METEOROLOGICAL DATA FOR AGRICULTURAL MODELS, A GENERAL ANALYSIS OF DIFFERENT DATA SOURCES

COST ACTION 718

'Meteorological Applications for Agriculture'

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1. Introduction

Agricultural models need meteorological information. For example estimation of crop yield or forecasting of outbreak of crop diseases or pests is largely based on meteorological conditions. To avoid the situation where lack of reliable meteorological data would hinder the further development of agricultural models also a continuous development in the meteorological observational practises and spatialisation methods is needed.

The availability of meteorological information can be improved by further developing meteorological observing networks and spatial interpolation methods and by a more effective use of weather radar and satellite information beside traditional meteorological observations. Automation of meteorological observing stations may have some impact on the availability of some meteorological parameters. The use of atmospheric models as a source of meteorological data is also an alternative that is worth to consider.

This document is a general analysis of different meteorological data sources. The information given in this report may be, to some extent, self-evident for those having meteorological background, either education or working experience. However, the agricultural modellers using meteorological data in their work may not be as familiar with different meteorological data sources or the accuracy of meteorological measurements and hopefully this short report gives in compact format useful information for them.

2. Meteorological data sources

The meteorological data sources discussed here are divided into three: 1) meteorological observing stations 2) remote sensing and 3) atmospheric models.

2.1 Meteorological observing stations

Meteorological observation network has traditionally been based on manual observing stations. There are synoptic, climate, precipitation, agrometeorological stations and meteorological observatories with special measurements. During the recent years the manual stations have been replaced with the automatic stations.

The meteorological parameters measured and the measuring frequency may to some extent vary from one station to another. The values given in this report represent a kind of “typical” station configuration and observing frequency (e.g. WMO, 1996).

Synoptic stations

The best known weather stations are the synoptic stations. At these stations comprehensive observations are made after every three hours. Observations include air temperature, air humidity, air pressure, wind speed, detailed cloudiness observations, current and past weather observation. In the evening and in the morning past 12 hours maximum and minimum temperatures and precipitation amounts are recorded. Also surface minimum temperature, surface state and snow depth values are measured.

Global solar radiation as well as long wave radiation components can be calculated based mainly on cloud observations. Evaporation can be calculated based on wind speed, air humidity and air temperature and radiation balance components.

Climate stations

At climate stations observations are made typically three times a day. The observations include maximum, minimum and prevailing air temperature, 24-hour precipitation sum, air humidity and wind speed measurements. Some stations may also record total cloudiness.

Precipitation stations

Precipitation stations record typically daily precipitation sums and depth of snow and state of the ground

Agrometeorological stations and observatories

The most comprehensive meteorological observations are made at these stations. Typically observations include radiation balance components (direct and diffuse solar radiation, reflected solar radiation and long-wave radiation), air and soil temperature, evaporation, air humidity, wind speed, dew duration, soil moisture. Agrometeorological or forestry research stations are tailored to measure those meteorological parameters that are most crucial for agricultural applications.

Automatic weather stations

Manual synoptic weather stations and also agrometeorological stations are nowadays often replaced by automatic weather stations (see e.g. De Leonibus and Vecchi, 2000 or http://www.eumetnet.eu.org/contaws.html). Automatic stations are typically equipped with air temperature, air pressure, air humidity and wind speed measuring instruments. It also is easy to include instruments that measure soil temperature, solar radiation, soil moisture or surface state. Nowadays there are also instruments that give an estimate of the present weather, visibility, precipitation amount and height of cloud layer.

2.2 Remote sensing

Remote sensing in the sense of meteorological observations means usually either radar or satellite observations. A good introduction to meteorological remote sensing can be found e.g. in Karlsson (1997).

Weather radar

Weather radar network covers large parts of Europe. Radar systems provide dense measurements in which typical time interval is 5-15 minutes and typical horizontal space resolution is 0.5-5 km even up to ranges of 250 km from the radar. Several international and national radar networks generate real time data products, each containing measurements from 1-20 radars. A European co-operation exists to create methods and tools for possible exchange of radar data covering the whole continent (EUMETNET OPERA programme, http://www.eumetnet.eu.org/contopera.html). Typical user products are images exhibiting instantaneous rainfall intensity or accumulated rainfall in longer periods (1-24 hours). Accumulated precipitation can be used to estimate flash floods and for high-resolution estimation of soil and vegetation water content. Automatic or subjective algorithms exist to detect and diagnose weather phenomena, which can be hazardous for agriculture, such as hail, risk for thunder and massive insect migrations. Doppler radars can be used to measure continuously vertical wind profiles (provided that precipitation or insects exist in the altitude measured). Doppler measurements will be assimilated into numerical weather prediction models (COST 717 action, http://www.smhi.se/cost717/). Local hazardous wind phenomena like downbursts and squall lines can be also detected with Doppler radars. Radar measurements are the only source for high quality nowcasting of precipitation, typically 1-4 hours ahead of the observation time. Such forecasts can be very important when agricultural actions are planned for the next few hours. The modern real time dissemination systems of radar products to users apply e.g. internet and automatic text messages to mobile phones

Satellites

Polar orbiting satellites, like NOAA polar orbiting environmental satellites (http://www.noaa.gov/), make overpasses roughly every 100 minutes. The geostationary satellites, e.g. METEOSAT, (http://www.eumetsat.de/) make measurements twice an hour, in the next generation satellites four times an hour. The instruments onboard satellites like AVHRR on NOAA (http://eosims.cr.usgs.gov:5725/sensor_documents/avhrr_sensor.html) and MVIR on METEOSAT make measurements at several wavelengths and these measurements can be used for example for the estimation of surface temperature, surface albedo, global radiation, surface moisture, precipitation amount or for the detection of forest fires. The spatial measuring resolution of NOAA satellites AVHRR instrument is about 1 km at nadir. In case of METEOSAT the spatial resolution is about 5 km in southern Europe and 15 in northern Scandinavia. The next generation METEOSAT satellites have somewhat higher spatial resolution (http://www.esrin.esa.it/msg/pag0.html).

New instruments e.g. Moderate Resolution Imaging Spectroradiometer (MODIS) that is a key instrument aboard the Terra (EOS AM-1) and Aqua (EOS PM-1) satellites (http://modis.gsfc.nasa.gov/) view the entire Earth's surface every 1 to 2 day with a resolution better than 1 km. EOS satellites are polar orbiting satellites and at high latitudes, e.g. in Scandinavia, they make overpasses more often than at lower latitudes. There exist also special research satellites like ERS (http://earth.esa.int/) that make measurements with very high spatial resolution. These overpass the same region quite seldom, roughly once a month.

European organisation for the exploitation of meteorological satellites (EUMETSAT) has started the development of a network of Satellite Application Facilities (SAF's) which together with the EUMETSAT central facilities, will constitute the future EUMETSAT Application Ground Segments for Meteosat Second generation (MSG) and EUMETSAT Polar Systems (EPS). The SAFs will be located in a National Meteorological Service or other approved institute of an EUMETSAT member state. The scope of the SAF activities shall be to deliver products or software to derive these products, at the level of geophysical parameters, based primarily on the satellite data. There are six different SAF programs and from the point of agrometeorology the Climate and the Land SAF are the most interesting. The Climate SAF is dedicated to climate monitoring and the Land SAF will concentrate on developing techniques for deriving land surface parameters and radiation surface fluxes over the continents from the data of EUMETSAT's satellites (http://www.eumetsat.de/).

2.3 Atmospheric models

Atmospheric models can be used also as a data source for agricultural models. The weather forecast models can be either global or they can be more local covering areas for example of the size of Europe. Beside routine weather forecast models also atmospheric research models with very high spatial and temporal resolution can be used for special research studies.

Weather forecast models

The increase of calculation capacity of computers has made it possible to reduce the grid size in the weather forecast models. Nowadays calculations of so-called high-resolution models like HIRLAM (http://www.knmi.nl/hirlam/) use resolutions of 15-30 km. The grid size of global models like ECMWF-model (http://www.ecmwf.int/) is at the moment about 40 km. The weather forecast models are at their best when describing meteorological conditions above lowest tens of meters above surface. However, the surface parameterizations of these models are improving all the time and also parameters like surface temperature can be obtained from these models with reasonable accuracy.

Limited area models are typically used to make two-day weather forecasts. Global models can be used to make ten-day forecasts. Recently even seasonal weather forecasts have been tested.

Research atmospheric models

For short time periods and limited areas it is possible to run special atmospheric research models with high temporal and spatial resolution (e.g. National Center for Atmospheric Research (NCAR) Land Surface Model, http://www.cgd.ucar.edu/cms/lsm/index.html or Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) mesoscale model, http://www.mmm.ucar.edu/mm5/). These models have a detailed description of the interaction between the surface and atmosphere and can thus simulate the state of atmosphere near the surface more in detail than the weather forecast models.

3. The applicability of different meteorological data sources

In Table I there are listed meteorological parameters and the methods that can be used for the estimation (measuring in case of instruments and calculation in case of models) of each parameter near the earth's surface. It is very difficult make an objective analysis of the quality or applicability of data obtained by different methods. For example some agricultural models may require meteorological measurements made at the simulation location and on the other hand for some applications very general meteorological data is enough. Thus the quality classification of different data sources given in Table 1 should be taken as a qualitative estimate.

TABLE I. Meteorological data available near surface from different data sources. Observing frequency and parameters measured represent a kind of “typical” station configuration. The number of ‘+’ signs is a qualitative estimate of the accuracy of data obtained using that method. Especially in the case of satellite measurements the table may not be complete.

Data source	Temporal resolution	Spatial Resolution	Parameter												
			Precip.	Air temp.	Air Hum.	Surf. temp.	Surf. moist.	Wind speed	Soil temp.	Weather	Snow	Solar Rad.	Longw rad.	Cloudin.	Evap.
Observing stations															
Manual meteorological station (SYNOP)	3-hours	Local	+++	+++	+++	+++		+++		+++	+++	+	+	++	++
Automatic (SYNOP) station	hourly	Local	++	+++	+++	+++		+++		+	+	++	++	+	+
Climate station	12-24 hours	Local	+++	+++	+++	+++		+++			+++			+	+
Precipitation station	12-24 hours	Local	+++								+++				
Agrometeorological station Meteorological observatory	hourly	Local	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Remote sensing															
Weather radar	5-15 min + a few hours forecasts	0.5-5 km	++					+		+				++	
Geostationary satellites	30 min	5 - 15 km	+	+		++	++	+			+	+	+	+	
Polar orbiting weather satellites (NOAA)	~ hours	1 km	+	+		++	++	+			++	+	+	+	
Polar orbiting research satellites (ERS etc.)	> month	~tens of metres	+	+		+++	+++	+			++			++	
Atmospheric models															
Global weather forecast models	hourly 10-day (seasonal) forecast	40 km	++	++	++	++	+	++	+	+	++	++	++	+	+
Limited area weather forecast models	hourly 48 h forecast	15-30 km	++	++	++	++	+	++	+	+	++	++	++	+	+
Research models	minutes	Local	++	++	++	++	++	++	++	++	++	++	++	++	++

Temporal resolution

Referring to Table I good (hourly or better) temporal resolution can be obtained while using automatic stations, weather radar, geostationary satellites or modelled data. From the synoptic stations we get 3-hourly data and it is enough for most applications but there may also be applications where a higher temporal resolution is needed. Polar orbiting meteorological satellites provide data after about every six hours and climatological and precipitation stations after every 12 or 24 hours. The polar orbiting research satellites measure the same district quite seldom, roughly once a month.

Spatial resolution

Meteorological observing stations are local, i.e., the measured results represent strictly the conditions only at the measuring location. However, the station locations have usually been selected carefully so that the station location is representative for the region. By spatial interpolation methods it is possible to spatialize the point values onto a grid and thus get a value of needed weather parameter into any desired location.

The polar orbiting research satellites can make measurements even with accuracy of a few tens of meters. The research meteorological models can be local or they can represent a small area with high spatial accuracy about one kilometre. The pixel size of weather radar is 0.5-1 km and polar orbiting weather satellites about 1 km or better (MODIS). The distance radar measurements are still useful vary depending on weather conditions. In case of high cumulonimbus clouds the precipitation amounts can be measured roughly even 200 km from the radar. In case of snowfall coming from low clouds the radius of the circle inside which reliable measurements can be made is only about 50 km. The accuracy of measurements made by geostationary satellites depends on the latitude. In southern Europe the pixel size is roughly 5 km but in northern Scandinavia worse than 10 km. The pixel size of weather forecast models is at the moment a few tens of kilometres.

Parameters measured and the accuracy of measurements

Synoptic, agrometeorological and automatic stations measure several meteorological parameters with good accuracy. If solar radiation or long wave radiation components are not measured they can be calculated with reasonable accuracy assuming that cloud observations area available. Evaporation can be calculated using parameterizations like Penman-Monteith- equation.

Weather radar measurements can be used for the estimation of precipitation amounts. The best results can be obtained if traditional surface measurements are combined with radar measurements. Radar data can be used for the estimation of rainfall intensity, for detection of hail risk, risk for thunder and massive insect migration. Based on weather radar data it is possible to make a few hours precipitation forecast, typically 1-4 hours ahead the observation time.

Satellite measurements are at their best when measuring surface temperature and moisture or when surface type, cloud cover or vegetation index is estimated. Measuring of e.g. air temperature or air humidity at a height of two meters is still a problem.

From weather forecast models it is possible to get estimates for several meteorological parameters as model grid square averages. The grid square averages can be further processed to take into account the sub-grid scale variation in the surface properties like for example hills or mountains. Usually weather forecast models use surface parameters in their calculations and for example two-metre temperature is calculated using surface and first model level temperatures. The first model level is typically a few tens of meters above surface.

5. Conclusion and some future aspects and recommendations

The meteorological station network is the most important meteorological data source and there is no reason to assume that any other method could replace this data source. The meteorological station network is undergoing a continuous transformation in many countries due to automation of stations. New instruments and observing methods are been developed. A small study about the influences –benefits and drawbacks– the automation of network has in respect of availability of meteorological data for agriculture would be beneficial to make in conjunction with COST-718.

From the point of many agricultural applications it is important that meteorological data is available as grid square values that enables running of agrometeorological models at any desirable geographical location. The spatialisation of meteorological data is a challenging task, especially in heterogeneous landscape. A lot of emphasis has been put on the development of spatialisation methods, there was for example a workshop (Gozzini and Hims, 1998) and a seminar (Bindi and Gozzini, 1998) during the antecedent COST action (COST-79). During COST-79 also an initiative to co-ordinate and compare several spatial interpolation methods was started (Gozzini and Paniagua, 2000). It seems quite implausible that a same interpolation method would be used in all European countries as many national meteorological services, as well as national or international institutes (like JRC e.g. van der Voet et al, 1993), have developed and implemented their own interpolation methods. However, co-operation in the development and testing of interpolation methods is beneficial to those participating in the work. A new COST action COST-719 “The use of Geographical Information Systems in Climatology and Meteorology” has recently started and close co-operation between these two actions is naturally very important for both actions.

There have been a lot of expectations concerning the meteorological observations using remote sensing methods. In spite of the development in the remote sensing instruments and data processing algorithms there is still quite a limited number of really operational applications where remote sensing can replace or remarkably supplement traditional meteorological observing network. In relatively densely populated Europe the maintenance of observing network is relatively easy to carry out and the value of remote sensing data may not bee as high as in sparsely populated regions. For example in Siberia or some parts of Africa or over the oceans remote sensing may be the only practical alternative to make meteorological observations. The assimilation of remote sensed data with ordinary meteorological measurements would add the use of remote sensed data.

Most countries have access to the numerical weather forecast model data. When using this data we should know answers to the questions like:

- Is the data obtained from these models accurate enough for agricultural models?
- Are there some differences between the parameters, e.g., are temperature predictions good but precipitation or solar radiation predictions systematically inaccurate?

In COST-718 we could study how to encourage the used numerical atmospheric model data as a data source in agrometeorological models.

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COST-717, Use of radar observations in hydrological and nwp models, http://www.smhi.se/cost717

ESA, Tracking the world's weather, http://www.esrin.esa.it/msg/pag0.html

ESA, Earth remore sensing, http://earth.esa.int
High Resolution Limited Area Model, http://www.knmi.nl/hirlam/

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