Satellite-Based Rainfall Estimates and Their Application in Global Flood and Landslide Calculations

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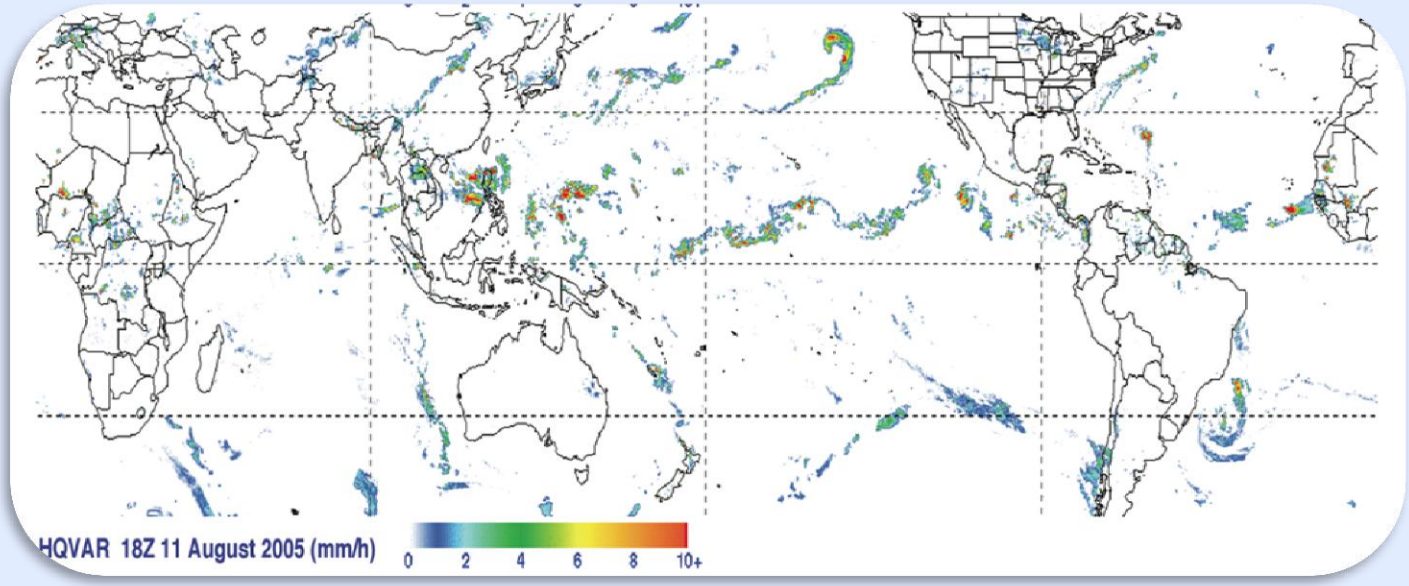


3-hr Rainfall Maps Using a Constellation of Satellites

•TRMM Multi-satellite Precipitation Analysis (TMPA) as key input to flood and landslide analysis/prediction

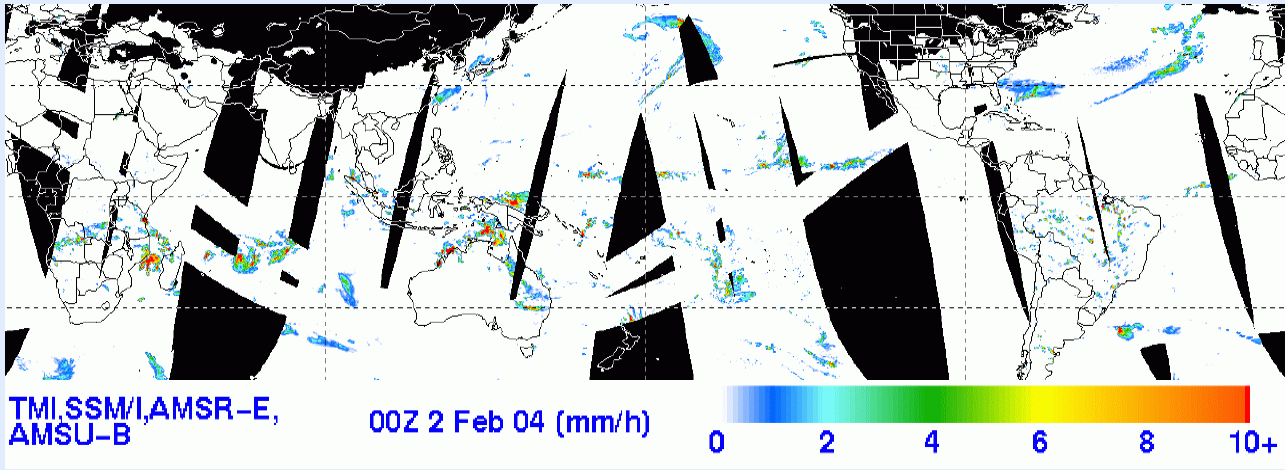
TRMM: Tropical Rainfall Measuring Mission

The NASA TRMM Multi-Satellite Precipitation Analysis

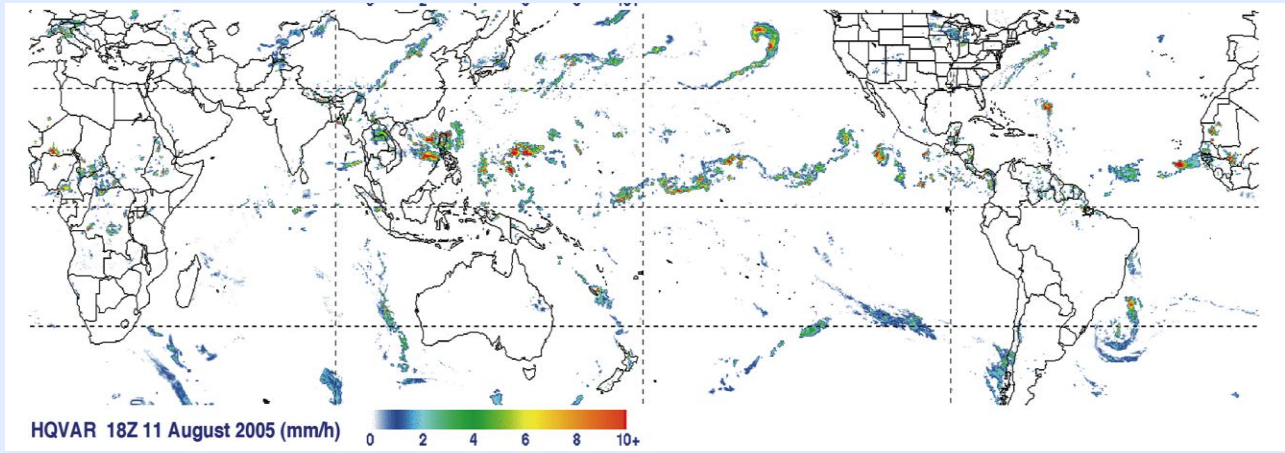
(TMPA or 3B42 [TRMM product number]) [Adler/Huffman]

3-hr window with passive microwave (gaps filled with Geo-IR) calibrated by TRMM

(0.25° grid)



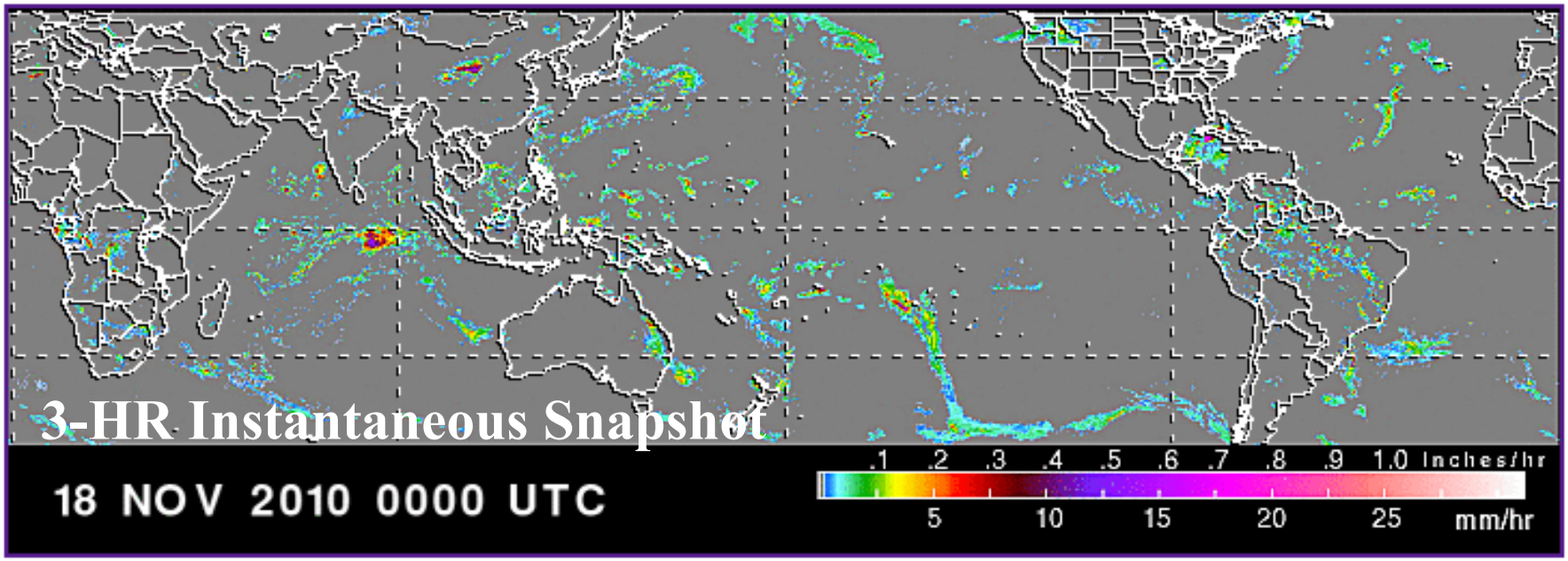
Research product uses TRMM radar information and monthly gauges; real-time product produced ~ 6 hrs after obs. time by TRMM/GPM data system

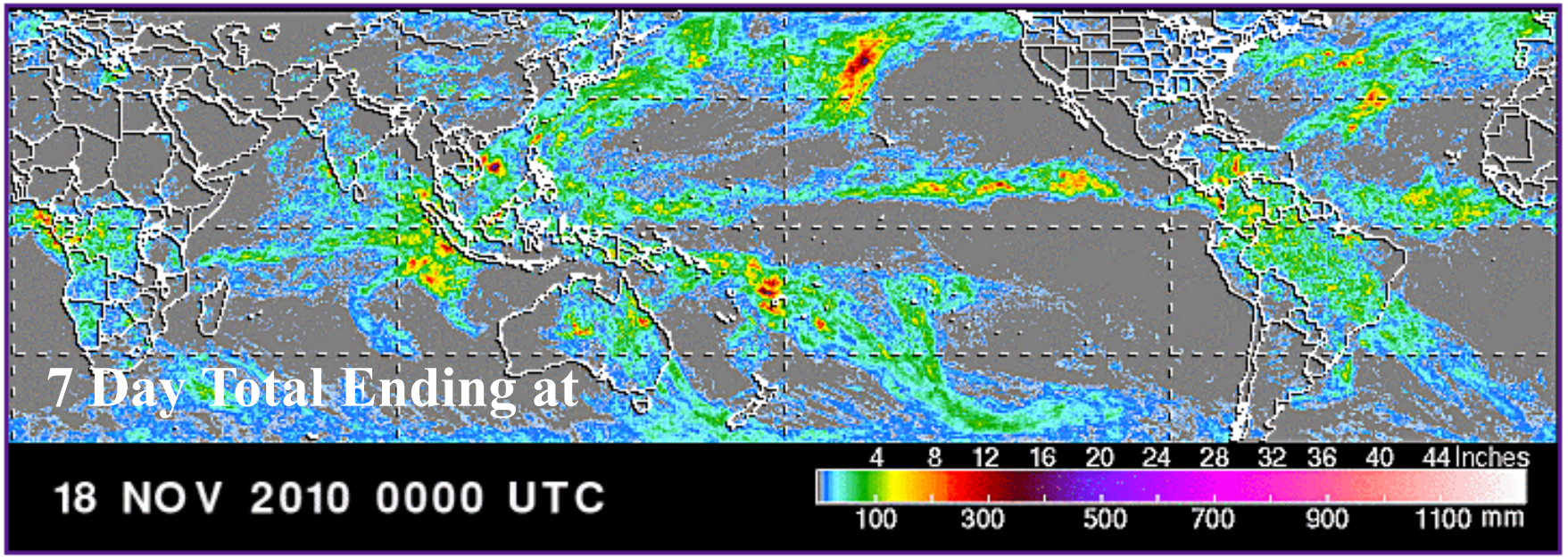


Huffman et al., 2007, J. Hydromet.

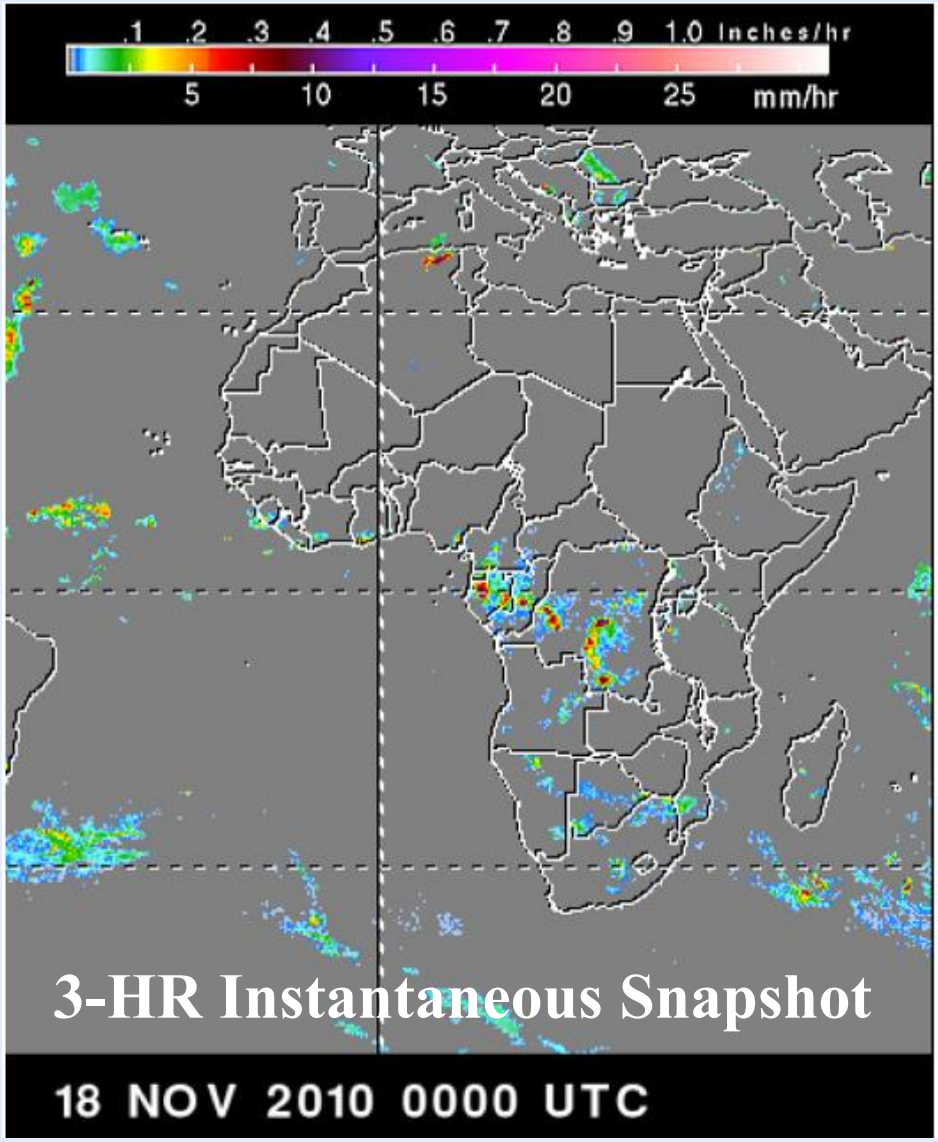
12+ years ('98-'10) of 3-hr analysis available.

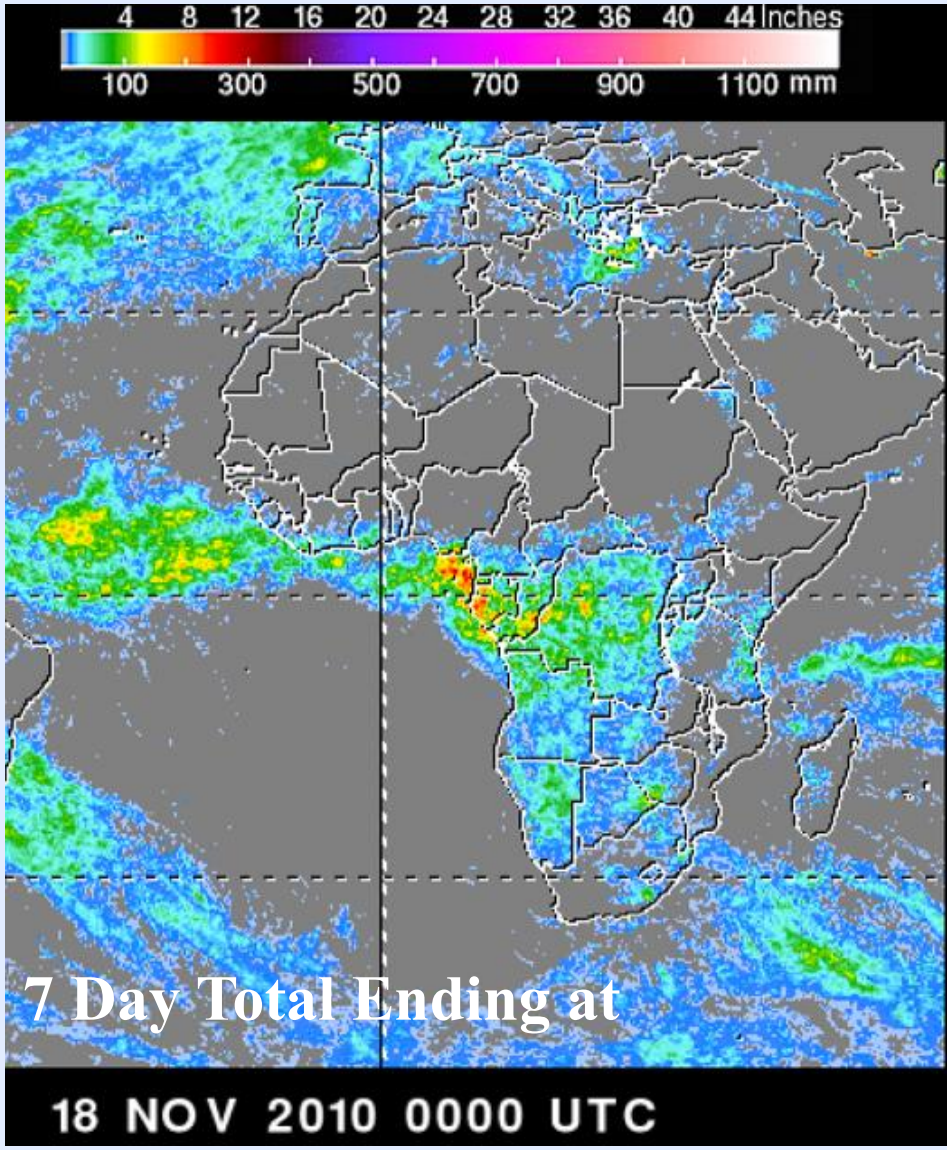
From TRMM Web Site (trmm.gsfc.nasa.gov)





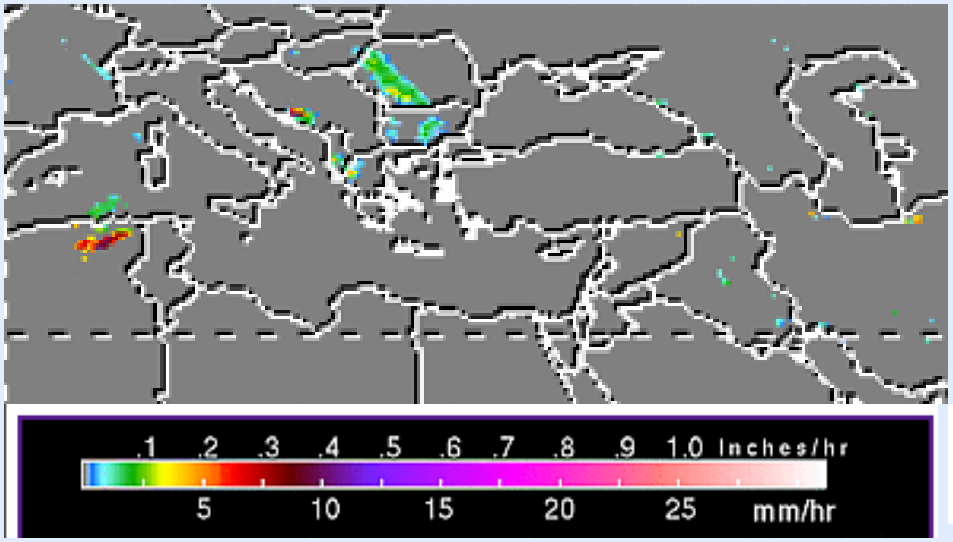
Regional Real-Time Data



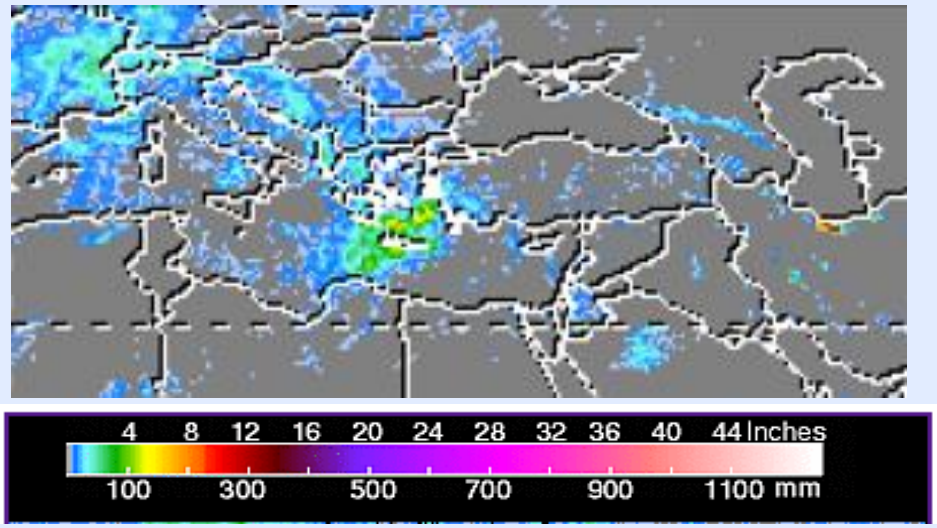


Regional Real-Time Data

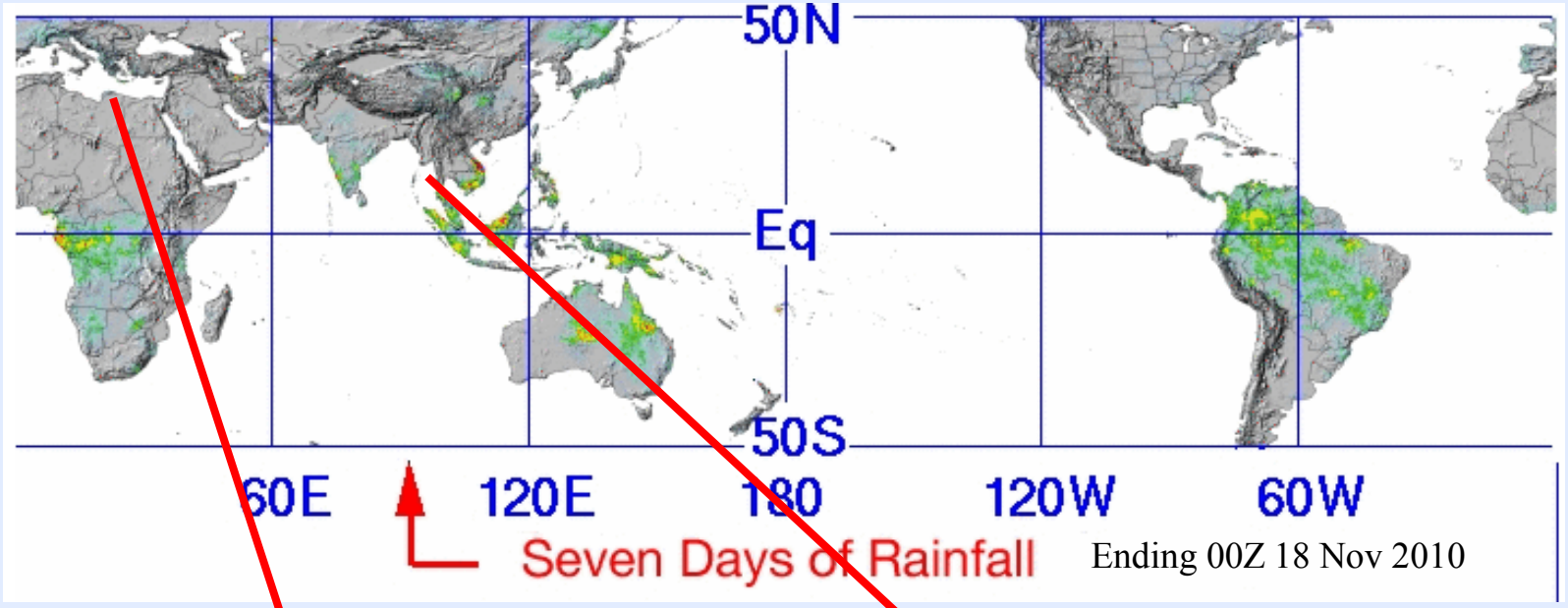
3-HR Instantaneous Snapshot at 18 Nov 00Z

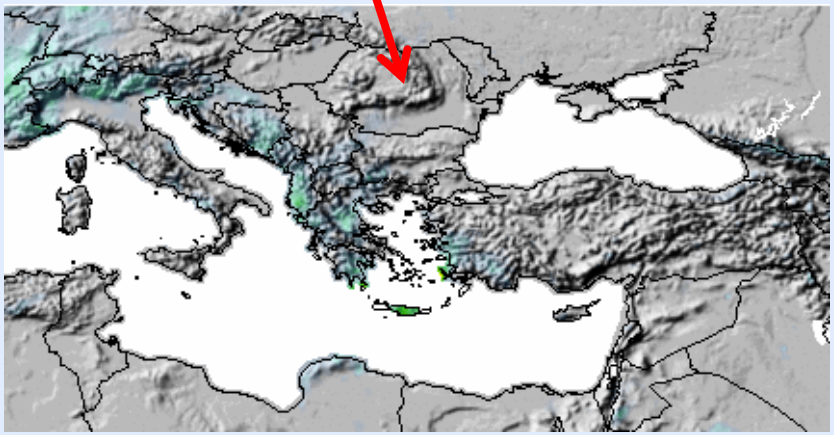


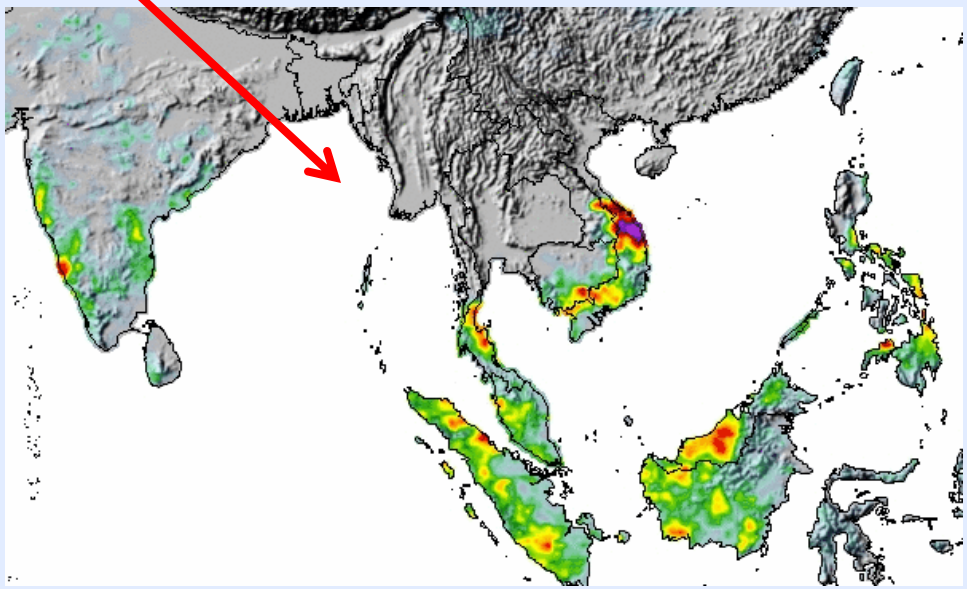
7 Day Total Ending at 18 Nov 00Z

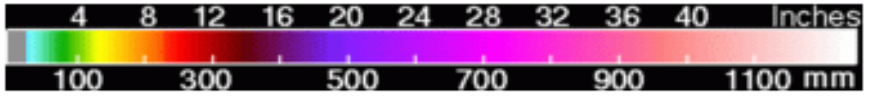


Monitoring Heavy Rainfall Events with Satellite Rainfall









Flood Calculations using Current (Curve Number [CN]) Hydrological Model

1) The CN-Model[1]

(Curve Number Model)

Geospatial Datasets

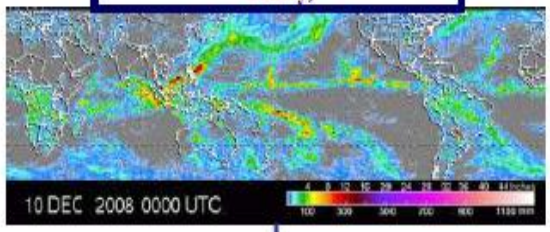
Topography (HYDRO1K)
Elevation, Slope, Flow Direction (Grid-to-grid routing)

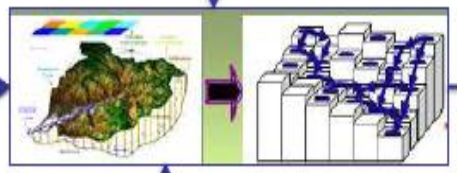
Soil Property (Source: FAO)
Sand, Foam, Silt, Clay

Land Cover (MODIS)
Shrub, barren, urban etc.

Antecedent Moisture Conditions
Concept of Antecedent Precip. Index

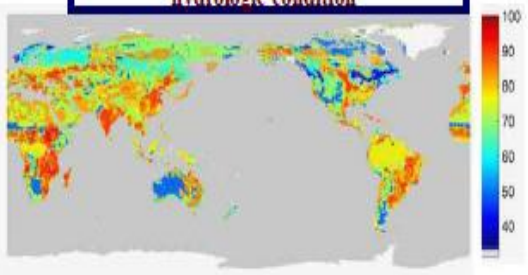
NASA TRMM-based [2]
Near Real-time Rainfall Estimates (3-hourly)





"Curve Number" approach to infiltration

NRCS Runoff Curve Number Map
USDA Soil Groups, under fair hydrologic condition



Near Real Time Global Flood Potential Map

Hong, Y., et al. (2007), A first approach to global runoff simulation using satellite rainfall estimation, Water Resour. Res., 43, W08502, doi:10.1029/2006WR005739

Hydrological Model Algorithmic Steps:

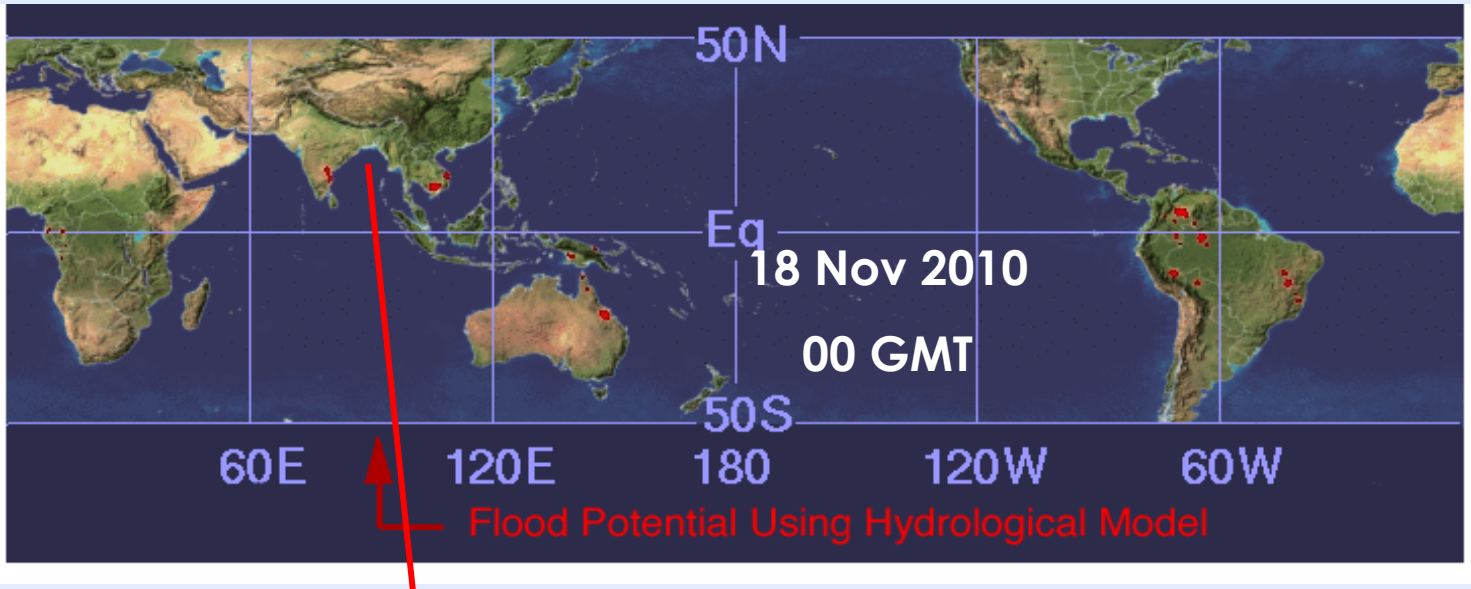
Step I: Rainfall-infiltration Partitioning (Distributed and Time-variant)

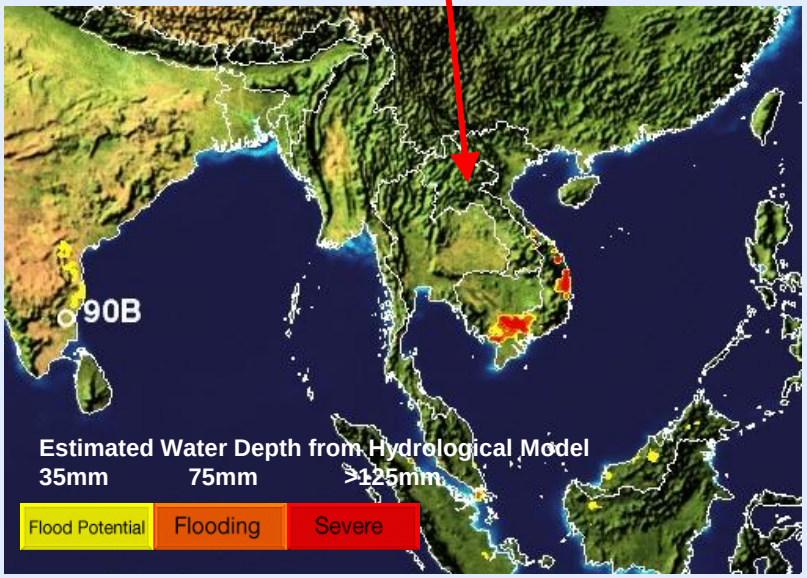
Step 2: Flow Routing using Macro-scale Grid-to-Grid Algorithm

Step 3: Result: Grid Point Hydrographs--Flood Inundation Mapping

On-line Global Flood Monitoring
Every Three Hours at 0.25 Degrees

http://trmm.gsfc.nasa.gov (Floods and Landslides)

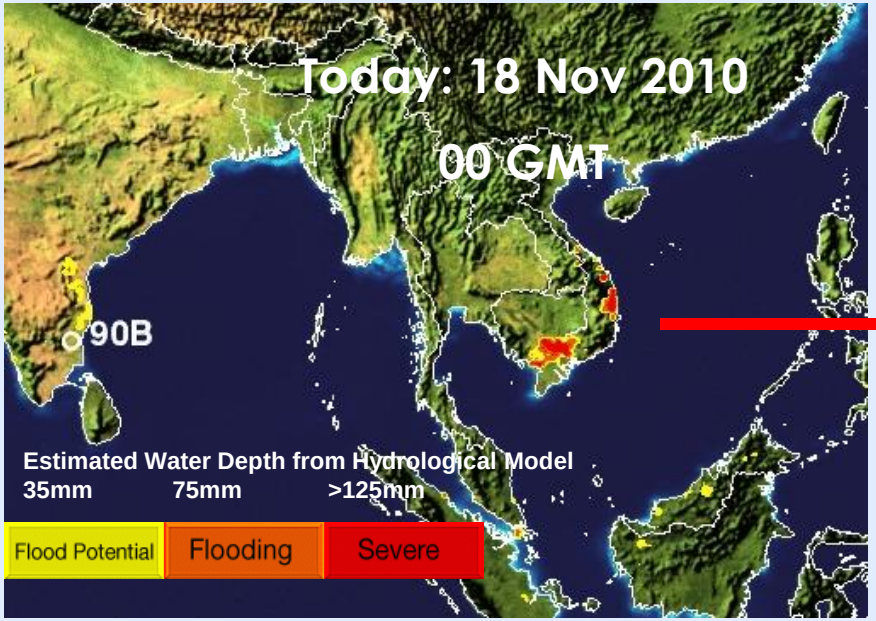


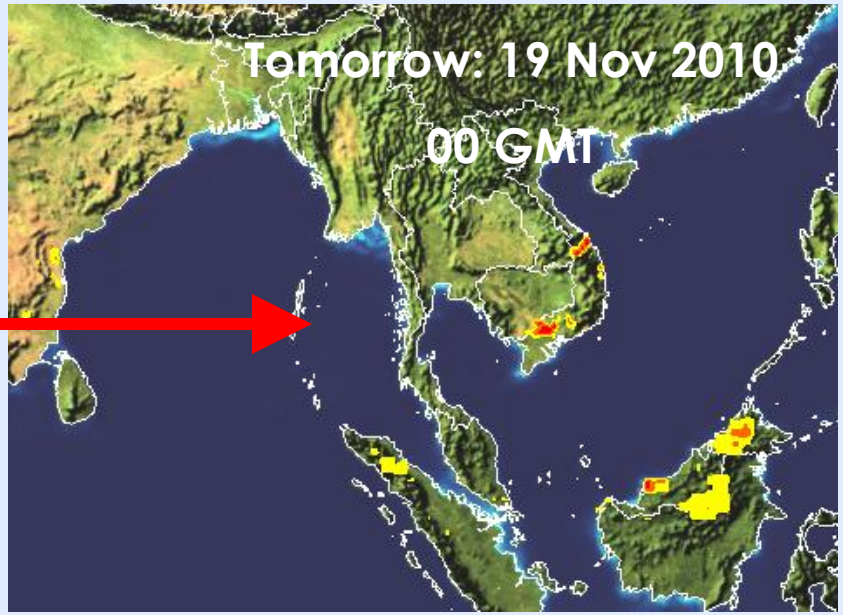


***Real-time** global estimation of **flood areas** using satellite-based rainfall and **a hydrological model** running globally, every three hours at 0.25°.*

24-HR Flood Forecast Using Precipitation Forecast from Global NWP Model (NASA GEOSS-5) and Hydrological Model

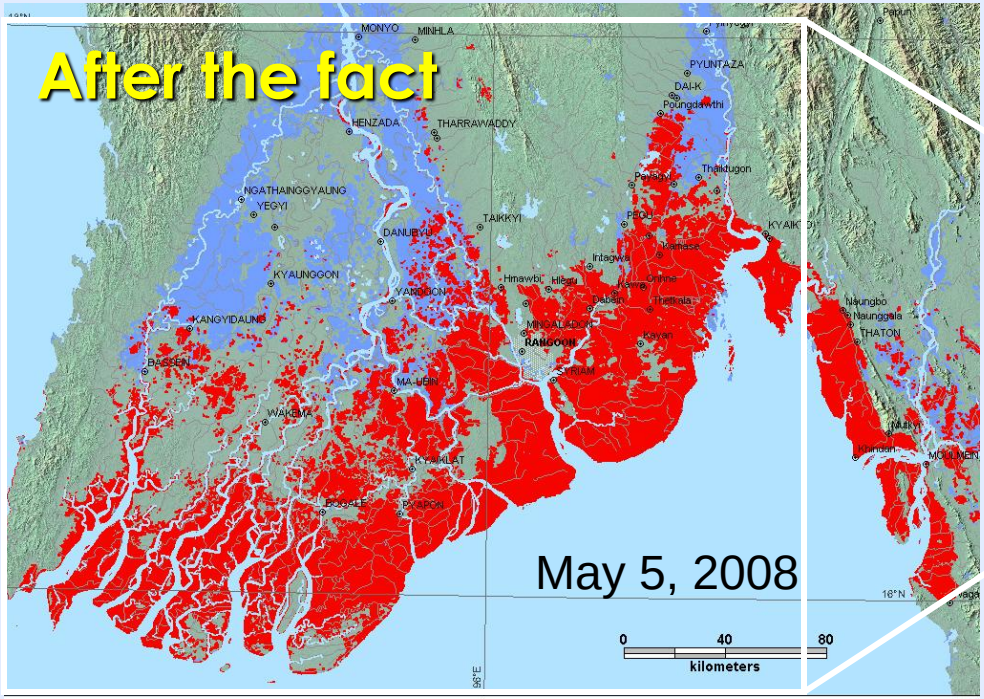
Model Precipitation Adjusted to Satellite Rainfall via Histogram Matching



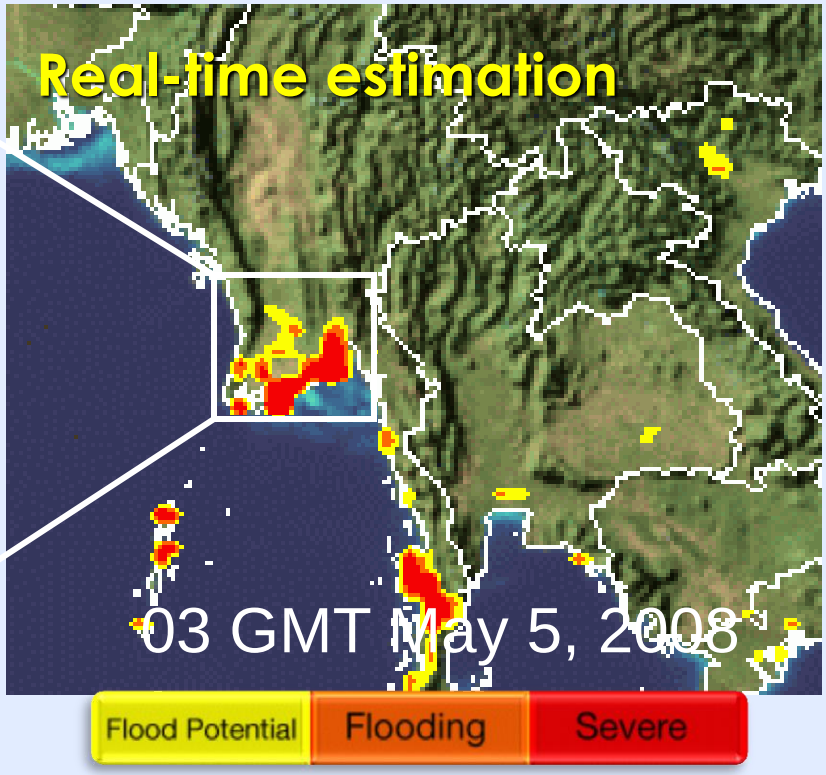


Two Satellite Views of Burma Flood

Post Analysis Inundation Map from Dartmouth Flood Observatory (using MODIS data)

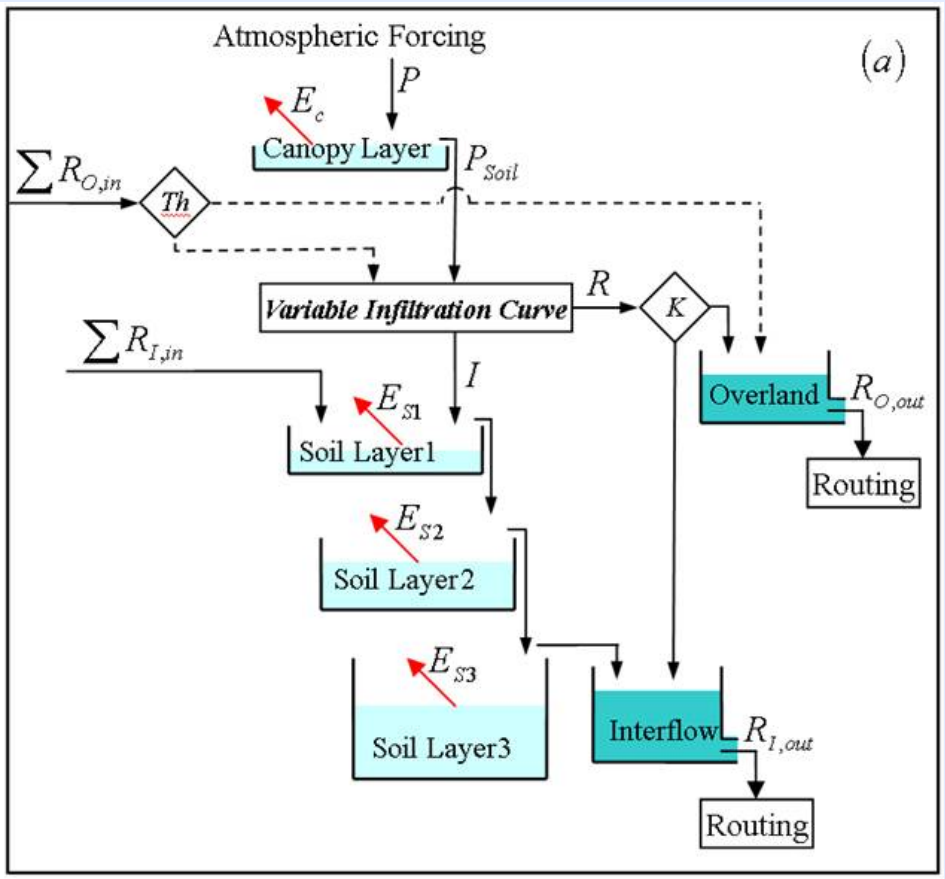


Real-time Inundation Estimate from Hydrological Model and Satellite Rainfall



New Hydrological Model Under Testing

NASA-OU CREST Distributed Hydrologic Model

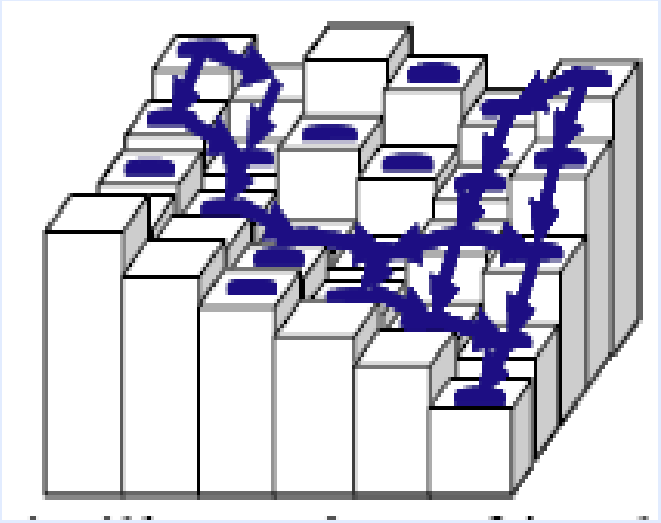


Coupled **R**outing and **E**xcess **ST**orage (CREST):

- **rainfall-runoff generation module, modified from UW-VIC model[1],**
- **parallel multi-linear storage module, modified from Xinanjiang model[2]**
- **newly developed grid-to-grid routing scheme.**
- **<u>1/8th degree global</u>**

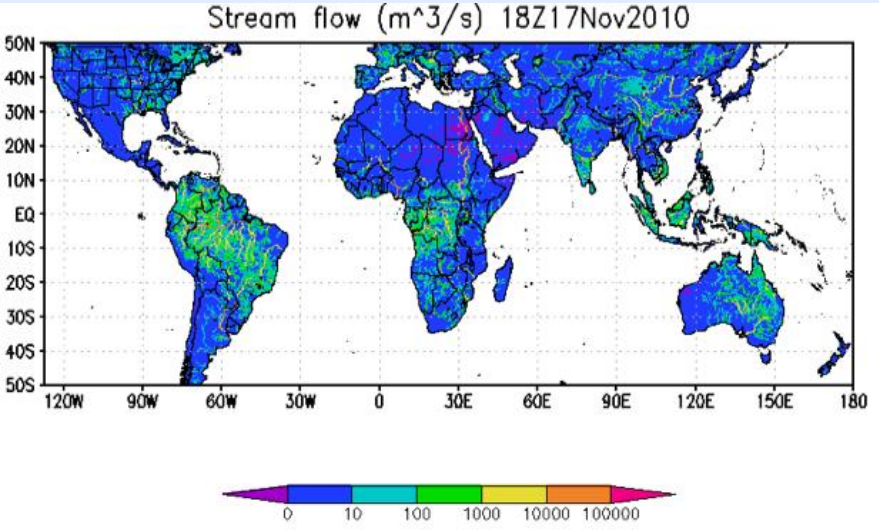
[1]Liang,et al. 1994
[2]Zhao & Liu, 1995

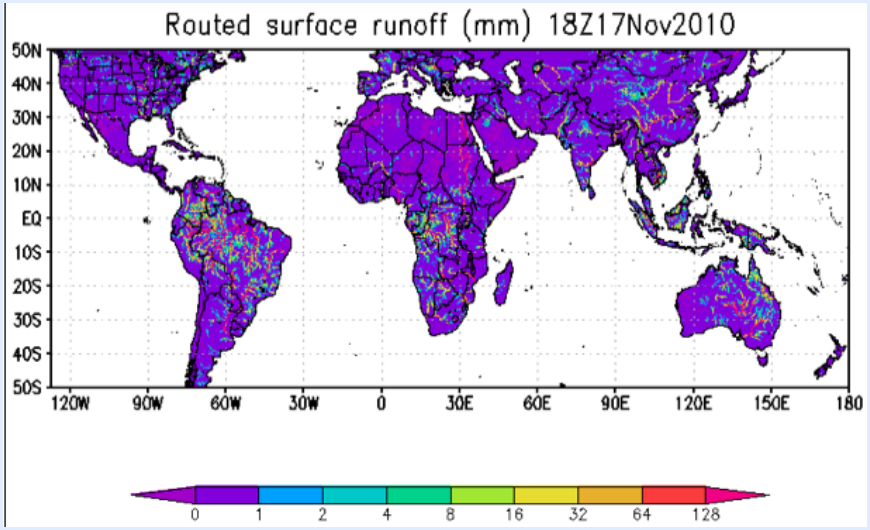
Cell-to-Cell Flow Routing

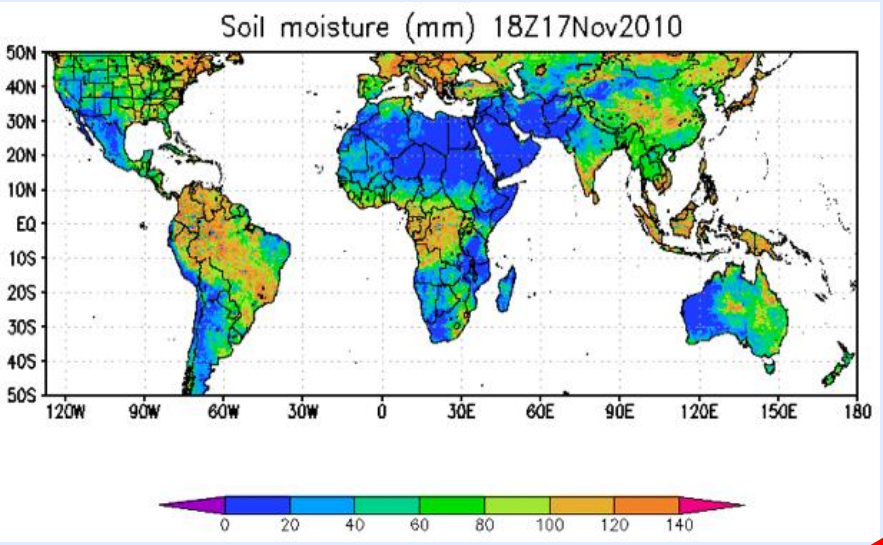


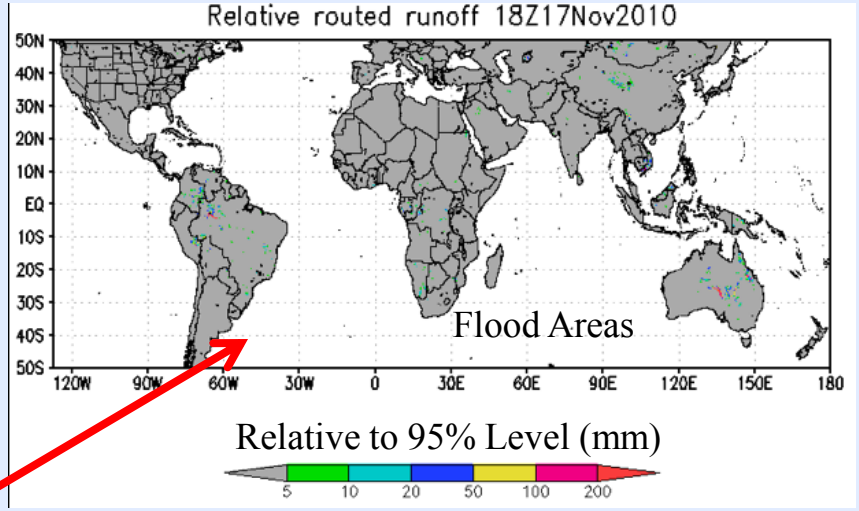
Wang J., Y. Hong., L. Li., J.J. Gourley., K. Yilmaz., Khan S. I., Policelli. F. S, Adler R. F., Habib S., Irwin. D., Limaye. S. A., Korme.T , and L. Okello, 2010, The Coupled Routing and Excess STorage (CREST) Distributed Hydrological Model. Hydrol. Science Journal (in press)

CREST Model Example Results (Today)



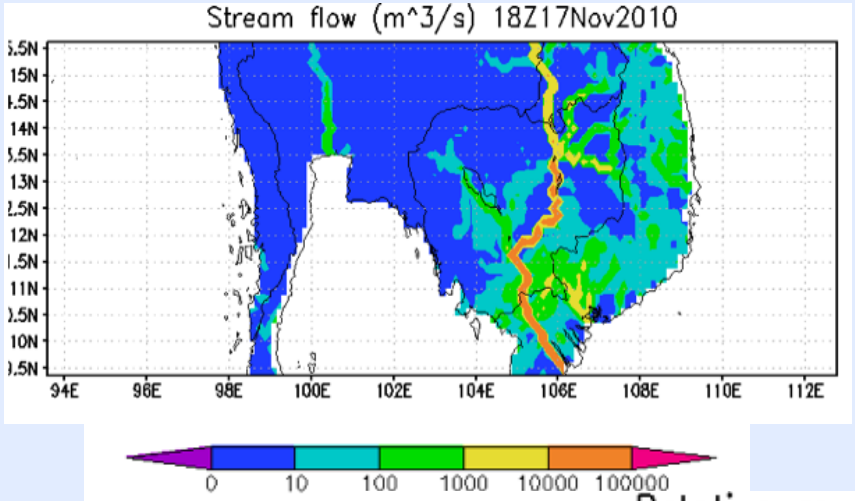


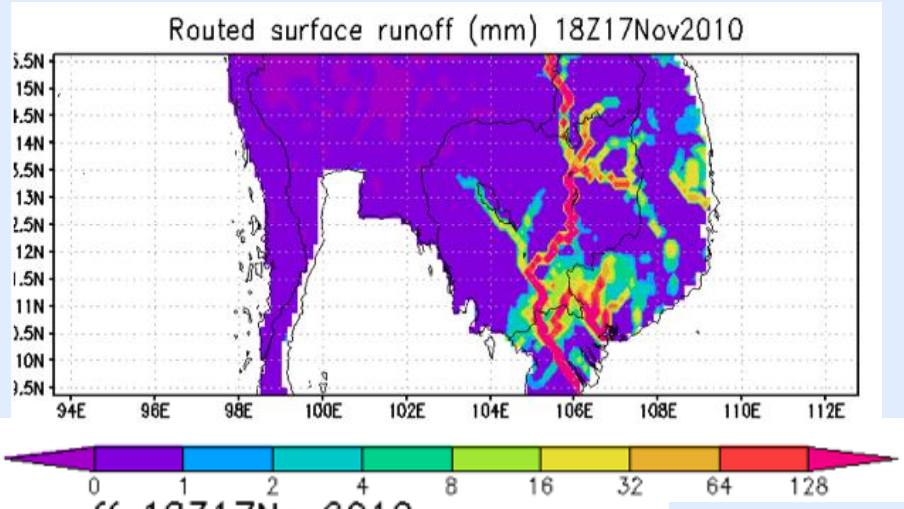


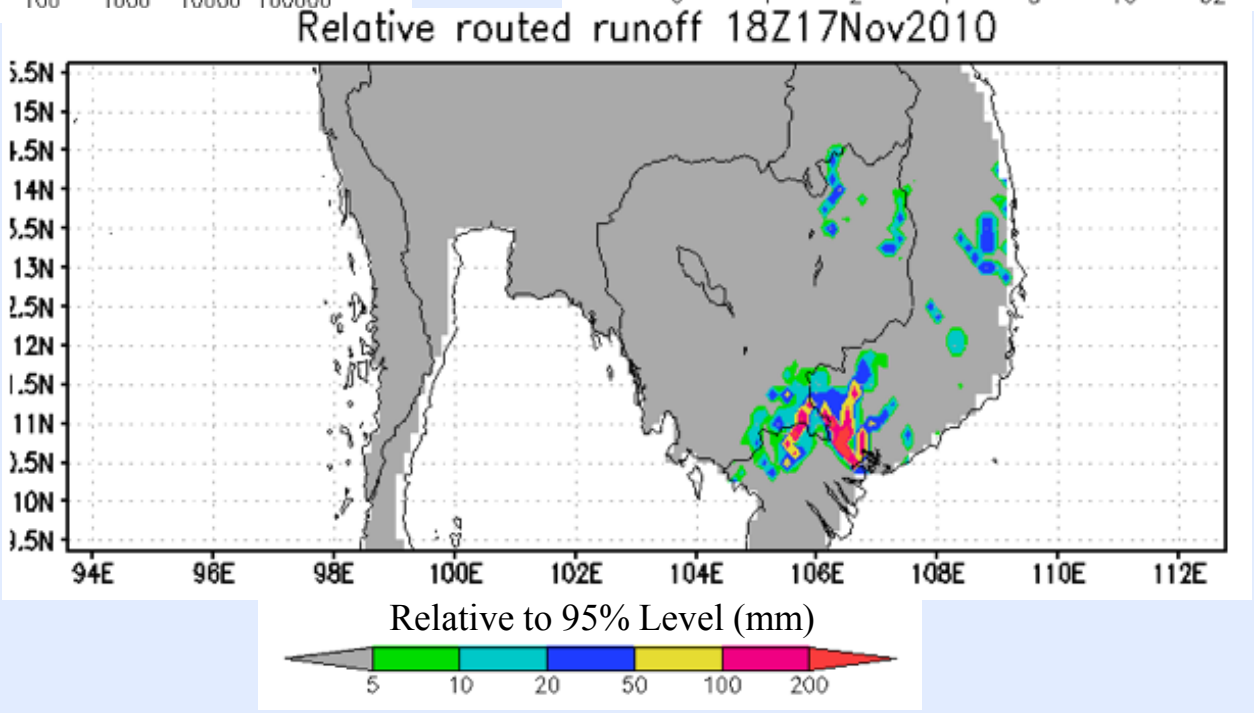


Reference Level: 95th percentile of Routed Runoff from 10-year global hydrology model run using satellite rainfall data

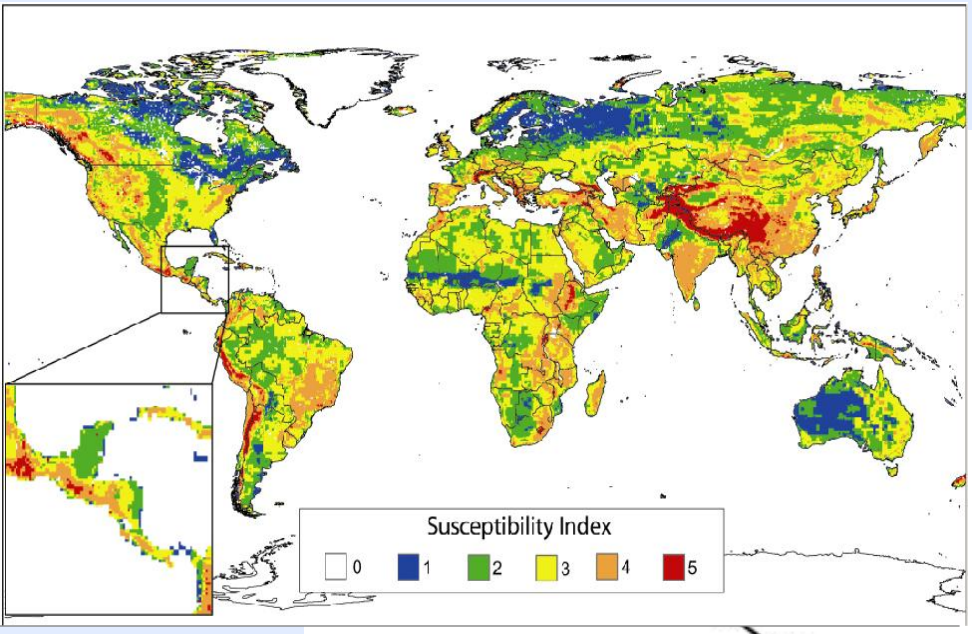
CREST Model Results for Today

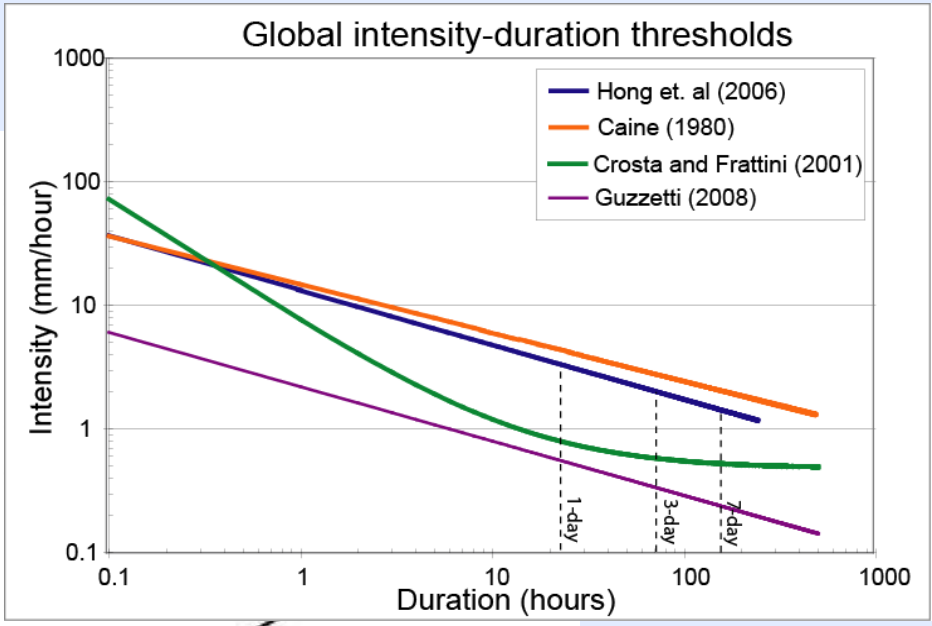






Global Landslide Occurrence Algorithm





Surface Data:

- Topographic variables
- Land cover
- Soil Type and Texture
- Drainage Density

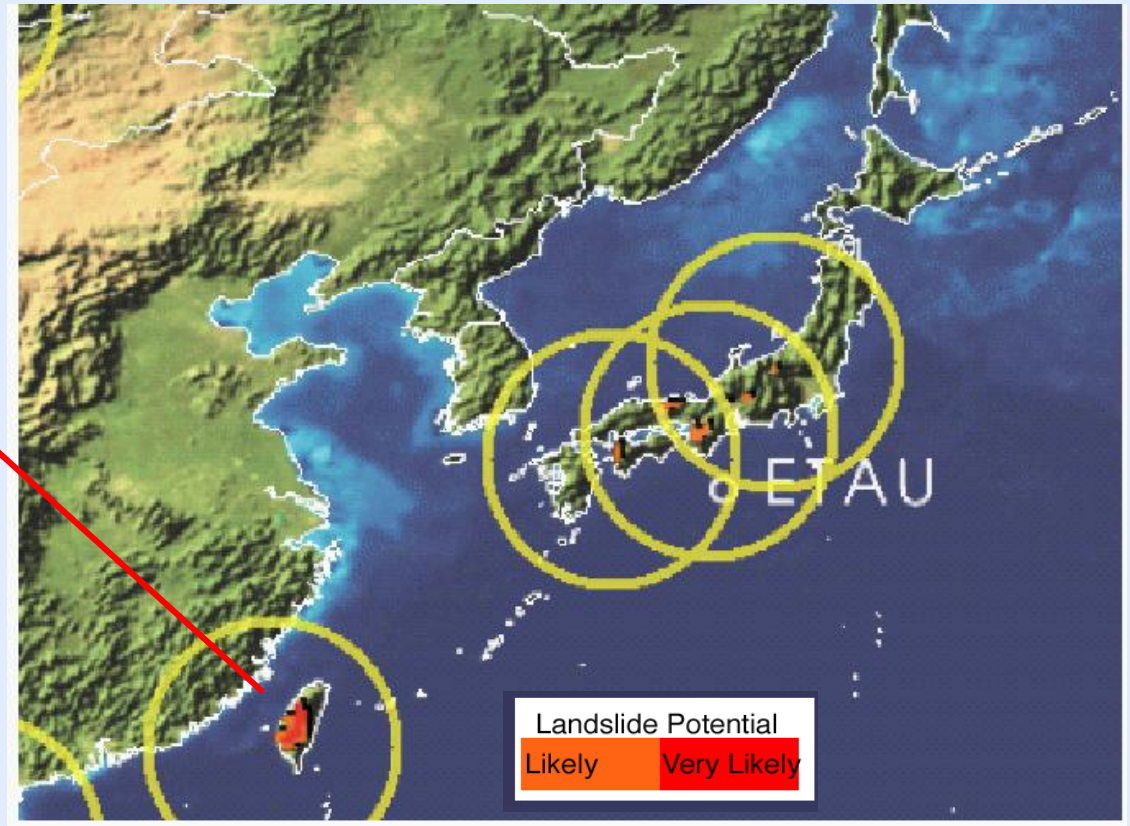
Circles enclose small areas of estimated landslide locations

Rainfall Data:
TRMM Multi-Satellite Precipitation Analysis (TMPA)
0.25° pixel resolution, 3-hourly

Example of Landslide Prediction

Typhoon Morakot (Etau) August 8, 2009

Numerous and **massive landslides** throughout Southern and Central Taiwan. Over 500 people killed in Shiao Lin

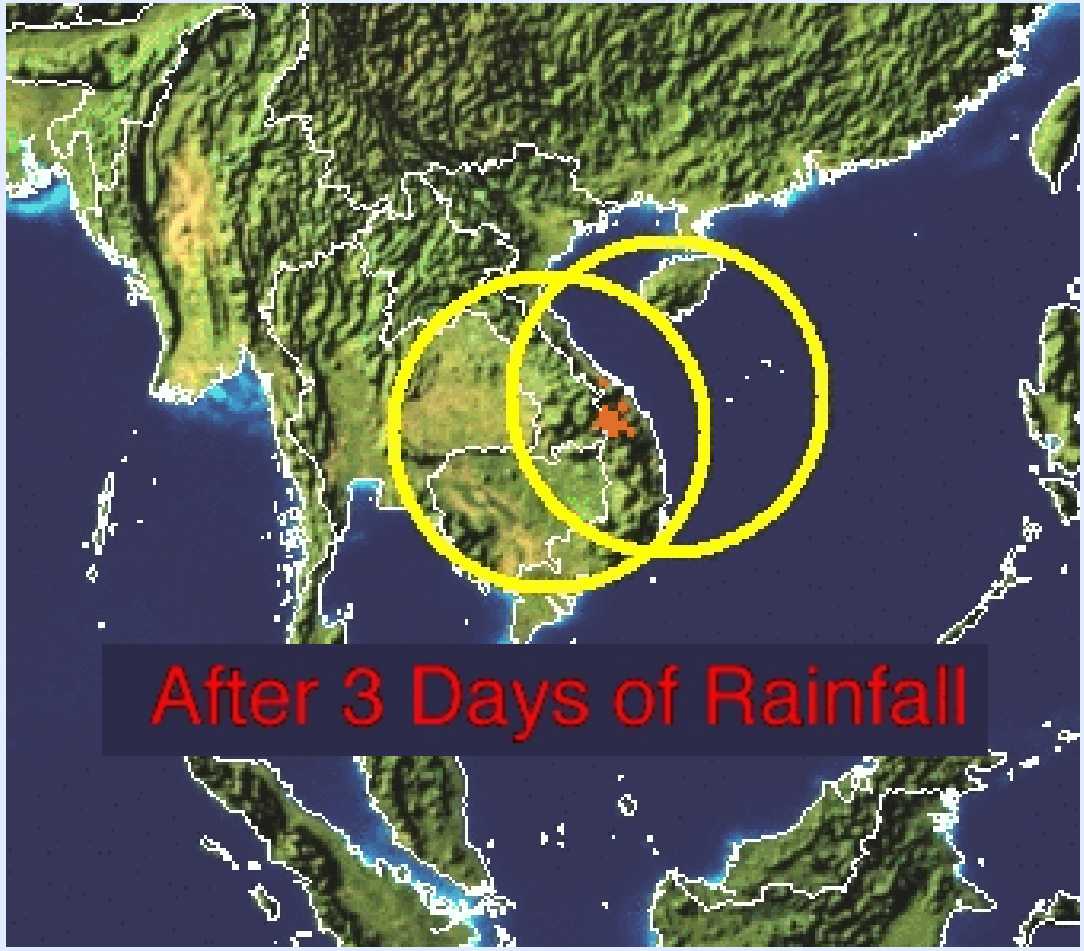


Today

18 NOV 2010 0000 UTC
(Observation Time Of Last Data)

Landslide Potential

Likely | Very Likely



Global Precipitation Measurement (GPM) mission

U.S. (NASA) Japan (JAXA/NICT)

Unify and advance precipitation measurements from space to provide next-generation global precipitation products within a consistent framework

Low Inclination Observatory (40°)

GMI (10-183 GHz)
(NASA & Partner, 2014)

- Enhanced capability for near-realtime monitoring of hurricanes & midlatitude storms
- Improved estimation of rain accumulation

GPM Core Observatory (65°)

DPR (Ku-Ka band)
GMI (10-183 GHz)
(NASA-JAXA, Launch 2013)

- Precipitation physics observatory
- Transfer standard for inter-satellite calibration of constellation sensors

Partner Satellites:

GCOM-W1

DMSP F-18, F-19

Megha-Tropiques

MetOp, NOAA-19

NPP, JPSS (sounders over land only)

Coverage & Sampling

- 1-2 hr revisit time over land
- < 3 hr mean revisit time over 90% of globe

Key Advancement

Using an advanced radar/radiometer measurement system to improve constellation sensor retrievals

U.S. Project Scientist: Arthur Hou - NASAGoddard

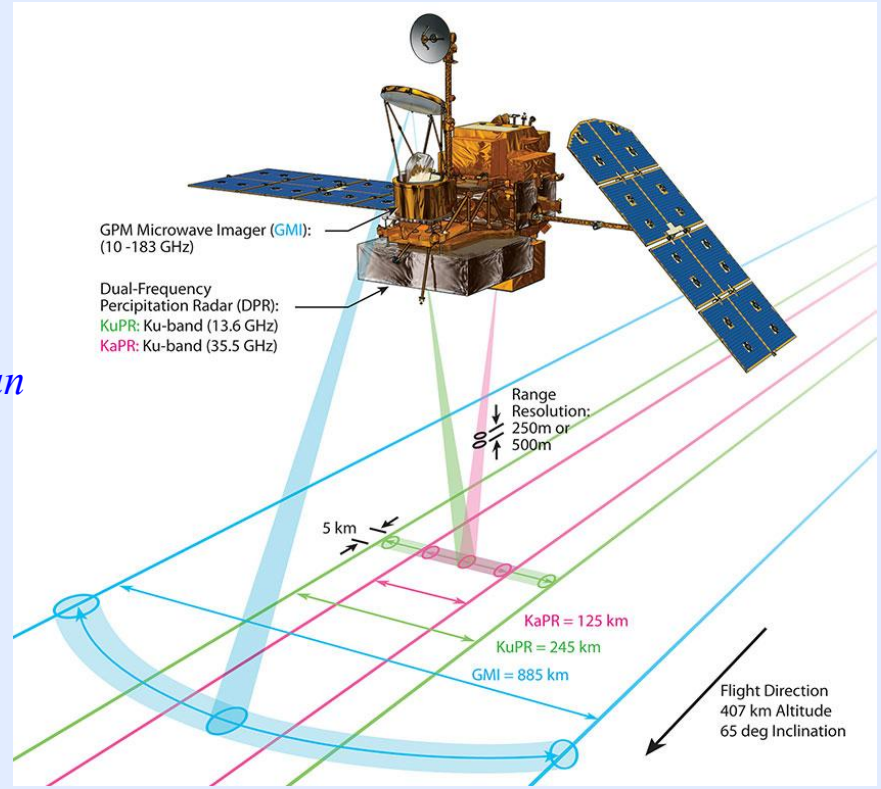
NASA-JAXA GPM Core Observatory

Dual-Frequency (Ku-Ka band) Precipitation Radar (DPR):

- *Increased sensitivity (~12 dBZ) for light rain and snow detection relative to TRMM*
- *Better measurement accuracy with differential attenuation correction*
- *Detailed microphysical information (DSD mean mass diameter & particle no. density) & identification of liquid, ice, and mixed-phase regions*

Multi-Channel (10-183 GHz) GPM Microwave Imager (GMI):

- *Higher spatial resolution (IFOV: 6-26 km)*
- *Improved sensitivity to light rain*
- *Improved signals of solid precipitation over land (especially over snow-covered surfaces)*
- *4-point calibration for nonlinearity removal and backup calibration reference during hot load anomalies*



Combined Radar-Radiometer Retrieval

- *DPR & GMI together provide greater constraints on possible solutions to improve retrieval accuracy*
- *Observation-based a-priori cloud database for constellation radiometer retrievals*

GPM Ground Validation

Three complementary approaches:

- ***Direct statistical validation (surface):***

  - Leveraging off operational networks to identify and resolve first-order discrepancies between satellite and ground-based precipitation estimates

- *Physical process validation (vertical column):*

  - Cloud system and microphysical studies geared toward testing and refinement of physically-based retrieval algorithms

- ***Integrated hydrologic validation/applications):***

  - Identify space-time scales at which satellite precipitation data are useful to water budget studies and hydrological applications; characterization of hydrological model and precipitation observation errors

Need for GPM Validation Sites in Middle and High Latitudes (e.g., snow)

International Collaboration on GPM Ground Validation

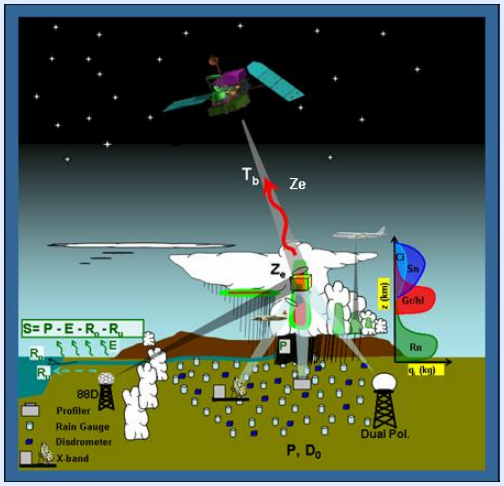
- *Joint field campaigns*
- *National networks and other ground assets (radar, gauges, etc.)*
- *Hydrological validation sites (streamflow gauges, etc.)*

Active Projects

- Argentina (U. Buenos Aires)
- Australia (BOM)
- Brazil (INPE)
- Canada (EC)
- Ethiopia (AAU)
- Finland (FMI)
- France (CNRS)
- Germany (U. Bonn)
- India (ISRO)
- Israel (Hebrew U. Jerusalem)
- Italy (CNR-ISAC)
- Italy (Sapienza U. Rome)
- South Korea (KMA)
- Spain (UCLM)
- United Kingdom (U. Birmingham)

Proposals in Development

- China
- Cyprus (CMS)
- Germany (MPI)
- Spain (Barcelona)
- Taiwan



Conclusions

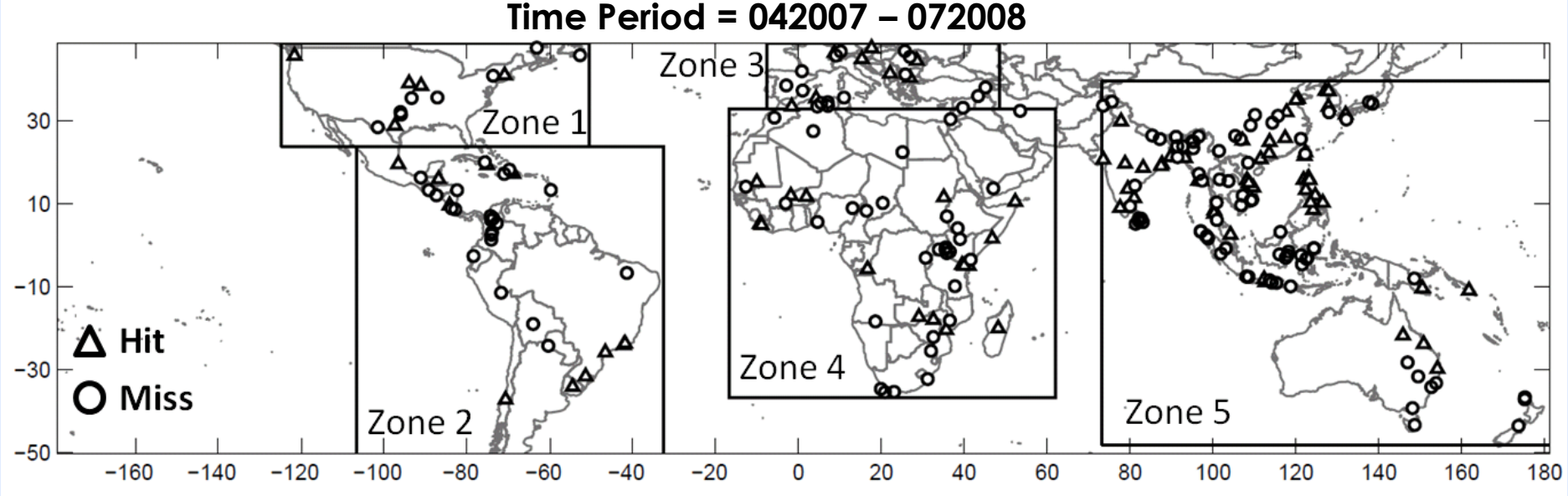
- Initial global flood and landslide models running in real-time with satellite precipitation estimates. Initial results are generally positive, but areas for significant improvement.
- Satellite precipitation estimation via passive microwave (workhorse of multi-satellite, merged products) has limits in shallow (warm) rain and time (and space) resolutions. Solutions include use of ancillary data, geo-IR, model-generated (high res.) estimation.
- Global Precipitation Measurement (GPM) mission offers opportunity for international collaboration in precipitation and hydrological validation and development of regional applications.

Evaluation using Dartmouth Flood Archive

- Flood Archive compiled by Dartmouth Flood Observatory
  - based on news reports, remote sensing sources, etc.
- Provides begin-end date & centroid of large flood events

Probability of Detection

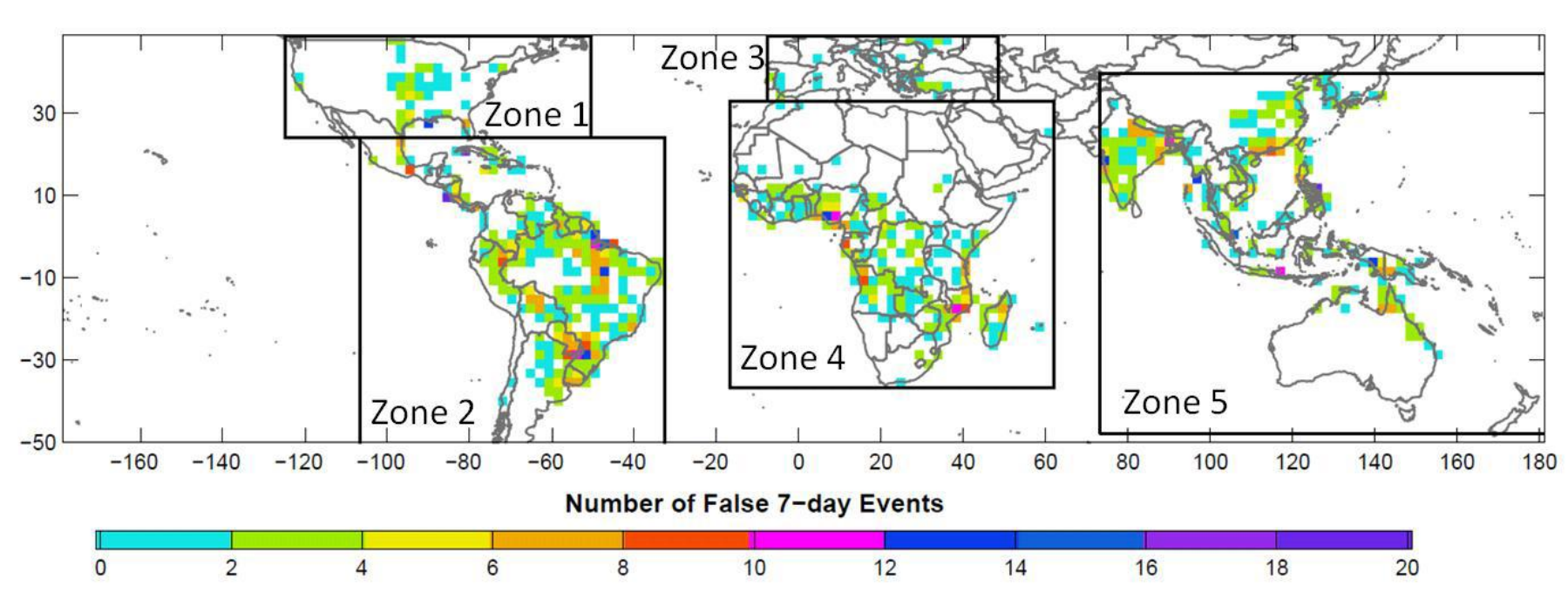
Flood = At least 2 contiguous cells > 75mm/3hr ; Time window :±1 days



93 events were detected out of 247
(38% probability of detection over the globe)

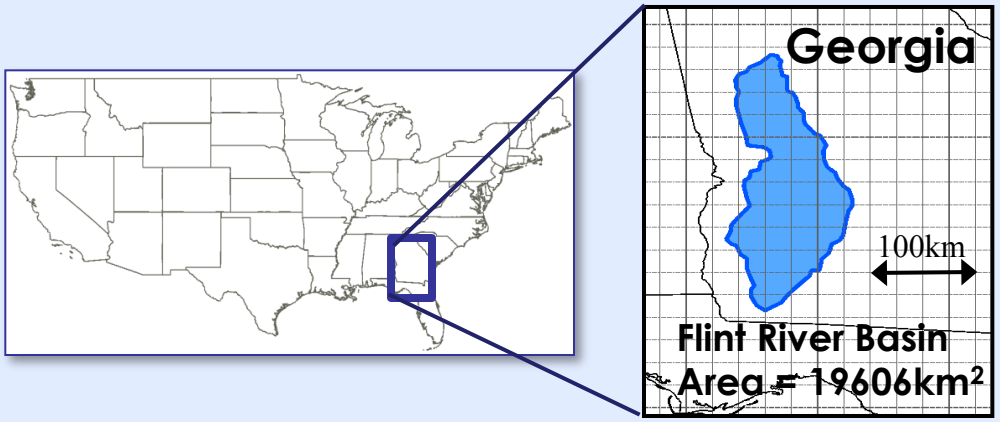
Yilmaz, K., R. Adler, Y. Tian, Y. Hong, H. Pierce, 2010. Evaluation of a Satellite-based Global Flood Monitoring System. International Journal of Remote Sensing.

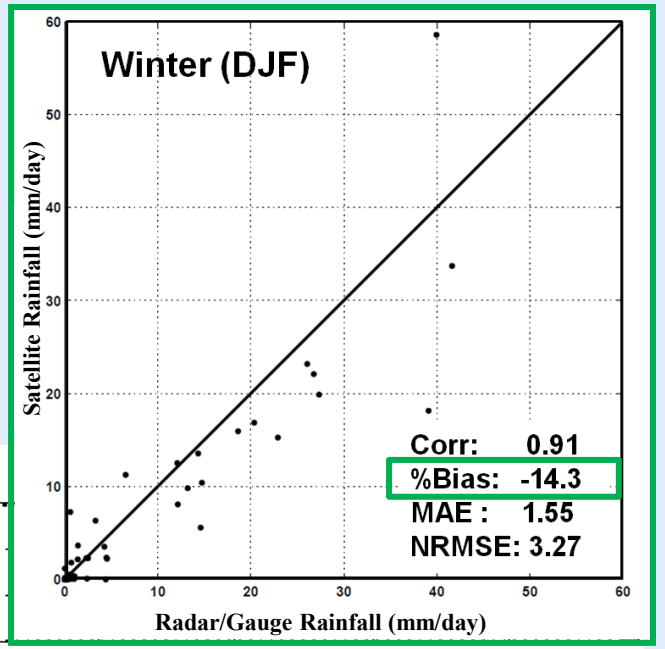
False Alarms

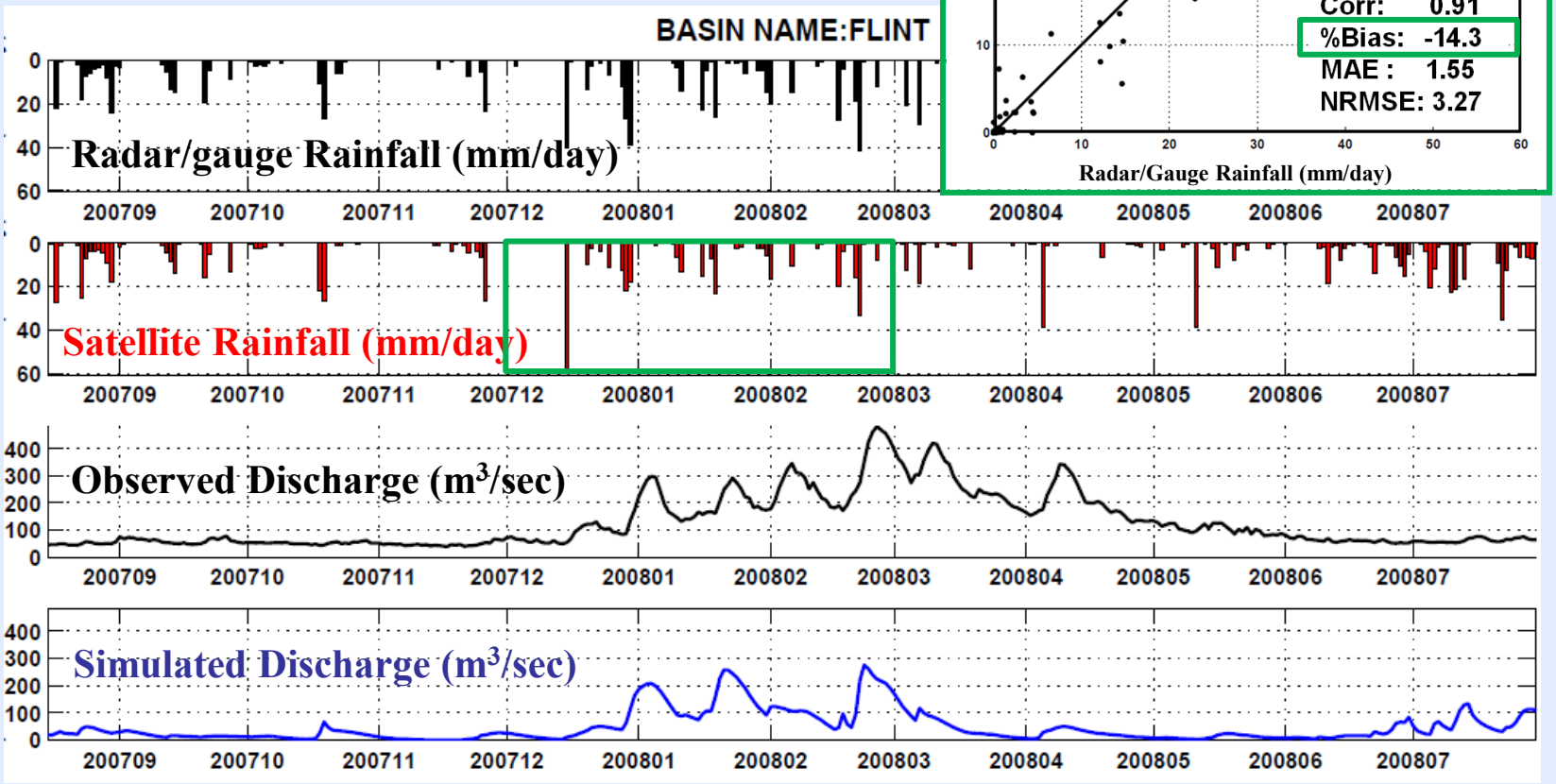


Map showing the number of simulated false 7-day events over the globe. Boxes denote the zones with different runoff threshold

Initial Results with New Model using default parameters

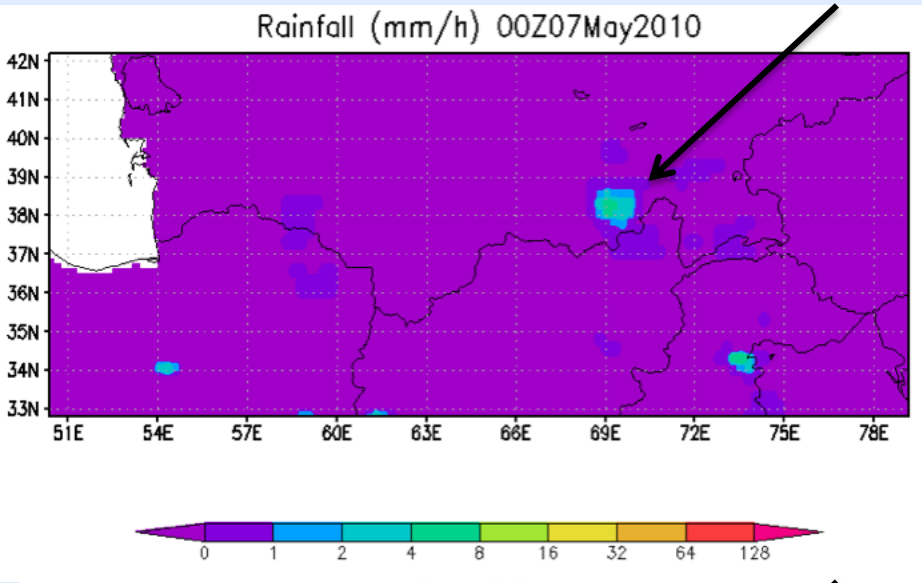


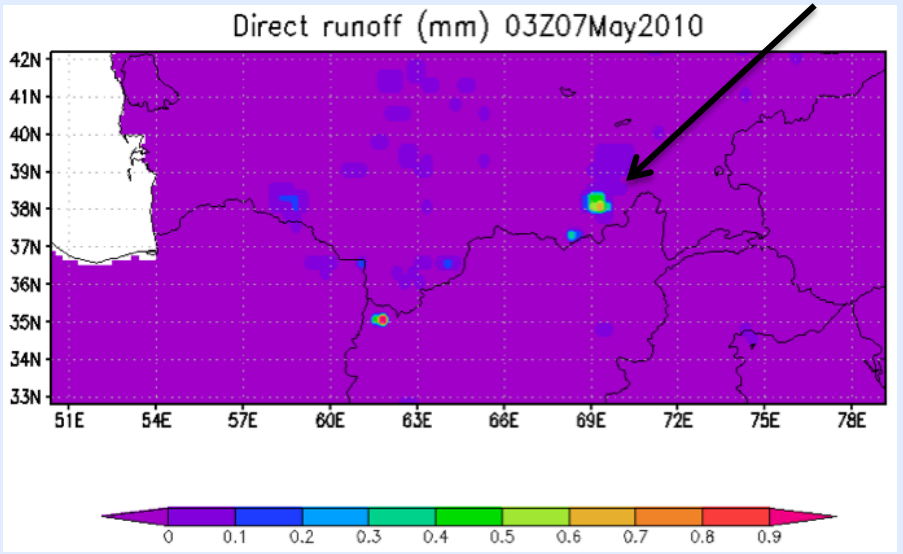


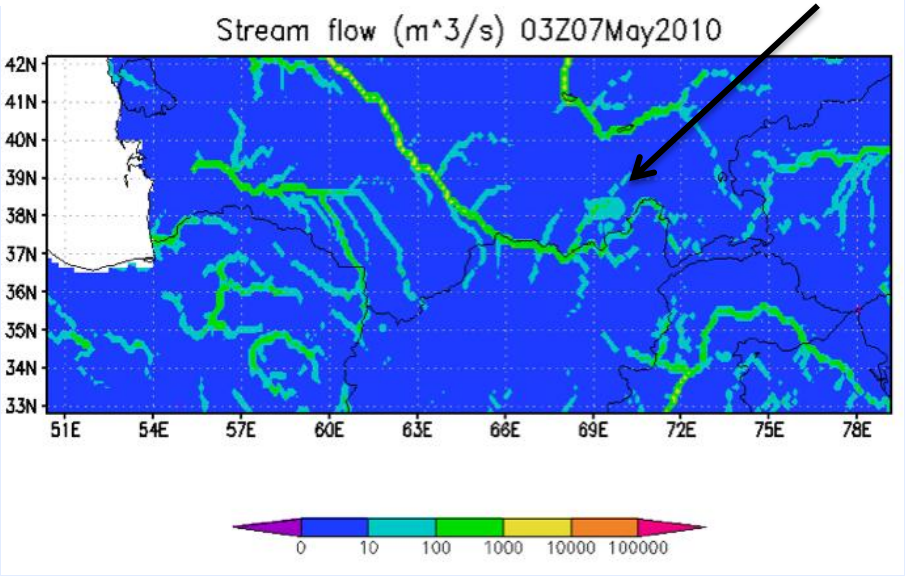


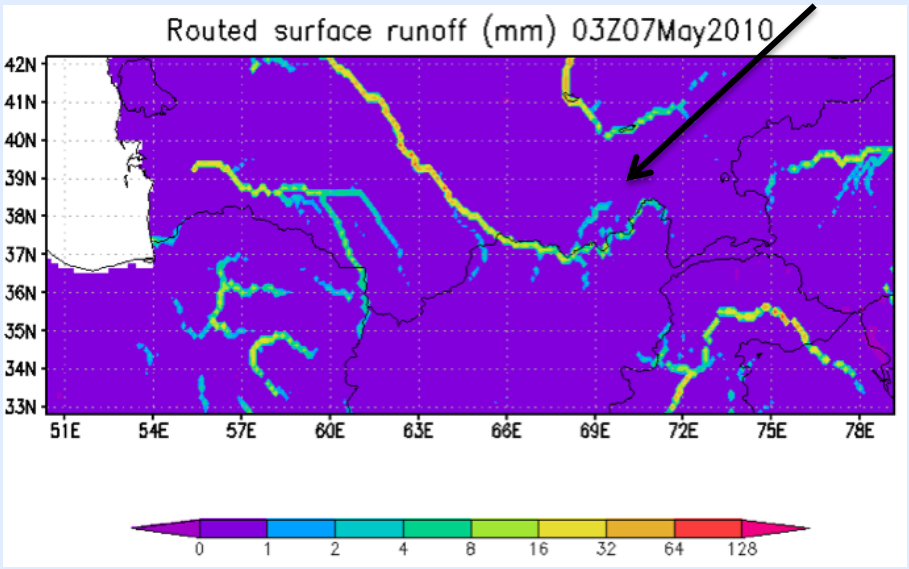
Tajikistan Flood 7 May 2010

Short-lived, small-scale rain event (shows up mainly on two, 3-hr intervals, not very heavy rain in satellite estimates). Barely shows up in enhanced direct runoff, routed surface runoff and streamflow from new model. Indicates small-scale (time and space) events not well captured by system—basic limitation due to sampling interval for rain from satellites.



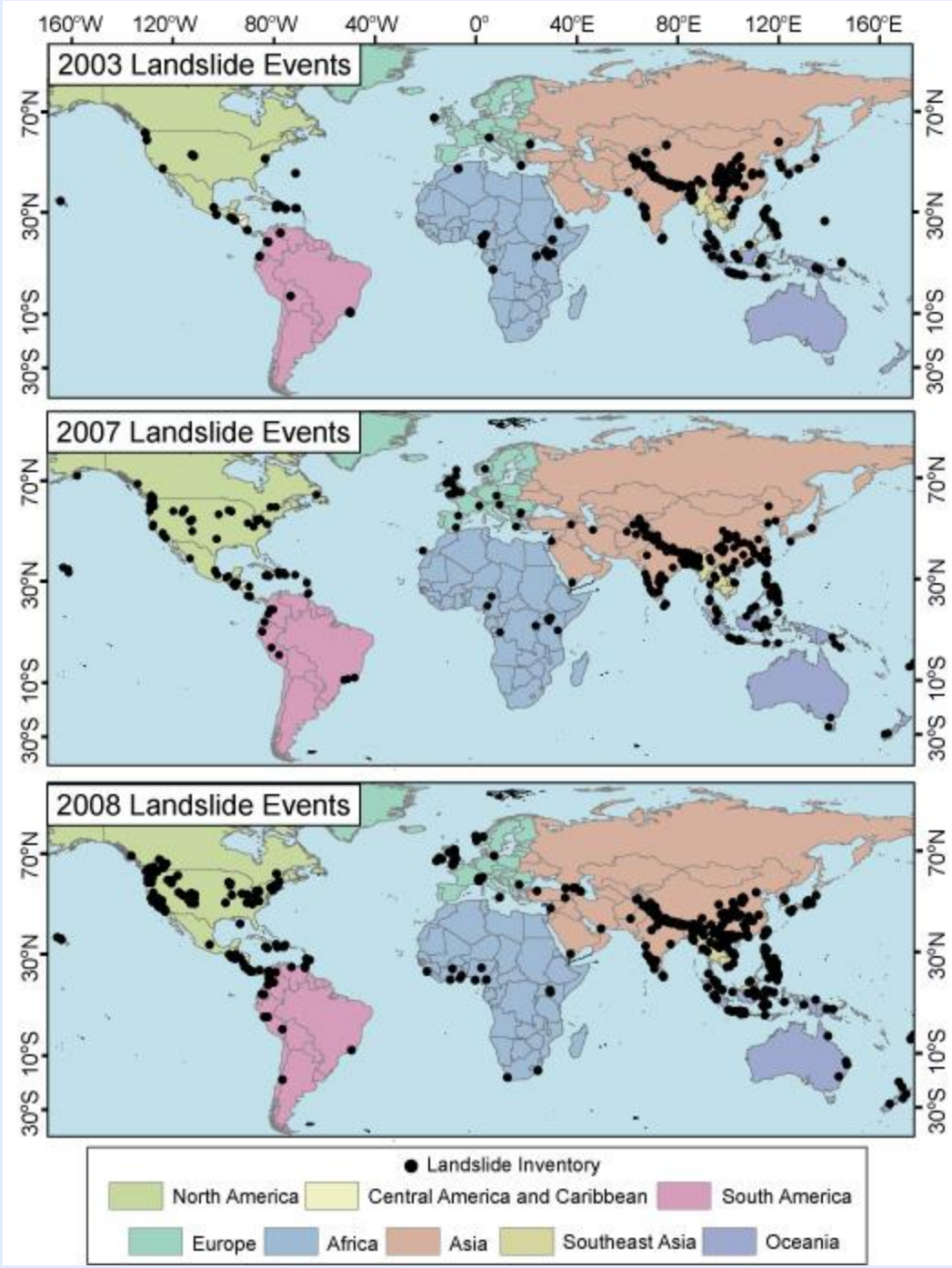






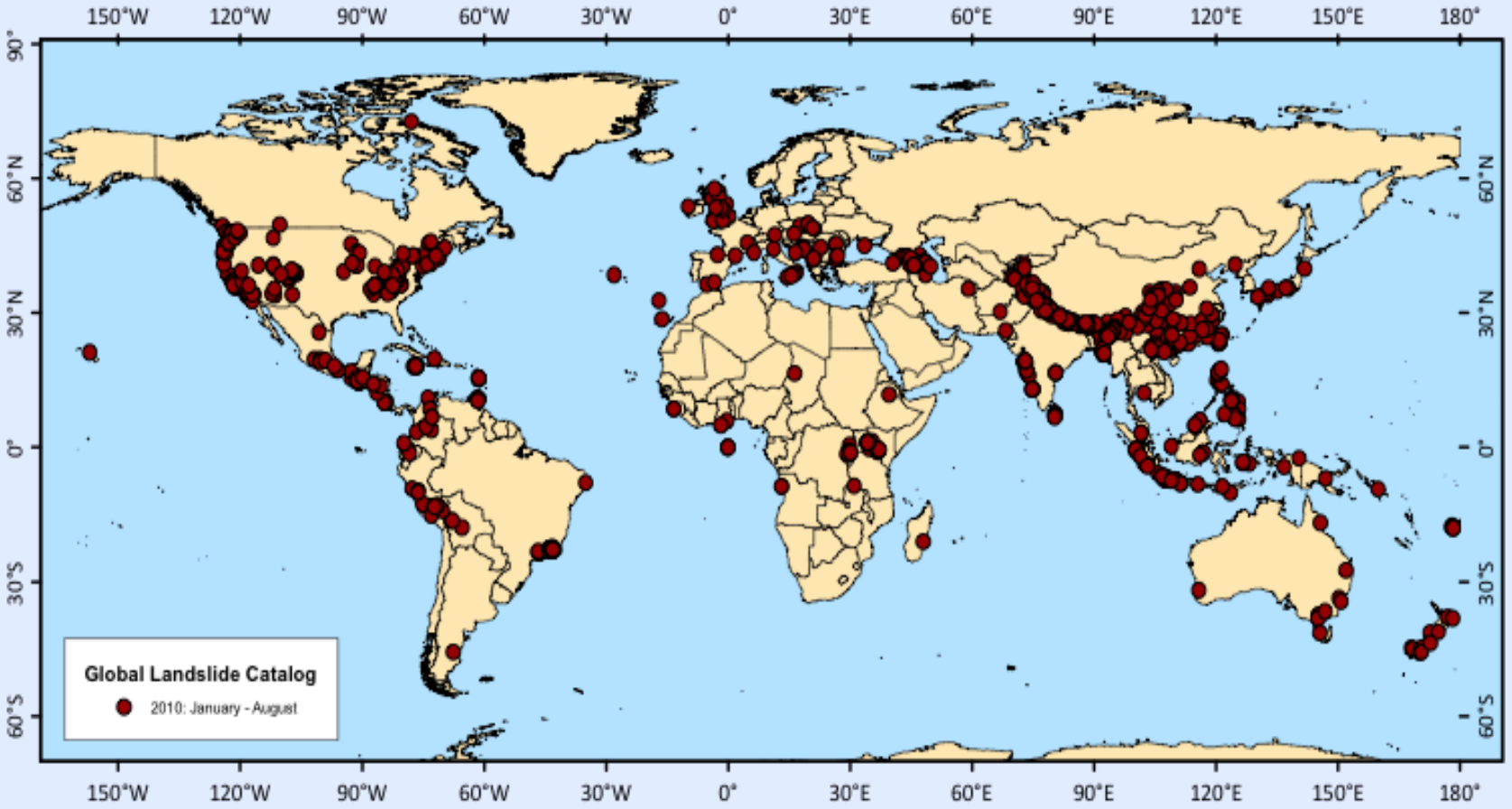
Global Landslide Event Inventory

- Three Year Database:
  - **1,181** events
  - **6,366** fatalities
- Reports from 67 countries
- Work is ongoing for 2010



Kirschbaum, D. B., R. Adler, Y. Hong, S. Hill and A. L. Lerner-Lam (2009). Journal of Natural Hazards

Landslide Inventory for January through August, 2010



925 Events 239 fatal events 4306 fatalities

Kirschbaum, D. B., R. Adler, Y. Hong, S. Hill and A. L. Lerner-Lam (2009). Journal of Natural Hazards

Evaluation of Global Landslide Algorithm

Skill Ratio

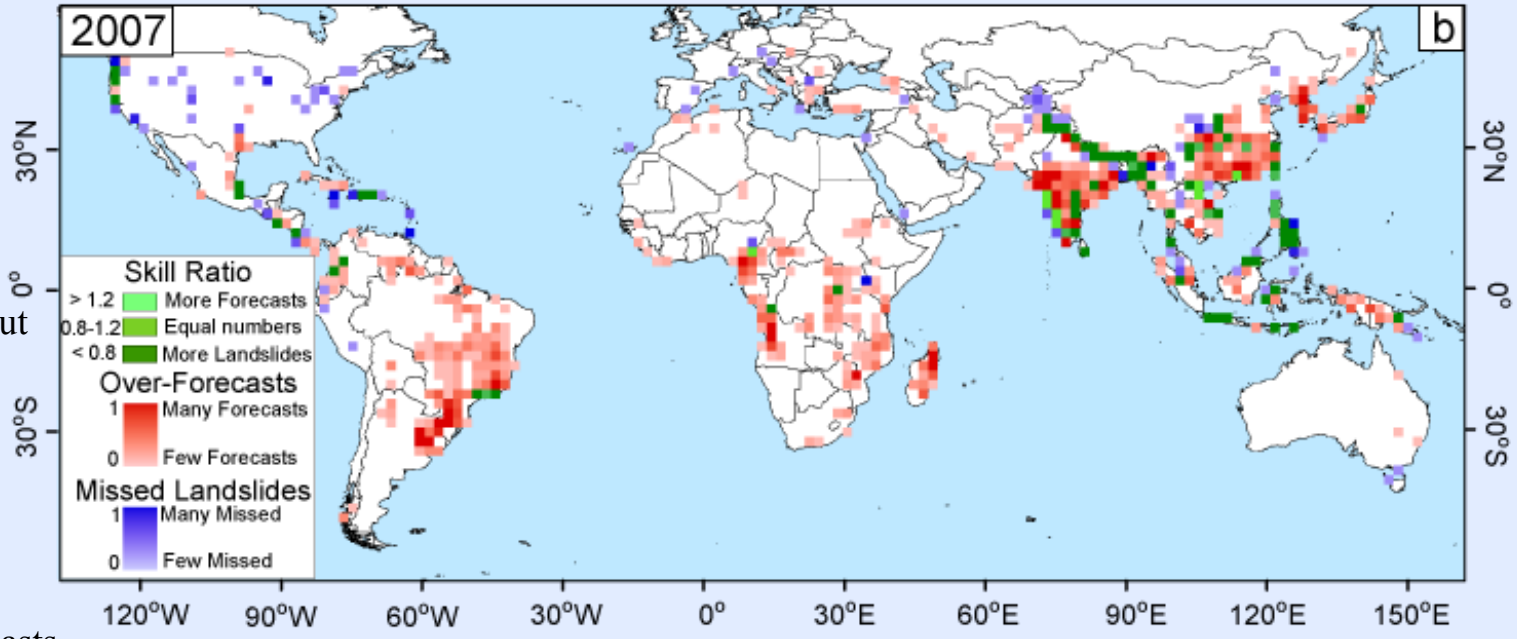
Forecast Density
Landslide Density

Over-Forecasts

Pixels with forecasts but no landslides, norm.

Missed Landslides

Pixels with landslides but no forecasts, norm.

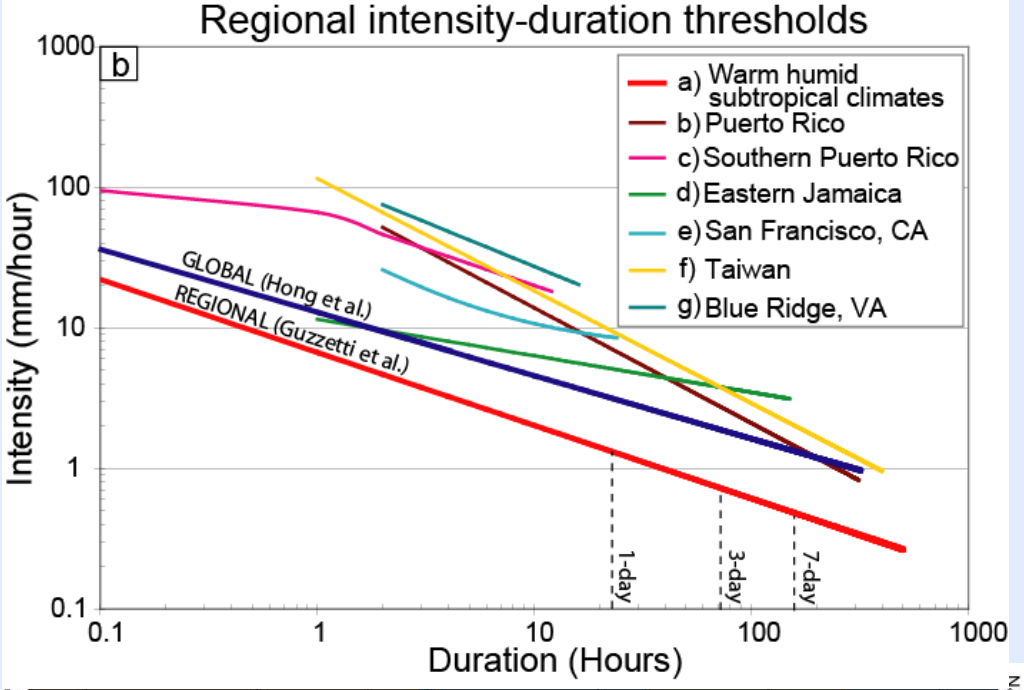


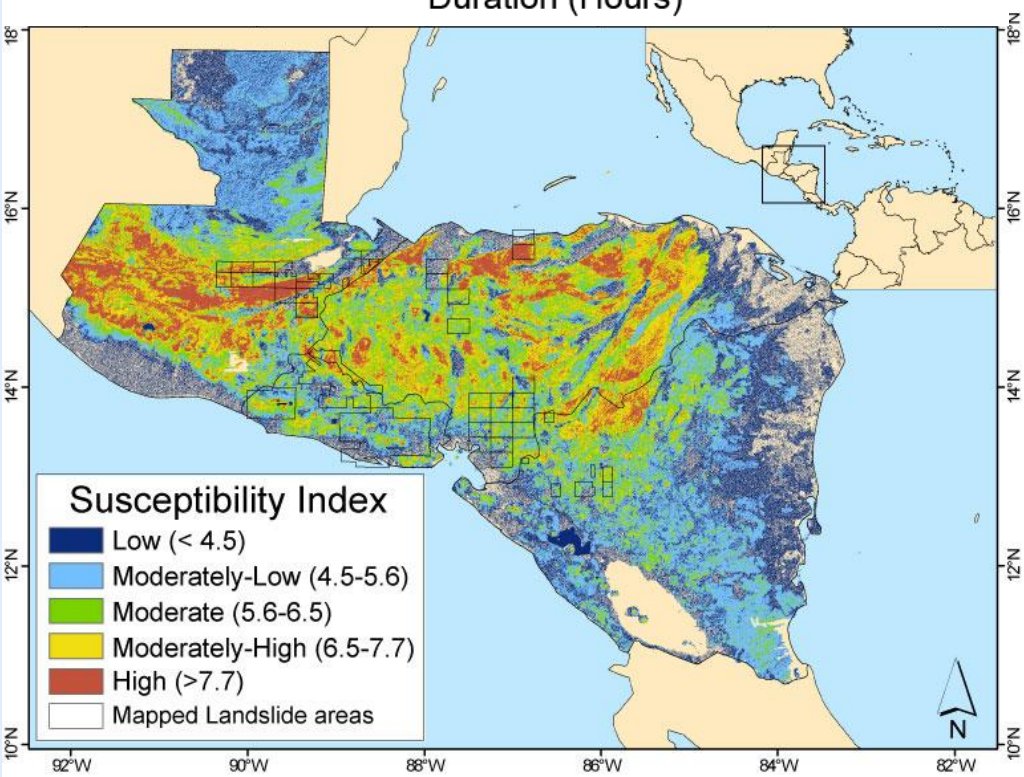
Kirschbaum, D. B., R. Adler, Y. Hong and A. L. Lerner-Lam (2009). "Evaluation of a Satellite-based Landslide Algorithm using Global Landslide Inventories." Natural Hazards and Earth System Sciences **9**: 673-686.

Regional Studies/Modeling

Kirschbaum

- Input into Land Information System (LIS) framework
- Empirical regional approach using higher resolution surface inputs and regional rainfall I-D thresholds
- Inclusion of soil moisture and antecedent precipitation
- Working towards a more physically-based landslide model for improved forecast accuracy

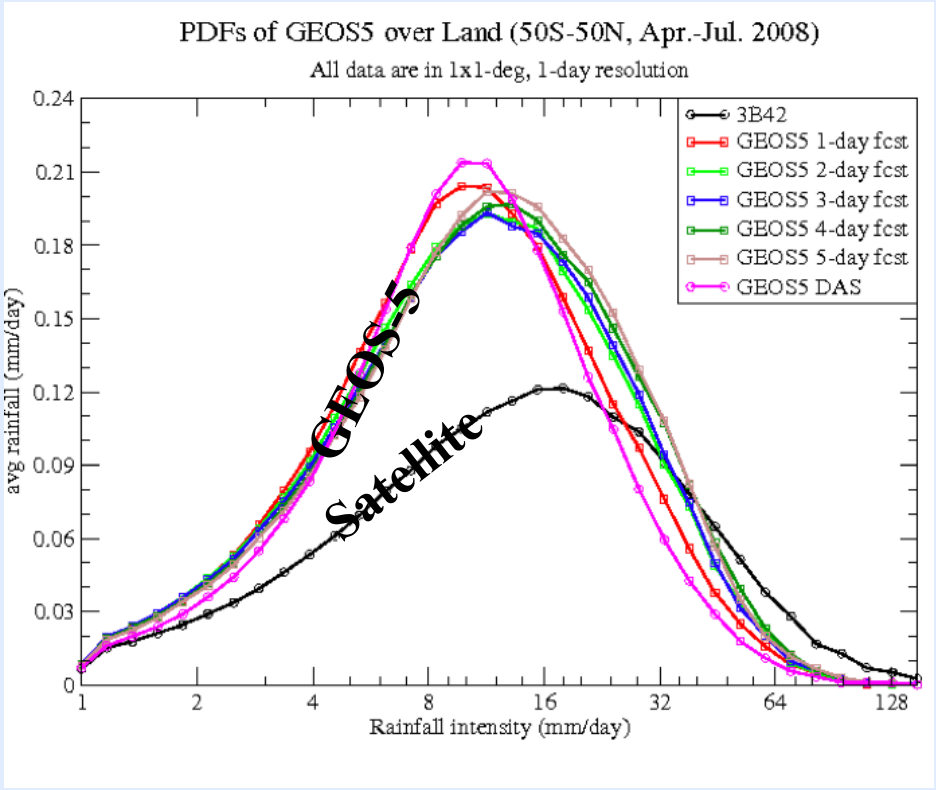


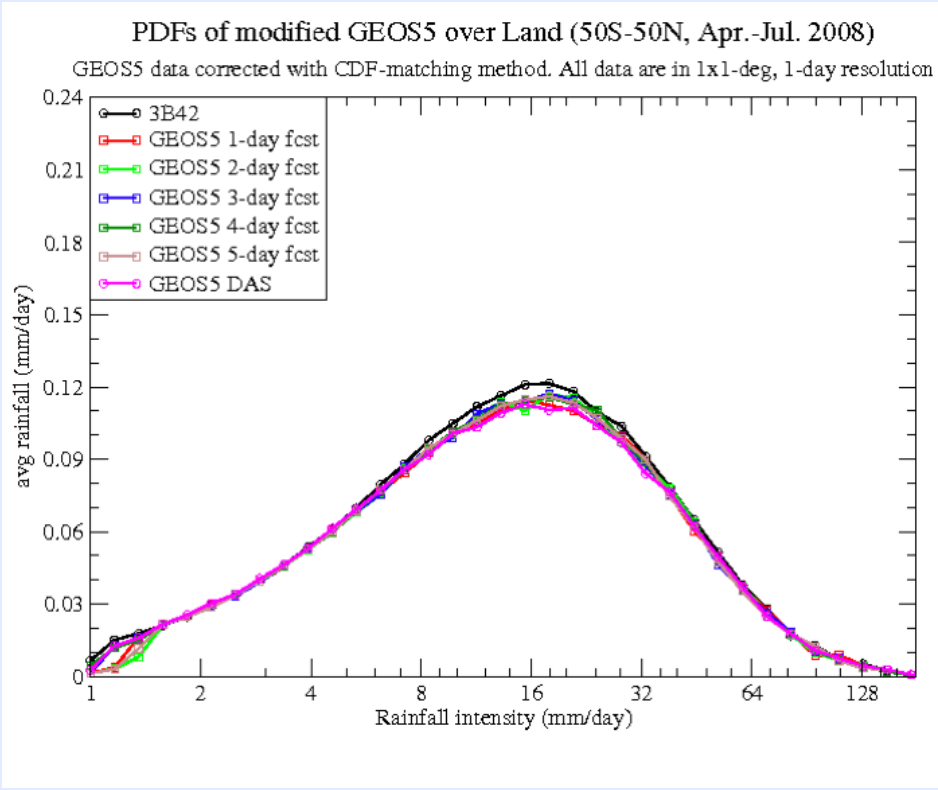


Correcting NWP using satellite rainfall data

GEOS-5 : Goddard Earth Observing System Model Version 5

PDF Matching: GEOS-5 PDF is corrected using Satellite (TMPA) PDF



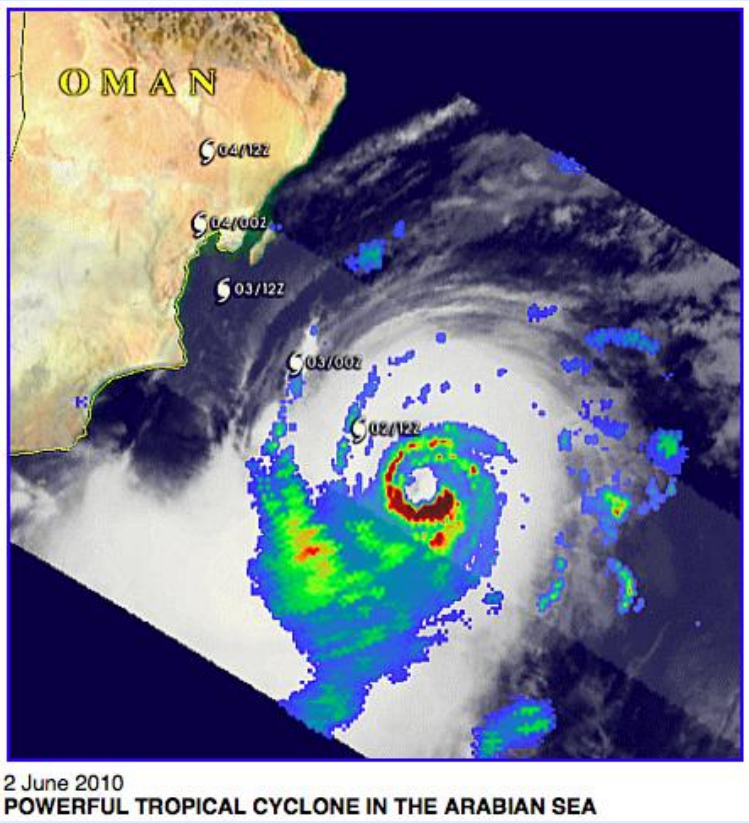


- **NWP Model outputs must be corrected before using for hydrologic applications**
- **NOTE: TMPA -> Snapshot vs. GEOS-5 -> long term average rainfall**

Tian, GSFC

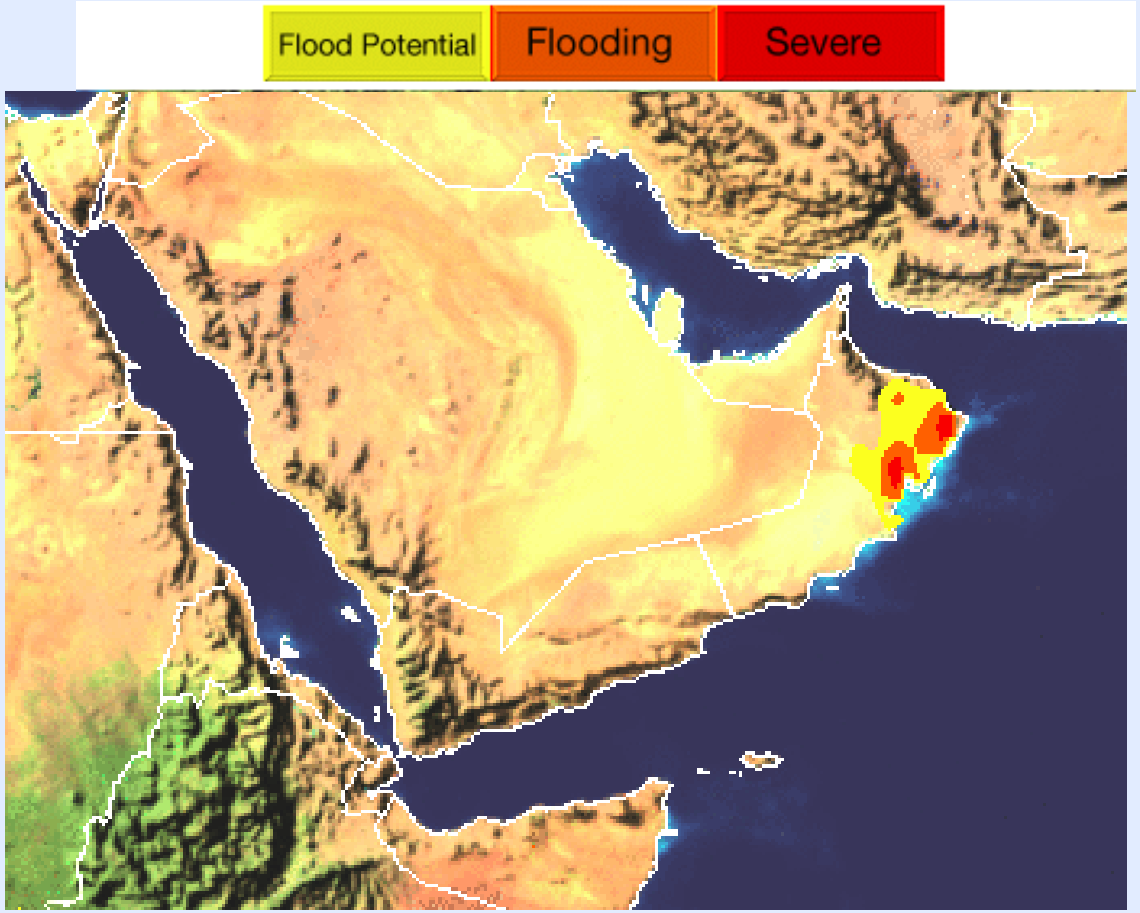
Flood Forecast Based on Satellite Rainfall, Global Model Forecasts and Hydrological Model

Experimental flood forecast (for tomorrow) for landfall of Tropical Cyclone Phet on Arabian peninsula using satellite rainfall (TRMM Multisatellite Precipitation Analysis (TMPA), 24-hr rainfall forecasts from global model and hydrological model. Forecasts are made globally at 0.25° lat./long. [Forecast made from data at 0900 GMT 3 June]



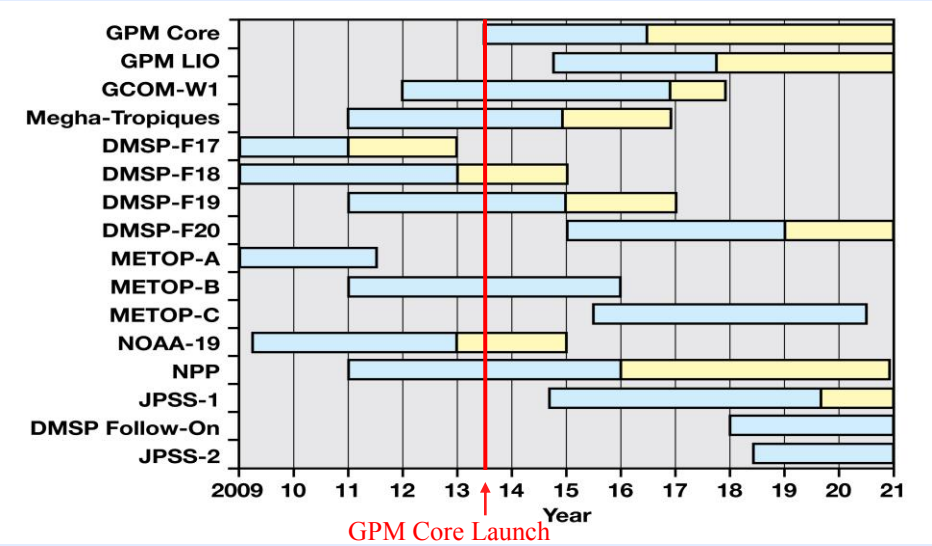
2 June 2010
POWERFUL TROPICAL CYCLONE IN THE ARABIAN SEA

Forecast Valid 4 June 2010 09 GMT



GPM Constellation Sampling and Coverage

Baseline Constellation Schedule

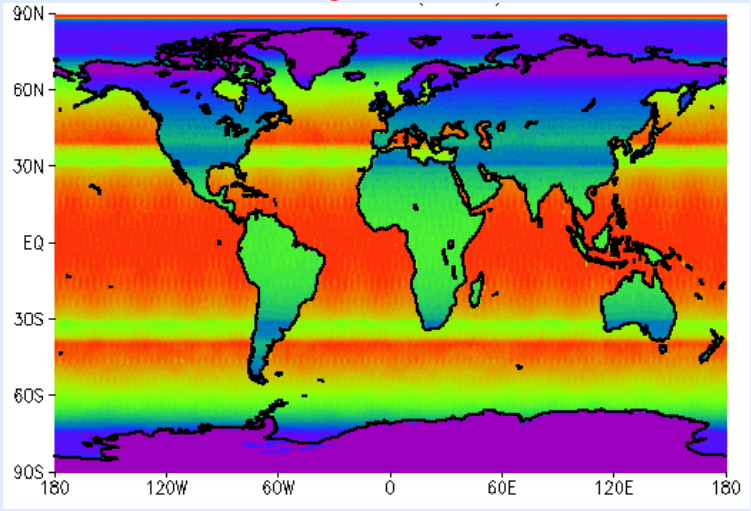


	Average Revisit Time (hr)				
Year	2013	2014	2015	2016	2017
	Land				
Tropics	1.9	1.5	1.5	1.6	2.4
Extratropics	1.3	1.0	1.0	1.2	1.4
Globe	1.6	1.2	1.2	1.4	1.8
	Ocean				
Tropics	3.2	2.6	2.6	2.6	4.9
Extratropics	3.3	2.6	2.6	2.6	3.4
Globe	3.2	2.6	2.6	2.6	4.2
	Land and Ocean				
Tropics	2.8	2.3	2.3	2.3	4.2
Extratropics	2.6	2.1	2.1	2.1	2.7

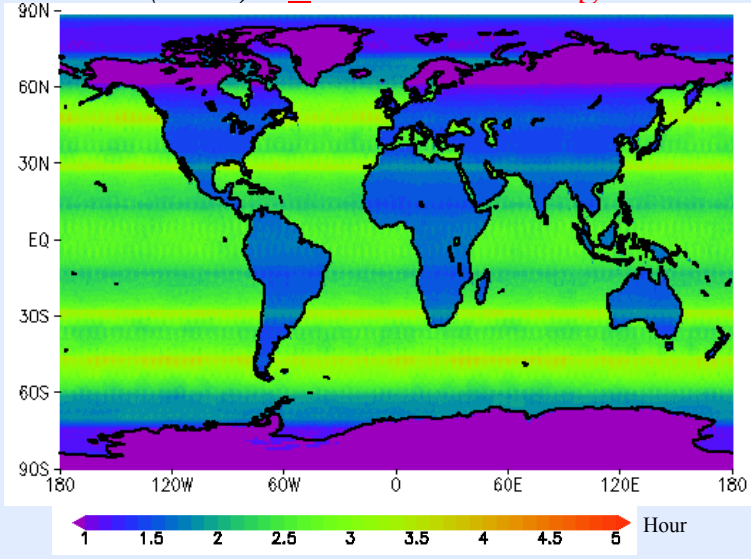
1-2 hr revisit time over land with inclusion of sounders

Current Capability:

≤ 3h over 45% of globe



GPM (2015): ≤ 3h over 90% of globe



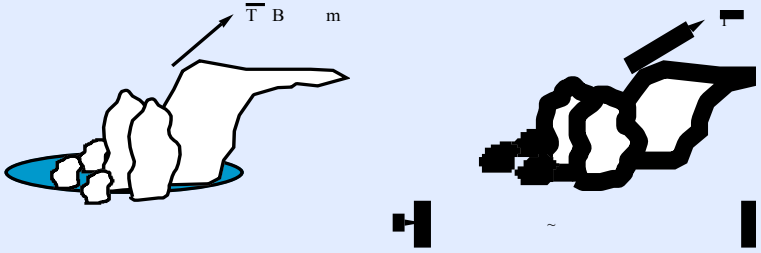
Next-Generation Global Precipitation Products

GPM Core: Reference Standard for Constellation Radiometers

- Intercalibrated constellation radiometric data reconciling differences in center frequency, viewing geometry, resolution, etc.
  - Converting observations of one satellite to virtual observations of another using non-Sun-synchronous satellite as a transfer standard
  - GMI employs an encased hot load design (to minimize solar intrusion) and noise diodes for nonlinearity removal to attain greater accuracy & stability
  - International working group (NASA, NOAA, JAXA, CONAE, CMA, EUMETSAT, CNRS, GIST, & universities) in coordination with WMO/CGMS GSICS
- Unified precipitation retrievals using a common cloud/hydrometeor database constrained by DPR+GMI measurements from the GPM Core Observatory

Optimally matching observed T_b with simulated T_b from an a priori cloud database

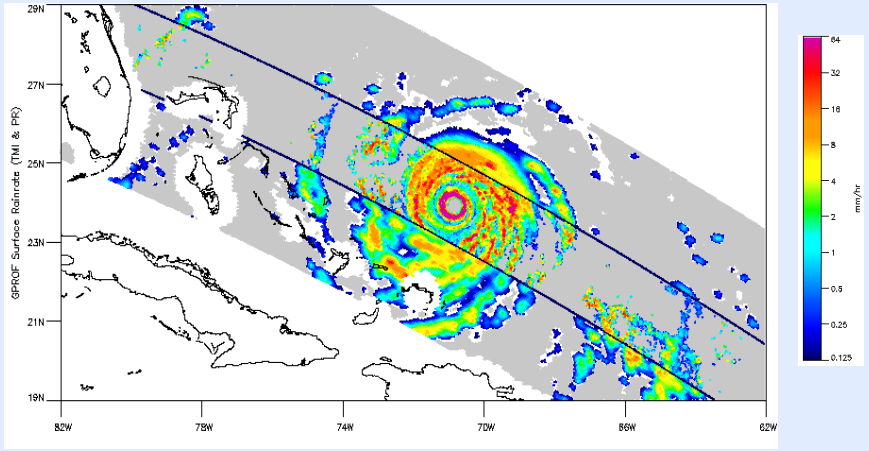
Simulated T_b *Observed T_b*



TRMM uses a model-generated cloud database

GPM uses a DPR/GMI-constrained database

Prototype GPM Radiometer Retrieval



Comparison of TRMM PR surface rain with TMI rain retrieval using an cloud database consistent with PR reflectivity and GMI multichannel radiances

Summary

- GPM is an international satellite mission specifically designed to unify and advance precipitation measurements from a constellation of microwave sensors for scientific research and societal applications.
- GPM is in the implementation phase at NASA and JAXA:
  - Core Observatory Launch Readiness Date: 21 July 2013
- NASA Precipitation Processing System is currently producing
  - Prototype intercalibrated L1 products for TMI, SSMI, AMSR-E, SSMIS, & WindSat
  - L3 merged global precipitation products using TMI, SSMI, AMSR-E, AMSU, & MetOp in near real-time for research & applications
- GPM next-generation global precipitation products build on intercalibrated microwave radiances and unified physical retrievals using a common hydrometeor database constrained by Core sensor measurements.
- Ground validation is key to algorithm physics improvement. NASA is conducting a series of joint field campaigns with domestic and international partners to refine algorithm assumptions and parameters.
- GPM is more than a partnership sharing space assets – it offers a programmatic framework for international science collaboration on radiometer intercalibration, precipitation retrieval, ground validation, and data utilization.

NASA Contact: Dr. Arthur Y. Hou (arthur.y.hou@nasa.gov)