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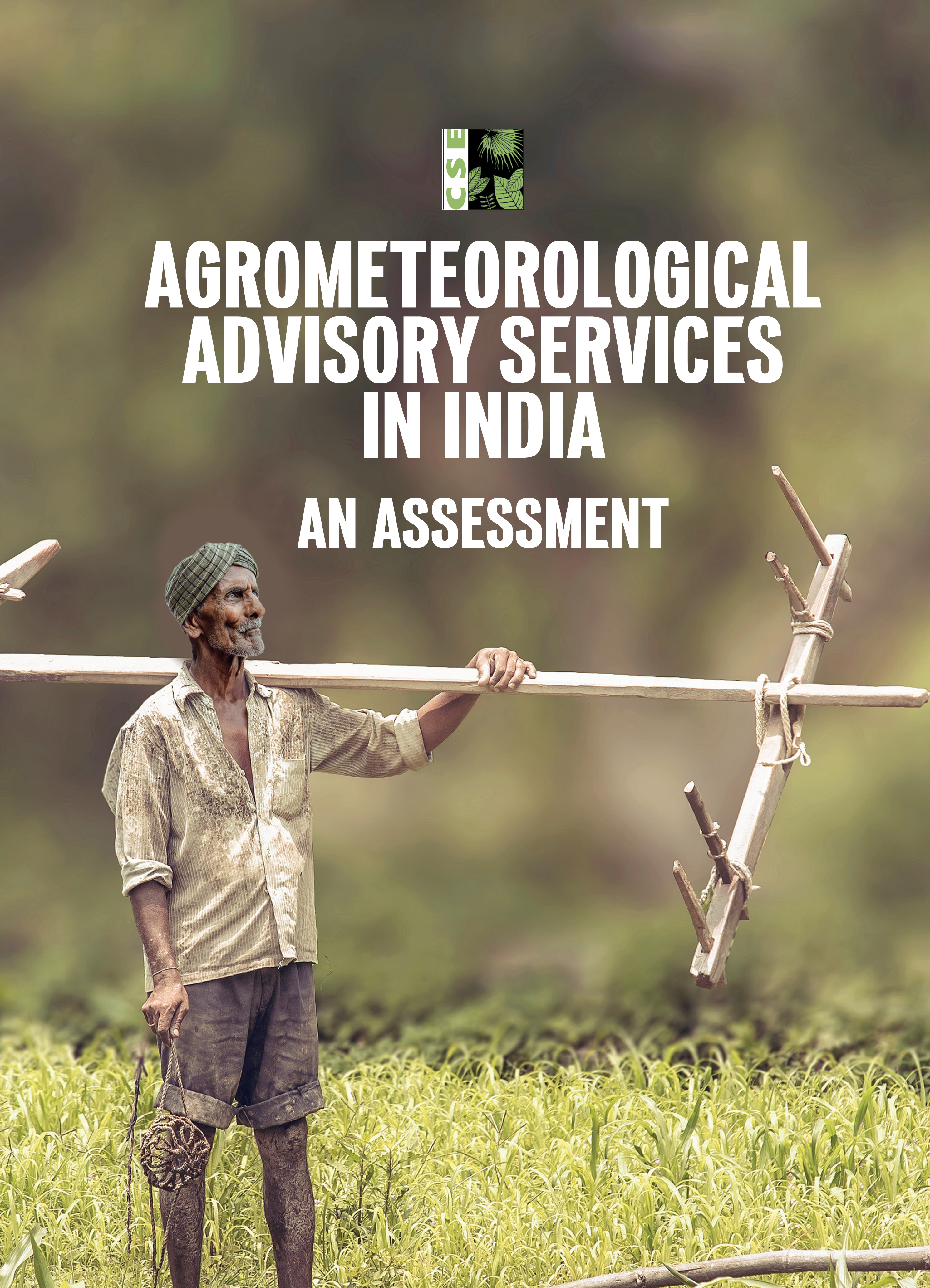
AGROMETEOROLOGICAL ADVISORY SERVICES IN INDIA

AN ASSESSMENT



AGROMETEOROLOGICAL ADVISORY SERVICES IN INDIA

AN ASSESSMENT

Centre for Science and Environment

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1. Background

1.1 Climate change impacts in India

The agricultural sector is the foundation of the Indian economy. It employs more than 50 per cent of India's workforce and contributes almost 17–18 per cent of its GDP.[1] At present, agricultural livelihoods are being severely impacted world over as a result of anthropogenic global warming and climate change. India's labour-intensive and subsistence-based agriculture sector is particularly vulnerable to this development.

Climate change has both direct and indirect effects on agricultural productivity, including changing rainfall patterns, severe drought, flooding and changes in the geographical redistribution of pests and diseases.[2] These impacts are highly unevenly distributed across the globe, with regions like South Asia (including India) and sub-Saharan Africa experiencing significantly more adverse effects than North America, Europe (particularly Eastern Europe) and South America.[3]

The expected decrease in agricultural production due to climate change is, following West Africa, most pronounced in India, with an anticipated decrease of 2.6 per cent by 2050, relative to a 2011 baseline. Food consumer prices are expected to rise by 4.6 per cent and food purchasing power is anticipated to decline by 6.2 per cent, with poor rural households hardest hit.[4] These climate changed-induced stresses are already playing their part—witness the unconscionable numbers of Indian farmers who have turned to suicide over the last three decades.[5]

India experiences a variety of climate risks, which are unevenly distributed within the country. These include (i) abiotic stresses such as floods, droughts, and extreme temperatures and, (ii) biotic stresses such as pests and diseases.

1.1.1 Abiotic stresses

a) Floods

Seasonal rainfall is on an increasing trend in the western coast, northwest India and northern Andhra Pradesh.[6] However, the trend is not evenly spread across the season; there are sharp spikes in short periods of time that make for extreme weather events rather than an agricultural boon.[7] Heavy rains also increase biotic stresses, particularly the likelihood of disease infestation.[8]

According to the Central Water Commission (CWC), over a period of 64 years (1953–2017), more than one lakh people have died as a result of floods and damage to crops in India.[9] The average annual loss India experiences as a result of floods is close to US $7.4 billion.[10] In 2018, Kerala experienced its worst monsoon flooding in a century as a result of unprecedented heavy rainfall. The floods caused losses of around US $4.25 billion, claimed hundreds of lives and displaced lakhs.[11] Farmers lost their entire year of crops, amounting to Rs 8 lakh crore, which is 20 per cent of Kerala's state GDP.[12]

b) Droughts

There has also been an increasing trend in the severity and frequency of drought across India.[13] Around 68 per cent of India's agricultural land is drought vulnerable.[14] In particular, there has been a decreasing trend in seasonal precipitation in parts of Gujarat, northeast India, Kerala and Madhya Pradesh.[15]

In 2016, around 33 crore people across 10 Indian states were affected by drought, contributing to almost Rs 6.5 lakh crore of economic loss in the country.[16, 17] The same year, Maharashtra faced the worst drought in almost half a century, with millions of families losing their crops and suffering from severe water shortages over months.[18] It is estimated that the drought caused the state's agriculture sector to decline by 2.7 per cent.[19]

c) Extreme temperatures
The average annual temperature in India has been on an increasing trend. While high temperatures can positively affect some crops, it destroys others. It is anticipated that with every 1°C rise in temperature during the growing period, there will be a decline of 4–5 million tonnes of wheat production in India. The same increase in temperature would see rice production decline by 10 per cent.[20] An estimated 75 million hours of work were lost in the country due to extreme heat in 2017—over 80 per cent of those losses were from the agriculture sector.[21]

d) Cyclones
The states of Andhra Pradesh, Telangana, Odisha, Tamil Nadu, West Bengal and Gujarat are the most prone to tropical cyclone disasters in the country. The eastern coast of India is more prone to cyclones than the west.[22] Cyclones can have a severe impact on agriculture, with the potential to destroy produce if adequate measures are not taken. In 2018, Cyclone Gaja destroyed nearly 1 crore coconut trees and affected at least 70,000 coconut farmers in Tamil Nadu.[23] The same cyclone damaged around 20,000 acres of banana plantation, causing losses worth Rs 500 crore.[24]

1.1.2 Biotic stresses
Biotic stress is defined as stress from damage by pests and plant diseases. There is an increasing consensus in the scientific community that rising abiotic stresses will exacerbate biotic stresses, including increased crop susceptibility to diseases and an increased prevalence of diseases, pests and parasites.[25] In India, a 2°C warmer world would exacerbate annual rice-crop losses due to pests and diseases by around 2 points (from 18 per cent to 20 per cent), and annual wheat crop losses by around 1.5 points (from 7 per cent to 8 per cent).[26] This is over and above the yield losses expected from abiotic stresses.

1.2 Agrometeorological services

Agrometeorology is the study and use of weather and climate information to improve the productivity of the agricultural sector.[27] For years, farmers have adapted to climatic changes with local and available knowledge, relying on some level of seasonal and climatic predictability. However, the current rate of climate change is overwhelming their traditional capacities, resulting in an increasing demand for effective and timely agrometeorological information and services.

By international agreement through the World Meteorological Organization, national weather, climate and water services are under governmental authority and responsibility. The governmental bodies responsible for such services are generally known as National Meteorological and Hydrological Services (NMHS), or National Meteorological Services (NMS).[28]

In India, the NMHS is the Indian Meteorological Department (IMD) under the Ministry of Earth Sciences (MoES), which is tasked with providing India's meteorological services. It does so through the Agrometeorological Advisory Service (AAS), created in 1988 (and currently housed in the IMD's Agrimet Division).[29,30]

This paper aims at assessing the challenges in providing agromet services to farmers in India, with a focus on subsistence farming. It is structured around the three sub-sectors which work together to provide such services:
(i) Weather forecasting;
(ii) Generation of agromet advisories; and
(iii) Dissemination of advisories.

Each of the first three sections analyses how a particular sub-sector is structured, with a final section on the key challenges facing each sub-sector. To build this understanding, we combined literature review with semi-structured interviews (over phone and in person) of government officials, representatives of private companies, research institutions and NGOs, as well as farmers covered by an international aid-supported project in Payal tehsil (Ludhiana, Punjab).

2. Weather forecasting

The effort to predict weather involves two components—data collection and modelling. Data about weather is collected over land surfaces (rain gauges, weather stations etc.), oceans (weather buoys), in the lower atmosphere (weather balloons and sensors on airplanes), and from space (satellites).

None of these technologies are substitutes for another. In general, weather stations and gauges record local weather, radar and upper-air sensors record regional weather, and satellites record global weather. Predicting the weather at any point involves understanding of regional and global weather patterns; hence, local weather forecasting has to be based on data from all of these technologies. Radar and satellite data is not fine-grained enough to pinpoint the weather in one farm or village; hence, observations from these sources need to be 'ground-truthed' based on observations from point data.[31]

Collected data is input into software programs that are equipped with equations describing the relationship between different weather parameters, especially their relationship over time. Through processing large amounts of historical weather data, these programmes are able to quantify the relationships between parameters. A collection of such quantified relationships is known as a numerical weather model.

The process of using historical data to enable the software to measure the relationships is known as 'training the model'. When current or real-time weather data is fed into a trained model, it can provide an estimate of the weather in the future—a forecast. A climate model is a specialized weather model that generates predictions over large geographical and time scales.

Building robust forecasts involves investing in both these components. The quality of data collected depends on the numbers, technological quality and maintenance of weather stations, buoys, radar, satellites and other data collection points. The quality of modelling depends on the sophistication of the software used, and the availability of super-computing power.

2.1 Public sector: Weather data collection network

2.1.1 The land-based observation network

The Indian Meteorological Department is an agency of the Ministry of Earth Sciences of the Government of India. Headquartered in Delhi (with regional offices in Mumbai, Kolkata, Nagpur and Pune), it is the principal civilian agency responsible for meteorological observations, weather forecasting and seismology.

The IMD operates approximately 1,400 automatic rain gauges (ARGs) and 700 automatic weather stations (AWSs) in the country.[32] ARGs collect data only on rainfall, with around 500 of the 1,400 equipped with additional sensors for temperature and humidity.[33] AWSs collect data on wind direction, wind speed, atmospheric pressure and solar radiation (in addition to data on rainfall, temperature and humidity).[34]

Some of the AWSs are additionally equipped to collect data on soil temperature, soil moisture, leaf temperature and leaf wetness. These are known as Agro-AWSs or agromet observatories. Apart from these, there is a network of observatories collecting weather data which is particularly relevant to agriculture—evaporation stations, evapotranspiration stations, soil moisture recording stations and dew fall recording stations.

Table: Central government's automatic data collection network

Type of equipment	Number
Automatic rain gauge	1,400
Automatic weather station (AWS)	700 (out of which 260 are 'agro-AWSs') [35, 36]
Evaporation stations	219[37]
Evapotranspiration stations	42[37]
Soil moisture recording stations	43[37]
Dew fall recording stations	76[37]
Doppler weather radars	25 (currently expanding to 55) [38, 39]
Upper air observational network	62 pilot balloon observation points 39 radiosonde observation points[40]
Lightning sensors (Indian Institute of Tropical Meteorology)	48 (to be expanded to over 65) [46, 47]

The IMD also operates Doppler Weather Radars (DWRs), which provide data about spatial distribution and type of precipitation, each over a 250 km radius, as well as an upper air observational network.

The government is currently in the latter stages of a modernization drive in data collection, which began around 2006–07. This is aimed at augmenting and upgrading on the earlier manual data collection systems.[41] For data collection on land, the plan was to have an AWS and two ARGs in each district.[42] There are currently 723 districts in India, so this goal is close to being realized.[43]

Recently announced expansions of the land-based observation network have focused on placing observatories in sensitive and remote zones (such as islands and the Himalayas), deepening the network in urban centres, and ensuring that all districts are covered.[44] Over the next two years, 400 new AWSs, 200 new ARGs and 30 new DWRs are planned to be added.[45]

In addition, the Ministry of Earth Sciences (through one of its research wings, the Indian Institute of Tropical Meteorology) has initiated establishment of a Lightning Location Network, which begun with 20 land-based lightning sensors in Maharashtra[46] and has currently expanded to 48 through the country. A further 20 are planned to be added this year.[47]

2.1.2 The ocean observation network

The Ministry of Earth Sciences deploys a wide range of ocean observation systems in different parts of the Indian Ocean, including moored buoys, drifters, current meters, wave rider buoys, cargo floats, tide gauges, coastal radars, and Acoustic Doppler Current Profilers (ADCP) (both drifting and moored).[48]

The ocean observing systems are primarily deployed, operated and maintained by four organizations, viz. National Institute of Ocean Technology (NIOT), Chennai; National Institute of Oceanography (NIO), Goa; Indian National Centre for Ocean Information Services (INCOIS), Hyderabad; and Survey of India, Dehradun. All the systems except tide gauges and coastal radar are deployed within India's Exclusive Economic Zone, outside jurisdiction of coastal states/UTs of India.[49]

Type of platform	Target	Commissioned (till June 2017)
Cargo floats	200	291
Drifters	150	103
Moored buoys	16	19
Tide gauges	36	34
Coastal radars	10	10
Current meter array	10	11
Acoustic Doppler Current Profiler (ADCP)	20	21
Tsunami buoys	7	9
Wave rider buoy	16	16

A key component of this network is the moored buoy array; in particular, the Research Moored Array for African–Asian–Australian Monsoon Analysis and Prediction (RAMA) located in the north Indian Ocean. The array collects data across 76 parameters focusing on the dynamics of air–sea interactions and ocean circulation, which informs our understanding of the Indian Ocean's role in the monsoon and formation of cyclones.[50]

2.1.3 The satellite observation network

The Indian Space Research Organization (ISRO) operates at least five meteorological satellites—Kalpana-1, INSAT-3A, INSAT-3D, INSAT-3DR, and Megha-Tropiques (the latter in collaboration with the French space agency).[51]

Extreme weather	IMD forecast available	Key data and data source
Cyclone	Included in country-wide daily weather-warning bulletin, with track and intensity forecast (six hours to five-day lead time)	Data: Wind, rainfall intensity, ocean-atmosphere interaction Source: Weather buoys, ships and airplanes, satellites.
Thunderstorm	Included in country-wide daily weather-warning bulletin (for coming week); Nowcast based on location to be initiated in 2019 (with few hours lead time)	Data: Precipitation, cloud formation Source: Radar, lightning sensors, satellites
Heatwave	Country-wide heatwave warning bulletin issued, as needed (five-day lead time)	Data: Temperature, particularly maximums and minimums Source: Weather stations
Drought	Country-wide weekly drought outlook; weekly, bi-weekly and monthly aridity maps through the monsoon season	Data: Rainfall, evapotranspiration, soil moisture Source: Agromet observatories
Hailstorm	Included in country-wide weather warning bulletin (five-day lead time); to be included in all-India thunderstorm Nowcast (few hours lead time)	Data: Precipitation, temperature, wind-speed, dew point Source: Radar, upper air observatories
Dust-storm	Included in country-wide weather warning bulletin (five-day lead time)	Data: Temperature, wind speed, humidity, evaporation, soil moisture Source: Agromet observatories

The INSAT series of satellites are equipped with Very High Resolution Radiometers (VHRR), and provide data on cloud motion vectors, cloud top temperature, water vapour content etc., which enable estimation of precipitation and weather forecasting.They are particularly useful in monitoring and predicting the track of cyclones.

The Megha Tropiques is equipped with four key systems supplied by or developed collaboratively with the French space studies agency CNES—an imaging radiometer, an atmospheric humidity sounder, a radiometer, and a radio occultation sensor—to record radiation, atmospheric temperature and atmospheric humidity. The mission aims to use this data to understand the water cycle and energy exchanges in the tropics in the context of climate change.[52]

2.1.4 State-level network

Some states have developed denser networks of land-based observatories. The Karnataka State Disaster Monitoring Centre, for example, has a plan to install automatic rain gauges in each of its approximately 6,500 gram panchayats and automatic weather stations in each of approximately 750 hoblis (an administrative classification of the state government comprising a cluster of adjoining villages).[53] The state currently has at least 2,700 ARGs installed and commissioned,[54] as well as approximately 1,300 AWSs.[55]

Tamil Nadu initiated an expansion of its network in 2008, with a plan to install an AWS in each of 224 blocks, as well as 100 ARGs.[56] It has since expanded the AWS network to cover all of its 385 blocks. Each AWS collects data on 10 parameters, including soil temperature and moisture and leaf wetness (effectively making them agromet observatories).[57]

Uttarakhand, Maharashtra and Odisha have announced plans to develop their own state-wide weather networks in the more recent past. Uttarakhand seeks an AWS in every panchayat,[58] Odisha plans to set up 6,500 ARGs and AWSs through the state,[59] and Maharashtra has commissioned an AWS for each of its 2,060 revenue circles (in partnership with Skymet, a private company).[60]

The state-level networks are developing very unevenly (see *Annexure: State-wise distribution of automatic weather stations and rain gauges*). Besides, coordination between the Central and state-level networks is mixed.

For example, Tamil Nadu's explicitly stated reason for expanding its own network was that data was not readily available from the then existing IMD automatic weather stations. Representatives of Nagaland's Disaster Management Authority say that they share data from their privately built network with the IMD, but that the IMD does not generate much data specific to the state.[61]

The IMD now makes AWS data publicly available on its website. However, its use of data from the rapidly expanding state-level network is still limited. Meteorologists at the IMD and the National Centre for Medium Range Weather Forecasting (NCMRWF) repeatedly emphasized that the network that they relied upon to generate their forecasts and advisories is the approximately 700 automatic weather stations and 1,400 automatic rain gauges which are directly under the IMD's control, and satellite data.

This may partly be because the reliance on the private sector by some states (like Maharashtra) is causing its own problems for integration of the national weather data collection network. We discuss this in our concluding analysis of gaps in weather data collection and forecasting

2.2 Public sector: Numerical weather modelling capabilities

2.2.1 Currently operational models

The IMD operates multiple models focused on generating forecasts for weather phenomena over land.[62] They are distinguished by their horizontal and vertical resolution, and their lead time. The resolution is the number of grid cells within the forecast—more cells generally mean greater precision. The lead time is the length of time between the issuance of a forecast and the occurrence of the phenomena that were predicted.

The Global Forecast System (GFS) is a global-scale model that was originally developed by the US National Centre for Environmental Prediction (NCEP). The version implemented by the IMD (T1534) provides forecasts at a resolution of approximately 12 km in the horizontal, with 64 layers in the vertical, and a lead-time of up to ten days.[63]

At the meso scale, the IMD uses the Weather Research and Forecasting (WRF) Model, developed jointly by several US government agencies. The model generates forecasts at a 9 km horizontal resolution, with 38 layers in the vertical, and a lead time of up to three days.[64] The IMD has recently operationalized a variant with a horizontal resolution of 3 km.[65]

The IMD uses the Global Ensemble Forecast System (GEFS) developed in the US to address uncertainty in weather observations. Ensemble forecasting is a technique which generates a number of individual forecasts, each with slightly different initial conditions, and uses the resulting set of forecasts to give a range of possible future states of the atmosphere. The GEFS generates a 21-member ensemble. The GEFS-T574 variant used by the IMD was (until recently) run at a resolution of 33–35 km on the horizontal, with 64 layers in the vertical, and a forecast length of up to eight days.[66] The horizontal resolution was upgraded to 12 km in June 2018.[67]

The IMD's Extended Range Forecast (ERF) System is an effort to generate useful forecasts for a multi-week lead time. The system is a suite of models run at different resolutions, and with different initial atmospheric and oceanic conditions. It is based on the Climate Forecast System (CFS) model developed by the US National Centres for Environmental Prediction, which is a medium- to long-range model designed to bridge weather and climate timescales. The ERF System runs the CFS model, as well as a bias-corrected variant of the CFS model, at a 38 km and a 100 km horizontal resolution (this totals up to a set of four model runs). This set is used to generate a probabilistic forecast for the next four weeks.[68]

The same CFS model can also be the basis for 'seasonal' forecasts, with a lead time of longer than a month.[69] However, the accuracy of such forecasts is currently deep in doubt; technocrats within the forecasting space have gone on record that such products are still in 'research mode',[70] and can be used by policymakers but are not meant to be used by farmers.[71]

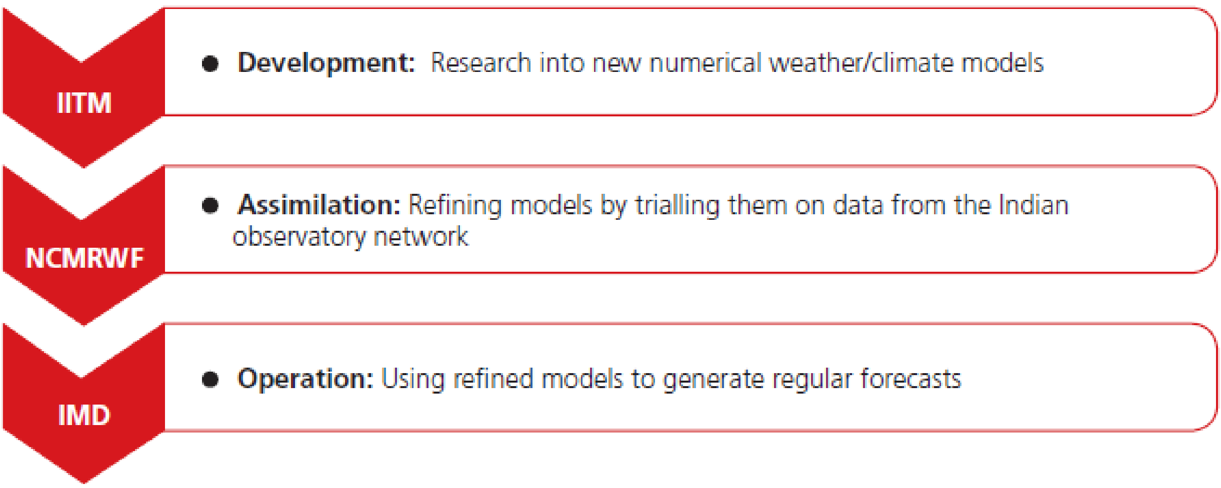
For agromet services, the IMD has been issuing rainfall, maximum and minimum temperature, relative humidity, surface wind and cloud cover forecasts with a five-day lead time at the district level since June 2008. These are generated through a multi-model ensemble (MME) system combining model outputs from five the National Centre for Medium Range Weather Forecasting (NCMRWF T-254), the European Centre for Medium Range Weather Forecasting (ECMWF T-799), the Japan Meteorological Agency (JMA T-959), the United Kingdom Meteorological Office (UKMO), and the National Centre for Environmental Prediction Global Forecast\System (NCEP GFS T-382).[72]

In addition to these models, the IMD also runs models specific to cyclones and hurricanes with a variety of horizontal and vertical resolutions. These are used to generate forecasts with a lead time ranging from hours (Nowcast) to days (short range).[73]

2.2.2 Models nearing operational use

The IMD's forecasts are based on models developed or adapted by the Indian Institute of Tropical Meteorology (IITM), and tested by the National Centre for Medium Range Weather Forecasting (NCMRWF).[74] All these institutions fall under the Ministry of Earth Sciences. The division of labour between them is roughly described by *Figure 1: Division of labour in Indian numerical weather modelling*, although there is continuous collaboration between them across these broad functions.

Figure 1: Division of labour in Indian numerical weather modelling



The NCMRWF is currently running one deterministic and one probabilistic model, both of which will likely (depending on performance) be handed over to the IMD for operational use soon. The deterministic model is the NCMRWF Unified Model (NCUM), which is able to better assimilate more satellite observations, and is more refined than previous models in its treatment of the radiative transfer of electromagnetic radiation through the earth's atmosphere. It runs at a horizontal resolution of 12 km and generates forecasts for a lead time of ten days.[75]

The NCMRWF Ensemble Prediction System (NEPS) is a global medium-range probabilistic forecasting system adapted from a model used by the UK MET Office. The most recent version used by the Centre prepares ten-day forecasts at a 12 km horizontal resolution, with 70 vertical levels.[76]

2.3 Private sector

There are a few private players in the weather forecasting space in India. The most widely known of these is Skymet, a Noida-based company established in 2003. Skymet operates approximately 6,500 Automatic Weather Stations, concentrated in north and west India.[77] It generates its forecasts based on proprietary numerical weather prediction models, developed in collaboration with the American National Centres for Environmental Prediction (NCEP) and statistically tailored to Indian conditions.[78] It operates based on multiple business models, including:

- Selling weather data from its network to other private players, especially crop insurance companie;[79]
- Contracting with state governments to set up weather stations (such as in Maharashtra);[80] and
- Collaborating with aid agencies to set up data collection and weather advisory pilot projects (such as its collaboration with USAID in Punjab);[81]

The National Collateral Management Services Limited (NCMSL) was launched in 2004 with the support of several public sector banks and the National Commodities and Derivatives Exchange. It initially focused on providing farmers with warehousing and certificates of crop quality to enable them to obtain low-interest credit from banks. The introduction of the Central government's crop insurance scheme caused it to diversify into setting up automatic weather stations.[82] It operates around 3,200 stations across 184 districts in 16 states, collecting data on temperature, rainfall, dew point, wind direction, wind speed, relative humidity and atmospheric pressure. The company prefers to complement the IMD's network, setting up stations where the IMD does not have an existing one.[83]

Other companies prominent in this space include the Kanpur-based Weather Risk Management Services (WRCS) (and its sister company Ingen), as well as global information technology conglomerate IBM (which acquired Atlanta-based The Weather Company in 2016). WRCS-Ingen operates an India-wide network of hundreds of automatic weather stations and generates forecasts based on the WRF model with a lead time of six days and a horizontal resolution of 3 km. It sells localized weather data to companies, helps compute weather-based insurance packages for farmers, and calculates risk to crops from weather anomalies.[84]

IBM-TWC does not operate weather stations in India. It uses its Weather Underground platform to crowdsource weather station data from its corporate clients (132 such stations are in India). The data is owned by the company/individual who owns the automatic weather station. Data owners can share their data with IBM on an online platform, in exchange for which they can access data from other weather stations, as well as IBM's services built on this network of data.[85] IBM similarly uses its Weather Channel smartphone app to crowdsource weather data from smartphone users, and its partnership with aviation data/software services company FlightAware to source weather data from airplane sensors.[86]

In collaboration with the American National Centre for Atmospheric Research, it has developed the Global High-Resolution Atmospheric Forecasting (GRAF) System, which is likely to be commercially available sometime in 2019. GRAF is an 'hourly-updating weather system' which operates at a resolution of 3 sq. km (potentially down-scalable to 500 sq. m, which compares favourably to existing global models which generally max out at 12 sq. km).[87]

The company uses this proprietary model, as well as models used by the US National Weather Service, the UK Met Office and the European Centre for Medium-Range Weather Forecasting (ECMWF), to provide general weather and industry-specific advisories, largely to corporate clients (such as Tata Coffee and the Mahindra Group).[88]

3. Generation of agrometeorological advisories

Localized weather forecasts must be combined with local crop data to generate advice for farmers. This involves coordination of the data and human resources of state and Central government agencies dealing with the often siloed fields of agriculture, meteorology, statistics and education.

3.1 Public sector: Institutions for crop-data collection

At present, primary statistics of crop production are collected and compiled by the state governments and consolidated for the nation as a whole by the Union Ministry of Agriculture. The Ministry compiles the crop production figures and releases a number of forecasts of crop production.[89]

In the states where land records are maintained (known as the 'temporary settlement' system, prevalent across 86 per cent of India's land area), records are generally collected by the state government's Revenue Department. A 'village accountant' employed by this Department is charged with carrying out field-to-field crop inspections in a village or a group of villages, in each crop season for an agricultural year.[90]

Based on records prepared by such village accountants for different crops, a 'Jinswar statement' is prepared, recording the area in the village under different crops. At the end of each agricultural year, land utilization area statistics are compiled by village, and aggregated at the revenue circle, tehsil and district levels. The district-wise area statistics are aggregated for the state-level by the State Agricultural Statistics Authority (SASA), which is generally the Director of the Statistical Bureau, or the Director of Agriculture, or the Director of Land Records. The final level of aggregation is undertaken by the Directorate of Economics and Statistics (DES) at the Central government's Ministry of Agriculture and Cooperation.[91]

In theory, therefore, detailed crop statistics are available at every level of governance. In combination with the IMD's meteorological forecasts, they could form the basis for robust localized advisories.

3.2 Public sector agromet institutions

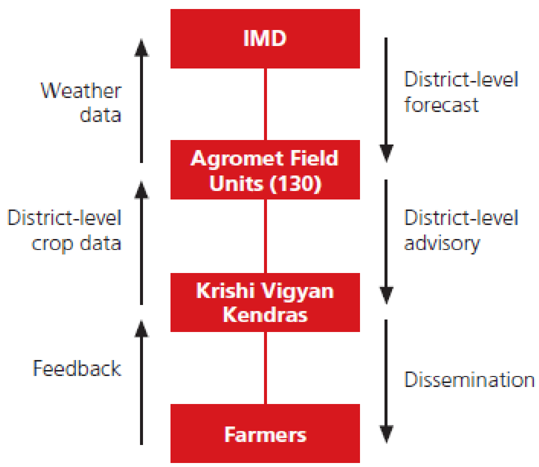
3.2.1 Agromet Field Units

Agromet Field Units (AMFUs) are institutions under the IMD's Agrimet Division, which are designed to specialize in converting weather information into usable advisories for farmers. Each AMFU records agrometeorological data (through weather stations, gauges etc.), which partly informs the IMD's forecasts. The AMFU receives district-specific forecasts from the IMD twice a week, each with a five-day lead time, as well as a weekly cumulative rainfall forecast.[92]

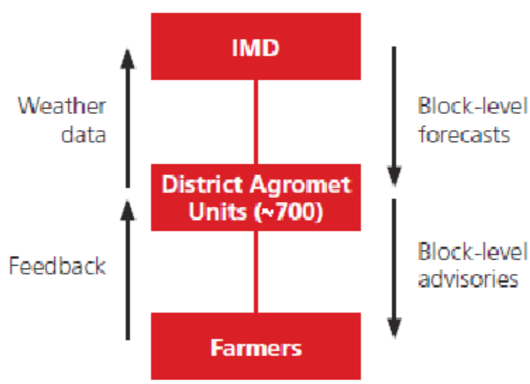
The weather forecasts are combined with the technical knowledge of the AMFU's advisory board, which consists of agricultural scientists representing a wide spectrum of agricultural disciplines (including protection against pests).[93] This results in the preparation of district-wide agro-advisories, which contain (in theory) location and crop-specific farm-level advisories, including descriptions of prevailing weather, soil and crop conditions, and suggestions for taking appropriate measures to minimize losses and optimize inputs in the form of irrigation, fertilizer or pesticides.

The AMFU network was originally set up to cover each of the approximately 130 agro-climatic zones in the country, each of which cuts across four to six districts. Hence, each AMFU at present issues district-level advisories for multiple districts. The government has initiated an upgradation of this network, towards creating an AMFU in each of the country's approximately 700 districts (known as the Grameen Krishi Mausam Seva programme). This deepening of the network is supposed to enable each district-level agromet unit (which are now commonly referred to as DAMUs) to issue block-level advisories. The deepening of the network will see the newer DAMUs being located in Krishi Vigyan Kendras, which are available in most districts.[94]

Old structure of the Agromet Advisory System



New structure of the Agromet Advisory System



3.2.2 Krishi Vigyan Kendras and Agricultural Technology Management Agencies

A Krishi Vigyan Kendra (KVK), literally translated as farm science centre, is an agricultural extension centre. These centres are manned by personnel trained in various agricultural disciplines and aim to apply agricultural research in a practical, localized manner. There are approximately 700 of them in the country, nearly one in every district.[95] Their functions include:

- On-farm testing to assess the location specificity of agricultural technologies under various farming systems;
- Organizing demonstrations to establish the production potential of technologies on the farmers' fields;
- Capacity development of farmers and extension personnel to update their knowledge and skills on modern agricultural technologies;
- Working as knowledge and resource centres of agricultural technologies to support public, private and voluntary sector initiatives in improving the agricultural economy of the district; and
- Providing farm advisories using ICT and other media means on varied subjects of interest of farmers.[96]

KVKs are often located in, or placed under the supervision of, agricultural research institutions. More than 400 of them are under State Agricultural Universities; the remaining are under institutes of the Indian Council for Agricultural Research (ICAR), state Agriculture Departments and NGO branches.[97] They are funded by the Central government, through the Indian Council for Agricultural Research.[98]

KVKs are currently being upgraded to serve as District Agromet Units (DAMUs). This involves equipping each KVK with an Automatic Weather Station, and adding personnel with expertise in agrometeorology.[99] A Memorandum of Understanding has been signed between the IMD and the Indian Council of Agricultural Research for this purpose.[100] The IMD is responsible for funding the AWSs and the new personnel, as well as installing and training them

The National Agricultural Research System

The Indian Council of Agricultural Research (ICAR) is an autonomous institution headquartered in New Delhi. It falls under the supervision of the Department of Agricultural Research and Education (DARE), which is ultimately under the aegis of the Central government's Ministry of Agriculture and Farmers Welfare.

The ICAR is at the apex of the Indian agricultural education complex, the largest of its kind in the world. Under its direct administrative and funding control are 101 ICAR Institutes, 14 national research centres, four Deemed Universities and a Central University work. In addition, it has regulatory powers (such as deciding the entrance requirements and syllabus) over approximately 65 State Agricultural Universities.

A State Agricultural University (SAU) is a university established by an Act of a state legislature, with a dedicated mandate to teach, research and provide extension services in agriculture and related disciplines. SAUs are autonomous and receive direct funding from the state governments, as well as substantial grants from national research institutions. While their main mandate is to provide formal degree programmes in major agricultural disciplines, SAUs provide extension and training support to the KVKs, which are responsible for training farmers. Apart from regulatory oversight, the ICAR also supports SAUs through regular grants, and hence has direct participation in their management.

Sources:

1. *Suresh Pal (ed.). 2017. 'Agricultural R & D Policy in India'. Accessed at: http://www.ncap.res.in/Document/Ag%20R&D%20Policy_NIAP_2017.pdf*
2. *Indian Council of Agricultural Research. 'ICAR Institutions, Deemed Universities, National Research Centres, National Bureaux & Directorate/Project Directorates'. Accessed at: https://icar.org.in/node/119*

respectively. The ICAR is responsible for operation and security of the AWSs, and guidance and supervision of the agrometeorological personnel.[101]

As the KVK network becomes the site of DAMUs, it is also important to note that they are going through a parallel change in their institutional role at the district level, which is not limited to their agrometeorological functions. This arises from the setting up of a new institution for agricultural technology at the district level—the Agricultural Technology Management Agency (ATMA).

An ATMA is an autonomous organization registered under the Societies Registration Act of 1860. It is the foundational unit of an initiative by the Central government (piloted between 1998 and 2005) to create a decentralized system of agricultural extension service providers which (i) integrates research and technology development with capacity building among farmers, and (ii) draws upon and coordinates public and private efforts in this sphere. The ATMA has considerable operational flexibility. It can receive and dispense government funds, enter into contracts, maintain revolving funds, collect fees and charge for services.[102]

An ATMA operates under the direction and guidance of a Governing Board (GB), which determines programme priorities and assesses programme impacts. It is headed by a Project Director (PD) who reports directly to the GB. The PD serves as chair of the ATMA Management Committee, which includes the heads of all line departments and the heads of research organizations within the district, including the Krishi Vigyan Kendra.[103] The KVK is thus a 'constituent member' of the ATMA, retaining its institutional identity and affiliation, but would implement programmes and procedures determined by the ATMA Governing Board and implemented by its Management Committee.[104]

To ensure that it does not become another government agency, the number of personnel assigned to an ATMA's headquarters is very small. The ATMA staff includes the PD, a deputy, an accountant, computer operator, secretary, driver and watchman. With the exception of the PD and DPD, all of the support staff is hired on a contract basis, so they are not regularized government employees.[105]

The model was piloted in 28 districts across the states of Andhra Pradesh, Bihar, Jharkhand, Himachal Pradesh, Maharashtra, Odisha and Punjab. Starting in 2007, as part of its 'Support to State Extension Programmes for Extension Reforms', the government funded the setting up of one in each district. Starting in 2015, the funding for the scheme has been divided between the Central and state governments, in a 10:90 ratio.[106] The Central government's annual fund disbursement is conditional on the state government submitting an appropriate State Extension Work Plan and earmarking its share of the funds.[107]

Exactly how this changes the KVKs role in agromet advisories is not yet clear. In theory, the ATMA model seems to provide an opportunity to raise more funds, which would be a positive for the KVK, but this is not necessarily the case (as discussed in the section on gaps). It can also be a site of partnerships with the private sector to enhance weather or crop data-gathering and forecasting at the local level, either as a customer or a co-investor, but evidence for (or against) this notion is thin on the ground.

3.3 Private sector

Many private and NGO sector organizations are working on generating advisories, but most are focused on the agri-business sector rather than farmers. Other organizations are focused on disseminating advisories generated by the government to farmers; examples of these are covered in the section on dissemination. There are relatively few private actors focused on innovating the process of linking local weather data with farm-level agricultural data, and providing value added agro-advisories targeted at farmers.

The Watershed Organisation Trust (WOTR) is a non-profit organization that has developed a weather-based and agromet advisory system called AGRIMATE and has piloted it in 61 villages within Maharashtra. AGRIMATE generates custom crop advisories for specific crops based on the IMDs weather forecasts of the local weather data collected from WOTR's AWSs. The system is integrated into a GIS platform that provides details of crops grown, soil fertility and quality, access to irrigation etc. of a certain farmer's land, based on the location of the farmland. Information on traditional knowledge and practices are also added to the system if there are any.[108]

Agrostar is a private company that has created a mobile-commerce platform through which farmers can access agromet advisories and buy Agrostar's products based on the advisories given. Agrostar does not generate any weather forecast modeling on its own but obtains weather forecasts from Accuweather online, which can be found on the Agrostar mobile app when farmers enter their location. Based on these forecasts, Agrostar provides its advisories to farmers through messages, the Agrostar call centre and the mobile app. The advisories are developed by a team of experts that come from agronomy backgrounds. The Agrostar call centre receives calls from around 1,000 farmers daily and has a reach of around a million farmers.[109]

CropIn is a data and software-oriented company using artificial intelligence and machine learning to provide farm management solutions. Although primarily a business-to-business company, it has collaborated with the governments of Andhra Pradesh and Karnataka on farm digitization and crop risk assessments,[110] as well as the Mahalanobis National Crop Forecast Centre to pilot a data-driven approach to optimizing crop-cutting experiments.[111] It is currently engaged in a World Bank-funded project focused on delivering advisories to vulnerable farmers in four districts in Bihar and Madhya Pradesh.[112]

In Bihar, CropIn has mapped (or geo-tagged) using satellite data the plots of 4,000 farmers across 200 villages. It collects socioeconomic information about farmers through 200 female local resource persons (one in each village), who are trained to collect such information and provide advice to farmers. It buys weather data from Skymet and IBM, which includes alerts for extreme weather (such as hailstorms, which are increasingly responsible for unprecedented impacts on crops in Bihar).[113]

Weather and crop information is combined through a proprietary software, with input from a team of ten agronomists (including meteorologists). Advisories generated are disseminated through a mobile-phone-based platform. Mobile phones are given to each of the 200 village-level local resource persons, who convey advice to each farmer based on their location and needs.[114]

Skymet, which is primarily engaged in construction of automatic weather stations (AWSs), has a more limited programme to distribute advisories.[115] Starting in 2015, it partnered with the United States Agency for International Development (USAID) for four years to expand the network of AWSs and reach of agromet advisories to farmers in thirty-one districts across nine Indian states. It has installed around 675 AWSs, 250 cameras and 250 location sensors at its USAID project locations to provide advisories to around 77,000 farmers via an Internet of Things (IoT)-based system. Based on the data collected by its AWS, ARGs, and crop sensors, Skymet creates weather forecasting models and models on future yield of crops.

The weather forecasts and crop advisories are given to farmers daily through Skymet's Skymitra mobile app and twice a week via SMS. Farmers are alerted about extreme weather conditions hours prior to the event via text messages. Farmers can also call a Skymet helpline or the interactive voice response system (IVRS) to have any queries addressed regarding forecasts and advisories. A board is placed in a communal meeting area, where most farmers tend to gather, which presents the seven-day weather forecast and is updated daily. The programme also aims to encourage farmers to purchase crop insurance.

CSE visited a Skymet-USAID project site at Payal tehsil in Ludhiana, Punjab, to collect impressions from local farmers and Skymet agents. The information collected from this visit has mixed implications for the sustainability of this model, which we discuss in Section 5.

4. Dissemination

Once agromet advisories are generated, they need to be spread widely to farmers, i.e. disseminated. A variety of dissemination methods are used. Information communication technology (SMSs, television, video messages, mobile applications, phone calls etc.) is taking a prominent role. More traditional methods such as group discussions, bulletin boards and newspapers continue to play a role.

4.1 Public sector

4.1.1 Central government

As part of the Gramin Krishi Mausam Seva (GKMS) programme, the IMD's AMFU/DAMU network sends farmers weather forecasts as well as crop- and location-specific agro advisories via SMSs. IMD also disseminates agromet information to farmers through public-private partnerships with multiple companies such as Reuters Market Light, IFFCO Kisan Sanchar Limited, NOKIA etc.[116]

IMD launched the mKisan portal in 2013 to enable advisory dissemination through free SMSs in both English and regional languages to registered farmers.[117] To avail of this service, farmers are required to register their name, crops and mobile number on the portal. Once registered, farmers are sent SMSs of the forecasts and advisories in one to two texts every Tuesday and Friday, as well as SMSs warning of extreme weather. Around 40 million Indian farmers are registered at present on the mKisan portal.

The AMFUs/DAMUs create the advisory and draft the SMS encapsulating it. Following this, the nodal officer of the AMFU logs onto the mKisan portal to automatically send SMSs to all farmers within that particular region. In coordination with the district-level Agriculture Extension personnel (DAO/KVKs, ATMA) and other NGOs, the AMFUs/DAMUs also send crop and location specific advisories to farmers via print, visual, radio, internet, mobile apps, bulletins, meetings/trainings, and Integrated Voice Response System (IVRS) for wider dissemination.[118] The IMD works with the Department of Telecommunications under the Ministry of Communications to ensure that messages are effectively disseminated.

As a way to provide agromet information to users at all times and ensure easy access, ICAR launched a website (Crop Weather Outlook) as a part of the All India Coordinated Research Project on Agro-Meteorology (AICRPAM). In some states, biweekly district level advisories are also available online for immediate access.

Generally, the advisory disseminated by the AMFU covers regular climate information and weather events such as cyclones, floods, hailstorms etc. However, the lead-time of the communication is dependent upon the nature of the weather event. While a cyclone warning can be made four days in advance, location-specific warnings of heavy rainfall and hailstorms can only be given a few hours in advance.[119]

Feedback is taken by KVKs and extension specialists from farmers on the quality, content, relevance of the forecast and advisory, and the effectiveness of the information dissemination system.[120] This gets relayed back to the AMFUs through district level extension services.

As discussed earlier, the IMD plans to improve dissemination by extending the AMFU network to the district level, by piloting block-level advisories, and by increasing enrolment on the mKisan system to 70–95 million farmers in the near future.[121]

4.1.2 State governments

State governments have their own Departments of Agriculture (or horticulture, or other related areas). These departments are first-line executive institutions engaged in agriculture extension, in parallel with KVKs. This complex system of extension services should, in theory, be able to muster enough human resources to serve farmers' needs (see *Figure 2: Agricultural extension systems in India*).

Figure 2: Agricultural extension systems in India

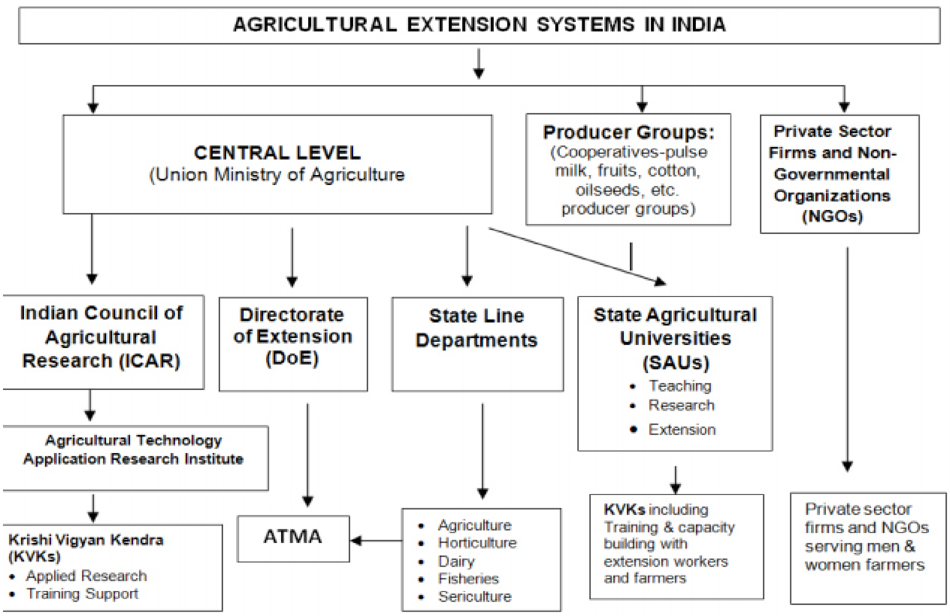


Fig. 1: Agricultural Extension Systems in India

Source: MS Meena et al. 2015. 'Indian Agricultural Extension Systems and Lessons Learnt: A Review. Accessed at: https://www.researchgate.net/publication/286220725_Indian_Agricultural_Extension_Systems_and_Lessons_Learnt_A_Review

However, from conversations with State Department officials (in three states—Punjab, West Bengal and Tamil Nadu), there is significant variation in the human resources employed by states. The Punjab Department of Agriculture employs 410 extension professionals, but is sanctioned to employ over 900; such a large number of vacancies indicates significant human resource constraints in the Punjab extension system. West Bengal and Tamil Nadu respectively have around 2,500 and 3,000 extension personnel working for their state agriculture departments.[122]

A similar picture emerges when relating the total number of extension personnel in each state (combining Central and state government employees) with the area under agriculture. Statistics available from 2012 suggest that an extension worker in Punjab has to cover, on average, as much as 2,982 hectares of net cropped area, where personnel in Tamil Nadu and West Bengal respectively cover around 600 and 850 hectares (see *Table 1: Human resources for agricultural extension in selected Indian states*).[123]

The system as a whole compares unfavourably with China, which employs six times as many extension personnel as India while having less area under cultivation.[124] In addition, state agriculture departments seem to employ less than half the extension personnel in these three states—400 out of nearly 1,400 in the case of Punjab—with the caveat that the figures being compared are across different years (2012 and 2019).

The minimum level of qualification required to work in extension is somewhat similar across the three states—Grade 12 pass to work at the grassroots; diplomas in agriculture for mid-level officers; and bachelor's or master's degrees in agriculture for more senior posts in extension. None of these states required any meteorology-specific qualifications; the closest was Tamil Nadu, where holders of a diploma in agriculture generally take one paper on meteorology.[125]

The extension personnel across these three states get weather forecasts directly or indirectly from the IMD, which they then combine with knowledge of agriculture (and related fields such as entomology) to generate holistic advice for farmers. This advice is communicated through radio, phone and mobile messaging. In Tamil Nadu, such information is also communicated through training camps, although it is unclear how regularly such camps are held, and whether they are effective in delivering timely weather information.[126]

Table 1: Human resources for agricultural extension in selected Indian states

	Punjab	West Bengal	Tamil Nadu
Number of extension personnel			
State Agriculture Department (2019)	~ 400	~ 2,500	~ 3,000
State and Central employees combined (2012)	1,398	6,164	8,320
Net cropped area/extension personnel (hectares) (2012)	2,982	859	606
Meteorology specific qualifications	None	None	Diplomas in agriculture include one course in meteorology. A diploma is the required minimum qualification for mid-level extension professionals.

Source: Discussions with state government extension officials; V.K. Sajesh and A. Suresh. 2016. 'Public-Sector Agricultural Extension in India: A Note'. Accessed at: http://www.ras.org.in/public_sector_agricultural_extension_in_india)

4.2 Private sector

Private players in the agromet advisory dissemination sub-sector include IFFCO Kisan Sanchar (public–private partnership), Reuters Market Light/Farmbee (private), and the Watershed Organization Trust (WOTR) (non-profit). These service providers disseminate weather forecasts and agromet advisories, while some of them also provide market based information (IFFCO Kisan and RML/Farmbee).[127] The methods of dissemination generally used by these players include means akin to those used by the government—SMSs, voice messages, mobile applications, call centres, in-person meetings etc.

IFFCO Kisan Sanchar Limited is a public–private service that was launched in India in 2007 and developed by the Indian Farmers Fertilizer cooperative Limited as a joint venture with Bharti Airtel, a telecom company, and Star Global Resources, a non-banking finance company.[128] IFFCO Kisan disseminates its agromet advisories and forecasts through its mobile app, a call centre helpline that farmers can ask queries on, and IFFCO Kisan's Green Sim card. Farmers that use the Green Sim receive three free voice-based messages daily on relevant, customized agromet information in their local language.[129] The company also provides personalized agromet advisories for those farmers that already use an Airtel number and opt to pay for their services. There are approximately 3 million farmers who receive these services on a pan-India basis.[130]

Farmbee, formerly known as Reuters market Light (RML), is a private company that provides weather forecasts and agromet advisories to farmers throughout the crop lifecycle and based on their location. RML/Farmbee has developed a mobile app that can be used in different local languages, including Hindi, Tamil, Marathi etc., by farmers who pay a fee in order to access agromet information pertinent to their location and crop. Farmbee also provides a helpline for farmers to call and have their queries answered, whether it is forecast, pest or crop stress related.[131]

WOTR's innovative automated advisory generation process was described in the previous section. WOTR's software-based AGRIMET system creates a user profiling system that matches the registered farmer to the relevant advisory based on the crop they grow and disseminates it to them via SMS. WOTR also disseminates manually generated advisories to farmers at the block level through multiple channels, including SMSs, wallpapers, village public address systems (loudspeakers) and Krushi Shalas etc. to facilitate wide outreach. Adoption of advisories put forth and best adaptation practices are promoted through conducting Farmer Field Schools, on-farm specialist support and engagement with farmer groups and local institutions.[132]

Certain trained village youth are tasked with the responsibility of displaying key weather information on blackboards at accessible areas in the village. Advisories are issued twice a week in the local language during the agricultural season and sometimes more frequently if the need arises. Dissemination is also supported by extension service professionals in areas where mobile connectivity and literacy levels are an issue. A feedback system is also implemented wherein crop-wise meetings are organized regularly with farmer groups to discuss advisories and obtain feedback in order to improve future advisories.

From the semi-structured interviews conducted with public and private stakeholders, many highlighted that farmers who had access to the agromet services would share the forecasts and advisories with farmers who may not have availed of the agromet service in the same area through word of mouth. Statements heard from focus group discussions and interviews held with farmers also confirmed that this was a mode of dissemination that was often employed to relay agromet information to the rest of the village.[133]

5. Gap analysis and conclusion

The Indian agromet advisory system is among the most advanced in the world. However, given the nature and criticality of the agriculture sector in India, as well as the challenges posed by climate change, the system struggles to cope with the challenges before it. This section breaks down the key challenges by subsector.

5.1 Challenges in the forecasting sector

For the purposes of agricultural advisories, there is an increasing requirement for weather forecasting to be more localized.[134] This is due to the high variability of weather patterns in India, even across short distances. In addition, farmers vary in their preferences and socioeconomic profiles.[135]

5.1.1 Infrastructure is unevenly distributed

The issue begins with the density of the observatory network. The Central government is currently operating on the understanding that the radial spacing of AWSs should be around 10 km from each other. Moreover, in mountainous and other topographically complex areas, the recommended radial spacing reduces to 5 km. Based on these thumb rules, the government considers that the country needs around 40,000 AWSs.[136]

The current network in the country, private and public sector combined, is in the range of 13,000 automatic weather stations and 8,000 automatic rain gauges (see *Annexure: State-wise distribution of automatic weather stations and rain gauges*). There are several gaps in the data available, particularly a lack of clarity in the data collection infrastructure owned/operated by state governments (as distinct from the private and Central government). Some experts estimated that the total data collection points in the country could exceed 30,000.[137]

It is clear, however, that there are drastic differences in the distribution of data collection infrastructure through the country. Consider the difference between Kerala, which has on average approximately one AWS per 87 sq. km, and Assam, which has one for every 472 sq. km. Within this range lie networks as diverse as Karnataka (one per 167 sq. km), Odisha (one per 281 sq. km) and Bihar (one per 313 sq. km).

These are states for which data is available on state-owned networks. There are other states covered by either the Central government or private networks, but which could not provide any data on state-owned networks. These include Punjab (one AWS for every 535 sq. km), Haryana (one every 574 sq. km), Uttar Pradesh (one every 1,005 sq. km) and Chhattisgarh (one per 2,703 sq. km). These states should ideally be the focus of investment in data collection.

A similar problem exists for automatic rain gauges, where 6,400 of the approximately 8,000 ARGs in the country are to be found in just one state, Karnataka. The only state with a significant projected expansion in its ARG network is Odisha, with around 6,000 planned.

The issue of investment in a more robust network is complicated by the variation in price estimates for weather stations. Estimates range from far less than Rs 1 lakh,[138] to 1–1.5 lakhs,[139] to close to 7 lakhs.[140] The variation arises in part from the identities of the manufacturer/provider and the procuring organization involved. However, the confusion is also due to the lack of standardization in the data required to be collected by a weather station. Only part of the AWS network collects soil and agriculture-specific data, which, for example, belies its importance to the agro-advisories sector.

This lack of standardization arises from the fact that the recent and ongoing expansion in the AWS network has proceeded with minimal coordination and oversight. A large number of AWSs and ARGs have been installed in 'project mode', i.e. with a focus on hitting short-term targets within a particular area or institution.[141] There has been a failure to consider how such network creation/expansion 'projects' will link into a larger weather data system, the consequences of which are discussed below.

5.1.2 Data quality is inconsistent and sharing is limited

The 'project' approach has led to a lack of quality control of weather stations, lack of attention to maintenance of stations after installation, and the lack of a common platform for data collation.

To some extent, the quality control problem predates the spread of automatic weather data collection technology. The IMD's historical data was often manually collected or corrected, and several experts have raised concerns regarding the laxity of the methods used.[142] The publicly available historical data record is hence unfit to build or refine reliable models of Indian weather,[143] and particularly inadequate in anticipating the local weather pattern shifts predicted by climate models.

This historic problem has been exacerbated by poor inspection and maintenance of automatic observatories, including basic failures such as a failure to prevent and replace stolen batteries.[144] A possible underlying cause is that maintenance is based on hiring a qualified local resident. The budget to sustain such a hire is often unavailable once the 'project' (i.e. installing the station/gauge) is considered complete. The result is a fundamental confusion regarding the exact extent of the 'operational' network (as opposed to the 'installed' network).[145]

Data from the private sector is based on a denser and more modern observation network, but is expensive (estimated at between Rs 12,000 and Rs 1,20,000

CAG Report exposes the poor state of weather data integration

A Comptroller and Auditor General (CAG) Report in 2017 reviewed the functioning of weather stations as part of an overall review of the national crop insurance scheme.

In Assam, due to non-receipt of funds, monitoring of weather stations could not be done, and it was not clear as to how the accuracy of weather data provided by them was ensured. In Rajasthan, a negligible number of weather stations were installed at ground level, casting doubt on the reliability and accuracy of the data collected.

In Maharashtra, some weather stations which were shown as installed were not in fact installed at the addresses indicated. In Maharashtra and Rajasthan, state governments could not furnish any document regarding the certification of AWS equipment provided by third-party data providers, which is required to be accredited under the NCIP guidelines.[146]

annually for data from a single observation point).[147] Besides, the track record of cooperation between the private and public sectors on this front is not encouraging. In its report on crop insurance schemes, the CAG found that, even though a Maharashtra state government resolution stipulated that weather data received by the insurance companies from a third-party data provider should be sent every week to the government, insurance companies' compliance record on this front was poor. Where they did submit such data, delays ranged between 19 to 34 weeks, in violation of the government resolution.[148]

It should be noted that all these states are among those with more developed networks. Some of them, such as Maharashtra, boast signature public–private partnerships in weather data collection.[149] The evidence so far indicates that a comprehensive weather data sharing policy for the country is required.

5.1.3 Advanced climate modelling demands better hardware and human resources

Data scarcity can be overcome, to some extent, by the use of sophisticated weather models. In particular, more refined models use 'data assimilation' techniques in order to increase the resolution of forecasts. However, such assimilation has its limits. It is very hard to generate a forecast for the block level based on district level data, while retaining a sufficient level of reliability as well as a sufficiently long lead-time.[150]

Developing forecasts which balance these requirements will require increased application of techniques such as probabilistic and multi-model ensemble forecasting, as well as more sophisticated data assimilation software. All of these require more super-computing power, which India has only recently begun upgrading in earnest. As of 2018, India is fourth in the world in operational super-computing power, with 8 petaflops, behind the UK (20.4 petaflops), Japan (20 petaflops) and the US (10.7 petaflops).[151]

However, all these countries are nearing significant upgrades of their own meteorological computing infrastructure, in recognition of the risk posed by growing unpredictability in weather patterns. Moreover, despite the investment in super-computing capabilities, the government is still struggling to employ sufficient numbers of professionals with the requisite software and modelling expertise.[152] Significant advances in this area will require hardware investments to be matched or out-paced by investments in human resources for weather modeling, especially at the state level.

5.2 Challenges in the agromet advisory sector

5.2.1 Advisories do not always usefully combine weather and agriculture data

Agromet advisories should ideally provide weather information, and add value to this information through advice on agricultural best practice that is tailored to the anticipated weather. As we can see from observing advisories issued in some large Indian states, this is not always the case (see *Annexure: IMD's district level advisory in different states*).

For example, in Assam, the advisory summarizes the maximum and minimum temperature, precipitation and wind conditions expected for the coming week. However, its recommendations do not tie back explicitly to the weather forecast. Recommendations for boro rice such as '[d]ue to favourable infestation of stem borer may be observed in boro paddy crop, farmers may apply Chloropyriphos 20EC at the concentration of 0.02% solution @ 2ml per 10 litre of water' do not add value based on weather forecasting.

Other statements in the Assam advisory are more weather related, such as the recommendation regarding wheat that '[a]s there is no possibilities of getting rainfall in the coming 5 days, farmers are advised to apply second irrigation in wheat crop at heading stage i.e. 70–75 days after sowing'. However, the recommendation to use irrigation to make up for precipitation shortfall is too general to add much value.

A similar problem exists with advisories issued in Gujarat. A sample advisory either offers advice unconnected to weather, such as '[h]arvest the matured spike in early morning hours' (for castor), or offers weather-related recommendations that are too general, such as '[w]eather is clear so harvesting should be done at early morning'.

Advisories issued in Kerala and Karnataka are somewhat more focused on offering weather-specific advice, such as '[s]ince air temperature is increasing, it is desirable practice to bury fresh or dried coconut husk around the palm to conserve soil moisture', and 'due to continuous dry spell since October month, the termite attack is common in horticulture and Forestry tree and shrubs hence control to apply Aldrin termicides for control of termites'. However, these states' advisories also contain examples of more generic advice without meteorological value-addition.

In addition, agromet advisories often contain recommendations for practices that are well out of date, in some cases recommending fertilizers or pesticides which are either prohibited, out of production, or not available locally.[153]

These facts prompt the larger question—Is a hybrid ' agromet' system the best way to deliver locally relevant crop advice based on weather forecasting? These two streams of information (crop and weather) need to eventually be combined. However it is difficult—tending to impossible—to build a single system of institutions with adequate capacity in the details of two highly specialized fields—agriculture and weather forecasting. This specialization problem rears its head repeatedly in the following two sections.

5.2.2 Micro-scale advisories are not available

The IMD's default level for forecasts is currently the district level. This is, however, widely agreed to be insufficient for the purposes of agro-advisories—by farmers, as well as experts in agriculture and meteorology.[154] Although generally located within an agro-climatic zone, each district spans hundreds to thousands of square kilometres; significant weather variations are found in India within distances of a few kilometres.

The IMD is piloting block-level advisories in around 200 out of the country's approximately 6,600 blocks, mostly in areas with denser weather networks.[155] These advisories utilize the newer ensemble (probabilistic) forecasting models developed by the NCMRWF and IITM, because the accuracy of single model forecasts falls to around 60 per cent at the block level.[156] However, the weather forecasts and advisories at both block and district levels suffer from the same issue—they do not communicate the level of certainty of the forecast.[157]

On the crop data side of advisory generation, the government itself considers that the present status of crop statistics is ‘far from satisfactory’.[158] Crop and pest calendars, for example, have not yet been updated to account for the long-term shift in harvesting seasons.[159] There have been frequent revisions, often quite significant ones, of crop estimates and the publication of final estimates is considerably delayed.

The main reason identified for this is that village-level officials who play a key role in collecting land-use statistics do not attach much importance to this work, an attitude that extends to the supervisory responsibilities of higher-level revenue officials.[160] One civil servant suggested that this is a natural outcome of the long-term decline in the role of the state Revenue Department in the agricultural space, initiated by the reduction of taxation of agricultural land.[161]

Even if this crop data system did work as designed, it would not meet the localized, personalized needs of farmers today. Developed countries have invested in infrastructure at the farm level—digital sensors which capture real-time data on advanced metrics including soil nutrients, plant colour, pest invasions and several others. This is one component of a basket of solutions collectively referred to as ‘precision farming’—other components include global positioning systems, automatic monitoring and control of the quantities of water, fertilizers and pesticides, and single-platform farm management software.[162]

Precision farming solutions as implemented in developed countries are not financially suitable for small land holdings—India’s average holding size continues to shrink and is currently just over 1.1 hectare.[163] Nevertheless, there are ways of managing the costs, such as ‘virtual land-holding consolidation’, i.e. considering contiguous individual farms as a ‘single’ field for the purpose of the data collection or farm management system, without changing actual ownership. Another possibility is to develop such infrastructure on a cooperative basis, treating small farms as management zones within a field, with a centralized entity providing information to the individual farmers.[164]

Whatever the strategy, implementing precision farming in India will need local institutions with adequate finance, expertise and institutional authority. It is an open question whether the Central government’s agrometeorology institutions can fill this gap. An expert familiar with the KVK network believed that there was no need for the Central government to develop block- or local-level infrastructure/expertise in agrometeorology. The explanations for this view are that agriculture is constitutionally a state subject, that state governments already operate at the block level, and that meteorology, especially, is a highly specialized field.[165] While this is true, the extension networks of the three state governments reviewed above do not employ meteorology experts, which is a significant gap in a system crucial to building climate resilience.

The struggle is not limited to government efforts. A paper currently in development assesses the success rate of WOTR’s advisories in Parbhani, Maharashtra for four key crops—cotton, soybean, pigeon pea and maize. It finds that the accuracy of the automated advisories was around 50 per cent for cotton, 40 per cent for soybean, 22 per cent for pigeon pea and 17 per cent for maize, i.e. not significantly better than traditional advisories.[166]

5.2.3 Lack of trained agrometeorologists

The deepening of the agromet advisory network will require an influx of trained agrometeorologists. It is not clear that the present state of the country's agricultural education system can meet this need. The system is struggling to produce trained professionals to staff its agricultural extension service network generally;[167] in the past, the country has used paraprofessionals to address chronic crises in agriculture and to compensate for an inadequate number of qualified personnel in the agricultural and rural development sector.[168]

The State Agricultural University system suffers from significant vacancies (around 50 per cent) in its teaching and research staff, a lack of high-quality students, lack of library and technological resources, and outdated syllabi. The lack of rigorous courses in climate change was pointed out by multiple experts.[169] A more-than-healthy portion of the SAUs staff is sourced from its alumni, and faculty's exposure to international best practices is limited.[170] One expert considered that administration in the system is bureaucratic and corrupt[171] and that, as a result, students are not industry ready.

This state of affairs ultimately results from the lack of funding priority allocated to these universities. SAUs get their annual budget from the state government. However, the budget grant is grossly insufficient across states, and is tilted towards meeting salary requirements. This exacerbates the shortage of infrastructure and technology.[172] On the demand side, state governments—at least in the three states reviewed above—do not seem to consider meteorology expertise as important for a robust extension network.

The trend in Central government expenditure has been to invest in the KVK system through the ICAR, with grant-based funding to the SAUs. This has resulted in the positive development of an increased number of scientists working on the field. However, because these staff spend the bulk of their time on extension and farmer capacity building, they are left with less time for research and training of fellow professionals.[173] Cross-disciplinary fields such as agrometeorology suffer particularly acutely from this fundamental gap. The evidence again points toward specialization and coordination, rather than a hybrid system.

5.3 Challenges in the dissemination sector

5.3.1 Advisories are not sufficiently regular and reliable

Discussions with farmers in in the Payal tehsil of Ludhiana, Punjab, revealed issues in receiving the advisories. The farmers expressed that they would receive SMSs from the government later than when they were expected to be received (i.e. Tuesdays and Fridays). Weather forecasts were not considered sufficiently accurate or specific enough to their location for them to be relevant and usable.

Farmers also reported a lack of response and disinterest displayed by those operating the government's agromet information helpline. Farmers recalled that they are made to wait on the phone for 20–30 minutes and did not get connected if they called multiple times. Farmers also recall receiving messages from IFFCO (a public–private partnership), but report that these dwindled over time, likely because the Green SIM through which IFFCO's services are provided was not recharged. For all these reasons, the farmers of this village barely relied on the government's agromet services.

Farmers' reliance on advisories differs between states. A 2014 assessment by CGIAR researchers uncovered the key role of diverse communications approaches. In villages where many communications channels were used to disseminate Agrometeorological Advisory Service (AAS) information, awareness and use of AAS advisories was higher. In regions with the highest levels of AAS awareness (Andhra Pradesh, Himachal Pradesh and Tamil Nadu), a greater diversity of communications channels was recorded overall. Gender inclusivity in dissemination efforts was also an important predictor of higher awareness and use of AAS advisories. Awareness of AAS was lower in states where women's participation in agriculture in the surveyed villages is lower (Gujarat, Punjab and West Bengal).[174]

The need for better dissemination is clear. Whether this will be met by the government is less so. The private sector has had more success in filling these infrastructural, data and effectiveness gaps at the local level. The utility and uptake of their agromet information was high, with farmers citing high levels of accuracy and relevance of the forecasting and agricultural information that was provided. However, efforts on this front are also constrained—by the need for a sustainable business model.

5.3.2 Inability/unwillingness to pay for weather information

Despite confirming the quality of the service and the fact that it saved them money (approximately Rs 40,000 annually), farmers in Payal, Ludhiana, reported that they were unlikely to pay for weather advisories. If these were shifted to a payment model, many responded that they would likely go back to monitoring the agromet advisories. The general sentiment was also expressed that if all else failed, they would be able to rely on their own eyes and traditional knowledge. Other private service providers reported a version of this experience (not limited to Ludhiana)—that there is an initial willingness to pay for advisories in areas where they are not available, until the government starts offering them for free.[175]

This makes sustainable business models in this space very difficult—WOTR, Skymet and CropIn report that their dissemination efforts for vulnerable farmers will continue to rely on grants or public funding.[176] Underlying this reluctance is the hard economic reality of subsistence farming. An official involved in agricultural extension services estimated that 85 per cent of farmers in India are subsistence farmers, and cannot be expected to pay for such services.[177]

Besides, this kind of information is difficult to monetize due to the communal sharing of agromet information once obtained. Farmers in Ludhiana mentioned that many of them would not need to pay for the service as they would receive the agromet information from another farmers who paid for it. A similar observation was made in a 2017 case study in Maharashtra, where farmers often shared agromet information with family and friends in communal spaces for discussion in the village.[178] A government official confirmed this, stating that having a profitable revenue model with subsistence farmers as the main customers is difficult as farmers would inevitably share it with many others.[179]

On the other hand, success has been anecdotally reported in providing fee-based advisories to certain market segments, with caveats.[180] In Payal tehsil, we found some willingness to pay for services if two conditions were met. The first was that sufficient trust-worthiness needs to be demonstrated by the service provider, through sustained engagement with farmers well before attempting to charge a fee for the service. Farmers recalled past cases of fraud when they paid private companies for certain agricultural services but instead were cheated, as a result of which they were apprehensive of paying for services.

The second is the availability of advisories that are sufficiently specific to the farm level. Farmers reported that this type of advisory would constitute a genuine value-add which they would be willing to pay for. Achieving this level of specificity would also, in theory, address the issue of advisories being shared quite freely. Efforts on this front have been made by WOTR, for example, which tries to combine weather data with data unique to each farmer.

Truly specific advisories, however, will need to integrate real-time farm-level data, as well as socioeconomic profile and personal preferences into creating advisories. There are technological solutions to achieve such results, but they run the risk of placing the eventual product out of the price range of subsistence farmers.

Agromet advisories create benefits for farmers and the broader economy,[181] but are not financially viable for subsistence farmers. It is also clear that—given the criticality of the sector to the political economy of the country—the onus of securing these benefits cannot be placed on individual farmers. These services must be treated as a public good.

5.3.3 ICT methods cannot replace warm-blooded dissemination

Over the past few years, an increasing emphasis has been placed on utilizing ICT in enabling agricultural productivity and resilience, but with a lack of recognition of its limitations. For instance, farmers have been observed not picking up advisory calls due to the misconception that doing so would deduct their phone credits.[182] Farmers are also reported as sometimes not looking at advisory SMSs in the midst of an inordinate number of advertisement texts.[183]

Studies show that a certain level of human interaction is necessary for the optimal uptake and use of ICT-based advisories. The ICAR considers that 'a key ingredient to [the] success of any Mobile Based Agro Advisory Service (MAAS) will be the "human touch"'.[184] Social factors are important in farmers' decision to use agromet information from any provider.[185] Key factors for enabling the uptake of agromet information are building mutual trust and adequately contextualizing climate information to ground level realities.[186]

In the case of the private sector, agents of private and public–private agromet information providers were seen as a social influence, drivers of discussion and, in effect, encouraged the uptake of agromet information.[187] A public sector expert considered that leaders at the gram panchayat level have been great agents of change and key focal points in information dissemination in the past.[188] Social connections built between the sarpanch (gram panchayat leader) and farmers are generally robust; hence, empowering them with the information, training and funds necessary to communicate weather and climate information can effectively encourage advisory uptake.[189]

Such 'soft' investments in dissemination cannot be replaced by investments in infrastructure and technology solutions for weather forecasting and agricultural extension; they are crucial to ensuring that information/advice generated by those 'hard' investments do not go to waste.

5.4 Conclusion

It is clear that the current system faces significant challenges. Some of these are fundamental, and can only be addressed through significant investments. Other challenges result from a lack of coordination or cooperation between different sectors, or levels or departments of government. Addressing these challenges will require some shifts in government policy.

The first critical shift must be back toward treating agromet advisories as a **public good**. The Central government-led system was originated on this basis. However, as capacity constraints become more obvious, the tendency has been to encourage the development of the private sector as an alternative to the public sector.

It is clear that the economic model of the private sector is not suited to individual farmers. The only existing examples providing affordable advisories (albeit laudable) are being supported by grants. The need is to expand public-sector investment and involvement in this network, but with modifications to the existing approach.

The agromet system cannot continue to be a Central government initiative. This approach has reached its limit. State governments need to take more responsibility for investment; in some cases, they are already doing so. In addition, the explosion of private sector investment must be harnessed toward creating a public good.

The Central government's role going forward must be focused on creating a **single platform for high-quality weather data**. This involves two components. First, by law, all weather data collected in the country, public or private, and across government departments and levels, must flow into a central database. Second, the data collected should be of sufficient quality. This can be achieved through the development of minimum standards (such as BIS) for weather equipment and data, including metadata. Some basic standards exist for equipment, but need to be updated to govern data, especially automatic weather data collection.

Conformity with these standards can be ensured through a viability gap funding policy. Payments under this policy can be structured to serve multiple aims. An initial grant to set up data collection in underserved areas can be combined with regular payments to ensure maintenance and upkeep. The latter payments would be conditional on meeting government prescribed standards for data collection. In addition, regular payments can be made based on the number of low-income farmers reached through advisories.

Finally, the **unified 'agromet' system needs to be replaced**. Capacity needs to be drastically expanded based on hiring specialists for meteorology, agriculture and extension. This capacity expansion and specialization is not sustainable purely as a Central government initiative. State governments need to employ meteorologists at the block level, as well as revive their extension systems to reach advisories to the farmers in most need.

This capacity expansion must be coupled with an emphasis on coordination. Ideally, specialized departments would improve their communication; however, experience shows this is not always the case. The existing hybrid agromet institutions can be the site of coordination—by developing technological platforms for combinations of such information, or convening specialists on a regular basis. They cannot be a replacement for expansion of specialized capacity.

The changing climate has the potential to invalidate centuries of agricultural knowledge accumulated in rural India. A modern agromet system is key to building resilience against this challenge. To an extent, the beginning of the technological and institutional base for such a system has been laid in India. Future policy in this area must focus on, and invest in, integration and coordination in technology and human resources, across fields, levels of government, and the private and public sectors.

6. Annexures

6.1 State-wise distribution of automatic weather stations and rain gauges

	Central government *(Source: IMD website, discussions with IMD regional centres, ISRO MOSDAC website, unless otherwise indicated)*	**State government**	**Private sector** *(Source: Discussions with company representatives and company website, unless otherwise indicated)*	**Density**
Andhra Pradesh	IMD—28 AWS, 70 ARG 2 DWR—1 in Machilipatnam (S-Band) and 1 in Visakhapatnam (S-Band) ISRO—130 AWS[187]	AP State Development Planning Society—1,170 AWS, 100 ARG (approx.) [188]	Skymet—106 AWS NCML—1	160,205 sq. km (28+130+1170+106+1) AWS = 1 AWS per 111 sq. km. 160,205 sq. km 170 ARG = 1 ARG per 942 sq. km
Telangana	IMD—12 AWS (out of which 3 are agro AWS), 55 ARG [189] 1 DWR in Hyderabad (S-Band)	Telangana State Development Planning Society—924 AWS[190]	Skymet—84 AWS	112,077 sq. km (12+924+84) AWS = 1 AWS per 109 sq. km 112,077 sq. km 55 ARG = 1 ARG per 2,037 sq. km
Assam	IMD—27 AWS (out of which six are agro AWS), 62 ARG ISRO—52 AWS (no recorded observations from 43 AWS) 1 DWR in Mohanbari (S-Band)	Guwahati local government —18 AWS (however, since 2017, state is not receiving data. State solely relies on IMD for data)[191]	Skymet—14 AWS NCML—55 AWS	78,438 sq. km. (27+ 52+18+14+55) AWS = 1 AWS per 472 sq. km 78,438 sq. km 62 ARG = 1 ARG per 1265 sq. km
Odisha	IMD—37 AWS (out of which nine are agro AWS), 170 ARG ISRO—112 AWS (no recorded observations from 111 AWS) 2 DWR with one in Paradip (S-Band) and one in Gopalpur (S-Band)	Orissa State Disaster Management Authority—320 AWS, 6000 ARG (currently in proposal stage to be enrolled in two years and placed at block and gram panchayat level)	Skymet—84 AWS NCML—5 AWS	155,707 sq. km (37+112+320+84) AWS = 1 AWS per 281 sq. km 155,707 sq. km (170+6000) ARG = 1 ARG per 25 sq. km
Uttarakhand	IMD—20 AWS (out of which two are agro AWS), 20 ARG ISRO—26 AWS (no recorded observations from 21 AWS) 2 DWR (one which is yet to be installed in Nainital)	107 AWS (one to two in every district), 28 ARG, 16 snow gauges, 25 surface field observatories (which include optical rain gauge and AWS)[192]	Skymet—38 AWS NCML—41 AWS	53,483 sq. km (20+26+107+25+38+41) = 1 AWS per 208 sq. km 53,483 sq. km (20+28+25) ARG = 1 ARG per 732 sq. km

	Central government *(Source: IMD website, discussions with IMD regional centres, ISRO MOSDAC website, unless otherwise indicated)*	**State government**	**Private sector** *(Source: Discussions with company representatives and company website, unless otherwise indicated)*	**Density**
Kerala	IMD—15 AWS (out of which only four to five are functioning), 28 ARG, 1 DWR in Kochi (S-Band) 100 AWS to be installed at state's request (by monsoon 2019) ISRO—68 AWS (currently not operational), 1 DWR in Thiruvananthapuram (C-Band)	100 AWS owned by state water authority 25 AWS owned by Vegetable and Fruit Promotion Council Kerala, a public–private company[193]	Skymet—95 AWS NCML—40 AWS	38,863 sq. km (15+100+68+100+25+95+40) AWS = 1 AWS per 87 sq. km 38,863 sq. km 28 ARG = 1 ARG per 1,387 sq. km
Jharkhand	IMD—16 AWS (out of which 3 are Agro AWS), 28 ARG ISRO—61 AWS (no recorded observations from 60 AWS) 1 DWR being set up in Ranchi, not currently operational. Some coverage from DWR Patna and DWR Kolkata.[194]	114 AWS (50 AWS installed, 64 planned)[195]	Skymet—25 AWS NCML—203 AWS	79,714 sq. km (16+61+114+25+203) AWS = 1 AWS per 190 sq. km 79,714 sq. km 28 ARG = 1 ARG per 2846 sq. km
Karnataka	IMD—27 AWS (out of which 8 are Agro AWS), 45 ARG.[196] ISRO—128 AWS (no recorded observations from 121 AWS) No DWR.[197]	920 AWS, 6400 ARG (one in each gram panchayat)[198]	Skymet—35 AWS NCML—33 AWS	191,791 sq. km (27+128+920+35+33) AWS = 1 AWS per 167 sq. km 191,791 sq. km 45+6,400 ARG = 1 ARG per 29 sq. km
Rajasthan	IMD—42 AWS (out of which nine are agro AWS), 66 ARG[199] 1 DWR in Jaipur (C-Band) ISRO—53 AWS (no recorded observations from 30 AWS)	Data not available	Skymet—1,019 AWS NCML—1,329 AWS	342,239 sq. km (42+53+1,019+1,329) AWS = 1 AWS per 140 sq. km 342,239 sq. km 66 ARG = 1 ARG per 5,185 sq. km
Uttar Pradesh	IMD—52 AWS (out of which eight are agro AWS), 120 ARG[200] 1 DWR in Lucknow (S-Band) ISRO—7 AWS (no recorded observations from any)	Data not available	Skymet—49 AWS NCML—134 AWS	243,286 sq. km (52+7+49+134) AWS = 1 AWS per 1,005 sq. km 243,286 sq. km 120 ARG = 1 ARG per 2,027 sq. km
Bihar	IMD—29 AWS (out of which 5 are agro AWS),[201] 32 ARG, 1 DWR in Patna (S-Band)	Data not available	Skymet—106 AWS 80 ARG NCML—181 AWS	99,200 sq. km (29+106+181) AWS = 1 AWS per 313 sq. km 99,200 sq. km (32+80) ARG = 1 ARG per 885 sq. km

	Central government *(Source: IMD website, discussions with IMD regional centres, ISRO MOSDAC website, unless otherwise indicated)*	**State government**	**Private sector** *(Source: Discussions with company representatives and company website, unless otherwise indicated)*	**Density**
Madhya Pradesh	IMD—52 AWS (out of which nine are Agro AWS), 100 ARG [202] one DWR in Bhopal (S-Band) ISRO—75 AWS (no recorded observations from 59 AWS)	Data not available	Skymet—819 AWS, 80 ARG NCML—282 AWS	308,252 sq. km (52+75+819+282) AWS = 1 AWS per 251 sq. km 308,252 sq. km (100+80) ARG = 1 ARG per 1,712 sq. km
Gujarat	IMD—36 AWS (only five to six operational), 1 DWR (in Bhuj), 65 ARG[203] ISRO—54 AWS (no recorded observations from 19 AWS)	Data not available	Skymet—1,084 AWS	196,024 sq. km (36+54+1,084) AWS = 1 AWS per 166 sq. km 196,024 sq. km 65 ARG = 1 ARG per 3,015 sq. km
Punjab	IMD—25 AWS (five to seven operational), 35 ARG 1 DWR in Patiala (S-Band) ISRO—19 AWS (no recorded observations from 5 AWS) Air Force Station, Patiala—1 AWS[204]	Data not available	Skymet—49 AWS	50,362 sq. km (25+19+1+49) AWS = 1 AWS per 535 sq. km 50,362 sq. km 35 ARG = 1 ARG per 1,438 sq. km
Nagaland	IMD—10 AWS (out of which one is Agro AWS), 12 ARG ISRO—7 AWS (no recorded observations from 5 AWS)	Data not available	Skymet—17 AWS	16,579 sq. km (10+7+17) AWS = 1 AWS per 487 sq. km 16,579 sq. km 12 ARG = 1 ARG per 1,381 sq. km
Maharashtra	IMD—54 AWS (out of which eight are Agro AWS), 98 ARG, 2 DWR with one in Mumbai and one more in Nagpur ISRO—126 AWS(no recorded observations from 97 AWS)	Maharashtra government has collaborated with Skymet to instal 2,067 AWS around the state[205]	Skymet—2,067 AWS NCML—834 AWS	307,713 sq. km (54+126+2067+834) AWS = 1 AWS per 99 sq. km 307,713 sq. km 98 ARG = 1 ARG per 3,139 sq. km
Himachal Pradesh	IMD—23 AWS (out of which 4 are Agro AWS, 63 ARG ISRO—1 AWS (no recorded observation)	Data not available	Skymet—53 AWS NCML—74 AWS	55,673 sq. km (23+1+53+74) AWS = 1 AWS per 368 sq. km 55,673 sq. km 63 ARG = 1 ARG per 883 sq. km
Delhi	IMD—11 AWS (out of which one is Agro AWS, one ARG, 1 DWR (C-Band) ISRO—2 AWS	Data not available	Skymet—3 AWS	1,484 sq. km (11+2+3) AWS = 1 AWS per 92 sq. km 1,484 sq. km 2 ARG = 1 ARG per 742 sq. km

	Central government *(Source: IMD website, discussions with IMD regional centres, ISRO MOSDAC website, unless otherwise indicated)*	**State government**	**Private sector** *(Source: Discussions with company representatives and company website, unless otherwise indicated)*	**Density**
Haryana	IMD—26 AWS (out of which two are Agro AWS, 34 ARG)	Data not available	Skymet—48 AWS NCML—3 AWS	44,212 sq. km (26+48+3) AWS = 1 AWS per 574 sq. km 44,212 sq. km 34 ARG = 1 ARG per 1,300 sq. km
West Bengal	IMD—27 AWS (out of which six are Agro AWS, 34 ARG, 1 DWR in Kolkata (S-Band) ISRO—13 AWS(no recorded observations from 4 AWS)	Data not available	Skymet—21 AWS	88,752 sq. km (27+13+21) AWS = 1 AWS per 1454 sq. km 88,752 sq. km 34 ARG = 1 ARG per 2610 sq. km
Tamil Nadu	IMD—37 AWS (out of which 6 are Agro AWS, 70 ARG, 2 DWR with one in Karaikal and one in Chennai (S-Band) ISRO—84 AWS(no recorded observations from 82 AWS)	385 AWS[206]	Skymet—24 AWS NCML—13 AWS	130,058 sq. km (37+84+385+24+13) AWS = 1 AWS per 239 sq. km 130,058 sq. km 70 ARG = 1 AWS per 1857 sq. km
Chhattisgarh	IMD—19 AWS (out of which 3 are agro AWS), 34 ARG	Data not available	Skymet—23 AWS NCML—8 AWS	135,191 sq. km (19+23+8) AWS = 1 AWS per 2703 sq. km 135,191 sq. km 34 ARG = 1 ARG per 3976 sq. km
Mizoram	IMD—8 AWS (out of which 1 is Agro AWS, 14 ARG ISRO—5 AWS(no recorded observations from any)	Data not available	Skymet, NCML—No presence	21,081 sq. km (8+5) AWS = 1 AWS per 1621 sq. km 21,081 sq. km 14 ARG = 1 ARG per 1505 sq. km
Meghalaya	IMD—7 AWS (out of which one is Agro AWS, 9 ARG ISRO—16 AWS (no recorded observations from 11 AWS), 1 DWR in Cherrapunjee (S-Band)	Data not available	Skymet, NCML—No presence	22,720 sq. km (7+16) AWS = 1 AWS per 987 sq. km 22,720 sq. km 9 ARG = 1 ARG per 2524 sq. km
Sikkim	IMD—4 AWS, 5 ARG ISRO—19 AWS (no recorded observations from 18 AWS)	Data not available	Skymet, NCML—No presence	7,096 sq. km (4+19) AWS = 1 AWS per 308 sq. km 7,096 sq. km 5 ARG = 1 ARG per 1,419 sq. km

	Central government *(Source: IMD website, discussions with IMD regional centres, ISRO MOSDAC website, unless otherwise indicated)*	**State government**	**Private sector** *(Source: Discussions with company representatives and company website, unless otherwise indicated)*	**Density**
Arunachal Pradesh	IMD—16 AWS (out of which one is Agro AWS, 24 ARG) ISRO—34 AWS(no recorded observations from 17 AWS)	Data not available	Skymet, NCML—No presence	88,743 sq. km (16+34) AWS = 1 AWS per 1774 sq. km 88,743 sq. km 24 ARG = 1 ARG per 3697 sq. km
Goa	IMD—3 AWS, 6 ARG 1 DWR in Panaji (S-Band) ISRO—14 AWS(no recorded observations from 4 AWS)	Data not available	Skymet, NCML—No presence	3,702 sq. km (3+14) AWS = 1 AWS per 217 sq. km 3,702 sq. km 6 ARG = 1 ARG per 617 sq. km
Jammu and Kashmir	IMD—21 AWS (out of which five are Agro AWS, 12 ARG One DWR in Srinagar (X-Band)	Data not available	Skymet, NCML—No presence	101,387 sq. km 21 AWS = 1 AWS per 4827 sq. km 101,387 sq. km 12 ARG = 1 ARG per 8488 sq. km
Manipur	IMD—10 AWS (out of which one is Agro AWS, nine ARG ISRO—6 AWS(no recorded observations from any)	Data not available	Skymet, NCML—No presence	22,327 sq. km (10+6) AWS = 1 AWS per 1395 sq. km 22,327 sq. km 9 ARG = 1 ARG per 2480 sq. km
Tripura	IMD—4 AWS (out of which one is Agro AWS, 8 ARG 1 DWR in Agartala (S-Band) ISRO—5 AWS (no recorded observations from 4 AWS)	Data not available	Skymet—No presence	10,492 sq. km (4+5) AWS = 1 AWS per 1165 sq. km 10,492 sq. km 8 ARG = 1 ARG per 1311 sq. km
TOTAL	1,816 AWS (incl. planned) 1,350 ARG 25 DWR	4,108 AWS (incl. planned) 12,528 ARG (incl. planned)	5,863 Skymet AWS + 3,236 NCML AWS = 9,099 AWS 160 Skymet ARG	Grand total in country = 15,023 AWS 25 DWR 14,038 ARG Grand total density = 3,287,263 15,023 = 1 AWS per 218 sq. km 3,287,263 14,038 = 1 ARG per 234 sq. km

6.2 District-level advisories in different states

Assam

(Source: http://imdagrimet.gov.in/sites/default/files/daas_bulletin/3.%20Bongaigaon%20-AAS%20eng_38.pdf)

Regional Agricultural Research Station, Gossaigaon

Gramin Krishi Mausam Sewa

Agromet Advisory Service Bulletin Issued jointly by

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Agromet Advisory Service Bulletin for the district of Bongaigaon
(Period: 9th – 13th March, 2019)

Bulletin No. AAS-Gossaigaon/2019/ 020 — Date of issue:08/03/2019

Significant past weather for the preceding week	Weather forecast valid up to 13th March, 2019
No information available	In the coming 5 days **clear sky** will prevail; **No** rainfall is predicted from **9th to 13th March, 2019**. The maximum temperature predicted is **27-30°C** and minimum of **14-16°C**. The expected morning and evening RH will be **75-78%** & **26-29 %**, respectively. Mostly **North easterly** wind with a speed of **10-11 Kmph** is expected.

AGRO-METEOROLOGICAL ADVISORIES

Crop	Crop Stage	Diseases/pest	Advisories
Boro rice	Maximum tillering stage	Stem borer, sheath blight	Due to favourable infestation of stem borer may be observed in boro paddy crop, farmers may apply Chloropyriphos 20EC at the concentration of 0.02% solution @ 2ml per 10 litre of water. Spray Carbendazim @ 0.5g/lit or Hexaconazole 2ml/lit, one at the appearance of the sheath blight disease, another 10 days after the first spray.
Chilli	Transplanting	-	About 4-5 weeks old seedlings of chilli are to be transplanted in the field with a row to row and plant to plant spacing of 45cm X 45cm respectively. Irrigation water of 4cm depth at 18-20 days interval should be provided by surface flooding method in the crops which were planted during the previous years.
	Fruiting	Fruit rot	Spray Captan 50 WP 0.2% (@ 2 g/lit. of water) or Dofolatan 0.2% against Fruit rot or anthracnose disease.
Ahu rice (transplanted)	Sowing	-	Sowing of ahu rice may be continued in nursery bed. After seed selection seed should be soaked in fungicidal solution for 24 hours. One litre of fungicidal solution is required to treat one 1 kg of seeds. The solution may be prepared by mixing 2.5gm of Mancozeb or Captan in one litre of water.
Sugarcane (Spring planting)	Planting	Termites, red ants & white grubs	March is suitable for spring planting of sugarcane. Malathion 5% dust @20-25kg/ha should be applied in trench/furrows before planting to protect the attack of termites, red ants & white grubs.
Pointed Gourd	Planting	-	During this time when vines of pointed gourd start to crawl, earthing up should be done. Rice straw should be placed at the base of the plant which helps the vine to crawl and preserves the moisture in the soil, reduces the weed emergence and prevents the fruit from coming in contact with soil and get damaged.
Wheat	Heading stage	-	As there is no possibilities of getting rainfall in the coming 5 days, farmers are advised to apply second irrigation in wheat crop at heading stage i.e. 70-75 days after sowing.
Fishery	-	-	It is time to make ready the pond for new batch of fishes. Dry up the bottom of the pond for 15-20 days and remove the upper layer of the bottom soil, then plough it and add lime. After 7 -15 das of application of lime add cow-dung, mixed it properly. Again, 7-15 days after addition of cow-dung add fertilizer.

(Advisories prepared based on Medium range weather forecast received from RMC, Guwahati)

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Gujarat

(Source: http://imdagrimet.gov.in/sites/default/files/daas_bulletin/Agro_Advisory_Bulletin%20No_20_08.03.2019_English%20format.pdf)

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Agromet Advisory Bulletin & District wise weather forecasts of NORTH WEST ZONE "KACHCHH"District

Significant past weather for preceding week (05.03.2019 to 08.03.2019)

Sr. No.	Name of Parameter	Value
1	Highest Temperature (^{0}C)	032.0
2	Lowest Temperature (^{0}C)	013.8
3	Range of Relative humidity (%)	0 - 88
4	Range of Wind Speed (kmph)	00 - 6
5	Range of Cloud Cover (okta)	0 - 4

Weather forecast period: 09.03.2019 to 13.03.2019

Parameters	Day-1 09/03/19	Day-2 10/03/19	Day-3 11/03/19	Day-4 12/03/19	Day-5 13/03/19
Rainfall (mm)	0	0	0	0	0
Max. Temp trend (°C)	32	32	33	32	32
Min. Temp trend (°C)	18	19	17	17	17
Total Cloud Cover (Octa)	0	2	1	0	1
Max. Relative humidity (%)	76	59	71	64	51
Min. Relative humidity (%)	42	33	37	36	30
Wind Speed (Kmph)	16	11	21	14	19
Wind Direction (deg)	248	198	285	298	141

Weather summary:-

As per IMD forecast for next five days, sky will remain cloudy during three days and no rainfall during five days forecasted period would occur. Maximum and minimum temperatures will be in between 32^{0C}- 33^{0C} and 17^{0C} -19 ^{0C} respectively. Relative humidity will be in between 30– 76 % during the period. South-westerly wind will be blow with the speed of 11-21 km/hr.

Take preventive measures against occurrence and spread of aphids in standing crops. Carryout land preparation and procure the certified seeds and fertilizers for sowing of summer crops.

Agro meteorological Advisories:-

Under this anticipated weather condition the Agro meteorological Advisory Board suggests farmers to take following steps.

Karnataka

(Source: http://imdagrimet.gov.in/sites/default/files/daas_bulletin/CHICKBALLAPURA%20%20%2008.03.19-e.PDF)

UNIVERSITY OF AGRICULTURAL SCIENCE, BENGALURU
GRAMIN KRISHI MAUSAM SEWA(GKMS)
AMFU OF IMD, BENGALURU

AGROMET-ADVISORY BULLETIN Date: **08.03.2019**

Issued jointly by, UAS, Bengaluru & Indian Meteorological Department

The forecast is valid for Chikkaballapur district

Weather forecast (Valid from 9th March 2019 to 13th March 2019)

Parameters	09.03.19	10.03.19	11.03.19	12.03.19	13.03.19
Rainfall (mm)	0	0	0	0	0
Max Temp Trend (°C)	34	34	35	34	34
Min Temp Trend (°C)	21	21	21	20	20
Total cloud cover (octa)	2	2	1	2	2
Relative humidity (%)Max	70	65	66	70	71
Relative humidity (%)Min	60	60	60	60	60
Wind speed(Km/hr)	4	5	5	6	6
Wind Direction (Degrees)	276	221	186	173	171

Forecast summary:

No rain forecasted by IMD, Bangalore during next 5 days. The Maximum temperature ranges from 34.0-35.0°C and Minimum of 20.0-21.0°C. Relative humidity 65-71 % during morning hrs and 60 % during noon is expected. Wind speed is 4-6 km/hr.

Weather Based Agro Advisories

Crop information and Crop Stages of the major Kharif/Rabi crops

District	*Kharif crops*			*Horticulture crops*	
Bangalore (U)	Ragi	Redgram	Maize	Grape	Mango
	-	-	-	-	-

G: Germination, **S**: Sowing, **EV**: Early vegetative, **VG**: Vegetative growth, TR: Tranplanting, **PI**: Peg initiation, **FLI**: Flag leaf initiation, **F:** Flowering, **PF**: Pod formation, **PM**: Pod Maturity, T: Tillering,, Ts: Taselling, **E**: Ear head emergence, **GF**: Grain filling, **H**: Harvesting **IBI**: Inflorescence Bud initiation , **PP(V)**: Pod Picking Vegetable , **F& FS**: Flowering to fruit setting, **FD**: Fruit Development, **H:** Harvesting, **M**: Maturation, B: Branching

Agromet Advisory:

Crop	Stage/ Condition	Pest and Disease	Agro advisories
	Agriculture crop		
Rabi crops	Poorvabhadra rainstar starts from March 4th and remains up to March 17th . The normal rainfall of Poorvabhadra rainstar is 8.5 mm. The grains of the harvested crops should be properly dried by retaining moisture percentage to 11-12 % in Cereals, 9% in Pulses, 8% in Oilseeds and 5-6% in Vegetable seeds for long storage & to minimize the store pest damage. In already harvested fields the farmers are advised to remove the half cutted stubbles of pigeon pea from their fields. This will avoid multiplication and spreading of sterility mosaic disease		
	Provide irrigation, as the fruits are in marble stage, this will helps for the better development of fruits. If sufficient water is available, irrigation can be given at 15-20 days interval starting from fruit setting till maturity. Due to continuous dry spell since October month, the termite attack is common in horticulture and Forestry tree and shrubs hence control to apply Aldrin termicides for control of termites. Spray Lamda Cyhalothrin 5EC @ 0.5 ml/ litre of water or sulphur dust (SULTAF) 80 W @3g/litre of water against the Powdery mildew diseases.		
	Animal Husbandry		
Dairy	Livestock management during summer:		

Kerala

(Source: http://www.kau.in/sites/default/files/aasreports/ekm_eng_10_bulletin_vab.pdf)

Kerala Agricultural University, Vellanikkara, Thrissur
Department of Agricultural Meteorology, College of Horticulture
Email: cohagmet@kau.in & kauagmet@yahoo.co.in
Agromet Advisory Service Bulletin
(Issued jointly by AMFU Thrissur, India Meteorological Department and Department of Agriculture)

ERNAKULAM DISTRICT

AAS 10/2019(20), Friday **08.03.2019**

CURRENT SYNOPTIC SITUATION: A cyclonic circulation lies over Comorin area & neighbourhood at 1.5 km above mean sea level. Another cyclonic circulation at 0.9 km above mean sea level lies over Southeast Arabian Sea off Kerala coast.

WEATHER FORECAST FOR THE NEXT FIVE DAYS:

Weather parameters	09.03.2019	10.03.2019	11.03.2019	12.03.2019	13.03.2019
Rainfall (mm)	0	0	0.5	0	0.1
Maximum temperature (°C)	33	33	33	33	33
Minimum temperature (°C)	26	26	26	26	26
Total cloud cover (octa)	3	4	6	5	3
Maximum Relative Humidity (%)	85	85	85	85	85
Minimum Relative Humidity (%)	65	65	65	65	65
Wind speed (kmph)	6	6	6	6	6
Wind direction (deg)	320	320	320	320	320
No rainfall is forecasted for coming five days in the district by India Meteorological Department.					

AGRO-METEOROLOGICAL ADVISORIES:

Crop	Crop stage	Pest/ Disease	Advisories
Coconut	-	Management	Since air temperature is increasing, it is desirable practice to bury fresh or dried coconut husk around the palm to conserve soil moisture. The husk can be buried either in linear trenches taken 3 m away from the trunk between rows of palms or in circular trenches taken around the palm at a distance of 2 m from the trunk. The trenches may be of 0.5 m width and depth. The husks are to be placed in layers with concave surface facing upwards and covered with soil. The beneficial effect of husk burial will last for about 5-7 years. Instead of husk, coir pith can be buried @ 25 kg / palm/ year.
Banana	-	Sigatoka disease	During this special weather condition, there is a chance of Sigatoka disease in banana. As a precaution, Spray 20 g *Pseudomonas* per one litre of water.
Vegetables (cowpea)	Fruiting stage	Stunted growth	Due to the increase in atmospheric temperature, the attack of insects such as thrips, mite and white flies etc. are more. As a result of this, there is a chance of stunted growth in vegetables. They can be controlled by applying 10 gms of Verticillium in 1 litre of water or neem based insecticides can be applied.
Animal Husbandry	Assure increased ventilation in the shed. (**CAADECCS, KVASU, Mannuthy**)		

Notes and references

1. FAO. 'India at a glance'. Available at: http://www.fao.org/india/fao-in-india/india-at-a-glance/en/
2. FAO. 'FAO's work on climate change'. Available at: http://www.fao.org/climate-change/en/
3. FAO. 2018. 'The State of Agricultural Commodity Markets'. Available at: http://www.fao.org/3/I9542EN/i9542en.pdf
4. Ibid.
5. *The Economic Times*. 'Is climate change the culprit behind floods and farming woes'. Available at: https://economictimes.indiatimes.com/news/politics-and-nation/is-climate-change-the-culprit-behind-floods-and-farming-woes/articleshow/60342865.cms; *The Guardian*. 2017. 'Suicides of nearly 60,000 Indian farmers linked to climate change, study claims'. Available at: https://www.theguardian.com/environment/2017/jul/31/suicides-of-nearly-60000-indian-farmers-linked-to-climate-change-study-claims
6. Ruchita S., and Rohit S. 2017. 'Effect of global warming on Indian agriculture'. *Journal of Climateology and Weather Forecasting*. Available at: https://www.omicsonline.org/open-access/effect-of-global-warming-on-indian-agriculture-2332-2594-1000195.php?aid=88308
7. Sourav Mukherjee et al. 2018. 'Increase in extreme precipitation events under anthropogenic warming in India'. Available at: https://www.sciencedirect.com/science/article/pii/S2212094717301068
8. Ruchita S., and Rohit S. 2017. 'Effect of global warming on Indian agriculture'. *Journal of Climateology and Weather Forecasting.* Available at: https://www.omicsonline.org/open-access/effect-of-global-warming-on-indian-agriculture-2332-2594-1000195.php?aid=88308
9. Akshit Sangomla. 2018. 'Floods damage 55,000 houses, kill 511 people this monsoon'. *Down to Earth*. Available at: https://www.downtoearth.org.in/news/natural-disasters/floods-damage-55-000-houses-kill-511-people-this-monsoon-61168
10. Ankur Nagar. 2018. 'How much do floods cost India?' *Medium.* Available at: https://medium.com/world-of-opportunity/how-much-do-floods-cost-india-4a9446117f71
11. *Asia Insurance Review.* 2018. 'India: Economic losses from Kerala floods total at least US$4.25bn'. Available at: http://www.asiainsurancereview.com/News/View-NewsLetter-Article/id/44165/Type/eDaily/India-Economic-losses-from-Kerala-floods-total-at-least-US-4-25bn
12. Rounak Kumar Gunjan. 2018. 'No Coffee, No Pepper: Kerala Farmers Hopeless as Floods Wash Off Entire Year's Crops'. News 18. Available at: https://www.news18.com/news/india/no-coffee-no-pepper-kerala-farmers-hopeless-as-floods-wash-off-entire-years-crops-1851359.html
13. Xiang Zhang, Renee Obringer, Chehan Wei, Nengcheng Chen and Dev Niyogi. 2017. 'Droughts in India from 1981 to 2013 and Implications to Wheat Production'. Scientific reports. Available at: https://www.nature.com/articles/srep44552
14. Chandra Prakash Kala. 2017. 'Environmental and Socioeconomic Impacts of Drought in India: Lessons for Drought Management'. Applied Ecology and Environmental Sciences. Available at: http://pubs.sciepub.com/aees/5/2/3/
15. Ruchita S., and Rohit S. 2017. 'Effect of global warming on Indian agriculture'. *Journal of Climateology and Weather Forecasting.* Available at: https://www.omicsonline.org/open-access/effect-of-global-warming-on-indian-agriculture-2332-2594-1000195.php?aid=88308

16. *The Guardian.* 2016. 'Indian drought 'affecting 330 million people' after two weak monsoons'. Available at: https://www.theguardian.com/world/2016/apr/20/india-drought-affecting-330-million-people-weak-monsoons
17. *Indian Express*. 2016. 'Rs 6,50,000 crore: That's the impact the drought will have on the Indian economy, says Assocham'. Available at: https://indianexpress.com/article/business/economy/rs-650000-crore-thats-the-impact-the-drought-will-have-on-the-indian-economy-says-assocham/
18. Rishi Iyengar. 2016. 'More Than 300 Million People in India Are Reeling From the Worst Drought in Four Decades'. *Time.* Available at: http://time.com/4309156/india-maharashtra-drought-water/
19. *DNA India*. 2016. 'Maharashtra drought-impact: Agricultural sector to decline by 2.7per cent'. Available at: https://www.dnaindia.com/india/report-maharashtra-drought-impact-agricultural-sector-to-decline-by-27-2190448
20. *The Lancet.* 2018. 'Lancet Countdown 2018 Report: Briefing for Indian Policymakers'. Available at: http://www.lancetcountdown.org/media/1421/2018-lancet-countdown-policy-brief-india.pdf
21. Ruchita S., and Rohit S. 2017. 'Effect of global warming on Indian agriculture'. *Journal of Climateology and Weather Forecasting.* Available at: https://www.omicsonline.org/open-access/effect-of-global-warming-on-indian-agriculture-2332-2594-1000195.php?aid=88308
22. National Disaster Management Authority. 'Cyclones and their Impact in India'. Available at: https://ncrmp.gov.in/cyclones-their-impact-in-india
23. *Indian Express*. 2018. 'Cyclone Gaja damaged nearly 1 crore coconut trees, 70,000 farmers hit: Tamil Nadu'. Available at: https://indianexpress.com/article/india/cyclone-gaja-damaged-nearly-1-crore-coconut-trees-70000-farmers-hit-tamil-nadu-5477078/
24. *The Times of India.* 2018. 'Cyclone Gaja destroyed banana plants on 20,000 acres of land in TN and loss estimated at Rs 500 crore, NCRB says'. Available at: https://timesofindia.indiatimes.com/city/chennai/cyclone-gaja-destroyed-banana-plants-on-20000-acres-of-land-in-tn-and-loss-estimated-at-rs-500-crore-nrcb-says/articleshow/66754229.cms
25. J. Singla and S.G. Krattinger. 2016. 'Biotic Stress Resistance Genes in Wheat'. Reference Module in Food Science. Available at: https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/biotic-stress
26. Damian Carrington. 2018. 'Crop losses to pests will soar as climate warms, study warns'. Available at: https://www.theguardian.com/environment/2018/aug/30/crop-losses-to-pests-will-soar-as-climate-warms-study-warns
27. Latief Ahmad, Raihana Habib Kanth, Sabah Parvaze, and Syed Sheraz Mahdi. 2017. 'Agro Meteorological Advisory Service'. Experimental Agrometerology: A Practical Manual. Available at: https://link.springer.com/chapter/10.1007/978-3-319-69185-5_17
28. WMO. 2017. 'Guidelines on the Role, Operation and Management of National Meteorological and Hydrological Services'. Available at: https://library.wmo.int/doc_num.php?explnum_id=4221
29. Ingrid Nesheim, Line Barkved and Neha Bharti. 2017. What Is the Role of Agro-Met Information Services in Farmer Decision-Making? Uptake and Decision-Making Context among Farmers within Three Case Study Villages in Maharashtra, India. Agriculture. Available at https://www.mdpi.com/2077-0472/7/8/70.
30. Latief Ahmad, Raihana Habib Kanth, Sabah Parvaze, and Syed Sheraz Mahdi. 2017. 'Agro Meteorological Advisory Service'. *Experimental Agrometerology: A Practical Manual.* Available at: https://link.springer.com/chapter/10.1007/978-3-319-69185-5_17
31. B. Espinosa, T.V. Hromadka, and R. Perez. 2015. 'Comparison of radar data versus rainfall data'. MethodsX. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4644244/

32. Discussions with expert in agrometeorology and expert in agricultural science and administration; IMD, 'ARG Network'. Available at http://aws.imd.gov.in/ currently shows 573 AWSs, but this is possibly because of lack of regular updates.
33. Discussion with expert in agrometeorology.
34. Data from AWS around the country is published in searchable form by the IMD at http://aws.imd.gov.in/
35. IMD. 'Network of Observatories'. Available at: http://www.imdagrimet.gov.in/node/97 .This number was initially 130, and the data available online from the agromet observatory network currently covers only 130 stations (aws.imd.gov.in). This covered each of the country's approximately 130 agro-climatic zones, which were delineated based on regional weather and crop profile, while taking into account administrative divisions. A full list of zones is available at IMD. 'Agroclimatic Zones of India'. http://www.imdagrimet.gov.in/node/3535
36. Manish Ranalkar, R.P. Mishra, U.K. Shende, R.D. Vashistha. 'Establishing a network of 550 automatic weather stations and 1350 Automatic rain gauge stations across India'. Available at: https://www.researchgate.net/publication/228907734_ESTABLISHING_A_NETWORK_OF_550_AUTOMATIC_WEATHER_STATIONS_AND_1350_AUTOMATIC_RAIN_GAUGE_STATIONS_ACROSS_INDIA_SCHEME (although only the soil-related data is available on the IMD's website).
37. IMD. 'Network of Observatories'. Available at: http://www.imdagrimet.gov.in/node/97
38. IMD. ' IMD Radar Network'. Available at: http://www.imd.gov.in/pages/services_radar.php ; IMD, 'Frequently Asked Questions on Radar and their answers'. Available at http://www.imd.gov.in/section/dwr/dynamic/radarfaq.pdf
39. *LiveMint*. 2018. 'IMD to add 30 doppler radars in country'. Available at: https://www.livemint.com/Science/VIlUXxg4fhF9JaYceFsbYI/IMD-to-add-30-Doppler-radars-in-country.html
40. IMD. 'Upper air meteorological Instrumentation'. Available at: http://www.imd.gov.in/pages/services_ui.php; and KC Sai Krishnan, Ranju Madan, and Ajit Tyagi. 'Modernisation of Observational Network of Indian Meterological Department'. Available at: https://www.wmo.int/pages/prog/www/IMOP/publications/IOM-104_TECO-2010/P5_10_Krishnan_India.doc
41. Which comprised/s around 530 surfaceobservatories,45 radiation observatories, 10 airpollution monitoring observatories, 62 Pilot Balloons, 39 Radiosonde and Radiowindobservatories, 219 agro-meteorological observatories and more than 700 hydro-meteorologicalobservatories. There are still additions being made to this manual data collection network, such as in Uttarakhand in 2016 (Gaurav Talwar. 2016. IMD to set up 16 surface meteorological observatories in Uttarakhand. Available at: https://timesofindia.indiatimes.com/city/dehradun/IMD-to-set-up-16-surface-meteorological-observatories-in-Uttarakhand/articleshow/50868294.cms), but, in general, the IMD's website and its officials emphasize the newer automated technology as the crux of their network.
42. Manish Ranalkar, R.P. Mishra, U.K. Shende, R.D. Vashistha. 'Establishing a network of 550 automatic weather stations and 1350 Automatic rain gauge stations across India'. Available at: https://www.researchgate.net/publication/228907734_ESTABLISHING_A_NETWORK_OF_550_AUTOMATIC_WEATHER_STATIONS_AND_1350_AUTOMATIC_RAIN_GAUGE_STATIONS_ACROSS_INDIA_SCHEME
43. Government of India, 'Districts'. Available at http://www.goidirectory.gov.in/district.php
44. Press Information Bureau. 2019. 'Govt. to launch an end-to-end prediction system for predicting thunderstorms/lightning by April 2019 - Indian Meteorological Department Strengthening Its Observational Network'. Available at: http://pib.nic.in/newsite/PrintRelease.aspx?relid=187488

45. Ibid; *LiveMint*. 2018. 'IMD to add 30 doppler radars in country'. Available at: https://www.livemint.com/Science/VIlUXxg4fhF9JaYceFsbYI/IMD-to-add-30-Doppler-radars-in-country.html
46. National Disaster Management Authority. 2018. 'Guidelines for Thunderstorm & Lightning / Squall/ Dust/hailstorm and Strong wind'. Available at: https://ndma.gov.in/images/pdf/Draft-Guidelines-thunderstorm.pdf
47. Anjali Marar. 2018. 'When lightning strikes, IITM's new app will ensure you are a safe distance away'. *Indian Express*. Available at: https://indianexpress.com/article/india/when-lightning-strikes-iitms-new-app-will-ensure-you-are-a-safe-distance-away-5451902/
48. Press Information Bureau. 2017. 'Ocean Observation System'. Available at: R. Venkatesan, JK Lix, A Phanindra Reddy, M. Arul Muthiah and M.A. Atmanand. 'Two decades of operating the Indian moored buoy network: significance and impact'. Available at: http://pib.nic.in/newsite/PrintRelease.aspx?relid=169321
49. Ibid.
50. Ibid.
51. ISRO. 'RAPID: Gateway to Indian Weather Satellite Data'. Available at: https://www.isro.gov.in/rapid-gateway-to-indian-weather-satellite-data; Press Information Bureau. 2016. 'GSLV Successfully Launches India's Weather Satellite INSAT-3DR'. Available at: http://pib.nic.in/newsite/PrintRelease.aspx?relid=149636;
52. ISRO. 2011. 'Megha-Tropiques'. Available at: https://www.isro.gov.in/Spacecraft/megha-tropiques
53. M.B. Maramkal. 2012. 'Karnataka first state to adopt telemetric rain gauging system'. The Times of India. Available at: https://timesofindia.indiatimes.com/city/mysuru/Karnataka-first-state-to-adopt-telemetric-rain-gauging-system/articleshow/17144186.cms
54. Government of Karnataka. 'Details of Telemetric 'Raingauges installed and Commissioned as on 02-07-2014' Available at: http://dmc.kar.nic.in/List_Trg.pdf. The list is from 2014 and has not been officially updated by the State Government. According to representatives from Skymet, the current number is closer to 5000.
55. Discussion with Skymet representatives.
56. Tamil Nadu Agricultural University. 'Establishment of Automatic Weather Station in 224 Blocks of Tamil Nadu'. Available at: http://agritech.tnau.ac.in/govt_schemes_services/govt_serv_schems_nadp_tnau%20_automaticweatherstation.html
57. Tamil Nadu Agricultural University. Available at: http://tawn.tnau.ac.in/General/HomePublicUI.aspx
58. United News of India. 2016. 'Uttarakhand to follow Karnataka model for advance weather warning system'. Available at: http://www.uniindia.com/uttarakhand-to-follow-karnataka-model-for-advance-weather-warning-system/states/news/583816.html; Gaurav Talwar. 2016. 'U'khand to establish own rain monitoring, weather forecasting system'. *The Times of India*. Available at: https://timesofindia.indiatimes.com/city/dehradun/Ukhand-to-establish-own-rain-monitoring-weather-forecasting-system/articleshow/52944649.cms
59. *The New Indian Express*. 2017. 'Weather stations to combat drought in State'. Available at: http://www.newindianexpress.com/states/odisha/2017/jul/25/weather-stations-to-combat-drought-in-state-1633209.html
60. India Today. 2017. 'Maharashtra becomes first Indian state to use Automated Weather Stations for farmers'. Available at: https://www.indiatoday.in/education-today/gk-current-affairs/story/maharashtra-first-indian-state-to-use-automatic-weather-stations-974573-2017-05-01 ; The Times of India. 2018. '2,000 auto weather stations in Maharashtra to give village-level updates'. Available at: https://timesofindia.indiatimes.com/city/mumbai/2000-auto-weather-stations-in-maharashtra-to-give-village-level-updates/articleshow/64250260.cms; Skymet Weather. 2018. 'Govt. of Maharashtra, Skymet join hands for agriculture sustenance through new age technology'. Available at: https://www.skymetweather.com/

content/weather-news-and-analysis/govt-of-maharashtra-skymet-join-hands-for-agriculture-sustenance-through-new-age-technology/

61. https://economictimes.indiatimes.com/news/politics-and-nation/weather-forecasting-in-times-of-extreme-weather-events/articleshow/69805112.cms
62. The corresponding organization for ocean-focused forecasting is the Indian National Centre for Ocean Information Services (NCOIS), which provides forecasts of the height, direction and period (of both wind waves and swell waves); sea surface currents; sea surface temperature; Mixed Layer Depth (the well mixed upper layer of the sea); depth of the 20 degree isotherm (a measure of the depth of the thermocline; astronomical tides; wind speed and direction; and oil-spill trajectory. It also provides more detailed forecast information for specific locations like fish landing centres, small fishing harbours, commercial ports, etc. as well as for the coastal waters of the maritime states, union territories and island regions of India. The forecasts are generated by a suite of numerical models, which are customized to simulate and predict Indian Ocean features accurately. The models used include WAVEWATCH III, MIKE and Regional Ocean Modeling System (ROMS) and General NOAA Oil Modeling Environment (GNOME). (M. Mohapatra. 2018. 'Contributions of IMD (supported by NCMRWF & INCOIS) as global centre'. Available at: http://www.wmo.int/pages/prog/www/BAS/documents/Doc-4-1-2-IMDcontributions.doc)
63. IMD. 2017. 'Forecast Demonstration Project (FDP) for Improving Heat Wave Warning over India'. Available at: http://nwp.imd.gov.in/heatwave-imp-rep_final-2017.pdf ; M. Mohapatra. 2018. 'Contributions of IMD (supported by NCMRWF & INCOIS) as global centre'. Available at: http://www.wmo.int/pages/prog/www/BAS/documents/Doc-4-1-2-IMDcontributions.doc
64. IMD. 2017. 'Forecast Demonstration Project (FDP) for Improving Heat Wave Warning over India'. Available at: http://nwp.imd.gov.in/heatwave-imp-rep_final-2017.pdf ; M. Mohapatra. 2018. 'Contributions of IMD (supported by NCMRWF & INCOIS) as global centre'. Available at: http://www.wmo.int/pages/prog/www/BAS/documents/Doc-4-1-2-IMDcontributions.doc
65. IMD. 2019. 'Celebration of 144th Foundation Day of India Meteorological Department (IMD) at Dr. Ambedkar International Centre, 15 Janpath Road, New Delhi on 15th January 2019'. Available at: .http://www.imd.gov.in/press_release/20190114_pr_403.pdf
66. IMD. 2019. 'Celebration of 144th Foundation Day of India Meteorological Department (IMD) at Dr. Ambedkar International Centre, 15 Janpath Road, New Delhi on 15th January 2019'. Available at: .http://www.imd.gov.in/press_release/20190114_pr_403.pdf; M. Mohapatra. 2018. 'Contributions of IMD (supported by NCMRWF & INCOIS) as global centre'. Available at: http://www.wmo.int/pages/prog/www/BAS/documents/Doc-4-1-2-IMDcontributions.doc
67. IMD. 2019. 'Celebration of 144th Foundation Day of India Meteorological Department (IMD) at Dr. Ambedkar International Centre, 15 Janpath Road, New Delhi on 15th January 2019'. Available at: .http://www.imd.gov.in/press_release/20190114_pr_403.pdf
68. M. Mohapatra. 2018. 'Contributions of IMD (supported by NCMRWF & INCOIS) as global centre'. Available at: http://www.wmo.int/pages/prog/www/BAS/documents/Doc-4-1-2-IMDcontributions.doc
69. IMD. 'Climate Forecast System'. Available at: http://www.imdpune.gov.in/Clim_Pred_LRF_New/Models.html
70. Ankur Paliwal. 2018. 'Why India Struggles to Predict the Weather Over Its Lands'. The Wire. Available at: https://thewire.in/environment/imd-weather-prediction-forecast-monsoons-drought-agrometeorology-kharif
71. Statement by KJ Ramesh (Director, IMD) at INAGMET-2019.
72. Parvinder Maini and Swati Basu. 2016. Economic impact of the agro meteorological advisory services of Ministry of Earth Sciences—A review. Accessed at: http://

metnet.imd.gov.in/mausamdocs/167125_F.pdf
73. M. Mohapatra. 2018. ‘Contributions of IMD (supported by NCMRWF & INCOIS) as global centre’. Available at: http://www.wmo.int/pages/prog/www/BAS/documents/Doc-4-1-2-IMDcontributions.doc
74. P. Mukhopadhyay, Medha Deshpande, R. Phani Murali Krishna, Malay Ganai, Snehlata Tirkey, Sahadat Sarkar, Tanmoy Goswami, Shilpa Malviya, Kumar Roy, Radhika Kanase and Greeshma Mohan. ‘Performance of High Resolution Weather Prediction Models (GFS T1534 and DEFS T574): Indian Summer Monsoon and Tropical Cyclone’. Available at: https://www.tropmet.res.in/~MOES/rac-2018/poster_rac2018%20Jan_MedhaSnehlata.pdf ; and discussion with meteorology expert.
75. M. Mohapatra. 2018. ‘Contributions of IMD (supported by NCMRWF & INCOIS) as global centre’. Available at: http://www.wmo.int/pages/prog/www/BAS/documents/Doc-4-1-2-IMDcontributions.doc
76. M. Mohapatra. 2018. ‘Contributions of IMD (supported by NCMRWF & INCOIS) as global centre’. Available at: http://www.wmo.int/pages/prog/www/BAS/documents/Doc-4-1-2-IMDcontributions.doc
77. Discussion with Skymet representatives.
78. Kavya Narayanan. 2019. ‘Sky’s the Limit: Could Skymet soon become India’s go-to monsoon forecaster?’. *First Post.* Available at: https://www.firstpost.com/tech/science/skys-the-limit-could-skymet-soon-become-indias-go-to-monsoon-forecaster-5297851.html; SkymetWeather. 2015. ‘CEO’s Take: Why Skymet Weather went wrong with its Monsoon forecast this year’. Available at: https://www.skymetweather.com/content/weather-news-and-analysis/ceos-take-why-skymet-weather-went-wrong-with-its-monsoon-forecast-this-year/
79. Rediff. 2016. ‘How Skymet weathered the storm’. Available at: https://www.rediff.com/business/special/special-amazing-story-of-how-skymet-weathered-the-storm/20160810.htm
80. SkymetWeather. 2018. ‘Govt. of Maharashtra, Skymet join hands for agriculture sustenance through new age technology’. Available at: https://www.skymetweather.com/content/weather-news-and-analysis/govt-of-maharashtra-skymet-join-hands-for-agriculture-sustenance-through-new-age-technology/
81. Skymet Weather. 2018. ‘USAID and Skymet Brings Agricultural Transformation’. Available at: https://www.skymetweather.com/content/weather-news-and-analysis/usaid-and-skymet-brings-agricultural-transformation/
82. Archita Bhatta and Rohini Rangarajan. 2015. The Weather Mart. *Down to Earth*. Available at: https://www.downtoearth.org.in/coverage/the-weather-mart-3619
83. NCML. ‘Commodity and Weather Intelligence and Consultancy’. Available at: http://www.ncml.com/services/marketing#station ; Archita Bhatta and Rohini Rangarajan. 2015. The Weather Mart. *Down to Earth*. Available at: https://www.downtoearth.org.in/coverage/the-weather-mart-3619
84. Archita Bhatta and Rohini Rangarajan. 2015. The Weather Mart. *Down to Earth*. Available at: https://www.downtoearth.org.in/coverage/the-weather-mart-3619 ; INGEN Technologies. INGEN AWS Grid. Available at: https://weather-risk.com/StatusRpt/IngenAWSGrid.aspx?Country=0&&StateID=0&&BlockSize=5.0&&Srce=RDM ; INGEN Technologies. 2014. ‘INGEN AWS’. Available at: https://www.weather-risk.com/WeatherSensor/SensorPdf/IngenAWS%20Brochure%20V6.01_1.pdf
85. https://www.wunderground.com/pws/overview
86. IBM: The Weather Company. 2019. ‘New Weather System Will Provide Vastly Improved Forecasting Around the World’. Available at: https://business.weather.com/blog/new-weather-system-improved-forecasting-around-the-world ; response by IBM representatives to mailed questionnaire.
87. IBM: The Weather Company. 2019. ‘New Weather System Will Provide Vastly Improved Forecasting Around the World’. Available at: https://business.weather.

com/blog/new-weather-system-improved-forecasting-around-the-world
88. Response by IBM representatives to mailed questionnaire; https://www.thehindubusinessline.com/economy/agri-business/ibms-the-weather-company-ramps-up-engagement-with-govt-private-sector/article29698282.ece
89. Anil Rai. 'Crop Area and Production Surveys'. Accessed at: http://www.iasri.res.in/ebook/EB_SMAR/e-book_pdf%20files/Manual%20III/17-Crop%20Estimation.pdf
90. Ministry of Statistics and Programme Implementation. 'Agricultural Statistics'. Accessed at: http://mospi.nic.in/23-agricultural-statistics
91. Ibid.
92. L.S. Rathore and N. Chattopadhyay. 2016. 'Weather and Climate Services for Farmers in India'. Accessed at: https://public.wmo.int/en/resources/bulletin/weather-and-climate-services-farmers-india; P. Maini and S. Basu. 2016. 'Economic Impact of the Agrometerological Services of the Ministry of Earth Sciences – A Review' Accessed at: http://metnet.imd.gov.in/mausamdocs/167125_F.pdf
93. 'KVK Recruitment 2019—Apply for Subject Matter Specialists'. Accessed at: https://www.indgovtjobs.in/2016/03/Krishi-Vigyan-Kendra-Recruitment.html
94. India Meteorological Department. 2016. 'GKMS-News Quarterly Newsletter Volume–4, Number-1, January-March, 2016'. Accessed at: http://www.imd.gov.in/advertisements/20160530_advt_25.pdf
95. Indian Council of Agricultural Research. 'Agricultural Extension Division'. Accessed at: https://www.icar.org.in/content/agricultural_extension_division
96. Ibid.
97. Discussion with expert in agricultural extension.
98. Discussion with crop science expert. Each KVK costs about Rs 1–2 crore to set up.
99. Discussion with expert in agricultural extension.
100. India Meteorological Department. 2015. 'Memorandum of Understanding between India Meteorological Department (Ministry of Earth Sciences and Indian Council of Agricultural Research for Establishment of District Agromet Units, Automatic Weather Stations, Data Sharing and Promoting Agro Advisories'. Accessed at: http://14.139.123.73/bhoomigeoportal/publication_pdf/Mou/MoU%20with%20IMD.pdf
101. Ibid.; discussion with expert in agricultural extension. Two personnel are to be hired at each KVK—one expert and one observer, whose monthly salaries are advertised as approximately Rs 50,000 and Rs 20,000 respectively. Calls have been put out for people qualified in agrometeorology, meteorology, soil physics, or agronomy (in that order). Agrometeorology is the most specialized and preferred area of expertise; the other specialties are agromet adjacent, and candidates with that expertise will be considered in case an agrometeorologist is not available.
102. K.M. Singh et al. 2009. 'Agricultural Technology Management Agency (ATMA): A Study of its Impact in Pilot Districts in Bihar, India'. Accessed at: https://mpra.ub.uni-muenchen.de/45549/8/MPRA_paper_45549.pdf
103. Ibid.
104. 'Agricultural Technology Management Agency'. Accessed at: http://www.manage.gov.in/publications/series2.pdf
105. Ibid.
106. A. Gulati et al. 2018. 'Agriculture Extension System in India: Review of Current Status, Trends and the Way Forward'. Accessed at: http://www.indiaenvironmentportal.org.in/files/file/Agriculture-Extension-System-in-India-2018.pdf
107. 'Guidelines for the Centrally Sponsored Scheme "National Mission on Agricultural Extension and Technology (NMAET)" to be implemented during the XII Plan'. Accessed at: http://krishivistar.gov.in/html/Doc/atmaguid23814.pdf
108. WOTR. 2013. 'AGRO-MET- Information Brief'. Available at: https://www.wotr.org/sites/default/files/AGROMET-6.9.13.pdf

109. Discussions with Pankaj Dwivedi of Agrostar.
110. Inc42. 2018. 'Karnataka Government Partners With CropIn For Data Driven Farming'. Accessed at: https://inc42.com/buzz/karnataka-government-partners-with-cropin-for-data-driven-farming/
111. SME Street. 2019. 'CropIn Concludes Partners With Central Government to Bring Efficiency in Agriculture Through Technologies'. Accessed at: https://smestreet.in/limelight/agri-news-cropin-concludes-partners-with-central-government-to-bring-efficiency-in-agriculture/
112. Pankaj Mishra. 2019. How the smartphone is changing farming in Bihar. Accessed at: https://timesofindia.indiatimes.com/home/sunday-times/how-smartphone-is-changing-farming-in-bihar/articleshow/68951960.cms ; Priti Kumar. 2017. Bringing technology to the doorsteps of India's smallholder farmers for climate resilience. Accessed at: https://blogs.worldbank.org/publicsphere/bringing-technology-doorsteps-india-s-smallholder-farmers-climate-resilience .
113. Discussions with Crop In representatives Kunal Prasad and Richa Hukumchand.
114. Ibid.
115. *Business Standard.* 2015. 'Skymet looks beyond blue skies'. Available at: https://www.business-standard.com/article/current-affairs/skymet-looks-beyond-blue-skies-115102701494_1.html
116. Ingrid Nesheim, Line Barkved and Neha Bharti. 2017. What Is the Role of Agro-Met Information Services in Farmer Decision-Making? Uptake and Decision-Making Context among Farmers within Three Case Study Villages in Maharashtra, India. Agriculture. Available at https://www.mdpi.com/2077-0472/7/8/70.
117. Ibid.
118. Press Information Bureau. 2015. Weather Forecast Services. Available at: http://pib.nic.in/newsite/PrintRelease.aspx?relid=124975
119. Dhruba Dasgupta. 2016. Extreme climate warnings save farm losses. India Climate Dialogue. Available at https://indiaclimatedialogue.net/2016/08/22/extreme-climate-warnings-save-farm-losses/
120. K.K. Singh. Weather Forecasting Services in India. Available at: http://www.iasri.res.in/ebook/TEFCPI_sampling/WEATHER%20FORECASTING%20AND%20AGROMET%20ADVISORY%20SERVICES%20IN%20INDIA.pdf .; Kalpana Venkatasubramanian, Arame Tall, James Hansen and Pramod Aggarwal. 2014. Assessment of India's Agro-Meteorological Advisory Service from a farmer perspective. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org
121. *Indian Express.* 2018. 'A decade on, IMD introduces block-level farmer advisories in 200 blocks'. Accessed at: https://indianexpress.com/article/cities/pune/a-decade-on-imd-introduces-block-level-farmer-advisories-in-200-blocks-5282866/ . Presentation by Dr. K J Ramesh (IMD) at INAGMET-2019.
122. Discussions with Deputy Director of Agriculture, Punjab Agriculture Department; Director, West Bengal State Agricultural Management and Extension Training Institute (SAMETI); and Assistant Director of Agriculture, Tamil Nadu.
123. V.K. Sajesh and A. Suresh. 2016. 'Public-Sector Agricultural Extension in India: A Note'. Accessed at: http://www.ras.org.in/public_sector_agricultural_extension_in_india. This analysis includes extension personnel employed with the State and Union Governments.
124. Ibid.
125. Discussions with Deputy Director of Agriculture, Punjab Agriculture Department; Director, West Bengal State Agricultural Management and Extension Training Institute (SAMETI); and Assistant Director of Agriculture, Tamil Nadu.
126. Ibid.
127. Ingrid Nesheim, Line Barkved and Neha Bharti. 2017. What Is the Role of Agro-Met Information Services in Farmer Decision-Making? Uptake and Decision-Making Context among Farmers within Three Case Study Villages in Maharashtra, India.

Agriculture. Available at https://www.mdpi.com/2077-0472/7/8/70.
128. Ibid.
129. IFFCO Kisan. 2017. Available at: http://www.iffcokisan.com/
130. IFFCO Kisan. 2017. AgroICT Services. Available at: http://www.iffcokisan.com/home/agroICT
131. Farmbee. 2018. Available at: https://farmbee.in/
132. Crispino Lobo, N. Chattopadhyay, E.V. Rao. 2017. Making Smallholder Farming Climate-smart. Integrated Agrometeorological Services. *Economic and Political Weekly.* 52 (1).
133. Discussion with farmers in Ludhiana.
134. Discussion with expert in meteorology.
135. Discussion with expert in agricultural science and administration.
136. Ministry of Agriculture. 2015. 'Guidelines for setting up Automatic Weather Stations (AWSs) and Automatic Rain Gauge (ARG) by private agencies and their accreditation standardization, validation and quality management of weather data etc.'. Available at: http://agricoop.nic.in/sites/default/files/aws_gui_cre.pdf. Private sector experts considered that it would be ideal to have AWSs within a range of hundreds of metres (rather than kilometers) of each other, and ARGs in each village. In addition, experts consider that the radar network needs to be denser, although estimates of the exact number of additional stations needed are not available. The same applies to the amount and quality of data sourced from meteorological satellites (Discussion with meteorology expert, and discussion with Skymet representatives).
137. Roundtable discussion organized by the Centre for Science and Environment on 28 March 2019.
138. Archita Bhatta and Rohini Rangarajan. 2015. The Weather Mart. *Down to Earth.* Available at: https://www.downtoearth.org.in/coverage/the-weather-mart-3619
139. Ibid.
140. Tamil Nadu Agricultural University. 'Establishment of Automatic Weather Station in 224 Blocks of Tamil Nadu'. Available at: http://agritech.tnau.ac.in/govt_schemes_services/govt_serv_schems_nadp_tnau%20_automaticweatherstation.htmll
141. Roundtable discussion organized by the Centre for Science and Environment on 28 March 2019.
142. Discussion with Skymet representatives; discussion with expert in agricultural science and administration; discussion with retired crop science expert.
143. Discussion with expert in meteorology.
144. Comptroller and Auditor General of India. 2015. 'Ministry of Earth Sciences'. Available at: https://cag.gov.in/sites/default/files/audit_report_files/Union_Compliance_Scientific_Departmen_Report_30_2015_chap_6.pdf
145. Roundtable discussions on 28 March 2019.
146. Comptroller and Auditor General of India, 2017. 'Performance Audit of Agriculture Crop Insurance Schemes'. Accessed at https://cag.gov.in/sites/default/files/audit_report_files/Report_No.7_of_2017_-_Performance_audit_Union_Government_Agriculture_Crop_Insurance_Schemes_Reports_of_Agriculture_and_Farmers_Welfare.pdf
147. Archita Bhatta and Rohini Rangarajan. 2015. The Weather Mart. *Down to Earth.* Available at: https://www.downtoearth.org.in/coverage/the-weather-mart-3619
148. Supra Comptroller and Auditor General of India, 2017.
149. *India Today.* 2017. 'Maharashtra becomes first Indian state to use Automated Weather Stations for farmers'. Available at: https://www.indiatoday.in/education-today/gk-current-affairs/story/maharashtra-first-indian-state-to-use-automatic-weather-stations-974573-2017-05-01 ; *The Times of India.* 2018. '2,000 auto

weather stations in Maharashtra to give village-level updates'.
150. Ankur Paliwal. 2018. 'Why India Struggles to Predict the Weather Over Its Lands'. *The Wire.* Available at: https://thewire.in/environment/imd-weather-prediction-forecast-monsoons-drought-agrometeorology-kharif
151. Press Information Bureau. 2018. MoES Commissions High Resolution Ensemble Prediction Systems for Probabilistic Weather Forecasts. Available at: http://pib.nic.in/newsite/PrintRelease.aspx?relid=179698 ; Sunderarajan Padmanabhan. 2018. 'India jumps to fourth place in computing capacity for weather forecasting'. *Down To Earth.* Available at: https://www.downtoearth.org.in/news/science-technology/india-jumps-to-fourth-place-in-computing-capacity-for-weather-forecasting-59444
152. Ankur Paliwal. 2018. 'Why India Struggles to Predict the Weather Over Its Lands'. The Wire. Available at: https://thewire.in/environment/imd-weather-prediction-forecast-monsoons-drought-agrometeorology-kharif
153. Roundtable discussion of 28 March 2019.
154. Discussion with farmers in Ludhiana, discussion with expert in agricultural science and administration, experts in meteorology and others.
155. Press Information Bureau. 2018. 'Met department issues district level weather forecasting covering all districts of the country'. Accessed at: http://pib.nic.in/newsite/PrintRelease.aspx?relid=180667 . Examples of such advisories are available online for a limited number of blocks (approximately 60) at: http://www.imdagrimet.gov.in/weatherdata/BAASBlockWindow.php
156. *The Hindu*. 2016. 'IMD to Issue Block Level Forecasts Soon'. Accessed at: https://www.thehindu.com/news/national/IMD-to-issue-block-level-forecasts-soon/article14025235.ece ; *Daily Pioneer*. 2018. 'IMD Ready with Tech for Localised Weather Forecast'. Accessed at: https://www.dailypioneer.com/2018/page1/imd-ready-with-tech-for-localised-weather-forecast.html
157. Examples of advisories available at: http://www.imdagrimet.gov.in/weatherdata/BAASBlockWindow.php
158. Ministry of Statistics and Programme Implementation, 'Agricultural Statistics'. Accessed at: http://mospi.nic.in/23-agricultural-statistics
159. Roundtable discussion of 28 March 2019.
160. Ibid.
161. Discussion with civil servant in Orissa.
162. V.M. Abdul Hakkim et al. 2016. Precision Farming: The Future of Indian Agriculture. Accessed at: http://jabonline.in/admin/php/uploads/170_pdf.pdf
163. NABARD. 2018. All-India Rural Financial Inclusion Survey 2016-17. Accessed at: https://www.nabard.org/auth/writereaddata/tender/1608180417NABARD-Repo-16_Web_P.pdf
164. Pinaki Mondal and Manisha Basu. 2009. Adoption of precision agriculture technologies in India and in some developing countries: Scope, present status and strategies Accessed at: https://www.sciencedirect.com/science/article/pii/S1002007109000173
165. Discussion with expert in agricultural extension.
166. Presentation by T. Pramod Shinde (Technical Officer, GKMS Unit, AMFU Parbhani, Maharashtra) at INAGMET-2019.
167. P.M. Tamboli and Y.M. Nene. 2013. 'Modernizing Higher Agricultural Education System in India to Meet the Challenges of 21st Century'. Accessed at: https://www.asianagrihistory.org/pdf/volume17/dr-tambolis-paper-17-3.pdf
168. Assa Kanté et al. 2016. 'Human Resource Development for Extension and Advisory Services: Training, Adult Learning, and Field Methods'. Accessed at: https://meas.illinois.edu/wp-content/uploads/2017/02/Kante-et-al-2016-HRD-AES-Training-Adult-Learning-and-Field-Methods-MEAS-Discussion-Paper.pdf
169. Comments by meteorological experts at INAGMET-2019.
170. P.M. Tamboli and Y.M. Nene. 2013. 'Modernizing Higher Agricultural Education System in India to Meet the Challenges of 21st Century'. Accessed at: https://www.

asianagrihistory.org/pdf/volume17/dr-tambolis-paper-17-3.pdf
171. Discussion with crop science expert.
172. P.M. Tamboli and Y M Nene. 2013. 'Modernizing Higher Agricultural Education System in India to Meet the Challenges of 21st Century'. Accessed at: https://www.asianagrihistory.org/pdf/volume17/dr-tambolis-paper-17-3.pdf
173. Suresh Pal (ed.). 2017. 'Agricultural R & D Policy in India'. Accessed at: http://www.ncap.res.in/Document/Ag%20R&D%20Policy_NIAP_2017.pdf
174. Kalpana Venkatasubramanian et al. 2014. Assessment of India's Agro-Meteorological Advisory Service from a farmer perspective. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Available online at: www.ccafs.cgiar.org
175. Roundtable discussion on 28 March 2019.
176. Discussion with Skymet representatives; discussion with Arjuna Srinidhi (WOTR); discussion with Kunal Prasad (CropIn).
177. Discussion with expert in agricultural extension.
178. Ingrid Nesheim, Line Barkved and Neha Bharti. 2017. What Is the Role of Agro-Met Information Services in Farmer Decision-Making? Uptake and Decision-Making Context among Farmers within Three Case Study Villages in Maharashtra, India. Agriculture. Available at https://www.mdpi.com/2077-0472/7/8/70.
179. Discussion with expert in agricultural extension.
180. RML services to pomegranate farmers in Maharashtra were cited as an example in the roundtable discussion on 28 March 2019. See also Marcel Fafchamps. 2012. Impact of SMS-Based Agricultural Information on Indian Farmers. Accessed at https://web.stanford.edu/~fafchamp/rml.pdf ; supra Nesheim et al. 2017.
181. Parvinder Maini and Swati Basu. 2016. Economic impact of the agro meteorological advisory services of Ministry of Earth Sciences - A review. Accessed at: http://metnet.imd.gov.in/mausamdocs/167125_F.pdf
182. Discussion with Skymet representatives.
183. Presentation by KJ Ramesh (Director General, India Meteorological Department) at INAGMET-2019.
184. Sheesham Rana. 2017 'Mobile Based Agro Advisory Services (MAAS) in India: An assessment of their effectiveness'. ICAR-NAARM. Available at: http://eprints.naarm.org.in/234/1/Final%20Project_Sheesham%20Rana_MAAS%20%2817-4-2017%29.pdf
185. Supra Nesheim et al. 2017.
186. Chandni Singh et al. 2016. The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India. Climate and Development, 10 (5). Available at: https://rsa.tandfonline.com/doi/full/10.1080/17565529.2017.1318744#.XHOM0OQzbIU
187. Supra Nesheim et al. 2017.
188. Discussion with expert in agricultural science and administration.
189. Arabinda Padhee. 2018. 'Climate-proofing Indian agriculture'. Accessed at: https://www.icrisat.org/climate-proofing-indian-agriculture/
190. Website of AP State Development Planning Society. Accessed at http://www.apsdps.ap.gov.in/pages/weather_observations/iu.html
191. Ibid.
192. Answer to question in Lok Sabha. Accessed at https://www.moes.gov.in/writereaddata/files/LS_S_170_09032016.pdf
193. Website of Telangana State Development Planning Society. Accessed at http://www.tsdps.telangana.gov.in/aws.jsp
194. Official in Assam Disaster Management Agency.
195. Official in Uttarakhand Disaster Management Authority.
196. Official in Kerala Disaster Management Authority.
197. Scientist in Meteorological Centre, Ranchi.
198. Jharkhand Space Applications Centre, 'AWS Network'. Accessed at http://jsac.

jharkhand.gov.in/pdf/AWS/AWS_newtork.pdf ; A Mukesh (2015), 'Rain gauge at police stations'. Accessed at https://www.telegraphindia.com/states/jharkhand/rain-gauge-at-police-stations/cid/1430873 ;

199. Answer to question in Lok Sabha. Accessed at https://www.moes.gov.in/writereaddata/files/LS_S_170_09032016.pdf
200. Scientist in Karnataka State Disaster Monitoring Centre
201. Scientist in Karnataka State Disaster Monitoring Centre
202. Answer to question in Lok Sabha. Accessed at https://www.moes.gov.in/writereaddata/files/LS_S_170_09032016.pdf
203. Ibid.
204. Ibid.
205. Ibid.
206. Scientist in IMD Nagpur
207. Scientist in IMD Chandigarh
208. *Times of India.* 2018. 2,000 auto weather stations in Maharashtra to give village-level updates. Accessed at: https://timesofindia.indiatimes.com/city/mumbai/2000-auto-weather-stations-in-maharashtra-to-give-village-level-updates/articleshow/64250260.cms
209. Tamil Nadu Agriculture Weather Network. Accessed at: http://tawn.tnau.ac.in/

India is one of the most vulnerable countries to the impacts of climate change. These impacts can be managed by equipping farmers with an accessible, relevant and reliable agrometeorological information system.

This paper examines the agrometerological space in India to ascertain the challenges that impede its ability to perform this function. It begins by setting out India's agricultural and climatic context and the key subsectors within the agromet advisories sector, including: (i) weather forecasting, (ii) generation of advisories, and (iii) dissemination of advisories. It identifies key public institutions and private players in each subsector and assesses the challenges unique to each subsector. It concludes with suggested policy shifts to address these challenges.

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