommendation of the Rathore Committee (2007), based on the above philosophy, both the services of IMD and NCMRWF have been merged into a single window system, under the scheme "Integrated Agrometeorological Advisory Services (IAAS)", operational at IMD, for efficient functioning and delivery.

The objectives of the Integrated AAS scheme were –

(*i*) to provide location specific weather forecast and Agrometeorological advisory services (AAS) as per different climatic conditions and cropping patterns,

(*ii*) to implement an efficient outreach system so that the farmers receive weather based agromet advisories specific to their areas and crops on real time basis and

(*iii*) to set up operational arrangements for AAS involving extension and information disseminating agencies.

The IAAS has been implemented by the five-tier structure with its new roles and responsibilities. Inter-Ministerial Advisory Committee would be constituted for overall monitoring and suggestion for upgradation of the Agrometeorological Service in the country. The apex tier was a steering committee, headed by Secretary, MoES. A Coordination cell has been set up at IMD New Delhi (Tier-1) to constantly monitor the overall activities of the integrated system working in the country. An executive Head Quarter of National Agrometeorological Services (Tier-II), already set up at Agrometeorological Division, IMD, Pune, managed the services through the network of State Agrometeorological t Service Centres (SAMCs) of IMD (Tier-III). The AMFUs, at Tier-IV, had been performing the core responsibility to translate weather forecast into farm advisories as they have the domain expertise. In order to develop a strong Agrometeorological extension and strengthen the outreach, the district level agencies such as District Agriculture Offices (DAOs), KVKs, Agricultural Technology Management Agencies (ATMA) and NGOs (Tier-5) had been engaged.

After adoption of IAAS, AAS network grew from 5 units in 1991 to 130 in the year 2007, to cover all districts of 127 ACZs in the country, with the constant efforts of the scientists from IMD and NCMRWF. As a first step under IAAS scheme, mechanism was developed to integrate weather forecast and climatic information along with agrometeorological information to prepare district level Agrometeorological advisories from 1 June 2008, outlining the farm management actions, utilizing Multi-model Ensemble (MME) based district level forecast, to harness favorable weather and mitigate impacts of adverse weather. The advisories were disseminated by the District Agricultural Offices of State Department of Agriculture and other disseminating agencies to the farming community for carrying out appropriate weather sensitive agricultural operation for better crop production.

5.2. *Gramin krishi mausam sewa (GKMS)*

District level AAS was successfully implemented with better outreach, but it was inadequate to cater the needs of farmers, owing to the wide range of crop types, cultivars, and climatic conditions (especially rainfall) that exist within a district. So, it was decided to extend the AAS upto Block level. Based on this idea, the IAAS scheme has been extended as "Gramin Krishi Mausam Sewa (GKMS)" scheme in XIIth Five Year Plan, subsequently augmenting the organizational setup of GKMS network, jointly by IMD and ICAR, at district level by establishing District Agrometeorological Units (DAMUs), in the premises of Krishi Vigyan Kendras (KVKs) under the network of ICAR, with the support of two additional manpower *viz.* one Subject Matter Specialist (Agrometeorology) and one Agrometeorological Observer, at each KVK, to take care of AAS related activities. ICAR- Agriculture Extension Division at its Headquarter and Agricultural Technology

Application Research Institutes (ATARIs) in different zones administer and coordinate through controlling authorities of KVKs (*viz.* SAUs, ICAR Centres, NGO KVKs, State Govt. KVKs) for recruitment of manpower, formation of expert panel and initiation of Agrometeorological services at block level, its dissemination and outreach. As on date, DAMUs have been established in 199 KVKs and block AAS have been rolled out to the farmers at micro-level.

To develop the proof of concept (POC) on block level AAS, ICAR's All India Coordinated Research Project on Agrometeorology (AICRPAM) launched a pilot project to develop and disseminate block-level AAS in 2011 through a network of 25 cooperating centres around the country (Vijaya Kumar *et al.,* 2017). It used IMD's block-level weather forecast and input from field information facilitator. The Agrometeorologist at AICRPAM centres developed AAS bulletin with the help of scientists from multiple disciplines. This project led the way to reach the farmers at micro-level from the district level. Besides, in early 2018 block level Agrometeorological advisory in pilot mode was initiated by IMD for more than 100 blocks collectively from 25 AMFUs spread across the country to understand the additional requirement of service and this helped to operationalize the service from DAMUs.

The main emphasis of the existing AAS system under GKMS (Fig. 4) is to collect and organize climate/weather, soil and crop information, and to amalgamate them with weather forecast to assist farmers to take decisions on day-to-day farm operations at finer spatial scales. Thus, Block level Agrometeorological advisories have been started experimentally with 8 DAMUs in Bihar in 2018-19 and later on with some more DAMUs in other States. Presently agromet advisories are being prepared by 130 AMFUs and 199 DAMUs, on every Tuesday and Friday, for all the agriculturally important districts (increased from 598 in 2013 to 700 in 2023) (Fig. 5) and around 3100 blocks in the country. Along with the biweekly bulletins, daily weather forecast and nowcast information are also disseminated to the farmers by Regional Meteorological centers (RMCs) and State Meteorological centers (MCs) of IMD.

Implementation of block level AAS will be more beneficial due to high resolution weather forecast with precision Agrometeorological advisories for the farmers of specific blocks. Network of AMFUs and DAMUs have been presented in Fig. 6**.**

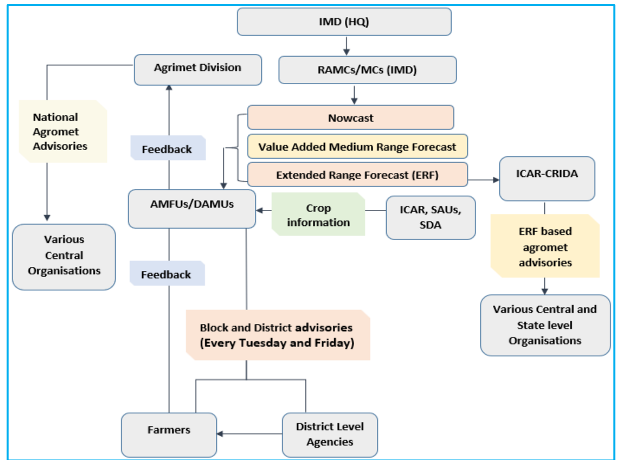


Fig. 4. Existing District and Block Level Agrometeorological Advisory Service System

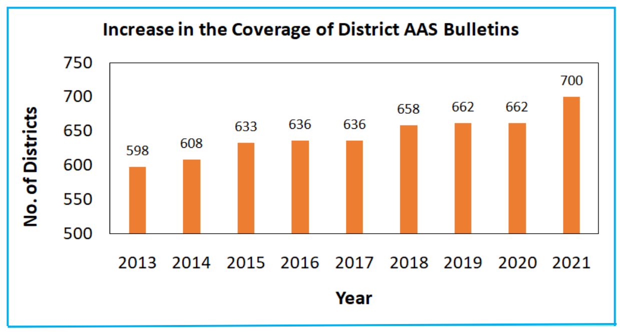


Fig. 5. Increase in the Coverage of AAS Bulletins at District level.

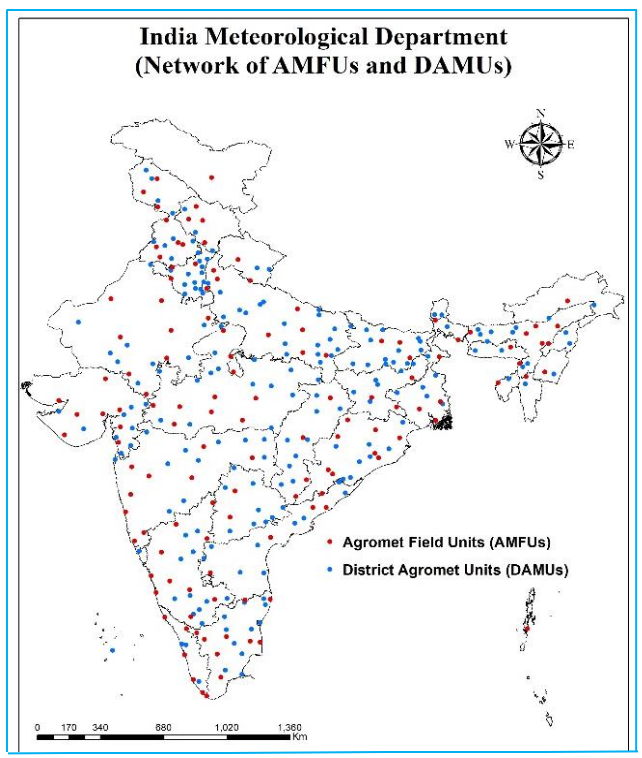


Fig. 6. Network of AMFUs and DAMUs under GKMS scheme.

5.3. *Milestones in agrometeorological services*

(*i*) 1945 **-** Farmers Weather Bulletin

(*ii*) 1976 **-**Agromet Advisory Services (AAS) at State Level

(*iii*) 1991 **-** AAS at Agroclimatic Zone Level

(*iv*) 2008 **-** AAS at District Level

(*v*) 2012 **-**Gramin Krishi Mausam Sewa (GKMS) Scheme

(*vi*) 2018 **-** Experimental AAS at Block Level (200 Blocks in 24 States)

(*vii*) 2023**-** AAS at block-level ~3100 blocks.

6. Weather forecast for agriculture: recent developments

During recent years, the skill of weather and climate forecasts in India has improved considerably. The improvement is noticed especially in monsoon forecasts, heavy rainfall warnings, tropical cyclone warnings and alerts, heat wave, cold wave, thunderstorm, hail storm *etc*. The successes in predicting the Tropical Cyclones, heavy rainfall events, deficient rainfall during monsoon are the best examples for the improvement in prediction capability during the recent years. Improved weather forecast also helped for development of reliable and robust Early Warning System on different extreme events.

A full range of NWP products at different spatial and temporal scales are routinely made available on the IMD website (https://mausam.imd.gov.in/). Weather forecasts generated at different temporal scales for agriculture sector include (*i*) Nowcast valid for 3 hours (Location specific), (*ii*) Short Range valid for 72 hours (Location/District/City), (*iii*) Medium Range valid for 3-10 days (City/District/ Met Subdiv.), (*iv*) Extended range valid for 4 weeks (Met Subdiv./State/Homogeneous regions), (*v*) Long range valid for a season (Homogeneous regions/country) and (*vi*) Early warning system on extreme events for cyclone, hailstorm, thunderstorm, cold and heat wave and drought. These forecasts are made available to planners and farmers well in advance to facilitate the decision makers.

With the developments continuously taking place in global observation system and its density (conventional & non-conventional), improved modeling strategies & computing resources in the country, the global model T254L64 with help from NCEP was made operational at NCMRWF in June 2007. The horizontal resolution of the forecast was ~48Km which became the basis for development of district level medium range forecast for 5 days.

Both the organizations, IMD and NCMRWF, implemented NCEP Global Forecast System GFS T574/L64 (horizontal resolution over the tropics ~ 22 km) in the year 2007. This incorporated Global Statistical Interpolation (GSI) scheme as the global data assimilation was for the forecast up to 7 days. Global data assimilation performed at NCMRWF were used as initial conditions to T574 model at IMD and this was made fully operational in December 2009, implemented on IBM based High Power Computing Systems (HPCS) (Rathore, 2013). It was run twice a day (00 UTC and 12 UTC). In addition to this, the meso-scale forecast system WRF (ARW) with 3DVAR data assimilation was being operated daily twice, at 27 km, 9 km and 3 km horizontal resolutions for the forecast up to 3 days using initial and boundary conditions from the IMD GFS-574/L64.

6.1. *District level medium range weather forecast*

IMD implemented an MME based district level quantitative forecasts in the operational mode since 1 June 2008, as required for the IAAS scheme of India (Rathore *et al.*, 2011; Roy Bhowmik and Durai, 2012; Chattopadhyay *et al.*, 2016a; Chattopadhyay *et al.*, 2016b). Five NWP models considered for this development work were: (*i*) IMD GFS T574, (*ii*) ECMWF T799, (*iii*) JMA T899, (*iv*) UKMO and (*v*) NCEP GFS. Model outputs of the constituent models were interpolated at the uniform grid resolution of 0.250 × 0.250 lat/long. Further, the weight for each model at each grid was determined objectively by computing the correlation coefficient between the predicted rainfall and observed rainfall. High resolution gridded rain gauge data, produced operationally at National Climate Centre (NCC) of IMD Pune, have been used for development and validation of the forecasts. The ensemble forecasts (day 1 to day 5 forecasts) were generated at the 0.250 × 0.250 resolution. The ensemble forecast fields were then used to generate district level forecasts by taking average value of all grid points falling in a particular district. The products comprised of quantitative forecasts for 8 weather parameters *viz.*, rainfall, maximum temperature, minimum temperatures, wind speed, wind direction, relative humidity (morning and evening) and cloudiness. These products were disseminated to RMCs and MCs of IMD, located in different states. These offices undertook value addition to these products using local conditions and synoptic interpretation of model output and communicated to 130 AMFUs on every Tuesday and Friday.

There was the growing demand from agriculture to increase the spatial resolution of weather forecast at block level as the Government has approved to extend the network of Agrometeorological units to district level for rendering block specific agrometeorological services to farmers. In the year 2017, computing resources for weather forecasting in the country was augmented to support operational run of very high resolution global forecast system model (GFS T1534). IMD also improved its spatial resolution of medium range forecast by running GFS model T1534 at 12.5 Km spatial resolution enabling to generate the forecast at sub-district level. The performance evaluation of GFS T1534 model forecast over Indian region for 2016-2017 Monsoon seasons has been studied by Mukhopadhyay *et al.* (2019).

6.2. *Block level weather forecast*

The basic data of blocks were retrieved from the local government directory website: https://lgdirectory.gov.in/welcome.do. Latitude, Longitude and altitude for 6872 blocks out of 7091 blocks in India were recorded from the standard world web site.

As the GFS model forecasts are obtained at regular grids and not at a particular location, hence forecast at a specific location is to use the interpolated value from the four grid points surrounding it. In case the distance of the location from the nearest grid is less than one fourth of the diagonal distance between any two grid points, then forecast given is for nearest grid forecast values, otherwise the interpolated value is considered. The block specific forecast products are prepared by using direct model output from IMD's GFS T1534 model (12.5 kms) for rainfall, cloud amount, maximum and minimum Relative Humidity, wind speed and direction for all five forecast days. Forecasts for maximum and minimum temperature were obtained by using the bias correction technique *i.e.*, Decaying Weighted Mean (DWM) procedure and T1534 model output. Further value addition is done by considering initial model forecast differences from observations, and model outputs from various models (WRF, NCUM, GEFS) including models from other countries (ECMWF, NCEP GFS). Thereafter subjective corrections are made based on official forecasts issued by RMCs and MCs at provincial level.

Block level probabilistic forecast: The Global Ensemble Forecast System (GEFS) T1534L64 (12 Km) with 21 Members is operationally run to generate forecast products available at 6 hourly intervals up to 10 days for preparing probabilistic forecast at block level. The relative percentage of ensemble members predicting an extreme event provides a level of confidence to the forecast. Probability of rainfall forecast for next five days in different category *viz.* light, moderate, heavy, very heavy *etc.* is produced routinely and probability is expressed in different categories i.e. 0-5%, 5-25%, 25-50%, 50-75%, 75-100%.

In operational Agrometeorological advisory services, medium range weather forecast for next five days is being used to prepare the advisories. Five days' model output of 12.5 Km spatial resolution generated from GFS T-1534 after value addition by RMCs and MCs is presently used in AAS for district and block level forecast generation. Extended range forecasts are also presently being integrated as weather outlook for next 6-12 days to prepare the advisories for subsequent week. Value addition or moderation of model output is carried out by the respective RMCs and MCs of IMD on regular basis, based on the local weather condition and regional model outputs. The verification of weather forecast is one of the important process of analyzing the accuracy and further skill of any forecasting system, thus is carried out every month on a routine basis.

7. Agrometeorological observational network and database management

The monitoring of physical processes in the boundary layer and in the soil within root zone are essential to evaluate their effects on animal and plant lives. Therefore, there is need for a network for recording Agrometeorological observations on physical elements like temperature, humidity, wind, sunshine, radiation, cloud, hail, dew, fog, rainfall, evaporation from soil surface and open water, transpiration from plants, runoff and water table, soil temperature and soil moisture etc. regularly.

7.1. *Agrometeorological observational network*

IMD, in association with other Govt. organizations, maintains networks of various meteorological observations, *viz.* surface, rain gauge, Radar and Satellite, for recording and monitoring of atmospheric and oceanic conditions and extreme weather events, research and development, weather forecasting and climate monitoring and prediction. Even though these observations are useful for extending AAS, a few Agrometeorological parameters need to be recorded at specific times of the day as per interest of agricultural operations, which worked as a driving force to establish a network of conventional Agrometeorological observatories for recording observations manually.

Each of the 130 AMFUs are equipped with a conventional Agrometeorological observatory, set up with the instruments supplied by IMD under GKMS scheme.

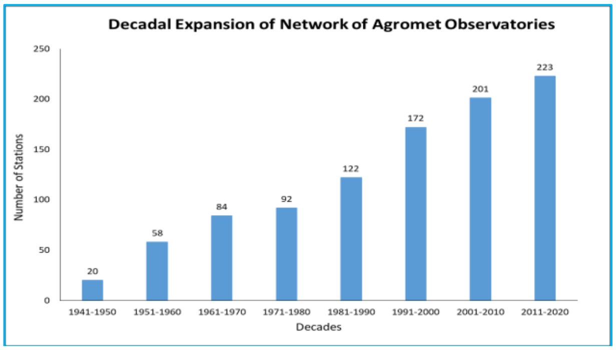


Fig. 7. Expansion of network of conventional Agrometeorological observatories in India

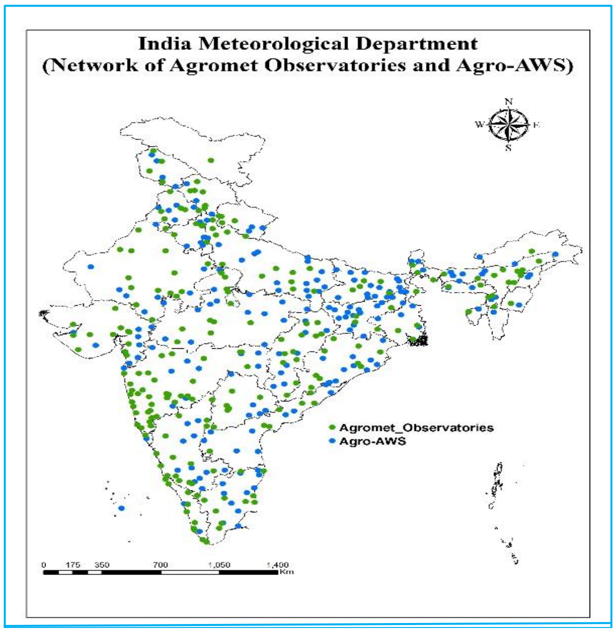


Fig. 8. Present network of Agromet observatories and Agro-AWS in India

Apart from AMFUs, various Agricultural Universities, State Departments and Research Institutes of Agriculture also establish conventional Agrometeorological observatories to fulfill their operational and research needs. The Agricultural Meteorology Division, IMD, Pune has been providing technical assistants to these organizations to set up these specialized observatories within the agricultural farm by way of selection of sites, testing and standardization, installation, periodical inspection and maintenance of meteorological instruments. In response, the collaborating organizations supply the Agromet data to IMD. The network of Agromet observatories expanded from 20 from mid 1940s to 223 by 2020 (Fig. 7), well distributed across the country.

Besides rainfall, as dewfall is also one of the secondary sources of moisture available to the crops, it plays the significant role in plant growth, particularly in arid and semi arid regions. Hence, dew observations have been collected from a network of total 75 stations for establishment of relation with crop growth and development. As discussed earlier, ET and soil moisture observations were also recorded from 42 and 43 stations, respectively (Agricultural Meteorology Division, IMD Pune, 2007).

In addition to above networks of conventional Agrometeorological observatories, a network of 200 Agro-AWSs has been set up, installing one Agro-AWS at each of the newly established DAMUs (in the premise of Krishi Vigyan Kendras) to record the diurnal changes in weather parameters. Along with other weather sensors, the Agro-AWSs also have soil moisture and soil temperature sensors at four depths up to one meter, as these parameters are very important for decision making in farm level risk management. It will fulfill the requirement of the country to have a benchmark district network of soil moisture and soil temperature observations. A number of state governments have come up with their own network of AWS and ARGs. Observations from these networks are also used for AAS. The Agrometeorological observational network is presented in Fig. 8.

7.2. *Agrometeorological database management*

The conventional Agrometeorological observatories under the network of IMD record various Agrometeorological parameters like dry and wet bulb temperature, maximum and minimum temperature, soil temperature at 5, 10 and 20 cm depth, rainfall, wind Speed and wind direction, sunshine duration, and evaporation. Observations for all these parameters, except rainfall and evaporation, are being recorded every day at 0700 and 1400 LMT at these observatories. Rainfall and evaporation are recorded at 0300 UTC. After recording observations, the Agrometeorological data are sent to IMD, which are subsequently scrutinized and archived at National Data Centre (NDC), IMD, Pune. These data are then supplied by NDC to various users such as Agricultural Universities, State Departments and Research Institutes of Agriculture *etc*.

During recent years, IMD developed a system in website of Agrometeorological Division (https://imdagrimet.gov.in/) for online reception of data, subsequent scrutiny and archival as well as online transmission of data to AMFUs and DAMUs and various organizations for fulfillment of their operational requirement.

The data received from the network of conventional Agrometeorological advisories and Agro-AWSs are being used for preparation of Agrometeorological products, generation of location specific Agrometeorological advisories and also supplied for carrying out weather forecast and research on Agriculture. These data further gain significant applications in operational Agrometeorological services with rapid expansion from district level to the block / sub-block level.

8. Research and development in agrometeorology for improvement in AAS

Research and Development activities in Agrometeorology in India started with the study of microclimate of crops (Fig. 9), one of the earliest investigations taken up by Agricultural Meteorology Division in Pune since 1932. The first Director of Agricultural Meteorology, Dr. L.A. Ramdas, had done extensive research and published number of research papers in this field. He led investigations at CAgMO on (*i*) exchange of moisture and heat between soil and exposed objects and the overlying air layers, (*ii*) micro-climate of crops, (*iii*) measurement and estimation of solar and atmospheric radiation, (*iii*) evaporation from water-filled pans and soils, (*iv*) evapotranspiration, (*v*) modification of soil temperatures, (*vi*) effects of mono-molecular films of substances on clean water surface, (*vii*) shrinking and swelling of soils, (*viii*) determination of resistivity of crops to atmospheric drought, (*ix*) prediction of clear season minimum temperatures *etc*.

After the significant works by Dr. Ramdas, the subject of Agrometeorology received intensive attention and significant contributions have been made by various scientists from IMD, ICAR, SAUs, Indian Institute of Technology (IITs), ISRO and various other organizations to develop wide range of agrometeorological products which subsequently enhanced quality of AAS in the country.

Significant research activities carried out in Agrometeoroloy in IMD during twentieth century were on (*i*) crop-weather relationship through collection of crop weather observations to understand, quantitatively, the role played by weather elements on growth and yield of crops like wheat, rice, cotton, sugarcane, groundnut, sorghum *etc*., (*ii*) Water requirement of crops through evapotranspiration and soil moisture studies, (*iii*) Desert Locust Meteorology, (*iv*) Agroclimatic Classification, (*v*) drought studies, (*vi*) Dry Farming Meteorology, (*vii*) Rainfall probability analysis for Agriculture, (*viii*) Wet and Dry Spells, (*ix*) pest and disease forewarning and (*x*) Remote sensing.

Significant research and development activities and output by various organizations are presented below.

Fig. 9. Micrometeorological observation in CAgMO, Pune during 1940s

8.1. *R&D in Agrometeorology in ICAR*

Research in Agrometeorology in ICAR was started with the initiation of the AICRPAM at ICAR-CRIDA during May 1983 with ten cooperating centres at Anantapur, Anand, Bangalore, Hisar, Jabalpur, Ludhiana, Mohanpur, Ranchi, Solapur and Varanasi. Further, three new centres*viz.*, Kovilpatti in Tamil Nadu and Ranichauri and Faizabad in Uttar Pradesh were added to the network. The programme was further strengthened with the addition of 13 new centres at Akola, Udaipur, Bhubaneswar, Bijapur, Dapoli, Jorhat, Kanpur, Palampur, Parbhani, Raipur, Chatha (Jammu), Samastipur and Thrissur from April 1995 during VIIIth Plan and thus, the project was extended to 25 SAUs in the country to carry out research with following major objectives:

(*i*) To study the agricultural climate in relation to crop planning and assessment of crop production potentials in different agroclimatic regions.

(*ii*) To establish crop-weather relationships for the major rainfed and irrigated crops in different agroclimatic regions.

(*iii*) To evaluate the different techniques of modification of crop microclimate for improving the water use efficiency and productivity of crops.

(*iv*) To study the influence of weather on the incidence and spread of pests and diseases of field crops.

Agrometeorological products / softwares developed include Spell (Dry & Wet) Estimator, Weather Cock and PET Calculator Software for uniform agroclimatic characterization, agro-climatic atlases, crop weather calendars for major crops, agro-climatic onsets of crop season, thumb rules and Decision Support System for major pest and diseases for a few agro-climatic zones, quantifying optimum weather requirements at different growth stages of major crops, heat unit requirement of crops, crop-wise manuals for weather-based decisions in crop management, thresholds of Percent Available for Soil Moisture (PASM) for different crop, evaluation of crop simulation model for different genotypes and weather insurance products etc. (http://www.cropweatheroutlook.in/crida/amis/annualreport.jsp).

8.2. *National databank on agrometeorology*

In the background of ongoing weather forecast based AAS in the country towards end of 20th century, there was dire need to create a Databank Facility in Agrometeorology at national level to ease out exchange of data and information among various research organizations and stakeholders. Consequently, an Agromet Databank was created at the ICAR-CRIDA, Hyderabad in year 2004 with the financial assistance from DST, Government of India and support of ICAR, Ministry of Agriculture. Objectives of the project are to collect, compile and computerize the weather and crop data generated at the various ICAR centres and SAUs in India and to make available the basic and derived agromet parameters and crop information to the users through the Agromet Databank Website, ARIS network of the ICAR and e-mail. The database contains eight basic weather parameters *viz.* Maximum and Minimum temperature, Rainfall, Wind speed, Relative humidity (morning and evening), Sunshine hours & Evaporation and Seven Derived weather parameters *viz.* Potential evapotranspiration, Actual evapotranspiration, Estimated soil moisture, Soil moisture index, Water deficit, Water surplus, Index of moisture adequacy on daily, weekly, monthly and seasonal basis for various locations in India. This Project was first of its kind in India and was poised to become the "National Databank on Agrometeorology". This helped in developing new agromet products/models for use in AAS to improve quality of agromet advisory bulletin.

Besides above development, DST supported research proposals from various agriculture universities to carry out field experiments for new agromet observations, development of database and agrometeorological models for area-specific agromet advisories and their use in AAS.

8.3. *R&D in Agrometeorology in ISRO*

Apart from IMD and ICAR, research activities have also been carried out by the organizations like Space Application Centre (SAC), National Remote Sensing Centre (NRSC) and Indian Institute of Remote Sensing (IIRS) under ISRO on application of Remote Sensing in Agrometeorology and many State Agriculture Universities (SAUs) on crop and location specific experiments.

8.4. *Desert locust meteorology (DLM) Scheme*

One of the major threats in Agriculture during twentieth century was Desert locust. As infestation of Desert locust is highly weather sensitive, a scheme was launched in IVth Five Year Plan in collaboration with Directorate of Plant Protection, Quarantine & Storage (PPQS), Faridabad and ultimately could be implemented from 1971 in following phases:

(*i*) Setting of micromet cum P. B. Observatories (PBO) at 7 locations.

(*ii*) Arranging special P.B flights as and when swarm is located, issuing special forecast for rainfall in locust prone region *i.e*. Rajasthan, Gujarat, Haryana and Punjab and

(*iii*) Research on meteorological aspects of locust.

Meteorological information is provided to PPQS and other concerned organizations throughout the year, especially in locust season during April to November in India. IMD is providing meteorological assistance for locust control to PPQS in three ways-

(*i*) Locust sighting observations from surface observatories of IMD.

(*ii*) Providing special wind data during locust swarm period.

(*iii*) Arranging for special forecasting of rainfall and wind data during locust season.

Wind at 150, 300, 600, 900 meter above ground level during swarm season along with rainfall data are supplied to the nearest locust offices during swarm season every year.

Apart from coordination with PPQS, IMD carried out significant research activities on meteorological aspects of Desert locusts. The findings (Maske and Rathore, 1982; Dubey *et al.*, 1987) helped substantially in preparation of meaningful Agromet advisories during outbreak of desert locust in recent years.

8.5. *Drought studies and dry farming research*

Among the various hazards of nature, drought is one of the most disastrous events. Drought is a period of drier than normal conditions that results in water-related problems. Several indices are being used in estimating the drought initiation and severity.

The problem of drought and desertification is alarming in India like any other places in the world. IMD, especially the Agrimet Division, has done a lot of research works to demarcate the areas prone to chronic, severe, moderate, occasional, and little crop droughts. The spread of drought areas in typical years have also been highlighted. The extent of crop transpiration deficits from monthly rainfall data had also been addressed. Water balance approach studies have been made to assess the agricultural drought at various growth stages of different dry farming crops during 1981 & 1982 using AE/PE ratio. Based on the monsoon rainfall for 113 years (1875-1987), an attempt has been made by the researchers to quantify drought for the country as a whole and identify drought years by developing drought index.

Many indices have also been developed during recent years by the research scientists of various other organizations which are used for understanding rainfall situations and subsequently used for AAS.

8.6. *District agriculture contingency plans*

It is noticed during recent years that crops experienced adverse impacts due to delayed onset of monsoon, aberrant distribution of monsoon rainfall leading to dry spells during crop season, monsoon failures resulting in drought, unseasonal and excessive rainfall, hailstorms, cyclones and floods *etc*. which caused severe production losses; even more severe impacts have been noticed on the sectors such as horticulture, fisheries, poultry than field crops, as it takes longer period to recoup the losses. Sometimes both floods and drought are seen in the same area also. The projected increase in droughts, cyclones, extreme precipitation events and heat waves is likely to lead to greater instability in food production.

The impacts of aberrant weather events on crops may be tackled, if cannot be prevented, by appropriate strategies of preparedness through proper Contingency planning in agriculture. Bal *et al.* (2021) explained District level contingency plans as technical documents, containing integrated information on technological solutions, for utilization by district authorities, to avoid adverse impacts on field crops, horticulture, livestock, poultry, fisheries etc. due to all the major weather-related aberrations including extreme events, *viz.* droughts, floods, heat wave, cold wave, untimely and high intensity rainfall, frost, hailstorms, pest and disease outbreaks and allied sectors. Under the initiative of ICAR-CRIDA, Hyderabad, a standard template was developed, to cover prevailing agro-ecological situations in the district, possible in-season contingencies and suggested adaptive strategies (Srinivasarao *et al.*, 2015), consisting of 2 parts deal with (a) district agricultural profile with information on rainfall, soil types, land use, irrigation sources, more dominant crops and cropping systems along with their sowing windows, livestock, poultry and fisheries information, production and productivity statistics, major contingencies faced by the district and digital soil and rainfall maps and (b) the detailed strategies to adopt weather-related contingencies with anticipated crops / cropping systems during delay in onset of monsoon, mid-season monsoon breaks in rainfed and irrigated situations and adaptation strategies for weather-related extreme events. These contingency plans provide options on selection of alternate crops / crop varieties in case of delay in onset of monsoon and also on agronomic measures for mid- and terminal-season droughts. Prasad *et al.* (2013) further suggested strategies for contingency situations in livestock, poultry and fisheries.

Well prepared contingency plans in advance help the scientists significantly in preparing location specific agromet advisories during adverse weather situations.

8.7. *Application of remote sensing in AAS*

Studies on application of Remote sensing in Agriculture started in early 1980s, led by SAC Ahmedabad in collaboration with various other organizations. Agrimet Division IMD Pune also participated in the research programmes of SAC Ahmedabad, like Crop Acreage and Production Estimation (CAPE) during 1980s and 1990s. A few Remote sensing based experiments have also been conducted using Hand held radiometer to study spectral radiance characteristics and vegetation indices to understand conditions of different crops under various moisture situation (Dubey *et al.*, 1995; Samui *et al.*, 2003; Ghosh *et al.*, 2003). Later on, SAC Ahmedabad in collaboration with IMD, ICAR and various SAUs carried out advanced research on application of Remote sensing on ET estimation, soil moisture estimation, crop condition assessment, various indices (Vyas *et al.*, 2015) etc. Thus, the methodologies developed are being used for analysis of satellite data for identification of crop stress for further utilization in agromet advisory preparation.

8.8. *Pest and disease forewarning models*

A large portion of farm produce is lost every year due to infestation of pests and diseases. Crop loss due to pests and diseases is alarmingly increasing over the years. Due to lack of proper forewarning techniques, operational plant protection is difficult in order to reduce such losses. Besides this, as a consequence of overuse, pesticide residues reach and pollute the ground water due to mismanagement and cause severe damage to the food cycle.

Since weather plays an important role in the incidence and spread of pests and diseases, studies on pest-weather relationship have been conducted by various ICAR institutes including ICAR-CRIDA, Hyderabad, ICAR-National Centre for Integrated Pest Management (NCIPM), New Delhi *etc*., SAUs and other leading organizations in the country. These studies help in (*i*) locating likely regions and periods of pest occurrence, (*ii*) providing advance warning to farmers of likely infestation and (*ii*) issuing advisories regarding the time and mode of protection measure.

During recent years, efforts are being made, in collaboration with ICAR-NCIPM, to make the findings of various pest-weather studies available to the scientists, facilitating them in preparation of more effective advisories for management of pest infestation.

8.9. *Agrometeorological products*

Many Agromet products are generated regularly by IMD, ICAR, SAC and other organizations, which are highly useful for the scientists at AMFUs and DAMUs to understand the status of soil, weather and crop conditions and subsequently utilize in preparation of Agrometeorological advisories. Among these Agrometeorological products, the satellite based products like Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI) and Temperature Condition Index (TCI) and Drought indices like Standardized Precipitation Index (SPI) and Aridity Anomaly Index (AAI) (Fig. 10) are most popular among the scientists.

9. Translating medium range weather forecast into Agrometeorological advisories

Generation of effective Agromet advisories depends on accuracy and spatial domain and temporal range of weather forecast. Every AMFU and DAMU has an Expert Panel at the station comprising of agricultural experts from different disciplines, agro-meteorologist and district agriculture officer of State Agriculture Department. Keeping in view of the requirements of farming community, Expert Panel translates district and block level quantitative forecasts, issued for major weather parameters *viz.*, rainfall, maximum temperature, minimum temperature, wind speed, wind direction, relative humidity and cloudiness for next 5 days and Met Sub-division wise forecasts for subsequent week, into crop / livestock specific advisories considering the state and stage of crops and status of livestock to guide the farmers on farm/livestock management practices

District and block-specific medium range weather forecasts and related advisories help in maximizing crop output and avert crop damage or loss. These help growers to anticipate and plan for weather related agriculture-specific operations during crop growing season. Such operations include cultivar selection, their dates of sowing/planting/transplanting, dates of intercultural operations, irrigation scheduling, fertilizer application, chemical application to manage disease and pest outbreaks, dates of harvesting and also performing post harvest operations. Agromet advisories on these farm operations are being generated by constantly analyzing actionable weather information, such as, to manage pests and disease outbreak through forecast of relative humidity, temperature and wind, to manage irrigation through rainfall and temperature forecasts, to protect crops from thermal stress through forecasting of extreme temperature conditions *etc*. and provided to the farming community.

The State composite bulletin is a composite of advisories issued at district level helping to identify the distressed districts of the state as well as to plan for arranging irrigation water and supplying appropriate farm inputs, such as seeds, fertilizers, pesticides *etc*. These bulletins are jointly prepared by RMCs and MCs of IMD and AMFUs of respective states and mainly used by State Government functionaries. These are also useful for the Fertilizer industry, Pesticide industry, Irrigation Department, Seed Corporation, Transport and other organizations who are involved in arranging inputs for agriculture. These bulletins provide significant inputs to the State level Crop Weather Watch Group (CWWG) meeting. Presently, these bulletins are issued for all the states of the country.

National Agromet Advisory Bulletins are prepared by the Division of Agricultural Meteorology, Climate Research & Services, IMD, Pune, using inputs from various state and district level AAS bulletins. Ministry of Agriculture is prime user of these bulletins, which help in identifying stress on various crops for different regions of the country and to take important decisions based on suitable advisories in CWWG meetings at National level. The bulletins are also used by a large number of other agencies including fertilizer and pesticide industries.

Due to the dynamic nature of atmosphere, there have been incidences of sudden changes in the weather patterns having a potentially adverse impacts on the standing crops. To address this issue, apart from issuing district and block level agromet advisories on every Tuesday and

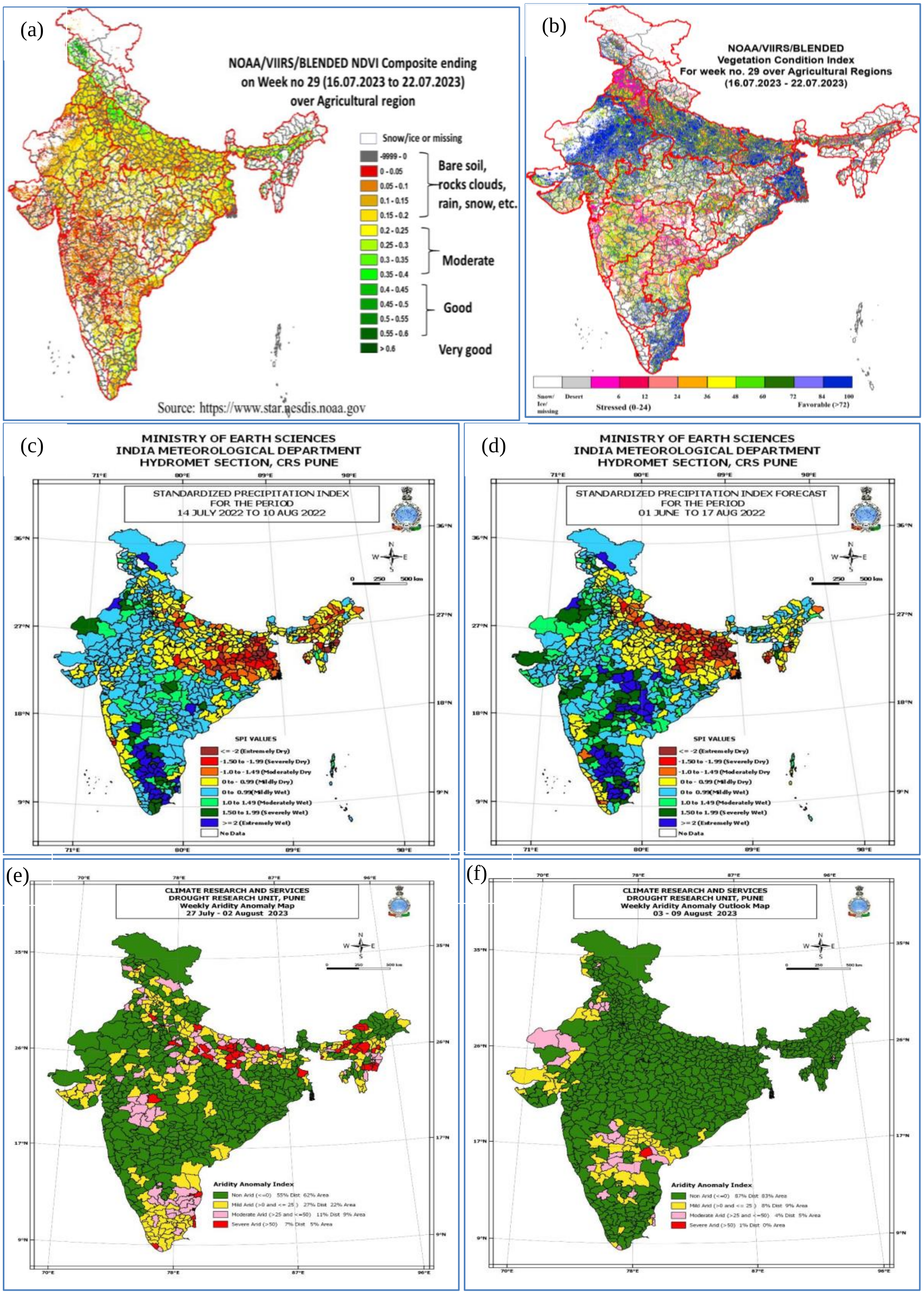


Fig. 10. (a) NDVI, (b) VCI, (c) SPI (observed), (d) SPI (forecast), (e) AAI (observed) and (f) AAI (outlook)

Friday, IMD started providing Impact Based Forecasts (IBF) for extreme weather events detrimental to crops along with possible measures for various districts in different states, since December 2021, as and when situation arises. The weather warnings for heavy rainfall, hailstorm, cold wave, frost, heat wave, high wind etc. at district level are issued by the concerned RMCs and MCs of the respective states and accordingly the appropriate farm operations to save the crops are prepared by AMFUs and DAMUs. The consolidated IBF is prepared by the RMCs and MCs of IMD and disseminated to the district collectors and Agricultural officers of the concerned districts.

ICAR-CRIDA, Hyderabad, in collaboration with IMD, started issuing Operational AAS Bulletin since 2014 based on Extended Range Weather Forecast (ERWF) for next 2 weeks during monsoon to help farmers to cope with climate risks and uncertainties and also effectively used seasonal climate forecasts. From *Rabi* 2017-18, IMD and CRIDA, jointly have started issuing AAS bulletin round the year based on temperature and rainfall forecast for 2 weeks and suitable contingent plans are being issued, as and when situation arises.

AAS bulletins issued at various spatial and temporal scales are presented in Fig. 11.

10. Agromet decision support system

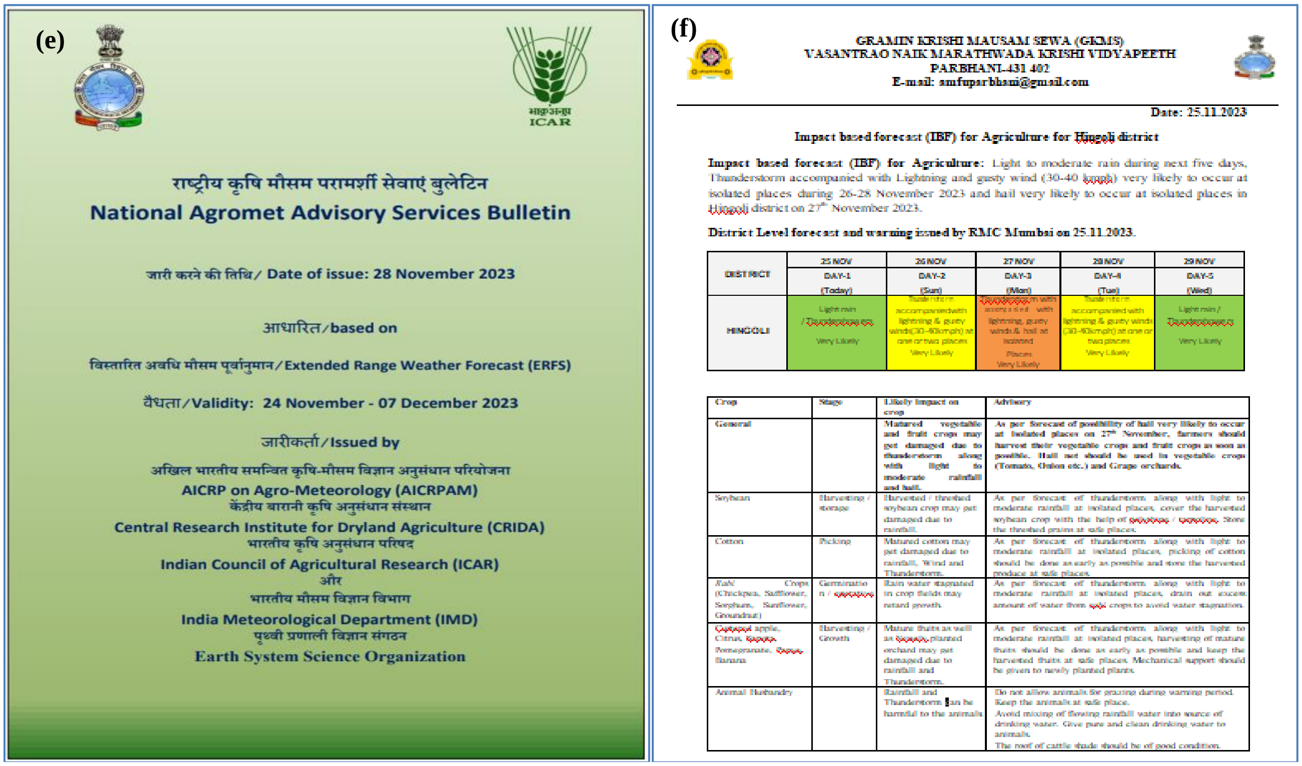
A dedicated portal ‘Agromet-DSS’ (https://agromet.imd.gov.in) has been developed during recent years for exchange of seamless data and information among concerned organizations in a more objective, timely, transparent and effective manner leading to improvement in the quality of services. Agromet-DSS facilitates the scientists / institutions with customized tools to integrate weather and crop information to prepare agromet advisories at finer scales in short time to serve farming community at micro level. Thus, this portal is presently used for value addition to district level weather forecasts by RMCs and MCs as well as for preparation of district and block level AAS bulletins by AMFUs and DAMUs. In addition, Agromet-DSS is also used for updating weather information and agromet advisories in mobile App ‘Meghdoot’.

11. Dissemination and outreach

In order to cater the weather information needed for the farming community, IMD started broadcasting FWBs in 1945 through AIR. With the further advancement of technologies, conventional media, such as, Television and print media, especially newspapers and magazines, started playing a major role for the outreach of agrometeorological information to the farmers. In the 1990s, efforts were made to include several other modes of communication, such as telephone, fax, internet, email, pamphlets and postal letters in addition to the extension networks of SDAs, SAUs and personal contacts.

With the rapid growth in the telecom industry and increased coverage in rural areas beyond 2000, mobile phones became the major tools for dissemination of Agrometeorological advisories. Thus, Short Message Service (SMS) and Interactive Voice Response (IVR) Technologies started playing a pivotal role in the wider outreach of AAS to the farming community of the country. To enhance the coverage of the services using these technologies further, IMD collaborated with several private agencies including Reliance Foundation, Reuters Market Light, IFFCO Kisan Sanchar Limited (IKSL), NOKIA-HCL, Handygo, Mahindra Samriddhi, Kisan Sanchar etc. as well as with National Bank for Agricultural and Rural Development (NABARD) and agriculture departments of various state governments for dissemination of agromet advisories through SMS and IVRS under public private partnership (PPP) mode. The information regarding weather and Agromet advisories was also integrated with the dedicated portal for the farming community (https://farmer.gov.in/FarmerHome.aspx), launched by the Ministry of Agriculture and Farmers Welfare (MoA&FW), Government of India. Agrometeorological information andservices were also included under Kisan Call Centres (KCCs) where queries of the farmers are answered in their regional languages by the experts through a Toll-Free number. Furthermore, a dedicated portal for sending SMS *viz.* mKisan (https://mkisan.gov.in) was also started in India in July 2013 to cater the specific needs of farmers by all Central and State Government Organizations engaged in Agriculture & allied sectors. Access to mKisan portal has been extended to the AMFUs to provide location and crop specific weather based information on farm agricultural practices to the farmers through SMS in various regional languages. In order to provide weather-based Agromet advisories to a greater number of farmers through this free SMS network, a system of registration through the Divisional website was developed by Agrimet Division, IMD, Pune with the help of National Informatics Centre (NIC), Pune to increase the number of farmers in the mKisan Portal. The cost effectiveness of SMS, and its wider outreach made it more economically feasible mode of information dissemination. Total 43.37 million farmers in the country received the Agromet Advisories through SMS directly. The yearly increase in the number of SMS sent through mKisan portal has been depicted in Fig. 12.


(a)
Gramin Krishi Mausam Sew
Experimental Block Level Agromet Advisory Bulletin
(A Joint Initiative of IMD & ICAR)
Agromet Advisory Bulletin
Date : 24-11-2023
Weather Forecast of NANDUBAR Block in NANDURBAR(Maharashtra) Issued On :2023-11-24(Valid Till 08:30 IST of the next 5 days)
Parameter | 2023-11-25 | 2023-11-26 | 2023-11-27 | 2023-11-28 | 2023-11-29
Rainfall | 0.0 | 0.3 | 43.1 | 0.0 | 0.0
Tmax(°C) | 31.7 | 31.3 | 30.3 | 25.0 | 26.4
Tmin(°C) | 18.0 | 18.4 | 13.8 | 13.5 | 14.1
RH-I(%) | 43 | 51 | 83 | 82 | 67
RH-II(%) | 30 | 33 | 41 | 62 | 43
Wind Speed(kmph) | 17 | 16 | 12 | 12 | 10
Wind Direction(Degree) | 71 | 77 | 68 | 90 | 64
Cloud Cover(Octa) | 0 | 3 | 7 | 1 | 0
Weather Summary/Alert:
According to weather forecast issued by India Meteorological Department, Regional Meteorological Center, Mumbai possibility of light to moderate rainfall during 25th to 27th November at isolated places. Weather Warnings :- 25th November: Thunderstorms accompanied with lightning and gusty winds reaching 30-40 km/hr and light to moderate rainfall very likely to occur at isolated places over district. 26th November: Thunderstorms accompanied with lightning and gusty winds reaching 30-40 km/hr, Hail and heavy rainfall very likely to occur at isolated places over district. Possibility of maximum temperature may below normal & minimum temperature may normal in between 29th November to 5th December 2023 over Madhya Maharashtra.
General Advisory:
As rainfall is forecasted carry out harvesting of mature crops and store at safe place. Avoid sowing, spraying and fertilizer, irrigation application, intercultural operations. Make arrangement of to drain out excess water from field. Farmers must use MEGHDOOT app for weather forecast based crop specific agromet advisories & DAMINI app for getting lightning alerts.
SMS Advisory:
As rainfall is forecasted carry out harvesting of mature crops and store at safe place.
Crop Specific Advisory:
Crop(Varieties) | Crop Specific Advisory
COTTON | As rainfall is forecasted carry out picking of cotton as early as possible & store at safe place. Make arrangement of to drain out excess water from field.
WHEAT | As rainfall is forecasted avoid sowing, spraying and fertilizer, irrigation application, intercultural operations. Make arrangement of to drain out excess water from field.
BENGAL GRAM/ CHICK PEA | As rainfall is forecasted avoid spraying and fertilizer, irrigation application, intercultural operations. Make arrangement of to drain out excess water from field.
MAIZE | As rainfall is forecasted avoid spraying and fertilizer, irrigation application, intercultural operations. Make arrangement of to drain out excess water from field.
(b)
Gramin Krishi Mausam Sewa (GKMS)
ALL INDIA COORDINATED RESEARCH PROJECT ON AGROMETEOROLOGY
Vasantrao Naik Marathwada Krishi Vidyapeeth Parbhani 431402
Parbhani District Level AAB No. : 68/ 2023-2024
Day & Date : Friday, 24.11.2023
Observed weather during last week
Weather Parameters
Weather Forecast
Date
Rainfall (mm)
Cloud cover
RH-I (%)
RH-II (%)
Wind Speed (km/hr)
Wind direction
Rainfall (mm) in last week
Rainfall (mm) from 01/01/2023 to till dated
Rainfall (mm) from 01/06/23 to till dated
Agromet Advisory
Soybean
Cotton
Custard apple
Citrus
Pomegranate
Banana
Fodder crops
Vegetable
Floriculture
Mulberry sericulture
Animal husbandry
Poultry
Principal Nodal Officer
Gramin Krishi Mausam Sewa (GKMS)
VNMKV, Parbhani
(c)
Agromet Advisory Service Bulletin for the State of Maharashtra
(Advisories mentioned in the bulletin are prepared by different AMFUs and DAMUs in Maharashtra)
Bulletin No. 94/2023
Issued on 24.11.2023
Weather warning
24 November : Thunderstorm accompanied with lightning at isolated places over Konkan and Madhya Maharashtra.
25 November : Thunderstorm accompanied with lightning at isolated places over Konkan, Madhya Maharashtra, Marathwada and Vidarbha.
26 November :
Heavy rainfall very likely at isolated places over Madhya Maharashtra (Nandurabar district), Marathwada (Chhatrapati Sambhajinagar district) and Vidarbha (Akola, Buldhana and Washim districts).
Hailstorm accompanied with thunderstorm, lightning very likely at isolated places over Madhya Maharashtra (Nandurabar, Dhule, Nashik and Jalgaon districts) and Marathwada (Chhatrapati Sambhajinagar district).
Thunderstorm, lightning & gusty winds (speed 30-40 kmph) very likely at isolated places over Vidarbha and with thunderstorm, lightning at isolated places over Madhya Maharashtra, Marathwada and Konkan.
27 November : Thunderstorm accompanied with lightning at isolated places over Konkan, Madhya Maharashtra, Marathwada and Vidarbha.
Agromet advisories
Farmers are advised to -
complete harvesting of rice and continue picking of cotton during clear weather. Keep the harvested produce at safer places,
postpone irrigation, spraying of insecticides, pesticides and application of fertilizers in rabi crops,
give mechanical support in orchards and staking to newly planted vegetables / creepers,
keep farm animals indoor during thunderstorm and lightning period.
Farmers of Nandurabar, Dhule, Nashik, Jalgaon and Chhatrapati Sambhajinagar districts are advised to use hailnets for protection of fruits and vegetables.
Summary of three days rainfall over the State (21 to 23 November 2023)
Dry weather prevailed over the state during the period.
Distribution of weather parameters and weather summary in the State (21-11-2023 to 23-11-2023)
Mean Maximum Temperature (°C) in Maharashtra for the period of 21.11.2023 to 23.11.2023
Maximum Temperature (°C) Anomaly in Maharashtra for the period of 21.11.2023 to 23.11.2023
(d)
राष्ट्रीय कृषि मौसम परामर्श सेवा बुलेटिन
National Agromet Advisory Service Bulletin
शुक्रवार दि 24 नवंबर 2023
(अवधि: 24 नवंबर से 28 नवंबर 2023)
Friday 24th November 2023
(For the period 24th to 28st November 2023)
कृषि मौसम विज्ञान प्रभाग,
भारत मौसम विज्ञान विभाग, पुणे
द्वारा जारी
Issued by
Agricultural Meteorology Division,
India Meteorological Department, Pune.


(e)

राष्ट्रीय कृषि मौसम परामर्शी सेवाएं बुलेटिन

National Agromet Advisory Services Bulletin

जारी करने की तिथि / Date of issue: 28 November 2023

आधारित / based on

विस्तारित अवधि मौसम पूर्वानुमान / Extended Range Weather Forecast (ERFS)

वैधता / Validity: 24 November - 07 December 2023

जारीकर्ता / Issued by

अखिल भारतीय समन्वित कृषि-मौसम विज्ञान अनुसंधान परियोजना

AICRP on Agro-Meteorology (AICRPAM)

केंद्रीय बारानी कृषि अनुसंधान संस्थान

Central Research Institute for Dryland Agriculture (CRIDA)

भारतीय कृषि अनुसंधान परिषद

Indian Council of Agricultural Research (ICAR)

और

भारतीय मौसम विज्ञान विभाग

India Meteorological Department (IMD)

पृथ्वी प्रणाली विज्ञान संगठन

Earth System Science Organization

(f)

GRAMIN KRISHI MAUSAM SEWA (GKMS)
VASANTRAO NAIK MARATHWADA KRISHI VIDYAPEETH
PARBHANI-431 402
E-mail: amfuparbhani@gmail.com

Date: 25.11.2023

Impact based forecast (IBF) for Agriculture for Hingoli district

Impact based forecast (IBF) for Agriculture: Light to moderate rain during next five days. Thunderstorm accompanied with Lightning and gusty wind (30-40 kmph) very likely to occur at isolated places during 26-28 November 2023 and hail very likely to occur at isolated places in Hingoli district on 27th November 2023.

District Level forecast and warning issued by RMC Mumbai on 25.11.2023.

DISTRICT	25 NOV DAY-1 (Today)	26 NOV DAY-2 (Sun)	27 NOV DAY-3 (Mon)	28 NOV DAY-4 (Tue)	29 NOV DAY-5 (Wed)
HINGOLI	Light rain / Thunderstorm Very Likely	Thunderstorm accompanied with lightning & gusty winds(30-40kmph) at one or two places Very Likely	Thunderstorm with accompanied with lightning, gusty winds & hail at isolated Places Very Likely	Thunderstorm accompanied with lightning & gusty winds (30-40kmph) at one or two places Very Likely	Light rain / Thunderstorm Very Likely

Crop	Stage	Likely impact on crop	Advisory
General		Matured vegetable and fruit crops may get damaged due to thunderstorm along with light to moderate rainfall and hail.	As per forecast of possibility of hail very likely to occur at isolated places on 27th November, farmers should harvest their vegetable crops and fruit crops as soon as possible. Hail net should be used in vegetable crops (Tomato, Onion etc.) and Grape orchards.
Soybean	Harvesting / storage	Harvested / threshed soybean crop may get damaged due to rainfall.	As per forecast of thunderstorm along with light to moderate rainfall at isolated places, cover the harvested soybean crop with the help of [illegible] / [illegible]. Store the threshed grains at safe places.
Cotton	Picking	Matured cotton may get damaged due to rainfall, Wind and Thunderstorm.	As per forecast of thunderstorm along with light to moderate rainfall at isolated places, picking of cotton should be done as early as possible and store the harvested produce at safe places.
Rabi Crops (Chickpea, Safflower, Sorghum, Sunflower, Groundnut)	Germination / vegetative	Rain water stagnated in crop fields may retard growth.	As per forecast of thunderstorm along with light to moderate rainfall at isolated places, drain out excess amount of water from rabi crops to avoid water stagnation.
Custard apple, Citrus, Papaya, Pomegranate, Guava, Banana	Harvesting / Growth	Mature fruits as well as newly planted orchard may get damaged due to rainfall and Thunderstorm.	As per forecast of thunderstorm along with light to moderate rainfall at isolated places, harvesting of mature fruits should be done as early as possible and keep the harvested fruits at safe places. Mechanical support should be given to newly planted plants.
Animal Husbandry		Rainfall and Thunderstorm can be harmful to the animals.	Do not allow animals for grazing during warning period. Keep the animals at safe place. Avoid mixing of flowing rainfall water into source of drinking water. Give pure and clean drinking water to animals. The roof of cattle shade should be of good condition.

Fig. 11. AAS bulletins issued at (a) Block level, (b) District level, (c) State level, (d) National level, (e) National level based on ERFS and (f) IBF based advisories.

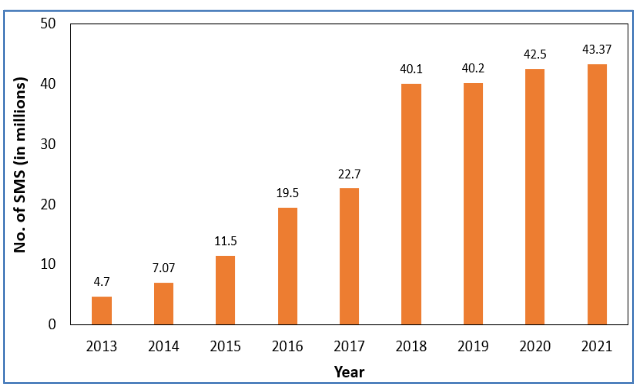


Fig. 12. Increase in the no. of SMS sent through mKisan Portal

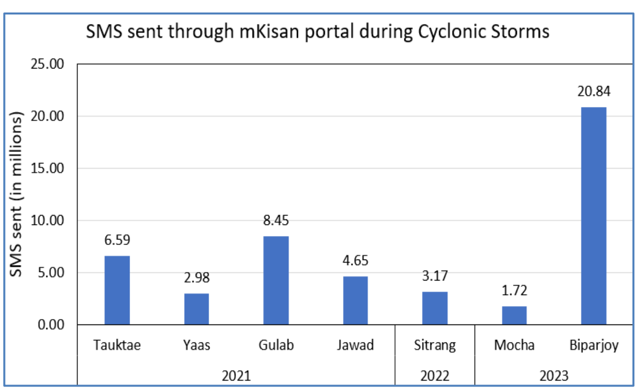


Fig. 13. SMS sent on alerts and warnings along with suitable remedial measures through mKisan portal during Cyclonic Storms

Apart from sending Agromet advisories regularly, SMS-based alerts and warnings along with suitable remedial measures are also being sent during extreme weather events like cyclone, deep depression etc. through Kisan Portal, e.g. alerts and warnings and agromet advisories were sent through SMS to 20.84 million farmers of Gujarat and Rajasthan during Cyclonic Storm "Biporjoy" over Arabian Sea during June 2023. SMS-based alerts and warnings sent during recent cyclonic storms have been presented in Fig. 13.

Widespread adoption of smartphones and increasing digital literacy helped social media to be emerged as a very strong medium, due to its interactive nature and direct engagement between users and experts, for outreach of Agromet advisories among the farmers. The social media messaging platforms, such as WhatsApp, thus have gained popularity for timely and faster dissemination of Agrometeorological advisories during recent times. At present 17,68,809 farmers of 1,34,879 villages in 4,015 blocks have been covered through 18,631 WhatsApp groups. SDA officials at District and Block levels are also included in these WhatsApp groups. Apart from this, a number of Facebook pages have also been created by several AMFUs and DAMUs for uploading the advisories on frequent basis. These platforms are also being used for efficient dissemination of short audio and video messages

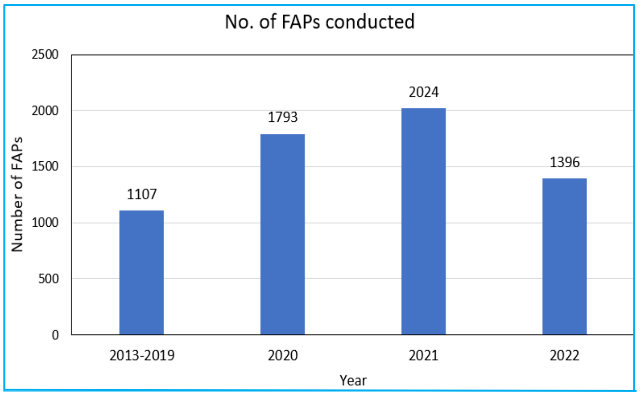


Fig. 14. No. of FAPs conducted for awareness of farmers regarding use of weather information in improved farming operations

with targeted advisories. These advisories are mostly in the regional languages, so that the farmers can easily understand and follow the suggestions provided.

IMD has also developed several mobile Apps such as Meghdoot, Mausam and Damini. The 'Mausam' app provides the information regarding weather forecasts and 'Damini' is for lightning alerts, while 'Meghdoot' is a dedicated App for Agromet services, which provides not only information on observed and forecast weather, but also district and block level crop specific advisories to the fingertips of the farmers. The advisories are also issued in vernacular wherever available. These weather forecasts are also accessible by farmers through another App 'Kisan Suvidha', launched by MoA&FW, GoI. Number of mobile Apps have also been developed by certain AMFUs and private organizations to provide customized location-specific weather based crop advisories to the farmers in different parts of the country. Furthermore, initiative on collaboration with State Government has been taken up for the integration of weather forecast and Agromet advisories with their mobile apps and websites. The integration has been completed for Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Kerala, Madhya Pradesh, Meghalaya, Nagaland, Odisha, Rajasthan, Tamil Nadu and Uttarakhand states and about 15.6 million farmers of the above-mentioned states are getting benefitted from weather forecast and agromet advisories.

IMD is also taking continuous efforts to popularize the services among the farming community by organising Farmers' Awareness Programmes (FAPs) in collaboration with AMFUs and DAMUs in various parts of the country. The details of FAPs organized by AMFUs and DAMUs during recent past have been presented in Fig. 14. 'Kisan Mela' is another important event organized by these centers to reach out to farmers and create awareness regarding various agromet products. Such kind of events are very effective to enhance their understanding and knowledge in use of weather information in improved farming practices.

In addition to other dissemination modes, recently updated website of Agrimet Division, Pune, in collaboration with NIC, is used for disseminating weather observations and forecasts and also AAS bulletins of various spatial and temporal scales as well as special bulletins prepared during extreme weather events like cyclones, deep depressions *etc*.

12. Feedback mechanism for AAS

In the complex and dynamic realm of agriculture in India, where climatic variations play a pivotal role, AAS have emerged as a crucial support system for farmers. These services aim to provide timely and relevant information to farmers, enabling them to take appropriate decisions in response to changing weather conditions. A key component of the success of AAS lies in the systematic collection of feedback from the farming community. These feedbacks are crucial for further modification and improvement of the AAS bulletins, ensuring that they align with the specific needs of diverse agricultural regions in India. In view of this, feedbacks are collected from the farming community at the end of the season to study the overall impacts of weatherbased advisories on improvement of growth and yield of crops as well as management of inputs during adverse weather situation. During recent years feedbacks are also being collected on weekly or fortnightly basis based on significant weather events. Apart from personal contact and phone calls, the social media messaging platform 'WhatsApp' also provides a forum for the farmers to ask questions and share their experiences in the form of feedback during recent times.

13. Economic impact assessment

Field experiments have been conducted from 2003-2007 at 15 locations across the country to assess economic impacts of AAS on field crops, vegetables and horticultural crops adapting the Impact assessment framework made by National Centre for Agricultural Economics and Policy Research (NCAP) (Rathore and Maini, 2008). An objective comparison between the AAS farmers (following weather forecast based agromet advisories issued by NCMRWF) against the non AAS farmers at village level. The studies showed that impact depended on the risk-taking ability of farmers. In quantitative terms, study reported about reduction in the cost of cultivation by 2-5% for the AAS farmers except in case of fruit growers, where the cost of cultivation has increased by 5-10%. This showed that the right selection of inputs like, fertilizers and seeds due to organization of awareness programme in the village and spraying of appropriate pesticides due to advisories saved input cost. It is also observed that the yield increased by almost 10-25% in most of the crops with maximum increase in the fruit crops.

To assess the economic impact of weather forecast-based advisories, multiple studies were also conducted by an independent third-party organization *viz.*, National Council of Applied Economic Research (NCAER), which is India's oldest and largest independent, non-profit, economic policy research think tank, in 1996, 2009, 2015 and most recently in 2019, respectively. The report of 2009 has estimated the economic benefit of these services at Rs. 50,000 crores per year, which, on extrapolation, may rise to Rs. 211,000 crores, if the entire farming community in the country were to apply Agromet information to their agricultural activities. The report of 2015 has shown that this service has a potential to generate around Rs 60,000 crore annual profit from top 14 principal crops, while the top 28 principal crops have the potential to realize an annual economic benefit of Rs 67000 crore.

The recent study of 2019 concluded that 98% of surveyed farmers (3,965 farmers across 121 districts of 11 states of India) made modifications to at least one of nine practices based on weather advisories. Average annual income of farming households increased from 1.98 Lakh, which adopted no modifications to Rs. 3.02 Lakh which adopted all the 9 practices. An additional annual income was estimated of Rs. 12,500 per agricultural household belonging to Below Poverty Line category in rain-fed areas, while total income gain was estimated at Rs. 13,331 crore per annum in rainfed districts.

14. Capacity building

In order to develop human resources in Agricultural Meteorology, IMD started imparting training since 1950. A separate training unit was started in Agrimet Division, IMD, Pune in 1976 to fulfil the training requirement of various stakeholders, including Professors, Scientists &officials from Agricultural Universities and other Research Organizations in the country. Several common as well as customized & refresher courses in the field of Agricultural Meteorology have been conducted for departmental and non-departmental candidates, from grassroot level (*i.e*. Observers) to senior officials. These courses got recognition from the World Meteorological Organization (WMO) and the training unit of Agricultural Meteorology division is presently working as part of the RMTC (Regional Meteorological Training Centre) of WMO.

More than 2500 Indian personnel have been trained in Agricultural Meteorology from IMD so far. Apart from the Indian personnel, participants from other countries such as Indonesia, Sri Lanka, Myanmar, Thailand, Bhutan, Nepal, Ethiopia, Kenya, Tanzania, Uganda *etc*. have also been trained. After obtaining the training, many countries started their operational agrometeorological activities for the benefit of end users.

Recently, some customized training programmes on various topics like pest and disease forewarning models, collection, and analysis of dynamic feedback from farmers, use of dynamic crop weather calendar *etc*., are being imparted to enhance the capacity of the scientists of AMFUs and DAMUs in order to strengthen the operational activities and enhance the outreach of services under GKMS scheme.

Apart from IMD, there is also long history of extending training in Agricultural Meteorology by various institutes of ICAR. ICAR-CRIDA, Hyderabad is engaged in development of manpower since inception of AICRPAM project. NCMRWF, IITM, ISRO-SAC, ICAR-Indian Agricultural Research Institute (IARI), New Delhi, ICAR-CRIDA and ICAR-Indian Agricultural Statistics Research Institute (IASRI), New Delhi contributed significantly in enhancement of skills of Agricultural scientists in agrometeorological observations and its analysis, crop/ livestock production system and extreme weather events, weather forecasting and system simulation modeling. These organizations also helped the scientists to gain knowledge in development of weather-based pest & disease forewarning models.

During last couple of decades, many SAUs also started Department of Agricultural Meteorology separately. This initiatives by the SAUs increased the number of manpower in this field many folds and helped in extending AAS more effectively.

15. Future plan

Successful implementation of AAS at subdistrict level and wider dissemination due to improvement in Information and Communications Technology (ICT) during recent years increased expectations among the end users. Demand for weather forecast at finer spatial scale (from block level to panchayat level) with longer duration (from 5 days to 10 days) started gaining momentum. To fulfil this requirement of farming community, emphasis is being given on introduction of high resolution models with appropriate accuracy along with assimilation of satellite data. Efforts are being made to use more and more data acquired from remote sensing sources, both the space borne and air borne platforms, coupled with weather information, for identification of crop stresses on near real time basis.

The country is still lacking adequate location specific information on weather and crops including impacts of adverse weather. Similar status is also noticed in case of availability of information on pest and disease infestation. Various Central and State organizations are joining hands for sharing weather data available from their respective network of AWS as well as for collection and management of crop data for preparation of region-specific climate risk matrix which will further help in proper planning under varying weather conditions.

A large number of farmers in the country are not aware of the AAS till date which exposes their crops to vagaries of weather during the crop growing season causing considerable losses. Efforts are being made, together by the government and private organizations, for wider awareness and dissemination of weather-based advisories on farm operations to the farmers with the objectives of helping them in saving their crops.

16. Conclusion

Indian economy is dependent on Agriculture from time immemorial. In view of dependence of Agriculture mostly on rainfall during the pre-independence era, the need of intimate scientific knowledge on the relation between weather and crops was felt by the Government and according to the recommendation of the Royal Commission on Agriculture, the Division of Agricultural Meteorology started functioning in 1932 at IMD Pune. From the beginning, the objectives of establishment of the Division were well understood by the scientists of IMD and accordingly, the weather services to the farmers have been started in the form of FWB in 1945. In view of improvement of the service, research activities have also been initiated in collaboration with ICAR and other Government organizations, which helped in establishment of observational system for acquiring weather and crop data and also development of methodologies for understanding crop stresses and related remedial measures.

As it was difficult for the farming community in the country to understand weather information extended through FWB and interpret the same in day-to-day farm operations, as per the recommendations of the National Commission on Agriculture (1976), IMD started AAS at state level in 1977. NWP model forecast based services to the farmers were started by NCMRWF at agro-climatic zone level in 1991. However, to avoid confusion among the farmers, as per recommendation of Rathore Committee (2007), two services were integrated into a single window system and started functioning as "Integrated Agromet Advisory Services (IAAS)" scheme in IMD, in XIth plan, at district level from 1 June 2008. The scheme was further extended as "Gramin Krishi Mausam Sewa (GKMS)" in XIIth plan and started catering service at block level from 2018.

Since commencement of service as FWB till date, there were lots of improvement in the service in terms of enhancement of quality of forecast at both spatial and temporal scales as well as understanding the impacts of aberrant weather on crops and subsequent preparation and dissemination of agromet advisories to the farmers. These stupendous tasks were made possible by integrated approach from all the leading organizations of the country like, IMD, NCMRWF, IITM, ICAR, ISRO, IITs, NIC, SAUs, SDAs *etc*. in respect of research and operational supports. Even though many objectives have been attained till date, still there is long way to go to fulfill the needs of the farmers. To achieve these targets, all the related organizations, Government and private, need to work together taking benefit from the fast-growing technologies to generate meaningful agromet advisories for next 10 days for the farming community at panchayat level.

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