SERVIR-Africa – Using GIS to Respond To Floods Distress Calls

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Abstract:

SERVIR-Africa is an ambitious regional visualization and monitoring system that integrates remotely sensed data with predictive models and field-based data to monitor ecological processes and respond to disasters. It aims to address a wide range of thematic areas that are important to the people of our region and their environment, turning data into actionable information for decision-makers. Floods are a form of disasters that commonly plague Africa, probably second only in impact to drought. This paper demonstrates the use of ESRI's ArcGIS products in an integrated platform to support flood disaster prediction and monitoring. The process starts with the identification of flood potential and flooded areas using satellite data and models. These are combined with field-based data collection and analysis of the socio-economic and ecological conditions of the area, and result in the dissemination of synthesized information products to aid in disaster response.

Key Words: Floods, Flood Model, Post-event Flood Mapping, Flood Potential, Flood Monitoring

Introduction:

Floods present major natural disasters that constantly afflict eastern and central Africa during the rainy seasons. The region has bi-modal annual rainfall seasons with the first rain season in March to May and the second season coming in September to November. However, variability and shifts in rain seasons have become so common with the seasons not just beginning earlier or later than expected, but also getting either prolonged or shorter than usual. The El Nino effect is also known to complicate matters for the region with the associated heavier than usual rains as experienced during November-January of 1997/1998 and 2009/2010 years. Whether the variability can be attributed to climate change or not is subject of another research. Shortened or absence of expected rain season has often resulted to drought that decimate social and economic livelihoods of the people characterized by famine and death of livestock. Intermittent floods and droughts have become the way of life in the region. It's for these reasons and more, collectively referred here as societal needs as identified by GEOSS that SERVIR-Africa was established

SERVIR-Africa Background

SERVIR-Africa is a regional visualization and monitoring system that fosters use of earth observations, field based data and predictive models for ecological processes monitoring and response to natural disasters for timely decision making to benefit society. SERVIR was initiated in Panama in 2003, focusing on Mesoamerica with seed funds from USAID. The effort intensively utilizes and integrates NASA satellite observations and predictive models, along with other geographic information (satellite, sensor, and field-based) to monitor and forecast ecological changes (e.g., land cover change) and respond to natural disasters such as extreme weather events, forest fires, floods, and volcanic eruptions. As a result of its successes, the model was replicated in Africa, giving rise to the third SERVIR node that would address similar issues in Africa. The African node was launched in November 2008 in Nairobi (Kenya) at Regional Centre for Mapping of Resources for Development (RCMRD). Formed in 1975 under the auspices of United Nations Economic Commission for Africa, RCMRD is a centre of excellence fostering the use of geo-information for sustainable development with membership drawn from East, Central and Southern Africa, see figure 1.

Figure 1 RCMRD's Contracting and Non-Contracting Member States.

SERVIR-Africa leverages existing initiatives in Africa (FEWS-NET, TIGER, AMESD, BIOTA, DEPHA, UNSDI-EA, etc.), taking advantage of RCMRD established regional training facility for geospatial technologies, its rich experience in analysis & geospatial product development in multiple areas, the Existing Portals, Systems and Networks and USAID's historical mapping projects in East Africa that can be incorporated into the SERVIR platform.

SERVIR-Africa Platform/System

SERVIR is an integrated platform for SERVIR-developed products and products of others addressing GEOSS nine societal benefit/application areas. These are Disasters, Health, Energy, Climate, Water, Weather, Ecosystems, Agriculture and Biodiversity. The vision for GEOSS is to realize a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information. Sound management of the Earth system, in both its natural and human aspects, requires information that is timely, of known quality, long-term, and global. Ensuring that such information is available to those who need it is a function of governments and institutions at all levels.

The SERVIR-Africa platform includes a web portal and geodata portal designed to facilitates exchange of data and information through information search and discovery, increase quality and accessibility of information, earth observation data and models, 3d visualization and other decision-support tools, geospatial web service hosting, national and regional training/capacity building, and support in the context of the international charter for space and major disasters. Figure 2a and 2b shows a user and a system perspective of the platform respectively:

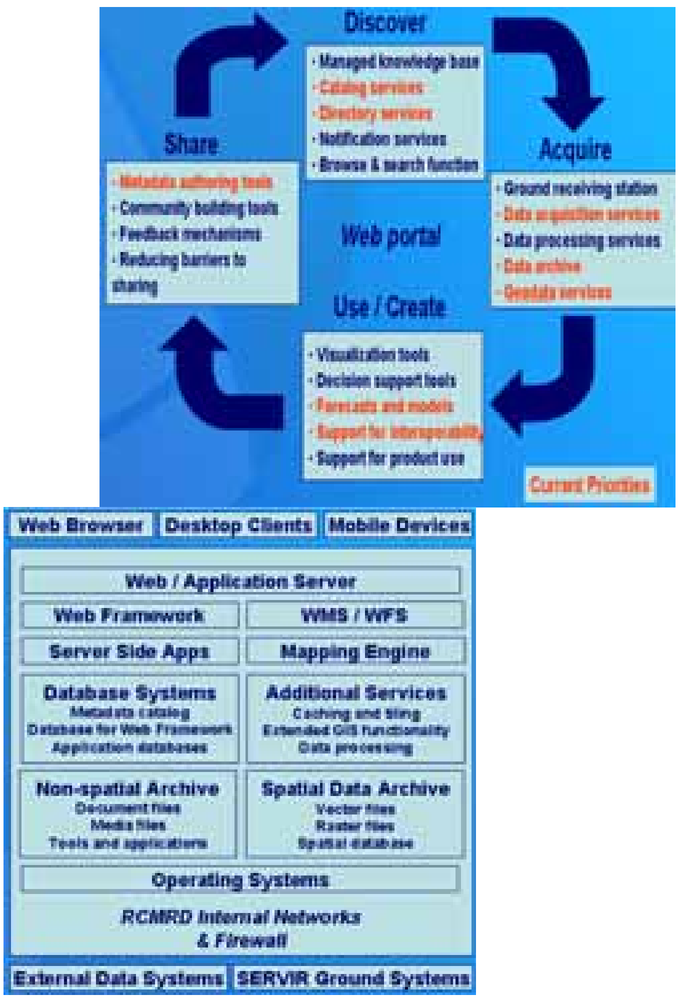

Figure 2 SERVIR-Africa (a) User and (b) System Perspective.

The SERVIR-Africa system architecture combines both two- and three-tier design. ESRI products forms the backbone of the system at the moment operating ArcGIS

9.3.1 Desktop with ArcSDE connection to Microsoft® SQL ServerTM relational database and an application server to handle requests from external clients as shown in Figures 3 and 4 below.

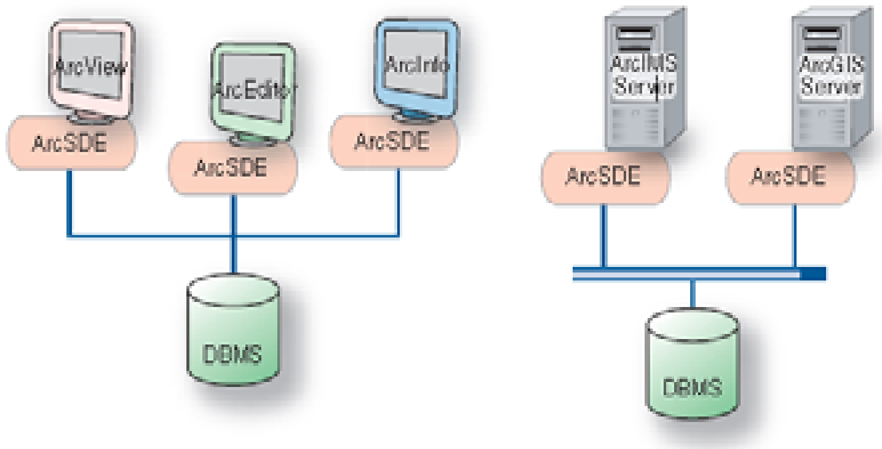

Figure 3 SERVIR-Africa System Architecture Design

In this architecture, enterprise ArcSDE geodatabases helps to leverage the organization's enterprise relational databases. The ArcSDE server handles simultaneous requests from multiple users to update and retrieve information in the multi-user geodatabases as shown in figures 5.

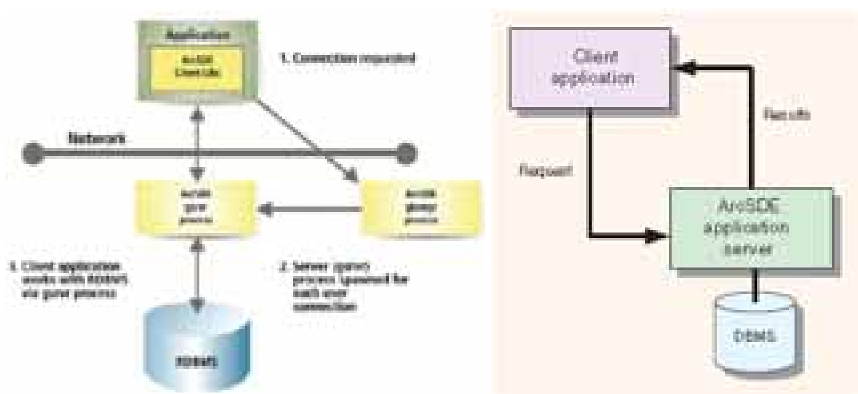

Figure 4 ArcSDE Handling of Client Requests

Natural Disasters In The Region

Major disasters in the Eastern and Southern Africa region are drought, flooding, epidemics, windstorm. Of these 95% of hazards are caused by drought and flooding, See the figure 5. Drought and flooding are responsible for 70% of life and 75% of economic losses. Flooding is the second major disaster in the region. The net effect on social-economic structures and infrastructure can be debilitating to the communities affected, not to mention the loss of human life, loss of livelihoods and displacement. Figure 6 below paints a realistic picture of what floods really are.

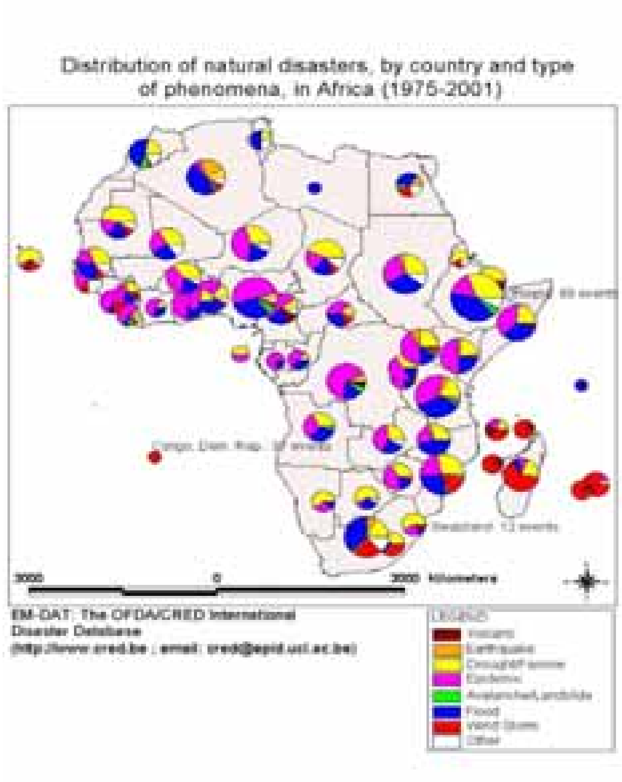

Figure 5 Distribution of Natural Disasters in Africa.

Figure 6 Floods disasters.

Globally Floods and associated landslides account for the largest number of natural disasters and affect more people than any other type of natural disaster. With the availability of satellite rainfall analyses at fine time and space resolution, it has also become possible to mitigate such hazards on a near-global basis through forecasts and prediction.The predictability lead time varies from minutes (flash flood) to weeks (stream flood). The key variables that need to be indicated in the prediction of flooding are the timing (when), the geographical area (where) and water level, and velocity. All of these indicators are monitored both from satellite and ground observations. SERVIR's approach to floods disaster mitigation in the region is three-pronged. These are flood potential monitoring, flood nowcasts & forecasts, and post-event flood mapping.

SERVIR's Flood Models

(1) Global Hazard Model – Flood (GHM- Flood)

For the SERVIR Africa flooding application, the key enabling NASA research result is the Goddard Space Flight Center (GSFC) Global Hazard Model – Flood (GHM- Flood), which uses as input data[1], the TRMM-based Multi-satellite Precipitation Analysis (TMPA) precipitation product- TRMM 3B-42 (Fig. 7),

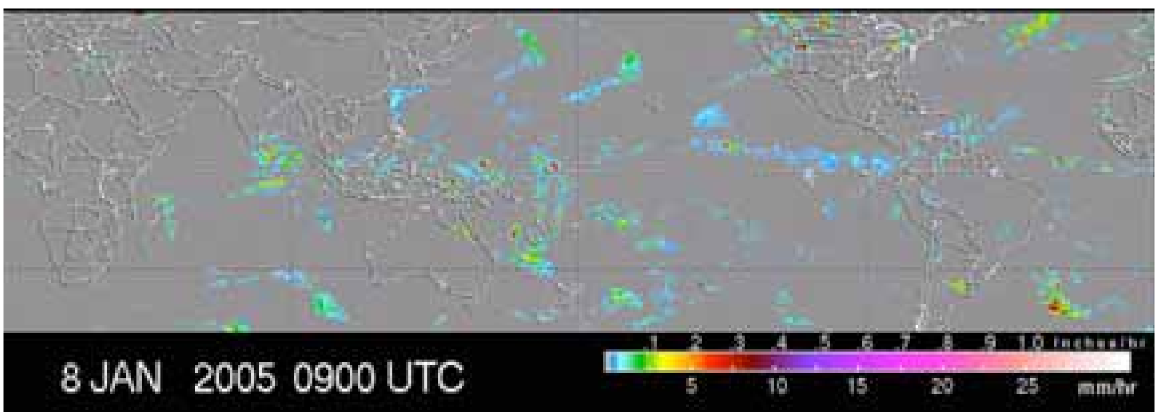

Figure 7 TRMM Global daily precipitation

the AMSR-E soil moisture product, the digital elevation data from the Digital elevation from SRTM mission (30m), the MODIS Land cover and evapotranspiration data products, and soil parameters provided by FAO. The TMPA product is a near real-time precipitation rate product at fine time and space scales (3-hr, 0.25° x 0.25° latitude–longitude) over the latitude band 50° N-S. This product makes use of TRMM's highest quality observations[5], along with high quality passive microwave-based rain estimates from 3-7 polar-orbiting satellites (e.g. AMSR, (2) SSMI/ DSMP, (2) AMSU/POES), and all the geosynchronous IR sensors (Meteosat, GOES, GMS). The combined quasi-global rain map at 3-hr resolution is produced by using TRMM to calibrate, or adjust, the estimates from all the other satellites, and then combining all the estimates into the TMPA final product. The technique uses as much microwave data as possible, and uses the geo-IR estimates to fill in gaps in the three-hour analysis. The calibrations are computed using monthly accumulations of matched data to ensure stability. The TMPA is a TRMM standard product. A real-time version of the TMPA merged product was introduced in February 2002 and is available on the U.S. TRMM web site (http://trmm.gsfc.nasa.gov).

(2) The CREST Model

The Coupled Routing and Excess STorage (CREST) distributed hydrological model is a hybrid modeling strategy that was recently developed by the University of Oklahoma (http://hydro.ou.edu) and NASA SERVIR Project Team (www.servir.net). CREST simulates the spatiotemporal variation of water and energy fluxes and storages on a regular grid with the grid cell resolution being user-defined, thereby enabling global- and regional-scale applications[8]. The scalability of CREST simulations is accomplished through sub-grid scale representation of soil moisture storage capacity (using a variable infiltration curve) and runoff generation processes (using linear reservoirs)[4]. The CREST model was initially developed to provide online global flood predictions with relatively coarse resolution, but it is also applicable at small scales, such as single basins.

The CREST Model can be forced by gridded potential evapotranspiration[2] and precipitation datasets such as, satellite-based precipitation estimates, gridded rain gauge observations, remote sensing platforms such as weather radar, and quantitative precipitation forecasts from numerical weather prediction models. The representation of the primary water fluxes such as infiltration and routing are closely related to the spatially variable land surface characteristics (i.e., vegetation, soil type, and topography). The runoff generation component and routing scheme are coupled, thus providing realistic interactions between atmospheric, land surface, and subsurface water.

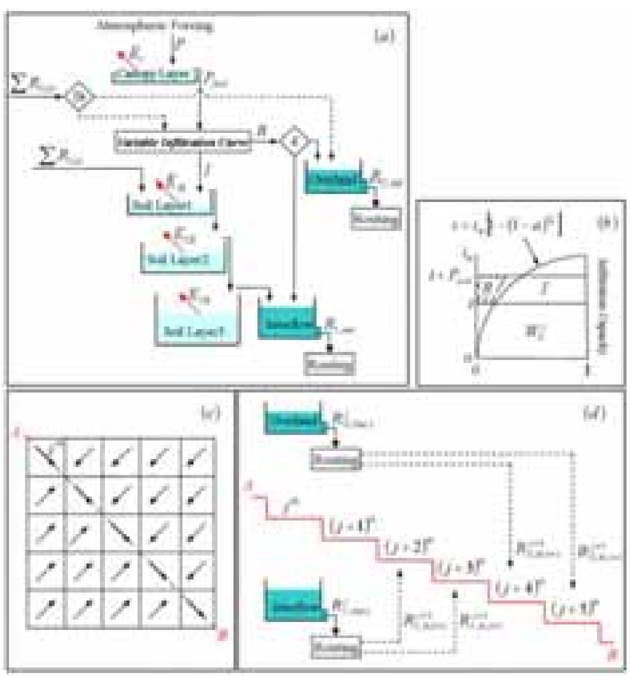

Figure 8 Core components of the CREST model: (a) vertical profile of a cell including rainfall-runoff generation, evapotranspiration, sub-grid cell routing and feedbacks from routing; (b) variable infiltration curve of a cell; (c) plan view of cells and flow directions; and (d) vertical profile along several cells including sub-grid cell routing, downstream routing, and subsurface runoff redistribution from a cell to its downstream cells.

CREST model implementation

Development and maintenance of the current official version of the CREST model is conducted at the University of Oklahoma, Remote Sensing and Hydrology Research Group (http://hydro.ou.edu) and Center for Natural Hazard and Disaster Research located in National Weather Center (http://nwc.ou.edu). CREST model was designed to enable multi-scale hydrologic modeling and hence suited for simulations ranging from global coverage (grid size of tens of kilometers) to regional coverage (grid size of 1km to a few kilometers). The following screenshots (Figures 9-16) demonstrate the GUI (graphical User Interface and the utility of CREST for a regional scale application focusing on Nzoia Basin in East Africa.

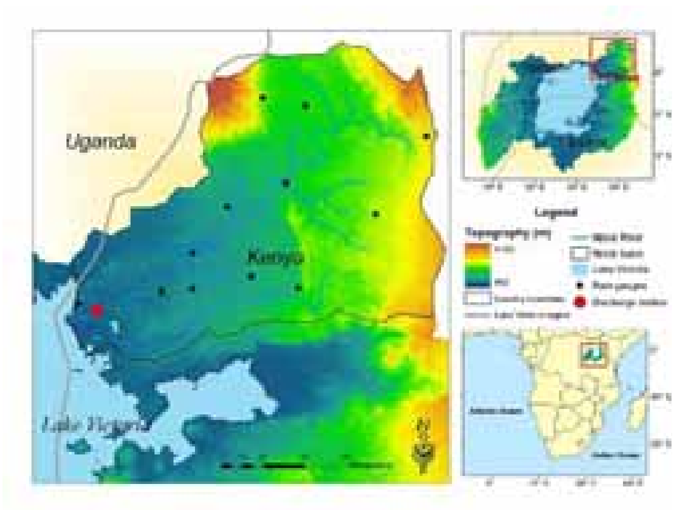

Figure 9 below of the Nzoia Basin study area

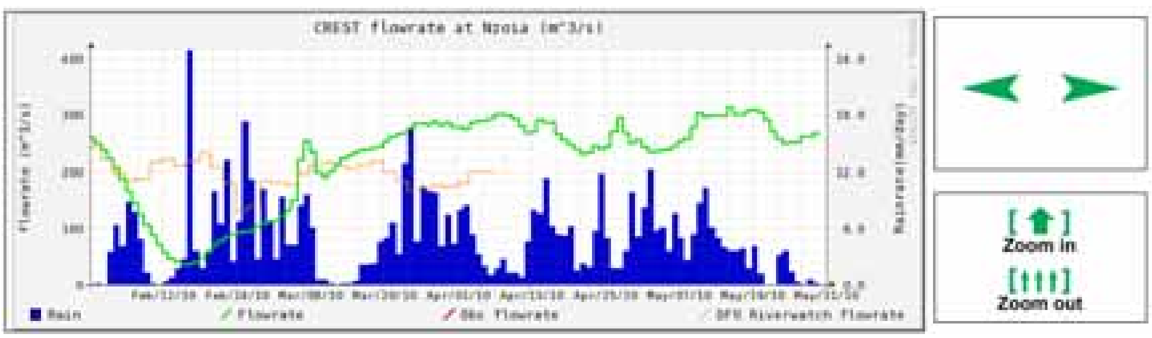

Figure 10 Flowrate of River Nzoia

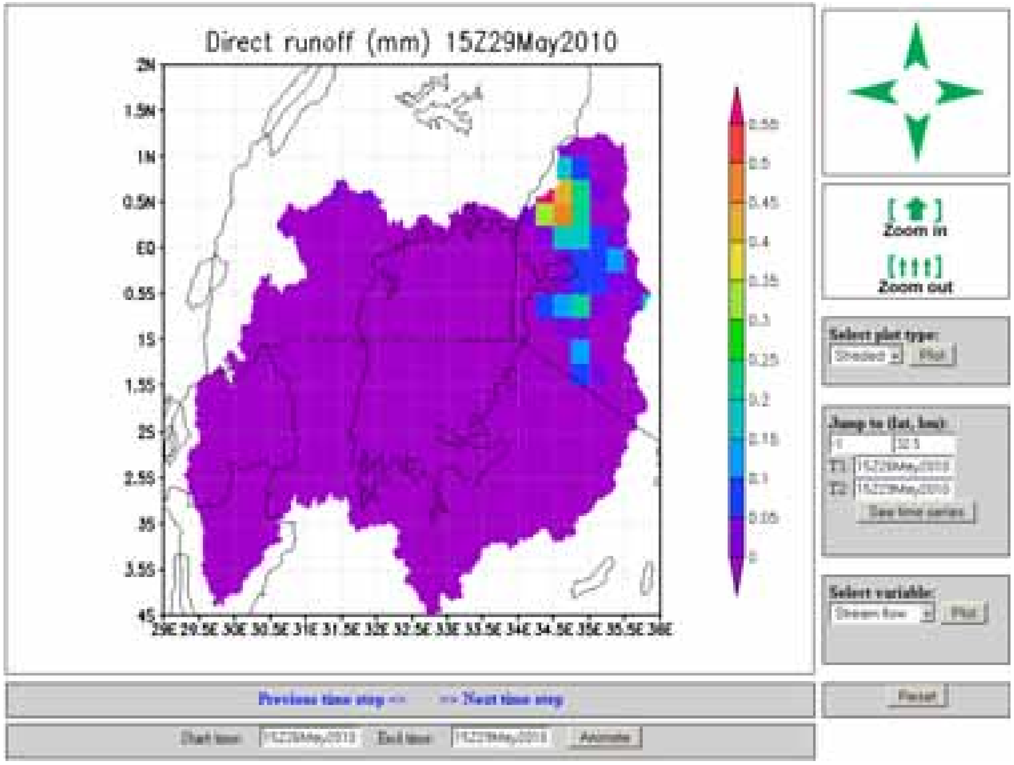

Figure 11 shows direct run off in mm of the river Nzoia

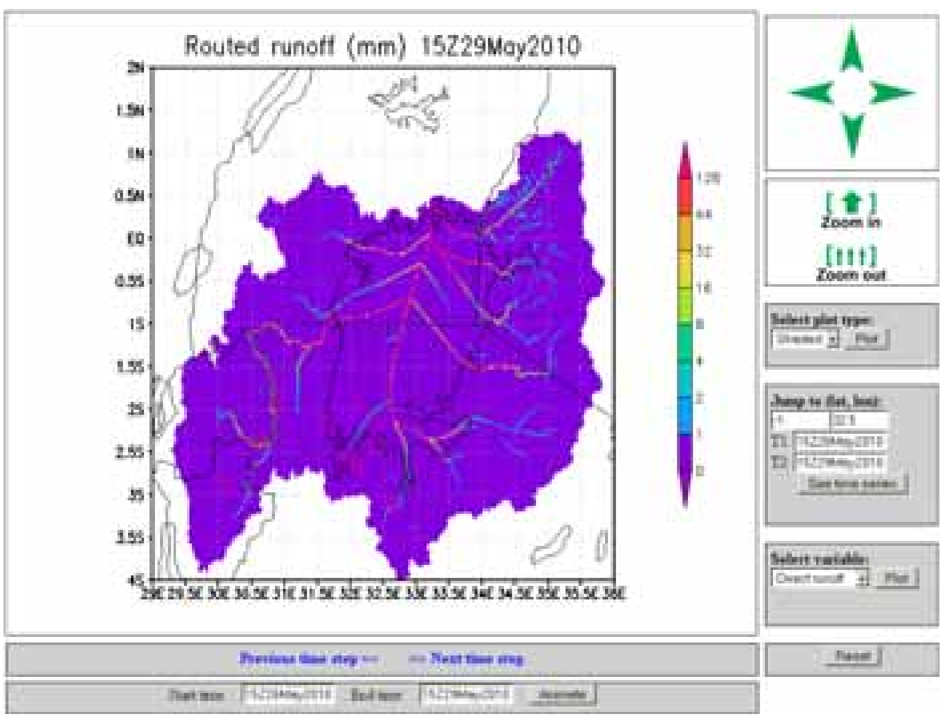

Figure 12 shows the routed run off of river Nzoia

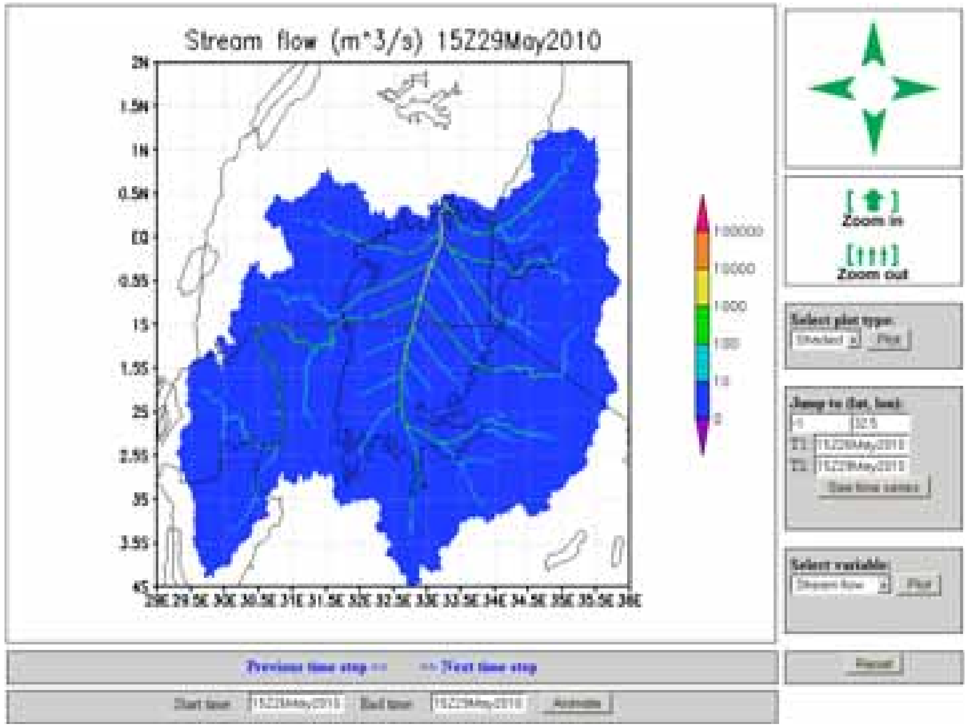

Figure 13 shows stream flow in cubic meters per second

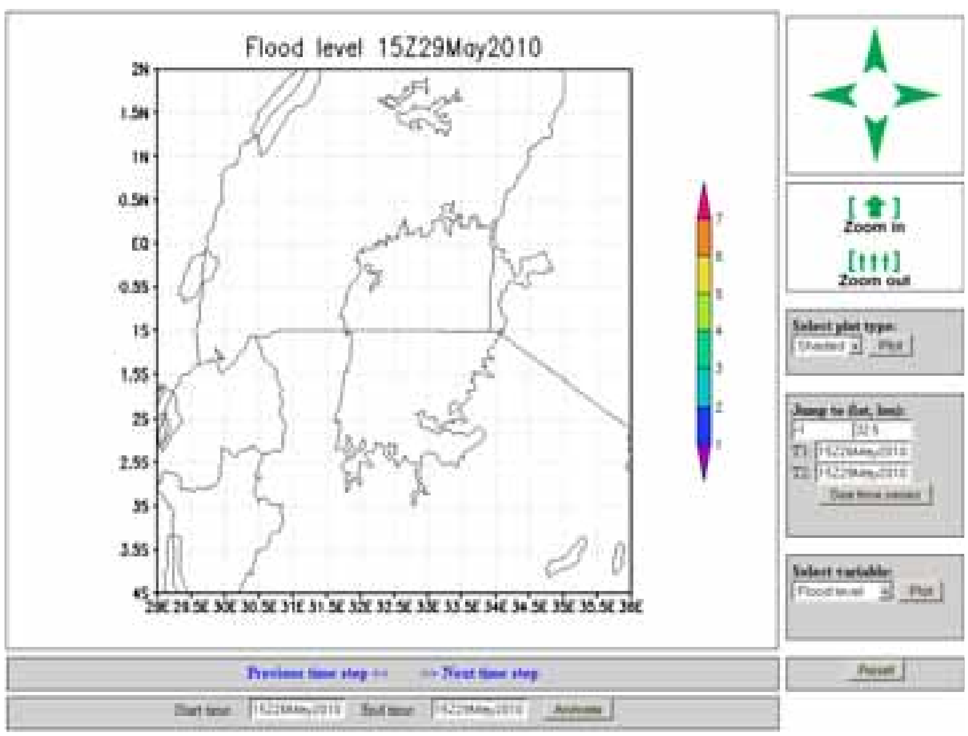

Figure 14 shows the flood level in the basin at a given date/time

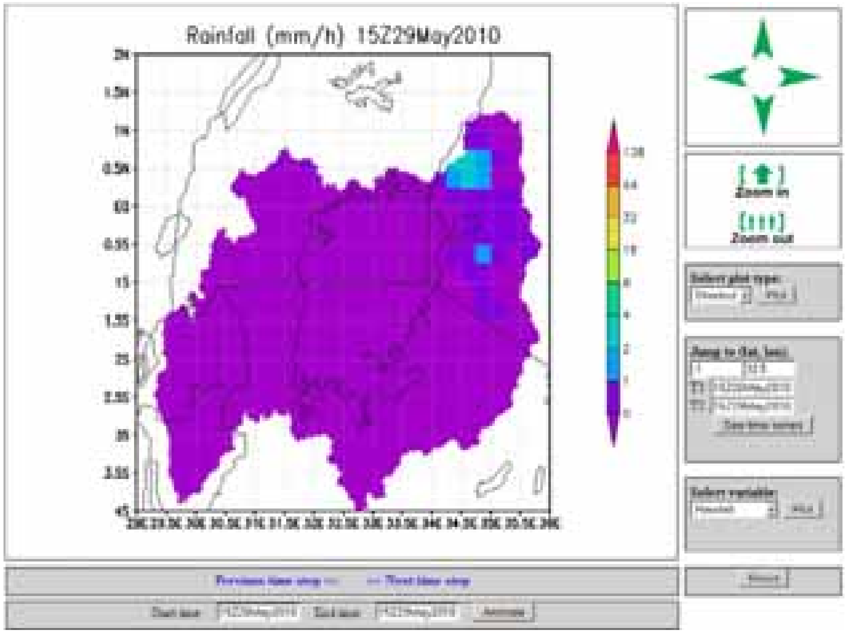

Figure 15 shows rainfall received in millimeters per hour

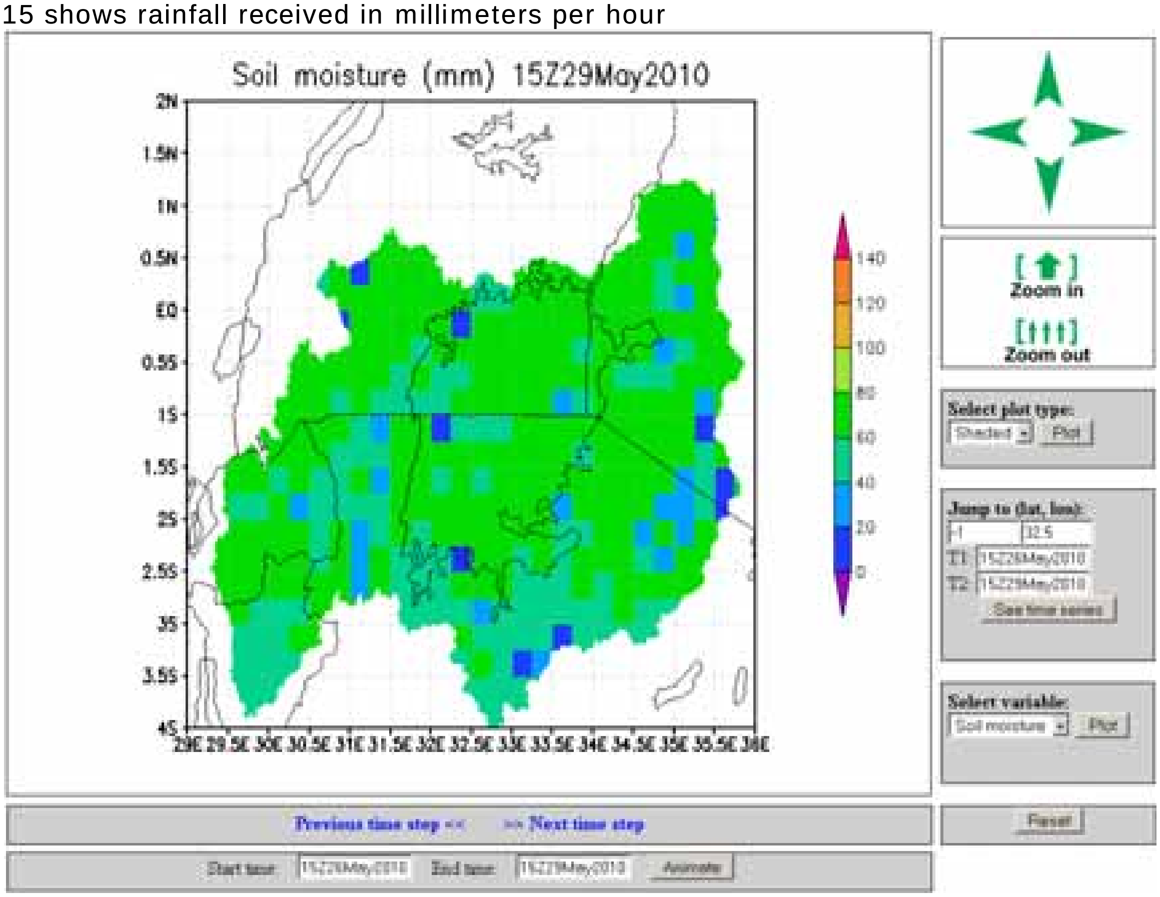

Figure 16 shows soil moisture in millimeters which is a key parameter in the model.

SERVIR's Post-Event Flood Mapping

For post-event flood mapping initial flood maps are produced manually by RCMRD and distributed on the SERVIR-Africa website. ArcGIS is extensively used in post-event flood mapping. Satellite images are acquired from NASA's MODIS and Earth-Observatio-1 (EO-1) satellites and processed using ESRI ArcGIS Desktop software. Processing includes compositing of the required bands from the satellite images and panchromatic sharpening to enhance spatial resolution both of which are supported by ArcGIS. Mapping of the flood areas is done by delineating the flooded polygons followed by integration of the satellite derived data with field based spatial data enabled in the GIS environment provided by ArcGIS. These products are disseminated to users through SERVIR-Africa's website. The other method being used for dissemination is web-mapping services which operate on ESRI's ArcGIS Server platform.

In future the post-event flood maps created for this project will be made by applying algorithms which discriminate standing water from dry land and existing water bodies using approximately 250m MODIS data from the NASA AQUA and TERRA satellites. The MODIS data is acquired for nearly the entire Earth's surface two times a day for sunlit conditions. Example of MODIS products is shown in Figure 18. The SERVIR-Africa project is working closely with the NASA MODIS Rapid Response team and the Dartmouth Flood Observatory to develop automated near-real time flood mapping products.

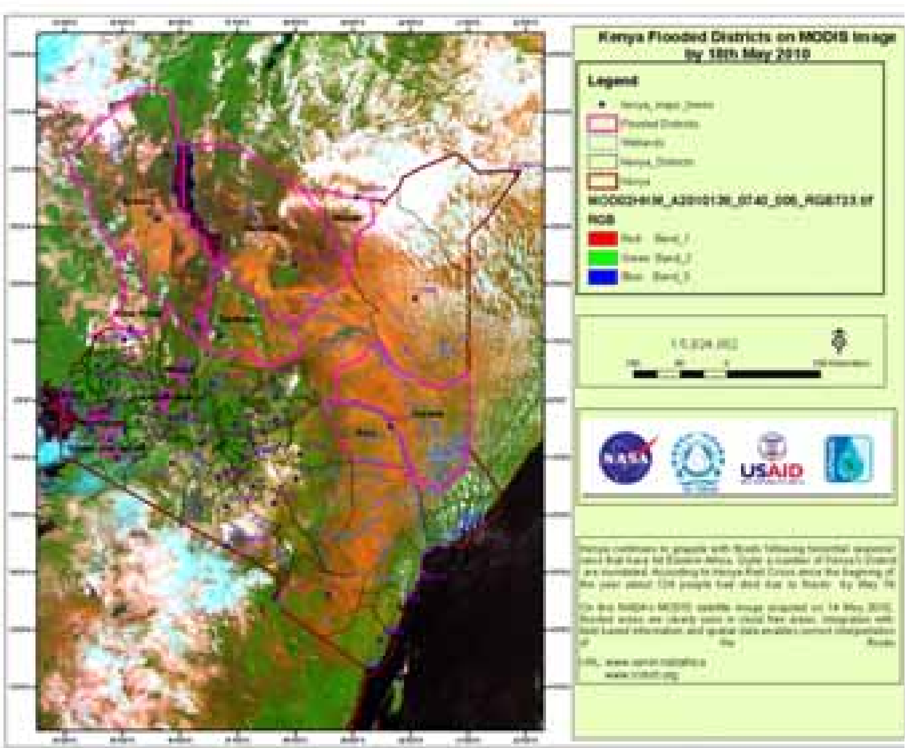

Figure 18: Monitoring Districts In Kenya experiencing floods on 18th May 2010 using NASA's MODIS satellite image in an ArcGIS platform

To enhance the utility of the MODIS flood maps, NASA and RCMRD are also collaborating to task the NASA EO-1 satellite for coverage of flooding events on an as-available basis. EO-1 provides higher resolution data (30m) for localized areas and 10m spatial resolution upon panchromatic sharpening. Figures 19-21 are examples of flood products developed from EO-1.

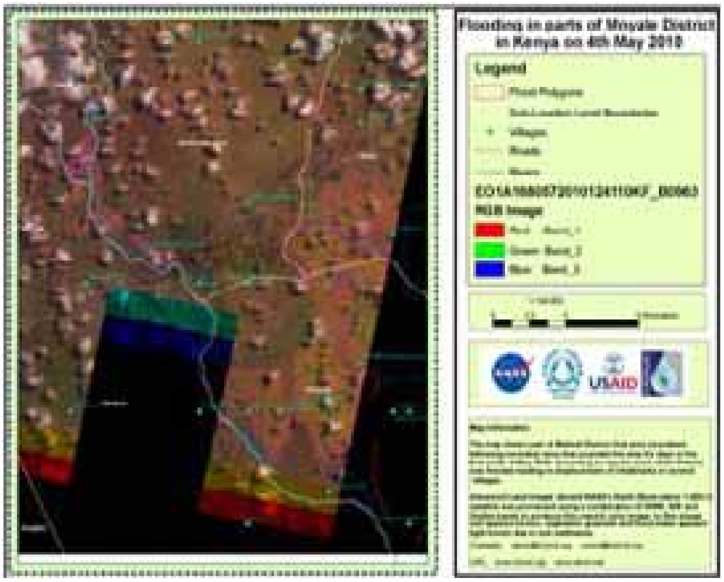

Figure 19 Post Flood mapping of Moyale District in Kenya using NASA's EO-1 ALI Satellite Image in an ArcGIS platform

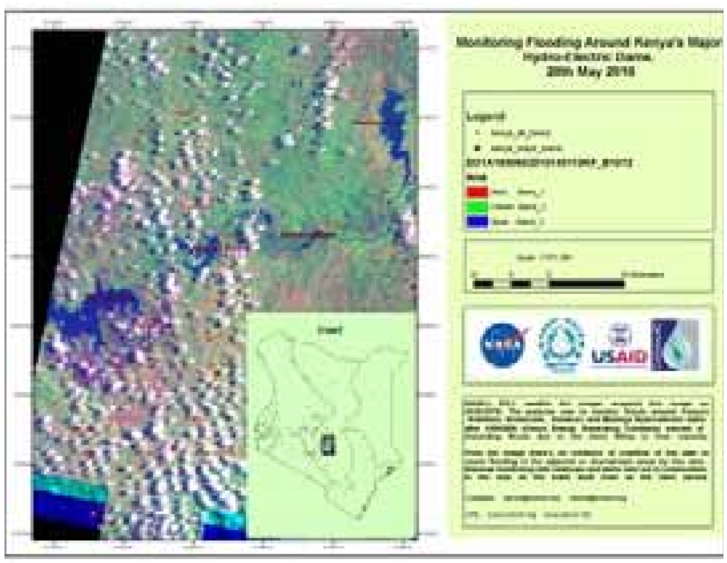

Figure 20 Monitoring Flooding in Kenya's Hydro-Electric Dams using NASA's EO-1 ALI Satellite Image in an ArcGIS platform

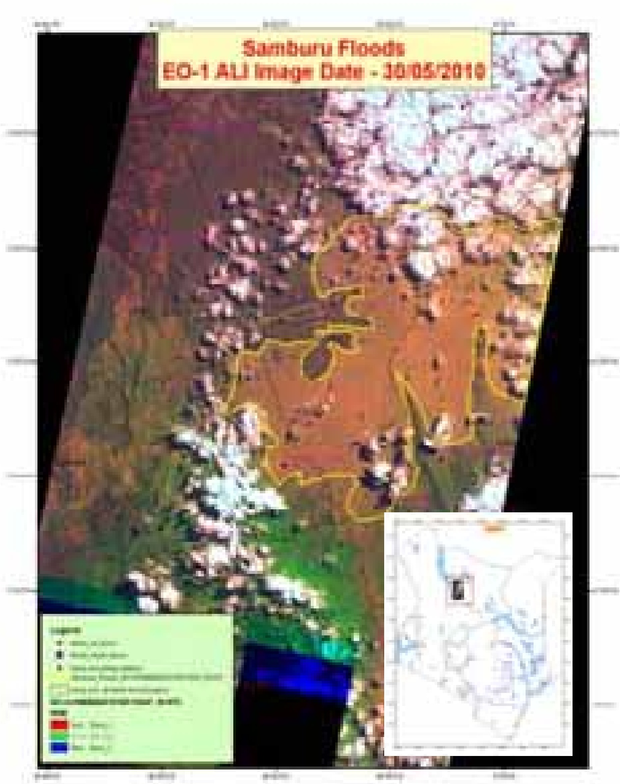

Figure 21 Monitoring Flooding in Kenya's Samburu District using NASA's EO-1 ALI satellite image in an ArcGIS platform

SERVIR-Africa is an ideal platform and system for monitoring not only flood and other disaster of interest in the region like volcanoes (see figure 22), but also deliver on other societal benefit areas as identified by Global Observation Systems of Systems.

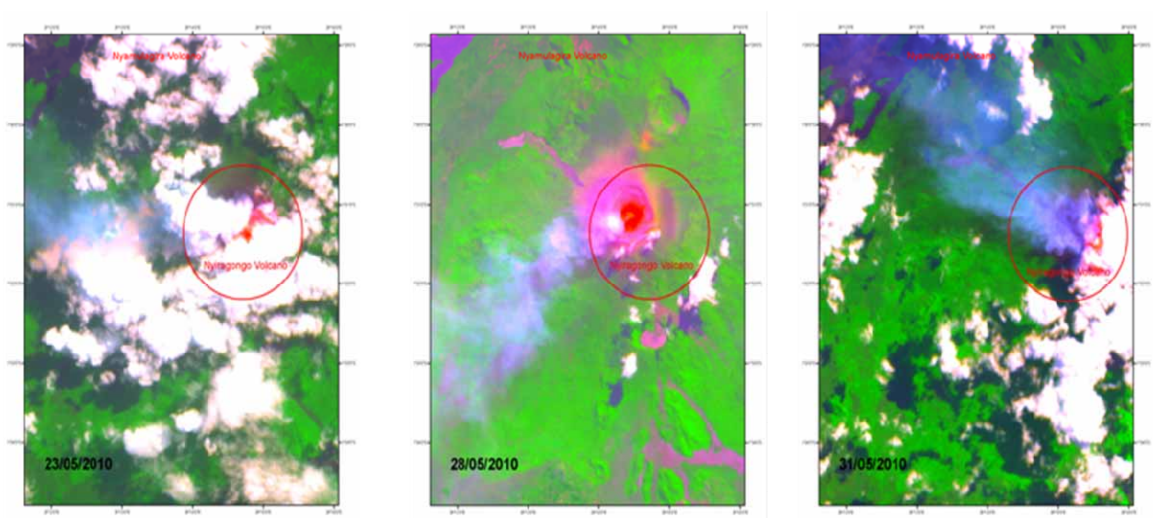

Figure 22 Other Disasters: Monitoring Nyiragongo Volcanic activity in 23rd, 28th, 31st May 2010 using NASA's EO-1 ALI satellite image. Lava (red-pinkish) and light-blue

smoke plume bellowing from the crater of the volcano can be seen clearly from this image. Processing was done using ArcGIS software.

Conclusion

The SERVIR Africa flooding application project is in its second year of development and it will take another 2 years to get it fully functional. The future satellite measurements such as soil moisture and precipitation will enhance the products and its applicability. RCMRD plans to expand this concept to its other member nations where they can be trained to take advantage of the capabilities as foreseen by this cooperation. The initial thrust is to use the TRMM precipitation, terrain data, soil properties and vegetation information to build flood potential maps. MODIS will be very helpful in generating the flood potential maps. Now, the plan is to work with the meteorological organizations of each member nation to utilize the precipitation forecast data. This information can be fed into the models to eventually develop the flood forecast maps or areas under flood risk.

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