Ensuring Sustainability in a Changing World

Oklahoma "Hurricane"— a very Wet Year: Space Perspective

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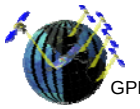
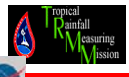
1. Quick review of satellite-based rainfall history and status
2. 2007 Jan-Aug Rainfall Pattern /Anomaly (US and Oklahoma)
3. TRMM Bird-view of Heavy Rainfall Events from Mar through Aug
4. Aqua and MODIS observed Flood inundation (Vis/IR/PMW)





NASA Goddard Earth Sciences and Technology Center, GSFC, Greenbelt, Maryland 20771

How to obtain Precipitation Information, Globally?

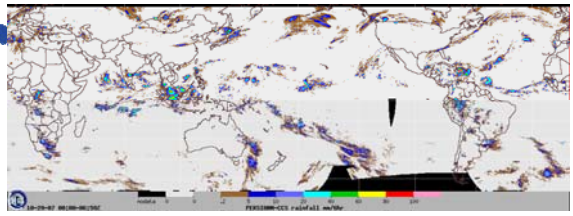
Rain gauge: point measurement, land only

(since 500 B.C., first known rain records using bowls)

Radar: limited coverage, mostly land

(since 1950s; 1964-NSSL Doppler; 1988-NEXRAD; 2003- phased-array)

Satellite: Near global coverage, no hydro-geopolitical boundary



"Satellite Remote Sensing is not an Option but the only option to get complete coverage of global precipitation info."

Brief history of Satellite-based Precipitation Estimation

1st Generation: GEO-IR; Geostationary Infrared/Visible

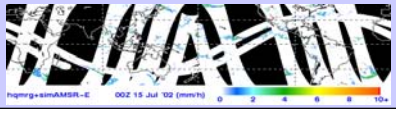
since 1970s

High spatial/temporal resolution (4x4km², 30-minute)

But Indirect physics to rain rates

2nd: LEO-MW

Low Earth Orbiting (Polar)-Microwave Rainfall Estimates Since 1987 (DMSP SSM/I)



Low temporal resolution

Better accuracy

3rd: Blending IR and MW (Active and Passive)

IR coverage in 1-H: 85-100%; but less accurate

MW coverage in 1-H: TMI+SSMI+AMSR+AMSU: <=30%; higher accuracy

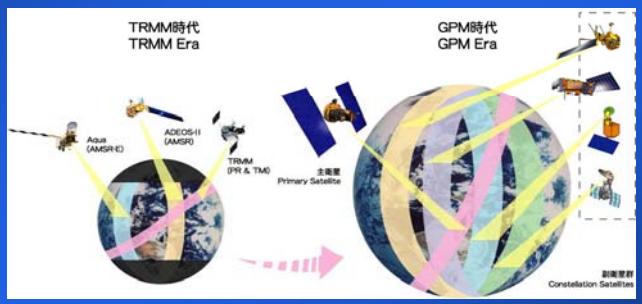
.AGPI (Adler et al. 1994); PDF Matching (Huffman et al. 1997);
. Artificial Neural Network (PERSIANN, Hsu; and Sorooshian et al. 1997)
.Cloud Morphing Rainfall Distribution (Joyce et al. 2004)
.Cloud Type-based Classification Scheme using ANN (CCS; Hong et al. 2004)

From Tropical to Global Precipitation Measurement

1998~~~2009-2012? (TRMM) 2007(delayed to 2012)~~GPM

GPM is an expanded mission of the current TRMM.
9-satelltie constellation system
Coverage: 50N-50S to 90N-90S
Time-space scale: 15min - 3 hour; 4km-25km

Dual-Frequency Precipitation Radar (DPR)
(Ku-Band-13.6 GHz; Ka-Band-35.55 GHz))
DPR will act as benchmark sensor to calibrate GPM other 8 satellites' sensors



GPM Targets:
+ Natural Hazards
+ Hydrology
+ Weather Forecasting

NASA TRMM/GPM Science Team Member since 2005

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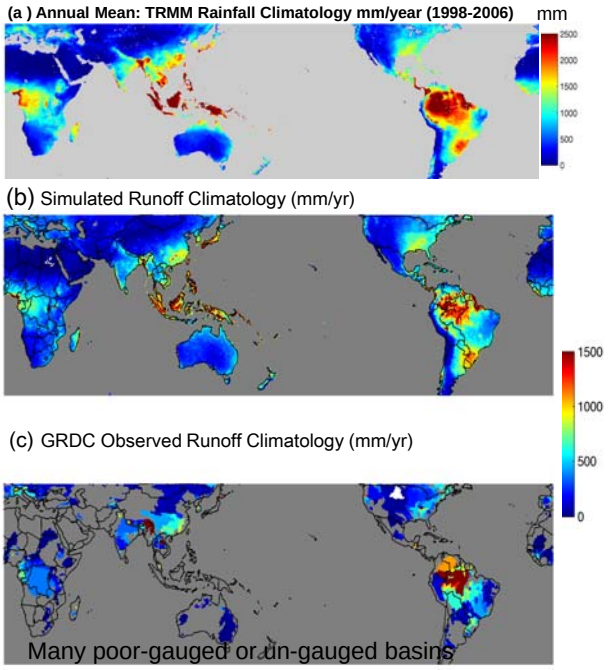
What happens after Rain Fall to ground? Apply Satellite Rainfall to Hydrology



Example:

(98-06) 9-year Runoff climatology simulated from TRMM Rainfall vs. GRDC Gauge Observations

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Hong et al., 2007 WRR

Current Global Precipitation Products

- Precipitation for Climate Studies (2.5°x2.5° Monthly; from 1979 - current)
  - GPCP Version 2 (Adler et al., 2003)
  - NOAA CMAP Precipitation (Xie and Arkin, 1997)
  - NASA GSFC 1° Daily (Huffman et al., 2001)
- High-Resolution Precipitation (for Weather & Hydrology)
  - **NOAA NESDIS HE, 1-h, 0.25° (Vicent et al., 1998)**
  - **NASA GSFC TRMM 3-h, 0.25° (3B42RT) (Huffman et al., 2002)**
  - **US/NRL 1-h, 0.1° (Turk et al., 2002)**
  - **UK Birmingham, 1-h, 0.25° (Tapoador et al., 2002)**
  - **NOAA CMORPH, 1-h, 0.08° (Joyce et al., 2004)**

(…have been involved in:)

- **UA PERSIANN: 3-h, 0.25° (with Sorooshian et al. 2002)**
- **UC Irvine CCS, 1-h, 0.04°, (Hong et al., 2004)**
- **NASA TRMM MPA, 3-h, 0.25°, (with Huffman et al. 2007)**

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In Summary: Satellite-based Precipitation Estimation

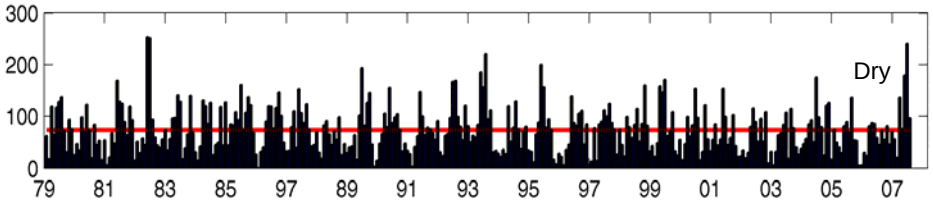
Witnessing the progress of Remote Sensing Precipitation:

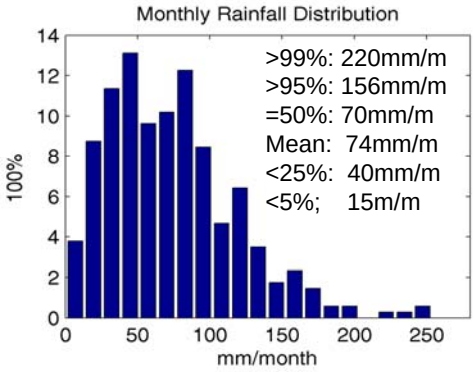
1) Single Channel → Multi-Sensors (IR/Vis+ PMW+ Space Radar)
2) Sole Source → Multi-sources (Gauge + ground radar + Satellite)
3) Spatial Resolution: 2.5°→ 1°→0.25°→ 0.04°(km)
4) Temporal scale: Month→Day→hour→30 minutes
5) Combined sensors provide useful info. of Rain and Flooding
6) Main advantages of satellite rainfall: large coverage

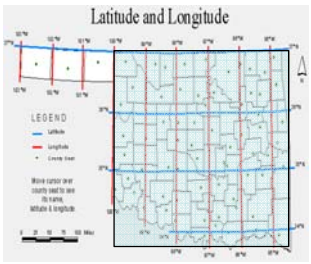
Relevant References:

Hong et al., 2003, ISERS, Image Segmentation
Hong et al. 2004, JAM, PERSIASNN-CCS
Hong et al., 2005, WRR, SONO
Hong et al., 2007, Int. Remote Sensing
With Huffman et al., 2007, J. Hydrometer, TRMM MPA

GPCP Monthly Rainfall Time Series since 1979 (mm/month)





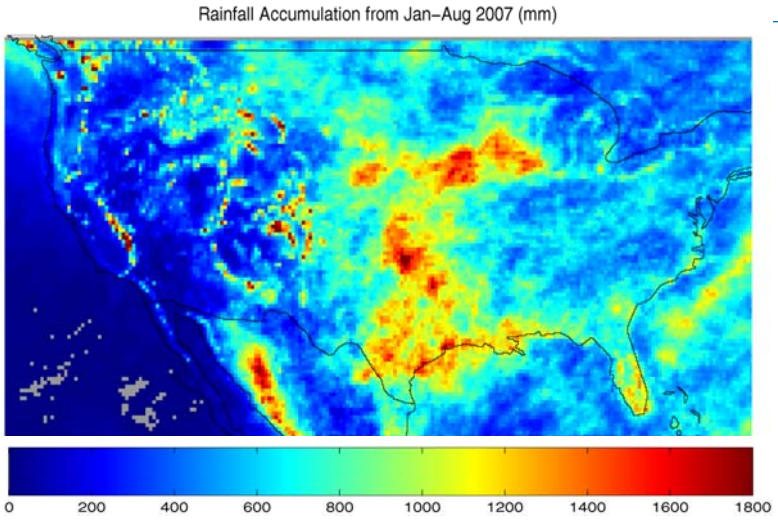


A Very Wet Year observed by TRMM-based Multi-satellite Precipitation Analysis (TMPA)

The 2007 rainfall Accumulation over the U.S. from Jan to Aug

The rainfall shown below were accumulated from 01/01—08/31, 2007.

Rainfall Band: extending from Texas northward through the Kansas and OH.

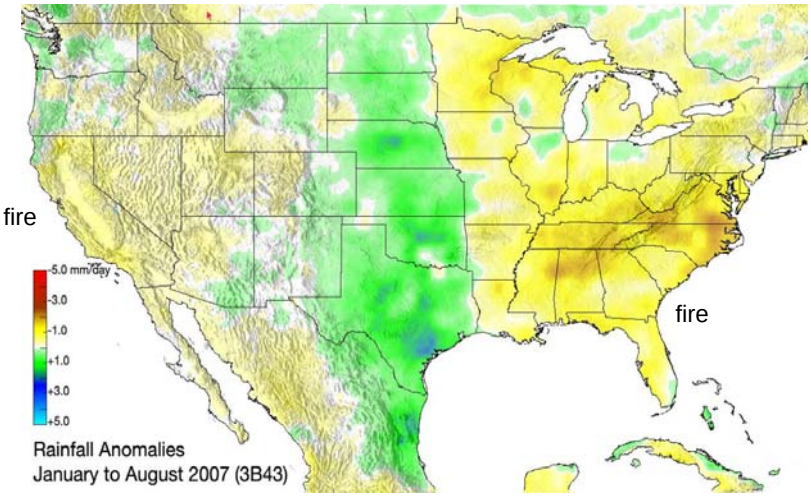


The 2007 rainfall Anomalies (Jan – Aug)

The rainfall anomalies were made by comparing TRMM Rainfall Climatology o the same period of 2007.

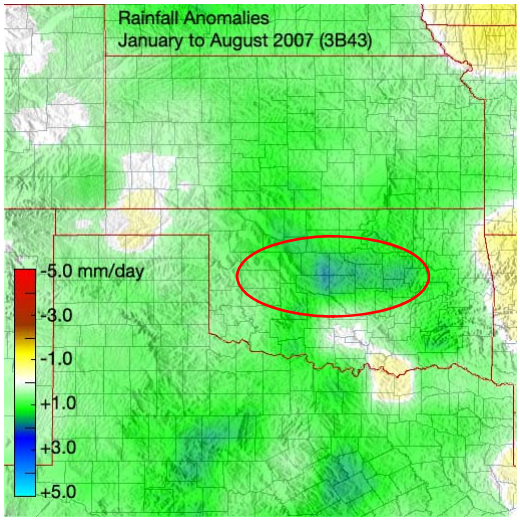
Drought: The eastern half and particularly the southeastern USA (Atlanta, Georgia, one of the driest years on record). Tropical storm Barry dropped some beneficial rainfall over the southeast in June 2007 but that was the exception in a very dry season with little rainfall from tropical cyclones.

Wet:. A large area extending from Texas northward through the Dakotas(Houston, Texas set rainfall records).



Oklahoma: a wet year

Except central south, east, and northwest panhandler (little dry)



TRMM Heavy Raining Events

March 29: Tornadic Thunderstorms
May 1-8: MIDWEST FLOODING:
June 14-20: Floods in TX and OK
June 20-28: More FLOODING
Aug 10-20: Hurricane Erin

Flood Observed from MODIS:

Visible/Infrared Channel
Microwave Channel

Late March: Snapshot of Tornadic Thunderstorms

(> 65 tornadoes reported in the OK, KS, and TX by late March 28, 2007).

TRMM Rainfall: March 29 at 3:35 PM local time;
Tornado approaching and touching down OK City at 4:20 PM.

Horizontal distribution of instantaneous rain intensity overlaid on IR clouds.

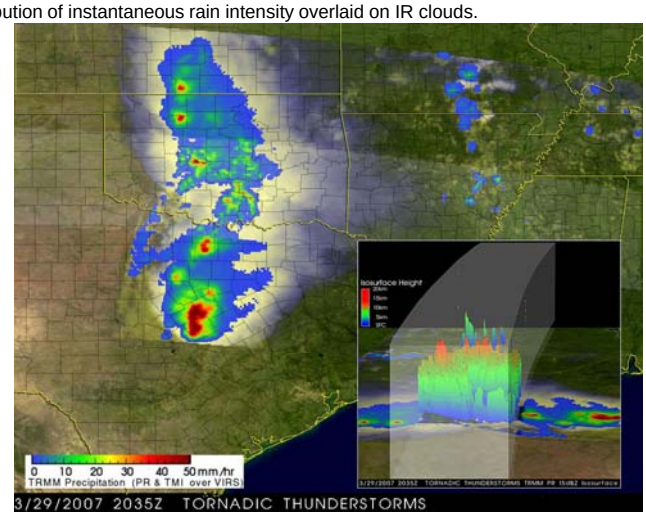
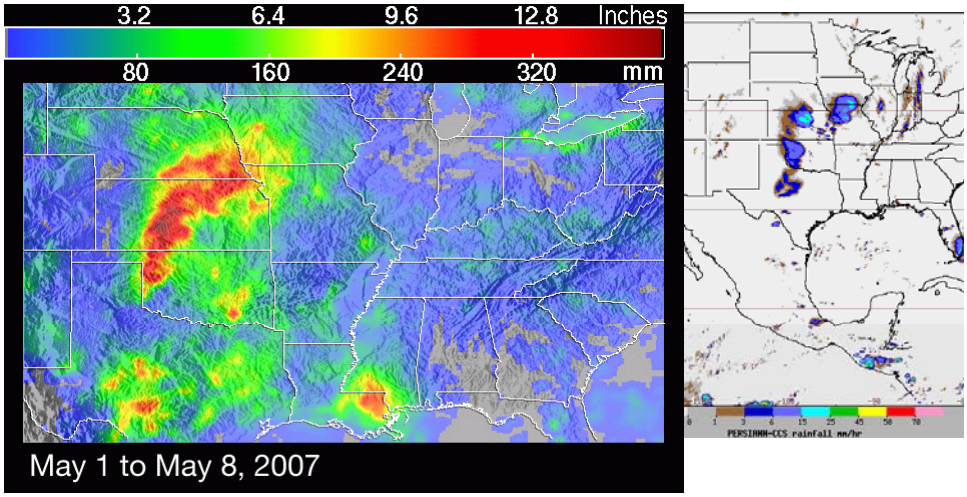


Image inset shows a 3D view of the storms from TRMM **P**recipitation **R**adar (PR), the first weather radar in space since 1997. The colors indicate the relative height of rain cells (15 dBZ echo surface) embedded within the storms.

MIDWEST FLOODING: May 1 to May 8, 2007

During the 7 days over 400 mm(15.7 in.) of rain fell in the mid-west, resulting in wide spread flooding.

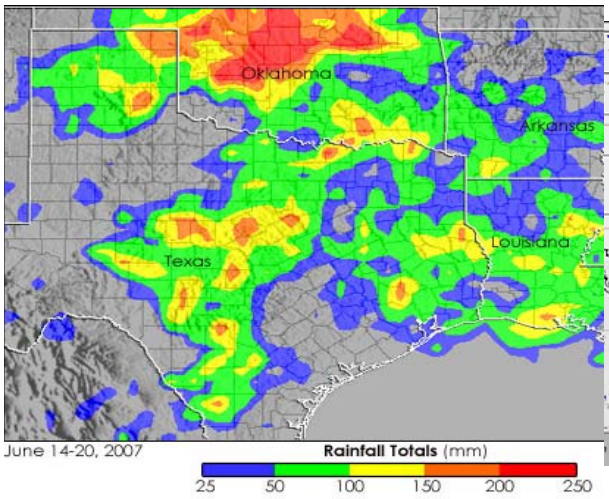


Exceptionally Wet Month in Texas and Oklahoma

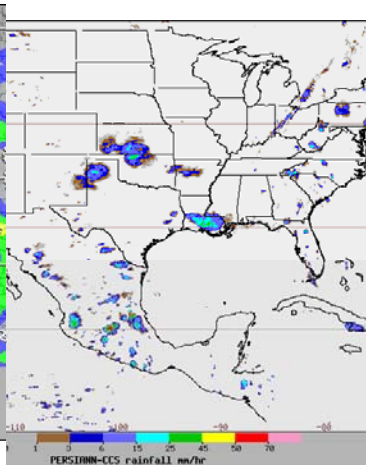
June 2007 was exceptionally wet for the Southern Plains of the United States. The heavy storms dumped up to 460 millimeters (18 inches) of rain.

For Austin, more than 30 inches of rain has fallen since January, making 2007 the wettest year on record so far according to local news reports.

Widespread rainstorms/floods over Oklahoma (June 14-20);



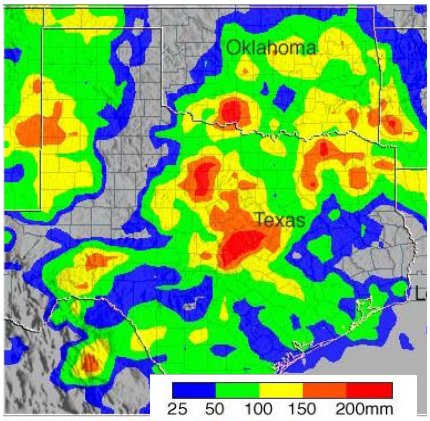
PERSIANN-CCS 30min 4km

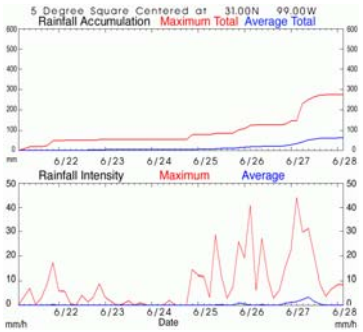


June: TEXAS, OKLAHOMA HIT WITH MORE FLOODING

>200 mm (~8 inches, red areas) fell over parts of Central Texas and southern Oklahoma.

A broad area of at least 50 mm (~2 inches) of rainfall covered almost all of Texas and Oklahoma.

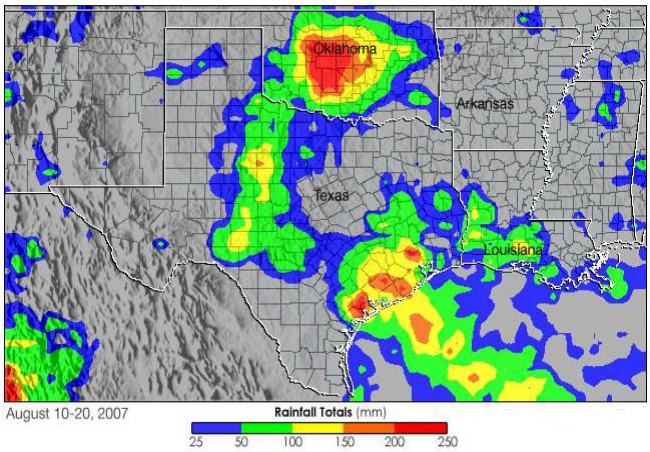




PERSISTENT ERIN BRINGS HEAVY RAINS, FLOODING TO TEXAS, OKLAHOMA
10 to 20 August 2007.

The band of heavy rain follows Erin's path from initial landfall along the central Texas Gulf coast as a tropical storm and on into West Texas and central Oklahoma as a long-lasting tropical depression.

The highest rainfall totals for the period (shown in red) are actually well inland on the order of 200 to 250 mm (~8 to 10 inches) over central Oklahoma. The central Texas Gulf Coast also received a substantial amount of rain, on the order of 100 to 200 mm (~4 to 8 inches), where Erin made landfall. A swath of two-inch-plus amounts (green areas) extends up through central Texas. So far, up to 7 people are reported to have died as a result of the storm.



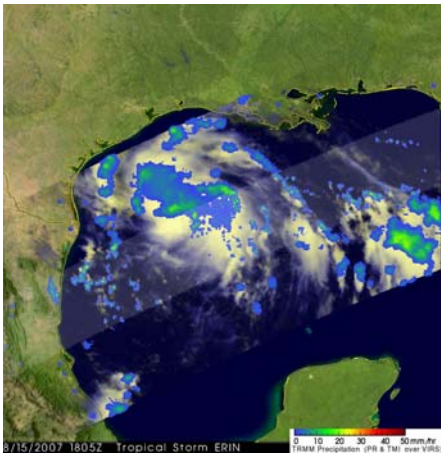
As of August 20, up to 7 people had died in floods caused by Erin's rains in Texas and Oklahoma, reported the *New York Times.* Before Erin, the summer of 2007 had already brought record rainfall and flooding across parts of the Southern Plains.

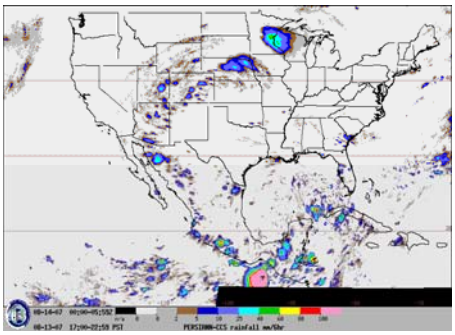
Aug 2007: Tropical Storm Erin continued to add more heavy rain to the region as a rather persistent tropical depression.

A tropical depression- 14 August 2007 (local time) in the central Gulf of Mexico.
It made landfall as a weak tropical storm early on the morning of the 16th of August.

This image shows Erin as it was approaching the Texas coastline at 1:05 pm CDT, overlaid on infrared (IR) data.
*Erin was **weak and poorly organized**. There is **no evidence of an eye**, the system is asymmetric with most of the rain north of the center, and there is very little banding or curvature in the rain field.*

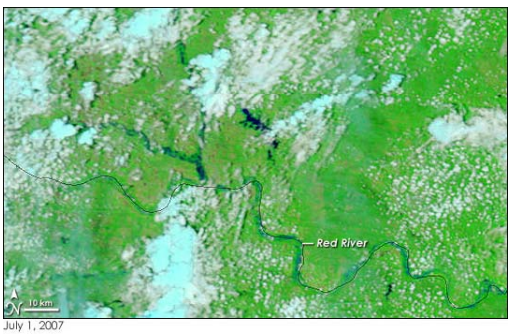
However, even weak systems are capable of producing heavy rain and flooding (next slide).





MODIS VIS/IR Images:

June 19, 2007



July 1, 2007

False Color (combined VIS/IR) to highlight the presence of water:
Water is black and dark-blue;
Clouds are light-blue and white.
Plant-covered land is green
Bare soil is tan-pink.

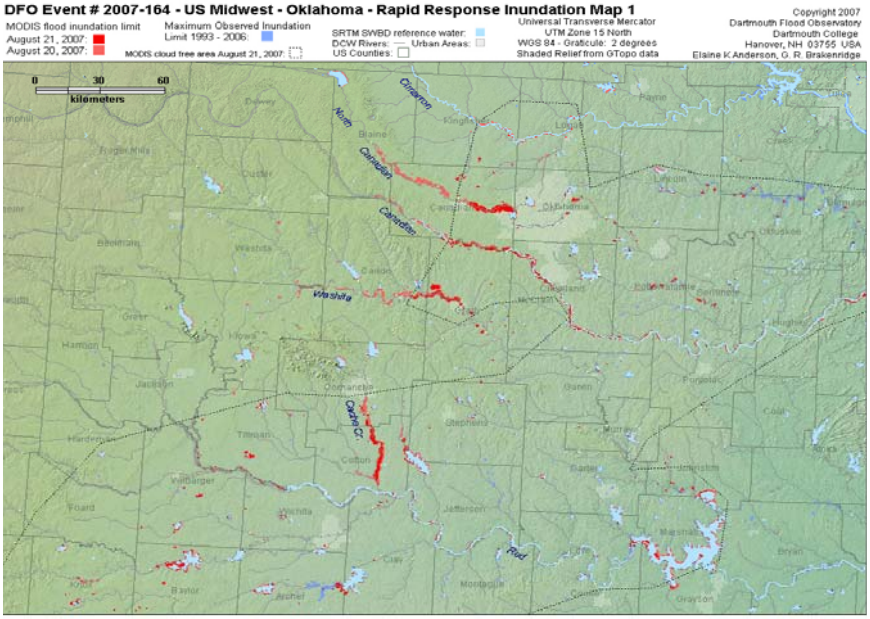
Before: June 19
Clouds/bare soil/vegetation/

After: July 1
Minor flooding was occurring along the Red River, and moderate to major flooding swamped its tributaries(Deep Red Creek and East Cache Creek).

Flooding: 08/16/07 - 08/27/07
USA Midwest - Oklahoma and Ohio

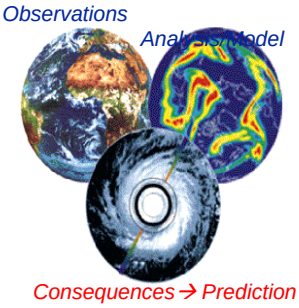
Credit: DFO 2007-164

AQUA AMSR-E Microwave + SRTM simulated Flood Inundation map



Towards an Integrated Water Monitoring System

Alterative: Space-based Flood/Water Use Monitoring System



Precipitation:
1)Satellites: NASA TRMM/GPM, NOAA CMORPH/HE, PERSIANN-CCS
2)Weather Radar in Space: TRMM PR

Runoff:
Aqua AMSR-E Microwave sensor
Hydro-Model

Lake/Reservoirs: LandSat TM, Water Elevation Radiometer;

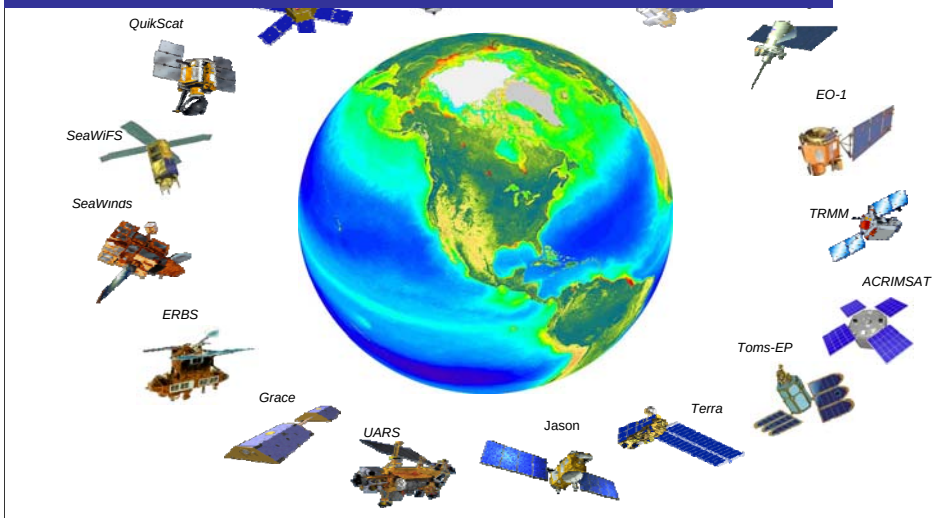
Soil moisture: Aqua AMSR-E and TRMM TMI

Irrigation:
1) Estimating ET using satellite remote sensing methods;
2) NDVI-Crop growth/decay Coefficient

Ground water storage change: NASA GRACE data

Thank you for your time and attention !
Question?

Comment?



June 18, 2007

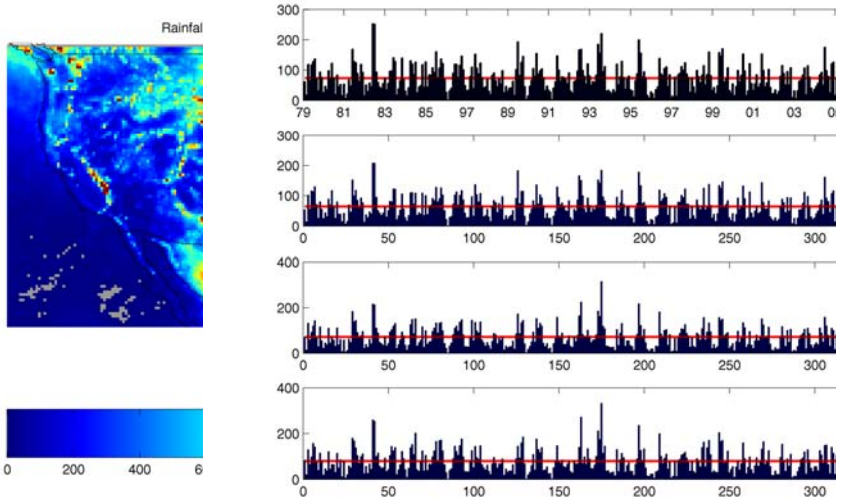
MODIS Vis/IR Images of Southern Texas :
Before: June 18

Flood stage: 14ft-flood; 19ft-major flood

After: July 8 (popcorn clouds and dark-colored water)

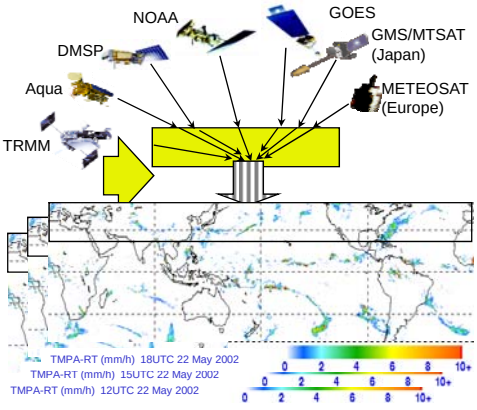
Observed flood stage: 21.6ft (NOAA/NWS)
The Nueces River was nearly seven and a half feet above flood stage. The water is spread well beyond its normal extent. The river cuts off portions of its flood plain and severely floods roads and structures near its banks.

The highest level ever recorded on the Nueces River was **26.57ft** on September 24, 1967.
The July 2007 is the **8th** highest on record.



A Very Wet Year observed by TRMM-based Multi-satellite Precipitation Analysis (TMPA)

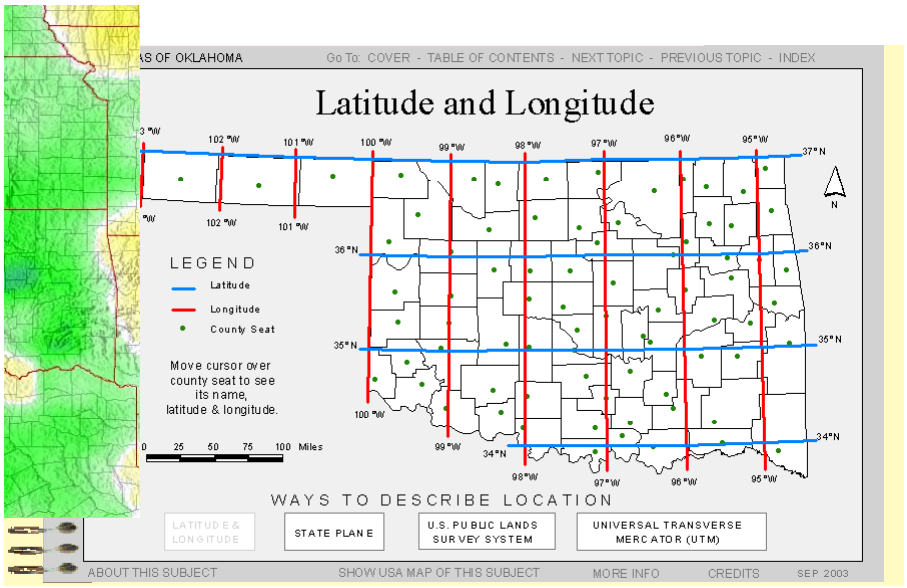
Real-time update every 3-hour at http://trmm.gsfc.nasa.gov

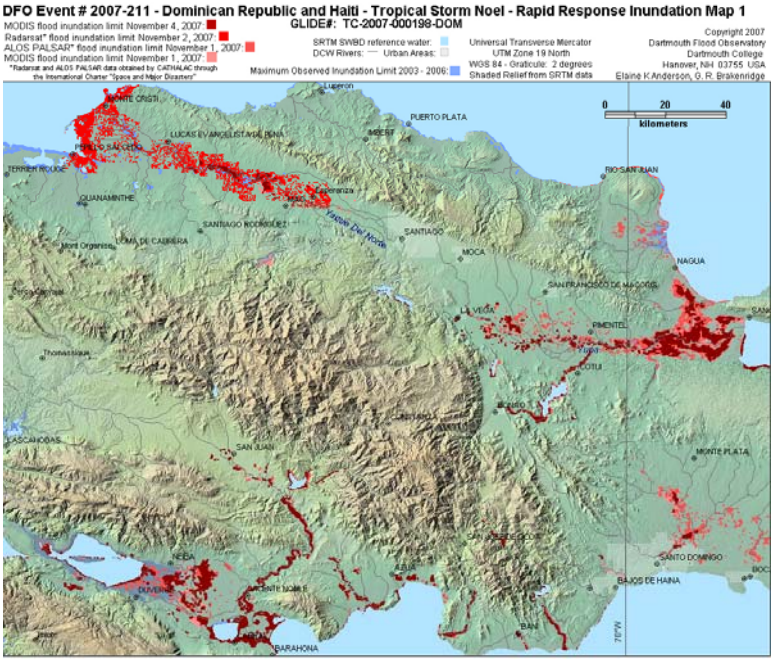


TMPA uses 4 polar-orbit microwave satellites (NOAA, DoD, NASA) and 5 geosynchronous IR satellites, all calibrated by TRMM

9+ years ('98-07') of 3-hr data available
Most requested TRMM product from NASA archive

With Huffman/Adler et al. 2007, JHM


AS OF OKLAHOMA
Go To: COVER - TABLE OF CONTENTS - NEXT TOPIC - PREVIOUS TOPIC - INDEX
Latitude and Longitude
LEGEND
Latitude
Longitude
County Seat
Move cursor over county seat to see its name, latitude & longitude.
0 25 50 75 100 Miles
WAYS TO DESCRIBE LOCATION
LATITUDE & LONGITUDE
STATE PLANE
U.S. PUBLIC LANDS SURVEY SYSTEM
UNIVERSAL TRANSVERSE MERCATOR (UTM)
ABOUT THIS SUBJECT
SHOW USA MAP OF THIS SUBJECT
MORE INFO
CREDITS
SEP 2003


DFO Event # 2007-211 - Dominican Republic and Haiti - Tropical Storm Noel - Rapid Response Inundation Map 1
GLIDE#: TC-2007-000198-DOM
MODIS flood inundation limit November 4, 2007:
Radarsat* flood inundation limit November 2, 2007:
ALOS PALSAR* flood inundation limit November 1, 2007:
MODIS flood inundation limit November 1, 2007:
*Radarsat and ALOS PALSAR data obtained by CATHALAC through the International Charter "Space and Major Disasters"
Maximum Observed Inundation Limit 2003 - 2006:
SRTM SWBD reference water:
DCW Rivers:
Urban Areas:
Universal Transverse Mercator
UTM Zone 19 North
WGS 84 - Graticule: 2 degrees
Shaded Relief from SRTM data
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Dartmouth Flood Observatory
Dartmouth College
Hanover, NH 03755 USA
Elaine K.Anderson, G. R. Brakenridge
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kilometers
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LA VEGA
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MONTE PLATA
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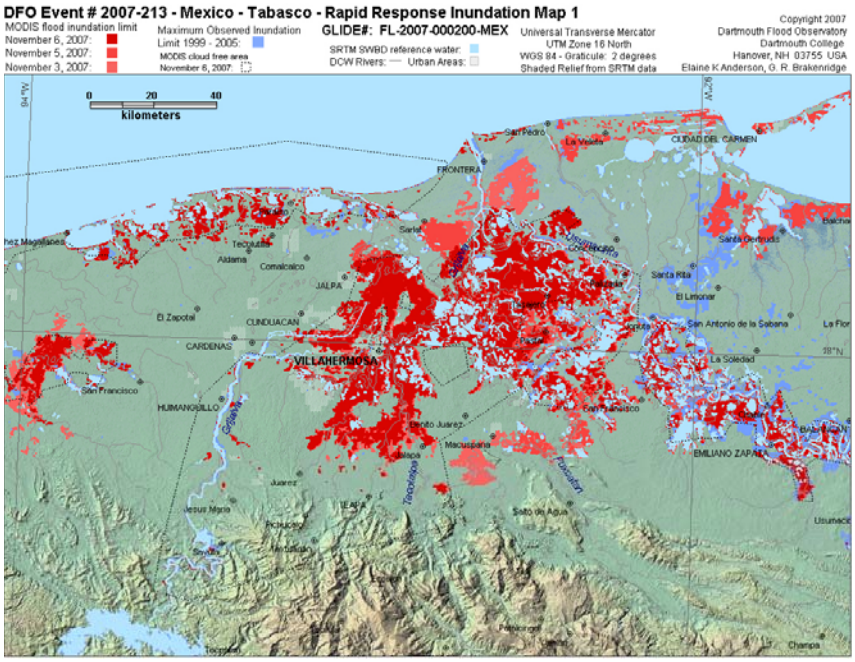
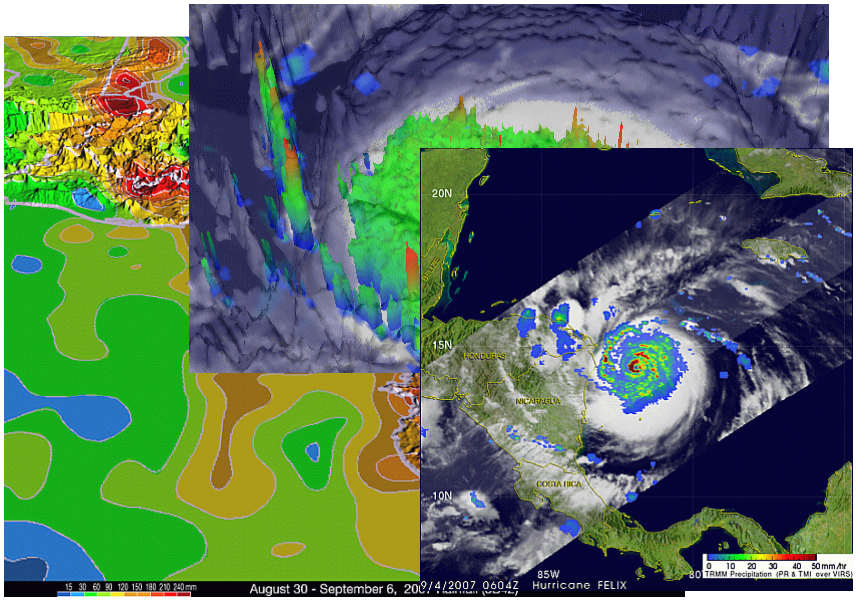
BAJOS DE HAINA
BARAHONA



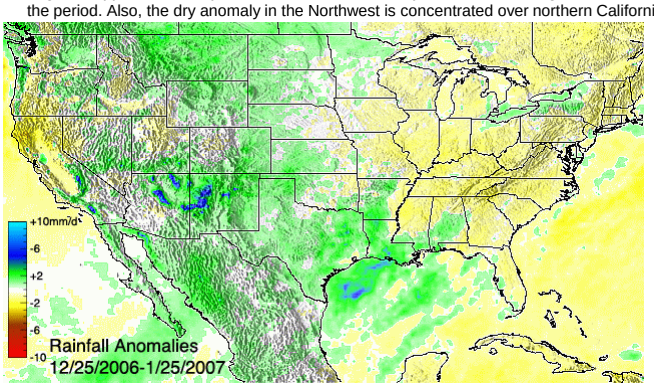
POWERFUL HURRICANE FELIX CROSSES CARIBBEAN BEFORE HITTING CENTRAL AMERICA Aug 30-Sep 6, 2007



TRMM SHOWS THE EFFECTS OF EL NIÑO OVER THE US

An anomalous warming of the central and eastern Pacific along the equator is part of a well known climate event--El Niño. The current El Niño began back in the Spring of 2006 and reached its peak in November and December. El Niño has far reaching effects. The anomalous warming of sea surface temperations in the eastern Pacific also shifts the focus for deep to that region. This in turn effects the general circulation pattern, which impacts both temperature and precipitation patterns well into middle latitudes. Deviations to the rainfall pattern across the US due to El Niño are well established based on past events. Most notably the northern Gulf Coast experiences above average rainfall as does California and the Southwest due to a stronger-than-average subtropical jet stream, while the Ohio Valley and the Northwest see below normal rainfall.

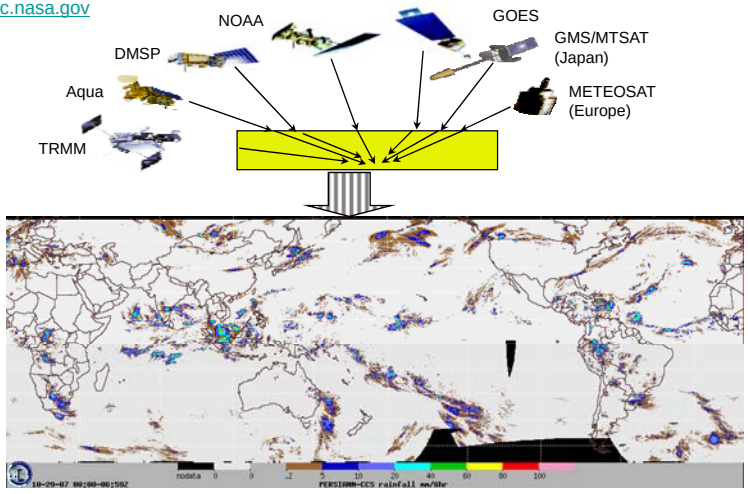
TMPA rainfall anomalies are shown here for the period 25 December 2006 to 25 January 2007 across the US. The anomalies are obtained by subtracting climatological values from the current values for the period. The climatology is based on data collected since TRMM's launch back in November of 1997. Several of the notable features associated with El Niño are evident. The northern Gulf Coast west of Florida is wetter than average as is southern California. The four-corners region is also very moist, which is typical for El Niño. Drier than normal conditions are evident over the Ohio Valley. There are some exceptions, however. Montana for example is usually drier than average but appears relatively moist, and Florida is usually wetter than average but shows below normal rainfall for the period. Also, the dry anomaly in the Northwest is concentrated over northern California.



Multi-satellite Global Precipitation Estimation

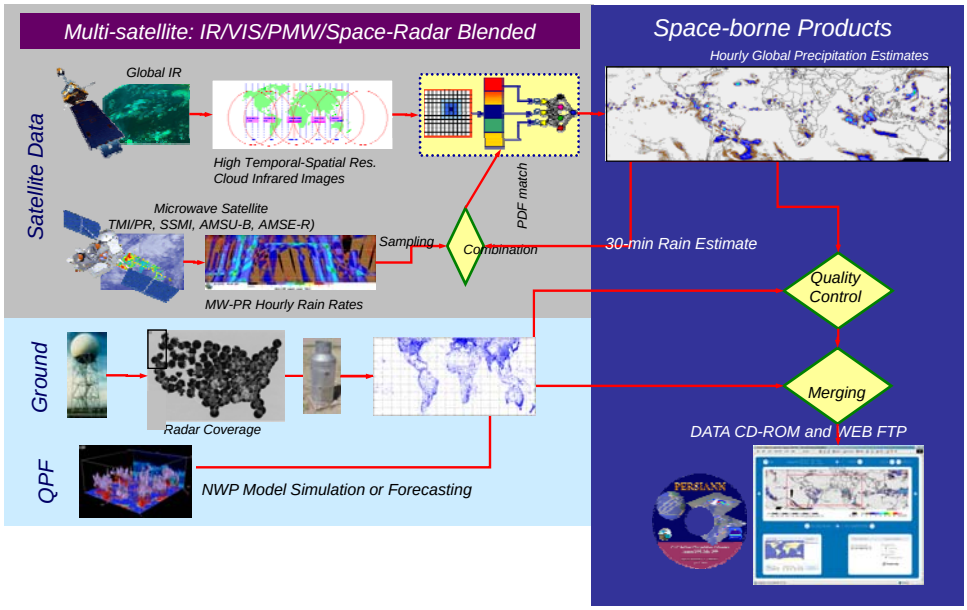
Satellite: Near global coverage, no hydro-geopolitical boundary

http://hydis8.eng.uci.edu/GCCS/
http://trmm.gsfc.nasa.gov



Hong et al., 2004; JAM; Hong et al., 2005 WRR; Hong et al., 2007 IJRS 30

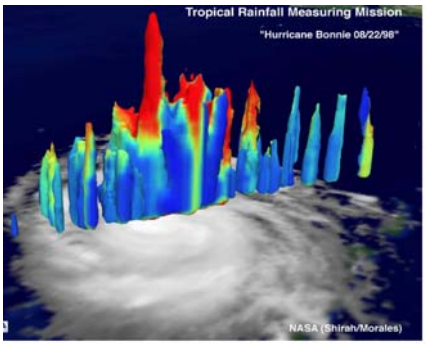
Deliver Research Quality Global Precipitation Products:
Merge Multi-Satellites, Multi-sources (Radar & Gauge, and Model)



Space Radar New Initiatives:
NEXRAD-In-Space (NIS): Geostationary Radar for Monitoring Hurricanes

NEXRAD-In-Space:

- **Space-borne 35-GHz Doppler radar in geosynchronous orbit** (alt. = 36,000 km, cover 48° latitude- 48° longitude)
- **Hourly observations of 3-D scan**
- 12 to 14 km horizontal resolution
- Vertical resolution of 300 m using pulse compression
- Rain detection sensitivity: ~ 5 dBZ (after 100 sample averaging)
- Vertical Doppler profile measurements with 0.3 m/s precision
- Real-time processing

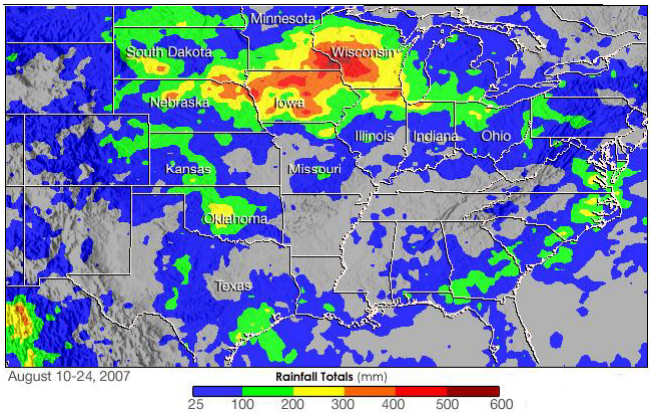


Mission Formation Stage:
Science Team Meeting in May, 2007

Personal communication:
Eastwood Im and Eric Smith et al.

http://trmm.gsfc.nasa.gov/publications_dir/midwest_flooding_10-24aug07.html

A line of powerful, drenching storms stretched across the upper Great Plains of the United States in the third full week of August 2007, while the remnants of Tropical Storm Erin drenched the already-sodden Southern Plains.
the MPA shows that some areas of Wisconsin and Minnesota received more than 500 millimeters of rain (dark red) during the stormy periods even more rain than Texas and Oklahoma received from the passage of Tropical Storm Erin.
Between August 21-24, these two storm systems collided in the Great Lakes and Ohio Valley areas and unleashed huge amount of rain. Flash flooding, strong winds, and tornadoes also occurred in many states, and more than 20 people were killed, according to news reports



The Oklahoma "Hurricane" 2007: Technical Overview of a Very Wet Year

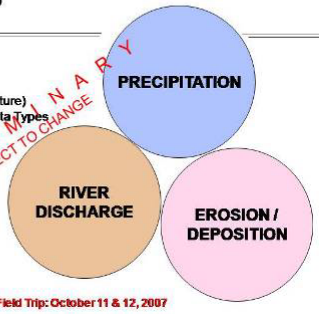
Objectives

- Provide 2007 Data Summaries
- Place Data in Historical Context
- Discuss Implications (Past, Present, Future)
- Construct a Map w/ Interdisciplinary Data Types

Some Disciplines Associated with Stewardship of the Oklahoma Landscape:

- Hydrology / Contaminant Chemistry
- Meteorology
- Geology / Agronomy
- Economics / Sociology
- Engineering
- Biology / Wildlife Management

PRELIMINARY SUBJECT TO CHANGE



Tentative Dates for Discussion Sessions and Field Trip: October 11 & 12, 2007