Lecture II

Hydrological modeling requirements for Water Resources Applications - Data Issues and Potential for the Use of Satellite Observations

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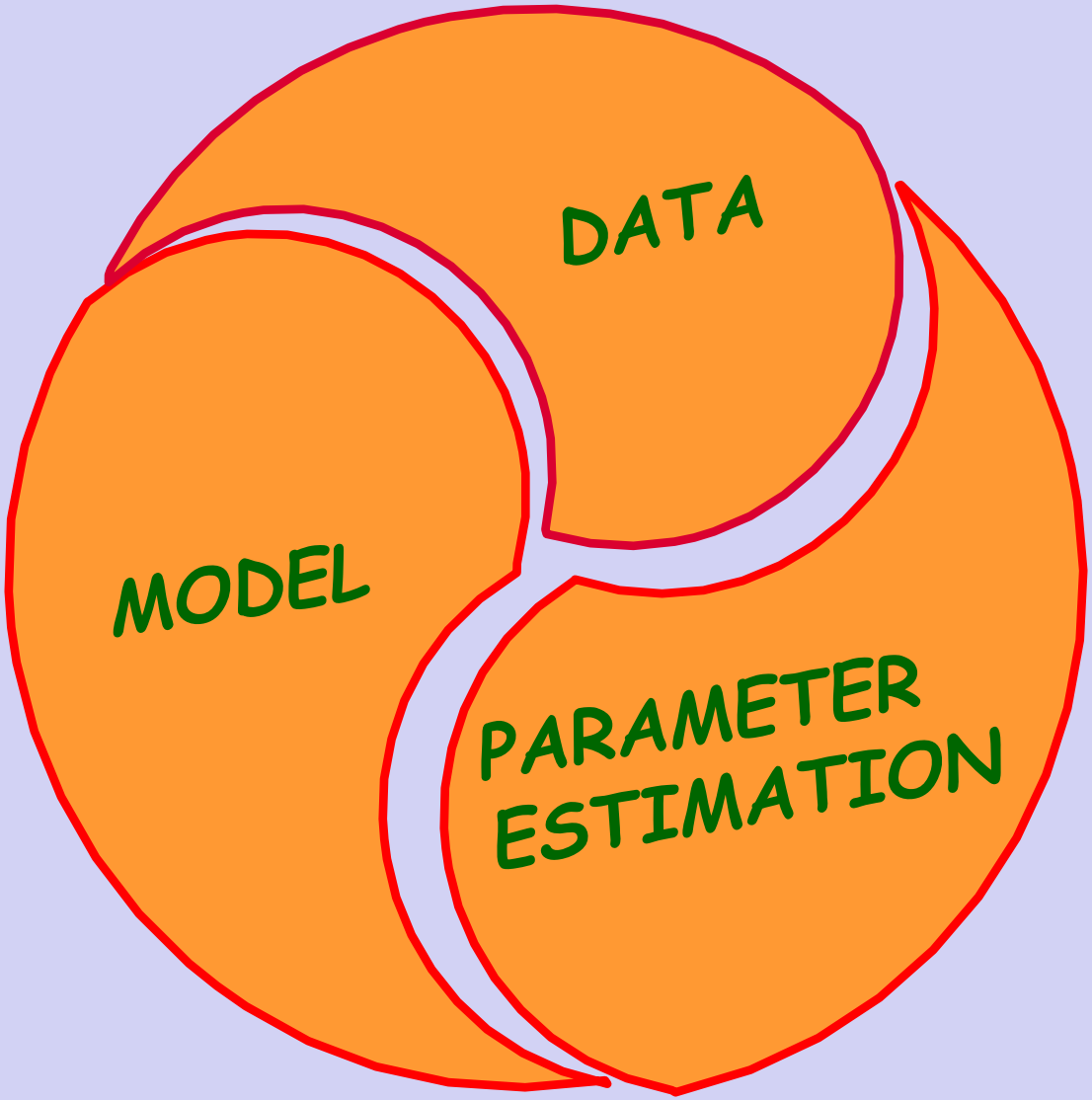
Center for Hydrometeorology and Remote Sensing

University of California Irvine

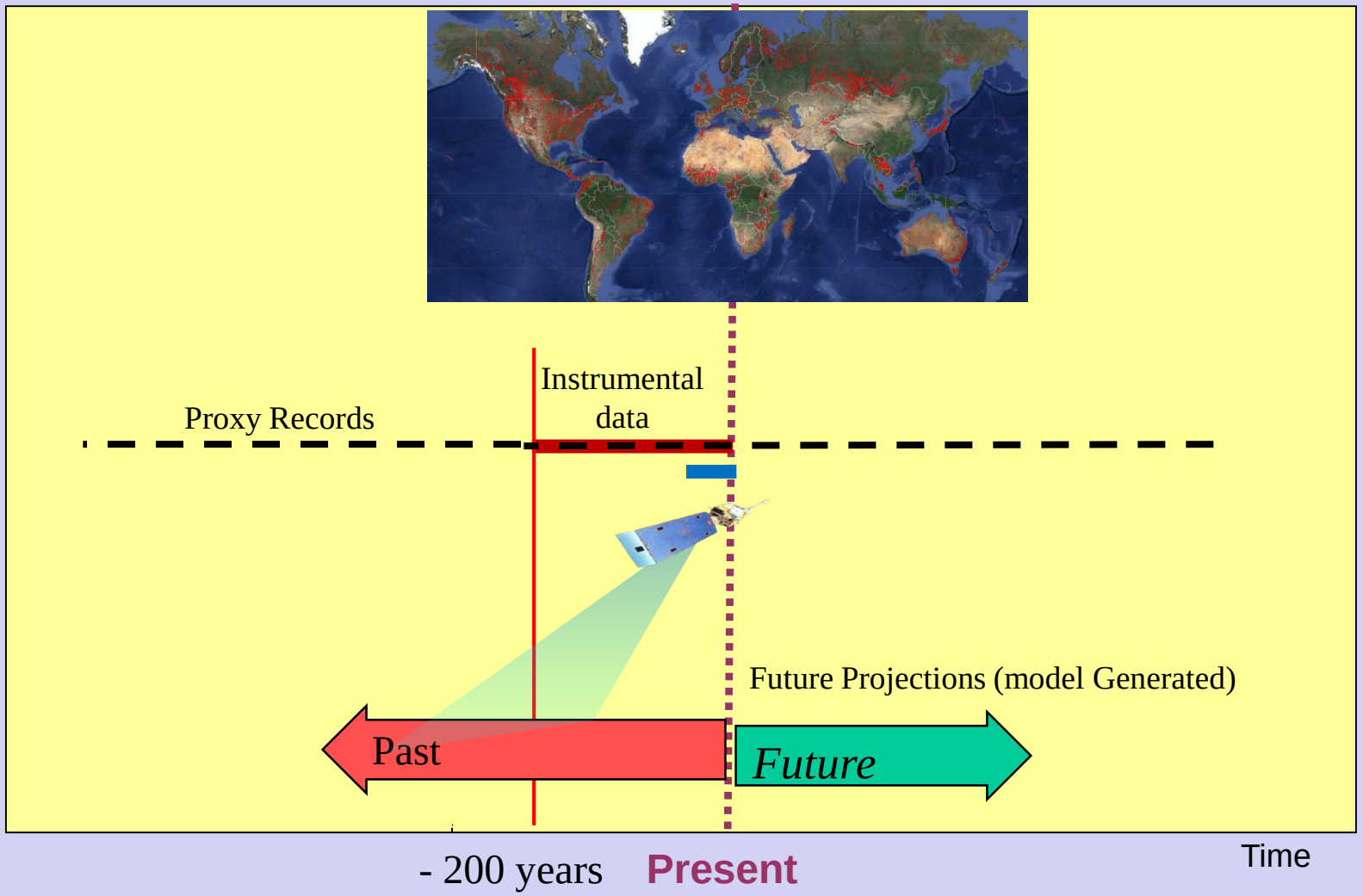
ICTP 5th Workshop on: Water Resources in Developing Countries: Hydroclimate Modeling and Analysis Tools

Trieste, Italy: May 27th – June 7th 2019

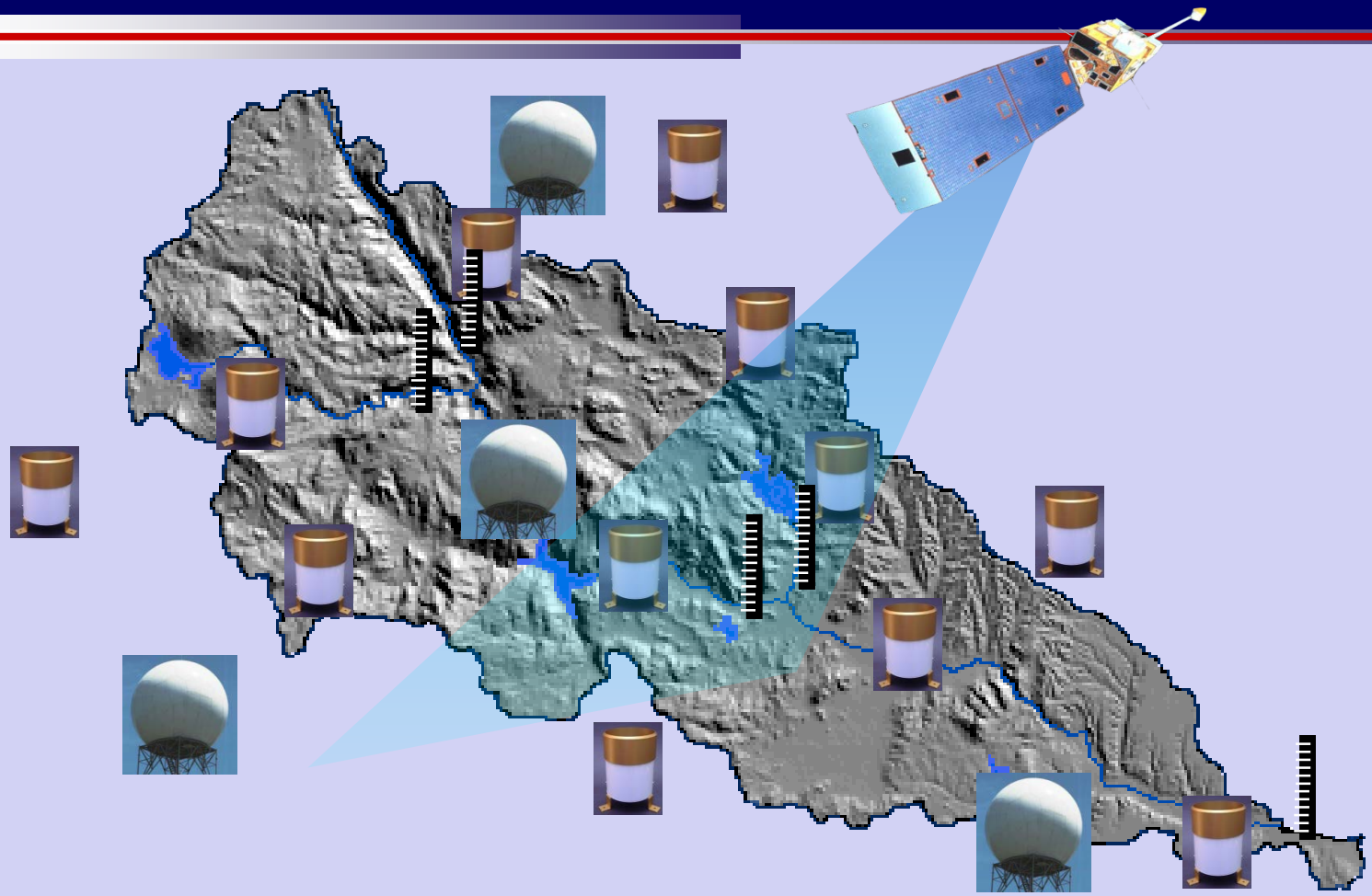
Data



Hydroclimate of the Past and Future: Observation &Modeling



Data Requirements for Hydrologic Modeling



Data Limitation is an Important Factor in Success of Hydrologic Modeling

Big Challenge For "us":

Adequacy of Hydrologic Observations

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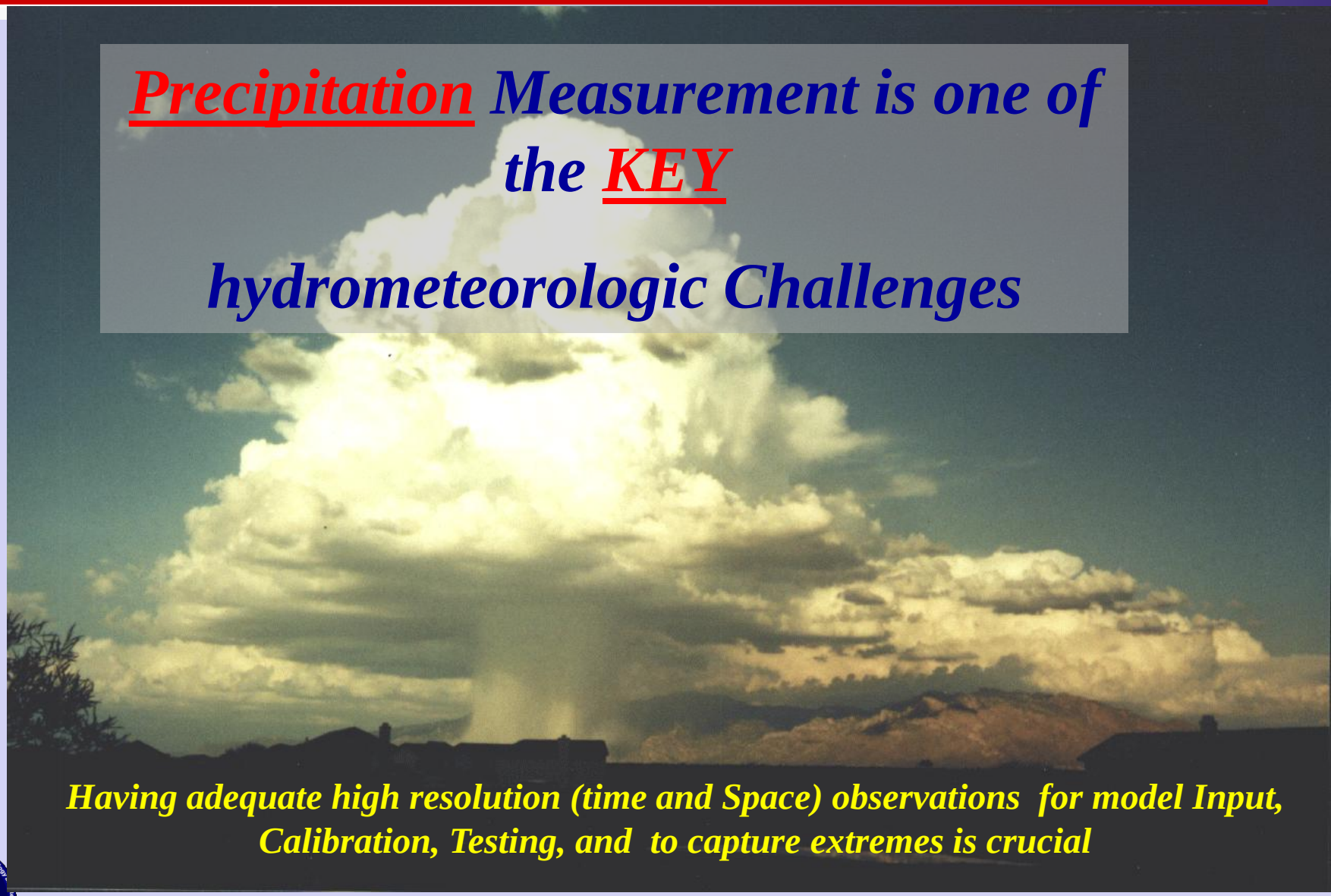
Observation of Primary Hydrologic Variables

Precipitation

Stream flow

A Key Requirement!



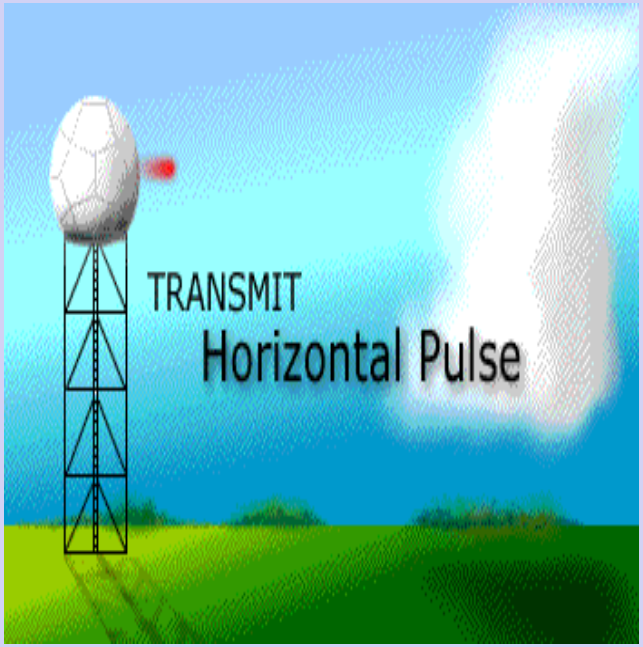
Precipitation* Measurement is one of the *KEY

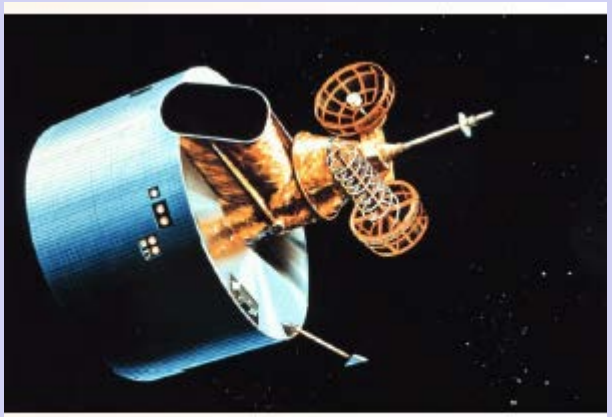
hydrometeorologic Challenges

Having adequate high resolution (time and Space) observations for model Input, Calibration, Testing, and to capture extremes is crucial

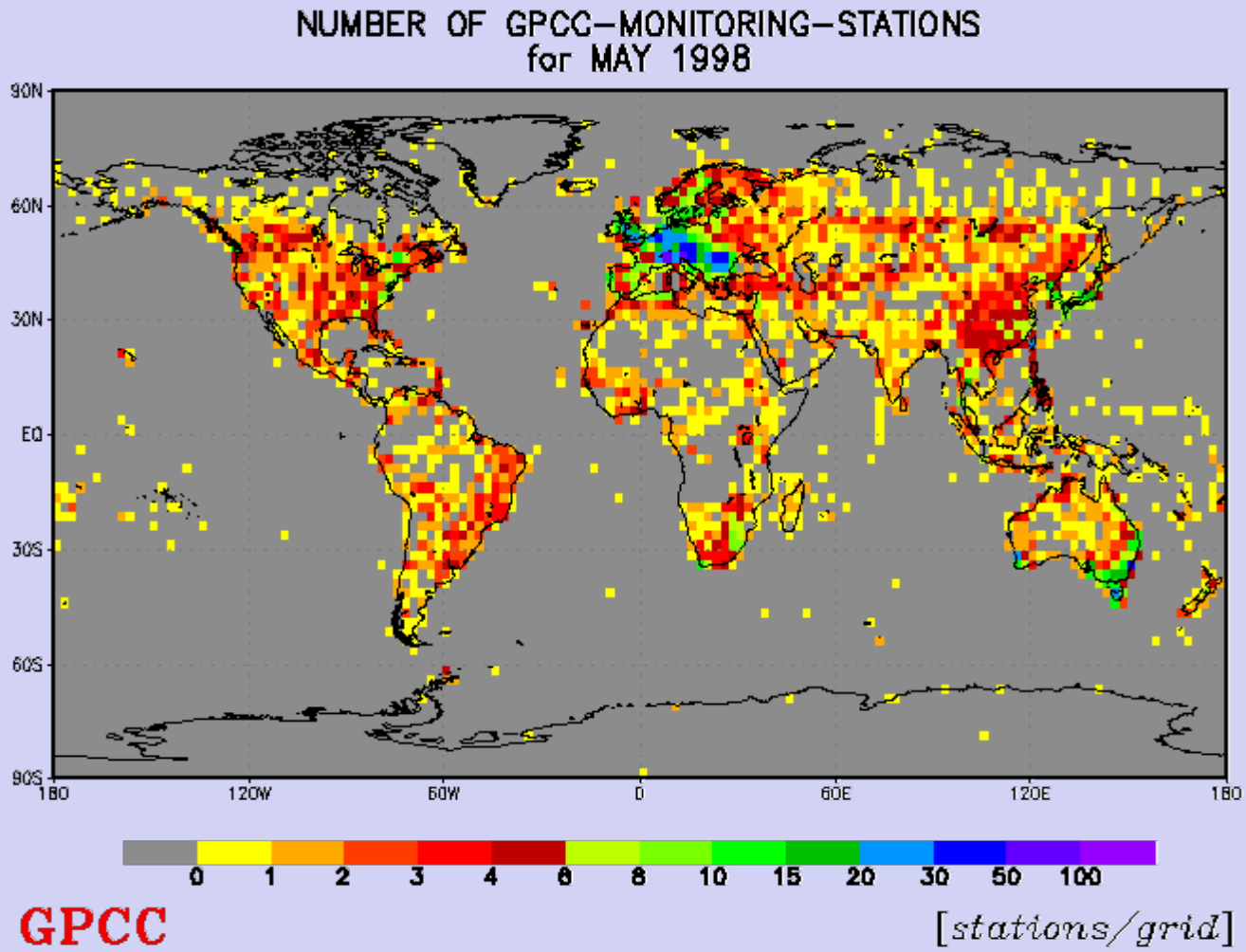
Precipitation Observations: Which to trust??

Rain Gauges



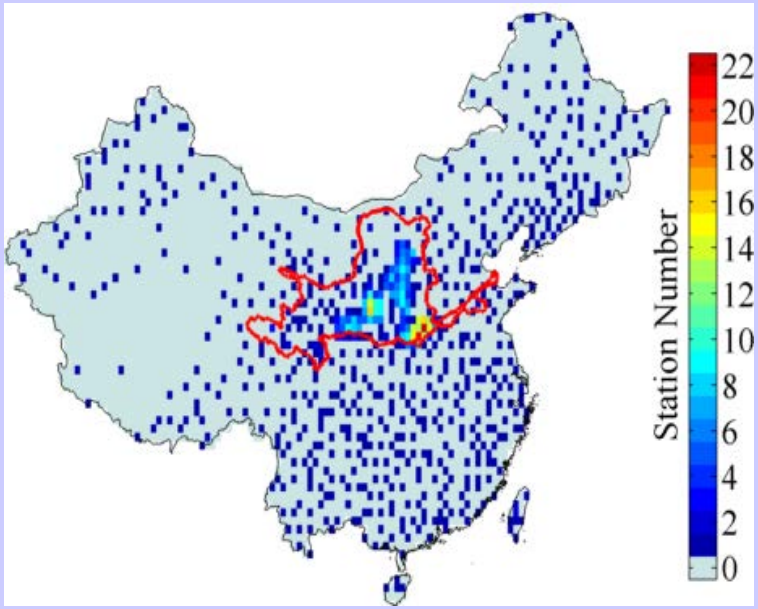


Satellite

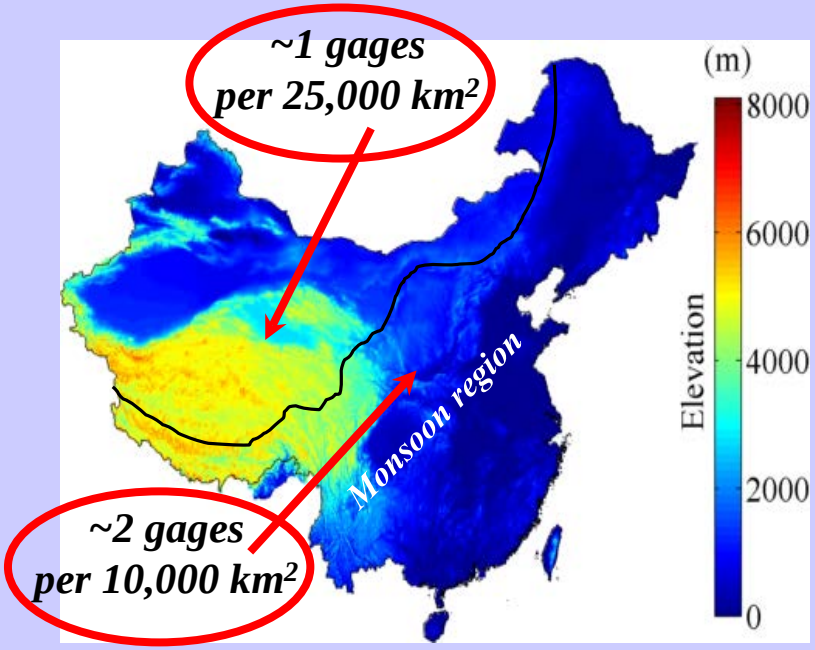


Number of range gauges per grid box. *These boxes are* ***2x2 degrees*** *(Source: Global Precipitation Climatology Project)*

Rain Gauge Coverage over China

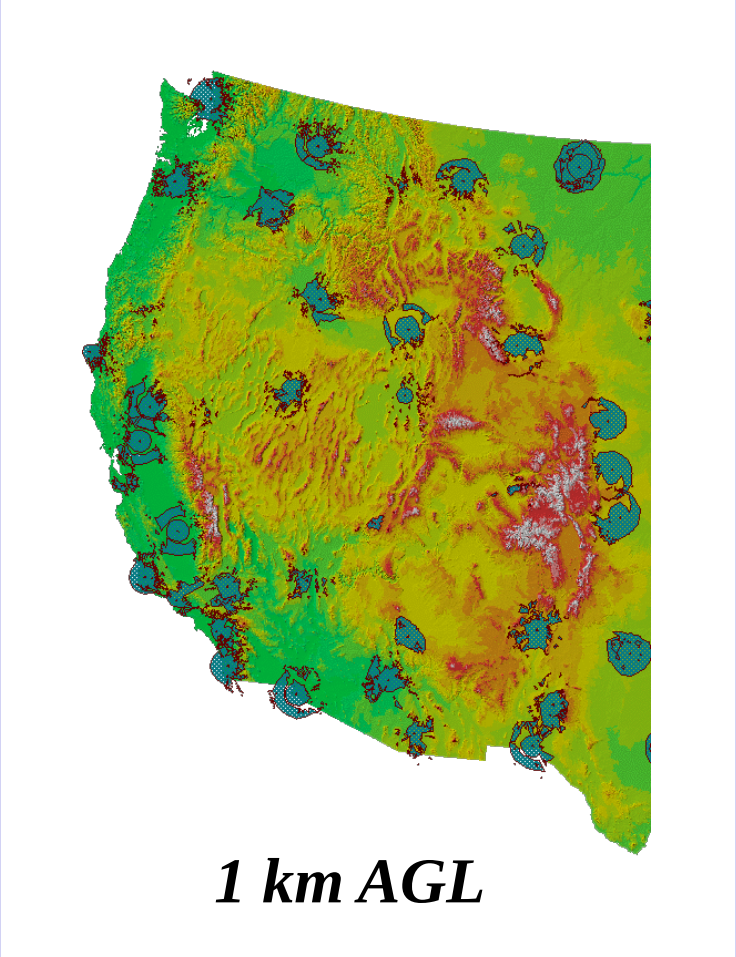


EA Rain Gauge Distribution

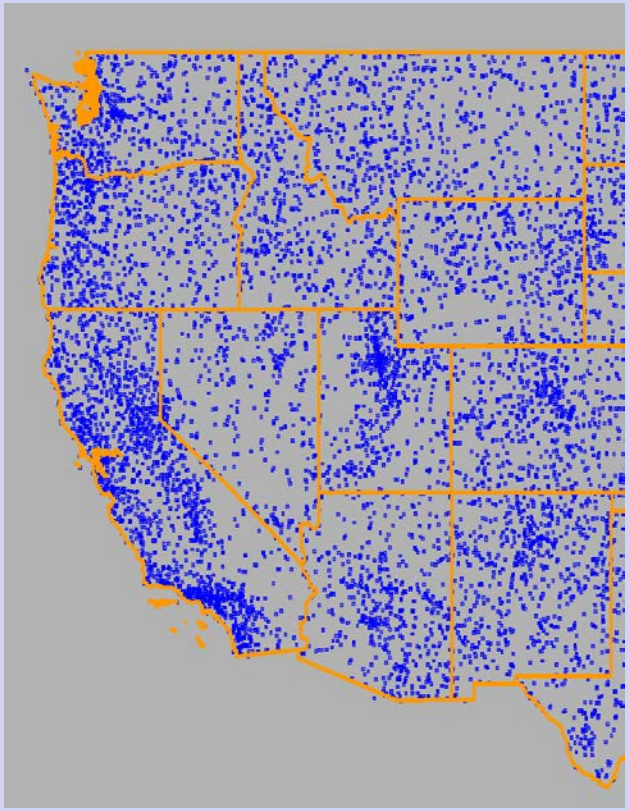


Elevation Map

Coverage of the WSR-88D and gauge networks

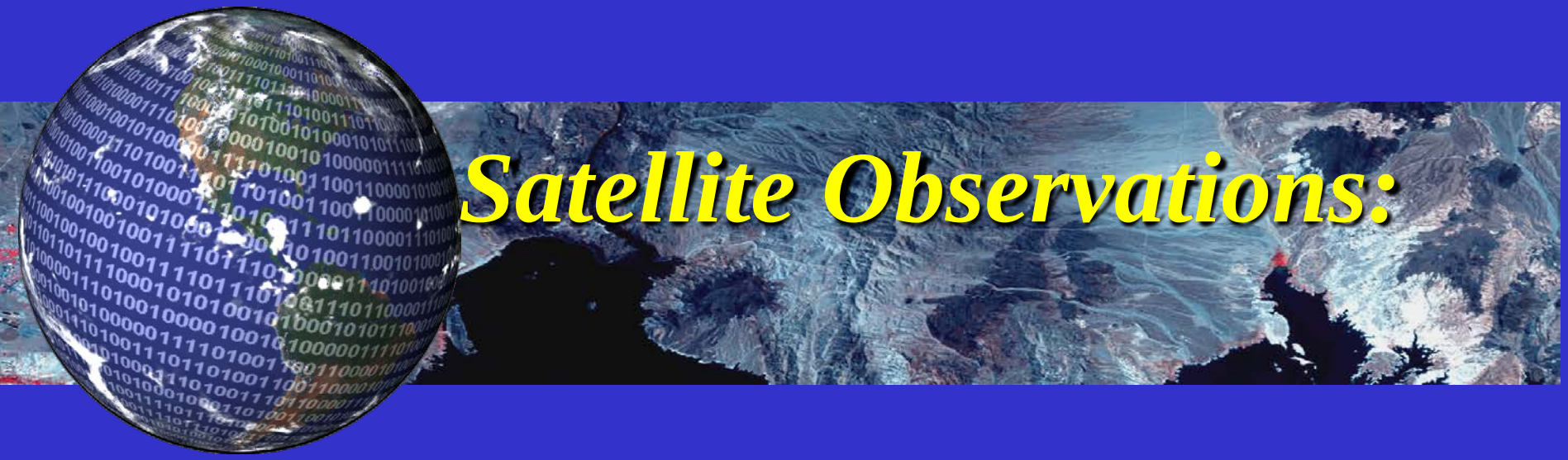


Maddox, et al., 2002



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

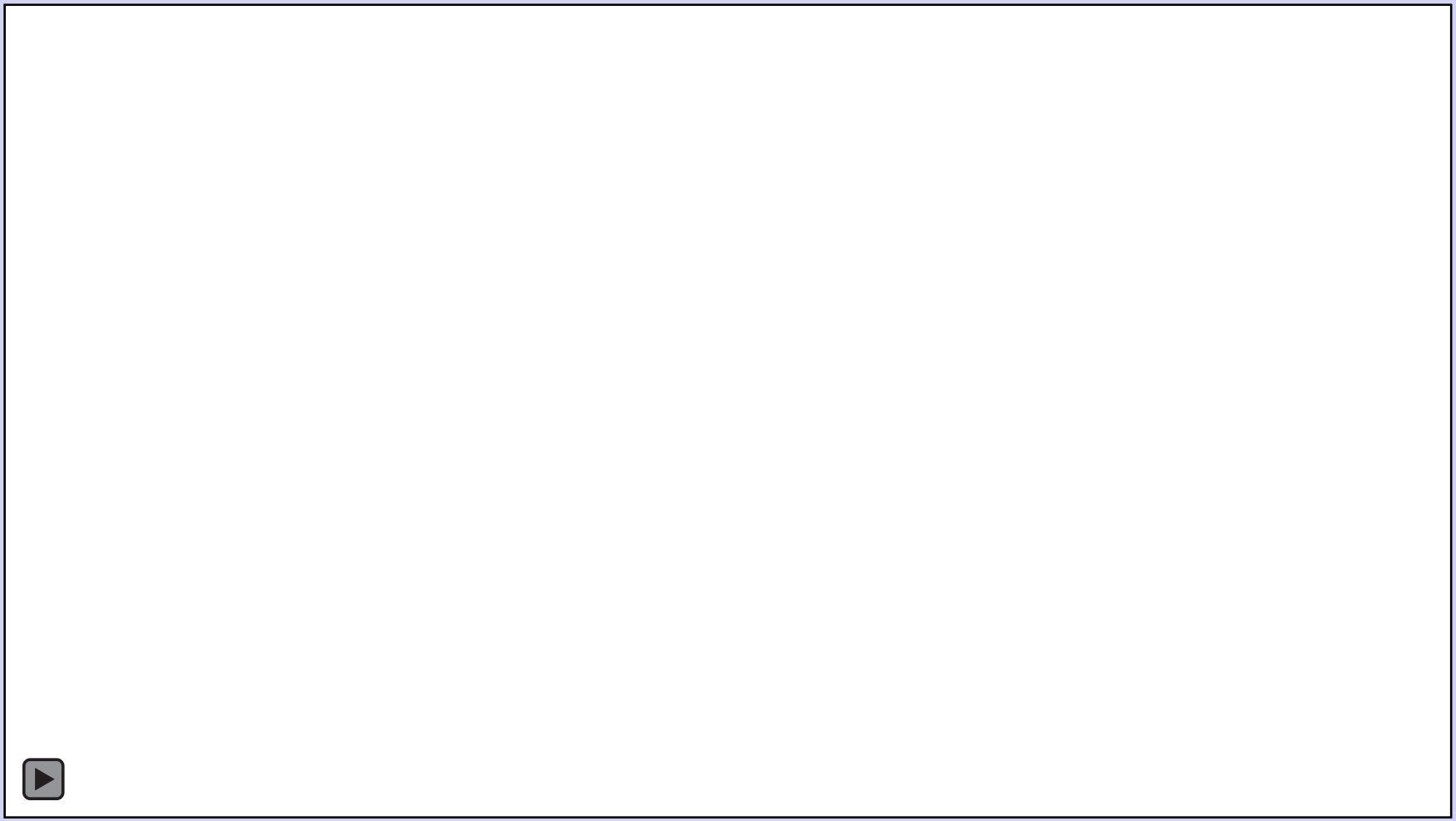
Space-Based Observations



Satellite Observations:

Earth Observing and Meteorological Satellites

Courtesy: NASA's ESE



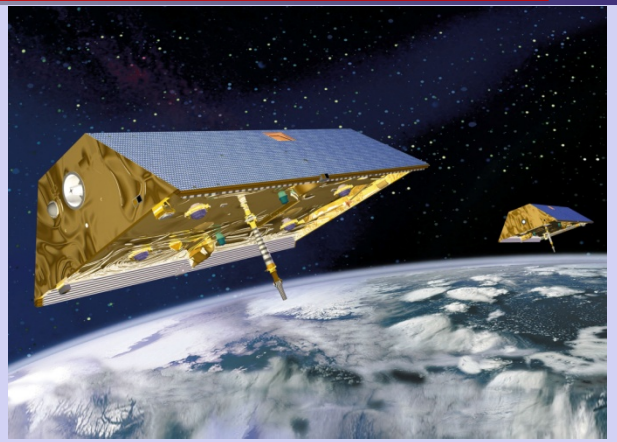
Hydrologically - Relevant Remote Sensing Missions

SMOS

ESA's Soil Moisture and Ocean Salinity (2009)

TRMM

The Tropical Rainfall Measuring Mission

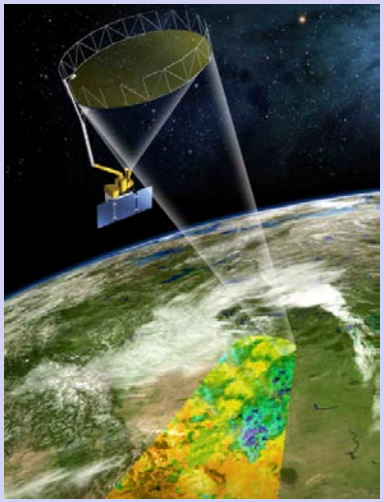


GRACE

Gravity Recovery and Climate Experiment (2002)

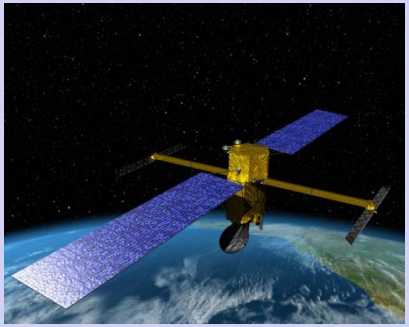
GPM

Global Precipitation Measurements (2014)



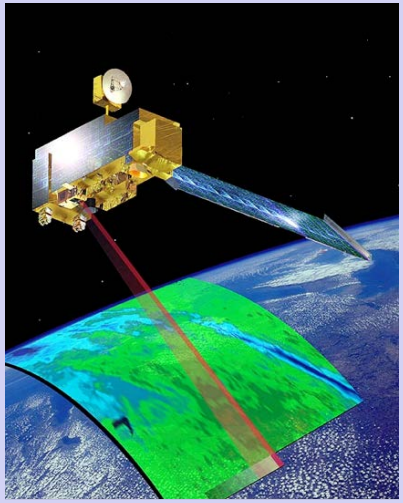
SMAP

Soil Moisture Active Passive Satellite(2014)



SWOT

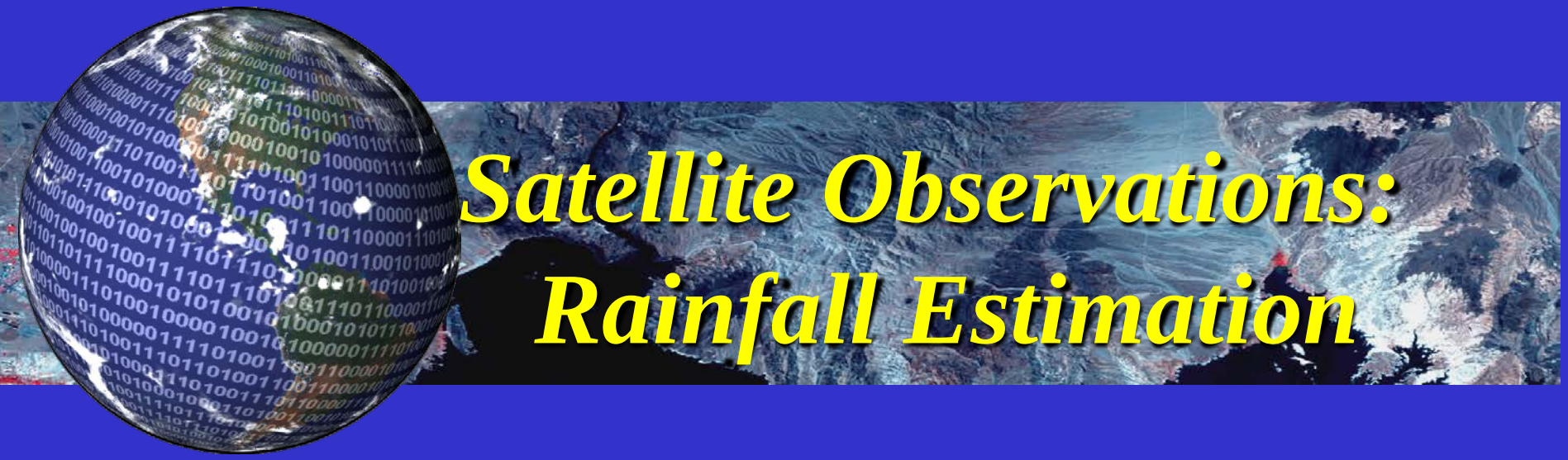
Surface Water and Ocean Topography (2020)



MODIS

Moderate Resolution Imaging Spectroradiometer (1999) , (2002)

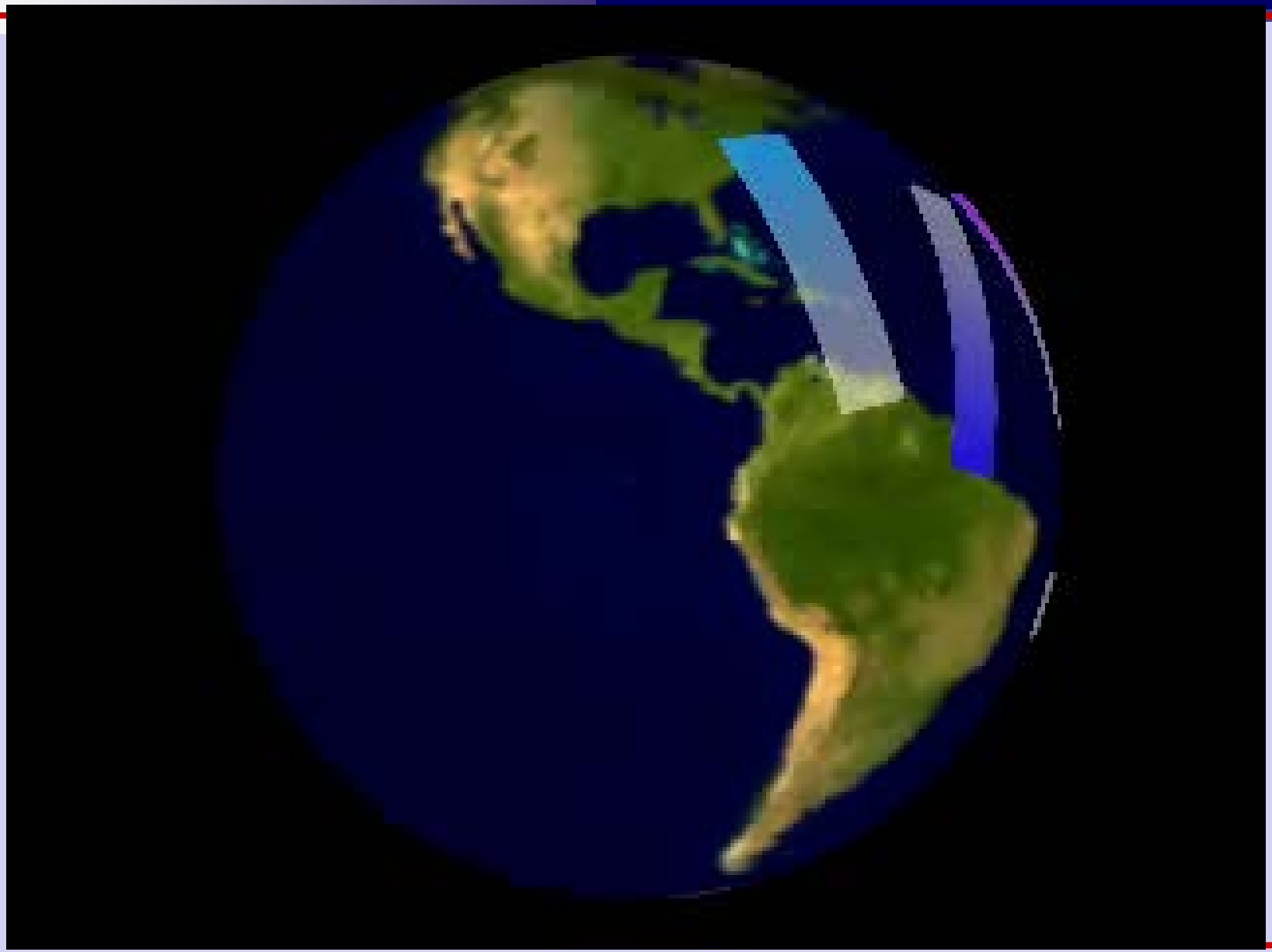
Precipitation Observations



Satellite Observations: Rainfall Estimation

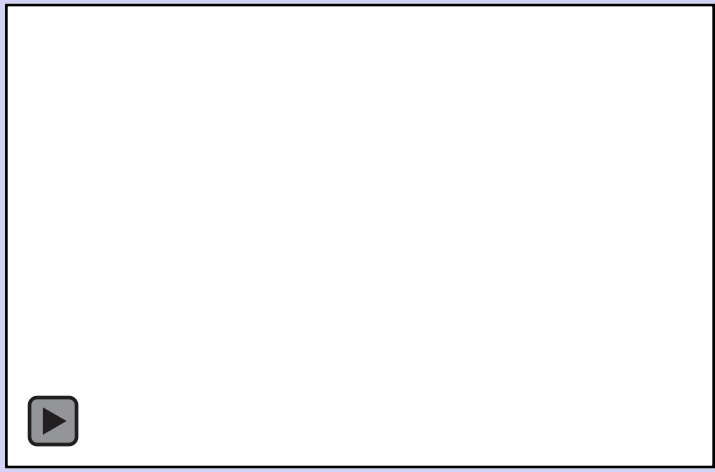
Geostationary Satellites Infrared (IR) Channel Tb

Polar Orbiting Satellites



Satellite precipitation retrieval instruments

1) Using GEO satellites (Infrared/Visible channels)



***Advantage*:**

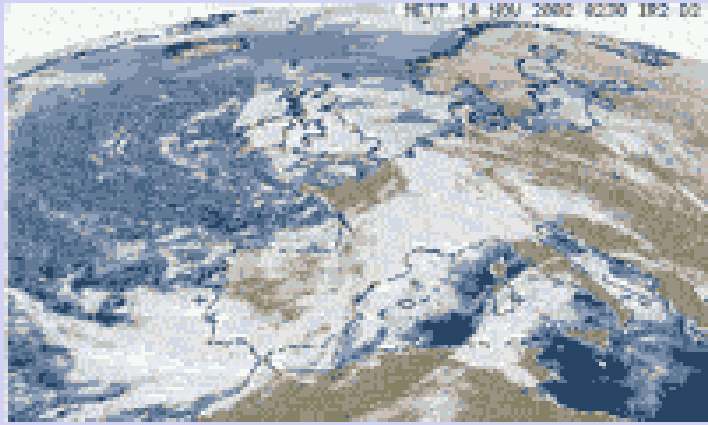
- *Good temporal and spatial resolution (30 min or less, 4 km)*

- *very good coverage*

***Disadvantage*:**

-Receives mostly cloud –top information

-Indirect estimation of precipitation.



Satellite precipitation retrieval instruments

2) Microwave

***Advantage*:**

- Responds directly to hydrometeors and penetrates into clouds

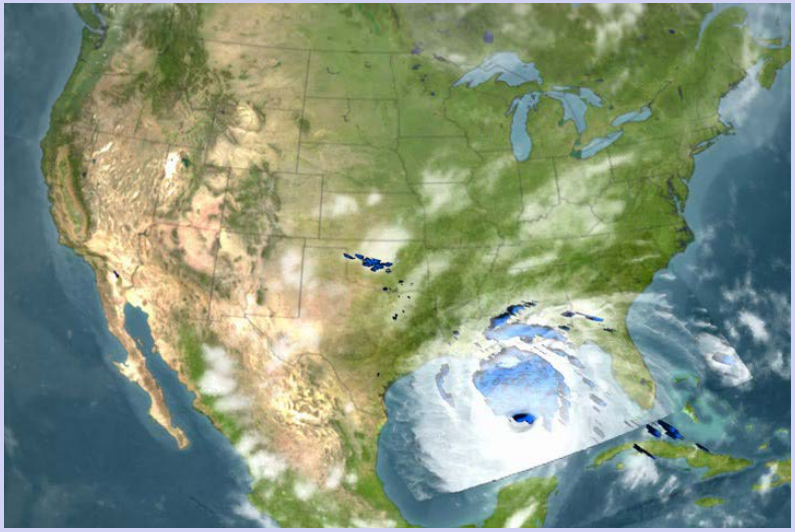
- More accurate estimates

***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

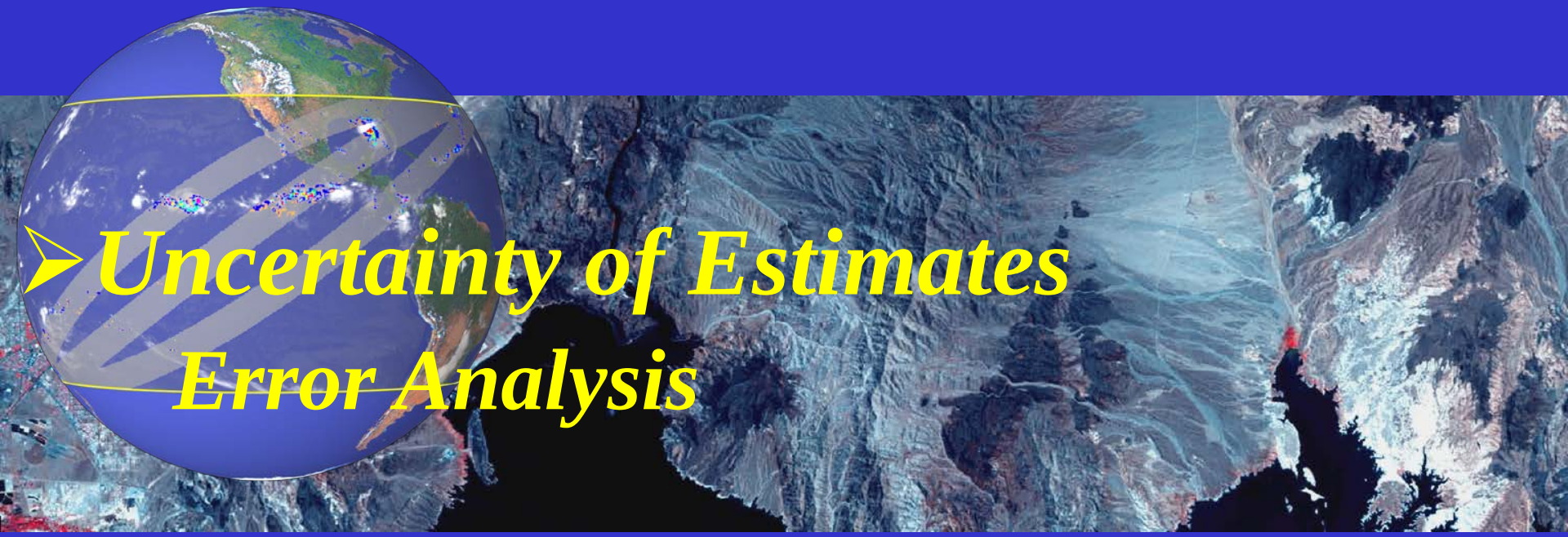
- good spatial resolution

***Disadvantage*:**

- Poor temporal resolution

GPM Animation

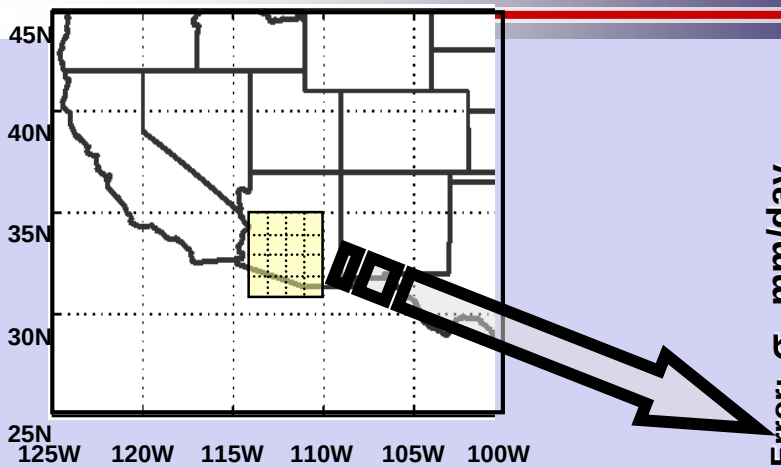
Courtesy: NASA's ESE

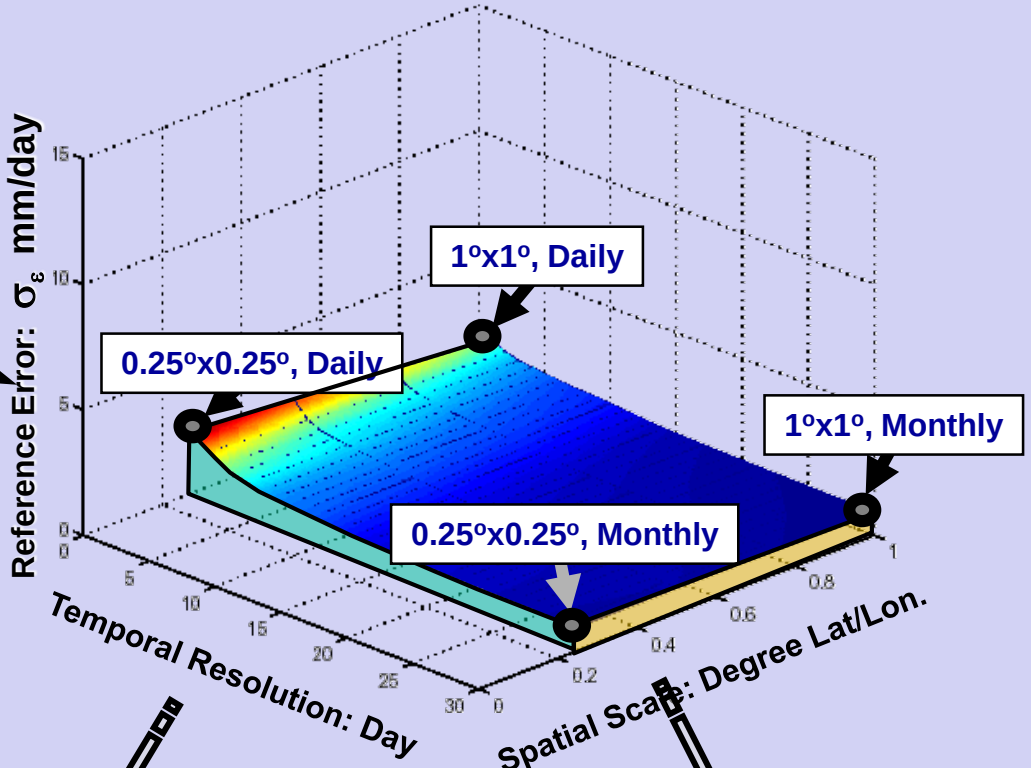


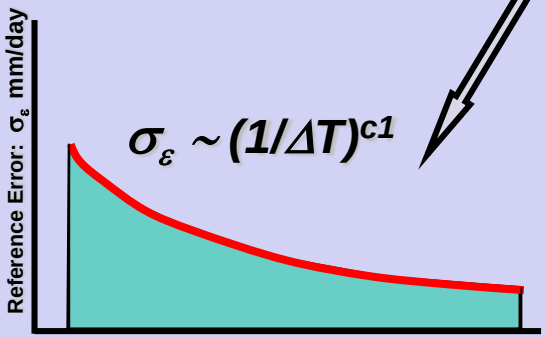
➢ *Uncertainty of Estimates*

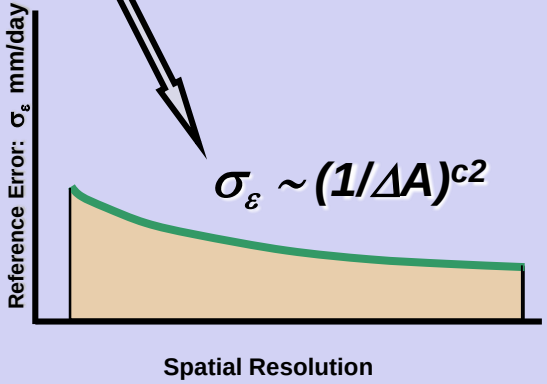
Error Analysis

Spatial-Temporal Property of Reference Error

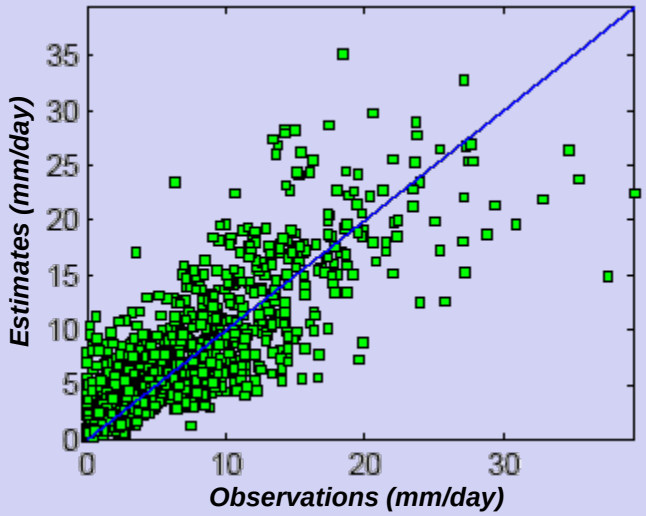


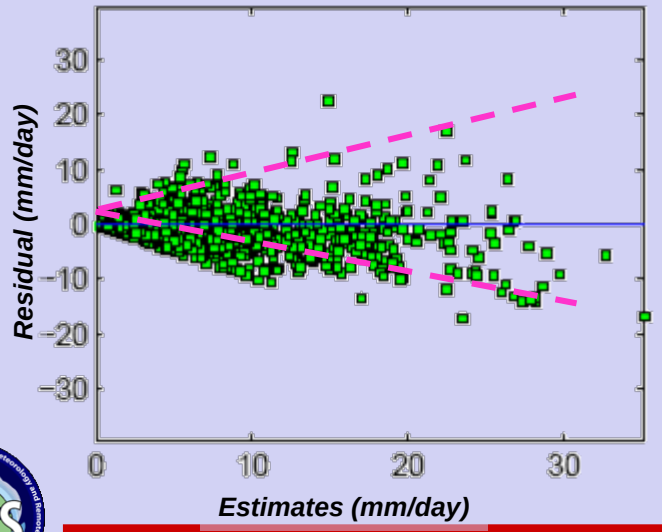


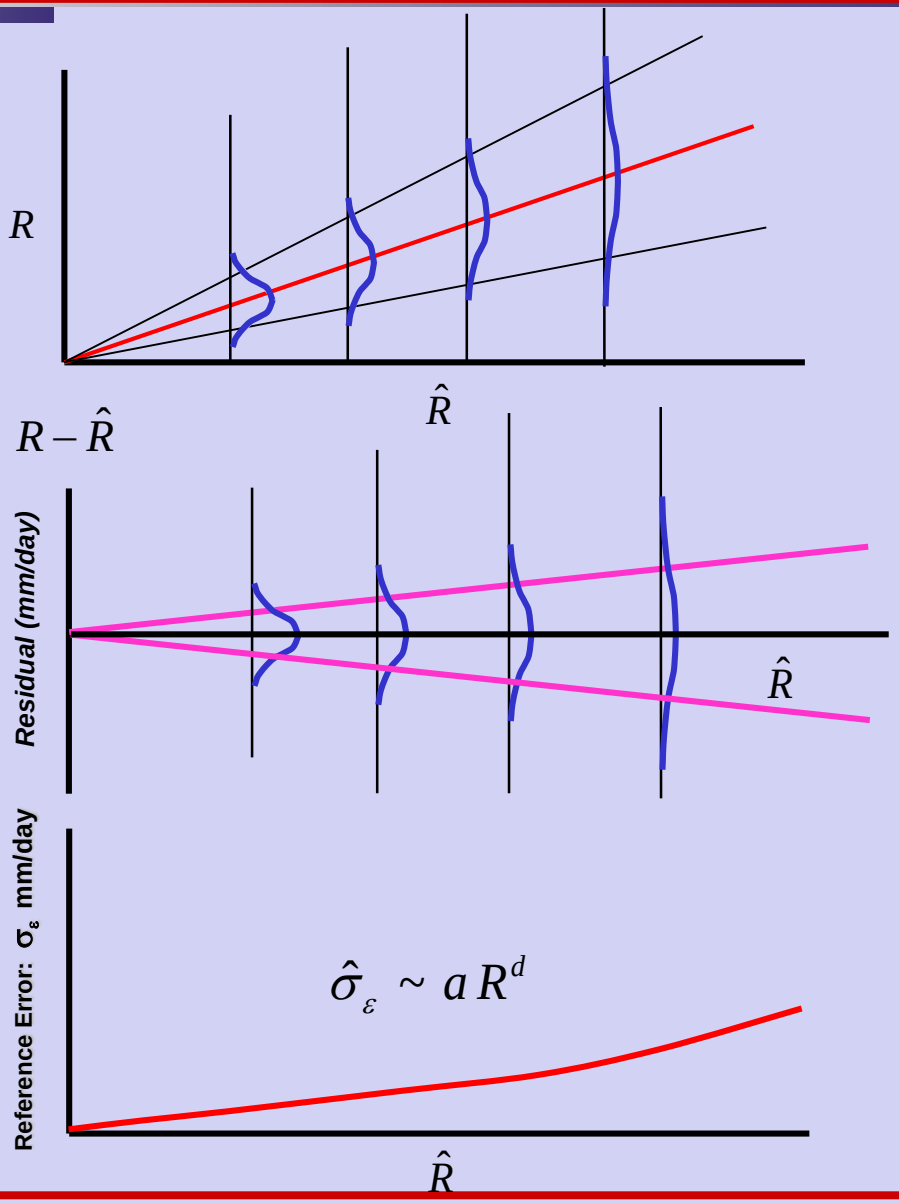




Reference Error: ΔT = 24-hour, $\Delta A = 0.25^o x 0.25^o$





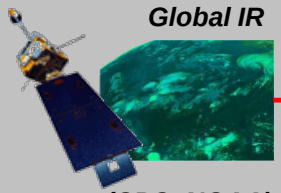


Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN)

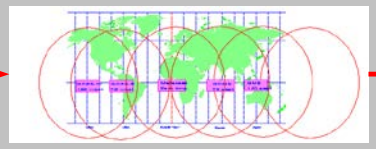
PERSIANN System "Estimation"

Satellite Data

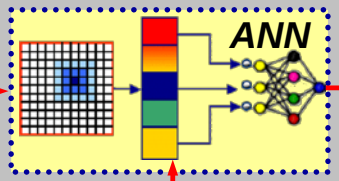
Global IR



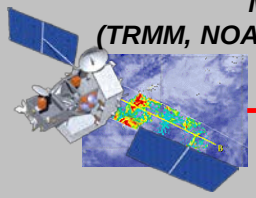
(CPC, NOAA)

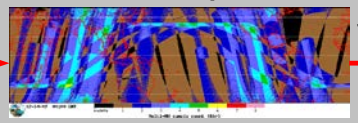


High Temporal-Spatial Res.
Cloud Infrared Images



MW-RR
(TRMM, NOAA, DMSP Satellites)





Sampling

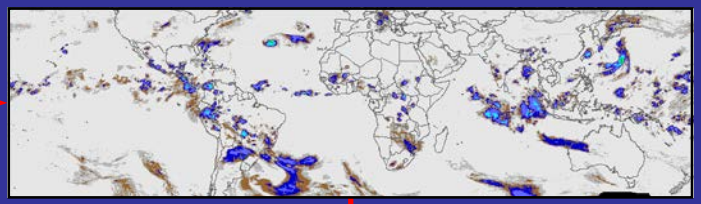
MW-PR Hourly Rain Rates
(GSFC, NASA; NESDIS, NOAA)

Feedback

Error Detection

Products

Hourly Global Precipitation Estimates

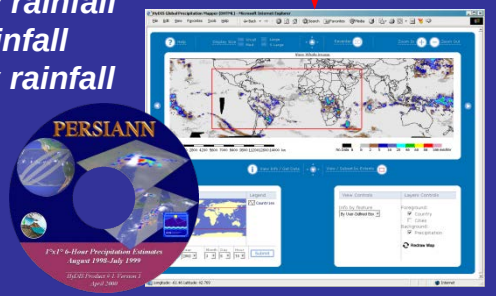


Hourly Rain Estimate

Quality Control

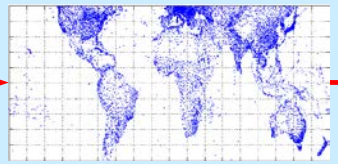
Merging

Merged Products
- Hourly rainfall
- 6 hourly rainfall
- Daily rainfall
- Monthly rainfall



Ground Observations

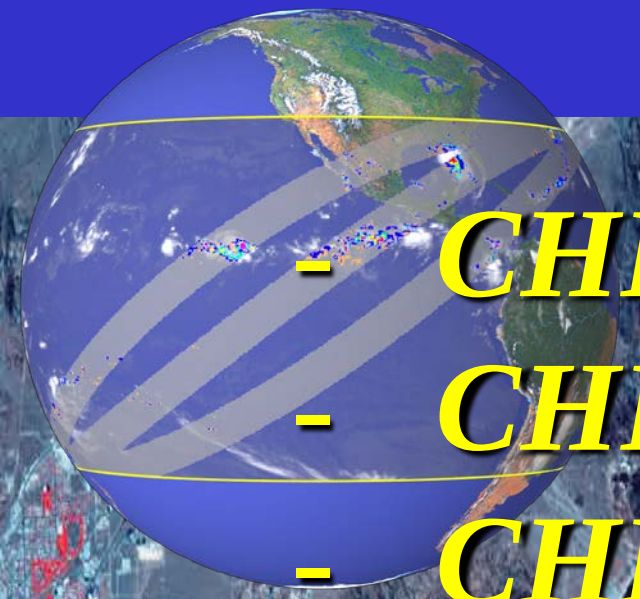
GPCC & CPC
Gauge Analysis



Gauges Coverage

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

PERSIANN Websites and Apps



- CHRS RainSphere
- CHRS iRain
- CHRS Data Portal
- PERSIANN-CONNECT

CHRS iRain and Rainsphere Development Team

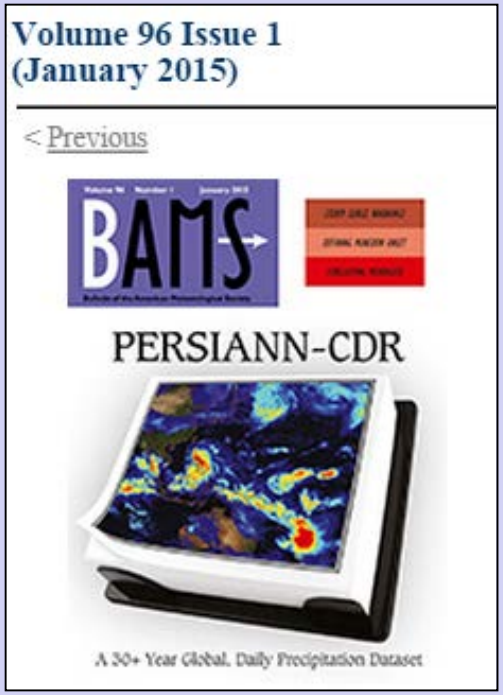
PERSIANN Extensions: Climate-Related

- PERSIANN- CDR (Climate Data Record)

PERSIANN -CDR

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

- *Daily Precipitation Data*
- *Data Period: 1983~2018*
- *Coverage: 60°S ~ 60°N*
- *Spatial Resolution: 0.25°x0.25°*

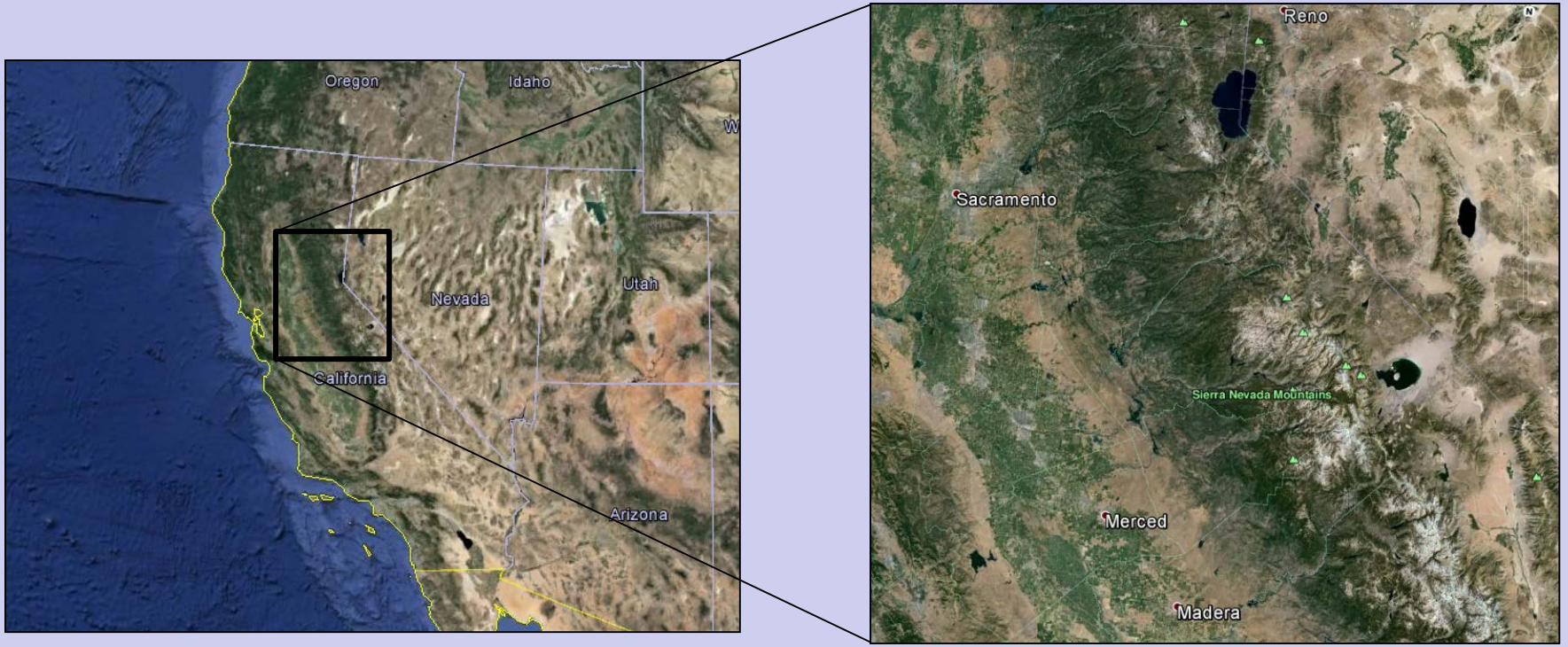


Ashouri, Hsu et al., BAMS, 2015.

Sierra-Nevada Mountain Region

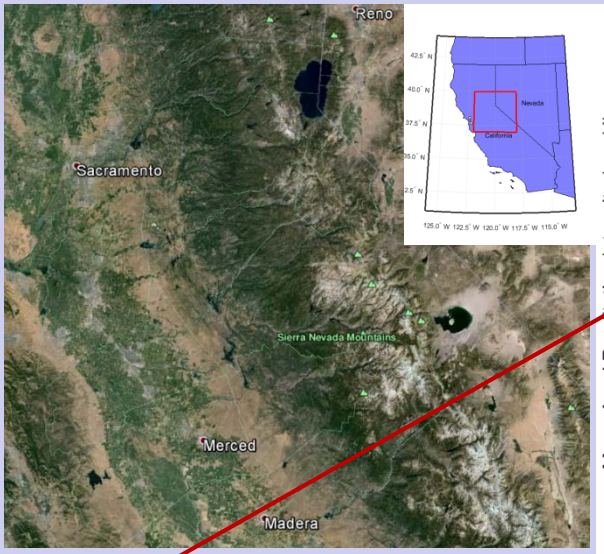
Area: 63,100 square kilometers (24,370 sq mi)

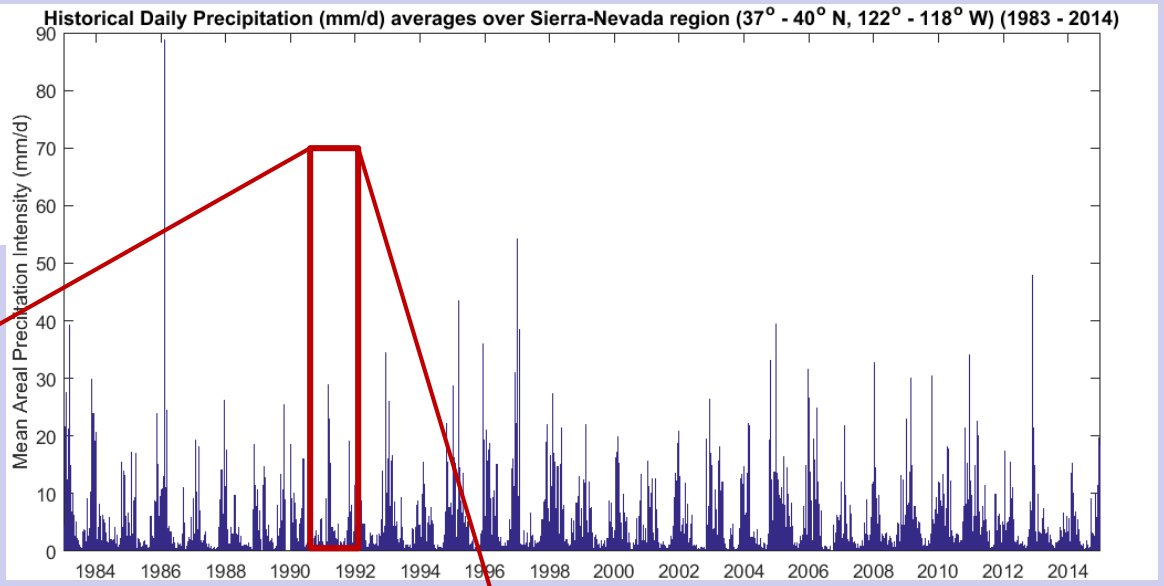
Length: 400 mile, Width: 64 mile.

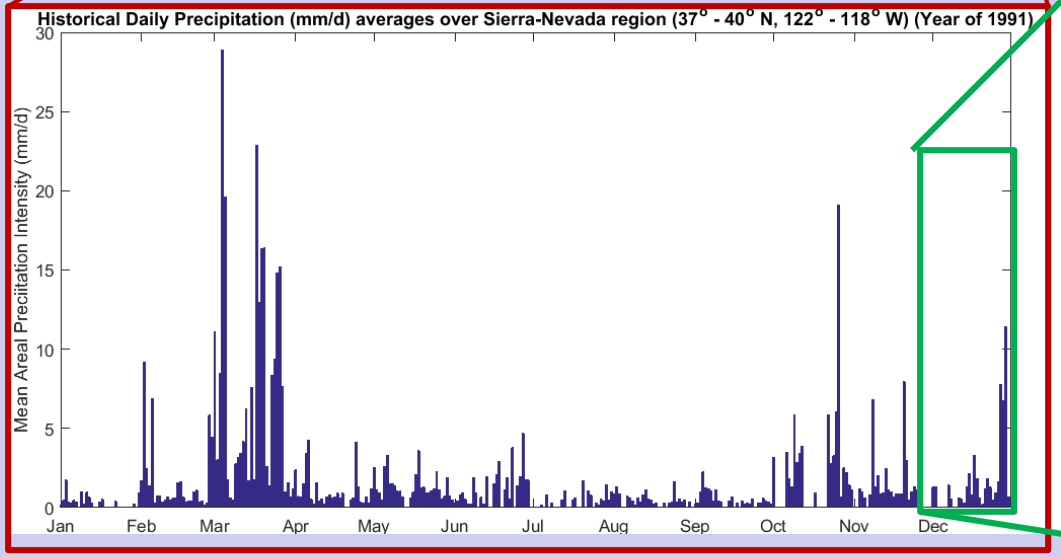


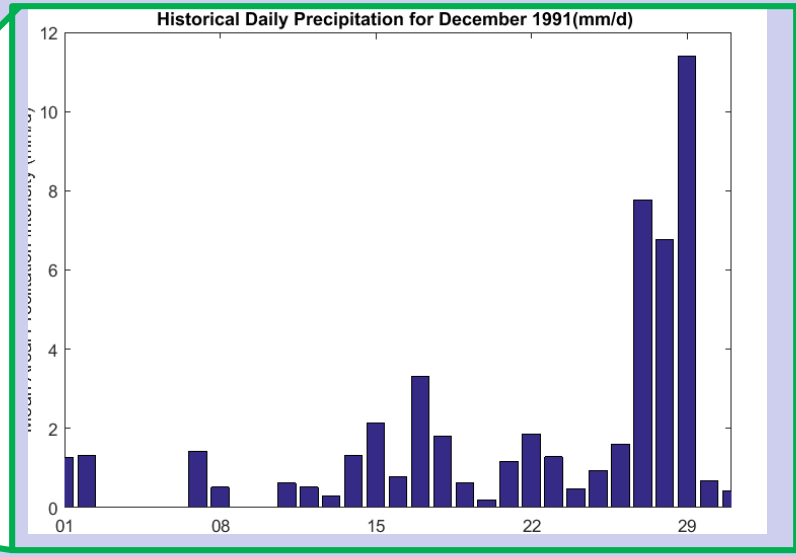
Map Source: Google Earth

Sierra-Nevada Mountain (California and Nevada)





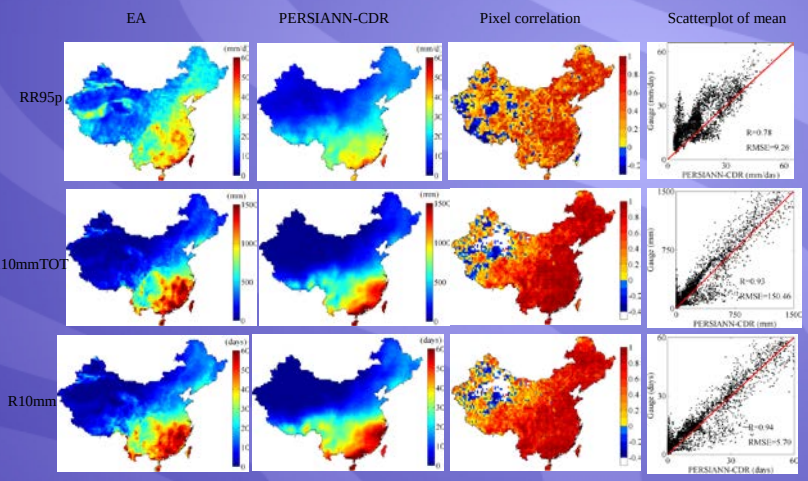


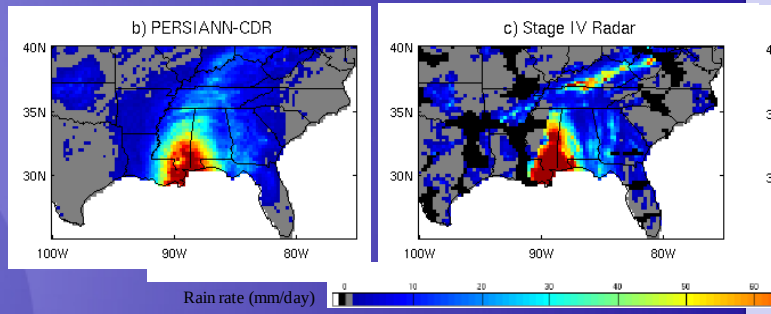


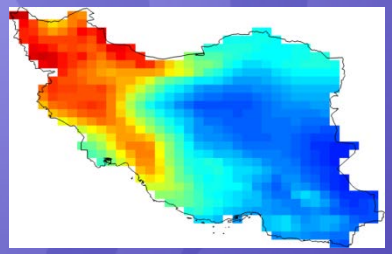
How Do we Judge the level of accuracy of PERSIANN-CDR??

Regional Evaluations of PERSIANN CDR

Many Regional Evaluation of PERSIANN CDR Have Already Been Reported:







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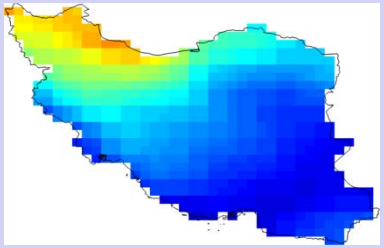
Hydrologically-Relevant Data

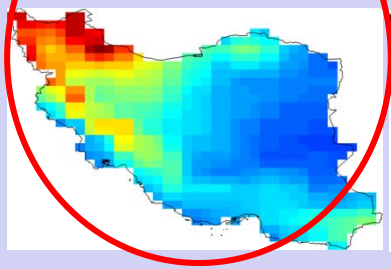
What is the value of this data set to application and Modeling communities?

Model historical simulation (1983-2005)

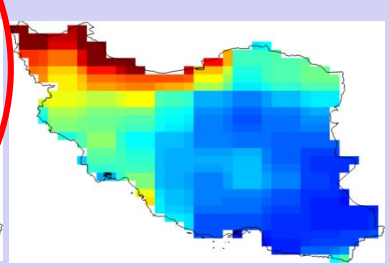
bcc_csm1_1_m
(Chinese GCM)



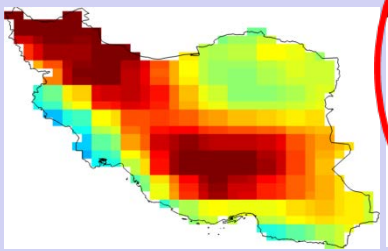
CCSM4
(NCAR, USA GCM)



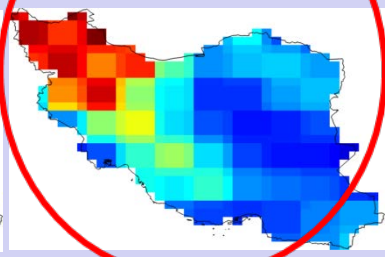
HadGEM2-ES
(U.K GCM)



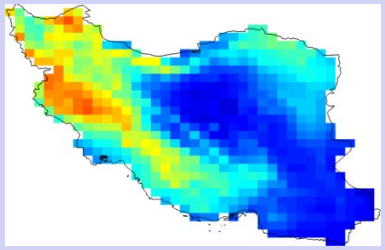
MIROC5
(Japan GCM)



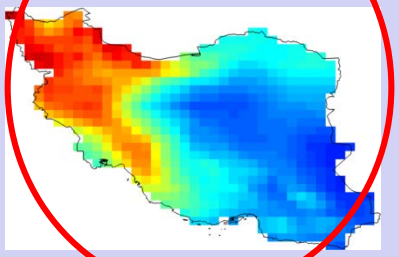
MPI-ESM-MR
(Germany GCM)

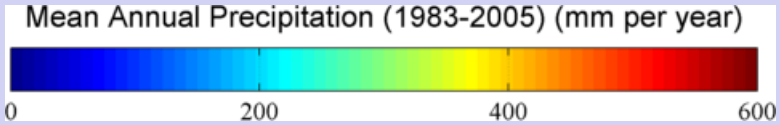


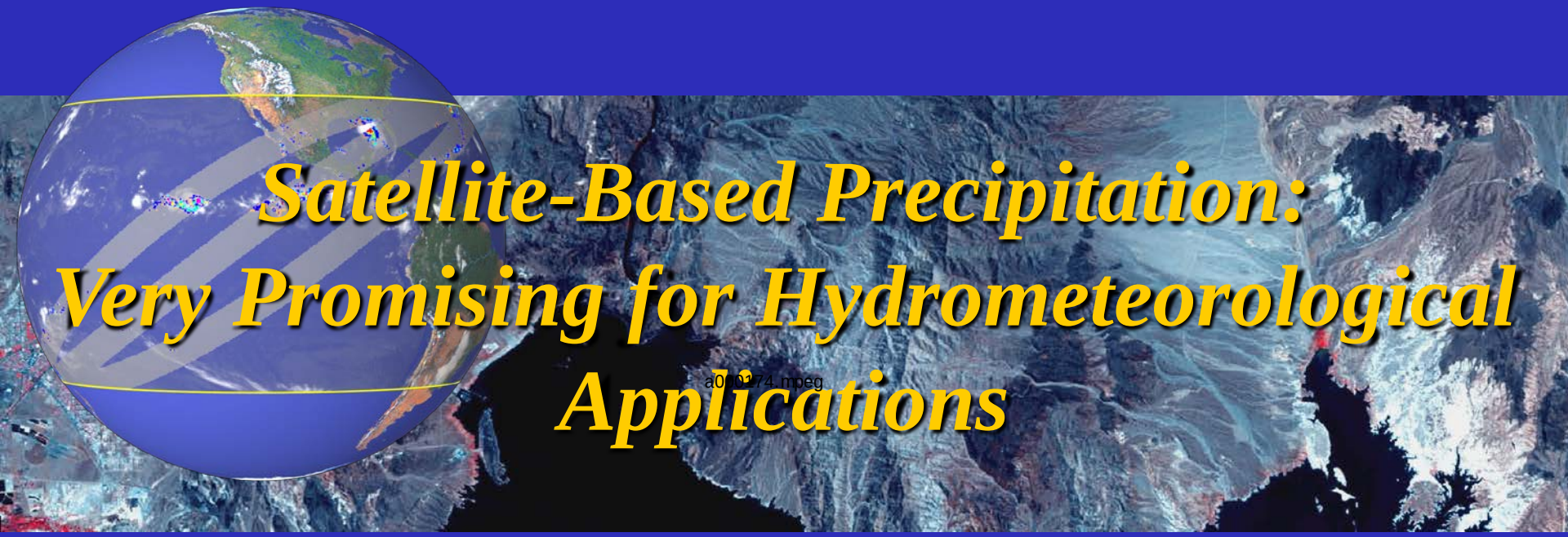
Observation
(CRU Dataset)



Remotely Sensed Estimates
(PERSIANN-CDR)







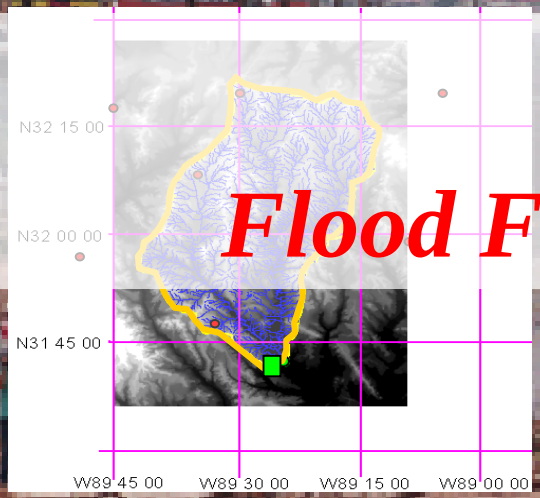
Satellite-Based Precipitation: Very Promising for Hydrometeorological Applications

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

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).

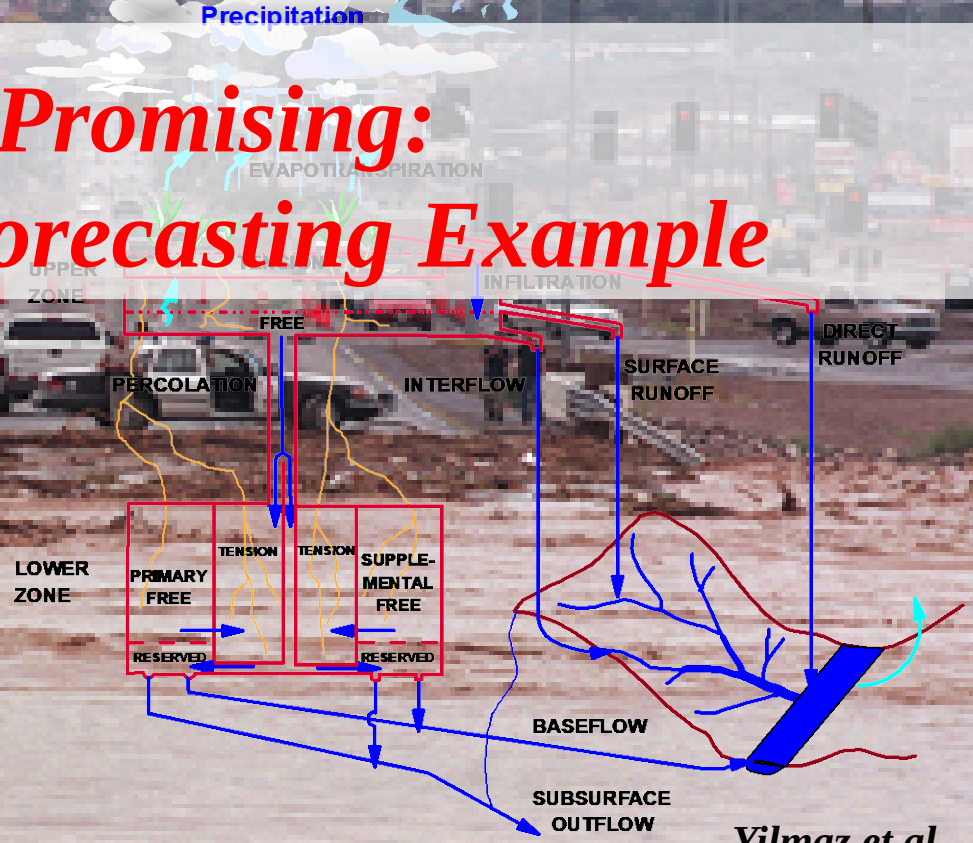
Promising:
Flood Forecasting Example



- Gages used by NWS

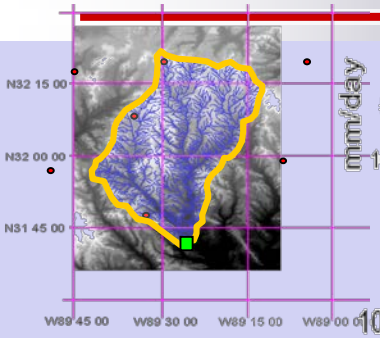
Leaf River Near Collins
Mississippi
USGS # 02472000

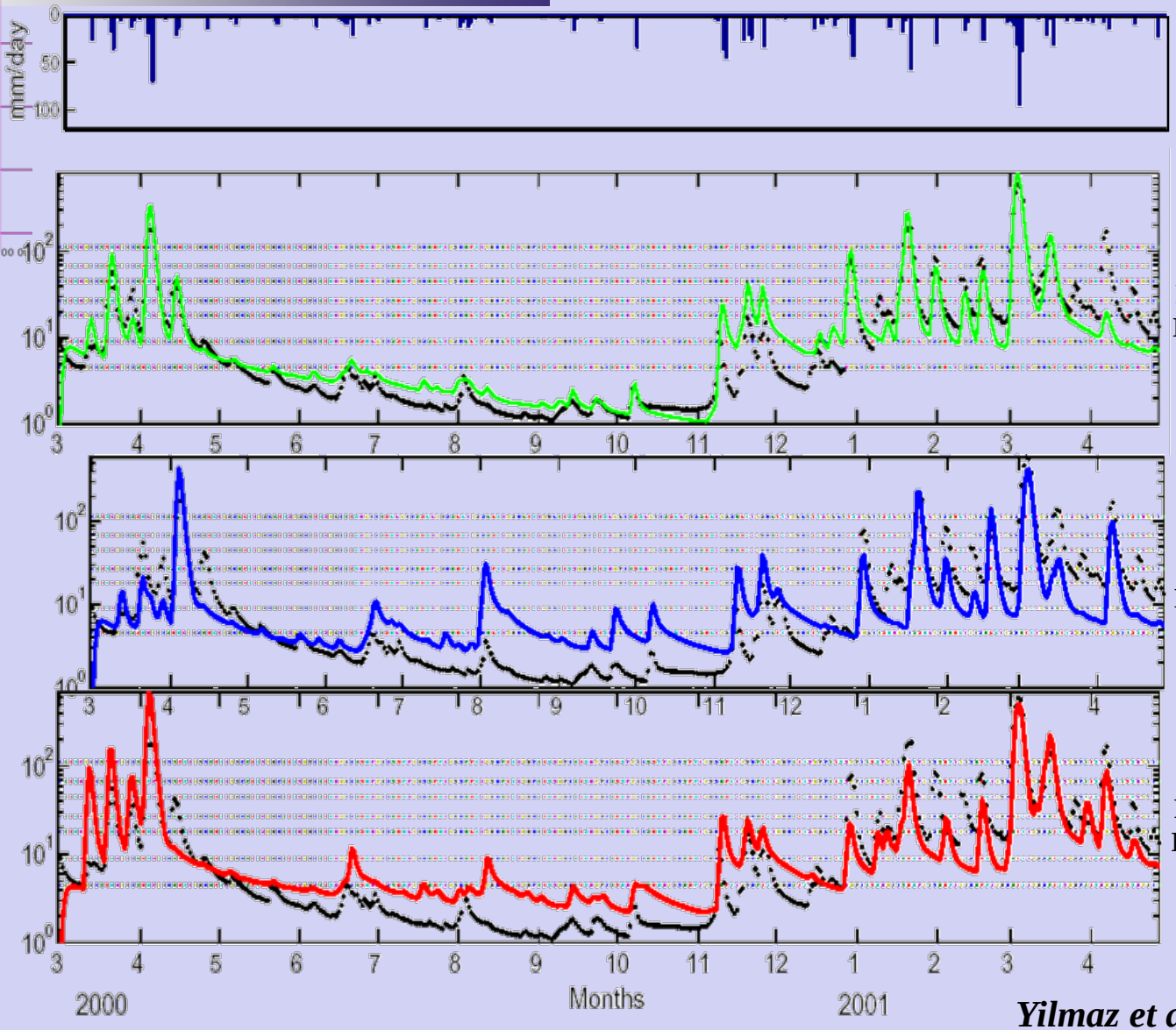
Basin Area : 753 mi²



Yilmaz et al. JHM 2005

Satellite Rainfall Estimation: Research at UC Irvine





RAINGAGE

Corr =0.95
RMS =23.9
BIAS =-1.32

RADAR

Corr =0.92
RMS =28.8
BIAS =-6.74

PERSIANN

Corr =0.94
RMS =22.6
BIAS =-5.15

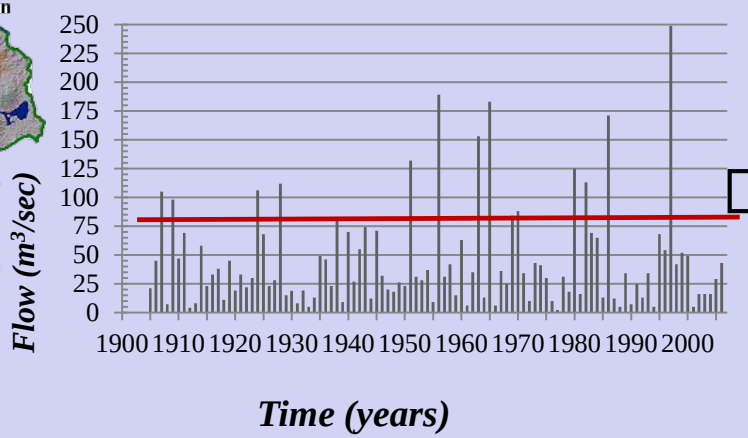
Yilmaz et al. JHM 2005

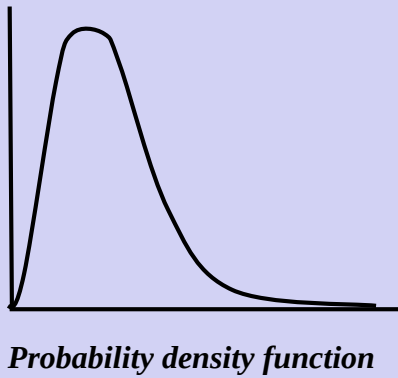
Addressing "Extremes" in Water Resources Planning:

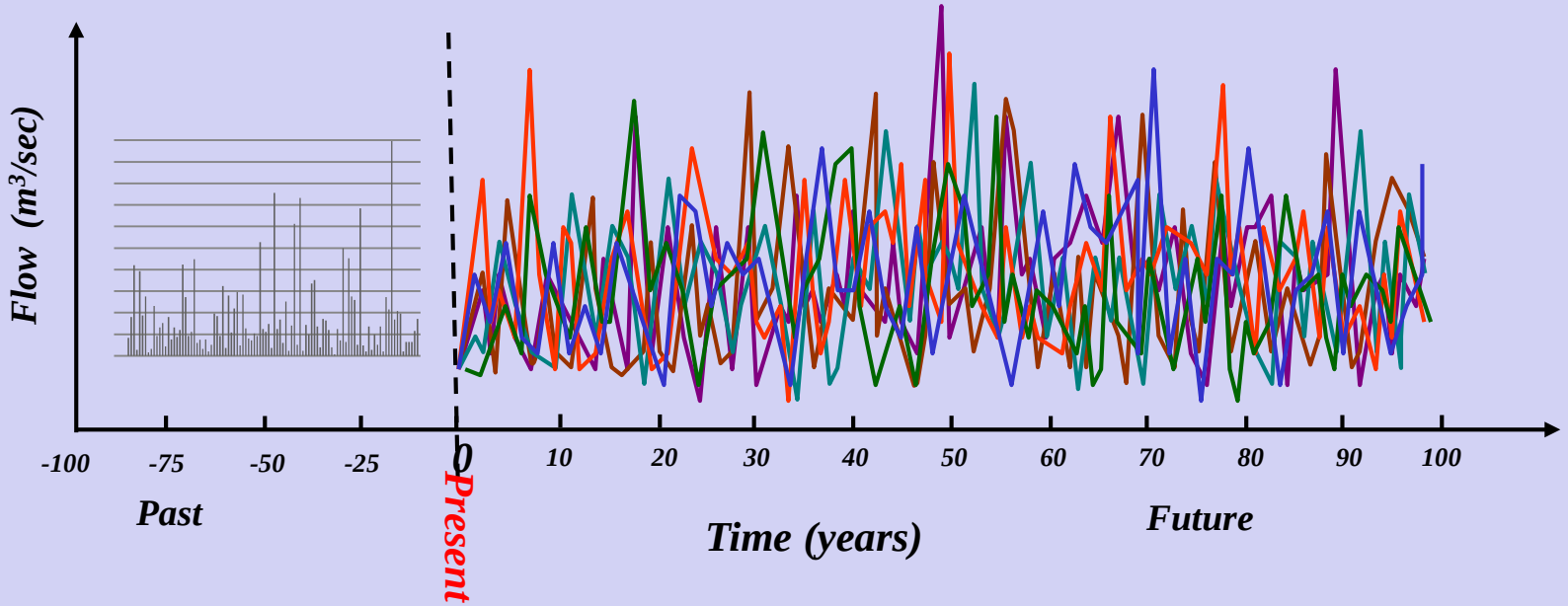
Statistical/Stochastic Hydrology

CENTER FOR HYDROMETEOROLOGY & REMOTE SENSING
CHRS
UCIrvine

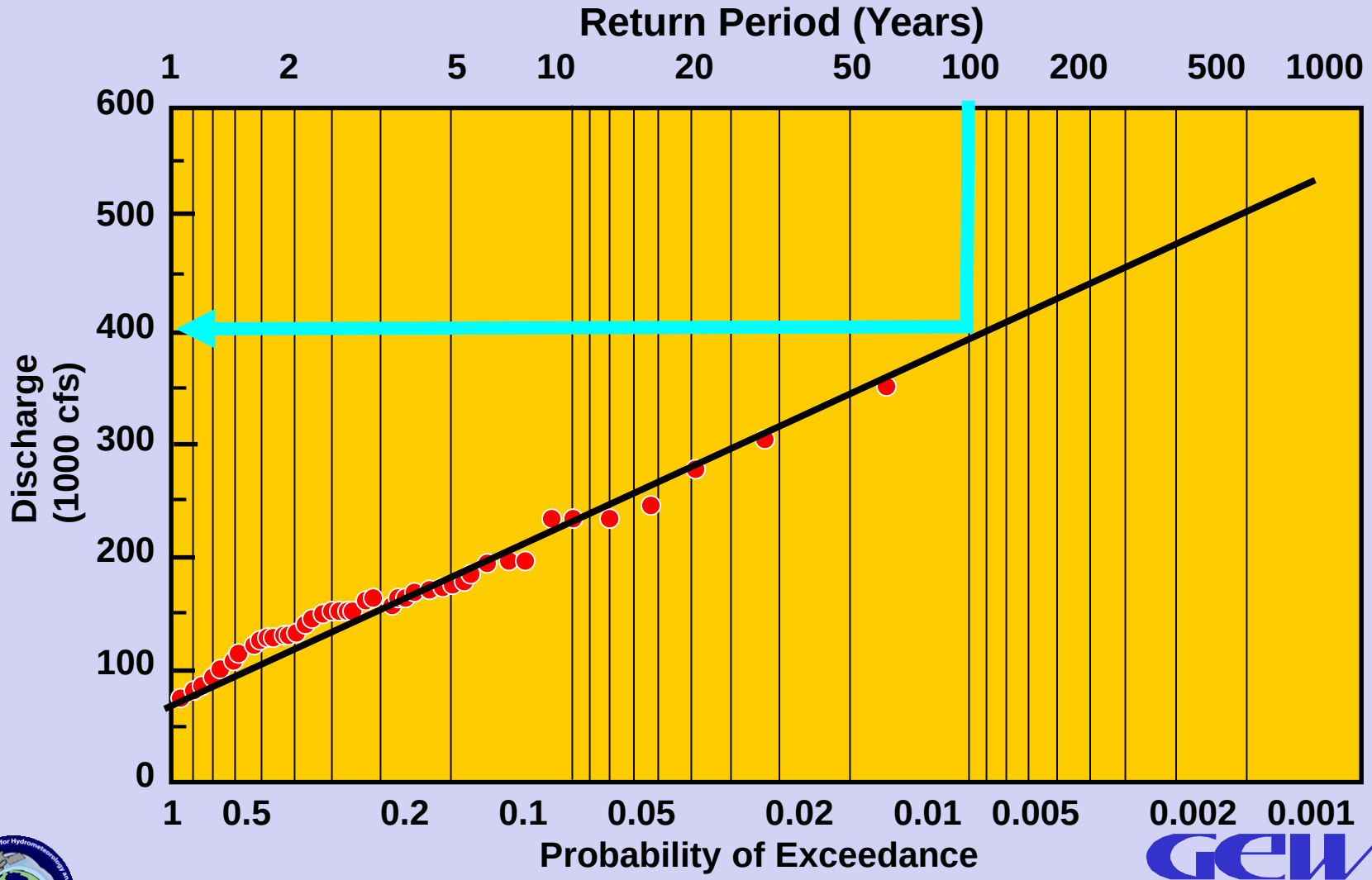
Statistical Hydrology: "synthetic" stream flow Generation



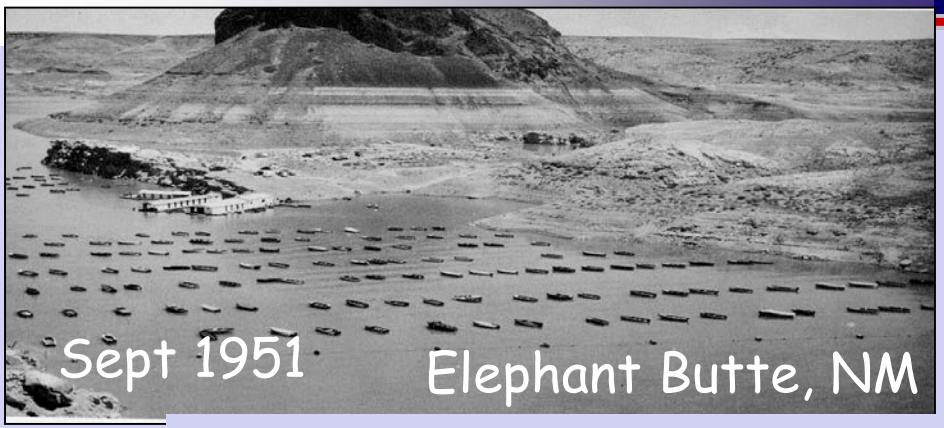




Flood Frequency Analysis: Stationarity!

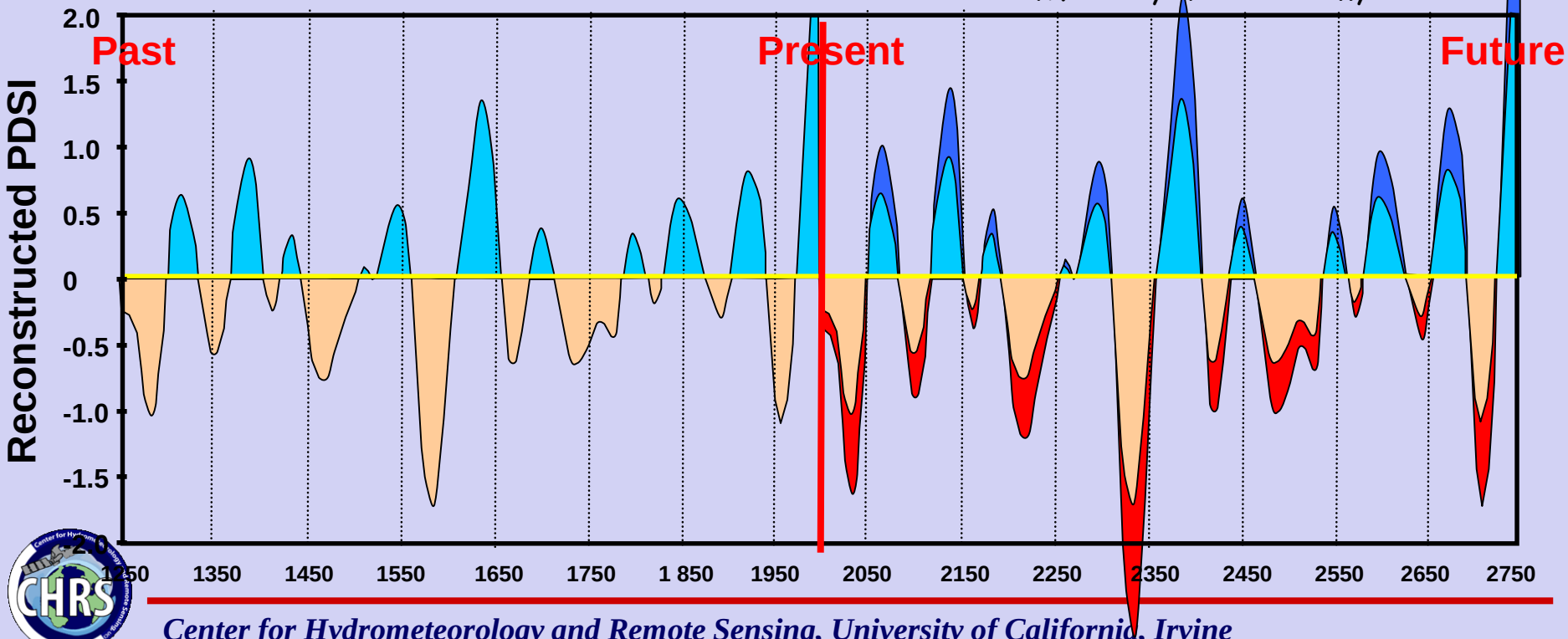


Statistical Hydrology Developed Based on Stationarity Assumption



Middle Rio Grande Basin, NM AD

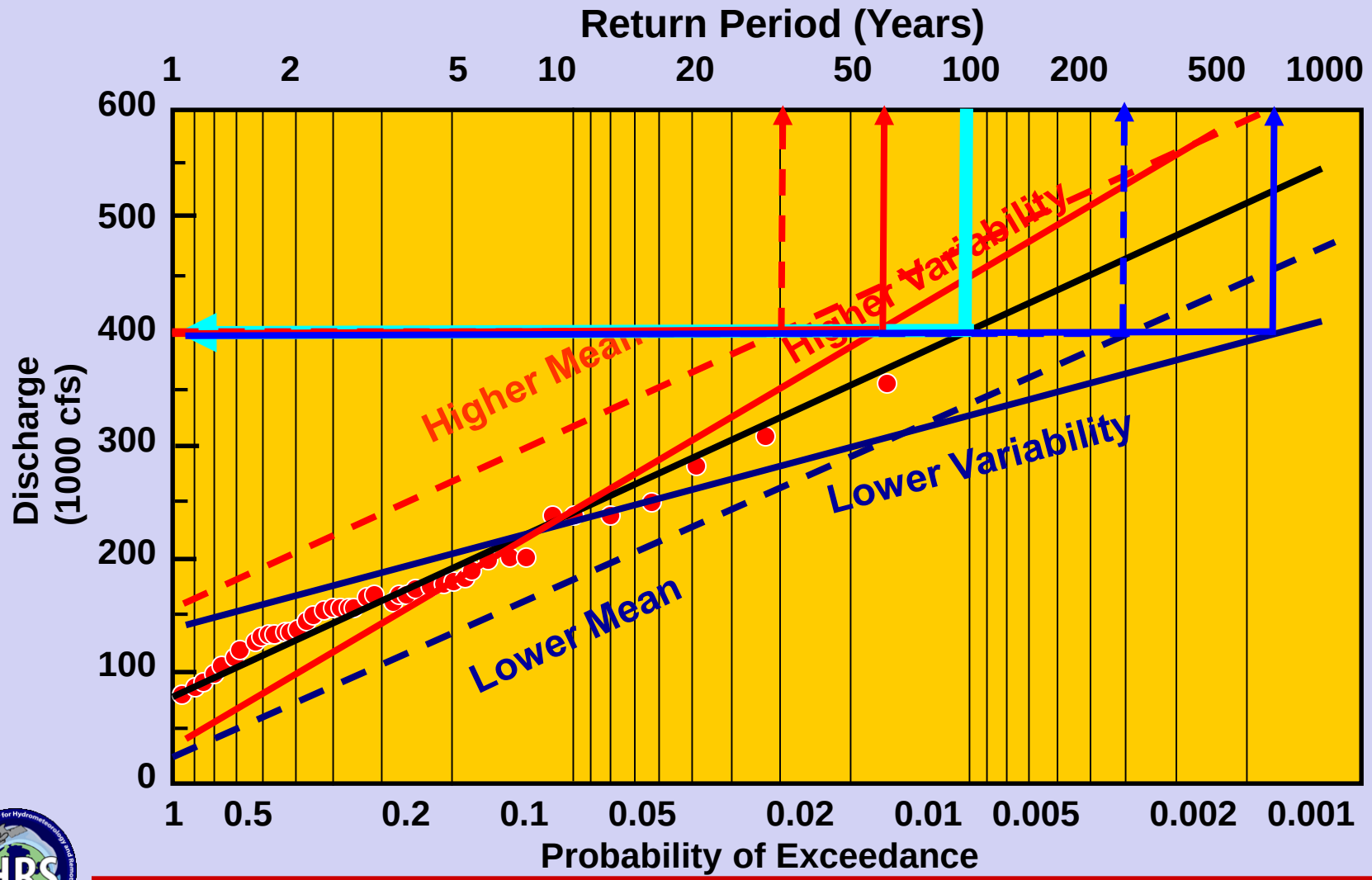
Grissino-Mayer, Baisan, Morino, & Swetnam, 2001



Potential Hydrologic Scenarios

1. Precipitation and Runoff Trends
   (e.g. increase/decrease)

2. Hydrologic Variability
   (e.g. magnitude/severity/duration)



Developing Rainfall Frequency Analysis (RFA) and Intensity-Duration-Frequency (IDF) Curves using PERSIANN-CDR

Mohammed Ombadi

Ombadi et al., ***WRR (2018)***

Pouya (Mohammad) Faridzad

Faridzad et al., ***J. of Hydrology (2018)***

Background

- **Rainfall Frequency Analysis (RFA)** is an important tool in designing hydrologic infrastructures such as: dams, canals, urban drainage systems, etc.

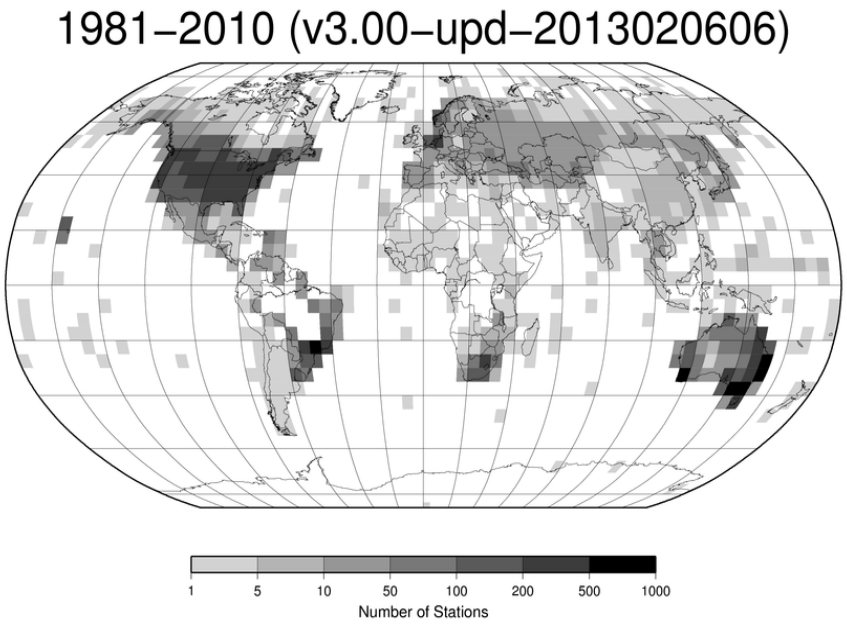
Common approach:

Using ground-based observations

✓ *Useful for the regions with sufficient gauges*

× *Poor gauge networks in many parts of the world*

× *Gauges may not capture the spatial and temporal variability of extreme events*



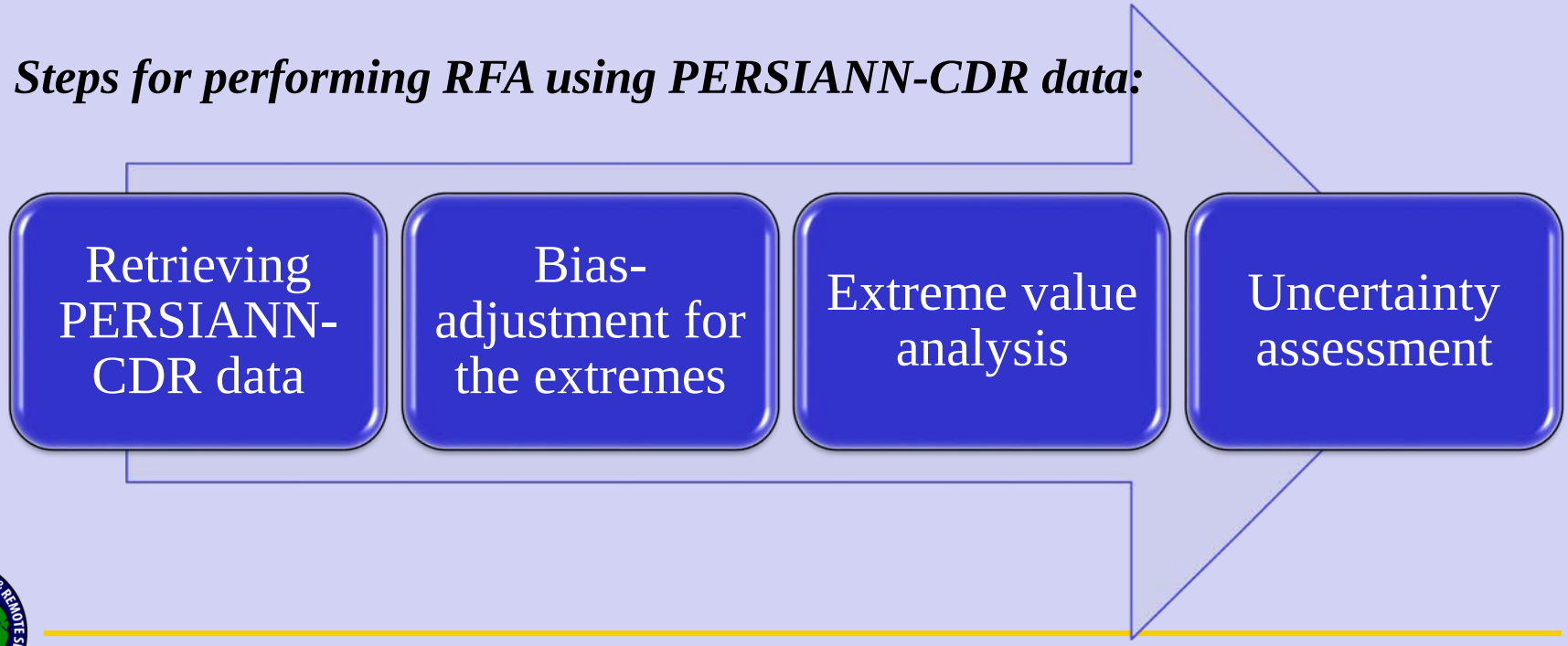
Global distribution of rain gauges with sufficient quality and record length in the Global Hydroclimatic data sets (GHCN)

RFA using PERSIANN-CDR

- **PERSIANN-CDR:** Advantages for RFA Application

  - ✓ ***High spatial resolution****: Captures the spatial variability of extreme events*
  - ✓ ***Global coverage****: Provides information about remote and ungauged regions*
  - ✓ ***35+ years of data****: One of the longest remotely sensed precipitation datasets*

Steps for performing RFA using PERSIANN-CDR data:



RFA using PERSIANN-CDR

Rainfall Frequency Analysis (RFA) for Ungauged Regions

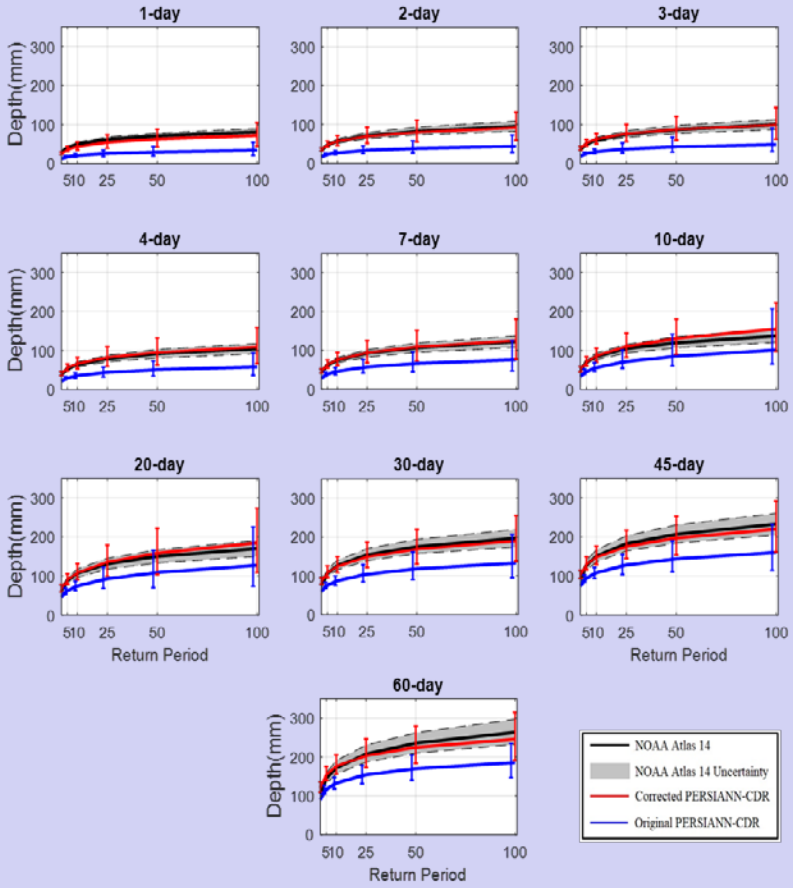
Using Remotely Sensed Precipitation Information

By: Faridzad et al., J. of Hdromet. 2018

- *20 river basins across the United States were analyzed*
- *PERSIANN-CDR estimates of extremes were adjusted using an elevation-based correction approach*
- *Maximum likelihood estimation was used to estimate the parameters of Generalized Extreme Value (GEV) Distribution.*

Main findings:

- *Consistent frequency estimates with NOAA Atlas 14*
- *Higher uncertainty bounds, due to the data length issue*



Frequency estimates and the 90% confidence intervals at a gauge location in Dirty Devil basin, UT

Intensity-Duration-Frequency (IDF) Curves

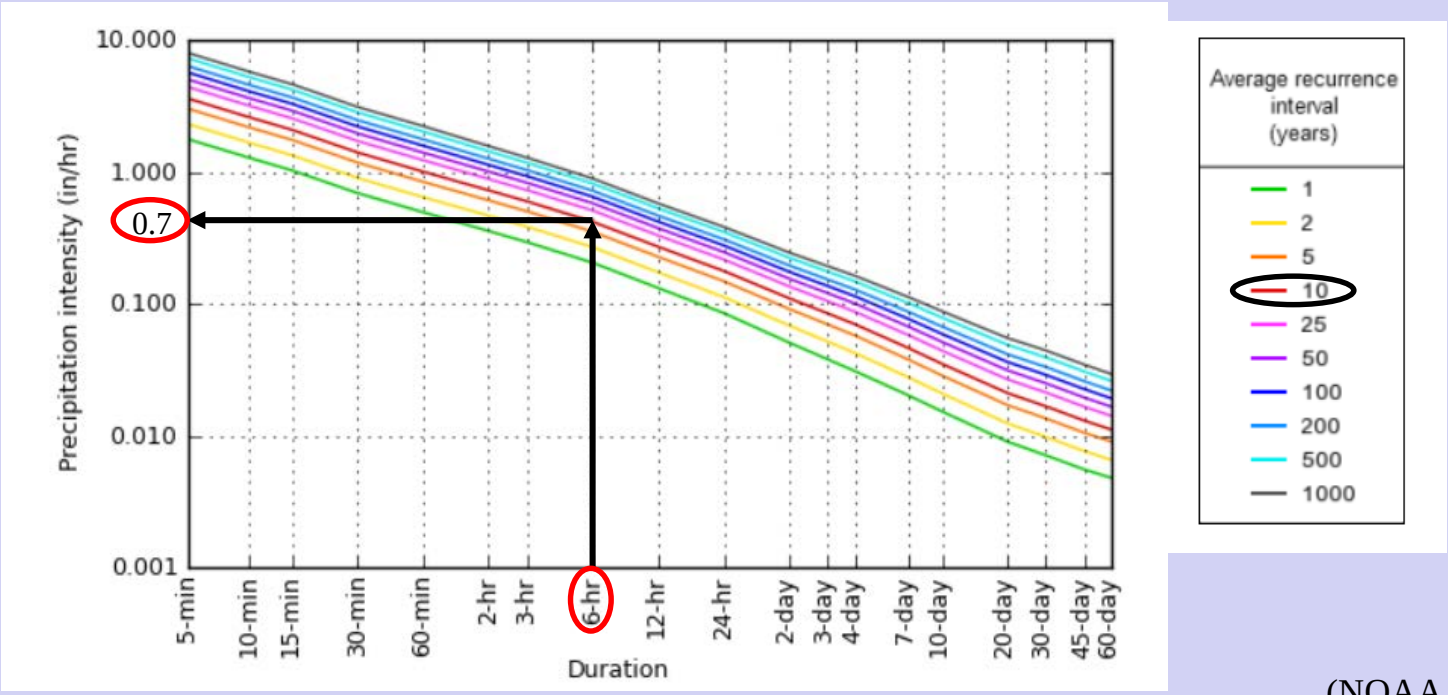
A mathematical relationship between rainfall intensity, duration and frequency of occurrence (i.e. return period)

$$IDF = f(i, d, T)$$

$$i \equiv rainfall\ intensity$$
$$d \equiv rainfall\ duration$$
$$T \equiv return\ period\ (years)$$

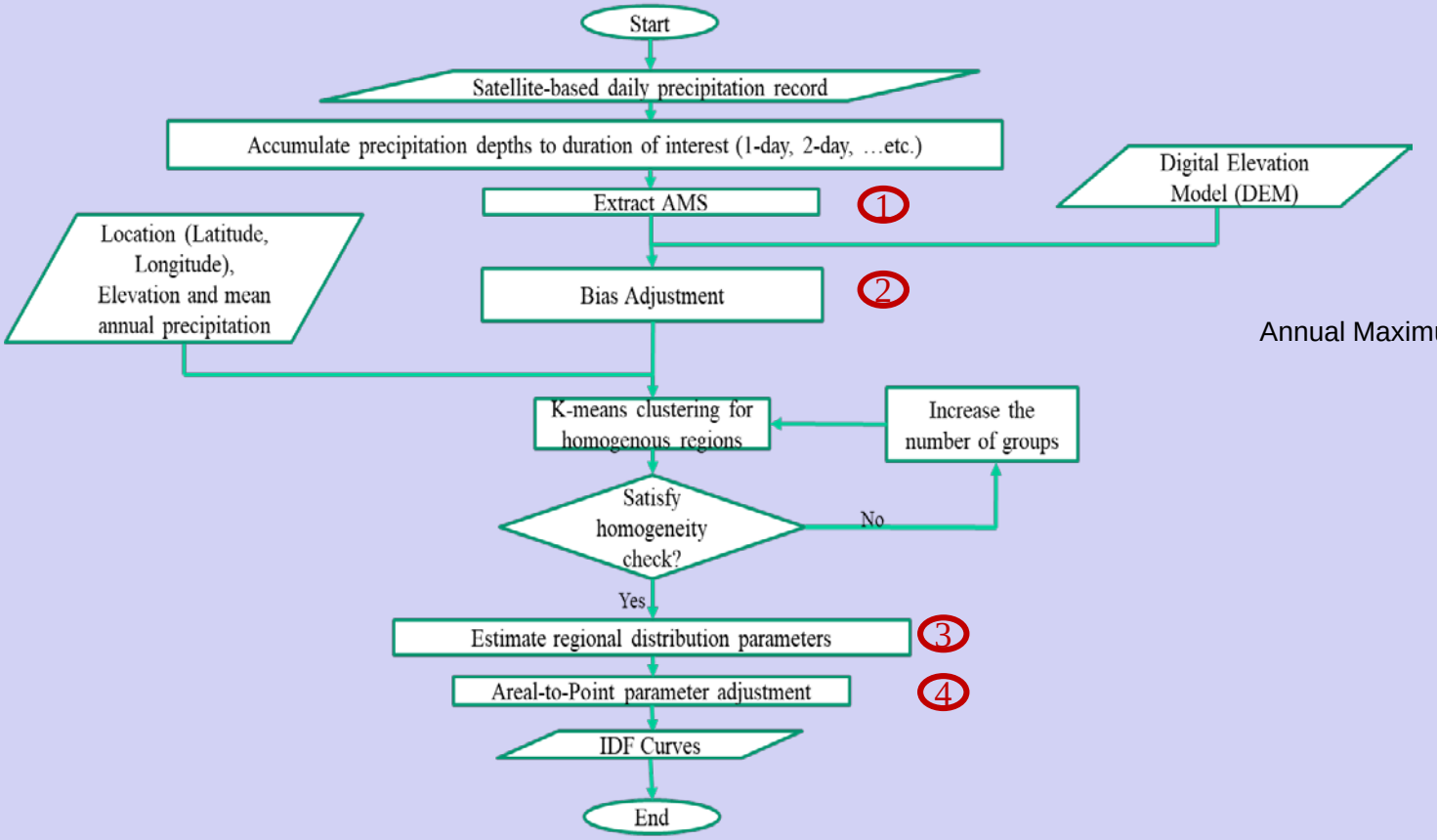
Intensity-Duration-Frequency (IDF) Curves

Point-based IDF curves at Los Angeles, CA



(NOAA Atlas 14)

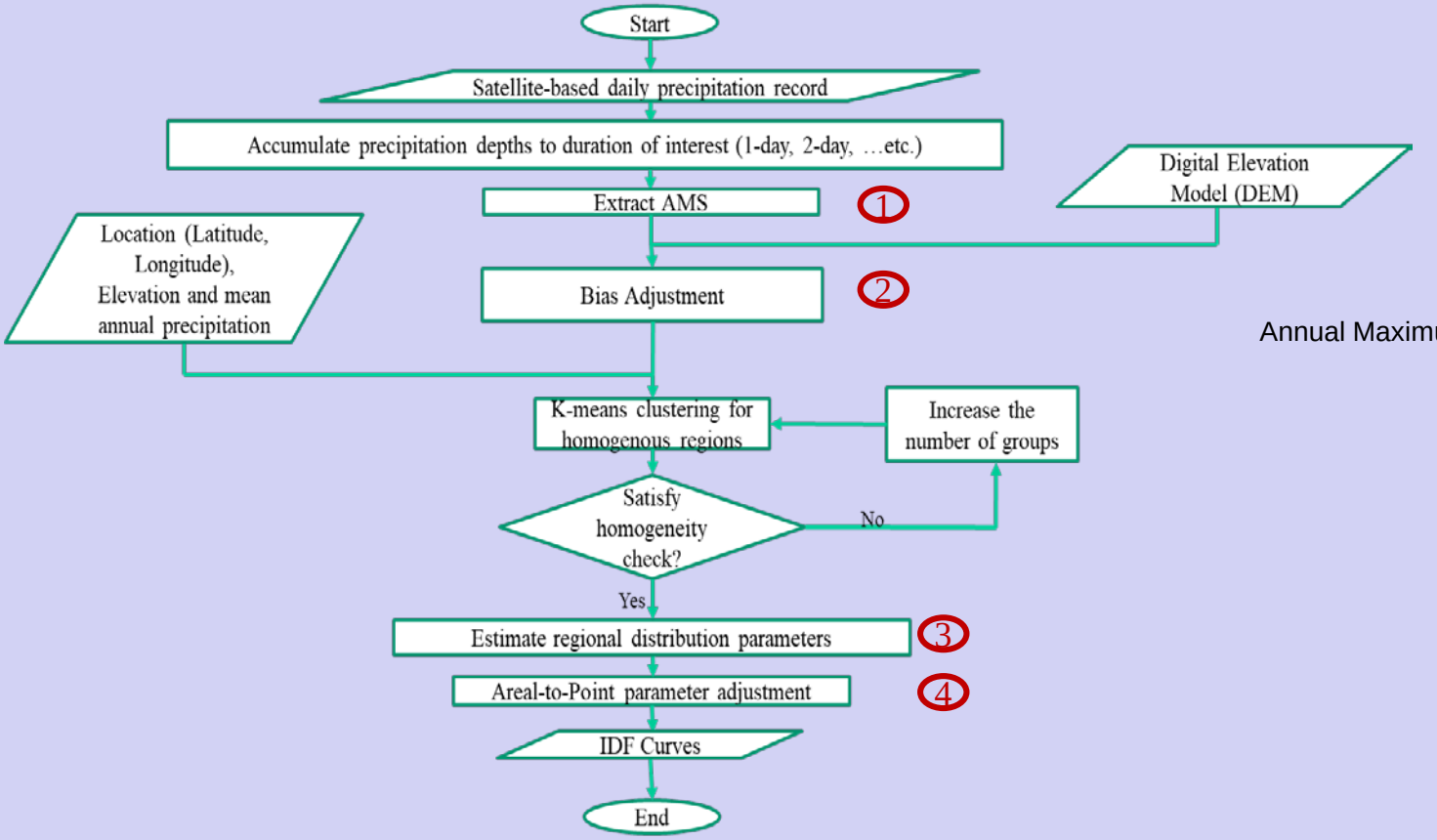
Developing IDF curves from satellite-based Precipitation



Annual Maximum Series (AMS)

(Ombadi et al., *WRR* 2018)

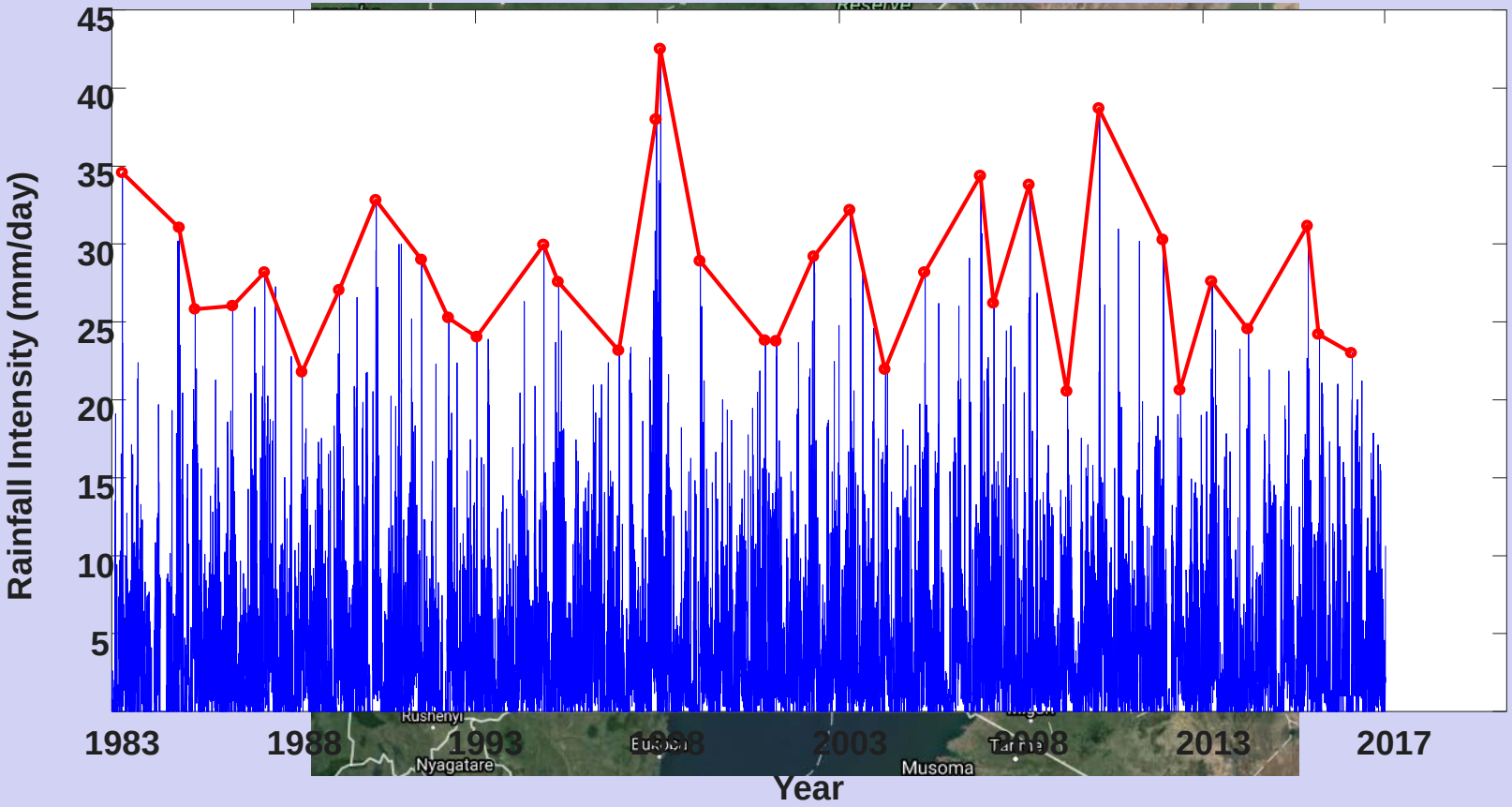
Developing IDF curves from satellite-based Precipitation



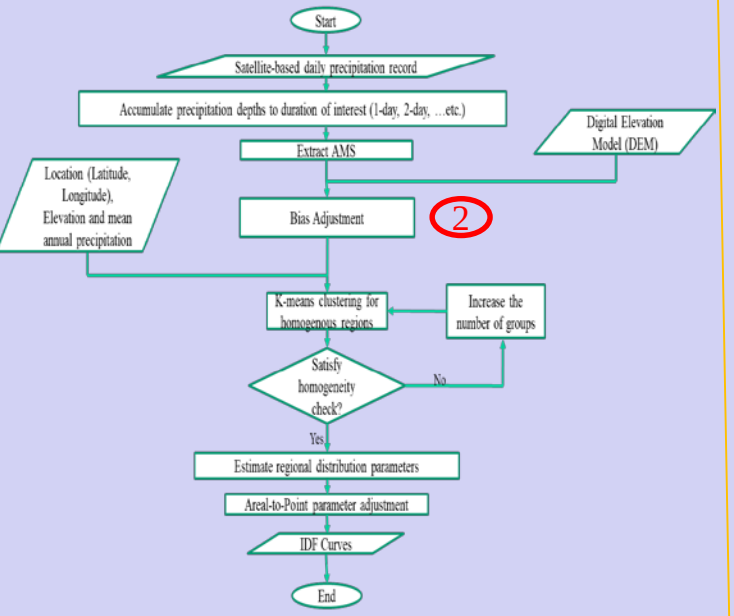
Annual Maximum Series (AMS)

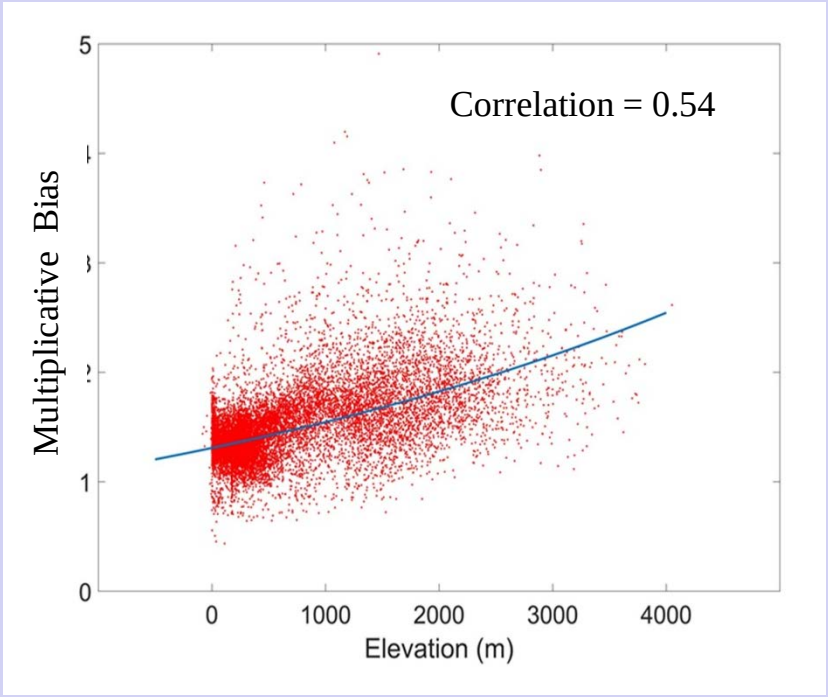
(Ombadi et al., *WRR* 2018)

1 Extracting Annual Maximum Series (AMS)



2 Bias in PERSIANN-CDR AMS over CONUS

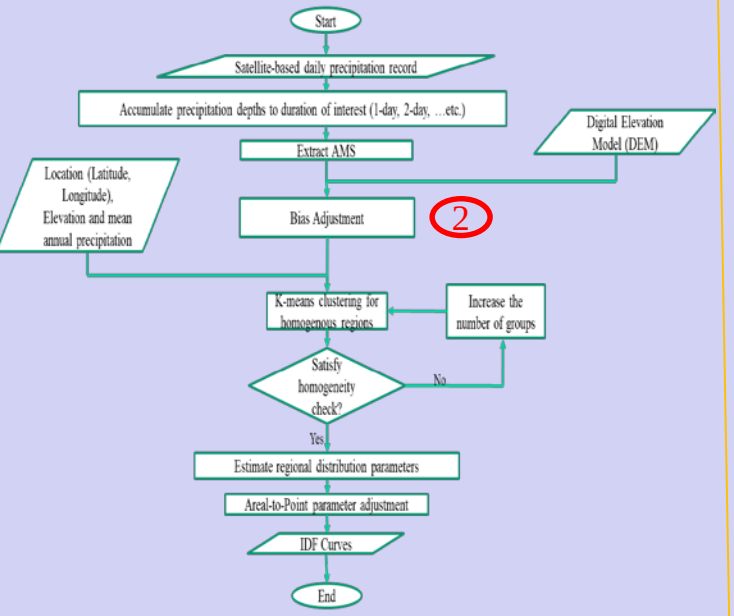




$$Multiplicative\ Bias = \frac{Ground\text{-}based\ Rainfall}{Satellite\text{-}based\ Rainfall}$$

(Ombadi et al., *WRR* 2018)

2 Bias Adjustment



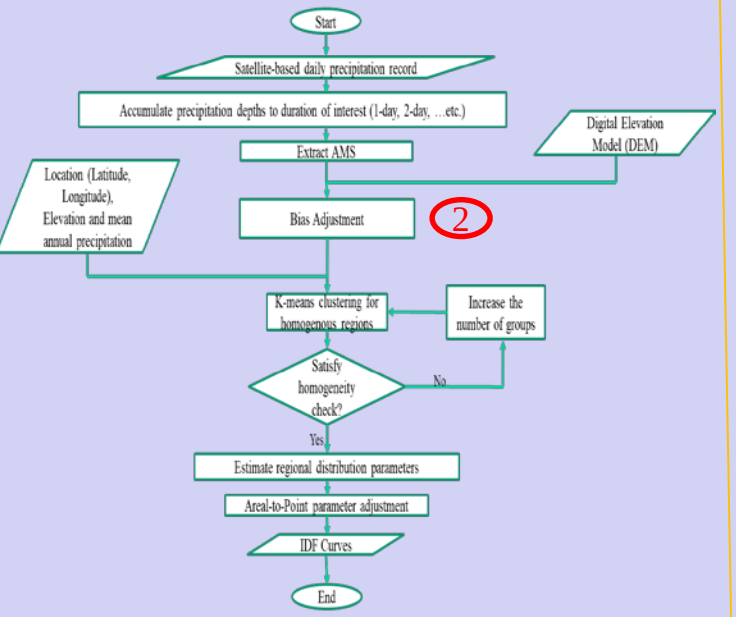
Bias Adjustment Model:

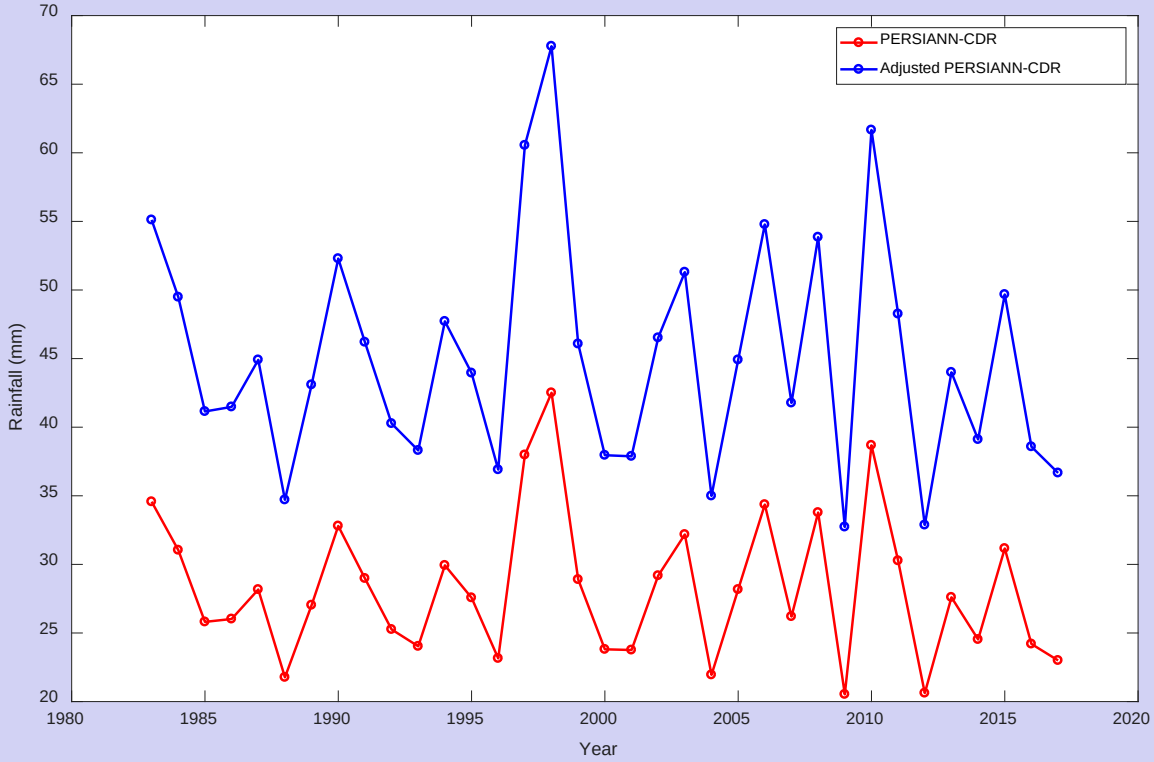
$$\bar{\zeta}_{(x,y)} = \alpha * e^{(\beta\, E_{(x,y)})}$$

$$\bar{\zeta}_{(x,y)} \equiv Adjustment\ Factor$$
$$E_{(x,y)} \equiv Elevation\ (meters)$$
$$\alpha, \beta \equiv parameters$$

(Ombadi et al., *WRR* 2018)

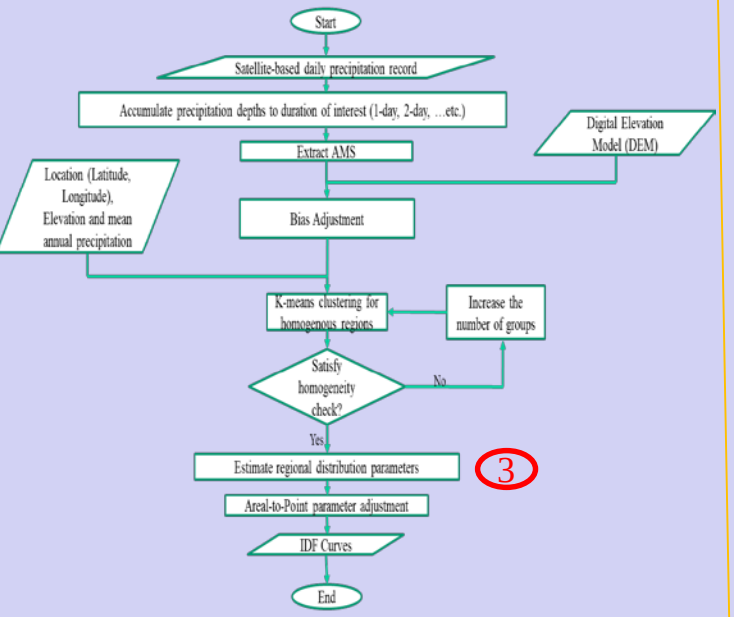
2 Bias Adjustment

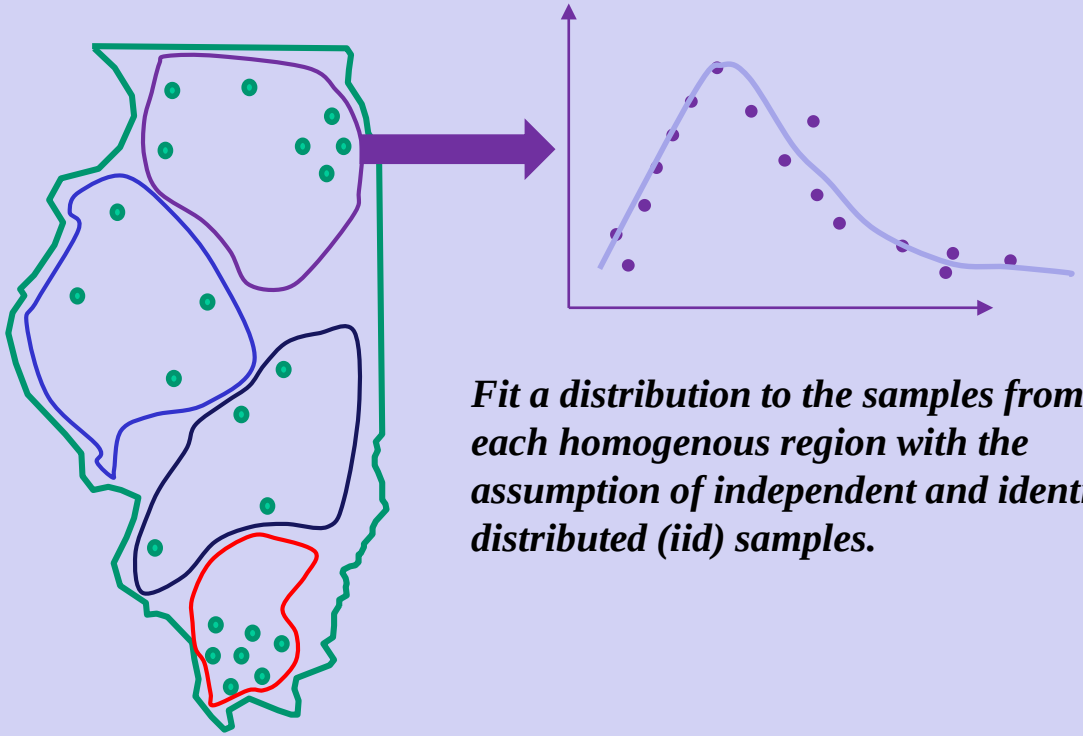




(Ombadi et al., *WRR* 2018)

3 Regional Frequency Analysis

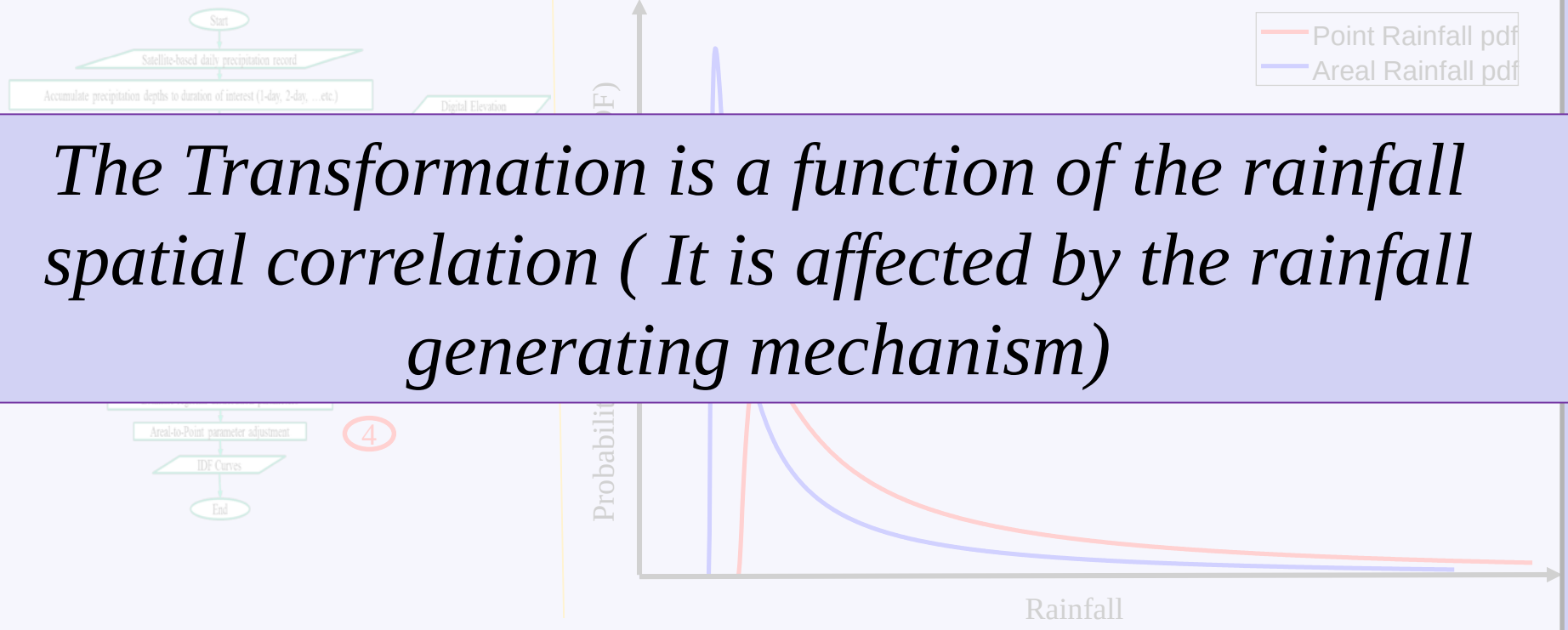




Fit a distribution to the samples from each homogenous region with the assumption of independent and identically distributed (iid) samples.

(Hosking and Wallis, 1993; Dalrymple, 1960)

4 Areal-to-Point Transformation



The Transformation is a function of the rainfall spatial correlation (It is affected by the rainfall generating mechanism)

(Ombadi et al., *WRR* 2018)

References

- **Ombadi, M, Nguyen, P, Sorooshian, S and Hsu, K (2018). Developing Intensity-Duration-Frequency (IDF) Curves from Satellite-based Precipitation: Methodology and Evaluation (*WRR* 2018).**
- **Faridzad M., Yang T., Hsu K., Sorooshian S., and Chan X (2018) Rainfall Frequency Analysis for Ungauged Regions Using Remotely Sensed Precipitation Information*; J of Hydrology 2018***
- Dalrymple, T. (1960). *Flood-frequency analyses, Manual of Hydrology: Part 3. US Geological Survey Water Supply Paper*, 1543 – A. Washington, DC: US Government Printing Office.
- Hosking, J. R. M. & Wallis, J. R. (1993). Some statistics useful in regional frequency analysis. *Water Resources Research*, 29 (2), 271 – 281. doi: 10.1029/92WR01980
- NOAA Atlas 14. Accessed at: http ://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

References

- **Ombadi, M, Nguyen, P, Sorooshian, S and Hsu, K (2018). Developing Intensity-Duration-Frequency (IDF) Curves from Satellite-based Precipitation: Methodology and Evaluation (*WRR* 2018).**
- **Faridzad M., Yang T., Hsu K., Sorooshian S., and Chan X (2018) Rainfall Frequency Analysis for Ungauged Regions Using Remotely Sensed Precipitation Information*; J of Hydrology 2018***
- Dalrymple, T. (1960). *Flood-frequency analyses, Manual of Hydrology: Part 3. US Geological Survey Water Supply Paper*, 1543 – A. Washington, DC: US Government Printing Office.
- Hosking, J. R. M. & Wallis, J. R. (1993). Some statistics useful in regional frequency analysis. *Water Resources Research*, 29 (2), 271 – 281. doi: 10.1029/92WR01980
- NOAA Atlas 14. Accessed at: http ://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

How Much Trust in Remote Sensing Observations??

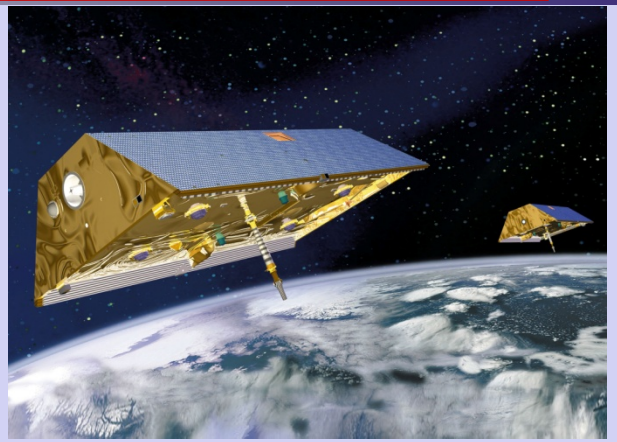
Hydrologically - Relevant Remote Sensing Missions

SMOS

ESA's Soil Moisture and Ocean Salinity (2009)

TRMM

The Tropical Rainfall Measuring Mission

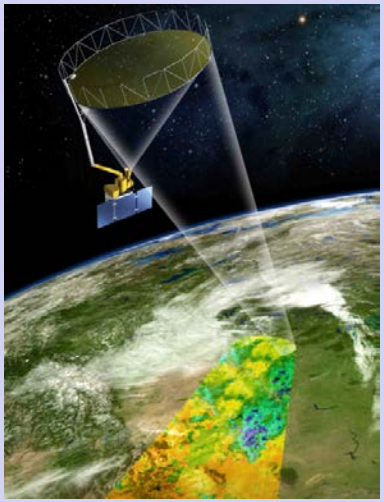


GRACE

Gravity Recovery and Climate Experiment (2002)

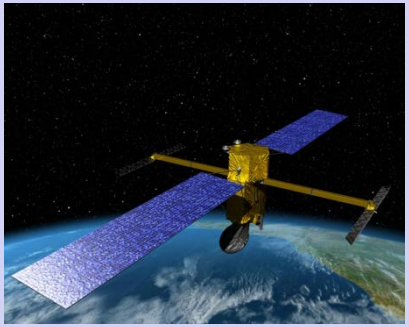
GPM

Global Precipitation Measurements (2014)



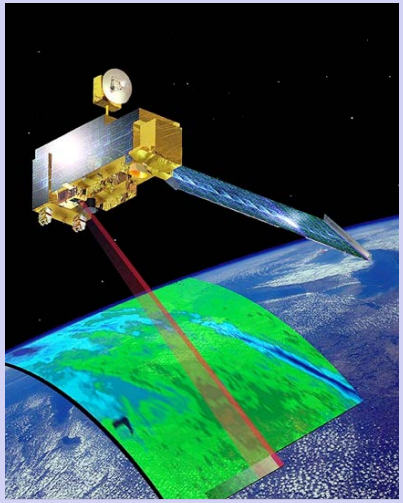
SMAP

Soil Moisture Active Passive Satellite(2014)



SWOT

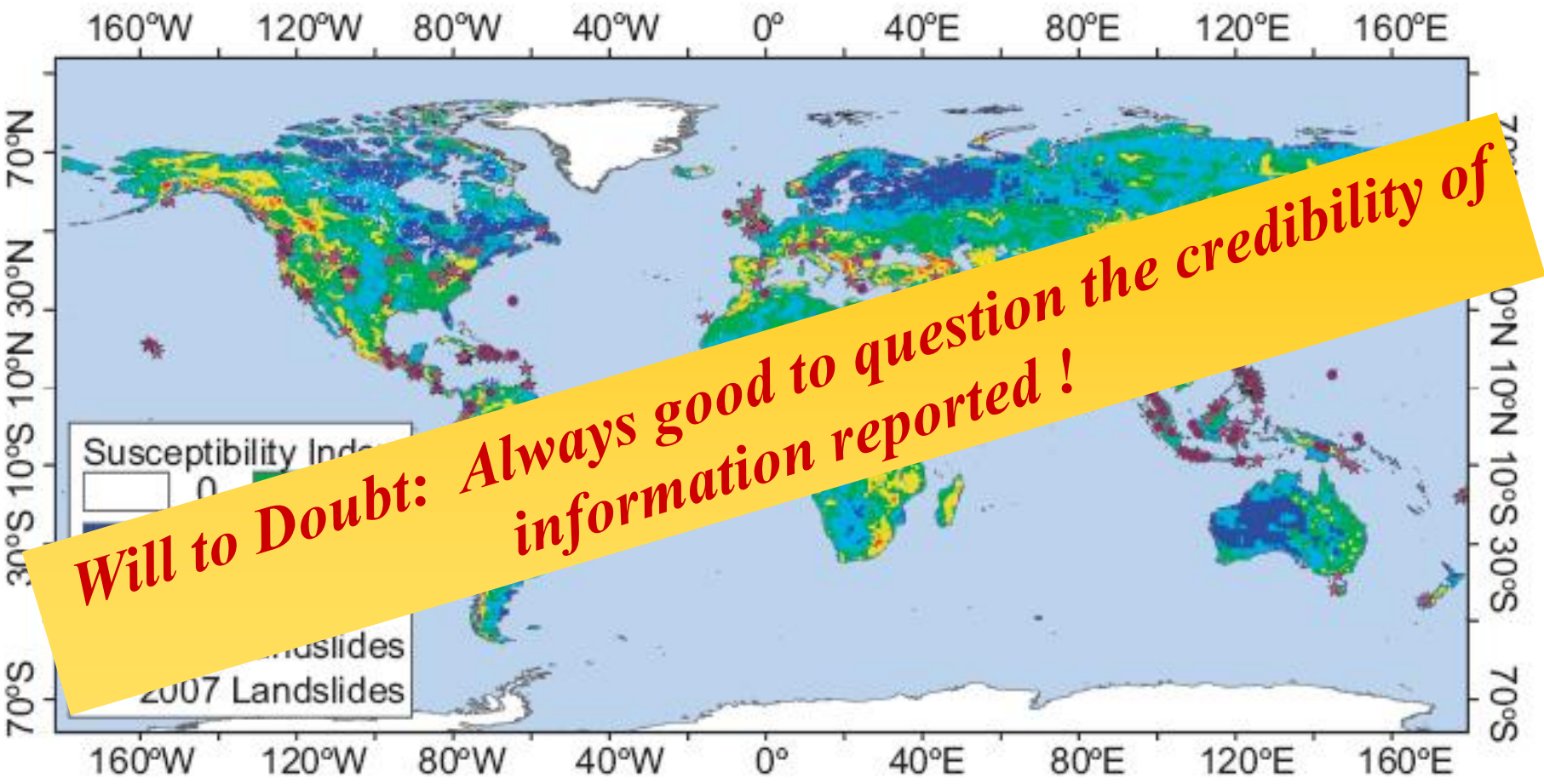
Surface Water and Ocean Topography (2020)



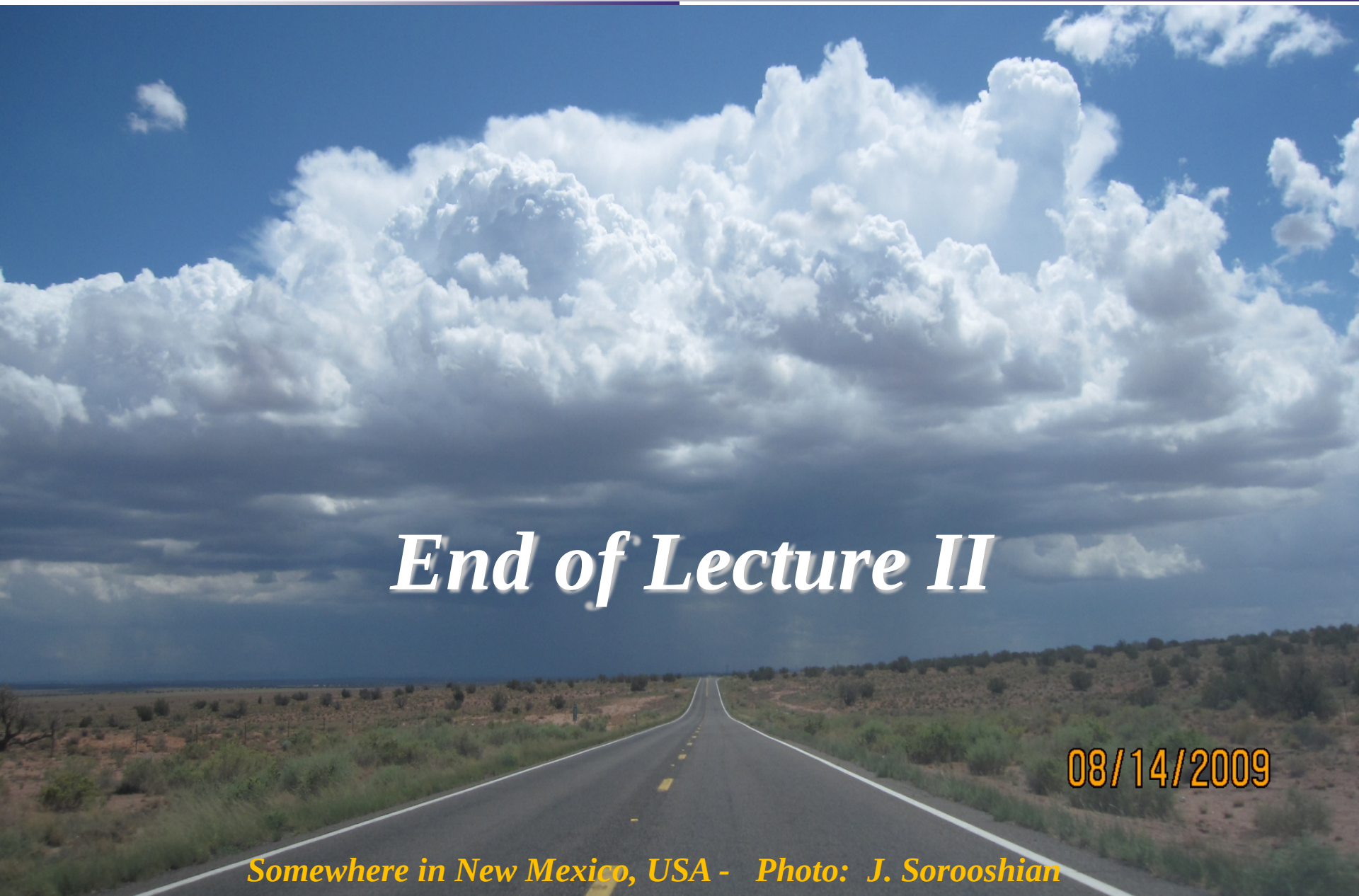
MODIS

Moderate Resolution Imaging Spectroradiometer (1999) , (2002)

Landslide Risk map:



Will to Doubt: Always good to question the credibility of information reported !



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