

Ensuring Water in a Changing World

*Satellite-Based Remote Sensing Estimation of
Precipitation for Early-Warning Systems:
Strengths and Limitations”*

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*Center for Hydrometeorology and Remote Sensing
University of California Irvine*



*Union Session: Grand Challenges in Natural Hazard Research & Risk Analysis
The 25th IUGG General Assembly
June 29th 2011, Melbourne - Australia*



University of California, Irvine (UCI) and Arizona (UA)



and many more ...

Google™



Required Hydrometeorologic Predictions

Short Range —————> Long Range
hours -----> days -----> weeks ----> months --> seasons ---> years -----> decades

Flash Flood Warning

Flash Flood Guidance

Headwater Guidance

Flood Forecast Guidance

Reservoir Inflow Forecasts

Spring Snow Melt Forecasts

Water Supply Volume

Short-range

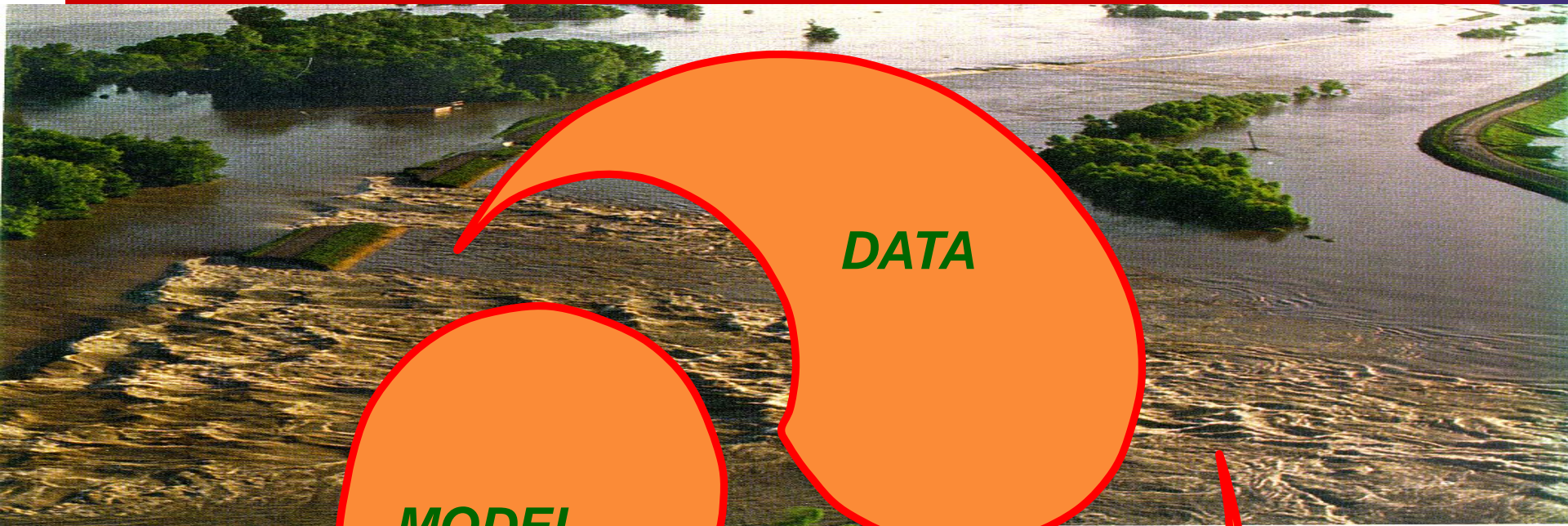
Mid-range

Long-range

Forecast Requirements



Hydrologic Forecasting

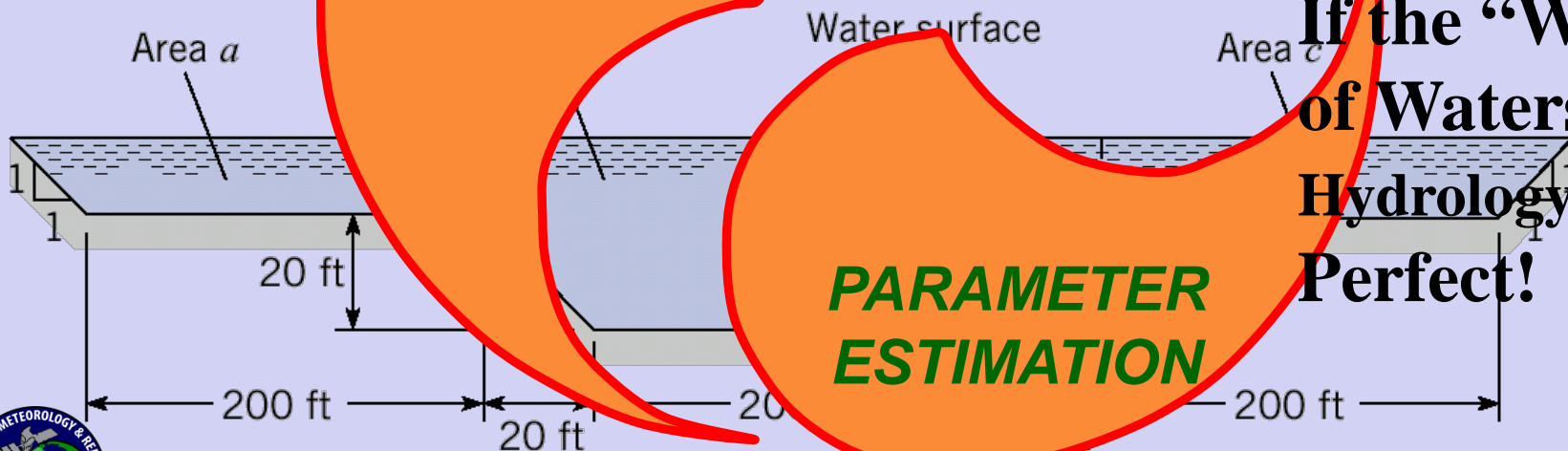


DATA

MODEL

**PARAMETER
ESTIMATION**

**If the “World”
of Watershed
Hydrology Was
Perfect!**



Required Hydrometeorological Predictions

Short Range — Long Range
hours ----> days ----> weeks ---> months --> seasons --> years -----> decades

Flash Flood Warning

Flash Flood Guidance

Headwater Guidance

Flood Forecast Guidance

Reservoir Inflow Forecasts

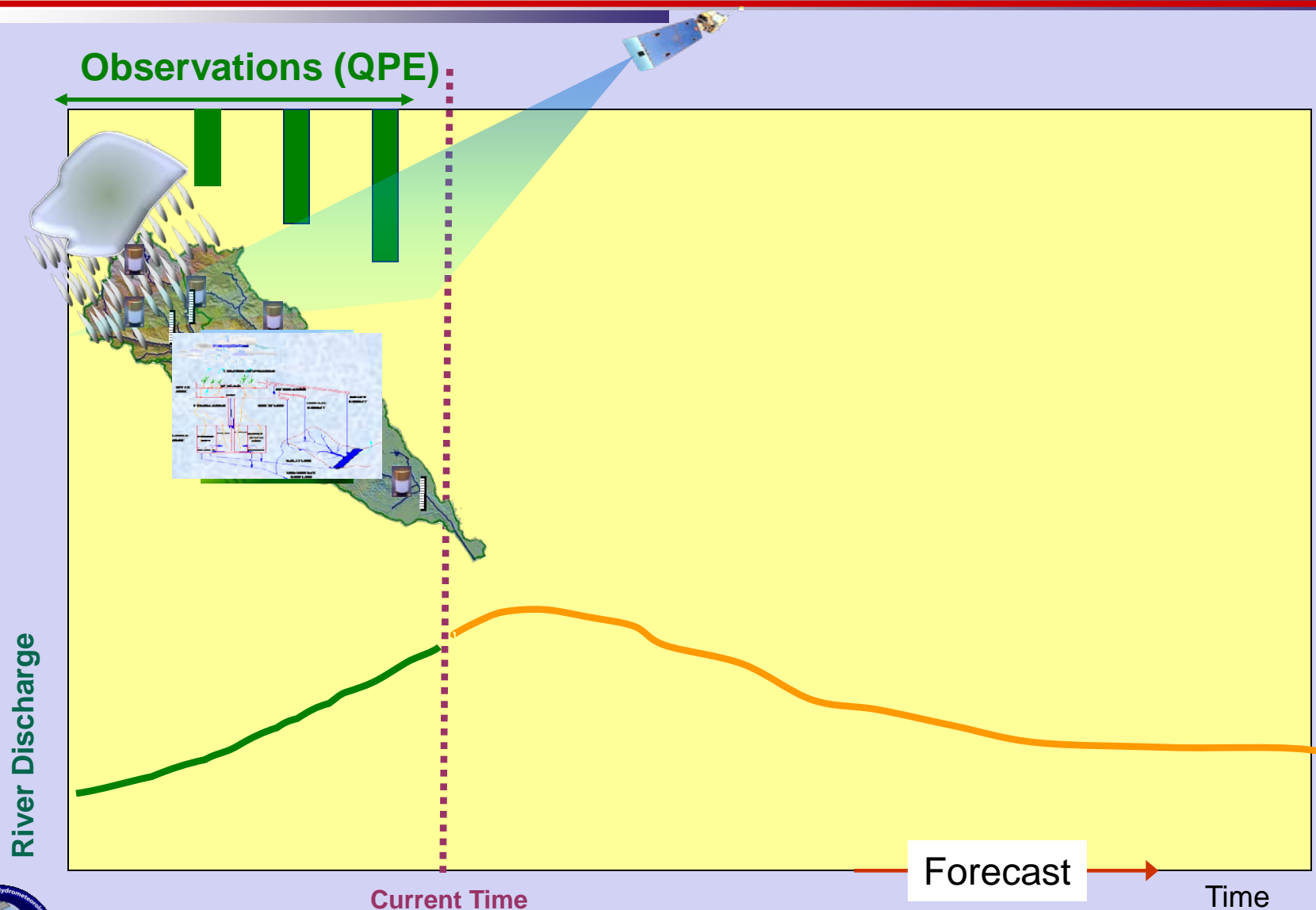
➤ flood and River flow forecasting

Water Supply Volume

Short-range



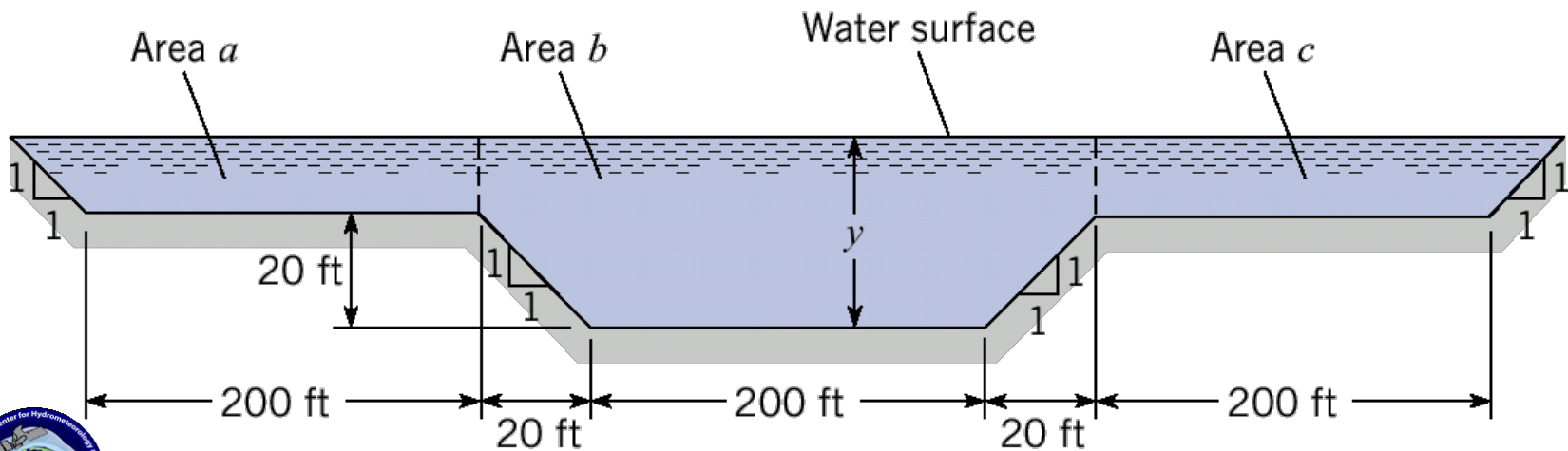
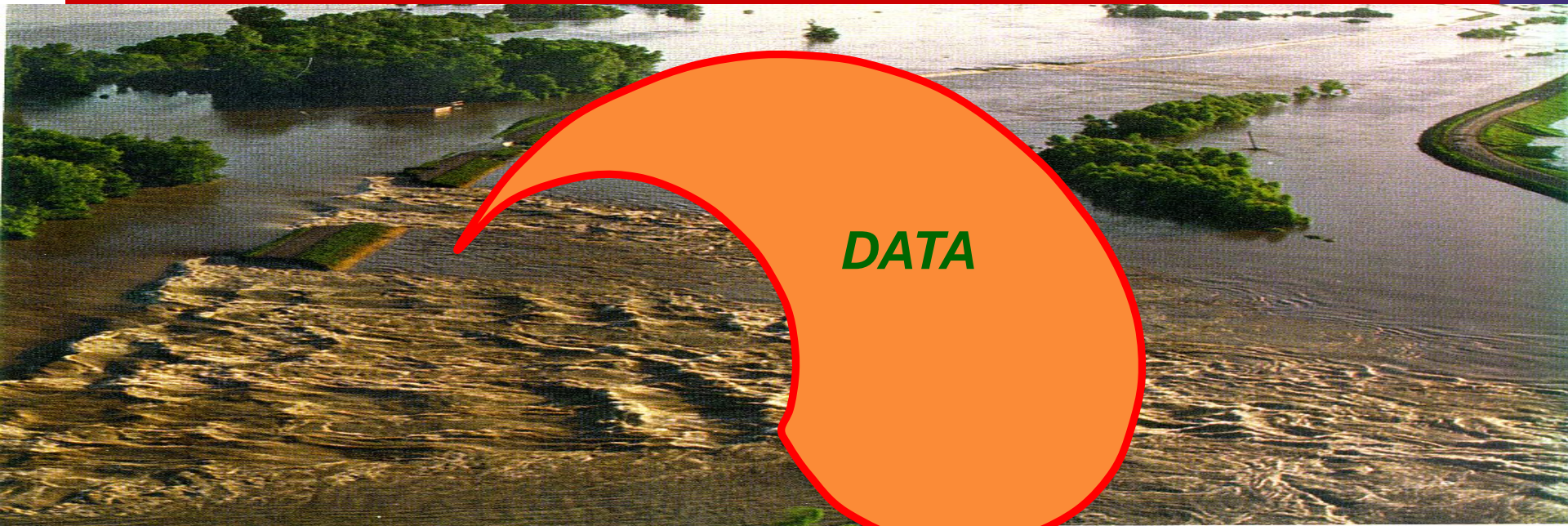
Common practice in Flood and River Flow Forecasting



Animation Assisted by: *Q. Xia & Gi-H. Park*

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Hydrologic Forecasting



Precipitation

Measurement and estimation has and continues to be one of the

KEY

hydrometeorologic Challenges

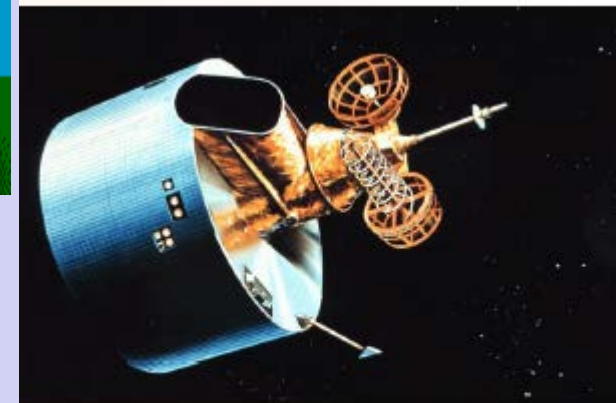
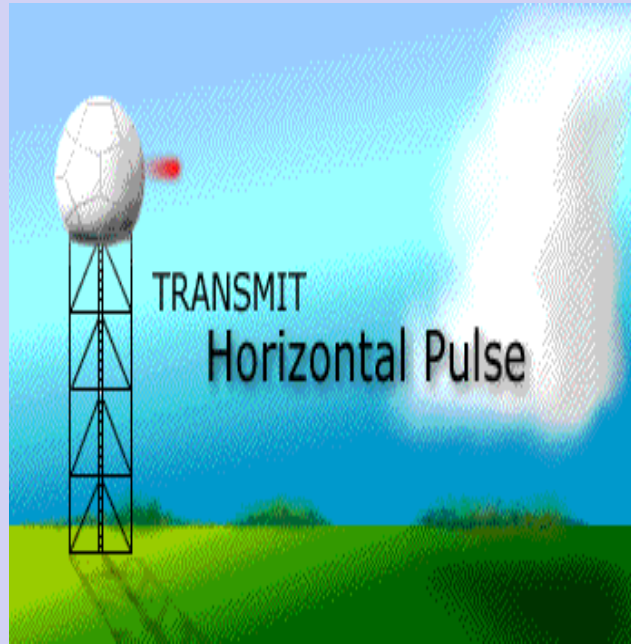
*Push towards High Resolution (Spatial and Temporal)
Observations and Modeling*



Precipitation Observations: Which to trust??



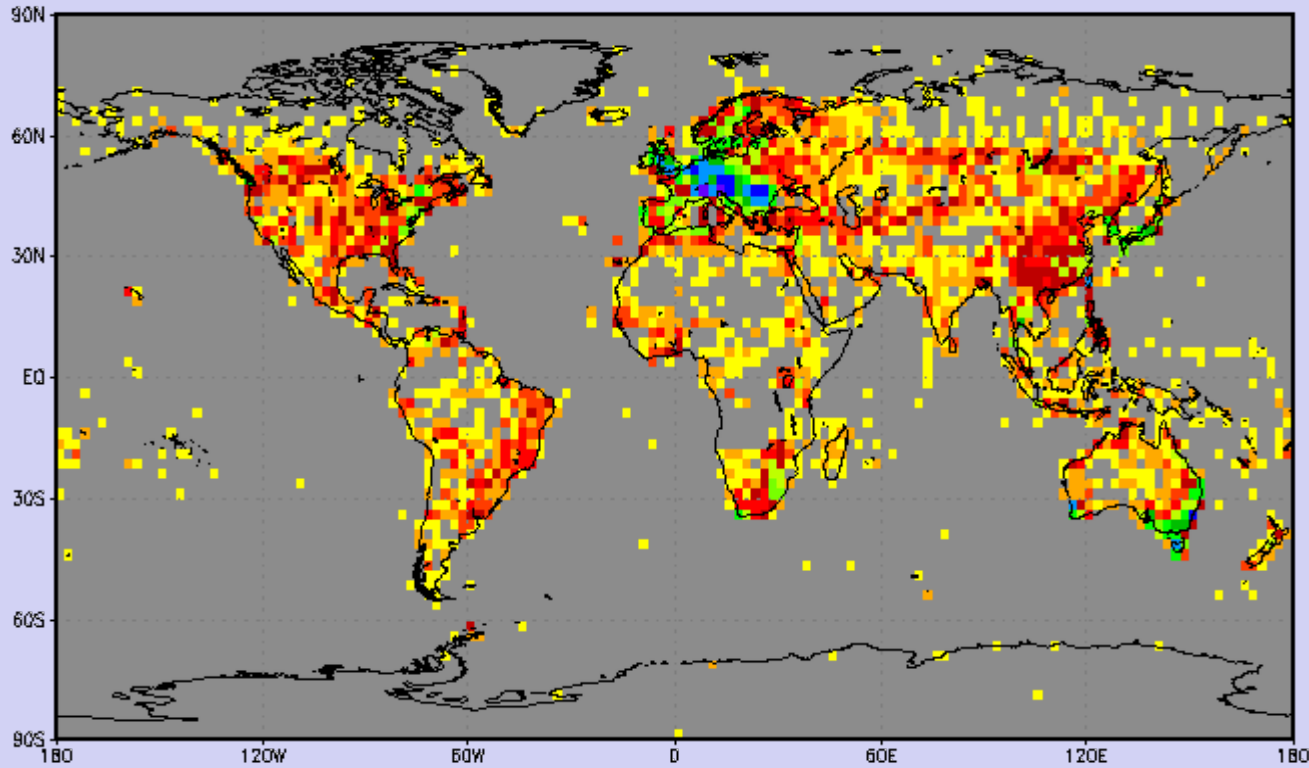
Rain Gauges



Satellite



NUMBER OF GPCC-MONITORING-STATIONS
for MAY 1998



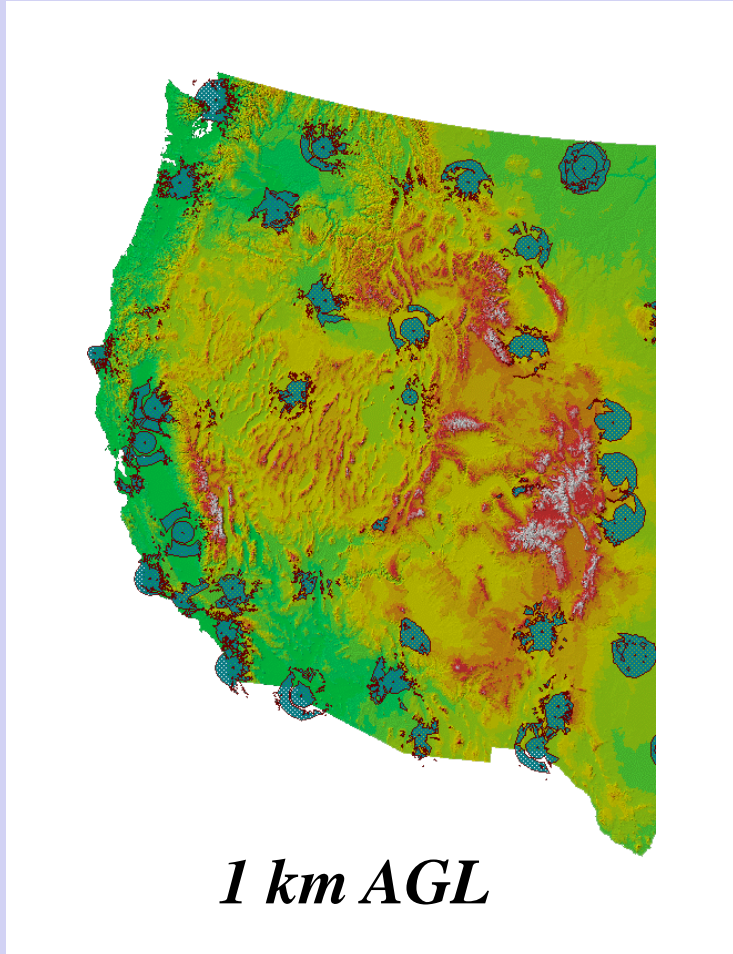
GPCC

[stations/grid]

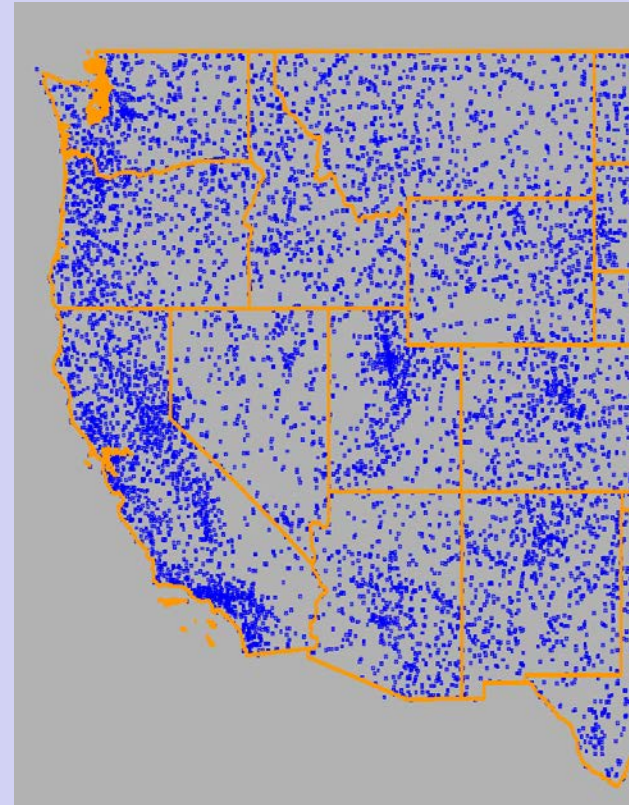
*Number of range gauges per grid box. These boxes are 2x2 degrees
(Source: Global Precipitation Climatology Project)*



Coverage of the WSR-88D and gauge networks



Maddox, et al., 2002

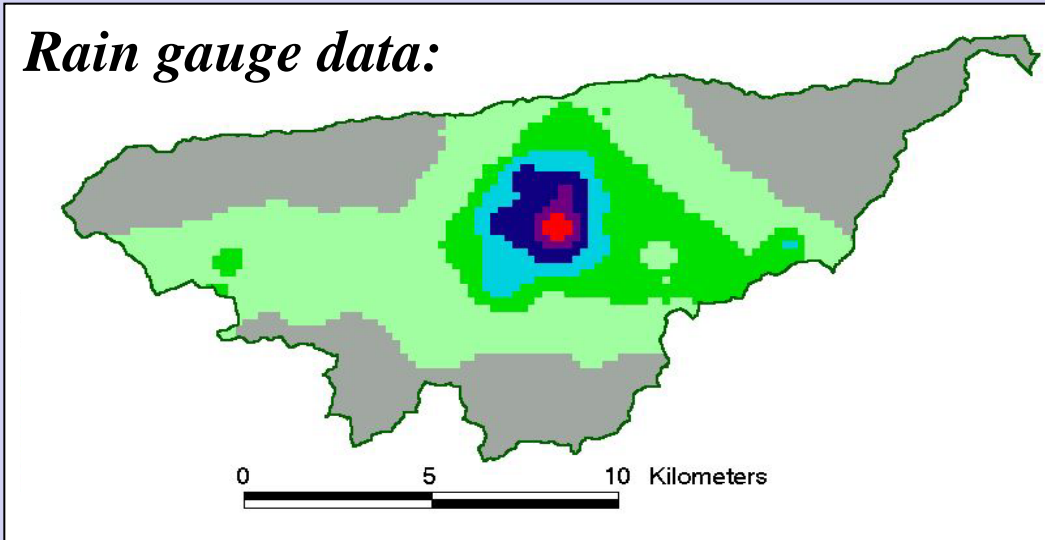


*Daily precipitation
gages (1 station per 600 km²
for Colorado River basin)
hourly coverage
even more sparse*



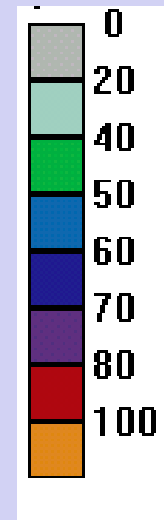
Radar-Gauge Comparison (Walnut Gulch, AZ)

Rain gauge data:

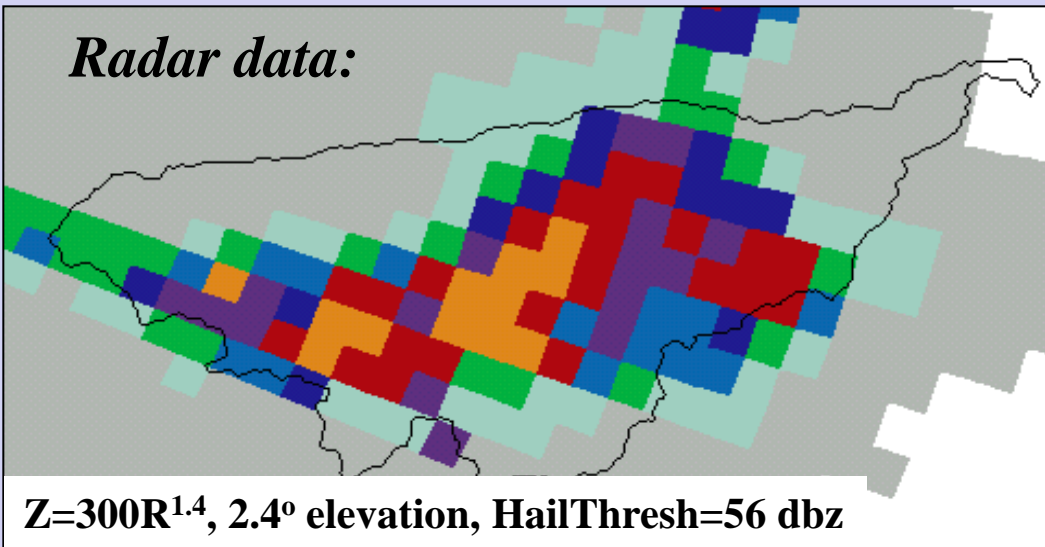


*Precipitation event:
Aug. 11, 2000*

Storm depth (mm)



Radar data:



*70% overestimation
by the radar!*

$Z=300R^{1.4}$, 2.4° elevation, HailThresh=56 dbz



Space-Based Observations



Satellite Observations: Rainfall Estimation



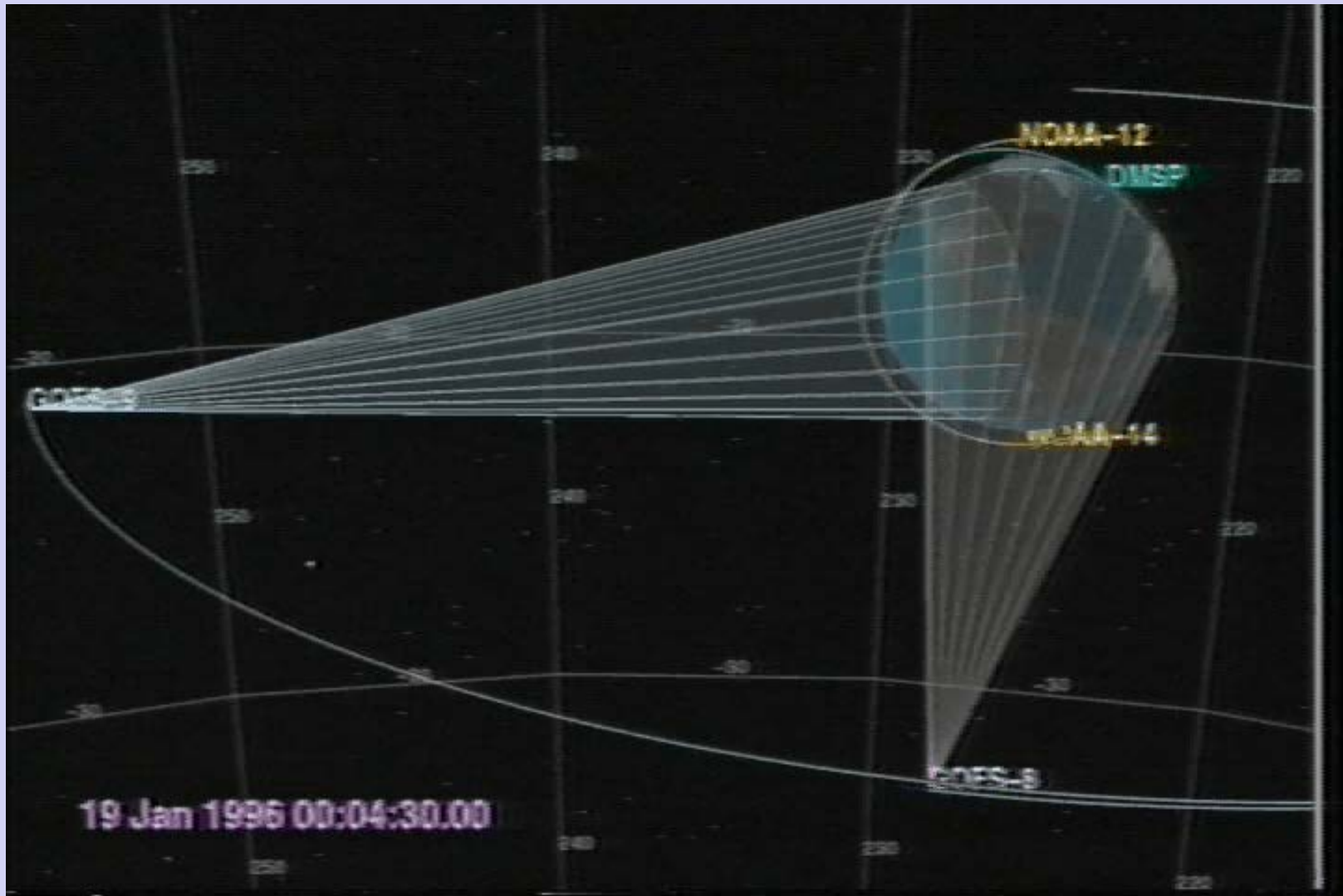
Satellite-Based Rainfall Estimation: Promising !

Observations from space: **Near-continuous, global coverage,**



Geostationary and Polar Satellites

Courtesy: NASA's ESE



19 Jan 1996 00:04:30.00



Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Satellite precipitation retrieval instruments

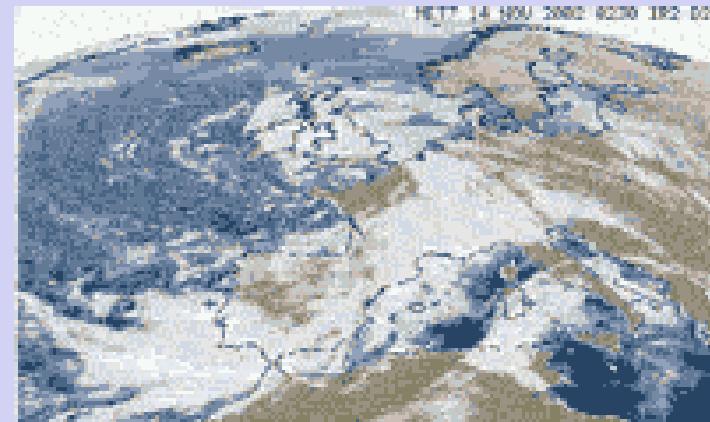
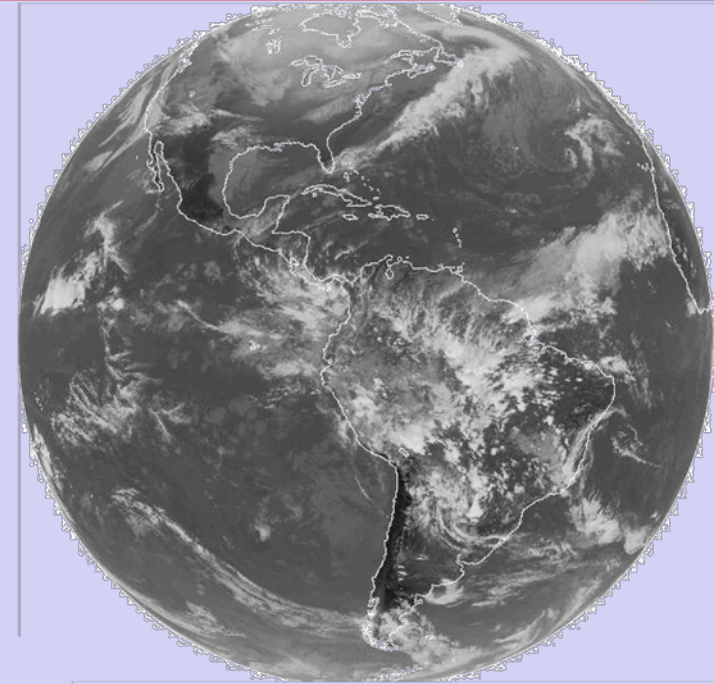
1) Using GEO satellites (Infrared/Visible channels)

Advantage:

- Good temporal and spatial resolution
(30 min or less, 4 km)*
- very good coverage*

Disadvantage:

- Receives mostly cloud –top information*
- Indirect estimation of precipitation.*



Problems with IR only algorithm

Assumption: higher cloud \rightarrow colder \rightarrow more precipitation



Satellite precipitation retrieval instruments

2) Microwave

Advantage:

- Responds directly to hydrometeors and penetrates into clouds
- More accurate estimates



Disadvantage:

- low temporal and spatial resolution (~5-50km)
- Heterogeneous emissivity over land:
(e.g., problem with warm rainfall over land)



Satellite precipitation retrieval instruments

3) Active Radar

Advantage:

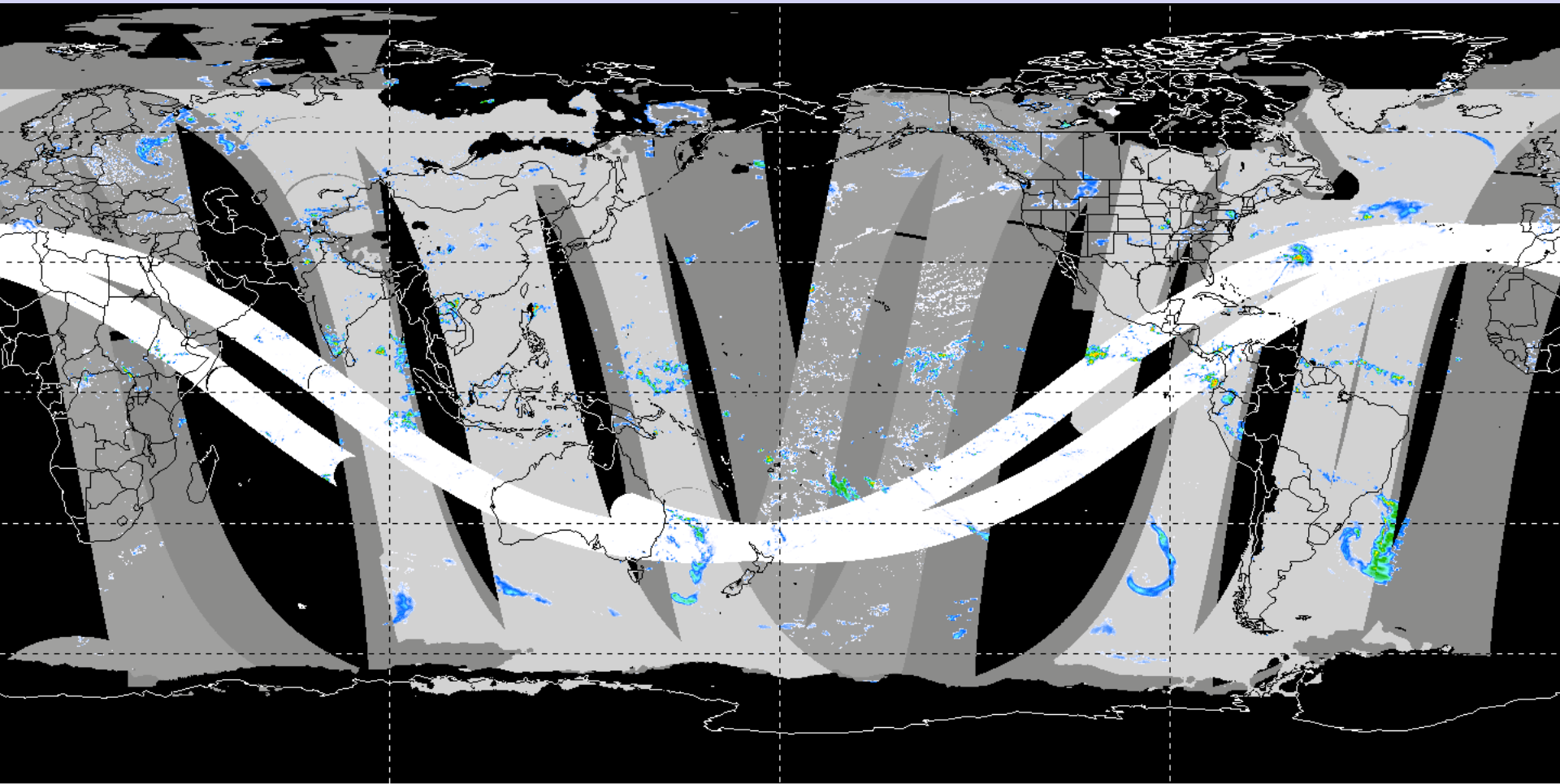
- More accurate*
- good spatial resolution*

Disadvantage:

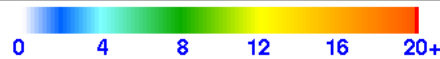
- Poor temporal resolution*



Typical Microwave Coverage in 3 Hr



Precip (mm/d) Aug 1987



<http://trmm.gsfc.nasa.gov/>

TMI – white

AMSR-E – medium grey

SSM/I – light grey

AMSU-B – dark grey



Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Conceptual Framework for higher resolution Precip.

*PMW
Rain
observation*



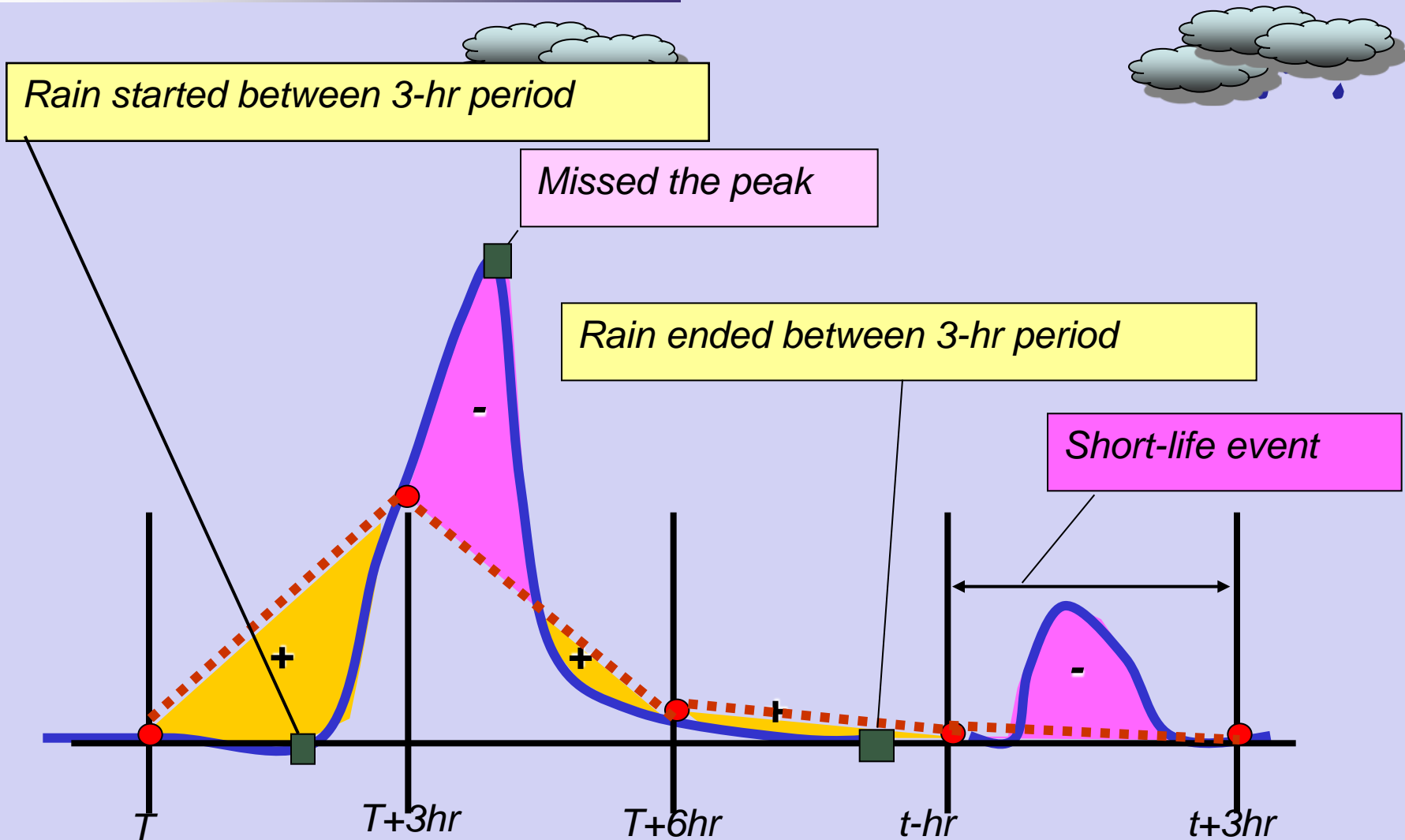
We have no idea what is going to happen until next PMW overpass



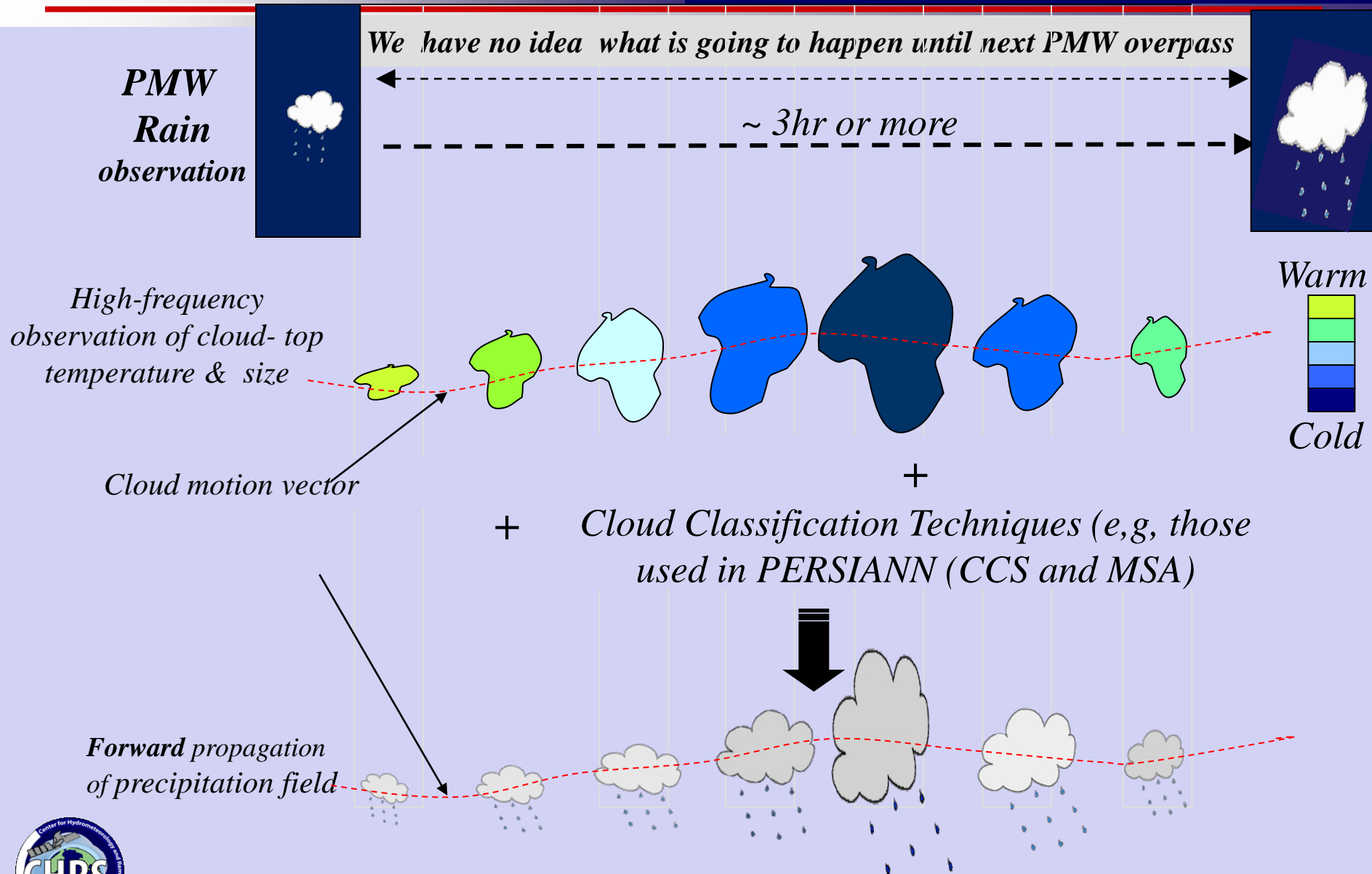
~ 3hr or more



Interpolation of 3-hour Precipitation



Conceptual Framework for higher resolution Precip.



Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)



PERSIANN System

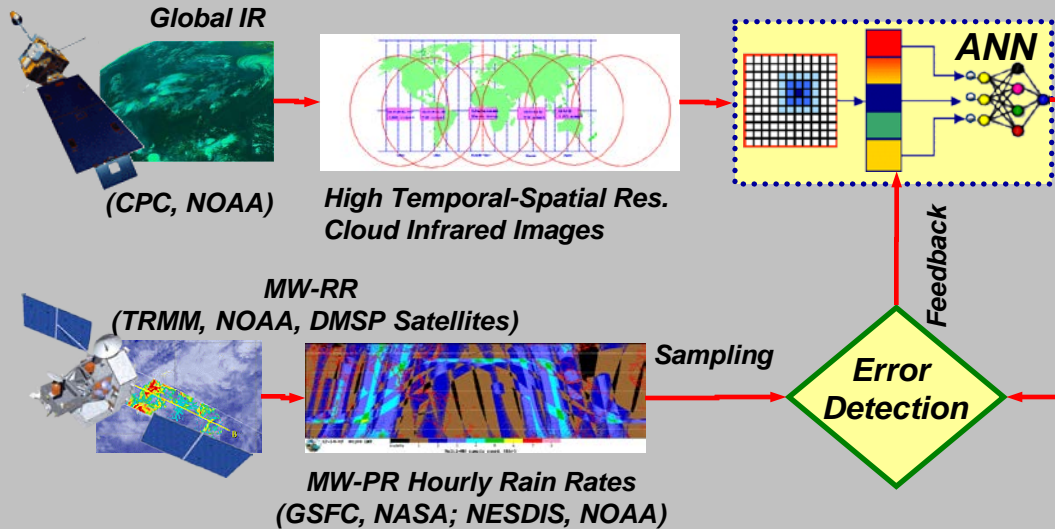
Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks



Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)

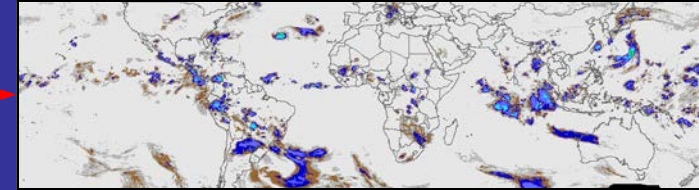
PERSIANN System "Estimation"

Satellite Data



Products

Hourly Global Precipitation Estimates



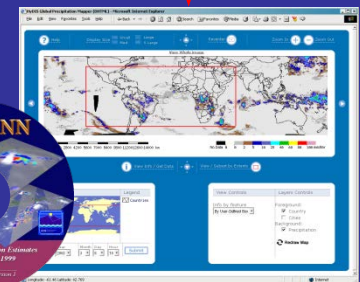
Hourly Rain Estimate

Quality Control

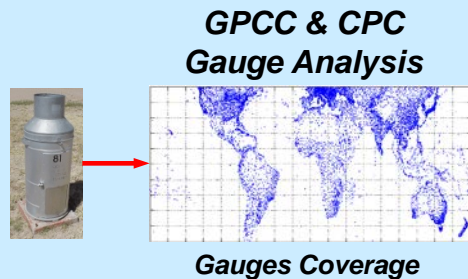
Merging

Merged Products

- Hourly rainfall
- 6 hourly rainfall
- Daily rainfall
- Monthly rainfall



Ground Observations

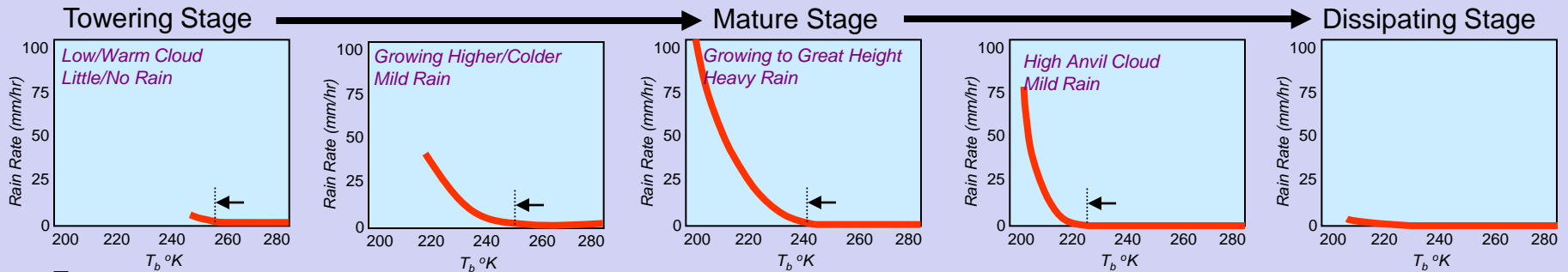
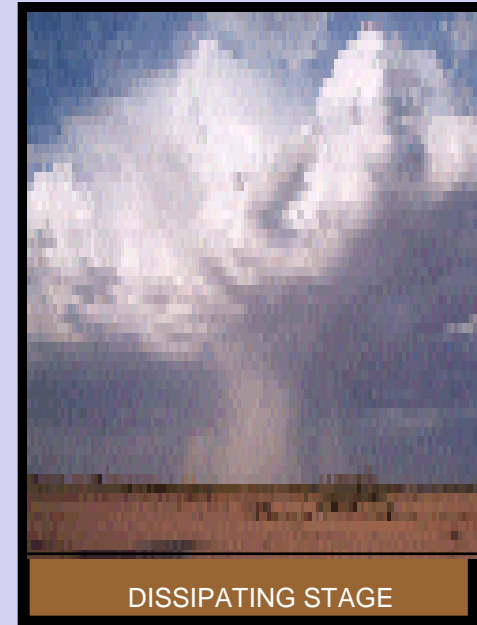




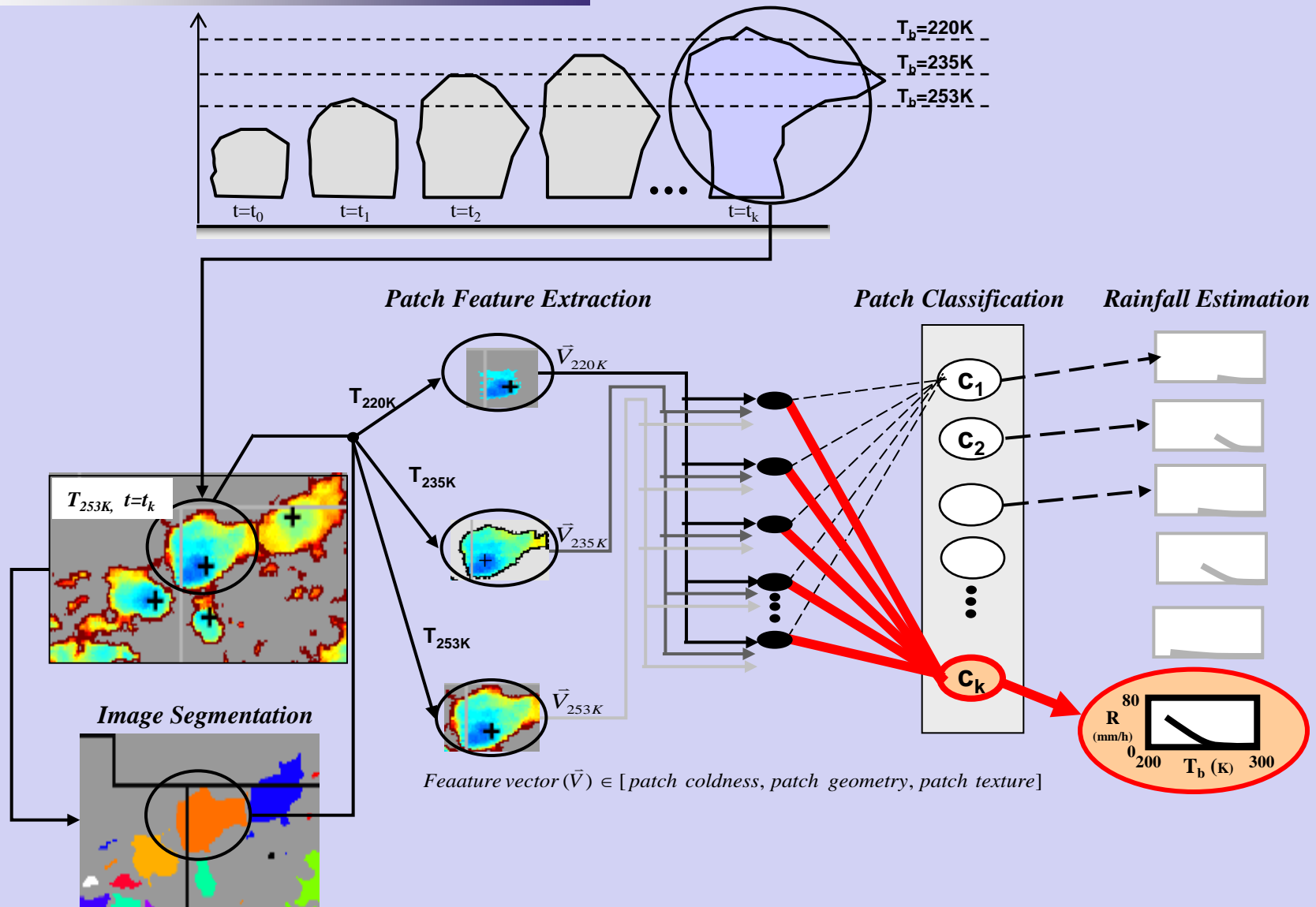
High Resolution Precipitation Estimates
PERSIANN-CCS



Stages of a Convective Storm and Rainfall Distribution



Cloud Segmentation Algorithm



Real Time Global Data: Cooperation With UNESCO

The screenshot shows a web browser window titled "HyDIS GWADI MapServer - Windows Internet Explorer" with the URL "http://hydis.eng.uci.edu/gwadi/ss.html". The browser's address bar and navigation buttons are visible. Below the browser window is the application interface. On the left is a "Map Layer Control" panel with two sections: "VECTOR LAYERS" and "PERSIANN/NESDIS Data". The "VECTOR LAYERS" section includes checkboxes for "Country" (checked), "Political Divisions", "Urban Areas", "GRDC Stations", "Streams", "Inland Water", "Continental Basins", "Major River Basins", "Tributary Basins", and "Small Watersheds". The "PERSIANN/NESDIS Data" section shows "For : 04-14-2008 @ 12 Hour UT" and options for "Latest Rain Totals" (3 hrs, 6 hrs, 12 hrs, 24 hrs, 48 hrs) and "Latest Heavy Rain" (3 hrs, 6 hrs, 12 hrs, 24 hrs, 48 hrs). The main map area displays a global map with a satellite-style background and a semi-transparent white box overlaid with the text "4 Many Features provided to users with Public Domain Software." in red. The map includes a scale bar at the bottom (0 to 6000 km) and logos for CHRS and NASA in the bottom right corner. The browser's status bar at the bottom shows "Done" and "Internet".



Real Time Global Data: Cooperation With UNESCO

Rainfall amounts at any point on the globe

G-WADI Pixel Query

Latitude: 31.444592°
 Mean 0.04° Elevation: 910 Meters
 Land Cover: Barren or Sparsly Vegetated

PERSIANN-CCS 0.04° Precipitation Accumulation
 For 2004-14-2008 11 UT

Duration	Amount
3 Hours	8 mm
6 Hours	4 mm
12 Hours	6 mm
24 Hours	6 mm

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Precip (mm)	5	8	7	6	4	3	1	3	12

Country Report

Map for Morocco
 AREA = 403860 0000 km² POPULATION: 27767920 0000

Heavy Precipitation Mapping Values are for hours preceding: 11 UTC on 04.14.2008

Precipitation Mapping Values are for hours preceding: 11 UTC on 04.14.2008

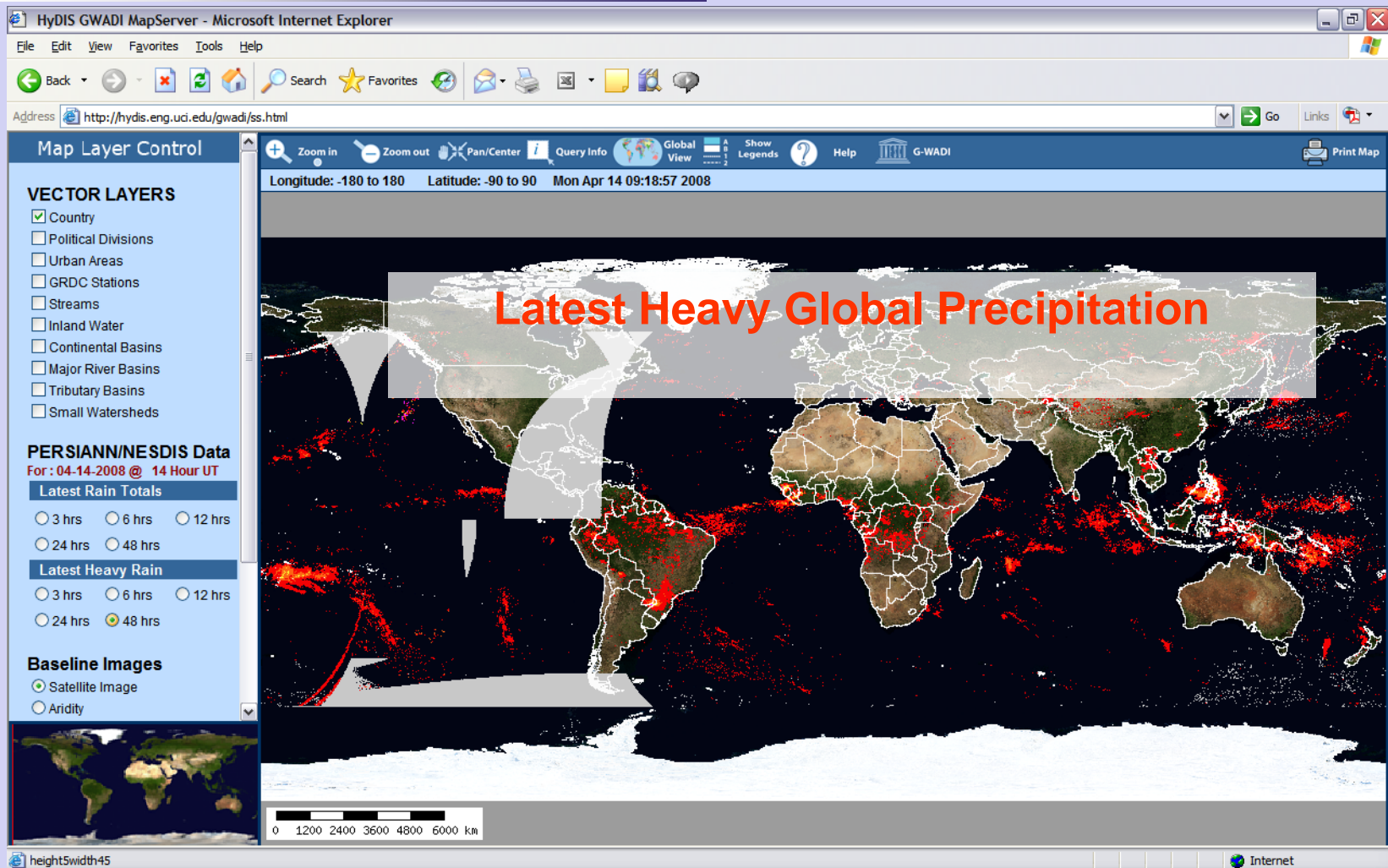
Watershed Report

Precipitation Accumulation In Basin 301049
 Hour: Values are for hours preceding: 11 UTC on 04.14.2008 UT

48



Real Time Global Data: Cooperation With UNESCO



PERSIANN Satellite Product On Google Earth

Google Earth

File Edit View Tools Add Help

Search

Fly To Find Businesses Directions

Fly to e.g., New York, NY

Accumulated Precipitation (mm)

0 10 50 150+ No data

CHRS

UCI

Places

Add Content

Temporary Places

GWADI Precipitation

Click for Info:

Current Accumulation Le...

Current 3 Hour Accumulatio

Click For Info

Current 6 Hour Accumulatio

Click For Info

Current 12 Hour Accumulatio

Layers

Primary Database

Geographic Web

Roads

3D Buildings

Street View

Borders and Labels

Traffic

Weather

Gallery

Ocean

Global Awareness

Places of Interest

<http://chrs.web.uci.edu/>

© 2009 Europa Technologies
© 2009 Tele Atlas
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 TerraMetrics

11°23'16.20" S 45°19'52.71" E elev -3383 m

© 2009 Google

Eye alt 14693.32 km

Home - CHRS HyDIS GWADI M... Google Earth gadgets 12:42 PM



*Good Progress To Date,
But a lot of work ahead and much to be
desired!*

a000174.mpeg



Achieving higher resolution for Hydrologic applications

There is no debate about the importance of GEO (VIS/IR) information for hydrological applications. However,

Questions:

Can Multi-spectral images help us to improve GEO-based precipitation estimation ?

How can we extract efficient information from LEO(PMW) and GEO (VIS/IR) images ?



The ABI (Advanced Baseline Imager) on GOES-R

- Currently many sensors provide multi-spectral images with high spatial and temporal resolution.*
- SEVIRI is a sensor on Meteosat Second Generation (MSG) satellite that has 12 spectral bands.*
- In Approx. 2015, ABI sensor on GOES-R will provide 16 spectral bands.*

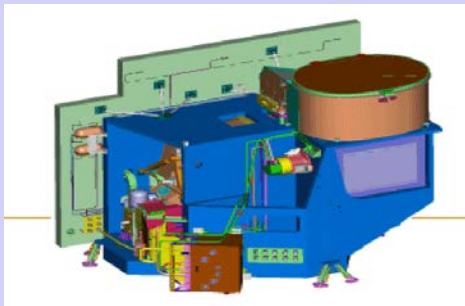
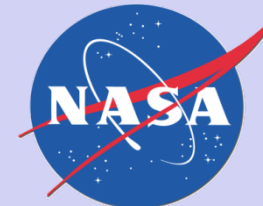


Figure courtesy of ITT Industries

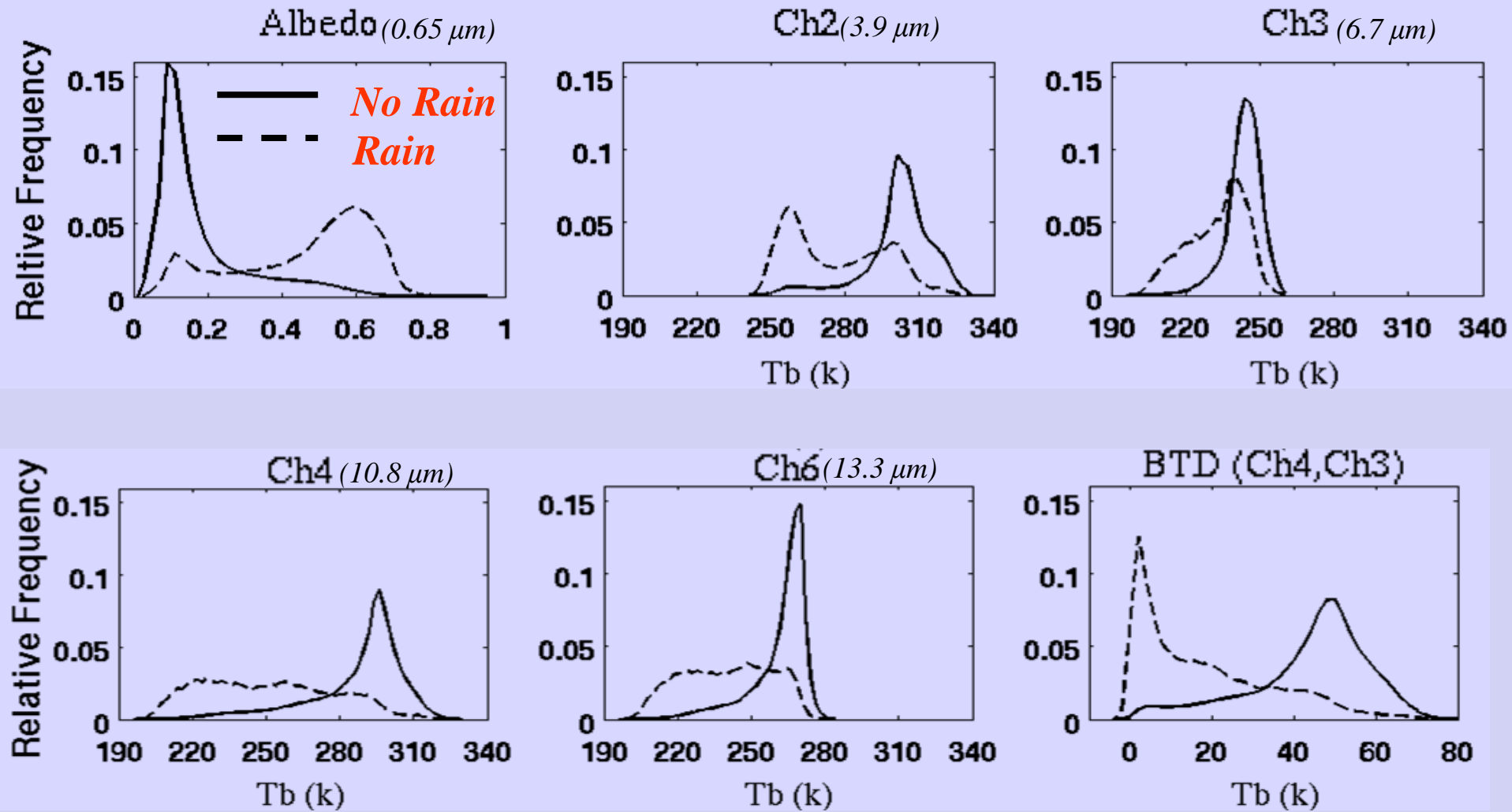


- Together a great opportunity to investigate the role of multi-spectral data for precipitation estimation*

Behrangi et al (2009 a & b)

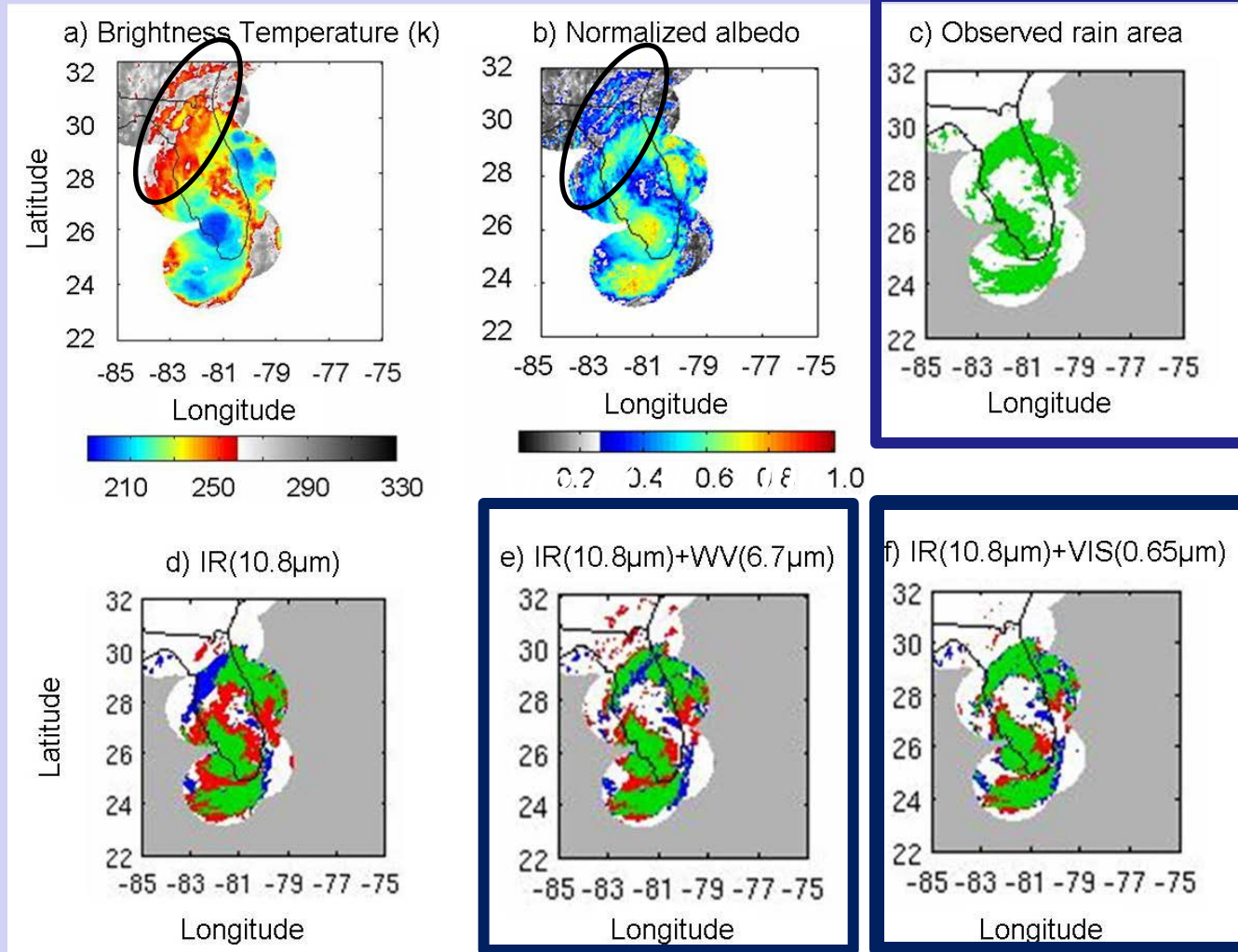


Relative-frequency dist. of different channels (rain / no-rain) conditions



By counting satellite pixels under rain and no-rain conditions we can plot the relative frequency curves for each spectral band. These curves indicate that different spectral channels show different capabilities to distinguish between rain and no-rain pixels

Case Study: Hurricane Ernesto August 30, 2006



Hit

Under Estimation

Over Estimation



GPM Mission: Target Date 2013-1014

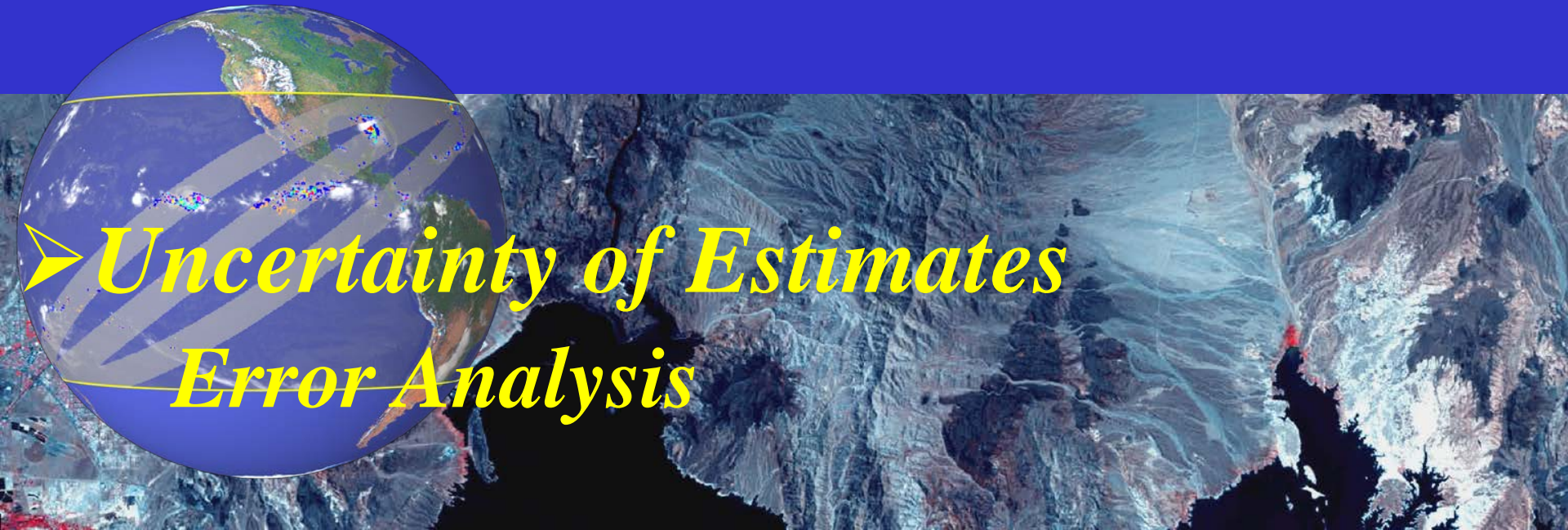
OBJECTIVES

- 1 Main satellite + 8 Smaller Satellites \
- Provide sufficient global sampling to significantly reduce uncertainties in short-term rainfall accumulations



Future looks bright and will bring us more advances for precipitation Estimation

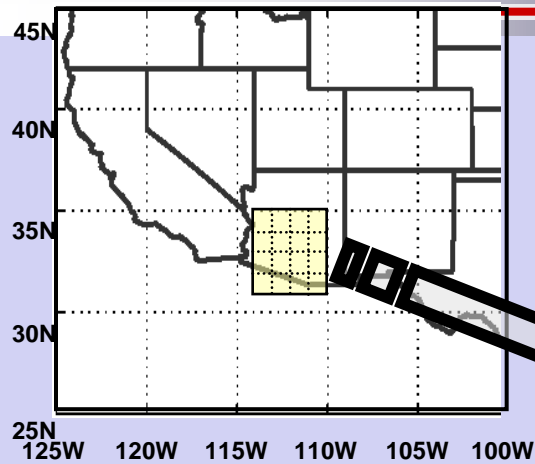




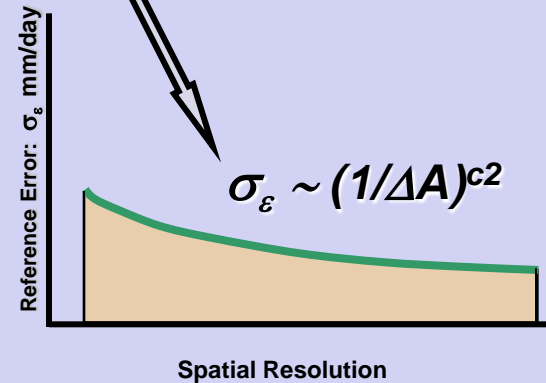
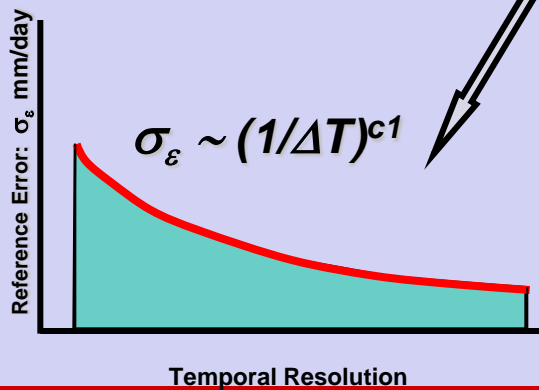
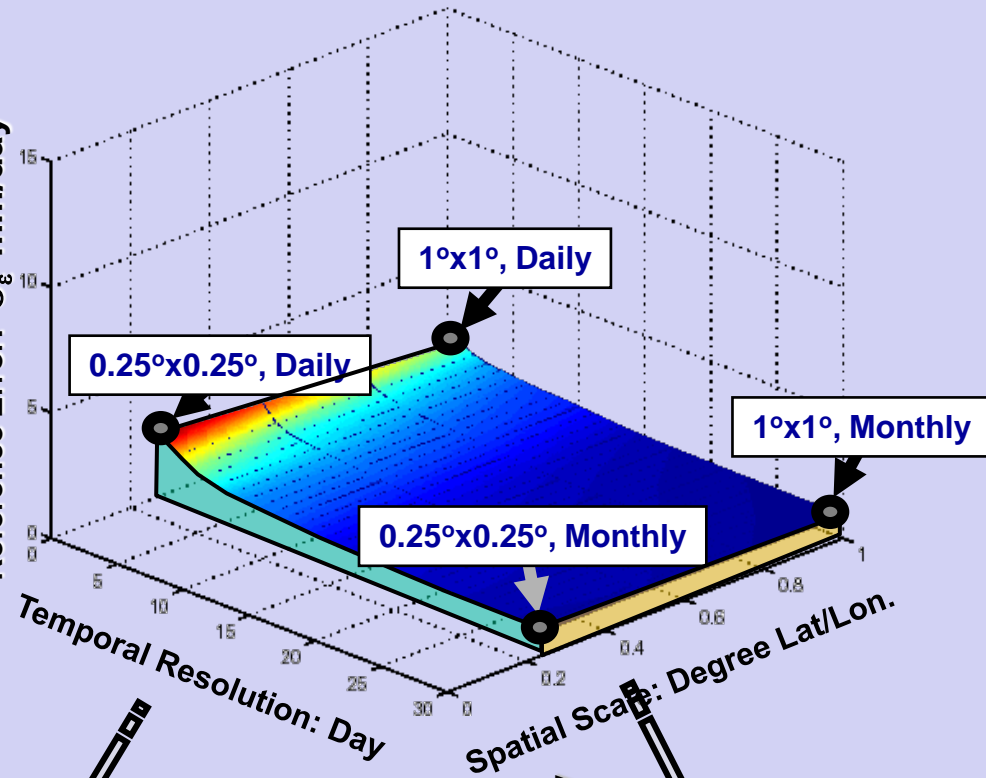
➤ *Uncertainty of Estimates*
Error Analysis



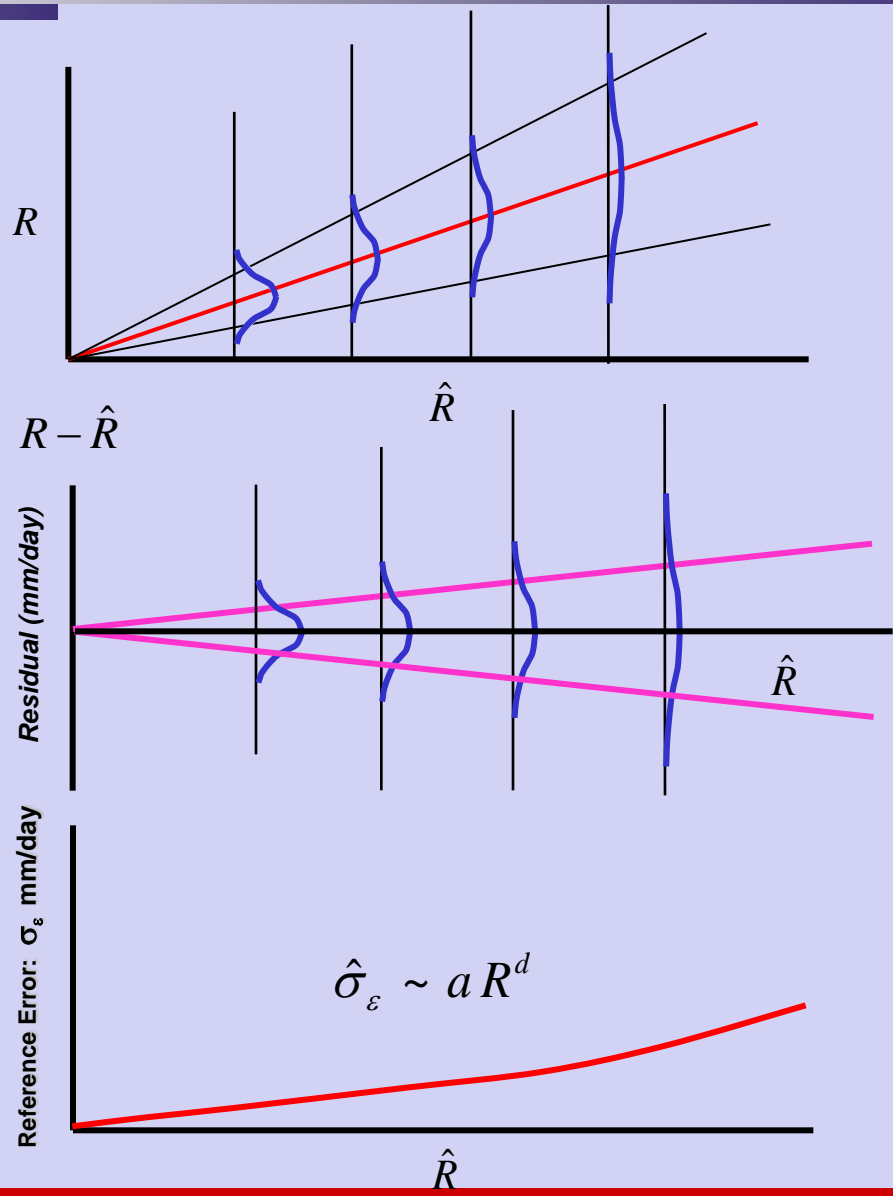
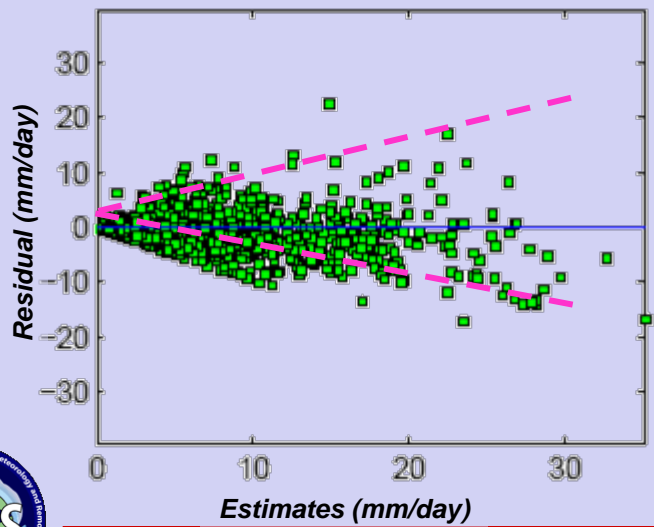
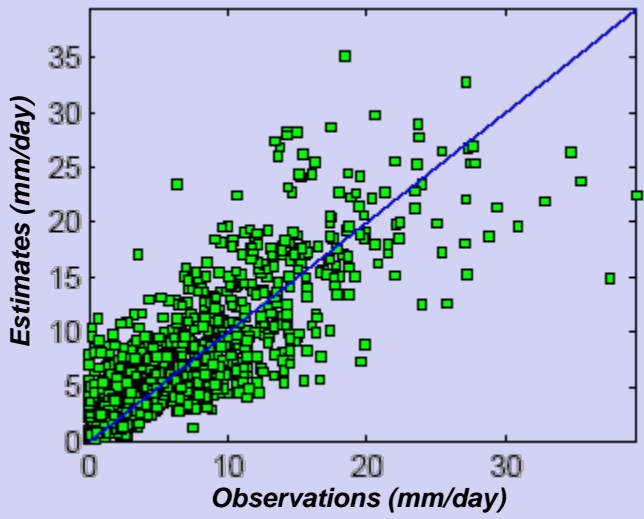
Spatial-Temporal Property of Reference Error



Reference Error: σ_ε mm/day

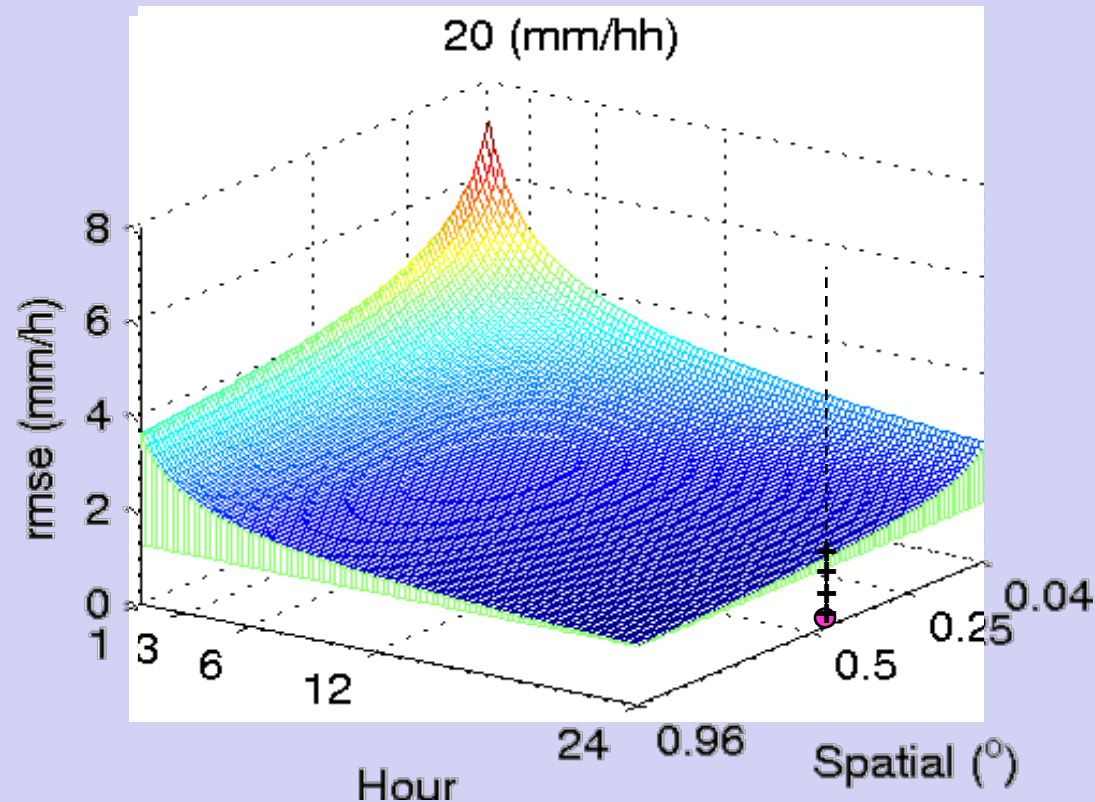


Reference Error: $\Delta T = 24\text{-hour}$, $\Delta A = 0.25^\circ \times 0.25^\circ$



Scaling Property of PERSIANN-CCS Reference Error

$$\hat{\sigma}_\varepsilon = a_1 \cdot \left(\frac{1}{\Delta A}\right)^{b_1} \left(\frac{1}{\Delta T}\right)^{c_1} (\hat{R})^{d_1}$$





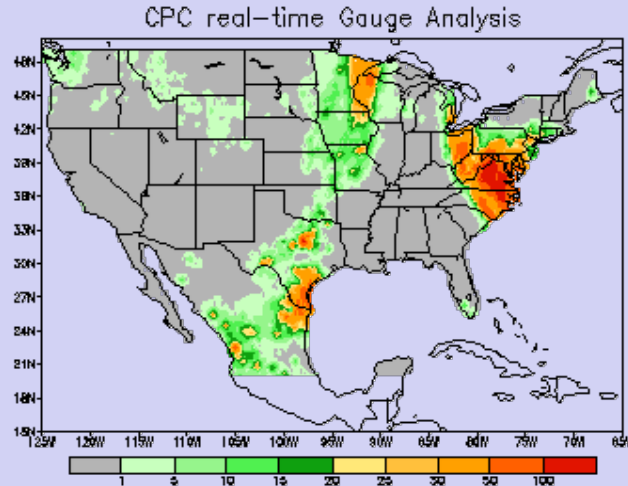
Validation and Application of Satellite Products



US Daily Precipitation Validation Page

http://www.cpc.ncep.noaa.gov/products/janowiak/us_web.html

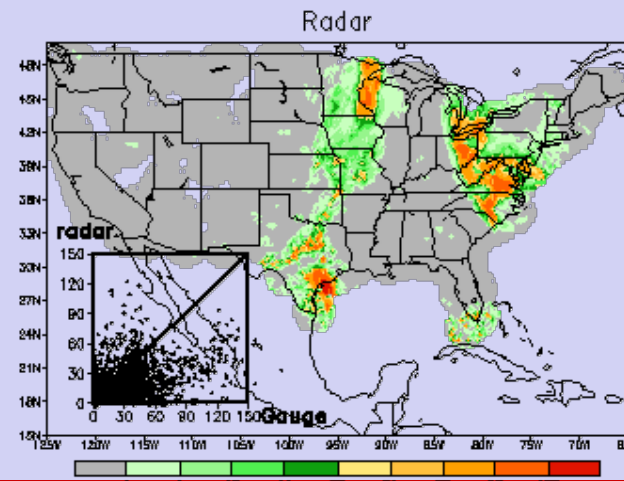
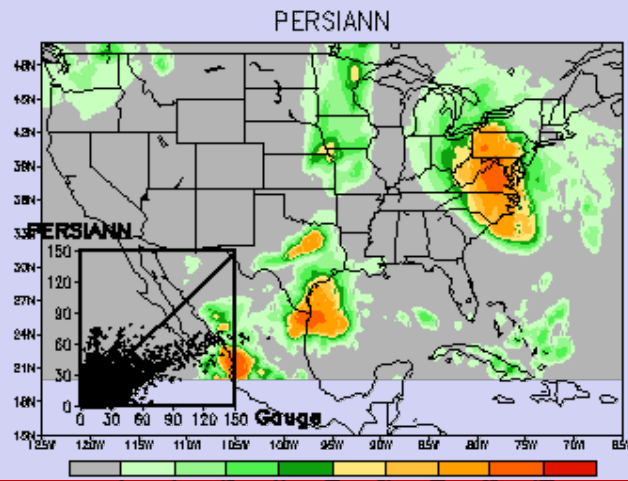
13Z 19Sep2003 thru 12Z 19Sep2003
Data on 0.25 deg grid (UNITS are mm/day)



	(G) gauge	(S) PERSIANN	(R) radar
Number of points:	13828.	13828.	13828.
# points w/rain:	4249.	4665.	2971.
Mean rain rate:	5.55	4.25	3.13
Cond. rain rate:	17.82	12.47	14.46
Max. rain rate:	181.99	79.07	131.45

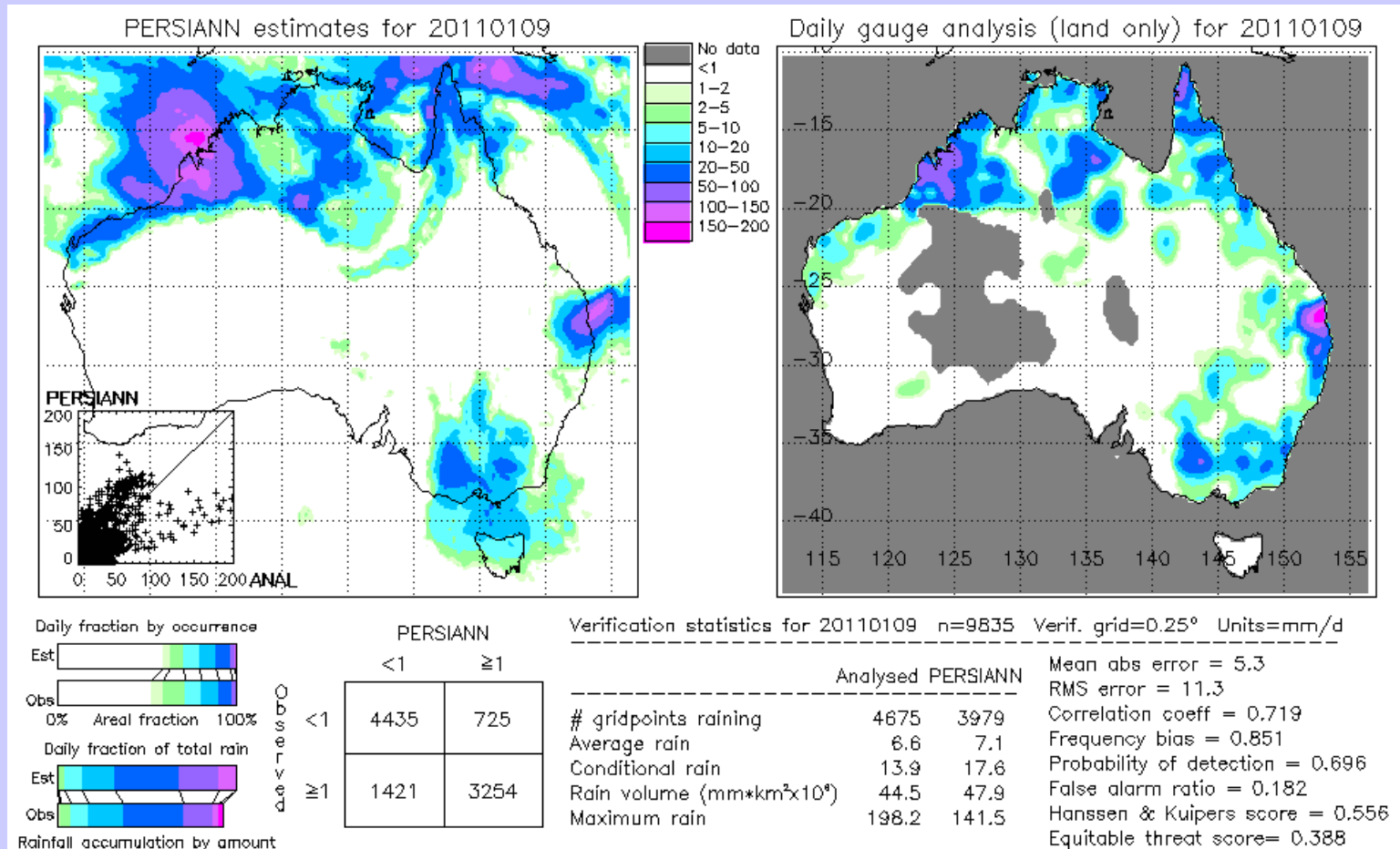
	G-S	G-R	R-S
Correlation:	0.827	0.726	0.606
Mean Absolute Error:	3.63	3.42	3.35
RMSE (mm/day):	9.44	11.23	8.66
RMSE (normalized):	1.70	2.02	2.77
Probability of Detection:	0.746	0.654	0.855
False Alarm Ratio:	0.321	0.065	0.455
Bias Ratio (rain:no rain):	1.098	0.699	1.570
Heidke Skill Score:	0.574	0.692	0.546
Hanssen-Kuipers Score:	0.589	0.634	0.660
Equitable Threat Score:	0.402	0.528	0.376

		PERSIANN		radar	
		< 1	≥ 1	< 1	≥ 1
gauge	< 1	8082.	1497.	9386.	193.
	≥ 1	1081.	3168.	1471.	2778.



Evaluation of PERSIANN Daily Rainfall

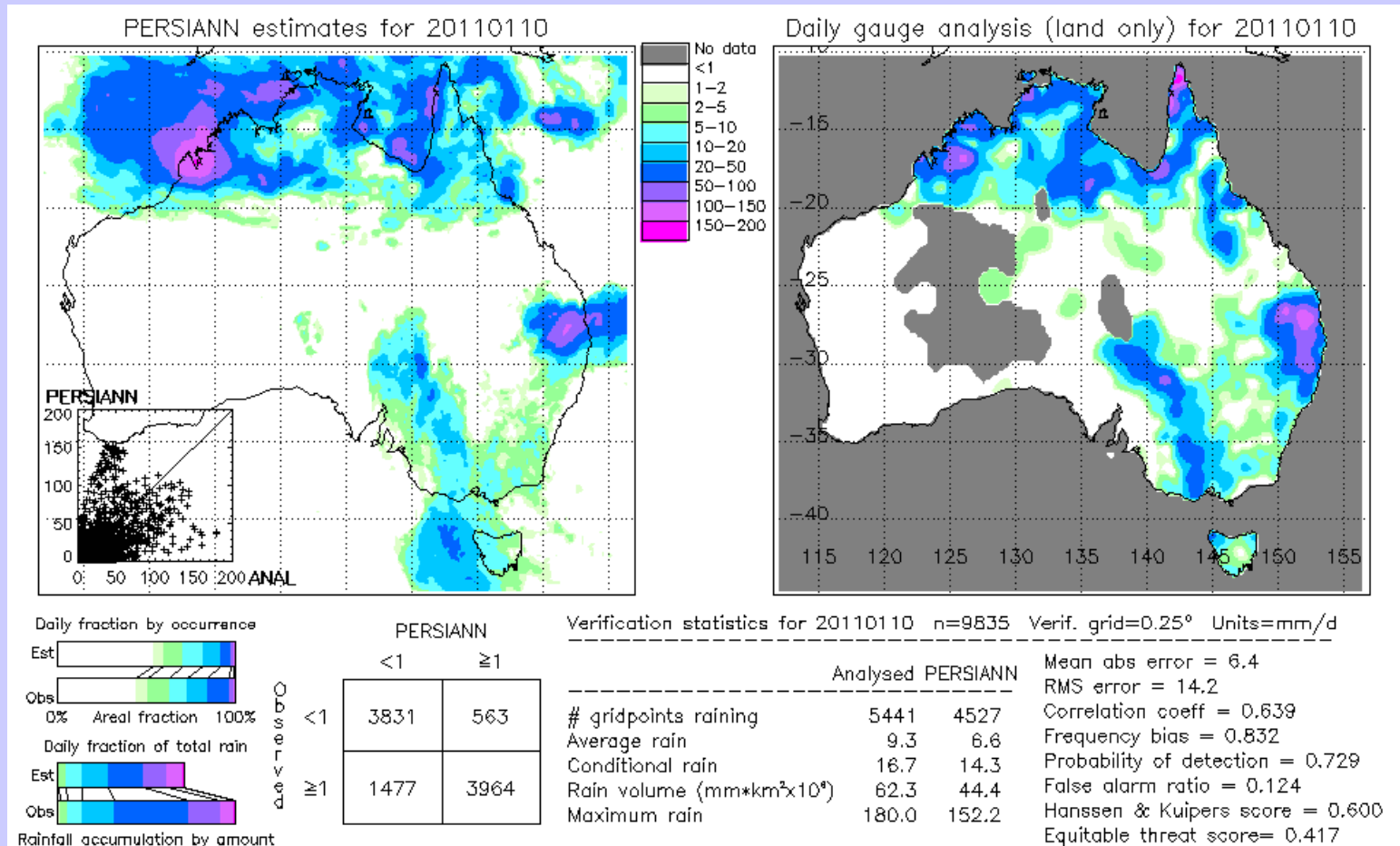
01-09-2011 (0.25-degree resolution)



Source: IPWG Validation over Australia: http://cawcr.gov.au/projects/SatRainVal/sat_val_aus.html

Evaluation of PERSIANN Daily Rainfall

01-10-2011 (0.25-degree resolution)



Source: IPWG Validation over Australia: http://cawcr.gov.au/projects/SatRainVal/sat_val_aus.html



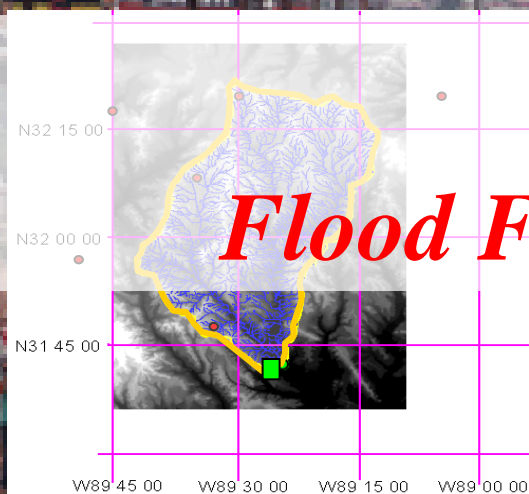
Satellite-Based Precipitation: Very Promising for Hydrometeorological Applications

a00074.mpeg



Satellite Rainfall Estimation for Operational Use

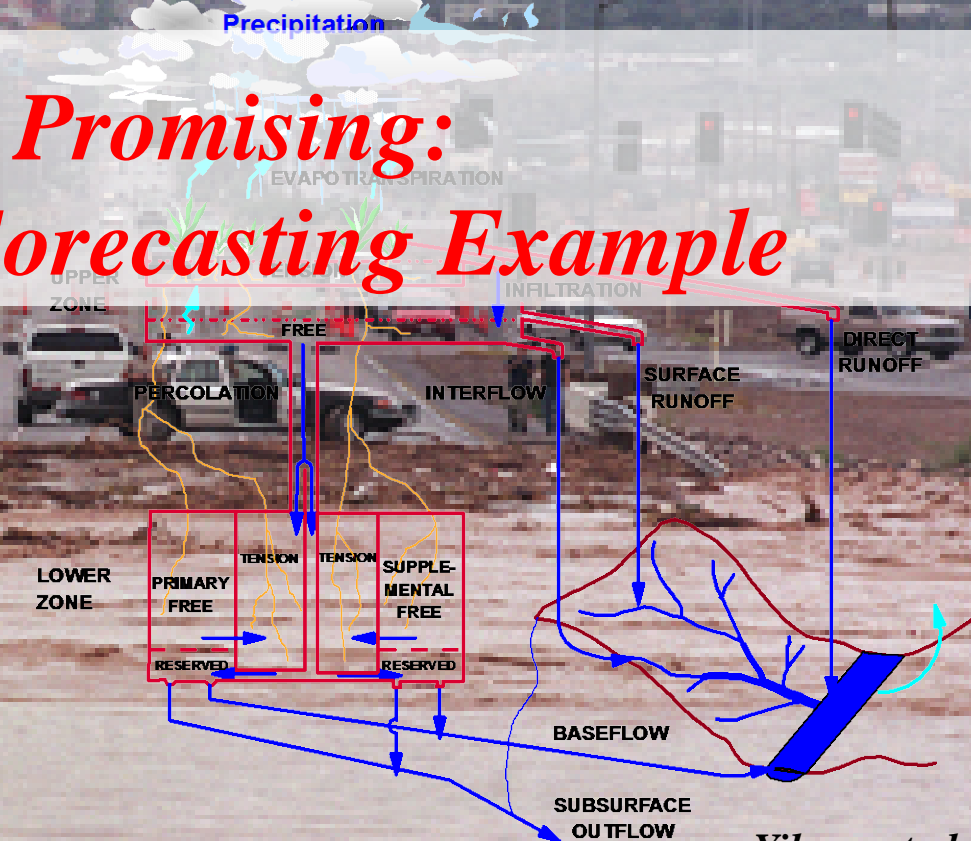
Streamflow forecasting of a catchment in US using UCI-PERSIANN rainfall Estimates for use in the US National Weather Service Runoff Forecasting System (NWSRFS).



● Gages used by NWS

Leaf River Near Collins
Mississippi
USGS # 02472000

Basin Area : 753 mi²

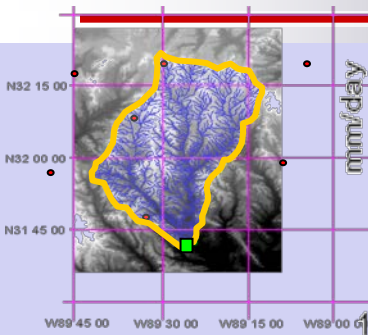


**Promising:
Flood Forecasting Example**

Yilmaz, et al. JHM 2005



Satellite Rainfall Estimation: Research at UC Irvine



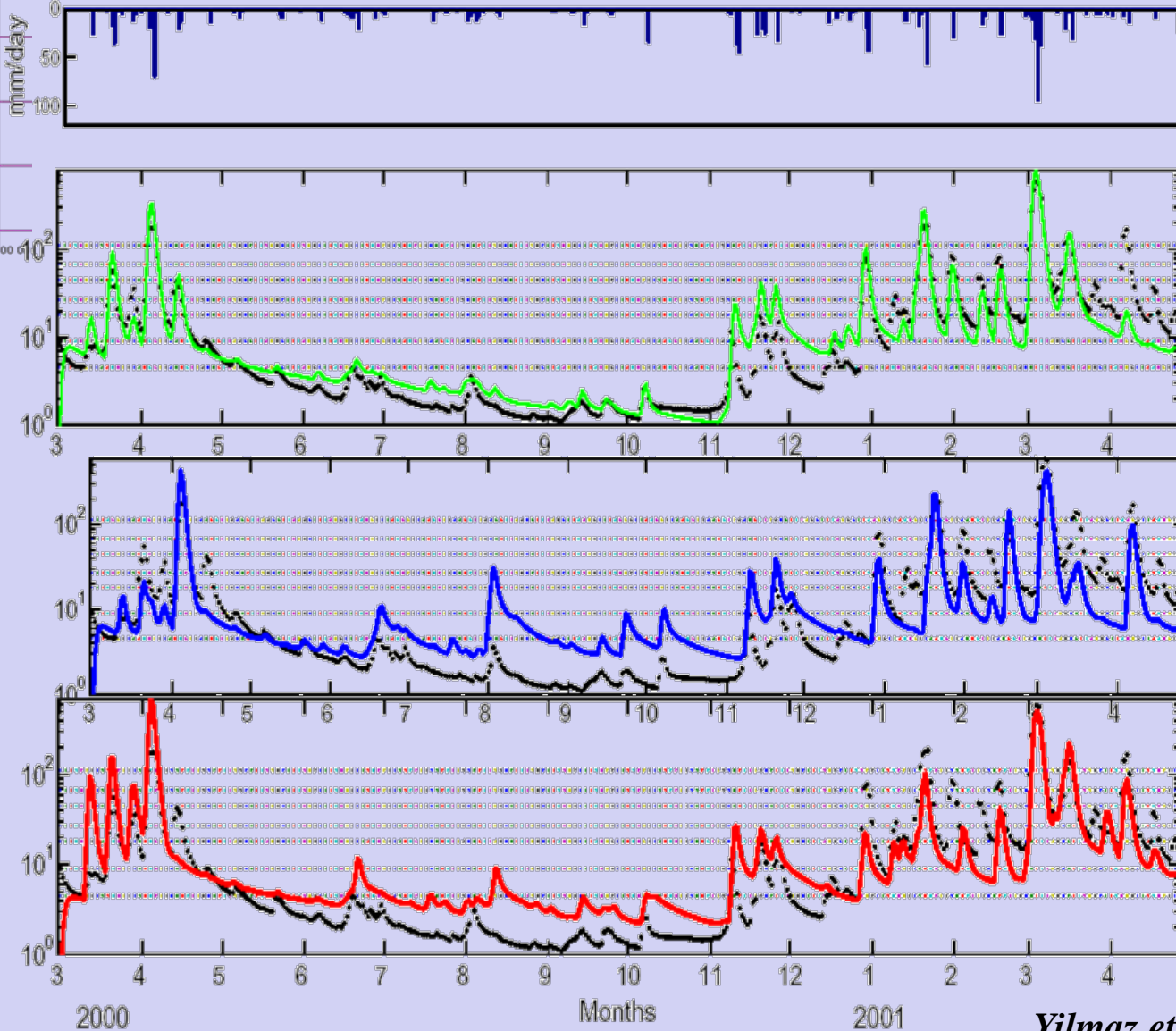
RAINGAGE



RADAR



PERSIANN



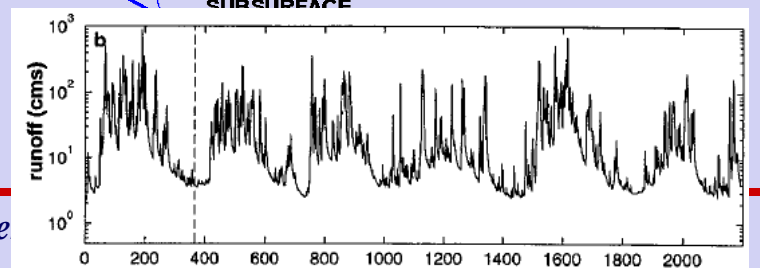
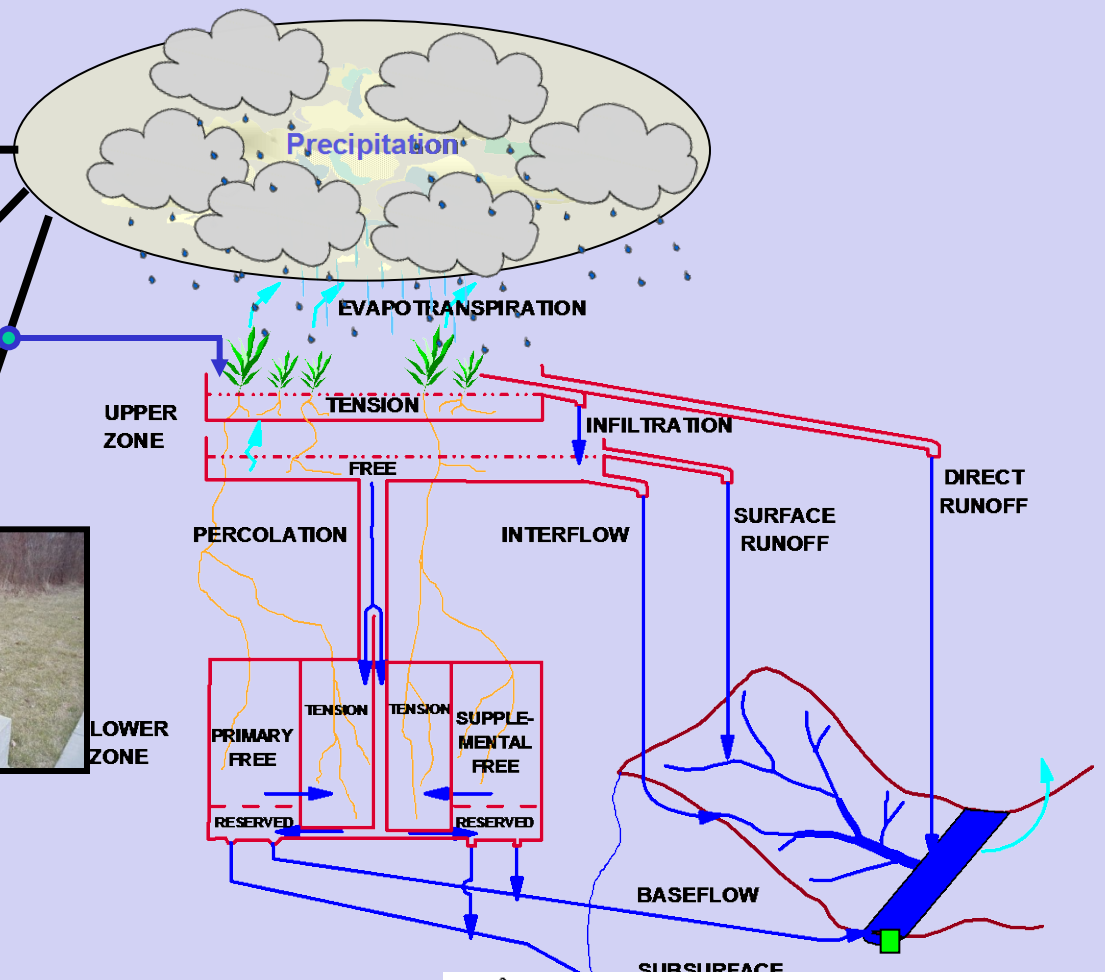
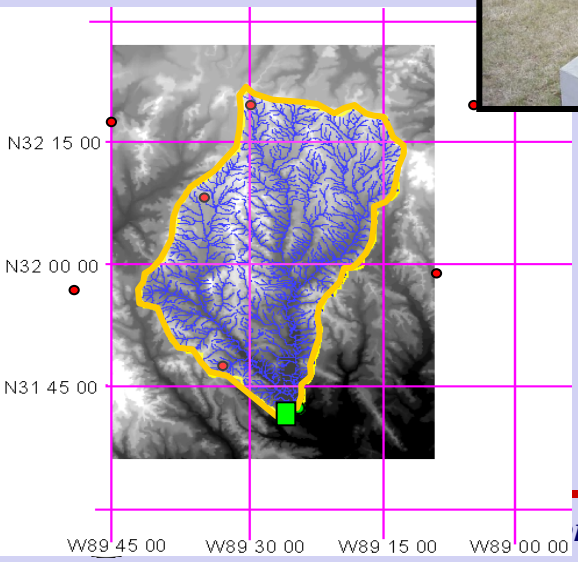
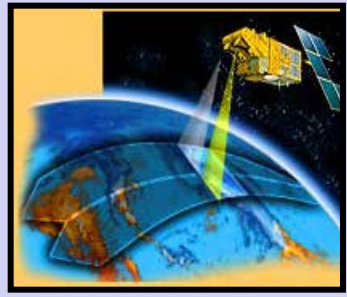
Corr =0.95
RMS =23.9
BIAS =-1.32

Corr =0.92
RMS =28.8
BIAS =-6.74

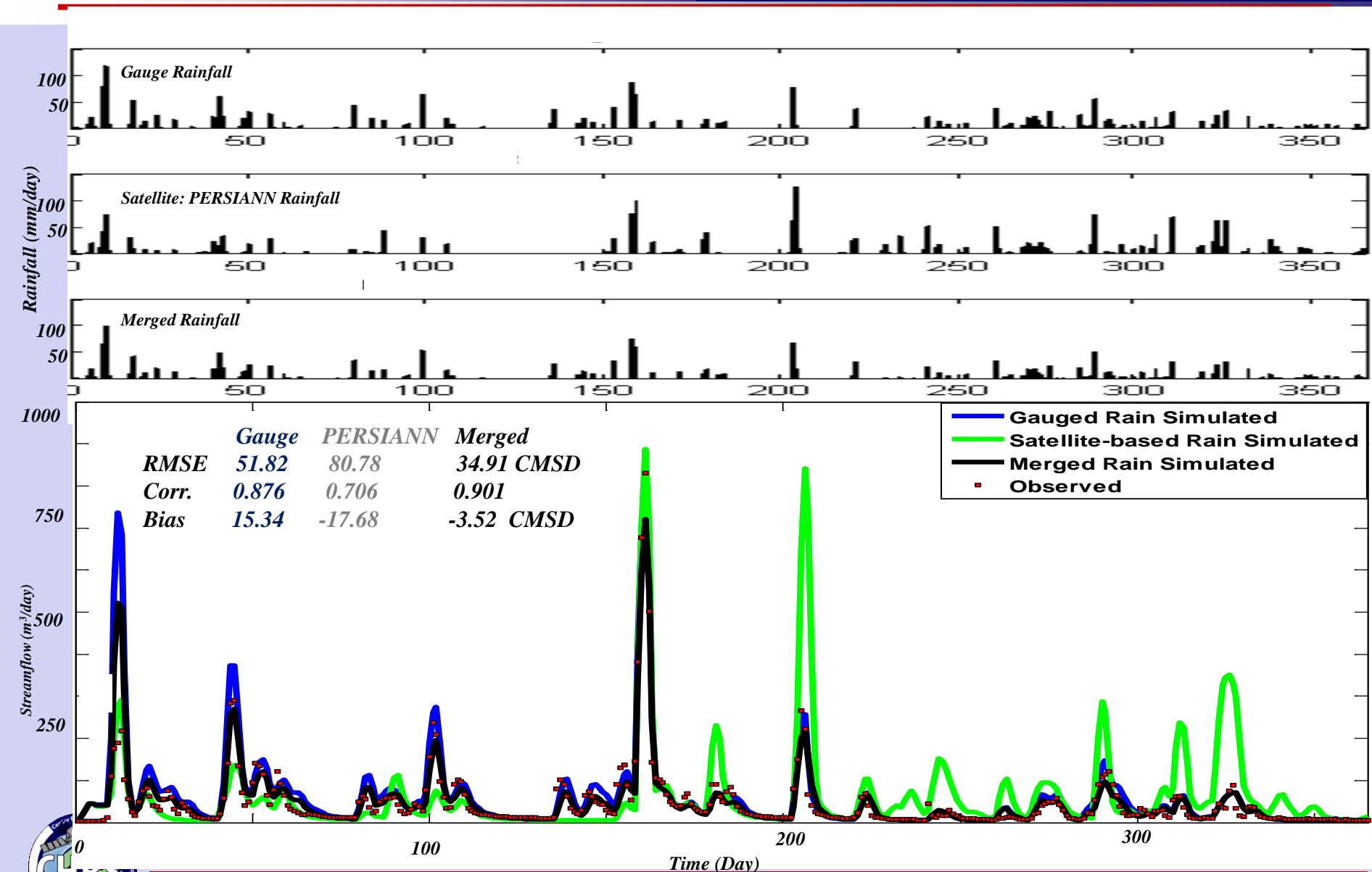
Corr =0.94
RMS =22.6
BIAS =-5.15



Basin Scale Precipitation Data Merging



Runoff Forecasting from Gauge, PERSIANN, and Merged Rainfall

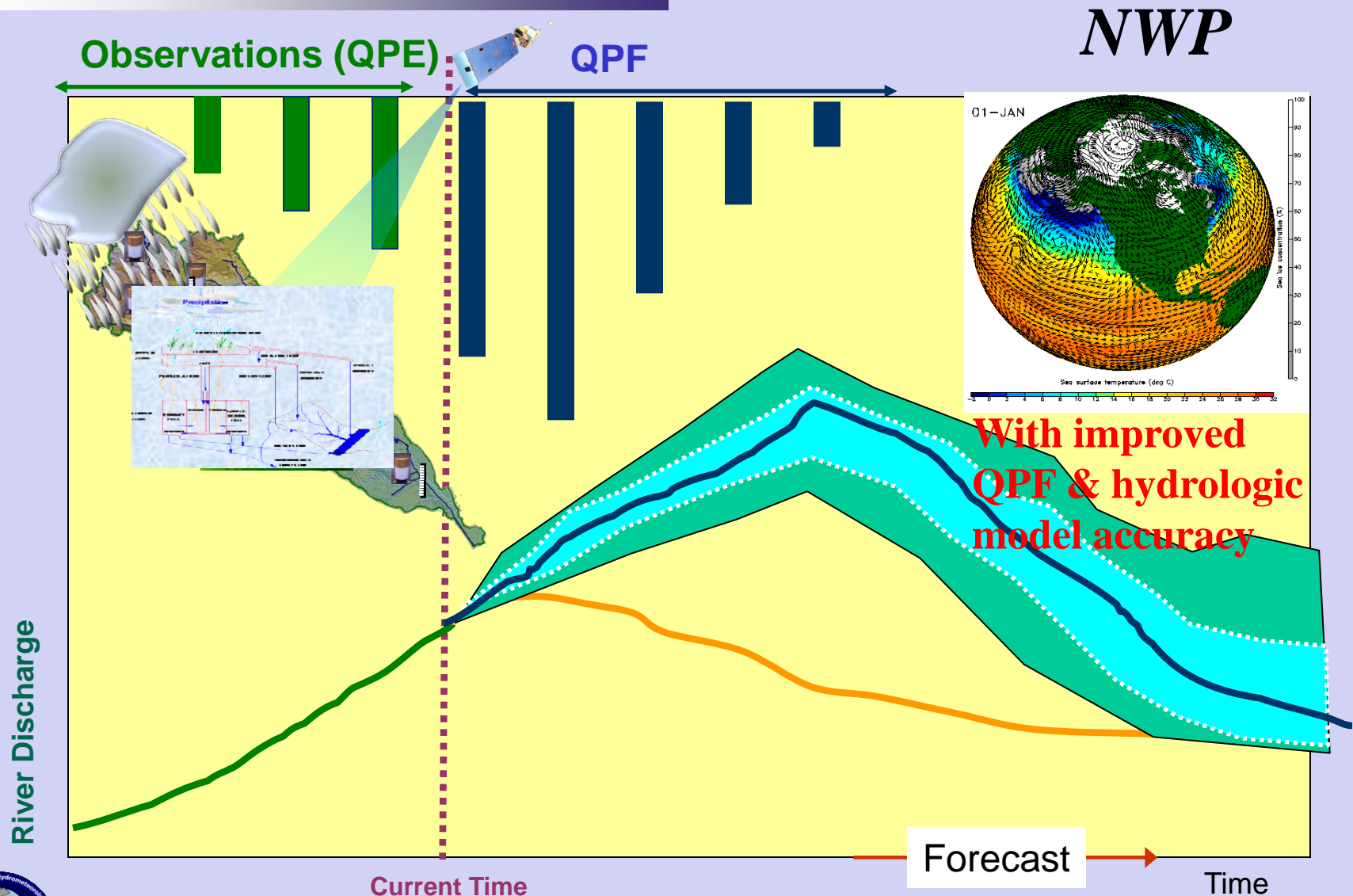


Estimating Future “Short-Term” Rainfall:

1- Models: (NWP - QPF)

2- Extrapolation-based Nowcasting

Efforts in Extending the Forecast Lead Time



Animation Assisted by: *Q. Xia, Gi-H. Park & L. Bastidas*

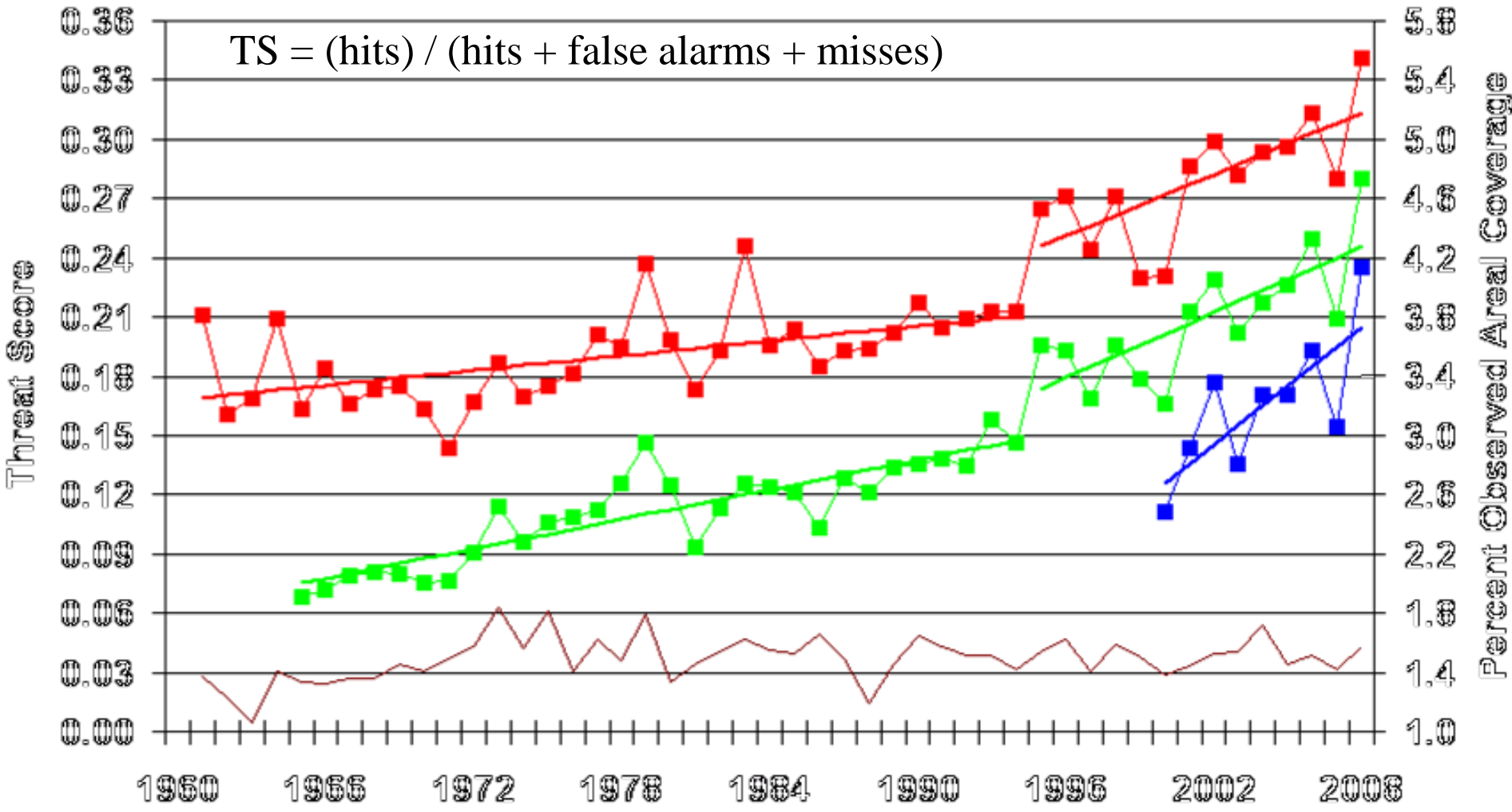
Center for Hydrometeorology and Remote Sensing, University of California, Irvine





HPC QPF verification 1-inch threat score

$$TS = (\text{hits}) / (\text{hits} + \text{false alarms} + \text{misses})$$



Day 1 Day 2 Day 3 Pct Coverage

In Brief:

While some of the results shown are based on very short life span of Satellite-Based Precipitation Research

They Are Very Promising!

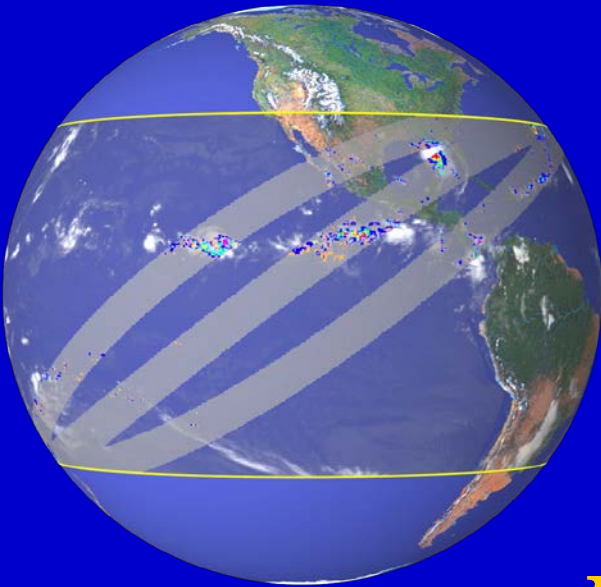




Thank You For the Opportunity

08/14/2009

Somewhere in New Mexico, USA - Photo: J. Sorooshian



BACK UP Material

