Challenges and Limitations of Hydroclimatological Forecasting and the Relative Role of its Three Pillars: Models, Observations and Parameterization

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Center for Hydrometeorology and Remote Sensing - University of California Irvine

CAHMDA/DAFOH Workshop

Center for Integrated Earth System Science

UT Austin– Texas : Sept. 8th -12th 2014

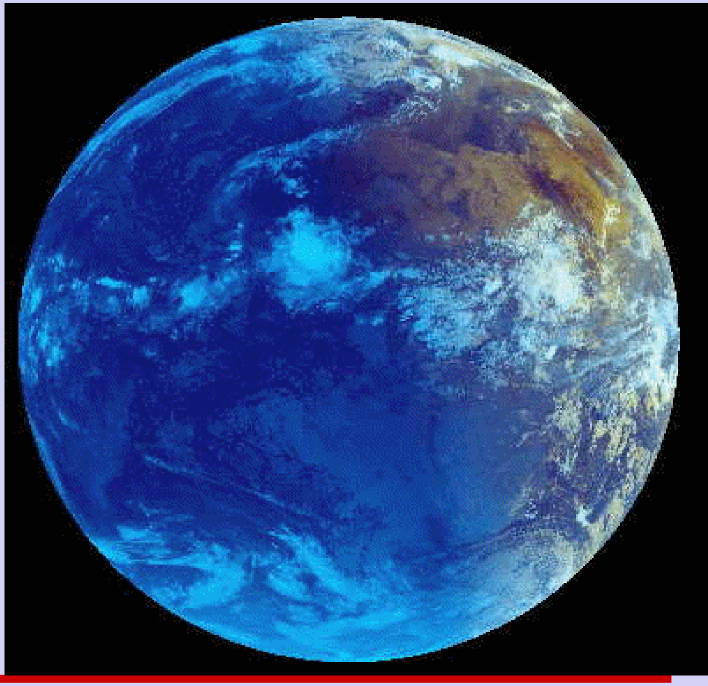
University of California Irvine (UCI)

Research Team: Present and Recent Past

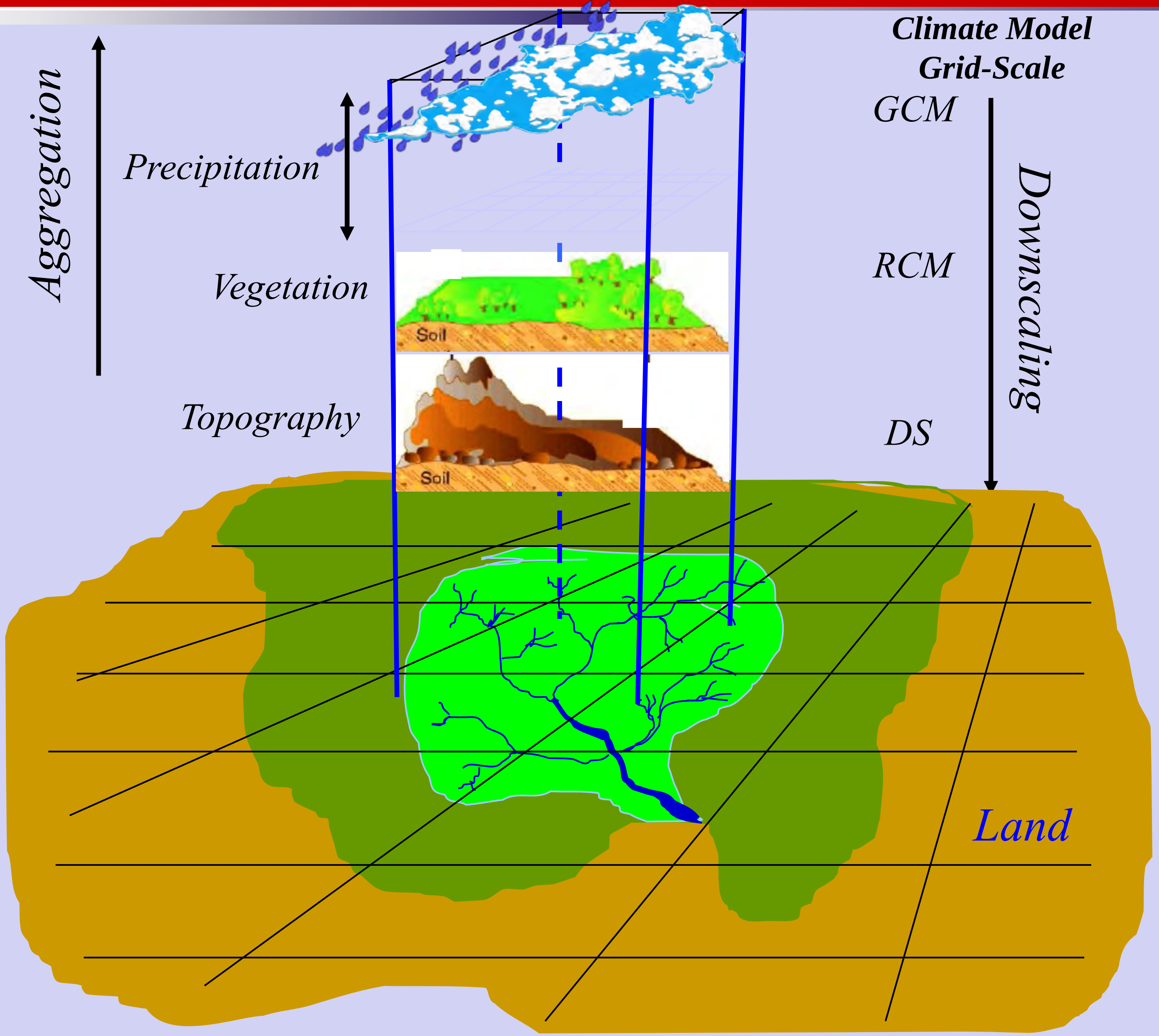
Climate, Hydrology and Water Resources

- ***How will Climate effect water Availability?***

- ***Can we predict the future changes which are responsive to "user" needs?***

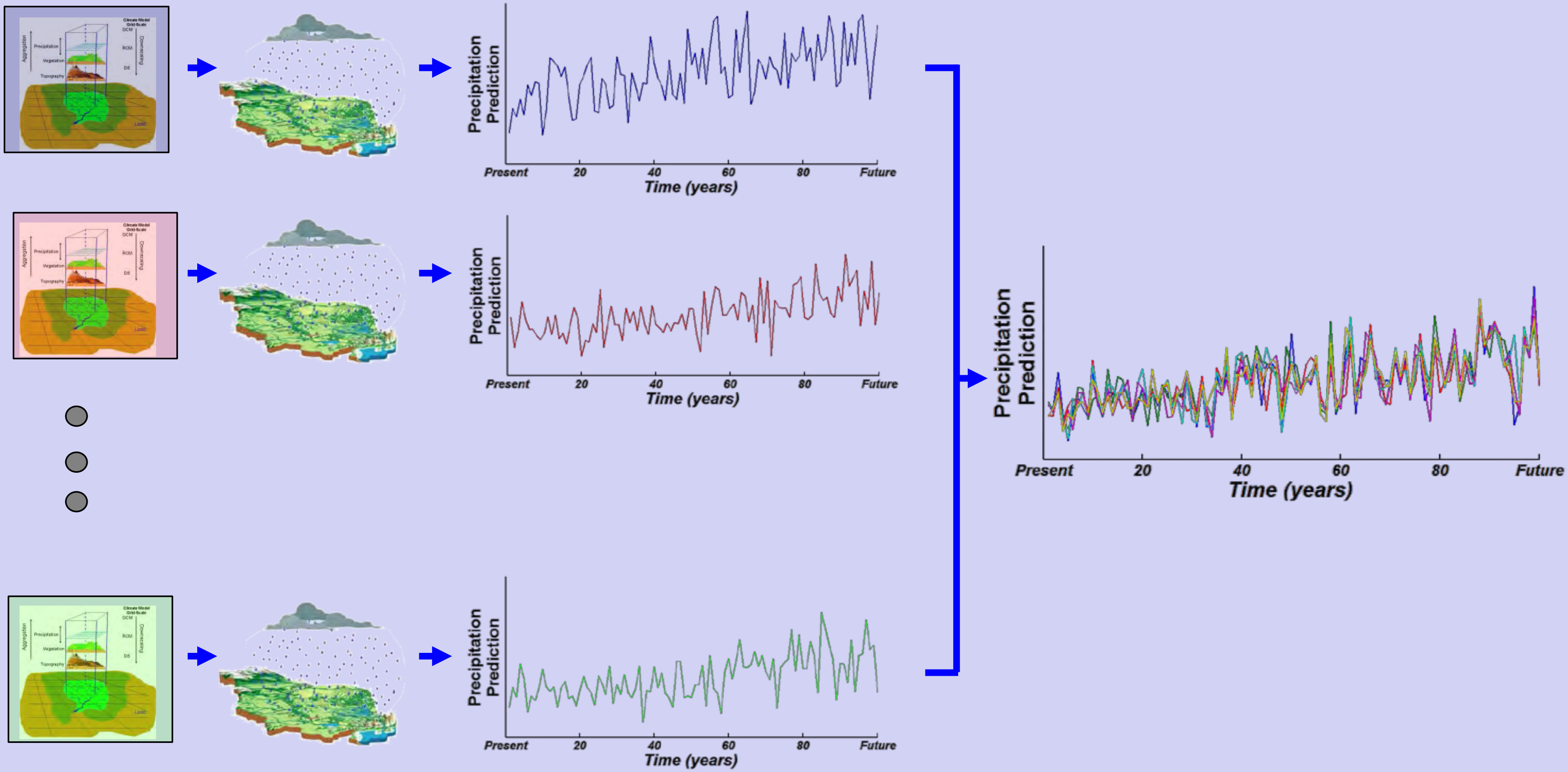


Climate Model Downscaling to regional/watershed Scale



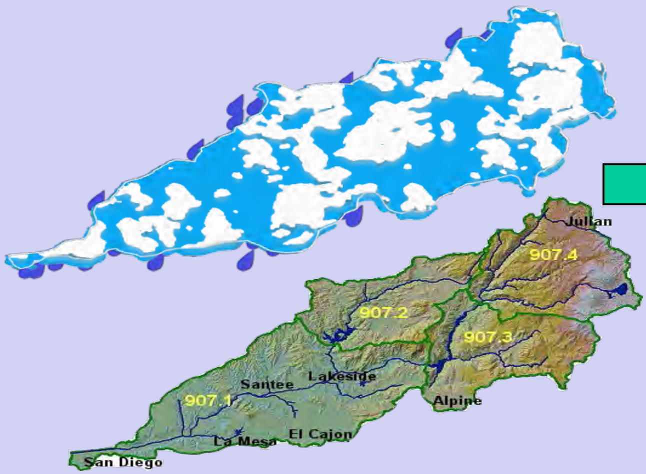
Ensemble Approach

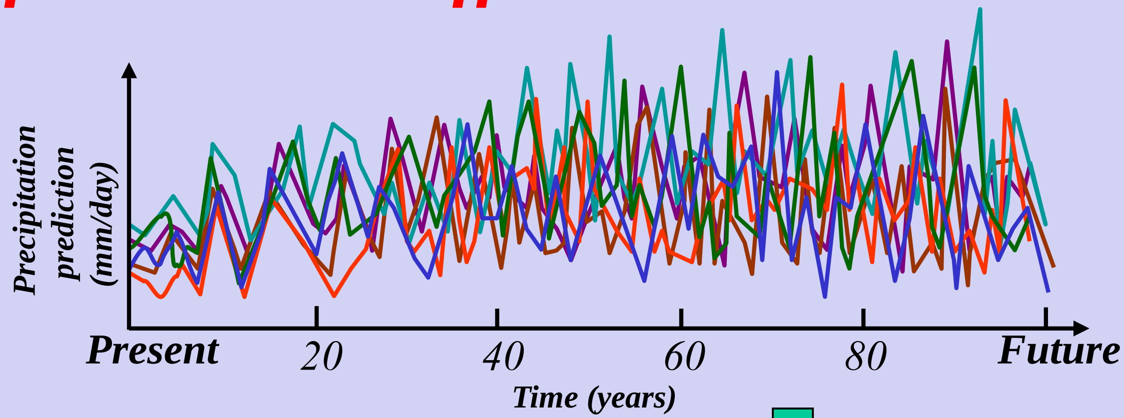
Generation of Future Precipitation Scenarios

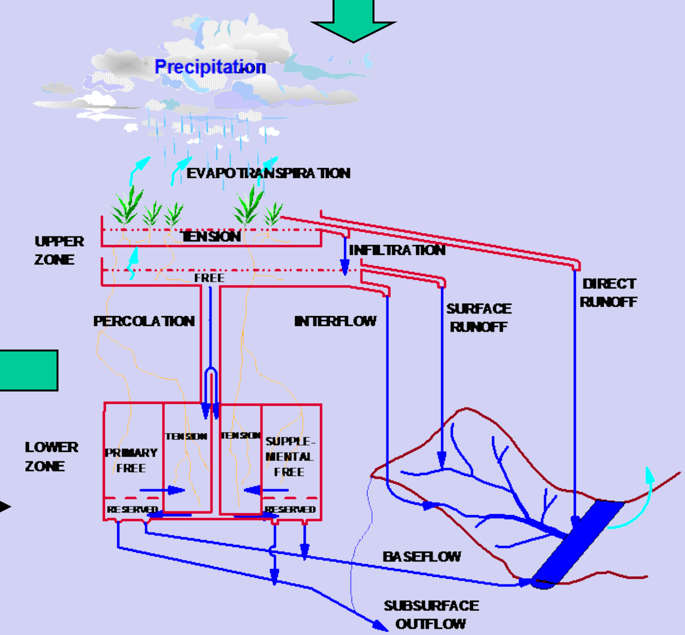


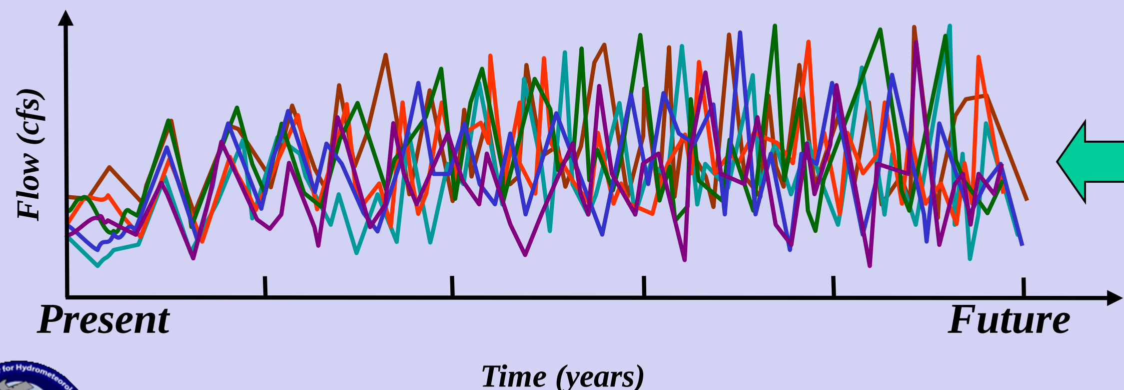
Downscaled Precipitation to Runoff Generation

Generation of Future Runoff Scenarios







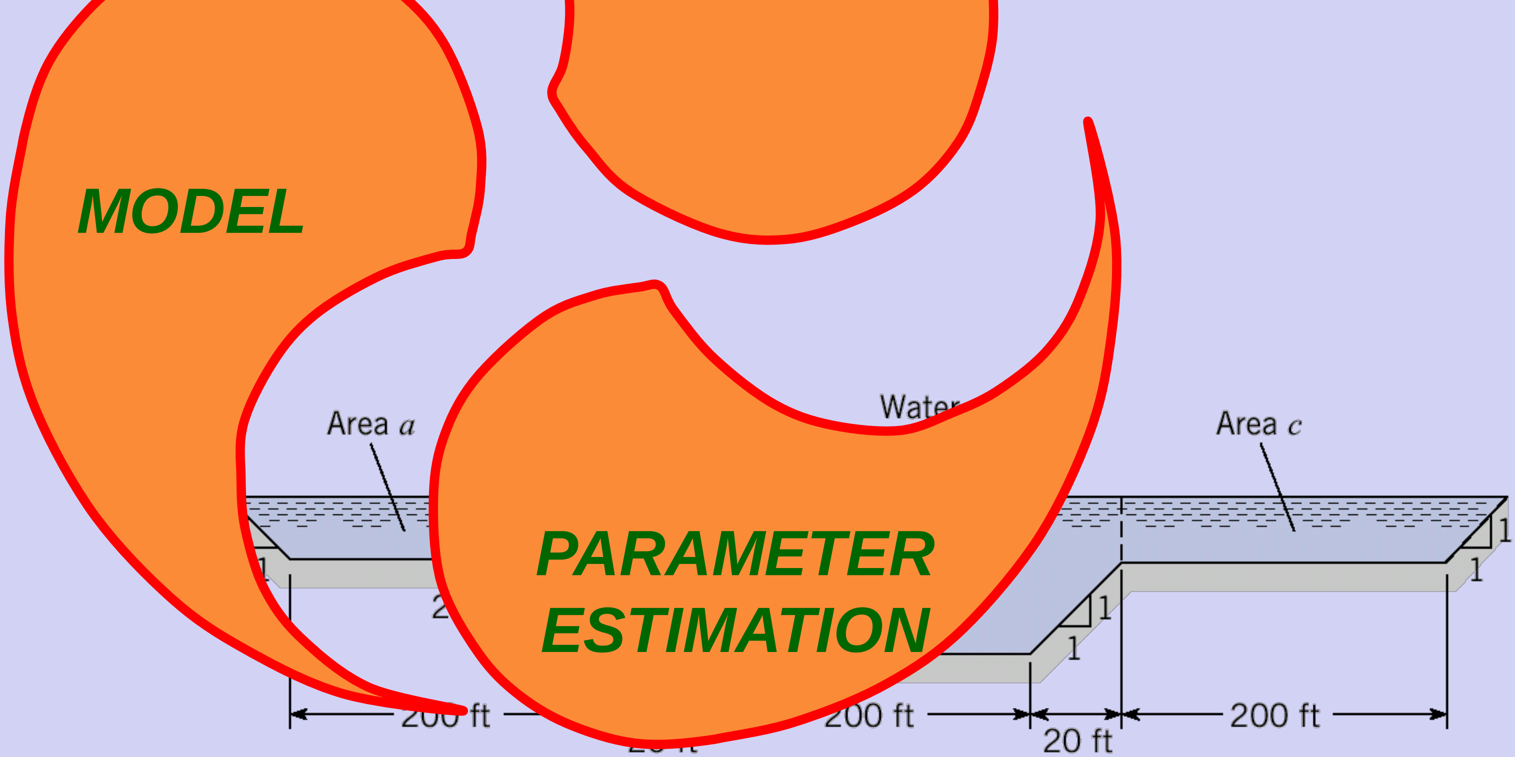


Brief Review of Rainfall Runoff modeling:

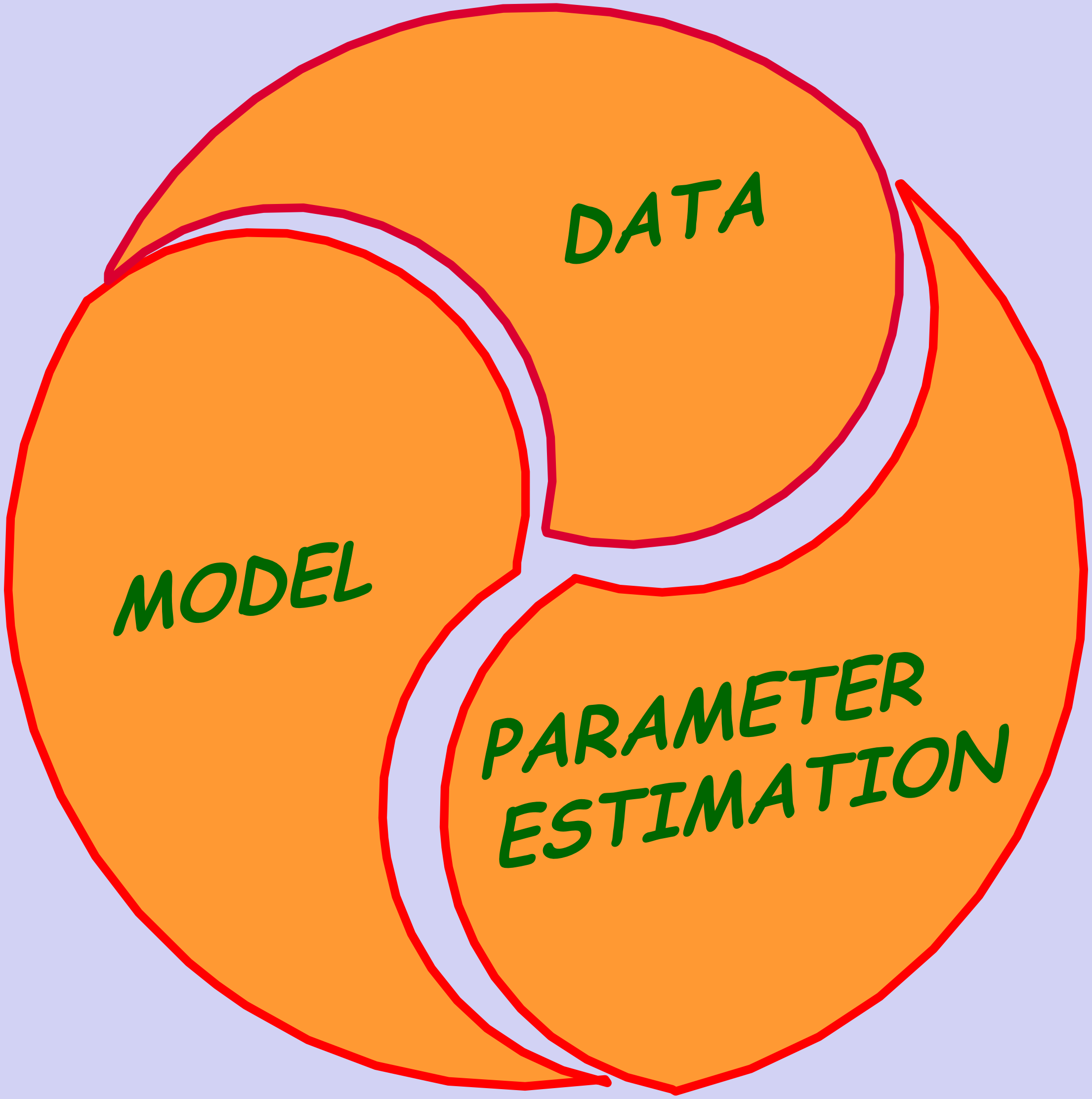
Progress in Hydrologic Modeling

Hydrologic Modeling: 3 Elements!

If the "World" of Watershed Hydrology Was Perfect!



Model Selection

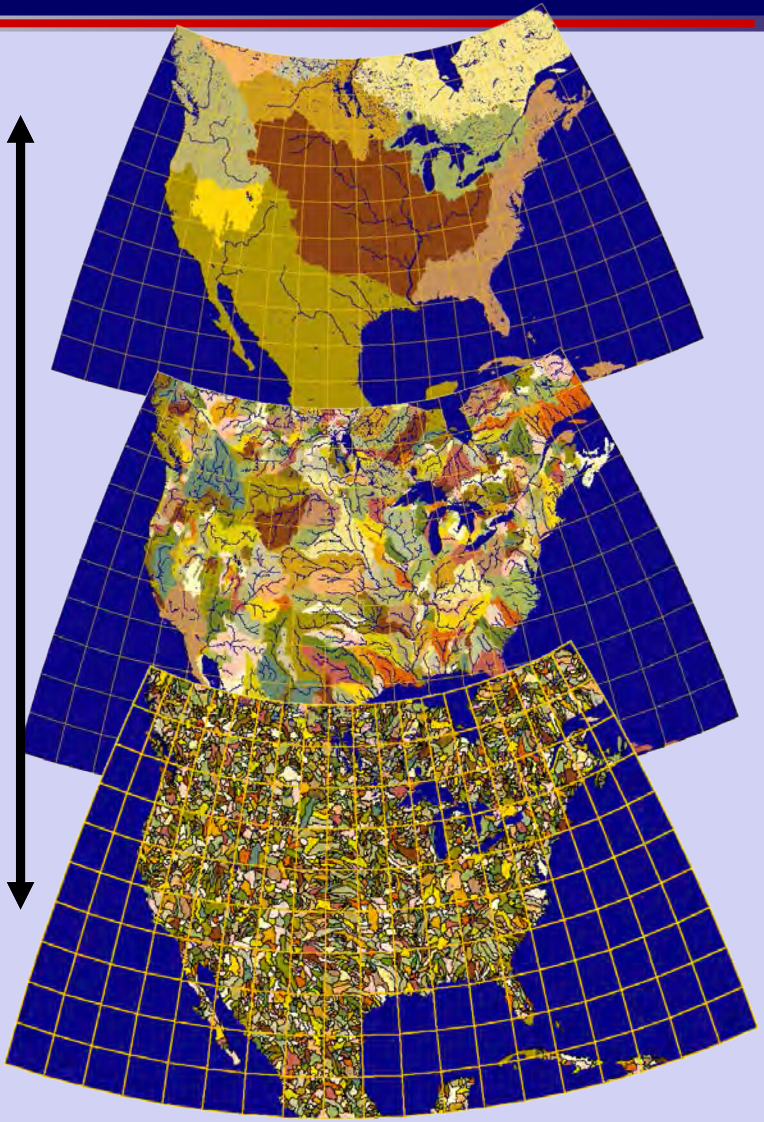


Hydrologic Modeling Challenges

Continental Scale:

Focus of Hydro-Climate modelers

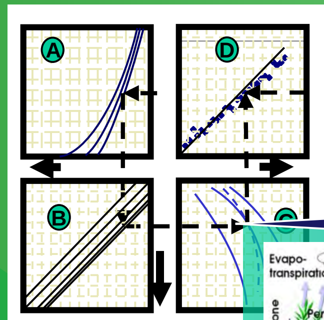
Different Scales
Different Issues
Different Stakeholders



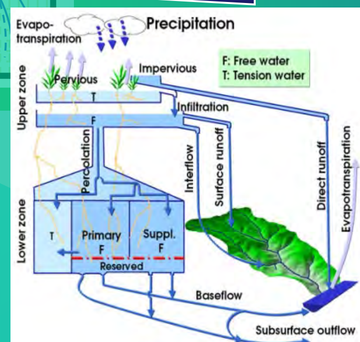
Watershed Scale:

Focus of Hydro-Met. Modeling
Where hydrology happens

Evolution of Hydrologic R-R Models

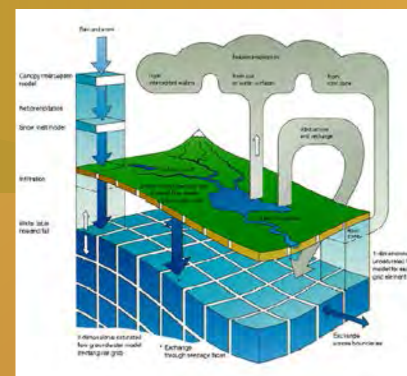


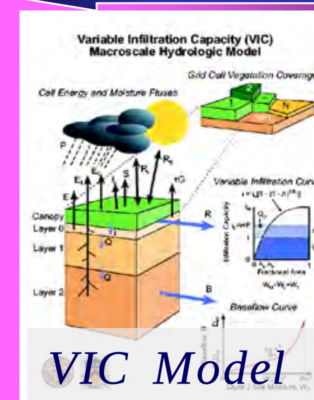
API Model



Lumped Conceptual

Distributed (Mike SHE)





VIC Model

Lumped

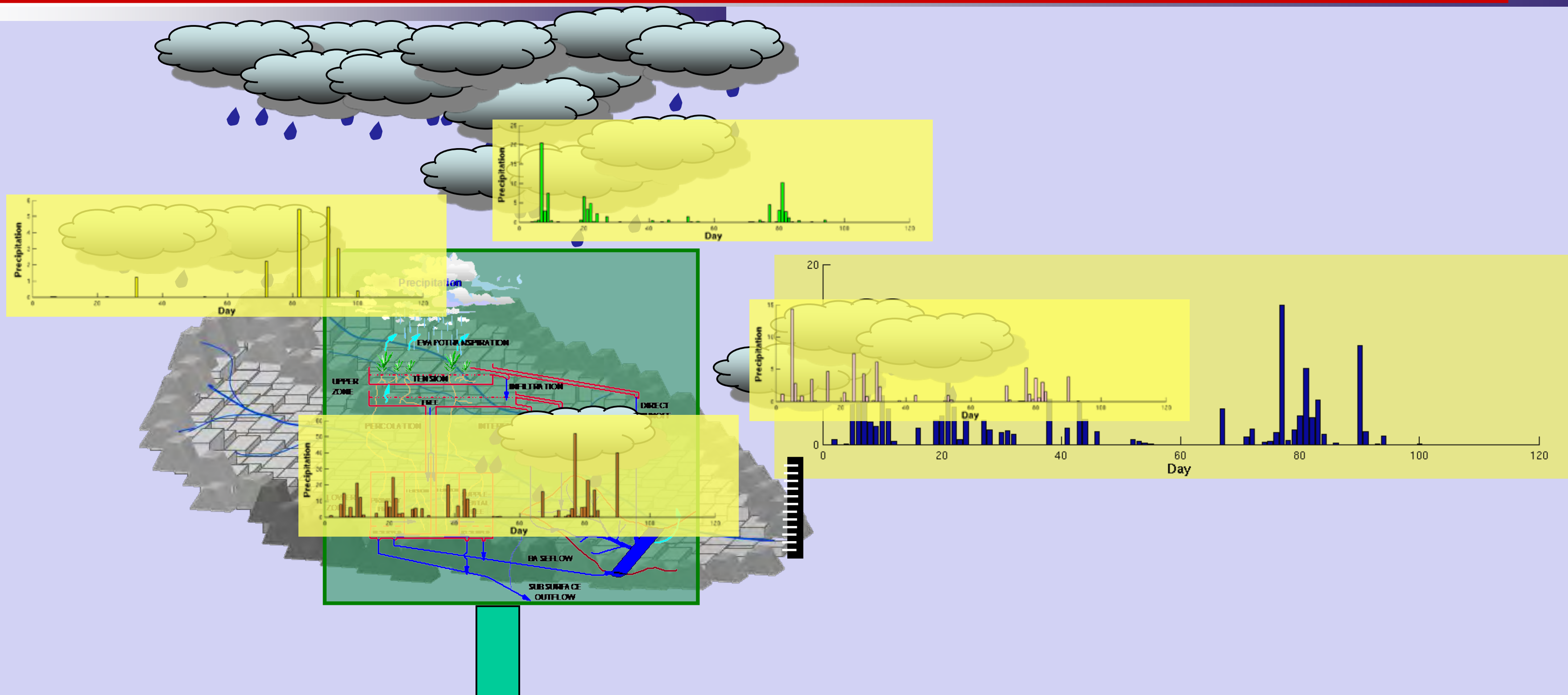
"Simple"

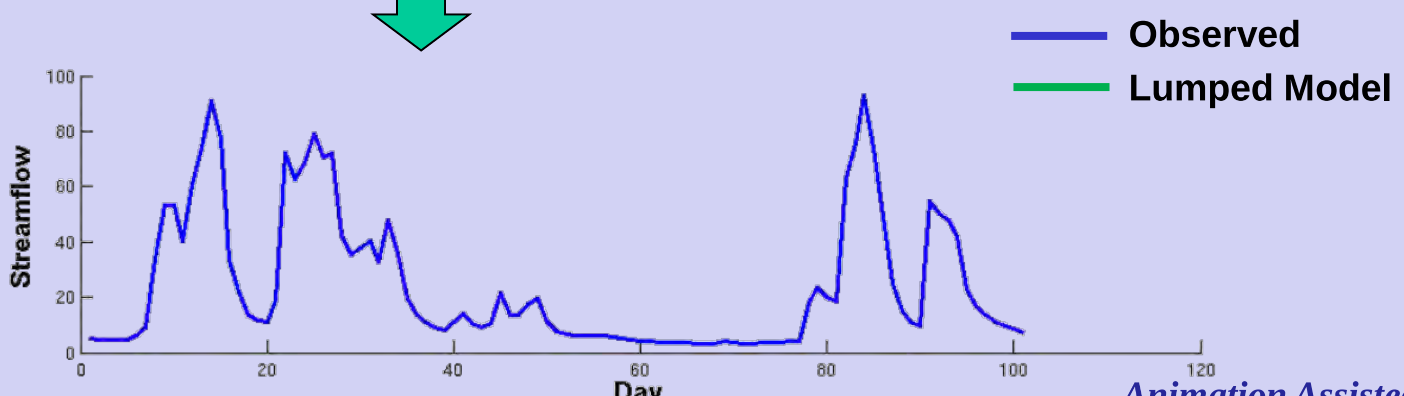
Time

Distributed

Physically-based

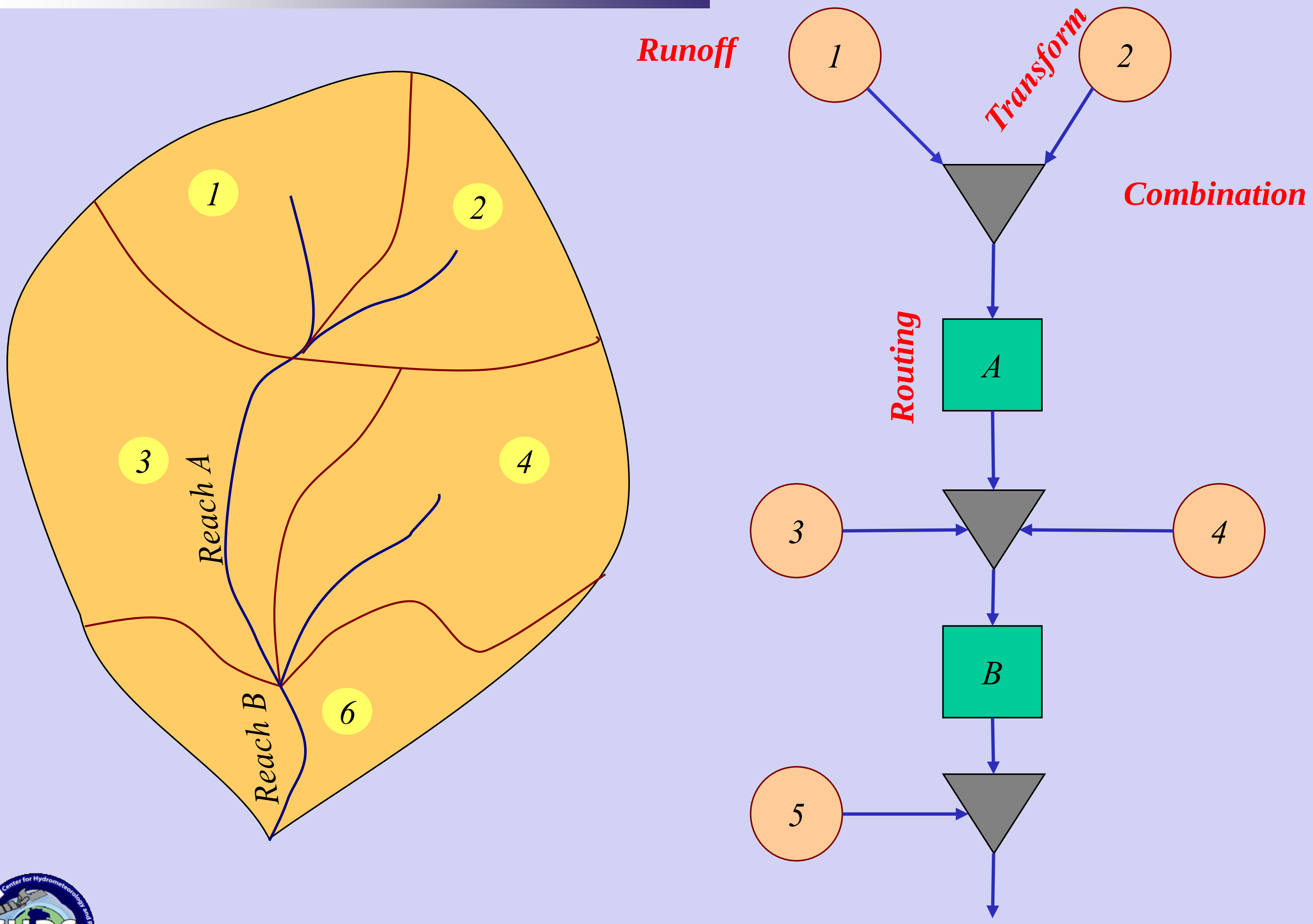
Hydrologic Modeling: "Lumped"



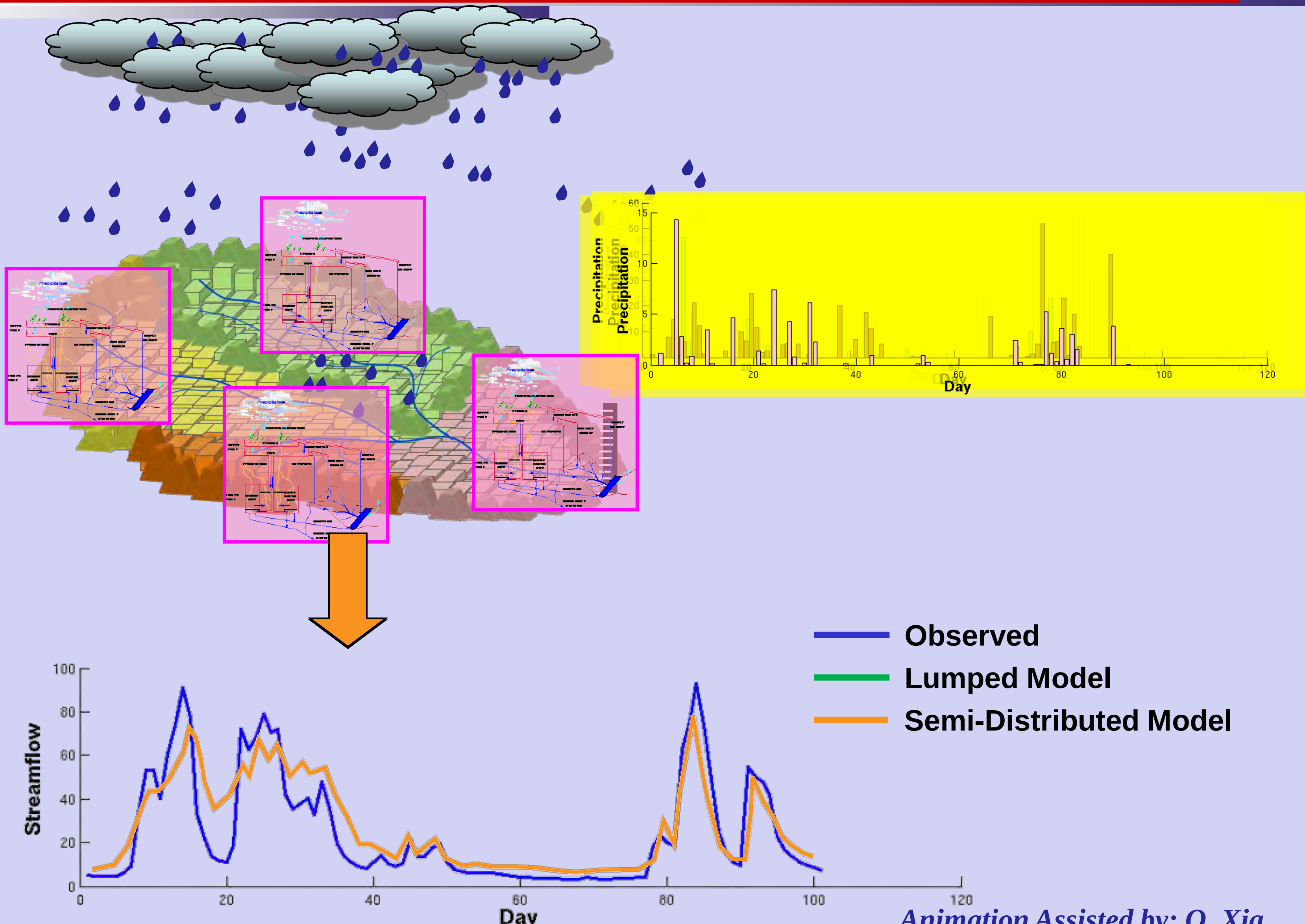


Animation Assisted by: Q. Xia

"Semi-distributed" Hydrologic Models

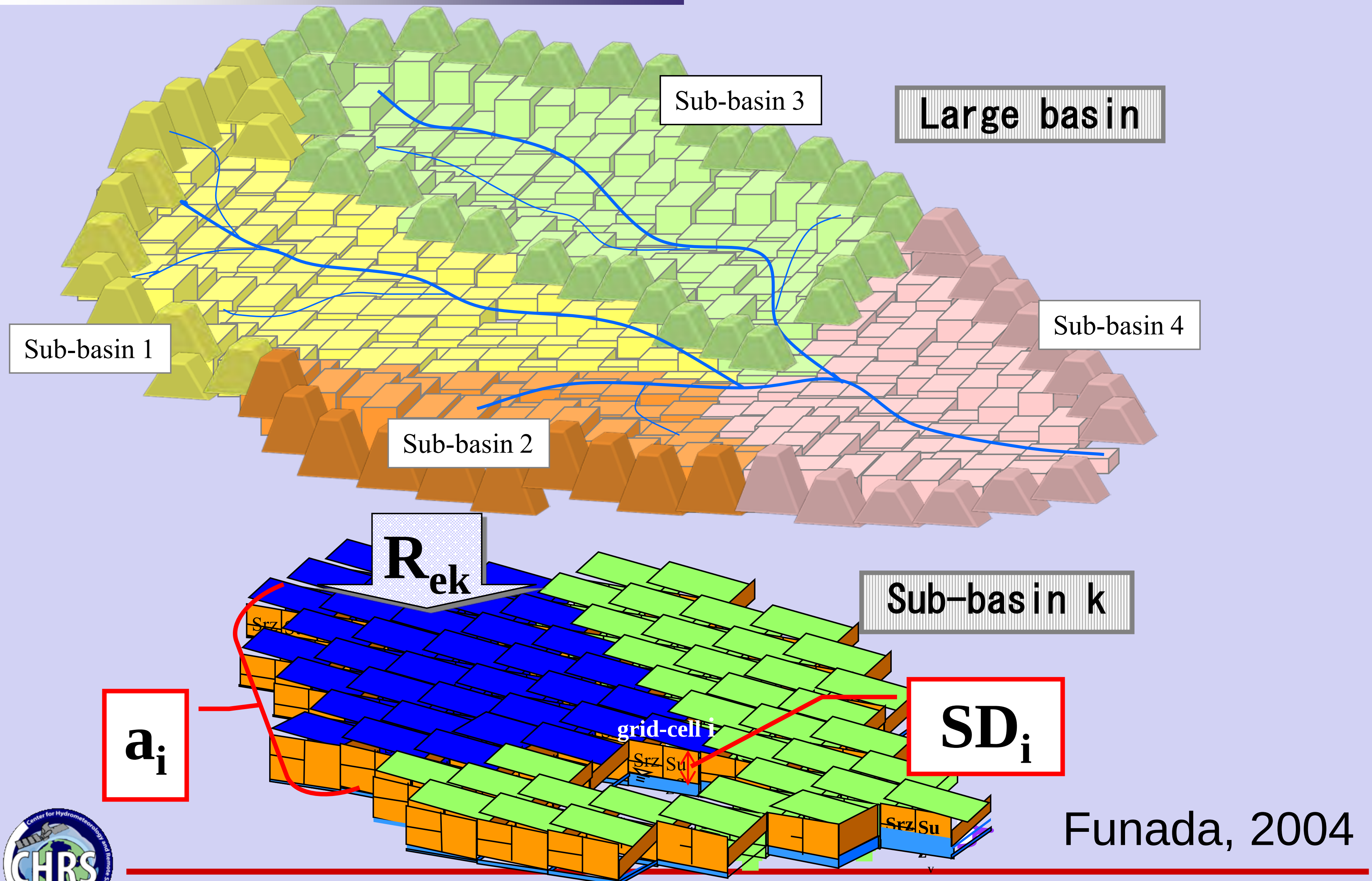


"Semi-distributed" Hydrologic Models

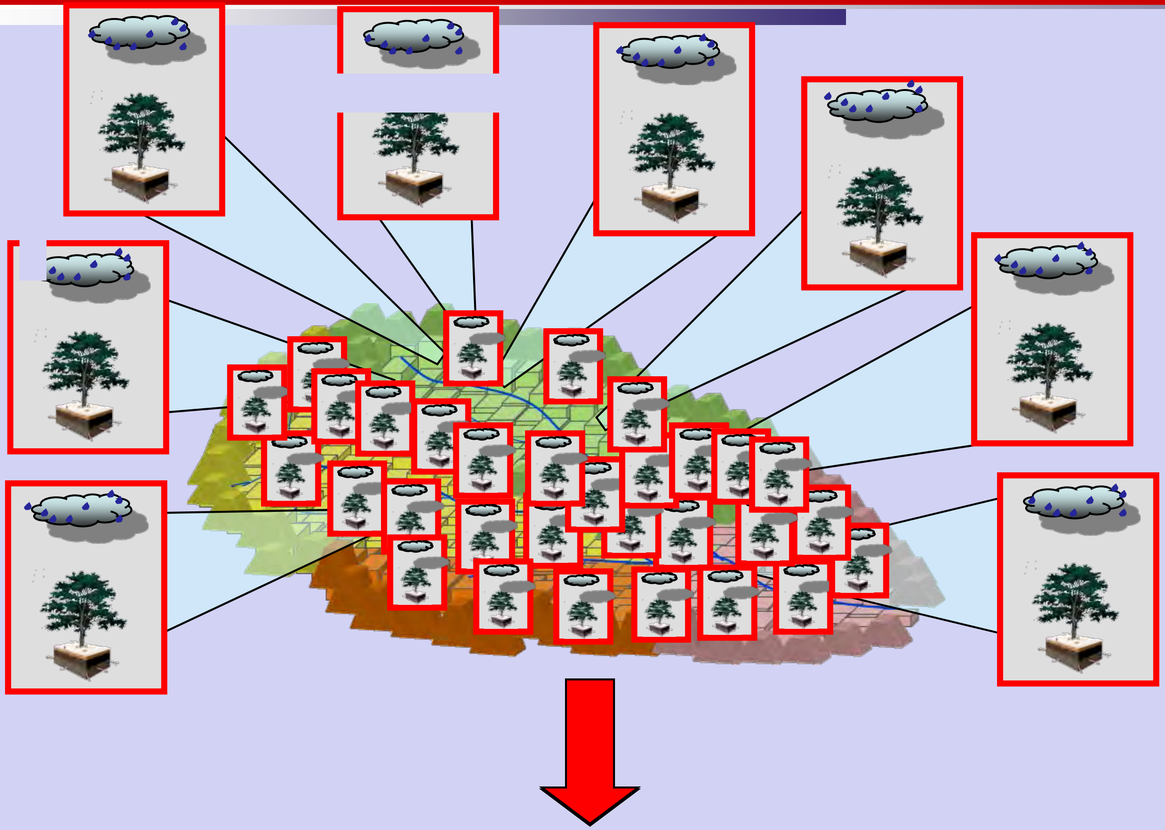


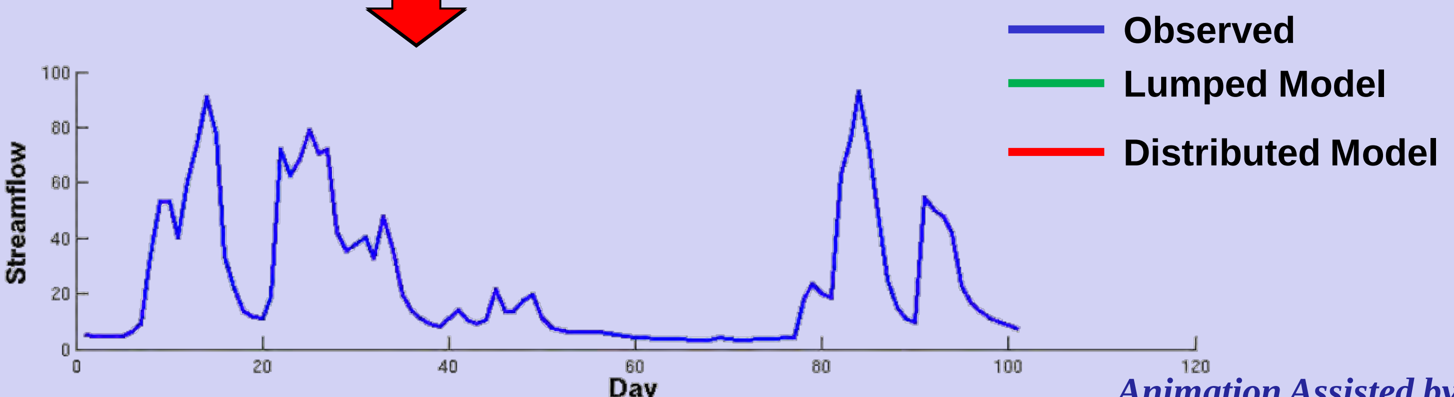
Animation Assisted by: Q. Xia

Example of Distributed Model Appl. in large Basins



Example of Distributed Hydrologic Model

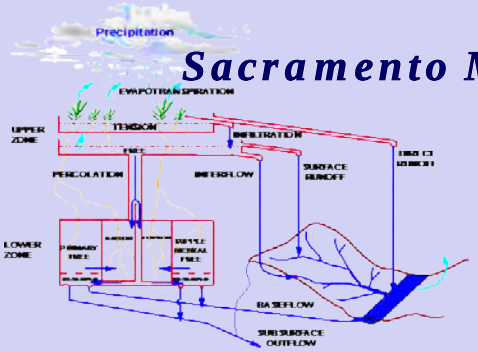




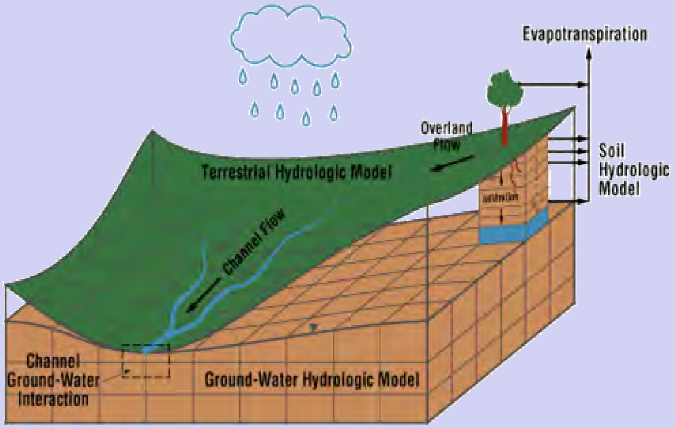
Animation Assisted by: Q. Xia

DMIP-1 Findings: In a Nutshell

Sacramento Model

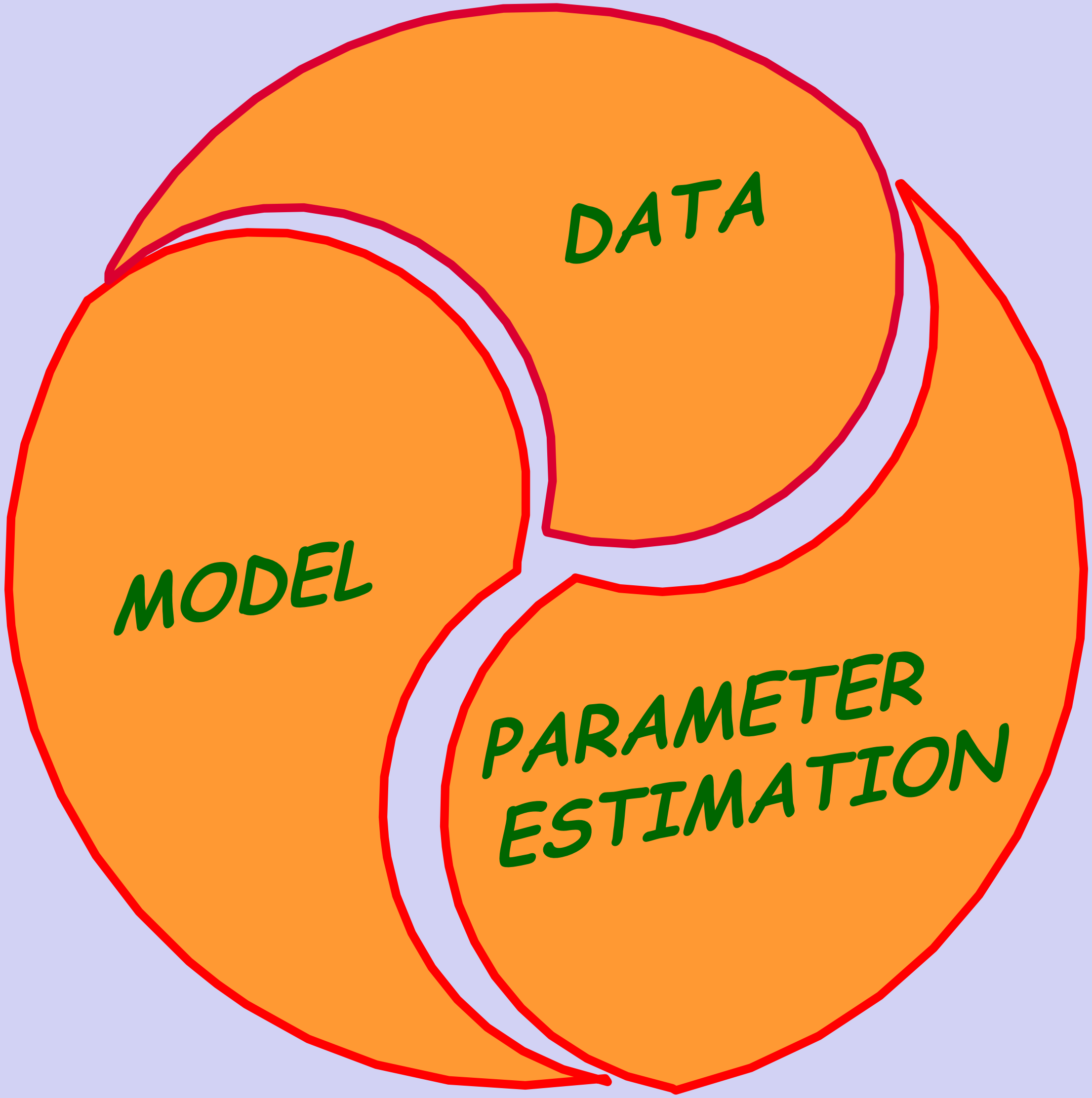


No Major Difference between the performance of Lumped and distributed models



DMIP 1 Results (From Reed et al., 2004)

Model Calibration/ Parameter Estimation



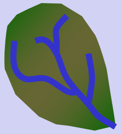
The Identification Problem

1. Select a model structure (Input-State-Output equations)

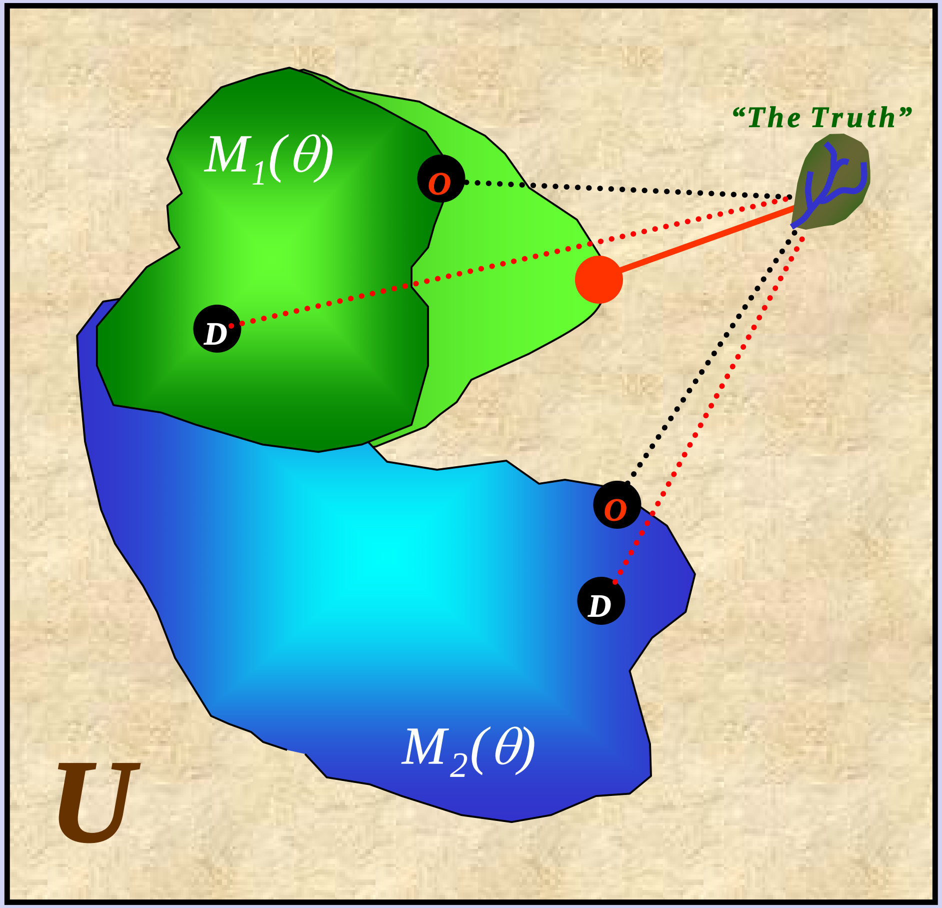
2. Estimate values for the parameters

U – Universal Set

B - Basin



$M_i(\theta)$ – Selected Model Structure

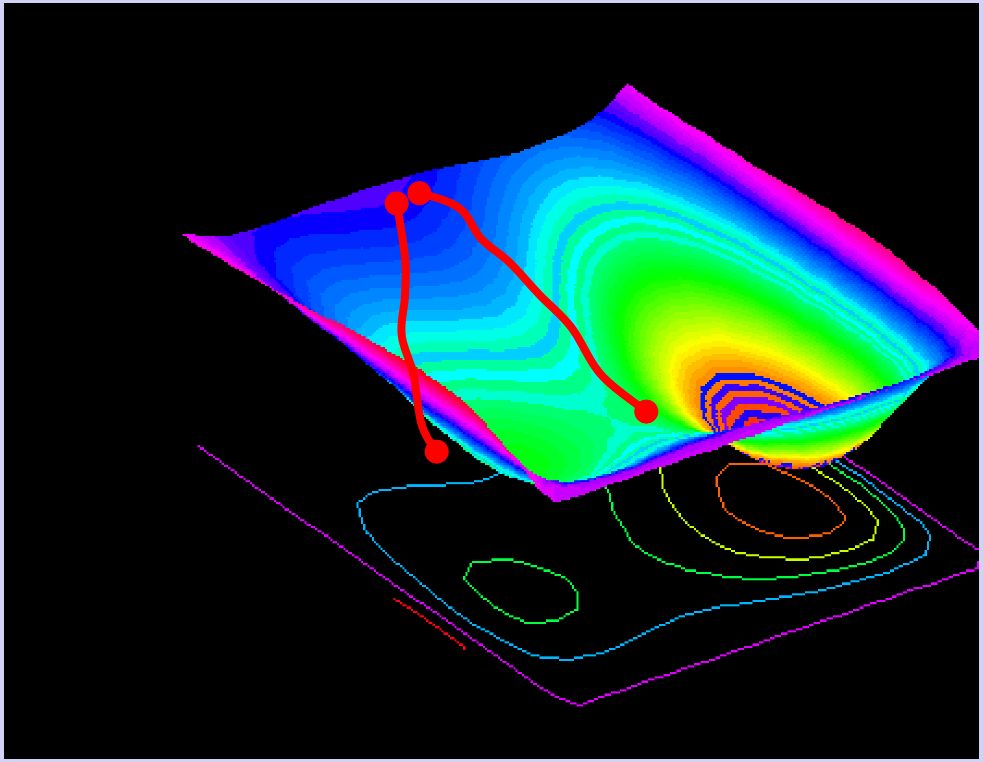


"Automatic" Calibration components

Objective Function

Search Algorithm

Sensitivity Analysis

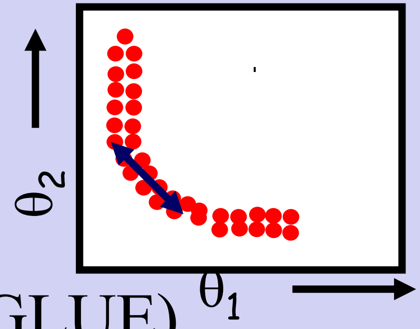


Parameter Uncertainty Methods

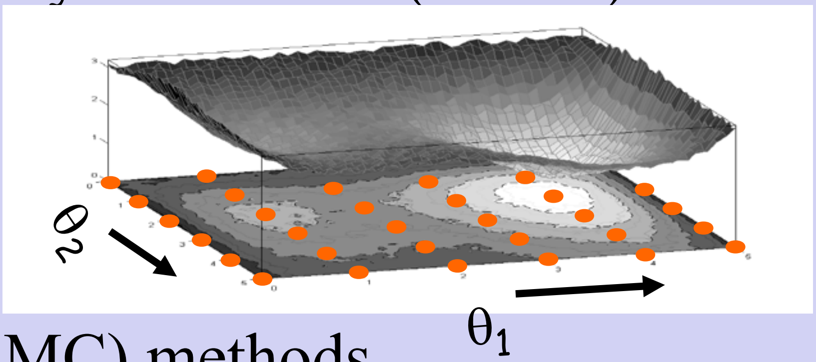
(1) First-order approximations near global optimum (Kuczera etal)

Limitations

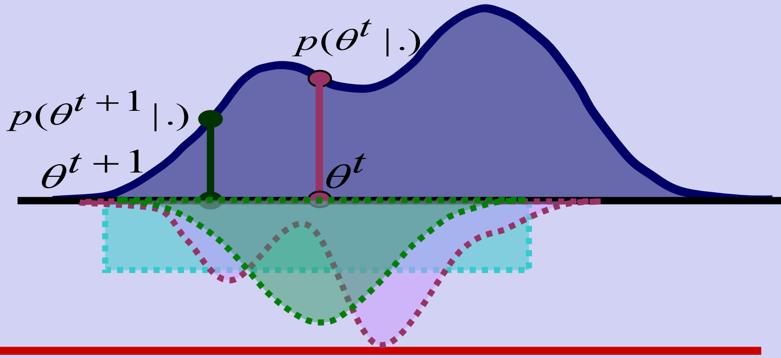
- **Assumes Model is Linear**
- **Assumes Posterior Dist. Guassian**



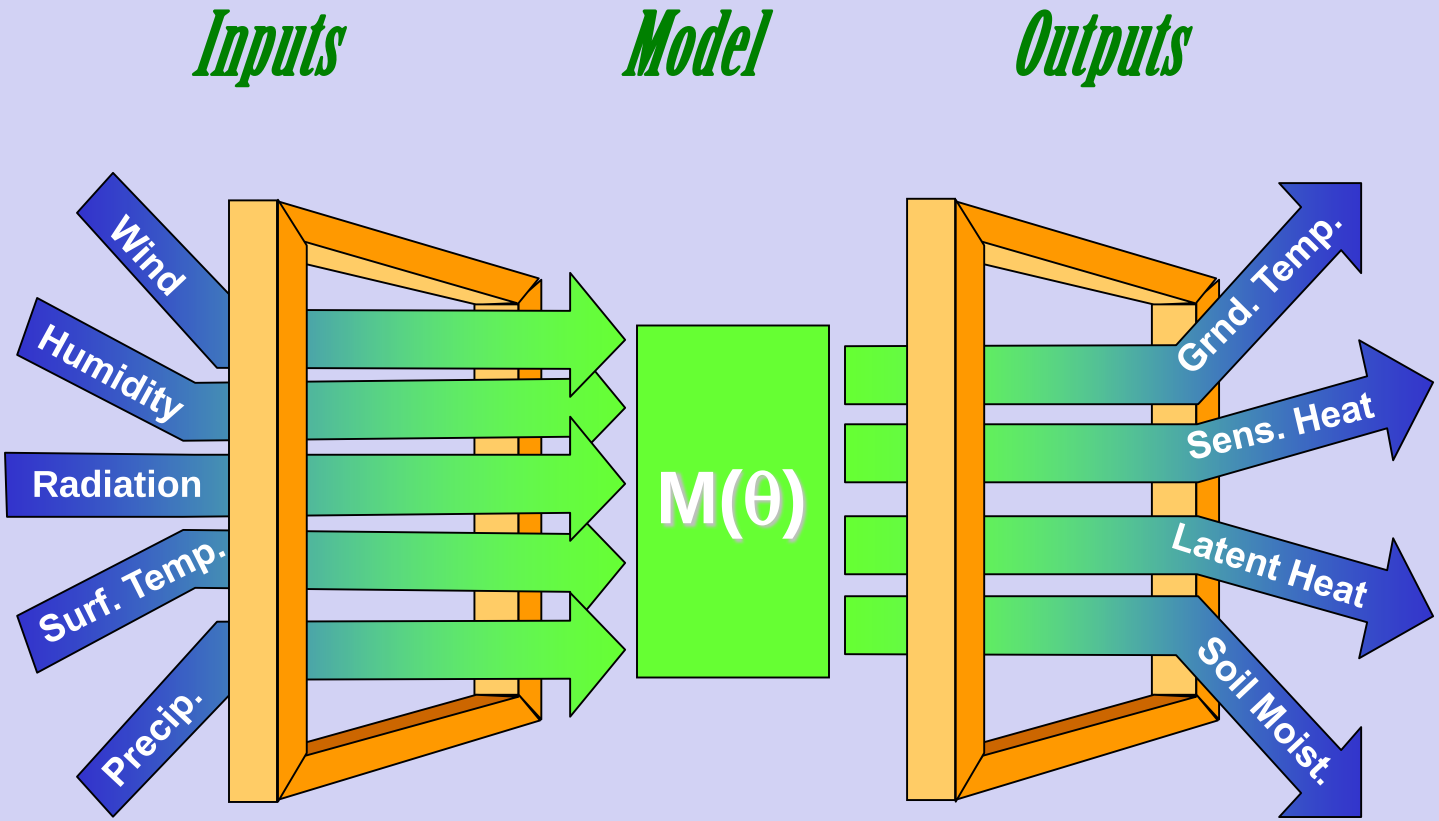
(2) Generalized Likelihood Uncertainty Estimation (GLUE) method (Beven and co-workers)



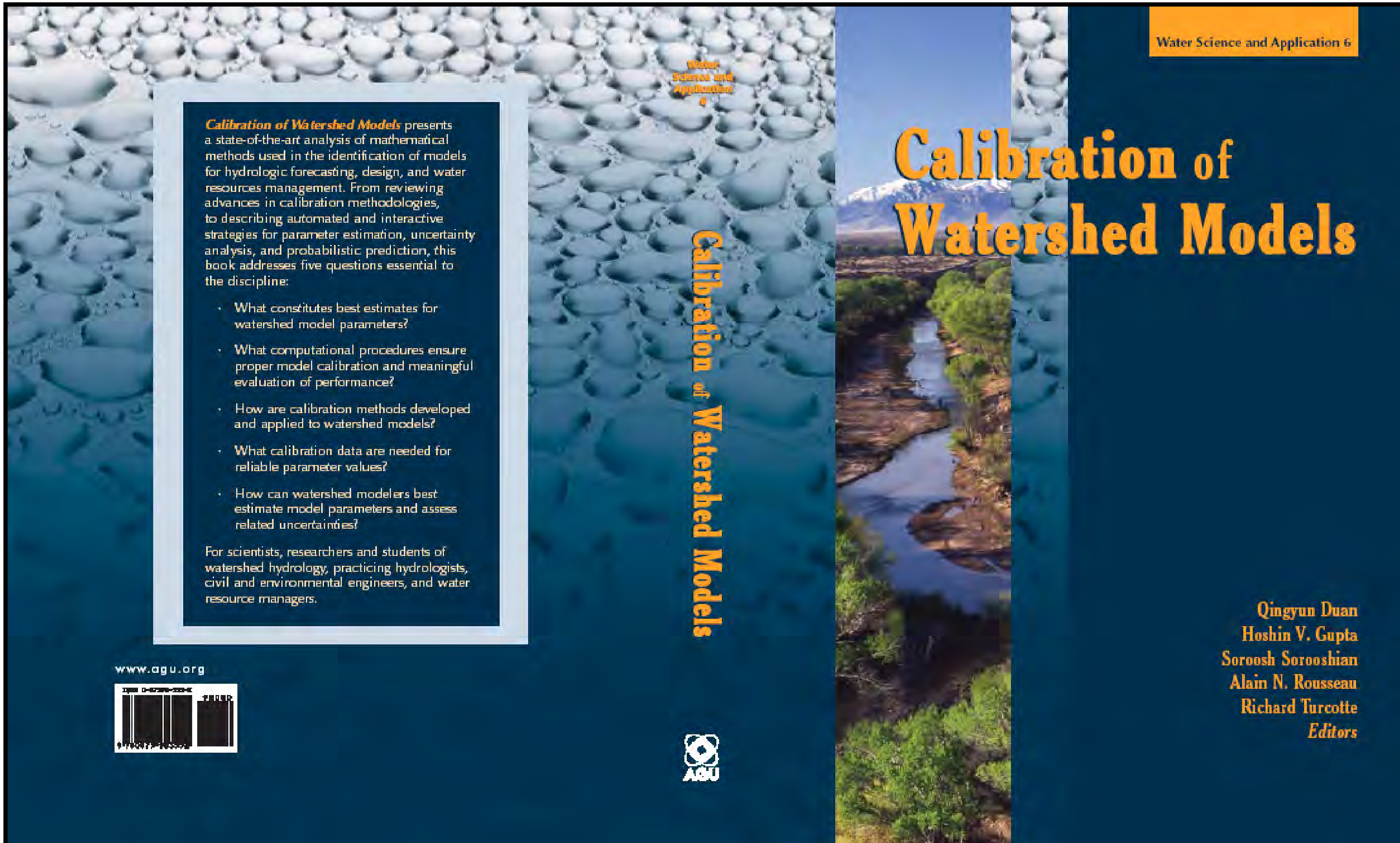
(3) Markov Chain Monte Carlo (MCMC) methods (Vrugt and others)



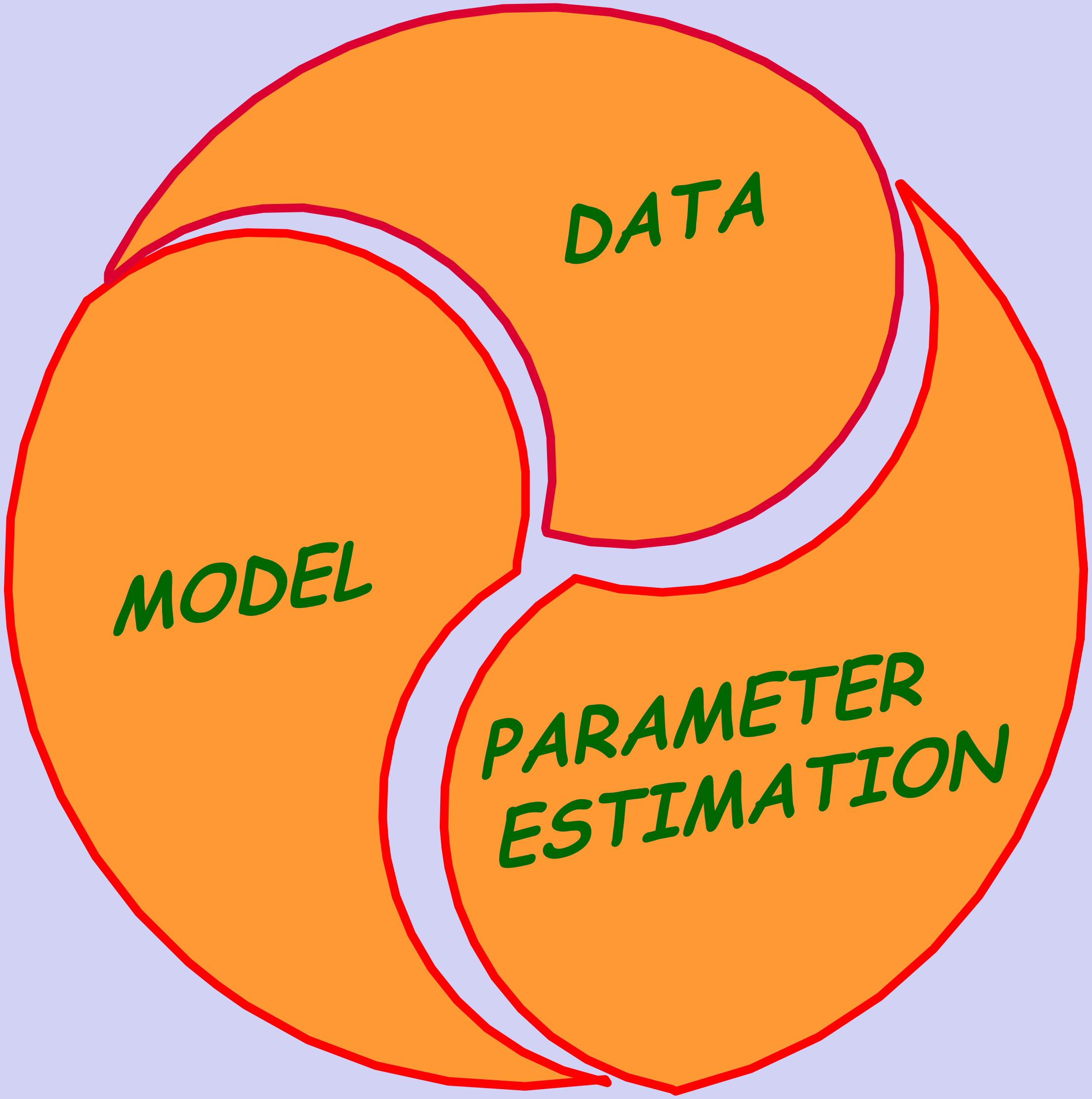
Multi-Objective Approaches



AGU Monograph – Now Available



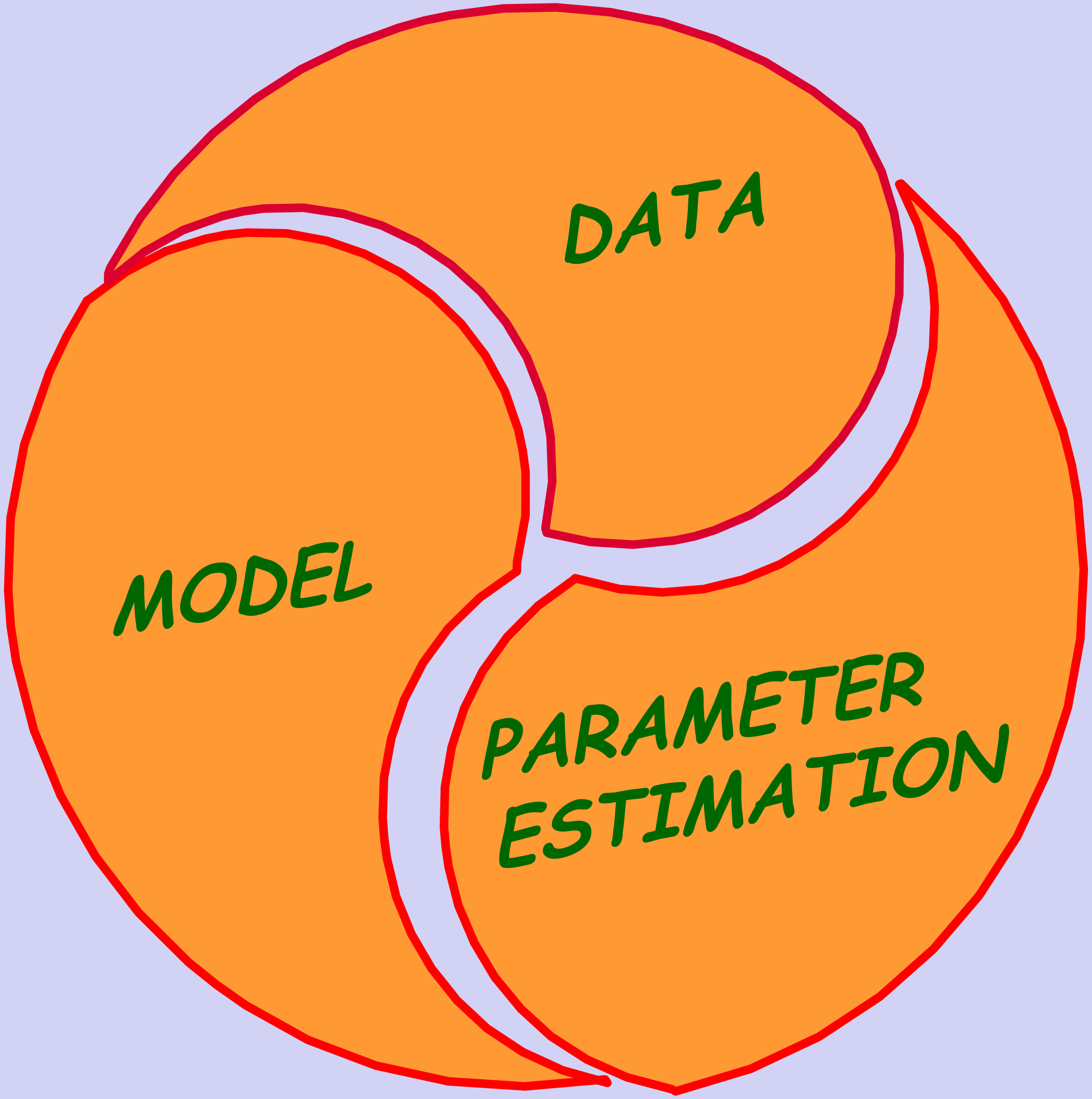
Data



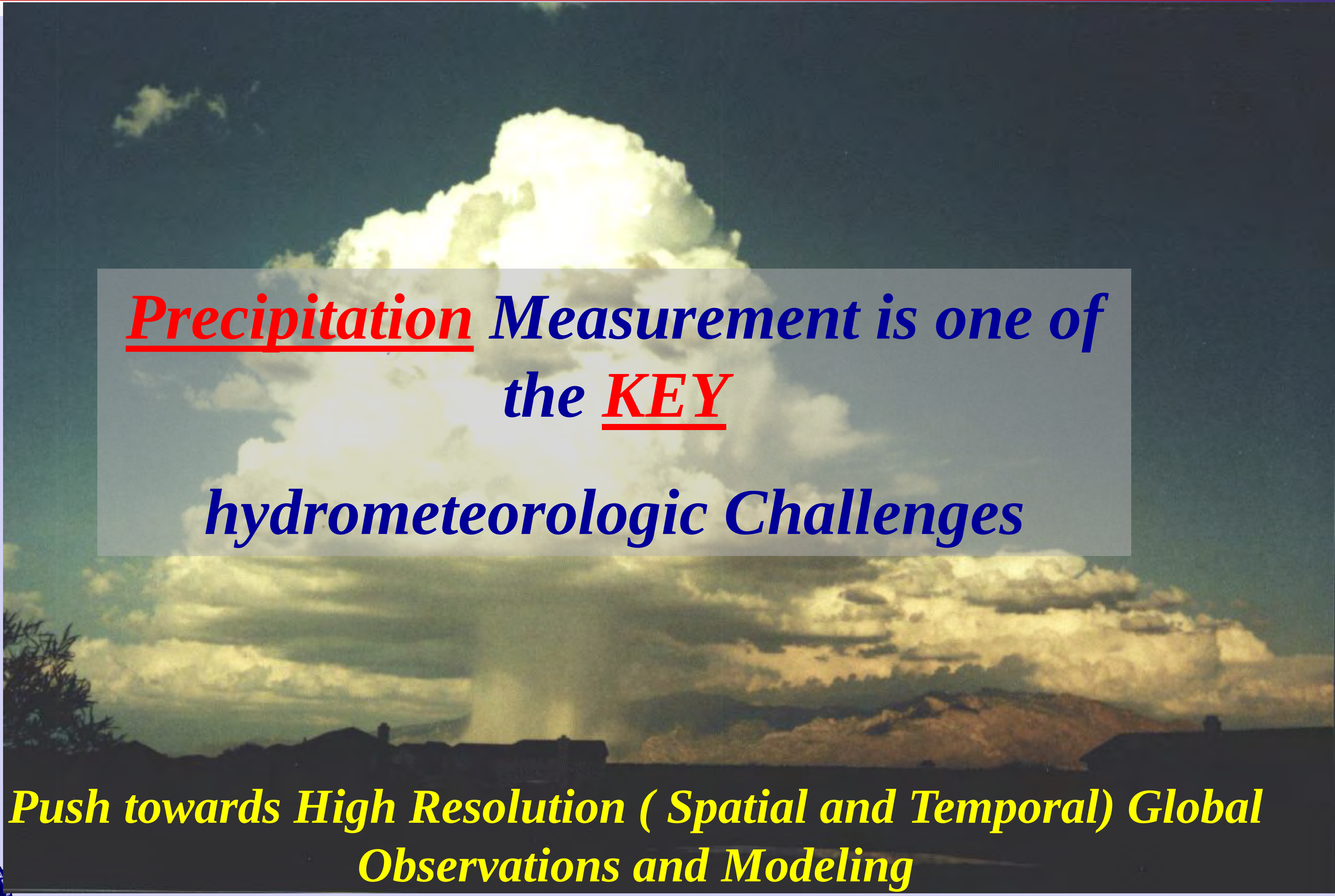
Big Challenge

Adequacy of Hydrologic Observations for model Input, Calibration and Testing

Among the 3 Pillars



A Key Requirement!



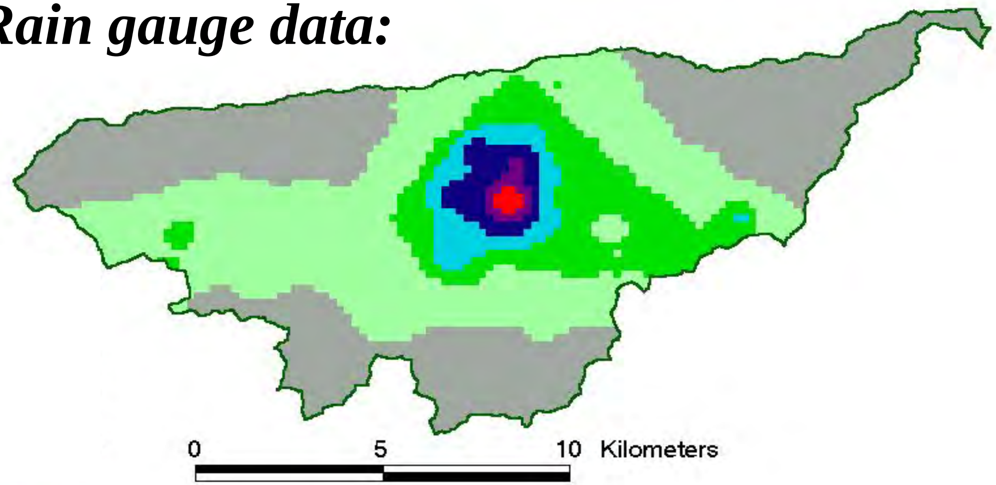
Precipitation* Measurement is one of the *KEY

hydrometeorologic Challenges

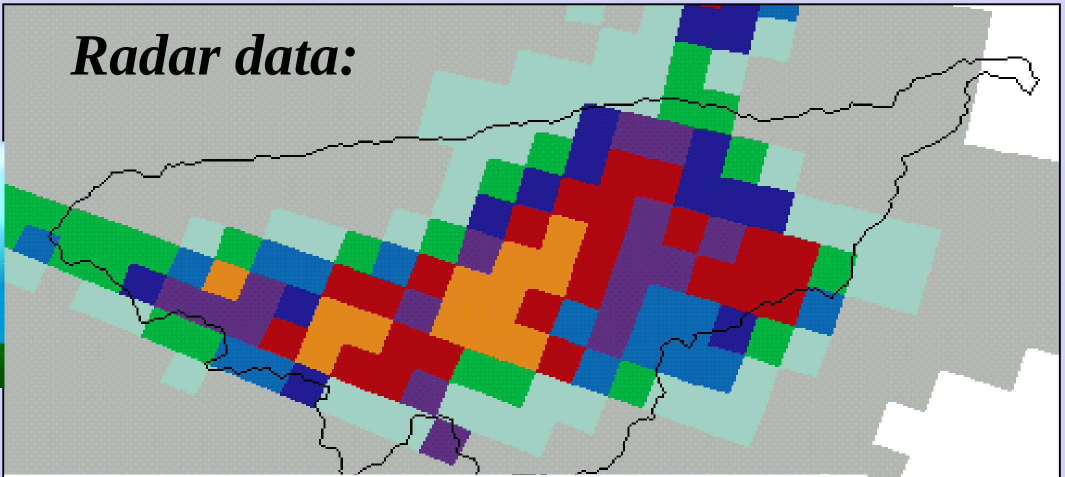
Push towards High Resolution (Spatial and Temporal) Global Observations and Modeling

Radar-Gauge Comparison (Walnut Gulch, AZ)

Rain gauge data:



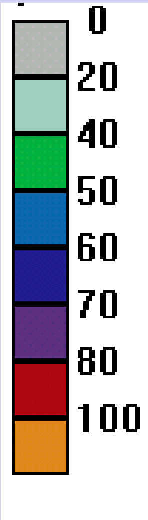
Radar data:



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

Precipitation event: Aug. 11, 2000

Storm depth (mm)

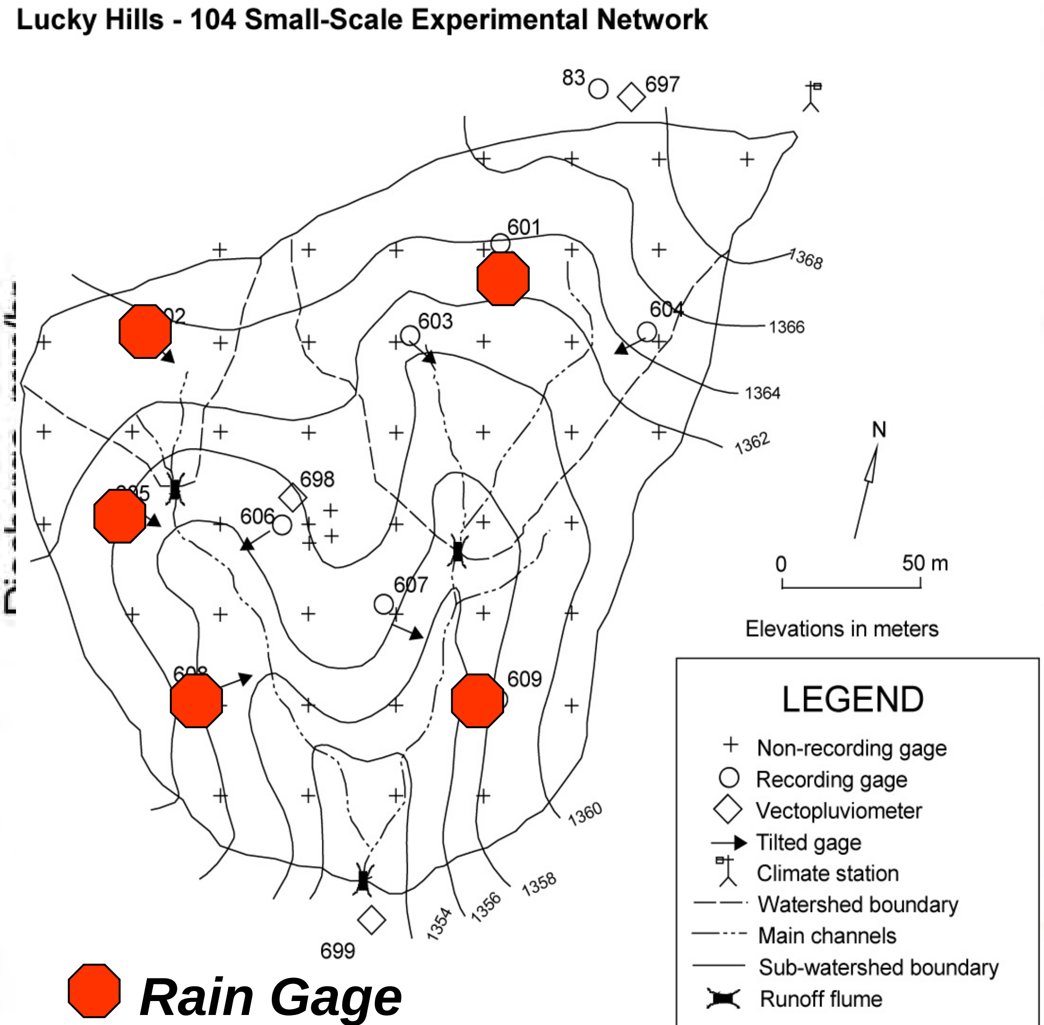


70% overestimation by the radar!

Morin et al ADWR 2005

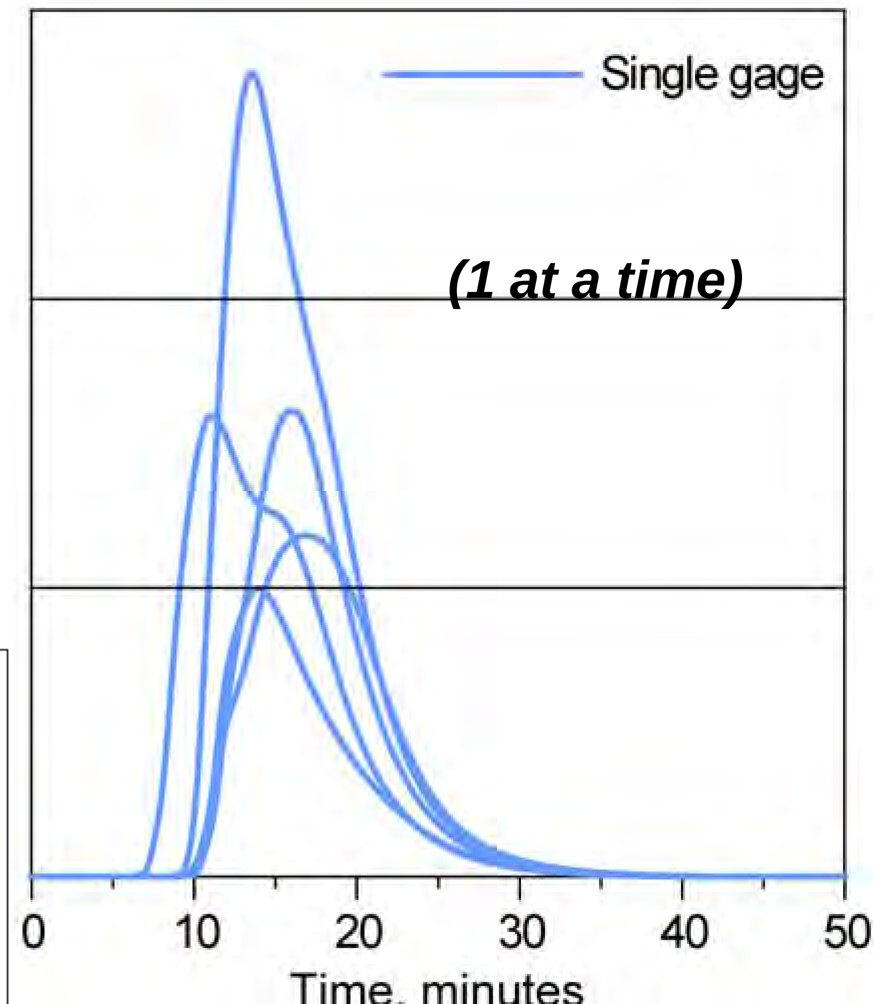
Uncertainty in Runoff Simulation due to Rainfall Variability

Small scale spatial variability of rainfall (on the order of ~150 m)



Rain Gage

Modeled runoff (KINEROS)



Faures, JM et.al. J.of Hydrology 1995

Western U.S. future model projections

Dr. Chiyuan Miao - BNU

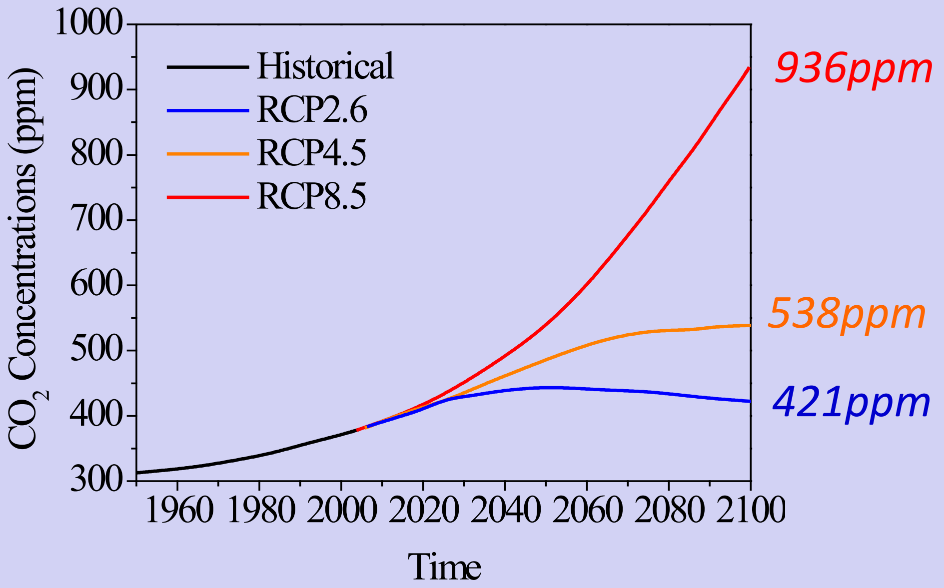
Future Modeling Scenarios – IPCC AR5

Representative Concentration Pathways (RCP) Scenarios:

RCP2.6: represent 'low' scenarios featured by the radiative forcing of 2.6 W/m² by 2100, the resulting CO_2-equivalent concentrations is 421 ppm in the year 2100 .

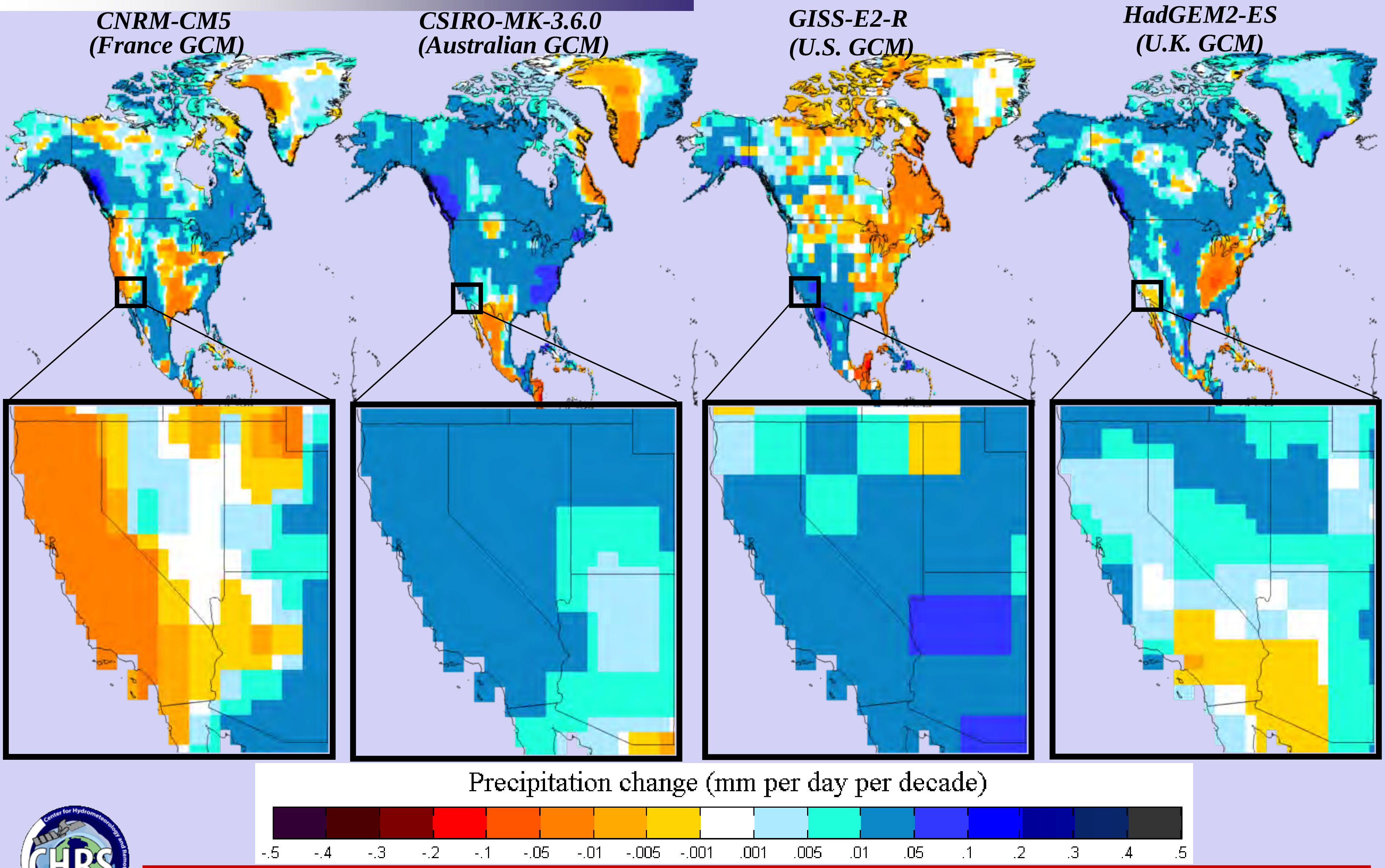
RCP4.5: represent 'medium' scenarios featured by the radiative forcing of 4.5 W/m² by 2100, the resulting CO_2-equivalent concentrations is 538 ppm in the year 2100 .

RCP8.5: represent 'high' scenarios featured by the radiative forcing of 8.5 W/m² by 2100, the resulting CO_2-equivalent concentrations is 936 ppm in the year 2100 .



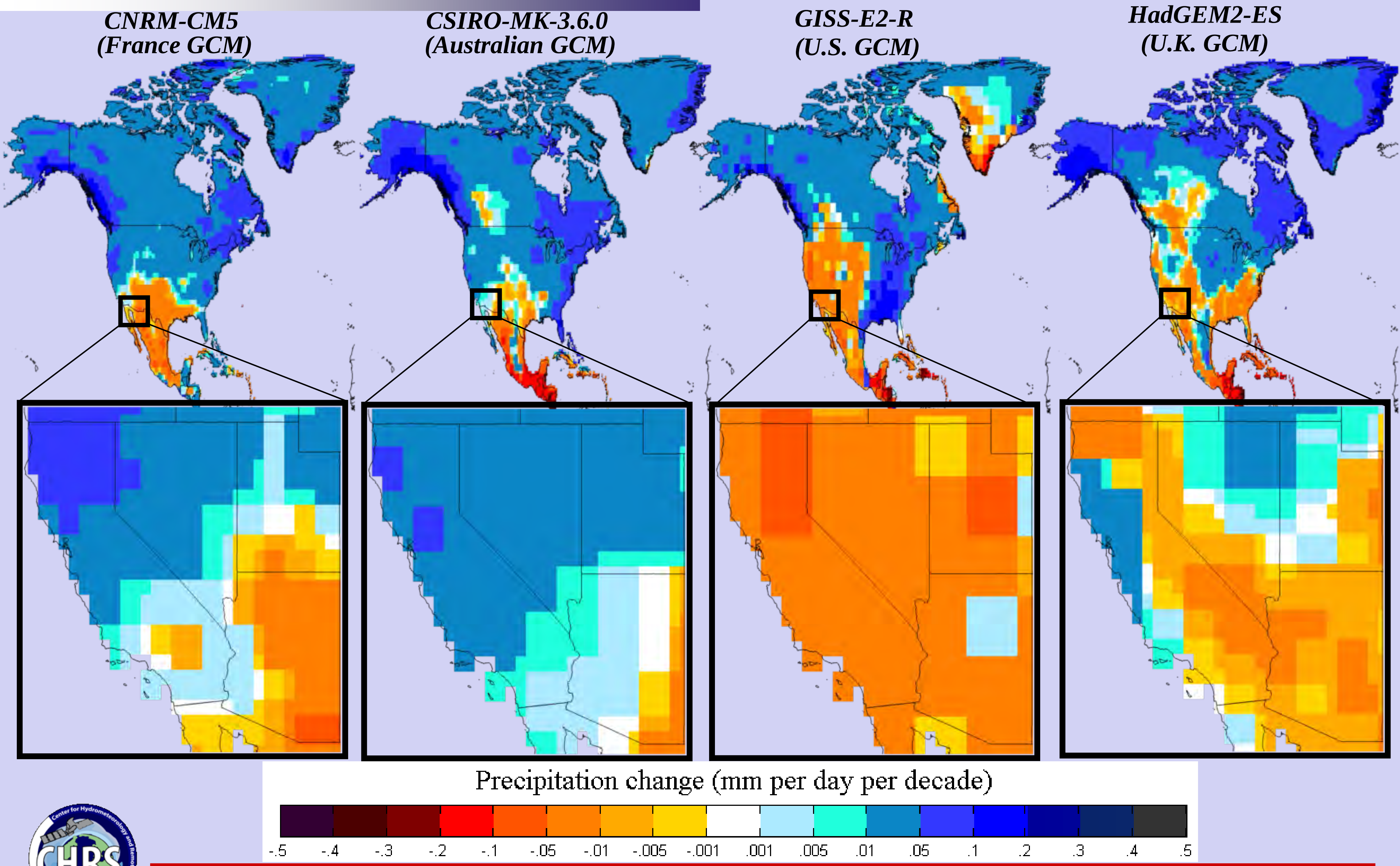
RCP2.6

Time period: 2006-2099



RCP8.5

Time period: 2006-2099

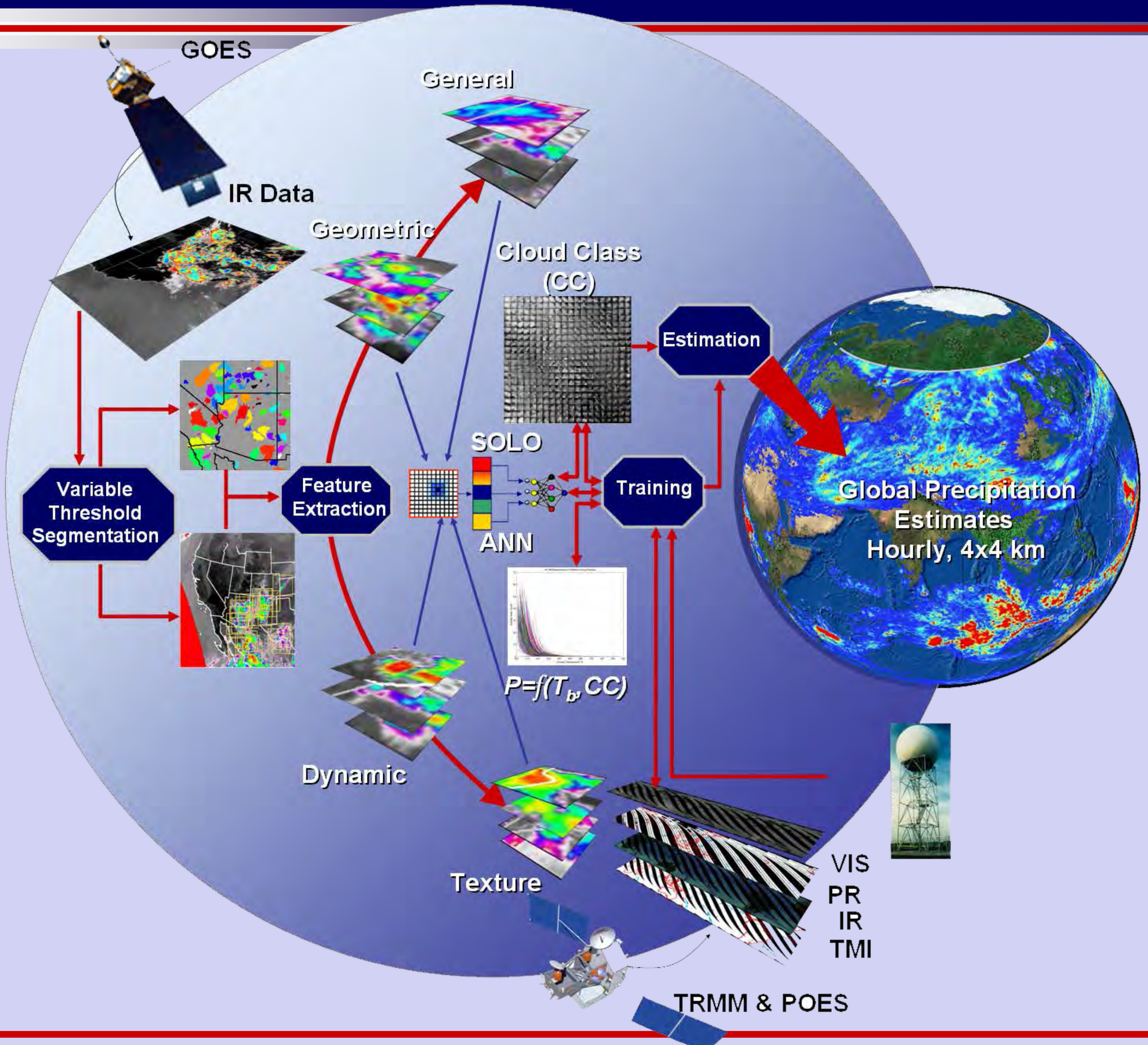


Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)

Kuolin Hsu
Algorithm Development

Bisher Imam
G-WADI site development

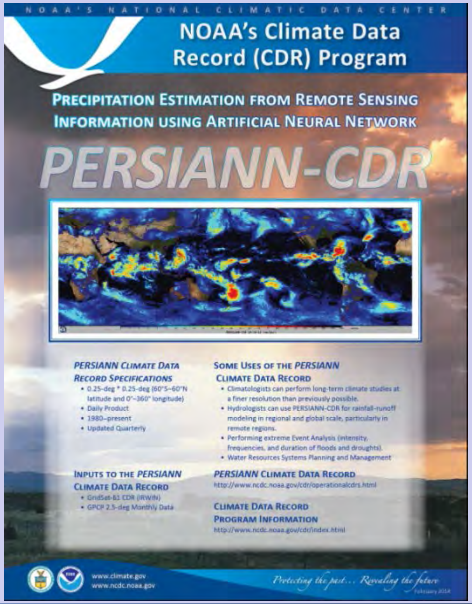
PERSIANN-CCS (Real-time 4 km)



PERSIANN-CDR:

Reconstruction of 30+ years of Daily, 0.25° Satellite-Based Precipitation observation

Ashouri et al., BAMS 2014 (to appear)



PERSIANN-C … ord

http://www.ncdc.noa…

NOAA

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News

Climate Data and Applications Workshop - A Focus on Precipitation - Dec 3-4, 2013

Congratulations Cheng-Zhi Zou

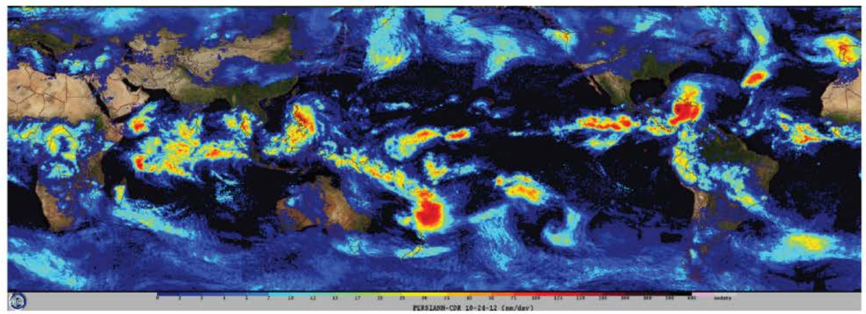
2013 CDR Annual Meetings Presentations now available

N O A A ' S   N A T I O N A L   C L I M A T I C   D A T A   C E N T E R

NOAA's Climate Data Record (CDR) Program

Precipitation Estimation from Remote Sensing Information using Artificial Neural Network

PERSIANN-CDR



PERSIANN Climate Data Record Specifications

- 0.25-deg * 0.25-deg (60°S–60°N latitude and 0°–360° longitude)
- Daily Product
- 1980–present
- Updated Quarterly

Inputs to the _PERSIANN_ Climate Data Record

- GridSat-B1 CDR (IRWIN)
- GPCP 2.5-deg Monthly Data

Some Uses of the _PERSIANN_ Climate Data Record

- Climatologists can perform long-term climate studies at a finer resolution than previously possible.
- Hydrologists can use PERSIANN-CDR for rainfall-runoff modeling in regional and global scale, particularly in remote regions.
- Performing extreme Event Analysis (intensity, frequencies, and duration of floods and droughts).
- Water Resources Systems Planning and Management

PERSIANN Climate Data Record

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

Climate Data Record Program Information

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

www.climate.gov
www.ncdc.noaa.gov

Protecting the past… Revealing the future

February 2014

SEARCH NCDC

…vironmental Satellites: Interim …d. The first step in establishing …taset itself, and supporting …rs Guidelines.

…ospheric, Oceanic, and …tures) that have been improved … are geophysical variables …cific to various disciplines. …ut.

Documentation
Algorithm Description Data Flow Diagram Maturity Matrix
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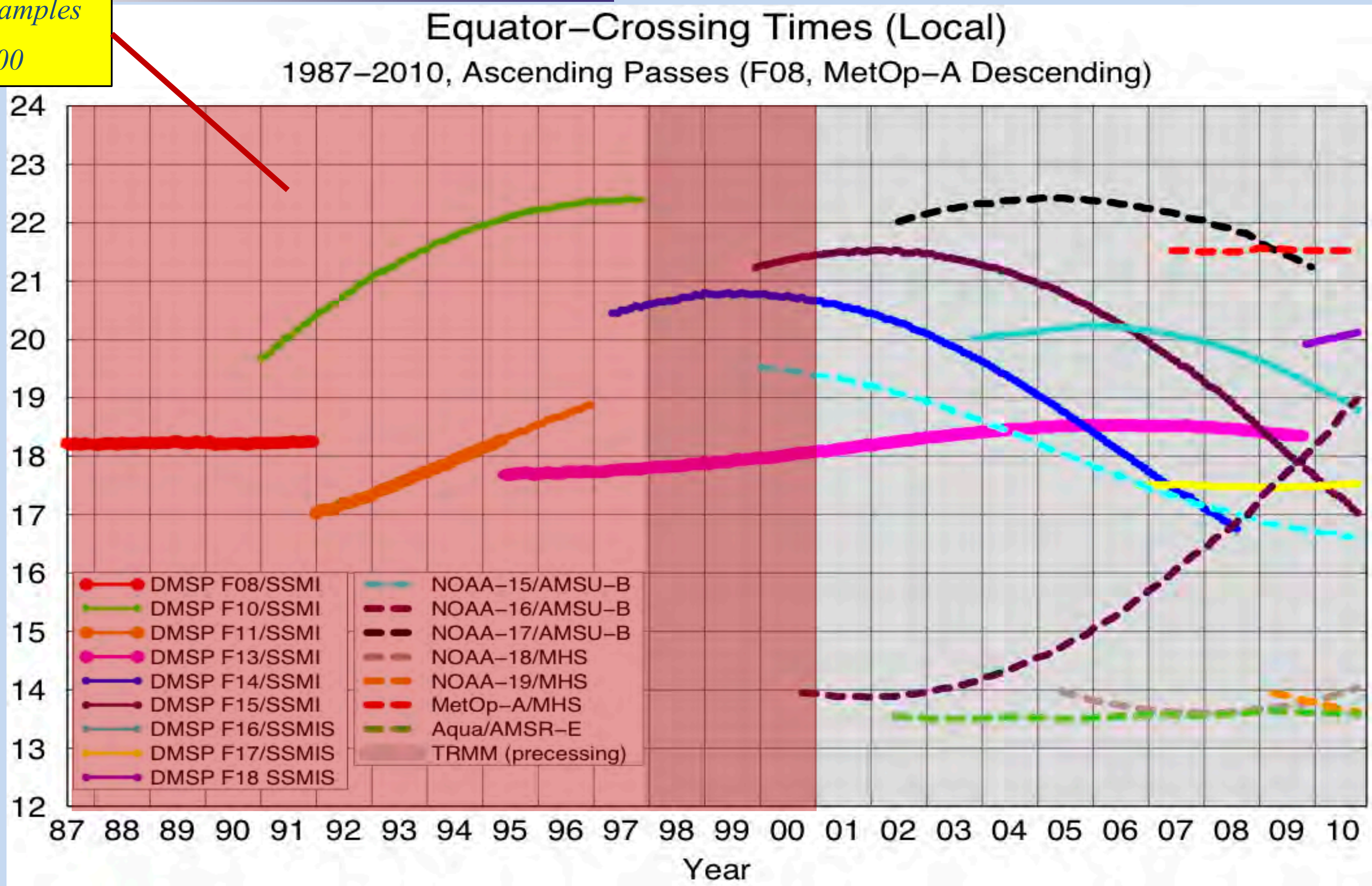
LEO Satellites for Precipitation Estimation

Limited PMW Samples
Before year 2000



Thickest lines denote GPCP calibrator.

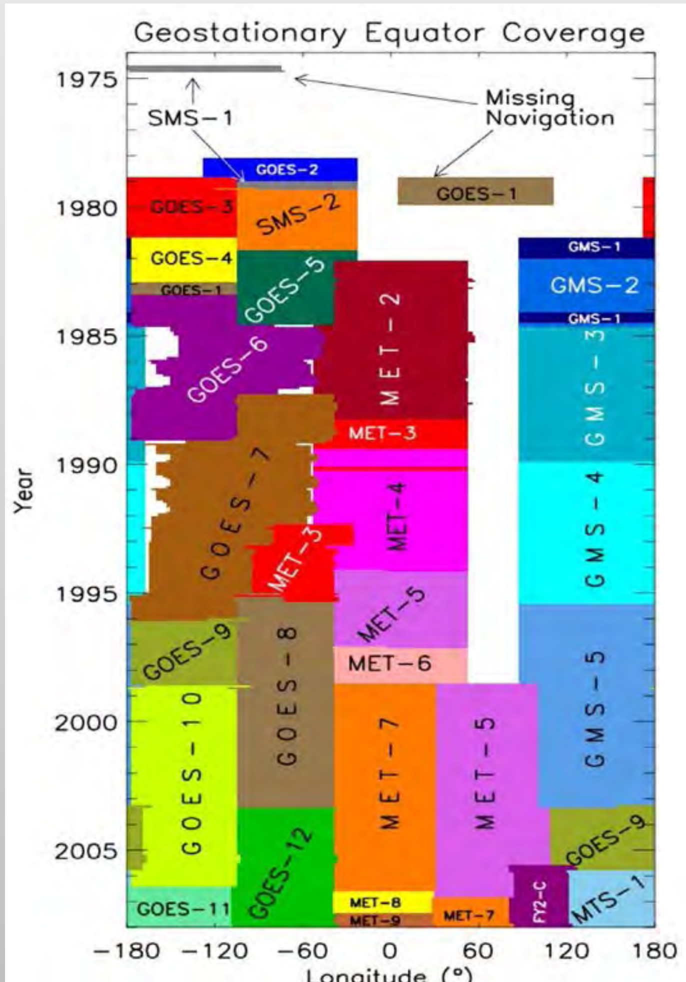
Image by Eric Nelkin (SSAI), 20 October 2010, NASA/Goddard Space Flight Center, Greenbelt, MD.

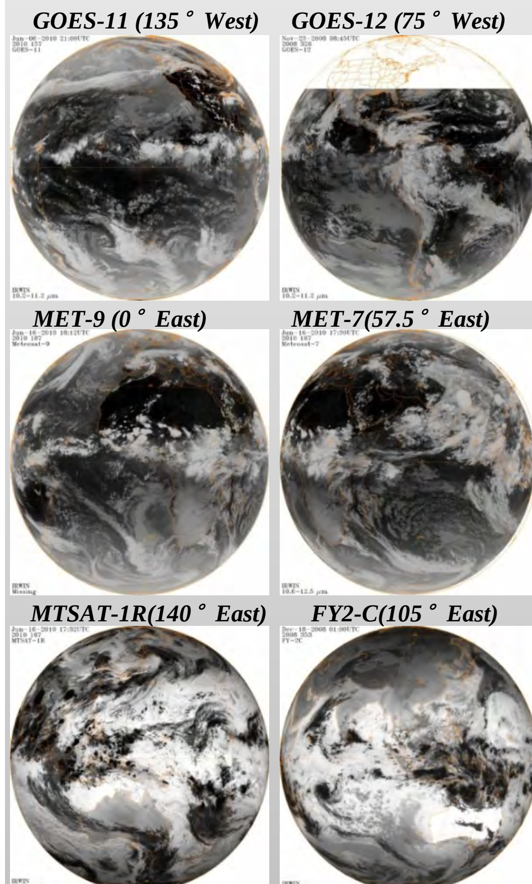
Historical GEO Satellite Data

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

  1979 to present

  10-km and 3-hour intervals





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

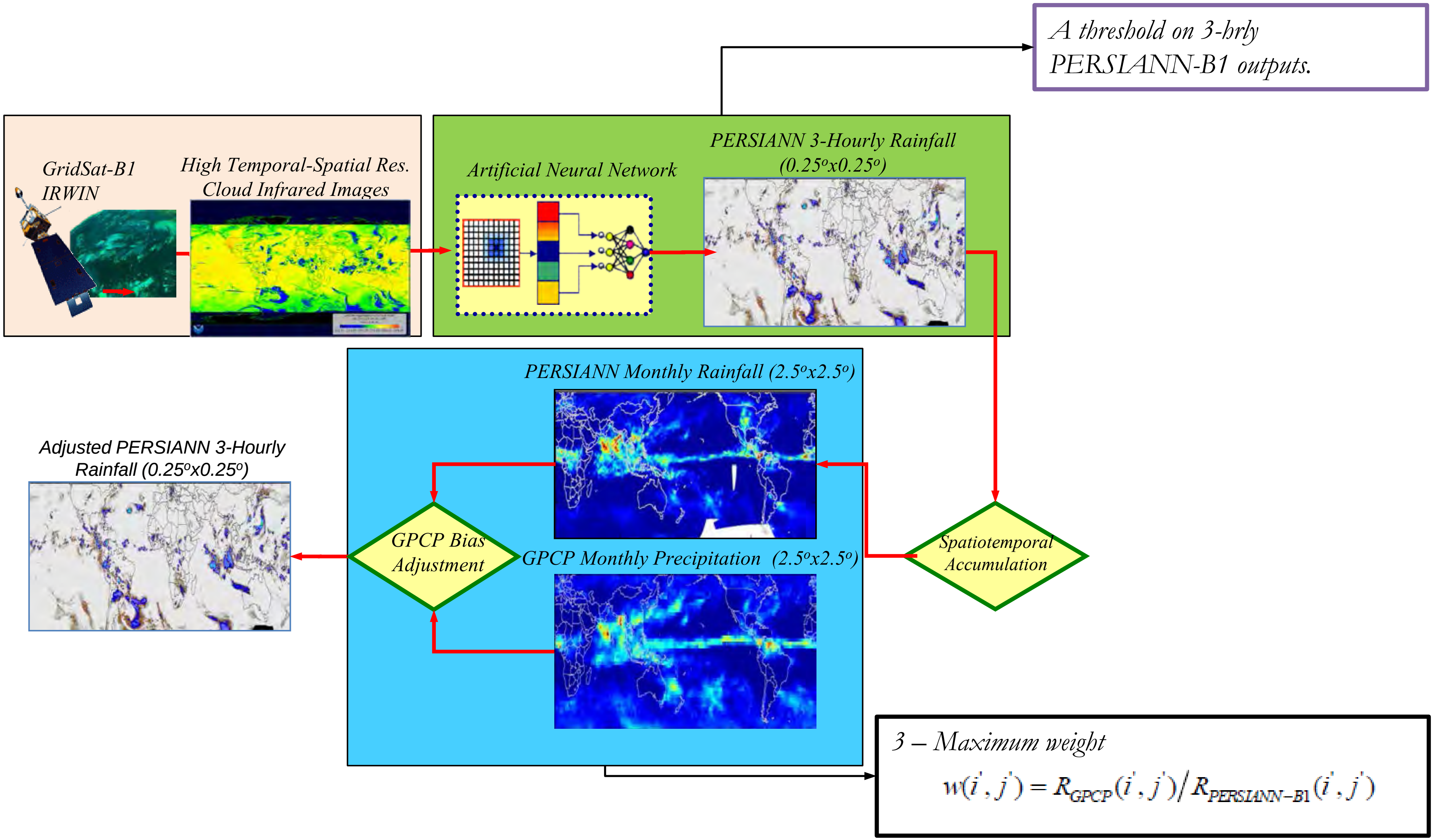
2. European Meteorological satellite (Meteosat) series

3. Japanese Geostationary Meteorological Satellite (GMS)

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

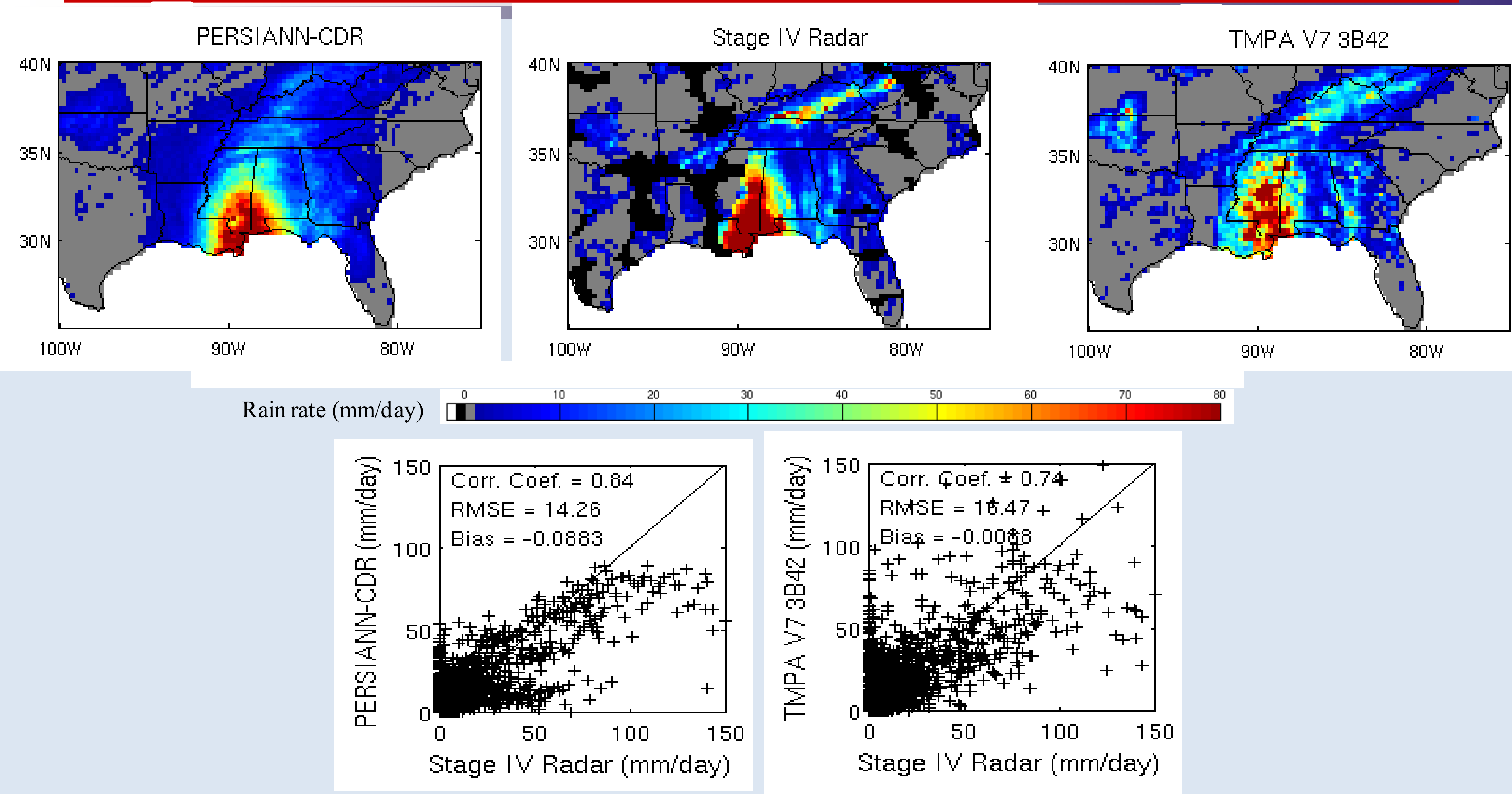
Source: NOAA NCDC

PERSIANN-CDR Algorithm



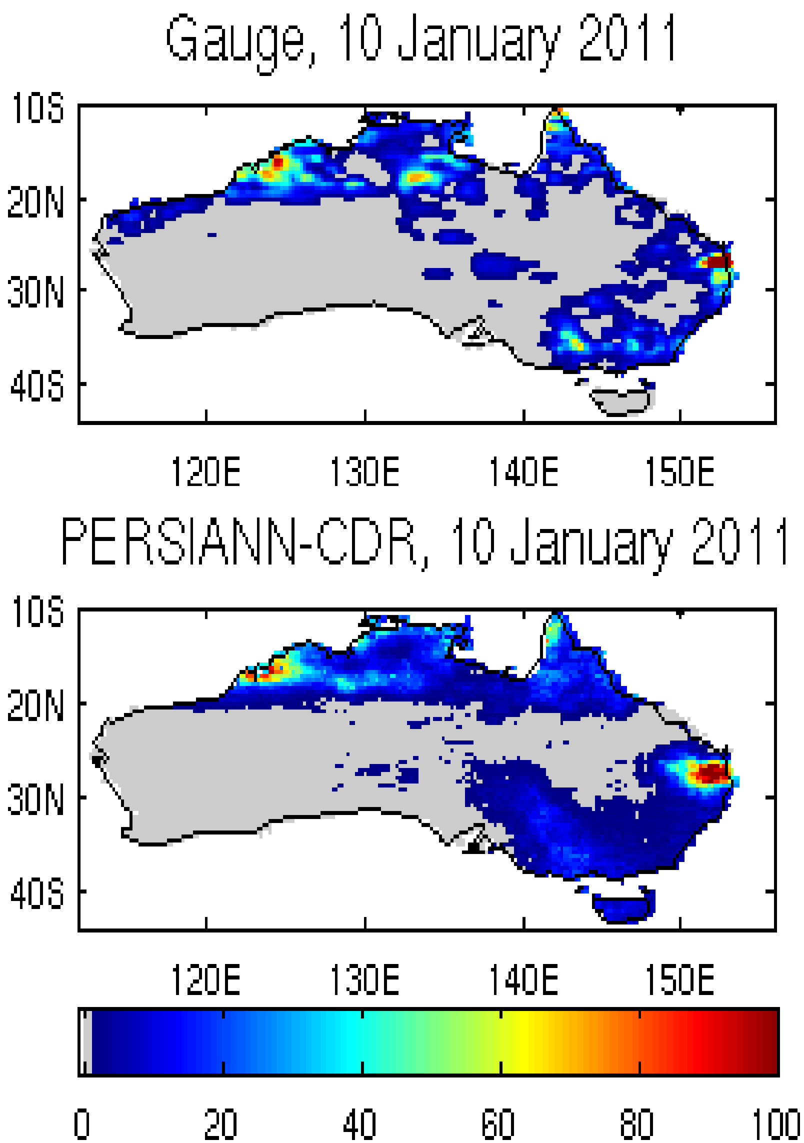
Testing and Validation of Satellite Products

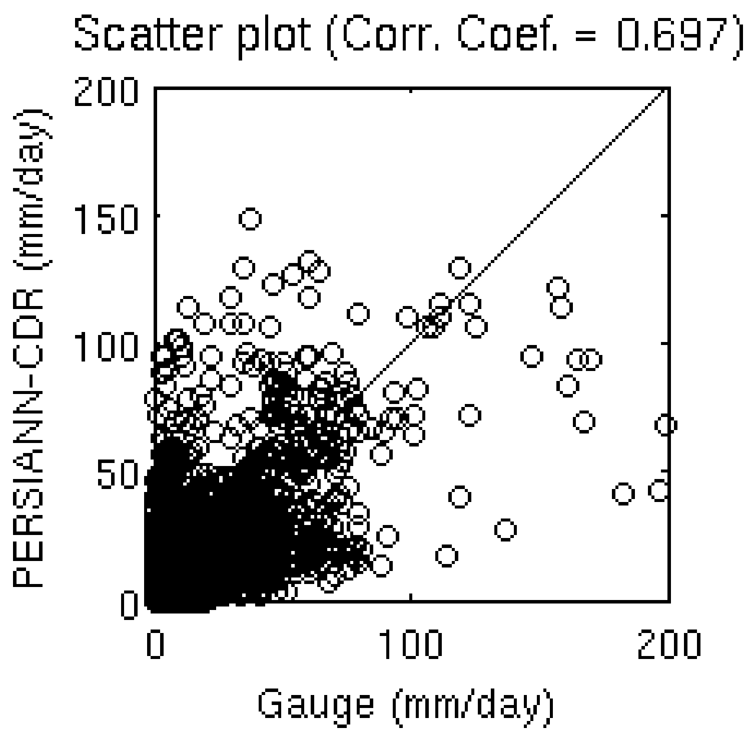
Testing of PERSIANN-CDR: Hurricane Katrina, 2005



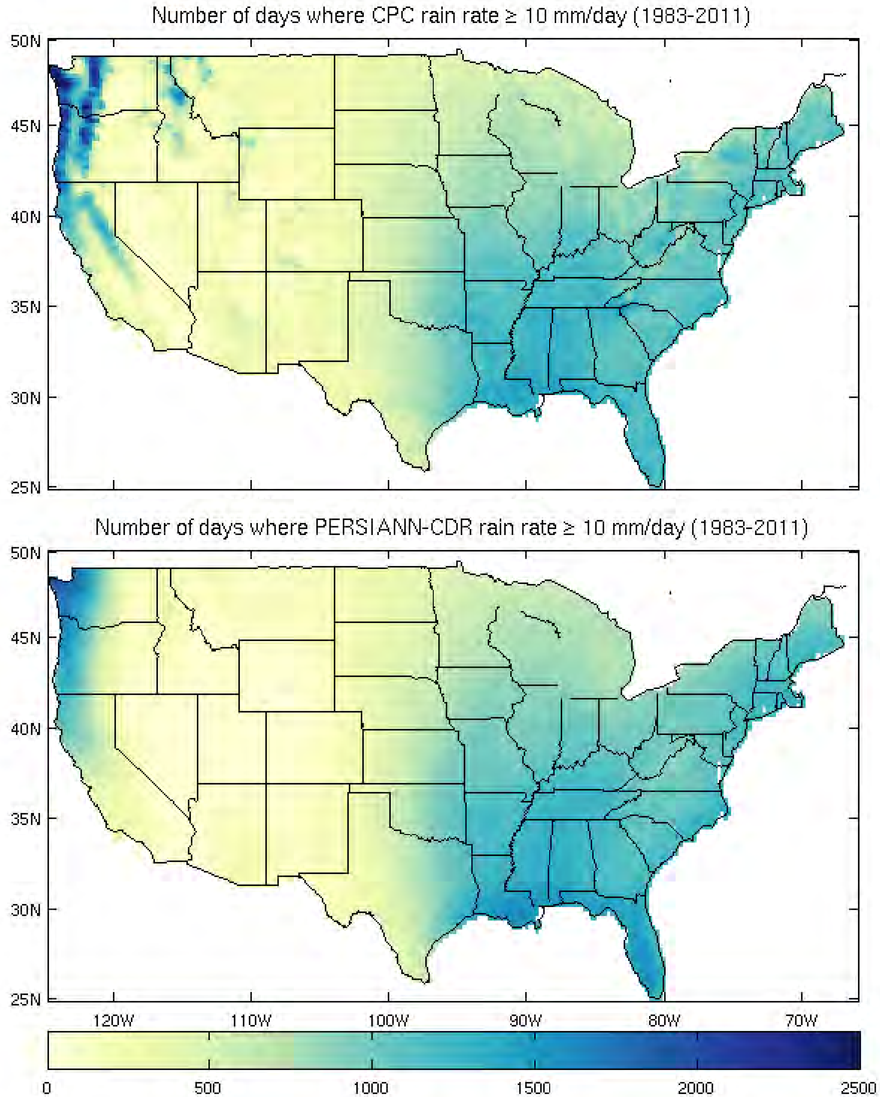
Rainfall (mm/day) over land during Hurricane Katrina on 29 August 2005 from PERSIANN-CDR (top row left), Stage IV Radar (top row middle, Lin and Mitchell 2005), and TMPA v7 (top row right, Huffman *et al*. 2007). Black and gray pixels show radar blockages and zero precipitation, respectively. Scatter plots of PERSIANN-CDR and TMPA versus Stage IV Radar data are provided in the bottom row.

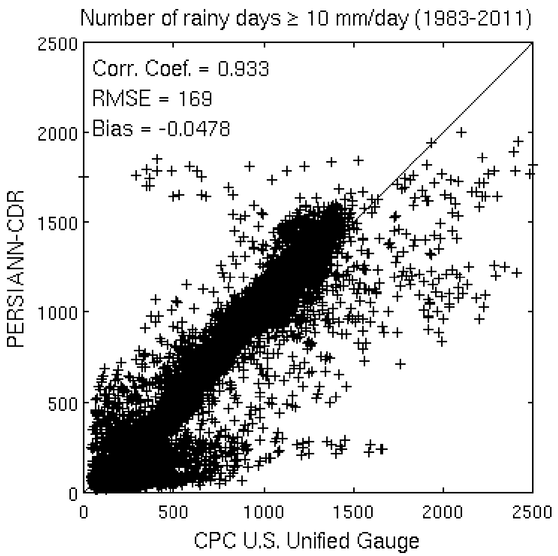
Validation of PERSIANN-CDR: Australia Flood Event



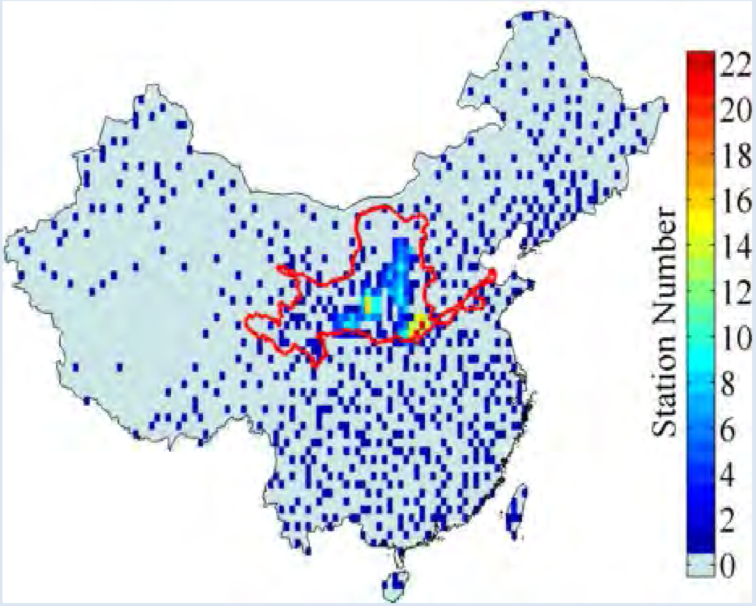


Testing of PERSIANN-CDR: Number of Rainy days >= 10 mm/day

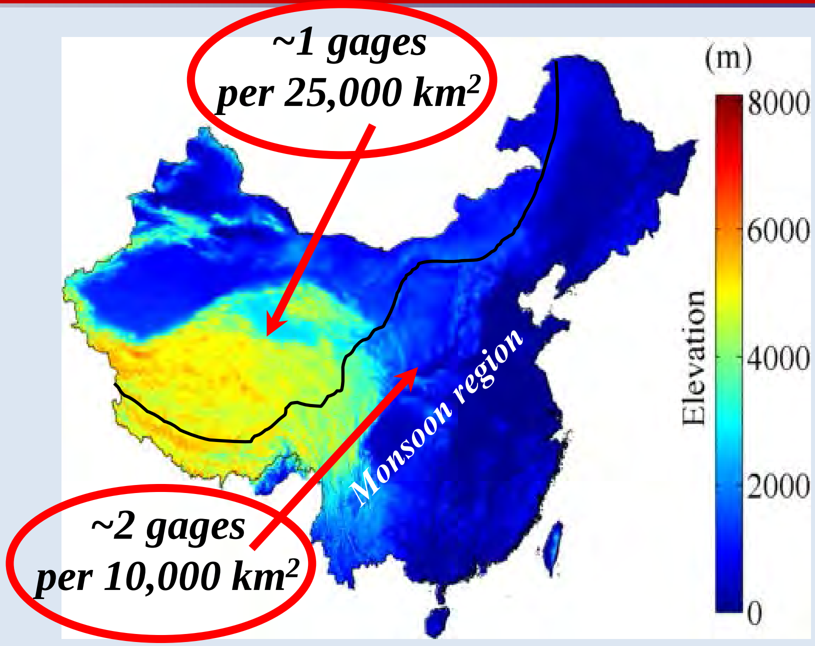




PERSIANN-CDR Evaluation over China



EA Rain Gauge Distribution



Elevation Map

Dr. Chiyuan Miao - BNU

Gauge data: *daily precipitation over East Asia (EA) (Xie et al., 2007)*

- *More than 2200 ground-based stations across China*
- *0.5° resolution*
- *Period 1983-2006*

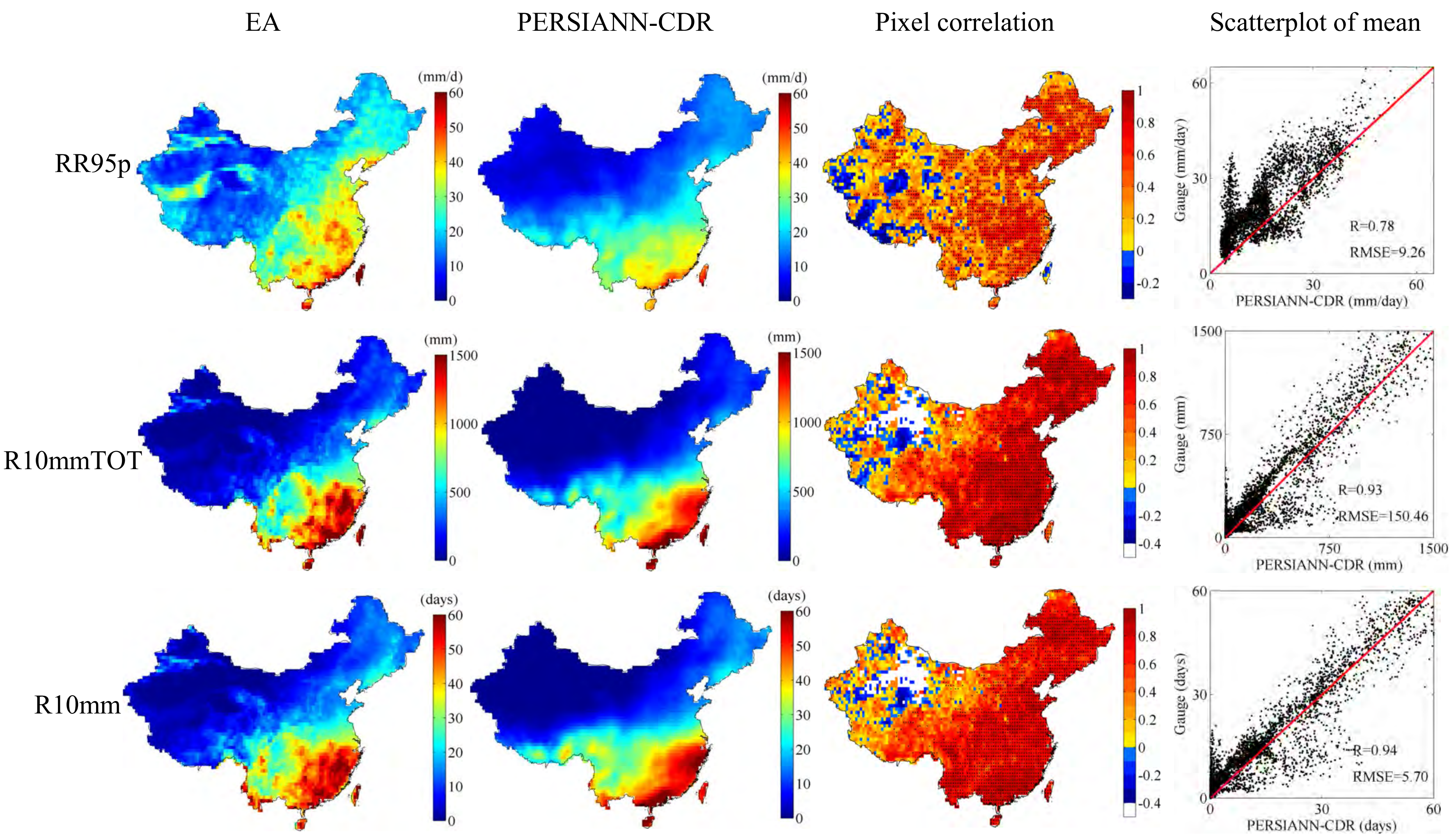
PERSIANN-CDR: *up scaled into the same resolution as EA (0.5°)*

Evaluation Indices

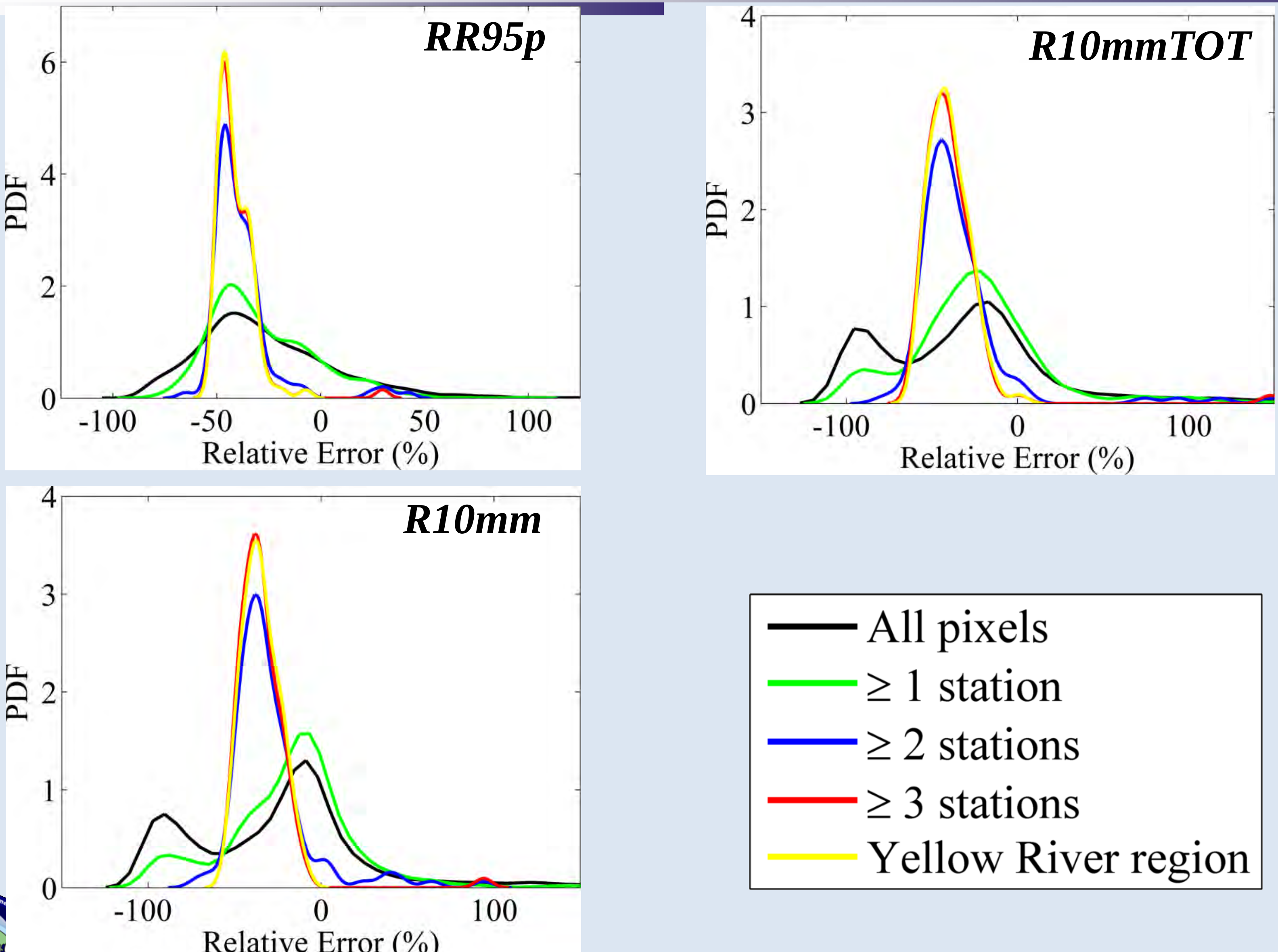
ID	Definition	Unit
RR95p	The 95th percentile of annual precipitation on wet days (precipitation ≥ 1mm)	mm/day
R10mmTOT	Annual total precipitation when daily precipitation ≥ 10mm	mm
R10mm	Annual count of days when precipitation ≥10mm	Days

Extreme precipitation indices used in the analysis

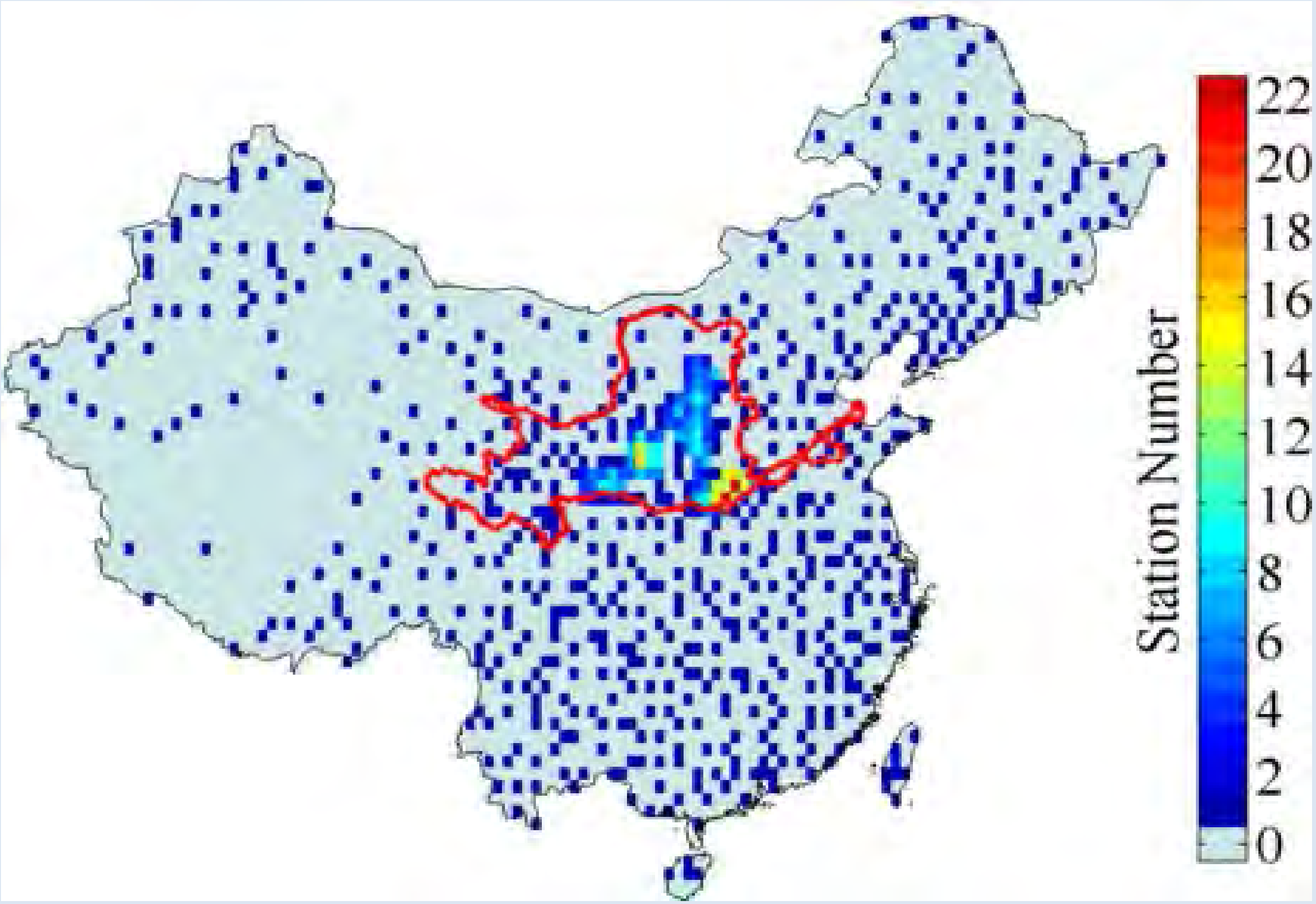
Results: Entire China



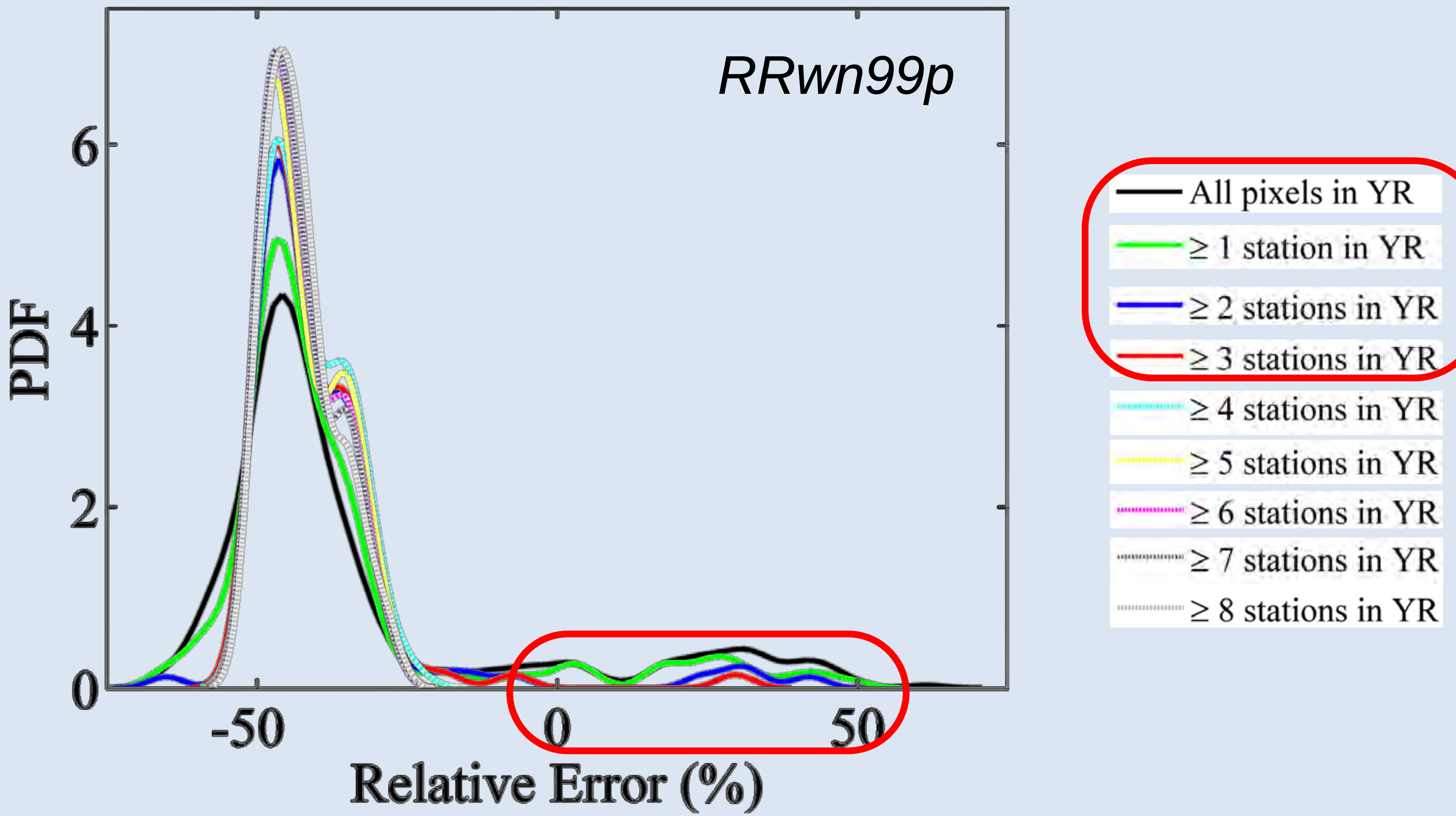
Prob. density functions (PDF) of Relative Errors for the Extreme Precipitation Indices: Different Gauge Densities.



PERSIANN-CDR Evaluation: Zooming over the Yellow River Region



PERSIANN-CDR Evaluation: Zooming over the Yellow River Region

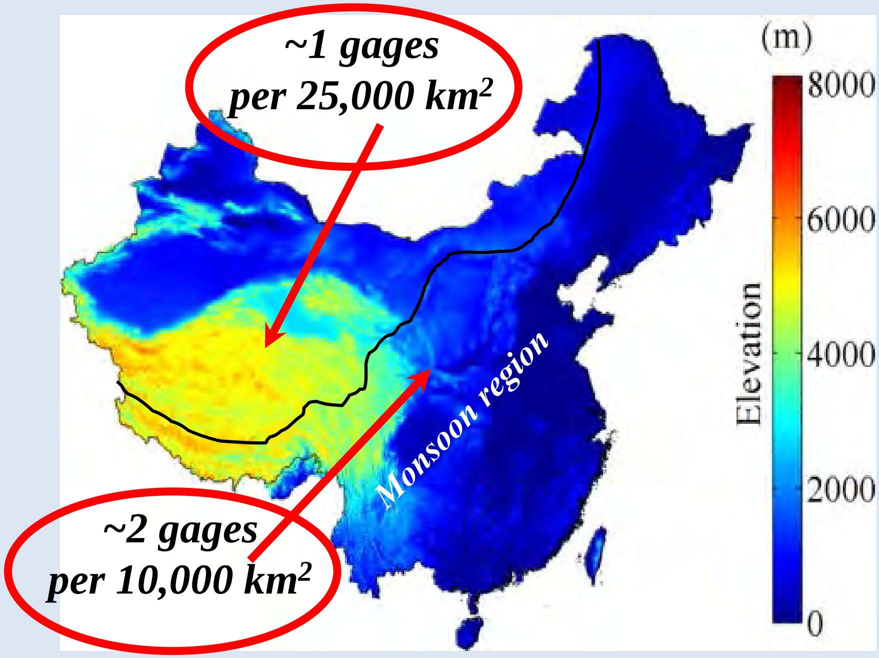


The probability density function (PDF) of the relative error for different gauge density

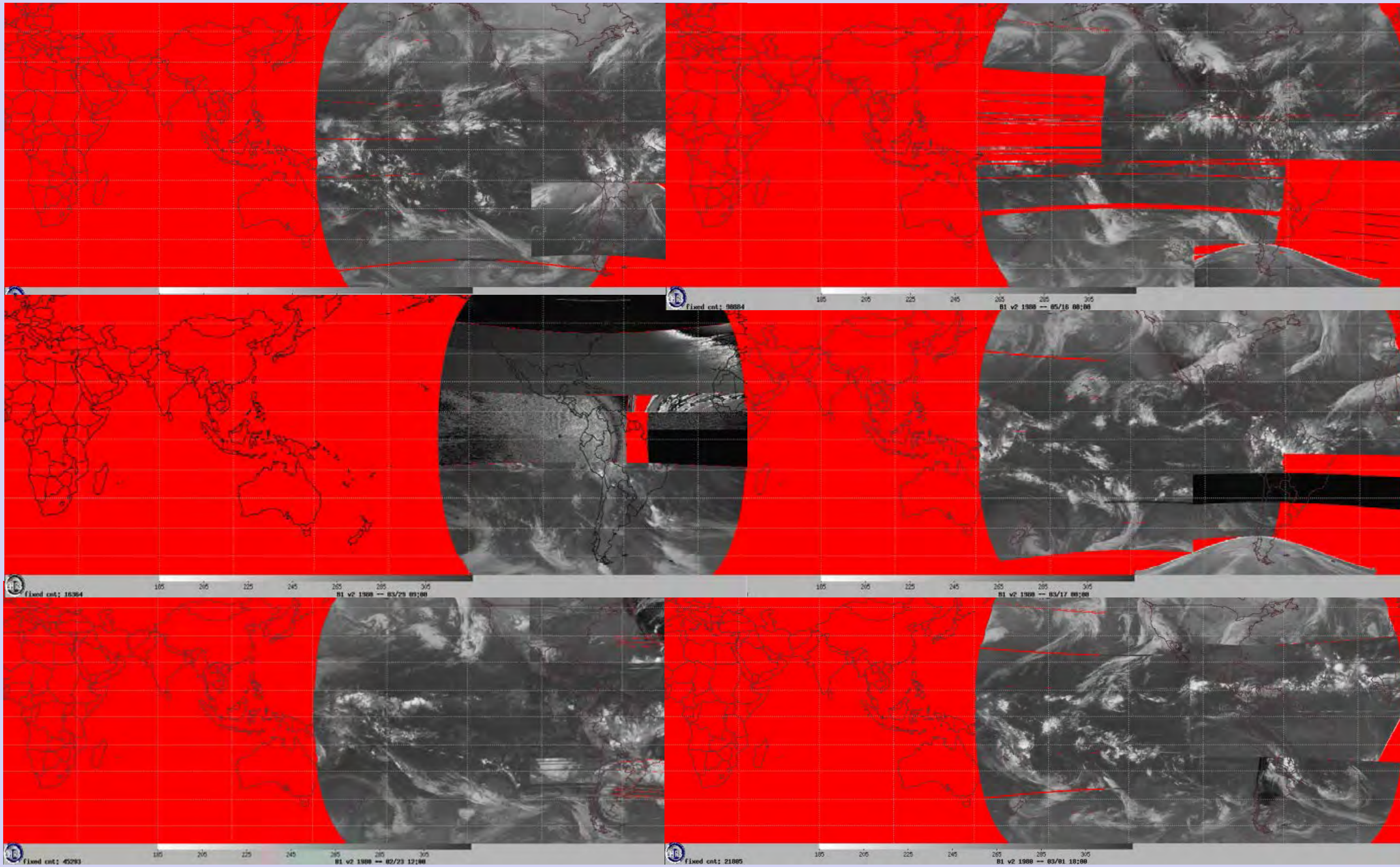
Potential Factors Influencing Agreement Between Gauge Data and PERSIANN-CDR

- ***Insufficient gauge density most likely leads to Spatial errors: Particularly over the Western and Northwestern Arid Regions.***

- ***The influence of topography on Spatial distribution of precipitation not fully captured by the interpolation process from points to grids.***



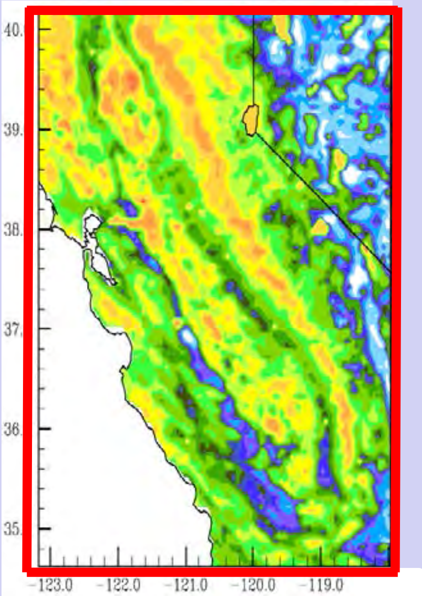
Devils are in details …



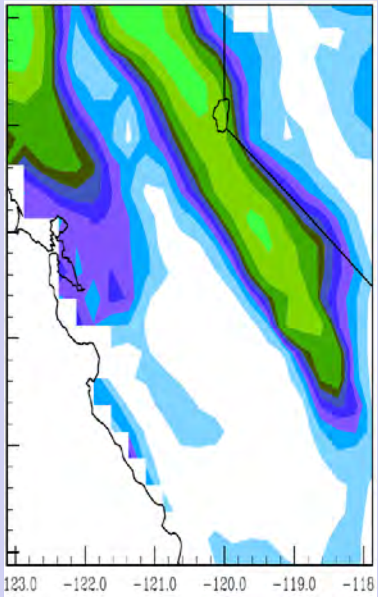
How about the testing of all other Remote Sensing Observations and Model Generated Data??

“Observed” vs “Model-Generated” Data

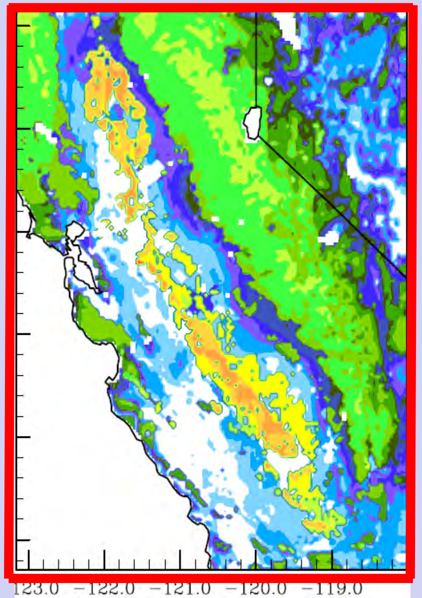
MODIS



GLDAS/Noah

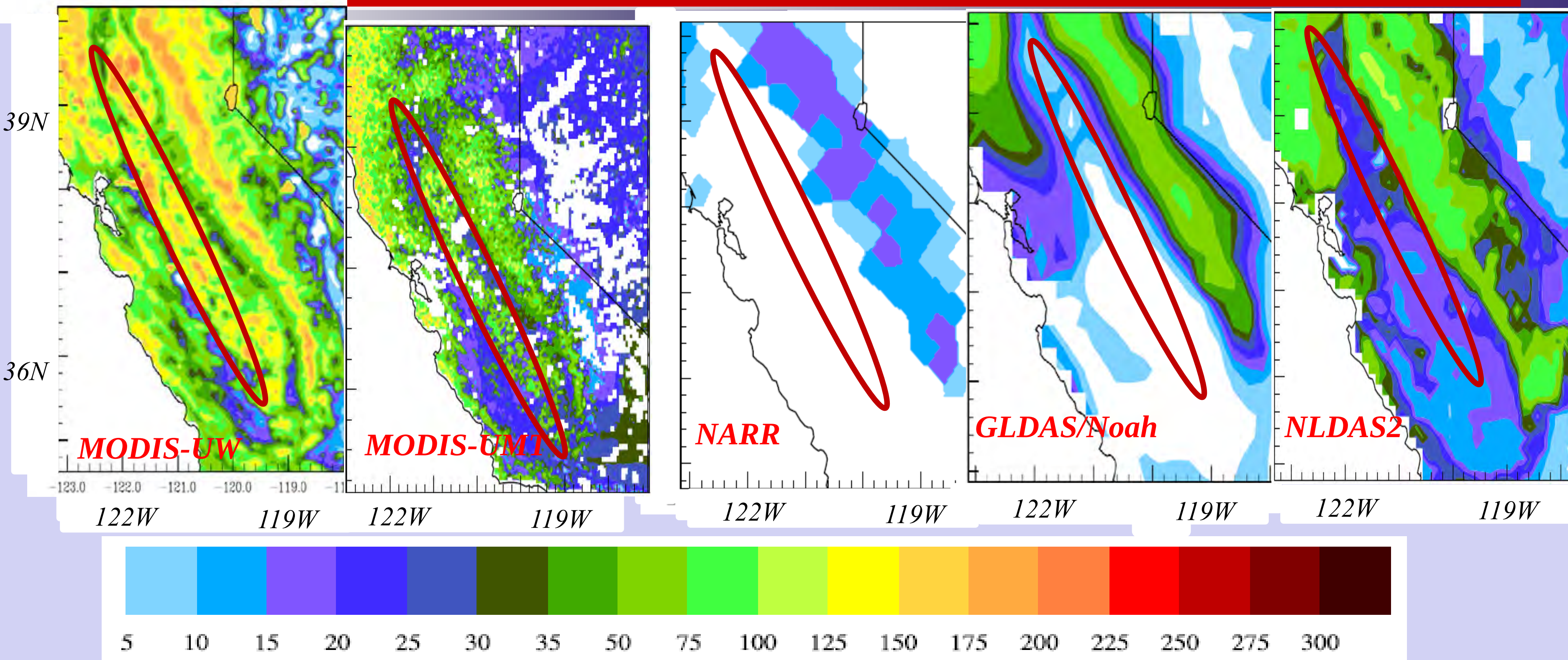


MM5R



Sorooshian et al. 2011 & 2012

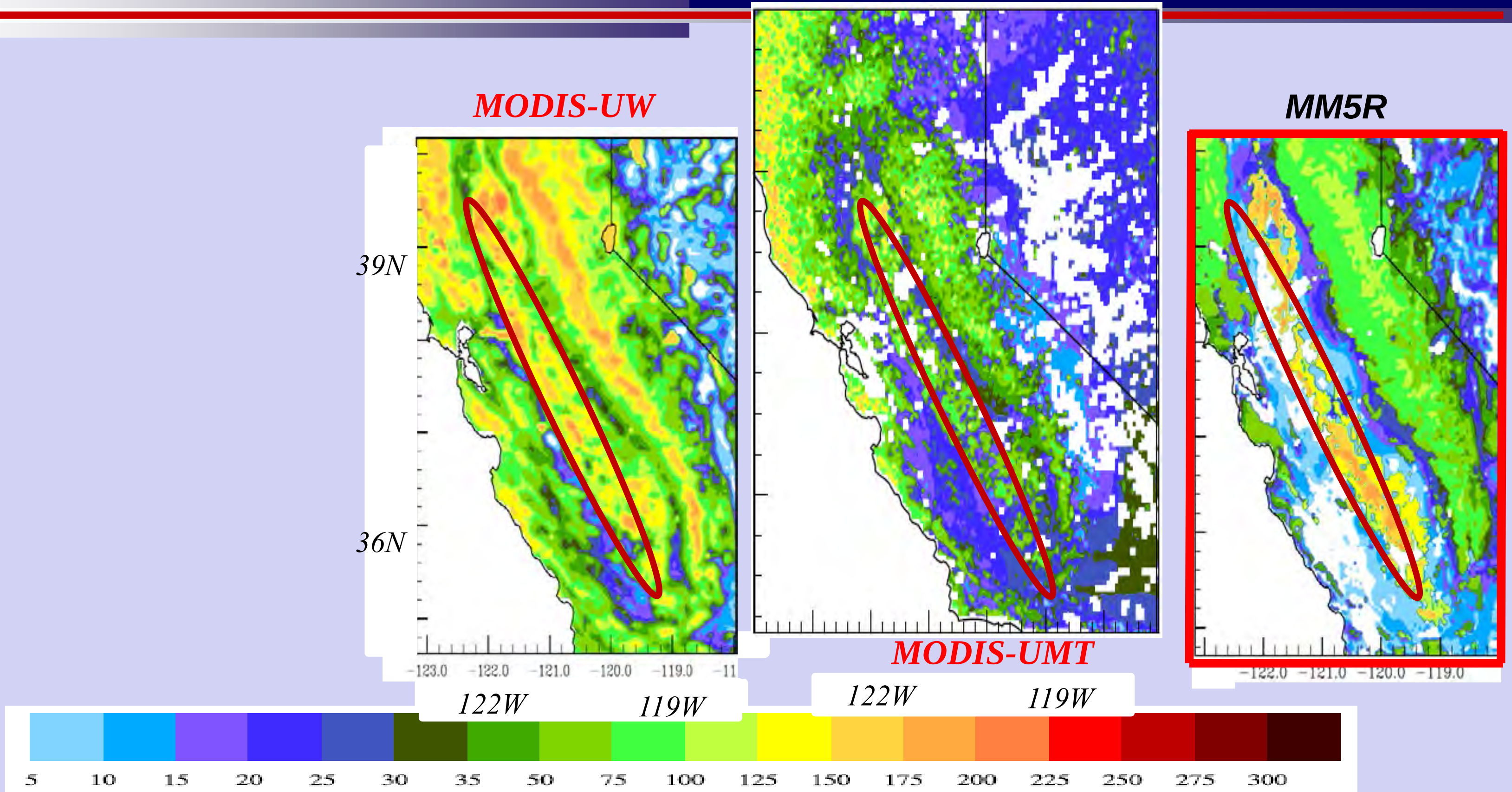
Actual ET Estimates From Different Data sets– JJA 2007



2007 JJA Monthly ET (mm)

Li et al, 2011

Actual ET comparison-spatial distribution – JJA 2007



Monthly ET (mm/month)

An Important Dilemma for the modeling application community will be:

Which Remotely Sensed ET Product should be used for model testing and validation??

What is the Message?

- *Despite advances to date, predicting the future Hydro-Climate variables will remain a major challenge:*

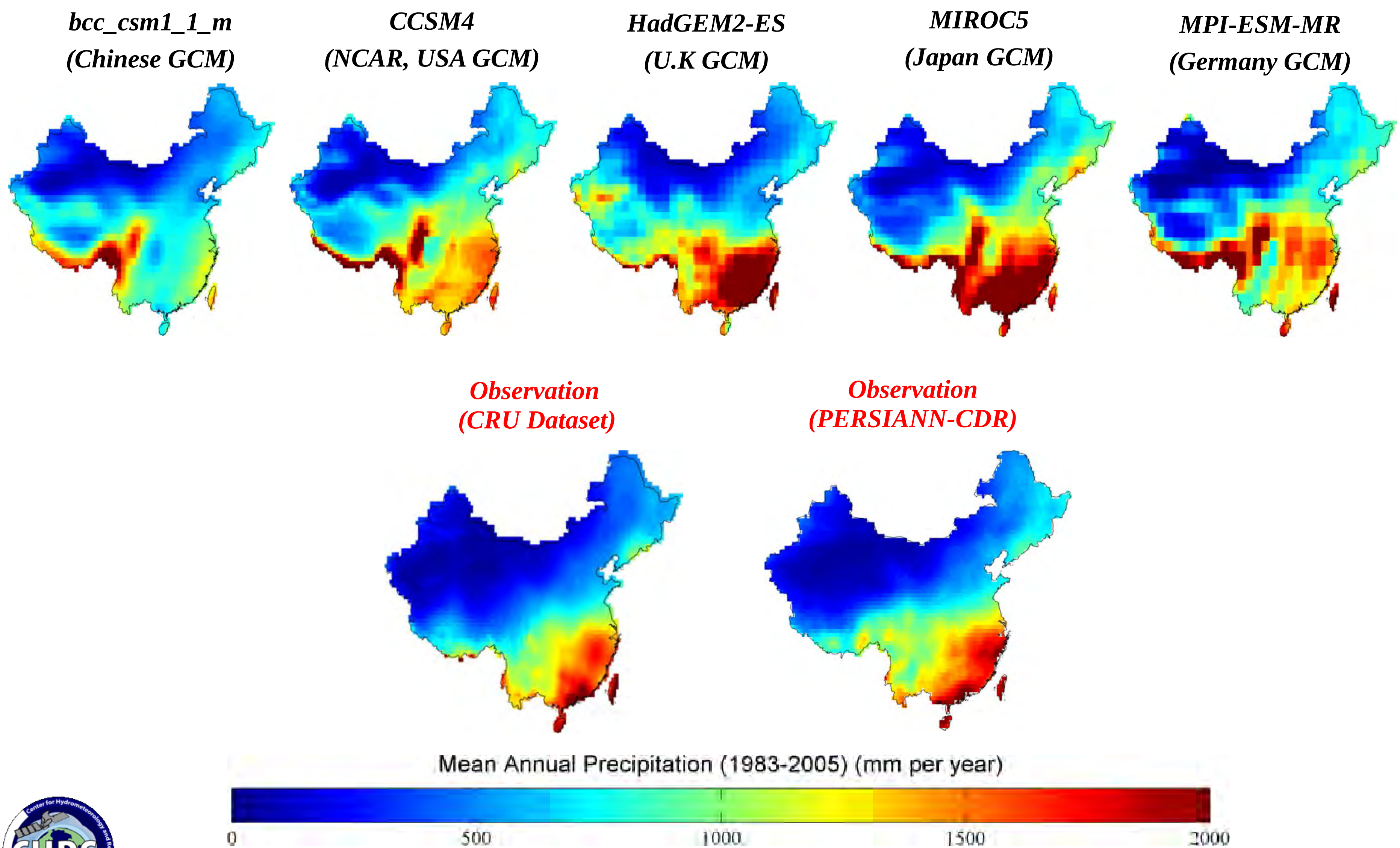
- *Nature is complex and observing and modeling its nonlinear behavior is very challenging. So, "have a will to doubt" the credibility of information "generated" by models.*

- *Long-term and sustained observation programs are critical, especially for model verification. Without some degree of verifiability, hard to expect their use*

Tibet: Confluence of Lhasa-Tsangpo Rivers August 23rd 2014

Back up slides

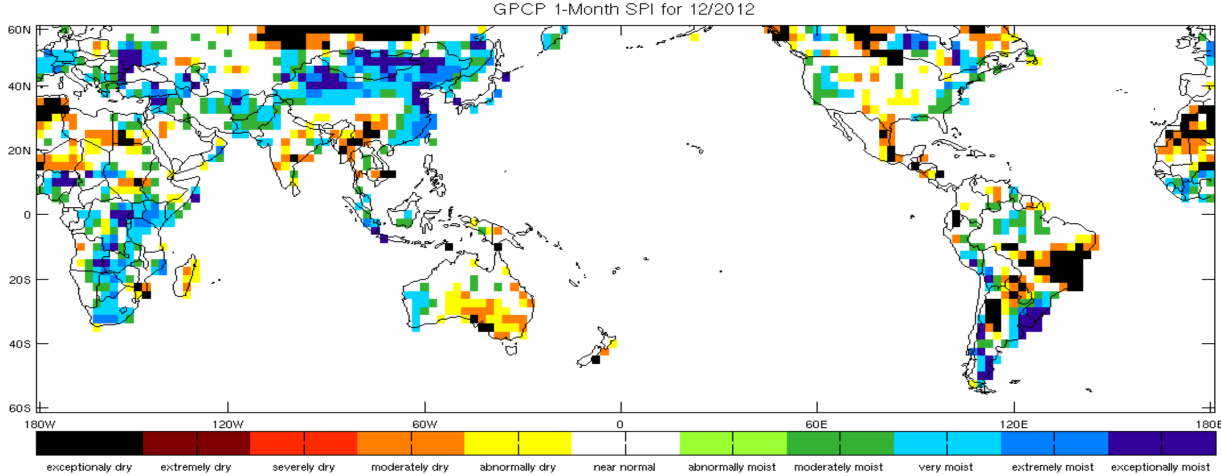
Model historical simulation (1983-2005)



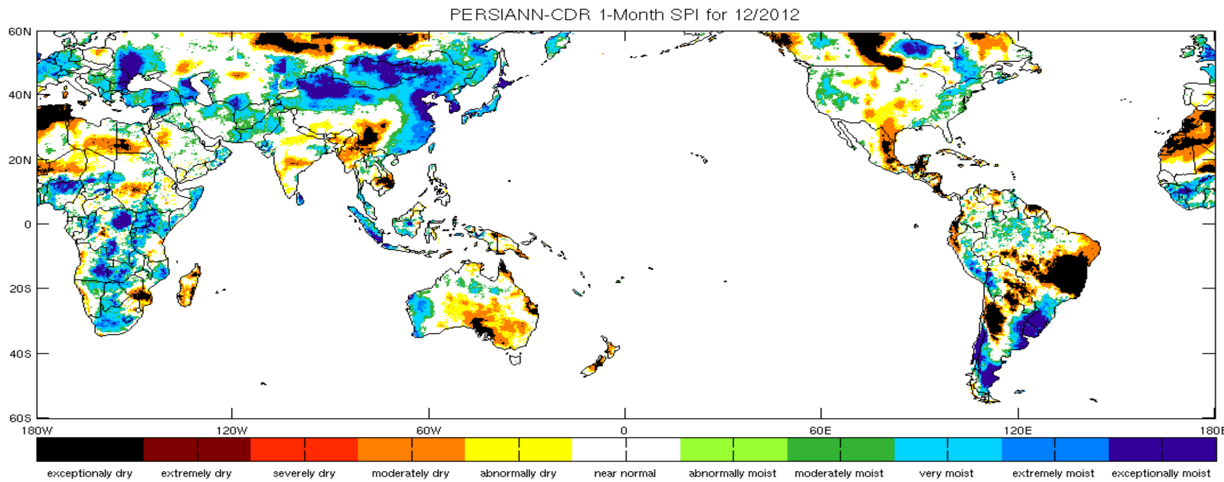
Global Drought Monitoring

Monitoring global "abnormal" wetness and dryness conditions using Standard Precipitation Index (SPI) method from GPCP 2.5-deg monthly (top) and PERSIANN-CDR 0.25-deg daily (bottom) for the period of 1983-2012. NOTICE the difference in spatial resolution

GPCP 2.5-deg monthly

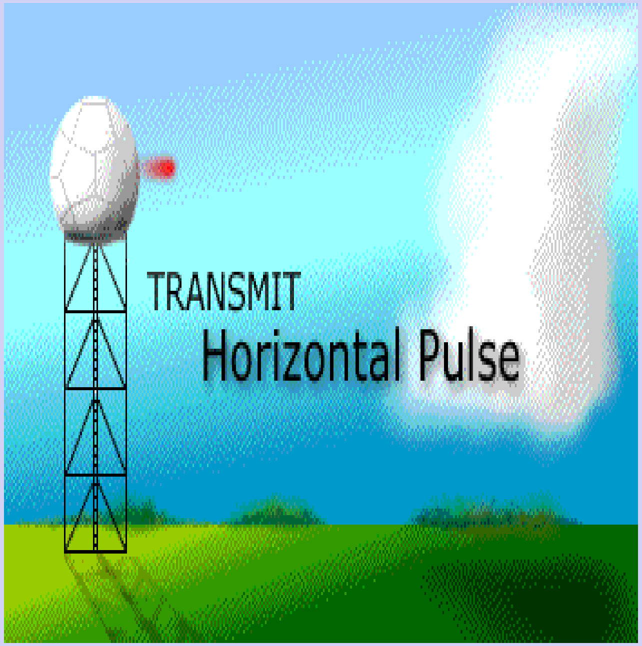


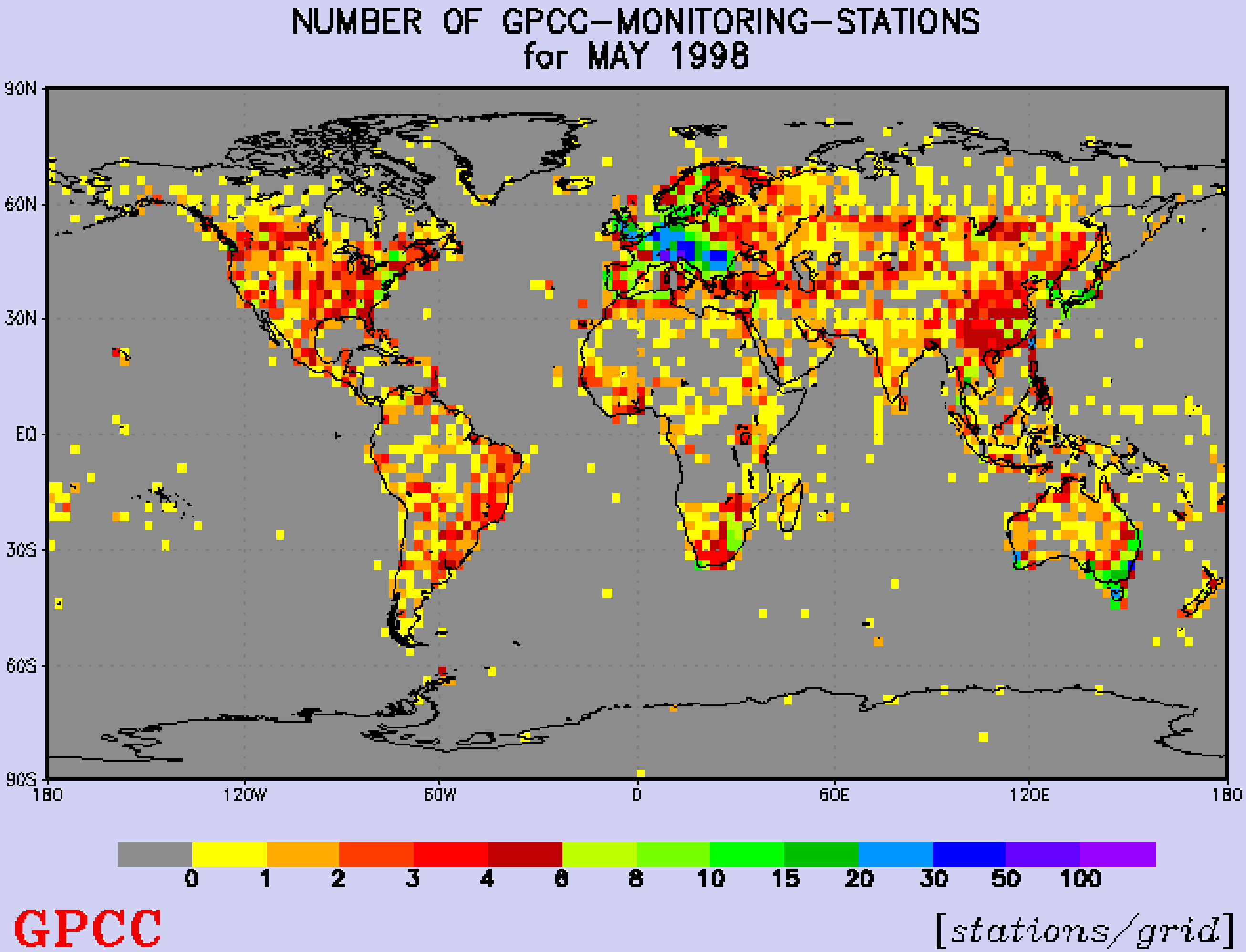
PERSIANN-CDR 0.25-deg daily



H. Ashouri

Precipitation Observations: Which to trust??

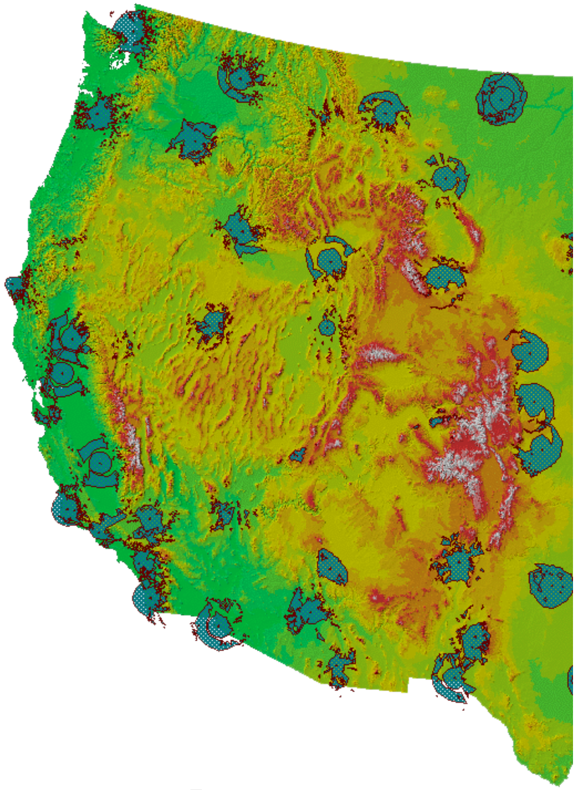




Number of range gauges per grid box**. These boxes are **2x2 degrees

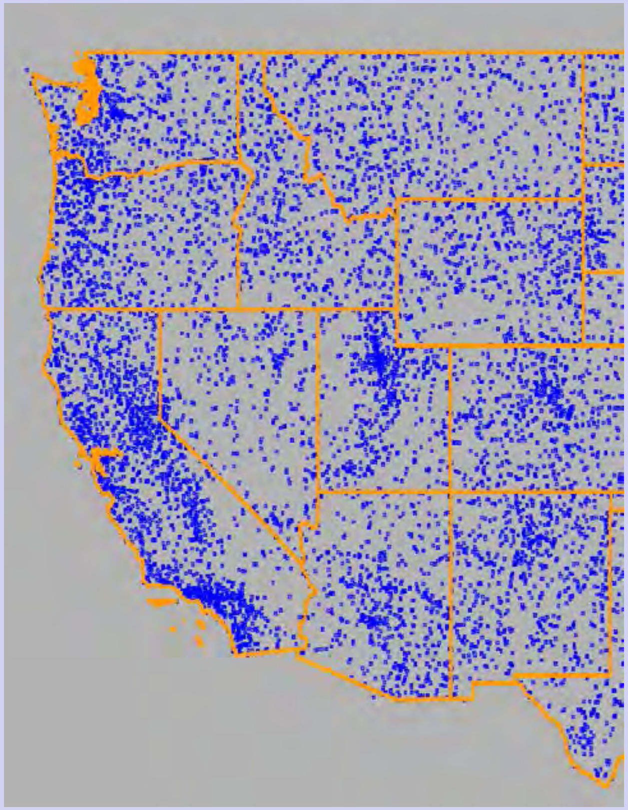
(Source: Global Precipitation Climatology Project)

Coverage of the WSR-88D and gauge networks



1 km AGL

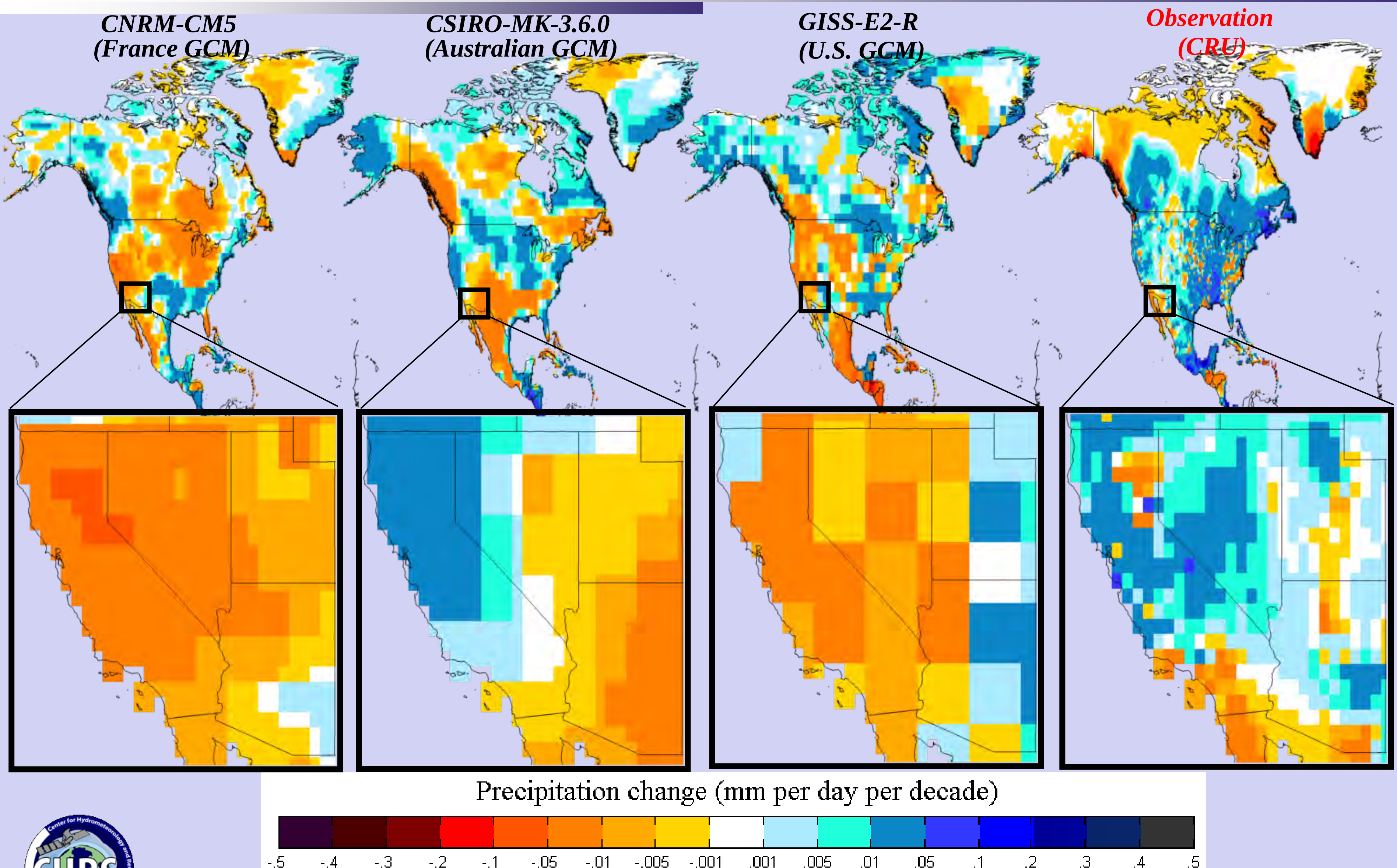
Maddox, et al., 2002



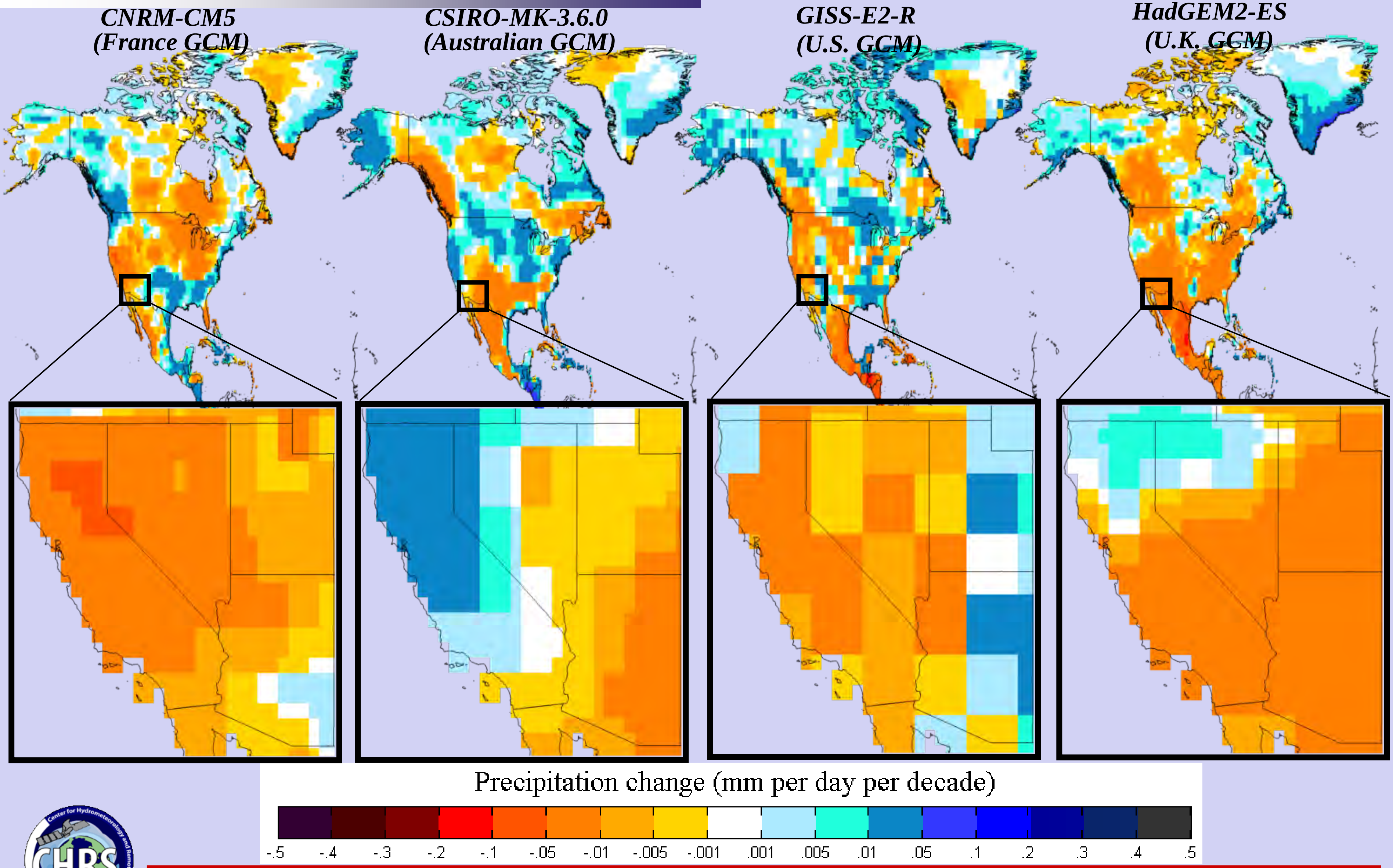
Daily precipitation gages (1 station per 600 km^2 for Colorado River basin) hourly coverage even more sparse

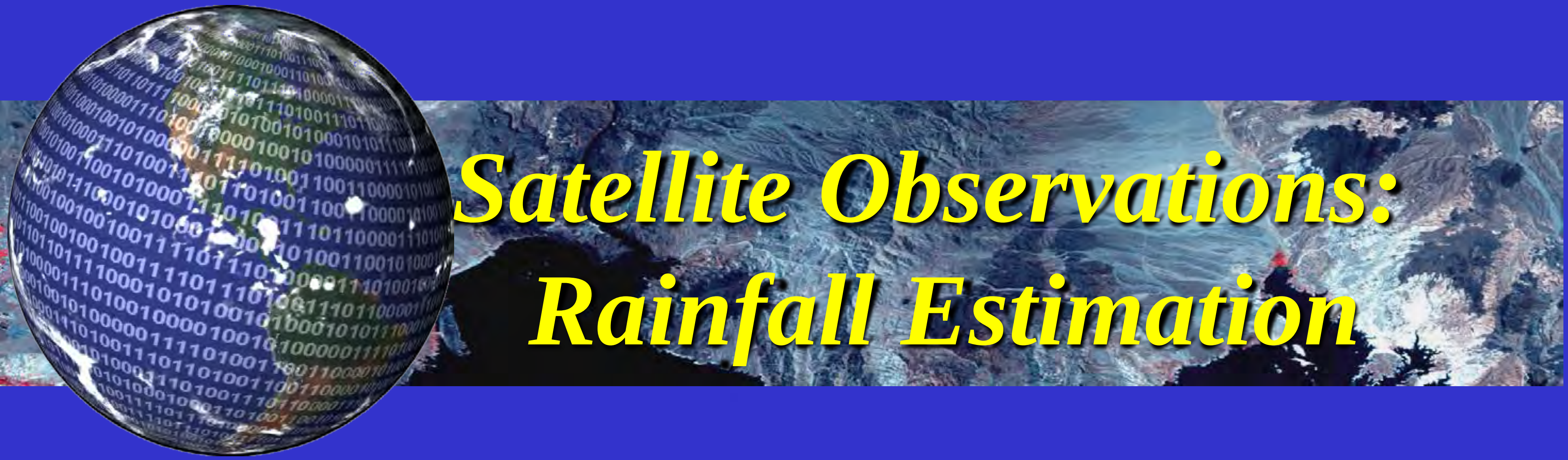
Western U.S. historical model simulations

Model historical simulation vs observation



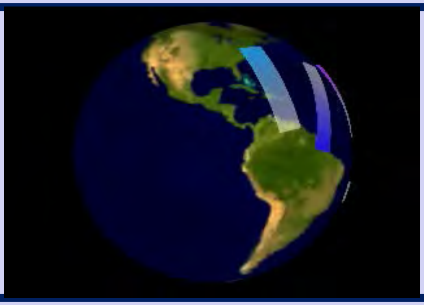
Model historical simulation



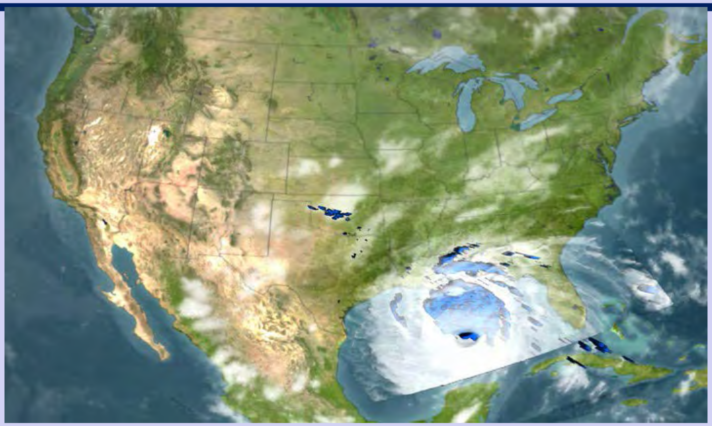

Satellite Observations:
Rainfall Estimation

Satellite Data for Precipitation estimation

Geostationary IR
Cloud top data
15-30 minute temporal resolution



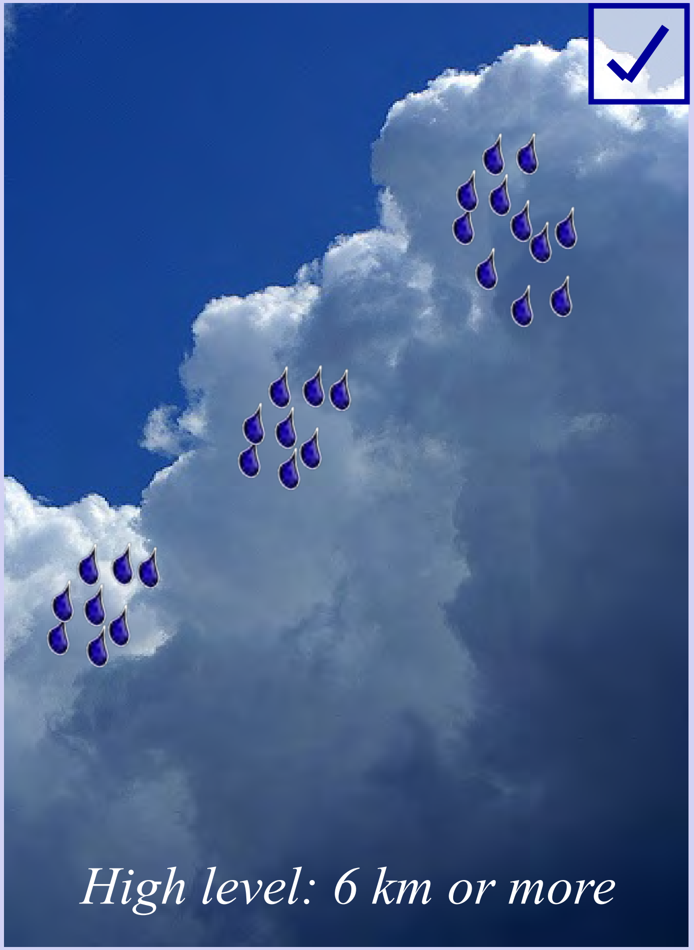
Passive Microwave (SSM/I)
Some characterisation of rainfall
~2 overpasses per day per spacecraft, moving to 3-hour return time (GPM)



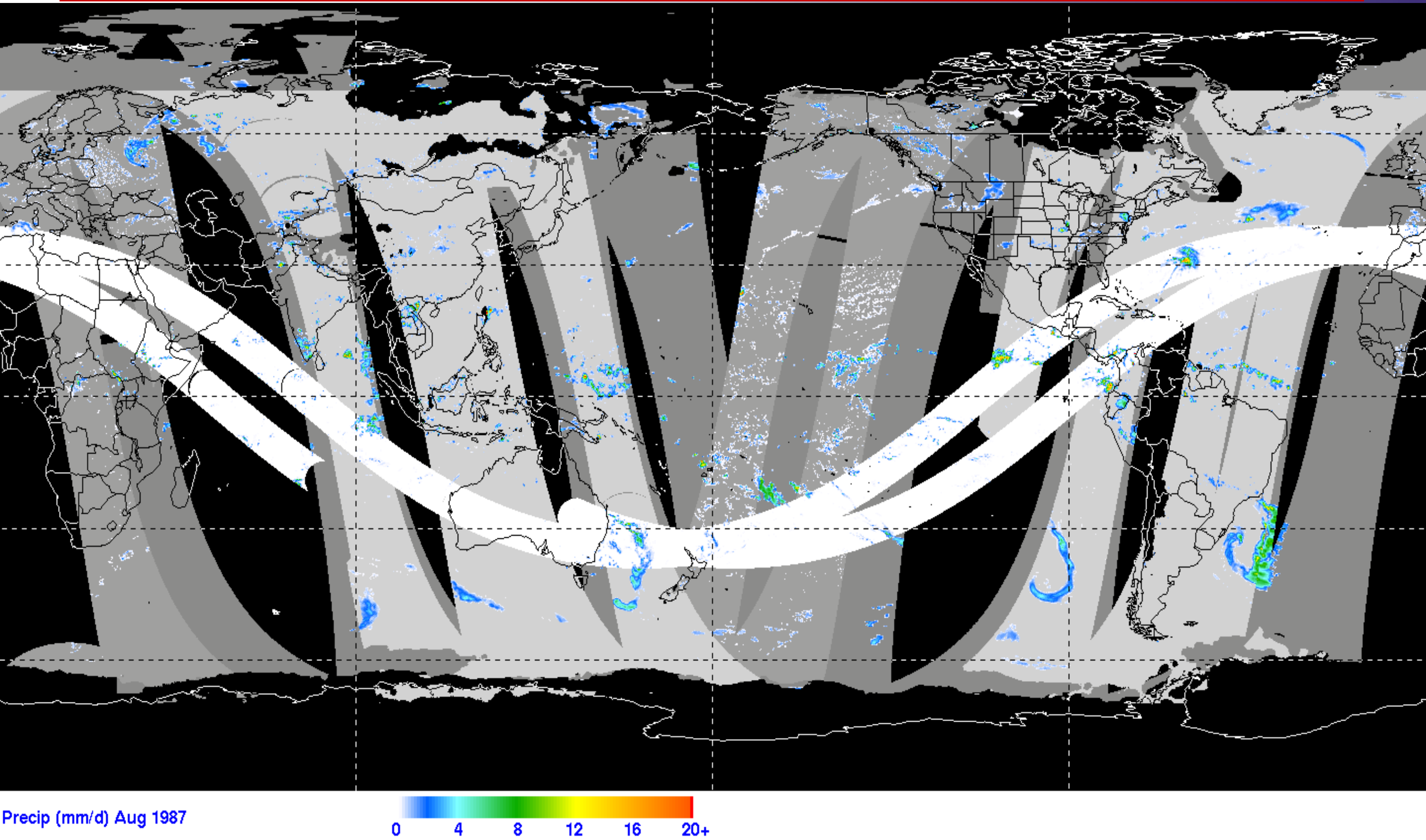
TRMM precipitation RADAR
3D imaging of rainfall
1-2 days between overpasses
(S-35°N-35 °)

Problems with IR only algorithm

Assumption: higher cloud → colder → more precipitation



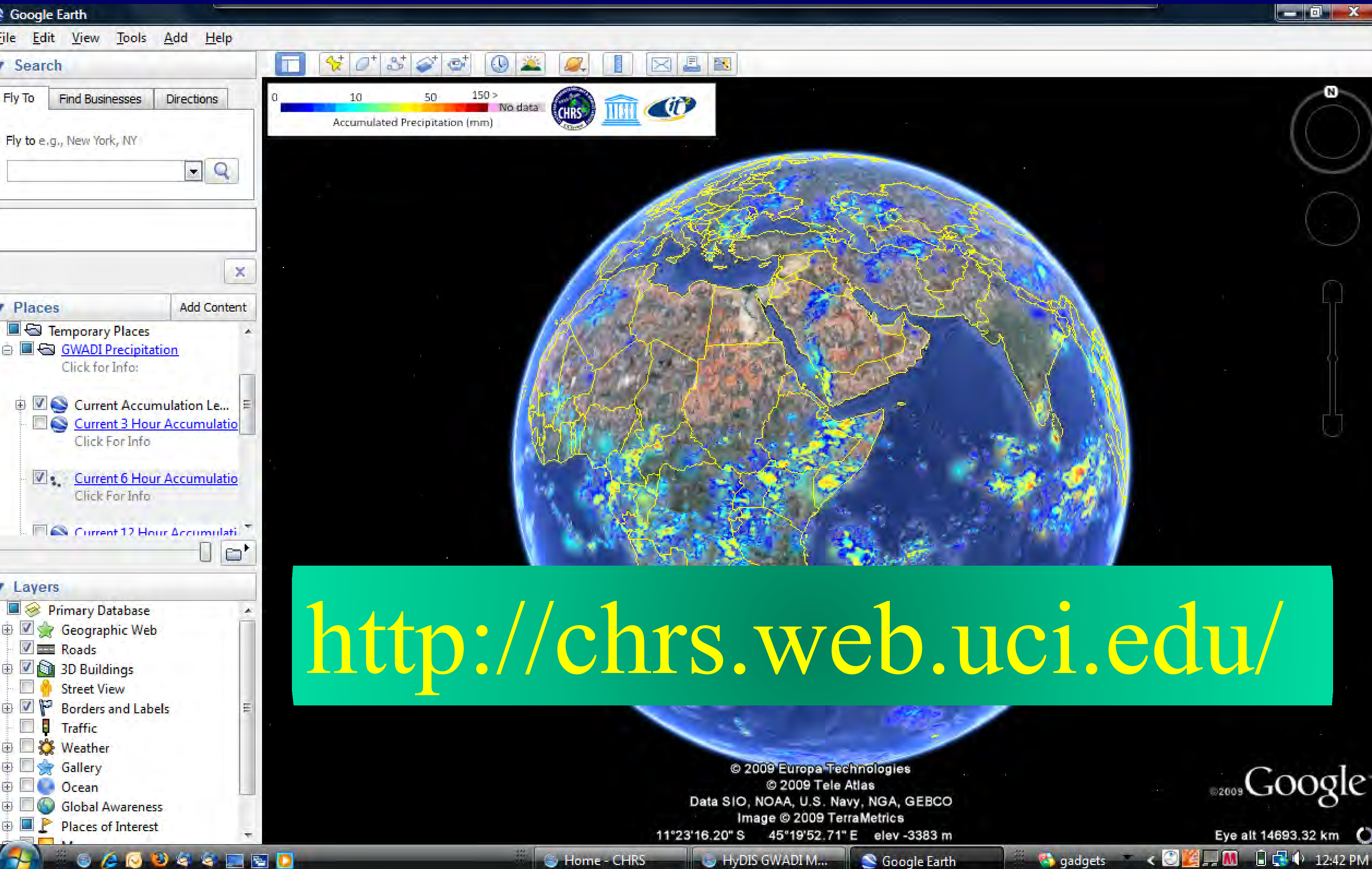
Current Microwave Satellite Configurations



Source: Huffman et al. 2007

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

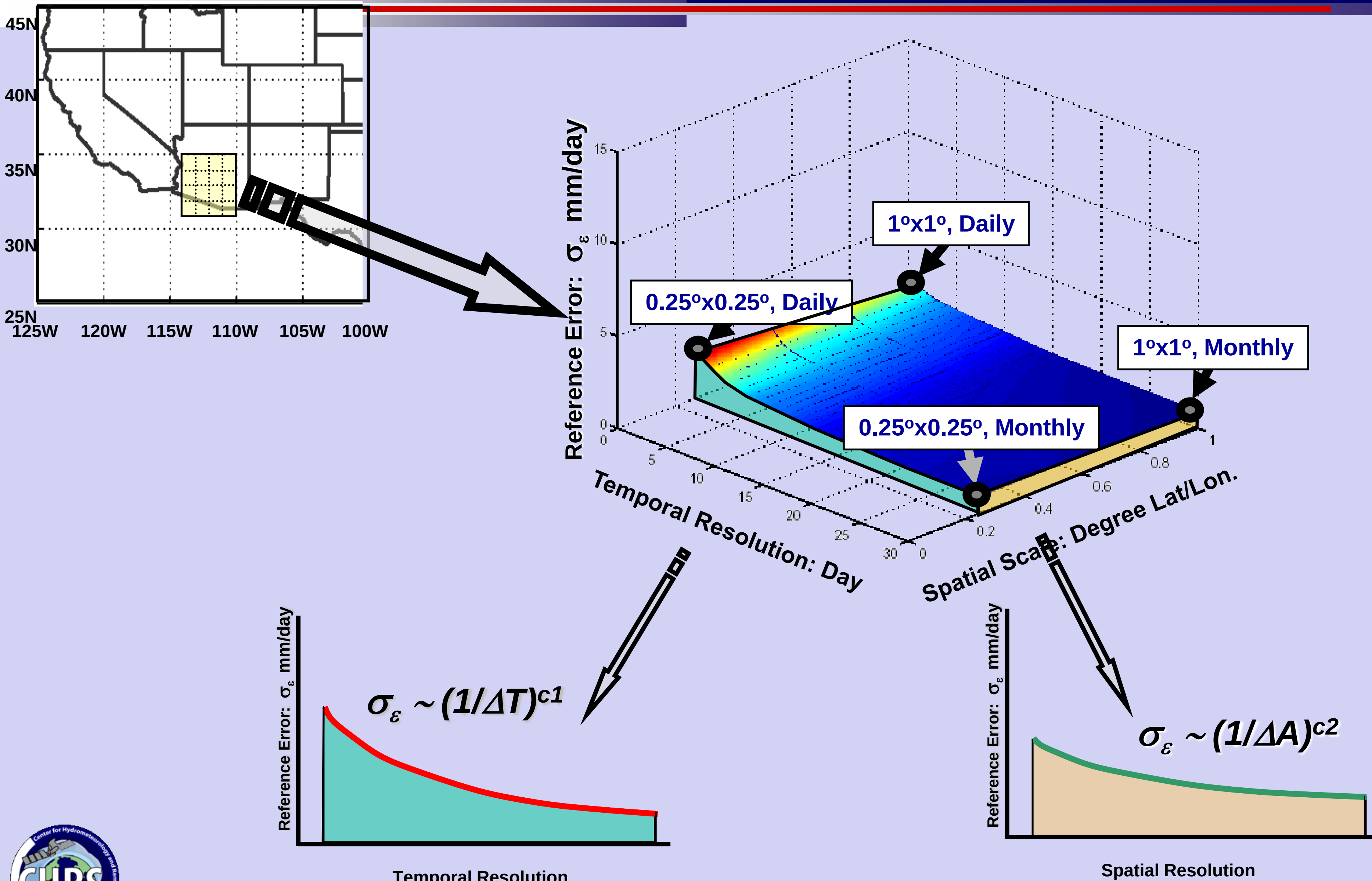
PERSIANN Satellite Product On Google Earth



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

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

Spatial-Temporal Property of Reference Error

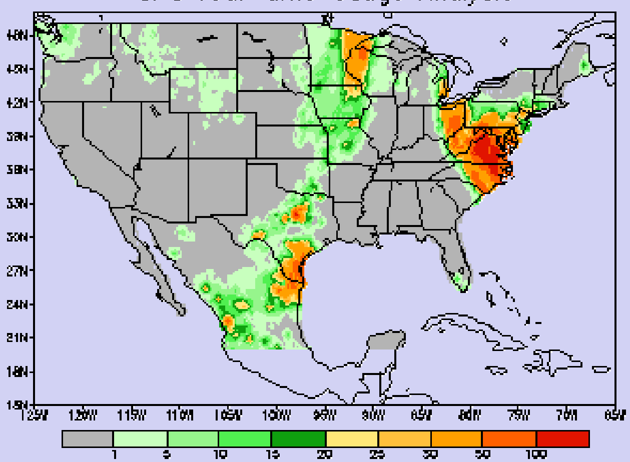


US Daily Precipitation Validation Page

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)

CPC real-time Gauge Analysis



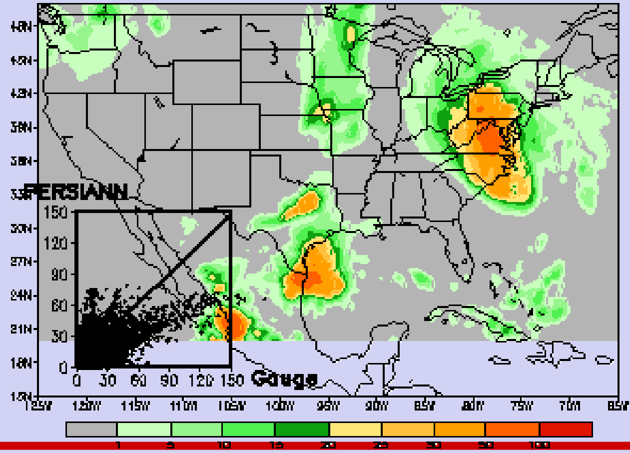
	(G) gauge	(S) PERSIANN	(R) radar
Number of points:	13828.	13828.	13828.
# points w/rain:	4249.	4665.	2971.
Mean rain rate:	5.56	4.25	3.13
Cond. rain rate:	17.82	12.47	14.46
Max. rain rate:	181.99	79.07	131.45

	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

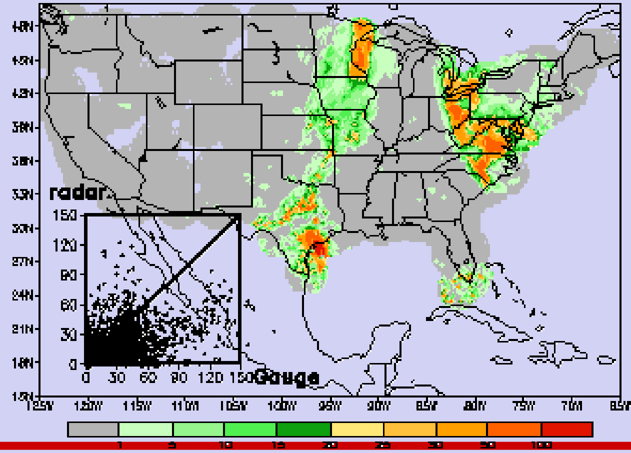
gauge	PERSIANN < 1	PERSIANN ≥ 1
< 1	8082.	1497.
≥ 1	1081.	3168.

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

PERSIANN

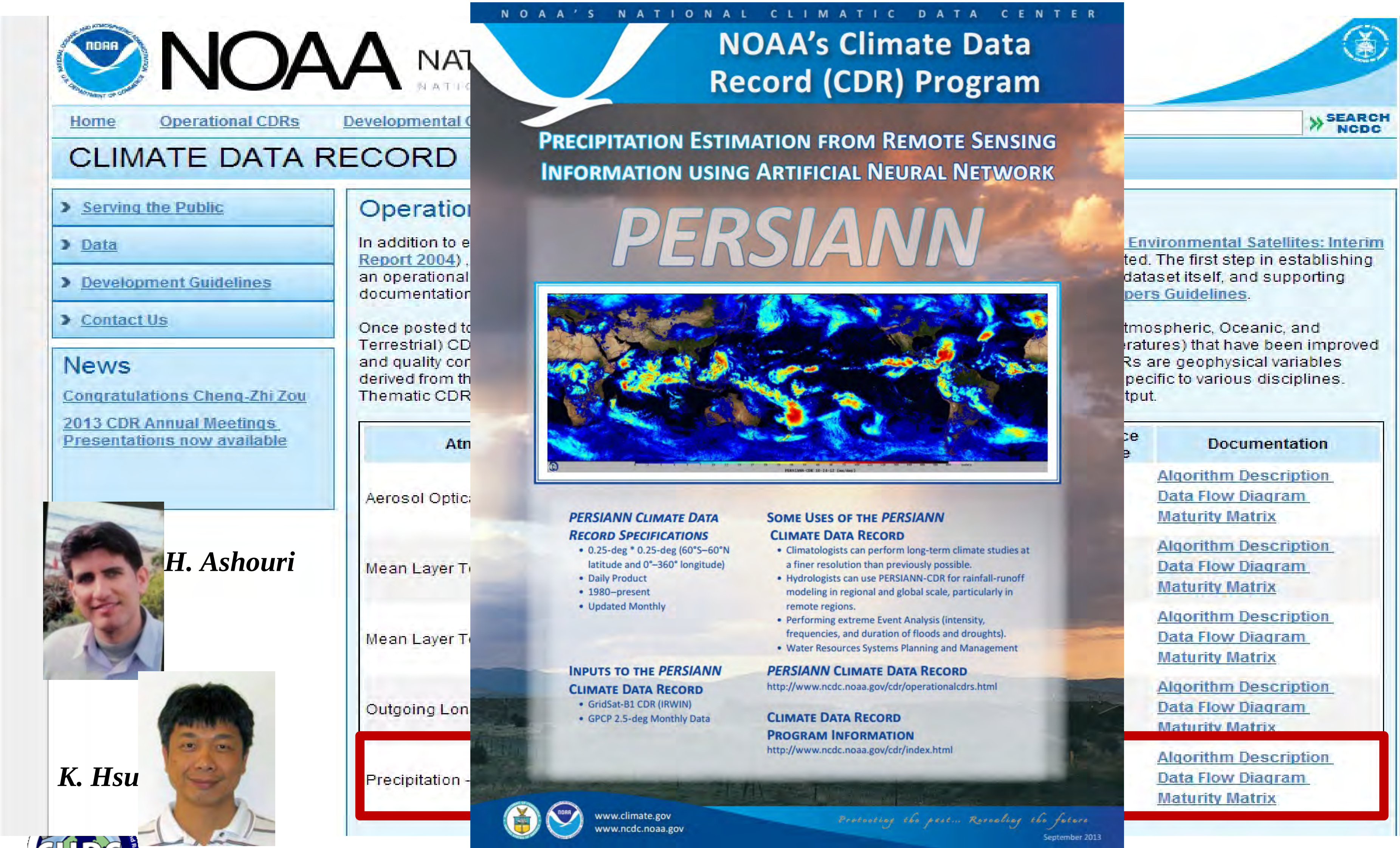


Radar



PERSIANN-CDR: PERSIANN Climate Data Record (30-yr, Daily, 25 Km)

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



H. Ashouri

K. Hsu

GPM Mission: Target Launch Feb. 2014

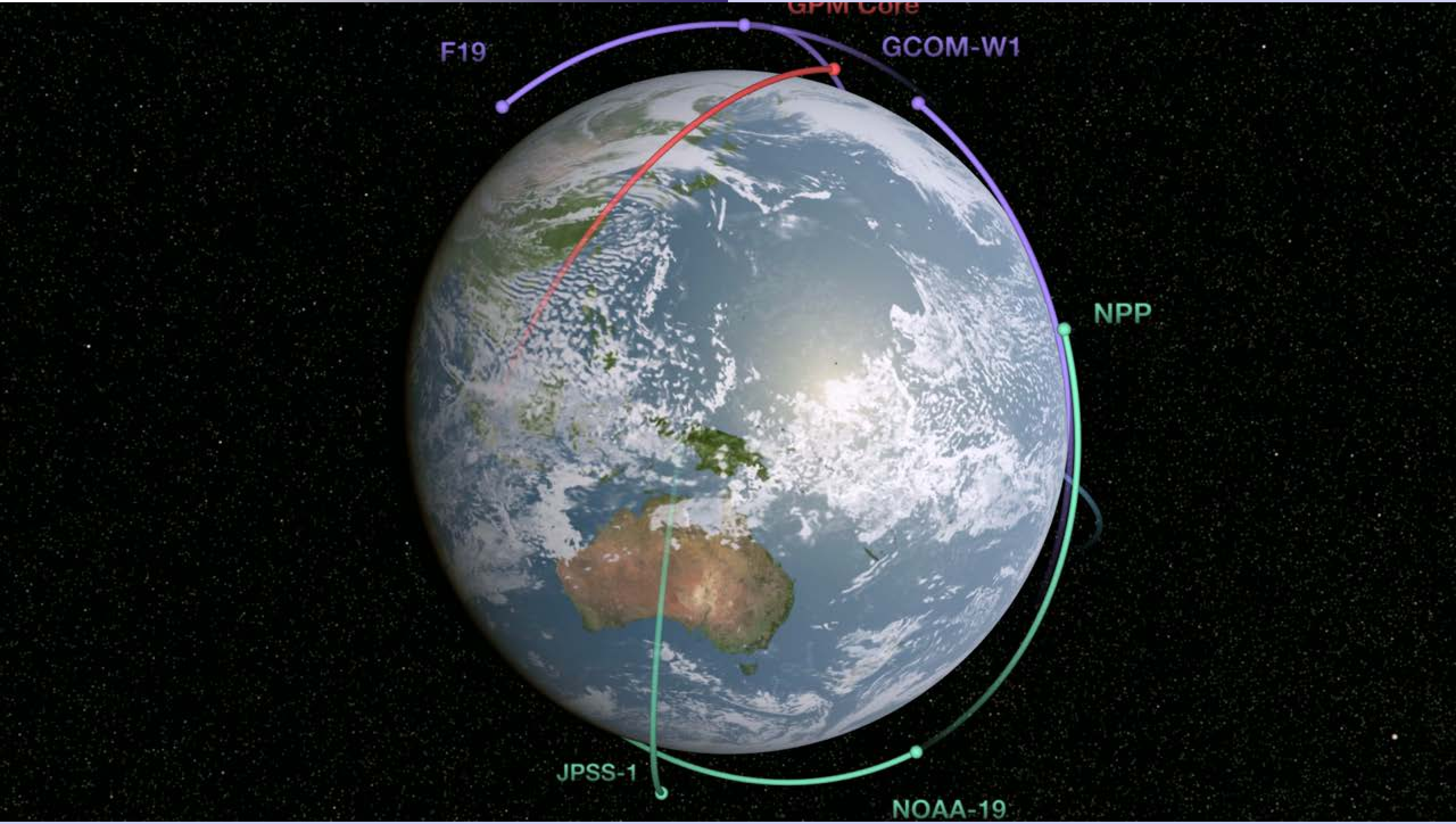
OBJECTIVES

- **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 more advances for precipitation Estimation

GPM Animation

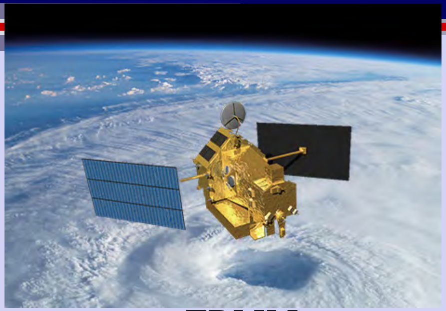
Courtesy: NASA's ESE



Hydrologically - Relevant Remote Sensing Missions

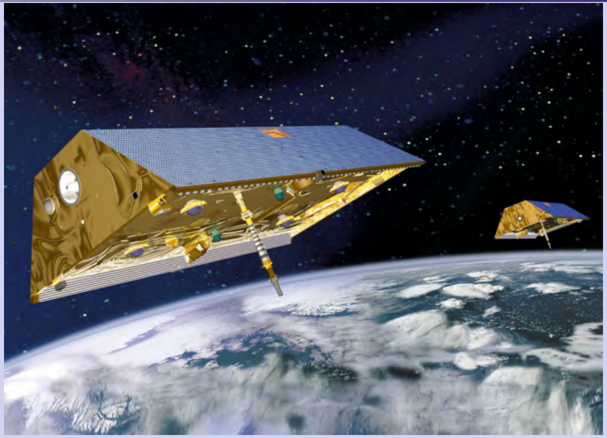
SMOS

ESA's Soil Moisture and Ocean Salinity (2009)



TRMM

The Tropical Rainfall Measuring Mission

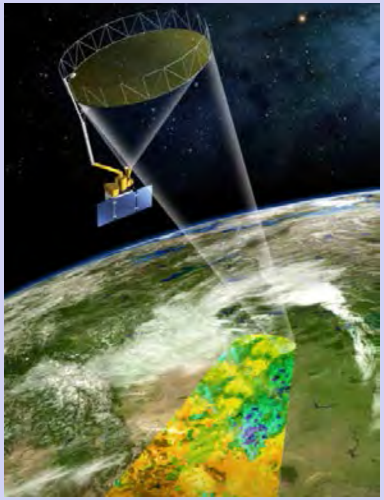


GRACE

Gravity Recovery and Climate Experiment (2002)

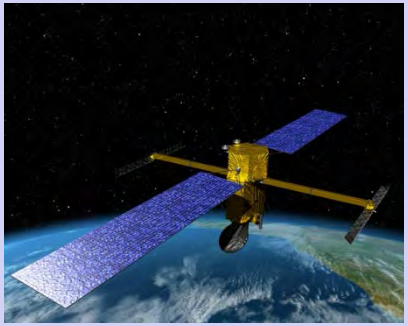
GPM

Global Precipitation Measurements (2014)



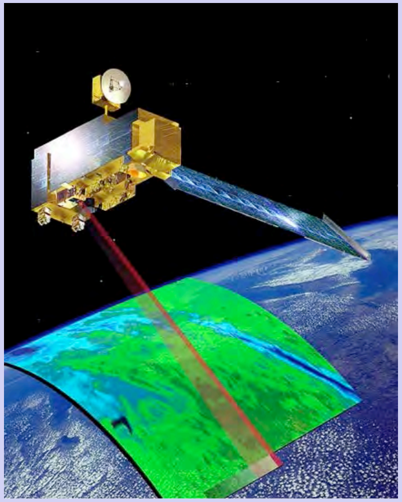
SMAP

Soil Moisture Active Passive Satellite(2014)



SWOT

Surface Water and Ocean Topography (2020)



MODIS

Moderate Resolution Imaging Spectroradiometer (1999) , (2002)