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Decision support system for digitally climate informed services to farmers in India

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ABSTRACT

India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) in collaboration with Indian Council of Agriculture Research (ICAR), State Agriculture Universities (SAUs) , Indian Institute of Technology (IITs) and other organizations is rendering weather forecast based District level Agrometeorological Advisory Service (AAS) for benefits of farmers in the country under the centrally sponsored scheme 'Atmosphere & Climate Research-Modelling Observing Systems & Services (ACROSS) ' of MoES. AAS, popularly known as Gramin Krishi Mausam Sewa (GKMS) provides advance weather information along, with crop specific agromet advisories to the farming community by using state of the art instruments and technology through efficient delivering mechanism of the information which ultimately enables farmers to take appropriate actions at farm level. The various components of GKMS viz. observing weather, its monitoring and forecast; crop specific advisory bulletin generation and dissemination; outreach and feedback have been/are being digitized to support integrating all the components of information generation and action suggested linked to these information. An Information and Communication Technology (ICT) based Agromet Decision Support System is developed for automation of the services provided under GKMS. This includes a dynamic framework to link the information of weather forecast, real time weather observation, crop-weather calendar etc. to translate weather forecast into actionable farm advisories for efficient farm level decision making in India. Apart from this, effort is being made to develop recent technology driven tools to estimate future yield of crops and prepare an irrigation schedule without a need of multiple parameters.

Keywords: GKMS, Weather Forecast, Agromet DSS, ICT and Advisory feedback

The developments in weather and climate information have created opportunities to better integrate scientific information into decision-making (Wilkinson, *et al.,* 2015). The relevance of weather and climate information is largely dependent on the ability of scientists to provide information that is fit-for-purpose (Daron, *et al*., 2015) and produced in formats that can be integrated into decision-making processes. In India, where managing weather and climate risks is intrinsically related to the socio-cultural context, differential vulnerability and economic development pathways, to cater the weather and climate information based need of farming community in India, India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) has started Farmers Weather Bulletin in 1945. Since then, with the advent of technology, extension of weather observation network and weather forecast the customized weather information in the form of advisory also follows era of evolution. In the year 1976 Agromet Advisory Services (AAS) initiated at state level followed by Agro-Climatic Zone (ACZ) level AAS using Medium Range Weather Forecast (MRWF) in the year 1991. In the year 2008 District Level agro advisories has been initiated by IMD, MoES in collaboration with Indian Council of Agriculture Research (ICAR) and State Agriculture Universities (SAUs) (Singh, *et al.,* 2019).

Presently, IMD in collaboration with ICAR and SAUs and other institutions is rendering weather forecast based District/Block level Agromet Advisory Services (AAS) for the benefits of farmers in the country under the scheme "Gramin Krishi Mausam Sewa (GKMS)". The agromet advisories are being prepared on every Tuesday and Friday for all the agriculturally important districts in the country and around 3100 blocks by 130 Agromet Field

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Units (AMFUs), co-located with SAUs, ICAR, Indian Institute of Technology (IITs) etc., and 199 District Agromet Units (DAMUs) established in the premises of Krishi Vigyan Kendras (KVKs) of ICAR. In the existing AAS system climate/weather, soil and crop information are collected and amalgamated with weather forecast to prepare advisory in Agromet DSS to assist the farmers in taking management decisions. The DSS has been defined in different way. Jones (1980) stated that "decision support system" as "a computer-based support system for decision makers who deal with semi-structured problems to improve the quality of decisions". Sheng and Zhang (2009) described it as "a human-computer system which is able to collect, process, and provide information based on computers". Yazdani, *et. al*. (2017) considered it as "a specific class of computerized information system, enabling to manage decision-making activities". Terribile, *et al.* (2015) explained it as a smart system that provides operational answers and supports decision-making to specific demands and problems based on collected data. So the Agromet Decision Support System may be described as a system which integrates all the data and information from various sources aiming at providing platform to the users (AMFUs/DAMUs and State Met Centres of IMD) for translation of weather forecast into effective advisory for the farmers.

Requirement of Agromet DSS to fill the gap area

The digital revolution is transforming all the sectors including agriculture; the rapid emergence of cutting-edge technologies such as, remote sensing, artificial intelligence, robotics and the Internet of Things (Nowak, 2021) has led to a big increase in the data volumes available from farms (Jedlicka and Charvat 2018) to understand variability within farms due to various management practices and local weather conditions. Many stakeholders and farmers, therefore, often find themselves surrounded by large volumes of data (Charvat, *et. al*., 2018) and further need techniques for inferring the information. They found it difficult to make proper decisions about agricultural management with the big amount of information (e.g. weather related, crop-related etc.) (Taechatanasat and Armstrong, 2014). Since it is challenging for stakeholder to transfer these data into practical knowledge platforms like decision support systems (DSSs) where forecast is translated into advisory based on the local condition viz. major crops their stage, crop health, soil moisture status etc. found effective to assist them in making evidence-based and precise decisions. With the extension of network and realization of gap area in operational AAS services centrally monitored Agromet DSS at IMD was started in monsoon 2018. Previously biweekly advisories were prepared standalone by the AMFUs and DAMUs. The weather forecast was also communicated to them through emails by SAMCs and units further communicate or sent the advisories to IMD through e- mails. The entire process was time consuming and faces the network glitch at many steps. With the start of DSS, efficiency of the AAS system increases many fold and it is also helpful in filling up the gap of communication lag and other monitoring associated activities.

MATERIALS AND METHODS

Agromet-DSS

Decision Support Systems (DSS) are "Interactive computer based systems that help decision makers to utilize data and models to solve unstructured problems" (Turban, 1995). These tools improve the performance of decision makers while reducing the time and human resources required for analyzing complex decisions. After successful implementation of the GKMS project at district level, and its way forward to reach upto block level in Indian condition where districts and blocks are in about 764 and 7,233 respectively. (Source: https://lgdirectory.gov.in/). Manual preparation of advisory was found challenging in operation of AAS in India. Hence, IMD in collaboration with Regional Integrated Multi-Hazard Early Warning System (RIMES), Thailand developed a decision support system named Agromet-Decision Support System (Agro-DSS: https://agromet.imd.gov.in/), with the provision for integration of all related activities in one platform. Provided module further customized in IMD as per the requirement of GKMS Services. ICT based Agromet Decision Support System is effective to meet the requirements of expanding network and GKMS and its centrally operational through servers located at IMD. The broad initiative of developing Agromet-DSS is to increase the efficiency of services through integration of all the allied activities through single platform.

Architecture of the system

Agromet DSS is a web-based portal, where information are collected from different sources into a single user interface and presents the most relevant information for their context. It is a password protected portal having three tier computing structure;

i. Presentation: Web-based front end modules are built using Model View Controller (MVC) architecture, served by MySQL database. Layer is also implemented using HTML and Javascript.

ii. Application: Server side application layer is implemented using PHP and Python, Shell script, GrADS, R, and generic mapping tools

iii. Date Layer: Database and management of the information is carried out using SQL server.

Weather forecast

Operational numerical weather forecasting services have improved in recent times due to advances in atmospheric modelling capabilities. IMD has also increased its spatial resolution of medium range forecast by running global circulation model at 12.5 Km spatial resolution and enabling to generate the forecast at sub-district level. A full range of Numerical Weather Prediction (NWP) products at different spatial and temporal scale are routinely made available on the IMD website (www.imd.gov.in). Weather forecast generated at different temporal scale 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), (vi) Early warning system on extreme events for Cyclone/Hailstorm/ Thunderstorm/Cold and Heat wave/Drought. These forecasts are made available to planners and farmers well in advance to facilitate the decision makers. In operational agromet advisory services,

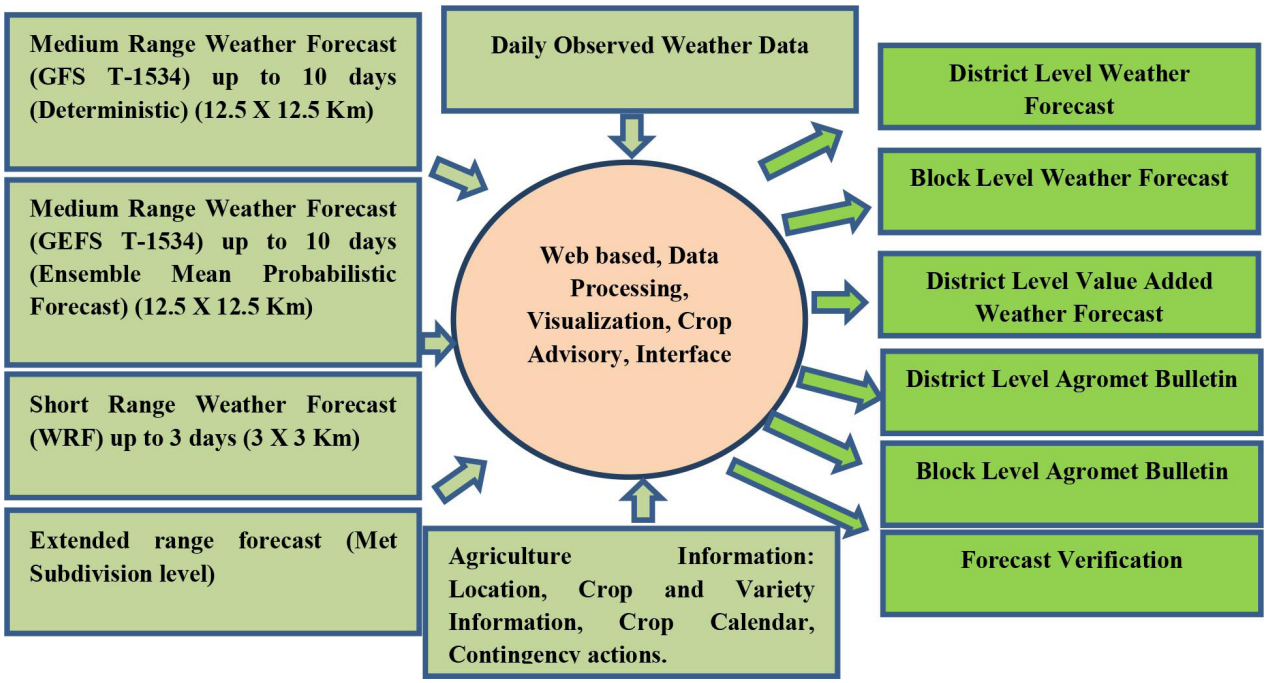


Fig. 1: An overview of Agromet-DSS

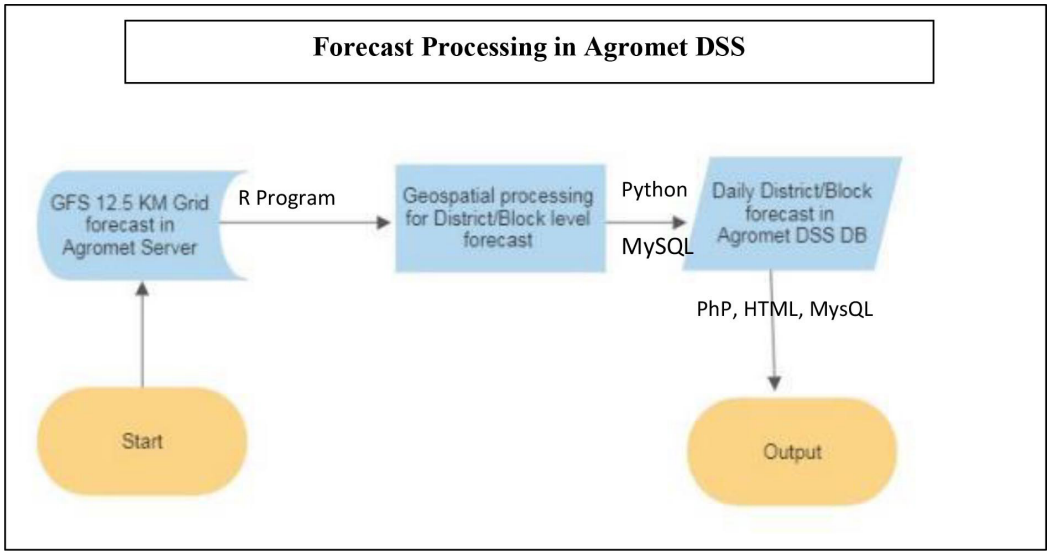


Fig. 2: Forecast integration in Agromet DSS

medium range weather forecast for next five days is being used to prepare the advisory. Five days' model output of 12.5 km spatial resolution generated from GFST-1534 is used in AAS for district and block level forecast generation. These forecast are updated on regular basis on Agromet DSS by 11 AM for further value addition and preparation of advisory details of forecast integration in Agromet DSS is explained in Fig. 2. Extended range forecast also integrated for next 6-12 days to include the advisory on subsequent week weather outlook also.

Value addition

Value addition or moderation of model output is carried out by the respective regional met centres of IMD on regular basis, based on the local weather condition and regional model outputs. Agromet DSS facilitate the value addition by providing the forecast in simple excel format for download and further upload after moderation. A dedicated window for moderation of forecast on Agro-DSS interface is also available and the choice is entirely based on the user as per the convenience. Moderation and storage of forecast through single platform is highly efficient for the users and also for the IMD to store the data for further use and monitor the timelines as well.

Monthly and seasonal verification

The verification of weather forecast is one of the important process of analysing the accuracy and further skill of any forecasting system. There are three important reasons to verify the forecast especially to monitor, to improve and to compare the forecast

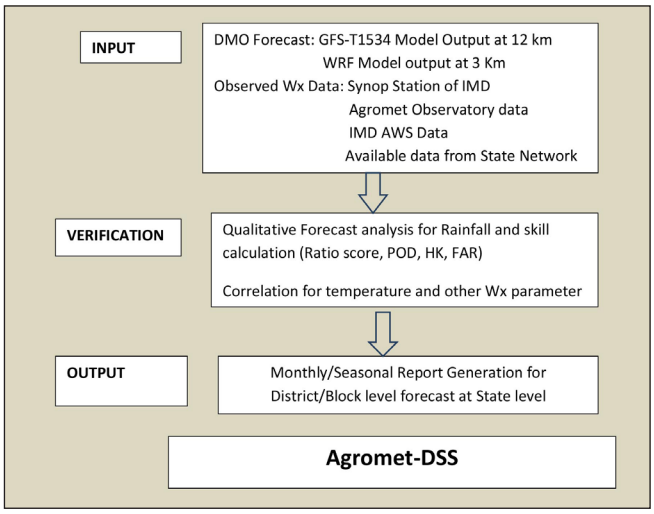


Fig. 3: Forecast verification in Agromet DSS

systems (https://www.cawcr.gov.au/). Monthly and Seasonal verification of direct model output and moderated forecast also performed on Agromet DSS on regular basis for states and country level. The forecast report also made available in DSS to make it available for the users. The verification is performed against rainfall observations received from the network of IMD and with the IMD gridded data for temperature verification. Forecast performance in Monsoon 2022 for temperature and rainfall are depicted in Fig 3-6

Formulae and error structure for forecast verification

I. Rainfall

A. Qualitative verification is done with the help of following scores;

Fore-cast / observation	Rain	No Rain
Rain	A (YY)	B (YN)
No Rain	C (NY)	D (NN)

A = No. of Hits (predicted and observed)

B = No. of False Alarms (predicted but not observed)

C = No. of misses (observed but not predicted)

D = No. of correct predictions of no rain (neither predicted nor observed)

1. **Forecast Accuracy (ACC) or Ratio Score or Hit Score** ***It is the ratio of correct forecasts to the total number of forecasts.***

$$ACC = \frac{Correct\ Forcast}{Total\ Forcast} = \frac{A+D}{N} = \frac{YY+NN}{YY+NN+YN+NY}$$

2. ***Hanssen and Kuipers Scores or True Skill Score (HK score):*** It is the ratio of economic saving over climatology due to the forecast to that of a set of perfect forecasts

$$HK = \frac{Correct\ Forcast - (Correct\ Forcast)_{random}}{N - (Correct\ Forcast)_{random,\ unbased}}$$

$$HK = (ACC)_{event} + (ACC)_{non\text{-}event} - 1 = \frac{AD-BC}{(A+C)(B+D)}$$

range : -1 to +1
perfect : 1
advantage : equal emphasis to yes/no-events

3. **Probability of detection (POD)** $= \frac{Correctrainforecast}{rainobservation} = \frac{A}{A+C}$

Range : 0 to 1; Perfect Score 1

4. Heidke Skill Score(HSS) $= \frac{\text{Correct Forecast} - (\text{Correct Forecasts})_{random}}{\text{N- (Correct Forecasts)}_{random}}$

$$HSS = \frac{2(AD - BC)}{(A+C)(C+D) + (A+B)(B+D)}$$

Range: -α to 1 Perfect: 1

5. **False alarm ratio** $= \frac{\text{False alarms}}{\text{Hits + False alarms}}$

$$FAR = \frac{B}{A+B}$$

II. Temperature, Wind Direction, Wind Speed, Cloud cover and Relative Humidity

1. Root mean square error between the sum of absolute difference between observed values and forecasted values.

2. Calculating the correlation between the observed and the forecasted value.

Bulletin preparation

Agromet-DSS has been customized with a standard template for advisory preparation where weather forecast, major crops, type of agricultural activities are already fed in the template with a dropdown option. Preparation of platform in provided template helps the users for performing the task within stipulated time and also helps them to refer the weather of adjoin location in single click.

Detailed flow chart for Agromet Advisory Services under GKMS is depicted in Fig. 7. Regional Meteorological Centres (RMCs) and Meteorological Centres (MCs) of IMD, located in capitals of different states across the country, communicate the value added District and block level weather forecasts for next 5 days and also subsequent week Met Sub-division wise rainfall and temperature forecast to the AMFUs and DAMUs for their respective states on every Tuesday and Friday.

Translating forecast into crop advisories

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 forecasts, issued for above listed parameters for next 5 days and Met Sub-division wise forecasts for subsequent week, into crop/

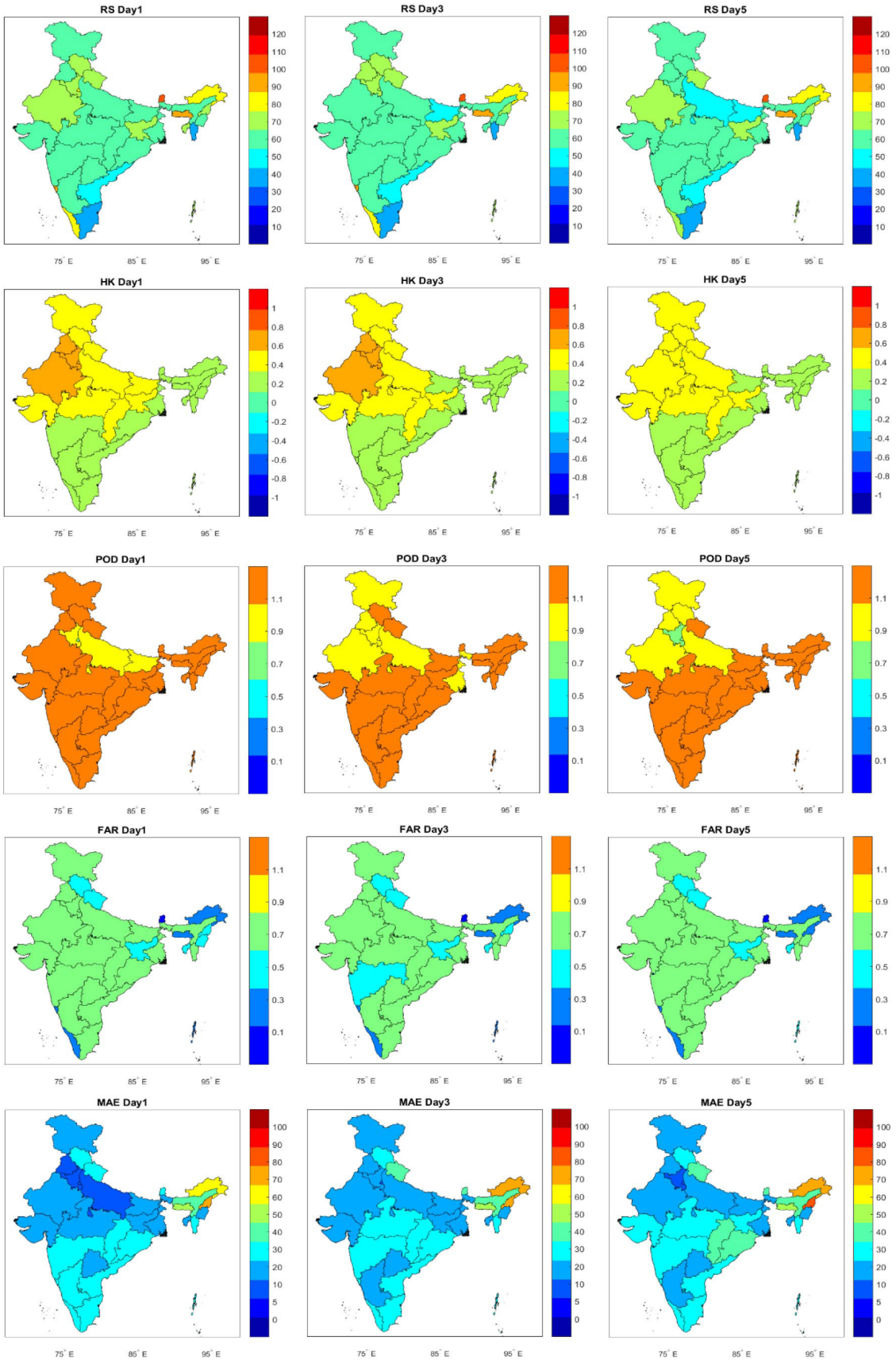


Fig. 4: Spatial distribution of rainfall skill scores

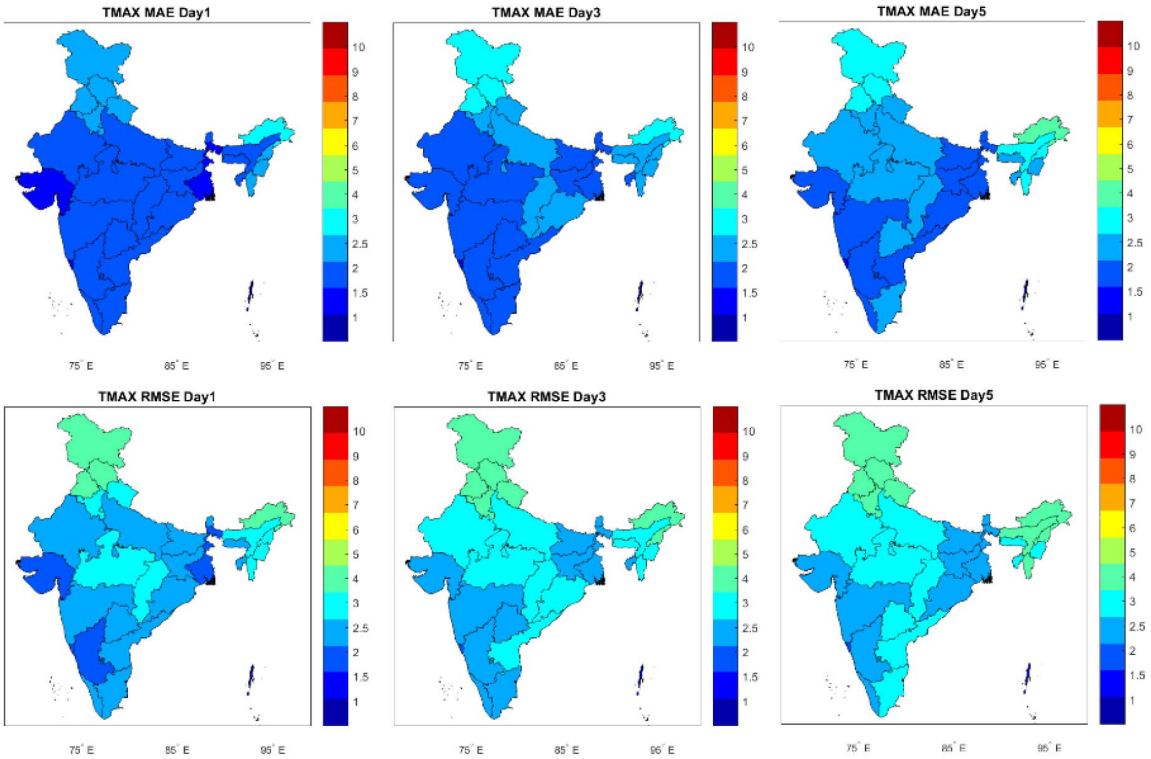


Fig. 5: Spatial distribution of temperature (Max) skill scores

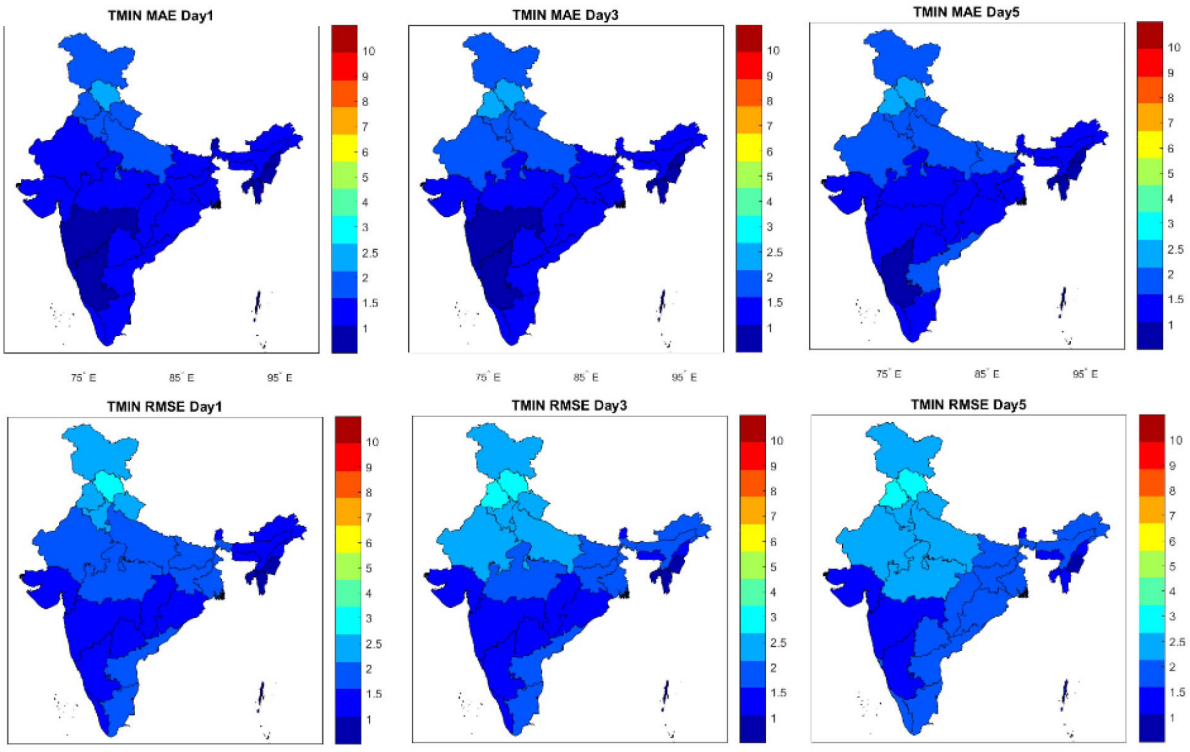


Fig. 6: Spatial distribution of temperature (Min) skill scores

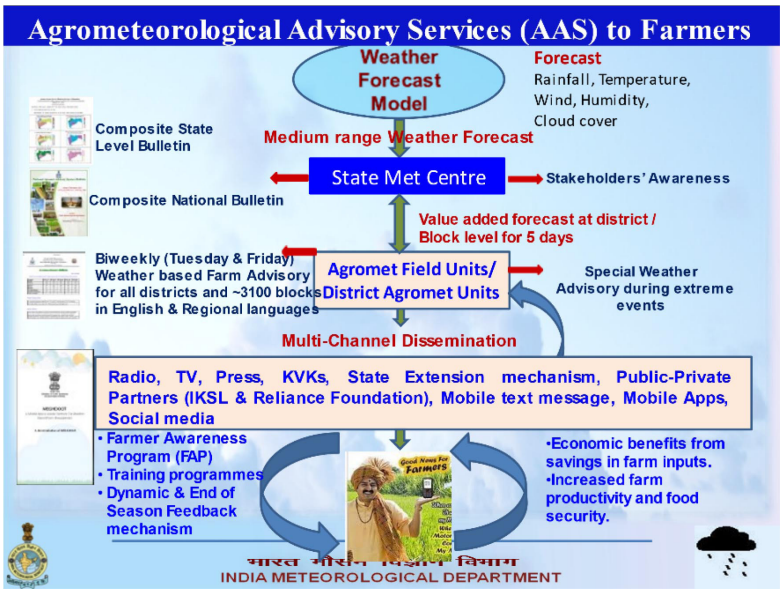


Fig.7: Agrometeorological advisory services under GKMS

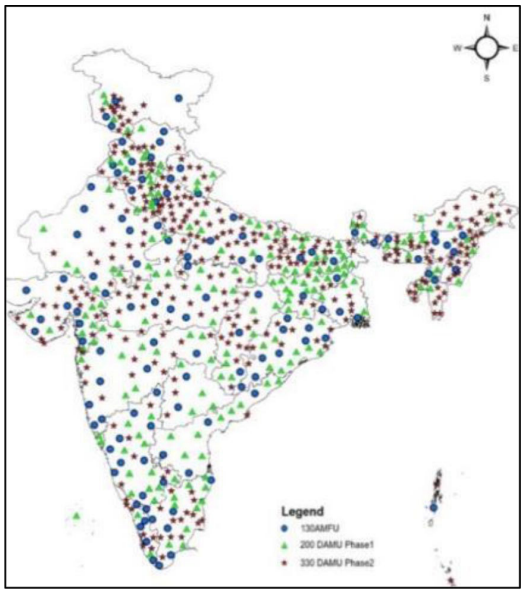


Fig.8: Distribution of district unit and Agro-AWS stations established in the country

livestock specific advisories considering the state and stage of crops and status of livestock to guide the farmers on farm/livestock management practices.

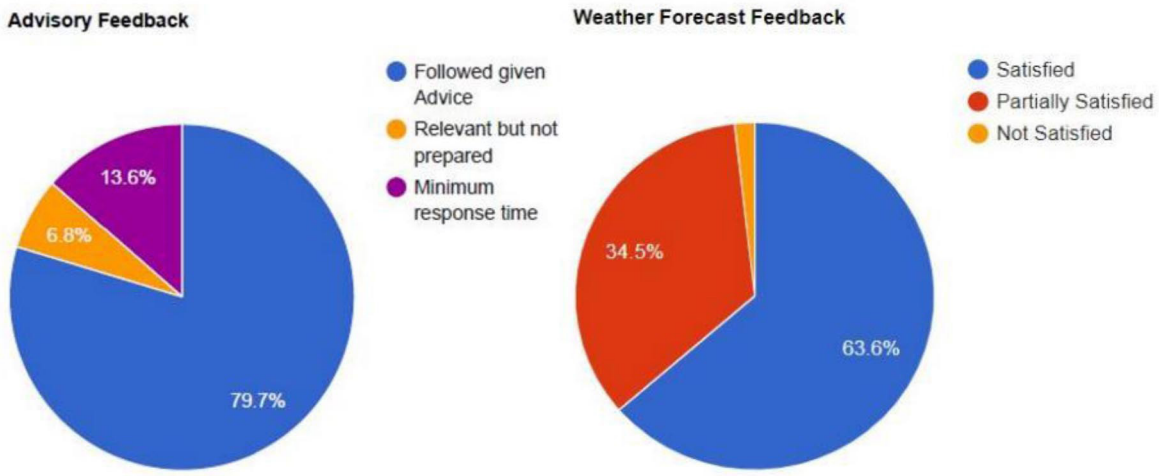
Agromet advisories are, thus, being issued on every Tuesday and Friday, based on District and block specific medium range and Met Sub-division level extended range forecast for subsequent week, to help the farming community to avert crop damage or loss and thereby in maximizing output. It also helps growers to anticipate and plan for chemical applications, irrigation scheduling, disease and pest outbreaks and many more weather related agriculture-specific operations. Such operations include cultivar selection, their dates of sowing/planting/transplanting, dates of intercultural operations, dates of harvesting and also performing post harvest operations. Thus, Agromet advisories help in increasing profits by consistently delivering actionable weather information, analysis and decision support for farming situations.

Agro-DSS has been using 329 district units (130 Agromet Field Units and 199 District Agromet Units) established by IMD across the country for preparation and dissemination of daily block level weather to all the blocks agromet advisory to all the districts and 3100 blocks twice a week. Recently 200 agriculture automatic weather station (Agro-AWS) has been established in the premises of Krishi Vigyan Kendras (KVKs). The stations are equipped with are equipped with sensors for measuring Air temperature, Relative Humidity, Rainfall, Sunshine duration, Wind speed and Wind direction along with soil moisture and soil temperature sensors at 10, 30, 70 and 100 centimeter depths. Soil moisture sensors are FDR type (frequency domain type), which uses the principle of electromagnetic pulse to measure the apparent permittivity (ε) of the soil according to the propagation frequency of electromagnetic waves in the medium, so as to obtain the soil moisture. These parameters are highly useful for decision making in farm level risk management including irrigation scheduling. It will fulfill the requirement of the country to have a benchmark district network of soil moisture and soil temperature observations. All the real time data is made available in the Agro-DSS for using preparation of bulletin, irrigation scheduling, estimating various bio-physical parameters for drought assessment etc. Distribution of district Units and Agro-AWS is depicted in Fig. 8.

Dissemination of advisory and forecast through API

A centrally operated data server with high capacity and efficiency is dedicatedly used for the AAS services where all the data (Weather forecast, Moderated forecast, Bulletins prepared etc.) are kept in structured format in MySQL database. To disseminate the forecast and advisory a dedicated App Meghdoot, is also designed and widely used by the farmers. Seamless dataflow from Agromet DSS to Meghdoot is managed through API. IMD has also initiated to enhance dissemination through API integration with State Department Mobile Apps and Websites. As of now integration has been completed with 12 states. About >6.5 million farmers in the states are accessing weather forecast and agromet advisory services.. The communication between two services through Application Program Interface (API) is feasible only due to structured database management in Agromet DSS web server, which helps in increasing the visibility of our services manifold.

Apart from this value added block level weather forecast and agromet advisories generated in Agro-DSS are shared through Whatsapp group covering 3651 blocks and Common Service Centre (CSCs). Weather forecast are also shared with 853 Mandis of Agricultural Produce Market Committee (APMC). Agromet advisory are also sent through Short Message Services (SMSs) using m-KISAN portal launched by the Ministry of Agriculture & Farmers' Welfare (MoA&FW), Govt. of India during extreme weather events. Recently SMSs has been sent to 3173651 numbers of farmers in the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Nagaland, Odisha, Tripura and West Bengal during Cyclonic Storm "SITRANG" over Bay of Bengal. Further, impact-based forecasts (IBFs) for agriculture are being issued based on the severe weather warnings (heavy rainfall / thunderstorm with gusty winds / cold wave / hailstorm / heat wave) for different districts and blocks of country. Biweekly extended range weather forecast for next two weeks. Agromet advisories are also being disseminated through a dedicated Mobile app 'Meghdoot', Agricultural



Agromet Advisory Feedback

No. of Records: 60 Date: 28.12.2022

Response 1 Advisory feedback	Nos	Response 2 Weather forecast feedback	**Nos**
Followed given Advice	47	Satisfied	35
Irrelevant	0		
Relevant but not prepared	4	Partially Satisfied	19
Unfavourable weather	0		
Minimum response time	8	Not Satisfied	1
Other not related to advisory	0		

Fig 9: Analysis of dynamic feedback generated in Agromet DSS

Technology Management Agency (ATMA), Self Help Groups, Farmers club, Farmers Producer Organisation (FPOs), Social media, Kisan Mitra; and the common APP of the Government of India - UMANG. Biweekly and weekly inputs are also provided to DD Kisan in 'Mausam Khabar' and 'Krishi Darshan' programmes respectively. Advisories are also issued by AMFU/DAMUs in case of extreme weather events.

Feedback and analysis: Understanding the potential and obligation of any service requires regular monitoring and feedback. In AAS end of season feedback and analysis was performed by almost all units for their jurisdiction and the practice is still continued by on AMFUs and DAMUs. For real time feedback/weekly feedback and analysis there is a separate module named "Dynamic Feedback Module" is placed in Agromet DSS. There is provision to feed the collected feedback on weather forecast and advisory in provided format on weekly basis. The module is customized to generate the report nation wise, state wise, unit wise, crop wise and crop stage wise also. An example of report generated for dynamic feedback collected in Andhra Pradesh in Monsoon 2021 is depicted in Fig. 9.

Crop weather calendar

The crop weather calendar is a useful tool to inform farmers about the effects of unfavourable weather (*viz.* rainfall deficit, unseasonal rainfall cold waves, heat wave and terminal heat etc.) on particular crop/variety in a particular location. IMD has prepared district level CWCs for major crops in India decades ago (IMD-AGRIMET, 1996). Later in 2005, IMD revised it by incorporating existing cropping patterns, soil types and conditions favourable for development of pests and diseases. All India Coordinated Research Project on Agrometeorology (AICRPAM) under ICAR has also prepared district level CWC for major crops in India (Rao, *et. al*., 2015). IMD also coordinate with GKMS units to prepare the CWCs for their own location using long term weather data of IMD and crop data collected in field condition. To link the advantages of using Crop Weather Calendar in advisory preparation, IMD in collaboration with ICAR-CRIDA developed the Dynamic Crop Weather calendar; a designated standalone module to address the real time crop phenological stage and their normal weather requirement. This module also helps in addressing the irrigation requirement of the crop based on water balance approach. The DCWC intends to atomize agromet advisories using prevailing and forecasted weather. Modules for predicting sowing dates and phenology were validated for principal crops and varieties at selected locations by Kumar, *et. al*. (2021) For 10 crops pooled over nine centres which shows close relationships with observed values (R^2 of 0.93). As if now IMD has validated the DCWC for about 200 locations, covering all the Agro-climatic Zones and Operational use of DCWC through Agromet-DSS will also be completed soon. Validation result of DCWC for Cotton growth stage prediction in Aurangabad Maharashtra is depicted in Fig. 10.

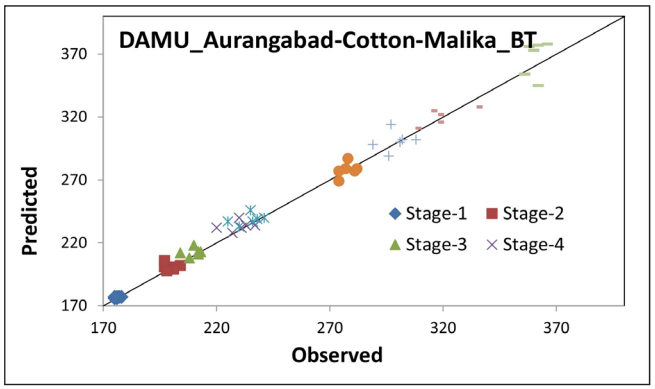


Fig 10: Validation result of DCWC

Features to be integrated/enabled in Agro-DSS

- Integration with the Automatic Rain Gauge (ARG) and Automatic Weather Station (AWS) established/ establishes by the State Government/central agencies for improvement of weather forecast and agromet advisory.
- Use of probabilistic weather forecast for block level agromet advisories.
- Development of Crop Weather Calendar (CWC) and Pest weather calendar in collaboration with CRIDA and SAUs.
- Geospatial analysis of soil moisture and soil temperature using Agro-AWS network and other water balance components.
- Forecasting pest & disease infestation using Forewarning models with the help of ICAR Institutes.
- Development of Agri-GIS for dissemination of District/ Block level advisory and display of other spatial products through GIS platform.
- Crowd sourcing platform developed for collection of observation on weather from local people.
- Advisory preparation and dissemination in all regional languages.
- Operationalization of use of 3 km model forecast in the states / regions equipped with AWS/ARG at sub-block / cluster of panchayat level.
- Automation of agromet advisory using AI/ML technique.
- High resolution observation by integrating Radar, Satellite and surface observation data at Sub-block level / Panchayat level.
- Personalized advisories as per the need of individual farmer.
- Crop weather calendar and climate risk matrix for all crops to translate the forecast in to location/crop specific advisories.

CONCLUSION AND WAY FORWARD

The risks confronting with agriculture production are very high due to weather variability. Weather forecast translated in agro advisory helps in taking the decision at field level in advance and avoids the associated risk. Increasing number of observatories, use of advance tools and techniques, expansion of existing Agromet Field Unit network, customized Decision Support is highly efficient to support the weather smart agriculture under existing scenario of digitization of information. However there is still gap area exists where Agromet DSS is required to be more robust, one of the prime requirement is Generation of Automatic Advisory using state of the art technologies like Artificial Intelligence, Neural Network etc. The automation of advisory will make the process quick and efficient to cater the need of all stakeholders. Recently various tools have been developed by IMD in collaboration with the different organisation (crop pest & disease forewarning, ISRO-IMD Vegetation Information System etc) which will also be integrated in Agro DSS to facilitate AMFUs & DAMUs for focusing on the regions affected by deficit of soil moisture, pest/disease attack etc. Soon, a satellite data and gridded weather data-based module will be developed and integrated into the Agro-DSS to estimate future yield of crops and prepare an irrigation schedule without a need of multiple parameters.

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Conflict of interest: The authors declare that there is no conflict of interest

Data availability: Review article, Forecast and Observed data (Rainfall and Temperature), Feedback data obtained from network of GKMS, Field observation of cotton crop obtained from DAMU, Aurangabad

Author's contribution: **K. K. Singh:** Conceptualization, overview; **Kripan Ghosh:** Review and Editing; **S. C. Bhan:** Conceptualization, overview; **Priyanka Singh:** Development of DSS software, data analysis, writing first draft, Lata Vishnoi: Development of DSS software, writing first draft, R. Balasubramanian: Writing and Editing, **S. D. Attri:** Conceptualization, overview; **Sheshakumar Goroshi:** Writing and Editing, **R. Singh:** Review and Editing;

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