# Near Real Time Flood Water Mapping and Modeling

Fritz Policelli

NASA GSFC Office of Applied Sciences

November 13, 2012


# Flood Mapping

# Satellite Data Sources for Flood Mapping

- NASA data is free and publicly available
  - **MODIS on Aqua and Terra satellites (250m)**
  - ASTER on Terra (30 m, revisit)
  - ALI and Hyperion on EO-1 (30 m, 3-4 day revisit)
  - Landsat 7 (30 m, 16 day revisit, scan line corrector issue)
  - LDCM to launch February 2014 (30 m, 16 day revisit)
- Other data sources available for purchase
  - Radar (RADARSAT, Terra SAR-X,
  - Optical (IKONOS, Quicksat,

# MODIS

- Terra Launch date, December 18, 1999
- Aqua Launch date, May 4, 2002
- ***MODIS LANCE system now providing***

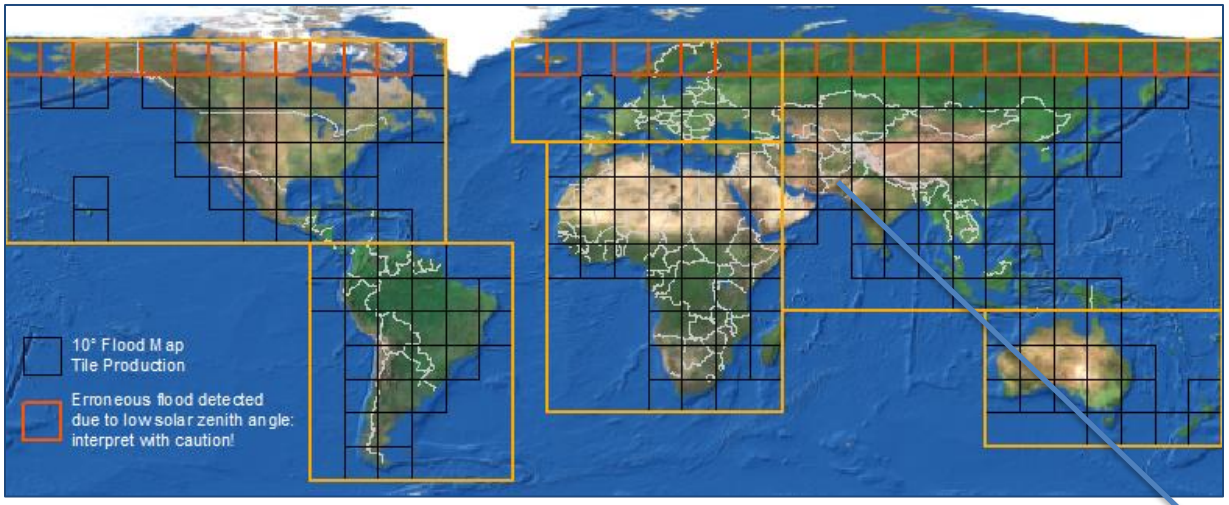
***lvl 1 and 2 products within 2.5 hours of observation***

- Follow-on sensor launched Oct. 28, 2011 (VIIRS on Suomi/ NPP)

## SPECIFICATIONS

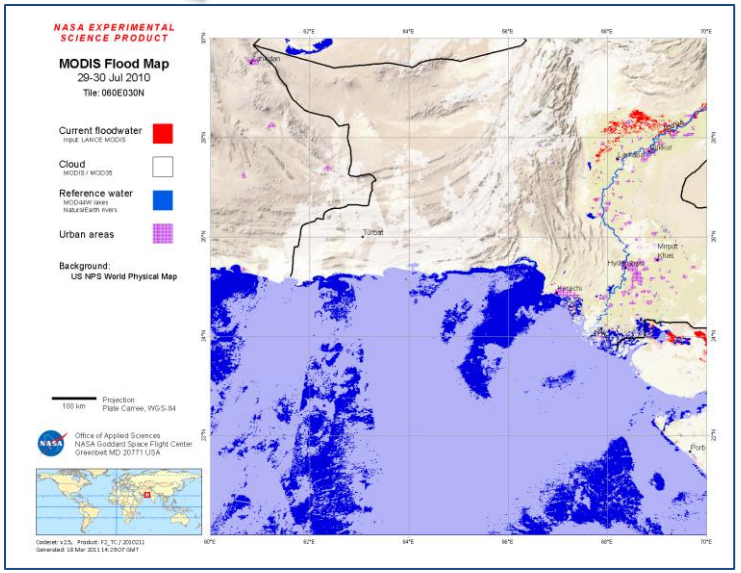
| | |
|---|---|
| **Orbit:** | 705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular |
| **Scan Rate:** | 20.3 rpm, cross track |
| **Swath Dimensions:** | 2330 km (cross track) by 10 km (along track at nadir) |
| **Telescope:** | 17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop |
| **Size:** | 1.0 x 1.6 x 1.0 m |
| **Weight:** | 228.7 kg |
| **Power:** | 162.5 W (single orbit average) |
| **Data Rate:** | 10.6 Mbps (peak daytime); 6.1 Mbps (orbital average) |
| **Quantization:** | 12 bits |
| **Spatial Resolution:** | 250 m (bands 1-2)<br>500 m (bands 3-7)<br>1000 m (bands 8-36) |
| **Design Life:** | 6 years |

# Experimental Global Near Real Time Surface Water Extent and Flood Extent Maps




http://oas.gsfc.nasa.gov/floodmap/

July 2010 Flooding in Pakistan



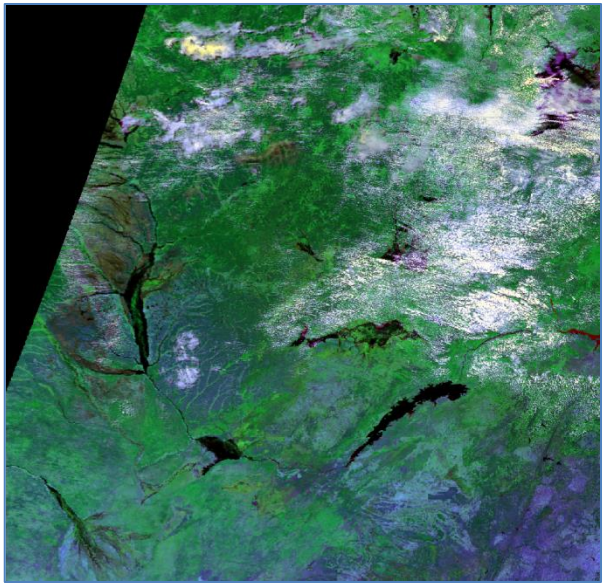

Dartmouth Observatory: http://floodobservatory.colorado.edu/LanceModis.html

# MODIS Images

Terra

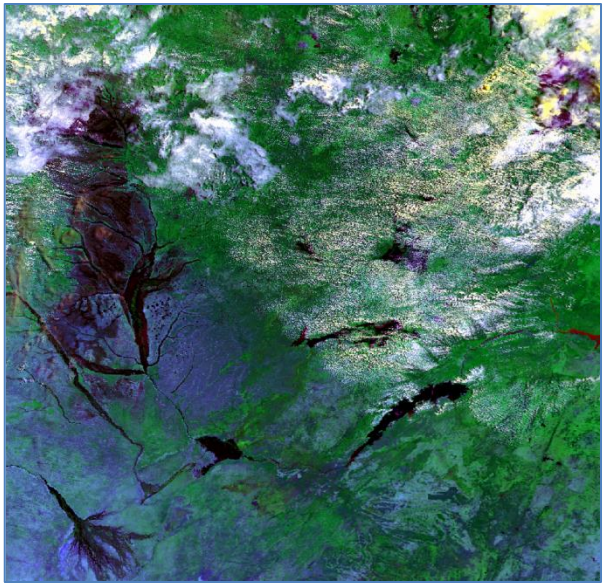
Aqua

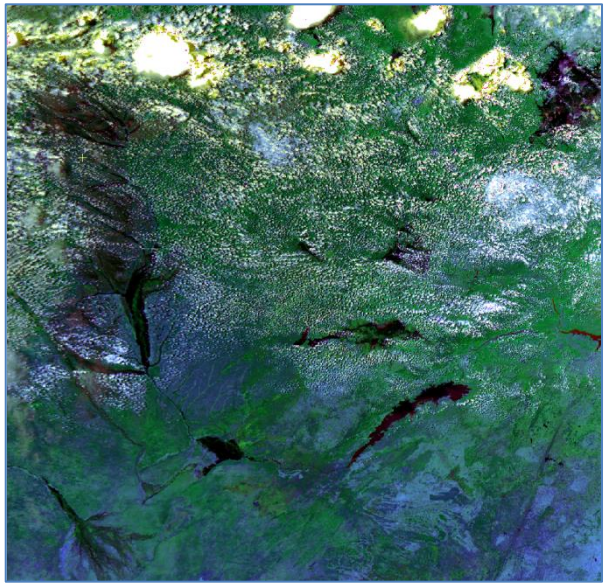
March 24, 2009



Tile h20 v10
Okavango Delta –
Lake Kariba

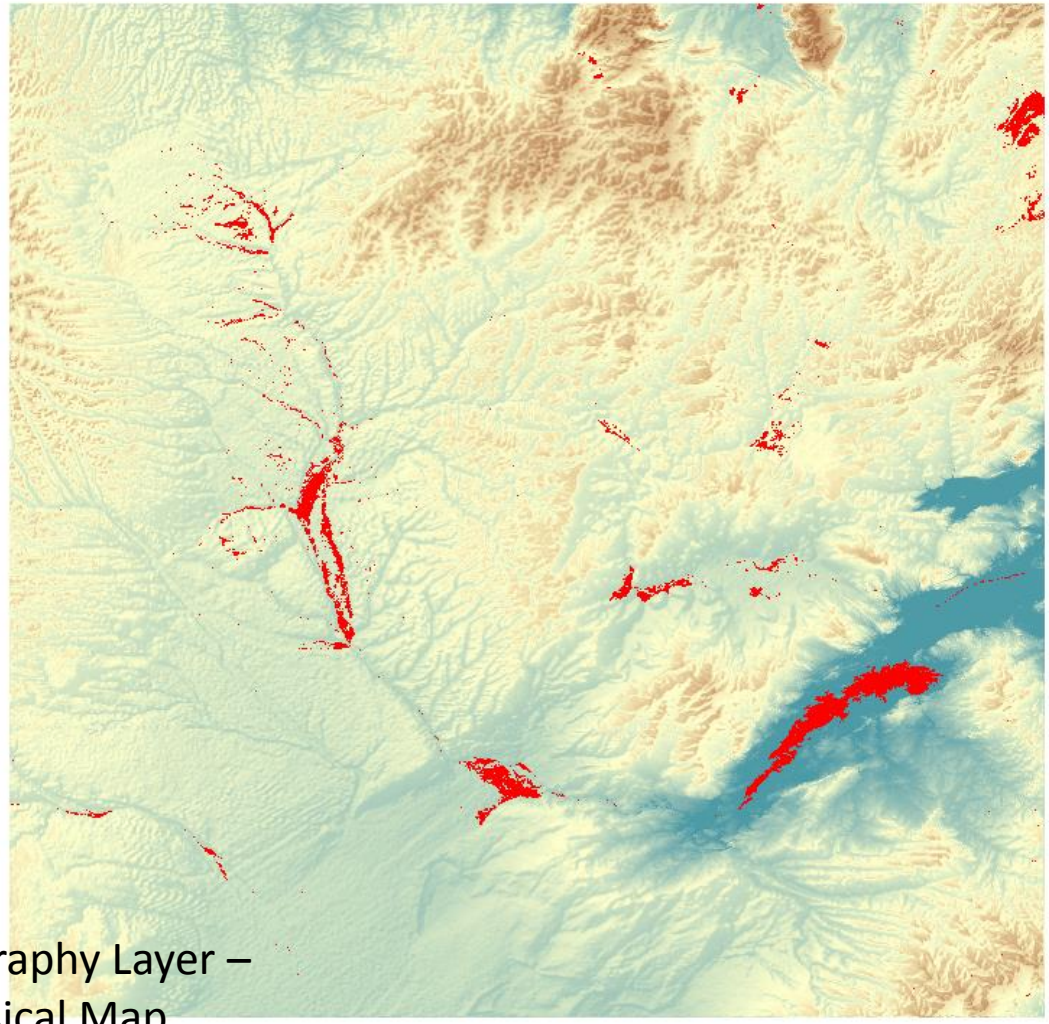
March 25, 2009





# Surface Water from MODIS Bands 1 and 2

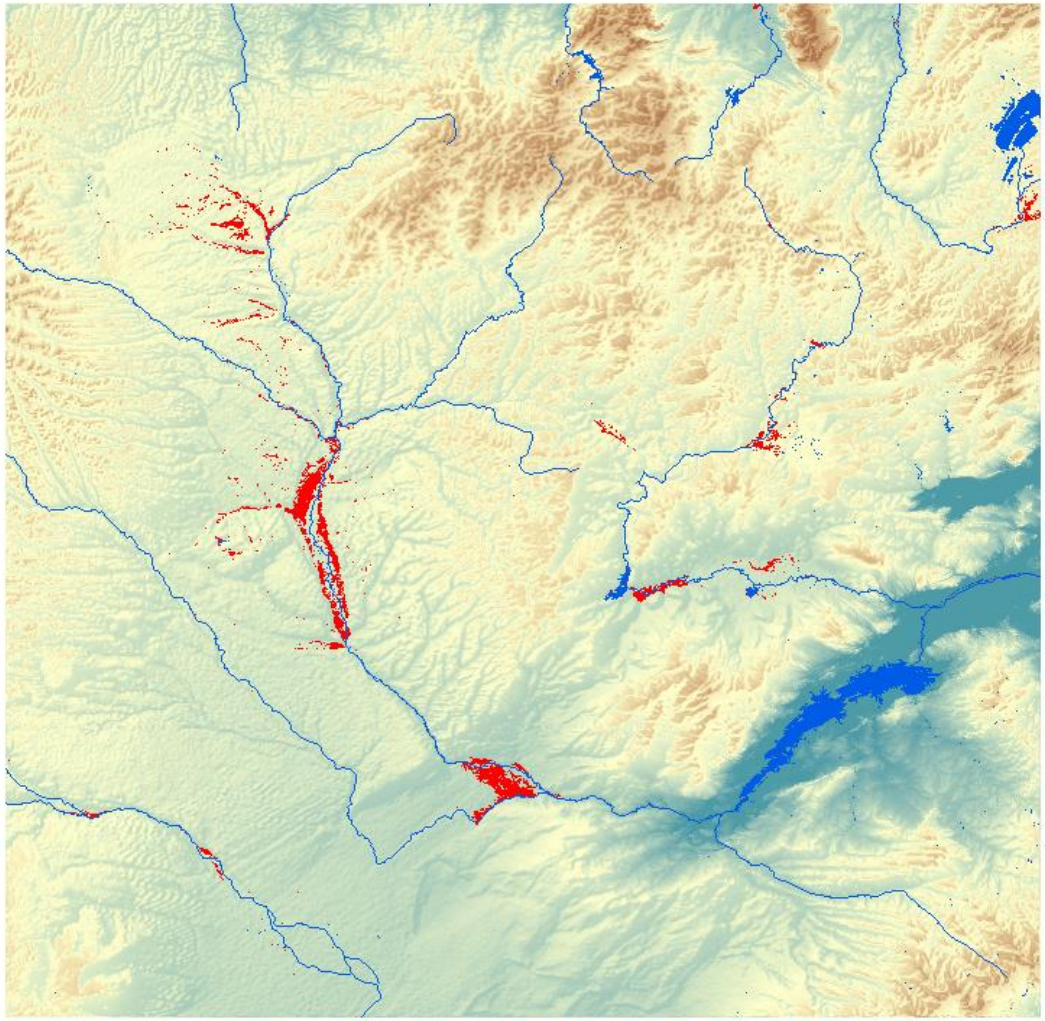
Dartmouth
Flood Observatory
Algorithm



Background Topography Layer –
US NPS World Physical Map

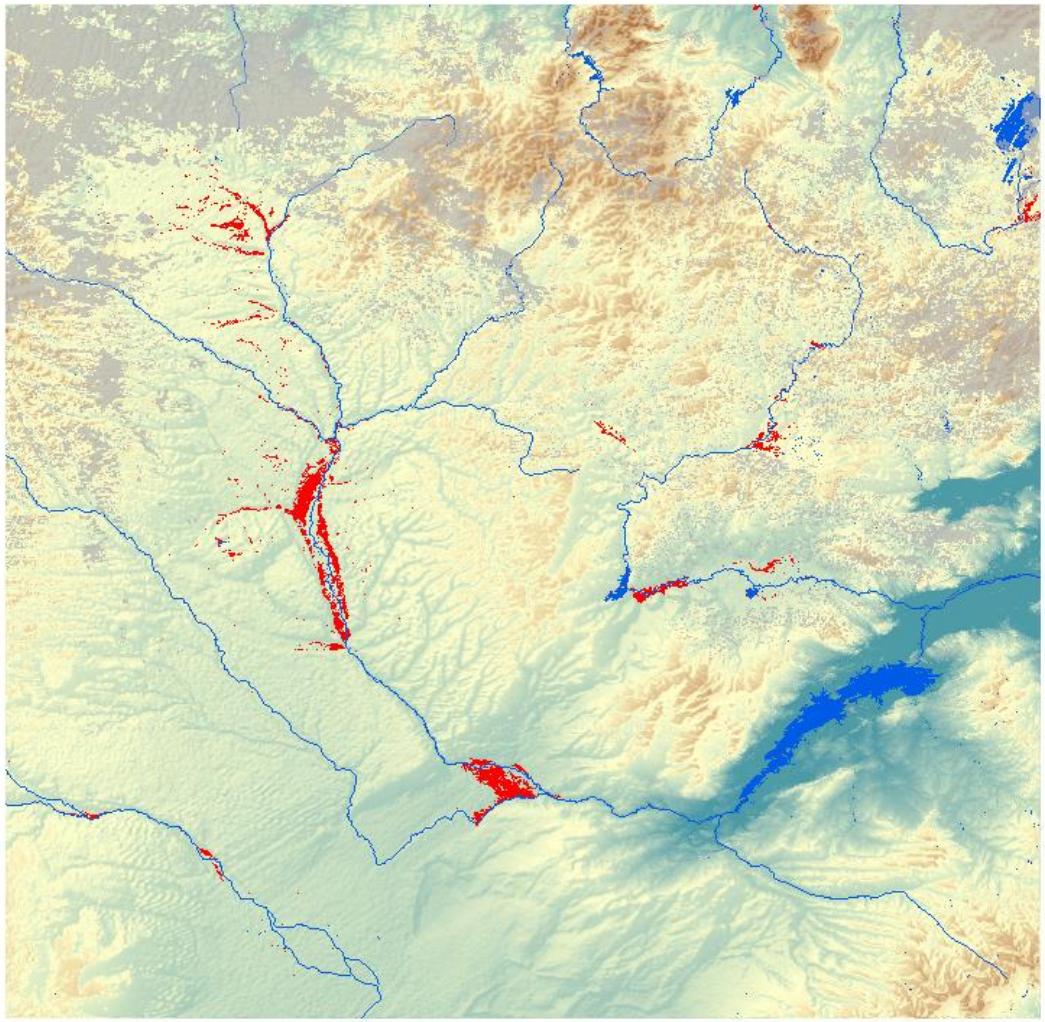
# Reference water overlay: lakes & rivers
# Remaining red = potentially flooded areas

MOD44W
overlay

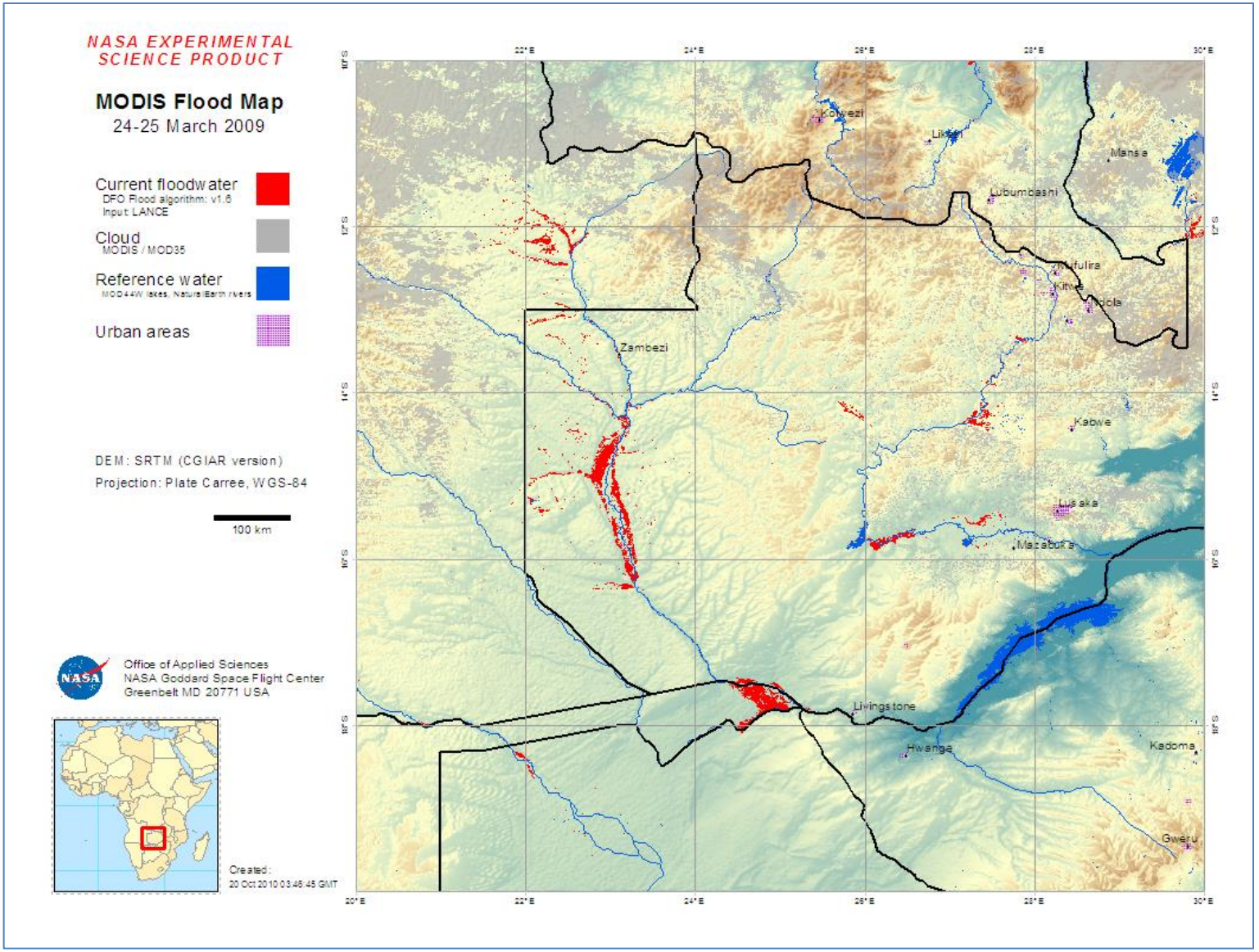


# Cloud areas masked

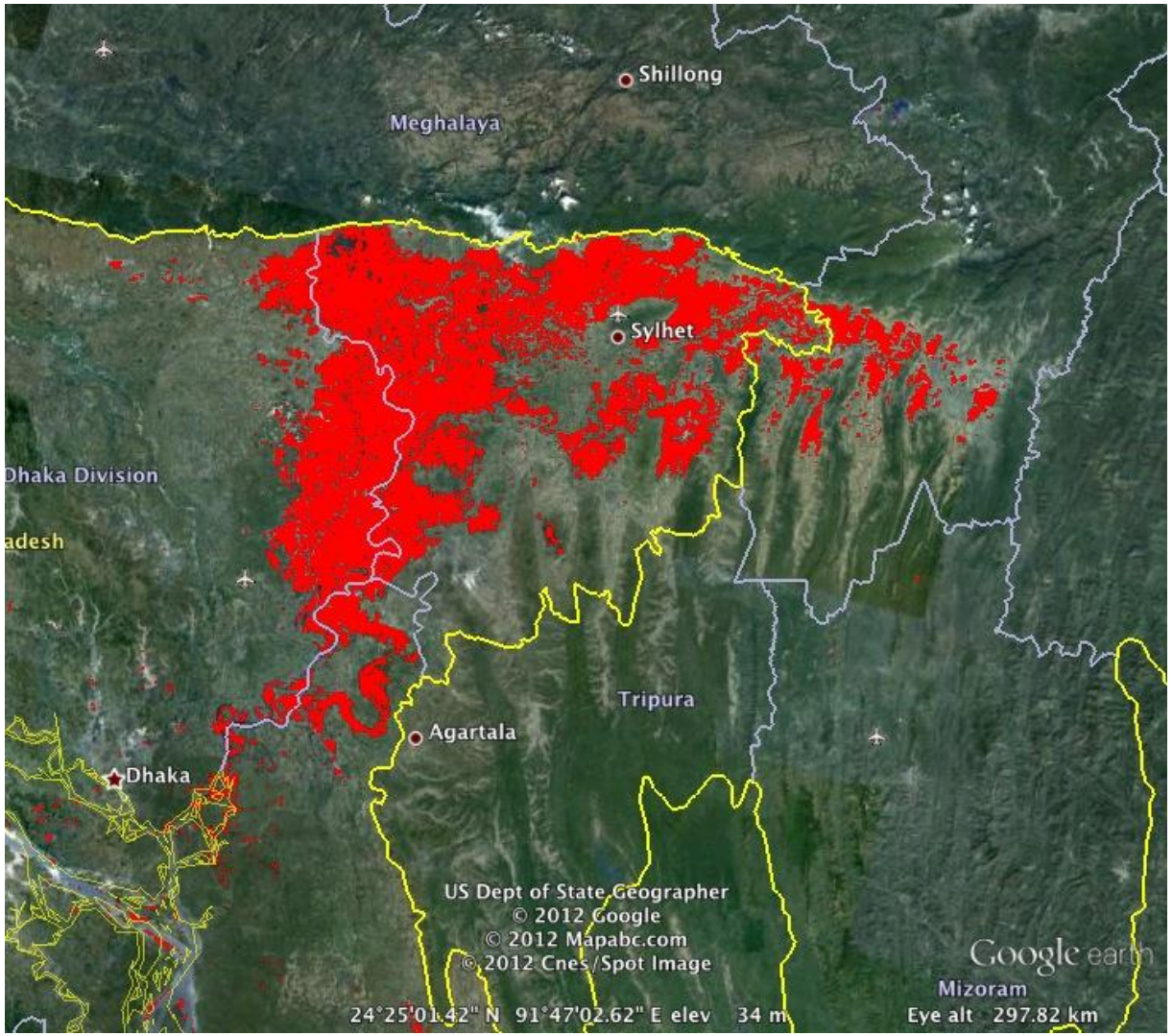
MOD35
Cloud product



# Annotations for published product



# View in Google Earth



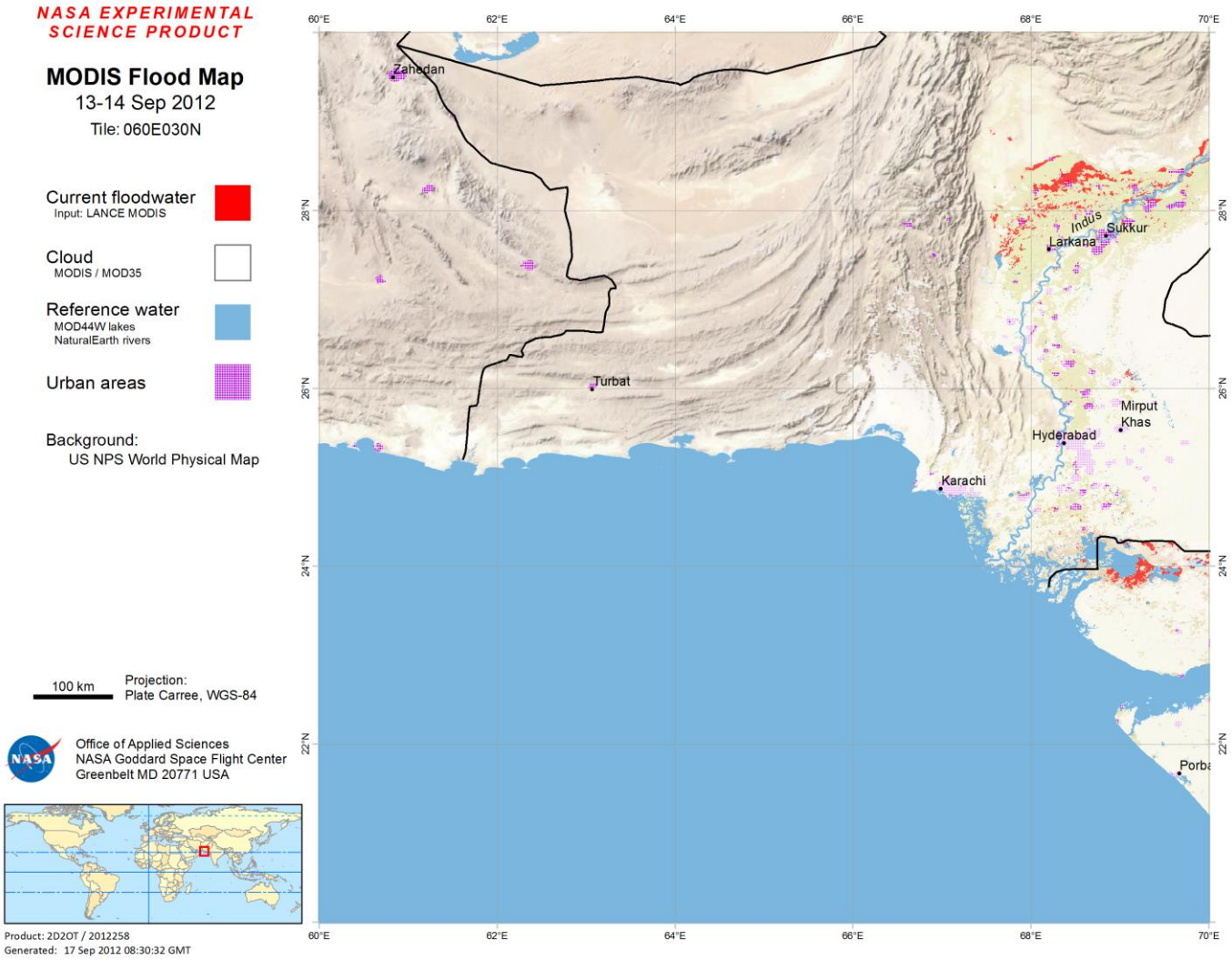

July 2012 Flooding in Assam, India

# 2012 Nigeria Floods


(Nigerian Tribute, Nov. 6, 2012) "The National Emergency Management Agency (NEMA), on Monday, released the number of casualties of this year's flooding across the country, which is regarded as the worst in five decades.

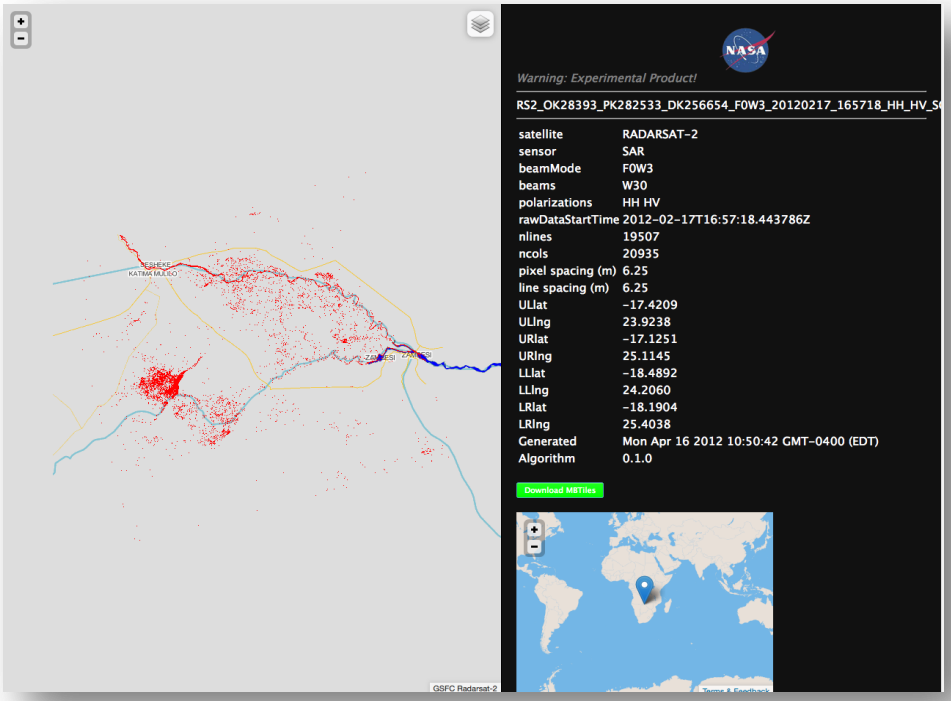
- The provisional figures released by (the Nigerian Emergency Management Agency) indicated that a total of 7,705,398 persons were affected by the flood between July 1, 2012 and October 31, 2012.
- It added that out of the affected population, 2,157,419 Internally Displaced Persons (IDPs) were registered across the affected states.
- The figure also showed that 363 persons died while 18,282 people were treated for injuries they sustained during the flooding."

# Pakistan Flooding 2012



# Radar Flood Mapping

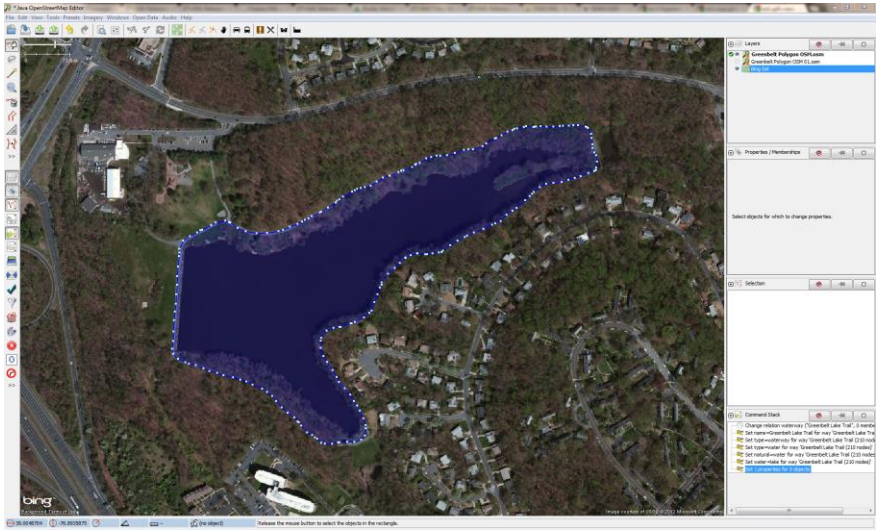
- Partnership with CSA under CEOS/ GEO flood pilot projects
  - CSA has provided 400 free tasking requests for RADARSAT 2
  - Approx. 160 tasking requests to date in 2 pilot regions
  - Maximum resolution:  3m
  - Project includes training and capacity building for use of radar data in partner areas through CEOS project (CSA and other funding)




Prototype Automated RARDARSAT 2  Flood Map:  April, 2012 Flooding in Namibia

# In-situ Measurements of Water Extent to Enhance Satellite Data
# Waterpedia Project: Collaboration with Open Street Map

P.I. : Dan Mandl, NASA GSFC



GSFC Lake & Greenbelt Lake – Students Taking GPS Points

Left: Neil Shah, Summer Intern, Univ. of Md College Park, major Aerospace Engineering, Middle: Chris Flatley, summer intern, Virginia Tech, major Computer Engineering

Joshua Bronston, Navajo Tech College
GSFC Coop student – Pursuing Masters in Computer Engineering

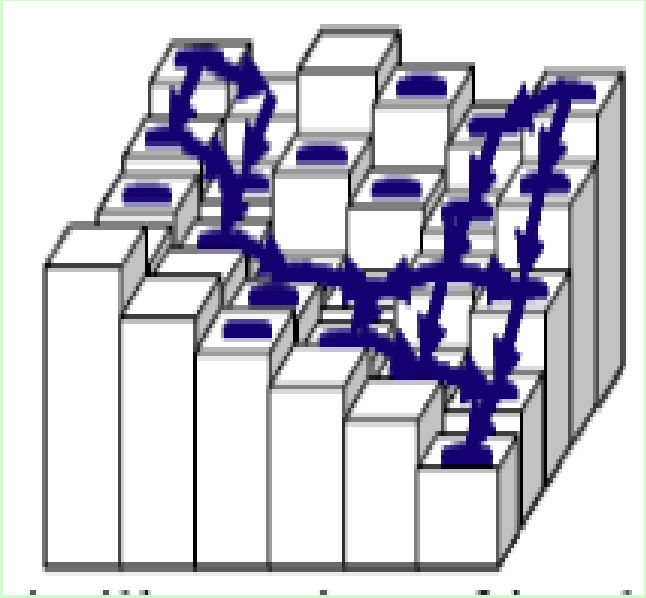
# Next Steps

- Complete MODIS flood map product improvements
- Validation/ incorporate lessons learned
- Process historical flood maps for MODIS record
- Transition MODIS flood mapping to operations – Pacific Disaster Center
- Fully automate RADAR flood mapping (for Caribbean)
- Landsat Flood Maps (for Caribbean)– 16 day revisit
- Investigate merged products


# Flood Modeling

# NASA/ OU CREST Cell-based Water Balance Model

## Cell-to-Cell Flow Routing



Storage = (Precip. — ET) + (Inflow – Outflow) - Infiltration

**Step I: Rainfall-infiltration Partitioning (Distributed and Time-variant)**

**Step 2: Flow Routing using Macro-scale Cell-to-Cell Algorithm**

**Step 3: Flood Inundation Mapping**

# CREST Flood Model Inputs

**Digital Elevation Model (and derived products) = SRTM Hydrosheds product**

- 90 m = highest resolution hydrologically corrected product available
- 250 m resampled product
  - Computational requirements for calibration
  - Direct Comparison with MODIS flood maps
- Evaluation using Landsat imagery of rivers

**Precipitation = TRMM TMPA-RT product**

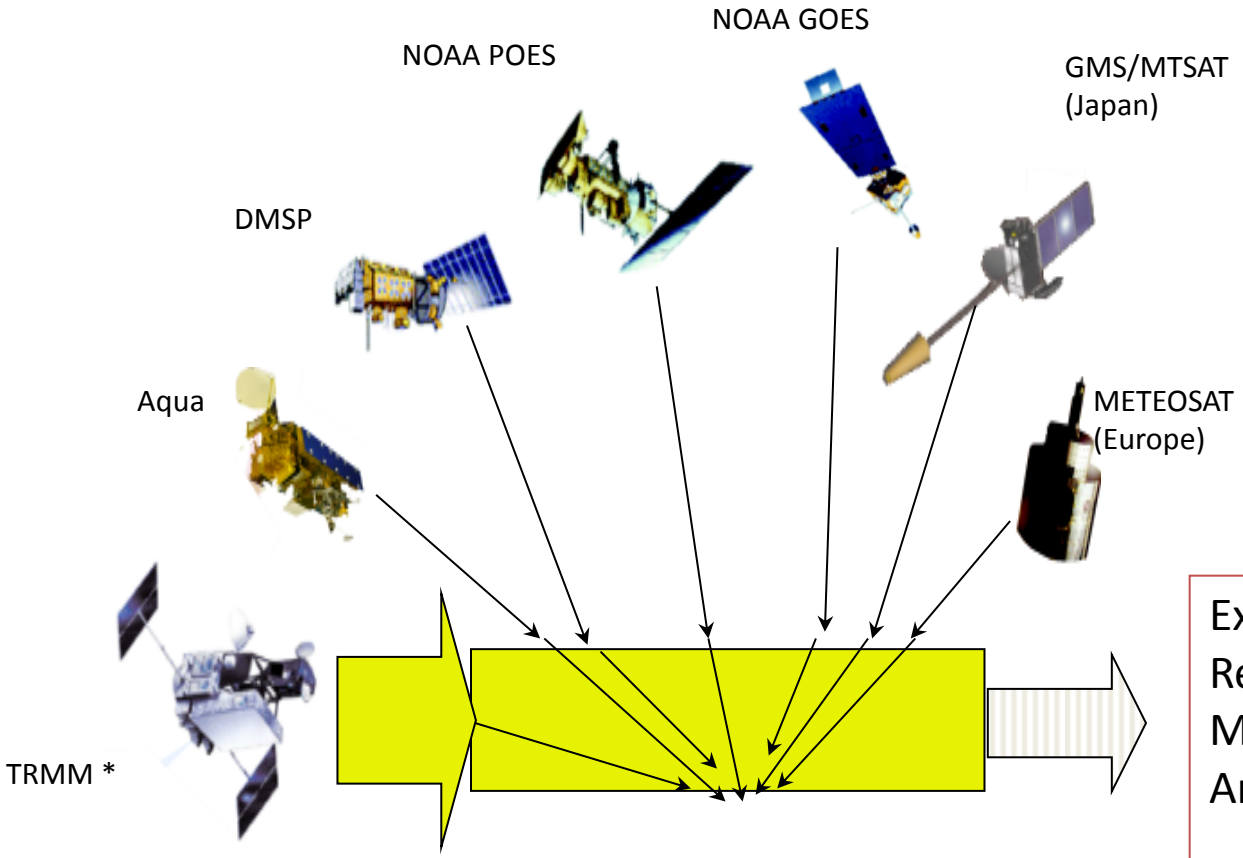
- 0.25 degree resolution product
- 0.10 degree “IMERG” product under development at NASA GSFC
- Evaluation using rain guage measurements

**Evapotranspiration = FEWSNET Climatology product**

- 0.25 degree monthly historical average
- Investigating use of ALEXI model data, daily NRT FEWSNET product
- In-situ Measurements?

**Stream gauge data for calibration !**

# Key Model Input - NASA Near Real Time *Rainfall Measurements*




Experimental Near Real-Time TRMM Multi-Satellite Precipitation Analysis (TMPA-RT)

* TRMM used to calibrated all other satellites

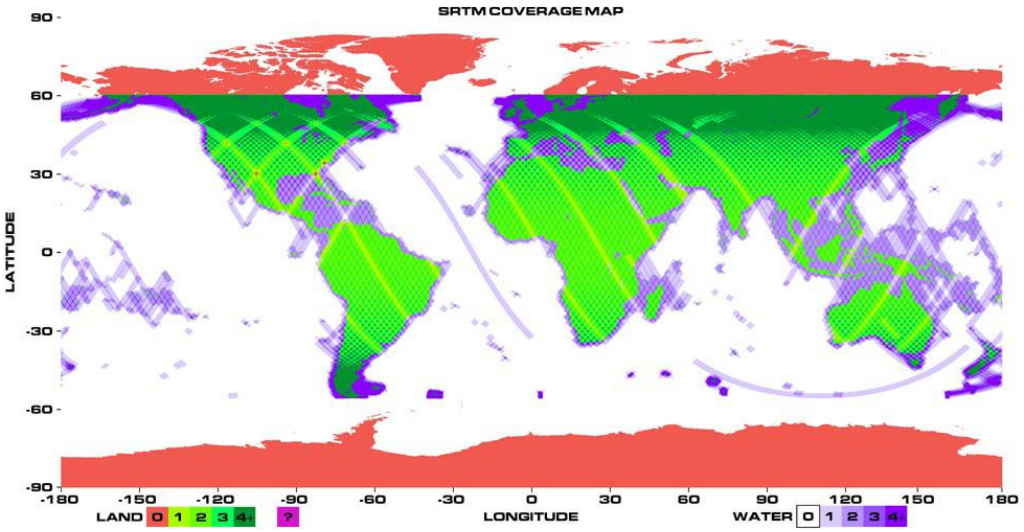
From: Hong, Adler

Global Precipitation Measurement (GPM) Mission to Launch February 2014

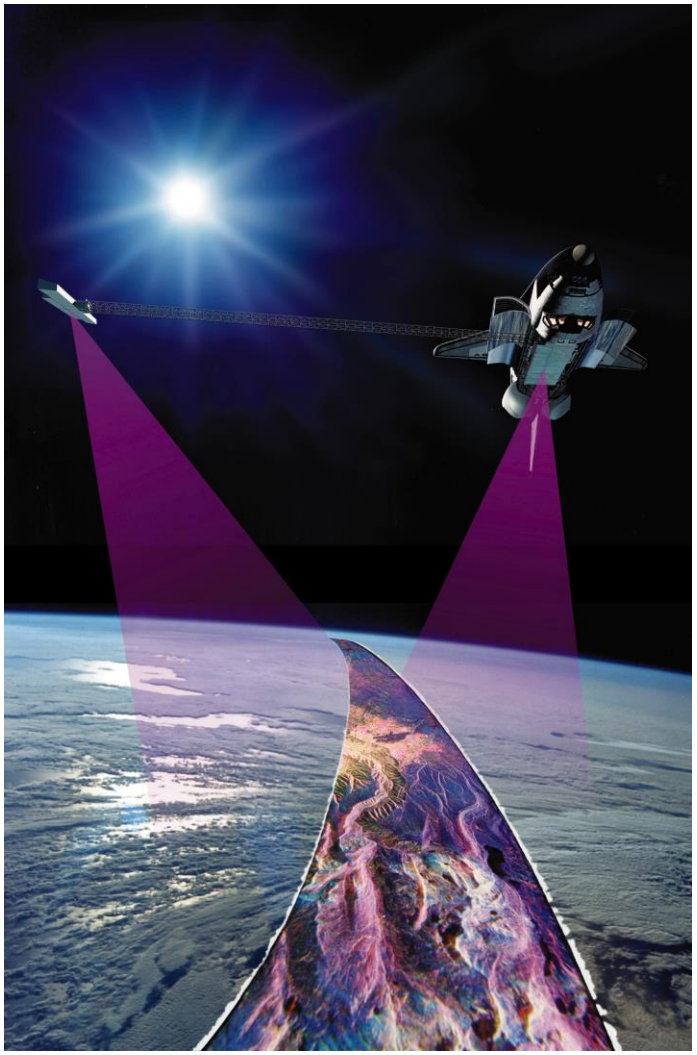
# Shuttle Radar Topography Mission - (SRTM)

Measurements: gridded elevation data of 80% of the Earth's surface

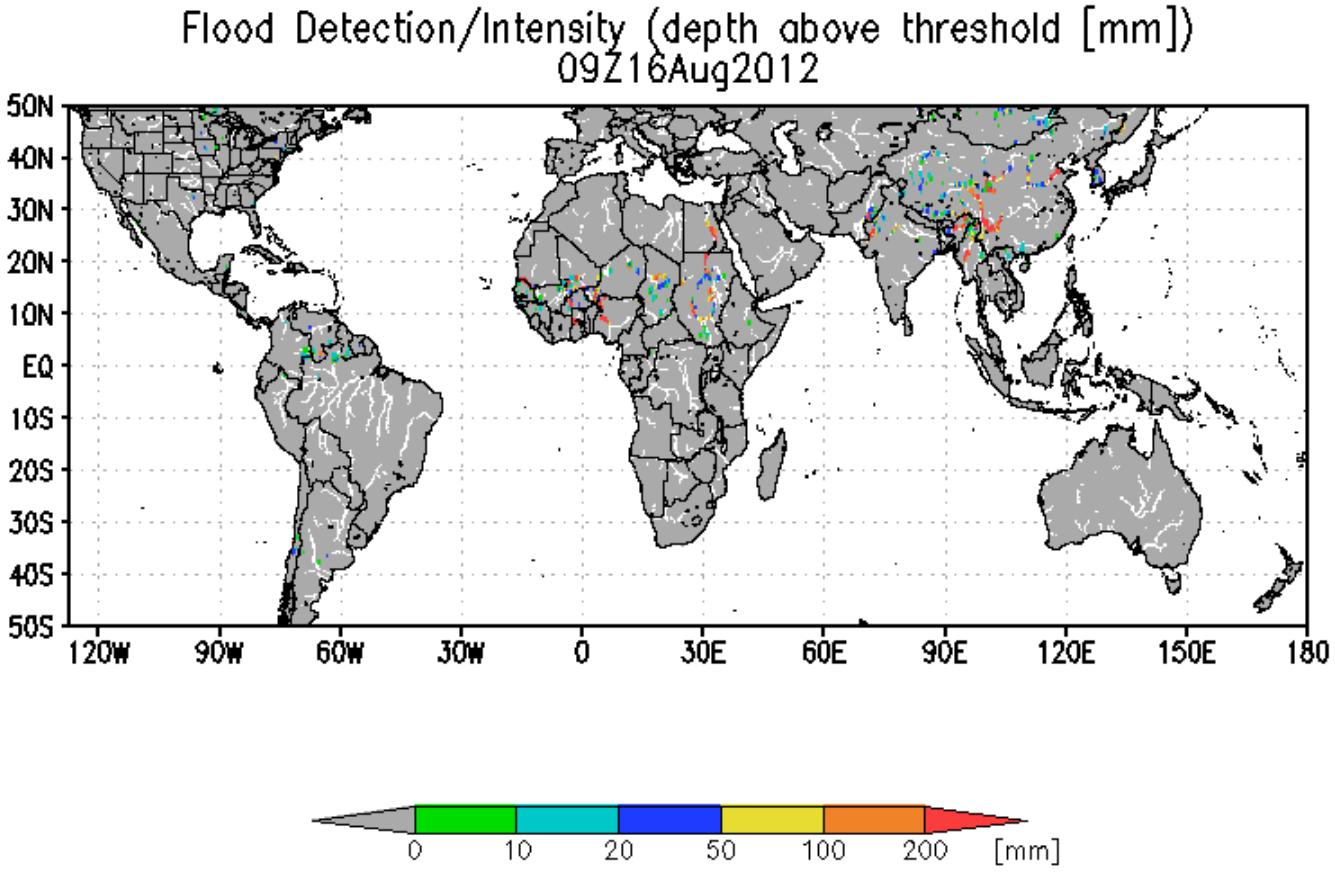
- 30m – 90m spatial resolution




**Most land surfaces between 60 degrees north latitude and 54 degrees south latitude.**



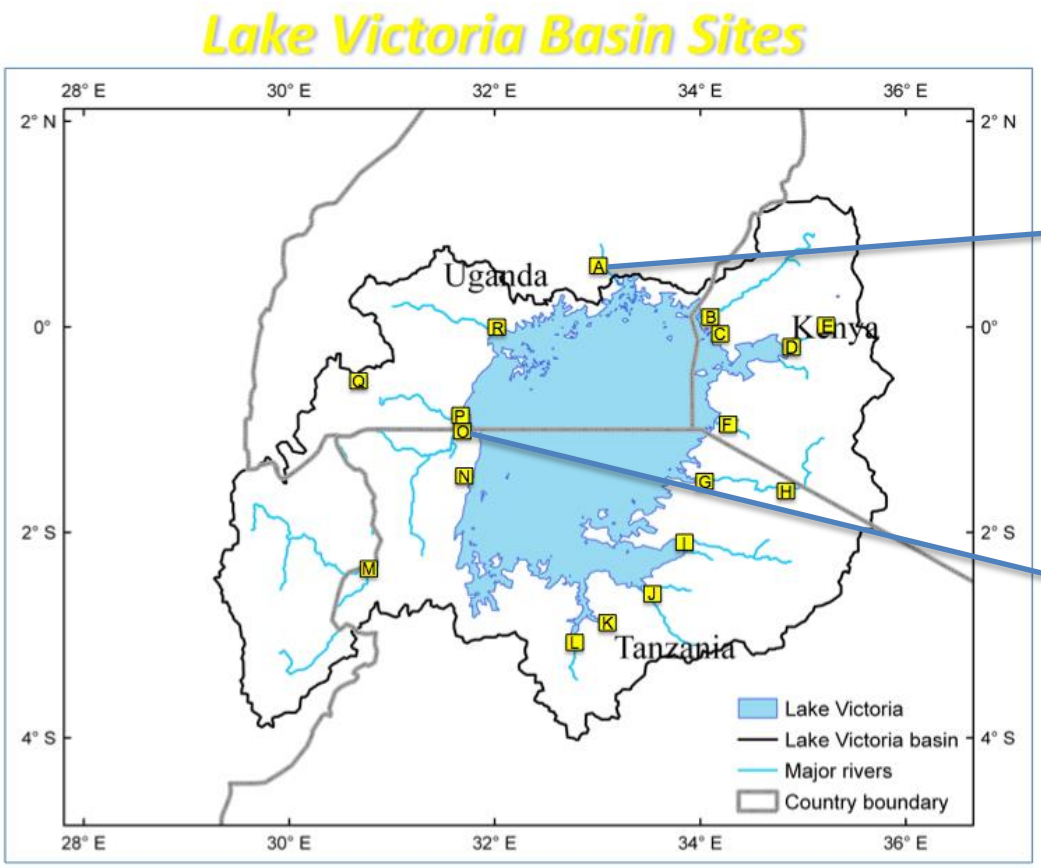
# CREST Global Flood Model

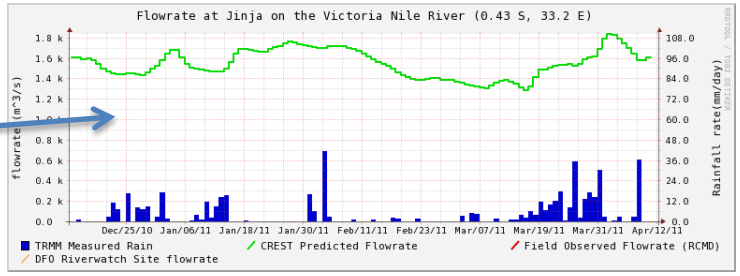


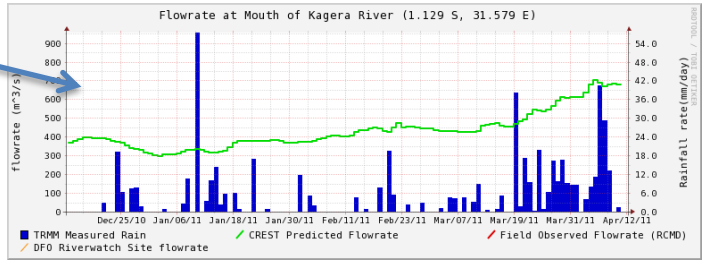

Spatial Resolution: 1/8th Degree

P.I. Bob Adler/ UMD ESSIC

# Lake Victoria Basin Flood Modeling

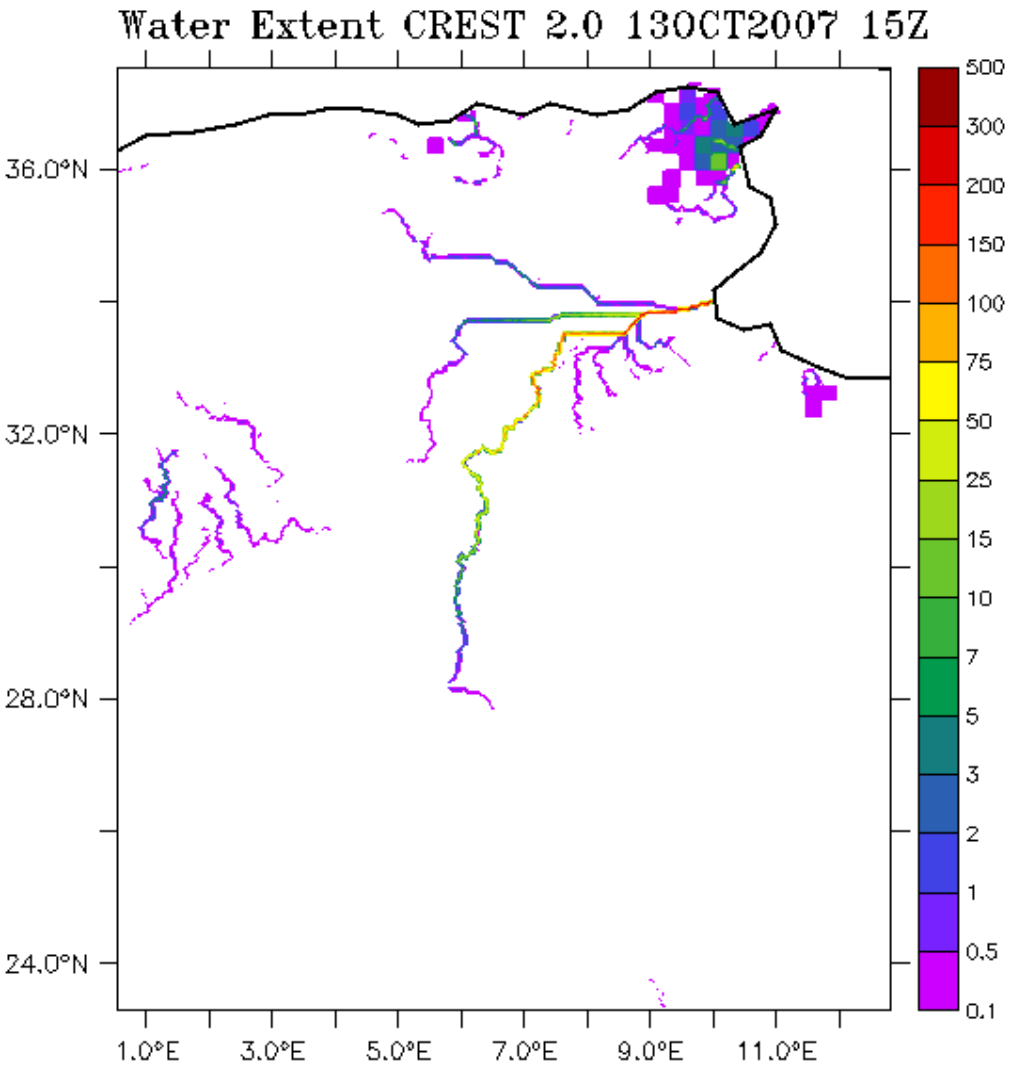


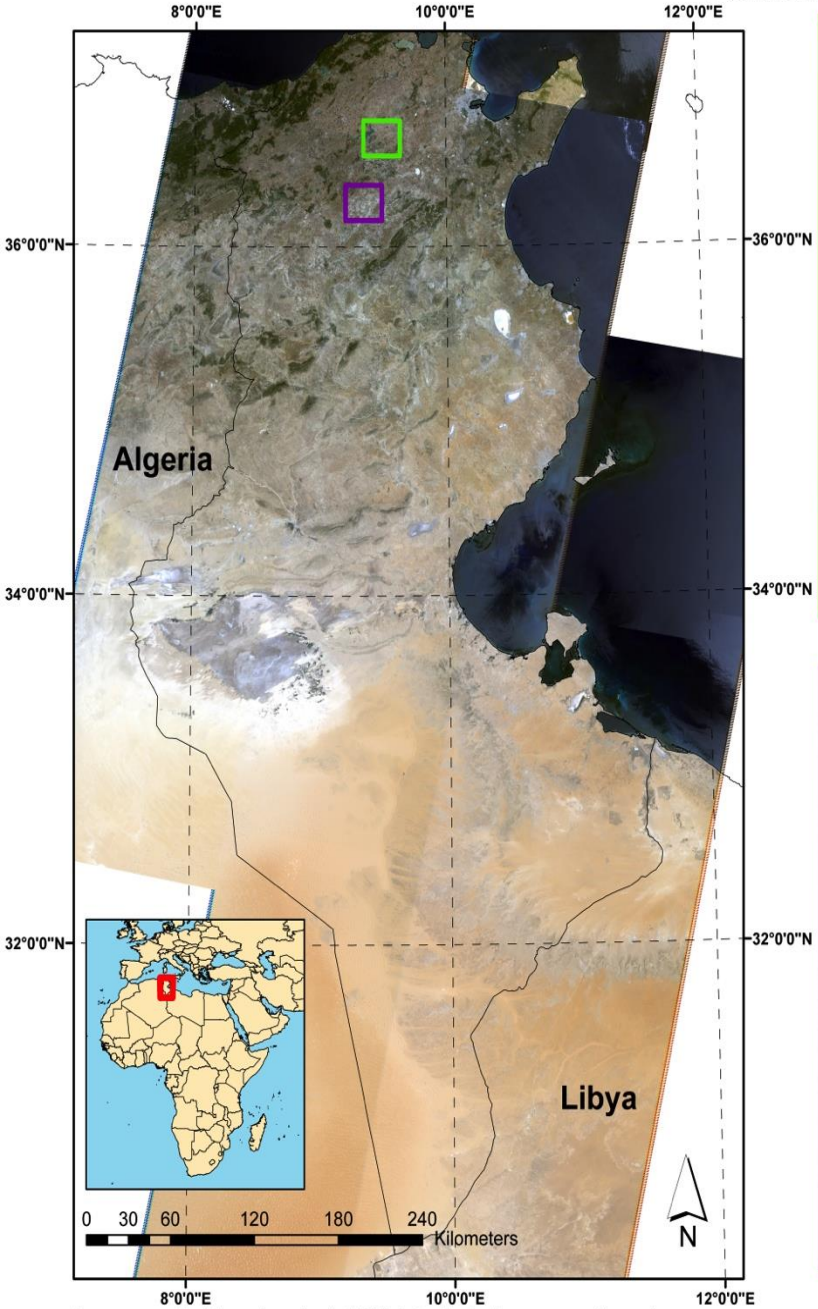

**SERVIR-Africa Project**

# Water Extent (mm) Tunisia Flood, 13th Oct. 2007
# CREST 2.0 Model Simulation – *initial results*




**NASA-USAID-World Bank**
**MENA WISP Project**

# Tunisia Flow Accumulation





HydroSHEDS Con 90m FAC


HydroSHEDS Con 250m FAC

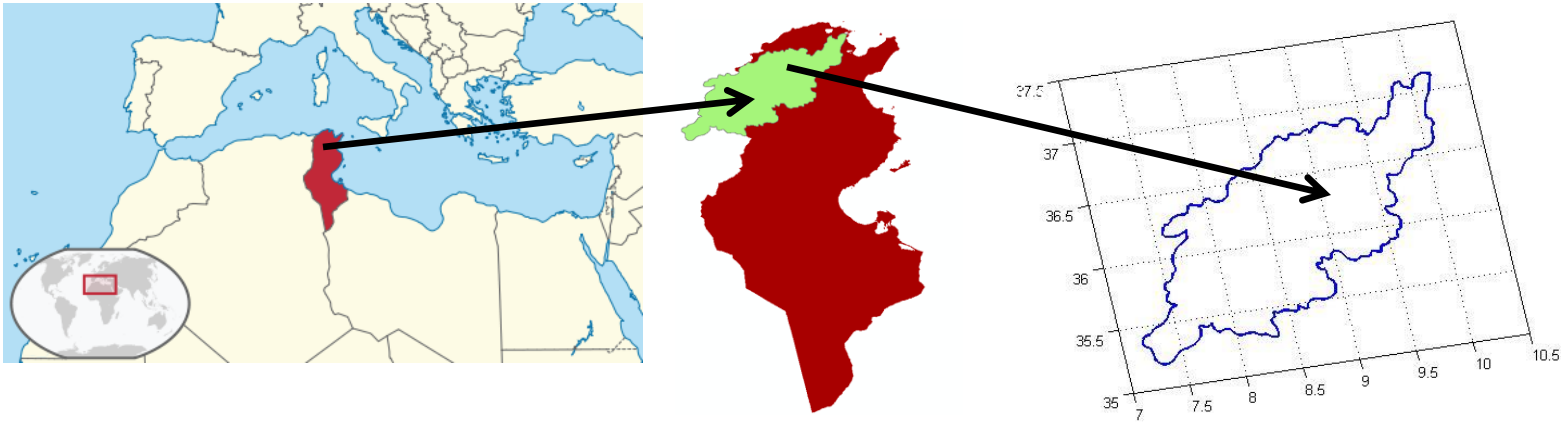

HydroSHEDS Con 90m FAC

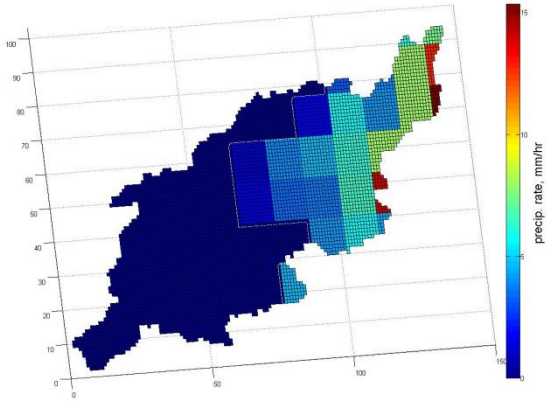

HydroSHEDS Con 250m FAC

Image created from Landsat 5 TM data includes scenes from June 2003 and June of 2011. Thematic mapper bands 3, 2, and 1 are displayed as red, green, and blue colors, respectively.

Map Created By: Katherine Melocik
Date Created: 11/08/2012
Data Sources: ESRI, NASA

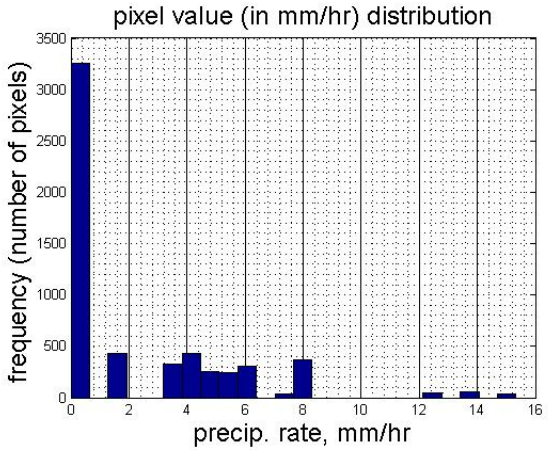
# TMPA-RT Satellite Precipitation Data
# Medjerda River Basin, northern Tunisia



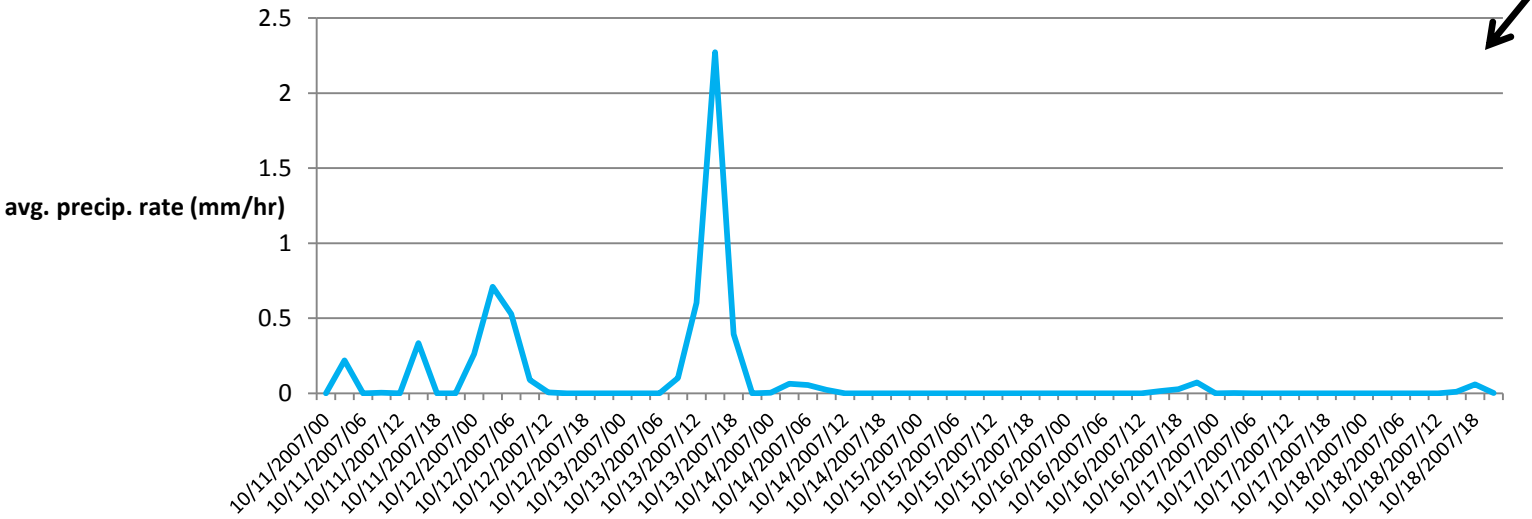

**Left:** Precipitation rates (mm/hr) over Medjerda River Basin, 10/13/2007, 18:00 Z

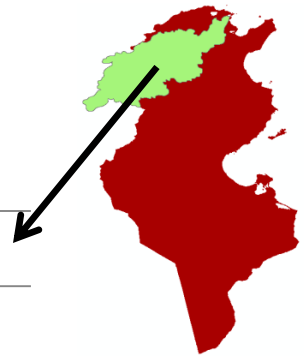
**Right**: Precipitation rate frequency distribution, Medjerda River basin, 10/13/2007, 18:00 Z




G.A. Michalitsianos, 2012

# TMPA-RT Satellite Precipitation Data
# Medjerda River Basin, northern Tunisia



# Flood Modeling Challenges

- Precipitation data accuracy and spatial resolution
  - New Retrieval Algorithms being developed for GPM mission
  - Combine NRT rain gauge and satellite data
- Elevation data accuracy and spatial resolution
  - 30m SRTM and ASTER DEMS – availabilty/ need hydrological correction
  - Purchase hi resolution LIDAR data for areas of interest
  - In the Future:  LIST (Tier 3 Decadal Survey Mission) !
- Dams/ hydrological infrastructure
- Require stream gauge data for calibration !
- Require precipitation forecasts from national Met Offices
- Calibration is computationally expensive
  - Parallel processing and super-computing assets


# Looking Forward to:

# GPM Mission

GPM Launch Feb. 2014

**IMERG Early Precipitation Product**

- Multi-satellite precipitation product currently under development at the NASA Goddard Space Flight Center.
- Products will be provided at 0.10 deg resolution, every 30 minutes.
- Data latency for the IMERG Early product is approximately 4 hours.
- This product uses techniques borrowed from TMPA, CMORPH, and PERSIANN. (note 1)

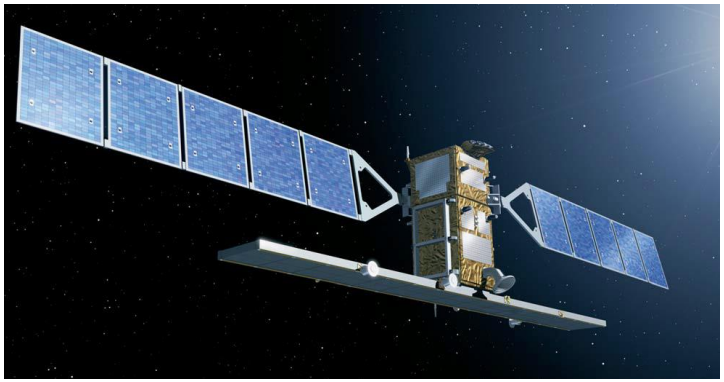
Note 1

a. Precipitation estimates are calculated using gridded and intercalibrated satellite microwave data,

b. then processed by both the CMORPH Kalman Filter Lagrangian time interpolation scheme and the PERSIANN Cloud Classification System re-calibration scheme, both of which use zenith-angle-corrected, intercalibrated geo-IR fields.

c. Finally, the CMORPH-Kalman Filter Lagrangian time interpolation uses the microwave and IR estimates, and input from the PERSIAN-CCS to create half-hourly estimates.

# ESA Sentinel 1 Radar Mission



Expected Launch: 2013
Expected Free and Open Data Policy

- C-Band Radar
- Six day orbital repeat
- Near real time delivery of data within an hour after reception by the ground station
- Four standard operational modes, designed for interoperability with other systems:
  - Strip Map Mode, 80 km swath and 5 x 5 m spatial resolution;
  - Interferometric Wide Swath Mode, 250 km swath, 5 x 20 m spatial resolution
  - Extra-wide Swath Mode, 400 km swath and 25 x 100 m spatial resolution
  - Wave Mode, low data rate and 5 x 20 m spatial resolution. Sampled images of 20 x 20 km at 100 km intervals along the orbit.

http://www.esa.int/esapub/bulletin/bulletin131/bul131a_attema.pdf


# Questions or Comments?

# Co-I's, Collaborators, Partners

- **Co-Investigators**
  - Bob Brakenridge: U. Colorado Flood Observatory
  - Dan Slayback (SSAI/ GSFC)
  - Stuart Frye (SGT/ GSFC)
  - Maura Tokay (SSAI/ GSFC)
  - Lola Fatoyinbo (NASA/ GSFC) with Stephanie Long (NASA intern)
  - Matt Smith (SSAI/GSFC)
  - John David (SSAI/GSFC)

- **Collaborators**
  - Ed Masuoka/ LANCE- MODIS Team
  - Pat Cappelaere (Vightel, Inc.)
  - Dan Mandl/ GSFC Sensor Web Team
  - Guy Seguin, Guy Aube, Andrew Eddy (Canadian Space Agency)
  - Chris Chiesa (Pacific Disaster Center)
  - Guoqing Sun (UMD)
  - Marc Imhoff (GSFC)

# Open Issues – Radar Flood Mapping (1)

Method 2 - development of a database of “dry scene” radar data

- limitations on view angle:

  From Guoqing Sun: “For the open water, we'd like to have lower backscattering so incidence angel should be larger but for radar to penetrate into vegetation revealing the flooded surface, the incidence angle should be smaller (looking steeper down) if the vegetation is dense and high. I think incidence angles of **30-40 degrees** should be fine.”

- scalability of this approach to global ?

More Radar data sources would enhance project

- Lost Palsar on ALOS
- Lost ASAR on Envisat
- Discussions with ESA:
  - Sentinnel 1 to Launch: 2013 (Last update: 16 March 2012)
  - Data policy to be free, open
  - Potential to submit tasking requests
- Discussions with DLR (Terra Sar-X)
- Discussions with ASI (Cosmo-Skymed)

Funding

# Letter of Support from World Food Programme

Fighting Hunger Worldwide

WFP
World Food Programme
wfp.org

16 November 2011

To Whom It May Concern

We are writing to express our interest and commitment to be your partner on the NASA grant proposal entitled "Near Real Time Flood Inundation Prediction and Mapping" that is submitted by G. Robert Brakenridge in response to the NASA Research Announcement "ROSES 2011; NNH11ZDA001N; FEASIBILITY STUDY-DISASTER".

The World Food Programme is the world's biggest humanitarian agency, its primary role being saving lives and livelihoods of vulnerable populations worldwide in crises provoked by both natural disasters and conflict. Understanding and being better prepared for these disasters is one of WFP's top priorities as we strive to reach the people in need in the fastest and most effective way possible. Over the past years, we has been investing in new tools and partnerships which can help us better forecast natural disasters and have a more precise knowledge of the situation on the ground once a disaster strikes. Floods and cyclones are among the most important shocks we have to deal with as they cause agricultural fields and irrigation systems to be wiped out and rivers to often swell.

The historical flood data from Dartmouth Flood Observatory at the University of Colorado is a crucial component for WFP preparedness analysis to advise preparatory measures. It is being used for floods modelling, which forecasts which areas will likely be flooded, and for WFP's Multi Risk Analysis, a truly ground breaking scheme that combines historical trends of disasters and analyses of environmental degradation to ascertain areas that are most likely to experience the greatest negative impact from natural shocks. Dartmouth's automatized NRT map product, based on MODIS sensor, also provides WFP with invaluable information in the early stage of a flooding, especially in planning and prioritizing the locations for needs assessments and logistical routes.

WFP strongly supports the Dartmouth Flood Observatory's bid for collaborating with NASA. The Dartmouth Flood Observatory's customization of NASA data for the WFP would ultimately have a considerable impact in facilitating WFP decision making and would be highly valuable for us. On the other side, Dartmouth would benefit from the large field presence of WFP throughout the world to validate the findings of the project.

We intend to carry out all our responsibilities identified in the above mentioned grant and agree that it correctly describes our commitment to the project. Thank you for considering the Dartmouth Flood Observatory's proposal.

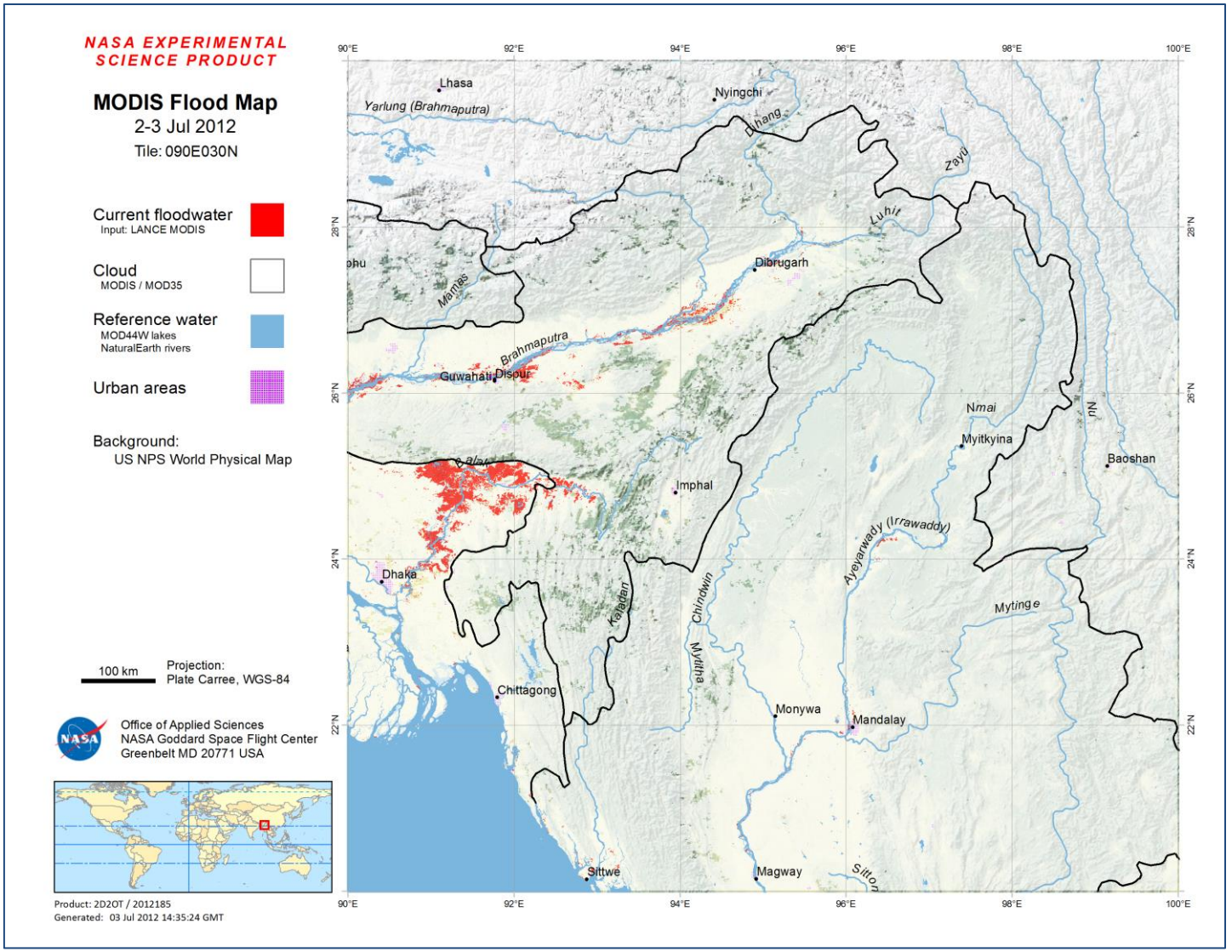
Sincerly,

Mr. David Kaatrud
Director of Emergencies
United Nations World Food Programme

Via Cesare Giulio Viola 68-70, Parco de Medici, 00148 Rome. ITALY
Email: david.kaatrud@wfp.org

Via Cesare Giulio Viola, 68/70, 00148 Rome, Italy Telephone: +39 06 65131 Fax: +39 06 6590632/7

# July 2012 Flooding in Assam, India



| Region | Governorate | Date |
|---|---|---|
| Grand Tunis | Tunis<br>Ariana<br>Ben Arous<br>Manouba | 30/10/2011 |
| Zaghouan | Zaghouan | 30/10/2011 |
| El Batan | Manouba | 02/11/2011 |
| Mjez El-Bab | BEJA | 30/10/2011 |
| Redayef | GAFSA | 23/09/2009 |
| Sabalet Ben Ammar (North-West of Tunis) | Ariana | 14/10/2007 |
| Grand Tunis | Tunis<br>Ariana<br>Ben Arous<br>Manouba | 13/10/2007 |
| Grand Tunis, Zaghouan, Nabeul<br>Other zones in coastline | Tunis<br>Ariana<br>Ben Arous<br>Manouba<br>Zaghouan<br>Nabeul | 17-23/09/2003 |
| | Jendouba<br>Béja<br>Manouba<br>Bizerte | January 2003 |

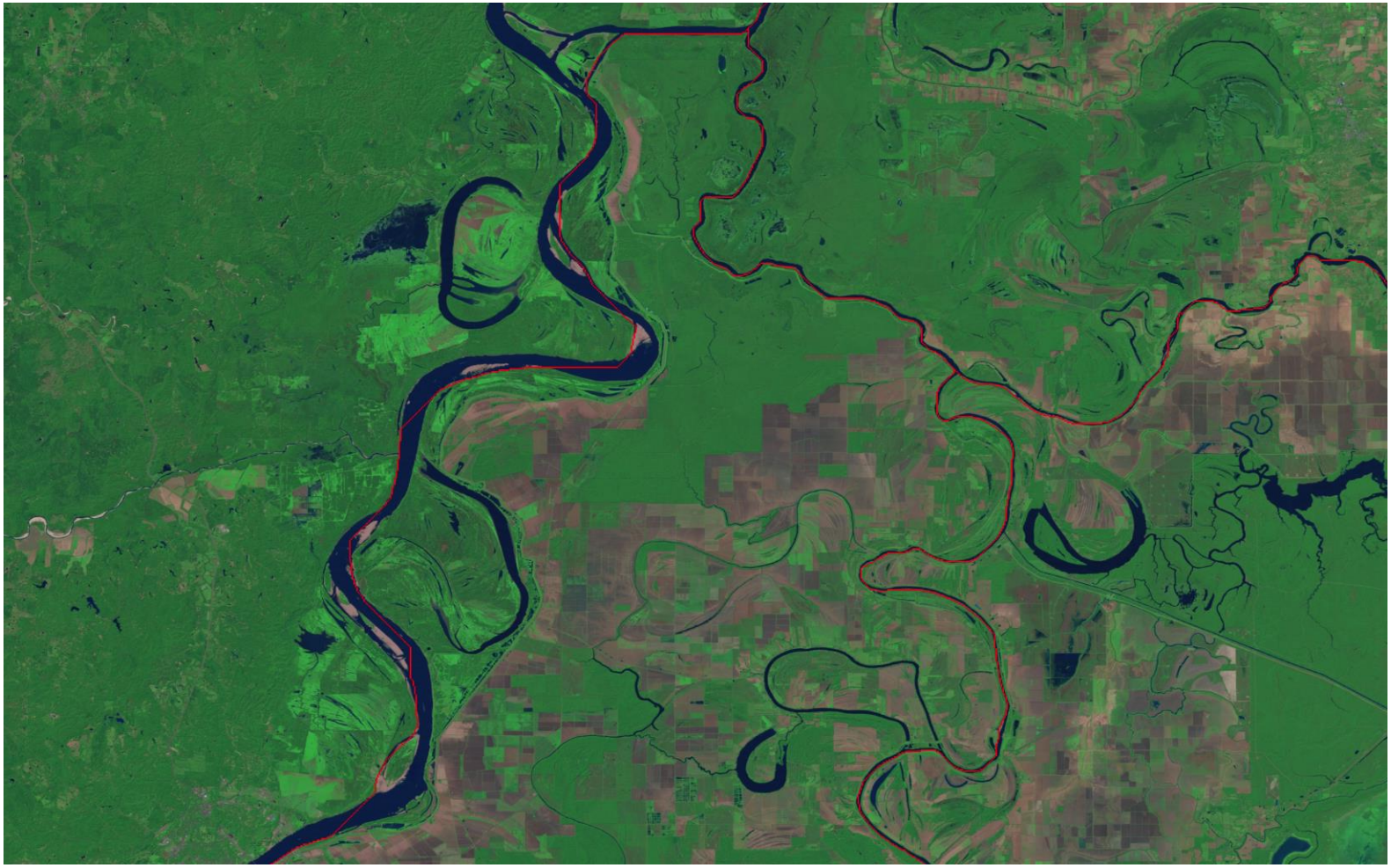
Dear Fritz,

Please find attached the file with the most important flood events in Tunisia since 2003.

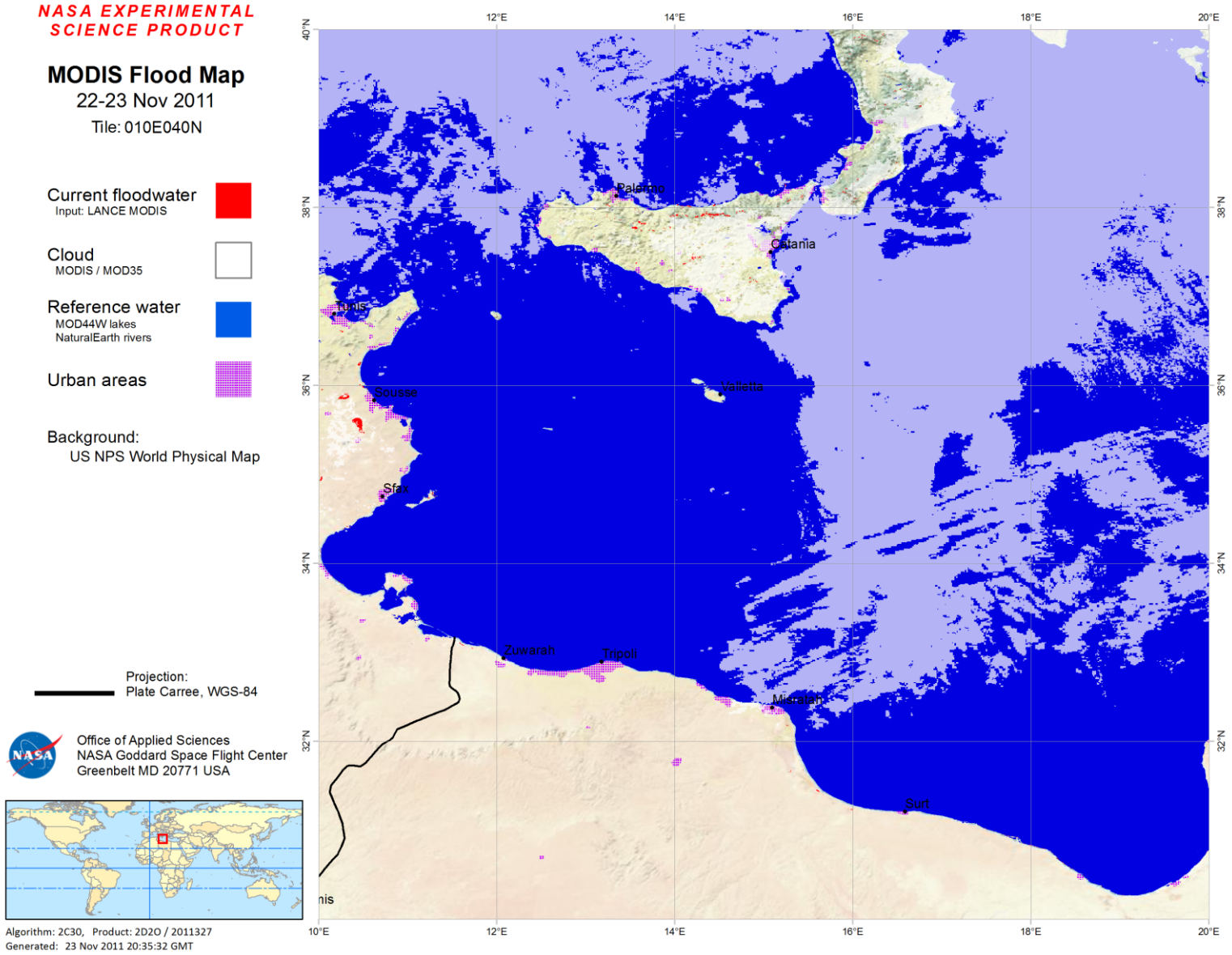
Best regards,
Sinan Bacha

# Evaluation/ Correction? Of DEMS

Landsat comparison with stream network from DEM



# MODIS Flood Map for Tunisia



# Early Contributions

- **Feedback from the World Food Programme**
  - World's largest disaster response organization ($3.1 billion USD/ 2011 budget)
  - US Government is its largest donor ($1.2 billion USD/ 2011 budget)

> (NASA and) "Dartmouth's automatized NRT map product, based on MODIS sensor, also provides WFP with invaluable information in the early stage of a flooding, especially in planning and prioritizing the locations for needs assessments and logistical routes"

- **Feedback from FEMA (Emphasis Added)**

Thank you Sir!

Just to be sure, we should pull our GIS data from here:
http://csdms.colorado.edu/pub/flood_observatory/MODISlance/
Can you provide a bit more detail on update schedule? We'll do our best to monitor based on a schedule so we can stay up to date with the latest Information.

**I really think this is going to make a huge difference in Response/Recovery operations at FEMA and USDA.**

Many thanks-
Regards,

Chris Vaughan
Remote Sensing Coordinator
Planning Division
Response Directorate, FEMA

# MODIS Flood Mapping Challenges

MODIS data advantages

- 2 daylight acquisitions/ day
- 250m spatial resolution

MODIS data limitations

- 250m spatial resolution
- cloud cover
- dense vegetation

Cloud shadow and Terrain shadow often mis-identified as water (spectrally similar)

- Developing monthly terrain shadow mask
  DEM: 30m ASTER DEM resampled to 250m

- Testing geometry-based cloud shadow mask
  MOD35 Cloud Detection, MOD06 Cloud Height