METEOROLOGICAL FORECASTING FOR AGRICULTURAL PRODUCTION

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Contents

Summary

A large part of agricultural production occurs in the natural environment and management of this production by humans is impacted by changes in weather and climate. Agricultural managers and producers, therefore, keep an eye on the weather and pay attention to weather forecasts to help them decide when to undertake production operations. The forecasts they utilize are predictions of precipitation (amount and type), temperature, solar radiation, humidity, wind and evapotranspiration. Forecasts of these weather variables are made as meteorological forecasts or climatological forecasts and are used in strategic, tactical, and operational decisions. Meteorological forecasts cover time periods of hours to less than 15 days into the future, while climatological forecasts cover time periods from 15 days into the future to months or years into the future. Strategic planning is long term planning that affects operations for several months to years, and makes use of climatological forecasts. Tactical planning involves decisions that impact different seasons of production, particularly the growing season of plants and can utilize either meteorological or climatological forecasts. Operational decisions are those decisions associated with a

particular production practice that will be accomplished within hours to days of the decision being made, and make use of meteorological forecasts.

1. Introduction

In this chapter meteorological forecasts are defined as forecasts of the state of the atmosphere, particularly the near surface atmosphere, from the present up to 15 days into the future. These forecasts may be contrasted with climatological forecasts which are defined as a forecast of the mean atmospheric conditions more than 15 days into the future. The major differences between the two forecasts are the lead time and the length of time the forecast represents. Lead time is defined as the length of time between when the forecast is made and delivered and the effective time of the forecast. Meteorological forecasts are made hours to days before the effective time of the forecast, while climatological forecasts are made months to years before the effective time of the forecast. For example, a “3-5-day forecast” has a lead time of 3 to 5 days. The strictest definition of a meteorological forecast is a forecast for the immediate future and includes forecasts from “Now” up to 15 days in the future. “Now forecasts” are forecasts with lead times of minutes to hours. Forecasts with a lead time greater than 15 days begin to fall in to a category more appropriately called “climatological forecasts”. The length of time that a meteorological forecast represents is generally a single day or part of a day, while climatological forecasts represent multiple days, to weeks, months, or years.

Meteorological and climatological forecasts can be “general” or “applied.” A general forecast represents the conditions without reference to a particular industry or activity, while an applied forecast takes the general forecast and applies it to an industry or activity such as agricultural production. It is in this context that meteorological and climatological forecasts are discussed in this chapter.

In addition to the lead time, the forecast details differ between a meteorological and climatological forecast. Meteorological forecasts provide estimates of actual temperature; humidity; precipitation probability, type, and amount; wind speed and direction; and sky conditions. Climatological forecasts are generally stated in terms of deviation from normal, such as above normal, normal, or below normal. Thus, the forecast is incomplete without the knowledge of the normal temperature and precipitation conditions for the time and location of the forecast. Normals are defined by thirty years of daily weather observations, and are updated every 10 years (e.g. 1961-1990, 1971-2000).

Meteorological and climatological forecasts for agricultural production differ from general meteorological and climatological forecasts in their application. For agricultural production the general forecasts are interpreted to indicate how the forecast conditions may impact the growth and development of crops, diseases, insect pests, and livestock; and how the conditions will affect production management practices. Thus, meteorological and climatological forecasts for agricultural production require knowledge of the circulation of the atmosphere and the factors that cause the day-to-day changes in the weather, and how agricultural organisms respond to short- and long-term atmospheric conditions. Crop canopies develop a micro-climate and it is within these conditions that the crop interacts with the soil, pests, and diseases. Therefore, the micro-meteorological conditions must be related to the synoptic-scale meteorological forecast.

For a meteorological or climatological forecast to be valuable management practices must be able to be changed to either take advantage of favorable conditions, or mitigate unfavorable conditions, and must be timely and have a reasonable degree of accuracy. Timely means the forecast is provided with enough lead time for an agricultural manager to take the action necessary to protect livestock or crops, or affect a management practice to take advantage of favorable conditions. While a perfect forecast (one that is accurate in detail and timing) has the potential to have the most value, even an imperfect forecast can have value if the forecast is in the "right" direction and provided with enough lead time for management practices to be effected. A highly accurate forecast can have no value if management practices cannot be applied to the crop or livestock before the forecast event. The development of meteorological forecasts for agricultural production requires people trained in agricultural meteorology which includes course work in both atmospheric sciences and agricultural sciences. While universities around the world often teach courses in both areas, few have programs that link the courses into the academic discipline of agricultural meteorology. In practice, agricultural meteorological forecasts are produced by meteorologists trained to develop general forecasts, and then learn how to apply the forecasts to agriculture once they are on the job.

2. Application of Agricultural Meteorological Forecasts

Meteorological forecasts for agricultural production can be provided for making strategic, tactical, and operational decisions. Lead time and number of days the forecast represents are the variables that determine whether a forecast is used for strategic, tactical, or operational decisions. Climatological forecasts are used in making strategic decisions. Both meteorological and climatological forecasts are used in making tactical decisions, and meteorological forecasts are used in making operational decisions.

2.1. Strategic

Strategic agricultural climatological forecasts provide the data and information for planning agricultural practices that change on a time scale of months to years. These include selection of crop or livestock species, crop rotation, size of farm, size and type of equipment, tillage practices, planting date, density, and spacing, cultivar selection, livestock stocking of pasture or range, design of livestock facilities, and investment decisions such as purchase of land, irrigation systems, and storage facilities.

Crop forecasts for strategic decisions require application of crop models to either existing climate data or forecast climate data. In practice, either historical daily weather data or weather data from weather generators are used with the assumption that the historical or generated data represent the future weather mean and variance. Weather generators are computer programs that create sequences of daily weather data that fits the known distribution of each weather variable. For strategic planning historical weather data is limited in the number of years and weather sequences that can be evaluated. Weather generators, on the other hand, provide an unlimited number of years and weather sequences to develop probabilistic forecasts of the effects of weather on cropping systems, and the response of these cropping systems to different management practices.

Crop models can also be used for strategic decisions related to the stocking rate of pastures or ranges. In this case, models of pasture or range plants are used to determine the quantity of feed available during different seasons of the year. The climate variables needed for these models are similar to those for crop models. Temperature, wind, and precipitation frequencies, amount and type are used to design facilities for protection from frequent inclement conditions at a location.

With the concern of rising atmospheric carbon dioxide and the potential increase of temperature and evaporative demand coupled with a changed precipitation regime, global climate models (GCMs) have been developed to predict the future climate. These climate forecasts have been coupled with land surface models and crop simulation models to evaluate how these predicted changes may affect agricultural crop production in different regions of the world. The results of these efforts have shown yield changes. For example in a study conducted by Purdue and Indiana Universities, in the Midwestern United States, maize (*Zea mays* L.) yields were projected to decrease in Illinois, while soybean (*Glycine max* (L.). Merr) and soft red winter wheat (*Triticum aestivum* L.) yields were projected to increase. However, there is great uncertainty in these projections, because the GCMs simulate climate change on the scale of degrees of latitude and longitude, while the crop models require weather data at a specific location so that the weather can be coupled to the soils and crops of a region. The uncertainty is also increased because the timing of temperature, precipitation, and solar radiation relative to the growing season are not clearly defined. The recent coupling of regional weather models to the GCMs is beginning to address this uncertainty as well as the uncertainties of the physical parameterizations of the models.

2.2. Tactical

Tactical agricultural meteorological forecasts provide meteorological data with lead times of months. These forecasts can be used to plan final changes in crop cultivar selection, timing of planting and harvest, planting density and spacing, timing of pest and disease scouting, in season cultivation, irrigation, fertility management, pre-season crop marketing decisions, and livestock purchase or culling for stocking of pastures or ranges.

A major difference between meteorological forecasts for agricultural tactical and strategic decisions is the tactical forecasts are made based on known conditions. For example, a forecast of soil moisture for a strategic decision will be made on mean soil moisture conditions at the start of a season and modified based on the historical variance of soil moisture about the mean. In a tactical forecast, the current state of moisture in the soil is known, and based on seasonal climate forecasts the timing of increases or decreases of soil moisture throughout the growing season predicted. Based on this forecast the current planting date of a crop can be adjusted to take advantage of favorable soil moisture during critical growth stages.

Many insect pests tend to overwinter in agricultural production regions. It means that the insects survive in the agricultural production region rather than migrate into the region each growing season. Current temperature observations, from January 1 (in the northern hemisphere) or from July 1 (in the southern hemisphere), coupled with seasonal temperature forecasts can be used to compute the accumulation of insect heat units to time scouting operations. The temperature forecasts can be made using the climatic mean temperature throughout the growing season at a location, or coupled with near temperature forecasts from the present out to 2 weeks in the future.

The coupling of the sea surface temperatures with the atmosphere is often used in developing seasonal climate forecasts. Especially, useful is the El Niño-Southern Oscillation (ENSO) which has been used to forecast seasonal weather in both the southern and northern hemispheres. In the northern hemisphere the strongest effects of ENSO changes are observed near the coast of the continents. With the present skill of forecasting ENSO conditions, application of the forecasts to tactical agricultural production decisions is common in those areas of the world where the ENSO effects are strongest.

2.3. Operational

The transition of forecasts from tactical to operational decisions is, in some cases, difficult to define. This is because forecasts for both tactical and some operational agricultural production decisions include current weather observations to the present, with forecasts of the important variables into the future. A major difference is that the decisions being made in an operational framework are generally days into the future, rather than weeks to months for tactical decisions. Such decisions can include timing of planting, cultivation, and harvest; irrigation scheduling; fertilizer and pesticide application; and livestock movement between pastures, or to shelter. Timing of planting is listed in both tactical and operational decisions. Decisions, about the time of planting, change from tactical to operational with the approach of the anticipated planting date.

Forecasts for operational decisions are interpretations of the general meteorological forecasts generated by computer weather forecast models initiated with hourly surface observations, twice daily atmospheric soundings, and satellite data from observations taken over the oceans. The general forecasts include temperature, precipitation probability and type, wind speed and direction, and cloud cover.

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Bibliography

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., (1998). Crop evapotranspiration; Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO, Rome, Italy, 300 pp. [This is the official Food and Agricultural Organization's document on computation of evapotranspiration.]

Doering, O.C., Ranolph III, J.C., Southworth, J., Pfeifer, R.A., Eds., (2002). Effects of Climate Change and Variability on Agricultural Production Systems. Kluwer Academic Publishers, Dordrecht, Netherlands, 271 pp. [This is a report on a study of the response of Midwestern United States of America agriculture to projected climate changes due to global warming.]

Elsevier Ltd. (2000). Agricultural and Forest Meteorology, Vol. 103, Issue 1-2, http://www.sciencedirect.com/science/journal/01681923 [This issue of Agricultural and Forest Meteorology presents 16 articles presented at a meeting on Agricultural Meteorology, and is a valuable resource for understanding the current state of Agricultural Meteorology and forecasting requirements.]

Griffiths, J.F., Ed., (1994). Handbook of Agricultural Meteorology. Oxford University Press, New York, NY, 320 pp. [This handbook is a general presentation of domestic crop and animal responses to weather and includes information that can be used to help develop meteorological forecasts for agricultural production.]

Hillel, D., (1998). Environmental Soil Physics. Academic Press, New York, NY, 771 pp. [This presents an in depth treatise on soil physics including soil water movement and retention and factors affecting soil temperature.]

National Weather Service, (2005). Climate and weather linkage. http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/climwx.shtm [This web site provides an introduction to the different teleconnections used in predicting long term weather.]

WMO, (1981). Guide to Agricultural Meteorological Practices. WMO-No.134, Geneva, Switzerland, 355 pp. [This World Meteorological Organization document provides information on agricultural meteorological forecasts, including types of forecasts needed for agricultural production.]

Biographical Sketch

S. E. Hollinger is Senior Professional Scientist Emeritus of the Illinois State Water Survey, Champaign, Illinois. Dr. Hollinger's research included development and use of maize and soybean crop models and field experiments to study the effects of weather on these crop growth and development. His field experiments included the use of mobile rain shelters to study the effects of drought on maize and soybeans at different growth stages, and the use of weather and flux instruments to continuously monitor the energy balance, carbon dioxide and water vapor fluxes from a no-till maize and soybean ecosystem. Although retired, Dr. Hollinger continues to collaborate with scientists at the Illinois State Water Survey studying the effects of weather on crops and the effects of crops on the weather.