Strengthening Operational Agrometeorological Services: A Critical Review

Shortcomings and Limitations in the Availability and Application of Agrometeorological Data

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Abstract

Operational agricultural meteorology services use a large range of physical and biological data. Agrometeorological data can be categorized as atmospheric and soil-parameter data, crop-stage data, and data on agricultural practices and production associated with field crops, fisheries, forestry, pastures, and rangelands. There are many shortcomings and limitations in the availability and application of these data that can hinder the accuracy and utility of products disseminated to agricultural decision makers. This paper surveys some methods, guidelines, and recommendations that agrometeorologists can use to overcome data shortcomings and limitations.

Introduction

The foundation of any scientific analysis is accurate and timely data. This is especially true in the field of agricultural meteorology where data are needed from a large range of physical and biological elements such as meteorological, climatological, remotely sensed, soil, and agronomic data. These data are used in agricultural applications as varied as dryland and irrigated crops, fisheries, livestock, forest, pastures, and rangelands. They are used by agrometeorological services for input into routine temperature and precipitation charts and graphs and into sophisticated crop models to aid agricultural decision makers. In addition, radar-based and remotely sensed data are becoming more widely used. However, there are many shortcomings and limitations with the availability and application of these data to be overcome. This paper will address these shortcomings and limitations and offer recommendations and guidelines to help agrometeorologists improve and strengthen their services and products.

Scope of Agrometeorological Data

A large scope of observed data can be used in operational agrometeorology. Of course, data needs are dependent on the application. The most basic agrometeorological applications are time series and spatial analyses of weather and phenological data. More advanced applications are crop yield, irrigation, and animal production models requiring an added layer of complexity to the standard weather data.

Agrometeorological data fall into roughly the following categories (WMO, 1981):

- Data relating to the state of the atmospheric environment;
- Data relating to the state of the soil environment;
- Biological (phenological) data relating to organism response (crops, livestock, fisheries, and pathogenic elements affecting them);

- Information concerning the agricultural practices used (management systems, chemical applications); and,
- Data on agricultural area, yield, and production (crops, animals, and forestry) used for model validation and econometric modeling.

The following list of elements and parameters is not exhaustive but it is provided to detail the large scope of data that agrometeorologists use (Hayhoe, 2000; WMO, 1993). Atmospheric data includes measurements on temperature, humidity (dewpoint), precipitation (including snowdepth), wind, sunshine and radiation, evaporation, soil moisture, and temperature. When dealing with transport of animal and plant diseases and insects, boundary layer data such as the surface, 850 millibars (mb) and 700 mb of wind speed, direction, temperature, and dewpoint are needed. Agrometeorologists also need climatological data for the various atmospheric data. Climatological data are averaged from monthly atmospheric data across a standard 30-year period. With the advent of weather generators to generate daily temperature, precipitation, radiation, relative humidity, and wind data for crop models, the amount of input parameters based on climate data can be overwhelming. The following is a partial list of input parameters for the WGEN weather generator used in the EPIC model (Richardson, 1984): 10-year frequency of 0.5 and 6-hour rainfall; number of years of 0.5-hour rainfall, monthly averages and standard deviations of maximum and minimum air temperatures and precipitation; monthly probabilities of a wet day after wet day, wet day after dry day, average number of days of rain per month, monthly average daily solar radiation, relative humidity, and wind velocity. Remotely sensed data includes radar rainfall estimates and satellites measurements of NDVI, temperature, and crop greenness. These remotely sensed data are temporally and spatially varied.

Soils data can include water-holding capacities (wilting point, field capacity), soil texture, nutrient contents, soil ph, organic carbon, and soil layer depth. For most operational agrometeorological applications, these soil data elements will not vary temporally. However, if erosion is being studied, historical erosion data will be used in the validation of the erosion model.

Agronomic data includes crop-management information such as planting dates; plant spacing and depth; phenological observations (various crop stages); irrigation management; cultivar selections; historical yield series; and disease, pests, and weed information. These data can be acquired through expert opinion, literature values, and agricultural statistics (Hayhoe, 2000). Information is also needed on the timing, amount, method, and type of chemical applications.

Livestock and fishery applications will include data on the animals and their diseases. Kapetsky (2000) lists water temperature, water availability, and effects of inclement weather as the obvious connections between meteorological data on inland fishing and aquaculture activities. Forest fire and forest management models will need data on the various characteristics of undergrowth and forest species.

Discussion of Shortcomings and Limitations

One of the most significant shortcomings is the quality of all these various types of agrometeorological data. With the meteorological and climatological data, the quality of the data can be affected by station placement, changes in station site, instrument error, and processing errors. The Guide to Agricultural Meteorological Practices (WMO, 1981) can give guidelines to some of these issues. A significant amount of work has been done on the quality of the atmospheric data. However, there is much work to be done on understanding the quality problems with collecting data on soils and phenological observations. One suggestion is for national agrometeorological services to work closely with national agricultural services to standardized phenological observations. Existing agricultural extension services should be a stating point for data standardization.

Vigorous quality control procedures will flag suspect data and disregard the suspect data (Arndt, et al, 1998). When adequate quality control procedures on atmospheric data have been implemented, this inevitably creates gaps in the temporal resolution of the dataset. Quality control improves data quality but it does not solve problems with the temporal resolution of the dataset. Whether the data is of bad quality or is missing altogether, the same problem exists: there is no data value for that particular time period (hourly, daily, weekly, decadal, monthly, etc). Therefore, data gaps appear in the dataset and need to be filled by some estimation method in order for a continuous dataset to be created.

Another problem is limited spatial resolution of the data. The spatial density of weather stations is sometimes not dense enough to adequately represent the area of concern. The nearest weather station may be 50 to 100 kilometers from an agricultural field. Also, topography needs to be taken into account when agricultural fields are in hilly or mountainous areas.

Hayhoe (2000) reviewed the data requirements, acquisition, and application of two widely used modeling systems: The Decision Support System for Agrotechnology Transfer (DSSAT) and the Erosion Productivity Impact Calculator (EPIC). One of the biggest problems stated in using these process models is assembling the required data.

The following is a summary from that paper on the shortcomings and limitations of applying agrometeorological data to multi-process crop models:

- Different models have different input formats;
- Scale of application ranges from precision farming to national or continental study;
- Inadequate solar radiation, wind, and relative humidity data;
- Lack of uniformity in collection methods and standards;
- Data were not collected to provide the detailed information to run the model at specific locations;
- Low temporal and spatial resolution;
- Soil and weather data are not spatially compatible (soil data recorded on areal basis and weather recorded at station locations);
- Large set of input data and multiple disciplines are needed to test comprehensive multi-process models;
- For site-specific applications, lack of weather data which accurately represented the field, especially for precipitation;
- Using the Theissen polygon method to calculate areal averages may not be optimum, co-kriging may be more appropriate;
- EPIC and similar models should be primarily used to provide relative comparisons instead of absolute numbers; and,
- Model errors were probably also caused by unreliable yield data, estimated soil parameters (hydraulic properties, slope, and slope length).

The paper concludes that these multi-process models have been used in a number of successful applications, and they have occasionally failed to explain the year-to-year variations. The clear reason for this was the limitations in the quality and quantity of input data. One study that uses EPIC to understand soil management in the Canadian Prairies suggests that the results should be presented as degradation classes rather than numerical values. One recommendation is that members of interdisciplinary modeling groups should present training sessions for scientists in developing countries.

From an Expert Group Workshop on Software for Agroclimatic Data Management, participants listed shortcomings and limitations to data management (Motha, 2000). While some of these were specific to software packages, they are also applicable to data availability and management techniques.

Shortcomings for Climatic Data Management

- Inadequate data exchange standards;
- Diverse and incomplete quality control standards;
- Lack of data continuity over long time periods;
- Inaccessible or difficult-to-access data sets;
- Cost of systems and data;
- Insufficient or absent metadata;
- Sparse station coverage in agricultural areas;
- Lack of long-term commitments to sustaining station networks;
- Widely diverse levels of expertise; and,
- A lack of full commitment to exchange necessary data sets at regional, national, and international levels.

Shortcomings for Crop and Soils Data Management

- Soils data sets lack a shared structure or standardization;
- Databases tend to offer more information about chemical (fertility) properties than soil physical properties;
- While pH data are available, there is a need for better pedon transfer functions;
- High resolution (field-scale) digital soils data are often not available;
- Soil observations (pedon descriptions) are not utilized to estimate soil biota; and,
- Many soil attributes and properties are under-utilized by crop growth models.

Shortcomings and Limitations in the Use of Current Software for Remote Sensing and Integrated Modeling Packages:

- Majority of the crop models are data intensive and the needed climate/crop/soil data are often not readily available, especially in the developing countries;
- While the modelers' data needs are often quite rigid and they expect the data to come from a single source, in reality data sources and formats are quite variable across countries;
- The problem is further complicated by the fact that climate, soil, and crop data are not often collected or available from the same location;

- A good majority of the current software packages that facilitate spatial analysis are not equipped to perform adequate temporal analysis; and
- In developing countries there is a growing "digital divide" between senior managers and their younger work force.

Overcoming Data Shortcomings and Limitations

There are several methods for overcoming data gaps in the temporal record. Jeffery, et al., (2000) discuss patched data sets that are continuous temporal weather data used for crop modeling. A patched data set is comprised of observed data, spatially interpolated data, and long-term means. For missing data or bad quality data, values are interpolated and in absence of observational data, mean daily values were supplied. Each data value is assigned a data flag denoting the source of the data.

Another method is to average climatically similar weather data into larger units. In the United States, the National Climatic Data Center devised 344 climate divisions across the country (Karl et al, 1986). Temperature and precipitation data in each climate division are averaged together into a single unit. This data is then used to compute various climate and agrometeorological indices such as Standardized Precipitation Index (SPI) and the Palmer Drought Index. The Joint Agricultural Weather Facility (JAWF) of the Department of Agriculture developed 350 sub-regions for the world based on similar climatic, geographic, and agricultural attributes (Puterbaugh, 2000). These regional files encompass all major agricultural areas, representing a wide variety of crops and climates. Stations are assigned into sub-regions based on station density, elevation, reliable reporting, availability of normals, and crop-area considerations. Weather data in each region is averaged together and various analyses of temperature, rainfall, potential evaporation, and estimated soil moisture can be made. These agriculture-based sub-regions help JAWF to effectively organize and analyze data from over 8,000 WMO weather stations and help eliminate missing data values.

GIS software and other means of interpolating weather data can be used to overcome this problem (Jefferies, 2000; Shannon and Motha, 2002). However, a more detailed overview of this using these tools will be discussed in the companion paper on analytical tools (Andresen, 2004).

With recent advances in computer technology, there are many database tools available that can help agrometeorologists maintain their many databases and provide the necessary links. These software packages include MS Excel, MYSQL, MS Access, and Oracle. There are many different examples of operational databases for dealing with weather, climate, soils, remotely sensed, and spatial data (Motha and Sivakumar, 2001; and Doraiswamy, et al., 2000).

Recommendations

There are several general and specific recommendations that can help agrometeorologists overcome the above shortcomings and limitations. Motha (2002) provided an excellent overview of some general recommendations on improving agrometeorological bulletins that can also be used for overcoming shortcomings on the application of agrometeorological data. Motha began by asking pertinent questions such as: What information does the user need? When does the user need this information? In order to answer these questions, there must be an established mechanism between the users of the information (farmers and decision makers) and the producers of the information (agrometeorologists and extension personnel). He also listed some of the following recommendations:

- Don’t promise too much too quickly.
- Relate the weather data to meaningful agricultural information.
- Don’t oversell the information.
- Establish credibility slowly but surely.
- Implement new products with proper introduction.
- Be proactive in demonstrating the usefulness of your products.
- Don’t hesitate to pool resources.
- Training and education are essential components.

The following is a list of specific recommendations and potential guidelines from the Expert Group Meeting on Software for Agroclimatic Data Management, October 16-20, 2000, held in Washington, D.C., USA (Motha, 2000). These recommendations were edited to list those items only pertaining to data limitations.

- More Automatic Weather Stations (AWS) are needed in order to provide coverage and support for risk management, crop assessment, crop productivity, fire and rangeland management, and natural resource conservation;
- There is a need for long-term support and commitment (funding, capacity) to sustain reliable station networks;
- Systems should be developed to facilitate data sharing/exchange;
- Continuous data records must be established using standardized methodologies (such as the Patched Point Dataset in Australia);
- Information delivery systems should be Internet-based (Internet data distribution);
- Systems should be able to link with other data providers to ensure that the appropriate information is accessible in a timely and usable format;
- Metadata information needs to be developed and should conform to International Organization for Standardization (ISO) standards;
- All data should be georeferenced and time-stamped for effective integration into GIS software systems;
- Member nations should make basic geopolitical data sets available on the Internet. WMO should maintain a web-site with links to these data sets;
- A website should be developed with pointers to relevant decision-support software, data, and development tools with the capacity for online demonstration of its ability;
- Soil data management systems should be harmonized and integrated, similar to Soils and Terrain Digital Database (SOTER);
- National systems need to be identified as sources of information;
- Since some models and databases are scale independent, an understanding of "data loss" from one scale to another must be acknowledged explicitly;
- Time trend analyses are needed for land use databases;
- National meteorological and hydrological services should be urged to share their knowledge and tools in spatial interpolation with database managers and application developers; and
- Special efforts must be made to develop and disseminate uniform formats and data sheets for recording crop and soils information in a format that is compatible for use with crop models and remote sensing applications.

Potential Guidelines for Improved Management of Databases in Support of Agroclimatic Applications to Assist Training and Capacity Building

- Data sets must have a minimum metadata base, standard format, standard quality control procedures, and adequate continuity of records;
- Personnel must be trained to recognize inconsistencies of data and establish appropriate patch-point methods to maintain continuity;
- Software must be compatible with both temporal and spatial data sets to allow for the integration of point source data with georeferenced digital data sets, modeling technology, and remotely sensed data;
- New technology in telecommunications should be used to bridge the gap between automated data collection systems and web-based information systems;
- GIS metadata are required for appropriate coordinate systems, projections etc.;
- A listserve or other virtual community should be established; International Soil Reference and Information Centre (ISRIC), Netherlands, will develop a website to serve as a portal for soil information, including metadata information on existing soil databases worldwide;
- Improved data exchange will be fostered by the continued development of geographic frameworks and adoption of standards;
- Guidelines need to include new measures and better assessment of soil data reliability given that more robust estimates are obviously linked to data quality and resolution (data resolution is a continuing need previously identified);
- Recommend determining indices of data reliability (quality) vs. error percentages and sources of the data (ISO metadata standards). Examples of error tracking and reporting from the agroclimatic community include the IQ index from France and the quality indices from South Africa;
- Guidelines need to emphasize explicit accounting for variability in the soils arena. The USDA Soil Survey uses a diversity index to characterize and report soil variability. Similar variability measures are the key and they should be associated with input to soil and crop models. Similarly, plant variability (e.g., emergence and growth) needs to be represented, especially if this variability is a key to management under a given production scenario;
- Guidelines are needed to report national crop yields including sub-national trends and geo-spatial time trends;
- An industry, international standard for agroclimatic data, particularly crop data, should be developed. Minimum metadata, database formats, and database content should be resolved, accepted by industry, international centers and academia, and published basic agroclimatic applications;
- More telecommunication research that develops new applications using web-based technologies and automated observations should be supported. These developments will help reach more users and encourage standardization;
- Current measures of standardization are considered mature for meteorological data, but poor for crop data and emerging for soils data. Hence, uniform measures of standardization for agroclimatic purposes must be established; and,
- Spatial interpolation methods for specific applications should be recommended.

Conclusions

This paper presents the interdisciplinary scope of agrometeorological data and discusses several of the shortcomings and limitations in their availability and application. Accurate and timely data are needed in operational agrometeorological services to generate reliable products for agricultural decision makers. One of the biggest limitations is the quality and quantity of input data for applications and models.

Even when appropriate quality control procedures are used and bad data are flagged, data gaps are created in the dataset. These data gaps still need to be filled by some estimation routine in order for a continuous dataset to be created for the various applications. Other limitations include the lack of detailed data for input into crop models and non-standard input formats and sources.

It is important for agrometeorologists to realize that there any many resources (papers, reports, and proceedings) that have been developed over the years by agrometeorologists across the world providing examples of their data problems and the solutions that they have developed. This paper highlights some of these procedures to overcome of these shortcomings and limitations and summarize general and specific guidelines and recommendations.

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