Welcome to
NASA Applied Remote Sensing Training (ARSET)
Webinar Series

Flood Monitoring using NASA Remote Sensing Data

Course Dates: November 19, 26 December 3, 10
Time: 8-9 a.m. Eastern U.S. Time (13-14 p.m. UTC)

ARSET

Applied Remote SEnsing Training
A project of NASA Applied Sciences

Course Objectives

- Introduce **near-global**, **publically-available**, **web-accessed**, Flood Monitoring Tools
- Present live demonstration of flooding events/ case studies using the web tools

Outline

- About ARSET
- Course Introduction and Overview
- Meteorology and hydrology parameters useful for flood monitoring
- NASA Remote Sensing and Earth System Models
  - *Fundamentals of Remote Sensing*
  - *Strengths and Limitations*
  - *Earth System Models*
- Overview of Flooding Tools to be covered

Applied Remote SEnsing Training (ARSET)

A NASA Applied Sciences Program

NASA Earth Science
Applied Sciences Program

Applications to Decision Making: Eight Thematic Areas

Agricultural Efficiency

Air Quality

Climate

Disaster Management

Ecological Forecasting

Public Health

Water Resources

ARSET

Objectives

- Provide end-users with **professional technical workshops**
- Build long term partnerships with communities and institutions in the public and private sectors.

Online and hands-on courses:

- **Who:** policy makers, environmental managers, modelers and other professionals in the public and private sectors.

  Where: U.S and internationally
- **When**: throughout the year. Check websites.
- Do NOT require prior remote- sensing background.
- Presentations and hands-on guided computer exercises on how to access, interpret and use NASA satellite images for decision-support.

Recent ARSET Courses: Water Resources/Flooding

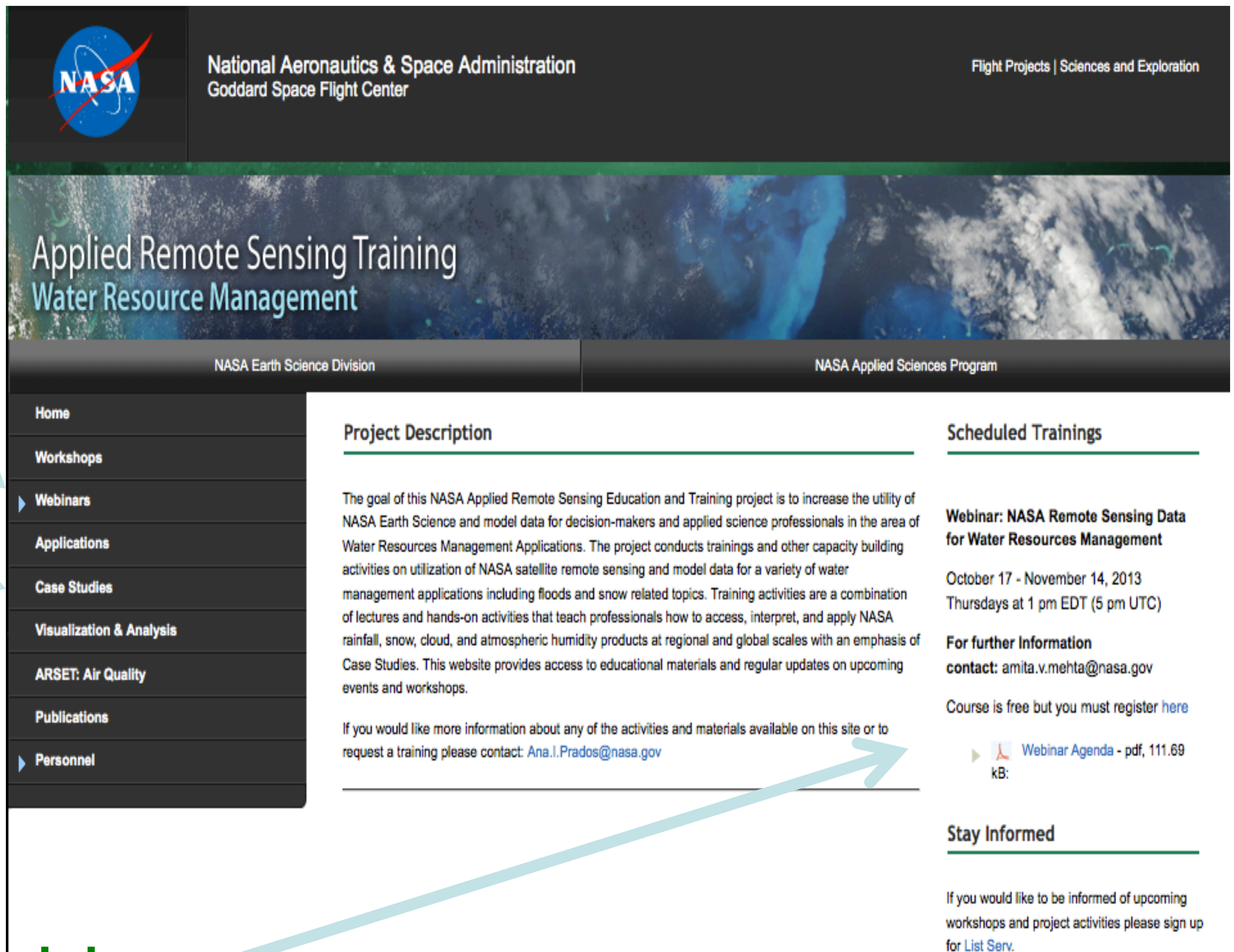
- Cartagena, Colombia, hands-on
  November 2011, Precipitation, Flooding
- University of Oklahoma, National Weather Center, hands-on
  June 2012
- First online course
  Fall 2012
  Precip/Flooding/Drought
- Second Online course
  Jan/Feb 2013
  Snow Products
- World Bank, DC, hands-on
  March 2013
  Flooding Applications

Attendees of the NASA water resources training at the University of Oklahoma on June 19-20, with course instructors Amita Mehta and Ana Prados. Preliminary end-user feedback included a) interest in follow-on advanced/online courses and b) additional topics in land products, e.g. ET and Landsat.

Who Can Benefit from ARSET Courses?

- **Public Sector:** Local, state, federal, international regulatory agencies, project managers, health and disaster management agencies, World Bank, United Nations
- **Private Sector:** industry, NGOs, consultants, and other organizations involved in capacity building
- **Scientists/Technical Experts**: Meteorologists, Modelers, Hydrologists, Agriculture, Health and Disaster Researchers

http://water.gsfc.nasa.gov/



Modules in English and Spanish

Case Studies

Upcoming trainings

Sign-up to listserv

Course Instructors

- Amita Mehta (ARSET) amita.v.mehta@nasa.gov
- Brock Blevins (ARSET) bblevins37@gmail.com

Guest Speakers:

- Elena Cristofori (ITHACA) ele.christofori@gmail.com
- Adriana Albanese (ITHACA) adriana.albanese@polito.it

ITHACA: **Information Technology for Humanitarian Assistance Cooperation and Action**

Other Contributions to this Course

Spanish Translation: David Barbato (ARSET)

General Inquiries/questions about ARSET:

Ana I. Prados (ARSET) apradosumbc.edu

Course Structure

- One lecture per week – every Tuesday from 19 November to 10 December (8-9 AM. Eastern US Time, 13-14 PM UTC)
- Webinar presentations can be found at: http://water.gsfc.nasa.gov/webinars/
- One assignment (after Week-4)
- Q/A : 15 minutes following each lecture and/or by email (amita.v.mehta@nasa.gov)

Certificates of Completion (upon request):
You must attend all 4 live sessions
You must submit the homework assignments

For Webinar Recording Link :

Contact : Marines Martins
Email: marines.martins@ssaihq.com

Introduction and Course Overview

Flood?

Flood:

Overflow of water from a water body on otherwise dry land

Measured in terms of stream flow or the rate at which a volume of water flows – measure of depth, width, and speed of water flow – expressed in cubic meters per second (m^3/s)

Flash Flood:

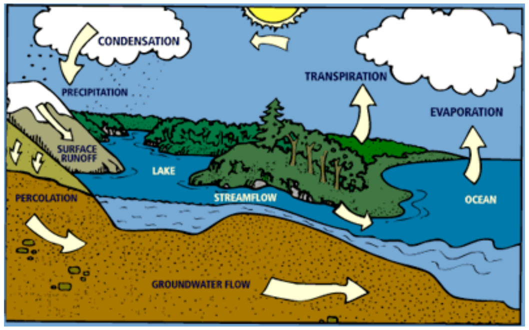
A flood caused by heavy or excessive rainfall in a short period of time, generally less than 6 hours

Inundation:

Usually dry land surface that is covered with water – due to flooding or heavy rain

Meteorology and Hydrological Information Crucial for Flood Monitoring

- Rain Rate and Accumulated Rain Amount
- Snow Melt Rate



- Terrain
- Soil Condition: soil moisture, temperature, and cover
- Reservoir/River Level
- Strom Water Drainage System (urban floods)

NASA has:

- Several satellites in orbit with various instruments or sensors

- plans for future satellite missions

- Several earth system models which use satellite remote sensing observations

-- Providing quantities useful for flood monitoring

NASA Satellites for Hydrology

Landsat (07/1972-present)

TRMM (11/1997-present)

Terra (12/1999-present)

Aqua (5/2002-present)

GRACE (3/2002-present)

TRMM: Tropical Rainfall Measuring Mission
GRACE: Gravity Recovery and Climate Experiment

Missions to be Launched in 2104:
GPM: Global Precipitation Measurements
SMAP: Soil Moisture Active Passive

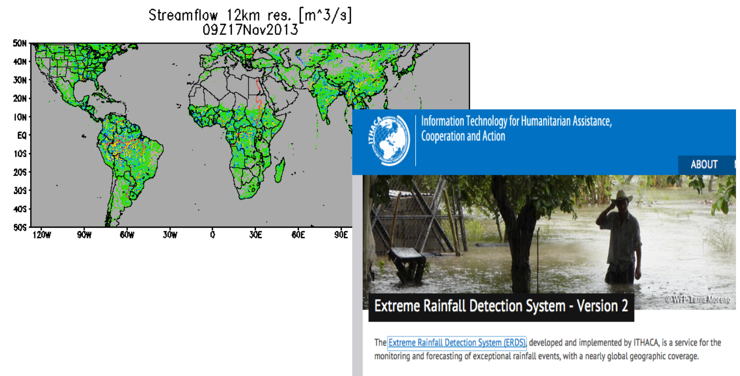
This course will focus on Flooding Tools that use measurements from TRMM and Terra/Aqua

TRMM TMI-PR-VIRS and multi-satellite merged data (Rain)

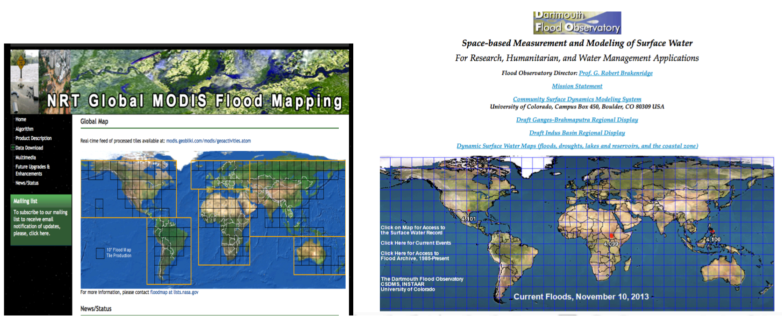
Terra/Aqua MODIS data (Land Cover)

Course Outline

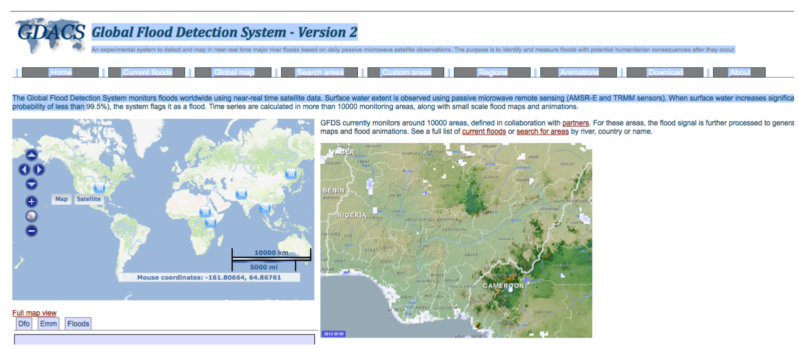
Week 1: Overview of Remote Sensing and Flooding Tools



Week 2: TRMM-based Tools - Extreme Rainfall Detection System and Global Flood Monitoring System



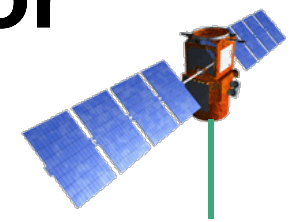
Week 3: MODIS-based Tools – MODIS Inundation and Dartmouth Flood Observatory



Week-4: Global Flood Detection System, multi-satellite flooding case studies with GIS

Fundamentals of Remote Sensing

Why use Remote Sensing for Studying Earth?



- Provides information where there are no ground-based measurements, including over un-gauged rivers and over oceans
- Provides global/near-global coverage with consistent observations
- Provides large-scale views and advance warning of impending environmental events and disasters.

How Do Satellites Make Measurements?

- Passive satellite sensors measure radiation reflected or emitted by the earth-atmosphere system
  - Radiance

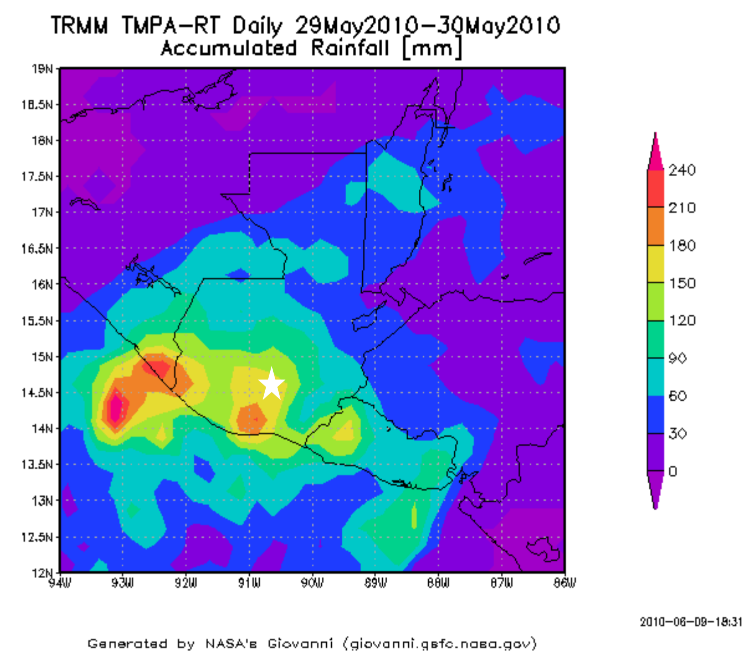
- Radiance is converted to a geophysical parameter

Examples:

Accumulated Rainfall

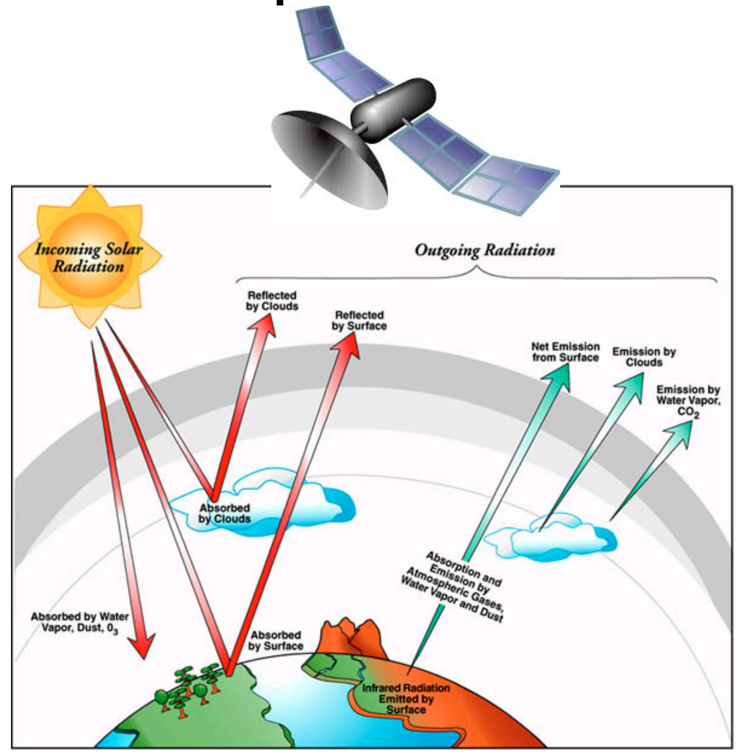
Snow Cover

Accumulated Rainfall Guatemala



Satellite Remote Sensing: measuring properties of earth-atmosphere system from space

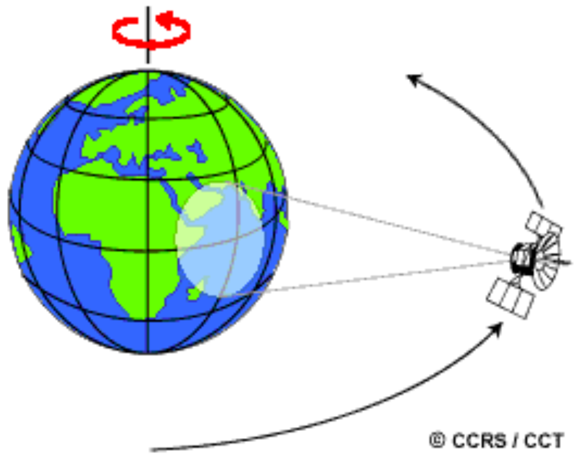
- The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions



- **Thus, satellite measurements contain information about surface and atmospheric conditions**

Types of satellite orbits

Geostationary orbit



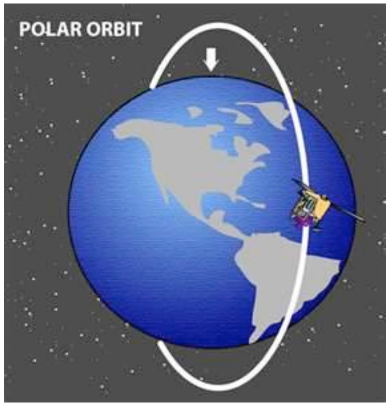
Fixed' above earth at ~36,000 km

Frequent Measurements

Limited Spatial Coverage

Low Earth Orbit (LEO)

Polar (Aqua, Terra)



Nonpolar (TRMM)

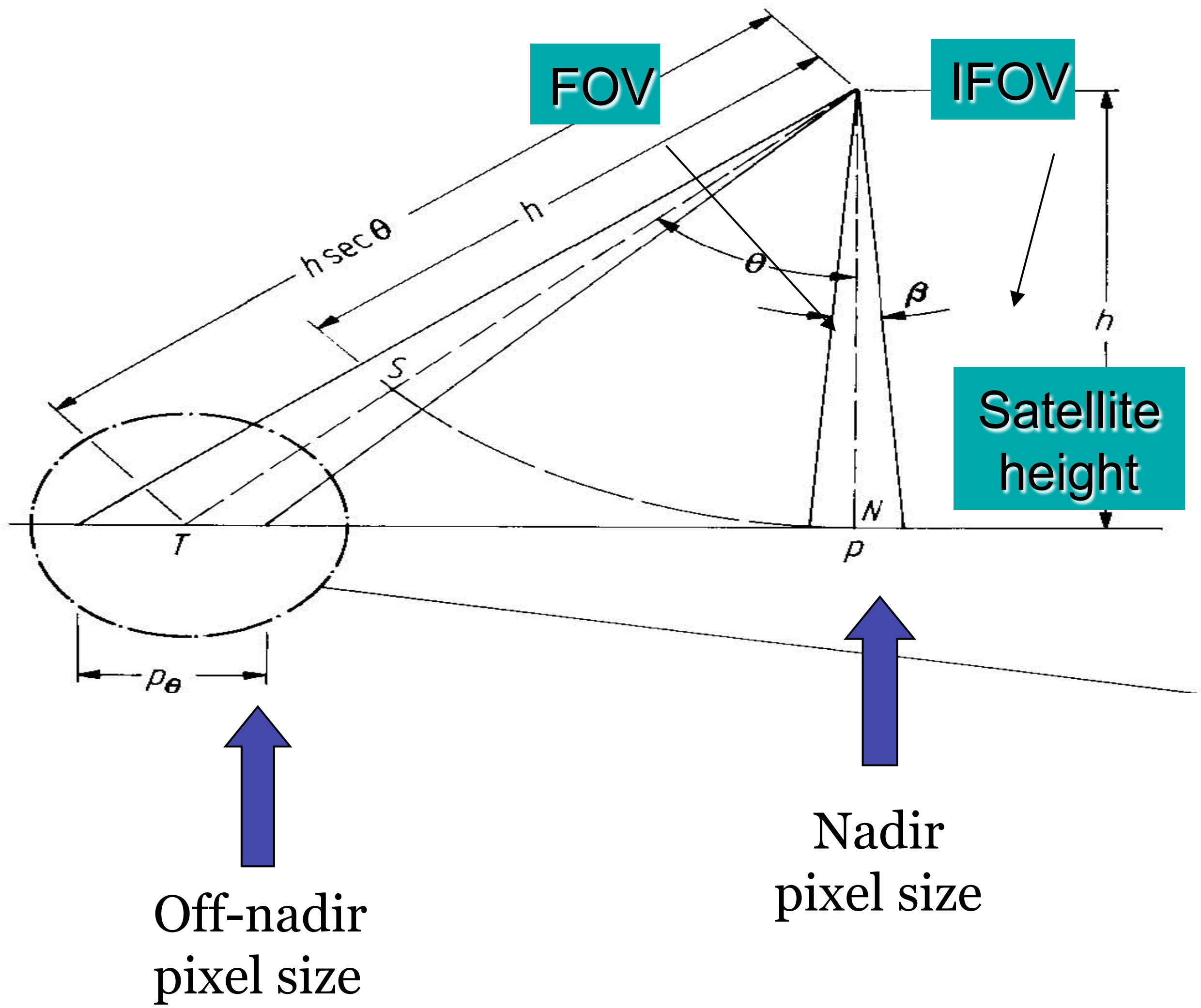
Circular orbit constantly moving relative to the Earth at 160-2000 km

Less Frequent measurements (< 2 times per day)

Large (global) spatial Coverage

Spatial Resolution

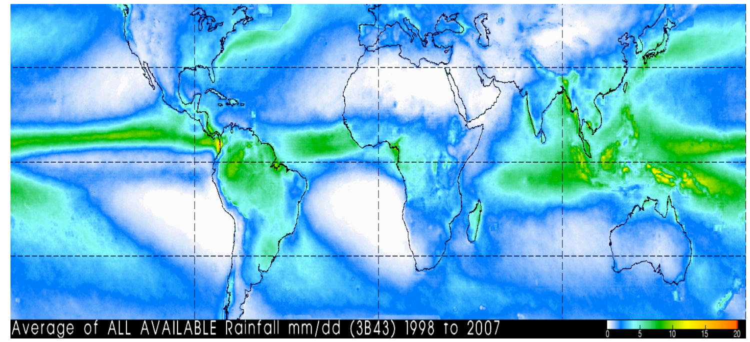
- Spatial Resolution : A simple definition is the pixel size that satellite images cover.
- Satellite images are organized in rows and column called raster imagery and each pixel has a certain spatial resolution.



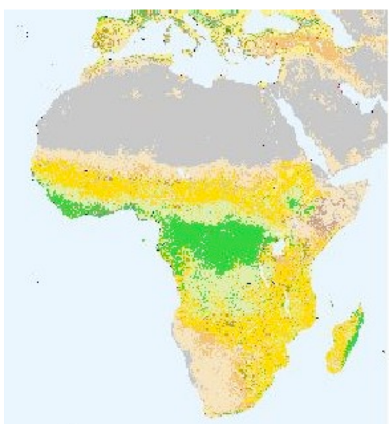
NASA Satellites Measurements with Different Spatial Resolutions

Landsat Image of Philadelphia
Spatial resolution: 30 m

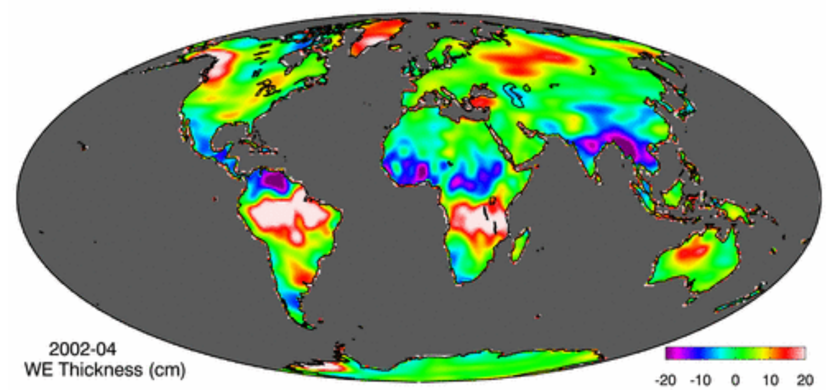
Rain Rate from TRMM
Spatial resolution: 25 km²



Land Cover from Terra/MODIS:
Spatial resolution: 1 km²
(From: http://gislab.jhsph.edu/)



Terrestrial Water Storage Variations from GRACE: Spatial resolution: 150,000 km² or coarser (Courtesy: Matt Rodell, NASA-GSFC)



Temporal Resolution of Remote Sensing Data

The frequency at which data are obtained is determined by:

- Type and height of orbit
- Size of measurement swath

Temporal resolution of Polar Orbiting Satellites Example: Terra, Aqua

- Observations available only **at the time of the satellite overpass.**
- IR based observations available 2X a day
- Visible observations available 1X a day
- Polar regions may have several observations per day.

Temporal resolution of nonpolar satellites

Example: TRMM

- Observations available only **<u>at the time of the satellite overpass.</u>**
- Observations available less than once a day

Note: derived products available at 3-hourly

Satellite data levels of processing and formats

Levels of Satellite Data Processing

Level 1 Products

Orbital data

Used to produce

↓

Level 2 Products

Orbital data

Used to produce

↓

Level 3 Products

Global composites
of level 2 products

More User Control → Less User Control

Harder to Use → Easier to Use

Remote Sensing Products: Limitations

- There are multiple sources of the same products, with varying spatial/temporal resolutions and accuracies

- There are many assumptions and approximations in going from raw data to specific quantity such as rain amount or

- Data quality can range from excellent to poor depending on:
  - Instrument capabilities
  - Instrument calibration and performance
  - The algorithms used to interpret the data

NASA Remote Sensing Quantities useful for Flood Monitoring

Satellite	Sensors	Quantities
TRMM	Precipitation Radar (PR) TRMM Microwave Imager (TMI) Visible Infrared Scanner (VIRS)	Rain Rate, Vertical Rain Rate Profile, Accumulated Rain
Terra and Aqua	MODerate Resolution Imaging Spectroradiometer (MODIS)	Snow Cover, Vegetation Index, Leaf Area Index, Land Cover, Cloud Cover
Aqua	Atmospheric Infrared Sounder (AIRS) Advanced Microwave Scanning Radiometer for EOS (AMSR-E)	3-dimensional Atmospheric Temperature and Humidity, Cloud Cover Snow Water Equivalent, Sea Ice, Soil Moisture, Rain Rate
Landsat	(Enhanced) Thematic Mapper (ETM)	Land Cover, Vegetation Index, Leaf Area Index
Grace	K-Band Ranging Assembly	Terrestrial Water

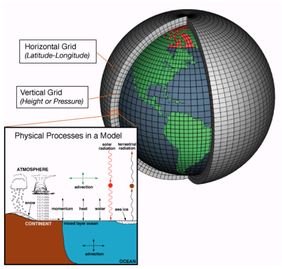
NASA Model-derived Quantities for Flood Monitoring

Value-added Information

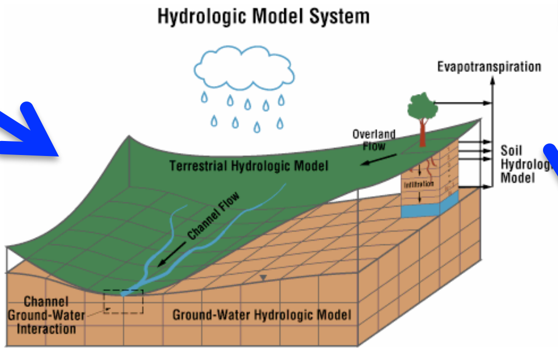
Remote Sensing + Surface Observations + Numerical Models

Satellite Data

surface Measurements and In-Situ Data



Atmosphere/ Land Models



Hydrology Model for Flood Monitoring/ Prediction

NASA Models for Weather, Climate, and Hydrological Quantities

(Atmosphere-Ocean-Land Models)

- GEOS-5 : The Goddard Earth Observing System Version 5
- MERRA: Modern Era Retrospective-analysis for Research and Application
- GLDAS : Global Land Data Assimilation System
- NLDAS : North American Land Data Assimilation System

NASA Models and Flood Related Quantities

Models	Quantities
MERRA	3-dimensional Winds, Temperature, Humidity, Clouds, Rain Rate ,Snow Mass, Snow Cover, Snow Depth, Surface Snowfall Rate, Evapotranspiration
GLDAS/NLDAS /VIC	Evapotraspiration, Multi-layer Soil Moisture, Snowfall Rate, Snow Melt, Snow-Water Equivalent, Surface and Sub-surface Runoff

NASA satellites and atmosphere-land models provide global scale geophysical parameters on hourly, daily, seasonal, multi-year time scales useful for flood monitoring and prediction

- Rain
- Temperature
- Humidity
- Winds
- Soil Moisture
- Snow/Ice
- Clouds
- Terrain
- Ground Water
- Vegetation Index
- Evapotranspiration
- Run off

For direct observations and/or for inputs to hydrology models

All these quantities are available from satellite observations as well as from models
Quantities in green are derived from satellite observations
Quantities in red are from land and atmosphere-land models in which satellite observations are assimilated

TRMM
Used for Extreme Rain Detection and Forcing Hydrologic Models

TRMM Rain Data

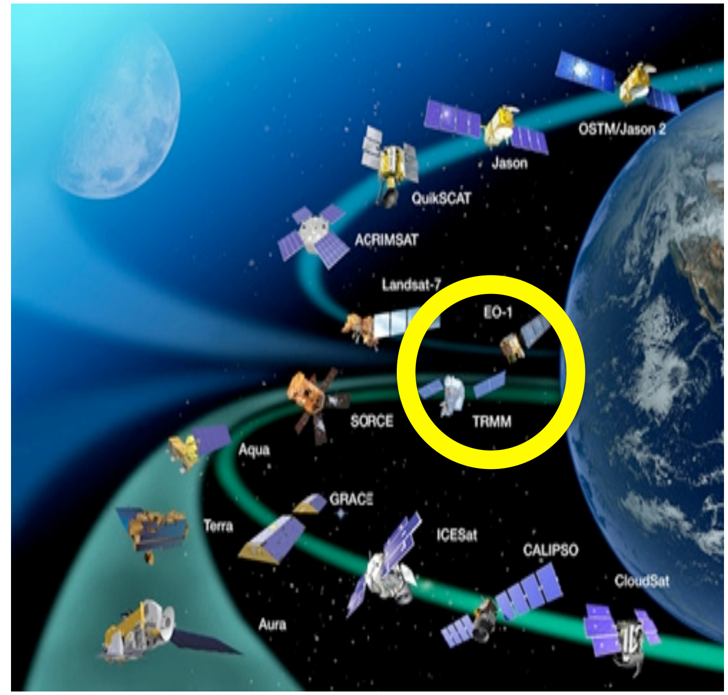
Tropical Rainfall Measuring Mission (TRMM) satellite observations used for flood monitoring:

The TRMM Multi-satellite Precipitation Analysis (TMPA): Quasi-Global, Multiyear, Combined-Sensor Precipitation Estimates at Fine Scales:

- *Monitor near-real time rainfall – including flood inducing extreme rain events*
- *Input/forcing to hydrological models that are used to calculate streamflow for mapping flood and landslide potential*

TRMM: Tropical Rainfall Measuring Mission
http://trmm.gsfc.nasa.gov

- The first satellite mission **dedicated to measuring tropical and subtropical rainfall** - Launched on 27 November 1997
- First satellite to carry a microwave Precipitation Radar
- Predecessor to Global Precipitation Measurement (GPM) mission to be launched in 2013-14.



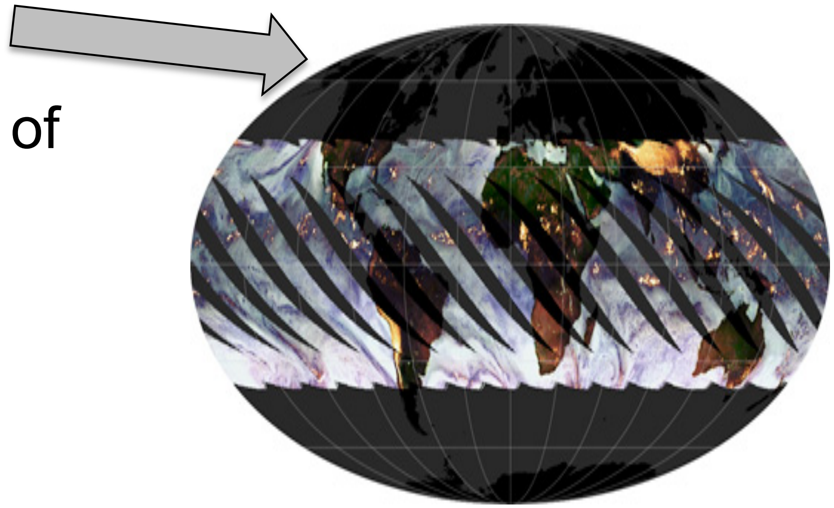
TRMM

- A non-polar, low inclination orbit Revisit time ~11-12 hours, but time of observation changes daily

- One active and two passive rain sensors

- *Precipitation Radar (**PR**)*
- *TRMM Microwave Imager (**TMI**)*
- *Visible and Infrared Scanner (**VIRS**)*

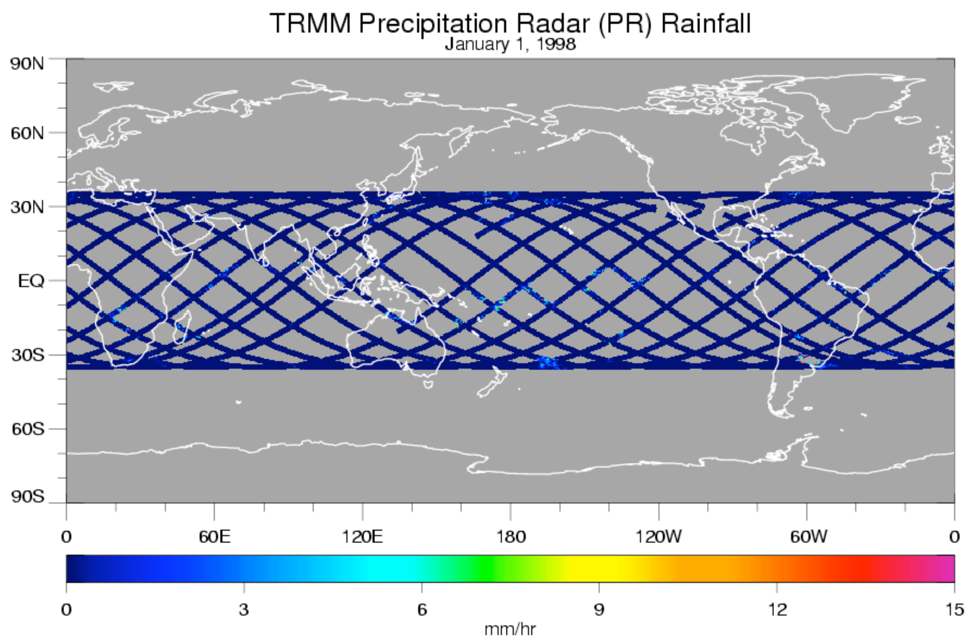
- Multiple rain products available from individual sensors, at varying spatial resolutions, (details given in Appendix)

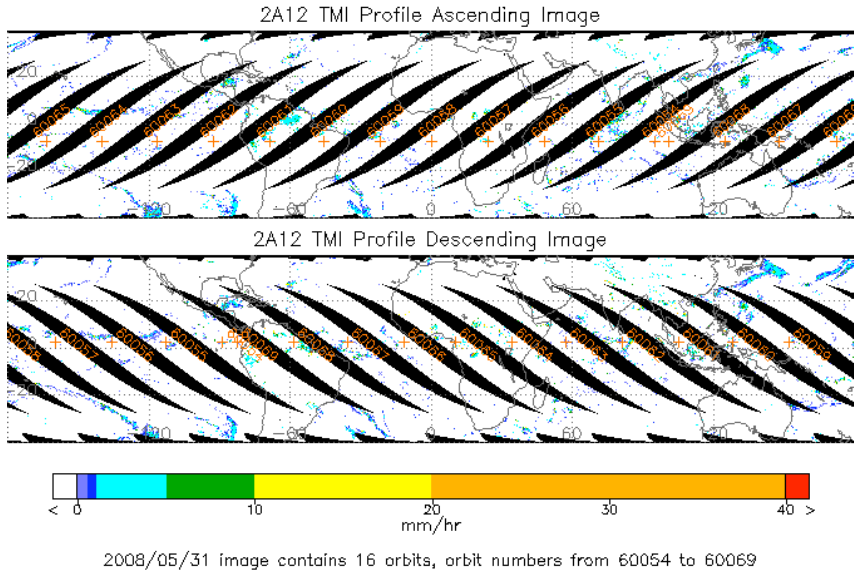


There are 16 TRMM orbits a day **covering global tropics between 35° S to 35°N latitudes**

Altitude - of approximately 350 Km, raised to 403 Km after 23 August 2001

TRMM PR and TMI Rain Data





PR: Swath = 220 km (247 km)
Pixel Size: 5 km

TMI: Swath = 760 km (870 km)
Pixel Size : 5 to 45 km
(channel-dependent)

Strength: High pixel resolution, Accurate measurements
Limitation: No global coverage on daily basis

TRMM Multi-satellite Precipitation Analysis (TMPA)
TRMM Product Name 3B42
(Used for flood monitoring applications)

TRMM 3B42:

Combines PR and TMI rain rates

Inter-calibrates passive microwave rain rates from **SSM/II, AMSR** and **AMSU-B** satellite sensors

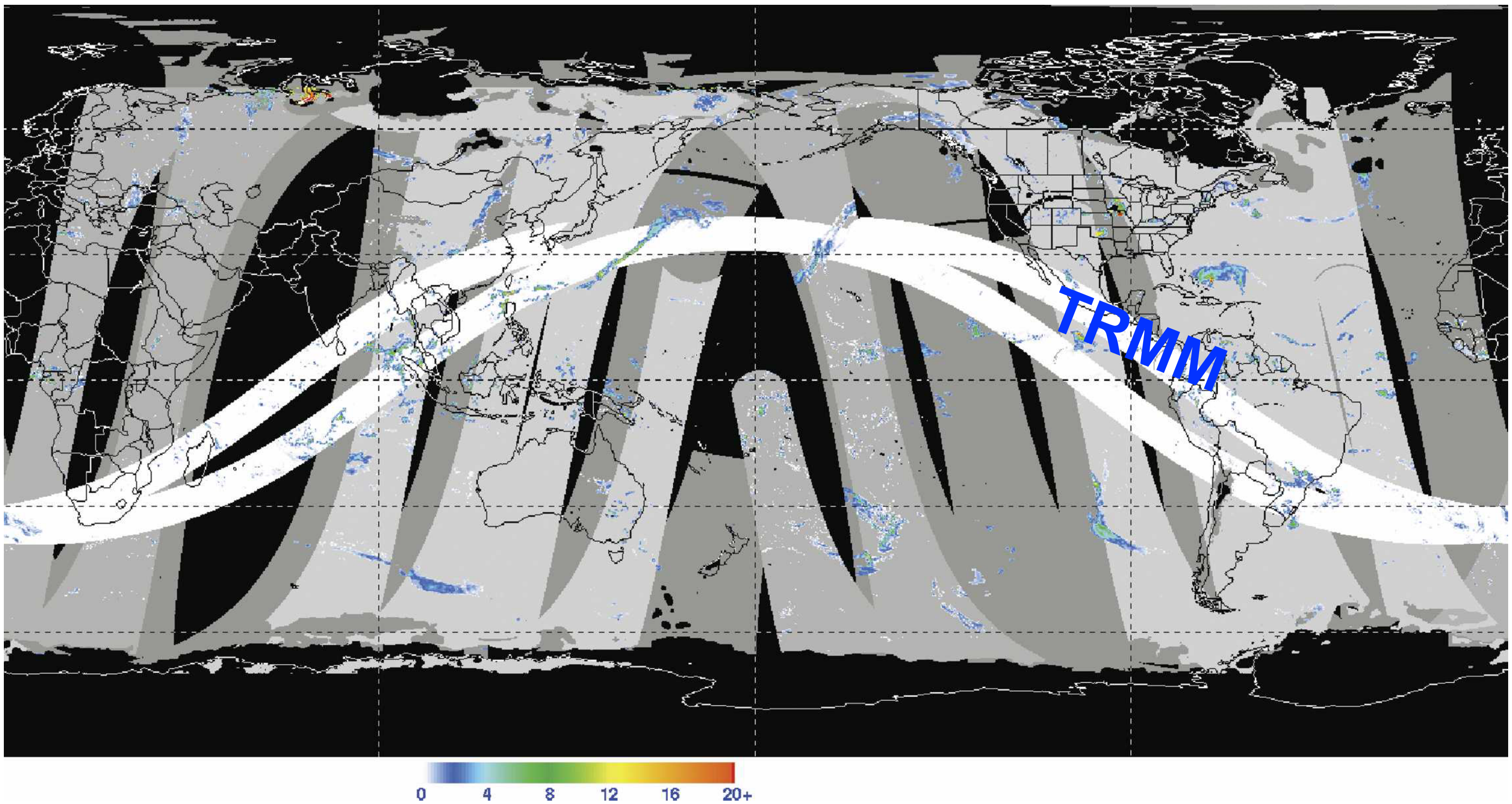
Inter-calibrates with national and international **geostationary and NOAA low earth orbiting satellites infrared measurements** by using **VIRS**

Final rain product is calibrated with rain gauge analyses on a monthly time scale.

SSM/I: Special Sensor Microwave Imager
AMSR: Advanced Microwave Scanning Radiometer
AMSU: Advanced Microwave Sounding Unit

The TRMM Multi-satellite Precipitation Analysis (TMPA)
Combined Microwave Estimates

(From Huffman et al. 2006, J. of Hydrometetorology)



Combined microwave precipitation estimate for the 3-h period centered at 0000 UTC 25 May 2004 in mm/h^{-1}. Blacked-out areas denote regions that lack reliable estimates

TMPA uses accurate PR/TMI rain rates to calibrate rain rates from other sensors to essentially increase temporal resolution from 12 hours to 3 hours

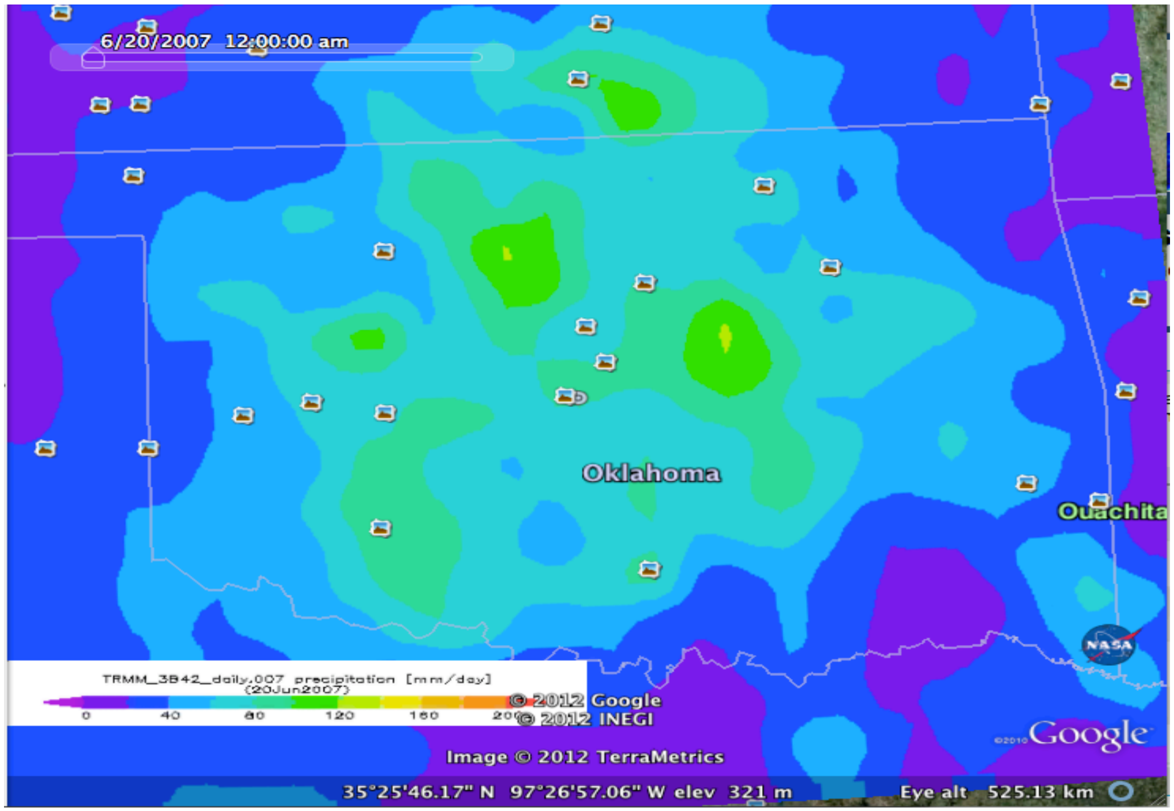
TMPA Surface Rain Rate Data (mm/hour)

TRMM 3B42RT : Near-Real Time

TRMM 3B42 : Adjusted with surface rain gauge measurements on monthly basis

Spatial Resolution:	0.25°x0.25° latitude-longitude
Spatial Coverage:	50° S to 50° N, Global
Temporal Resolution:	3-hourly,Daily,
Temporal Coverage:	1998 to present

Example: Flood Monitoring



Heavy rains (in mm/day) and flooding over Oklahoma as observed from TRMM (6/20/2007)

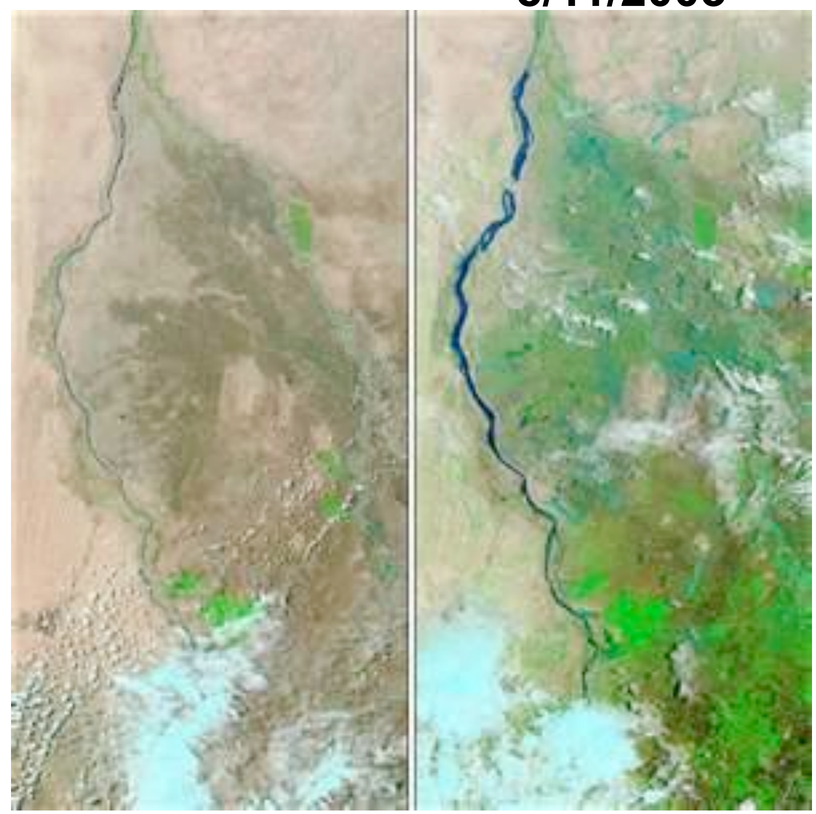
Terra/Aqua
MODIS
Used for Inundation Mapping

MODerate Resolution Imaging Spectroradiometer (MODIS)

http://modis.gsfc.nasa.gov

- Flying on-board Terra and Aqua – polar orbiting satellites
- Global measurements, 2 times per day
- 36 spectral bands observing atmosphere, ocean, and land properties
- Measurement footprints vary from **250 m to ~1 km**

Aqua **6/19/2003** **Terra** **8/11/2003**



Flooding along the White **Nile**, Sudan
From : Natural Hazards
earthobservatory.nasa.gov

MODIS Data for Inundation Mapping

MODIS Data:

Reflectance in Optical Bands 1, 2, and 7

Spatial Resolution: 250 m x250m
Spatial Coverage: Global
Temporal Resolution: Daily, 8-day, 16-day
Temporal Coverage: 1998 to present

Note: MODIS also provides observations of snow cover, vegetation indices

Strength: Globally consistent
Limitation: Data can not be retrieved when clouds are present

Modern Era Retrospective-analysis for Research and Applications: MERRA

http://gmao.gsfc.nasa.gov/merra/

- Merges remote sensing and in-situ observations with the latest Earth systems models
- Weather, climate, climate variation for both research and applied decision making

MERRA Temperature, Humidity, and Wind

Surface skin and Air Temperature
Temperature Profile
East-West and North-South wind components
Humidity (Water Vapor) Profile

Spatial Resolution:	2/3°x1/2° latitude-longitude and 1.25°x1.25, 42 vertical levels
Spatial Coverage:	Global
Temporal Resolution:	Hourly, Daily, Monthly
Temporal Coverage:	1979 to present

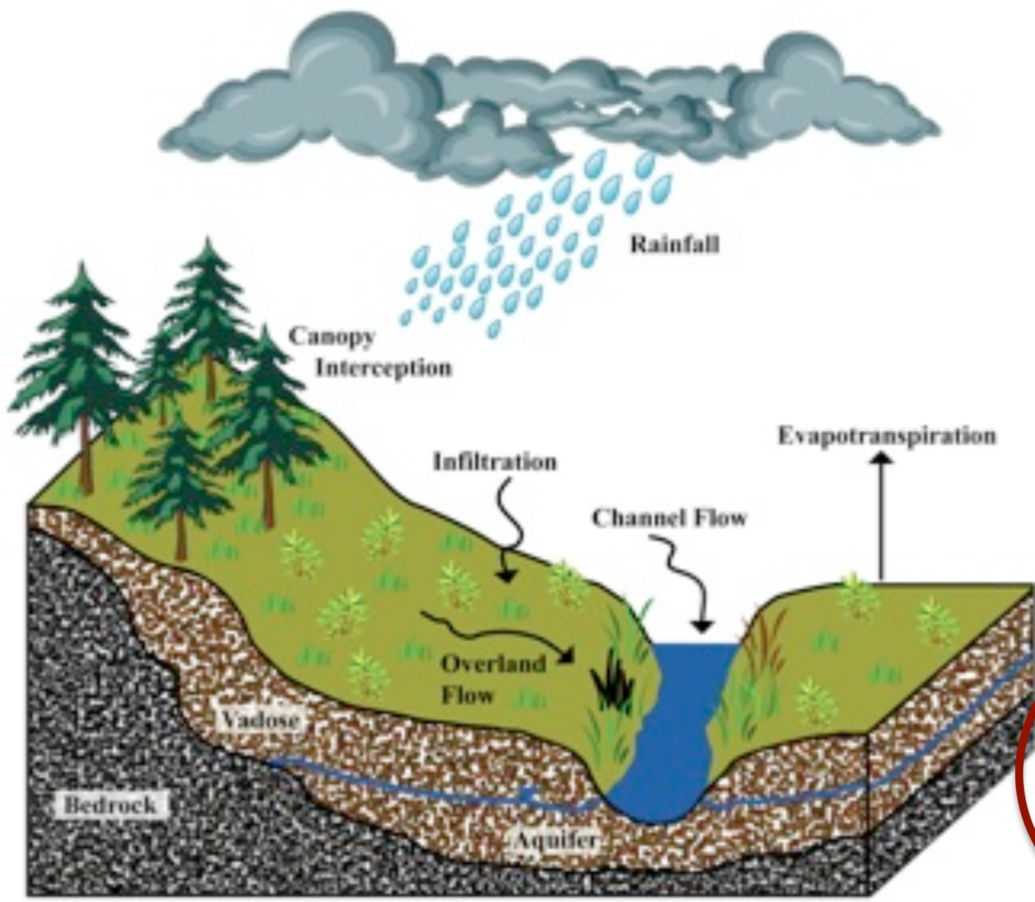
Overview of Flood Monitoring Tools

Remote Sensing and Flood Monitoring
Basic Concepts

- **Satellite Observations**
  - Direct use in detection of surface water/inundation
  - In observing flood-related weather quantities : Rainfall, Temperature, Humidity, Winds

- **Hydrologic Models**
  - Forced with satellite-based land and atmospheric measurements [rain, air temperature and humidity, wind speed, radiation, vegetation, soil type, terrain]
  - Hydrological Models route water within a channel/ river basin/watershed region according to the atmospheric and surface conditions, calculation of Streamflow – indicative of flooding conditions

Hydrological Models



Mathematical representation of water cycling processes in the atmosphere-land system

Calculates run-off and streamflow of water -- used in detecting flooding conditions

From Remote Sensing Measurements

for given atmospheric and surface conditions --rain, air temperature and humidity, wind speed, solar radiation, vegetation, soil type, terrain

Streamflow--the water discharge that occurs in a natural channel. Measured in cubic meters per second -- volume of water flowing per unit time (m^3/s)

Web Tools for Flooding Applications

Provide any or all of the following on global and/or regional basis:

- Near-real time flood monitoring: Flood probability/potential, extreme rain, streamflow, inundation extent)
- Flood forecasting: Flood probability/potential, extreme rain, streamflow, inundation extent)
- Information about past flooding events
- Additional information (for example about – weather, land-cover, roads, dams, population density etc.)

Interactive Flood Tools

- NASA-TRMM Current Heavy Rain, Flood, and Landslide Estimates
- Global Flood Monitoring System (GFMS)
- Extreme Rainfall Detection System (ERDS)
- Global MODIS Inundation Mapping
- Dartmouth Flood Observatory (DFO)
- Global Disaster Alert and Coordination System (GDACS)/
  Global Flood Detection System (GFDS)

All the tools include Interactive Maps and Regional Sub-setting and zooming capability of flooding events

Types of Flood Tools

- Tools based on Remote Sensing observations and Hydrologic Models
- Inundation Mapping Tools based on MODIS
- Experimental Flood Mapping based on Passive Microwave Brightness Temperatures
- Disaster Mapping

Flood Tools Using TRMM and Hydrologic Models

Near-global

Regional

Flood Tool	Satellite/ Instrument Or Model	Quantities Used as Inputs	Hydrological Model
NASA-TRMM	TRMM/ TMPA-RT	Rain Rate	NRC-CN[1]
GFMS	TRMM/ TMPA- RT MERRA	Rain Rate Surface Temperature Winds	VIC- UMD DRTR[2]
DFO	TRMM/TMI and Aqua/ AMSR-E	37 Ghz Brightness Temperature	Global Runoff Model
SERVIR	TRMM/ TMPA-RT	Rain Rate	CREST[3]

[1]Natural Resources Conservation Service (NRCS) runoff curve number (CN) method

[2]The University of Washington Variable Infiltration Capacity (VIC) land surface model coupled with the University of Maryland Dominant River Tracing Routing (DRTR) model

[3] The Couples Routing and Excess Storage (CREST) distributed hydrology model

Remote Sensing based Flood Tools

Flood Tool	Satellite/ (Instrument	Quantity Used
MODIS NRT	Terra and Aqua/ MODIS	Reflectance Bands 1, 2, 7
DFO	Terra and Aqua / MODIS	Reflectance Bands 1, 2, 7
ERDS	TMPA-RT/ NOAA-GFS	Rain Rate
GFDS	TRMM/TMI and Aqua/AMSR-E TRRM/TMI	37 Ghz Brightness Temperature

GDACS (Not a Flood Tool but a Disaster Alert System)

Uses GFDS, and other remote sensing data and maps
TRMM/TMPA Rain Rat
RadarSAT, erraSAR-X, Synthetic Aperture Radar Reflectivity
SPOT-5 Worldview-1/2 , Visible/near-IR Images

Information Provided by the Flood Tools

		Flooding Monitoring Output		
Flood Tool	**Rainfall (Used as Input)**	**Flood potential/ Intensity**	**River Discharge/ Streamflow**	**Inundation Map**
NASA-TRMM	X	X		
GFMS	X	X	X	
SERVIR	X		X	
MODIS/NRT				X
DFO			X	X
GDACS/ GFDS	X	X		X

More About the Flood Tools

Flood Monitoring Tool	Spatial Coverage and Resolution	Comment
NASA-TRMM NRT	50°S-50°N 12 Km	Includes GFMS, Landslide Potential
GFMS	50°S-50°N 12 Km	Will be available at 1Km resolution. Predictive capability will be added soon
MODIS NRT	Global 250 M	May not be effective in presence of clouds
DFO	Global 250 m and 10 km →	Same as MODIS NRT. River discharge data derived from TMI and AMSR
SERVIR	East Africa 1 km	Regional, Disaster monitoring tool with multiple information layers
GDACS	Global – a few meters to Kms	Disaster Alert tool. Uses US and European satellite images, including commercial satellites. Post-flood images available for selected cases
GFDS	Global 10 km	Flood Potential

Summary

- Several global and regional flood monitoring tools are available based on NASA remote sensing observations

- Most tools have interactive, near-real time flood mapping – flood potential, streamflow/run-off, or inundation

- Tools vary in spatial/temporal extent and resolution

- Regional evaluation by end-users is recommended

Coming Up Next Week-

Overview and demonstration of Flooding Tools:

Extreme Rainfall detection System (ERDS)

Global Flood Monitoring System (GFMS)

Thank You!

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