Remote Sensing Precipitation Using GEO Satellite Information

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New and emerging remote-sensing technologies for precipitation data sets and their applications and validation

The IPWG7 Training Course Program
17-20 November 2014
Tsukuba International Congress Center, Tsukuba, Japan

Outline

- ***Precipitation Measurement***
- ***GEO Satellite Information for Precipitation Retrieval***
- ***Precipitation Estimation from Remote Sensing Information using Artificial Neural Networks (PERSIANN)***
- ***PERSIANN-Climate Data Record (PERSIANN-CDR)***
- ***Summary***

Extreme Precipitation & Flash Flooding

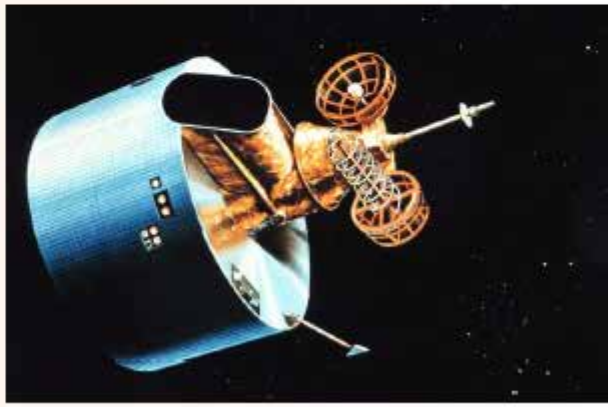
Floods caused by extreme precipitation are the most widespread nature disasters

High spatial and temporal resolution of precipitation measurement is needed for operational hydrology

Precipitation Observation

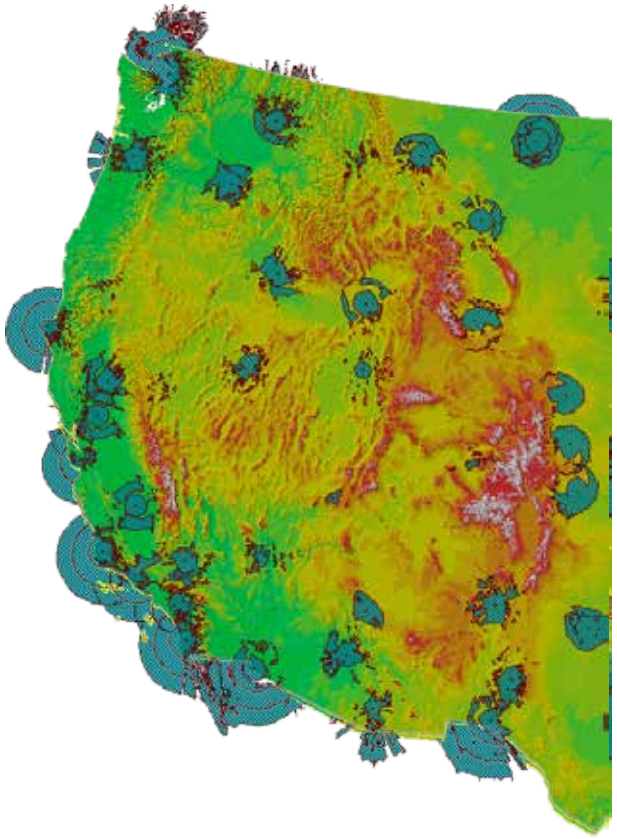
WSR-88D Radar

Rain Gauges

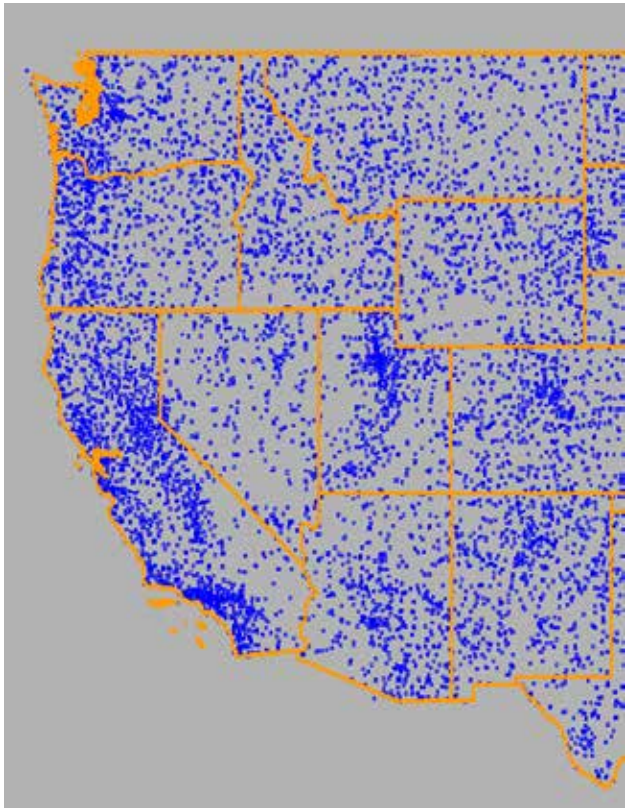


Satellite

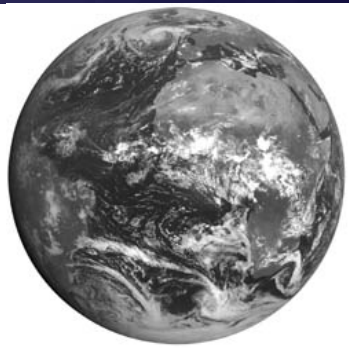
Coverage of the WSR-88D and gauge networks



1 km AGL

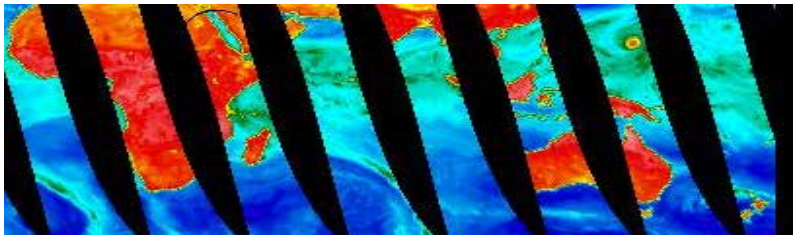


Satellite Precipitation Monitoring



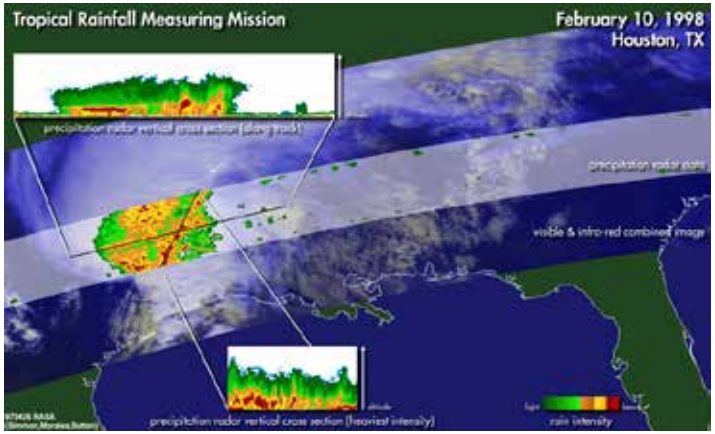
Meteosat 7 (EUMETSAT)

Geostationary IR
Cloud top heights only
15-30 minute data



SSMI 85GHz (DMSP)

Passive Microwave (SSM/I)
Some characterisation of rainfall
~2 overpasses per day per spacecraft, moving to 3-hour return time (GPM)

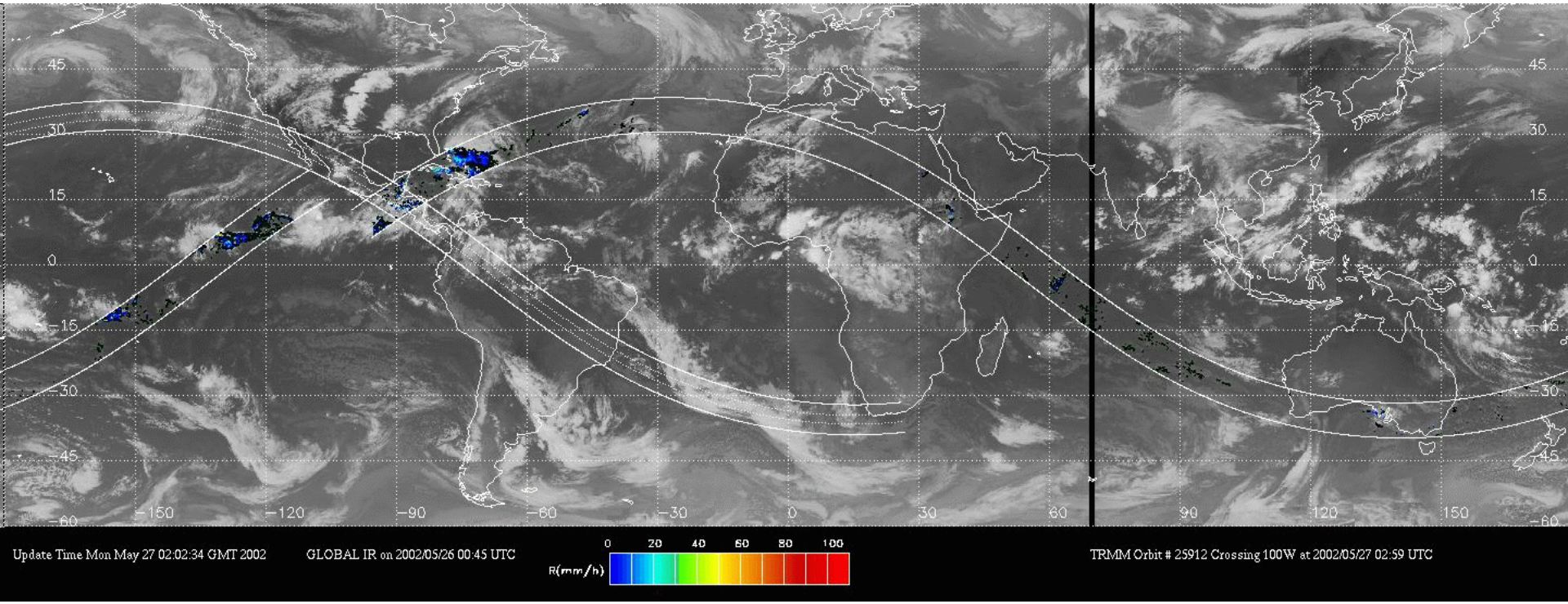


TRMM PR (NSA/JAXA)

TRMM precipitation RADAR
3D imaging of rainfall
1-2 days between overpasses
(35 ° N-35 ° S only)

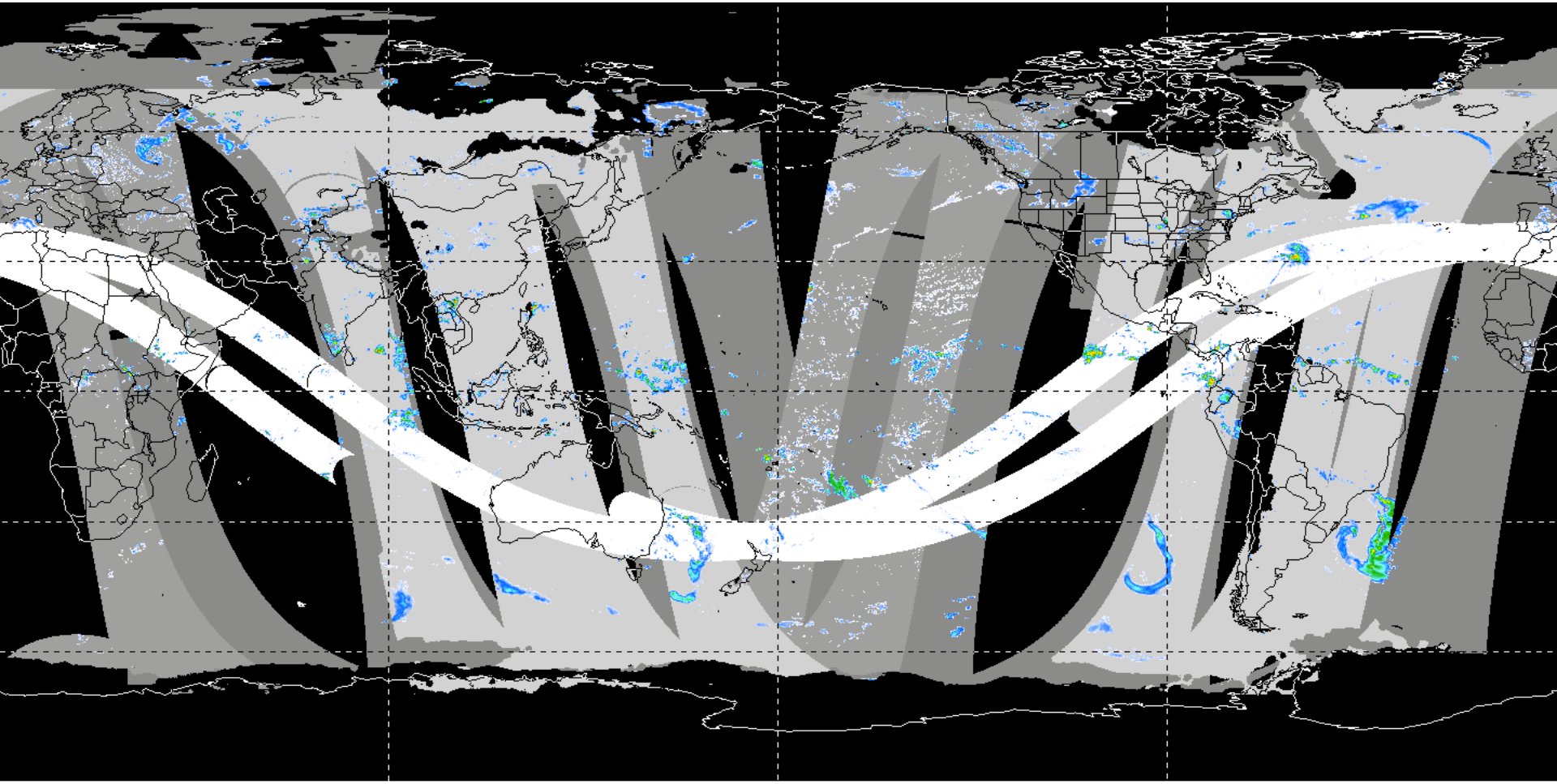
TRMM Rain Rate

“Instantaneous” rain rate from TRMM



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

Typical Microwave Coverage in 3 Hr



Precip (mm/d) Aug 1987

0 4 8 12 16 20+

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

TMI – white

SSM/I – light grey

AMSR-E – medium grey

AMSU-B – dark grey

Mission Elements:

- ***GPM Core Satellite***
- ***Constellation Satellite Members***
- ***Precipitation Processing System (PPS)***
- ***International Ground Validation (GV) Network & Research Program***
- ***International Body of Science and Engineering Teams***

Building on the Rich Heritage of the Tropical Rainfall Measuring Mission (TRMM), the GPM Mission is....

- the Flagship Mission for Global Water and Energy Cycle (GWEC) research.
- an International Partnership Constellation Mission--Potential missions by ESA (E-GPM) and CNES-ISRO (Megha-Tropiques) are currently under consideration.
- an important contribution to the U.S. Climate Change Science Program (CCSP) and the U.S. Weather Research Program (USWRP).
- an outstanding example of peaceful uses of space, according to the United Nations, enabling important societal applications involving fresh water resources and environmental forecasting.
- a prototype for the emerging Global Earth Observation System of Systems (GEOSS), a coordinated international effort to provide comprehensive, long-term, and systematic observations of Earth.

An International Partnership Mission to Understand Global Precipitation and Its Impact on Humankind

NASA
www.nasa.gov

Science Mission Directorate
http://science.hq.nasa.gov

GPM
http://gpm.gsfc.nasa.gov

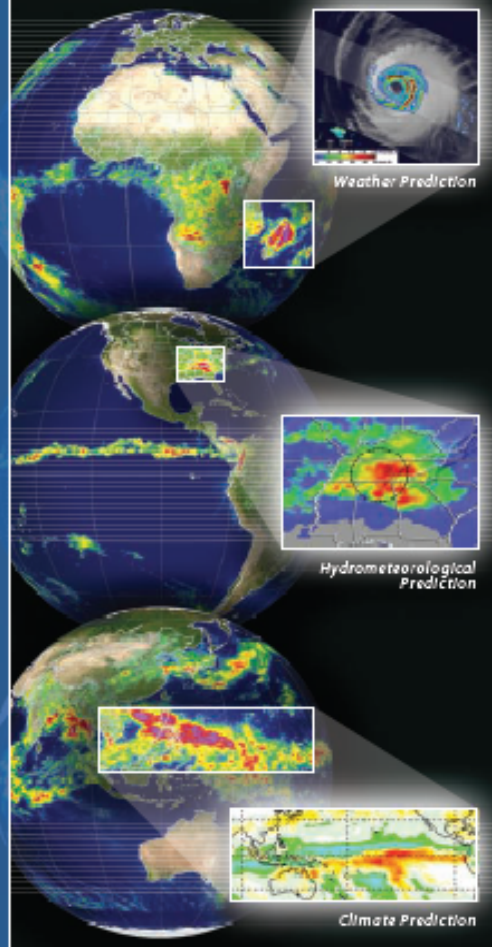
One of the next generation of systematic measurement missions that will measure global precipitation, a key climate factor, with improved time resolution and spatial coverage.

National Aeronautics and Space Administration

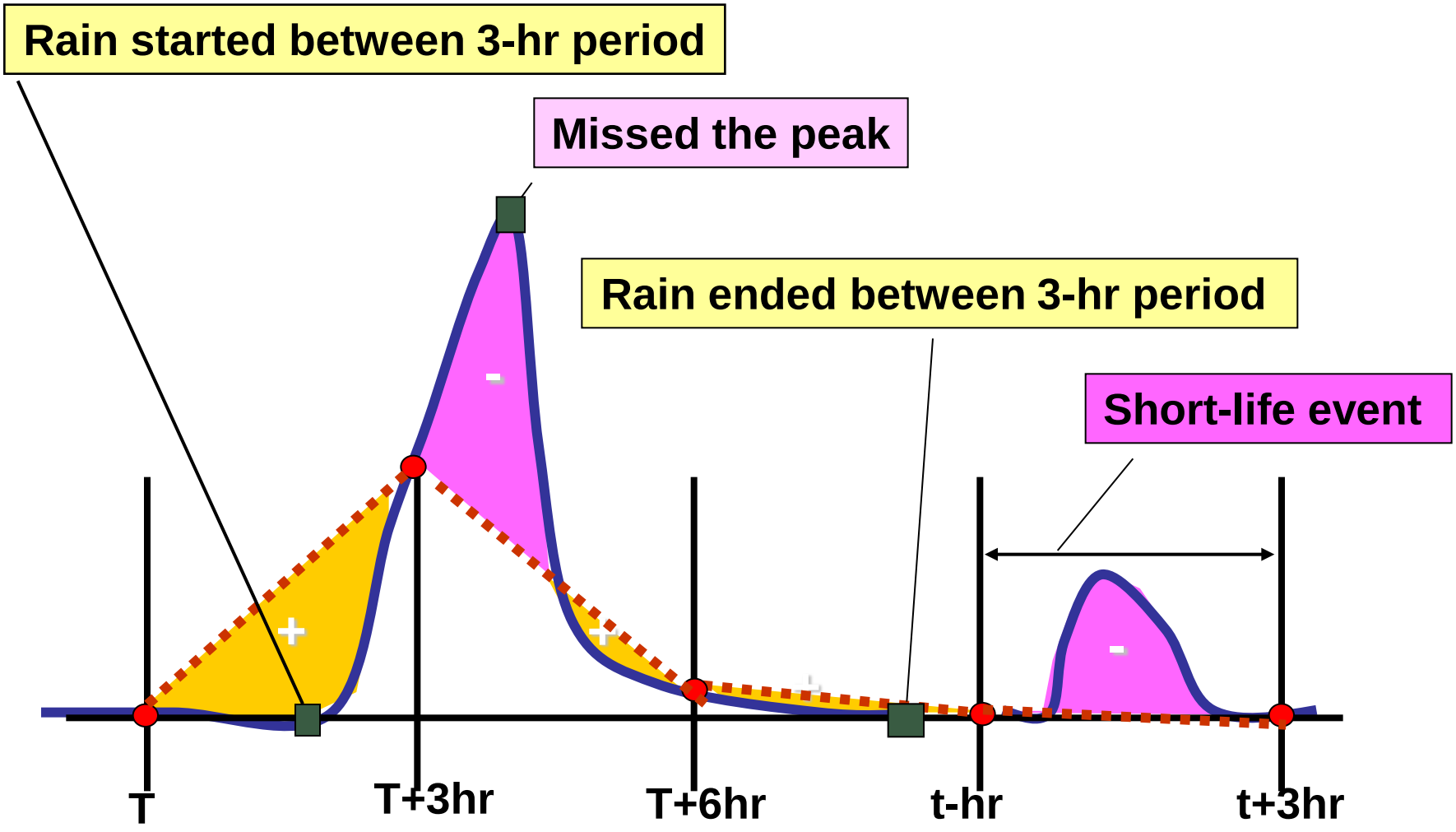
National Aeronautics and Space Administration

GLOBAL PRECIPITATION MEASUREMENT

GPM



Interpolation of 3-hour Precipitation



Rain Estimation from Geostationary satellite (VIS/IR)

Advantages:

- ***Good space and time resolution (half-hour, 4 km)***
- ***Observations in near real time***
- ***Near global coverage***

Disadvantages:

- ***Measures cloud-top properties instead of rain***
- ***May mistake cirrus for rain clouds***
- ***May not capture rain from warm clouds***

VIS/IR Rainfall Estimates

- *IR brightness temperature*

  Deeper clouds à colder à heavier rainfall

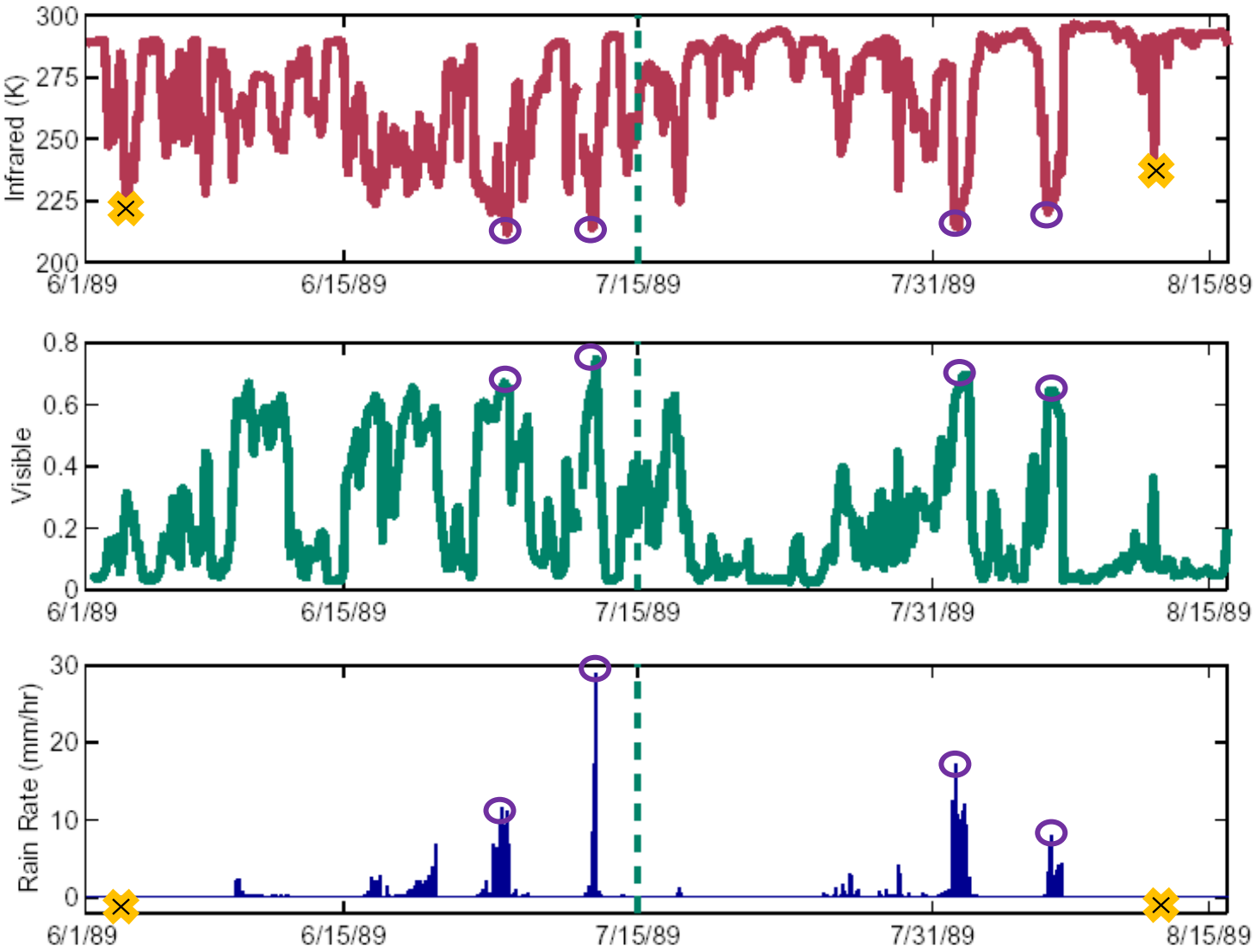
  Low clouds à Warm à no rain

- *VIS reflectivity*

  Thicker clouds à brighter: heavier rainfall

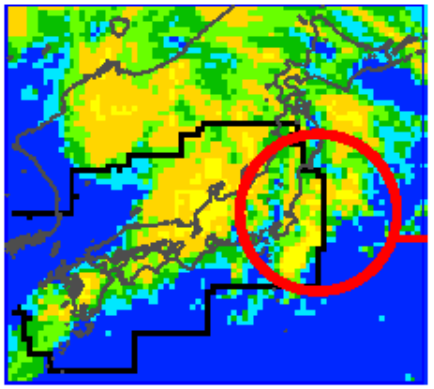
  light clouds à Dark: no rain

VIS-IR Image vs. Rainfall



VIS-IR Image vs. Rainfall

Infrared Imagery: (0400 UTC, 6/5/89)



210 230 250 270 K

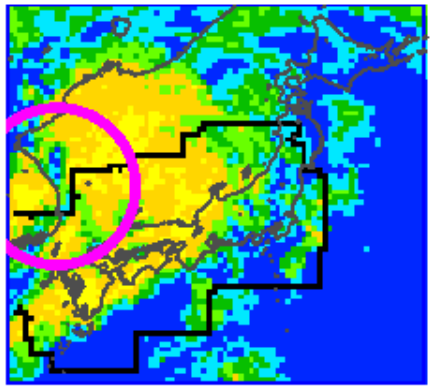
A

Cold-Thin clouds

B

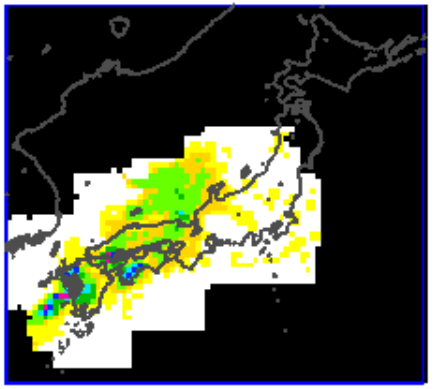
Warm-Thick clouds

Visible Imagery: (0400 UTC, 6/5/89)

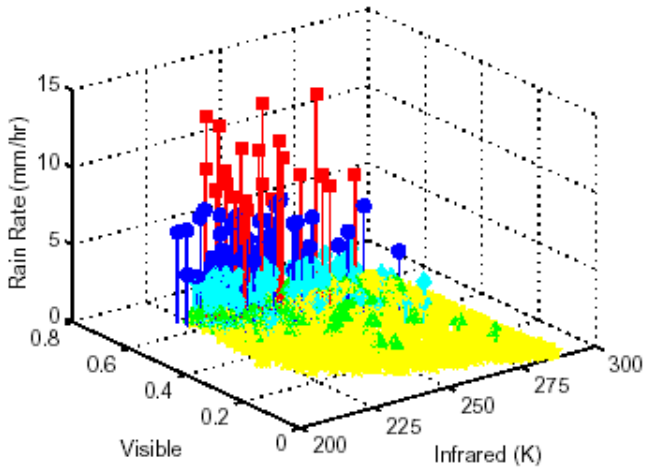


.8 .6 .4 .2

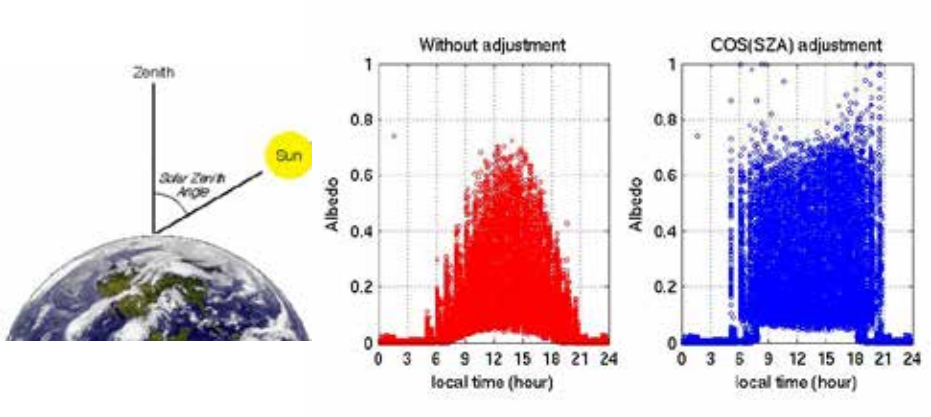
(c) Ground-based Rainfall Measurement

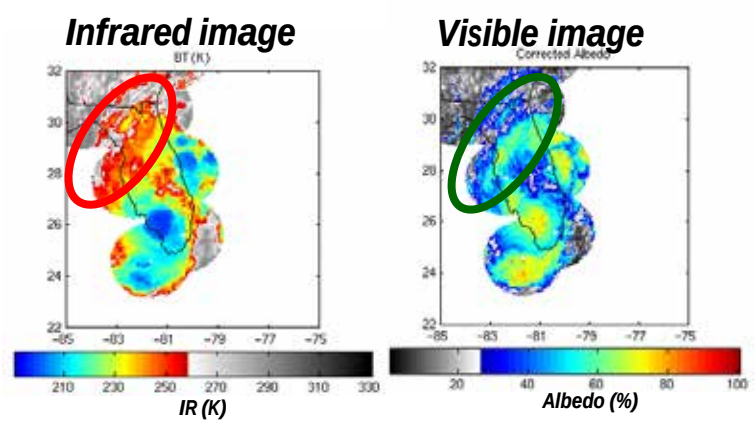


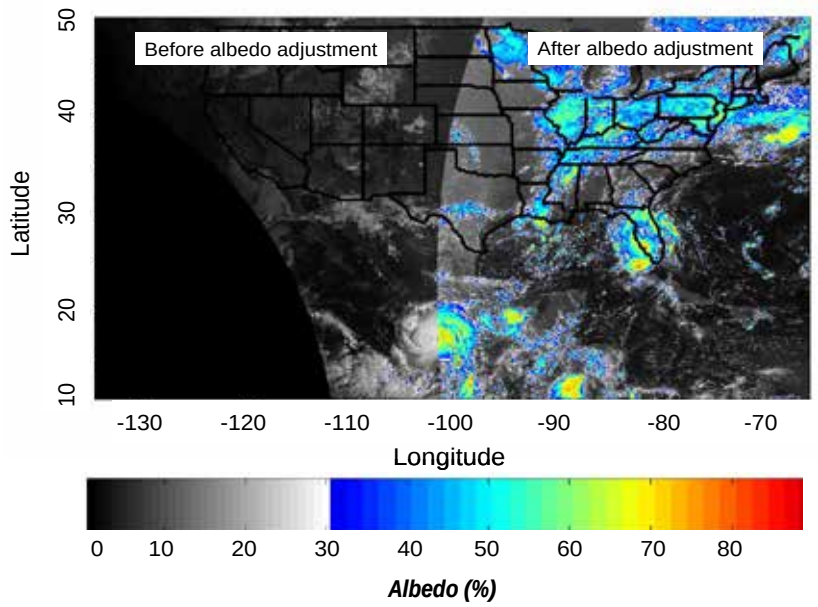
NaN 0 .5 3 7 (mm/hr)

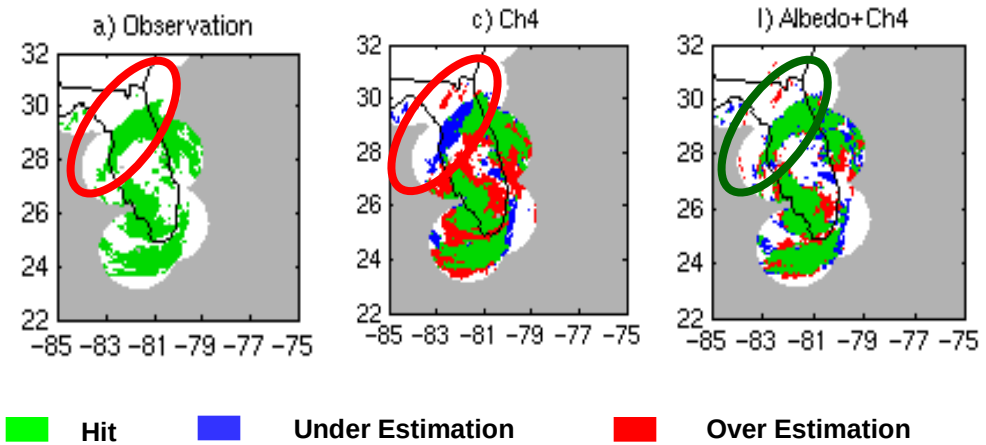


Multi-spectral Image for Rain Classification



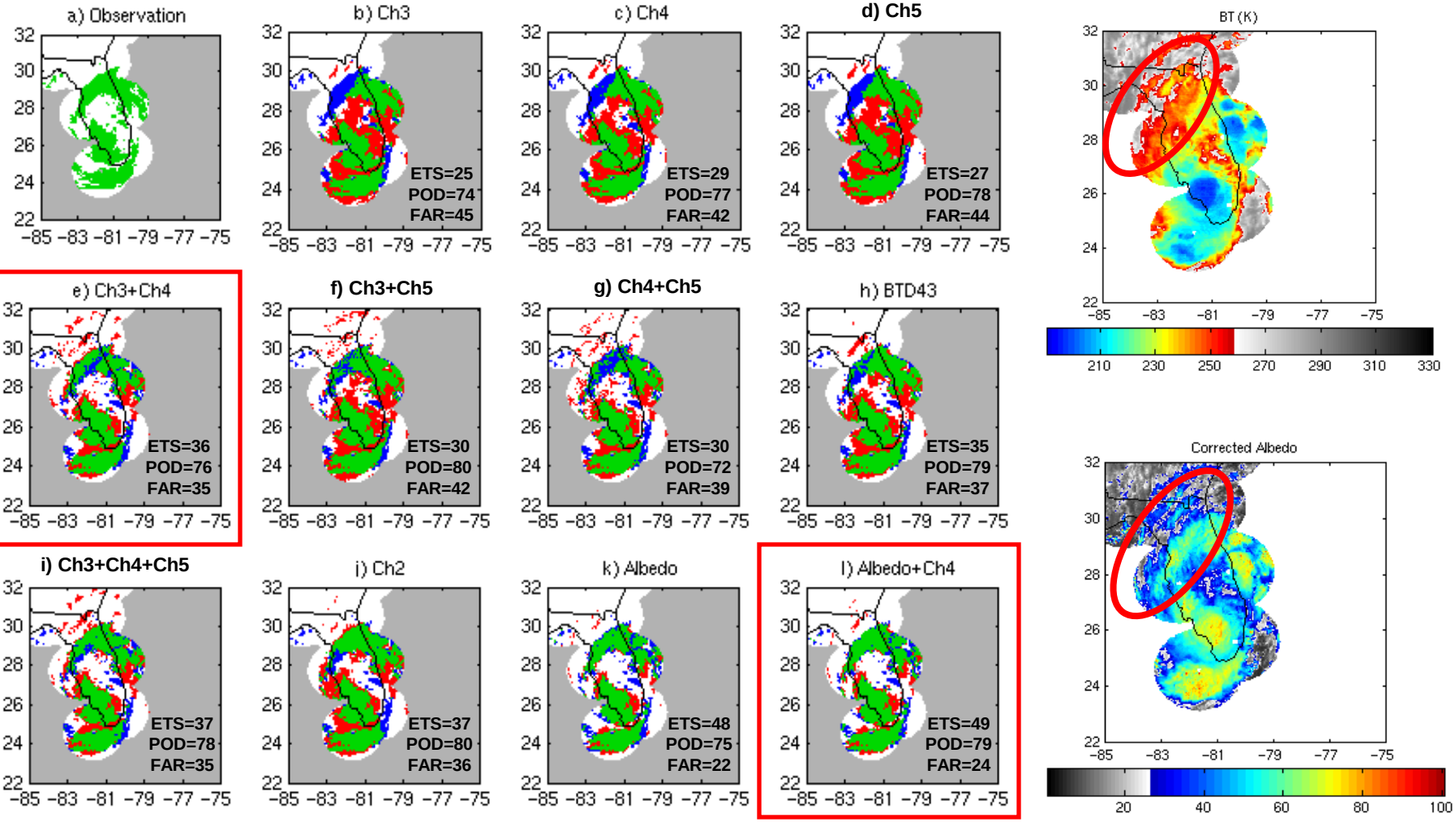






Ali et al., J. Hydrometeorology, 2009

Florida : Hurricane Ernesto August 30 2006

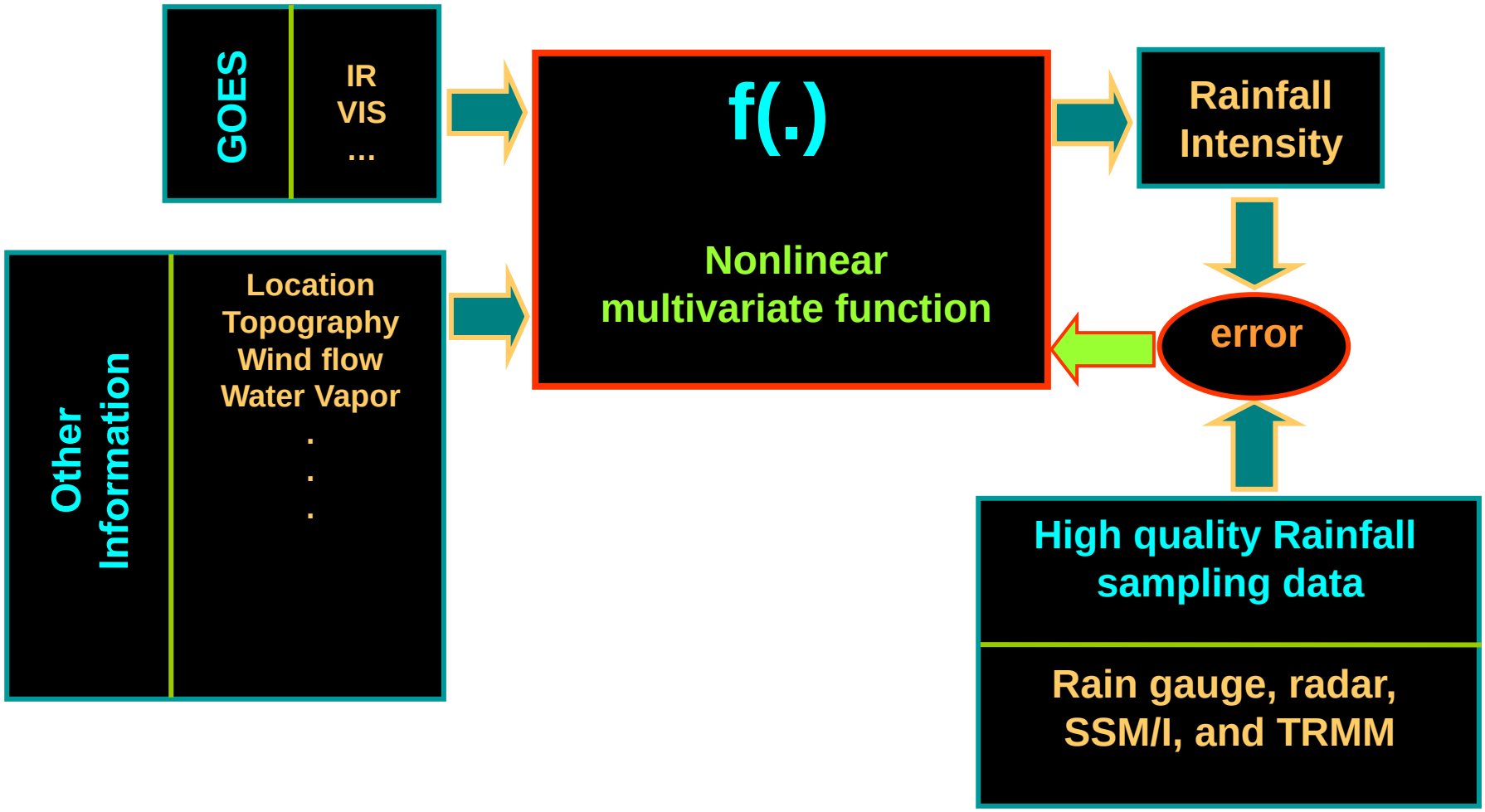


Hit **Under Estimation** **Over Estimation**

Ch 1 : 0.6 µm Ch2 : 3.9 µm Ch3 : 6.5 µm Ch4:10.7µm Ch5 : 13.3µm

Ali et al., J. Hydrometeorology, 2009

A Strategy for Satellite Precipitation Estimation



Some IR based Algorithms

- ***Global Precipitation Index (GPI):*** *Arkin and Meisner, 1987*
- ***Negri-Adler-Wetzel (NAW) technique:*** *Negri et al., 1984*
- ***Convective Stratiform Technique (CST):*** *Adler & Negri, 1988*
- ***AutoEstimator:*** *Vicente et al., 1998*
- ***Hydro-Estimator:*** *Scofield and Kuligowski, 2003*
- ***Tropical Applications of Meteorology using SATellite data (TAMSAT):*** *Grimes et al., 1999*
- ***PERSIANN/PERSIANN-CCS.PERSIANN-MSA:*** *Hsu et al., 1997; Sorooshian et al., 2000; Hong et al., 2004; Behrangi et al., 2009*
- *and many more …*

PERSIANN System

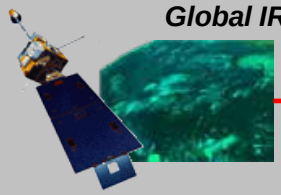
Precipitation **E**stimation from **R**emotely **S**ensed **I**nformation using **A**rtificial **N**eural **N**etworks

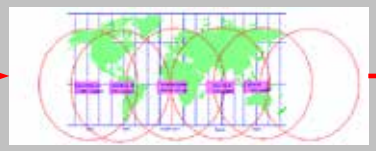
Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks

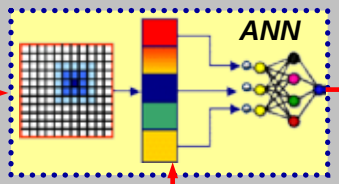
PERSIANN System "Estimation"

Satellite Data

Global IR



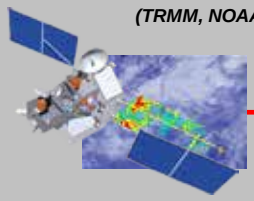


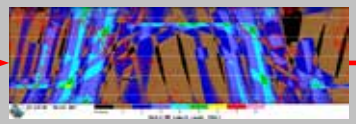


High Temporal-Spatial Res.
Cloud Infrared Images

Feedback

MW-RR
(TRMM, NOAA, DMSP Satellites)





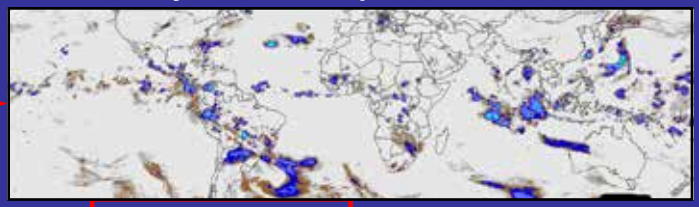
Sampling

Error Detection

MW-PR Hourly Rain Rates

Products

Hourly Global Precipitation Estimates



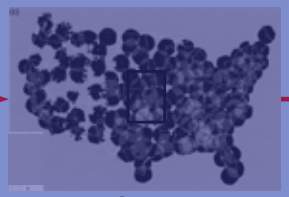
Hourly Rain Estimate

Quality Control

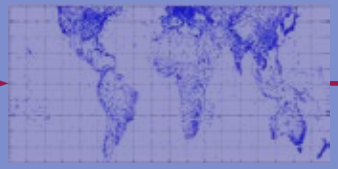
Merging

HyDIS WEB

Ground Observations



Radar Coverage

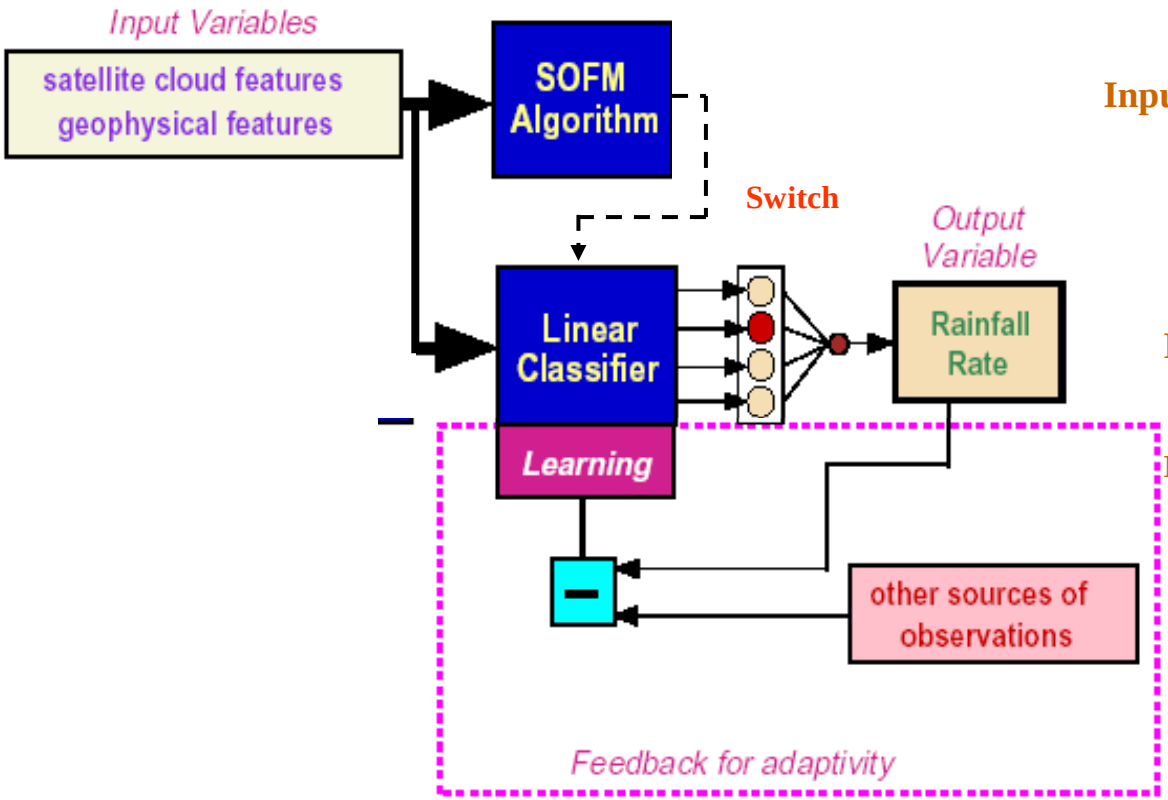


Gauges Coverage

Sorooshian et al., BAM, 2000

Designing the PERSIANN System

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

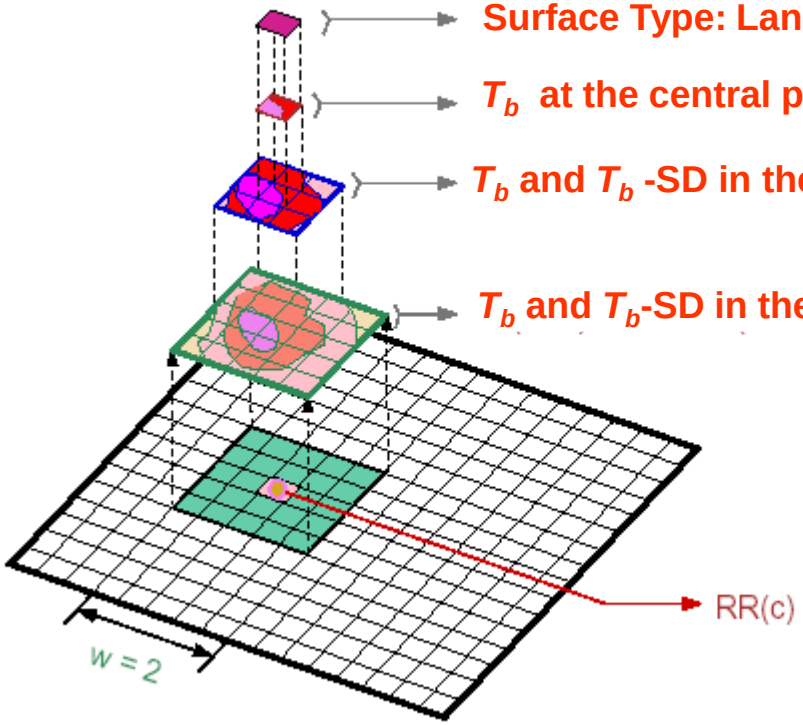


Input feature Classification

Rain Rate Estimation

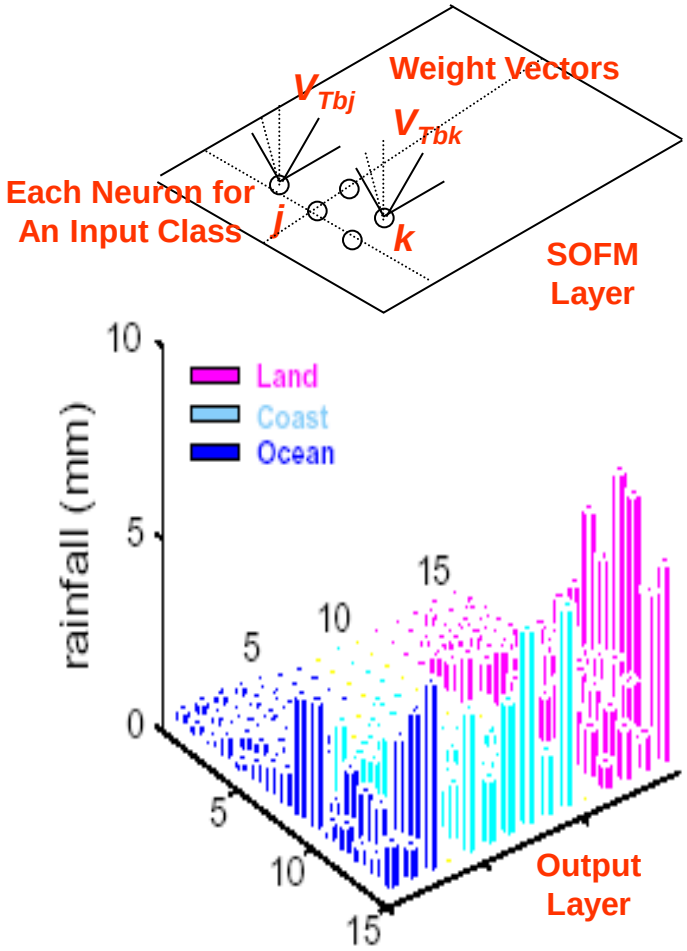
Error Detection-Correction

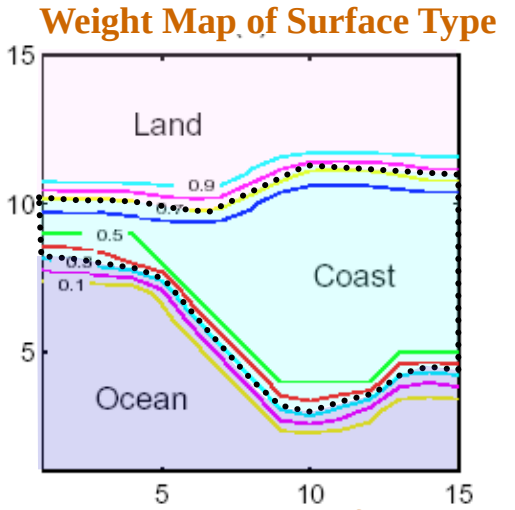
Input Variables

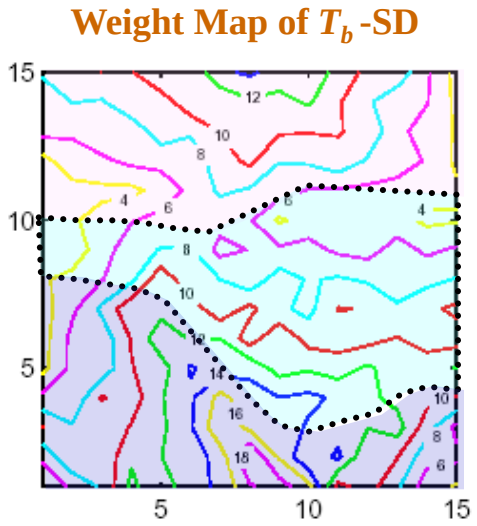


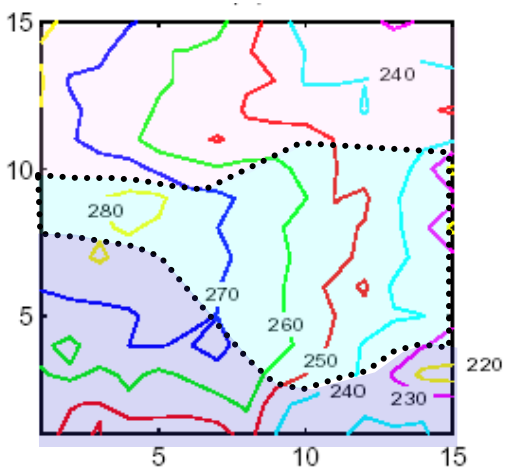
SOFM Classification Map (After Training)

Comparing the rain rate distribution on the output layer with the weight distributions of input variables on the SOFM layer





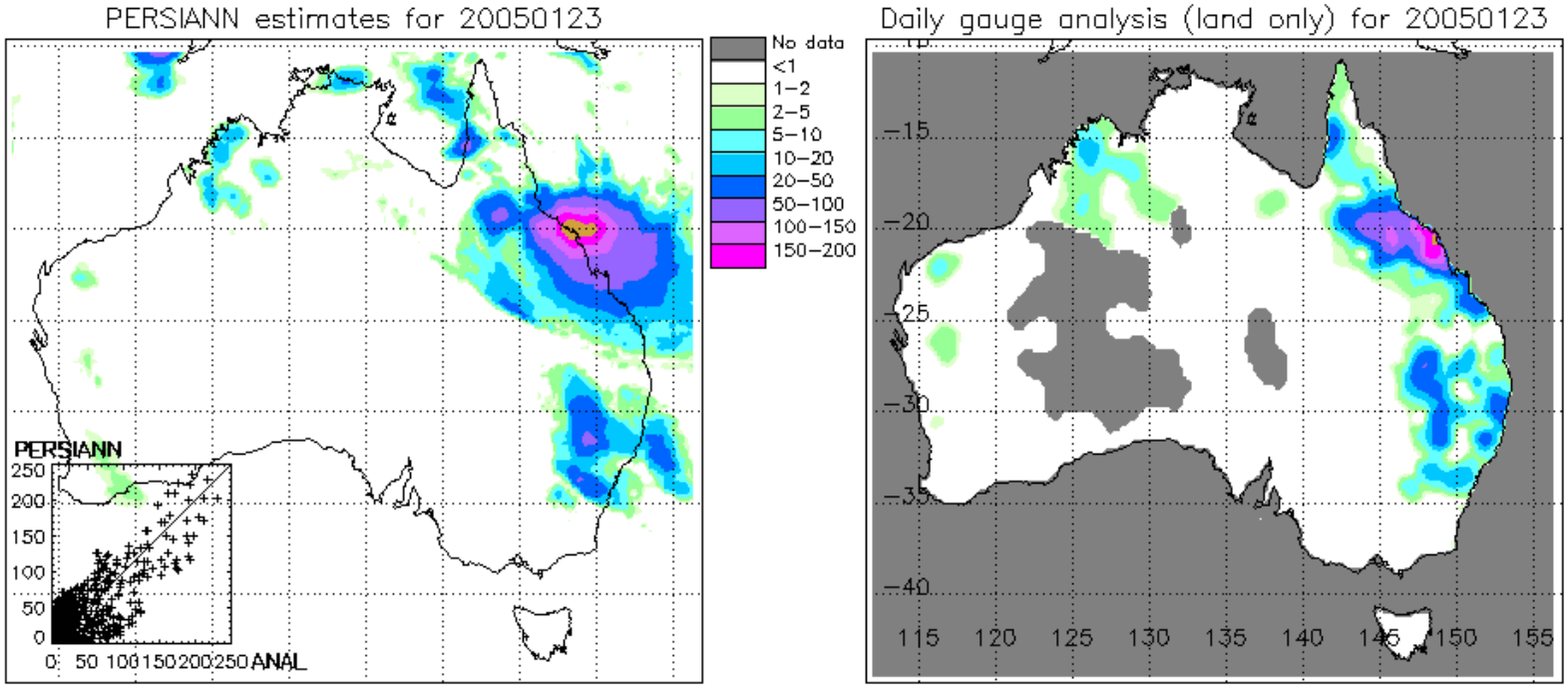


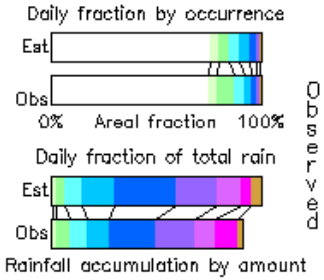


IPGW Validation of Precipitation Measurement (Australia)

http://www.bom.gov.au/bmrc/SatRainVal

Daily Rainfall: January 23, 2005





Observed \ PERSIANN	<1	≥1
<1	6743	653
≥1	735	1704

Verification statistics for 20050123 n=9835 Verif. grid=0.25° Units=mm/d

	Analysed	PERSIANN
# gridpoints raining	2439	2357
Average rain	3.8	4.2
Conditional rain	15.4	17.4
Rain volume (mm*km²x10⁶)	25.8	28.1
Maximum rain	231.5	236.4

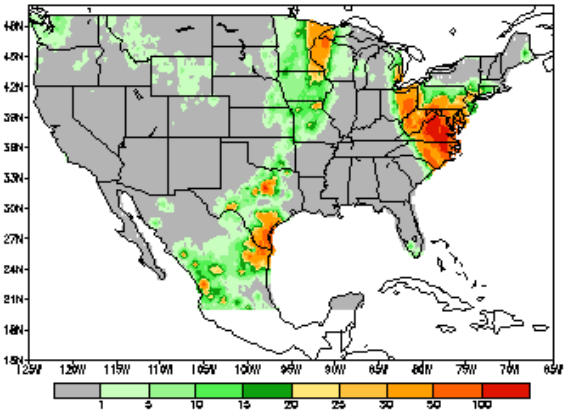
Mean abs error = 3.0
RMS error = 8.6
Correlation coeff = 0.840
Frequency bias = 0.966
Probability of detection = 0.699
False alarm ratio = 0.277
Hanssen & Kuipers score = 0.610
Equitable threat score= 0.446

IPWG Validation of Precipitation (US)

http://cics.umd.edu/ipwg/us_web.html

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

CPC real-time Gauge Analysis



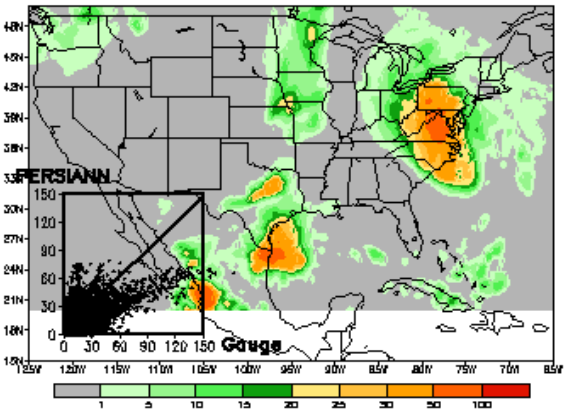
	(G) gauge	(S) PERSIANN	(R) radar
Number of points:	13828.	13828.	13828.
# points w/rain:	4249.	4665.	2971.
Mean rain rate:	5.55	4.25	3.13
Cond. rain rate:	17.82	12.47	14.46
Max. rain rate:	181.99	79.07	131.45

	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

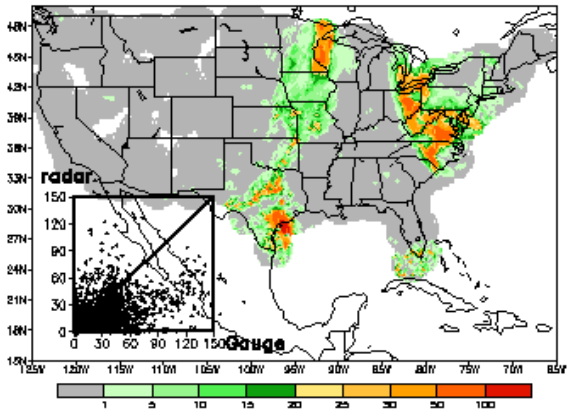
gauge \ PERSIANN	< 1	≥ 1
< 1	8082.	1497.
≥ 1	1081.	3168.

gauge \ radar	< 1	≥ 1
< 1	9386.	193.
≥ 1	1471.	2778.

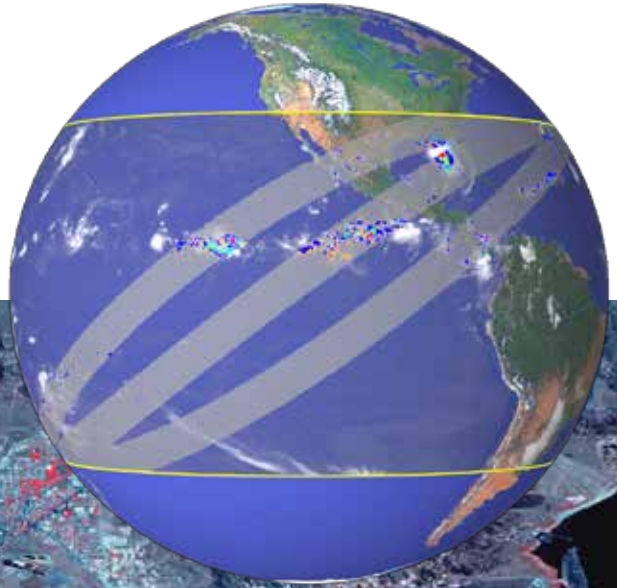
PERSIANN



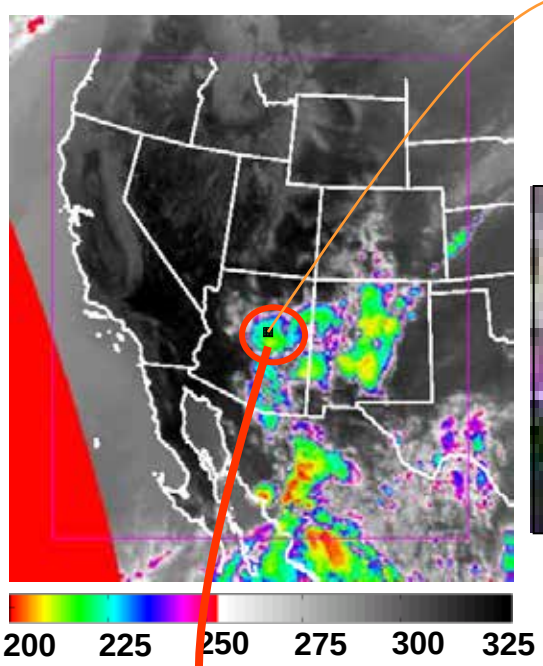
Radar

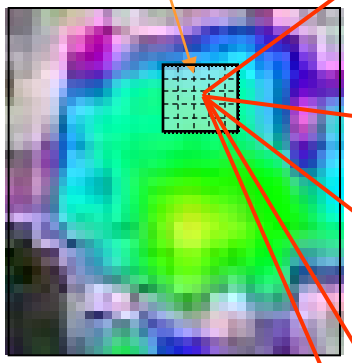


Rainfall Estimation Using Satellite-Based Cloud Classification Maps



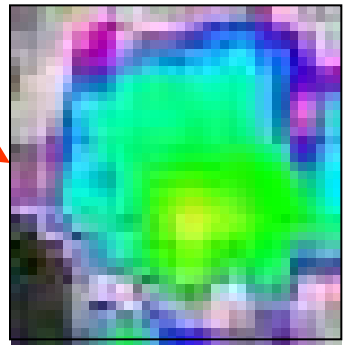
Satellite Image Feature Extraction





Pixel information

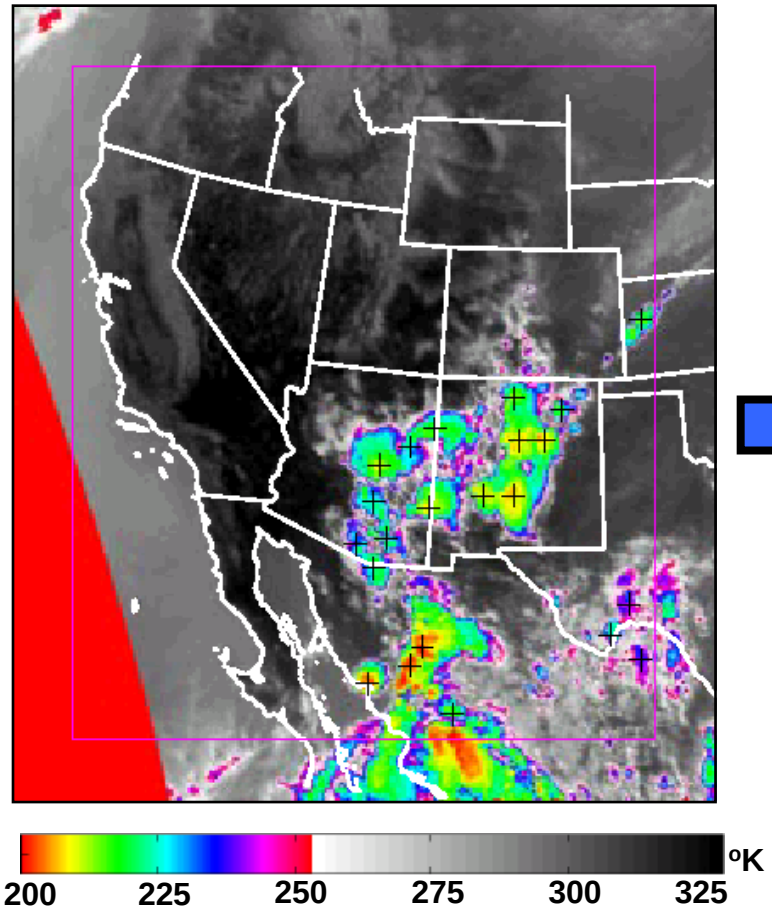
Cloud information



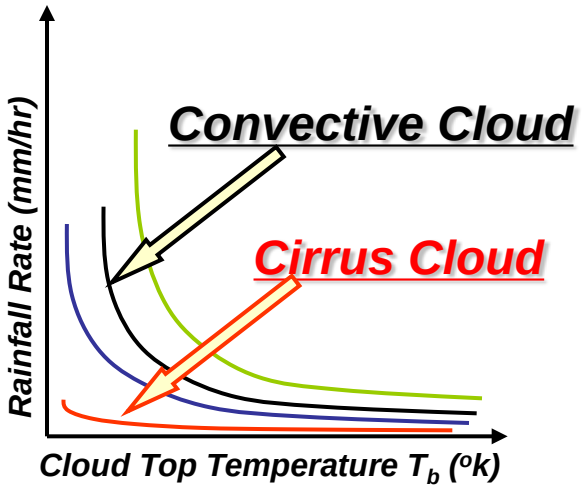
- T_b: IR temperature of calculation pixel
- m_{3x3}: Mean temperature of 3x3 pixels
- s_{3x3}: Standard deviation temperature of 3x3 pixels
- m_{5x5}: Mean temperature of 5x5 pixels
- s_{5x5}: Standard deviation temperature of 5x5 pixels

Cloud Types and Rainfall Distribution

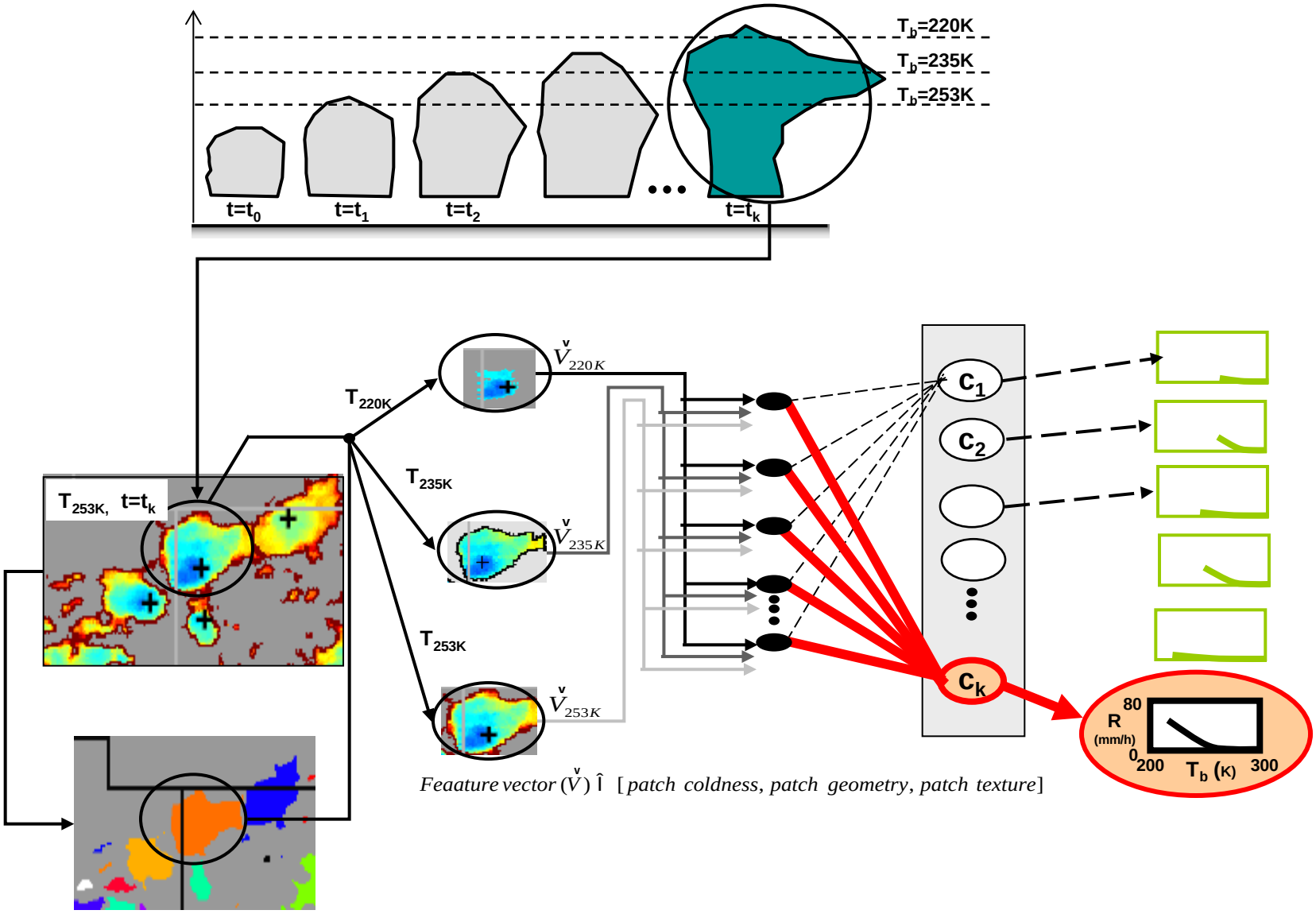
Cloud Type Classification



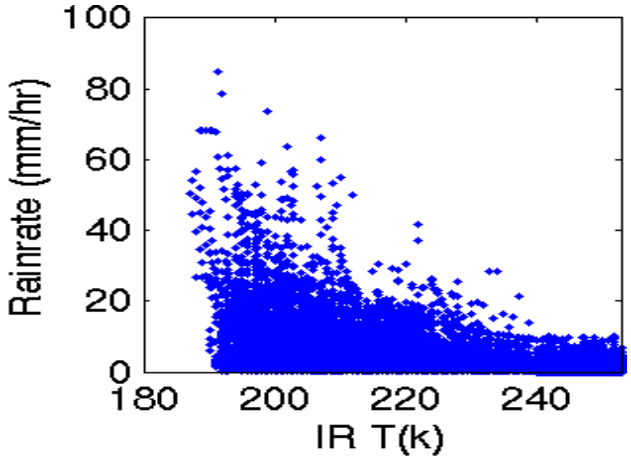
T_b–R relationship

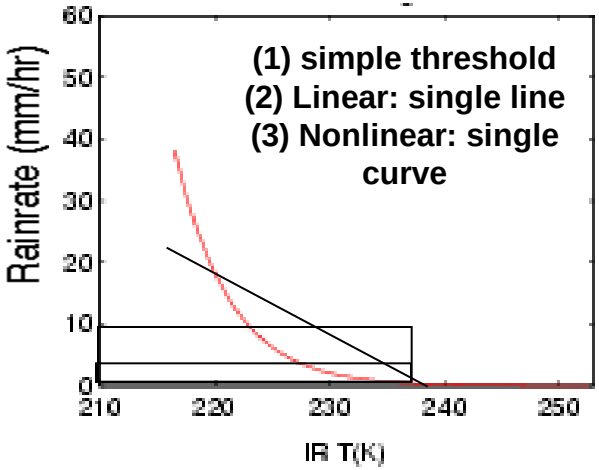


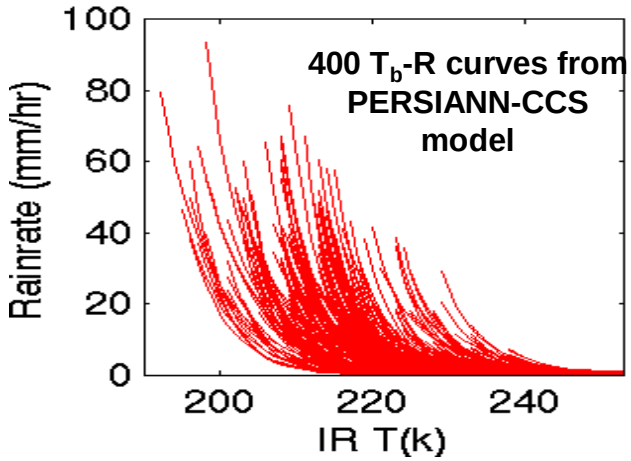
Patch-based Approach (PERSIANN-CCS)



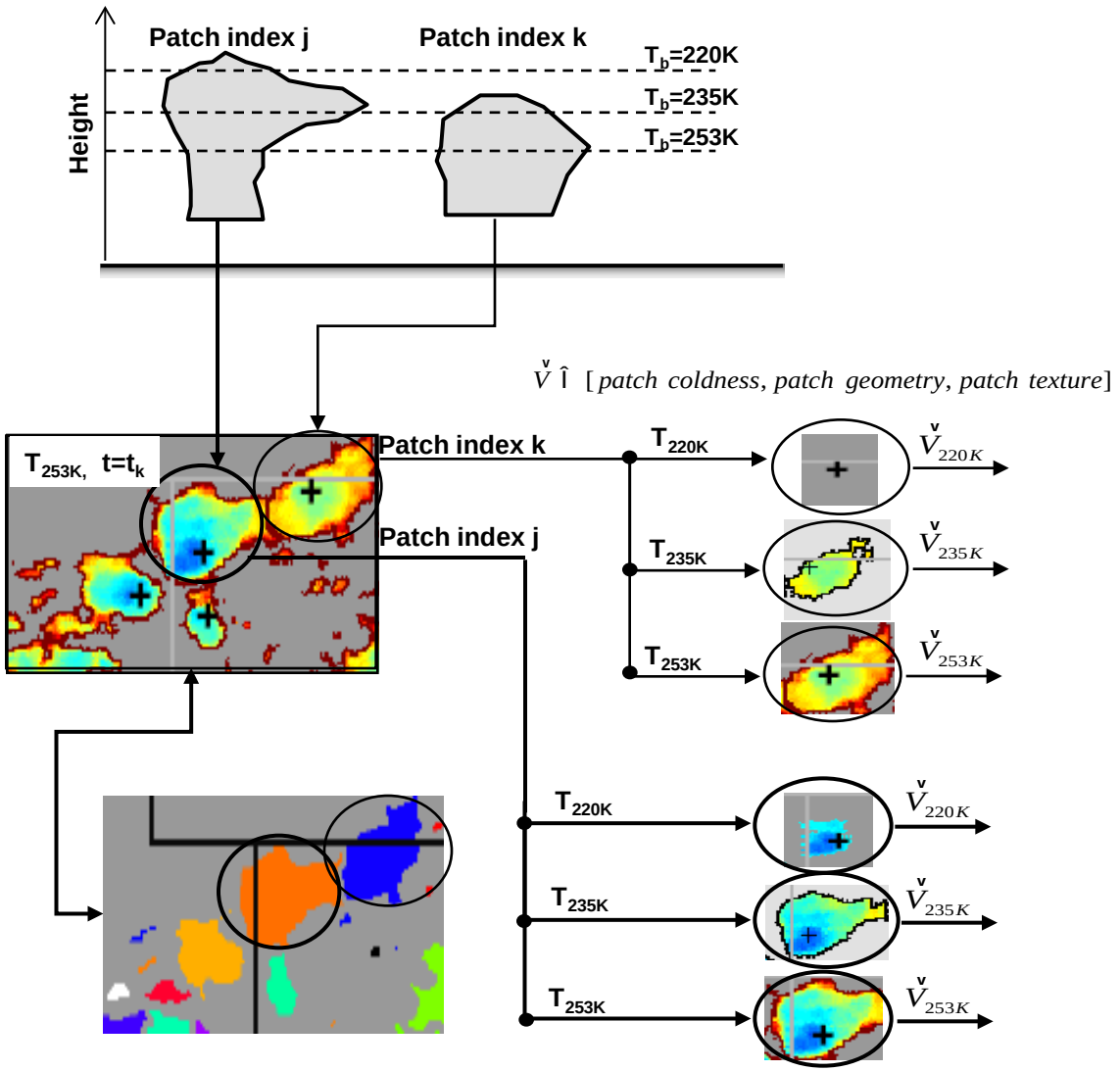
Multiple vs. Single Curve Fitting Models

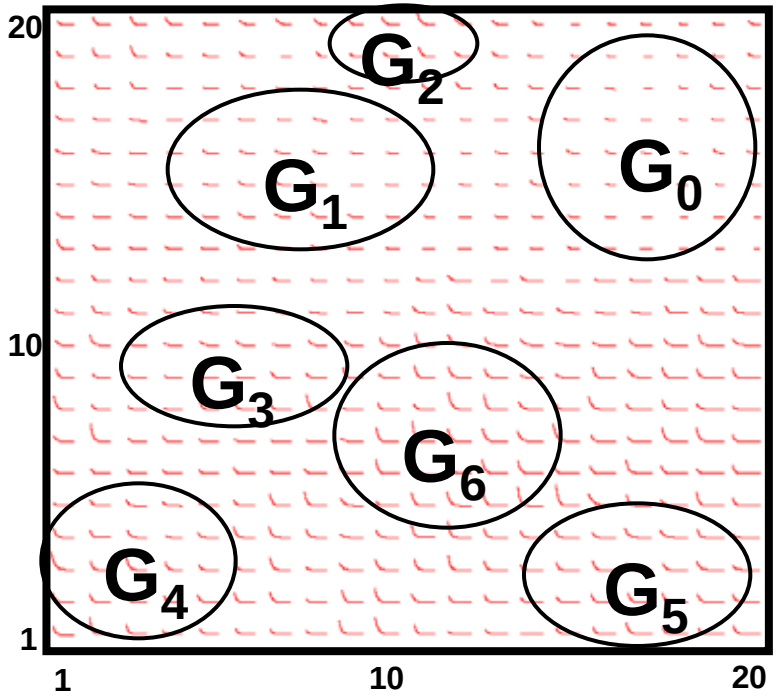


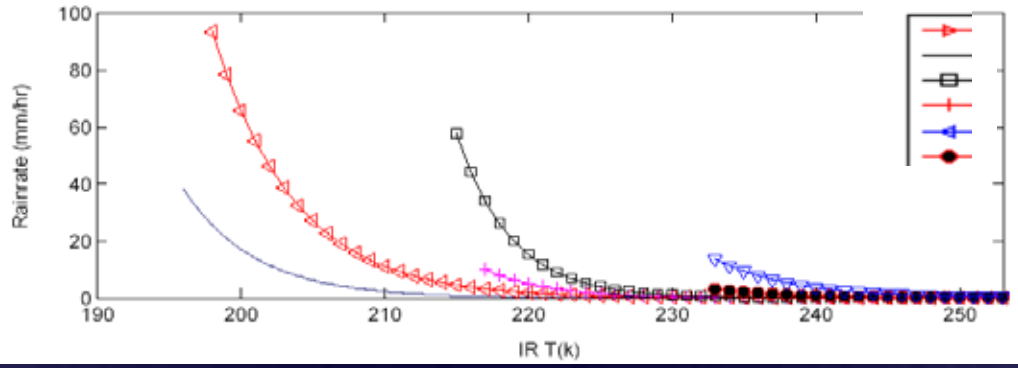




Features Extraction

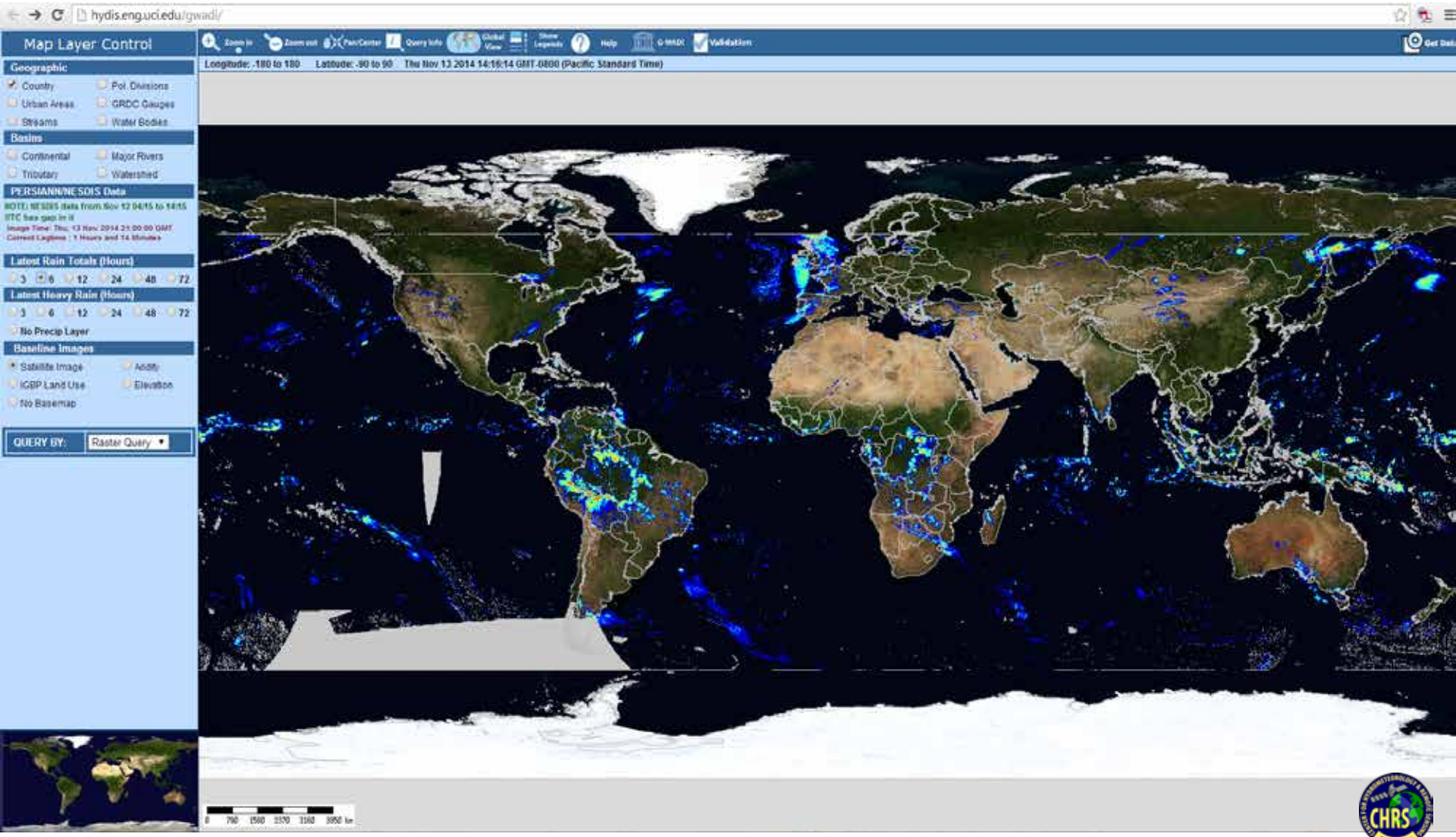



20
10
1
1
10
20
G2
G1
G0
G3
G6
G4
G5

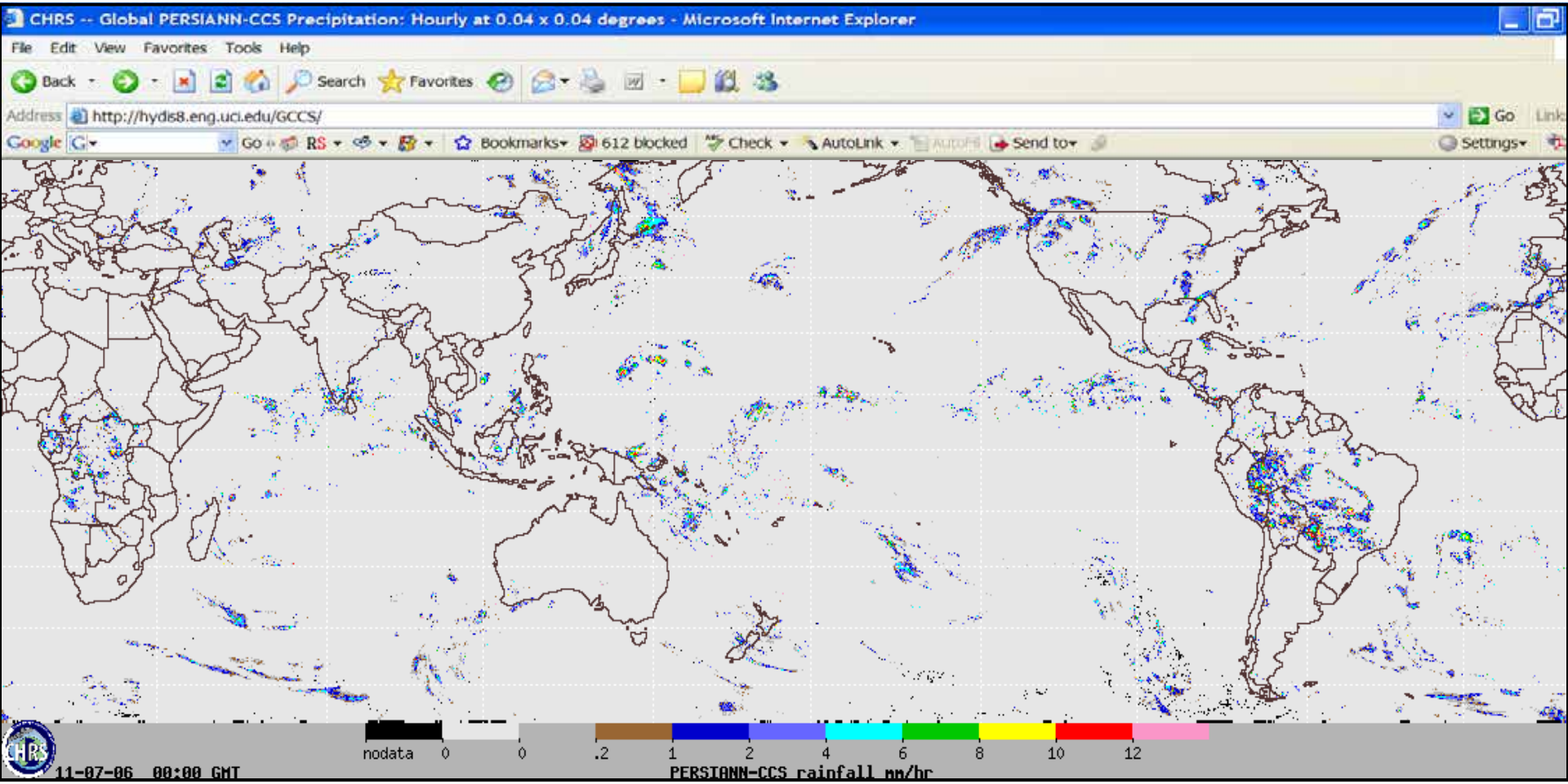

Rainrate (mm/hr)
IR T(k)
0
20
40
60
80
100
190
200
210
220
230
240
250

Near Real Time Global Precipitation Data

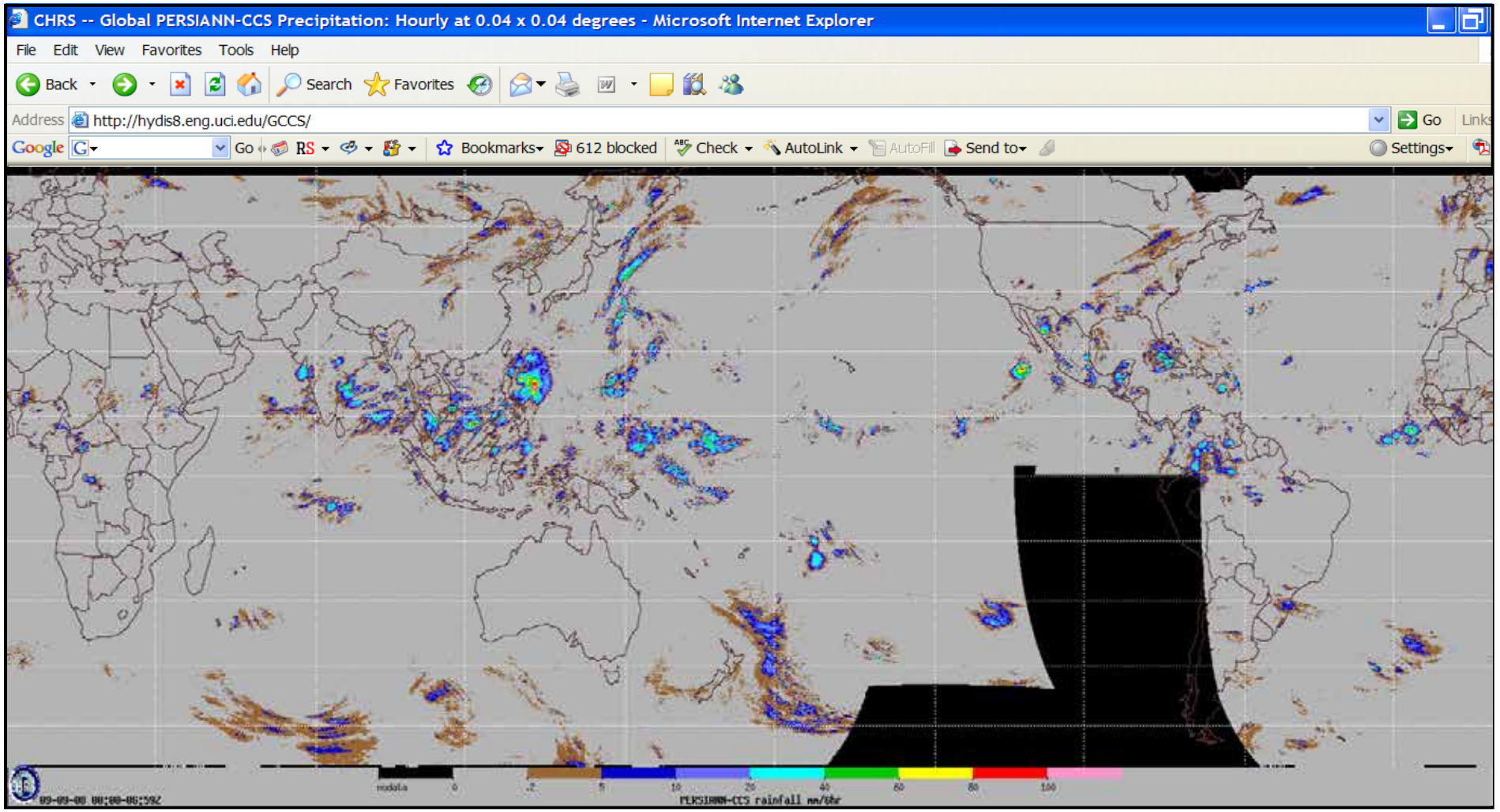
http://hydis.eng.uci.edu/gwadi/



Global PERSAINN-CCS Hourly Estimates



Six-Hour PERSIANN-CCS Rainfall

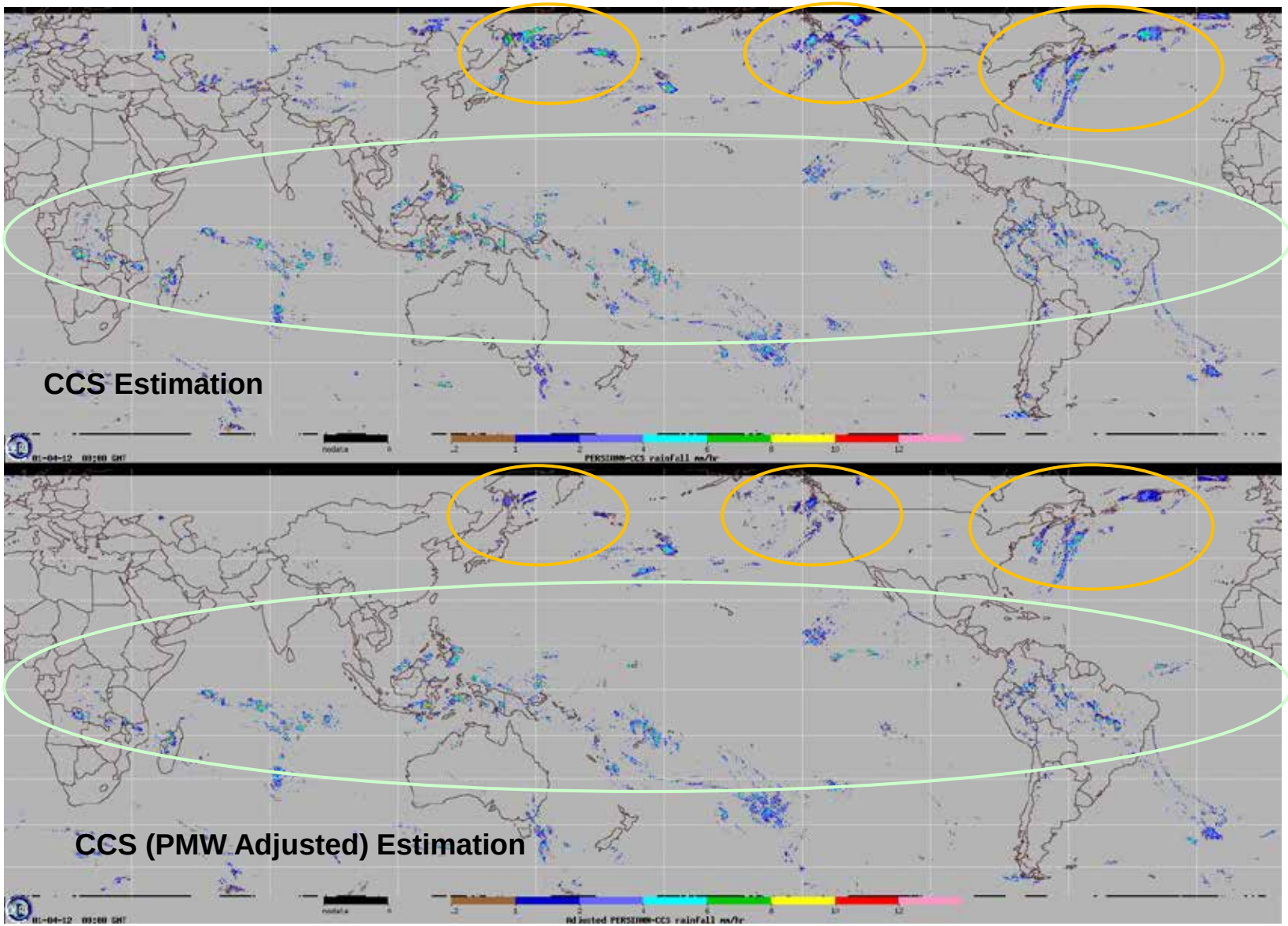


Continue Development

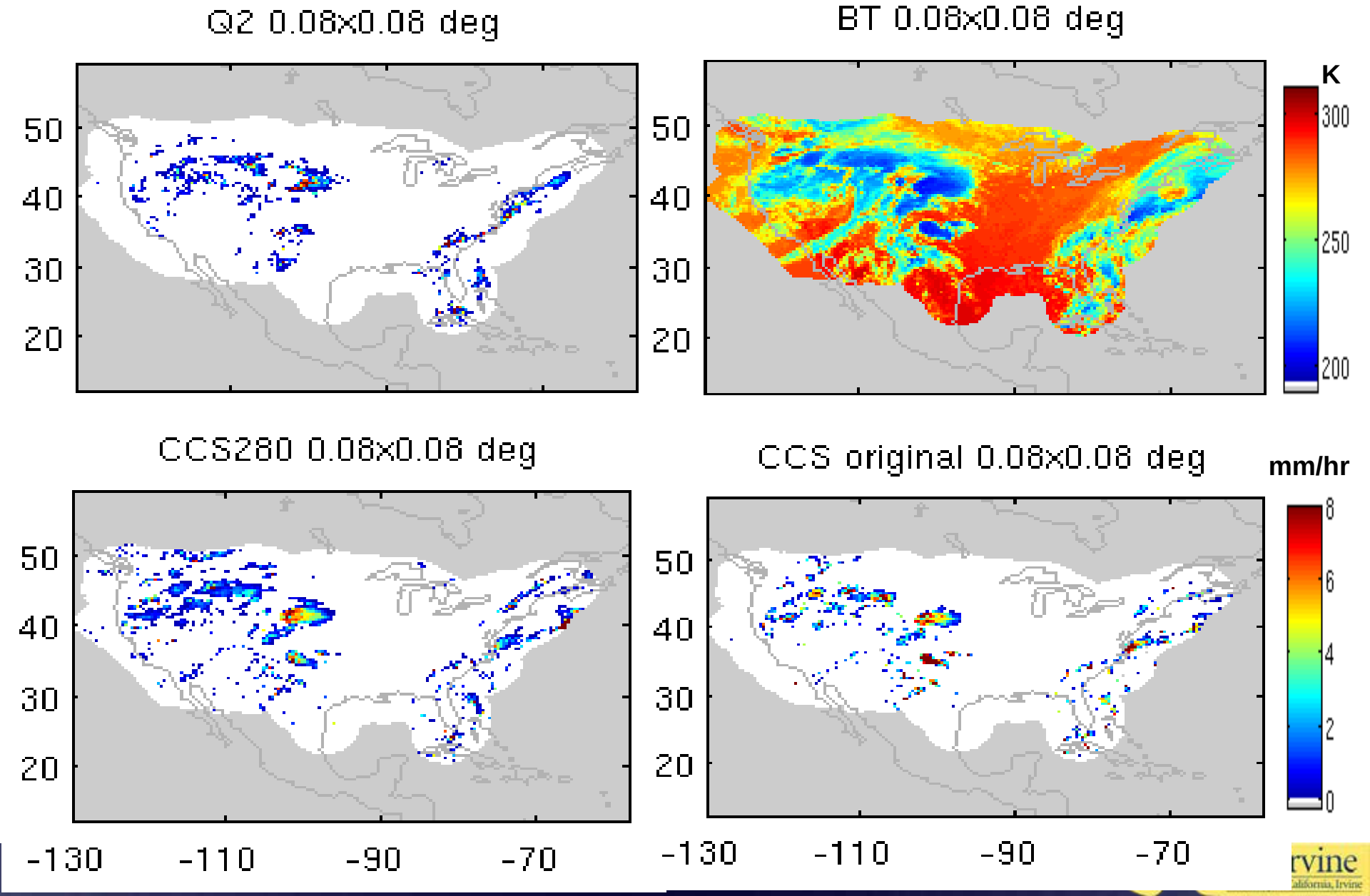
- *Adjust PERSIANN-CCS precipitation estimates using passive microwave rainfall*

- *Improve rain estimation from warm clouds*

PERSIANN-CCS Hourly Estimates: Jan 4, 2012

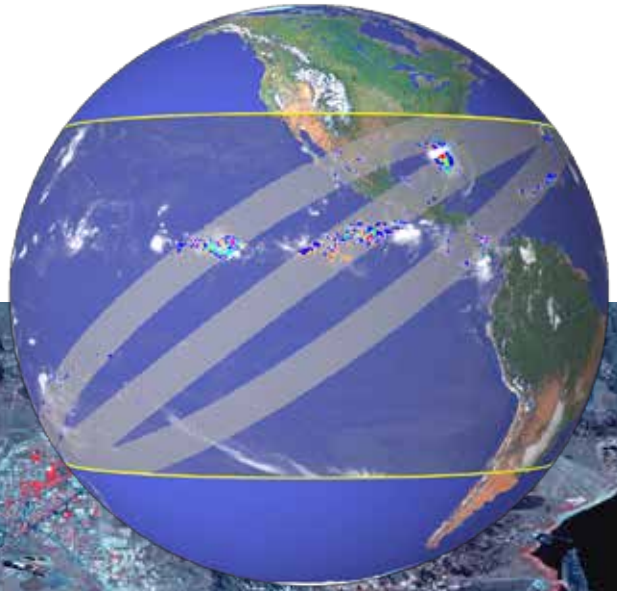


Change Threshold from 253K to 280K



PERSIANN Precipitation Climate Data Record

Reconstruction of 30-year+ Daily Precipitation Data



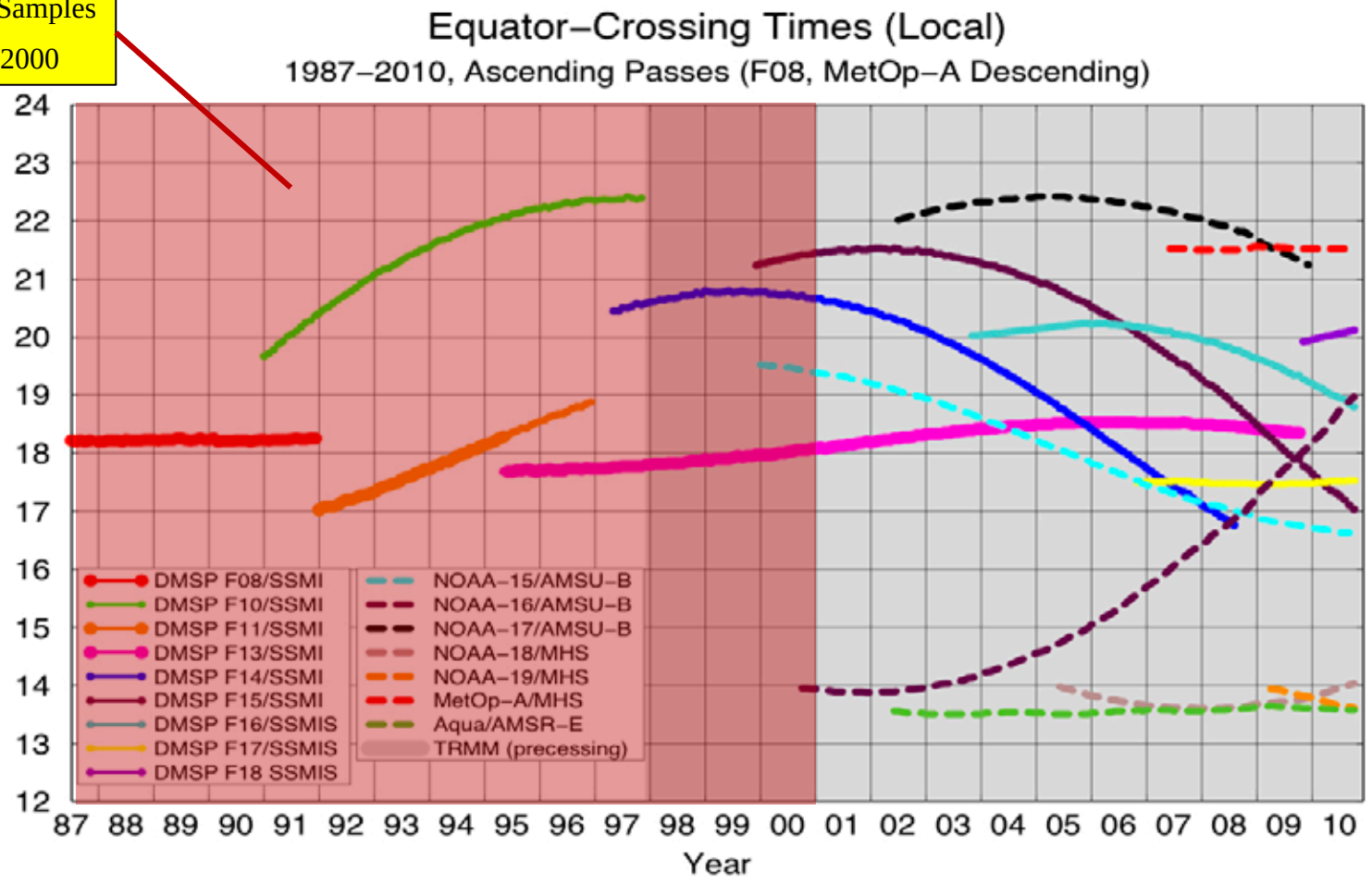
PERSIANN Precipitation Climate Data Record

http://www.ncdc.noaa.gov/cdr/operationalcdrs.html

- *Daily Precipitation Data*
- *Data Period: 1983~2014*
- *Coverage: 60°S ~ 60°N*
- *Spatial Resolution: 0.25°x0.25°*

LEO Satellites for Precipitation Estimation

Limited PMW Samples
Before year 2000

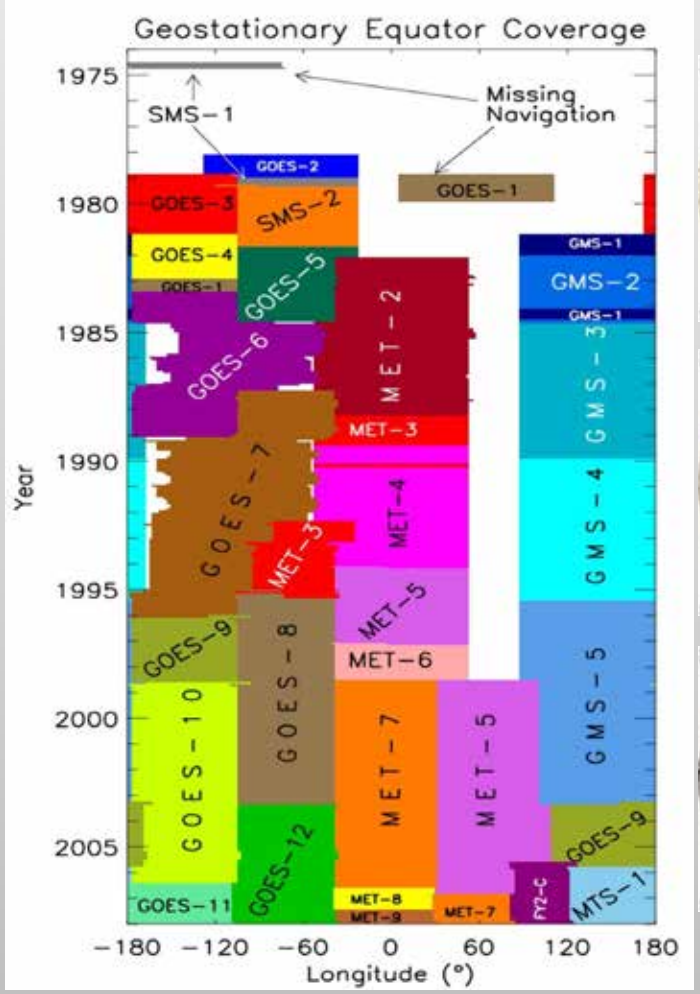


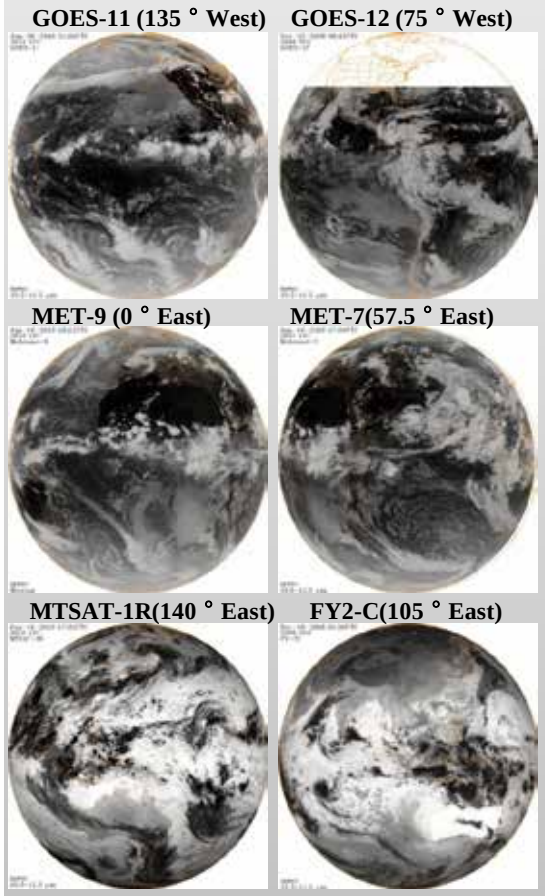
Thickest lines denote GPCP calibrator.

Image by Eric Nelkin (SSAI), 20 October 2010, NASA/Goddard Space Flight Center, Greenbelt, MD.

Historical GEO Satellite Data

- **International Satellite Cloud Climatology Project (ISCCP)**
  1979 to present
  10-km and 3-hour intervals





1. U.S. Geostationary Operational Environmental Satellite (GOES)

2. European Meteorological satellite (Meteosat) series

3. Japanese Geostationary Meteorological Satellite (GMS)

4. The Chinese Fen-yung 2C (FY2) series.

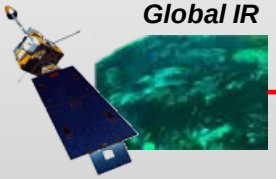
Source: NOAA NCDC

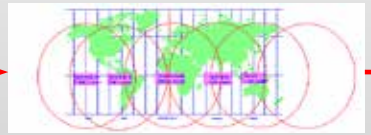
Bias Adjustment of PERSIANN Estimates

PERSIANN structure in a simple scheme

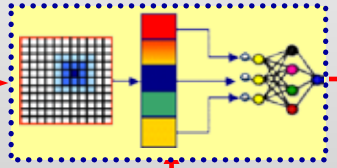
Satellite Data

Global IR



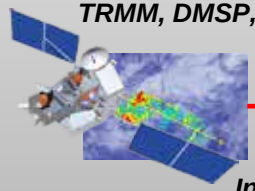


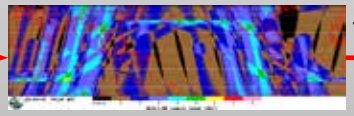
High Temporal-Spatial Res. Cloud Infrared Images



Feedback

TRMM, DMSP, NOAA Satellites





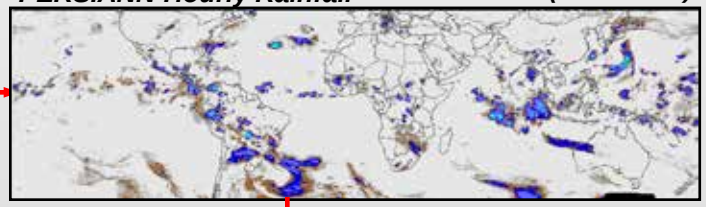
Sampling

Instantaneous PMW Rain Estimates

Parameter Adjustment

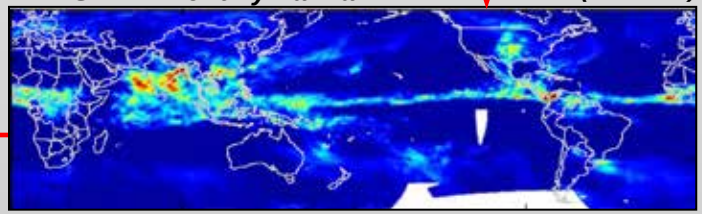
Products

PERSIANN Hourly Rainfall (0.25°x0.25°)



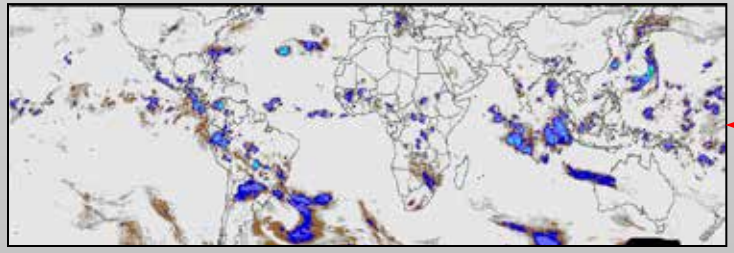
Tempo-Spatial Accumulation

PERSIANN Monthly Rainfall (2.5°x2.5°)



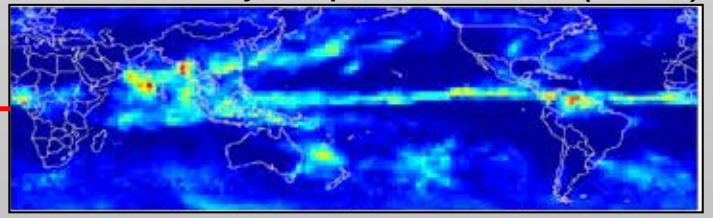
PERSIANN Adjusted (Monthly Scale)

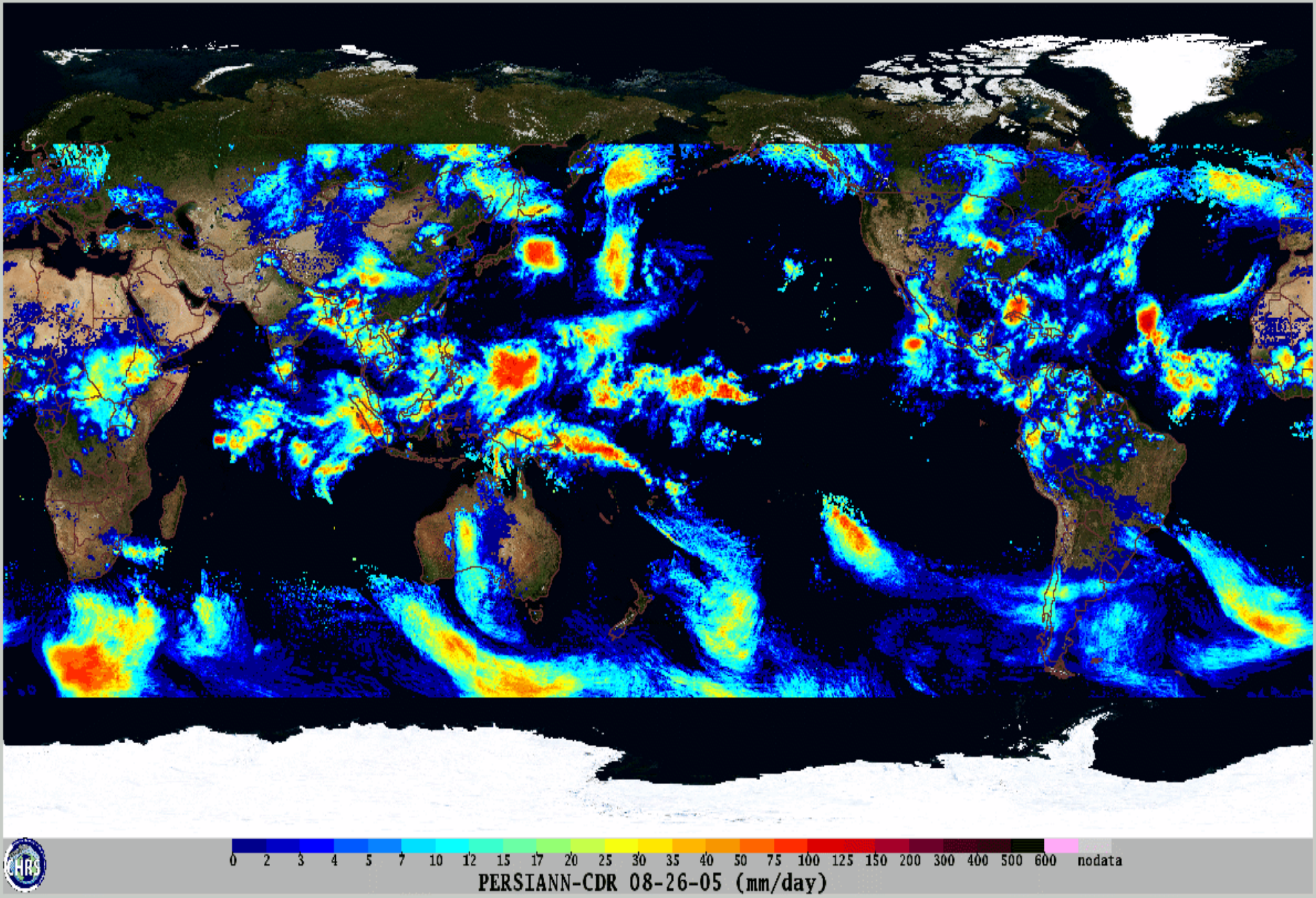
Adjusted PERSIANN Hourly Rainfall (0.25°x0.25°)



Bias Adjustment

GPCP Monthly Precipitation (2.5°x2.5°)

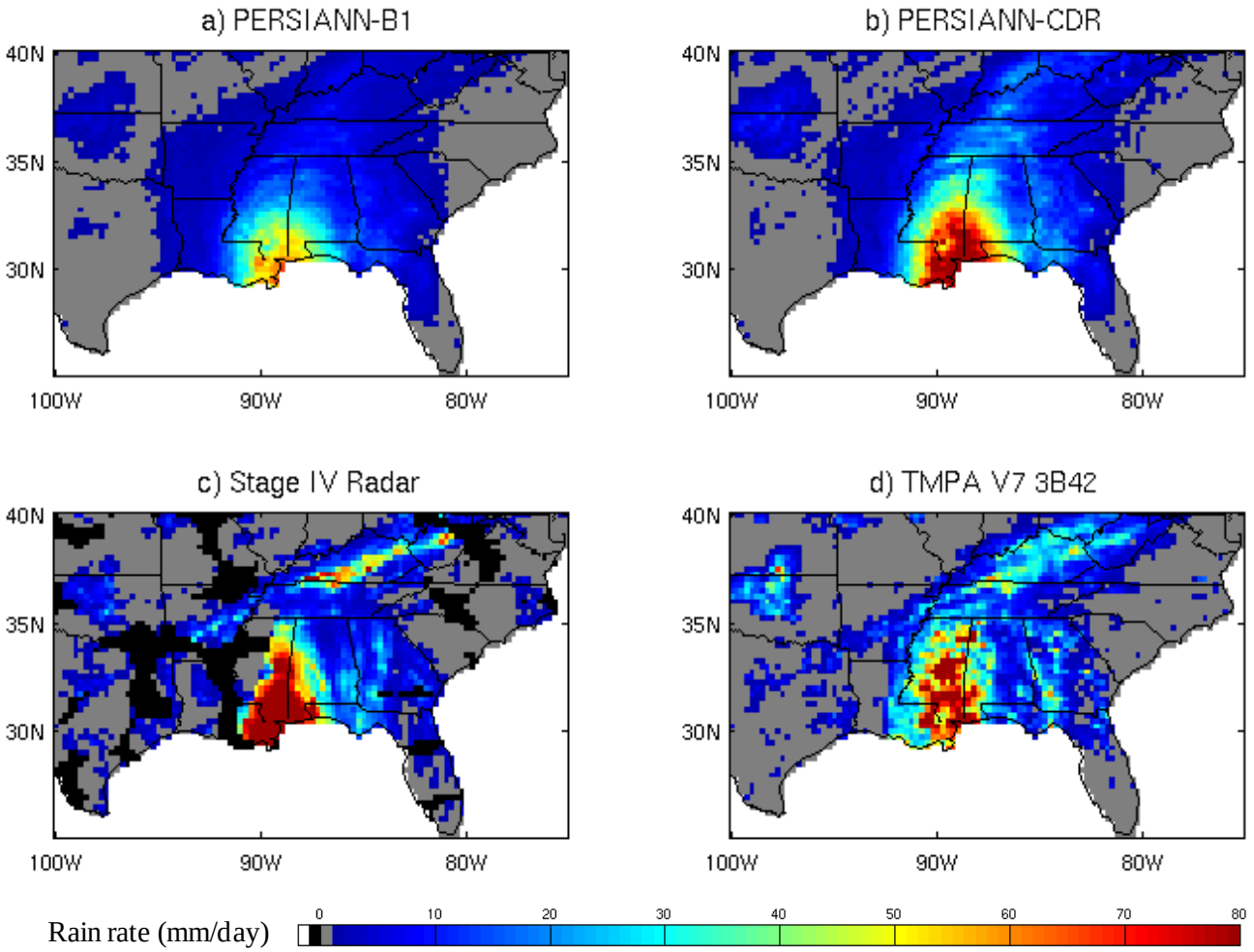



0 2 3 4 5 7 10 12 15 17 20 25 30 35 40 50 75 100 125 150 200 300 400 500 600 nodata
PERSIANN-CDR 08-26-05 (mm/day)

Daily Precipitation: Hurricane Katrina, 2005

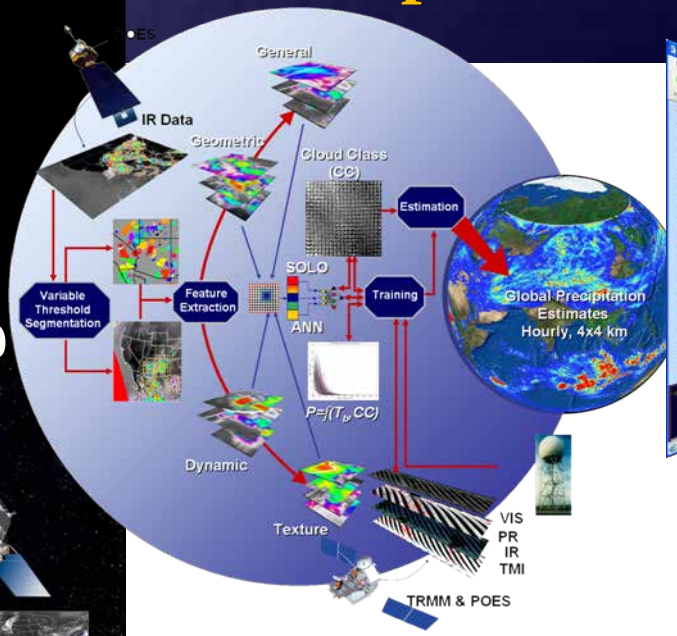
PERSIANN w/o GPCP adjustment

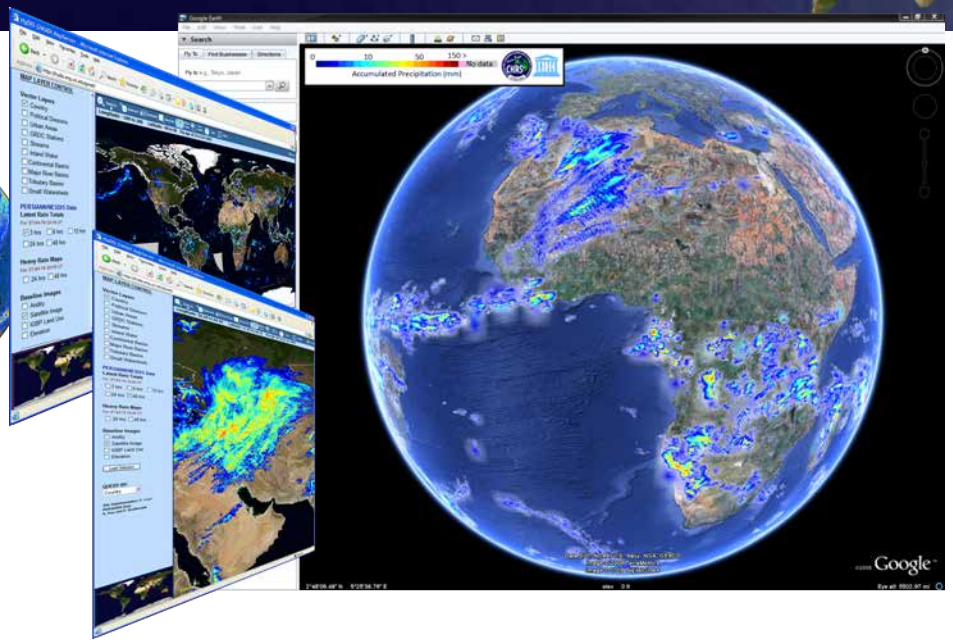
PERSIANN w/o GPCP adjustment



Satellite Precipitation Data for Hydrologic Applications

Algorithm





Web Services

Applications

Drought Management

Flood Forecasting

Water Resources

CHRS UCIrvine

UCIrvine University of California, Irvine

Summary

Advantages of GEO-based precipitation retrieval:

- ***Good space and time resolution***
- ***Observations in near real time***
- ***Near global coverage***

Improve IR-based estimation by:

- ***Extending from pixel to texture based classification***
- ***Extending from single IR band to multi-spectral bands***
- ***Integrating information with LEO satellite PMW measurements***
- ***Merging estimation with ground measurements***
- ***Applying advanced machine learning methods to learn cloud-rain system***

Thanks !!