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## **SERVIR-AFRICA: DEVELOPING AN INTEGRATED PLATFORM FOR FLOODS DISASTER MANAGEMENT IN AFRICA**

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**KEY WORDS:** Floods, Flood-Model, Flood-Mapping, Flood-Potential, Flood-Monitoring, CREST-Model, Global-Hazard-Flood-Model

### **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 natural disasters. It aims addressing societal benefits including floods and turning data into actionable information for decision-makers. Floods are exogenous disasters that affect many parts of Africa, probably second only to drought in terms of social-economic losses. This paper looks at SERVIR-Africa's approach to floods disaster management through establishment of an integrated platform, floods prediction models, post-event flood mapping and monitoring as well as flood maps dissemination in support of flood disaster management.

### **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.

RCMRD MEMBER STATES

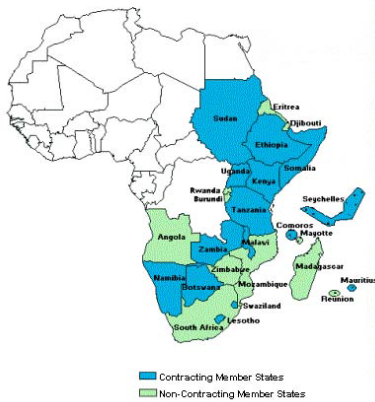


Figure 1 RCMRD’s Contracting and Non-Contracting Member States.

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 2 shows the system perspective of the platform:

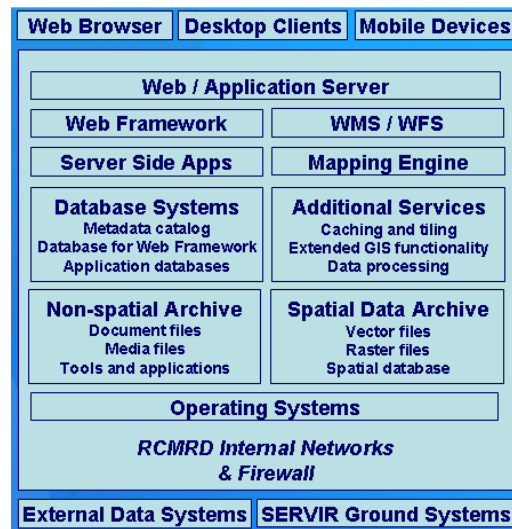


Figure 2 SERVIR-Africa System Perspective.

### 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 3. 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 4 below paints a realistic picture of what floods really are.

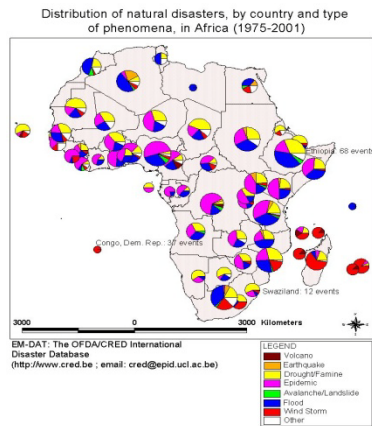


Figure 3 Distribution of Natural Disasters in Africa.



Figure 4 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 (Habib, 2009), the TRMM-based Multi-satellite Precipitation Analysis (TMPA) precipitation product- TRMM 3B-42 (Fig. 5),

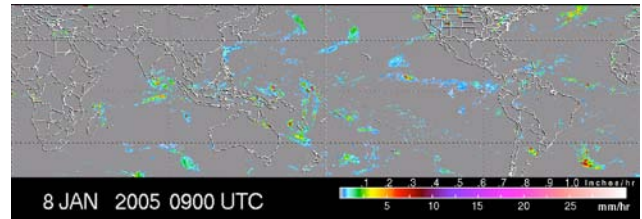


Figure 5 TRMM Global daily precipitation

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 (Hong et al, 2008), 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](http://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<sup>[8]</sup>. 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) (Artan et al, 2007). 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 (Olivera et al, 2000) 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.

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 (Hong & Adler, 2007) 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 7-14) demonstrate the GUI (graphical User Interface and the utility of CREST for a regional scale application focusing on Nzoia Basin in East Africa.

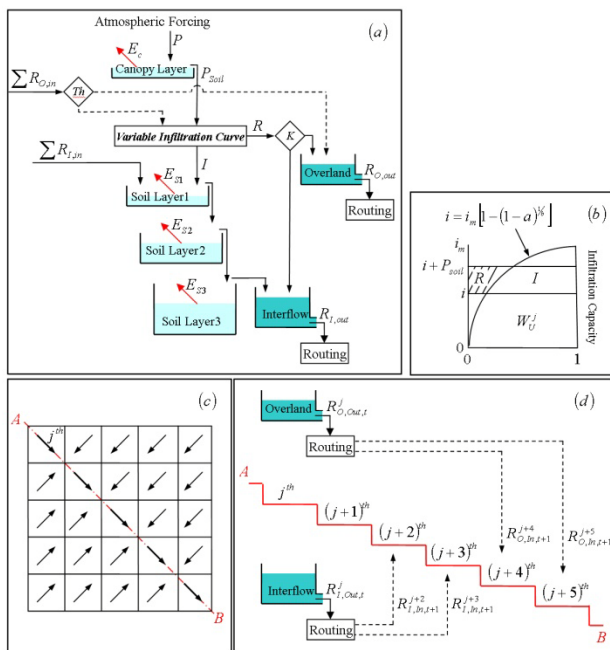


Figure 6 Core components of the CREST model: (a) vertical profile of a cell including rainfall-runoff generation, evapotranspiration, sub-grid cell routing and feedbacks from routing; (b) variable infiltration curve of a cell; (c) plan view of cells and flow directions; and (d) vertical profile along several cells including sub-grid cell routing, downstream routing, and subsurface runoff redistribution from a cell to its downstream cells.

### CREST model implementation

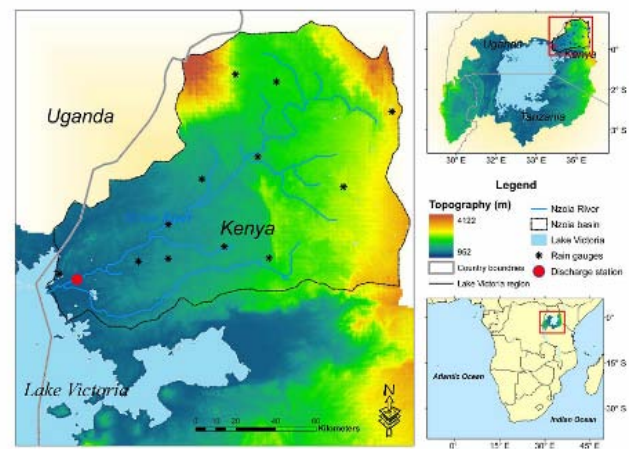


Figure 7 below of the Nzoia Basin study area

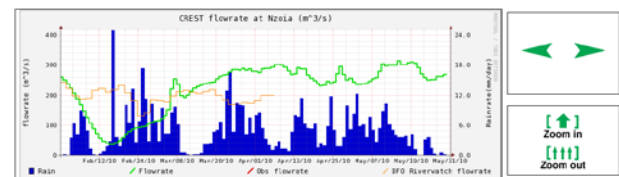


Figure 8 Flowrate of River Nzoia

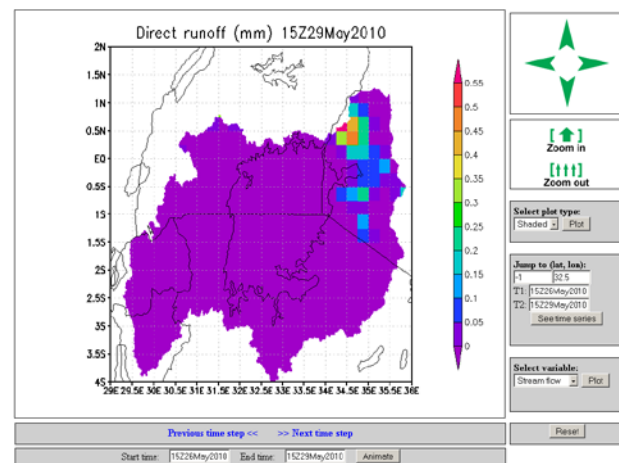


Figure 9 shows direct run off in mm of the river Nzoia

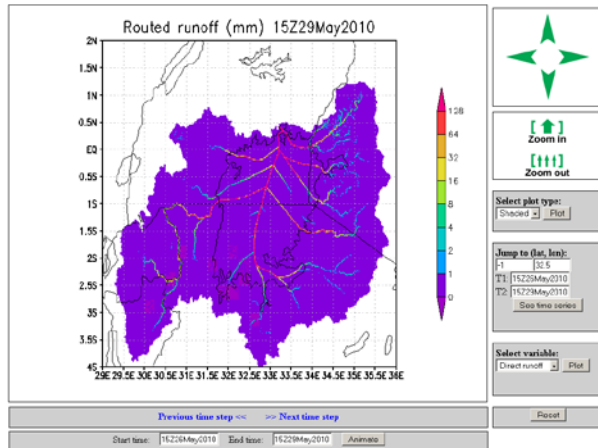


Figure 10 shows the routed run off of river Nzoia

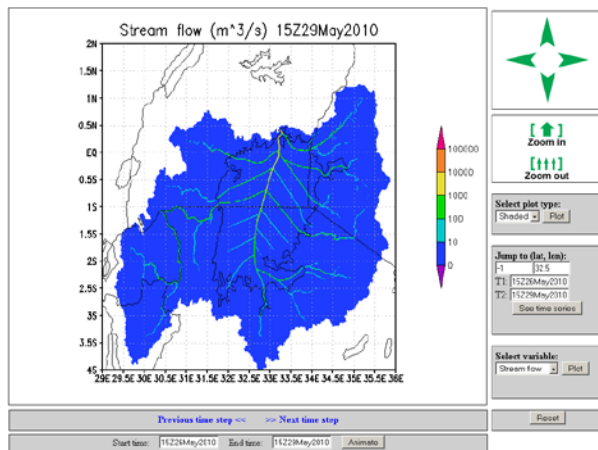


Figure 11 shows stream flow in cubic meters per second

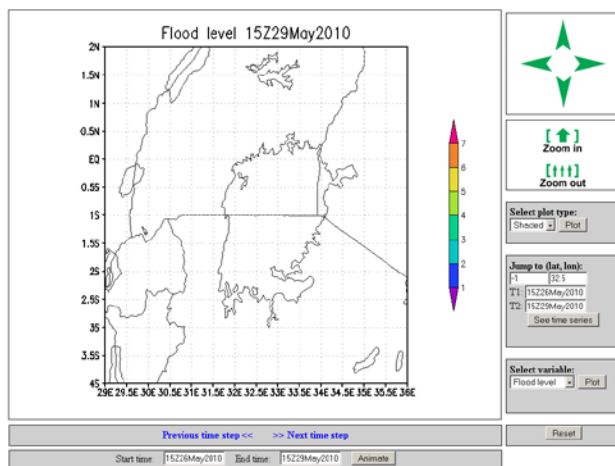


Figure 12 shows the flood level in the basin at a given date/time

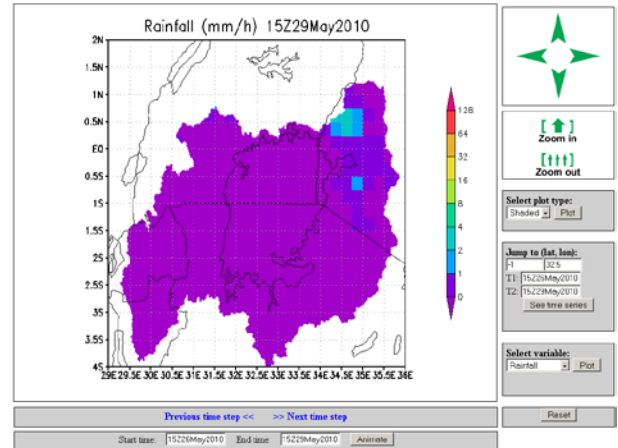


Figure 13 shows rainfall received in millimeters per hour

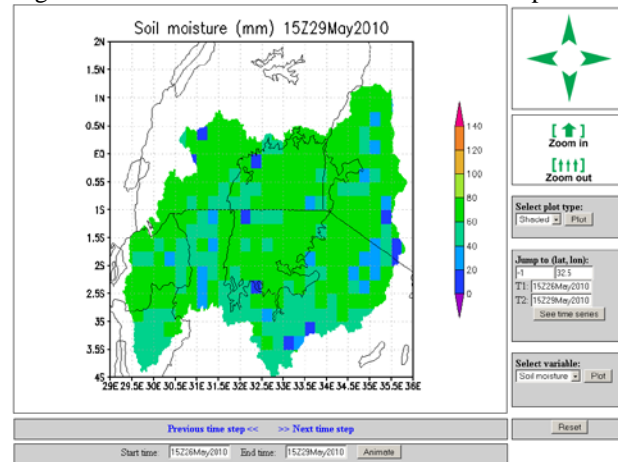


Figure 14 shows soil moisture in millimeters which is a key parameter in the model.

### 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-Observation-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 15. 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.

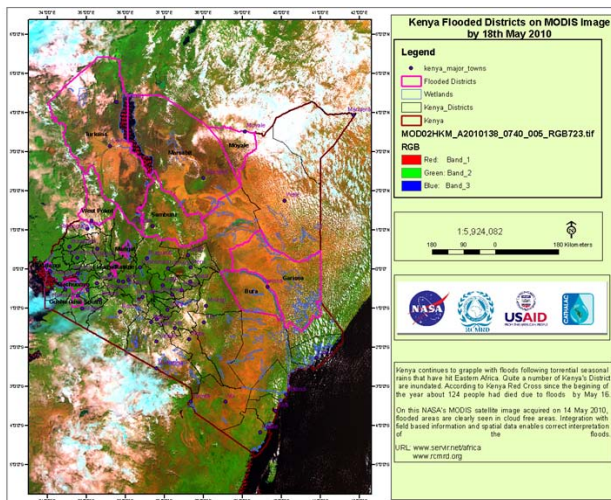


Figure 15: Monitoring Districts In Kenya experiencing floods on 18<sup>th</sup> May 2010 using NASA's MODIS satellite image in an ArcGIS platform

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 16-18 are examples of flood products developed from EO-1.

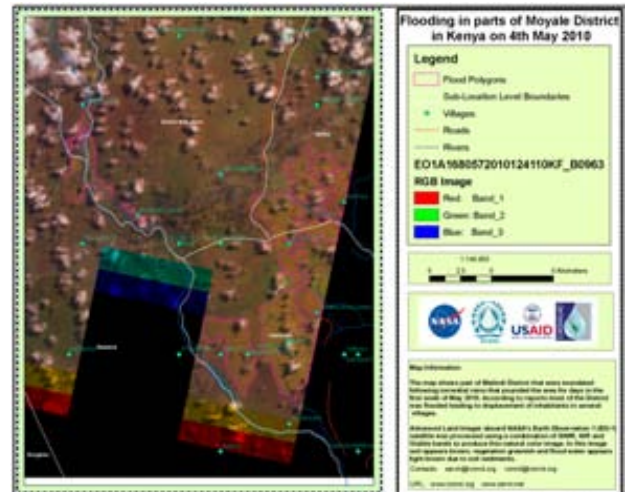


Figure 16 Post Flood mapping of Moyale District in Kenya using NASA's EO-1 ALI Satellite Image in an ArcGIS platform

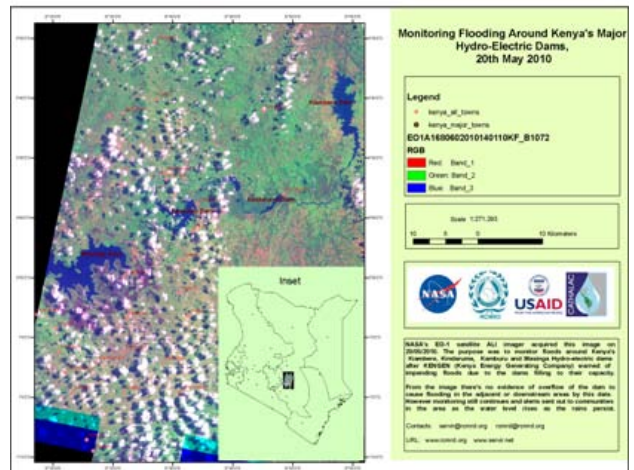


Figure 17 Monitoring Flooding in Kenya's Hydro-Electric Dams using NASA's EO-1 ALI Satellite Image in an ArcGIS platform

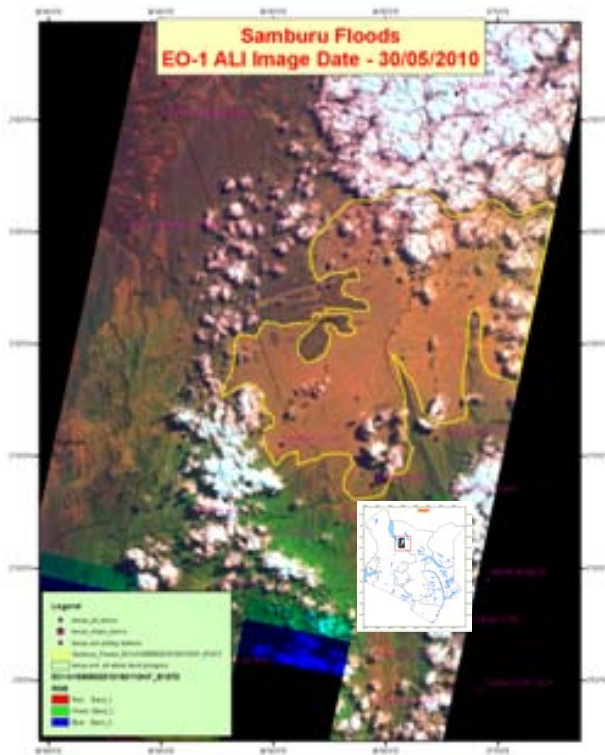


Figure 18 Monitoring Flooding in Kenya's Samburu District using NASA's EO-1 ALI satellite image in an ArcGIS platform

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

## 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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# SERVIR-Africa: Developing an Integrated Platform for Floods Disaster Management in Africa



8<sup>th</sup> International AARSE Conference  
25 - 29 October 2010,  
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**SERVIR-Africa, RCMRD, Nairobi**  
**[www.servir.net](http://www.servir.net)**





# Outline

- SERVIR background and SERVIR-Africa
- Disasters in Africa
- Flood estimation
  - Flood potential
  - Flood forecasts
  - Rapid flood mapping
- Satellite data acquisition for disaster assessment
- SERVIR-Africa System Infrastructure
- Web-based information dissemination
- Looking ahead

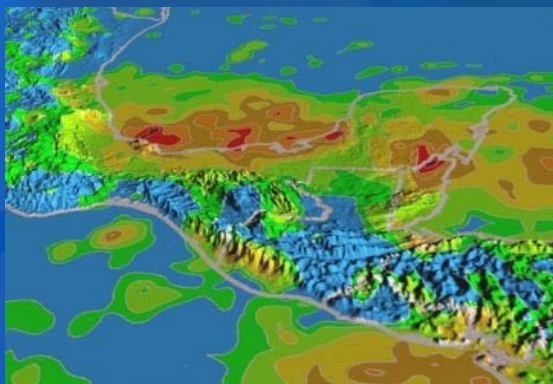


# SERVIR

## Regional Visualization and Monitoring System “to serve”

*Enabling the use of Earth observations and models for timely decision making to benefit society*

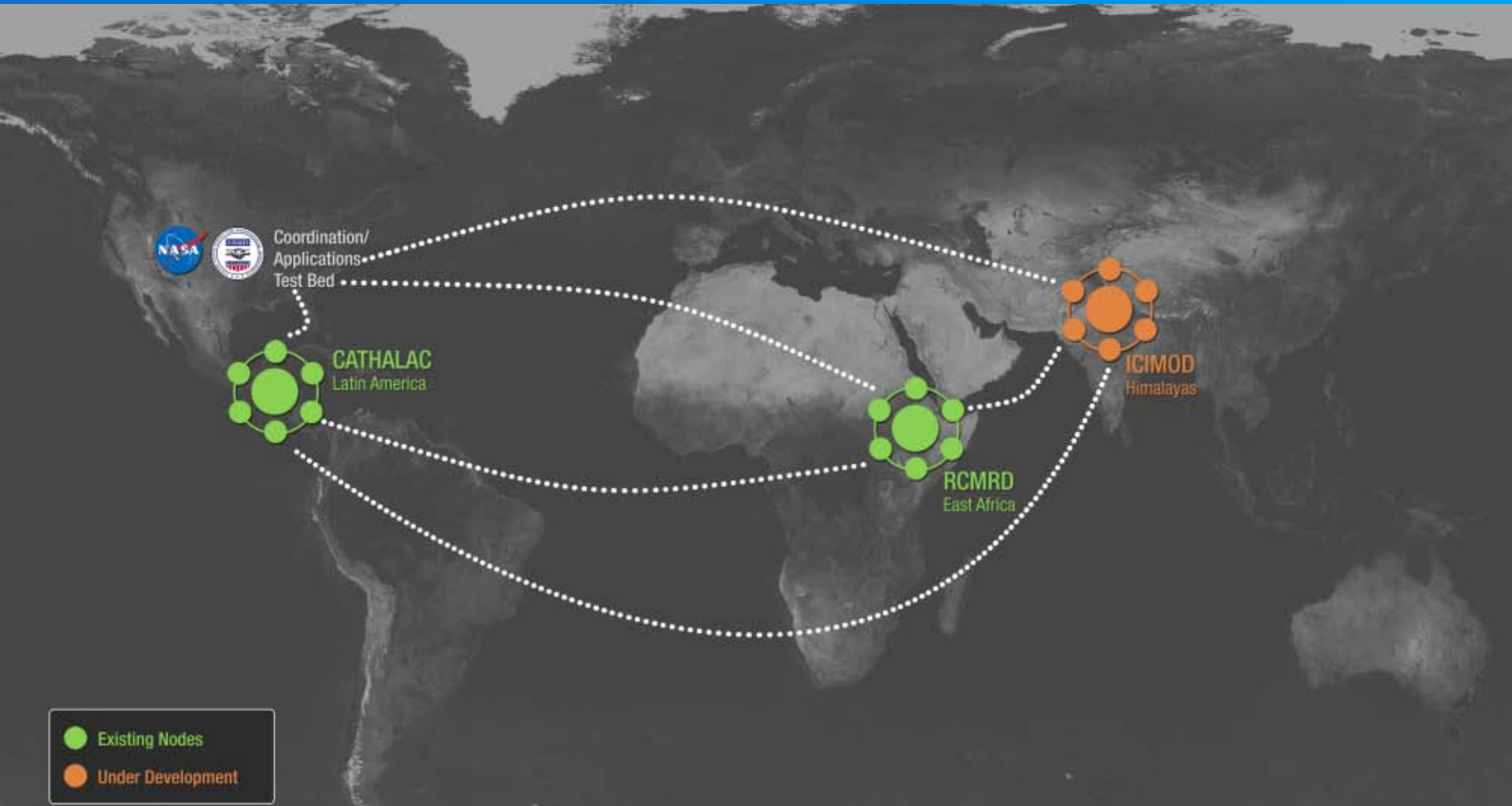
*Low cost system that capitalizes on existing space and ground based assets and is operated and controlled by host nations*



- Data and Models
- Online Maps
- Visualization
- Decision Support
- Training
- Partnerships



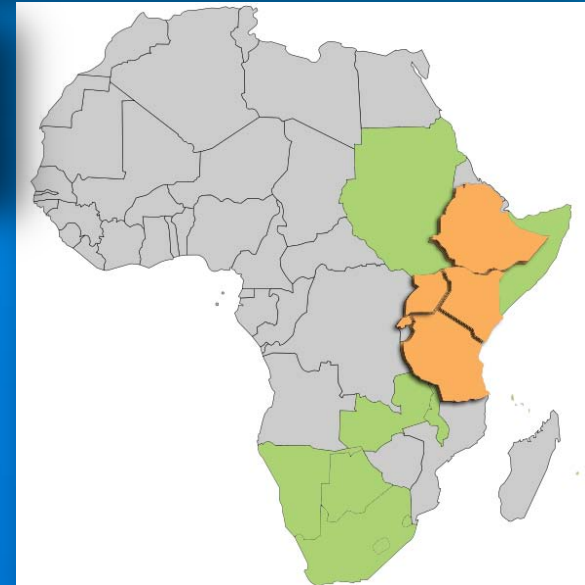
# SERVIR Nodes & Coordination Office





# SERVIR-Africa: phased approach

- Project launched Nov'08 at RCMRD
- RCMRD, inter-governmental organizational promoting development and use of RS/GIS; actively engaged in human and institutional capacity building.
- RCMRD has 17 contracting member states  
Botswana, Comoros, Ethiopia, Kenya, Lesotho, Malawi, Mauritius, Namibia, Somalia, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia , Rwanda & Seychelles
- Phase 1 focusing on East Africa  
Kenya, Tanzania, Uganda, Ethiopia, Rwanda



SERVIR Phase 1 countries (orange);  
RCMRD member states (green)



# Seek to address the nine societal benefit areas identified by GEOSS

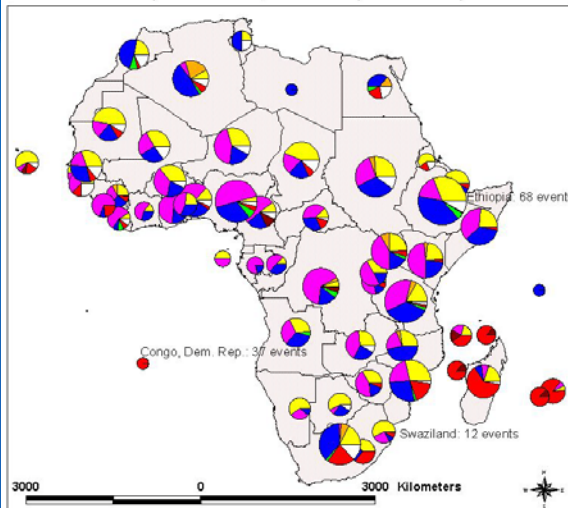
## THE GLOBAL EARTH OBSERVATION SYSTEM OF SYSTEMS





# Disasters in Africa

Distribution of natural disasters, by country and type of phenomena, in Africa (1975-2001)



EM-DAT: The OFDA/CRED International Disaster Database  
(<http://www.cred.be> ; email: [cred@epid.ucl.ac.be](mailto:cred@epid.ucl.ac.be))



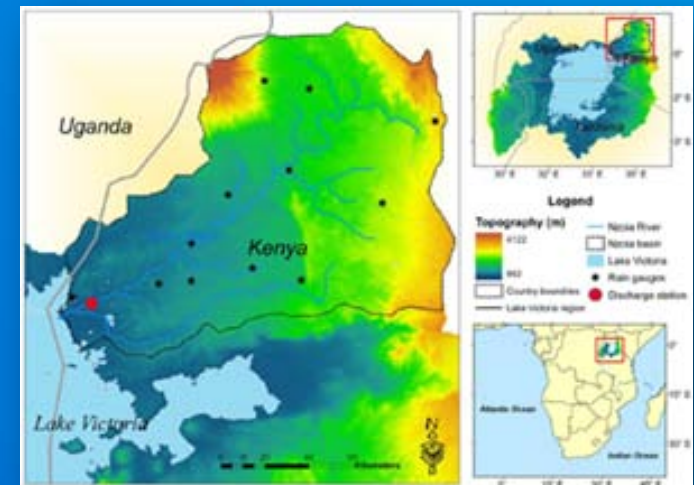
- Most common are:
  - Droughts
  - Wind storms
  - Floods
  - Epidemics
- 95% of natural hazards affecting region caused by droughts and flooding
- These hydro-meteorological hazards responsible for 70% of loss of life and 75% of economic loss





# Focus on Floods Disaster Zones

- SERVIR-Africa to provide robust capability to forecast, detect, and monitor flood conditions in Lake Victoria Basin by using satellite observations, in situ data, and meteorological and hydrological models.
- Project undertaken by NASA, USAID, and RCMRD
- Scientific expertise leveraged from NASA Goddard Space Center, Oklahoma University, and Dartmouth Flood Observatory
- RCMRD to build adequate technical capacity to operate models and generate maps by late 2010





# The Lake Victoria Basin – Floods Effects

- Lake Victoria basin an important geographic area providing for livelihood of sizeable East Africa population
- Area extremely prone to flooding and causing human catastrophe every season
- Estimated impact of flooding in Kenya and East Africa:

Ref: RCMRD data	Kenya 200-6	E. Africa 2006
Property Loss (\$US)	250 Million	400 Million
Displaced Persons	300,000	850,000
People needing emergency relief service	250,000	700,000
Deaths	260	1000



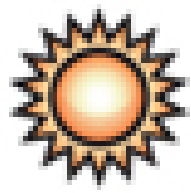


# Flood Estimation

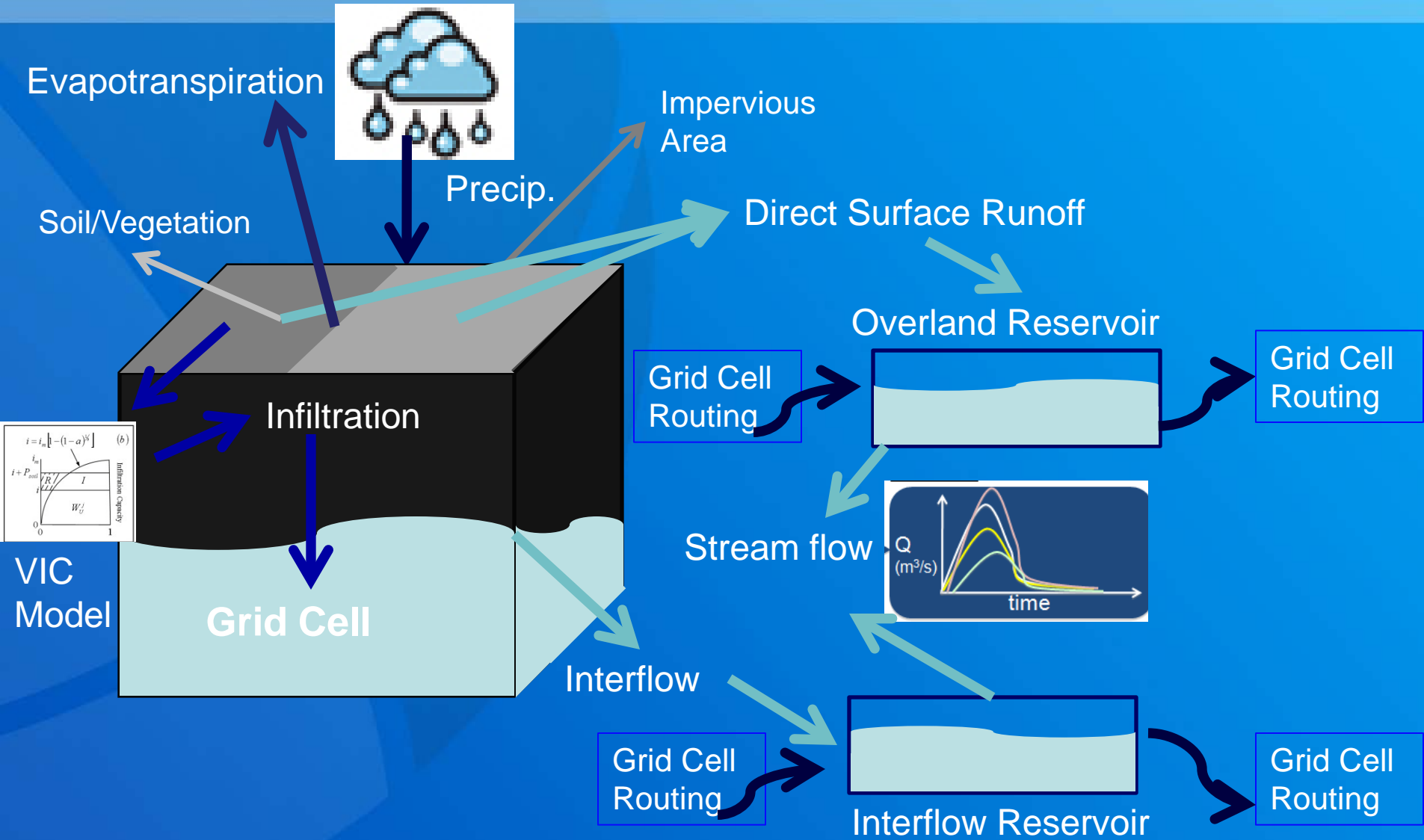
- In phase-1 area, using regional hydrologic model based estimation, as well as satellite data-only techniques to estimate floods.
- For flood estimation, using hydrologic modeling
  - Precipitation is derived from satellite datasets
  - Mass balance equations in the model computes excess ponding on surface, which contributes to flood estimates
  - Near real time at various spatial resolutions, at 3 hour temporal frequency
  - Flood estimation is done using observed data, and is higher resolution. Forecasting depends on global climate models for forecast fields and is at coarser spatial resolution.
- For flood estimation, using satellite data-only
  - Satellite observed changes in surface conditions are used as proxy for flooding
  - Provides spatial extent of flooding using near real-time processing of satellite products



# Hydrologic Water Balance Model



Coupled Routing and Excess Storage (CREST) Distributed Hydrological Model



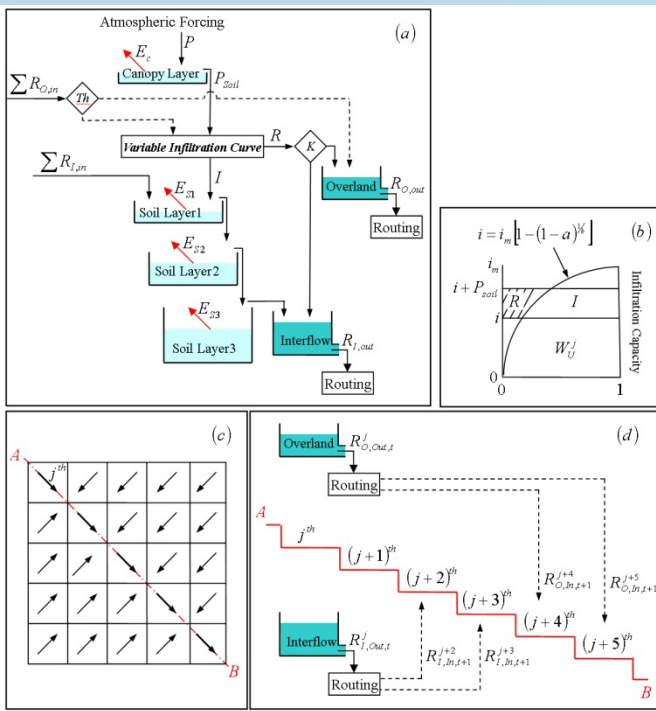


# Hydrologic Water Balance Model

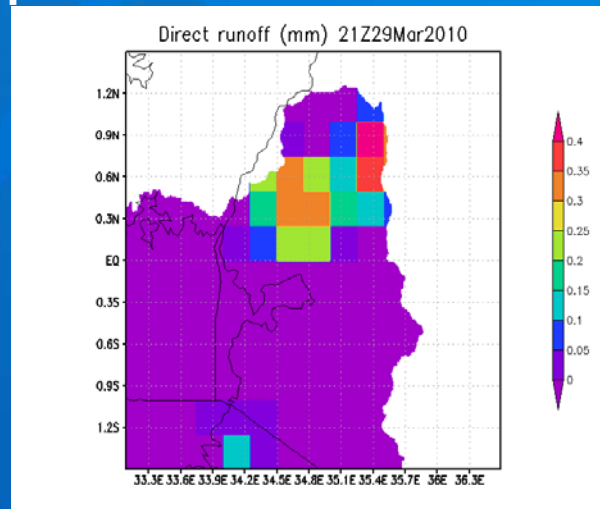
- For each grid cell, mass balance is computed to account for
  - In-flows (surface flow coming into the grid cell, precipitation)
  - Out-flows (evapotranspiration, infiltration and runoff)
- Runoff computed using NRCS Curve Number (CN) method.
  - Combines the land use, soil type, and hydrologic antecedent conditions.
  - Global maps of base CN values are available.
  - Transient CN values are computed using recent precipitation estimates.
  - Infiltration computed using Variable Infiltration Model (VIC).
- Difference between the in-flows and out-flows gives ponding at the grid surface. That ponded water is routed downstream using flow accumulations based on digital elevation model (DEM).



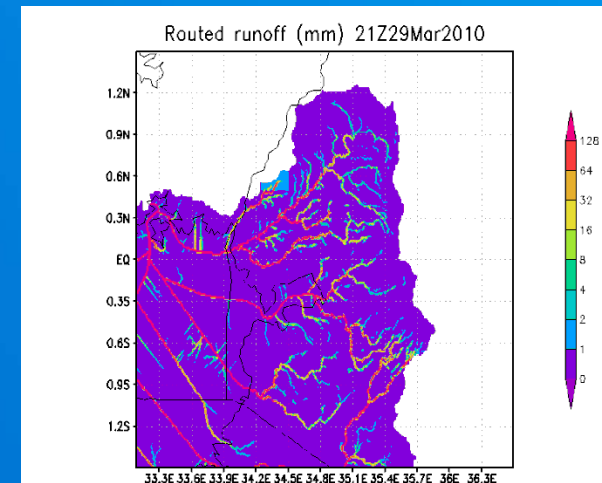
# CREST Model Components and Outputs



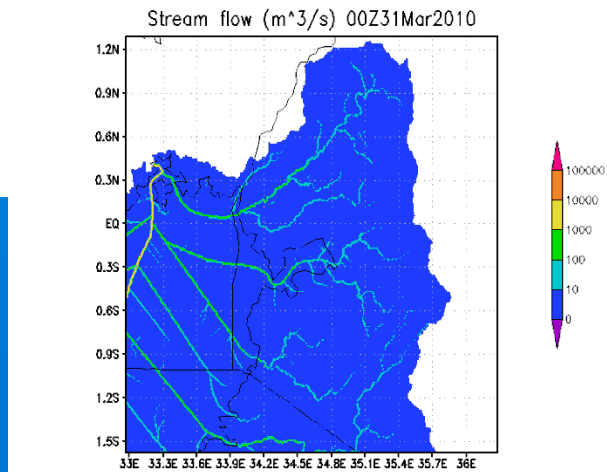
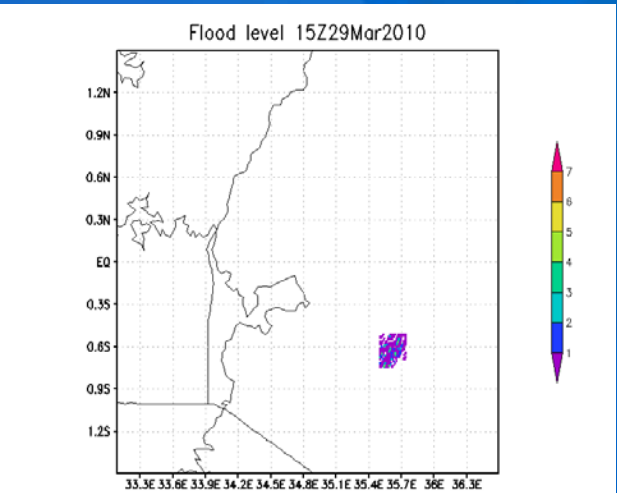
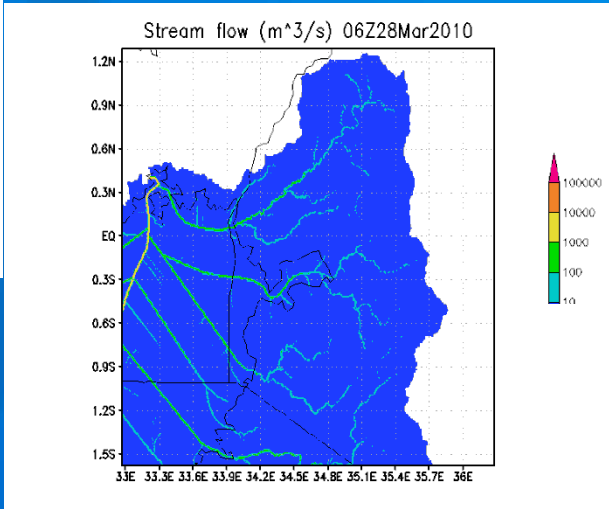
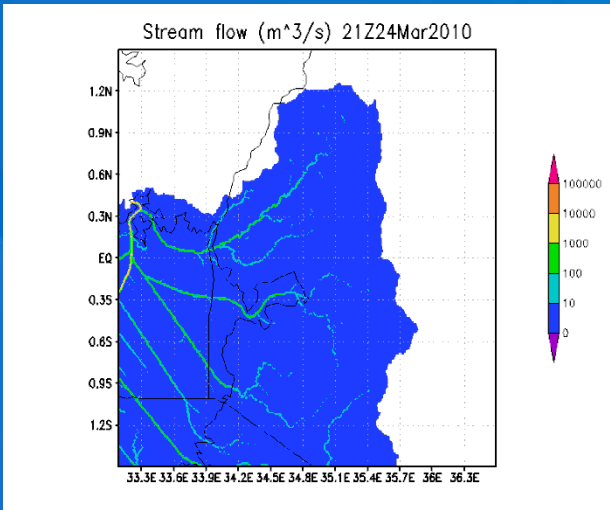
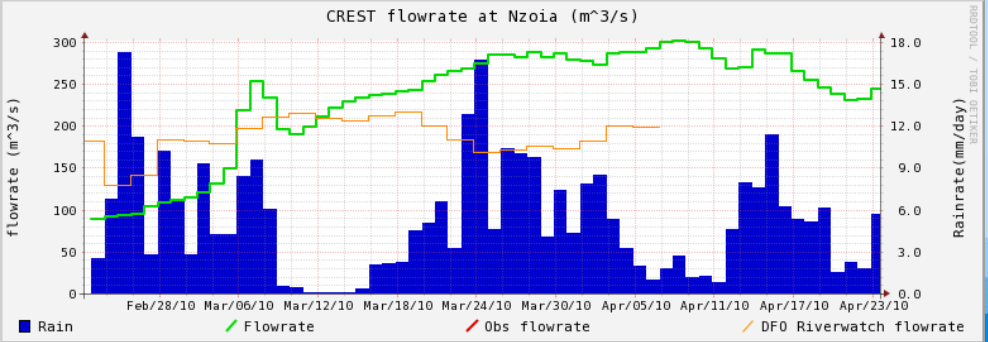
Direct run off in mm of the North East part of River Nzoia Basin



Routed run off (mm)



Core components of CREST model



Stream Flow progression

Flood level



# Model Calibration for Nzoia Basin

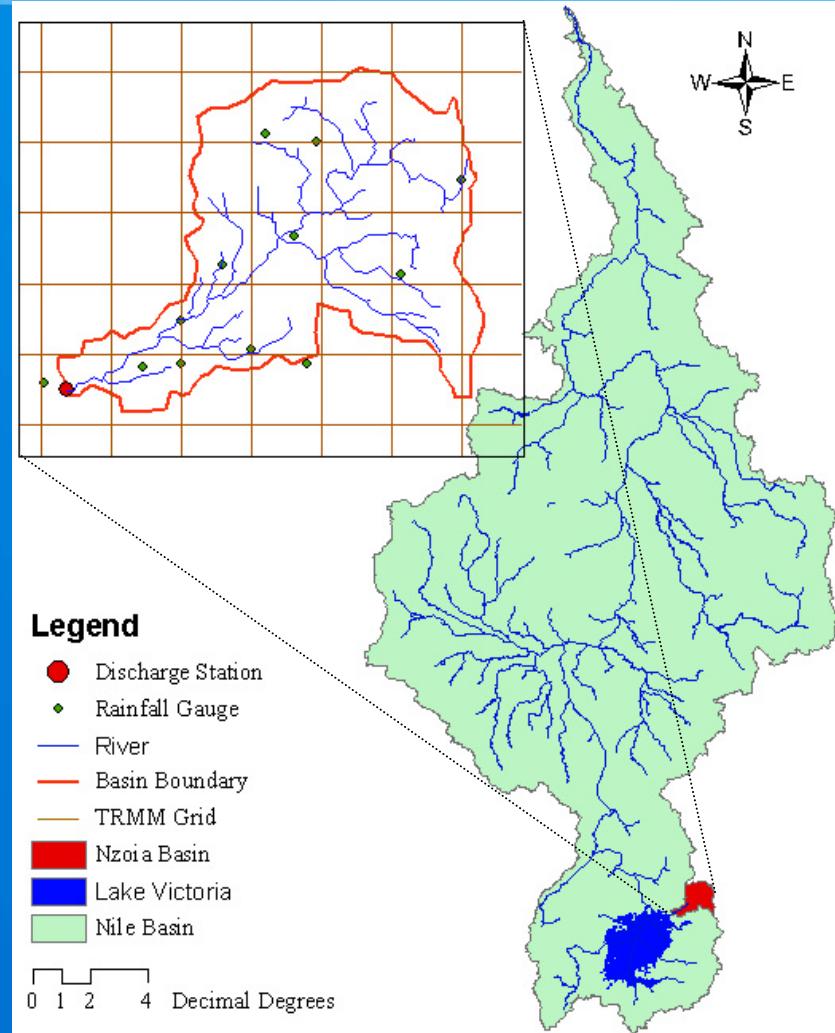
**Prelim Result:** Nzoia Basin, sub-basin of Lake Victoria, a flood-prone region in Kenya

MEASURED DISCHARGES - NZOIA

DATE	Q M3/S
1-Mar-85	24.77
1-Mar-85	24.10
2-Mar-85	24.10
2-Mar-85	23.42
3-Mar-85	15.36
3-Mar-85	15.36
4-Mar-85	15.36
4-Mar-85	15.36
4-Mar-85	15.36
5-Mar-85	15.36
5-Mar-85	15.36
6-Mar-85	15.36

MEASURED DISCHARGES - NYANDO

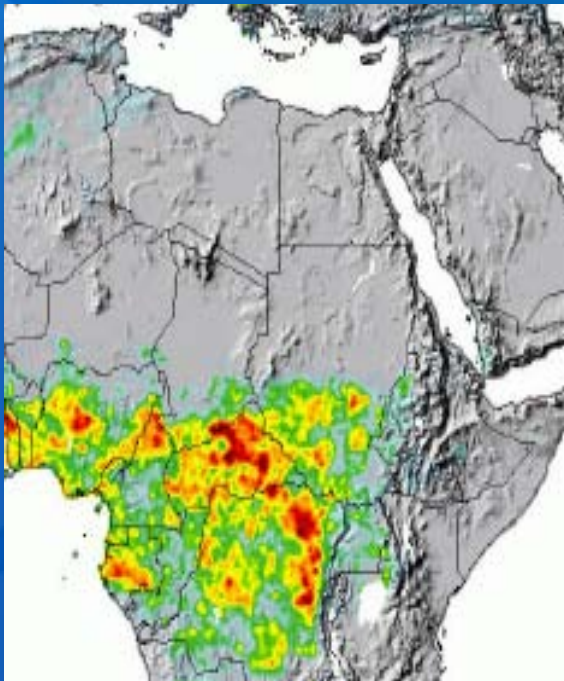
DATE	WL[M]	[m <sup>3</sup> /s]
9-Jan-68	0.32	5.59
3-May-68	2.59	127.25
1-Jun-68	0.95	21.21
18-Jul-68	0.85	16.62
16-Aug-68	1.44	39.39
20-Aug-68	1.97	64.72
22-Aug-68	2.06	70.08
30-Aug-68	1.23	29.88
6-Sep-68	0.91	20.02
17-Sep-68	0.69	13.97
10-Oct-68	0.5	9.36
16-Oct-68	0.39	7.66
22-Oct-68	0.37	7.14
22-Nov-68	0.28	6.1
14-Dec-68	0.47	9.16



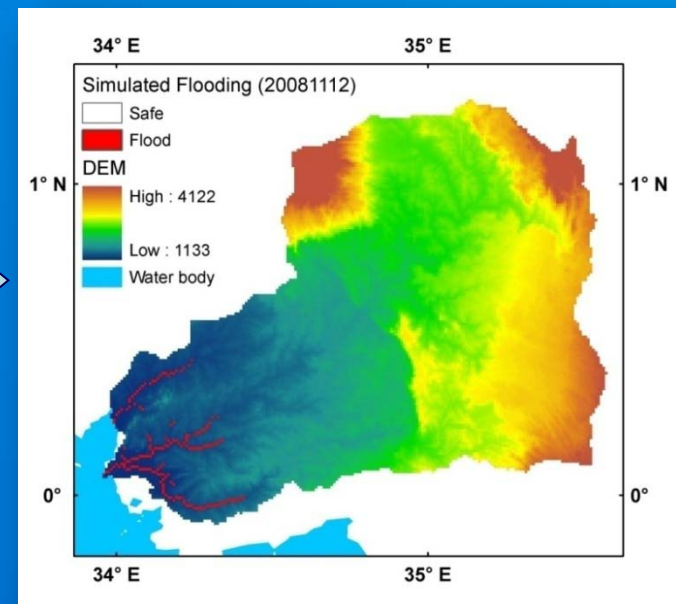
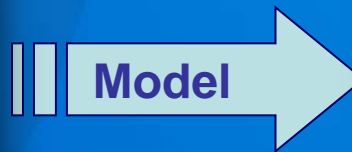


# Flood Potential Mapping

- Purpose of the effort is to estimate flood potential at high resolution for populated flood-prone areas.
- The real time hydrologic model performs a water mass balance for every time-step, and the residual water ponded at each grid cell indicates flooding potential.



TRMM 3B42 precipitation

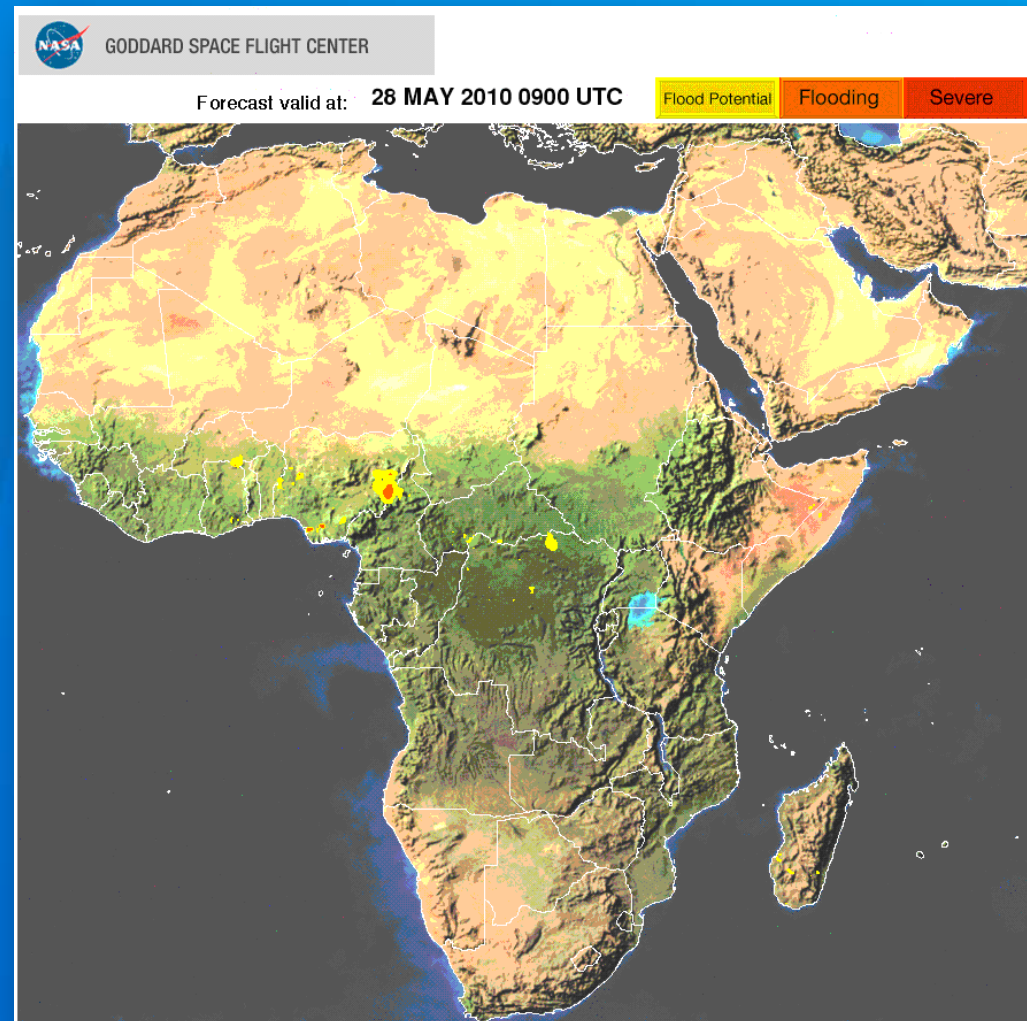


Flood potential



# Flood Forecast Mapping

- Forecasting (continental level), at 25 km, uses hydrologic model in conjunction with precipitation forecasts from Global Climate Model (NCEP and GEOS-5).
- These forecasts updated every three hours.
- Expect to produce higher resolution (12.5 km) flood forecast maps using 2<sup>nd</sup> generation global hydrological model developed in partnership with Oklahoma Univ.
- Also, developing higher resolution forecast (1-5km) for Lake Victoria Basin.



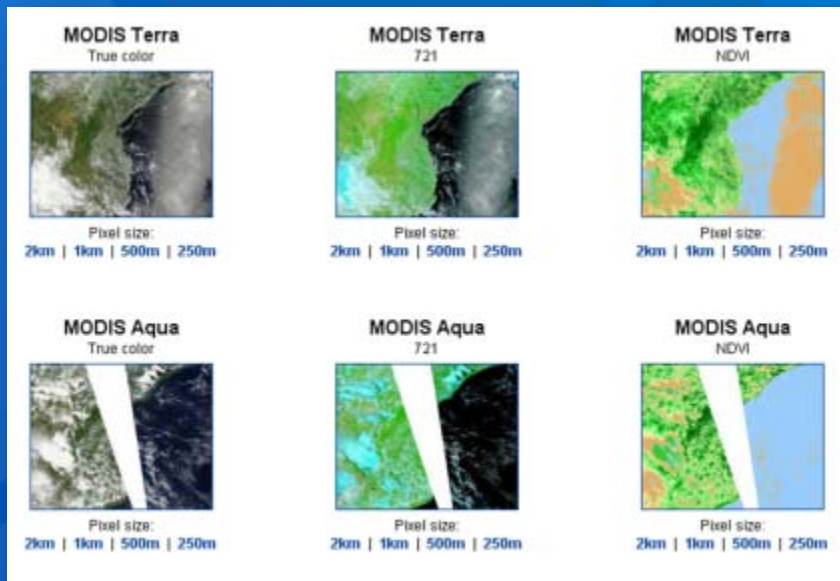
Flood Forecast





# Rapid Flood Mapping Using Satellite Data

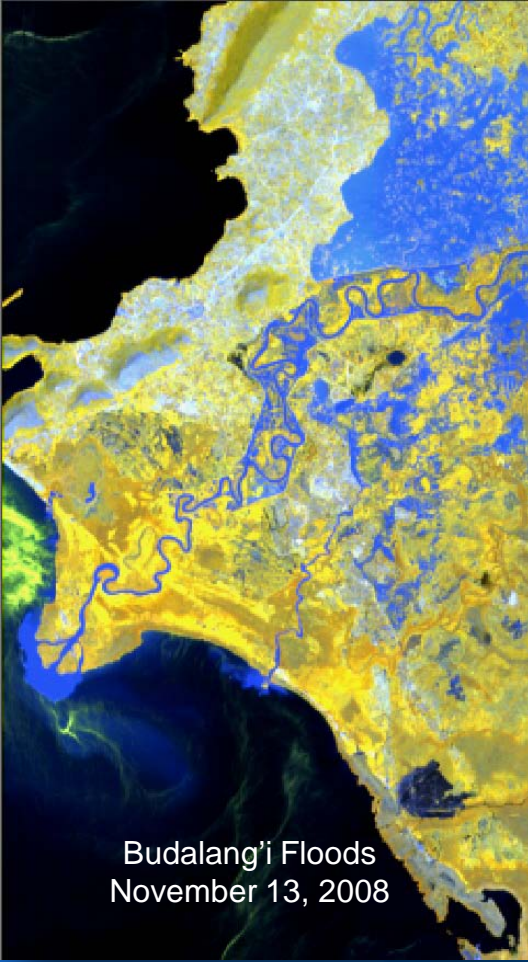
- NASA's MODIS Rapid Response System provides calibrated products to SERVIR within 5-6 hours from data acquisition.
- These products are used to create flood maps using a rapid, semi-automated approach developed by Dartmouth Flood Observatory.
- NASA working to reduce lag time to under 3 hours & trying to fully automate flood mapping process.



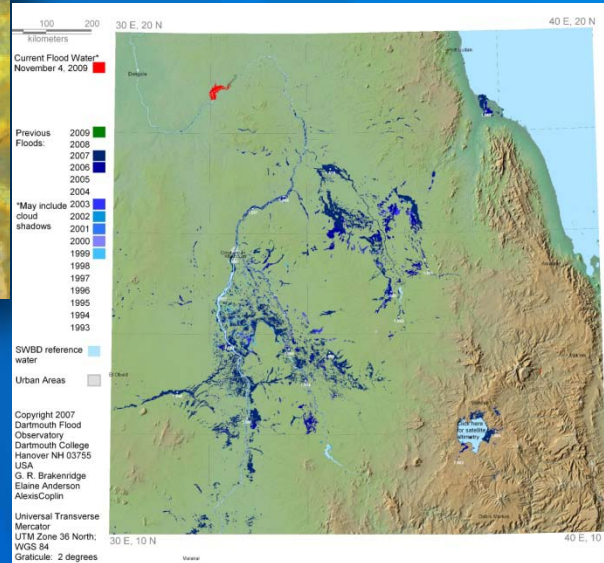
Flooding in Mozambique  
January 27, 2008



# SERVIR'S Post-event Flood Mapping



NASA's tasking request system for EO-1 to acquire baseline and post-event imagery of flooded areas.



ENVISAT & GEONETcast receivers  
installed at RCMRD



# Web-based Information Dissemination

- Results disseminated through SERVIR-Africa web portal
- Enabling discovery, access, visualization of products
- Release 1 to be launched soon

## Geospatial Data

The screenshot shows the SERVIR-Africa GeoData Portal interface. At the top, there are navigation links for HOME, SEARCH, and LAUNCH MAP VIEWER. A search bar contains the text 'Kenya' with a search button. Below the search bar, there are search filters and a list of search results. The first result is 'Kenya Lakes', followed by 'Kenya Soils', 'Kenya Roads', 'Kenya - Boundaries', 'Kenya Administrative Units', 'KENYA - AGRO-ECOLOGICAL ZONES', 'Kenya - Rivers (Africover)', 'Kenya - Roads (Africover)', and 'Kenya Rivers'. Each result includes a thumbnail image and a brief description. The 'Kenya Soils' result is expanded, showing a detailed description of the SOIL MAP OF KENYA. At the bottom, there are links for 'See results through REST' and 'API: GEORSS ATOM HTML FRAGMENT KML'.

## Interactive Maps

The screenshot shows an interactive map interface. On the left, there is a 'Layers' panel with a tree view showing 'Disasters' (GDACS - Flood Disasters), 'Ecosystems' (Landsat, SRTM), and 'NASA NEO'. Below the layers panel is a 'Layers currently on map' section showing 'Landsat' and 'GDACS - Flood Disasters'. The main map area displays a satellite image of Kenya with a semi-transparent map overlay showing flood disaster data. A 'Layer Information' panel is open at the bottom, showing details for the 'GDACS - Flood Disasters' layer, including its name, type, provider name, and URL.

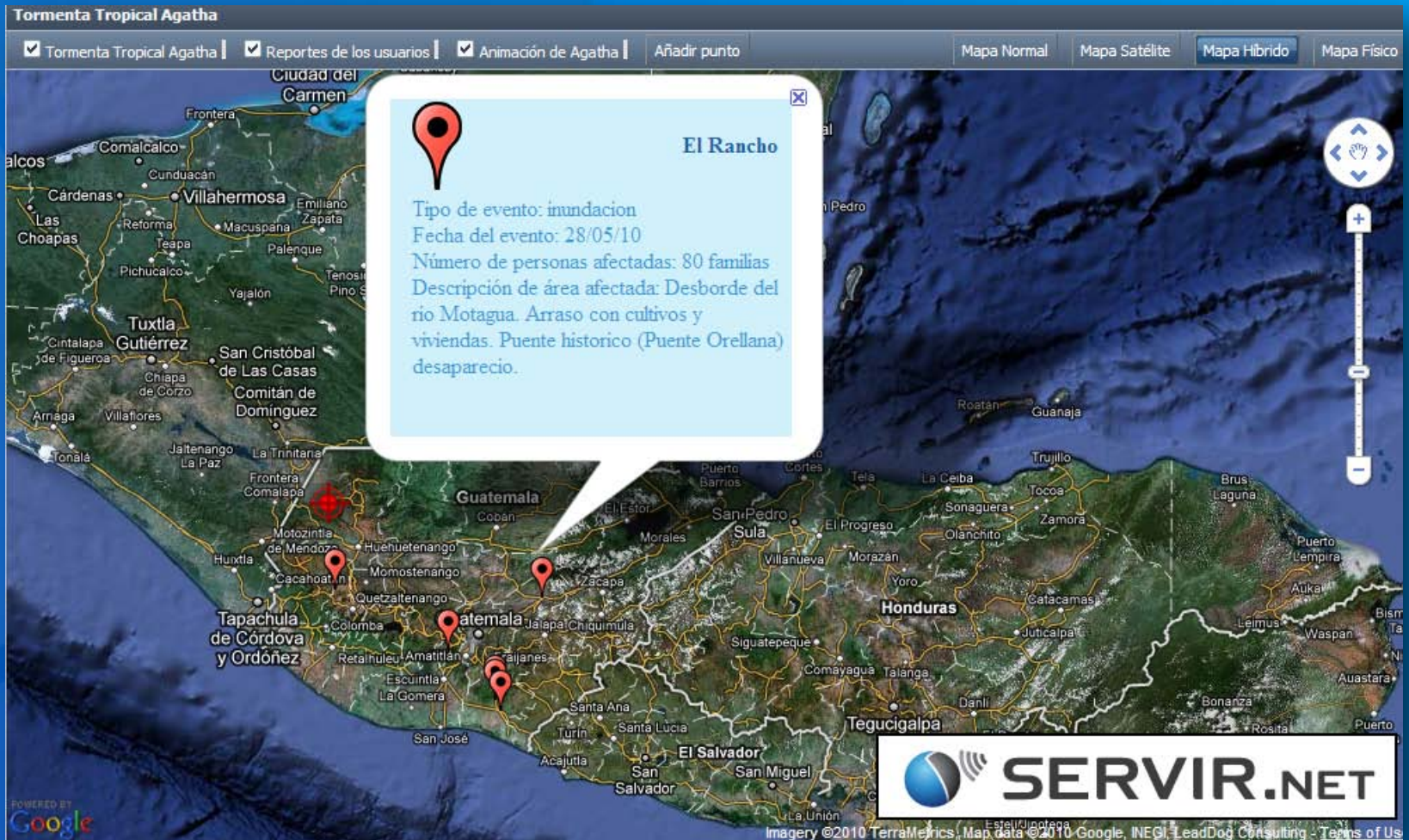
## Analyses, Printable Maps

The screenshot shows a printable map titled 'CHARTER CALL 309 FLOODING EVENT IN TANA RIVER, KENYA'. The map displays a detailed view of the Tana River region in Kenya, with various geographical features and flood disaster data overlaid. The map includes a legend, a scale bar (1:250,000), and contact information for the Charter Call ID 309. The legend identifies symbols for Villages, Roads, Rivers, Flood Area, and Areas of Influence. The contact information includes the website www.africover.org and the logo for the International Geosphere and Biosphere (IGBP).



# Looking Ahead: Event Monitoring System (“human sensor web”)

“Volunteered data” from community, e.g. photos, situation reports





# Looking Ahead: Opportunities for Collaboration

- Joint research to improve flood model/forecasting
- Ground observations - key to validating flood estimates generated using models or satellite data
- Joint training - building local capacity to run models
- Outreach - engage end-users to make use of information (and share back information) to mitigate potential hazards.
- Geospatial database and web map services training





# Summary

- SERVIR is transitioning NASA research into operational flood products
- Flood potential and forecast maps being generated using hydrologic model based approaches
- Flooding potential also being assessed using satellite data alone
- Flood extent being mapped using MODIS and EO-1 data
- Information being disseminated via SERVIR web portal
- Effort is strengthening scientific foundation and capacity for disaster management
- Public engagement is key and requires more emphasis

<http://www.servir.net>

**Thank You...!**

**SERVIR-AFRICA**  
Regional Visualization and Monitoring System

