Lecture I
The Role of Hydrological Cycle in the Climate System: Modelling, Observations and process studies

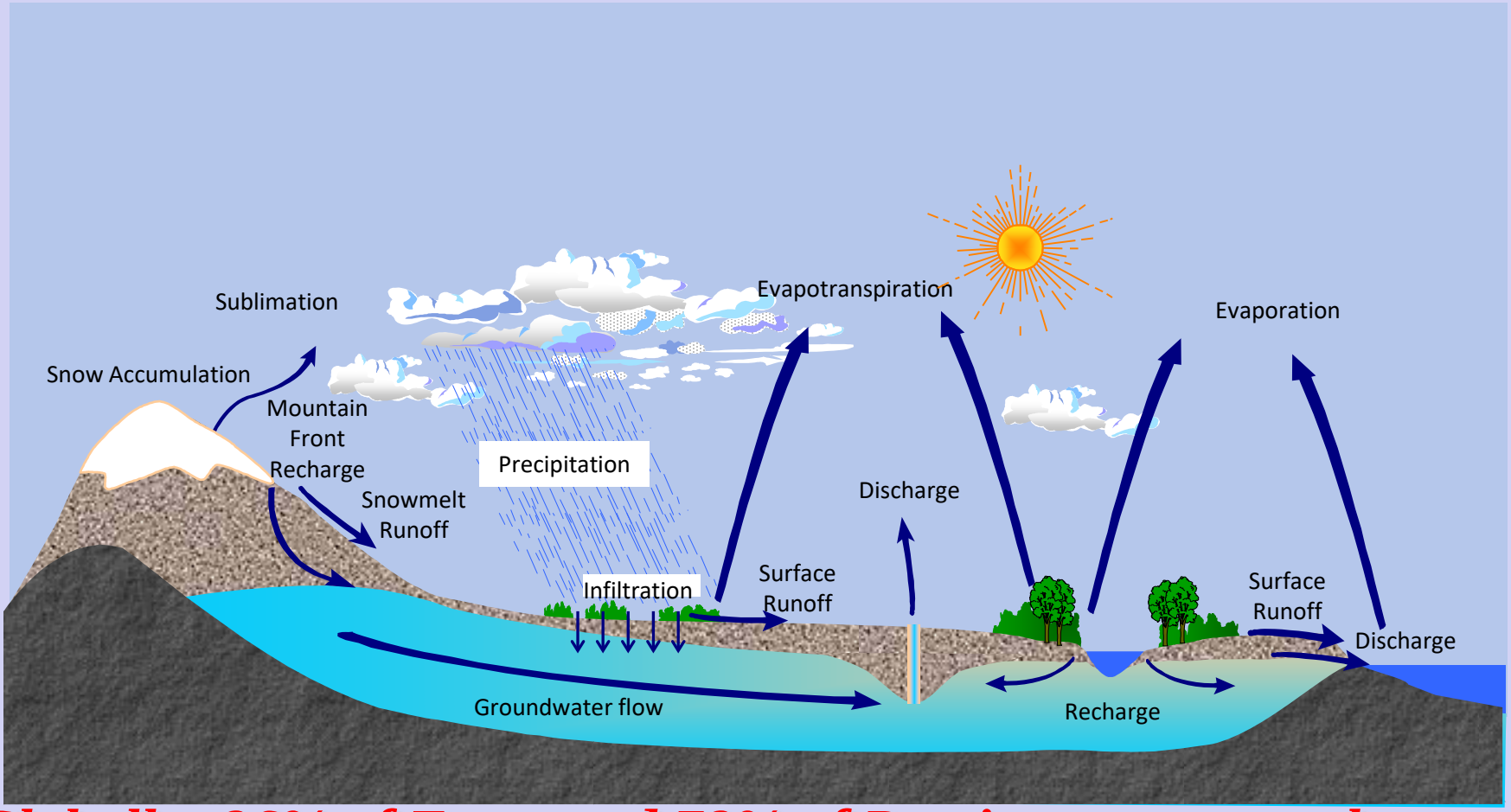
Soroosh Sorooshian

Center for Hydrometeorology and Remote Sensing
University of California Irvine

ICTP-Africa Joint School on Rainfall and Water Resources Management- July 25-28 2022, Organized by UNESCO office in Kigali Rwanda

University of California Irvine (UCI)
Research Team: Present and Recent Past

Studying the Hydrologic Cycle at Various Scales

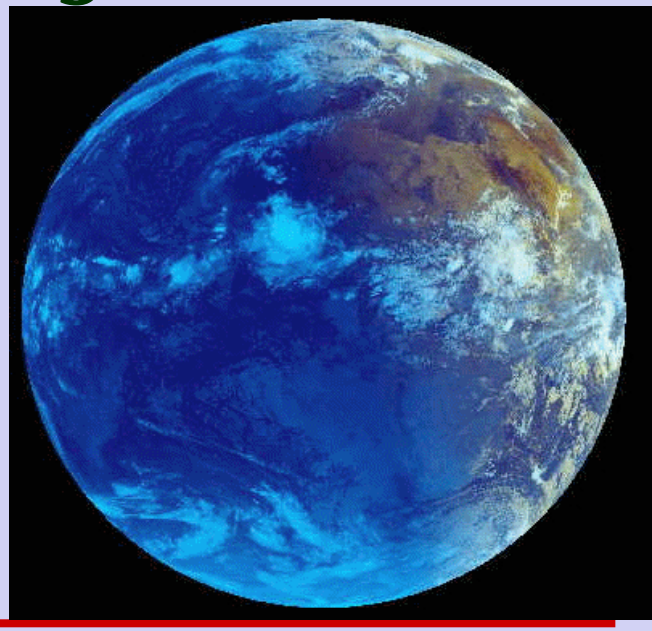


Globally: 86% of Evap. and 78% of Precip. occur over the oceans

Climate, Hydrology and Water Resources

- ***How will Climate change affect precipitation variability and water Availability?***

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



Two Primary Water Resources/Hydrology Challenges:

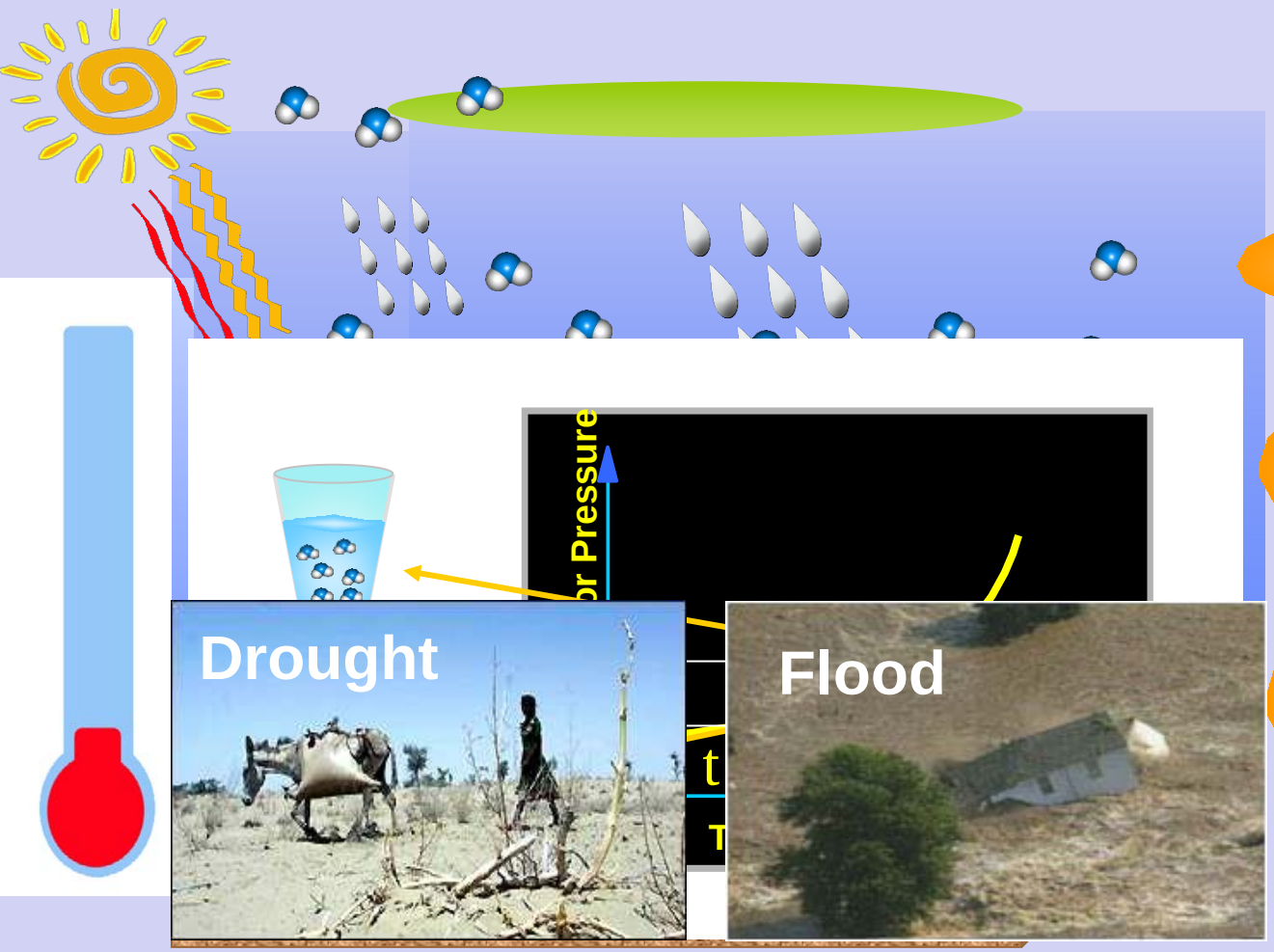
- *Hydrologic Hazards (Floods and Droughts)*

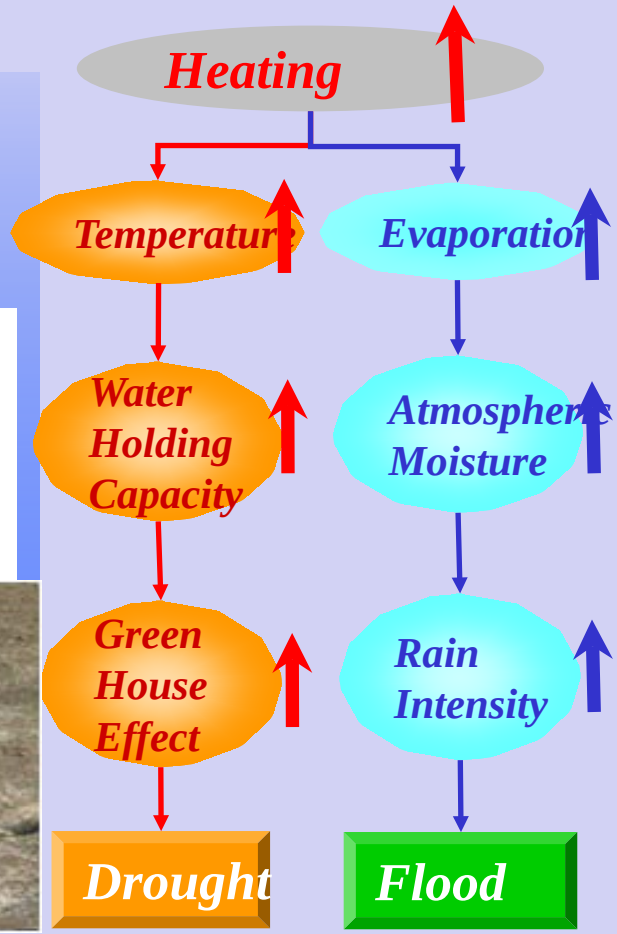
- *Water Supply Requirements (Quantity and Quality)*

A Key Consideration:

The Link Between Climate and Hydrology

Global Warming And Hydrologic Cycle Connection



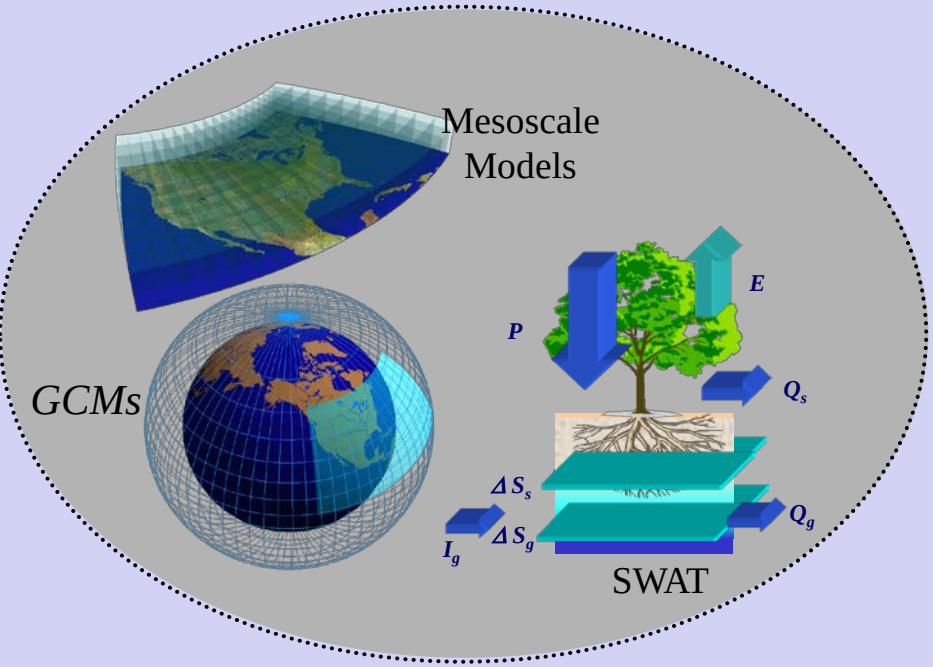


Created by: Gi-Hyeon Park

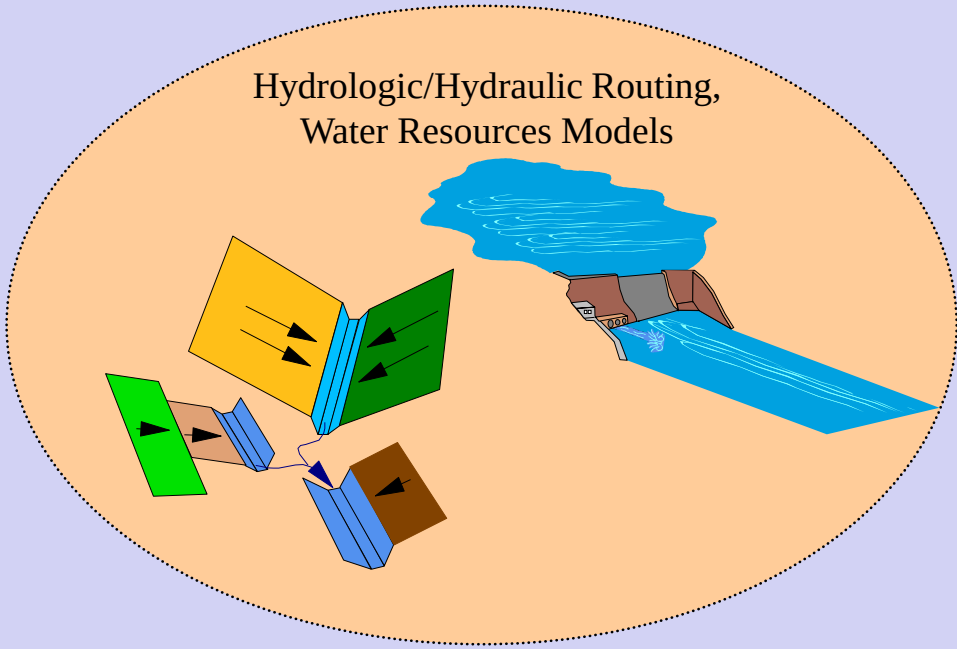
Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Hydroclimate Science and Hydrologic/Water Resources Engineering

SCIENCE



ENGINEERING



Hydroclimate Science

Hydrologic/Hydraulic and Water Resources Engineering

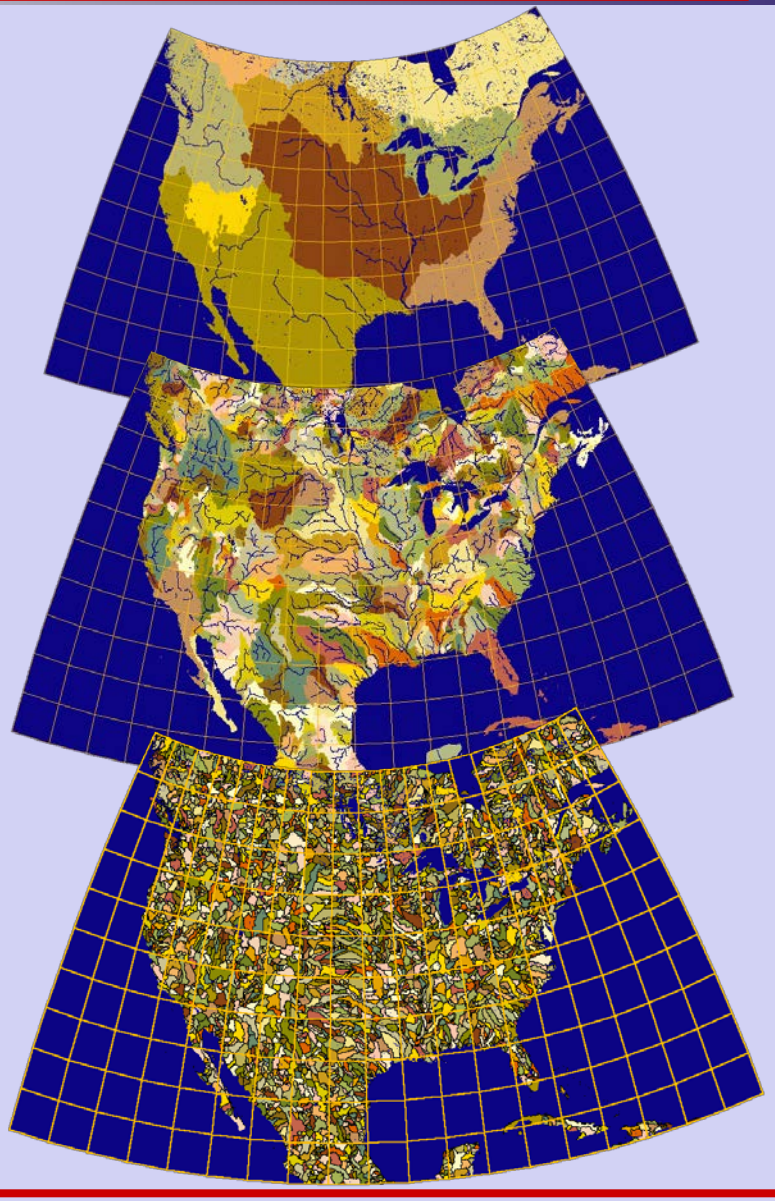
River Basins and Watersheds

Continental Scale:

Different Scales
Different Issues

Watershed Scale:

Where hydrology happens
Where stakeholders exist



Information Relevant to Water Resources Planning

- Models Projections
- Observations

Required Hydrometeorologic Predictions

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

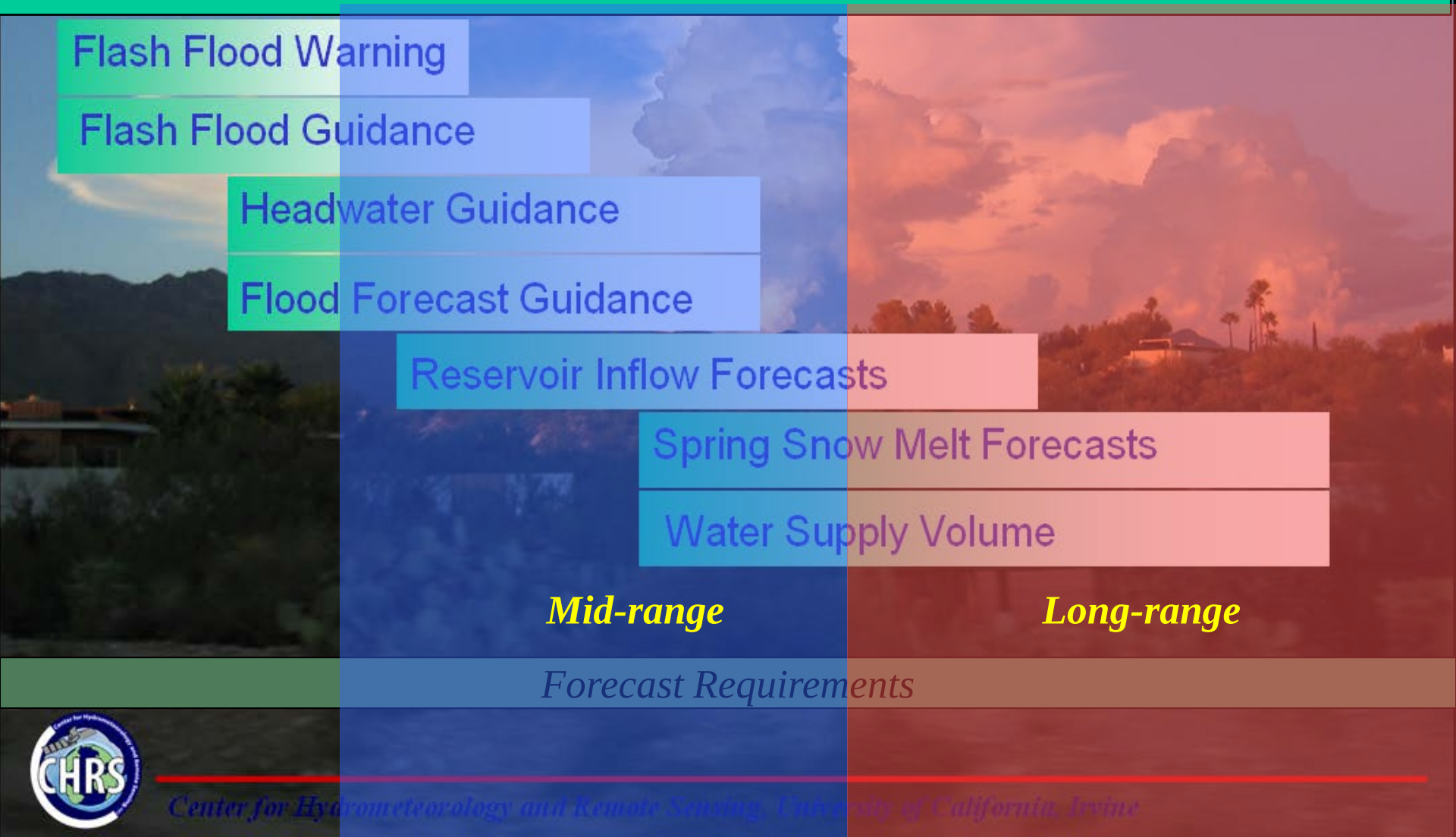
Short-range	*Mid-range*	*Long-range*

Forecast Requirements

Required Hydrometeorologic Predictions

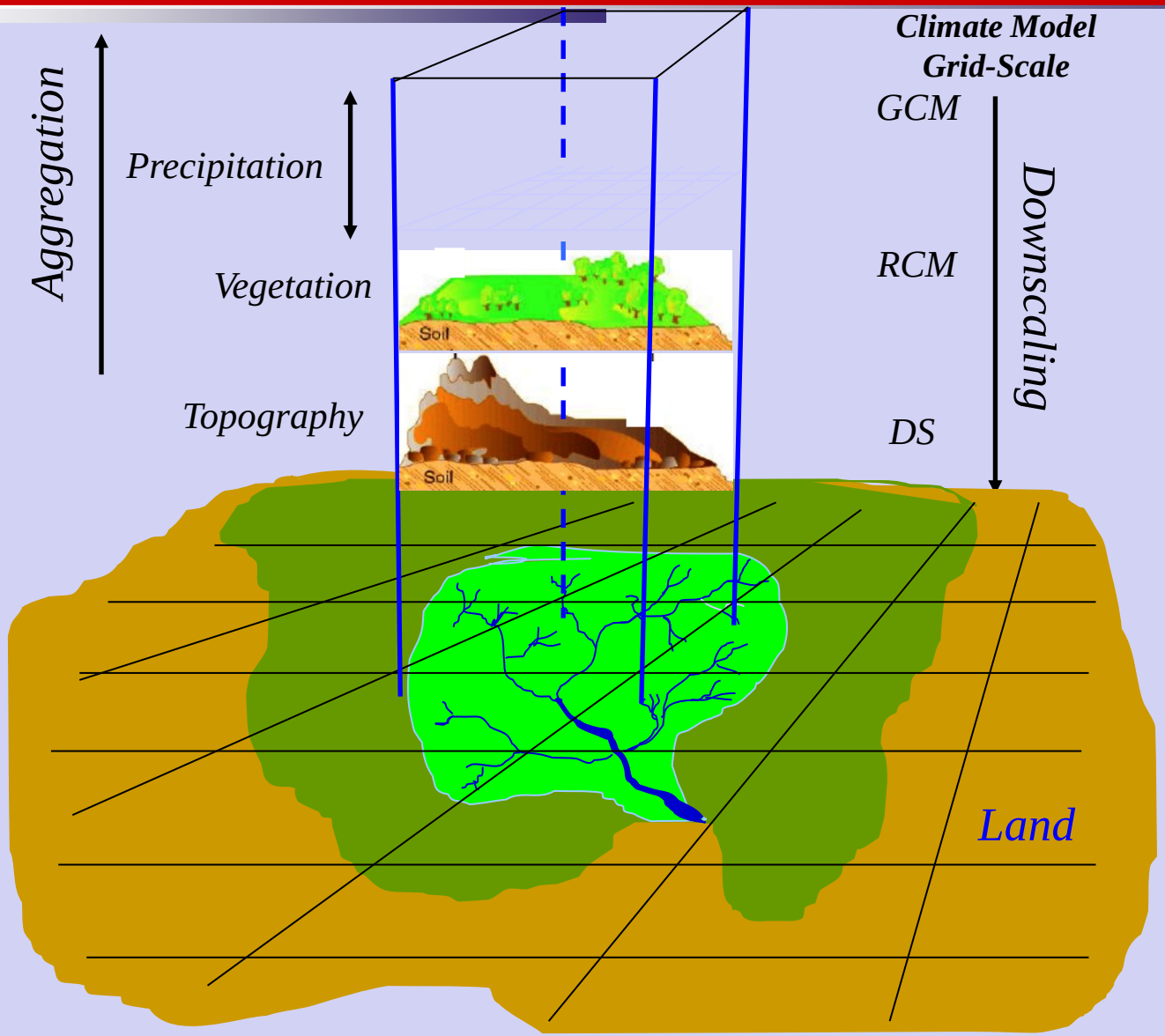
Short Range ⟶ **Long Range**

hours ⟶ days ⟶ weeks ⟶ months ⟶ seasons ⟶ years ⟶ decades



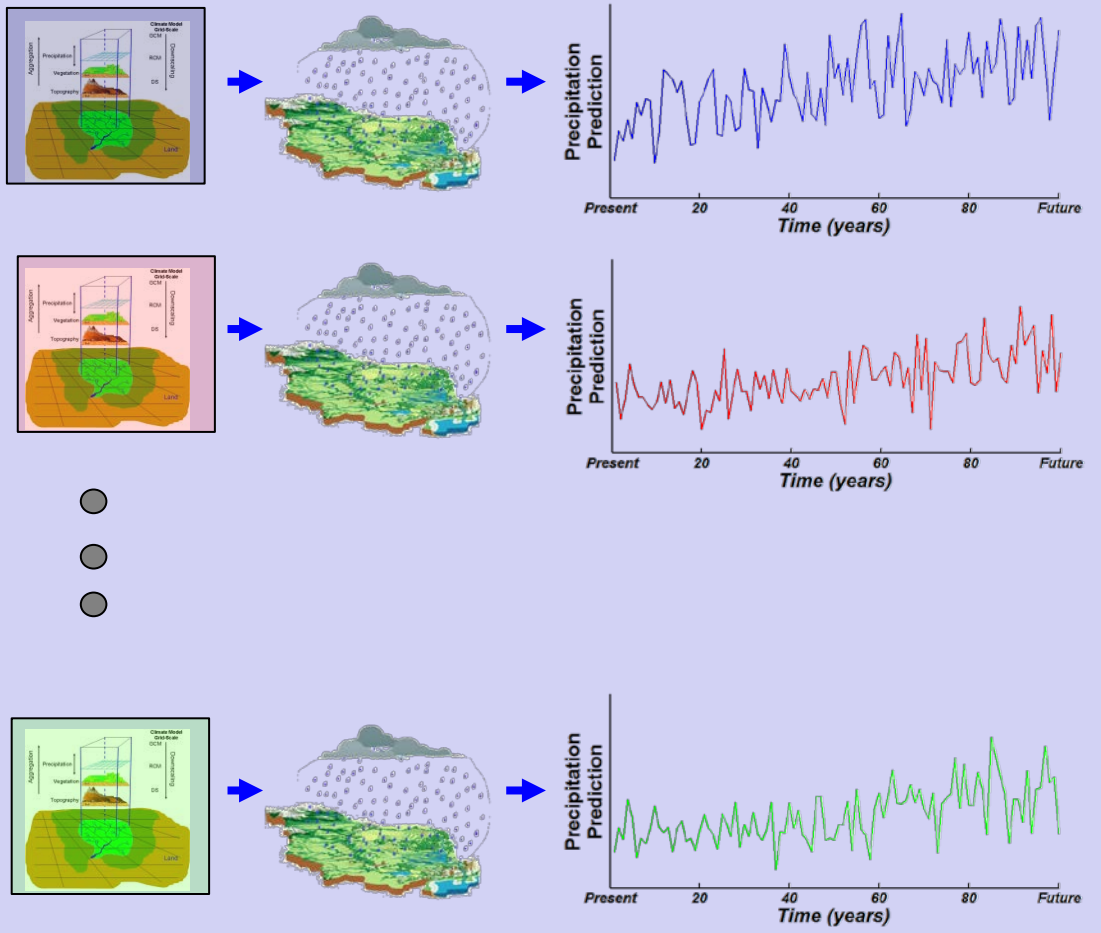
Forecast Requirements

Climate Model Downscaling to regional/watershed Scale



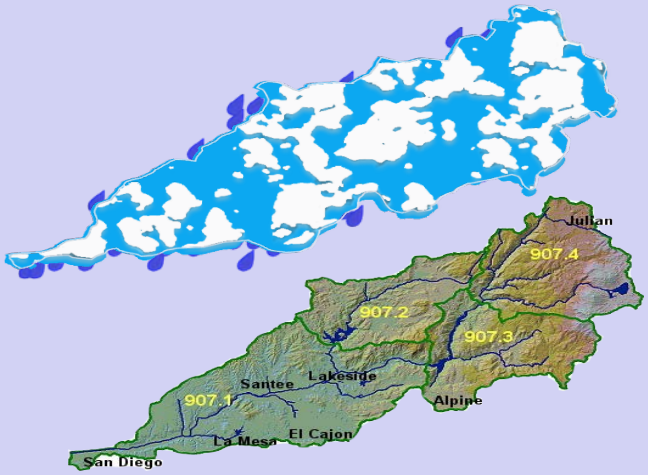
Ensemble Approach

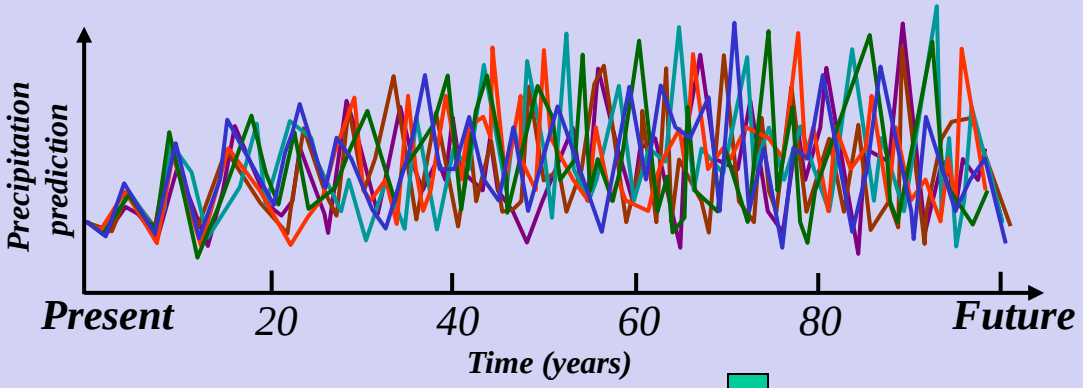
Generation of Future Precipitation Scenarios

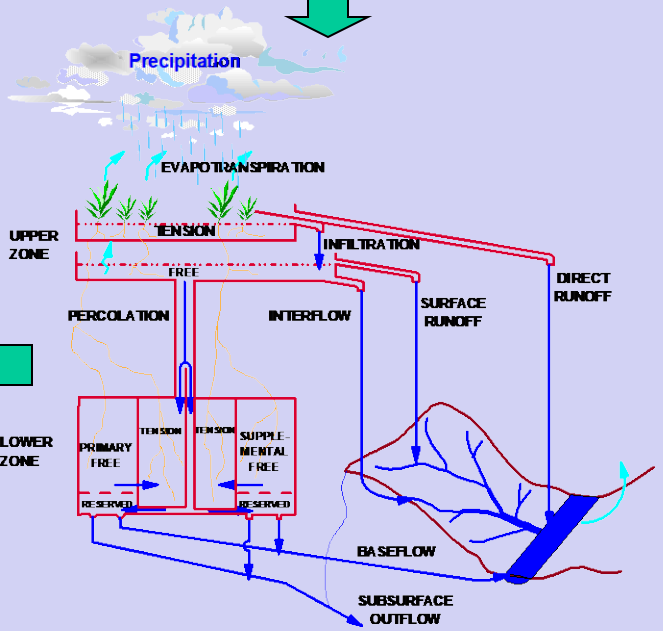


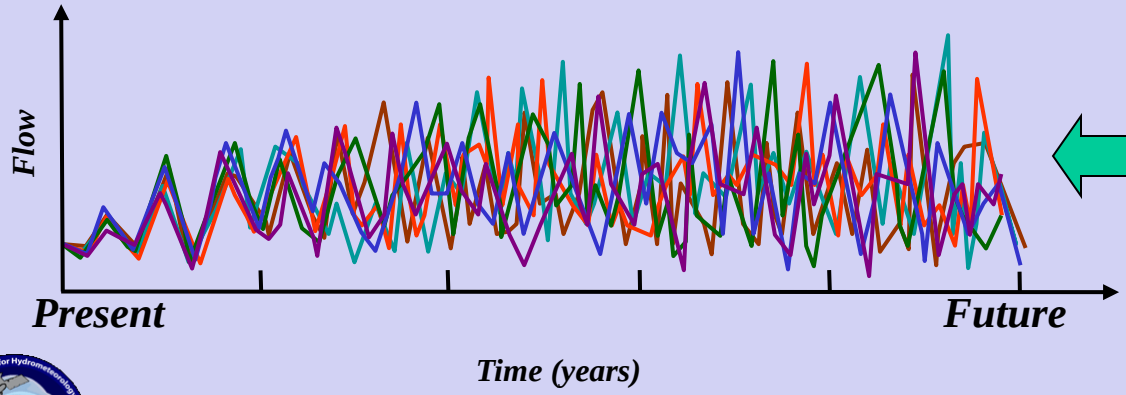
Downscaled Precipitation to Runoff Generation

Generation of Future Runoff Scenarios









Seasonal-Scale Predictions

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

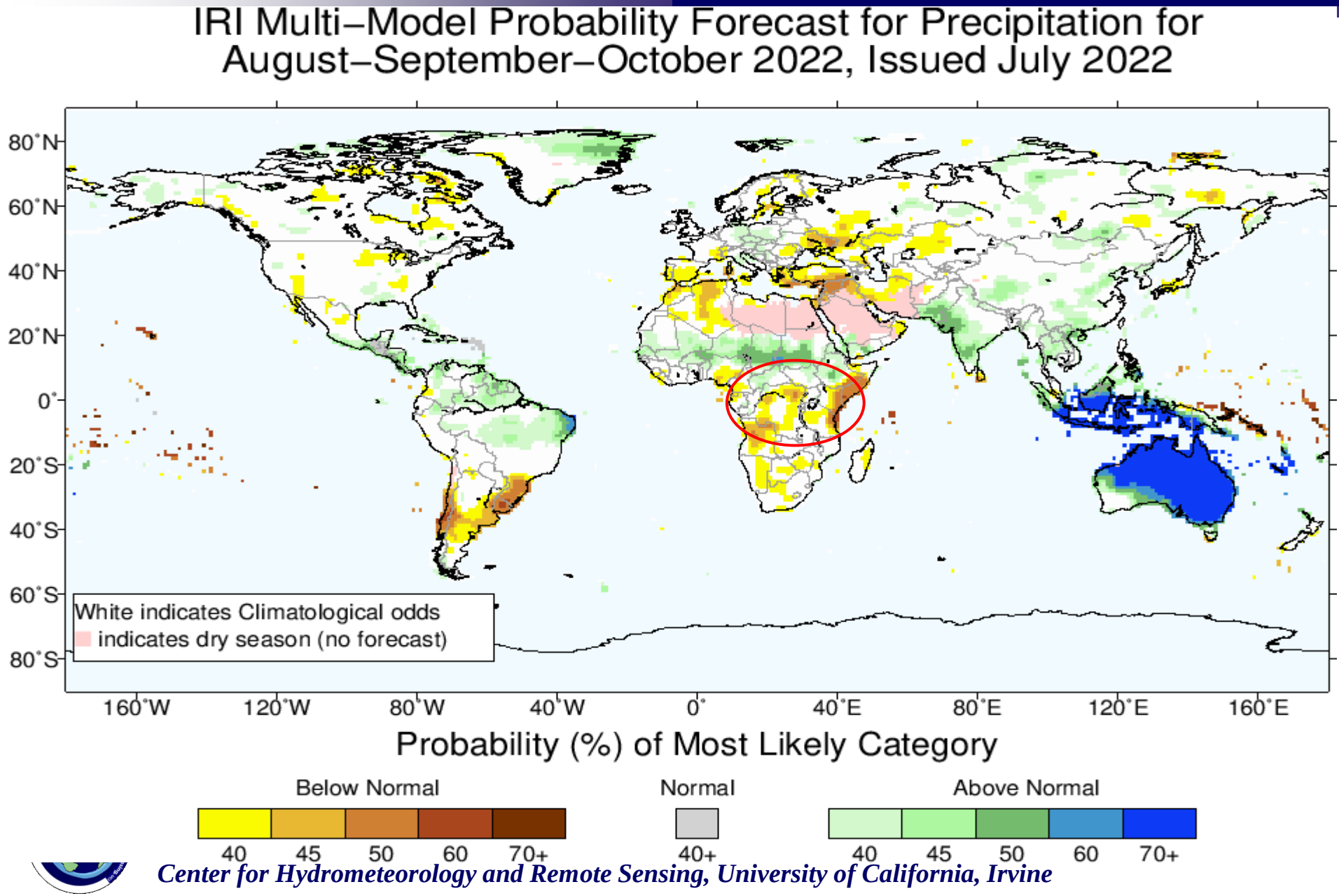
Spring Snow Melt Forecasts

Water Supply Volume

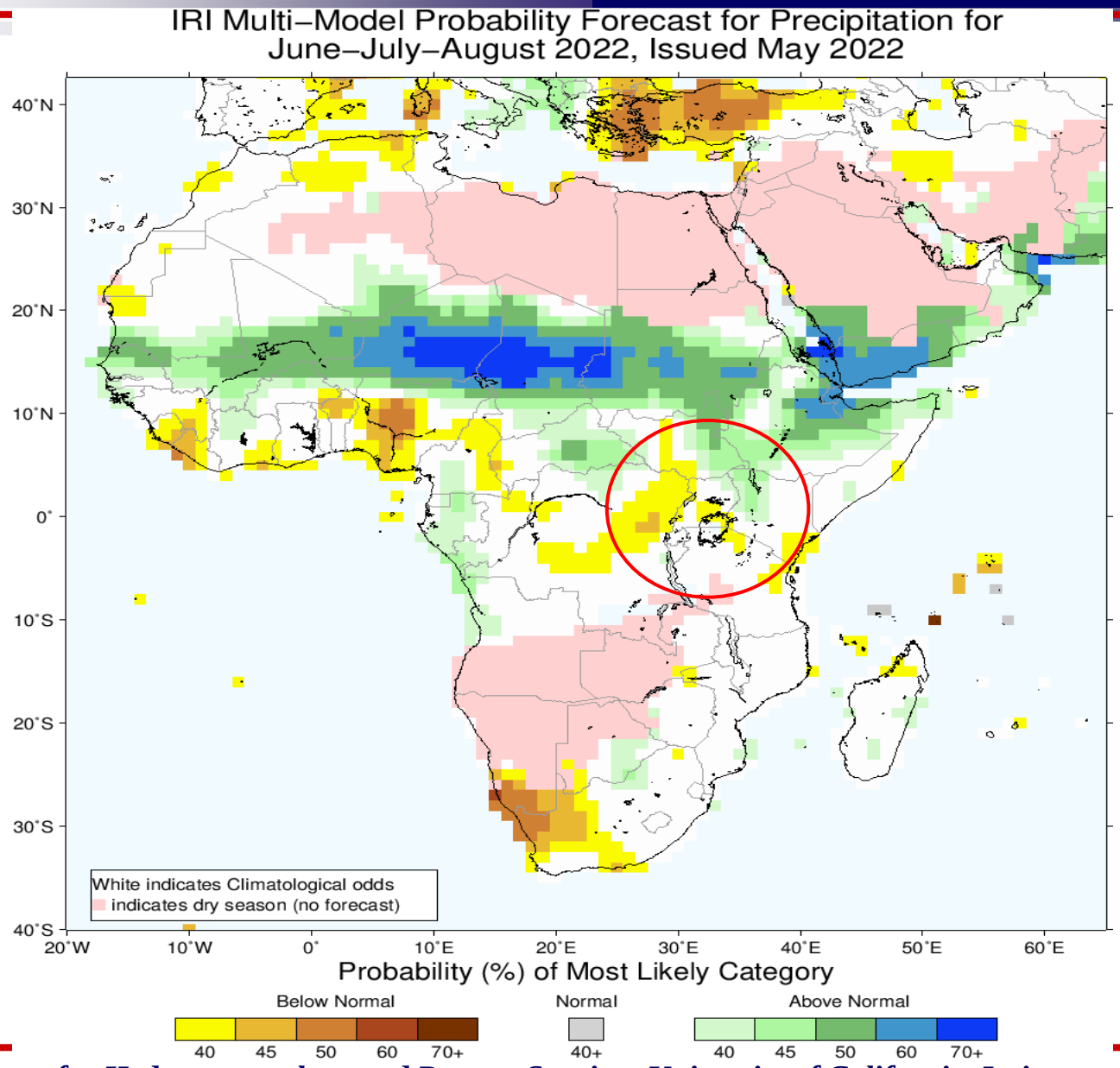
Mid-range

Forecast Requirements

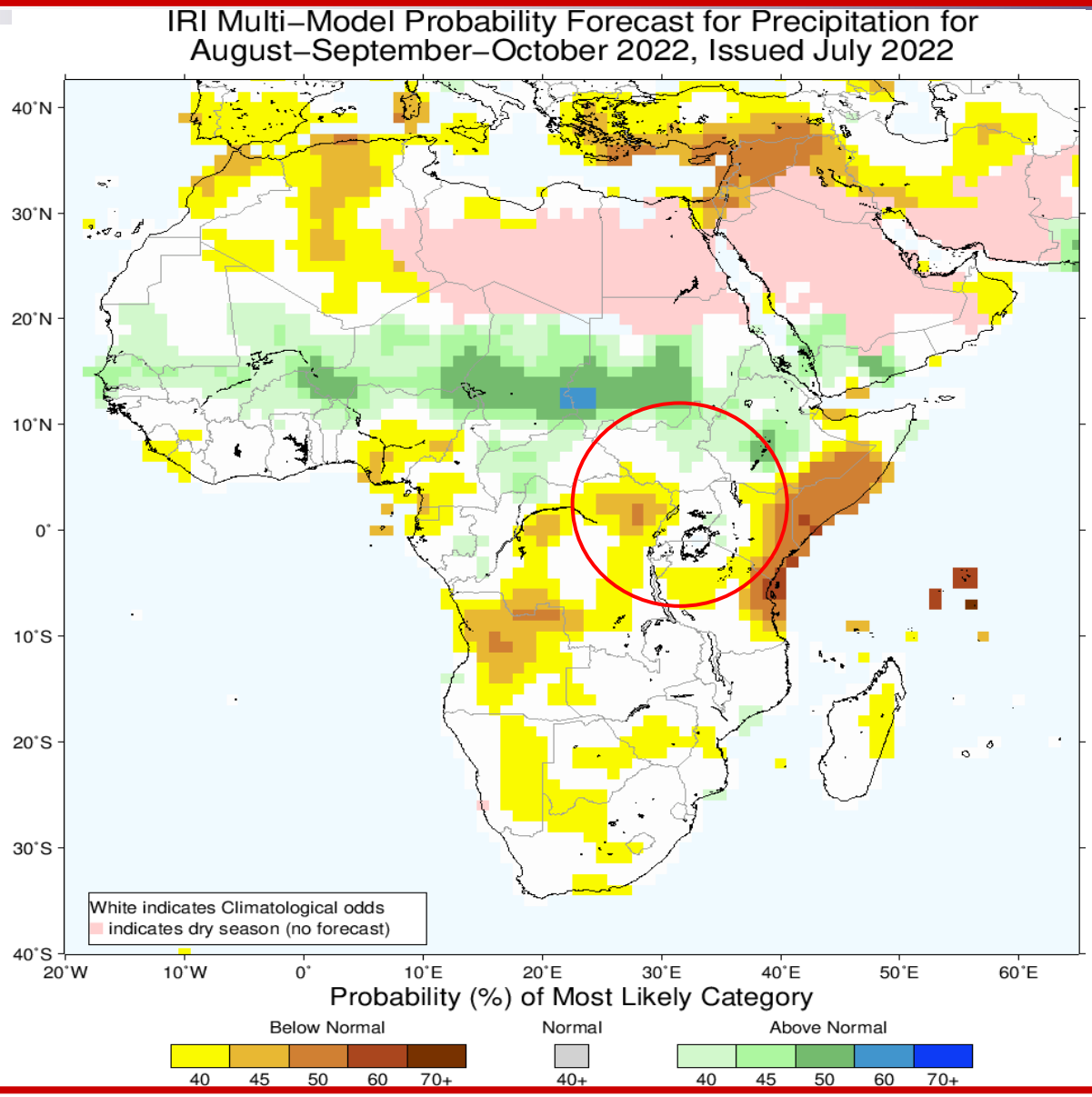
IRI 3-Month Multi-Model Probability Precipitation Forecast



IRI 3-Month Multi-Model Probability Precipitation Forecast



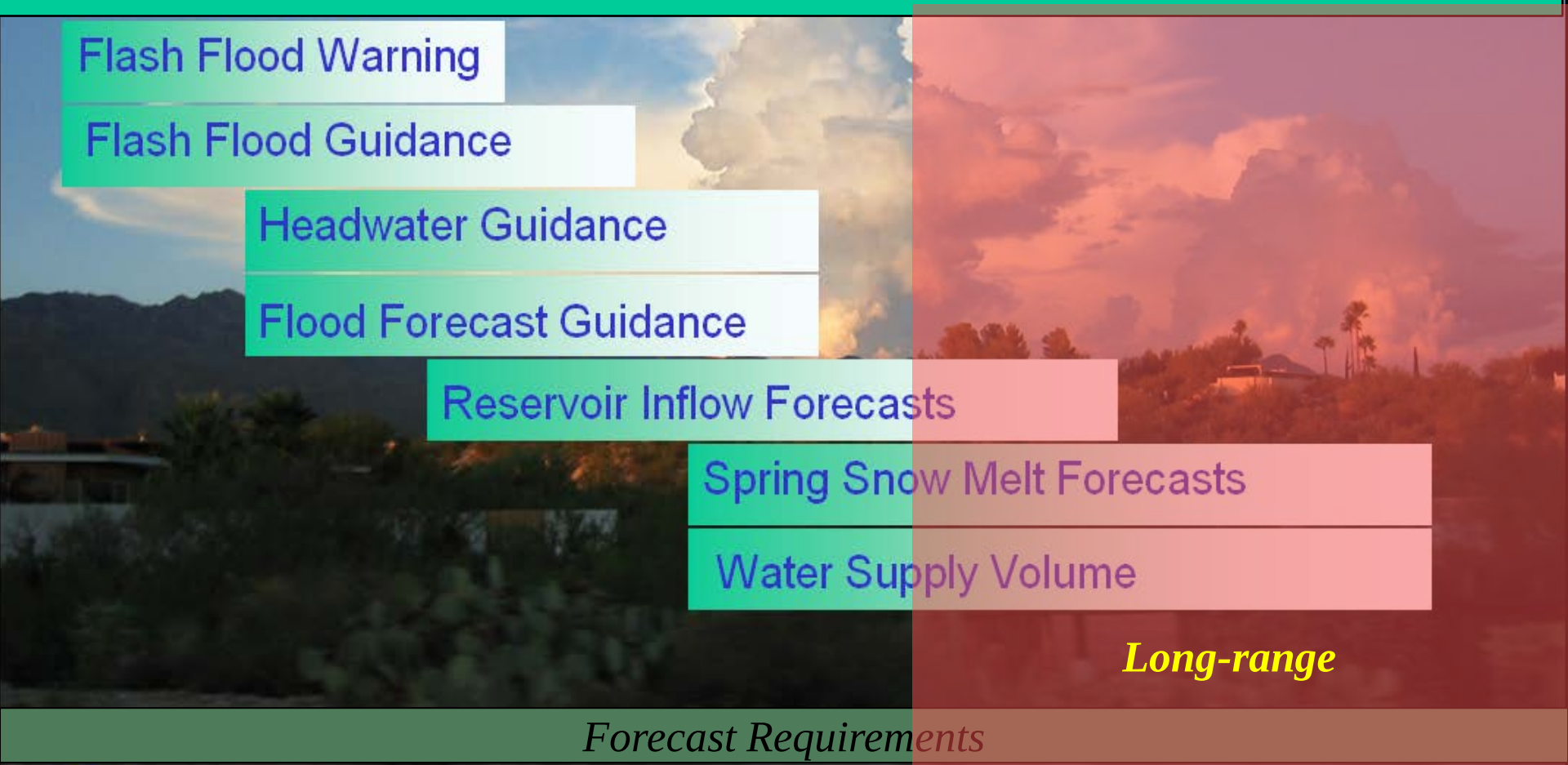
IRI 3-Month Multi-Model Probability Precipitation Forecast



Climate-Scale approaches to addressing hydrologic extremes

Short Range → Long Range

hours → days → weeks → months → seasons → years → decades



Forecast Requirements

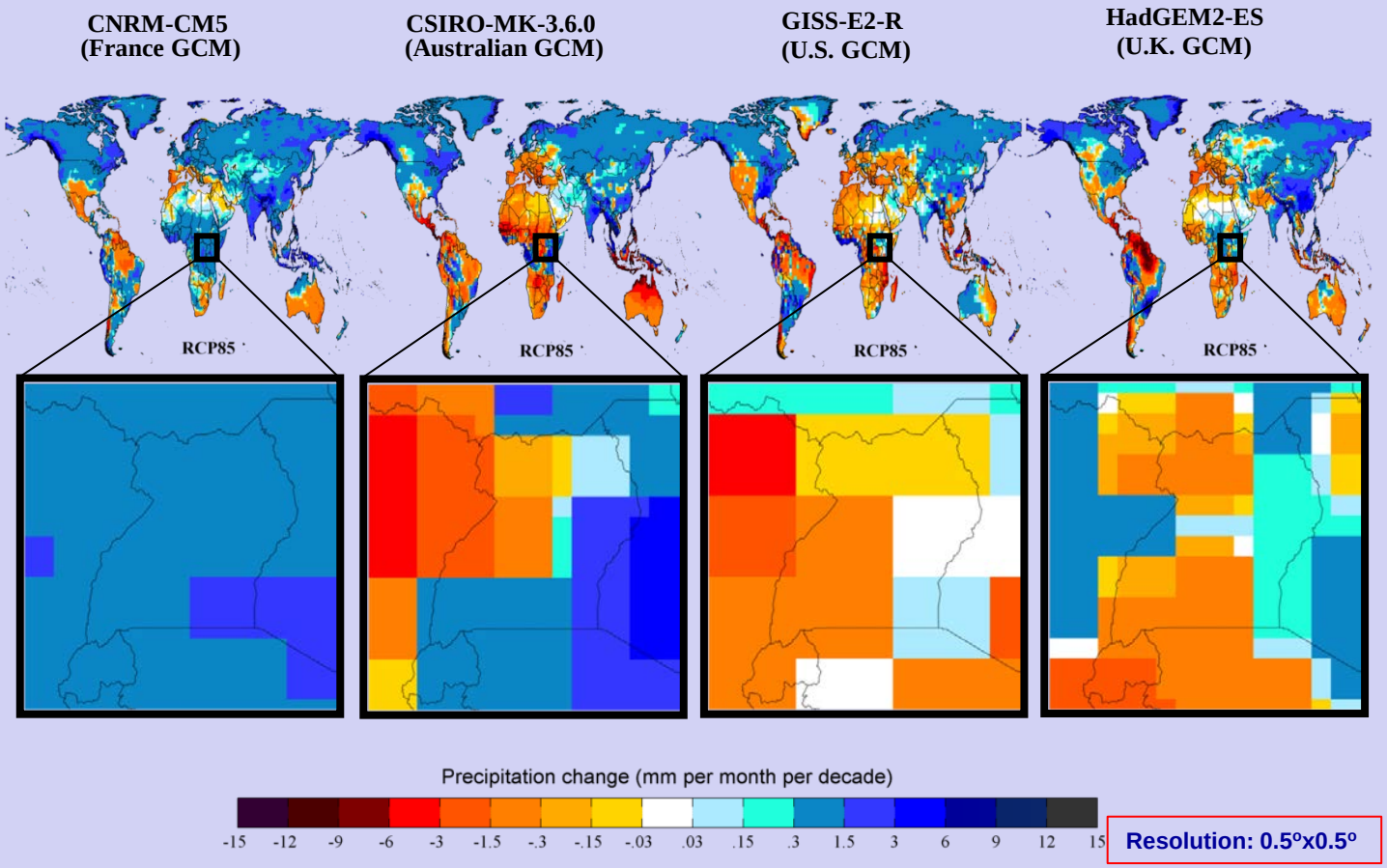
Uganda-Rwanda: future model projections

Dr. Chiyuan Miao - BNU

RCP8.5 ("High": 8.5 W/m^2, Equivalent CO_2 conc. 936 ppm by 2100)

IPCC AR5 Scenarios

Time period: 2006-2099

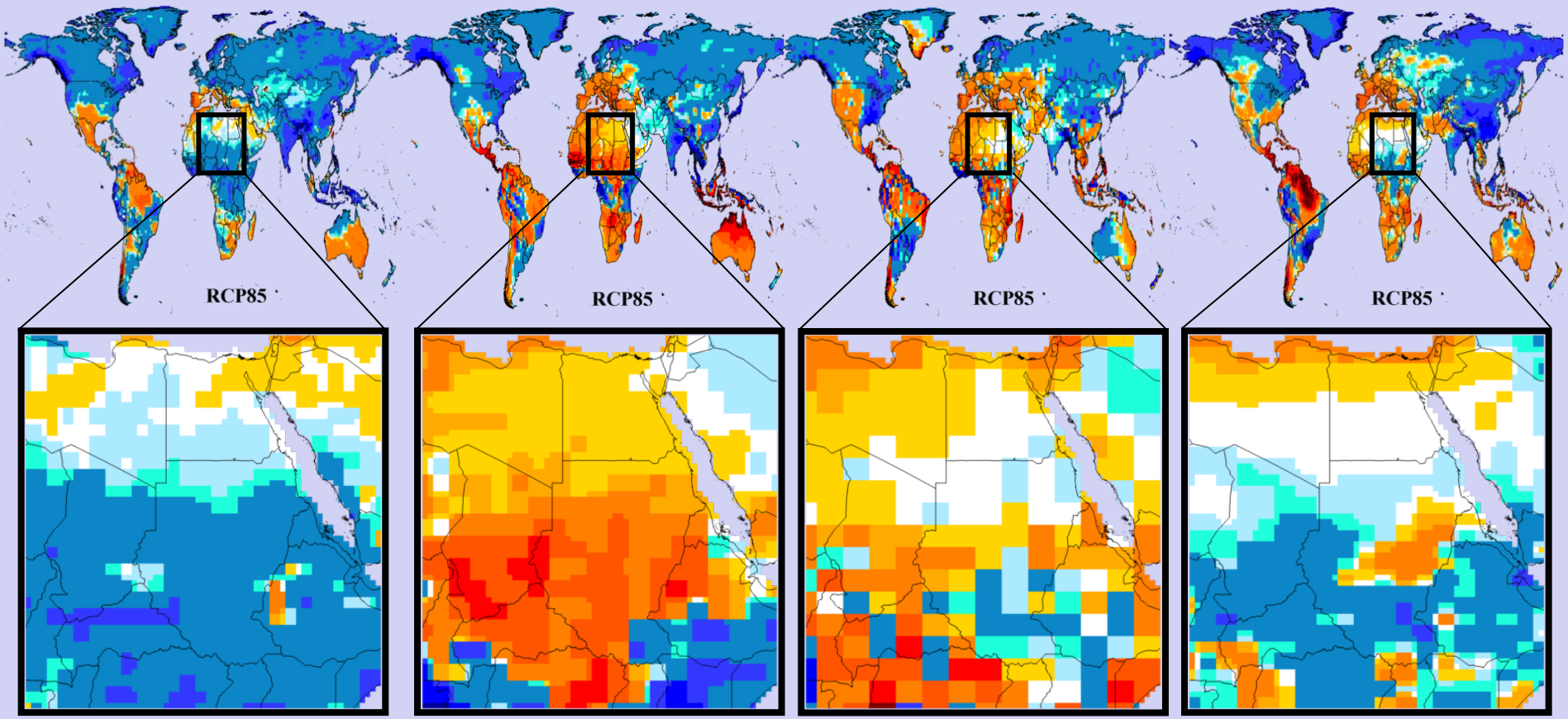


North East Africa

IPCC AR5 Scenarios

Time period: 2006-2099

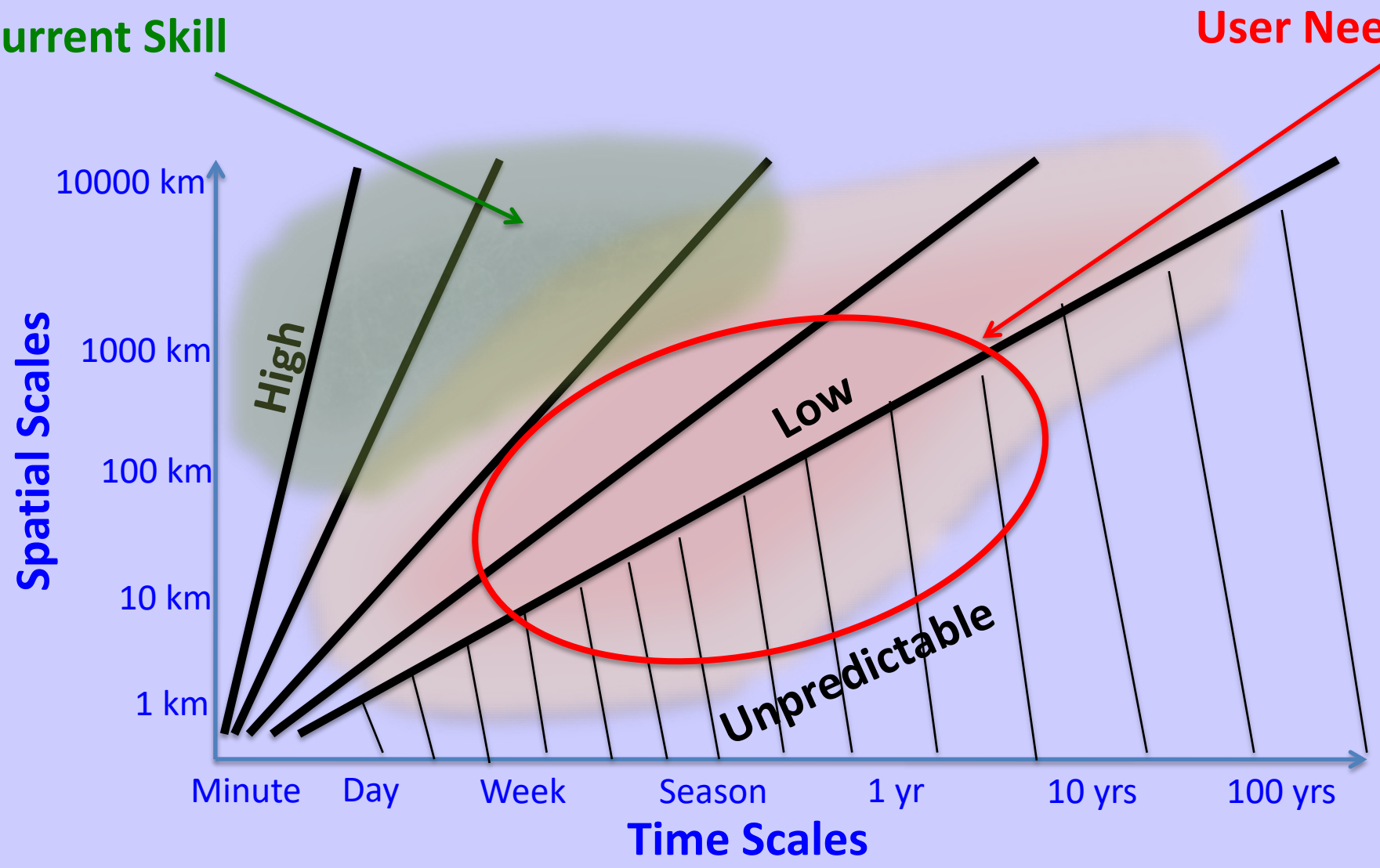
RCP8.5 ("High": 8.5 W/m^2, Equivalent CO_2 conc. 936 ppm by 2100)



Resolution: 0.5°x0.5°

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

Drought Predictability



Provided by Siegfried Schubert 2011

What is the Message?

- *Presently, the accuracy of Hydroclimate model predictions fall short of meeting the requirements of water resources planning.*

- *Hardly used for operational Purposes and unwise to push their use while highly uncertain.*

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

Primary Solution To Satisfy Water Resources Needs and Address Hydrologic Extremes

Engineering Approach:

Control, Store, Pump, Transfer and a lot more!

A Century of Water Resources Development: Engineering success

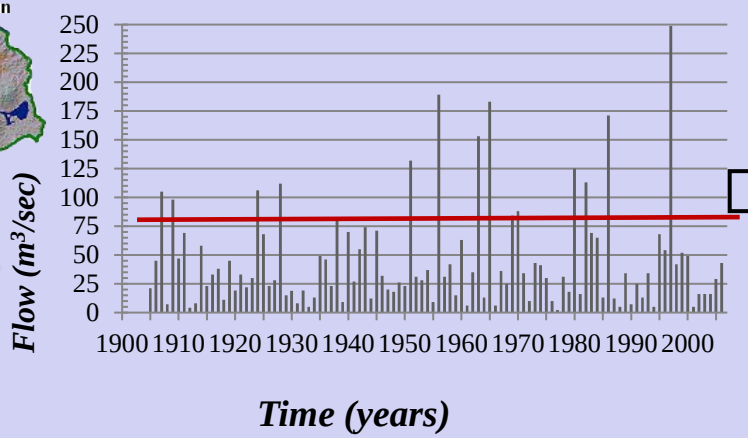
Central Arizona Project Aqueduct

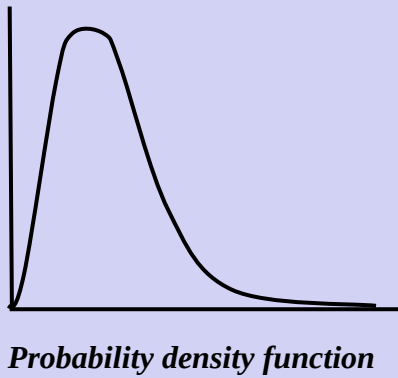
Addressing "Extremes" in Water Resources Planning:

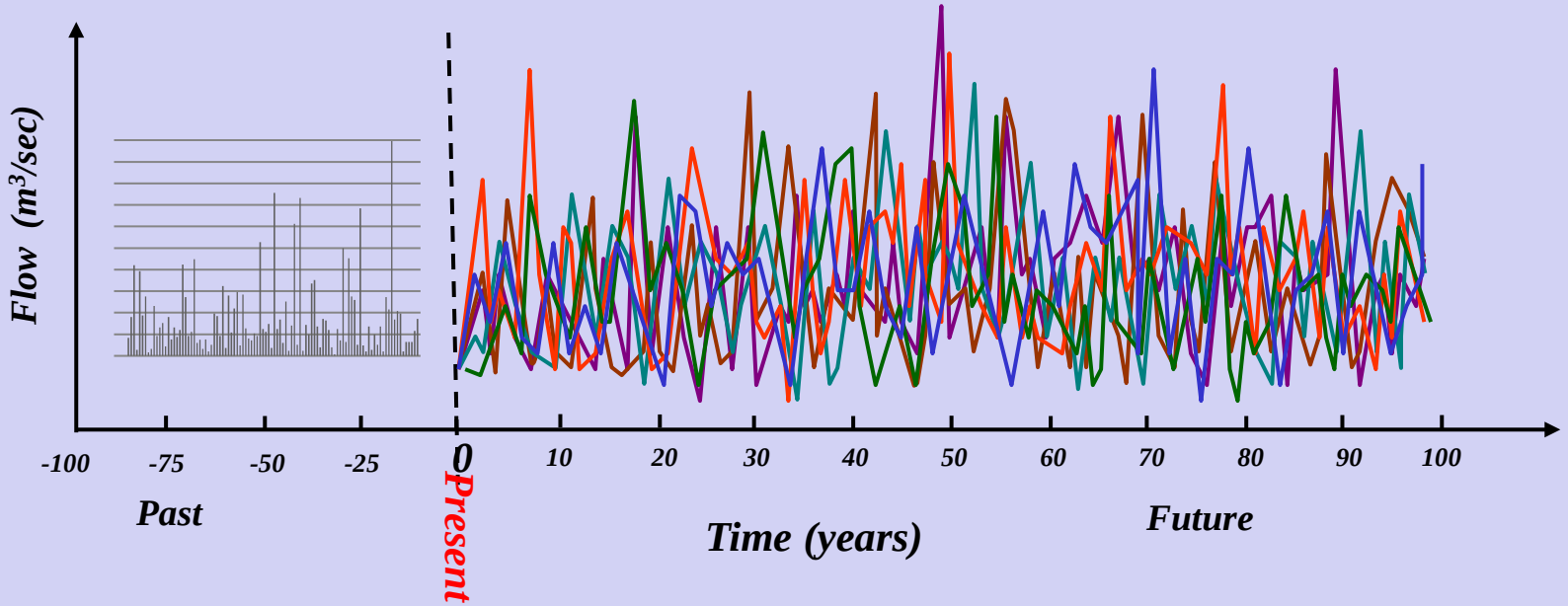
Statistical/Stochastic Hydrology

CENTER FOR HYDROMETEOROLOGY & REMOTE SENSING
CHRS
UCIrvine

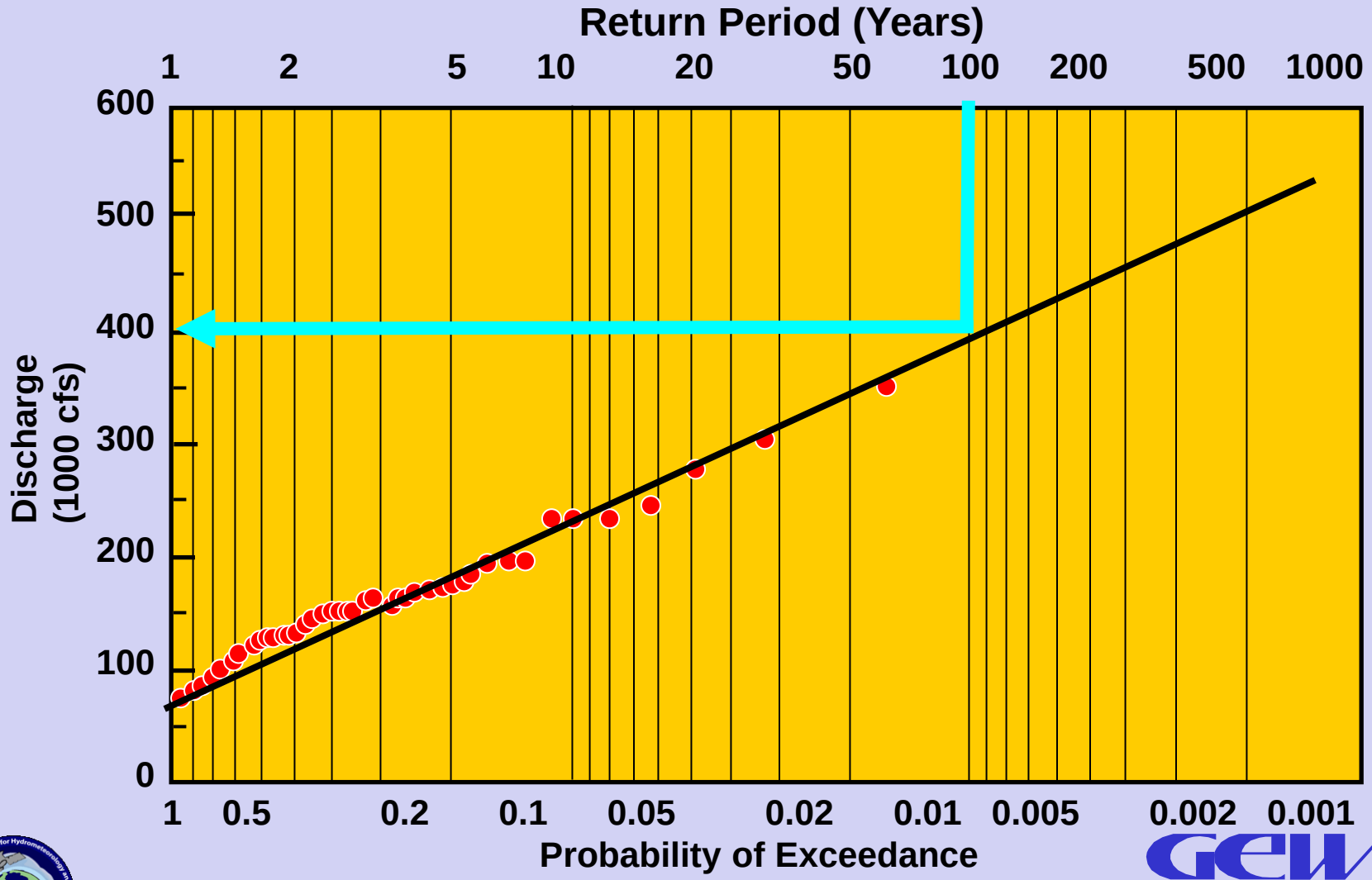
Statistical Hydrology: "synthetic" stream flow Generation



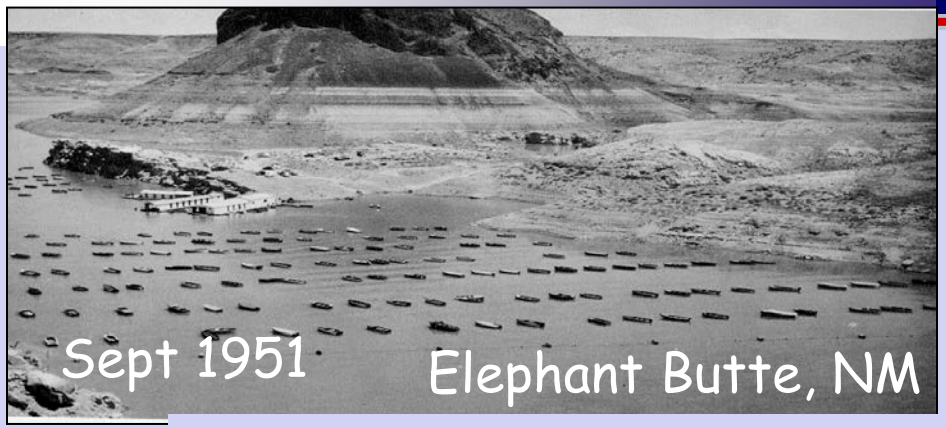


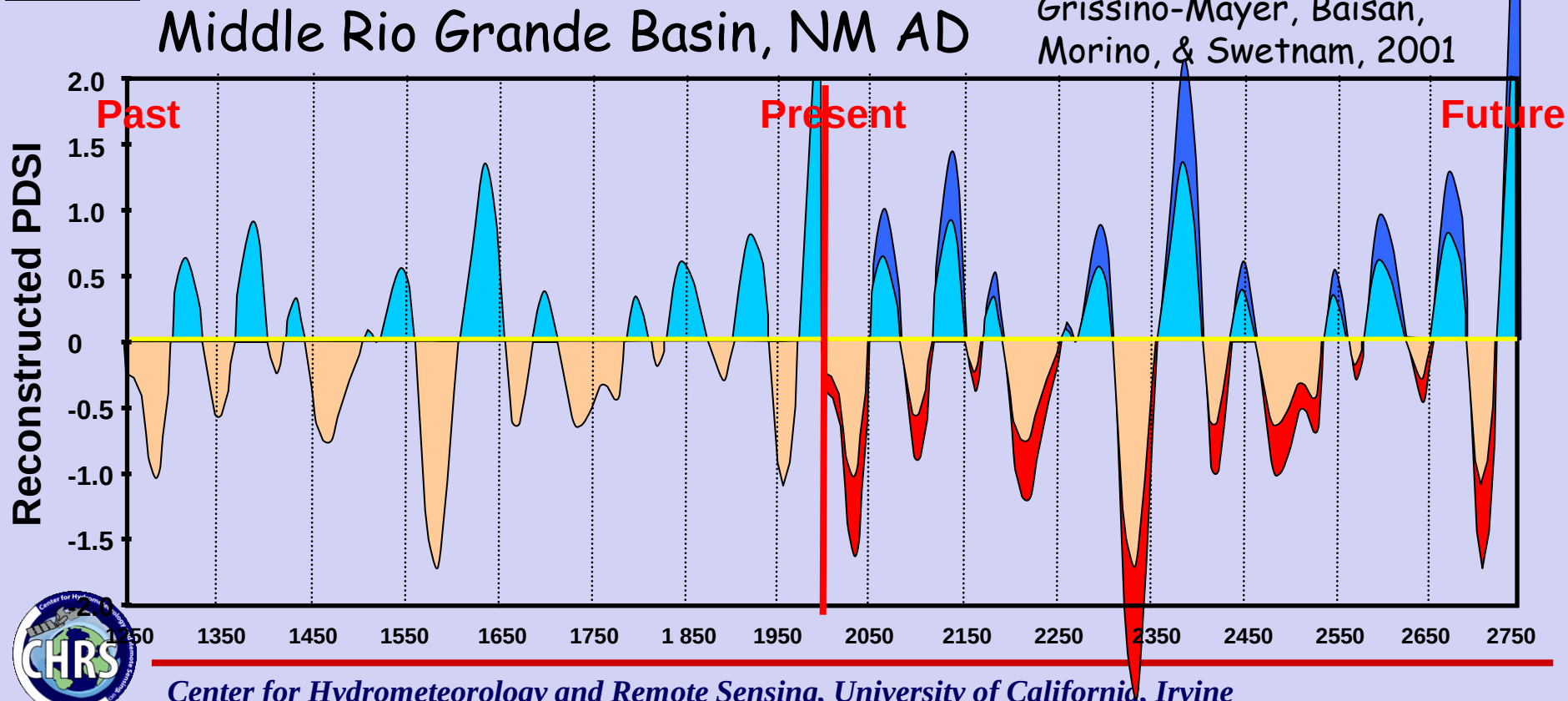


Flood Frequency Analysis: Stationarity!



Statistical Hydrology Developed Based on Stationarity Assumption

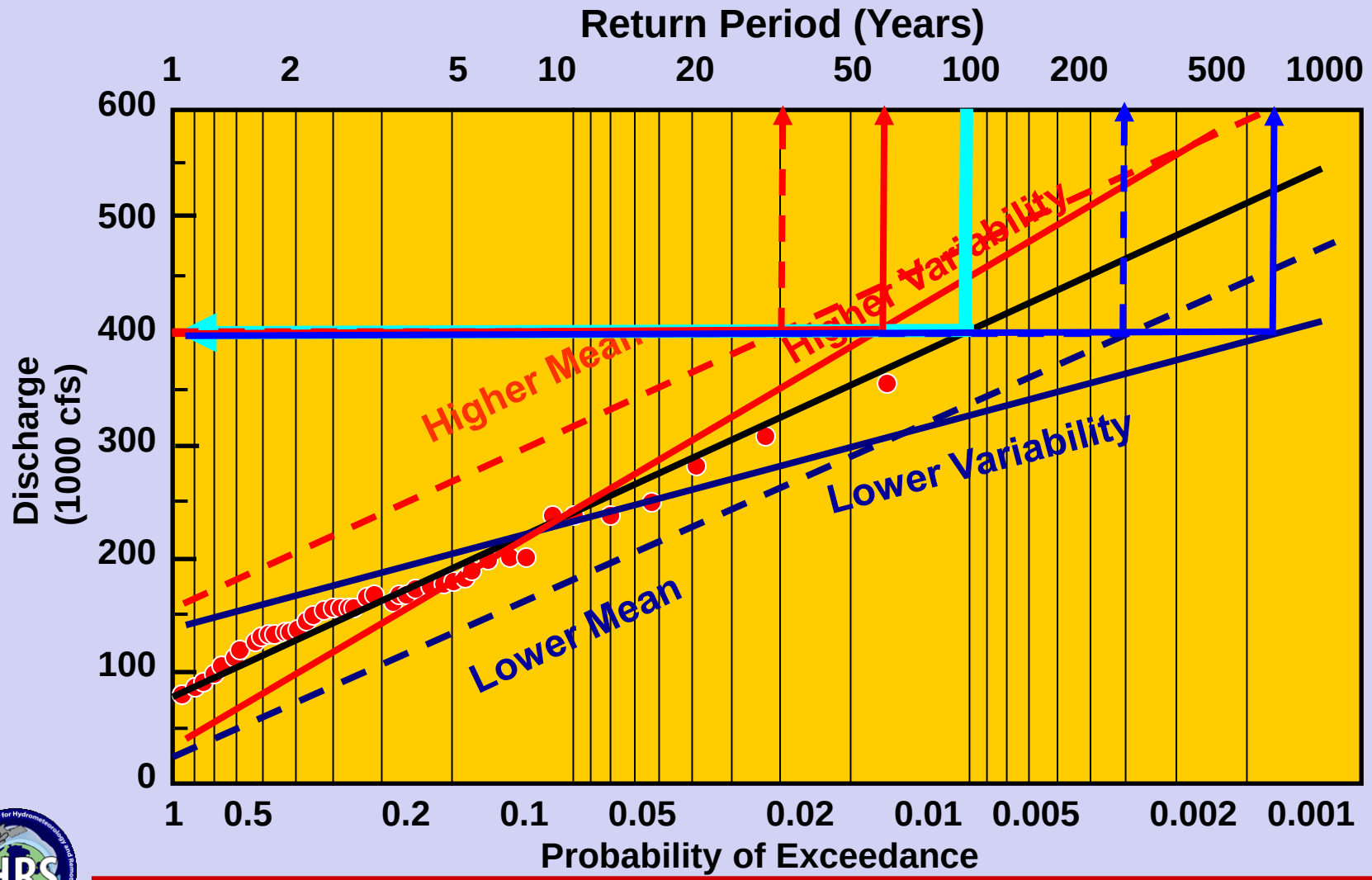




Potential Hydrologic Scenarios

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

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



Required Hydrometeorological Predictions

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

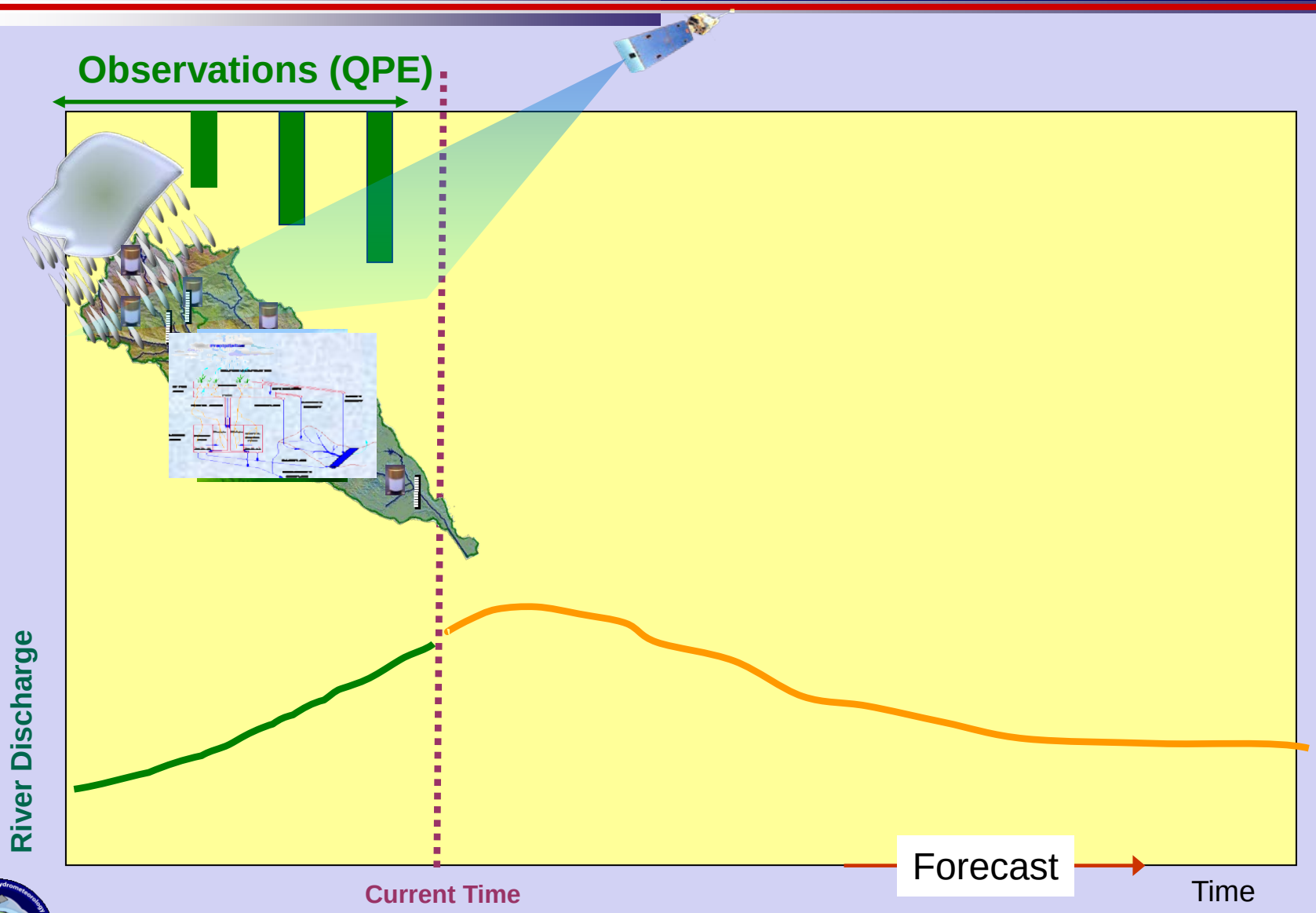
Spring River Flow Forecasts

Water Supply Volume

Short-range

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

Common practice in Flood and River Flow Forecasting



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

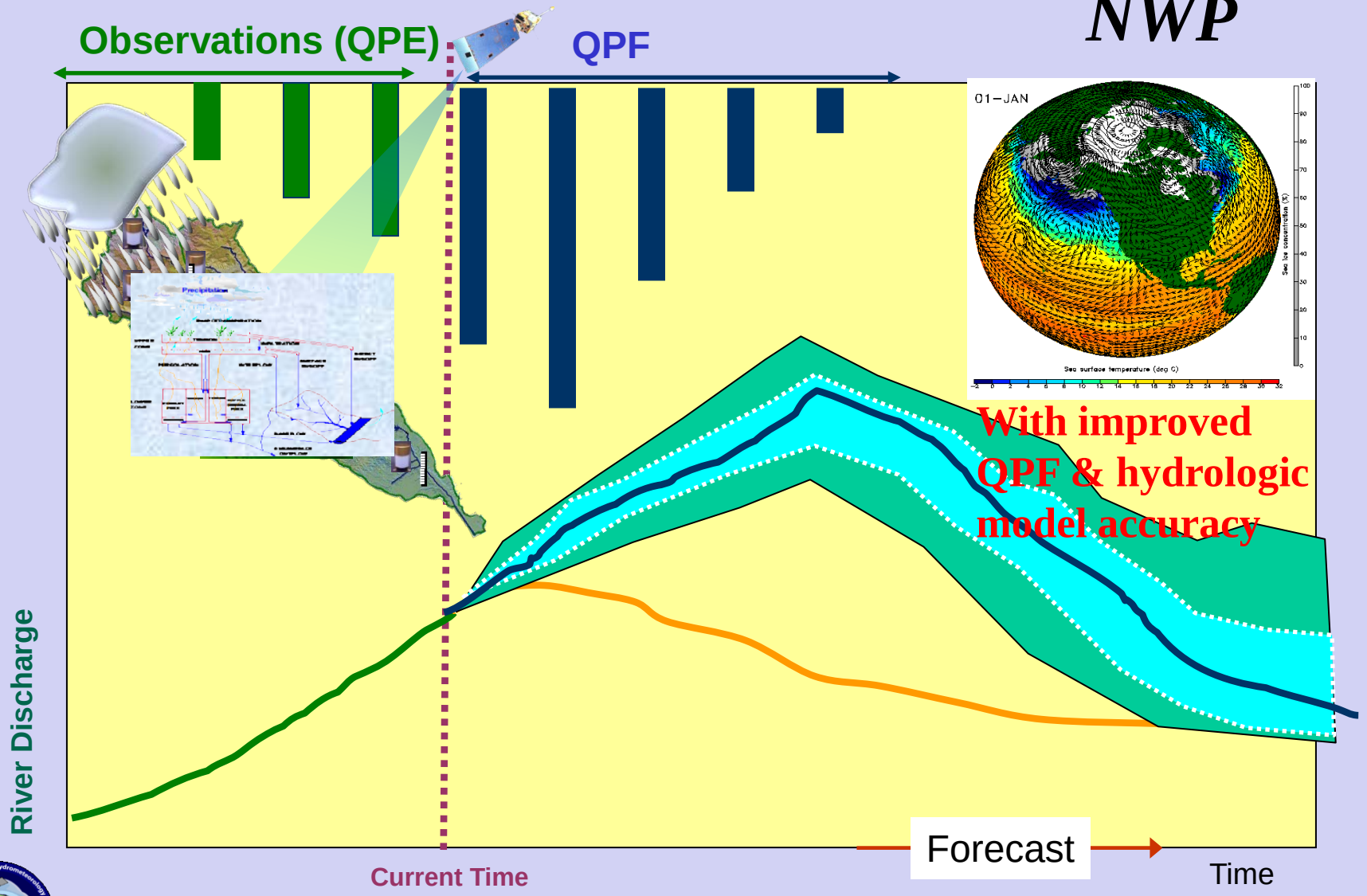
Extending the Short-term flood Forecasts

Estimating Future "Short-Term" Rainfall:

1- Models: (NWP - QPF)

2- Extrapolation-based Nowcasting

Efforts in Extending the Forecast Lead Time

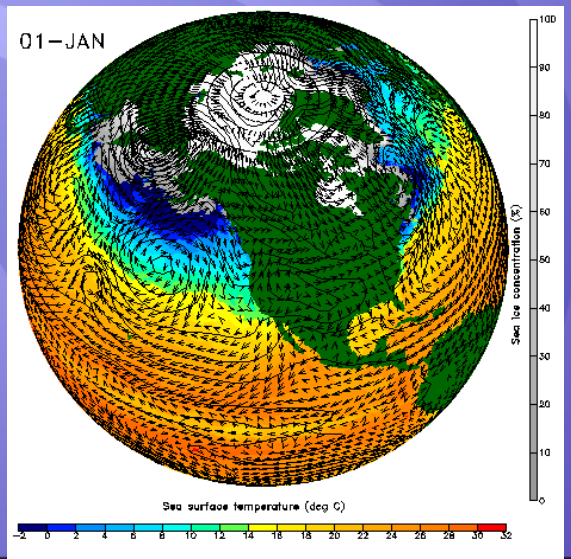


Animation Assisted by: Q. Xia, Gi-H. Park & L. Bastidas

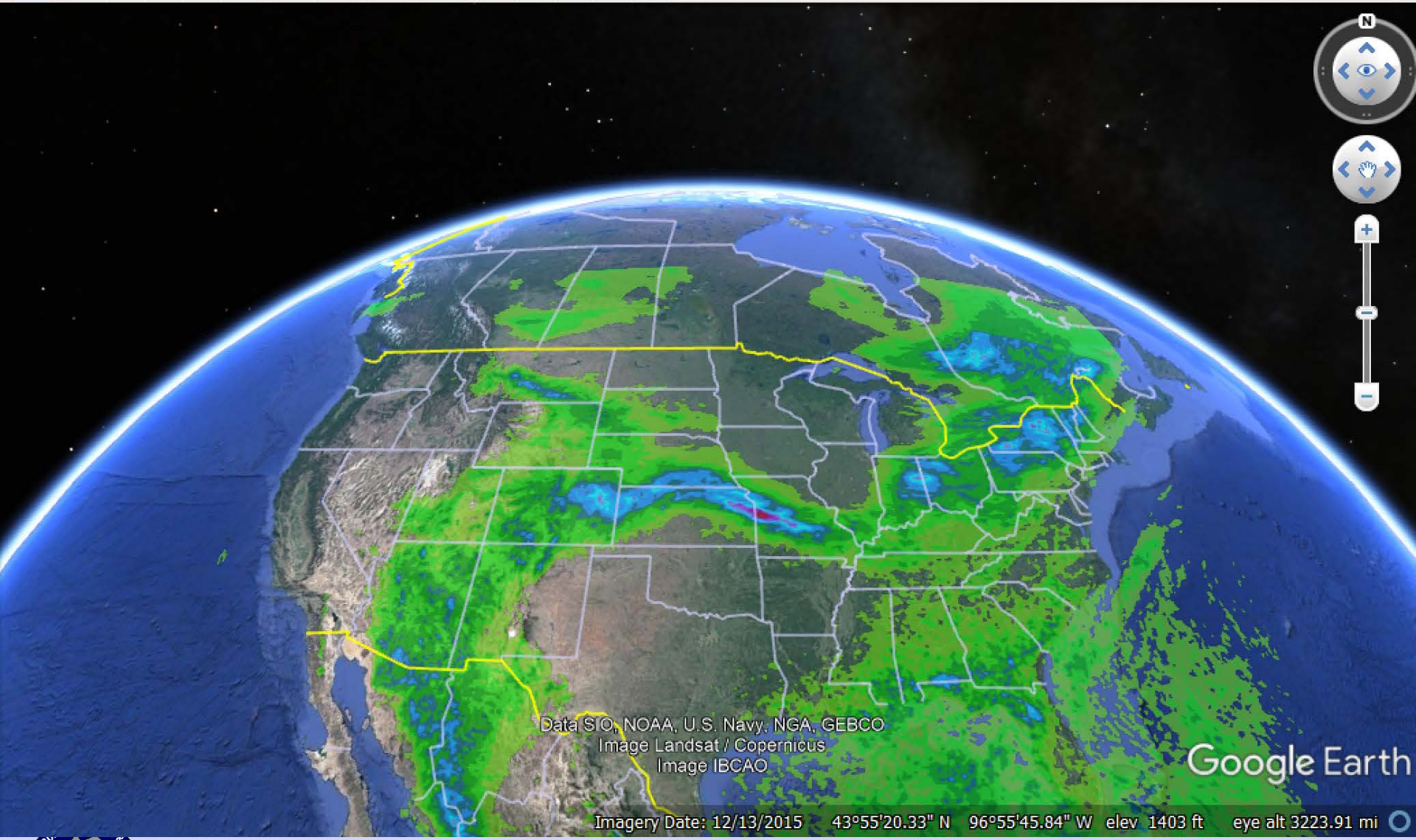
Center for Hydrometeorology and Remote Sensing, University of California, Irvine

Progress in QPF to extend the lead time of hydrologic forecasts

NWP

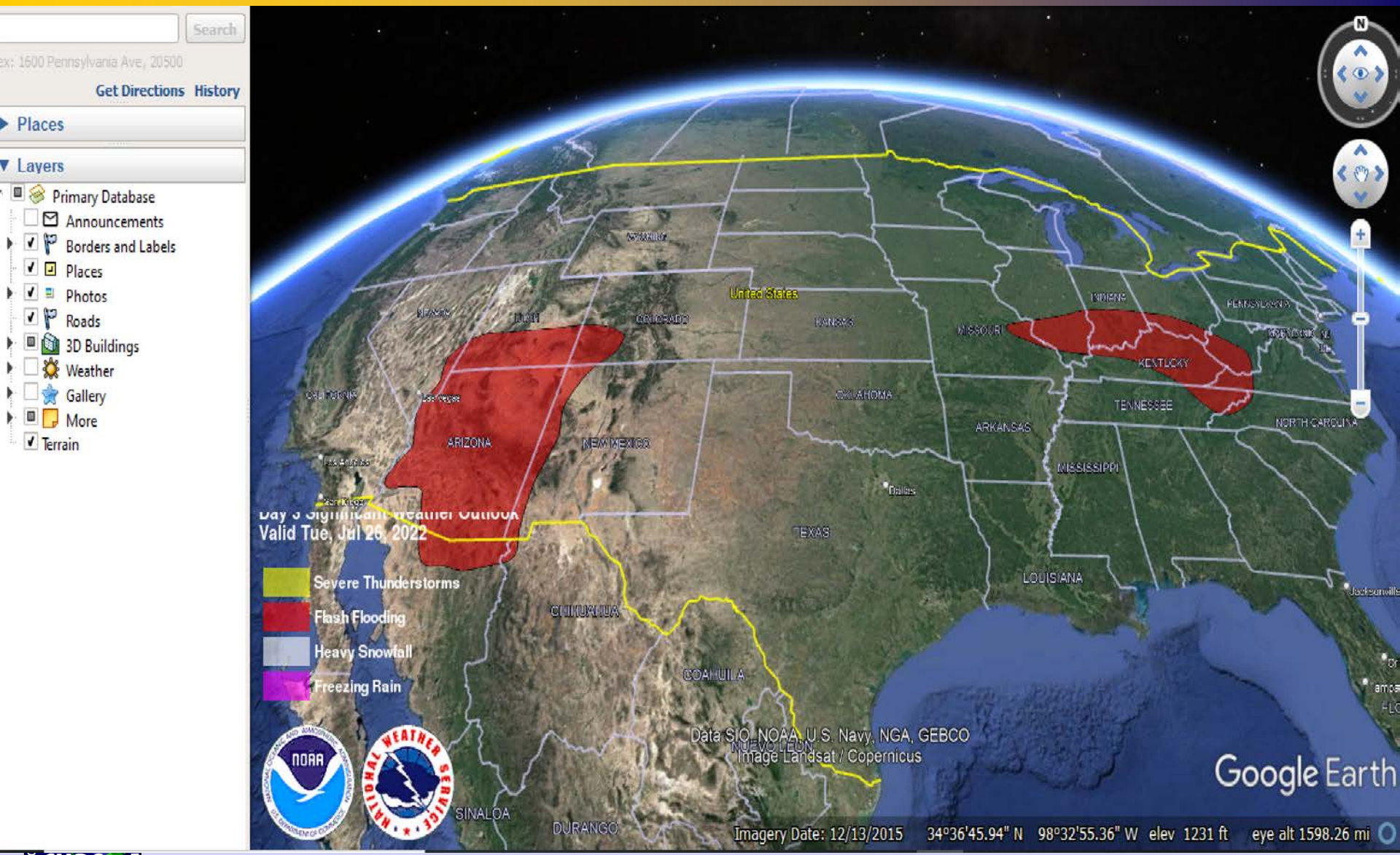


Quantitative Precipitation 24 Hour Forecast (QPF): Issued July 24 2022



Source: NWS-WPC website:https://www.wpc.ncep.noaa.gov/kml/kmlproducts.php#qpf

Day 3 Significant Weather Forecast valid for Tue, Jul 26, 2022



Watches and Warnings

NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

HOME | FORECAST | PAST WEATHER | SAFETY | INFORMATION | EDUCATION | NEWS | SEARCH | ABOUT

Local forecast by "City, St" or ZIP code
Enter location ... Go
Location Help

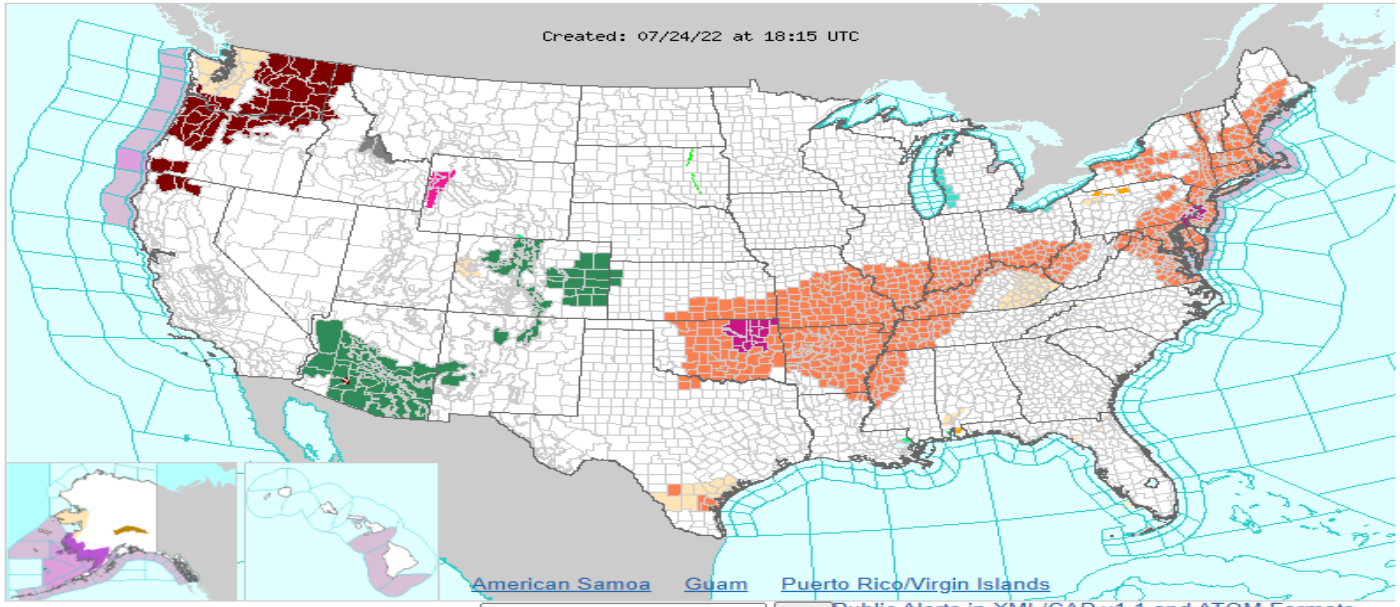
Intense Heat Continues; Severe Weather and Flooding Possible

Intense heat will continue in portions of the U.S. with numerous record high temperatures in the Northeast and Mid-Atlantic and oppressive heat indices from the East to the southern Plains. Severe thunderstorms capable of producing flash flooding will be possible in the eastern Great Lakes and Northeast. Flash flooding is also possible in the Four Corners region from monsoon showers/storms. Read More >

WRN

ACTIVE ALERTS | FORECAST MAPS | RADAR | RIVERS, LAKES, RAINFALL | AIR QUALITY | SATELLITE | PAST WEATHER

Customize Your Weather.gov
City, ST
Enter Your City, ST or ZIP Code
Remember Me
Get Weather
Privacy Policy

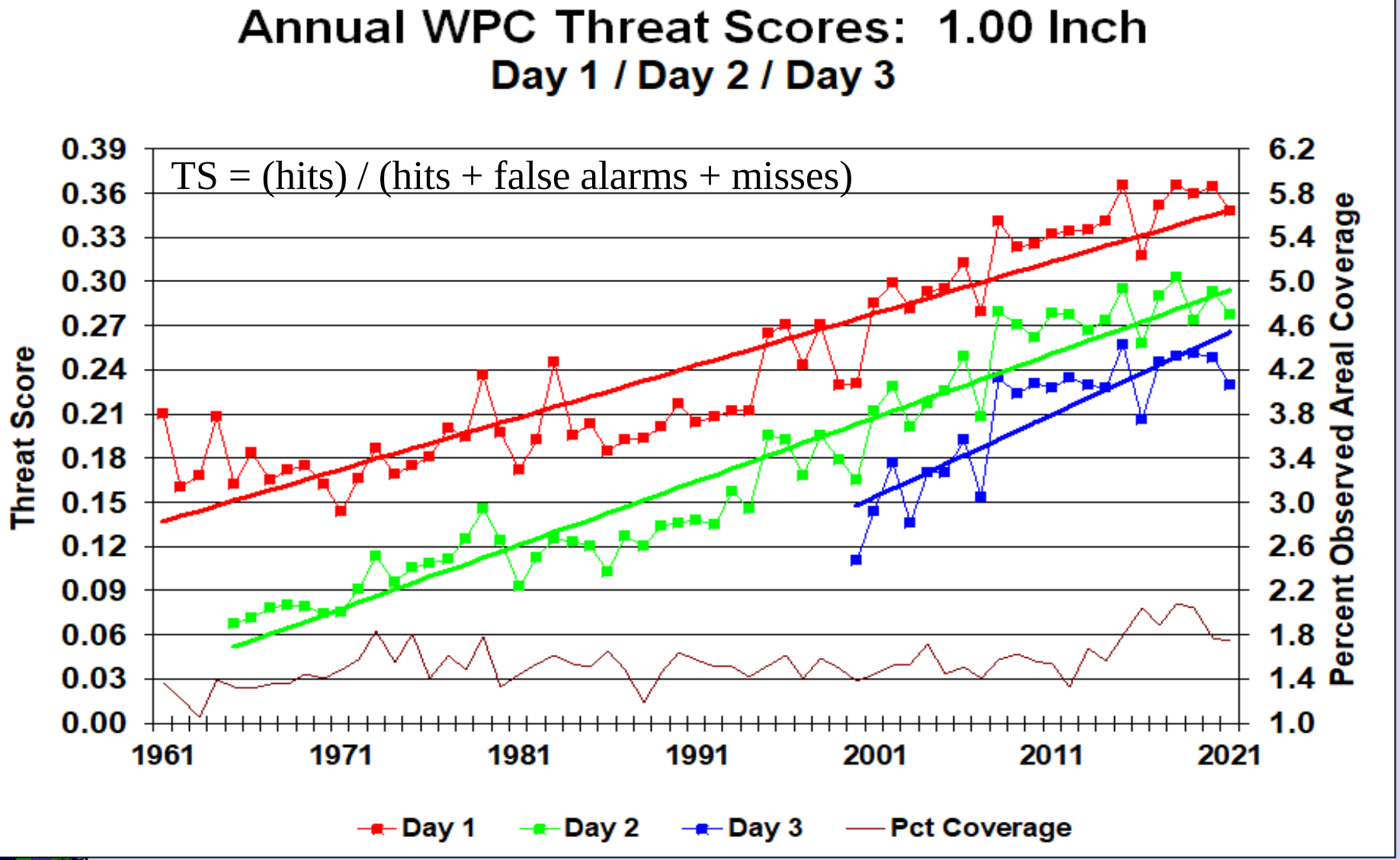


Click on the map above for detailed alerts or Warnings By State Go Public Alerts in XML/CAP v1.1 and ATOM Formats

- Severe Thunderstorm Warning
- Flash Flood Warning
- Flood Warning
- Excessive Heat Warning
- Flash Flood Watch
- Gale Warning
- Red Flag Warning
- Heat Advisory
- Flood Advisory
- High Surf Advisory
- Small Craft Advisory
- Rip Current Statement
- Beach Hazards Statement
- Flood Watch
- High Wind Watch
- Excessive Heat Watch
- Special Weather Statement
- Marine Weather Statement
- Air Quality Alert

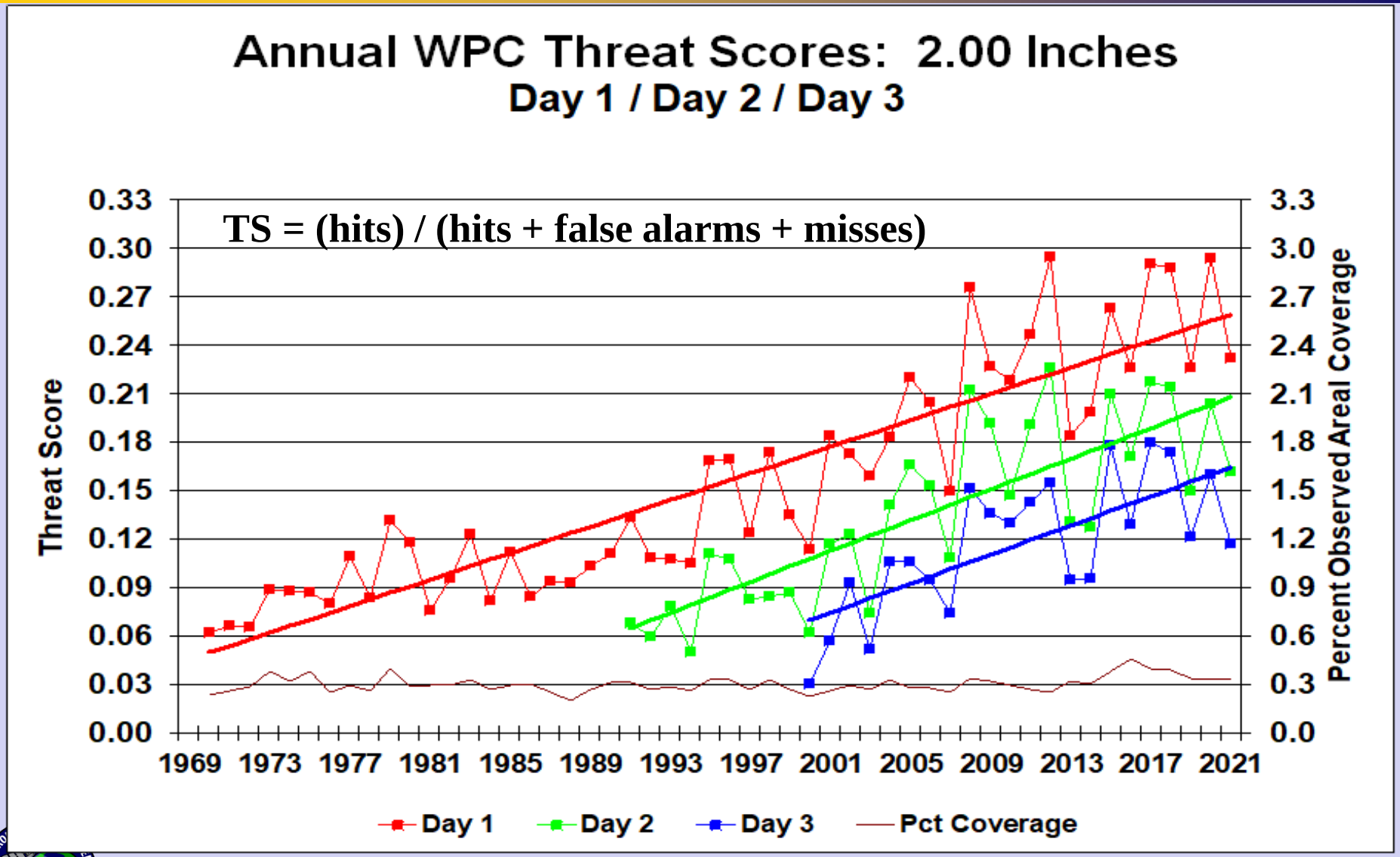
HPC QPF verification: 1-inch threat score

https://www.wpc.ncep.noaa.gov/images/hpcvrf/wpc10yr.gif

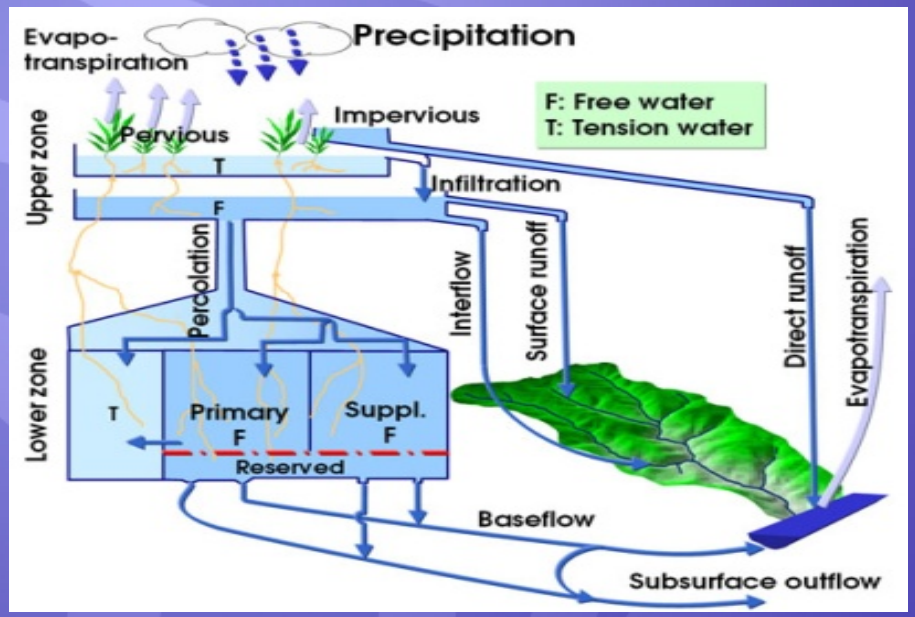


HPC QPF verification *2-inch threat score*

https://www.wpc.ncep.noaa.gov/images/hpcvrf/wpc10vr.gif



Progress in hydrologic modeling

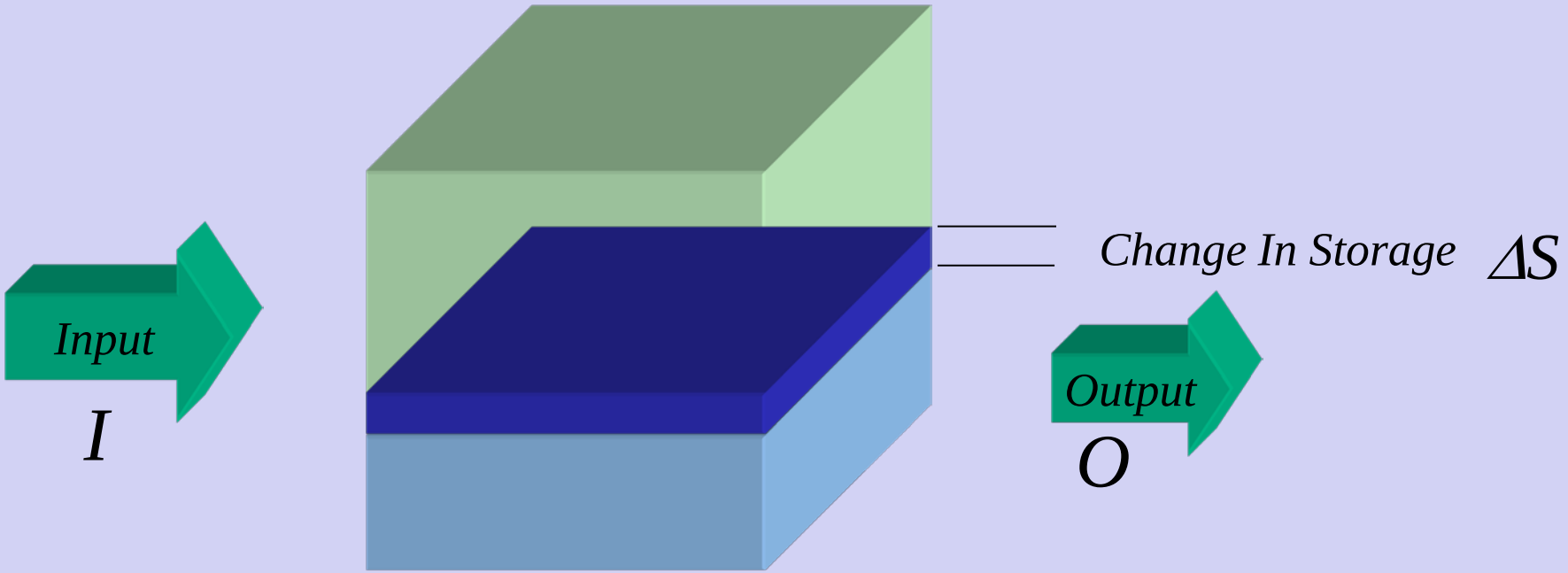


Brief Review of Rainfall Runoff modeling:

Progress in Hydrologic Modeling

CENTER FOR HYDROMETEOROLOGY & REMOTE SENSING
CHRS
UCIrvine

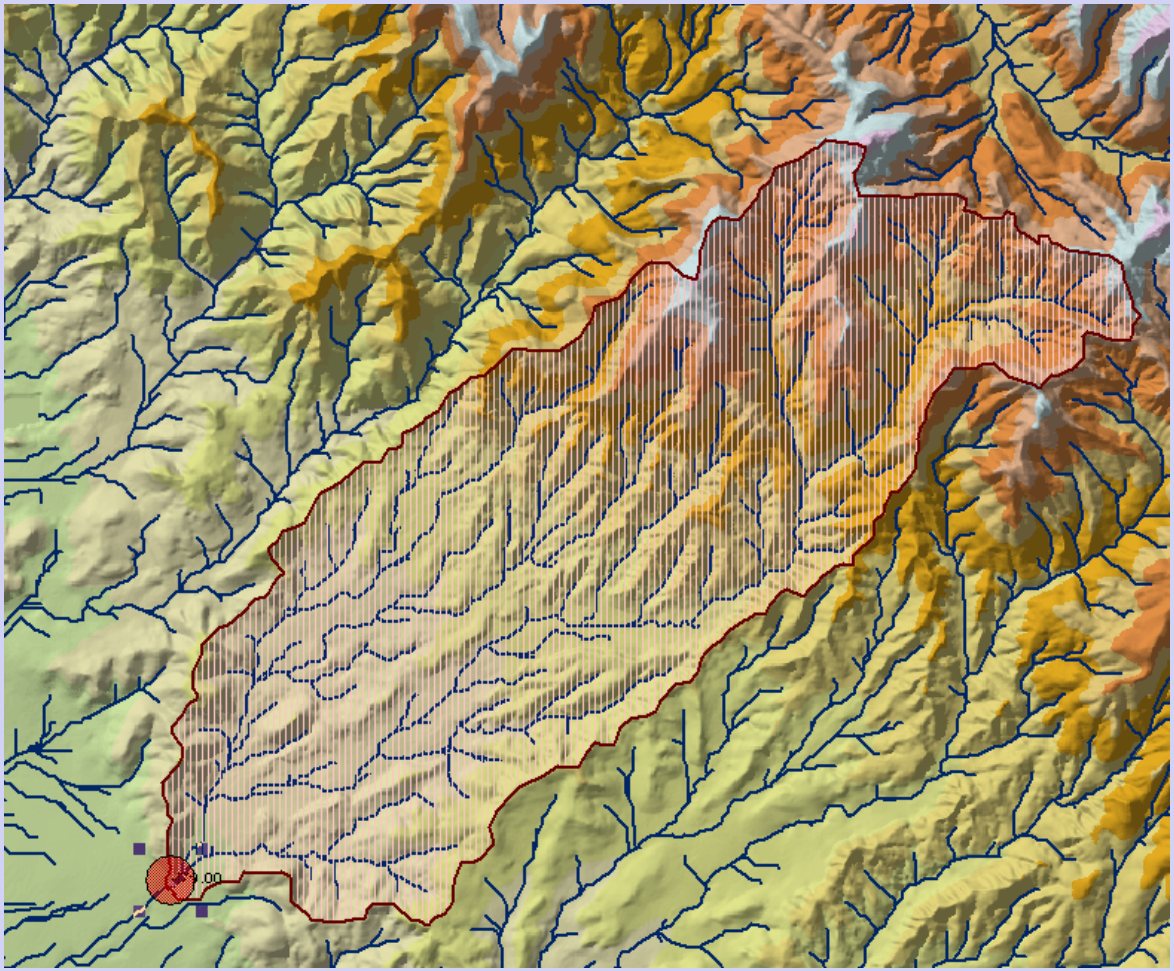
Fundamental Law

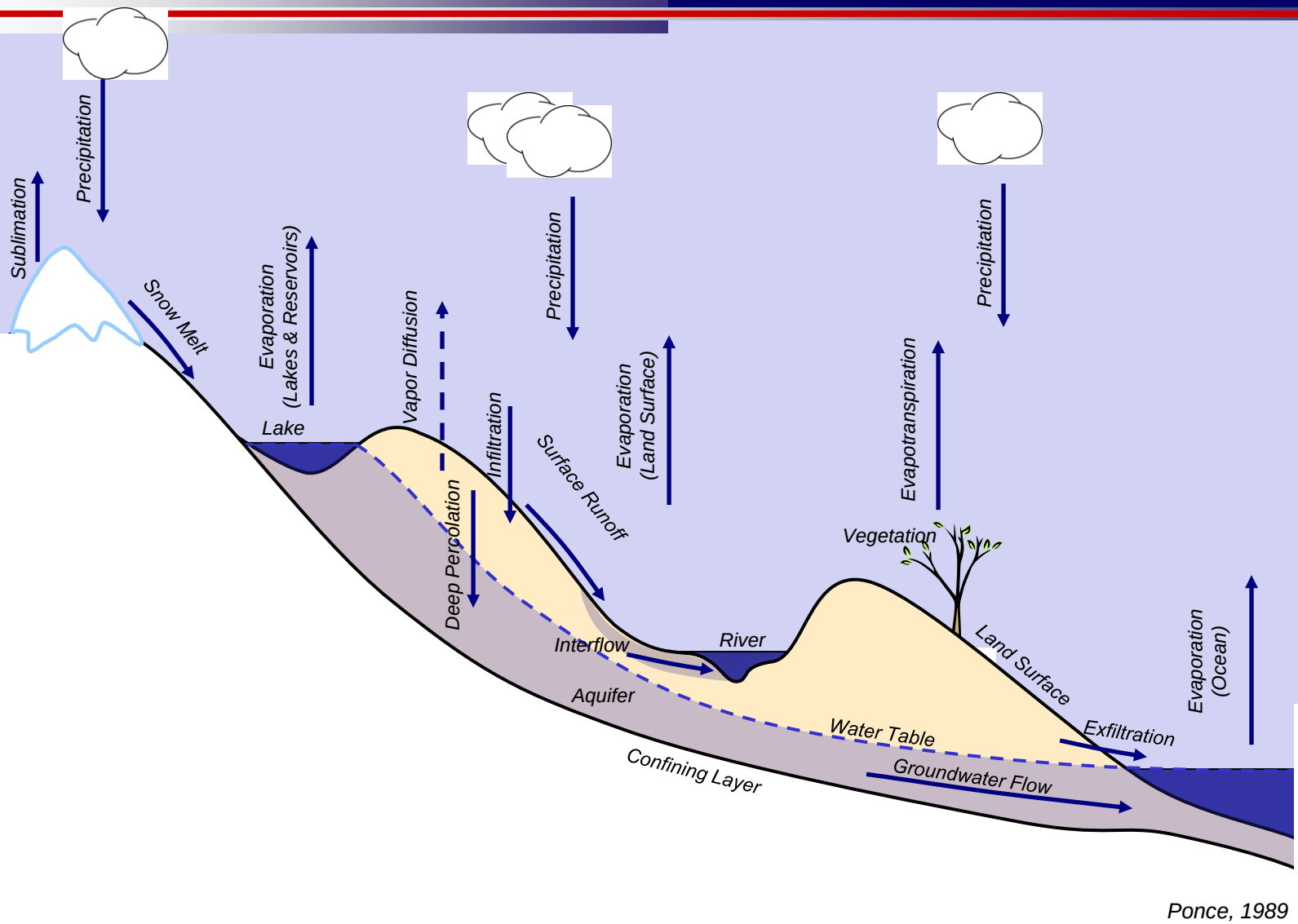


$$I - O = \Delta S$$

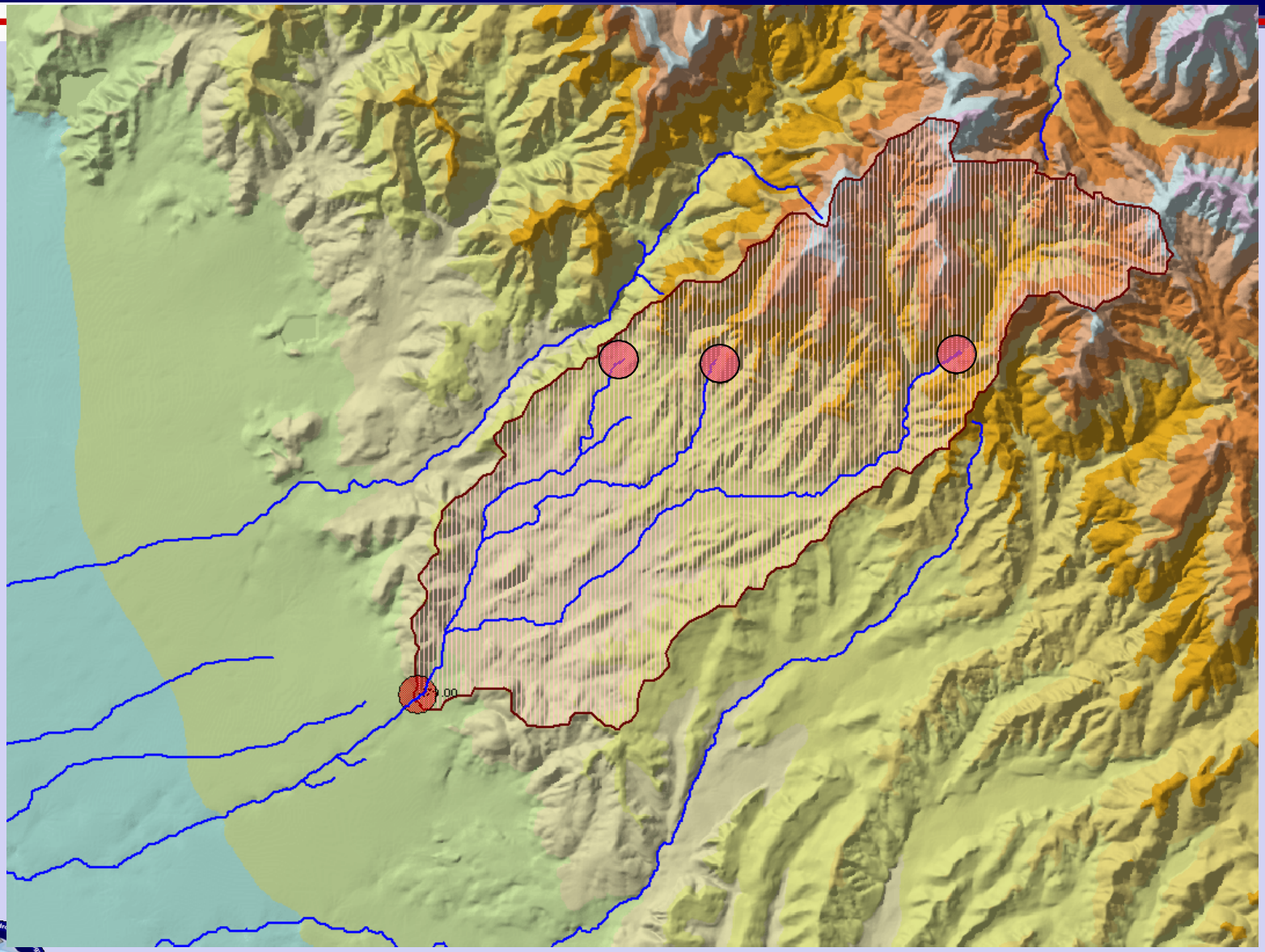
The Watershed

Area km2	12.78
Perimeter km	19.344
Min Elevation m	478.00
Max Elevation m	1756.00
Mean Elevation	930.34
Max Flow Length	8.878

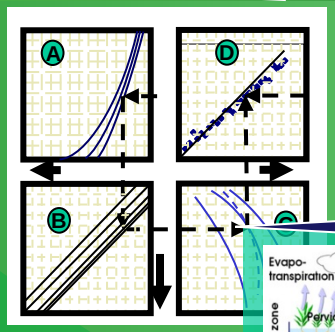



Precipitation
Sublimation
Snow Melt
Evaporation (Lakes & Reservoirs)
Lake
Vapor Diffusion
Infiltration
Deep Percolation
Surface Runoff
Precipitation
Evaporation (Land Surface)
Evapotranspiration
Vegetation
Precipitation
Interflow
River
Land Surface
Evaporation (Ocean)
Aquifer
Water Table
Exfiltration
Confining Layer
Groundwater Flow
Ponce, 1989

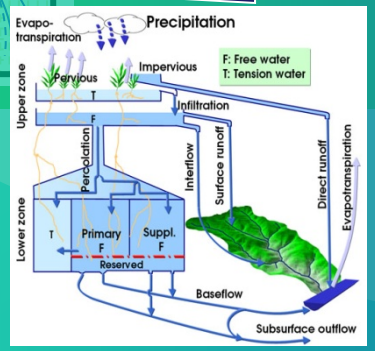
Trace The Water Drop



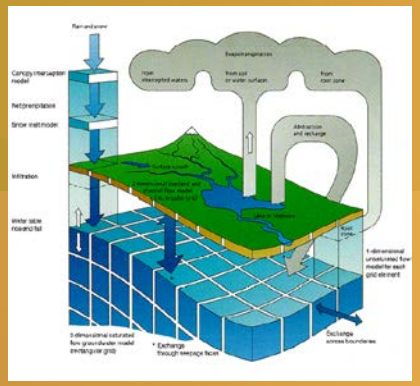
Evolution of Hydrologic R-R Models



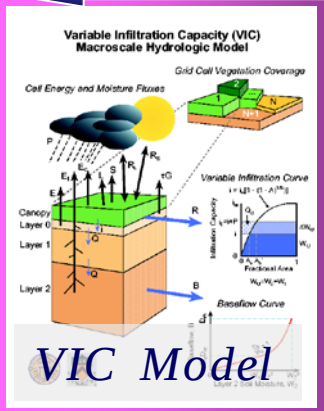
API Model



Lumped Conceptual



Distributed (Mike SHE)



VIC Model

Lumped "Simple"

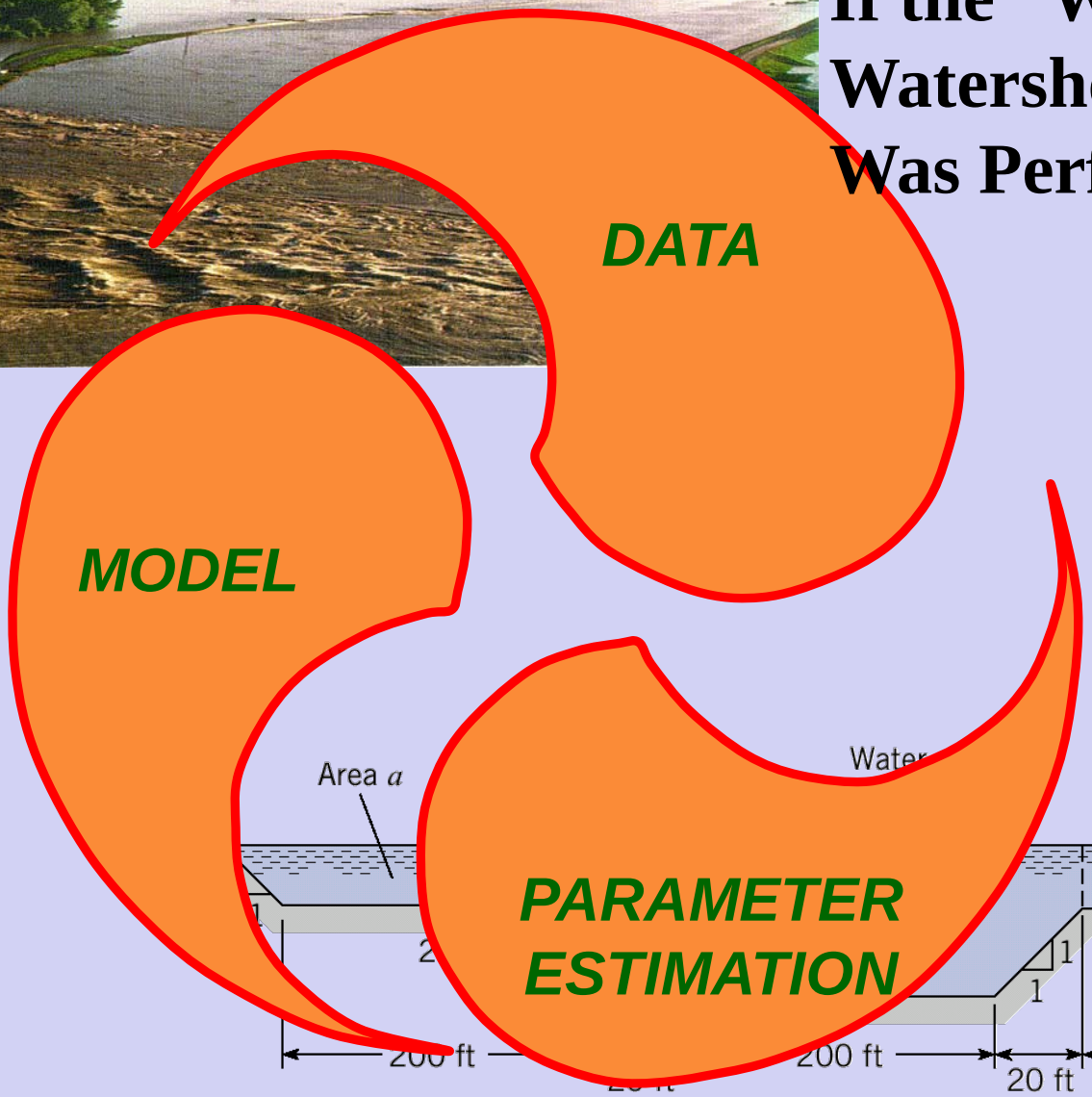
Time

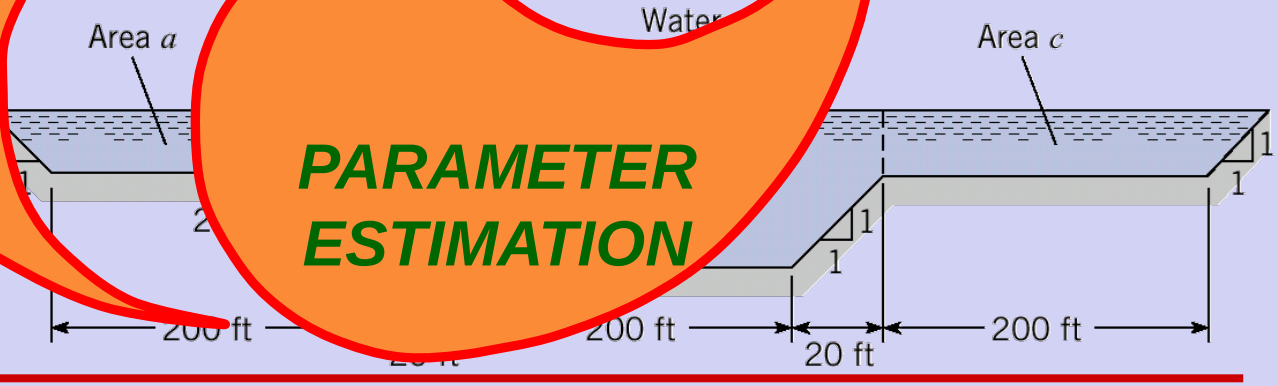
Distributed

Physically-based

Hydrologic Modeling: 3 Elements!

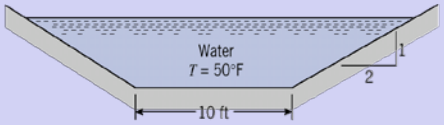
If the "World" of Watershed Hydrology Was Perfect!

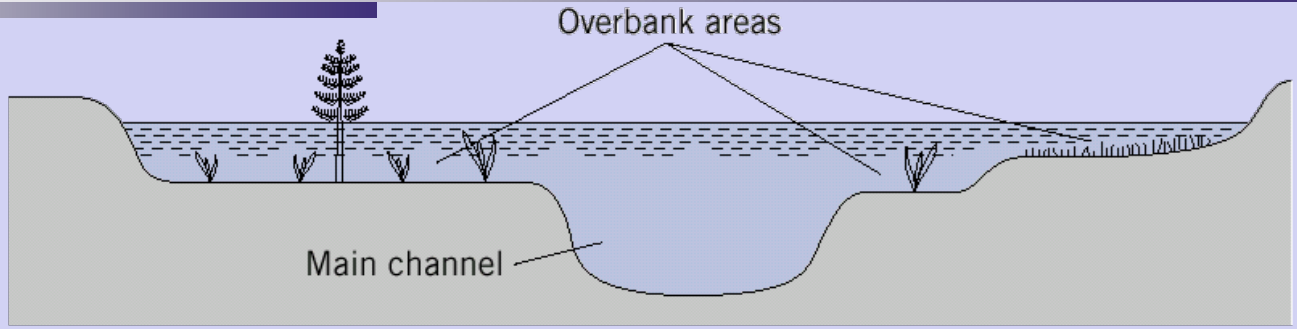


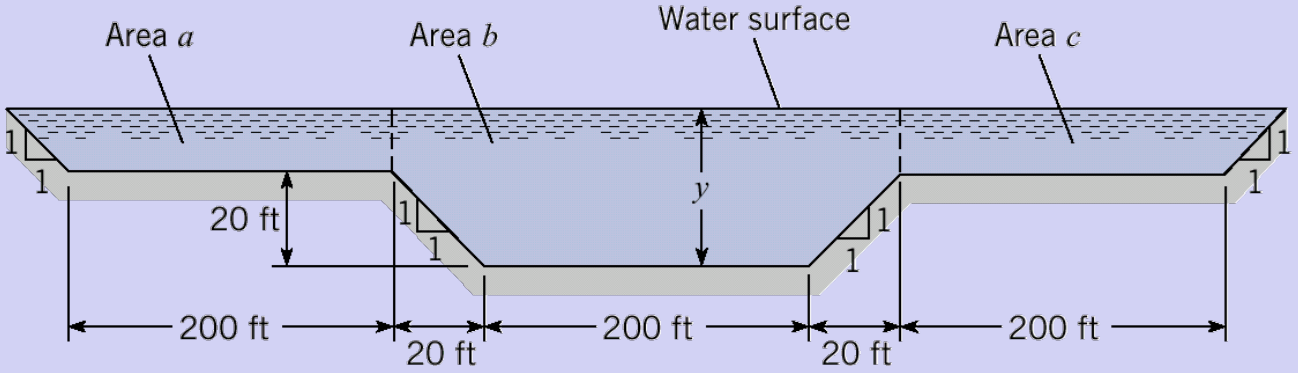


Flow in Channels: How far can we go simplifying?

$$V = n^{-1} R^{2/3} S^{1/2}$$

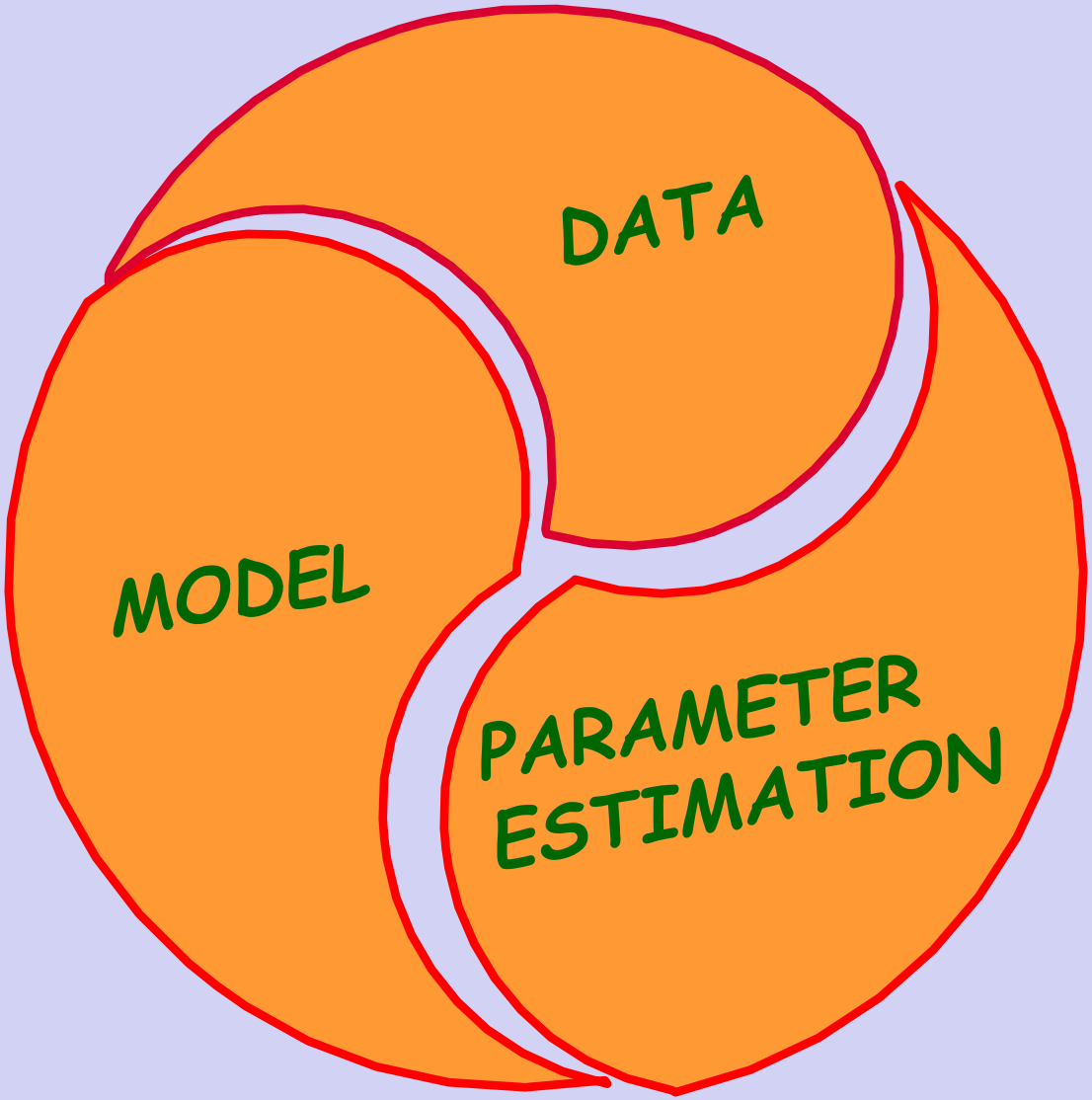




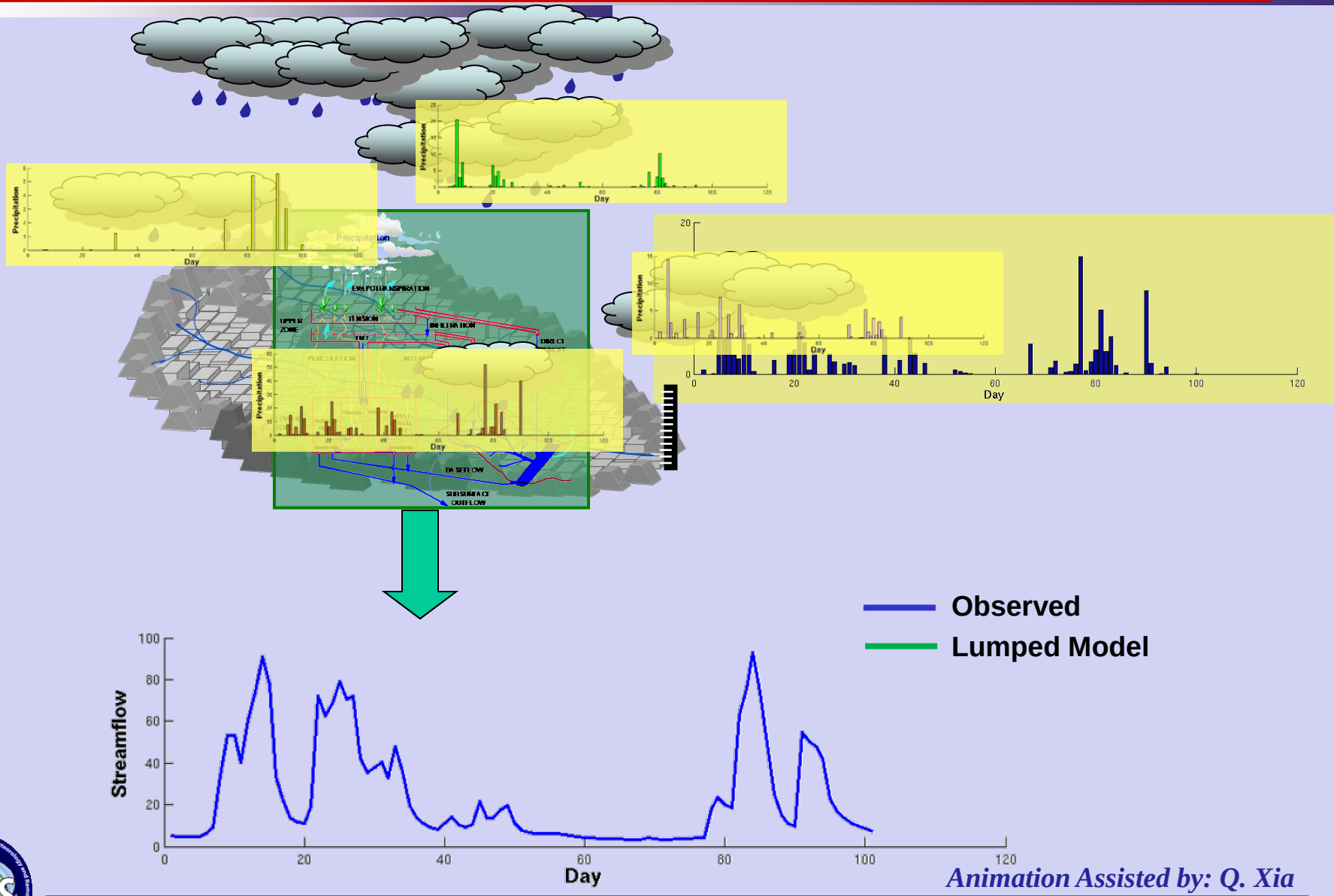


n – Manning Coefficient
R – Hydraulic Radius
S – Energy Slope

Hydrologic Modeling

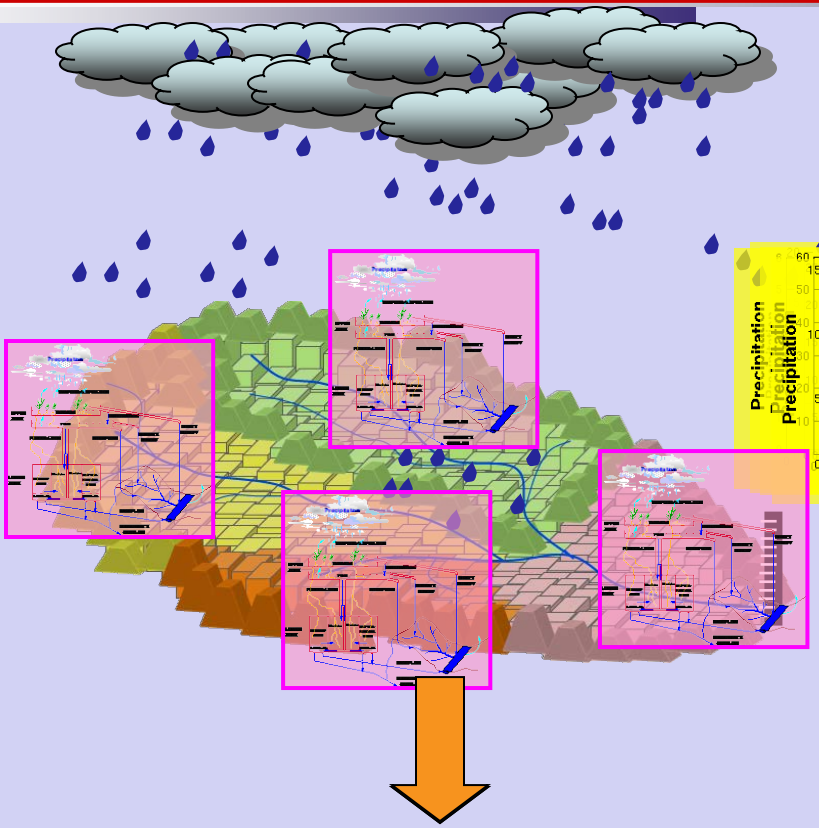


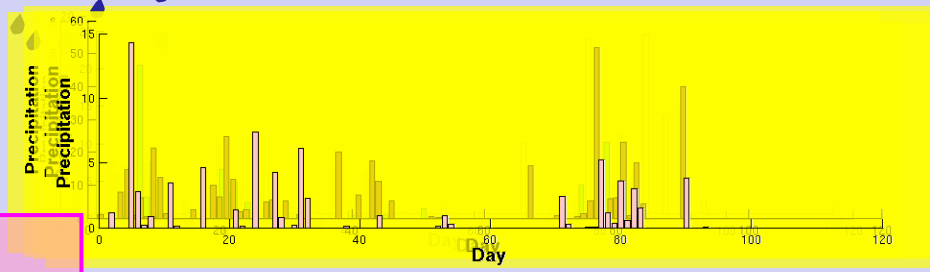
Hydrologic Modeling: "Lumped"

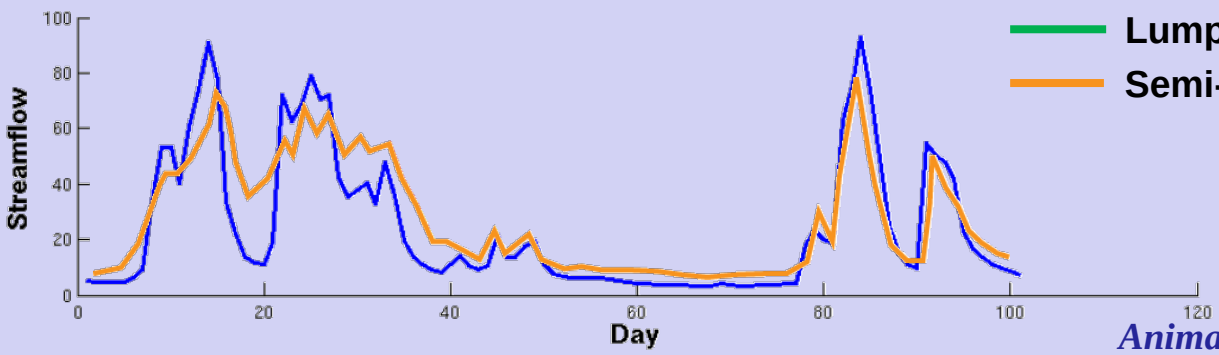


Animation Assisted by: Q. Xia

"Semi-distributed" Hydrologic Models

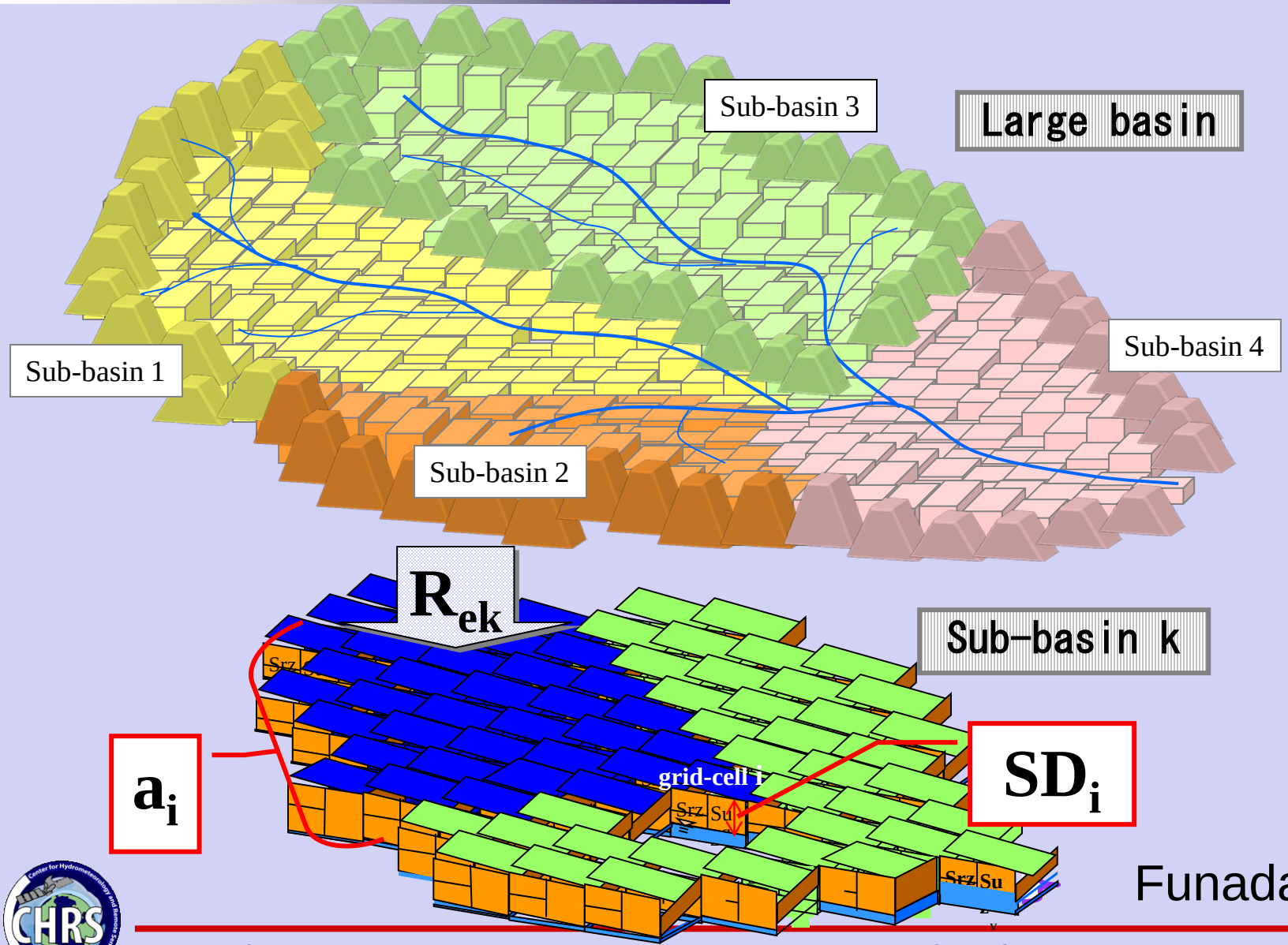






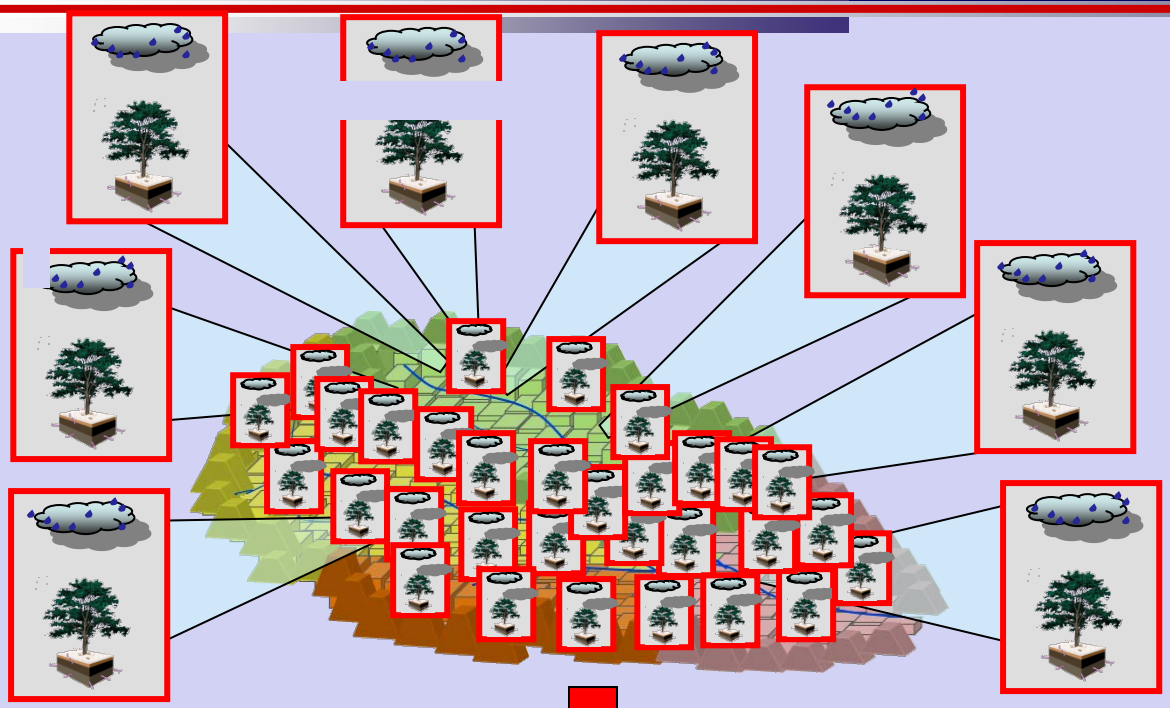
Animation Assisted by: Q. Xia

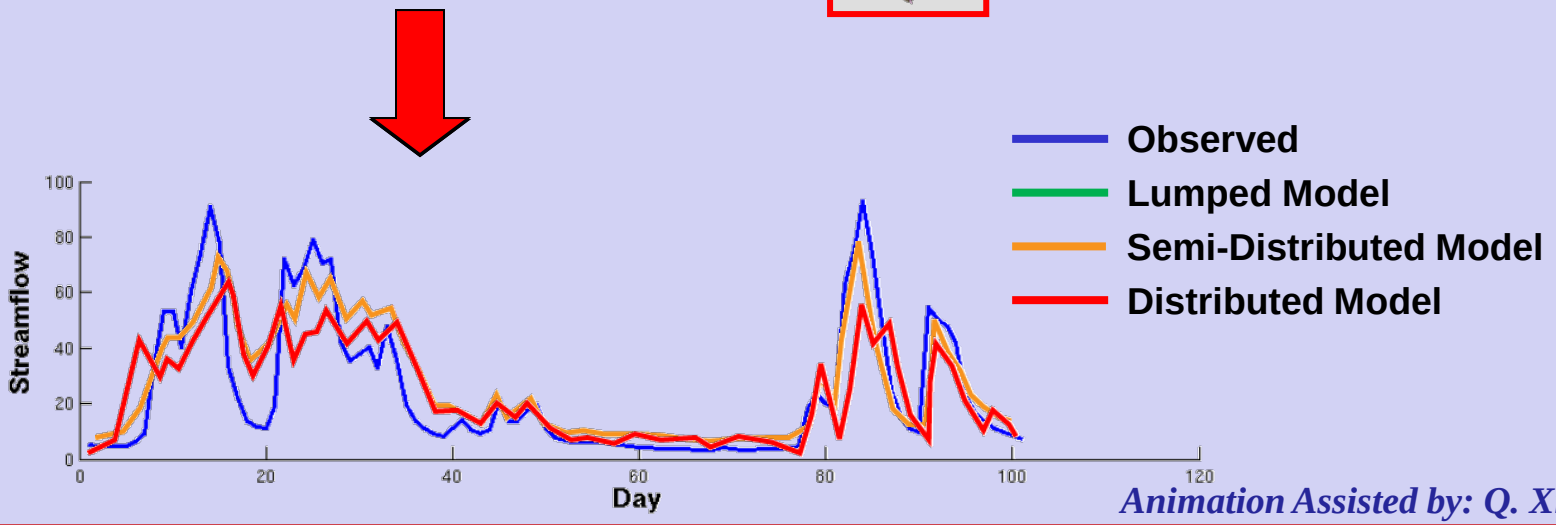
Example of Distributed Model Appl. in large Basins



Funada, 2004

Example of Distributed Model

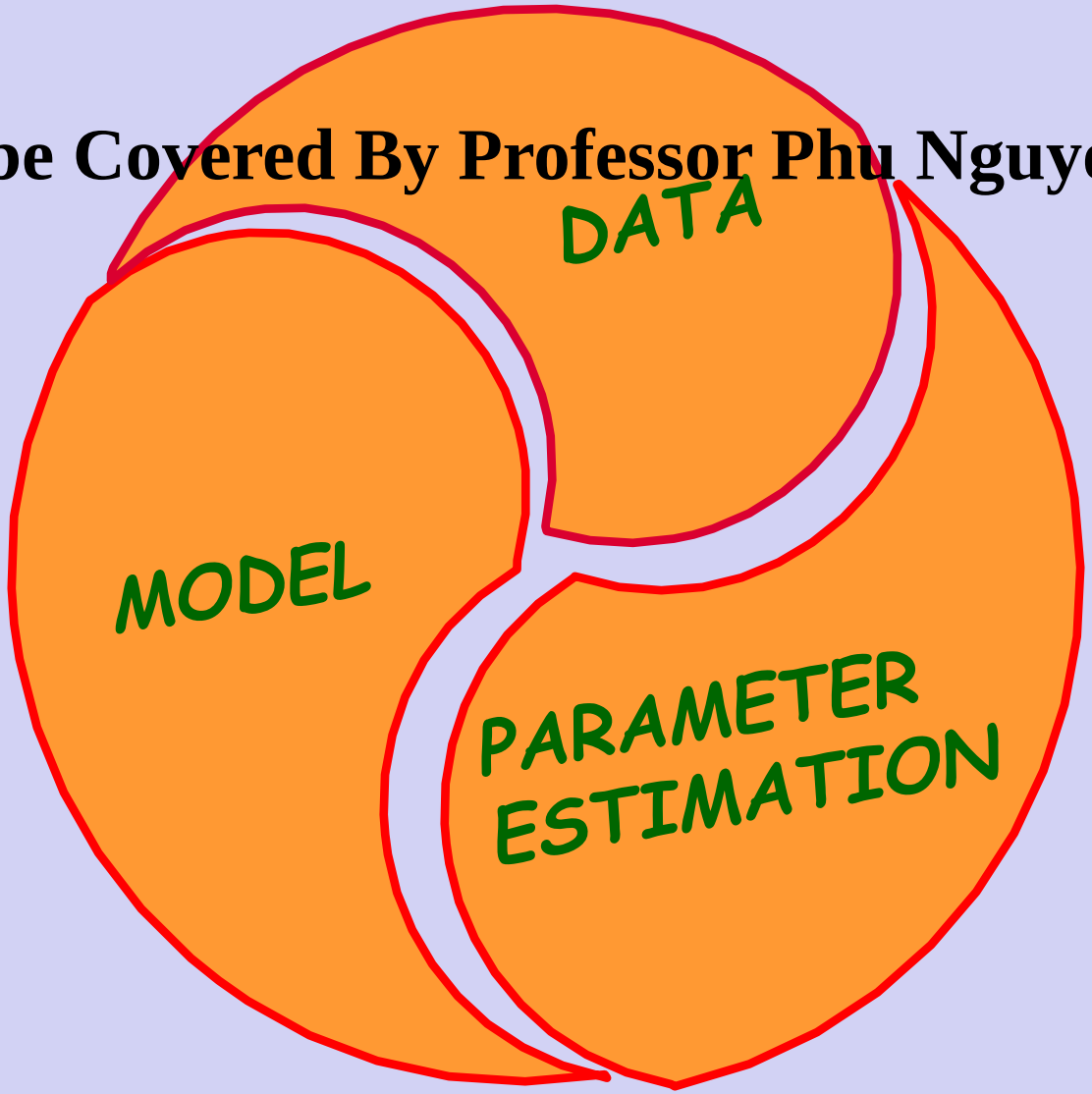




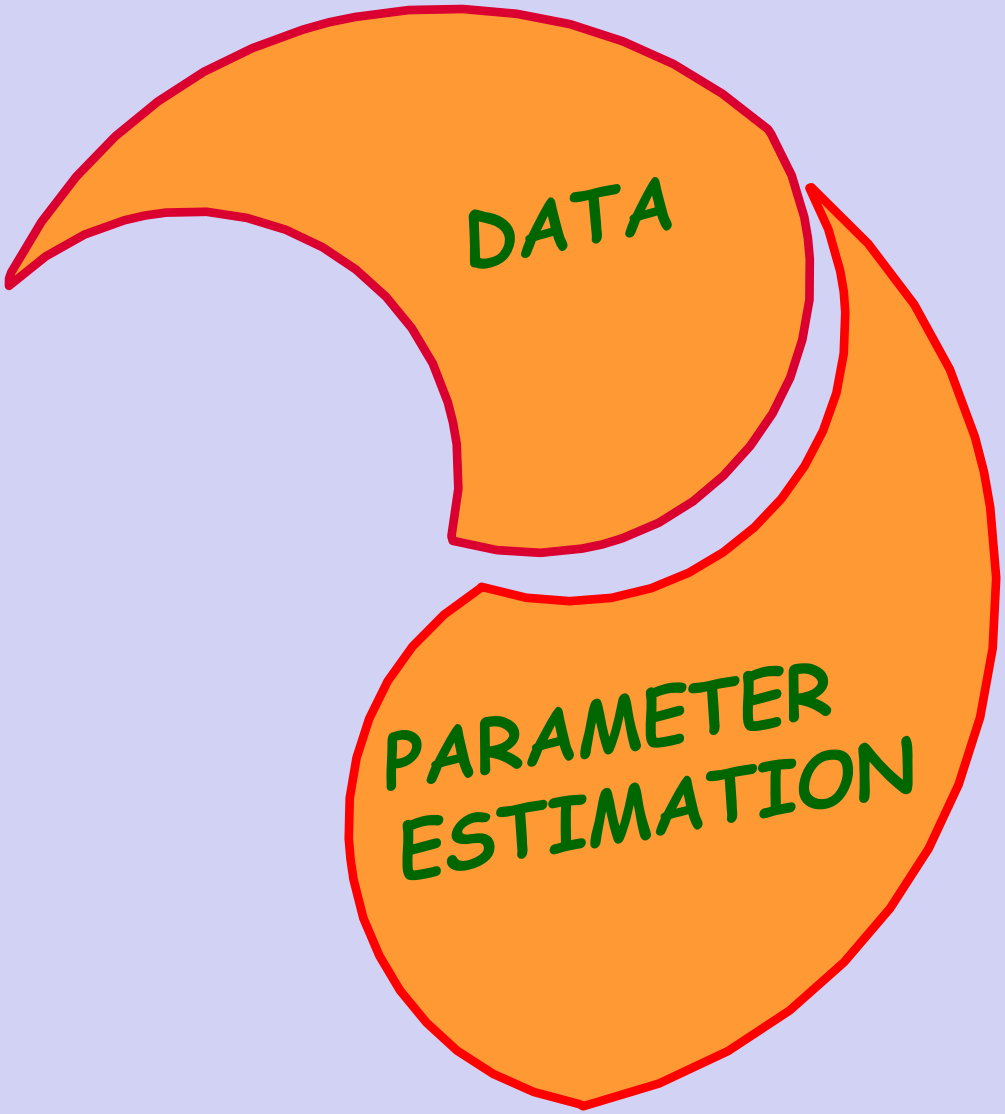
Animation Assisted by: Q. Xia

Hydrologic Modeling

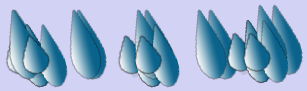
Will be Covered By Professor Phu Nguyen



Model Calibration



A look into the "heart" of R-R Models



PD = f(Z, X)

Percolation Process is the Core element in Partitioning the rain between the various stores

UM

UC_t

UK

percolation

PD = f(Z, X)

LM

LCt

LK

Streamflow

Rainfall

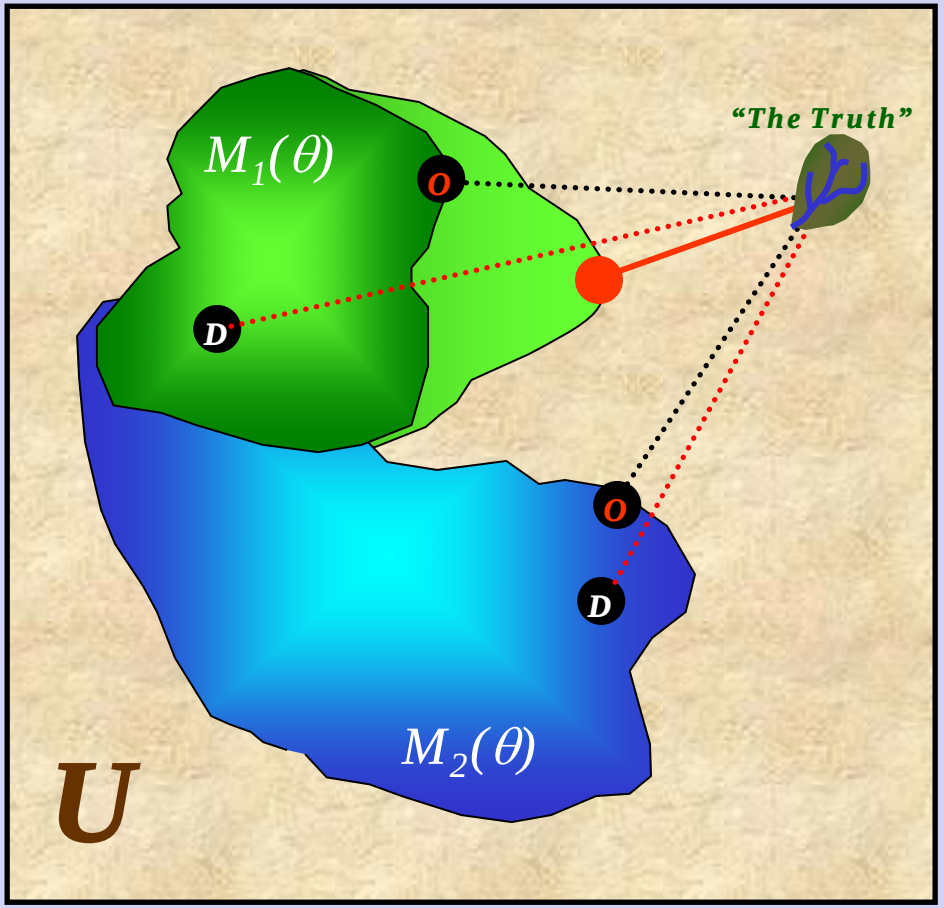
The Identification Problem

1. Select a model structure (Input-State-Output equations)
2. Estimate values for the parameters

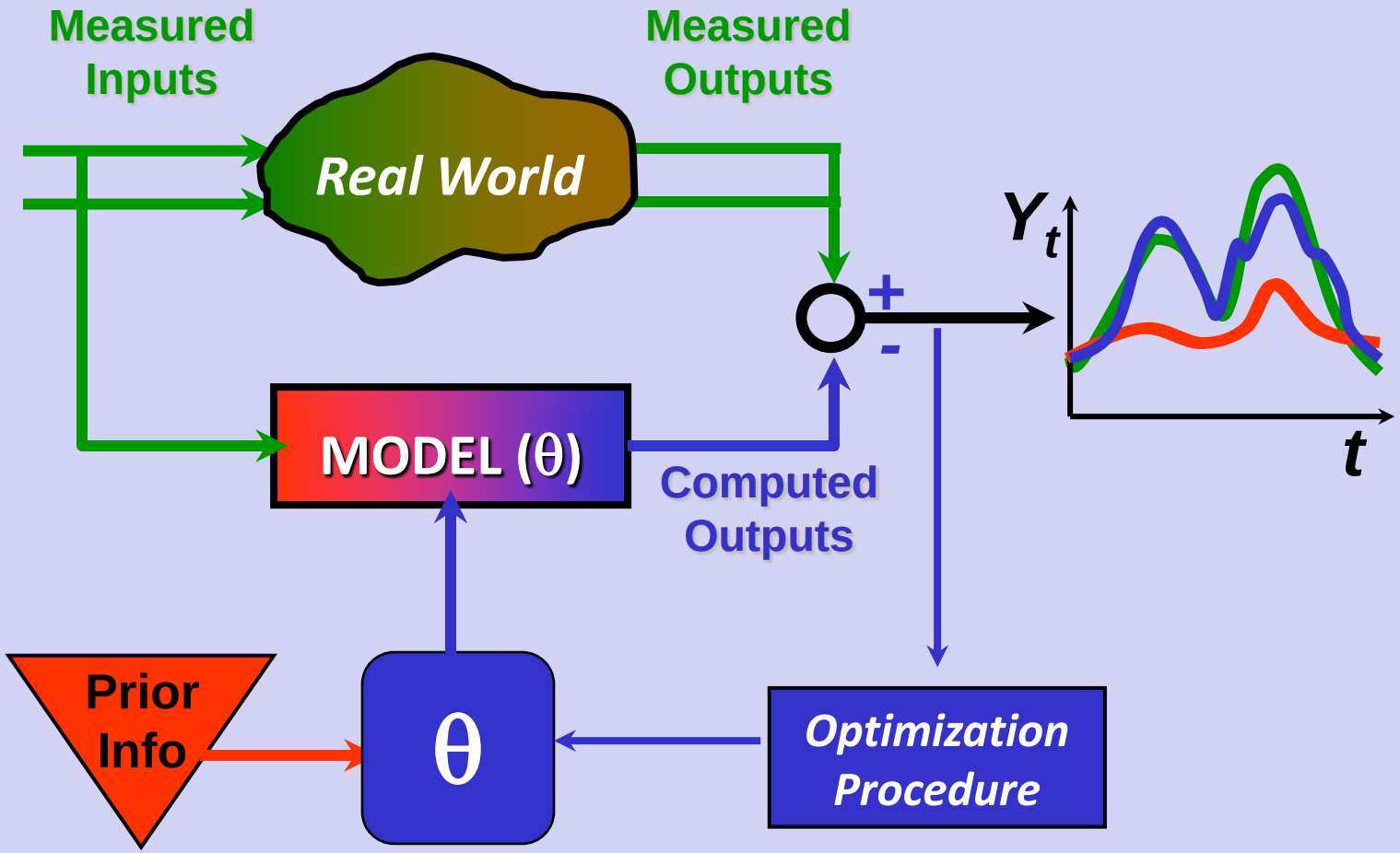
U – Universal Set

B - Basin

$M_i(\theta)$ – Selected Model Structure

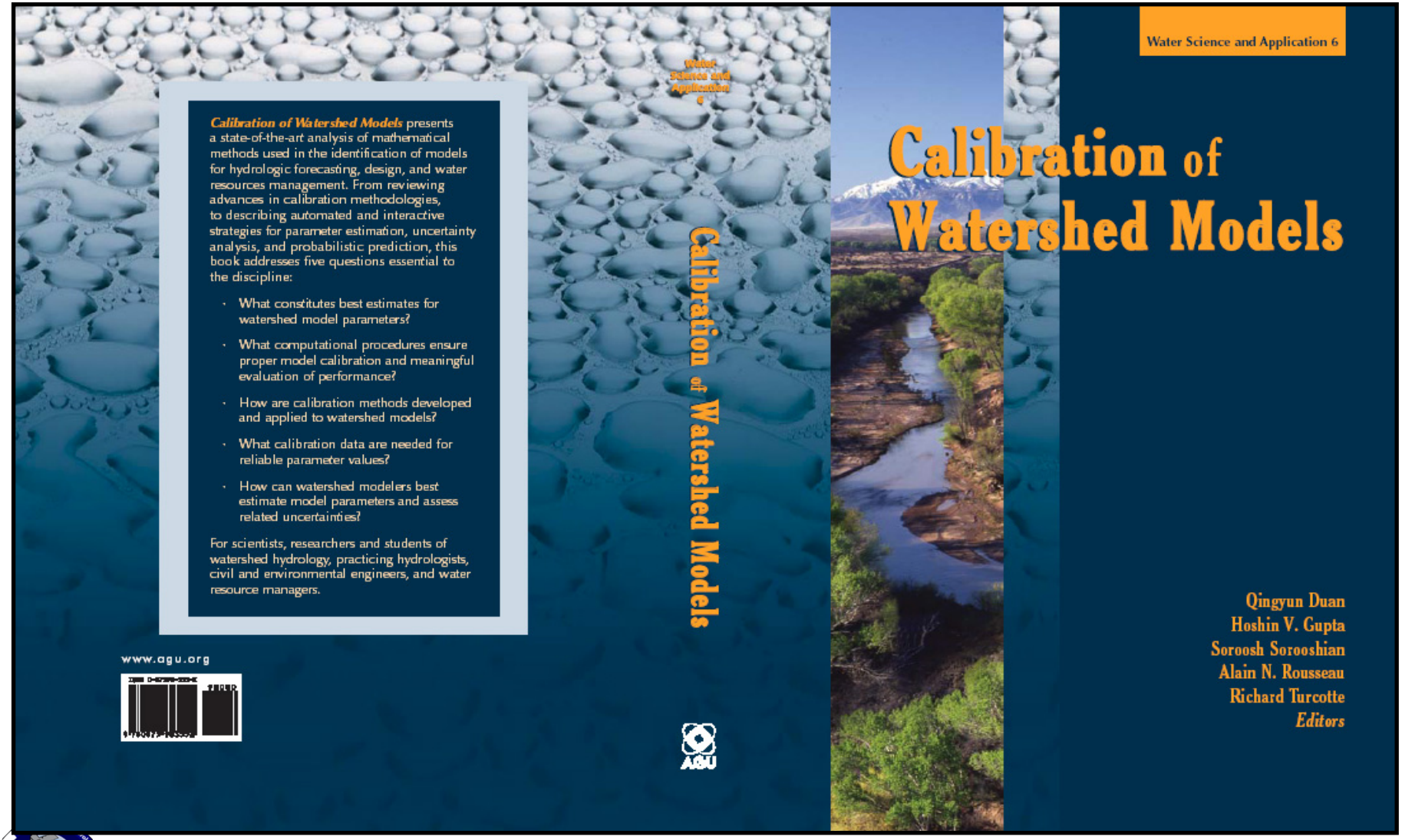


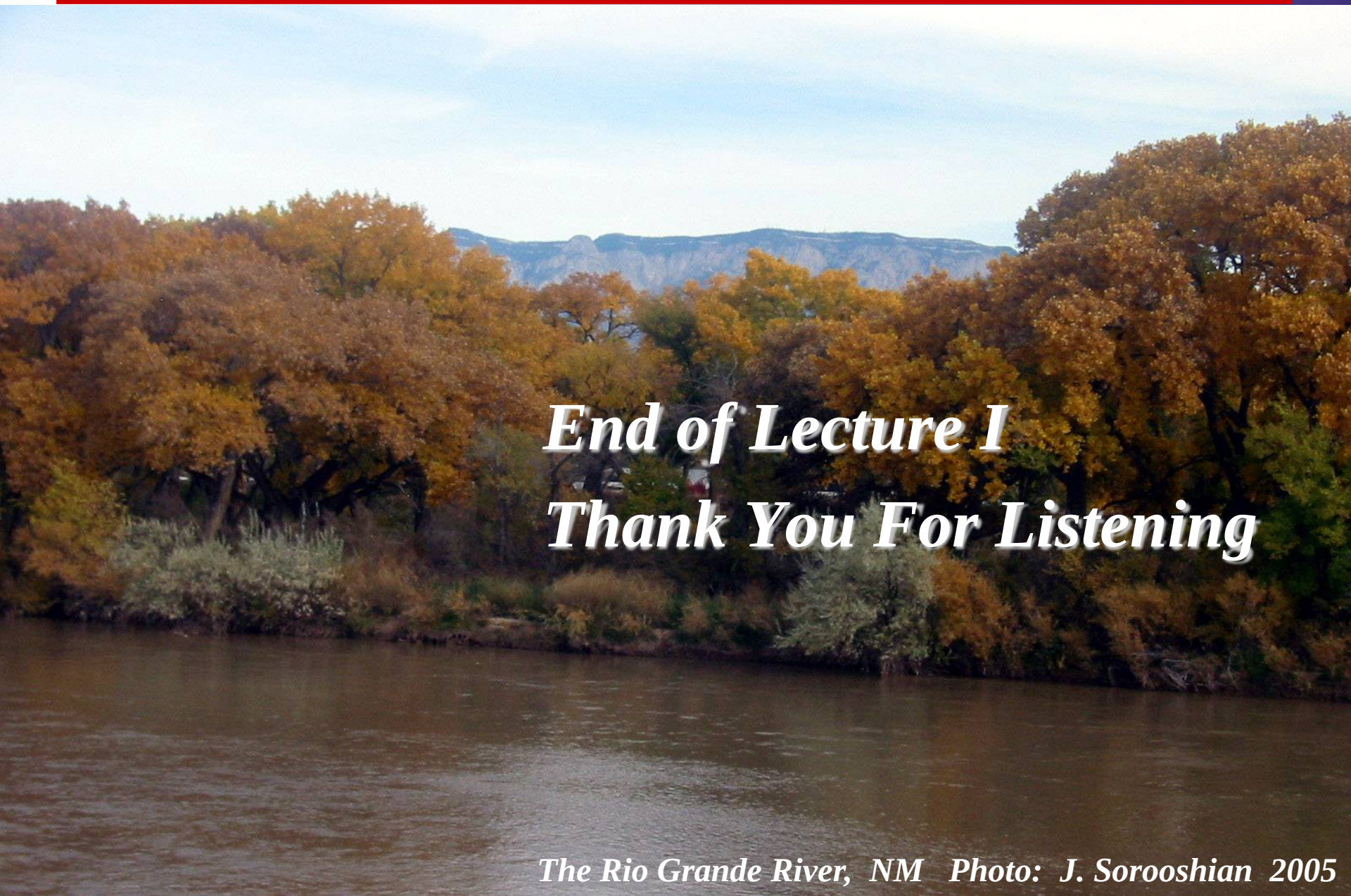
The Concept of Model Calibration



"Calibration: constraining the model to be consistent with observations"

AGU Monograph – Now Available





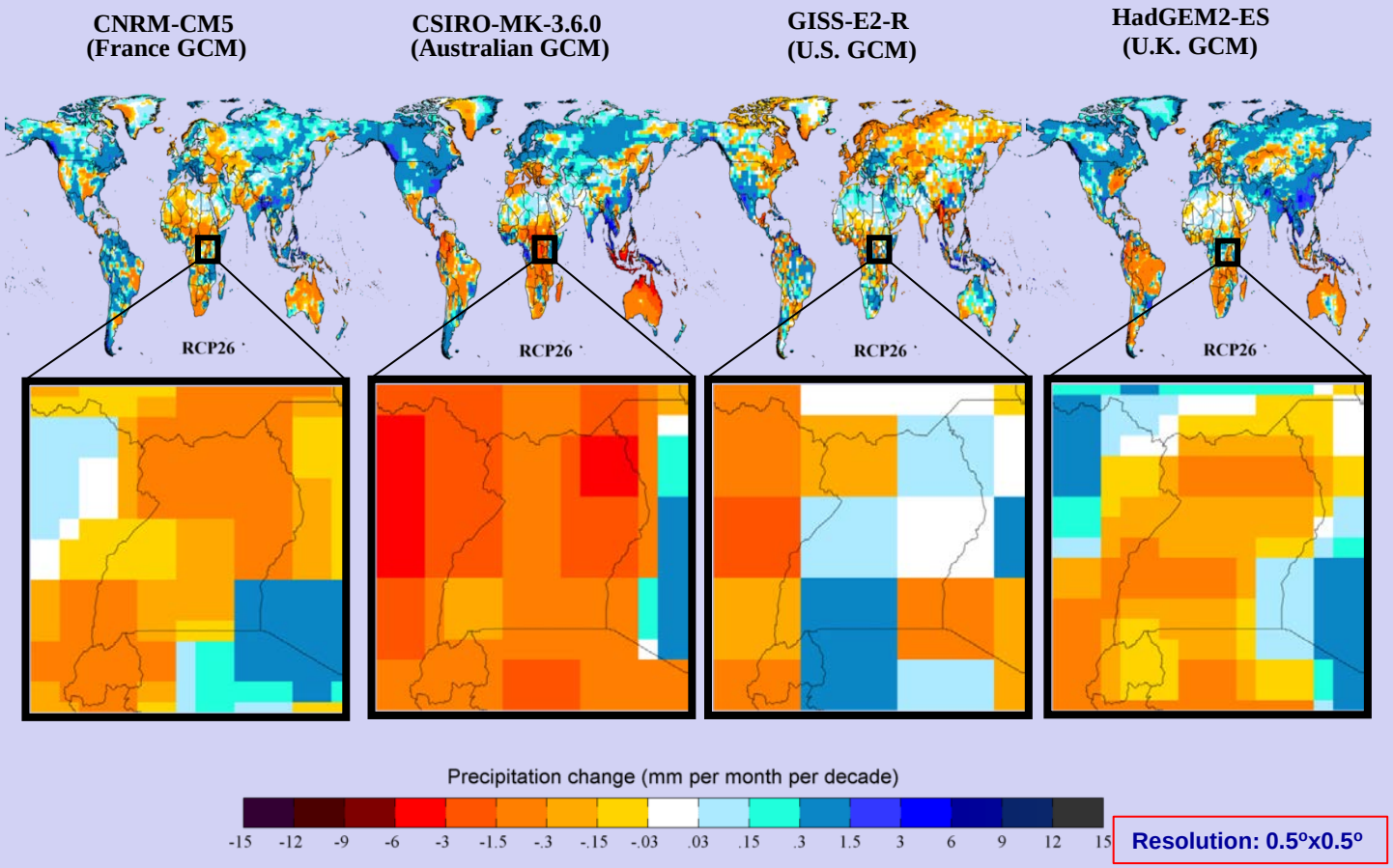
The Rio Grande River, NM Photo: J. Sorooshian 2005

Backup Material

RCP2.6 ("Low": 2.6 W/m^2, Equivalent CO_2 conc. 421 ppm by 2100)

IPCC AR5 Scenarios

Time period: 2006-2099



Resolution: 0.5°x0.5°

IPCC AR5 Scenarios

Time period: 2006-2099

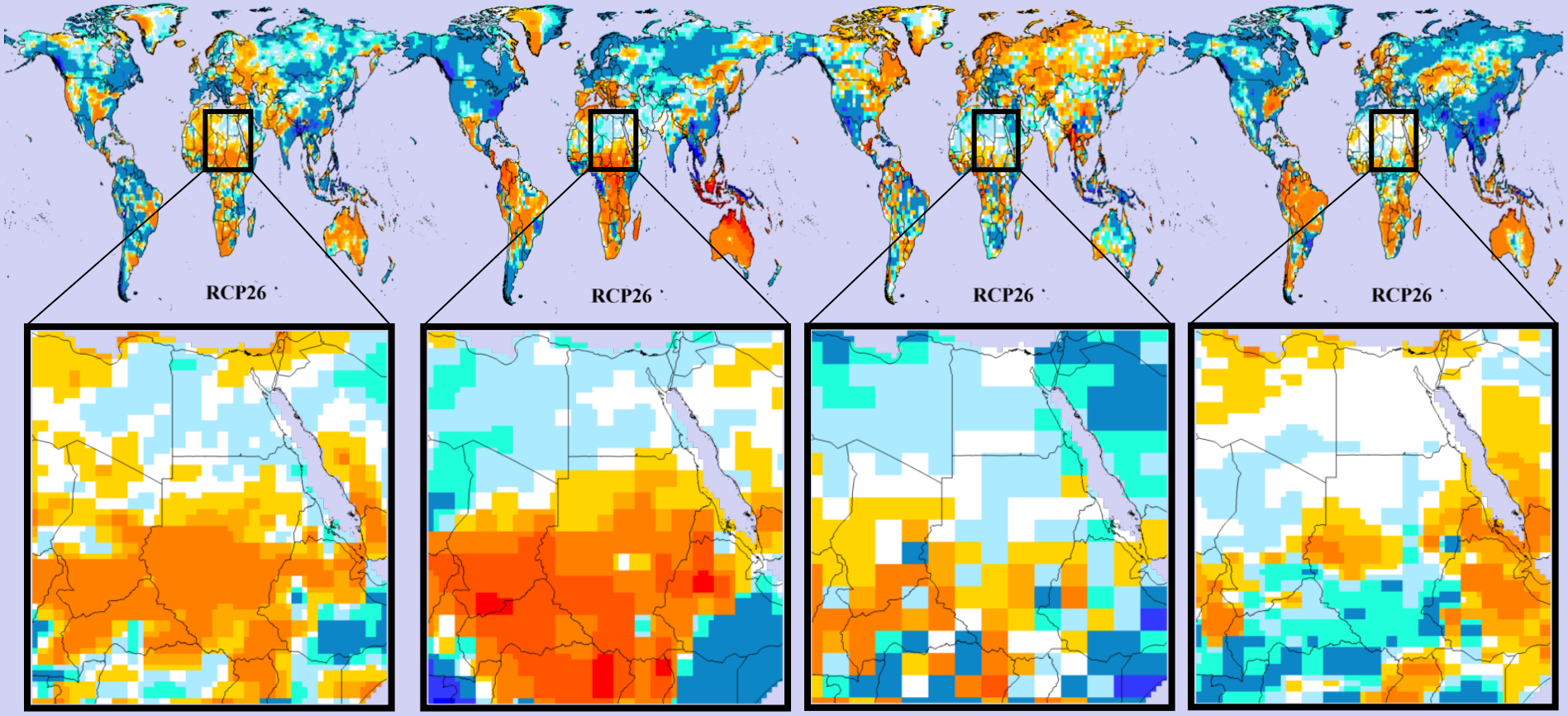
RCP2.6 ("Low": 2.6 W/m^2, Equivalent CO_2 conc. 421 ppm by 2100)

CNRM-CM5 (France GCM)

CSIRO-MK-3.6.0 (Australian GCM)

GISS-E2-R (U.S. GCM)

HadGEM2-ES (U.K. GCM)



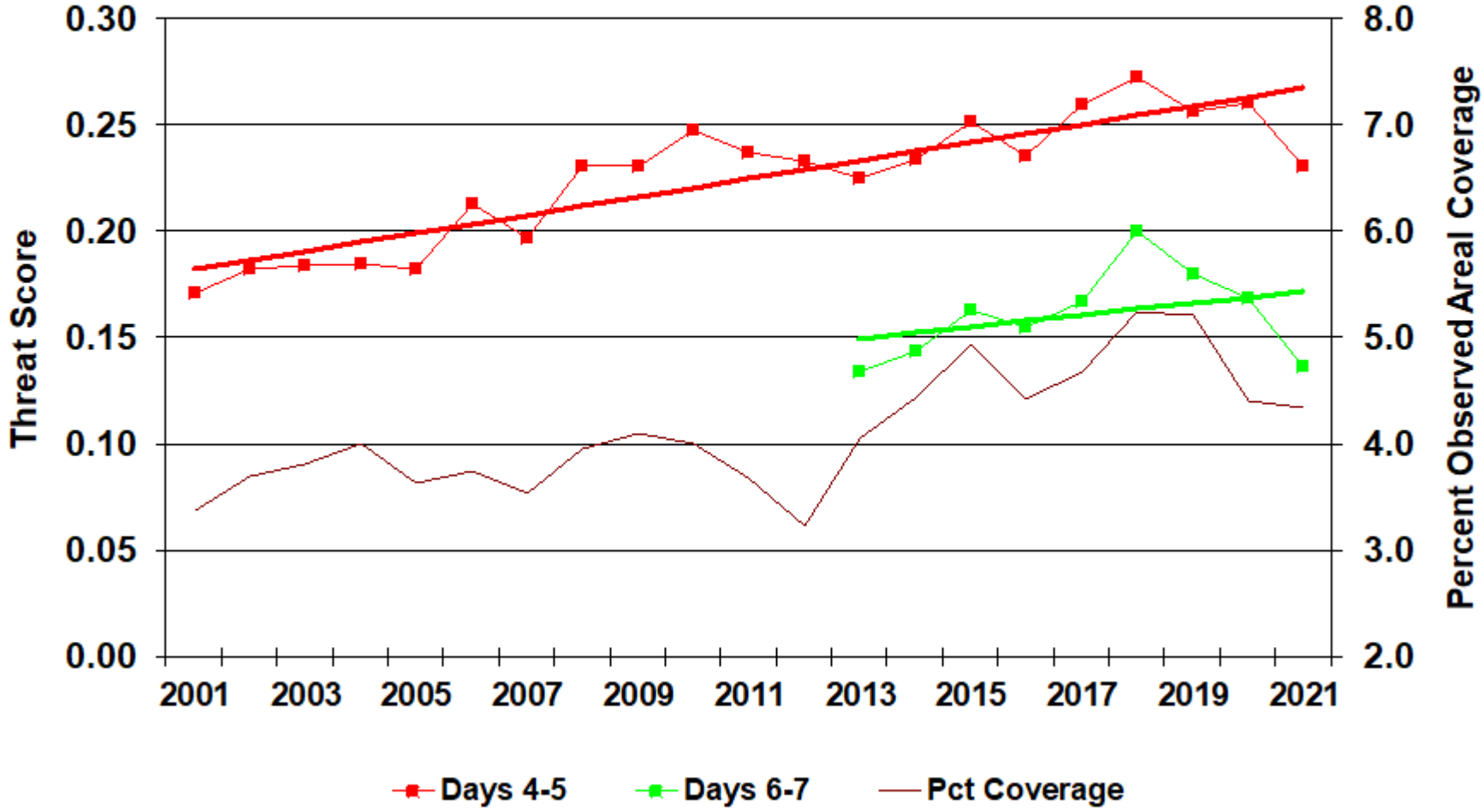
Precipitation change (mm per month per decade)

-15 -12 -9 -6 -3 -1.5 -.3 -.15 -.03 .03 .15 .3 1.5 3 6 9 12 15

Resolution: 0.5°x0.5°

Annual WPC Threat Scores: 1.00 Inch

Days 4-5 / 6-7



Quantitative Precipitation Forecast (QPF)