# The african side of the Mediterranean basin : a pixel-by-pixel ecoclimatic classification

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# THE AFRICAN SIDE OF THE MEDITERRANEAN BASIN: A PIXEL-BY-PIXEL ECO-CLIMATIC CLASSIFICATION[1]

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## ABSTRACT

Satellites for the Observation of the Earth's Resources collect regular and frequent information on the planet surface, and on the changes caused by natural phenomena or human activity. This information, distributed in geo-referenced form, can be easily and usefully merged with other derived from different sources, like raster or vectorial layers, socio-economic or agronomic databases, etc.

Since 1998, the new SPOT4 platform has had a sensor, called VEGETATION, that issues 1km images covering the whole planet, with the exception of the polar areas. The bands of the electromagnetic spectrum captured by the sensor have been specifically chosen so as to monitor the condition of the vegetal biomass. Therefore, these images are specially suitable:

to zone vast regions according to the length, intensity and shape of their vegetation cycles;

to monitor the cropping season, comparing the current vegetation dynamics with the expected one, that can be derived from images collected during previous years.

Very recently images of 1km of VEGETATION for all continents have been made available on the Internet free. At present, 10-day composites can be downloaded for the sensor's four radiometric bands and the NDVI, defined further on.

This paper presents an example based on a time series of NDVI VEGETATION images. The objective is to construct an eco-climatic classification of the vegetation cycles of the southern (African) coast of the Mediterranean sea. The input images are 10-day (*dekadal*) composites relative to year 2000. The final product, a raster classified map of the region of interest, is briefly commented.

## 1. INTRODUCTION

A great deal of information is necessary for appropriate policy-making and territorial management, whatever the scale level. Details on many different aspects, derived from various sources, are usually put together by a suitable tool like a GIS.

Any case study built upon concepts like *sustainable development*, *rural development* or *production*, *crop monitoring*, *natural resources* cannot ignore the great variety that a vast region like the Mediterranean Basin presents over space. Even spatially contiguous areas can exhibit, for a lot of reasons related to local micro-climates, type of soil, hydrography etc., a greatly diverse ability to sustain an adequate crop production.

Detailed identification of the various types of vegetation cycles existing in a region, and their description in terms of intensity and stability over time can be an important basis for the analysis of several phenomena, not only from a strictly rural or economic point of view, but also at the socio-demographic level. Migrations are often triggered by repeated crop failure, or by a prolonged production level below what can be historically considered as *normal* for the region concerned.

Remotely-sensed imagery can be used for different purposes.

To construct land cover maps. Such maps are available, issued by various Projects, for both the European Continent and the whole planet.

CORINE (CEC, 1993), funded by the European Commission and derived from high resolution imagery

[1] A twin version of this paper, describeing a classification carried out on the north-eastern coast of the Mediterranean, has been presented at the International Conference on “Environmental Problems of the Mediterranean Region” (EPMR 2002), Nicosia, April 2002.

(LANDSAT and SPOT) by visual interpretation, offers a classification of land covers for Europe and some North-African countries.

PELCOM (Pan-Europe Land COver Monitoring, Mucher et al., 1999) is a project, also funded by the EC, that has produced a 1.1 Km. land cover raster map of Europe, based on NOAA-AVHRR images, meant as an input for dynamic environmental models on a continental scale.

The IGBP Project (see Townshend, 1994; Townshend et al., 1994; Belward, 1997) has produced a 1.1 km land cover classification of the whole Earth, based on NOAA-AVHRR images. A new Project, co-ordinated by the EC Joint Research Centre located in Ispra (Italy), named GLC2000 (Global Land Cover) is now being carried out on a voluntary basis by several Agencies and Research Organisations all over the world. The purpose is the construction of a global Land Cover Map from the SPOT4-VEGETATION images for year 2000.

For eco-climatic zoning, based on the cycle of some Vegetation Index. These studies are relevant from the agronomic point of view, and very useful to estimate the agricultural production capabilities in scarcely accessible areas, under *normal* seasonal conditions. This appears to be particularly useful for Early Warning international Agencies: beside those offered by the specialised scientific literature, references focused on these kinds of applications can be found in publications of international organisations like FAO or the USAID.

For crop production monitoring studies, in which the *current* vegetation development is compared with the level *expected* under normal conditions, usually determined from the available information relative to the preceding years (Griguolo, 1994).

To detect land cover changes (Gomerasca, 2000; Lunetta and Elvidge, 1999). Just to mention an example, an Atlas of the coastal changes which have occurred in Europe over twenty years (from the seventies to the nineties) based on high resolution imagery and CORINE, has just been published by the EC (Perdigao and Christensen, 2000).

This paper will briefly describe the general characteristics of VEGETATION images, and will outline the multivariate statistical methodology that can be used for multi-temporal processing. The literature already offers several examples of analyses that use VEGETATION images to study the Mediterranean region or similar environments (Lobo et al., 2000; Lobo and Pineda, 2000; Gond et al., 2000). Here an exercise is presented in which a time series of 10-day (*dekadal*) NDVI SPOT4-VEGETATION images[2,] spanning the whole year 2000, is used to construct a pixel-by-pixel raster classification of the vegetation cycles in the countries lying along the African coast of the Mediterranean. The output map, that can be used as input for various environmental or meteorological models, is briefly commented.

## 2. SPOT4-VEGETATION IMAGES: AN OVERVIEW

In order to obtain a synthetic view of the globe from a set of often cloudy or defective daily images, the Maximum Value Composite (MVC) algorithm is applied. A pixel-by-pixel mosaicking process is performed, choosing the *best* view for each pixel from the set of daily available views. For all four bands (B0 = blue, B2 = red, B3 = near infrared and MIR = medium infrared), the selected reflectance corresponds to the viewing with the *best ground NDVI*. Cloudy or bad quality views are excluded, if possible.

Pixels on sea or great lakes are set to zero; the sensor is not programmed above the oceans. Unfortunately, above water the MVC algorithm gives bad results when clouds are present, as it chooses clouds that have a higher NDVI value, instead of water. For this reason, the presence of water is determined from a sea/land static indicator, derived from the *Digital Chart of the World*. In order to cope with the inaccuracy of the Chart, and with the cases of tides or growing river deltas, all lands have been expanded by 5 km: this causes all coast lines to be surrounded by a halo of pixels that are often heterogeneous, as they are mostly water, but sometimes clouds.

[2] Images recording the reflectance on the sensor's four radiometric channels are coded 16-bit per pixel. For each pixel, the 8-bit value of the NDVI (Normalised Difference Vegetation Index) is computed from the directly measured radiometric reflectance according to the following definition:

$$NDVI \quad \frac{NIR \quad R}{NIR \quad R}$$

where *NIR* and *R* represent the reflectance on the near-InfraRed and Red channels (respectively known as the B3 and B2 channels in the case of the VEGETATION sensor).

The NDVI is a good indicator of the amount of healthy vegetal biomass on the ground. Its value ranges from 1 to +1. Positive values of the index are associated with the presence of vegetation: the higher the value, the more dense and vital the vegetation. Bare soils are characterised by values close to zero, water by negative values.

Figure 1 visualises this effect. It shows Cyprus and the sea around it, drawn from one of the dekadal images: the pale grey halo of “pseudo-land” is well visible. When a multi-temporal series of images is processed this creates some inconvenience, as the halo values may in some cases represent clouds, and this causes a salt-and-pepper effect in the classified image. It is therefore necessary to find a way to mask the haloes, excluding them from the clustering process. This can be done applying a reliable water mask, if available, or via a preliminary classification, excluding thereafter some classes identified as internal or coastal waters.

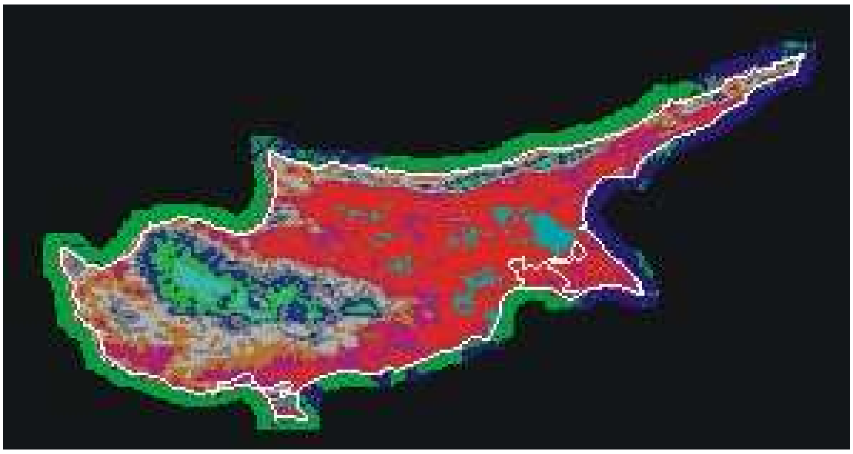


Fig. 1. Example of the 5-pixel wide halo along coastlines.

The VEGETATION products are always delivered in the Hierarchical Data Format (HDF), a platform-independent format developed by the National Centre for Supercomputing Applications (NCSA) to assist users in the transfer and manipulation of scientific data across diverse operating systems and machines. HDF files can be read using the HDF software library (freeware from the NCSA), or HDF-compatible image reading tools (some of which are mentioned at the end of this paper). The images contained in HDF files can be loaded as raw bitmaps, skipping the header.

Multitemporal applications of the VEGETATION data put severe requirements for what concerns the geometrical registration consistence of images. To improve the quality of the products, ground control points are systematically used. The current data base is composed of about 3500 ground control points, regularly distributed over the globe. Their location accuracy is about 100m.

As the main use of *VEGETATION* data is the monitoring of vegetation evolution for agriculture (crop monitoring), forestry and the environment, a set of images covering a large period of time is usually required: e.g., a complete growing season for agriculture. The data quality has increased since the satellite was launched, owing to a more accurate treatment and a richer set of GCP: currently, the multitemporal registration is better than 500 m for 95% of the points.

The classification exercise described in this paper is based on the series of the 10-day (*dekadal*) NDVI images drawn from the database obtained from the EC Joint Research Centre in Ispra (Italy) for some methodological experiments aimed at land cover recognition in the frame of the GLC2000 Project mentioned before. Unfortunately, as the zoning is limited to capture the seasonality during year 2000, the issued classified map can hardly be attributed a general validity. At the moment, the series of the available VEGETATION images, started in 1998, is still too short to enable reliable zoning studies or monitoring analyses, that request a comparison of the current season's dynamics with soundly determined historical behaviour.

In order to cope with clouds or mists, the 36 NDVI images we used had been produced as dekadal *maximum value composites* (a VEGETATION product known as S10). This means that values of contiguous pixels can have been observed on dates up to nine days distant in time. It means also that two consecutive values for a pixel could actually differ in time from 1 to 19 days.

Cloudy, foggy or misty pixels were not previously detected and marked with a specific code, in order to ease the reconstruction by interpolation of values missing in each pixel's series. Clouds can be recognised from some particular combinations of values that characterise them in some of the radiometric channels (Gobron et al., 2000; Kempeneers et al., 2000), but cannot be detected with certainty on a NDVI image.

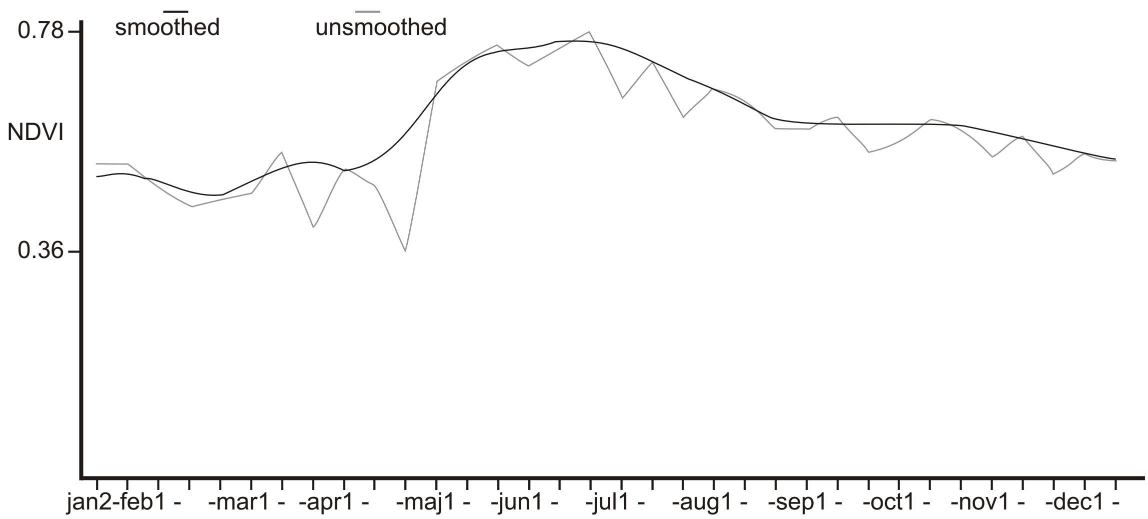



Fig. 2. The irregular curve in red represents the unsmoothed observed NDVI series for a generic pixel; the more regular curve in blue shows the same series after filling the negative peaks caused by partial cloudiness or mist, and smoothing with a weighed 3-order moving average, using equal weights.

Yet, as the presence (albeit partial) of clouds or mist in a pixel decreases the value of the NDVI, some evident irregularities occurring on each pixel's NDVI time series can be identified as due to clouds or mist, and corrected. Figure 2 shows an example of the untreated NDVI time series for a pixel, together with the one obtained after correction: first the negative peaks (caused by total or partial cloudiness or mist) are filled, then the series is smoothed via a weighed moving average (m.a.) procedure. The m.a. order and the weights applied can be chosen by the user.

## 3. METHODOLOGY AND SOFTWARE TOOLS

The zoning was carried out using the last version of the package ADDAPIX (Griguolo, 1996), presented for the first time at the "Expert Consultation on the Co-ordination and Harmonisation of Databases and Software for Agro-climatic Applications", held in December 1993 at FAO Headquarters in Rome (Griguolo and Santacroce, 1996). Initially conceived for pixel-by-pixel zoning, it was then extended by adding the capability to monitor the current cropping season (Griguolo, 1994). After a number of DOS-based releases, a Win32 version is now being prepared.

The package is specially oriented at Early Warning applications in developing countries, where timely ground-collected data are seldom available and remotely-sensed images offer (in spite of their discussed reliability) a quick and cheap method to monitor the growing season. Partial results can be updated as soon as a new image is available, usually each ten days.

The package has proved useful for the automatic production of agro-climatic maps that can be made more detailed by simply increasing the number of the classes. Several regional applications have been carried out, among which it is worth to mention its use in the construction of a Crop Production System Zone Atlas for the IGADD countries in the Africa Horn (Santacroce, van Velthuizen and Verelst, 1995).

The clustering method used in ADDAPIX helps to make critical areas emerge, and the package includes also some tools aimed at easing the inspection of the behaviour of suspicious or dubious pixels.

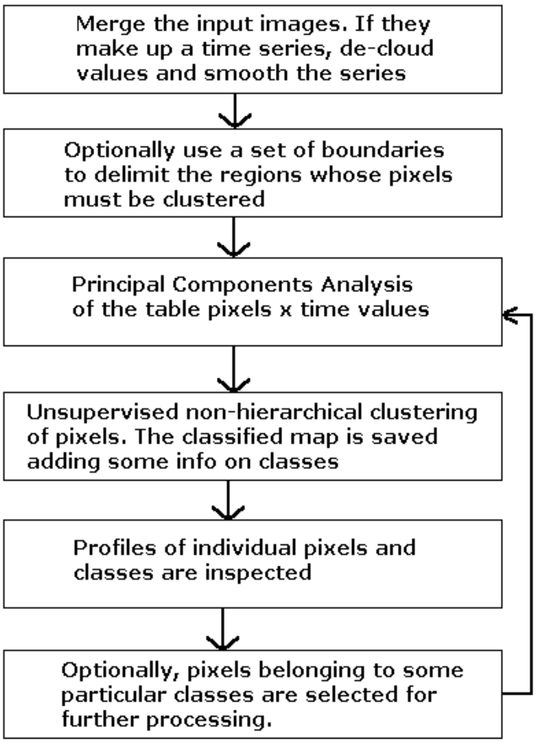
Pixels are clustered via a *menu-controlled sequence* of computing procedures: table 1 shows the sequence usually followed for zoning. For a useful review on the clustering of remotely-sensed images, refer to Bonn and Rochon, 1996; Lillesand and Kiefer, 1987; Mather and Tso, 2001.

The Principal Components Analysis is aimed at reducing the dimensionality of the description, limiting it to the most relevant factors. This has the double advantage of speeding up the subsequent clustering operation (which is computationally heavy, owing to the high number of pixels) and reducing the effect of errors, as values unexpected on the basis of the existing structure of correlations are most likely loaded onto the last and less relevant Components. The user decides *interactively* how many Components are to be passed on to the clustering routine that follows.

The first Principal Component can or cannot be used for clustering: the decision is left to the user. It is certainly very relevant and must be used in our case, as it captures the most important factor, i.e. the opposition between highly vegetated and rather arid pixels. It can be ignored when the input images are pure radiometric bands, as in that case the first Principal Component simply expresses the illumination level in each pixel.

As we shall see, when an NDVI time series is analysed few Principal Components are generally sufficient to synthesise the phenomenon of interest with little loss of information.

Table.1. The zoning sequence.




The non-hierarchical clustering routine, belonging to the family of the k-means algorithms, automatically loads the indicated Principal Components and computes a user-chosen number of partitions, each with the requested number of classes. This number can be quite high, thus enabling a detailed exploration of the various possible vegetation profiles. The average profiles of the classes are computed and saved.

When the final classified image is inspected, the user can sometimes realise that an excessive variability within the analysed area hinders the singling out of some particular feature. The analysis can then be repeated with a higher number of classes, but it is also possible (and often more convenient) to perform a further more detailed analysis considering as active only pixels belonging to some user-chosen classes, for which a deeper insight is desired.

Another reason to select (or exclude) some of the classes issued by a previous classification is to create a *thematic map,* where only pixels whose cycles have certain desired features are marked as active. This is typical when the final objective is to monitor the current cropping season: only pixels characterised by a vegetation cycle that indicates a potentiality of production during the season of interest should be selected.

## 4. EXAMPLE OF CLASSIFICATION ON VEGETATION DATA

Thirty-four dekadal NDVI images relative to year 2000 (from the second decade of January to the second of December) were used to cluster the vegetation cycles. The first image of January and the last of December, immediately preceding and respectively following the selected series, were used in the smoothing process.

The size of each image is 1450 lines by 5300 pixels. Sea water and large internal water bodies were masked by means of a preliminary classifications, two classes of which could be identified as -at least partially- composed of water. The information derived from these two classes were combined with a suitable dilatation of the existing water mask to built up the mask eventually applied. The national boundaries were then overlaid, and used to restrict the clustering to the countries lying on the northern African coast. Each pixel series was de-clouded and smoothed with a 3-order moving average.

The data table was submitted to a Principal Components Analysis. Owing to high correlations among the dates, five Principal Components, summarising 99.2% of the overall variance, were retained and submitted to the clustering procedure. The first PC, that alone summarises 92.3% of the global variance, captures the strong opposition between the very arid Sahara pixels and the vegetated pixels mostly present near the coast or in the Atlas mountains. It can therefore be assumed as an indicator of the average intensity of vegetation during the year in each pixel. All other PCs somehow interpret the form of the cycle.

Several different partitions were computed. The best ones were inspected in detail. Figure 3 maps the best partition with 14 classes, whose profiles are shown in figure 4. Due to the high number of desert pixels, ten of the classes are very arid. The difference in their profiles, shown in figure 5, is scarcely significant: all of them show almost no cycle, and the difference in their NDVI value is mostly due to the type and colour of the soil.

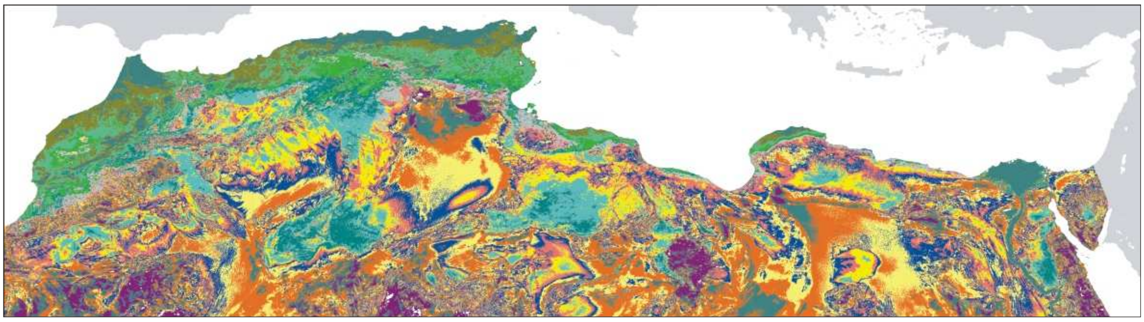


Fig. 3. The preliminary classification in 14 classes. Owing to the high number of arid pixels, the non-hierarchical procedure tends to allocate many classes for them, capturing even small differences in the NDVI value.

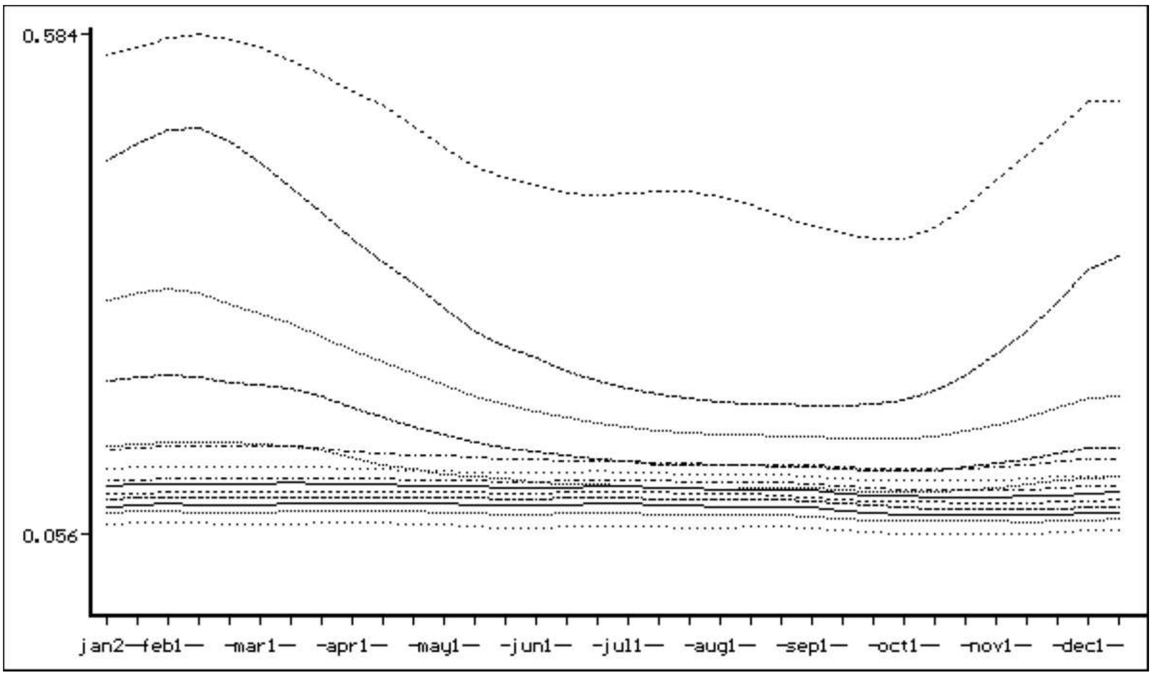



Fig. 4. The time profiles of the 14 classes in the initial partition. Only few show the existence of a cycle. The most vegetated class gathers pixels located on the Nile Delta and along the Mediterranean coast.

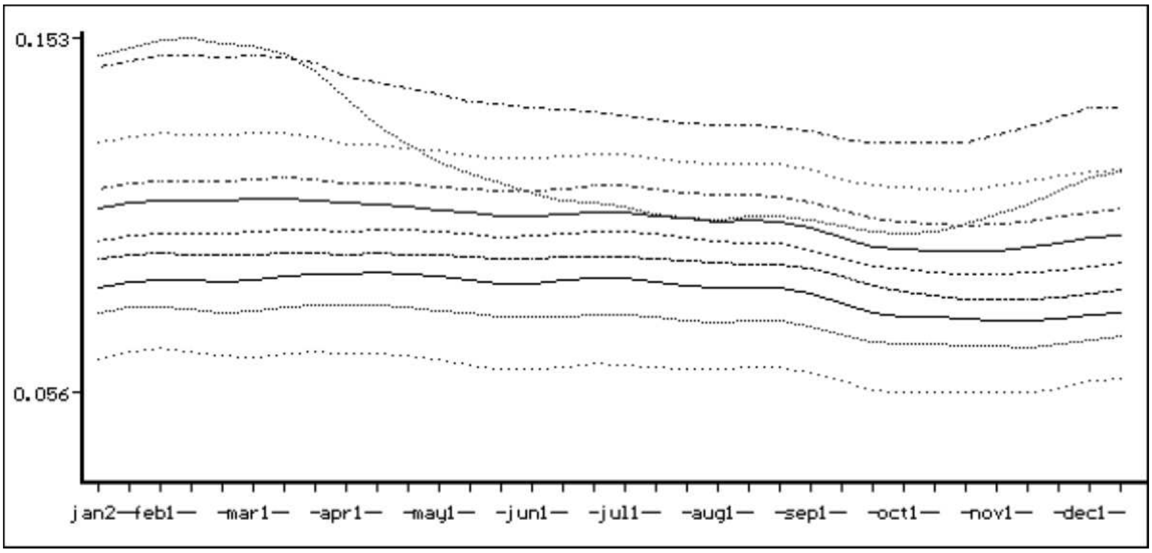



Fig. 5. Profiles of the 10 arid classes. The 8 classes with the lower NDVI values were merged into two classes only.

As the small number of vegetated classes hides differences in the behaviour of the vegetation, the 14 classes were recoded into 8, merging the 8 most arid ones into two. The result is the partition mapped in figure 6. The four arid classes were then masked, while pixels belonging to the four most vegetated clusters were re-classified in ten classes. The final classification in 14 classes, a part of which is shown in figure 7, was obtained by adding the four arid ones to the ten vegetated classes.

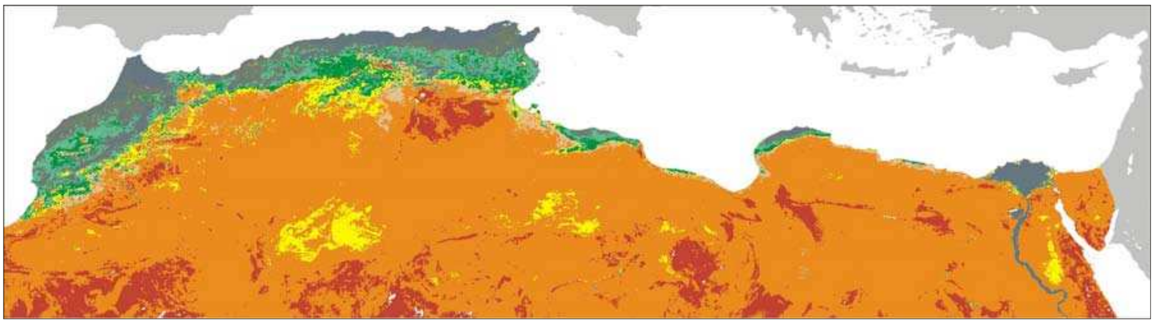


Fig. 6. Provisional classification obtained by merging the 8 most arid classes into two. The four more vegetated classes along the coast, shown here in green shades, were submitted to a further more detailed classification.

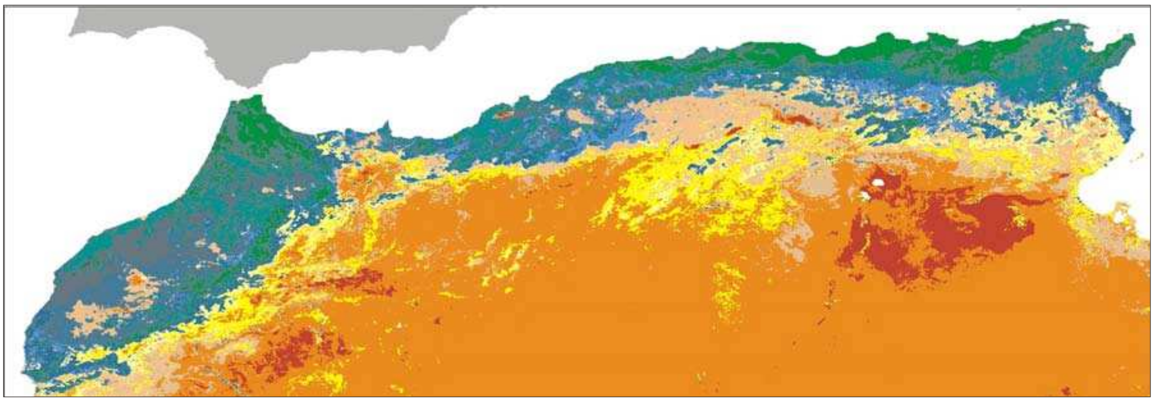


Fig. 7. The north-western region in the 14-class final partition. Permanently arid pixels are included in four classes, while the other ten classes are used to capture differences in the cycles of vegetated pixels.

Figure 8 displays two details of the final classification: pixels assigned to class 8, characterised by the double vegetation cycle shown in figure 9, are mostly located along the Nile, its delta and in El Fayoum. Yet, some pixels with similar characteristics, probably irrigated and with a double cropping season, are found also in Morocco.

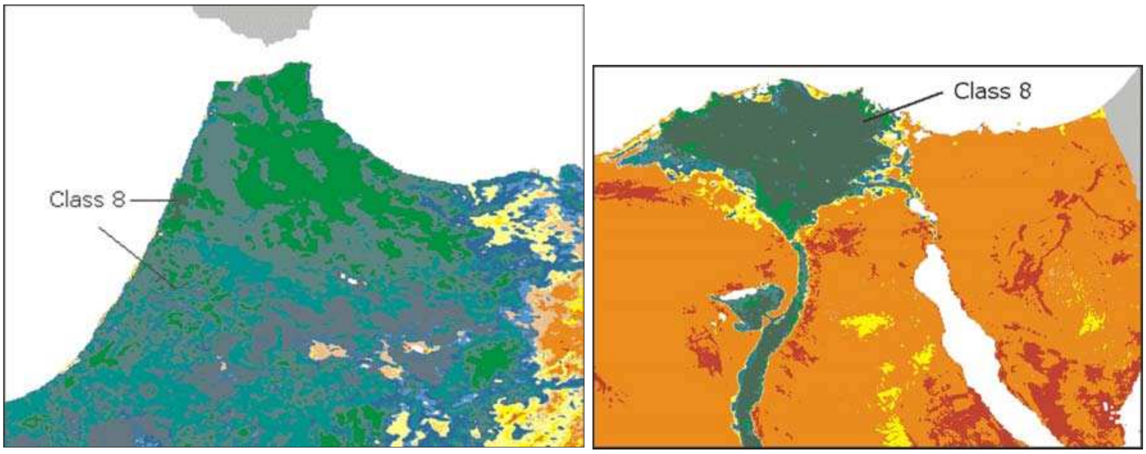



Fig. 8. Details of the final partition, showing the location of class8 characterised by a double cycle.

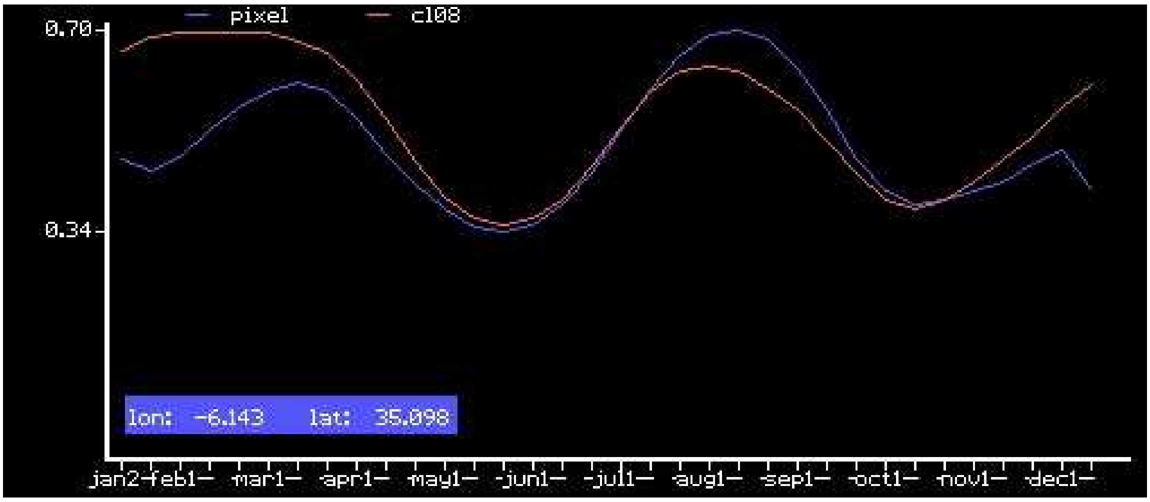



Fig. 9. In blue, the vegetation cycle of the pixel whose geographical co-ordinates are displayed, in Morocco. The pixel is assigned to class8, whose average cycle is displayed in red.

The final output is a raster classified map that embeds also the average profiles of the classes. ADDAPIX includes some graphic tools that allow the user to visualise the class profiles and to query the map, displaying the time series of each pixel by clicking the mouse on it. This way the classified map can also be used as a kind of interface that gives access to all the information included in the input images. The geographic co-ordinates of pixels are shown on the screen and updated when the mouse is moved on the image. In any case it should be stressed that the final destination of this type of product is into a GIS, in which it can be easily integrated with other geographic information.

In order to give an idea of their features, the classes have been split into four groups, according to some kind of similarity. Here I will limit myself to present, unfortunately in a very rough form, some results for the three groups relative to the vegetated classes.

Figure 10 shows the location and the profile of classes 8 and 1, the two most vegetated ones. As already said before, class 8 is characterised by a double cycle, while class 1 shows high NDVI values, quite steady, with a minimum in summer. Its pixels are mostly located on the Mediterranean coast, but there are also some in the interior of Morocco. Pixels belonging to the other vegetated classes are in grey; arid pixels are shown in shades of yellow to red.

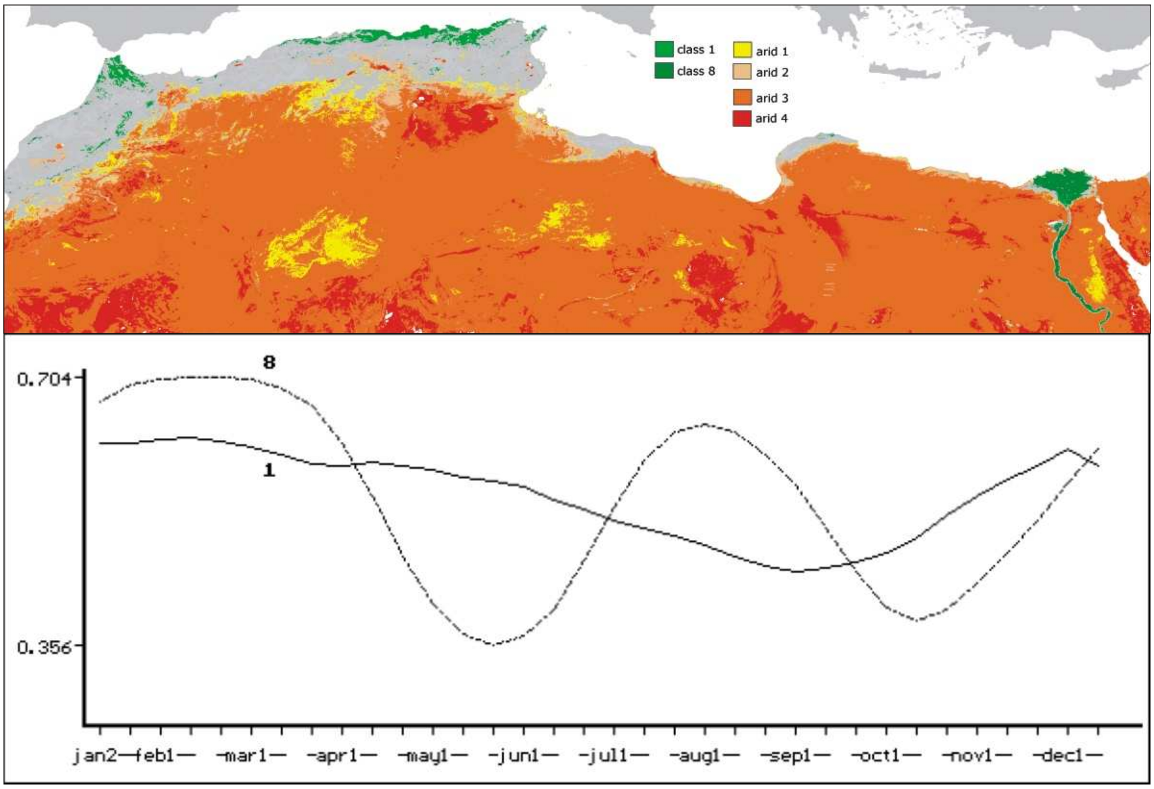



Fig. 10. Location and profiles of classes 8 and 1.

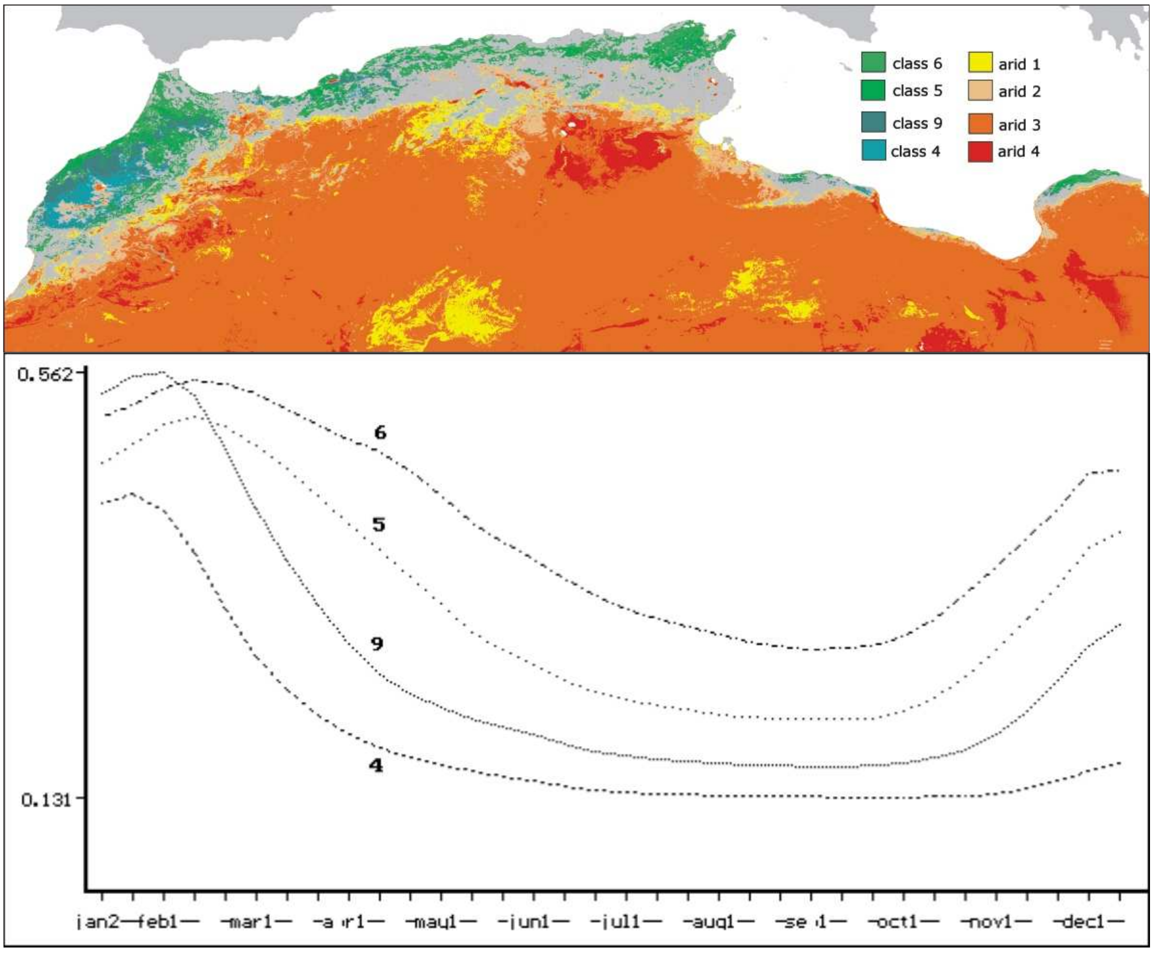



Fig. 11. Location and profiles of classes 6, 5, 9 and 4.

The cycles of the four classes shown in figure 11 have similar shape, but the intensity is quite different. In all of them vegetation starts to grow in October, reaching its maximum in February/March, then decreasing and reaching a minimum during the summer. The four classes differ above all in the minimum vegetation level. Class 4, located in the South of Morocco, has for most of the year a level similar to that of the arid classes, but differs from them for the short-length vegetation peak between December and February.

Figure 12 shows location and behaviour of the four classes for which the vegetation growth is less pronounced. They are located on the desert border, and can be considered transition classes between those closer to the coast, in which production is possible, and the very arid ones. The cycle shape is not qualitatively different from that of the classes displayed in figure 11, with a maximum in late Winter and a minimum during Summer, but the NDVI values reached during the growth stage are inferior. The vegetation peak is still significant and several months long for classes 3 and 10, while classes 2 and 7 are very arid, not very dissimilar from the desert classes.

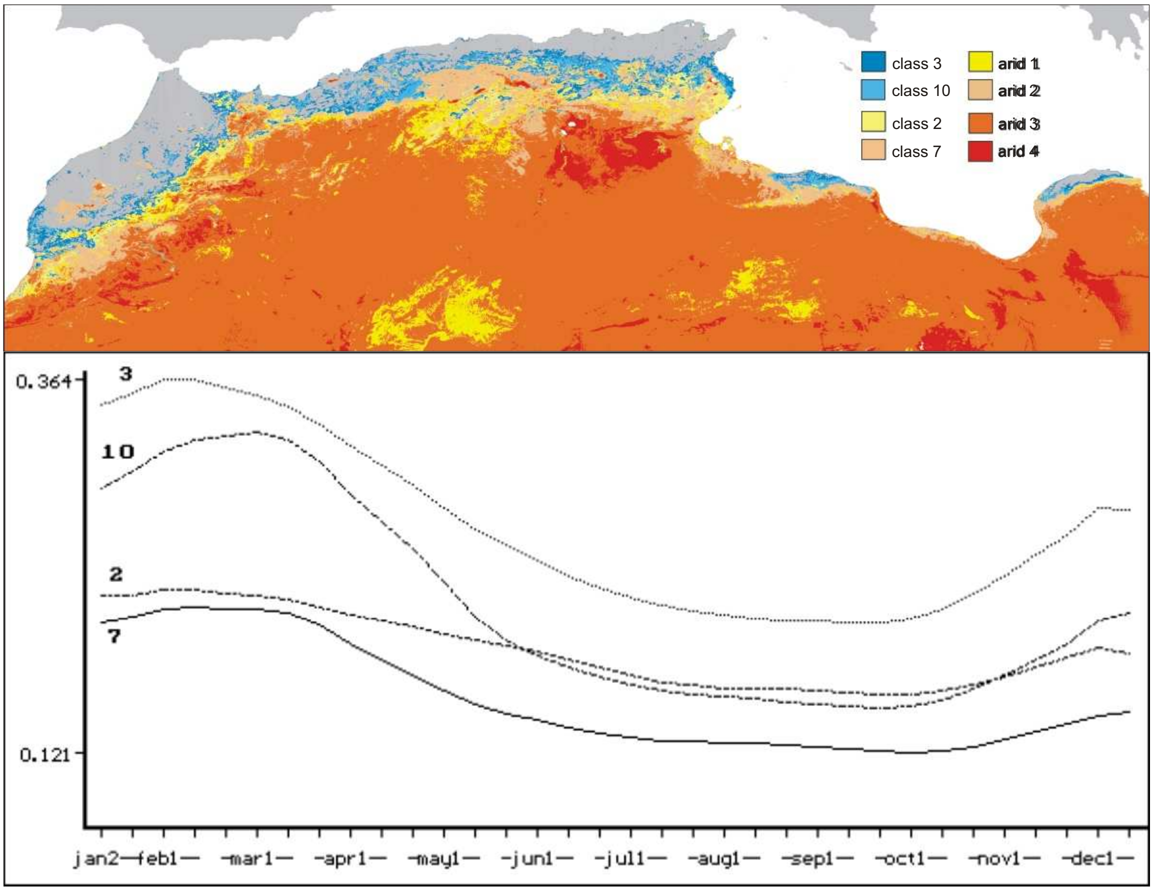



Fig. 12. Location and profiles of classes 3, 10, 2 and 7.

## 5. FINAL REMARKS

The various analyses carried out, besides the one described here, showed with evidence that an unsupervised classification method tends to capture in different classes the most frequent groups of pixels, even though they are quite similar. This is what happened with our first classification in which arid pixels, though scarcely different from one another, were allocated ten classes. The lesson to be learnt is that the region to be classified must be neither too large nor too unhomogeneous: cycle differences and emerging behaviours are better captured by dealing with quite small and homogeneous regions. Hence, it is better first to stratify the region of interest according to some reasonable criteria, then classify each stratum separately and eventually mosaic the results. This is what we tried very roughly to do here, singling out very arid pixels and masking them, to then re-classify the others. Of course, this should have been done in a more systematic and consistent way (1994), “The 1 km global resolution data set: needs of the International Geosphere Biosphere Programme”, *International Journal of Remote Sensing*, 15(17), pp. 3417-3441.

A supervised approach would not have this drawback, as pixels would be assigned to the most similar pre-defined theme irrespective of their number. However, there would have been other drawbacks.

Owing to the high geometrical accuracy of the imagery, the 1 km resolution is sufficient to allow local peculiarities, albeit spatially limited, become visible on the classified map. They can be explored by evoking the pixel profiles. Obviously, for an appropriate interpretation the expertise of an agronomist with a good knowledge of the region of interest is necessary.

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## Appendix: Some useful links to VGT images and software downloading

SPOT4-VGT images for all continents (10-day syntheses) can be downloaded free of charge, after registering, from the page http://free.vgt.vito.be

Files downloaded from the SPOT4-VGT site are zipped, and each includes, besides the four spectral bands and NDVI, several other planes, all in HDF format. They are quite large, as each concerns a whole continent (though some continents are split). The cropping of a Region of Interest (say, a Country) from a set of input files requires a slightly complex sequence of operations: first each desired plane must be unzipped, then its header must be interpreted, and eventually the RoI is extracted. Some specialised software is needed, and when several input files are processed errors are possible. After spending too much time in this kind of operations, I decided to write a Win32 programme able to perform the cropping in a fully automatic way, and to make it available to the community of VGT users. The utility, that certainly will make your life easier, should you decide to download VGT images without having at your disposal an expensive commercial product like ERDAS-IMAGINE, PCI or ENVI, can be obtained connecting to the page http://cidoc.iuav.it/~silvio/crop_vgt.html

The package ADDAPIX can be downloaded from the author's page:
http://cidoc.iuav.it/~silvio/addapix.html or from the FAO site http://metart.fao.org

The AICON (the ARTEMIS Image CONverter) programme, that can be used to extract RAW (or BIL) images from files in HDF format (for those downloaded from VITO the CROP_VGT utility is more handy), and to re-project them if necessary to a different geographical projection, can be downloaded from http://cidoc.iuav.it/~silvio/aicon.html or from the FAO address given above, where also the small utility VEGINF32 is available, used to list the contents of an HDF file.

For information on the GLC2000 Project (workshop materials, documents, PowerPoint presentations, methodological contributions, software and useful links) the page of the Global Vegetation Monitoring Group http://www.gvm.sai.jrc.it is really precious.

For more information on the HDF format, a HDF FAQ is available on the Internet, together with a lot of other items like utility programs, tutorials, etc. In particular, an excellent HDF tutorial has been developed by the NCSA and can be viewed at the Internet address
http://hdf.ncsa.uiuc.edu/tutslects.html.