Shortcomings and Limitations in Analytical Tools and Methods of Provision of Operational Agrometeorological Services

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Abstract

Improvements in communication technology and in the understanding of the physical components of the plant/earth/atmosphere interface have combined to increase the quality, sophistication, and potential utility of agrometeorological services offered to or provided to the agricultural industry. Regardless, many problems and shortcomings in analytical techniques and in the way in which the products are provided remain. These include long-term issues such as the spatial analysis of agrometeorological variables as well as new concerns such as the economic challenges facing many elements of the agricultural industry worldwide. Recent advances in the development of spatial analytical techniques such as Geographic Information Systems (GIS) offer some solutions to these difficulties. To become more effective, agrometeorologists need to demonstrate the utility of their products, including potential economic benefits. Finally, in order to provide the best quality agrometeorological information in the future, greater collaboration is needed among the major participants in the information provision system: farmers, agricultural meteorologists, and agricultural extension services.

Introduction

Demand for meteorological and climatological information in support of worldwide agricultural operations has increased dramatically in recent years, the result of increasing economic and environmental pressures as well as recognition of the importance of such information in operational decision making (Motha, 2001). Users of the information include individual growers, commercial agribusinesses, and local or national government agencies. The information itself is typically utilized in a variety of activities, ranging from tactical issues such as monitoring plant disease risk to strategic problems like the selection of climatologically suitable crop varieties for a given location. Overall, agrometeorological information products should be designed and developed with several important requirements in mind:

- *Accuracy*. The information should address or pertain to a solvable issue or problem based on sound science.
- *Robustness*. The method or product should be versatile to effectively operate under a variety of conditions.
- *Meaning*. The information should be helpful and easily understandable by the user.
- *Timeliness*. The information can be created and provided in a reasonable time frame.
- *Environmentally sound*. The information supports or encourages environmentally friendly procedures and techniques.
- *Economics*. The information can be economically justified by the user.

Of these requirements, accuracy might be considered the highest priority, although meaning and timeliness have also been identified by individual growers as critical (Carlson, 1989).

Once target problems, issues, and possible solutions have been identified, meteorological services must also consider possible approaches to the development of agrometeorological products. An excellent scheme suggested by Maracchi, et al., (2002), includes: assessment of spatial scales involved and feasibility of possible methodologies, identification of possible models and model data requirements, integration of ground-based and remotely sensed data, and estimation of the cost-effectiveness of the methodology.

Limitations of Analytical Tools: Some Examples

While progress has been made in the number of types, capabilities, and overall usefulness of agrometeorological information, shortcomings and limitations remain. A list of some major limitations includes:

- Data scarcity/paucity in meteorological, climatological, agronomic, soil and other similar data bases needed for agrometeorological assessment (e.g., see Stefanski 2004 paper in this volume);
- Difficulty in application of the tool or method;
- Accuracy of the methodology (e.g., integrated pest management (IPM) methods, long-lead weather forecasts);
- Complete automation of the method or tool in question, desirable for many operational applications, may not be possible (e.g., field scouting and biofixes are still necessary in many IPM techniques);
- Use of "Black Box" approaches may result in unintentional errors;
- A trade off in accuracy and complexity between empirical and deterministic approaches remains (e.g., crop models);
- No simple method exists for spatio-temporal analyses; and,
- There is no internationally agreed-upon measurement standard for leaf wetness, a key variable for the determination of plant foliar disease risk.

While far from being an exhaustive list, these issues provide examples of current difficulties and limitations facing providers of meteorological services. Some illustrative application examples follow.

Among the most troublesome of these analytical difficulties is the scarcity and/or poor quality of input data, for which there are limited solutions. Complicating matters further, users of agrometeorological information frequently need to provide the information in a two-dimensional spatial format across the area(s) of interest, which typically requires spatial interpolation or some type of objective analysis performed on the original data, usually taken from individual locations. Typical procedures used for interpolation include kriging, co-kriging, and the inverse weighted-distance method, or other schemes. However, while these schemes are used almost universally in data analysis, there are potential pitfalls. For example, failure to consider topographical features in an area of interest may result in a highly erroneous averaged surface far different from the observed surface. This problem was well illustrated by Daly, et al., (1994), who developed the Parameter-elevation Regressions on Independent Slopes Model (PRISM) technique that accounts for the physical impact of topography on spatially averaged climatological variables in the western United States. Another potential problem is the application of the analytical technique in an area of uneven spatial density or coverage, a condition present in many operational networks around the world. The solution by interpolation is estimated with a cubic spline technique. In the original, unedited version of this product, the presence of physical boundaries such as lakes and local station microclimates result in artificial gradients and erroneous estimated values. Such errors can only be prevented by careful, informed human analysis of the output (very difficult to do in an automated fashion), or by the incorporation of additional data into the original analysis.

One must also consider that, even under the best circumstances, error and uncertainty can be introduced during each stage of analysis. This error, whether the result of inadequate input data or the analytical method itself, may be passed cumulatively on to each successive analytical stage in a "cascade of uncertainty," resulting in relatively (and sometimes unexpectedly) high errors in the final output product. This type of problem is illustrated in the results of a recent experiment in the United States to determine small scale, localized spatial variability of leaf wetness duration and its impact on associated foliar plant disease risk associated with apple scab (Venturia inaequalis).

In this experiment, leaf wetness was monitored at eight different sensors placed at different locations in the same field in an identical fashion (all within 100 meters distance of each other). A 9^{th} sensor was placed outside the orchard/plant canopy in the same fashion for reference. The method of Jones, et al., (1980) was used to determine the risk of foliar infection based on the length of leaf wetness duration and average air temperature during the wetting event. There are three resulting levels of infection: light, moderate, and heavy. There was a large variability of the degree of infection among the different sensors for some events (e.g., the event on calendar day 170), even though the sensors were located in the same field. Given a spatially interpolated surface of wetness duration derived from individual data of much less station density (and typical of most operational agrometeorological networks), it is logical to assume that the variability of the dependent disease infection level variable would be at least equal if not greater in magnitude. In essence, the local level variability described here can be interpreted as unavoidable "white noise" or random error associated with the data, which may be carried on through additional analytical stages and serve as an upper limitation of the accuracy of the information product.

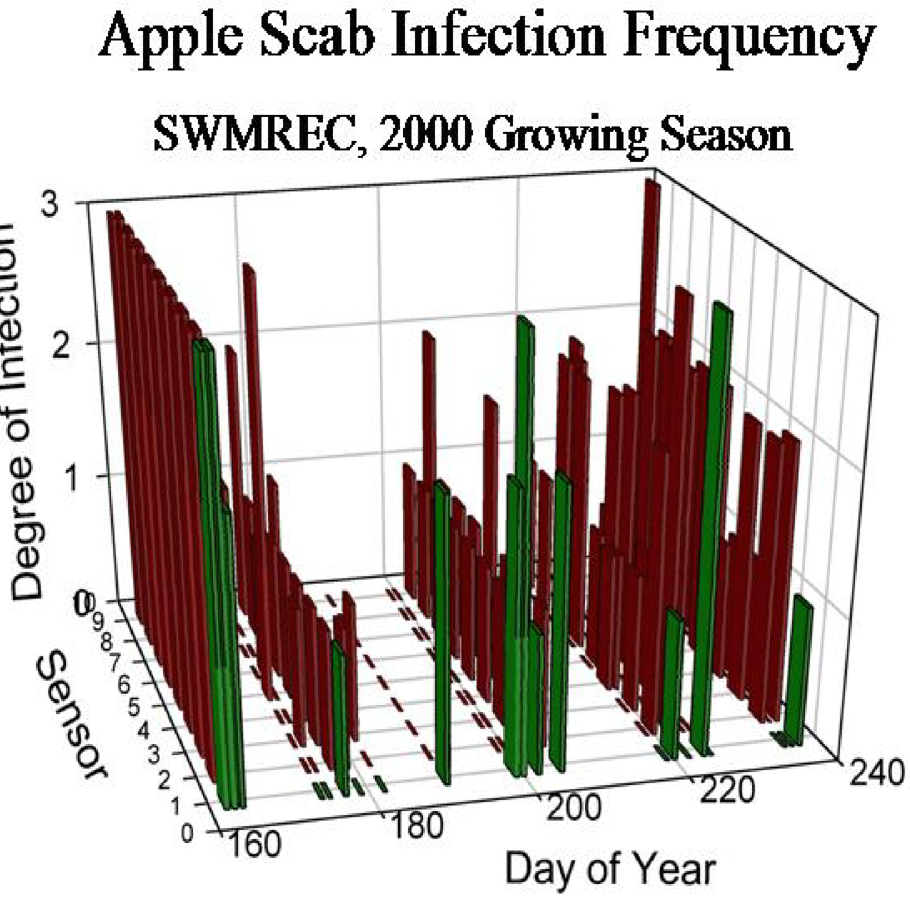

Figure 1. Model estimated apple scab disease infection frequency and severity vs. calendar day, 2000 growing season, Benton Harbor, Michigan, USA. The severity or degree of infection is given numerically from 0-3, with "0" indicating no infection and "3" indicating a heavy infection.

The degree of spatial continuity of meteorological and climatological variables (a factor that must be considered in analytical processing or in the creation of derived products) is strongly dependent on the variable type. A landmark study by Gandin (1970) analyzed the spatial variability of several different meteorological variables over extended periods of time in the former USSR and concluded that three different levels of station density are needed for representative operational networks: a relatively sparse network on the order of 150-200 kilometers (km) between stations for air pressure, soil temperature at depth, and solar radiation; a second intermediate group of medium density of 50-60 km for air temperature and humidity, wind speed, and cloud cover; and a third group of relatively high station density at 30 km for the most discontinuous variables including precipitation, snow cover, and other localized meteorological phenomena. Similar results were obtained in a subsequent study by Hubbard (1994) in the Great Plains region of the United States.

Unfortunately, for those who utilize such data operationally, there are other complicating factors to consider. Besides the differences between variable types, there may also be differences in spatial variability between climate types for the same climate variable (Camargo and Hubbard, 1999). Lastly, developers of agrometeorological products frequently are faced with decisions regarding the order of spatial averaging between the input variables and the output variables (i.e., should spatial averaging take place before or after individual analytical processing steps?). In a study of meteorological variables used to estimate potential evapotranspiration (PET) in the United States, Ashraf, et al., (1997) concluded that the order of averaging was of relatively little importance in comparison to the method of spatial interpolation (best results in the study were obtained with kriging and co-kriging procedures).

Some Limitations of Provision

Besides shortcomings in the analytical methods used to prepare and develop agrometeorological information, there are also concerns with its provision. Some major issues include:

- Lack of a standardized communication technology format. Advances in communication technology have occurred rapidly in the past few decades, leaving some segments of the agricultural industry around the world without access to timely and useful information disseminated over relatively new media like the worldwide web;
- Shrinking resources for agricultural extension services. Agricultural extension services have been integrally involved in the two-way interaction between the providers and users of agrometeorological information and have traditionally been supported financially by local, state, or federal government services. Due to decreasing fiscal resources in many areas of the world, some of these services have been replaced by private, commercial services, or are no longer available; and,
- Lack of communication between providers of service and the users. Consider the simple hypothetical example of operational agrometeorological information provided to the industry but not fully utilized because the user either does not consider it accurate or useful, or does not understand how to properly use it.

One final special limitation worth mentioning is the issue of globalization of agriculture, in which technological advances have led to more efficient production, increasing numbers of global markets for commodities, and a transport system that enables distribution of those commodities worldwide. In combination, globalization has raised the level of competition between food producers, benefiting producers with relatively low costs and penalizing those with high costs (Blank, 2002). It is essential for providers of agrometeorological information to understand the economic impacts of globalization and resulting changes in the operations of their respective agricultural industries.

Some Possible Solutions and Directions

New techniques and technologies have made it possible to address some of the concerns raised above. These include:

- Use of remotely sensed data or regional climate model output to supplement existing data networks;
- More effective analysis of existing data with GIS;
- Incorporation of automated weather stations. Typically, the output from such stations is more comprehensive. They may also provide data in more convenient formats (e.g., digital, real-time). However, it is critical to remember network quality and standardization issues;

- Greater collaboration between providers and users of agrometeorological information, including training and education. This is especially true given expectations of further technological improvements and government fiscal shortfalls in the future (National Research Council, 2003). Remember that communication with clientele is a "two-way street," and requires actively engaging clients for feedback and ideas for product improvements and new research directions. Also, given the financial challenges facing agriculture around the world, try to first determine and then demonstrate the utility of the information provided, including economics if possible;
- Provide further technical training for service providers or require minimum background when hiring, especially when they lack background or experience in agricultural science. It is important for service providers to learn and know the problems and issues of agriculture from the perspective of the grower or industry; and,
- Charge some type of fee for service. Many governmental agrometeorological service providers around the world have instituted fees for certain types of services in recent years. While some information users may refuse or be unable to pay for services, fees may help supplement operational expenses.

Of the listed issues, the first three are of special interest to all providers of agrometeorological information, as they may supplement or improve the quality of the input data used to create information products, directly impacting the quality of the output. GIS software and techniques are now used routinely for processing and analyzing all types of input data and information (e.g., Shannon and Motha, 2002; Bernardi, 2002; Hayhoe, 2001).

Finally, when supplemental remotely sensed or station data are not available for analysis, there may be one further option. Improvements in the complexity, accuracy, and timeliness of regional scale climate simulations (RCMs) have resulted in a relatively new source of potential input information. These simulations process massive amounts of input data over a given region and provide an even larger range of gridded output including variables not routinely measured such as net radiation, latent heat flux, and boundary layer height. Spatial and temporal resolution may be much finer than in operational weather forecast or climate model simulations, typically on the order of 10 km on an hourly basis. While not real data, the output from such systems may provide usable estimates for a whole range of potential analytical applications, such as forest fire potential, mesoscale weather forecasts, and hydrological forecasting (Mass, 2003).

Conclusions

While scientific and technological advances have resulted in higher quality information and increased capabilities in providing agrometeorological information, major difficulties remain. Remotely sensed data technologies and GIS analytical techniques should help reduce some of these problems in the future. In an era of decreasing fiscal resources and globalization of agriculture, greater collaboration is needed between major participants in the system: i.e., growers, agricultural meteorologists, and agricultural extension services. Agricultural meteorologists need to demonstrate and publicize the utility and effectiveness of their products, including economics.

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