6th Workshop on Water Resources in Developing Countries: Hydroclimate Modeling, Information Tools and Simulation Techniques
May 20-31, 2024

Satellite precipitation estimation at CHRS UCI: Algorithm Development & Challenges

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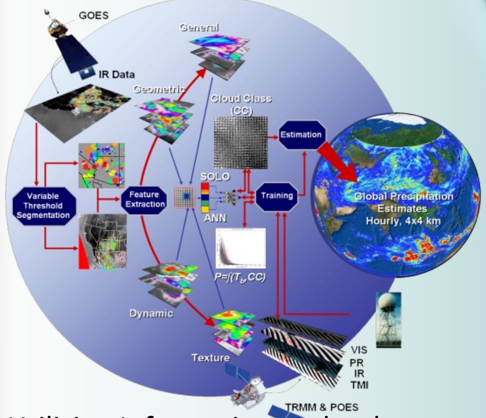
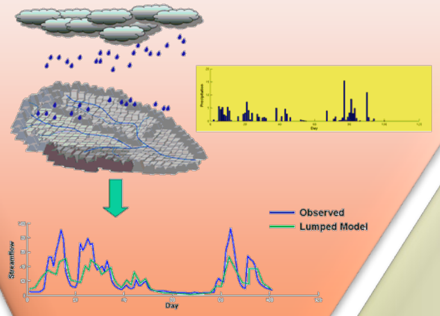
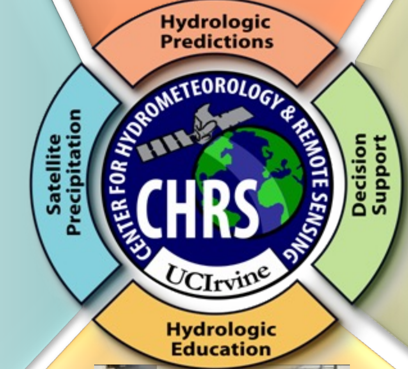
Develop state-of-the-art systems to estimate rainfall from satellite observations at global scale and high spatial and temporal resolutions



Utilizing Information Technology to provide world-wide access to real-time global precipitation products: http://hydis.eng.uci.edu/gwadi/

Improve the performance and reliability of hydrologic, flood, and water supply forecasting models, particularly those used by the National Weather Service and other operational agencies.



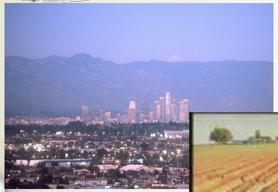


Improve California's water supply management through:

- Forecast system (CaliForecast)
- Improved decision optimization

Nearly 70% of our supply is in Northern half

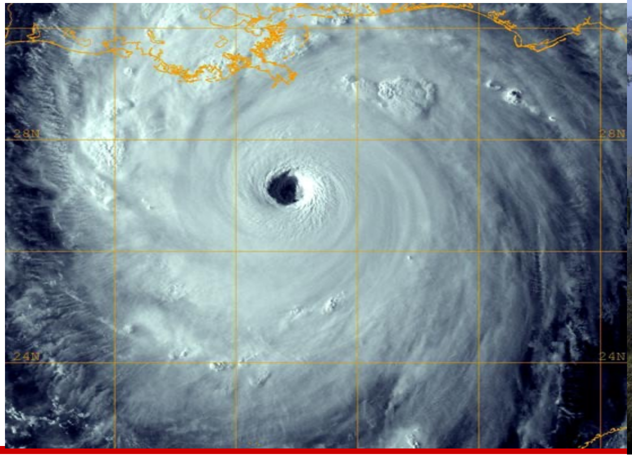
Almost 75% of our demand is in the Southern half



Prepare the next generation of hydrologists and water resources engineers

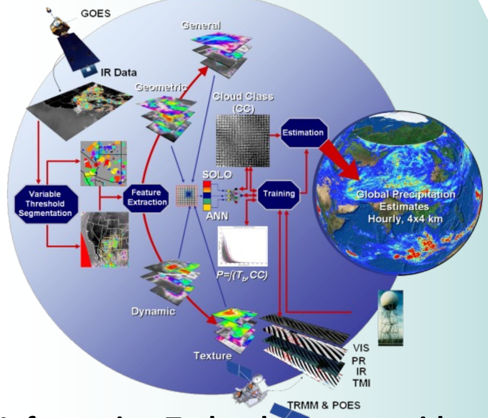
Floods caused by extreme precipitation are the most widespread nature disasters

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

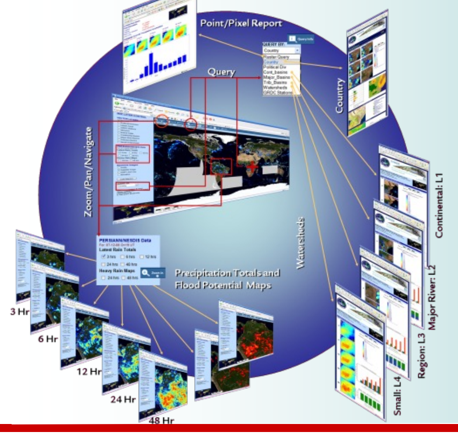


Remote Sensing Precipitation

Develop state-of-the-art systems to estimate rainfall from satellite observations at global scale and high spatial and temporal resolutions



Information Technology to provide world-wide access to real-time global precipitation products: http://hydis.eng.uci.edu/gwadi/



Goal:

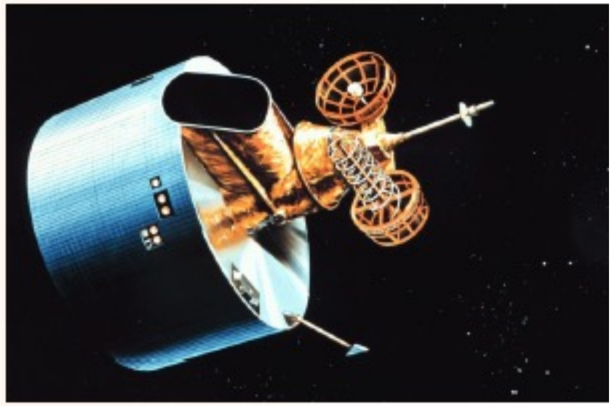
High spatial and temporal resolution of precipitation measurements at global scale for hydrological applications:

- Short-term operational applications
  - Flood forecasting
  - Data assimilation in numerical weather models
- Long-term climate extreme event analysis
- Hydro-climate studies
- Validation of GCM models

Precipitation Observation

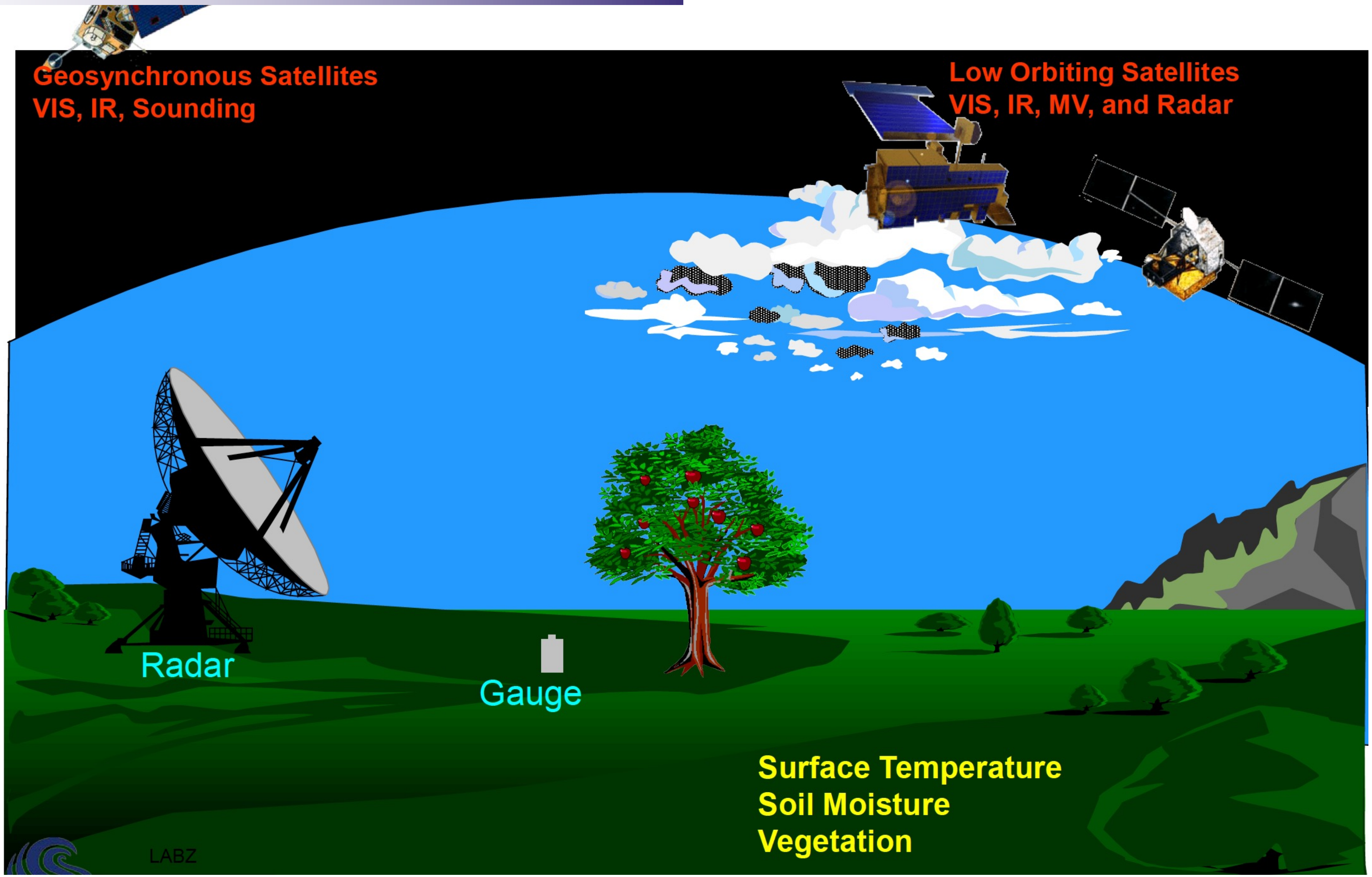
Rain Gauges

WSR-88D Radar

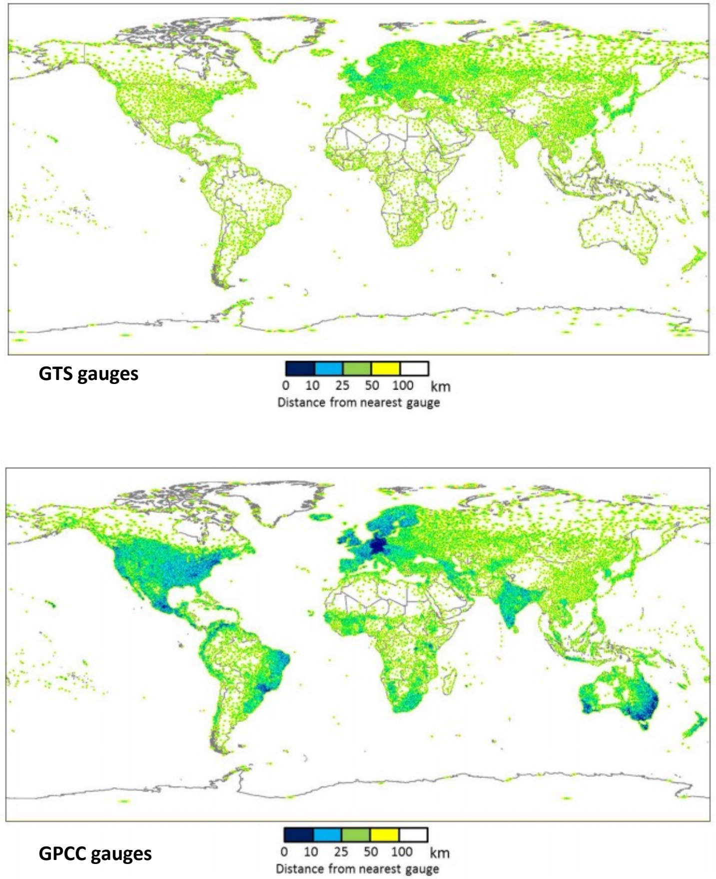


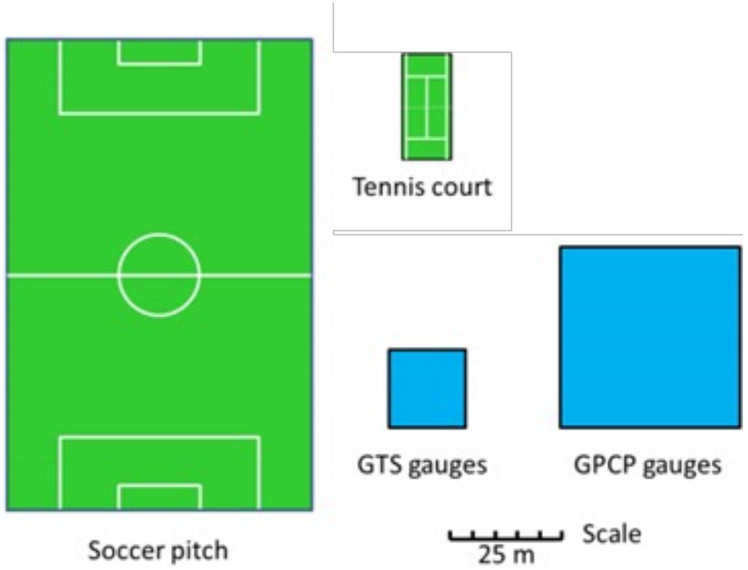
Satellite

Multiple Sources for Rainfall Estimation



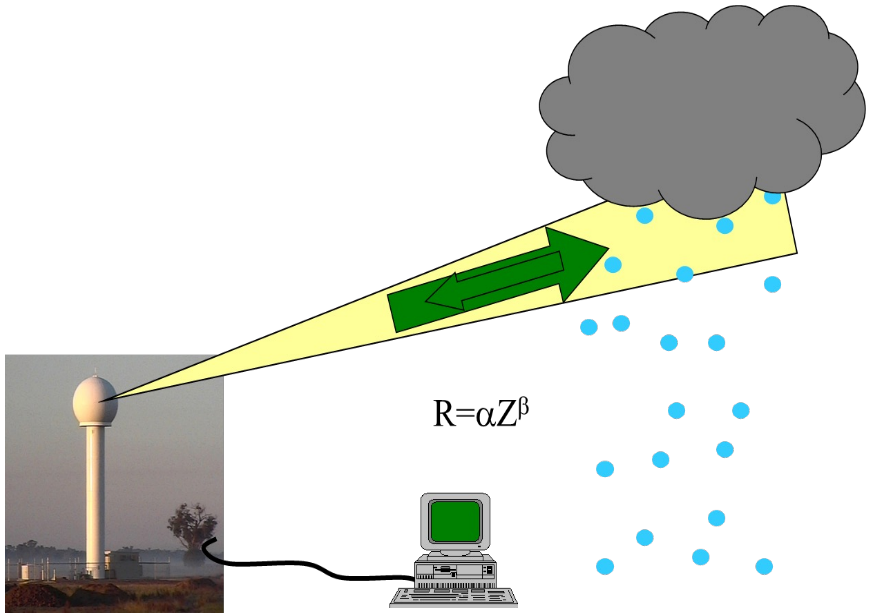
Precipitation Observation



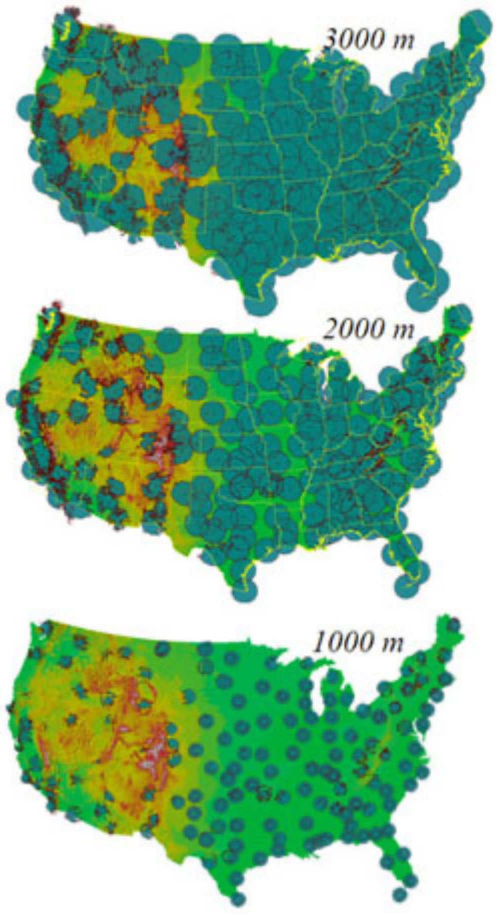


Source: Kidd et al. 2016

Precipitation Observation



Source: Walker and Western

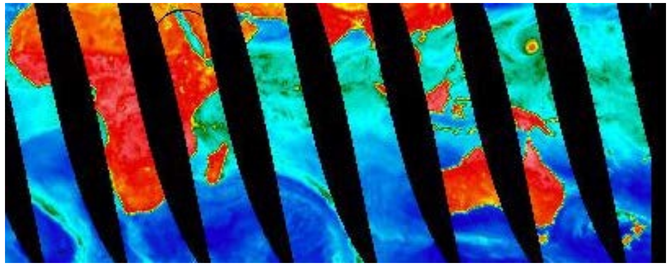


NEXRAD Radar coverage

Satellite Precipitation Monitoring

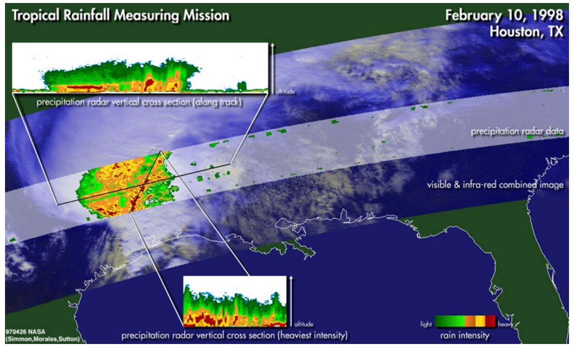
Meteosat 7 (EUMETSAT)

Geostationary IR
Cloud top heights only
15-30 minute data



SSMI 85GHz (DMSP)

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

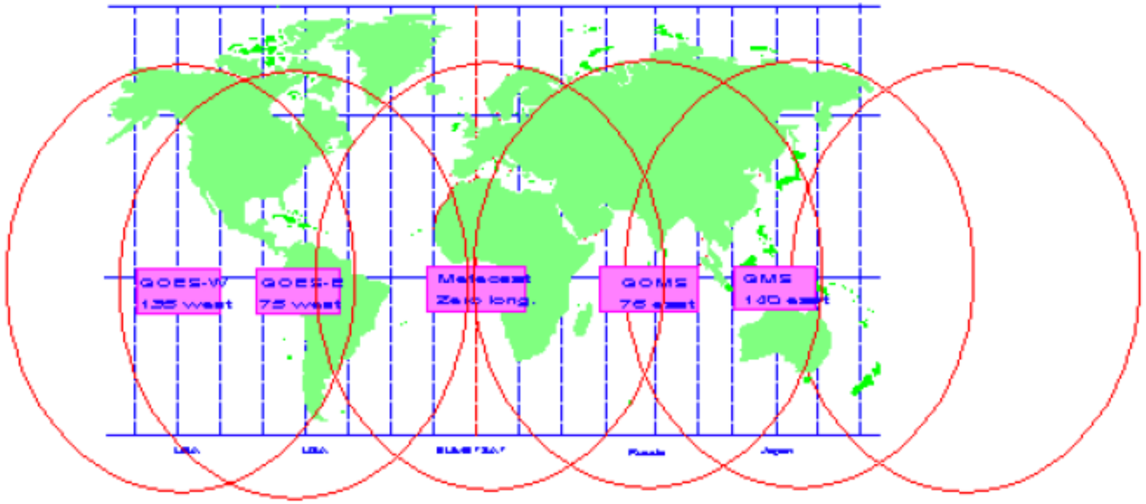


TRMM precipitation RADAR
3D imaging of rainfall
1-2 days between overpasses
(35°N-35°S only)

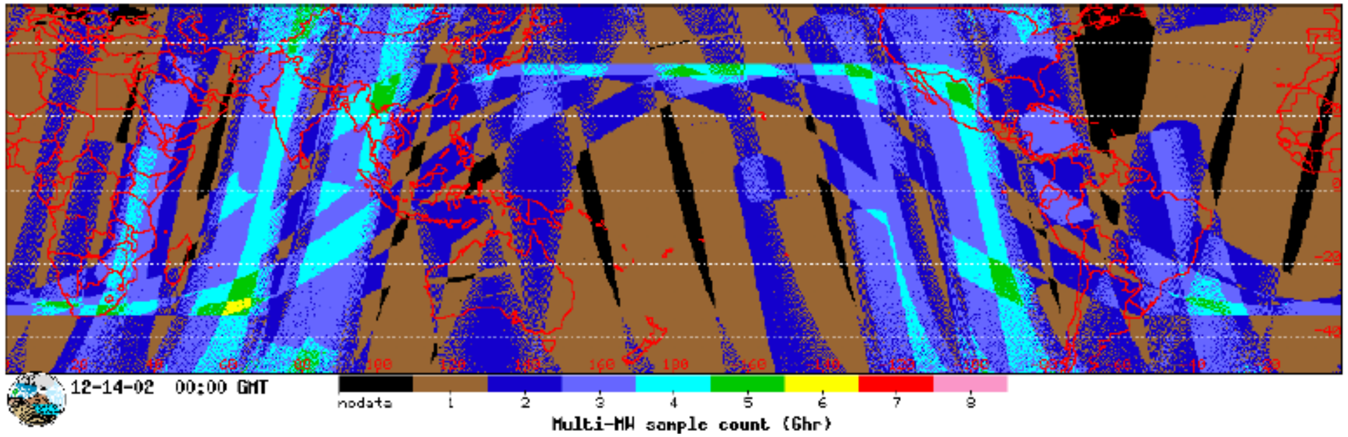
TRMM)

Observations from Satellites

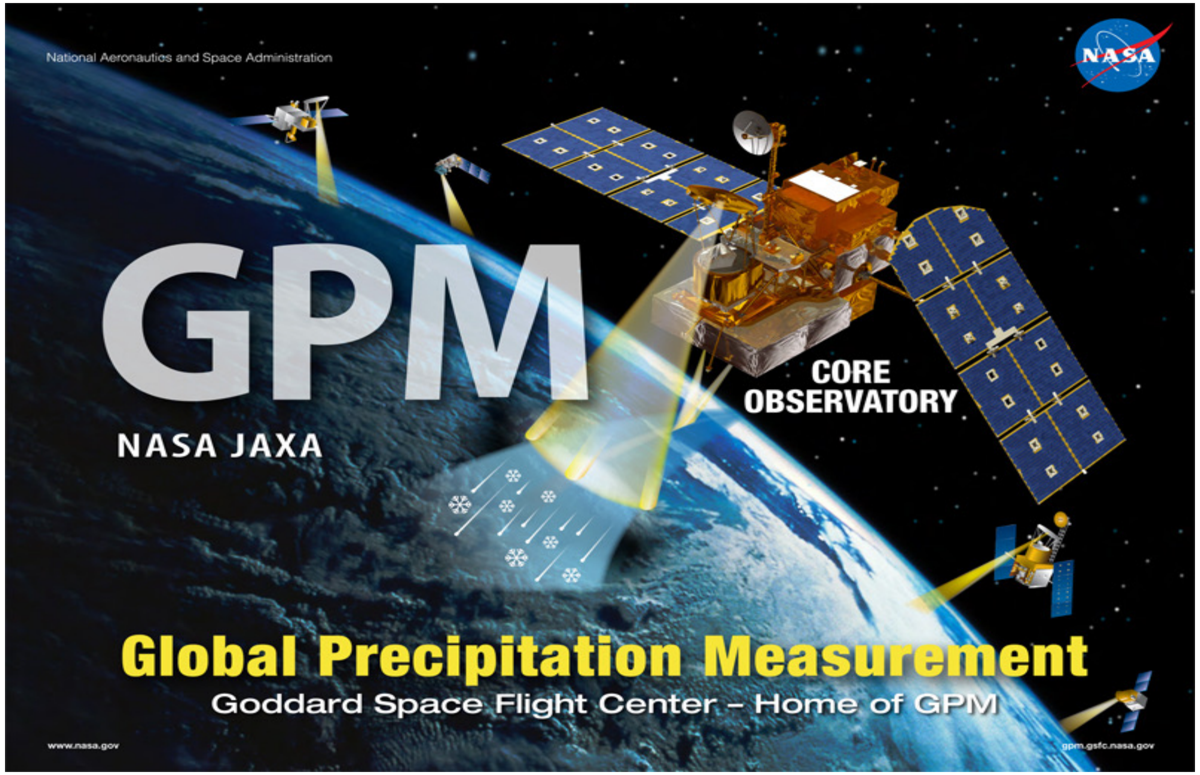
GOES GMS METEOSAT (30-minute Coverage)



TRMM, NOAA-15, -16, -17, DMSP F-13, F-14, F-15 (Six-Hour Sample Counts)



Global Precipitation Measurement (GPM)

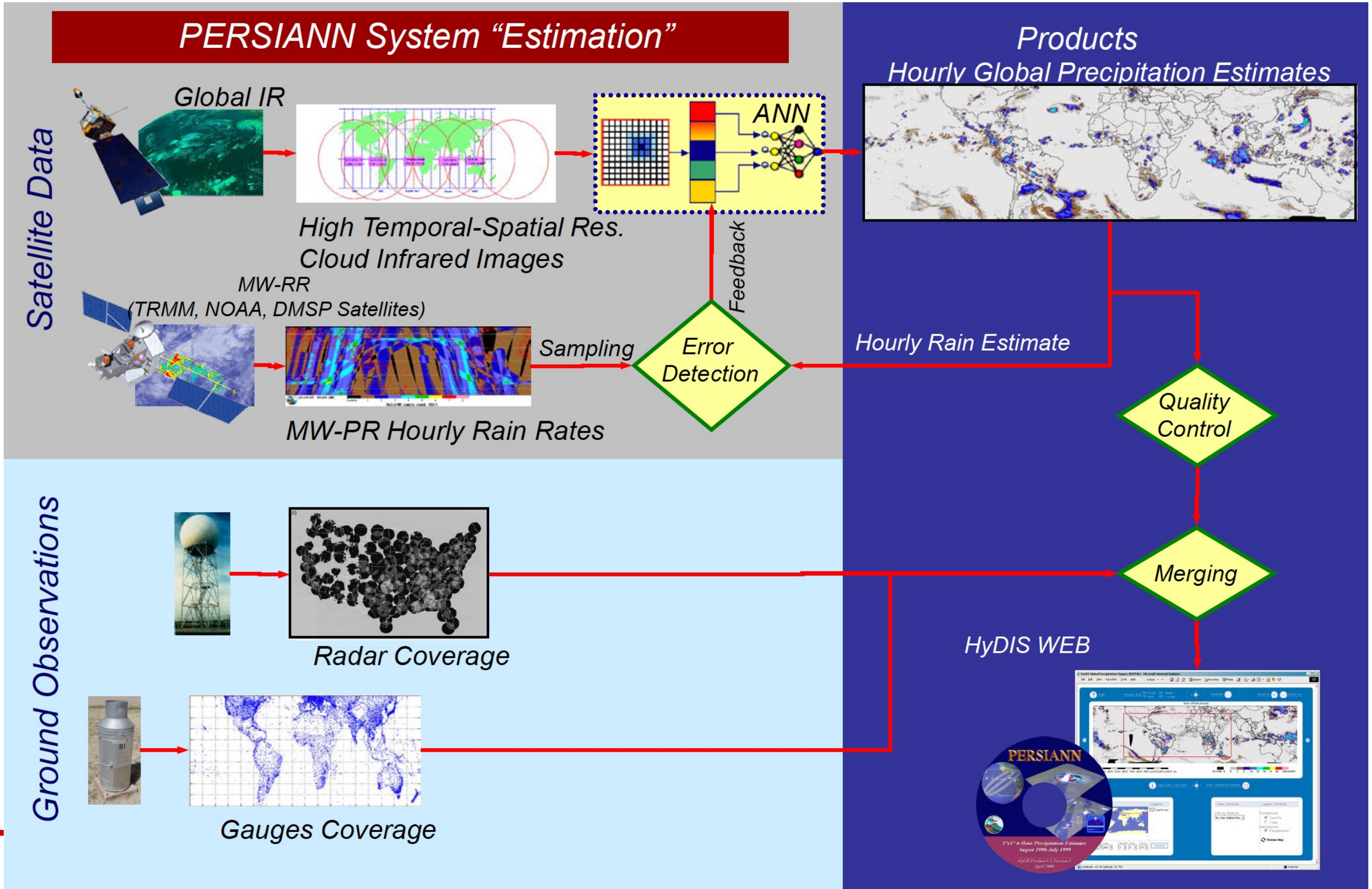


The GPM spacecraft collects information that unifies data from an international network of existing and future satellites to map global rainfall and snowfall every three hours.

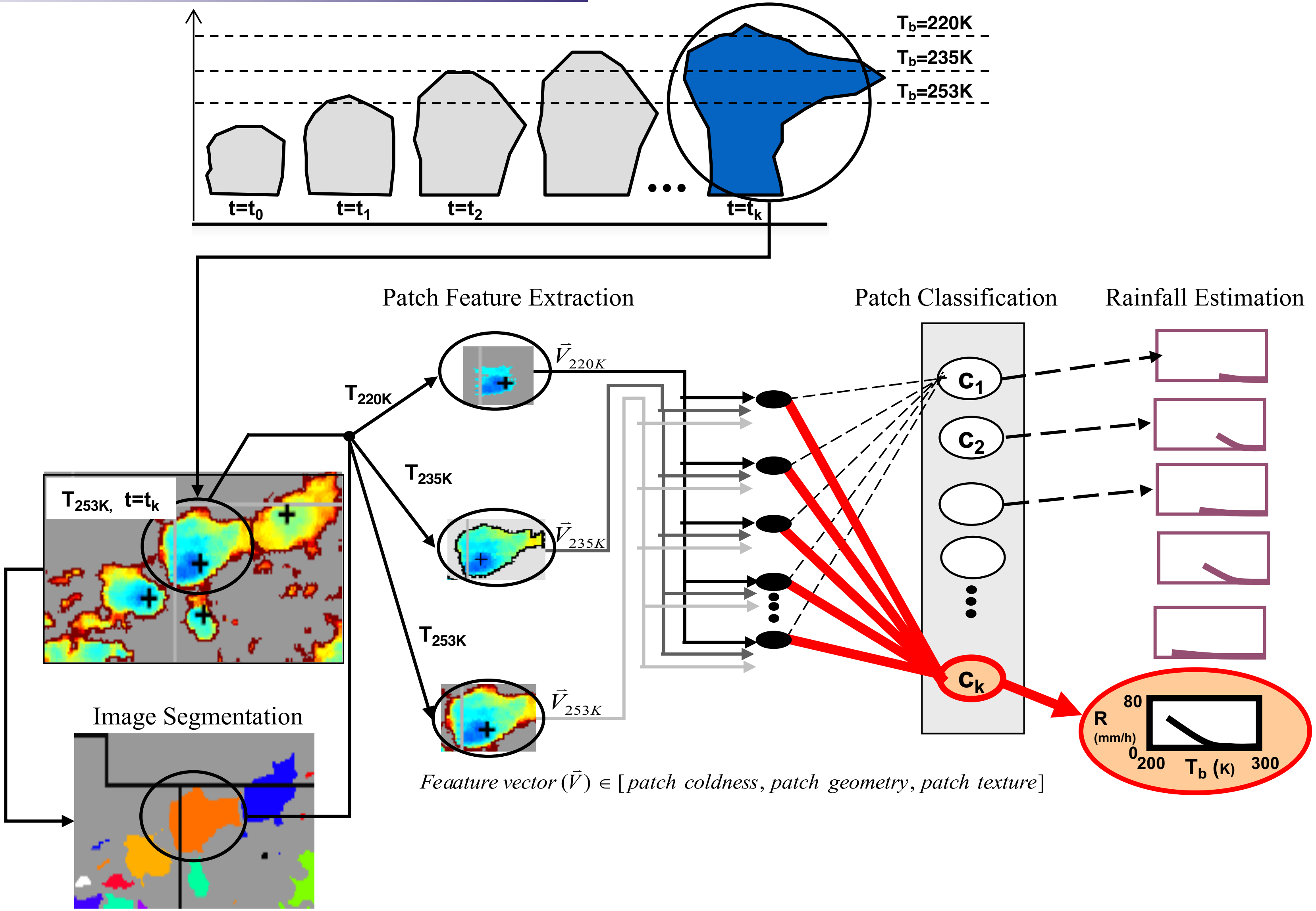
Tanegashima Space Center, Japan

Friday, Feb. 28, 2014

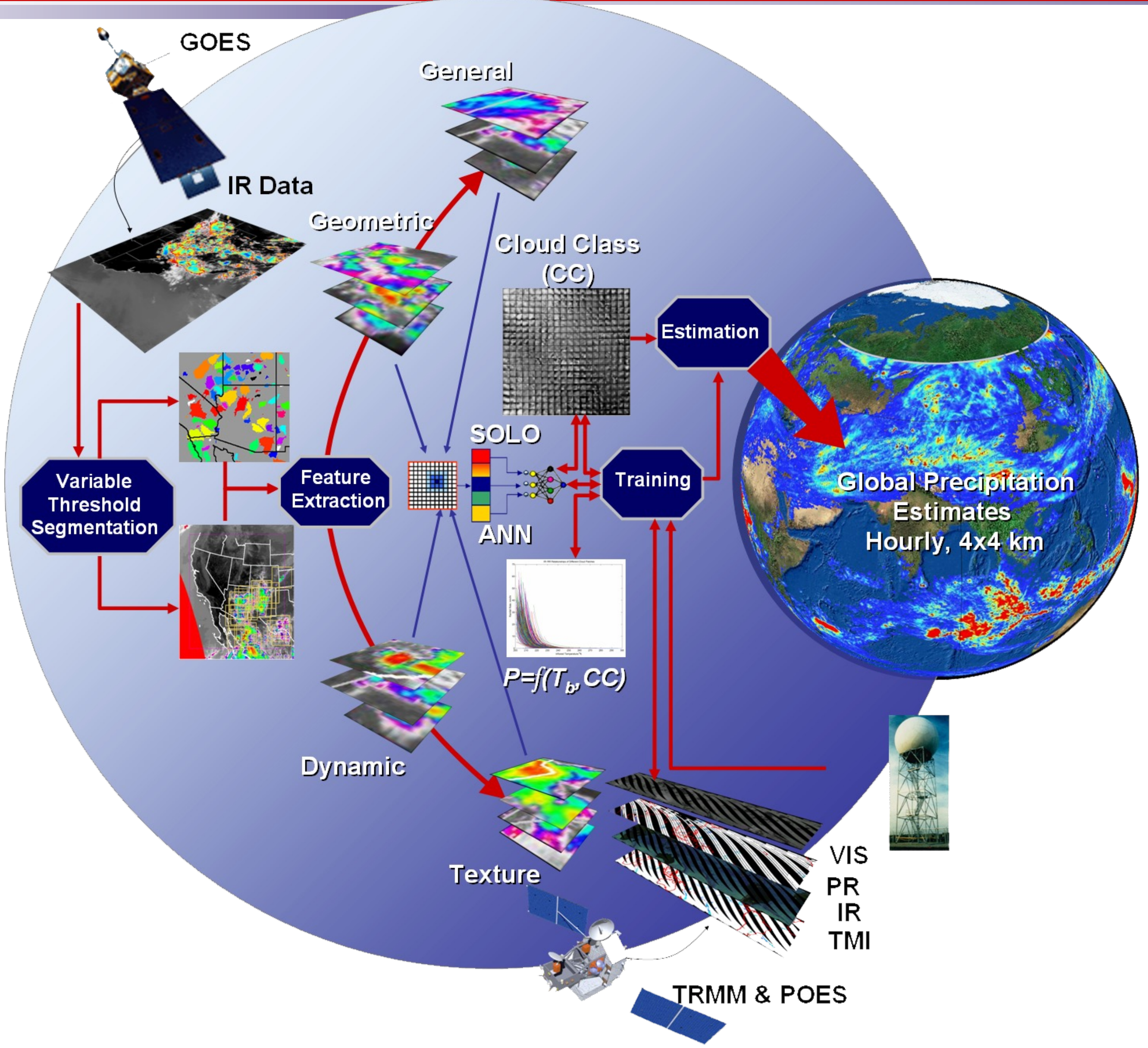
Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)



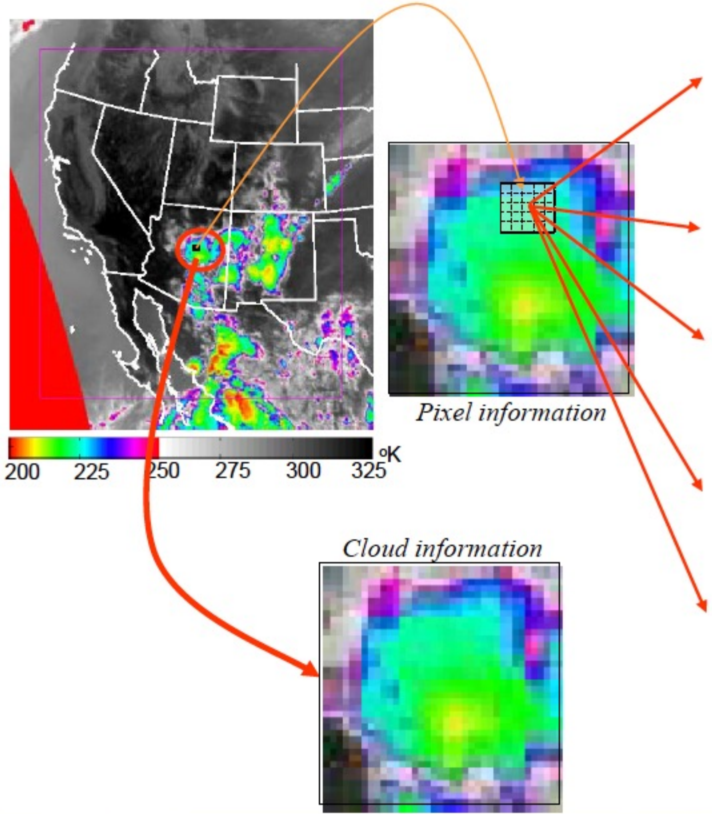
Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Cloud Classification System (PERSIANN-CCS)



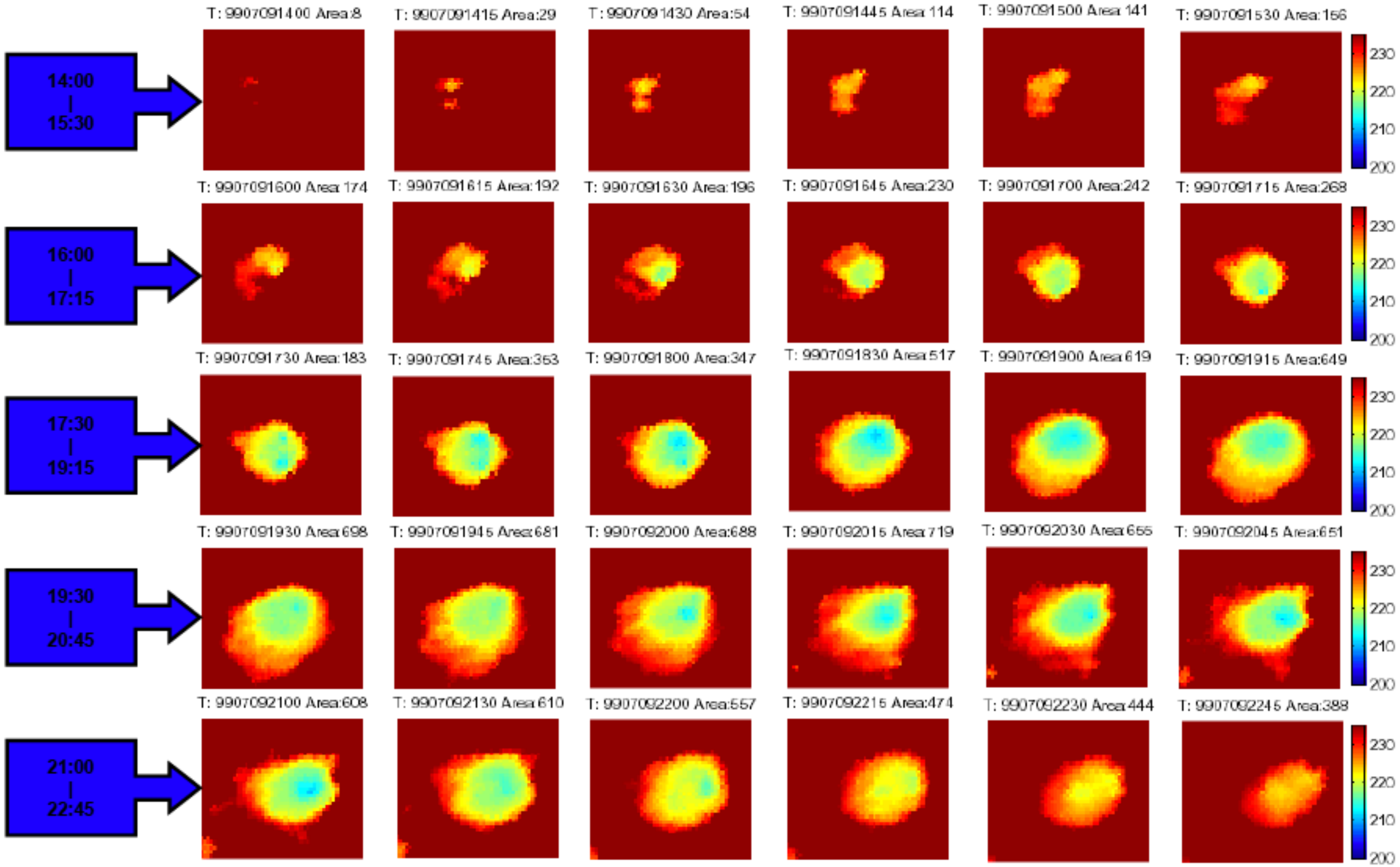
PERSIANN-CCS (Real-time 4 km)



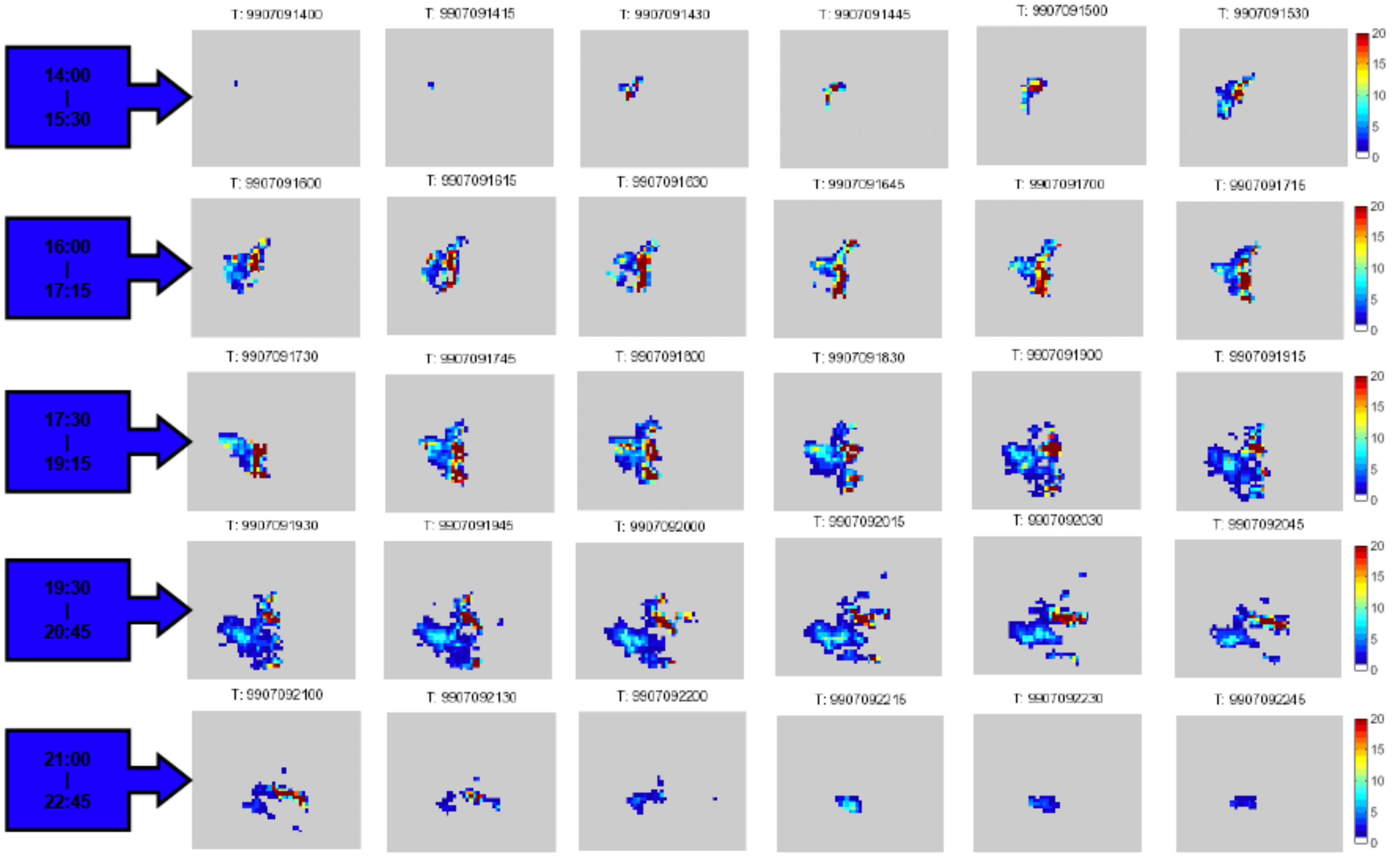
Cloud Feature Extraction



- T_b: *IR temperature of calculation pixel*
- μ_{3x3}: *Mean temperature of 3x3 pixels*
- σ_{3x3}: *Standard deviation temperature of 3x3 pixels*
- μ_{5x5}: *Mean temperature of 5x5 pixels*
- σ_{5x5}: *Standard deviation temperature of 5x5 pixels*



14:00
15:30
16:00
17:15
17:30
19:15
19:30
20:45
21:00
22:45
T: 9907091400 Area:8
T: 9907091415 Area:29
T: 9907091430 Area:54
T: 9907091445 Area:114
T: 9907091500 Area:141
T: 9907091530 Area:156
T: 9907091600 Area:174
T: 9907091615 Area:192
T: 9907091630 Area:196
T: 9907091645 Area:230
T: 9907091700 Area:242
T: 9907091715 Area:268
T: 9907091730 Area:183
T: 9907091745 Area:353
T: 9907091800 Area:347
T: 9907091830 Area:517
T: 9907091900 Area:619
T: 9907091915 Area:649
T: 9907091930 Area:698
T: 9907091945 Area:681
T: 9907092000 Area:688
T: 9907092015 Area:719
T: 9907092030 Area:655
T: 9907092045 Area:651
T: 9907092100 Area:608
T: 9907092130 Area:610
T: 9907092200 Area:557
T: 9907092215 Area:474
T: 9907092230 Area:444
T: 9907092245 Area:388
230
220
210
200


14:00
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T: 9907092100
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T: 9907092245
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15
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5
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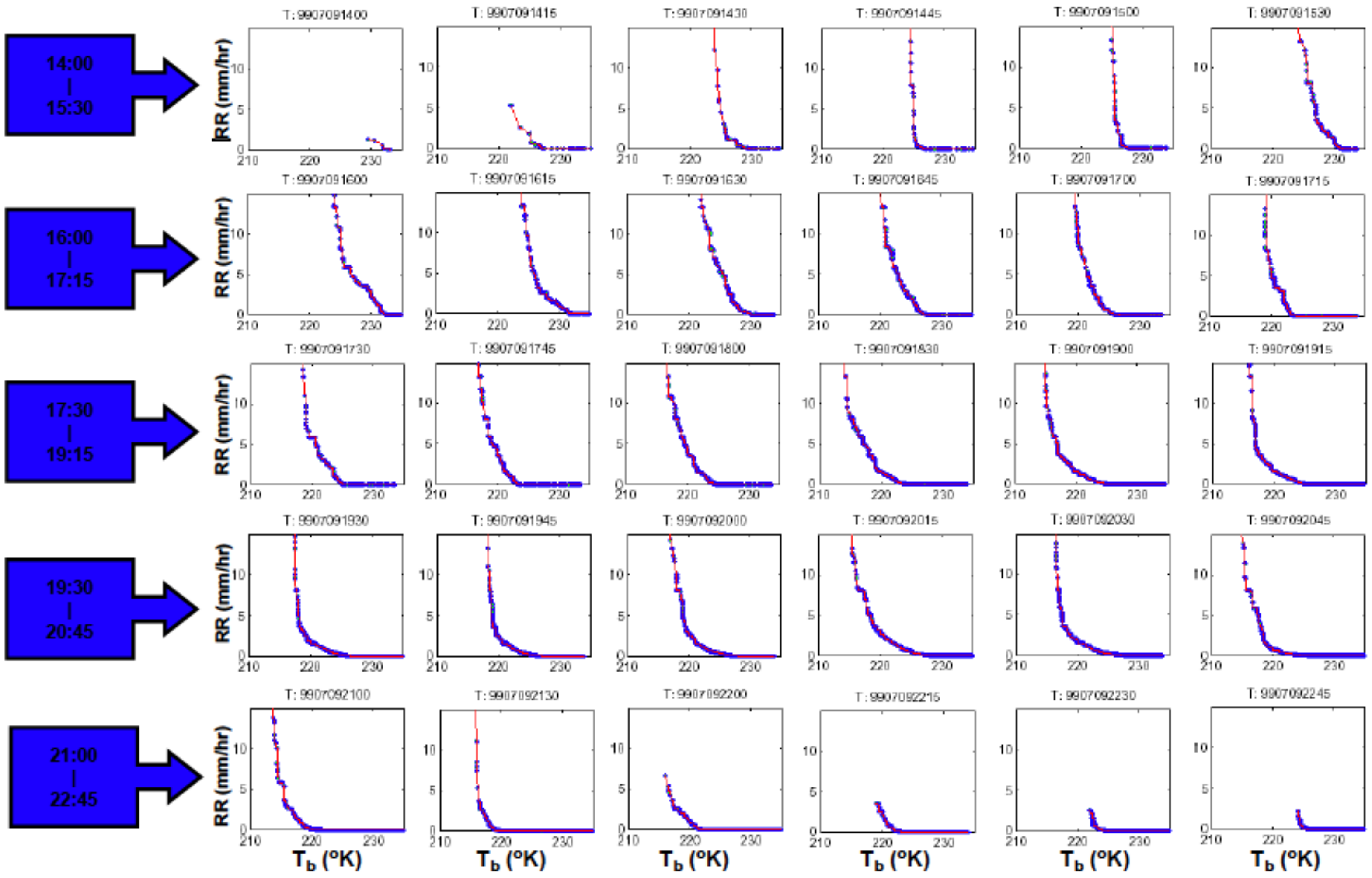

14:00
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19:15
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20:45
21:00
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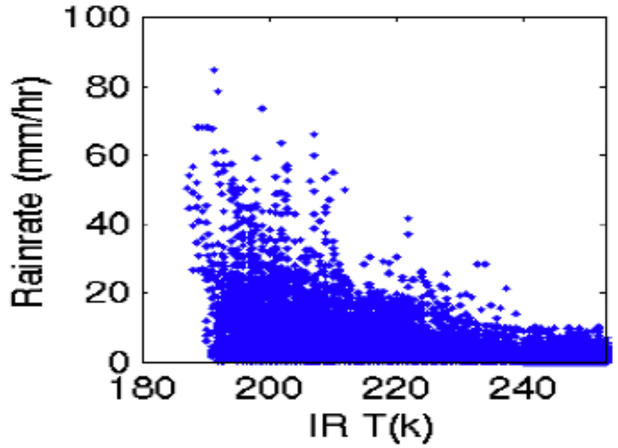
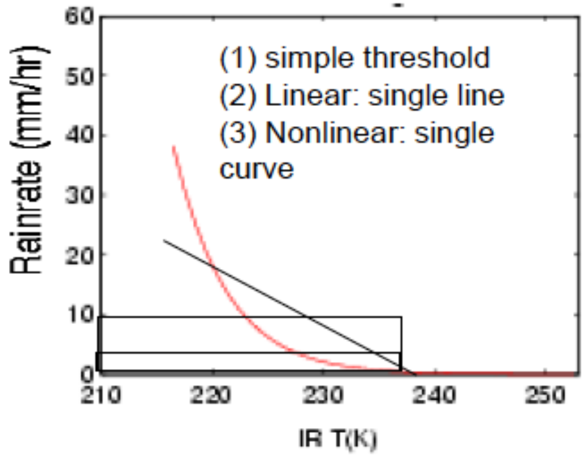
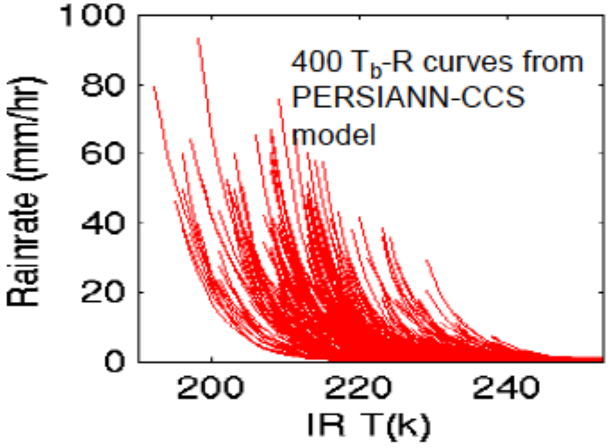
T: 9907091915
T: 9907091930
T: 9907091945
T: 9907092000
T: 9907092015
T: 9907092030
T: 9907092045
T: 9907092100
T: 9907092130
T: 9907092200
T: 9907092215
T: 9907092230
T: 9907092245
RR (mm/hr)
T_b (°K)

Multiple vs. Single Curve Fitting Models







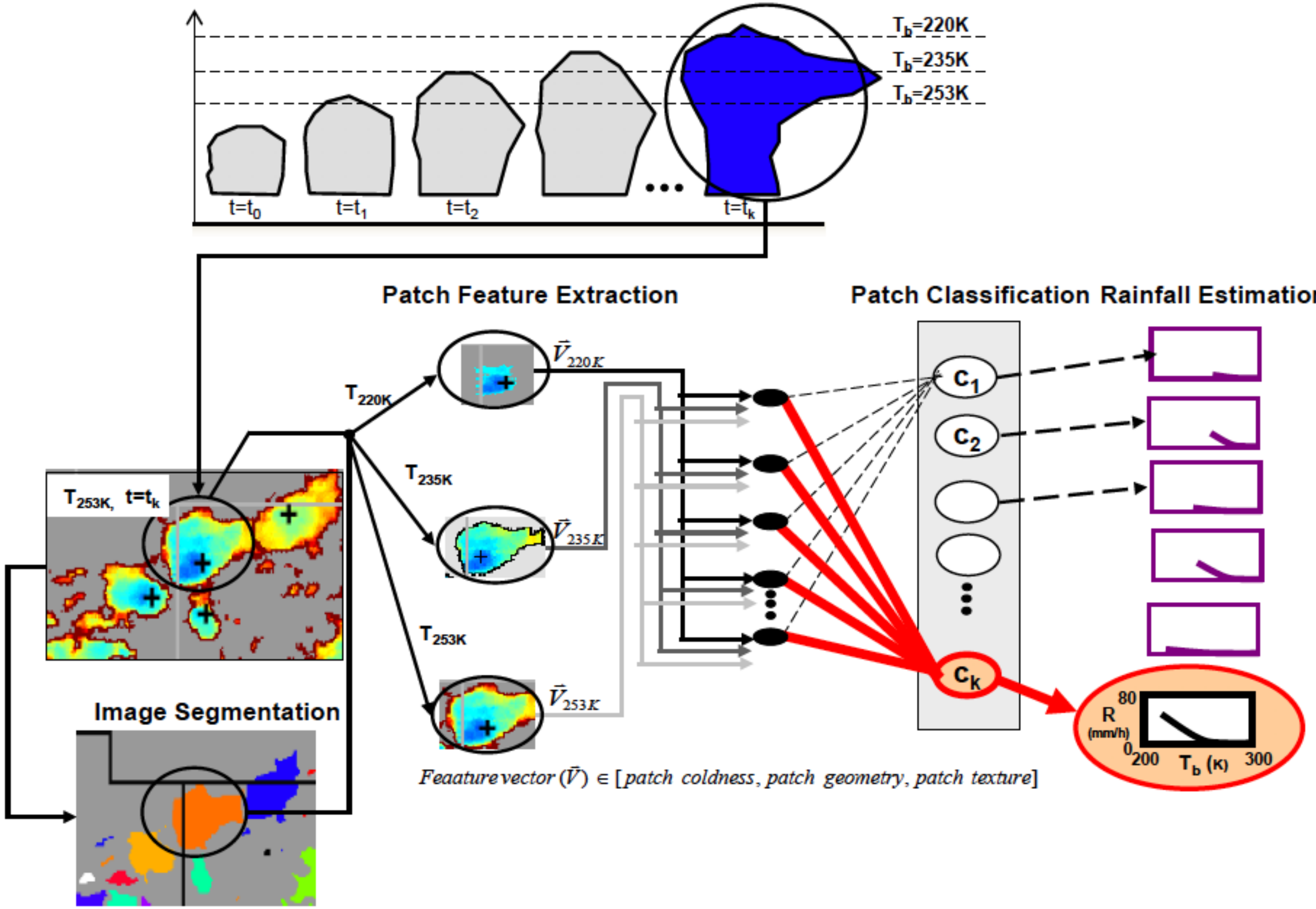
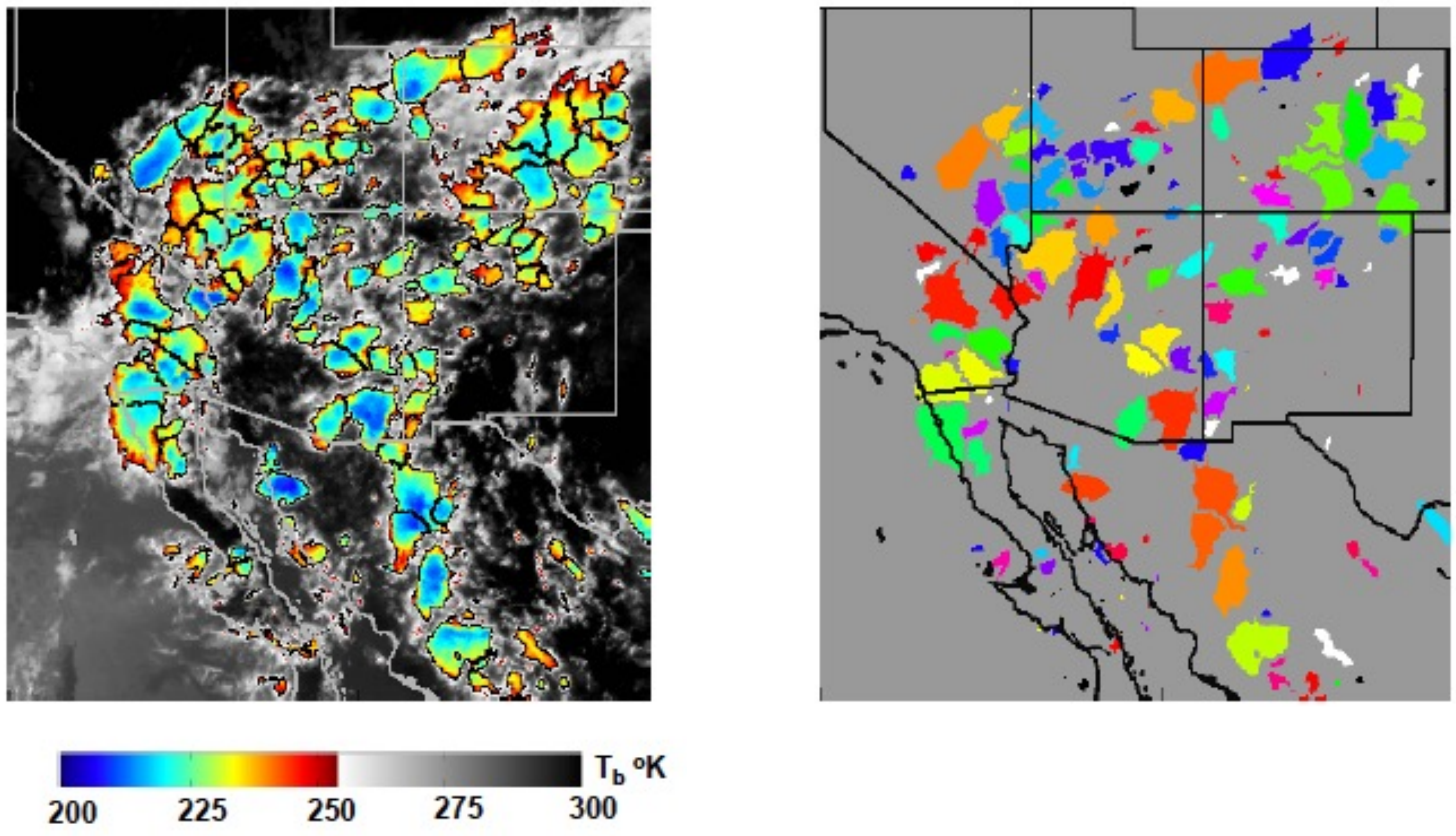

T_b=220K
T_b=235K
T_b=253K
t=t_0
t=t_1
t=t_2
t=t_k
Patch Feature Extraction
Patch Classification
Rainfall Estimation
T_{220K}
T_{235K}
T_{253K}
$\vec{V}_{220K}$
$\vec{V}_{235K}$
$\vec{V}_{253K}$
T_{253K}, t=t_k
Image Segmentation
C_1
C_2
C_k
80
R (mm/h)
0
200
T_b (K)
300
Feaature vector ($\vec{V}$) ∈ [patch coldness, patch geometry, patch texture]

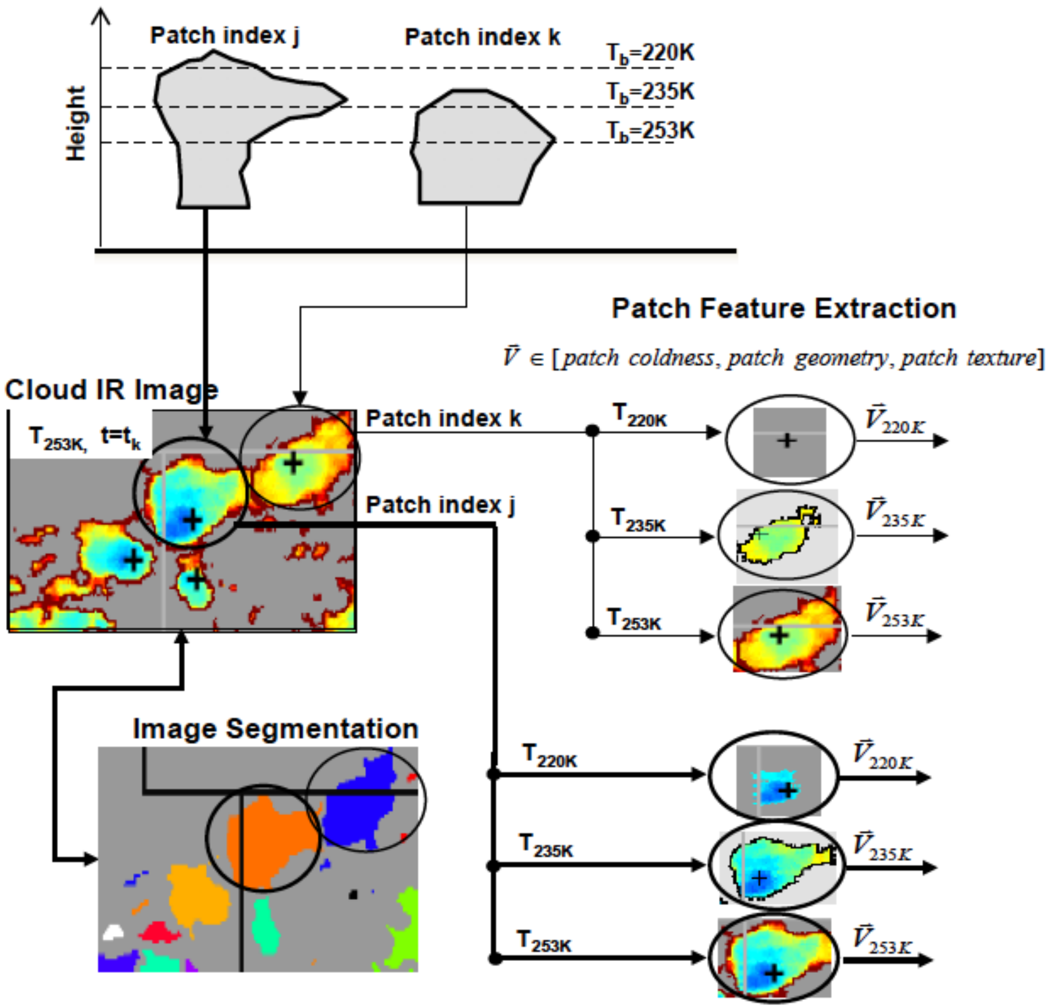
Image Classification and Rainfall Estimation

- *Cloud Segmentation (Cloud Patch vs. Pixel Window)*
- *Cloud Feature Extraction*
- *Cloud Patch Classification*
- *Cloud Coverage and Rainfall Distribution*

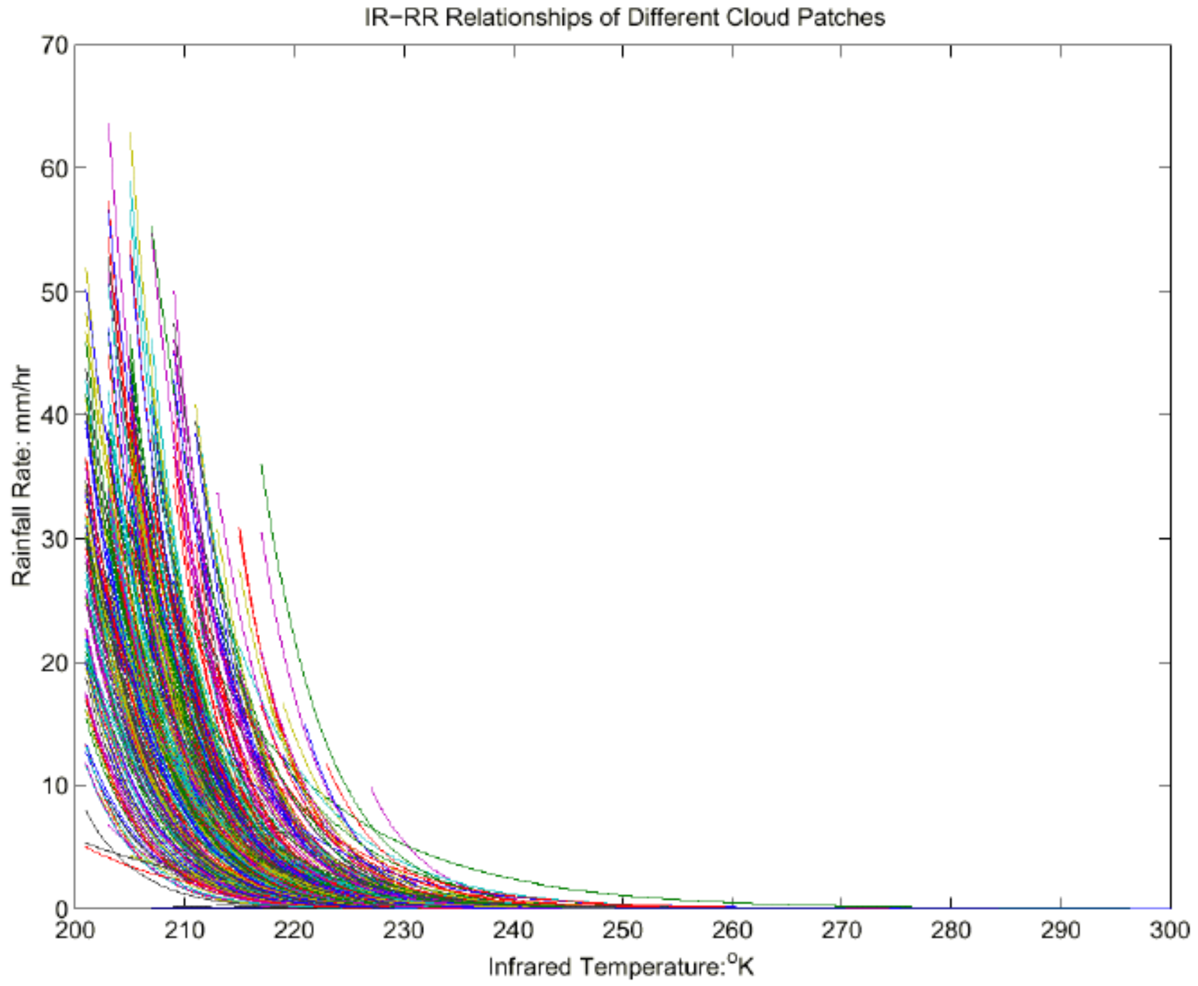
Cloud Segmentation Algorithm



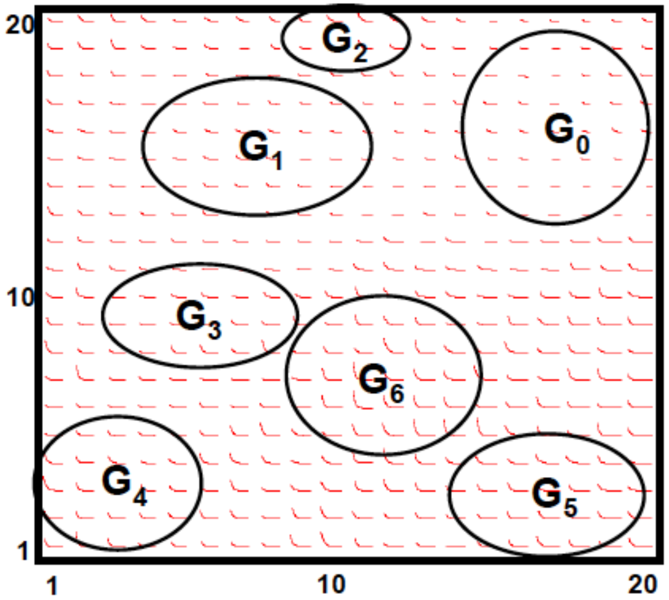
Features Extraction

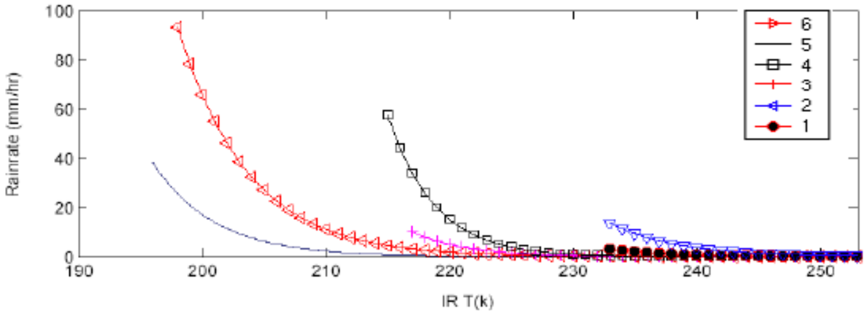


IR-RR Relationship of Various Cloud Patches

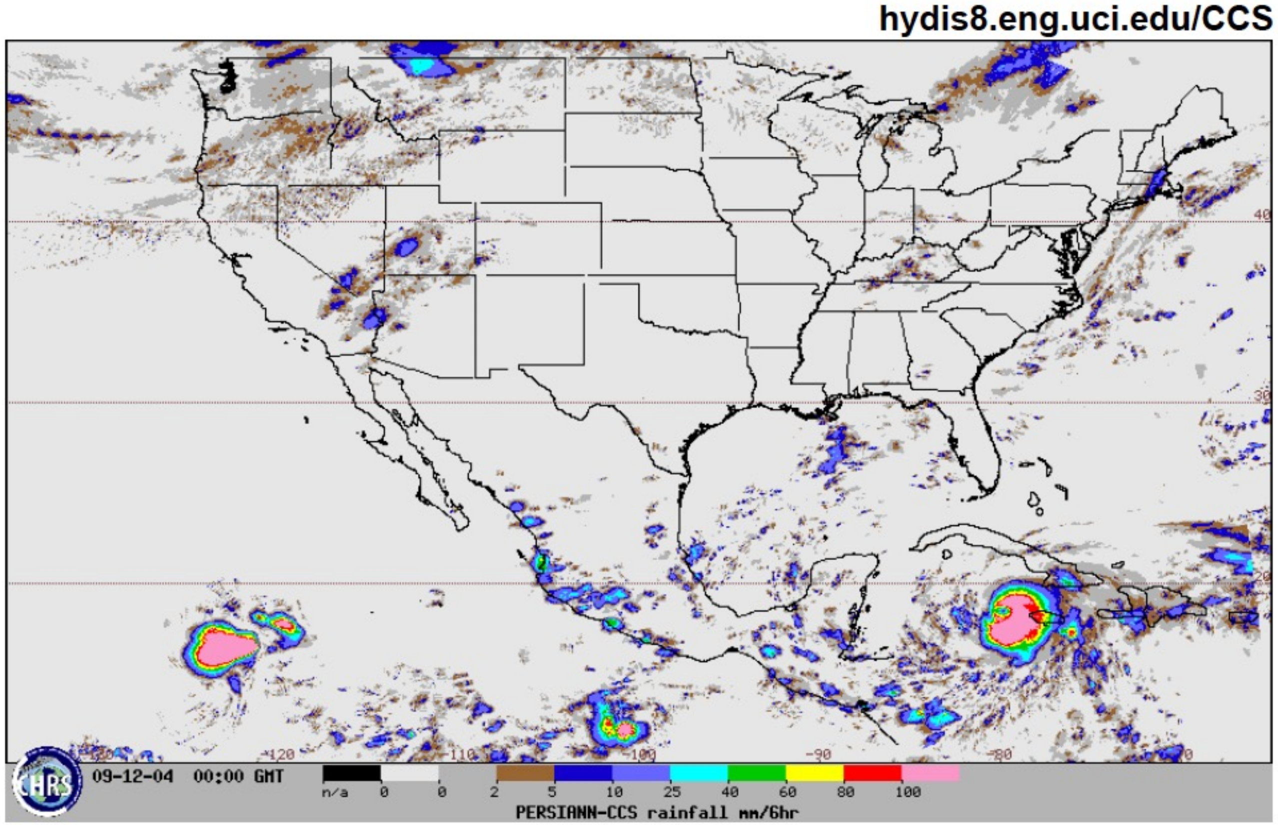


IR-RR Relationship of Various Cloud Patches

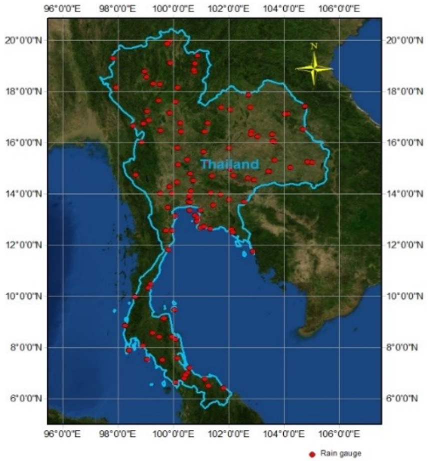


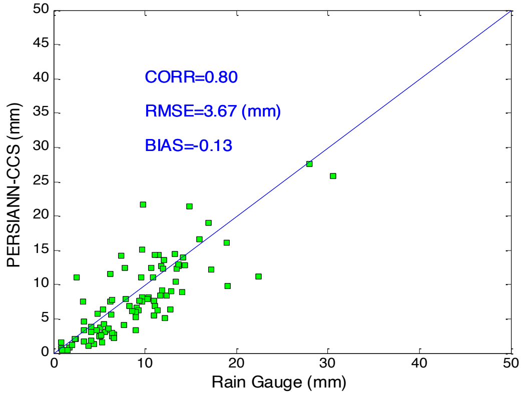


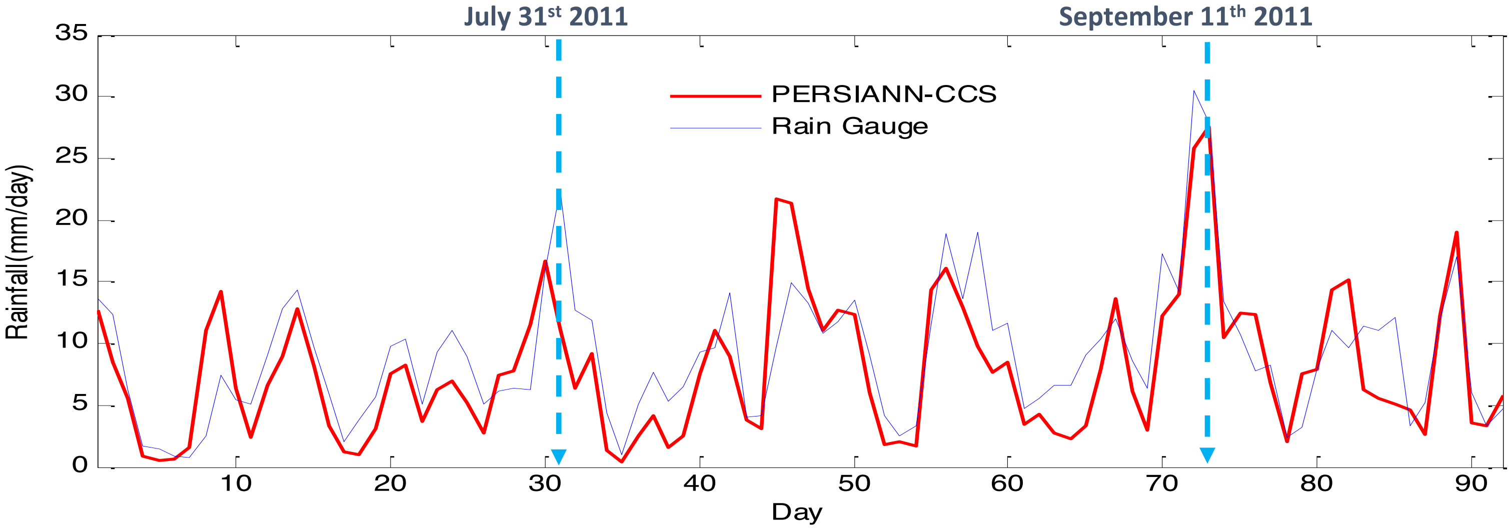
Six-Hour Accumulated Rainfall: Hurricane Ivan September 2004



Thailand Flood 2011

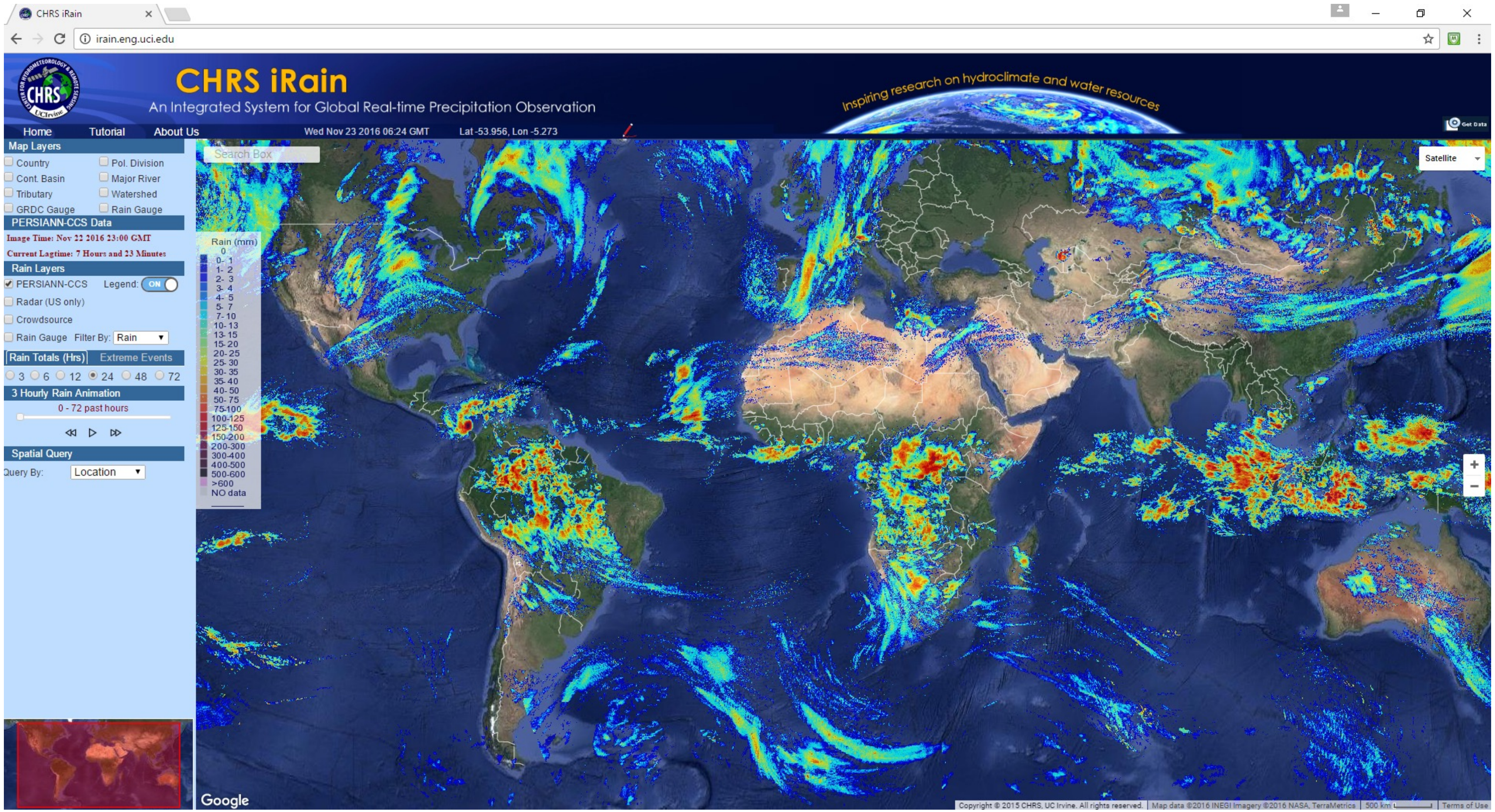




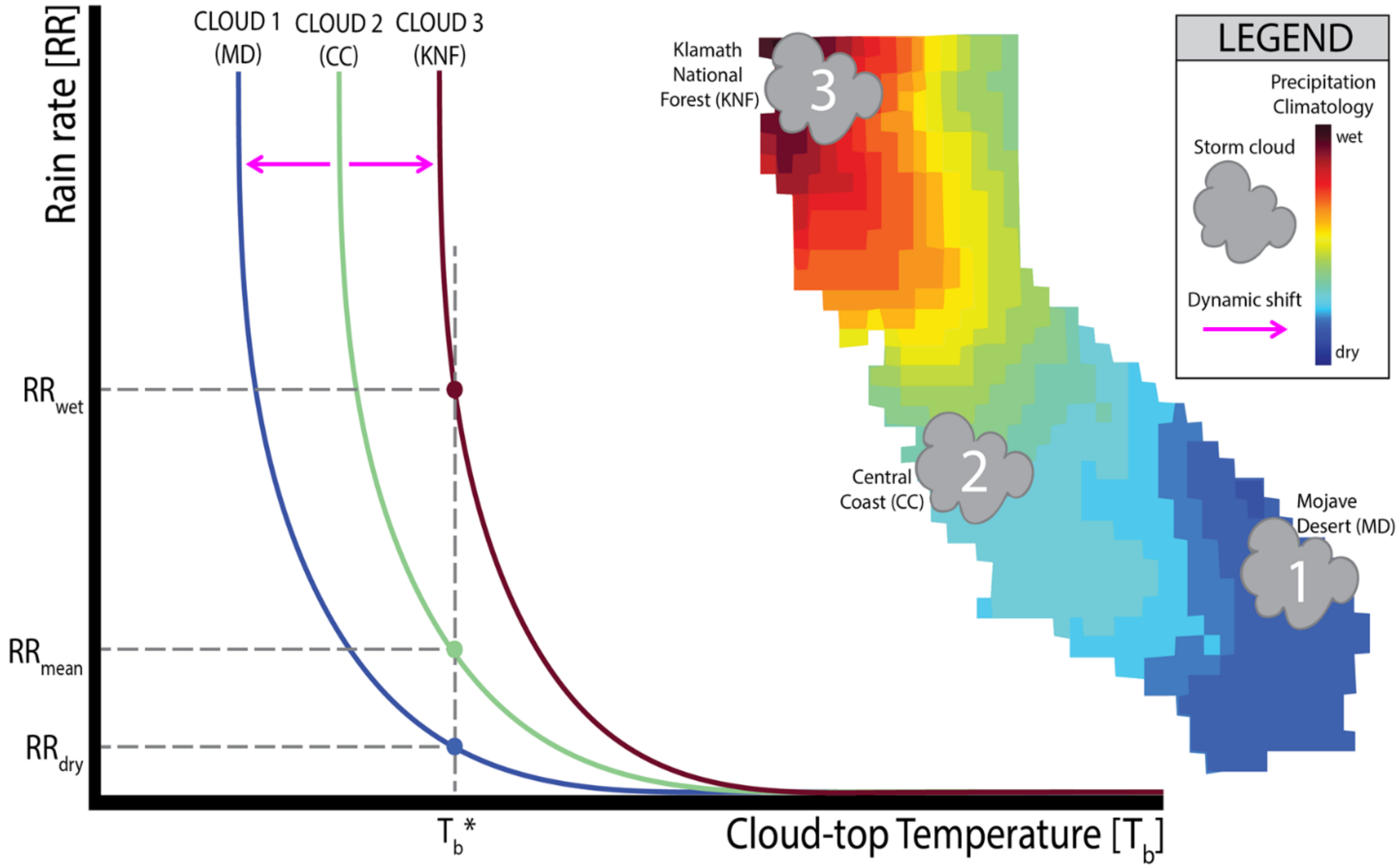


Hsu, Sellars and Nguyen et al. 2013

iRain: http://irain.eng.uci.edu/

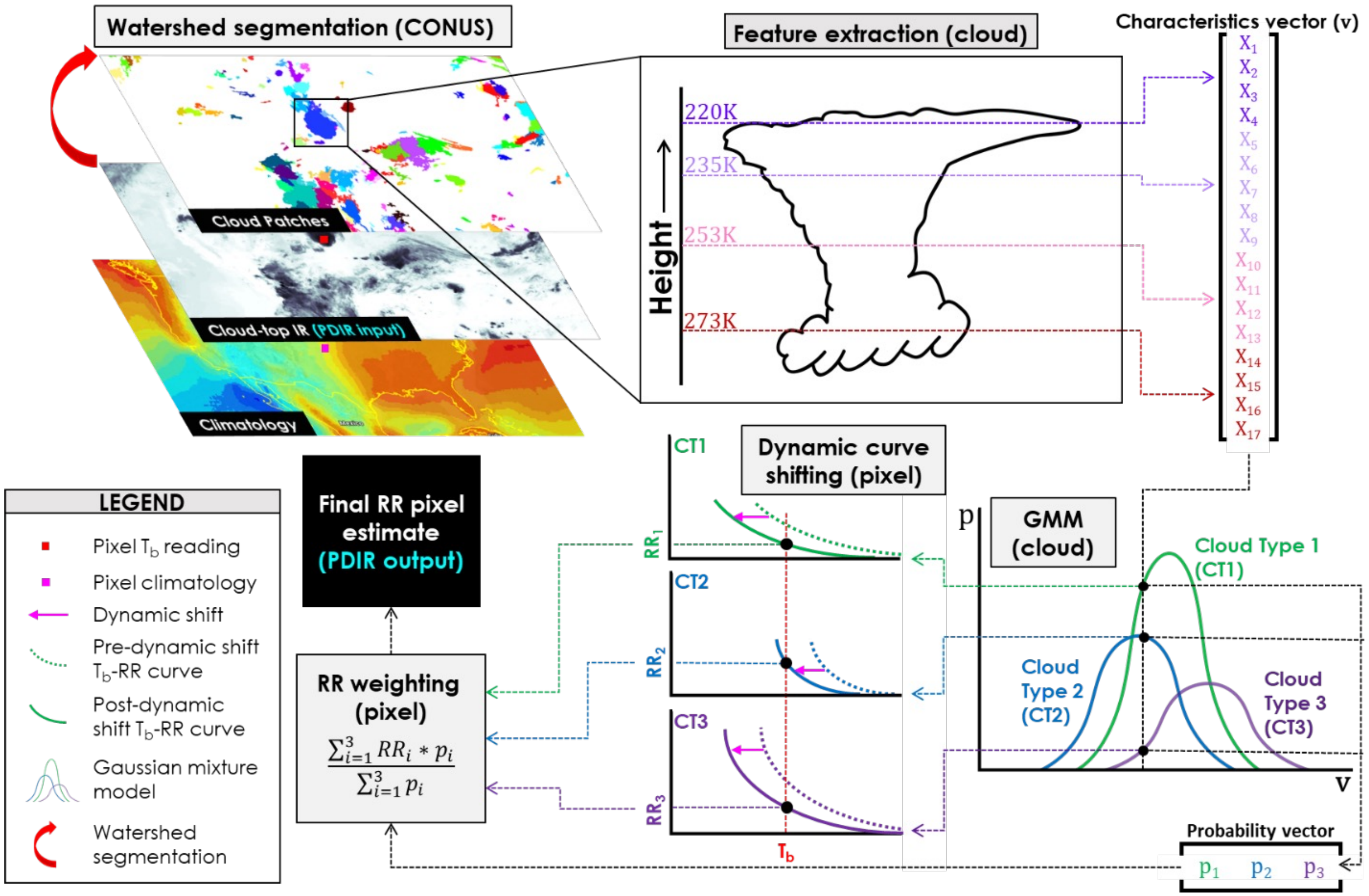


PERSIANN Dynamic-Infrared Rain rate model (PDIR)



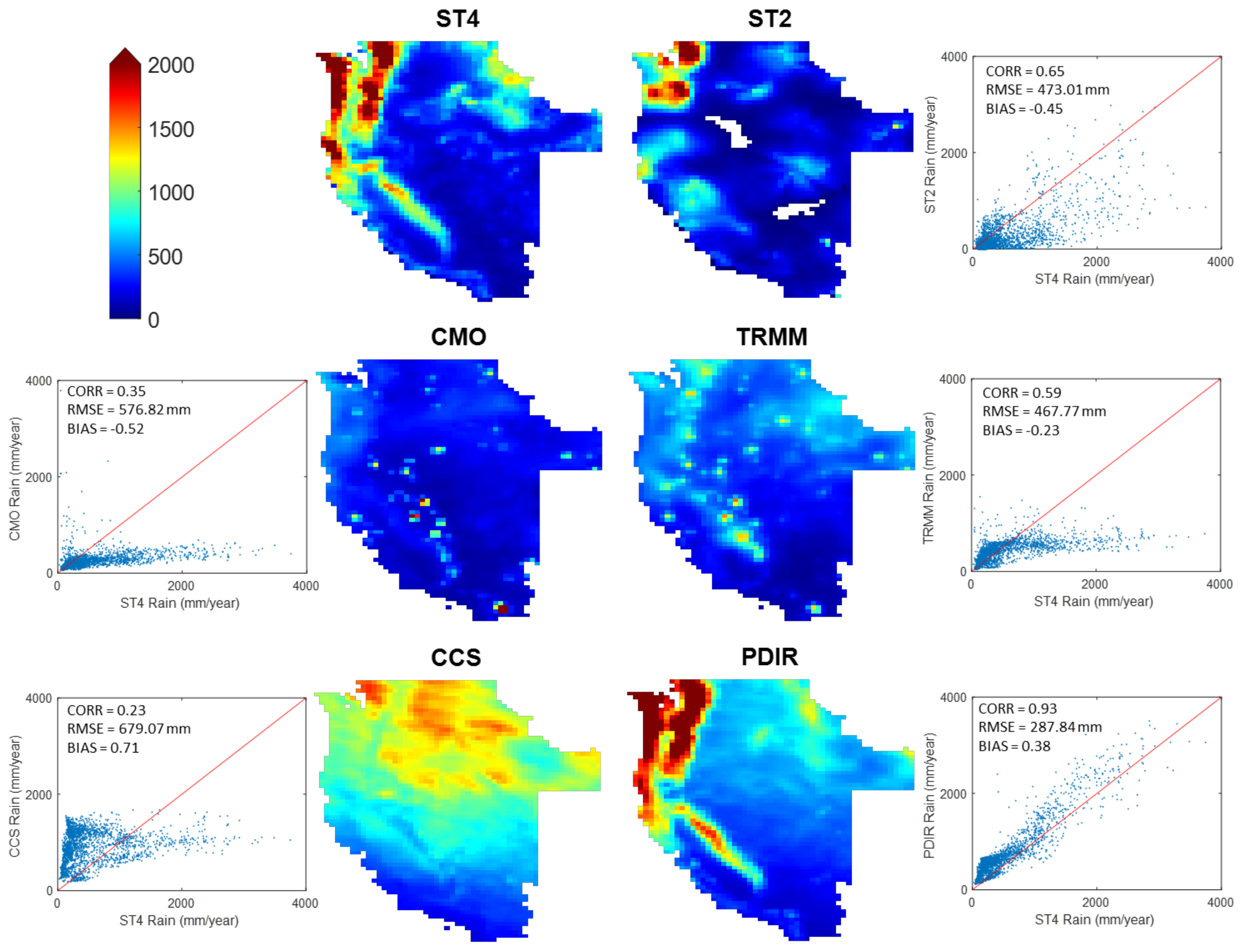
The dynamic cloud-top brightness temperature (T_b)-rain rate (RR) model

PERSIANN Dynamic-Infrared Rain rate model (PDIR)



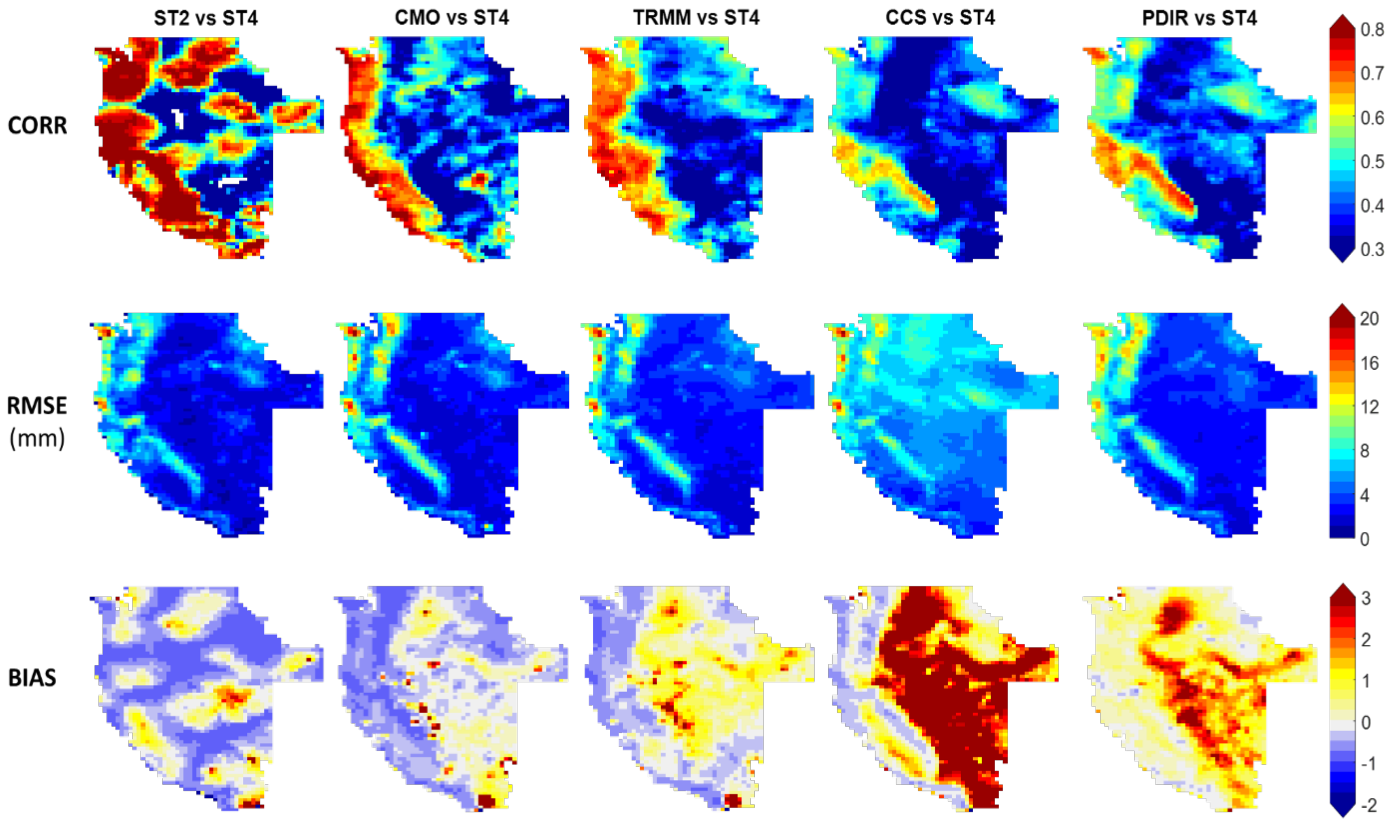
The workflow of PDIR from input to output

PERSIANN Dynamic-Infrared Rain rate model (PDIR)



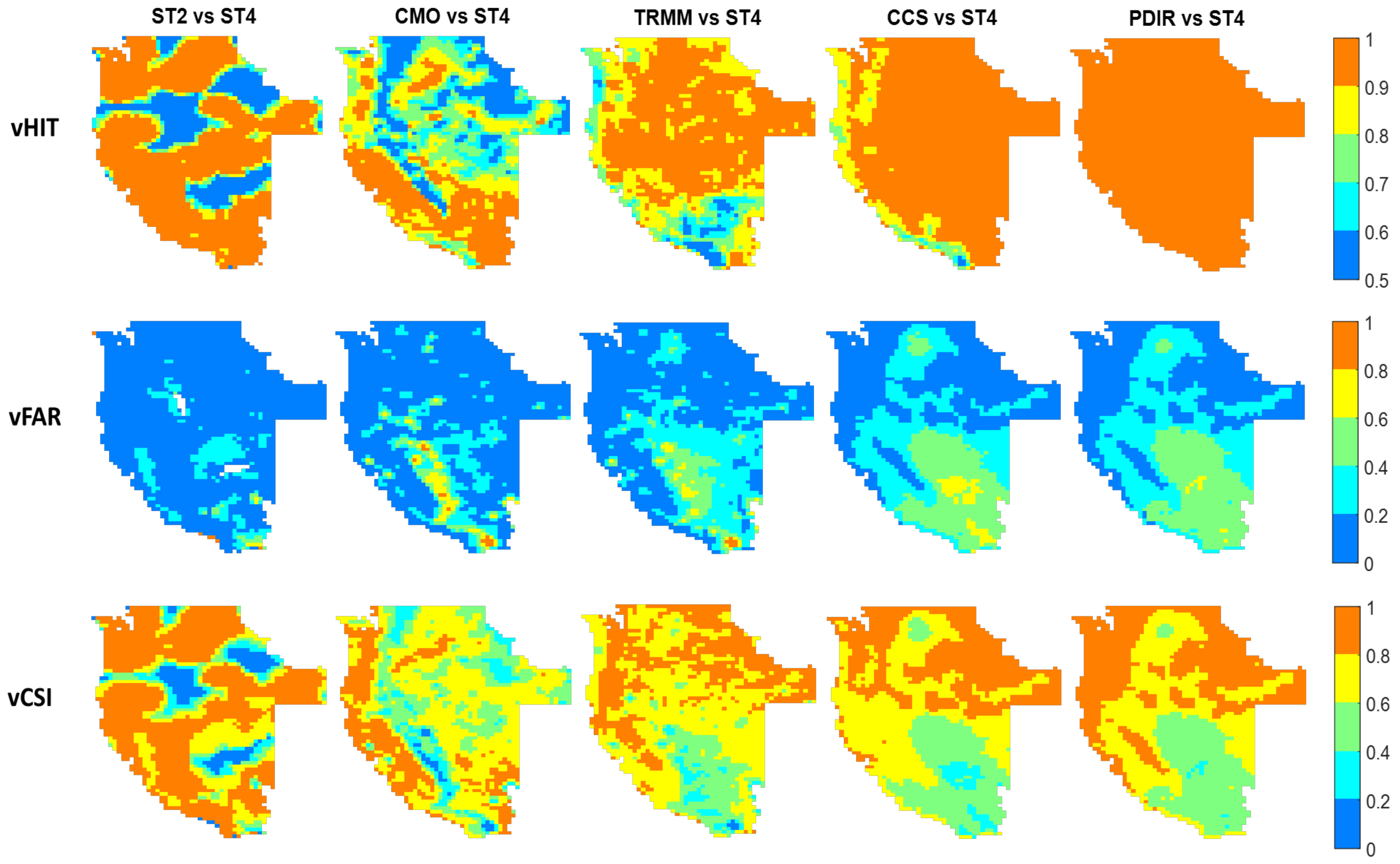
Average annual rainfall in mm/year for the validation period (2008-2013) for the baseline product Stage IV (ST4), the near real-time Stage II (ST2), the three satellite-based precipitation products (CMORPH (CMO), TRMM, and PERSIANN-CCS (CCS)) and the new product, PDIR.

PERSIANN Dynamic-Infrared Rain rate model (PDIR)



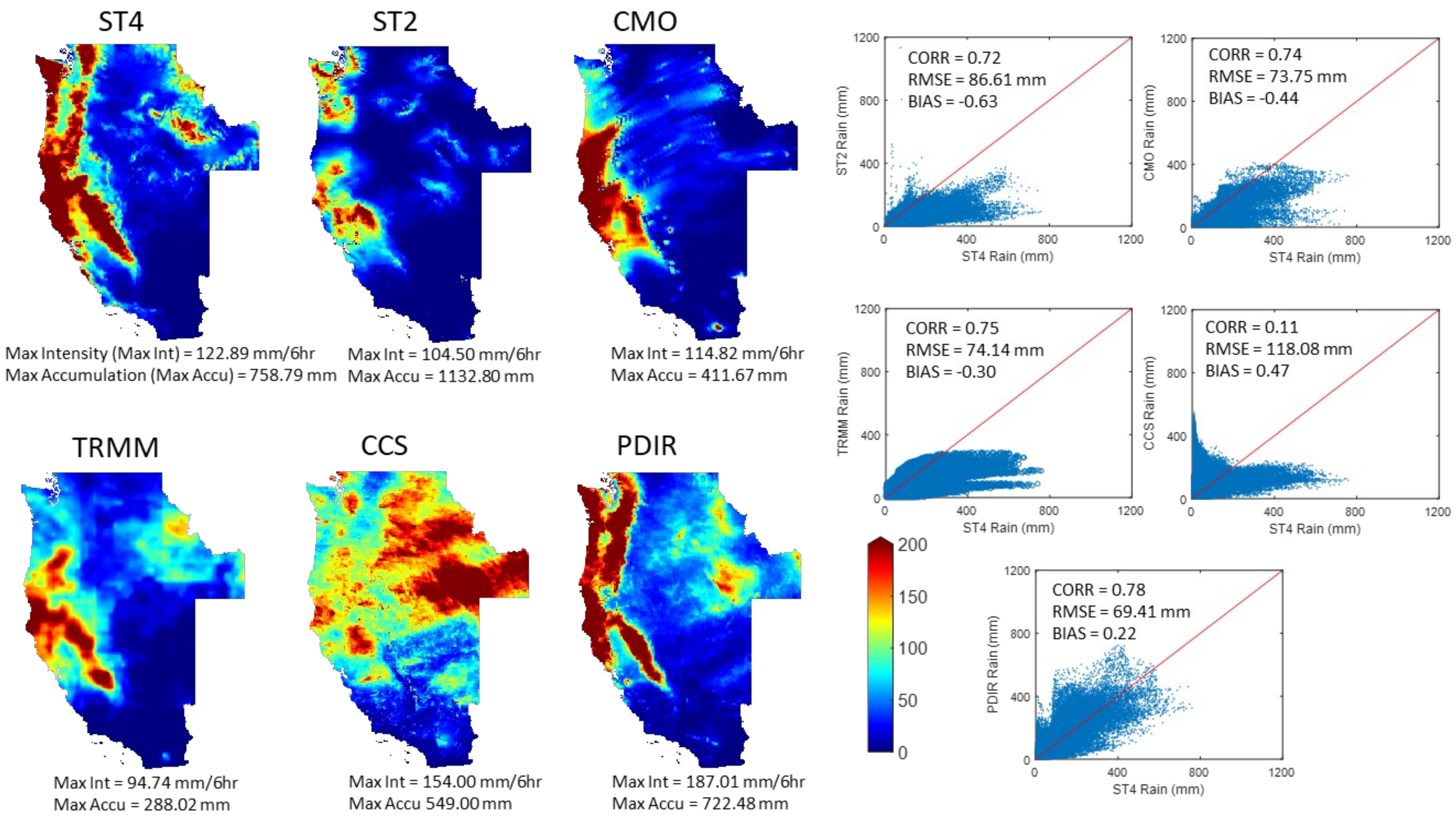
Continuous comparison metrics for daily rainfall

PERSIANN Dynamic-Infrared Rain rate model (PDIR)



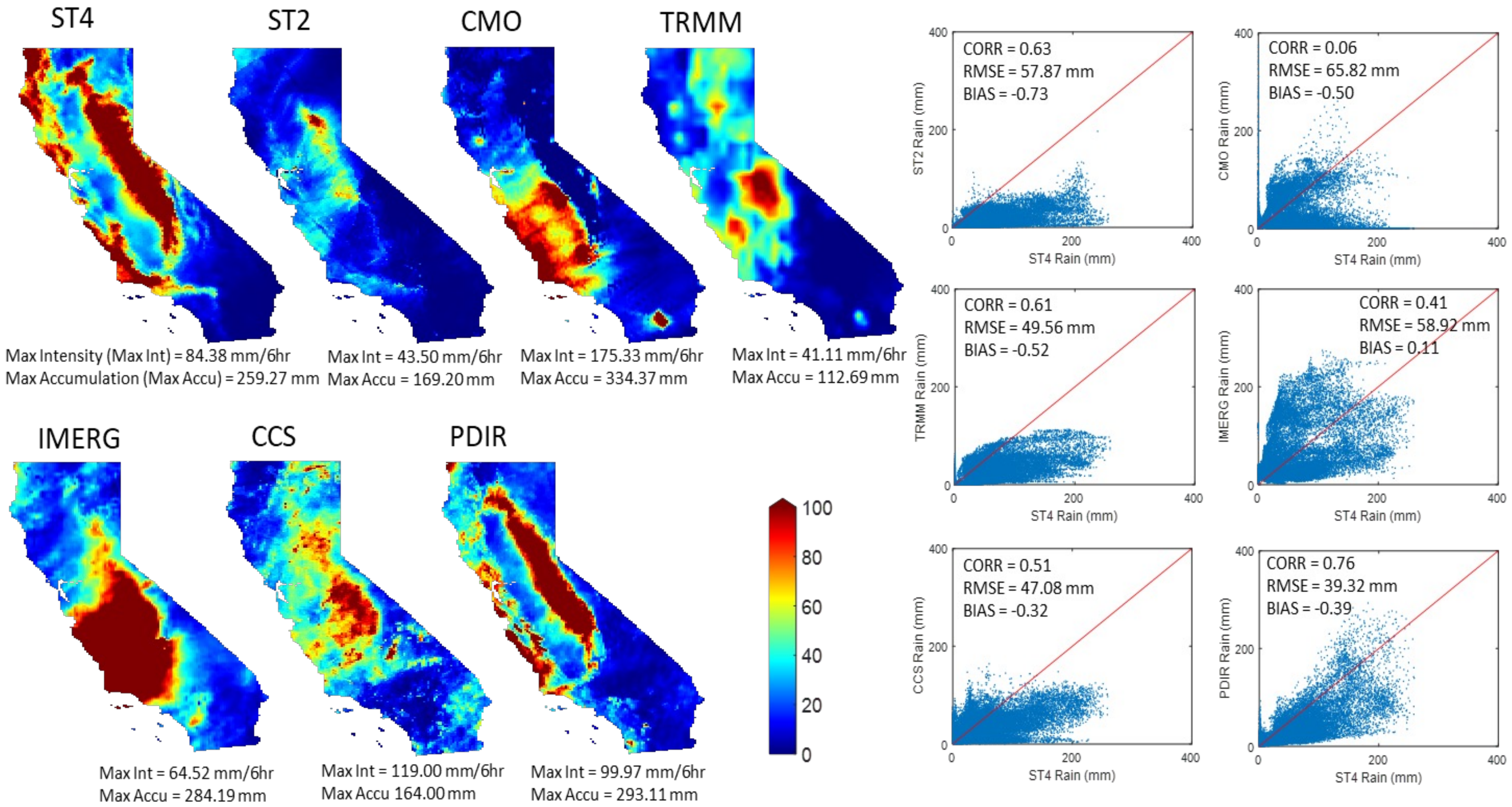
Volumetric categorical indices for daily rainfall

PERSIANN Dynamic-Infrared Rain rate model (PDIR)



Rainfall during the period November 28th, 2012 to December 7th, 2012 associated with an extreme AR event over California

PERSIANN Dynamic-Infrared Rain rate model (PDIR)



Rainfall during the period March 20, 2018 to March 25, 2018 associated with an extreme AR event over California

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

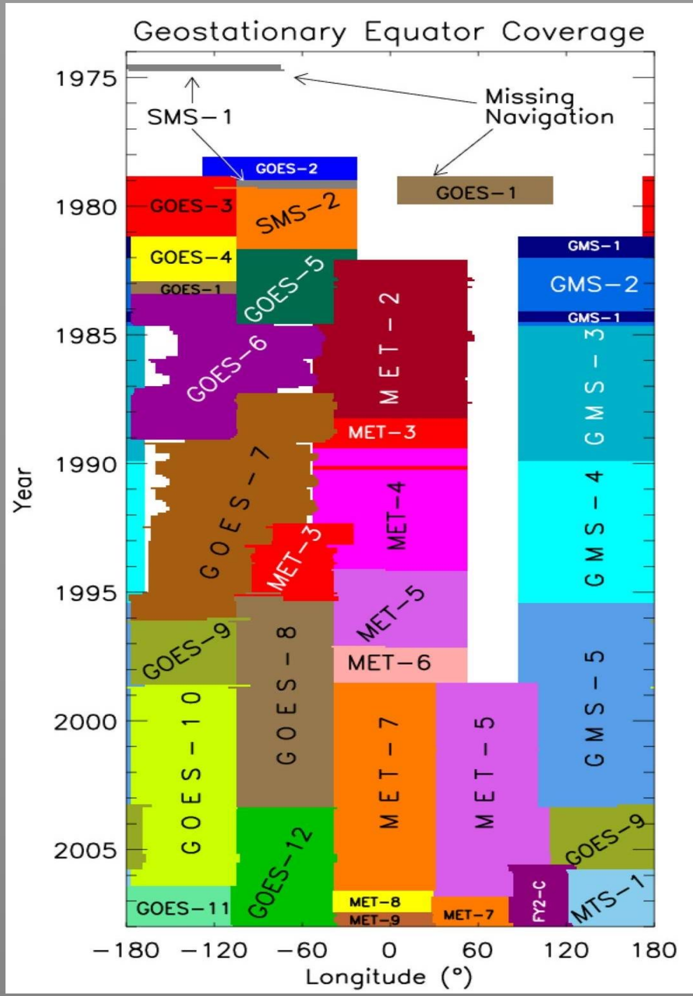
- **Daily Precipitation Data**
- **Data Period: 1983~2023**
- **Coverage: 60°S ~ 60°N**
- **Spatial Resolution: 0.25°x0.25°**

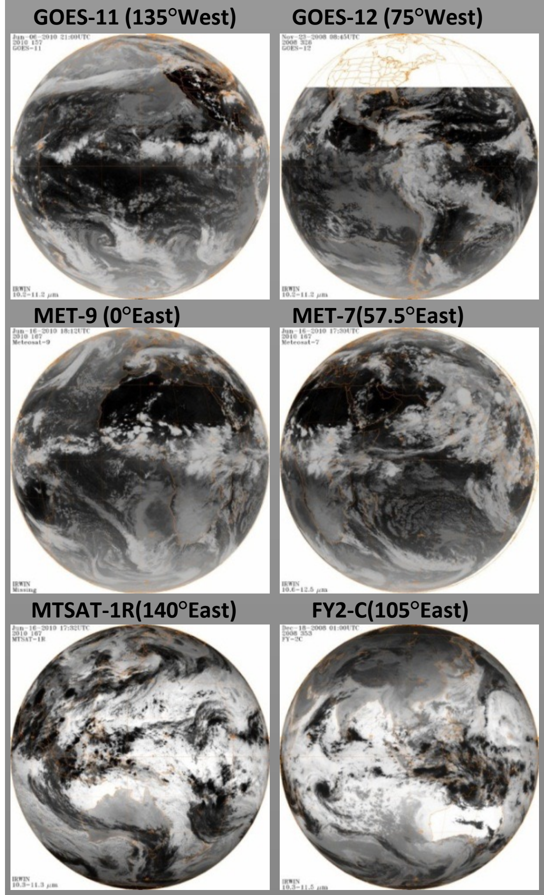
Historical GEO Satellite Data

- **International Satellite Cloud Climatology Project (ISCCP)**

  1979 to present

  10-km and 3-hour intervals



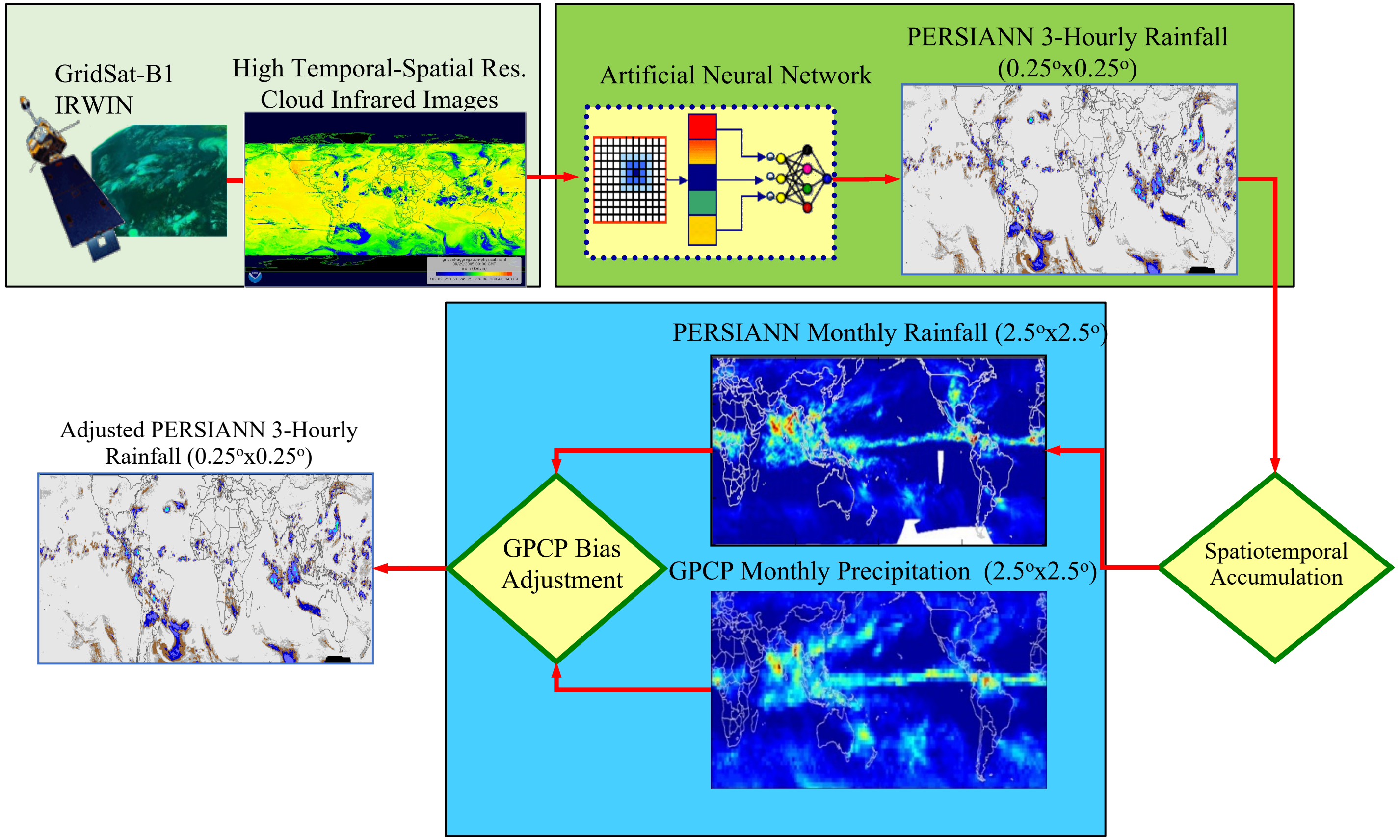


1. U.S. Geostationary Operational Environmental Satellite (**GOES**)
2. European Meteorological satellite (**Meteosat**) series
3. Japanese Geostationary Meteorological Satellite (**GMS**)
4. The Chinese Fen-yung 2C (**FY2**) series.

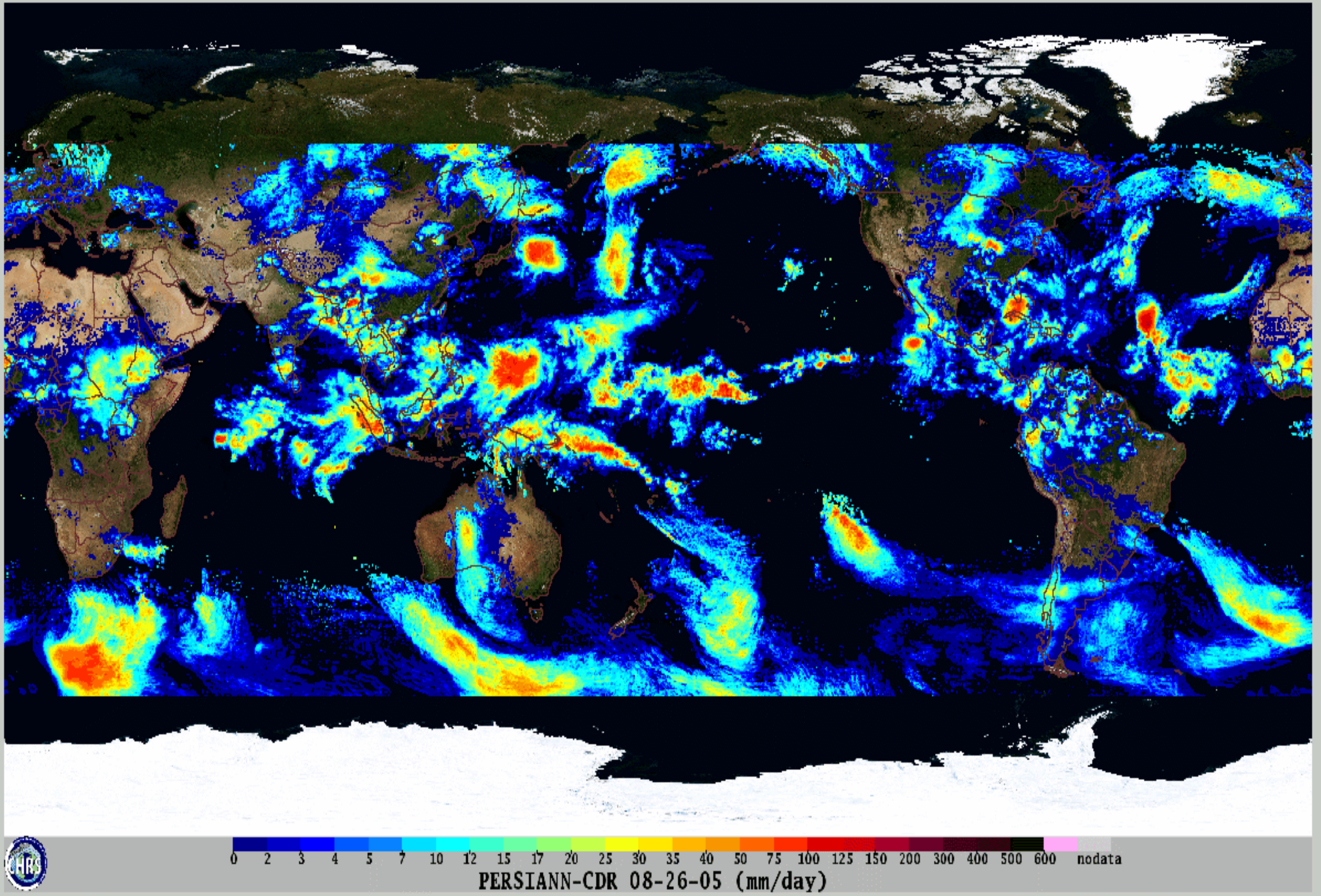
Source: NOAA NCDC

PERSIANN-CDR

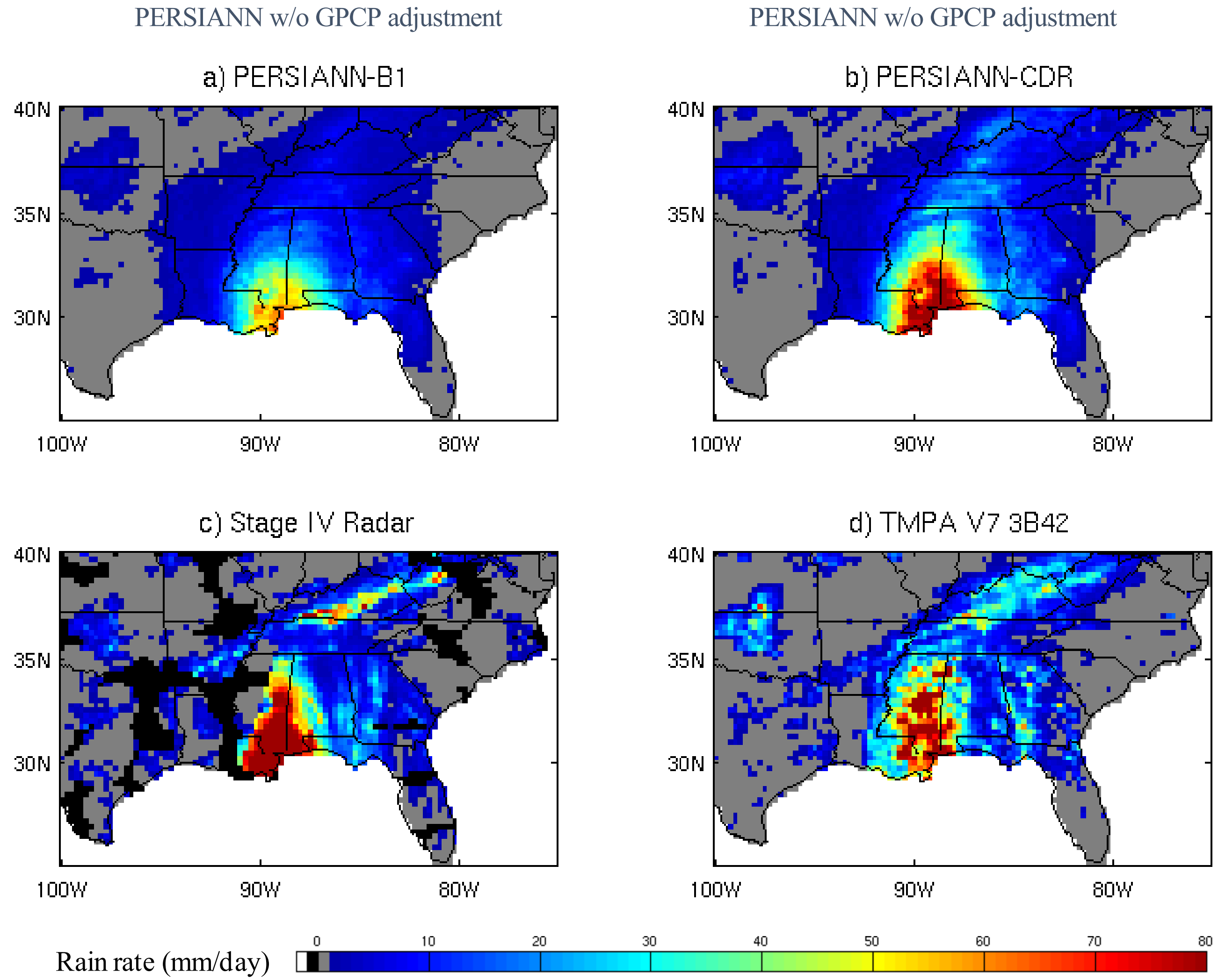
- PERSIANN estimation at 0.25° every 3-hr from GridSat B1 IRWIN
- Monthly accumulation and bias adjusted using GPCP monthly estimation at 2.5°
- Bias adjustment of short-term 3-hr estimation



Ashouri et al, BAMS, 2015


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)

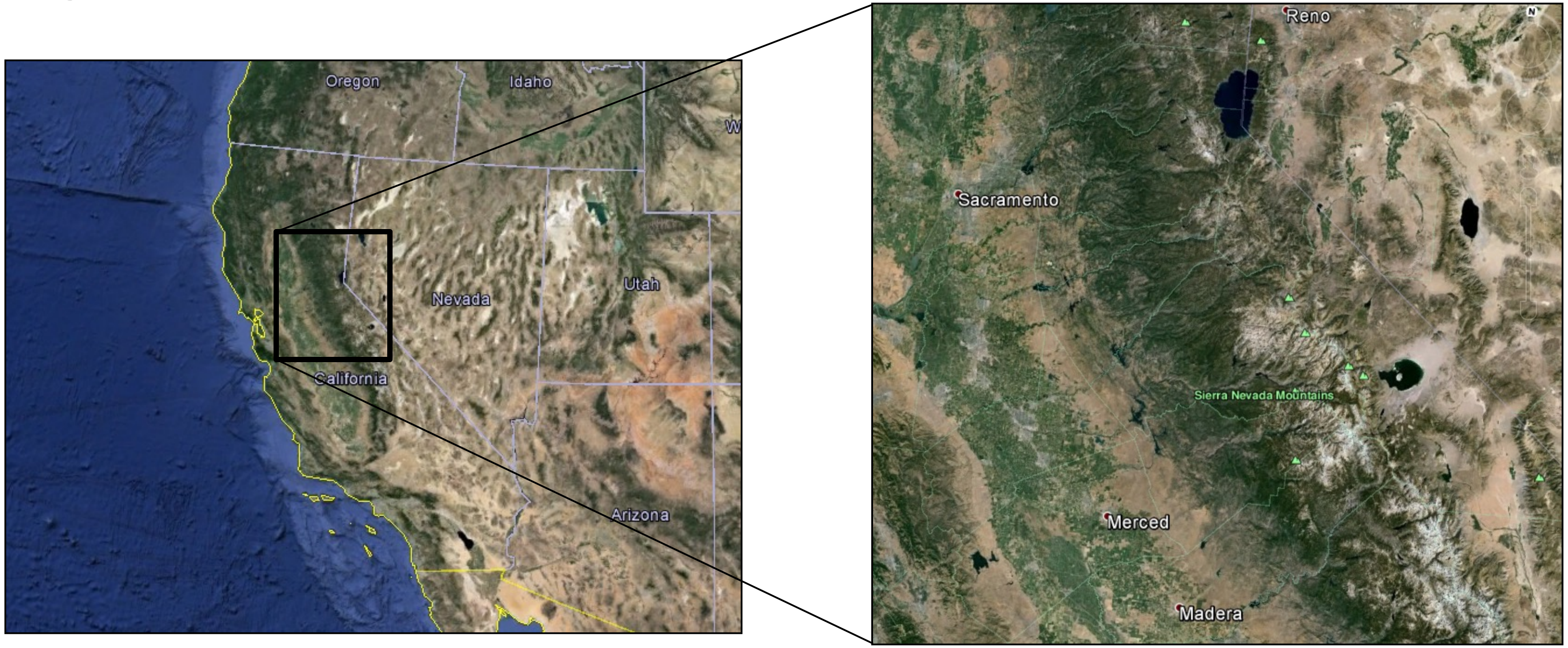
Daily Precipitation: Hurricane Katrina, 2005



Sierra-Nevada Mountain Region

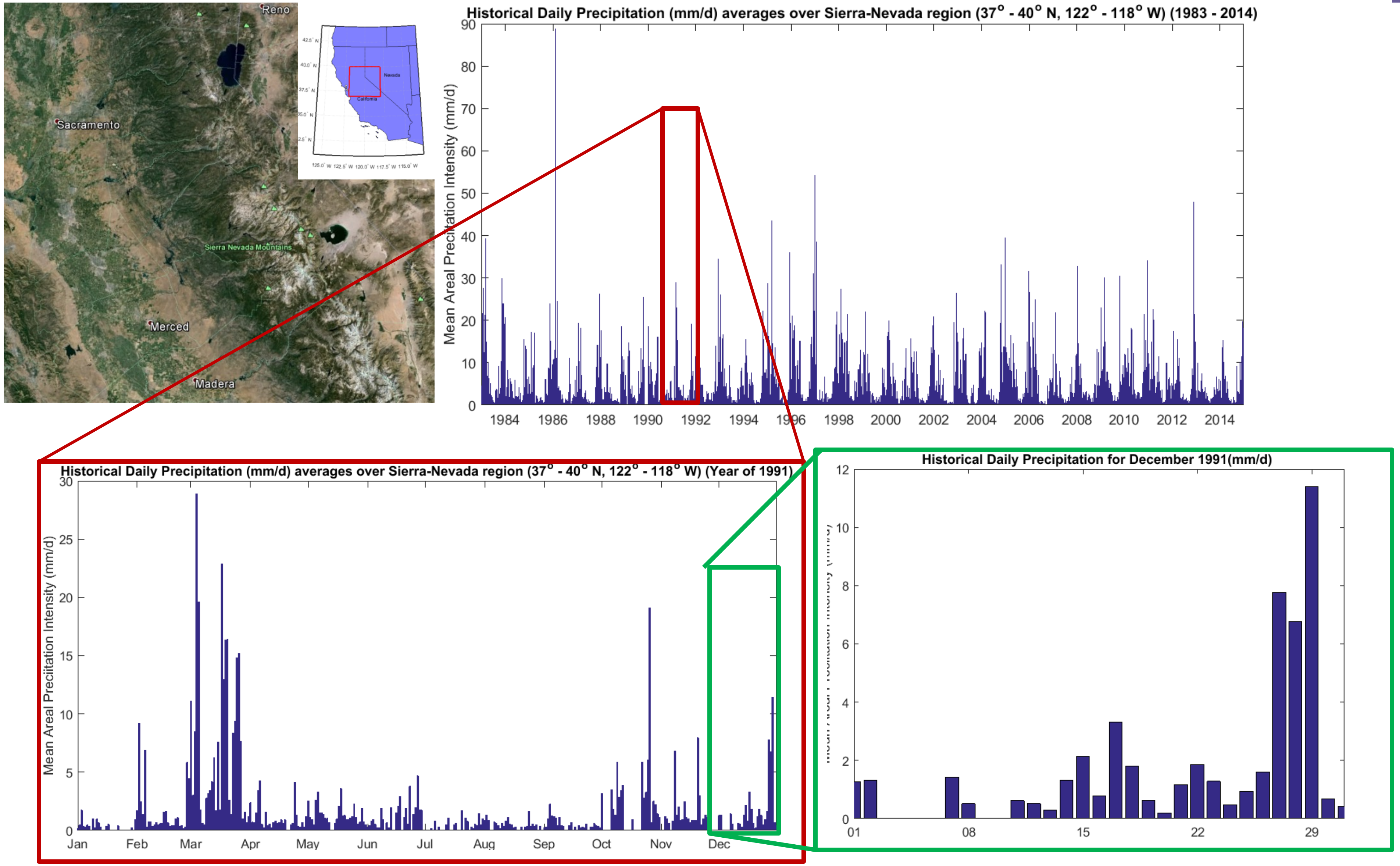
Area: 63,100 square kilometers (24,370 sq mi)

Length: 400 mile, Width: 64 mile.



Source: Google Earth

Sierra-Nevada Mountain (California and Nevada)



Applications

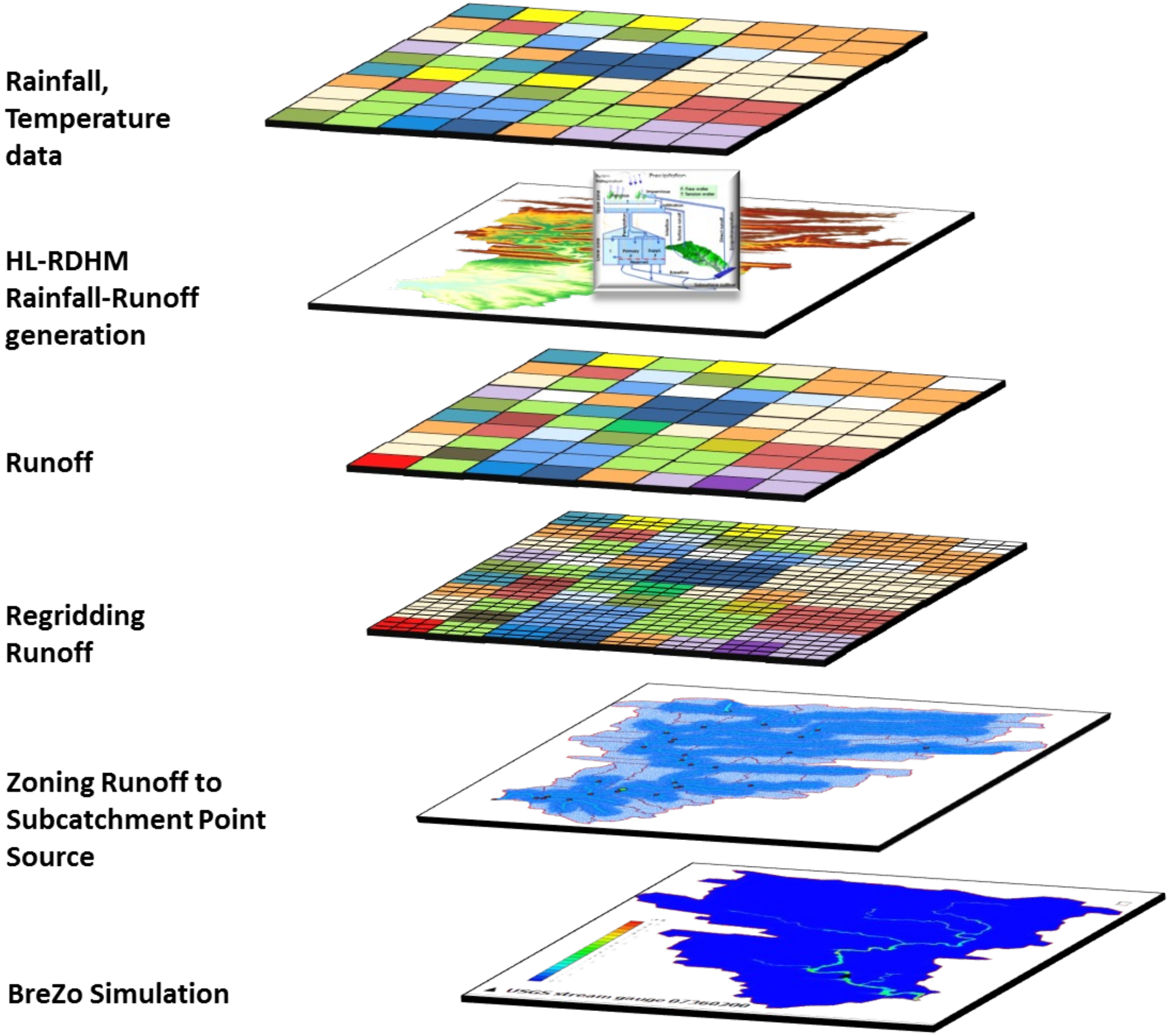
HiResFlood-UCI model and near real-time PERSIANN-CCS for flood forecasting

Nguyen, P., A. Thorstensen, S. Sorooshian, K. Hsu, A. AghaKouchak, B. Sanders, V. Koren, Z. Cui, and Michael Smith, 2015. A high resolution coupled hydrologic-hydraulic model (HiResFlood-UCI) for flash flood modeling. Journal of Hydrology. 2015. DOI:10.1016/j.jhydrol.2015.10.047.

Nguyen, P., A. Thorstensen, S. Sorooshian, K. Hsu, and A. AghaKouchak, 2015: Flood Forecasting and Inundation Mapping Using HiResFlood-UCI and Near-Real-Time Satellite Precipitation Data: The 2008 Iowa Flood. J. Hydrometeor, 16, 1171–1183. DOI http://dx.doi.org/10.1175/JHM-D-14-0212.1.

HiResFlood-UCI model

Coupling HL-RDHM with BreZo



Nguyen, P., A. Thorstensen, S. Sorooshian, K. Hsu, A. AghaKouchak, B. Sanders, V. Koren, Z. Cui, and Michael Smith, 2015. A high resolution coupled hydrologic-hydraulic model (HiResFlood-UCI) for flash flood modeling. Journal of Hydrology. 2015. DOI:10.1016/j.jhydrol.2015.10.047.

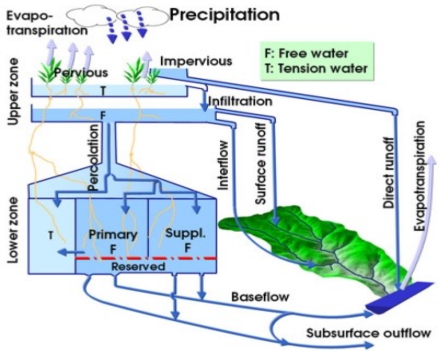
Development of HiResFlood-UCI

Model Heritage

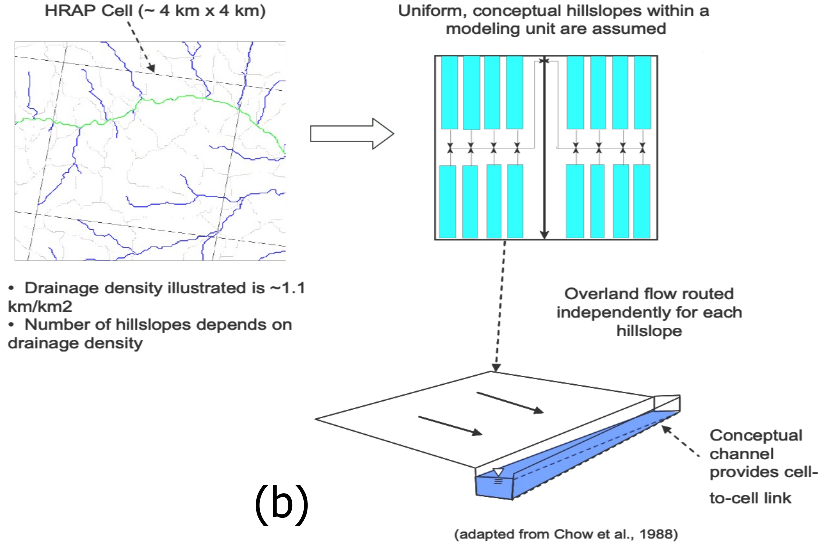
HL-RDHM

HL-RDHM involves four main components: snow-17, SAC-SMA, Continuous API and Overland and Channel Routings (Rutpix7, Rutpix9).

HL-RDHM was designed and implemented for the entire CONUS at two spatial resolutions of 1 HRAP (~4km) and 1/2 HRAP (~2km).



(a)



(b)

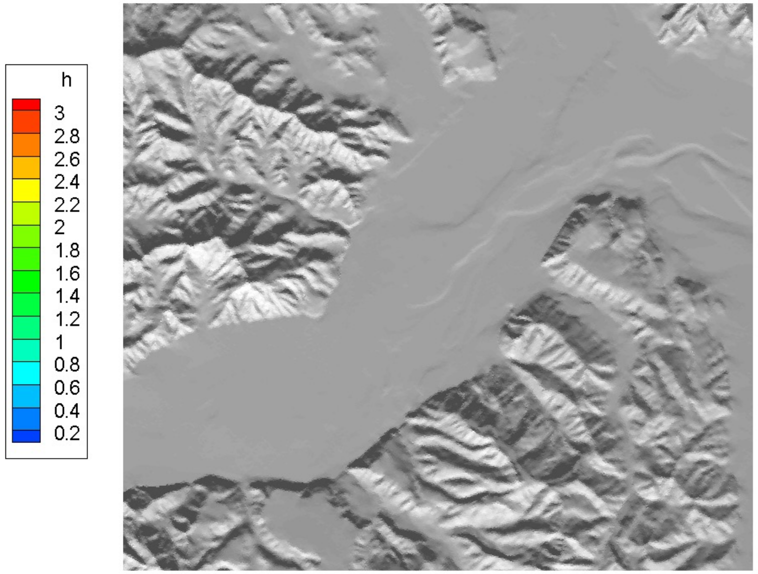
HL-RDHM model: (a) SAC component, (b) Routing scheme

Development of HiResFlood-UCI

Model Heritage

BreZo (Sanders & Begnudelli)

Hydraulic model solving the shallow-water equations using a Godunov-type finite volume algorithm that has been optimized for wetting and drying applications involving natural topography and runs on an unstructured grid of triangular cells.



Demo of BreZo simulation

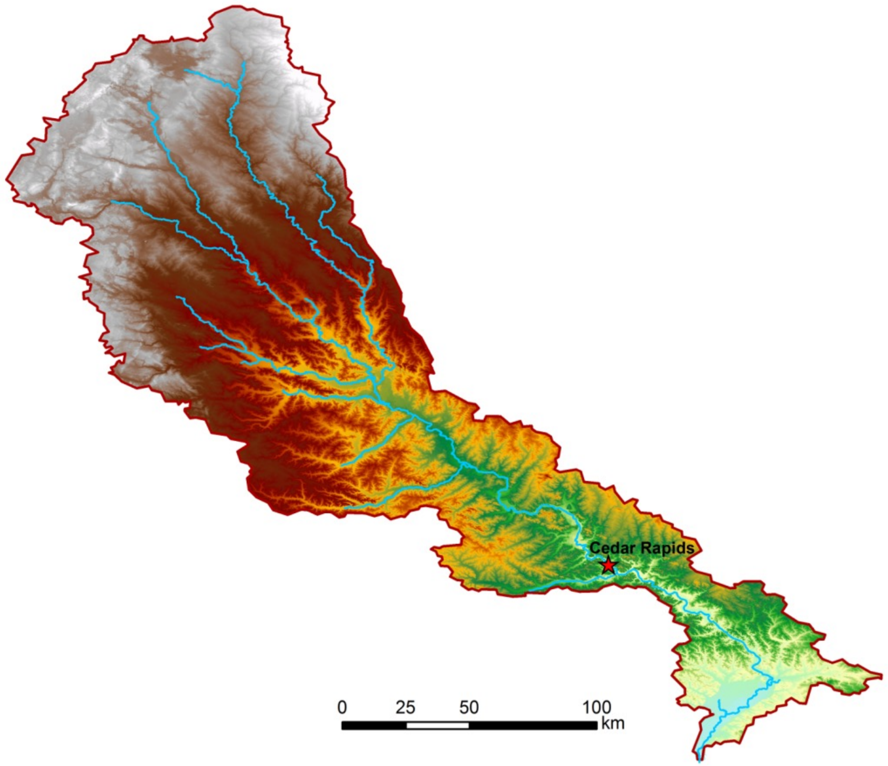
Iowa Flood 2008

Cedar River 2008 Flood

- Some areas flooded beyond 500-year flood level
- 20,000 evacuated
- 3,900 homes under water

Application of HiResFlood-UCI for flood forecasting

Model implementation

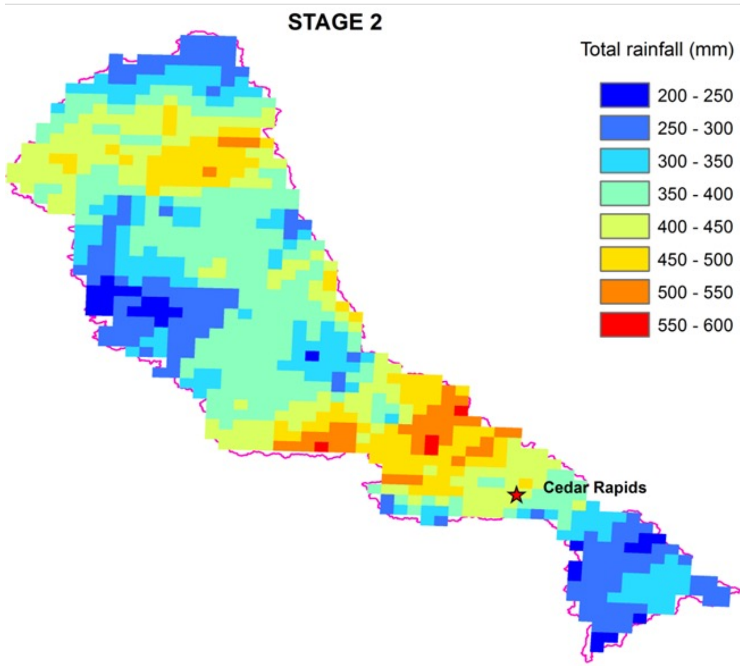


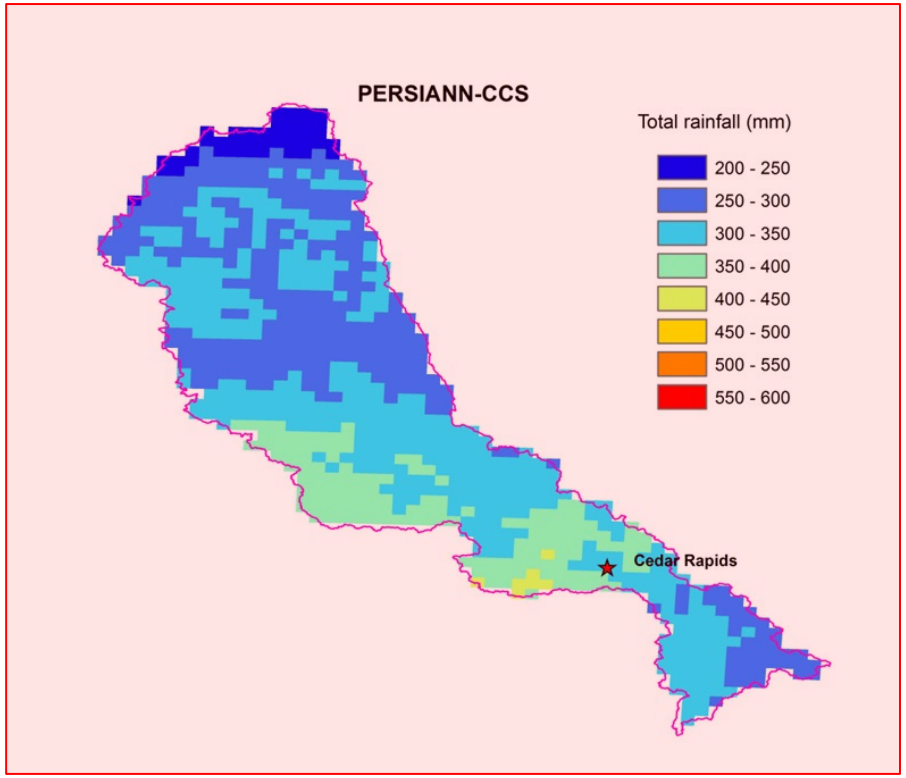
30m DEM

Watershed delineation results

Application of HiResFlood-UCI for flood forecasting

Near real-time precipitation data

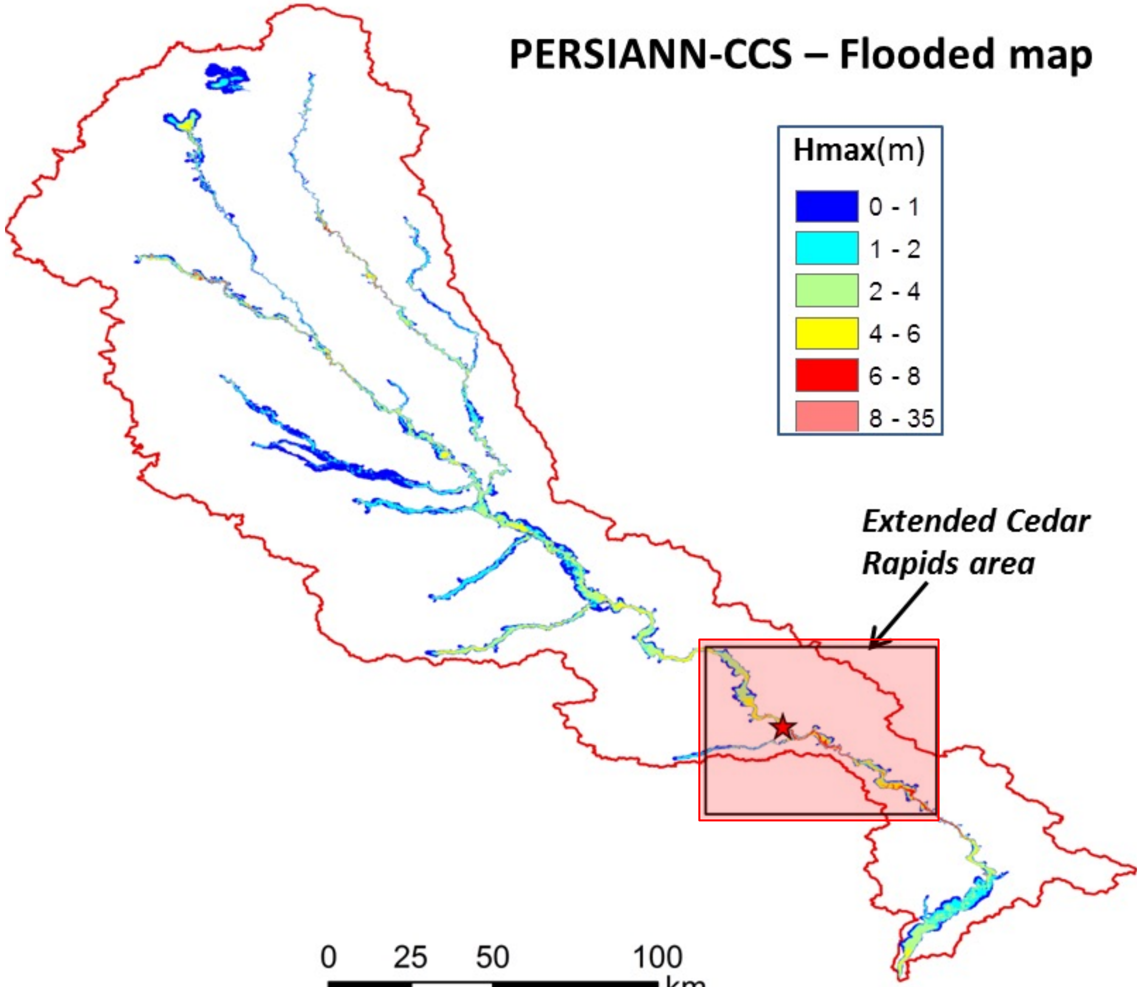




Total precipitation during the event from 29 May 00:00 to 25 June 23:00 2008

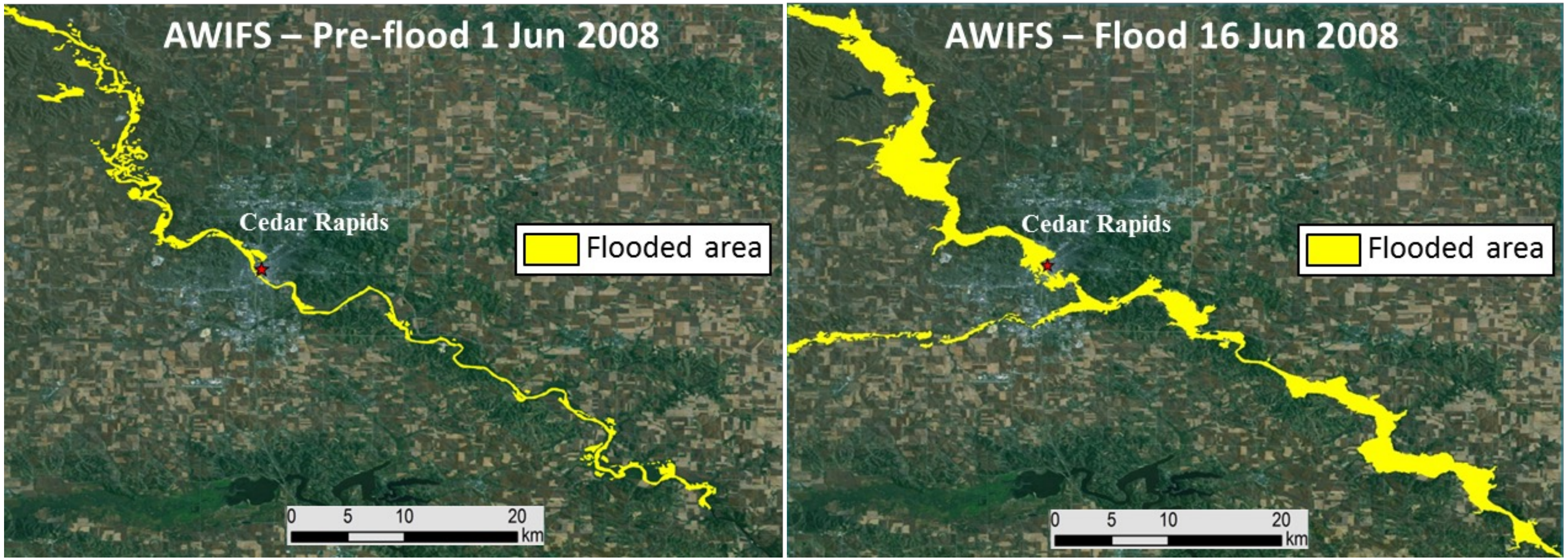
Application of HiResFlood-UCI for flood forecasting

Flooded map



Application of HiResFlood-UCI for flood forecasting

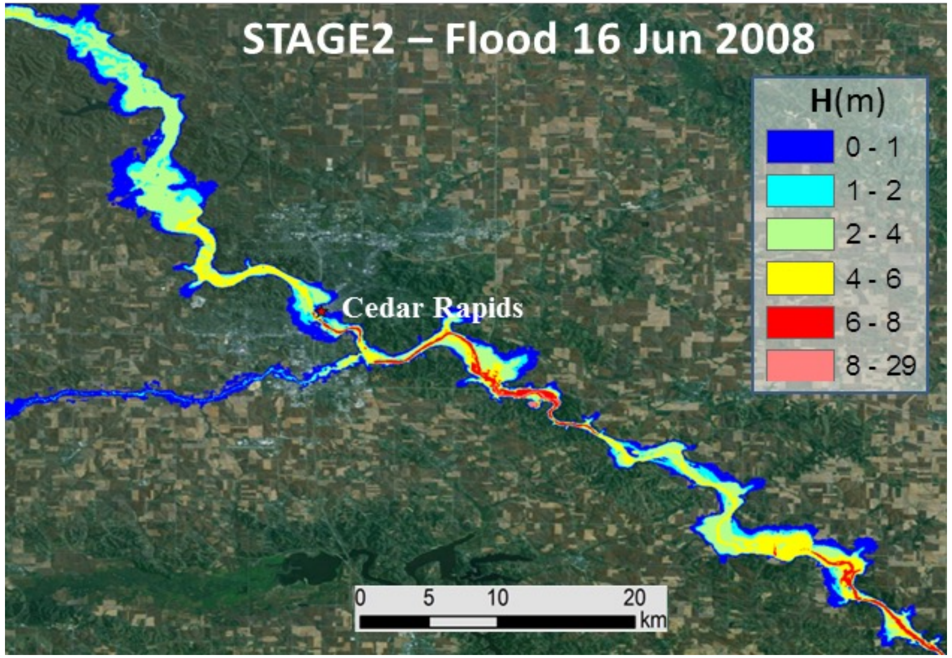
Flooded map

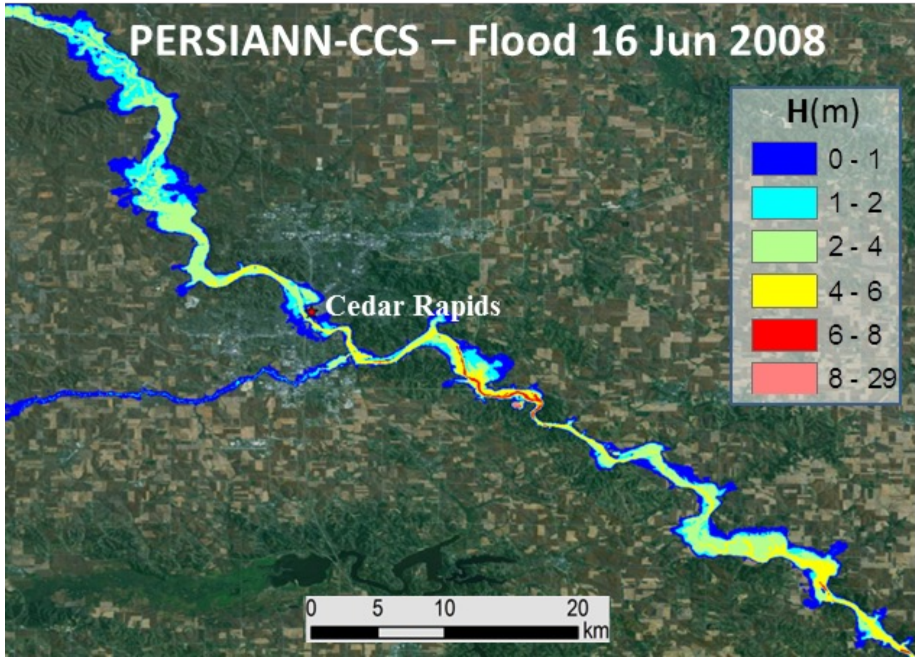


Cleaned flooded maps of pre-flood and flood over the extended Cedar Rapids area

Application of HiResFlood-UCI for flood forecasting

Flooded map



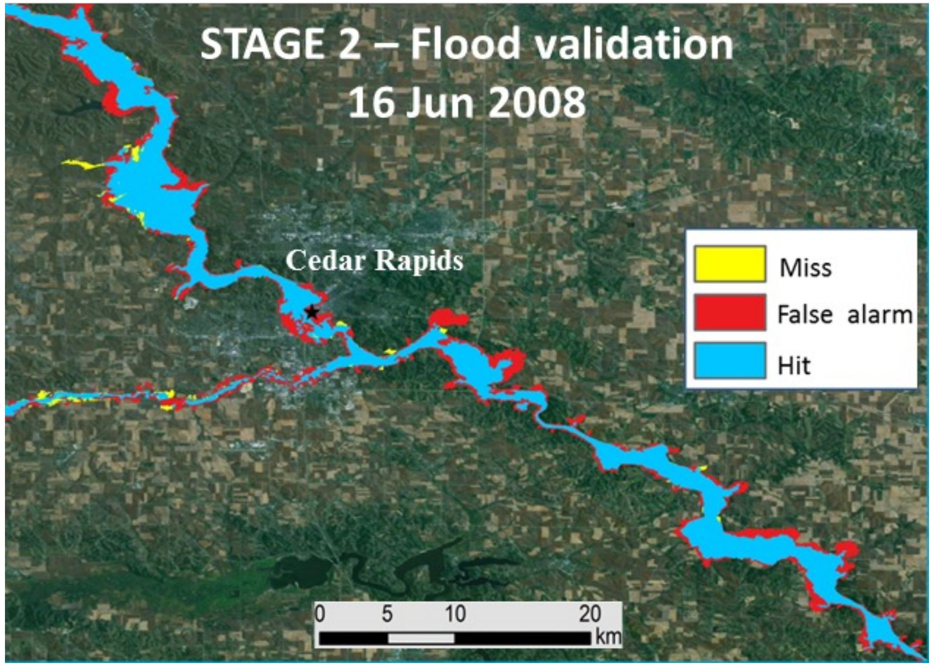


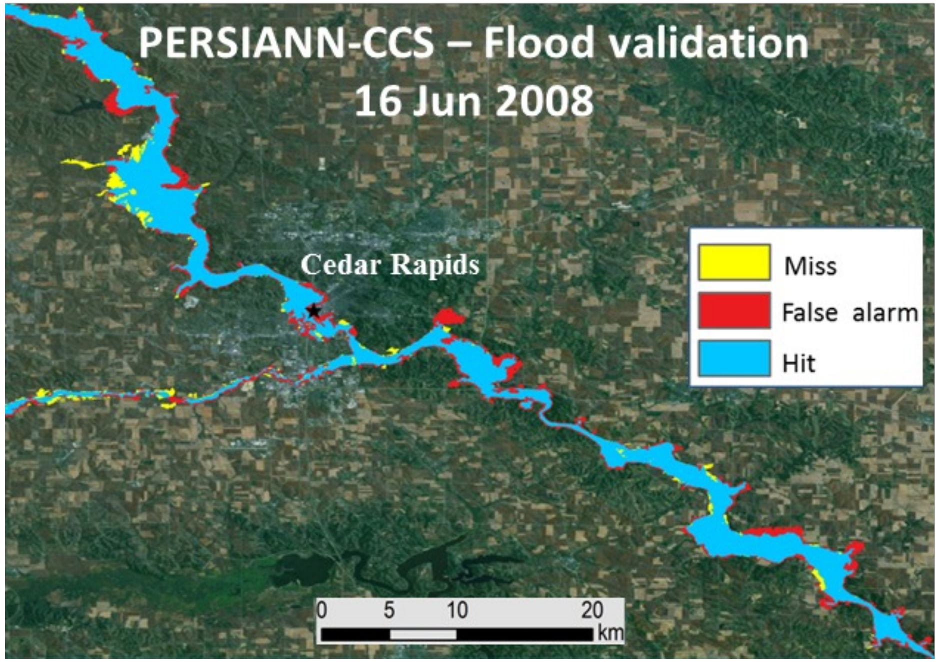
Modeled flood depth maps with Stage 2 and PERSIANN-CCS precipitation data

Application of HiResFlood-UCI for flood forecasting

Flooded map

Precip. input	CSI	POD	FAR
STAGE 2	0.672	0.965	0.311
PERSIANN-CCS	0.727	0.925	0.227





Validations of flooded maps from the model (with STAGE2 and PERSIANN-CCS precipitation) using AWiFS areal imagery

Nguyen, P., A. Thorstensen, S. Sorooshian, K. Hsu, and A. AghaKouchak, 2015: Flood Forecasting and Inundation Mapping Using HiResFlood-UCI and Near-Real-Time Satellite Precipitation Data: The 2008 Iowa Flood. J. Hydrometeor, 16, 1171–1183.
DOI http://dx.doi.org/10.1175/JHM-D-14-0212.1.

Global Rainfall Trend Analysis

Nguyen, P., A. Thorstensen, S. Sorooshian, H. Ashouri, H. Tran, K. Hsu and A. AghaKouchak.
Global precipitation trends across spatial scales. 2016. Under preparation.

Rainfall Trend Analysis

Mann-Kendall Test

We test the null hypothesis H_0 that there is no significant trend in the data at significance level α=0.05 (or 95% confidence level)

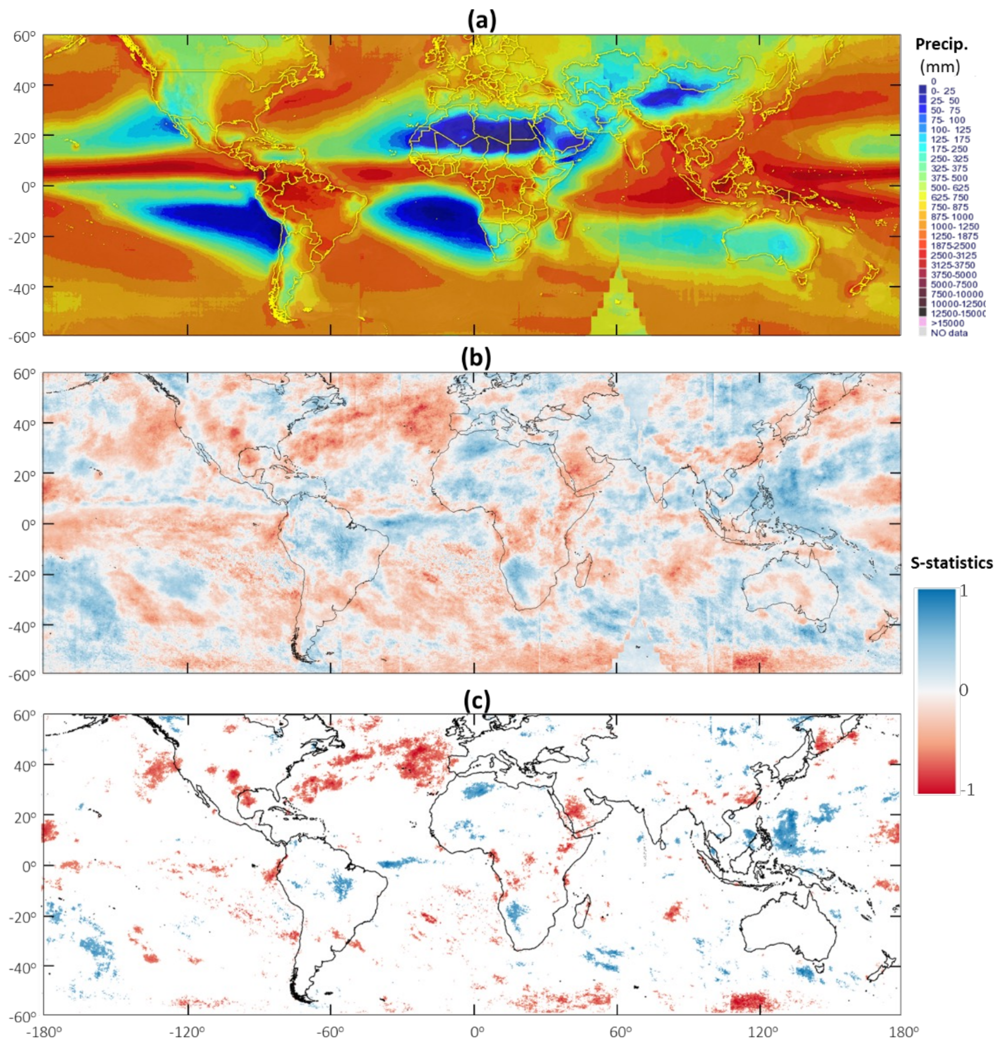
$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$

$$sgn(x_j - x_k) = \begin{cases} +1 & if\ (x_j - x_k) > 0 \\ 0 & if\ (x_j - x_k) = 0 \\ -1 & if\ (x_j - x_k) < 0 \end{cases}$$

$$z = \begin{cases} \dfrac{S-1}{\sqrt{\dfrac{n(n-1)(2n+5)}{18}}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sqrt{\dfrac{n(n-1)(2n+5)}{18}}} & if\ S < 0 \end{cases}$$

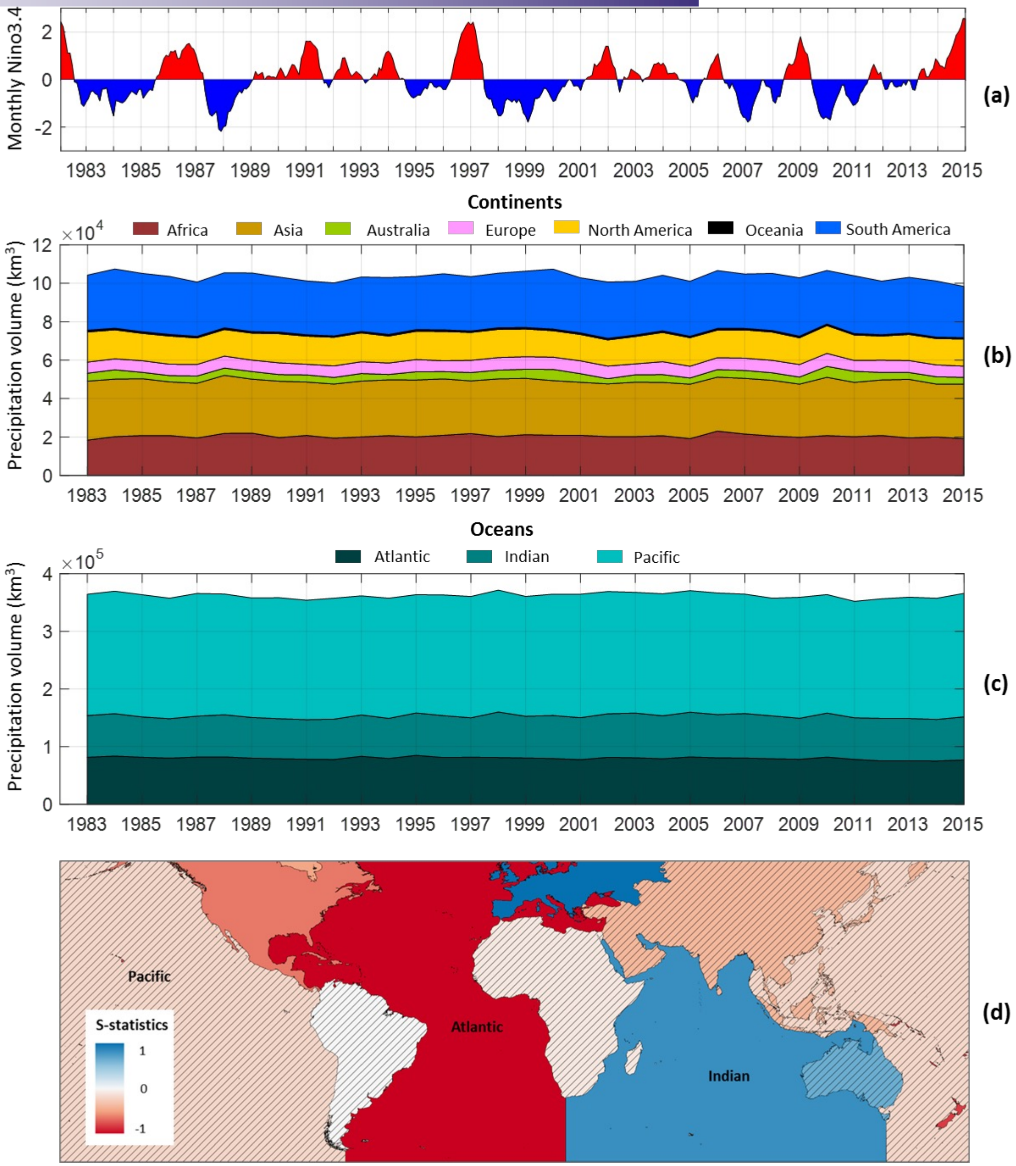
$$p = 0.5 - \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{-t^2/2}\, dt$$

Rainfall Trend Analysis



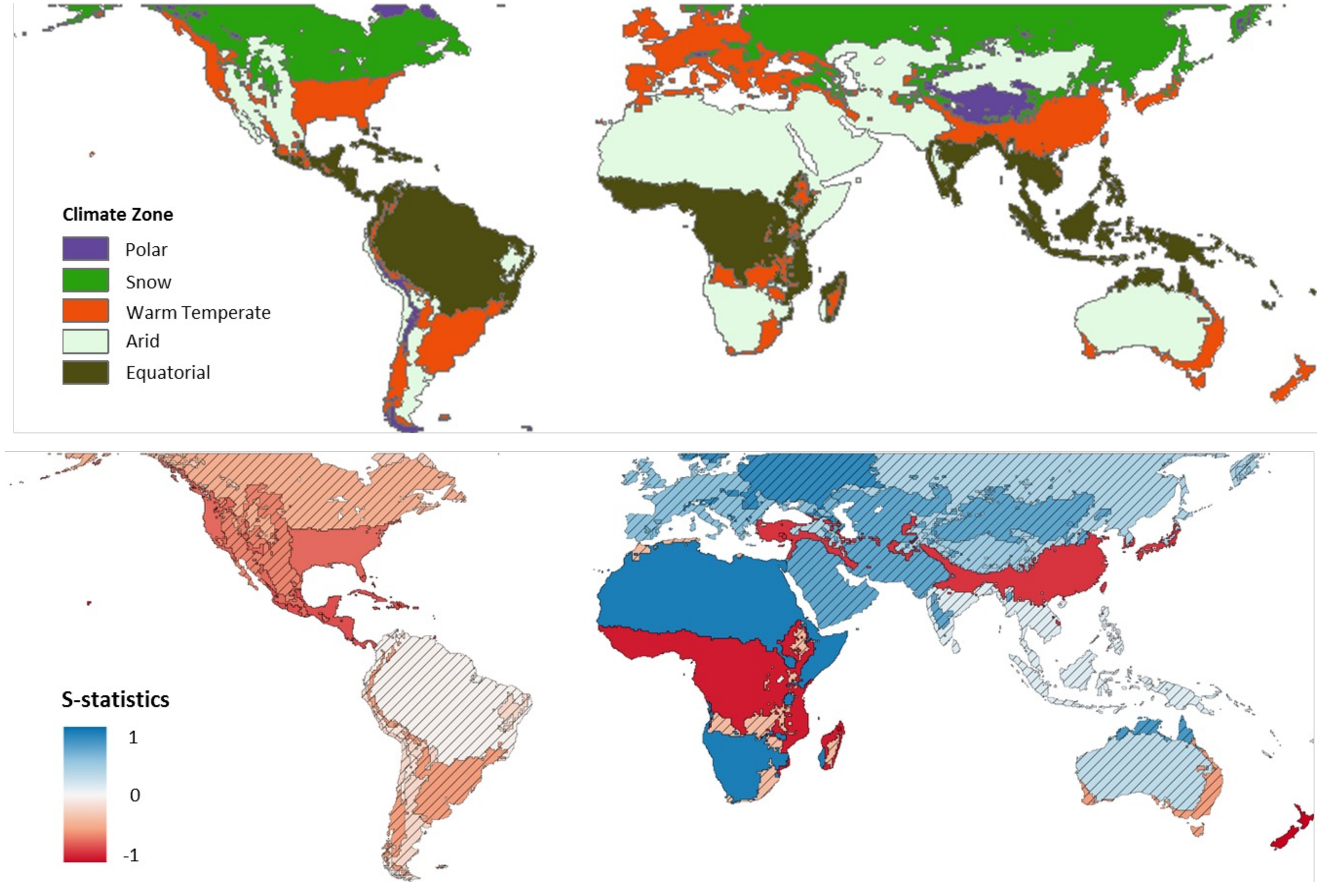
Annual mean precipitation in mm (a) and pixel-based precipitation trends (b, c) from 1983 to 2015 from PERSIANN-CDR

Rainfall Trend Analysis



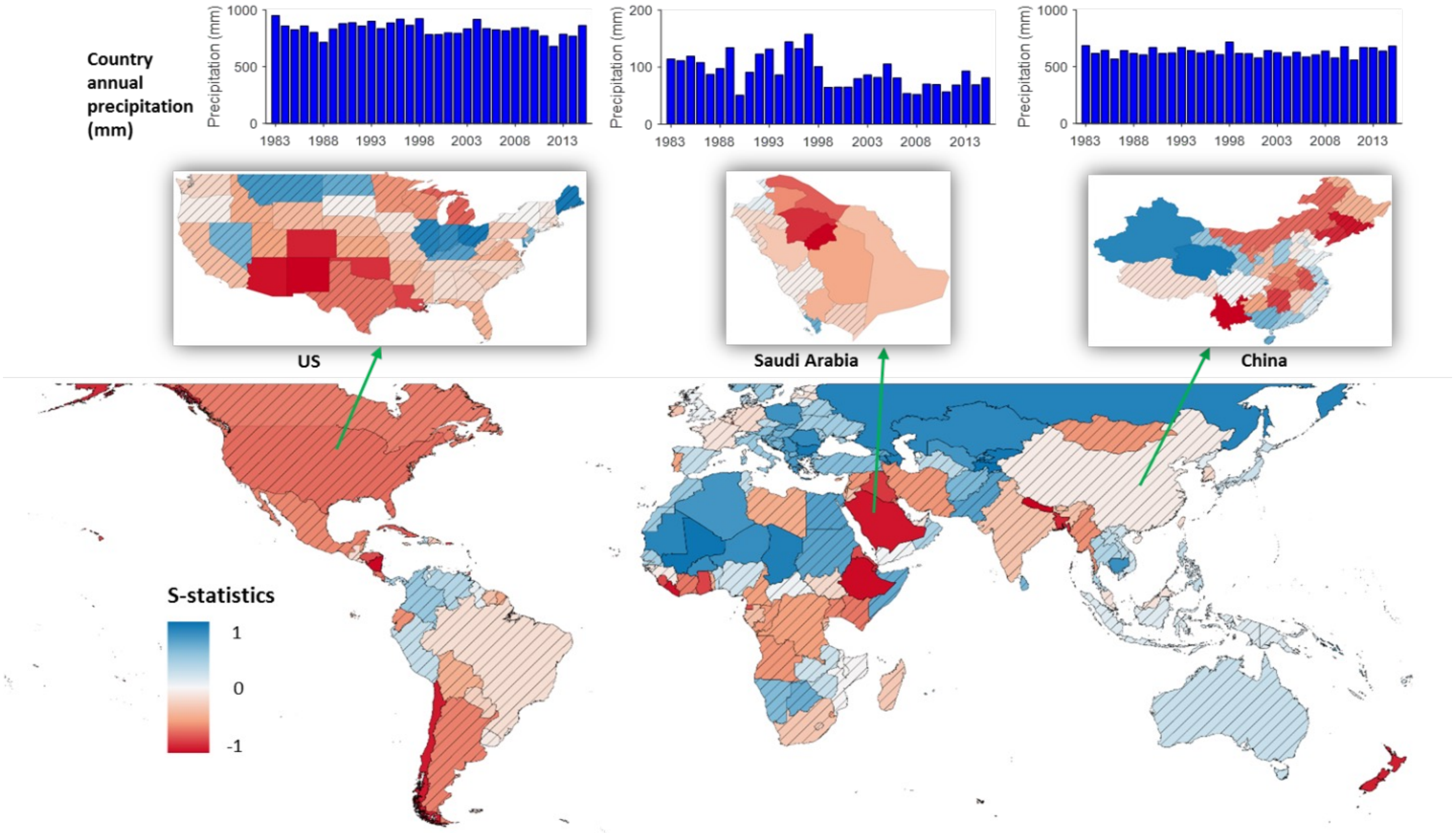
Monthly Nino3.4 (a) Changes in precipitation volume (b, c) and precipitation volume trends (d) over continents and oceans.

Rainfall Trend Analysis



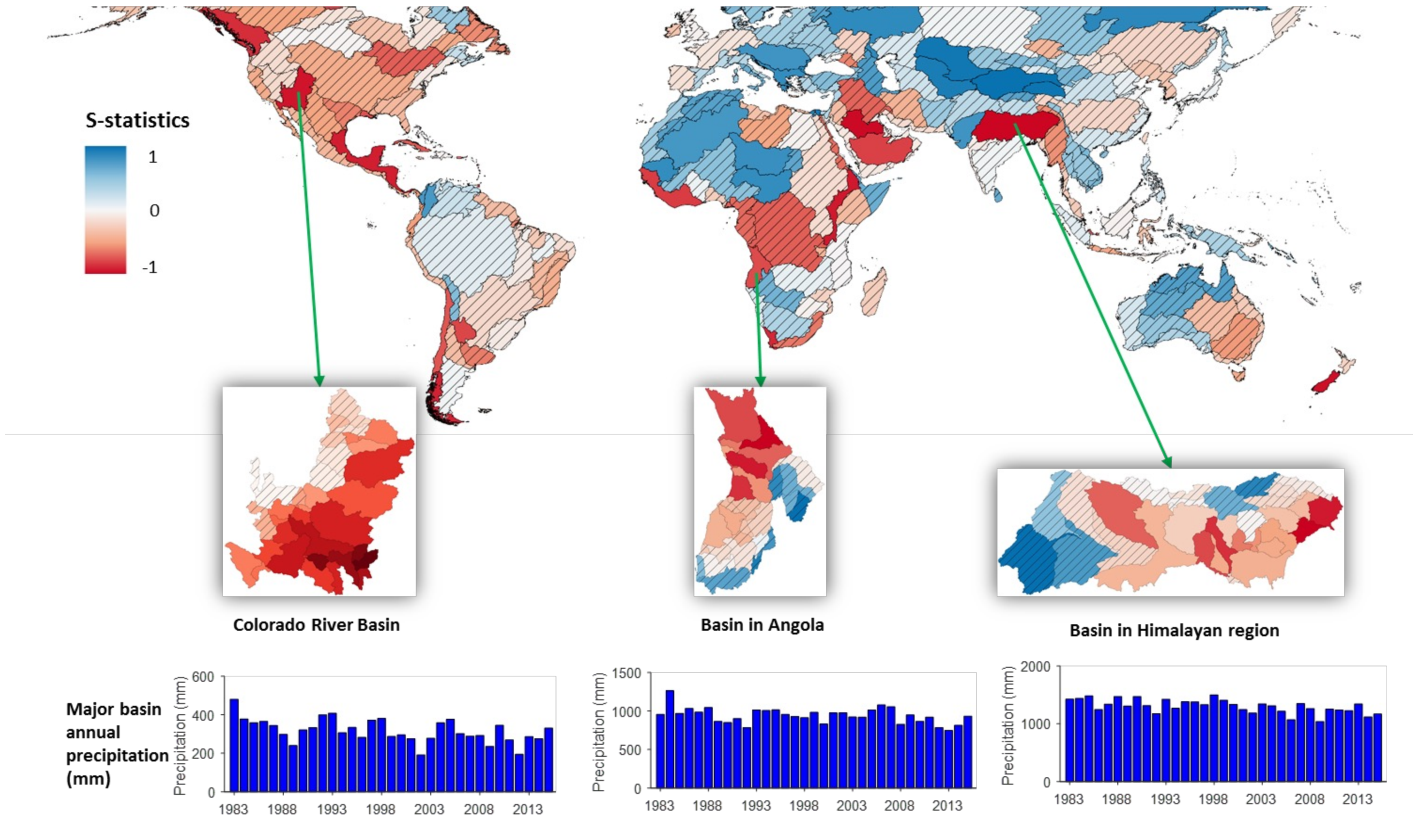
Precipitation trends from 1983 to 2015 over climate zones (60°N - 60°S)

Rainfall Trend Analysis



Precipitation trends from 1983 to 2015 over 201 countries (60°N - 60°S) and state/province political divisions of US, Saudi Arabia and China

Rainfall Trend Analysis



Precipitation trends from 1983 to 2015 over 237 global major basins

Thank you for your attention!

Questions?

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Kuolin Hsu (kuolinh@uci.edu)
Phu Nguyen (ndphu@uci.edu)