

Chapter 9

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ARTEMIS software used by FAO for remotely sensed data

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Abstract

Since 1988, the Food and Agriculture Organization of the United Nations (FAO) has been using data from low-resolution satellites to monitor rainfall and vegetation conditions over large areas. These data are provided operationally in near real-time through the FAO *Africa Real Time Environmental Monitoring Information System (ARTEMIS)*. Primary users of ARTEMIS data are the FAO's Global Information and Early Warning System (GIEWS), the FAO Emergency Centre for Locust Operations (ECLO) and the FAO Agrometeorology Group. Originally, the focus of *ARTEMIS* was on Africa and the system provided Cold Cloud Duration and Estimated Rainfall Images derived from the METEOSAT satellite and NDVI images from the NOAA-AVHRR sensors. Over the past few years *ARTEMIS* has increased its geographic coverage, as well as its range of products. Since 1998, the system includes imagery at resolutions between 1 and 8 km, with global coverage. A variety of image software applications for display and analysis have been developed in tandem with the *ARTEMIS* data products. These are now widely used in both developed and developing countries and, in particular, at several national and regional organizations involved in early warning for food security. Both image data and software tools are fully PC compatible and do not require specialized hardware.

9.1 Introduction

Accurate and up-to-date information on food supply and demand are essential components of early warning for food security and planning of famine mitigation scenarios. Within the Food and Agriculture Organization (FAO) of the United Nations, the collection, analysis and dissemination of this kind of information is handled by its Global Information and Early Warning System (GIEWS), which was established in the wake of the world food crisis of the early 1970's. GIEWS aims to provide policy-makers and relief organizations with the most up-to-date information available on all aspects of food supply and demand, and provides warnings of imminent food crises, so that timely interventions can be planned and undertaken. As part of its activities, GIEWS monitors the condition of food crops in all regions and countries of the world and information is gathered on all factors that might influence planted area and yields. In many drought-prone countries, there is a lack of continuous and reliable information on agro-meteorological and crop conditions. In lieu of direct field observations, satellite remote sensing provides a low cost alternative for monitoring large areas in near real-time. The satellite systems used are characterized by a low spatial and high temporal

resolution. The provision of satellite information to GIEWS is handled by the *ARTEMIS* system of the FAO Environment and Natural Resources Service (formerly Remote Sensing Centre).

9.2 Real-Time Environmental Monitoring Information System (*ARTEMIS*)

In the field of environmental monitoring, remote sensing imagery is managed by *ARTEMIS*. Since August 1988, *ARTEMIS* has been operationally receiving, processing, archiving and disseminating low-resolution remote sensing imagery in support of FAO's programmes on early warning for food security, migrant pest and disease control. The *ARTEMIS* system was implemented by FAO in close co-operation with NASA Goddard Space Flight Centre, USA, the National Aerospace Laboratory (NLR) of the Netherlands and the University of Reading, U.K. with funding support from the Government of the Netherlands.

ARTEMIS is now fully operational and supported by the FAO Regular Programme.

ARTEMIS supports the operational monitoring of seasonal growing conditions and vegetation development over Africa, based on hourly Meteosat and daily NOAA-AVHRR data, for use in early warning for food security and desert locust control. This includes routine distribution of *ARTEMIS* images, containing information about rainfall and vegetation activity, by electronic means to users at FAO Headquarters and at regional and national levels. FAO continues to support the establishment and/or improvement, of local reception and/or processing systems using low-resolution environmental satellites, including the development of improved interpretation techniques and user-friendly analysis software.

ARTEMIS system has a direct reception capability for digital transmissions from METEOSAT satellite. In addition, images recorded by the GOES and GMS satellites and relayed through

METEOSAT are received every three hours. The METEOSAT system is operated by EUMETSAT. GOES system is operated by the US National Oceanic and Atmospheric Administration (NOAA). GMS system is operated by the Japanese Space Agency (NASDA) and the Japan Meteorological Agency (JMA).

ARTEMIS uses Meteosat-based product, such as the Cold Cloud Duration (CCD), to estimate ground rainfall and the NOAA/AVHRR-based assessments of vegetation cover, such as the Normalized Difference Vegetation Index (NDVI), for operational monitoring of crop conditions to supply to the FAO Global Information and Early Warning System (GIEWS). Assessment of crop growing conditions and related food production outlook is based on agrometeorological observations combined with remote sensing and other relevant socio-economic information. Other uses include the FAO Emergency Centre for Locust Operations (ECLLO) to monitor potential breeding areas of Desert Locust over the Sahara desert and the FAO Agrometeorology Group.

In order to expand the capabilities of the *ARTEMIS* system in support of food security, crop forecasting, locust control, animal health, water resources management and forestry applications, FAO, in cooperation with the European Commission through its Space Applications Institute of the Joint Research Centre (JRC), and now through a project funded by EU, has implemented a routine flow of global 1 kilometre resolution VEGETATION data from the SPOT-4 satellite. FAO is presently negotiating a formal agreement with NASA for the development of the use of earth observation data from the TERRA satellites. Similar discussions are ongoing with EUMETSAT and ESA concerning the future Meteosat Second Generation (MSG) and ENVISAT satellite missions respectively.

ARTEMIS archive contains products derived from four different series of satellites by a number of processing centres and are available at daily, 10-daily, and monthly intervals. They can be seen at <http://metart.fao.org> where some agrometeorological products and tools are also available. The data sets that are available now are given in the table below:

Continent/Product:	Source:	Resolution	Coverage	Update	Start
Africa:					
• Cold Cloud Duration	FAO-ARTEMIS	7.6km	Africa	Daily	1988
• Estimated Rainfall	FAO-ARTEMIS	7.6km	W/E Africa	Dekadal	1988
• Interpolated Est. Rainfall	NOAA/FEWS	7.6km	Africa	Dekadal	1995
• NDVI - GAC	NASA-GSFC/FEWS	7.6km	Africa	Dekadal	1982
• NDVI - HRPT	Centre AGRHYMET	1km	W. Africa	Dekadal	1997
• NDVI - HRPT	DMS-Zimbabwe	2km	S. Africa	Dekadal	1997
• NDVI - VEGETATION	SPOT/JRC	1km	Africa	Dekadal	1998
Asia/Pacific:					
• Cold Cloud Duration	Univ. of Hawaii/JMA	5km	Asia/Pacific	Daily	1996
South/Central America:					
• NDVI – GAC	NASA-GSFC	8km	S/C America	Dekadal	1982
Global					
• NDVI - VEGETATION	SPOT/JRC	1km	Global	Dekadal	1998

9.3 Data Analysis Techniques

The image data described in the previous section can be used in various ways to extract information on crop growing conditions and, through that, provide an indication of expected yields and production. The imagery can be used directly for this analysis, or can be used as

input into models. However, it should be noted that within the work of the GIEWS, several information sources in addition to remote sensing are used to determine the status of food crops for a given growing season. Other sources, including ground-based reports, are used with the imagery as part of an approach known as "convergence of evidence". Some of the techniques that can be applied are now described:

- Quantitative information is derived through agro-meteorological models (Gommes, Snijders and Rijks, 1998). These models have been developed using station-based information on, among others, observed rainfall. *ARTEMIS* imagery can be used in two different ways here:
 - directly, as input to the model, when there are gaps in the ground-based set of data. Estimated rainfall imagery can be used, for instance, as a surrogate for observed rainfall.
 - indirectly, as an aide to the spatial interpolation of results derived from modeling of point-based observations, by taking into account the spatial information provided by, for instance, CCD or NDVI imagery.
- Visual analysis of image series. A sequence of images covering an area can provide important information on the performance of the growing season. CCD imagery will show clearly the arrival and retreat of the inter-tropical cloud belt. Much of this kind of analysis is done throughout the growing season and can be complemented by the creation of difference images, whereby the current, real-time image is compared to, for instance, the same period of a drought year, or the average. However, while this approach gives all the spatial details, it is difficult to identify the temporal behavior.
- Time series analysis. A very illustrating technique is to extract NDVI or CCD values for certain zones (for instance provinces) and to plot the current season and the average or a previous year as time series. Both normal and cumulative curves are used. This

technique allows an easy identification of zones that have below-normal vegetation development or rainfall. Although this visualizes very well the time component of the imagery, the spatial component has been reduced to only one zone.

- Clustering of image series. An approach to integrate both the time and space components of an image series is through a multi-temporal classification. The clustering of the temporal profiles of all image pixels can be done using directly the image values, a "zoning" approach, or by using the difference with a reference data set, a "monitoring approach." The result of such analysis is an image indicating the areas with similar temporal behavior. Contrary to the two previous techniques, this approach is only applicable towards the end of the growing season.
- Statistical methods using NDVI imagery. Researchers have investigated the relation between NDVI behavior and biomass productivity, in particular for grasslands. Within FAO this is currently not used, also because the relation with, for instance, crop yield is difficult to establish and often accompanied by a variation that can be higher than the normal year to year variation of average yield over a country or province.

9.4 Software Tools

Commercially available software packages for the display and analysis of satellite derived images have been found difficult to use with the images available through *ARTEMIS*. 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. This situation led to the development of custom-made software. The most successful was *IDA (Image Display and Analysis)*, that was initiated by the USAID-FEWS

project. *IDA* was designed for early warning and developed to run on almost *any DOS-based PC* and made widely available in the public domain. The fact that no investment in special hardware was required made *IDA* very popular, in particular in developing countries, and the proliferation of *IDA* has been such that its file format (an 8-bit line/pixel image with a 512 byte header) is now used as a de-facto standard.

Several tools have been developed by, or with involvement of FAO, for processing of satellite derived images. Many of the tools are available free at the FAO FTP site: FTP.FAO.ORG, *Subdirectory SDRN*. Among all, this paper will present:

- **WinDisp**: a *Windows/NT* evolution of the *IDA* program. Builds upon the same functionality as *IDA*, but extended among others with many graphical and vector functions.
- **SEDI**: the "*Satellite Enhanced Data Interpolation*" module of *WINDISP*. A program that allows interpolation of point data (e.g. data from rainfall gauging stations) with satellite images (e.g. CCD) as background reference. The interpolation is based on the assumption that a positive relationship exists between the point data and the satellite data (Hoefsloot, 1995).
- **ADDAPIX**: a PC based program for multi-temporal classification of image series on a pixel-by-pixel basis (Griguolo, 1996).

9.5 WinDisp

WinDisp is a public domain, easy to use software package for the display and analysis of satellite images, maps and associated databases, with an emphasis on early warning for food security. *WinDisp* was originally developed for GIEWS. It allows:

- Display and analysis of satellite images
- Compare two images and analyze 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 specialized legends
- Write and execute batch files to an automate routine
- Build a customized project interface for providing users with detailed menus of available data for a country or a specific area.

WinDisp was developed as the map and image display module of the GIEWS Workstation, permitting GIEWS economists to analyze, integrate, and overlay digital map and satellite data in common windows on their desktop PCs. It was designed to make the display and analysis of satellite images, maps and associated databases as simple as possible. *WinDisp* is an essential component of the **GeoWeb System** (<http://geoweb.fao.org/>) which is a Web based application that allows custom access to various information used by FAO's Global Information and Early Warning System analysts to assess the crop and food supply situation for all countries in the World.

The database of the *GeoWeb System* includes: maps (administrative boundaries, rivers, roads, cities); crop maps (main and all growing areas for the main crops of some countries, planting and harvesting calendars); thematic maps allowing to map statistical data (population and crop production) by administrative region; satellite images, including Cold Cloud Duration (CCD) for Africa and Asia, Normalized Difference Vegetation Index (NDVI) for Africa and SPOT-

vegetation images for the whole world; satellite images statistics (only for some african countries, allowing to see a time series of the average values of CCD or NDVI images over defined zones of the country; crop calendars.

WinDisp is often termed the successor to the *Image Display and Analysis (IDA)* software. *IDA* was developed in the mid-1980s by the USAID Famine Early Warning System (FEWS) Project. *IDA* has been used extensively within the early warning community for the analysis of low resolution, high frequency satellite imagery in near real-time. *WinDisp* has evolved from an *MS-Windows* based image display tool for viewing *IDA* images in Versions 1.0 and 2.0, to a fully functional, multilingual, image analysis and map display software tool for early warning in its current version.

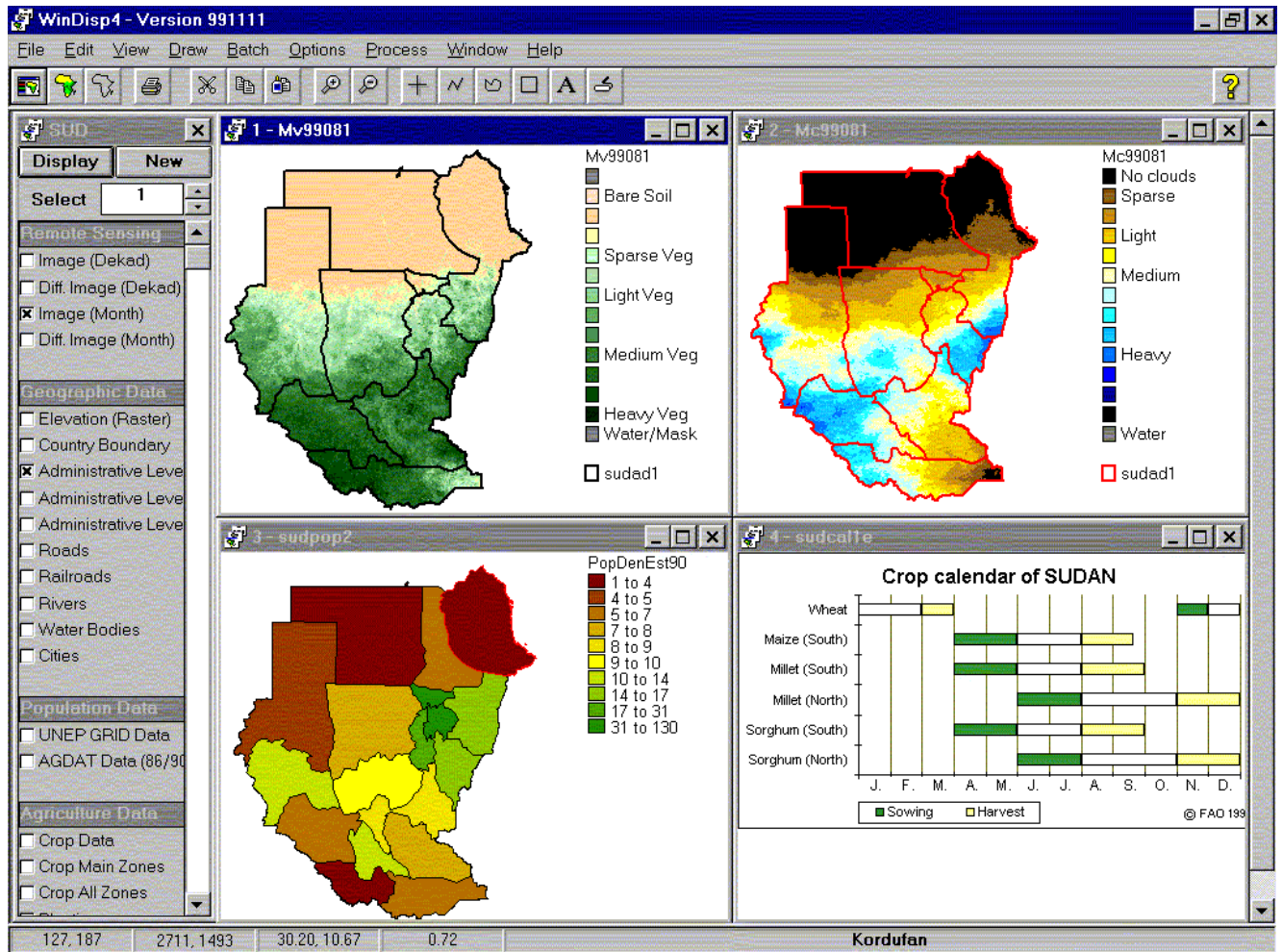


Fig. 1. WinDisp 4.0 screenshot

FAO enhanced the capabilities of *WinDisp* which resulted in the current Version 3.5 to support multilingual versions of the menus and on-line help files as part of the effort to distribute the Workstation to other early warning units in non-English speaking countries. A multi-lingual dictionary currently allows the user to choose between English and French versions of the software. The dictionary can also be adapted for other languages. Currently all *WinDisp* menus, the on-line help, and reference documents are now available in English, French and Spanish. The multi-lingual dictionary can be modified to support other languages. *WinDisp* 4.0 offers new functions with respect to Version 3.5 including on-screen digitizing, the use of ESRI Shape

files as a vector file format, and far greater options for developing, automating and customizing map and image legends. Software, manual and data can be downloaded free from:

<http://www.fao.org/WAICENT/faoinfo/economic/giews/english/windisp/windisp.htm>



Fig. 2. FAO GIEWS GeoWeb System

9.6 Satellite Enhanced Data Interpolation

The *Satellite Enhanced Data Interpolation (SEDI)* method originates from the FAO Harare based Regional Remote Sensing Project. It sought to assist the interpolation of rainfall data gathered at station level with the Meteosat cold cloud duration images received from the FAO *ARTEMIS* Project. At a later stage the method was applied to other parameters as well (e.g. potential evapotranspiration and altitude, crop yields and NDVI).

The concepts of this interpolation method have already been described, although deviations exist from the basic idea. A comparable method called co-kriging is applied mainly to geology and ground water studies. *SEDI* is a simple and straight forward method for “assisted” interpolation. 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. Three requirements are a prerequisite for the successful application of the *SEDI* method:

1. The availability of the parameter to interpolate as *point data* at different geographical locations (e.g. rainfall, potential evapotranspiration, crop yields)
2. 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).
3. A relation between the two parameters (*negative of positive*; rainfall/CCD is positive, PET/altitude is 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 the first point as a field. The calculation can be influenced by setting a number of input parameters. Rainfall data are gathered on a dekadal basis. Plotted on a map this could give the following picture:

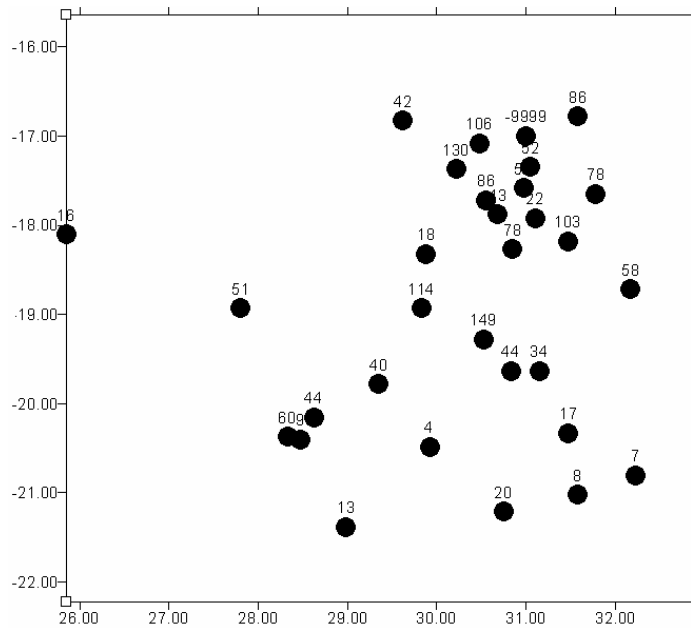


Figure 3. Rainfall (mm) for Zimbabwe second dekad of January 1991

The geostationary METEOSAT satellite makes infrared temperature pictures of the earth every half 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” (CCD). 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. Below is an example, represented by gray shading in the black and white version.

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:

1. Extracting values from the image and calculating the ratio of point and image values
2. Gridding the ratios to form a regularly spaced grid.
3. Multiplying grid with image to obtain estimated image.

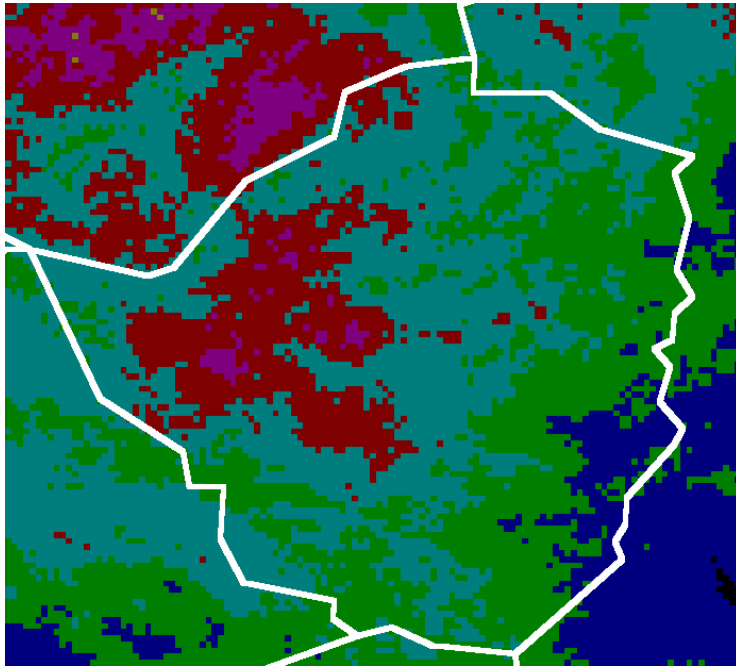


Figure 4. Cold Cloud Duration image for Zimbabwe, second dekad of January 1991

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 (Figure 5).

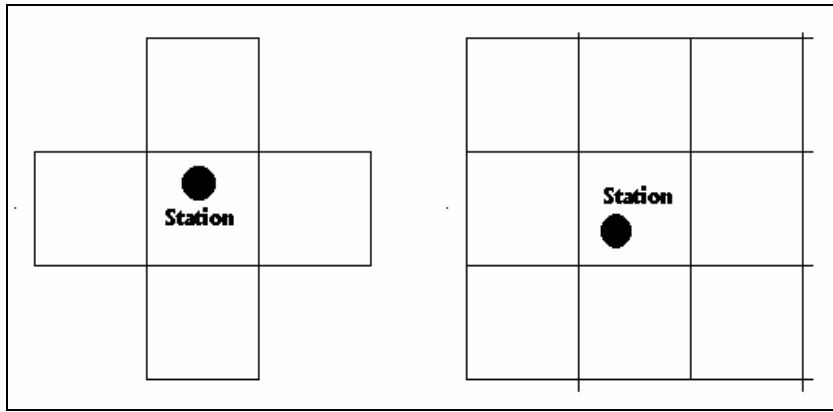


Figure 5. Extracting 5 or 9 pixels per point value

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 the following table:

Tabel 1. Calculating the ratios

Station	Rainfall	CCD value	Ratio
Name	(mm)	(hours)	
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

Should the relation have been negative, the ratio is calculated as follows:

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

Step 2: Creating a regularly spaced grid from the ratios. The second step constitutes of the creation of a grid from the irregularly spaced ratios:

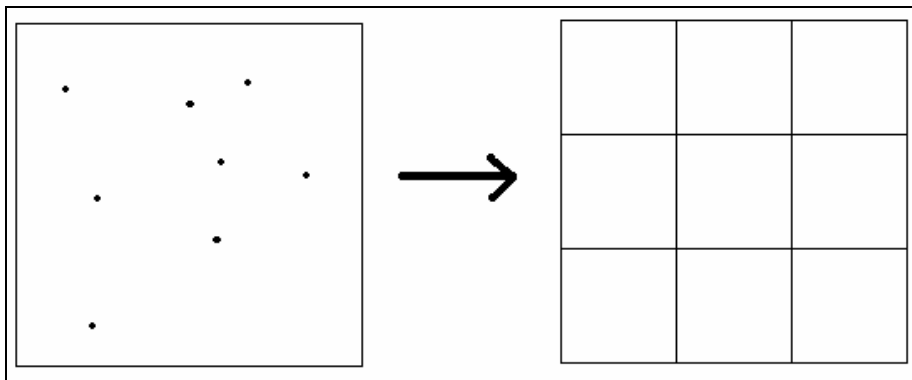


Figure 6. Creating the ratio grid

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 an accurate, dense grid, while a high value creates a coarse, less accurate and more general grid. (ii) **the number of stations per gridpoint** 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 gridpoint within this radius is higher than the specified number of stations, a value is calculated. Otherwise the gridpoint 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 is simple. By multiplying the grid (step 2) with the background image, 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.

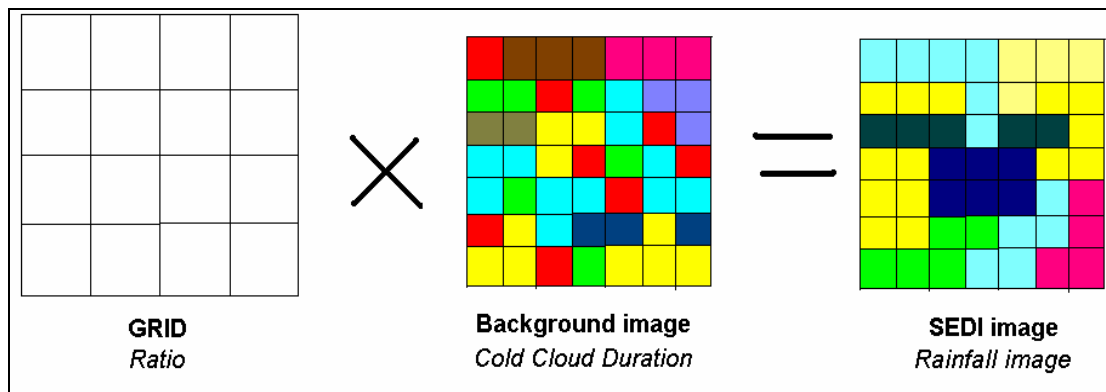


Figure 7. Creating the SEDI image form ratio grid and background image

9.7 ADDAPIX

ADDAPIX is a menu-driven collection of programs that carries out the various steps of an analysis aiming at clustering **pixel-by-pixel** a time series of regularly collected images. Each pixel is represented by the series of its values: pixels with globally similar cycles are assigned to the same class. The output is an *IDA* or *WinDisp* compatible classified image, where all pixels belonging to a class are assigned the same value (colour).

Pixel-by-pixel clustering a set of images (or two related sets, as is the case with monitoring) is a way to extract the essential information from an extremely large amount of data, being able to transmit it in a synthetic and easy-to-understand way. The difference between a *pattern recognition* and a *constructive classification* should be clearly understood: in both cases the

objective is to reduce the overwhelming number of patterns (profiles, behaviours...) characterizing the focused statistical units (pixels) to a limited number of types (classes, groups, clusters...). In pattern recognition, these target types objectively exist, or have been defined *prior to the classification*, and the technique is aimed at deciding to which ideal type a given unit is more similar (*recognition*). In the case of a *constructive classification* the types, representatives of the average features of the classes issued by the procedure, are a result of the computation, a construction of the method itself (hence the term *constructive*).

The input images are suitably merged and the merged database file is submitted to a Principal Components Analysis: the PCs are saved both numerically and - on user's request - as images in IDA format for displaying. A file containing a user-chosen number of highly explanatory PCs, selected by the user, is passed on to a non-hierarchical Clustering Analysis. Then the *classified* image is shown on the screen and the mouse is used to display graphically the profile of any pixel at will, together with the profile of its class for comparison. *This is indeed a fast and impressive way to browse through a very large merged database* by means of an synthetic image. This can also be done without going through the clustering phase, provided the image files have been previously merged within the package.

In *ADDAPIX*, an *unsupervised exploratory approach* has been assumed. In the resulting partition the most frequent groups of similar patterns are singled out as classes, while rare patterns are assigned to the most alike class where they can sometimes appear as *outliers*, behaving quite differently with respect to the class' average profile. Depending on the nature of the input images and on how they are pre-processed, *ADDAPIX* can operate pixel-by-pixel for both *zoning* or *monitoring*.

When interpreting the results of an NDVI-based **zoning analysis**, the user should keep in mind that the value taken by the NDVI in a pixel is an indicator of the local vegetation activity, *weighed with the rate of vegetation-covered soil*. This means that a low cycle could derive from the presence of suffering vegetation, but also from very healthy vegetation covering for any reason only part of the pixel. Land use/cover information should be considered for an accurate interpretation.

In a **monitoring analysis** the clustering is based on a high number of pixel-by-pixel comparisons between *current* (i.e., concerning the season to be monitored) and *reference* NDVI values. In line of principle, each pixel's vegetation cover rate can be the same in the two series, and the uncertainty mentioned above should not influence the outcome. Yet, reference values actually represent the situation at a past time (or its average over a past time interval), and some changes in land use/cover (desertification, erosion, irrigation, urbanisation...) might have occurred in the meanwhile, influencing the calculations and somehow affecting interpretation. This does not appear a severe problem, especially if the reference series is updated every year, skipping less recent years when the series is sufficiently long.

Figure 8 shows the procedures available in the **ADDAPIX zoning** menu: they are usually run sequentially. The core consists of a Principal Components Analysis (ACOMPIX) followed by a non-hierarchical Clustering (NGPIX). Some other procedures allow to merge the input images (PREPDATA); to BOUND or SELECT the pixels to be clustered according to various options; to examine graphically the detailed behaviour of each pixel (DISPLAY).

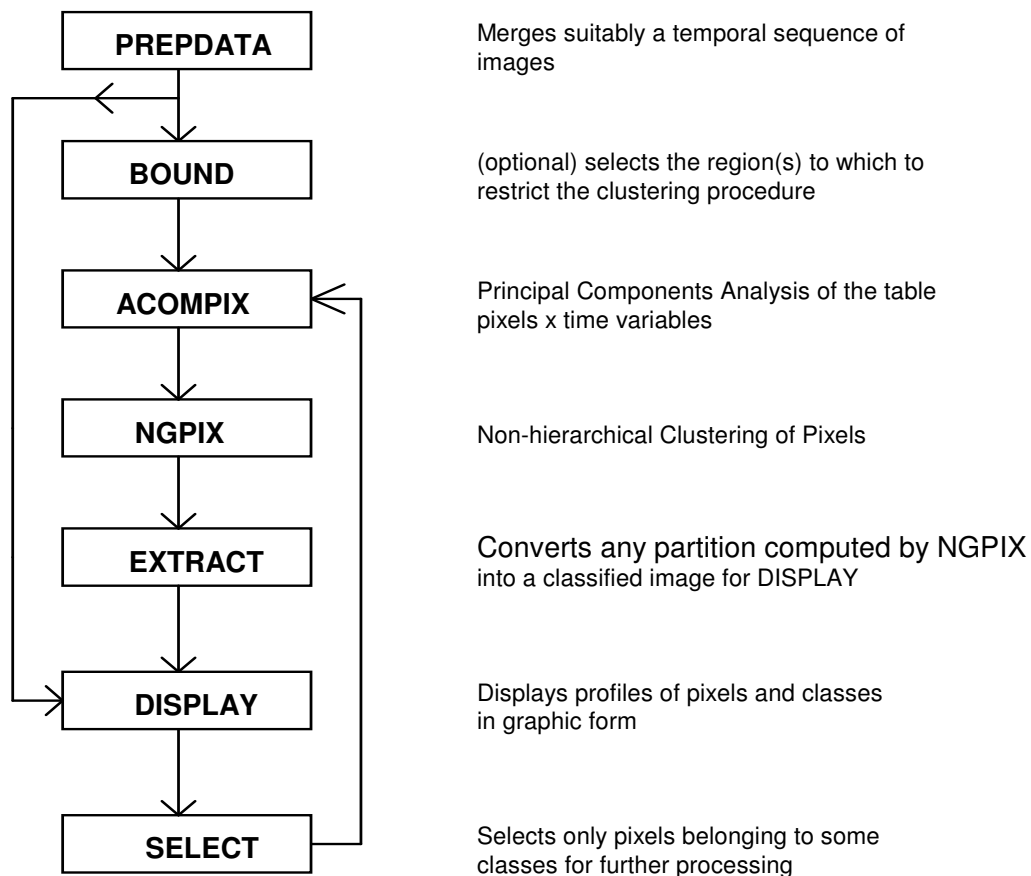


Figure 8. The program chaining for zoning mode in ADDAPIX

In **monitoring** mode, the series of images relative to the season to be monitored or assessed (in short, "the current season") and the corresponding "reference" images -relative to the same area and the same time units and representing the situation assumed as "normal"- are separately merged, reconstructed, and smoothed when appropriate. The **DIFFER** utility is then run to compare, pixel by pixel, the current and the reference series: according to the user's choice, for each pixel and each time unit the absolute or the percentage differences are saved and submitted to the clustering chain. Pixels with similar performance over time should be assigned to the same class. The output partition can be examined with the **DISPLAY** utility: for each pixel, the current and the reference profile, the difference profile and the average profile of the class to which it belongs can be simultaneously displayed.

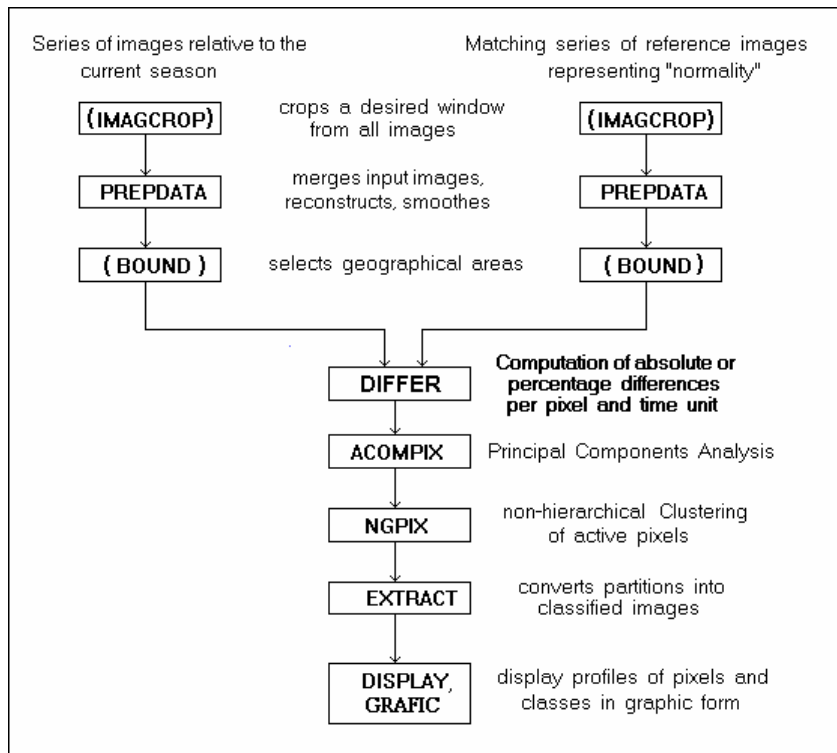


Figure 9. The program chaining to perform a monitoring or an assessment analysis

A new *MS-Windows* version of *ADDAPIX* is under development. The current *MS-DOS* version has been used, among others, for some zoning analyses such as the preparation of the IGADD CPSZ Electronic Atlas (FAO, 1995). An example of the monitoring mode of *ADDAPIX* is given below.

Every year, the FAO-GIEWS prepares a preliminary assessment of the cereal production in Western Africa. It is based on a wide range of sources, including a joint GIEWS and CILSS crop assessment mission. The SDRN *ARTEMIS* and AGROMET groups prepare for the assessment an analysis of satellite and station derived data. The current examples illustrates the use of the satellite derived data. For the 1999 analysis the monthly NDVI images were compared with the 1982-97 average images. Basically it consists of a clustering of time profiles of NDVI differences into 4 classes. The resulting classified image was then imported

into *WinDisp*, to add a legend and annotation, and to prepare a printable image. The resulting image is shown below.

The analysis clearly shows that the 1999 season performed rather well. Class 2 indicates area's where the NDVI values were slightly above normal throughout the season, indicating an early start and a late ending of the season. Classes 3 and 4 indicate area's where the season started as normal, but that experienced a prolonged rainy season towards the end. In grey, class 1, those area's are indicated where the season behaved as normal. These include not only the Sahara, but also considerable area's in the south.

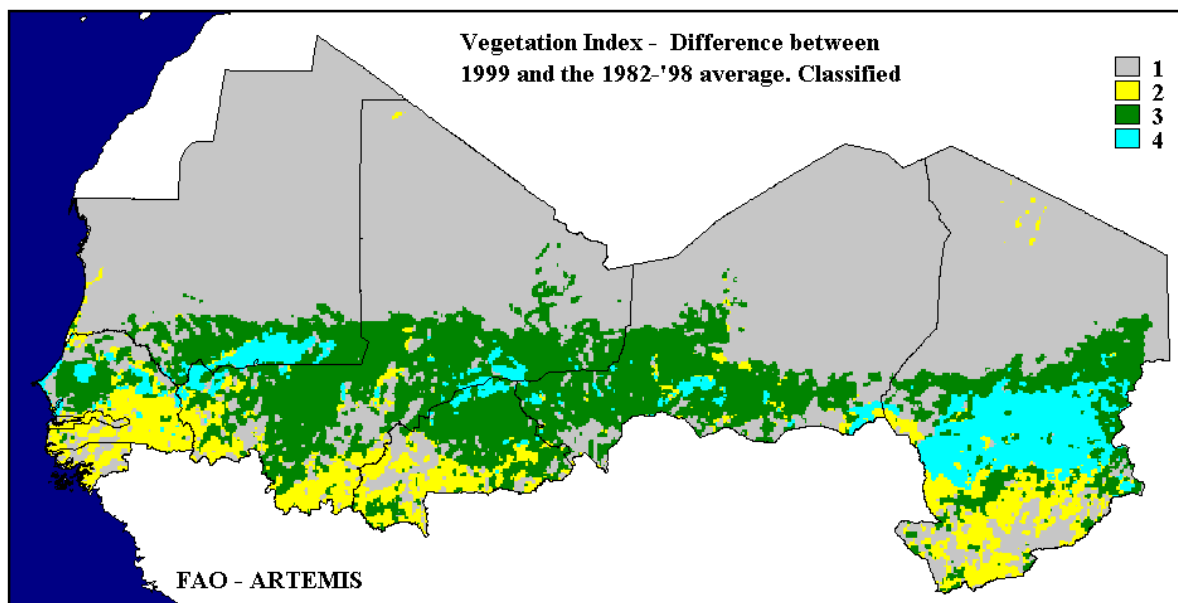


Figure 10. Classified image using NOAA-GAC NDVI data

9.8 Conclusions

A general overview of technical capabilities of ARTEMIS group has been provided with a particular reference to its archive of remotely sensed environmental satellite images and main software applications developed for image display and analysis. Three software applications have been presented: *WinDisp*, *SEDI* and *ADDAPIX*. It is important to stress the effort made to standardize the data format to be compatible with other kind of GIS or mapping applications distributed commercially. This effort continues in parallel for regularly updating of *ARTEMIS* datasets archive and for developing of software applications.

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