Challenges and Limitations of Hydroclimatological Forecasting for Water Resources Management and Future Prospects

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University of California, Irvine (UCI) Past Research Team

and many more …

Information Required for a Range of Scales:

Continental Scale:

Different Scales
Different Issues

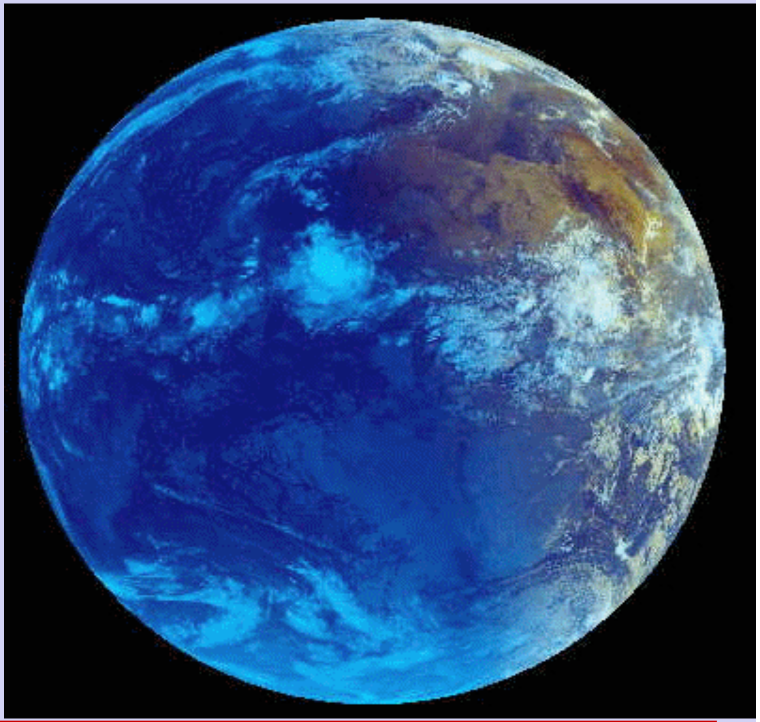
Watershed Scale:

Where "hydrology" happens
Where stakeholders reside

Climate, Hydrology and Water Resources

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

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



Information Relevant to Water Resources Planning

- Models Projections

- Observations

Prediction Requirements for Water Resources

Short Range -> Long Range

hours - - - -> days - - - -> weeks - - -> months - - -> seasons - - -> years - - - - - -> decades

Flash Flood Warning

Flash Flood Guidance

Headwater Guidance

Flood Forecast Guidance

Reservoir Inflow Forecasts

Spring Snow Melt Forecasts

Water Supply Volume

Short-range | ***Mid-range*** | ***Long-range***

Forecast Requirements

Required Hydrometeorological Predictions

Short Range – · – · – · – · – · – · – · – · – · – · – · – · – · – · – · Long Range

hours – – – –> days – – – –> weeks – – –> months – –> seasons – –> years – – – – –> decades

Flash Flood Warning

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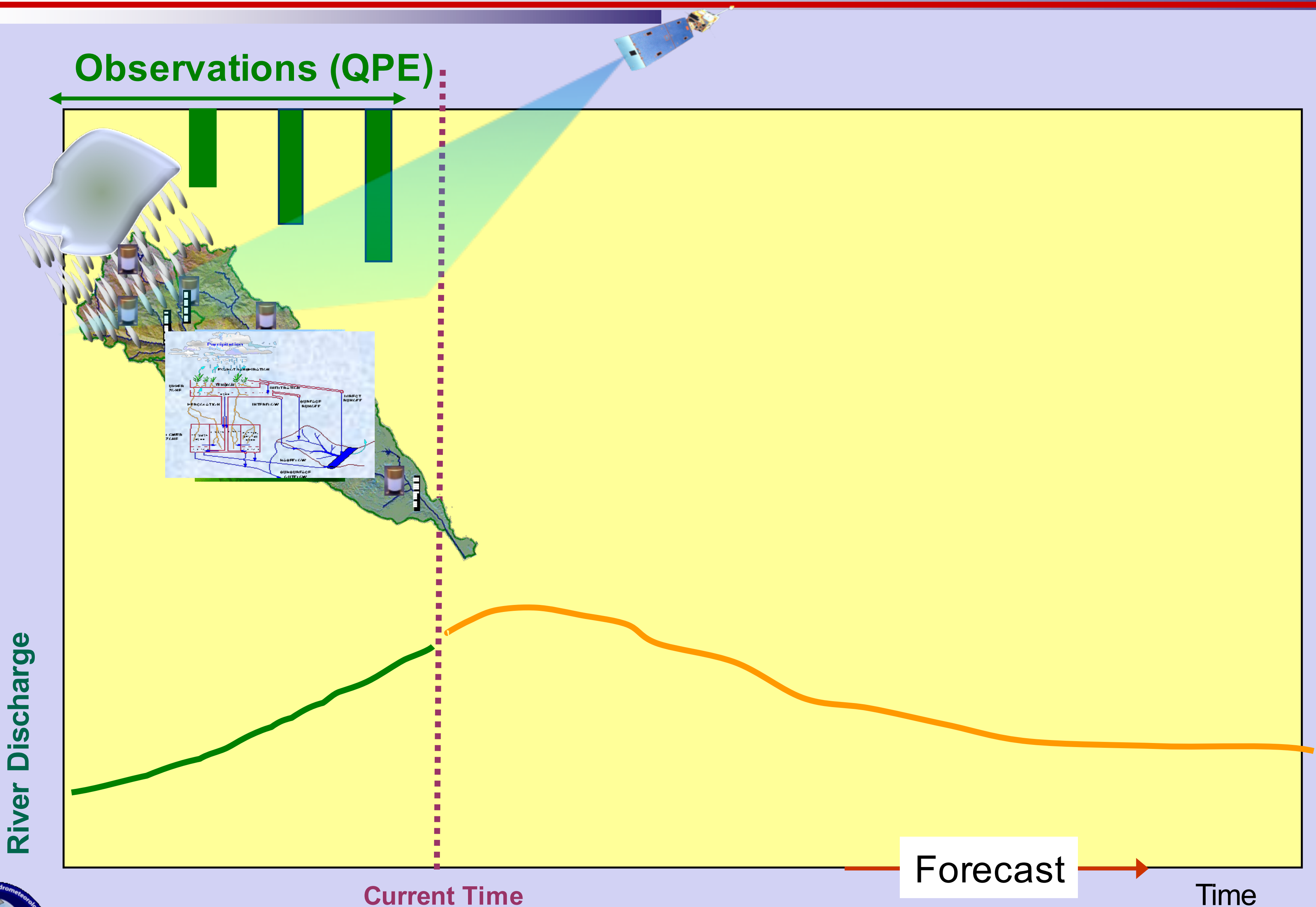
Reservoir Inflow Forecasts

Water Supply Volume

- ***Weather Scale:***
  - ***flood and River flow forecasting***

Short-range

Common practice in Flood and River Flow Forecasting



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

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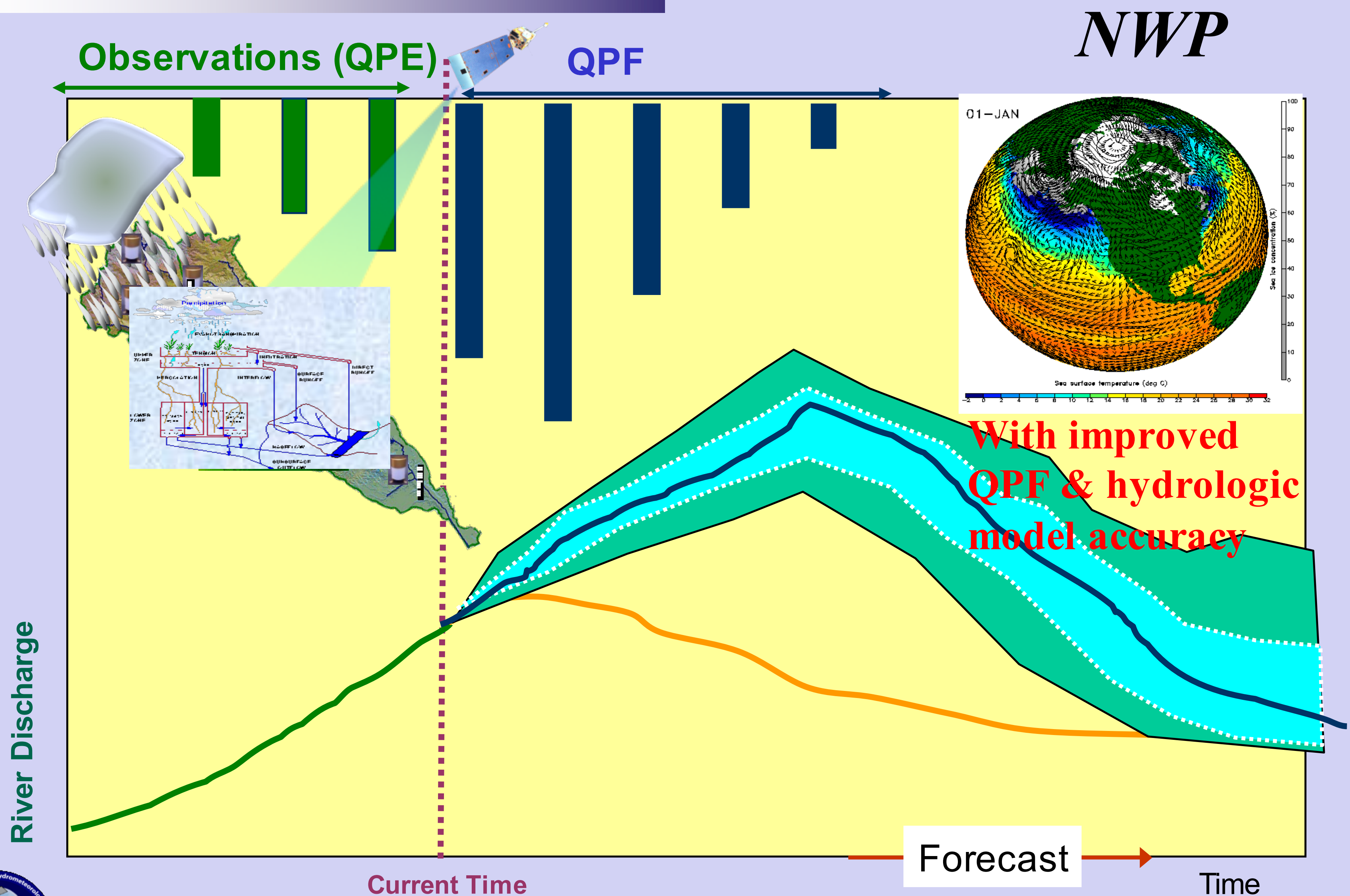
Efforts in Extending the Forecast Lead Time



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

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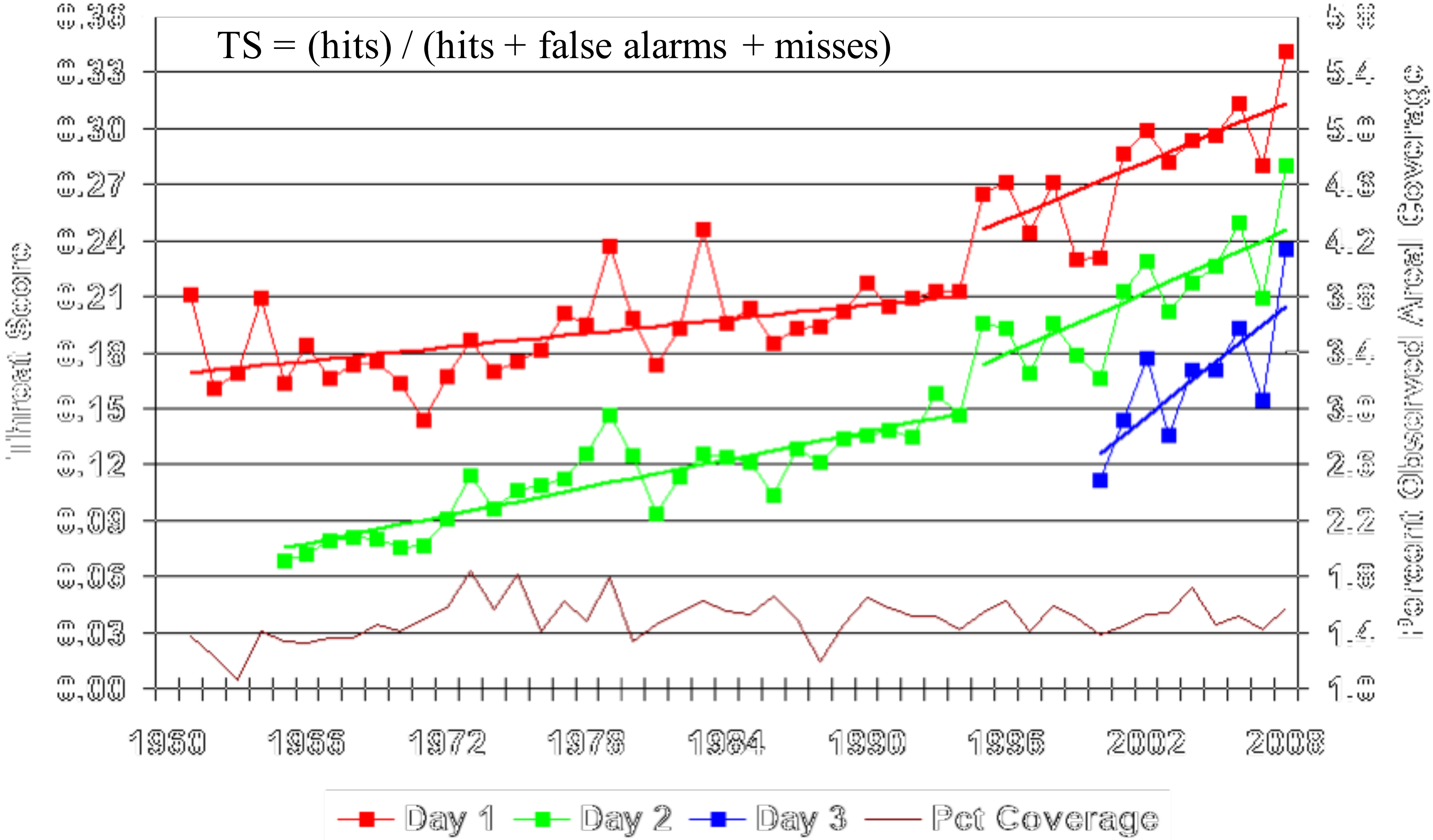
Provided by: J. Hoke

HPC QPF verification

1-inch threat score



Prediction Requirements for Water Resources

Short Range - · - · - · - · - · - · - · - · - · - · - · - · - · - · - · - · - - - - -> Long Range

hours - - - -> days - - - -> weeks - - -> months - - -> seasons - - -> years - - - - - -> decades

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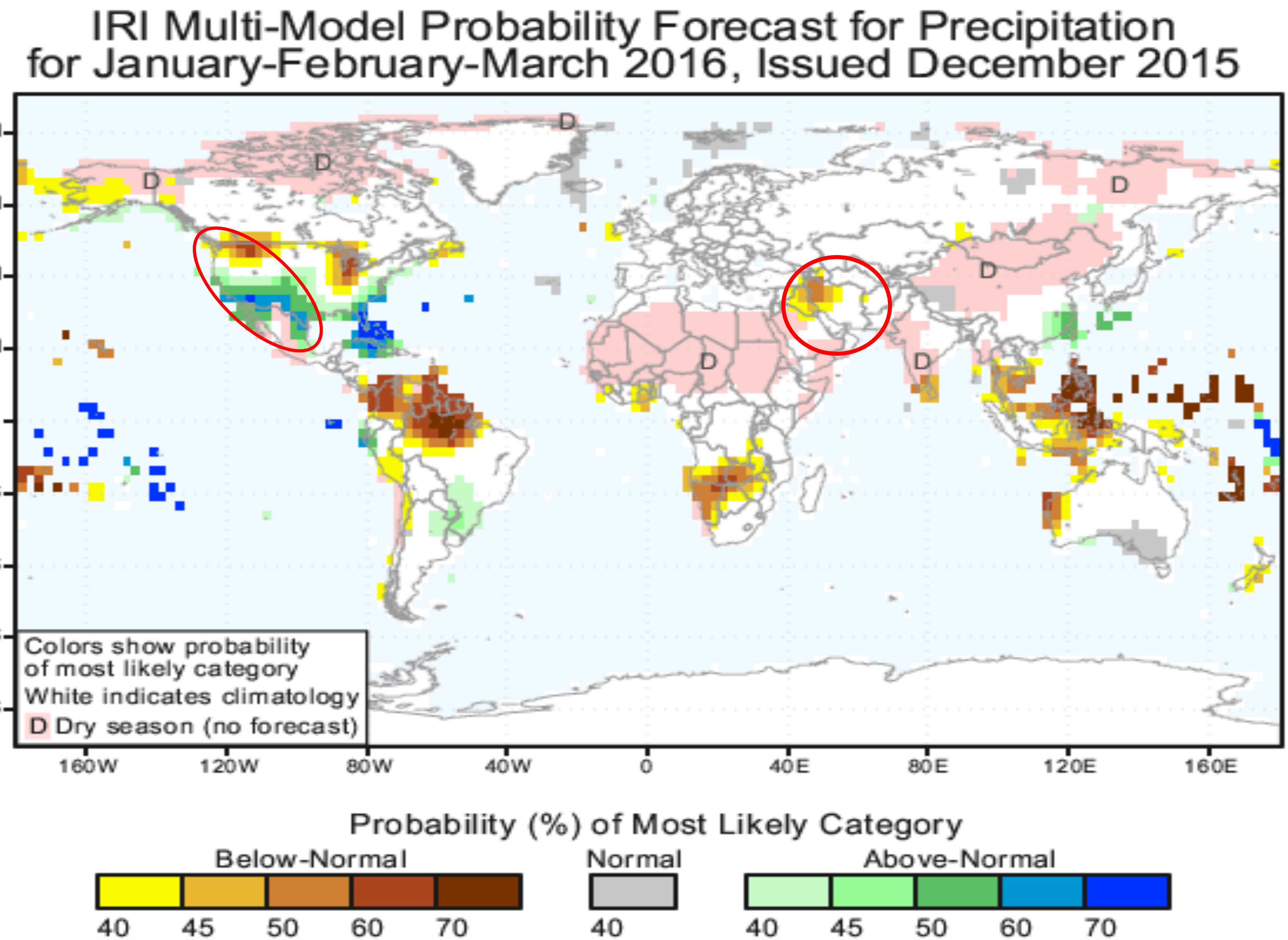
Water Supply Volume

Mid-range

Forecast Requirements

IRI 3-Month Multi-Model Probability Precipitation Forecast



Climate-Scale approaches to addressing hydrologic extremes

Short Range - · - · - · - · - · - · - · - · - · - · - · - · - · - - - - -> Long Range

hours - - - -> days - - - -> weeks - - -> months - - -> seasons - - -> years - - - - - -> decades

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Water Supply Volume

Long-range

Forecast Requirements

Future Precipitation projections by IPCC climate models

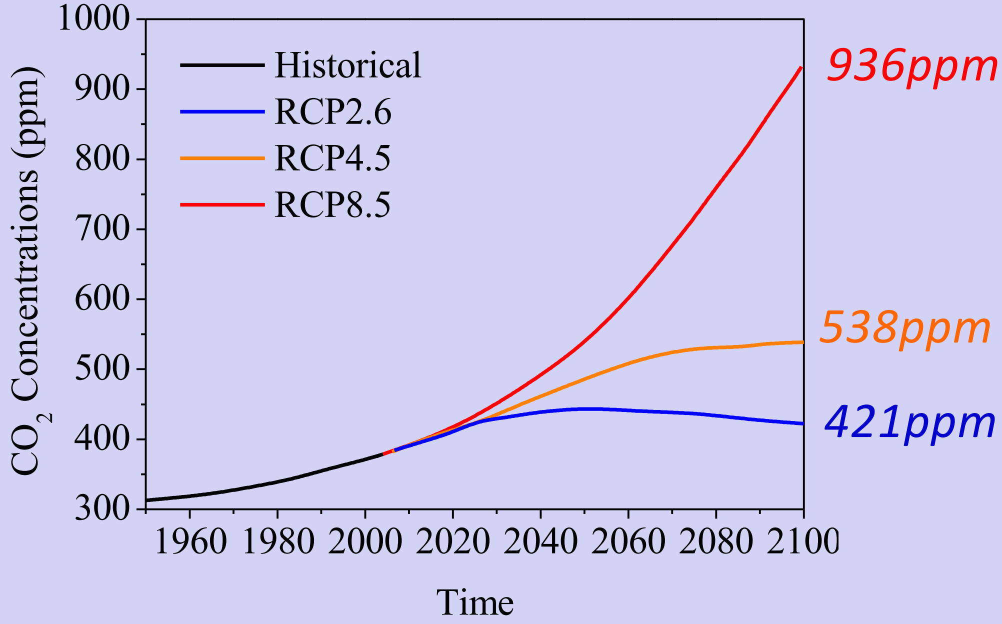
Future Modeling Scenarios – IPCC AR5

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 .

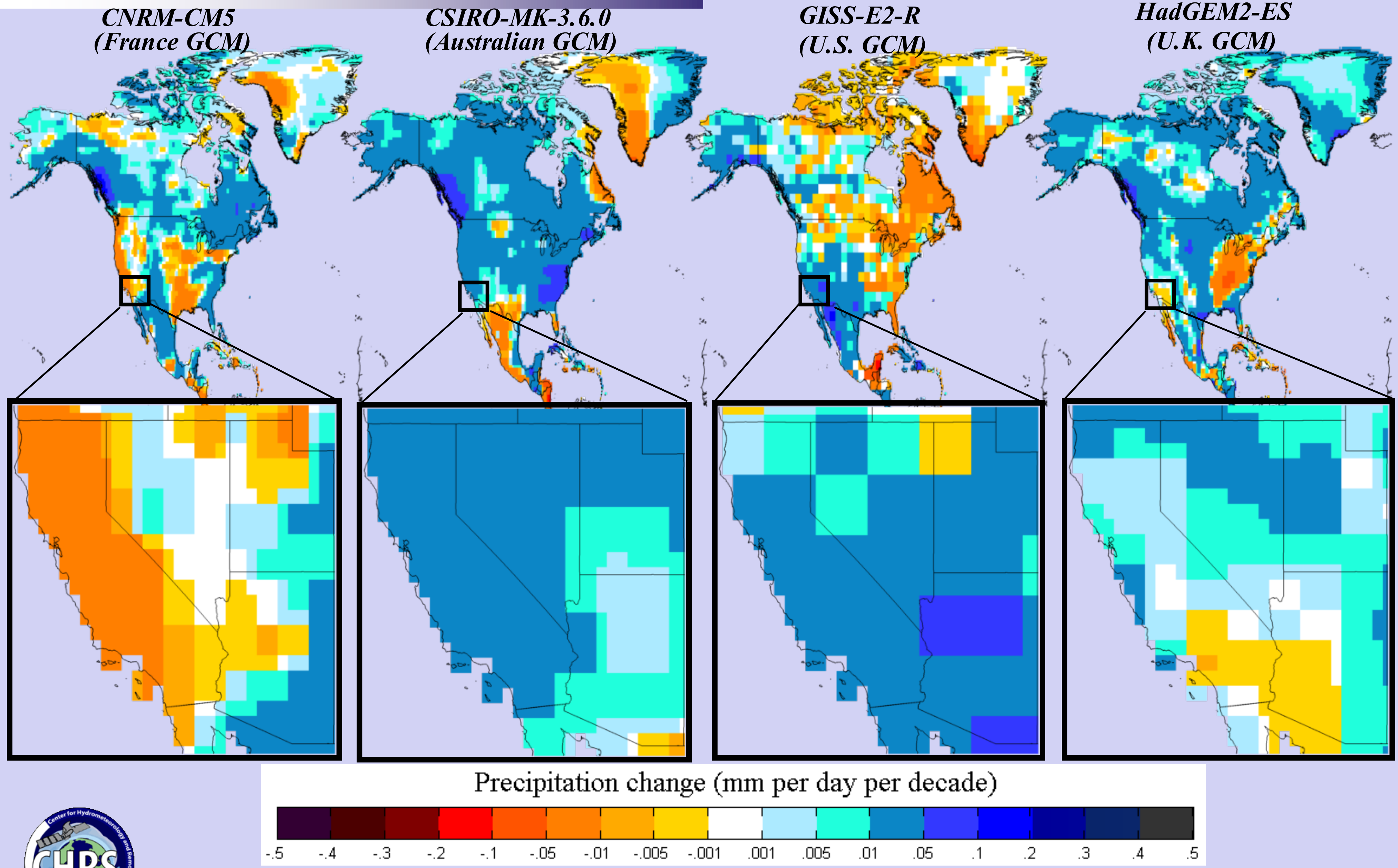


Western U.S. future model projections

Dr. Chiyuan Miao - BNU

RCP2.6

Time period: 2006-2099



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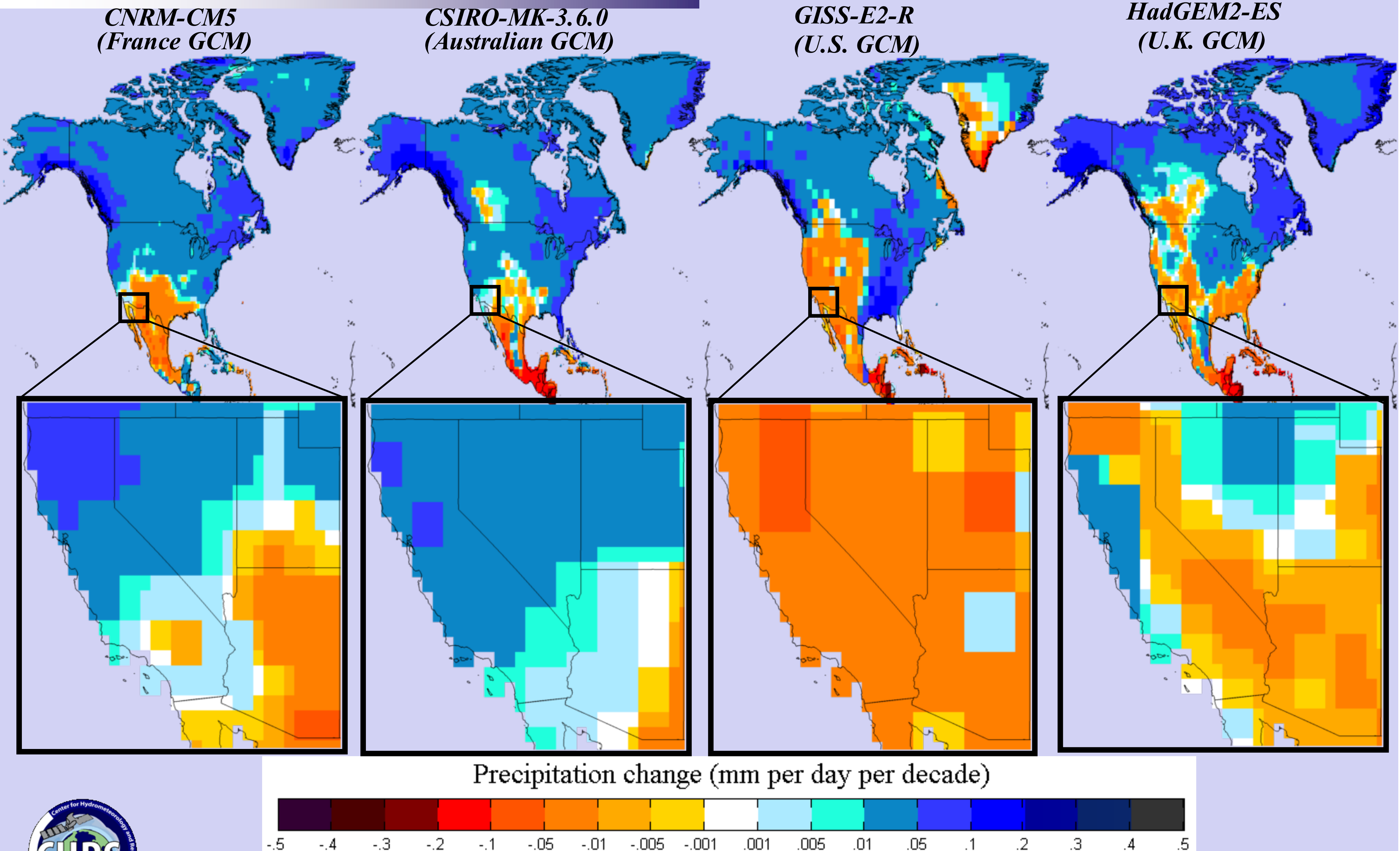
RCP8.5

Time period: 2006-2099



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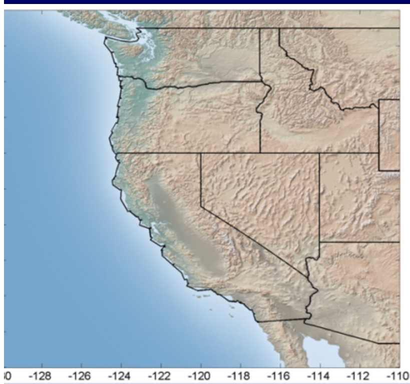
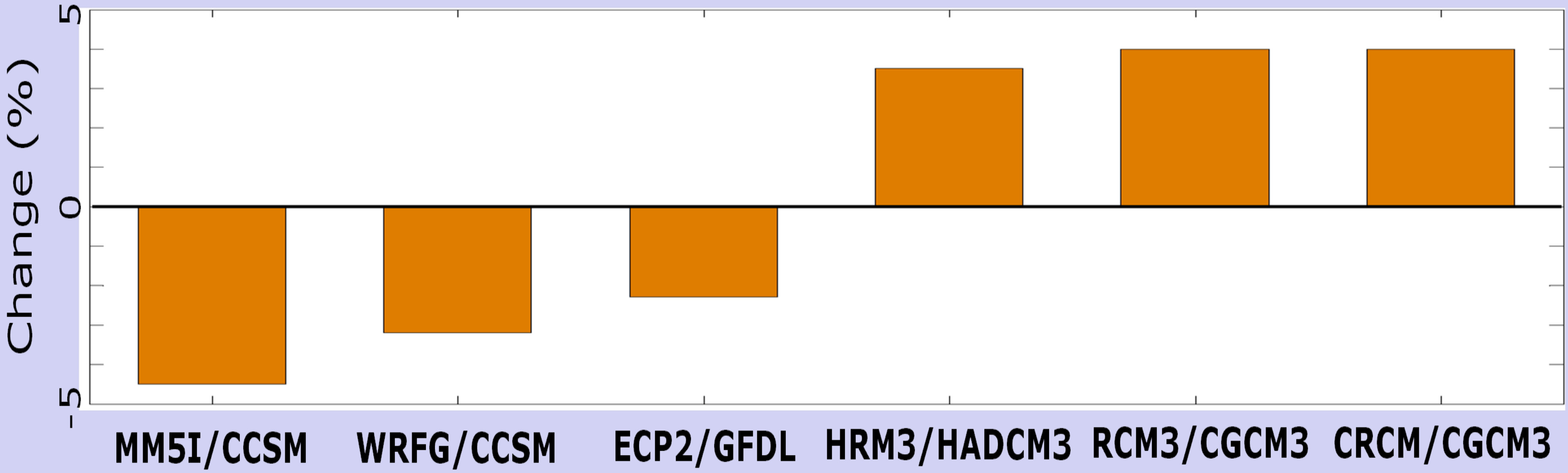
Recent Evaluation of RCM/GCM over Western U.S.



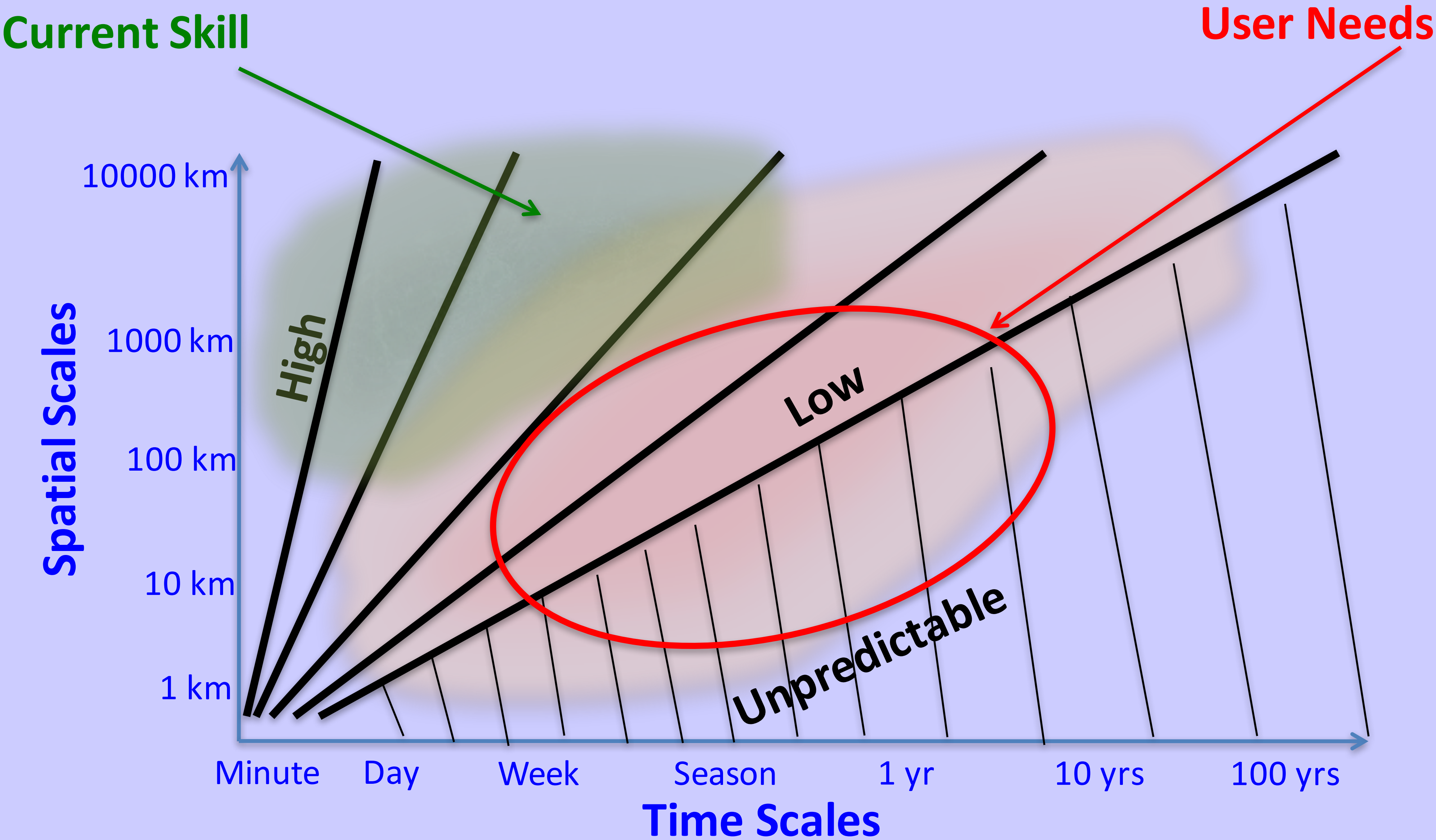
Models indicate different signs and magnitudes of changes in the mean precipitation over the Western U.S. under the SRES A2 emissions scenario.



Trend of area-average precipitation (comparing 2040-2070 with 1970-2000)

Wei Chu 2011

Drought Predictability



Provided by Siegfried Schubert 2011

Take Home Message

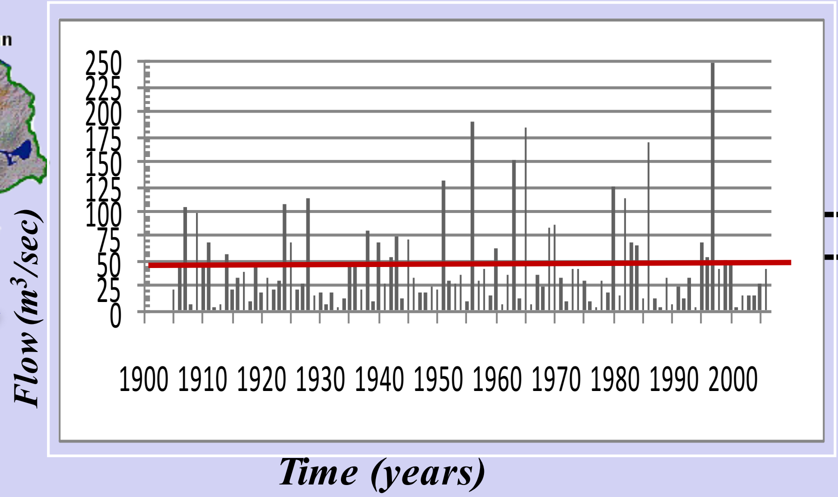
- ***The "accuracy" of Hydroclimate model predictions continue to improve, but presently fall short of meeting the requirements of water resources planning.***

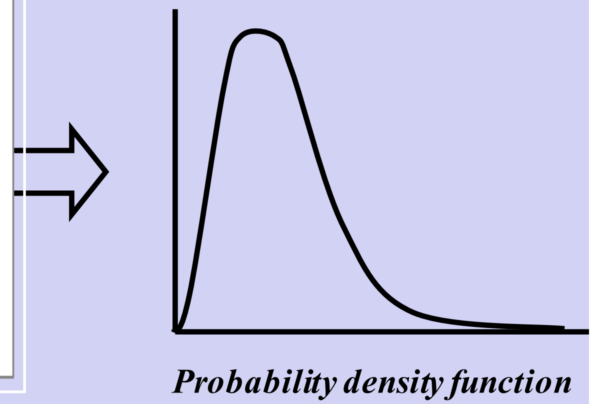
- ***Building trust in their projections requires testing and validation of their performance against historical observations of sufficient resolution (both spatial and temporal).***

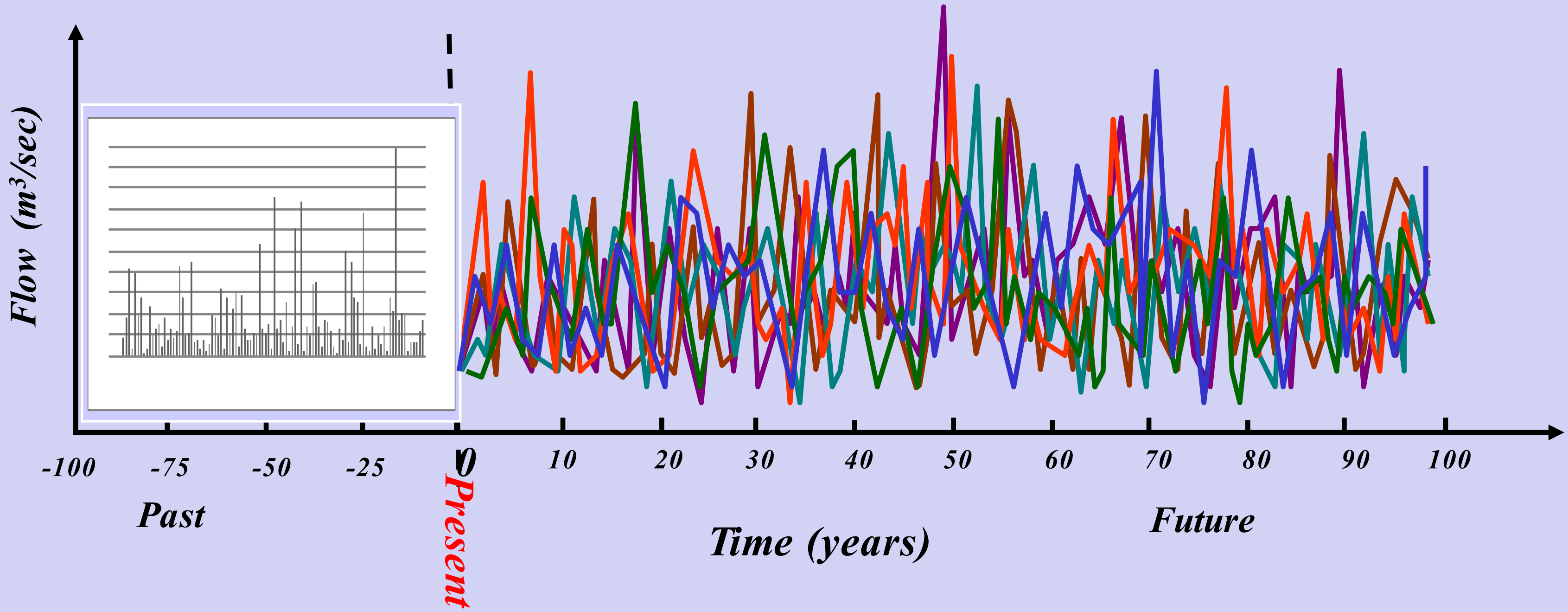
Addressing "Extremes" in Water Resources Planning:

Stochastic Hydrology

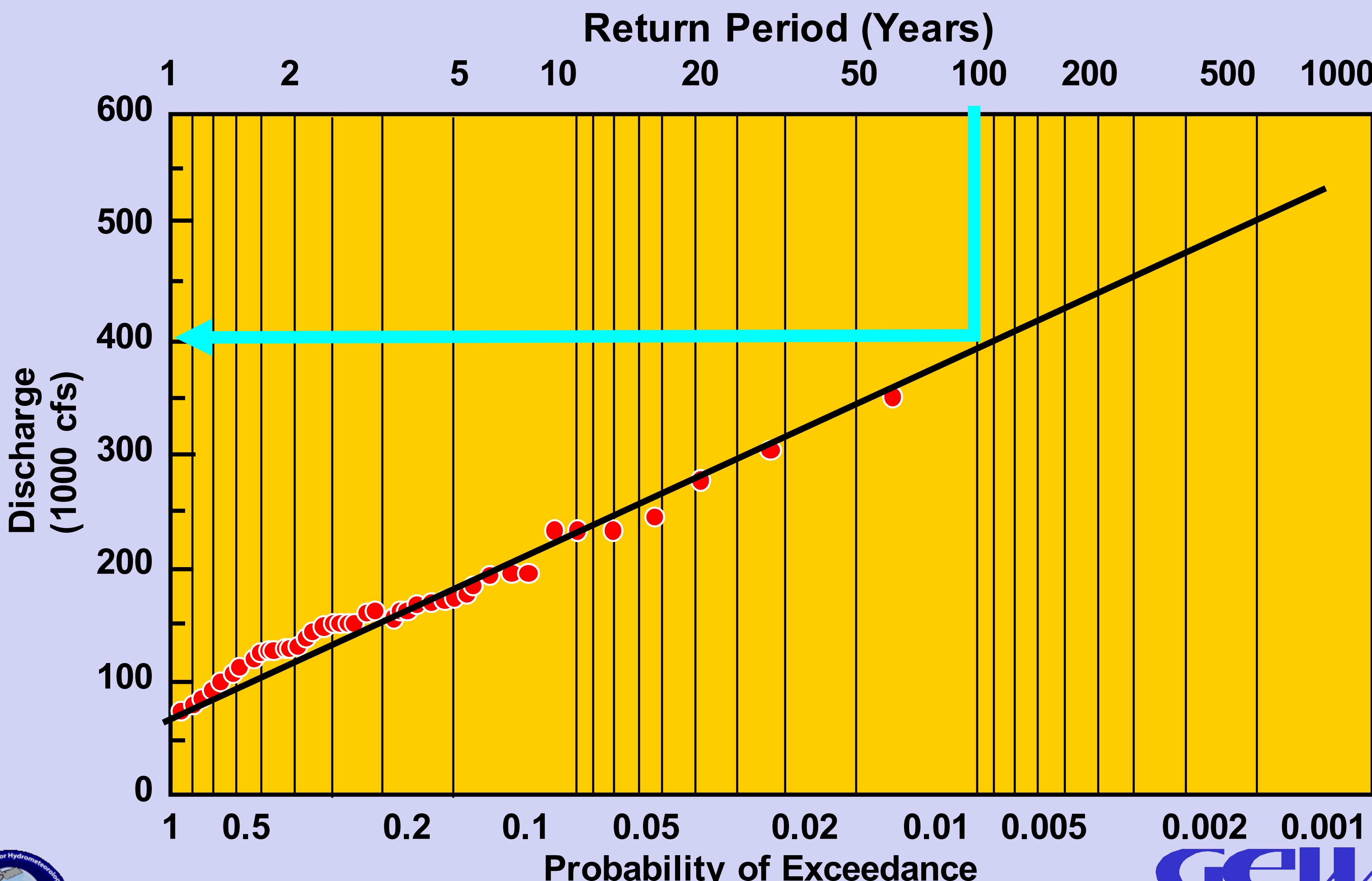
Statistical Hydrology: "synthetic" stream flow Generation



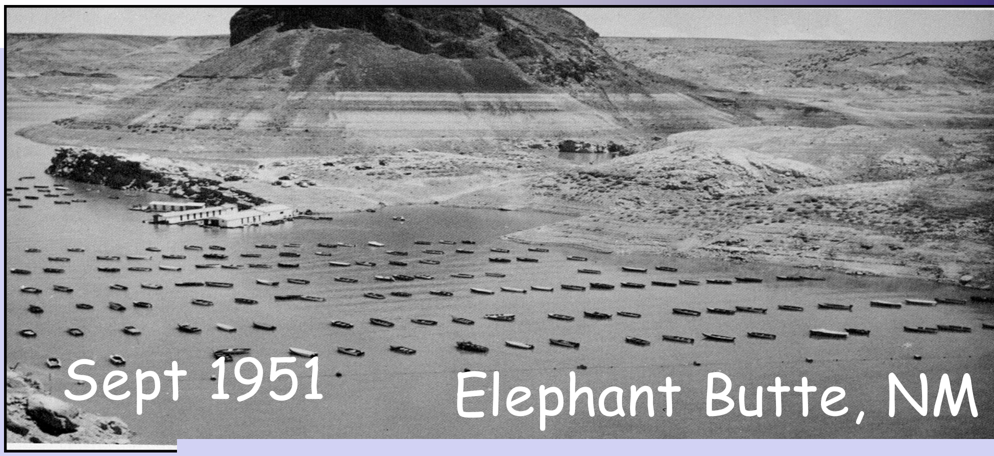


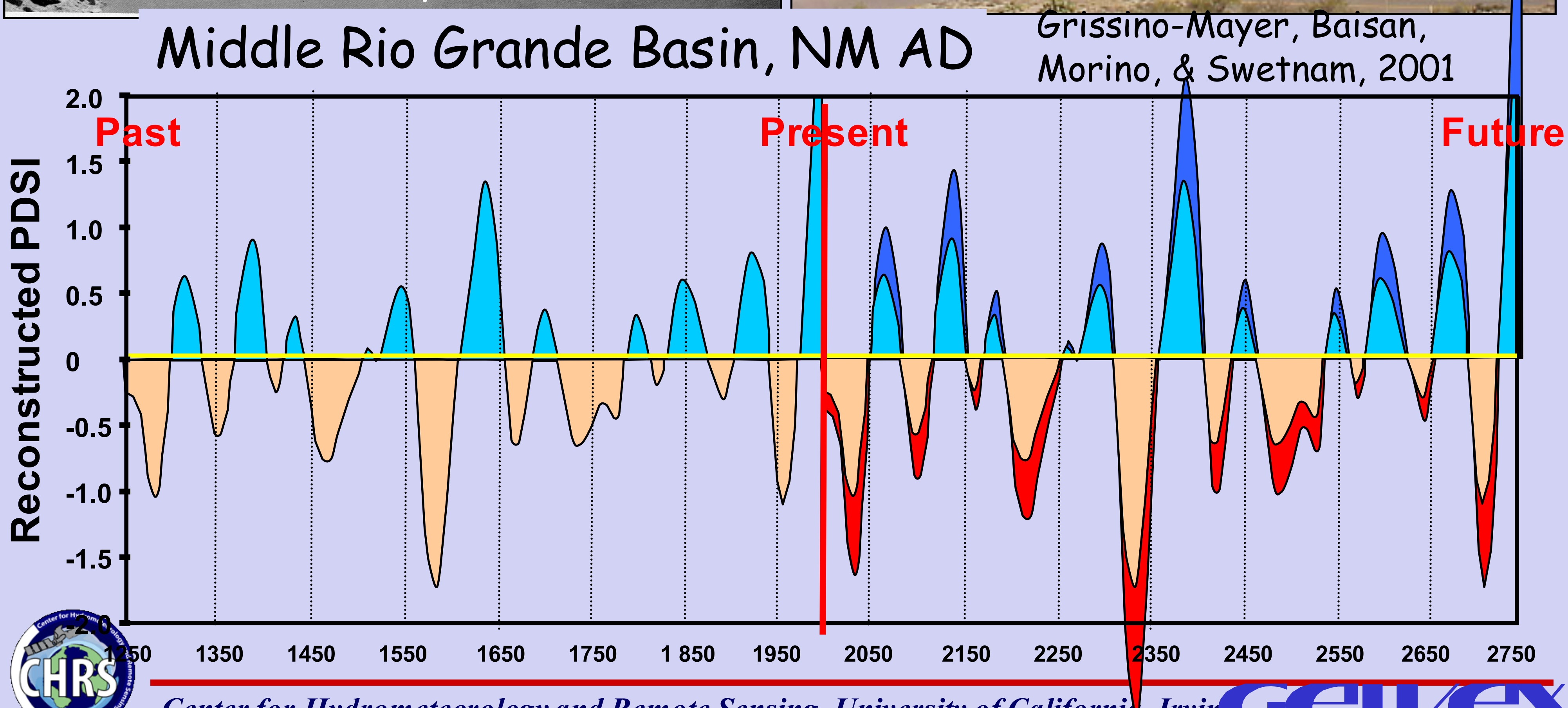


Flood Frequency Analysis: Stationarity!



Statistical Hydrology Developed Based on Stationarity Assumption

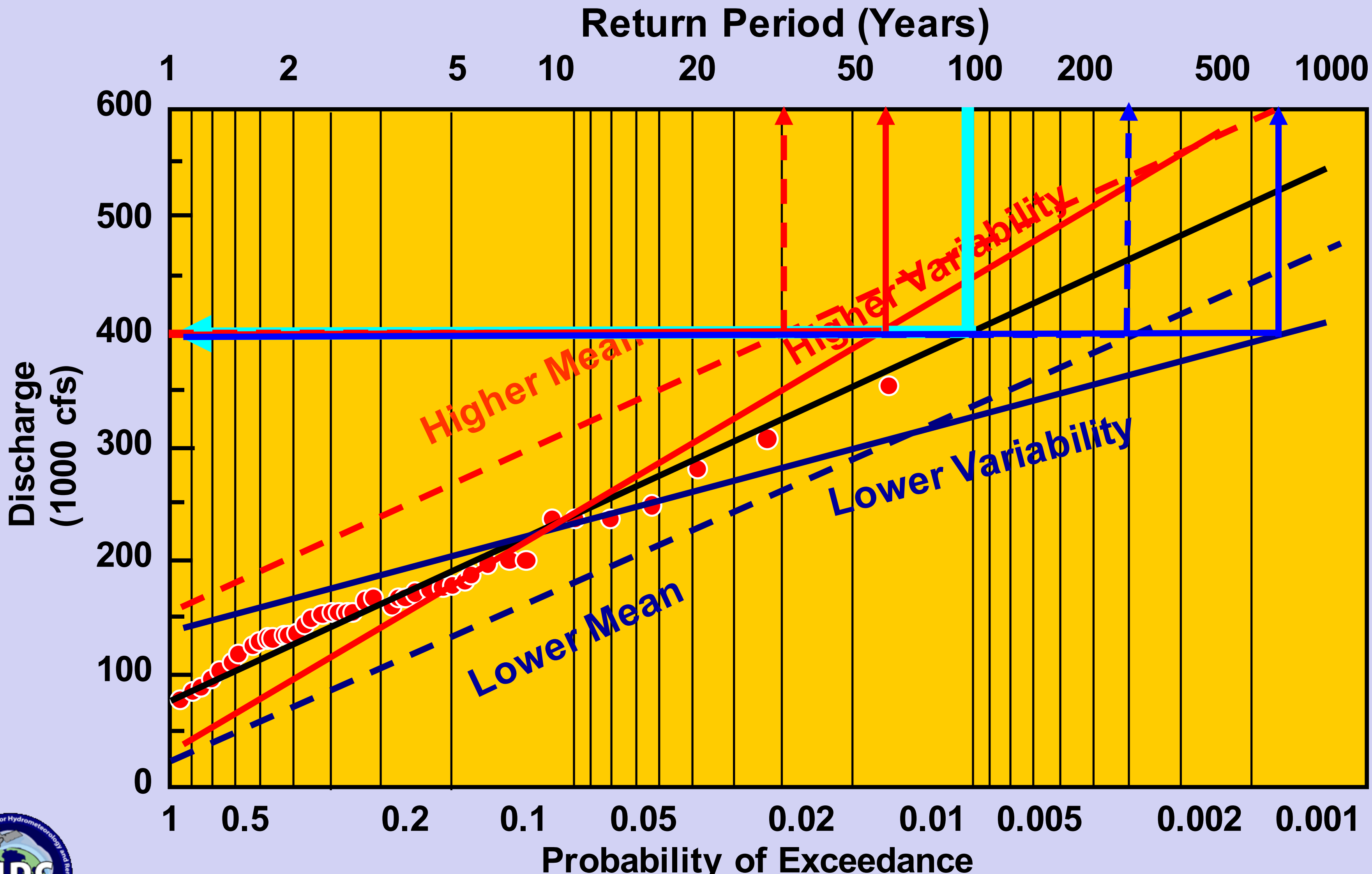




Potential Hydrologic Scenarios

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

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



Hydrologically-Relevant Data

SAHRA

Big Challenge For “us”:

Adequacy of Hydrologic Observations

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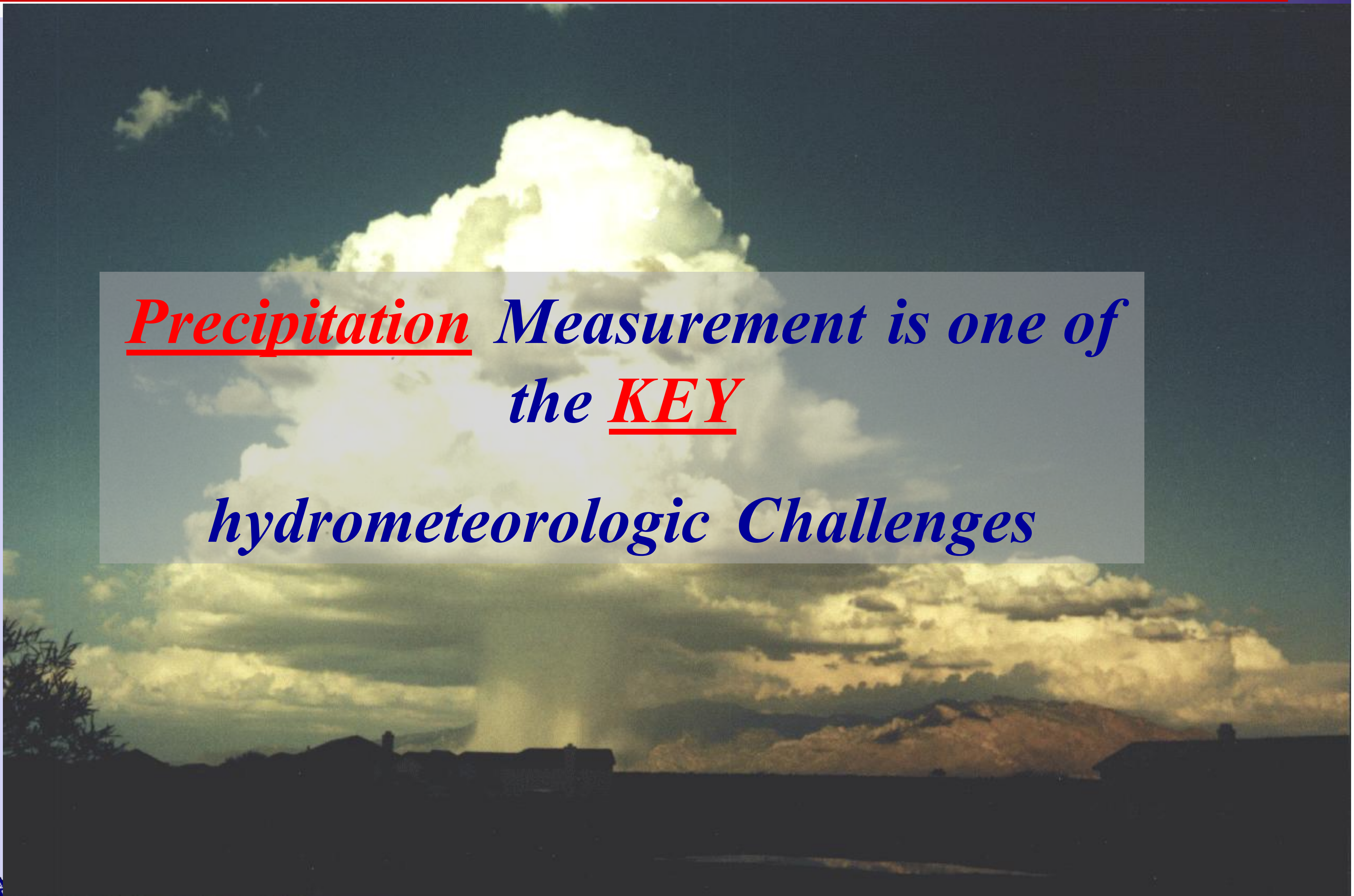
A Key Requirement!

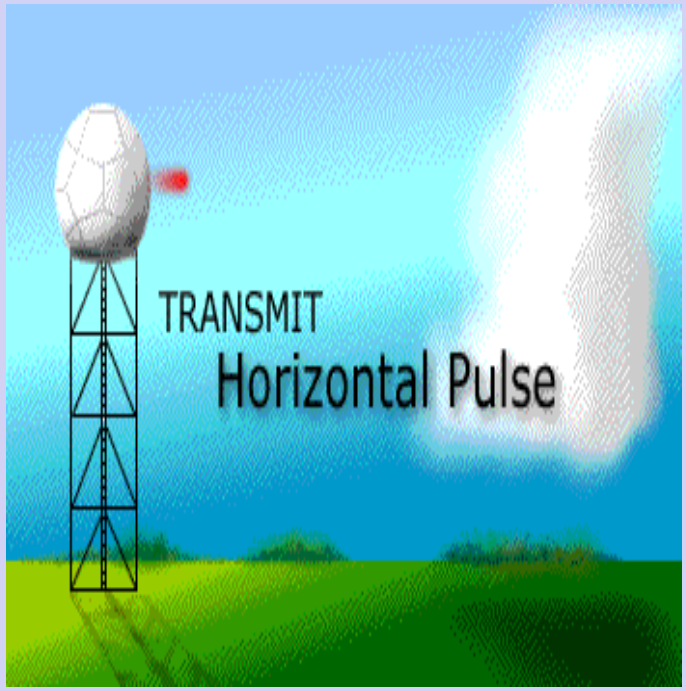


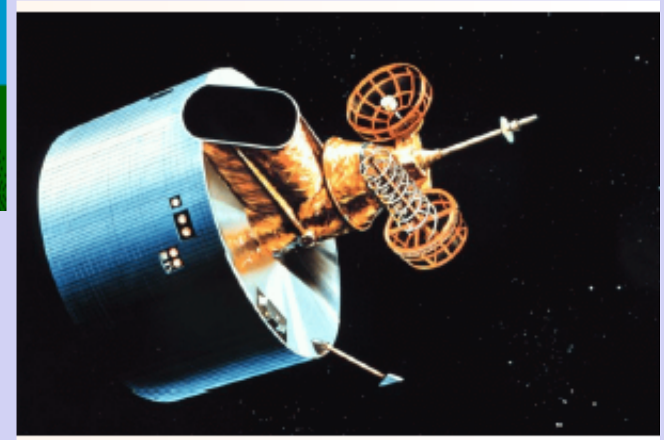
Precipitation ***Measurement is one of the KEY***

hydrometeorologic Challenges

Precipitation Observations: Which to trust??

Rain Gauges





Satellite

Even A Bigger Challenge!

Having adequate high resolution (time and Space) observations of precipitation for model Input, Calibration & Testing, and to capture extremes?

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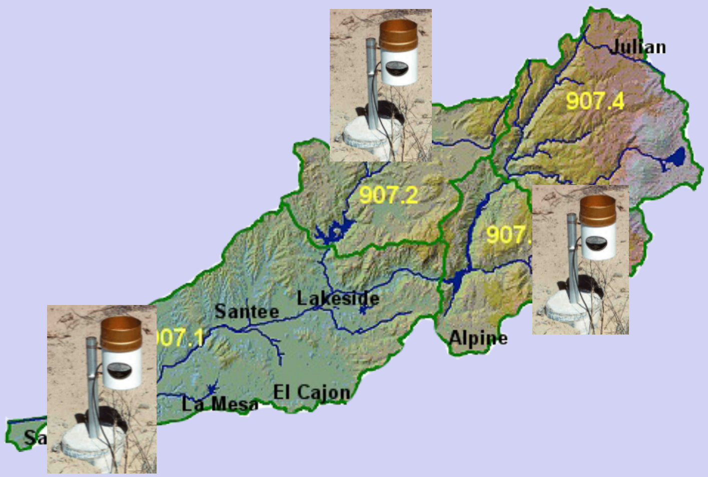
2 Precipitation Scenarios with different Temporal properties

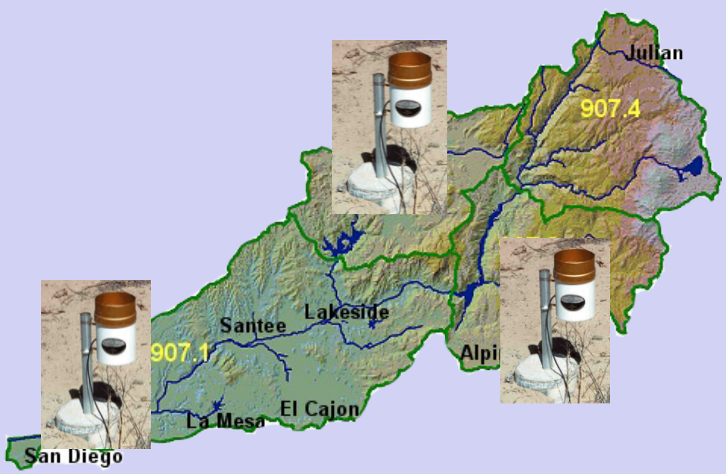
Monthly Total

A



100 mm

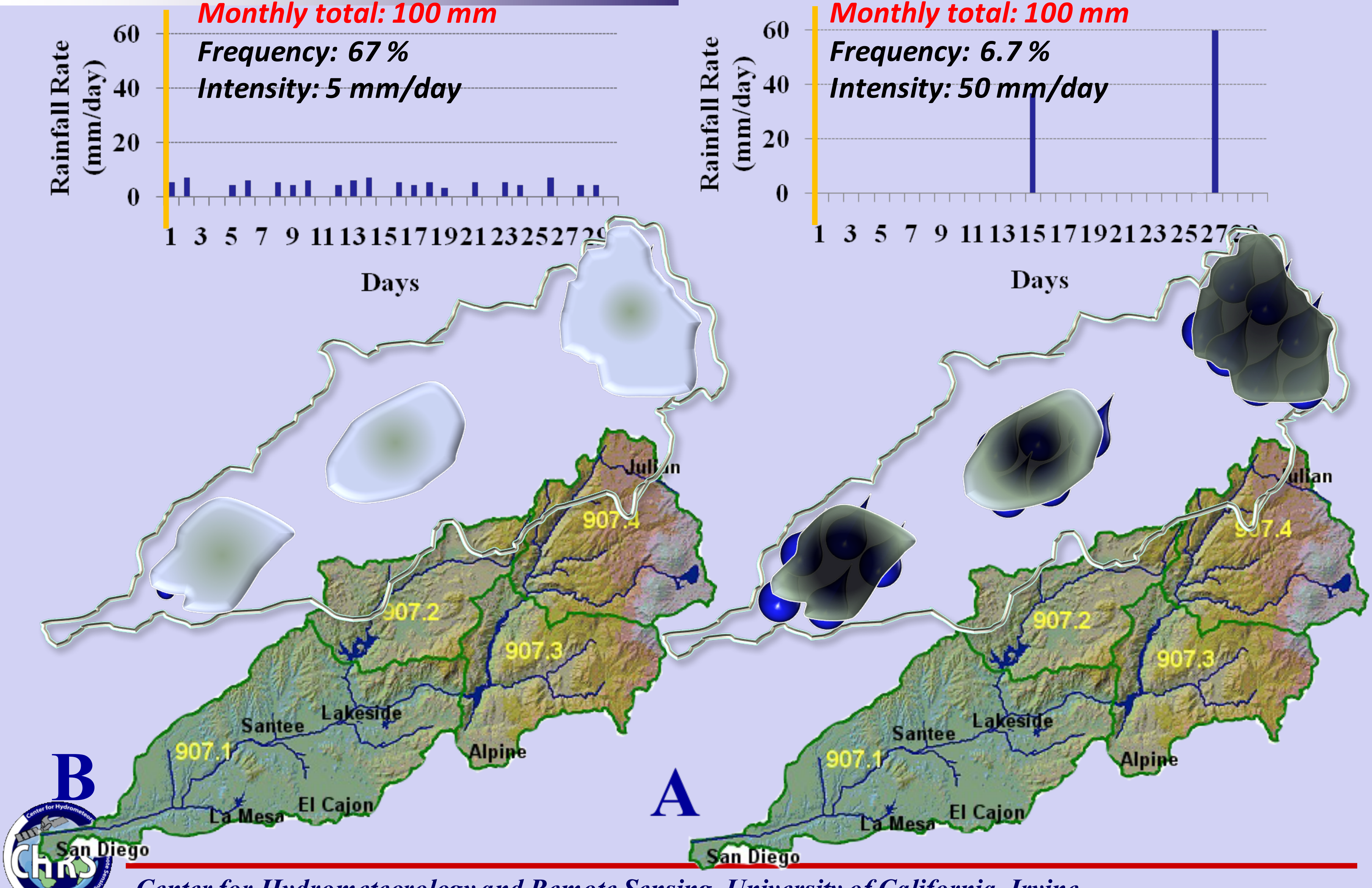
B



100 mm

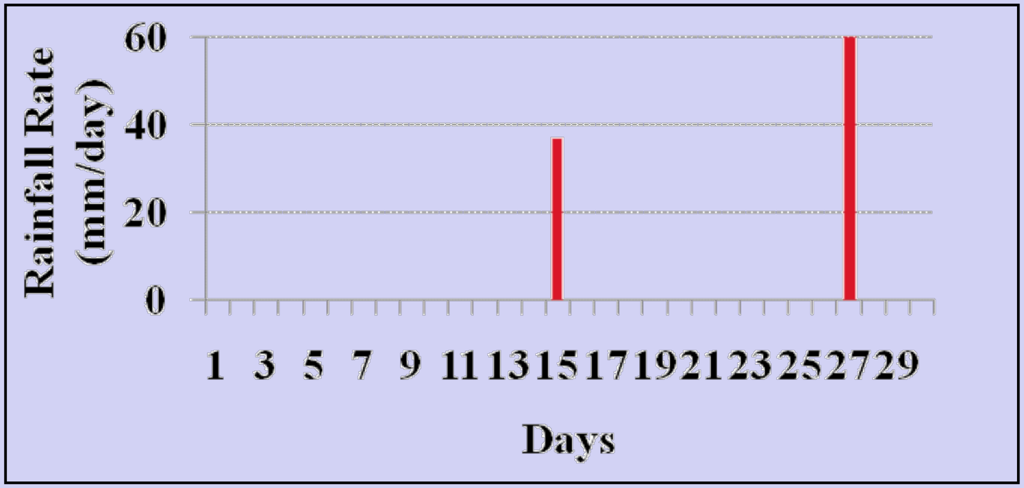
Idea from: K. Trenberth, NCAR

Temporal Scale Importance: *Daily Precip. at 2 stations*



Importance of Temporal Scale : Daily Precip. at 2 stations

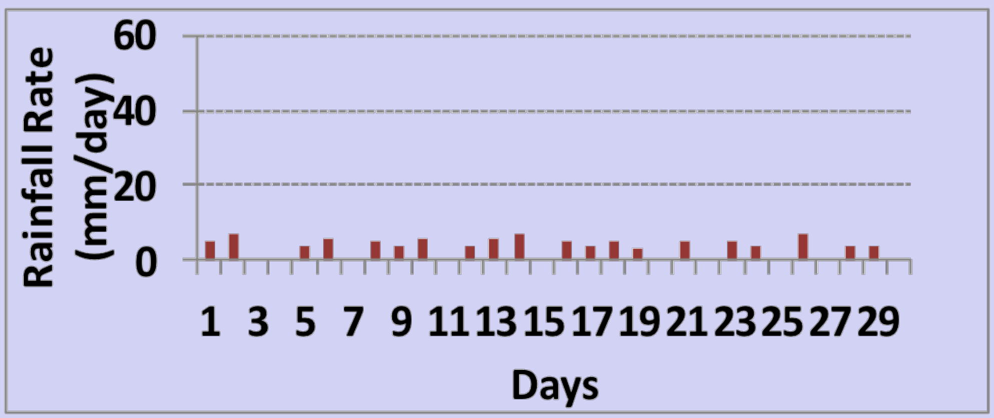
A



Frequency 6.7%
Intensity 50.0 mm

- ***Localized Flooding***
- ***Stream bed Recharge***

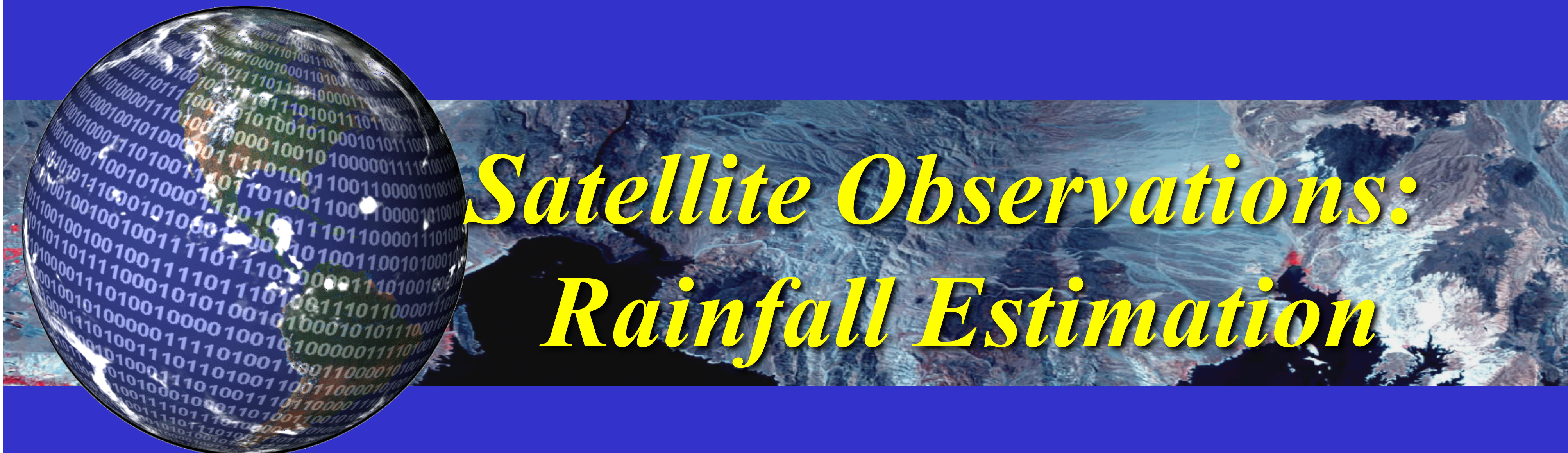
B



Frequency 67%
Intensity 5.0 mm

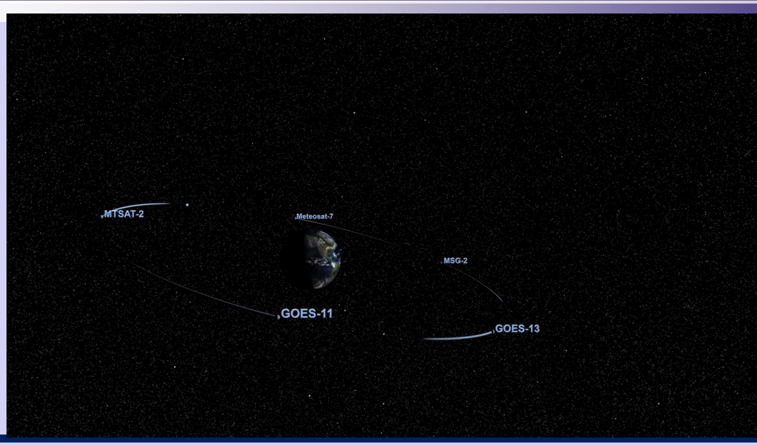
- ***soil moisture replenished***
- ***Little (if any) runoff***

Idea from: K. Trenberth, NCAR

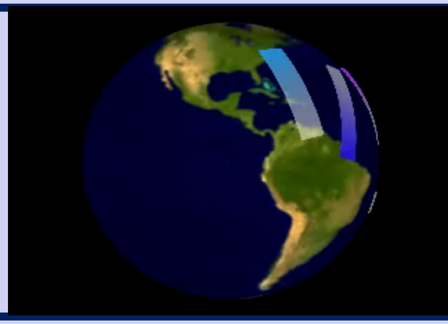


Satellite Observations: Rainfall Estimation

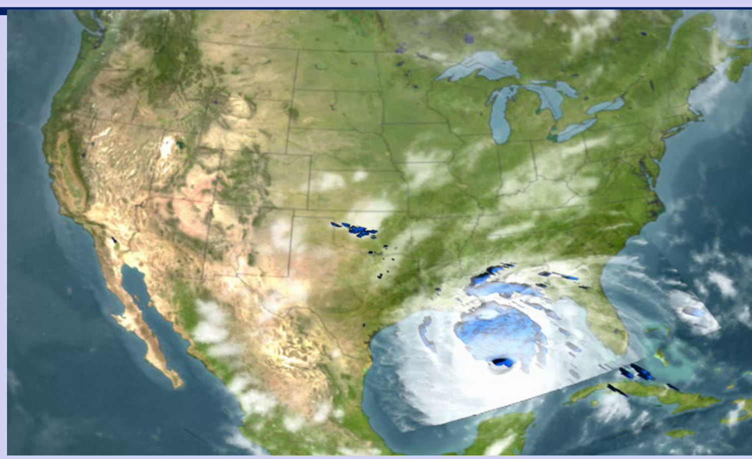
Satellite Data for Precipitation estimation



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)

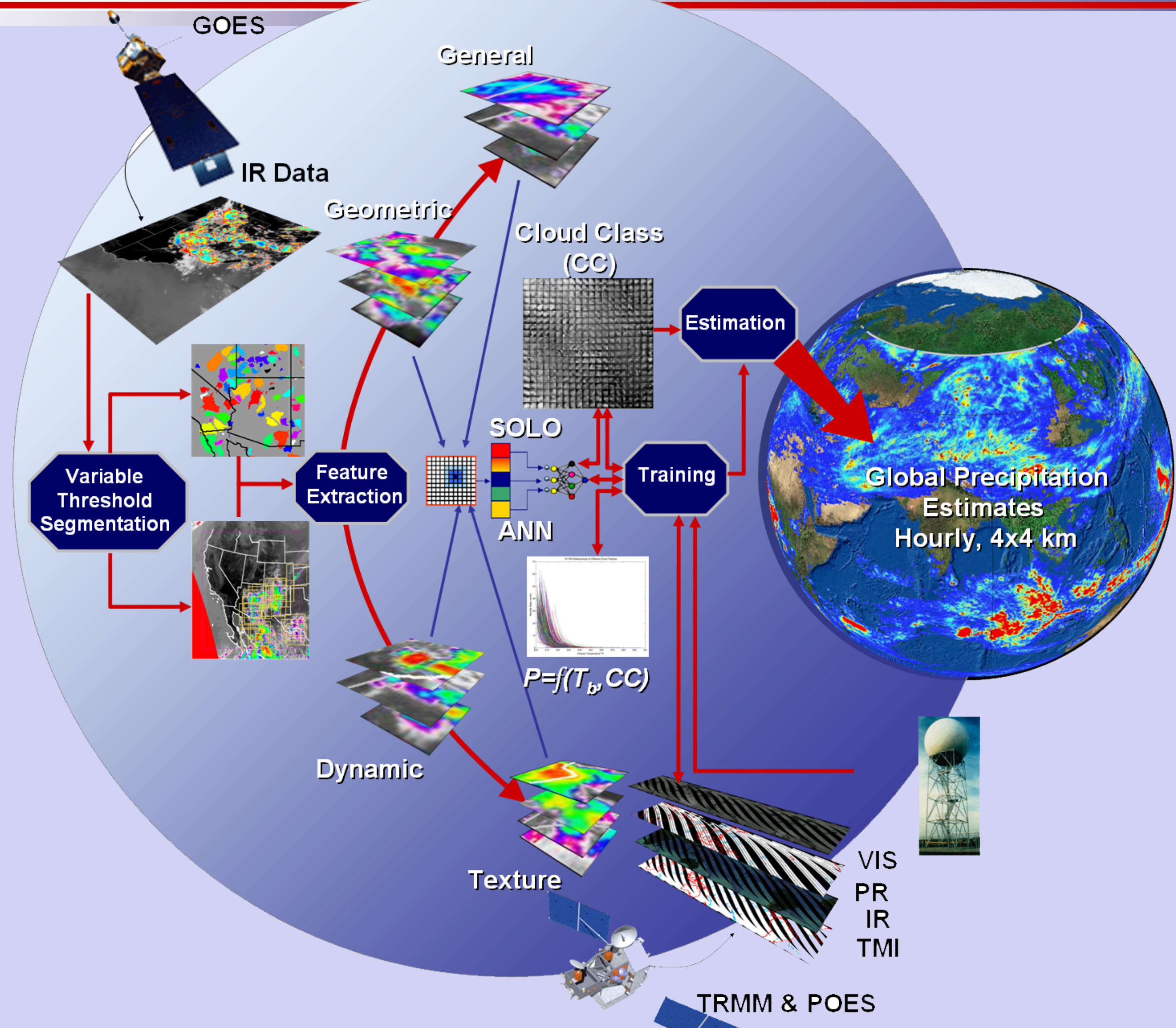


TRMM precipitation RADAR
3D imaging of rainfall
1-2 days between overpasses
(S-35°N-35 °)

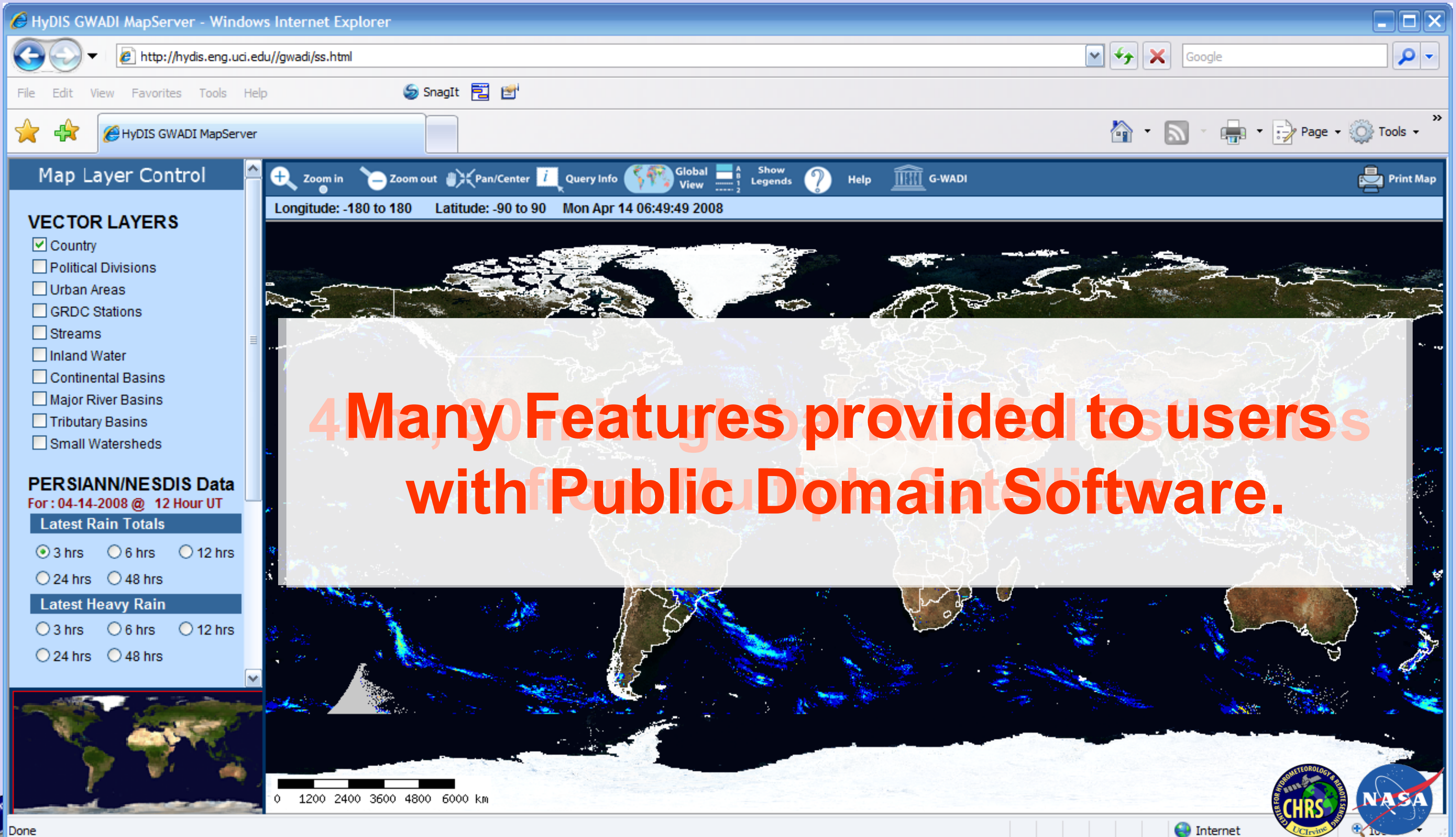
Problems with IR only algorithm

Assumption: *higher cloud → colder → more precipitation*

PERSIANN-CCS (Real-time 4 km)



Real Time Global Data: Cooperation With UNESCO



Many Features provided to users with Public Domain Software.

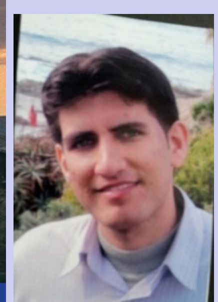
PERSIANN Extensions: Climate-Related

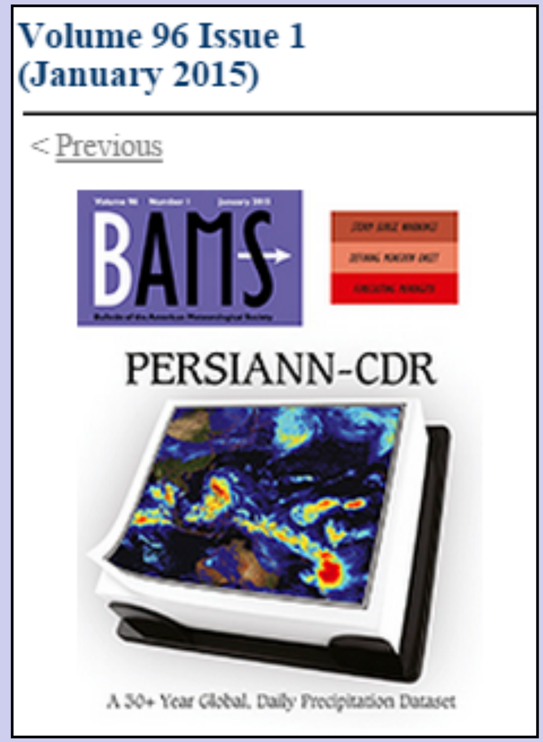
- PERSIANN- CDR (Climate Data Record)

PERSIANN -CDR

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

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



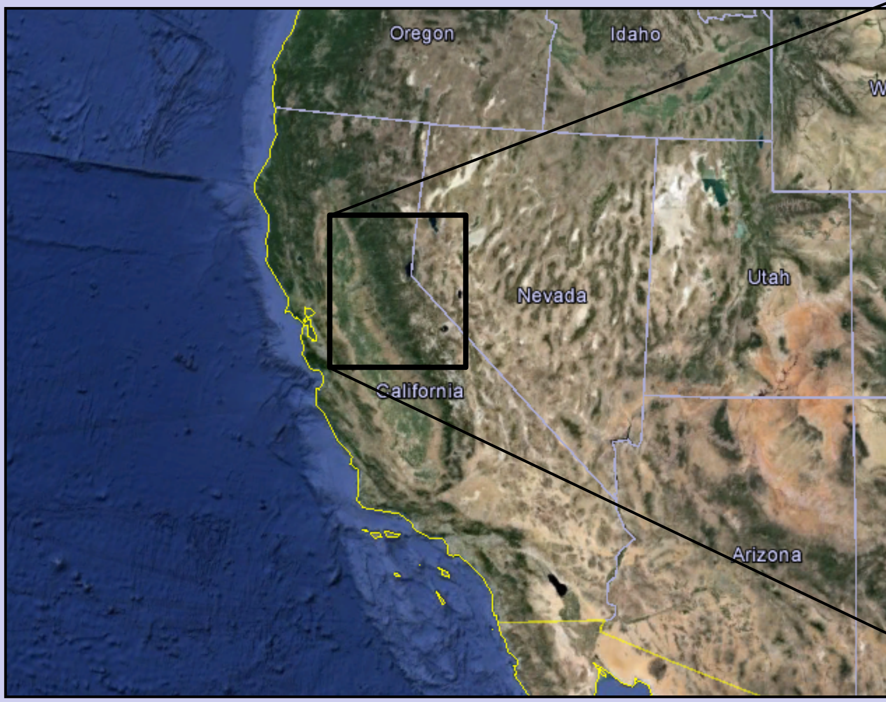


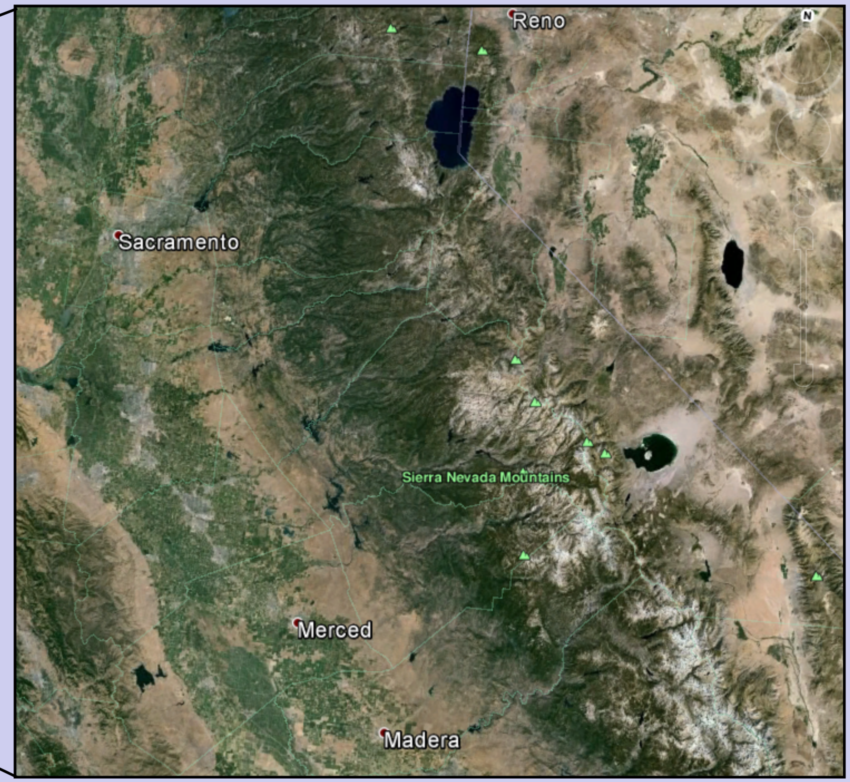
Ashouri, Hsu et al., BAMS, 2015.

Sierra-Nevada Mountain Region

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

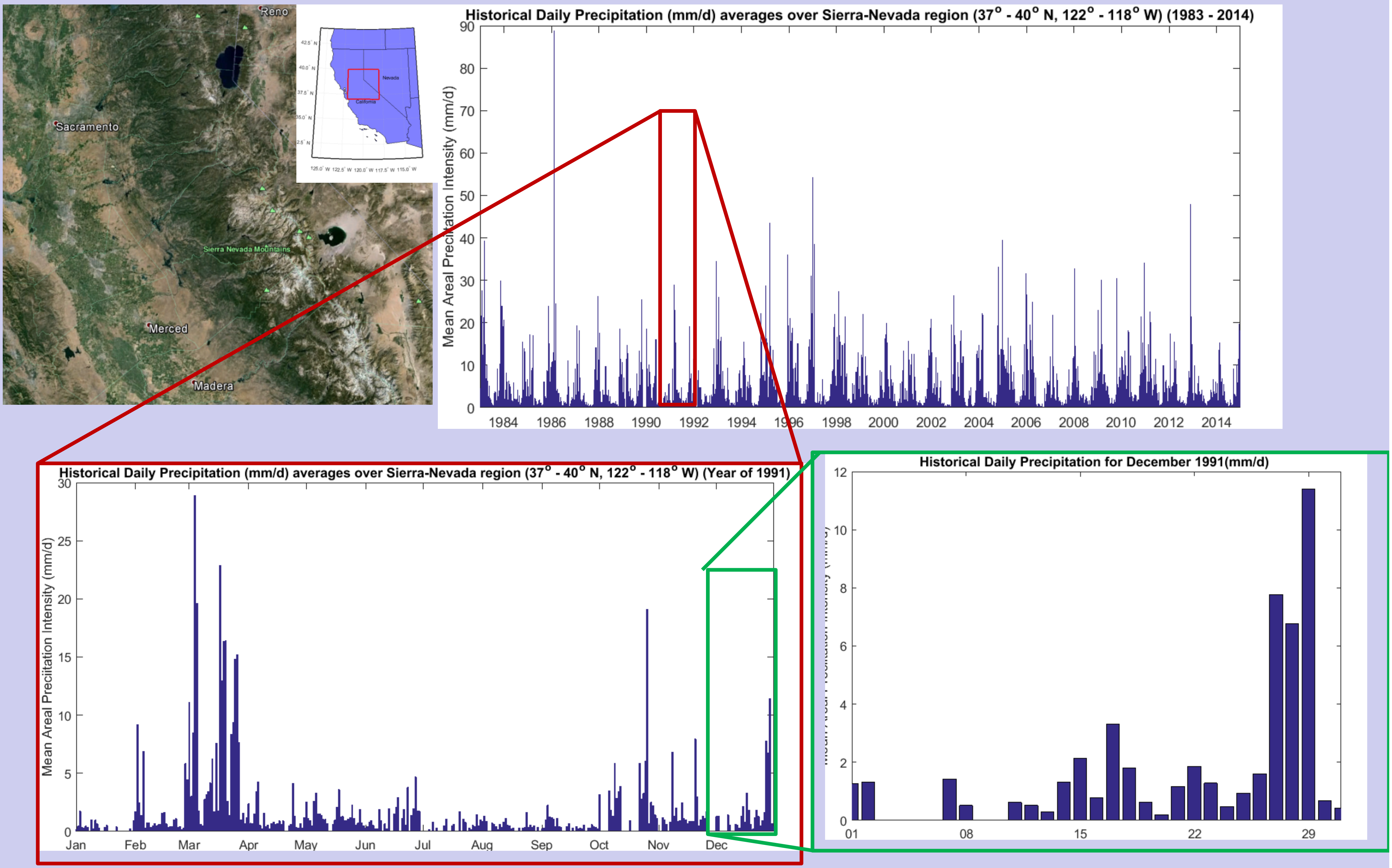
Length: 400 mile, Width: 64 mile.





Map Source: Google Earth

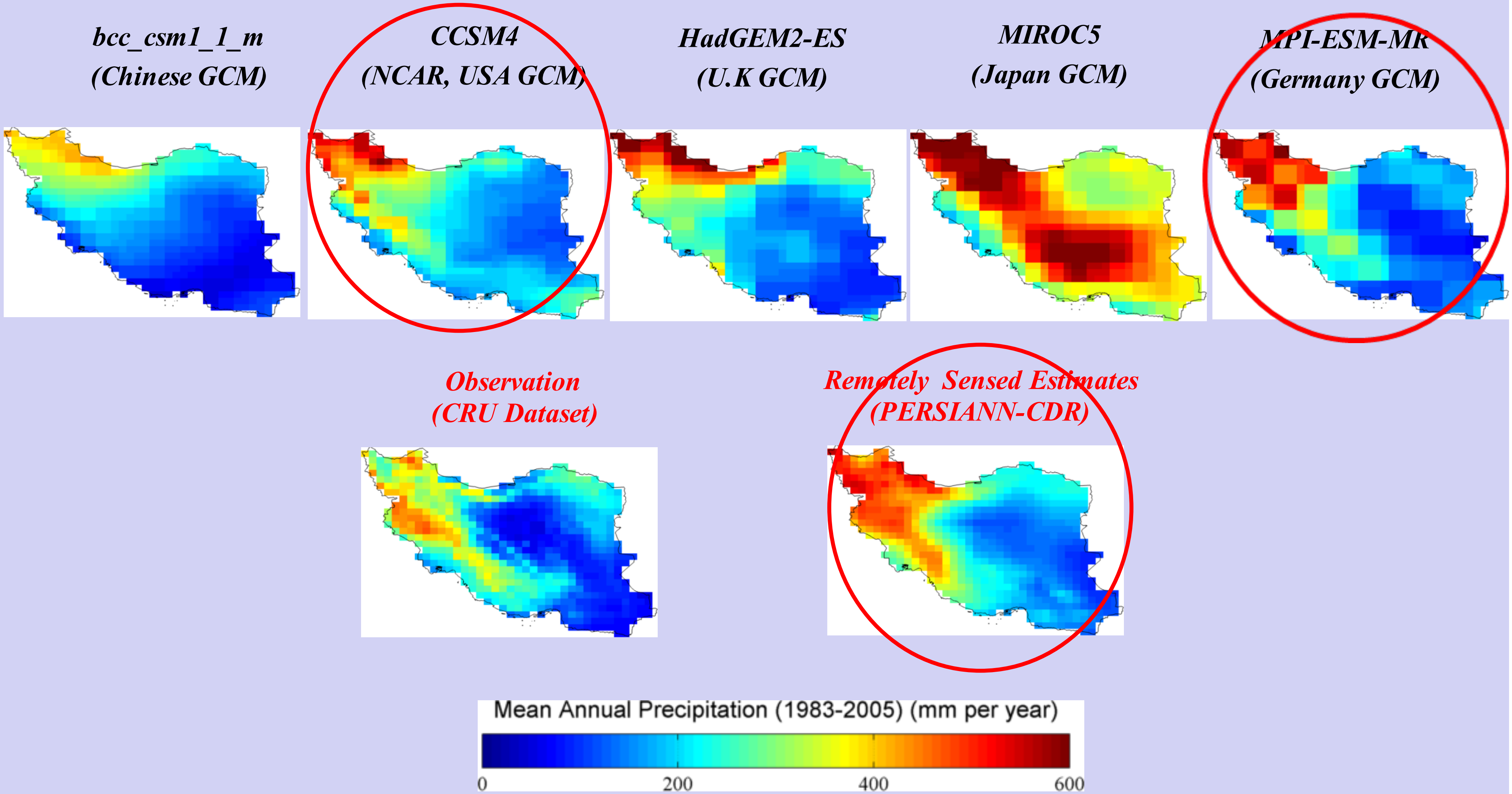
Sierra-Nevada Mountain (California and Nevada)



Hydrologically-Relevant Data

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

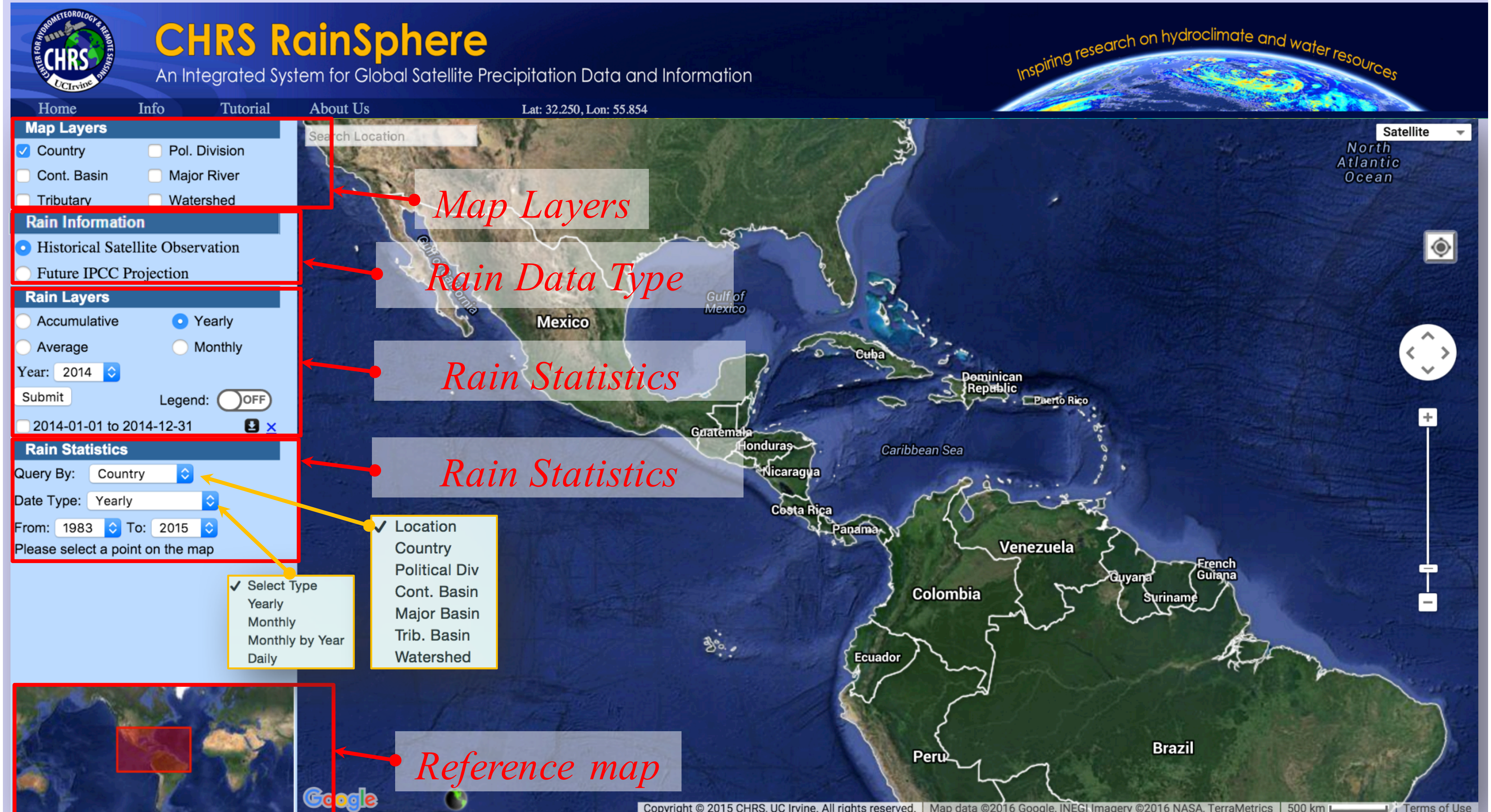
Model historical simulation (1983-2005)



CHRS RainSphere

An Integrated System for Global Satellite Precipitation Data and Information

CHRS RainSphere



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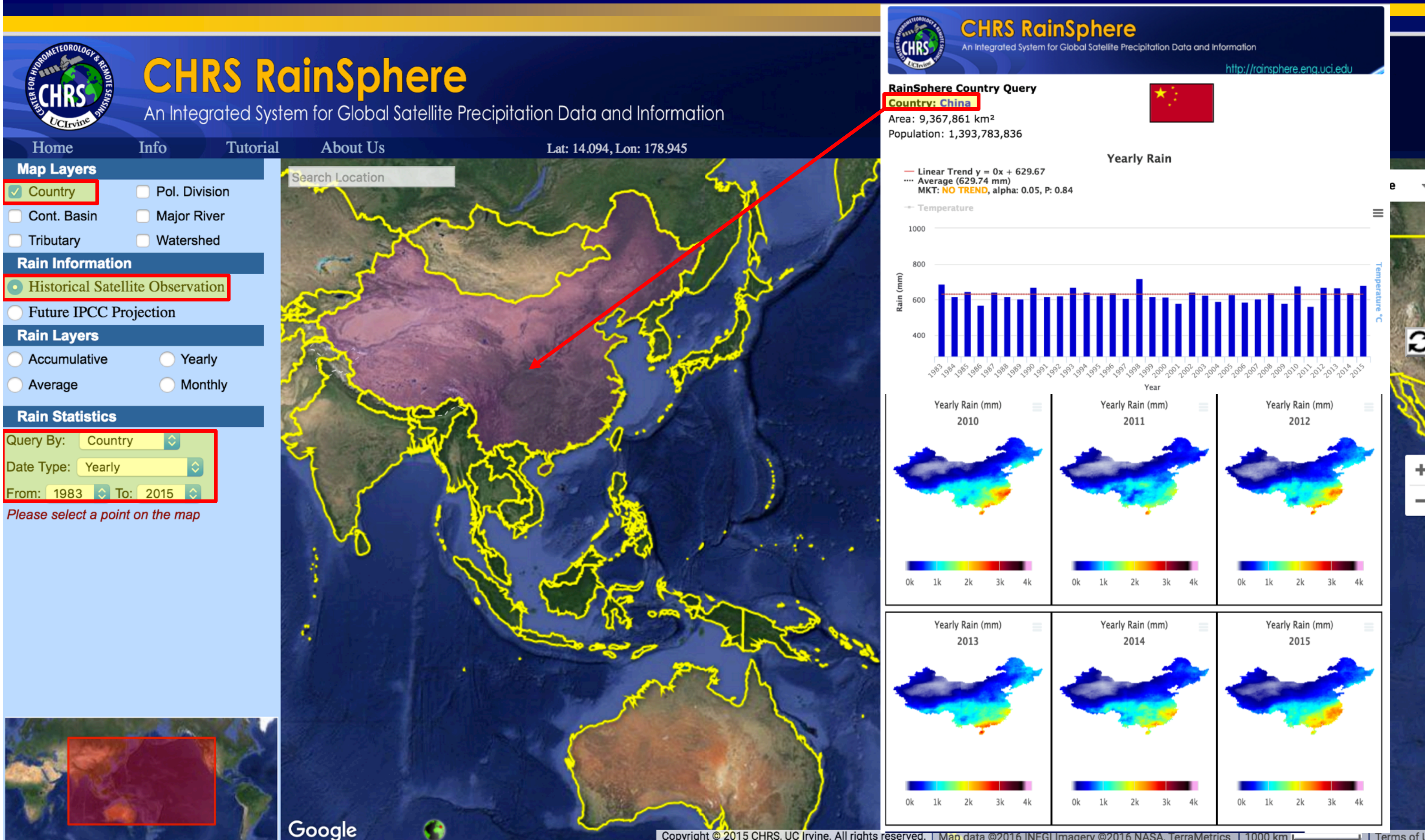
CHRS RainSphere



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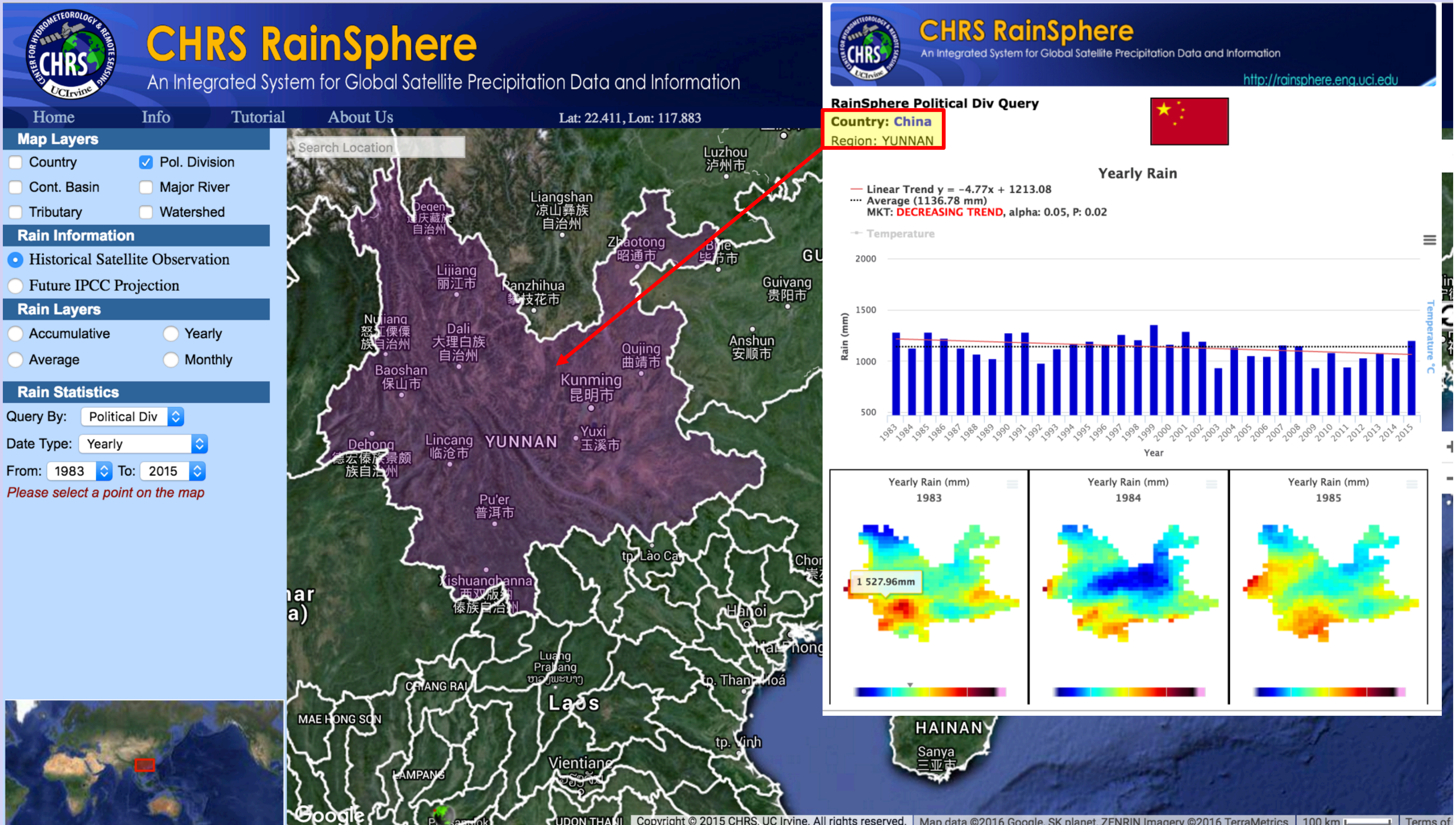

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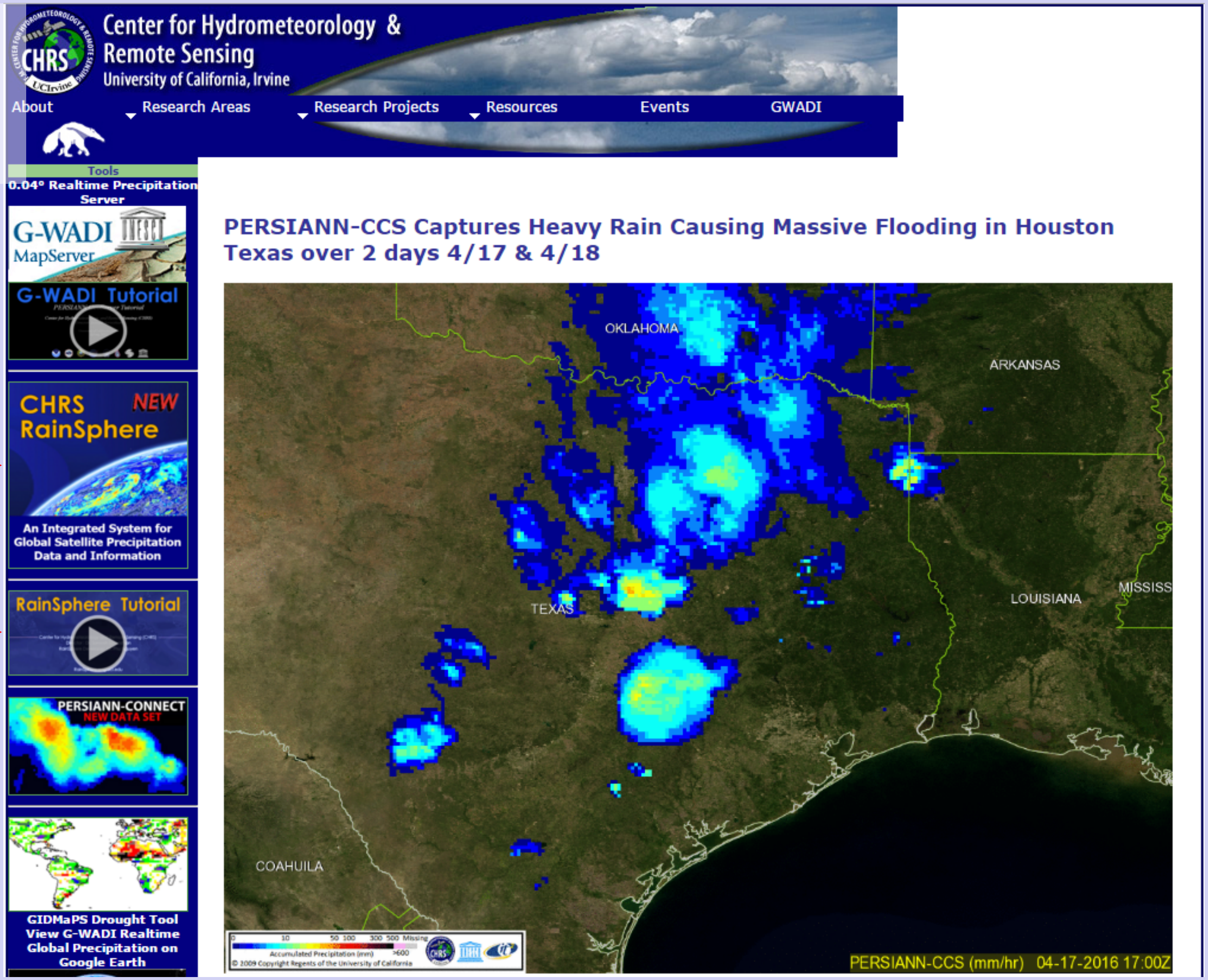
CHRS RainSphere

CHRS home page:
chrs.web.uci.edu

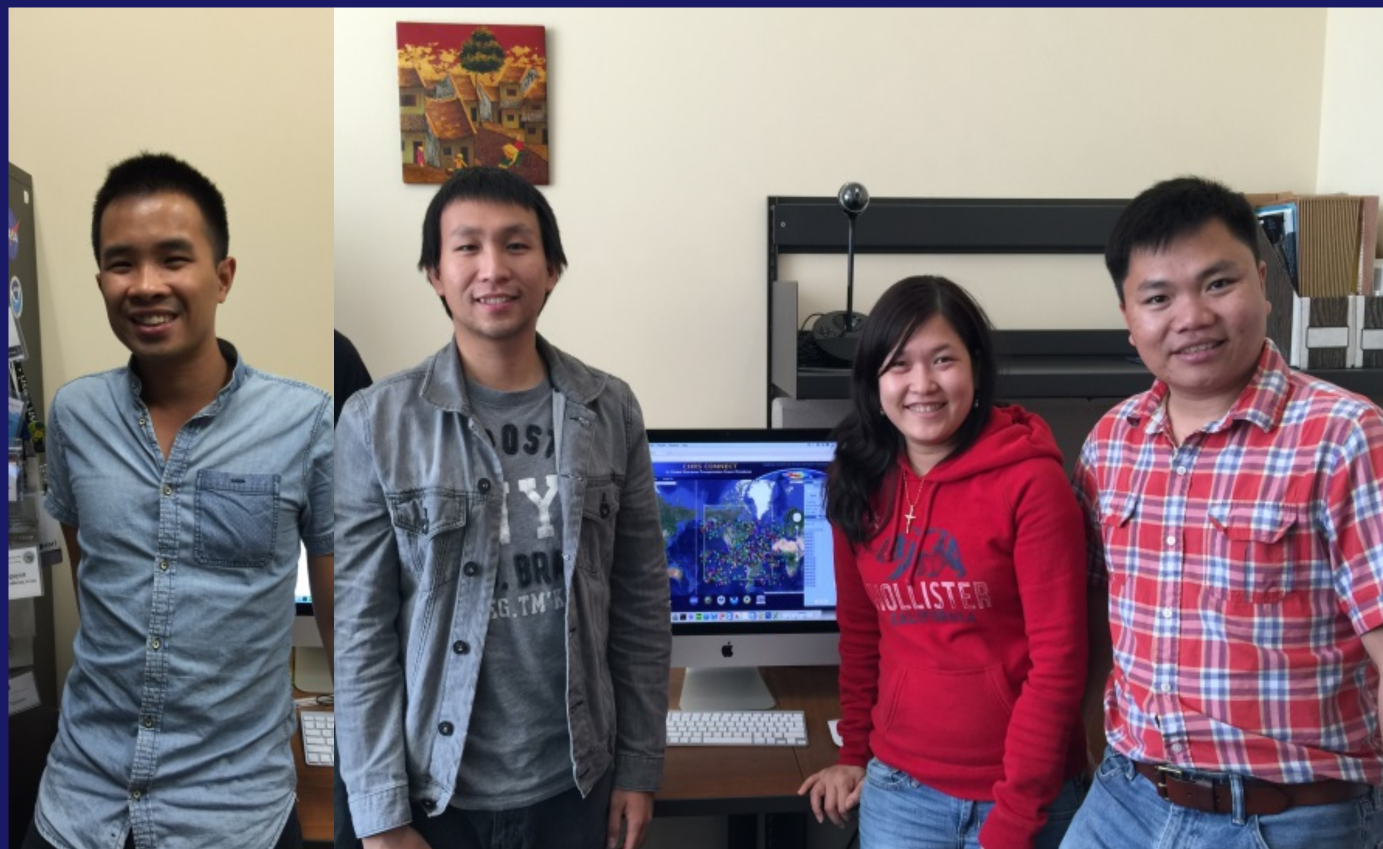


RainSphere →

Tutorial →

CHRS RainSphere Development Team

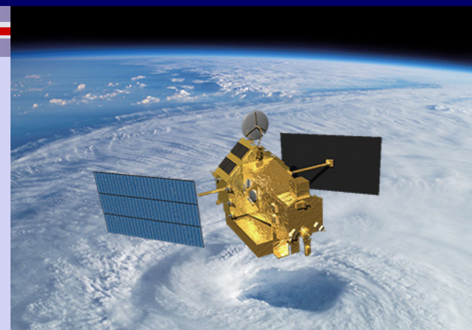
CHRS RainSphere Development Team



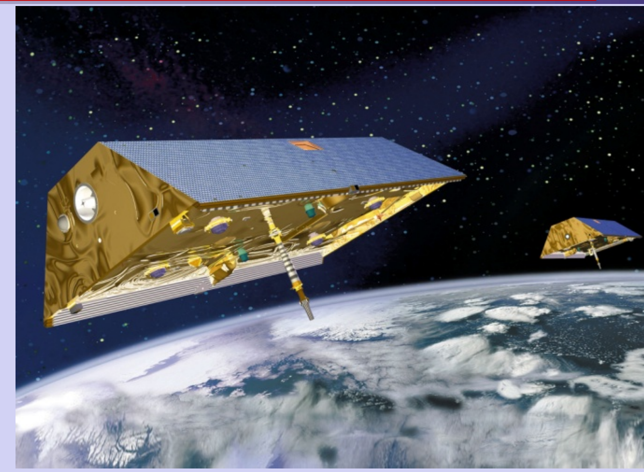
So: What about all the Remote Sensing Observations and Model Generated Data??

Hydrologically - Relevant Remote Sensing Missions

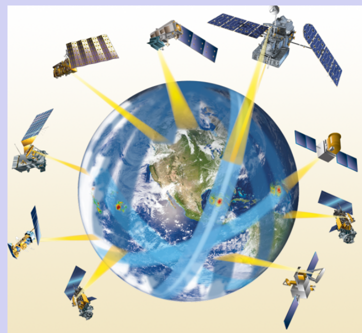
SMOS
ESA's Soil Moisture and Ocean Salinity (2009)



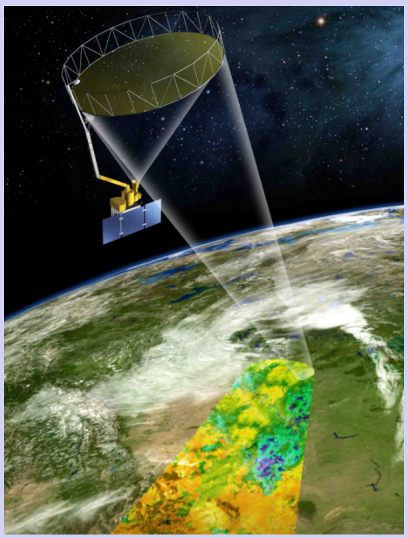
TRMM
The Tropical Rainfall Measuring Mission



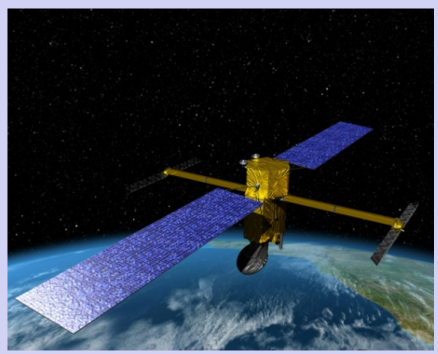
GRACE
Gravity Recovery and Climate Experiment (2002)



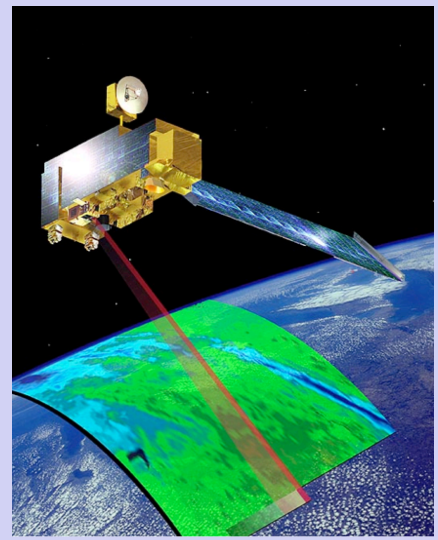
GPM
Global Precipitation Measurements (2014)



SMAP
Soil Moisture Active Passive Satellite(2014)

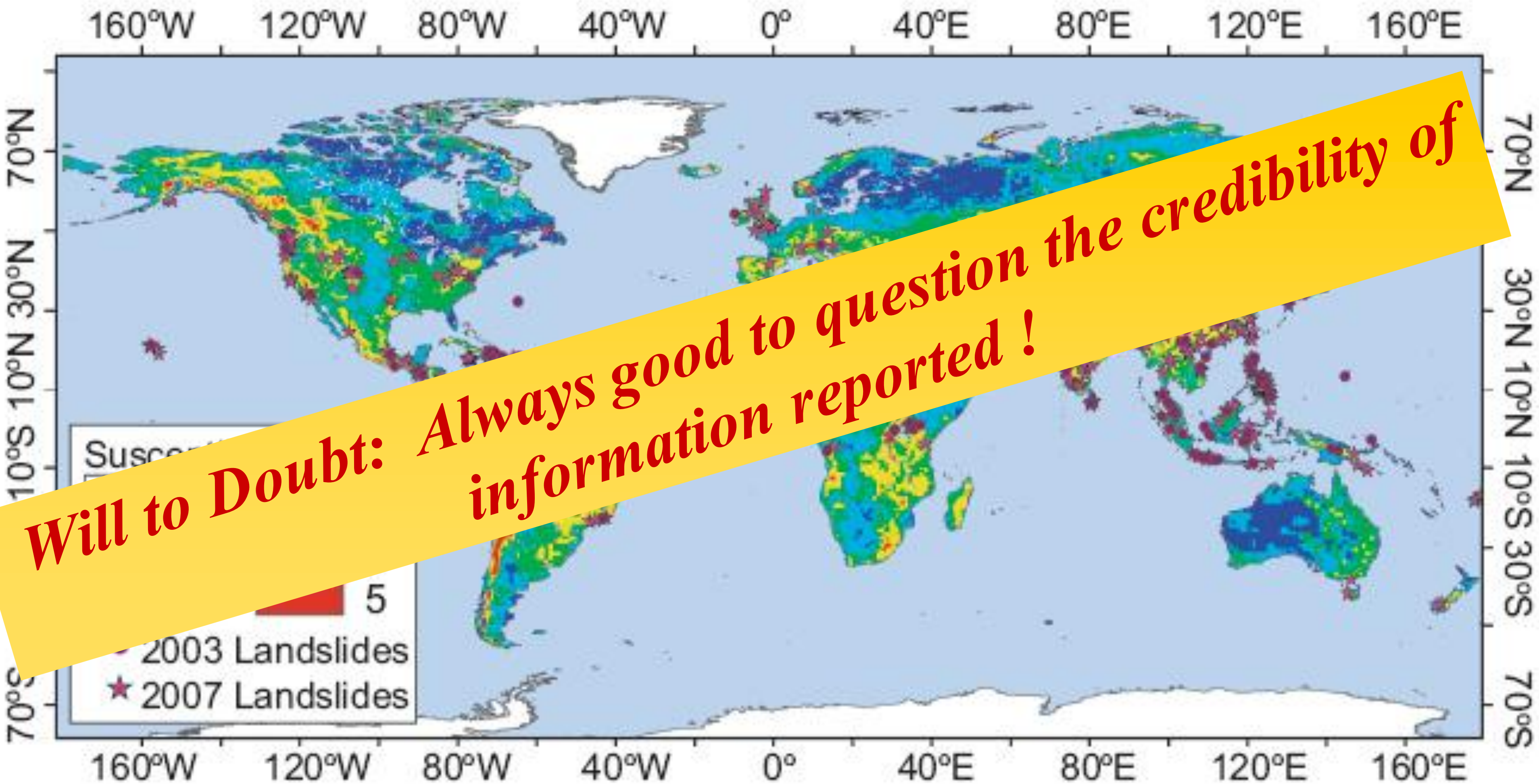


SWOT
Surface Water and Ocean Topography (2020)



MODIS
Moderate Resolution Imaging Spectroradiometer
(1999) , (2002)

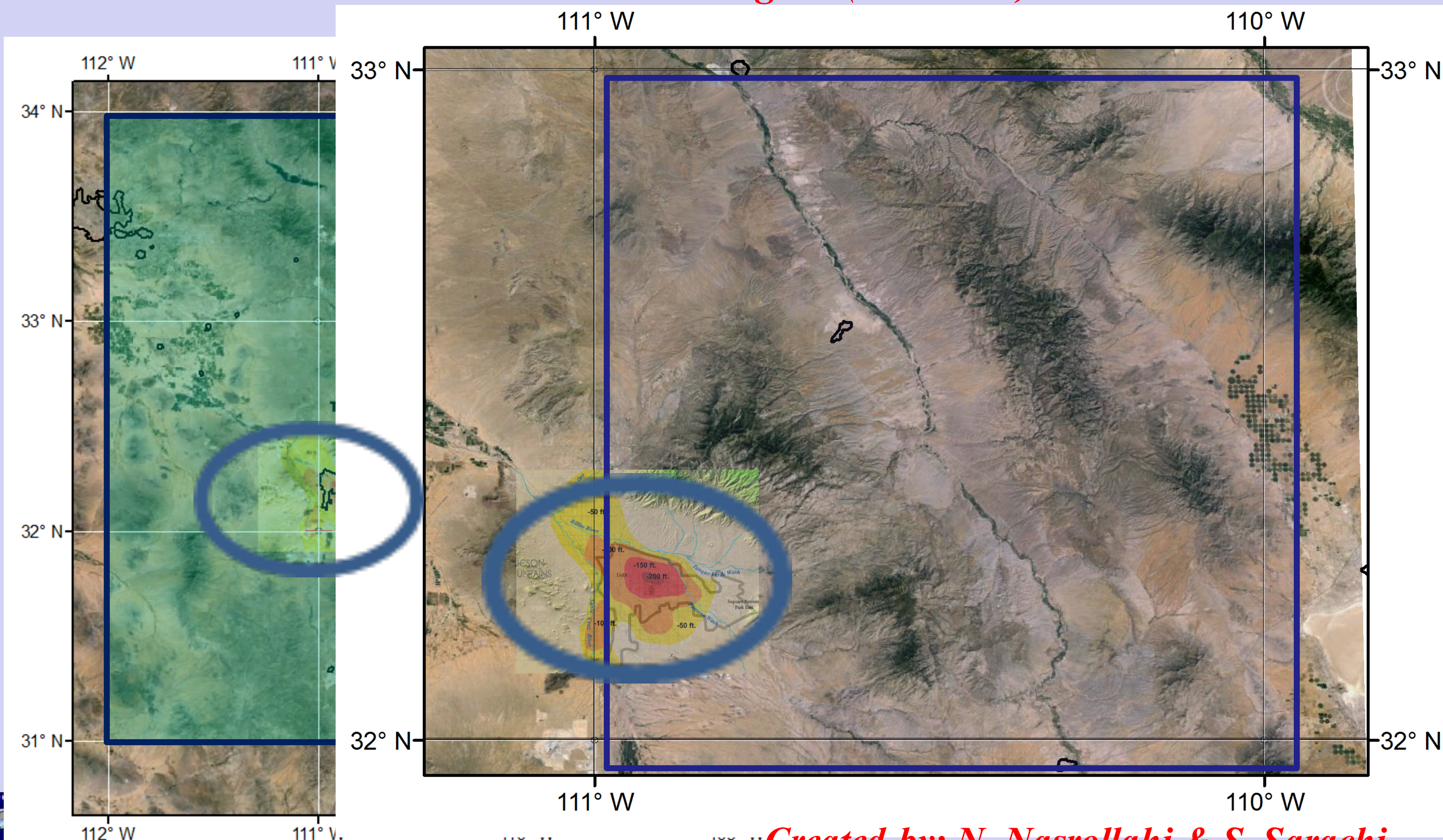
Landslide Risk map:



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

GRACE Satellite Footprint

1 Degree (~100 Km) resolution



Created by: N. Nasrollahi & S. Sarachi

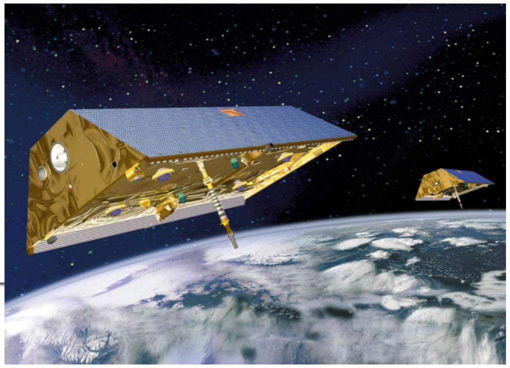
Finally: Recent Reaction to Overblown Stories About Ground Water Detection by Remote Sensing

Groundwater

Technical Commentary/

Bringing GRACE Down to Earth

by William M. Alley[1] and Leonard F. Konikow[2]



GRACE

Gravity Recovery and Climate Experiment (2002)

Introduction

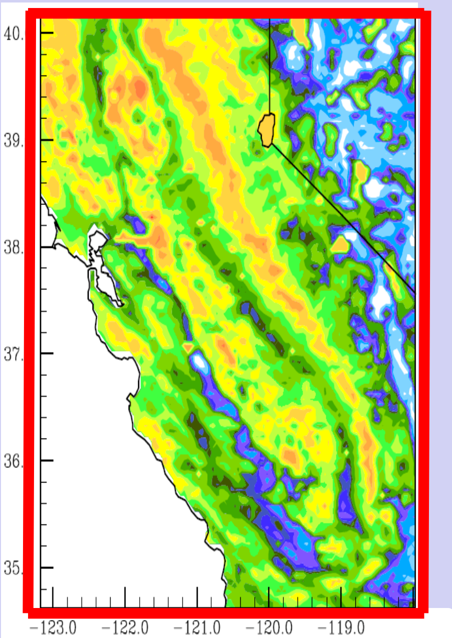
NASA's Gravity Recovery and Climate Experiment (GRACE), which is a joint mission of the United States and Germany, uses a pair of coupled satellites to measure spatial and temporal changes in the Earth's gravity field. From these data, estimates of changes (time-variable anomalies) in mass are derived. In turn, the mass changes are attributed primarily to changes in water content (Tapley et al. 2004; Tiwari et al. 2009; Rodell et al. 2009; Famiglietti and Rodell 2013). Changes in water mass can arise from several hydrologic components, including soil

GRACE Provides a One-Dimensional Indicator of the Status of a Large Three-Dimensional Groundwater Body: It Is Not a Management Tool

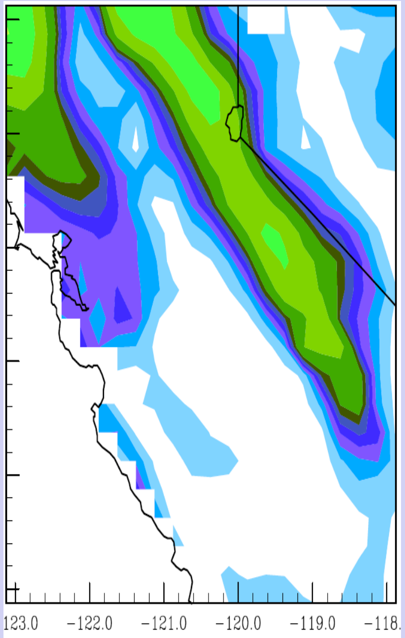
GRACE data provide precise monthly estimates of total change in water storage (accuracy of 1.5 cm equivalent water height) over a large footprint—a resolution on the order of 200,000 km^2 (Famiglietti and Rodell 2013). Many aquifers that play a critical role in meeting human needs, however, occur at scales of 100s or 1000s of km^2, much smaller than the GRACE footprint.

“Observed” vs “Model-Generated” Data

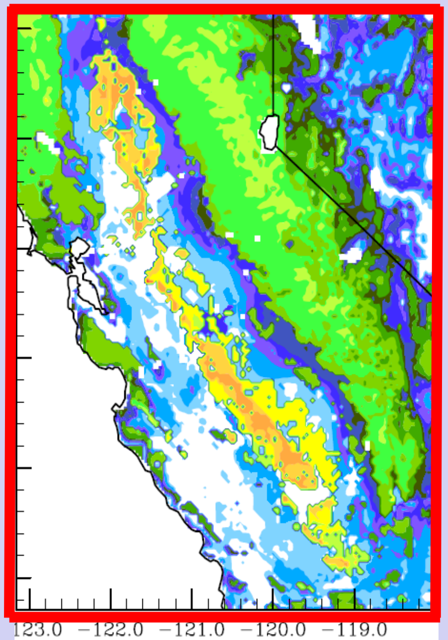
MODIS



GLDAS/Noah

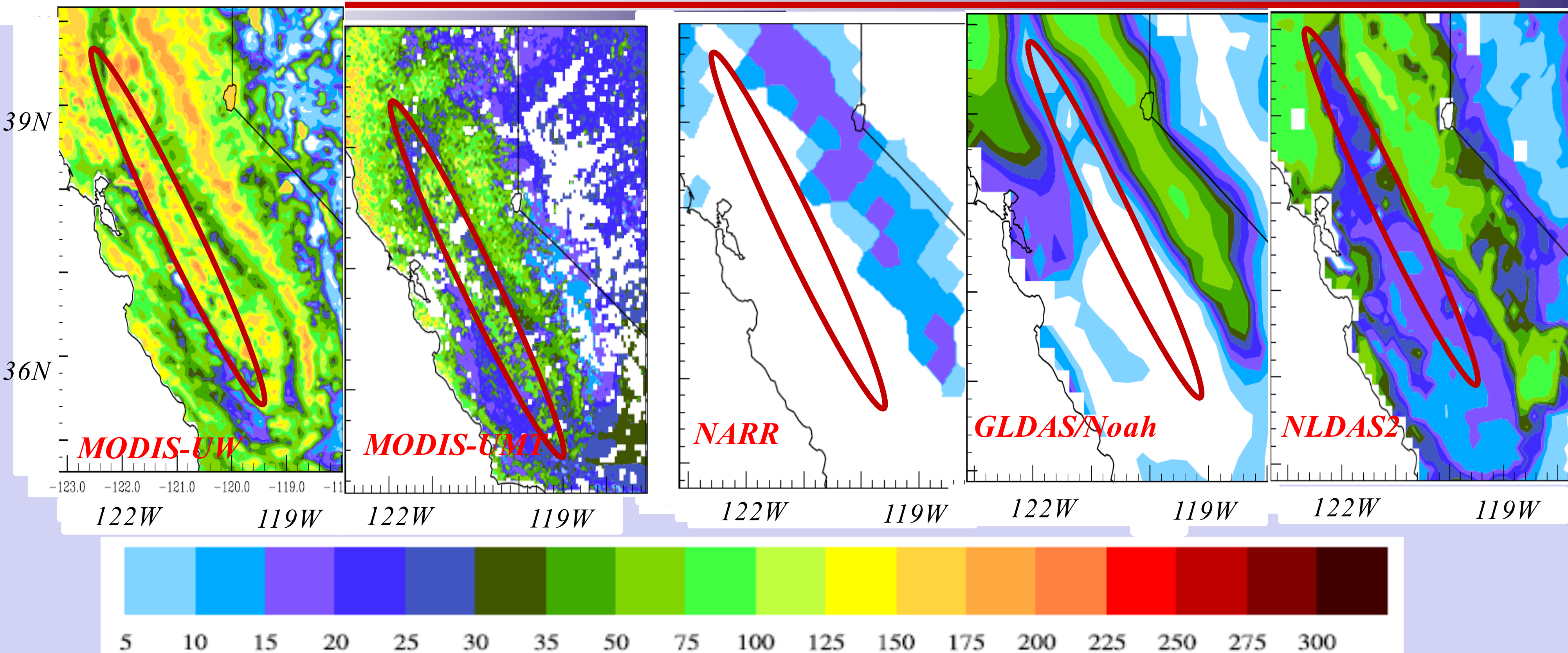


MM5R



Sorooshian et al. 2011, 2012 & 2014

Actual ET Estimates From Different Data sets– JJA 2007



2007 JJA Monthly ET (mm)

An Important Dilemma for the modeling application community will be:

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

Sorooshian et al. 2011, 2012 & 2014

Take Home Message

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

- ***Nature is complex and observing and modeling its***
challenging. So, "have a
will to doubt
"generated" by models.

Factoring in Resiliency in water resources system's design and planning is still the safest approach!

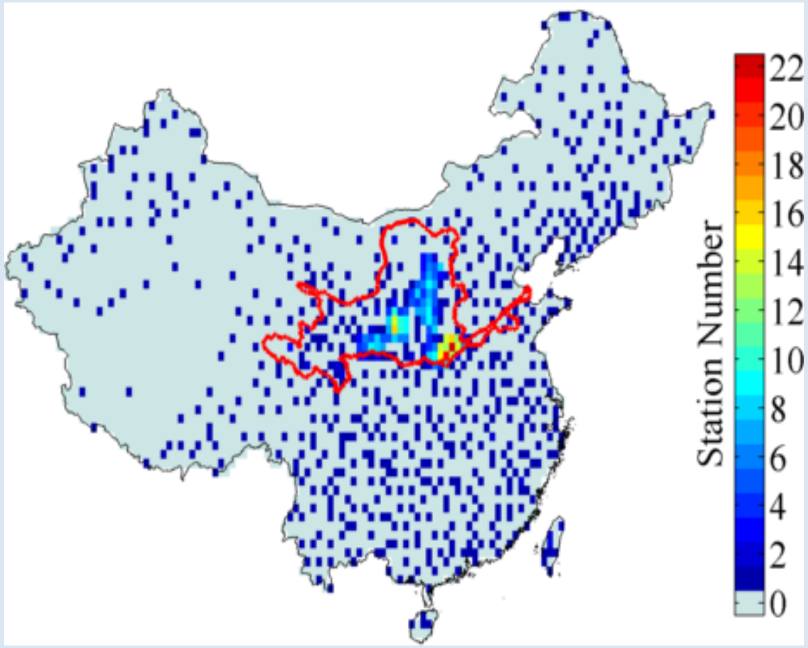
- ***Long-term and sustained observation programs are critical, especially for model verification. Without some degree of verifiability, hard to expect their use***

Thank you for the Invitation

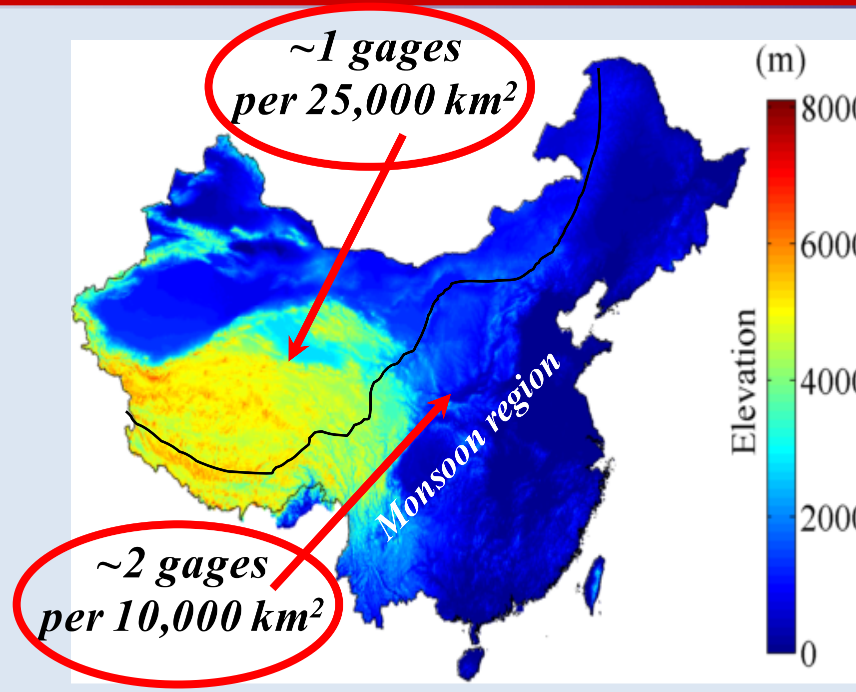
Somewhere in New Mexico, USA - Photo: J. Sorooshian

Back up slides

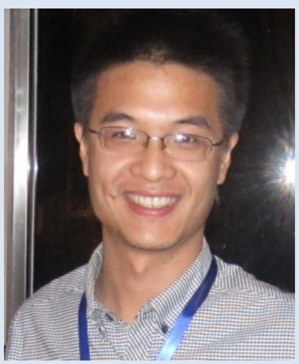
PERSIANN-CDR Evaluation over China



EA Rain Gauge Distribution



Elevation Map



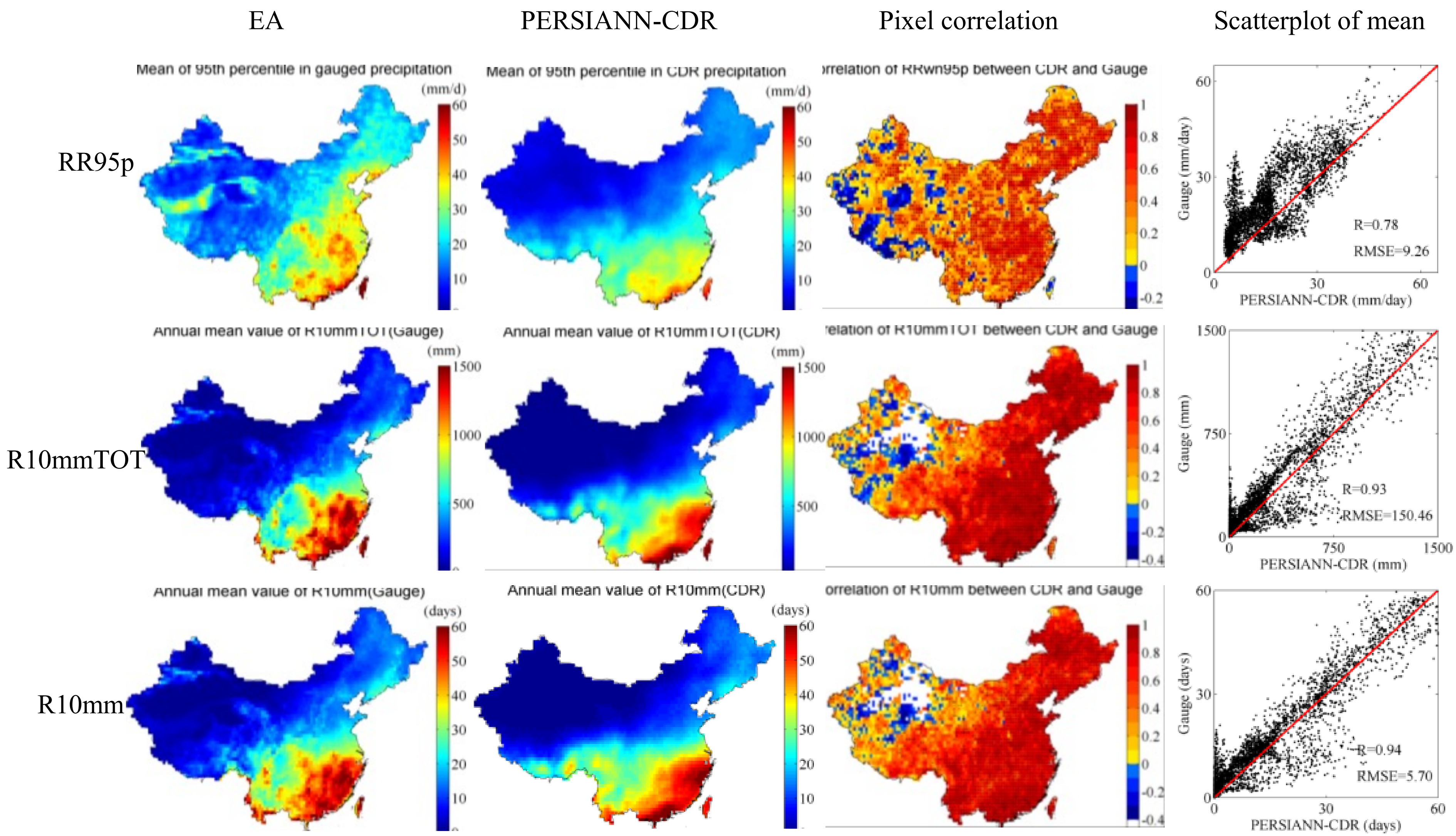
Dr. Chiyuan Miao - BNU

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°)*

Results: Entire China



Recent Evaluation of RCM/GCM over Western U.S.

Wei Chu 2011

Regional Models	Climate Models			
	GFDL	**CGCM3**	**HADCM3**	**CCSM**
CRCM	—		—	—
ECP2		—	—	—
HRM3	—	—		—
MM5I	—	—	—	
RCM3	—		—	—
WRFG	—	—	—	

<u>**Outputs of six RCM/GCM sets:**</u>

North American Regional Climate Change Assessment Program (NARCCAP)

Emissions Scenario:

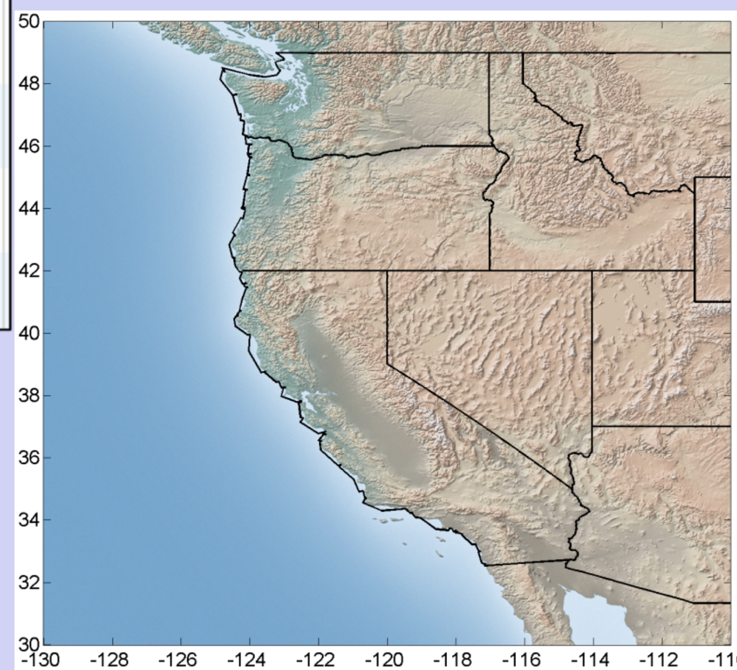
A2: regionally oriented and fast economic growth

Current period: 1971-2000

Future period: 2041-2070

Spatial Res.: 50 km

Temporal Res.: daily



study region

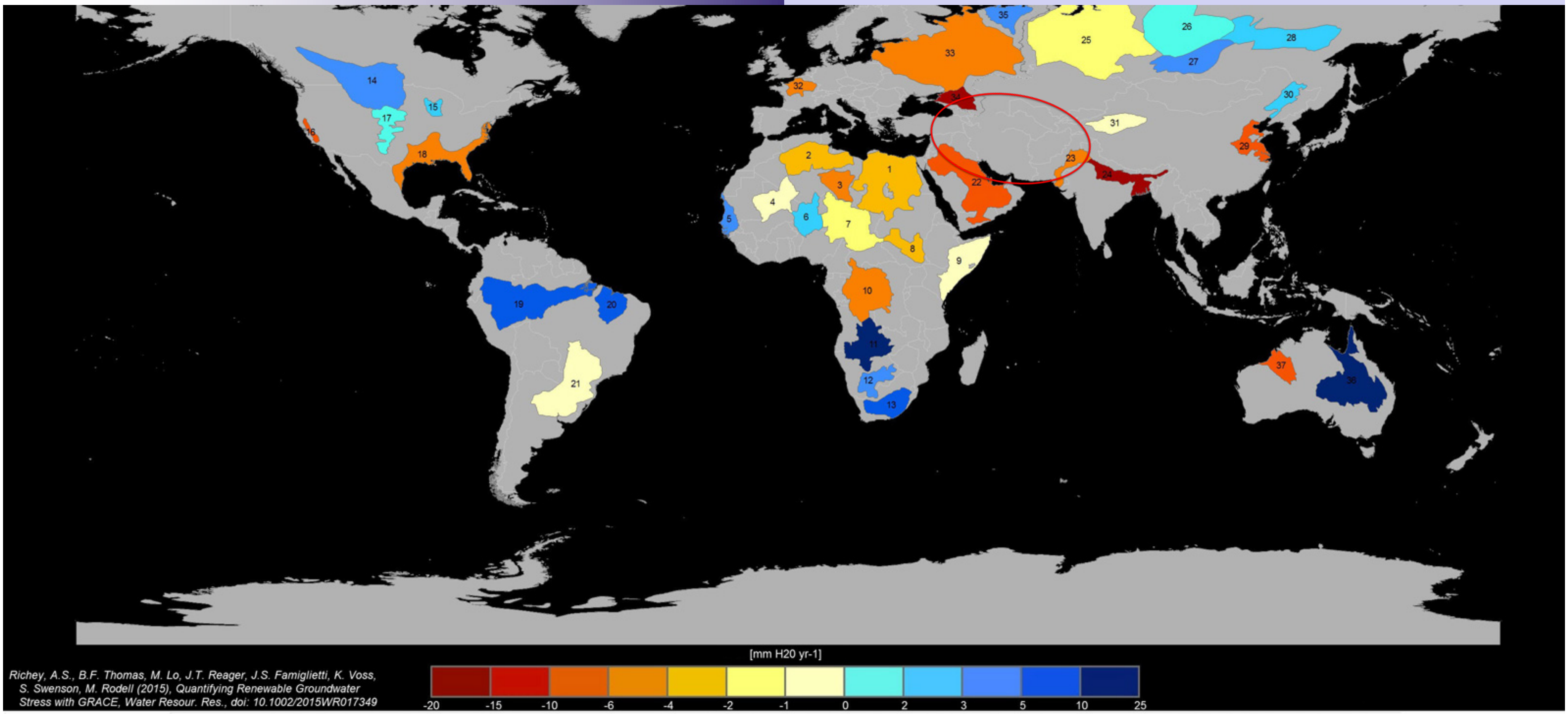
PERSIANN Satellite Product On Google Earth

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

Mobile Devices App:

- *Rain Mapper*
- *Irain*

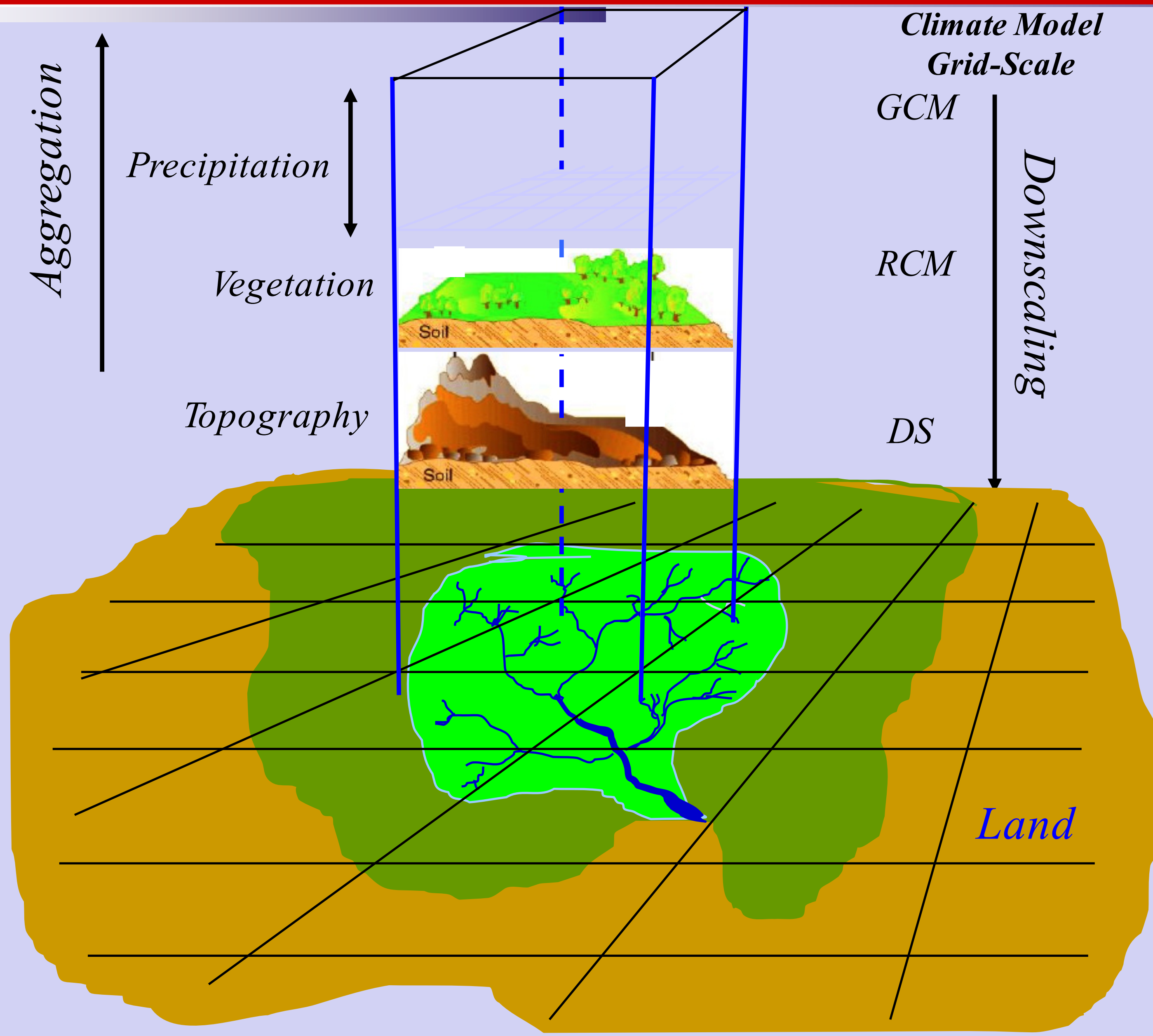
Recent report on Ground Water - GRACE Satellite



1 Nubian Aquifer System (NAS)
2 Northwestern Sahara Aquifer System (NWSAS)
3 Murzuk-Djado Basin
4 Taoudeni-Tanezrouft Basin
5 Senegalo-Mauritanian Basin
6 Iullemeden-Irhazer Aquifer System
7 Lake Chad Basin
8 Sudd Basin (Umm Ruwaba Aquifer)
9 Ogaden-Juba Basin
10 Congo Basin
11 Upper Kalahari-Cuvelai-Upper Zambezi Basin
12 Lower Kalahari-Stampriet Basin
13 Karoo Basin
14 Northern Great Plains Aquifer
15 Cambro-Ordovician Aquifer System
16 Californian Central Valley Aquifer System
17 Ogallala Aquifer (High Plains)
18 Atlantic and Gulf Coastal Plains Aquifer
19 Amazon Basin
20 Maranhao Basin
21 Guarani Aquifer System
22 Arabian Aquifer System
23 Indus Basin
24 Ganges-Brahmaputra Basin
25 West Siberian Basin
26 Tunguss Basin
27 Angara-Lena Basin
28 Yakut Basin
29 North China Aquifer System
30 Song-Liao Basin
31 Tarim Basin
32 Paris Basin
33 Russian Platform Basins
34 North Caucasus Basin
35 Pechora Basin
36 Great Artesian Basin
37 Canning Basin

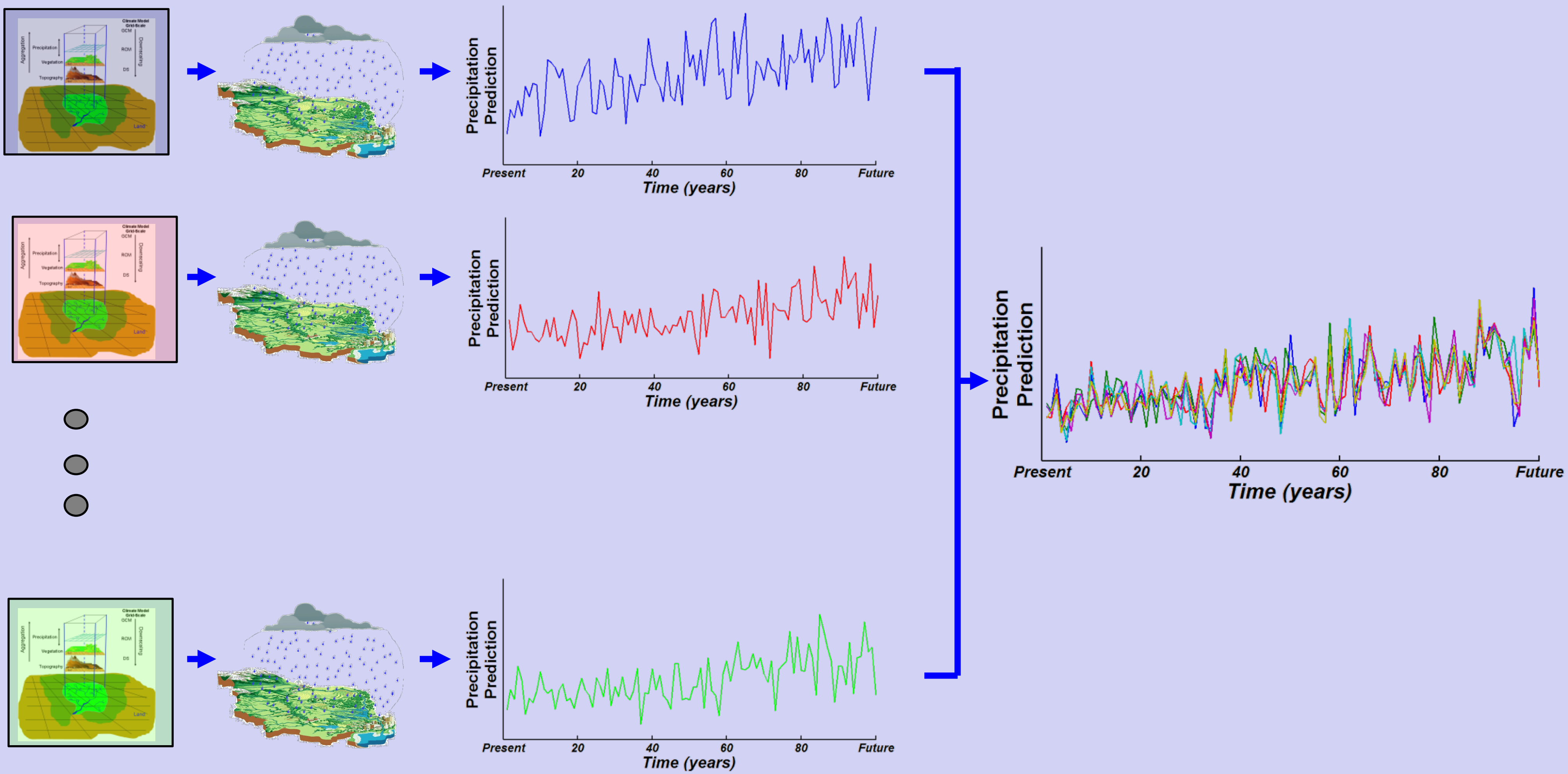
Richey et al: WRR 2015

Climate Model Downscaling to regional/watershed Scale



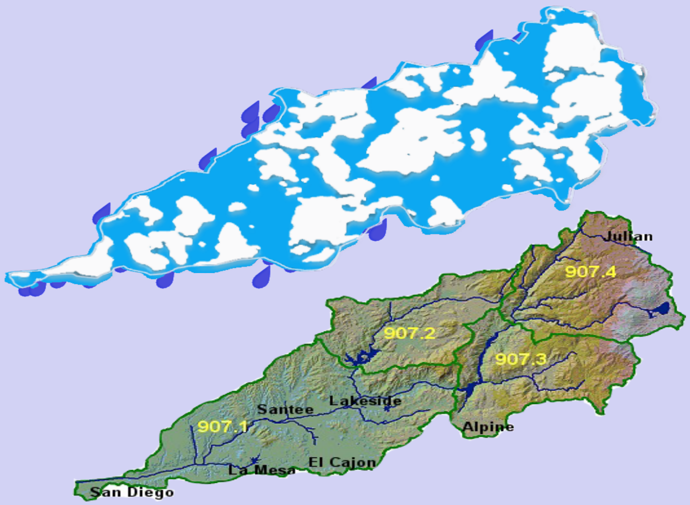
Ensemble Approach

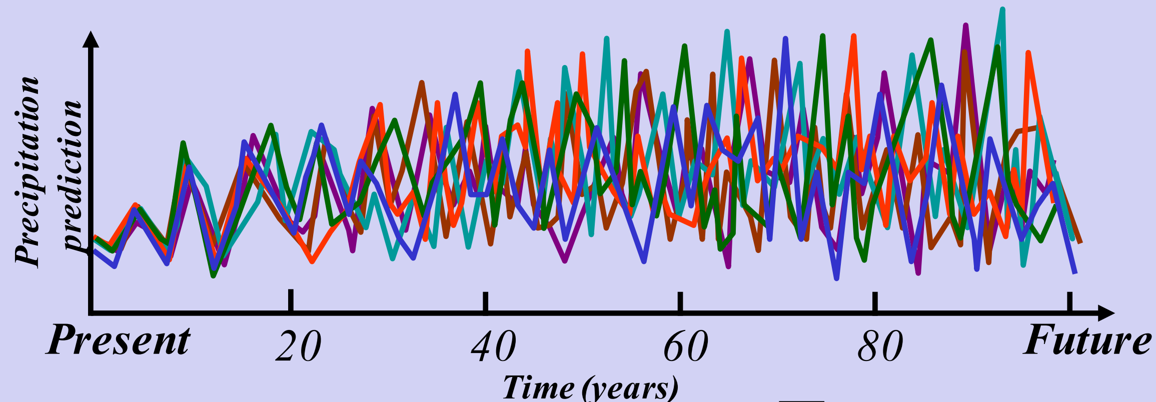
Generation of Future Precipitation Scenarios

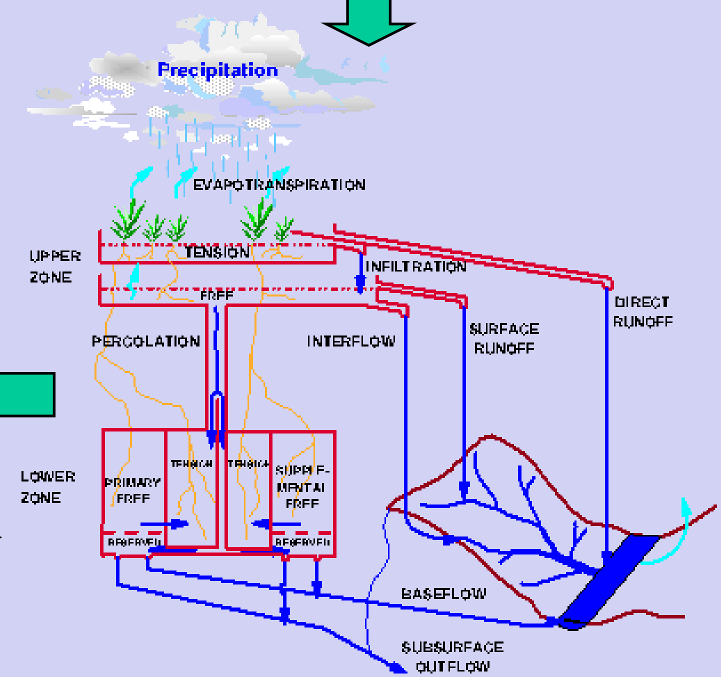


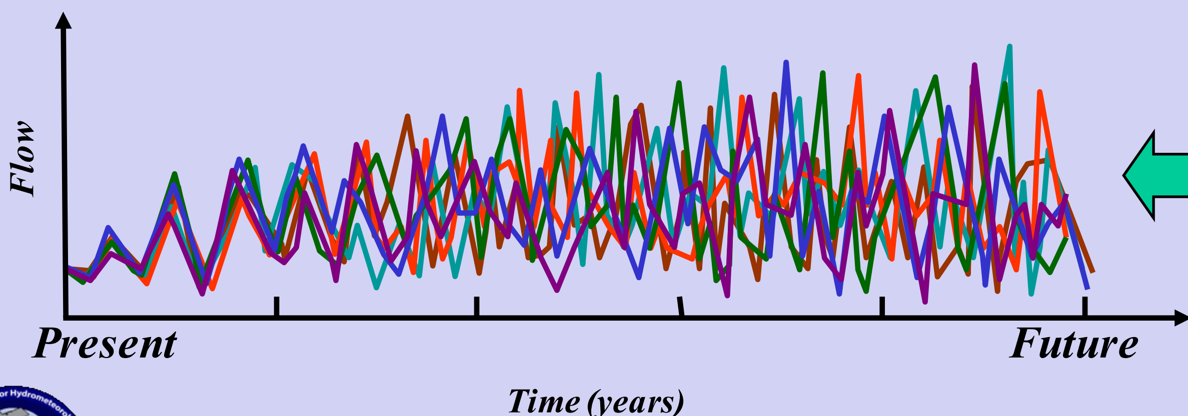
Downscaled Precipitation to Runoff Generation

Generation of Future Runoff Scenarios

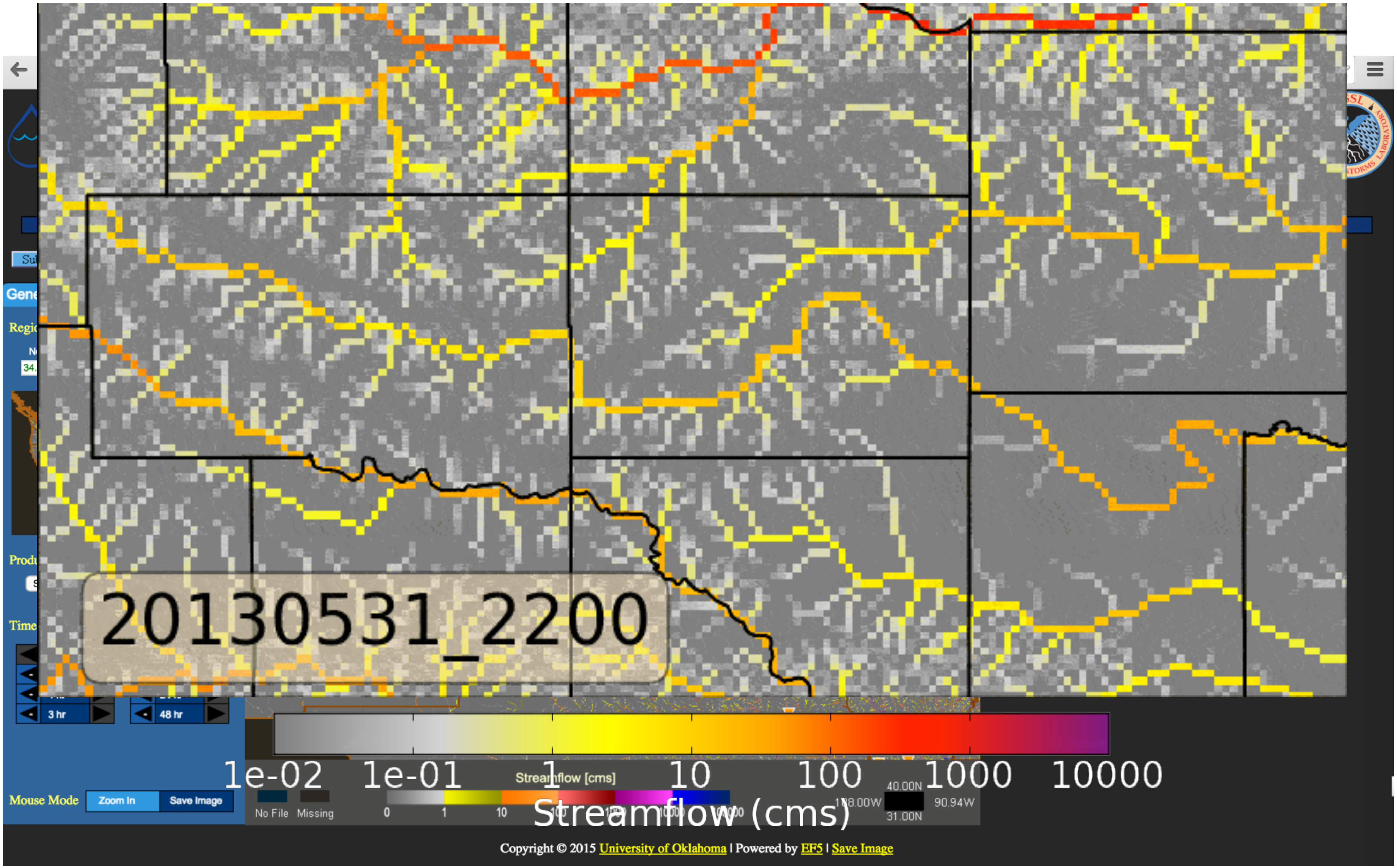








EF5 – Oklahoma Univesity (http://flash.ou.edu)



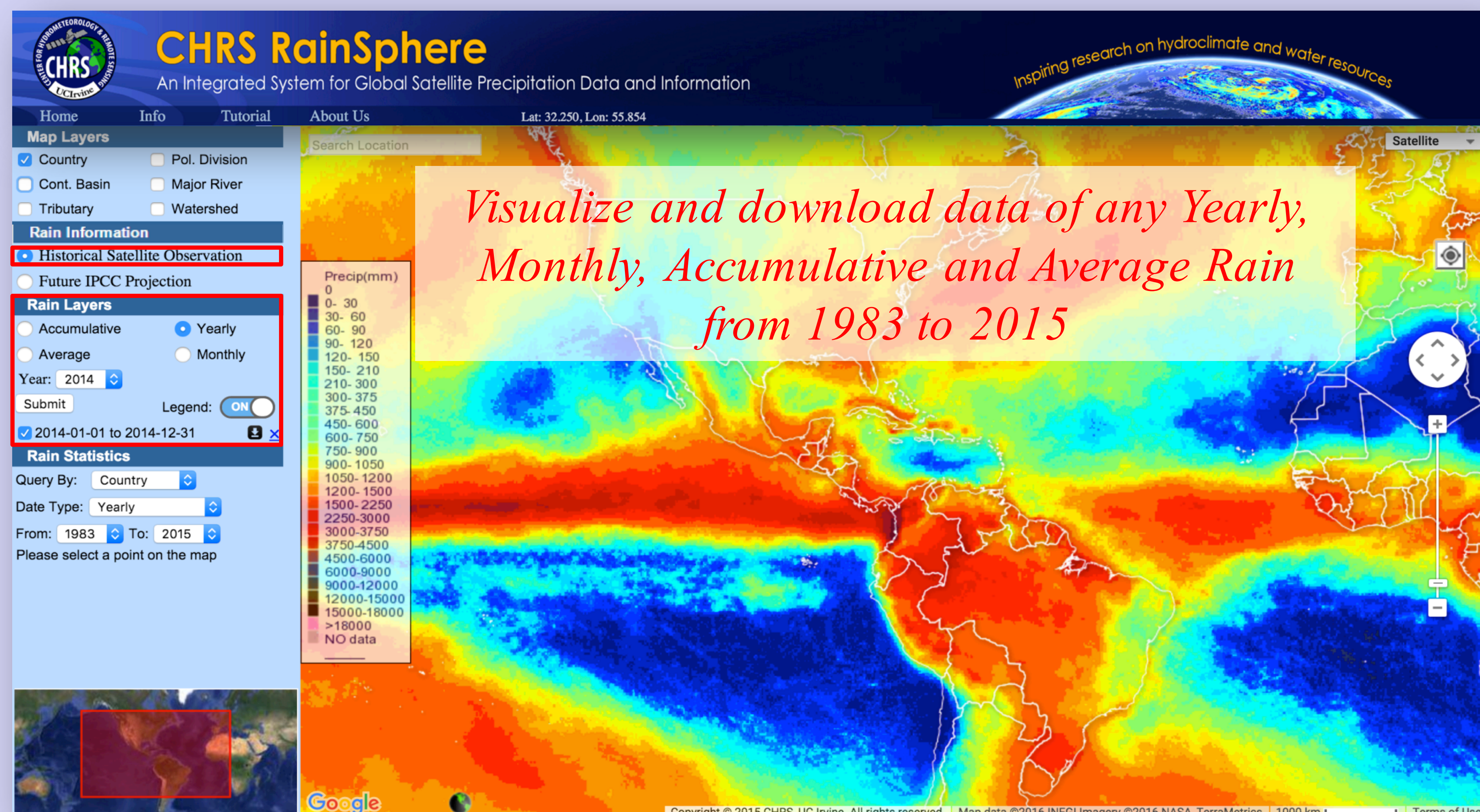
Evaluation Indices

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

CHRS RainSphere

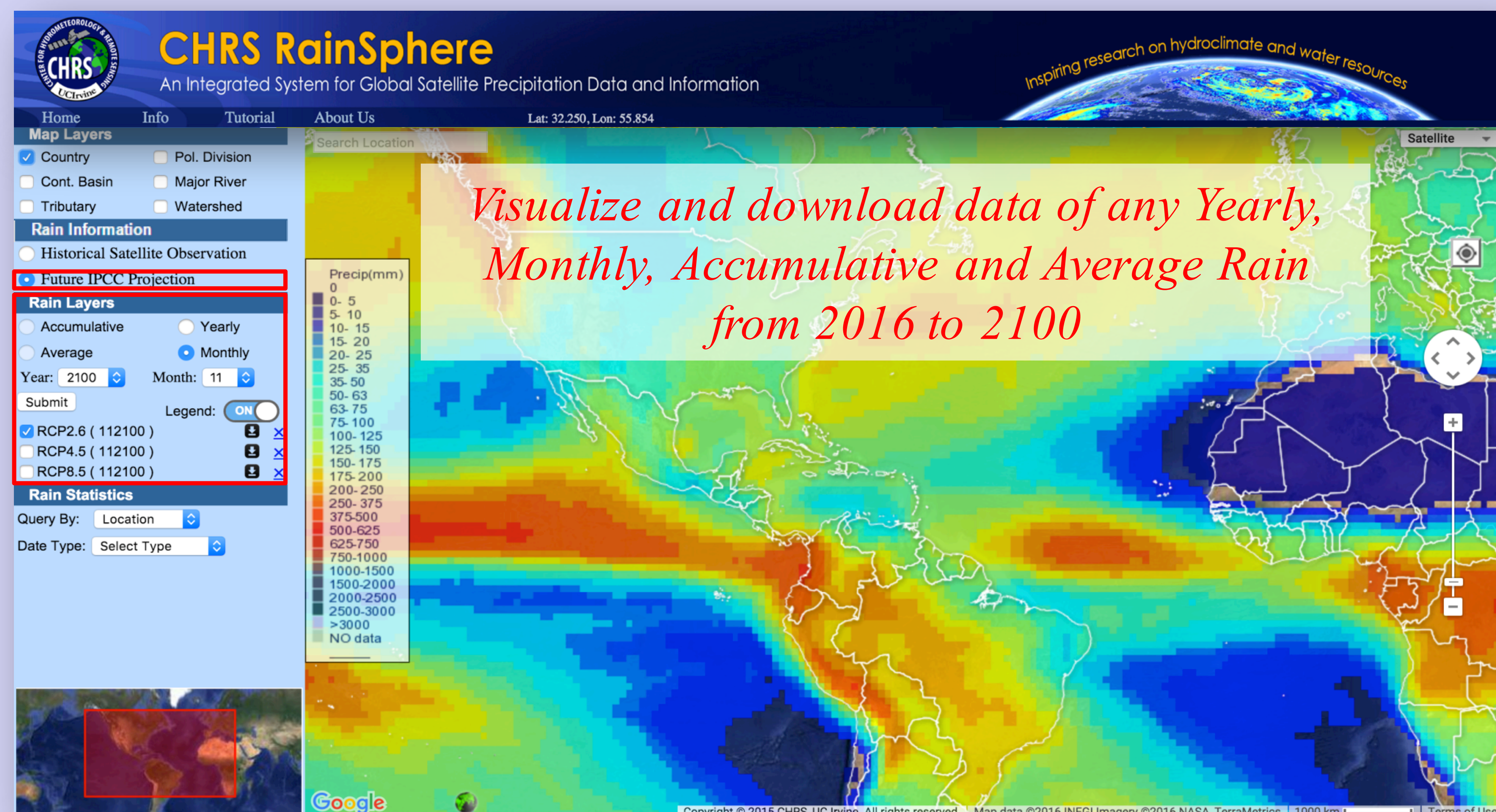
Historical Satellite Rain Observation (PERSIANN-CDR)



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

CHRS RainSphere

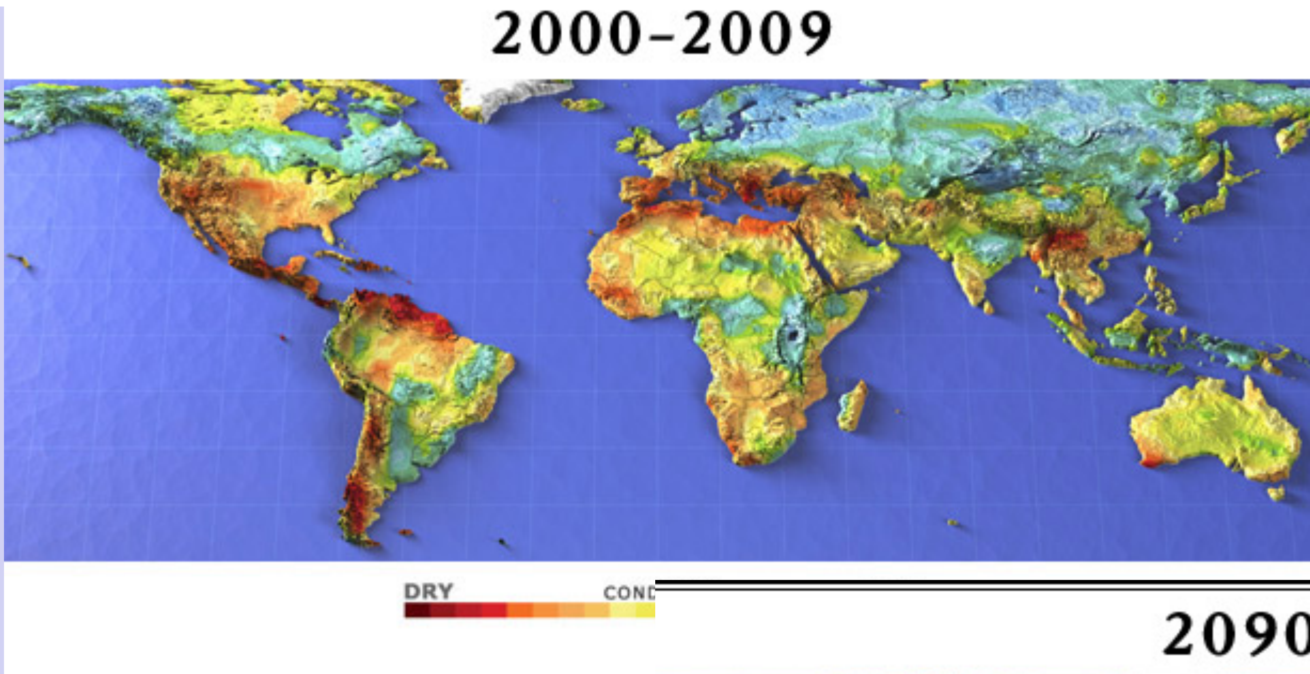
IPCC Rain Projection

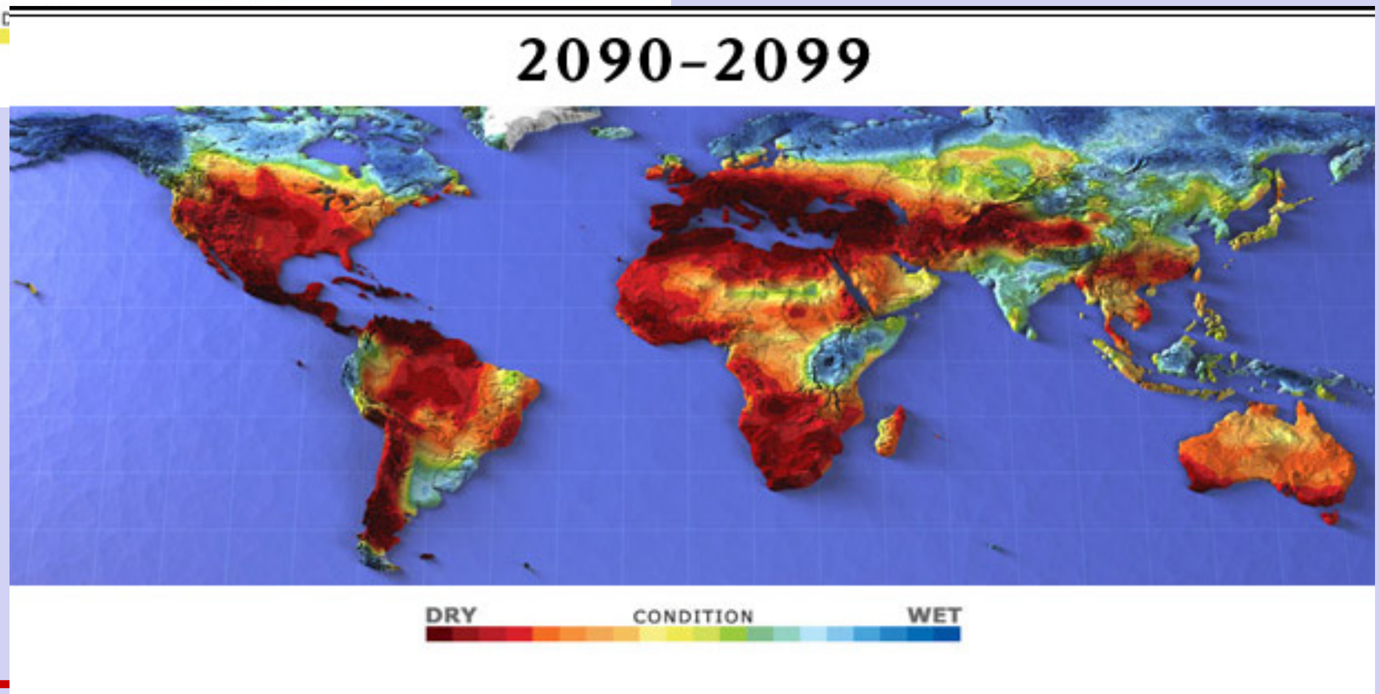


Visualize and download data of any Yearly, Monthly, Accumulative and Average Rain from 2016 to 2100

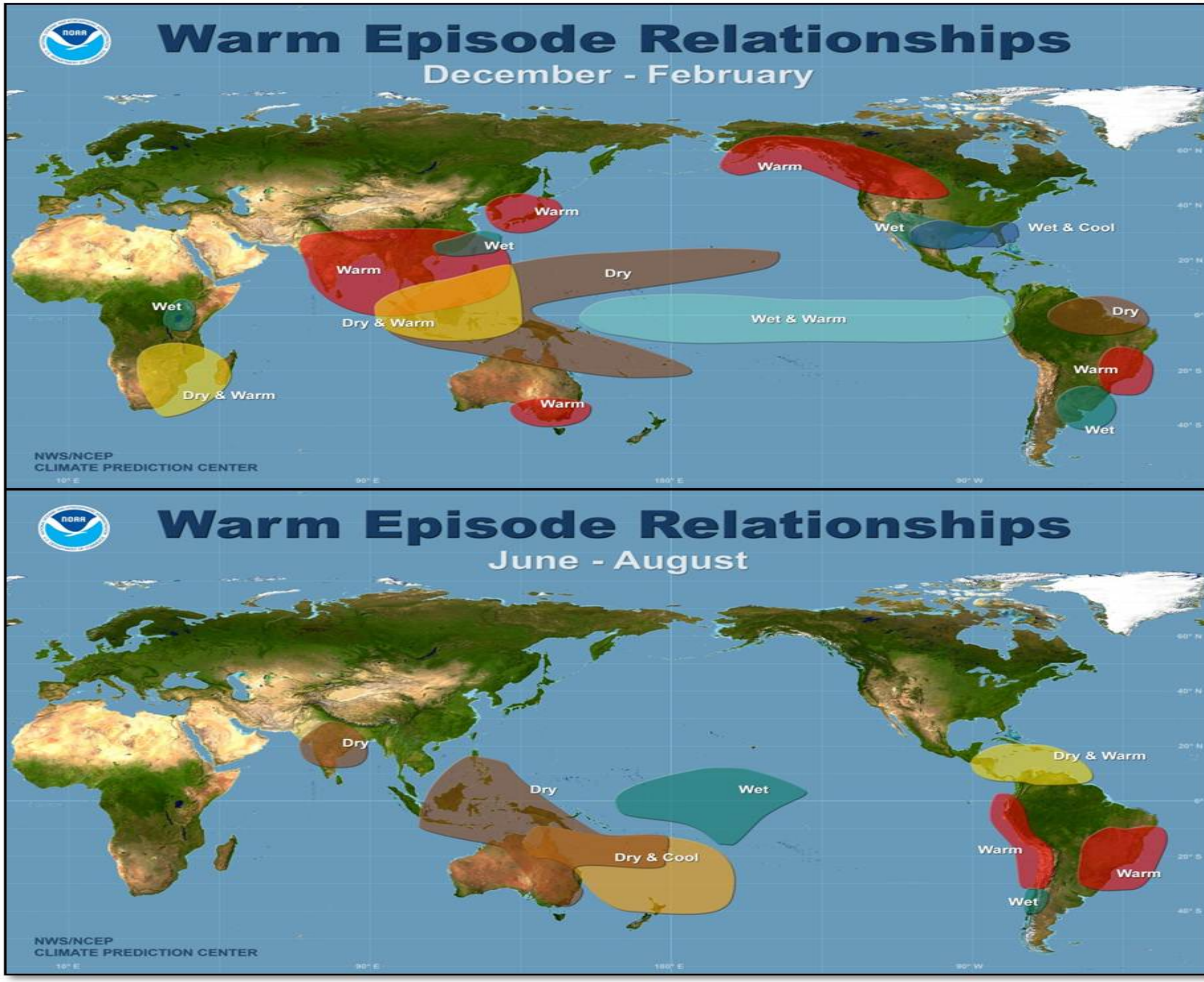
Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Global Climate: Past Decade and Prediction of End of 21st Centaury



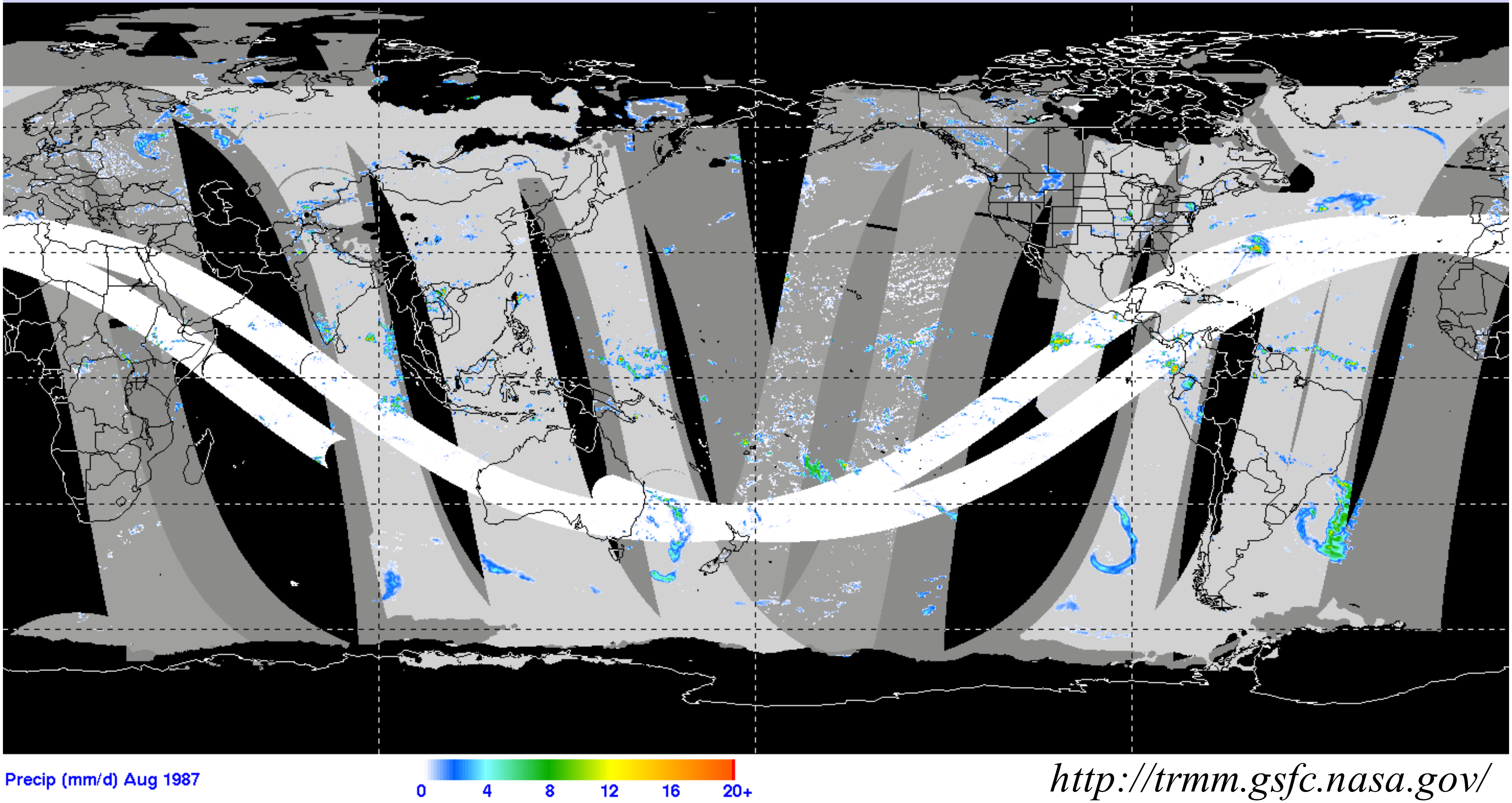


El Nino: Known Regional Influences



High Resolution Images can be found at:
http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/ENSO-Global-Impacts/

Typical Microwave Coverage in 3 Hr



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

TMI – white

SSM/I – light grey

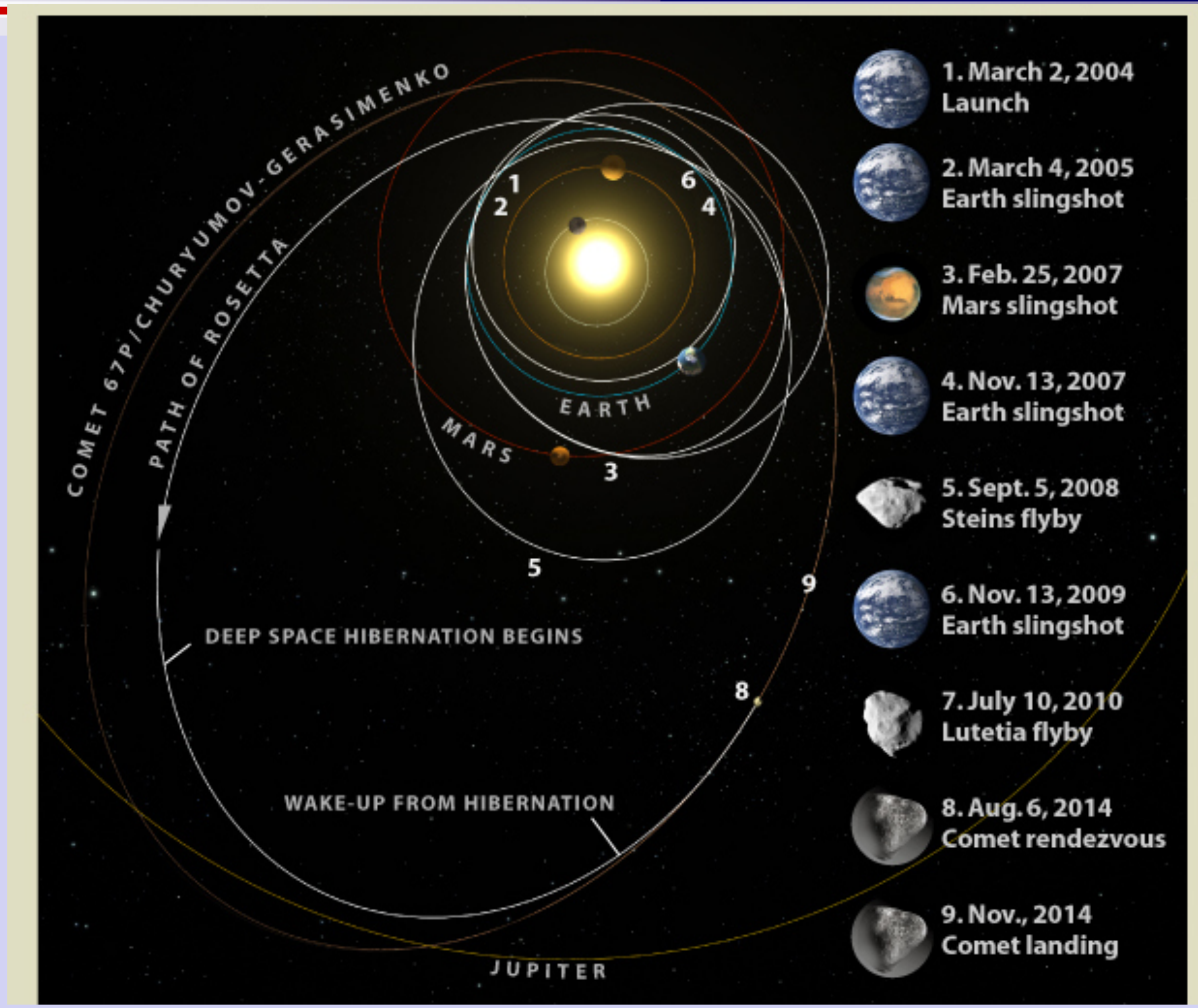
AMSR-E – medium grey

AMSU-B – dark grey

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

Planetary Physics: Remarkable Precision and Accuracy

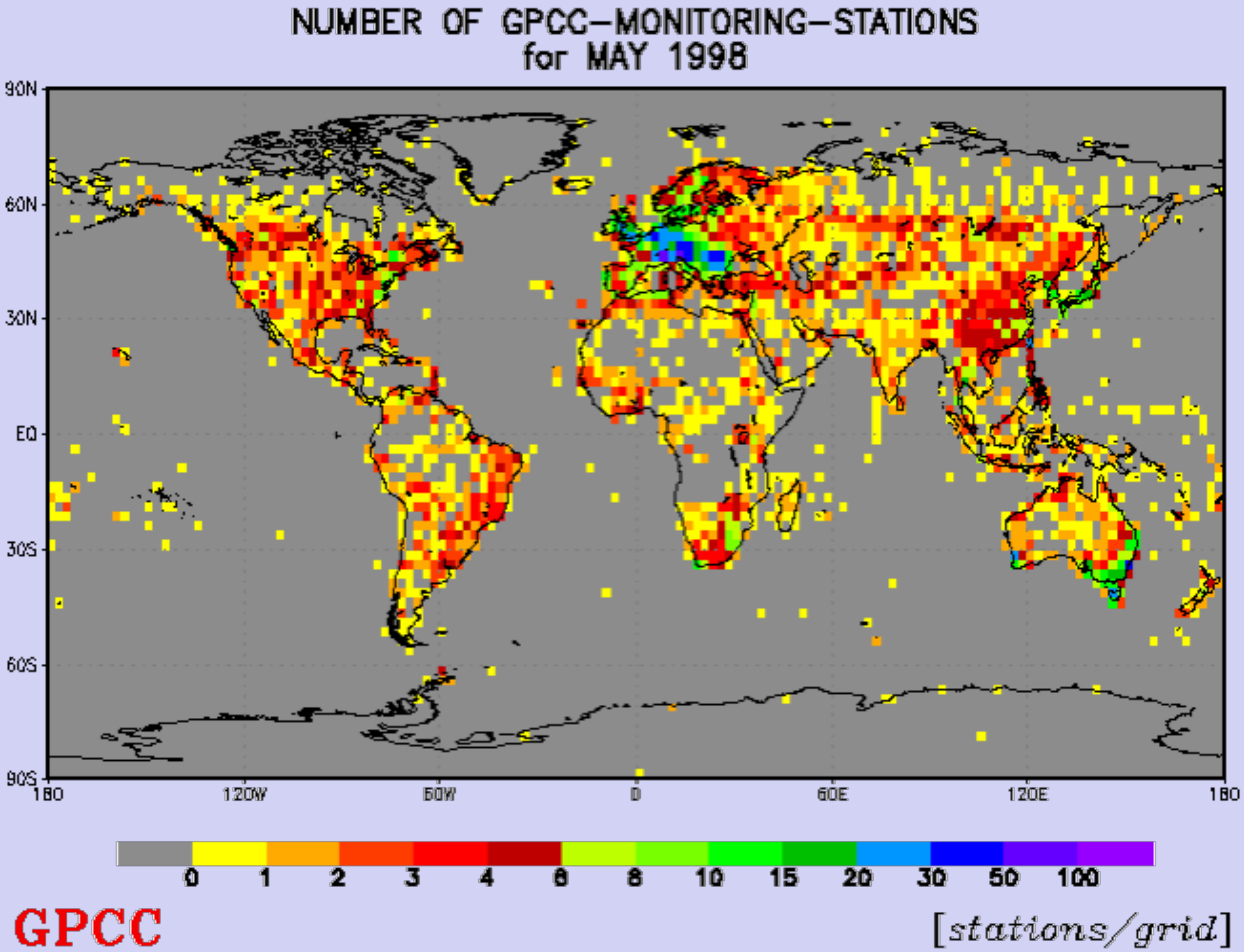
Launched From earth 2004



Rosseta Mission By ESA

comet 67P

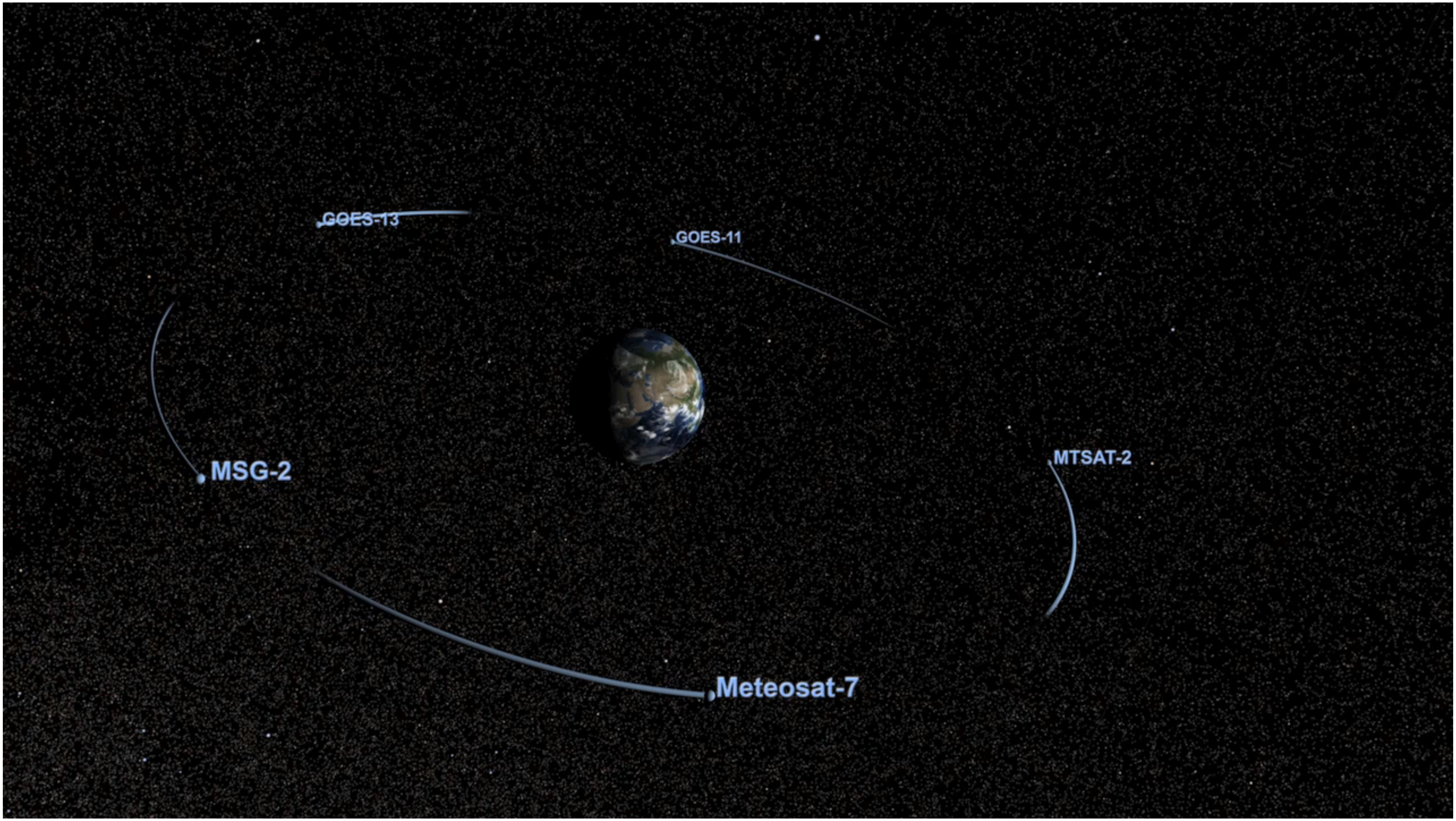
- *Distance travelled:* 6 Billion Km.
- *Time:* 10 years, 9 months and 28 days
- *Rendezvous:* 24 Million Km away from Earth



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

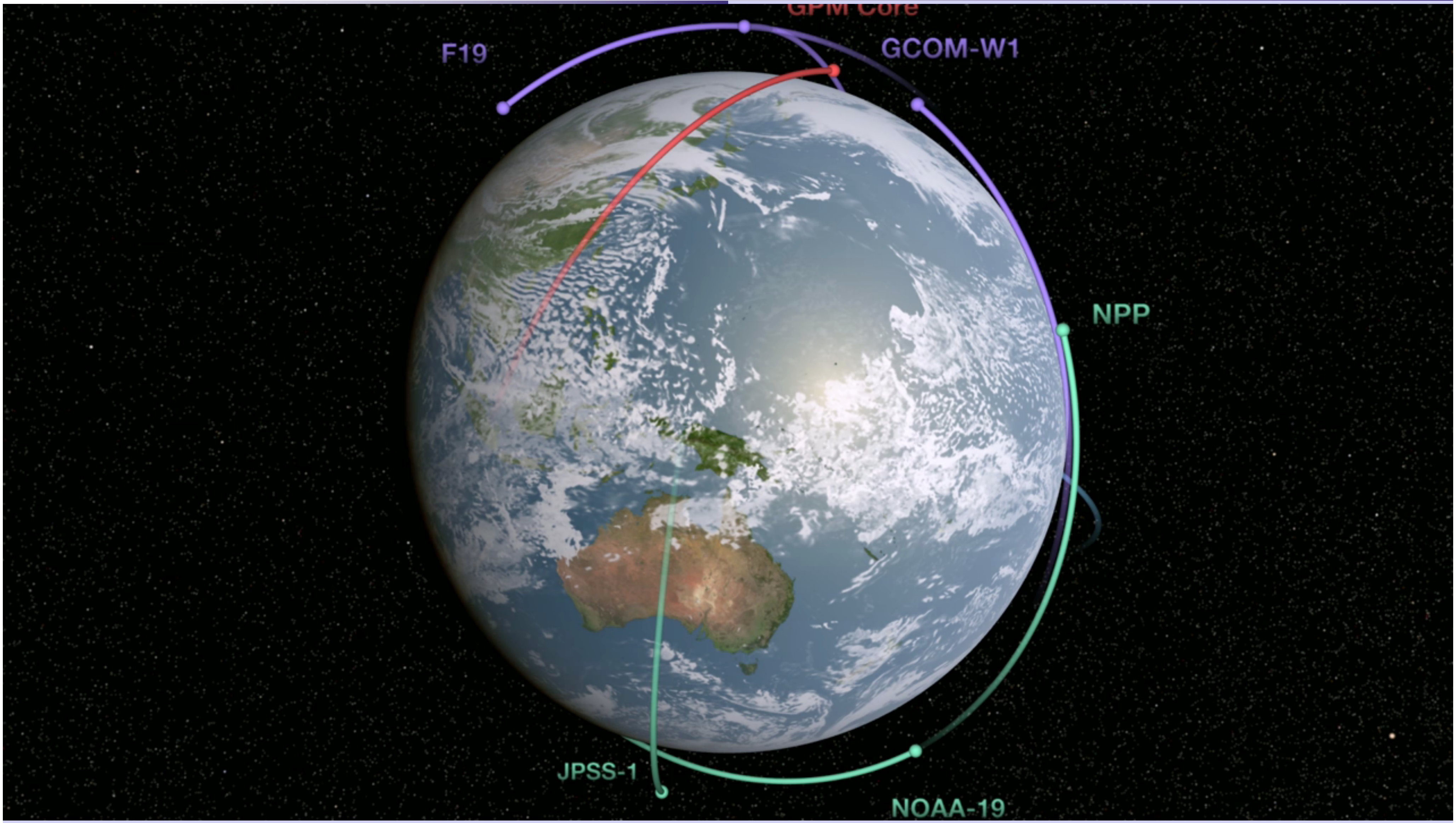
(Source: Global Precipitation Climatology Project)

Geostationary Satellites Infrared (IR) Channel Tb



GPM Animation

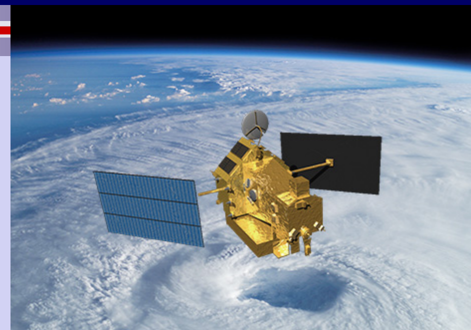
Courtesy: NASA's ESE



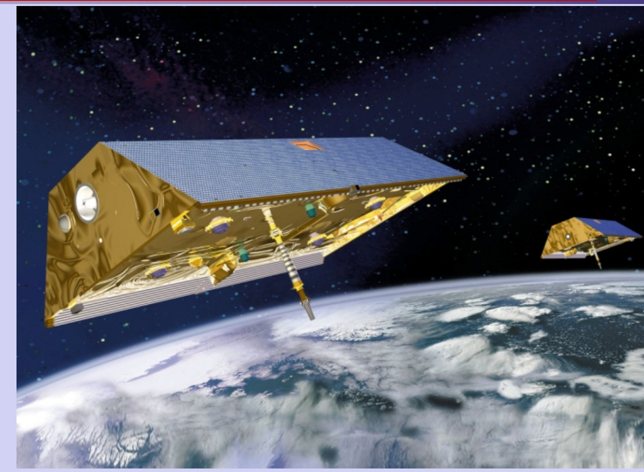
How about the testing of all other Remote Sensing Observations and Model Generated Data??

Hydrologically - Relevant Remote Sensing Missions

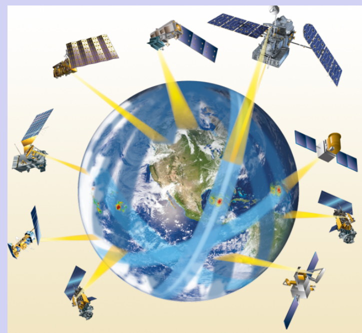
SMOS
ESA's Soil Moisture and Ocean Salinity (2009)



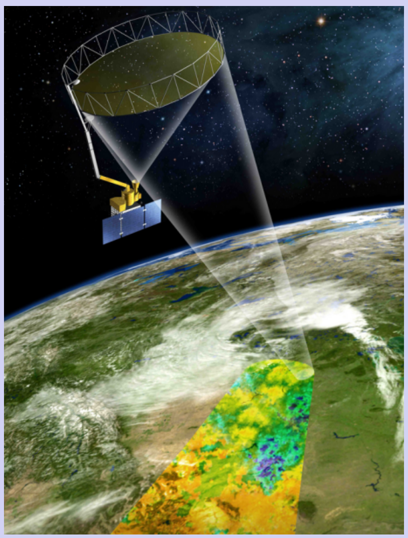
TRMM
The Tropical Rainfall Measuring Mission



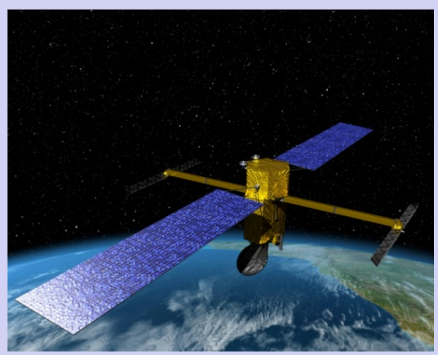
GRACE
Gravity Recovery and Climate Experiment (2002)



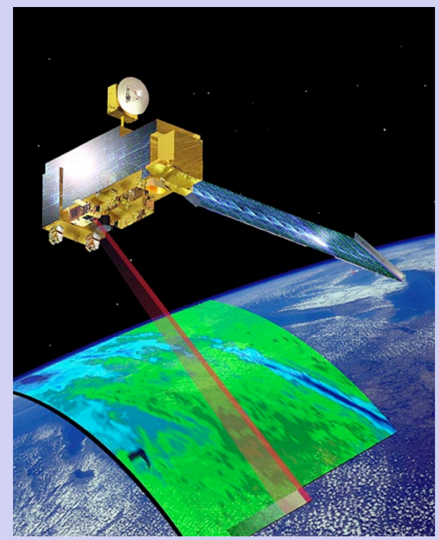
GPM
Global Precipitation Measurements (2014)



SMAP
Soil Moisture Active Passive Satellite(2014)

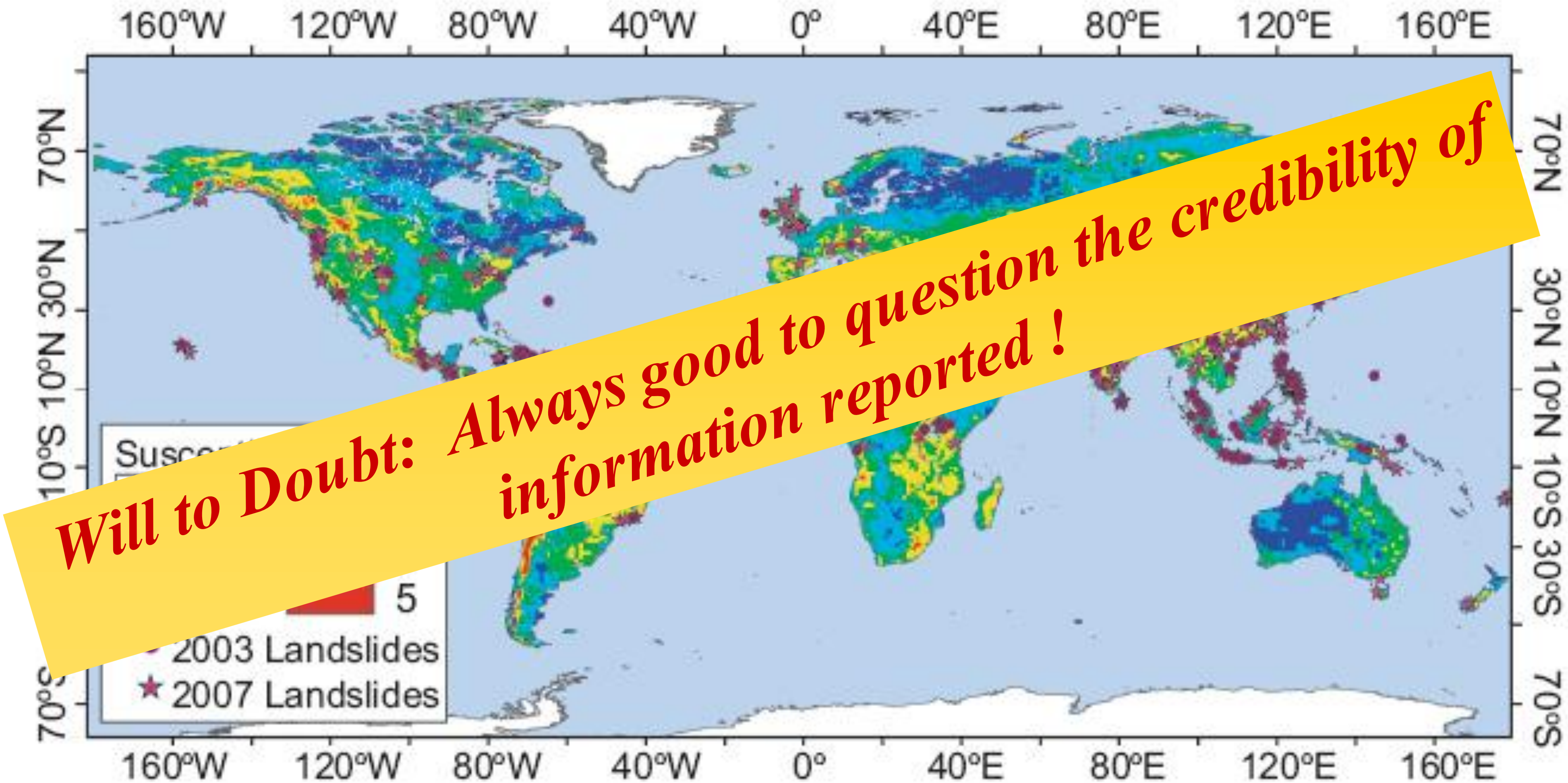


SWOT
Surface Water and Ocean Topography (2020)



MODIS
Moderate Resolution Imaging Spectroradiometer (1999) , (2002)

Landslide Risk map:



What is the Message?

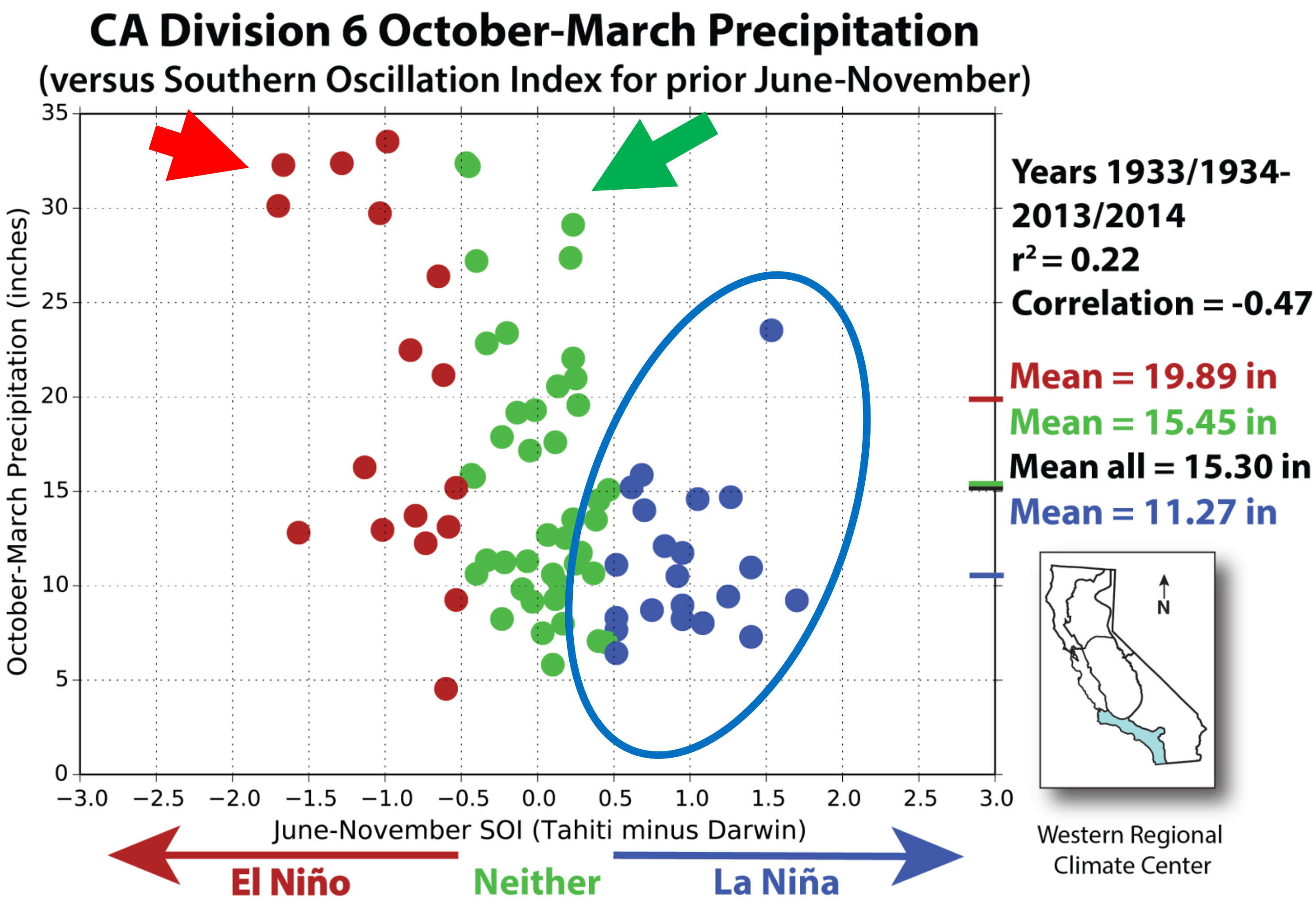
- ***Despite advances to date, predicting the future Hydro-Climate variables will remain a major challenge:***

- ***Nature is complex and observing and modeling its … challenging. So, "have a will to doubt … "generated" by models.***

Factoring in Resiliency in water resources system's design and planning is still the safest approach!

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

ENSO Example: South Coast California



El Nino winters may be very wet.

Very wet winters are typically El Nino winters, but not always...

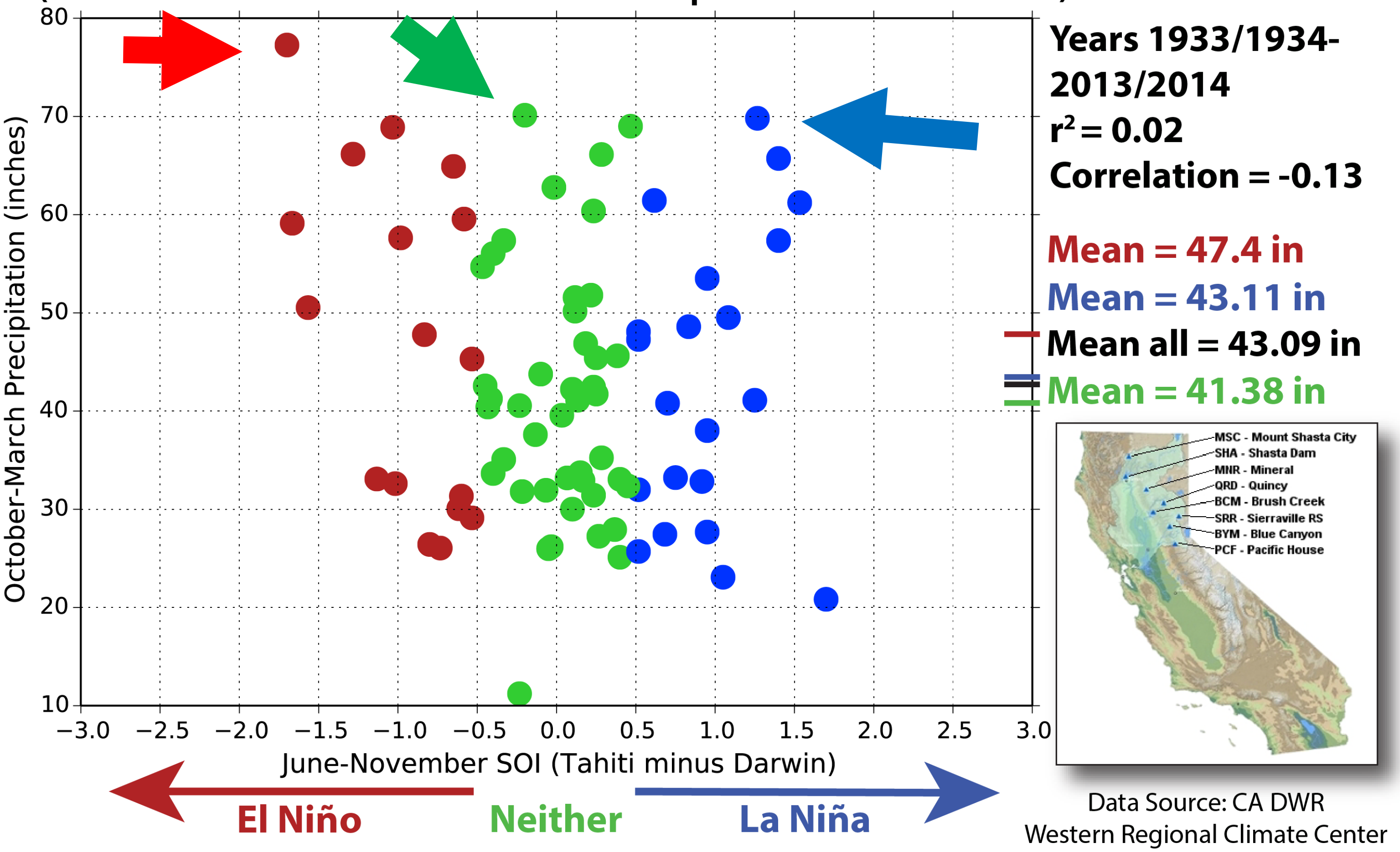
La Nina winters are typically dry, but reliably not wet.

* Redmond and Koch 1991, Methodology

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

ENSO Example: California 8-Station Index

CA 8-Station Index October-March Precipitation
(versus Southern Oscillation Index for prior June-November)



Data Source: CA DWR
Western Regional Climate Center

El Nino winters may be very wet.

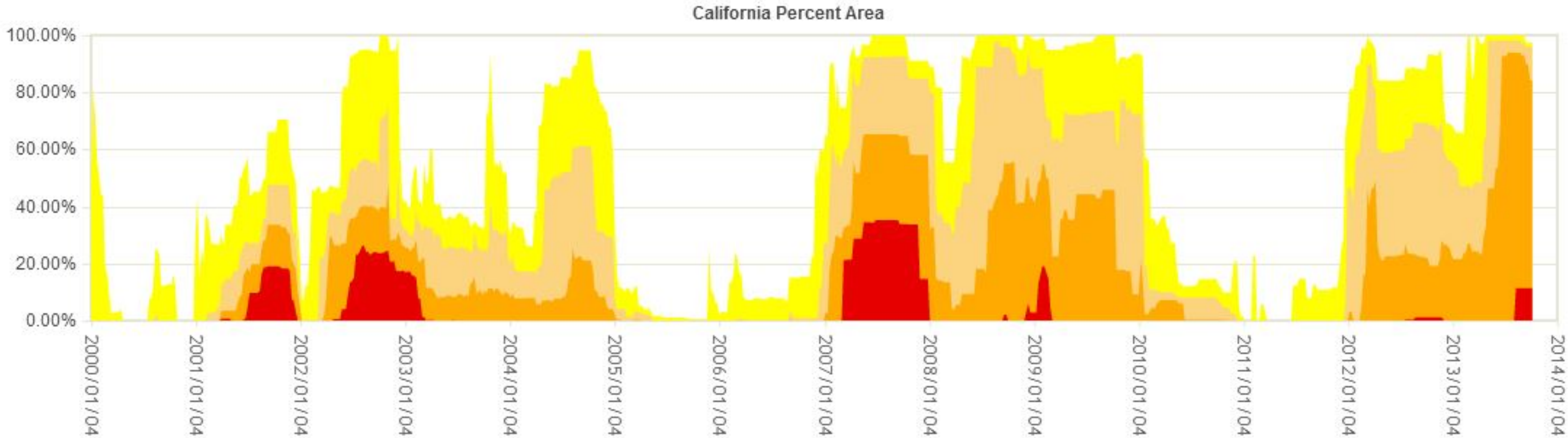
Neutral winters may be very wet.

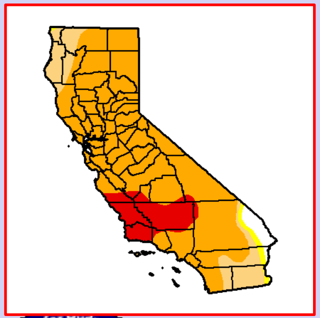
La Nina winters may be very wet.

*** Redmond and Koch 1991, Methodology**

California Drought Conditions (2000 ~ Present): high variability but no trend

"The U.S. Drought Monitor, a composite index that includes many indicators, is the drought map that policymakers and media use in discussions of drought and in allocating drought relief."

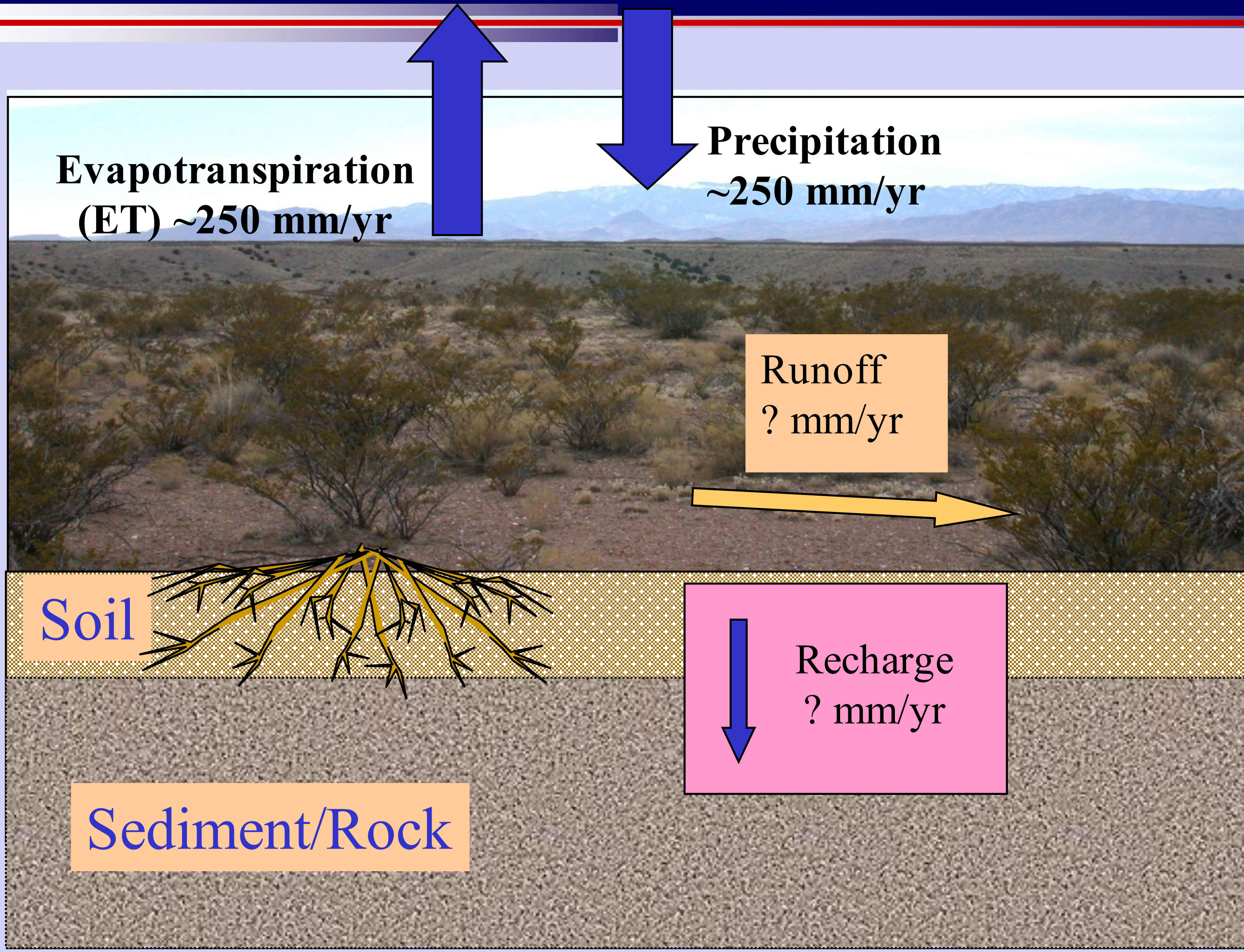




U.S. Drought Monitor for California – Oct.8 2013

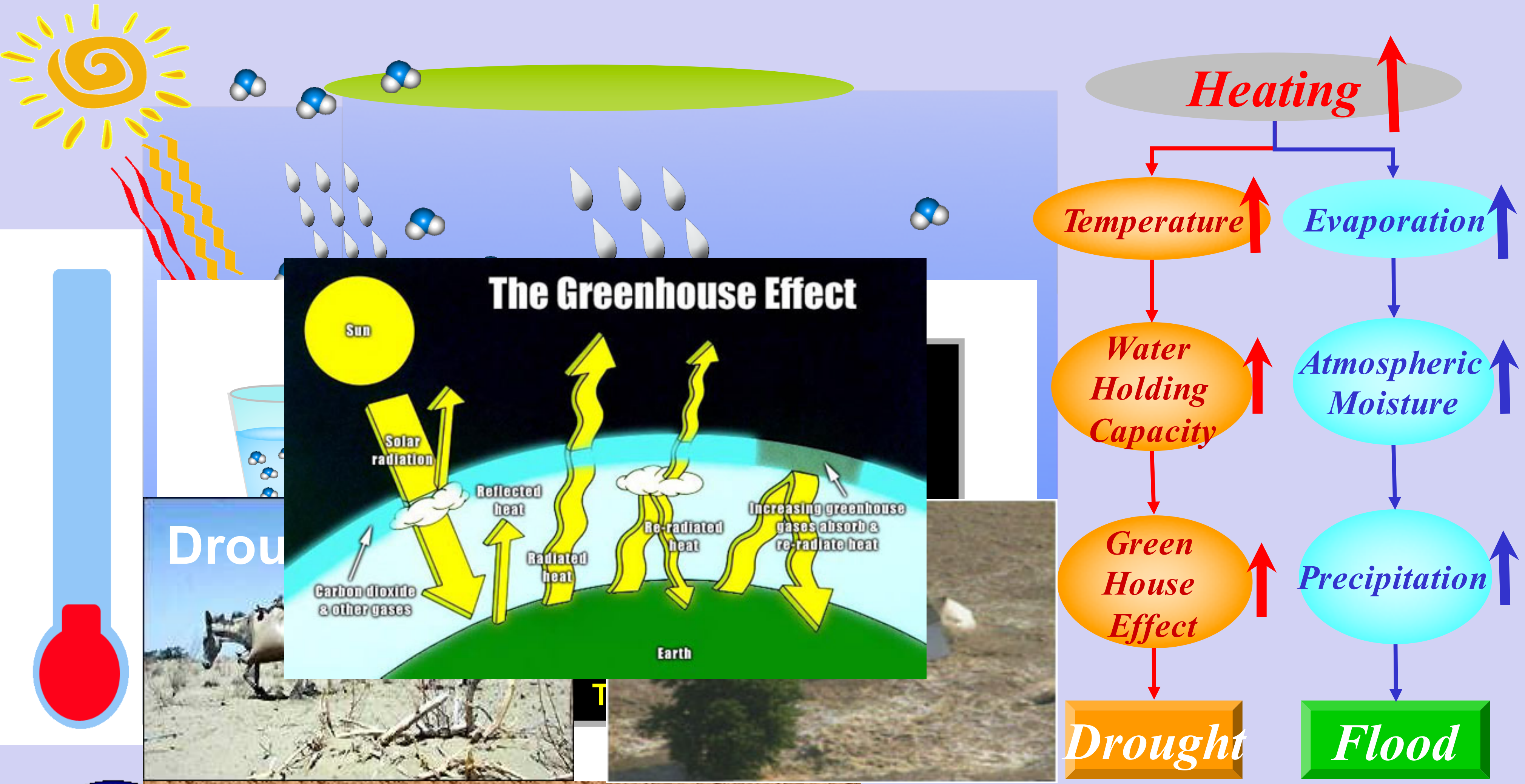
Data Source: http://droughtmonitor.unl.edu/DataArchive.aspx

Water balance in Semi Arid Regions



Source: Eric Small, NMT now at CU Boulder

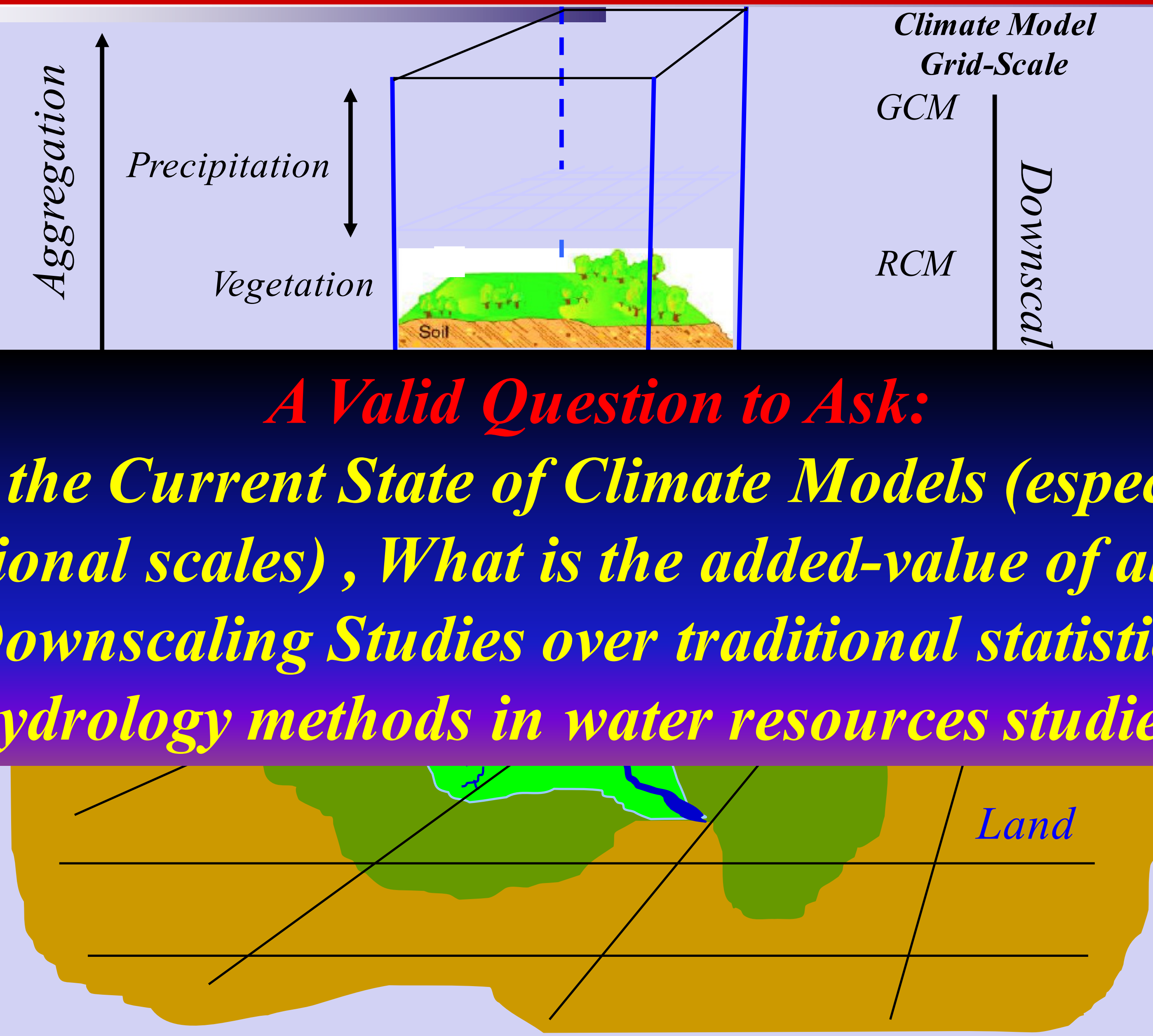
Global Warming And Hydrologic Cycle Connection



Created by: Gi-Hyeon Park

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

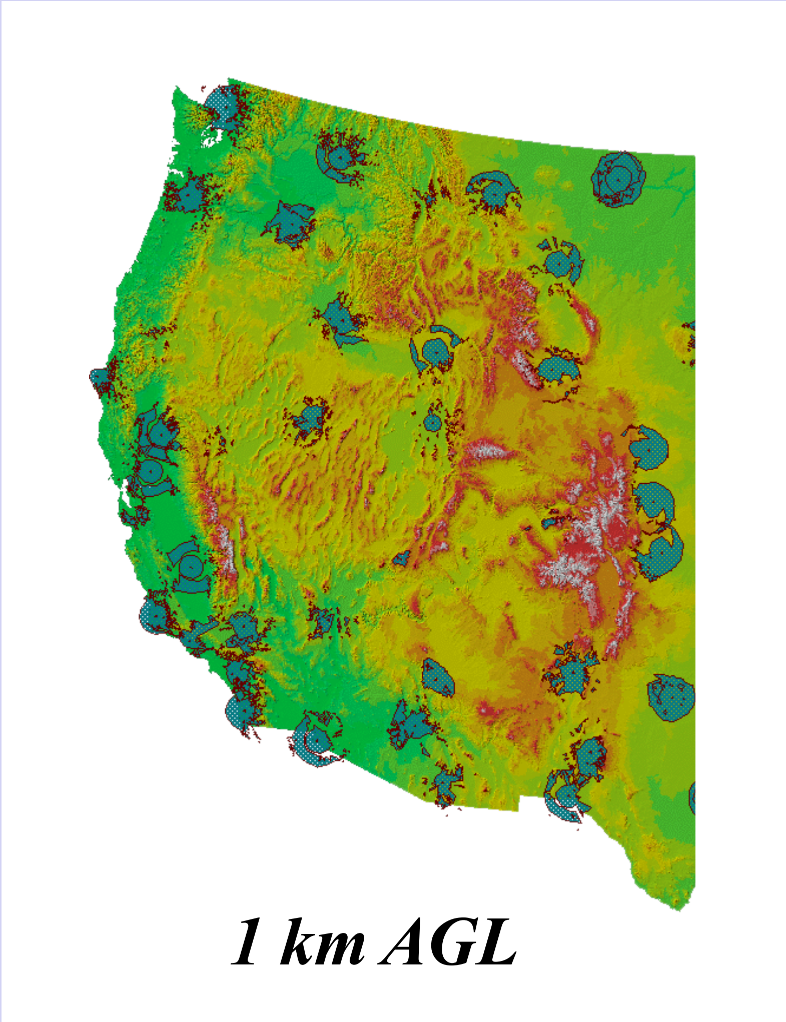
Climate Model Downscaling to regional/watershed Scale



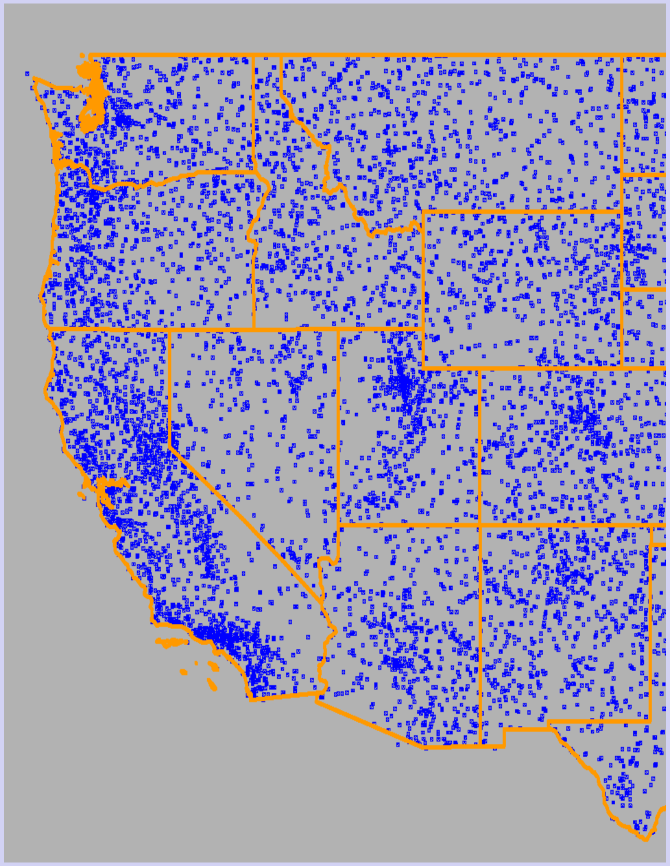
A Valid Question to Ask:

Given the Current State of Climate Models (especially at regional scales) , What is the added-value of all the Downscaling Studies over traditional statistical hydrology methods in water resources studies?

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

***P**recipitation **E**stimation from **R**emotely **S**ensed **I**nformation using **A**rtificial **N**eural **N**etworks (PERSIANN)*

Kuolin Hsu
Algorithm Development

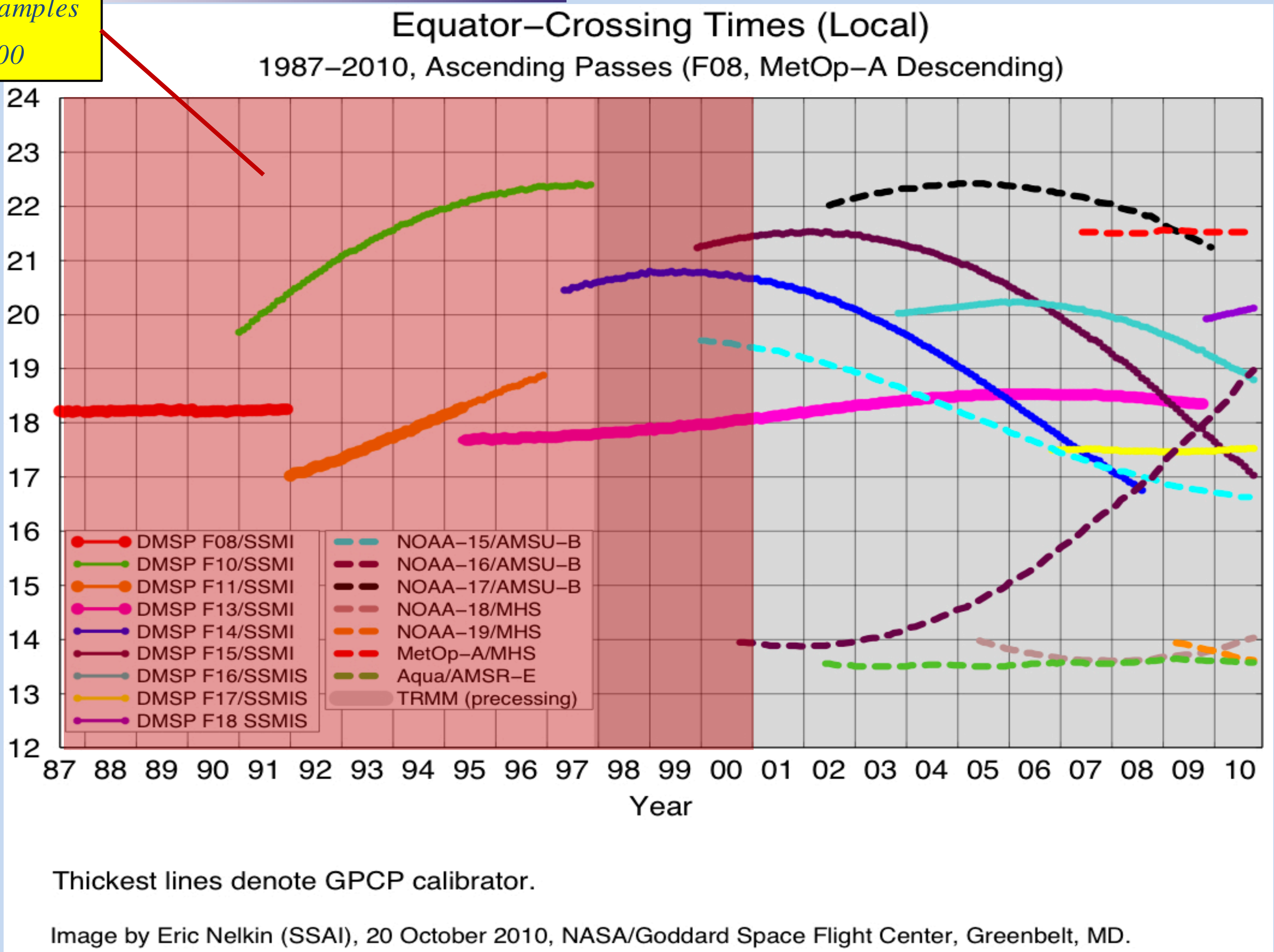
Bisher Imam
G-WADI site development

CHRS

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

LEO Satellites for Precipitation Estimation

Limited PMW Samples Before year 2000

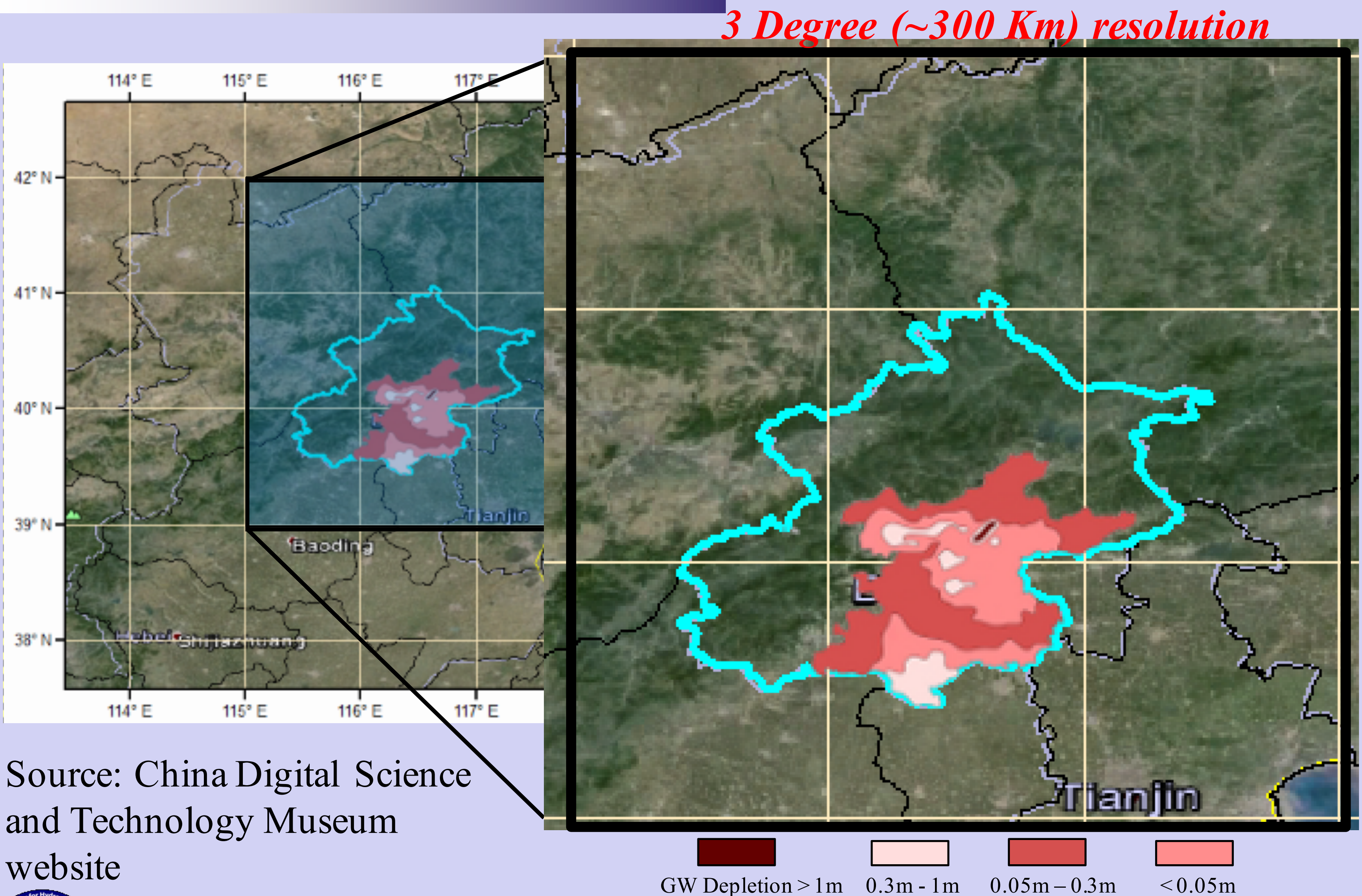


Observation of Primary Hydrologic Variables

Stream flow

Precipitation

GRACE Satellite Footprint



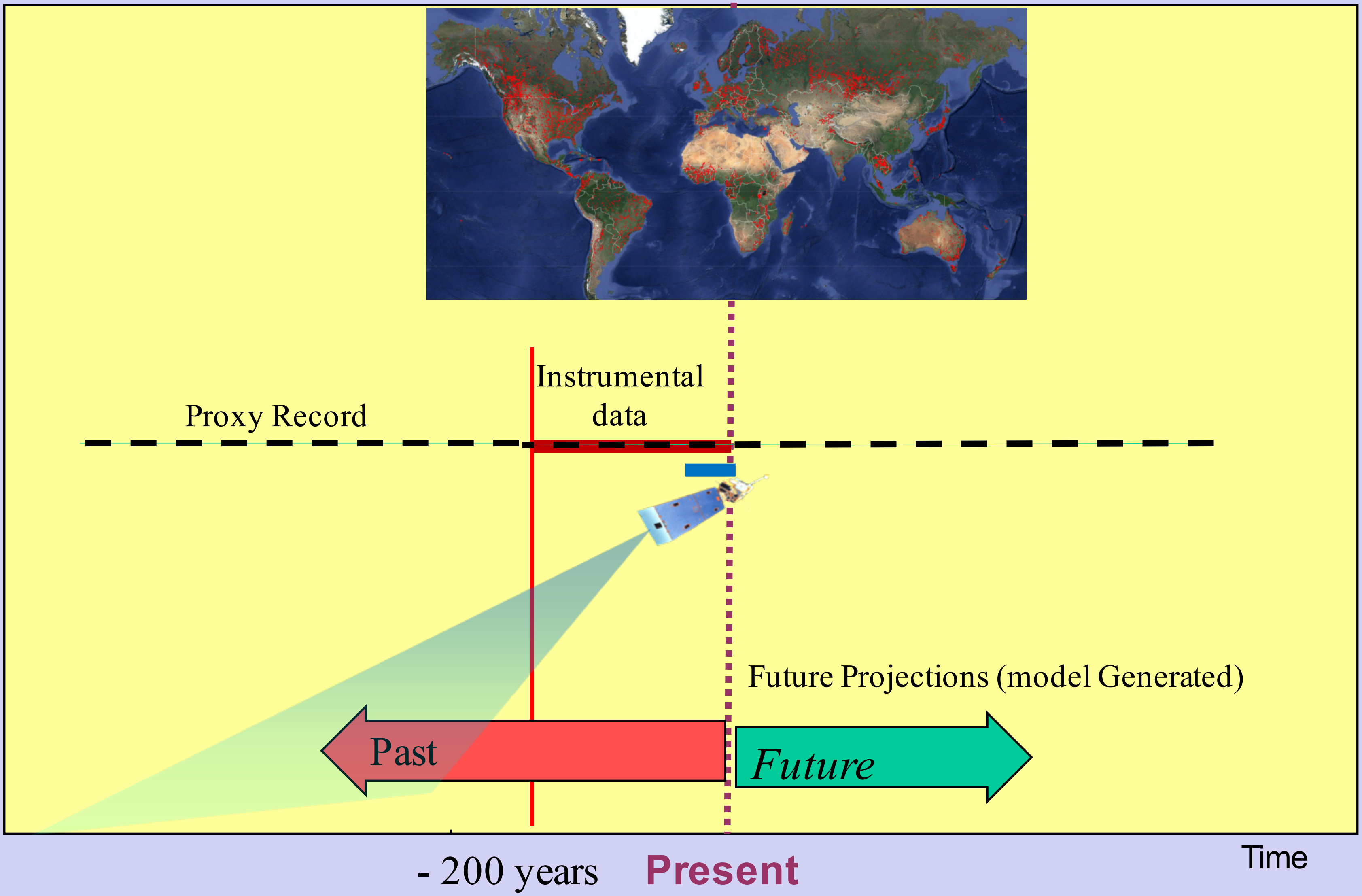
Source: China Digital Science and Technology Museum website

Created by: N. Nasrollahi. Tiantian Yang & S. Sarachi

Stresses On Water Resources:

- ***Population Impact*** ***(More Certain!)***
- ***Climate Impact*** ***(Uncertain!)***

Hydroclimate of the Past and Future: Observation &Modeling



Some Definitions and Scope of this Presentation

Definitions

"Tools" : Models

" Data" : - In-situ and RS Observations

- Model-Generated

Scope: Focus on Precipitation