INSTALLATION, SETUP AND USE OF A LOW COST C-BAND METEOSAT-8 GROUND RECEIVING STATION IN RWANDA

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ABSTRACT:

This paper provides a description to setup and operate a low-cost Meteosat Second Generation ground receiving station. A C-band receiving configuration, relevant for Africa, is described using as an example the operational system at the Geographic Information Systems & Remote Sensing Research and Training Centre (CGIS) of the National University of Rwanda (NUR) in Butare. Additional software developed is firstly the MSG File-Manager, performing the data transfer between the receiving station and the data processing and archiving system in an orderly manner. Secondly, for data import, a software tool called the MSG Data-Retriever is developed which facilitates the import of the raw compressed (time series) data into common used image processing software package formats. The data is geometrically and radiometrically calibrated during the import. Thirdly, in order to process the images additional tools to handle and analyse time series data are developed and integrated in the ILWIS software package (shareware). Procedures and software described are developed to ensure a low-cost alternative to build a Meteosat time series archive coupled with free- or shareware processing tools to retrieve (regular) products relevant for e.g. environmental and hydrological applications by non-meteorological organizations in Africa dealing with geo-spatial temporal data analysis.

RÉSUMÉ:

L'article fournit une description de l'installation et des procédures d'opération d'une station de réception à bas coût du satellite Meteosat de seconde génération. Une configuration de réception en Bande C, adaptée à l'Afrique, est décrite en prenant comme exemple le système opérationnel du Centre de Formation et de Recherche en Système d'Information Géographique et Télédétection de l'Université Nationale du Rwanda de Butare. Des logiciels additionnels développés sont premièrement le MSG « File Manager », responsable du transfert des données entre la station de réception et le système de traitement et d'archivage des données d'une manière ordonnée. Deuxièmement, le MSG « Data Retriever » a été développé en tant qu'outil d'import de données, en facilitant l'import des séries d'images brutes compressées vers les formats communément utilisés par les logiciels de traitement d'images. Les données sont géométriquement et radiométriquement calibrées durant l'import. Troisièmement, et afin de traiter les images, des outils additionnels ont été développes, et integrés dans le logiciel shareware ILWIS pour manipuler et analyser les séries temporelles d'images. Les procédures et les logiciels décrits ont été développés pour proposer une alternative a bas coût permettant de construire une archive de séries temporelles d'images Meteosat couplées avec des logiciels freeware ou shareware pour extraire des produits utiles à des applications environnementales et hydrologiques pour des organisations non météorologiques en Afrique impliquées dans l'analyse geo-spatiale et temporelle d'images.

MOTS CLES: Meteosat deuxieme generation, EUMETCAST, station de réception a bas prix, réception proche du temps réel, MSG File-Manager, MSG Data-Retriever, outils de traitements d'images shareware.

1. Introduction

Natural resources management calls for an informed participation of different stakeholders concerned with sustainable development. Timely, accurate and comprehensive information about natural resources forms the basis of effective resources management. It is now widely recognized that the monitoring and assessment of these resources, in terms of both quantity and quality, require adequate meteorological, hydrological and other related data. Satellite observations can assist in enhancing the observation capabilities by providing additional data and variables such as rainfall (Maathuis et al, 2006) complementing and integrating ground observations. Especially the new Meteosat programme, using the Spinning Enhanced Visible and Infrared Imager (SEVIRI), could play a major role in this respect. Stationed over Africa this satellite provides a continuous "eye in the sky" and from the recordings provided the relevant (dynamic) environmental variables can be retrieved to assess the actual conditions of the natural resources. This paper describes the effort conducted to receive this data using a low cost ground station, the online archiving system that has been developed to store the data, the import routines for the images as well as the enhanced ILWIS RS/GIS functionality (shareware) for time series analysis combined with common Windows tools for time series visualization. Such a system is a very efficient tool to assist the relevant Authorities in Africa to prepare Integrated Resource Management Plans as part of their contribution to national and regional development.

2 The SEVIRI radiometer on MSG and Ku-Band reception over Europe

MSG-1 was launched on the 28th of August 2002 and after a testing period commenced routine operations on the 29th of January 2004. Then the satellite was renamed to Meteosat-8. On the 21st of December 2005, as a backup of Meteosat-8, MSG-2 was successfully launched and commissioning tests are currently under way. This will ensure continuous satellite observations for the next decade. The advanced SEVIRI radiometer onboard the MSG series of geostationary satellites enables the Earth to be scanned in 12 spectral channels from visible to thermal infrared (including water vapour, ozone and carbon dioxide channels) at 15 minute intervals. The specifications of SEVIRI have been chosen carefully to match operational requirements. Each of the 12 channels (table 1) has one or more specific applications in mind, either when used alone or in conjunction with data from other channels. Each has a well established heritage, ensuring that their characteristics are well understood so that the data can be used on an operational basis. The actual instrument includes a primary mirror with a diameter of 51 cm and infrared detectors. The raw images are generated through a combination of an east-west scan obtained from the spinning of the entire satellite at 100 revolutions per minute, together with a stepping of a telescope mirror from south to north after each scan line. The spatial resolution of the SEVIRI instrument has been slightly increased (at intervals of 3 km) compared to its predecessors, the High Resolution Visible (HVR) channel even has a sampling distance interval of just 1 km. Meteosat-8 data can be directly received via the EUMETSAT Multicast Distribution System (EUMETCast) or obtained from the archive at EUMETSAT (http://archive.eumetsat.int/).

Table 1: SEVIRI channels and their applications

Band	Center	Min	Max	Nadir Res	Row x Cols	Repetition	Application
1	0.635	0.56	0.71	3000	3712 x 3712	15	Surface, clouds, windfield
2	0.81	0.74	0.88	3000	3712 x 3712	15	Surface, clouds, windfield
3	1.64	1.5	1.78	3000	3712 x 3712	15	Surface, cloud phase
4	3.9	3.48	4.36	3000	3712 x 3712	15	Surface, clouds, windfield
5	6.25	5.35	7.15	3000	3712 x 3712	15	Water vapor, high level clouds, atmospheric instability
6	7.35	6.85	7.85	3000	3712 x 3712	15	Water vapor, atmospheric instability
7	8.7	8.3	9.1	3000	3712 x 3712	15	Surface, clouds, atmospheric instability
8	9.66	9.38	9.94	3000	3712 x 3712	15	Ozone
9	10.8	9.8	11.8	3000	3712 x 3712	15	Surface, clouds, windfield, atmospheric instability
10	12	1100	13	3000	3712 x 3712	15	Surface, clouds, atmospheric instability
11	13.4	12.4	14.4	3000	3712 x 3712	15	Cirrus cloud heights, atmospheric instability
12	-	0.4	1.1	1000	11136 x 7700	15	Surface, clouds

From its geostationary position Meteosat-8 continuously scans the Earth surface and transmits the data to the EUMETSAT Primary Ground Station in Darmstadt (Germany). The received data is pre-processed and rectified into a so called Level 1.5 data-format; furthermore the data is compressed and split in small data-packages. These packages are sent to the uplink station in Usingen (Germany) and are subsequently transmitted to the HotBird-6 satellite (combined with some other services) for European reception.

Anywhere within this area, using a satellite dish oriented and directed towards the HotBird-6 satellite position, the DVB (digital video broadcasting) signal can be received and the LNB (low noise block) of the dish converts the signal to a lower frequency. The DVB-PCI card in the computer demodulates and decodes the continuous DVB data-stream. Data from Meteosat-8 are available in a Low Rate Image Transmission (LRIT) and High Rate Image Transmission (HRIT) mode. After central ground processing at EUMETSAT, images in full resolution are transmitted in HRIT mode, within five minutes of observation. LRIT disseminates a sub set of the HRIT SEVIRI imaging data in 5 spectral channels in a 'slightly lossy' compressed form within 15 minutes of observation. Figure 1 shows how EUMETCast fits within the overall EUMETSAT Ground Segment architecture.

Figure 1: EUMETCast system overview for Ku and C-Band reception
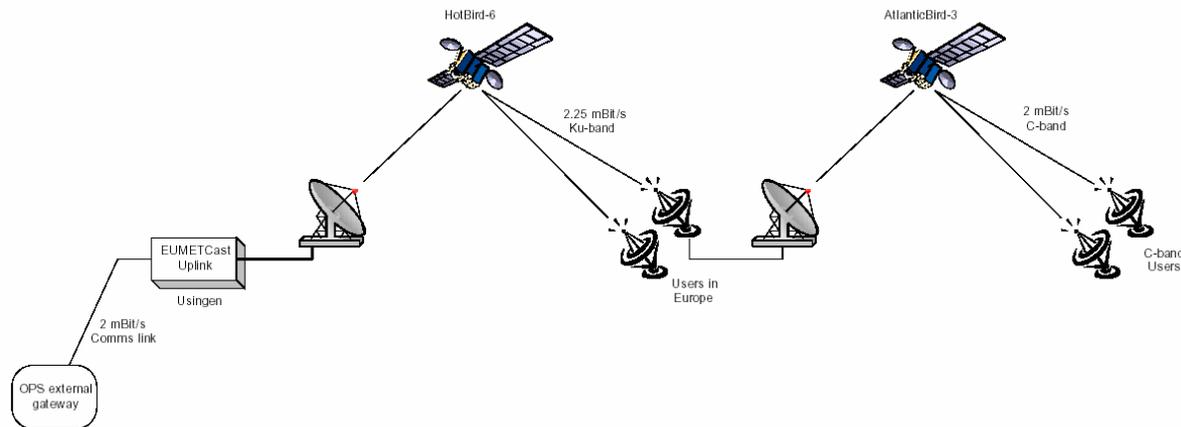
3. EUMETCast C-band reception in Africa

The EUMETCast service for Europe is based on Ku-band transmissions and is only guaranteed to cover the EUMETSAT Member States and Co-operating States. The dissemination service for Africa is a C-band based transmission also covering selective regions outside the EUMETSAT Member States and Co-operating States and recently even an extension of this service to South America commenced (through Globecast Spain). For Africa the EUTELSAT AtlanticBird-3 satellite carries the C-Band dissemination service for MSG. The format of the C-band dissemination is the same as for HotBird-6 dissemination. The data is re-transmitted to AtlanticBird-3 via the Fucino ground station in Italy (figure 1). C-Band covers the frequencies 3.70 GHz to 4.2 GHz. The EUMETSAT Council decided to use EUTELSAT's AtlanticBird-3 satellite for the C-Band dissemination of MSG data to Africa as this frequency is less susceptible to intensive rainfall as it causes attenuation of the Ku-band signal which might result in reception failure. This satellite is stationed at 5° West and is one of EUTELSAT's 'Atlantic Gate' series of satellites. The C-band beam used covers the whole of Europe and Africa. All of Europe and Africa – apart from parts of Morocco, southern Algeria, Mali and Niger, lie within the 39 dBW contour of the footprint. For the areas outside the 39 dBW a larger diameter antenna is required (of 3 meter) for good signal reception in Africa.

Within the current EUMETCast configuration, the multicast system provided is based on a client/server system developed by Tellique Kommunikationstechnik GmbH. The server side is implemented at the EUMETCast uplink site (Usingen, Germany) and the client side is installed on the individual EUMETCast reception stations. Encoded data/product files are transferred via a dedicated communications line from EUMETSAT to the uplink facility where they are transmitted to a geostationary communications satellite for broadcast to user receiving stations. Each receiving station decodes the signal and recreates the user data/products according to a defined directory and file name structure. A single reception station can receive any combination of the provided services. Data whose access is controlled in accordance with EUMETSAT Data Policy is encrypted, and decryption at the user station is carried out by an eToken decryption scheme. At CGIS-NUR a research and education license was obtained from EUMETSAT allowing free reception of the 15 minute HRIT SEVIRI data, together with other services provided such at the 'Vegetation for Africa', the Satellite Application Facility products as well as foreign satellite data.

4. Antenna setup and hardware configuration at CGIS-NUR, Butare, Rwanda

Figure 2: Satellite Dish installed at CGIS-NUR in Butare

At the CGIS-NUR premises a C-band reception facility was assembled using a local purchased 2.4 diameter dish equipped with a California 3.70 GHz to 4.2 GHZ LNB. This was done in March 2006 (figure 2). The satellite pointing tool, available from the EUMETSAT (http://www.eumetsat.int), was used for approximate pointing of the antenna (azimuth of 273.73 degree and elevation angle of 49.54 degree respectively). A Super California Magicbox III digital satellite TV receiver was borrowed from the satellite dish vendor in Kigali. A coaxial cable from the LNB was connected to the digital satellite receiver and through a SCART-cable this receiver was linked to a TV-set. This configuration was used for accurate pointing of the antenna, to ensure maximal signal reception before connecting it to the DVB-board inserted in the receiving computer.

The recommended DVB-board for C-band reception in Africa is the V@box 2030 Broadlogic PCI-card (http://www.vboxcomm.com). To obtain the PCI board proved to be difficult as vendors prefer to sell complete reception systems.

EUMETSAT recommends setting up the EUMETCast PC as a receiving station and ftp server only and not to install and run other application software. Peaks in disk and bus usage could interrupt DVB data reception. The receiving and processing station hardware configuration used at CGIS-NUR are ordinary Pentium 4 (3.2 GHZ) systems with Microsoft Windows XP SP2 Operating System and two LaCie Big Disk Extreme Terra Byte high speed USB-2.0 external disks. The computers are linked with a cat-5 twisted cable RG-45 allowing a data-transfer of 1 Gbps between the two systems. At a later stage the systems can be connected to the CGIS network through a hub to access the archive from all work places within the Institute. Additional attention was given to the electricity supply which can be fluctuating and irregular available during day time and even absent during night time in southern Rwanda. A set of batteries connected to a converter/charger unit and UPS was installed to ensure continued day time operation when the power might be shortly off (and the generator at the CGIS-NUR compound takes over) and has sufficient capacity to keep the receiving station running during night time operation when the generator is off as well. The (millisecond) power fluctuation before the batteries take over is handled by the UPS, to ensure continuous power supply.

The hard and software configuration for DVB reception at CGIS-NUR was conducted in three steps. First the DVB-PCI board was inserted in the computer and the driver that comes with the board was installed. Then the V@box Broadlogic 2030 DVB-PCI card was configured in accordance with the specifications given in the EUMETCast Technical Description (EUMETSAT, 2004). The software scans automatically for available Packet or Program Identifier (PID) numbers. The PID numbers were selected manually to receive the respective channels. The announcement channel PID must be selected in order to provide any of the services offered. The DVB-board has to have a pre-defined IP-address (192.168.238.238). If the DVB board is properly installed (and the driver is loaded and configured) a green LED indicator becomes active at the back of the DVB board, another one becomes active when the signal (and the data) is locked as well.

Next step is the installation and configuration of the tq®-TELLICAST software. The tq®-TELLICAST software is available from several commercial outlets or can be obtained directly from EUMETSAT. The tq®-TELLICAST client software carries out decryption of data based on a key code, error correction and management of received files. As the current EUMETCast operates a tq®-TELLICAST server, the tq®-TELLICAST client software is mandatory and a license is required for each user. The software can be installed when the signal is locked by the DVB-board. The software will ask for a username and password which should have been obtained from EUMETSAT. A shortcut is created in the tray bar of the start menu. In the "recv.ini" file important start-up parameters are given, such as the Interface-address which should match the IP-address of the DVB board. Through a web-based shell the actual state of multicast reception is

shown. The icon on the Start Menu will initially be yellow or red and remain so until it has successfully connected to the DVB driver application, then it will turn green. To ensure correct reception of data the receiving station must have a defined directory structure setup. The reception software will deposit the product files into these directories. This directory can be shared so the data can be accessed by the processing-archiving system or through a Local Area Network.

Finally the eToken USB key and software has to be installed and configured. A EUMETCast Key Unit (EKU) is required for the reception of those data whose access is controlled in accordance with EUMETSAT Data Policy, referred to as 'licensed' services. The EKU is a USB device used in conjunction with a corresponding username and password to facilitate the reception of licensed services. Only data described as 'essential' are available on EUMETCast without the need to operate an EKU. A copy of the EKU Software is included in the EUMETCast Client Software licence package CD-ROM as well as the installation instructions. The EKU will illuminate with a red light (initially this will flash) when properly configured.

Figure 3: Receiving and processing stations at CGIS-NUR

Currently every 15 minutes the high resolution visible (HRV) and 11 low resolution channels are received. The HRV channel consists of 24 segments stored as separate files, the low resolution channels consists of 8 segments. At CGIS-NUR selected segments covering the African continent are stored in their original lossless wavelet compressed file format. This results in the smallest demand for external USB-storage disk space, coupled without further user interference (fully automated, only a provisional system check once a day). In total approximately 7000 files, equivalent to 4.5 Gb, are stored per day. The additional hard- and software cost for one ground receiving station (excluding 2 computers and UPS-battery) is about 2300 Euro. Most expensive is the storage capacity needed in order to construct an online archive. If this 2 TB storage is excluded a C-band ground receiving station can be created for less than 1000 Euro.

In order to receive the continuous data stream the receiving station has to be operational on a 24 hours / day basis. To start the MSG ground receiving station the systems are switched on. At the receiving station the Broadlogic and TQ software automatically start, the signal is locked, a signal strength bar indicates the current signal strength (usually about 80 %) and the TQ icon (at the lower right hand tray bar) changes colour from its initial yellow appearance within a few seconds. Optionally the web-shell can be opened to see the actual status on the channels received.

5. The MSG File-Manager and the MSG Data-Retriever

At CGIS-NUR all EUMETCast data is received but only part of the high rate information transmission (HRIT) data covering Africa is archived. A software tool called the MSG File Manager has been developed at ITC to move the relevant data, based on the acquisition date and time, to specific folders on the processing system's attached USB-terabyte disks. A directory structure is automatically created under the main directory where the raw data is moved to, with Year – Month – Day sub-directories. The tool also creates entries in a log file if data is missing and optionally it can send warning emails if large problems, like system failures may occur. As the File-Manager was not designed to delete any data, another simple batch tool can be used to selectively delete the segments outside the specific area of interest. The batch file can be executed at a suitable time by the system operator to release disk space. If the batch file is copied into the Month sub-directory all selected segments in the Day sub-directory of that month are deleted. One manual operation per month is therefore required by the system administrator to maintain control over the data-archive to store only the area of interest. Given the fact that a Move command is used by the File-Manager the raw data is physically removed from the receiving station. The remaining hard disk capacity of the receiving station at

CGIS-NUR for temporary storage is approximate 60 GB. With an overall data load of 7.5 GB / day the processing station can be turned off during the weekend and MSG File-Manager operations can be resumed after a couple of days without having a problem of running out of disk space storage on the receiving station. This reduces the capacity needed for the power backup system.

The problem with MSG data is that the file format is not standard. None of the commonly used remote sensing packages is able to open or process the raw compressed images. To make use of the data one can choose between expensive specialized meteorological software or a few simple but affordable software solutions that convert them into jpeg or png pictures. The latter has the disadvantage that image properties are lost and the geo-location as well as the radiometric calibration information that is transmitted together with the images remains unused. Therefore it was decided that the solution with the most future prospects was to implement a driver for reading the images in the Geospatial Data Abstraction Library (GDAL, http://www.gdal.org). GDAL is a translation library for raster geospatial data formats that is released under an MIT style Open Source license. All source code is in C++, and great effort is put into keeping the code platform-independent. Drivers for writing files in popular RS formats (e.g. ENVI, ERDAS, ILWIS, GeoTiff) but also picture formats like JPEG, GIF and BMP have already been implemented by the community, so appending a driver for reading MSG image files to this driver was seen as the most appropriate solution.

A software development effort was initiated at ITC. Most of the information needed for the development of specific algorithms is available in documents supplied (online) by EUMETSAT (EUMETSAT, 1999, 2001a, 2001b, Govaerts and Clerici, 2004). This includes a full description of the header section of the files and the projection used in the images. One of the algorithms developed is correctly re-composing the images from the multiple compressed data files / segments. According to the provided documentation the algorithm must take care of scan direction, image compression, bit-depth, image size and proper alignment of the image strips of the high resolution band. Verification tests were performed in order to assess the correct use of the available alignment information. Another algorithm developed performs the radiometric calibration using the relevant header / footer (PRO / EPI) parameters and applying appropriate formulas that calculate the resulting pixel values into the required unit. A third algorithm determines the geo-location of each pixel. The algorithm described by EUMETSAT directly calculates latitude and longitude from pixel positions. The incorporation of the GDAL driver required a two-step procedure for correctly assigning geo-location information to pixels. Therefore a two step approach was incorporated: from a pixel position, first, the location in a newly developed projection for geostationary satellites is calculated and then the latitude and longitude are obtained. Automatic geo-location has the advantage that no manual steps are needed to transform the images to a known projection (Maathuis and van Leeuwen, 2005). Further driver development is ongoing to facilitate import of the Satellite Application Facility products (in GRIB and BUFR formats) that are also received via the EUMETCast service.

The developed driver for reading raw compressed MSG images is included in the GDAL library. Interested parties have to manually enable the driver, as it depends on source code that performs wavelet decompression that must be downloaded directly from EUMETSAT (free source code, but subject to a non-transferable license agreement). Therefore parties having appropriate license agreements can use it freely. The command-line utilities that come with GDAL facilitate the use of the library to transform MSG images into widely applied RS data formats; currently 25 output formats are available in the library. In-house experiences with these command-line utilities revealed that composing such a command-line string is an error-prone process (given the many options available). Therefore a Microsoft Windows based user-interface was developed that generates the necessary command-line syntax. The user only needs to express the "query" by making appropriate choices using checkboxes, radio buttons, list boxes, selection of area of interest, etc. Through the user interface all relevant parameters can be adjusted and a time series can be easily constructed. The user interface facilitates retrieval of original DN values (10 bit-depth), compressed DN values to 8 bit-depth, Top of Atmosphere radiances in 2 different units (W/m2/sr/um or mW/m2/sr/cm-1)-1), computation of Top of Atmosphere reflectance for the visible channels or Top of Atmosphere temperature (in Kelvin) for the thermal channels. The geometric precision is within a pixel for the low resolution bands and Geographic coordinates and UTM projection conversion is possible (a pixel size dimension has to be entered). For more flexibility, with the option "Show Command Line" the corresponding command-line string for performing a certain import is revealed. This string can than be

copied into a batch file which can be called from within an ILWIS script in order to perform similar imports multiple times.

6. Shareware multi temporal image processing, analysis and visualization tools

With the shareware release of ILWIS 3.3 (http://www.itc.nl/ilwis) additional tools have been integrated to perform dedicated analysis using time series of e.g. Meteosat-8 data. To deal with multi temporal image files ILWIS utilizes the concept of a map list. This list provides the temporal reference to a sequence of individual image files in a time series. The GDAL-driver and Windows based Data-Retriever interface facilitate easy geometric and radiometric calibrated data retrieval into the ILWIS data format and the multi temporal images are assigned to an appropriate map list. An algorithm can be entered through the ILWIS command line to be executed on all the images in a map list. On top of the previous existing capability additional software functionality for time series data analysis and visualization have been implemented. The first added option discussed is the possibility to calculate using multiple map lists. Up to ten map lists can be used in a computation using the ILWIS command line and the algorithm is applied to each sequential numbered image in each of the individual map lists. Also a Map List Calculation user-interface is developed that facilitates generation of command line algorithms, but it is only able to use up to four map lists at a time. The resulting output map list can be visualized using the animation option with a user defined refresh rate in ILWIS or exported to multiple BMP files to create an (annotated) animation using Windows Movie Maker. To view the values of all images of a map list at a certain location a Maplist Graph function has been developed. Options are available to continuous update the graph display while the mouse pointer moves over an image. The Y-axis can also be adapted according to user defined value ranges. The data stack at a certain selected pixel location can be copied to clipboard for further treatment in a spreadsheet. Another function called Maplist Statistics allows aggregation of a time series of images using a number of statistical functions such as: average, median, minimum, maximum and standard deviation. More functions will be implemented. All images in a map list are used and per pixel (using all layers for that pixel in the map list) the computation is performed and a new output image is created.

To automate certain procedures the ILWIS script language can be applied. A script is a sequenced list of ILWIS commands and expressions. Each line in a script is a statement that can also be executed manually via the ILWIS command line of the Main window. ILWIS will execute all statements in the script in batch. Via a script, it is possible to handle e.g. necessary object management (e.g. copy or delete), display of objects (open or show) and create and calculate maps. All Map calculation and ILWIS Expressions to perform operations can be used. Furthermore, it is possible to call other scripts and start other Windows and Java applications from within a script. A script can use parameters which replace (parts of) object names, operations, etc. Parameters in scripts work as DOS replaceable parameters in DOS batch files, and are specified in the Parameter Tab and represented in the script editor as %1, %2, %3, up to %9. By creating a script, it is possible to build a complete image analysis routine. Sample scripts to calculate e.g. NDVI, TNDVI and WSVI have been developed. Also Java applets have been created which e.g. allow computation of MSG satellite and sun azimuth and zenith angles based on date and time and are called from within ILWIS scripts. It is envisaged to release these utilities as well as other relevant information through a dedicated page available via the main ITC website.

7. Conclusions

The system-configuration described here provides a low cost alternative to the "non-traditional meteorological" user community in Africa, applying the Meteosat data to a multitude of important environmental science related applications. The MSG SEVIRI sensor capabilities and current favorable data distribution policy – license agreement of EUMETSAT, for Research and Education Institutes like the CGIS-NUR, has recently opened the way for new initiatives.

With the low cost hard and software configuration described to receive, handle, store and analyse multi temporal Meteosat images, CGIS-NUR is in a good position to offer this enhanced capability for further (inter) national research and capacity building and can actively collaborate and contribute to international networks as the data received cover the whole African continent. With time an archive is constructed

consisting of images recording the dynamics and the state of the environment every 15 minutes. This archive can be utilized for further CGIS-NUR Research and Development to obtain a better insight in the changing conditions of the environment and to provide national authorities as well as international bodies (e.g Nile Basin Initiative) with information to assist in their policy making process. The challenge for the period ahead is to utilize this capability to produce various (dynamic) Meteosat derived (regular) products required by e.g. environmental organizations to assist them in reaching their (Millennium) development objectives. CGIS-NUR is readily equipped to take up this challenge and to further develop their capacity through active (inter) national collaboration.

8. Acknowledgements

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