Nile Basin Initiative

Water Resources Planning and Management (WRPM)

Remote Sensing for DSS in Nile Basin Water Management

Inventory – Product definition – Way forward

Final Report

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October 2008

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Acronyms

AFWA	Air Force Weather Agency
ALEXI	Atmosphere-Land Exchange Inverse Model
ALOS	Advanced Land Observing Satellite from Japan
AMSR-E	Advanced Microwave Scanning Radiometer - EOS onboard Aqua
AMSU	Advanced Microwave Sounding Unit
APAR	Absorbed Photosynthetically Active Radiation
Aqua	Satellite with among others MODIS sensor of NASA
ASAR	Advanced Synthetic Aperture Radar onboard Envisat
ASCAT	Advanced Scattero Meter onboard meterological operational (MetOp) platforms
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer onboard Terra
AVHRR	Advanced Very High Resolution Radiometer onboard NOAA
AWiFS	Advanced Wide Field Sensor onboard IRS
BCM	Billion Cubic Meters
BGC	Bio Geochemical Cycles
bsa	black sky albedo
CAMS	Climate Assessment and Monitoring System
CARSP	Commercially Available Remote Sensing Products
CCD	Cold Cloud Duration
CGP99	Southern Great Plains Experiment 1999
CMAP	CPC Merged Analysis of Precipitation
CN	Curve Number
COLA	Center for Ocean-Land-Atmosphere Studies
CRU	Climate Research Unit
DAAC	Data Active Archiving System
DAO	Data Assimilation Office
DAP	Directly Accessible Portal
DEM	Digital Elevation Model
DMSP	Defense Meteorological Satellite Program
DSS	Decision Support System
DSS-RS	Decision Support - Remote Sensing
DUE	Date User Element program of ESA
DVP	Dedicated Viewing Portal
E	Evaporation
ECMWF	European Centre for Medium-Range Weather Forecast
ENSAP	Eastern Nile Subsidiary Action Program
ENVISAT	Environmental Satellite of ESA
EOS	Earth Observing System
EPS	EUMETSAT Polar System
ERA	ECMWF Re-analysis Data Archive
ERS	European Remote Sensing satellite
ESA	European Space Agency
ESRI	GIS and Mapping Software supplier
ET	Evapotranspiration
ET0	Reference Evapotranspiration
ET_{act}	Actual Evapotranspiration
ETM+	Enhanced Thematic Mapper Plus
ET_{pot}	Potential Evapotranspiration
FAO	Food and Agricultural Organization
FEWS	Famine Early Warning Systems
fPAR	fraction of Absorbed Photosyntetically Active Wavelengths
FVC	Factor of Vegetation Cover

Fyuing	Geostationary satellite over Asia
G	Soil Heat Flux
GCPC	Global Combined Precipitation Data
GeoSFM	Geospatial Stream Flow Model
GIAM	Global Map of Irrigated Areas
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	Geographic Information System
GLC2000	Global Land Cover 2000 of the JRC
GLCF	Global Land Cover Facility
GMIA	Global Map of Irrigated Areas
GMS	Geostationary satellite over Australia
GOES	Geostationary satellite over America
GPCP	Global Precipitation Climatology Project
GPP	Gross Photosynthetic Product
GRACE	Gravity Recovery and Climate Experiment
GTOPO	Global Topographic Data
GTS	Global Telecommunication System
H	Sensible Heat Flux
IDW	Inverse Distance Weighting
IGBP	International Geosphere Biosphere Programme
IKONOS	commercial very high resolution earth observation satellite
ILRI	International Livestock Research Institute
INSAT	Geostationary satellite over Asia
IRS	Indian Remote Sensing Satellite
IT	Information Technology
ITC	International Institute of Geo-Information Science and Earth Observations
IWMI	International Water Management Institute
JASON	ocean surface topography satellite from NASA
JAXA	Japan Aerospace Exploration Agency
JERS	Japanese Earth Resources Satellite
JRC	Joint Research Institute
KLMNN	series of polar orbiting satellites of NOAA
LAI	Leaf Area Index
LAN	Local Area Network
Landsaf	Land Surface Analysis Satellite Applications Facility
Landsat	satellite of NASA
LCCS	Land Cover Classification System
LCRS	Laboratory for Climatology and Remote Sensing
LE	Latent Heat Flux
LISS	Linear Imaging and Self Scanning Sensor onboard IRS
LPRM	Land Parameter Retrieval Model
LST	Land Surface Temperature
MARS	Monitoring Agriculture through Remote Sensing techniques, EU - JRC project
MERIS	Medium Resolution Imaging Spectrometer onboard Envisat
Meteosat	Geostationary satellite over Europe and Africa
MetOP	European polar-orbiting meteorological satellites
METRIC	Mapping EvapoTranspiration at high Resolution with Internalized Calibration, model for calculating evapotranspiration
MI	Moisture Index
MODIS	Moderate Resolution Imaging Spectroradiometer onboard Aqua and Terra satellites
MSG	MeteoSAT Second Generation
MSMMN	Murrumbidgee Soil Moisture Monitoring Network
MSPPS	Microwave Surface and Precipitation Products System
MSS	Multi Spectral Scanner, sensor onboard Landsat 1,2,3,4 and 5

MW	Micro Wave
NASA	National Aeronautic Space Administration
NBI	Nile Basin Initiative
NDVI	Normalized Difference Vegetation Index
NESDIS	National Environmental Satellite Data and Information Service
NGO	Non-Governmental Organisation
NILESAP	Nile Subsidiary Action Program
NIR	Near Infra Red
NOAA	Satellite
NPP	Net Primary Production
NSIDC	National Snow and Ice Data Center
P	Precipitation
PAP	Partially Accessible Portal
PAR	Photosyntically Active Radiation
PECAD	Production Estimates and Crop Assessment Division (USDA)
Poseidon	ocean surface topography satellite from NASA
PR	Precipitation Radar
PUM	Product User Manual
Quickbird	commercial very high resolution earth observation satellite
RCMRD	Regional Centre for Mapping of Resources for Development
RH	Relative Humidity
Rn	Net Radiation
RS	remote sensing
RTNEPH	Real Time Nephanalysis Cloud Model
RUE	Radiation Use Efficiency
SADC	Southern Africa Development Community
SAP	Subsidiary Action Program
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
SeaWIFS	Sea-viewing Wide Field-of-view Sensor, onboard GeoEye's OrbView-2 (SeaStar) satellite
SEBAL	Surface Energy Balance Algorithm for Land, model for calculating evapotranspiration
SEBS	Surface Energy Balance System, model for calculating evapotranspiration
SHARE	Soil Moisture for Hydrometeorologic Applications in the SADC Region
SMEX02/03/04	Soil Moisture Experiment 2002/2003/2004
SMOS	Soil Moisture and Ocean Salinity mission of ESA
SPOT	Satellite Pour l'Observation de la Terre 1,2,3,4 and 5 from the French Space Agency
SPOT Vegetation	Earth observation sensor onboard the SPOT satellite
SPOT VGT	SPOT Vegetation
SRTM	Shuttle Radar Topographic Mission
S-SEBI	Simplified Surface Energy Balance Index
SSM/I	Special Sensor Microwave/Imager
SVP	Shared Vision Program
SWI	Soil Water Index
SWIR	Short Wave Infra Red
T	Transpiration
Tact	Actual Transpiration
TAMSAT	Tropical Applications of Metereology using SATellite and other data
Terra	Satellite with among others MODIS sensor of NASA
TESSEL	Tiled ECMWF Surface Scheme for Exchange over Land
TIR	Thermal Infrared
TM	Thematic Mapper, sensor onboard Landsat satellite 5
TMI	TRMM Microwave Imager

T_{pot}	Potential Transpiration
TRMM	Tropical Rainfall Measuring Mission
USDA	United States Department of Agriculture
USDA-FAS	USDA Foreign Agricultural Service
USGS	US Geological Survey
VIC	Variable Infiltration Capacity model
VIRS	Visible and InfraRed Scanner onboard TRMM
VIS	Visible Reflectance
VUA	Vrije Universiteit Amsterdam
WMO	World Meteorological Organization
WRPM	Water Resources Planning and Management
WRSI	Water Requirement Satisfaction Index
wsa	white sky albedo

Executive Summary

A Remote Sensing (RS) scoping study was conducted to support the Decision Support System (DSS) for the Water Resources Planning and Management project (WRPM) of the Nile Basin Initiative (NBI) with spatial data derived from satellites. RS has developed to one of the most powerful scientific disciplines for providing operational tools and products for water resources management. Many active data archives at NASA, USGS, USDA and LANDSAF have been created during the last couple of years. The existence of these satellite data archives covering land properties, land surface state variables, and land surface physical processes is hardly known, and the strong advances in RS technologies over recent years were relatively unnoticed in many circles

This study shows that RS data could be accessed without any restriction (provided that a fast fiberglas telephone line is available) in many cases. RS data can be merged to determine spatial products that could serve as input into the DSS. The key public data archives are specified in this report. The general validation has been checked from the international literature, and a summary of this literature has been prepared. The RS data needs to be collected, stored, processed and disseminated by a future Regional DSS-RS center that will manage the geographical data. Our selection of primary RS data for application in the Nile Basin was based on a study of the data needs of the SAP and SVP programs. The advantage of RS data is that it is not biased, covers the entire 3 million km^2 Nile basin, and is available shortly after satellite overpass. This significantly augments DSS systems and encourages “evidence based decision making”.

The most exciting component of this study is a description of a number of ”special purpose RS products” that can directly support various aspects of river basin management: (i) hydrology, (ii) water accounting, (iii) disaster management, (iv) irrigation management, (v) wetland management, (vi) watershed management and (vii) land degradation. A first round of products have been identified and defined and the products are demonstrated through examples. The satellite data collected for the creation of the examples, was transferred to the Regional DSS Center. It is expected that a second round for improved definitions of special purpose RS products is required after user consultations. The users should first be exposed to the products and such use of spatial data. In many cases, the jump between having no spatial data for water resource management, to having a full complement of spatial data, is significant and it requires time to digest and adopt this wealth of information.

A framework for a future Regional DSS-RS center is provided. Major hardware and software requirements are specified, along with the required human resources to implement such a program. The program should give priority to image processing and gradually create more special purpose RS products jointly with a reliable and efficient website that can serve a large group of stakeholders. Data should be posted for individual retrieval by water stakeholders in the Nile Basin.

Field data is fundamental for the ground truthing of satellite data and for determining error bands. RS does not replace regular field data collection, but instead helps with spatial interpolation and to describe features of areas where no field observations are made. The confidence in RS products can grow only if levels of uncertainty are clearly indicated.

The consultant has interviewed several key institutes and RS experts on this program. Collaboration with RCMRD should focus on training and land use mapping. An exchange program with FAO-Nile should be promoted for making effective use of complementary data sets in agricultural water management.

This innovative approach to water resource management is unique for international river basins in the world, and is only possible by combining all the data archives and latest RS algorithms; this would not have been possible one year ago. Considering the great potential and enthusiasm received during the two training and awareness workshops, it is recommended to start the implementation of the Regional DSS-RS center during the course of 2008.

1 Introduction

1.1 Background

The objective of the Water Resources Planning and Management Project (WRPM) is to enhance analytical capacity to support basin-wide management, and protection of the Nile Basin water resources in an equitable, optimal, integrated, and sustainable manner. The purpose of developing a Decision Support System (DSS) is to facilitate the establishment of this analytical capacity. The Nile Basin DSS will provide a common, basin-wide platform for communication, information management, and analysis of Nile Basin water resources. Coupled with human resources development and institutional strengthening, the Nile Basin DSS will provide a framework for sharing knowledge, understanding river system behaviour, evaluating alternative development and management schemes, and supporting informed decision-making from a regional perspective, thus contributing to sustainable water resources planning and management in the Basin.

It is anticipated to establish a Remote Sensing (RS) unit that will operate under the aegis of the regional Decision Support System (DSS), and that will enrich existing databases with a spatial data layer. The purpose of the Remote Sensing Scoping Project described later in this report is to identify the need for, and define the functions of the proposed Decision Support Remote Sensing (DSS-RS) unit. The Terms of Reference for this scoping study are provided in Appendix 1.The work also includes pilot activities on archiving and processing of remote sensing data as well as a regional awareness/training workshop.

The main problem in remote sensing applications is that at the one hand the end-user is not familiar with the growing potential of remote sensing techniques, and on the other hand the remote sensing provider does not understand water policy and water management operations and decision processes very well. The onus is largely on the RS specialists to create dialogue with the user community and show relevant examples of RS use for different purposes, from which users can then select for their specific needs. Some iterative rounds may be required to get a fully operational product. The current report is a first attempt to define the operational products that will contribute to establishing the knowledge base and decision support for the Nile Basin water resources management.

The consultant has carried out this study essentially as a desk top study. Additional information on the Nile basin system and from the various organizations involved, has been collected during 3 different visits to the study area. During December 2007, the remote sensing centres in Nairobi and Entebbe were visited. The results are described in chapter 4. In February 2008, the consultant has provided a short training course on the collection and processing of satellite images for the Regional DSS center in Addis Ababa. This was meant as an internal training and to foster discussion on the operational product. Another round of training was held during the regional awareness/training workshop with the national DSS specialists and their counterparts in March 2008, also in Addis Ababa. The list of participants is included in Appendix 2. Returns from a participant satisfaction questionnaire showed that the vast majority of the group was satisfied with the contents of the course. A set of 5 DVD's with satellite data was prepared and transferred to the DSS.

1.2 Physical features of the Nile basin

The Nile basin, which is home to and a source of livelihood for approximately 160 million people, is the longest river in the world having a total length of about 6700 km, traversing an extremely wide band of latitude, from 4-degree south to 32-degree north. The area draining into the Nile river system (about 3 million km^2) extends over ten African countries.

The two main river systems that feed the Nile are the White Nile the Blue Nile and the Atbara. The White Nile has sources on the Equatorial Lake Plateau (Burundi, Rwanda, Tanzania, Kenya, Democratic Republic of the Congo and Uganda) and is fed by substantial flow from the Baro-Akobo-Sobat system that originates in the foothills of south-west Ethiopia. The Blue Nile, has sources in the Ethiopian highlands surrounding Lake Tana. The Tekeze-Setit-Atbara system also contributes to the flow of the main Nile further downstream of Khartoum.

Average annual runoff of the Nile Basin is estimated to be approximately 85 billion cubic meters (BCM). Compared to other major river basins, the Nile Basin displays sharp disparity in water availability among sub-basins. Arid portions (perhaps one-third of the area of the Basin) yield negligible flows, while the Eastern Highland of Ethiopia, comprising only 15–20 percent of the land area of the Basin, yields 60–80 percent of the annual flow in the lower Nile (see Figure 1). Figure 1 is computed from TRMM-based rainfall and MODIS-based ET data. It not only shows the hydrological function of the basin, but also demonstrates the power of RS to measure water flows across areas for which no data is available.

The basin is home to a diversity of ecosystems, which are threatened by high population density and limited development over decades. The outflow of the basin into the Mediterranean Sea is marginally adequate to flush the system of pollutants and to maintain the salt balance at the interface with the sea. This implies that additional consumptive1 water resources development must be offset by reductions in consumptive use elsewhere. The relationship between land cover, land use, water use, and the economic and environmental benefits derived from the consumptive use, is thus crucial for effective land-use and water-use planning in the Nile Basin.

[1] Consumptive water uses—most commonly EvapoTranspiration (ET) from natural vegetation, forests, irrigated and unirrigated crops, wetlands and free water surfaces—result in reduced availability to downstream users. Non-consumptive uses such as hydropower generation and most domestic uses, especially where treatment plants are in place, may change the location and timing of water availability, but do not change the quantity of water in the basin in a particular hydrological cycle.

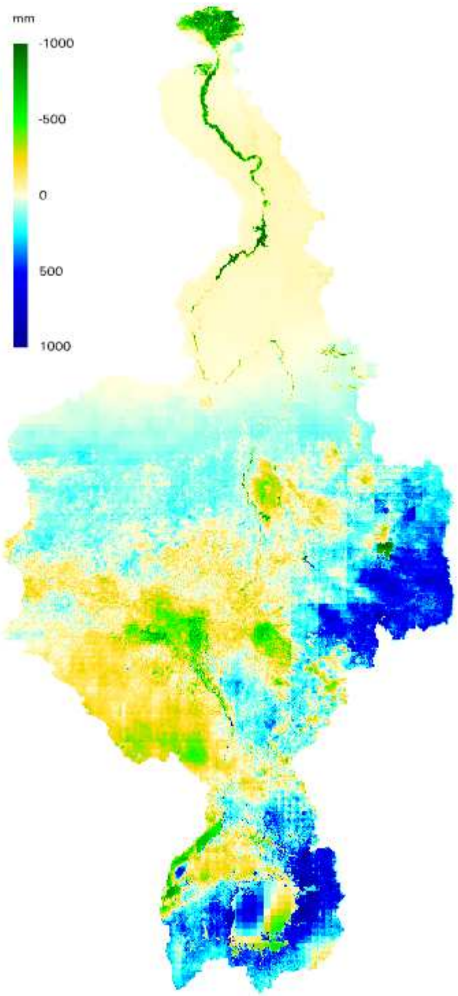


Figure 1 Climatological rainfall surplus of the Nile Basin. The rainfall is based on the period 1998 to 2007. The climatology is taken from 1960 to 1990

1.3 Remote sensing in a nutshell

Remote Sensing (RS) measurements consist of the detection and recording of reflected and emitted spectral radiation from the earth's land surface by sensors in satellites (see Figure 2). Radiation occurs in various wavelengths (visible, infrared, thermal, microwave, etc.) that can be interpreted individually or in spectral combination to estimate land surface properties, state variables and land surface physical processes.

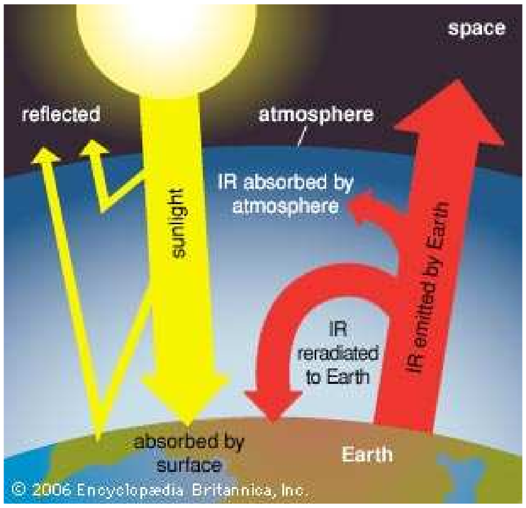


Figure 2 Interactions between radiation, land surface processes and satellite measurements. Radiation is either reflected or emitted from the land surface

The relationships between spectral radiance and land surface properties and state variables are empirical or physical. The latter means that a relationship is derived from theory or physical laws and described mathematically (e.g. temperature can be computed directly from measured radiation and the Planck function without any further information). Other relationships have an empirical character. This means they are derived from experimental measurements and are subject to random variation (e.g. the trend between microwave emissivity and surface soil moisture is soil dependent). Another example of an empirical relationship is the relationship between spectral reflectance and certain land cover classes and crop types. The spectral signature is not unique and ground truth data needs to be collected. While the physical relationships can be applied unconditionally, the empirical relationships need to be verified for each application through measurement.

The relationships between radiances and land surface physical processes are sometimes very complex and obscure. The combination of surface albedo, vegetation cover, leaf area index, surface temperature, and surface roughness makes it for instance feasible to compute actual evapotranspiration (ET), but inter-relationships between these processes are complex and require innovative modelling algorithms Remotely sensed radiance data are 'true measurements' and the radiance has to be converted into representations of land surface physical process. ET is calculated by combining (i) individual physical relationships, (ii) individual empirical relationships and (iii) a physical-mathematical interpretation algorithm that combines items (i) and (ii) with additional ground-based weather data. Hence, RS requires the involvement of simple and complex physical-mathematical models to interpret radiance quantitatively into something that is more useful for water resources management.

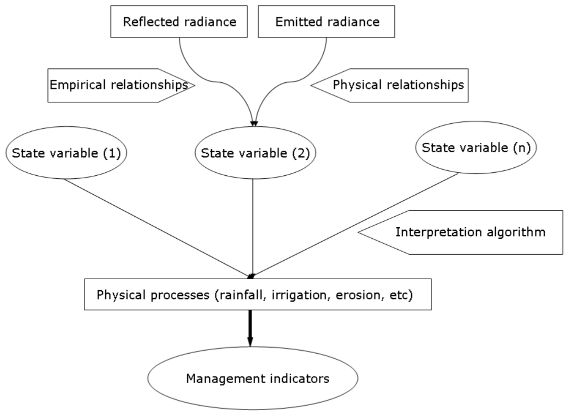


Figure 3: Schematic representation of how spectral radiances, measured by satellites, are used to infer land surface physical processes, and indicators that can be used for the management of water, land, and agricultural resources

Remotely sensed data from satellites is a complementary spatial data source to conventional ground-based measurements. Spatial data is not a substitute for conventional data, but assists with the interpretation of point data into a spatial context. Most analyses based on RS data also depend on additional ground-based measurements. RS approaches are of particular value on locations where spatial analysis of very large areas is required for policy development, large scale planning, and inter-basin or other land management decisions.

Most RS data – especially when dealing with pixel sizes of 250 m and larger - are available and accessible to the public. The Data Active Archiving System (DAAC) from the US Geological Survey (USGS) and National Aeronautic Space Administration (NASA) are good examples of such open access databases. Other RS data can be purchased on the commercial market. Because many RS data sets are archived since the early 1980s, it is also possible to create time series analysis. Temporal changes in land features such as vegetation cover, cropping patterns, and extent of wetlands could for instance be quantified.

The vast swath width of certain sensors makes it feasible to spatially cover large river basins across administrative borders in a standardized and unbiased manner. Because the RS techniques are based on spectral radiances and specified algorithms, the results are scientifically credible and trusted by authorities across borders of countries. The neutral and objective nature of remotely sensed data and analyses facilitates and encourages exchange of information and collaboration.

The earth observation system is composed of a constellation of satellites, each of them having its own measurement characteristics. Basically 4 different categories can be discerned on the basis of spatial detail:

- Geostationary satellites
- Satellites with low resolution images
- Satellites with high resolution satellites
- Satellites with very high resolution satellites

The geo-stationary satellites have the same angular speed as the rotation of the earth, which allows them to spot the same area of interest continuously. Because of this special character, the time interval between consecutive images is very small, i.e. 15 minutes. The orbiting satellites have a shoot-and-come-back character. They operate along ascending and descending tracks. While most satellites have an orbit across the poles, the TRMM satellite flies diagonally and thus only covers the region between 35° South and 35° North. During the overpass, satellites have a certain swath width that they can cover. Large swath widths allow a swift spatial cover of the earth, and thus a short revisit period. A smaller swath will require many more days to cover the earth, and the time between consecutive images can be weeks.

Low resolution images usually have a swath width of a few thousand kilometres and a repeat cycle of 1 or 2 days. Their pixel dimension varies between 250 to 1000 m. Examples of satellites in the optical region are AVHRR, MODIS, SPOT-Vegetation, MERIS, SeaWiFS and AWiFS. The passive microwave satellites have pixel dimensions between 20 km to 250 km, depending on the electromagnetic frequency. Examples are TRMM, AMSR-E and Grace. The raw data is usually freely available.

High resolution images have swath sizes between 50 to 200 km and pixel dimensions in the order of 10 to 30 m. This level of detail allows individual fields, ecosystems and water points for cattle to be visible. The orbits and coverage of Landsat, IRS and ALOS are more or less fixed. These satellites pass over at certain days and do not have much flexibility in their operation. Images such as SPOT and to a lesser extent ASTER, have the capability to be programmed. They have the capacity to tilt the camera for a more flexible operation. High resolutions are not for free, and the cost of the raw data varies between US$ 50 (e.g. ASTER) to US$ 5000 (e.g. SPOT).

During more recent years, a new category of very high resolution images have been introduced for the identification and monitoring of topographic features and for urban and industrial applications. With their spatial resolution of 0.5 to 2 m, these satellites can observe infrastructural changes, environmental violations and certain vegetation species, amongst others. This category of satellites can be well programmed and acquire images for specified areas of interest. The swath width of 20 to 50 km is very small. The costs are between US$ 20 to US$ 40 km^{-2}. Typical examples are Ikonos and Quickbird.

A list of potentially suitable satellite sensors for land and water resources management in the context of the Nile Basin is provided in Appendix 4.

1.4 RS data requirements

Knowledge of spatial and temporal variations of all elements of the hydrological cycle and their relationship with vegetation, economic activities, and the environment at large is an essential prerequisite for efficient and sustainable management of water resources. Sound decisions regarding resource allocation and usage, which are key elements for good water governance, require a robust and reliable knowledge base. Information gathered through non-conventional means, such as remote sensing imagery and derived products, can become fundamental components of RS.

Users of RS data are expected to be found to belong to the same group of data users as the DSS. In addition, it is expected that the spatial maps to be produced by the DSS-RS unit will attract other groups of users of less professional background, but with a genuine interest in water and environmental management.

This section outlines the contribution of RS data to analyses and policy decisions for water resource management in the Nile basin. In compiling this list we tried to indicate whether the contribution that RS can make, is predominantly in terms of **historical** understanding, or for real time application, or for **planning** future interventions. By "historical understanding" we mean the establishment of benchmark conditions and trends. By "real time application" we mean the use of currently (real time) observed features to estimate phenomena such as floods or crop water stress prediction in irrigated areas. “Planning future interventions” entail measuring and monitoring of indicators that give insights on “manageable” and “managed” water resources. This could be wetland conservation, reforestation or modern irrigation systems.

Our basic approach will be to collect existing RS data for the Nile Basin from the public data archives of NASA, USGS, ESA, and other agencies, and store them in the Regional DSS Center in Addis Ababa. In addition, we will apply a number of standard interpretation algorithms to produce special purpose RS products for use in the execution of the Shared Vision Program (SVP) and SAP projects. The physical processes that these programs encapsulate are related to and associated with certain RS data needs as specified in Table 1 and Table 2 for SVP and SAP respectively.

Table 1 RS data needs assessment for SVP

Projects	**Goal**	**Physical processes**	**RS data requirements**	**Historical (H), Real-time (R) or Planning (P)**
Nile Trans-boundary Environmental Action	Environmental sustainability	Deforestation; Land degradation; Soil erosion; Soil salinization.	Forested area; Vegetation cover on hill-slopes; Soil salinity; Water quality.	H, P
Nile Basin Regional Power Trade	Institutionalize regional power markets	Not applicable (Na)	Not applicable	Not applicable
Efficient Water Use for Agricultural Production	Increase water productivity	Crop production; Consumptive use; Effective rainfall; Irrigation.	Irrigated area; Irrigation intensity; Biomass production; Crop type; Crop yield; Crop ET; Rainfall; Vegetation cover; LAI; Crop nitrogen status.	H
Water Resources Planning and Management	Management and protection of Nile Basin waters	Hydrological cycle; Overall water stress; Surface water allocation; Groundwater allocation.	Land cover; Rainfall; Runoff; ET (actual, potential, deficit); Net Groundwater use; Change in total water storage.	H, R P
Confidence Building and Stakeholder Involvement	Develop trust in regional cooperation	Na	Na	Na
Applied Training	Strengthen institutional capacity	Na	Na	Na
Socio-economic development and benefit sharing	Cooperative development	Na	Na	Na

Table 2 RS data needs assessments for SAP

Projects	**Goal**	**Physical processes**	**RS data needs**	**Historical (H), Real-time (R) or Planning (P)**
Eastern Nile Planning Model	Sustainable development and management of eastern Nile waters	Optimization of water allocation and economic benefits	Land cover; ET (actual, potential, deficit); Biomass production; Economic water productivity; Net Groundwater Use; Change in total water storage.	H, P
Baro-Akobo Multi-purpose water resources	Flood management, hydropower development, environmental, and natural resources protection, water conservation, irrigation.	River overflow; Flood extent; Inflow in reservoir; Reservoir storage; Land degradation; Loss of biodiversity; Water logging; Irrigation; Crop production.	Land cover; Rainfall; ET; Soil moisture; Vegetation cover; LAI; Crop type; Open water surfaces; Lake levels.	H, P
Flood preparedness and early warning	Reduce damage and loss of life from major floods	River overflow; Inundation; Crop failure.	Land cover; Rainfall ; ET; Soil moisture; Vegetation cover; LAI; Biomass production; Open water surfaces; Lake levels.	H, R
Transmission interconnection	Promote regional power trade	Electricity demand; Power generation.	Topography	H
Regional power trade	Hydropower generation	River flow; Reservoir storage; Turbine power generation.	Rainfall; ET actual; ET potential; Irrigated area.	R
Irrigation and drainage	Increase agricultural productivity and consolidate conservation of water resources	Irrigation and drainage; Agronomy.	Irrigated area; Irrigation intensity; Crop types; ET; Biomass production; Crop nitrogen status; Crop yield.	H, R, P
Watershed management	Increase land productivity and sustainable land cover practices	Hydrological cycle interactions with land cover practices	Land cover; Rainfall; ET; Soil moisture; Vegetation cover; Biomass production; Water quality.	H, P

1.5 Link to Decision Support System

The Regional Decision Support System (DSS) Center has a wide focus to assist with various types of water policy making and environmental monitoring. One component of the generic DSS system deals with data collection and archiving. Whereas DSS systems are traditionally based on measured ground data, this study will demonstrate how DSS archives could be complemented with spatial data from satellites. Remote sensing is an attractive form of data to be added to the DSS, because:

- it is measured by electronic sensors and political conflicts of interest are excluded;
- the data is public property and can be freely exchanged;
- it exhibits a spatial variation;
- data is quickly available after satellite coverage;
- large areas can be covered;
- historic datasets are archived and can be retrieved.

The drawback is that an interpretation algorithm is required to convert the radiances into surface properties, state variables, and physical land surface processes. Although RS data is based on measurements, it is not exact. The accuracy of these interpretation algorithms for land use, rainfall, erosion, solar radiation, net primary production etc., must be verified. Field data is required to draw confidence limits for remote sensing data. In case of acceptable levels of confidence, the data can be stored in a geographical database. An accuracy label should preferably be added to the data (see chapter 7).

The RS data should be regarded as an additional layer of information. The DSS should connect the RS data layers to other sources of data or to models. The other sources of data consist of field data, such as measurements of groundwater tables, stream flow, etc. The RS data can be used also in association with hydrological simulation models for the basin. While some data should be regarded as model input data (e.g. land use, crop coefficients, rainfall), other RS data should be used for model calibration (e.g. soil moisture, actual evapotranspiration). Thematic models, such as flood risk mapping and early drought warning can also utilize RS data.

A significant GIS database will be constructed as part of the DSS that is being developed. This data consists of soil types, geological formations, terrain slopes, basin boundaries, roads, streams, administrative boundaries and many more themes. The RS data should be organized in such a way that it complements and facilitates connection to the existing GIS database.

This first chapter described the overall framework of the position of the RS data. In subsequent chapters, the source, contents, and quality of the RS data will be described and elaborated on.

2 Summary of scientific achievements

There is a growing international literature on the use of remote sensing for water management. It is beyond the scope of the current consultancy assignment to summarize 30 years of research work from international institutes and national universities. That would lead into too many details, at the cost of the general understanding on how RS as a technology could best be applied in the Nile Basin. Books and chapters prepared by Engman and Gurney (1991), Vidal (1995), Stewart et al. (1996), Bastiaanssen (1998), Schultz and Engman (2000) and Savenije et al. (2008) can be used as reviews on RS for hydrology and water management. Instead, this chapter addresses only a few key developments that are relevant and thought meaningful for the DSS of the Nile Basin. References to thematic review papers are provided at each section.

2.1 Rainfall

The detection of the spatio-temporal patterns of rainfall with remote sensing technologies has been studied for a long time. There are essentially 4 different technologies available to estimate rainfall remotely:

- Cloud indexing
- Top cloud temperatures
- Microwave emissivity
- Radar reflectivity

The most important atmospheric indicator of rainfall is the presence of clouds. Cloud indexing (Barret, 1988) is a technology to identify different types of rain clouds and estimate the rainfall from the number and the duration of clouds. There are two types of rain estimation methods based on threshold values: cloud top brightness and cloud top temperatures. Brightness is based on reflectivity; temperatures are based on emissivity of radiation in the thermal infrared range.

Dugdale and Milford (1986) developed the concept of Cold Cloud Duration (CCD), using the thermal channel of Meteosat, to generate time series of cloud temperatures for tropical altitudes in Africa, where most rainfall comes from large convection storms. They suggested that the duration above a threshold temperature value is representative of the amount of rain that is generated.

Microwave techniques are a promising alternative for measuring rainfall because of the potential for sensing the rain itself and not a surrogate of rain, such as the cloud type. Microwave radiation with wavelengths in the order of 1 mm to 5 cm results in a strong interaction between the raindrops and the radiation. This is because the drop size of rain is comparable with this wavelength. The collocation between two passive microwave polarizations at the same frequency minimizes the background effects of the land surface emissivity. A uniform background has a positive effect on the accuracy of rainfall. Water surfaces have for instance a low and relatively constant emission which contrasts with the higher emissions produced by precipitation-sized particles in the atmosphere. The more recent introduction of sensors with higher frequency channels has improved the identification of precipitation over land.

Radar measurements of rainfall are based on the Rayleigh scattering caused by the interaction of rain and the radar signal (Cracknell et al. 1991). Space borne radar measurement of rain intensity is possible with the Precipitation Radar aboard TRMM by assessing the attenuation of the radar signal by the rain. The radar has a pixel size of 4 km and can oversee a swath of 220 km. The surface is used as a reference target for determining the path averaged rain intensity that is independent of the reflectivity/rain intensity law and the radar calibration. The radar equation basic to most radar studies of rainfall is represented as:

$$P=cZ/r^2$$

Where P is the mean received power from the target, c is the speed of light (constant), Z is a reflectivity factor specific to the type of precipitation in the target area, and r is the range between the radar and the reflecting shower of rain. Hence, objects far away from the radar source are not detected. The reflectivity factor Z is of special significance because it represents a set of physical conditions. Unfortunately, it is usually necessary to evaluate this factor empirically on a region-by-region basis over lengthy periods of time. So, rain radar systems – both ground-based and satellite-based – need calibration for proper rainfall estimates.

Combining visible, infrared, passive microwave and radar is likely the best spectral satellite-based rainfall monitoring system. TRMM consists of a closely knit combination of (i) a multi-channel dual polarized passive microwave radiometer TRMM Microwave Imager (TMI), (ii) a 14 ^{GHz} Precipitation Radar (PR) and (iii) a 6-channel visible/infrared (VIS/TIR) radiometer with a spatial resolution of 2 km. Due to the low altitude of TRMM (350 km), TMI has a 900 km wide swath on the surface. The orbit elevation of 350 km is low for acquiring a 24 km pixel size for the passive microwave 19 ^{GHz} channel. The orbit is inclined at 35° so that the overpasses occur at different local times on successive days. More details on the unique TRMM sensor specification can be found in Kummerow et al. (1998).

Review papers on rainfall are prepared by Barret (1988), Barret and Beaumont (1994), Petty (1995), Pretty and Krajewski (1996), Kummerow et al. (1996), Smith et al. (1998), Kidd (2001) and Huffman et al. (2007). These papers provide rather complete background on the retrieval of rainfall from satellites.

2.2 Soil moisture

Soil moisture can also be determined from satellite data. The three major different types of algorithms could be classified into:

- Thermal infrared
- Passive microwave
- Active microwave

The strong advantage of thermal infrared radiation is the spatial resolution of 1 km. Landsat and ASTER can measure surface temperature at 60 &120 m, and 90 m spatial resolution respectively, but this size is inconvenient for the coverage of the 3 million km^2 wide Nile Basin. The relationship between land surface temperatures and soil moisture is neither unique nor linear; instead, the relationship has to be determined for every single situation as it is governed by weather conditions and vegetation development conditions. Empirical solutions between surface temperature and soil moisture will therefore not work very well, and physically based solutions are found through the mechanisms of evapotranspiration (ET). There are several types of bio-physical relationships between ET and soil moisture reported on in the international literature:

- soil moisture = f (latent heat flux, net available energy)
- soil moisture = f (ET_{act}, ET_{pot})
- soil moisture = f (T_{act}, T_{pot})
- soil moisture = f (stomatal resistance)

A value for moisture in the sub-soil can be derived by calculating the soil moisture available for root water uptake by vegetation. If vegetation abstracts water from the root zone at an unlimited rate, then we know that moisture is abundantly present. If the ET process of latent heat transfer is slowed down by stomatal closure, it is likely to be constrained by low sub-soil moisture content values. Hence, the magnitudes of ET can be used to assess the sub-soil moisture conditions. From a management point of view, it is preferred to have information on the water available to plants, something that microwave-based surface soil moisture mapping cannot provide.

The disadvantage of using thermal infrared radiation for the mapping of sub-surface soil moisture is that cloud free atmospheres are required. This is a serious restriction to the operational implementation of thermally-based moisture mapping procedures in the humid tropics. Whereas thermal moisture mapping could work well for Egypt, Sudan and large tracts of Ethiopia, it will fail to work in the Equatorial Lake region. We therefore have to review microwave-based soil moisture mapping.

The microwave region is the longer wavelength region that is not vulnerable to atmospheric interferences from clouds. Microwave radiation can be actively generated (radar), or measured from the natural emission of the land surface climatic system. It is common to express the wavelength of microwaves into band numbers and frequencies. The product of wavelength and frequency is equal to the speed of light, being constant at $3x10^8$ m s^{-1}. Wavelength and frequency are thus inversely proportional. The key is provided in Table 2. Measurements of high frequency – thus low wavelength – have much smaller pixel sizes (e.g. 5 km at 90 GHz) than at lower frequency (e.g. 56 km at 7 GHz). Soil moisture mapping requires lower frequencies to penetrate into the soil body, and unfortunately this goes along with large pixel dimensions. The lowest frequency radiometer currently in orbit is the AMSR-E instrument on NASA’s Aqua satellite. AMSR-E observes the passive micro-wave signal at 6 dual polarised frequencies, the lowest of which is C-band (6.92 GHz). It provides global coverage in two days or less. The future SMOS sensor will be equipped with an L band two-dimensional interferometer, which is expected to increase the absolute surface moisture mapping to 0.04 cm^3 cm^{-3} at 50 km pixel size with intervals of 3 days. SMOS is scheduled for launch in early 2009.

Table 3 Specification of micro-wave bands and relationship to TRMM and AMSR-E measurements

Band number	TRMM (GHz)	AMSR-E (GHz)	Wavelength (cm)	Frequency (GHz)
P-band			30 to 100	1.0 to 0.3
L-band			15 to 30	2.0 to 1.0
S-band			75. to 15.0	4.0 to 2.0
C-band		6.9	3.75 to 7.5	8.0 to 4.0
X-band	10.7	10.7	2.4 to 3.75	12.5 to 8.0
Ku-band	19.4	18.7	1.67 to 2.4	18.0 to 12.5
K-band	21.3	23.9	1.1 to 1.67	26.5 to 18.0
Ka-band	37.0	36.5	0.75 to 1.1	40.0 to 26.5
-	85.5	-	-	-

Passive microwave remote sensing is based on the measurement of emitted radiation from the land surface in the centimeter wave band (see Table 2). Within the microwave spectrum, lower frequencies (L and P band) are less affected by vegetation and can sense a deeper soil layer. The microwave emissivity of soils has an inverse relationship with top soil moisture.

The largest obstacle in soil moisture retrieval procedure is the correction for the interference of vegetation. The top-soil microwave emission signal has to penetrate through the vegetation cover. Further to that, the vegetation also emits microwave radiation, both upwards and downwards. The downward radiation is reflected at the soil-plant interface. Hence, the total passive microwave signal measured by the satellite needs to be decomposed to isolate the components that describe the soil related emissions. This requires information on the vegetation transmissivity (optical depth), single scattering albedo, surface temperature and canopy temperature. The various vegetation correction methods published in the international literature all have different performance qualities for soil moisture retrieval. The major challenge is to overcome the problems posed by the complex vegetation and earth surface structures. A successful retrieval algorithm for soil moisture must be sensitive to soil moisture, but relatively non- responsive to factors such as the surface roughness, leaf water content.

There have been numerous field experiments which have tested the reliability of remotely sensed soil moisture estimates in the US. The Southern Great Plains Experiment 1999 (SGP99) was held in Chickasha Oklahoma where winter wheat and rangeland was the predominant land surface type. The Soil Moisture Experiment 2002 (SMEX02) in Walnut River watershed in Ames Iowa, was done on a mixture of corn, and soya beans. In the SMEX03 (Soil Moisture Experiment in 2003) in Little River Watershed, the land surface was a mixture of peanuts, vegetables, cotton and pasture, and for SMEX04 (Soil Moisture Experiment in 2004) in Walnut Gulch, Arizona, the land surface cover was primarily brush and grass covered rangeland vegetation.

In Australia, in situ soil moisture time series are available from the Murrumbidgee Soil Moisture Monitoring Network (MSMMN); see Draper et al. (2000). The surface (0 to 7 cm) soil moisture is observed at 17 stations with a 30 minute interval. The only European site which complies with these criteria is the REHMEDUS network in Spain where the University of Salamanca has collected bi-weekly data from 23 stations since 1999.

The best statistical agreement between all these ground observations and surface-soil moisture based on passive microwave sensors displayed correlation coefficients of 0.83 and RMSE of 14.6%.

Radar transmits a pulse of electromagnetic radiation and then measures the backscatter. The sensitivity of the backscattering coefficient of the radar beam to soil moisture, leaf moisture, soil salinity and surface roughness prevents a straightforward signal interpretation.

The ERS scatterometer is an active microwave instrument that sends out a short pulse towards the earth's surface and measures the reflected pulse energy. Since the reflectivity of soil increases strongly with increasing soil moisture content, scatterometers provide measurement of soil moisture (Wagner et al., 2007). The ERS scatterometer is operated in C-band (5.3 GHz) and measures the vertically polarised backscatter simultaneously with three antennas at different azimuth and incidence angles. The spatial resolution of the backscatter data is approximately 50 km. The backscatter measurements are affected – besides soil moisture – by surface roughness and vegetation. Using concepts of change detection, the dynamics of the backscatter signal are attributed to soil moisture, assuming that vegetation changes are minimal.

The conclusion regarding soil moisture mapping is that microwave is preferred, but that it need to be interpreted into sub-surface values, and at a much smaller scale, to be relevant for water management applications. Research on within-microwave pixel variations of soil moisture is underway. Procedures to downscale AMSR-E data into a finer spatial resolution are under development (e.g. Hemakumara et al., 2004; Dasgupta and Qu, 2004). Top-soil moisture can also be converted into sub-soil moisture values using land surface algorithms or simple hydrological models (Entekabi et al., 2005).

For review papers on soil moisture, the reader is referred to Choudhury et al. (1995) and Njoku and Entekhabi (1996), Jackson et al. (1999), Scott et al. (2003), Wagner et al. (2007) and de Jeu et al. (2008). The journal Remote Sensing of Environment had a special issue in September 2004 (volume 92, issue 4) related to the SMEX04 soil moisture experiments.

2.3 Evapotranspiration

Competition for our fresh water supplies is increasing: between inflow, in-stream ecological requirement, and off-stream usage and consumption; between storage and natural flows; between agriculture and cities; between agriculture and recreation; between different agricultural sectors; environment and endangered species (Ritter, 2005). Evapotranspiration, or ET, tells us who is consuming the water through the process of evaporative depletion. ET is next to rainfall the second largest component of the water balance. In irrigation schemes and in wetlands, ET may exceed rainfall. The dynamic components of the latent ET water flow reflect complex interactions between climate, land use, soil types and soil wetness. The spatial and temporal variations are thus significant and more complex to determine than rainfall. Spatial ET maps are fundamental for understanding how and where water in the basins is depleted.

Remote sensing tools have been developed over the last 25 years to estimate spatially distributed ET. Different parts of the electro-magnetic spectrum can in principle be used in combination with a suite of interpretation algorithms and field scale weather data to estimate ET. The most relevant part of the electromagnetic spectrum for ET mapping is the thermal infrared region. Surface temperature is a key parameter of every flux in the land surface energy balance:

$$\mathbf{R_n = G + H + LE}$$

Where R_n is the net radiation, G is the soil heat flux, H is the sensible heat flux and LE is the latent heat flux. The latent heat flux is the equivalent energy amount (Wm^{-2}) of the ET flux (kg m^{-3} s^{-1} or mm d^{-1}). Approximately 28 Wm^{-2} are required to maintain an ET rate of 1 mm d^{-1}. Being a component of both, ET is the link between the energy and water balance. The net radiation provides most of the necessary energy to drive the ET process. Net radiation is computed from shortwave and longwave radiation exchanges (see Figure 4).

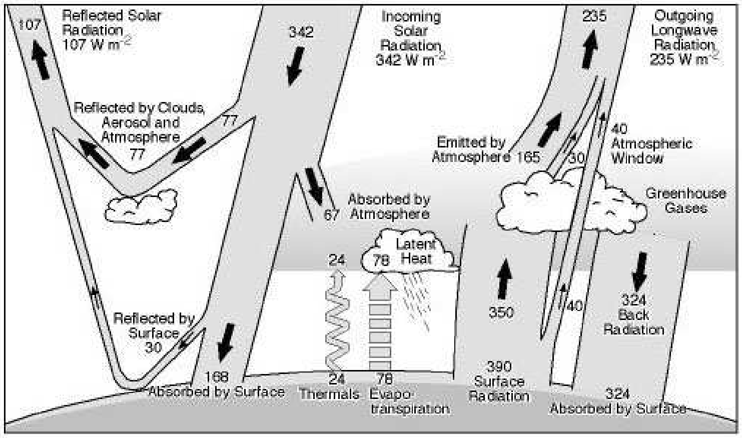


Figure 4 Schematic diagram of the energy balance in conjunction with the radiation balance

Surface temperature determines the long-wave outgoing radiation, being one component of the net radiation R_n. Surface temperature is the primary variable determining the thermal gradients into the soil (i.e. the soil heat flux G) and into the atmosphere (i.e. sensible heat flux H). A warmer land surface creates higher G and H fluxes and a lower R_n flux. From a budget perspective it can thus be argued that LE must be relatively low at warm surface temperatures. This is a physical correct manner to quantify ET, and it is the basis for several energy balance algorithms such as EARS (Rosema, 1990), SEBI (Menenti and Choudhury, 1993), SEBAL (Bastiaanssen et al., 1994), SEBS (Su et al., 2002), S-SEBI (Roerink et al., 2003), METRIC (Allen et al., 2007) and ALEXI (Anderson et al. 2003) etc. There are several validation and inter-comparisons of ET in the literature. One of the problems in ET validation is the lack of reliable ground measurements at the scale of a pixel (typically 1 km). Nevertheless, attempts are made during specifically designed large scale field experiments (e.g. Kite and Droogers, 2000). Several papers report a reliability of between 90 to 98 %.

To meet the limitation of cloud cover in thermal infrared ET mapping, a microwave version of SEBAL has recently been developed by WaterWatch. This model has been applied to the Nile Basin and the results are encouraging (see chapter 6).

More complex ET models can be constructed by assimilating remote sensing data of albedo, vegetation cover, LAI, solar radiation, soil moisture and surface temperature into numerical land surface models. These numerical models could be designed for global land surface hydrology, watersheds and for more local scale hydrological conditions. One example of such an attempt to compute ET for Africa is the Variable Infiltration Capacity (VIC) model of Princeton University. The terrestrial water cycle (evaporation, runoff, soil moisture, snow) is computed by observed and remotely sensed precipitation and temperature.

The University of Montana is working very hard on a global ET model that is based on a two-layer version of the Penman-Monteith equation for soil and vegetation. The resistances are computed from LAI.

Papers summarizing ET applications in water management have been prepared for Asia by Bastiaanssen and Harshadeep (2005) and for the western US by Allen et al. (2005; 2007). The use of ET in water management requires a paradigm shift in thinking about water consumption. In general, decision making in water management are based on rainfall, water levels in reservoirs, streams and aquifers and sometimes on the basis of discharge rates. These are all parameters that are easy to observe. The concept of controlling ET, and by that, affecting stream flow and meeting environmental flow requirements, is a rather new one (Bastiaanssen et al., 2008). ET as controlling mechanism for regulating consumption will take time to understand and be accepted by water policy makers and water managers. We believe, however, that real water saving through ET reduction is fundamental for the Nile Basin where almost all water resources are consumed and little is left for outflow to the Mediterranean Sea.

Major review papers focusing on RS algorithms for estimating ET are prepared by Moran and Jackson (1991), Kustas and Norman (1996), Coureault et al. (2005) and Kalma et al. (2008).

2.4 Solar radiation

Solar radiation is the primary energy source that governs the ET process and thereby the depletion of water from the Nile Basin. ET increases with solar radiation through complex relationships. The Penman-Monteith equation expresses these bio-physical relationships mathematically. A second important feature of solar radiation is the regulation of the photosynthesis process; there is no photosynthesis – hence no dry matter production – without solar radiation. Dry matter production is fundamental for the production of food, fodder and wood: three basic products that have significant impact on the livelihood of poor rural people. While high levels of solar radiation is beneficial for high levels of dry matter production, cloudy skies with less radiation are a basic need for the generation of rainfall, besides causing lower ambient temperature that are more comfortable for living. Hence, it is also good to have low solar radiation values.

The highly dynamic character of clouds complicates the measurement of solar radiation in the Nile Basin where a limited number of weather stations is present. Remote sensing models to calculate solar radiation have therefore been developed. These algorithms are based on visible reflectance measurements of geo-stationary satellites. The brightness of the image is a good proxy of the reflected radiation at that pixel.

The solar radiation at the ground can be calculated from the at-satellite measured radiation at the top of the earth's atmosphere, the amount absorbed in the atmosphere (dependent on the amount of water vapour present), the amount reflected from the surface (surface albedo) and the amount reflected from clouds (cloud albedo):

$$\mathbf{I}_{\mathbf{ground}} = \mathbf{I}_{\mathbf{Top\ of\ Atmosphere}} - \mathbf{I}_{\mathbf{Cloud\ Albedo}} - \mathbf{I}_{\mathbf{Surface\ Albedo}} - \mathbf{I}_{\mathbf{Atmospheric\ Absorption}}$$

Other small effects include ozone absorption and Rayleigh (or molecular) scattering. The surface albedo can be calculated for each pixel by measuring the brightness of that pixel. The brighter the clouds appear, the more radiation is reflected by clouds and less radiation reaches the ground. Since the top atmosphere radiation, the atmospheric effects, and the surface albedo, are estimated relatively accurately, it is possible to calculate the cloud albedo and so estimate the solar radiation at the land surface.

The largest source of uncertainty in the calculations of solar radiation from satellites is the reflected radiance measurement. Since cloud tops are not flat but are irregularly shaped, the reflected radiation from a given cloud may vary with the relative positions of the sun and satellite, i.e. bi-directional reflectance. This introduces an error of approximately 5% into the model. The next largest source of error is the estimation of water vapour in the atmosphere. It is measured at an uncertainty of approximately 2%.

Results of using MSG data for South Africa with the solar radiation model developed by the Landsaf team in Portugal are presented in Figure 5. This model computes the clear sky and clouded sky atmospheric transmittances separately. The SEVIRI radiometer on MSG has 3 different channels at around 0.6, 0.8 and 1.6 µm. These spectral reflectances are first transformed into a broad-band albedo for the top atmosphere. The latter parameter includes effects arising from Rayleigh scattering above the clouds, radiation reflected by the clouds - which is attenuated by the atmosphere - and the radiation reflected by the surface - which is attenuated by the atmosphere and the cloud. The clear sky transmittance is computed from direct as well as diffuse radiation after scattering. The diurnal cycle of surface albedo, spherical albedo, water vapour, total ozone amount and the visibility are considered in the MSG model (Brisson et al., 1999). There is a small bias with an overall underestimation of 4% by MSG in South Africa. Without any calibration of the model, this is an encouraging result.

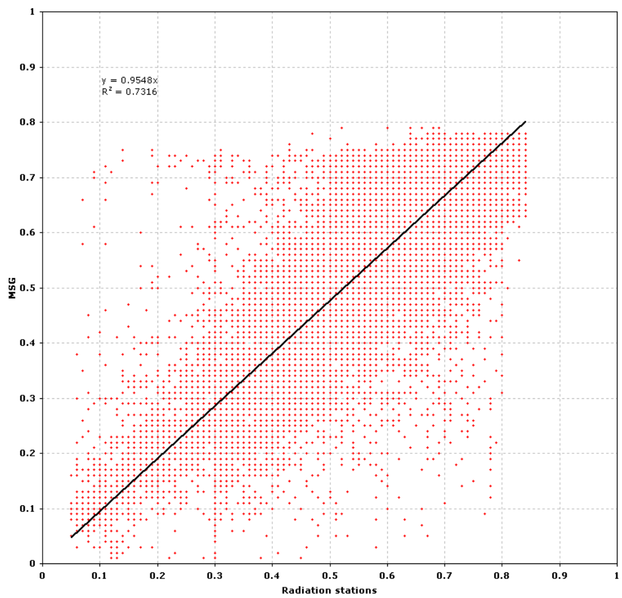


Figure 5 Validation of shortwave atmospheric transmissivity for solar radiation in the Western Cape using MSG images acquired between July 2005 and July 2007

Testing the satellite method of determining solar radiation in Australia was undertaken using pyranometer data from 9 network sites from July and August 1997. The majority of measurements agreed within 6%. The Australian method tends to slightly over-estimate the radiant exposure in wet, cloudy conditions, and to under estimate it in dry conditions.

Review papers on solar radiation calculations from satellites were prepared by Gautier et al. (1980), Raschke (1995) and Brisson et al. (1999), among others.

2.5 Land degradation

Land degradation denotes a broad category of induced changes in the landscape which cause negative effects. Land degradation or soil degradation is a general term used for a large number of unfavourable processes such as surface runoff, rill and gully formation, erosion, mass movements (slides, slumps & rockfall), wind erosion, salinization, chemical (acidification & toxicity), physical (soil sealing & crusting), biological degradation and desertification.

Such phenomena are often man-induced, although climate change could lead to similar negative effects and consequences. Severe land degradation affects the availability of arable land, and decreases wealth and economic development. A downward eco-social spiral is created when marginal lands are nutrient depleted by unsustainable land management practices which result in lost soil resilience that lead to soil degradation and permanent damage. If multiple types of land degradation forms are combined, desertification will be accelerated.

Wind erosion is a function of speed and direction of wind, land use/cover and the soil properties. Water erosion is a function of land use/cover, vegetation cover, rainfall, topography, soil characteristics and land management. Traditionally aerial photo interpretation is used for the detection of erosion. Now optical satellite systems are most frequently applied in erosion research. The limitation of spectral variety and spatial resolution of satellite data often makes it difficult to discriminate between degrees of land degradation. It is needless to say that remote sensing data cannot be used to analyze all types of land degradation.

Vrieling (2006) showed that satellite remote sensing can contribute to erosion assessment. The efficacy of most methodologies depends largely on site characteristics. For semi-arid areas, many interesting techniques such as SAR interferometery and spectral un-mixing of optical data can be applied to assess erosion status. However, these techniques will only work under specific circumstances and cannot be transferred to other environments. Due to the complexity of erosion processes, regional differences, and scale dependency, it is unlikely that a standardized operational erosion assessment system with satellite data will develop in the near future.

Whereas the changes in physical soil conditions are hard to quantify – changes can be seen but the interpretation is not unambiguous – changes in vegetation cover are straightforward to detect.

Monitoring of vegetation cover change is classically done using time series of NDVI. Since vegetation degradation is one form of desertification, the net primary productivity can also be taken as an indicator of land degradation that represents the overall physical and chemical soil condition (see Figure 11). It has been shown by various authors that NOAA-based NDVI data have a good correlation with Net Primary Production. Indeed, the MODIS land science team is now computing NPP from NDVI and complemented by other information using global scale ecological production models (e.g. Field et al., 1995). The bottleneck in these numerical models is converting absorbed radiation measurements into dry matter estimates. This so called radiation or light use efficiency should be related to the governing ambient conditions such as temperature, vapour pressure deficit, radiation and soil moisture availability.

The stomatal response model developed by Jarvis (1976) and Stewart (1988) is excellently suitable to describe the carbon intake as a function of these ambient conditions. The Surface Energy Balance Algorithm for Land (SEBAL) computes the biomass production according to the biological regulation mechanism of stomata as mathematically defined by the Jarvis-Stewart model.

A rather comprehensive book on the spatial detection of land degradation has been prepared recently by Bolle et al. (2006). It describes the theoretical processes of remote sensing, and addresses various applications of land degradation in the Mediterranean region. The background of reflectance of degraded land is explained well in van der Meer and de Jong (2005).

3 Remote sensing data archives available for the Nile Basin

3.1 Types of data providers

In Chapter 2 we gave a brief overview of scientific progress in RS and water management internationally. Whilst progress has been interesting and encouraging, only a few models and selected data sources are processed systematically and posted in active data archives for public usage. Only data that meets general quality standards are supposed to be made available, but some data in some archives is of poor quality and some excellent data is for economic reasons not systematically organised. The scientific community in this field is sometimes reluctant to make their results publicly available and their results are also not always tailored for the needs and priorities of water managers. This is regretted because good data is as scarce as water. NASA – and to a lesser extent ESA - have worked on active data archives that will promote the application of RS technologies in water management. The only problem is that they do not provide a guide on how to best utilize the spatial data that they provide. This chapter therefore provides a global inventory and the products that can be derived from it will be discussed in chapters 5 and 6.

This chapter describes the results of an international survey of the availability of remote sensing data to support basin scale water resources management. We only give a summary overview of the world wide available remote sensing data sets. We attempt to distinguish between products that have potential for use in the Nile basin, and products that are too site specific or have not been validated widely. The overview is therefore not exhaustive and includes key data providers only. The key websites – including links – are described.

While searching for Nile basin datasets, it became apparent that some data-archives are completely open and data can be downloaded immediately, while in other cases permission is required or a (infinitely long) request procedure needs to be completed prior to the data release (see Table 4). Some data sets are directly accessible as operational products or – in our vocabulary – a Directly Accessible Portal (DAP), which will be described in Appendix 5.

NASA, USGS and NOAA are all American governmental institutions dealing with earth science and climatology. Under their governing law, they are encouraged to release their publically funded tools and products to everyone who is interested. This policy allows unrestricted use of data. User-friendly interfaces have been built to accommodate the global satellite user community and guide users to the data layers they are searching for. Their servicing system is very well organised and they also provide excellent support if required. Further to the posting of raw data, they also offer processed products with transparent algorithms and a comprehensive description of them. Data quality control is provided at different levels, and the user can select the data from a wide variety of well described quality levels: from raw data to level 3 quality checked data. NBI can benefit from these pre-processing and archiving facilities. The challenge is to select the right database layers and to compose the correct datasets for sound and relevant applications. Most NASA, USGS and NOAA data belongs to the DAP category.

The European Space Agency (ESA) is, by its international character and multiple-donor thrust from the various nations, more difficult to manage from a political point of view. The mission and objectives are not clearly spelt out, and end-users are limited to a few classical government organizations who have access to scheduled data. It is as a result difficult to get access to satellite data from for instance ENVISAT (structured to aid the management of natural resources). Data requests have to go through user groups first which are composed mostly of scientists not engaged in development of operational products. The good news is that in the framework of "the living planet" program, the contribution of open access data archives are encouraging and there is thus "a wind of change". Hence, while data access is beyond the capacity of the American archives, this may change in the future. Most ESA data falls in the PAP category. More information on non-DAP data archives can be found in Appendix 6.

Table 4 Different categories of public land-water related spatial databases

Description	Product	Acronym	Dissemination policy
Data archives with geo-data	Directly Accessible Portal	DAP	Free
Controlled release of geo-data	Partially Accessible Portal	PAP	Permission required
Dedicated products for resources management	Dedicated Viewing Products	DVP	Only bitmap pictures
Web portal via commissioned order	Commercially Available Remote Sensing Products	CARSP	Subscription or licensing

Several existing international programs or projects in the Nile basin have created websites where spatial data can be viewed, but the data is not accessible. Some examples of these categories are the Famine Early Warning Systems (FEWS) network from USGS that is implemented through the Climate Prediction Centre of NOAA. The Air Force Weather Agency (AFWA) is another example of an institute that displays data to be viewed, but does not provide the real data. These are typical DVP products.

If the Regional DSS Center is highly interested in these operational – and sometimes excellent – DVP products, they should try to establish a special agreement with the organizations to provide them with the data.

The last category of RS data providers is the commercial sector that will make data or services available at a charge (CARSP). These advisory firms have their own RS algorithms that they apply only after being financially compensated for their efforts.

Hydrological information can often be difficult to obtain due to a region's inaccessibility, the sparse distribution of gauge stations, or the slow dissemination of data. Hydrological products from satellites are unaffected by political and logistical considerations and can provide accurate measurements.

The next section elaborates on the most important data bases for certain specializations. The inventory of RS databases for the Nile Basin is based on operational experiences in other countries, as well as an extensive e-search on the World Wide Web. The compilation is not– and cannot – be exhaustive. The selection of the best products for NBI will be discussed further in Chapter 5.

3.2 Inventory of selected water-related remote sensing data archives

Rainfall

Although weather radar technology enables us to map rainfall over land in a spatially distributed manner, a network of ground based radar devices is – due to the high costs - not present in the Nile Basin. There are different methods to determine rainfall from satellites. One of the oldest and most widely used techniques is the mapping of cloud cover. The presence of clouds can be identified by means of visible reflectance (VIS) in combination with dark clouds that usually contain a higher amount of water vapour. Clouds that are filled with water vapour are usually cooler at the upper part of the cloud. Cold Cloud Duration (CCD) mapping is a relatively old Thermal Infra Red (TIR) technology to register the temporal variation in cloud temperatures. The advantage of VIS/TIR technology is that they can be measured from the Meteosat Second Generation (MSG) satellite with a 15 minute time interval for the entire Nile Basin. The drawback is that relationships between reflectance and thermal infrared emittance at the one hand, verses rainfall at the other hand, have a strong empirical character.

To address the problem of incomplete ground data and non-uniqueness of VIS/TIR data, the United States Department of Defence has established a constellation of polar orbiting satellites that carry passive microwave sensors. The Special Sensor Microwave/Imager (SSM/I) instrument is a commonly used solution to the estimation of rainfall. Variations in the amount of energy received at different frequencies are an indication of the rate at which the rain is falling near the ground while the satellite is overhead.

The Advanced Microwave Sounding Unit-A (AMSU-A) is a multi-channel microwave temperature/humidity sounder that measures global atmospheric temperature profiles and provides information on atmospheric water in all of it's forms (with the exception of small ice particles, which are transparent at microwave frequencies). Information from AMSU-A on the presence of clouds is used to correct the infrared measurements for the effects of clouds. AMSU has two channels at 23.8 and 31.4 GHz to identify precipitation and correct for surface emissivity, atmospheric liquid water, and water vapour effects. These window channels are also used to derive rain rate, sea ice concentration, and snow cover for example.

There are several operational rainfall products for East Africa (see Table 5). Most products are based on a combination of visible (VIS) and infrared (IR) measurements from geostationary satellites, in combination with a microwave imager such as from SSM/I and TRMM.

Table 5 Selected RS-based precipitation products for the Nile Basin

Satellite	Acronym	Website	Pixel size (km)	Repeat cycle (days)	Data category
TRMM	NASA/JAXA	http://trmm.gsfc.nasa.gov/	25	0.125	DAP
MSG	FEWSNET	http://earlywarning.usgs.gov/adds/dwndailyrfe.php	8	1	DAP
AMSU	MSPPS	http://www.orbit.nesdis.noaa.gov/corp/scsb/mspps/	100	1	DVP
Combi	AFWA	http://www.pecad.fas.usda.gov/cropexplorer/imageview.cfm?regionid=eafrica	25	10	DVP
MSG	TAMSAT	http://www.met.reading.ac.uk/~tamsat/cgi-bin/latest_rfe.cgi	2.5	10	DVP
MSG	EARS	http://www.ears.nl/rainfall_field.php?lang=en	2.5	1	CARSP

The joint U.S.- Japanese Tropical Rainfall Measuring Mission (TRMM) satellite carries an improved passive microwave detector similar to the SSM/I. TRMM was the first satellite to have an active space-borne Precipitation Radar (PR) at 13.6 GHz. The microwave Precipitation Radar (PR) is capable of providing information on the horizontal and vertical distribution of rainfall at resolutions of 4 km and 250 m respectively. Similar to weather radars on the ground, the PR, as it orbits the earth, emits pulses of electromagnetic energy and measure the energy reflected from precipitation in the atmosphere below. The PR is able to detect a raindrop's size, speed, and altitude.

The combination of both passive and active microwave sensors on the TRMM observatory, leads to greatly improved products of spatial measurement of precipitation. Figure 6 shows the result of product 3B43 and the definition of the various TRMM products is elucidated in Figure 7. The TRMM Microwave Imager (TMI) was developed from the SSM/I instrument, with the addition of a 10.7 GHz channel. The frequency of the passive microwave radiometers vary between 10 to 85 GHz. This, together with the Visible and Infrared Scanner (VIRS), constitutes the passive rainfall sensors. The drawback is that passive microwave sensors cannot measure precipitation continuously and that the weak signal requires large pixel dimensions (~25 km). The main difficulty in rainfall measurements is related to the period over which integrated rainfall is estimated. TRMM offers a range of operational products to boosts its application in the public domain (see Table 6).

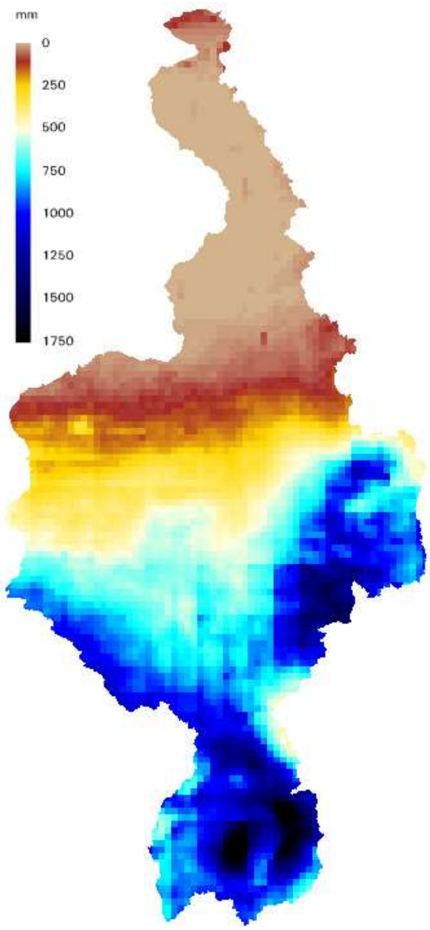


Figure 6 Example of the non-calibrated TRMM rainfall distribution across the Nile Basin on the basis of 3B43 product, between 1998 and 2006

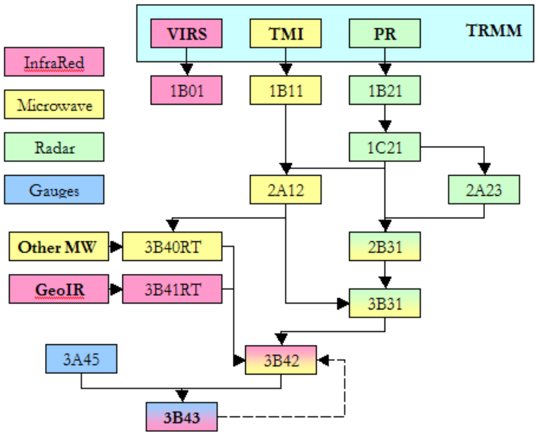


Figure 7 Multiple sensor configuration of TRMM and their interactions

Table 6 Various TRMM products available

ID	Product name	Time resolution	Space resolution
1B01	Visible and Infrared radiance	92.5 min, 16 orbits per day	2.4 km
1B11	Microwave brightness temperature (TMI)		5.1 km
1B21	Precipitation Radar power (PR)		5.0 km
1C21	Precipitation Radar reflectivity		5.0 km
2A12	TMI hydrometeor profile		5.1 km
2A23	Precipitation Radar rain characteristics (PR)		5.0 km
2B31	Combined rainfall profile (TMI, PR)		5.0 km
3B31	Combined rainfall (TCI)	Month	5° and 0.5°
3A45	CAMS or GCPC gridded rain gauge	Month	2.5°
3B42	TRMM and other-GPI calibration rainfall	3-hour	0.25°
3B43	TRMM and other sources rainfall	Month	0.25°

The most recent and best estimates of precipitation is provided by the level 3 product 3B42 (3 hourly) and 3B43 (monthly). These level 3 products combine information from the three TRMM instruments with information from other satellites calibrated with precipitation gauge data from the Global Precipitation Climatology Project (GPCP). The drawback is the large spatial resolution of 25 km.

Soil moisture

In Chapter 2 we showed that there are basically 3 different technologies available for the estimation of surface soil moisture: (i) the scatterometer, (ii) the passive microwave sensor and (iii) the radar. The soil moisture of the sub-soil can be derived from thermal infrared radiation, or from a combination of remote sensing measurements in conjunction with simple hydrological models that describe the relationship between moisture in the top soil and moisture in the sub-soil. Although scientific progress in the field of data assimilation and soil moisture estimation is encouraging, the operational products are in their infancy and sub-soil moisture values are not operationally available. The DAP, PAP and CARSP products based on these data are listed in Table 7.

Table 7 Various RS-based soil moisture products for the Nile Basin

Satellite	Acronym	Website	Pixel size (km)	Repeat cycle (days)	Data category
AMSR-E	NASA	http://www-nsidc.colorado.edu/data/amsre	25	3	DAP
AMSR-E	VUA	http://www.geo.vu.nl/~jeur/lprm	25	3	DAP
ERS	SCAT	http://www.ipf.tuwien.ac.at/radar/ers-scat/home.htm	50	30	DAP
ENVISAT	ASAR	http://www.ipf.tuwien.ac.at/radar/index.php?go=scansar	1	30	PAP
model	PECAD	http://www.pecad.fas.usda.gov/cropexplorer	100	1	DVP
model	COLA	http://wxmaps.org/pix/soil10.html	50	1	DVP
MODIS	SEBAL	http://www.waterwatch.nl	1	1	CARSP

AMSR-E daily L3 surface moisture maps are archived and distributed by the Snow and Ice Distributed Active Archive (DAAC) at the National Snow and Ice Data Center. AMSR-E is a conically scanning total power passive microwave radiometer sensing microwave radiation (brightness temperature) at 6 frequencies with horizontal and vertical polarized radiation between 6.9 to 89 GHz.

AMSR-E passes the equator around 01h30 (descending) and 13h30 (ascending). The most reliable emitting layer temperature estimates will occur during the night time because near-surface air, canopy and surface soil temperatures are then all uniform and have the same temperature value. AMSR-E based soil moisture is not measured when snow cover, frozen ground, dense vegetation, precipitation, open water or mountainous terrain occur in the sensor footprint. Currently areas with dense vegetation, permanent ice and snow are masked. The limitations of AMSR-E are the coarse footprint resolution (56 km), the "sparse vegetation cover" requirement, and the shallow sensing depth.

The method developed by Njoku is the official AMSR-E soil moisture science team contribution, and is based on polarization ratios, which effectively eliminate or minimize the effects of surface temperature. Currently NSIDC only uses the 10.7 GHz channel (X-band) as the C-band is disturbed by radio frequencies. Daily soil moisture maps are generated on a nominal 25-km grid by time-compositing the level 2B parameters separately for ascending and descending passes. NSIDC has announced during May 2008 that reprocessing has begun for all AMSR-E Level 3 land products. The land products have moved from Beta to Transitional or Validated states and incremented from Version 01 to Version 02. Reprocessing began with 19 June 2002 (the start of the AMSR-E mission) and will continue through the present.

Top soil moisture is alternatively derived - by the Free University of Amsterdam (VUA) - by using the Land Parameter Retrieval Model (LPRM). The dataset covers the period of 1978 to present and has a 2 to 3 day revisit time at the equator for both day and night time overpasses. The LPRM is based on a forward radiative transfer model to retrieve surface soil moisture and vegetation optical depth. The land surface temperature is derived separately from Ka-band. A unique feature of this method is that it may be applied at any microwave frequency, making it very suitable to exploit all the available passive microwave data from historic satellites.

While the NSIDC only uses the X-band, the VUA uses either C-band or X-band. Other differences between the NSIDC algorithm and the VUA algorithm are the method for modeling vegetation optical depth and the estimation of soil/canopy temperature. Comparisons between the operational products for the Nile basin are presented in Figure 8 and Figure 9. It can be noted that the NSIDC has more continuous and natural spatial patterns than the VUA model. The data also seems to be more complete than for VUA, which contains a relatively large fraction of missing pixels.

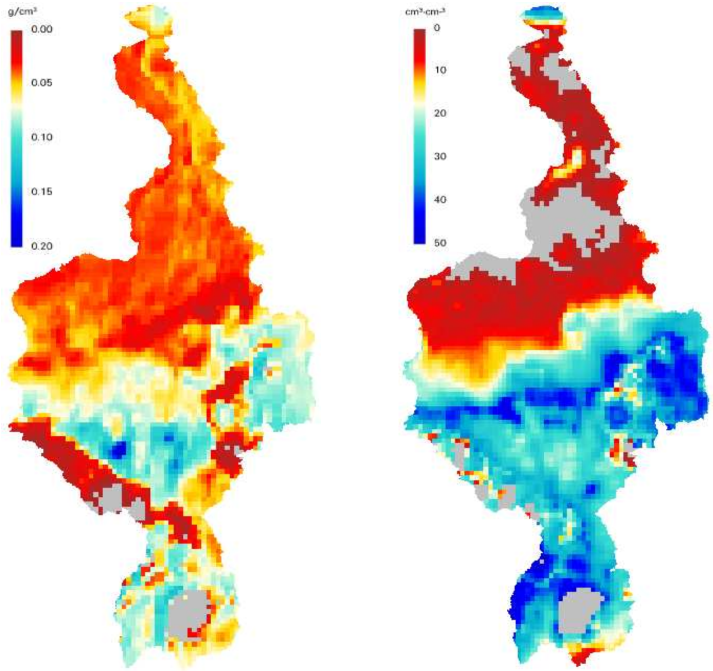


Figure 8 Monthly average soil moisture distribution in the Nile Basin in September 2003 according to NSIDC (left) and VUA (right) AMSR-E algorithms

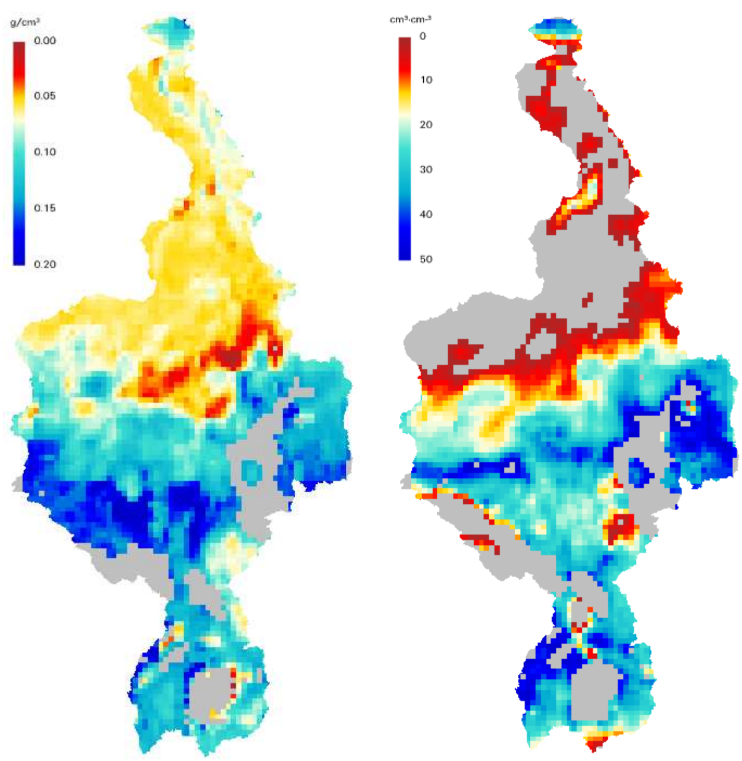


Figure 9 Daily soil moisture conditions in the Nile Basin at 14 September 2003 according to NSIDC (left) and VUA (right) AMSR-E algorithms

Global, coarse-resolution soil moisture data (25-50 km) are derived from backscatter measurements acquired with scatterometers onboard the satellites ERS-1 and ERS-2 (1991 to present) and the three MetOp satellites (2006-2020). The University of Vienna provides two different products:

- Level 2 products representing the soil moisture content within a thin soil surface layer (< 2 cm) during the time of overflight of the satellite.
- Level 3 products representing the water content in the soil profile, regularly sampled in space and time.

The Level 2 surface soil moisture data are derived using a change detection method that relies upon the multi-incidence observation capabilities of the ERS and METOP scatterometers to model the effects of vegetation phenology. The surface soil moisture values are scaled between 0 and 1, representing zero soil moisture and saturation respectively. Retrieval is not possible over tropical forest which affects about 6.5 % of the land surface area.

Level 3 soil moisture products are obtained by some kind of modelling approach using the ASCAT Level 2 and other data sources as input. A typical Level 3 product is an estimate of the soil moisture content for different soil layers and different temporal and spatial sampling characteristics, tailored to the needs of specific user groups. Our standard Level 3 product is the so-called Soil Water Index (SWI) that is a measure of the profile soil moisture content obtained by filtering the surface soil moisture time series with an exponential function.

One of the few operational soil moisture databases created on the basis of Synthetic Aperture Radar is the archive of the University of Vienna. The ASAR aboard Envisat combines large-area coverage and short revisit periods, albeit at a degraded spatial resolution compared to conventional SAR imaging modes. There are probably more commercial providers who could create soil moisture products based on SAR, but they have no DAP programs to make their services available.

SEBAL calculates soil moisture of the sub-soil on the basis of thermal infrared imagery. An empirical relationship between the degree of soil moisture saturation and evaporative fraction of the energy balance is applied (Scott et al., 2003). The evaporative fraction is determined from thermal infrared imagery. FAO provides a global soil map with information on the saturated soil water content.

These RS techniques for the retrieval of soil moisture still require validation against conventional methods. Several factors make soil moisture validation extremely difficult: (i) there is a mismatch in scale between satellite footprints and a ground sampling, and (ii) soil moisture is spatially highly variable, influenced by various land surface and meteorological factors at different scales and (iii) soil moisture is highly variable in time.

Evapotranspiration

Most ET modelling work based on satellite images has been conducted in the research arena, and very few examples exist of making ET maps available in an operational context. Yet the demand for it is growing, and a breakthrough in the generation of ET data archives is expected in the next couple of years. Despite several attempts by the University of Montana, under the aegis of NASA, to prepare an operational ET product based on MODIS data, this so called MOD 16 product has not been accomplished. Although theoretical models are sound, applications create various kind of problems. First results for Africa are shown in Figure 10. The ET fluxes appear to be very low as compared to the annual rainfall.

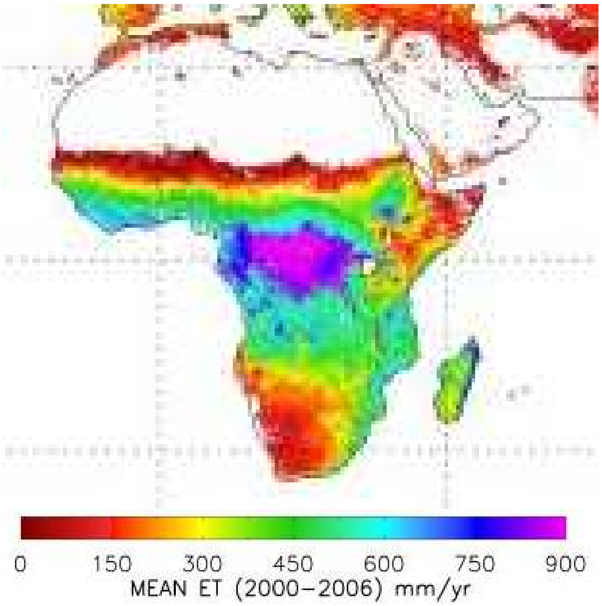


Figure 10 Actual ET over Africa computed with the latest prototype MODIS 16 product developed by the university of Montana

Princeton University is computing the terrestrial water cycle (evaporation, runoff, soil moisture, snow) using the VIC land surface model, forced by observed and remotely sensed precipitation and temperature. This seems to be an example of a product in progress, but the data could not be accessed.

The physical Soil-Vegetation-Atmosphere-Transfer scheme TESSEL - used by the global ECMWF numerical weather prediction model – is used in conjunction with MSG data to compute ET fluxes. Each pixel is considered as a mix of homogeneous entities called "tiles" representing a particular cover type (bare soil, grassland, crops, forest). Some parameters are defined at the pixel level and are thus shared by all the tiles composing the pixel, while others are defined at the tile level, most of them are extracted from the ECOCLIMAP database. The resulting ET value for each pixel is obtained through weighting of each tile in the pixel.

The SEBS model from the International Institute of Geo-Information Science and Earth Observations (ITC) is applied and tested in several countries as an academic model. No examples for the Nile Basin could be found.

In addition to public services, there are commercial companies that provide remotely sensed-ET maps upon request. EARS in Delft (NL) is one such firm that sells evapotranspiration maps for Africa. Their calculations are based on Meteosat images and the spatial resolution is approximately 5 km. The product is on the market since the end of the seventies and it is the longest existing operational ET product in the world.

WaterWatch in Wageningen (NL) provides an operational ET service upon request, and their SEBAL-based ET product utilizes low resolution MODIS images (250 to 1000 m) accomplished with high resolution images (ASTER, Landsat, IRS, SPOT) if required. A microwave version of SEBAL is available since early 2008 for applications during rainy periods and frequent cloud covered areas. An example of regional scale weekly applications can be viewed via Google Maps (www.waterwatch.nl/flevoland and www.boerinbeeld.nl).

Table 8 Selected RS-based evapotranspiration products for the Nile Basin

Satellite	Acronym	Website	Pixel size (km)	Repeat cycle (days)	Data category
MODIS	Montana	http://secure.ntsg.umt.edu/projects/index.php/ID/9a3dae27/fuseaction/projects.detail.htm	1	3	DAP
MSG	VIC	http://hydrology.princeton.edu/model_code.php	25	3	DAP
MSG	TESSEL	http://landsaf.meteo.pt	3	1	PAP
MSG	SEBS	http://www.itc.nl/research/policy/spearhead5/watercycle/EAGLE.asp	5	1	PAP
MODIS	SEBAL	http://www.waterwatch.nl	1	1	CARSP
MSG	EARS	http://www.ears.nl/evapotranspiration_field.php	5	1	CARSP

Other relevant water related data

More water related data can be collected that provide insights in the functioning of the Nile basin water resources. Table 9 provides a synthesis of selected databases that contain interesting data. The data is related to water levels, meteorological conditions etc. The NASA's Earth Observing System (EOS) Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/) provides a wealth of data which, if properly combined and interpreted, is useful for water management. Water management goes beyond hydrological processes such as precipitation and soil moisture. The EOS data gateway is the common warehouse for TRMM, AMSR-E, ASTER, AVHRR, Landsat and MODIS data. The DSS-RS unit should become a frequent visitor of this website.

Well organized MSG related data can be obtained via the Land Surface Analysis Satellite Applications Facility (LANDSAF) program. Landsaf is an Eumetat program from the European Space Agenca (ESA) that is jointly executed by several national meteorological institutions in Europe in conjunction with the University of Valencia. The Landsaf data is hosted at the Portuguese Institute of Meteorology and it has a very user friendly interface. (http://landsaf.meteo.pt). The purpose of Landsaf is to increase the benefits from the MSG satellite. The data consists of land surface temperature, downwelling surface solar radiation, downwelling surface long-wave radiation, surface albedo, snow cover, fractional vegetation cover, LAI and fPAR.

The Climate Research Unit (CRU) of the University of East Anglia (http://www.cru.uea.ac.uk/) has developed an excellent historic collection of global meteorological data from field weather stations. CRU prepared high resolution gridded data sets from single weather station observation points using advanced geo-statistical procedures. They offer various datasets since 1901 to 2002 with a global coverage at a pixel size of 50 km. Most routinely measured meteorological datasets are covered.

The World Water and Climate Atlas of the International Water Management Institute (IWMI) includes monthly and annual summaries of precipitation, temperature, humidity, hours of sunshine, evaporation estimates, wind speed, total days with and without rain, days without frost and Penman-Monteith reference evapotranspiration rates. This core data is assembled from weather stations around the world for the period 1961-1990 and taken from the Climate Research Unit.

The MARS Food program of the Joint Research Institute of the European Union receives 10-daily and monthly outputs of the European Centre for Medium-Range Weather Forecast (ECMWF) atmospheric model. The original global data at 1 degree resolution are downscaled to 0.5 degree grids. This weather data set contributes to the calculation of ET. In addition to that, ECMWF offers their ERA40 data product, which is a re-analysis of a 40 year record of integrated measured and simulated data using data-assimilation technologies among others.

Table 9 Selected RS products to support water management in the Nile Basin

Theme	Product	Website	Pixel size (km)	Repeat cycle (days)	Data category
Solar radiation	Landsaf	http://landsaf.meteo.pt	5	1	DAP
Climatology	CRU	http://www.cru.uea.ac.uk/cru/data/	50 km	1	DAP
Climatology	CRU	http://www.iwmi.cgiar.org/WAtlas/atlas.htm	17	30	DAP
Climatology	ECMWF	http://mars.jrc.it/marsfood/ecmwf.htm	50	1	DAP
Climatology	ERA40	http://data.ecmwf.int/data/d/era40_daily/	50	1	DAP
Climatology	NASA	http://gmao.gsfc.nasa.gov/operations/summary.php	50	1	DAP
Water levels	Jason	http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/gr_regional_summary.cfm?regionid=eafrica	na	3	DAP
Water levels	TU-Delft	http://rads.tudelft.nl/rads/data/authentication.shtml	na	na	PAP
Aquifer storage	GRACE	http://grace.jpl.nasa.gov/	250	30	DAP

The USDA, NASA and University of Maryland have a joint program to collect water level data from satellites. The Poseidon altimeter on the Topex satellite – and its successor Jason - was used successfully for this purpose. Laser altimeters measure the time of returning microwaves. The instrument is a single-band (13.65 GHz) radar altimeter. Although the Poseidon instrument is meant for use of sea surface elevations and sea currents, approximately 100 lakes located around the world are included in the dataset. Lakes covered in the Nile basin are Lake Nasser, Lake Victoria and Lake Tana. These lake levels are thus known with a high precision to the global world.

Radar altimetry is another technically viable methodology for acquiring levels of rivers and lakes. Altimetry has the advantage of not being effected by clouds, night time conditions, or even vegetation. The accuracy of altimetry measurements vary over land surfaces by tens of centimeters, mainly because of the heterogeneity of the reflecting surface. Satellite radar altimeters can thus potentially monitor height variations of inland waters (Birkett, 1998; Vorosmarthy et al., 1999). To the author's knowledge, there is however no database available to collect this data. There are several commercial agencies that could do the radar altimetry interpretation, if required.

The twin satellites of GRACE map the Earth's gravity fields by making accurate measurements of the distance between the two satellites, using GPS and a microwave ranging system. This is a cost-effective way to map the Earth's gravity fields with unprecedented accuracy. The results from this mission will yield crucial information about the distribution and flow of mass within the Earth and its surroundings such as runoff and ground water storage on land masses. The GRACE data is divided into three levels. The Level-1B products are processed to produce the monthly gravity field estimates in form of spherical harmonic coefficients. Occasionally, several months of data are combined to produce an estimate of the mean or static gravity field. These estimates are labelled Level-2. After validation, all Level-2 and accompanying Level-1B products are released to the public through two portals. The GRACE Tellus website provides time-series of surface mass anomalies in map forms, after suitable treatment for smoothing and corrections. The GRACE Tellus website provides time-series of surface mass anomalies in map forms, after suitable treatment for smoothing and corrections. This site also provides products created synergistically with GRACE and TOPEX/Jason-1 missions. Monthly variations of water storage are highly valuable for determining basin scale water balances. The large pixel size of 250 km is a major drawback today, and likely this limitation of spatial scale will be improved in the future.

One of the remote sensing products that is highly valuable for disaster management is the location of floods. Remote sensing observations provide spatially distributed information that can be exploited to improve flood forecasting and risk mitigation. These observations provide potential tools for improving the detection and monitoring of flooding events - particularly within data poor regions of the world lacking extensive ground-based rainfall observations. Of particular importance is information concerning antecedent soil moisture conditions. Soil moisture determines the partitioning between infiltration and overland flow and thus surface runoff generation during rainfall. If properly interpreted, passive microwave observations from AMSR-E can provide large-scale estimates of antecedent surface soil moisture conditions and enhance forecasting and monitoring of regional-scale flooding events. Such microwave observations provide an all weather monitoring system - capable of penetrating dense cloud cover typically associated with large-scale flooding events. Regional-scale flooding events are typically associated with near-surface saturated conditions over very large areas.

The Darmouth Flood Observatory detects and locates floods each day (http://www.dartmouth.edu/~floods/). Frequent updates of surface water conditions world-wide are provided, in particular, by sea winds microwave scatterometer data from the NASA QuikSCAT satellite, AMSR-E daily soil moisture products (from the AQUA satellite) and MODIS optical imaging. Figure 11 and Figure 12 are examples of maps showing flooded areas.

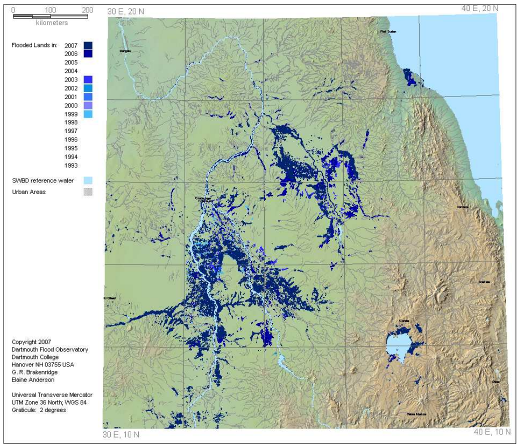


Figure 11 Flooded areas in the basin of the Blue Nile. The flood plains around the major rivers of south-eastern Sudan and Lake Tana are clearly visible

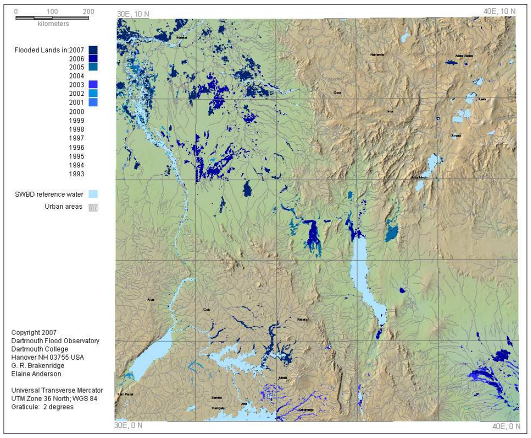


Figure 12 Flooded areas in the basin of the White Nile. The Sudd and Machar wetlands are clearly visible

A discharge estimator is obtained for selected river reaches (now numbering over 3000). This estimator is a ratio of calibration-target radiance (for a local land parcel unaffected by the river) to measurement-target radiance (for a pixel centred over the river reach). As rivers rise or fall, reach surface water areas increase or decrease. The much lower microwave emission from water than land surfaces, allows consistent measuring of these changes through the ratio. The ratio also removes the effect of most other factors. Water discharge values can be derived by using rating curves based on local available ground-based gauging station data to convert the calibrated RS signal. This product of Darmouth Flood Observatory is referred to as River Watch.

NASA has also developed a flood product. Their product is based on TRMM data (http://trmm.gsfc.nasa.gov/publications_dir/potential_flood_hydro.html. It is a 3B42 daily TRMM product. This kind of product suggests that a similar model could be tailor made for the Nile Basin. NASA has jointly with the USGS developed the Geospatial Stream Flow Model (GeoSFM). GeoSFM is based on TRMM rainfall, land cover, soil type and slope. The predictions of the model are displayed in the operational product (www.fews.net).

3.3 Inventory of selected land-related remote sensing data archives

Land cover

The terms "Land cover" and "land use" are often used interchangeably by water managers. Whereas "land cover" describes physical features, "land use" includes the use and management of land (e.g. land cover is grass and land use is wetland pastures or city parks). Land use is a description of how people utilize the land, and the resultant socio-economic implications thereof. Urban and agricultural land uses are two of the most commonly recognized high-level classes of use. The origin of the terms "land cover" and "land use" and the implications of their confusion are discussed in Fisher et al (2005).

The spatial resolution of Landsat data makes it suitable to multi-spectrally indentify land cover and land use classes. It is therefore not surprising that some land cover databases- such as AfriCover - are based on Landsat measurements. The MERIS sensor aboard Envisat has with its 300 m multispectral data (15 bands in the 0.30 to 1.04 um range), also the capacity to contribute to continental land cover mapping. Figure 13 shows the impact of pixels size on the quality of the land cover map that results from image classifications. MERIS seems to be a good trade-off between 30 m Landsat images vs. 1 km pixels from NOAA-AVHRR, SPOT-Vegetation and MODIS. It should be noted that a Landsat coverage for the Nile Basin will yield into a giant file size, and that such accuracy is probably not needed for operational applications.

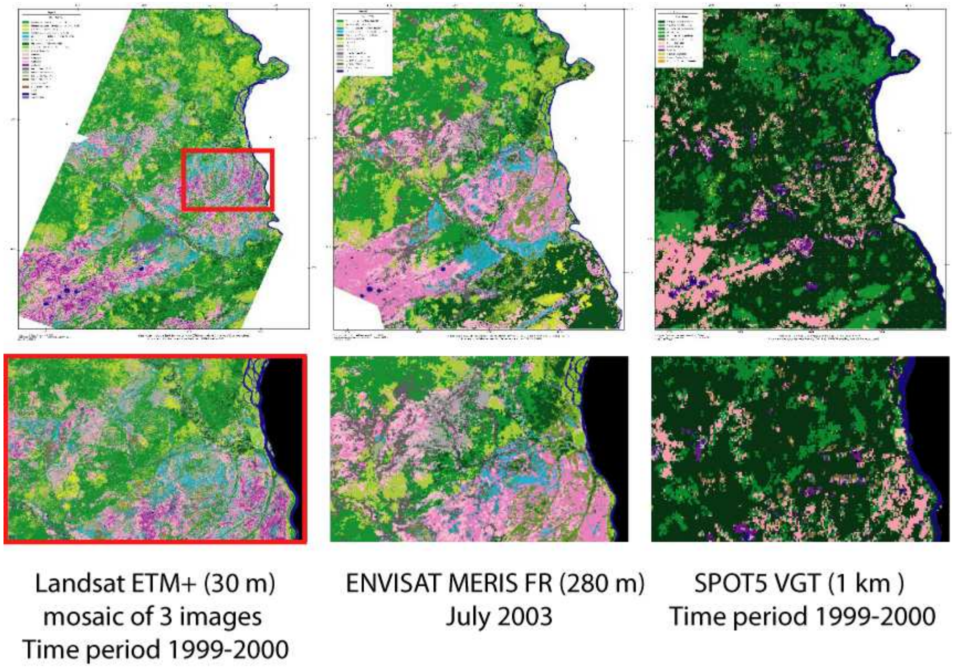


Figure 13 Impact of spatial resolution on land cover spatial mapping accuracy (source: JRC GlobCover project)

Various land cover databases have been prepared for Africa using Landsat imagery. The most detailed one is Africover. The purpose of Africover is to establish a digital geo-referenced database on land cover at a 1:200,000 scale (1:100,000 for small countries). The Africover project has been prepared in response to a number of national requests for assistance with the development of reliable and geo-referenced information on natural resources required at sub-national, national and regional levels (see Table 10).

Table 10 Selected RS-based land cover products for the Nile Basin

Theme	Product	Website	Pixel size	Data category
Landsat Geocover	NASA Stennis Space Center	http://glcf.umiacs.umd.edu/data/mosaic	30 m	DAP
Landsat Geocover	University Maryland	http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp	30 m	DAP
Landsat	Africover	http://www.africover.org	30 m	PAP
MODIS	IGBP	http://edcdaac.usgs.gov/modis/mod12q1v4.asp	1 km	DAP
Multiple	Various	http://edcsns17.cr.usgs.gov/glcc/glcc_version1.html#Africa	1 km	DAP
JRC	Global Land Cover 2000	http://ies.jrc.cec.eu.int/31.html	1 km	PAP
ESA	GlobCover	http://ionia1.esrin.esa.int/index.asp	300 m	PAP

Several low resolution 1 km land cover datasets have been created for Africa as well. The core set of the USGS land cover dataset for Africa consists of: Global Ecosystems, IGBP Land Cover Classification, US Geological Survey Land Use/Cover System, Simple Biosphere (2) Model and the Biosphere-Atmosphere Transfer Scheme (see Table 10). The advantage of this group of course land cover products is their complete coverage of the Nile Basin.

The current most detailed global scale portrait ever of the earth's land surface is GlobCover. GlobCover is a global land cover map to a resolution three times sharper than the Global Land Cover 2000 map and the various USGS land cover maps. Envisat's Medium Resolution Imaging Spectrometer (MERIS) instrument is being used in Full Resolution Mode for the GlobCover project, acquiring images with a spatial resolution of 300 metres. GlobCover supersedes the current GLC2000 map (see Table 10Table 1). The MERIS FR Composite products are temporal composites of surface reflectance generated on a bimonthly and yearly basis. The bimonthly MERIS FR composite is computed every 2 months and provides, for each spectral band, the average surface reflectance calculated from all valid observations of this 2 months period. The yearly MERIS FR composite is computed by averaging the surface reflectance values of the bimonthly product generated over one year. GlobCover has 22 land cover classes, and they are defined according to the UN Land Cover Classification System (LCCS).

Irrigated area

The land use class "irrigated land" is a particular form of agricultural land cover. The first global digital map of irrigated areas, based on cartographic information and FAO statistics, was developed in 1999 by the University of Kassel. Since 1999 the spatial resolution has been improved, and the latest version was released in February 2007 (http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm). The map provides the degree to which each grid of 10 km was equipped for irrigation, i.e. irrigation density. It is compiled by combining sub-national irrigation statistics with geo-spatial information on the position and extent of irrigation schemes.The latest version of the map was prepared jointly by the University of Frankfurt and FAO. Whereas this Global Map of Irrigated Areas (GMIA) is excellent for a coarse identification of irrigated areas in the Nile Basin, the fraction of land being irrigated and the irrigation density it provides, could probably be improve (see Figure 14).

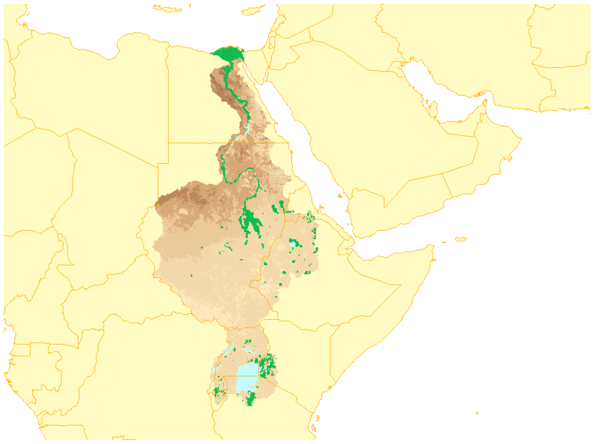


Figure 14 Example of the GMIA irrigated area map of the Nile Basin. Pixels depicted in green contain at least some form of irrigated land. The fraction of land irrigated in each pixel is an attribute in the database

Another global irrigated area product was launched by IWMI during May 2007 (http://www.iwmigiam.org/info/main/index.asp). Multiple resolution time series data is used, including (i) AVHRR 4-band and NDVI 10-km monthly time series for 1981-1999, (i) SPOT vegetation NDVI 1-km monthly time series for 1999, and (iii) rainfall 50-km monthly time series for 1961-2000. Additional major global data sets used were (a) GTOPO-30 1-km elevation, (b) JERS SAR data for rainforests during two seasons in 1996, and (c) University of Maryland Global Tree Cover 1-km data for 1992-93. The results of the FAO and IWMI statistics on irrigated land are summarized in Table 11. The IWMI areal statistics suggest an 21% lower acreage of irrigated land in the basin of the Nile than the FAO statistics. These discrepancies can be related to definitions of irrigated land and especially be ascribed to the irrigation density variations that occur within 10 km pixels that are flagged as irrigated land.

Table 11 Irrigated land in the Nile basin according to two leading RS-based data sources

	GIAM (IWMI) (ha)	GMIA (FAO) (ha)	Difference (%)
Egypt	2,144,099	3,245,650	+51.3
Sudan	1,737,118	1,946,200	+12.0
Ethiopia	184,239	160,785	-12.7
Eritrea	17,107	28,124	+64.4
Kenya	85,401	66,610	-22.0
Uganda	30,017	9,120	-69.6
Burundi	11,793	14,400	+22.1
Rwanda	80,067	4,000	-95.0
Uganda	30,017	9,120	-69.7
Congo DRC	21,833	10,500	-51.9
Nile Basin	**4,341,691**	**5,494,509**	

Vegetation properties

There are many satellites that are equipped with a red and near-infrared spectral band for the purpose of measuring vegetation vigour based on vegetation indices. Several types of vegetation indices exist, but after 30 years of research, the Normalized Difference Vegetation Index (NDVI) is still the most widely used and accepted standard for vegetation cover mapping. There are several simple algorithms to relate NDVI to vegetation cover, and it is generally accepted that these two parameters are interchangeable.

The longest NDVI time series is provided by NOAA Global Inventory Modelling and Mapping Studies (GIMMS), which was previously referred to as the Pathfinder dataset. The NDVI of GIMMS is measured by the Advanced Very High Resolution Radiometer (AVHRR) instrument onboard the NOAA satellite series 7, 9, 11, 14, and 16. The 8 km pixels of the GIMMS dataset are corrected for calibration, view geometry, volcanic aerosols, and other effects not related to vegetation change.

The SPOT-Vegetation dataset was first introduced in 1998 at the launch of SPOT-4, and is a 1km NDVI product that is suitable for various land cover and land degradation studies. Additional NDVI datasets are now being produced by MODIS, MERIS and MSG. Hence, there are currently 4 satellites operational for continuous surveying of large scale NDVI patterns. The advantage of the MODIS data set is its availability at both 250 and 1000 m resolution. MERIS can offer the same product with 300 m pixel size, but the raw data from ENVISAT are more difficult to get access to. MSG has the great advantage of providing 15 minute NDVI measurements, which makes this product attractive for weather conditions with frequent clouds. The spatial resolution of MSG-based NDVI values at the equator is 1 km, but the pixel size degrades when moving away towards the poles.

Table 12 Selected RS-based vegetation related products for the Nile Basin

Theme	Product	Website	Pixel size (km)	Repeat cycle (days)	Data category
NDVI	MODIS 13A2	http://edcdaac.usgs.gov/modis/mod13a2v5.asp	1	16	DAP
NDVI	GIMMS	http://glcf.umiacs.umd.edu/data/gimms	8	15	DAP
NDVI	Vegetation	http://www.spot-vegetation.com/	1	10	PAP
LAI	MODIS 15A2	http://edcdaac.usgs.gov/modis/mod15a2v5.asp	1	8	DAP
fPAR	MODIS 15A2	http://edcdaac.usgs.gov/modis/mod15a2v5.asp	1	8	PAP
LAI	MSG	http://landsaf.meteo.pt/algorithms.jsp?seltab=7	3	10	PAP
fPAR	MSG	http://landsaf.meteo.pt/algorithms.jsp?seltab=8	3	10	PAP
NP	MODIS 17A2	http://edcdaac.usgs.gov/modis/mod17a2.asp	1	8	DAP
NPP	MODIS 17A3	http://edcdaac.usgs.gov/modis/mod17a3.asp	1	365	DAP
Biomass	SEBAL	http://www.waterwatch.nl	1	7	CARSP

The rate of degradation and depletion of natural resources in the Nile basin has been accelerated in proportion to the increasing population pressure: deforestation, desertification, soil erosion and salinization. Landsat provides satellite imagery on a regular basis with a spatial resolution of 30 meters that supports the quantification of these degradation processes at field level.

Leaf Area Index

Leaf Area Index (LAI) is a dimensionless variable (m^2/m^2), which defines an important structural property of a plant canopy. LAI is defined as the total leaf area per unit ground area. It accounts for the surface of leaves contained in a vertical column normalized by its cross-sectional area. It thus defines the area of green vegetation that interacts with solar radiation and is the interface between the vegetation canopy and the atmosphere for ET and carbon dioxide exchanges for biomass production.

Routine LAI products are offered on the basis of MODIS and MSG measurements (see Table 12). Most algorithms for retrieving LAI employ a semi-empirical exponential relationship with NDVI and LAI. The regression coefficients can be empirically fitted to different vegetation types

Fraction of Absorbed PAR (fPAR)

fPAR measures the proportion of available radiation in the photosynthetically active wavelengths that are absorbed by a canopy. Because of the tight relationship with vegetation cover, the MODIS product 15A2 provides LAI and fPAR together. Both variables are used as satellite-derived parameters for calculating photosynthesis, evapotranspiration, and net primary production, which in turn are used to calculate the water productivity of crops, savannah and vegetation types including forests.

Net Primary Production

The MODIS product 17A2 is based on the original work of Monteith (1972) which relates Net Primary Production (NPP) to the amount of Absorbed Photosynthetically Active Radiation (APAR). The MODIS algorithm uses input from MODIS LAI/FPAR (MOD15A2), land cover, and biome-specific climate data from NASA's Data Assimilation Office (DAO).

The MODIS Net Primary Production (NPP) product 17A3 is based on the concept of radiation use efficiency (RUE). Solar radiation in the wavelength band from 0.4 - 0.7 μm is potentially useful for photosynthesis, and radiation in this band is called photosynthetically active radiation (PAR). On average about 45% of the shortwave radiation reaching the earth's surface from the sun is in the PAR spectral region. Some of this PAR is absorbed by plants (APAR) to fix CO2 from the atmosphere as carbohydrate for growth and respiration. The amount of new growth that is produced from a given amount of APAR is a measure of the plant's RUE. It depends on the physiological characteristics of the plant, and also on the environmental conditions at any particular time. For example, a fast growing forb may have an intrinsically higher RUE than a slow-growing pine tree, but both plants might have a wide range of RUE depending on factors such as air temperature and the availability of water and essential nutrients in the soil.

Although the use of remote sensing data can provide global coverage on a frequently updated cycle, the RUE approach to estimating NPP involves many simplifications and approximations, ignoring much of the ecophysiological complexity of the real terrestrial primary production processes. In order to capture some of that complexity in the simple remote sensing approach, MOD 17A3 is based on a sophisticated ecosystem process model to set the parameter values for our simpler remote sensing algorithm. The model is called Biome-BGC, a computer program that estimates biogeochemical cycles (BGC) represented by fluxes and storage of energy, water, carbon, and nitrogen for the vegetation and soil components of terrestrial ecosystems. The model uses a daily time-step, which is composited to create an 8-Day Net Photosynthesis product (MOD17A2), and the annual Primary Production product, MOD17A3.

The reliance of BGC on soil moisture and ET flux has prompted SEBAL to describe the RUE as a function of biome type and the state conditions of heat, radiation, vapour pressure deficit and most importantly: soil moisture. In this way, a feedback between soil moisture and biomass production is built in, and this results in an adequate biomass production model for all land cover classes present in the Nile Basin. An example is provided in Figure 15.

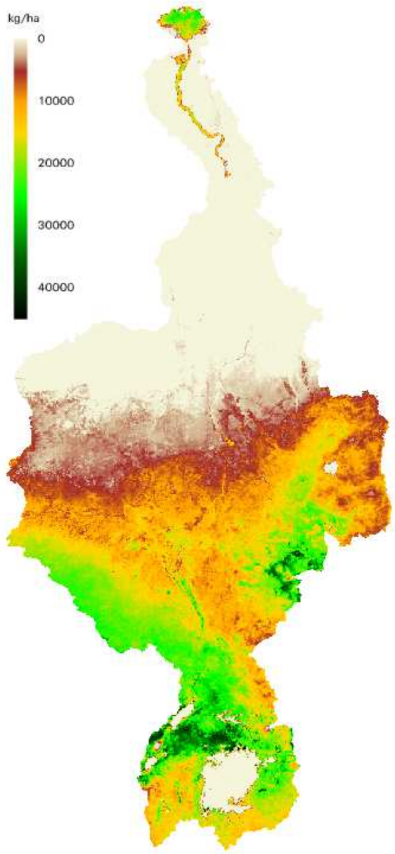


Figure 15 Example of annual biomass production computed from the SEBAL model

3.4 Other interesting data

The NASA Shuttle Radar Topographic Mission (SRTM) provides digital elevation data (DEMs) for over 80% of the globe. Version 3 is available since 2007. SRTM was flown aboard the Shuttle Endeavour in February 2000. The data can be downloaded from http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

A map of the population density is useful information for calculating per capita availability of water resources and for assessing food security from staple food production. Maps of population densities can be found at UNEP through http://grid2.cr.usgs.gov/globalpop/africa/

The International Livestock Research Institute plotted the density of cattle in Africa by recording number of animals according to administrative units (http://www.ilri.org/InfoServ/Webpub/Fulldocs/Mappoverty/media/30.htm). Pastoralists in some African countries are interested in maintaining high stocking densities for security, savings, status, and subsistence. High density, however, may be a reflection of overgrazing and resultant land degradation. Figure 16 shows the density of cattle in Africa. Linking this information to biomass production provides an understanding of the fodder situation and the livelihood of pastoralists. Water productivity per livestock unit can be computed as well, which is relevant for general discussions on water depletion in the Nile Basin.

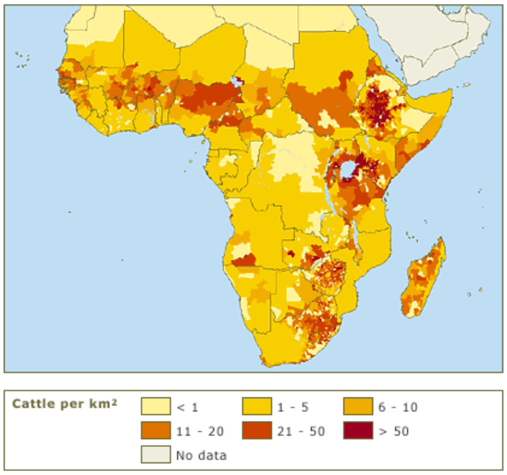


Figure 16 Example of a cattle density map of Africa (source: ILRI institute)

The USDA has prepared an erosion hazard map. Their "Vulnerability to Water Erosion" map is based on existing GIS data layers (http://soils.usda.gov/use/worldsoils/mapindex/erosh2o.html). The hillslopes of Ethiopia with intensive rainfall are regarded as high risk areas. Erosion mapping models for the Nile Basin should be made to refine these types of global maps.

4 Role of existing international RS institutes in the Nile Basin

4.1 General

Part of the consultancy mission was to describe the roles and capacity of other international remote sensing institutes in the Nile Basin. National institutes were not considered because they have a different mandate: to study the natural resources in their own country. They thus have not much insight in the natural resources processes abroad. Most national institutes or organizations are not in the position to provide a basin wide overview of the land and water resources. The national remote sensing institutes in places such as Cairo, Khartoum and Kigali to mention a few, are thus not included in this survey.

One exception of a semi-national institute is the Nile Forecasting Centre at the Planning Section of the Ministry of Water Resources in Egypt. The center was established as part of an international exchange program with FAO. The RS work of this institute has a basin-wide focus on rainfall, and their work is very valuable for stream flow forecasting. Their long track record in image analysis and flood forecasting is impressive. Because it is not the objective of the center, they do not have all RS skills necessary to technical support the establishment of a Decision Support-Remote Sensing unit (DSS-RS).

An interview was conducted with the Regional Centre for Mapping of Resources for Development (RCMRD) in Nairobi and the FAO Nile office in Entebbe, Uganda. The visits took place in December 2007.

4.2 Regional Centre for Mapping of Resources for Development (RCMRD)

The RCMRD was established in the seventies in response to a need for improved surveying and mapping capacity in eastern Africa. The RCMRD was started with assistance from Kenya, and thus established its office in Nairobi. There are now 11 member states in Africa contributing financially to the upkeep of the Centre. The RCMRD generates income from consultancy projects. These projects range from urban mapping, to deforestation and water quality monitoring.

The RCMRD provides training courses related to integrated water resources management. In their approach, integrated water resources management is achieved by combining information on soil types, land cover, groundwater mapping, models, decision support systems, etc. Although useful by itself, this will not contribute to good basin management. It is not the RCMRD's aim to provide operational remote sensing products. They don't do any real-time image processing to serve certain demands. Neither do they provide data or information on hydrological related processes such as rainfall, ET, soil moisture, and meteorology. The RCMRD does not have an irrigation or wetland focus. They have a wealth of experience in crop monitoring, but are not utilizing this in an operational context.

Due to its expertise in land cover mapping, the RCMRD contributed to the establishment of AfricoCover (www.africover.org). The first phase of this FAO project has been completed (Sudan, Kenya, Uganda, Rwanda, Burundi). Unfortunately, not all Nile Basin countries took part in the construction of this database, so that a complete overview is missing. This will jeopardize the consistency of making standardized special purpose RS products for the whole basin. Although the land cover data has great value, it is for the lack of completeness and inconsistency not feasible to apply it under NBI.

The Geonet project with FAO – World Food Program and ESA - is a recently started activity at RCMRD meant to assist with crop yield predictions (www.gmfs.info). The Geonet work has nodes in Nairobi and Gabaronne. Their products are based on SPOT-Vegetation and the data is acquired from VITO (B).

The RCMRD has its own receiving facility for MERIS data. The data covers eastern Africa. NOAA images are not received. The MERIS receiving station will be upgraded during 2008 to receive MODIS and MSG data (eventually also AASTR data). To promote the usage of imagery, the RCMRD has a policy to provide satellite data free of charge. Data can be downloaded or acquired on DVD for which, in the latter case, a small service fee is charged. The Landsat data is available since 1972 and all images used by previous USGS projects with RCMRD are archived and could be distributed. The RCMRD collects and stores ASTER data. The institute is negotiating with SPOT on a subscription. High resolution imagery from IKONOS and KompSat can be obtained at market prices.

The RCMRD has received excellent support from the USGS during the FEWS (Famine Early Warning System) project which continued over a long period. The FEWS collaboration has now come to an end. FEWS computes crop yield from water balances and ET. The regulation of ET by soil moisture is explicitly recognized in their modelling approach. A team of NASA specialists has recently visited the RCMRD to discuss collaboration on African disaster management, including issues such as Rift Valley Fever, climate and ecology, flooding and landslides.

In conclusion it can be mentioned that RCMRD has a good grasp of international RS experience and that they can assist NBI with data provision and training. Their role in operational basin management is limited in potential.

4.3 FAO-Nile office

The FAO-Nile office has been established as a FAO field node with the purpose to describe the overall agricultural conditions in the Nile Basin and with a particular link with water resources management (www.faonile.org). The FAO-Nile office in Entebbe collects and disseminates RS data among others. Their main agricultural water management data stream is composed of rainfall, potential ET, land cover, land use, and irrigation mapping. Their work contributes to the establishment of the following information:

- Water productivity
- Water use survey
- Nile decision support tool
- Nile basin database
- GIS information products
- Scenarios of water demand
- Monitoring network

One of the recent activities is the land cover to land use conversion mapping project. This is a great activity meant to improve local agricultural water management practices by studying crops and location specific phenomena. The purpose of irrigation mapping is to create polygons showing irrigated areas, crop types, cropping calendars, crop yields and agricultural water use. The statistical crop acreage data at district level are disaggregated according to NDVI time profiles measured by MODIS images, together with the prevailing climate and terrain conditions. Land above certain altitudes and exceeding certain slopes will for instance be excluded from certain crop types. Climate can also be used to compute the risks of cultivating certain crops or to recommend crops most likely to succeed. The combination of the 250 m MODIS images and 90 m SRTM elevation model yields a 90 m land use map. Agricultural production will be differentiated according to different farming systems. The land cover to land use conversion is a project in progress, and final results could not be demonstrated to the consultant, also not during May 2008 when a second meeting was held in Wageningen.

In addition, the FAO-Nile office is working on crop water requirements. They are also reviewing watershed boundaries of the Nile basin.

4.4 Possible cooperation with DSS-RS unit

The consultant can see an important role for the RCMRD: provision of general background training on image processing, GIS database building, and transfer of knowledge on natural resources management throughout eastern Africa. Their experience with operationalization of the FEWS network and now with the ongoing FAO Geonet project is of great value. Conceptually wrong designs and other mistakes at the DSS-RS could be partially prevented by inviting the RCMRD team members to directly share their experiences. Exchange issues should be related to (i) planning of image processing under time constraints, (ii) methods to disseminate the data to all countries in the region, (iii) fostering of usage of the data, (iv) protocols for validation, and (v) feedback from users and how to deal with comments and remarks, and get satisfied end-users.

The low emphasis of the RCMRD on operational use of RS will not make them a suitable partner for concurrent image processing. They could however be asked to prepare a standardized land use map for the entire Nile Basin that meets the requirements of NBI, especially with their MERIS reception facility. This requirement is necessary to implement the SVP and SAP programs. These programs are oriented on land use classes such as wetlands and irrigated areas. These are land use classes because land cover classes are insufficient for proper understanding and use of land and water resources. The RCMRD experience gained from the Africover preparations will be very valuable in this respect.

The FAO-Nile program could partner well with the DSS-RS unit in developing a future irrigation performance monitoring program under the new Remote Sensing DSS. An exchange of databases between the FAO-Nile office program and the DSS-RS is anticipated. The DSS-RS could help the FAO program by sharing the ET and biomass production results. FAO could enhance the DSS by making the agricultural land use database available. The agricultural database linked to land use will in addition provide useful information on crop yields, irrigation systems etc. These FAO-Nile databases could be paramount for the validation of the DDS-RS products. Furthermore, collaboration should be searched with FAO on their experiences with the dissemination of maps and data bases through the World Wide Web. The hard and software requirements for a solid Local Area Network need to be determined.

5 Standard operational processing of RS data

5.1 General

Having reviewed the international progress in remote sensing science, and the various public domain databases available for the collection of spatially distributed land and water management data, we deal in this chapter with the first steps of making a final selection of the best possible RS data for water management in the NBI program. It is necessary to make a distinction between three types of RS data:

- Primary RS data
- RS information products
- Special purpose RS products

The main argument of having 3 different categories of data is mainly related to (i) the level of own interpretation (from nothing to full knowledge based added value modelling) and (ii) the users of the data. Professionals in RS and GIS have an entirely different demand for data than the high level decision maker.

A selection of primary RS data has to be made first, which dictates the further options for the establishment of operational products. We recommend the maximum exploration of MODIS, AMSR-E, TRMM and MSG data. Because of the excellent pre-processing facilities of MODIS and its wide range of standardized products, it is an excellent product to use. MSG data may be used as an alternative in a later stage when all the RS products have been tested on MODIS. The advantage of MSG is that 15 minutes images can be acquired. The opportunities for cloud free products are thus much greater than for MODIS. As the Landsaf program finds its way towards operation, DSS-RS will gradually pick up more of their thoroughly tested data.

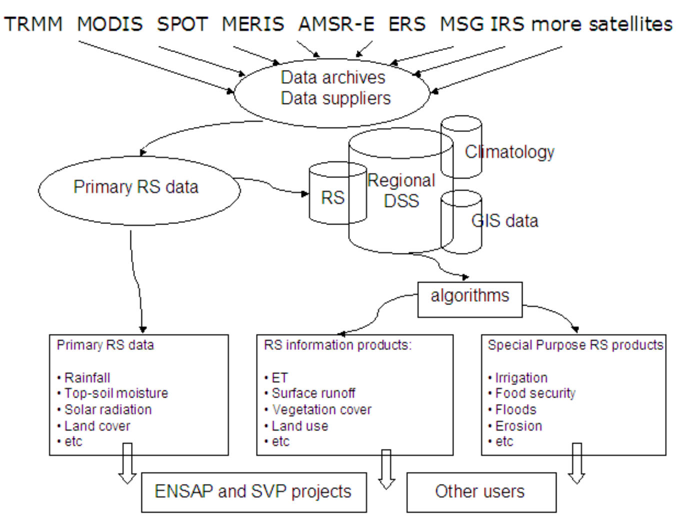


Figure 17 Overall structure of satellite data and algorithms to create primary RS data, RS information products and special purpose RS products

Following the diagram of Figure 17, we will first discuss the primary RS data that we recommend for systematic collection and downloading by the DSS-RS unit which is feasible without any interference from third parties. The primary RS data follows from the data needs of the SAP and SVP programs (see inset). The users of primary RS data are RS experts, GIS experts and database experts that know how to deal with raw raster-based RS data. At a second level, the RS information products are derived from various RS data sources combined with auxiliary data using simple or more sophisticated algorithms. The majority of these algorithms are described in the international literature and in handbooks. Other algorithms such as SEBAL or soil moisture downscaling have propriety rights. RS information products provide essential data to engineers, agronomists, hydrologists, ecologists, economists, and earth-scientists.

Standard list of RS parameters that have sufficient accuracy to support the execution of SVP and SAP projects under NBI

Primary RS data	RS information products
Rainfall	Evapotranspiration (ET_0, ET_p, ET_a)
Top-soil moisture	Sub-soil moisture
Solar radiation	Ponded water surfaces
Surface albedo	Interception
Surface temperature	Surface runoff
Lake levels	Change in total water storage
Terrain elevation	Vegetation cover
Land cover	Land use
Irrigate area	Irrigation intensity
Vegetation index	Soil salinity
Leaf Area Index	Biomass production
Fraction PAR	Crop type
Net Primary Production	Crop yield
Storage change	Crop coefficient

Special Purpose RS products are derived from analysis of RS data in conjunction with auxiliary data. It goes a step further than RS information products. The user community of RS consists of water policy makers, water managers, irrigation departments, wildlife departments, electricity boards, wetland stakeholders, water user associations, NGO's, etc. The common dominator is that they all plan, manage and monitor water resources, food production, livestock density etc. This group has interest in easily understandable indicators to gauge how well they control their own systems that they are responsible for. The special purpose RS products are described further in chapter 6. The indicators proposed in the inset are dealt with in chapter 5.

5.2 Primary RS data

5.2.1 Water applications

Primary RS data in the context of the DSS-RS is data that can be acquired from public domain archives without any further processing or other interference. That does not mean that the data is free from errors, because data level 3 may have been subject to more data quality checks than data level 1.

Table 13 provides an overview of primary RS data available for operational water management. The selection of land applications is presented in section 5.2.2. We recommend the use of low resolution images that can encompass vast parts of the basin with a single image, and that will keep the operational costs to an acceptable level. All data in Table 13 can be acquired free of charge. Lower resolution images have a short repeat cycle that enables capturing of the dynamics of the hydrological processes. The final selection of preferred primary RS data from the database discussed in Chapter 3 is based on the following criteria:

- Likelihood to fill gaps in basin wide data requirements;
- Level of operational service of the data archive;
- Proven accuracy of the data;
- Available peer reviewed literature;
- Documented methodologies;
- Documented application studies elsewhere.

Some of the selected themes of Table 13 will be discussed further, and examples will be provided. It is not feasible to do this for all primary RS products. More examples and demonstration of earlier applications can be found at the respective URL's provided in Chapter 3.

Table 13 Recommended primary remote sensing data for water management in the Nile Basin. The DSS-RS unit should systematically collect, archive and disseminate this data.

Water Management	Recommended satellite-sensor combination	Time interval	Spatial resolution
Rainfall	TRMM – 1C21 & 3B42	3 Hourly	4 km
Rainfall	TRMM - 3B43	Monthly	25 km
Top-soil moisture	Aqua – AMSR-E	Daily	25 km
Solar radiation	MSG - SEVIRI	Half hourly	3 km[2]
Surface albedo	Terra-MODIS & Aqua-MODIS, MOD43B3	16 day	1000 m
Surface temperature	Terra-MODIS & Aqua-MODIS MOD11A2	8 day	1000 m
Lake levels	Jason – Poseidon	Two-weekly	Na
Storage change	Grace	monthly	250 km

An example of the spatial distribution of annual rainfall throughout the Nile basin is shown in Figure 6. The TRMM annually averaged rainfall between 1998 and 2006 is shown. This 3B43 product was calibrated only against ground radar stations outside the Nile Basin. It is necessary to calibrate the rainfall against independent data sources gathered within the boundaries of the Nile basin. The highest rainfall (>2200 mm yr^{-1}) appears to fall in the tropical forest of DRC. The strong North-South rainfall gradient in the semi-arid climatic zone of southern Sudan is clearly visible. The orographic character of rainfall is evident; especially around the mountain ranges that divides the Equatorial Lakes region from the rainforest in DRC. At the windward side of the region rainfall is 2200 mm yr^{-1} and drops to 800 mm yr^{-1} on the leeward side! The Ethiopian highlands also form a clear barrier for moist atmosphere. Rainfall over the Gambela plain area can be as high as 2000 mm yr^{-1}. While the 3B43 product is suitable for seasonal basin analysis (especially after calibration), the 1C21 (precipitation radar reflectivity) and 3B42 (TRMM multi-sensor rain calibrated with GPI data) datasets are excellent for the shorter term description of flood and erosion risk.

Alternative soil moisture products to choose from are the AMSR-E passive microwave data and the ERS-Scatterometer data. After studying results from both products in the Nile Basin, it was decided that AMSR-E provides a more realistic picture. The moisture signal of the wetlands and the savannah especially, are picked up more properly by AMSR-E. The NASA moisture algorithm (Njoku) results distributed through NSIDC has less striping effects than the moisture algorithm of

[2] The SEVIRI pixel size at the equator is 1 km, and it will deteriorate to 3 km when moving towards the tail end of the Nile Basin

the Free University of Amsterdam (de Jeu). Although the latter algorithm was favoured (according to recent literature) for field campaigns in USA, Spain and Australia, we believe that the NASA model shows more consistency and performs better for landscapes with dense vegetation cover in the Nile basin.

Top-soil moisture data can be, besides describing land wetness in general, employed to determine flood risks, flooded areas, and overland flow due to surface runoff. Surface runoff occurs when the rain or irrigation water cannot infiltrate into the soil due to a large degree of soil moisture saturation. Figure 18 shows the basin wide spatial variation of topsoil moisture content. Soil moisture in the upper soil depth of approximately 5 cm in the wet region is typically 0.15 to 0.20 cm^3 cm^{-3}, which arises in the Bahr el Ghazal, Bahr el Bahr El Jebal and the Gambela plane areas that all have high rainfall. The deserts of the Sahara hold only 0.05 cm^3 cm^{-3}. The location specific maximum soil moisture values throughout the year can be obtained from the time series. The higher soil moisture content occurs in the lower end of the Sudd wetlands from where the White Nile emerges after the confluence of the Jebal and Ghazal. Also the Machar wetland areas and their vast surrounding river plains have a surface soil moisture content of 0.3 cm^3 cm^{-3} or more (see Figure 18). The latter demonstrates that the signal to noise ratio of AMSR-E is good, and that temporal differences in moisture content are captured well.

Irrigated land is, from these measurements, not standing out as having wet top-soil. This is somewhat unexpected. An explanation could be that the best irrigation practices occur when the topsoil is dry and the sub-soil is wet. But there must always be some fields that have received irrigation water just prior to image coverage. Rice cultivation regions especially should exhibit high top soil moisture values throughout the summer season in Egypt. We therefore believe that the low top-soil moisture over irrigated land is merely related to dense cropping patterns that masks the wet topsoil. The optical depth of the crops is apparently lower than for natural vegetation types. The AMSR-E data is available with a daily time step, and we think that despite the underestimation of soil moisture in irrigated land, it is still useful for other applications.

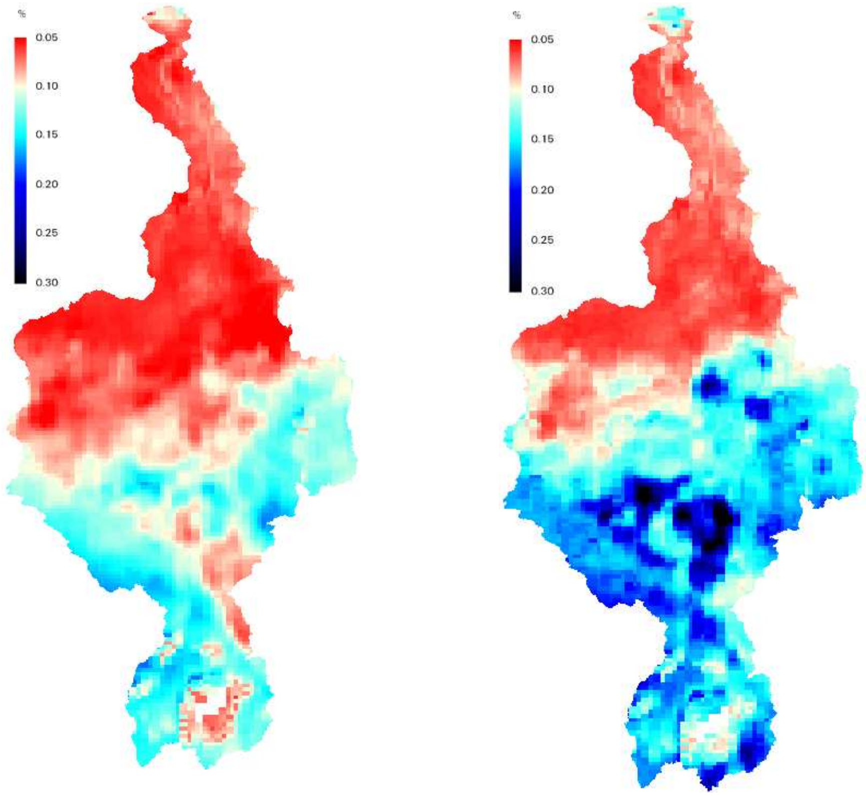


Figure 18 Spatial patterns of annually averaged top soil moisture (part A) and the maximum values that occurred at least once a year (part B) during the calendar year 2007 and based on the standardized NSIDC data

Due to moving clouds and continuously varying solar angular position, solar radiation at the surface is a highly dynamic process that needs to be captured by very frequent satellite measurements. Geostationary satellites are excellent vehicles to fulfil this requirement. Various meteorological and climate research groups have developed operational products. The LANDSAF product from the Meteorological Department in Portugal is recommended because it has a proper operational status. Validation by the consultant with pyranometers in The Netherlands, South Africa and Hungary showed very encouraging results, for both hourly solar radiation as well as daily total solar radiation. The validation picture for South Africa was demonstrated in Figure 5.

Surface albedo describes the part of the solar radiation that is reflected from the land surface back into the atmosphere. Absorbed solar radiation is an important component of net radiation. Absorbed radiation is the non-reflected component of solar radiation. The surface albedo values also provide valuable information on the top soil moisture conditions. Darker soils usually have a wetter top layer or contain more organic matter. Various good products of surface albedo exist, and the MODIS data has been selected mainly for the sake of consistency with other MODIS products. It should be mentioned that we have equal trust in other albedo products.

Surface temperatures can be used for drought monitoring (heat anomalies) and for the computation of ET and soil moisture. Surface temperature should also be obtained from the MODIS website. The MODIS-based surface temperatures (black body) are available together with the thermal infrared surface emissivity. This allows direct computation of the physical surface temperature (grey body). The MODIS site offers 1, 8 and 16 day thermal infrared products. Daily thermal images are very relevant during periods of drought and during these warm days, it is not likely to have an impenetrable cloud cover. The Equatorial Lake region can have long periods with prevailing clouds and this humid region of the Nile basin could be better monitored with MSG thermal images. We recommend the DSS-RS unit to consider MSG once the MODIS thermal products have been used operationally without problems.

5.2.2 Land applications

The primary remote sensing products to support land management in the Nile basin are specified in Table 14. These products are more valuable if they are integrated with water related data. The SRTM Digital Elevation Model is recommended for use. Flow routing is fundamental for assessing downstream access to surface water availability. Flood risk mapping and surface water inflow into wetlands can be calculated if the upstream catchment area is known. The catchment delineation is a straightforward procedure when the digital SRTM data is available.

The land cover maps from MODIS and IGBP are recommended as standard maps, mainly because the definition of the legend is good and the number of classes is appropriate. Two types of savanna (woody savanna, savanna) and two types of crops (crops and cropland/natural vegetation mosaic) are presented on these maps. The maps have a pixel resolution of 1 km (see Figure 19). It should be noted that most global land cover maps are based on the standard IGBP data set and that only marginally application specific modifications are built in. Except for Africover, most land cover maps are prepared globally and have a generic legend. The GlobCover product of JRC is a very new product that is worth further exploring. For this reason, GlobCover is added to Table 14 as well.

The GMIA irrigated area product from FAO is considered as being superior for the Nile Basin. Comparison of GMIA with MODIS images showed a good agreement. Small scale irrigation practices outside the Nile Basin in ancient oasis are also properly indicated on GMIA, and this increases the trust in the product.

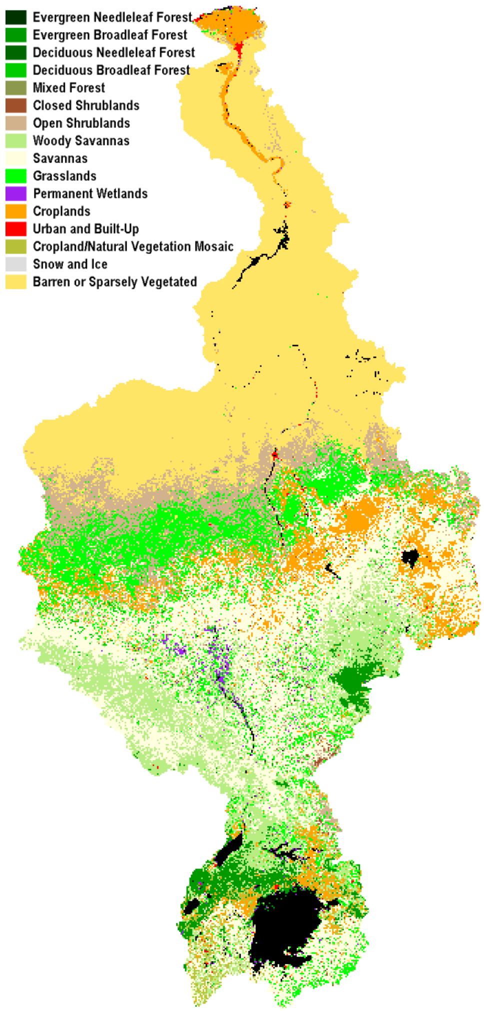


Figure 19 Example of the IGBP land cover map for the Nile Basin

The level of detail of the land cover maps is insufficient for the proposed NBI applications such as water accounting, land degradation, food and fodder production, wetland health, etc. Land cover data is only the first quantitative description of the land statistics. We recommend the generation of land use maps for an adequate interpretation of hydrological processes and water management options.

We recommend the Normalized Difference Vegetation Index (NDVI) as the basic spectral vegetation index. The NOAA-GIMMS time series measured by the AVHRR radiometer spans a period of almost 23 years between 1st July, 1981 to December 31st, 2003. Its 15 day interval in conjunction with 8 km pixel size makes it suitable to study long term changes in vegetation cover. The MODIS-based NDVI series were introduced in December 1999 and could be used for monitoring of NDVI into the future. There is a 4 year overlap with the NOAA data, being sufficient for a comparative study to detect systematic shifts in the time series trends. The advantage of the MODIS dataset is that it can be recorded with a 250 m resolution. This sharpening factor of 16 yields much better quality NDVI maps (see Figure 20). The 250 m resolution image shows reservoirs, green river corridors and variations within mountainous forests, the 1000 m not. This could be an advantage for studying smaller scale processes such as land erosion and agricultural water management indicators.

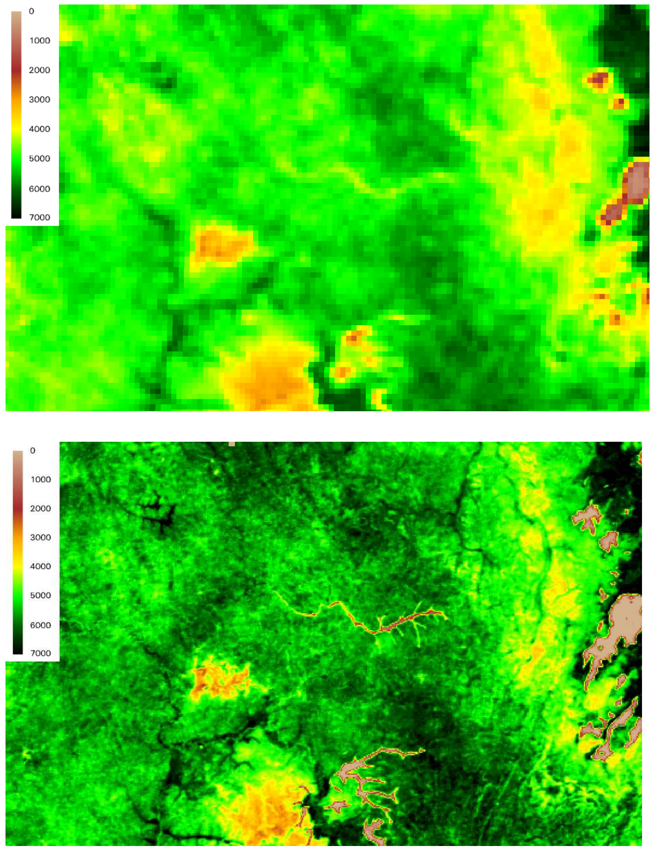


Figure 20 Impact of NDVI spatial resolution on utilization of the data for water management

For LAI, we also recommend the use of the MODIS data set. The land science team of MODIS has developed a good set of algorithms to estimate LAI, fPAR and NPP in a consistent way. The relationships between NDVI, fPAR, LAI and NPP are biome dependent, and are based on a long history of fundamental research. The MODIS 8-day products went through reasonable cloud fill algorithms. The data flow is thus reasonably well ensured, although it cannot be guaranteed. The MODIS LAI and fPAR products usually come together in one single file. Whereas LAI is merely meant to describe the vegetation development and its ability to intercept solar radiation and generate transpiration and carbon fluxes, fPAR describes the part of the Photosynthetic Active Radiation that is intercepted and converted into biomass production. Net Primary Production (NPP) describes the dry matter produced from the photosynthesis process as an absolute quantity.

Table 14 Recommended primary remote sensing data for land management in the Nile Basin

Land Management	Recommended satellite-sensor combination	Time interval	Spatial resolution
Terrain elevation	Spaceshuttle- SRTM	Na	90 m
IGBP land cover	Terra-MODIS & Aqua-MODIS	Na	1000 m
GlobCover	Envisat - MERIS	Na	300 m
GMIA irrigated area	Terra MODIS & Aqua-MODIS	Na	10 km
Vegetation Index	NOAA-AVHRR & Terra – MODIS & Aqua – MODIS MOD13A2	15 days 16 days 16 days	8000 m 1000 m 250 m
Leaf Area Index (LAI)	Terra-MODIS & Aqua MODIS MOD15A2	8 day	1000 m
Fraction Absorbed PAR (fPAR)	Terra-MODIS & Aqua-MODIS MOD15A2	8 day	1000 m
Net Primary Production (NPP)	Terra-MODIS & Aqua-MODIS MOD17A3	8 day	1000 m

The focus on low resolution imagery does not imply that high (10 to 60 m) and very high resolution (1 to 5 m) images should be excluded from implementation at the DSS-RS. Special studies such as for instance in the Kagera integrated water management study, may require spatially detailed maps of crop types, wetland habitats, etc. Since these images will not form part of the weekly operational image processing, they are not further discussed here. They belong to the category of ad hoc projects.

5.3 RS information products

Combinations of multiple primary RS data – complemented by auxiliary data – will yield series of RS information products that describe hydrological and biological processes. RS information products – according to our definition - cannot be found on public websites, and thus some form of post-processing needs to be undertaken. For the sake of ownership integrity, the DSS-RS unit should undertake this additional image processing and interpretation by themselves. It is wise to plan for additional modelling assistance from other sources.

Spatial rainfall and soil moisture data at 25 km is a good start for various analyses. Spatial disaggregation of rainfall into 3 to 5 km pixels will enhance applications considerably. The downscaling of rainfall data - in both time and space - is based on fusing raw TRMM data (product 3B43) with 4 km TRMM products (1C21 and 3B42). Eventually the cloud albedo and cloud temperatures from the MSG can be used as a proxy for disaggregating the 25 km monthly TRMM rainfall into 3 km pixels. An example of TRMM & MSG data fusion is presented in Figure 21. It should be mentioned that this data fusion approach is not a tailor made product yet, but that developments are underway.

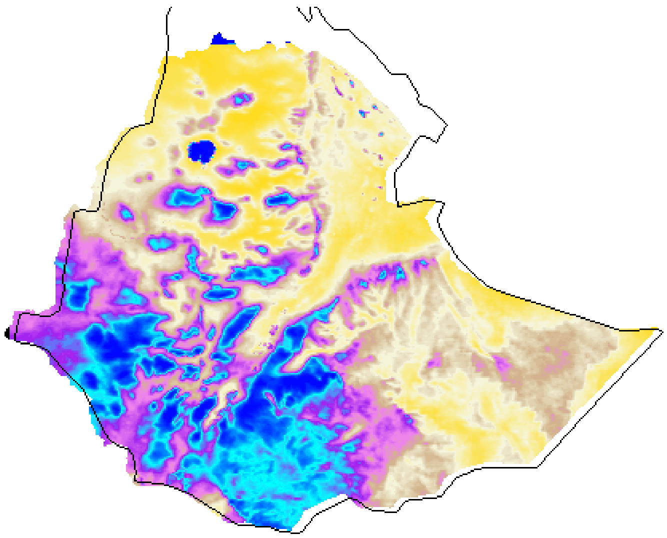


Figure 21 Spatially sharpened gross rainfall estimates from the combined TRMM and MSG product for the Ethiopian highlands. The dis-aggregated rainfall is presented at 3 km pixels

Net rainfall is equal to gross rainfall less interception losses. Interception can be up to 20 to 40 % in tropical rain forest and in crops grown on center pivot irrigation systems. Various interception equations exist in the international literature. Rainfall interception can be computed from short term gross rainfall, LAI and vegetation cover. Review papers on this topic are prepared by Dunkerley (2000), Hall (2003) and Bruynzeel et al. (1999). We recommend the interception equation provided by Braden (1995), which provides a good trade-off between physical processes and practical solutions. The equation has a few easy to calibrate parameters, which promote its use. This interception equation can be used also in situations of overhead irrigation.

Overland flow due to surface runoff occurs when rainfall or irrigation exceeds the soils infiltration capacity. The infiltration capacity can be limited due to sloping terrain, low permeability or soil moisture saturation. When the actual moisture storage capacity is restricted, water will flow over the surface to lower lying terrain. These concepts are embedded in the Curve Number (CN) method of the Soil Conservation Service (SCS) that is globally accepted as a superior equation to predict surface runoff. The challenge in the SCS equation is to solve CN. CN can, however, also be computed analytically as the difference between actual and saturated soil water content and the integration depth over which this storage occurs. The combination of soil saturated moisture content and real surface moisture content from AMSR-E will make it feasible to solve CN in a physical manner. This will make it feasible to compute surface runoff.

Table 15 Summary of the recommended RS information products for the Nile Basin

Water Management	**Recommended satellite-sensor combination**	**Time interval**	**Spatial resolution**
Precipitation	TRMM – 1C21 & 3B42 & 3B43 MSG - EVIRIS	Monthly	3 to 5 km
Sub-soil moisture	Terra – MODIS & Aqua-MODIS & Aqua – AMSR-E	1 day	1 km
ET	Terra- MODIS & Aqua-MODIS & Aqua - AMSR-E	1 to 8 days	1 km
Ponding water surfaces	Terra – MODIS & Aqua-MODIS & Aqua – AMSR-E	1 day	1 km
Interception	TRMM – 1C21 & 3B42 Terra – MODIS & Aqua-MODIS	1 day	1 km
Surface runoff	Terra – MODIS & Aqua-MODIS & Precipitation & Interception	1 day	1 km
Change in total water storage	Grace	Monthly	250 km
Vegetation cover	NOAA-GIMMS & Terra – MODIS & Aqua - MODIS	15 days 8 days 8 days	8000 m 1000 m 250 m
Land use	Envisat - MERIS & Resourcesat - AWiFS	5 yearly	300 m 60 m
Irrigation intensity	Terra – MODIS & Aqua – MODIS		
Soil salinity	Landsat – Thematic Mapper	year	30 m
Biomass production	Terra- MODIS & Aqua-MODIS & Aqua - AMSR-E	1 to 8 days	1 km
Crop types	Landsat – Thematic Mapper & Resourcesat - AWiFS	year	30 to 60 m
Biomass production	Aqua-MODIS & Aqua-AMSR-E	1 to 8 days	1 km
Crop yield	Crop types & biomass production	season	30 to 60 m
Crop coefficient	Crop types & ET		30 to 60 m

Comparative and operational energy balance models for ET are provided by SEBAL (1 km) and EARS (5 km). These two ET models are currently found frequently outside academic institutions, and operationally applied in water resources management. The ET models from the universities of Princeton, Montana and ITC are research versions, and they are not operational. The MODIS16 ET product is under preparation. The need for 1 km ET data under all weather conditions has prompted us to advise NBI to use the new microwave version of SEBAL. SEBAL has a long track record and is applied in more than 30 countries worldwide. The first version of SEBAL was constructed in the Western Desert of Egypt, thus inside the territory of the Nile basin. SEBAL has been extended with a microwave 'cloud resistant' module recently. Figure 22 demonstrates the results of annual ET for the Nile basin, using average meteorological conditions, and the MODIS and AMSR-E 8 day intervals for 2007.

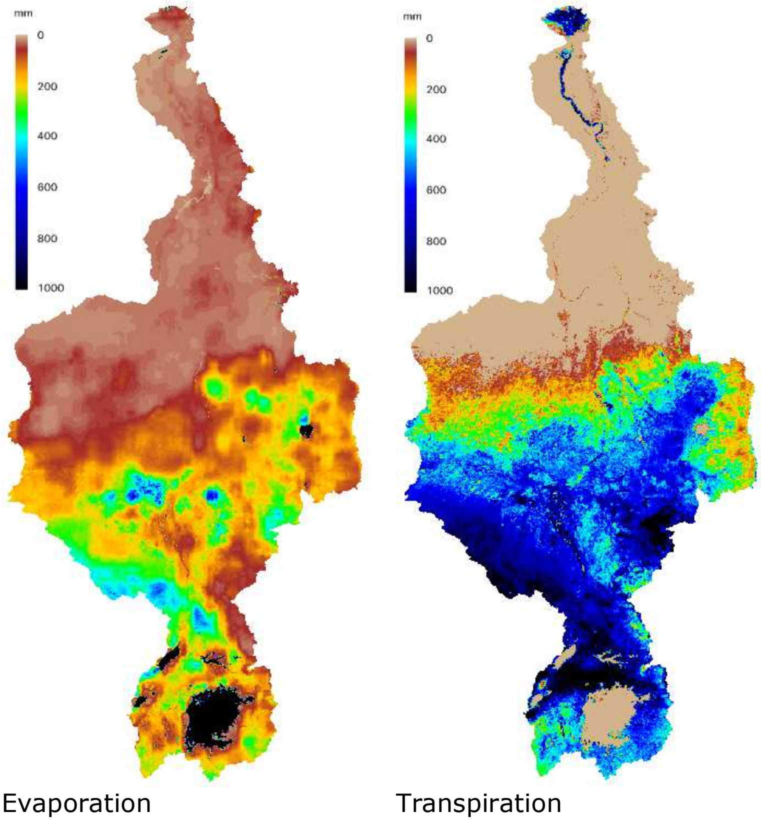


Figure 22 Example of the annually accumulated E and T calculations based on a microwave version of SEBAL for the year 2007, using climatologically average weather data. Areas with non-beneficial evaporation E can be spotted

Except in irrigated areas, high transpiration values appear to coincide with areas of high rainfall. The results shown in Figure 22 could not be validated in the absence of ground-based ET fluxes. This is not an exception, and most river basins in the world have no equipment to measure ET fluxes in an operational manner at the scale of 1 km. The ET data is therefore compared against earlier ET studies conducted in the Western Desert of Egypt, Egyptian Nile Delta, the large scale irrigation schemes of Sudan, the Sudd Wetlands and the Central Rift Valley lakes in Ethiopia and Kenya (although outside the Nile basin). The results were encouraging with differences in seasonally accumulated ET values being less than 5 to 10 %.

Another realism check on the ET map was made by subtracting the ET pixel data from the longer term rainfall in the Nile basin (see Figure 1). Areas with negative P-ET values are all irrigated land, wetlands, lakes or reservoirs. It is correct to conclude that in these areas ET exceeds P because they receive additional water from rivers, irrigation canals or aquifers. The water yield from the Ethiopian plateau is high, and it drains into the Blue Nile. This is in line with the general hydraulic perception that the majority of the Nile water is produced in the tributary of the Blue Nile. The water production from the east shore of Lake Victoria is also significant. The results for the savannah in Sudan and Ethiopia are plausible also, because annual ET is just slightly lower than annual rainfall.

The vegetation cover is the fraction of the ground covered by vegetation. Vegetation cover is a useful tool for monitoring the overall condition of green vegetation; it reflects indirectly the presence of moisture in the ground because lush green and biological active vegetation cannot exist without available moisture. The vegetation cover can be derived from the spectral vegetation index using established empirical relationships. These relationships are well described in the international literature, and with the NDVI data at hand, it is straightforward to convert NDVI into vegetation cover.

Public domain land cover maps are suitable for deriving some first order statistics of the Nile basin. For more exact analysis of the economic and ecological values, a more detailed land use is deemed necessary. We suggest that a basin-wide land use map be prepared on the basis of 56 m ResourceSat and 300 m MERIS images. The advantage of MERIS is the availability of multiple spectral bands with a 300 m pixel dimension. The IRS ResourceSat AWiFS data has the great advantage of having 56 m pixels and a repeat cycle of 5 days. The swath width of 750 km is ideal to cover the Nile Basin with a few images.

The major conclusion that can be drawn from Table 15 is that gross rainfall, interception, surface runoff, ET, soil moisture, and change in storage can be computed operationally with time intervals of 8 days to one month. When combined together, this will create an attractive dataset for near-real time monitoring of the hydrological condition of the Nile. Since the data will be acquired for every pixel, first order estimates of water balance in un-gauged basins can be prepared.

Most models used for RS information products can be programmed and operated by the DSS-RS unit. Some models are subject to a propriety right. In the latter case, a license agreement needs to be negotiated with the owner of the intellectual property. The DSS-RS unit should include software maintenance agreements and on-call assistance for support during the execution process.

6 Special Purpose RS products

6.1 General

Primary RS data and RS information products describe properties (e.g. elevation, land cover, albedo), surface state conditions (e.g. soil moisture, surface temperature) and land surface physical processes related to them (rainfall, ET, floods, erosion). This was expanded on in Chapter 5. As indicated before, none of the physical environmental processes are directly measurable and interpretation algorithms are needed for their accurate quantification. Water policy makers and water managers, however, need information tailored for their decision making processes. Their emphasis is on public, societal and hence political goals. They deal with issues such as shared benefits of water resources for all stakeholders, the mitigation of natural hazards (incl. floods and droughts), productive use of scarce water resources, conservation of biodiversity, sufficient power generation to ensure electricity supply, creation of attractive living environments, eradication of famine, reduction of water pollution, prevention of land degradation and soil erosion, etc. Such decision processes require evidence based supporting tools and models specialized for the Nile Basin with its unique geo-physical character. We propose the use of specific RS based "indicators" which managers can use to assess and validate a wide range of land use options and their impacts on water resources without intensive measurement. We will discuss such indicators in this chapter and will refer to them as integral parts of our Special Purpose RS products that we are developing. By creating a set of thematically different indicators, it will become easier for policy makers to watch only their own indicator of interest.

We believe that the provision of Special Purpose RS products and the indicators will increase the utilization and value of the remote sensing data base. Although the generation of higher level information requires more intense image processing, advanced technical skills in the DSS-RS unit, more manpower and involvement of consultants for advice and data quality control, the final product will enhance the usage of remote sensing as a new source of spatial data. Well formulated special purpose RS products will facilitate real-time decisions, especially when they are delivered timely and their definition is supported by the end-user. Special purpose RS products will no doubt have to be modified as experience grows and new opportunities and challenges emerge. A tentative list of operational activities requiring special purpose RS products for the 2008 was discussed during the NBI-WRPM workshop in February 2008. Management indicators will be developed for the following operational activities:

- Description and assessment of hydrological processes, including water balances;
- River basin management for sustainable and productive use of water resources;
- Disaster management, including early warning systems for floods and droughts;
- Agricultural water management (including food security), irrigation management, rain-fed agriculture and livestock agriculture;
- Environmental management, including wetlands, biodiversity and soil salinization;
- Watershed management, including land degradation, deforestation and erosion.

The link between the indicators developed for these activities and the support for the Basin-wide Shared Vision Project (SVP) and the Subsidiary Action Programs (SAP) is described in Table 16. The relationship between the indicators and the programs will improve once application studies arise. Special Purpose RS products should be made available to a wide as possible user base.

Table 16 Relationship between special purpose RS indicators and the Basin-wide Shared Vision Project (SVP) and Subsidiary Action Programs (ENSAP and NILESAP)

Type of indicator	SVP	SAP
Indicators for assessing and describing hydrological processes	Water Resources Planning and Management (WRPM)	Watershed management
Indicators for river basin management	Water Resources Planning and Management (WRPM)	Eastern Nile planning model Baro-Akobo multipurpose water resources
Indicators for disaster management	Na	Flood preparedness and early warning
Indicators for agricultural water management	Efficient water use for agricultural production	Irrigation and drainage
Indicators for environmental management	Nile trans-boundary environmental action	Baro-Akobo multipurpose water resources
Indicators for watershed management	Nile trans-boundary environmental action Efficient water use for agricultural production	Watershed management

6.2 Indicators to assess and describe hydrological processes

RS cannot replace hydrological measurements because (i) not all processes can be estimated by RS and (ii) RS is only an indirect measurement (i.e. estimate) of hydrological processes. Nevertheless, hydrological processes can be described with RS for areas which otherwise would not have been possible. Such areas include for example, very large areas, inaccessible areas, areas without hydro-meteorological gauging stations, etc. We believe that gross rainfall, ET, interception, and surface runoff as overland flow, can be estimated with reasonable accuracies (90 to 95 % on a seasonal basis) from RS methods. The accuracy for storage changes is less evident. When put together, RS methods can be used to calculate a simple water balance. A generic water balance of the unsaturated/saturated soil column can be described by the following equation:

$$\mathbf{P_{gross} - P_{int} + I_{rr}^{SW} + I_{rr}^{GW} = ET_{act} - q_0 - q_{ground} - \Delta S}$$

Where
P_{gross} = gross precipitation
P_{int} = intercepted rainfall
I_{rr}^{SW} = irrigation by surface water resources
I_{rr}^{GW} = irrigation by groundwater resources
q_0 = surface runoff
q_{ground} = exchange between the saturated soil and its surrounding groundwater system (seepage, leakage or lateral drainage)
ET_{act} = actual evapotranspiration (without interception)
ΔS = change in storage

The water balance changes with the various physical processes that are land use dependent. While irrigation water supply I_{rr}^{SW} and drainage flows q_{ground} are important for irrigated crops, they can be ignored for savannah and forests. The missing terms of the water balance of irrigated crops are the irrigation applications I_{rr}^{SW} and I_{rr}^{GW} as well. Irrigation water supply from surface water and groundwater resources cannot be determined with RS. However, if the groundwater component q_{ground} is ignored or it is imbedded in the supply (net supply viz-a-viz gross supply) because it is small anyway, then the total of I_{rr}^{SW} and I_{rr}^{GW} could be assessed from the other terms. If the surface water resources I_{rr}SW diverted from rivers and released from reservoirs can be estimated from flow records, it will become possible to even determine I_{rr}^{GW} and q_{ground} as being the net groundwater use from the conservation of mass. (e.g. Ahmad et al., 2005). If release data from reservoirs are not available, surface water resources can be estimated from reservoir capacities in combination with information on water levels. For small sub-basins, the total volume of surface water resources could be estimated from the water yield of upper catchments.

In the case of wetlands, the water balance reduces to:

$$\mathbf{P_{gross} - P_{int} + q_{flood} = ET_{act} - q_{ground} - \Delta S}$$

By combining inflow from floods (q_{flood}) with outflow from drainage (q_{ground}), it becomes feasible to define and compute a 'net exchange' of water to or from wetlands. Values of this net exchange will indicate the amount of wetland withdrawals from surface and groundwater resources.

Areas with a deep water table and absence of a streamflow network have the simplest form of water balance. In the case of forests and savannah, the water balance reduces to:

$$\mathbf{P_{gross} - P_{int} = ET_{act} - q_{ground} - \Delta S}$$

Where q_{ground} depicts the free drainage that is either stored in an aquifer system or finally flows to a stream by means of baseflow. By combining hydrological processes with land use maps, one can make a first order approximation of groundwater extractions for irrigation, net exchange between wetland and their surrounding areas, and recharge of aquifers underneath savannah and other types of natural land cover. The latter information is paramount for the application of more advanced hydrological models that describe the behaviour of aquifers, irrigation canals and river hydrology. The additional water balance information can also be of great support for quick assessment of the magnitude of flow processes without setting up advanced and time consuming hydrological models.

One should be aware that irrigation supplies, surface runoff and groundwater exchanges balance at a larger scale. The largest possible scale for water balance calculation is the total basin of the Nile where P_{gross}-P_{int}-ET_{act}= q_0 + ΔS (where q_0 now denotes the total runoff to the sea or inland depressions). Thus at a larger scale, the water balance becomes more simple because external actual exchanges of mass can then be disregarded, and they all become internal (and disappear from the equation). We recommend the DSS-RS unit to prepare a standard set of water balance terms for each land use type as specified in Table 17. These water balances should be prepared for each pixel of 1 km x 1 km, and the time interval should be one week.

Table 17 Water balance determination by land use class. It is assumed that P_{gross}, P_{int}, ET_{act} and q_0 can all be spatially estimated from RS with sufficient acccuracy

Land use	q_{ground}	Irr^{SW}	Irr^{GW}	q_{flood}
Open savannah	Yes	-	-	-
Woody savannah	Yes	-	-	-
Natural forest	Yes	-	-	Yes[3]
Plantation forest	Yes	-	-	-
Irrigated crops	Yes	Yes	Yes	-
Rain-fed crops	Yes	-	-	-
Fishponds	Yes	Yes	Yes	-
Natural wetlands	Yes	-	-	Yes
Managed wetlands	Yes	-	-	Yes
Lakes	Yes	-	-	Yes
Reservoirs	Yes	-	-	Yes
Phreatophytes	Yes	-	-	-
Saline sinks	Yes	-	-	Yes
Deserts	Yes	-	-	-
Oases	Yes	-	-	-
Shrubland	Yes	-	-	-
Grazing land	Yes	-	-	-
Open water bodies	Yes	-	-	-
Uncultivated bare land and rocks	Yes	-	-	-
Urban settlements	Yes	Yes	Yes	Yes[4]
Industries and ports	Yes	-	-	Yes
Snow and glaciers	Yes	-	-	Yes

List of RS indicators for assessment and description of hydrological processes

- Combined groundwater runoff , drainage, seepage or leakage, q_{ground}
- Irrigation water supply from surface water resources, I_{rr}^{SW}
- Irrigation water supply from groundwater resources, I_{rr}^{GW}
- Inflow from surrounding high water levels

6.3 Indicators for river basin management

Good river basin management should fulfil a minimum set of goals. The most important broader set of goals are:

- Meeting water demands for all water use groups;
- Productive use of water resources for best economic and environmental benefits;
- Security during droughts and floods;
- Minimum non-recoverable losses;
- Sufficient food, feed and wood production;
- Prevention of physical degradation of natural land use types;
- Prevention of environmental degradation due to pollution, erosion, contamination, etc.

[3] Gambella and Northern Sudd are examples of naturally flooded forests
[4] Inundations are associated with overland flow

Water accounting is a relatively new procedure, developed by Molden (1997), to quantify water flows in relation to their usage. It does not relate water use to water demand, but only accounts for the flow of water use in a basin. It describes the inflow from upstream surface water systems in relation to the committed outflow to downstream areas or other nodes for which formal agreements are established. Water accounting describes how water is used, and to what extent it can be managed. It is a basic analytical framework that, when completed, can be used to identify target values for good river basin management and to assess the deviations from these targets.

Water flow in the basin could be classed as "managed", "manageable" and "non-manageable" flows. Managed flows are regulated by existing and functioning infrastructure, such as groundwater abstractions for drinking water supply, diversions to irrigation systems and water treatment plants. Manageable flows are flows that can be influenced by interventions such as land use changes in cropping patterns, expansion of urban areas etc. Manageable flows could be both existing practices and future planned practices. Non-manageable flows occur in natural land use classes where human interventions are minimal or completely absent. Examples are streams and aquifers without management. The water balance and water usage in non-manageable flows is governed by natural processes. Water accounting thus integrates hydrological flows with management options and land use. Land use is critically important for appraising the range of possible human interventions, the economic value and the environmental value (that is why we need this badly in the Nile basin).

Consumed water is water that is lost from the basin and no longer available for downstream diversion. Consumed water represents evaporation (E), transpiration (T), export of bottled water outside the basin area, vaporization from cooling towers in thermal plants, etc. Consumed water can also be water that goes to saline sinks or gets polluted to such a degree that it cannot be re-used. Although water in saline depressions, playas (i.e. sebkha) and non-exploitable aquifers are physically present in the basin, it is not available for usage. We therefore referred to it as being consumed.

The <u>depleted fraction</u> describes the ratio between consumed water (being dominantly ET) and the total supply from rainfall and inflow from upstream areas. A basin is hydrologically closed if the full supply of water is consumed and nothing is left to drain into the sea or inland depressions. The depleted fraction in such a case is equal to one. It can exceed unity if consumption exceeds the total supply and ΔS at basin scale from aquifers, lakes and reservoirs becomes negative. The depleted fraction thus describes the overall water resources situation in a basin, and indirectly also its sustainability by the deviation from unity.

$$\text{Depleted fraction} = \frac{\text{ET}}{\text{Rainfall + Inflow}}$$

The water used in a basin (depletion of the water resources) will produce a certain intended product or good. The *beneficial fraction* describes the fraction of consumed water that contributes to economic or environmental value. Transpiration is generally considered to be beneficial because water vapour exhalation through the stomata occurs jointly with carbon inhalation and lead to Net Primary Production (NPP). Whereas transpiration (T) results in dry matter production through carbon assimilates, evaporation (E) will not contribute to dry matter production. Hence, E is basically not beneficial, unless the loss through E leads to economic and environmental goods such as fishing, hydropower, and wetlands. Transpiration from salt tolerant plants and phreatophytes are over against that considered as non-beneficial. RS can facilitate in the computation of actual E and T fluxes, and can, in combination with land use, contribute to understanding beneficial vs non-beneficial consumption (see Table 18).

$$\text{Beneficial fracton} = \frac{\text{Economical + Environmental ET}}{\text{Total ET}}$$

A logical next step is to describe the dry matter production that is resulting from economical and environmental T. Food, fodder and wood from biomass production is both proportional with the total economic value and with the environmental value. This can be expressed as the *biomass water productivity* (see Figure 23):

$$\text{Biomass water productivity} = \frac{\text{Biomass production}}{\text{ET}}$$

The *utilized fraction* reveals the degree that renewable water resources are tapped and exploited. The *utilized fraction* is expressed as the actual / potentially utilizable water resources. The total potential utilizable flow is the net water production (P-ET) from areas where P>ET fulfil, supplemented by inflow and corrected for committed outflow. Committed outflow can be an (international) water treaty that specifies certain volumes of water to be delivered at a given administrative boundary. Committed outflow could be the environmental water demand of an aquatic ecosystem or an inter-basin water transfer arrangement. The utilized volume is water that is managed in water consumption areas where ET>P (irrigated areas, reservoirs, controlled wetlands). Managed flows also occur in the domestic, industrial, recreational and tourism water use sectors, although most of this water is recovered by return flow.

$$\text{Utilized fraction} = \frac{\Sigma(\text{ET - ET}_{\text{natural}})_{\text{ET>P managed}} + \text{other consumptions}}{\Sigma(\text{P-ET})_{\text{P>ET}} + \text{Inflow} - \text{Committed outflow}}$$

Another measure that is part of the water accounting is the *recoverable fraction* (Perry, 2007). Recoverable flows are water flowing to drains and back into the river or percolating into freshwater aquifers from which it can be re-used, or water that feeds rivers by means of baseflow. This water is non-consumed water that could potentially be re-used.

$$\text{Recoverable fraction} = \frac{\text{Non-consumed water}}{\text{Recoverable water}} = \frac{(q_{\text{ground}} + q_0)_{\text{all land use on aquifer}}}{(q_{\text{ground}} + q_0)_{\text{all land use}}}$$

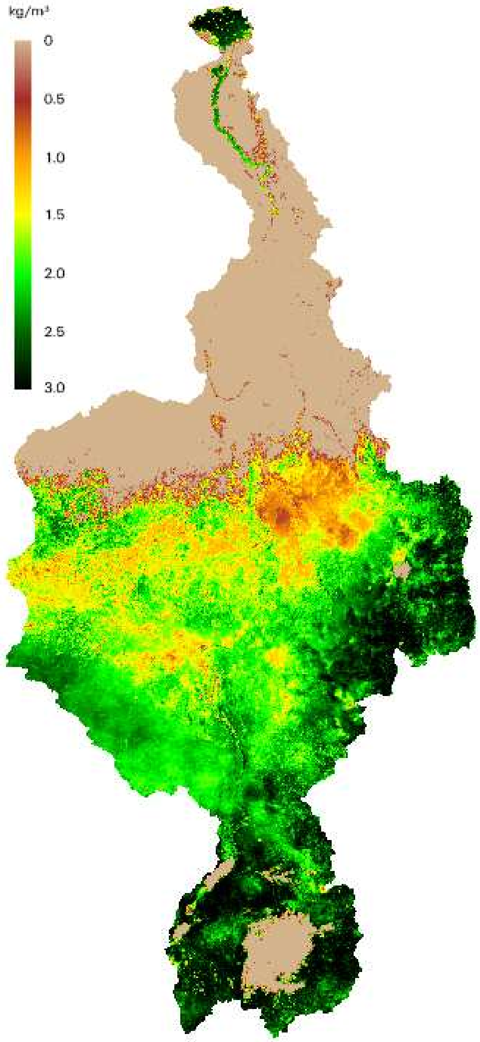


Figure 23 The biomass productivity of all ecosystems present in the Nile Basin. Ethiopia and Uganda seems to be most productively utilizing the water resources

Another way to depict evaporative depletion is to class the water flows into manageable classes: non-manageable, manageable, and managed water flows. These flows are highly land use dependent, and the key is therefore provided in Table 18. This key is rather generic, and could be used for the water accounts of every sub-basin of the Nile system.

$$\text{Manageable fraction} = \frac{ET_{\text{manageable land use}}}{\text{Total ET}}$$

Table 18 Breakdown, by land use class into manageable ET flows and the evaporation losses (depletion of water resources through evaporation) into beneficial and non-beneficial use.

Land use	Management	Beneficial – economical	Beneficial – environmental	Non-beneficial
Open savannah	Manageable		T	E
Woody savannah	Non-manageable		T	E
Natural forest	Non-manageable		T	E
Plantation forest	Manageable	T		E
Irrigated crops	Managed	T		E
Rain-fed crops	Manageable	T		E
Fishponds	Managed	E		
Natural wetlands	Non-manageable		T and E	
Managed wetlands	Managed		T and E	
Lakes and rivers	Managed		E	
Reservoirs	Managed	E		
Phreatophytes	Manageable			E and T
Saline sinks	Manageable			E and T
Deserts	Non-manageable			E and T
Oases	Non-manageable		T	E
Shrubland	Non-manageable	T		E
Grazing land	Manageable	T		E
Uncultivated bare land and rocks	Non-manageable			E
Urban settlements	Managed		T	E
Industries and ports	Managed			E and T
Snow and glaciers	Non-manageable			E

The analysis in Table 19 demonstrates that the majority of the water resources are used by the savannah ecosystem (38.6 % by savannah and 24.7 % by the woody savannah). The value of this water use is environmental. A total of 94% is T and this water depletion is highly beneficial. The data reveals that most of the water resources are located in the land use class "rain-fed croplands" where precipitation of 862 mm exceeds the ET of 770 mm. This class occupies 8% of the basin area and contributes significantly to runoff generation. The beneficial to non-beneficial fraction of water consumption in this class is quite good. The land use classes "urban" and "barren land" clearly have low beneficial ratios, due to unavoidable E.

Water accounting also shows production per unit of land and per unit of water. The data reveals that open shrub land at 4.06 kg m^{-3} has the greatest biophysical water productivity. The evergreen broadleaf forest has the lowest productivity, mainly because of the very high ET fluxes exceeding 1800 mm/yr.

Table 19 Water accounting for rainfall and ET across the entire Nile Basin during 2007. The simple IGBP land cover map has been used for this purpose

Land use	Area (m^2)	Land use (%)	Rainfall (mm)	ET (mm)	ET (mcm)	ET (%)	Transpiration (mm)	Beneficia ratio (T/ET)
Evergreen Needleleaf Forest	1488125952	0.0	1215.4	986.9	1468.6	0.1	924.4	0.937
Evergreen Broadleaf Forest	84784425984	2.8	1608.5	1885.7	159877.1	7.5	1795.4	0.952
Deciduous Needleleaf Forest	209267712	0.0	1241.4	1132.2	236.9	0.0	1101.7	0.973
Deciduous Broadleaf Forest	11967012864	0.4	1029.6	1134.3	13574.1	0.6	1110.8	0.979
Mixed Forest	7525886976	0.2	1170.6	1249.1	9400.7	0.4	1173.4	0.939
Closed Shrublands	10083603456	0.3	839.6	823.2	8300.6	0.4	820.3	0.997
Open Shrublands	2.54377E+11	8.3	361.4	378.7	96343.0	4.5	377.2	0.996
Woody Savannah	3.74488E+11	12.2	1407.9	1401.7	524927.3	24.7	1324.5	0.945
Savannah	7.66563E+11	25.0	1066.4	1070.5	820622.1	38.6	1010.0	0.943
Grasslands	3.18064E+11	10.4	627.7	624.2	198548.8	9.3	605.8	0.971
Permanent Wetlands	14423970816	0.5	1022.1	1231.1	17757.1	0.8	1144.6	0.930
Rainfed croplands	2.41634E+11	7.9	862.1	769.6	185964.4	8.8	738.6	0.960
Urban and Built-Up	6223776768	0.2	573.9	331.2	2061.2	0.1	253.2	0.765
Cropland/Natural Vegetation Mosa	29297479680	1.0	1495.9	983.7	28818.5	1.4	971.1	0.987
Snow and Ice	0	0.0	0.0	0.0	0.0	0.0	0.6	0.000
Barren or Sparsely Vegetated	9.43867E+11	30.8	54.1	60.6	57209.4	2.7	28.3	0.466

The combination of rainfall, ET (E & T) and land use data (eventually land cover data if land use data is not available) complemented with external inflow and committed outflow make it possible to prepare standardized water accounts. We propose water accounting to become a standard procedure for the total Nile Basin system as well as for its tributaries. The water accounting indicators that we recommend for seasonal and yearly processing are specified in Table 20.

Table 20 Overview of water accounting indicators. Net production occurs when precipitation exceeds ET for a given land use type. Net consumption occurs when ET exceeds precipitation

Description	Analytical function
Depleted fraction	ET / (rainfall + inflow)
Beneficial fraction	Beneficial T / Total ET
Biomass water productivity	Biomass/ET
Utilized fraction	net consumption / (net production + inflow – committed outflow)
Recoverable fraction	Area of managed flows / aquifer area underneath
Manageable consumption	($ET_{rainfed\ crops}$+$ET_{forest\ plantation}$+other consumption) / ET_{total}
Managed consumption	(ET_{irr}+$ET_{reservoir}$+ $ET_{wetlands}$ + other consumption) / ET_{total}
Non-Manageable consumption	$ET_{natural\ land\ use}$/ET_{total}

6.4 Indicators for disaster management

6.4.1 General issues

Anomalies in weather conditions can result in short, intensive storms, through to elongated periods of severe drought. In this section we will focus on warning systems for floods and droughts, but will not address storms and typhoons. While natural disasters cannot be prevented, their effects on livelihood, famine, and welfare could be mitigated if people are timely informed of an approaching disaster. Excessive amounts of flood water can be controlled with weirs and sluices. Water could be diverted into low lying areas upstream of metropolitans to reduce high peaks in water levels, and to prevent water flooding streets and houses. Dikes and levees could temporally be reinforced with military assistance, and watch teams could be created and sent to areas with the greatest risks for flooding. The inhabitants of flood prone regions should be informed timely to evacuate or to prepare themselves for floods. Floods are not always only disastrous. Water from flood spates can also be stored in wadis and in soils to grow essential staple and cash crops. For farmers to be ready for water harvesting, spate irrigation and recession agriculture, they have to be alerted well in time.

Droughts, which are on the other end of the spectrum, occur when rainfall is below average for an elongated period, and water supply from rivers and aquifers is insufficient to meet the total water requirements. Timely recognition of droughts is crucial for water resource conservation. Once water flowed downstream, it is no longer available for keeping crop lands and wetlands moist.

The DSS-RS unit should create an Early Warning System for both floods (Nile-Flood) and droughts (Nile-Drought). Traditionally such systems are based on field data collection. Such data gathering at national scale is slow and inconvenient. The international status of the basin further exacerbates a tardy data collection process. Satellite data have the advantage to be digital, spatially distributed, and readily available and accessible. TRMM 3 hourly data (and AMSR-E and MODIS data) are usually available within 24 hours after image acquisition and storage in their data archives. This quick data delivery is fundamental for an efficient and effective operational Nile-Flood and Nile-Drought product.

6.4.2 Flood management

A flood information tool needs to be developed that could standardize the interpretation and predictive capability of excessively large stream flow events. A daily flood risk map should be compiled using a simple decision model that utilizes satellite measurements of (i) soil moisture, (ii) local rainfall over the flood prone area and (iii) the cumulative surface runoff from upstream catchment areas. Runoff is generated from overland flow (storm flow) in conjunction with baseflow (groundwater outflow). Stormflow can be computed from curve number methods. Baseflow is only a certain fraction of $P-P_{int}-ET-q_0$. Upstream water excess could be approximated from rainfall, ET, surface runoff, and likely some geohydrological information. Hence the total runoff from all upstream pixels can be computed as a total volume of water. Routing of the runoff can be achieved from the DEM. Once the total volumetric runoff (m^3) from upstream areas in a given pixel exceeds a certain threshold value, a flood is likely to arise, especially when soils on the flood plain are already moist and local rainfall occurs simultaneously. A daily flood forecasting system is suggested that computes the accumulated upstream runoff value on a daily basis, and compares it with local soil water content and rainfall.

The RS information can be coupled to classical GIS maps such as population density, soil type, land use, slopes and terrain elevation, for an improved understanding of the physical conditions on the flood plain. Daily maps of flood risk classes ("no risk", "become alert", "risk", "extreme risk") for pre-defined intervals of upstream runoff volume could be disseminated via the NBI website and Google Earth. These maps could also be published in local newspapers, if the situation becomes threatening.

Further to that, the duration of floods is crucial for the damage assessments and the need for people to receive additional aid programs. A long flood will have more devastating effects and could adversely affect food production. The availability of continuous daily AMSR-E soil moisture data will make it technically possible to monitor a flood event. The example of Figure 24 shows the duration of the 2007 floods in Sudan. We have considered here multiples of 8 days for practical reasons, and this interval could be cut back if required. The areas having 100 days with high topsoil moisture content are permanently wetlands. Large areas with 50 days of flooded water are indicated. The areas of the Bahr-el-Sobat appear to have periods with two months of floods uninterruptedly. Also the areas along the banks of the Blue Nile are seriously affected. These areas match very well with the Darmouth Flood Observatory (Figure 11 and Figure 12).

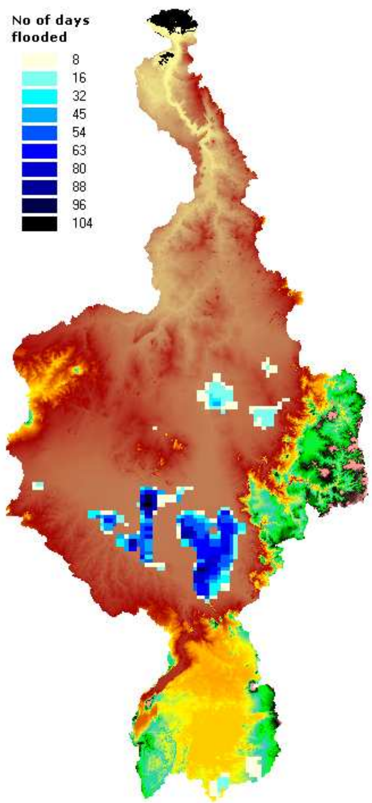


Figure 24 Example of flood damage indicators in southern and central Sudan during 2007

Combining daily AMSR-E surface soil moisture data at 25 km resolution, with 8-day visible reflectance and thermal products of the MODIS satellite will sharpen the AMSR-E soil moisture data to maximally 1 km. Reflectance of water bodies decreases with increasing wavelengths and water bodies always have a relatively low thermal emitted radiation. This characteristic can be used to distinguish moist land, water bodies and flooded land from other areas within the 25 km x 25 km AMSR-E box. Surface temperature reduces due to evaporative cooling, and cold pixels can be used to identify areas with water bodies (see Figure 25). Combining different satellite data sources will make it feasible to create a pixel size for flood risk prediction of approximately 1 km (MODIS) to 3 km (MSG). MSG is mentioned here because of the availability of hourly thermal images and improved chances of cloud-free temperature data.

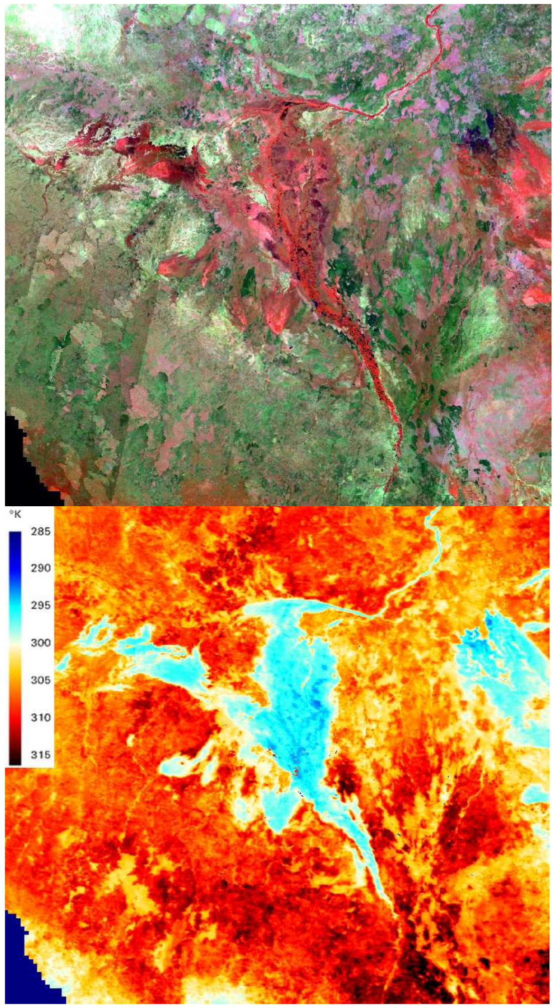


Figure 25 Example of surface reflectance (upper part) and surface temperature (lower part) from MODIS in the flooded Sudd during January 2007. A data fusion between AMSR-E and MODIS is suggested to spatially sharpen the daily flood risk map

6.4.3 Drought management

Aridity is defined as the difference between rainfall and reference ET_0. It is also customary to define it as a ratio P/ET_0. Negative values of $P-ET_0$ suggest a shortage of rainfall to meet water demands of unstressed and well watered grassland. The aridity level increases with decreasing $P-ET_0$ values. Egypt is an example of an arid country. Egypt is hyper-arid, but has no drought. Hence it is important to distinguish these two aspects of water shortage. Droughts in Egypt should be more related to the anomalies in water availability and soil moisture levels, and to a lesser extent to the climatic conditions. Egypt will have a drought if the water supply from Lake Nasser is no longer guaranteed as a result of falling lake levels caused by decreased inflow from upstream Nile catchments. The infrastructure is based on the Nile flow and society relies on the average flows and diversions. A problem arises if the soils are drying up and water supply to the growing population cannot longer be guaranteed. The inhabitants of Ethiopia or Sudan do not need a warning during the dry season, because they have adapted to such conditions. They do need a warning, though, in case river discharges are lower than normal and wells and pools are drying.

While quick warning systems of droughts are not as crucial as for floods, an extensive drought period could gradually become a serious constraint for normal living. Water and power supply cuts, drying wells and water points, crop failure and fire risks in natural landscapes, are examples of consequences of extensive droughts. The looming character of a drought event provides options to conserve water as long as it is feasible. During a period of drought, drainage water should be contained and prevented from flowing to the sea or sinks. Extra groundwater abstractions should be allowed during droughts to ensure water supply to the domestic and industrial sectors (provided that artificial recharge occurs during wet years to compensate for the additional abstractions). Water allocation to irrigation, reservoirs, wetlands, industries and domestic water users has a certain priority sequence. Water from reservoirs and aquifers should not be supplied to irrigated rice fields if water is required for power generation. Agriculture is a large consumer, and water supply in this sector should firstly be allocated to the user groups that use lower volumes of water to generate higher economic value (value per unit of water). A lack of power supply due to a shortage of hydropower , or power generated from thermal plants due to lack of cooling capacity, will be catastrophic for the commercial industry. Under all circumstances, the priority should go to drinking water supply to maintain health of aged and sick people. A next priority is the safeguarding of power generation industries. Irrigation and wetlands are third and fourth priority respectively.

Water conservation requirements and – ultimately - water re-allocation during droughts should be monitored continuously. This can be accomplished by means of spatial recording of cloud cover (MSG), surface temperature (MSG or MODIS), rainfall (TRMM), soil moisture (AMSR-E), ET-deficit (MODIS) and biomass production (MODIS). The DSS-RSD unit should develop the Nile-Drought algorithm which combines the satellite-based info in the logical framework depicted in Figure 26. The deviations from normal values should be defined on the basis of longer term average values. The proposed model will identify anomalies.

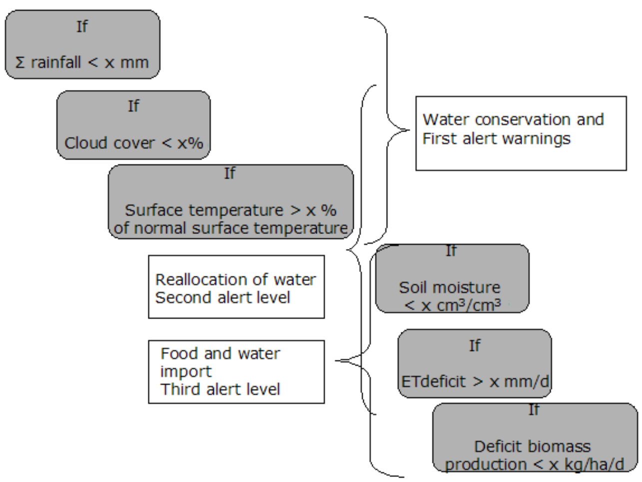


Figure 26 A prototype, integrated multiple-sensor data system for creating different drought alert levels and interventions.

The first alert level is triggered if the combined signal from rainfall, cloud cover and surface temperature reveals extra-ordinary dry, cloudless conditions and warm land surfaces. An example of warm land surfaces is presented in Figure 27. The MODIS surface temperature has been lapse corrected to eliminate elevation effects. The dryland pixels are 20 to 25 degrees warmer than the open water temperatures.

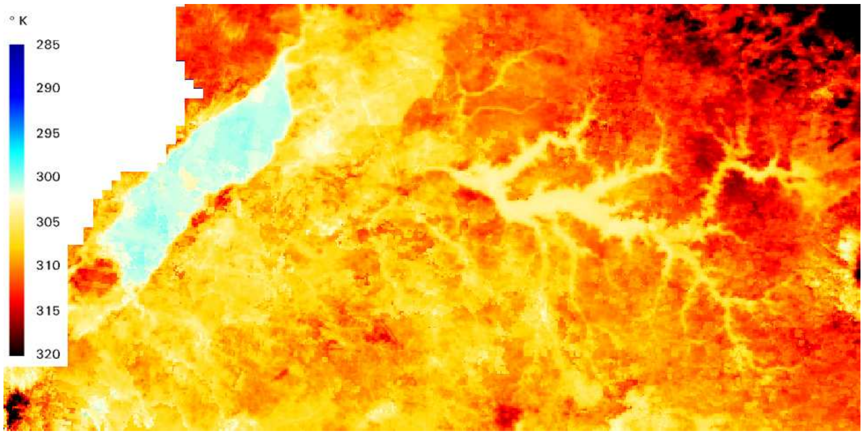


Figure 27 The surface temperature from MODIS in January 2007 for the landscape in Uganda surrounding Lake Albert and Lake Kyoga

At an early stage, this may not be a problem, and authorities may review options to retain water. If the signal continues for consecutive days and soil moisture keeps on depleting to a point that results in a serious deficit in ET fluxes (the deficit is the difference between actual and potential ET, see Figure 28), water allocation should be re-examined. Supply of water to power plants and the domestic sector should be guaranteed. A third level of high alertness can be introduced if the production rate of vegetation slows down seriously. The severity level is worse if food, fodder and wood production cannot longer be ensured. Shortage of staple food and cattle feed will create famine and may coincide with a great risk of forest fires and extinction of biome types and reduced biodiversity. Satellites cannot measure damage caused by drought in the domestic and industrial sector. For this reason, the drought damage indicator in Figure 26 is related to biomass production.

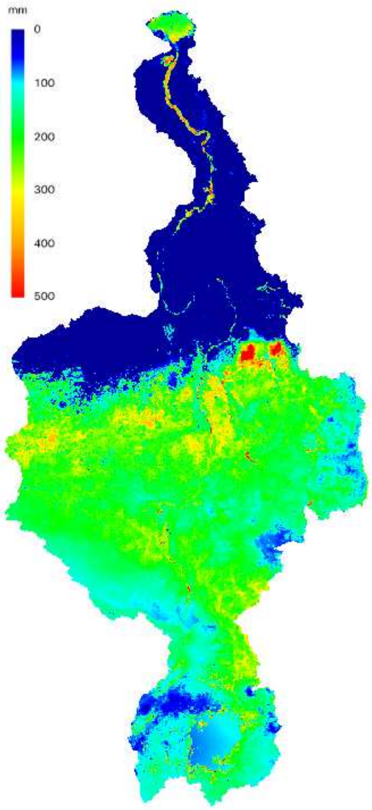


Figure 28 Example of the annual water stress expressed as an ET deficit ($ET_{potential} - ET_{actual}$) during 2007. The largest deficit (>300 mm yr^{-1}) are found in a line between the pastures of Kassala and Kordofan, the Nile Valley and Fayoum Depression

If droughts have a short return period, it is likely that managed water use is not in agreement with the natural water resources conditions and the renewable water volumes: more water is used than available from upstream surplus. Under such conditions of anthropogenically induced drought, options of more permanent water saving need to be investigated. The latter could be accomplished by studying the frequency distributions of ET_{act} and ET_{pot} for each land use class, and determine options to reduce consumptive use so that more water remains in the surface water network. Figure 29 shows the population of ET pixel values in the Nile Delta. The majority of the pixels with irrigated land exhibit an ET between 750 to 1300 mm yr^{-1}. This is a significant range in this population, and it would be worth exploring whether this range could be reduced by the introduction of water conservation programs for establishing more uniformity in water consumption. We have seen from other examples in this report, that the Nile water has a high economic-beneficial fraction and a high water productivity. So, it is questionable whether these well producing irrigation systems should be cut on their supplies. It is anyway a good example to show that water resilience could be inspected by using the frequency distribution of ET in each land cover or land use class.

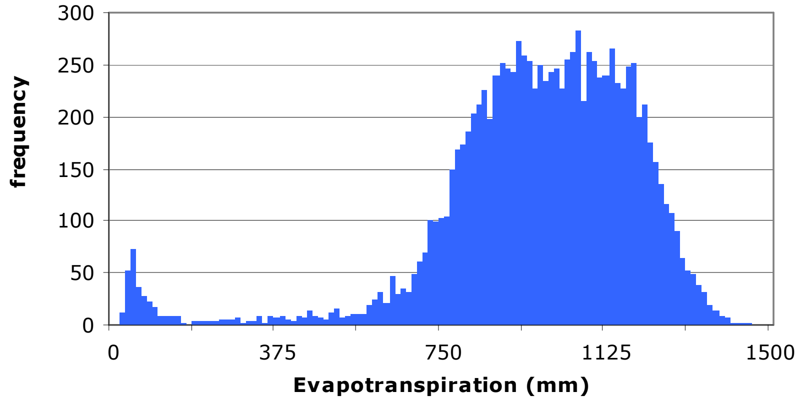


Figure 29 Example of frequency distribution of ET_{act} in the land use class "irrigated crops". The wide spread suggests that options for water conservation are feasible. Irrigation is categorized as "manageable water users"

List of RS indicators for disaster management

- Flood alert level indicator (soil moisture, local rainfall, upstream rainfall)
- Flood damage indicator (soil moisture duration)
- Drought alert level indicator (rainfall, cloud cover, surface temperature, soil moisture, ET_{act}, ET_{pot})
- Drought damage indicator (potential and actual biomass production)
- Water saving indicator (land use, ET_{act}, ET_{pot})

6.5 Indicators for agricultural water management

6.5.1 Irrigated crops

The arid and semi-arid climates in the Nile Basin require water supplementation to the sparse rain water supplies. More than 90% of the irrigation schemes are located in Egypt and Sudan (see Figure 14). Because of the relatively high water allocation to irrigated crops in comparison to water supply to industries and domestic sectors, good water governance in the irrigation sector has to be critically reviewed. Sets of irrigation efficiencies and irrigation performances were promoted since the seventies to assist with the evaluation of management of irrigation systems (e.g. Bos and Nugteren, 1974; Bos et al., 2005). The challenge is to get access to the required flow data to implement these analytical frameworks. Realizing that canal flows, crop production and soil moisture are not measured, not stored and not disseminated, Bastiaanssen and Bos (1999) and later Bastiaanssen et al. (2000) made an appeal for a performance assessment framework on the basis of remote sensing data. The standard list proposed for implementation in the Nile basin is portrayed in Table 21. The purpose of each indicator is indicated.

Table 21 Irrigation performance indicators based on RS data

Indicator	Purpose of indicator	Definition	Period
Crop water consumption	To give an estimate of total water depletion in irrigated agriculture	ET_{act}	Season
Land productivity	A measure of farm sustainability in agriculture	Bio	Season
Water productivity	A measure of the benefits derived from scarce water resources	Bio / ET_{act}	Season
Irrigation productivity	A measure of the benefits derived from managed water use	ΔBio/ΔT_{act}	Season
Annual cropping intensity	A measure of intensity of irrigated agriculture	Number of crop cycles	Years
Crop water stress	A measure of the adequacy of irrigation water supplies	T_{act} / T_{pot}	Week
Reliability	To indicate the degree of continuity and quality of irrigation services	Temporal variation of T_{act}/T_{pot}	Season
Equity	To indicate how uniformly accessible scarce water resources are.	Spatial variation of soil moisture	Week
Beneficial fraction	Assessing fraction of water used for producing an economic good	T_{act} /ET_{act}	Season
Employment	To provide an indication of social rural development	Jobs per crop / ET_{act}	Year
Water sustainability	Evaluate amount of natural resources and service level	Soil moisture changes	Years
Crop sustainability	To determine farmer's capability to remain economically viable	NDVI changes	Years

One of these aspects is water stress in irrigated crops. Crop water stress is a combination of water and farm management. If a system is managed properly, the crop should have sufficient water during moments when the yield response to water is sensitive (usually during flowering). Intentionally induced water stress could be beneficial for the harvest index of for instance grapes, but is non-beneficial for the harvest index of potatoes. Hence every crop needs a certain crop water stress strategy, and Figure 30 shows an example on how T_{act}/T_{pot} can be computed on a weekly basis from MODIS images and used for optimizing the moment and duration of water stress.

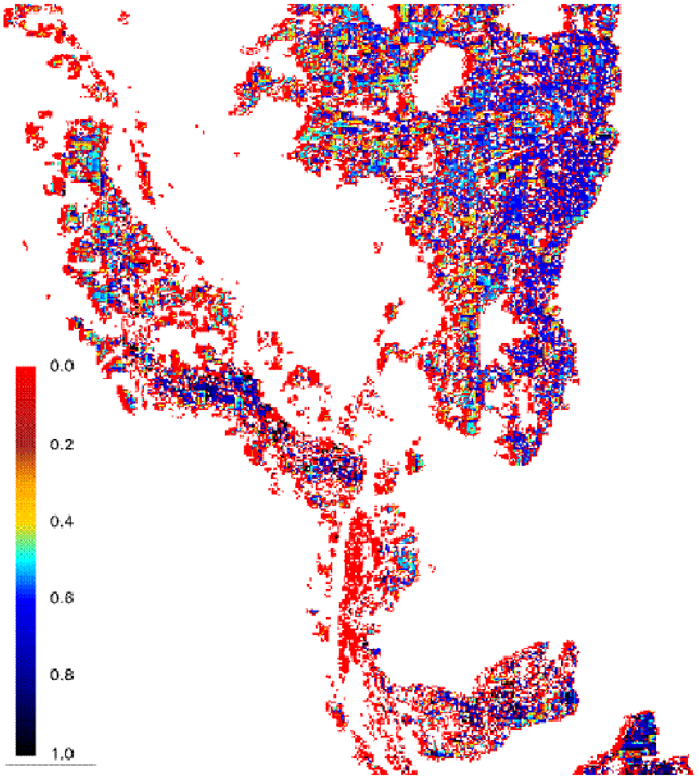


Figure 30 Spatial distribution of crop water stress in the Gezira and adjoining irrigated land is Sudan. Only blue pixels are irrigated

A preliminary test was conducted using selected indicators for irrigation schemes in the Nile Basin. The schemes selected are from Sudan and Egypt, because irrigation is extensive in these two countries. Whereas in Fayoum (Egypt) and Gezira (Sudan) flood irrigation systems are typically managed by the Government, the Western Desert and Kenana schemes are managed by commercial enterprises. The Eastern Desert was included because of its lower soil suitability for irrigation. Because rainfall has a significant impact on agricultural water management practices, the indicators are computed by season. The rainfall distribution in the Nile Basin is typically bi-modal.

Table 22 RS results for the management of irrigated summer crops in selected schemes

	Unit	**Purpose**	**Eastern Nile Delta**	**Western Desert**	**Fayoum**	**Gezira**	**Kenana**
Bio	Kg/ha	Land productivity	23983	12943	19319	8307	21618
Bio/ET_{act}	Kg/m^3	Water productivity	3.4	6.0	4.1	1.6	2.5
$\Delta Bio/\Delta T_{act}$	Kg/m^3	Irrigation water productivity	3.4	6.0	4.1	1.9	2.9
ET_{act}	mm	Crop water consumption	706	214	470	435	856
T_{act}/T_{pot}	-	Crop water stress	0.82	0.54	0.59	0.58	0.86
CV T_{act}/T_{pot} time	-	Reliability	0.070	0.070	0.180	0.127	0.166
Coeffcient Variation soil moisture space	-	Equity	0.615	0.363	0.172	0.084	0.089
T_{act}/ET_{act}	-	Beneficial fraction	0.96	0.93	0.99	0.59	0.93

Conclusions for the summer situation:
Eastern Nile Delta: This area is a large water consumer, but almost all water is beneficially used. The production per unit of land is very good. There is ample water availability with little crop water stress, although the spatial distribution is not uniform (more wet in direction of Mediterranean Sea and heterogeneity as a result of soil fertility variation). The reliability of the irrigation service is very high. The water productivity is average.

Western Desert: The water consumption is very low, and most water is beneficially used. The water productivity is extremely high, partially because there is significant crop water stress. Water is thus used wisely, and it goes at the costs of crop volume production (but at the benefit of fruit quality). A significant variation in water productivity among farms is apparent. The irrigation service is extremely reliable (probably due to groundwater supply).

Fayoum: This area, characterized by a depression, is an average water consumer with a good water productivity. The yields are lower than in the Delta region, mainly due to an overall water stress situation. The crops are moderately stressed, due to a combination of limited water and salinity. It seems that there is not enough water to meet the crop water requirements, and the irrigation service is not meeting expectations, leading to a low reliability of water supplies. The water stress is rather uniformly distributed across the depression.

Gezira: This area has moderate water consumption rates, and a large fraction of the evaporative depletion is non-beneficial due to uncontrollable rainfall rates. The agricultural production is far below average, which designates this area as being poor in productive use of water resources. Due to abundant summer rainfall, water stress is uniformly distributed. The water supply seems insufficient to meet crop water requirements.

Kenana: This sugarcane estate is the highest water consumer and also the largest food producer of the five areas investigated. The crop water productivity therefore is average. Despite the intensive summer rainfall, the non-beneficial fraction is relatively low, and most water is used for crop production. The land wetness can be classified as moist and uniform. The crop water stress is very low and the agricultural production is close to potential. Some temporal variation in crop water stress is noticeable, which can probably be explained by the difference in age of sugarcane fields and difference in varieties.

Table 23 RS results for the management of irrigated winter crops in selected schemes

	Unit	**Purpose**	**Eastern Nile Delta**	**Western Desert**	**Fayoum**	**Gezira**	**Kenana**
Bio	Kg/ha	Land productivity	18845	8611	18888	10790	17975
Bio/ET_{act}	Kg/m^3	Water productivity	5.9	12.2	7.5	3.6	3.3
$\Delta Bio/\Delta T_{act}$	Kg/m^3	Irrigation water productivity	6.1	13.6	7.6	3.1	2.8
ET_{act}	mm	Crop water consumption	317	71	251	296	537
T_{act}/T_{pot}	-	Crop water stress	0.79	0.48	0.63	0.56	0.73
CV T_{act}/T_{pot} time	-	Reliability	0.091	0.091	0.161	0.119	0.226
Coeffcient Variation Soil moisture space	-	Equity	0.818	0.372	0.165	0.118	0.198
T_{act}/ET_{act}	-	Beneficial fraction	0.97	0.89	0.99	0.94	0.97

Conclusions for the winter situation:

Eastern Nile Delta: Due to the climatic conditions in the northern latitude of the Nile Basin, the overall evaporative depletion during the winter season is moderate. The production is high and it results in a substantially higher crop water productivity during the winter as compared to the summer. There is ample water supply during winter and crop water stress is hardly noticeable. There is a distinct spatial variation in the water availability across this region, despite that the water service is temporary stable and very reliable. The same was also observed for the summer season.

Western Desert: This area has extreme low water consumptions and supreme water productivities. The area is a very good example of productive use of water in agriculture. Like in summer, deficit irrigation is practiced throughout the winter, yielding significant crop water stress values. These practices are systematic, and the management is consistent in this region.

Fayoum: Fayoum is doing very well during the winter irrigation season. Crop production is good and water consumption is relatively low due to less evaporative demand and prevailing shortage of irrigation water. The irrigation system is water short, and induced crop water stress is widely practiced. Almost all water is used beneficially. The reliability of the irrigation supply is below average.

Gezira: Both agricultural production and water consumption are low during the winter season. The crops are severely water stressed throughout the area. The stress levels are constant, and this can only be explained by low irrigation water supplies. One possible reason is the sedimentation of rivers and canals. The water productivity is below average.

Kenana: The warm climate of southern Sudan causes the crop water consumption to be high, also during the winter season. The production is in line with water depletion. The dry winter will cause the non-beneficial losses to be negligible. There is a considerable variation of crop water stress noticeable throughout the season.

6.5.2 Rain-fed crops

Rain-fed agriculture is a large land use class in the Nile basin and it produces the majority of staple food. Many rural families depend on their own crop production. The total cultivated cropland area in the Nile Basin is estimated to be 23,952,885 ha. Of this area 20,234,886 ha (85 %) consists of rain-fed crops (IWMI, 2007). Rockstrom (1999) argued that global food security depends on the food production in these types of rain-fed agricultural systems. The land and water productivity for rain-fed crops can be computed in the same way as done for the irrigated crops. The water productivity of the rain-fed crops in Sudan and Ethiopia is higher than for the irrigated crops. Apparently rain-fed crops are more resilient to water scarcity. They seem to create deeper root systems, and have larger stomatal apertures due to an environment with humid atmosphere and low vapour pressure deficit. The atmospheric vapour pressure deficit in rain-fed crops is lower than for irrigated crops in an arid landscape, and lower vapour pressure deficit increases the stomatal aperture and the water productivity (e.g. Bierhuizen and Slayter, 1965).

Because of the limited possibilities to manage water on rain-fed land – except micro water harvesting approaches – there is no long list of management indicators as outlined for irrigated crops in Table 21. It is suggested to consider:

- Land productivity
- Water productivity
- Beneficial fraction
- Water sustainability
- Crop sustainability

6.5.3 Livestock

Livestock (cattle, sheep, goats, camels) need grazing land for production of milk and meat. Livestock also has a positive contribution to traction and fertilizing of poor soils, besides it being a cultural heritage to include livestock in functions and ceremonies. Hence, livestock is the life blood for nomads and tribes that live on pasture and savannah areas of the Nile Basin. The livestock feed requirements can be met by natural grazing areas and wetlands. Drinking water for livestock is from lakes, wetlands, and water points. The livelihood of livestock farmers is highly dependent on their livestock health. An indicator for grass production and the availability for livestock is thus of essence. We suggest to combine maps of livestock density with biomass production of certain regions to estimate biomass production / livestock and livestock/water consumption. These ratios will assist with economic valuation of milk and cereal production (see Figure 31).

Live animal data is expressed in ”livestock units” (LU) for comparison of different species across geographical regions. The livestock unit is a standardized animal unit obtained by multiplying total number of animals with a conversion factors that takes into account "feed requirements" for the animal. Conversion factors have been used for compiling the livestock unit for each country/region (http://www.fao.org/es/ess/os/envi_indi/annex2_p.asp.)

Areas with 10 to 150 ton LU^{-1} can be found within the "grazing land" class. This represents a large variation, and is valuable information for livestock specialists. The water consumption is on average 0.5 LU per 1000 m^3 water with a range between 0.1 to 0.9 LU. Hence one LU consumes the same amount of water (2000 m3) as is required for the production of 2 tons of cereal at a crop water productivity of 1 kg m^{-3}. This places water consumption into the proper perspective and it can fascilitate national agricultural policy strategies if water shortage becomes a more frequently returning problem.

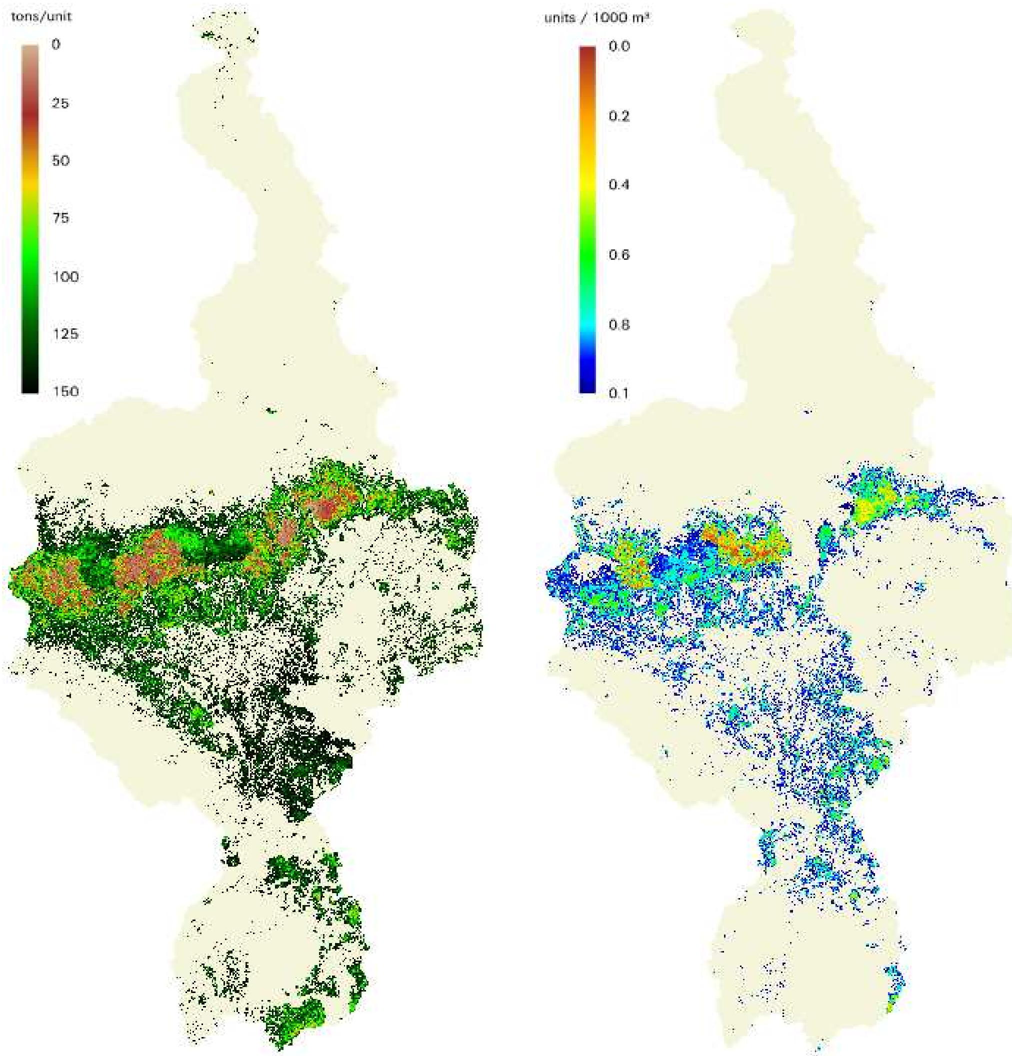


Figure 31 Suggested indicators for livestock water management: biomass production per livestock unit and livestock unit per unit of water consumption for grassland areas in 2007

RS indicators for agricultural water management

- Land productivity (kg/ha)
- Water productivity (kg/m^3)
- Irrigation performance list
- Pasture biomass production / livestock
- Pasture livestock / water consumption

6.6 Indicators for environmental management

6.6.1 Wetlands

The Nile basin has many different types of wetlands. The lake equatorial region has wetlands in Rwanda, Tanzania and Uganda. The Sudd wetland along the banks of the White Nile is among the largest wetlands in Africa (approximately 4 million ha) and the 3rd largest world Ramsar site. The Gambella plains and the Baro-Akoba-Sobat marshlands on the border between Ethiopia and Sudan are also vast areas with typical wetland vegetation. Egypt has coastal wetland regions along Lake Burulus and Lake Manzalah. Each of these Nile basin wetlands has their own natural character.

Wetlands are exposed to flood water, and therefore are by default dynamic systems. Peak discharges from rivers and monsoonal rainfall tend to change ponded surfaces, lagoon dynamics and channel dynamics. These all have an influence on overall wetland dynamics and the ecohydrology of the system that determine the habitats for flora and fauna.

The ecological value of wetlands is vested in its rich flora and fauna. Wetlands usually have a relatively high biodiversity, especially when they are large and inaccessible for humans. The interaction between people and wetlands in their natural states is traditional low. Wetlands are flat areas and inundated or saturated with surface water. They have the ability to buffer floods during peak flows and act as a sponge. They are home to a variety of fish species and lush vegetation on their fringes provides grazing for livestock. Local communities can make a living from them. Wetlands are usually well preserved natural systems and they are in many cases used to promote eco-tourism. The flood plane areas around Lake Tana in the Ethiopian Highlands are good examples of eco-tourism.

The dark site is that wetland areas shrunk by 50% on a global scale during the last decade. A common reason for vanishing wetlands is their conversion to much needed productive land resources. Farmers in Uganda are for instance using the marshlands of Kyoga lake for the cultivation of rice. Oil companies have started to explore for oil in the wetlands of the Sudd. They are constructing flood protection measures and excavate drains to lower the water levels to assist in oil exploration. The result of these human interventions is shrinking wetlands, and reduced biodiversity.

Besides antrophogenic influences, wetlands also respond to climate changes. Global warming of several degrees will wreck wetlands and fundamentally alter the ecology, biodiversity and species composition. Diminished rainfall and higher ET rates will cause lower water tables in swamps and lower inflow to the wetlands. The water supply to wetlands can be computed from the incremental ET (ΔET) of a wetland as compared to surrounding land. If the rainfall in the areas adjacent to wetlands can be assumed similar, then the incremental ET can be ascribed to incoming flood water. The net flood water (flood water in – drainage out) can be computed from the water balance of the swamp ($q_0=P_{gross}-P_{int}-ET_{act}$), see section 6.1. The component of q_0 that is not evaporated as ΔET, is the drainage water that leaves the swamp through an outlet or via the underlying aquifer.

Good wetland management aims to sustain biome types and conserve wildlife. A wetland is regarded as sustainable if the following criteria are met:

- The permanent swamp area does not shrink. A permanent swamp consists of open water bodies, including surrounding wet soils and/or abundant green vegetation. The swamp in its entirety (including its immediate surrounds) should be conserved.

- The permanent swamps are healthy. Meaning the growth of vegetation meets certain minimum biomass production as well as animal fodder production criteria.
- The temporary swamps have enough open water for long enough to sustain certain species.
- Natural land cover within swamps is not changing.
- The soil wetness meets certain criteria.
- Net flood volume/required flood volume > 1.

Satellite-based RS technologies cannot be used to map species, habitats and livestock densities. Such information needs to be collected from field surveys. Helicopters and aerial photography are often used to survey cattle density. Some satellite RS wetland indicators can, however, be developed to monitor conditions over short periods:

- Estimation of net floodwater volume
- spatial changes in permanent swamp areas, broken down into open water bodies, wet soils and wetland vegetation;
- duration of ponding surfaces;
- water stress in wetland vegetation;
- long term changes in vegetation cover and growth structure.

The rhythm of vegetation dynamics in swamp vegetation is significant. An example of the temporal variability of the green vegetation index is shown in Figure 32. The green vegetation index is a reflection of fractional ground cover. A higher index indicates a more vigorous vegetation cover. The graph shows the temporal pattern of 3 individual pixels over the period July 1981 to December 2003. The trend line is flat for all 3 pixels, which implies that no systematic changes in vegetation cover arose over a long period in the Sudd wetland.

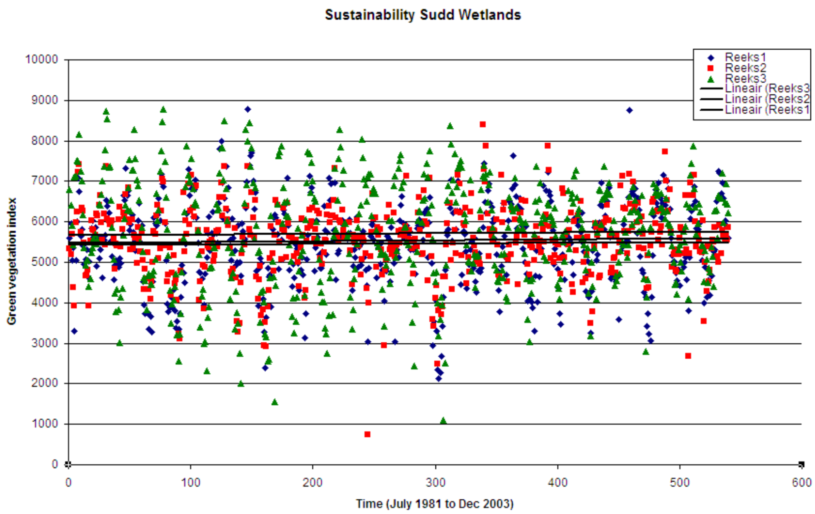


Figure 32 Temporal trend of green vegetation index as an indication of vegetation ground cover for 3 ecosystems within the Sudd between 1981 to 2003. The data represented by the red squares show less seasonally variability than that represented by the green triangles. All 3 areas appear to be sustainable

6.6.2 Biodiversity

Biodiversity is the variety and abundance of species, their genetic composition, and the natural communities, ecosystems, and landscapes in which they occur. Biodiversity is often used as a measure of the health of biological systems. Biodiversity is a measure of the relative diversity among organisms present in a given ecosystem.

Biodiversity cannot be surveyed by means of satellites. The spatial heterogeneity of the vegetation ground cover can however be used as a rough indicator of biodiversity. Vegetation ground cover is always between 0 and 100%. Trends in cover changes will show whether the vegetation is growing or dying. When remote sensing is used to record vegetation cover, the vegetation is broken up in sets of discrete pixels. Each pixel at one given moment has a certain value for vegetation cover. In homogeneous ecosystems, the vegetation cover of adjacent pixels will be similar. A diverse ecosystem which for example varies in altitude - such as a river valley or gorge- will not have similar vegetation cover values across pixels within the given ecosystem. Papyrus on the bank of the river and acacia bushes uphill exhibit spatial contrasts in vegetation cover.

There are different mathematical techniques available to describe the spatial variation and level of heterogeneity of vegetation cover. Among them are semi-variograms and wavelets. The semi-variogram describes the lag distance at which the ecosystem behaves spatially homogeneous (i.e. range), as well as levels of minimum (nugget) and maximum variation (sill). Heterogeneous ecosystems with significant biodiversity will have a large range because at a smaller scale they will show significant variances. Homogeneous systems show similar spatial behaviour at a much shorter range. More spatial variance in vegetation cover will result into a higher sill. So, high sill levels and large range values reflect an ecosystem that has significant spatial variations in vegetation ground cover, both locally and across the entire ecosystem. This semi-variogram analysis does not provide any information on the temporal dynamics of these systems.

The duration of the various plant phenological phases is also an indication of the variety of plant species present in a given pixel. Species which are seasonally green will have a time profile different to evergreen, perennial vegetation. This temporal aspect of vegetation cover change can be described by means of Fourier analysis. Menenti and Azzali (1993) applied a Fourier analysis to the entire continent of Africa and they were able to reproduce the rhythm of vegetation cover by means of amplitudes and phases. This implies that the temporal variability of complex vegetation cover changes during seasons over a long period can be reduced to just a few Fourier numbers.

The mathematical definition of spatial coherence and temporal changes of vegetation cover makes it possible to precisely quantify the spatial-temporal heterogeneity of vegetation cover. Each pixel in the Nile basin can be expressed into a range, sill, nugget, and Fourier-based amplitudes and phases. Although this is not a full representation of species and habitats, it can be used as a surrogate for biodiversity because biodiversity and vegetation cover are indissolubly related.

6.6.3 Soil salinity

The introduction of irrigation systems in Sudan and Egypt during the 20th century has increased the evapotranspiration of irrigated crops to a rate which exceeds the precipitation. Salts brought in by irrigation water do not evaporate. As water vaporizes into the atmosphere, the salts remain behind in the soil. Fresh water is required to leach these saline soils. Flushing out accumulated salts into the drainage network is environmentally sound, but care should be taken that saline water is discarded and is not dumped in wetland areas.

The Mediterranean Sea causes intrusion of saline water that makes the groundwater in the northern part of the Delta brackish. It results in saline soils with a lower production capacity. Salt sinks and depressions occur also in the Nile Basin. Lake Qarun in the Fayoum depression is an example of a saline sink supporting a natural ecosystem.

Although limited, there are a few RS scientists that are developing physical and empirical methods to detect soil salinity remotely. We propose nevertheless to start developing a bio-physically based RS method to detect soil salinity on a regular basis. We recommend soil salinity detection to become an operational activity when other special purpose RS indicators are implemented and working to satisfaction.

List of RS indicators for environmental management

- Net floodwater volume
- Spatial changes of permanent swamps
- Duration of ponding surfaces in wetlands
- Water stress in wetland vegetation
- Longer term vegetation cover change in swamps
- Range, nugget and sill for spatial heterogeneity of vegetation cover
- Amplitudes and phases for temporal heterogeneity of vegetation cover
- Soil salinity of irrigated crops

6.7 Indicators for watershed management

For our purpose a distinction is made between watershed management and river basin management. Watershed management deals more with the landscape and degradation processes related to it, while river basin management is more related to water resources and its allocation for use.

The upper parts of watersheds are often forested because such areas have steep slopes which are not suitable, or are too remote, for settlements. Forests in the Nile basin are mostly natural but plantations do occur as well. Plantations contribute to the economic value of water in that their water use results in wood products. The water used by natural tropical rainforest also has economic return in terms of wood products, but they create environmental value in addition.

The forests in the Nile basin are threatened by over exploitation. Forests are cleared in various parts of Burundi, Rwanda and Uganda as a source of fuel and timber, but also to make land available for agriculture. High local and international demand for wood products put these humid, tropical countries under pressure to over utilize their natural forests. Such over exploitation leads to increased erosion, loss of fertile soil and sedimentation of reservoirs and other infrastructures.

Changes due to deforestation and reforestation can be best described by means of studying the time series of vegetation cover in the land cover class “forest”. It would be interesting to have both a long term change indicator and a short term indicator. To serve the need for 5 yearly updates on the overall vegetation condition in watersheds, 5 year products of vegetation change can be produced.

Figure 33 shows the change in vegetation cover, where the vegetation cover is expressed as the NDVI for the whole NOAA-GIMSS period between 1981 and 2003. NDVI changes (expressed in Δ NDVI/5 years, although a longer record is considered) and the change in NDVI as percentage of mean NDVI are presented. Positive values indicate increasing vegetation, while negative values show the areas with decreasing vegetation cover. Areas with negative change are most prominently present around the Lake Victoria. Large tracts in Tanzania and Uganda are under threat of land degradation. This not only occurs on the plane areas around Lake Victoria, but the riparian vegetation on the lake shores also seems to be exposed to a serious deterioration of the vegetation. New settlements are probably established at the costs of environmental services. Other degraded areas can be detected as well.

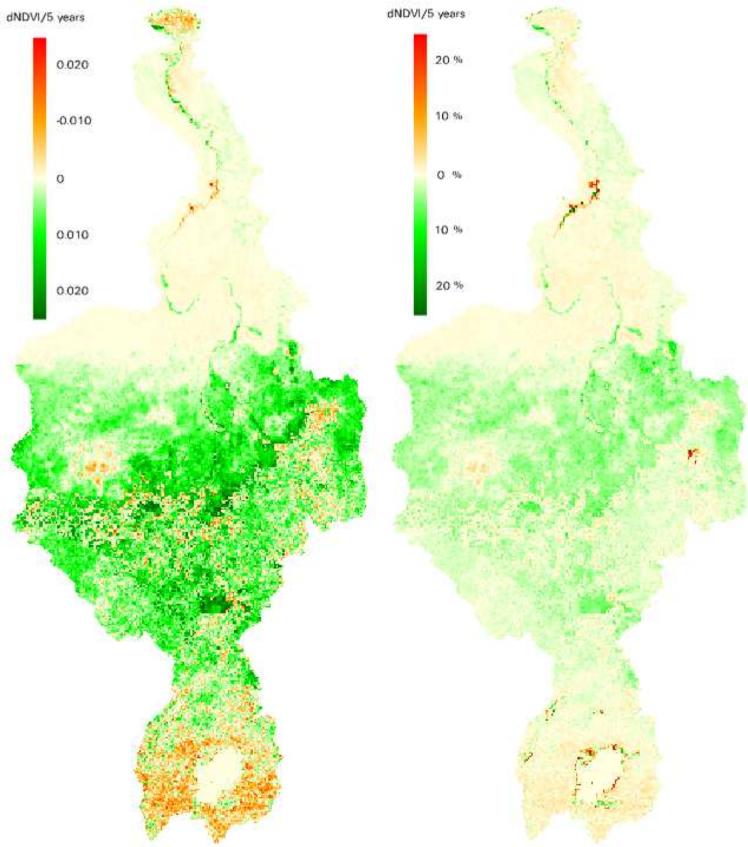


Figure 33 Land degradation in the watersheds of the Nile Basin between 1981 and 2003

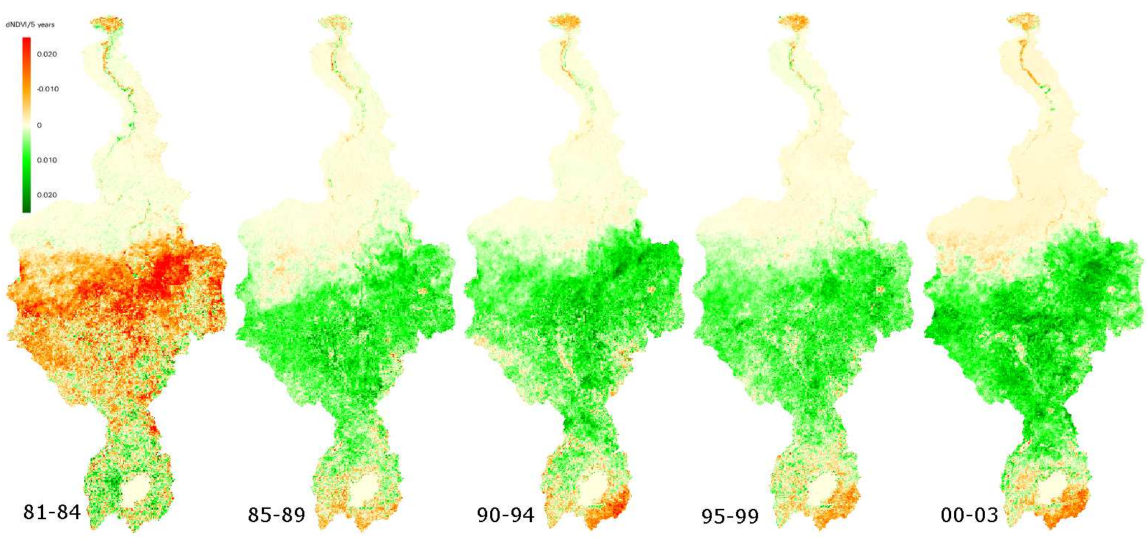


Figure 34 Five year vegetation cover change indicators for the Nile Basin

It is obvious that the Nile Basin went through a period of drought during the early eighties. Ethiopia and Sudan were seriously hit during these times with famine and cattle being unable to survive the thirst and hunger. The good news is that the whole region between Lake Victoria and Khartoum shows (since 1985) good recovery and growth in vegetation ground cover.

Figure 34 shows that the land degradation south-east of Lake Victoria started to emerge from the end of the eighties. Intensive overgrazing or deforestation took place during the first part of the nineties. The Mara and Mwanza area continued to be under pressure during the first part of 2000. This phenomenon can also be observed for the Nile Delta during this period of observation. By continued mapping of these types of indicators, using the recent MODIS time series, it will become clear whether the degradation process has been reversed.

Forests usually have a high ET. By removal of forest, the total ET of an upstream watershed will decrease, and more water remains in the basin. Clearing of forests will therefore enhance streamflow. While this is considered to be good from a water resources management point of view, it could lead to unsustainable water supplies. We therefore recommend that forest management and erosion management be combined with water management. This brings us to the broader issue of land degradation.

Erosion is displacement of solids (sediment, soil, rock and other particles) usually by the agents of currents such as wind, water, or ice by downward or down-slope movement in response to gravity. Erosion risk mapping thus should be built on the following elements:

- vegetation cover;
- rainfall intensity;
- terrain slope;
- soil texture.

The best available dataset on vegetation cover is the 250 NDVI from MODIS. This data is updated every 8 days. The shortest rainfall product comprises 3 hourly intervals. Erosion risk maps could be made at 3 hourly intervals by combining the above mentioned spatial data sets. There is however no need to update these maps on a regular basis, because interventions by means of tree planting and terracing take a long time before they become effective. Annual erosion risk maps are sufficient for bringing the topic to the attention of watershed managers and for ensuring budgets for future interventions. Erosion risk maps can help to understand the level of urgency for action, and to assess the efficacy of policy implementation in this regard.

It is not expected that erosion risk maps will change much from year to year. Erosion risk maps could be used to give priority to reforestation in areas that are prone to the erosion.

List of RS indicators for watershed management

- change in vegetation cover;
- change in forest area;
- change in maximum LAI in forests;
- change in duration of conditions if forests where LAI>3;
- change in areas with high erosivity and erosion potential.

7 Data organization and handling in the DSS-RS unit

7.1 Auxiliary geographical databases

Topographical maps with inventories of roads, canals, infrastructure, and cover classes, etc., are traditionally used to support water management. Such maps can be complemented by elevation maps, soil maps, geological maps, aquifer maps, watershed boundaries, climate maps, population density maps etc. All of these are constructed from intensive field surveys and measurements. Digitizing of maps of this kind has led to the generation of GIS data. GIS data is expressed by polygons. The shape of each polygon defines the geographic boundaries of a particular value (or a class interval of values) of a certain feature (e.g. clay content, livestock unit density). These polygons are stored as vector data. The pixel values of RS consist of raster data. There are methods to convert vector maps into raster maps and vice versa. The digital character of both datasets and the common coordination system makes it feasible to couple GIS to RS data.

A common map projection system should be developed. The DSS-RS unit should standardize their map projections for all spatial data that they are going to collect over the next years. Without identical map projections, GIS layers will not be exchangeable. The GIS-RS exchanges will also not work properly without it.

Digital Elevation Models (DEM) describe terrain elevation, terrain slope and terrain aspect, and they can be prepared from laser altimeter measurements or from radar interferometry. The SRTM - DEM from NASA - is a good data base that is available for the entire Nile Basin. The DEM could be used for the delineation of the watersheds and sub-basins. These water divides are key for the separation of water flows across the network of streams and rivers. Delineated watersheds and sub-basins are required for various hydrological and water management applications discussed in Chapter 6.

There are websites available that provide global shape files of streams, rivers, country boundaries, location of urban areas, bridges etc. These databases have a very general character, and are considered useful as an overlay to understand where areas with bumper yields occur, drought stress has damaging effects on livestock, or where drained wetlands are located. It is recommended that the DSS-RS unit makes the necessary arrangements to collate all this GIS data.

An interesting geographical database is provided by the Global Land Cover Facility (see chapter 3). The high accuracy of geo-referencing of these free Landsat images are extremely useful to help with adding coordinates and projection systems to other GIS and RS maps. We recommend that the DSS-RS unit uses these Landsat images of the Global Land Cover Facility as the standard for geo-referencing and projections. A copy of all Landsat images that encompass the Nile Basin has been handed over to the DSS.

Early in 2008 the decision was made by USGS to provide all Landsat images for Africa free of charge. There is an unequalled 35-years record of the earth's surface which is of great value for land degradation management and forest management. Landsat-1 was namely launched in 1972. The full archive of historical Landsat-7 data acquired since the launch in 1999 will become available for selection and downloading by the end of September 2008. It is planned to have an automatic processing facility for concurrent Landsat-7 images by February 2009. Any image selected by a user will be processed to a standard product recipe and staged for electronic retrieval. Images can be selected using the USGS Earth Explorer tool at http://earthexplorer.usgs.gov.

7.2 Operational services

The standard operational processing of Special Purpose RS products has to be done at different time steps. The collection and storage of all the data from the primary RS data and secondary RS information products is a continuous effort. The preparation of special purpose RS products depends on the indicator in question and the time of the year. While the image processing for floods needs for instance to be conducted with daily intervals during the flood season, the same indicators could be ignored outside the period during which floods occur. The majority of the indicators need to be computed for intervals ranging from weekly to monthly. Other indicators need to be computed only once per season or year. The delivery schedule of the indicators has practical consequences for the organization of the DSS-RS unit: days with peaks in image processing are alternated with periods of normal image processing. This will require some flexibility in the availability of staff hours. An impression of the required frequency of delivery of products is provided in Table 24.

Table 24 Operational image processing schedule for the Special Purpose RS products

Theme	Day	Week	Month	Season	Year
Hydrology	-	-	q_0, q_{ground} Irr^{SW}, Irr^{GW}	-	-
River basin	-	-	-	-	Fractions Consumptions Productivities
Nile-Flood	Flood alert	Flood alert	Flood damage	-	-
Nile-Drought	Drought alert	Drought altert	Drought damage	Water savings	-
Irrigation		Crop water requiremen Crop water stress	-	Irrigation performance Land & water productivity	Water & crop sustainbility
Rain-fed	-	-	Food production	Land & water productivity	Water & crop sustainbility
Livestock	-	-	Feed production	Land & water productivity	Water & crop sustainbility
Wetlands	-	Land wetness		Flood duration	Vegetation cover Biodiversity
Soil salinity	-	-	Salinity	-	-
Land degradation	-	-	-	-	Vegetation cover change
Forestry	-	-	-	-	Area LAI
Erosion	-	Risk indicators	-	-	-

Image processing work consists of downloading and importing of standard images provided by data archives of MODIS, AMSR-E, TRMM, MSG and MERIS. These archives need to be monitored continuously, and tailor made software need to be prepared for the collection of these images once they are posted in the archive. MODIS provides certain software to assist with the import of the images but for importing other images special software need to be developed. Software to convert primary RS data to secondary RS information is another important requirement. The complexity of such software will vary from simple transformations of radiation temperature into physical temperature; NDVI; vegetation cover; to advanced models such as SEBAL, to compute ET fluxes and biomass production for example. Land use classification can be done with most commercial software packages, and there is no need to develop a special model for this purpose.

Special Purpose RS products require a complete new set of models that needs to be prepared and adapted during the operational implementation of the DSS-RS unit. Among these models are algorithms that compute irrigation performance from RS primary and secondary data, or algorithms to predict floods and droughts. These models can be made within the image processing software and be tailor made to the Nile basin needs. It is beyond the scope of the current consultancy work to prepare these models. The methodology used to develop each indicator is, however, described in chapter 6.

7.3 Quality control

Any new product needs to be introduced properly. This certainly applies to RS technology. Users need to build confidence in a new technology for it to be implementation effectively. While a large group of end-users are receptive to the general concept that satellites provide measured and unbiased information, and that electronic sensors are accurate and to be trusted, there is another group of end-users that will not accept modern technologies as a substitute to their traditional sources of information (especially when they evidence poor management practices). The traditional sources are mainly (i) measured rainfall by gauges, (ii) measured water levels, (iii) field surveys of deforestation or wetland deterioration, (iv) statistical surveys on crop production, etc. As mentioned earlier in this report, RS cannot replace classical field measurements: it only helps to provide an integrated spatial picture of variations, and it provides data for all kinds of areas, including non-secure and remote areas.

The confidence in RS technology should be enhanced by means of:

- Validating RS products and provide levels of uncertainty.
- Calibrating RS products and provide the residual errors after calibration.
- Assessing agreement between quantitative RS information and qualitative subjective estimates that are acquired through conventional survey techniques.
- Positive feedback from improved decision making processes.

Validation is the process where deviations between observations and predictions are checked against certain criteria. The RS products should be validated before being released and shared with third parties. Putting accuracy labels to RS data will be a major achievement and will assist in getting the technology to be received by a larger audience. The best is to incorporate uncertainty in data sets by classing data into broader range classes which have larger confidence than individual numbers. For example, instead of using a single rainfall value (which in itself is subject to variation) to represent rainfall in a pixel, one can rather use a range class which incorporates at least the standard deviation of measured rainfall value. RS predictions are thus only valid within a certain range of certainty. For land use and crop type classes, an error matrix need to be prepared that expresses for every land use class the accuracy and reliability.

Calibration is also the process of establishing the relationship between a predicted and a measured quantity. TRMM data needs calibration as outlined in Chapter 2. Other RS data that require calibration are soil moisture, land use, crop types, biomass production and crop yield data among others. The DSS-RS unit should maximally utilize existing datasets on rainfall, soil moisture and crop yield data for the calibration process. Rainfall data is collected routinely and stored systematically. We have seen that also several rain data archives of the Nile basin exists (see chapter 3). Variation in space, time and depth makes soil moisture very difficult to measure accurately on the ground and the same is true for ET. There are, therefore, hardly any operational soil moisture monitoring sites in the Nile Basin.

The same comment on incomplete ground-based datasets applies to crop yield data. It is extremely difficult to measure crop yield. It may be more effective to collect such data from farmers. If done in this manner it is termed “secondary” data because it was not measured. Ministries of Agriculture often publish such data in agricultural bulletins and it is then used by FAO for their Aquastat Database. It is not always clear that this data in not measured. Although it is useful to compare RS data with secondary data, it cannot be used for calibration purposes. At this stage only rainfall data from RS can be calibrated. Calibration of remotely sensed data of soil moisture, biomass production, ET and crop yield need to be done from field experiments in countries outside the Nile Basin. Several of these large scale field experiments, have been conducted over the last 20 years, of which at least two were in Africa: HAPEX-Sahel (Goutorbe et al. ,1993) and Safari2000 (Hanan et al., 2001).

Despite the more than 30 years of remote sensing research, there exists no operational procedure to determine land use and crop types. Most classification algorithsm are a mixture of supervised and unsupervised classification methods. Supervised classification requires land use of a set of fields to be inspected, where after this field knowledge is used to establish a calibration between land use classes and spectral reflectances. The spectral signatures are namely not unique; they vary with the background reflectance of soils, angle of the leaves, position of the sun, age of the vegetation etc. An unsupervised cluster analysis can mathematically differentiate classes that have similar spectral signatures. The unsupervised classification requires calibration afterwards.

Calibration protocols need to be developed. It is for instance better to calibrate rainfall on a weekly scale, rather than on a daily scale. Both ground measurements and satellite estimations are more accurate when a slightly longer time scale is applied. The calibration procedure should start with the selection of calibration pixels, i.e. pixels that are part of the RS product, but on which intensive ground sampling takes place. These pixels should preferably be located in different agro-ecological zones. The fact that rainfall is estimated with reasonable accuracy over a given land cover type does not mean that it has a similar performance over another type of land cover.

The pixel size of most products is 1 km to 25 km. This implies that rainfall, ET, soil moisture, LAI, biomass production etc. should all be measured at this scale. It goes without saying that this is not straightforward. A soil moisture pit represents for instance only a small area of typically 1 m x 1m. Because of natural heterogeneity in soils, land use, crop types and farm management, it is not likely that a single moisture pit can represent a MODIS pixel of 1 km or an AMSR-E pixel of 25 km. It would in such cases be necessary to have a large number of moisture pits (n=10 to 20) where soil moisture is measured accurately. A reliable value for one large RS pixel could be obtained from averaging individual point measurements.

The SEBAL ET predictions have been thoroughly validated in three Nile basin countries (Egypt, Sudan and Kenya). The Egyptian validation set of ET fluxes were measured by Bowen ratio flux towers over date palms surrounded by sebkha in the Qatarra Depression at ancient oases that have shallow water tables (Bastiaanssen and Menenti, 1990). The Sudanese validation was applied to the Sudd wetlands where the SEBAL ET volumes where compared with rainfall, inflow, and outflow of this large ecosystem (Mohamed et al., 2005). The accuracy of SEBAL in pastures and savannah in Kenya was verified by Farah (2001) using Bowen ratio flux towers in the catchment of Lake Naivasha (which is just outside the Nile Basin, 100 km North of Nairobi situated in the Central Rift Valley). In all cases, the ET fluxes deviated approximately 10 to 15 % on an individual day, and only a few percent on an annual time scale. To gain the confidence of users in the Nile Basin, it is nevertheless recommended to validate SEBAL-based ET products. To the consultant's knowledge there is no ET flux station in the basin. There will be some lysimeter data, and it will be useful to obtain these data. It is not clear how many lysimeters are currently in operation that could be used for real time validation of SEBAL. We recommend the NBI organization to invest in the installation of scintillometers that can measure ET fluxes – and other energy balance terms – across a path length of 2 to 10 km (http://en.wikipedia.org/wiki/Scintillometer).

The DSS-RS unit needs technical support from one or more RS experts to ensure that the quality control procedures are technically sound, repeatable, consistent, and well applied. It is also good to attend to the reliability of the field data sets, before using them to calibrate and validate RS products.

7.4 Dissemination

RS pixel data can be read by raster-based image processing software. This data format is suitable for transfer to national DSS specialists who have GIS systems and specialists that can deal with this data. Raster-based data is, however, unsuitable for the majority of end-users. Data thus needs to be converted and presented in a different format. It is suggested to organize this data conversion centrally at the DSS-RS unit. Otherwise every country does the conversion in its own uncontrolled fashion and thus running the risk of losing the benefits of the RS products. Other means of disseminating the results should also be investigated. The various categories of end-users first need to be identified to ensure appropriate and effective dissemination of results; these are:

- NBI offices
- National line agencies
- Water resources planning committees
- Donor agencies
- Local water bureaus
- Local wildlife conservation bureaus
- Water user associations
- Water boards
- Advisors
- Consultants
- NGOs
- National and internal media

We propose the creation of a comprehensive RS website where most of the results are posted, can be reviewed, and where at least graphical results can be downloaded. It is probably excessive to stage all data for electronic retrieval because this will be very large data sets. It is recommended that all the original raster and vector data are sent to the national DSS center but that results for the entire basin are shown on a comprehensive RS website.

The website should be organized thematically and deal with the various operational management themes for which special purpose RS products have been developed. These management themes should have their own ULR so that specific users can go straight to specific information. The overall presentation of information should be in the form of professional mapping. The primary RS data and secondary RS information should be placed more to the background. The user should be able to find his theme of interest easily, without the need to go through lengthy procedures that deal with RS data. A good example can be found on the Crop Explorer of the USDA Foreign Agricultural Service (http://www.pecad.fas.usda.gov/cropexplorer/imageview.cfm?regionid=eafrica). This USDA site shows final maps and provides good background services for interested groups that want additional information. The maps also display the deviations from normal circumstances in the same period of the year, which highlights all anomalies directly.

Considering the dynamic character of the DSS-RS data – several indicators are provided with a weekly interval – it is suggested to produce a one page electronic newsletter on a weekly basis. It should be a summary of salient findings related to the latest Nile conditions. If received by a wide audience, it will spur more visitors to use the website. The electronic newsletter should be sent to all persons that subscribe to it on the website.

Local magazines on water, food, climate, agriculture, forestry and nature should be contacted to write popular articles on information obtained from the DSS-RS maps. This will foster public engagement in management of the Nile water resources: especially for the large group that has no access to internet.

During periods of severe floods and droughts, maps and bulletins should be sent to local newspapers. National drought and flood watch teams should get SMS messages to timely inform them of forthcoming events.

7.5 User consultations

RS is a new technology, and early adaptors of the technology can hardly wait to start using it. The bulk of the stakeholders will resist new technologies if they do not see the profits or advantages thereof. Moreover, not everybody has access to a good internet connection. The process to persuade and convince people of the benefits and to build their confidence in the use of the RS products takes time. Introducing the technology suddenly and quickly will not be effective in establishing a satisfied and permanent user base. Time and patience is needed and the expectations of the DSS-RS unit should not be too high. The early adaptor's enthusiasm must be used to create interest of a larger group of water policy makers and water managers in the Nile Basin.

The package of special purpose RS products should be discussed with the various stakeholder groups. Are the wetland specialists satisfied with the information? Do the irrigation managers want other types of information? The suggestions described in Chapter 6 are mainly based on the perception of the consultant. This perception is based on experiences of offering RS services to basin management and agricultural water use management in several places in the world (The Netherlands, China, Tunisia, South Africa, Pakistan, Sri Lanka). In none of these a complete spectrum of RS options from primary data to special purpose RS products has been offered and the DSS-RS unit is perhaps the first one of this kind in the world. The closest service of this kind is in The Netherlands where farmers get weekly information via internet about the growing conditions of their own fields (www.mijnakker.nl in Dutch).

Feedback from the users of the RS data is fundamental for improving the system and satisfying the user needs. User's confidence with the technology and the supplier's response to user's management needs must both be enhanced through an iterative process. Initiating operational RS products will give the users an opportunity to get exposure to the product, and master the topic of spatial water management. After these first experiences, a discussion can be held on fine tuning gaps between supply and demand for RS data. We recommend feedback sessions with the user community at least twice a year. This can later be reduced to once a year. Otherwise there will be a risk that a great product is created, but that not enough people realize the existence of it.

7.6 Hardware and software requirements

The DSS-RS unit should be equipped with sufficient capacity to retrieve, store, process, and archive all RS data. The hardware should have a Local Area Network (LAN) server with a capacity of 1 terabyte. One MODIS reflectance image has 7 individual bands of 1000 m pixel size, and the file size when stored as signed 16 bit data varies between 70 Mb (Transverse Mercator projection) to 120 Mb (geographic projection). For each 8 days, minimally 5 MODIS products need to be downloaded, such as NDVI, LAI, etc. A single band NDVI file with a pixel size of 250 m will need a memory of 120 Mb for signed 16 bit data. An equivalent quantity of data is to be received from other satellites, and this brings the total capacity of primary RS data to 1.2 Gb. After running the various algorithms and models, the number of output data layers will be double the amount of input data layers. For one period of 8 days, a total capacity of 2.5 GB is required. An annual cycle with 45 periods of 8 days will occupy approximately 20 Gb. This will be over 0.1 Terabyte per year.

Image processing needs to be done on desk top computers. The satellite input data needs to be transferred from the server to the desktop computer where all image processing takes place. No data should be transferred through the LAN during data processing. Routine image processing couples raw RS data with auxiliary data, and this results in rapid accumulation of the number of data layers. Such temporary data layers are needed to bridge the gap between input and output data.

Input data consists of primary RS data, while secondary RS information and special purpose RS products form outputs. Both input and output data need to be archived. The intermediate products for constructing for instance drought and flood indicators can be deleted. The input and output data will be archived together with the models on the server. Every model may have specific coefficients to fine tune for each application; it is therefore recommended to store models jointly with their input data. That leaves the option to re-compute time series of certain parameters, when necessary. The server is thus the central unit for data retrieval, data storage and for dissemination.

The Regional DSS Center of the WRPM has purchased several high quality servers that are operational. These servers could be used for the RS program. We estimate that in the end a total capacity of 1 terabyte should be made available for the DSS-RS unit. A proper back-up system should be put in place. Once the DSS-RS unit is up and running for some time, the IT specialist of the Regional DSS Center should establish contact with the IT specialists at the USGS to exchange experience on handling the large data flows and on storage of images.

Further to a strong central server, at least 4 modern desk top computers should be made available for image processing. Computers with a memory of 2 to 4 GB RAM and a harddisk capacity of 120 GB are recommended. The screen size should be minimally 19 inch for a proper display of the images. Nowadays flat screens have sufficient quality.

It is suggested to use ERDAS Image software for the processing of satellite images. ERDAS is the world leading software and it has several standard options built in, as well as convenient options for data exchange with ArcGIS. Both ERDAS and ARC software originated from ESRI and this rules out compatibility problems. It is for instance easy to import the raster-data from ERDAS IMAGINE into ArcGIS. One of the strong features of ERDAS IMAGINE is the model generator. This allows the user to set up a model with graphical interactions. Since modelling is a dominant process – and it needs to be done in a flexible mode because models require adjustments – a user friendly modelling interface is of essence. The Regional DSS Center already has one license for ERDAS IMAGINE. The use of ERDAS IMAGINE during the two training sessions in February and March gave satisfactory results. Most course participants did not have an ERDAS IMAGINE experience before, but they left the course after 2 weeks with significant hands on experience. The purchase of floating licenses that can be installed on the server and accessed from various working nodes is recommended.

It will be handy to have a central plotter for the printing of large maps and posters. This can be done in conjunction with the other activities foreseen under the DSS. It is however not strictly necessary to have such a plotter for the RS work.

8 Human resources

8.1 Staffing plan

Smooth operation of the DSS-RS unit will require a multi-disciplinary team with a balanced experience between RS science and water management applications. One person should be in charge of the group and take care of organizational issues and maintaining external contacts. The team should have another position for a chief scientist with a physical-mathematical background and a strong international orientation. This senior scientist should be familiar with the structure of the models, how they work, assumptions on which the models are based, etc. The routine work of processing large stacks of images should be done by junior engineers with a basic degree in GIS/RS. The total team should have sufficient skills in hydrology, water management, agronomy, forestry, and natural land cover management. It is essential for the team to understand the link between the image views and the reality on the ground. This is feasible only if practical knowledge is embedded in the DSS-RS team. Practical knowledge of the Nile basin physical processes is also an advantage when the RS results need to be interpreted and explained.

Initiation of the RS unit will require a minimum of 3 persons. Depending on work load and distribution of tasks, more persons could be recruited. It will be best to begin with a small team and a reduced scope for the operational system; first focus on operational management indicators, and start with the production of a smaller set of key indicators. Once feedback is received from the use of a few key indicators, and sufficient financial resources are available, staff can be increased. The first priority is to get a group up and running.

The recruitment plan is therefore rather straightforward. The minimum team composition is a senior team leader, a senior modeller and one junior image processor (see Table 25). They should start organizing the image data flow and design the archives on the server. One of the main activities is to start with the retrieval of the routinely available primary RS data. This has been explained and suggested to the DSS staff during the internal training workshop held in February 2008. January 1st 2008 is recommended as the starting date for the spatial database. If deemed necessary for certain purposes, older data could be retrieved from the same global data archives such as the NDVI time series to detect vegetation cover change. The consultant has transferred some older image data records to the DSS. The latter data base includes monthly TRMM rainfall since 1997, 10-day SPOT NDVI since 1998, 15-day NOAA NDVI since 1981 among others.

Table 25 Proposed team composition of the DSS-RS unit

Position	Tasks
Senior Team Leader	▪ Assignment and prioritizing of image processing tasks ▪ Organization of field validation programs ▪ Holding user needs assessment sessions ▪ Website maintenance ▪ Data dissemination ▪ Establish contacts with other RS data archive centers ▪ Training of staff of national DSS centers
Senior Modeller	▪ Spatial modelling of land and water physical processes ▪ Development of new bio-physical models ▪ Development of data fusion technologies including disaggregation ▪ Validation of the models ▪ Collection and studying of national and international literature ▪ Presentations at NBI occasions ▪ Training of staff of national DSS centers
Junior Image Processors	▪ Data retrieval from global websites ▪ Geometrical corrections and projection standardization ▪ Removal of cloud effects on images ▪ Application of standard algorithms and models ▪ Preparation of standard outputs, including maps ▪ Data storage and archiving

The Team Leader should be a senior person that is committed and motivated to create spatial products for the Nile Basin which are transparent and accessible to everybody. It will be a leap-frog process which requires strong leadership and politically correct behaviour in an international context with potential water conflicts. The Team Leader should have the confidence to report on poor water management if that becomes apparent. The person should be familiar with the NBI organizations. The person should be a senior with a track record in leading groups and with minimally 15 years of working experience. Because of the broader scope of the duty, the Team Leader does not require a specific degree. Any academic degree in natural resources management or Information Technology would suffice.

The Senior Modeller should have a background in hydrology, climatology and environmental physics. The person should preferably have a Ph.D. degree in this field and proven experience in modelling. The candidate should be able to understand existing RS models that convert primary RS data to secondary RS information products. The person should be able to adjust the models if necessary. This person should also calibrate and validate the models and assign levels of uncertainty to data before it is disseminated. The candidate should have minimally 10 years of working experience.

The bulk of the image processing needs to be executed by a junior processor. The team could start by hiring one person, and gradually build on by recruiting additional persons if the work load requires it. The person should have a background in RS and GIS. He/she should have working experience with ERDAS IMAGINE and ArcGIS. The ability to attend to precision and detail is a pre-requisite. Accurate and careful organization of data and accurate geo-referencing will have a positive effect on respectively the accessibility and quality of the images. A masters degree will be desirable for this position, and a bachelor degree would be required.

8.2 Supervision

The Senior Modeller should be held responsible for the quality of the work. The results of the Junior Processors need to be checked for consistency. To use the water balance as an example: highland savannah should have an ET that is lower than rainfall. If ET exceeds rainfall, a flag should be raised because it is physically not consistent. The problem needs to be detected and it could in this case be an over estimation of ET or an under estimation of rainfall. The Senior Modeller should also collect international literature and national data for verifying the reality of the image processing results. The Senior Modeller provides daily supervision to the Junior Processors.

The Senior Modeller reports to the Team Leader. The Team Leader will evaluate the work of the Senior Modeller on the basis of validation reports and the timely delivery of data. Some of the products need to be posted on the web with very short repeat cycles, and this requires strong discipline and good planning. Trust in the product will decay if frequent users of the data do not find their updates to be posted on time.

The Team Leader reports to the Technical Advisor of the DSS. When issues of international relevance arise – such as droughts and floods, or sudden changes in logging of forests - the Team Leader should report it directly to the Director of the WRPM unit. While the Senior Modeller is responsible for the quality of the work, the Team Leader is responsible for the overall success of the RS program. The Team Leader should bring the RS results under the attention of all stakeholders and his/her performance can be appraised from the number of hits on the DSS-RS website. The Team Leader is responsible for timely feedback sessions and user consultations. Hard work on the wrong product is a waste of resources, and this should by all means be prevented.

The work of the Senior Modeller and his team needs to be discussed with an international consultant. This consultant should visit the DSS-RS unit quarterly and evaluate progress in collaboration with the Senior Modeller. Advice can be obtained on how to fine-tune certain aspects of the processing and modelling chain. The Team Leader is responsible for the generation of the water accounting and should report to the international expert who will do the auditing. The accuracy of the products should be independently assessed. It is advised to conduct some inter-comparison studies with other rainfall products over eastern Africa.

The international RS expert should also hold consultations with the Team Leader. The expert should have the capacity to provide advice on the operational production of RS data, besides providing comments on the website and the usage of the data.

The success of the DSS-RS unit depends on the extent of data usage. An improvement of water management indicators implies that a reference year should be selected. This could be 2008. Improved management of scarce water resources in the Nile Basin could be achieved by several interventions, including the establishment of a new generation of leaders, a well functioning NBI entity, monitoring systems in place, changing climate, etc. An improved spatial data information system will indirectly help to improve management. The extent of the RS data usage is therefore probably the best indicator of success because manifold factors determine the improvement of water management in the Nile basin.

8.3 Training program

RS has recently advanced and made the technology more robust. The advances can be ascribed to the launch of more satellites dedicated to measure specific environmental processes, better algorithms to convert spectral radiances to physical processes on the land surface, and a more general interest in IT technology with more powerful computers. Regular refresher courses are crucial to keep staff of the DSS-RS up to speed with respect to the newest developments in RS technologies for water management.

During the current consultancy, two special training courses were held:

- introduction to RS for water management of DSS staff (February, 2008)
- introduction to RS for water management and image processing for national DSS contact persons (March, 2008)

Both training sessions were held at the WRPM office in Addis Ababa. The participants were satisfied and amazed by the potential use of RS. While GIS is a standard and accepted methodology for DSS, RS is relatively new. The second training session in March took 14 days, and 70 % of the time was spent on computer applications and modelling with RS data. The building of experience and confidence of future users of the RS technology allow them to grasp the opportunities and limitations of the technology. One day (in March) was dedicated to policy makers, as this group is responsible for fundamental decisions on flood mitigating, for assigning new areas for irrigation, etc. Being aware of the opportunities enhances their ability to run their SAP and SVP projects.

The DSS-RS unit should first get more training to get them to an international standard. After some time, these experts should themselves be able to provide similar courses to the user community. The following educational plan is appropriate:

- Introduction to RS.
- RS for water management (beginners and/or advanced users).
- RS for water policy makers.

The course on “Introduction to RS” should contain the basic radiation physics that are fundamental for appraising RS. The course contents should address image downloading, importing, geometric corrections and other standard image processing issues such as re-sampling, classification, raster to vector conversion. The course is meant for persons that have never attended RS courses at the university, but became - or will be - professionally involved in RS.

The course “RS for water management” assumes that basic RS handling is familiar to this group of participants. The course will cover the physical models for estimating rainfall, ET, soil moisture, interception and overland flow. The various models will be explained, and the course participant will apply them for a sub-basin in the Nile to describe the hydrological process.

The course “RS for water policy makers” will deal with the special purpose RS products. The rationale behind these indicators needs to be explained, and examples will be computed jointly during the classes. The participants will learn how to make recommendations for improved water resources management on the basis of these indicators. The senior water managers will be invited to the last day of the course to make them aware of the progress of the technology and to facilitate a direct dialogue between RS producers and high level decision makers.

The course participants should be persons that work at the national DSS nodes, complemented by other interested persons from the various NBI centers. While the first rounds of training should be provided by an international consultant, these sessions should gradually be taken over by the senior staff members of the DSS-RS unit. These courses could be presented annually.

9 Conclusions

- Water usage in the Nile basin is gradually increasing relative to water input through rainfall. This is causing severe competition between the various water use sectors (agriculture, industry, domestic water users, natural ecosystems, etc.) Effective management and allocation of this scares commodity will require the best skills and the most up to date technologies because human well being, economic sustainability and natural ecosystems will depend on the quality of future management of the water resources. Rigorous, evidence based, high quality, water management plans are paramount to assist managers in this challenging task.

- Remote sensing has advanced over the last couple of years to a level that meets the required accuracy for applications in water management (more than 90 to 95 % accuarcy). Several data active archives have been established that post quality controlled data in the public domain. These are described in the report.

- The existence of these public data archives is hardly known, and application of this valuable resource is lacking because the databases provide in most cases only raw data and information on individual natural processes. Such data need to be collated and interpreted for creation of advanced products that support international river basin management.

- This consultancy study has created a framework for assimilating and integrating primary remote sensing data, and for preparing the necessary models to develop value added products that assist with an evidence based decision making process in international river basin management.

- RS data can be divided into primary RS data, RS information products, and special purpose RS products. This distinction helps users to know what levels of skills, own effort, and processing are required in order to create products tailored for their specific purpose.

- The opportunities posed by, and the constraints imposed by RS will become apparent if higher level decision makers are aware of the technology and are trained to implement it with confidence. Potential applications promoted in this report are: (i) assessment and management of hydrological processes; (ii) river basin water accounting; (iii) disaster management (including the management of floods and droughts); (iv) agricultural water management; (v) environmental water management (including wetlands and land degradation); and (vi) watershed management.

- A DSS-RS unit should be created and start to collect RS data for the Nile Basin retrospectively from January 2008. The unit should consist of minimally 3 persons, and gradually increase their level of service. Weekly, monthly, seasonally and annual products should be made.

- Calibration, validation, the allocation of accuracy labels, and allocation of confidence limits, are important components of RS datasets that are posted on the web. The proposed website for the Nile basin DSS-RS unit should incorporate the above features and the style and content of the website should follow that of international programs such as Fewsnet and Fas.

- User consultations with the various end-users in the Nile Basin should be held to acquire proper feedback and understanding on how special purpose RS products could be improved. The DSS-RS unit can profit from the international experiences of the RCMRD in Nairobi and the FAO-Nile office in Entebbe.

- If properly implemented, the RS unit has the potential of creating a great spatial data base and to derive fundamental insights of the functioning of the Nile Basin that is not feasible from using conventional field data. RS will however never replace the existing field data collection schemes.

References

(incomplete)

Allen, R.G., M. Tasumi, A. Morse and R. Trezza, 2005. A Landsat-based energy balance and evpotranspiration model in Western US water rights regulation and planning, Irrigation and Drainage Systems (19), nos. 3-4:251-268

Allen, R.G., M. Tasumi, A. Morse, R. Trezza, J.L. Wright, W.G.M. Bastiaanssen, W. Kramber, I. Lorite and C.W. Robinson, 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (Metric) – applications, ASCE J. of Irrigation and Drainage Engineering 133(4): 395-406

Anderson, W.P. Kustas, J.M. Norman, 2007. Upscaling tower and aircraft fluxes from local to continental scales using thermal remote sensing, Agron. J. no. 99: 240-25

Barret, E.C., 1988. Precipitation monitoring by satellites. Remote sensing for studies of global environmental changes, ISPRA Courses RS/88/10, Commission of European Communities, Joint Research Centre, Ispra, Italy

Barret, E.C. and M.J. Beaumont, 1994. Satellite rainfall monitoring: an overview, Remote Sensing Reviews 11: 23-48

Bastiaanssen, W.G.M., D.H. Hoekman and R.A. Roebeling, 1994. IAHS Special Publication

Bastiaanssen, W.G.M. and N.R. Harshadeep, 2005. Managing scarce water resources in Asia: the nature of the problem and can remote sensing help? Irrigation and Drainage Systems (19), nos. 3-4: 269-284

Bastiaanssen, W.G.M., R.G. Allen, P. Droogers, G. D'urso and P. Steduto, 2007. Twenty-five years modeling irrigated and drained soils: State of the Art, Agricultural Water Management, doi: 10.1017/j.agwat.2007.05.013, 92(3): 111-125

Bastiaanssen, W.G.M., W. Bingfang, D. Olson and J. Liping, 2008. Real water savings and ET reduction: the Hai Basin paradigm, Water Front, World Water Council, Stockholm

Birkett, C.M., 1998. Contribution of the TOPEX NASA radar altimeter to the global monitoring of large rivers and wetlands. Water Resour. Res., 34 (5), 1223-1239

Bolle, H.J., M. Eckhardt, D. Koslowsky, F. Maseli, J. Melia-Miralles, M. Menenti, F.S. Olesen, L. Petkov, I. Rasool and A. van de Griend, 2006. Mediterranean land-surface processes assessed from space, Springer-Verlag, Berlin and Heidelberg, ISBN 10 3-540-40151-2: 760 pp.

Brakenridge, G.R., S.V. Nghiem, E. Anderson and R. Mic, 2007. Orbital microwave measurement of river discharge and ice status, Water Resources Research, vol .43, W0445, doi 10.1029/2006WR005238

Brisson, A., P. Le Borgne and A. Marsouin, 1999. Development of algorithms for surface solar radiance retrieval at O&SI SAF low and mid latitude, Meteo France/CMS, Lannion

Choudhury, B.J., Y.H. Kerr, E.G. Njoku and P. Pampaloni, 1995. Passive microwave remote sensing of land-atmosphere interactions, VSP publishing, Utrecht, Netherlands

Coureault, D., B. Seguin and A. Olioso, 2005. Review on estimation of evapotranspiration from remote sensing data: from empirical to numerical modeling approaches. Irrigation and Drainage Systems 19: 223-249

Cracknell, A.P. and L.W.B. Hayes, 1991. Introduction to remote sensing, London: Taylor Francis

Draper, C.S., J.P. Walker, P.J. Steinle, R.A. de Jeu and T.R. Holmes, 200x. Remotely sensed soil moisture over Australia from AMSR-E.

Dugdale, G. and J.R. Milford, 1986. Rainfall estimation over the Sahel using Meteosat thermal infrared data, in ISLSCP, parameterization of land-surface characteristics: use of satellite data in climate studies, ed. E. Rolfe and B. Battrick, Paris, European Space Agency: 315-319

Fisher, P. , 2005. Land use and Land cover: Contradiction or Complement. Peter Fisher, David Unwin Re-Presenting GIS: 85–98, Chichester: Wiley

Engman, E.T. and R.J. Gurney, 1991. Remote sensing in hydrology, London: Chapman and Hall: 225 pp.

Gautier, C., G. Diak and S. Masse, 1980. A simple physical model to estimate incident solar radiation at the surface from GOES satellite data, J. Climate Appl. Meteo. 19: 1005-1012

Grimes, D.I.F., E. Pardo-Iguzquiza and R. Bonifacio, 1999. Optimal areal rainfall estimation using raingauges and satellite data, J. of Hydr. 222: 93-108

Jeu, de, R.A.M., W. Wagner, T.R.H. Holmes, A.J. Dolman, N.C. van de Giesen and J. Friesen, 2008. Global soil moisture patterns observed by space borne microwave radiometers and scatterometers, J. of Geophysical Research (special issue on remote sensing in hydrology)

Hurk, van den, B.J.J.M., W.G.M. Bastiaanssen, H. Pelgrum and E. van Meijgaard, 1997. A new methodology for initialization of soil moisture fields in weather prediction models using METEOSAT and NOAA data, J. of Applied Meteorology, 36: 1271-1283k

Jackson, T.J. et al.,1999. Soil moisture mapping at regional scales using microwave radiometry: the southern great plains hydrology experiment, IEEE Trans Geosci Rem Sens 37: 2136-2151

Hemakumara, M., 2007. Ph.D. thesis

Huffman, G.j., R.F. Adler, D.T Bolvin, G. Gu, E.J. Nelkin, K.P. Bowman, Y. Hong, E.F. Stocker and D.B. Wolff, 2007. The TRMM multisatellite precipitation analysis (TMPA): quasi-global, multiyear, combined-sensor precipitation estimates at fine scales, J. of Hydrometeorology 8: 38-55

Kidd, C., 2001. Satellite rainfall climatology: a review, Int. J. of Climatology 21: 1041-1066

Kummerow, C., W.S. Olson and L. Giglio, 1996. A simplified scheme for obtaining precipitation and vertical hydrometer profiles from passive microwave sensors, IEEE Transactions in Geoscience and Remote Sensing 34: 1213-1252

Kummerow, C., W. Barnes, T. Toshiaki, J. Shiue and J. Simpson, 1998. The Tropical Rainfall Measuring Mission (TRMM) sensor package, J. of Atm. And Oceanic Technology 15: 809-817

Kustas, W.P. and J.M. Norman, 1996. Use of remote sensing for evapotranspiration monitoring over land surfaces, Hydrological Sciences Journal 41(4): 495-516

Meer, van der, D. and S.M. de Jong (2005). Imaging spectrometry, basic principles and prospective applications, Kluwer Academic Publishers

Mohamed, Y.A., van den Hurk, B.J.J.M., Savenije, H.H.G., and W.G.M. Bastiaanssen, 2005. The Impact of the Sudd wetland on the Nile Hydroclimatology, Water Resources Research 40, W08420: 1-14

Monteith, J.L., 1972: Solar radiation and productivity in tropical ecosystems. J. Appl. Ecology, 9, 747-766

Moran, M.S. and R.D. Jackson, 1991. Assessing the spatial distribution of evapotranspiration using remotely sensed inputs, J. of Env. Quality 20: 725-737

Njoku, E.G. and D. Entekhabi, 1996. Passive microwave remote sensing to soil moisture, J. of Hydr. 184: 101-129

Njoku, E, T. Jackson, V. Lakshmi, T. Chan and S. Nghiem, 2003. Soil moisture retrieval from AMSR-E, IEEE transactions on geoscience and remote sensing 41(2): 215-229

Norman, J.M. et al., 2003. Remote sensing of surface fluxes at 101 m pixel resolutions, Water Resources Research vol. 39(8): 1221

Owe, M., R. de Jeu and J. Walker, 2001. A methodology for surface soil moisture and vegetation optical depth retrieval using the microwave polarization difference index, IEEE transactions on geoscience an remote sensing 39 (8): 1643-1654

Petty, G.W., 1995. The status of satellite-based rainfall estimation over land. Remote Sensing of Environment 51: 125-137

Petty, G.W. and W.F. Krajewski, 1996. Satellite estimation of precipitation over land, Hydrological Science Journal 41: 125-137

Pickup,G. and V.H.Chewings (1994): A grazing gradient approach to land degradation assessment in arid areas from remotely-sensed data, Int. J. Remote Sensing, 15,597-617

Raschke, E., 1995. Radiation and water in the climate system, remote measurements, NATO-ASI series I: Global Environmental Change, vol 45, Springer: 614 pp

Running, S.W., P.E. Thornton, R.R. Nemani, J.M. Glassy. (2000) Global Terrestrial Gross and Net Primary Productivity from the Earth Observing System. In: Methods in Ecosystem Science, O.Sala, R. Jackson, and H.Mooney Eds. Springer-Verlag New York.

Savenije et al., 2008. Remote sensing in hydrology, J. of Geophysical Research

Schultz, G.A. and E.T. Engman, 2000. Remote sensing in hydrology and water management, Springer Verlag Berlin

Smith, E.A. et al., 1998. Results of the WetNet PIP-2 project, J. of Atmospheric Sciences 55: 1483-1536

Snijders, F.L., 1990. Rainfall monitoring based on Meteosat data, a comparison of techniques applied to the Western Sahel. Int. J. of Remote Sensing, 12(6)

Stewart, J.B., E.T. Engman, R.A. Feddes and Y. Kerr, 1996. Scaling up in hydrology using remote sensing, John Wiley & Sons Ltd., Chichester, ISBN 0-471-96829-3: 255 pp.

Vidal, A., 1995. Remote sensing and geographic information systems in irrigation and drainage, methodological guide and applications, ICID, ISBN 81-85068-72-0: 126 pp.

Vorosmarty, C. J., Birkett, C. M., Dingman, S.L. & Forrest, D, 1999; The contribution of satellite radar altimetry to the determination of river dicharge and lake / reservoir stage from space: a feasibility study for North America.

Vrieling, A., 2006. Satellite remote sensing for water erosion assessment: a review, Catena 65: 2-18

Wagner, W., V. Naeimi, K. Scipal, R. de Jeu and J. Martinez-Fernandez, 2007. Soil moisture from operational meteorological satellites, Hydrogeology Journal 15 : 121-131

Appendix 1: Terms of Reference RS consultancy

1 Objective **of** Consultancy

Primary objective of this consultancy is to identify the need for and define the functions of the proposed RS/GIS Unit under the Regional DSS Center. The work also includes pilot activities on archiving and processing of remote sensing data as well as a regional awareness/training workshop.

2 Scope **of** work

This consultancy assignment includes the necessary consultations, compilation and analysis of information, preparing specifications for the proposed unit as well as conducting awareness workshops on GIS and Remote Sensing to participants selected from NBI programs/projects and hosting institutions of National DSS Units. The work starts with a short inception step, during which the consultant shall work from his/her home venue reviewing relevant documents on NBI programs/projects, and other relevant documents. Following the inception step, the Analysis step follows, where the consultant shall visit selected NBI institutions and consult with program/project staff. The analysis step shall last about two months. At the end of the analysis step, the consultant shall submit draft final report and detailed syllabus of the awareness/training workshop. The scope of work shall include, but not limited to, the following:

A - Inception

I. Review relevant project documents under NBI programs: the objective of this review is to understand the broader context and needs for establishing the Remote Sensing/GIS unit to support the development of the Nile Basin DSS and other NBI programs/projects.

II. Draft and submit Inception report: based on the review of documents, the Consultant shall submit an inception report to the WRPM project. The inception report shall contain preliminary identification of needs for remote sensing information products, revised methodology for subsequent stages of work, outline of the final report and revised work schedule.

B – Analysis

III. **Identify needs for remote sensing information products:** this task shall be based partly on preliminary work the WRPM project has conducted with respect to data/information requirements to support the implementation of NBI programs. The task also includes consultations with NBI Secretariat, staff of the WRPM project, Eastern Nile Technical Regional Office (ENTRO), and NEL-CU. The assessment shall focus on current as well as projected future data/information requirements.

IV. Prepare an **inventory** of world-wide availability of remotely sensing products (raw data as well as processed/derived information products) and their relevance for use in the Nile Basin, i.e. to address the needs for such information products identified above. The inventory shall contain as a minimum the following information:

a. Themes covered by the data
b. Spatial coverage and resolution
c. Record length (in time) and temporal resolution
d. Sources of data, accuracy, availability (public domain or commercial, if commercial – indicate cost and contact of custodians), relevant documentation, etc
e. Potential application areas in the Nile Basin

V. Formulate the s**tandard remote sensing (spatial information) products** required: based on the analyses carried out as part of this consultancy, the consultant shall prepare a detailed description of the various remote sensing information products that are required to support NBI programs, in general, and the Nile Basin DSS, in particular. Emphasis shall be given to the requirements for the Nile Basin knowledgebase, monitoring of river basin state of water resources, preparation and implementation of investment projects at subsidiary level, i.e. through the EN – and NELSAP.

VI. Conduct high-level **assessment of potential contributions** of a remote sensing/GIS unit and identify its main functions. In consultation with the WRPM project staff, and relevant staff of selected NBI programs/projects also identify main functions of the unit and its capabilities including:

   a. Defining the remote sensing data processing agenda for the unit, including:

      i. Design of standard business process for the unit covering aspects of data acquisition, processing, and dissemination
      ii. Data quality control and quality assurance procedures
      iii. Standard data archiving systems

   b. Identifying potential regional/international (Remote Sensing) institutions, such as the Regional Centre for Mapping of Resources for Development in Nairobi, with which the unit can be twined for better synergy. Work shall also include areas of future cooperation with such institutions.

VII. Prepare a detailed technical specifications of the facilities required to establish the RS/GIS unit, including:

      i. General organization of the unit, including office space requirement and staffing
      ii. Preparation of a detailed technical specification of hardware and software and
      iii. Preparation of profiles of technical staff required to make the proposed remote sensing unit operational

VIII. Initiate the preparation of selected remote sensing data/images: once relevant remote sensing images have been identified, the consultant shall assist the WRPM project in initiating the downloading, processing and archiving of remote sensing imagery. This activity shall serve as the starting point for the proposed remote sensing unit. These pilot activities shall focus, at a minimum, on the following:

   a. Data types/themes

      i. Digital elevation models
      ii. Rainfall estimates (daily/monthly)
      iii. Land use/cover
      iv. Thermal information
      v. Others (to be identified during initial stages of the study)

   b. Sample applications

i. Delineation of watershed boundaries and classification of watersheds
ii. Estimation of Evapotranspiration (for selected watersheds)
iii. Delineation of flooded areas
iv. Water quality applications
v. Delineation of eco-hydrologic systems (wetlands, degraded land, etc)
vi. Trend detection (trends in wetlands, changes in forest/vegetation cover, etc)
vii. Others (to be identified during initial stages of the study)

IX. Prepare and submit draft final report: the report shall be reviewed by the WRPM project.

C – Synthesis

X. Provide short awareness/training workshop on processing of remote sensing data for selected participants from the Nile Basin. It is estimated that about 25 – 30 people shall participate in the workshop. The workshop shall last about 10 days and shall be conducted at the WRPM PMU in Addis Ababa, Ethiopia. The workshop shall cover, at the minimum, the following:

a. Introduction to remote sensing and GIS technology and its applications in water resources management
b. Practical (hands-on) sessions on using standard remote sensing/GIS software identified under (vii) above. Examples of such software are Arc GIS, ERDAS-Imagine, etc.
c. Practical sessions on selected applications relying on examples as given in (vi) above
   i. Rainfall data processing, ET estimation,
   ii. Estimation of catchment water balance,
   iii. Groundwater recharges,
   iv. Application of Remote sensing in flood management and drought monitoring

All practical sessions in the workshop shall be based on the data archived at the WRPM PMU as part of this consultancy. All software acquired for the workshop shall belong to the WRPM project.

Enhance and submit final report based on the inputs/comments from the WRPM project.

3 Deliverables

The following are the main deliverables of this Consultancy:

Inception Report containing:

Compilation of preliminarily identified needs, potential remote sensing products available world wide
Methodology for subsequent stages of the consultancy
Revised work schedule and Table of Content of the Final Report
Proposed syllabus for the training/awareness workshop

Systematic compilation of selected RS information products

Final Report with the following technical annexes:

Inventory of remote sensing products

Key identified functions and processes for the Remote Sensing unit
Technical specifications of hardware/software
Profiles of human resources for the proposed Remote Sensing/GIS unit
Summary of standard procedures for process of remote sensing products
Syllabus of training/awareness workshop

Technical Workshop on Remote Sensing/GIS applications

Appendix 2: List of participants awareness workshop March 2008

RS - GIS Training Workshop participants

11th -22th March, 2008

Addis Ababa, Ethiopia

SN	Name	Position	Country	Email
1	Dr.-Ing. Gabriel Ndikumana	NDSS Specialist	Burundi	gndikumana@nilebasin.org
2	Mr. Astere Nindamutsa	NDSS Counterpart	Burundi	bwatemba_2006@yahoo.fr
3	Dr.-Ing Bertin Chibanvunya Bagula	NDSS Specialist	DR Congo	bcbagula@nilebasin.org
4	Mr. Mohammed Yasser Elwan	NDSS Specialist	Egypt	yelwan@nilebasin.org
5	Mr Mohammed Roushdy	RDSS Network Member	Egypt	m.roushdy@hri-egypt.org
6	Mr. Deksyos Tarekegn	NDSS Specialist	Ethiopia	dtarekegn@nilebasin.org
7	Dr. Mohammed Abdullahi Hassan	NDSS Specialist	Kenya	mhassan@nilebasin.org
8	Mr. Antoine Niragire Twagirumukiza	NDSS Specialist	Rwanda	niragire@yahoo.co.uk; nantoine@nilebasin.org
9	Mr. Odilo Mukiza	NDSS Counterpart	Rwanda	odilonrw@yahoo.com
10	Dr. Salih Hamad Hamid	NDSS Specialist	Sudan	salihhhamid@yahoo.co.uk
11	Mrs. Widad Mutwakil Saad Alla	NDSS Counterpart	Sudan	widdam@hotmail.com
12	Dr. George V. Lugomela	NDSS Specialist	Tanzania	gvlugomela@nilebasin.org
13	Mr. Hosea Sivonike Sanga	NDSS Counterpart	Tanzania	hoseasanga@yahoo.com
14	Mr. Ssebuggwawo Vincent	NDSS Specialist	Uganda	Ssebuggwawo@yahoo.com; Ssebuggwawo@nilebasin.org

15	Dr. Solomon Seyoum Demissie	Water Resources Specialist	PMU	sdemissie@nilebasin.org
16	Mr. Ephrem Getahun Hailu	IT/GIS/DB Specialist	PMU	egetahun@nilebsin.org
17	Mr. Jemal Dagnew Mensur	IT Specialist	ENTRO	jdagnew@nilebasin.org
18	Mr. Tsegaye Debebe Kassa	GIS Specialist	MoW, Ethiopia	tsegaye_d@yahoo.com
19	Mr. Solomon Kebede G/Egizy	Hydrology Technitian	MoW, Ethiopia	solzem@yahoo.com

Appendix 3: Program awareness workshop March 2008

Tuesday March 11 (Annemarie)

- ERDAS Imagine software
- Data formats
- Import/export of data

Wednesday March 12 (Annemarie)

- Geometrical corrections
- Reprojection
- Remote sensing and GIS integration

Thursday March 13 (Annemarie)

- Basin delineation
- Exercises with basin delineation
- Land cover maps

Friday March 14 (Annemarie)

- Introduction to remote sensing
- Image processing
- Multi-spectral imagery
- Model maker

Saturday March 15 (Annemarie)

- Vegetation indices
- Time series analysis
- Land cover classification

Monday March 17 (Wim)

- Rainfall
- Soil Moisture
- Exercises

Tuesday March 18 (Wim)

- Evapotranspiration
- Vegetation water stress
- Biomass production
- Exercises

Wednesday March 19 (Wim)

- Irrigation and drainage
- Irrigation performance indicators
- Water productivity
- Exercises

Thursday March 20 (Wim)

- Water accounting
- Land degradation indicators
- Drought monitoring
- Flood indicators
- Exercises

Friday March 21 (Ephrem)

- ArcGIS software
- GIS data layers for Nile Basin
    - Digital Elevation map
    - Slope map
    - Soil map

Appendix 4: Earth observation satellite systems for general applications in land and water management

Since the launch of earth observation satellites with the purpose of describing land surface processes during the 1970s, a suite of different sensors have been brought to space. One has to distinguish between spectral radiometers (that measures radiation in a specific part of the spectrum) and the satellite platform or 'mission' that can be considered as the engine that pushes the radiometer forward. For good reasons, one satellite often hosts multiple spectral radiometers.

Despite the fact that satellite radiometric measurements, after 30 years of research and applications, became common instruments to describe the state variables of the atmosphere such as cloud cover, water vapour content and aerosols in weather prediction and climatological studies, the applications in the water resources community are unfortunately limited. This can be partially attributed to water manager's focus on local scale, rather than large scale water management issues. Climatic processes cover continental scales, are more appropriate scales for satellite applications.

Growing recognition of the river basin as the basic unit for integrated water resource management, has resulted in renewed interest to describe hydrological processes and water management with satellites. It is expected that in the coming decade, satellites will be used more commonly to describe or predict key hydrological phenomena such as floods, droughts, groundwater processes, water productivity, etc. Space programs of NASA and ESA now dedicate more attention to measurement of hydrological processes in large river basins. They are moving their interests from global scale to river basins. It is therefore a good opportunity to explore technical technical opportunities in this field.

It is convenient to discern the various radiometers by their spectral interval:

- Visible and near-infrared radiometers (0.3 – 3.0 μm)
- Thermal-infrared radiometers (3.0 – 15 μm)
- Passive microwave radiometers (0.1 – 30 cm)
- Active microwave radiometers (0.1 – 30 cm)

Remote sensing in land and water resources management can be broadly grouped into three different categories:

a. monitoring of basin scale flow processes with the emphasis on rainfall, soil moisture, ET and river flow;
b. identification of local agricultural and ecological practices;
c. surveying field layout, plot boundaries and legislative aspects;

Category (a) requires repetitive image collection, and is therefore often based on lower resolution images (250 to 1100 m) with a potential repeat cycle of one day. MODIS is an excellent new option in this category because it is with 36 bands an imaging spectrometer (31 bands in the visible and near-infrared part of the spectrum) that acquires images twice daily. The morning overpass is on Terra and the afternoon overpass is on Aqua (see Table 1). The 2nd generation Meteosat satellite (MSG2) was launched successfully on December 21 (2005), and this sensor provide multi-spectral images (12 channels in the visible and near-infrared part of the spectrum) with an intermittency of 15 minutes only! Its positioning above the African equator makes this imager suitable for monitoring the hydrological processes in the Nile Basin.

Table 1 Selected visible and near-infrared radiometers and their associated satellite platforms

Satellite	Radiometer	Launch year	Pixel resolution	Revisit period	Number of bands	Swath width
				(days)		(km)
Landsat	MSS	1972	80 m	16	4	185
NOAA	AVHRR	1982	1100 m	1	2	2500
Landsat	(E)TM	1984	30 m	16	6	185
SPOT	XS	1986	10 to 20 m	23	4	60
IRS	LISS	1988	5 to 25 m	24	4	141
SPOT	Vegetation	1998	1000 m	1	3	2200
Terra	ASTER	1999	15 to 30 m	23	9	60
Terra	MODIS	1999	250 to 1000 m	1	31	2500
Ikonos	-	1999	1 to 4 m	variable	4	15
Quickbird	-	1999	1 to 4 m	variable	4	62
Aqua	MODIS	2002	250 to 1000 m	1	31	2500
Envisat	MERIS	2003	300 m	3	15	1500
IRS	AWIFS	2004	56 m	5	4	350
MSG-2	-	2005	1000 m (at equator)	continuously	13	geo-stationary

Category (b) is based on multi-spectral images designed for earth resources monitoring at field scale (15 to 30 m). Visible and near-infrared radiometers with a spatial resolution of approximately 20 meter are very common and useful to discern land cover classes, crop types, soil types and bio-physical parameters such as leaf water content, fraction of photosynthetical radiation (fPAR) etc. Landsat, SPOT and IRS images specified in Table 1 are often used for this purpose. There are costs involved in acquiring these images.

Category (c) needs the involvement of very high-resolution images (1 to 5 m) suitable to detect small objects on the earth surface. Commercially available very high resolution visible and near-infrared radiometers with a spatial resolution of 0.5 to 3 meter can be used for precision farming (e.g. N-applications, malfunctioning irrigation devices) and to detect topographical features such as canals, bridges etc. Ikonos and Quickbird imagery typically belong to this category of images.

Thermal-infrared applications in hydrology and water resources management are typically related to the determination of energy balances and evapotranspiration. The first publications in this field stem from the 1960s and 1970s (e.g. Jackson et al., 1977). Water depletion by evaporation is important for understanding the processes resulting from ET (beneficial & non-beneficial) as well as it provides an indication of water stress experienced by vegetation. Table 2 describes the space and time domains related to the retrieval of thermal infrared data, being required for ET computations.

Skin temperatures that can be derived from thermal infrared measurements can also be used for the determination of precipitation. The latter technology is also known as the cold cloud duration (Dugdale and Milford, 1986) which is based on the fact that top cloud temperatures are related to the amount of precipitable atmospheric moisture present in the clouds.

Table 2 Thermal infrared radiometers and accompanying satellite platforms

Satellite	Radiometer	Launch year	Pixel resolution	Revisit period	Number of bands	Swath width
				(days)		
Meteosat[5]		1977	5000 m	30 minutes	1	geo-stationary
NOAA	AVHRR	1982	1100 m	01	3	2500 km
Landsat	(E)TM	1984	60 to 120 m	16	1	185 km
ERS	ATSR	1996	1000 m	23	2	1500 km
Terra	MODIS	1999	250 to 1000 m	1	5	2500 km
Terra	ASTER	1999	15 to 90 m	23	5	60 km
Aqua	MODIS	2002	250 to 1000 m	1	5	2500 km
Envisat	AATSR	2002	1000 m	1	2	2500 km
MSG-2	GERB	2005	3000 m	15 minutes	1	geo-stationary

The category of microwave satellites can be divided into passive and active systems. The strong advantage of microwave technology is that microwaves penetrate through the atmosphere under all weather conditions. Contrary to images acquired with optical sensors, microwave satellites are 'weather' proof. Microwaves with different frequencies are available in operational satellites and they range from longer wavelengths 1.42 GHz (L-band) 21 cm, via 5.3 GHz (C-band) 5.6 cm, 6.6 GHz 4.5 cm to smaller wavelengths 37.0 GHz 0.81 cm.

Passive microwave remote sensing is based on the measurements of emitted radiation from the land surface in the centimeter wave band, and is largely determined the physical temperature and the emissivity of the radiating body. The microwave emissivity is a strong function of the surface soil moisture conditions and the vegetation optical thickness and roughness. The basic capabilities of passive microwave technologies for soil moisture are well understood after more than 20 years of research. Space borne passive radiometers have, however, a very large pixel size, which makes them suitable only for regional scale applications (such as operationally monitoring land wetness throughout the entire Nile Basin).

Active microwave radar technologies have a spatial resolution that is compatible with the optical satellites. Active microwave systems have a radar antenna beam that illuminates the ground. Due to the satellite motion and the along-track (azimuth) beam width of the antenna, each target element only stays inside the illumination beam for a short time. This process is equivalent to a long antenna (so called Synthetic Aperture) illuminating the target. Active microwave systems are

[5] Meteosat is the geostationary satellite over Africa and Europe. America has GOES, Asia has INSAT and Fyuing and Australia has GMS

therefore often referred to as SAR systems. A summary of operational systems is provided in Table 3.

Table 3 Selected microwave radiometers and accompanying satellite platforms

Satellite	Radiometer	Launch year	Pixel resolution	Revisit period	Frequency	Swath width
				(days)		
Nimbus passive	SSMR	1978	25 to 150 km	17	37 GHz (25 km) 6.6 GHZ (150 km)	1400 km
DMSP	SSM/I	1987	15 to 70 km	17	86 GHz (15 km) to 19 GHz (40 x 70 km)	1400 km
Topex	Poseidon altimeter	1992	2.2 km	10	14 GHz	-
TRMM passive	TMI	1997	9 km X 16 km	2	10.7 GHz to 86 GHz	760 km
Radarsat Active	-	1995	8 to 100 m	24	5,3 GHz	50 to 500 km
ERS Active	AMI	1991	12.5 m	23	5.3 GHz	100 km
ERS Active	Scatterometer	1991	50 km	3	5.3 GHz	500 km
Jason	Poseidon altimeter	2001	2 km	10	14 GHz	-
JERS Active	SAR	1992	12.5 m	46	1.275 GHz or 23 cm (L band)	75 km
Envisat	ASAR	2002	150 m	3	c-band	405
Envisat	RA2 altimeter	2002	1.7 km	16	13.6 GHz (KU band)	

Appendix 5 Directly Accessible **Portals**

Landsat GeoCover Mosaics

The GeoCover mosaic is a global set of regional images mosaicked from the Landsat GeoCover data set. This project was designed at NASA Stennis Space Center (https://zulu.ssc.nasa.gov/mrsid/). It is also called GeoCover circa 1990 (based on Landsat 5-TM) and circa 2000 (based on Landsat 7-ETM).

More information:
http://glcf.umiacs.umd.edu/data/mosaic/

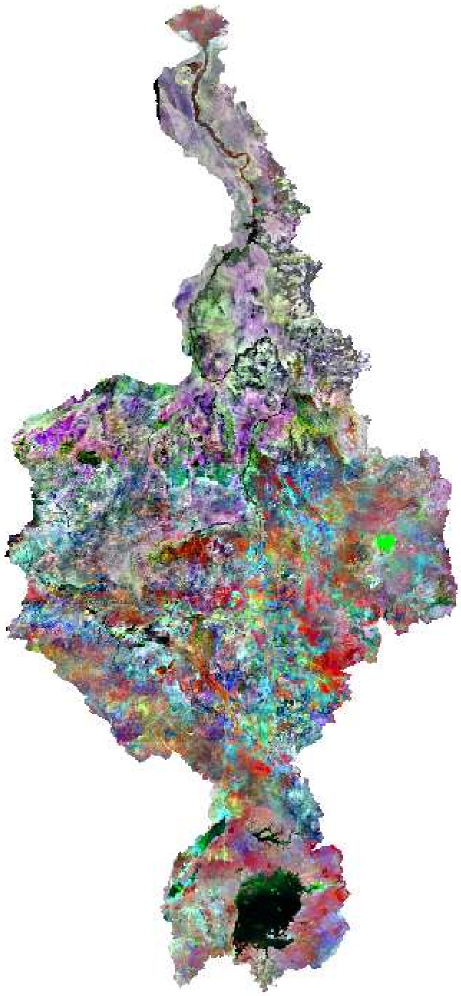
Data download:
http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

Data availability:
Datasets are created with images from circa 1990 and 2000.
Use is free to all. The US Government holds the ultimate ownership.

Resolution:
Spatial -> 14.25 meter.

Swath width:
Available for the entire earth land surface

Image information:
UTM
MrSid format



Landsat 7ETM GeoCover mosaic

Landsat 5TM & 7ETM Images

Landsat provides high resolution satellite imagery on a regular basis. The spatial resolution of 30 meters allows interpretation at field level, while the temporal resolution of 2 times every 16 days allows a solid analysis in time. Both Landsat 5 and 7 provide important observations of the Earth, that have been used by government, commercial, industrial, civilian, military, and educational communities worldwide in a wide range of applications in such areas as global change research, agriculture, forestry, geology, water resource management etc.

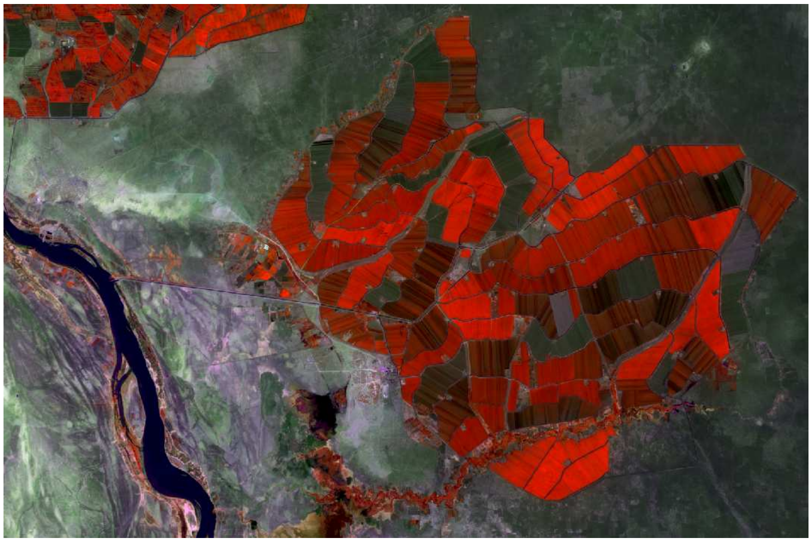
More information:
http://landsat.usgs.gov/

Data download:
http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

Data availability:
Data availability on the GLCF website is variable for each path/row. More images are available commercially.
Landsat 5 TM has been running since March 1, 1984 until present (with some gaps due to power problems).
Landsat 7-ETM is available since April 15, 1999, but due to a Scan Line Correction failure images are Scan Line corrected since July 14, 2003 and not suitable for image classification anymore.

Resolution:
Spatial -> 30 meter.
Temporal -> overpass every 16 days

Swath width:
Available for the entire earth land surface



Subset of a Landsat 7ETM scene (path 173 row 51, 21 April 2003)

SRTM: Surface Elevation Model (DEM)

SRTM DEM:
The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe

More information:
http://srtm.csi.cgiar.org/Index.asp

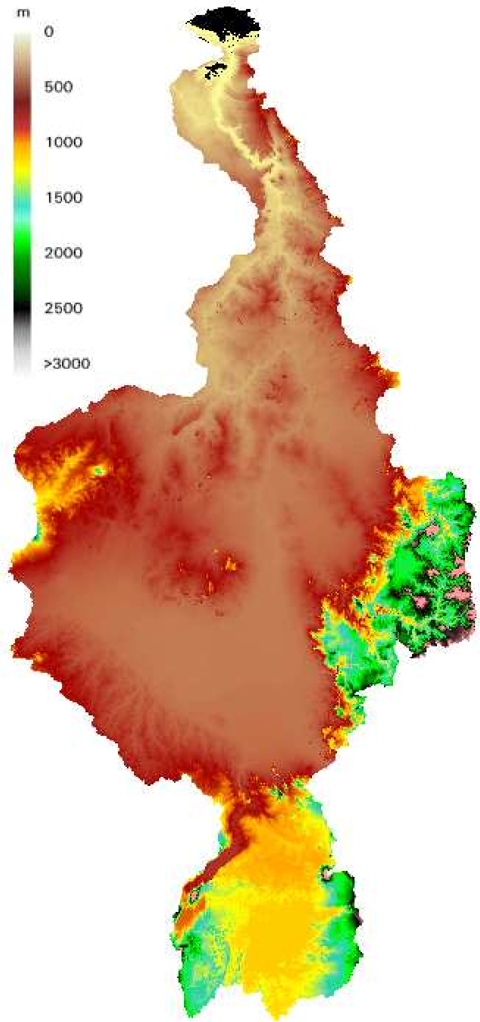
Data download:
http://srtm.csi.cgiar.org/Index.asp

Data availability:
Version 3 is available since 2007. SRTM was flown aboard the Shuttle Endeavour in February 2000.

Resolution:
Spatial -> 3 arc second (approx. 90-m resolution) at the equator.

Swath width:
Available for 80% of the land surface (for some countries a 1 arc second data product is available), for most of the area between 60 N and 56 S latitude.

Image information:
Geographic latlon WGS 84
signed 16bit integer
Units: [meters]
Fill value: -32768



SRTM Digital Elevation Model version 3 (resampled to 1-km)

MODIS: land cover (IGBP scheme)

MOD12Q1A:
MODIS/TERRA land cover type yearly L3 global 1km sin grid v004

5 different land cover classifications. Landcover type 1 includes the 17 IGBP classes.

More information:
http://edcdaac.usgs.gov/modis/mod12q1v4.asp

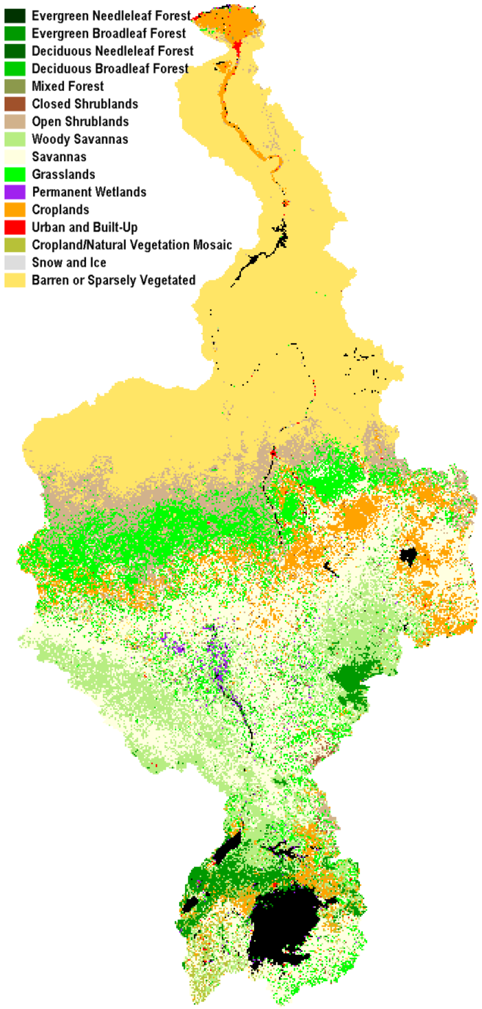
Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(registration required)

Data availability:
Started in 2001, this was supposed to be a yearly updated product. After 2004 no updates.

Resolution:
Temporal -> 2001 (?)
Spatial -> 1-km

Swath width:
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS=16, unsigned 8bit integer
Units: [-]
Scale factor: 1
Fill value: 255



MODIS IGBP land cover

Band 1: Land cover classification scheme IGBP
Band 2: University of Maryland modification of the IGBP scheme
Band 3: MODIS LAI/fPAR scheme
Band 4: MODIS Net Primary Production scheme
Band 5: Plant Functional Types scheme

MODIS: land cover dynamics

MODIS IGBP land cover

MOD12Q2:
MODIS/TERRA land cover dynamics yearly L3 global 1km sin grid v004

The MOD12Q2 product provides estimates of the timing of vegetation phenology at global scales. It identifies the vegetation growth, maturity, and senescence marking seasonal cycles. The product is produced twice a year, using 24 months as input.

More information:
http://edcdaac.usgs.gov/modis/mod12q2v4.asp

Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(registration required)

Data availability:
Started in 2001, this was supposed to be a yearly updated product. After 2004 no updates.

Resolution:
Temporal -> twice a year, 2001-2004
Spatial -> 1-km

Swath width:
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS=8, unsigned 16bit integer
Units: [-]
Scale factor: 1
Fill value: 32767

Band 1: Onset Greennes Increase (days since January 2000)
Band 2: Onset Greennes Maximum (days since January 2000)
Band 3: Onset Greennes Decrease (days since January 2000)
Band 4: Onset Greennes Minimum (days since January 2000)
Band 5: NBAR EVI Onset Greenness Minimum (NBAR EVI value) [scaling factor: 0.0001]
Band 6: NBAR EVI Onset Greenness Maximum (NBAR EVI value) [scaling factor: 0.0001]
Band 7: NBAR EVI Area (NBAR EVI area) [scaling factor: 0.01]
Band 8: Dynamics QC (concatenated flags) [scaling factor: na] [fill value: 65535]

Africa Land Cover Characteristics Data Base

The Africa land cover data base is one portion of a global land cover characteristics data base that is being developed on a continent-by-continent basis. The data base is based on 1-km AVHRR data spanning April 1992 through March 1993. Each data base has unique elements and a core set of derived thematic maps produced through the aggregation of seasonal land cover regions. The core set consists of: Global Ecosystems, IGBP Land Cover Classification, US Geological Survey Land Use/Cover System, Simple Biosphere (2) Model and the Biosphere-Atmosphere Transfer Scheme.

More information:
http://edcsns17.cr.usgs.gov/glcc/glcc_version1.html#Africa
http://edcsns17.cr.usgs.gov/glcc/afdoc1_2.html

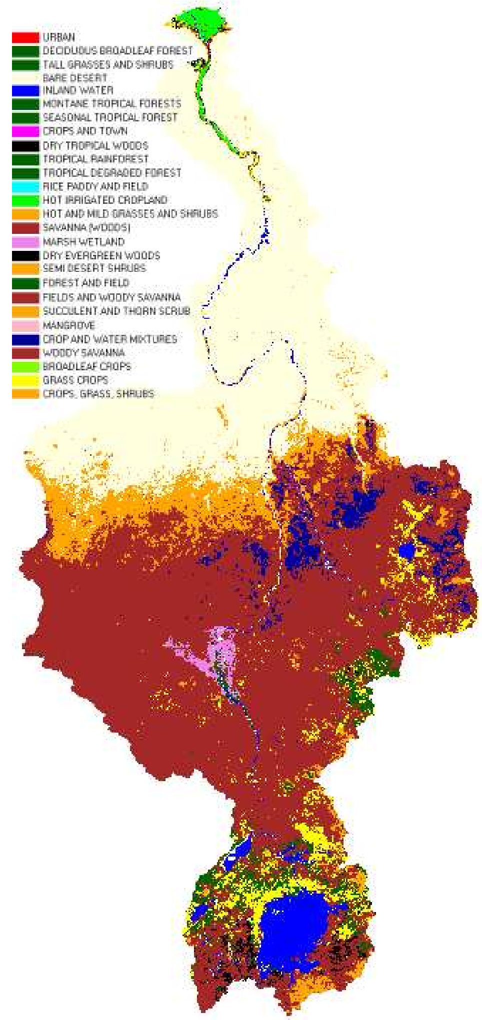
Data download:
ftp://edcftp.cr.usgs.gov/pub/data/glcc/af/lambert/

Data availability:
April 1992 – March 1993

Resolution:
Spatial -> 1-km
Temporal -> monthly NDVI Composite Images are available for the period April 1992 - March 1993

Swath width:
Products at continental scale

Image information:
Flat, headerless raster format
Pixel values correspond to class numbers defined in classification scheme legends
Single-band images
Available in either Interrupted Goode Homolosine and Lamber Azimuthal Equal Area projections.



Global Ecosystems

IWMI: irrigated areas of the world

An irrigated Area Map of the World (1999) derived from Remote Sensing

Multiple resolution time series data used in the study were: (a) AVHRR 4-band and NDVI 10-km monthly time series for 1981-1999, (b) SPOT vegetation NDVI 1-km monthly time series for 1999, and (c) Rainfall 50-km monthly time series for 1961-2000. Additional major global data sets used were (a) GTOPO-30 1-km elevation, (b) JERS SAR data for the rainforests during two seasons in 1996, and (c) University of Maryland Global Tree Cover 1-km data for 1992-93.

More information:
http://www.iwmigiam.org

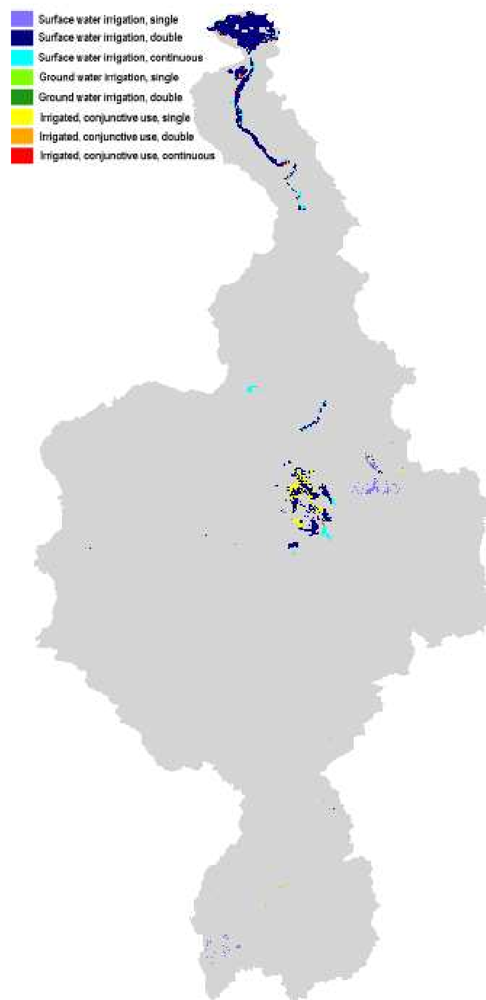
Data download:
http://www.iwmigiam.org/info/gmia/gmia_340_class_image_preview.asp
(registration required)

Data availability:
Data for nominal year 1999 available

Resolution:
Temporal -> 1999
Spatial -> 10-km

Swath width:
Global coverage

Image information:
Geographic (latlon)
Thematic unsigned 8-bit
Units: [28 classes]
Scale factor: 1
Fill value: 0



Irrigated areas

FAO: Global Map or Irrigation Areas

Global Map or Irrigation Areas

The first global digital map of irrigated areas on the basis of cartographic information and FAO statistics was developed in 1999. Since 1999 the spatial resolution has been improved, the latest version was made available in February 2007. The map was developed by combining sub-national irrigation statistics with geospatial information on the position and extent of irrigation schemes to compute the fraction of 5 arc minute cells that was equipped for irrigation, which is called irrigation density.

More information:
http://www.fao.org/nr/water/aquastat/irrigationmap/index.stm

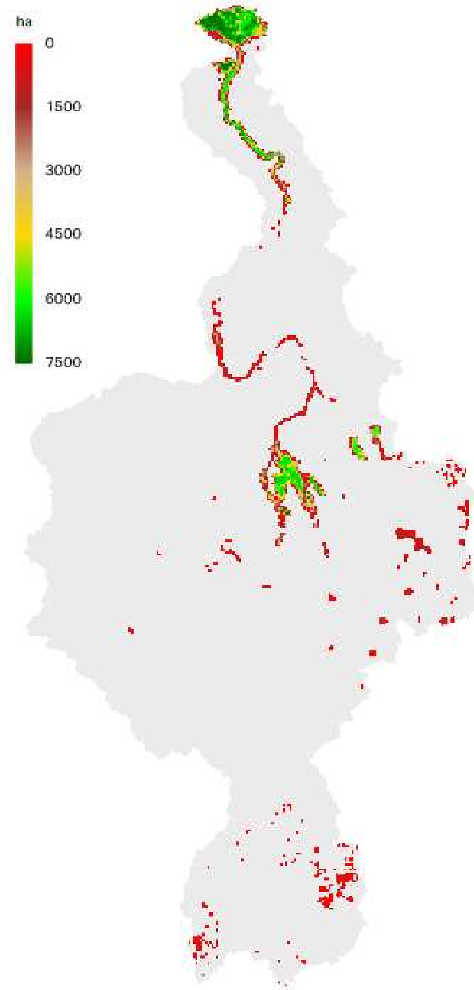
Data download:
http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm

Data availability:
Global coverage. Area equipped for irrigation is expressed as percentage of total area or in hectares per cell. Data available as ASCII grid and shapefile (slightly lower precision).

Resolution:
Temporal -> last update in February 2007
Spatial -> 5 arc minutes

Swath width:
Global coverage

Image information:
Geographic (latlon)
Float
Units: % or ha
Scale factor: 1
Fill value: -9



FAO map of irrigation density (ha per pixel of 5 arc minutes, 1 pixel around 8000 ha)

Famine Early Warning Systems (FEWS) Network: Daily Rainfall Estimate

The FEWS RFE 2.0 algorithm has been implemented by NOAA's Climate Prediction Center, and uses an interpolation method to combine Meteosat and Global Telecommunication System (GTS) data, and included warm cloud information for the decadal estimates.

The satellite rainfall images are generally 1 or 2 days behind the current date, depending upon the local time zone of the user; thus, the links below are set up for multiple days. If the 1- or 2-day old images are not available, try one of the earlier dates. The U.S. Air Force images start from the last satellite rainfall image and go forward 3 days (24-, 48- and 72 hour forecasts). If the forecast images are unavailable, try an earlier date.

More information:
http://earlywarning.usgs.gov/adds/overview.php

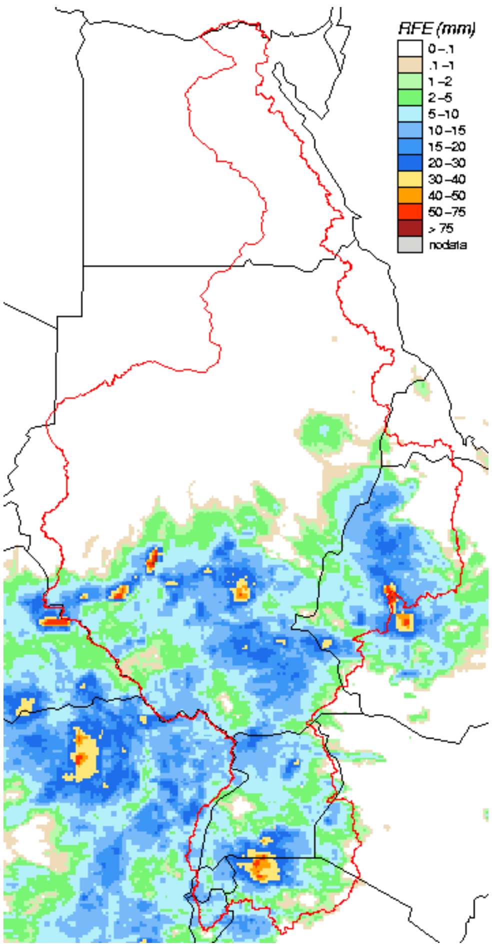
Data download:
http://earlywarning.usgs.gov/adds/dwndailyrfe.php

Data availability:
2002-2007

Resolution:
Spatial -> 8-km
Temporal -> daily

Swath width:
Africa cover

Image information:
Each file contains the ARC/INFO created .bil image and related files (i.e. .bil, .blw, .hdr, .stx, .clr) for that day.
Data is in 8-km resolution, and in Conical Albert Equal Area projection since October 2000.



Daily rainfall on October 1, 2007

TRMM: monthly rainfall data

3B43:
Monthly 0.25° x 0.25° TRMM and Other Sources Rainfall Data
01/01/1998 – Current product

Precipitation rate estimations based on Tropical Rainfall Measuring Mission (TRMM) and Other Data (geosynchronous IR and rain gauges).

More information:
http://trmm.gsfc.nasa.gov/trmm_rain/Events/trmm_climatology_3B43.html

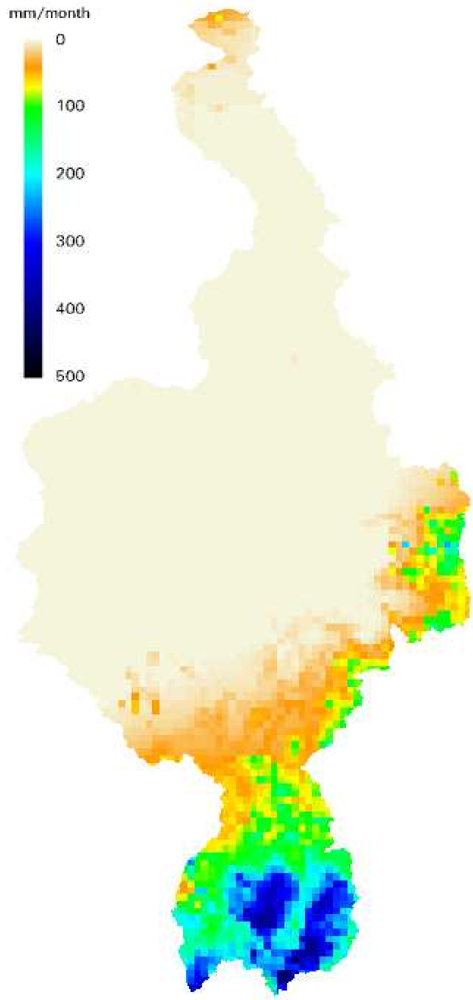
Data download:
http://daac.gsfc.nasa.gov/precipitation/data_products.shtml
(available immediately after month ends)

Data availability:
1998 – current

Resolution:
Temporal -> monthly
Spatial -> 0.25 degrees ~ 25-km

Swath width:
Depending on instrument, for example 247 km for Precipitation Radar, 878 km for Microwave Imager, both onboard TRMM.
Prior to February 2000 the global band extended from 40 degrees North to 40 degrees South, after February 2000 from 50 degrees North to 50 degrees South latitude.

Image information:
Geographic (latlon)
SDS, 4-byte float
Units: [mm/hour], ranging from 0.0 to 10 mm/hour
Scale factor: 1
Fill value: 0



Monthly rainfall product January 2007

TRMM: 3-hourly rainfall data

3B42:
3-Hour 0.25° x 0.25° merged TRMM and satellite estimates:
01/01/1998 – Current" product

3B-42 estimates area produced in four stages: (1) calibration and combination of microwave estimates precipitation, (2) infrared precipitation estimates are created using the calibrated microwave precipitation, (3) combination of microwave and IR estimates, (4) rescaling to monthly data.

More information:
http://trmm.gsfc.nasa.gov/3b42.html

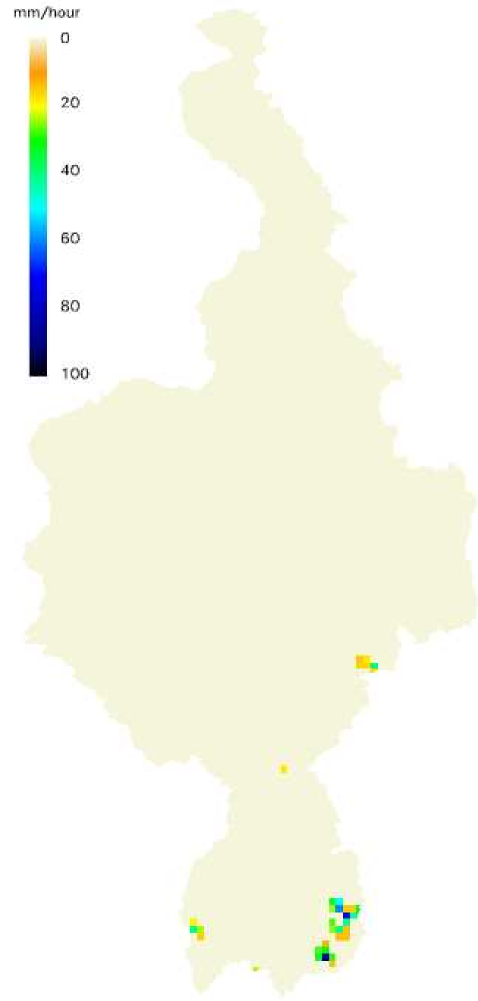
Data download:
http://disc.sci.gsfc.nasa.gov/data/datapool/TRMM_DP/01_Data_Products/02_Gridded/06_3-hour_Gpi_Cal_3B_42/
(available within hours)

Data availability:
1998 – current

Resolution:
Temporal -> 3-hourly
Spatial -> 0.25 degrees ~ 25-km

Swath width:
Depending on instrument, for example 247 km for Precipitation Radar, 878 km for Microwave Imager, both onboard TR MM.
Prior to February 2000 the global band extended from 40 degrees North to 40 degrees South, after February 2000 from 50 degrees North to 50 degrees South latitude.

Image information:
Geographic (latlon)
SDS, 4-byte float
Units: [mm/hour], ranging from 0.0 to 100 mm/hour
Scale factor: 1
Fill value: 0



3-hourly rainfall product
15h-18h, 1 January 2007

VUA-NASA Soil Moisture Algorithm
based on AMSR-E

The VUA-NASA Land Surface Parameters constitute a global database of Surface Soil Moisture, Land Surface Temperature and Vegetation Water Content. The parameters are derived from passive microwave remote sensing (e.g. AMSR-E and TRMM), using the Land Parameter Retrieval Model (LPRM).

More information:
http://www.geo.vu.nl/~jeur/lprm/

Data download:
The entire VUA-NASA retrieval products are available upon request, but will be available on a map server in the very near future (see ADAGUC website for further info). 2002-2007 AMSR-E soil moisture directly available at: http://www.geo.vu.nl/~holt/grid25/

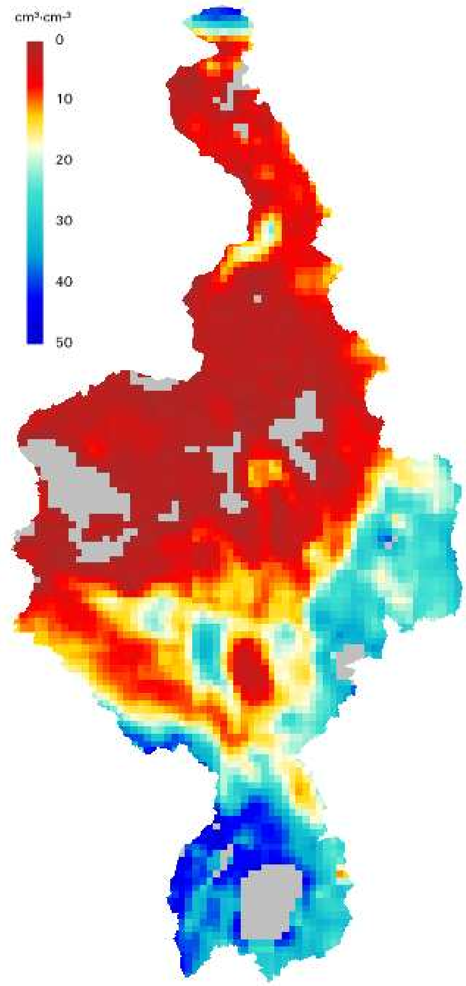
Data availability:
1978 to present, global

Resolution:
Spatial -> 0.25 degree
Temporal -> 2-3 day revisit time at the equator for both day and night time overpasses

Swath width:

Image information:
Soil moisture is expressed in volume %.

The files are ASCII raster files (converted from Matlab).



Monthly soil moisture in January 2003

IWMI World Water and Climate Atlas

The IWMI World Water and Climate Atlas includes monthly and annual summaries for precipitation, temperature, humidity, hours of sunshine, evaporation estimates, wind speed, total days with and without rainfall, days without frost and Penman-Monteith reference evapotranspiration rates. The core of the Atlas is data assembled from weather stations around the world for the period 1961-1990.

More information:
http://www.iwmi.cgiar.org/WAtlas/atlas.htm

Data download:
http://www.iwmi.cgiar.org/WAtlas/Atlasreg.htm
(registration needed)

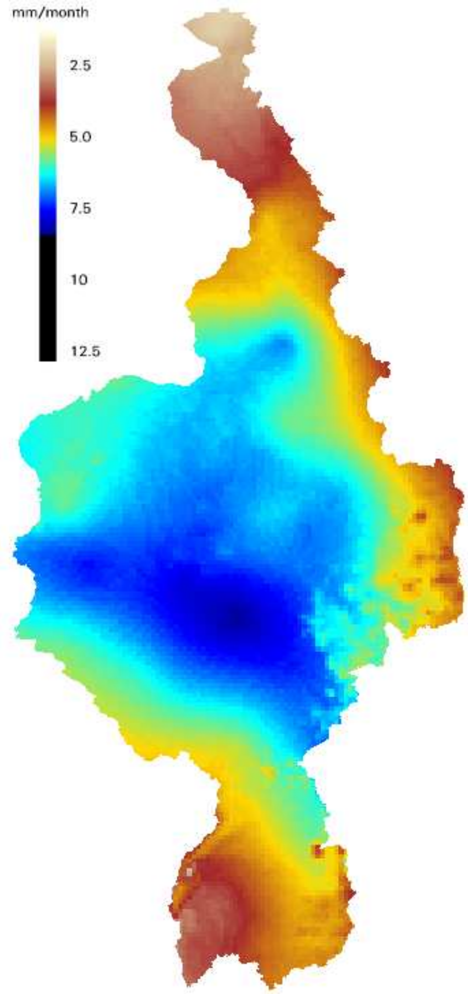
Data availability:
Monthly and annual averages, based on 1961-1990 period

Resolution:
Spatial -> 0.25 degree
Temporal -> monthly or annual (average)

Swath width:
Global coverage

Image information:

dTr	(daily temperature range [°C])
RH	(average relative humidity [%])
sunp	(sunshine [% of max hours])
Tavg	(average daily temperature [°C])
wnd	(average windspeed [m/s] at 10m)
frs	(days per month with ground frost)
p50	(mean monthly rainfall [mm])
rd0	(days per month with rainfall)
ETo_pm	(Penman-Monteith reference ET [mm/day])



Reference Evapotranspiration in January

NSIDC Soil Moisture Algorithm
based on AMSR-E (Njoku)

AMSR-E daily L3 surface moisture maps are will be archived and distributed by the Snow and Ice Distributed Active Archive (DAAC) at the National Snow and Ice Data Center. Daily soil moisture maps are generated on a nominal 25-km grid by time-compositing the level 2B parameters separately for ascending and descending passes.

More information:
http://www-nsidc.colorado.edu/data/amsre/

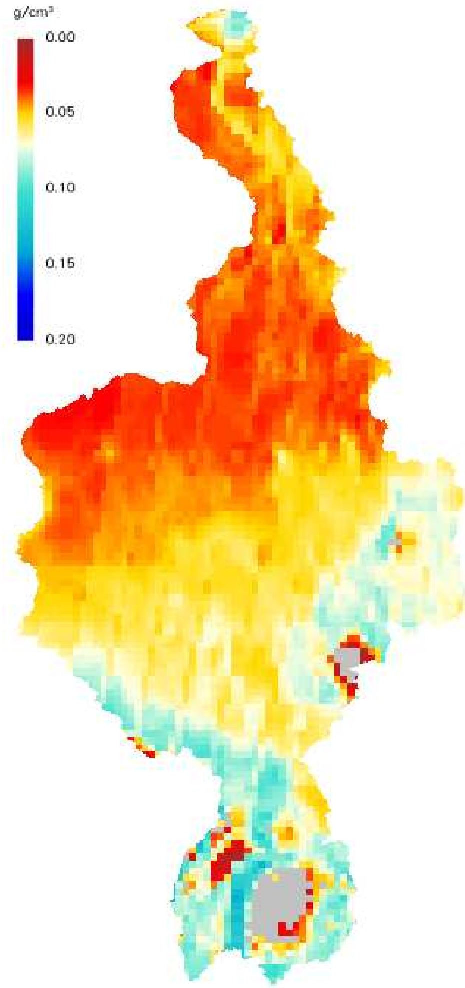
Data download:
http://www-nsidc.colorado.edu/~imswww/pub/imswelcome/index.html

Data availability:
Since May 4, 2002 until present.

Resolution:
Spatial -> 25-km grid
Temporal -> daily, weekly and monthly products

Swath width:

Image information:
Soil moisture at 10.7 GHz resolution. A value of -9999 indicates no retrieval due to bad Tb data in the retrieval channels, or screening by land surface classification. Divide data values by 1000 to obtain soil moisture in g/cm3. Range is 0 to 500. g/cm3 ~ cm3/cm3



Monthly soil moisture in January 2003

MODIS: surface reflectance

MOD09A1 (or MYD09A1 for Aqua):
MODIS/TERRA SURFACE REFLECTANCE 8-DAY L3 GLOBAL 500M SIN GRID V004

The MODIS Surface Reflectance products provide an estimate of the surface spectral reflectance as it would be measured at ground level in the absence of atmospheric scattering or absorption. Low-level data are corrected for atmospheric gases and aerosols, yielding a level-2 basis for several higher-order gridded level-2 (L2G) and level-3 products.

More information:
http://edcdaac.usgs.gov/modis/mod09a1v5.asp

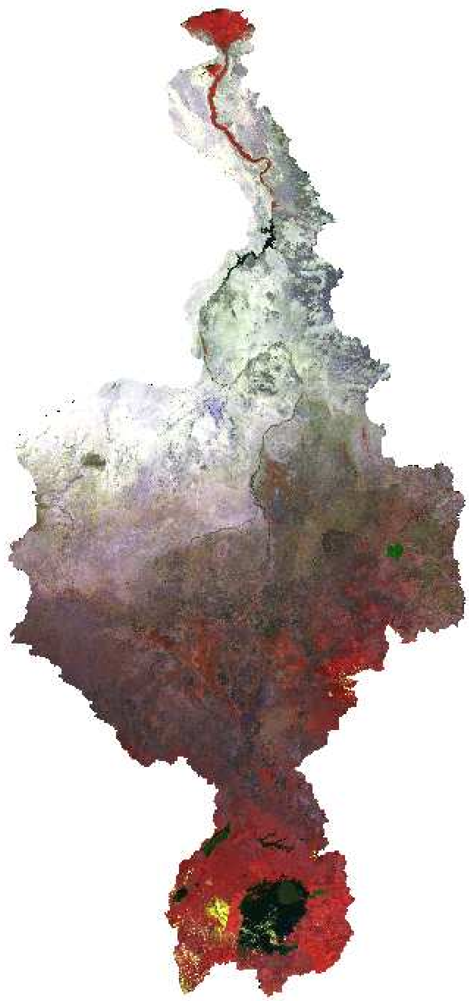
Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(available within 2/3 days)

Data availability:
MODIS -> December, 1999 (Terra)/May 4, 2002 (Aqua) – current

Resolution:
Temporal -> 8-day product (but daily available (1x Terra, 1x Aqua))
Spatial -> 500-m

Swath width:
2300 km at 110° (±55°) from 705 km altitude
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS = 13, signed 16bit integer (valid range: -100 : 16000)
Units: [-]
Scale factor: 0.0001
Fill value: -28672



8-day MODIS surface reflectance
RGB-217 - 9 January 2007

Band 1: 620-670 nm (red)
Band 2: 841-876 nm (NIR)
Band 3: 459-479 nm
Band 4: 545-565 nm
Band 5: 1230-1250 nm
Band 6: 1628-1652 nm
Band 7: 2105-2155 nm

MODIS: albedo

MCD43B3:
MODIS/TERRA-AQUA ALBEDO 16-DAY L3 GLOBAL 1KM SIN GRID V005

This is a combined product; both Terra and Aqua are used in its generation.

More information:
http://edcdaac.usgs.gov/modis/mcd43b3v5.asp

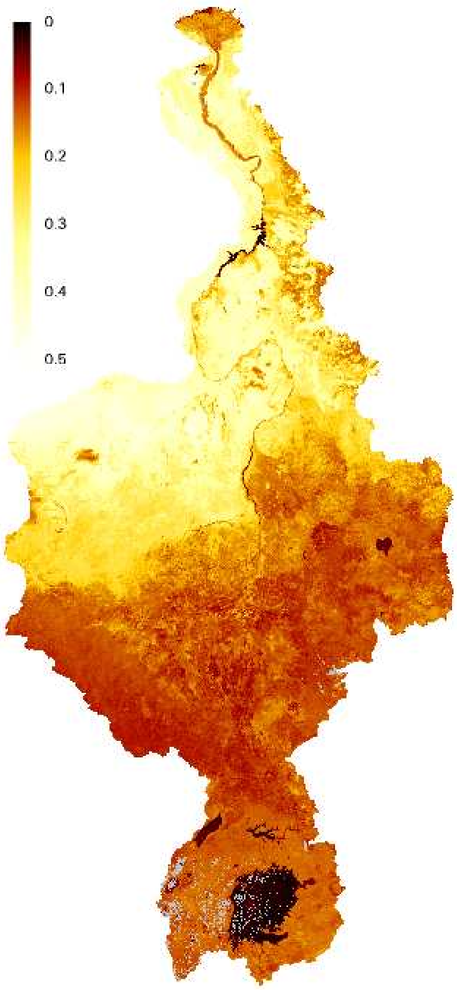
Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(available within hours/few days)

Data availability:
MODIS -> December, 1999 (Terra)/May 4, 2002 (Aqua) – current
MDC43B3 product -> from 2002 combined Terra/Aqua product, 2000 and 2001 Terra only

Resolution:
Temporal -> 16-day product (but daily albedo is also available (1x Terra, 1x Aqua)
Spatial -> 1-km and 500-m

Swath width:
2300 km at 110° (±55°) from 705 km altitude
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS=20, signed 16bit integer, data range 0-32766
Units: [-]
Scale factor: 0.0010
Fill value: 32767



16-day black sky albedo product
9 January 2007

Band 10: black sky shortwave albedo = directional-hemispherical reflectance = albedo in the absence of a diffuse component

Band 20: white sky shortwave albedo= bi-hemispherical reflectance = albedo in the absence of a direct component when the diffuse component is isotropic

To translate bsa and wsa to blue sky albedo (actual albedo), the MODIS team has created a actual albedo computation package:
http://www-modis.bu.edu/brdf/userguide/tools.html (does not work)

MODIS: NDVI

MOD13A2:
Vegetation Indices 16-Day L3 Global 1km

Also 250-m and 500-m products, as well as monthly vegetation indices products available.

More information:
http://edcdaac.usgs.gov/modis/mod13a2v5.asp

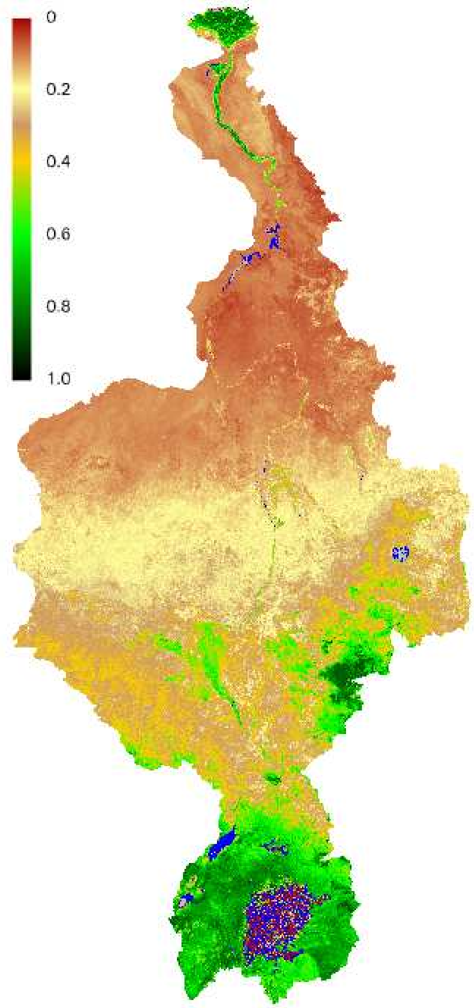
Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(available within hours/few days)

Data availability:
MODIS -> December, 1999 (Terra)/May 4, 2002 (Aqua) – current

Resolution:
Temporal -> 16-day product (but NDVI is daily available (1x Terra, 1x Aqua))
Spatial -> 1-km (or 250-m, or 500-m)

Swath width:
2300 km at 110° (±55°) from 705 km altitude
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS=11, signed 16bit integer, data range -2000 - 10000
Units: [-]
Scale factor: 10000
Fill value: -3000



16-day NDVI product
17 January 2007

Band 1: NDVI

SPOT Vegetation NDVI

SPOT Vegetation

More information:
http://www.spot-vegetation.com

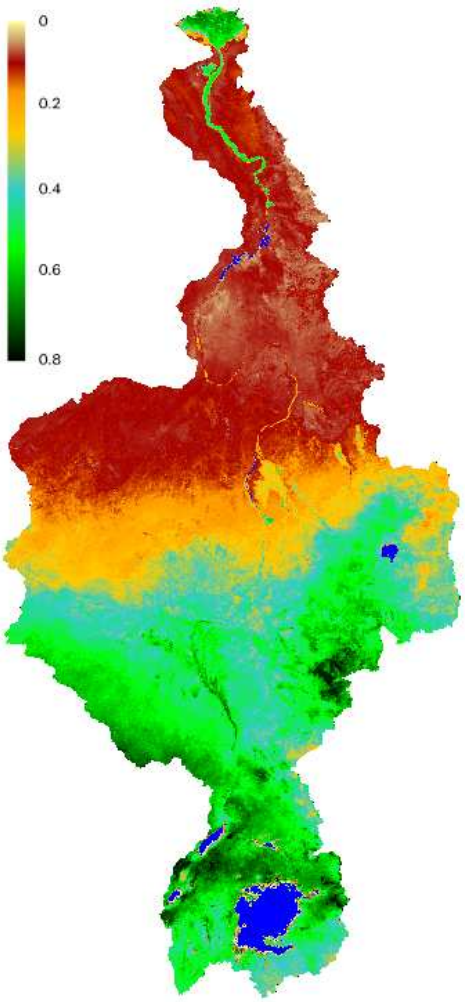
Data download:
http://free.vgt.vito.be/

Data availability:
Freely available 3 months after insertion in the Vegetation archive. Registration required.

Resolution:
Spatial -> 1-km
Temporal -> 10-day global syntheses

Swath width:
Global syntheses

Image information:
Real NDVI = 0.004 * DN – 0.1



GIMMS NDVI for the period 1-15 January 2003

GIMMS (Global Inventory Modeling and Mapping Studies)

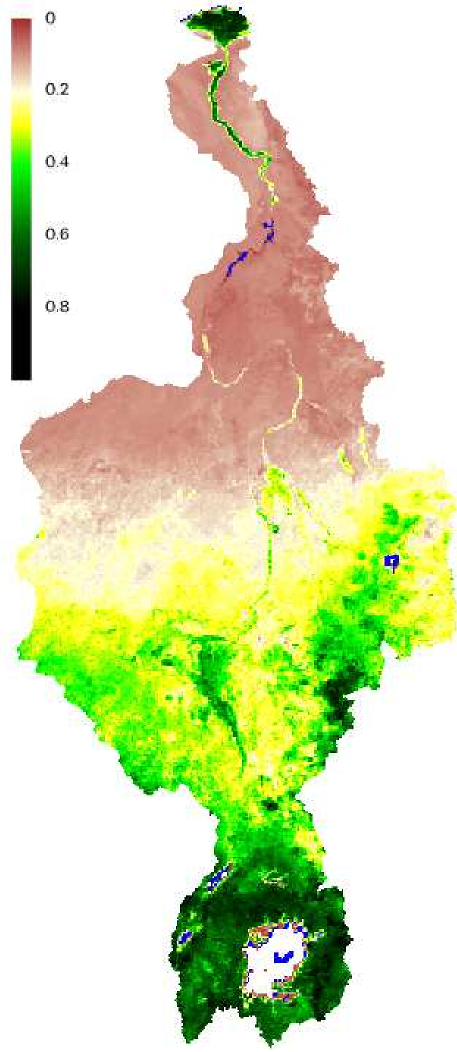
GIMMS is a NDVI product derived from imagery obtained from the Advanced Very High Resolution Radiometer (AVHRR) instrument onboard the NOAA satellite series 7, 9, 11, 14, and 16. This NDVI dataset has been corrected for calibration, view geometry, volcanic aerosols, and other effects not related to vegetation change.

More information:
http://glcf.umiacs.umd.edu/data/gimms/
Data download:
ftp://ftp.glcf.umiacs.umd.edu/glcf/GIMMS/

Data availability:
Available for a 22 year period spanning from 1981 to 2003. GIMMS is available in Albers projection (each continent a separate file) or in Geographic Coordinates (whole globe).

Resolution:
Spatial -> 8-km Albers Equal Area Conical projection using the Clarke 1866 ellipsoid
Temporal -> 2 15-day composites per month, the first for day 1-15, the second for day 16 to the end of the month.

Image information:
All the files are in integer, IEEE standard format (big endian), signed 16-bit.
To recover the -1 to 1 range of NDVI, use the formula NDVI = fix (raw/10000)/10.
NDVI values are multiplied by 10000, water pixels have a value of -10000 (-0.1), and -5000 (-0.05) are masked pixels, and missing are -2000 (-0.02) plus the flag 6.



GIMMS NDVI for the period 1-15 January 2003

MSG: Leaf Area Index

Leaf Area Index (LAI) product:
The LAI product is obtained directly from the cloud-free FVC (Factor of Vegetation Cover) product. The algorithm for retrieving LAI employs a semi-empirical exponential relationship with the FVC product. Although this relationship is unique for all biomes, the coefficients can be empirically fitted to different vegetation types.

More information:
http://landsaf.meteo.pt/algorithms.jsp;jsessionid=C0EE8963099941E395B62EC6441A4818?seltab=7
(Product User Manual PUM)

Data download:
http://landsaf.meteo.pt/
Registration needed

Data availability:

Resolution:
Temporal -> 10-day and monthly basis
Spatial ->

Swath width:
Four specific regions (Europe, N_Africa, S_Africa and South America)

MODIS: Net Primary Production

MOD17A3:
MODIS/TERRA Net Primary Production Yearly L4 Global1km SIN GRID

This is a beta product (V003).

More information:
http://edcdaac.usgs.gov/modis/mod17a3.asp

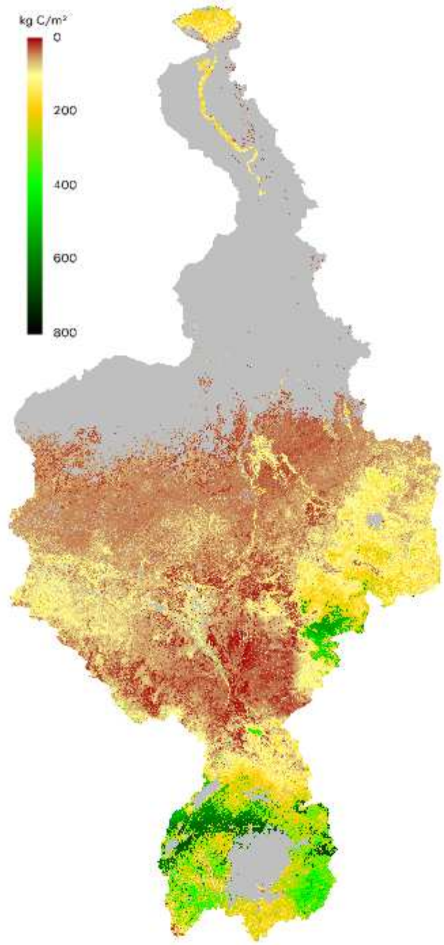
Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(available within hours/few days)

Data availability:
MODIS -> December, 1999 (Terra)/May 4, 2002 (Aqua) – current
MOD17A3 product -> from January 1, 2001 to December 31, 2002

Resolution:
Temporal -> yearly product
Spatial -> 1-km

Swath width:
2300 km at 110° (±55°) from 705 km altitude
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS=2, signed 16bit integer, data range -30000 - 32700
Units: [kgC/m2]
Scale factor: 0.0001
Fill value: 32767



8-day Net Primary Production product
9 January 2007 (grey = barren/sparse vegetated/ water)

MODIS: Net Photosynthesis

MOD17A2:
MODIS/Terra Net Photosynthesis 8-day L4 Global1km ISIN GRID

These products are still experimental in nature upon their initial release. Investigations are underway to assess the scientific validity of these products.

More information:
http://edcdaac.usgs.gov/modis/mod17a2.asp

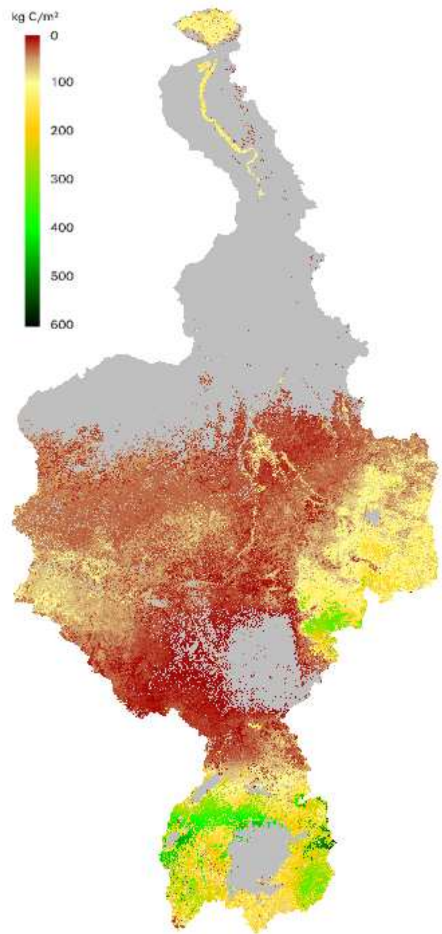
Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(available within hours/few days)

Data availability:
MODIS -> December, 1999 (Terra)/May 4, 2002 (Aqua) – current
MOD17A2 product -> August 29, 2002 (2002241) - October 7, 2002 (2002280

Resolution:
Temporal -> 8-day product
Spatial -> 1-km

Swath width:
2300 km at 110° (±55°) from 705 km altitude
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS=2, signed 16bit integer, data range 0 - 30000
Units: [kgC/m2]
Scale factor: 0.0001
Fill value: 32767



8-day Net Photosynthesis product
9 January 2007 (grey = barren/sparse vegetated/ water)

MODIS Gridded 1KM 8-day Composite GPP
MODIS Gridded 1KM 8-day Composite (GPP minus maint resp) as PsnNet

MODIS: Leaf Area Index (LAI) and fPAR

MOD15A2:
MODIS/TERRA (or Aqua) leaf area index/fpar 8-day L4 global 1km sin grid v005

There also exists a combined Terra/Aqua product (version 4).

fPar is the fraction of photosynthetically active radiation that is absorbed by the plant canopy. The LAI is the total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows.

More information:
http://edcdaac.usgs.gov/modis/mod15a2v5.asp

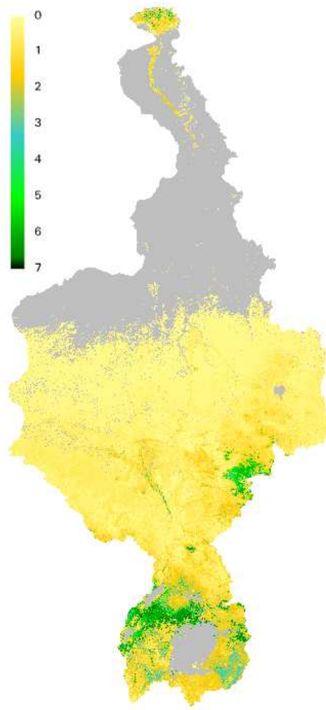
Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(available within hours/few days)

Data availability:
MODIS -> December, 1999 (Terra)/May 4, 2002 (Aqua) – current
Combined product: 2000 - current

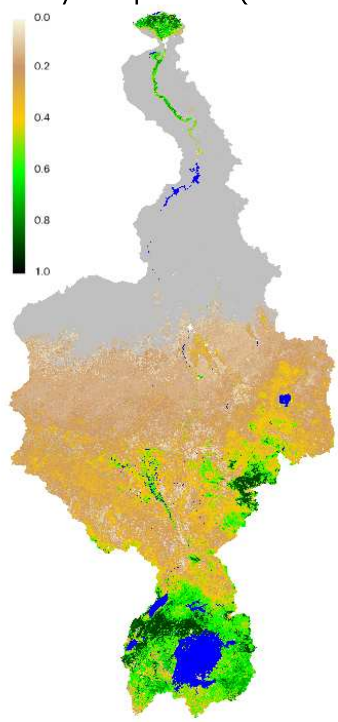
Resolution:
Temporal -> 8-day product (but LAI is daily available (1x Terra, 1x Aqua))
Spatial -> 1-km

Swath width:
2300 km at 110° (±55°) from 705 km altitude
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS=4, unsigned 8bit integer, data range 0-100
Units: [m2/m2]
Scale factor: 0.01
Fill value: 255



8-day LAI product (9 January 2007)



8-day fPAR product (9 January 2007)

Band 1: fPAR (in %, scale factor 0.01, fill value 255)
Band 2: Leaf Area Index

MODIS: surface temperature

MOD11A2:
MODIS/Terra Land Surface Temperature/ Emissivity 8-day L3 Global 1km SIN Grid V005

MOD11A1 is comprised of daytime and nighttime LSTs, quality assessment, observation times, view angles, clear sky coverage, and emissivities estimated in Bands 31 and 32 from land cover types.

More information:
http://edcdaac.usgs.gov/modis/mod11a1v5.asp

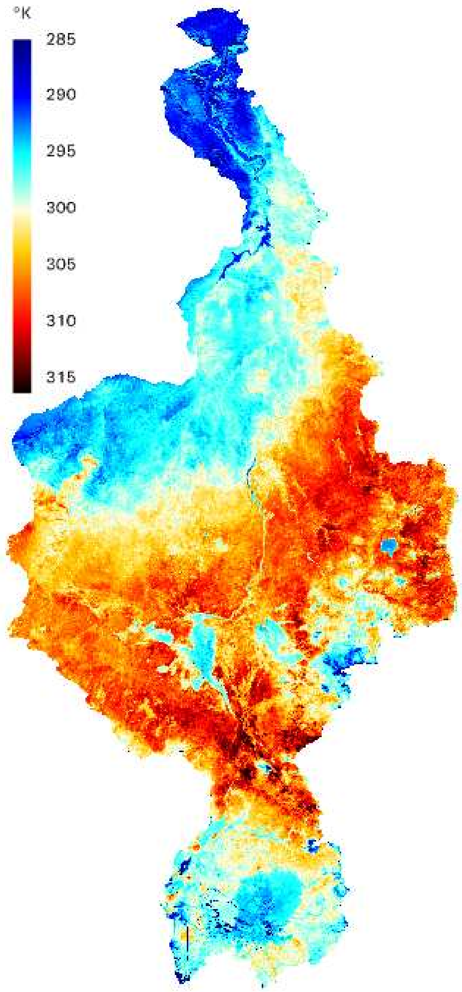
Data download:
http://edcimswww.cr.usgs.gov/pub/imswelcome/
(available within 2/3 days)

Data availability:
December 1999 - current

Resolution:
Temporal -> 8-day product (but daily temperature available (1x Terra, 1x Aqua))
Spatial -> 1-km

Swath width:
2300 km at 110° (±55°) from 705 km altitude
Global coverage

Image information:
MODIS Sinusoidal GRID projection
SDS = 13, unsigned 16bit integer, data range: 7500-65535
Units: [Kelvin]
Scale factor: 0.0200
Fill value: 0



daily MODIS surface temperature
9 January 2007

Band 1: LST_Day_1km (Daily daytime 1km grid land surface temperature

ECMWF atmospheric model outputs

MARS Food regularly receives daily, 10-daily and monthly outputs of the European Centre for Medium-Range Weather Forecast (ECMWF) atmospheric model. The original global data at 1 degree resolution are preprocessed by Meteoconsult and finally transformed into 0.5 degree grids.
Available parameters are:
Average, maximum and minimum temperature;
Precipitation sum;
Evapotranspiration sum (ES0 bare soil, E0 over water, ET_0 Penman-Monteith);
Global radiation sum;
Average, minimum and maximum snow depth;
Climatic water balance.

More information:
http://mars.jrc.it/marsfood/ecmwf.htm

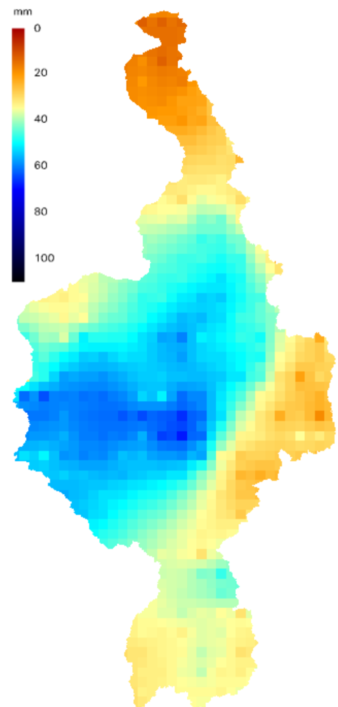
Data download:
http://marsfood.jrc.it/meteo/frameview.phtml?&winwidth=960&winheight=610&language=0&displaytype=multidate
(available within 2/3 days)

Data availability:
The prototype version makes available data from January 1989 until now. A time series for more than 40 years however exists.

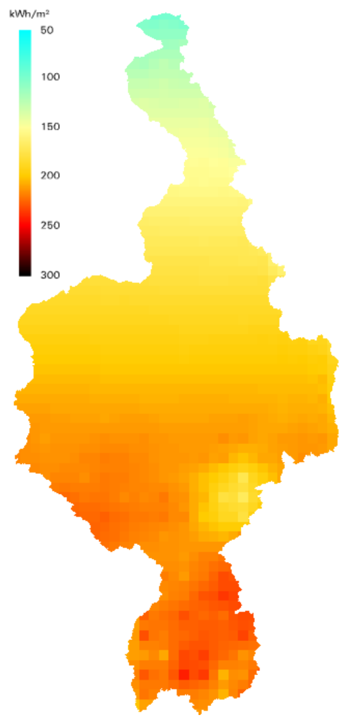
Resolution:
Temporal -> 10-day product available on internet
Spatial -> 0.5-degree (50 km)

Swath width:
Global coverage

Image information:
Available as GeoTIFF in Geographic projection.



Penman-Monteith ET_0 (mm/decade) in the first decade of January 2007



Global radiation (kWh/m2) in the first decade of January 2007

al Reservoir and Lake Monitor

The USDA-FAS , NASA and University of Maryland collaborate in the routine monitoring of lake and reservoir height variations for approx. 100 lakes located around the world. Near-real time radar altimeter data from the Poseidon instrument (onboard Jason, in the past onboard TOPEX) are utilized.

More information:
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/index.cfm

Data download:
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/index.cfm

Data availability:
Products should be delivered within 7-10 days after satellite overpass.

Resolution:
Accuracy -> the time series of height variations are expected to be accurate to better than 10cm rms.
Temporal -> 10-day repeat orbits, available since September 1992.

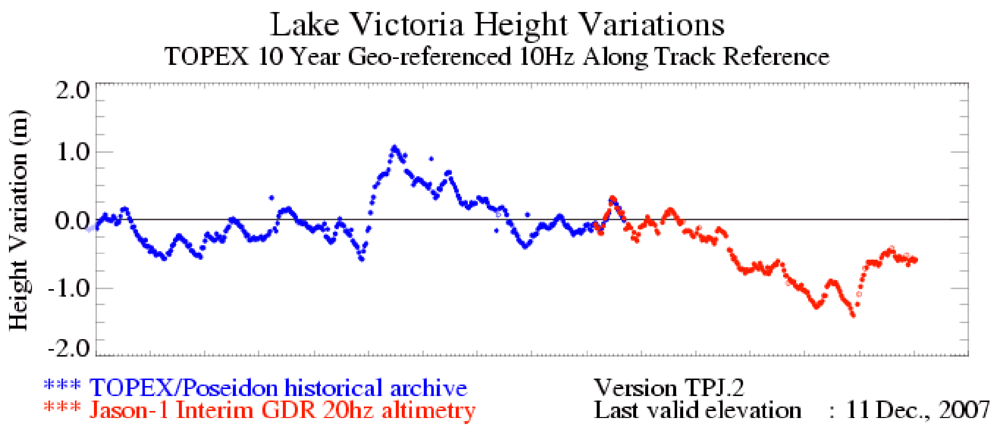
Swath width:
Available for 100 lakes located around the world

Image information:
No image

YYYYMMDD	lake height variation with respect to 10-year mean level
20070108	-0.71
20070118	-0.7
20070128	-0.62
20070207	-0.64
20070217	-0.62
20070227	-0.62
20070308	-0.65
20070318	-0.62
20070328	-0.63
20070407	-0.67

Lake height measurements of Lake Victoria

Import instructions:
Lake levels are presented graphically and in a table.



Appendix 6 Partially Accessible Portals

'all from the LCRS

The Laboratory for Climatology and Remote Sensing (LCRS) aims to develop a reliable methodology for the spatial estimation of rainfall which is based on remotely sensed data (space born and ground based). Rain retrieval is based on passive optical systems (e.g. Meteosat, Goes) as well as active microwave sensors (Weather RADAR, TRMM).

More information:

Data download:
http://lcrs.geographie.uni-marburg.de/index.php?id=31

Data availability:

Resolution:
Spatial ->
Temporal ->

Swath width:

Image information:

MSG Rainfall 21-30 November 2007

AFWA/WMO Precipitation

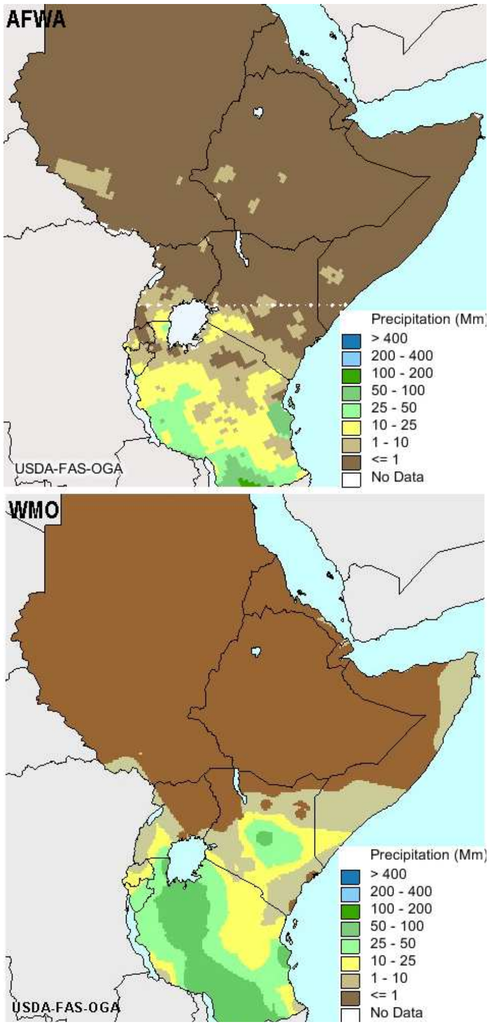
Air Force Weather Agency (AFWA) daily precipitation is estimated by blending four different data sources together: Special Sensor Microwave/Imager (SSM/I) satellite, geostationary satellite such as GOES, Meteosat and GMS, Real Time Nephanalysis Cloud Model (RTNEPH) and WMO ground station data. Decadal precipitation is then calculated for each grid cell by adding the ten daily precipitation records.
WMO precipitation are generated by Inverse Distance Weighting interpolation method, based on daily ground station data from the World Meteorological Organization's (WMO) Global Telecommunication System (GTS).Approximately 2800 stations report each day, and decadal precipitation is calculated by adding the ten daily precipitation records and eliminating any station that reported eight days or less.

More information:
AFWA:
http://www.pecad.fas.usda.gov/cropexplorer/description.cfm?legendid=1&regionid=eafrica&data_type=afwa
WMO:
http://www.pecad.fas.usda.gov/cropexplorer/description.cfm?legendid=1&regionid=eafrica&data_type=wmo

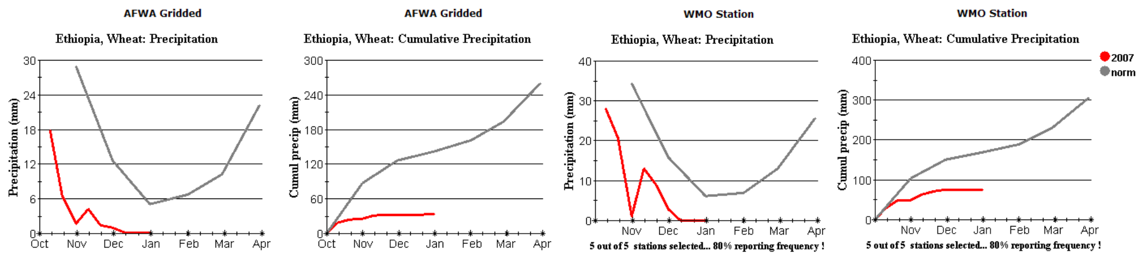
Data download:
http://www.pecad.fas.usda.gov/cropexplorer/imageview.cfm?regionid=eafrica
Click on the maps to see charts of actual precipitation compared to normal data by sub-region.

Data availability:
Updates regularly (about every two weeks?)

Resolution:
Spatial -> charts for sub-regions
Temporal -> decadal



AFWA & WMO decadal precipitation from 21 to 31 December 2007



An example of the available charts for a sub-region: precipitation and cumulative precipitation for the Ethiopia wheat region.

Microwave Surface and Precipitation Products System (MSPPS)

MSPPS project is dedicated to the retrieval of near-real-time operational surface and precipitation products using antenna temperatures from the AMSU-A and AMSU-B/MHS instruments on board of NOAA's KLMNN' series and the EUMETSAT Polar System's (EPS) MetOp series polar-orbiting satellites. This project has advanced from 5 products at its Day-1 phase to 9 products at the Day-2 phase. The current Day-2 MSPPS products include: rain rate and falling snow, total precipitable water, cloud liquid water, snow cover, snow water equivalent, sea ice concentration, ice water path, emissivity (23.8 GHz, 31.4 GHz, and 50.3 GHz), and land surface temperature . The MSPPS geophysical products depicted on this web site are Day-2 products undergoing extensive validation. The algorithms are also under continuing development.

period 1-15 January 2003

More information:
http://www.orbit.nesdis.noaa.gov/corp/scsb/mspps/algorithms.html#ARR

Data download:
http://www.orbit.nesdis.noaa.gov/corp/scsb/mspps/main.html

Data availability:

Resolution:
Spatial ->
Temporal -> 10

Swath width:

Image information:
MSPPS Level-2 and Level-3 data are stored in the HDF-EOS format.

NOAA/NESDIS Experimental Products

This page provides 24-hour rainfall rate estimates for areas covered by the Meteosat-9, Meteosat-7, and MTSAT-1 satellites. Rain rates were estimated from cloud-top temperatures and AVN model data using algorithms which, to date, have only been calibrated over the continental United States. The first eight characters of each file name shows the year, month, day, and time for the observation; estimated rainfall is for the 24 hours prior to that time. No archive for this data currently exists, and we do not have data prior to what is on this page.

More information:

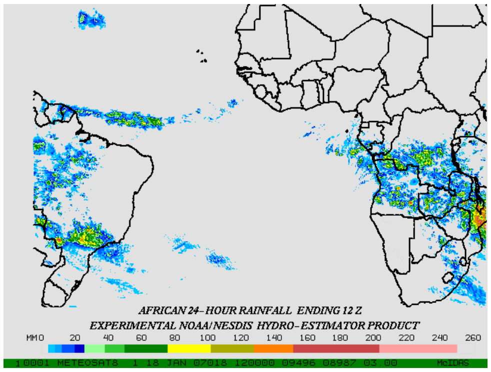
Data download:
http://www.orbit.nesdis.noaa.gov/smcd/emb/ff/world.html

Data availability:

Resolution:
Spatial ->
Temporal ->

Swath width:

Image information:



African 24-hour rainfall 18 January 2007

TAMSAT Tropical Applications of
Meteorology using SATellite and other data

A routine product of TAMSAT is the ten-daily, Meteosat-derived rainfall estimate for seasonally arid areas of Africa, based on the recognition of storm clouds in the thermal infra-red imagery. It assumes that cold cloud duration is linearly related to rainfall, and this linear relationship is found from historical raingauge data.

More information:
http://www.met.reading.ac.uk/~tamsat/data_sel/data_descrip/

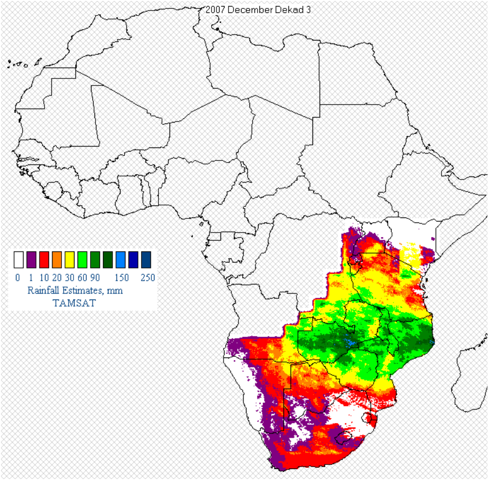
Data download:
http://www.met.reading.ac.uk/~tamsat/cgi-bin/data_sel.cgi

Data availability:
An estimate is given every 10 days, since 1996 (since 1988 for northern Africa, but those years are not available on the internet)

Resolution:
Spatial ->
Temporal -> Decadal and monthly

Swath width:
Product is produced for Africa

Image information:



Latest rainfall estimate (3rd decade of December 2007) (hashed areas show where is no calibration)

ASCAT soil moisture

Global soil moisture data are derived from backscatter measurements acquired with scatterometers onboard the satellites ERS-1 and ERS 2 and the two MetOp satellites. Level 2 products represent the soil moisture content within a thin soil surface layer (<2 cm) during the time of satellite overflight. Level 3 products represent the water content in the soil profile, regularly sampled in space and time.

More information:
http://www.ipf.tuwien.ac.at/radar/index.php?go=ascat

Data download:
http://www.ipf.tuwien.ac.at/radar/index.php?go=data

Data availability:
Data available for scientific purposes only, on request, since 1991 to present.

Resolution:
Spatial -> 25-50 km
Temporal ->

Swath width: global product

Image information:
Level 2 soil moisture data area scaled between 0 (zero soil moisture) and 1 (saturation). No retrieval over tropical forest.
Level 3 soil moisture products are obtained by a modeling approach using the ASCAT level 2 and other data sources as input. A standard level 3 product is the Soil Water Index.

period 1-15 January 2003

Soil Moisture for Hydrometeorologic Applications in the SADC region (SHARE)

SHARE is one of ESA's DUE Tiger projects, and aims at enabling an operational soil moisture monitoring. It uses data delivered from ENVISAT's ASAR sensor operated in global mode and the METOP scatterometer sensors. Currently three products are available: coarse resolution soil moisture (derived from backscatter measurements with scatterometers on-board the ERS-1 and ERS-2 and the three METOP satellites), a scaling layer which allow interpretation of the coarse resolution soil moisture at 1 km resolution and an experimental high resolution soil moisture product (based on ENVISAT ASAR Global Mode data).

More information:
http://www.ipf.tuwien.ac.at/radar/share/

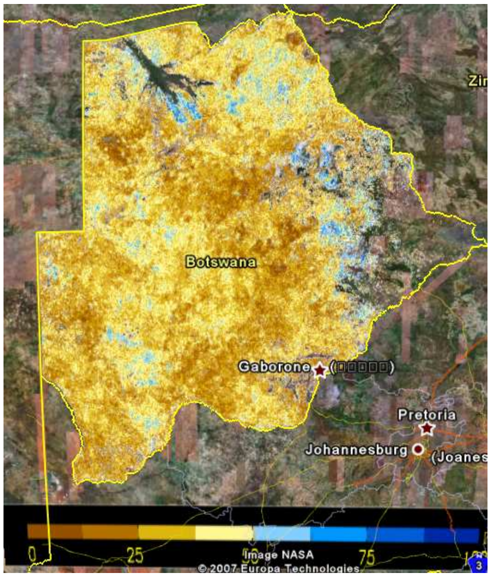
Data download:
http://www.ipf.tuwien.ac.at/radar/share/index.php?go=data&c=&Y=&M=

Data availability:
January 2005- December 2006 (experimental) and 1991- present (coarse resolution)
Image views available in Google Earth. Data available for scientific purposes only, on request: http://www.ipf.tuwien.ac.at/radar/share/index.php?go=archive.

Resolution:
Spatial -> 1-km (experimental) and 25-50 km
Temporal -> weekly (experimental)

Swath width:
Product available for the region of the Southern Africa Development Community (SADC).

Image information:
The experimental High Resolution Soil Moisture represent soil moisture in upper most soil layer (< 5 cm). Global coarse-resolution soil moisture data represent soil moisture within a thin soil surface layer (< 3 cm) during the time of overflight.



Monthly soil moisture in Botswana in December 2006

VUA Land surface Temperature (LST)
and Soil Moisture

The VUA-NASA Land Surface Parameters constitute a global database of Surface Soil Moisture, Land Surface Temperature and Vegetation Water Content.
The parameters are derived from passive microwave remote sensing data, using the Land Parameter Retrieval Model (LPRM). The dataset covers the period of 1978 to present and has a 2-3 day revisit time at the equator for both day and night time overpasses.
The LPRM is based on a forward radiative transfer model to retrieve surface soil moisture and vegetation optical depth. The land surface temperature is derived separately from Ka-band. A unique feature of this method is that it may be applied at any microwave frequency, making it very suitable to exploit all the available passive microwave data from historic satellites (see table below).

period 1-15 January 2003

More information:
http://www.geo.vu.nl/~jeur/lprm/

Data download:

Data availability:
The entire VUA-NASA retrieval products are available upon request, but will be available on a map server in the very near future. TRMM LST and soil moisture is available from 1998 to 2007.

Resolution:
Spatial ->
Temporal ->

Swath width:
global product

Image information:
Soil moisture is expressed in volume %.

Available Products

Satellite	Years	Product
SMMR	1978 to 1987	LST, Soil moisture (C and X-band), Vegetation Optical Depth (C and X-band),
SSM/I	1987 to 2004	LST, Soil moisture (Ku-band), Vegetation Optical Depth (Ku-band),
TRMM-TMI	1998 to 2007	LST, Soil moisture (X-band), Vegetation Optical Depth (X-band),
AMSR-E	June 2002 to present	LST, Soil moisture (C and X-band), Vegetation Optical Depth (C and X-band),

AFWA and WMO Percent Soil Moisture

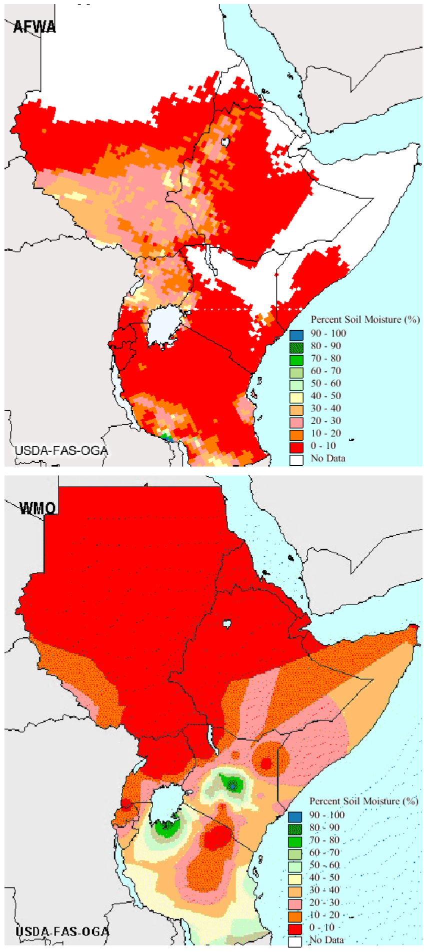
Available water is calculated by the modified Palmer two-layer soil moisture model which accounts for the daily amount of water withdrawn by evapotranspiration and replenished by precipitation. Air Force Weather Agency (AFWA) daily precipitation is estimated by blending four different data sources together: Special Sensor Microwave/Imager (SSM/I) satellite, geostationary satellite such as GOES, Meteosat and GMS, Real Time Nephanalysis Cloud Model (RTNEPH) and WMO ground station data. Decadal precipitation is then calculated for each grid cell by adding the ten daily precipitation records.
WMO precipitation are generated by Inverse Distance Weighting interpolation method, based on daily ground station data from the World Meteorological Organization's (WMO) Global Telecommunication System (GTS).Approximately 2800 stations report each day, and decadal precipitation is calculated by adding the ten daily precipitation records and eliminating any station that reported eight days or less.

More information:
AFWA:
http://www.pecad.fas.usda.gov/cropexplorer/description.cfm?legendid=40&regionid=eafrica&data_type=afwa
WMO:
http://www.pecad.fas.usda.gov/cropexplorer/description.cfm?legendid=40&regionid=eafrica&data_type=wmo

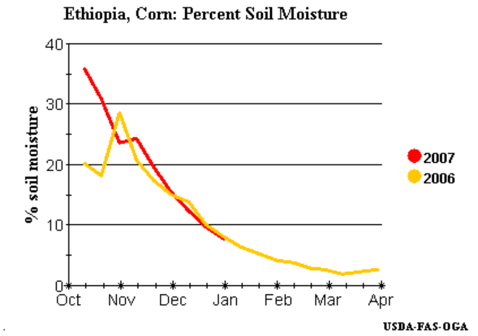
Data download:
http://www.pecad.fas.usda.gov/cropexplorer/imageview.cfm?regionid=eafrica
Click on the maps to see charts of actual precipitation compared to normal data by sub-region.

Data availability:
Updated regularly (around every two weeks).

Image information:
Percent soil moisture is the available water for the plant divided by the total water holding capacity of the soil profile.



Soil Moisture 21-31 December 2007



Soil Moisture in the Corn region of Ethiopia

Famine Early Warning Systems (FEWS) Network: Water Requirements Satisfaction Index (WRSI)

Maps portray WRSI values for particular crops from the start of the growing season until this time period. It is based on the actual estimates of meteorological data to-date. The water requirement satisfaction index (WRSI) is an indicator of crop performance based on the availability of water to the crop during a growing season.

WRSI for a season is based on the water supply and demand a crop experiences during a growing season. It is calculated as the ratio of seasonal actual evapotranspiration to the seasonal crop water requirement.

For example, if the cumulative crop water requirement up to this period was 200 mm and only 180 mm was supplied in the form of rainfall, the crop experienced a deficit of 20 mm during the period and thus the WRSI value will be ([180 / 200] * 100 = 90.0%).

More information:
http://www.fews.net/imagery/?pageID=imageryWrsi

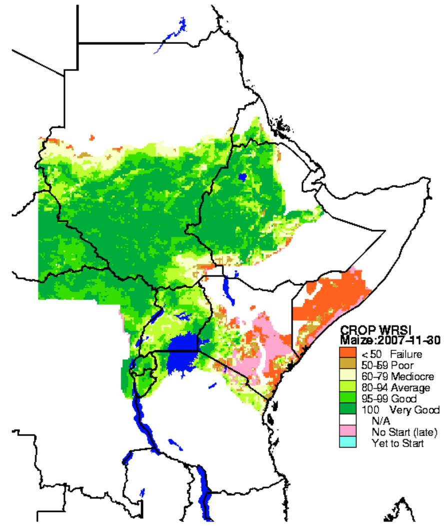
Data download:
http://earlywarning.usgs.gov/adds/index.php?img1=mi&extent=af

Data availability:

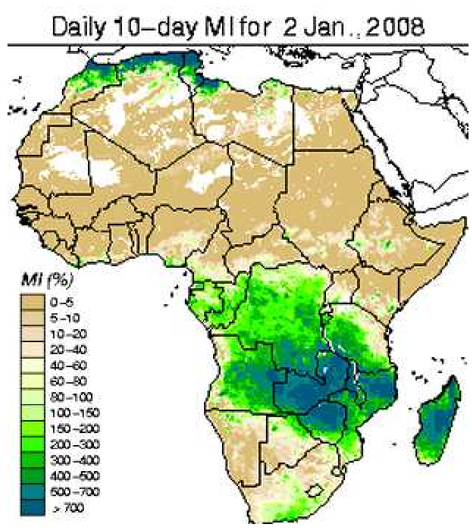
Resolution:
Spatial ->
Temporal ->

Swath width:

Image information:



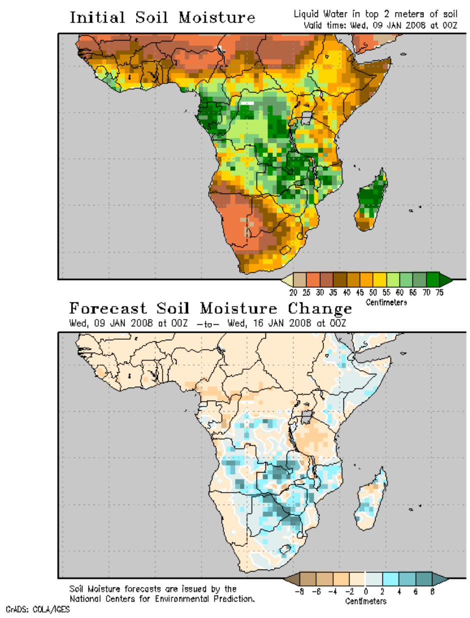
WRSI image for Maize, dated 30 November 2007



10-day Moisture Index

Short-Term Climate Outlooks:
Temperature, Precipitation and Soil Moisture

The Center for Ocean-Land-Atmosphere Studies (COLA) produces short-term climate outlooks:
The climate outlook for temperature shows the 0-7 day and 8-15 day means plus the departure of the first 7-day mean from the CRU 100-yr climatology.
The climate outlook for precipitation shows the 0-7 day and 8-15 day accumulations plus the departure of the first 7-day accumulation from the CMAP 25-yr climatology.
The climate outlook for soil moisture shows the current analysis and the forecasted change over the next 7 days.



WRSI image, dated 9 November 2007

More information:
http://wxmaps.org/pix/clim.html

Data download:
http://wxmaps.org/pix/clim.html

Data availability:

Resolution:
Spatial ->
Temporal ->

Swath width:

Image information:

MSG: Leaf Area Index

Leaf Area Index (LAI) product:
The LAI product is obtained directly from the cloud-free FVC (Factor of Vegetation Cover) product. The algorithm for retrieving LAI employs a semi-empirical exponential relationship with the FVC product. Although this relationship is unique for all biomes, the coefficients can be empirically fitted to different vegetation types.

More information:
http://landsaf.meteo.pt/algorithms.jsp;jsessionid=C0EE8963099941E395B62EC6441A4818?seltab=7
(Product User Manual PUM)

Data download:
http://landsaf.meteo.pt/
Registration needed (approval within 3 days)

Data availability:
Europe, Africa and South America

Resolution:
Temporal -> daily (in future also 10-daily and monthly products available)
Spatial -> 1-3 km

Swath width:
Four specific regions (Europe, N_Africa, S_Africa and South America)

Image information:

MSG: land surface temperature

Land Surface Temperature LST:
LST is the radiative skin temperature over land. The retrieval of LST is based on clear-sky measurements from MSG system in the thermal infrared window. Theoretically LST values can be determined 96 times per day, but in practice cloud cover reduces this number of observations.

More information:
http://landsaf.meteo.pt/algorithms.jsp;jsessionid=C0EE8963099941E395B62EC6441A4818?seltab=0
(Product User Manual PUM)

Data download:
http://landsaf.meteo.pt/
Registration needed (approval within 3 days)

Data availability:
Europe, Africa and South America

Resolution:
Temporal -> every 15-minutes
Spatial ->

Swath width:
Four specific regions (Europe, N_Africa, S_Africa and South America)

EARS MSG products: Evapotranspiration

Daily and decade products of surface and air temperature, surface albedo, global and net radiation, sensible heat flux, actual and potential evapotranspiration and rainfall based on MSG satellite data

More information:
http://www.ears.nl/africanowcast.php

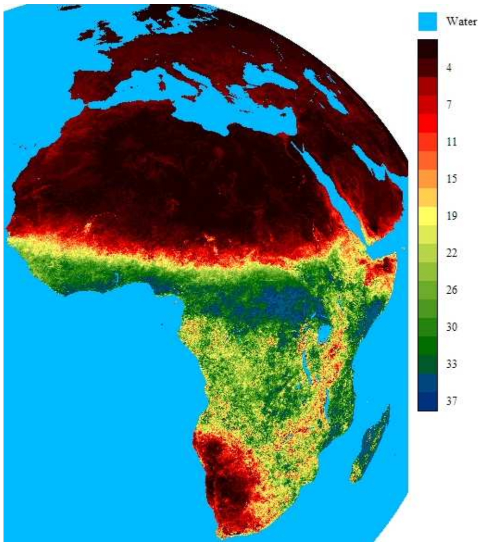
Data download:
http://www.ears.nl/evapotranspiration_field.php

Data availability:
Air temperature, net radiation, evapotranspiration and rainfall products available for latest decade in Google Earth. Products may be created for the past 10 years on request.

Resolution:
Spatial -> 0.025 degree resolution
Temporal -> daily and decadal

Swath width:
Africa cover

Image information:
Images usually resampled to lat-long, coded as generic binary.
Latest decade available in Google Earth



MSG Evapotranspiration 21-30 November 2007

MSG: transmissivity

Down-welling Surface Short-wave Radiation Flux: The DSSF product is generated with a temporal frequency of 30 minutes at the full spatial resolution of the MSG/SEVIRI instrument. It is based on the three short-wave MSG/SEVIRI channels (VIS, NIR, SWIR). Furthermore information on cloud cover, dynamic information on the atmospheric water vapour content and climatologic values are used. Transmissivity is a product generated during the generation of DSSF.

More information:
http://landsaf.meteo.pt/algorithms.jsp?seltab=1
(Product User Manual PUM)

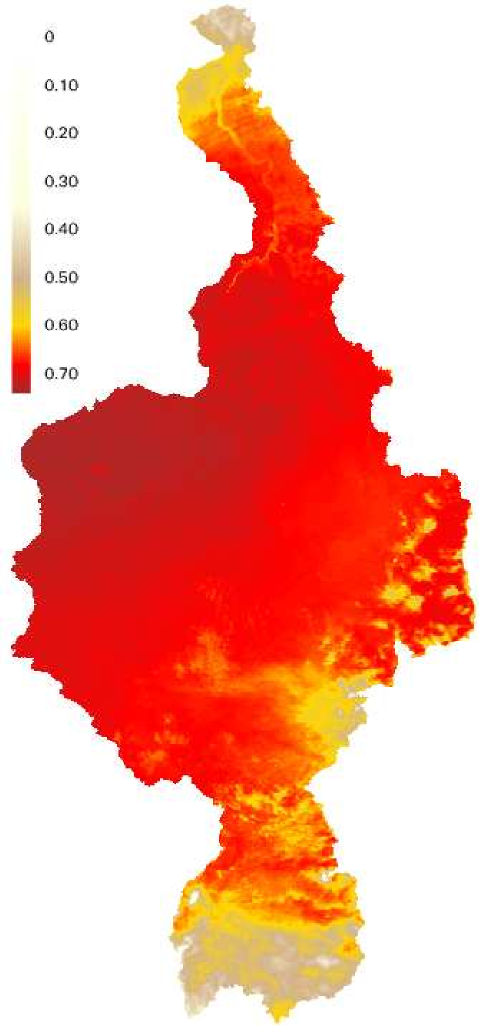
Data download:
http://landsaf.meteo.pt/
Registration needed

Data availability:

Resolution:
Temporal ->
Spatial ->

Swath width:
Four specific regions (Europe, N_Africa, S_Africa and South America)

Image information:



Average transmissivity 1-8 January 2007