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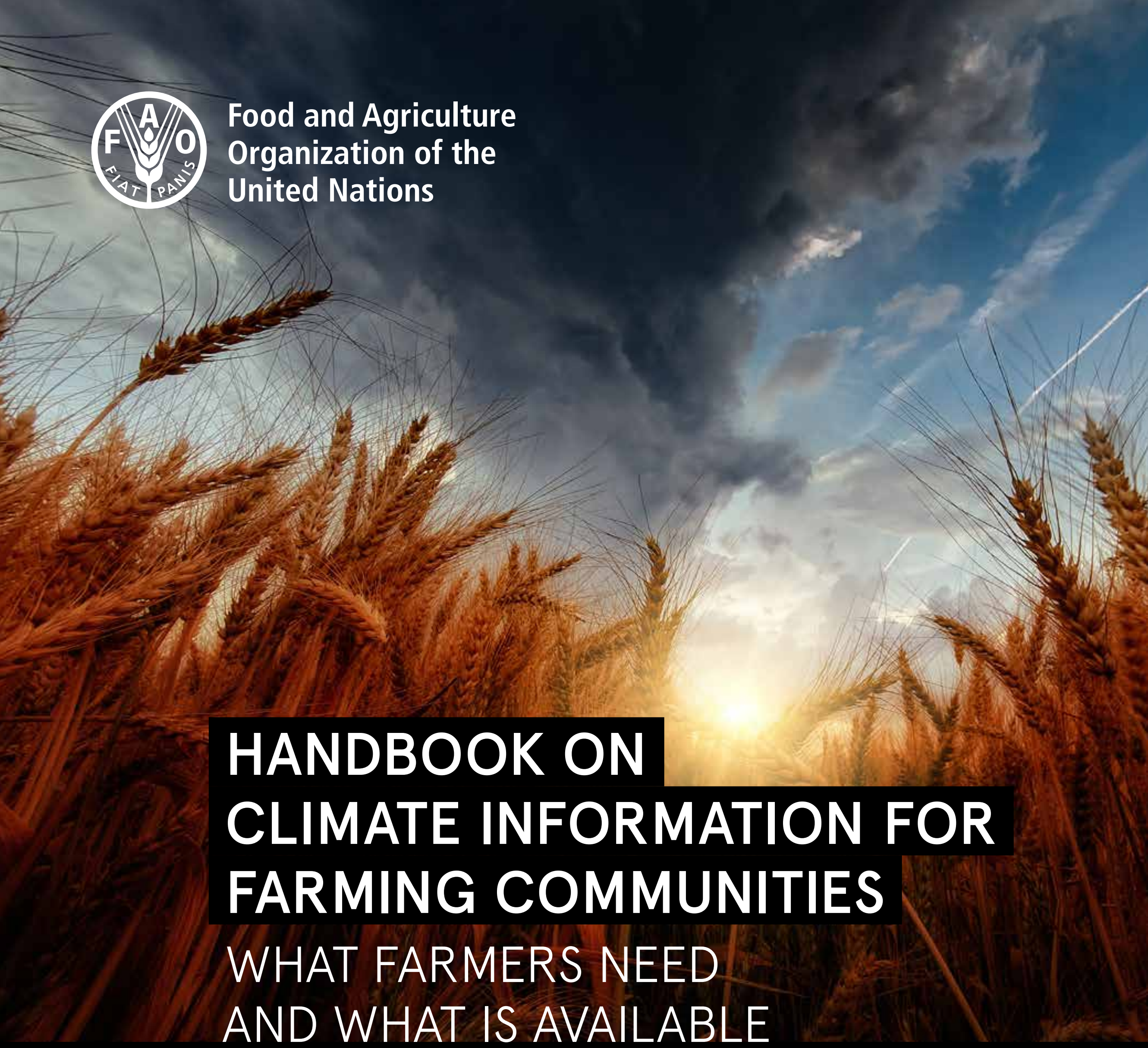
Organization of the
United Nations



HANDBOOK ON CLIMATE INFORMATION FOR FARMING COMMUNITIES

WHAT FARMERS NEED AND WHAT IS AVAILABLE

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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FOREWORD

Future climate projections indicate that, in addition to other impacts, there could be a decrease in food security from a global level to the local level, especially among developing countries. In Africa agriculture accounts for 65 percent of the employment and 35 percent of the *gross domestic product* (GDP), but poverty remains high in rural areas where most of the population depends on agriculture.

Nevertheless, agricultural productivity in Africa remains far below the standards of the developed world. Over 90 percent of agriculture is dependent on rainfall without artificial irrigation; only 5 percent of the cultivated land in Africa uses irrigation, while in Asia, 38 percent of the arable land is irrigated. The techniques used in Africa to cultivate the soil still fall far behind those that have been adopted in Asia and the Americas, because in Africa there is a lack of irrigation, fertilisers, pesticides as well as access to high-yield seeds.

Environmental conditions and management are the main factors determining the availability of agricultural products at the local level (farm, village). The environment encompasses biophysical factors (climate, water, soil, pests, land available, etc.), while management involves decisions taken by the farmers themselves. Similarly, the impacts of climate change will vary substantially depending on individual locations as well as the differences in environmental conditions and management. Climate change adds complexity to the challenge of meeting food demands subject to variable climate, while at the same time maintaining sustainability of agriculture. These challenges underline the importance of implementing sustainable agriculture practices to ensure food security in the future. In order to enhance climate change adaptation and resilience on the part of farmers, these practices should follow the *Agroecology* principles. *Agroecology* is a holistic approach to agriculture whereby traditional knowledge accumulated by peasant farmers over last few centuries has been combined with recent scientific knowledge. One of the main objectives of this document is to serve as a guide placing a strong emphasis on the combination of traditional and scientific knowledge.

New approaches and methods are subsequently required to manage climate uncertainties at the local level. In addition, by providing tailor-made climate information at the local level, food security at the household level can be improved, especially within smallholder farming communities. Climate information includes different types of weather forecasts and agrometeorology products. *Agrometeorology* has the threefold objective of studying the agroclimatic resources, assessing their impact (positive and negative) on agriculture and using this knowledge to improve yields. While the progress made has facilitated the task of climate data collection, processing, analysis, interpretation and preparation of information, the challenge of communicating an accurate interpretation of information that meets the needs of the user persists, even today. There is a significant gap between users about what information is available, where it can be found and how it can be used in agricultural management decisions. Another main objective of this guide is to provide information that will bridge the gap.

A majority of the agrometeorological information, despite rapid technological advances, does not reach the smallholder farmers with limited means. Effective use of weather and seasonal forecasts, as well as agrometeorological advisories can reduce the climate risks of farming communities by providing them with well-adapted guidelines on management of agroclimatic resources at the local level. Two reasons for this dissemination gap have been found, particularly in developing countries. Firstly, the meteorological service is not decentralized, as a result, the work with local extension staff and farming communities is very limited; therefore, the integration of weather forecasts and local knowledge is ineffective. Secondly, agrometeorological data must be collected at the local level in order to represent the farming environment realistically.

In most countries, climate information for farmers is disseminated through media and the National Extension Service provides technical advice. However, in order to respond to the need for developing education programmes for farmers, FAO developed a programme called *Farmer Field Schools* (FFS) in Indonesia in 1989. The aim of the program was to provide support for farmers on how to better manage their production systems for sustainability. The first FFS was developed in Indonesia to educate rice farmers on how to reduce rice pests, thus improving the management of the entire ecosystem by enhancing the natural enemies as well as the productive capacity of healthy plants. The FFS subsequently developed new programmes in African countries successful in increasing the crop species, as pastoralists cover large parts of Africa and are especially vulnerable to food insecurity and climatic changes. In many cases, pastoralists lack specific educational programmes, therefore the FFS adapted its programme to suit pastoral needs by developing specialised *Agro-pastoral Field Schools* (APFS). These agro-pastoral field schools focus on the understanding that complex, local problems require local knowledge and solutions. Field school facilitators work along with the farmers/pastoralists during the entire cropping season in a participatory manner by introducing and experimenting with new practices and varieties to increase productivity and resilience, with a view to improve their livelihood.

The content of this guide is twofold: to describe the most important weather and agroclimatic products that are available by the *National Meteorological Service* (NMS) and to identify the most important needs of farmers concerning climate information. Special consideration will be given to the local knowledge used by rural farmers, too often neglected, but a key factor to their ability to cope with climate variability and change.

An additional objective of this guide is to improve communication among the NMS staff, in particular, meteorologists and agrometeorologists and to encourage APFS trainers and facilitators to be more aware of their respective availability. Furthermore, one of the most important aims is the exchange of agroclimatic information that corresponds to the needs of all concerned, thus facilitating the assessment of the existing climatic risks in farming activities.

The integration of the *Response Farming in Rainfed Agriculture* (RF) approach into FFS is feasibly an effective way to reconcile NMS products with the needs of farmers. RF is a method used for identifying and quantifying rainfall variability at a local level to assess the climatic risks of farming communities. The *Climate-Responsive Farming Management* (CRFM) approach is an enhanced version of RF that uses modern and digital technologies, such as specific computer software, automatic weather stations, real-time telecommunication and smartphone applications. This approach can be implemented at a minimum cost at the farming level.

ACKNOWLEDGEMENTS

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[1] GCP/MOZ/112/LDF Project "*Strengthening capacities of agricultural producers to cope with climate change for increased food security through the Farmers Field School approach*".

[2] GCP/ANG/050/LDF IRCEA Project "*Integrating climate resilience into agricultural and agro-pastoral production systems through soil fertility management in key productive and vulnerable areas using the Farmer Field School approach*".

ACRONYMS

APFS	Agro-Pastoral Field School
CRFM	Climate-Responsive Farming Management
DST	Decision Support Tools
FAO	Food and Agriculture Organization of the UN
FFS	Farmer Field School
GCM	General Circulation Model
GIS	Geographical Information System
GTS	Global Telecommunication System
ITK	Indigenous and Traditional Knowledge
NatAgMet	National Agrometeorological Service
NMS	National Meteorological Service
PICSA	Participatory Integrated Climate Services for Agriculture
RF	Response Farming in Rain-fed Agriculture
WHARF	World Hunger Alleviation through Response Farming
WMO	World Meteorological Organization of the UN

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SECTION 1

INTRODUCTION

- SOCIO-ECONOMICS TRENDS AND ENVIRONMENTAL CHALLENGES
- CLIMATE AND AGRICULTURE
- CLIMATE INFORMATION PRODUCTS AND SERVICES REQUIRED BY AGRICULTURE
- INFORMATION GAPS

1.1 SOCIO-ECONOMIC TRENDS AND ENVIRONMENTAL CHALLENGES

By 2050 the world's population is expected to reach 9.1 billion, which is 34 percent higher than today. Most of this growth will occur in the developing countries. Urbanization will continue to accelerate and about 70 percent of the world's population will be urban (compared to 49 percent today). In order to feed a larger, more urban and affluent population, food production (net of food used for bio-fuels) should increase by 70 percent. Annual cereal production would need to rise to about 3 billion tonnes as opposed to the current 2.1 billion tonnes, while annual meat production would need to increase to over 200 million tonnes in order to reach 470 million tonnes (FAO, 2009a).

These population trends will put enormous pressure on the agriculture, forestry and fisheries sectors to provide food, feed and fibers as well as income, employment and ecosystem services. At the same time, these sectors will also be expected to respond to the challenge of climate change. The challenge is to dramatically increase agricultural production to meet global food security, while maintaining the natural resource base and responding to climate change through adaptation and mitigation measures (FAO, 2009b).

1.2 CLIMATE AND AGRICULTURE

Agriculture is an economic activity that produces food necessary for human livelihood and it is highly dependent upon weather and climate; however, agriculture is also likely to be very vulnerable to climate variability and change. Agriculture constitutes the principal livelihood for 70 percent of the poor throughout the world, many of the poor and hungry being smallholder farmers, herders, fishermen and forest-dwellers, as well as indigenous people living in climate sensitive and vulnerable areas. Nearly half of the economically-active population in developing countries relies on agriculture for its livelihood.

In Africa, agriculture accounts for 65 percent of the employment and 35 percent of *Gross Domestic Product* (GDP)[3] but the poverty level remains high in rural areas where most of the population depends on agriculture for their income. Nevertheless, agricultural productivity in Africa falls far behind standards in the developed world. Over 90 percent of agriculture depends on rainfall without the aid of artificial irrigation. Only 5 percent of the cultivated land in Africa is irrigated and the majority of the farmers depend on

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[3] http://www.worldbank.org/en/results/2013/03/28/agriculture-development-in-west-africa-improving-productivity-through-research-and-extension

rainfall, while in Asia, 38 percent of the arable land is irrigated[4]. The techniques used to cultivate soil in Africa still fall far behind those that have been adopted in Asia and the Americas because of the lack of the benefits of irrigation, fertilisers, pesticides and access to high-yield seeds as well.

Developing countries represent 80 percent of the world's population and are home to about 500 million small farms supporting around 2 billion people. Three out of every four poor persons live in rural areas, the majority depending on agriculture for their daily livelihood. Agriculture as an economic activity contributes to both the development and the livelihood of small farms.

Climate variability and climate change are the main causes of stress on food production and availability. Depending on the level of development, roughly 20 to 80 percent of the inter-annual variability of yields is caused by the changes in weather and 5 to 10 percent of national agricultural production is lost annually due to weather variability. Chronic losses and indirect negative effects (i.e. diseases, pests...) exceed by far the effects of extreme (i.e. statistically rare) climatic events. In fact, production losses due to pests, diseases and weeds are estimated at 26 to 30 percent for sugar beet, barley, soybean, wheat and cotton, and 35, 39 and 40 percent for maize, potatoes and rice, respectively (Oerke, 2006). Post-harvest losses are also of the same order of magnitude.

At the same time, climate should be considered as a "*resource*" and not merely as a hazard. If resources are to be used in a sustainable way they must be assessed in quantitative terms and properly managed. Solar radiation, rainfall and temperature condition the primary production potential and together with mineral nutrition and management they influence the attainable production. Sciencebased climate information generated through observations, data and diagnostics can be used to assist farmers with planning their activities.

The main factors determining the availability of agricultural products at the local level (farm, village) are environmental conditions and management. The environment encompasses biophysical factors (i.e. weather, climate, water, soil, pests, land available, etc.), while management involves decisions taken by the farmers themselves. Management decisions are determined by expertise on the interaction between the environment, the characteristics of crops and animals, technology, economic factors and the institutional context (including customs, government rules, etc.). However, where subsistence farmers are concerned economic factors play a relatively minor role.

By exploiting climate information and services for decision-makers, the agriculture sector will be better placed to provide food for a more highly populated and increasingly urban world. Technology used for collecting and disseminating reliable climate information has improved, nevertheless, this information does not necessarily reflect the needs of

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[4] https://www.howwemadeitinafrica.com/agriculture-africa-potential-versus-reality/

users. For example, while significant progress has been made in operational seasonal climate forecasts, they are mostly global-scale products and do not provide reliable information on user-relevant scales. In today's constantly changing environment, farmers need accessible as well as viable climate services to adequately manage climate risks and exploit climate resources, so as to take advantage of favourable weather and minimize problems due to unfavourable weather conditions.

New approaches and methods are further required for managing climate uncertainties at the local level, as well as for improving food security in the household by providing tailor-made climate information within smallholder farming communities.

1.3 CLIMATE INFORMATION PRODUCTS AND SERVICES REQUIRED BY AGRICULTURE

The main factors that have the strongest influence on crop production and need to be considered are in particular, those that influence crop growth and development. The two most important elements are *temperature* and *water availability*; in both situations daily and seasonal variations are common and temporal and spatial quantities are crucial. The agroclimatic zones help with the planning of agriculture on a regional or national scale and should include adaptations that may be necessary due to climate variability and climate change[5]. Once the agricultural system has been established there are on-going operational activities that are also influenced by the weather and climate. Decisions related to these management practices can be made in response to the weather to optimize the production or minimize the risk of the farming systems. Climate information is commonly used for planning the crop season and for making strategic decisions, such as defining the crop, the variety, planting date, total water demand for irrigation and other; weather information is used for operational decisions such as the exact date to plant based on soil water content, whether to make an application, anticipate harvest (in case of forecast of rainfall), irrigation management and others.

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[5] Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer), noting changes in the components of the climate system (atmosphere, hydrosphere, cryosphere, lithosphere biosphere). Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines "climate change" as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is an addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between "climate change" attributable to human activities altering the atmospheric composition and "climate variability" attributable to natural causes.

The farmers who have been cultivating the land for a long time in a specific area will have accumulated a lot of traditional knowledge about the effects of weather and climate on the production systems. This indigenous knowledge can be used together with a scientific analysis of the long-term climate data and the seasonal climate forecasts to facilitate weather sensitive decisions regarding the crop production systems. Agriculture provides jobs in many sectors including education, research, extension, agro-industries and processing, commodities and trade, infrastructure, transportation and pharmaceuticals. The main climate services supporting the agriculture sector are:

- Weather forecasting;
- Seasonal climate forecasting;
- Climate change projections;
- Statistical assessments of the future frequency of extreme weather and climate events;
- Agrometeorological crop monitoring;
- Agrometeorological advisories.

Meteorological and agrometeorological station networks are designed to observe the data of meteorological and biological phenomena including crop damage. The method of observation can be categorized into two major classes, manually observed and *Automatic Weather Station* (AWS[6]) but a third source for meteorological data is satellite remote sensing technology. Remotely sensed data and AWS systems provide in many ways an enhanced and very feasible alternative to manual observation with a very short time delay between data collection and transmission.

An effective use of the weather and seasonal forecasts and the agrometeorological advisories can reduce climate risks of farming communities and provide them with well-adapted guidance on the management of agroclimatic resources at the local level.

It is clear that weather forecasts are a prediction of the future weather and supplied in ***real-time*** one or more times per day. The seasonal climate outlook provides the probabilities of rainfall and temperature over a three-month period. The agrometeorological products are elaborated ***after the event*** at the end of the day, of the *dekad*[7] and of the month.

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[6] The modern AWS is powered by rechargeable batteries and a solar panel. For data communication, several options do exist. They are equipped with a SIM (Subscriber Identity Module) card and a GPRS (General Packet Radio Service) contract with sufficient good GSM (Global System for Mobile Communications) coverage in the area. All relevant weather variables are permanently measured by the AWS and automatically sent to a central climate data base server for further archiving and processing.

[7] Dekad refers to the 10-day period of the month: 1st dekad from 1 to 10, 2nd dekad from 11 to 20, 3rd dekad from 21 to the end of the month (i.e. 28, 29, 30 or 31).

1.4 INFORMATION GAPS

While good progress has been made with climate data manipulation, analysis, interpretation and the preparation of information, the challenge of communicating accurate information that meets the users' needs exist, still today. There is a significant gap among users concerning the awareness of what kind of information is available, where it can be found and how it can be used in agricultural management decisions. If climate and weather information are available but not used to modify the crop management, their value is lost.

Despite rapid technological progress, much of the weather and agrometeorological information does not reach small farmers due to the lack of communication, because it has not been adapted to the farming scale, or it has not been translated into the local language. There are two main reasons for this dissemination gap, particularly in developing countries. Firstly, the meteorological service is not decentralized, as a result, working with local extension staff and farming communities is very limited. Consequently, the integration of meteorology and local knowledge is ineffective. Secondly, agrometeorological data must be collected at the local level so that it can realistically represent the farming environment. Concerning meteorology and climatology, the main constraints limiting the dissemination of climate information services (GCOS, 2006) are:

- Some policies are against free data dissemination, either because of financial pressure leading to institutional cost recovery, privatization, or few resources due to low prioritization in national budgets.
- Archives of meteorological observations are not digitized, completed or quality-controlled.
- Gaps exist for near-real-time observations that are essential for operational management and early warning systems, when meteorological stations have stopped functioning and time series have been stopped. This has serious implications for analysis, especially for climate change-related trends.
- Lack of understanding on how to make the best use of satellite data services.

SECTION 2

WEATHER AND CLIMATE

- BASIC DEFINITIONS
- MAIN SOURCE OF WEATHER AND CLIMATE INFORMATION
- AREA OF REPRESENTATIVENESS OF METEOROLOGICAL OBSERVATIONS
- WEATHER AND CLIMATE FORECAST
- CLIMATE-RELATED DATA PRODUCTS

2.1 BASIC DEFINITIONS

Considering that meteorology refers to a science dealing with the atmosphere and its phenomena, there is a difference between *weather* and *climate*. The difference between weather and climate is the measure of time. *Weather* is the state or condition of the atmosphere at a specific place and time (as represented by weather elements such as air temperature, pressure, humidity, precipitation, wind, solar radiation) over a short period of time. *Climate* represents the integrated composite of the long-term prevailing weather and can be represented by a long-term average (30 years) of specific elements, together with their variation or the frequency of occurrence of extreme weather conditions. In simple terms, climate is what you expect and weather is what you get. This climate information in particular, refers to the different types of weather forecasts, climate data and agrometeorology products.

2.2 MAIN SOURCE OF WEATHER AND CLIMATE INFORMATION

The main source of weather and climate information is the *National Meteorological Service* (NMS). The NMS owns and operates most of the national infrastructure needed to provide the weather, climate, water and related environmental services for the protection of life and property, economic planning and development, as well as for the sustainable exploitation and management of natural resources. NMS can be an Agency under the Ministry of Commerce, the Ministry of Transport, the Ministry of Defence and rarely is under the Ministry of Agriculture. Although a typical NMS structure consists of various components, in this context the most important ones are:

» Observation and Data Collection Unit;
» Data Collection, Archiving and Processing Unit;
» Forecasting Unit;
» Climatology Unit;
» Advisory service, including the Agrometeorology Unit;
» Products Dissemination Unit.

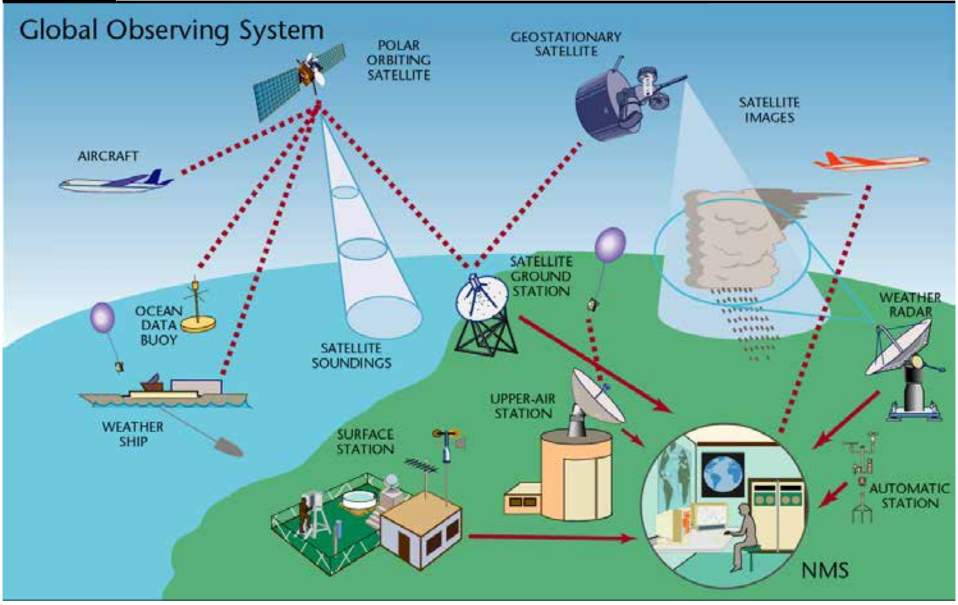
The observation and data collection unit provides the foundation for the entire operation of the NMS and in many countries, especially those with large areas and a small population may consume more than half of the total resources of the NMS. This unit involves the operation of surface and upper air stations networks, weather radar and of the operation of meteorological satellites, as well as the national contribution to and reception of worldwide data from the *Global Observing System* (GOS) of the WMO *World*

Weather Watch[8]. The GOS is comprised of operationally reliable surface-based and space-based subsystems and includes observing facilities on land, at sea, in the air and in outer space (**Fig. 1**). These facilities are owned and operated by the member countries of the WMO (i.e. the NMSs) each one undertaking certain responsibilities for the agreed global scheme so that all countries can benefit from the consolidated efforts.

Weather and climate information provided by the NMS covers several products. The most important ones are the following:

- Daily weather forecasts;
- Monthly climate outlooks;
- Seasonal climate outlooks;
- Observed climate change signals;
- Climate change vulnerability assessment maps;
- Advisories/Alerts on extreme climate events such as droughts and floods;
- Climate data, maps and atlas;
- Agro-ecological maps;
- Dekadal Agrometeorological Bulletins;
- Seasonal distribution maps of onset and cessation of rains;
- Length of growing period maps;
- Maps on chances of dry and wet spell of given lengths;
- Maps on rainfall variability during different seasons.

FIGURE 1 **Schema of the national observing system as part of the Global Observing System**



Source: http://www.wmo.int/pages/prog/www/OSY/GOS.html

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[8] http://www.wmo.int/pages/prog/www/OSY/GOS.html

Meteorological stations located at sites that have been selected to ensure the observations[9] are representative of the wider area around the station and not unduly influenced by local effects. Measurements of all of the elements are either made manually (every hour) or automatically logged at the Automatic Weather Station (AWS) at minute intervals from all sensors. Data are then transmitted to a central collecting system where the data are passed through numerous quality control checks and can easily be stored and shared. Most of the surface meteorological stations are located at the airports because of facilities that are available with a capacity to connect them to the *Global Telecommunication System* (GTS). The main function of the GTS is to collect real-time meteorological data worldwide, process and distribute the data back to the users and serve as input for the *Global Circulation Models* (GCM) or decision support systems, such as the *Smart Campo*[10]. The major sources of uncertainty in weather forecasting are caused by the climate variability and the initial model inputs. Although uncertainty decreases as the season progresses, the input of realtime weather data is still a big challenge. In each country of the world there is a network of meteorological stations covering the national area, however, in practice it is difficult to obtain a reliable series of daily measurements of the variables representative of the regions due to the poor density of these stations, particularly in developing countries. For example, Africa's conventional synoptic stations[11] number just over 1,150 that is the equivalent of a density of 1 per 26,000 km^2 (Washington *et al.*, 2004) while one station should represent an area ranging from 2,000 km^2 to 10,000 km^2 for a plane or homogeneous relief (WMO, 2017a). In various developing countries the density also has a negative trend, that is, a decrease in the number of operational stations. Furthermore, in Africa and in other world regions not all historical meteorological and climate data can be used to further refine climate forecasting, the reason being that much of the historical data continues to be paper-based and are inaccessible to the main centers needing digital data to feed the GCMs (Bernardi, 2008). Moreover, in most developing countries a relatively small number of stations at the national level – as compared to all available stations - are connected in real-time through a telecommunications system. Therefore, the density of stations that hamper the ground resolution of related weather and climate products is greatly reduced.

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[9] The observations are generally "ground based", i.e. they are measured on or at the surface level of the ground.

[10] Smart Campo: http://ensoag.com/smart-campo/

[11] Synoptic weather stations collect meteorological information at synoptic time 00h00, 06h00, 12h00, 18h00 (UTC) and at intermediate synoptic hours 03h00, 09h00, 15h00, 21h00 (UTC). The common measurement instruments are the anemometer, wind vane, pressure sensor, thermometer, hygrometer and rain gauge. The weather measurements are formatted in a special format and transmit to WMO to help the weather forecast model. The purpose of the synoptic observations includes mapping large-scale weather systems (in real time and for climatology). They also provide the basis for the proper analysis and verification of the operational weather models.

2.3 AREA OF REPRESENTATIVENESS OF METEOROLOGICAL OBSERVATIONS

The *area of representativeness*[12] of a meteorological station is the land area measured in square meters where the values measured are identical to those given by the reference instrument. This area differs from one parameter to another and it is not a fixed attribute of observation, since it depends on user requirements and, for agrometeorological applications, is generally used at local scale. This is the main reason and extremely important for relying on meteorological data which has been or is measured and collected at a station located next to the farmers' field. Data collected from the actual field produces the most accurate results and, whether it is dealing with historical weather conditions, soil sampling, nitrogen recommendations or growth stage predictions, more effective and site-specific information will produce more field-specific results.

In Africa, where the most limiting crop-growing factor is the availability of water, obtaining accurate meteorological data from the on-farm weather station is clearly needed, given that rainfall is the parameter with the highest variability in space and time. In the case where this option is not available the only possibility is to use weather data from public sources – like NMS – whose weather stations are located near larger cities or airports where large discrepancies occur. In order to better respond to the need of climate information, parallel meteorological observing networks have been installed in several countries and are managed by national and local public institutions other than the NMS, such as universities, the Ministry of Agriculture, private companies, farming communities and individual large-scale farmers. Nonetheless, in some cases these institutions lack coordination and synergy with the NMS and, as a result, the quality of the measurements is poor. The use of the nearest single network station as data source encounters two main problems, namely the usefulness of the station observations and the extrapolation of these data for the specific location. One of the reasons is that meteorological parameters all have great variability, depending on the station site and very often farmers rely on weather data collected at airports or in towns typically not close to the farms. The farm could be as far as 50 to 80 km away from an airport or town weather station, resulting in poor agronomic decisions due to the lack of local weather data. Real-time meteorological data from the on-farm station can enable predictive models to guide farmers' decision-making on critical crop stages, the timing of field operations, pest and disease pressure, equipment deployment, soil needs and nutrient requirements.

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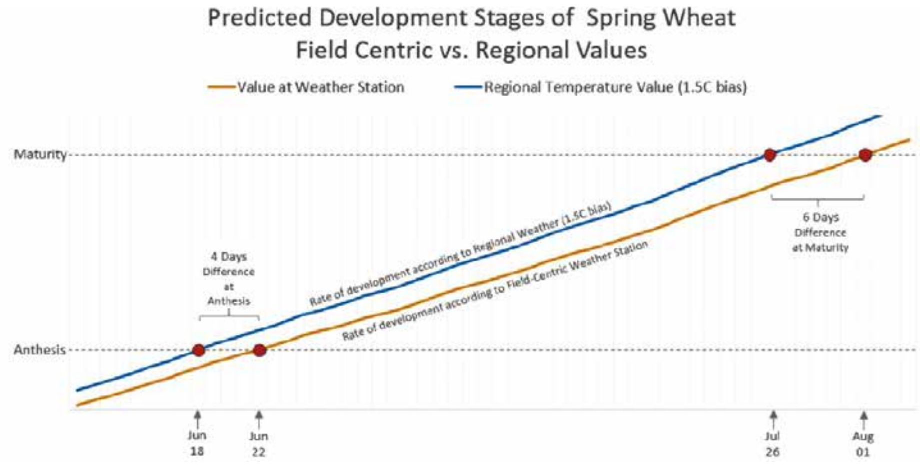
[12] https://www.wmo.int/pages/prog/www/IMOP/publications/IOM-55_Part-I.pdf

The chart below (**Fig. 2**) shows the discrepancies obtained by reading current air temperatures at three weather stations in northwest Missouri (USA). The northernmost station is near the airport; the middle station is 3.5 km from the airport; the southernmost station is 6.7 km from the airport. From the airport weather station to the middle station there is a difference of 1.4°C. From north to south there is a difference of 2.5°C and during the growing season such temperature differences will have a major effect on the crop's development rate. In practice, the weather conditions at the airport do not adequately represent the surrounding region. The air temperatures can be used to calculate the *Growing Degree Days* (GDD) and derive the growth and development of a crop. A cooler day will accumulate little to no GDD while a warm day will accumulate more GDD. Given that crops respond to heat, GDD can be correlated to crop development and consequently, the accumulation of GDD since planting can be used to predict crop staging. Taking into consideration the prediction of a certain growth stage based on GDD, the chart below shows the differences in prediction for flowering (anthesis) and for maturity in wheat, based on the actual temperature compared to a regional temperature (1.5°C bias). In this example, the temperature from the actual weather station shows flowering occurring on 22 June. Regional temperature values predict a fourday discrepancy (18 June) and the discrepancy in predicted dates of maturity increases to six days (1 August vs. 26 July). This is not acceptable. In short, the choice of weather sources, that is, on-farm versus regional, can strongly influence the accuracy of the prediction.

FIGURE 2 **Differences in predicted development stages for flowering (anthesis) and maturity of wheat, based on the actual temperature compared to a regional temperature.**

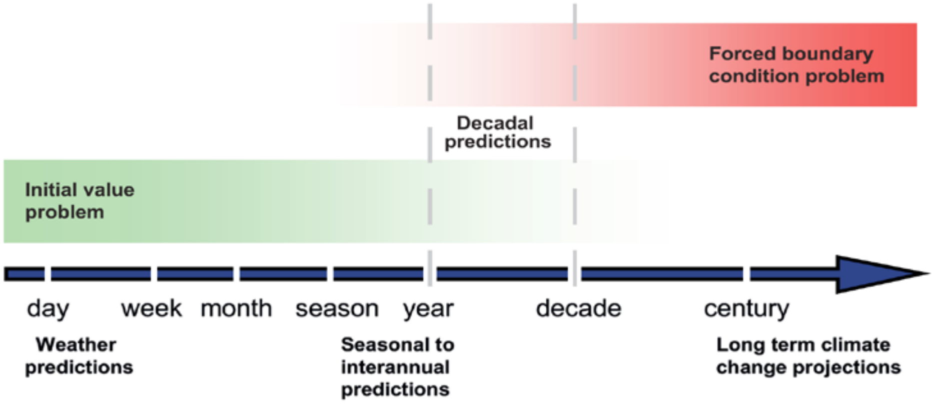


Source: https://www.farmersedge.ca/many-weather-stations

2.4 WEATHER AND CLIMATE FORECAST

Weather forecasting products vary from place to place and from season to season, but they generally refer to the main weather elements affecting farm planning and/or operations such as: sky coverage by clouds, hours of sunshine, solar radiation, precipitation, temperature (maximum, minimum and dew point), relative humidity, wind speed and direction, extreme events (heat and cold waves fog, frost, hail, thunderstorms, wind squalls and gales, low pressure areas, different intensities of depressions, cyclones, tornados). Nowadays, many institutes use numerical weather prediction, which is a set of mathematical models that simulate the physics laws of the atmosphere on a global scale to predict the future evolution of the atmosphere. These models require an initialization of the system, the current weather conditions at the global scale, and from this point they produce a simulation that follows a fixed time-step. However, errors can occur when, due to the complexity of the physics of the atmosphere, phenomena evolve at a higher resolution than the model because of incomplete measurement of the initial condition. Forecasts are hence adversely affected by the errors that have evolved over time and, as a result, they become less accurate as the range of the forecast increases. Trained observers, automatic weather stations or buoys routinely collect the traditional observations made on the surface, for example, atmospheric pressure, temperature, wind speed, wind direction, humidity and precipitation. During the data assimilation process, information obtained from the observations is used in conjunction with the numerical model's most recent forecast for the time that observations were made for the production of the meteorological

FIGURE 3 A schematic view illustrating the progression from an initial-value based prediction on short time scales to the forced boundary-value problem of climate projection on long term scales. Decadal prediction occupies the middle ground between the two.



Source: Kirtman *et al.*, 2013

analysis. It is important to note that the skill of numerical prediction in regions with a scarce observation network is lower, due to the lack of sufficient information required by models to properly set up the initialization of the atmosphere.

Orography plays a crucial role in the evolution of weather on a very local scale. The resolution of the models is usually not enough to exactly reproduce the orography and the forecasts are affected by this bias. A regional model can be used in the case where we need to move to a very high resolution. Regional models are similar to global models but differ from higher resolutions and limited spatial domains. This means that global models will be used to prepare the boundary conditions for the regional models to simulate the evolution of the atmosphere at the global level, after which the higher resolution model is run with a better topographic model and lower time step. This solution can better simulate the weather evolution at a very local scale. In addition, another limiting factor for making predictions in the tropics is the origin of the precipitation in tropical areas. In this region a large part of the total amount of rainfall is through convective systems that are not well simulated by the global models (due to a resolution problem). There are some possible adjustments to made (parameterization of the model) linked to the typical climatic distribution of the convective system, but the prediction of the rainfall amount during the rainy season in tropical areas is still very challenging.

The output from the model provides the basis for the weather forecast. Four types of forecasting techniques are listed below:

- *Persistence forecasting* is based on the concept that current weather conditions can reveal clues for tomorrow's forecast. Meteorologists who rely on this forecasting method to predict the current conditions will persist or continue unchanged. They make observations using thermometers and barometers to assess the weather, which allows for them to theorize if the next few days will feature similar weather patterns. This forecasting technique works best in areas with predictable weather patterns, such as in tropical zones or arctic regions.
- *Synoptic, or analogue forecasting* is a method for predicting the weather based on accepted theories and principles of meteorology. This technique requires some skill and training and incorporates weather maps, radar and satellite images. Forecasters combine these tools with information about atmospheric pressure, air-flow and temperatures to deliver a forecast. Synoptic forecasting served as the primary method of predicting the weather through the 1950s and '60s. It's still currently used for short-term predictions.
- *Statistical or climatological forecasting* allows meteorologists to make predictions based on historical trends. It assumes consistent weather patterns over time. Forecasters examine historical information about average, high and low temperatures to estimate future temperature ranges. They also examine historical storm records and precipitation amounts and use these records as a basis for forecasting. For example, a statistical forecaster may state that the next month will bring rain and cold temperatures because it is considered to be the normal condition for this area at that time of year.

» *Computer modelling* forecasts represent the most advanced method of predicting the weather. This method relies on mathematical formulas that are designed to model atmospheric and weather conditions. Meteorologists can calculate future conditions by inputting current weather data.

Weather and climate forecasting are classified into different groups - the shorter the range the higher the predictability - and the more important and suitable the forecast is for agriculture. These groups are as displayed in the table below **Table 1**. The characteristic size and lifespans of typical atmospheric phenomena and its relationship with weather forecasting are shown in **Fig. 4**.

TABLE 1 **Definitions of weather forecasting and climate outlook ranges**[a]

TYPE	RANGE	PARAMETERS	TEMPORAL RESOLUTION	SPATIAL RESOLUTION	TYPE OF PRODUCTS
Now-casting (NC)	0-2 hours	Description of current weather parameters and description of forecast weather parameters for 0-2 hours. A relatively complete set of parameters can be produced (i.e. air temperature and relative humidity, wind speed and direction, solar radiation, precipitation amount[b] and type, cloud amount and type, and the like).	Minutes	1-2km	Text, graphics.
Very Short-Range Weather Forecasting (VSRWF)	up to 12 hours	A relatively complete set of weather parameters can be produced (i.e. air temperature and relative humidity, wind speed and direction, solar radiation, precipitation amount and type, cloud amount and type and the like).	Eight times a day at three-hour intervals	15-25km	Text, graphics, time-series, maps.
Short-Range Weather Forecasting (SRWF)	12-72 hours	A relatively complete set of weather parameters can be produced (i.e. air temperature and relative humidity, wind speed and direction, solar radiation, precipitation amount and type, cloud amount and type and the like).	Eight time a day at three-hour intervals	25-80km	Text, graphics, time-series, maps.

[a] http://www.wmo.int/pages/prog/www/DPS/GDPS-Supplement5-AppI-4.html

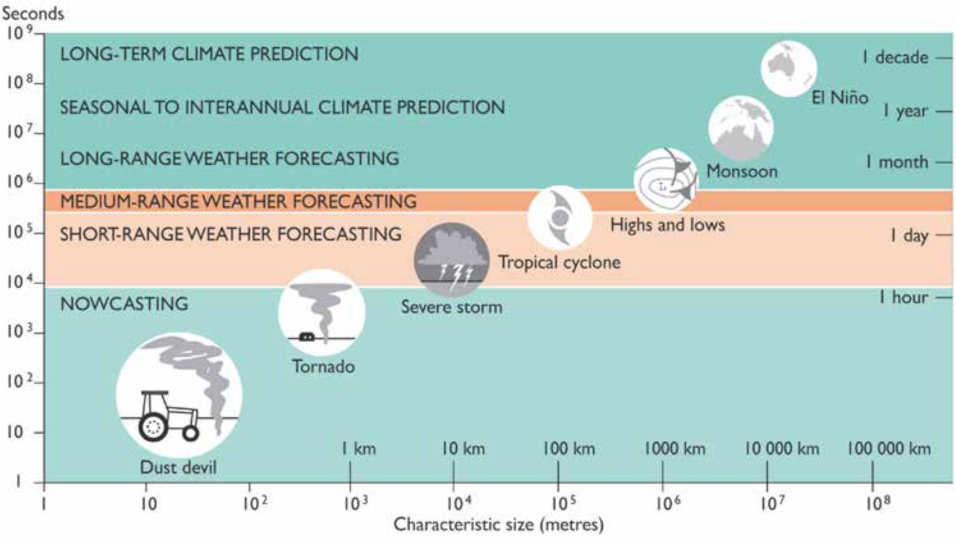
[b] Precipitation amount is given in probabilities.

TYPE	RANGE	PARAMETERS	TEMPORAL RESOLUTION	SPATIAL RESOLUTION	TYPE OF PRODUCTS
Medium-Range Weather Forecasting (MRWF)	72-240 hours (3-10 days)	A relatively complete set of weather parameters can be produced (i.e. air temperature and relative humidity, wind speed and direction, solar radiation, precipitation amount and type, cloud amount and type and the like).	Twice a day	25-80km	Text, graphics, time-series, maps.
Extended-Range Weather Forecasting (ERWF)	10-30 days	A description of main weather parameters usually averaged and expressed as a departure from climate values for that period.	Once a day	80-150km	Text, graphics, time-series, maps.
Long-Range Weather Forecasting[c] (LRWF)	30 days up to 2 years	Usually restricted to some fundamental weather parameters (i.e. temperature and precipitation).	Once a month	80-150km	Text, graphics, time-series, maps.
Monthly Climate Outlook	Current month (not necessarily the following month)	A description of averaged main weather parameters (i.e. temperature and precipitation) expressed as a departure in percentage (i.e. deviation, variation, anomaly) from climate values.	Once a month	150-400km	Text, maps.
Three-month Climate Outlook	90-day period (not necessarily the following 90-day period)	A description of averaged main weather parameters (i.e. temperature and precipitation) expressed as a departure in percentage (i.e. deviation, variation, anomaly) from climate values.	Once every 3 months	150-400km	Text, maps.
Seasonal Outlook	Three-month period	A description of averaged main weather parameters (i.e. temperature and precipitation) expressed as a departure in percentage (i.e. deviation, variation, anomaly) from climate values for that season.	Once every 3 months (during the season)	150-400km	Text, maps.

[c] In some countries long-range forecasts are climate products.

TYPE	RANGE	PARAMETERS	TEMPORAL RESOLUTION	SPATIAL RESOLUTION	TYPE OF PRODUCTS
Weather Information & Severe Weather Alert	Occasionally	Weather information, when sudden and important changes of the weather conditions are detected, or severe weather is anticipated. Severe weather alerts include advisories and warnings. Preliminary warnings are issued before severe weather alerts and give information about the type, place and time of the expected severe weather. Preliminary warnings are usually issued several hours earlier than the severe weather alert, giving a crucial time advantage to the mitigation of weather disasters.			Text.

FIGURE 4 The characteristic size and lifespans of some typical atmospheric phenomena and their relationship to weather forecasting and climate prediction.



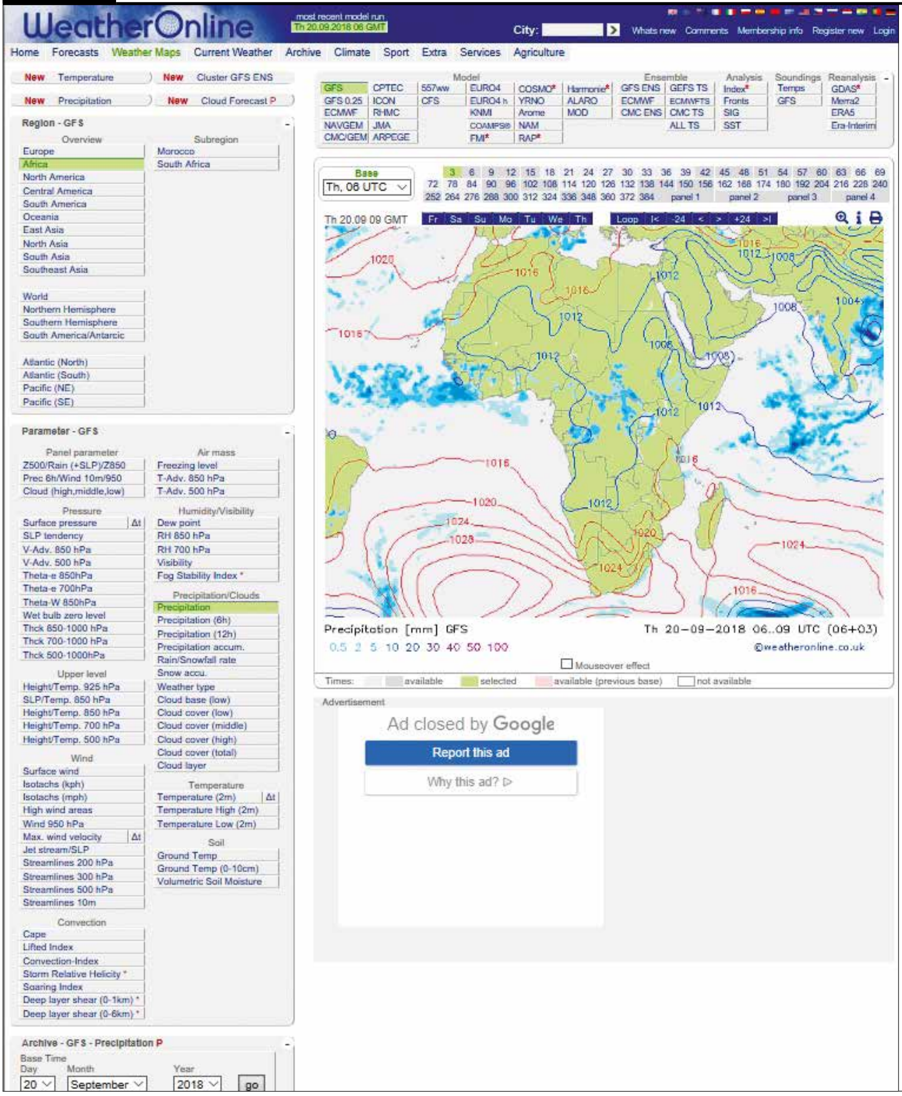
Source: J.W. Zillman, 1999 https://library.wmo.int/pmb_ged/bulletin_48-2_en.pdf

2.4.1 **WEATHER FORECASTING**

2.4.1.1 Short range weather forecasting

Analysis techniques, extrapolation of trajectories, interpretation of forecast data and maps are derived from the NWP (*Numerical Weather Prediction*) such as LAM (*Local Area Model*) and GM (*Global Model*). The basic information is represented by data from networks of automatic weather stations, maps from meteorological radars, images from meteorological satellites, NWP models, local and regional observations (**Fig. 5**, **6** and **7**).

FIGURE 5 Short-range rainfall forecast for Africa based on NWP model

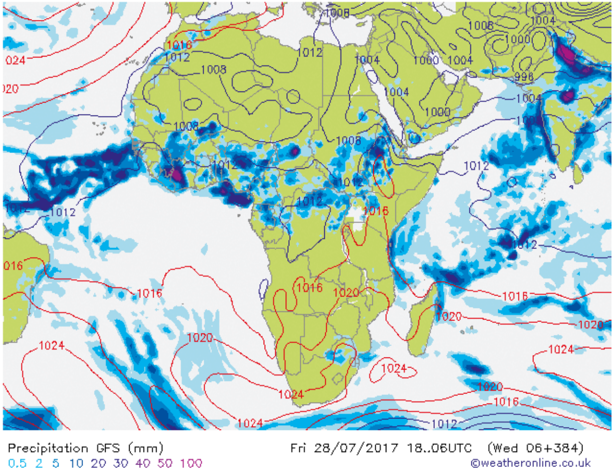


Source: http://www.weatheronline.co.uk/Africa.htm

FIGURE 6 Weather overview for Africa

Source: http://www.weatheronline.co.uk/Africa.html

FIGURE 7 Short-range surface pressure (hPa) and precipitation (mm) forecast for Africa



Source: http://www.weatheronline.co.uk/Africa.html

The dissemination of weather prediction is one of the products typically provided by the National Meteorological Services. The most common means of dissemination is mass media, mainly television, radio and newspapers, whereas facsimile, telephone and pagers specifically target certain user groups; moreover, the Internet has increasingly gained importance in weather information distribution. These products represent the most common type of information to reach farmers to base their decisions such as planting dates, harvest date, etc.. The products are distributed at both the national and provincial level but are not tailored to the specific needs of the farmers as they have been designed for a more generic domain. The main means of distribution for rural areas at the local level is radio bulletins while weather forecasts are the main sources for extreme events alerts that are generic and not applicable to a specific location.

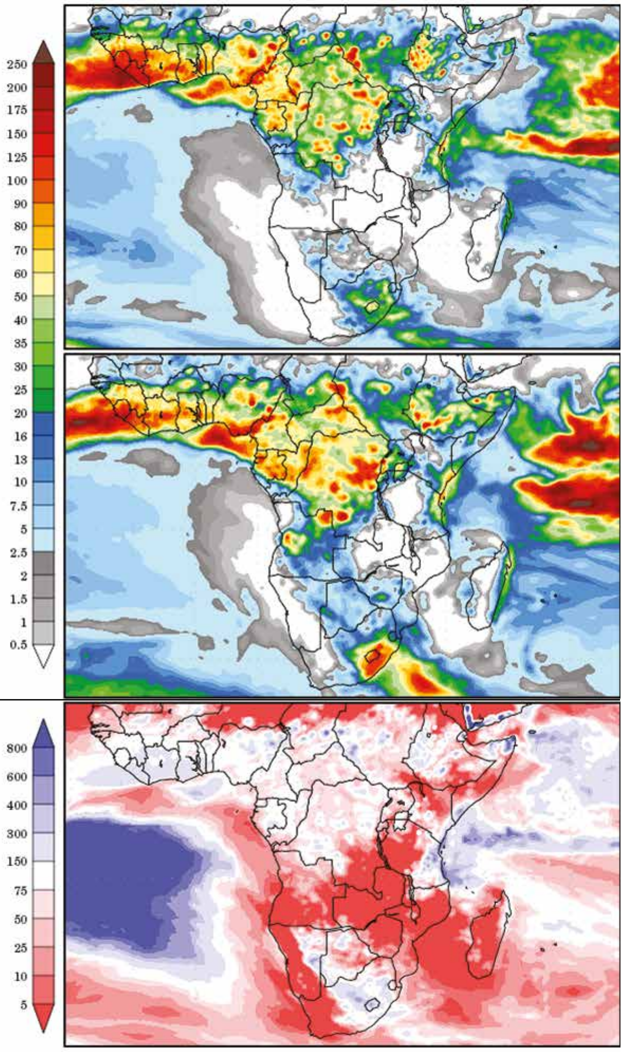
2.4.1.2 Medium-range weather forecasting

Interpretations of forecast data and maps are mainly derived from the NWP (*Numerical Weather Prediction*) models. Techniques of “*ensemble forecasting*” are used to overcome the problem of the depletion of skills found in forecasts based on NWP models. Instead of using only one model run, slightly different initial conditions are used for several runs and an average, or “*ensemble mean*” of the different forecasts is created. This ensemble mean will likely have more skills because it averages out the various potential initial states and essentially smooths the chaotic nature of climate. It is also possible to forecast the probabilities of different conditions (**Fig. 8**).

It is generally believed that probabilistic forecasts provide the best and most complete weather forecast for customers, especially at longer lead times. However, the fact that many customers demand a simple deterministic forecast must be taken into consideration. Furthermore, where a deterministic forecast is to be produced, the use of an EPS (*Ensemble Prediction System*) can provide a more reliable forecast than a single deterministic NWP run. This is particularly true for midterm forecasts and can help reduce jumpiness during the run-to-run of the forecast system at any time range. For this reason, every weather forecast should communicate two things: the usefulness of the model and its limitations. How to present uncertainty is essentially a question of how to present the possible future configurations of a model.

Increasing the timespan of the forecast typically decreases forecast accuracy because random errors and models’ parameterization problems will contribute to producing different predictions at the smallest change. Adding some information about the evolution of the uncertainty of the weather prediction it is very useful for numerous decision-making processes. The typical measures of uncertainty include the confidence interval, the mean absolute percentage error, centile distribution and other simple statistics on the different model outputs. Effectively, these simple methods do a good job of representing uncertainty. An example of a more complex representation of uncertainty, is the plotting of the future evolution of the analysed parameters of different runs from the same model with similar initial parameterization (spaghetti plots).

FIGURE 8 Medium-range rainfall forecasting for Africa



PRECIPITATION (mm)
DURING THE PERIOD:

Wed, 12 Jul 2017 at 00Z
-to-
Thu, 20 Jul 2017 at 00Z

Thu, 20 Jul 2017 at 00Z
-to-
Fri, 28 Jul 2017 at 00Z

PRECIPITATION (% of normal)
DURING THE FIRST PERIOD:

Wed, 12 Jul 2017 at 00Z
-to-
Thu, 20 Jul 2017 at 00Z

GrADS/COLA

Precipitation forecasts from the National Centers for Environmental Prediction. Normal rainfall derived from Xie-Arkin (CMAP) Monthly Climatology for 1979-2003. Forecast Initialization Time: 00Z12JUL2017

Source: http://wxmaps.org/pix/prec10.html

In addition, another strategy for communicating this uncertainty is to translate this evolution into a probability value. In this case, the information is translated into a percentage value of the occurrence of a certain event (e.g. extreme rainfall) during the following days. As a result, it is quite normal for the medium-range forecast to be associated with a probabilistic distribution. It is often argued that it is easier to make a decision based on a deterministic forecast than a probabilistic one. However, when the forecaster issues a deterministic forecast the underlying uncertainty still exists, therefore, they make a prediction with the most likely outcome.

In order to make a forecast for a specific event that is likely to occur an in-depth knowledge of the needs of the end-user is strongly recommended. An optimal decision cannot be made without the cost–lost ratio of the user. In many cases the forecasters should convey the risks and impacts associated with worst-case scenarios together with the most likely outcome. It is generally believed that all of these outputs require a specific interpretation and the large public tends to misunderstand the real content of the forecast. For this reason, training end-users on how to interpret the products before their dissemination is strongly advised.

2.4.1.3 Seasonal climate forecasting

Seasonal climate forecasting is used to provide forecasts in advance, for example, for which variety to plant and what time of year, when and where disease outbreaks are likely to occur and whether to reduce livestock numbers if a drought is predicted. The timing of daily weather events throughout the growing season is impossible to predict. However, the large-scale ocean–atmosphere interactions that control the seasonal patterns at the regional level could have some influence on the synoptic weather events important to agriculture on a smaller scale. Some of these patterns are the frequency and persistence of rainfall events, the distribution of dry spell durations, the timing of season onset and the probabilities of intense rainfall or extreme temperature events. This is a realistic scenario in the regions where "*teleconnections*[13]" are strong, even though there is still a great deal of uncertainty. On a global scale some climate variability is related to large-scale interactions between the oceans and the atmosphere. Furthermore, a better understanding of the role of the large-scale climatic phenomena, such as the *El Niño Southern Oscillation* (ENSO), the *North Atlantic Oscillation* (NAO) and the *Madden Julian Oscillation* (MJO) has increased the ability to predict climate fluctuations in several parts of the world, especially in the tropics. This capability to make predictions has improved to such an extent that seasonal time-scale predictions are now routinely made by main operational meteorological centers around the world.

As previously mentioned, climate variability has a major impact on agriculture. Farmers are not necessarily prepared for expected weather conditions and make decisions based on their understanding of the general climate patterns in their regions. Better climate predictions provided three to six months in advance would help shape appropriate decision making, reduce impacts and take advantage of the favorable conditions forecasted. Seasonal

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[13] Teleconnection in atmospheric science refers to climate anomalies related to each other at a large distance (typically thousands of kilometers). The most emblematic teleconnection is the link between the sea-level pressure in Tahiti and Darwin, Australia, which defines the Southern Oscillation.

forecasting is an attempt to predict the probability distribution for weather parameters (i.e. rainfall, temperature) several months in advance. The methodology is based on averages over a month or season and how the probability distribution differs from "*climatology*".

BOX 1 Regional Climate Outlook Forums

Since late 1990s, the *Regional Climate Outlook Forums* (RCOFs[a]) have been coordinated by WMO, the National Meteorological Services (NMSs), regional Climate Centers and other producers of climate predictions, regional institutions and international organizations. RCOFs join together experts from climatologically homogeneous regions to provide consensus-based climate prediction and information, usually for the current season, which is subsequently reanalysed and downscaled at the national level. RCOFs operate in many parts of the world, serving mainly developing countries[5]. It is estimated that a seasonal forecasting approach that would provide a 30 percent decrease in seasonal uncertainty, would increase annual profits by approximately 5 percent in Western Australia (Cantelaube *et al.*, 2005). For example, in Africa RCOFs provide information for large areas (about 2.5°x2.5°) indicating the probability of rainfall for each zone. The numbers for each zone indicate the probabilities of rainfall in each of the three categories, above, near, and below normal. The top number indicates the probability of rainfall occurring in the above normal category; the middle number is for near normal and the bottom number for the below normal category. In many regions, the users benefitting from the Forum contribute to its organization and to the breadth of the sessions, thus ensuring its applicability to the needs of users.

The Forums attract practitioners and decision-makers from sectors such as:

» Agriculture and food security

» Water resource

» Energy production and distribution

» Public health

» Disaster risk reduction and response

» Outreach and communication

Other sectors such as tourism, transportation, urban planning, etc. are increasingly involved.

Based on the needs of specific sectors specialized, sector-oriented outlook forums, such as the Malaria Outlook Forums (MALOFs) in Africa, are being held in conjunction with Regional Climate Outlook Forums.

[a] RCOFs: http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html

[b] GHACOF: Greater Horn of Africa COF. SARCOF: Southern African Regional COF. PRESAO: Prévision saisonnière en Afrique de l'Ouest (seasonal prediction for West Africa). PRESAC: Prévision saisonnière en Afrique Centrale (seasonal prediction for Central Africa). FOCRAII: Forum on Regional Climate Monitoring, Assessment and Prediction for Regional Association II (Asia). SSACOF: Southeastern South America COF. WCSACOF: Western Coast of South America COF. FCCA: Foro Regional del Clima de América Central (Regional Climate Outlook Forum for Central America). PICOF: Pacific Islands COF. SEECOF: Southeastern Europe COF.

BOX 2 El Niño-Southern Oscillation (ENSO)

Seasonal climate forecasts are based on the *El Niño-Southern Oscillation* (ENSO) that refers to shifts in *Sea Surface Temperatures* (SST) in the eastern equatorial Pacific and related shifts in barometric pressure gradients and wind patterns in the tropical Pacific (the Southern Oscillation). ENSO activity is characterized by warm (*El Niño*), neutral, or cool (*La Niña*) phases identified by SST anomalies. Although the ENSO phenomenon occurs within the tropical Pacific, it affects inter-annual weather variability in many other regions of the world. In West Africa, for example, it can affect the seasonal rainfall related to the 3 months of July, August and September, during which 90 percent of total annual rainfall occurs.

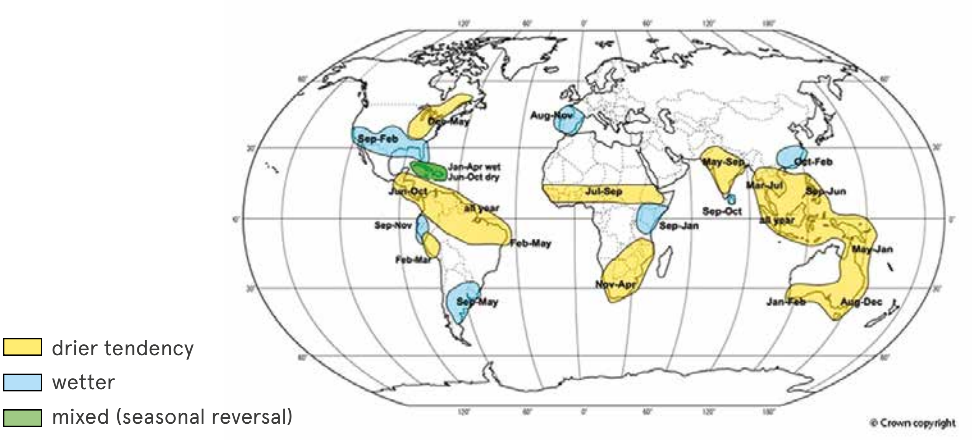
Climatic impacts of ENSO events are shown in **Fig. 9, 10, 11 and 12** (from: UK Met Office) [a]. The maps provided below summarise the main impacts on seasonal precipitation and near-surface temperatures over land areas for El Niño and La Niña events. For each region marked, the colour indicates the tendency and the text indicates the seasonality of the impact. The maps are based on analyses of historical datasets extending over several decades and on information in peer-reviewed publications. Each ENSO event is different and occurs in conjunction with other climatic events. Not all impacts occur in all events and impacts may not be confined to the regions indicated. Therefore, these maps should not be regarded as forecasts for a current event but rather as an indication of areas where impacts are likely based on historical evidence.

Most of these occur during the northern hemisphere winter (**Fig. 9 and 10**), from December to February. During the warm event (El Niño) there are generally warmer conditions in the north-western region and north-eastern coast of North America, south-eastern Brazil, part of the east coast region of Asia and India, with warmer and dryer conditions in southeast Africa. Wetter and cooler conditions prevail during an El Niño in the southern part of the United States, with wetter conditions along the northeast coast of Argentina and dryer conditions along the northeast coast of Brazil. During the northern hemisphere summer, from June to August, there is little impact of El Niño in the northern hemisphere. The main impacts of El Niño during this period are warmer conditions along the south-eastern coast of Brazil and north-eastern coast of Argentina, and cooler and dryer conditions in the southern central Pacific Ocean. Although La Niña events are characterized by opposite conditions of El Niño events, the effects around the world are not necessarily the opposite of the effects of El Niño. The **Fig. 11 and 12** also depicts the impacts of opposite event called La Niña.

[a] http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal/gpc-outlooks/el-nino-la-nina/enso-impacts

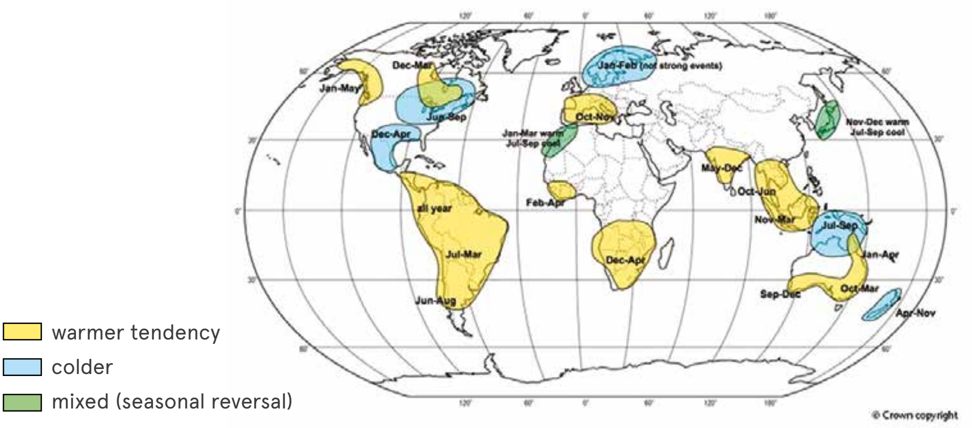
Research over the last century and particularly in the last couple of decades has shown that potentially, the seasonal climate is predictable in many regions of the world (Goddard *et al.*, 2001). Seasonal forecasts are based on several global ocean-atmospheric forcing phenomena. The most important oceanic factor influencing rainfall patterns in most of the tropics is sea-surface temperature anomalies and pressure difference. A probabilistic rainfall forecasting system based on the identification of lag relationships between values of *Southern Oscillation Index* (SOI) has been proposed to provide a quantitative measure of

FIGURE 9 **El Niño precipitation impact**



Source: UK Met Office

FIGURE 10 **El Niño temperature impact**



Source: UK Met Office

the phase of the ENSO cycle and future rainfall (Stone *et al.*, 1996). The system provides a rainfall probability distribution three to six months in advance for most regions worldwide.

Several international research institutes provide regular seasonal climate forecasts such as the *International Research Institute for Climate and Society* (IRI[14]) (**Fig. 13**), the *European Center for Medium-Range Weather Forecast* (ECMWF[15]) (**Fig. 14**). The *Global Forecasting Center for*

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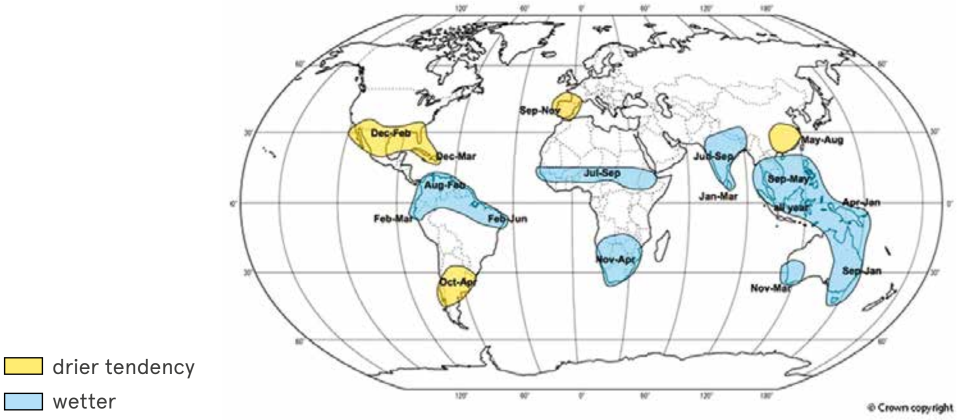
[14] IRI: http://iridl.ldeo.columbia.edu/maproom/?bbox=bb percent3A-20 percent3A-40 percent3A55 percent3A40 percent3Abb

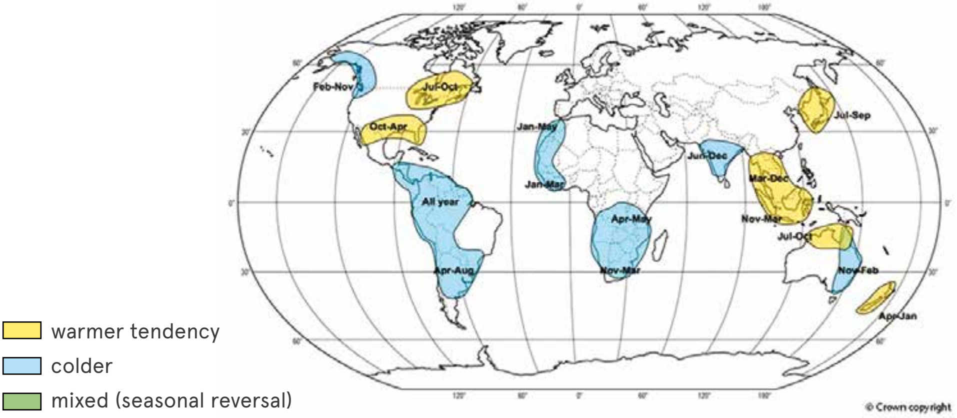
[15] ECMWF: http://www.ecmwf.int/

FIGURE 11 La Niña precipitation impact



Source: UK Met Office

FIGURE 12 La Niña temperature impact



Source: UK Met Office

Southern Africa at CSAG[16] (*Climate Systems Analysis Group*) also develops and provides seasonal climate forecasts, however, this particular distribution has been temporarily suspended.

Good correlations do exist between cropping seasons in West Africa, Southern Africa and the October-December "short rains" in East Africa. Seasonal forecast maps are prepared by the *Regional Center for Agro-Hydro-Meteorology* (AGRHYMET) for the Sudano-Sahelian region (**Fig. 15**), by the *Climate Prediction and Applications Center* (ICPAC) for the Eastern African

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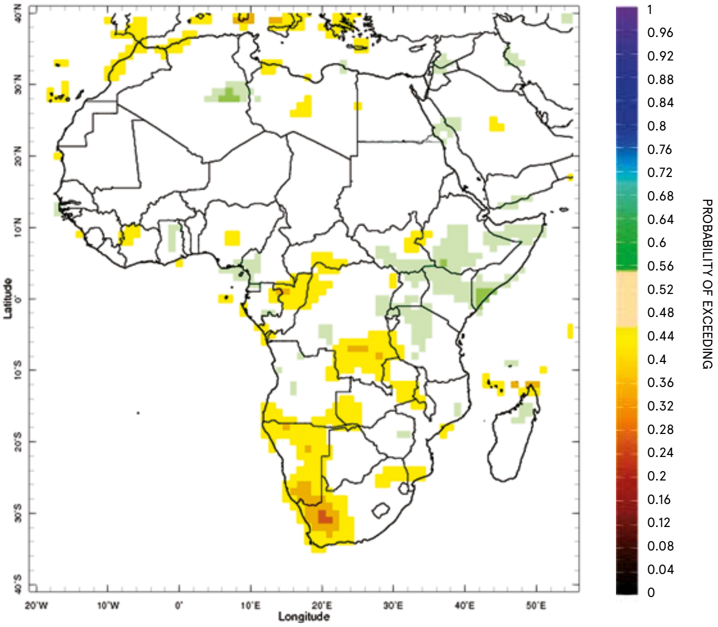
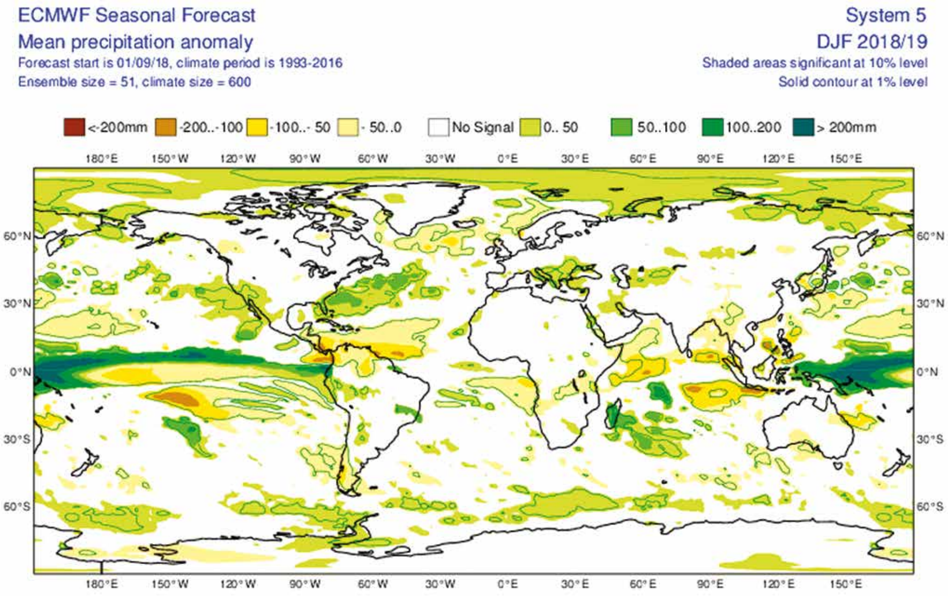
[16] CSAG: http://www.csag.uct.ac.za/

FIGURE 13 Seasonal Precipitation Forecast for Dec 2018 – Feb 2019 for Africa



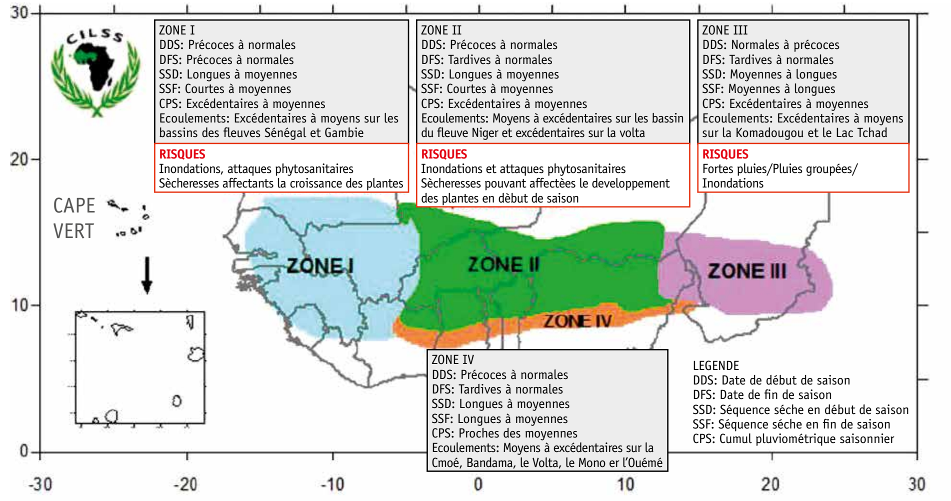
Source: http://iridl.ldeo.columbia.edu/maproom/Global/Forecasts/NMME_Seasonal_Forecasts/precipitation.html

FIGURE 14 Seasonal rainfall forecast for Dec 2018 – Feb 2019



Source: ECMWF

FIGURE 15 Rainfall outlook for the season 2017 for the Sudano-Sahelian region



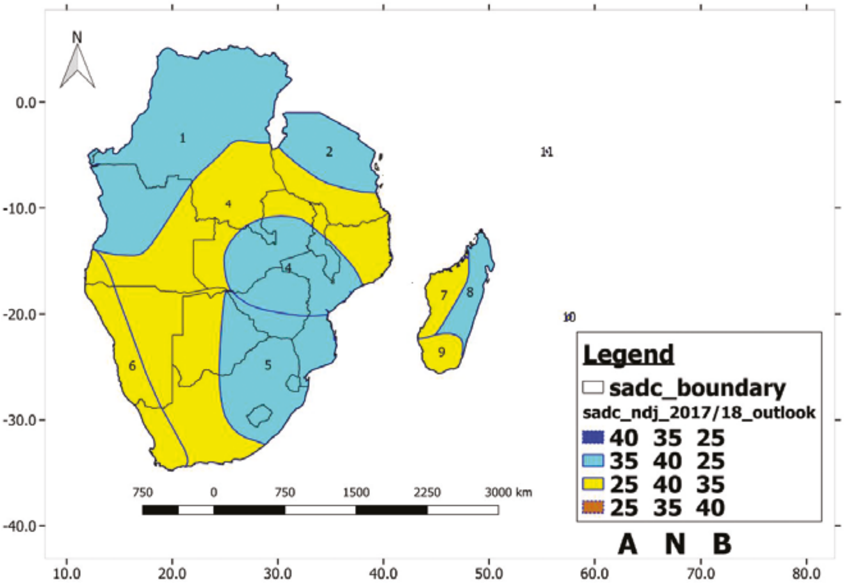
Source: http://www.agrhymet.ne/PDF/carte_synthese_presass2017.pdf

region (**Fig. 16**) and by *Southern Africa Regional Climate Outlook Forum* (**Fig. 17**) for the Southern African region. These maps are an example of a good *climate product*, nevertheless, they do not represent a *climate service* that adequately meets the needs of farmers. The output of the model was originally developed to support national meteorological and hydrological services to spatially downscale the forecasts. However, in several countries the seasonal forecasts reaching national stakeholders in the original form, format and scale are not improved versions and have not been adapted to the needs of stakeholders within their countries (Hansen *et al.*, 2011). During recent years some National Meteorological Services have produced a downscaling of the seasonal forecast for the country (**Fig. 18**) in order to compensate for this gap. Several of the constraints regarding the use of seasonal forecasts, as well as the beneficial effects for farmers in Sub-Saharan Africa, have been identified by the empirical research (Hansen *et al.*, 2011) as follows:

Information content:

- Coarse spatial scale lacks local information
- Lack of information about timing of rainfall
- Lack of information about season onset or length
- Ambiguity about forecast categories
- Forecasts not in local language
- Accuracy not sufficient.
- Probabilistic output (not well managed by local population)

FIGURE 16 **Rainfall outlook update for Nov 2017 – Jan 2018 for the Southern Africa region**



Source: http://csc.sadc.int/images/documents/SARCOF%2021_Statement.pdf

Access:

- Inequitable access;
- Forecasts made available too late (two weeks of delay from the production of the forecast);
- Neglected communication of favorable forecasts and bias towards adverse conditions.

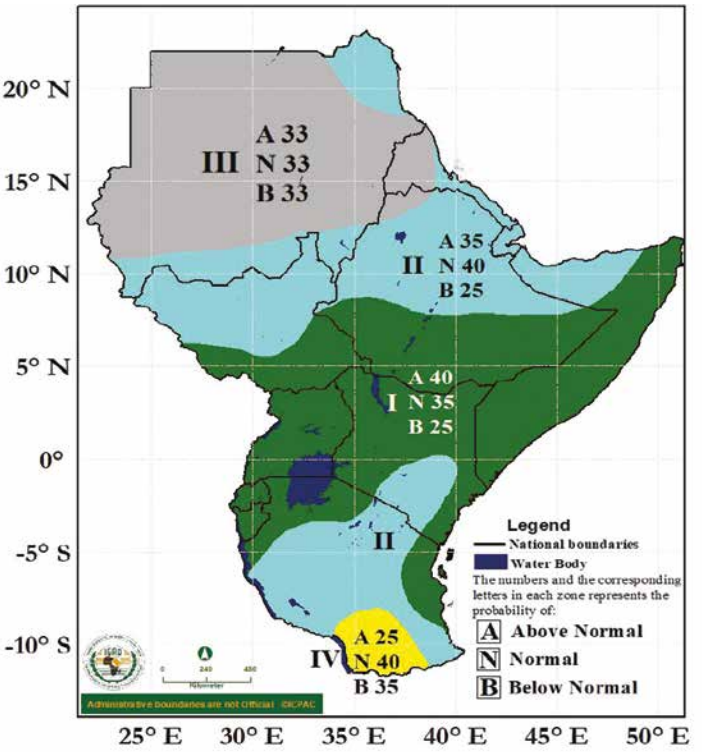
There are still large discrepancies between what is needed by farmers and the seasonal forecast information that is routinely available. In order to respond to practical needs, the structure of seasonal forecasts should take into account:

i. downscaling and local interpretation;
ii. the growing season weather beyond the seasonal average;
iii. accuracy expressed in transparent, probabilistic terms;
iv. interpretation of results in terms of agricultural impacts and management implications.

To make use of seasonal forecast information at local level it should include:

- Forecast probability distribution of seasonal rainfall total plotted against the climatological distribution;
- Comparison of the time series of historic climate observations (i.e. monthly rainfall amount) against hind-casts (i.e. results of statistical calculation determining probable past conditions);
- Same information for number of rainy days.
- Map of probability of extreme events (dry spells and extreme rainfall events)

FIGURE 17 **Rainfall outlook update for October to December 2018 for the Eastern African Region**



Source: http://www.icpac.net/images/bulletin/seasonal/GHACOF%2050%20Bulletin.pdf

In this context, IRI has developed quantitative seasonal climate forecast information down-scaled[17] locally for farmers and for other local agricultural decision makers. This information includes:

a. a forecast probability distribution of total seasonal rainfall plotted against the climatological distribution;
b. a time series of historic climate observations and hind-casts;
c. the same information for the number of rainy days (**Fig. 19**).

Several studies have confirmed that farmers can actually get substantial benefits when they communicate with the experts producing climate information products and, more importantly, when their needs are taken into account. Field surveys indicate that between 30 percent and 80 percent of farmers who reported receiving seasonal forecast information had changed their management (such as the time of planting and crop variety) based on

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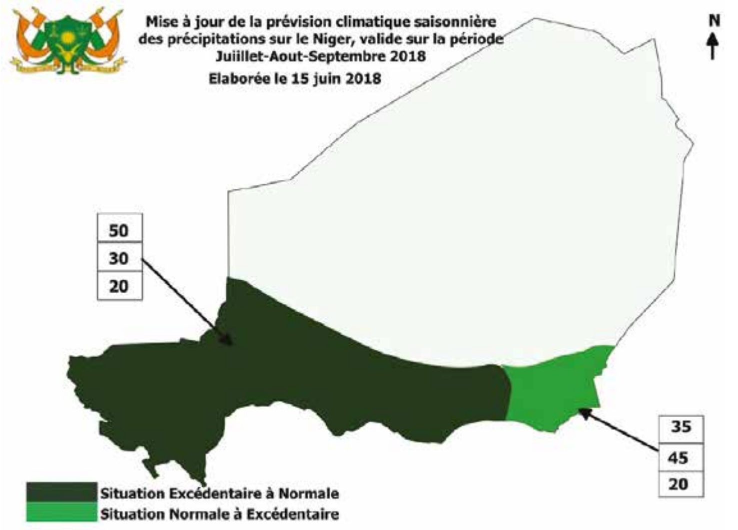
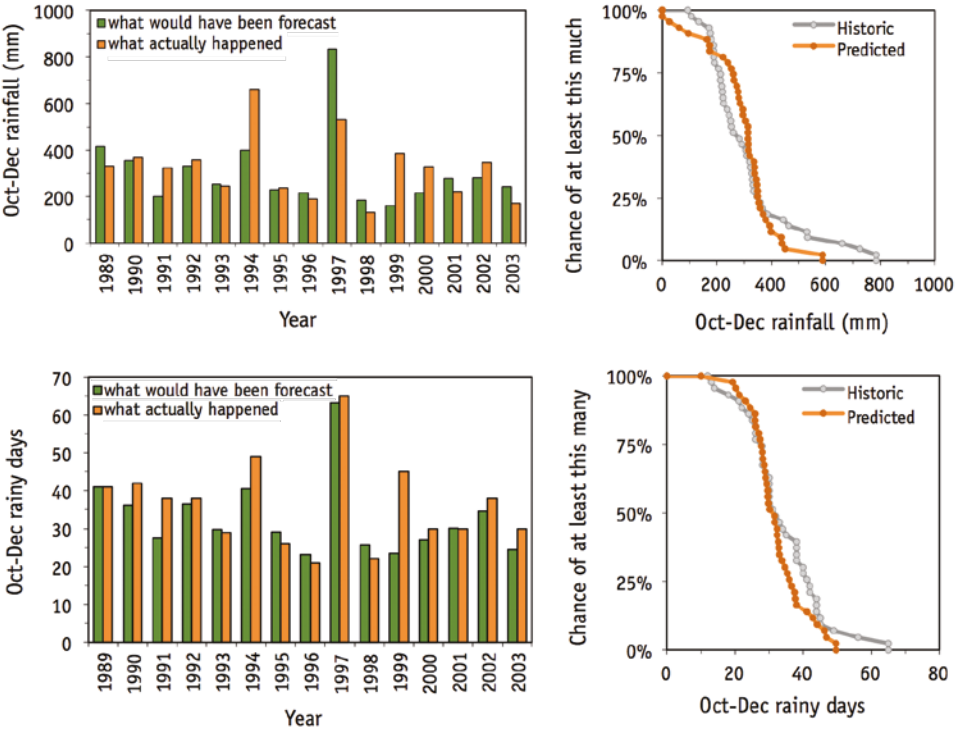
[17] The International Research Institute for Climate and Society (IRI) (http://portal.iri.columbia.edu/portal/server.pt). http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=8235654

FIGURE 18 Seasonal rainfall forecast for July to September 2018 for Niger



Source: https://www.meteo-niger.org/content.php?page=131

FIGURE 19 Downscaled forecast of total rainfall for October-December 2004 in Katumani, Kenya.



Source: adapted from Hansen *et al.*, 2011 the forecasts (Hansen *et al.*, 2011). Frequency is an important element to consider because farmers can readapt their cropping strategies based on the forecast. Therefore, as some decisions need to be taken in advance, farmers have enough time to change their strategies (organize the harvest or the planting, variety of choice etc.). The frequency of weather forecasts should be daily, every 3 days and weekly. Intra-seasonal forecasts should be every month and seasonal forecasts before each season. Finally, there should be a 10-year mediumterm projection, as well as a 20-30 years scenarios for climate change projections.

The spatial resolution should support the local, sub-national, national, regional and international needs, which means information for decisions on agronomic, livestock and fishery management practices. Sub-national needs include food availability, monitoring, storage and input supply, marketing, procurement and credit. National needs include information for developing policies, planning and action plans. Food security, management of trans-boundary pest and diseases, river water monitoring, and tracking for extreme events, such as drought and river floods are among the most common regional and international needs. At the local level, the use of seasonal rainfall forecasts and its dissemination by the National Meteorological Services has substantially improved the pre-season management decisions by farmers, in particular.

The links to regional African and international centers producing seasonal climate forecasts are listed below:

Regional African seasonal forecasts

- **CILSS Regional Center for Agro-Hydro-Meteorology (AGRHYMET)**
  http://www.agrhymet.ne/eng/index.html
- **IGAD Climate Prediction and Applications Center (ICPAC)**
  http://www.icpac.net
- **African Center of Meteorological Applications for Development (ACMAD)**
  http://www.acmad.net/new/
- **Southern African Development Community (SADC) Climate Services Center**
  http://www.sadc.int/news-events/newsletters/climate-outlook/

International seasonal forecasts

- **International Research Institute for Climate and Society (IRI)**
  http://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-climate-forecasts
- **European Center for Medium-Range Weather Forecasts (ECMWF)**
  https://www.ecmwf.int/
- **NOAA Climate Prediction Center (CPC) NMME**
  http://www.cpc.ncep.noaa.gov/products/international/nmme/nmme.shtml

Crops mainly respond to daily variations of rainfall and temperature. Before climate change was detected, the use of long-term climatic records (about 30 years) determined the probability of the occurrence of a wide range of agro-climatic parameters important to agriculture and the risk associated with them. However, this time period used in response to farming approaches has diminished to approximately ten years due to conditions caused by a changing climate (ZumaNetshiukhwi, 2013). Consequently, agricultural management decisions based on seasonal rainfall forecast are now better developed (**Table 2**).

TABLE 2 Management decisions by farmers using seasonal rainfall forecasts

UNDER PREDICTED DRY SEASON (BELOW NORMAL RAINFALL)	UNDER PREDICTED NORMAL TO WET SEASON (NORMAL TO ABOVE NORMAL RAINFALL)
Ensure land is cultivated in a timely fashion prior to drier conditions.	Ensure land is cultivated in a timely fashion prior to the onset of good rainfall events.
Order inputs (seedlings, sees and fertilizer) prior to engaging in planting.	Order inputs (seedlings, sees and fertilizer) prior to engaging in planting.
Concurrently check weather forecasts and climate predictions. Draw up an operational plan for the season.	Concurrently check weather forecasts and climate predictions. Draw an operational plan for the season.
Minimize planting density by at least 25%-50% ha^{-1}	Introduce normal to higher planting density ha^{-1}
Minimize labour and other input use.	Ensure there is sufficient labour and apply fertilizer.
Plant just before the expected onset of the 1st rainfall event.	Adopt sequential planting and intercropping.
Adopt drought tolerant crops such as sorghum, millet and cassava.	Plant crop varieties (diversify).
Control weeds frequently.	Control weeds more frequently.
Introduce water conservation methods such as using different types of mulch.	Strengthen the use of terraces and ridges/dykes to reduce erosion and surface run-off.
Minimize the area under cultivation.	Enlarge the area under cultivation.
Adopt water conservation measures.	Store water to apply in the occurrence of long dry spells.

Source: Zuma-Netshiukhwi, 2013

RCOFs do not, however, adequately disseminate seasonal forecasts to smallholder farmers (Mafongoya P.L. *et al.*, 2017). The main reasons are the following:

- Forecasts are not specific enough for the needs of end users. This includes issues of poor spatial resolution and response to local scale agricultural decision-making needs and a lack of information on intra-seasonal rainfall distribution;
- Poor interpretation and communication of forecasts, which leads to misunderstanding and low dissemination rates;
- Farmers' inability to respond to forecasts due to their lack of access to seed, fertiliser, labour and credit, which would allow them to make adjustments in relation to the expected seasonal climate;
- Poor distribution of the forecast due to lack of communication channels. The forecast often reaches farmers when the event has already occurred or without allowing enough time to modify the management.

2.4.1.4 Climate change projections

Climate change projections are used to indicate precipitation and temperature patterns in the 30to50-year time frame. They can serve as a guide for major investment decisions related to longterm water management such as, for example, whether to build new reservoirs and where. Crop yield scenarios are also available now. Access and quality of data for climate-scenario development are key issues for the success of any scenario-development project. The first step to be taken is to assess the availability of historical climate data for the region's baseline climate and to analyse existing meteorological data (i.e. temperature, precipitation, wind, etc.) and other climate-related measurements.

The following aspects of the region's historical climate data should be considered:

i. the number of stations;
ii. areal coverage of the data;
iii. length of the records;
iv. quality of the records.

Quality control of observational data is generally a time-consuming process that requires planning the project, as the availability of historical data is key to understanding future changes in climate. In addition to historical meteorological data, other types of data are also important for climate-scenario development. The properties of the land surface (i.e. soil type, land cover type like forest, grassland, urban, river basins) are key to determining what is needed for physically based models. Other data depend on the nature of the vulnerability and adaptation assessment and may include population, energy, and emissions data. The *local climate* can be regarded as the result of a combination of the local geography (physiography) and the large-scale climate (circulation):

Local climate, $y = f(X, L, G)$
where X = Regional climate; L = local geography; G = Global climate

Global Climate Models (GCMs) provide projections of the future climate at a resolution of about 100km. Furthermore, some regional climate models (RCM) are available e.g. the *Cordex Initiative*[18] that could reach 0.25° resolution, after which the downscaling technique (**Fig. 20**) is used to generate finer resolution climate information from coarse resolution numerical models such as GCM or RCM. Currently, Regional climate change projections at the country level as provided by international institutes like the UNDP *Climate Change Country Profiles*[19] can be found on the Internet where also raw data of the

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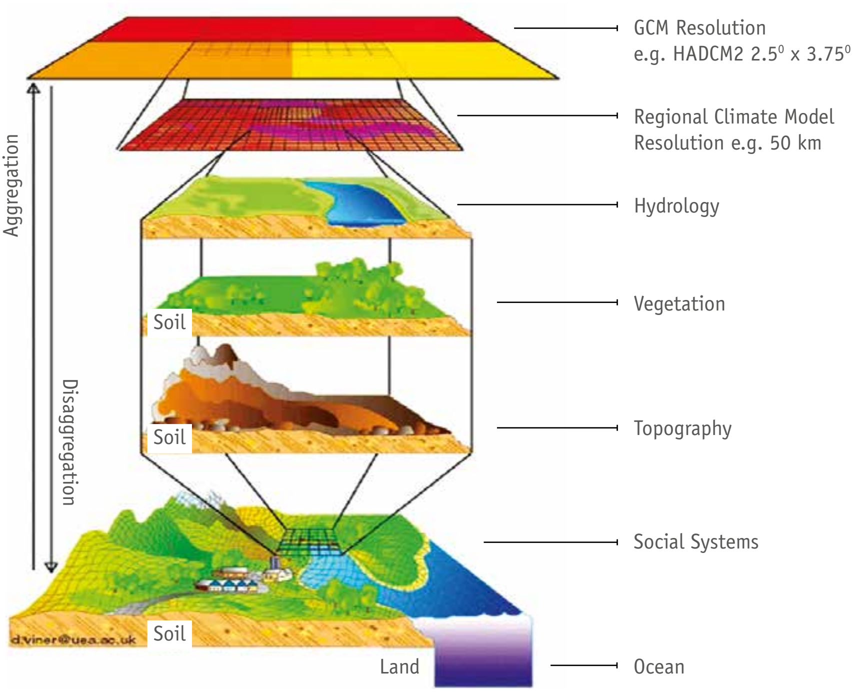
[18] Cordex Initiative: http://www.cordex.org/data-access/esgf

[19] University of Oxford, School of Geography and the Environment: http://www.geog.ox.ac.uk/research/climate/projects/undp-cp/

FIGURE 20 **Downscaling of global circulation models (± 200km) to local scale (1-10km)**



Source: adapted from Viner *et al.*, 2012

climate projection is available through the *Coupled Model Intercomparison Project* (CMIP[20]). In situations where proper equipment and skilled staff are available, specific software can be obtained and used to get projections for each individual region. **PRECIS**, developed by UK Met Office is one of these.

Some providers of future climate projections at the country scale are listed below:

- **World Bank - Climate Change Knowledge Portal** – http://sdwebx.worldbank.org/climateportal
- **ClimateWizard** – The Nature Conservancy, University of Washington and University of Southern Mississippi – http://climatewizard.org
- **Climate Information Platform** – CIP, Climate Systems Analysis Group, University of Cape Town – http://cip.csag.uct.ac.za/webclient2/app
- **PRECIS** (Providing Regional Climates for Impacts Studies) – http://www.metoffice.gov.uk/research/applied/international-development/precis/introduction

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[20] CMIP: https://www.wcrp-climate.org/wgcm-cmip

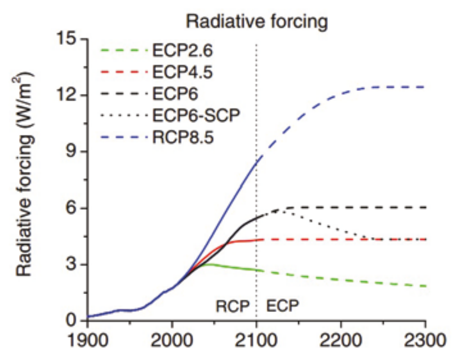
BOX 3 Representative Concentration Pathways (RCPs)

How can the models simulate the future projection of the climate? As seen in the previous chapters the evolution of the climate is not only dependent on the atmosphere physics evolution, but also on forcing from the earth system. Changes in the earth radiative budget is one of the main drivers of the future evolution of climate. For this reason, the scientific community of the IPCC has developed an RPC approach in order to define a set of ideas on the future evolution of climate.

The projection of radiative forcing is the main input for different climate models from different institutions used for obtaining comparable sets of climate evolution, which can be grouped into homogenous classes. Essentially, the evolution of climate represents four possible anthropic responses to climate change. The most optimistic response (RCP 2.6) is linked to a proactive mitigation policy by a majority of the countries worldwide, while the pessimistic one (RCP 8.5) is a situation where there are no mitigation policies.

Effects of these different pathways on the climate simulation are the results that can be obtained in different climatic parameters evolution. The future global temperature evolution displayed in the chart below shows a more optimistic scenario that could span from +0 to +1.5°C at the end of the century, as well as a pessimistic one that forecasts +2.5-+3.5C° at the end of the century

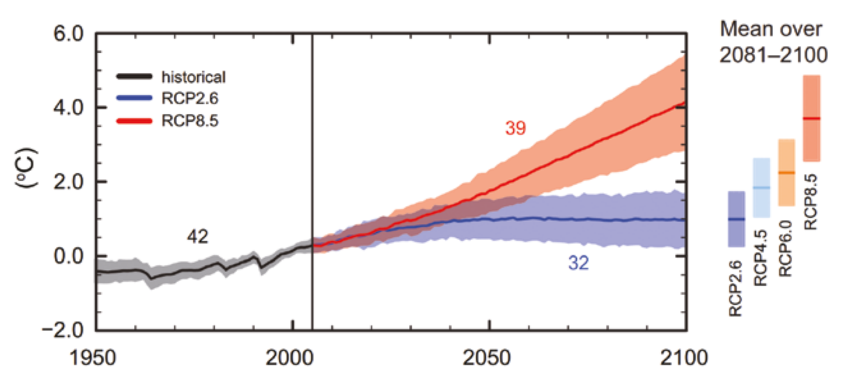
FIGURE 21 Extension of the RCPs (radiative forcing and associated CO_2 emissions).



ECP is extended concentration pathway. The SCP6 to 4.5 (supplementary concentration pathway) shows an alternative extension for RCP6.

Source: Van Vuuren *et al.*, 2011

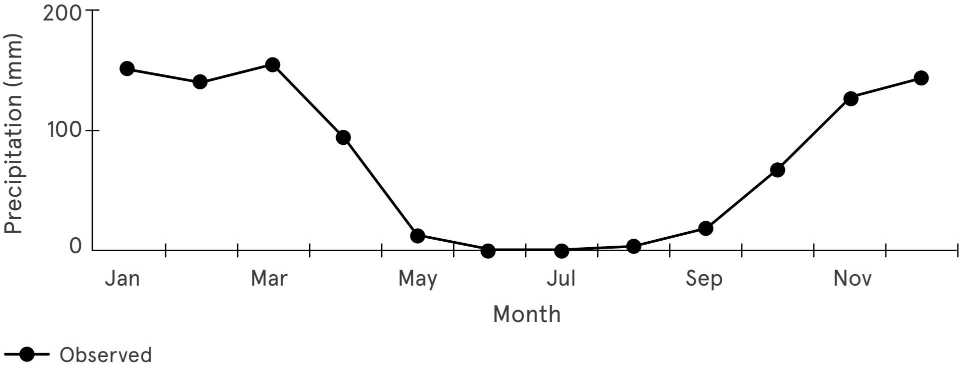
FIGURE 22 Global average surface temperature change



Source: IPCC, 2013

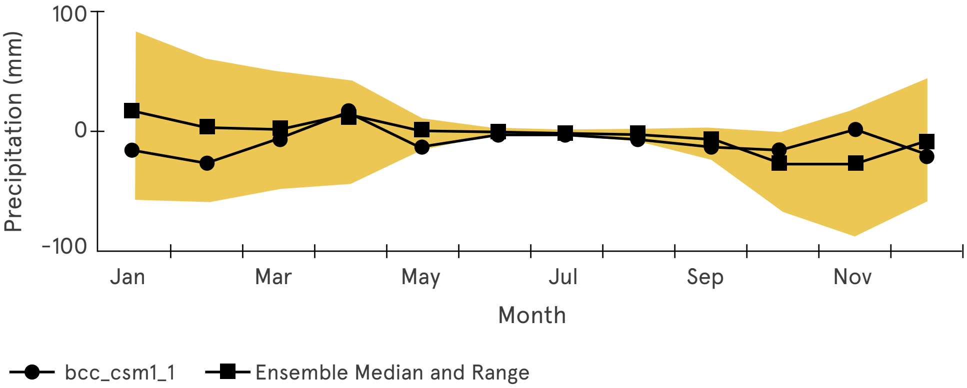
The **Fig. 23** shows the historical observed monthly rainfall (mm) for Angola from 1986 to 2005 while the **Fig. 24** shows the projected change in monthly rainfall (mm) for Angola from 2080 to 2099.

FIGURE 23 Historical observed monthly rainfall (mm) for Angola (1986-2005)



Source: http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_future_climate&ThisRegion=Africa&ThisCcode=AGO

FIGURE 24 Projected change in monthly rainfall (mm) for Angola (2080-2099). Comparison between one model and ensemble median and range



Source: http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_future_climate&ThisRegion=Africa&ThisCcode=AGO

2.5 CLIMATE-RELATED DATA PRODUCTS

If climatic events can be predicted to a degree that allow for an effective response from the agricultural sector, then this would potentially have a major impact on worldwide food security. Consequently, farmers should be better prepared for climatic anomalies and hence, less vulnerable. Understanding and interpreting local weather data as well as the relationship between weather and climate are the first important steps towards recognising larger-scale global climate changes.

Climate is sometimes referred to as "*average*" weather for a given area. For example, the National Meteorological Services around the world have used values such as maximum and minimum temperatures and precipitation amounts for the past 30 years to compile "*average*" weather for any given area. However, variations, patterns and extremes must also be included in order to more accurately define the climatic character of an area. In brief, climate is the sum of all statistical weather information that helps describe a place or region and can be applied more generally to large-scale weather patterns in time or space (e.g. an Ice Age climate or a tropical climate). To investigate how changes in climate are caused by the human factor, weather data can be used starting from the origins of historical records as long as the data are accurate. Detailed daily weather data are collected at surface meteorological stations (weather stations) throughout the world. The following factors can nevertheless limit the accuracy of the data:

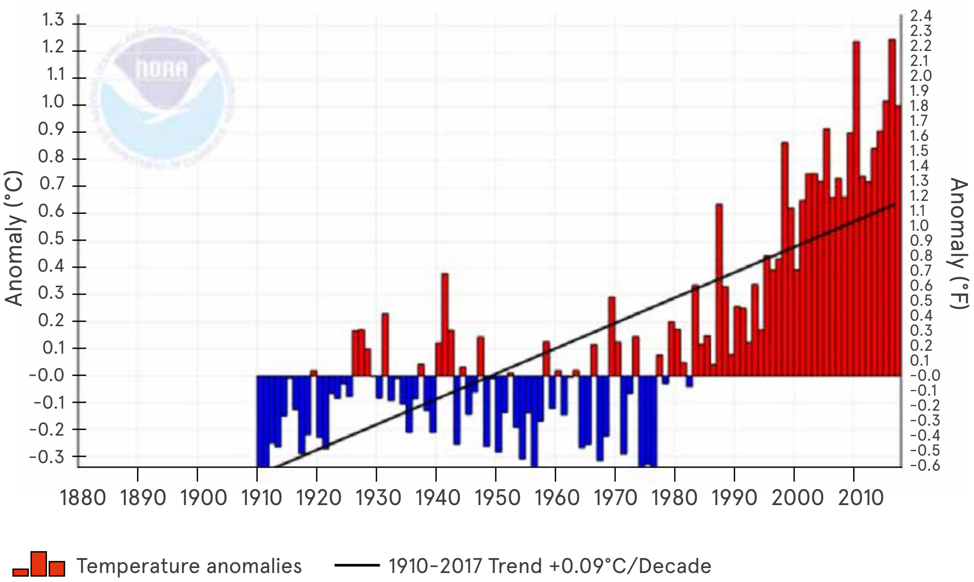
» Many stations are in or near urban areas that often experience warmer temperatures than in the surrounding countryside. This is due to the heat absorbing properties of concrete and asphalt and the lack of shade and evaporative cooling from vegetation. This phenomenon is known as the "*heat island effect*";
» Many weather stations have been moved from rural locations to airports making it difficult to interpret and compare measurements over time.

Historical climate information consists of data records on climate in the past, but it is important to take into consideration which timescale is the most relevant for decision-making. Different timescales will allow users to put their climate analysis into the context of climate change, climate variability, and inter-annual variability.

Fig. 25 shows land temperature anomalies (°C) in Africa from 1910 to 2017. The term *temperature anomaly* means a departure from a reference value or long-term average. A positive anomaly (*red*) indicates that the observed temperature was warmer than the reference value, while a negative anomaly (*blue*) indicates that the observed temperature was cooler than the reference value. Based on this figure it is possible to gauge the following components of climate variability:

» Inter-annual (red and blue values): how climate can shift from year to year.
» Long-term trend (black line): how climate can shift over the long-term (beyond 30 years). The most important contributor at this timescale is the impact from climate change. Here, the long-term trend shows an increase in temperature over a time span of more than 100 years.

FIGURE 25 Africa Land Temperature Anomalies from 1910 to 2017



Source: https://www.ncdc.noaa.gov/cag

2.5.1 **CLIMATE DATA**

Global climatological and real-time meteorological stations data from different sources are received in various forms (i.e. hand-written report, formatted and non-formatted text, spread sheets, ASCII text, spatially interpolated data, etc.). During recent years the demand for climatological and agro-climate data (including remotely sensed data) has increased almost at the same rate as the time-processing performance of computers. Indeed, there is a large demand due to a higher resolution (in time and space) needs for running specific applications for a defined location or area as well as a defined time interval. Of course, the demand for data is linked to the demand for tools (methods and software) for example, when applied to crop phenology modelling or estimating crop water requirements but also deriving meteorological parameters from satellite imagery. Climatological databases must be assembled for crop monitoring and forecasting systems because year-to-year climate variability is a dominant factor in the variability of crop yields. As crop water consumption depends on several variables, such as temperatures and wind speed, agrometeorological databases should ideally include more than rainfall only. Climate conditions can vary significantly even over small distances. The main sources of historical climatological data are listed in the annexes.

2.5.1.1 Point climate data

The representativeness and homogeneity of climatological records are closely related to the location of the observing site. A station sited on or near a steep slope, ridge, cliff, hollow, building, wall or other obstruction is likely to provide data that are more representative of the site alone and not of a wider area. A station that is or will be affected by the growth of vegetation, including even limited tree growth near the sensor, growth of tall crops or woodland nearby, erection of buildings on adjacent land, or increases (or decreases) in road or air traffic (including those due to changes in the use of runways or taxiways) will provide neither broadly representative nor homogeneous data. A climatological observing station should be sited at a location that permits the correct exposure of the instrumentation and allows for the widest possible view of the sky and surrounding countryside, if visual data are required. Guidelines on where to install a weather station are defined by the World Meteorological Organization (WMO, 2017).

The density and distribution of climatological stations to be established over a land network within a given area depend on the meteorological elements to be observed, the topography and land use in the area, and the requirements for information about the specific climatic elements concerned. The rate of variation of climatic elements across an area will differ from element to element. A sparse network is sufficient for the study of surface pressure, a fairly dense network for the study of maximum and minimum temperature, and very dense networks for examining the climatology of precipitation, wind, frost and fog, especially in regions of significant topography.

Stations should be located with respect to representative climatic characteristics that are consistent with all types of terrain, such as the plains, mountains, plateaus, coasts and islands and surface cover such as forests, urban areas, farming areas and deserts within the area concerned. For example, there may be a need for a greater density of stations where activities or health are sensitive to climate and a lesser density in locations with fewer people, as far as data used in sectorial applications within an area is concerned. When planning a land network, compromises have to be made between the ideal density of stations and the resources available for installation, operation and management of the stations. The distribution of stations in a regional basic synoptic network from which monthly surface climatological data are collected should be such that every 250,000 km^2 are represented by at least one station and up to 10 evenly distributed stations if possible. Networks of principal climatological stations should have a maximum average separation of 500 kilometres.

As mentioned in paragraph 2.2 in every country in the world there is a network of meteorological stations. However, in practice it is difficult to obtain a reliable series of daily measurements of the parameters for representative sites, due to the poor density of these stations particularly in the developing countries. For example, Africa’s conventional synoptic stations[21] number just over 1,150 stations giving a density of 1 per 26,000 km^2 (Washington *et al.*, 2004) while the area representing 1 station should range from 2,000 km^2 to 10,000 km^2 for a plane or homogeneous relief (WMO, 2017a). Although several projects have supported the installation of new weather stations in Africa, the density of the network is still far from ideal. In various developing countries the density also has a negative trend, that is, a decrease in the number of operational stations caused by problems with the solar panel, data-logger or with the communication parts, such as the modem.

2.5.1.2 Gridded climate data

Meteorological stations should be installed following WMO's standards[23] and taking into account their density, which is particularly poor in developing countries. To overcome this gap and to estimate climate data for points on the Earth where meteorological stations are not available, data sets of spatially irregular (i.e. not evenly distributed over land) and meteorological observations are interpolated and may be combined with satellite-based information to obtain a regular grid of weather parameters. Such datasets allow estimates of climate parameters at locations far from the vicinity of meteorological stations, thereby allowing studies of local climate in data-sparse regions. To create gridded data sets observations from an evenly distributed network of stations are needed in digital format.

2.5.2 SPATIAL INTERPOLATION

Spatial interpolation is the process of using points with known values to estimate values at other unknown points. The spatial interpolation of climatic data aims at estimating the value of rainfall, temperature, or any other climatic parameter at a given site based on the observations at neighbouring locations. Operational climatology and agrometeorology are regularly confronted with problems, such as when estimating missing data. Area averaging, the estimation of missing data and gridding, are some of the most useful applications of spatial interpolation techniques to climatology and agrometeorology. From a methodological point of view, the problems of missing data interpolation and of data gridding are thus largely the same. Over recent years, with the development of *Geographic Information Systems* (GIS), there has been an increased need for gridded datasets, i.e. datasets in which the value of a climatic parameter has been estimated at regularly spaced points.

Geographically referenced data from a variety of sources must be used in conjunction with data provided by ground meteorological network and information obtained from

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[21] Synoptic weather stations collect meteorological information at synoptic time 00h00, 06h00, 12h00, 18h00 (UTC) and at intermediate synoptic hours 03h00, 09h00, 15h00, 21h00 (UTC). The common measuring instruments are the anemometer, wind vane, pressure sensor, thermometer, hygrometer and rain gauge. Weather measurements are formatted with a special format and transmit to WMO as an input to the weather forecast model. The purpose of the synoptic observations includes mapping large-scale weather systems (in real time and for climatology) and also to provide the basis needed for proper analysis and verification of the operational weather models.

satellite imagery. Activities such as the mapping of potential distribution of pests rely on agrometeorology applied software for climatic databases. GIS tools are used for *geo-statistics*[22] and spatial interpolation routines such as transforming the point value into interpolated surfaces. As interpolated surfaces must represent the ground truth with great detail, several techniques are used in order to "*help*" the interpolation of the selected parameter to obtain a continuous surface with the highest resolution.

Spatial interpolation techniques are required mainly in crop forecasting for food security. In fact, the estimation[23] of crop yields is based on station values of climatic and agronomic parameters, while the estimates of food production are averaged at districts and provinces level. Crop yields must therefore be area-averaged, which implies that yields must be computed for a number of locations thus exceeding the number of available meteorological stations.

There are many methods of spatial interpolation such as the method of "*inverse distance weighting*" *(IDWA)* and the method of "*Thyssen's polygons*", to name just a few. In addition, the cokriging method allows for carrying out an optimum estimation by taking more than one variable into account, i.e. taking advantage of the relations between the variables to improve the estimation. For instance, altitude is an important additional variable when estimating temperatures. The choice of an interpolation method depends on the purpose of the application, the availability of data as well as efficiency of data processing and costs. Therefore, the interpolation methods to be used must take into consideration the spatial and temporal variability of the different types of meteorological data in relation to the meteorological processes.

The *New_LocClim* (Local Climate Estimator) tool developed by FAO can estimate local climatic conditions for any location on Earth for which no observations are available. The user can choose among several popular interpolation techniques (*Nearest neighbour, IDWA, modified IDWA, Cressmanns method, Distance functions, Polynomials, Shepard's method, Kriging, Thin plate splines*). Furthermore, altitude regression and local or regional horizontal gradients can be taken into account. New_LocClim uses the FAO climatic database with observations from nearly 30,000 stations worldwide but users also have the option to process their own data. See the annex for more details.

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[22] Geo-statistics is a branch of statistics that deal specifically with spatial data. It means that each data value is associated with a location in space (geographic coordinates) and there is at least an implied relationship between the location and the data value. In a very simplistic way, it can be viewed as a methodology for interpolating data on an irregular pattern or, in another way, the estimate of missing values at one point in space based on the known values and characteristics of neighbouring entities. In the recent years, geo-statistics had a very wide of applications and spatially interpolated climate data on grids, often referred to as 'climate surfaces', are used in many applications, particularly in environmental, agricultural and biological sciences. The spatial resolution of the climate surfaces used in a particular study depends on the needs for that application and on the data available. For many applications, data at a fine (≤1 km^2) spatial resolution are necessary to capture environmental variability that can be partly lost at lower resolutions, particularly in mountainous and other areas with steep climate gradients (Bernardi *et al.*, 2006).

[23] The term "*estimation*" is used for the value eventually obtained through interpolation techniques at a point where no observation is available. The term does not imply any connotation of "*forecasting*" in this context. The predicted (estimated, missing, interpolated) values are based on the "*known*" or "*observed*" ones.

2.5.3 DIGITAL DATA FORMATS

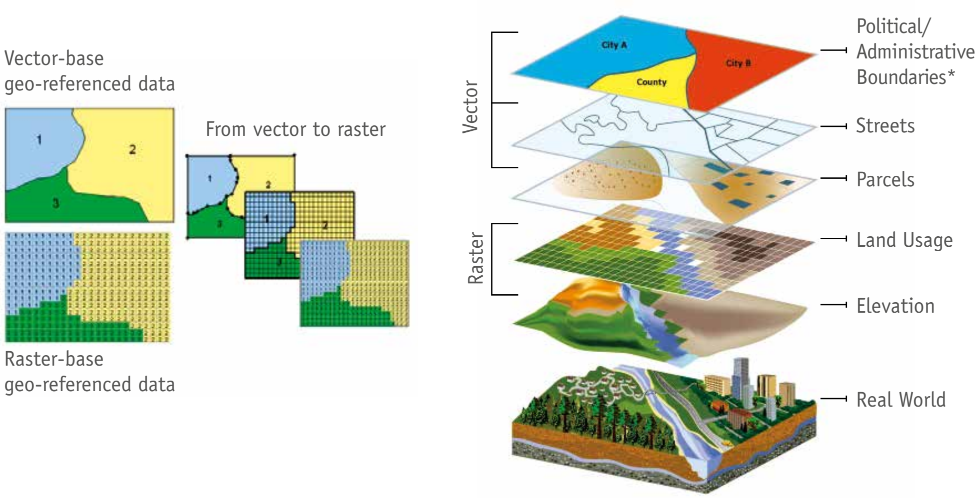
Spatial interpolation uses vector points with known values to estimate values at unknown locations in order to create a raster surface covering an entire area. Therefore, the interpolation result is typically a raster layer. *Vector* data represent features as discrete points, lines, and polygons, while *raster* data represent the landscape as a rectangular matrix of square cells (**Fig. 26**). Raster datasets are composed of rectangular arrays of regularly spaced square grid cells. Each cell has a value representing a property or attribute of interest.

While any type of geographic data can be stored in raster format, raster datasets are especially suited to the representation of continuous data rather than discrete (i.e. elevation, vegetation, roads, buildings) to represent real-world features (**Fig. 27**). In the same way, climatic parameters can also be added to represent environmental conditions for a specific area.

In terms of digital images, spatial resolution refers to the number of pixels utilized in construction of the image. Images with higher spatial resolution are composed of a number of pixels that is greater than those of lower spatial resolution.

A measure of the accuracy or detail of a graphic display is expressed in dots per inch, pixels per line, lines per millimetre, etc. It is the measure of how fine an image is, which is usually expressed in dots per inch (dpi). The minimum difference or distance between two independently measured or computed values or objects can be distinguished by a measurement or analytical method, or by the sensor being applied. It provides a limit to

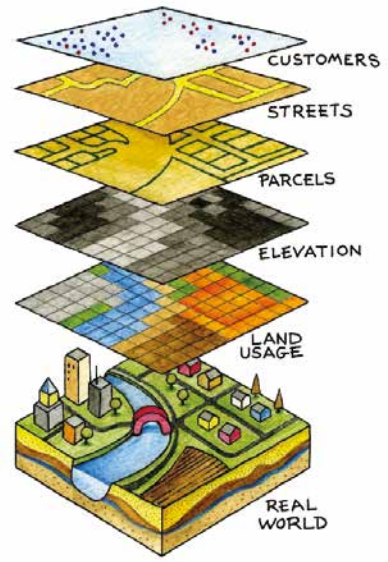
FIGURE 26 Vector and raster geo-referenced datasets



* i.e., zip codes, city limits, political districts, area codes, residential and businness customers, etc.

Source: https://unstats.un.org/home/

FIGURE 27 Real-world features illustrated by raster datasets

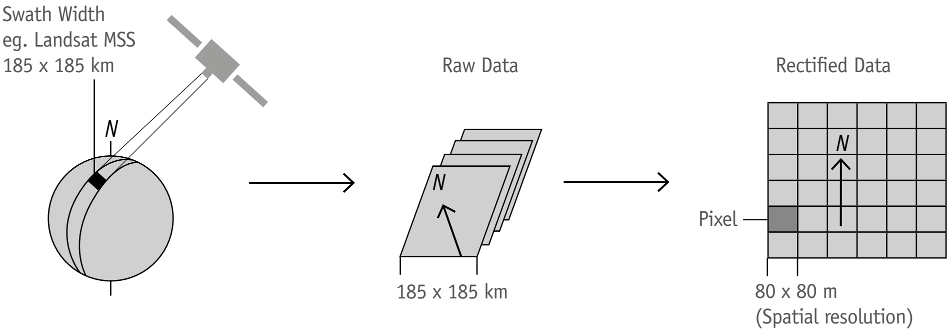


Source: https://unstats.un.org/home

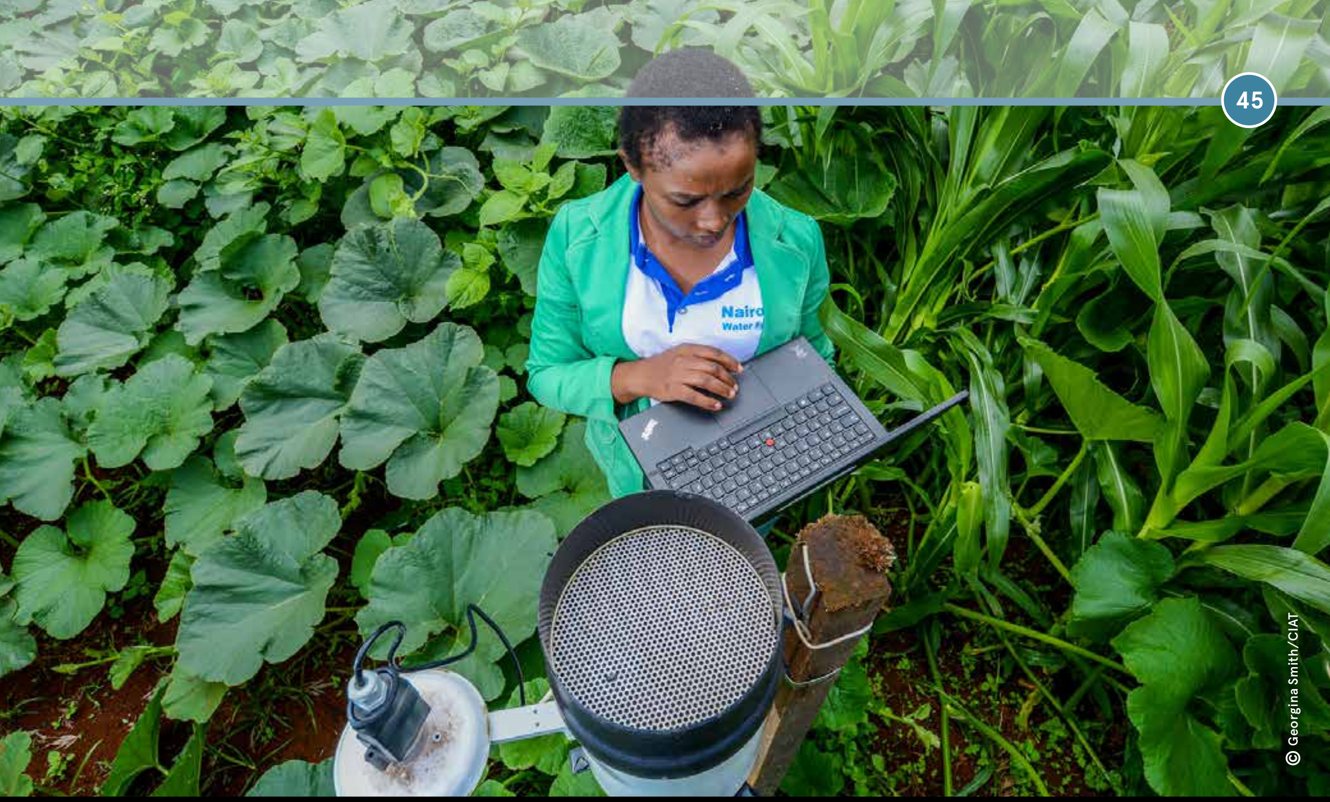
precision and accuracy. It is often called *spatial resolution* but it also applies to spectral and temporal aspects of remote sensing imaging systems.

Resolution is the accuracy at which a given map scale can depict the location and shape of map features; the larger the map scale, the higher the possible resolution (**Fig. 28**). As a map scale decreases the resolution diminishes and feature boundaries must be smoothed, simplified, or not shown at all. The size of the smallest feature can be represented on a surface and small areas may have to be represented as points.

FIGURE 28 Spatial resolution of a raster satellite imagery



Source: http://www.fao.org/docrep/003/t0355e/t0355e04.htm



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SECTION 3

AGROMETEOROLOGY PRODUCTS

- AGROMETEOROLOGY
- AGRICULTURAL RELEVANT RAINFALL/CROPPING SEASON PARAMETERS
- AGROMETEOROLOGICAL ANALYSIS
- AGRO-ECOLOGICAL ZONING
- FARMING SYSTEMS
- CROP CALENDAR AND CROP GROWING SEASON
- AGROMETEOROLOGICAL CROP MONITORING
- AGROMETEOROLOGICAL ADVISORIES
- REMOTE-SENSING BASED PRODUCTS

3.1 AGROMETEOROLOGY

Agrometeorology deals with the meteorological, hydrological, pedological and biological factors that affect agricultural production as well as the interaction between agriculture and the environment. The main objectives of *agrometeorology*[24] are: (i) to study the agro-climatic resources (ii) to assess their impact (positive and negative) on agriculture and (iii) to use the knowledge to improve yields. Weather and climate influence agricultural production and various climatic factors have been used to classify the world into agro-climatological or agro-ecological zones, according to the potential distribution of a range of crops.

Agrometeorology is also concerned with all of the weather-sensitive elements of agriculture production, including pollination, animal migration, pests, transport of pathogens by wind, irrigation, climate manipulation and artificial climates, weather risk assessments, the use of weather forecasts in farming, crop yield and phenology forecasts and particularly advice to farmers, as well as the required data and methods. Modern agrometeorology relies on a package of new tools that include data acquisition techniques (ground observation, aircraft and satellite), data transmission techniques (including the Internet) and data analysis (models and other software).

The estimation of vulnerability and the frequency of extreme weather events and/or damaging factors as a function of their intensities are the core of the methodology for Early Warning Systems. From an agrometeorological point of view, early warning indicators and risk management systems are the most obvious and efficient contributions being made to improve the adaptation to climate variability and change. In particular, the use of agrometeorological tools can provide a current and future assessment of the impact of climate variability on crops (i.e. date of planting, length of growing season, yield, weather-based index, etc.) at the regional, national and local level.

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[24] Agricultural meteorology (or *agrometeorology*) refers to the interaction between meteorological and hydrological factors, on the one hand, and to agriculture in the widest sense including horticulture and animal husbandry and forestry on the other. Agricultural meteorology deals with the meteorological, hydrological, pedological and biological factors that affect agricultural production as well as the interaction between agriculture and the environment. Its objectives are to explicate these effects by applying this supportive knowledge and information in agrometeorological practices and through agrometeorological services. At the same time farmers are provided guidance on how to be prepared. Guide to Agricultural Meteorological Practices (GAMP), 2010 Edition (WMO-No.134). Updated in 2012 http://www.wmo.int/pages/prog/wcp/agm/gamp/gamp_en.php

3.2 AGRICULTURAL RELEVANT RAINFALL/ CROPPING SEASON PARAMETERS

The total rainfall and its distribution are key factors for the definition of the *agro-ecological zoning* (AEZ) and *farming systems*. Main field crop productions, in general terms, are determined by agro-climatological conditions. Water availability constraints are rooted mainly in the variability and unpredictability of seasonal rainfall. For crop production the rainfall amount can be divided into three component parameters:

- *Season duration*: for crop production potential: the number of days from the onset to the final rainfall date. For a specific crop: the rainfall onset date/crop germination (whichever is later) date to the rainfall stop/crop maturation date (whichever is earlier);
- *Rainfall intensity*: the average rainfall per day during the rainy/wet season (intensity index);
- *Rainfall distribution* throughout the season, including the number of rainy days and the duration of dry spell periods.

Meteorological parameters are measured on a daily basis at a precise location following WMO guidelines (WMO, 2017) where agrometeorological stations are installed. In general, data are sent to the National Agrometeorological Unit at the end of each 10-day (dekad) period. Data include:

- Maximum and minimum air temperature in degrees Celsius;
- Soil temperature in degrees Celsius at 5, 10, 20, 30, 50, 100 cm depths;
- Sunshine duration in hours;
- Radiation in mega joules per square meter;
- Wind speed in meters per second at 2 and/or 10 meters height;
- Calculated relative humidity by percentage at 09:00 and 15:00;
- Pan evaporation in millimetres per day;
- Calculated potential evapotranspiration in millimetres per dekad (10-day period)
- Rainfall in millimetres per day.

3.3 AGROMETEOROLOGICAL ANALYSIS

In most farming systems crop calendars serve as a natural guide for farmers during their decisionmaking process. These calendars are generally based on the long-term climatic pattern and their past experience in a specific region. In a climate change scenario, the long-term average used as a reference for agricultural practices could be altered, in which case traditional crop calendars would not be appropriated any longer due to the impact on the starting date and the length of the growing season. Traditional strategies developed by local farming communities may not be effective in an environment where climate variability and extreme weather events have become more pronounced as a result of climate change. Farming practices need to adapt to the new trends and agrometeorological tools can provide climate information to contribute to the decision-making. Agrometeorological analysis requires that the following eight components be developed:

1. Historical climate data archive;
2. Archives on climate impacts on agriculture;
3. Monitoring tools using systematic meteorological observations;
4. Monitoring tools using seasonal forecasts;
5. Climate data analysis (to determine the patterns of inter-annual and intra-seasonal variability and extreme weather events);
6. Crop simulation models;
7. Software to provide information on the characteristics of system vulnerability and adaptation effectiveness, such as resilience, critical thresholds and coping mechanisms (this information is required to identify the opportunities for adaptation measures and the potential of specific adaptation practices);
8. Methods to develop crop weather insurance indices to reduce the losses of climate impacts in agriculture.

The improved use of climate knowledge and technology includes the development of monitoring systems and response mechanisms to current weather, both for farms and governments. Technology includes mainly the modeling of future impacts based on current weather (within season) and decision tools of varying complexity. In practice, the decision tools are tables/flow-charts or software that assist farm-level management decision-making based on three types of inputs:

- The knowledge of local environmental/agricultural conditions
- The measurement of local "decision parameters" by local extension officers or farmers
- Economic considerations (i.e. cost of inputs versus expected output).

Forecasting is the basic element of all warning systems and adaptation policies that must be applied to four aspects of food security (availability, stability, access and biological utilization), which allows decision-makers enough time to react to warnings with the highest possible degree of reliability (the more long-term the forecasts the less reliable and detailed they are). Firstly, in many cases the most urgent need for food information in a country are related to the early identification of food crises amongst specific vulnerable population groups as well as for relief assistance; secondly, domestic food production and the annual quantification of national cereal import requirements. The lack of systematic information is a serious constraint for the effective planning of commercial and non-commercial food imports and monitoring relief operations, including targeting beneficiaries and matching types, quantities, timing and duration of relief to actual requirements. For this reason, timely crop forecasts are imperative as well as information on cross border or internal flows of people, food and livestock, grazing conditions and herd sizes, market prices of agricultural inputs, basic foods, livestock and other major determinants and indicators of the food security status, as well as the risks of acutely and chronically vulnerable groups. Behavioural responses of population groups subject to acute food shocks caused by armed conflict or drought must continually be monitored to understand the seriousness of the local food crises. In addition, the identification of vulnerable groups using rapid and qualitative methods to complement available data is essential to planning an appropriate response in a timely fashion. The response can vary depending on the spatial and temporal span of the forecast, as illustrated in the following **Table 3**.

TABLE 3 **Agricultural decisions at a range of temporal and spatial scales that could benefit from targeted climate forecasts**

FARMING DECISION TYPE	FREQUENCY (YEARS)
» Logistics (e.g., scheduling of planting/harvest operations)	» Intra-seasonal (<0.2)
» Tactical crop management (e.g., fertiliser/pesticide use)	» Intra-seasonal (0.2–0.5)
» Crop type (e.g., wheat or chickpeas) or herd management	» Seasonal (0.5–1.0)
» Crop sequence (e.g., long or short fallows) or stocking rates	» Inter-annual (0.5–2.0)
» Crop rotations (e.g., winter or summer crops)	» Annual/bi-annual (1–2)
» Crop industry (e.g., grain or cotton; native or improved pastures)	» Decadal (~10)
» Agricultural industry (e.g., crops or pastures)	» Inter-decadal (10–20)
» Land use (e.g., agriculture or natural systems)	» Multi-decadal (>20)
» Land use and adaptation of current systems	» Climate change

Source: Meinke and Stone, 2005

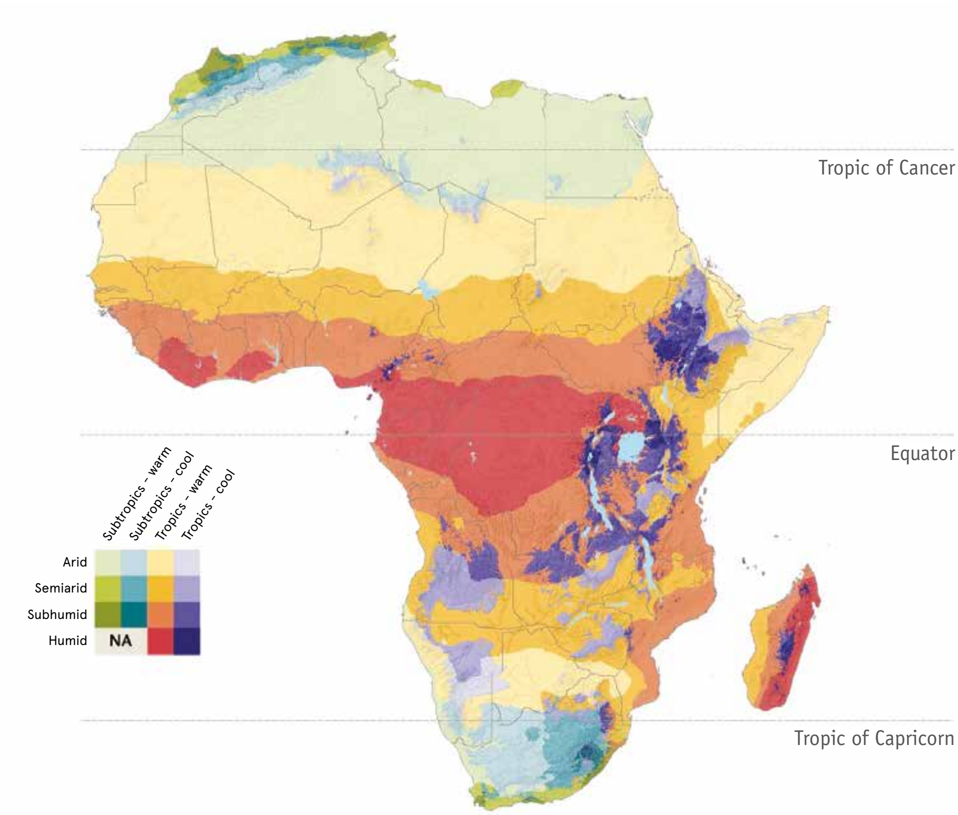
3.4 AGRO-ECOLOGICAL ZONING

While monitoring food crops production a distinction should be made between data used for the *agro-ecological classifications* and data used for real-time crop monitoring during the agricultural season. A preliminary phase necessary for all environmental conditions consists of dividing the area into *agro-ecological zones* (**Fig. 29**) according to the available resources (soil quality and fertility; temperature, rainfall, water balance and other meteorological data) and the main production systems. The purpose of zoning is to separate areas with similar sets of potentials and constraints for agricultural production. Specific technical agrometeorological advices can then be formulated to provide the most effective support to each zone during the monitoring of the cropping season. This classification is used to varying degrees in different countries depending on the availability of information.

Climatic classifications can be based on a historical series of meteorological data (the most frequent being rainfall), length of the rainy season, pedological maps and maps of plant cover or grazing areas. The degree of detail in the maps is variable but maps are at times the only source of information for such studies. The classifications are not usually changed unless a new methodology offering a more precise analysis is adopted. AEZ is therefore one of the fundamental preliminary elements of the agricultural production monitoring process. On the other hand, the yields of the principal crops are broadly linked to several factors that can be summarized as follows:

- The agro-ecological zone and the type of agricultural production, including specific normal climatic conditions (rainfall, temperature) and special conditions (tornado, hail, fires at the end of the dry season) combined with the average soil fertility;
- The traditional combination of crops and growing methods: varieties, planting date, mixes and respective densities of the species, fertilizer used and maintenance. The incidence of disease and pests linked to the agroclimatic conditions of the production area, to the varieties and production techniques (multiple cropping, fertilizing, protection), etc.;
- The priority given to food/cash crops produced by the household or to other activities that affect the available workforce at certain times of the year, the priority being based on the expected income;
- The distribution and density of the population.

FIGURE 29 Agroecological zones of Africa



Data source: Sebastian 2009.

Note: Moisture classes are defined as follows: Arid=length of growing period (LGP) of less than 70 days; Semiarid= LGP of 70-180 days; Subhumid= LGP of 180-270 days; and Humid= LGP of greater than 270 days.

HarvestChoice
BETTER CHOICES, BETTER LIVES

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI

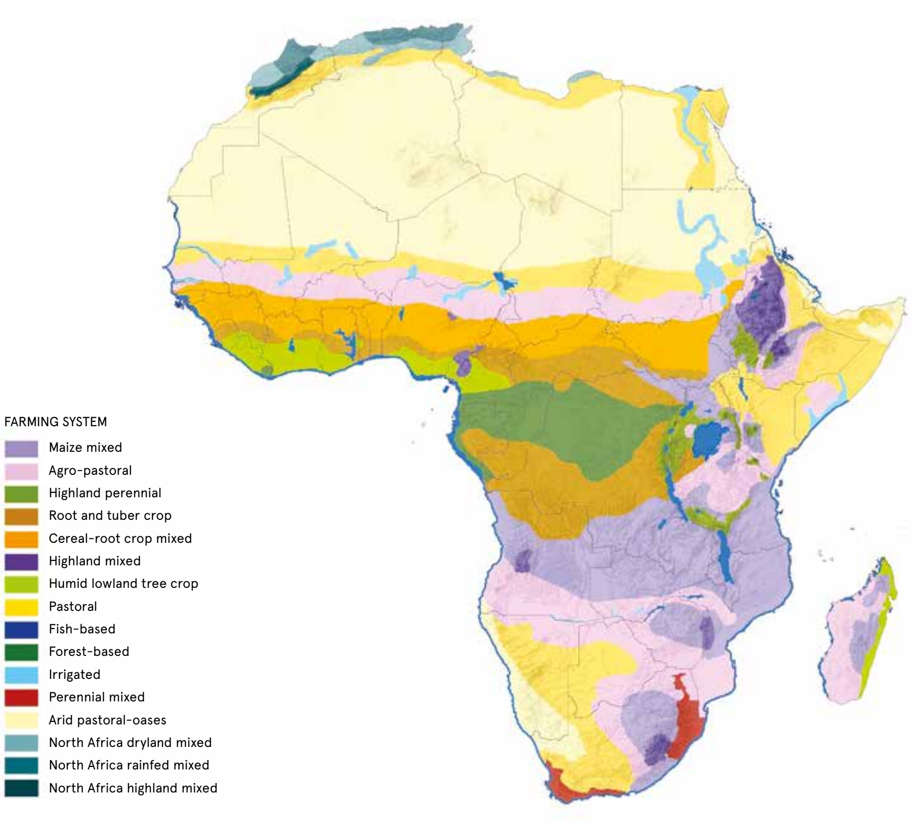
Source: adapted from https://harvestchoice.org

3.5 FARMING SYSTEMS

A *farming system* is defined as a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, for which similar development strategies and interventions would be appropriate. Depending on the scale of the analysis, a farming system can encompass a few dozen or many millions of households (**Fig. 30, 31**). The classification of the farming systems of developing regions has been based on the following criteria:

» Available natural resource base, including water, land, grazing areas and forest; climate, of which altitude is an important determinant; landscape, including slope; farm size, tenure and organization;

FIGURE 30 Farming systems zones of Africa



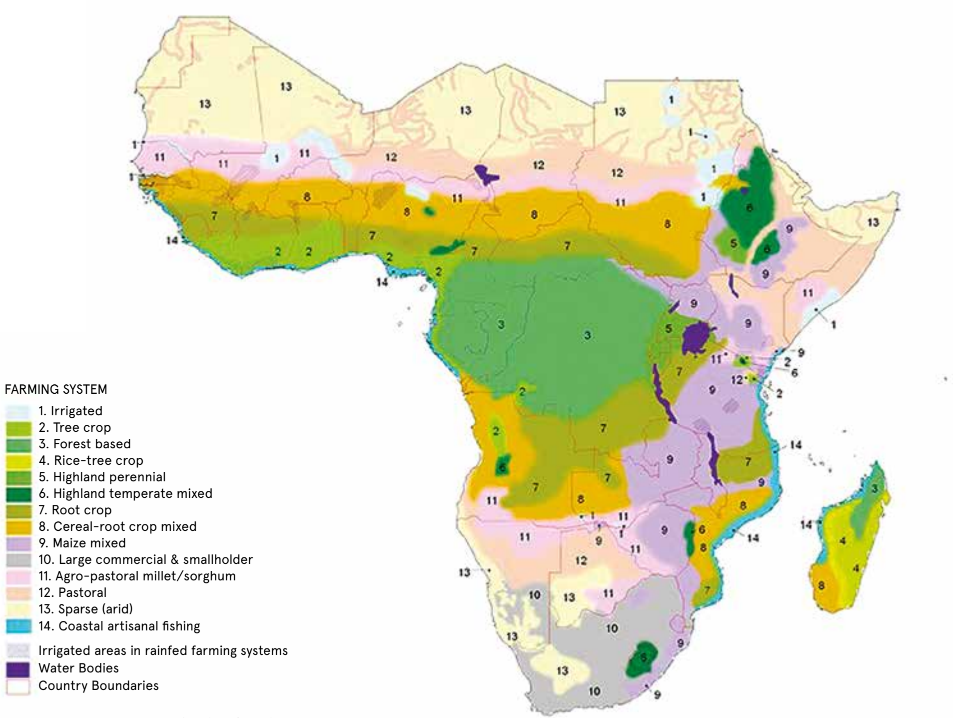
Data source: Dixon, Boffa and Garrity 2014.
Note: See glossary for definitions of specific farming systems.

Source: adapted from https://harvestchoice.org

- Dominant pattern of farm activities and household livelihoods, including field crops, livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities; taking into account the main technologies used, which determine the intensity of production and integration of crops, livestock and other activities.

The aim of this classification is to produce more tailored information and analysis for similar farming systems. It is clear that different farming systems need different information (i.e. irrigated and cereal-root crop systems) and for this reason, a classification is crucial for defining which products are needed.

FIGURE 31 Major Farming Systems in sub-Saharan Africa



Notes: Projection = Geographic (Lat/Long)

The designations employed and the presentation of the material in the map do not imply the expression of any opinion whatsoever on the part of FAO concerning the legal or constitutional status of any country, territory or sea area, or concerning the delimitation of frontiers.

Adapted from http://www.fao.org/farmingsystems

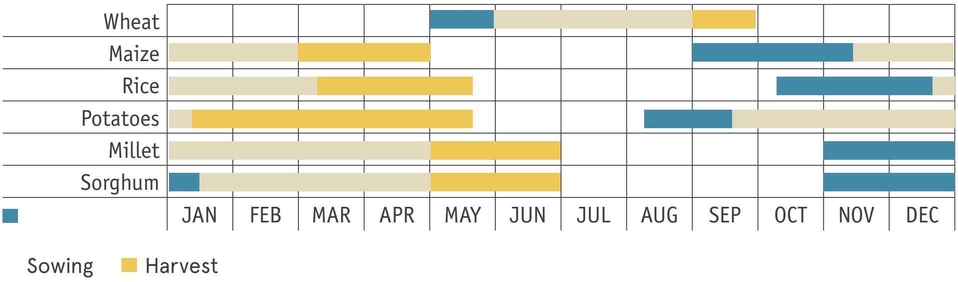
3.6 CROP CALENDAR AND CROP GROWING SEASON

The crop calendar contains information on planting as well as sowing and harvesting periods of locally adapted crops in specific agro-ecological zones (**Fig. 32**). It also provides information on the sowing rates of seeds, planting material and the main agricultural practices and furthermore, it helps farmers and extension staff to make the appropriate decisions on crops and their sowing period with respect to the agro-ecological dimension.

The crop calendar is also useful for identifying the most appropriate products during the monitoring of the campaign. In fact, different phases are more or less vulnerable to climatic stress, for instance, in the early phase of sowing the detection of dry spells are more important than in the middle of the season. Moreover, different crops face their most sensible phases to drought stress during different periods of the season. Hence, the effectiveness of advice for farmers is basically linked to the overlapping of the climate anomalies with a specific crop and its vulnerability to drought or intense rains.

The length of the "*growing season*" or "*growing period*" (LGS or LGP), as defined by the *Agro-ecological Zones* project, is the period (in days) during a year when precipitation exceeds half the potential evapotranspiration. A period required to evapotranspire an assumed 100mm of water from excess precipitation stored in the soil profile is sometimes added and no provisions are made for stored soil moisture. LGS is useful for determining crop cycle lengths and calendars under average conditions, but the actual years may sometimes deviate significantly from the average. There are several methods that can be used to determine the length of the growing period based on water availability for

FIGURE 32 Crop calendar of Angola



Source: FAO/GIEWS

the crops. One of the most common methods is the calculation of the growing period based on a simple water balance model, by comparing water availability with crop water demand (precipitation with PET), using monthly values. PET (or ETP) is the *Potential Evapotranspiration*, i.e. a measure of evaporative power of the atmosphere. A "*normal*" growing period (also called a Type 3 season) is characterised by a dry period, a moist period (also called intermediate period) and a wet (or humid period). A normal growing season (**Fig. 33**) has the following characteristics:

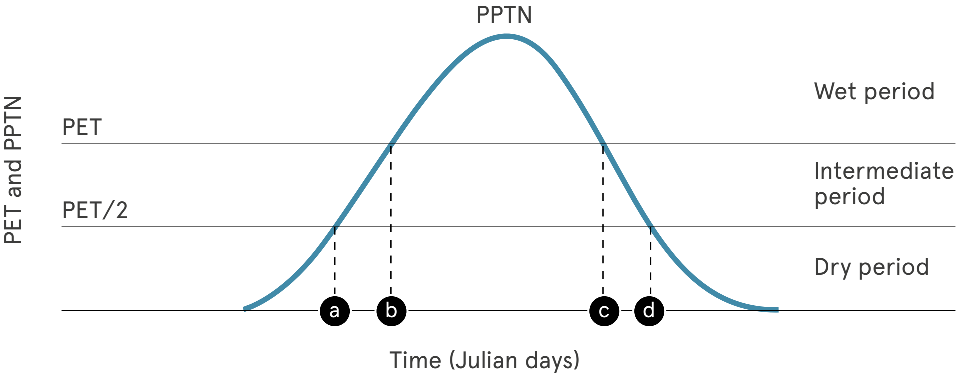
» Beginning Period
The beginning of the growing period occurs when precipitation (PPTN) equals PET/2 and marks the start to the normal rainy season, shown as ***a*** in **Fig. 33**. A value of PET/2 has been chosen as germinating crops do not evapotranspire at the full rate of PET and false starts during the rainy season are eliminated. The beginning marks the transition from the dry period to the "*intermediate*" period when PET/2 < PPTN< PET.

» Wet (humid) Period
This is the period during which precipitation exceeds PET. The beginning and ending dates (shown as ***b*** and ***c*** in **Fig. 33**, respectively) are the two points where the precipitation and PET curves cross.

» End to the Growing Period
The end of the growing period occurs at the point where the PPTN curve crosses the PET/2 curve (labelled as ***d*** in **Fig. 33**).

In addition to a normal growing period (marked as graph number 3 in **Fig. 34**), five other types can be defined. Beside each season type described below is the corresponding graph number in **Fig. 34**.

FIGURE 33 **Normal growing season**

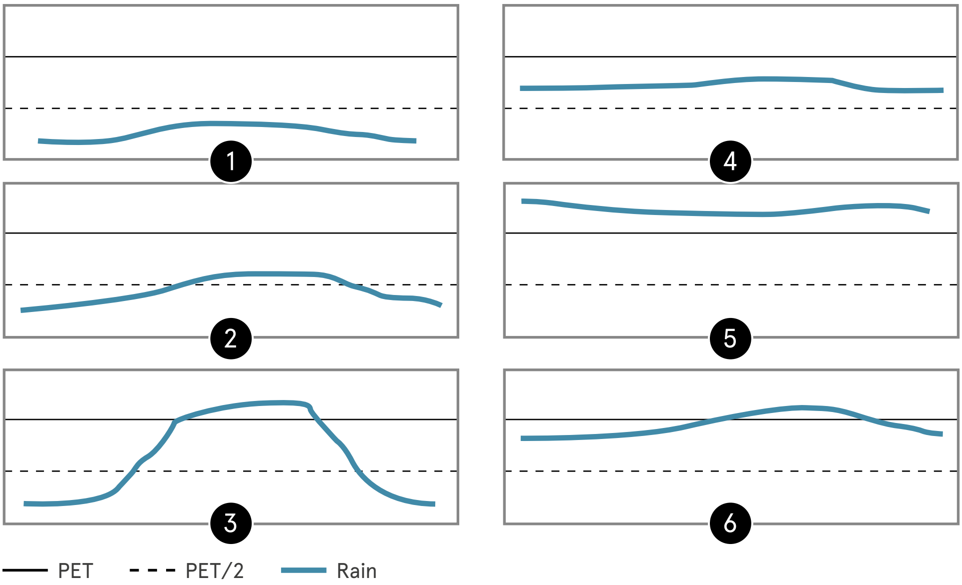


Source: http://www.fao.org/nr/climpag/cropfor/lgp_en.asp

The additional season types are as follows:

- **All year-round dry period (Type 1)**
  The average monthly precipitation for every month of the year is lower than PET/2. Areas with all year-round dry periods have been inventoried separately as areas with a growing period of 0 days.
- **Intermediate dry growing period (Type 2)**
  Throughout the year, the average monthly precipitation does not exceed the full rate of the average monthly PET, but it does exceed PET/2 for a period. The beginning and the end of such an intermediate growing period are defined as the points where the precipitation curve crosses the one PET/2 curve and no humid period exists.
- **All year-round intermediate growing period (Type 4)**
  During the entire year, the rainfall stays permanently between PET and PET/2. This is a very rare type of season with no beginning or end.
- **All year-round humid growing period (Type 5)**
  During this kind of season, the average monthly precipitation of the year exceeds the full rate of the average monthly PET. Thus, there is no true beginning to the growing period or to the humid period. Areas with all year-round humid growing periods are inventoried as areas with a normal growing period of 365 days.
- **Intermediate-humid growing period (Type 6)**
  This type of season has both an intermediate and a humid period but no dry period (i.e., a period in which the precipitation curve drops below PET/2).

FIGURE 34 Six types of growing periods



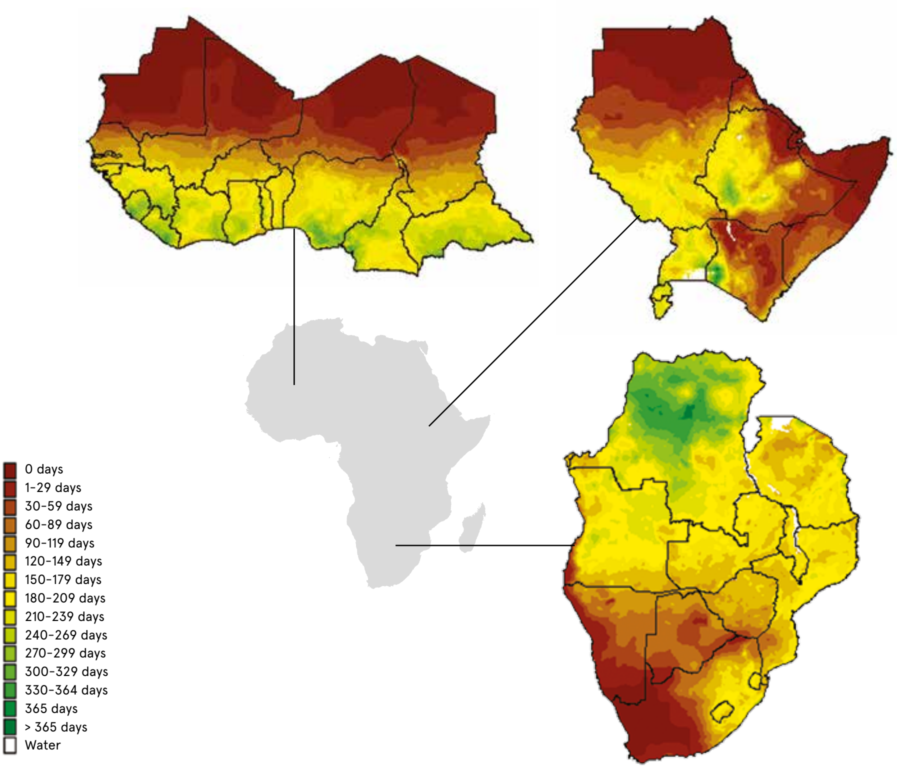
Source: http://www.fao.org/nr/climpag/cropfor/lgp_en.asp

At this point, it is important to stress the fact that a late start in the season or an early end of the season, compared to the climatology, could cause a reduction in the yield. If these trends are consistent, over time we could obtain some trend analysis with the climatic dataset and attempt to predict the future evolution of the season dynamics, thus preventing some of the losses due to the changing rainfall pattern.

The zones with less than a 60-day growing period are also those where the crops most resistant to drought could not survive. Normally these zones are dedicated to transumance pastoralism. Here we need to remember that an early end of the rainy season in the pastoral zones could bring on an anticipated movement of troops to agricultural zones where the crops are not completely harvested; as a result, this would generate conflicts between breeders and farmers.

Fig. 35, 36 and **37** refer to digital maps showing the length of the growing season for Western, Eastern and Southern Africa.

FIGURE 35, 36 & 37 **Western, Eastern and Southern Africa - Length of Growing Season**



Source: http://www.fao.org/nr/climpag/cropfor/lgp_en.asp

3.7 AGROMETEOROLOGICAL CROP MONITORING

The aim of agrometeorological crop monitoring is to follow-up on the state[25] of the crops and to provide information on pests and diseases, as well as information on crop stresses (i.e. excess and/or deficit of water). In many countries, dekadal meteorological data are the main input for modelling the crop performance which, for example, can be correlated with historical crop statistics to forecast attainable yields at the country or provincial level. Depending on the complexity of the crop model, the scale of application and the purpose of the analysis, real-time input data can be limited to the main limiting factor which in most countries is rainfall. In addition, basic reference data for the specific station or region are also needed, as listed below:

- Long-term climate data and crop statistics;
- Actual planting dekad;
- Length of the growing season for the crop variety;
- Soil water holding capacity.

In order to get information on crop conditions, the dekadal monitoring should include:

- Variety of the grown crop;
- Stage of development attained by the crop;
- General assessment of crop performance;
- Damage by pests, diseases and adverse weather;
- State of weeding in the crop field;
- Plant density;
- Soil moisture.

The crop yield forecasting is a direct output of crop monitoring that can provide advance information to the various participants along the agricultural production chain from farmers to consumers; moreover, it is an important tool for government agencies such the National Statistics and the Ministry of Agriculture. Crop yield depends largely on the weather conditions and the measurements from existing meteorological stations that have the potential to provide reliable, timely and cost-effective weather predictions. The data provided by the weather station can be used to generate crop yield forecasts based on crop growth simulation models and other indicators. These methodologies have been a major subject of applied research among various agronomic, meteorological and environmental observation institutions. The results of this research generate hundreds of specialized papers every year and some very objective tools that can be adapted to any

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[25] Crop observations: variety of the grown crop; actual planting dekad; plant density; stage of development attained by the crop; general assessment of crop performance; damage by pests, diseases and adverse weather; state of weeding in the crop field; date of maturity for the crop variety.

local situation. However, many national agencies dealing with crop forecasts are reluctant to establish a system based on these tools, which results in a crop yields forecast based on subjective observations like field surveys and farmer interviews. Remote sensing from satellite images to precision agriculture applications contributes significantly to providing a timely and accurate picture of the agricultural sector, because it can collect information over large areas with a high revisit frequency. Furthermore, the use of climate forecasting from seasonal to inter-annual timescales is a new way to deal more effectively with the effects of climate variability at the national and regional level.

In the near future continued efforts will be made to seek more integrated applications aiming to combine the use of weather and climate seasonal forecasts, remote sensing, crop growth simulation models, geospatial analysis, field experiments and on-farm validation in order to assess crop yield before harvest with higher accuracy. There are three specific areas where the progress made will result in a vast improvement in forecasting of the seasonal climate impact on crop production. These areas are the following:

i. integrating crop models and climate models;
ii. enhancing the use of remote sensing and spatial data;
iii. doing more research on climate prediction. More attention will be given to the "*weather within climate*" leading to improvements in prediction of the higher-order weather statistics that determine climate impacts on the cropping system and to a better characterization of climate prediction at finer spatial and temporal scales (Hansen *et al.*, 2006).

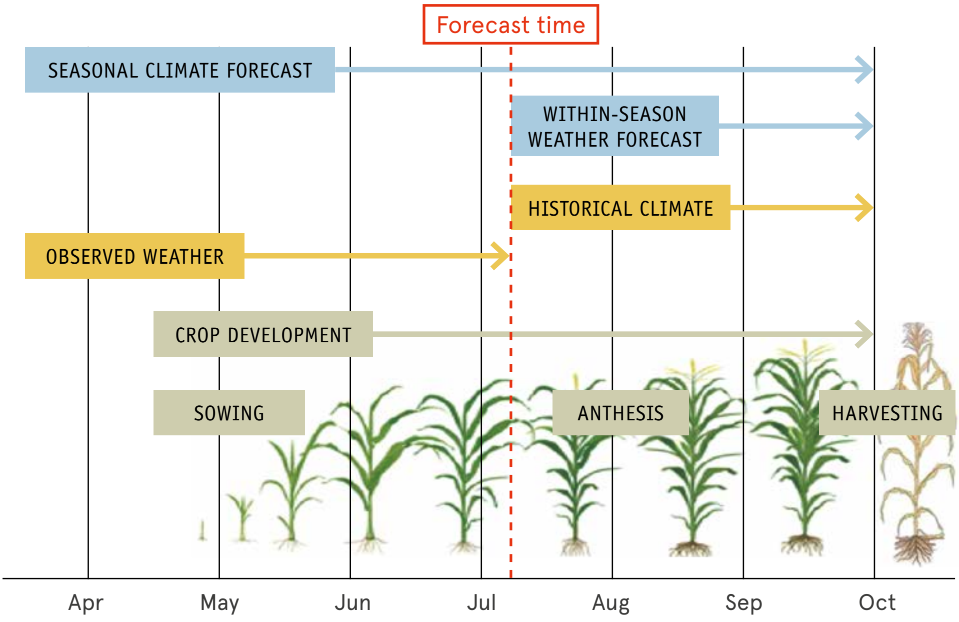
The integration of remote sensing, yield gap and crop growth simulation models represents the main alternative to crop yield forecasting (Basso *et al.*, 2013). Remote sensing can quantify the crop condition at any given time during the growing season in a spatial context, while the crop growth simulation model can describe crop growth every day throughout the season. Remote sensing provides indirectly a measure of the main variables used by the crop model either at a spatial or a temporal scale, which can then be used to adjust the model simulation. At the same time the yield gap provides a strong agronomic explanation of the yield potentials and the causes leading to the gap.

As a result of this spatial heterogeneity in the determinants of yield, several studies show that reproducing yields at multiple sites, farms, and regions can be problematical for most crop models. Unsatisfactory model performance at the regional scale are often caused by the inappropriate consideration of factors and processes that determine yield variability and/or the aggregation of input data. All of these factors may inconsistently reproduce the spatial variability of growing conditions (i.e. climate and soils, pests and diseases, etc.) within a region because of the low density of meteorological station; as a result, there is a lack of representativity as respect to the agro-environment. In addition, factors explaining spatial yield variability across regions often differ from those describing temporal variability within regions. In brief, there is no single modelling approach that performs equally well across various regions (Challinor *et al.*, 2009). A feasible alternative to these complexities is the use of agrometeorological models requiring less input variables like the FAO *Crop Specific Soil Water Balance* (CSSWB) that has been integrated into the FAO *AgroMetShell*[26] software (more in the Annex).

Future developments regarding crop growth modelling will focus on embedding crop models within climate models. This should be prepared in a way that will allow for a forecast of the main patterns of meteorological conditions to be used as input in the crop model to provide better crop growth indicators. This could improve the statistical regression for yield forecasting (Cantalaube and Terres, 2005). In most cases, the operational crop yield forecasting system integrates weather observations from the current date (Forecast time) either with weather forecasts or with sampling from climatology for the remainder of the growing season. Weather observations are collected 3-5 months before sowing in order to take into account water dynamics in the soil at the root level. The seasonal climate forecast is an important tool that provides very useful information about rainfall and temperature, up to three to six months in advance on the possible pattern for the current growing season (**Fig. 38**).

A general idea of the required infrastructure is provided in the diagram in **Fig. 39** showing the *FAO Agrometeorological Crop Monitoring and Yield Forecasting* (ACMYF) approach at the national level. Its implementation and efficiency are directly linked to the quality of the meteorological stations network and the related telecommunication system.

FIGURE 38 **Schematic timing of the forecast time as related to weather forecasts, seasonal climate forecasts and historical climate throughout the growing season's phases, from sowing to harvesting**



Source: author

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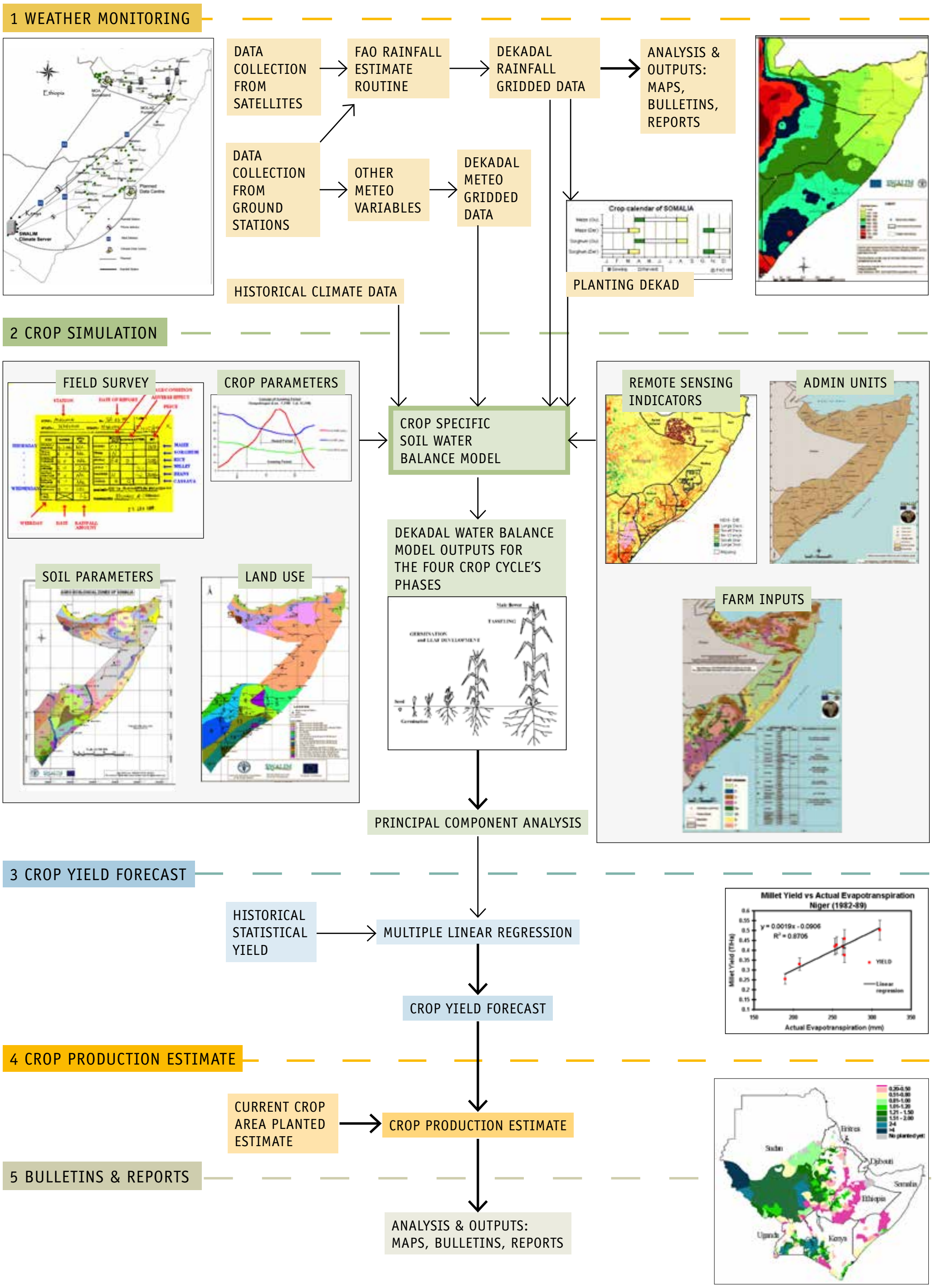
[26] FAO AgroMetShell: http://www.hoefsloot.com/agrometshell.htm

FIGURE 39 FAO agrometeorological crop monitoring and yield forecasting approach in Somalia



Source: M. Bernardi, 2012

The main components of an ACMYF are:

- Historical climate data archive;
- Historical crop statistics at national, sub-national, local and farm level;
- Archives on climate impacts on agriculture;
- Monitoring tools using real-time meteorological observations and satellite imagery;
- Monitoring tools using climate seasonal forecasts;
- Climate data analysis (to determine the patterns of inter-annual and intra-seasonal variability and extreme weather events);
- Software to provide information on the characteristics of the agricultural system vulnerability (such as changing variety, planting dates or cropping pattern) and adaptation effectiveness (such as resilience, critical thresholds and coping mechanisms). This information is required to identify the opportunities for adaptation measures, and the potential of adaptation practices;
- Methods to develop crop weather insurance indices to reduce the risk of climate impacts in agriculture.

A distinction should be made when monitoring food crops production between data used for agro-ecological assessments and those used for crop monitoring during the agricultural season. A preliminary phase for all environmental conditions consists of dividing the area into agro-ecological zones according to available resources (soil quality and fertility; temperature, rainfall, potential evapotranspiration, radiation, wind) and the main production systems. Agro-ecological zoning is therefore one of the fundamental preliminary elements of the agricultural production monitoring process.

3.8 AGROMETEOROLOGICAL ADVISORIES

Advisories can be based on the outcome of response farming exercises from the sowing period to time of harvest, using climatic variability data and statistics of recent past or simple online agrometeorological information. All agricultural activities from the pre-sowing to postharvest phase are influenced by weather. For this reason, weather-based advisories should provide a clear modification of management based on meteorological conditions to help farmers with day-to-day agricultural operations well in advance. This in turn helps to mitigate the adverse impact of weather conditions. *Response farming* (RF), a method for identifying and quantifying the seasonal rainfall variability to address the risks of the farmers at the field level for rainfed crops, is a classic example of such advisories (Stigter, 2002). The hypothesis is that the solutions to farming problems may be found by improved forecasting of expected rainfall behaviour during the cropping season(s). RF also means adapting crops to the on-going rainy season by relying on the guidance of agronomic operations based on past experience, preferably taken from an interpretation of meteorological rainfall records together with traditional knowledge when available.

In general, agrometeorological advisories mean providing crop-wise farm management information tailored for weather-sensitive agricultural practices such as sowing, irrigation scheduling, pest and disease control operations, fertilizer application. Advisories should include:

» Special warnings on the appropriate measures to be taken to save crops from adverse weather;
» Information on crop planning, variety selection, selection of proper sowing/harvesting time;
» Location of specific packages and practices for the cultivation of different crops suitable for the agro-climatic zone;
» Spraying conditions for insect weed, or disease problems;
» Problems related to animal health and their products;
» Wildfire rating forecasts in wildfire prone areas;
» Livestock management information for housing, health and nutrition.

Agrometeorological advisories should focus on:

» *Advice on above-ground and below-ground microclimate management or manipulation, such as shading, wind protection, mulching, other surface modification, drying, storage, or frost protection*. Scientists have developed shelterbelts to protect crops and soils in different farming systems from the prevailing conditions of several regions. Nevertheless, only appropriate design rules drawn from this supportive research can contribute to the actual agrometeorological services for the farmers.
» *Establishing measures to reduce the impacts and mitigate the consequences of weather and climate related natural disasters for agricultural production*. There is a large amount of existing literature on the damage to agriculture caused by natural disasters but preparedness measures and the related supportive research are scarce (e.g. Stigter *et al.*, 2003b); although agrometeorological services have often been developed based on research. When temperatures fall to below freezing point at night during springtime (in association with cold waves) orchards will experience frostbite. Low temperatures damage flowers irreversibly and as a result the autumn fruit harvest will suffer. If the occurrence for frost is well forecasted the advisory system should indicate that sprinkler irrigation be used for flowers on the previous day. Spraying the flowers with water prevents them from freezing and safeguards the buds, thus preserving the fruit in future.
» *Monitoring and early warning exercises directly connected to measures previously established in agricultural production to reduce the impacts and mitigate the consequences of weather and climate related natural disasters for agricultural production*. Agricultural drought occurs in situations where crops fail to mature due to insufficient soil moisture. In the case of field crops, drought monitoring can be done by taking advantage of the relationship between water use and productivity. Several methods are described in available publications on how to monitor drought by the use of water and the productivity of crops.

- *Climate and weather predictions and forecasts for agricultural and related activities used on a variety of time scales, from years to seasons and from a variety of sources.* An accurate interpretation of farming activities is essential since climatologists produce climate predictions. Forecast skills are important, as is the capacity of target groups to correctly assimilate the information, which is equally important.
- *Development and validation of adaptation strategies for increased climate variability and climate change, as well as to other changing conditions in the physical, social and economic environments of livelihood of the farmers.* These strategies must be developed together with the farmers to improve previously existing adaptation measures.
- *Specific weather forecasts for agriculture, including warnings for suitable conditions for pests and diseases and/or advice on countervailing measures.* Considerable losses in the production of food grains are caused by the occurrence of pests and diseases.

3.9 REMOTE-SENSING BASED PRODUCTS

In the near future the enhanced use of a wide range of spatial data sets from ground observations (i.e. soil surveys, crop management) and remote sensing (i.e. rainfall, temperature, vegetation indices) will contribute substantially both to the skill and the spatial specificity of climate-based crop forecasting. Spatial databases are available or are being developed in many parts of the world for soil properties and land cover. Satellite remote sensing provides a good selection of spatially explicit information regarding the land surfaces and atmosphere using spatial resolutions that continue to improve with new sensors (Hansen *et al.*, 2006).

Remote sensing has the potential to produce several solutions for climate-based crop forecasting such as:

- Satellite rainfall and temperature estimates provide near-real-time information in locations where these variables are not directly measured or sensor data are not accessible (i.e. RainFall Estimate, LSE[27]). Combined with soil and management information, spatially contiguous rainfall data have the potential to simulate crop yields anywhere across a given area.
- Remote sensing has some potential to monitor cropped areas, planting dates and phenological stages.
- Remote sensing vegetation indices provide information about the state of the crop canopy that can be used to update the state variables of a crop simulation model during the growing season, calibrate model input parameters, or statistically correct final yield simulations.

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[27] Eumetsat Land Surface Analysis (https://landsaf.ipma.pt/en/)

Seasonal climate forecasts and remote sensing of the state of the crops complement each other. Remote sensing has the potential to reduce the crop model component of uncertainty by providing refined estimates of crop state variables up to the time of the forecast, while skilful seasonal forecasts reduce climatic uncertainty from the time of the forecast through the remainder of the season (Hansen *et al*., 2006).

3.9.1 **FAO – GIEWS**

The FAO *Global Information and Early Warning System on Food and Agriculture* (GIEWS)[28] monitors the condition of major food crops across the globe to assess production prospects. In support of the analysis and supplement ground-based information, GIEWS processes remote sensing data to derive seasonal indicators that can provide a valuable insight into water availability and vegetation health during cropping seasons. Seasonal indicators are designed to allow for easy identification of areas of cropped land with a high likelihood of water stress (drought). These indices are based on remote sensing data of vegetation and land surface temperatures, combined with information on agricultural cropping cycles derived from historical data and a global crop mask. The final maps highlight anomalous vegetation growth and potential drought in crop zones during the growing season. See the annex for more details.

3.9.2 **USDA – CROP EXPLORER**

The *Crop Explorer*[29] web site developed by USDA (US Department of Agriculture) features near real-time global crop condition information based on satellite imagery and weather data. Thematic maps of major crop growing regions depict vegetative vigor, precipitation, temperature, and soil moisture. Time-series charts provide growing season data for specific agrometeorological zones. Regional crop calendars and crop area maps are also available for selected regions.

Thematic maps are viewed at the regional level and can be selected for any 10-day period during the current growing season. Previous growing seasons can be selected from the dropdown list for the two last complete years and historical data are available upon request. Thematic maps are grouped into three categories: Weather; Soil Moisture; and Vegetation Index. Time-series charts provide the same set of data types but for sub-regions that define specific agrometeorological zones. The sub-regions are organized by country and in some regions, ranked by commodity production.

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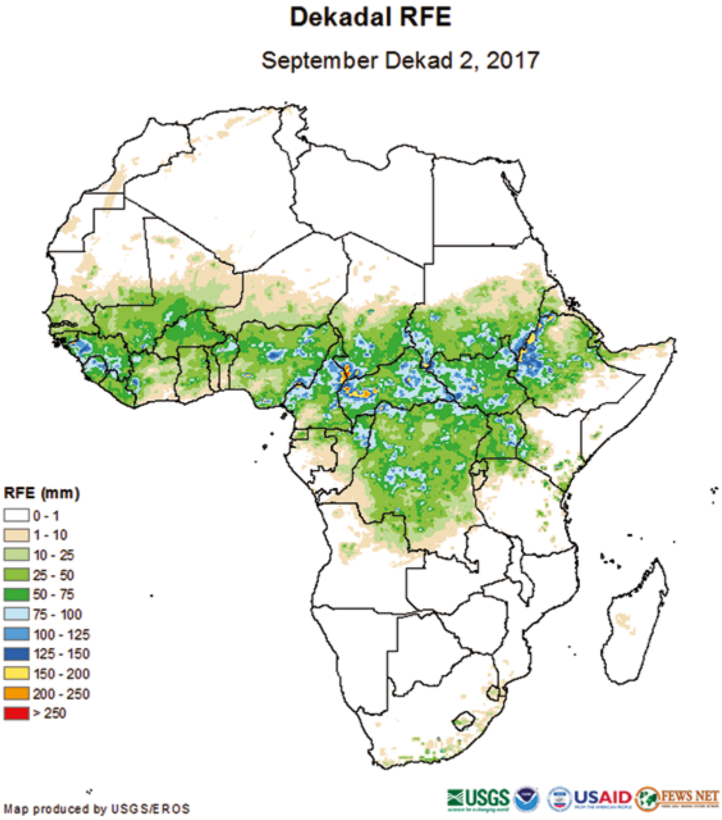
[28] FAO GIEWS: http://www.fao.org/giews/en/

[29] USDA Crop Explorer: https://ipad.fas.usda.gov/cropexplorer/

3.9.3 RAINFALL ESTIMATE BY REMOTE SENSING

Rainfall is the main variable needed in crop yield forecasting as well as rain gauges, which are located at meteorological stations and provide a direct measurement of rainfall. However, the spatial density of rain gauge networks (especially of gauges whose data are available in real time) is typically far too coarse to capture the spatial variability of rainfall on small scales. Radar provides an indirect measurement of rainfall but only for regions within a few hundred kilometres. New techniques have been developed to derive *RainFall Estimates* (RFE) from remotely sensed data, which are less direct and less accurate than rain gauges or radar. These data have the advantage, however, of high spatial resolution (4 km) and complete coverage over oceans, mountainous regions and sparsely populated areas where other sources of rainfall data are not available. The Climate Prediction Center of the U.S.

FIGURE 40 Rainfall (mm) estimate by remote sensing for 2nd dekad of September 2017 for Africa

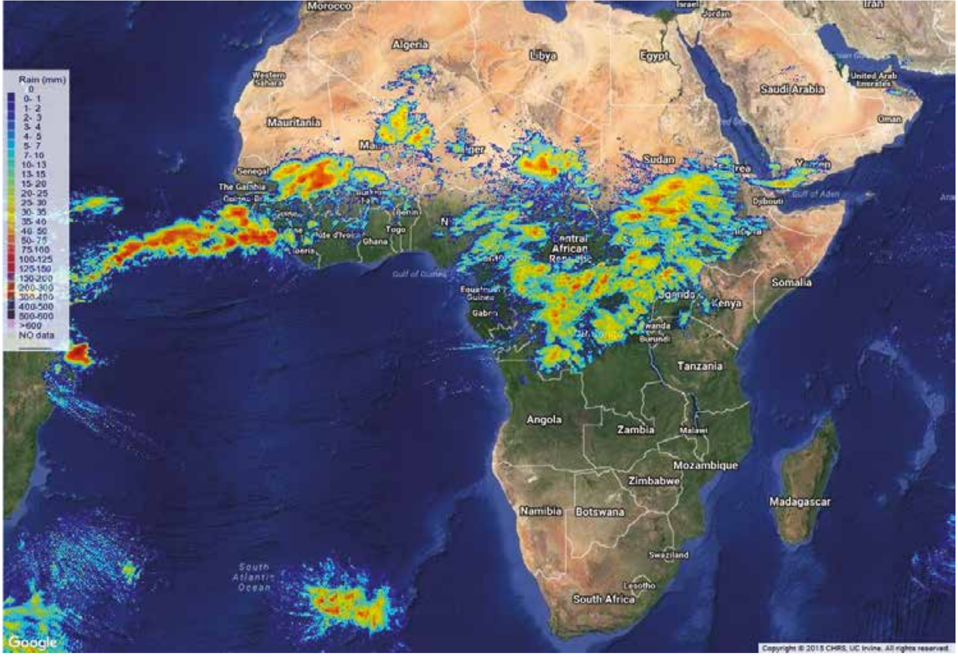


Source: USGS FEWS-NET

National Oceanic and Atmospheric Administration (NOAA-CPC[30]) produces RFE[31] for Africa based on an interpolation method combining data from the geostationary Meteosat[32] satellite with rainfall data from ground meteorological stations to obtain daily estimates (**Fig. 40**). These products are disseminated every 10-day by *FEWS-NET*[33]. Although the method still requires improvement of the accuracy of RFE, especially in areas with low real-time gauge densities and complex topography, this product is an important alternative source of rainfall data.

The current operational *PERSIANN* (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) system developed by the *Center for Hydro-meteorology and Remote Sensing* (CHRS) at the University of California (UCI) uses neutral network function classification/approximation procedures to compute an estimate of rainfall rate at each 0.25° x 0.25° pixel of the infrared brightness temperature image provided by geostationary satellites (**Fig. 41**).

FIGURE 41 Total 48-hours total rainfall estimate from a satellite for Africa



Source: http://irain.eng.uci.edu

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[30] NOAA-CPC: http://www.cpc.ncep.noaa.gov/

[31] Meteosat satellite produces infrared temperature images every half an hour. In tropical regions it can be assumed that areas with temperatures lower than about –40°C are covered with rain clouds. The cumulated number of hours in a given period (i.e. day) with this low temperature is defined as "Cold Cloud Duration" (CCD) and can be represented as a digital image. The relationship between rainfall data provided through connected to the WMO's Global Telecommunication System (GTS) and CCD is positive, in other words, high rainfall values generally coincide with high CCD values. As a result, a geo-referenced image is produced to provide daily amount of rainfall over a specific region, namely RainFall Estimate (RFE).

[32] Meteosat: http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Meteosat/index.html

[33] FEWS-NET (RFE) https://earlywarning.usgs.gov/fews/product/48

Weather forecast for comming 5 days :
1)Rainfall: Light to moderare rains
2)Temperature: 29-33°C
3)Wind Speed: 10-16 km/hr
ACRC
ANGRAU-Hyderabad

© F. Fiondella (IRI/CCAFS)

SECTION 4

WHAT KIND OF CLIMATE INFORMATION IS NEEDED BY FARMERS

- KEY DECISIONS
- DECISION-MAKING BASED ON WEATHER AND CLIMATE INFORMATION
- PARTICIPATORY INTEGRATED CLIMATE SERVICES FOR AGRICULTURE
- HANDBOOK FOR COMMUNITY AGROMETEOROLOGICAL PARTICIPATORY EXTENSION SERVICE

4.1 KEY DECISIONS

For farmers and extension agencies like the Agriculture Department who provide support services in terms of crop management advisories, key decision points impacted by climate information are provided in **Table 4** (Madhavan M. and Rengalakshmi R., 2015).

TABLE 4 Key decision points impacted by climate information

KEY DECISION POINTS	KEY CLIMATE VARIABLE THAT INFORMS THE DECISIONS
Sowing period	Onset of monsoon
Choosing of crops/crop variety	Total rainfall forecast and its intra-seasonal distribution
Irrigation management – in terms of timing of irrigation and quantity of water to be applied	Total rainfall and its intra-seasonal distribution
Resource Use Allocation – both labour and finance	Total rainfall forecast and its intra-seasonal distribution
Fertilizer application – the quantity and type of fertilizer as well as the timing of application of fertilizers on crops	Forecast of the distribution of rainfall across the crop growth stages
Timing of pesticide application	Wind direction, wind speed and distribution of rainfall across the crop growth stages
Time of Harvest	Forecast of the distribution of rainfall during the crop maturation stages

There are four fundamental principles with the purpose of generating climate information for selected agricultural areas that must be followed in order to collect and obtain agronomic and meteorological data. The following four principles (Murphy and Holden, 2001) are the basis of policy decisions related to meteorology and rural environmental management:

1. Improve the quality of weather forecasts by providing accurate information on finer scales and tailoring forecasts to a wide range of specific users;
2. Increase the density and geographical representativeness of meteorological observations, thus making the data more valuable to a wide range of users;
3. Develop interactive access to data for use in models tested for local conditions;
4. Educate current and potential users about the value of climate information.

In brief, an increase in the number of observing stations (at least for rainfall measurements) in those areas is needed. The agro-climatic information as a matter of course requires, in the first instance, identifying the "**agro-climatic baseline**"[34] of each

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[34] Agro-climatic baselines for each area should be based on accurate analysis of an ensemble of information including historical meteorological records, agro-ecological regions, agro-climatic classification and livelihood zones.

of the areas designated for intervention. It is important to recognize that both types of information must address these 3 major challenges:

1. The lead time is too short and does not allow for making the appropriate decisions or taking action;
2. The space-resolution is too low for location-specific information;
3. The content format and delivery are not tailored for key users.

The most useful weather forecast information that can assist farmers in making decisions on agricultural management is the early indication of the characteristics of the rainy season. It should include:

- Onset date of the main rains;
- Quality of the rainy season (rainfall amount);
- Cessation date of the main rains;
- Temporal and spatial distribution of the main rains;
- Timing and frequency of active and dry periods (wet and dry spells);
- Probability of extreme events.

Primary producers use agrometeorological information for decision-making with a range of scales that can vary from several days to the entire cropping season, or inter-annual time periods. These decisions relate to the choice of crops (e.g. wheat if suitable pre-season and seasonal rainfall is expected; sorghum for warmer or drier regimes); the choice of cultivar (early or late flowering); mix of crops; fertiliser use; pest and disease control; timing of the harvest; irrigation scheduling; the area planted with a given crop (and/or rotation of fields); timing and amount of tillage and stocking rates. Strategic planning and marketing decisions mostly use climate information for the following year.

The four major types of climate information needed by farmers and to be included into the *Farmer Field Schools* (**FFS**) approach are:

a. Before the beginning of the season, the interpretation of the agrometeorological crop risk analysis to assess the most suitable crop(s) for the region based on crop water requirements and other agrometeorological analysis.

b. Before the beginning of the season, the interpretation of the statistical analysis of rainfall for the determination of the optimum planting date(s) for a specific region;

c. Before the beginning and the end of season, seasonal climate outlooks (possibly for each agro-climate zone: arid, dry semi-arid, wet semi-arid, sub-humid, humid) in order to adapt to the various situations due to the uncertainty inherent in the seasonal climate forecasts, and put contingency plans into place for multiple possible scenarios;

d. Throughout the season, 3-day weather forecasts for rainfall and temperature (with a particular focus on forecasts of weather extreme events such as drought, heavy rains and strong winds) and 10-day agrometeorological advices on better adaptation of farmers' practices.

It is important to note that, except for the "*c*" type, other types of information should be tailored to farming communities at the local level and presented in a way that makes it easy to understand. In principle, the four types of climate information are produced by the National Agrometeorology Unit **(NatAgMet)** in close collaboration with local agrometeorology and agricultural research units; after which they are disseminated to FFS farmers with the assistance of the agricultural extension officers at the local level.

Field surveys have shown that farmers would like to receive additional relevant information through the NatAgMet (Venkatasubramanian *et al.*, 2014):

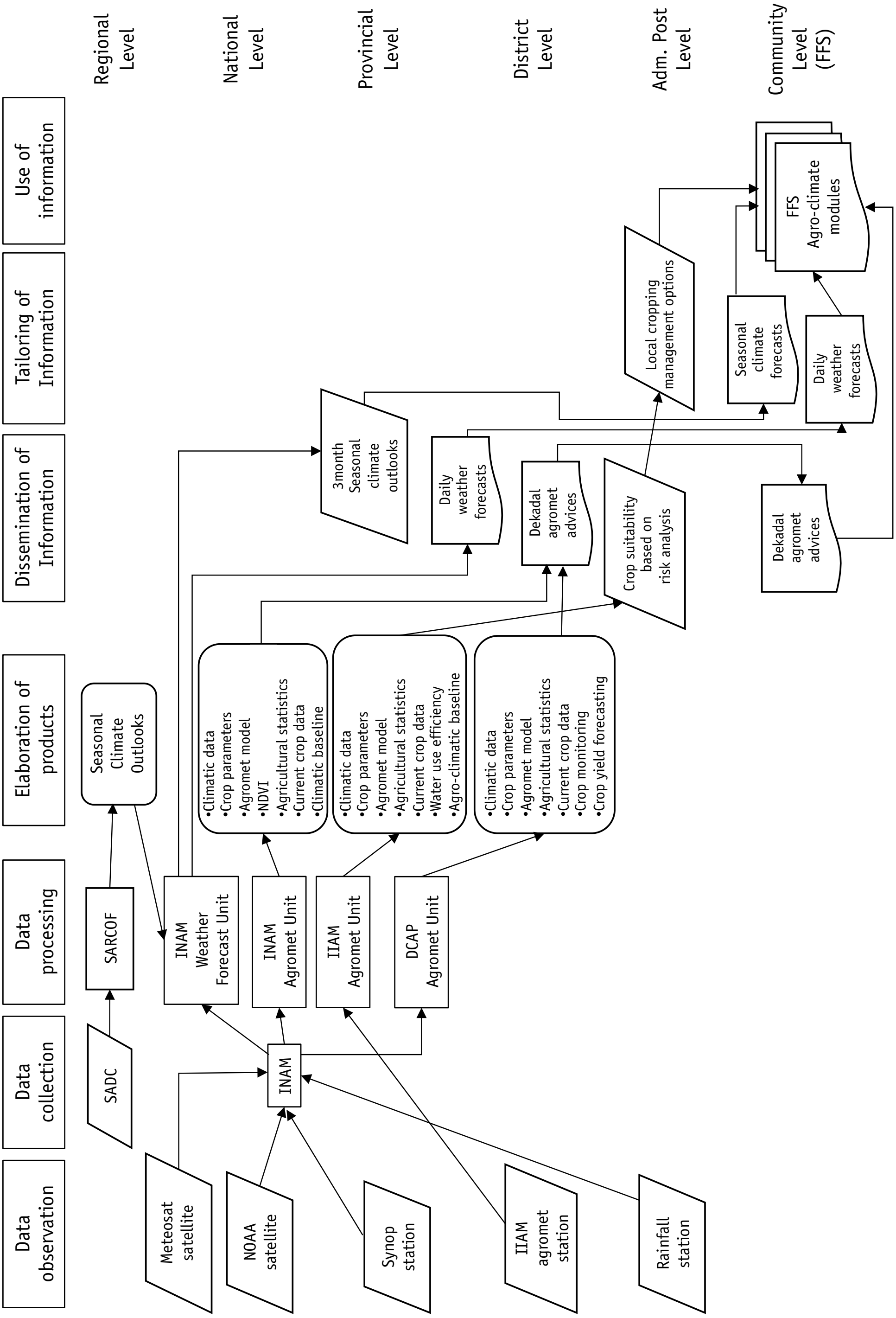
- Water management, especially during times of shortage;
- New varieties of seeds and information on why certain seeds failed and how to prevent it;
- Wind speed to help decide the time for spraying pesticides, weedicide and fungicide;
- Harvesting time for specific crops;
- Risk of frost in winter;
- Market produce prices;
- Mechanization possibilities on the farm;
- Protecting crops during sudden variations in temperature;
- Better use of fertiliser;
- Soil nutrient management strategies;
- Alternative crops during delays or breaks in rainfall;
- New pests expected in each season and suitable pesticides;
- Organic farming. At present, advice is tailored to conventional chemical-based farming but some farmers are seeking information on how to switch to organic farming. Those farmers already using organic farming need more specific and detailed information;
- New mechanization techniques to reduce the cost of cultivation and new machines for harvesting and sowing seeds;
- Storage facilities;
- Dealing with wild animals, particularly those attacking crops and farmers;
- Sharing new research results on agriculture.

In practice, the goal is to reach a synergy among all institutions that would provide a complete set of agro-climate information into the FFS approach, as presented below in **Fig. 42**, which is a schematic diagram of the agro-climate flow of information in Mozambique.

4.2 DECISION-MAKING BASED ON WEATHER AND CLIMATE INFORMATION

Effective advisory services for climate information provide a reliable source for farmers when it is time to make decisions in the face of an increase of climate uncertainty. These services help them to use the best adaptation practices and to improve management of climate-related agricultural risks. However, smallholder farmers are facing many challenges on how to use climate-related information. Based on a review of climate services pilot

FIGURE 42 Schematic diagram of the planned agro-climate flow of information on the FFS project in Mozambique



Source: M. Bernardi, 2014

projects and national programs across Africa and South Asia, these challenges are identified as (Venkatasubramanian *et al.*, 2014):

- *Salience*: tailoring content, scale, format and lead-time to farm-level decision-making;
- *Access*: providing timely access to remote rural communities with marginal infrastructure;
- *Legitimacy*: ensuring that farmers own climate services and shape their design and delivery;
- *Equity*: ensuring that women, poor and socially marginalized groups are served;
- *Integration*: providing climate information as part of a larger package of agricultural support and development assistance, enabling farmers to act on received information.

The correct interpretation of accurate information at the right time is key to the decisionmaking process, but the complexity of different decision-making factors makes this task difficult. The ability to interpret and translate agrometeorological information and apply it to a local context provides the needed access to farmers. However, the salience and credibility of this information is fundamental. Salience, by definition, refers to agrometeorological advisories during specific stages in crop growth, that is, crop and location specific. Credibility refers to the accuracy of the farmers' perception of agrometeorological information under the assumption that most of the information is correct. Eight decision-making situations related to agricultural practices have been identified based on a review of available literature, as well as interviews in villages where the studies were carried out:

- When to labour the fields;
- When to sow;
- When to add fertilizers;
- When to apply pesticides;
- When to irrigate;
- When to harvest;
- When to sell;
- Choice of crops.

Generally, weather forecasts were 60–80 percent wrong according to most farmers. The uncertainty in particular referred to rainfall and the amount of rainfall. The farmers explained that: "When forecasts are correct, we all know that it will rain, while with uncertainty, forecasts are mostly wrong". The unpredictability of climate and weather leaves the farmers unprepared for the upcoming growing season, thus making long-term planning a challenge. Hence, farmers make decisions based on their understanding of local climatic patterns, finding their own understanding more credible and also specifically tailored to their individual farm rather than other sources of information. This situation, which is typical of many farming societies, leads to conservative farming strategies since farmers believe their own insights to be the most rational strategy. However, it is also a strategy that may sacrifice productivity in order to reduce the risk of loss (Nesheim *et al.*, 2017). Farm practices during the pre-planting and planting period may differ significantly depending on the rainfall forecast. In the case of extreme situations, management practices would adapt as follows (**Table 5**):

TABLE 5 Key decisions in pre-planting and planting periods

IF RAINFALL SHOULD BE HIGH	IF RAINFALL SHOULD BE LOW
» Measures to affect drainage of excess rainfall » Choice of higher water requirement food or cash crops with particular desirable traits and large potential yields (in quantities and economic return) » Choice of inter-cropping two or more crops in the same plot, known to be advantageous with adequate rainfall » Planting in narrow rows, with high seed densities and initial fertiliser rates to maximise production » Dry planting prior to the onset of rains	» Land preparation and pre-plant tillage oriented towards water retention of all rainfall » Lower water requirement crops which offer insurance for the family food supply » Mono-cropping to ensure at least subsistence level production if rainfall should be low » Wide rows (lower densities), reduced seed and fertiliser rates for more assured and cost-effective food production with limited water » Planting delayed until the soil contains sufficient water to germinate and support seedlings through possible early season dry spells.

Source: Pfeiffer, 2002

Throughout field surveys, farmers recommended some improvement in communications channels:

- Increase the radius of advisories provided through mobile phones (voice mails and SMS);
- A toll-free number (call center) for agrometeorological advice that farmers can call for information and clarifications;
- Provide advisories on television stations in addition to the state-level forecasts currently relayed;
- Flash news on important weather events on all channels;
- Printed advisory bulletins displayed in the central points in the village that are accessible to all (e.g. bulletin boards, shops, milk collection booths etc.);
- Use of pictures in textual advisories to make them more comprehensible;
- Specific FM radio stations in local languages on weather-related advisories for agriculture and livestock;
- Regular training and interaction in the village with agrometeorologists;
- Specific trainings and discussions for women farmers in the village;
- Organizing farmers into FFS to attend meetings with NatAgMet and helping disseminate vital information in the village;
- Larger farmers' role in disseminating activities through the appointment of village level volunteers who could receive bi-weekly advisories from NatAgMet and communicate them to the rest of the village;
- Use of less technical language in advisories for easy interpretation.

However, while planning climate advisory services in rural areas, special care should be taken to identify gender-specific preferences for communications channels considered to be appropriate for daily schedules and tasks. In fact, while male farmers expressed their interest in radio and television, women farmers might be unable to listen to the radio or watch television during the day due to the fact that they are occupied with household and field related activities. Key challenges and recommendations for the best use of climate information are shown in **Table 6**.

TABLE 6 Key challenges and recommendations for the best use of climate information

KEY CHALLENGES	RECOMMENDATIONS
Salience: tailoring content, scale, format and lead-time to farm-level decision-making	» Local downscaling, improved resolution of rainfall forecasts and value-addition is paramount to ensure salience for local farmer needs and usability by farmers; » For smallholder farmers with less than an acre of land, AAS advisories are not of much relevance due to the small scale of operations.
Access: providing timely access to remote rural communities with marginal infrastructure	» Broadcast NatAgMet advisories over a microphone at the village level; » Display NatAgMet bulletins in strategic places in the village; » Presence of a local agrometeorological knowledge center/hub improved access and usability of NatAgMet advisories; » Smallholder farmers can be reached successfully with agrometeorological information using a diversity of communication channels (agricultural extension, presence at farmer fairs, local knowledge center/hub, face-to-face village meetings and training by agricultural experts, SMS and voice messages, etc.).
Legitimacy: ensuring that farmers own climate services, and shape their design and delivery	» Collaboration with local NGOs or projects to promote the use of advisories serves to increase the range and subsequent adoption of agrometeorological advisories by embedding it into local practice; » When there is sustained interaction between farmers and agrometeorologists and agricultural scientists, higher use of advisories ensues; » A larger farmers' role is recommended throughout the process of appointing a designated agrometeorological contact point at the village level to communicate with extension service staff and disseminate advisories to the village; » The use of "progressive" farmers to organize training and disseminate information to other farmers is an effective strategy; » Appointment of local farmers from villages to manage and record data collected from manual weather stations in the village is a reliable way to make the process of information collection and dissemination more inclusive and open. It also increases open discussions amongst farmers who spread information by word of mouth.
Equity: ensuring that women, poor and socially marginalized groups are served	» Training and discussions in villages with agricultural experts are the preferred form of communication, thus ensuring that all farmers can attend. Wide community mobilization and inclusion of all farmers within the community (not only male farmers of high socio-economic status) is critical during village discussions to promote a widespread adoption and use of NatAgMet advisories; » When women farmers are fully engaged, the adoption and use of NatAgMet advisories is maximized; » Women groups play a positive role in gathering agrometeorological information from agrometeorologists and agricultural scientists and disseminating it via word of mouth; » Care should be taken to identify gender-specific preferences for appropriate communication channels for daily schedules and tasks.

Source: Venkatasubramanian *et al.*, 2014

4.3 PARTICIPATORY INTEGRATED CLIMATE SERVICES FOR AGRICULTURE

The *Participatory Integrated Climate Services for Agriculture* (PICSA[35]) provides significant support with an approach aiming to assist farmers with making informed decisions based on accurate, location specific, climate and weather information; locally relevant crop, livestock and livelihood options and with the use of participatory tools to aid their decision making. The PICSA approach has been designed for field staff with a view to provide support with improved resources and information that will help with job performance. A field manual is provided by the PICSA approach whose purpose is to facilitate making decisions based on accurate, locationspecific climate and weather information, locally relevant crop, livestock and livelihood options accompanied by the use of participatory tools to aid their decision making. This field manual, which serves as a guide for facilitators (e.g. NGO and extension field staff who have received training in the use of the PICSA approach) describes the 12 steps required for working though the PICSA approach with farmers' groups. The step-by-step sequence provides a practical and logical process to help planning and decision-making (**Fig. 43**).

4.4 HANDBOOK FOR COMMUNITY AGROMETEOROLOGICAL PARTICIPATORY EXTENSION SERVICE

New approaches are needed to improve the adoption of adaptation practices and participatory approaches for addressing community concerns and they are preferred over traditional top-down methods. The *Participatory Rural Appraisal* (PRA) that has been introduced emphasizes ownership, planning, management and analysis of data by rural people. However, the suitability of the PRA for promoting sustainable agriculture productivity, especially amongst smallholder farmers, requires further development. The *Community Agrometeorological Participatory Extension Service* (CAPES) uses the participatory techniques and the need for agrometeorological services as its base for promoting sustainable agriculture productivity. The IDRC/CCAA[36] project that was conducted in both Zambia and Zimbabwe from 2007-2010 examined the possibility of developing an effective CAPES' strategy with the participation of farmers as an attempt

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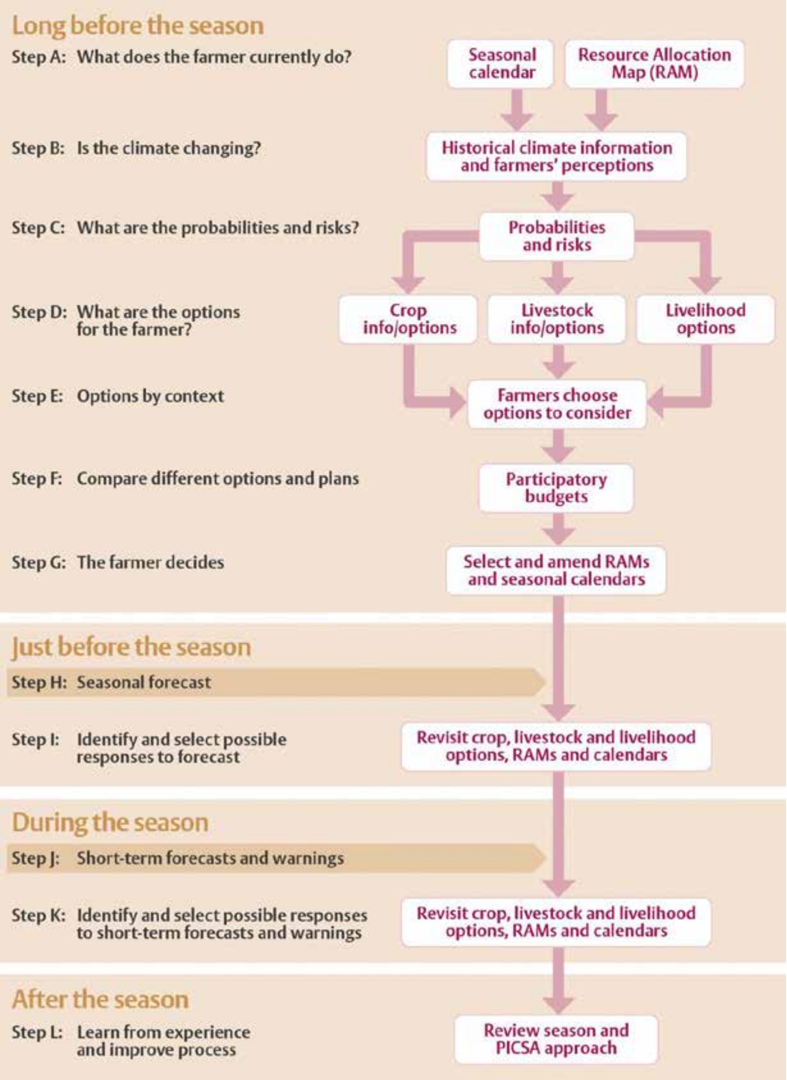
[35] PICSA: http://www.walker.ac.uk/projects/participatory-integrated-climate-services-for-agriculture-picsa/

[36] IDRC/CCAA: https://www.idrc.ca/en/article/new-pathways-resilience-interactive-report-ccaa-program?PublicationID=1131

to develop agriculture adaptation interventions. The objective was to make agriculture more sustainable by using available climate forecasts. The *Handbook for Community Agrometeorological Participatory Extension Service* (CAPES[37]) is a guide on how to build the capacity of the agrometeorological extension officers to use CAPES' strategies.

FIGURE 43 Schematic flow chart with an overview of the whole PICSA process



Source: http://www.walker.ac.uk/media/1114/picsa-field-manual-final-english-11-03-16.pdf

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[37] CAPES: http://www.agrometeorology.org/files-folder/repository/HandbookCAPES.pdf

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SECTION 5

CLIMATE INFORMATION AND LOCAL KNOWLEDGE

- LOCAL KNOWLEDGE
- FARMERS KNOWLEDGE ABOUT CLIMATE INFORMATION
- EMBEDDING FARMERS KNOWLEDGE INTO AGROMETEOROLOGICAL TOOLS

5.1 LOCAL KNOWLEDGE

Indigenous knowledge is a combination of local and traditional knowledge developed by the community that is unique to a culture or society. It can be defined as "*knowledge that an indigenous or local community accumulates over generations of living in a particular environment*". This knowledge is passed on from generation to generation, usually by word of mouth and cultural rituals and has been the basis for agriculture, food preparation, health care, education, conservation and a wide range of other activities that sustain societies in many parts of the world. It can also provide complementary information (**Box 3**), however, one barrier to documenting and sharing this type of knowledge is the language. Indigenous knowledge is transmitted in the local language for which there is often no written form and the meaning, therefore, is sometimes modified when translated.

Farmers continuously make decisions related to farm management based on their accumulated experience as well as other currently available quantitative/qualitative information.

Thus, the local farming systems developed over generations for field practice and its evolution are continuously integrating changing environmental and socio-economic conditions. Farming practice fine-tunes at a micro-AEZ level to optimise, within the sphere of farmers current knowledge, the overall output and to minimise the failure risk level given that it constitutes the farmers family survival.

BOX 3

WHY IS INDIGENOUS KNOWLEDGE IMPORTANT?

- Indigenous knowledge provides locally developed problem-solving strategies for local communities, especially the poor. It represents an important component of global knowledge on development issues.
- Indigenous knowledge is an under-utilized resource in the development process.

WHY SHOULD THE DEVELOPMENT COMMUNITY BE CONCERNED?

- Learning from indigenous knowledge can improve understanding of local conditions.
- Understanding indigenous knowledge can increase responsiveness to clients.
- Adapting international practices to local conditions can improve the impact and sustainability of our work.
- Investing in disseminating indigenous knowledge can help to reduce poverty.
- Sharing of indigenous knowledge within and across communities can enhance cross-cultural understanding.

Source: World Bank. Indigenous Knowledge for Development.
Available online at: http://www.worldbank.org/afr/ik/broch.pdf

5.2 FARMERS KNOWLEDGE ABOUT CLIMATE INFORMATION

Farmers (even illiterate) integrate knowledge and practical field experience accumulated over generations, including overall climatic conditions and their gradual/cyclic changes. Although farmers often refer to short periods, the accumulated knowledge/experience over generations remains global. Generally, local knowledge is not expressed in quantitative terms but is related to specific micro-climatic observations and qualitative changes observed over years. In many cases indigenous knowledge describes phenomena correctly but it draws conclusions that tend to be inaccurate. Nevertheless, at the same time it offers the basis for new observations and helps to arrive at more accurate conclusions (**Box 4**).

BOX 4 What is indigenous knowledge

Indigenous or "local" knowledge (IK) is *unique* as it is an integral part of the culture and history of every local *community* or society. IK is commonly held by communities rather than by individuals. It is the **basis** *for local-level decision making* in agriculture, health care, food preparation, education, natural resource management and a host of other activities in communities. IK provides problem-solving strategies for communities. It is mainly *tacit and cultural knowledge*[a] and therefore difficult to codify, as it is embedded in community practices, institutions, relationships and rituals. We need to learn from local communities how to improve the development process.

ONE EXAMPLE

Maasai (Tanzania) alternate the use of their natural grassland according to the seasons, which requires a timely decision on when and where to move next. Droughts are predicted as well as weather related diseases by watching the movements of celestial bodies in combination with observing the date of the emergence of certain plant species (e.g. Ole Kitolya). Such "early warning signals" of an approaching environmental disaster are used to determine preventive measures, prepare for mitigation and decide on the course to take of the community, using the natural resources. Similarly, estimates of animal fertility can be drawn from such forecasts with its implications on stocking rates and density[b].

LESSON

Traditional expertise in astronomy and weather forecasting in combination with conventional agricultural meteorology could enhance local forecasts on harvests and food security.

[a] Three different types of knowledge within an organisation (Choo, 1998):
- **tacit** knowledge is represented by individual/group experience and expertise (is implicit, rarely documented);
- **explicit** knowledge is based on policies, procedures, instructions, standards and results, readily communicated, often in written form and provides a record of "organisational or institutional memory".
- **cultural** knowledge: the basis for what we deem to be fair/trustworthy, an underlying comprehension of how we treat new truths and situations. It is often tied to an organisation's vision, mission, overall philosophy

[b] Database of Indigenous Knowledge and Practices (World Bank 2000). http://web.worldbank.org/archive/website01219/WEB/0__CO-44.HTM

BOX 5 **Climatic calendar**

One of the most famous long-term previsions was the "*hundred years*" climatic calendar based on long-term observations and the cyclic characteristics of climatic conditions. Based on the incidences of seven known "planets" of the solar system on the European climatic conditions, the Cistercian Abbey Mauritius Knauer developed his impressions in the "*Calendarium œconomicum practicum perpetuum*"(1658) including weather predictions for a period of 300 years. This calendar was still being used in rural communities for seasonal climatic predictions at the beginning of this century. The centennial calendar is based on detailed weather observations of the Abbey Moriz Knauer that were carried out from 1652 to 1658 in the monastery of Langheim near Lichtenfels in Oberfranken (Germany). The compilation was originally intended to help predict the weather in this region, in order to optimize the monastery farming. Abbot Knauer erroneously assumed that the weather conditions repeated in a fixed 7-year cycle due to the influence of the then known 7 "planets" (Sun, Moon, Saturn, Jupiter, Mars, Venus, Mercury). Thus, according to his theory a weather prediction was available for each day of the upcoming 7-year cycles. On this basis the Abbey then drew up the "weather predictions" from 1600 to 1912. It is possible that these predictions of the calendar are sometimes accurate, but from a meteorological point of view this is purely coincidental and in no way scientifically justified.

However, every population on the globe that developed similar approaches based on astral observations and/or climatic conditions at a specific day/period considered it to be a sign for the coming season climatic conditions. While scientific forecasts focus on estimates of total seasonal quantities or their evolution, farmers often evaluate seasons in terms of types and time (*onset, duration, etc.*) of rainfall. Unlike scientific forecasts, which are formulated in reference to "zones", the production and application of local forecasts are strongly localised. They are derived from an intimate interaction with the micro-environment whose rhythms are interconnected with the cycles of family and community life. Recently, special attention has been devoted to farmers' invaluable local knowledge, which has been integrated into "scientific" measurable values.

5.3 EMBEDDING FARMERS KNOWLEDGE INTO AGROMETEOROLOGICAL TOOLS

Agrometeorology plays a very important role in the use of specific tools (i.e. simulation modelling of impacts on crop water use and yield, caused by modifying practices, notably fertiliser rates and plant populations) to provide adaptation options for specific agro-ecological regions. During this process it is important to include the *local*, *traditional* or *farmers knowledge*, an integral part of the culture and history of every local community or society. Building communication approaches on existing indigenous knowledge of weather and climate are essential to developing agricultural advisory services for vulnerable communities. Moreover, local knowledge should be combined with suitable climate information to provide management alternatives and for an effective communication system to support informed decision-making. One of the major challenges will be to record indigenous knowledge before the tradition is lost.

Based on past field experience, local communities have developed traditional systems for short-term weather forecasting; sky colour, development of specific living organisms and other local observations are traditionally taken into consideration for short to medium term weather forecasting (**Box 6**). Longer-term previsions also exist within traditional beliefs, for example:

- Use of environmental indicators, such as the time and abundance of fruit production of specific local trees, behaviour of insects and birds;
- Weather during moon period changes and their significant impact on the new moon period;
- Seasonal previsions based on specific pre-season climatic conditions;
- Specialised "prediction" knowledge (*i.e. marabous*) and claims/beliefs of direct command over rains (i.e. *'sa tatta'* known in Burkina Faso as 'rainmakers').

In Burkina Faso, when asked whether they had noticed any change in the climate during their lifetime, most farmers interviewed responded that climate variability had increased. In their view it rained less than before, the rains began late or end prematurely and dry spells during the season were more protracted and frequent. In other words, predicting rain has become like the national lottery whereby one can randomly win or lose but the majority of the time one loses. Climate variability has weakened farmers' confidence in local forecasts of rainfall patterns. Some elders recalled that in the past they had been able to predict the rain onset so accurately that with the knowledge that rains would soon follow they could mobilize family labour to plant on dry soil. Now their sons refuse to go to the field until it actually rains.

Because they have lost confidence in their ability to predict rainfall, farmers are open to and keenly interested in alternative sources of rainfall information. They have no objection to the introduction of scientific information nor do they regard it as a threat to the integrity of local cultural traditions. Farmers tend to mix traditional farming knowledge with extension advice and local technology with development innovations. Even in the case of local forecasting knowledge farmers are used to combining a variety of environmental observations and spiritual traditions. (Roncoli *et al.*, 2002).

Farmers' forecasts diverge from the scientific ones in important ways, in particular the parameters and scale they address and the measurement of accuracy. Local forecasts focus on rainfall characteristics that are the most relevant to farmers such as time of onset, duration, and distribution. To evaluate seasonal rainfall, farmers consider the number, type, and timing of rains rather than total rainfall quantity, the key variable in scientific forecasting. A forecast of "*abundant*" seasonal rainfall often translates into expectations of a longer season. Currently, science is unable to predict the reliably of duration and distribution of

BOX 6 Burkina-Faso: rainfall forecast by farmers

Indicators on which farmers rely the most are fruit production of certain trees at the onset of the rainy season and temperatures during the dry season. They also observe the intensity and direction of winds and behaviour of birds and insects throughout the year (**Table 7**).

Farmers make rainfall predictions based on a classification of the calendar year with two principal periods: a 7 month dry season and a 5-month rainy season. The dry season includes a cold-dry period and a hot-dry period. The rainy season includes an early part, the main part of the rainy season and a late part during which staple crops mature. During each period farmers expect natural phenomena such as temperatures, winds, clouds and rain to conform to a certain pattern defined as the norm. Farmers consider deviations from the norm to be inauspicious, resulting in abnormal rainfall and poor crop performance. Among the earliest indicators are the starting date, intensity and duration of the cold-dry period. If the cold-dry period begins early or ends late, farmers expect the rains to do likewise. Elderly farmers predict the onset of rains by counting 182 days from the beginning of the colddry period. That is, farmers count 91 days for the cold-dry period plus 91 days for the hot-dry period before the next season should start. Night temperatures may fall to 15° C or below during cold-dry season (late November to early February). According to farmers, intense cold during this period corresponds to abundant rainfall in the following season. Interruptions to the cold, such as several days of warm temperatures, causes drought spells during the rainy season.

A cold-dry period is followed by a hot-dry period from late February to early May. Intensely hot temperatures are also believed to be a sign of abundant rainfall. Morning fog or rain in April cools temperatures when they should be hot, which is considered to be a bad sign. Cold temperatures that persist beyond early morning indicate rain failures and violent winds during the dry season also indicate aborted rain events. On the other hand, strong but not destructive eastward winds and hot but not extremely high temperatures at the beginning of the rainy season signal a regular and favourable seasonal rainfall. During the rainy season farmers can expect rain after a humid day if winds blow toward the east. Farmers can also expect hail early in the rainy season and believe that the occurrence of hail means a good performance of leguminous crops.

TABLE 7 Local trees used as indicators to forecast rainfall by Bonam farmers

MORÉ	FRENCH	SCIENTIFIC	FRUITS RIPEN	INDICATES
kankanga	figuier	*Ficus gnanphalocarpa*	May=June	Water table near ground surface
sibga	raisinier	*Anogeissus leiocarpus*	May=June	Abundant fruit yield = abundant rainfall
lenga	citronnier de mer	*Xymenia Americana*	May	Abundant fruit yield = abundant rainfall
taanga	karité	*Butyrospermum parkii*	June	Abundant fruit yield = abundant rainfall
roanga	carroubier africain	*Parkia biglobosa*	March=April	Abundant fruit yield = abundant rainfall
pusga	tamarinier	*Tamarindus indica*	June	Abundant fruit yield = abundant rainfall
sabtuloga	bouleau d'Afrique	*Lannea acida*	April	Abundant fruit yield = scarce rainfall
nobga	prunier	*Sclerocarya birrea*	May	Abundant fruit yield = scarce rainfall

Source: Roncoli *et al.* 2002

seasonal rainfall, but the integration of scientific forecasts with local knowledge might allow for making some deductions in this regard. Farmers' forecasts also differ from scientific ones in that they address local rather than regional scale and crop and climate interaction rather than precipitation per se. Farmers recognize that rainfall may have different implications for each crop species according to when and how it occurs. For instance, the same amount of rainfall can lead to radically different production outcomes if it occurs by means of one single rain event. Water-deficit periods that occur during establishment or heading will cause more damage than those occurring during other crop growth stages. Another important aspect of the farmers' forecast is the subjectivity of its evaluation. While the scientific forecasts have detailed evaluation procedures and can isolate the factors, the farmers' forecast is subjective depending on their perception of the event and can be influenced by other factors, such as yield, to determine the quality of the forecast.

Systematic documentation and subsequent integration of indigenous knowledge into conventional weather forecasting system is one of the strategies recommended to help improve the accuracy of rainfall forecasts experiencing with an increased climate variability. Although farmers listen to weather forecasts on the radio, the poor and the marginalised farmers prefer to use a traditional knowledge system for their agricultural practices. Weather and climate are assessed and predicted by locally observed variables and experiences using the combination of plants, animals, insects and meteorological and astronomical indicators (**Box 7, 7a, 8**). When scientific climate forecasting deviates from traditional forecasts, farmers are predisposed towards indigenous information because it works well with their culture. This has been tried and tested over years in a language that they understand (Makwara, 2013). Although traditional climate prediction and scientific seasonal forecasts have been thought useful, due to the increasing variability in climate, most farmers are enthusiastic about training for how to apply science-based information/ products to the farm decision-making process.

An important question for smallholder farmers in rainfed areas is whether to dry plant before the rains start, or to wait for adequate soil moisture content before planting. There are number of advantages and disadvantages in either case. Based on the probability analysis of "false" rain start (or significant "dry spell"), the risk level of planting before the season onset could be evaluated[38]. On the other hand, delay in planting (including the time required to plant the projected area) would gradually reduce the production potential. It should be emphasised that the risk level of dry planting changes with crop species/ cultivars, seasons, locations and the delay in the season onset. As rainfall onset delays, the principal risk is shifted from the amount of rainfall per se to the length of the rainy period. Delayed rainfall onset, or a short rainfall period is overcome by the pre-germination of seeds and/or planting material, in order to reduce the field crop cycle.

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[38] Relatively light pre-season "convective" rains should be taken in account, since germination could be initiated.

BOX 7 **Zimbabwe: weather and seasonal climate indicators used to predict rainfall**

KNOWLEDGE OF LOCAL INDICATORS BASED ON PLANTS

Feature	Observation	Implications
Wild fruits	Mukute: (water berry) significant flowering	Starting from July through October is a signal of good rains in the coming season
	Muonde: (Fig tree) and Mukute: (water berry) flowering and generation of new leaves	It indicates near rainfall onset
	Mumveve/Kagelia: when it gives a lot of juice during the dry season	It indicates abundant rainfall in the coming season
	Musekesa (bean pod tree Brachystegia spiciformis): significant flowering starting from July through October	It is a signal of good rains in the coming season
	The shooting of the sausage tree Muchakata and Mushuku	It indicates the onset of the rainy season
	Uapaca kirkiana and Wild loquat: significant flowering and good fruit bearing	It is widely considered to be the good indicator of impending drought

KNOWLEDGE OF LOCAL INDICATORS BASED ON BIRDS

Feature	Observation	Implications
Birds	Location where Machesa build their nests in the dry season near the river-bed.	Nests near the river indicates dry years, while nests far from rivers indicate rainy years
	Whether a black crow builds a nest in an area. They normally build the nests in an area, swallows and water fowls lay eggs on raised patches in river valley, water fowls breed on the ground under cover of grasses and reeds	It is an indication that the area will not receive rains because the birds would not take the risk to lay eggs, so low rainfall to drought conditions will be expected
	Large numbers of white and black stock (Mashohori) in October and November	It indicates an imminent rainfall onset and a good rainfall season, a normal to above normal season, a lot of insects (birds' food) is anticipated
	Dendera singing especially at dawn.	Rains are going to fall within a day or in a week's time
	Cuckoo bird (Kohwera) birdsong, especially in the afternoon from around 14:00 hrs in October and November	Sign of imminent rainfall onset and a good rainfall season. Its sound resembles the clattering of rainfall
	Swallow (Nyenganyenga) flocks seen flying throughout the area or appearance in November. Appearance of large swarms of swallows	It indicates heavy rain to come at that particular time. When they come it indicates imminent rainfall onset. A lot of insects (birds' food) is anticipated.

Source: Enock, 2013

BOX 7a Zimbabwe: weather and seasonal climate indicators used to predict rainfall

KNOWLEDGE OF LOCAL INDICATORS BASED ON PLANTS

Feature	Observation	Implications
Insects	Spiders hastily struggling to get indoors or into hiding places	It is an indication of the beginning of manhuruka rains
	Black and brown ants collecting food in the houses in large number	Impending rains and long wet spell
	Black and brown ants bring out the dead and damp food after a wet spell	Short dry weather after which the rains will resume
	Cicada singing in large numbers in September	It marks the beginning of a normal to above normal season
	Mbalavala butterflies (black bordered charaxes)	Indication that wet conditions are approaching
	Charaxespollux appearance of many butterflies	Indication of early rainfall onset and also give a prospect of a good season
	Appearance of black butterflies in a particular area	Signals a very good rainfall season over that area
	Appearance of madumbwi (red ants) Treiberameisen	Indication of imminent rainfall onset and signifies a prospect for good season
	Appearance of many termites, when flying ants are seen during rainy season mujuru (Termite Ancistrotermes sp)	This shows the sign of having more rainfall in the year
	Appearance of armyworms (mhuturu) Spodoptera exempta	Indicates near rainfall onset
	Appearance of army worms on trees in October	Signifies abundant rainfall in the upcoming season as they multiply when there is plenty of food
	Appearance of madhumbudya (grass-green grasshoppers), occurrence of more grasshoppers in a particular year	Indicates less rainfall and hunger

Source: Enock, 2013

BOX 8 Upper north-west Himalayas of India: weather forecast

People predicted weather after observing the visible spectrum around the sun or moon. If the spectrum around the sun had a greater diameter than that around the moon, they predicted rainfall after a day or two.

Some people based their weather prediction on the nature of the solar halo, specifically: "if the spectrum around the sun has a larger diameter then rainfall is assured".

All the photometers are a luminous phenomenon produced by the reflection, refraction, diffraction or interference of light from the sun or moon. The visible spectrum of light around the sun or moon is called halo, or corona according to its distance from the sun or moon. If the distance is higher, then it is called the halo phenomenon, which is caused by a layer of thin veil of cirrus clouds i.e. non-rain bearing clouds. But if the distance is less, it is called corona phenomena produced by somewhat dense clouds, which may cause rainfall. The accuracy of this indigenous observation can be as high as 50 percent.

Indigenous technology knowledge for watershed management in upper north-west Himalayas of India (GCP/RAS/161/NET)

http://www.fao.org/docrep/X5672E/x5672e00.htm#Contents

Local knowledge is self-explanatory: knowledge held locally, by local people. This may appear simple but it is actually more complex, for example, knowledge may be generated locally and refer to local situations and circumstances. At the same time, it may originate from elsewhere but be locally adapted to match local circumstances. It is sometimes difficult to know where the knowledge originated. Knowledge is often the product of many minds spread over generations and geographical areas, which is added to or adapted as it develops over time. Many indigenous practices are spread across a number of countries, or regions, or even other parts of the globe, making it hard to tell if these practices are really local or if they have been imported. Local knowledge is an important component that must be integrated into agrometeorological data and information collected at the farming level. This integration is an additional component of the *Climate-Responsive Farming Management* approach to be discussed later.

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SECTION 6

DISSEMINATION OF CLIMATE INFORMATION TO FARMERS

- BASIC PRINCIPLES
- FARMER FIELD SCHOOLS – CONCEPT
- CLIMATE FIELD SCHOOLS

6.1 BASIC PRINCIPLES

The main areas where agrometeorological information is used are:

- *Production*: people and techniques related to the actual production of crops, livestock, forestry and inland fisheries products;
- *Extension*: people and techniques responsible for ensuring the dissemination and efficient use of the messages (in the local language and in very simple terms);
- *Commercial*: manufacturing, marketing and trading farm tools and inputs (fertiliser, pesticides, machinery, infrastructure) and manufacturing livestock and poultry vaccines and other animal related products;
- *Policy decision- making*; people and regulations at international, national, regional and local levels (national and international institutions, ministries, administrations and municipalities).

For this reason, diverse communication tools are needed for the people involved in these different categories: producers need very concrete recommendations for planting, crop and natural resources management, harvesting; extension agents need guidelines, tools; traders need analytical documents on data and methodologies; decision-makers need short documents with highlights and precise recommendations for action. Agrometeorologists need to recognize the characteristics and needs of the target audience in order to communicate effectively, taking into account the various audiences listed above. This helps them translate agrometeorological information into methods facilitating its interpretation by farmers or other users.

The *National Agrometeorological Service,* often the original source of agrometeorological advice should ask questions like: What are the characteristics of the target audience? What type of farming systems do they operate? What information do they need? What are their levels of education or literacy? What language would they be comfortable using? What is their socio-economic status? What is their gender? What media or channel can be appropriate to transmit information? Unless such questions are taken into account communication becomes difficult. For example, in the case of improved practices of adaptation to climate variability and change, the technical areas in which agrometeorological communication could be relevant are:

- Physical adaptive measures (i.e. link canals, irrigation, water harvesting, storage facilities for retaining water, micro-climate manipulation, drainage, increased soil carbon concentrations;
- Adjustment of existing agricultural practices to match anticipated risks (i.e. adjustment of cropping pattern, selection of adapted varieties of crops, diversification of cropping and/or farming systems, better storage of seeds and fodder, dry seed beds; switch to alternative crops, more efficient use of irrigation water on rice paddies, more efficient use of nitrogen application on cultivated fields, improved water management including water harvesting);
- “Tactical” day to day planning of farm operations;

- Longer term weather warning (early warning systems);
- Seasonal and decade-long forecasts for planning of operations and warning.

Table 8 shows the categories of data required for customizing communication products, their potential sources and examples of intended use for agrometeorological applications and services.

TABLE 8 **Categories of data required for customizing communication products, their potential sources and examples of for agrometeorological applications and services intended for use**

CATEGORY	TYPES OF DATA	POTENTIAL SOURCE	EXAMPLES OF INTENDED USE FOR AGROMETEOROLOGICAL APPLICATIONS AND SERVICES
Meteorological and climatological	Historical daily/dekad/ monthly data on rainfall, temperature (max, min) solar radiation, relative humidity, evaporation etc.	National Hydrometeorological services, meteorological agencies, agrometeorological centers and universities	Evaluations of water supply, calculations of water requirements, dates of onset and cessation of the rainy season, dry spells, rainfall intensity, water balance, calculation of GDD and others
	Historical daily/dekad/ monthly data on wind speed and direction	Meteorological and agrometeorological centers	Designing wind breaks and shelter belts, definition of proper condition for application of pesticides
	Hourly and daily data on leaf wetness, temperature and relative humidity	Agrometeorological stations	Estimation of pests and disease incidence, definition of timing of pesticide application
Land and soil	Land slopes, surface drainage, water table	Geological department, public works, land and water resources, river authority	Definition of land suitability, water source and availability
	Soil properties (depth, texture, structure, fertility, water holding capacity, available water, salinity, acidity and other problems)	Soil research institutes, agriculture department, soil testing laboratory, national soil bureaux	Calculation of water balance, definition of water stress characteristics and fertiliser recommendations
Crops and cropping systems	Crops, varieties, duration, mono-cropping, mixed, rely, inter cropping systems	Department of agriculture	Matching crops and cropping systems with the rainy season; crop and varietal choice decisions
Agronomic management	Time of sowing, planting, quantify and time of fertilizer application, weeding, thinning, row width, method of irrigation, pest and disease control measures, time and method of harvesting	Department of agriculture, community representatives, farmers surveys, focus group meetings	Developing management alternatives, planting time, plant population, row spacing, fertilizer application options.

CATEGORY	TYPES OF DATA	POTENTIAL SOURCE	EXAMPLES OF INTENDED USE FOR AGROMETEOROLOGICAL APPLICATIONS AND SERVICES
Socio-economic and market information	Livelihood groups, livelihood objectives, risk perception, market demand, access to credit, inputs, commodity price etc.,	Community representatives, key informants, local institutions, community-based organisations, etc.,	Input optimisation, identification of target groups within the community, crop and varietal choice
Institutions	Availability of enabling institutions, mandates, structure, facilities, technical capacity, technical advice, access to support (transport, market), local cooperatives, micro financing etc.	National level relevant ministries, departments	Identification of focal agencies for implementing agrometeorological products and services and their relevance to contribute to the overall processes.

Source: Gommes *et al.*, 2010

It is important to continuously monitor and evaluate the effectiveness of communication by answering the following key questions:

- Has the information reached the user?
- Has the user used the information?
- How has the information helped the user to adapt the management?
- Has the information been helpful (by how far)?
- What feature did the user like or dislike about the delivery system?
- What improvement would the users suggest?
- How can diverse types of agrometeorological data be integrated into useful information that responds to the often-dissimilar application needs of farming communities?
- What type of information is needed by diverse groups of end-users, given their different farming socio-economic and cultural systems?
- Were the communication technologies appropriate for each social group?

Impact of information on local farm's output by surveys and/or focus groups should provide a quantitative basis to improve information, services and their communication systems. Linking climate and meteorological knowledge to farmers' action is more likely to be effective if it is perceived by farmers to be simultaneously salient, credible, and legitimate. These terms are described as follows (Cash and Buizer, 2005):

- *Salience* relates to the perceived relevance of climate and weather information: does the system provide information that farmers think they need, in a form and at a time that they can use it?
- *Credibility* addresses the perceived technical quality of information: does the system provide information that is perceived to be valid, accurate, tested, or more generally, at least as likely as alternative views to be "*true*".

- *Legitimacy* concerns the perception that the system has the interests of the farmer in mind and is not simply a vehicle for pushing the agendas and interests of other actors.

Six limiting factors to farmers' use of climate forecasts and suggestions for corrective action are given in **Table 9.**

A practical approach related to farmers' needs in terms of climate information is found in "*Response farming in Rainfed Agriculture*" (RF). RF is a methodology based on the idea that farmers can improve their return by closely monitoring on-farm weather and by using this information for their day-to-day management decisions (Stewart, 1988). RF will be explored in Chapter 7.

TABLE 9 **Factors limiting farmers' use of climate and weather forecasts**

	CAUSES	EFFECTS	CORRECTIVE ACTION
Credibility	Previous forecasts are perceived as being 'wrong' and the communicator is not generally trusted	Farmers will ignore the forecasts and reject any associated advice	Give probabilistic forecasts and rely on trusted communicators. Encourage feedback from the farmers to improve forecasts.
Legitimacy	Forecasts are perceived as superseding farmers' local knowledge	Farmers will ignore the forecasts and reject any associated advice	Attempt to incorporate local knowledge into the forecast and important to involve farmers in developing the advice information
Scale	Forecasts provide no information about events in their local area	Farmers will not incorporate forecasts into their decision-making processes	Need to work with farmers to analyse the implications for the local area. Attempt to provide regional or local scale forecast information, in probabilistic format
Procedures	Forecasts produced at the wrong time, to the wrong people, or is unexpected	Farmers will not incorporate forecasts into their decision-making processes	Repeat communication to resolve the timing, involvement of relevant key players
Choices	Forecast information does not contain enough information to alter any specific decision	Farmers will not change decisions in response to a forecast	Need to improve forecast skill and encourage farmers to make incremental decisions ("lean" rather than "jump")
Cognition	Forecasts are new in format, confusing, and different.	Farmers will either not incorporate forecasts or they will do so in a way that is counter-productive	Need to work repetitively with farmers to decipher the meaning of forecasts for their region and to correct mistakes

Source: Patt & Gwata 2002

6.2 FARMER FIELD SCHOOLS – CONCEPT

The *Farmer Field Schools* (FFS[39]) is an approach to extension based on the concept and principles of people-centred learning and was developed as an alternative to the conventional, top-down, extension approaches. It uses innovative and participatory methods to create a learning environment including learning networks, in which land users have the opportunity to learn about particular production problems and ways to address them through individual observation, discussion and participation in practical learning-by-doing field exercises. The approach can be used to encourage farmers to investigate and overcome a wider range of problems, including soil productivity improvement, conservation agriculture and control of surface runoff, water harvesting and improved irrigation.

The FFS approach was originally developed to train rice farmers on integrated pest management in Southeast Asia. Farmers meet every week from the period of planting to the harvest to check on how the crops are growing, look at the amount of moisture in the soil, and count the number of pests and beneficial organisms such as earthworms and spiders; in addition, they do experiments in the field. FFS has evolved over the years and is being used for many crops to solve several issues in various geographical settings across the world. A group of farmers joins together in one of their fields to learn about what has an effect on their crops and how to farm better by observing, analysing and experimenting new ideas. Facilitators, trained by master trainers using detailed curriculum and training modules, provide support. These facilitators, who are often responsible for more than one FFS, ensure that a range of top-level scientific expertise is brought to FFS by way of the master trainers and training modules. The FFS is therefore an ideal approach to linking field and extension services to scientific research; most importantly, this is achieved by equally distributing information and knowledge in all directions.

The FFS approach is a direct response to improved access for support on learning about integrated farm management of the farming communities. As a result of the *Participatory Assessment and Planning* (PAP) exercise, the farming communities or groups indicate their priorities for technical information particularly in relation to agrometeorological management, improving the efficiency planting, fertiliser use, increasing output and controlling costs.

Concept and principles of the FFS approach are:

- *Farmers are experts*. Farmers learn by carrying out for themselves the field studies/comparisons related to the specific farming practice they feel the need to learn about (*learning by doing*);
- *Field based education*. Real-life examples in the field (farmer domain) are the primary learning material. Farmers interact in small sub-groups (10-15 farmers) to collect and analyse data, make action;

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[39] Source: http://www.fao.org/farmer-field-schools/en/

» *Farmer driven research* should be a response to field needs as part of the research network and supporting educational programmes;

» *Decisions based on farmer analyses*. They share with others in the group for further discussion, questioning and refinement;

» *Extension workers are facilitators not teachers*. Extension workers offer guidance to farmers' activities only;

» *Problem-Posing/Problem-Solving*. Problems and challenges confronted in the field during the season are tackled in real-time using numerous analytical methods within farmers' groups;

» *Holistic approach*. It integrates all technical, ecological, socio-economical and educative aspects;

» *Group dynamics*. They are built within farmers' groups to improve communication skills, problem solving and leadership towards a higher quality of farm management skills.

The facilitator of an FFS is normally an extension worker or another farmer who has "graduated" from another field school[40]. The facilitator guides the group, helps them decide what they need to learn and how to find possible solutions, as well as answers any queries they may have. The farmers draw on their own experience and observations to make decisions on how to manage their crops. During a cropping season the supported group is required to hold two or more open field days to demonstrate to other farmers what they are doing. Farmers also host exchange visits for members of other field schools and in turn visit field schools, thus giving them an opportunity to share ideas and to witness how other farmers deal with similar problems. At the end of the cropping season the farmers graduate and may receive, for instance, a certificate from the field school organizer. The members are then qualified to start a new field school as a facilitator. The curriculum of the field schools includes team-building and organization skills, as well as special topics chosen by individual field school members. Field schools are designed to stimulate local innovation for sustainable agriculture and to empower farmers by educating farming communities on how to implement decision-making skills in their own fields.[41]

FFS is an empowering approach. A typical FFS will have 15-25 members who learn to identify, analyse and understand challenges and mobilize solutions. This organizational capacity can be used for many challenges that are not focusing only on productivity; for example, it can be applied in particular to the value chain, that is to credit and other financing modalities, to processing, to marketing and to sales and investments. The FFS extension approach is found to be effective with enhancing farm incomes as well as technical expertise and yields, as they represent an effective mechanism for group training that can reach thousands of small-scale farmers with knowledge and technical content that

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[40] The facilitor's competency is based on field experience and update training and not necessarily on formal training. Notably, in West Africa there are no diplomas, there is no graduation document nor is there a graduation procedure.

[41] As mentioned above in West Africa there is no graduation process or certificate. However, facilitators can start a new FFS only if they have completed a cycle.

can be adapted to their own unique circumstances. These processes empower famers both individually and collectively to more effectively participate in the process of agricultural development. From a sustainability point of view, it is recommended that the FFS approach be used as a means or a platform for disseminating *Climate Change Adaptation* (CCA) technologies among farmers. The FFS approach aims at reinforcing rural populations' CCA capacities, a concept which has been adopted for the integration of new resilient practices, such as the use of meteorological data in farmer decision processes, the use of resilient seed varieties, agricultural facilities and integrated pest management, etc.

FFS is an extension approach built upon the principles of adult education and experiential participatory learning processes. It provides a forum where farmers can meet and discuss real issues and explore together possible solutions that they can implement themselves. A typical FFS involves practical hands-on oriented learning processes where groups of farmers (20-30) with a shared interest within a given micro-catchment meet on a regular basis (ranging between weekly to biweekly depending on the specific needs of the group) to study the "*how and why*" of a situation in a given context, under the guidance of a facilitator (**Box 9**). The approach has been adapted in particular to field learning

BOX 9

Characteristics of a typical FFS

- A group of 20–25 farmers, assisted by a project-trained facilitator, prepares two training plots of around 1000 m^2 total. The FFS group spends roughly one-half day per week setting up experiments, making observations and jointly managing the two plots, one using local, conventional farming methods and a second plot testing new practices appropriate to the crop and location.
- Exercises are explicitly designed to introduce topics in synchrony with the specific growth stages of the crop, over the course of a cropping season.
- Farmers are asked to summarize their observations with depicting the status of the observed plots, including plants, insects, water levels, weeds, etc. Drawings are used as an effort to engage less literate farmers.
- Additional "special topics" are introduced over the course of the season to introduce or reinforce key concepts, e.g. demonstrations of pesticide toxicity, soil water-holding capacities, composting methods, etc.
- Exercises include agronomic techniques for planting, soil fertility management and integrated pest management (IPM), varietal comparisons and marketing.
- At the end of the FFS season an "open house day" is generally held in which other farmers from the community and from adjacent communities are invited, along with local government personnel and civil society to see presentations by FFS farmers and to discuss their outcomes from the season.
- The land used is either donated by the community, rented from a local farmer, or seeds, inputs and labour are provided and proceeds from harvest go to the land owner.

Settle *et al.*, 2014.
http://rstb.royalsocietypublishing.org/content/roysptb/369/1639/20120277.full.pdf

activities that require unpacking the underlying basic science to enhance the farmers' conceptual understanding of relations and interactions. Farmers under the guidance of a facilitator make regular field observations, relate their observations to the ecosystem and combine their local experience with "new" information before making the appropriate management decisions.

The learning process is systematic and guided by situation-specific curricula following natural cycles of the subject, which could be crop, animal, natural resource, or a community problem that requires collective action. A typical module of the curriculum may follow a "*seed to seed*" or "*egg to egg*" approach where a concept starts with the planting of a crop and is completed when the following season's crop is planted. Key livelihood issues that affect the community are integrated into the curriculum such as special topics based on farmers' priorities. Over the last fifteen years, the FFS approach has been successfully implemented in a mono-crop rice production system in South East Asia to adapt to complex and diverse resource-poor smallholder farming systems, with strong interactions between crop and livestock components.

6.3 CLIMATE FIELD SCHOOLS

The *Climate Field Schools* (**CFS**) based on the Farmers Field Schools' model were piloted by the project to disseminate knowledge about climate change, its causes, potential impact on livelihoods and local coping strategies. With curricula adapted to address local conditions such as specific climate change-related knowledge and skills, CFS can help farmers to adapt, develop better climateresilient integrated farming systems and improve their ability to cope with disasters and other environmental challenges. The CFS aim to enhance the capacity of extension workers and farmers to understand and apply climate information to reduce risks in agriculture. It is an innovative way to address problems on climate extremes, essentially through capacity building of farmers. Through CFS, the farmers and extension agents learned to identify what crops are suitable to grow at the onset of a predicted climate event. In addition, it helps the farmers in scheduling appropriate farm operations.

The objectives of the CFS program are to:

- Enable extension staff and farmers to understand climate related risks in agriculture and the crop management system;
- Show the importance of climate in plant growth and development, as well as its relationship with plant pests and diseases;
- Familiarize the participants on forecast implementation, climate parameters and instruments;
- Help farmers learn to integrate weather and climate information with disaster management and agricultural planning;

- Create awareness of participants on disaster risk reduction and climate change adaptation.

In general, the CFS is designed as a training program to be conducted over a period of 3 months. The farmers are taught how to read climate forecasts together with their indigenous knowledge on climatic phenomena in relation to agriculture. Other topics include land preparation, weather forecasting, use of fertilizer, pest management and soil analysis, etc. Climate forecast information is integrated into farming in the CFS (**Table 10**). The CFS also teaches farmers about climate change and its impact on agriculture so that in future they can use seasonal outlooks and other forecast products for planning and decision-making.

TABLE 10 **Indonesia. Key modules being developed in the CFS programme**

Knowing about elements of weather and climate	» To introduce elements of weather and climate » To build the ability to differentiate between weather and climate
Process of rainfall formation	» To study the process of rainfall formation » To develop a better understanding of the importance of forests in retaining water
Developing understanding on terminologies used in Seasonal Climate Forecast	» To develop the capacity to understand the meaning of NORMAL, BELOW NORMAL, and ABOVE NORMAL » To develop the capacity to translate the seasonal climate forecast to local conditions (in their farm) taking into consideration the trend in rainfall data measured by the farmers.
Developing the understanding of probability concept (Forecast Contains Errors)	» To develop a better understanding of the probability concept and skill for forecasts in climate forecasting and how it is related to decision making
Introduction to measuring's tools for weather/climate. Weather measurement. Equipment and ways of calibrating data	» To introduce instruments used for measuring weather/climate parameters » To learn factors affecting the accuracy of data measured by non-standard instruments » To learn how to calibrate data which is not measured using standard method
How to use climate forecast information for setting up planting strategies	» To develop a better understanding of how climate extreme events will affect the crops (i.e. relationship between cropping rotation and planting time on damage level) » To develop a better capacity to use seasonal climate forecasts for setting up cropping strategies (to avoid or minimize the effects of floods and drought)
Learning about the water balance concept and its use to assess crop water requirement and flood risk	» To develop a better understanding of the meaning of rainfall deficit from evapotranspiration » To develop a better capacity to estimate irrigation water requirements based on simple water balance » To assess risk of floods from water balance analysis
Assessing the economic value of climate forecast information	» To develop a better capacity to quantify the economic benefits of using climate forecast information

Source: Boer *et al.*, 2010

Information may be available through the NatAgMet but often the problem is the "*last mile*", that is, getting this information to the farmers who need it. Moreover, there is not enough extension staff to serve all farmers in an area or country.

Therefore, there is a need to integrate the concept of FFS into CFS and train the farmers and other agents for the CFS. In this way, "*farmer-to-farmer extension*" will be able to reach all farmers demanding weather forecasts and climate information. This information supplied by the NatAgMet can be disseminated to the community in a simple and accessible way[42]. During the rainy seasons, a contact person who has been supplied with a mobile phone receives the weather forecast for the coming week every day and during periods of unusual weather. The contact person then places marks next to simple graphics on a white panel in the middle of the farming community indicating whether there will be rainfall, dry spells, storms, high winds, or risk of floods, bush fires, heat wave etc. Additional information can be added such as the dates that the rains are expected to start and stop and if the rains are expected to be heavy or light. This helps farmers plan their activities and assess the best times for planting, maintaining and harvesting their crops, significantly reducing risk of losses from unpredictable weather patterns. This approach is very easy to understand for farmers with low literacy levels and it is more accessible than other methods such as radio weather forecasts, which may not reach everyone. This method has proved to more effectively overcome the challenges of other early warning systems that struggle to get the information down to the "*last mile*" for farmers on the ground.

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[42] ActionAid. Early warning weather information, Senegal, http://www.fao.org/3/a-bt151e.pdf

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SECTION 7

AN INTEGRATED APPROACH

RESPONSE FARMING IN RAINFED AGRICULTURE

7.1 INTRODUCTION

Among some of the agrometeorological tools, agro-ecological zoning determines the planning of agriculture at a regional or national scale as well as the adaptability that may be necessary under conditions of climate variability. Once the agricultural system has been established there are daily operational activities that are also influenced by the weather and climate. Decisions related to these management practices can be made in response to weather in order to optimize the production or minimize the risk of the farming system. The farmers who have been cultivating the land for a long time in a specific area will have accumulated a great deal of local knowledge about the effects of climate and weather on the production systems. This local knowledge can be used together with the scientific analysis of long-term climate data and the seasonal climate outlooks to facilitate climate sensitive decisions regarding the crop production systems. This joint knowledge will then become the "*farming management in response to weather and climate*".

However, in many developing countries there is a marked divide between the weather and climate information supplied by the NMS, and how rural farmers need to plan their activities while adapting to the increased climate variability. The implementation of the *Response Farming in Rainfed Agriculture* (RF) approach into the FFS framework is one option. RF is a method used for identifying and quantifying the rainfall variability for rainfed crops at the local level to assess the climatic risks of farming communities.

7.2 CONCEPT

The concept and practice of RF have both existed in traditional agriculture in many parts of the world for centuries. Farmers tend to adapt their field practices to long and short-term changing environmental conditions. RF is a support tool for decision-making that uses an analysis of the rainfall data to formulate recommendations for different farming practices, depending on the starting date of the rains each season. In fact, farmers apply RF using locally available knowledge and facilities, thus practicing their adaptability and coping strategies. On one hand, computers offer extended memory and analytical power that can be combined with the recent progress made by agricultural research. On the other hand, farmers possess vast knowledge and accumulated experience related to local micro-environmental conditions. Integration of both approaches would enable a systematic response farming that would further improve the decision-making process on the farms.

The original RF[43] concept (Stewart, 1988) focused on rainfall and its interaction with the farming system management at the farm level. Initially adopted to describe strategies for coping with seasonal rainfall variability, the aim of the RF was to improve tactical decision-making at the farm level based on the quantitative observations and analysis of local environmental factors, as well as the integration with farming systems strategies. The development of the RF[44] approach was accomplished by using three types of studies:

- Rainfall data analysis to identify suitable crop species and cultivars for production in a given location, in particular research on crop water balance mechanisms and crop water production functions;
- Prediction of seasonal rainfall characteristics to provide pre-plant and planting time guidance for farm decisions;
- Simulation of the impacts of crop water use and yield caused by modifying practices, notably fertilizer rates and plant populations.

7.3 METHODOLOGY

The methodology developed uses the analysis of the total season rainfall supply (mm) and/or the duration of the rainfall season (days) as related to the day of onset of the rains. It is important to understand that RF does not require a last-minute formulation of new planning or changes in direction. Due to the relatively short time period between the implementation of either option, main elements (i.e. soil labour, seeds, fertilisers, tools) for both solutions need to be available before the onset of the season. At the farm level this would mean a simple A or B cropping system planned well in advance and followed through using a step-by-step process, according to the development of the current season weather conditions. Usually plan A would apply in seasons with a relatively early onset of rains and represents the optimal choice of decisions and actions. Plan B would be invoked if the rain onset does not occur before a specified critical date. Farmers should be familiar with both sets of procedures in advance and prepared to execute either.

RF is defined as a flexible system of farming in which key decisions affecting crop water utilization and crop yield are modified each season in response to pre-season and early season predictions of season rainfall parameters. RF utilizes localized daily rainfall records to develop forecast criteria for rainfall in the current growing season to influence decisions that set yield ceilings, as well as a set of alternative recommendations for all forecast contingencies. The methodology identifies and quantifies rainfall related risks and guides

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[43] Response Farming was developed from research on rainfall behaviour and its predictability in a cropping system project in Kenya sponsored by USDA and USAID.

[44] Response Farming in Rainfed Agriculture: http://pdf.usaid.gov/pdf_docs/PNAAZ896.pdf

strategies to be addressed at the farm level. The approach combines a seasonal rainfall forecast with the appropriate agronomic response tactics for crop and cultivar selection, fertilizer application, row and plant spacing and other crop establishment practices. In RF, the time of the season onset is the predictor of seasonal rainfall behaviour, with prediction criteria and recommendations for procedures drawn from analyses of historical rainfall. The RF prediction is made at the onset of the rainfall season.

The analyses of the duration of the rainfall season (days) and/or the total season water supply (mm) related to the day of the rain onset are the main deterministic elements, also called the predictor. The growing season intensity index (mm/day), calculated by dividing the season's water supply by the rainfall duration, shows the average daily wetness of a growing season or the suitability of recorded rains for support to the different crops). In practice, there are two steps to "*Response Farming*" which are the following:

1. Prior to each growing season a forecast is made based on the expected season rainfall amount and its duration and intensity index (amount/duration). The farmer then modifies the pre-plant and planting time decisions to maximise crop yields and returns per unit of expected rain;
2. A second improved forecast (around 30 days after crop germination) guides adjustments of fertiliser rates (upward, if rains are good) or plant populations (downward if rains are poor).

7.4 ONSET OF RAINFALL SEASON

The methodology that has been developed then uses the analysis of the total season water supply (mm) and/or the duration of the rainfall season (days) as related to the day of rainfall season onset. The onset is defined as cumulative rainfall of 10 mm, however other amounts and lengths of time have been used by various authors (Tesfaye, 2004).

Based on field research, different criteria have been elaborated for the rainfall season onset:

- 20 mm in 1 or 2 days;
- 25 mm in 10 days;
- 25 mm in 7 days including 4 rainy days;
- 20 mm in 2 days and no dry spell > 10 days in next 30 days;
- 20 mm in 3 days and no dry spell > 7 days in next 30 days.

Many traditional farmers have long used the RF approach to reduce the level of risk as well as to increase the returns on their efforts. For example, farmers in semi-arid areas of Ethiopia base their management decisions on an observed date of the onset of the rainy season. They have observed that seasons with an early onset of rains have a longer duration, with larger water amounts. Therefore, the growth of crops and cultivars has a longer duration. During seasons with a late onset of rains, the season is expected to be shorter. For instance, Sivakumar (1988) believed that the onset of rains began after 1 May, when rainfall accumulated for over 3 consecutive days and was at least 20 mm and when no dry spell exceeded 7 days within a 30-day time period. The criteria are based on the observations made on the establishment of the millet crop in the Sahelian region. The end of the rains must also satisfy the production criteria. The rain at the end of the season that effectively increases the crop water supply (at least 10 mm) will determine the date of the final rains.

RF analytical algorithms for the calculation of rainfall probabilities, assessment of sources and degree of risk to crop production, simulation of impacts of alternative management decisions and designing finally adapted cropping system, are based on the following considerations:

- Rainfall probabilities are related to time periods of specific crop growing stages, rather than to fixed calendar periods. Each season's point of reference is the first day after soil water build-up from early rains becomes adequate to effect germination. Farmers signal for sowing may be either a fixed calendar date, or attainment of some arbitrarily selected build-up of stored soil water (i.e. onset);
- Total seasonal rainfall, which directly impacts on crop production. "*Effective*" seasonal rainfall is the amount of water stored in the future crop root zone at the time of germination, plus the amount, which falls during the season progression from germination to crop maturity.

7.5 RAINFALL FLAG

RF is based on decision support tools (diagram and tables), which are derived from the analysis of historical rainfall impacts on crop production. The main graph used for RF is a plot (*rainfall flag*) of the seasonal rainfall versus the date of onset of the rainfall season for a certain number of years. This "*rainfall flag*" scatter diagram shows how the seasonal rainfall amount, the approximate duration of the rainy period, and suitability for maize production are related to the date of onset of the "long rains" (**Fig. 44**), with addition lines showing the intensity index being added. The diagram is based on the analysis of 27 years of total rainfall[45] (in mm) at Katumani (Kenya) as related to the date of the rainfall season onset and its duration. An assumption is made that the amount of rainfall received each season is dependent on the date of the rainfall season onset; this onset date can be used as a "*predictor*" of the seasonal rainfall characteristics. The assumption is also made that little stored soil water is available at the beginning of the season for crop production.

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[45] Similar flags could be established considering the "effective rainfall" or the amount of rainfall, which the maize crop should have utilised in each season in the record, or in technical terminology, the crop evapotranspiration (ET).

Farmers could as a result be guided by historical rainfall to make cropping management decisions. The following points have been taken into account for the analysis of this graph:

- The indicated points represent total seasonal rainfall (vertical axe) related to the season duration[46] and/or the date of rainfall season onset (horizontal axe);
- The "*slope*" of the flag indicates that generally an early rainfall season onset yielded higher total seasonal rainfall when compared to a late onset;
- Average "*intensity*" of rains during the season is shown on reference lines from 2 to 5 mm/day.

The proposed example shows that the total seasonal rainfall varies largely over the years, between 113 mm and 660 mm, as can be observed on the vertical scale. Horizontal lines at 350 mm and 200 mm establish three categories of seasons, roughly denoting expected maize yield levels: above 350 mm a "*good*" crop is expected, dropping to "*fair*" and "*poor*" and finally to "*failure*" at a level below 220 mm of seasonal rainfall. A vertical line separates early rainfall season onset dates (up to 11 March) from late onsets. This arbitrary line was designed to separate mostly satisfactory maize seasons (whatever the total rainfall recorded) from those not considered to be satisfactory, in general terms.

Although the overall success rate amounts to 52 percent (37 percent good plus 15 percent fair/poor) versus 48 percent failure (*or close to 1 year out of 2*), crop risks appear to noticeably decrease during early onset seasons when 64 percent good maize crops (*2 seasons on 3*) have been recorded (**Table 11**). In addition, there is a 22 percent probability of a fair to poor but still successful crop. On one hand, when an early rainfall season onset is recorded globally the probability of failure is reduced to 14 percent (*one season in seven*). On the other hand, when the rain onset is late the risk of failure is as high as 84 percent (*five seasons out of six*). Clearly, in the case where rains start after 12 March maize should not be recommended as a principal food crop at Katumani and should be replaced by crops with lower water requirements such as sorghum, millet, beans, cassava, etc. The type of crops will depend on the choices made by farmers, local markets or other factors.

This example is taken from the analysis of 30 years of rainfall records at Niamey (Niger) but it is not crop specific. The rainfall season onset is defined as 40 mm of rainfall stored in the surface soil. **Fig. 45** shows how the seasonal rainfall characteristics are impacted by the date of onset and how it can be seen as a single record or as two separate records, one from 1954 to 1970 and the other from 1971 to 1983. Each circle represents one year in the records. **Table 12** shows the median rainfall amount during the early seasons as high (590 mm) while that of late seasons as very low (351 mm). This means that the farmer has to take into consideration different crops and different levels of inputs, for example, different land preparation and tillage practices and different row spacing with different plant population.

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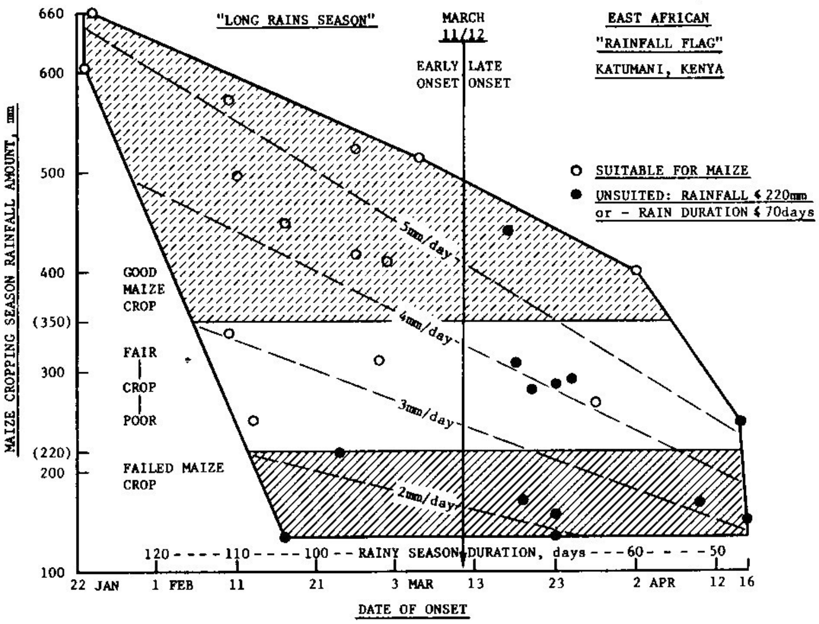
[46] For many photo-sensitive crops maturation would take place on a fixed date, regardless of the planting date. However, early planting would increase the probability of good harvests for pedological and climatic reasons.

FIGURE 44 “Rainfall flag” scatter diagram (seasonal rainfall versus cropping season duration) for maize production related to the date of the onset of the “long rains” at Katumani, Kenya



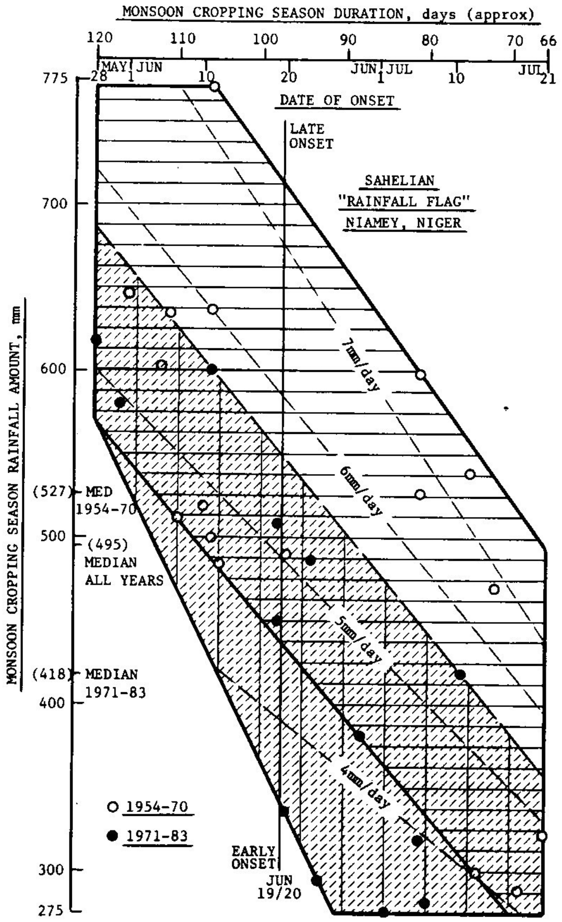
Source: Stewart, 1988

TABLE 11 Number of years and probabilities (%) of good, fair to poor or failed maize crop yields related to the date of rainfall onset and the amount of seasonal rainfall for 30 years of records at Katumani, Kenya

CROPPING SEASON ONSET PERIOD	RAINFALL RECORDS (NO. YEARS)	RAINFALL SEASON DURATION >70 DAYS		FAILED MAIZE CROP	
		Good crop (Total Rainfall >349m (%)	Fair/poor (Total Rainfall 221-349mm) (%)	Total rainfall < 221mm (%)	Rainfall season duration < 70 days (%)
All onset dates (23 Jan-16 April)	27	37	15	26	22
Early onset (before 11 March)	14	64	22	14	0
Late onset (after 12 March)	13	8	8	38	46

Source: Stewart, 1988

FIGURE 45 “Rainfall flag” graph (seasonal rainfall versus cropping season duration) for 30 years of records (1954-1983) in Niamey, Niger



Source: Stewart, 1988

TABLE 12 Median values of monsoon cropping season rainfall characteristics for 30 years (1954-1983) at Niamey, Niger

RAINFALL RECORDS (NO. YEARS)	ONSET PERIOD	MONSOON CROPPING SEASON RAINFALL MEDIAN VALUES			
		Onset (date)	Amount (mm)	Duration (days)	Intensity (mm/day)
30	All onset dates 28 May-21 July	20 June	494	99	4.68
14	Early onset (before 19 June)	10 June	590	113	4.91
16	Late onset (after 20 June)	6 July	351	82	4.07

Source: Stewart, 1988

Tables 13 and 14 represent median values of monsoon cropping season characteristics for the records 1954-1970 and 1971-1983 respectively. The rainfall analysis denotes a marked decrease in annual rainfall: over the period 1921-1970 it was 594 mm; over the period 1954-1970 it was 603 mm; and over the period 1971-1983 it was 504 mm. There has been a shift towards a later onset of the monsoon of about 11 days, that is, from a median date of 12 June in the pre-1971 period to 23 June thereafter.

TABLE 13 Median values of monsoon cropping season rainfall characteristics for 17 years of records (1954-1970) in Niamey, Niger

RAINFALL RECORDS (NO. YEARS)	ONSET PERIOD	MONSOON CROPPING SEASON RAINFALL MEDIAN VALUES			
		Onset (date)	Amount (mm)	Duration (days)	Intensity (mm/days)
17	All onset dates 1 June-21 July	12 June	519	107	5.16
9	Early onset (before 16 June)	10 June	603	112	5.16
8	Late onset (after 17 June)	12 July	480	76	5.44

Source: Stewart, 1988

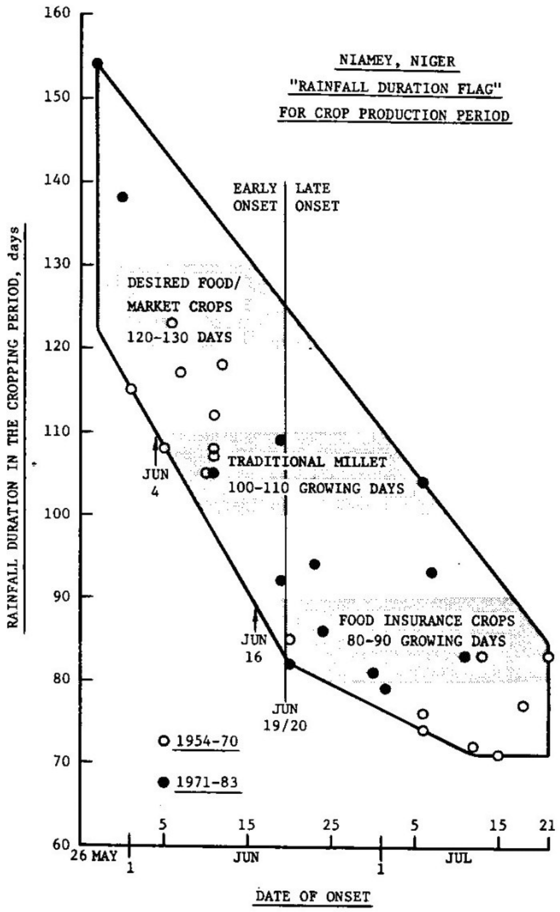
TABLE 14 Median values of monsoon cropping season rainfall characteristics for 13 years of records (1971-1983) in Niamey, Niger

RAINFALL RECORDS (NO. YEARS)	ONSET PERIOD	MONSOON CROPPING SEASON RAINFALL MEDIAN VALUES			
		Onset (date)	Amount (mm)	Duration (days)	Intensity (mm/days)
13	All onset dates 28 May-11 July	23 June	418	93	4.20
7	Early onset (before 23 June)	19 June	508	105	4.66
6	Late onset (after 24 June)	4 July	306	84	3.45

Source: Stewart, 1988

Another way to analyse a long series of rainfall records is presented in **Fig. 46** showing the “rainfall duration flag” to assist farmers with selecting crops and cultivars based on different onset dates.

FIGURE 46 "Rainfall duration flag" graph (rainfall duration versus onset date) for 30 years of records (1954-1983) in Niamey, Niger



Source: Stewart, 1988

7.6 DATA REQUIREMENT

The basic RF concept needs some datasets such as long-term daily rainfall and local information about cropping patterns including planting dates and species planted. In particular:

» *Climate data.* The main requirement is the long-term daily rainfall amount datasets meeting the WMO standards requiring 30 years of continuous data. Daily rainfall data can then be analysed to obtain the onset date of the first rains for each year as well as rainfall probabilities.

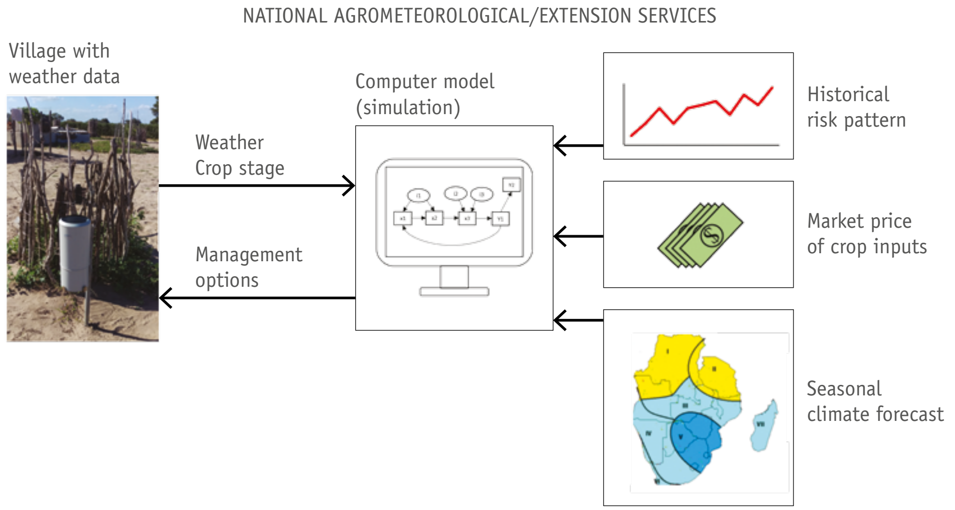
- *Crop data.* Historical crop yield data, preferably for the same cropping seasons is needed, or for a better analysis the crop water balance for the cropping seasons can be used. With this data the yield functions for the specific crop and for specific locations (i.e. soil type and climatic conditions specific) can be built. This data should also include a wide range of rainfall crop water balance values and other agronomic management practices such as fertilizer application and plant population. This will allow for the design of a generic yield function for the crops and location. This graph can be used in conjunction with the "*rainfall flag*" analysis.
- *Local knowledge.* Information on typical farm practices of the region should also be available. The farmers' best practice operations such as the land preparation, planting and weeding methods and timing should be documented, including information about the planting dates and the cultivars/landraces planted as well as the range of other typical agronomic practices (e.g. fertilization types and levels, pest/disease control).
- *Soil data*. A critical factor is the soil water holding capacity for the range of soil types in the area; this information can be extracted from the soil depth and soil type. In addition, other issues such as the slope of the lands and the typical soil fertility should also be available for the model inputs.

7.7 PRACTICAL CONSIDERATIONS

Farmers apply "*response farming*" unknowingly by using locally available knowledge and facilities in order to practice their flexibility and coping strategies. Although the concept is integrated into traditional farm decision-making, this process can be difficult due to the relatively limited experience of each farmer (or group) and by flawed human memory. On one hand, today's computers offer us both perfect memory and vast analytical power, which could be combined with recent advances from agricultural research. This should translate to improved productivity, food security and market output. On the other hand, farmers do have vast knowledge and accumulated experience related to local "*micro-environmental conditions*", which cannot be attained entirely by scientific knowledge. Integrating both approaches would enable systematic response farming to further enlighten the decision-making process for farmers.

RF is a methodology based on the observation that farmers can improve their returns by closely monitoring on-farm weather conditions during their daily management decisions. Initially adopted to describe strategies for coping with seasonal rainfall variability, RF aims at improving tactical decision-making at the farm level based on the quantitative observation and analysis of local environmental factors. The original RF concept focuses on rainfall and its interaction with the farming system management at the farm level. The concept is that improved information about rainfall prospects and impacts of alternative actions can equip farmers to meet more closely their goals of sustainable production under a variable climate (Stewart, 1988, 1995). Initially adopted to describe strategies for coping with seasonal rainfall variability, RF aims at improving tactical decision-making at the farm level, based on the quantitative observation and analysis of local environmental factors and integration with farming systems strategies (**Fig. 47**). Seasonal rainfall variability and uncertainty, with respect to the direction and extent that variability will assume during any given season, represent the greatest source of risk to crop yields in the semi-arid tropics and subtropics. RF provides a method for identifying and quantifying seasonal rainfall variability and its related risks and addresses the latter at the farm level (Stewart, 1991). This is accomplished through the improved prediction of expected rainfall behaviour during the approaching crop season and enabling improved decisions at the field level as regards crop and cultivar selection, fertilizer application and other crop establishment practices.

FIGURE 47 Schematic diagram of the response farming approach to support management options at the local level



Source: Adapted from chart by R. Gommes, 2010

7.8 LIMITING FACTORS

The implementation of RF at the local level requires taking into consideration potential limiting factors that could jeopardize its use. These limiting factors need to be examined from the various points of view of those involved so that the system is acceptable to all concerned:

- *Technical aspect*. The availability of the long-term climate data provided by the NMS in the specific country is critical. All activities must be conducted in conjunction with the NMS and the products they are dealing with should be promoted. In the case where the data are not available, remote sensing data from the satellites can be utilized. This would mean however, that its application would become dependent on high technology and therefore would not be easily accessible to the extension staff. Other technical information that may lack enough data are the climate characteristics for the specific new cultivars of some crops. The necessary criteria for the onset of rains in a specific area could be adjusted in conjunction with the soil scientists/land-use planners and the farmers, according to the clay content and other properties of the specific soil.
- *Extension Staff.* A critical factor is the assignment of these tasks and also the availability of training on RF. However, the implementation must be based on the close collaboration of extension staff with the NatAgMet staff from the NMS. As the extension staff establishes the link between farmers and the NatAgMet, they must be able to assess the benefits for farmers as well as to translate the information into the local languages. It is essential that these activities be developed in a participatory manner. One of the limiting factors is in the case where extension staff is transferred out and replaced by new staff in need of training.
- *Farmers*. In order to incorporate local knowledge into the process, farmers must be available to utilise the information provided. As with most new technologies, there will be those farmers willing to take the risk with new methods who will become the early adopters, while the others will follow their example after a season or two, when the *"farmer to farmer"* communication and learning is in place. However, farmers can make a great contribution to the development of the applications and should be able to extend the yield function for the other crops. These products can then be used in conjunction with the seasonal forecasts on a regular basis to make decisions according to the risk factor.
- *Communication*. This is an aspect that can cause the failure of a new application. In fact, the proper channels must be available to facilitate the transfer of the information from the source to the recipient. The role and responsibility of each player must be well defined as the NatAgMet needs to know when, where and what information should be given to the extension staff. Furthermore, which information and how it is to be delivered to the farmers in their agricultural region is a necessary requirement.

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SECTION 8

ENHANCED INTEGRATED APPROACH

CLIMATE-RESPONSIVE FARMING MANAGEMENT

8.1 INTRODUCTION

An enhanced integrated approach, the *Climate-Responsive Farming Management* (CRFM), has been created based on the concept of *Response Farming in Rainfed Agriculture*. The CRFM uses digital technology (e.g. specific computer software, automatic weather stations, real-time telecommunication, smartphone applications) for an integrated approach taking into account local knowledge to implement a practical advisory service at the farming level with a minimum cost. Advice to farmers is based on historical weather data and risk assessment related to current weather conditions, as well as an analysis of optimal management practices related to actual weather conditions and farming. An important goal of CRFM is to fill in the "*last mile*" between the producers of weather and climate information and the farmers, in order to produce reliable advice. CRFM is based on decision support tools, which derive from the analysis of past environmental impacts.

8.2 CONCEPT

Due to the unreliability and unpredictability regarding the onset, intensity and total amount of seasonal rainfall, it is very difficult for farmers to know what cropping decision to take (e.g. when and what to plant, at what densities, what fertilizer input level to be applied, etc.) to enable optimal productivity. For many poor families these decisions are literally life and death decisions. Facing these uncertainties farmers commonly adopt a cautious approach, sacrificing potentially higher yields in exchange for more dependable harvests. The result is low average agricultural production and per capita food availability.

Farmers productivity is compromised by the uncertainties they face; although farmers have accumulated a large field of experience at the micro-ecological level, a single strategy has been used repeatedly in the past and changes in farming practices are slow to occur. There is no direct access to relevant scientific/technical information; furthermore, there is limited latitude for experimenting on their own with alternative cropping strategies, including new species, varieties, crop management techniques, etc. Further cropping options could be integrated into farmers' decision-making process to optimise their food production, if broader information sources and specialised analytical tools were made available. To improve the traditional practices of smallholder farmers, cropping strategies specifically tailored to their changing local environment as well as production objectives need to be developed. Based on historical data and local knowledge, applied research effort would focus on the critical cropping decisions.

The social nature of local knowledge presents an opportunity for NatAgMet to develop new means of communication for their forecast products where farmers can participate as agents, as well as consumers. Documentation of local knowledge in the context of weather and climate forecasting has become mandatory in order to maintain its relevance in the face of increased climate variability and climate change. Moreover, the documentation of local knowledge in local languages as well as English has become essential for adequate information sharing and the preservation of traditional indicators, which have proven useful for smallholder farmers. Given that the elders are the custodians of this indigenous knowledge and they are dying without passing down the knowledge, as was the case in the past, thorough documentation becomes even more important (Kolawole *et al.*, 2014). In general terms, in the field of climate forecasts' application, climate scientists have an active role as the "*sources of knowledge*" while the farmers have a passive role as "*recipients of forecasts*". However, the forecast users (i.e. farmers) are also active players in the production and transmission of information. The time depth and fine spatial scale of farmers' observations could provide meteorologists with useful information and support on the production of scientific knowledge. Some features of indigenous knowledge, such as its social nature and the correspondence between some of its components and the sources of modern science, could help NatAgMet to develop a new means of communication for their forecast products. The efforts of farmers to seek out climate information on their own and to discuss forecasts in groups deepen their understanding and broaden their use of climate information. The farmers are therefore capable of participating as "*agents*" as well as "*consumers*" in the broad social system of forecast development. In this way, farmers' indigenous knowledge constitutes a resource with great potential value for agencies that develop and disseminate forecasts (Orlowe *et al.*, 2010). Basically, before implementing any development interventions, communities must be strongly engaged and take into account local knowledge for enhanced productivity; in particular by creating climate-responsive farming management approaches in close collaboration with agrometeorologists, extension officers, FFS trainers and farmers.

8.3 METHODOLOGY

More efficient and relevant agrometeorological advisories are key to helping farmers reduce the risks and stabilise their yields through optimal management of resources and inputs. The CRFM approach builds on the original RF concept with a primary goal of adjusting farm management strategies based on current and future weather conditions. This goal can be achieved by enhancing the following elements:

a. Installing a set of automatic weather stations (AWS) at the farming level for a real-time collection of meteorological data by NatAgMet;
b. Identifying the agro-ecological zones of the concerned area;
c. Assessing climate risk for agriculture of the concerned area;
d. Downscaling climate seasonal forecasts at local level;
e. Gathering information on the use of local knowledge on farming practices before, at the beginning and at the end of the cropping season;

f. Using remote sensed data to improve spatial climate assessment obtained by meteorological networks;

g. Integrating local knowledge with real-time weather forecasts and meteorological data analysis based on rainfall probability and crop simulation models;

h. Transforming data analysis into clear, practical and locally adapted management options;

i. Implementing smartphone applications for a real-time dissemination of weather and climate information;

j. Building a closer partnership between NatAgMet, extension staff, FFS trainers, and farmers, including a feedback system;

k. Enhancing farmers' capacity to make use of agrometeorological advisories.

The elements listed above are part of an iterative cycle (**Fig. 48**) which includes the following four phases (Zuma-Netshiukhwi, 2013):

» *Diagnosis phase*. Description of farmers' needs in relation to the agrometeorological information and advisories using diagnostic surveys, including relevant qualitative and

FIGURE 48 Farmers' operational plan based on four phases to produce real-time agrometeorological advisories

Diagnosis phase →

- Identification of decision problems and information requirement for the farming area
- Identification of agro-ecological zone and livelihood of farmers
- Identification of different types of farming systems
- Identification of traditional indicators from local knowledge used for weather forecasting and climate predictions
- Identification of available climate and meteorological information
- Identification of sources of real-time weather and climate forecast products
- Identification of remote sensing products
- Identification of existing channels of information dissemination

Planning phase →

- Stakeholder analysis on their importance and role
- Collection of historical climatic data for the farming area
- Real-time collection of meteorological data by stations located in the farming area
- Analysis of seasonal forecasts
- Assess historical climate risk patterns for crops and cropping systems as related to rainfall amount and duration
- Analysis of rainy season characteristics, onset, end and length of growing period
- Analysis of crop yield time series depending on inputs and management practices
- Data analysis based on crop simulation model
- Development of sets of advisories and intervention
- Identification of suitable methods of information dissemination

Implementation phase →

- Daily/Weekly dissemination of weather forecast
- Monitoring of operational plan execution
- Reporting on decisions executed
- Reporting on general observations during the growing season
- End of season's report and review of impact assessment findings
- Adjusting cropping practices based on farmers' objectives and climate patterns (e.g. best planting dates, matching crop maturity to expected rain duration, matching average daily water requirements to average seasonal rainfall patterns, land allocation under various crops, plant populations, fertiliser application, weeding, intercultural operations and harvesting)

Dissemination and Assessment phase

- Reviewing of decisions executed and examining observations during growing season
- Development of new strategies and dissemination of advisories for the coming season
- Preparation of advisories incorporating optimal management strategies
- Identification of appropriate communication channel to deliver the information
- Organization of climate workshops to enhance the decision capacity and feedback from the farmers

Source: Modified from Zuma-Netshiukhwi, 2013 participatory methods. Identify typologies within the farming community and among stakeholders relevant to the system.

- *Planning phase*. Collection of historical climatic data for the farming area and real-time collection of meteorological data. Analysis of seasonal forecasts and meteorological data and designing of advisories. Development of sets of intervention and identification of suitable methods of information dissemination by using participatory tools and techniques such as workshops, focus groups, key informants, formal and informal interviews, action planning, look and learn, role-play, learn by doing, observations and transect walks.
- *Implementation phase*. Provision of agrometeorological advisories with detailed agrometeorological information, such as sowing dates, crop cultivars, soil water capacity, irrigation scheduling, rainfall probabilities, etc.
- *Dissemination and impact assessment*. Identification of dissemination methods as preferred by the farmers (e.g. SMS, monthly meetings, on-farm visits, climate field schools). Strategies identified and screened during the planning and testing of implementation stages are sent to the users. At this stage, new strategies could be developed based on the weather forecast and climate information.

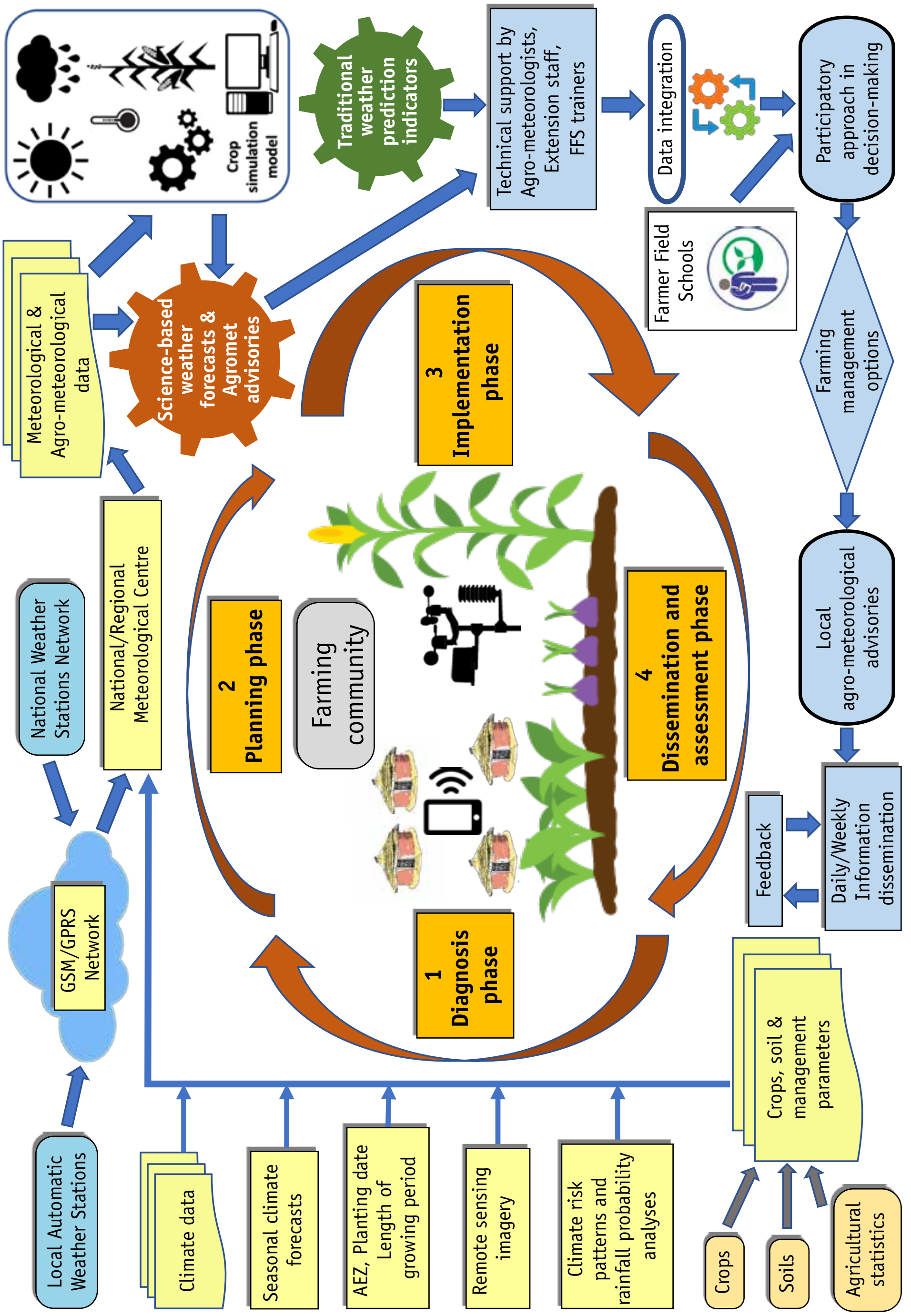
The CRFM aims at improving tactical decision-making at the farm level based on the quantitative observation and analysis of local environmental factors and integration with farming systems strategies. The proposed farmers' operational plan based on four phases has been schematically drawn in a diagram (**Fig. 49).**

8.4 REQUIRED INFRASTRUCTURE

Basically, the required infrastructure of CRFM is comparable to the RF approach but with important changes such as: (i) analyses of meteorological data measured by automatic weather stations installed at farming level, (ii) use of specific software for computing all parameters needed to elaborate agrometeorological advisories, (iii) use of smartphone applications to receive real-time weather forecasts and climate information. However, agrometeorological analyses remain an important support system for farming activities and, in particular, to the decision-making process through the participatory approach that is the core of the farming community and of the CRFM approach. In practice, the CRFM approach will make use of:

- Modern data sourcing either by automatic weather stations at the farming level and by satellite imagery;
- Real-time weather forecasts;
- Seasonal climate forecasts;
- Rainfall probability analysis to determine optimum planting dates;

FIGURE 49 Schematic diagram of the climate-responsive farming management approach to support agrometeorological advisories at the local level



Source: Bernardi, 2019

- Agro-ecological zoning;
- Real-time modelling of crop development;
- Collection of traditional weather prediction indicators;
- Integration of local and indigenous knowledge into the decision-making process through a participatory approach with farming community;
- Smartphone applications for information dissemination from and to the farming communities;
- Strong cooperation among all staff belonging to NetAgMet, extension, FFS and farming community.

The most important enhancement is represented by the installation of a set of automatic meteorological stations (AWS[47]) covering the different agro-ecological zones of the farming area and connected via GPRS to the central database of the NMS and the use of various agrometeorological software for example, to compute rainfall probabilities to determine optimum planting dates and to monitor crop development.

8.5 DATA REQUIREMENT

The management of climate related risks is directly linked to the seasonal behaviour and management alternatives of each farming area. Data should be equipped to generate answers related to "*who*", "*what*", "*where*", and "*when*" questions. The design of cropping system decision packages requires a large series of data. Concerning climate data and weather forecasts, the CRFM approach requires the availability of reliable climate data and weather forecasts for the end users to facilitate local-tailored decision-making, for example:

- Climate records for last 30 years of: rainfall, max/min temperature, relative humidity, wind, solar radiation, evaporation;
- Climate risk patterns based on daily rainfall data analysis to obtain the rainy period duration and delayed rains onset and early cessation of rainfall for each year;
- Short-range weather forecasts of up to about 1 week (ref. Para 2.4.1.1);
- Medium-range weather forecasts of time scales beyond the short range and up to two weeks (ref. Para 2.4.1.2);
- Climate outlooks: monthly, seasonal and inter-annual time scales (ref. Para 2.4.1.3);
- Remote sensing-based products (ref. Para 3.9).

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[47] Rechargeable batteries or solar panel can power a typical AWS. For data communication there are several options. They can be equipped with a SIM (Subscriber Identity Module) card and a GPRS (General Packet Radio Service) contract with sufficient good GSM (Global System for Mobile Communications) coverage in the area. All relevant weather data are permanently measured by the AWS and automatically sent to Internet climate databases. Data can then easily be downloaded from the Internet in automatic mode.

Other data requirements are as follows:

a. Land characteristic
- → Land slope;
- → Soil depth and water holding capacity;
- → Soil fertility.

b. Cropping systems
- → Agro-ecological zoning;
- → Crops species and cultivars (cycle-maturity, specific pedo-climatic requirements);
- → Cropping system: mono-cropping, associations;
- → Planting: timing, seed rate, plant spacing/arrangement;
- → Fertilization and pest/disease control management;
- → Weed and plant population control.

c. Support services:
- → Socio-economic: access to credit, to inputs (seeds, fertiliser, other supplies);
- → Technical advice;
- → Institutional: government support, infrastructures (transport, markets).

8.5.1 CLIMATE RECORDS

A time series of measurements of sufficient length, consistency and continuity to determine climate variability and change must be made available for all stations located in the range of the farming community (see Para 2.5). Such measurements provide an objective basis for the understanding and prediction of climate and its variability, such as global warming. In the case of a lack of stations in the farming area, data from neighbouring stations can be interpolated to estimate climate data at the local level as described in Para 2.5.2.

8.5.2 CLIMATE RISK PATTERNS

Rainfall analyses using long-term rainfall records are applied to the probability of events or sequences of events of known importance to farmers and extension staff. These include the start of the growing season, the frequency of dry spells within the season, the frequency of high intensity erosive rainfall events, the impact of prolonged wet spells on plant disease or the length of the growing season. These analyses provide a useful framework for making medium-term strategic choices concerning agricultural practices that are directly influenced by single or a combination of climatic events. This type of analysis can be performed with the appropriate software such as *RAINBOW*[48] or *R-Instat*[49] listed in the

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[48] RAINBOW: http://iupware.be/?page_id=874

[49] R-Instat: http://r-instat.org/index.html

Annex. For example, within a crop species, different varieties show different adaptability to environmental stresses such as temperature and rainfall (**Table 15**). This can be exploited by studying the variety-by-location interactions and by developing adaptation maps for different varieties. Doing this for a range of species can enhance production for an entire region (IRI, 2007).

TABLE 15 **Effect of climate variability on pearl millet crop performances and adaptation options**

CLIMATE PARAMETERS	EFFECTS ON CROPS AND NATURAL RESOURCES	ADAPTATION OPTIONS
Late onset of rains	Shorter rainy season, risk that longcycle crops will run out of growing time	Early-maturing varieties, exploitation of photoperiodization, P fertilizer at planting
Early drought	Difficult crop establishment and need for partial or total re-sowing	P fertilizer at planting, water harvesting and runoff control, delay sowing (but poor growth due to N flush), exploit seedling heat and drought tolerance
Mid-season drought	Poor seed setting and panicle development, fewer productive tillers, reduced grain yield per panicle/plant	Use of pearl millet variability: differing cycles, high tillering cultivars, optimal root traits, etc.; water harvesting and run-off control
Terminal drought	Poor grain filling, fewer productive tillers	Early-maturing varieties, optimal root traits, fertilizer at planting, water harvesting and run-off control
Excessive rainfall	Downy mildew and other pests, nutrient leaching	Resistant varieties, pesticides, N fertilizer at tillering
Increased temperature	Poor crop establishment (desiccation of seedlings), increased transpiration, faster growth	Heat tolerance traits, crop residue management, P fertilizer at planting (to increase plant vigor), large number of seedlings per planting hill
Unpredictability of drought stress	See above	Phenotypic variability, genetically diverse cultivars
Increased CO_2 levels	Faster plant growth through increased photosynthesis, higher transpiration	Promote positive effect of higher levels through better soil fertility management
Increased occurrence of dust storms at onset of rains	Seedlings buried and damaged by sand particles	Increase number of seedlings per planting hill, mulching, ridging (primary tillage)
Increased dust in the atmosphere	Lower radiation, reduced photosynthesis	Increase nutrient inputs (i.e. K)

Source: Hellmuth *et al.*, 2007

8.5.3 CROP SIMULATION MODELS

The minimum meteorological parameters commonly used as input for running the crop simulation models are rainfall, maximum and minimum temperature and solar radiation. These models are usually run daily in steps, the important ones being simulated processes of plant growth, water infiltration into the soil, transpiration, soil evaporation, runoff and deep percolation. Crop models are scientific tools generally used at the technical institution level to analyse the impact of alternate management practices on crop yields and economics. The crop models are not specifically designed for the farmers, but are tools to be used by the technical institutions, extension agencies to prepare crop specific management alternatives. These models are tools created for the "*what if*" questions, which quickly enable the decision maker to look at the quantitative results. The models could improve the components of localized climate risk management in three different ways:

- Increased precision and reliability: the decision-tables can be improved by using simulation models to better understand the impact of local weather conditions on crops;
- Simulation of technical and economic management options to decide on the most appropriate strategy;
- Real-time updating: models could be run with currently recorded data including real time rainfall, soil moisture data and other information retrieved from automatic weather stations.

8.5.4 SURVEY TO ASSESS WEATHER PREDICTION TRADITIONAL INDICATORS

Indigenous knowledge can support the understanding of weather and climate patterns to make decisions about crops and farming practices. However, increased rainfall variability in recent years associated with climate change has reduced farmers' confidence in indigenous knowledge. As a result, farmers' adaptive capacity has reduced and their vulnerability to climate change has increased. The integration of indigenous knowledge into scientific climate forecasts at the local level is an important step to enhancing the resilience of communities vulnerable to climate change. The first step is to conduct a survey to assess the use of science-based and traditional weather and climate forecasts (**Table 16**). The survey can be based on a *Rapid Rural Appraisal* (RRA) that serves as a guide to address community problems by the delivery of information (ZumaNetshiukhwi, 2013). RRA refers to a collection of field techniques that are primarily used to gather knowledge from local people in a manner that is quicker, more cost effective and often more informative than questionnaire surveys (Chambers, 1994). RRA can be conducted by a series of meetings with farmers in the region. This methodology is critical for establishing the general traditional knowledge that exists within the community and how this could be integrated into weather forecasts. RRA plays an important role in collecting information from a cross-section of villages within a short space of time. RRA can be applied with the following objectives:

- To analyse the farming systems for their indigenous knowledge, particularly on rainfall forecasting;
- To understand current agrometeorological advisories and services (if any) and sources of weather/climate information;
- To identify and select appropriate channels for information communication/ dissemination;
- To develop some tailor-made advisories together with farmers for improved on-farm decisions making for such matters as crop type, cultivar and planting date selection;
- To monitor and evaluate the use and adoption of these advisories;
- To discuss these matters with farmers in monthly meetings;
- To derive rules for procedures without the involvement of scientists each and every time, for creating extension potential, extension training and extension practice.

TABLE 16 **Questionnaire on use of science-based weather/climate forecasts and advisories and traditional weather/climate forecasts/predictions**

Province	
District	
Municipality	
Closest meteorological station	
Name of farmer	
Gender	
Status	
Age	
Educational background	
Full-time farmer	
Farm size (ha)	
Allocated land to farming system (ha)	(1) Crops: (2) Livestock: (3) Mixed farming: (4) Agroforestry: (5) Fruit trees: (6) Other:
Type of crops:	(1) Maize (2) Sorghum (3) Millet (4) Soybean (5) Vegetables
1. Do you receive any seasonal climate predictions and if so how often before, during and after the growing season?	
2. Through which media do you receive these seasonal climate predictions?	

3. How do you use these seasonal climate predictions?	
4. Are you able to understand and interpret such predictions?	
5. How much value do you put on these seasonal climate predictions?	
6. What other science-based weather/climate information and advisories (e.g. weather forecasts, early warnings of drought, frost, hail and/or heavy wind etc.) do you make use of?	
7. How much value do you put on these other science-based weather/climate information and advisories?	
8. What traditional climate predictions do you make use of? Combinations of plants, animals, insects, and meteorological and astronomical indicators?	
9. When do you make use of traditional climate predictions? Before, during or at the end of the season?	
10. How much value do you put on these traditional climate predictions?	
11. What other traditional weather/climate predictions do you make use of?	
12. When do you make use of traditional weather/climate predictions? Before, during or at the end of the season?	
13. How much value do you put on this other traditional weather/climate predictions?	
14. How reliable do you think the seasonal climate forecasts are for you?	
15. How reliable do you think the traditional climate predictions are for you?	
16. How reliable do you think the other science-based weather/climate forecasts are for you?	
17. How reliable do you think the other traditional weather/climate predictions are?	
18. What is the meaning of normal, below normal and above normal?	
19. What do you understand about 30%, 60% and 80% probability of rainfall?	
20. Are you able to use the seasonal climate forecasts in planning your farm activities or in any other way?	
21. Are you able to use other science-based weather/climate forecasts and advisories in any way?	

22. Are you able to use traditional climate predictions and/or other traditional weather/ climate information and advisories in any way?	
23. If above normal rainfall is predicted, what kind of adjustments in farming practices do you make?	
24. If a drought is predicted, do you make any adjustments to your activities?	
25. Do you make deliberate efforts to obtain climate prediction information?	
26. Do you make a deliberate effort to obtain other sciencebased weather/climate forecasts and advisories?	
27. Do you make a deliberate effort to obtain traditional climate predictions and/or other weather or climate information and advisories?	
28. Would you consider paying for seasonal climate forecasts?	
29. Would you consider paying for any other science-based weather/climate forecasts and advisories?	
30. Would you consider paying for any traditional climate predictions and/or other traditional weather/climate information and advisories?	
31. From which institutions or organizations do you receive other science-based weather/climate information and advisories other than the seasonal climate forecasts?	
32. From whom do you receive traditional climate predictions and other traditional weather/climate information?	
33. Should climate predictions be made available to you and which method(s)/channel(s) of information transfer would you prefer?	
34. Should other science-based weather/climate forecasts and advisories be made available to you and which method(s)/channel(s) of information transfer would you prefer?	
35. How often do you have meetings with the local extension officers?	
36. Do you receive any climate forecasts and/or science-based weather/climate related information and advisories from your extension officers?	
37. Do you receive any traditional climate predictions and/or other weather/climate related information and advisories from your extension officers?	

Source: modified from Zuma-Netshiukhwi, 2013

8.5.5 INTEGRATING SCIENCE-BASED WEATHER FORECASTS AND TRADITIONAL WEATHER PREDICTIONS

Farmers use weather and climate related indicators in their traditional forecasts and predictions, mostly for immediate or seasonal rains and droughts. Agricultural decisions are made according to traditional knowledge and the understanding of the environmental conditions in their local area, obtained from years of experience. The understanding of the farmers' perception of weather and climate is a critical step to facilitating effective communication on science-based agrometeorological knowledge. Science-based weather forecasting, climate prediction and lowyield farming continued successfully except in the case of natural disasters (Zuma-Netshiukhwi *et al.*, 2013).

Farmers have realized that science-based weather or climate related forecasts and predictions, as well as other science-based agrometeorological advisories, protect them better than traditional knowledge since the new knowledge-based decision making has been put into practice. Farmers are indeed aware of the disadvantages of traditional knowledge and of those found in science-based knowledge (**Table 17**); however, this awareness can also contribute to the improvement of the new knowledge-based decision-making (Zuma-Netshiukhwi *et al.*, 2013).

TABLE 17 **Disadvantages of using traditional weather/climate forecasts/predictions and disadvantages of using science-based weather/climate forecasts/predictions**

DISADVANTAGES OF TRADITIONAL WEATHER/ CLIMATE FORECASTS/PREDICTIONS	DISADVANTAGES OF SCIENCE-BASED WEATHER/CLIMATE FORECASTS/PREDICTIONS
» They are only momentary but can work well when combined with scientific forecasts/ predictions. » They are culture-based and interpreted differently in different areas. » They do not provide long-term predictions, some seasonal indications apart. » They cannot predict mid-season dry spells or the probabilities. » They do not indicate rainfall distribution but only provide an indication of when to prepare for the onset. Occasionally they provide information on the quality of the season to come. » Some scientific forecast/prediction experts do not trust their judgement as, unfairly, they consider that their predictions are based on superstition.	» They are not easily available and accessible for use in agriculture. » Their advantages are not documented so that farmers can understand. » They are difficult to interpret and it is not easy to make decisions based on the probabilistic information given. » They are not point specific and there is a a need for reliable downscaled weather/climate forecasts/predictions.

Source: Zuma-Netshiukhwi *et al.*, 2013

The exchange of knowledge can take place as soon as farmers have decided to share their knowledge on traditional forecasting and decision-making. The result of the survey, as described in the previous paragraph, is the base for gathering local information on the use of traditional weather predictions. Based upon this information, decisions can be made through a participatory approach on how to integrate new science-based information into traditional forecasting methods to produce practical advisories. In general, farmers demonstrate a great willingness to learn about sciencebased agrometeorological advisories. Furthermore, interaction with the farmers during workshops would allow for a two-way participation and offer an opportunity to understand their perception of the advisories. A permanent platform for exchanging knowledge is then established during these workshops to build permanent dialogues with the farmers, the result being a dual learning process. Integration of agrometeorological products with local knowledge on weather forecasting and climate prediction can improve adaptation strategies and ensure that new knowledge, products, and services are implemented at the farming level. Through this interaction process, farmers can learn and gradually apply the weather and climate products as well as other science-based agrometeorological knowledge to agricultural decisionmaking. This kind of *farmerto-farmer* extension is fundamental for reaching the majority of farmers and acquiring a good understanding of the advisories and use of agrometeorological advisories. Training on the application of science-based agrometeorological advisories, such as: crop suitability, cultivar selection, planting date, planting density, weeding, water management, pests and diseases and fertilizing is an important objective. If the necessary steps are taken to guide farmers on how to better adapt to climate variability, this objective is attainable.

8.5.6 USE OF SMARTPHONE APPLICATIONS

The number of smartphone applications for farmers is rapidly increasing. Among these mobile phone applications, a large number can provide smallholder farmers with agricultural and related information. For example, the **Apps4Ag Database**[50] boosts information dissemination, knowledge exchange, extension and advisory service delivery, farmer engagement, and marker access for both agricultural inputs and outputs. Apps4Ag is a comprehensive, up-to-date, database with the best applications for agriculture. For smallholder farmers, one of the main challenges is the provision of weather forecasts and climate information for location specific, timely and relevant information in economically sustainable ways through a smartphone application. The application will allow the development of participatory decision-making approaches enabling farmers to interpret information at the local level and decide on management options. Furthermore, the application will allow the feedback between farmers and service providers.

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[50] Apps4Ag: https://www.apps4ag.org/database.html

Because of the challenges faced by many forms of agricultural production posed by increasing climate variability as well as associated extreme events and climate change, agrometeorological information has become even more essential. Detailed observations and real-time dissemination of meteorological information are important for tactical agrometeorological decisions during the short-term planning of agricultural operations at different crop growth stages. In order for farmers to ensure the timely and efficient use of meteorological and climatological information, it is important to fully appreciate the effects of weather and climate on soils, plants, animals, trees and related production in farming systems, regardless the type of decision.

The *Smart Campo* mobile app, for example, is an innovative way to help farmers make decisions based on weather and climate information. The purpose of the Smart Campo app is to offer practical solutions to producers based on the monitoring and forecasting of weather and climate. This app helps the experts keep track of weather and forecasted data for their fields and crops. In addition, users can register fields to track information such as rain accumulated, the growing degree days, maximum and minimum mean temperature and more. Users can also select days of the week to be notified on crop and weather specific data for their fields. Farmers can check current weather conditions from available stations to obtain updates on: rainfall, air temperature and growing degree days, cumulative temperature, accumulated chill hours, extreme weather events.

8.5.7 **SUMMARY**

In order to face seasonal climate variability new approaches are being developed to enable production optimisation of peasant rainfed production systems within farmer's objectives and opportunities. *Climate-Responsive Farming Management* (CRFM) is one of the techniques based on four steps:

- **i.** Rainfall analysis to quantify onset relationships to season parameters;
- **ii.** Training of extension staff to determine the date of onset at the start of each season and to understand how expected rainfall amounts, duration and intensity indices relate to dates of onset;
- **iii.** For each rainy season as the onset is identified, extension staff inform farmers in the location of expected rainfall season characteristics;
- **iv.** Farmers are provided with general guidelines to give direction to their responses to rainfall forecasts and to enable formulation of suitable strategy for coping with the seasonal rainfall variability.

Agrometeorological advisories on farming management should obtain answers to the following questions:

- » What are the farmers targets related to their specific resource access?
- » What are the main parameters farmers and their community are using during the decision-making process?

- What type of risk do farmers consider to be a priority?
- What level(s) of risk are farmers ready to take?
- During past experiences what reduced/raised farmers' fear of technology changes (content or approach) in terms of technical or non-technical factors?

Regardless, constraints involving the use of information can be characterised as technical, financial, legal, cognitive and institutional. The problem of communication breakdown/failure has also been identified as a critical issue in seasonal climate forecasts. Agrometeorologists need to recognise the characteristics of the target audience in order to encode in a way that facilitates the task of decoding for farmers or other users. Therefore, NatAgMet service should ask questions such as:

- What are the characteristics of the target group audience?
- What type of farming systems do they operate?
- What is their level of education and literacy?
- What is their native language?
- What is their socio-economic status? How many farmers are women? Gender differences in decision-making?
- What media or channel could be used to best transmit information?

Briefly, CRFM is based on decision support tools, which derive from the analysis of past climate and environmental impacts. There are several options for modernising and adapting CRFM to farmers' needs:

- The use of modern data sourcing either by satellite imagery or/and by automatic collection of field data;
- Real-time modelling of crop development;
- Integration of science-based weather forecasts and traditional weather predictions;
- Participatory approach in decision-making;
- The use of smartphone applications to delivery weather forecasts and agrometeorological advisories to the farmers and to receive real-time feedback from the farmers.

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ANNEXES

THIS SECTION PROVIDES **BASIC DATA**, **METHODS** AND **TOOLS** NEEDED TO COLLECT, PROCESS AND ANALYSE AGROMETEOROLOGICAL AND CLIMATIC DATA.

- **METEOROLOGICAL AND CLIMATE DATA**
- **METHODS**
- **TOOLS**
- **EQUIPMENT**

METEOROLOGICAL AND CLIMATE DATA

DATA

- **NOAA - CPC Africa weather and climate**
  http://www.cpc.ncep.noaa.gov/products/international/africa/africa.shtml
- **NOAA - NCDC Climate dat**a
  https://www.ncdc.noaa.gov/cdo-web
- **FAO - Crop information:**
  http://www.fao.org/land-water/databases-and-software/crop-information/en
- **FAO - Crop calendar:**
  http://www.fao.org/agriculture/seed/cropcalendar/welcome.do
- **GCIAR - Historical raster data**
  http://www.cgiar-csi.org/data/uea-cru-ts-v3-10-01-historic-climate-database
- **WorldClim – Raster climate data**
  http://www.worldclim.org
- **USGS - FEWS-Net:**
  https://earlywarning.usgs.gov/fews/search/Africa
- **USDA - Crop explorer:**
  https://www.pecad.fas.usda.gov/cropexplorer
- **IFPRI – Harvest choice**
  https://harvestchoice.org/products/data
- **IRI– ENACTS:**
  http://iri.columbia.edu/resources/enacts
- **CCAFS:**
  http://www.ccafs-climate.org/data
- **Agro-climate of Mozambique**
  http://mz.agroclimate.org

HOURLY DATA

- **Weather underground**
  https://www.wunderground.com/history/
- **SASSCAL WeatherNet**
  http://www.sasscalweathernet.org

DAILY DATA

- **Tutiempo**
  https://en.tutiempo.net/climate/africa.html

MONTHLY DATA

- **IRI - Maproom**
  https://iridl.ldeo.columbia.edu/maproom/index.html
- **All Met Sat**
  http://fr.allmetsat.com/climat/afrique.php
- **Weatherbase**
  http://www.weatherbase.com/weather/country.php3?r=AFR&refer=&regionname=Africa
- **UN Data**
  http://data.un.org/Explorer.aspx?d=CLINO
- **NOAA – Data prior to 1960**
  https://www.lib.noaa.gov/collections/imgdocmaps/data_rescue_home.html

METHODS

- **FAO - Crop Monitoring Box User Guide**
  http://www.hoefsloot.com/wiki/index.php?title=Main_Page
- **FAO - AgroMetShell Manual**
  http://www.fao.org/3/a-au031e.pdf
- **FAO - AgroMetShell Tutorial**
  http://www.hoefsloot.com/Downloads/Tutorial%20on%20crop%20forecasting%20in%20Afghanistan.pdf
- **WMO - GAMP – Guide to Agricultural Meteorological Practices**
  http://www.wmo.int/pages/prog/wcp/agm/gamp/documents/WMO_No134_en.pdf

TOOLS

FAO – AGROMETSHELL

AGROMETEOROLOGICAL TOOLBOX

AgroMetShell (AMS) is a freeware integrated toolbox developed by the *Climate and Environment Division* (CBC[51]) of FAO for agrometeorological crop monitoring and forecasting to assess the impact of weather conditions on crops using statistical and crop modeling approaches. It is a collection of tools for the integrated analysis of ground data and low-resolution satellite information, which have been brought together under a common interface. AMS is built around a database of crop, weather and climate data that are used to compute a crop-specific soil water balance and to derive some agronomic/agrometeorological value-added variables (indicators) used to assess crop conditions. The software integrates data analysis and IDA[52] image functions. The current visual menu offers easy access to some of the most frequently used functions: all of the buttons in the visual menu have their equivalent in the main pull-down menus. The program includes a database containing all of the weather as well as climate and crop data needed to analyse weather impact on crops. Data can be input into the database using a variety of options, for instance, they can be typed in from the keyboard, read from WINDISP[53] format images or imported from ASCII files.

The main functions of AMS include the following:

- Database functions (configure, input, output & manage data);
- Daily input of 10-day crop-specific soil water balance to monitor crops and carry-out risk analyses;
- Several methods of spatial interpolation of agro-climatic variables and other indicators and their output in gridded format;
- Various calculations such as calculation of crop water consumption (potential evapotranspiration), rainfall probabilities, growing season characteristics and statistical analyses.

The core of the program is the FAO *Crop Specific Soil Water Balance* (CSSWB). FAO CSSWB can be operated in monitoring mode or in risk analysis mode. The first mode is an analysis for one growing season covering many stations in a specific area, usually a country or a

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[51] FAO Climate and Environment Division: http://www.fao.org/climate-change/en/

[52] IDA (Image Display and Analysis) is the format of the geo-referenced images processed by WINDISP (see below).

[53] WINDISP is a map and image display software developed by FAO to process raster imagery and it is a component of AgroMetShell.

province in a country. The second (risk analysis mode) covers the same type of analysis for one station only but over many years. The FAO Crop Specific Soil Water Balance produces a number of outputs: water balance variables such as soil moisture, actual evapotranspiration over the vegetative phase or the water stress at flowering, etc. They can be mapped separately for crop monitoring. For crop forecasting, the water balance variables are normally averaged over administrative areas and then compared with crop yields through multiple regressions to derive a Yield Function that in turn can be used to estimate yields. In addition to the CSSWB, AgroMetShell proposes many other useful tools for example, the calculation of rainfall probabilities, spatial interpolation tools and the determination of growing season characteristics based on climatological parameters.

FIGURE 50 Main modules of FAO AgroMetShell software

DATABASE

- By Country, by Station, by List
- Meteorological
- Climatic
- Agronomic
- Soil
- Import
- Export

CROP SPECIFIC WATER BALANCE MODEL

- Maize
- Millet (bulrush)
- Tef
- Wheat
- Sorghum
- Finger Millet
- Flooded rice
- Upland rice
- ETP
- Any crop

SPATIAL INTERPOLATION

- Inverse distance
- SEDI (inverse distance)
- SEDI (regression)
- Cokriging

AGROMET TOOLS

- Solar radiation estimate
- Dekadal from monthly
- Day and night-time temperatures
- ET0
- LGP
- Potential yield
- Risk analysis

STATISTICAL TOOLS

- Correlation
- Multiple regression
- PCA
- Trends
- Gamma distribution

IMAGE ANALYSIS

- Display
- Color table edit
- Image calculation with formula
- Cut-off image values
- Rescale image
- Simple variogram
- Create image from other outputs

Available at:
http://www.hoefsloot.com/agrometshell.htm

FAO – NEW_LOCCLIM

LOCAL CLIMATE ESTIMATOR

New_LocClim (Local Climate Estimator) is a free-ware tool developed by the *Climate and Environment Division* (CBC[54]) of FAO in collaboration with the German Weather Service to estimate local climatic conditions for any location on Earth for which no observations are available. The user can choose among the popular interpolation techniques (*Nearest neighbour, IDWA, modified IDWA, Cressmanns method, Distance functions, Polynomials, Shepard's method, Kriging, Thin plate splines*). Furthermore, altitude regression and local or regional horizontal gradients can be taken into account. New_LocClim uses the FAO climatic database with observations from nearly 30,000 stations worldwide but users can also process their own data.

The program can run in 3 modes:

1. In *Single-Point Mode*, the user selects a location anywhere on land and the programme displays the mean annual cycle of 8 climatological variables (monthly means of minimum, maximum and average daily temperature, precipitation, potential evapotranspiration, wind speed, water vapour pressure, and sunshine fraction or sunshine hours). Since the annual cycle of long-term average can be regarded as smooth, a Fourier interpolation of the monthly values is used to obtain expectations on daily and decadal time scales as well. Furthermore, various features of the growing season defined by Franquin's method, can be calculated, i.e. dates of beginning and end, days over the threshold and heating degree days. The interpolation error is then estimated. A regional map displays the features of the stations surrounding the selected location and an Observation-Altitude Plot that allows for an investigation of the altitude dependence of the climate variables. The user receives warnings in case of extrapolation (horizontal or with respect to altitude), strange data, or lack of neighbouring stations given the chosen settings. All information can be exported as maps or tables.
2. The *Workbench Mode* produces and exports regional maps of the variables listed in point 1. Furthermore, spatial and altitude statistics can be calculated. This mode allows for a selection of a region by country or by rectangle from a world map. In addition to using the data of the built-in FAO database, the user can import his own data to be interpolated and spatially analysed.
3. The *Automatic Mode* produces tables of the desired climatological variables and/or growing season features in a variety of formats for arbitrary self-defined grids and self-defined digital elevation models.

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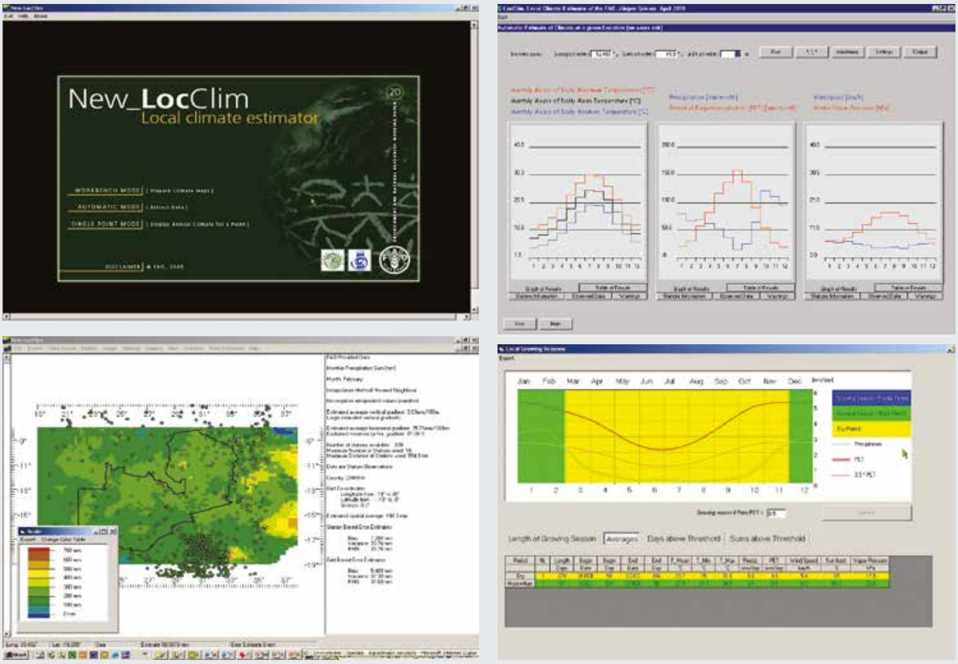
[54] FAO-Climate and Environment Division: http://www.fao.org/climate-change/en/

New_LocClim can also calculate the length of the "*growing period*" or "*growing season*" (LGP or LGS, see section 3.5) as defined by the *Agro-Ecological Zones*[55], which is the period (in days) during a year when precipitation exceeds half the potential evapotranspiration. LGP is useful for calculating agricultural potential and can be used as the criterion for classifying areas for roughly determining crop cycle lengths and calendars.

FIGURE 51 **Screenshots of New_LocClim software**



Available at:
http://www.juergen-grieser.de/downloads/ClimateInterpolation/ClimateInterpolation.htm

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[55] GAEZ (Global Agro-Ecological Zones): http://www.fao.org/nr/gaez/en/

FAO – WAPOR

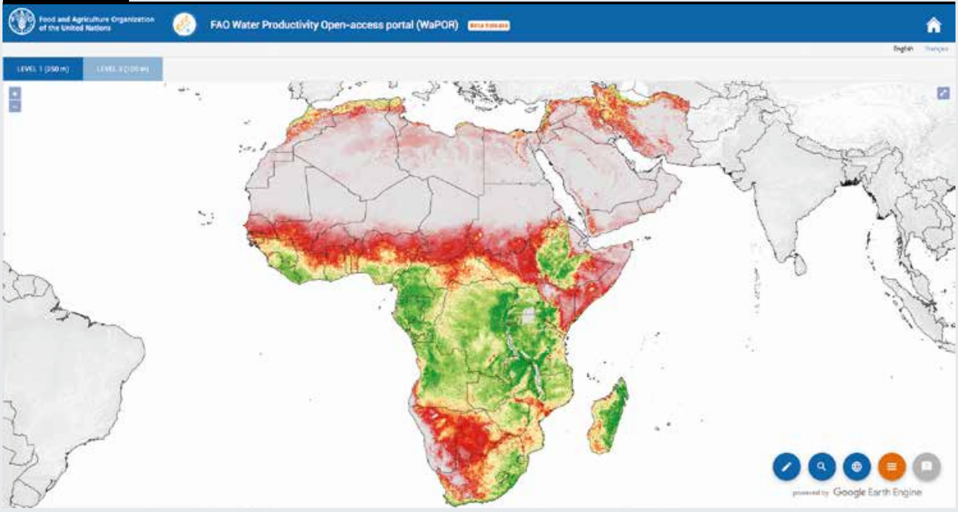
WATER PRODUCTIVITY OPEN-ACCESS PORTAL

The portal to monitor Water Productivity through Open access of Remotely sensed derived data (WaPOR) developed by the *Land and Water Division* (CBL[56]) of FAO monitors and reports on agriculture water productivity over Africa and the Near East. It provides open access to the water productivity database and its thousands of underlying map layers, it allows for direct data queries, time series analyses, area statistics and data download of key variables associated to water and land productivity assessments.

Differentiated for the three spatial levels, water and land productivity will be assessed as follows:

- On level I, water productivity will be monitored looking at biomass produced per cubic meter of water consumed and a distinction will then be made between irrigated and rainfed agriculture. Land productivity will be monitored in terms of biomass production per hectare. Land and water productivity will be calculated on pixel basis, which can be aggregated to country or river basin level.
- On level II, land and water productivity will be monitored for a selected set of countries/river basins while distinguishing several main crops under irrigated or rainfed agriculture. Land productivity will be expressed in terms of yield (kg/ha) and water

FIGURE 52 Screenshot of WaPOR portal



Access at:
https://wapor.apps.fao.org/home/1

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[56] FAO Land and Water Division: http://www.fao.org/land-water/en/

productivity will be calculated as production per volume of water (kg/m^3). Water used for agricultural production is expressed in actual evapotranspiration where a distinction is made between evapotranspiration originating from precipitation ("green" water) and incremental evaporation from irrigation ("blue" water).

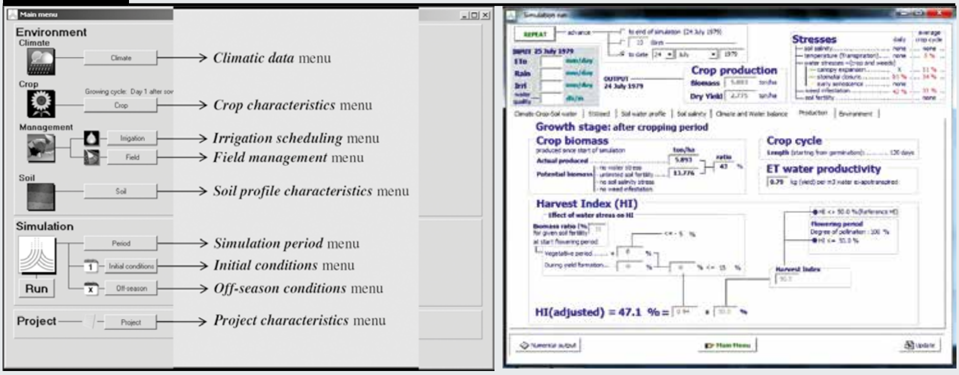
- On level III, land and water productivity will be monitored for a selected set of irrigation schemes to assess the functioning of the irrigation system and to propose improvements in the systems. On this level land and water productivity will be calculated similarly to level II but in addition, economic water productivity for multiple uses of water will be assessed in terms of economic return per amount of irrigation water used. Water productivity plays a central role in the performance assessment of irrigation. The performance assessment in the irrigation schemes selected for this programme will be the basis for irrigation modernization. After modernization of an irrigation scheme the water services provided to all water users should be more reliable, more cost effective, more adapted to increased variability in climate due to climate change and more environmentally friendly.

FAO – AQUACROP

CROP-WATER PRODUCTIVITY MODEL

AquaCrop is a crop growth model developed by the *Land and Water Division* (CBL[57]) of FAO to address food security and to assess the effect of environment and management on crop production. AquaCrop simulates yield response to water of herbaceous crops and is particularly suited to address conditions where water is a key limiting factor in crop production. When designing the model an optimum balance between simplicity, accuracy and robustness was pursued. To be widely applicable AquaCrop uses only a relatively small number of explicit parameters and mostly intuitive input-variables requiring simple methods for their determination. On the other hand, the calculation procedures are grounded on basic and often complex biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system.

FIGURE 53 Main menu of AquaCrop software



Available at:
http://www.fao.org/aquacrop/en

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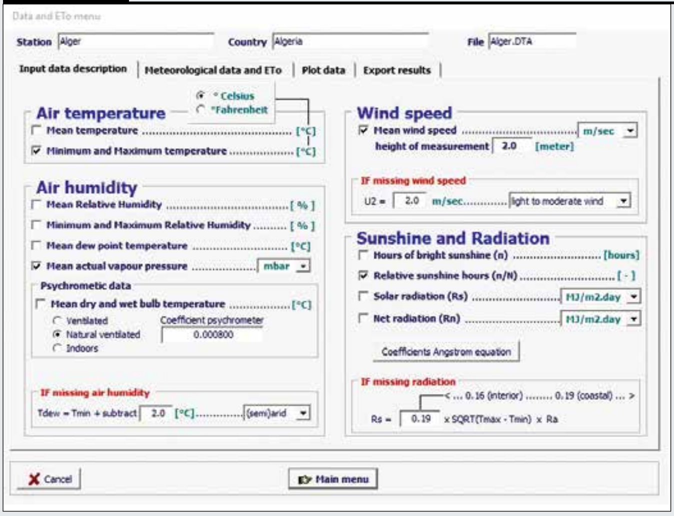
[57] FAO Land and Water Division: http://www.fao.org/land-water/en/

FAO – ETO CALCULATOR

CALCULATION OF REFERENCE EVAPOTRANSPIRATION

ETo calculator is software developed by the *Land and Water Division* (CBL[58]) of FAO. Its main function is to calculate reference evapotranspiration (ETo) according to FAO standards. ETo represents the evapotranspiration rate from a reference surface not short of water. A large uniform grass field is considered on a worldwide scale as the reference surface. The reference crop completely covers the soil, is kept short, well-watered and actively growing under optimal agronomic conditions. The ETo calculator assesses ETo from meteorological data by means of the FAO Penman-Monteith equation. This method has been selected by FAO as the reference because it closely approximates grass ETo at the location evaluated, is physically based and explicitly incorporates both physiological and aerodynamic parameters.

FIGURE 54 Main menu of ETo Calculator



Station Alger
Country Algeria
File Alger.DTA

Air temperature
● ° Celsius
○ °Fahrenheit
☐ Mean temperature .... [°C]
☑ Minimum and Maximum temperature .... [°C]

Air humidity
☐ Mean Relative Humidity .... [%]
☐ Minimum and Maximum Relative Humidity .... [%]
☐ Mean dew point temperature .... [°C]
☑ Mean actual vapour pressure .... mbar
Psychrometic data
☐ Mean dry and wet bulb temperature .... [°C]
○ Ventilated
● Natural ventilated
○ Indoors
Coefficient psychrometer 0.000800
IF missing air humidity
Tdew = Tmin + subtract 2.0 [°C].......... (semi)arid

Wind speed
☑ Mean wind speed .... m/sec
height of measurement 2.0 [meter]
IF missing wind speed
U2 = 2.0 m/sec.......... light to moderate wind

Sunshine and Radiation
☐ Hours of bright sunshine (n) .... [hours]
☑ Relative sunshine hours (n/N) .... [-]
☐ Solar radiation (Rs) MJ/m2.day
☐ Net radiation (Rn) MJ/m2.day
Coefficients Angstrom equation
IF missing radiation
< ... 0.16 (interior) .... 0.19 (coastal) ... >
Rs = 0.19 x SQRT(Tmax - Tmin) x Ra

Available at:
http://www.fao.org/land-water/databases-and-software/eto-calculator/en/

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[58] FAO-Land and Water Division: http://www.fao.org/land-water/en/

FAO – GIEWS

EARTH OBSERVATION PORTAL

The FAO *Global Information and Early Warning System on Food and Agriculture* (GIEWS)[59] monitors the condition of major food crops across the globe to assess production prospects. To support the analysis and supplement ground-based information, GIEWS processes remote sensing data to derive seasonal indicators to provide a valuable insight on water availability and vegetation health during cropping seasons. The seasonal indicators are designed to allow easy identification of areas of cropped land with a high likelihood of water stress (drought). The indices are based on remote sensing data of vegetation and land surface temperature combined with information on agricultural cropping cycles derived from historical data, as well as a global crop mask. The final maps highlight anomalous vegetation growth and potential drought in crop zones during the growing season.

In addition to rainfall estimates and the *Normalized Difference Vegetation Index* (NDVI), GIEWS and FAO *Climate and Environment Division* (CBC)[60] have developed the *Agricultural Stress Index* (ASI), which is a quick-look indicator for the early identification of agricultural areas probably affected by dry spells or drought, in extreme cases. The satellite data used in the calculation of the mean *Vegetation Health Index* (VHI) and the ASI is the 10-day (dekadal) vegetation data from the METOP-AVHRR sensor at 1 km resolution (2007 and after). Data at 1 km resolution for the period 1984-2006 were derived from the NOAA-AVHRR dataset at 16 km resolution. The crop mask is a modified version of an EC-JRC[61] data set that compiles several different sources of land cover data, including GlobCover V2.2, Corine-2000, AfriCover, SADC data set and USGS Cropland Use Intensity Data Set.

The *Agricultural Stress Index* (ASI) is an index based on the integration of the *Vegetation Health Index* (VHI) in two dimensions that are critical for the assessment of a drought event in agriculture: temporal and spatial. The first step of the ASI calculation is a *temporal* averaging of the VHI, which assesses the intensity and duration of dry periods occurring during the crop cycle at pixel level. The second step determines the *spatial* extent of drought events by calculating the percentage of pixels in arable areas with a VHI value below 35 percent (this value was identified as a critical threshold in assessing the extent of drought in previous research by Kogan, 1995). Finally, analysts classify each administrative area according to the percentage of the affected areas to facilitate a rapid interpretation of results.

The *Vegetation Health Index* (VHI) is a composite index and the elementary indicator used to compute the ASI. It combines both the VCI and the Temperature Condition Index

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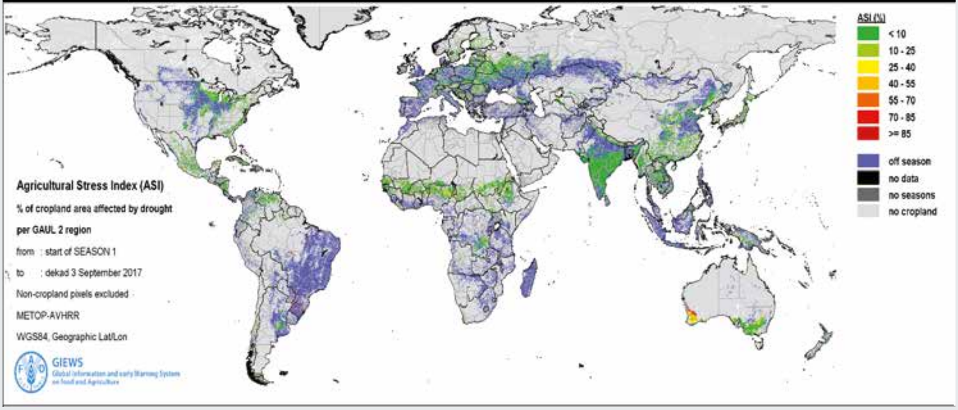
[59] FAO GIEWS: http://www.fao.org/giews/en/

[60] FAO Climate and Environment Division: http://www.fao.org/climate-change/en/

[61] Joint Research Centre of the European Commission (https://ec.europa.eu/jrc/en/mars)

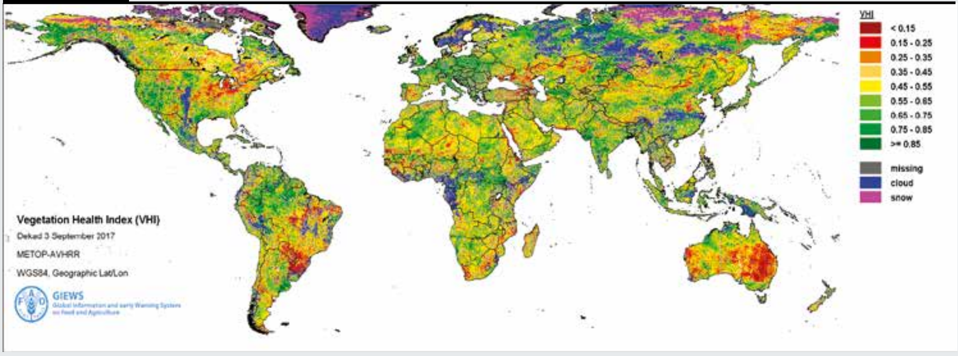
(TCI). The TCI is calculated using a similar equation to the VCI but it relates the current temperature to the long-term maximum, as it is assumed that higher temperatures tend to cause deterioration in vegetation conditions. A decrease in the VHI following, for example, a decline in the VCI (relatively poor green vegetation) and an increasing TCI (warmer temperatures) would signify stressed vegetation conditions, and over a longer period would be indicative of drought. The VHI components (VCI and TCI) are given equal weights when computing the index. The VHI images are computed for the two main seasons and in three modalities: dekadal, monthly and annual.

FIGURE 55 ASI, percentage of cropland area affected by drought (September 2017)



Source: http://www.fao.org/giews/earthobservation/asis/index_1.jsp?lang=en

FIGURE 56 Vegetation Health Index (September 2017)



Access at:
http://www.fao.org/giews/earthobservation/index.jsp?lang=en

Source: http://www.fao.org/giews/earthobservation/asis/index_2.jsp?lang=en

FAO – GAEZ PORTAL

GLOBAL AGRO-ECOLOGICAL ZONES

The *Agro-ecological Zones* (AEZ) methodology has been continuously developed over the past 30 years to assess agricultural resources and potential. It is the result of an intensive collaboration between the FAO *Land and Water Division* (CBL[62]) and *International Institute for Applied Systems Analysis* (IIASA[63]) Rapid developments in information technology have produced increasingly detailed and manifold global databases that made the first global AEZ assessment possible in 2000. Since that time, global AEZ assessments have been performed every few years and with each update of the system, the issues addressed, the size of the database and the number of results have multiplied. This is the most ambitious assessment so far and the goal is to make the entire database and all results of this assessment publicly available. This amounts to many terabytes of data that cover five thematic areas:

- Land and water resources, including soil resources, terrain resources, land cover, protected areas and selected socio-economic and demographic data;
- Agro-climatic resources, including a variety of climatic indicators;
- Suitability and potential yields for up to 280 crops/land utilization types under alternative input and management levels for historical, current and future climate conditions;

FIGURE 57 GAEZ portal

Access at:
http://gaez.fao.org/Main.html#

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[62] FAO Land and Water Division: http://www.fao.org/land-water/en/

[63] IIASA: http://www.iiasa.ac.at/

- Downscaled actual yields and production of the main crop commodities;
- Yield and production gaps, in terms of ratios and differences between actual yield and production and potentials for main crops.

The GAEZ database provides the agronomic backbone for various applications including the quantification of land productivity. Results are commonly aggregated for current major land use/cover patterns and by administrative units, land protection status, or broad classes reflecting infrastructure availability and market access conditions. With this large amount of data a new system had to be created to make the data accessible to a variety of users. The result is the GAEZ Data Portal is an interactive data-access facility, which not only provides free access to data and information and allows visualization of data, but also provides the user with various analysis outputs and downloads options.

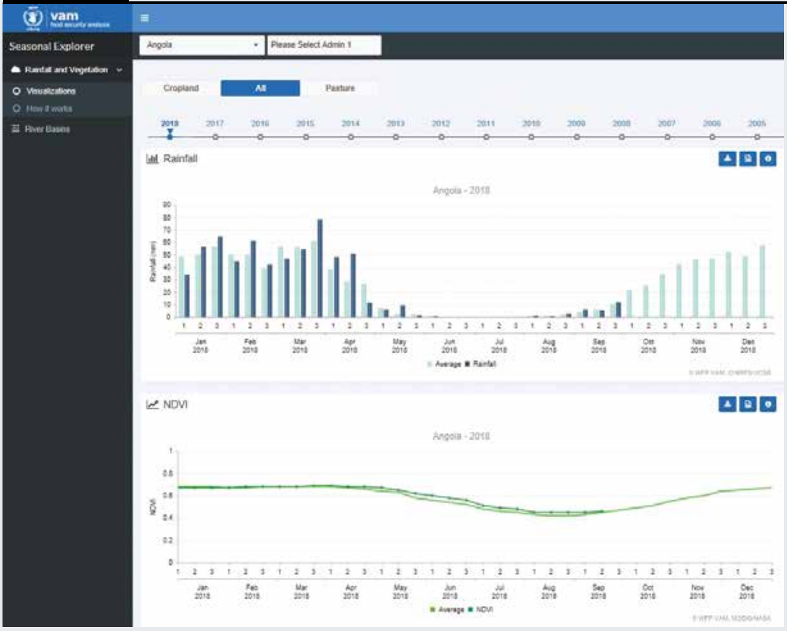
WFP-VAM – SEASONAL EXPLORER

The *WFP-VAM*[64] *Seasonal Explorer* is used for monitoring the performance of the agricultural seasons. This system will allow users to assess the performance of the current and past rainfall seasons, the timing and intensity of drier or wetter than average conditions and their impact on vegetation status at the subnational level for most countries.

Users can download time series datasets for a near-global set of administrative divisions, dating back to 1981 for rainfall and 2002 for vegetation. The primary data sources are **CHIRPS**[65] gridded rainfall dataset produced by the Climate Hazards Group at the University of California, Santa Barbara and the MODIS NDVI CMG data made available by NOAA-NASA.

Data coverage is limited to countries within 50N to 50S. Countries that extend beyond these geographical limits will be partially included up to those limits. Hence, a rainfall plot for the Russian Federation will refer only to the part of the country south of 50N. At the subnational level, only the administrative divisions that are fully contained within those limits have data to display.

FIGURE 58 Main menu of Seasonal Explorer



Available at:
http://dataviz.vam.wfp.org/seasonal_explorer/rainfall_vegetation/visualizations

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[64] WFP-VAM: http://vam.wfp.org/

[65] CHIRPS – Climate Hazard Group: http://chg.geog.ucsb.edu/data/chirps/

WFP VAM – SEASONAL MONITOR

The *WFP-VAM*[66] *Seasonal Monitor* tool helps to examine real time satellite data streams and seasonal forecasts to assess the progress of the growing season and to highlight potential developments that may be of humanitarian concern.

FIGURE 59 Main screen of seasonal monitor

The WFP Seasonal Monitor: Examining real time satellite data streams and seasonal forecasts to assess the progress of the growing season and to highlight potential developments that may be of humanitarian concern

Available at:
http://vam.wfp.org/sites/seasonal_monitor/index.html

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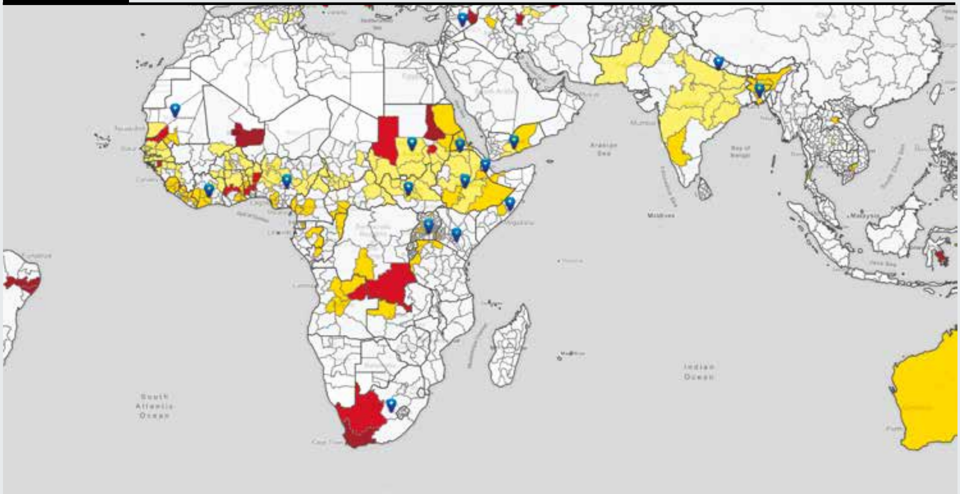
[66] WFP-VAM: http://vam.wfp.org/

JRC – ASAP PORTAL

ANOMALY HOTSPOTS OF AGRICULTURE PRODUCTION

ASAP is an online decision support system for early warning about hotspots of *agricultural production anomaly* (crop and rangeland), developed by the *Joint Research Center* (JRC)[67] for food security crises prevention and response planning anticipation. ASAP provides information at two levels: (i) monthly identification of agricultural production hotspot countries and summary narratives by JRC experts for agriculture and food security analysts and (ii) ten-day automatic warnings at province level and weather and Earth Observation vegetation indicators for JRC and external technical experts. The hotspot identification focuses on 80 countries. The automatic warnings at provincial level are published on the ASAP Warning Explorer every ten days, two or three days after the end of each ten-daily period (e.g. 2nd-3rd, 12th-13th, 22nd-23rd of each month). The hotspot assessment is published during the last week of each month with information related to the previous 30 days.

FIGURE 60 **ASAP anomaly map**



Access at:
https://mars.jrc.ec.europa.eu/asap/

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[67] Joint Research Centre of the European Commission (https://ec.europa.eu/jrc/en/mars)

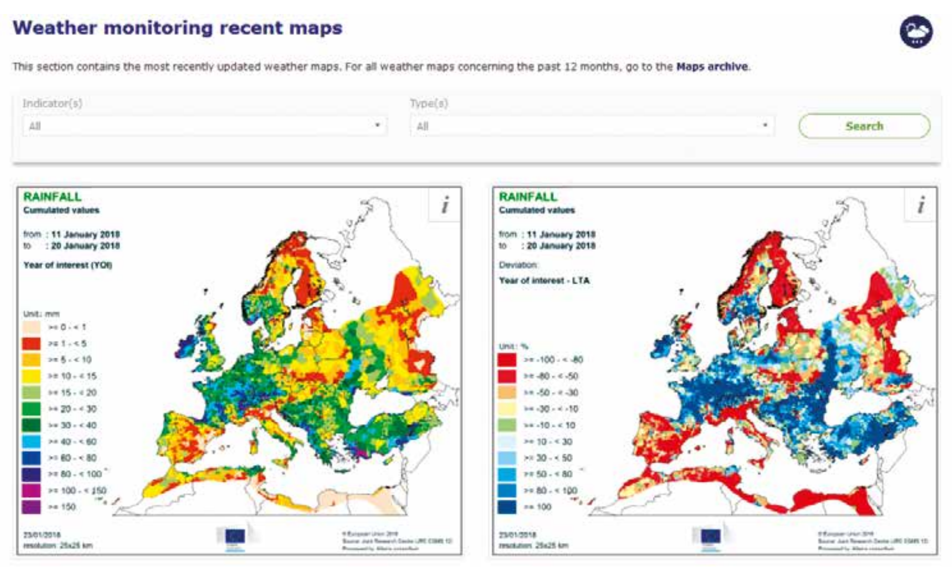
JRC – MARS EXPLORER

CROP AND WEATHER MONITORING IN EUROPE

The *MARS Explorer* is an e-service provided by the *Joint Research Center* (JRC)[68] to display recent information on weather conditions and the progress of crop growth across the European Union. The data displayed are based on meteorological station data and crop simulations, originating from the MARS Crop Yield Forecasting System. The images are pre-prepared and can be easily downloaded and reused provided the original format is maintained and the source acknowledged. Graphs and maps are updated three times per month.

Full analyses of the weather conditions and crop monitoring as well as crop yield forecasts in the European Union and neighbouring countries are available in the JRC MARS Bulletins Crop monitoring in Europe.

FIGURE 61 **Rainfall maps of Europe displayed at MARS Explorer measured in mm and percentage**



Weather monitoring recent maps

This section contains the most recently updated weather maps. For all weather maps concerning the past 12 months, go to the **Maps archive**.

Indicator(s): All

Type(s): All

Access at:
http://agri4cast.jrc.ec.europa.eu/mars-explorer

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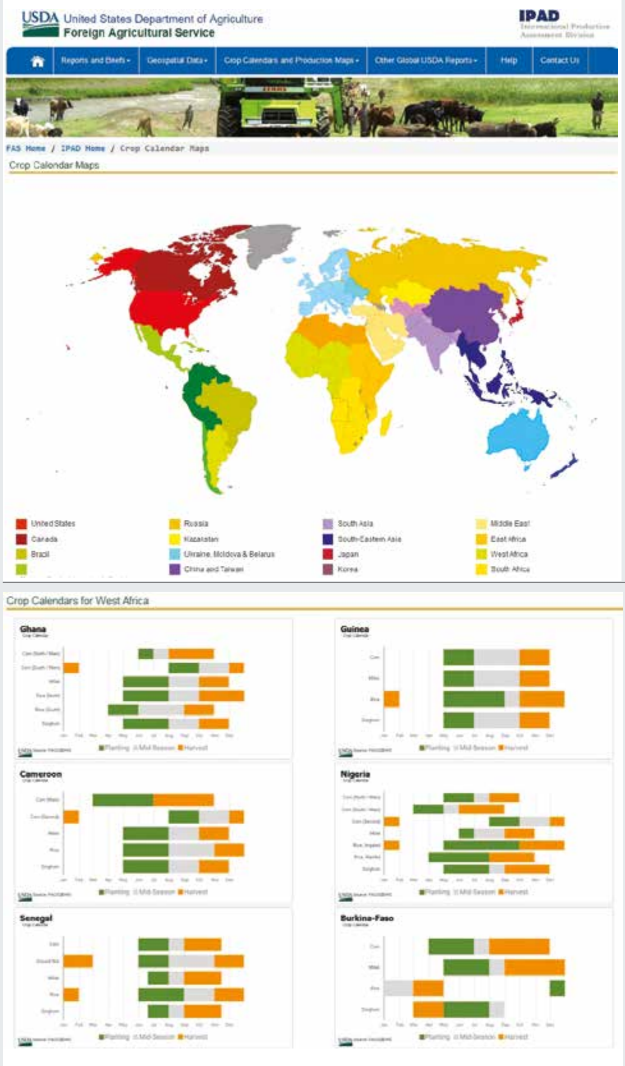
[68] Joint Research Centre of the European Commission (https://ec.europa.eu/jrc/en/mars)

USDA – FOREIGN AGRICULTURAL SERVICE

CROP CALENDAR

The *Crop Calendar* developed by the US Department of Agriculture (USDA[69]) is a tool that provides timely information about main crops cultivated in all countries of the world. It contains information on planting, mid-season and harvest of local crops.

FIGURE 62 Screenshots of Crop Calendar



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[69] USDA: https://www.usda.gov/

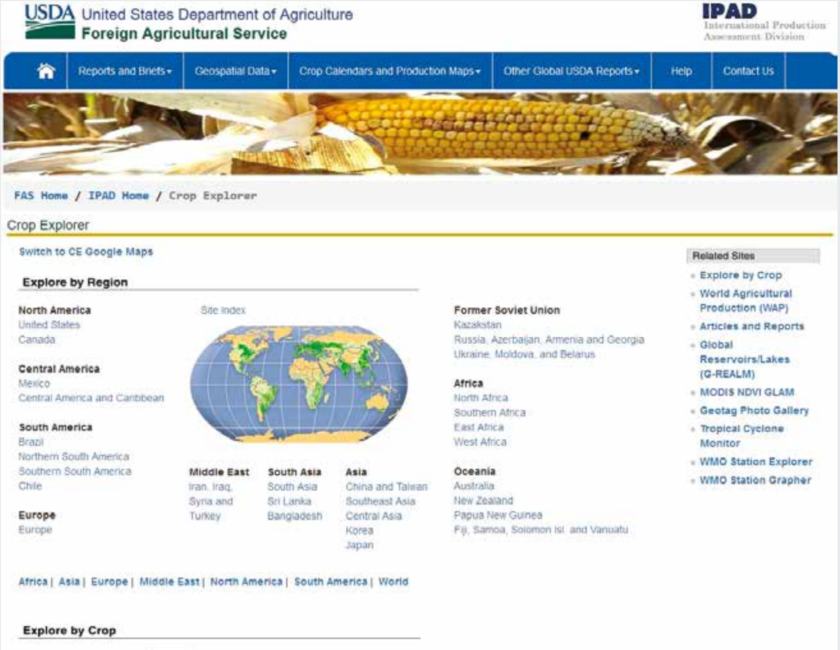
USDA – FOREIGN AGRICULTURAL SERVICE

CROP EXPLORER

The *Crop Explorer* Web Site developed by the US Department of Agriculture (USDA[70]) features near-real-time global crop condition information based on satellite imagery and weather data. Thematic maps of major crop growing regions depict vegetative vigour, precipitation, temperature, and soil moisture. Time-series charts depict growing season data for specific agro-meteorological zones. Regional crop calendars and crop area maps are also available for selected regions.

Thematic maps are viewed at the regional level and can be selected for any 10-day period in the current growing season. Previous growing seasons can be selected from the dropdown list for the last two complete years. Historical data are available upon request. Thematic maps are grouped into three categories: Weather; Soil Moisture; and Vegetation Index. Time-series charts depict the same set of data types but for sub-regions that define specific agro-meteorological zones. The sub-regions are organized by country and in some regions, ranked by commodity production.

FIGURE 63 **Main menu of Crop Explorer divided by regions**



Access at:
https://ipad.fas.usda.gov/cropexplorer/Default.aspx

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[70] USDA: https://www.usda.gov/

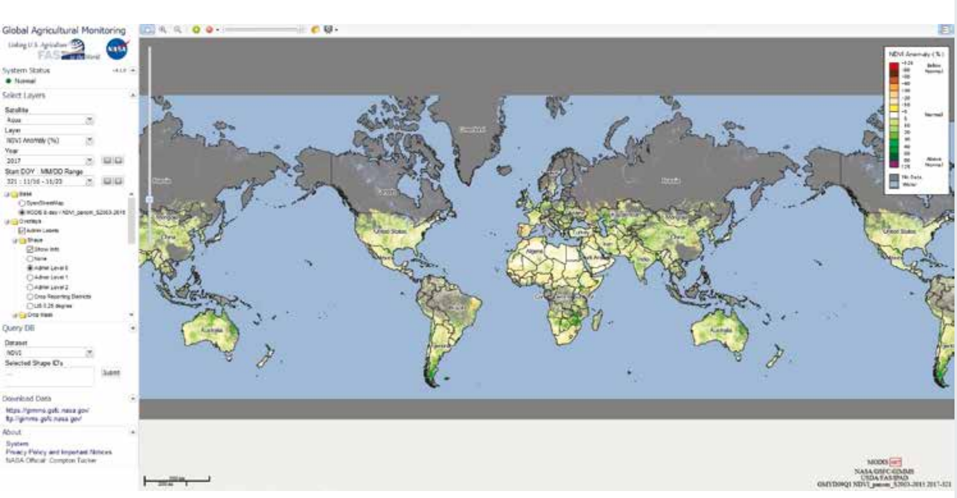
USDA – FOREIGN AGRICULTURAL SERVICE

GLOBAL AGRICULTURAL MONITORING

The GIMMS *Global Agricultural Monitoring* (GLAM) System has been developed jointly by USDA[71] and NASA[72] to view MODIS NDVI imagery and retrieve MODIS NDVI time series data. The system provides near real-time and science quality Terra and Aqua MODIS 8-day composited, global NDVI datasets.

The GIMMS MODIS GLAM System is developed and provided by the NASA/GSFC/GIMMS group for the USDA/FAS/IPAD Global Agricultural Monitoring project. The USDA/FAS/IPAD mission is to provide objective, timely, and regular assessment of the global agricultural production outlook and conditions affecting global food security.

FIGURE 64 Main menu of GLAM



Access at:
https://glam1.gsfc.nasa.gov

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[71] USDA: https://www.usda.gov/

[72] NASA: https://science.gsfc.nasa.gov/earth/

HARVESTCHOICE

MAPPR

MAPPR is a spatial visualization and analysis tool developed jointly by IFPRI[73] and the University of Minnesota[74] offering easy access to over four hundred layers of spatially explicit, agriculture related indicators for sub-Saharan Africa. Use the drawers to the right to explore Harvest Choice's collections of bio-physical, crop and livestock production, socioeconomic, markets, and agricultural R&D investment data. Each layer consists of about 300,000 10km x 10km grid cells covering the entirety of the sub-Saharan African region.

Layers of data may be overlaid and exported to PNG for re-use in reports and presentations. Each layer is also available for download in raw ASCII raster format for use in desktop GIS. Maps may be embedded in external websites using a simple HTML snippet. The base maps are interchangeable using the toolbox to the right.

A number of spatial querying and analysis tools are built into the application:

» Point and polygon statistics will return a table of values for the selected indicators at the selected locations (or aggregated over a specific hand-drawn area);

» Domain statistics will produce a summary table and graphs of indicators aggregated across the selected geographic domains (e.g. agro-ecological zones, farming systems, etc.);

» A market-shed analysis produces layer statistics aggregated to 2hr, 4hr, 6hr and 8hr timetomarket zones for any selected point on the map.

FIGURE 65 Main menu of MAPPR

Access at:
http://apps.harvestchoice.org/mappr

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[73] IFPRI: http://www.ifpri.org

[74] University of Minnesota: https://twin-cities.umn.edu

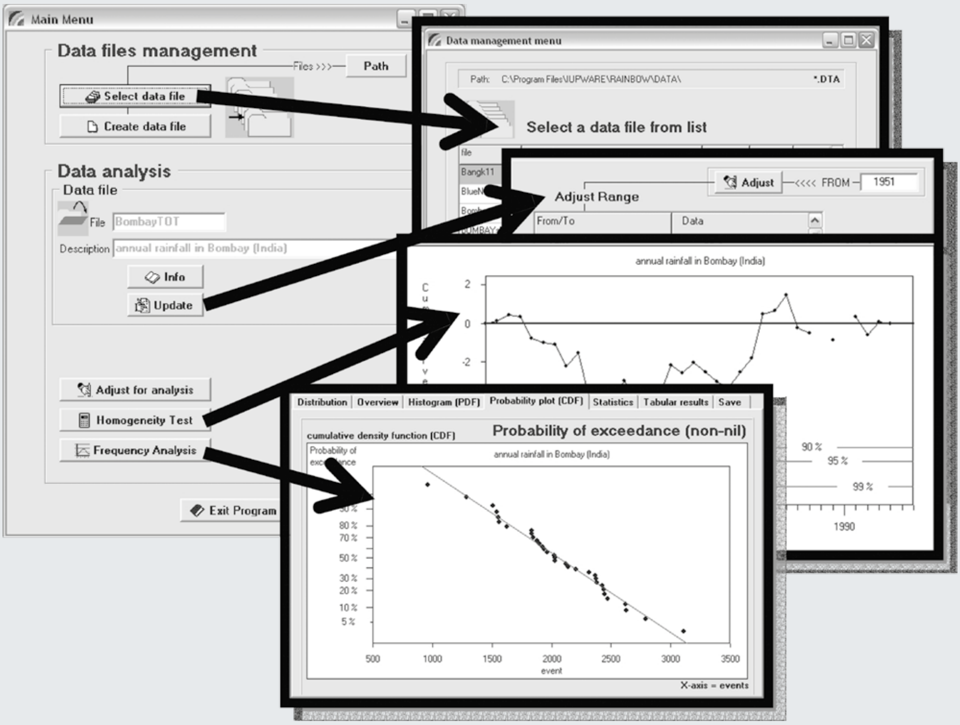
KU LEUVEN – RAINBOW

HYDRO-METEOROLOGICAL FREQUENCY ANALYSIS

RAINBOW is a software package for hydro-meteorological frequency analysis and testing the homogeneity of historical data sets. A common problem in many areas of water resources engineering is that of analysing hydrological and meteorological events for planning and design projects. For these purposes information is required on rainfall events, flow depths, discharges, evapotranspiration levels, etc. that can be expected for a selected probability or return period. With the help of the software package RAINBOW the magnitudes for such events can be estimated by means of a frequency analysis on historical data.

Frequency analysis. When opting for a frequency analysis, a menu is opened that contains various folders where a probability distribution can be selected, the data transformed, and results can be viewed or saved on disk. Apart from graphical methods (probability plot and a histogram of the data superimposed by the selected probability function) for evaluating the goodness of fit, RAINBOW also offers statistical tests for

FIGURE 66 Structure of the RAINBOW program



File: BombayTOT
Description: annual rainfall in Bombay (India)
Path: C:\Program Files\IUPWARE\RAINBOW\DATA\ *.DTA
<<<< FROM 1951

Available at:
http://iupware.be/?page_id=874

investigating whether data follow a certain distribution (Chi-square and the Kolmogorov-Smirnov test). When the goodness-of-fit is inadequate, one can either select another distribution or attempt to normalize the data by selecting a mathematical operator to transform the data. RAINBOW also allows for analysing a time-series with zero or near zero events (the so called nil values) by separating temporarily the nil values from the non-nil values. By calculating the global probability, the nil and no-nil rainfall are combined again. When the probability distribution can be accepted, the user can view the calculated events that are expected for selected probabilities or return periods.

Homogeneity test: Frequency analysis of data requires that the data be homogeneous and independent. The restriction of homogeneity assures that the observations are from the same population. RAINBOW offers a test of homogeneity, which is based on the cumulative deviations from the mean.

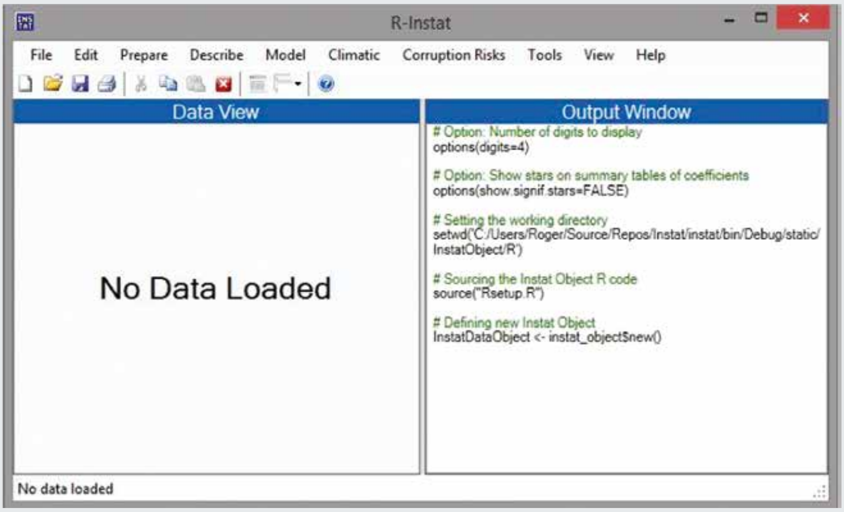
R–INSTAT

STATISTICAL SOFTWARE

R-Instat is a free, open source statistical software that is easy to use even by persons with limited computer skills. It encourages good statistical practices and learning by opening the door for training to emphasise concepts rather than theory. This software is designed to support improved statistical literacy in Africa and beyond, through work undertaken primarily in Africa. Ideally, in resource rich environments students should become familiar with more than one package and RInstat could sometimes be a useful addition to the mix. In resource-poor environments R-Instat combined with R-Studio is designed to fit student needs.

R-Instat provides a front-end to R, designed to broaden the users of the software, particularly in Africa. "*R*[75]" is an open source programming language and software environment for statistical computing and graphics that is supported by the R Foundation for Statistical Computing. The R language is widely used among statisticians and data miners for developing statistical software and data analysis. R's reputation has grown incredibly in recent years. The original Instat was an easyfor-use statistics package produced at the University of Reading (UK) and designed to support good statistical practice. It also has a special menu for the analysis of historical climatic data. The ideas behind Instat have motivated the structure of the R-Instat menus and dialogues, although no line of the original code remains.

FIGURE 67 **R-Instat main interface**



No Data Loaded

```
# Option: Number of digits to display
options(digits=4)

# Option: Show stars on summary tables of coefficients
options(show.signif.stars=FALSE)

# Setting the working directory
setwd('C:/Users/Roger/Source/Repos/Instat/instat/bin/Debug/static/
InstatObject/R')

# Sourcing the Instat Object R code
source("Rsetup.R")

# Defining new Instat Object
InstatDataObject <- instat_object$new()
```

No data loaded

Available at:
http://r-instat.org/index.html

---

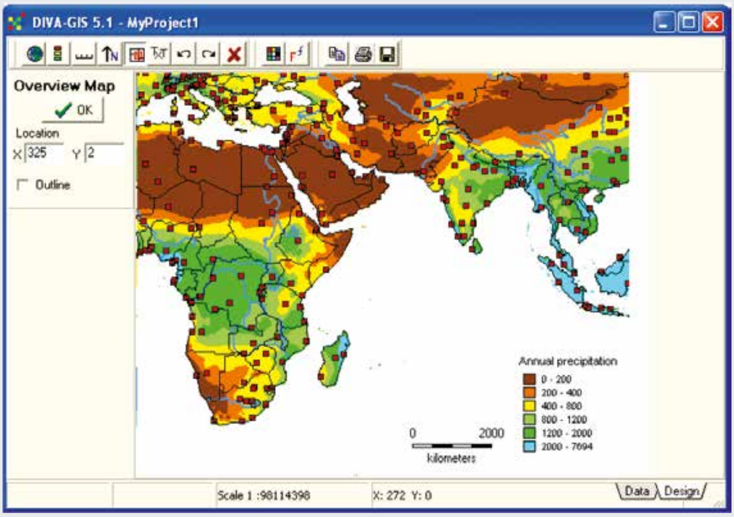
[75] R project: https://www.r-project.org/

DIVA-GIS

GIS COMPUTER PROGRAM

DIVA-GIS is a free computer program for mapping and geographic data analysis under a geographic information system (GIS). DIVA-GIS can make maps of the world or of a very small area by using for example, state boundaries, rivers, a satellite image, and the locations of sites where an animal species was observed. Free spatial data[76] are available worldwide to be used in DIVA-GIS or other programs. DIVA-GIS is particularly useful for mapping and analysing biodiversity data, such as the distribution of species, or other 'point-distributions'. It reads and writes standard data formats such as ESRI shape-files, so interoperability is not a problem. DIVA-GIS runs on Windows only. The program can be used to analyse data, for example by making grid (raster) maps of the distribution of biological diversity, finding areas that have high, low, or complementary levels of diversity and to map and to query climate data. Predictions of the species distributions can be made with the use of BIOCLIM or DOMAIN models.

FIGURE 68 **Main menu of DIVA-GIS program**



Location X 325 Y 2

Scale 1 :98114398

X: 272 Y: 0

Available at:
http://www.diva-gis.org

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[76] Free data sets at: http://www.diva-gis.org/Data

WORLDCLIM

GLOBAL CLIMATE DATA

DIVA-GIS is associated with the *WorldClim* version 2, which is a free-ware climate data for ecological modelling and GIS. WorldClim supplies average monthly climate data for minimum, mean and maximum temperature and for precipitation for 1970-2000. Various variables can be downloaded for different spatial resolutions, from 30 seconds (~1 km^2) to 10 minutes (~340 km^2). Available parameters: maximum temperature (°C), minimum temperature (°C), average temperature (°C), precipitation (mm), solar radiation (kJ m^{-2} day^{-1}), wind speed (m s^{-1}) and water-vapour pressure (kPa). Each download is a "zip" file containing 12 GeoTiff (.tif) files, one for each month of the year (January is 1; December is 12).

In addition, 19 standard Bioclimatic parameters are also available for WorldClim version 2, which are the average for the years 1970-2000. Each download is a "zip" file containing 19 GeoTiff (.tif) files, one for each month of the variables. Bioclimatic variables are derived from the monthly temperature and rainfall values to generate more biologically meaningful variables. These are often used in species distribution modelling and related ecological modelling techniques. The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation) seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g., temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). A quarter is a period of three months (1/4 of the year). They are coded as follows:

- BIO1 = Annual Mean Temperature
- BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
- BIO3 = Isothermality (BIO2/BIO7) (* 100)
- BIO4 = Temperature Seasonality (standard deviation *100)
- BIO5 = Max Temperature of Warmest Month
- BIO6 = Min Temperature of Coldest Month
- BIO7 = Temperature Annual Range (BIO5-BIO6)
- BIO8 = Mean Temperature of Wettest Quarter
- BIO9 = Mean Temperature of Driest Quarter
- BIO10 = Mean Temperature of Warmest Quarter
- BIO11 = Mean Temperature of Coldest Quarter
- BIO12 = Annual Precipitation
- BIO13 = Precipitation of Wettest Month
- BIO14 = Precipitation of Driest Month
- BIO15 = Precipitation Seasonality (Coefficient of Variation)
- BIO16 = Precipitation of Wettest Quarter
- BIO17 = Precipitation of Driest Quarter
- BIO18 = Precipitation of Warmest Quarter
- BIO19 = Precipitation of Coldest Quarter

Available at: http://worldclim.org/version2

EQUIPMENT

ENSOAG LLC – SMART CAMPO MOBILE APP

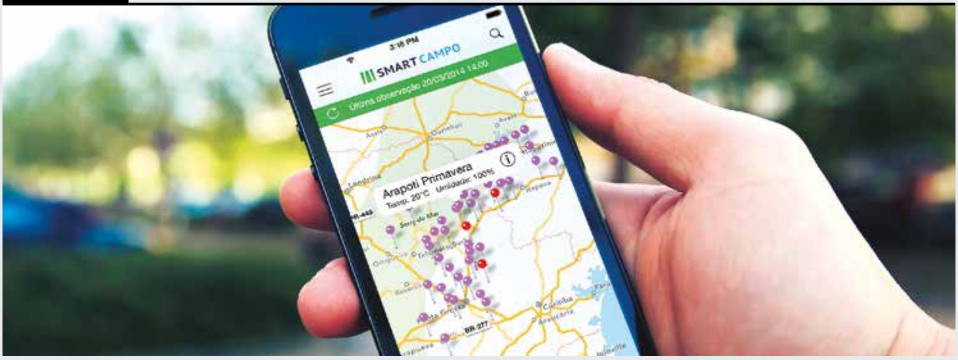
The *Smart Campo*® mobile app is an innovative way to help farmers make decisions based on weather and climate information. Farmers can check current weather conditions in Paraguay and Paraná, Brazil from available stations to obtain updates on:

- Rainfall
- Air temperature and growing degree days
- Cumulative temperature
- Accumulated chill hours
- Extreme weather events

They can also generate custom reports of farms and fields based on planting date, soil texture and irrigation practices, including information about:

- Total and daily average rainfall since planting
- Mean value of the reference index for agricultural drought (ARID)
- Total reference evapotranspiration (ETo)
- Mean maximum and minimum air temperatures
- Cumulative degree days (Tbase=10°C)
- Extreme events: days with a maximum above 35°C, minimum less than 0°C and number of days with extreme rainfall

FIGURE 69 **Main menu of Smart Campo**



Available at:
http://ensoag.com/smart-campo

Farmers may also choose whether to receive daily or weekly notifications with weather conditions observed in their fields. Smart Campo® is available for iOS (iPhone) and Android phones and can be downloaded from App Store and Google Play.

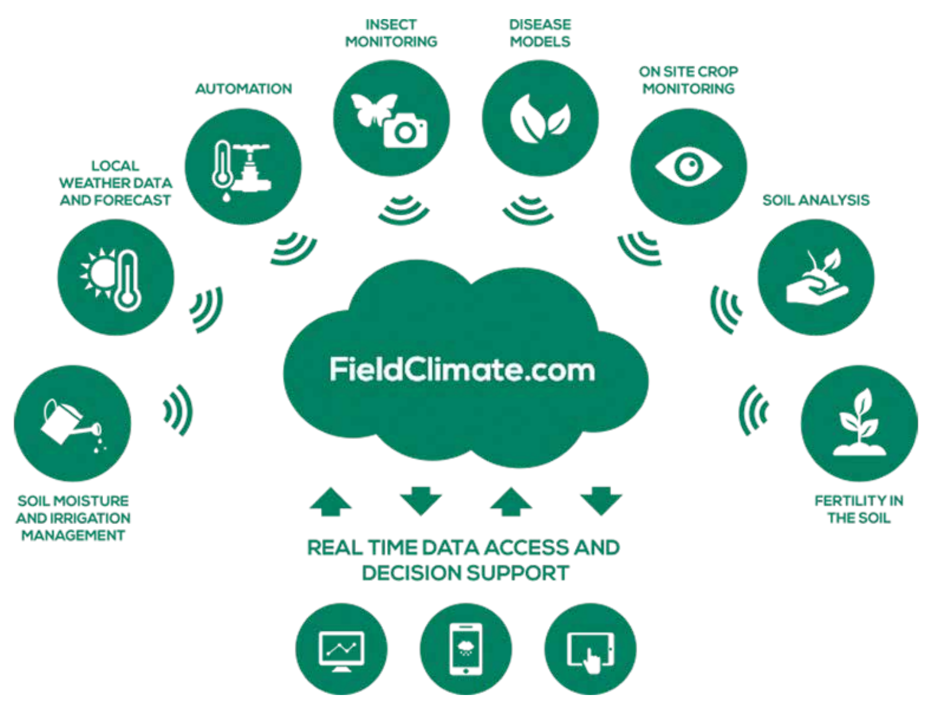
FIGURE 70 **Weather forecasts for selected stations with Smart Campo**

PESSL INSTRUMENTS

AUTOMATIC WEATHER STATIONS

Pessl Instruments[77] produce and export worldwide the agrometeorological monitoring systems *iMetos®*, available everywhere on the web platform *FieldClimate.com* that include a free app for the smartphone. *FieldClimate.com* is the first ever web platform for collecting and displaying agrometeorological data of tens of thousands of weather stations installed all over the world. A holistic solution supporting the farm management such as weather stations with a disease model for many crops, measured data combined with localized high precision weather forecast service, devices with soil moisture sensors and decision support systems (DSS) for irrigation management, controller for internet automation, on-site soil nutrient analysis solutions and electronic traps for insects monitoring is also available.

FIGURE 71 **Holistic solution for decision agriculture supported through FieldClimate.com**



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[77] PESSL: http://metos.at/home/it/

FIGURE 72 Automatic weather station iMETOS 3.3

In order to enhance climate change adaptation and resilience on the part of farmers, the sustainable agriculture practices should follow the *Agroecology* principles. *Agroecology* is a holistic approach to agriculture whereby traditional knowledge accumulated by peasant farmers over last few centuries has been combined with recent scientific knowledge. Among rural farmers, climate information is disseminated mainly through extension staff to provide technical advice. To respond to the need for developing education programmes for farmers, the *Farmer Field Schools* (FFS) programme was firstly developed by FAO in 1989 in Indonesia with the aim to provide support for farmers on how to better manage their production systems for sustainability. The publication of this handbook has been technically and financially supported by two FAO projects having the objective to enhance the FFS programme in Angola and Mozambique.

The Project GCP/ANG/050/LDF IRCEA, *"Integrating climate resilience into agricultural and agro-pastoral production systems through soil fertility management in key productive and vulnerable areas using the Farmer Field School approach"*, aims to strengthen the climate resilience of the agropastoral production systems in key vulnerable areas through mainstreaming of *Climate Change Adaptation* (CCA) into agricultural and environmental sector policies, programmes and practices and capacity building and promotion of CCA through soil fertility and Sustainable Land Management practices using the FFS approach.

The Project GCP/MOZ/112/LDF, *"Strengthening capacities of agricultural producers to cope with climate change for increased food security through the Farmers Field School approach"*, aims to enhance the capacity of Mozambique's agricultural and pastoral sectors to cope with climate change, by upscaling farmers adoption of CCA technologies and practices through a network of already established FFS, and by mainstreaming CCA concerns and strategies into on-going agricultural development initiatives, policies and programming.

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