Statement of Guidance for Agricultural Meteorology

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Weather data are needed on a regular basis by the agriculture, forestry, rangeland, and fisheries sectors for both strategic and tactical applications. These data assist the agricultural community in a variety of aspects such as monitoring pests, crop infections, fire danger ratings and water availability as well as providing information for research applications. The collection of agrometeorological data is critical for running different crop weather- yield models for the assessment of the state of the crops and for forecasting their yields.

Agricultural meteorology is one of the fields of hydrometeorology for which satellite data are very important. Agrometeorological parameters are naturally variable in time and space. Ground observations alone cannot provide sufficient spatial and temporal resolution for the purposes of large scale environmental monitoring. The increasing availability of more frequent high resolution remote sensing data is expected to open up new areas for agricultural applications.

This Statement of Guidance (SOG) has two sections: one for in-situ observations and a second for space-based observations. In some cases a given parameter may have both types of observations as part of its description. At the end of the SOG there is a summary of key comments and recommendations.

INSITU OBSERVATIONS

Soil temperature

In addition to the standard weather elements such as air temperature, precipitation, relative humidity, wind speed/direction and solar radiation, it is important to also collect soil moisture and soil temperature data at strategically located stations. These data are critical for monitoring drought, satellite remote sensing ground truth procedures and soil moisture model initialization and verification. Optimum monitoring of soil moisture requires measurements to depths of 50-100 cm every 5-7 days.

Soil temperature directly influences crop growth by providing necessary warmth to seeds, plant roots, and microorganisms within the soil profile. The physico-chemical as well as life processes are also directly affected by the temperature of the soil. Under low soil temperature conditions nitrification is inhibited and the intake of water by roots is reduced. Extreme soil temperatures injure plants affecting growth and development. .

Therefore all categories of agricultural meteorological stations should also include soil-temperature measurements. The levels at which soil temperatures are observed should include the following depths: 5, 10, 20, 50 and 100 cm. At the deeper levels (50 and 100 cm), where temperature changes are slow, daily readings are generally sufficient. At shallower depths the observations may comprise, in order of preference, either continuous values, daily maximum and minimum temperatures, or readings at fixed hours (the observations being preferably not more than six hours apart). When soil-temperature data are published, information should be given on the way the plot is maintained. The depths of the thermometers at 5, 10 and 20 cm should be checked periodically and maintained. When soil temperatures are measured in a forest, the reference level for the depth measurement should be clearly indicated: whether the upper surface of the litter, humus or mass layer is considered to be at 0 cm; or whether the soil-litter interface is taken as zero reference. Whenever the ground is frozen or covered with snow, it is of special interest to know the soil temperature under the undisturbed snow, the depth of the snow and the depth of frost in the soil. Measurement of the thermal properties of the soil (e.g. specific heat, thermal conductivity), temperature profiles and changes in these profiles should be included.

Soil moisture

Soil moisture is a key variable in controlling the exchange of water and heat energy between the land surface and the atmosphere through evaporation and plant transpiration. As a result, soil moisture plays an important role in the development of weather patterns and the production of precipitation. Simulations with numerical weather prediction models have shown that improved characterization of surface soil moisture, vegetation, and temperature can lead to significant forecast improvements.

Soil moisture is one of the most useful variables in agrometeorology. Optimum monitoring of soil moisture requires in-situ measurements to depths of 20, 50, and 100 cm every 5-7 or 10 days, with horizontal resolution better than 100 m. Time Domain Reflectometry (TDR) is used to determine moisture content in soil and porous media, where over the last two decades substantial advances have been made; including in soils, grains and food stuffs, and in sediments. The key to TDR's success is its ability to accurately determine the permittivity (dielectric constant) of a material from wave propagation, and the fact that there is a strong relationship between the permittivity of a material and its water content. Care should be taken to carefully cailbrate TDR instruments to estimate soil moisture for the specific soil properties at each site.

Snow depths and coverage

Snow depths and coverage from mountainous areas provides a source of irrigation water during the summer and it is recommended that these data be collected on a routine basis. These data are collected by manual measurements and the use of instruments such as snow pillows. Spatial coverage can be monitored by satellites. A combination of these methods is recommended.

Phenology

Phenology is the science which deals with the recurrence of the important phases of animal and vegetable life in relation to the change of seasons during the year. There is every chance that phenological observations, i.e. recording of the dates such events as leafing, flowering, fruiting and leaf-fall of trees, migration of birds, the appearance of insects and the like which recur every year, may provide some indication at least in a quantitative way, of the nature of the coming season. The dates of manifestation of phytophase constitute an integral of climatic effects as they take into account the weather over past periods and also the weather at the moment. It is hoped that, when phenological observations have been collected for a sufficiently long period, some empirical relationships between phenological events and agricultural operations may be obtained. Such relationships will be of much value from the agricultural point of view,

Observations on crop phenology according to standard description of crop growth stages, along with the standard weather data, are crucial for a number of applications including crop management, especially pests and diseases and for use in crop and bio-geophysical models for forecasting crop yields and simulating soil carbon and nitrogen dynamics. Phase (stage) of plant development is a good indicator of biological time. Phases differ in such crop parameters as colour, height of plant, reproductive stages, and leaf area index (LAI). On the basis of relevant techniques and available satellite data it is possible to detect principal phases for cereals (for example the "Green wave").

Sand and Dust Loads

There is an increasing frequency of occurrence of sand and dust storms in different parts of the world and they carry considerable impacts on agricultural productivity in the near term and on soil productivity losses in the long term. It is essential to include measurements of aeolian sedimentation loads in the standard agrometeorological stations of NMHSs. It is also essential to include a routine and comprehensive analysis of wind speed and direction data and disseminate this information to the users. These data should be applied to analyze the impact of sand storms on agriculture. Use of air quality networks to aid in data collection on dust and sand storms may also be examined.

Frost / Freeze

The critical temperature needed for damage to occur may vary depending on the duration that temperatures remain near or below the freezing point. The detection and prediction of frost occurs when the air temperature is near or below 0°C. Frosts are frequently classified as either advective or radiative and this also defines their impact on the different types of crops. During radiative frost occurrences the frost line often does not reach more than 1-2 m above ground so that only the crops close to the ground are are generally affected by frost.

Fires

In agriculture, fire is both a tool and a hazard. In some areas fire is used to burn off or clear old growth after harvest. Wild fires, both grass and tree born, pose threats to farming. Using fire for old growth clearing require meteorological information to enhance control aspects and to minimize air quality issues.

Radiation and Thermal balance at the ground surface

A detailed investigation into the processes which control the thermal balance at the ground surface is necessary for an understanding of physics of air and soil layers near the ground. A knowledge of the radiant energy received from the sun and the sunlit sky and its absorption by the ground and air layers near it and of the radiative exchange between the ground and the atmosphere in the infra-red regions of the spectrum is of great importance. Apart from the fact that solar radiation is a major contributor to all atmospheric processes, the duration and intensity of this radiation are important for photo-synthesis which plays a vital role in plant growth. Measurement of surface albedo from various soils and crops is of importance for estimating the radiative contribution to global warming.

Evapotranspiration measurement through Lysimeters

The determination of the moisture balance at the ground surface is of importance for estimating water surpluses and deficits in agricultural and forest systems. Measurements that facilitate the estimation of water and heat balances in the air layers near the soil surface help us to develop a comprehensive understanding of physical processes necessary for predictive modelling. A full appreciation of the problems is connected with the reliable measurement of the factors involved, particularly evaporation and evapotranspiration (ET).

Precise measurement of water requirements of crops can be made using lysimeters. ET data gathered using this methodology is useful for studying water deficit/surplus during the life span of different crops and developing crop water requirements. In irrigated areas, the strategy is to maximise crop yields by optimising irrigation amounts and scheduling. In dryland farming, it is essential to carefuly economize on water use. It is therefore necessary to obtain data on water requirements of various crops during their different phases, under different meteorological conditions in various agroclimatic zones.

Dew

Dew is an important source of moisture for plant growth, particularly in the arid and semi–arid climatic zones which receive low amounts of rainfall. Dew is defined as the deposition of water drops by direct condensation of water vapour from the adjacent clear air, upon surfaces cooled by nocturnal radiation. Dew is an important secondary source of moisture for crops during the non-rainy season and plays vital role in plant growth. Dew occurrences benefit the plants in the following ways, (1) it is directly used by plants from absorption by leaf surface; (2) it reduces transpiration and helps conserve moisture; and (3) it helps acceleration of photosynthesis by plants in forenoon hours due to water saturation of leaves during night. These benefits are significant particularly in arid and semi-arid areas.

Precipitation

The traditional measurements of precipitation using rain gauges remain very important since this is the ground truth for remotely sensed estimates. The surface raingauge network is the foundation for many agricultural applications such as crop forecasting, disease and pest warnings, and short-term advisories for farmers. Automatic weather stations (AWS) in agricultural areas are becoming more widespread in their deployment. Newer methods such a Doppler radar help in spatial estimates. This technique has great potential in flood forecasting, irrigation applications and improving drought factor and soil moisture estimation.

Wind Speed and Direction

Wind speed and direction measurement is becoming increasingly important in the application of pesticides and in the estimation of crop water use (evapotranspiration). An important input for pesticide spraying and crop water use is the measurement of a wind speed and direction at the two-meter level. Many NMHSs do not report this value, as the current standard is 10 meter level, and the addition of this dataset may be valuable parameter in future farming methods. The requirement to provide high quality and more frequent resolution wind speed and direction data will require insitu measurements from a local network or mesonet in agricultural areas.

SPACE-BASED AND REMOTELY SENSED OBSERVATIONS

Recent advances in satellite technology in terms of high resolution, multi-spectral bands provide useful information for agricultural operations. Integrated use of satellite data and conventional meteorological observations is found to be very useful to extract information relevant to agriculture. Meteorological satellites play an important role in retrieval of the following parameters.

Air Temperature at 2 meters (Shelter)

Air temperature at 2 meters, including minimum/maximum values along with canopy temperature, are important factors of consideration for assessment of crop development and crop stress. This shelter temperature is more directly related to the air temperature than the surface temperature. Using short-range forecasts from NWP models can be more useful for this parameter.

Precipitation

Microwave imagers and sounders offer information on precipitation of marginal horizontal and temporal resolution, and acceptable/marginal accuracy (though validation is difficult). Satellite-borne rain radars, together with plans for constellations of microwave imagers, offer the potential for improved observations. There are a lot of applications for precipitation estimation on the basis of cloud type detection. Such techniques are applicable only for specific territories and intervals in vegetation periods. There are several techniques to derive rainfall from satellite observations. Visible/infrared observation: It is based on visible sensors that rely on the identification of cloud types. In the infrared based methods, the most common approach is to find out cold clouds within overcast areas. Rainfall estimation techniques based on microwave frequencies are more direct in nature.

Evapotranspiration

Evaporation from soil surface and transpiration from canopy are key land surface processes that control photosynthesis. Actual (AET) and potential (PET) evapotranspiration can be derived using (i) single (e.g. S-SEBI model) source and (ii) Two-source (e.g. ALEXI) energy balance approach and retrieved land surface variables are such as: LST, NDVI, albedo, insolation. It should be noted that this parameter can be obtained only very indirectly from satellite observations.

All sky insolation

Incident solar radiation falling on earth surface is the main driving variable for land-atmosphere exchange processes. The different approaches for estimating shortwave (0.3 – 4.0μm) solar radiation at ground using satellite data fall, broadly, in two categories: 1) statistical and 2) physical or radiative transfer techniques. These were developed and tested on sensors onboard geostationary satellites such as: MSG SEVIRI on Meteosat (EUMETSAT), VISSR on GMS (Japan), GOES (USA). The physical retrieval requires tuning of atmospheric turbidity parameters (water vapour and aerosol) and cloud attenuation coefficients.

Solar Radiation

Incoming solar radiation is the primary source of plant photosynthesis. Solar radiation also plays important role in evapotranspiration. Visible observation from satellites provides an excellent source of information regarding the amount of radiation reaching the plant canopy.

Surface Albedo

It is an important parameter used in global climatic models to specify the amount of solar radiation absorbed by the surface. The amount of solar radiation (0.4 – 4.0 µm) reflected by a surface is characterized by its hemispherical albedo, which may be defined as the reflected radiative flux per unit incident flux. This is important parameter for computing net shortwave radiation in land surface radiation budget. Pre-requisite is generation of broadband surface reflectance. The computation is basically double integration, over wavelength and angular geometry. The following algorithms of albedo retrieval using broad VIS reflectance from geostationary sensor data are in use world over.

(i) Conversion of broadband reflectance to shortwave band
(ii) Minimum ground brightness in a time series
(iii) Contrast ratio approach
(iv) BRDF method

Variations of surface albedo can serve as diagnostic of land surface changes and their impact on the physical climate system can be assessed when routinely monitored surface albedo is used in climate models. For clear sky conditions, the surface albedo may be estimated by remote sensing measurements covering optical spectral bands. It is useful for monitoring crop growth, prediction of crop yield and monitoring desertification. Landsat TM optical band data is used for computation of regional surface albedo. NOAA-AVHRR Ch1 and Ch2 data are also used for surface albedo on snow and forest cover.

Frost / Freeze

The monitoring of large scale frost conditions can be accomplished by remote sensing under clear sky conditions. Transient phenomena of this type require high frequency measurements (as high as every 15 minutes) with high horizontal resolution (better than 1 km). Geostationary satellites are optimum regarding frequency of observations (but they lack acceptable spatial resolution). Research polar satellites have adequate horizontal resolution (better than 100 m), but lack acceptable observing frequency. Currently monitoring frost by remote sensing can be obtained on large scales only. Local frost monitoring is best achieved by insitu high frequency temperature measurements strategically placed to capture frost events.

Fires

The current capability for detecting fires with satellites is improving. Capabilities are marginal, and no instrument meets all requirements. The MODIS on EOS AM and PM has enabled near real time fire detection four times per day through data direct broadcast and ground processing with internationally distributed processing packages. NPOESS and METOP satellites are or will be marginally meeting requirements for monitoring fires, and problems regarding data delay and data accuracy seem to have been overcome. Geostationary monitoring of fires (GOES 8 – 12) is showing promise and indicating that a trade-off between spatial and temporal resolution can be made. Satellite images are widely used for evaluation of big enough forest fire areas or fire consequences. Also, MSG SEVIRI can be used for fire monitoring.

Land Surface Temperature

Surface temperature is used for various agro-meteorological applications such as surface heat energy balance, characterisation of local climate in relation to topography and land use, mapping of low temperature for frost condition (night time) or winter cold episodes (day/night), derivation of thermal sums for monitoring crop growth and development conditions. It can be estimated from remote sensing measurement at thermal IR (8-14 um) of the radiant flux and some estimate of surface emissivity. Surface temperature is an important quantity for crop modelling such as energy and water exchange between atmosphere and land surface. Three major categories of LST retrieval algorithm have been developed (i) Mono window, (ii) Split window and (iii) multiangle methods based on sensor characteristics. Accurate freeze forecast based on satellite surface temperature estimates permits farmers to protect crops only when there is a significant freeze threat. Very-short range NWP model output can also be used for this parameter.

Soil Moisture

Microwave sensors are the best soil moisture sensors. This sensor can provide estimates of soil moisture only in surface layers up to 10 cm thick. Using the water content in the top 10 cm of the surface layer, the moisture content can be calculated within acceptable limits and with minimum error. Generally, surface soil moisture is estimated using thermal infrared include (i) Apparent thermal inertia (ii) temperature-vegetation triangular space (iii) morning rise in LST. Satellite microwave remote sensing is used to estimate soil moisture based on the large contrast between the dielectric properties of wet and dry soil. The microwave radiation is not sensitive to atmospheric variables, and can penetrate through clouds. Also, microwave signal can penetrate, to a certain extent, the vegetation canopy and retrieve information from ground surface. The data from microwave remote sensing satellite such as: WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT are used to estimate surface soil moisture.

Current active and passive microwave sensors determine soil moisture of upper few cm only with resolutions on the order of tens of meters for SAR systems and tens of kilometres for passive systems. Noting the usefulness of this parameter, even with the reduced resolutions of current measurements, some problems can be addressed.

Advanced scatterometers enable derivation of soil wetness of the first few centimetres that is potentially useful for agrometeorological studies. Over local terrain, soil wetness can also be observed by passive microwave emission radiometry. On a global scale, L-Band radar may provide 30-50 km resolution coverage.

Quantitative measurements of soil moisture in the surface layer of soil have been most successful using passive remote sensing in the microwave region. The potential exists today to retrieve soil moisture estimates from space-based instruments at frequencies of about 6 GHz (C band). However, observations at frequencies between 1 and 3 GHz (L band) are best suited for detection of soil moisture because energy is emitted from a deeper soil layer and less energy is absorbed or reflected by vegetation.

Fraction of Photosynthetically Active Radiation (FPAR)

FPAR is defined as the fraction of photosynthetically active radiation absorbed by a plant canopy. It excludes the fraction of incident PAR reflected from the canopy and the fraction absorbed by the soil surface or the combination of forest floor and understory, but includes the portion of PAR which is reflected by the soil/understory and absorbed by the canopy on the way back to space. Green FPAR refers to the fraction absorbed by green leaves only after the removal of the contribution of the supporting woody material to the PAR absorption. The instantaneous green FPAR is integrated over the day with a weight equal to the cosine of the solar zenith angle to obtain the daily green FPAR presented in the map.

Absorbed Photosynthetically Active Radiation

It is the fraction of the PAR absorbed by the canopy and used in carbon dioxide assimilation. The APAR results from a leaf radiation balance. It is a key parameter in productivity analysis and eco-system modelling. The productivity of vegetation canopy can be studied from estimation of APAR derived from optical remote sensing data. Remote sensing of APAR has been achieved through estimation of downwelling PAR at the surface, PARd, and the fraction of PAR intercepted by the canopy.

Vegetation type and cover

The majority of agrometeorological calculations, reviews, and forecasts are prepared for specific crops. Present-day operational satellite imagery from multi spectral channels enable high resolution, farm scale estimation of crop health and crop types however the availability may be limited by continuous cloud cover at times. Remotely sensed determination of crop health and types need to be integrated with ground-based observations to ensure the accuracy of the final product. Remote sensed data can also be used in the estimation of fuel loads and curing values for fire risk forecasts.

The VEGETATION programme of the SPOT-4 and SPOT-5 Earth observation satellite is conceived to allow daily monitoring of terrestrial vegetation cover through remote sensing, at regional, continental and global scales. The VEGETATION instrument is an imaging system in 4 spectral bands: blue (0.43-0.47 microns), red (0.61-0.68 microns), near infrared (0.78-0.89 microns) and SW infrared (1.58-1.75 microns). The red and near infrared are particularly well adapted to describe the vegetation photosynthesis activity, while the SW infrared is a good detector for the ground and vegetation humidity. VEGETATION uses telemetric optics giving a quasi constant spatial resolution through the field of view (2200 km on the ground): this resolution is 1.15 km at nadir, and still 1.7 km on the sides of the field of view (101°).

Vegetation indices (VI)

A VI is a quantitative measure used to measure biomass or vegetative vigour, usually formed from combinations of several spectral bands, whose values are added, divided or multiplied in order to yield a single value that indicates the amount on vigour of vegetation. Vegetation Indices are the simplest approach to characterize vegetation parameters and for evidencing their spatial and temporal variation for crop growth stages. Several vegetation indices were defined starting from the first simple ratio between infrared and red spectral channels. These include the Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil Adjusted Vegetation Index (SAVI), up to the more recent Soil and Atmosphere Resistance Vegetation Index (SARVI). Vegetation indices have been also used for agricultural drought quantification and mapping. In particular, Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI) have been developed and tested for drought monitoring. Maximum greenness during the growing season represents the maximum value of the NDVI during the growing season, as determined from the seasonal trajectory of the NDVI curve. Total greenness during the growing season represents the area under the NDVI curve for the growing season period. This product is prepared using the NDVI and surface temperature data, obtained from satellite measurements and corrected for atmospheric effects. The units are “NDVI days”. The images are able to show the amount and duration of chlorophyll in the 2 growing seasons and the differences, both positive and negative, between the 2 years in various regions.

Leaf area index (LAI)

LAI is one of the principle variables sought from agrometeorological satellite data for use in crop simulation models. LAI is defined as the total leaf area per unit ground surface area and it is used for the assessment of the state of the crops. In the calculation of LAI from NDVI, different algorithms are used for different vegetation types. The spatial coverage is acceptable for the NOAA and Terra satellites (with an observing cycle from 5 to 7 days). The time of delay of up to 1 day is acceptable, which is met by almost all instruments. The horizontal resolution of 0.25–1.0 km is acceptable. The measurement accuracy is a drawback as all instruments are below threshold, so it is necessary to launch instruments enabling better techniques (more spectral bands in the visible and higher spatial resolution). There should be a good network for recording leaf temperature and leaf wetness, as they are useful in forewarning diseases in crops.

Sea surface temperature

Remote sensing methods help greatly in optimisation of ocean resources. Several parameters relating to the oceans including fisheries is studied using satellite. One of the important parameters that can be measured with sufficient accuracy is the Sea Surface Temperature (SST) which is related to the concentration of fish population. SST derived from NOAA-AVHRR satellite serves as a very useful indicator for fish aggregation. Based on the thermal features location of potential fishing zones are being identified.

To address the needs of agricultural meteorology, the following specific recommendations are listed.

Specific

- Soil moisture and temperature data at strategically located stations to depths of 20, 50 and 100 cm every 5-7 days, and 10 days are needed for monitoring drought and for soil moisture model initialization /verification;
- Measurement and forecast of wind speed at the crop canopy level (two meter level) will enable safer application of pesticides as well as provide better estimation of crop water use. In areas of high agricultural production establishment of mesonets is recommended.
- Combining weather radar information with rain gauge networks can enable better evaluation of precipitation distribution at the farm scale and offers significant improvements in flood forecasting and irrigation requirements.
- Sand and dust loads along with comprehensive analysis of wind must be included in the standard agrometeorological stations of NMHSs in order to analyze the impact of sand storms on agriculture
- Leaf area index and land cover measurements with higher spatial resolution are needed; the polar orbiting instruments should be enhanced to resolve sub 1 km features;
- Optimum network of observations of evapotranspiration will help in scheduling irrigation as well as use of water at critical stages of crops.
- Enhanced observations of dew, leaf temperature, and leaf wetness are required for disease forecasting.
- Multifrequency synthetic aperture radar systems could offer significant improvements for canopy structure and water content determinations; the continuous application of GIS and Remote Sensing technologies are necessary to evaluate soil moisture and vegetation state of the crops, and also o accomplish spatial and temporal analysis at the same time and scale (local, regional or global level).
- Systematic observations on the characteristic micro-climates of the air layers close to the ground in the open and inside various crops would provide useful information.