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FAO activities to develop agro-climatic datasets and tools for the needs of irrigation management

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Abstract

The improvement of irrigated crop system management has become a priority for economic and environmental reasons. In many cases, irrigation control is mainly a question of management of water resources, equipment and manpower. It therefore depends on choices to define the water supply strategies for optimal crop production and economic returns under conditions of reduced water supply and to advise farmers to optimize timing and application rate of crop irrigation for optimal yields and income also under limited water supply. The choice of cropping plan stands on farm constraints: (i) crops to irrigate, production and margin objectives; (ii) irrigation programme, i.e. a set of decision-making rules concerning irrigation management. To define the best strategy, the irrigation programme is elaborated taking account of the agronomic parameters of each crop, the soils and climate characteristics and, particularly, climate variability. However, the accuracy of these strategies is often limited by the availability of climatic data at a specific temporal or spatial resolution and by the availability of adequate crop information for regional applications. These are just few examples of the problems to deal with in the planning and operational activities related to the irrigation management. To minimize the impact of such a problems, the Food and Agriculture Organization of the United Nations (FAO) has developed application tools to address the lack of agro-climatic data at worldwide level. FAO is a specialized UN Agency dealing with agriculture, forestry and fishery, particularly in developing countries. One of its technical services (Environment and Natural Resources Service, SDRN) has the responsibility to provide information on environment and natural resources as related to food and agriculture and it includes, among others, expertise in remote sensing and GIS. The Agro-meteorology Group is part of SDRN and it is responsible

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to provide global environmental digital datasets, to collect meteorological data in real-time, to develop methodologies, models and tools for data standardization, collection, spatialization and analysis. Data and tools are developed taking into account technical specifications of decision support systems for irrigation planning and management developed by other FAO services.

INTRODUCTION

Agriculture today represents 69% of the freshwater withdrawal at world level and for most developing countries it reaches levels of 85 to 95%. Irrigated agriculture today, representing less than 20% of the cultivated land, produces 40% of the world food supplies and almost 60% of cereal production. The volume of water diverted for agriculture as percentage of total renewable water resources indicates human pressure on water resources. In general, it is considered that countries using more than 20% of their water are water scarce because at that level the lack of water becomes a constraint to economic development. Many countries already use more than 40% of their resources.

Overall, the potential for expansion of irrigated agriculture is still important for increasing production in those countries where insufficient or erratic rainfall constrains rainfed agriculture. Yet, in an increasing number of countries and regions, irrigated agriculture has already reached its limits. FAO (Food and Agriculture Organization of the United Nations) has studied the trend of long-term developments, world–wide (FAO, 2003). The world crop production is expected to rise over the 34 year period from 1997 to 2030 by 55%, against 126% over the preceding 34 years period. The increment in developing countries is expected to be higher, 67% for the future, against 191% in the past. The nature of the demand will also change as incomes rise and urbanization continues. Although net food imports into the developing countries will increase, most of the increasing demand in those countries will be met by increased local production. This increase in demand will be meet in three ways:

- by increasing yield,
- by expanding the arable land area,
- and by increasing the frequency with which the land it is cropped.

The FAO study estimates that in 2030 irrigated land is expected to account for 38% of the total increase in arable land and for over 70% of the increase in cereal production. Irrigation is essential for food production to overcome deficiencies in rainfall and to stabilize agricultural production especially in arid and semi-arid areas. The food requirements of an ever-increasing world population higher necessitate agricultural production, a large share of which comes from irrigated lands. As the availability of water resources for irrigation becomes increasingly difficult, water and the cost of water resource development becomes a severely limiting factor enhancing irrigated agriculture.

BACKGROUND

Management of water resources

The great challenge for the coming decades will be the task of increasing food production with less water, particularly in countries with limited water and land resources. While on a global scale water resources are still ample, serious water shortages are developing in the arid and semi-arid regions, as existing water resources reach full exploitation.

Irrigation scheduling concerns the farmers' decision process of “when” to irrigate and “how much” water to apply in order to maximize their profit. This requires knowledge on crop water requirements and yield responses to water, the constraints specific to each irrigation method and irrigation equipment, the limitations relative to the water supply system and the financial and economic implications of the irrigation practice.

A large number of tools are today available including procedures to compute crop water requirements, to simulate soil water balance, to estimate the impact of water deficits on yields and to estimate the economic returns of irrigation. The adoption of appropriate irrigation scheduling practices could lead to increased yields and greater profit for farmers, significant water savings, reduced environmental impact of irrigation and improved sustainability of irrigated agriculture.

For a cropping system, irrigation control is essentially based on the management of available means: water resources, equipment and manpower. It depends on choices to define the water supply strategies for optimal crop production and economic returns under conditions of reduced water supply and to advise farmers to optimize timing and application rate of crop irrigation for optimal yields and income also under limited water supply. The definition of an irrigation programme must be elaborated taking into account of: the agronomic parameters of each crop, the soil and climate characteristics of the farm and, particularly, the climate variability. In fact, the best combination of the satisfaction of the "crop water requirements" will produce the highest economic return over a range of climatic scenarios.

Irrigation strategies

Irrigation management depends on strategic choices such as the selection of cropping plan according to farm constraints (which crops, which crops to irrigate and which production and margin objectives) and an irrigation programme, which is a set of decision-making rules concerning irrigation management. An irrigation programme must be defined upon the agronomic parameters of each crop (water requirement, stress sensitivity, sensitive periods, etc.), the soil and climate characteristics of the farm. To select the best strategy, it is particularly important to take account of climate variability.

In fact, the best combination of the satisfaction of the "crop water requirements" will produce the highest economic return over a range of climatic scenarios. Weather variability remains one of the main factors behind the inter-annual variability of agricultural production (Gommes, 1998). It is possible to evaluate a strategy for an average climate year but the risk, for example in a dry year, will be not estimated. It is possible to choose the "crop satisfaction of water requirement" combination which gives the best average economic result for the set of scenarios. This procedure allows the farmer to assess the risk taken for each type of year.

The accuracy of these strategies is often limited by the availability of climatic data at a specific temporal or spatial resolution and by the availability of adequate crop information for regional applications. Therefore, these strategies cannot be implemented if climatic data or adequate crop information are not available for the location and at a specific temporal or spatial resolution. In many cases, data are simply extrapolated or even taken from the closest meteorological station without taking in consideration the representativity of that station vis-à-vis the farm's location. In this case specific techniques must be used to interpolate climatic data from several neighbouring stations to obtain accurate values. This paper describes current FAO's activities in this field and future developments.

FAO's activities in irrigation management

FAO was founded in 1945 with a mandate to raise levels of nutrition and standards of living, to improve agricultural productivity, and to better the condition of rural populations. Among other activities, FAO collects, analyses, interprets and disseminates information relating to nutrition, food, agriculture, forestry and fisheries.

Being knowledge a basic tool for agriculture development, FAO promotes the direct transfer of skills and technology through field projects, but also undertakes a variety of information and support services. World-wide databases are maintained on topics ranging from fish marketing information to trade and production statistics and records of current agricultural research. The information gathered by FAO is un-restricted and made available to global community through various technology such as Internet. Dissemination is made by the World Agricultural Information Center (WAICENT) (http://www.fao.org/waicent/index_en.asp).

Water resources, development and management service

The Water Resources, Development and Management Service (AGLW), in the Agriculture Department of FAO, is concerned with sustainable use and conservation of water in agriculture. It assesses water resources and monitors agricultural use; assists in water policy formulation and promotes irrigated agriculture and efficient water use through management innovations, modernization and institutional reforms. The programmes and activities of the Service include the development of water resources through small scale irrigation and appropriate water control technologies; best practices for sustainable water use and conservation and the avoidance and mitigation of adverse environmental effects of water development. AGLW is directly involved in the development of computer applications with regard to irrigation management and planning.

Agro-meteorology Group

The Agro-meteorology Group is placed within the Environment and Natural Resources Service (SDRN) in the Department for Sustainable Development. SDRN, which is the FAO focal point for environmental data. The Agro-meteorology Group maintains a large world-wide climatic database to provide needed inputs for various applications including irrigation management. During recent years, strong efforts have been made in order to make this database available to a larger audience by attaining two objectives: developing agrometeorological tools such as spatial interpolation routines, and disseminating climatic data through intranet and internet. The Agro-meteorology Group collects near real-time precipitation data from various sources for several hundred stations around the world to be used for the agrometeorological crop monitoring and yield forecasting. Data cover almost 30000 weather stations worldwide, focusing on developing countries in Africa, south and central America, southeast Asia, and Mediterranean countries. Data, including normals (30-year averages) as well as time series, come from a number of sources, mainly National Meteorological Services and international research centres. More information at: http://www.fao.org/sd/EN3_en.htm

Irrigation management needs

AGLW is one of the clients of the Agro-meteorology Group and their collaboration has been active since many years, particularly, in the field of crop water requirements. This includes topics such as: estimating reference evapotranspiration, defining crop coefficients, crop yield modelling including soil moisture balance, climatic data needs. In particular, this paper illustrates some software developed by AGLW for irrigation management and the inputs provided by the Agro-meteorology Group such as agro-climatic datasets at global, regional and local level as well as tools for spatial interpolation. Taking adavantage of modern communication facilities, in the near future these products will be available to a larger audience.

DATA AND TOOLS

Demand for data and tools

During recent years, the demand for climatic and agro-climatic data (including remotely sensed data) has increased almost at the same rate of the time-processing performance of computers. There is indeed a demand due to a higher resolution (in time and space) needs to run specific applications for a well defined location or area and for a well defined time interval. In many cases, FAO has demonstrated the potential of new sets of data, such as remotely sensed data, and the demand has pushed the development of related application tools. Of course, the demand for data is linked to the demand for tools (methods and software) applied to, for example, crop phenology modelling or estimating crop water requirements but also deriving meteorological parameters from satellite imagery. Most of the tools elaborated by the Agro-meteorology Group are largely demand- and tool-driven and are elaborated in regional food security projects in direct response to national requirements, i.e. the crop forecasting activities (Frère and Popov, 1986).

The modularity of software and common file formats constitute central issues in the FAO philosophy as regards the development of tools. Modularity and standard file formats are central issues in software applications development. One of FAO's main tasks in its normative role is to facilitate the development and adoption standards and guidelines to improve the effectiveness of programmes in agricultural development and food security world-wide (FAO, 1995). The adoption of standards is fundamental to ensure quality, accessibility, usefulness and timeliness of agricultural information. Standardization has been applied mainly to agro-meteorology and remote sensing applications software in order to accommodate different operational practices in each country such as different time intervals (days, pentads, weeks...) used to report crop and weather data. Standardization considerably reduces the software development and training. In this way, file and data management and analysis (processing) can be treated separately.

Various software have been developed by following this philosophy and many applications rely on GIS tools used for geo-statistics and spatial interpolation routines, like transforming point value into interpolated surfaces. As the interpolated surfaces must represent the ground truth with great detail, several techniques are used in order to "help" the interpolation of the selected variable to obtain a continuous surface with the highest resolution. To get this, remotely sensed products like digital elevation models (DEM[2]), Normalized Difference Vegetation Index (NDVI[3]), Cold Cloud Duration (CCD[4]) are

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[2] A Digital Elevation Model is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals. Several DEMs are in a raster form. In a raster or cell-based system, the map is represented by a geometric array of rectangular or square cells, each with an assigned value.

[3] The Normalized Difference Vegetation Index (NDVI) provides a measure of the amount and vigor of vegetation at the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigor and amounts of vegetation. NDVI is derived from data collected by National Oceanic and Atmospheric Administration (NOAA) satellites, and processed by the Global Inventory Monitoring and Modeling Studies (GIMMS) at the National Aeronautics and Space Administration (NASA). NDVI is a nonlinear function that varies

used. However, the main weak point of these techniques lies in analysing the datasets to perform the spatial interpolation in the correct way, i.e. "driving" the interpolation throughout a statistical process of the variables to interpolate in order to determine the best fitting of the parameters of the interpolation. The techniques developed for spatial interpolation of agro-climatic variables have been implemented into specific software and applied either to create “gridded climate surfaces” and to estimate values for any point of the earth. The outputs can be imported directly into some of the software developed by AGLW for irrigation management like CROPWAT and SIMIS.

Cropwat

CROPWAT is a computer program to calculate reference evapotranspiration, crop water requirements, crop irrigation requirements, scheme water supply, to develop irrigation schedules under various management conditions and to evaluate rainfed production and drought effects. CROPWAT is a decision support system developed by AGLW having as main functions:

- to calculate: reference evapotranspiration, crop water requirements, crop irrigation requirements;
- to develop: irrigation schedules under various management conditions, Scheme water supply;
- to evaluate: rainfed production and drought effects, efficiency of irrigation practices.

CROPWAT (Smith, 1992) is meant as a practical tool to help agrometeorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation. The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided. Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in two publications (Doorembos et al., 1992 and Doorembos et al., 1986). CROPWAT includes a revised method for estimating reference crop evapotranspiration, adopting the approach of Penman-Monteith as recommended by an FAO Expert Consultation (Smith et al, 1992) and further details on the methodology are provided in a publication (Allen et al, 1998). Detailed information and all programs are available for download at the web page: http://www.fao.org/ag/AGL/AGLW/cropwat.stm.

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between -1 and +1. Values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation.

[4] The geostationary METEOSAT satellite produces infrared temperature images every half an hour. In tropical regions it can be assumed that areas with temperatures lower than about –40°C are covered with rain clouds. The cumulated number of hours in a given period (i.e. 10-day) with this low temperature is defined as “Cold Cloud Duration” (CCD) and it can be represented as a digital image. The relationship between rainfall and CCD is positive, in other words, high rainfall values generally coincide with high CCD values.

Climwat

Calculations of crop water requirements and irrigation requirements are carried out with inputs of climatic and crop data. Standard crop data are included in the program and climatic CLIMWAT is a climatic database to be used in combination with the computer program CROPWAT and allows the ready calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops for a range of climatological stations worldwide. A database facility CLIMWAT has been developed which allows a direct link from CROPWAT to an extensive climatic database of 3262 stations of 144 countries worldwide in Asia, Africa, Near East Asia and North Africa, Europe, Central and South America. CLIMWAT database includes data from a total of 3262 meteorological stations from 144 countries. data can be obtained for 144 countries through the CLIMWAT database (Smith, 1993). The original database was compiled by the Agro-meteorological Group and has been converted into a format suitable for use by CROPWAT. The climatic datasets (including maximum and minimum temperature, mean daily relative humidity, sunshine hours, wind speed, precipitation, calculated values for reference evapotranspiration and effective rainfall) are available for download at the webpage: http://www.fao.org/ag/AGL/AGLW/climwat.stm.

Simis

Rural livelihoods and water conservation will gain from improved water management. While good decisions rely on good information, the usefulness of information depends very much on how well it is organized and how easy it is to use. Water management decisions on irrigation schemes can be improved if good information is available and accessible. SIMIS (Scheme Irrigation Management Information System) is a decision support system aimed at assisting the managers and staff of irrigation systems in their daily tasks. A SIMIS project stores information about climate, soils, crops, irrigation network, land tenure, land use and the maintenance needs of an irrigation scheme. SIMIS processes information to provide crop water requirements and estimate irrigation needs at farm and canal level. By interacting with the user it generates water delivery schedules for different modalities of water distribution (proportional, rotational and semi-demand) and seasonal irrigation plans. SIMIS also provides support on accounting, calculating water fees, maintenance control and performance indicators.

SIMIS (FAO, 1999) is a set of computer programs aimed at facilitating the management tasks of the irrigation systems. Besides the water management activities, all major issues of day-to-day management activities are also addressed, including accounting, crop production, control of maintenance, water fees, and other relevant tasks. SIMIS is a decision-support software that has been developed for the purpose of facilitating the management tasks of irrigation schemes. This program is not limited to the water aspects but covers all the major issues of the day-to-day management activities and also includes control of maintenance, accounting, water fees and other relevant tasks. The basic approach in the development of SIMIS was to furnish a set of programs (in English, French and Spanish) that could be used in most irrigation systems, leaving aside those that are too specific to be treated by a general system. SIMIS can simulate different scenarios that can be compared with the current situation and it can be a useful tool in the rehabilitation and modernization of an irrigation scheme and in the design. Detailed information are available at the web page: http://www.fao.org/ag/agl/aglw/simis.stm.

Faoclim-2

Climatic databases must be assembled for crop monitoring and forecasting systems because year to year climate variability is a dominant factor in the variability of crop yields. As crop water consumption depends on several variables, such as temperatures and wind speed, agro-meteorological databases should ideally include more than only rainfall. Climate conditions can vary significantly even over small distances.

At a continental scale, such as in Africa, the number, length and timing of rainy and cropping seasons are extremely diverse. Towards better understanding and modelling, FAO has assembled a major world-wide database of agro-climatic parameters, published as the FAOCLIM-2 on CD-ROM. The database covers more than 25,000 stations and focuses on monthly averages and time series, which are essential tools for variability analyses and risk studies. FAOCLIM-2 provides a user-friendly interface to the agroclimatic database and makes monthly climate data available to a wider circle of users. Copy of the CD-ROM can be obtained by sending a request with the postal address to Agromet@fao.org.

Spatial Interpolation

The spatial interpolation of agro-climatic data aims at estimating the value of rainfall, temperature, or any other agro-climatic parameter at a given site based on the observations at neighbouring locations. This is a problem the operational agro-climatology and agro-meteorology are regularly confronted with, for instance when estimating missing data. From a methodological viewpoint, the problems of missing data interpolation and of data gridding are thus largely the same. Over recent years, with the development of Geographic Information Systems (GIS), there has been an increased need for gridded datasets, i.e. datasets in which the value of an agro-climatic parameter has been estimated at regularly spaced points.

Geographically referenced data from a variety of sources must be used in conjunction with data provided by ground meteorological network and information obtained from satellite imagery. Activities such as mapping of potential distribution of pests rely on agroclimatic databases and agro-meteorology applied software. GIS tools are used for geo-statistics and spatial interpolation routines, like transforming point value into interpolated surfaces. As interpolated surfaces must represent the ground truth with great detail, several techniques are used in order to "help" the interpolation of the selected variable to obtain a continuous surface with the highest resolution.

It is mainly in crop forecasting for food security that the Agro-meteorology Group has been led to use spatial interpolation techniques: estimation[5] of crop yields by using station values of climatic and agronomic variables, but food production data must be presented by districts and provinces. Yields must thus be area-averaged, which implies that yields climates must be computed for a number of locations exceeding the number of available meteorological stations. Area averaging, the estimation of missing data and gridding are among the most useful applications of spatial interpolation techniques to agroclimatology and agro-meteorology.

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[5] The term “estimation” is used for the value eventually obtained through cokriging at a point where no observation is available. The term does not imply any connotation of “forecasting” in this context. The predicted (estimated, missing, interpolated) values are based on the “known” or “observed” ones.

There are many methods of spatial interpolation including, for instance, the method of "inverse distance weighting" and the method of Thyssen's polygons, to name just a few. It also exists the cokriging method allowing to carry out an optimum estimation taking more than one variable into account, i.e. taking advantage of the relations between the variables to improve the estimation. For instance, altitude is an important additional variable when estimating temperatures. The choice of an interpolation method depends on the purpose of the application, the availability of data, efficiency of data processing and costs. Thefore, the interpolation methods to be used must consider the spatial and temporal variability of the different types of meteorological data in relation to the meteorological processes.

Satellite enhanced data interpolation

The Satellite Enhanced Data Interpolation (SEDI) method aims to assist the interpolation of various agro-meteorological paramters measured or calculated at station level. SEDI is a simple and straightforward method for "assisted" interpolation. SEDI takes advantage of the correlation between an environmental variable, for instance the above mentioned NDVI/biomass and crop yields. One of the ways to approach this is co-kriging, a variant of kriging using one or more auxiliary variable and exploiting both the spatial features of the variable to be interpolated and the correlations between the variable and the auxiliary variables (Bogaert et al, 1995). The method can be applied to any parameter of which the values are available for a number of geographical locations, as long as a "background" field is available that has a negative or positive relation to the parameter that needs to be interpolated. The concepts of this interpolation method and software implementing the technique have been described by Hoefsloot, 1996 and it has also been applied to the estimation of missing data in agricultural statistics maps (Gommes and Hoefsloot, 1998). Three requirements are a prerequisite for the successful application of the SEDI method:

- The availability of the parameter to interpolate as point data at different geographical locations (e.g. rainfall, potential evapotranspiration (PET), crop yields);
- The availability of a background parameter in the form of a regularly spaced grid (or field) for the same geographical area (e.g. CCD, NDVI, altitude).
- A relation between the two parameters (negative or positive; rainfall/CCD is positive, PET/altitude is negative; Yield/NDVI is positive, temperature/altitude would be negative). A Spearman rank correlation test can reveal whether a relation exists, and how strong this relation is.

The SEDI method yields the parameter mentioned under point 1 as a field. The calculation can be influenced by setting a number of input parameters. Rainfall data are gathered on a dekadal basis and plotted on a map (Fig.1). The geostationary Meteosat satellite gets infrared temperature pictures of the earth every half an hour. In tropical regions it can be assumed that areas with temperatures lower than about minus 40 degrees Celsius are covered with rain clouds. The cumulated number of hours in a dekad with this low temperature is called "Cold Cloud Duration" (Fig. 2). It is represented as an image. An image is a regular structure with rows and columns, like a chessboard. The building blocks of the image are called "pixels". A pixel represents one data value. Pixels can be assigned a color depending on the value they represent. The relation between rainfall and CCD is a positive one. In other words: high rainfall values generally coincide with high CCD values. The SEDI process is done in three steps:

- Extracting values from the image and calculating the ratio of point and image values
- Gridding the ratio's to form a regularly spaced grid.
- Multiplying Grid with image to obtain estimated image.

Step 1: Extracting values from the image and calculating the ratio's. For every point value in the input rainfall data, a value can be extracted from the CCD image. The SEDI method will find the pixel that coincides with a rainfall station and extract the pixel value. In some cases the value of one pixel does not give satisfactorily results. Therefore the SEDI software allows the user to extract the values of more than one pixel from the image, and take its average as image value for the station (Fig. 3). For every station a rainfall value and a CCD value are now given. The Spearman rank correlation coefficient (using the rainfall/CCD data pairs) yields a positive value. This means the relation between rainfall and CCD is positive (as to be expected). The ratio between rainfall and CCD value is now calculated as showed in Table 1. Should the relation have been negative, the ratio is calculated as follows:

$$\frac{StationValue}{HighestPossiblePixelValue - PixelValue}$$

Step 2: Creating a regularly spaced grid from the ratios. The second step constitutes of the creation of a grid from the irregularly spaced ratio (Fig. 4). The ratio grid is created with the inverse distance method with a weighting power of 2. The software allows the user to set: (i) the distance between the grid lines. A low distance creates a accurate, dense grid, while a high value creates a coarse, less accurate and more general grid. (ii) the number of stations per grid point determines the number of stations included in the calculation of a point in the grid matrix. (iv) the maximum radius for interpolation determines whether a value is calculated for a point in the grid matrix. If the number of stations around this grid point within this radius is higher than the specified number of stations, a value is calculated. Otherwise to the grid point is assigned a missing value, and the resulting image will be 'empty' at that particular point.

Step 3: Creating the SEDI image. The last step encompasses the creation of the SEDI image. The process consists in multiplying the grid (step 2) with the background image and an estimate for the value to interpolate is obtained. In terms of rainfall and CCD: a rainfall image is obtained by multiplying the ratio grid with the background image (Fig. 5).

Displaying and analysis tool

Commercially available software packages for the display and analysis of satellite derived images have been found difficult to use with the images available through FAO-ARTEMIS (Advanced Real Time Environmental Monitoring Information System). The main reason being that these packages offer the "classical" types of analytical procedures used for satellite data, with multi-band imagery and "false-color" composite displays. The ARTEMIS images, on the contrary, are multi-temporal, single-band and single theme. Furthermore, most packages did not support the geographic projection used for the original Africa images and this situation led to the development of a custom-made software. A specific DOS-based freeware software, named IDA (Image Display and Analysis), was originally developed by the USAID (US Agency for International Development) Famine Early Warning System (FEWS) Project. IDA became soon extensively used, in particular in developing countries for the analysis of low resolution, high frequency satellite imagery in near real-time as produced by ARTEMIS. An important result was that its file format (an 8-bit line/pixel image with a 512 byte header) is now used as a de-facto standard. With the technical collaboration of other partners such as USAID-FEWS, SADC-RRSP (Southern African Development Community, Regional Remote Sensing Project), USFS (US-Forest Service), USGS (US-Geological Survey) EROS Data Center, FAO-ARTEMIS, and the financial support of the European Commission, a Windows version of IDA, named WinDisp version 5.1, has been developed. It allows to:

- Display and analyse satellite images,
- Compare two images and analyse trends in a time-series of images,
- Extract and graph trends from a number of satellite images such as during the growing season for comparison with other years,
- Compute new images from a series of images,
- Display tabular data in map format,
- Build custom products combining images, maps and specialised legends,
- Write and execute batch files to automate routine and tedious tasks,
- Build a customized project interface for providing users with detailed menus of available data for a country or a specific area.

Software, manual and data can be downloaded from the FAO website: http://www.fao.org/WAICENT/faoinfo/economic/giews/english/windisp/windisp.htm.

LocClim

LocClim 1.0 (Local Climate Estimator) is a computer programme that estimates the climate for any location on Earth. It is based on the database of the Agro-meteorology Group and it was developed and programmed by Dr. Jürgen Grieser of the German Meteorological Service. If local climate is estimated from observations at nearby stations usually two different kinds of methods are used. They follow different and, in fact, opposite assumptions about spatial climate variability. If spatial climate variability is seen as a sum of a completely systematic structure plus spatially uncorrelated noise, interpolation functions (like splines, regression surfaces) lead to best estimates. If on the other hand spatial climate variability is seen as purely stochastic with spatial correlations on all scales, averaging procedures (like simple averaging, inverse distance averaging or kriging) give best results. However, spatial climate variability is both systematic and stochastic on all scales. This is the reason why LocClim uses a combination of both kinds of methods. LocClim is based on a mathematical hypothesis of the climate at any location on Earth. LocClim not only calculates an estimate for different climate variables at given locations; LocClim also provides quite a variety of tools to improve the estimates and gives warnings in case of different kinds of pitfalls. For any given location LocClim searches for the nearest stations that fulfil certain given criteria (absolute number, maximum distance, altitude constraints). If desired LocClim fits a linear altitude function through the observations to reduce all of them on the elevation of the desired location. This minimises the systematic error resulting from the different elevations of the neighbouring stations. The altitude of the desired location can either be given by the user or taken from a DEM (digital elevation model) with a spatial resolution of 10 km. and an altitudinal resolution of 20 m. (DEM downgraded from the NOAA/NCDC, US-National Oceanic and Atmospheric Administration/National Climatic Data Center, Global Land One-kilometre Base Elevation). If desired LocClim performs a climate gradient correction by fitting a plane surface to the observations over the latitude-longitude plane. Thus the smooth geographical climate variation is taken into consideration. If desired a shadowing routine can be applied that gives neighbours hidden by closer neighbours a lower weight than they should have by inverse distance averaging. This has two advantages. Stations in the shadow of other stations get less weight (i.e. they do not give new information about the vicinity of the desired location) and on the other hand stations which stand alone in a vast area get a larger weight because of the larger area they represent. Using the Inverse Distance Weighted Average (IDWA) approach, LocClim offers:

- An estimate of the climate (expectation values of seven variables) at any location you specified either by co-ordinates or by a mouse click on a map,
- An estimate of the uncertainty of the given results with respect to regional variability,
- An estimate of the altitude dependency of the variables,
- An estimate of the horizontal gradient of the variables,
- Estimates of monthly as well as decadal and daily expectation values,
- Calendar day on which the variables have their maximum and minimum,
- Number of days with expectation value above a threshold.

LocClim can also calculates the length of the "growing period" or "growing season" (LGP or LGS), as defined by the Agro-Ecological Zones project (FAO, 1978), which is the period (in days) during a year when precipitation exceeds half the potential evapotranspiration. A period required to evapotranspire an assumed 100mm of water from excess precipitation stored in the soil profile is sometimes added. The present program makes no provision for stored soil moisture. LGP is useful in calculating agricultural potential, it can be used as a criterion for classifying areas and in roughly determining crop cycle lengths and calendars. The calculation of the growing period is based on a simple water balance model, comparing precipitation with PET, using monthly values. LocClim can also produce its results in CROPWAT file format. Copy of the CD-ROM can be obtained by sending a request with the postal address to Agromet@fao.org.

RESULTS AND DISCUSSION

Throughout its software and database development, the Agro-meteorology Group supports the use of agro-climatic data to worldwide users. Software allows to create the outputs according user's requirements or other software's format such as CROPWAT and SIMIS. A new software named AGROMETSHELL is under development which integrates agro-meteorological tools for wider applications. Furthermore, ad-hoc agroclimatic digital datasets have been prepared such as the “World Climate Classification Maps”, the “Crop Production System Zones (CPSZ)” and the “Long-Term Average Maps of Rainfall and of Potential Evapotranspiration for Africa”. More recently, an important step forward has been taken in order to allow the access of agroclimatic data to internal (throughout Intranet) and external (throughout Internet) FAO users.

Agrometshell

This software is based on existing software such as FAOMET (Gommes and See, 1993) developed by the Agro-meteorology Group and widely used by most of National Early Warning Units for Food Security and by world-wide agricultural applications centres. It represents an essential tool for agro-meteorological data analysis and for the FAO crop yield forecasting methodology. Among its various components, the AGROMETSHELL toolbox includes an interpolation routine to estimate missing point values and three spatial interpolation routines to create digital surfaces: inverse distance, SEDI (inverse distance and regression), cokriging.

Faoclim-2003

FAOCLIM-2003 is the name of the climatic database under development set up in the FAO Oracle Data Warehouse. At present, global climatic and real-time meteorological data from different sources are collected by the Agro-meteorology Group under various forms (e.g. hand-written report, formatted and non-formatted text, spreadsheet, ASCII text, spatially interpolated data, etc.). Depending on the various input formats, data are either manually entered and stored digitally or processed by the Data Management Module of CLICOM (Climate Computing) software developed by the World Meteorological Organization (WMO, 2001), or by the Automated Climate Data Management (ACDAM) software developed by FAO (Verelst, 1998). Digital gridded datasets at various scales are also stored in the database. The new database will allow to: (i) incorporate climatic and real-time meteorological data (at station level and gridded) into a modular database running under a Relational Data Base Management System; (ii) provide an interface under MS-Access and responding to Agro-meteorology Group's needs; (iii) provide browsing and retrieval of basic data to internal FAO's users such as AGLW's and GIEWS's technical staff; (iv) provide browsing and retrieval of basic data to external FAO's users.

CONCLUSIONS

Some applications developed by the FAO Agro-meteorology Group have been presented. They are conceived to process near real-time agrometeorological and remotely sensed data, particularly, for the needs of irrigation management. In developing new applications, both the standardisation of data format and the modularity have a basic role to allow an easy exchange with other agrometeorological applications developed inside and outside FAO. These are the basic principles orienting the technical support on agroclimatic data and applications to the final users. Irrigation strategies require the availability of climatic data at a specific temporal or spatial resolution and of adequate crop information for regional applications. It requires the meteorological and remote sensing data collection and analysis at near real-time. The integration of GIS, remote sensing and agro-meteorology supports the development of methodologies/models and tools for data standardization, collection, spatialization and analysis. This procedure allows the production of environmental digital datasets at local, national, regional and global scale. In order to fully support the end-users' needs, the networking and information sharing must be implemented.

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Tables

Table 1. Calculating the ratios

Station Name	Rainfall (mm)	CCD value (hours)	Ratio
Station 1	23.4	56	0.42
Station 2	12.4	12	1.03
Station 3	54.3	96	0.57
Station 4	6.7	8	0.84

Figures

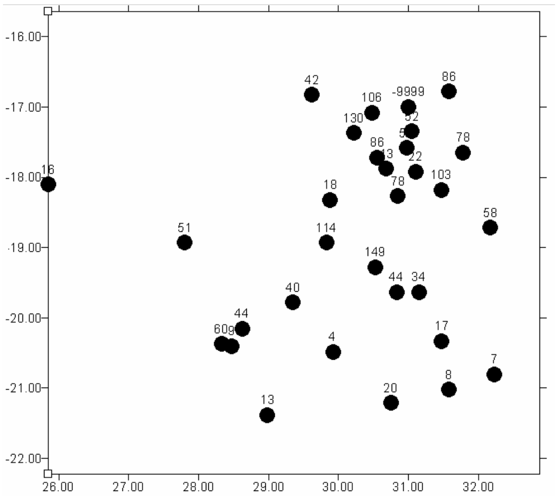

Fig. 1. Rainfall (mm) for Zimbabwe of second dekad of Januray 1991.

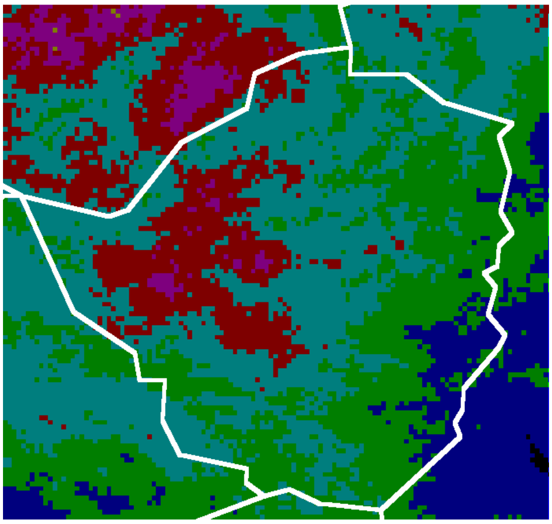

Fig. 2. Cold Cloud Duration image for Zimbabwe, second dekad of January 1991.

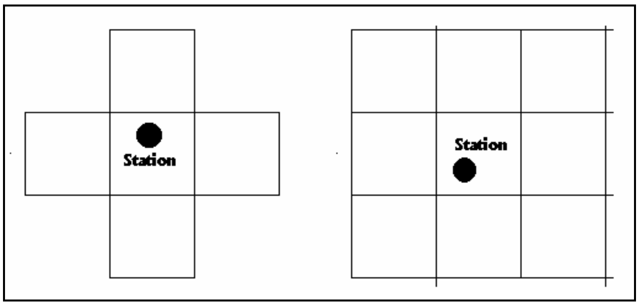

Fig. 3. Extracting 5 or 9 pixels per point value.

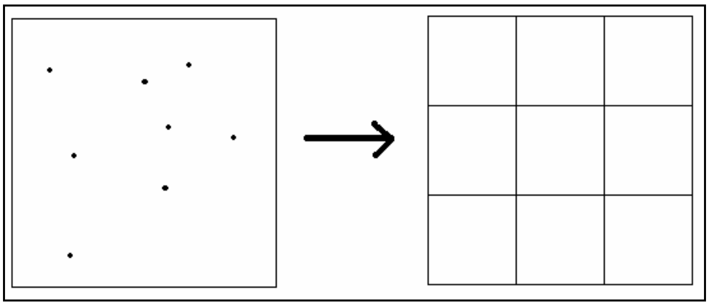

Fig. 4. Creating the ratio grid.

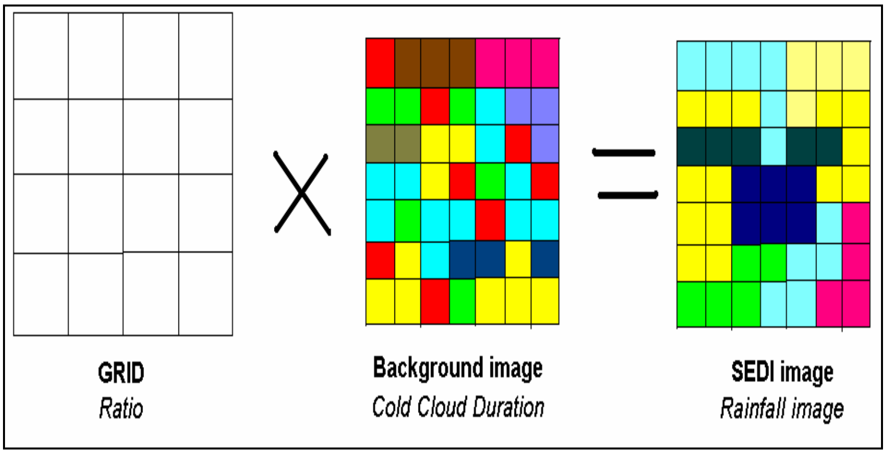

Fig. 5. Creating the SEDI image form ratio grid and background image.