Establishing and Improving Linkages between National Weather Service and Agricultural Sector: A USDA Perspective

Raymond P. Motha
U.S. Department of Agriculture, World Agricultural Outlook Board
Washington, D.C.

Abstract

Agricultural production is highly dependent on weather, climate, and water availability. Weather variables such as precipitation, temperature, and radiation are crucial for plant growth and development. Some of the important extreme weather and climate events from an agriculture and livestock point of view are tropical storms (cyclones, hurricanes, typhoons, etc.), flooding, and storm surges; floods (other than those related to tropical storms), heavy rains during monsoon and water logging; severe thunderstorms, hailstorms, tornadoes, and squalls; drought and heat waves; cold spell, low temperature, frost, snow, and ice storms; dust storms and sand storms; weather conducive to fires (lightning); and weather encouraging pests and diseases of crops and livestock.

Introduction

Air and soil temperatures are important factors for the development rate of plants. Each crop experiences an optimum temperature range for plant growth. Periods of extreme temperature values, which are well below the threshold value or well above the maximum value are hazardous to plant development and growth. Periods of extreme temperature conditions such as those experienced during extreme cold spells causing cold stress and frost, or high temperatures and heat waves leading to heat stress can affect agricultural production. Snow and ice storms in late spring or early autumn are very hazardous to many temperate crops, exposing them to layers of snow and ice and causing freezing of the crop.

Similarly, extreme moisture conditions, namely dry desiccating winds, drought episodes, and low moisture availability as well as heat spells, affect agriculture. High soil moisture in situations of water logging and flooding associated with heavy rainfall and tropical storms also adversely effects plant growth and development since it influences the rate of transpiration, leaf-area expansion and, ultimately, plant productivity. Drastic changes in rainfall distribution can have a very significant impact, particularly in climatically marginal zones such as arid, semi-arid, and sub-humid areas where the incidence of widespread drought is frequent.

There are, however, some advantages to dry spells or drought at certain stages of the development of crops such as sugar cane where a brief dry spell is essential during the pre-harvest stage. This helps to concentrate or increase the sucrose content of the cane. Additionally, there is often a lower incidence of pests and diseases in periods of drought. Grain crops need an optimal dry-down period prior to harvesting as well.

Since there is a direct relationship between weather and fire danger and weather and fire behavior, knowledge of past, present, and future weather is desirable. This should include temperature, relative humidity, wind, precipitation, and thunderstorm data. Information is also required on the state of forest litter and its ability to burn.

The ability of cattle in the open air to withstand low temperatures is fairly strong. However, it is the secondary effect of weather often accompanying a cold wave that causes widespread livestock losses. Snow covers forage and drinking water supplies freeze. As a result, cattle caught in a winter storm can starve rather than die directly from the cold temperatures. Livestock are adversely affected by high temperature together with high relative humidity. Meteorological data on these aspects are very useful in forecasting extreme episodes and minimizing losses.

All of these relationships illustrate the importance of weather and climate information for agriculture, forestry, and livestock. Accurate information on meteorological events is extremely important to farmers in maximizing their production, modifying the crop environment, protection from frost and strong winds, and also irrigation scheduling. The extension of cultivation into less suitable climates increases the potential risk of damage due to the increased likelihood of meteorological extremes. The successful development of a country's agricultural economy is, therefore, dependent on the use of climatic information. This dependence grows with both agricultural and technological expansion. Meteorological data are essential not only for operational applications to sustain agricultural development at the local level but also for research studies to foster new long-term agricultural strategies.

What is clearly demonstrated by the discussion is the strong influence of meteorological factors on every facet of agriculture. Farmers understand this importance; namely, the success or failure of their livelihood often depends on daily and growing-season weather events. Agricultural extension personnel are trained to assist farmers and agriculturalist with new innovative technologies to cope with nature's vagaries and to sustain agricultural development. Scientists and researchers are diligently gaining better insight and knowledge into the operational understanding and interrelationships needed to improve models and applications of science and technology. Decision makers at all levels, from local community officials to national government policy-makers, are utilizing information technology more efficiently to collaborate and develop local, regional, and national policy.

A major hurdle must be overcome for many of these interrelationships to be achieved. Agricultural meteorology bridges two disciplines of science; i.e., meteorology and agriculture. While meteorology is very important to agricultural applications, the field of atmospheric science is sufficiently broad to cover other important economic sectors such as the transportation industry and commerce. Very often, meteorological services are located in transportation or commerce agencies of the Federal Government. It becomes an essential task to establish a channel of communication agencies involved in national weather services and agencies involved with the agricultural sector of society to ensure that necessary data, information, technology, and policy flow to all appropriate users. The remainder of this paper reviews ways of establishing and improving linkages between national weather services and the agricultural sector.

Agricultural Weather and Climate Services - A USDA Perspective

The climate and weather services requirements of individual United States Department of Agriculture (USDA) agencies reflect the varied and diverse missions and programs that currently exist throughout the Department. Internet access to both real-time and historical climate data, along with software tools to support critical economic and natural resource decisions have now become essential to the Department's mission. This paper, however, provides a historical perspective of the role of climate in agriculture leading up to the present status. It outlines these critical mission areas and their dependence on climate information to support climate-based decisions dealing with production agriculture, water supply availability, drought assessment, and other natural resource conservation activities.

A Brief History of Climate and Agriculture: 1890 - 1940

The National Weather Service was created as a branch of the Signal Service, later the Signal Corps of the Army, by a Joint Congressional Resolution approved February 9, 1870. It provided "for taking meteorological observations at the military stations in the interior of the continent and at other points in the States and Territories of the United States, and for giving notice on the northern lakes and at the seacoast, by magnetic telegraph and marine signals, of the approach and force of storms." (NOAA, 2003.)

"While the Weather Service was originally designed for the benefit of navigation on the seacoast and the Great Lakes, it was soon extended to include the interior districts and the great rivers of the central valley. The benefits of a National Weather Service were soon recognized and business industries, the general public, and farmers demanded special forecasts and warnings applicable to their needs. These demands soon became so voluminous that the urgent need of a new organization, devoid of militarism, and with a more scientific status, became apparent. Accordingly, when this need was brought to the attention of Congress, an Act, approved October 1, 1890, transferred the weather service of the Signal Corps to the Department of Agriculture effective July 1, 1891." (NOAA, 2003.)

The Act of October 1, 1890, charged the Chief of the newly created civilian agency with the following duties: The Chief of the Weather Bureau, under the direction of the Secretary of Agriculture (Commerce), shall have charge of the forecasting of weather, the issuing of storm warnings, the displaying of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers, the maintenance and operation of seacoast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation, the reporting of temperature and rainfall conditions for the cotton interests, the displaying of frost and cold-wave signals, the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties (15 U.S.C. 313).

The Weather Bureau was transferred from the Department of Agriculture, where it had been a constituent bureau since July 1, 1891, (Act of October 1, 1890, 26 Stat. 653) to the Department of Commerce (DOC) on June 30, 1940, under authority of Reorganization Plan No. IV of the President, which was submitted to the Congress on April 11, 1940. In his message submitting Reorganization Plan No. IV, with reference to the Weather Bureau, the President said: “The importance of the Weather Bureau's functions to the Nation's commerce has also led to the decision to transfer this Bureau to the Department of Commerce. The development of the aviation industry has imposed upon the Weather Bureau a major responsibility in the field of air transportation. The transfer to the Department of Commerce, as provided in this plan, will permit better coordination of Government activities relating to aviation and to commerce generally, without in any way lessening the Bureau's contribution to agriculture." (NOAA, 2003.)

USDA Weather and Climatic Research

During USDA's 49-year stewardship of climate and weather services, a significant number of research activities were focused on the relationship between climate and agriculture with the establishment of the Climatic and Physiographic Division in 1935. Scientific research was aimed at discovering the interaction of climate and erosion, the stages of natural and culturally induced erosion, and the characteristics of erosional landforms. Climatic studies, employing existing Weather Bureau records as well as original field observations, were concerned with drought and wind erosion, the long-term aspects of rainfall, and the short-term problems of rainfall intensity and storm patterns (NARA, 2003).

The 1938 seminal publication by C.W. Thornthwaite, USDA Soil Conservation Service, summarized the role of climate factors in water and wind erosion, intensity and duration of rainfall for reservoir design, frequency of rainless periods for determining drought and consequent erosion hazard, rainstorm morphology, spacing of rain gauges, determination of the maximum storm, field moisture deficiency as a climate factor, and studies of evaporation (Thornthwaite, 1938).

This research culminated in the publication of the *Atlas of Climatic Types in the United States 1900-1939* (Thornthwaite, 1941). The atlas categorized climate by moisture regimes (i.e., super-humid, humid, sub-humid, semiarid, and arid), provided definitions of effective precipitation, the use of vegetation as a climatic indicator, and discussed climatic variation. The atlas also contained annual crop season climate type maps for the period 1900-1939. Normal crop season maps were also published. Climate mapping has seen a renaissance with USDA co-sponsored efforts performed in partnership with Oregon State University (Daly, 2002).

DOC and USDA Weather, Climate, and Agriculture Activities: 1941 - 1979

With the outbreak of World War II, the Weather Bureau had very little statistical data describing foreign climates in a useable form at the outbreak of war. Significant efforts were placed in summarizing climate for armed forces aviation, gathering upper air information, standardizing climate summary punch card formats, determining degree-day climatologies, and the standardization of procedures to process and publish climate summaries.

As a result of security plans formulated previously by the Defense Meteorological Committee, the Weather Bureau, in December 1941, was enabled to continue forecast and warning service to the public and comply with security requirements. Most of the weather service provided to public individuals was in the form of operational advisories. For example, orchardists desiring to spray fruit trees were informed as follows: "Spraying conditions satisfactory next three days" (NOAA, 2003).

In 1971 the Department of Commerce published a "Federal Plan for a National Agricultural Weather Service" (NOAA, 1971). This plan summarized user requirements and potential service value, the National Oceanic & Atmospheric Administration (NOAA) Agricultural Weather Service Program, and NOAA's Plan for an Improved Agricultural Weather Program. Implementing an Agricultural Weather Service relied on cooperation between the National Weather Service, Environmental Data Service, State Universities, State Climatologists, and the Department of Agriculture. The plan was never implemented for a variety of reasons.

In August of 1979, the General Accounting Office published a report titled "Agricultural Weather Information is Not Effectively Communicated to Users" (GAO, 1979). The purpose of the report was to survey the agricultural community in order to clarify the Department of Commerce (DOC) and USDA respective roles, responsibilities, and goals, in order to establish an effectively coordinated Agricultural Weather Service Program. The GAO report stated that, "Congress has never specifically mandated the extent to which NWS should provide specialized weather services for users, such as agricultural weather information, and recommended that Congress clearly define NWS's role and responsibilities for providing such services." The report concluded, "Agricultural weather information is not being communicated to users and potential users. The need for certain improvements in the program has been noted by the Departments of Agriculture and Commerce. As a result, the Departments have reached some agreements to improve cooperation; however, much more remains to be done."

The 1979 report recommended that the "DOC, in cooperation with the Secretary of Agriculture, clarify and strengthen the roles of your Departments in the Agricultural Weather Service Program. This should include: 1) improving the methods for publicizing and communicating weather information to users and potential users, and 2) providing program coordination by updating the "Federal Plan for a National Agricultural Weather Service."

The Joint Agricultural Weather Facility

In response to the GAO report, an Interagency Agreement between the DOC and USDA established the Joint Agricultural Weather Facility (JAWF), which has been in existence for 25 years. The JAWF was created as a world agricultural weather information center located in USDA and is jointly staffed and operated by DOC/NOAA/NWS/Climate Prediction Center (CPC) and USDA/OCE/World Agricultural Outlook Board (WAOB). The JAWF is located in Washington, D.C., and serves as USDA's overall focal point for weather/climate information and agricultural impact assessments.

JAWF consists of a team of NWS operational meteorologists and WAOB agricultural meteorologists that monitors global weather conditions and prepares real-time agricultural assessments (Puterbaugh, et al., 1997; Motha and Heddinghaus, 1986). These assessments keep USDA commodity analysts, the Chief Economist, and the Secretary of Agriculture and top staff well informed of worldwide weather-related developments and their effects on crops and livestock. When integrated with economic analyses and information, these routine and special crop-weather assessments provide critical information to decision makers formulating crop production forecasts and trade policy. JAWF's primary mission is to monitor global weather and determine the potential impacts on agriculture. JAWF meteorologists rely heavily on weather and climate data from over 15,000 stations from international and U.S. sources. Consequently, one of JAWF's most critical tasks is to process large volumes of data in an efficient and timely manner, and to generate products and agricultural assessments that are meaningful to the user community (JAWF, 1994).

For over two decades, JAWF has developed techniques for the acquisition, processing, and archival of these data, creating a blend of "existing" and "newly-developed" methods and products used in agrometeorological data management and analysis. A database management system (DBMS) effectively handles large volumes of available information and allows full integration of data into other Windows-based packages (Puterbaugh, et al., 1997). Products currently utilize Geographical Information System (GIS) techniques at JAWF, providing the agricultural meteorologists with additional tools to produce crop-weather assessments and enhancing analytical techniques. JAWF's assessments are the final product of a series of steps that include: 1) meteorological data acquisition and management, 2) data processing, 3) data analysis, and 4) product and information dissemination.

DOC and USDA Agricultural Weather and Climate Activities in the 1990s

Agricultural weather activities and user needs took on greater importance and urgency with the termination of the NWS Agricultural Weather Program on April 1, 1996. An NWS letter to Agricultural Weather Services Customers (NOAA, 1996) stated that, "the NWS will make every effort to maintain agricultural weather observation networks in the months ahead. The inventory of NWS weather observing equipment will be examined closely to determine what data sources will remain available for use by private meteorologists. The NWS will continue observations and records pertaining to recording and predicting the nation's climate and for other programs such as public forecasts and warnings. The basic data critical to making agricultural forecasts is still available to all users such as freeze and frost warnings."

A paper presented to the American Meteorological Society 10th Conference on Applied Climatology (Motha et al., 1997) provided a comprehensive definition of climate services for agriculture. Accurate and timely weather and climate information is needed for operations risk assessment and research. Examples include agricultural yield and productivity, natural resource conservation, forest fire potential, insurance and compliance programs, crop disaster assistance and emergency relief programs, integrated pest management, and crop yield modeling. The role of data collection and product generation in USDA for agricultural weather and climate monitoring and impacts assessment was addressed. The important roles of national, regional, and state climate offices in providing climate services were also highlighted. This is essential because not all data flow into the NWS offices but are available at local, state, or regional offices for unique or specific applications. The cooperative network, for example, represents the entire suite of local station networks operated by federal, regional, and state agencies. Moreover, access to the full suite of historical meteorological data for analog comparisons may also necessitate coordination with various agencies and data sources.

In 1998, the DOC requested the USDA to prepare a report of requirements for weather and climate data, services, and information. An interagency USDA committee produced a report titled "Operational Meteorological Data Requirements (USDA, 1999). Nine USDA agencies contributed to the report; the World Agricultural Outlook Board and Joint Agricultural Weather Facility, Farm and Foreign Agricultural Services, Farm Service Agency, Risk Management Agency, Forest Service, Natural Resources Conservation Service, Agricultural Research Service, Cooperative State Research, Education, and Extension Service, and National Agricultural Statistics Service.

While the requirements of USDA are numerous, they can be categorized into four basic areas that are covered by weather service operations as follows:

- *Current Measurement and Observational Data and Services* - These services consist of the operation of acquisition programs, observing systems, data collection and quality control, and networks to provide the data essential to defining the state of the atmosphere and its impacts on man and his activities. They are largely concerned with assembling weather observations into useable databases and providing them for use in analyses and applications;

- *Climate Services* - These services provide for the acquisition, storage, management, and summarization of historical weather data. They also include the analyses of climatological data to characterize climate conditions or regimes for different geographical areas or time periods. Climate services also include the development of normals, freeze probabilities, and drought indices;
- *Forecasting Services* - Prediction of future weather events or climatic conditions and their associated probabilities;
- *Other Services* - Consultation, analyses of particular weather events, interpretation of forecast materials, monitoring and summarizing recent weather events, weather briefings and summaries, special studies and analyses, and user education.

Converting voluminous weather data into crop-specific agronomic information that can be easily understood by its non-meteorological community is one of the largest challenges faced by USDA. The worldwide scope of production agriculture and exchange of agriculture products has driven the need for a wide variety of weather and climate data. Fifteen general data requirements are described in Table 1 that describes the type of data required, desired reporting frequency, and the significance to agriculture.

National & International Agricultural Production General Data Requirements		
Data Type	Time Period	Agricultural Significance
National and International Surface Observations	Hourly and/ or 3-hourly	Required to monitor current conditions affecting agriculture and in planning agricultural activities
Local and Regional Automated Weather Data Networks	15-minute intervals, hourly	Required for accurate assessments of rainfall rates that affect erosion and runoff processes. Precision agriculture needs high resolution spatial and temporal data for irrigation, research and regulatory issues, livestock operations, and crop management
Cooperative Network Surface Observations (station level)	Daily	Required for daily monitoring of agrometeorological conditions that affect agricultural operations and production. Many of these sites are located in agriculturally important areas
Global Daily Summary Data (station level)	Daily	Required for daily monitoring of global weather conditions that affect agriculture
Global Weekly Summary Data	Weekly	Required for determining the cumulative effects of weather on agriculture during the growing season
Global Monthly Summary Data	Monthly	Required for determining the cumulative effects of weather on agriculture on a monthly scale
CLIMAT Data for the World	Monthly	Required for quality control of Global Monthly Summary Data
Global Normals	Daily, Weekly, Monthly	Required to determine anomalous weather conditions that may affect agriculture
Freeze Dates	Spring and Fall	Required for Weather Risk Assessment and Crop Vulnerability
Historical Data	Daily, Weekly, Monthly	Required for analog growing season comparisons
Global Satellite Data (cloud imagery)	Variable Hourly to Daily	Required to document significant weather features and likely coverage within a crop area and in quality control of surface data
Sea Surface Temperature Data	Weekly and Monthly	Required for monitoring El Niño-La Niña conditions
Radar Data	Variable	Required to augment precipitation data in areas of limited data coverage
Upper Air Data (all mandatory pressure levels)	Variable	Required to monitor weather patterns on a synoptic scale that are affecting agriculture
Forecasts and Outlooks (local, regional, national, and international)	Hourly, 1-3 days 3-5 days, 6-10 days, Monthly, Seasonal, El-Niño, La-Niña	Required for plant disease forecasting, agricultural research and extension service models, resource allocation, policy-level briefings and decision making, drought and flood monitoring, daily weather write-ups, and weekly briefings to the Secretary and top staff

Table 1. National and international agricultural production general data requirements.

Weather plays a vital role in all phases of agricultural production. In addition to general weather requirements for agricultural production, each type of agricultural activity has a unique set of weather variables that affect it. Twenty-two specific weather data elements are given in Table 2. Individual agricultural activities are described for each weather element.

Specific Weather Data Requirements for Agricultural Activities		
Data Type	Time Period	Agricultural Activities
Temperature (global)	Hourly and accumulated means and extremes	Planting, harvesting, crop-weather monitoring, freeze detection/protection, defoliation, crop modeling, disease risk, lambing and calving shelter, pest control, sheep shearing, PET computations, vapor pressure deficit computations, chill hours for stone fruit, growing degree day computations
Maximum Temperature (global)	Daily and Weekly Extremes	Required to determine optimum or unfavorable conditions for crops and livestock, crop modeling, extreme events monitoring, snow cover estimations, growing degree day computations
Minimum Temperature (global)	Daily and Weekly Extremes	Required to determine optimum or unfavorable conditions for crops or livestock, freeze detection, defoliation, crop modeling, overwintering conditions, and extreme events monitoring, snow cover estimations, growing degree day computations
Precipitation (global)	Daily	Planting, harvesting, fertilizer applications, cultivation, spraying, irrigation, crop-weather monitoring, crop modeling, disease risk, livestock and poultry protection and watering, extreme events (drought or flood) monitoring, snow cover estimations
Rainfall Intensity	15-minute, Hourly	Flood potential, erosion, runoff, water quality
Dew Point and Humidity (global)	Hourly	Harvesting, determine freeze potential, pollination, spraying, drying conditions, vapor pressure deficit computations, crop stress potential, PET computations
Hail	Hourly	Crop damage, risk assessment, productivity impact
Temperature Inversions	Hourly	Aerial spraying for agriculture, frost protection measures
Atmospheric Pressure (global)	Hourly	General crop-weather monitoring, type of freeze (radiation, advection etc.)
Sky Cover (global)	Hourly	Fertilizer application, spraying or dusting, PET computations
Cloud Height (global)	Hourly	Fertilizer application, spraying or dusting,
Present Weather (global)	Hourly	Snow Cover estimations, fieldwork, crop stress potential
Wind Speed (global)	Hourly	Planting, defoliation, harvesting, freeze potential/protection, lambing and calving shelter, pest control, pruning, PET computations, spraying or dusting, pollination, blizzard conditions
Wind Direction (global)	Hourly	Freeze potential/ protection, cold or warm air advection over crop areas
Vapor Pressure Deficit (global)	Hourly	Derived from temperature and dew point
Solar Radiation, Duration of Sunshine, or Amount of Cloud Cover (global)	Daily	PET computations, crop modeling, planting, harvesting
Snow Depth (global)	Daily	Monitor overwintering conditions for winter wheat, prepare water supply forecasts for water users in the western U.S., estimate soil moisture reserves for the next growing season
Soil Moisture (global)	Daily	Planting, harvesting, fertilizing, crop modeling, transplants, spraying, irrigation, monitoring of growing conditions, stress indices
Blizzards, Hurricanes, Tropical Storms	Daily	Crop monitoring, risk and productivity damage assessments, resource conservation
Storm Tracks/Storm Strengths	Daily	Agricultural impacts, risk management, flood potential, drought monitoring
Soil Temperature (global)	Daily	Planting, overwintering conditions, crop modeling, transplants, fertilizing
Pan Evaporation (global)	Daily	Irrigation scheduling, water budget computations, PET comparisons, crop-water usage

Table 2. Specific weather data requirements for agricultural activities.

For decision making, USDA needs current weather information for research and to assist growers with their management operations. This includes strategic decisions (what to plant), or tactical decisions (when to irrigate). As a result, USDA agencies that assist farmers in their decision-making require a more detailed set of weather requirements. The weather data requirements for 14 specific agricultural activities, ranging from soil preparation to freeze protection, are published in the USDA report. Near real-time access to these weather data through the Internet is highly desirable and preferred.

Historical and current weather data are also used by insurance services and compliance programs as an additional information resource in determining if losses are reasonable and if producers and reinsured companies are in compliance with the insurance contracts. USDA also had a leading role in the National Drought Policy Commission (NDPC) and is working on drought policy issues, which require monitoring of drought conditions and forecasting (NDPC, 2000).

Weekly Weather and Crop Bulletin

The *Weekly Weather and Crop Bulletin* (*WWCB*) is deeply rooted in the past. The *WWCB* originated in 1872, two years after the U.S. Congress passed a resolution that was signed by President Ulysses S. Grant on February 9, 1870, to establish a new service in the War Department for taking meteorological observations. The Secretary of War promptly assigned the new service to the Chief Signal Officer of the Army, General Albert J. Meyer, who named it "the Division of Telegrams and Reports for the Benefit of Commerce." In 1872, the Division began publishing the *Weekly Weather Chronicle* for the benefit of commerce and agriculture. This publication was the forerunner of today's *WWCB* and contained a 2-page printed release that contained a general summary of weather for each week ending on Wednesday.

The publication has evolved over the past 129 years into one that provides an invaluable source of information pertinent to regional, national, and international agro-business. Since 1978, the *WWCB* has been produced by JAWF and jointly operated by the DOC's CPC, USDA's WAOB, and the National Agricultural Statistics Service (NASS). The publication is a shining example of how two major departments within the Federal Government can mutually cooperate, combining meteorology and agriculture to provide a service that benefits the economic well being of the Nation. Data and information contained within the *WWCB* are generated by the efforts of thousands of people, including about 3,000 county extension agents, NASS crop reporters, field office personnel, State Universities, National Weather Service Forecast Offices, and more than 5,000 weather observers, mostly volunteer, working with the NWS. The *WWCB* highlights weekly meteorological and agricultural developments on a national and international scale, providing written summaries of weather and climate conditions affecting agriculture, as well as detailed maps and tables of agrometeorological information appropriate for the season.

The national portion of the *WWCB* summarizes weather and crop information supplied by thousands of people throughout the Nation, including about 3,000 county agents of USDA's Cooperative Extension Service; a core of NASS volunteer crop reporters, sending in information to the State Statisticians of NASS; NOAA meteorologists, and more than 5,000 weather observers, mostly volunteer, working with the NWS. NASS volunteer crop reporters are persons who voluntarily report information about their farms or localities for use in NASS forecasting and estimation programs.

NASS tracks crop progress based on data collected from county extension agents and volunteer crop reporters. Each Monday during the growing season, weekly crop reports are prepared based on information gathered from these co-operators. The NASS headquarters in Washington, D.C., manages a network of 44 field offices serving the 50 states, through cooperative agreements with State departments of agriculture or universities. At the same time, NOAA meteorologists in designated weather offices in each State (or State climatologists or personnel from land-grant universities in a few States) summarize weekly weather observations received from rural observers and urban weather stations. These detailed weather and crop summaries are released to the public each Monday afternoon and are transmitted to NASS in Washington for publication in the *WWCB*. These reports usually discuss crop weather conditions suitable for fieldwork and crop development, pest and disease outbreaks, soil moisture conditions, crop progress, and pasture and livestock conditions.

The *WWCB* emphasizes the cumulative influence of weather on crop growth and development. Weather conditions influence important farming operations such as planting and harvesting, and greatly influence yield at critical stages of crop development. The bulletin provides timely weather and crop information between regular monthly *Crop Production* and *World Agricultural Supply and Demand Estimates* reports.

The main users of the *WWCB* include crop and livestock producers, farm organizations, agribusinesses, State and national farm policy-makers, foreign buyers of agricultural products, and Government agencies. Agricultural statistics are used to plan and administer other related Federal and State programs in such areas as consumer protection, conservation, foreign trade, education, and recreation.

U.S. Drought Monitor

The NDPC found that about 22 Federal programs have some responsibility for drought monitoring, prediction, and research. In relation to monitoring and prediction, these programs focus on weather patterns, climate, soil conditions, and streamflow measurements. Examples of three major networks are USDA's Soil Climate Analysis Network (SCAN)/Snow Telemetry Network (SNOTEL), the NOAA/NWS's Cooperative Observer Network (COOP), and the U.S. Geological Survey's streamgaging and groundwater monitoring network. Federal programs often join with universities, private institutions, and other non-Federal entities to provide additional information. This is especially crucial for agriculture as data observation networks are often sparse in rural agricultural areas. It is well recognized that comprehensive weather, water, soil moisture, mountain snow amount, and climate observations are the foundation of the monitoring and assessment activity that alerts the nation to impending drought.

The vigorous debates and discussions during the NDPC meetings helped to formulate an important new operational drought product. This product was important to develop as it became the first prototype tool to integrate the basic data on current conditions and translate these data into meaningful information to the user community. The emergence of the U.S. Drought Monitor (Svoboda, et al., 2002), established in 1999, was a major advancement in drought monitoring products. The Drought Monitor classifies drought severity into five categories. The category thresholds are determined from a number of indicators, or tools, blended with subjective interpretation. The United States Drought Monitor was developed as an operational tool for monitoring drought conditions, including aerial extent, severity, and type, around the country. The Drought Monitor has become a highly successful tool for assessing the development and duration of drought conditions. The USDA, DOC, and the National Drought Mitigation Center publish the drought map and text weekly and post them on the Internet (http://drought.unl.edu/dm). The product serves as an exemplary case of interagency cooperation. A major strength of the Drought Monitor is its inclusion of input from climate and water experts from around the country.

The Monitor requires a major collaborative effort to pull together the various sources of weather data and compile them in a single, comprehensive, operational, national report. The map not only delineates stages of drought but also specifies drought type when the impacts differ. For example, if severe drought affects wildfire danger and water supplies, but is not in a significant agriculture area, then the map would depict W (water) and F (wildfire danger) only. If drought affected a major crop area, that area would be denoted with "A" for agriculture. The map also reflects forecast trends. If the forecast of drought is expected to intensify, a "+" is depicted in affected area. Similarly, if the forecast calls for rain to diminish drought conditions, a "-" is depicted in the affected area. No change in the drought classification forecast is depicted by no sign. The text of the Monitor provides a detailed discussion of the map.

The Drought Monitor itself is not an index, nor is it based on a single index, but rather is a composite product developed from a rich information stream, including climate indices, numerical models, and the input of regional and local experts around the country. No single definition of drought works in all circumstances (Wilhite, 2000). Water planners and agricultural producers may rely on completely different sets of indicators. The Drought Monitor authors must rely on a number of key and ancillary indicators from different agencies. The map fuses these indicators, using human expertise from across the United States, into an easy-to-read image presenting a current status of drought conditions. The Drought Monitor process is an evolving one as new, or better, indicators and information sources become available.

Lead responsibility for preparing the Drought Monitor rotates among nine authors from four agencies who sequentially take 2 to 3 week shifts as the product's lead author. Nationwide experts respond to the lead author's first draft when it arrives by Internet and through an e-mail list-server every Monday. An interactive process continues until the final product, both the map and text, are released on Thursday morning.

Classification of drought magnitude in the Drought Monitor is based on farm levels using a percentile approach. The percentiles are standardized for the year rather than for all times of the year at once. They are not meant to imply an average areal extent value for the United States at any given time. The categories include: D0 (abnormally dry), 21 to 30 percent change occurring in any given year at a given location; D1 (moderate drought), 11 to 20 percent chance; D2 (severe drought) 6 to 10 percent chance; D3 (extreme drought), 3 to 5 percent change; and D4 (exceptional drought), 2 percent or less change.

The Drought Monitor's severity categories are based on six key physical indicators and many supplementary indicators. The indicators are the Palmer Drought Severity Index (PDSI; Palmer 1965); CPC Soil Moisture Model Percentiles (CPC/SM); Huang, et al., 1996); U.S. Geological Survey (USGS) Daily Streamflow Percentiles (http://water.usgs.gov.waterwatch/); Percent of Normal Precipitation (Willeke, et al. 1994);

Standardized Precipitation Index (SPI; McKee, et al., 1993); and remotely sensed Satellite Vegetation Health Index (VT; Kogan, 1995).

Ancillary indicators include the Palmer Crop Moisture Index; the Keetch-Byram Drought Index (KBDI; Keetch and Byram, 1968); evaporation-related observations, reservoir and lake levels, and ground water levels; USDA field observations of surface soil moisture; and USDA snow pack and snow water equivalent measurements.

Classification of drought impact types is also included in the Drought Monitor. The categories include agriculture (crops, livestock, range, and pastures), water (streamflow, snow pack, groundwater, reservoirs), and fire (wildfire - forest and range fires). Crop stress is often the earliest indicator of a developing drought situation because of the plants need for moisture and moderate temperatures during critical phases of development. On the other hand, hydrological impacts of a major drought often linger for months or even years after agricultural concerns disappear. Thus, it is essential to monitor the evolution of drought types as well as overall conditions.

Finally, as mentioned earlier, a significant key to the outstanding success of the Drought Monitor is the process of gleaning information from many experts located across the country. Their input and verification of impacts at the regional and local levels are critical in both the production of the Drought Monitor and in establishing and maintaining the credibility of the product. These experts include regional and state climatologists, agricultural, and water resource managers, hydrologists, NWS field office employees, and others. The list of expert reviewers has grown to nearly 150. A Drought Monitor Workshop is held annually to allow all participants to meet and share ideas for improvement in the process and the product. The Drought Monitor is a dynamic product that is the focus of constant searching for timely and better indicators to assist the user community. This user community ranges from a farmer to a government policymaker.

Operations of the Joint USDA/OCE/WAOB and MSU/DREC Agricultural Weather and Data Center

An example of how this national cooperative effort is applied to research and extension activities at the state level is illustrated by the JAWF-DREC operation. The Mississippi State University (MSU) Delta Research and Extension Center (DREC), located in Stoneville, Mississippi, is situated on one of the largest agricultural experiment stations in the world. The crop research area covers about 1,650 acres, including approximately 200 acres of federally owned land. Field plots occupy about 1,200 acres, with soil types ranging from very fine sandy loams to heavy clays. Over fifteen governments, states, and private organizations are involved in agricultural research and production in the 18 countywide areas of the state called the Delta.

In May 1996, a Weather/GIS Data Center was established at MSU/DREC in order to meet the local demands for adequate coverage of agricultural weather information required in research and production agriculture. The main mission of the Data Center was to ensure the collection and archival of vital agricultural weather data in the Mississippi Delta. A partnership between the WAOB and DREC was established in October 1998, with the WAOB field office co-located with the DREC-Weather/GIS Data Center. The purpose of the joint Data Center is to collect, quality control, manage and disseminate agricultural weather data, and serve the local needs for agricultural weather information and services in the Delta. As a result, WAOB partnerships with other institutions engaged in agricultural weather activities and climate services have grown to include USDA's National Resource Conservation Service (NRCS); the states of Missouri, Alabama, and Iowa; and the Regional Climate Centers (RCCs). At the same time, WAOB continues to work closely with the NWS to support the modernization of the crucial COOP Network, to ensure continuity in the national surface observation network.

- *Products and Services:* The joint DREC-WAOB Agricultural Weather Data Center provides weather and climate data, geographic queries, crop progress information, products developed using GIS, and weekly weather briefings to researchers, producers, county extension agents, and agricultural industries in the Delta. The primary mechanism used to disseminate the Delta weather data is through the DREC – Weather/GIS website, while the WAOB field office website is used to disseminate the table of regional "Weather Data for Mississippi and the Missouri Bootheel." To date, over 350,000 users have visited the DREC website to access Delta weather data and products. The Data Center also handles numerous requests for information related to climate services, including temperature and precipitation data, wind data, average first and last frost or freeze dates, solar radiation, and pan evaporation data. Contributions to the monthly MSU-Extension Service (ES) agriculture newsletter also helps distribute data and information to users.

The DREC - Weather/GIS Data Center also produces several agro-meteorological products that are derived from weather data and prior research on crop phenology. Crop growth simulation models are available for rice and cotton. A Rice DD50 model is a program that interactively "grows" a rice crop based on accumulated heat units (derived from temperature data) that are related to the crop's phenological development (Ramirez and Bauer, 1974). From the website, growers can choose their individual counties and varieties of rice to obtain information on stages of crop development as well as crop management recommendations. For future dates, the program uses 30-year historical norms to finish growing out the crop until a predicted harvest date. This helps farmers anticipate growth stages for planning future management decisions in order to increase revenues and/or decrease losses. Researchers and Extension personnel also use this program to complete comparative variety studies and aid in diagnosing problems in clients' fields.

Research experiments from 1993 through 1996 resulted in a new MSU-ES recommendation being introduced into the cotton production industry in the Mississippi Delta. This MSU-ES recommendation, called the "Node Above White Flower Five Rule," calls for the collection of DD60 heat unit data after a cotton plant reaches a certain growth stage. This recommendation requires vigilant monitoring of the cotton plants when nearing maturity by researchers and producers to identify that date at which a flower blooms on the fifth node (branch) from the top of the plant (terminal). From that date, the cotton boll that is made from that flower needs 350-Degree Day heat units based on 60 degrees Fahrenheit (DD60) to become large enough to be safe from certain insect damages. At the point in which a certain amount of heat units are accumulated, certain crop damaging pests are no longer a threat and thus no longer in need of being controlled. As a result, applications of pesticides for certain pests can be terminated (Harris, et al., 1997), thus saving the producer as well as the environment an average of two insecticide applications. Since the benefits from this recommendation require a researcher or producer to keep a vigilant watch of each field and variety, the recommendation suggests obtaining data from a nearby weather station or extension office (Cochran, et al., 1998) to aid in the determination of cotton development.

Planting recommendation reports are also available on the DREC - Weather/GIS Data Center's web page. The MSU-ES recommends time windows for planting crops. Some of their recommendations are based on weather scenarios. Planting recommendations for corn and soybeans are based on 30-year normals, and are used for the timing "trigger" as when to plant. MSU-ES's current recommendation is plant as early as a farmer wants depending on the amount of risk the farmer is willing to accept for the chance of frost or freeze each crop can withstand. Probability maps are produced ranging from 10 percent, 50 percent, and 90 percent chance of occurrence.

The cotton planting recommendation is based on soil temperature. When soil temperatures reach a certain level in the spring, producers are advised to plant cotton when there is an accumulation of fifty DD60s in the next 5 days. These calculations of future heat units are needed to ensure that soil temperatures will remain at favorable levels for seed germination. To calculate these future heat units, forecasted model output of temperature data from the National Weather Service's medium range forecast model is used for locations in Mississippi as well as surrounding states. The 5-day forecasted maximum and minimum temperatures from the model are downloaded and placed into a database. The DD60 data are calculated from the forecast temperature and stored in the database. Using Geographical Information System (GIS) software, contour maps of the DD60 data are then generated on a map of the state of Mississippi. The data are separated into three gradations, "favorable," "marginal," and "unfavorable," to plant cotton for that day. The map is re-drawn nightly and the gradations move from south to north as the temperatures increase in the spring until state-wide soil temperatures reach favorable levels for cotton planting.

The Essence of Agricultural Weather and Climate Services for the 21st Century

Although many essential elements of an effective agricultural weather and climate services system exist, portions are poorly funded and others suffer from a lack of coordination. Management tools, such as GIS, powerful desktop computers, and the Internet, give us an opportunity to improve our efforts in the future. Four areas where these management tools will likely enhance agrometeorological services in the future include:

- A temporally and spatially diverse climate database that supports a wide variety of user-oriented analysis tools;
- A national, interactive climate information system that delivers a family of user-selectable products to meet customer needs via the Internet;
- A climate applications research program that provides national leadership to address climate-relevant natural resource and economic needs; and,
- An education program that provides training, educational materials, and workshops to improve the use of climatic information in all sectors of the user community.

Achieving these goals requires leadership and coordination among agricultural weather and climate service providers at the national, regional, and state levels and with the user community at all levels. From the NWS, adequate funding is essential for the maintenance of a modernized observational network that includes data needed for agricultural analysis. Further, cooperating agencies must provide recognition and support for the urgency of NWS to improve both short-term forecasts and long-range outlooks. While the accuracy of these forecasts has improved in recent years, natural disaster reduction and mitigation of extreme events in agriculture will be enhanced by further improvements.

Agricultural agencies are tasked with helping the people protect soil, water, and wildlife as well as sustain agricultural growth and development. As advances in information and biological technologies move forward, fundamental changes will likely occur through the agricultural sector in the 21st Century. The demand for weather and climate information will likely continue to expand for a wide spectrum of agricultural applications. In government, the information will be used for crop, forest, pasture and livestock conditions, irrigation reserves, crop-yield potential, and marketing outlooks. In research, the information will be used to develop model simulations (yield, physiology, pest, and irrigation management), weather-based generators, and scenario analyses in operational applications. In farming and agribusiness, the information will be used for advisories, daily farm management decisions, and long-term agricultural planning. Finally, more coordinated and integrated national policy on natural disaster reduction and mitigation of extreme events on agriculture will necessitate linkage of operational services with communities affected by these events.

In order to satisfy the user community, fundamental data observations of sufficient quality and quantity, accurate forecasts relating to episodic events affecting agriculture, and accurate long-range outlook to offer guidance for scenario analyses will be essential components of a data base system. However, it is important to recognize that many agricultural areas face limitations, not only with the type of data available but also more fundamental issues. These include: insufficient density of basic data observations in many agricultural areas; the lack of timely access to comprehensive data bases; the availability of data in no-standard formats; and, the lack of a unified climate data base with appropriate software to create products necessary for agricultural applications. These problems must be overcome before significant advancement can be made.

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