AGRICULTURE GLOBAL PRACTICE TECHNICAL ASSISTANCE PAPER

INCREASING AGRICULTURAL PRODUCTION AND RESILIENCE THROUGH IMPROVED AGRO-METEOROLOGICAL SERVICES

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PREFACE

Informing farmers' production decisions with timely weather forecasts and related climate information services is a fundamental means of improving agricultural productivity. In Sub-Saharan Africa, where agriculture is overwhelmingly rainfed and yield gaps are very high, access to these information sources will be instrumental in reducing the vulnerability of African smallholders by enabling them to manage risk more effectively. The information and communication technologies needed to improve and expand agro-meteorological observation systems are widely available and readily transferable from one setting to another.

In addition to news and weather services that farmers can use in making immediate and short-term decisions, these channels are useful for longer-term, educational purposes as well—purposes that in more industrialized countries typically fall under the rubric of agricultural research and extension. In countries like Ethiopia and Kenya, which are the focus of this report, the generation of adaptive farming technologies and methods and their effective dissemination to producers who are prepared to use them will determine a great deal. The farmer who is comfortable referring to sources of information that he or she has come to trust can be an active agent in what Theodore Schultz once called "transforming traditional agriculture." Farmers who remain unreached by these services are far less well positioned to do so. And we should remember just how much we are asking of them as we seek to "enlist" them as agents of change and even drivers of economic development.

Schultz is more than a passing reference here. In 1964 he argued persuasively that farmers in low-income countries were rational actors who made efficient use of the resources available to them. He depicted them as rational but highly constrained in terms of access to resources and knowledge. This may seem intuitive now, but back then in the larger field of development economics, it was revolutionary—enough so to eventually earn him a Nobel Prize in Economics in 1979. Our language has changed somewhat, and Shultz's use of the term "knowledge" clearly encompassed information available to the farmer and the farmer's skill and know-how. And the issues touched upon in this document touch upon those as well.

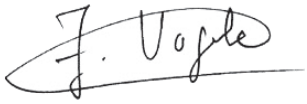
This is not only about the farmers themselves, however. It also relates to the institutions and policies of the country in which they live and operate. As its name clearly suggests, "agricultural meteorology" is very much an interdisciplinary field. This is more than a question of what academic discipline agro-meteorologists consider themselves primarily affiliated with, or whether they consider themselves agriculturalists or meteorologists. It also has much to do with how a national government organizes itself institutionally—in this case how jurisdiction over agricultural meteorology is divided between and assigned

to national hydro-meteorological services and to ministries of agriculture and the extension services and national agricultural research systems they generally run.

In this document, the author refers to the creation of financially sustainable weather observation networks in Guinea and the Philippines that are likely applicable to many developing settings, including those of East Africa and the Horn of Africa. The author also addresses a practical imperative that is familiar to virtually every initiative that achieves a new level of investment and commitment by central governments allocating scarce public resources. This is the need to prove its worth quickly and decisively early on. Agricultural meteorology needs to generate and to demonstrate significant impacts to persuade higher levels of government such as finance ministries and executive leadership that public financial commitments are good investments.

The public sector comes to mind first because so many of the benefits generated by improved agro-meteorological services are public goods. The public sector is, however, by no means the only prospective source of financial or technical support. This document also refers to the civil society and nongovernmental organizations (NGOs) that operate within developing countries and to the pool of potentially interested private investors, whether they are based in the country concerned or outside it. International development agencies like the World Bank are clearly interested parties as well. Everything we need is already available to us and should be used.

Juergen Voegele
Senior Director



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ACRONYMS AND ABBREVIATIONS

ATA	Agricultural Transformation Agency
AWS	Automated Weather Station
CCAA	Climate Change Adaptation in Africa
CCM	Certified Consulting Meteorologist
CCU	Climate Change Unit
CIMO	Commission for Instruments and Methods of Observations
CLPA	Climate Prediction and Adaptation
CRDI	International Development Research Centre
CSO	Civil Society Organization
DMCH	Drought Monitoring Centre Harare
DMCN	Drought Monitoring Centre with headquarters in Nairobi
EIAR	Ethiopian Institute of Agricultural Research
FAO	Food and Agriculture Organization (of the United Nations)
FEWSNET	Famine Early Warning Systems Network
FIM	Finnish Markka
FIR	Far Infrared
GDP	Gross Domestic Product
GIS	Global Information System
GMFS	Global Monitoring for Food Security
GMT	Greenwich Mean Time
GPS	Global Positioning System
HARITA	Horn of Africa Risk Transfer for Adaptation
ICPAC	Climate Prediction and Applications Centre
ICT	Information Communication Technology
ICTP	Inter-Centre Training Programme
IDRC	International Development Research Centre
IFC	International Finance Corporation (of the World Bank Group)
IGAD	Intergovernmental Authority on Development
ILRI	International Livestock Research Institute
IRI	International Research Institute for Climate and Society
JRC	Joint Research Center of the European Union
JRC-IPSC	JRC Institute for the Protection and Security of the Citizen
KARI	Kenya Agricultural Research Institute
KMD	Kenya Meteorological Department
KMS	Kenya Meteorological Services
KRCS	Kenya Red Cross Society
MOU	Memorandum of Understanding
NDVI	Normalized Difference Vegetation Index
NGO	Nongovernmental Organization
NHMS	National Hydro-Meteorological Services
NMA	National Meteorological Agency
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OU	University of Oklahoma
PAGASA	Philippine Atmospheric, Geophysical, and Astronomical Services Administration
QC/QA	Quality Control/Quality Assurance
REST	Relief Society of Tigray
SMS	Short Message Service
SRG	Standard Rain Gauge
TAHMO	Trans-African Hydro-Meteorological Observatory
TMA	Tanzania Meteorological Agency
US	United States
USAID	U.S. Agency for International Development
UV	Ultraviolet
VPI	Vegetation Productivity Index
WBBGT	Wet-Bulb, Black Globe Temperature
WFP	World Food Programme
WPF	Weather Philippines Foundation
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

BACKGROUND

Agriculture sustains humanity.[1] The global population stands at some 7.3 billion as of 2014 (Population Institute 2014). Combined with rising incomes and changing consumption patterns and expectations about living standards typical of urbanizing populations throughout much of the developing world, along with population growth and rising demand for food and other agricultural products, agricultural production is severely challenged, locally, regionally, and globally.

Further complicating this challenge are the approximately 860 million people living at or below the US$1.25 per day poverty line. As many as 75 percent of these individuals live in least-developed countries and work small plots for both subsistence and local markets. In these countries, agricultural production tends to be a proportionately significant driver of economic development.

Most smallholder farms are less productive and less profitable than they could be, and the gaps between actual and potential yields are very large. Smallholders lack access to inputs such as modern seed and fertilizer and to services such as credit and information which are instrumental in enabling more modern farmers to manage risk and optimize production using more productive technologies and management practices. This lack of information and technical knowledge results in a skills gap that inhibits their adoption of these technologies and practices and reduces their efficiency when smallholders attempt to modernize their operations (World Bank 2007). Public extension programs tend to be underfunded and have limited contact with farmers in low-income countries, and they are generally not effectively supported by agricultural research systems that generate applied knowledge. Supporting infrastructure is most often lacking as well, making coordination between the different actors in the supply chains linking farmers to consumers difficult and expensive, increasing costs and lowering revenues.

[1] "Agriculture" is defined here as the art, practice, and science of farming, including cultivation of the soil for the growing of crops (food, animal feed, fiber, industrial feedstock, and fuels) and the rearing of livestock and poultry for meat, milk, eggs, hide/fur/leather, feathers, bone, sinew, wool, and dung. More broadly it also encompasses forestry, fisheries, and aquaculture.

Agriculture is highly sensitive to weather and climate. In India, for example, annual productivity depends heavily on each year's monsoon rainfall. A good monsoon year sees plentiful rainfall over wide areas and results in a bountiful harvest. A bad monsoon year, with limited amounts of rain or rain limited to certain areas, results in a poor harvest and often widespread food insecurity. The great sensitivity of agriculture to weather in the short term and to climate in the medium to long term make it the economic sector's most vulnerable to climate variability and change.[2]

Agricultural meteorology or "agro-meteorology" took shape as a field of applied science at the end of the nineteenth century, at the beginning of the global effort to apply scientific principles to improving agricultural productivity. Meteorological considerations enter into assessing the performance of plants and animals whose growth is a result of the combined effect of genetic characteristics and their response to the local environment. The weather is a major component of the local environment, which also includes soil properties, terrain, other plants, farming practices, and so on. For more than a century, agricultural meteorologists have worked to develop tools, techniques, and practices that farmers can use to make agriculture more resilient.

Applying meteorological information to enhance agricultural productivity entails helping farmers to capitalize on opportunities presented by favorable weather and climatic conditions, while working with them to mitigate, to the extent practical, the impacts of adverse conditions. Agro-meteorological services are intended to enable producers to maximize their returns on investments in seed, seedlings, animals, feed, fertilizers, and human effort while improving their ability to manage risk.

Agricultural meteorologists work with local extension agents, soil scientists, agronomists, experts in livestock and poultry, hydrologists, and agricultural engineers to monitor, interpret, and forecast the effects of weather and climate on plant distribution, crop yield, water-use efficiency, phenology of plant and animal development, the energy balance of managed and natural ecosystems, and, conversely, the impact of vegetation on climate and weather.[3] Typical challenges include optimizing the timing of planting and harvesting of various crops, properly applying irrigation systems, and forecasting the emergence and onset of a wide range of plant and animal pests and molds and fungi to ensure timely applications of insecticides and fungicides. Agro-meteorologists can also provide forecasts in support of controlled burns and aid in the management of wildland fires.

On seasonal and interannual timescales, agricultural meteorologists assist farmers and government ministries of agriculture in forecasting the size and quality of yields and in estimating the condition of winter crops. In recent years, supporting agricultural adaptations to seasonal and interannual variability—most often expressed in terms of warm or cool, wet or dry periods lasting through a season, to several years, to a decade—has also become an important area of endeavor for agro-meteorologists. They seek to mitigate the negative impacts of seasonal and interannual weather risks by advising farmers on which crops to plant in coming seasons, the purchase of crop insurance,

[2] **"Weather"** refers to atmospheric phenomena that have timescales that range from hours to days to one or two months, whereas **"climate"** refers to atmospheric conditions that have timescales that range from a few months to a season to a year to a decade or more, or even longer. In this sense, the terms "weather" and "climate" identify regions along a continuous spectrum of atmospheric conditions, weather describing rapidly changing events, and climate describing slowly changing ones. Climate can be represented in terms of a normal, long-term average, and year-to-year fluctuations—the interannual variability—around which that average when viewed over a period of a few hundreds of years, has fallen within a bounded "range" of values. Common drivers of climate variability are the oscillations that occur in Earth's coupled ocean-atmosphere system. An example is the El Niño and La Niña (ENSO) events, shifts of warm, tropical Pacific Ocean currents that can dramatically affect seasonal weather patterns around the world. Other drivers include volcanic eruptions and solar phenomena. Sometimes climate varies in ways that suggest a component of randomness is inherent in Earth's climate system. **"Climate change"** is a long-term continuous change (either increase or decrease) in a climate normal (for example, an increase in the long-term average temperature) and/or the range of climate variability (for example, more frequent, more intense thunderstorms together with fewer small showers). As the range increases, the year-to-year variations in a variable such as temperature or precipitation should be expected to be greater, and so new extreme values are likely.

[3] In the last 20 to 25 years, weather forecasts have come to routinely demonstrate high levels of accuracy in the 0- to 7-day range, and sometimes in as many as 10 to 12 days. Climate outlooks, such as seasonal forecasts, are far less accurate, but in many cases, such as when there is a strong planetary signal, such as an El Nino or La Nina in the equatorial Pacific, are sufficiently reliable to be used in decision making and will generally show over a period of years a significant improvement in outcomes over chance.

changes in farming practices (for example, contour plowing, building of dams), and so on.[4]

Much of the work of agricultural meteorologists is done with the same observations, numerical models, and analysis and forecast techniques used by general meteorologists in a national hydro-meteorological service. However, many agro-meteorological services require special observations in the fields, crop and ecological models, and tailored techniques for purposes of analysis and forecasting. Agro-meteorologists therefore require not only a sound knowledge of applied meteorology and climatology, but also an understanding of agronomy, plant physiology and plant and animal pathology, and common agricultural practices. The World Meteorological Organization (WMO) has recognized the need for specialized training of agricultural meteorologists through the publication of detailed guidelines for their training (WMO 2009).

THIS REPORT

This study was undertaken in support of the World Bank project, **Agroweather Tools for Adapting to Climate Change**. The overall goal of this pilot project is to establish community-based agro-weather risk management tools. These tools are to be supported by a flow of weather and climate information via information and communication technology (ICT) delivery systems. The project has short-, medium-, and long-term objectives. In the short term, the project will raise awareness of the practical utility of agro-weather information products and services and of their direct application to farmers' needs and concerns. It will seek and incorporate feedback from partners as the specific products are developed. In the medium term, the project will build a community-based platform to facilitate better access to relevant agro-weather information and decision support systems. In the long term, it will expedite the flow of products, services, and information to decision makers at national and local levels, and will ultimately be instrumental in increasing food supply, increasing income, and sustaining the health of the environment.

This report is based on the premise that the provision of meteorological and climatological products and services to farmers and government officials will improve agricultural production and help build resilience in the face of increasing variability, from seasonal to decadal timescales. While some advice is provided on how farmers can use meteorological and climatological information in their operations, this is not the main thrust of the report. It focuses instead on the generation and provision of such information in a timely manner and in formats that inform decision making by farmers and by ministerial staff. This is intended to support the Agroweather Information project in increasing the adaptive capacity of farming communities in Kenya and Ethiopia. The project seeks to improve farmers' access to relevant information on weather and climate, and to develop farm management capabilities in a context of climate change. The project will also raise awareness of the practical utility of agro-weather information products and improve extension services.

For these purposes, six types of activities were undertaken:

1. Assess the current level of agro-meteorological observation networks and monitoring capacity vis-à-vis international standards and suggest strategies for improvement.
2. Review a number of traditional and nontraditional agro-weather observation systems and their relevance.
3. Identify adoption barriers associated with traditional and nontraditional approaches and how they may be overcome.
4. Quantify the costs and benefits of the traditional and nontraditional approaches, and provide expert advice on cost-effective strategies for upscaling agro-meteorological observation systems.
5. Identify business models, including innovative public-private partnerships and key private sector players, that can ensure the sustainability of the agro-meteorological observation systems.
6. Make recommendations on global best practices for institutional strengthening and capacity building to support development and testing of new principles and approaches.

These activities cover a broad range of issues, some technical, others dealing with policy and procedure, and still others dealing with government organization.

[4] Here we take the word "mitigate" to mean "to lessen" or "to make less severe." One can mitigate risks but never eliminate them. As opposed to "acceptance," "mitigation" is inherently proactive.

While World Bank staff are the report's primary intended audience and will determine its ultimate distribution, the document is likely to be of interest to people at the World Meteorological Organization, national hydro-meteorological services, and ministries of agriculture and environment (well beyond those in Ethiopia and Kenya), among others.

The recommendations presented in the report are more indicative than definitive and are intended to provide general advice about guiding the transformation of agro-meteorology in this part of Africa. More detailed on-the-ground surveys and fact-checking will be required to inform decision making regarding policy, investment, and operations.

CHAPTER ONE
AGRO-METEOROLOGICAL OBSERVATION NETWORKS

While the national agricultural meteorology programs in Ethiopia and Kenya are very limited, a number of international development agencies and NGOs are operating in both countries and have been implementing various agro-meteorological services as components of more general initiatives to improve agricultural productivity and resilience. Although a comprehensive review of all of the actors at work in the area of agro-meteorology and agro-climatology in the two countries was far beyond the remit or the resources of this study, a number of the more prominent agencies and organizations at work in the field are described in this chapter.

IGAD CLIMATE PREDICTION AND APPLICATIONS CENTRE

The countries of East Africa and the Horn of Africa are prone to extreme weather and climate events such as floods and droughts which have severe impacts on agricultural production. In 1989, 24 countries in eastern and southern Africa established a Drought Monitoring Centre with headquarters in Nairobi (the DMCN) and a subcenter in Harare called the Drought Monitoring Centre Harare (DMCH) in response to devastating weather-related disasters. In October 2003, the heads of state and governments of the Intergovernmental Authority on Development (IGAD) held their 10th Summit in Kampala, Uganda. The DMCN was adopted as a specialized IGAD institution and renamed the IGAD Climate Prediction and Applications Centre (ICPAC) in order to more fully reflect all its mandates, mission, and objectives within the IGAD system. A protocol integrating the institution fully into IGAD was signed on April 13, 2007. Today, the center is responsible for 11 member countries: eight IGAD member countries, namely, Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan, Republic of South Sudan, and Uganda, as well as Burundi, Rwanda, and Tanzania.

ICPAC intends to become a regional center of excellence in climate prediction, producing applications for climate risk management, environmental management, and sustainable development. Its mission is to provide timely early warning weather information that enables its member countries to cope with various risks associated with climate variability and change. Its responsibilities extend to environmental management, sustainable development, and poverty reduction.

ICPAC produces a variety of climate status reports, weather forecasts, and climate outlook products, including 10-day, monthly, and seasonal climate and weather bulletins, climate watch and El Niño updates, and annual climate summaries. It also provides Normalized Difference Vegetation Index (NDVI) data, using satellite imagery of land-cover vegetation from the National Oceanic and Atmospheric Administration (NOAA). ICPAC's "customers" are national hydro-meteorological services and various ministries of the governments in the region.

KENYA

The agriculture sector is the largest contributor to Kenya's gross domestic product. In 2005, agriculture, including forestry and fishing, accounted for about 24 percent of the gross domestic product (GDP), as well as 18 percent of wage employment, and 50 percent of export revenue. Kenya is a leading producer of tea and coffee, and the third-leading exporter of fresh produce, such as cabbages, onions, and mangoes. Small farms grow most of the corn and also produce potatoes, bananas, beans, and peas. An estimated 15 to 17 percent of Kenya's land area has sufficient fertility and rainfall to be farmed, with 7 to 8 percent high-quality farmland. In 2006, almost 75 percent of working Kenyans made their living by farming. About one-half of Kenya's total agricultural output is nonmarketed subsistence production.

At the top of its list of responsibilities, the Kenya Meteorological Service (KMS) gives the "[p]rovision of meteorological and climatological services to agriculture, forestry, water resources management, civil aviation and the private sector including industry, commerce and public utilities for the better exploitation and utilization of natural resources for national development." The KMS aptly posts its information resources online, making them accessible to a wide variety of users. The information presented goes into substantial detail regarding such matters as measurement data, observing equipment, and the layout of meteorological observatories (box 1.1). Some of the observing equipment is locally fabricated in the KMS calibration laboratory.

From the reported data, the Agro-meteorological Section of the KMS produces periodic *Weather and Crop Reviews*, such as the Review for Dekad 7 (appendix B) (figure 1.1).

Many of the instruments and observing approaches used by KMS are traditional. Data are collected for 10-day periods (dekads) and then reported to the Agro-meteorological Section of KMS. No direct or systematic interaction with farmers is reported. The KMS website suggests that the KMS is primarily in the data collection business, with little attention given to products and services for delivery to farmers.[5]

The KMS also produces longer-range quarterly *Outlooks* containing agro-meteorological information. These *Outlooks* are disseminated by press release and then sent to government ministries. Farmers are advised to remain in liaison with the Ministry of Agriculture for recommendations about appropriate crops based on the most recent information about upcoming rains. The *Outlooks* are posted to the KMS Facebook page where they are easily accessible to farmers. However, the primary audience appears to be the Ministry of Agriculture that uses the information to promote foot security among other purposes.

Kenya swings between drought and flood virtually every year. Because much agricultural land, along with towns and villages, are located along Kenya's streams and rivers, flooding can have major impacts both locally on individual farmers and nationally on the nation's food supply. (Maps in figure 1.2 illustrate major floods in Kenya.) Heavy flooding in March and April of 2013 was the subject of

[5] A reviewer reported that there is an ongoing devolution process in KMS with respect to its agro-meteorology service. Reportedly, KMS has established 47 county offices in this devolution process. These offices are currently staffed only with a head, but the plan is to dispatch one hydro-meteorologist and one agro-meteorologist to work at each county office. The county office will work with county government to provide more geographically tailored info. The author was unable to find any further information on this effort.

BOX 1.1. AGRO-METEOROLOGICAL STATIONS

In Kenya there are two types of stations: GRADE A and GRADE B. Grade A stations are operated and manned by Kenya Meteorological Department (KMS) staff, while Grade B stations are run by other organizations, for example, Ministry of Agriculture, universities, and agricultural research institutions.

Currently there are 13 agro-meteorological stations in the country (11 Grade A and 2 Grade B).

Types of Observations

In all of these stations, normal meteorological parameters are measured on a daily basis and the data are conveyed to the Agro-meteorological Section of KMS after every 10 days. The data include the following:

- Air temperature in degrees Celsius (maximum, minimum, wet bulb, dry bulb, dew point)
- Soil temperature in degrees Celsius at 5-, 10-, 20-, 30-, 50-, 100-centimeter depths
- Sunshine duration in hours
- Radiation in megajoules per square meter
- Wind speed in meters per second at 2-meter height.
- Calculated relative humidity (%) at 0900 hours and 1500 hours
- Pan evaporation in millimeters per day
- Calculated potential evapotranspiration in millimeters per dekad (10-day period)
- Rainfall in millimeters per day

These observations are made in 32 stations spread throughout the country. In addition to the above, the following crop data are obtained from the 13 agro-meteorological stations (Grade A and B):

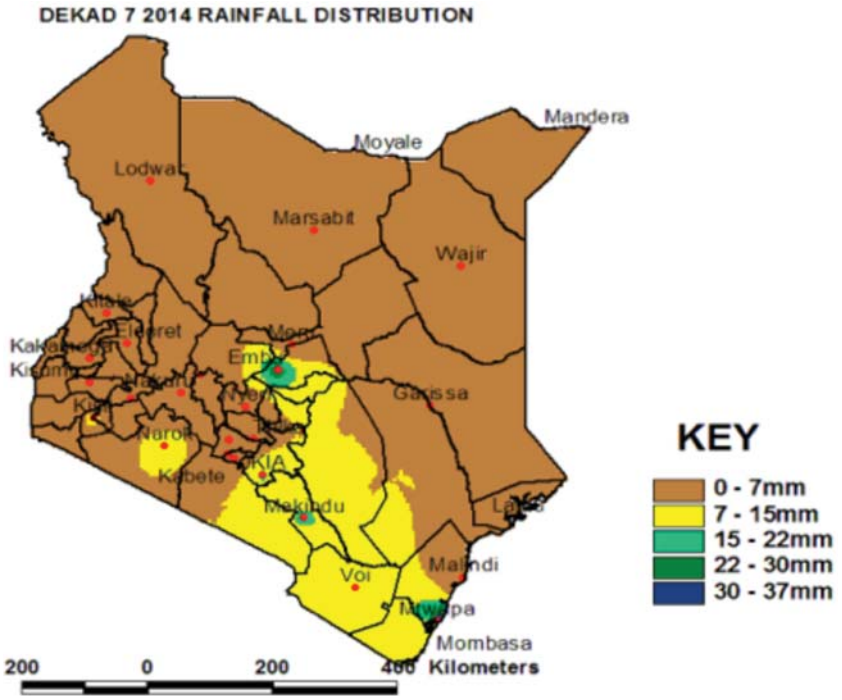
- Variety of the grown crop
- Stage of development attained by the crop
- General assessment of crop performance
- Damage by pests, diseases, and adverse weather
- State of weeding in the farm
- Plant density
- Soil moisture

Expected yield (assessed visually), is normally observed at the end of each 10 days and along with the meteorological data is communicated to the agro-meteorological section to facilitate crop-weather impact analysis.

In order to obtain a general overview of crop performance in the country, especially on the main staple crops in the country—namely, maize, beans, and wheat—all 32 stations report on the stage of crop development, general assessment of crop performance, and yield expected (visual) from the farmers' farms on the basis of what they see from nearby farms and oral interviews with farmers they come across from areas far from their reach.

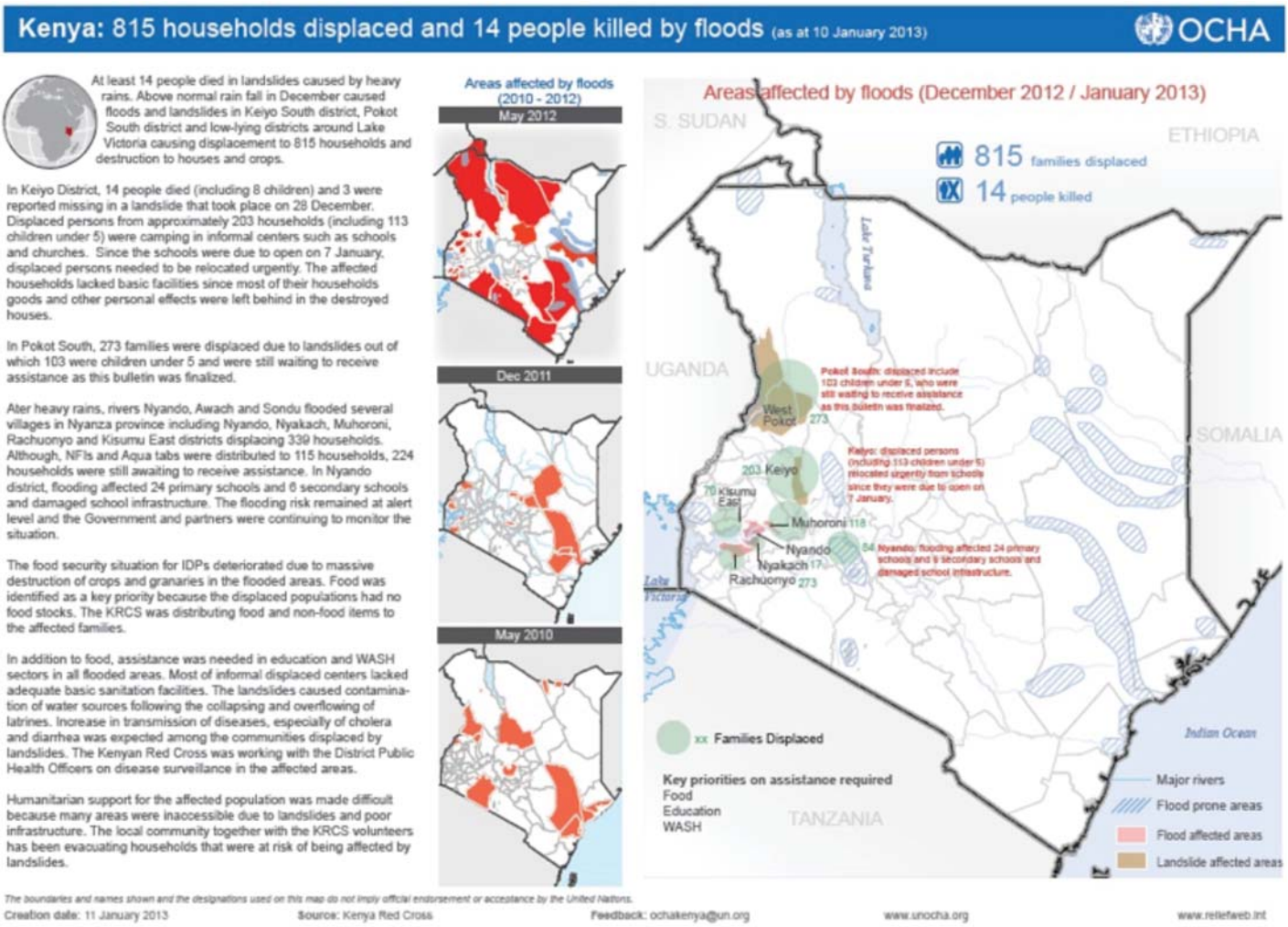
Source: Kenya Meteorological Department (KMD). Undated.

FIGURE 1.1. ILLUSTRATION IN A KMS REVIEW



Source: Dekad 7 (March 1–10) 2014 Rainfall Distribution. Extracted from *Kenya Meteorological Service Dekadal Agro-Meteorological Bulletin Weather and Crop Review for Dekad 7.*

FIGURE 1.2. RECENT FLOODS AND IMPACT IN KENYA



Source: United Nations Office for the Coordination of Humanitarian Affairs and Kenya Red Cross, January 11, 2013.

an article by Thomson Reuters Foundation correspondent Katy Migiro in which Kenya Red Cross Secretary General Abbas Gullet was quoted as follows: "For the farming communities that have lost their livelihoods, they will need assistance for the next three to six months. The pastoralist communities that have lost their animals also would need assistance, so another vicious circle" (http://www.trust.org/item/20130425095508-c7hi9?view=print). Gullet went on to lament the fact that virtually all of the rainwater from the floods poured into the Indian Ocean and Lake Victoria, rather than being stored. During the following dry season, drought would set in and aid agencies would spend millions of dollars trucking water to many of the same areas that experienced floodwaters.

KMS recognizes the need to expand more into the area of agro-meteorology, and a number of initiatives are under way toward this purpose. These include the continued development of RANET-Kenya for getting information out to rural areas via radio and Internet. KMS has also started a pilot effort of roving agro-meteorological seminars with support from the WMO and the U.S. Agency for International Development (USAID). While this will cover only a limited number of communities during the specified pilot period, the seminars are expanding awareness of the usefulness of agro-meteorological information. Agro-meteorology is also represented in Care International's Participatory Scenario Planning efforts and in ICPAC programs supported by the Rockefeller Foundation.

The **Institute for Meteorological Training and Research** (IMTR) offers a six-month course in Applied Agricultural Meteorology covering bio-meteorological interrelationships, agro-meteorological observations and

measurements, soil science and agro-ecological zoning, crop and animal production, agronomy, statistics in agro-meteorology, ICT, and remote sensing.

The **Kenya Agricultural Research Institute** (KARI) is Kenya's national institution for research and development in food crops, horticultural and industrial crops, livestock and range management, land and water management, and socioeconomics. KARI has been developing weather- and climate-related technologies to help farmers cope with the difficult conditions found in many parts of Kenya, conditions that are being exacerbated by increasing interannual variability. With support from the Rockefeller Foundation, the KARI Climate Change Unit (CCU) was established in 2010. The Unit facilitates collaborative work on regional climate change science and adaptation and mitigation mechanisms, and engages in capacity building for researchers working on these issues. Activities relate to science and theory, assessments, integrated soil fertility management, conservation tillage, rainwater harvesting, pest management, weed control, and carbon sequestration. CCU's mandate also includes developing or adopting technologies and methods that can be applied to cope with climate change impacts on food insecurity, water scarcity, and the emergence of pests and diseases.

As a result of these initiatives by KARI, traditional farmers have been informed by timely information about the timing of the two annual rainy seasons, helping them to effectively plan farming activities throughout the year. This has become more important in recent years, as droughts and dry spells have become more frequent, from once every ten years or so to as often as once every three years. While many Kenyan radio stations issue weather forecasts, only a few provide practical information directed at farmers. KARI identified a need to provide combined information from both the meteorology department and agricultural experts. The strategy is to provide a detailed weather forecast around one month before each planting season which tells farmers how much rain is predicted, when it will start, and therefore what types of crops to plant. When rainfall predictions are good, they can invest in hybrid seeds and fertilizer, and maximize their yields. When predictions are for a dry season, choosing drought-resistant crops is a better option.

KENYA—NONGOVERNMENTAL ORGANIZATIONS AND OTHER PARTNER AGENCIES

Outside the agencies of the Kenyan government, important work in agro-meteorology is being done by international development agencies and nongovernmental organizations (NGOs), often in partnership with the KMS. Here we discuss a few of these.

The Syngenta Foundation for Sustainable Agriculture

The Syngenta Foundation for Sustainable Agriculture has a number of regional divisions carrying out projects to increase crop productivity, protect the environment, and improve health outcomes across East Africa. Its projects include teaching farmers how to conserve water through minimum tillage and rainwater harvesting, and providing microfinance solutions to growers. Syngenta also provides thousands of Kenyan farmers with index-based weather insurance coverage through the *Kilimo Salama* ("Safe farming" in Kiswahili) program. The coverage targets two main types of farmers: larger-scale barley, wheat, coffee, maize, export ornamentals, and vegetable growers; and smallholder and subsistence farmers who grow mostly for local consumption. Kilimo Salama is a partnership between Syngenta and UAP Insurance Kenya and telecommunication operator Safaricom.

Kilimo Salama uses automated, solar-powered weather stations and a low-cost, mobile phone payment and data system to offer thousands of farmers in parts of western and central Kenya affordable "pay-as-you-plant" crops. The weather stations were installed and maintained by Syngenta, while being overseen by the Kenyan Ministry of Agriculture, which served as the neutral party as required by reinsurers.

When weather data transmitted over Safaricom's 3G data network from a particular station indicates that drought, excessive rains, or other extreme conditions have occurred and likely crippled crops, all farmers registered with that station automatically receive payouts directly via Safaricom's M-PESA mobile money transfer service. The payouts compensate farmers for losses to crops like maize, wheat, beans, and sorghum, with credits for fertilizer and seed to help them restart farming after a loss.

"Extreme weather, particularly drought, traps many African farmers in poverty because it robs them of the means to recover," said Marco Ferroni, Executive Director of the Syngenta Foundation (http://www.eurekalert.org/pub_releases/2010-03/bc-fmp030210.php). "We have in Kilimo Salama a microinsurance strategy that will work. By utilizing state-of-the-art risk management tools, revolutionary mobile phone technologies, and the knowledge and expertise of farmers and rural business men and women, we have developed for the first time a model for providing farmers with reliable, low-cost cover from the vagaries of extreme weather."

"We believe Kilimo Salama can revolutionize insurance and make it accessible to farmers," said James Wambugu, Executive Director of UAP Insurance Kenya. "By using the weather stations to verify local weather conditions, we are avoiding claims procedures that have created mistrust and led people to avoid insurance. As such, this strategy has the potential to make agricultural micro-insurance affordable and attractive for smallholder farmers and economically viable for insurance companies in developing countries that had previously written off the agricultural sector" (Red Orbit 2010). Originally established in Kenya and Tanzania, this index-based insurance was extended to farmers in Rwanda in February 2014 (box 1.2).

Discussion. While weather index agricultural insurance has a number of attractive features, it can give rise to a number of issues as well, and some of these are present in the Syngenta effort in Kenya. The Syngenta Foundation is effectively the same organization as Syngenta, a major supplier of seed and agricultural inputs. Syngenta weather index insurance is sold as a part of the seed and agricultural inputs supply chain. Syngenta is also supplying the meteorological observations in Kilimo Salama project, in which they only work with Safaricom, one of several mobile operators in the region. Participating farmers are therefore limited in their options to Syngenta and Safaricom products. This suggests the potential utility of a functioning regulatory framework to foster a more competitive marketplace in which farmers have more alternatives available to them in terms of product and service providers.

Other insurance-related programs at work in the region include the International Livestock Research Institute's (ILRI) livestock insurance program and the World Food Programme (WFP) R4 initiative, which will be discussed below. How these or Syngenta's initiatives relate to the activities of the National Hydro Meteorological Service (NHMS) is unclear.

BOX 1.2. RWANDAN FARMERS TO BENEFIT FROM INSURANCE AGREEMENT

Rwandan small-scale farmers will be part of 1 million farmers in East Africa to insure their crops against unpredictable weather and other related problems.

This follows the signing of two grants agreements of $3.9 million (about Rwf 2.6 billion) signed on February 5, 2014, in Nairobi by International Finance Corporation (IFC) and Syngenta Foundation for sustainable agriculture. The agreement would enable expansion of index-based insurance to small-scale farmers in Rwanda, Kenya, and Tanzania.

The grants were issued by the Global Index Insurance Facility, a multidonor trust fund financed by the European Union, Japan, and the Netherlands and implemented by IFC and the World Bank. It is estimated that the project will bring index insurance to approximately 1 million small-scale farmers within two years.

Marco Ferroni, the Executive Director of Syngenta Foundation for Sustainable Agriculture, said Syngenta has developed a product dubbed "Kilimo Salama," being administered by selected insurance firms in the region.

In Rwanda, for instance, Syngenta Foundation is offering the product in partnership with SORAS Insurance Company and the international reinsurer, Swiss Re Corporate Solutions.

"Our aim through this initiative is geared towards enhancing food security as well as minimizing poverty among other sufferings to majority of farmers in the region," said Ferroni, noting that the insurance product is accessible to all categories of farmers—small-scale and large-scale farmers.

In late 2012, the government of Rwanda in partnership with the Syngenta Foundation for Sustainable Agriculture introduced Kilimo Salama, the scheme that uses satellite stations to monitor how rainfall variability and drought affect crop production.

So far, many Rwandan farmers have gained from the crop insurance product; with a recent example of 7,086 maize farmers from Bugesera, Ngoma, and Kirehe districts who received their insurance payout totaling Rwf 42.1 million last Tuesday.

Source: Ministry of Rwanda Ministry of Agriculture and Animal Resources.

Weather index insurance programs appear to be a promising area for public-private partnerships, given for instance the strong interests that private insurance companies have in high-quality forecasts and observations.

Trans-African Hydro-Meteorological Observatory

Another NGO promoting agro-meteorology in Kenya and elsewhere in Africa is the Trans-African Hydro-Meteorological Observatory (TAHMO), a collaboration between Oregon State University and Delft University of Technology. The TAHMO seeks to build a dense network—a station every 30 kilometers—of hydro-meteorological stations across Sub-Saharan Africa. This effort recognizes that accurate, high-resolution temporal and spatial hydro-meteorological data are essential to supporting agriculture, combating diseases, and enabling weather prediction and climate modeling (box 1.3).

Its first step has been an effort to catalog and make accessible all the currently collected weather and climate data for Sub-Saharan Africa to encourage climate analyses, avoid redundancy in future TAHMO hydromet station installations, and prioritize the coming years of effort.

The long-term goal of a station every 30 kilometers entails the production and deployment of some 20,000 such stations. It is TAHMO's intent to utilize innovative sensors coupled with rapidly evolving information and communication technologies, for example, cell phones, so that each station costs no more than $200. The stations will be placed at schools and universities and integrated in local educational programs. Data from the stations will be combined with those from models and satellite sensors to obtain detailed insight into the distribution of water and energy stocks and fluxes.

TAHMO has built and demonstrated a prototype acoustic disdrometer (rain gauge) that can be produced for €10, less than 1 percent of the cost of a commercial equivalent with similar specifications (Hut 2010). The disdrometer was developed in the Netherlands and tested in Tanzania for a total project cost of €5000. TAHMO has been seeking out other innovative ideas for instrumentation via open design competitions in Kenya.

ETHIOPIA

Agriculture accounts for over 40 percent of GDP and 80 percent of exports, and engages 80 percent of the labor force in Ethiopia. The country has vast areas of fertile land, a diverse climate, generally adequate rainfall, and a large labor pool. Around 75 percent of Ethiopia's approximately 85 million people are dependent on subsistence agriculture, which is almost entirely rain fed and small scale. Both farmers and pastoralists are highly dependent on the weather for their livelihoods.

Coffee, tea, and, more recently, flowers are the only major commercial crops. Ethiopia is Africa's second biggest maize producer. Its livestock population is believed to be the largest in Africa, accounting for 10.6 percent of Ethiopia's export income in 2006/2007—with leather and leather products making up 7.5 percent and live animals 3.1 percent.

ETHIOPIA—GOVERNMENT AGENCIES

The National Meteorological Agency

Ethiopia's National Meteorological Agency (NMA) operates an extensive observing network, with four categories of observing stations:

- **First Class—22 Synoptic stations** where meteorological observations are made for the purposes of synoptic meteorology. Observations are taken of 18 atmospheric variables every hour, 24 hours a day.
- **Second Class—>150 Principal or Indicative stations** where meteorological observations are made for climatological purposes. Observations are taken of 13 atmospheric variables every three hours at the following Greenwich Mean (GMT) times (0300, 0600, 0900, 1200, 1500 GMT).
- **Third Class—Ordinary stations** where three meteorological elements are observed: maximum air temperature in a day, minimum air temperature, and total rainfall. Observations are taken at 0600 and 1500 GMT.
- **Fourth Class—Rainfall Recording stations** where the total rainfall amount over a 24-hour period is observed. Observations are taken at 0600 GMT.

BOX 1.3. IMPROVED ACCESS TO WEATHER INFORMATION LEADS TO BETTER FARMING OUTCOMES

"When every drop of rain counts: Managing climate risks in the Greater Horn of Africa." Ochieng Ogodo

In her small vegetable plot in Kenya's Kitui county, Mary Mueni Samson scrutinizes a rain gauge and carefully notes the results. It is the middle of one of the worst droughts to hit East Africa in recent decades. And though Kitui has been spared the worst of it, Samson's modest harvest of green grams is due in no small measure to her close eye on the weather.

"I read our rain gauge every day and keep records," she says. "In the past, weather forecasting was a distant drum to many of us, but it now plays a tune we understand well. It helps us know the amount of rains we get in a season and this helps us in planning."

Samson's skill and knowledge in using weather data to plan her activities is an important strategy for coping in this already dry region, where rains are less and less dependable. Along with many of her neighbors, she has learned to gather data and apply forecasts to her farming decisions as a member of the Uuniko Farmers Field School.

Erratic weather, little rain

According to Edward Nduli, secretary to the field school, life has been a struggle for decades in this part of Kenya, but things were never as bad as they are today.

"For a region where the majority of us are small-hold farmers who depend on crop production for our livelihoods, the advent of unpredictable seasonal variations visited upon us serious challenges for survival," he says. The last good rains he can remember were back in 1997. But thereafter, he says, "We saw the decline of rains with extreme erratic seasons, and this has continued since. [Before,] we knew short rains from October to December, while the long ones came March to May," says Nduli. "But the years changed and yields came down significantly… we started relying on relief food from local NGOs and international organizations like Red Cross, Panda, and (German aid agency) GTZ."

Information worth paying for

In Kenya, a partnership with the national meteorological department, the International Crops Research Institute for the Semi-Arid Tropics, the Kenya Agricultural Research Institute, and the University of Nairobi has made significant inroads in study sites in three Kitui county locations: Kaveta village in Central district, Kyome village in Migwani district, and Kitoo village in Mutomo district. According to William Githungo of the Kenya Meteorological Department, the project has made an important contribution by integrating climate information with knowledge on dry land agriculture techniques—and helping farmers translate this knowledge into their decisions. In surveys conducted in 2010, over 80 percent of farmers involved in the study rated the improved information so useful that they would be willing to pay for it. "Evaluation," he says, "has shown that farming decisions based on forecast information may contribute substantially to reduce risk and improve productivity and profitability."

Adapting farming techniques in Kenya

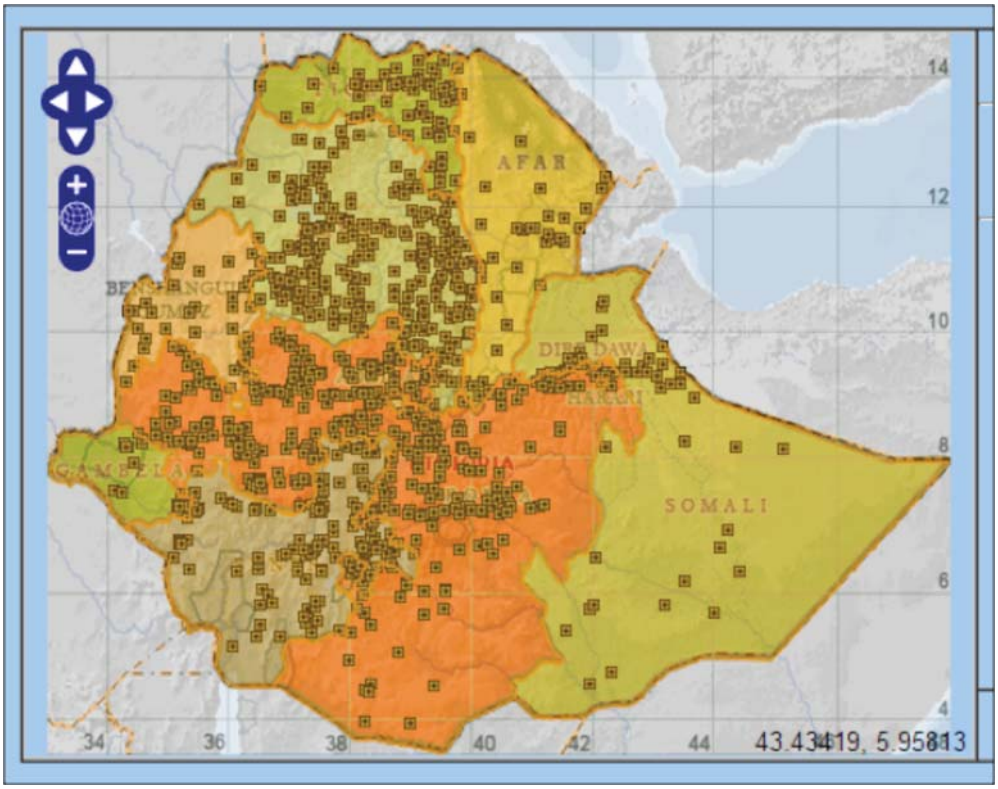
Initial research stages with the Uuniko Farmers Field School involved consultation between forecasters, researchers, and farmers. The team then focused on testing farming approaches and technologies of greatest interest to local communities. Each season, they set up demonstration plots: one set served as an experimental control, and was cultivated using traditional farming methods; in another, water and soil fertility management techniques—such as terracing fields, using fertilizers, and customizing the selection of crop and seed varieties—were chosen in light of seasonal forecasts, and input from farmers. When much better yields resulted from enhanced farming practices tailored to climate data, the school began using these strategies as a group. Rainwater run-off that once went to waste, for example, is now being diverted to gardens. The community is also constructing ground water tanks as a means to harvest water for dry spells. Households have learned effective ways to use animal manure and crop residues to nourish their soils, saving valuable money on fertilizers. Farmers have seen a significant increase in harvests, even with little rainfall. With more water available from harvesting techniques, members of the group are practicing agroforestry with fruit trees and eucalyptus. Nutritious grains like sorghum, green gram, lablab beans, and finger millet are moving to the center of farming activities because of their drought tolerance. As a result of these efforts, says Nduli proudly, "We are no longer major receivers of relief food."

Source: CCAA Human Impact Stories. IDRC/CRDI website. (Accessed November 14, 2014.)

It is unclear how many total stations the NMA has in operation, but numbers between 400 and 1,200 are reported in the literature (see figure 1.3). Most of these are likely Ordinary or the Rainfall Recording stations.

Common comments about the data from this assembly of stations are that (1) while the number of stations is reasonably good, *coverage is uneven*, and is particularly sparse in the lowlands, with greater concentration in the central parts;

FIGURE 1.3. DISTRIBUTION OF AGRO-METEOROLOGICAL STATIONS IN ETHIOPIA



Source: National Meteorology Agency, Ethiopia.

(2) stations are marked by data gaps; and (3) data from some stations may not be easily accessed in part because records are a mixture of paper and digital materials.

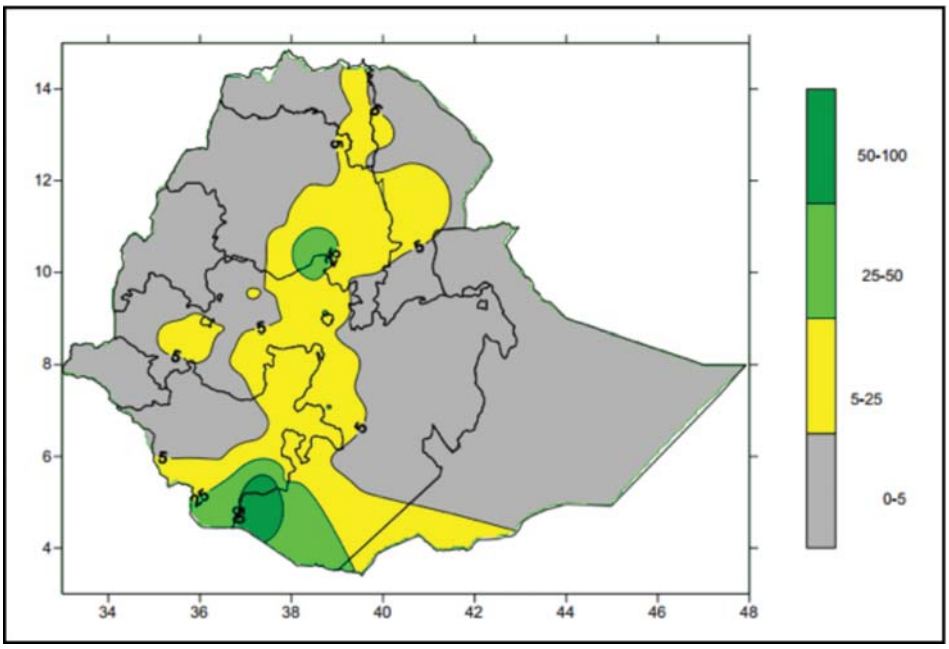
Data from this network are transmitted to the NMA's central office for analysis. The information produced subsequently by NMA includes daily weather reports, 10-day weather summaries and 10-day forecasts, monthly weather summaries and forecasts, and three seasonal predictions a year covering the two rainy seasons and the dry season, known as *Bega*. The service also provides maps showing rainfall received as a percentage of normal rainfall, vegetation conditions, and impacts on crop and livestock production.

Other items under "Data Service" include the "NMA Data Policy," "NMA Service Charges," "Dataset and Information," and the "Data Request Form." These describe the policies for those outside NMA who need specific data sets. Only a limited number of top government agencies and researchers collaborating with NMA can routinely receive data for free. The NMA makes little mention of any support for agricultural research and development on its website, and linkages to the Ministry of Agriculture or to NGOs working in Ethiopian agriculture appear to be limited. Dekadal, Monthly, and Seasonal Bulletins issued by Agormet are posted in highly accessible PDF format for easy dissemination.

Extracts from the NMA dekadal report for February 11 through 20, 2014, are presented in figures 1.4 and 1.5.

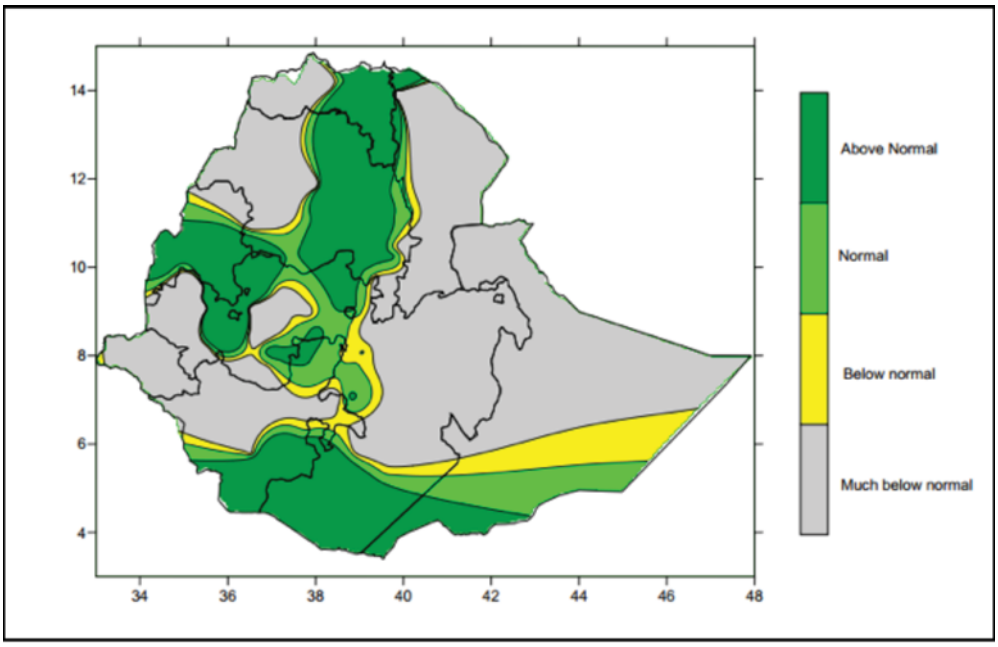
The Rockefeller Regional Project on Agro-met advisory to farmers—Training of Trainers on Weather and Climate Information and Products for Agricultural Extension Services in Ethiopia, began in 2010. While NMA is the lead government organization, the Ministry of Agriculture and its Rural Extension Service also play central roles. The WMO's Agricultural Meteorology Programme of the Climate Prediction and Adaptation (CLPA) Branch of the Climate and Water Department has been a key supporting partner, responsible for the implementation of many aspects of this program.

FIGURE 1.4. RAINFALL DISTRIBUTION (IN MILLIMETERS) FOR FEBRUARY 11–20, 2014



Source: National Meteorology Agency, Ethiopia.

FIGURE 1.5. OBSERVED VERSUS NORMAL RAINFALL (FEBRUARY 11–20, 2014)



Source: National Meteorological Agency, Ethiopia.

Note: This plot shows the observed versus normal rainfall for the period: <50 percent, much below normal (gray); 50 to 75 percent, below normal (yellow); 75 to 125 percent, normal (light green); >125 percent, above normal (dark green).

This Ethiopian program was based on the experience and success of the WMO Roving Seminar Programme in West Africa and other African countries, in particular Mali, on the application of agro-meteorology to directly assist farmers in making operational decisions.

The goal is to exploit Ethiopia's extensive observing network in ways that provide better practical knowledge of agro-meteorological services and applications to farmers in order to improve farming practices and increase or secure agricultural production. To meet this goal, the

Rockefeller Foundation supported NMA to engage with the Ministry of Agriculture and provide training to agricultural extension agents and agricultural experts and to assist them in providing better practical knowledge of agro-meteorological services and applications to farmers.

Based on these experiences and with feedback from the Ministry of Agriculture, the objectives of this project are twofold. One objective involves "training the trainers" in meteorological and agricultural agencies to familiarize agricultural extension services with the use of weather and climate information that NMA provides in operational farm management. The other objective involves discussing with farmers the information they need to make decisions, which is the heart of the training and thus closes a feedback loop. Around 26,000 extension agents work in some 600 administrative districts in Ethiopia—a number well beyond the project's ability to reach. Training of trainers therefore selectively targets 30 extension agents in each of the country's 10 regions.[6] The WMO seminars also increase the interactions between the local agricultural extension services and the local NMA staff. This is crucial for NMA to provide better services for the agricultural community.

As a result of these efforts, the **Ethiopian Agricultural Research Institute** and **Agricultural Transformation Agency** have already put in place the use of agro-meteorological advisories over selected districts in Ethiopia. Several reports about this program note that working closely with farmers is important to determine and then service their agro-meteorology information needs and to support adaptation to changing climate, and so enhancing food security.

The report focused almost exclusively on NMA, presenting it as the governmental organization dealing with agro-meteorology and agro-climatology. While NMA is nationally mandated to deal with meteorological issues and has a network of meteorological stations dispersed throughout the country, a number of other government agricultural research institutions (both federal and regional), operate in the field as well, in addition to universities and agricultural technical and vocational training colleges. Some, perhaps most, of these research and academic establishments have agro-met divisions or departments as well as agro-climatic research and studies. They also have meteorological stations, some of which are under the direct control of NMA.

Ideally, the assessment would have covered these research and academic institutions, providing a more complete picture of the current level of agro-meteorological observation networks and monitoring capacity across the country.[7] Unfortunately, locating these various institutions provided to be difficult as many have a limited Web presence and little of their work is documented in accessible English-language publications, so their (potentially significant) contributions remain obscure.

Ethiopian Institute of Agricultural Research (EIAR)

The EIAR is a semiautonomous federal institution that in the last three years has taken the lead in reaching out to farmers regarding agro-weather and agro-climate research and extension. Its Division of Agrometeorology, Biometrics, and GIS Research has been engaged in a wide range of climate research aimed at enhancing the application of climate information by smallholder farmers. Since 2010, that division of EIAR has been piloting tailored decision support tools in the form of agro-weather and agro-climate advisories to farmers in the four major agricultural states of Ethiopia—Amhara, Tigray, Oromia, and the Southern region.

This climate change adaptation initiative, *Making Ethiopian Agriculture Climate Resilient: Towards Networking and Coordination to Mainstream Climate Change Adaptation into Food Security and Sustainable Development*, has been funded mostly by the Rockefeller Foundation, with a significant contribution from the government. This project has different components such as climate modeling, impact and adaptation assessment, and climate mainstreaming. The component

[6] A reviewer noted that these statistics are likely somewhat out of date; they are the statistics cited in the documentation for the program. The reviewer indicates that the total number of extension workers, often referred to as "development agents" (DA) is more than 60,000, and the actual number of kebele administrations is more than 1,000.

[7] A reviewer noted that these diverse research and academic institutions have significant agricultural monitoring capacity because they are better staffed than NMA.

piloting tailored climate products to farmers was among the major ones. This was a phase one project and was completed last year.

A second phase project with additional funds from the Rockefeller Foundation was launched in 2013, *Reducing the Vulnerability of Smallholder Farmers in Ethiopia to Climate Variability and Change through Application of Climate Information and Best Bet Management Practices*. This second phase has components addressing different aspects of agro-advisories to farmers.

In addition, the EIAR has been working together with regional and international partners like the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), the International Maize and Wheat Improvement Center (CIMMYT), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the Inter-Centre Training Programme (ICTP), and so on, on the issue of climate-induced risks in agriculture. The EIAR also operates 30 agro-meteorological stations established in its research centers and subcenters.

Ethiopian Ministry of Agriculture

The Ethiopian Ministry of Agriculture has branch offices and agents posted in each administrative unit across the country, from the federal level down to peasant associations. The presence throughout the lowest levels allows the Ministry to collect data to estimate crop yield and production forecasts by direct observations of fields using teams of contract farmers. This information is rolled up through the national agricultural bureaucracy to the regional and federal levels, where dekadal and monthly bulletins are prepared and disseminated. These contain information on farming activities, rainfall, and crop status, and provide an early warning of possible crop failures.

Agricultural Transformation Agency

The Agricultural Transformation Agency was recently established as a federal government organization to support the transformation of agricultural practices on the many smallholder farms in Ethiopia. The agency has initiated the Climate and Environment for the Sustainable Development program. Under this program, it has already put in place the use of agro-meteorological advisories over selected districts in Ethiopia. The agency has found that working closely with farmers is important for determining and then servicing their agro-meteorology information needs and for supporting adaptation and food security.

NONGOVERNMENTAL ORGANIZATIONS AND OTHER DONOR AGENCIES IN ETHIOPIA

In Ethiopia, at least five international NGOs are involved in climate monitoring and yield estimation in Ethiopia.[8] These include Global Monitoring for Food Security (GMFS), the Agriculture Unit of the Joint Research Center of the European Union, Institute for the Protection and Security of the Citizen (JRC-IPSC), the Famine Early Warning Systems Network (FEWSNET), the World Food Programme (WFP), and the Food and Agriculture Organization (of the United Nations) (FAO). The GMFS, the JRC-IPSC, and the FEWSNET rely on remote-sensing imagery in their crop monitoring, using the analyses of crop and vegetation responses derived from NDVI or vegetation productivity index (VPI) imagery and water balance modeling based on rainfall estimates or similar products as well as outputs from global climate models.

The FAO and the WFP are extensively involved in Ethiopia's crop and food supply assessment mission. The information generated is used by government and international agencies for the contingent planning in humanitarian assistance, then in routine development plans through technology extension services. It is only WFP, in collaboration with the agriculture ministry and NMA, that has developed a weather-based risk financing tool known as Livelihood Early Assessment and Protection (LEAP), of which the Water Requirement Satisfaction Index is a part.

A handful of Ethiopian universities have only recently come to include climate and climate change in their curricula, including postgraduate programs in meteorology offered by Arba Minch, Mekele, and Haramaya Universities. This leaves relatively few technically capable

[8] "Support to Food Security Information Systems in Ethiopia." Mid-Term Evaluation Report by Vianney Labé.

individuals who can translate weather and climate information into productive and profitable farming.

At the present time, the main effort to provide agricultural meteorological services to farmers and pastoralists in Ethiopia appears to be put forth in four separate projects supported largely by the Rockefeller Foundation as part of its global "Building Climate Change Resilience" initiative. These projects involve EIAR, NMA, Mekele University, and Oxfam America, as well.

Syngenta has not extended its crop insurance effort to Ethiopia, where it has focused instead on genetic studies aimed at improving crops. This may have been to avoid duplication of efforts with Oxfam America and other development agencies which have been encouraging such insurance efforts. Ethiopian insurance companies are also offering what appear to be similar products.

In the **Horn of Africa Risk Transfer for Adaptation** (HARITA) project, during the period from 2007 to 2012, Oxfam America, Swiss Re, and their partners developed and implemented a pilot integrated risk management framework in Ethiopia's drought-prone northernmost state of Tigray. This program enabled farmers to strengthen their food and income security through a combination of improved resource management (risk reduction), insurance (risk transfer), and microcredit (prudent risk taking). The pilot project was funded by the Rockefeller Foundation and Swiss Re. As of June 2014, the techniques piloted in the HARITA project continue as Oxfam's Rural Resilience (R4) Initiative, implemented in partnership with the World Food Program, and begin expansion in both Ethiopia and other African countries. Companies like **Nyala Insurance**, which have been involved in this project, have experienced considerable success in designing innovative weather insurance products that protect a range of farmers.[9]

The current approach of many groups offering index insurance products is to use point observations to decide payouts. This may create problems in the future when attempts are made to move from pilot projects to large, regional-scale efforts. Even if efforts to deploy more surface stations are successful, the separation between stations, together with large regions of complex terrain, suggests that scaling up such insurance programs may be problematic in many areas. Obtaining the spatial information on precipitation distribution using satellite sensors calibrated by the ground station data and sometimes surface radars appears to be a viable approach.

In the HARITA project, IRI Columbia University developed an automated system that calculates insurance premiums and payouts from satellite-based rainfall estimates (Osgood 2010). Further, the Enhancing National Climate Services (ENACTS) program, a joint development effort by Ethiopia National Meteorological Agency, the International Research Institute for Climate and Society, and the University of Reading, demonstrated that combining satellite and gauge data overcomes, to a degree, the shortcomings of the interpolated gauge and satellite estimates taken by themselves.[10] Others, such as Rojas and Ahmed (2012), have explored the possibilities of extending similar index-based insurance across all of drought-prone Sub-Saharan Africa using satellite data to compute the required indices.

These satellite-based techniques for estimating rainfall use both downward pointing radars (an active sensor) and radiometers that are sensitive to the visual, infrared, and microwave emissions from the precipitating cloud. By observing both visual and infrared emissions, clouds are located and their height (related to the type of cloud) estimated. The microwave signal provides information on the presence of raindrops. Such schemes work well, but they require ground truth data from surface rain gauges for calibration.

Like scans from surface-based radar, satellite-based techniques provide remotely sensed area measurements. These are in contrast to the point measurements of traditional rain gauges and allow meteorologists to see in some degree of detail what is happening over a wide area, filling the gaps between surface-based sites. However, all schemes for remotely sensing area rainfall need surface measurements for calibration. This is best accomplished on the fly

[9] An informative brief published by the International Food Policy Research Institute in its series 2020 Vision for Food, Agriculture, and the Environment titled "Innovations in Insuring the Poor: Providing Weather Index and Indemnity Insurance in Ethiopia" by Eyob Meherette, December 2009. http://www.ifpri.org/.

[10] Climate Services Partnership. http://www.climate-services.org/.

in real time, rain event by rain event. This in turn requires near-real-time, high-quality data streams, produced via reliable communications and high-speed quality control and quality assurance (QC/QA)/archival systems.

Discussion and Recommendations

In both Kenya and Ethiopia, weather and climate are recognized as very important factors influencing agricultural production by the national hydro-meteorological services, KMS and NMA, respectively, together with the efforts from KARI (Kenyan Agricultural Research Institute) and EIAR, and their associated ministries of agriculture.

In both Ethiopia and Kenya, information on weather and climate in farming and herding areas is being used by the government to estimate the amount of food being produced. However, it was difficult to find from Web searches much evidence of agricultural weather services being provided to farmers to assist in increasing agricultural productivity and improving resiliency. (Indeed, agricultural meteorology has a low profile on the websites and in the official statements of both KMS and NMA.) The programs supported by the Syngenta Foundation (Kenya) and the Rockefeller Foundation (Ethiopia) appear to be the best documented efforts.

An excellent example of regional-scale meteorological products in support of agriculture is the analysis and forecast products and services provided by ICPAC. These are essential for an effective agricultural meteorology program. However, ICPAC is at a long administrative and bureaucratic distance from the farmers who could use this information. The challenge to nascent agricultural meteorologists in both Kenya and Ethiopia is to interpret these (and other locally produced) products in light of local farmer needs, then put the resulting information into comprehensible messages that support appropriate actions in local agricultural communities. That does not appear to be happening, except in the most general way.

Laichena (2010) of the Kenya Institute for Public Policy Research and Analysis (KIPPRA) has provided a reflection on why neither KMS nor the Kenyan Ministry of Agriculture have developed a strong agricultural meteorology program, given that they both recognize the importance of weather and climate to their nation's agricultural productivity (similar thoughts apply to NMA). The reasons Laichena offers are numerous, including a strong focus on aviation weather by KMS and the dominance of conservative elements ("we have not done this before") in both KMS and the Ministry of Agriculture, as well as tradition-bound farmers. Consequently, agricultural meteorology does not have a strong, well-placed champion among the agricultural communities or among the many competing interests within the government.

Meteorology and climatology are areas of endeavor in which real-time environmental data streams are essential. The same data that are used to prepare and verify daily forecasts, when accumulated over time, become the basis for climatological analysis and prediction. KMS and NMA are severely constrained by their lack of real-time environmental data on the meso- and micro-scales.[11] Without such data at the relevant temporal and spatial scales, it is not possible to effectively forecast either day-to-day weather or seasonal climate at the farm level, which is, of course, the scale of most interest to farmers.

Weather forecasts (zero hours out to about one week) improve only when there are data to verify forecasts and assess forecast skill. Meteorologists learn to identify key weather features and build their understanding of the unique aspects of a particular place or region only through thorough analysis of the details of ever-evolving weather patterns over that region. One common approach to forecasting both weather and climate that can be used to some extent to provide local information from larger-scale forecasts is "downscaling."[12] However, even with downscaling, it is necessary to have good observational coverage of the

[11] **Mesoscale** and **microscale** have a variety of definitions. Here we consider the mesoscale to be events with space scales of a few kilometers to a few tens of kilometers and with timescales from 0 to 48 hours, with a strong focus on 0 to about 6 hours. We consider microscale to be events with space scales of few meters to a few kilometers and with timescales from 0 to no more than an hour or so.

[12] In meteorology and climatology, **downscaling**, or "localization," is the process of deriving finer-resolution information (for example, for a particular location) from coarser-resolution numerical model output. Most agricultural impacts researchers feel that the horizontal resolution of most numerical models is generally too coarse to be used effectively by farmers in its original format. While much useful information can be derived from course definition numerical model output without the need for downscaling (such as national- and regional-scale estimates appropriate to the ministry level), to support decisions at the farm scale, it is necessary to try to add value to a forecast scenario by making it more applicable for finer-resolution decisions such as the timing of planting and harvesting.

region to provide verification of the downscaled values. An effective verification process allows the downscaling technique to be fine-tuned to improve its performance.

NGOs appear to be the most important players in agricultural weather and climate services in both Kenya and Ethiopia. The Syngenta Foundation for Sustainable Agriculture reports note that the Ministry of Agriculture is short on technical staff, but good at contracting. Working with the Ministry of Agriculture, they are operating an agro-meteorological observing network, monitoring the weather (especially precipitation), and providing an innovative insurance program founded on those observations. Similar observations probably apply to the experience of the Rockefeller Foundation in Ethiopia.

Both the International Development Research Centre (IDRC) and the TAHMO have innovative programs underway to collect and provide weather and climate information to farmers. These appear to be both complementary and collaborative with the KMS. Both efforts emphasize the importance of grassroots efforts to reach the rural poor. In the case of Ethiopia, the bureaucratic culture in NMA seems to be more closed than that in Kenya, so it is not clear how these initiatives will fare when they attempt to expand in that country. While there are no international standards per se for agricultural meteorology, given the great diversity within agriculture around the globe, a number of best practices can be inferred:

- Understand the decisions made by farmers which can be influenced by agro-meteorological information.
- Express agricultural meteorological information in terms that farmers can quickly understand and apply in their decision making.
- Deploy observing systems and observational networks that are crop focused—that measure quantities directly relevant to the weather and climate experienced in the farm fields.
- Utilize communication means (radio, cell phone/ Short Message Service (SMS) messaging, printed materials) that are easily accessed and utilized by the farmers.
- Communicate to farmers how proper utilization of weather and climate information can increase their productivity while reducing risk. Provide practical, weather- and climate-based advice on what and when to plant, irrigation and water management, what pesticide and fertilizer to use at the correct timing, as well as other relevant agricultural support services.

In the performance of such activities, the agricultural meteorologist is part of a team. Agricultural extension personnel, who are usually deployed by the ministry of agriculture, play an important intermediary role between developers of agro-meteorological products (national hydro-meteorological services; ministries of agriculture, the environment, and water; universities; research institutes) and farmers. Communications media, particularly radio and cellular telephones, are vital, making telecommunication companies an important part of the agro-meteorologist's team. Finally, international development agencies and NGOs may be important team members who provide resources and expertise not locally available.

A key reason for low-level use of agro-meteorological services in African countries such as Kenya and Ethiopia is often the lack of effective liaison by extension agents between the institutions providing agro-met information and the farming community. This challenge is compounded by insufficient education and training of the farmer-users on how to effectively utilize such information, including the farm advisory services that provide specific agricultural advice from general weather and climate information. Education and training for both groups are essential.

Given their different core missions, national hydro-meteorological services should for the most part play a supporting role, collecting agro-meteorological data, performing quality assurance and control, and then generating products and services at the proper temporal and spatial scales, while the ministry of agriculture focuses on delivery of weather and climate products to farmers through extension programs. All this suggests that special efforts are needed to strengthen the weather and climate capabilities of both the NHMS and the extension programs within the ministries of agriculture. Success in providing improved services requires close collaboration between the two entities.

Extension agents should be knowledgeable about farm-focused weather and climate information and be able

to communicate their knowledge clearly to farmers. They should also be able to assist farmers in utilizing that information in their decision making. Extension agents also need to represent farmers' needs to the agro-meteorologists for additional weather and climate products and services. In the end, the whole national agricultural meteorology program should be driven by farmers' needs.

To this end, one might explore opportunities to leverage the activities already under way by other international development agencies and NGOs, such as those being operated by the Rockefeller Foundation (Ethiopia) and by IDRC and the Syngenta Foundation (Kenya, Tanzania, Rwanda, and perhaps elsewhere). Activities that could be leveraged include the following:

- Joint training of agricultural meteorologists, extension agents, agronomists, and farmers which demonstrates the importance of agro-meteorological information for agriculture should be continuous and structured to facilitate the implementation of agro-meteorological information in farmer decision making;
- Continual improvement of the forecasts to make them more farm focused—that is, applicable to local conditions—instead of being based on large areas (this likely will require the development of downscaling schemes as well as the establishment of meso- and micro-scale environment observing networks);
- Strengthening of teamwork and coordination between meteorologists, agriculture personnel, and the communications services/media for expediting the delivery of tailored agro-meteorological extension services to farmers; and
- Development of a system whereby real-time data at agricultural meteorological stations can be available locally to the farmers, especially pastoralists with poultry, cattle, sheep, and goats, as requested.

In addition, better understanding is needed about the joint (multipartner) business practices and finances behind the procurement, installation, and management of agro-meteorology observing systems by entities other than NHMS. It may be that both regulation to ensure a free market and incentives to encourage following best practices are required.

CHAPTER TWO

TRADITIONAL AND NON-TRADITIONAL AGRO-WEATHER OBSERVATION SYSTEMS

Observations and measurements of both atmospheric and biological variables are essential in any agro-meteorological or agro-climatological endeavor. In order for agro-meteorologists and agro-climatologists to assist farmers and others in the agriculture sector with planning, forecasting, and other services that can be essential to personal survival and economic success, data, quantitative and qualitative, are required which describe the ever-evolving states of the atmosphere and the biosphere. Parallel agricultural data are also needed to assess the impacts of agricultural activities and processes on the environment and climate.

The necessary types of observations and measurements and their spatial density and temporal frequency depend on the purposes for which the data will be used. Characterization of the agro-climate of a region, monitoring and prediction of the evolving climate, and management of natural resources requires local, regional, and national coverage over a period of a few decades of a number of atmospheric variables. To ensure that the observations are representative of an area, spatial density of observations depends on the topography of the region of interest, with complex, mountainous terrain requiring many more points of observation than open plains.[13] For climatologic purposes, a temporal frequency of once or twice per day measurements is often satisfactory. To detect small climatological trends in data from a limited number of years of observation requires careful selection of instruments and a good QC/QA process (see below).

Long-term climatological information provides the background conditions within which day-to-day weather and farming operations are carried out. Such operations

[13] Agriculture in mountainous regions is often highly dependent on small regions with favorable **microclimates** scattered within larger regions that are generally unfavorable to farming or herding. Even in open country, observations are likely representative of a region only 3 to 5 kilometers in radius around the observing point.

include numerous weather-influenced decisions, such as when to plant, proactive responses to pests and diseases, management of irrigation, and when to harvest. Also included in such daily operations is the early warning of the onset of natural hazards (for example, flash flooding, wildfire, late or early frost, heat stress on livestock), together with monitoring of such events as they unfold. To provide information in support of the many weather decisions necessary in day-to-day farming operations, more frequent and additional observations are needed. The preparation of advisories and services on farming methods, including irrigation, pest management, and other types of microclimate manipulation, also require specialized data. To support such standard agro-meteorological activities, hourly or even one- to five-minute observations are often necessary.

An important step in the observation and measurement process is QC/QA of the data to ensure its quality. This needs to be a rigorous process to ensure that failing sensors and drifts in calibration are identified as early as possible and that accuracy and precision of measurements remain within the desired bounds. Even with simple measurements such as temperature, the QC/QA process has to be thorough to ensure that all reported values, particularly those of extremes, are meaningful. Therefore, QC/QA is particularly important where the goal is the detection of trends that are small in magnitude from a limited number of years of data. All too often, instrument calibration drift or malfunction has been interpreted as an emerging trend.

Experience has shown that a combination of automatic checking and review by trained human eyes is the best for such efforts. As a general rule in the QC/QA process, no data are ever discarded but rather are flagged to call the attention of users to the data being out of bounds.

As important as the data is the observing site metadata associated with them. Such metadata are essential in understanding the properties of the data streams. These metadata need to be comprehensive, including not only such basic information as station location and observing procedures, but also detailed data on the particular instruments in use. An example of the importance of the latter is the need to understand the cause of an abrupt warming in temperature data. This can easily be due to a change-out in the sensor making the measurement rather than to a natural event. Only by exploring the metadata can the cause of such apparent warming be identified. Such factors must be taken into account when the goal is to estimate changes of a few tenths of a degree in mean values over long periods of time.

Commercial sources have developed and provide a very wide range of equipment and systems to acquire, store, transmit, and process data on the atmospheric and biological variables of interest to agricultural meteorologists and climatologists. The next two sections review limited samples of these items, focusing on items of particular interest to the agro-meteorologist.

TRADITIONAL INSTRUMENTATION

What we call "traditional instruments" for the most part were devised in the 19th century and refined during the first half of the 20th century. They are characterized by the need for trained humans to read, record, and send in the collected data for others to scrutinize in a QC/QA process, and then analyze for operational use. In many cases, instrument components are fragile and require careful handling. Often, routine resupply of expendables is necessary. Most such instruments require regular maintenance and calibration.

A selection of traditional instruments is presented and discussed in the following paragraphs. These illustrate both the diversity of hardware and the range of measurements necessary to support agricultural meteorological operations. All of the systems presented remain widely used.

RAINFALL INSTRUMENTS

The most basic of all agricultural measurements is that of rainfall. Since the dawn of history, farmers have observed the amount of rainfall by collecting rainwater in various devices. Many of these devices are simple containers of various configurations that are read by eye. By the mid-1950s, more elaborate recording mechanical devices had become available. In recent years, not only the quantity of rain that falls, but the rate at which it does so have become of interest.

TEMPERATURE AND HUMIDITY INSTRUMENTS

Temperature measurements are fundamental to many agricultural products and services. For example, soil temperature determines optimal planting dates while growing degree days allows farmers to follow the maturation of crops such as corn and plan for harvest dates. Most traditional temperature sensors are some form of liquid-in-glass thermometer or utilize the distortion of bimetal or liquid-filled metal devices.

The moisture content of the air is another atmospheric variable of great importance. Usually this is expressed in the form of either "dewpoint" or "relative humidity" (though exactly what this last quantity means is often poorly understood). Many other moisture variables are used specifically in particular applications.

Data on moisture, together with corresponding temperature data, allow agro-meteorologists to advise farmers on heat stress on animals. Such data can also be accumulated in ways that allow the prediction of the emergence or appearance of a range of molds, fungi, and insect pests on crops, allowing farmers to minimize damage by taking appropriate preventative measures. Humidity data are also essential to assess wildfire danger.

A number of instruments can be used to provide a continuous record of temperature and moisture. Simple systems using clockwork chart drives have been devised. The most common example is the hygrothermograph.

TRADITIONAL AGRO-METEOROLOGY INSTRUMENTS

Temperatures within crop canopies—such as in orchards—can be of interest to assist in preventing frost damage and monitoring for the possible onset of plant diseases and various pests. Farmers and agricultural meteorologists use any of several "orchard grove thermometers" to keep track of temperatures in orchards and fields.

The grass minimum temperature is the minimum temperature measured (usually somewhat after sunrise) in open air in short turf, with the bulb of the thermometer just in contact with the tips of the blades of grass (usually about 5 centimeters above the ground).

This quantity is important to the agricultural meteorologist because the temperature at the surface often varies substantially from the air temperature as measured at 2 meters. Under dry conditions, during a hot summer day, the "grass temperature" might be much higher than the air temperature. Conversely it can be much, much lower at night during dry spells under a clear sky. In fact, the grass minimum temperature might be 0°C (32°F) or less, while the 2-meter air temperature recorded simultaneously is 4°C to 5°C or higher. This can produce a condition known as ground frost and is important information for farmers so that protective measures can be taken.

The temperatures at various depths in the soil impact plant germination and how rapidly plants take up water and nutrients, and thus affect the rate of plant growth. Soil temperature affects the breakdown of parent material and how fast microorganisms work. Both are important in adding and returning nutrients to the soil. Further, certain plant diseases and pests thrive in certain soil temperatures, so knowledge of soil temperature is important for taking appropriate measures.

A variety of thermometers, both liquid-in-glass and dial-type using bimetal strips, have been developed to measure soil temperatures at a variety of depths. Measurements are taken under grass cover or bare ground, depending upon the intended purpose.

There is no easy traditional way to measure the profile of soil moisture. This is unfortunate because soil moisture is often a quantity of great interest to farmers and agro-meteorologists alike. The gravimetric method is the only approach that was developed prior to the modern era (and is still used for calibration purposes because it provides a direct measure of the water content of the soil).[14] In this method, a soil core down to the depth of interest is taken using a standard Kirg tube; the core is sliced into segments, and each (moist) segment is weighed. The segments, one at a time, are dried in an oven to remove

[14] The gravimetric method is described in detail in Johnson, A.I., 1962: Methods of Measuring Soil Moisture in the Field—*Evaluates methods for measuring soil moisture and describes the equipment used.* Contributions to the hydrology of the United States—Geological Survey Water-Supply Paper 1619-U.

all moisture, and then weighed again. The difference in the before and after weights is a direct measure of the soil moisture. This is clearly a time-consuming process that requires both extensive training and specialized facilities.

In arid environments, in addition to measuring the water arriving via rainfall or the flow of streams and rivers across an area, net evaporation from the surface land and water bodies must also be determined. Such information is essential for planning and implementing irrigation programs, as well as estimating the return on investment to be received from implementing strategies to reduce water loss from crops and the soil.

Weighing lysimeters are used to directly measure the loss of moisture from both plants and soil (Davie 2002). These are complex devices to operate and maintain, and are usually found only in agricultural research institutes and universities. As a substitute, agro-meteorologists and agricultural engineers have devised what is termed (in the United States) the "Class A Evaporation Station."

NONTRADITIONAL INSTRUMENTS

AUTOMATIC WEATHER STATIONS

Since the end of World War II, meteorological observing and measuring equipment has evolved rapidly in parallel with the growth of modern technology. While numerous novel approaches to sensing temperature, humidity, precipitation, and other atmospheric variables have been developed, perhaps the greatest advances have been in the replacement of human observers and handwritten observing forms by electronic data logging and transmission systems. Within a few seconds of being made, observations from across a wide region can be collected at a central location, error-checked, and made available to meteorologists and other users.

Many of these technologies can be packaged to produce "automatic weather stations," some examples of which are shown below. These stations can be configured with a wide variety of sensors to provide data to meet specific operational requirements. An on-board computer or "data logger" handles the collecting and initial processing of sensor readings. Many of these systems can provide automated generation and transmission of meteorological reports, make special observations when preset thresholds are crossed, and provide alert messages when preset thresholds in key variables are exceeded.

Automatic weather stations are most powerful when operated in a network across a region. The data streams can be brought to a central location for quality checking, analysis, merger with other data such as terrain and soil maps and information on when to plant, irrigate, fertilize, and harvest. Individual stations will usually have some storage capability, so that when communications to the central collection point are interrupted, data continue to be collected. It is then forwarded to the central collection point when communications are restored. The network of individual station computers manages all the necessary communications protocols.

Using a network of automated systems to provide weather and climate observations has many advantages over traditional manual systems. These advantages can be summarized as follows:

- Standardization of observations, both in time and quality
- Greater reliability—real-time continuous measuring of parameters on a 24/7 basis
- Improved accuracy (eliminates reading errors, subjectivity)
- Collection of data in a greater volume, for example, one-minute or five-minute data as opposed to hourly or once per day
- Automatic adjustment of sampling intervals of different parameters in response to changing weather events
- Automatic QC/QA during collection and reporting stages, including automatic alerts to users and maintenance personnel when errors are detected
- Automatic message generation and transmission, including alerts when critical thresholds are crossed
- Automatic data archiving
- Access to data, both real time and archived, locally or remotely
- Collection of data in remote, harsh, or dangerous climates

Automated observations also bring their own set of disadvantages. Some of these are as follows:

- There is a high initial cost of instrumentation and associated equipment and then ongoing costs of operation, such as for maintenance, electrical power, communications, security, and so on.
- It is not possible to observe all desirable parameters automatically; at key locations, it may be necessary to augment automatic observations with a human observer to obtain information such as cloud coverage and cloud types.
- If solar panels are used to power a station, this may limit the amount and type of instrumentation, local computing, and telecommunication equipment that can be used.
- Final quality control is best carried out by a staff of trained operators working on a 24/7 basis.
- The high volume of data generated requires the development of a data archival system that can be costly in its own right, which will require periodic forward migration as software changes.
- Routine preventative and as-required corrective maintenance, together with periodic sensor calibrations, require a staff of trained maintenance technicians.

Maintenance and calibration of the numerous devices and sensors comprising automatic weather stations require technicians with training and experience, spare sensors, repair parts and expendables, and the availability of appropriate facilities. Most such stations are designed to operate in mid-latitude conditions and in areas where significant supporting infrastructure is routinely available.

Most commercially available automatic weather stations are designed for use in the moderate climate zones of the northern hemisphere, although the meteorological and climatological requirements for observations are valid for all climatic zones. Special attention must be given to the design of automated systems intended for service in the tropics, deserts, and mountainous regions, as well as climates susceptible to severe weather events such as hurricanes. Extremes in temperature, humidity, wind, precipitation, and solar radiation together with sea salt–enhanced corrosion, birds and insects, and lightning can all pose special challenges for automatic weather stations.

Unfortunately, there are no standardized practices and only limited guidance available on implementing and maintaining observing systems in harsh climatic environments. Each such observing system must therefore be designed as a one-off, often trial-and-error configuration. Special instruments, hardened computers, and stronger towers, as well as more frequent routine maintenance, will likely be required, all of which comes with significant additional costs.

SPECIAL AGRO-METEOROLOGY RELATED SENSORS FOR USE WITH AUTOMATIC WEATHER STATIONS

In this section, we show a few illustrative examples of instruments that have been developed to assist the agro-meteorologist.

Water from rain or dew remaining for any extended period of time on the leaves of many different types of plants, particularly those with a dense leaf canopy, is a major contributing factor to the emergence of plant disease. For example, limited air circulation and longer leaf wetness favor late blight development on tomatoes, as well as potatoes.[15] An agro-meteorologist can contribute significantly to an integrated pest management program by providing data on leaf wetness.

In addition to soil temperature and soil moisture content, soil salinity is a vitally important measure, particularly in irrigated areas.

In hot and humid environments, livestock health is a continuing issue. One measure of animal comfort (and of people as well) is the Wet-Bulb, Black Globe Temperature (WBBGT). Experience and field testing has shown that heavy physical effort by livestock and humans should be avoided if WBBGT > 32.9°C. WBBGT is widely used in

[15] Late blight is a serious plant disease that mainly attacks potatoes and tomatoes, although it can sometimes be found on other crops, weeds, and ornamentals in the same botanical family. Late blight was a factor in the Irish potato famine in the 1850s, where entire potato crops rotted in the field or in storage because of late blight infection.

the feedlot industry to mimic the effect of solar radiation on the comfort of cattle. It also can be used for comfort measurements of other animals and humans.

Other animal comfort measures that can be derived by data collected with an automatic weather station include the following:

- Temperature Humidity Index (THI)
- Heat Load Index (HLI)
- Accumulated Heat Load Units (AHLU)
- Current evaporation rate and total evaporation for the day

Temperature Humidity Index, Heat Load Index, and Accumulated Heat Load Units are important measures of animal comfort. As livestock starts to experience even mild heat stress, feed uptake drops, weight gain slows, and fertility rates drop. In dairy cows the milk production drops. As the heat stress worsens, animals can die unless appropriate steps are taken. Even one heat event managed correctly can pay for the cost of an automatic weather station. In times when heat stress is not an issue, the agro-meteorologist can use the information to link animal comfort to feed consumption and live-weight gain.

The current evaporation rate is a measure of the rate of loss of surface moisture. The evaporation rate can be determined from a Class A pan by monitoring it continuously with an automatic weather service. These data can be related to the rate of evaporation in animal pens, also affecting in-pen humidity readings and thus, cattle comfort. The current evaporation rate is also very useful in irrigation scheduling.

Another quantity of interest to the agro-meteorologist is the net radiation received by the surface (usually covered with some type of plants). The main applications for net radiation data are in the study of evapotranspiration and in climatology, meteorology, and hydrology for the measurement of the overall radiation balance.

Net radiation is the balance between incoming radiation from the sun and sky and outgoing radiation from the ground. Short-wave radiation of 0.3- to 3-µm wavelength reaches the Earth's surface, where some of the radiant energy is reflected and the rest is absorbed by the surface. Incoming long-wave Far-Infrared (FIR) radiation from 4.5 to more than 40 µm is also absorbed by the surface, which heats up and emits FIR back to the sky. The four components of net radiation are thus the incoming and reflected solar radiation (from which the surface albedo may be calculated) and the downward and upward infrared radiation. Simple net radiometers combine two sensors, one pointed toward the ground and one pointed toward the sky. The sensors are wired together so that output of the system is the sum (the net) of the four radiation components. Even simpler systems use only one system to view both the sky and the ground.

Radiation instruments were historically quite expensive. In recent years, however, much less expensive instruments have become available. While these lack the precision of the more expensive systems, they can produce data perfectly adequate for a wide range of agro-meteorological purposes.

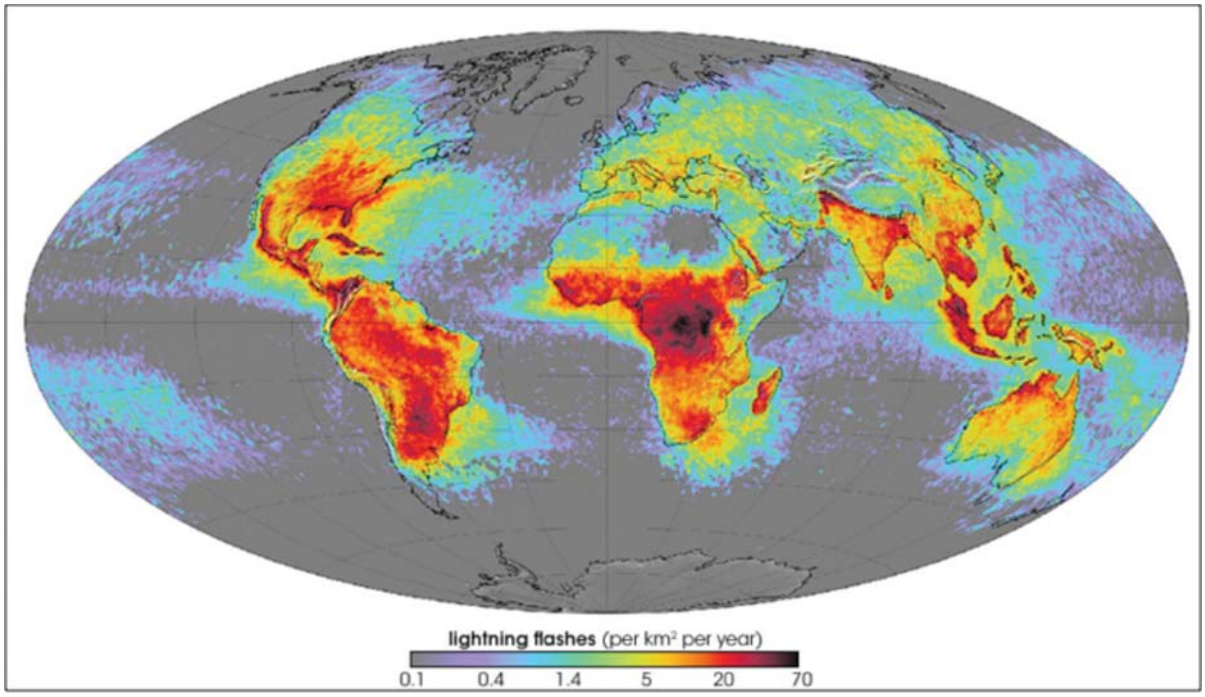
Measuring precipitation is a challenge with any automated station. Most of the readily available systems have moving components that can produce a variety of errors and have ongoing maintenance requirements. Fortunately, various systems to measure rainfall without moving parts have come on the commercial market in recent years. These include laser distrometers and small vertically pointing radars. Low-maintenance precipitation measurement systems offer a major advantage over the common tipping bucket and weighing gauge processes.

Systems such as those shown here are relatively expensive. However, considering over the life of the instruments (10, 20, or more years) the potential savings from the reduced maintenance requirements, such instruments become more cost effective.

AREA RAINFALL ESTIMATES FROM LIGHTNING LOCATING SYSTEMS

The instruments considered up to this point provide surface-based, point-location measurements. While such measurements are essential to an agro-meteorologist, they do not provide a full picture of what is happening weather-wise over a region. This is especially true with

FIGURE 2.1. GLOBAL LIGHTNING FREQUENCY



Source: Image from National Aeronautic and Space Administration (NASA); data for 1995–2002.
Note: Annual global lightning (flashes per square kilometer per year). As implied by the mapping of lightning frequency shown here, thunderstorms are concentrated in Sub-Saharan Africa and other tropical regions of the world, where many developing countries are located. The equatorial regions of Africa and South America can experience thunderstorms on more than 140 days per year with some areas having storms more than 200 days per year. Such storms account from much of the annual rainfall in these regions.

regard to rainfall. The traditional tool for the meteorologist in monitoring rainfall over an area has been weather radar, an active sensing technology.[16] However, weather radars are expensive to procure, install, operate, and maintain. Consequently, weather radars have proved impractical for many of the least-developed countries in Africa.

A significant fraction of the total annual precipitation in Sub-Saharan Africa is produced by thunderstorms. Thus it is very fortunate that in recent years, significant advances have been made in lightning location technologies that now allow such passive systems to serve, in large part, as substitutes for weather radars.[17] Given that these lightning location technologies are much less expensive to install and maintain, they may be an attractive alternative to weather radar for many countries in Africa.

While a single lightning sensor can provide useful information regarding lightning strikes within its detection range (a few hundred kilometers), operating a network of such sensors spaced a few hundred kilometers apart allows the monitoring of thunderstorms over or advancing into a region in detail. Recent developments in lightning detection (both cloud-to-ground and in-cloud), location, telecommunication, and timing technologies have greatly enhanced the capability to acquire and quickly process signals from a network of lightning sensors deployed across a region, resulting in useful data sets of time and location of discharge occurrence, intensity and polarity, and other factors. These networks now also allow the near-real-time monitoring of the evolution of the occurrence of lightning flashes in a particular storm, from which much can be inferred regarding the state of the producing thunderstorm (figure 2.1).

[16] Radar is an "active sensing technology" in the sense that electromagnetic pulses are generated by the radar and emitted into the atmosphere to produce electromagnetic echoes. These echoes are then processed by the radar system to determine the location and movement of particles in the air.

[17] Lightning locating systems are "passive sensing technology" in that they do not emit electromagnetic radiation but rely on detecting electromagnetic signals produced by nature in the lightning discharge.

Using correlations between spatial and temporal densities of flashes and storm rainfall, maps of lightning flash rates can be presented in formats similar to what is done for radar reflectivity. These pseudo-reflectivity values can be used to enhance thunderstorm prediction and could serve as a cost-effective radar alternative in underdeveloped regions of the world. By applying formulae similar to those used with radar reflectively fields, the lightning-based values can be used for precipitation estimates. When accumulated through time, just as is done with radar-based precipitation estimates, one can display accumulated (estimated) rainfall over periods ranging from one hour to several days, weeks, or months.

The lightning detection and locating and associated signal processing systems marketed by Vaisala, Earth Networks, the U.S. Precision Lightning Network (USPLN), and others, and the value-added resellers such as Weather Decision Technologies, Inc., illustrate what can be done with modern detection techniques and advanced signal processing systems.

For current purposes, lightning detection and locating sensors are well suited for installation on or proximate to cell towers (see discussion in **Chapter 6**). A network of such detectors is very attractive because the sensors are passive with low power requirements while the telephone network supporting local cell service provides the reliable, wide-bandwidth communications necessary to rapidly move the lightning data back to a central server for processing.

Total lightning and other lightning detection systems have one shortcoming. They require that lightning occur before they can be used to infer the presence of deep convection, precipitation, and other weather elements. With deep convection, this means the initial stages of the formation of a cloud cannot be detected. Further, much rainfall comes from stratiform (layered) clouds that seldom produce lightning. Lightning detection networks need to be complemented with other observation systems to detect precipitation associated with forming thunderstorms and stratiform clouds.

DISCUSSION

Traditional instrumentation still has many applications, particularly with regard to agro-meteorology. Many of the instruments are suitable for reading by individuals with only modest training, offering opportunities to involve local people in the observing process. Although reporting can be slow, in the age of cell phones it can be made much faster than the traditional mail-at-the-end-of-the-month approach. The primary disadvantages are that many of the instruments are fragile and easily broken, the readings are subject to a variety of errors, and the whole system is manually operated, limiting the data available for real-time operations and making the development of a central archive a challenge.

In many situations, traditional instrumentation has been supplanted by automatic observing systems, which offer many opportunities for improving meteorological services of all types. Automatic weather stations are most powerful when operated in a network where the data streams from the various observing stations are brought together in real time at a central collection facility. One can then follow in near real time the evolution of weather as it happens across a region.

Automatic weather stations bring their own challenges. Many of these can be addressed through a careful system design process. A backward planning process is often the best design approach. In this case, the products and services to be supported immediately and in the future by the automated observing network are detailed first. These products and services should be defined very carefully and in complete detail. User input is critical to this discussion. For example, a NHMS should undertake the establishment of an agro-meteorological network in close consultation with academic institutions, the ministry of agriculture, and agriculture extension programs in particular.

Site selection can be challenging because a number of criteria must be met. Access to power (unless a solar panel is practical), telecoms (which may include access to a cell network), security, lightning protection, and access for technicians are among these. Planners must also determine how representative a given site is.

The standard WMO guidelines and recommendations for site selection should be followed to the extent possible (WMO 2010). However, these recommendations are largely for synoptic observing stations, often located in the large open spaces of airfields. Thus, they may not always

be appropriate for the meso- or microscale observations needed by agro-meteorologists. The WMO Integrated Global Observing System (WIGOS) program has begun to recognize the need for local networks.

The stations of the proposed network should be flexible enough to absorb new hardware and software components as technology changes and upgrades become available. Since the controller, data logger, or similar device is the heart of any automated weather station, special attention needs to be given to its specifications to ensure ease of use and flexibility in swapping out existing sensors or installing additional ones. This often means initial over-specification on the capabilities of the data logger and the available bandwidth on the communications system. Good design favors the use of open-source software and avoids use of proprietary software wherever possible. In addition to making changes to sampling rates, a proactive quality assurance program is necessary.

The central data archive needs to be designed early in the process, when planners need to determine what data will be stored and how metadata will be handled and made available.[18] Network metadata are an essential part of the data archive. At a minimum, these metadata should include a thorough history of the site and each instrument and observing system used in the network. This technical history of the network is essential to climatological work.

Forward migration of the archive as software and hardware changes occur needs to be considered—a data archive should be considered a national resource to be preserved in perpetuity. Maintenance, both preventive and corrective, and calibration are expensive and time consuming, but they are essential if a sufficient return-on-investment is to be obtained from the network. The NHMS needs to allocate sufficient funding to support the long-term life cycle of the network.

Finally, the human side of upgrading a network from manual to automatic needs to be carefully considered and factored in to plans. Human observers may be suspicious that deployment of automatic systems will mean the loss of employment. They may also doubt that sufficient funds will be forthcoming to properly maintain the automatic equipment.

One approach is to offer former observers the first opportunities for training to become the operators, QC/QA specialists, and maintenance technicians for the upgraded network. This may represent a major investment to raise their skills to the levels needed. The training should therefore be started well in advance of system deployment as a central part of a transition plan. These individuals should be involved in the planning and implementation of upgrades and extensions of the network so they develop a sense of ownership for the upgraded network.

[18] Most archives are set up to receive all data collected. The QA process does not discard any data but provides flags on data that are questionable or missing. These flags become part of the data set. This allows future users to access the "raw data" and then provide any filtering or corrections as they see fit.

CHAPTER THREE

ADOPTION BARRIERS FOR AGRO-WEATHER OBSERVATIONS

As may be inferred from previous comments, this report recommends each nation have a comprehensive agricultural meteorology program supported by a nationwide observing system. However, there are a number of significant adoption barriers to establishing and sustaining such national programs. These can be classified as *cultural, bureaucratic,* and *financial*.[19]

CULTURAL BARRIERS

Cultural barriers can crop up in many guises, including the all too familiar, "we've never done that before and are not going to start now," in bureaucracies. Here we comment on cultural barriers likely to be encountered in the field, where agro-meteorologists, working with and through agricultural extension agents, attempt to encourage small landholders to make better use of modern weather knowledge. Around the world, farmers tend to be conservative in their farming practices. This seems to be particularly true with small landholders living at or near the subsistence level and in areas where local village or tribal links remain strong. In many settings, local indigenous weather predictors rely on close observation of plants, animals, and other natural indicators. Many have long experience with farming and weather events in the area. Local lore, such as the phenology of plants and animals in the area, can provide insights into local, microscale weather and climate phenomena, as can careful study of the clouds that come and go overhead.[20]

[19] Due to the lack of materials either published or posted to easily identified websites, this section is necessarily somewhat broad and lacking in specificity. There may well be tighter connections between the NHMSs in Kenya and Ethiopia, their respective Ministries of Agriculture and their research institutes, and farmers than what is suggested here. However, those connections are not readily apparent from a distance. The thoughts expressed here were formulated after a careful reading of several reports by nongovernmental organizations operating in the two countries and from what could be gleaned from the various websites of the organizations of interest, and after discussions with individuals who had worked in those countries.

[20] **Phenology** is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate, as well as habitat factors (such as elevation).

As an example of a local indigenous weather forecaster, consider 73-year-old Wilson Yoeze, resident of the Same district, one of the seven **districts** of the Kilimanjaro Region of **Tanzania**). He has been predicting local rainfall since 1965, looking to the skies and to local flower and tree species for clues to the weather. "When we started," he says, "we were depending on observations of certain signs. We looked at stars and clouds. . . . There are clouds that only appear when the season is about to begin." According to Yoeze, if a single thick cloud leads the sky cover as it moves from east to south, a good rainy season is on its way. Another sign of long rains is the appearance of a bright star from the east known as *ngate kere*. "When none of these appear," he says, "there will be no rain at all and starvation will be great" (Ogodo 2012). Indigenous weather forecasters often have significant influence on critical farming events such as dates of planting and harvest, or the movement of livestock to winter or summer pastures. They also may predict rain or dry weather, and so strongly influence decisions about water management. To date, the methods of indigenous weather predictors have been poorly understood, but locally, their advice is actively sought out by many farmers.

Traditional forecasters have long guarded their knowledge and shared their predictions only with the elders and farmers in their villages. In spite of their mysterious ways, at the local level, their predictions can add a degree of precision that has been missing from the coarse regional outlooks typically provided by national hydro-meteorological services. Given the strength of tribal organizations and the tight knit populations in many villages, the best approach appears to be for agro-meteorologists to work with and through local indigenous weather forecasters. One such effort is found in the Tanzania Meteorological Agency (TMA). According to research team leader Henry Mahoo of Sokoine University of Agriculture, in Same district, the TMA and indigenous forecasters now work together on a consensus forecast that bridges the two knowledge systems. As a result, he says, "the image of indigenous forecasters is now positive to both farmers and district authorities." Same District Council has since committed funds to sustain these consensus forecasts. In general, it may take special training by experts in indigenous knowledge and traditional lore of agro-meteorologists for them to be effective in such an approach.

This suggests that an agro-meteorologist coming into a new region should start by building positive relationships with the local indigenous weather forecasters. Further, the agro-meteorologist might consider recruiting local indigenous predictors and farmer-leaders to become local observers. Such individuals can be provided with a set of simple meteorological instruments, and the necessary training to use them. It is now fairly easy to work up a system whereby such individuals can complete simple reports on a cell phone and submit them to a central number. Such local readings, properly quality assured and controlled, can be an important meso- and microscale supplement to data from standard observing sites. This involvement should build a local sense of ownership of the agro-meteorological program in the area, so that it is no longer perceived as being dictated from the national capital. Quality assuring and controlling such data is a not a trivial matter and requires significant investment of staff time, hardware, software, and funds.

BUREAUCRATIC BARRIERS

The agro-meteorologist and agro-climatologist are specialists in the same way the aviation meteorologist, the hurricane forecaster, the fire weather meteorologist, and the river hydrologist are specialists. Where the national agricultural weather program is situated within a government varies by country, most often in either the agriculture ministry or the national hydro-meteorological service.

The national hydro-meteorological service has professional and technical personnel to support data collection, access international model output, do the necessary analysis and synthesis of data and model output, and produce the general forecasts that agro-meteorologists need to provide specialized products and services for the agricultural community. Agricultural observing networks can provide the national hydro-meteorological service forecasters with meso- or microscale data. Such fine-scale data can allow the general forecasters to follow the evolution of weather systems in ways that might not otherwise be possible. Data from the agricultural network also help further develop the nation's general climatological database. The national hydro-meteorological service is clearly a professional home for the "meteorology" in "agricultural meteorology program."

On the other hand, the work of agro-meteorologists supports and extends the work of agricultural extension agents, who are almost always employees of the ministry of agriculture. Agro-meteorologists will often accompany extension agents into the field to meet with farmers and discuss their weather and climate issues, and will work closely with farmers, agronomists, agricultural engineers, and extension agents to address a wide range of agricultural problems. The agro-meteorologist needs the support of extension agents in organizing local people to serve as volunteer observers and to acquire land for automatic weather stations. The senior leadership of an agricultural meteorology program needs frequent access to the senior leadership of the ministry of agriculture to ensure the resources of the national agro-meteorology program are properly focused on the nation's agricultural priority areas. The ministry of agriculture is clearly the professional home for the "agro-" in "agro-meteorology program."

The agricultural meteorology program—and by extension, its staff—can easily find itself trying to work within the different rules, policies and procedures, and performance expectations of two different government agencies. That is not a good situation.

Complicating the question of where an agricultural meteorology program would be most suitably located is the deep institutional conservatism typical of so many government bureaucracies.

Complicating this decision is the fact that government bureaucracies tend to be very conservative and seldom welcome significant changes. This conservatism all too often leads to the "not invented here" syndrome or to competitive empire building by senior managers. In too many cases, these last are accompanied by a reluctance to openly share real-time and archived data or to adopt the open software systems that provide virtual sharing of such information between the national hydro-meteorological service, relevant government ministries, academia, and the private sector.

Much depends on the policies and procedures of the country involved as well as institutional cultures of the national hydro-meteorological service and the ministry of agriculture. The challenge to the nation's senior leadership is to establish clear policies and procedures that push the national hydro-meteorological service and government ministries in the desired direction, and then to put in place an incentive structure that will make ensure these policies and procedures are followed.

A memorandum of understanding between the national hydro-meteorological service and the ministry of agriculture is a highly useful way to arrive at a consensus about what the responsibilities and objectives of a national agricultural meteorology program are. The memorandum can serve as a reference for the development of a standard operating procedure in which the specific agencies that agro-climatologists and agro-meteorologists are responsible to is specified. It can also stipulate the responsibilities of the concerned institutions and agencies and the indicators that will be used to rate their performance, as well as the financial commitments that will be required of them in covering salaries, facilities, and operating expenses. Nepal provides an excellent example of an agricultural information management system that provides weather and climate information to government institutions and farmers alike.[21] The national agricultural meteorology program is a field-oriented organization position, with only limited desk time for most professional staff. Responsibilities for linking to regional programs such as Regional Center for the Training and Application of Operational Agro-meteorology and Hydrology (AGRHYMET) and ICPAC, as well as international aid agencies should be specified. A joint annual evaluation process, of both program and individuals, including feedback to the user community, should be described in detail.

Whether or not the ministry of agriculture is the administrative home of the national agro-meteorology program, that program will necessarily be a bridging activity that links the national hydro-meteorological service to the extension programs of the ministry of agriculture.

[21] An example of the development of such an agricultural management information system providing timely essential weather and climate information to government authorities and key user groups such as farming communities is being developed for Nepal. For more details, see http://moad.gov.np/ppcr/datadigization.pdf.

FINANCIAL BARRIERS

Finances are always a particular challenge in small government organizations such as the national hydro-meteorological service, and even for small programs within large ministries, such as an agricultural extension service. Their budgets are almost always set by central government authorities, often through drawn out administrative and legislative processes. Neither the hydro-meteorological service nor the extension services are generally considered high-profile agencies at higher levels of the national power structure, and both tend to lack champions at those levels. This lack of popularity has important ramifications for a national agro-meteorology program.

Regardless of how well they are funded, the national hydro-meteorological service and the ministry of agriculture are the primary caretakers for their country's "weather asset" and its "agricultural asset," respectively. Any effort to establish an agro-weather or agro-climate program, together with an appropriate observing network, must involve both—especially regarding budget matters.

A number of national hydro-meteorological services around the world are strongly focused on aviation meteorology. In some countries, there is a separate agency with its own budget—often more generous than the one for the NHMS—handling aviation meteorology at the country's internationally recognized airports. This has occurred in large part because of the visibility of aviation weather services to senior government leaders and high-ranking staff, as well as to top business personnel, all of whom fly frequently (and formal requirements from international agencies such as the International Civil Aviation Organization [ICAO] to have airports so recognized).

A comprehensive agro-meteorology program, implemented in partnership between the NHMS and the ministry of agriculture can attain prominent visibility with top government officials when the use of its information by farmers has a dramatic impact on agricultural production. This is more likely to happen once each of the required elements is in place: trained professional staff, support staff, hardware and software, national observing system, and so on. Trained staff must be recruited, an observing system established and made operational, new agro-meteorological products and services designed and implemented (with significant input from the potential users), and farmers trained by agricultural extension agents and agro-meteorologists in how to use the information in those products and services.

Owing to financial constraints, particularly in the least-developed countries, many national hydro-meteorological services have very limited numbers of staff. Retaining staff, particularly those with expertise in areas like climate impacts, is difficult. Providing time and support for the professional development of staff, participation in international meetings, and undertaking new initiatives in small organizations places additional burdens on those who are left to attend to day-to-day work, decreasing morale and reducing support for new ventures.

Changing this situation requires convincing the highest levels of government that investment in NHMS funding and staff will have significant positive impacts on the country. This is a challenging task for the leadership of an NHMS. The impacts may not be seen for three, five, or more years after the investment is made, while government leaders tend to focus on much shorter-term issues. In many respects, this is a circular problem in that to justify investment, performance has to be demonstrated, but the performance cannot be demonstrated until well after the investment is made.

It is during this initial three- to five-year period that NGOs and international aid agencies can have an impact, covering many of these start-up costs and providing the nascent agro-meteorology program the time needed to demonstrate its value to the government.

For this approach to result in a sustainable program, it may be necessary for the NGOs and international aid agencies to make parallel investments in the national hydro-meteorological service and ministry of agriculture. (Some examples of this have been mentioned previously.) Such parallel investments may be necessary because few if any of the national hydro-meteorological services and agricultural extension services in the least-developed countries and some of the more-developed ones appear to have staff with the skill sets required. These include strategic planning;

end-to-end systems engineering leading to acquisition and installation of high-tech equipment; and new business development, marketing, new product development, and design and implementation of delivery systems.

These are the same skills that are required to establish a comprehensive agricultural meteorology program and agricultural weather observing network of the sort recommended here. Expertise and experience on such matters must be brought in from NGOs, private sector consulting companies, and universities with agricultural programs in Africa, Europe, and North America. This should be done through appropriate contractual, collaborative, or partnership agreements in a tightly coordinated effort that provides initial support and capacity building, while leaving the ownership of the program with the NHMS and responsible ministries.

To be sustained over the long term, a comprehensive agricultural meteorology program must have sufficient impact on its country's agricultural production to attract budgetary support from the highest levels of national government. Alternatively, the program may find a way to partner with interested private sector entities, though a combination of public and private funding sources may be preferred.

CHAPTER FOUR

COST-EFFECTIVE STRATEGIES FOR UPSCALING AGRO-METEOROLOGICAL OBSERVATION SYSTEMS

Quantifying the costs and benefits associated with an agro-meteorology program is a challenging exercise. It is particularly challenging in developing countries such as Ethiopia and Kenya where agricultural production is based on a very large number of often very small farms that cultivate a wide variety of crops and raise a variety of different livestock animals.

Because no comprehensive study of the costs and benefits of agro-meteorological services appears to have been carried out anywhere in East Africa, this analysis is limited to a review of the few relevant studies that have been undertaken, and to reporting preliminary results that are indicative in nature.

ESTIMATING A COST-BENEFIT RATIO FOR AGRO-METEOROLOGICAL SERVICES

Experience in other countries shows that agro-meteorological services help guarantee that farming is as efficient as possible (minimizing costs) and results in a good quantity of high-quality agricultural products (maximizing the return on farmers' investments). These benefits come through improving the bases on which farmers make decisions. Each such decision that is informed by enhanced meteorological or climatological information results in reduced costs for routine farming activities and enhanced income at the end of harvest.

The benefits stemming from ordinary farming decisions made with enhanced weather and/or climate information have been the subject of a number of studies. The most relevant of these appears to be that by Ansalehto et al. (1985). This study was a joint project of the Finnish Meteorological Institute, the Agricultural Research Centre, and the Association of Agricultural Producers in Finland. The goal was to identify the requirements for further agrometeorological research and the need for daily services

to Finnish farmers, to estimate costs and benefits of such services, and to make suggestions for the development of an agrometeorological service for the country as whole.

In three growing seasons from 1982 through 1984, the working group offered experimental services to 230 farmer-participants, all in a small area in southern Finland. These farmers were offered weather forecasts specifically tailored to agricultural purposes through an automatic answering machine, five days a week for each of the three growing seasons (May to September). Farmers were presumed to be able to make good use of the specialized meteorological information on their own; they were not given any training on how to use the information.

To evaluate the economic impact of this prototype service, questionnaires were sent to the farmers. The responses to this survey revealed that it was very difficult for many farmers to assess the amount of economic benefit they had gained from the specialized meteorological services. However, based on the responses of the farmer-participants taken as a whole and on other agro-economic data, the potential benefits and losses were considered and the cost-benefit ratio was estimated by agronomic experts to be about 1/30.

For a similar service covering all the agricultural regions of Finland, the researchers estimated the cost to be about FIM 4.2M a year, assuming strong leveraging of existing observing networks and other assets.[22] Thus, the expected yearly benefit for Finland as a whole resulting from the provision of specialized agro-weather services would be an increase of about FIM 120/year in national agricultural production.

Further, extrapolating from the study's findings with 230 farmer-participants, this net benefit would result from the following areas where farmers had to make decisions:

- Sowing: ~FIM 44.5M/year
- Spraying and protection: ~FIM 29.6M/year
- Harvesting: ~FIM 44.5M/year
- Other actions: ~FIM 7.4M/ year
- **Total:** ~FIM 120M/year

Following are a few comments on the results drawn from the Ansalehto et al. (1985) study:

- Across the 230 farmer-participants, each individual farmer likely saw only a small net benefit or even a net cost, perhaps sufficiently small to be lost in normal year-to-year variations. But collectively, averaged across the three seasons, the overall net benefit was found to be significant.
- The biggest impacts were associated with the planting and harvesting phases, so products and services supporting these activities should be a priority for an agro-meteorology program.
- Recall that the farmer-participants received no training on how to best use the forecast products that were provided. One can easily imagine that with a program of aggressive initial training followed up with annual update and refresher training, it is likely the cost-benefit ratio might change to 1/50 or even 1/100.
- For planning purposes, it seems reasonable to assume that cost-benefit ratios in the range of 1/30 to 1/50 to 1/100 (➔ low/medium/high) bracket the likely values for most agro-meteorology programs.
- The Finnish Meteorological Institute had a well-developed observing system installed across the country at the time of the study. Thus, capital costs were taken to be very low, with most of the costs coming from refining and enhancing the prototype service used in the study. Continuing annual costs were taken to come mainly from the addition of necessary new staff. The cost-benefit ratio was based only on the increased continuing costs.
- If there are capital costs and they are paid using local funds, then they should be amortized over the life of the equipment and the facilities. This would increase the cost-benefit ratio (make it less attractive) to some extent. On the other hand, if the capital costs are paid by an agency external to the nation, then they would not need to be amortized. It is this last situation that is assumed in what follows.

[22] FIM = Finnish markka. All FIM amounts in the text are in 1984 values. Finland converted to the Euro (February 2002), however, pseudo exchange rates are still maintained for calculation purposes, for example, in 1984, US$1 = 6.0100 FIM ➔ FIM 4.2M ~ US$699,000, while FIM 120M ~ US$20 million. Taking into account inflation in the two currencies, in 2013 ➔ FIM 4.2M ~ US$938,000, while FIM 120 M ~ US$27 million.

POTENTIAL IMPACTS ON ETHIOPIA AND KENYA

Utilizing the information from the report by Ansalehto et al. (1985) as discussed above and further informed by the estimation process outlined in Hautala et al. (2008), we can make some rough estimates of the economic impacts of various types of agro-meteorology programs.

Much depends on the type of agro-meteorology program that is implemented. Three alternatives warrant note: Traditional/Minimal, Transitional, and Modern/Advanced. In each case, there is an initial capital cost for procurement and deployment of equipment, routine maintenance of facilities, and hiring and training of staff to use the new observations, new tools, and new techniques to provide more and better products and services. There is also an ongoing annual cost for staff, maintenance of equipment and facilities, and continued training. In light of the Finnish report, I assume that the cost-benefit ratio will improve significantly with both an increasing suite of meteorological and climatological products and services together with vigorous training of farmers on how to interpret the information and apply it to everyday decisions.

Again, all the numbers here are only rough estimates but should be of the right order of magnitude.

Let us assume three types of agro-meteorology programs:

Traditional/Minimal—mostly traditional instrumentation, with automated systems at only a very limited number of locations; limited professional agrometeorological staff ➔ very limited field training or extension work; no real-time operations (more or less the current status in both Ethiopia and Kenya)

- Initial capital investment in equipment, facilities, training: US$3 million
- Continuing annual cost: US$1 million
- C/B ratio: 1/30 ➔ ~ US$30 million increase in agricultural production

Transitional—still mostly traditional instrumentation, but more automated systems in regional networks; staff of agro-meteorologists and supporting technicians still modest in size but now sufficiently large to begin routine training of farmers and support weather- and climate-related extension work; limited real-time operations

- Initial capital investment: US$20 million
- Continuing annual cost: US$5 million
- C/B ratio: ~1/50 ➔ ~ US$250 million increase in agricultural production

Modern/Advanced—national network of automated systems supplemented by traditional instrumentation, professional staff now able to support full-scale real-time operations and fieldwork for training and extension support

- Initial capital investment: US$50 million
- Continuing annual cost: US$10 million
- C/B ratio: 1/100 ➔ US$1 billion

Applying these results to Ethiopia and Kenya:

In Ethiopia, agriculture accounts for about 39.4 percent of the national GDP = US$41.72 billion (2012 estimate or about US$16.44 billion).[23] Thus a traditional, minimal agro-meteorology program would increase the agricultural contribution to GDP by about 0.18 percent; a Transitional program, by about 1.5 percent; and a modern/advanced program, by about 6.1 percent.

In Kenya, agriculture accounts for about 24 percent of the national GDP = US$40.70 billion (2012 estimate or US$10 billion).[24] A traditional or minimal agro-meteorology program would increase the agricultural contribution to GDP by about 0.30 percent; a Transitional program, by about 2.5 percent; and modern/advanced program, by about 10 percent.

Thus, the magnitude of the benefit to be gained by delivery of a full suite of agro-meteorological products and services, coupled with an aggressive training program for farmers on how to use this information in their routine decisions, can encourage the nation's leadership to maintain and further develop the program delivering such services.

It is a combination of (1) the development and delivery of a suite of agrometeorological products and services,

[23] http://www.worldbank.org/en/country/ethiopia.

[24] http://www.worldbank.org/en/country/kenya.

coupled with (2) an aggressive training program for farmers, which produces the maximum level of success. And (3) access to risk management tools including insurance and microcredits.

- The above benefits will be realized only once the agro-meteorological program fully matures. This will take several years following establishment or significant enhancement, so the above figures may be considered estimates for an objective of increased economic benefits to be realized at the 5- to 10-year point. Of course, more moderate benefits will be realized within a few years, with incremental amounts coming as the program moves toward attaining the above objectives.
- A minimal or traditional program does not contribute much to the national GDP. One has to decide if it is even worth doing, as the small amount of resources deployed might have a bigger impact if used for other purposes.

Again, the crops grown, agricultural practices followed, and environmental conditions found in Ethiopia and Kenya are very different from those in the regions examined in the two studies adapted here. It would be worthwhile to carry out a careful agro-economic study of the benefits likely to accrue from an agro-meteorological program in Ethiopia and Kenya, if only to have more confidence in the findings.

OTHER BENEFITS

There are also significant additional economic benefits obtained through mitigation of and recovery from the impacts of hazardous weather and climate events, which may require extraordinary decisions by farmers. Enhanced agro-weather and agro-climate forecasts and warnings can prevent, at least partially, some of the damage caused by drought and floods. A big element of this mitigation is the removal of the "surprise factor" wherein farmers are caught unaware of impending hazardous weather.

Early warning of climate-scale events such as droughts or flooding allows farmers to shift seed types to ones more tolerant of the anticipated conditions. Livestock can be moved or sold in anticipation of loss of pasturage. Aid agencies can also ready emergency supplies if famine begins to develop.

One of the ways a national agro-meteorology program can assist farmers in dealing with hazardous weather is by serving as a "neutral party" supporting weather indexed insurance. Here an automated observing network, overseen by the agro-meteorology program, can play an important role in providing verification values for fields near the station and ground truth/calibration for satellite sensors used to cover a wider area.

Weather indexed insurance is a risk management tool that is gaining wide acceptance as an alternative to a traditional crop insurance program. As the name implies, weather indexed insurance is based on local weather indices. Payouts are triggered by the specified components of a weather index rather than crop yields. The components of a weather index include measurable weather variables, such as temperature or rainfall; a specified duration; and specific weather stations. Once the weather data have been obtained from the agreed upon station(s), an index can be derived by reviewing how the weather variables have impacted past crop yields over time. In addition, a weather index will account for the impact of weather factors on crops during different stages of development. For example, insurance will payout if data from a nearby weather station shows too much rainfall or not enough by a certain key date in the growing season. The payout amount will be indexed to historical accumulated rainfall for the area.

Multiperils insurance, based on a sequence of several indices covering the growing season, can encompass the full range of hazardous weather events, giving farmers comprehensive coverage.

Weather crop index insurance is being currently used in Malawi, Tanzania, Rwanda, India, and the Philippines. The World Bank is reportedly working with Jamaica on weather insurance for their coffee crop. A weather crop index insurance program was launched in Kenya in 2010 to insure tea, coffee, and corn producers against drought. There is anecdotal evidence that this is helping to sustain the livelihood of some small-scale Kenyan coffee producers (Njagi 2014).

Both the insurance company and the farmers rely on a neutral party, such as a national agricultural meteorology program, to ensure that the observing network is operating continuously and producing good data.

COST-EFFECTIVE STRATEGIES FOR IMPROVING AGRO-METEOROLOGICAL OBSERVATION SYSTEMS

In practice, many countries appear to have at least two agro-meteorological observation systems. One is based on the traditional instruments previously described and utilizes observers or local volunteers with only modest training. The other is a national network of automatic weather stations. When managed properly, the two systems complement one another.

ENHANCED TRADITIONAL NETWORKS

As its simplest, an observing site in a traditional network has only a small rain gauge. The several hundred station network reported for Ethiopia appears to be of this type. The observations from such networks are usually recorded by hand and often mailed into a central office.

Such observations, when passed by a rigorous quality assurance process, provide invaluable data for both long-term climate studies and monitoring of how given growing seasons are evolving. Again, Ethiopia appears to provide a good example.

The attractiveness of a traditional network is that it is (relatively speaking) inexpensive to establish and maintain. In some cases, the equipment, such as rain gauges, can be locally fabricated. The primary disadvantages are the limited amount of data provided and the slowness with which the data are collected.

Such traditional networks can be enhanced by providing additional instruments together with the necessary training for properly reading them and recording the observations. For example, many traditional stations of the U.S. Cooperative Observer Network also include minimum and maximum temperature data. To minimize costs, these can be obtained from instruments such as the Grove Thermometer (which gives minimum and current temperatures) or the Six's Thermometer in (which gives minimum, maximum, and current temperatures).

A simple data sheet can be used to record the data by hand in a format that then can be transmitted by cell phone as well as be mailed to a central location at the end of a specified time period. The cell call goes to an automated receiving system that records the data, does simple error checking, and provides a first-order analysis.

Such a cell-phone-based approach can provide critical temperature and precipitation data on a once-per-day basis. This is often a good first step toward operational agro-weather forecasting focused on providing farmers with daily weather and climate updates and advisories (perhaps through the same cell phone used to send the data, but also through radio and other media).

Such upgrades to a traditional network cost a few hundred U.S. dollars per station, but US$50,000 to US$75,000 to install the central data-collection computer. There will be deployment and training costs to get the new equipment into the field and to show the observers or volunteers how to operate it. There will be continuing charges for the cell services and maintenance of the central computer. It may be desirable to train the operators at the central computer to a higher skill level in programming and system administration. Additional personnel should include a small team of three or so quality assurance meteorologists who review the raw data in parallel with the automated procedures, flagging questionable data.

MODERN AND ADVANCED NETWORKS

There are several different costs involved in developing a national agro-meteorological observation system. As suggested in the previous section, these can be categorized as either capital or one-time costs or continuing costs.

Examples of capital or one-time costs for each site.

- Purchase or long-term lease of the site
- Civil works and site preparations as needed (access road, security fence, electrical power if available or else a solar panel/battery system—this last is a good back-up against outages even if electrical power is available)
- Tower or mast
- Instrumentation
- Data logger and software
- Telecom interface (could be microwave radio, cell phone connection, hard wire to Internet, and so on; can be two-way to allow remote interrogation of the data logger)

- Cables and related hardware
- Labor for site improvements, installation, and so on
- Miscellaneous costs, such as shipping costs related to getting equipment on site

Site costs can run between US$10,000 and US$100,000 per site, depending on the number and types of instruments installed. A good mean cost would be US$30,000. These costs do not include site acquisition or preparation costs or shipping costs for equipment.

Central data collection facility

- Facility preparation (space modifications, provision of power, provision for air conditioning, dehumidification, heating as necessary)
- Telecom interface for receiving incoming data streams (and transmitting commands to data loggers in the field)
- Computer(s) for receiving, decoding, quality checking, and basic analysis (this could be the same system that receives data from the traditional network)
- Display system

Central data collection facility costs can run between US$50,000 and US$350,000. These costs do not include facility preparation costs.

Central maintenance facility

- Facility preparation (space modifications, provision of power, provision for air conditioning, dehumidification, heating as necessary)
- Facility furnishings, to include workspace for maintenance and calibration, and storage space for spare instruments, repair parts, and expendables
- Tools and calibration equipment
- Miscellaneous costs, such as shipping costs

Central maintenance facility costs can run between US$50 and US$250,000. These costs do not include facility preparation costs or shipping costs for equipment.

Examples of continuing costs

Staff—compensation, benefits, and training/professional development activities. All staff should have appropriate university degrees in areas related to meteorological observations or agro-meteorology

Data analysts—responsible for all aspects of receiving, decoding, and quality checking of received data; will require close interaction with the technical staff that performs maintenance of the automatic weather stations and the observers in the enhanced traditional network

Software developers—responsible for the software in the data loggers in the field and the central computer

Technical maintenance/calibration staff—responsible for routine maintenance and calibration of equipment, and for corrective maintenance as required

Staff costs are difficult to address because much of the relevant information, such as typical salary data, are not available. Further, the number of people required is not known. But if we assume 8 to 10 people of the above types are assigned to operate, maintain, and further develop the hardware and software at the central control facility, and an average compensation (salary + benefits) of $15,000/year, then we get $120,000/year to $150,000/year in staff

Operating costs

Telecom charges

Repair parts and spare instruments

Expendable supplies for operating and maintaining the data collection system

Vehicles, fuel, and related (a small group of vehicles are needed for all agro-meteorologists to go out in the field to study local conditions and to support technical maintenance/calibration staff making routine site visits)

Operating costs can run between US$25,000 per year and US$250,000 per year.

In light of the above cost analysis, the following strategy should be cost-effective.

Step 1a: In parallel, build up and enhance the existing traditional network of rain and temperature observations taken by observers and volunteers. Where the cell network allows, provide observers with cell phones to call in their observations once per day.

Step 1b: In parallel, establish an automated dial-in data delivery system so that people can begin sending information. This computer should be of sufficient capability to service both the dial-in delivery of data from network of traditional sites, data from traditional sites

received via the mail, and the acquisition of data from the modern or advanced sites. Note that this central data collection goes in at this early stage, so that it is ready to receive data from the automatic weather stations (as well as from the enhanced traditional network).

Step 2. Select sites for the installation of the automatic weather stations supporting agro-meteorology. Bear in mind that this is an agro-meteorology network, so the stations will be concentrated in agricultural regions with sites selected to be representative of local farming operations. Ideally sites would be within, but distinct from, fields. However, this is not always practical, so sites at the edge of fields may be utilized.

Some candidate sites, in descending priority, are as follows:

Agricultural farms and test plots maintained by the ministry of agriculture

Plots of land on large-size farms. Farmers with large landholdings are more likely than small landholders to let one have a small plot in a field for this purpose. Small landholders need to grow crops on every square foot they have.

Other government facilities such as airports, military training areas, public utilities

Synoptic observing sites operated by the national hydro-meteorological service

Airfields

University and high school grounds

Step 3. Begin with a small number of automatic weather stations deployed to key locations. As the stations come online, evaluate how well the central data collection computer is working.

Step 4. Add more stations to lower-priority sites as funds permit. This process could take several years. The staff at the central data collection facility and the agro-meteorologists they support gradually come to understand how to utilize the growing data streams to produce new products and services.

The data stream from both the enhanced traditional network and the growing automatic weather station network may have significant value to others in the government, the agri-business community, the regional water management/hydro-electric community, and so on. It is strongly recommended that the raw data from both systems be archived, together with relevant metadata and data quality control flags where erroneous data are suspected. Further, the archived data should be accessible to the public as quickly as is practical.

CHAPTER FIVE

MODELS FOR SUSTAINABILITY OF AGRO-METEOROLOGICAL OBSERVATION SYSTEMS

National hydro-meteorological services face a wide variety of challenges. These include all or some combination of severely constrained budgets; limited infrastructure, with little or no technical support, internal or external; noncompetitive salaries, so limited ability to train and then to retain talented staff; lack of access to training or the latest information on weather and climate monitoring and forecasting in their region. Thus setting up, operating, and sustaining a nationwide (or at least agricultural region-wide) agro-meteorological observing network that collects data centrally in real time may seem to be an impossibility.

To overcome the various obstacles to setting up and sustaining an agricultural network, the leadership of the national hydro-meteorological service must look outward, first within the government, then to international aid organizations, and finally to the private sector. The ministry of agriculture is an obvious partner, but the ministries of energy, transport, natural resources, environment, and emergency services should also be considered as potential partners. A business case specific to each agency can be developed showing the value of real-time data and the tailored products and services that flow from such data to the accomplishment of that agency's mission. While not all agencies can provide financial support, access to land, facilities, professional and technical staff, and morale support in budget requests can be in-kind outcomes. International development agencies can provide capital funds for initial equipment purchases and training of staff, as well as access to technical expertise not otherwise available. However, most such aid programs are for a specific period of time, usually just a few years.

Perhaps the greatest obstacle to operating and sustaining an agricultural network that provides data in real time to a central office is the cost of required telecommunications network. This cost is one that few national hydro-meteorological services can cover. Unless the national government operates a nationwide telecommunication network (and some do, for law enforcement, military coordination, and the like) which

can be accessed at little or no charge by the NHMS, then it is necessary for the NHMS to consider nontraditional approaches. The following paragraphs discuss one such possibility: working with local telecommunications/cell phone companies through a public-private partnership.

One note of caution: public-private partnerships have been tried in many contexts. While some have worked well, others have not. It is important to recognize at the outset that while the NHMS has a primary interest in providing improved service to the nation, the private sector partner(s) are interested only in increased profitability. Public-private partnerships must be carefully constructed so as to produce results that satisfy all the parties involved.

Further, as an alternative to a partnership approach, the national authority regulating or licensing telecommunications/cell phone companies could require such companies provide such connection and transmission services to NHMS and other government agencies at little or no cost through the regulatory process. While an attractive shortcut to establishing a partnership arrangement, it likely would create an adversarial relationship with the telecommunications company, forestalling access to sites, technical staff, and support within the government. In any event, while such low- or no-cost connections might be justifiable in the case of true emergencies, such as flash flooding or wildfires, they are harder to justify for routine day-to-day services.

A Nontraditional but Viable Approach

A nontraditional approach to meeting some of these challenges to establishing and sustaining weather observing networks is through a partnership with a public or private utility company or service that operates a telecommunications network. An obvious first choice is the cellular telephone network, but one should not overlook the possibilities offered by railways, electrical utilities, aviation route control networks, law enforcement networks, and so on. Here we focus on the cellular telephone network, but the principles would be more or less the same with other utilities, public or private.

Leveraging cellular telephone networks as the foundation for an agro-meteorological observing network offers the national hydro-meteorological service opportunities to address deployment, telecommunications, and maintenance issues. Such leveraging can provide long-term sustainability for an observing network that otherwise might be impossible.

Leveraging can occur through the following:

- Utilize inexpensive feature phones provided to volunteer observers to send data from enhanced traditional observing sets *and* to return weather and climate information to users.
- Make cellular telephone network towers (hereafter "cell towers") the locations of choice for the network of automatic weather observing stations. Ideally, instruments can be either on the tower or in the security area at its base.
- Utilize the communications network that supports the cellular telephone network as the means to collect observations.
  - If this is not feasible to put instruments on the tower or in the security area, then a nearby observing station still can be linked to the telecommunications network via a short-haul, low-power microwave transmission system.
- Utilize the technical staff of the telephone company to install and maintain the observing equipment.

For the above to occur, business models are needed that provide a "win" for the national telecommunications company and the national hydro-meteorological service. It is likely that to make such a partnership viable, the business arrangements will also involve some combination of private instrument manufacturing companies, international weather data aggregators/distributors, and international aid organizations.

THE SPREAD OF THE CELLULAR TELEPHONE NETWORK ACROSS SUB-SAHARAN AFRICA

The leveraging of local cellular telephone networks is viable in large part due to the rapid rate at which such networks are spreading across the globe, including all of Sub-Saharan Africa. In developing nations, the cellular phone has become a "leapfrog" technology. Such nations will almost certainly never have a hardwired telephone

network. Everywhere there are people, cell towers are becoming ubiquitous. Even rural areas are rapidly receiving cellular telephone coverage. Populated areas often have several different telephone service providers. While there will likely remain areas without cellular telephone coverage for some time to come, these are almost certainly remote areas with few inhabitants.

Where they exist as for-profit ventures, the telephone companies have strong incentives for maintaining the functionality of the equipment supporting the services they provide. They have the cash flow to provide security, reliable electrical service, and wide bandwidth connectivity at each cell tower. The companies also have trained electronics and mechanical staff to properly install and maintain the equipment at each cell tower site. The companies are always looking for more paying customers and new services they can sell. Weather information, particularly agro-weather information, is likely an attractive product for cell companies to market.

In nations where the telephone company exists as a state-owned or state-controlled enterprise, similar arguments apply, except that the company then has a stronger incentive to provide important public services at very low cost or even for free (though publically owned companies often still have to recover all or at least a significant fraction of their operating costs).

CONCERNS REGARDING REPRESENTATIVENESS

Observations at cell towers have been challenged on the grounds of failing to meet the WMO observing standards for representativeness. As an example of this common criticism, Bakhtin et al. (2012) commented:

> [S]ome scientists, and decision makers have expressed a lot of doubt (the discussion was initiated by WMO secretariat on CIMO[25]-XV meeting in Helsinki at 2010) regarding quality of the data obtained by such "non-standard" stations. The terms "non-standard" in this case is [sic] not correspond to the sensors—all of them are standard, but it is corresponding to the installation site. The point is that the CIMO guide exactly describes all the requirements to the place, surroundings and the heights of installation of each individual sensor. The cell tower meteorological station is not satisfying any of these requirements.

To address this criticism, the authors instrumented cell towers and performed comparison studies of observations from two cell tower stations with those from corresponding "nearby" (7. 2 kilometers and 5.4 kilometers distant) observing sites that meet the requirements of the WMO's Commission for Instruments and Methods of Observations (CIMO) guide.

In their study, Bakhtin and his colleagues found surprisingly high correlations between observations of temperature, humidity, pressure, and wind speed at a cell tower site and a nearby standard station. Only the wind direction measurements exhibited a loss of correlation when the instrument was in the "wind shadow" of the cell tower. This situation can be monitored through a quality assurance process because orientation of the wind sensor relative to the cell tower is known from site metadata. An effective solution is to utilize two wind direction sensors, one on each side of the tower. The findings indicate that for many purposes meteorological stations mounted on cell towers are able to provide usable data for the main meteorological parameters.

PUBLIC-PRIVATE PARTNERSHIPS

In the absence of a direct budget increase from the national government, a sustaining arrangement with the private sector—broadly termed a "public-private partnership"—is a potentially viable approach to improving the capacity of the national hydro-meteorological service for implementing and sustaining an agro-meteorology program and supporting observation network. Based on the literature on development in Africa, it appears that Uganda has already adapted national policies in this direction and is enjoying some success, including, for example, the Mobile Weather Alert forecasts for fishermen on Lake Victoria (WMO 2012).

[25] CIMO is the WMO's Commission for Instruments and Methods of Observations. This is the group within the WMO that sets the standards for observations and measurements of the atmosphere.

The foundation for such partnerships is the fact that weather data and products developed using that data have value. While the value for the data from a single location is usually minimal, it increases rapidly as the area covered and the density of coverage increases. Specialty data, such as might be produced by an agro-meteorological observing network, also have a relative high value to certain business sectors.

The situation is complicated by the fact that a national hydro-meteorological service owes its customers and users a certain mandated level of service provided essentially free of charge. However, by partnering with private sector entities, such as data aggregators and distributors, the national hydro-meteorological service can market its data and perhaps some of its products both locally and around the world.

It may also be there are local and regional private sector customers that the national hydro-meteorological service is under no obligation to support anything more than the standard weather and climate information provided to all its customers or users. Partnering with an appropriate private sector weather forecast company that will use the local data to produce tailored products (for an appropriate fee) is another way of realizing some of the value inherent in the data.

A telephone company may be interested in working with the national hydro-meteorological service on providing telecommunications and other services to sustain the observing network for a variety of reasons. A simple but important reason is to be seen as a good member of the community, providing service to the national hydro-meteorological service on a pro bono (no cost) basis as the actual costs to the cell company are likely small.

Another reason is motivated by the fact that accessing weather information is one of the major uses of cell phones. Partnering with the national hydro-meteorological service to bring in local data is a way of fostering the development of applications for the dissemination of local weather information via cell phones. This in turn fosters the sale of more phones and more minutes of usage, increasing revenue to the cellular company. It could be that the phone company would provide telecommunications and other support if the national hydro-meteorological service makes it the primary means by which the resulting decision support information is disseminated to the farmers and others (roughly analogous to the early morning farm report, which the radio stations broadcast for free because they can sell commercial time at the beginning and the end of the report).

In reality, a public-private partnership can be quite complex and have nuances that are not always apparent at the beginning to the staff of the national hydro-meteorological service. As an example, consider that a seemingly simple business arrangement for taking advantage of the cell phone opportunity might entail a national hydro-meteorological service partnering with the cellular telephone company and a private sector weather company to establish and sustain a weather observing network. The resulting data are then provided to the national hydro-meteorological service at little or no charge for use within the country while the private sector weather company and the cell company cover their costs and make a profit by marketing the data worldwide. However, such a simplistic arrangement is not likely to be attractive to either the cellular telephone company or the private sector weather company, because it puts all the risk on these two entities.

A solution is for the national hydro-meteorological service, with initial support from a development agency, to take on some of the responsibility and some of the risk for sustainability through commercialization both within the country and perhaps a defined regional marketplace. The role of the development agency is to cover the capital costs, as is the case today, while ensuring that the NHMS staff receives the necessary training and professional development required to be a full partner in such a multiplayer effort. The national hydro-meteorological service would remain responsible for the provision of those services mandated by its nation's government and the sponsoring development agency, and will have to learn how to balance that role with internal and regional commercialization efforts. Success by the national hydro-meteorological service, demonstrated by continuing operation of the observing network at five years after commissioning, could be rewarded by further investment by the development agency.

As a side note on this, the development agency can play important roles in fostering regional collaboration. This not only increases the size of the potential business

opportunity for the private sector companies but also is essential to having an effective early warning network.

Unfortunately, few of the African national hydro-meteorological services have staff with the skill sets required (strategic planning; end-to-end systems engineering leading to acquisition and installation of high-tech equipment; new business development, marketing, sales; new product development and delivery) to fully play the roles necessary to acquire, install, maintain, and sustain a modern weather observing network. History suggests that this is also true for most nongovernmental organizations or government aid agencies.

One option is carefully crafting public-private partnerships with private sector entities that have these skills. These partnerships should stipulate that the private sector partner will assist designated individuals in the national hydro-meteorological service in acquiring such skills. The international development community should encourage and foster such public-private partnerships by requiring a realistic sustainability plan as a condition for funding.

The private sector entities can be either local, such as the cellular network company, the local electrical utility, or the national airline, or international. Examples of the latter are Earth Networks and Accuweather from the United States and MeteoGroup from the United Kingdom; there are also entities that might be considered "semi-private," such as MeteoFrance International, which could play useful roles.

Finally, it is unfortunate, but we have an example of how not to attempt to build a weather network based on cell phone towers in Africa. This is provided by the "Weather Information for All Initiative." This was a multipartner effort launched with great fanfare in 2008 that collapsed within about 18 months. These should be borne in mind when entering into a public-private partnership.

Two success stories suggest themselves as examples of how novel approaches can produce observing networks that are sustainable.

GUINEA

The nation of Guinea is prone to severe local storms during portions of each year. In order to better protect the country's population against these hazardous events, the Direction Nationale de la Météorologique (National Meteorological Directorate) identified the need for an efficient weather information system that operated in real time to support storm monitoring, nowcasting, and the production of storm warnings when appropriate.

The Directorate partnered with Earth Networks, Inc. and Cellcom (the national telephone company) to design, install, and operate an early warning system. The resulting system of lightning locating stations went online in August 2013. A total of 12 such stations were installed at cell tower sites across Guinea. Each station consists of a total lightning sensor combine with an automatic weather station.

The data from this system are used to produce localized warnings on severe storms; radar-like, real-time displays of storms over Guinea; rainfall estimates for various accumulation times; and two-week hydrologic forecasts for national and hydrological services and other government and industrial users.

Earth Networks has many of the upfront costs associated with installing and operating this network. That company is doing so as it views the Guinea network as a demonstration that this technology is mature and can work well in the difficult environments of Africa.

PHILIPPINES

The Philippines are a subtropical nation of thousands of islands spread over 300,000 square kilometers. Consequently, the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), the national hydro-meteorological service, faces daunting geographic and logistic challenges in developing a national hydro-meteorological observing network. PAGASA must also deal with several typhoons per year as the Philippines lie on the main tropical cyclone track in the Western Pacific.

Recently, PAGASA, through its parent organization, the Department of Science and Technology, received a special government appropriation to deploy about 85 automatic weather stations and automatic gauging stations. While these stations will be helpful when installed, this still left many data void regions.

BOX 5.1. WEATHER PHILIPPINES FOUNDATION TO ROLL OUT 1,000 WEATHER INSTRUMENTS IN 2014

To help provide accurate localized weather forecasts and mitigate risks during times of natural calamities, Weather Philippines Foundation (WPF) is completing its rollout of about 1,000 automated weather instruments to various cities and provincial capitals nationwide in 2014.

Most of the instruments consist of automated weather stations (AWS) which are capable of determining temperature, pressure, humidity, wind speed and direction, solar radiation, and rain locally. Localized weather data is then processed to provide the localized weather forecasts.

WPF completed 402 AWS in 2013 and conducted training on the use of this hardware as well as related software found in weather.com.ph. The provinces, cities and various media as well as private individuals relied on the AWS and its website for the latest forecasts during the onslaught of super typhoon Yolanda.

"This is in line with the foundation's thrust to contribute in disaster risk reduction and climate change adaptation. Tools in the website, for instance, assist and provide complimentary information to LGUs in planning and decision-making during severe weather situations," said WPF General Manager Celso C. Caballero III.

To complement its initiative, the foundation trained about 358 city and provincial risk reduction personnel, public information officers and administrators nationwide to maximize use of tools on its website www.weather.com.ph.

WPF reported installation of 205 AWS in all cities and provincial capitals of the League of Cities of the Philippines and League of Provinces of the Philippines last year.

The rollout of another 197 AWS were made possible by private donors and site partners such as mall chain SM and Pilmico Foods Corp. Rappler, Globe Telecoms, Primer Group, iAcademy, Geiser-Maclang and Cebu Pacific.

WPF is a non-profit organization founded by Aboitiz Foundation Inc., Unionbank and Europe's leading weather service provider mminternational (formerly Meteomedia). WPF aims to deliver critical and accurate localized weather information readily available through the WPF website, www.weather.com.ph.

Source: Extracted from Aboitiz Foundation, 2014.

To address the need for a dense national hydrometeorological observing network, in 2012, Aboitiz Foundation, UnionBank, and a European weather service provider MMinternational (formerly Meteomedia) founded the Weather Philippines Foundation, Inc. The intent of the foundation is to improve understanding of the importance of nationwide disaster preparedness and promote timely responses to threatening weather conditions. The first steps the foundation has made have been to establish a weather portal and to begin deploying automatic weather stations. Since its founding, many local, provincial, and national organizations as well as large industrial and financial concerns have joined with the foundation to support its deployment of weather stations.

In 2012, the foundation deployed 82 weather stations. By the end of 2013, there were 402 stations deployed. The goal is about 1,000 such stations across all the inhabited islands (box 5.1). The foundation's automatic weather stations are considered a supplement to the official stations operated by PAGASA. The data from PAGASA's stations and MMinternational forecasts are made readily available to the general public through the WPF website (http://www.weather.com.ph).

It appears that this is a private venture, with the intent to complement and augment PAGASA's observing system. The data from the stations are used by MMinternational in its commercial weather forecasting operations around the world.

CHAPTER SIX
BEST PRACTICES FOR INSTITUTIONAL STRENGTHENING AND CAPACITY BUILDING

For an agro-meteorological program to have a significant impact on overall national agricultural production, the organizations involved—primarily the national hydro-meteorological service, but also the extension program of the ministry of agriculture—must change to faster, more focused ways of providing decision support services to farmers. The comments that follow focus mainly on the national hydro-meteorological service, but parallel remarks likely apply to the extension program as well.

Currently, the national hydro-meteorological services in many African countries base their forecasts almost completely on numerical model output from various meteorological centers in the developed world provided at no cost through the World Meteorological Organization.[26] This model output is coarse in spatial resolution, with new output usually available every three, six, and twelve hours each day. Such output is suitable for forecasting on the synoptic (large) scale and, to some extent, on the sub-synoptic scale, but not for forecasting on the meso- and micro- (or "farm") scale, the scales on which the weather events that impact people, livestock, and crops occur. In the current forecast process, only limited use is made of local data in part because of the small amount that are available. A consequence of this situation is that farmers do not receive timely agro-weather information at temporal and spatial scales of real use to them in planning and conducting day-to-day activities.

Once the enhanced traditional observing network is in place and providing high spatial density, once-per-day observations of a few key variables, and the network of automatic weather stations starts to extend across key parts of the nation (specifically, the agricultural regions), forecasters at the national hydro-meteorological service will start to have timely access to much more local data. Applied meteorological studies utilizing these new data streams will produce new analysis and forecast products tailored to support farmers' decisions.

[26] These centers include, among others, those of the U.S. National Oceanic and Atmospheric Administration (NOAA), the United Kingdom Met Office, the European Center for Medium Range Weather Forecasting, Météo France, and the Japanese Meteorological Agency.

To get the full value from these new data sources, refocusing and perhaps redeployment of staff and resources will be necessary. Near-real-time quality assurance of the incoming data, even when prescreened by numerical systems, still requires careful examination by trained eyes. Forecasters will need to consider meso- and microscale meteorological events, preparing nowcasts and short-range, more detailed forecasts for the period 0 to 48 hours out. They will now be able to watch weather evolving and so develop capabilities to issue warnings of the imminent onset of hazardous conditions. The agro-meteorologist will participate in this short-range forecasting, producing tailored products for the agricultural community. Since the national network of automatic weather stations will build out gradually over a period of years, these changes will be evolutionary rather than revolutionary.

STRATEGIC AND IMPLEMENTATION PLANS

The evolving situation described in the preceding paragraphs is a classic example of a capacity building effort that involves individuals, organizational structures and operating procedures, and an infusion of new technology. Developing the ability to plan and then execute that plan as described in this section will result in greatly increased managerial capacity and technical capabilities within the national hydro-meteorological service.

To ensure that the end result is the one desired—an effective agro-meteorology program for the nation—a comprehensive strategic plan together with a detailed implementation plan are essential. The strategic plan should be short, providing a vision, clear statements of high-level goals and objectives, and target dates for meeting those goals. The implementation plan should be comprehensive and detailed. It should describe the strategic and tactical actions necessary to attain the goals, and lay out a detailed timeline for completing them. These plans must reflect a systems perspective. They are probably best developed using a backward planning approach.

Planning with a systems perspective means accounting for the behavior over time of a system as a whole in the context of its environment. Systems concepts and language bring a precision to developments of concepts of operations, design studies, and requirements documents that are hard to obtain any other way.

In the case of establishing and sustaining an agro-meteorology program, this means one must examine the "system" that extends from the observations taken in the field to delivery of products that influence decision making by farmers. In considering this chain of sequential activities, one must avoid linear, reductionist thinking that focuses too narrowly on isolated parts of this system.

BOX 6.1. DEFINING CAPACITY BUILDING UNDER THE PIC DIRECTIVE

Capacity building can be defined as an evidence-driven process of strengthening the abilities of individuals, organizations, and systems to perform core functions sustainably, and to continue to improve and develop over time. Community capacity building often refers to strengthening the skills, competencies and abilities of people and communities in developing societies so they can overcome the causes of their exclusion and suffering. According to the United Nations Development Programme:

> In the global context, "capacity" refers to the ability of individuals and institutions to make and implement decisions and perform functions in an effective, efficient and sustainable manner. At the individual level, capacity building refers to the process of changing attitudes and behaviours—imparting knowledge and developing skills while maximizing the benefits of participation, knowledge exchange and ownership. At the institutional level it focuses on the overall organisational performance and functioning capabilities, as well as the ability of an organization to adapt to change.
>
> Institutional Capacity Building addresses Capacity Building beyond the provision of education and training of professionals. It aims to enhance the capacity of governments, business, non-governmental groups and communities to plan and manage resources efficiently and effectively. It also aims to improve institutional arrangements for sustainable development. This implies addressing Capacity Building on a long-term, strategic level. Concepts such as leadership, awareness, and constituency building are part and parcel of institution building.

Source: Excerpt from Promoting International Collaboration (PIC). Undated.

Rather one must consider both the parts to the system and especially the interconnections between them, and on how the various parts interact through those interconnections to produce the desired results. Some of these interconnections will be the forward path along which observations are made, data are collected and quality assured, analyses are made and forecasts produced and both delivered to uses. Other paths in the system may double back to give rise to feedback loops. For example, the data quality assurance effort will result in communications to observers in the enhanced traditional network and to technical staff responsible for the corrective maintenance program, so that data quality remains high. The "environment" includes the farming community, other government agencies, the universities, private sector entities, and international and nongovernmental organizations.

In general, backward planning means focusing first on the overall goals and objectives for the program as a whole, then working backward, determining system requirements—that is, stating what is necessary in terms of staff skills and expertise, organizational procedures and policies, and technological capabilities—to attain the goals. For this to happen, as "Requirements and Architecture" and "Detailed Design" are developed, they will include specific performance metrics that will form the basis for the testing and evaluation to be carried out under "Integration, Test, and Verification" and "System Verification and Validation."

There are a variety of backward planning approaches that can help guide planning and ensure that all essential points are covered. One that is relevant to the development of an agro-meteorology program is the V-model. The V-model emphasizes early identification of goals and objectives, formulation of a concept of operations that reflects both user needs and the operating environment, thorough and testable system requirements, detailed design, implementation, rigorous acceptance testing of the implemented system to ensure it meets the stated requirements (system verification), measuring its effectiveness in addressing goals (system validation), and ongoing operation and maintenance. While rigid in process, the V-model is flexible in application.

The strength of the V-model is that the requirements and design phases are linked to the system's actual performance through "implementation" at the bottom (via interconnections on the forward path) and through extensive and comprehensive "Verification and Validation" processes (establishing a set of nested feedback loops). These last are all too often overlooked or glossed over in all too short "acceptance testing."[27]

It may be advantageous for present purposes to think in terms of multiple but strongly coupled planning efforts carried out by working groups. The coupling comes through the overall goals and objectives for the agro-meteorology program and the associated concept of operations.

CONCEPT OF OPERATIONS

Once the high-level goals and objectives have been established, the first and in many ways most important element in the system design process is the development of a concept of operations for attaining those goals.[28] The concept of operations provides a conceptual view of how the agro-meteorology program will meet the needs of the various users of its products and services without being overly technical or formal. The users may be farmers, colleagues in the ministry of agriculture's extension service, senior management in the ministry of agriculture and other ministries, and so on. The government or international agency funding the program during establishment and then during operations should be included as a "user." The concept of operations should address in conceptual or scenario fashion how the needs of each of these users will be met.

[27] Validation can be expressed by the query "Are you building the right thing?" Verification can be expressed by "Are you building it right?" Another way of expressing this difference is to note that verification is always done against the requirements (technical terms) and validation is always done against the real world or the user needs as articulated in the concept of operations.

[28] A useful overview of the concept of operations and where it fits within a systems development process is available at the Mitre systems engineering guide (http://www.mitre.org/publications/systems-engineering-guide/se-lifecycle-building-blocks/concept-development/concept-of-operations) as well as in IEEE Computer Society, March 19, 1998, *IEEE Guide for Information Technology—System Definition—Concept of Operations (ConOps) Document* (IEEE Std 1362-1998). This guide was originally intended for software development projects but is easily adapted to other types of projects. It does not specify the exact techniques to be used in developing the ConOps document, rather, it provide approaches that might be used. This document states that the main objective of a concept of operations is to "communicate with the end user of the system during the early specification stages to assure the operational needs are clearly understood and incorporated into the design decisions for later inclusion in the system and segment specifications."

The relevant portions should be iterated with the users to ensure all concerned understand what is planned.

The intent of the concept of operations is to facilitate a common understanding of ideas, challenges, and issues related to establishing a national agricultural meteorology program between the national hydro-meteorological service and those it will support with this program. It should include the full range of factors that are needed to support the establishment of the program (that is, policy and procedures, organizational structures, leadership, personnel, training, materiel, facilities, and resources). It is also critical that the concept of operations addresses annual operating costs to be incurred once the program is established (that is, operation and maintenance of the observing system, applied research and development [R&D] to develop new tools and techniques using the data streams, continued training and professional development for staff) and describes how these costs will be met. As the name suggests, the concept of operations should be stated at a conceptual level, without much in the way of details or selection of a specific solution.

As the national agricultural meteorology program comes into existence, the concept of operations helps sustain a common vision of the program. In accordance with the verification and validation feedback loops in the V-model, the original concept of operations developed at the beginning of system acquisition should be updated after developmental and operational testing to convey how the agricultural meteorology program will actually work. This update is needed since the program may come to include some additional capabilities not originally envisioned at the beginning, and may not include some capabilities that were omitted for financial or other reasons.

For those individuals charged with developing the program, the concept of operations is a first step toward developing system requirements.

PARALLEL, COUPLED DEVELOPMENT EFFORTS

Once the initial concept of operations for the nascent agrometeorology has been developed, senior management of the national hydro-meteorological service can then assign specific design responsibilities to working groups. Senior managers must insist that the working groups coordinate with one another as they carry out their assigned tasks. Each working group may also use the V-model to organize its work. Regular systematic reports to senior management are essential for coordination.

Possible working groups might include the following[29]:

- **Agro-meteorological products and services:** What are the products and services that will be delivered by the program? How and by whom will these products and services be produced? Are new analysis tools or forecast techniques required? If so, how will these be developed and tested? What meteorological data streams are required by those producing the new products and services? What agricultural data are needed? Can these be supplied by the ministry of agriculture? How will routine validation and verification of these products and services be accomplished? What training will analysts and forecasters require? Outside the "regular" customers or users, how will data be shared?
- **Organization and staffing of the agro-meteorological program.** How will the new agro-meteorological program fit into the existing organization structure? How will it be connected to the extension program of the ministry of agriculture? A distributed approach, with most of the human resources well out in the field, may be optimal, but how does that fit with overall ministry and governmental policy? How many professional (forecasters and analysts), technical (systems administration, software support, data quality assurance), and support, maintenance, and calibration staff are required? What are the required qualifications for each position? What are the initial performance expectations for each position? Who will evaluate the performance of each individual in the program? From where will these individuals come (internal transfers, new hires, or elsewhere)? What training will they require? Where will they be located?
- **Customer or user relations for the agro-meteorological program.** Who are the

[29] The various working groups listed here should be taken as illustrative, not definitive, as should the questions that follow each one.

customers or users for agro-meteorological decision-support information? What information does each one require? Does this change through the course of the year? How will the products and services produced by this program be delivered to users? How will the users be trained to properly apply the new products and services in their decision making? What are the roles for the agro-meteorologist and the extension agents of the ministry of agriculture in this training effort? What communications medium is appropriate to each customer or user? Does the mass media—radio, TV, Internet—have a role in dissemination? How will the information be packaged (tabulations, graphics, downloads, and so on)? How does each group of customers or users provide feedback on the information they receive, and who is responsible for acting on that feedback?

» **Enhanced traditional network design**. What additional observations can reasonably be asked of local volunteers? What additional instruments and related items are required? How many spares and repair parts are likely to be needed? Who will be responsible for installation and maintenance? What is the best approach to once-a-day collection of the volunteer's observations—should they use a cell phone? Should mail-in of observation forms continue to be required? How will quality assurance be performed on the incoming data? How will the volunteers in the field receive feedback on the quality of the observations they provide? What training do these people require? Who should deliver that training?

» **New agro-meteorological network design.** Where in the nation are measurements needed immediately? Where in the nation are measurements needed over the next three years? What quantities need to be measured at each location? Longer term, what additional locations and measurements may be required? How do we provide for access, power, telecommunications, security, and maintenance at each location? What capabilities do we want in the data logger? What command-and-control capabilities do we want from the central data collection facility? What policies and procedures do we need to develop for routine and corrective maintenance? What policies and procedures do we need to develop for calibration? How many spare sensors, tools and equipment, and repair parts do we need initially? Is there adequate space somewhere for a maintenance and calibration and equipment storage facility? Should all this be kept centrally or should some of it be at regional locations? Who do we want to be able to program the data loggers? How will the maintenance staff contribute to the metadata file for each site? How many maintenance people are needed, and where will they be stationed around the country? How many vehicles do they need? What training does the maintenance and calibration staff requires and how will it be provided?

» **Central data collection facility.** Where will the central facility be located? What are the space, environmental conditions, power, telecommunications, and security requirements for the central facility and data archive? What size of computer, capacity of storage system, emergency power system, and what size of technical and maintenance staff will be required to maintain everything in the facility? Who will be responsible for keeping the central collection computing systems up to date and functioning properly? Who will provide system administration for the central collection facility systems? Who will develop the software for screening the data as it arrives? What tests, by data item, should this initial screen provide? How many analysts per shift will be required to ensure continuous quality assurance of the incoming data, both from the enhanced traditional network and the agro-meteorological network? How will the computer screen and the analysts deal with errors discovered in data? What elements of metadata will be maintained, and who is responsible for maintaining each element? What are the desired policies and procedures for handling missing or erroneous data as it goes into the data archive?

Note how often "training" is mentioned in the working group descriptions. Making training and professional development of operational staff has to be a top priority. Similarly, it is essential that staff members who have been trained are subsequently properly utilized and retained. Where deployment of new equipment is involved, it is important to ensure that training is accomplished in

parallel with the deployment of the equipment so that those trained can immediately make use of their new knowledge and skills.

EXAMPLE OF AN AGRO-METEOROLOGICAL NETWORK

A good example of a very effective agro-meteorology program serving a diverse group of farmers and others in the agricultural industry, including state and federal agencies, is provided by the Oklahoma Mesonet. The Oklahoma Mesonet is a network of 120 environmental monitoring stations covering the state of Oklahoma. It was designed and implemented by scientists, engineers, and students of the University of Oklahoma (OU) and at Oklahoma State University (OSU). At each site, the environment is measured by a set of instruments located on or near a 10-meter-tall tower. The measurements are packaged into "observations" every 5 minutes; the observations are then transmitted to a central facility every 5 minutes, 24 hours per day, year-round. The Oklahoma Climatological Survey (OCS) at OU receives the observations, verifies the quality of the data and provides the data to Mesonet customers. It only takes 5 to 10 minutes from the time the measurements are acquired until they become available to the public. For more detail on the Oklahoma Mesonet, see http://www.mesonet.org/index.php.

CHAPTER SEVEN
FINAL THOUGHTS

Ethiopia, Kenya, and nearby countries in Africa urgently need to find more effective adaptation strategies to manage growing weather and climate risks. This is particularly the case in regard to their agricultural base since so many of their citizens are smallholder farmers working at or just above subsistence levels. These weather and climate risks present such a complex set of challenges that government institutions, NGOs, and donor organizations cannot address them one at a time, in isolation from the others. A comprehensive systems approach—in the broadest sense of that phrase—appears to be essential.

Enhancing and strengthening the capabilities and capacities of key government agencies, more specifically the national hydro-meteorological services together with the ministries of agriculture, water, energy, and emergency management, will be essential to build levels of resilience to the environmental changes anticipated to unfold in the next few decades. Given the limited resources available, it is likely that everyone involved in agriculture in this region, from the farm to the national ministry, will need to adopt novel collaborative approaches and become much more flexible in terms of plants sown and agricultural techniques used if farmers are going to continue to produce the food needed by the people of these nations. This will include utilizing new types of partnerships and collaborations, in particular ones involving the private sector.

There are numerous issues that must be addressed to provide the range of agro-meteorological services that are almost certainly going to be essential in the medium future. This report has discussed some of them, focusing somewhat narrowly on possibilities for improvements to surface observations and measurements, given that the resulting data are the foundation for producing many types of products and services, and particularly so for those supporting agricultural decisions at all levels.

The coming changes will also provide unique opportunities. The NHMSs in this region have historically been starved for funds, resulting in minimal staffing, inability to retain key staff, deferred maintenance or replacements, and a strong dependence on financial assistance from aid and development agencies to carry out new initiatives. The recent renewed interest by several different NGOs and aid agencies in agro-meteorology and agro-climatology provides a unique opportunity for the NHMSs to demonstrate their value to their nation, build stronger relationships with natural allies like the ministry of agriculture and influential private sector entities, and so become more competitive for increased government funding.

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APPENDIX A

LESSONS TO BE LEARNED FROM THE WEATHER FOR ALL INITIATIVE

"The world's poorest are also the world's most vulnerable when it comes to the impact of climate change, and the least equipped to deal with its consequences. Today you find cell phone towers in almost every part of Africa. We have never been able to establish weather monitoring on that scale, until now. By bringing together the expertise and resources of different public and private actors, this project may help to save lives and improve the livelihoods of communities in Africa living on the frontlines of climate change."

Kofi Annan,
former UN Secretary General,
announcing the Weather for All Initiative

THE WEATHER INFORMATION FOR ALL INITIATIVE—A FAILED EFFORT

Launched with great fanfare in 2008 by Kofi Annan and the Global Humanitarian Forum (GHF), the Weather Information for All (WIFA) initiative was a public-private partnership formed to increase access to reliable weather and climate information throughout Africa. As announced, the GHF, WMO, Earth Institute at Columbia University, mobile telecommunication companies Ericsson and Zain, and NHMSs and governments of participating countries were to work together to install 5,000 new automatic weather stations at new and existing mobile network sites across the continent by 2013 (GHF 2008).

The project aimed to use the mobile telecommunications network to improve both the continent's weather observing network and the availability of weather information through the dissemination of forecasts and early warnings through mobile short message service (SMS; Ericsson 2013).

This increased access to weather information was intended to help those rural communities most affected by and vulnerable to hazardous weather events and variations in seasonal to interannual climate. For example, seasonal outlooks could help farmers decide what and when to plant, likely increasing their crop yields and incomes. Communities, health agencies, and governments could also use early warning of weather patterns to take preventative action to limit the spread of climate-sensitive diseases like cholera and malaria. Early warnings could also be used to alert people on Lake Victoria, where an estimated 5,000 fishermen die each year due to storms and accidents (GHF 2008). Of the three planned phases of the WIFA initiative, only the first was completed before the GHF ceased all activities in 2010 due to lack of funds (WMO 2013).

In this first phase, 19 automatic weather stations fabricated by Fairmount Weather Systems Ltd. were installed on existing Zain and Ericsson mobile network sites around Lake Victoria, in the nations of Kenya, Tanzania, and Uganda.

Unfortunately, to the best that can be determined, this effort soon failed. Between November 2009 and May 2011, contact was lost with all 19 weather stations.[30]

LAKE VICTORIA PROJECT(S)

After the initial launch of the WIFA initiative, a subproject within the initiative was started by the Kofi Annan Foundation. This was intended to improve the weather and climate information received by fishermen and farmers around Lake Victoria (Kofi Annan Foundation 2013). The project was based in Rarieda Constituency in Saiya County, Kenya, and was supported by the Svenska PostkodStiftelsen, Health and Climate foundation, Aga Khan University and African Centre of Meteorological Applications for Development (ACMAD).

As a first step toward building a lake weather observing network that would meet real needs, surveys were designed and conducted to determine how the communities around Lake Victoria used the weather information they received and to determine what additional services could meet their needs.

Like the WIFA initiative, this subproject also ended when GHF ceased activities in 2010. It does not appear that any weather observing equipment was deployed.

Less than a year later, management of the WIFA initiative was passed to the ACMAD, where a new project known as Mobile Weather Alert was created to build off of the work previously done under the WIFA initiative (WMO 2013).[30] The objective of this new project was again to use existing mobile phone technology, infrastructure, services, and applications to develop and demonstrate a sustainable warning service in the region around Lake Victoria.

Ericsson, WMO, MTN Uganda, the Uganda Department of Meteorology, the National Lake Rescue Institute, and the Grameen Foundation worked together to test and deliver a range of mobile communication options for pre-disaster weather alerts for fishermen. The pilot study was launched in May 2011 in Uganda at a district along Lake Victoria called Kalangala. A survey of 1,000 fishermen

[30] For details, see http://betastations.fairmountweather.com/all_locations_page.php.

found that they valued the possibility of receiving accurate and specific weather information to their mobile phones in addition to the general weather forecasts on the radio (Ericsson 2012).

No information about the Mobile Weather Alert project can be found after May 2011.

WEAKNESSES LEADING TO THE COLLAPSE OF THE WIFA INITIATIVE

It appears that the WIFA initiative failed within two years of being announced. Further, it appears to have accomplished little beyond having introduced to the region the idea that cell towers might open opportunities not previously considered.

The available reports suggest the following weaknesses in the WIFA initiative led to its demise:

- Lack of sufficient capital at start-up and subsequent inability to attract funds for the realization of the announced plan
  - Simply put, broad ambition was not matched with sufficient capital. Consequently, the program's vision had to be continuously scaled back into various "pilot zones," "concept testing," and "community based impacts." It finally reached the point where the broad national and international developmental impact had been designed out of the initiative. In summary, WIFA promised too much for the available resources, and delivered too little to have a real impact.
  - Unable to synchronize funding, an implementing agency, measurement system manufacturing, and deployment cycles, it failed to produce a coherent, sustainable program. WIFA's failure became another example of the very different timescales on which the public and private sectors operate.
  - Despite good intent and high-level political support, the organizers did not seem to have a business plan focused on funding for long-term sustainability; there was no obvious path to data or content commercialization with the insurance industry, the energy industry, the media, and consumers. Lack of such a sustainability plan likely deterred many of the potential investors one would like to attract to such an effort.
- Technology and operations
  - Technology focused on lowest-cost sensors and related field equipment rather than robust, environmentally appropriate, low-maintenance hardware.
  - There was minimal innovation or recognition of opportunities offered by leapfrog technologies.
- Perhaps most importantly, lack of buy-in by the local national hydro-meteorological services in the region
  - The limited involvement of, and hence limited sense of ownership of the program by the services in the participating countries (P. Partanen 2013, personal communication) almost certainly doomed this program from the start. However, it is unclear that the services, even if they had been involved, had the required expertise or resources to play the roles necessary for the success of the program.
  - Siting concerns by the services over representativeness were not properly addressed.
  - Public-private partnerships between the NHMS and the providers of the systems were not properly addressed.
- Lack of application development
  - Impactful humanitarian applications of the data were never able to get off the ground; data collection was seen as an end in itself.
  - Little attention was given to converting data to actionable information for commercial applications such as energy or utility, insurance, TV, and mobile media.

APPENDIX B

KMS WEATHER AND CROP REVIEW

KENYA METEOROLOGICAL SERVICE
DEKADAL AGROMETEOROLOGICAL BULLETIN

WEATHER AND CROP REVIEW FOR DEKAD 7, 2014
1–10 MARCH, 2014

HIGHLIGHTS ON RAINFALL AND TEMPERATURE

Rainfall activities in the country tended for increment as compared to the previous dekad.

Eastern Region received the highest amount of rainfall countrywide with Mwea station recording 47.7mm as compared to 53.7mm recorded in Kisii station in Lake region in the previous dekad. In Western and North Eastern regions, there was no rainfall within the dekad. In Rift Valley region, Narok station recorded the highest amount of

rainfall of 12.4mm. In the Coastal region, Mtwapa station received the highest amount of rainfall with 37.1mm. In Nairobi Dagoretti received the highest amount of rainfall of 6.6mm and in Lake region, Suba station recorded 23.1mm. In Central region, Thika station recorded the highest amount of rainfall of 5.2mm

There was a general increase in the maximum temperature country wide. Lodwar station recorded the highest maximum temperature of 38.4°C compared to 37.7°C recorded in the Wajir station in the previous dekad. The minimum temperature increased significantly in most stations in the country with Nyahururu station in Central region recording the lowest temperature of 6.9°C compared to 7.5°C reported in the same station in the previous dekad.

For a more comprehensive summary of rainfall and other meteorological parameters.

CROP AND WEATHER REVIEW FOR DEKAD 7; 1–10 MARCH 2014

NYANZA AND WESTERN REGIONS

Kakamega

The station did not record any rainfall. The mean air temperature was 23.4°C. There were no records on sunshine duration and Evaporation Pan.

No phenological report

Kisii

The station recorded rainfall amount of 8.1mm. The mean air temperature and Pan

Evaporation were 23.0°C and 57.6 mm respectively. No records on Sunshine duration.

No phenological report

RIFT VALLEY REGION

Kitale

The station did not record any rainfall. There were no records of average air temperature and sunshine duration. The Van Evaporation record was 61.5mm.

No phenological report.

Eldoret-Kapsoya

The station received no rainfall during the dekad. The average air temperature and pan evaporation reported were 18.9°C and 82 mm respectively. There was no report on sunshine duration.

No phenological report.

CENTRAL KENYA HIGHLANDS AND NAIROBI AREA REGION

Nyeri

The station received rainfall amount of 1.8mm over the dekad. The average air temperature was 19.4°C. There was no report on pan evaporation and sunshine parameters. *Maize crop was at the wax ripeness stage and in failure state due to insufficient rainfall with below normal yield being expected.*

Kabete

The station recorded rainfall amount of 4.2 mm over the dekad. The average air temperature recorded was 19.6°C. There was no report on sunshine duration and the Pan Evaporation was 61mm. *Maize was at flowering stage and in poor state due to insufficient rainfall. Below normal yield is expected.*

Thika

The station recorded rainfall amount of 5.2 mm. The mean air temperature and pan evaporation recorded were 22.3°C and 57.8 mm respectively. There was no report on sunshine duration. *Maize was at harvest stage and in poor state as it had been adversely affected by insufficient rainfall. Below normal yield is expected for the crop.*

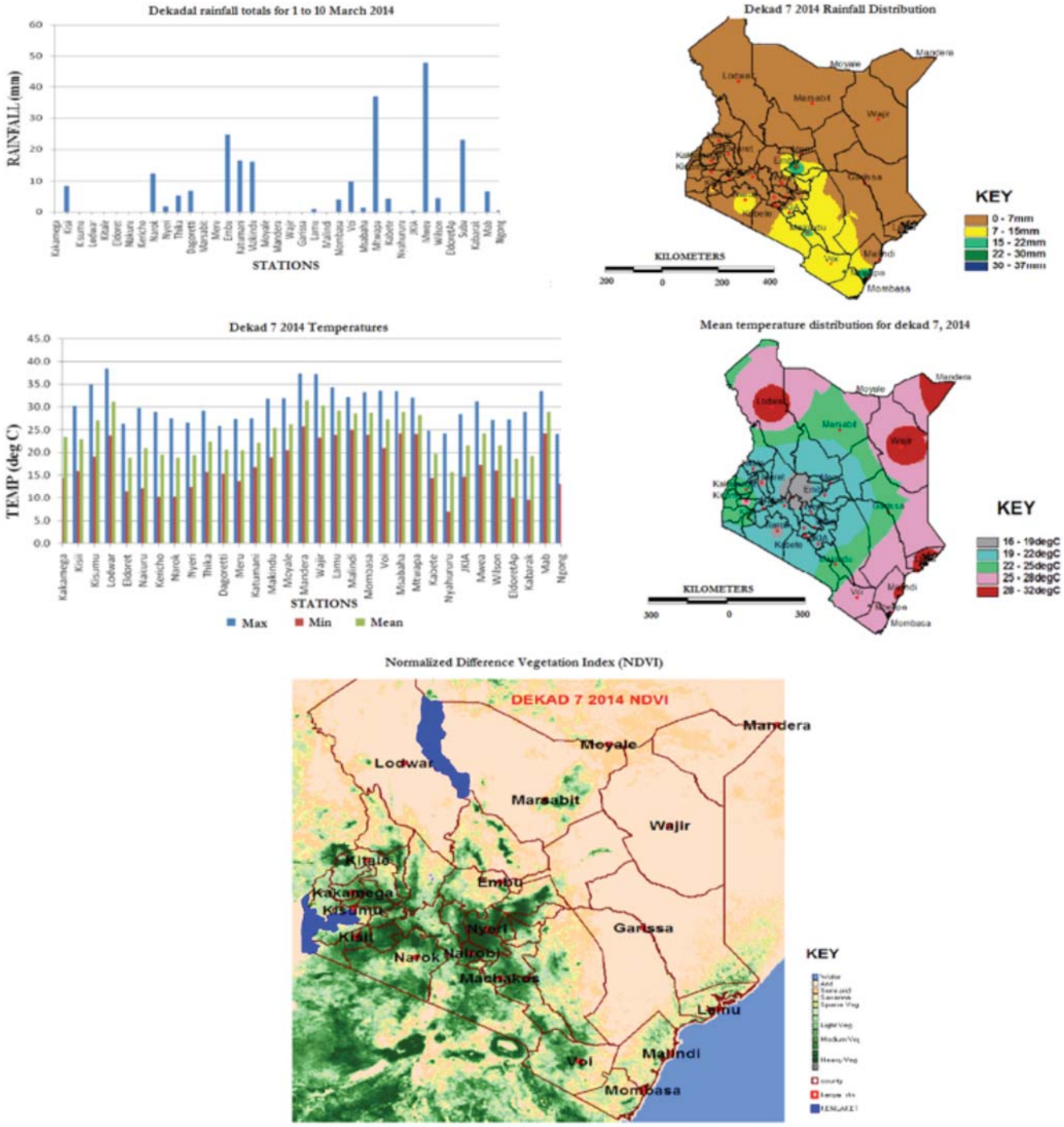
Nyahururu

The station recorded rainfall amount of 0.2 mm. The mean air temperature and pan evaporation recorded were 15.6°C and 71.7 mm respectively. There was no report on sunshine duration. *No phenological report.*

Dagoretti

The station reported rainfall amount of 6.6 mm during the dekad. The average air temperature and Pan Evaporation were 20.6°C and 62.6 mm respectively. No report on sunshine duration. *Maize had been disposed at their wax ripeness stage.*

FIGURE B.1. ANALYSIS OF RAINFALL, TEMPERATURE, AND VEGETATION CONDITIONS



EASTERN KENYA REGION

Meru

The station recorded no rainfall. The average air temperature and Pan Evaporation recorded were 18.9°C and 57.5mm respectively. No report on Sunshine duration. *Maize and was at maturity stage and in fair state with below normal yield being expected.*

Embu

The station reported rainfall amount of 24.9 mm. There was no report on Temperature, Van Evaporation and

Sunshine duration respectively. *Maize was at maturity stage and in fair state with below normal yield being expected.*

Katumani (Machakos)

The station recorded rainfall amount of 16.4 mm. The average air temperature reported was 22.1°C. There was no report on pan evaporation and Sunshine duration. *Maize was at harvesting stage and in poor state due to adverse effect by too much sun. Below normal yield is expected for the crop.*

COASTAL REGION

Msabaha

The station received rainfall amount of 1.3 mm. The average air temperature and Pan Evaporation recorded was 28.8°C and 55.3 mm respectively. There was no report on sunshine duration. *Mangoes were at 100 percent fruit setting stage and in good state.*

Mtwapa

The station received rainfall amount of 37.1 mm. The average air temperature recorded was 28.1°C. There was no report on sunshine duration and Pan Evaporation.

Mangoes were at flowering stage and in good state.

EXPECTED WEATHER AND CROP CONDITIONS DURING THE NEXT 10 DAYS; 11–20 MARCH 2014

- **Counties within the Lake Victoria Basin, Highlands west of the Rift Valley, Nyamira, Kericho, Bomet, Uasin-Gishu, Nakuru, Narok, Trans Nzoia, Elgeyo Marakwet, Nandi, Laikipia, Kajiado, Vihiga and Busia**), are expected to experience rains in few places in the morning during the first few days and the rest other days would be sunny interval. In the afternoons, there would be showers and thunderstorms interchanging with sunny intervals throughout the forecast period. *The afternoon showers will continue to improve the state of the crops and the vegetation, which are still in farms in the region.*
- **Over the Northwestern counties (Turkana, West Pokot and Samburu),** Rains over few places in the morning in the first few days and sunny intervals for the rest of forecast period. In the afternoons, expect mainly sunny intervals with showers and thunderstorms over few places throughout the forecast period. *The wet condition is expected to resurrect then pasture and vegetation in this region.*
- **The Central highlands including Nairobi area (counties of Meru, Murang'a, Kiambu**, **Nyeri, Nairobi, Embu, Nyandarua, Tharaka and Kirinyaga),** are expected to experience mainly cloudy early morning with rains over few places giving way to sunny intervals throughout the forecast period. In the afternoons, sunny intervals, showers and thunderstorms are expected over several places throughout the forecast period. *The expected showers will continue to enhance the state of the crops and vegetation in the region.*
- **Northeastern counties (counties of Marsabit, Mandera, Wajir, Garissa and Isiolo),** are expected to experience rains over few places coupled with sunny intervals throughout the day during the forecast period. *This dry condition will continue to worsen the state of pasture and vegetation in this region.*
- **Southeastern lowlands (counties of Taita Taveta, Makueni, Machakos and Kitui),** are expected to experience cloudy mornings breaking into sunny intervals in the morning session over the forecast period and during the afternoon session showers over few places giving way to sunny intervals throughout the forecast period.
- *The wet conditions forecasted will regenerate the crops, pasture and vegetation in the region.*
- **In the Coastal strip (counties of Mombasa, Malindi, Kilifi, Lamu, Kwale, etc.**), is expected to experience mainly showers over few places, giving way to sunny intervals during the morning session and sunny intervals in the afternoon throughout the forecast period.
- *The showers expected will have a refreshing impact on the crops in this region.*

For feedback or further guidance, Contact:

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AGRICULTURE GLOBAL PRACTICE TECHNICAL ASSISTANCE PAPER

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