Weather Information for Sustainable Agriculture in India

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1 Introduction

Agriculture sector, world over, has experienced a phenomenal growth since middle of the last century. The growth in India, driven by Green Revolution, has made a tremendous contribution towards aggregate supply of food grains, ensuring food security to the growing population with the total foodgrain production increasing from about 50 m tonnes at the time of independence to more than 250 m tonnes now. This growth, however, is fast approaching the plateau; and sustainability of this growth faces serious challenges. Some of the problems such as the loss of soil productivity from excessive soil erosion and associated plant nutrient losses, surface and ground water depletion both in terms of quality and quantity and pollution from pesticides, fertilizers and sediments, impending shortages of non-renewable resources and low farm income from depressed commodity prices and high production costs are assuming serious proportions. Besides, most of the increase in production and yield has been restricted to food grains that too in wheat and rice, primarily because crop varieties covered in the green revolutions have high water requirements and are not suitable for use under rain fed conditions. They also require high input resources for giving maximal yields. Thus the green revolution has remained confined to irrigated areas at the cost of other crops, particularly coarse cereals and pulses. But the law of diminishing returns is catching up even for the areas benefited by Green Revolution.

Therefore, the area and input intensive agriculture is leading us into an era of unsustainable agricultural growth and the crucial components of sustainable agricultural production and distribution system such as integration of natural biological cycles and controls; protection and renewal of soil fertility and the natural resource base; optimisation of the use of non-renewable resources and of on-farm & off- farm inputs; ensuring dependable farm income; promoting opportunity in family farming and farm communities; reducing adverse impacts on health and safety of the farming community; and other aspects of integrated soil, crop, livestock, water and pest management. All these components of sustainable agriculture, in addition to other management and input interventions, also require weather and climatic information. Weather and climatic information plays a major role in the entire crop cycle right from selecting the most suitable crop/variety upto post harvest operations and marketing; and if provided in advance can be helpful in inspiring the farmer to organize and activate their own resources in order to reap the benefits by judicious application of costly inputs. Hence, the meteorological information may help the farmer make the most efficient use of natural resources, with the aim of improving agricultural production; both in quantity and quality. It becomes more and more important to supply meteorological information blended with weather sensitive management operations before the start of cropping season in order to adapt the agricultural system to increased weather variability. Subsequent to this, weather forecast based Agro-meteorological advisories become vital to stabilize their yields through management of agro-climatic resources as well as other inputs such as irrigation, fertilizer and pesticides. Meteorological information also plays an important role in the following operations in agriculture:

- Higher and regulated crop yields;
- Lower production costs
- Environmental protection
- Better product quality
- Land management: diversification, soil conservation
- Water management: issues related to farm irrigation, urban water needs, water conservation measures
- Combat unfavourable consequences of weather including pest and disease management
- Breeds and varieties adapted to local agroclimatic conditions
- Better consideration of meteorological factors that affect animal behaviour and health
- Multiple cropping system for irrigated areas and tree based farming system rainfall area
- Integrated pest management
- Soil and water conservation
- Watershed management
- Agroforestry systems in dry lands/ sloppy areas and erosion prone areas
- Water technology

Hence, the meteorological services can help the farmers & the planners exploit the potential of good weather and minimize the impact of bad weather as there exist tremendous opportunities for applications of meteorology in both day to day and long term planning in agriculture and such applications could contribute substantially to promote sustainable agriculture and poverty alleviation; and the management of agrometeorological data is the key to these applications. Weather information and advisories are assuming greater significance under the increased variability in the changing climate.

Usefulness of Weather Forecasts for Agriculture

- Climate-based strategic agronomic planning:

  For optimal productivity at a given location, crops and cropping practices must be such that their cardinal phased weather requirements match the temporal march of the relevant weather elements, and at the same time endemic periods of pests, diseases and hazardous weather are avoided.

  In such strategic planning of crops and cropping patterns, short –period climatic data, both routine and processed (such as initial and conditional probabilities) , have a vital role to play.

- Occurrences of erratic and adverse weather

  Agronomic strategies have to be devised to cope with the effects of erratic and adverse weather on agricultural production. For examples, delay in the start of crop season can be countered by using short duration varieties of crops and thicker sowings and the effects of frosts can be prevented by resorting to irrigation or lighting trash fires.

Medium range weather forecasts with a validity period that enable farmers to organize and carry out appropriate cultural operations to cope with are clearly useful. The following kind of forecast is mainly useful in operational agrometeorology

Usefulness of Short and Medium Range Forecast for agriculture is in the following activities

- ❖ Preparatory activities, including land preparation and preparation of plant material
- ❖ Planting or seeding/sowing; Management of crops, fruit trees and vines;
- ❖ Application of fertilizer, irrigation; thinning, topping, weeding; pest and disease control; Management of grazing systems;
- ❖ Harvesting, on-farm post-harvest processing
- ❖ Transport of produce; Livestock production activities (for dairy enterprises, beef systems, lamb and other livestock systems).

2. Weather and Climate Observation System

India Meteorological Department (IMD) has progressively expanded its infrastructure for meteorological observations on real time basis and to provide current and past observations for operational and research use. Surface observatories are located one in each district so as to meet the requirements of agricultural, transport and other sectors. IMD's present Upper air observational network comprises of radiosonde and pilot balloon, RS/RW observatories, Doppler Weather Radar etc. spread all over the country. Also a Doppler Weather Radar (DWR) provides velocity and spectrum width data (in addition to reflectivity). This capability permits the forecaster to view weather events like thunderstorms, hailstorm, heavy rainfall etc. in greater detail. The Doppler radar shows promise in depicting wind field patterns associated with cyclones, which can be used in assessment of wind damage potential and determination of the associated storm surge affecting the meteorological, hydrological and aviation products which are very useful in estimating the storm's center, fixing its position and predicting its future path. In Numerical Weather Prediction models the Doppler data in digital form can directly be assimilated, which results in better rainfall estimation, better prediction of the storm track and point of landfall for tropical cyclones.

IMD is observing weather with satellite and radar. At present IMD is receiving and processing meteorological data from two Indian satellites Kalpana-1 and INSAT-3A. Kalpana-1 and INSAT-3A both have three channel Very High Resolution Radiometer (VHRR) for imaging the Earth in Visible (0.55-0.75 um), Infra-Red (10.5-12.5um) and Water vapour (5.7-7.1um) channels having resolution of 2x2 kms in visible and 8x8 kms in WV and IR channels. In addition the INSAT-3A has a three channel Charge Coupled Device payload for imaging the earth in Visible (0.62-0.69um), Near Infra Red (0.77-0.86um) and Short Wave Infra Red (1.55-1.77um) bands of Spectrum. All the received data from the satellite is processed and are archived in National Satellite Data Centre (NSDC), New Delhi.

The payload of INSAT-3D adds a new dimension to weather monitoring through its atmospheric sounding system, which provides vertical profiles of temperature, humidity and integrated ozone from surface to top of the atmosphere, and is expected for the next seven years making a difference for the weather forecasting and disaster warning systems for the country. This has two kinds of payloads ‘Imager’ and ‘Sounder’. The six channel imager consists of broad visible (VIS), short-wave infrared (SWIR), Middle infrared (MIR), water vapour (WV) and two split-thermal infrared (TIR) bands. The optical bands (VIS & SWIR) have spatial resolution of 1 km. The MIR and TIR bands have 4 km spatial resolution. The WV band has 8 km spatial resolution. The 19 channel sounder will be able to probe the vertical structure of the atmosphere at regular time interval in a day. The Imager data will be able to provide satellite meteorological (satmet) products such as rainfall, land surface temperature (LST), land surface albedo, incident solar radiation, cloudiness, upper troposphere humidity (UTH), outgoing longwave radiation (OLR). The combination of all these products from 3D, improved weather forecasts, vegetation index product from INSAT 3A CCD and in situ data are valuable ingredients to generate real-time value-added information for enhanced operational agro-met advisory services in the country. The long-term datasets from INSAT suite will be able to aid in digital agro-climatic characterization.

IMD is maintaining a network of agro-meteorological observatories in farm environment. Beside this network, there are evapotranspiration (ET) stations, pan evaporation stations, soil moisture (SM) observatories, dew fall and radiation observations. Agrometeorological Automatic Weather Stations (Agro-AWS) have been installed at 127 Agrometeorological Field Units (AMFUs). The data are being received in AWS Laboratory, Pune regularly. IMD has drawn plans to upgrade and strengthen its observation network in the coming years. Nationwide network of Automatic Weather Stations and Doppler Weather Radar network will also increase.

IMD has long time series of various climate data in its archive. National Climate Center (NCC) at Pune generates many climate data products for smaller spatial and temporal scales for the user community. These data products include (i) Daily gridded (1^o X 1^o) rainfall and temperature data, (ii) Daily gridded (0.5^o X 0.5^o) rainfall data, (iii) District wise normal for various surface parameters, (iv) Marine climate summaries for Indian Ocean region. IMD operationally prepares gridded rainfall data on 0.5^o X 0.5^o spatial resolution by processing spatially continuous satellite derived rainfall (TRMM) and weather observation from existing weather network (IMD Gauge). These Data help in monitoring strength of monsoon, studying oscillation of different Periodicity, extended range prediction and to fine tune the dynamical models. The Centre will very soon bring out daily rainfall data on 0.25^0x 0.25^0 spatial scale. Similarly daily gridded temperature data would also be brought out on smaller spatial scale.

3. Weather forecasting System

India experiences large spectra of weather events having spatial scale of less than 1 km to more than 1000 km and temporal range of less than an hour to more than a week. Different parts of the country experience different kinds of weather conditions such as Winter season (Jan-Feb) is characterised by Western Disturbances, Cold Wave, Fog; Pre-Monsoon (Mar-May) by Cyclonic Disturbances, Heat Wave, Thunder Storms, Squalls, Hail Storm, Tornado; Monsoon (Jun-Sep) by Southwest Monsoon Circulation, Monsoon Disturbances; and Post-Monsoon (Oct-Dec) by Northeast Monsoon, Cyclonic Disturbances. Meteorological Department in the country was one of first scientific departments which started scientific research on weather systems as early as in 18th century. Indian monsoon is a field of active research all over the world as it is a unique weather event which covers several oceans and continents but depicts its characteristic phase over Indian sub-continent. The monsoon rains are crucial for agricultural production in the country as most parts of the country depend on this rain for day-to-day agricultural operations.

Prediction of weather systems in different spatial and temporal scale over the Indian region therefore assumes considerable importance. Several organisations are engaged in developing techniques for prediction of these systems. In the recent past, IMD has made enormous improvement in the accuracy and lead time of forecasts for various usage including AAS. IMD's forecast system for agromet purpose is discussed.

IMD has made Global Forecast System (GFS T574/L64, based on NCEP) operational in December 2009, implemented on IBM based High Power Computing Systems (HPCS). This incorporates Global Statistical Interpolation (GSI) scheme as the global data assimilation for the forecast up to 7 days. In horizontal, it resolves 574 waves (» 22 Km in the tropics) in spectral triangular truncation. The model has 64 vertical levels (hybrid; sigma and pressure). Currently, it runs twice in a day (00 UTC and 12 UTC). In addition to this, the meso-scale forecast system WRF (ARW) with 3DVAR data assimilation is 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 (horizontal resolution over the tropics ~ 22 km). At ten other regional centres of IMD, very high resolution mesoscale models (WRF at 3 km resolution) are made operational. NWP based objective forecast products are prepared to support cyclone warning service. Doppler weather and mesoscale dynamical model based nowcast system was made operational for the national Capital of Delhi. A full range of NWP products at different spatial and temporal scale are routinely made available on the IMD web site www.imd.gov.in.

Next generation model will target more accurate ways to initialize forecasts by improving data assimilation techniques, more accurate parameterizations, and improved estimates of uncertainty in the modelling system and in forecasts. Coupling of the atmosphere to the underlying surface – land and ocean – is important and also critical for forecast lead times extending into fortnightly and monthly timescales. To adequately resolve the transient systems responsible for rainfall during monsoon and their movement, it is important to use models with high resolutions both in the horizontal and vertical. By 2020, plan is to run global models of about 10 km resolution with about 100 levels in vertical (high-resolution GFS such as T1148-L64 (16 km) to T1500-L128 (13 km)), and regional models with about one km resolution. The physical parameterizations will need to be improved/optimized for higher resolution models. As the model grid size approaches the horizontal scales of moist deep convection special attention will be given to the parameterization of moist processes. Cloud resolving models are required to be embedded in the global and meso-scale models as clouds are the major cause of uncertainty in present day models. All current and future global NWP system will have to address the uncertainty inherent in the prediction over all temporal and spatial scales. The challenge is to increase the number of ensemble members which will further improve its value for all applications

Recent studies suggest that an interactive upper-ocean in a high resolution coupled general circulation model significantly enhance the prediction skill of weather in medium range. Experiments at ECMWF and other centers have started showing the benefits of coupling in improving the skill in medium and 2 weeks to 1 month monsoon forecasts. Therefore ocean model with very high vertical resolution (1 m) in the upper ocean has to be coupled with a higher frequency (1 hour) of interaction with atmosphere model. Ocean data assimilation will be required to initialize the ocean model properly. Similarly a land surface model with its assimilation has to be also coupled to form the full 'Coupled Earth System Model'.

District level medium range weather forecast

IMD implemented a Multi-model Ensemble (MME) based district level quantitative forecasts in the operational mode since 1 June 2008, as required for the Integrated Agro-advisory Service of India. Five NWP models considered for this development work are: (i) IMD GFS T574, (ii) ECMWF T799, (iii) JMA T899, (iv) UKMO and (v) NCEP GFS. Model outputs of the constituent models are interpolated at the uniform grid resolution of 0.25^0X0.25^0lat/long. Further, the weight for each model at each grid is determined objectively by computing the correlation co-efficient between the predicted rainfall and observed rainfall. High resolution gridded rain-gauge data produced operationally at National Centre of IMD Pune are used for development and validation of the forecasts. The ensemble forecasts (day 1 to day 5 forecasts) are generated at the 0.25^0X0.25^0resolution. The ensemble forecast fields are then used to generate district level forecasts by taking average value of all grid points falling in a particular district. The products comprise of quantitative forecasts for 7 weather parameters viz., rainfall, maximum temperature, minimum temperatures, wind speed, wind direction, relative humidity and cloudiness. These products are disseminated to Regional Meteorological Centres and Meteorological Centres of IMD located in different states. These offices undertake value addition to these products using local conditions and synoptic interpretation of model out put and communicate to 130 AgroMet Field Units (AMFUs) on every Tuesday and Thursday.

Long Range Forecast

IMD has been issuing long-range forecasts (LRF) based on statistical methods for the southwest monsoon rainfall over India (ISMR) for more than 100 years. The forecast for the South-West monsoon rainfall is issued in two stages. The first stage forecast for the seasonal (June to September) rainfall over the country as a whole is issued in April and the update of the April forecast is issued in June. Along with the update forecast, forecast for seasonal rainfall over four broad geographical regions of India and July rainfall over country as a whole are also issued.

For issuing the forecast for the seasonal rainfall over the country, a new statistical forecasting system based on the ensemble technique was introduced in 2007. The 8 predictors considered for the new ensemble forecast system are given in the Table. For the April forecast, the first 5 predictors given in this table are used. For the updated forecast in June, last 6 predictors are used.

Table: Details of the 8 predictors used for the new ensemble forecast system

Details of 8 predictors	Predictor	Used for forecasts in
1	NW Europe Land Surface Air Temperature	April
2	Equatorial Pacific Warm Water Volume	April
3	North Atlantic	April and June

	Sea Surface Temperature	
4	Equatorial SE Indian Ocean Sea Surface Temperature	April and June
5	East Asia Mean Sea Level Pressure	April and June
6	Central Pacific (Nino 3.4) Sea Surface Temp.Tendency	June
7	North Atlantic Mean Sea Level Pressure	June
8	North Central Pacific wind at 1.5 Km above sea level	June

Dynamical (Numerical) Forecasting System for Month and Season

The experiments of this study were carried out with the National Centers for Environmental Prediction (NCEP) seasonal forecasting model (SFM), which provides regional details for the Global Spectral Model (GSM). The SFM (Kanamitsu et al. 2002) uses the spectral transform method to solve the primitive equations. The model is a non-hydrostatic global spectral model with a triangular truncation of 62 spherical harmonics (T62), equivalent to a horizontal resolution of about 280 km was chosen. The model of this study used a vertical sigma coordinate system which contains 28 layers. The basic model Physical processes and parameterization schemes were developed from reanalysis-II version of NCEP Medium Range Forecast model.

The ensemble simulation was carried out for 31 year period from 1982 to 2012 to prepare model climatology. Each forecast was initialized at first 10 days of each month and run continuously for next five months. The initial conditions corresponding to 0000Z UTC were obtained from NCEP reanalysis. The forecasted SST from Coupled model, NCEP Climate Forecast System version 2 (CFSv2) were used as SST condition. SST Boundary condition prepared by averaging of CFSv2 SST forecast for first 10 days initial conditions of each month (Total 40 members). For making real time forecast, initial and boundary conditions are taken from NOAA operational Modal archival and distribution system.

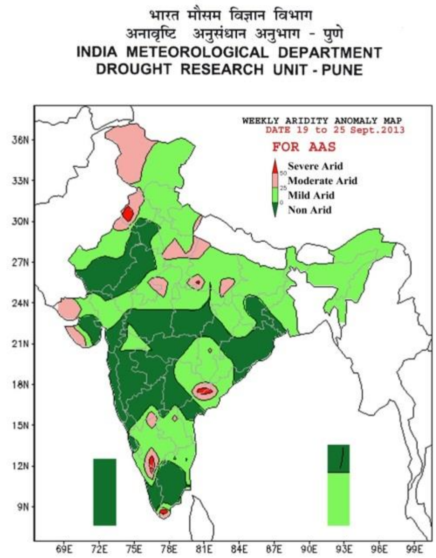
Special weather forecast for extreme events

Special weather forecast for agriculture provides the necessary meteorological input to assist farmers in making decisions. The requirements for these special forecasts will vary from season to season and crop to crop. Special forecast issued are as follows:

- Tropical storms (cyclones, hurricanes, typhoons, etc.) associated with high winds, flooding and storm surges.
- Floods (other than those related to tropical storms) heavy rains due to monsoons, water logging and landslides.
- Severe thunderstorms, hail storms, tornadoes and squalls.
- Drought and heat waves.
- Cold spells, low temperature, frost, snow and ice-storms.
- Dust storms and sand storms.
- Pest and diseases of crop and livestock.

Early Warning Systems

IMD has developed early warning systems for extreme weather events like drought, flood, tropical cyclone, heat and cold wave, fog, hail. For drought monitoring and assessment, IMD has established system for real-time monitoring of rainfall on daily, weekly, monthly and seasonal basis for the districts/ meteorological subdivisions/ state in the country. IMD is preparing indices based aridity anomaly maps on weely basis that gives information about the moisture stress experienced by growing plant. This analysis would indicate qualitatively retardation in the plants growth and so poor yields. Indirectly, this may also be helpful for irrigation scheduling, the amount and the time at which the water is badly needed by the plant.



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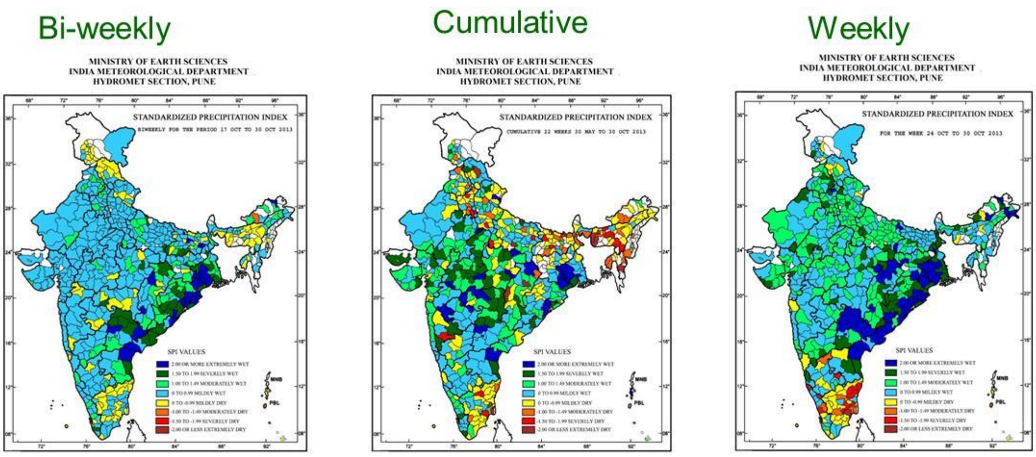
IMD is also preparing Standard Precipitation Index maps which describe dry and wet periods in the same way. SPI is appropriate tool for monitoring agricultural drought but in combination with other information: water balance, crop condition, etc. Computation of SPI is done at a monthly time scale.



4. Agromet Advisory Service in India:

Agrometeorological Advisory Service (AAS) rendered by India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) in active collaboration with ICAR, State Agriculture Universitie, State Department of Agriculture etc. is a step to contribute to weather information based crop/livestock management strategies and operations dedicated to enhancing crop production and food security. The main emphasis of the existing AAS system is to collect and organize climate/weather, soil and crop information, and to amalgamate them with weather forecast to assist farmers in taking management decisions. This has helped to develop and apply operational tools to manage weather related uncertainties through agro-meteorological applications for efficient agriculture in rapidly changing environments.

The information support systems under AAS include:

- Provision of weather, climate, crop/soil and pest disease data to identify biotic and abiotic stress for on-farm strategic and tactical decisions,
- Provide district specific (Pan India) weather forecast (rainfall, cloudiness, maximum/minimum temperature, wind speed, wind direction, maximum/minimum relative humidity) up to 5 days with outlook for rainfall for remaining two days of a week,
- Translate weather and climate information into farm advisories using existing research knowledge on making more efficient use of climate and soil resources through applications of medium range weather forecast. A broad spectrum of advisories include weather sensitive farm operations such as sowing/ transplanting of crops, fertilizer application based on wind condition & intensity of rain, pest and disease control, intercultural operations, quantum and timing of irrigation using meteorological threshold and advisories for timely harvest of crops.
- Introduction of the state-of-art technologies such as remote sensing, GIS and crop simulation model based decision support system for agro-meteorologists to adapt agricultural production systems to weather & climate variability and to the increasing scarcity of input such as water, seed, fertilizer, pesticide etc.,
- Develop effective mechanism to on time dissemination of agromet advisories to farmers,
- Effective training, education and extension on all aspects of agricultural meteorology.

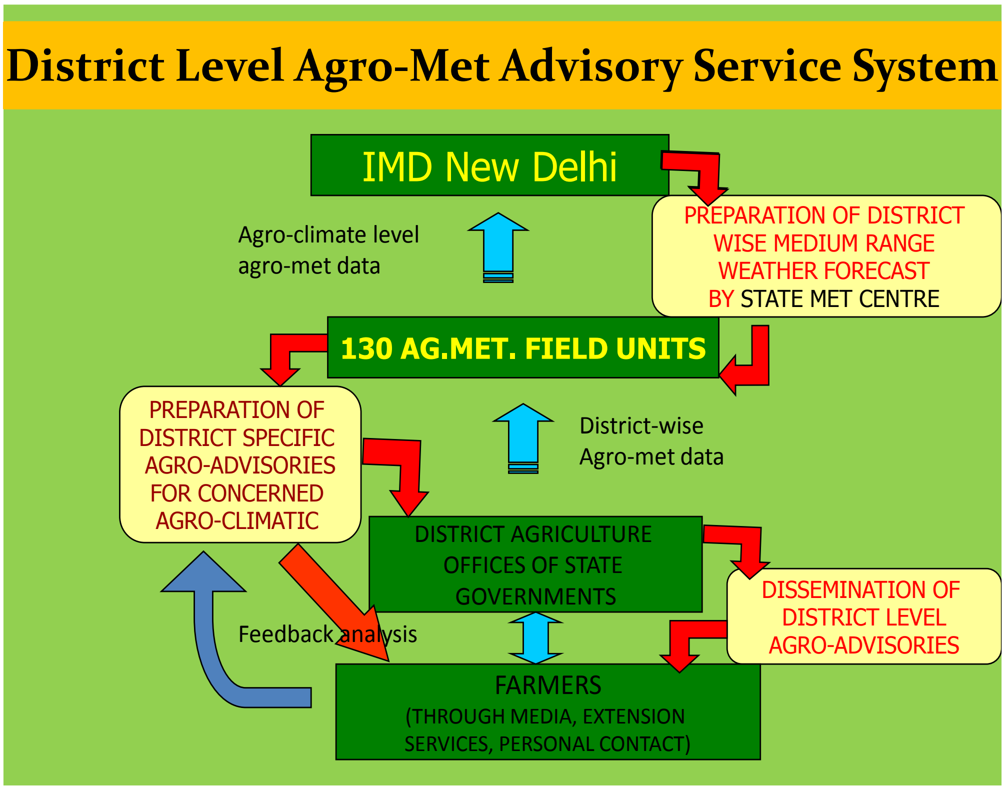
Being a multidisciplinary and multi-institutional project, AAS project is being implemented through five tier structure to set up different components of the service spectrum. It include meteorological (weather observing & forecasting), agricultural (identifying weather sensitive stress & preparing suitable advisory using weather forecast), extension (two way communication with user) and information dissemination (Media, Information Technology, Telecom) agencies.

Agro-meteorological support for farm management

Weather based farm advisories as support system has been organized after characterization of agro-climate, including length of crop growing period, moisture availability period, distribution of rainfall and evaporative demand of the regions, weather requirements of cultivars and weather sensitivity of farm input applications. All this is used as background information. Following are the ingredients of a typical Agromet Advisory Bulletin to reap benefits of benevolent weather and minimize or mitigate the impacts of adverse weather;

i. District specific weather forecast, in quantitative terms, for next 5 days for rainfall, cloud, max/min temperature, wind speed/direction and relative humidity, including forewarning of hazardous weather event likely to cause stress on standing crop and suggestions to protect the crop from them.

ii. Weather forecast based information on soil moisture status and guidance for application of irrigation, fertilizer and herbicides etc.
iii. The advisories on dates of sowing/planting and suitability of carrying out intercultural operations covering the entire crop spectrum from pre-sowing to post harvest to guide farmer in his day–today cultural operations.
iv. Weather forecast based forewarning system for major pests and diseases of principal crops and advises on plant protection measures.
v. Propagation of techniques for manipulation of crop's microclimate e.g. shading, mulching, other surface modification, shelter belt, frost protection etc. to protect crops under stressed conditions.
vi. Advisory on contingency plan under extreme weather situations.
vii. Reducing contribution of agricultural production system to global warming and environment degradation through judicious management of land, water and farm inputs, particularly pesticides, herbicides and fertilizers.
viii. Advisory for livestock on health, shelter and nutrition.



The support on above is rendered through preparing district specific agrometeorological advisory bulletins by Agro-Meteorological Field Units (AMFUs). Inter-disciplinary group of agricultural and extension specialists at AMFUs formulates weather based farm advisory bulletin. These bulletins contain location specific and crop specific farm level advisories tailored to meet the farmers' need. The bulletins are encoded in a format and language which is easy to comprehend by the farmer in his decision making processes. The agrometeorologists play a vital role in the encoding and decoding of the messages from the meteorologists to the agricultural sector. Crop weather calendars initially developed by IMD is used in preparation of weather based advisory bulletin. Recently All India Coordinated Research Project on Agrometeorology (AICRPAm) units in dfferent states coordinated by CRIDA, Hyderabad have refined these calendars including pest & disease component which is very useful in crop specific advisory preparation.

The Agro-met Advisory Bulletins are issued at district, state and national levels to cater the needs of local level to national level. The State Level bulletin is a composite of district bulletins helping to identify the distressed district of the state as well as plan the supply of appropriate farm inputs such as seeds, irrigation water, fertilizer, pesticides etc. These bulletins are jointly prepared by State Meteorological Centre of IMD and AMFUs and mainly used by State Government functionaries. National Agromet Advisory Bulletins are prepared by National Agromet Advisory Service Centre, IMD, Pune, using inputs from various states. This bulletin helps identify stress on various crops for different regions of the country and suitably incorporate advisories. Ministry of Agriculture is prime user of these bulletins, which help take important decisions in Crop Weather Watch Group (CWWG) meetings at national level. The bulletins are also used by a large number of other agencies including fertilizer, pesticide industries.

Agricultural scientists at Agrometeorological Field Units have started using water balance, crop simulation models as a decision support tool for helping with weather forecast based farm management decision making. Agro-meteorological Field unit can objectively assess the impact of skipping irrigation at a particular phenophase of a crop on its dry matter yield though with some uncertainties. Agrometeorologists can consider many of the factors involved, and answer the question with a reasonable estimate. The crop models are also being used as technique for prediction of different phenophases and final yield.

5. System of Agrometeorological Advsiory Dissemination

The task is to provide information to help farmers make the best possible use of weather and climate information (Aggarwal, 2002). Critical factors for successful dissemination include relevance of information to weather & climate sensitive decision making in agriculture, followed by good outreach and uptake at grass root level. To ensure delivery of information to the farming community, a multi-mode dissemination system for agro-meteorological advisories is essential in which beside the conventional modes (radio, television & print media), the emerging modes of communication such as mobile phones and internet are also deployed. To smarten the service through continuous up-gradation of service one needs back flow of information on quality and relevant of information or demand for specific product, hence two way communication has to be integral part of the dissemination system.

AAS has considered different aspects pertinent to the flow and content of information and accordingly evolved a strategy for dissemination of agro-meteorological information. Although concerted efforts are being made to set up two way communications, but as of now the information flow is largely one-way. Although, Agro-meteorological Field Units (AMFUs) have limited interaction with the farmers, good communication and working relationships have been set up with the agricultural extension, Krishi Vigyan Kendra (Agriculture Science Centres), Kisan (Farmer) Call

Centre etc. to promote participatory methods for interactions with farmers. Information is disseminated through multi-modes of delivery including mass and electronic media. It include, All India Radio, Television, Print Media (local news paper in different vernacular languages), internet (Web Pages) as well as group and individual relationships through email, telephone etc. The agrometeorological bulletins always contain dynamic information hence, repetitive dissemination is being made. This reiterative process also helps to address large temporal and spatial variability having significant influence of weather & climate on agriculture.

The use of electronic media such as e-mail or the Internet depend on the availability and access of these methods to the users which is picking up in India particularly through initiative of Department of Information technology, who is in the process of setting up a very strong net work of common service centres (CSC). AAS is a scalable system which can be incrementally developed and extended to cover all the farmers (crops) of India in a cost-effective manner. It enables the farmer to receive both crop and location-specific expert advice in a timely manner. With the advent of computers and Internet, emphasis is often being given to electronic communication systems. However, TV and radio services are still the best ways of communicating advisories among rural people as these are not only fast methods, but also large and illiterate masses can be contacted. Broadcasting of advisories in vernacular language provides an edge on other means of communication. Under Integrated Agromet Advisory Service (IAAS) scheme at IMD/MoES efforts are being made to strengthen the outreach of the agromet advisory as per the need of the farmers. Under the project advisories are primarily disseminated to the farmers by mass mode, outreach at village level and human face for advisory dissemination. Advisories are being disseminated to farmers through following the multi-channel system;

i. All India Radio (AIR) and Doordarshan
ii. Private TV and radio channels
iii. Newspaper
iv. Mobile phone / SMS
v. Internet
vi. Virtual Academy / Virtual Universities / NGOs
vii. Kisan Call Centres / ICAR and other related Institutes / Agricultural Universities / Extension network of State
viii. Krishi Vigyan Kendra (KVKs)

For dissemination through SMS on mobile phone, an information platform has been created which allows the existing Agromet Field Units (AMFUs) to provide the information in a convenient and timely manner. The advisories are crop and location specific and delivered within actionable time to the farmers. Under IVR system the information from AMFUs for each state are collected and then stored, and converted into voice where the farmer would be calling and receiving the desired information. IMD is sending these SMS to farmers with the help of many private and government companies. IMD has so far partnered with Reuter Market Light (RML), Handygo, NOKIA, IFFCO Kisan Sanchar Ltd. (IKSL), National Bank for Agriculture and Rural development (NABARD), Maharashtra State Agriculture Department (Government of Maharashtra) and KISAAN SMS portal. Number of farmers covered under SMS is presently 4.7 million.

6. Capacity Building

Efforts made by Ministry of Earth Sciences, India Meteorological Department (IMD), Indian Council of Agriculture Research (ICAR), State Agricultural Universities (SAUs), Union/State Departments of Agriculture and other collaborative agencies through Agrometeorological Advisory Service (AAS) have demonstrated the role of weather forecast in increasing overall preparedness of farmers, leading to substantially better outcomes overall. However, more efforts are needed to assist farmers to further develop their adaptive capacity with improved planning and better management decisions. Hence, more effective approaches to delivery of climate and weather information to farmers through participatory, cross-disciplinary approach is being carried out through enhancing awareness of information user groups. It is done through organizing farmer's awareness programs, roving seminar that brings together research and development institutions, relevant disciplines, and farmers as equal partners to reap the benefits from weather and climate knowledge. Given the current concerns with climate change and it's impacts on crop productivity, these programmes focus on need to sensitize the farmers about the increased weather variability, in their regions, and different adaptation strategies that can be considered to cope with the extreme weather situations.

Such programs help increase the interaction between the local farming communities and the Meteorological Centres (MCs), AgroMeteorological Field Units (AMFUs) and Krishi Vigyan Kendra (KVK). Considering above, a large number of such seminars are organized in different agro-climates of the country to sensitize farmers about the weather and climate information and it's applications in operational farm management. These are jointly organized by India Meteorological Department (Ministry of Earth Sciences), Indian Council of Agriculture Research and State Agricultural Universities, Local NGOs and other stake holders.

In order to develop a local (village) level rain measuring network and improve the rainfall linkage with the AAS system, 5 rain gauge made of plastic are distributed to the selected group of progressive farmers during the meeting who are trained to record and report the rainfall observation to the concerned AMFUs who in turn communicate the data to IMD. So far such programmes have been organized at the following 104 Agromet Field Units.

IMD has brought out Agromet Brochure in different languages highlighting the activities of Integrated Agromet Advisory Services for the benefit of the Indian farmers. These are circulated to the concerned organizations/institutes like Ministry of Agriculture (Central & State), Indian Council of Agricultural Research (ICAR), State Agricultural Universities, Regional Research Institutes, Krishi Vigyan Kendras, Department of Space, NGOs and all other organization directly and indirectly related to the agricultural services in the country. Besides, farmers are being aware of the service through participation of Kisan Mela, field visit, field demonstration, field day, farmer field school. During this programme farmers are explained about various services in simple components and in local language and the importance of the service, discuss with them what they already know about the skill and determine where knowledge is missing, allow the famers to record the weather observations using various weather instruments and familiarise the agro-meteorologist about the problems faced by the farming community and expectations from the service providers.

7. Crop Yield Forecasting

Reliable and timely forecast of agricultural commodity provides important and useful input for proper, foresighted and informed planning. This enables planners and decision makers to predict how much to import in case of shortfall or optionally, to export in case of surplus. It also enables government to put in place strategic contingency plans for redistribution of food during times of famine. In India, there is also growing need for micro level planning and particularly the demand for crop insurance, which increases the need for field level yield statistics. Forecasting Agricultural Output using Space, Agrometeorology and Land based observations (FASAL) involves developing econometric, remote sensing and agromet based model to generate multiple crop yield forecasts at national, state and district level starting with crop sowing to end of season for 11 major *Kharif* and *Rabi* crops viz: Rice, Jowar , Maize, Bajra, Jute, Ragi , Cotton, Sugarcane, Groundnut, Rapeseed & Mustard and Wheat.

IMD is implementing Agromet component of the scheme in coordination with 23 State Agromet Centres (SAMCs), 46 principal Agro-Met Field Units (AMFUs) and IASRI in the country to develop agromet models and issue in-season crop yield forecast based on statistical and crop simulation models. This information is shared with Mahalanobis National Crop Forecast Centre (NCFC), New Delhi.

8. Future needs and strategies:

Though Agro met Advisory service is being provided efficiently at district level in the country, still there is need to strengthen in terms of observation, seamless weather forecast, manpower, real time information flow, research and development (R&D), dissemination etc. There is need to develop methodologies for remote sensing and conventional data merging. Concerted efforts are needed for ground based data collection, satellite data collection, GIS software applications, operational applications of meteorological satellite data, weather radars and the monitoring of cropping season by meteorological and remote sensing data to equip AAS units to generate better advisories. Though district level medium range weather forecast is being prepared for agromet services, there is an urgent need to develop and issue high resolution accurate weather forecasts to help tailor crop plan for the farmers at village level. Thus there is a need to scale up the service from district to block level with dissemination up to village level across the country to meet the end user’s requirement. Such idea leads to take up the new concept of establishing the Garmin Krishi Mausam Sewa (GKMS) scheme under Integrated Agromet Advisory Services in the country during the XIIth Five Year Plan. Some of the important activities being planned under GKMS are as follows.

Seamless weather forecast

a. Block level forecast

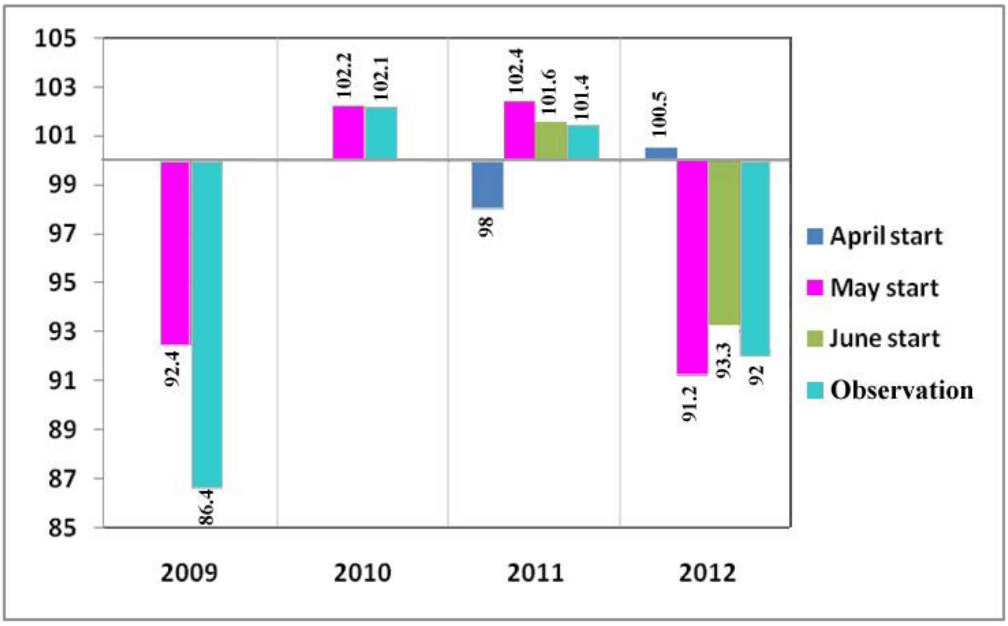
Though district level medium range weather forecast is being prepared for agromet services, there is an urgent need to prepare and issue high resolution (9 Km x 9 Km or finer using WRF model) accurate weather forecast at sub-district level. Thus it is proposed to generate block level forecast during XIIth Five Year Plan. On pilot mode block level weather forecast for the parameters like rainfall, maximum and minimum temperature, cloud amount, maximum and minimum relative humidity, wind speed and wind direction for 342 blocks in the country considering one district per state is being developed. This procedure would be followed until the bias removal techniques and high resolution (10-12Km) GCM becomes operational. Neural networks would be tried for MME forecasts and Kalman filter would be tried for maximum and minimum temperature as the bias removal techniques. As such, this forecast has been started for 37 selected districts in the country. By the end of XIIth FYP, block level forecast along with advisories will be scaled to cover the maximum districts in the country.

b. Extended Range Forecast

b.1. Under National Monsoon Mission set up by Ministry of Earth Sciences, Indian Institute of Tropical Meteorology (IITM), Pune in collaboration with IMD and National Centre for Medium Range Weather Forecasting (NCMRWF) has started experimental forecast for monsoon rainfall during next four pentads (up to 20 days) issued every week. IMD has started National Agromet Advisory bulletins based on Extended Range Weather Forecast during southwest monsoon 2013 to fulfil the needs of farmers and other users. Bulletin was prepared and issued for the next fortnight with update on every Friday. Successful implementation of this initiative would help the farmer to get more lead time to manage his weather based farm management.

b.2. In another effort entitled "Development and Application of Extended Range Forecast System (ERFS) for Climate Risk Management in Agriculture" supported by Ministry of Agriculture, Government of India, the key objectives to develop the experimental extended range test forecast from month to season scale for Indian region and its application for the development of climate risk management tools to address these risks with the involvement of agricultural scientists, farmers and service support agencies at field levels. This project integrates risk management and climate science research, involving leading institutions of India and abroad. The project adopts a very strong demonstration approach, focusing on select districts in nine states that face significant livelihood impacts due to variability in the southwest monsoon: Andhra Pradesh, Gujarat, Maharashtra, Madhya Pradesh, Orissa, Himachal Pradesh, Rajasthan, Tamil Nadu, and Uttarkhand.

These forecast products include both type of forecasts viz., deterministic as well as probabilistic forecasts. Methods used to generate the deterministic rainfall and mean temperature forecast include Singular Value Decomposition (SVD) based Regression, Supervised Principal Component Regression, Canonical Correlation Analyses. In these regression techniques, predictors (independent variables) are different general circulation models' rainfall and temperature products while the predictand (dependent variables) is IMD rainfall and temperature. All these above stated forecasts were combined using some statistical techniques and has been converted in probabilistic forecast to see the chance of occurrence of particular event. Probabilistic forecast is made in three categories viz. Below Normal, Near Normal and above normal. These categories are based on the previous year's observed data set (IMD's gridded data). The experimental forecast products thus generated since monsoon 2009 were disseminated to all the selected demonstration sites through IMD for its verification and application purposes. The performance of experimental test forecast products were evaluated at each selected pilot demonstration sites with the observed data of temperature and rainfall during the month. Performance of real time experimental forecast for summer monsoon seasonal rainfall (JJAS) is shown in the figure:



Climatic Risk Management

The idea of informed decision making at farm/ farming system level gains more reality if integrated with reliable seamless weather forecast during crop season. Crop simulation models and DSS are being increasingly used in decision making for risk minimization in agriculture. These models need daily weather data for crop season. The major challenge in linking seasonal forecast to crop model is mismatch between spatio-temporal scale of forecast and crop model. On the one hand, these forecasts are available at bigger spatial domain for a month or season and on the other, crop simulation models can be run at point scale or smaller grid space. Forecast needs to be downscaled spatially and temporally. Crop model based generated viable management options against a given forecast require frequent validation through farmers participatory meetings. In order to make use of extended range forecast for decision making on strategic agriculture planning and risk management and integrate with ongoing advisory service system, a range of climatic risk management tools were developed.

1. Extended/ seasonal climate forecast.
2. Climatic risk matrices: Climate risk analysis for crop under various farming situations showing the impact of soil (type and depth), time of planting and weather requirement and extremes at various phenopahese. Abiotic stresses are quantified.
3. Stochastic Weather generator: Downscaling can be achieved by linking a seasonal forecast with a weather generator. Nonhomogeneous hidden Markov model (NHMM) or HMM are used as a promising approach to constructing multi-station weather generators. A number of weather realizations is made.

4. Crop simulation model and Decision support system: Crop models embedded in Decision Support System for Agro-technology Transfer (DSSAT), InfoCrop, APSIM etc. are a process-oriented, management-level model of crop growth and development and can be linked to daily sequence of desegregated weather data to generate crop growth performance against number of weather realizations.
5. Farmers participatory meeting: A very critical process to validate/refine the above findings as viable options for farm management.

Pilot study demonstrated use of monthly forecast on rainfall and temperature by establishing an end-to-end information generation and application. This was implemented with participation of agricultural universities/research centers, service support agencies at field levels and farmers for better crop planning and management in the following areas:

- Land preparation
- Nursery raising
- Irrigation scheduling
- Urea application to rainfed crops in normal rain forecast
- Frequent intercultural operation to conserve soil moisture
- Contingency plan under delayed monsoon onset rains
- Temperate apple crops- Chilling hours to help skip hormonal spray for bud breaking/ flower setting
- Nomadic farming hills- sheep, goat
- Livestock- malnutrition and disease infection under deficit rainfall

Future plan includes the integration of ERFS experimental system in IMD for its operationalization, generation of seamless weather forecast for agriculture risk management, expand to all parts of the country and R&D for continuous improvement in weather forecast products at fortnightly to monthly scale.

eAgromet system

As there is a need to develop a computer-based decision support system and to automate the process of advisory bulletin preparation and dissemination, IMD in collaboration with IIIT, Hyderabad is generating a software for preparation of advisory bulletin under the scheme "IT-based eAgromet software for automated AAS bulletin preparation" to prepare district/block level AAS bulletins. It simplifies the preparation of district level AAS bulletin as it acts as an organizing tool for weather forecasts and agromet advisories with the help of repository of past AAS bulletins. A server has been launched by IIIT for the said purpose. Number of AMFU scientists has already been trained and remaining AMFU scientists will be trained in utilization of the software and it will be implemented in GKMS.

Smart Dissemination System

IMD in collaboration with National Remote Sensing Centre (NRSC) is planning to use geoportal 'BHUVAN' to establish direct (virtual) interaction between farmers and the scientists to solve the field specific problems on real time basis by generating customized advisory and thus to minimize risk factor at farm level. Registered farmers raise queries and upload the crop images on operational farm activities to get specific advice. As geoportal is GPS enabled, this will help to get the location specific feedback from the farmers as well as status of the crops, which will enhance the ability of the scientists to prepare agromet advisories more customized to individual's need. Also BHUVAN portal will provide a plateform for the dissemination of the existing and proposed agrometeorological products over a wide area and for a large number of users.

Use of satellite data to derive new product including alerts

The regular and national scale agrometeorological monitoring of the physiological processes and growth indicators require retrieval of basic land surface variables using spatial observations from the suit of current and future Indian geostationary satellite sensors. Satellite based agrometeorological products and the interpretation of the same in terms of crop and soil moisture status will help the experts to address spatial variability in framing the advisories and ultimately improve the quality of the advisories at higher resolution. A number of new products for agromet services are being generated recently. IMD in collaboration with Space Application Centre (SAC), Ahmedabad is using the Normalised Difference Vegetation Index (NDVI), derived from INSAT 3A CCD data, for agromet advisories. IMD is developing the softwares "Operationalization of Satellite Data Based Soil Moisture Monitoring System in India" in collaboration with IIT, Roorkee and "Determination of Soil Moisture over India using Space Borne Passive Microwave Sensors on board SMOS" in collaboration with ICRS, Jodhpur. Soil moisture data generated using this software will be used in water balance, irrigation scheduling and determination of sowing dates etc. for AAS. Besides, it is proposed to generate a number of satellite products in preparation of agromet advisories including alerts to the farmers with respects to extreme weather.

Activities under CREAM and R&D related to weather and climate

Climate induced vulnerability of agriculture cause plateau in agriculture productivity in the country in recent past. Projected climate change can influence pest and disease dynamics resulting in crop losses. An improved adaptation strategy, particularly in the Rainfed areas where climate variability is large, holds the key to improving food production for the growing population in India. It is important to address the climatic risk in agriculture which requires development of risk management tools and their integration in GKMS. A Cell for Research and Excellence in Agriculture Meteorology (CREAM) is proposed to be established at IMD New Delhi interfacing with IARI New Delhi for irrigated farming and CRIDA, Hyderabad for dry land farming. CREAM will attempt to channelize/operationalise the R&D work for climate risk mitigation in the farming sector in India and also help in RA-II region under WMO as Agromet Advisory Service of IMD is well recognized by world community. R&D work projected under CREAM will synergize with the relevant programme/activities of CRIDA (AICRPAM and NICRA) for agricultural research programmes. Its objective includes (i) to develop climatic risk management tools, (ii) to help farmers cope with climate risks and uncertainties (iii) to help reduce the vulnerability of agroecosystems to climate variability and change, (iv) to help achieve greater efficiency in natural resource use in agriculture, (v) to establish a World Class Training Programme in Agricultural Meteorology, (vi) to organize periodic Symposia/Conferences on Agrometeorological Research and Applications.

Economic impact assessment

Impact assessment framework made by National Centre for Agricultural Economics and Policy Research (NCAP) was adapted to assess economic impact by taking field experiments conducted from 2003-2007 at 15 locations spread in country covering filed crops, vegetables and horticulture (Rathore and Maini, 2008). Forecast based agro-advisories were issued by NCMRWF to AAS users. An objective comparison between AAS and non AAS farmers at village level shows that impact depends on the risk taking ability of farmers. In quantitative terms, study reports that the AAS farmers were able to reduce the cost of cultivation by 2-5% except in case of fruits where the cost of cultivation has increased by 5-10%. This shows that the right selection of fertilizers and seed due to organization of awareness programme in the village and spraying of appropriate pesticide due to advisory 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.

National Council of Applied Economic Research (NCAER), an independent agency, during 2009-2010 estimated that the economic benefit from the use of weather information as the product of the percentage of farmers receiving information, scenario-wise, times the percentage of farmers benefiting from the information times average profit, crop-wise, attributable to weather information times the total national production of crops. Conversion factors, crop-wise, were used to convert farmers' financial profits to economic profits (NCAER, 2010), At present only 10 to 15 percent of the farmers are benefitting from the SMS services. The economic profit estimates vary between Rs. 50,000 crore (where currently 24 percent farmers receive weather information by all means) to Rs. 211,000 crore (where all farmers receive weather information).

In order to judge worthiness and role of the agromet service in improving the agricultural production system and farm management, its economic impact will be assessed through conducting extensive feedback surveys as guided by an independent agency. Studies will be undertaken at different representative sites covering principal crops. The study will be made comprising of *kharif* (monsoon) and *rabi* (winter) crop seasons including livestock. The objective of the studies will be to observe whether weather based advisories have a positive impact on the overall yield and also help in reducing the cost of cultivation.

Gramin Rainfall Monitoring Mission (GRaMM)

IMD with help of other govt. organizations is planning to monitor the rainfall at village level in India by creating network of manual rainguages under the project called GRaMM (Gramin Rainfall Monitoring Mission). Village Panchayat office will be involved in this project for upkeep, measurement and communication of rainfall every day. This village level raingauge network in future will facilitate the existing gridded data modelling framework to process and create the spatial continuous rainfall grids at every kilometre or even finer scale.

Rainfall Visualizer Tool

Rainfall visulaizer is a simple tool developed under ACCA project operating Telangana region of Andhra Pradesh which enables the farmers to track the village level rainfall situation of current season in comparison with previous years rainfall. By entering the current year's daily rainfall data farmers can observe the three curves which depicts current season rainfall progressing curve compared to the wet, dry and last year's rainfall. They can easily understand the value of comparing the present rainfall situation with the good, bad and normal situations from the point of view of learning from their own past experience. For them it can be a useful tool to discuss the current situation and regulate their actions based on their past experience. The Visualizer provides the farmers a tool to track the current rainfall to know which particular trend (good, bad, or normal) it was most likely to follow. This in turn would help them to decide on their irrigation, fertilizer and pesticide application planning in the current season as well as prepare them for the rabi season. The tool would help them especially in deciding the number of irrigations that may be required so that in times of water shortage the farmers could save water for critical irrigation.

References

Aggarwal, P.K., 2002. Climate Change and Agriculture: Information Needs and Research Priorities. International Conference on Capacity Building for Climate Change 21 October 2002. www.ficci.com/media-room/speeches-presentations/2002/oct/oct-climate-aggarwal.ppt

Kanamitsu M., A. Kumar, H Ming, H. Jung, J. Kyung, W.I Wang, F Yang, S. Hong, P. Peng, W. Chen, S. Moorthi and M. Ji: 2002, NCEP Dynamical forecast System 2000., *Bull. Amer. Meteor.Soc.*,***83***, 1019- 1037.

National Council of Applied Economic Research (NCAER). 2010. Impact assessment and economic benefits of weather and marine services. Supported by Ministry of Earth Sciences, New Delhi.

Rathore, L.S. and Parvinder Maini. 2008. Report on Economic impact assessment of agrometeorological advisory service of NCMRWF. Ministry of Earth Sciences, New Delhi