THE NARMA-GEOLAND2 E-STATION: AN EARTH OBSERVATION BASED DECISION SUPPORT SYSTEM TOOL FOR REAL TIME ENVIRONMENTAL MONITORING IN AFRICA

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ABSTRACT:
Natural Resource Monitoring in Africa (NARMA) is one of the Core Information Services of EU-FP7 project Geoland2 addressing important sectoral policies that concerns with the development of an environmental monitoring capacity over African countries for the needs of the European Commission (EC) services and for regional and continental EC partners in African countries. The overall project include the installation of more than fifty dedicated systems in the African continent for the acquisition and processing of Earth Observation data. The system is constituted by the e-Station, a computer processing chain plugged behind an EumetCast receiving station. The e-Station is developed for data management, i.e. organization and re-formatting of the data received at the station, data post processing according to NARMA procedures, data visualization (web based technology) and participatory reporting (web based technology). The whole system is developed on Open Source solutions, and entirely programmed in script language. The key objective of the system is to provide an easily maintainable and expandable solution for automated and systematic processing. The e-Station is organized in such a way that data remain accessible for other technical solutions, for the development and prototyping of new applications using any software, and for the feeding of external operational applications, e.g. models. The paper shows the organization of the entire system and an example application for the western Africa regions.

1. INTRODUCTION

According to the recent IPCC 4th Assessment Report developing countries are particularly vulnerable to the ongoing and projected climate changes, and Africa, due to its weak adaptive capacity, is likely to be the most vulnerable (Boko et al., 2007).

The population of the African continent was over 880 million in 2005, with a growth rate of 2-4%, twice the global mean. The growing population, with a projection to double in the next twenty years, will exacerbate existing problems and impacts on food production, safe water provision, and natural-resource-based livelihoods.

Climate exerts a significant control on the day-to-day economic development of Africa, particularly for the agricultural and water-resources sectors, at regional and local scales. Africa's climate high variability manifests in climate extremes such as droughts and floods, both products of extreme precipitation events. Droughts and floods have increased in frequency and severity over the past 30 years.

Drought is one of the major environmental problems, that adversely affects the lives of a large number of people, causing considerable damage to economies, the environment, and livelihoods. In many African countries that have a subsistence lifestyle, the impact of drought usually extends to famine, particularly when crops and rangeland depend mostly on rainy season.

The devastating drought in the Sahel during the 70s and the 80s is among the most undisputed and largest recent climate event recognized by the research community (Govaerts and Lattanzio, 2008). Between the early 1970s and the mid 1990s the African Sahel experienced one of the most dramatic long-term changes in climate observed anywhere in the world in the twentieth century, with rainfall declining on average by more than twenty per cent (Hulme et al., 2001). This reduction has been much more moderate in regions other than the Sahel. This period of climatic desiccation was associated with a number of very severe droughts, most notably in the early 1970s and 1980s, during which hundreds of thousands of people and millions of animals died (Glantz, 1996).

Early warning of drought and monitoring of the natural environmental resources are crucial components of famine mitigation plans. In sub-Saharan Africa there is a lack of information about drought because the weather station network is limited and rainfall data are often not available early enough to enable timely drought detection and impact assessment.

In order to improve the lives and prospects of the 350 million disadvantaged people in Africa currently enduring poverty and hardship, and whose livelihoods depend heavily on their environment, a common initiative of the European Commission and the African Union Commission has been established. The AMESD (African Monitoring of the Environment for Sustainable Development) is an international initiative of the European Commission and the African Union Commission supported through the 9th EDF Intra-ACP funds and the 9th EDF Regional Indicative Programs.

AMESD initiative takes the Preparation for Use of MSG in Africa (PUMA) project a stage further by extending the operational use of Earth observation technologies and data to environmental and climate monitoring applications. It will also be the precursor of the extension of Europe's Global Monitoring of the Environment and Security (GMES) initiative to Africa.

In the frame of GMES, the joint initiative of EC and ESA, the EU-FP7 project Geoland2 intends to constitute a major step forward in the implementation of the Land Monitoring Core Service (LMCS). The focus for Geoland2 is to build services by designing, integrating, and testing operational processing lines

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and to demonstrate robust provider-user relationships for large scale products.

Natural Resource Monitoring in Africa (NARMA) is one of the Core Information Services (CIS) of Geoland2 addressing important sectoral policies that concerns with the development of an environmental monitoring capacity over African countries for the needs of the EC services and for regional and continental EC partners in African countries. The overall project include the installation of more than fifty dedicated systems in the African continent for the acquisition and processing of Earth Observation data.

Both AMESD and NARMA projects have the objective of providing all the African nations with the capabilities to manage their natural resources and ensure long term sustainable development.

2. AFRICAN MONITORING NEEDS

African countries decision-makers in national governments and regional organizations need ready-to-use information on environment on which to base appropriate policy responses. Dynamic information on the location, condition and evolution of environmental resources is needed for Europe (both the EU and its Member States) to properly define, target, deliver and evaluate its development aid strategies and programs.

In the frame of previous EU-FP6 project Geoland, the Observatory on Land cover and Forest change (OLF) has defined and developed an innovative approach for mapping anomalies in the environmental status, i.e. vegetation cover, at continental scale in Africa (Stroppiana et al, 2009).

In the new framework, due to the near real time characteristics for monitoring natural resources the objectives were targeted more towards regional and local user needs.

Five Thematic Areas were identified within AMESD and NARMA as priority to be implemented by Regional Implementation Centres (RICs) one for each Regional Economic Communities (RECs) (Fig 1):

- ECOWAS (Economic Community of West African States) through the RIC Agrhymet in Niamey has the priority of water management for cropland and rangeland
- CEMAC (Communauté Economique et Monétaire des Etats d'Afrique Centrale) through the RIC CICOS (International Commission for Congo-Oubangui-Sangha Basin) in Kinshasa has the priority of environmental aspects of watersheds for water resource management
- IGAD (Inter Governmental Authority on Development) through the RIC RCMRD (Regional Centre for Mapping of Resources for Development) and ICPAC (IGAD Climate Prediction and Applications Centre) in Nairobi has the priority of land degradation mitigation and natural habitat conservation
- SADC (Southern African Development Community) through the RIC BDMS (Botswana Department of Meteorological Services) in Gaborone has the priority of agricultural and environmental resources management
- IOC (Indian Ocean Commission) through the RIC MOI (Mauritius Oceanography Institute) in Quatre-Bornes - Mauritius has the priority of coastal and marine management

The environmental monitoring system is based on satellite observation of the continent, providing information on the natural environment on a regular time basis distributed to African countries through the EumetCast system. Data, products and information are made available automatically to each PUMA station users.

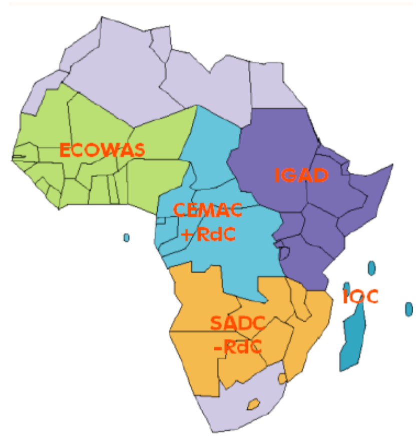

Figure 1. AMESD thematic areas and regional centres

3. THE NARMA E-STATION

The name e-Station stands for 'environmental Station'. It is an automatic and independent system, which in first place collects Earth Observation data, i.e. from the EUMETCast ingests them (transforms the original file format into a unique file format) and performs some processing including the computation of environmental indicators. The e-Station is strongly oriented to run standardised processing chains. This means that it does not replace the desktop software users are used to, such as the freeware ILWIS, which are more relevant for ad-hoc processing. A desktop application would better read information from the e-station, just like any local hard drive on personal PC.

3.1 Concept and functionalities

The role of the E-Station is to assist the thematic expert in the writing of their environmental reports. Ideally, the thematic expert work has to be decoupled from the data processing (formats extractions, formats changes, re-projection, data combinations, repositories management, data bases feeding, etc.) in order to save the man-hours for interpretation and communication.

The main input of these reports is remotely sensed data, acquired either by Meteosat Second Generation (MSG) and SPOT/VEGETATION and local information collected by the expert. The idea that triggered the development of an e-Station is that the technical burden (data collecting, data processing, archive management, product standardization) is generally too heavy and sometime too specialized for a regular time basis bulletin.

Basically, the e-Station performs three main different functionalities:

- **Get** Earth Observation data from EUMETCast and, optionally, from other sources.
- **Ingest** the whole or a subset of these data, i.e. convert them to a 'common' format and copy the results to an appropriate location.
- **Derive** from the 'ingested' data some products/indicators, which can be simply a temporal synthesis or more complex environmental indicators.

The e-Station is programmed in such a way that it tries generating information in the best delay (as soon as possible), retries if some piece of input information was missing, checks that the data storage is not critically filled, offers auto cleaning of old information, etc.

Figure 2 shows a scheme of the e-station. The system ingests data from a receiving station and allows to produce report facilitating data analysis and visualization. The e-station is constituted by two component, the Processing server and EMMA station.

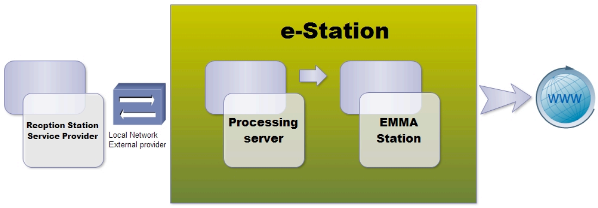

Figure 2. Overview of the e-Station

The Processing Server of the e-Station is in charge with the processing and archiving of EO data, it offers almost automatic maintenance of the system, makes available a pre-configured reporting tool, so that User time can be fully dedicated to discuss environmental issues.
To visualise the data stored on the e-station, the system offers EMMA (Environment Monitoring and Mapping for Africa), a web-browser based application, allowing to display the information stored in the system and to write environmental reports on a collaborative way. EMMA is also designed for providing standards in term of reporting, such as pre-defined regions of interest or predefined colours ramps. It is a tool for a team mandated to deliver on time environmental information to its administration. Figure 3 show an example of the EMMA browser visualization.

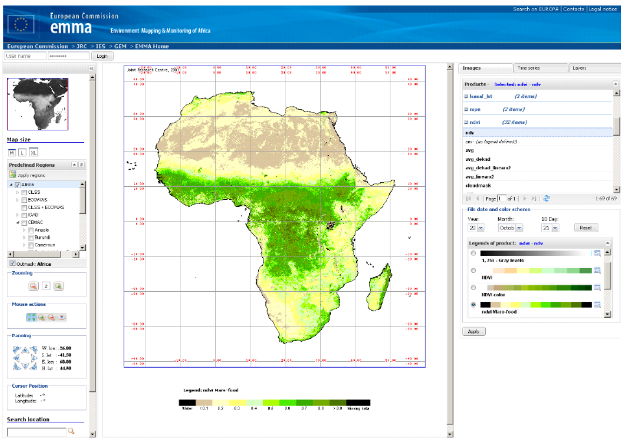

Figure 3. Visualization browser of the e-Station

3.2 Delivering information

NARMA provides to African users (RECs / RICs) through EUMETCast and e-Station different typology of product with increasing level of information.
Basic products are represented by satellite pre-processed data, such as NDVI time series derived from SPOT/Vegetation (S10), Land Surface Temperature (LST) from Meteosat Second Generation (MSG) data. Additional source of EO data are represented by MODIS data. Main part of these data (Table 1) comes from the experience of VGT4Africa project (http://www.vgt4africa.org/).

From those input products, environmental indicator are derived from the analysis of time series of satellite data to provide the users (RICs) with updated information on natural resources (Table 2). Finally a third level of information is foreseen through the calculation of integrated indicators. Recently, it has become clear that no single indicator or index is adequate for monitoring environmental anomalies on a regional scale (Stroppiana et al., 2009); instead, a combination of monitoring tools integrated together is preferable for producing regional or national maps (Martini et al., 2005). These data are produced from the integration of multi-source indicators through different approaches to be defined with user consensus.

Product	**Name**	**Availability**
Vegetation index	NDVI	1998 - Now
Water index	NDWI	1998 - Now
Dry Matter Productivity	DMP	1998 - Now
Vegetation Productivity	VPI	1998 - Now
Water Body seasonality	SWB	Jul 1999 - Now
Phenology	PHENO	Jul 2007 - Now
Leaf Area Index	LAI	Jul 2007- Now
Green Cover Fraction	fCover	Jul 2007- Now
Albedo	BBDHR	Jul 2007- Now

Table 1. Data available from VGT4Africa experience.

3.2.1 Satellite products and pre-processing: The received data are first reformatted into a unique standard: geotif + internal compression (LZW) 1 km resolution. The spatial extension can be full Africa or one of the regional centers. The Meteosat derived data are broadcasted either in Meteosat specific format for SEVIRI data (Landsaf data are disseminated in HDF5).
SPOT/Vegetation NDVI is generated with a maximum value composite (maximum NDVI on 10-days); nevertheless, some noise in the data can be found in some regions, especially Gulf of Guinea and central forests of Africa. For this reason, three methods are considered for correcting noise along the time series:

- apply a linear filtering removing a drop in the time series
- use MSG NDVI time series to correct the Spot/VGT time series (curve fitting)
- , replace pixel time series with MSG time series (Sarr and Lacaze, 2008) if VGT NDVI quality is too bad.

To complete the time series filtering, it is recommended to produce a map of reference quality. Time series quality is considered with respect to the noise in NDVI value in particular in relation to some areas that are particularly affected by cloud/atmospheric contamination. The aim of quality analysis is to identify geographic areas with persistent problems in order to mask that out or to indicate them as not reliable for NDVI use (Boschetti et al., 2009).

3.2.2 Indicators: Statistical values of basic products like NDVI or LST time series are required by indicator computation. Minimum and maximum are used to compare actual NDVI to a long term reference or to interpret the observation rescaling it on the pixel NDVI values possible excursion. Minimum and maximum are computed with different criteria in relation to the meaning that those values assume in the various indicators formula. For example, a value can be compared to the absolute minimum that the specific dekad presented in the data (see VCI below) or to phenological meaningful minimum value related to vegetation growth (see NGI below).
Average, median and standard deviation are also computed for the S10/NDVI time series. They are computed for the overall archive, and also for each dekad of the year. These statistical estimators are most of the time used in input of other products and integrated indicators.
The environmental indicators (Table 2) are derived from the analysis of the SPOT/VGT and MSG time series and aim to provide information on natural resources dynamics. These indicators are a qualitative proxy of ecosystem conditions and production and are not intended as quantitative measures of processes.

Environmental indicators description	
Standardized NDVI	sNDVI
Vegetation Condition Index	VCI
Normalized Growth Index	NGI
vegetation productivity index	VPI
fractional cover	fCover
Land surface temperature, daily & 10-day	LST
Temperature condition index	TCI
Vegetation Health Index	VHI
Surface water monitoring and its synthesis	SWB

Table 2. Example of defined integrated indicators.

As an example we describe the first three indicators (sNDVI, VCI and NGI) actually used by ECOWAS to produce bulletins on agricultural and pastureland (see next paragraph).
- *Standardized NDVI* (sNDVI) indicator provides information on current standardized gain or loss of vegetation with respect to the dekad average. It is computed as follows:

$$sNDVI = (NDVI_{dek} - NDVI_{avedek}) / \sigma_{dek} \quad (1)$$

where $NDVI_{dek}$ = NDVI value of the current dekad
$NDVI_{avedek}$ = average NDVI value of the dekad within the time series
σ_{dek} = standard deviation of NDVI value of the dekad within the time series

Positive values means the current dekad is above the average, negative is below. It can be directly interpreted in term of gain or loss. Rescaling to the standard deviation gives the order of magnitude.
- *Vegetation Condition Index* (VCI) indicator is suitable for describing spatial variations of vegetation conditions (Fig. 4). It is computed as follows (Liu and Kogan, 1996):

$$VCI = (NDVI_{dek} - NDVI_{min\,dek}) / (NDVI_{max\,dek} - NDVI_{min\,dek}) \quad (2)$$

where $NDVI_{dek}$ = NDVI value of the current dekad
$NDVI_{mindek,\ maxdek}$ = minimum and maximum value of the NDVI value of that dekad within the time series

Dekad minimum and maximum are computed per dekad, from the beginning of the archive to the year before. In consequence, during the current season, one can have negative value, indicating NDVI below observations up to last year or positive value, indicating NDVI above observations up to last year.

- *Normalized Growth Index* (NGI) indicator provides information of actual vegetation conditions with respect to the expected growth. It is computed as follows:

$$NGI = (NDVI_{dek} - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) \quad (3)$$

where $NDVI_{dek}$ = NDVI value of the current dekad
$NDVI_{min,\ max}$ = minimum and maximum value of the NDVI value within the time series

It is particularly useful for comparing temporal profiles (Fig. 5)

4. ECOWAS CASE STUDY

The Agrhymet Regional Implementation Center of the ECOWAS region has to report on seasonal condition for all the countries of the CILSS and of the Gulf of Guinea. Main objective identified by AMESD concerns with crops and pasture lands monitoring to produce, since July, qualitative information on areas where drought could bring to significant loss in crop and biomass production and comparison to cattle needs.
In Sahelo-Sudanian zone rainfall is concentrated between June and September, and presents a spatial and temporal variability that results in local or general dry spells that may affect crops and rangeland production. Population lives in rural areas and his economy depends on crop and pasture production, so early identification and localization of drought affected areas is crucial to ensure population food security.
Various drought indices have been developed and used in many parts of the world (including Africa) to monitor the spatial extent and severity of drought conditions. Generally, drought indices, like SPI – Standardized Precipitation Index (McKee et al., 1993), are developed based on cumulative precipitation deficit. A significant drawback of climate-based drought indicators is their lack of spatial detail. In addition, meteorologically based indices are dependent on data collected at weather stations, that in Africa have very sparsely distribution. Recent advances in operational space technology have improved our ability to address many issues of early drought warning and monitoring efficiency.
One of the most popular methods is based on the NDVI. Despite the potential application of the NDVI, numerous shortcomings have also been revealed. For heterogeneous land cover, the NDVI is normally higher in areas with more favourable climate and soil and more productive ecosystems (forest) than in areas with less favourable environmental conditions (dry steppe). To reflect the ecosystem's features and to separate the weather signal from the ecological signal, the NDVI was modified into the VCI-Vegetation Condition Index (Unganai and Kogan, 1998).

NDVI has been used successfully to identify stressed and damaged crops and pastures but interpretative problems can arise when these results are extrapolated over non-homogeneous areas. Thus, the application of the NDVI for spatial vegetation analysis, especially for the assessment of weather impacts on vegetation in non-homogeneous areas, requires stratifying the NDVI values to eliminate the differences in vegetation related to specific environmental and economic conditions (Kogan, 1990). To overcome this limitation, it was suggested that NDVI values should be estimated relative to their historical values.

4.1 An application example for the year 2009

Figure 4 shows the seasonal evolution of the NGI for the Senegal and part of Mauritania and Mali. The maps indicate the response of the vegetation to the precipitation occurring between the month of June and beginning of August. The growth of vegetation is evident in the south-western part of Mali and in the Casamance region of Senegal.
It is possible to observe that an area of values lower in the pastureland region at the border between Senegal and Mauritania.

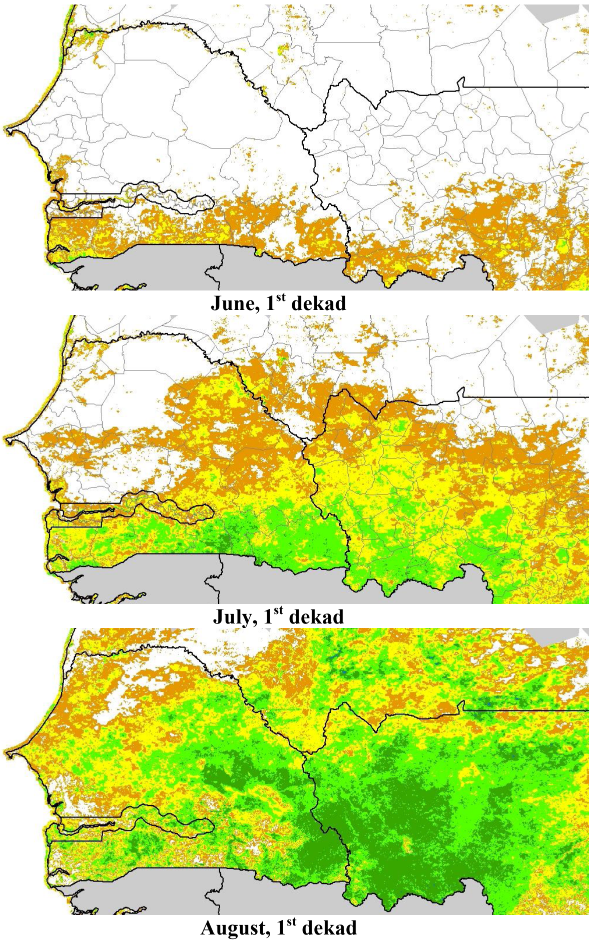

Figure 4. Maps of the seasonal evolution of NGI in 2009

In figure 5 we show the temporal profile of the NGI indicator for two areas one in Mali and the second in Burkina Faso. Blu and yellow lines in the graph shows the maximum and the average value of NGI. The situation of current season is presented in magenta. Fig. 5a highlights an area where there is a 2-3 dekad delay in the vegetation development, while Fig. 5b refers to an area where the response of the vegetation to the climatic year is better than its average.

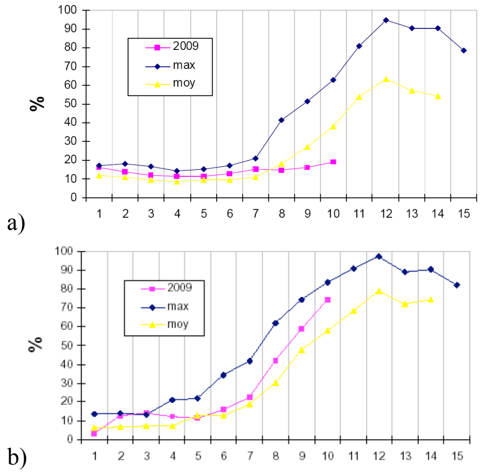

Figure 5. Profiles of the NGI indicator from May to September.

5. DISCUSSION AND CONCLUSION

In the frame of international initiative and programmes AMESD and NARMA (EU FP7 Geoland-2) a system has been developed and implemented with the objective of providing all the African nations with the capabilities to manage their natural resources and ensure long term sustainable development.
The timely provision of information on the conditions and status of the natural resources, mainly vegetation cover and its development, is a crucial element for the stake holder that have the responsibilities of managing the environment and of responding to the needs of the populations exploiting natural resources in this environment.
The characteristics of the e-Station, that is connected to the PUMA satellite receiving stations in all the sub-Saharan Africa nations, allows to further extend the operational use of Earth Observation technologies and data to environmental and climate monitoring applications.
The application example of the ECOWAS appears very appealing and opens new possibilities to the different regions and thematic areas of the entire African continent also considering the climate change scenarios and their possible impact on populations.

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