Lecture I
Hydrological modeling requirements for Water Resources Applications - Model Calibration and parameter Estimation Issues

Soroosh Sorooshian

Center for Hydrometeorology and Remote Sensing

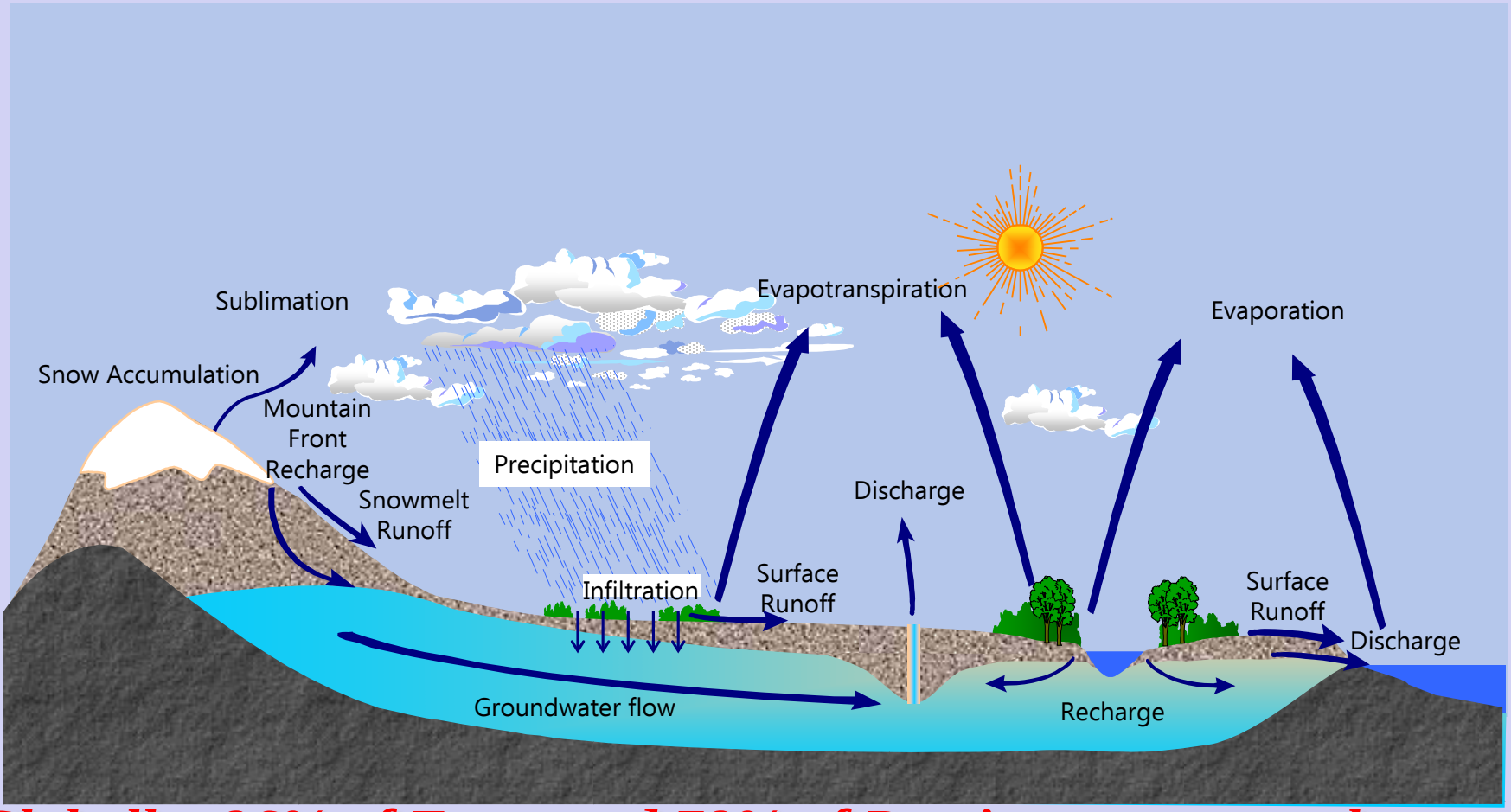
University of California Irvine

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

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

University of California Irvine (UCI) Past

Studying the Hydrologic Cycle at Various Scales

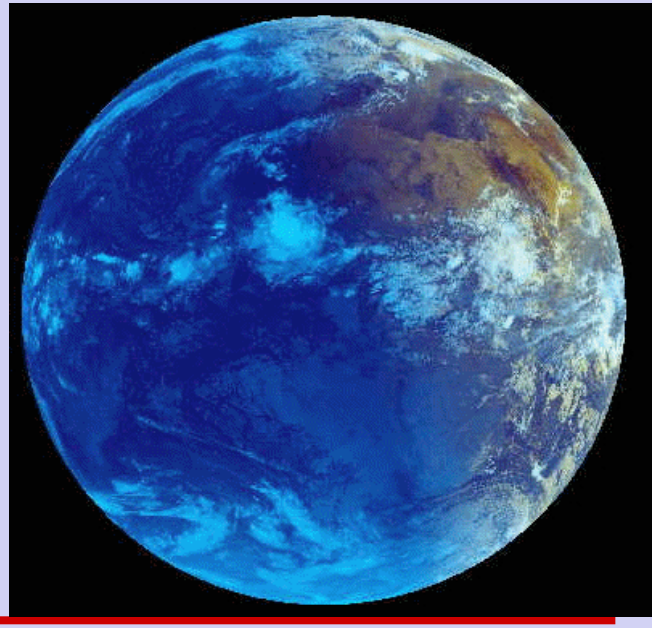


Globally: 86% of Evap. and 78% of Precip. occur over the oceans

Climate, Hydrology and Water Resources

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

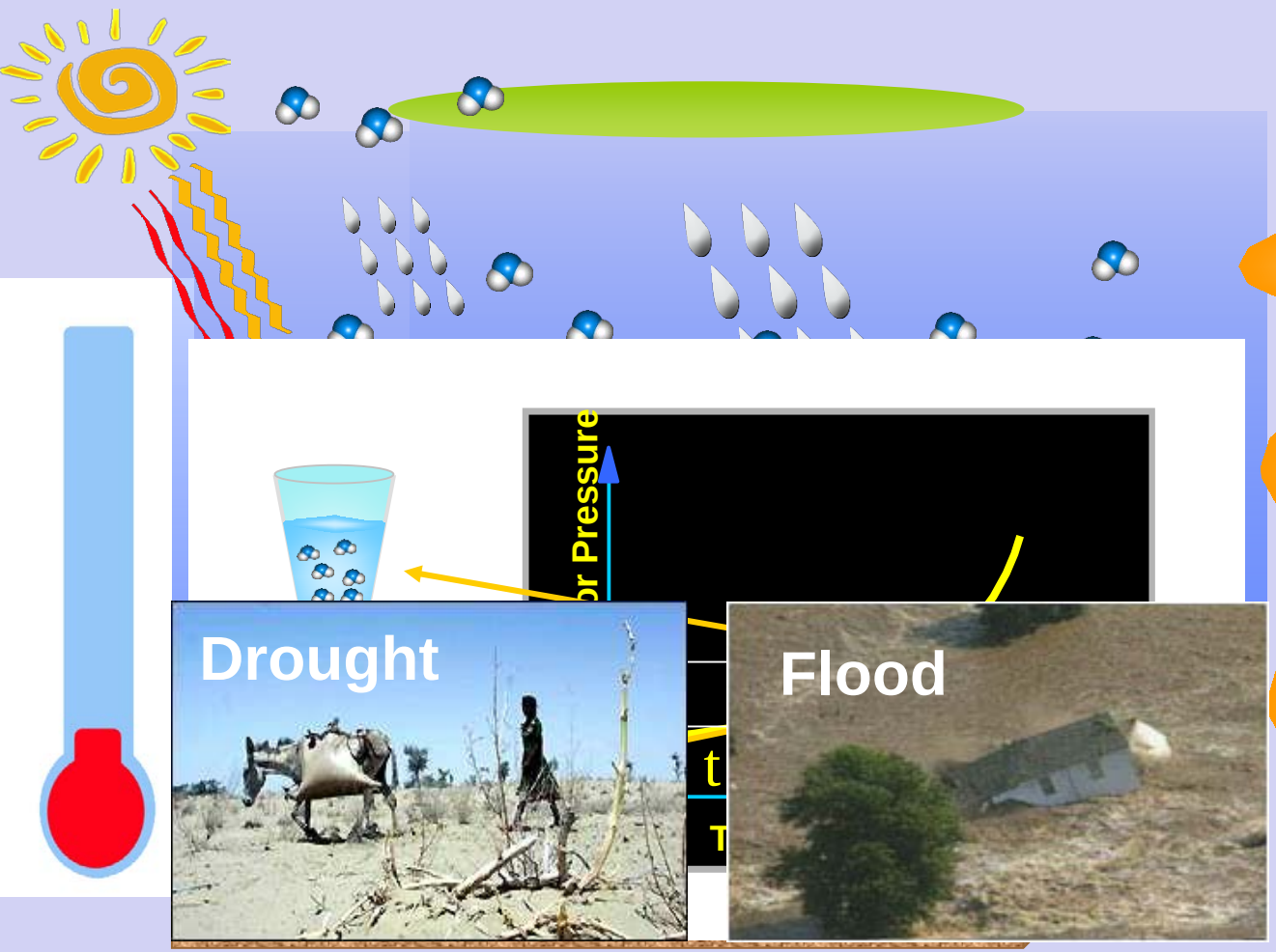
- *Can we predict the future changes which are responsive to "user" needs?*

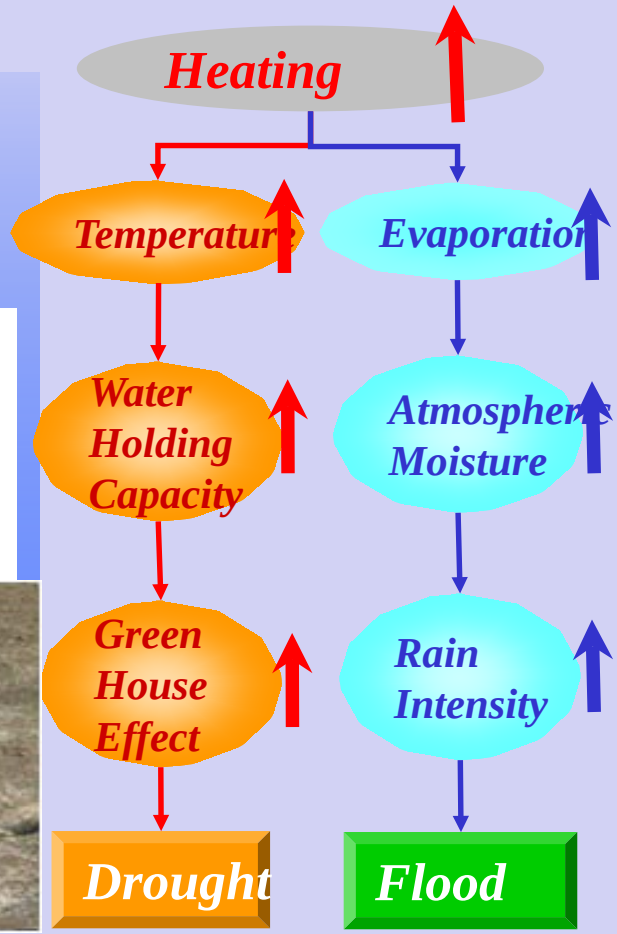


A Key Consideration:

The Link Between Climate and Hydrology

Global Warming And Hydrologic Cycle Connection





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Two Primary Water Resources/Hydrology Challenges:

- ***Hydrologic Hazards (Floods and Droughts)***

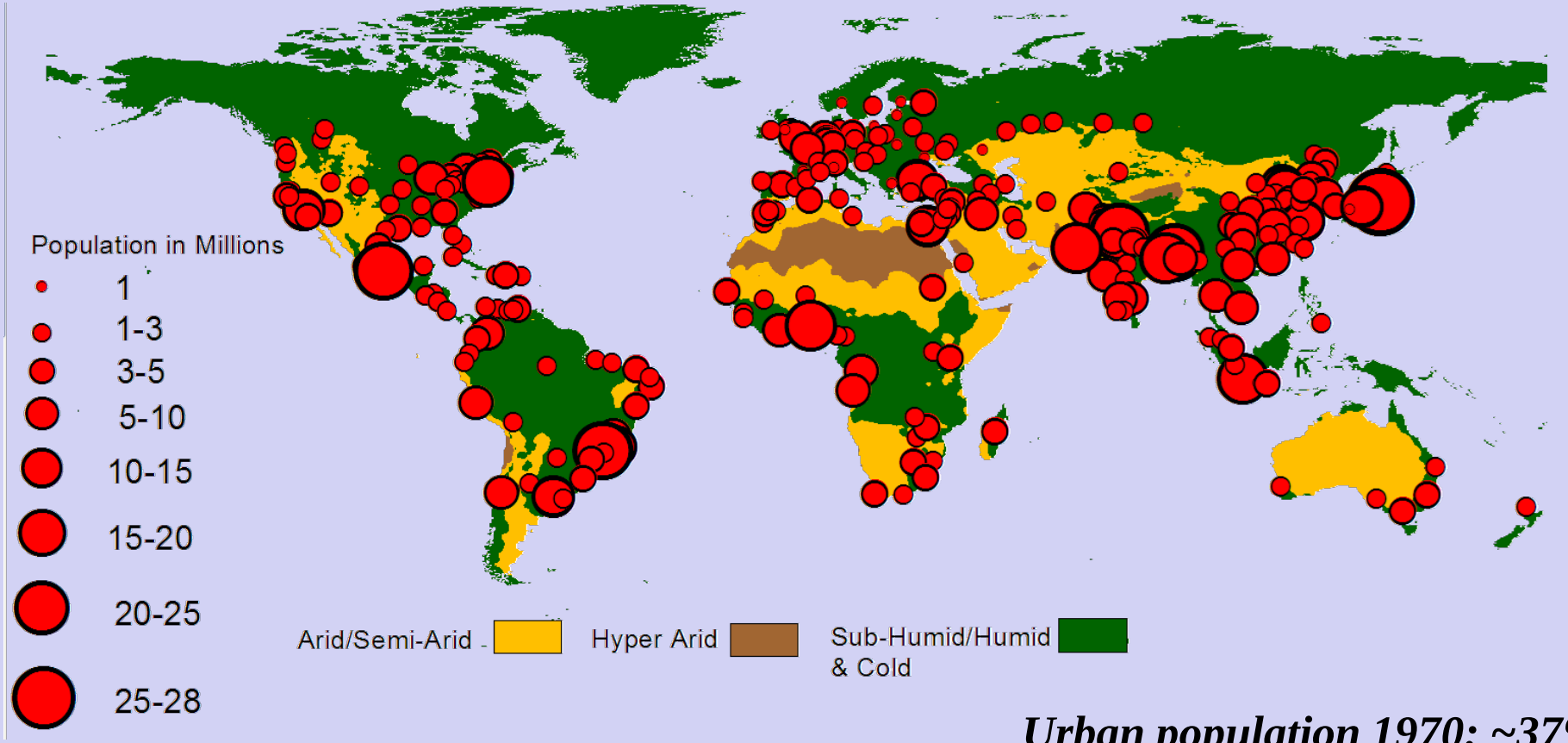
- ***Water Supply Requirements (Quantity and Quality)***

Stresses On Water Resources and Related Ecosystems:

- ***Population Impact*** *(More Predictable!)*
- ***Climate Impact*** *(Less Predictable!)*

Increasing Population: Number of Mega Cities

Projected Global Population: 8.3 Billion by 2025



Urban population 1970: ~37%
2010: ~53%

Took 200,000 years of human history for world's population to reach 1 billion; and only 200 years more to reach 7 billion plus.

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

Capturing and regulating Stream flow: Reservoirs

The old:

(500-800 yr old Dam: Southern Iran)

And the new

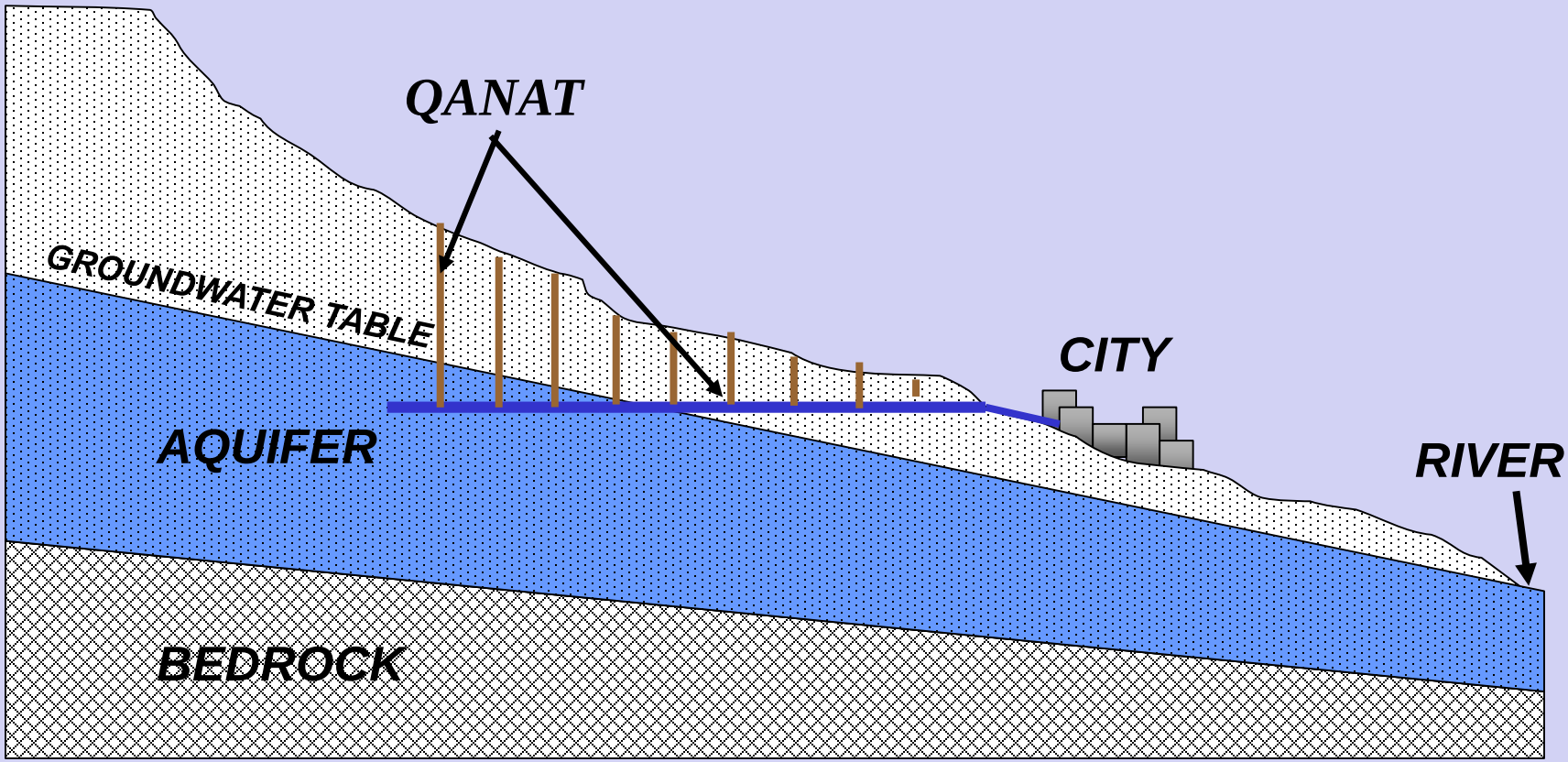
Roman Aqueducts Raised Water Works to Functional Art

Gravity flows of imported surface water sustained ancient Roman cities.

SAHRA

Today's Large Aqueducts are transforming many regions

A Qanat is a horizontal well!



Qanat is not the shortest distance from the surface to the groundwater

Source: Prof Majid Hassanizadeh

Repair of a Qanat in Yazd, Iran

Source: Prof Majid Hassanizadeh

Ground Water Extraction

The way it is now

Mechanical Pumps: Ground Water Over Pumping

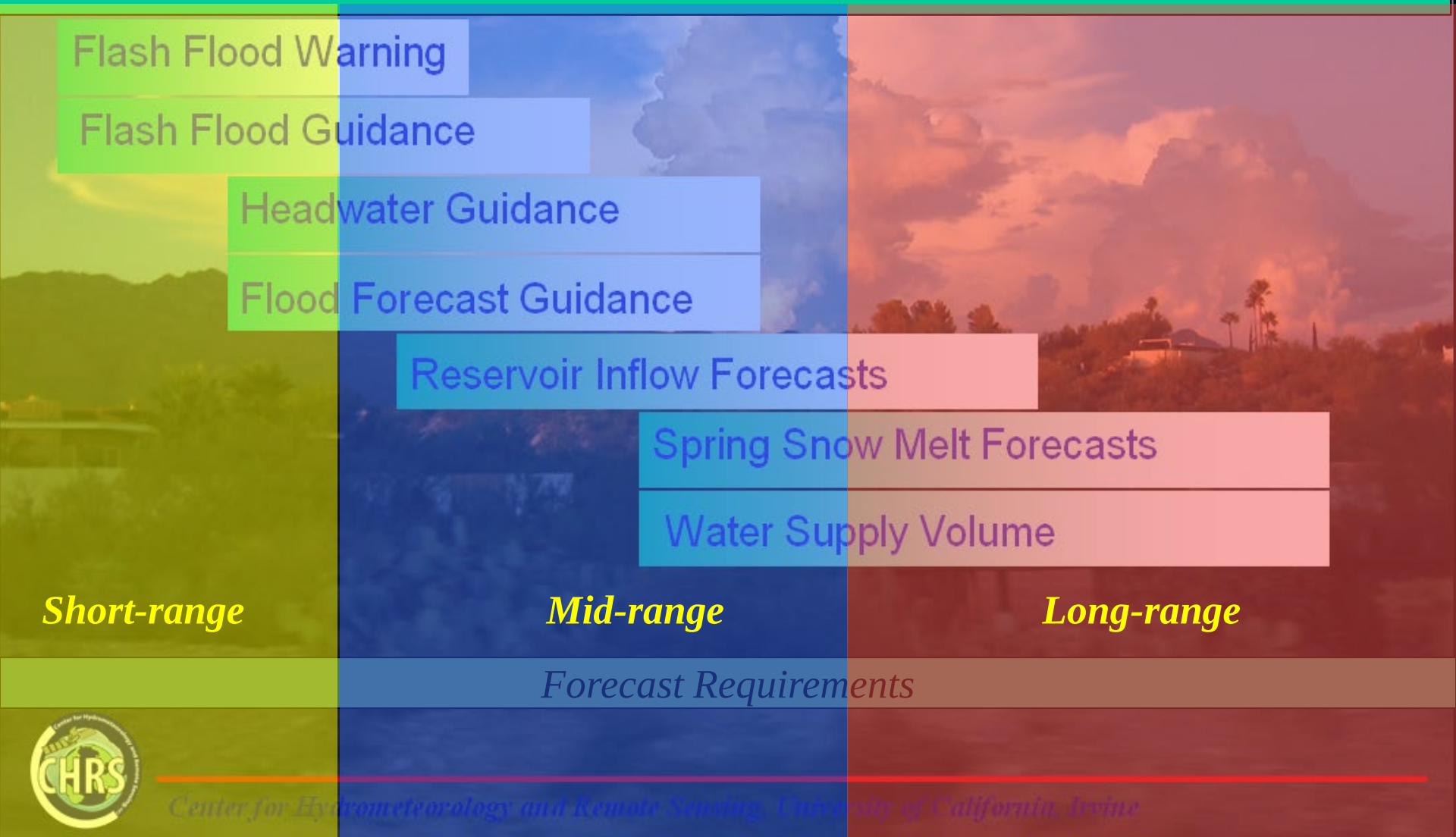
Information Relevant to Water Resources Planning

- *Models Projections*
- *Observations*

Required Hydrometeorologic Predictions

Short Range ← · — · — · — · — · — · — · — · — · — · — · — · — · — · — · — · — → **Long Range**

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



Forecast Requirements

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

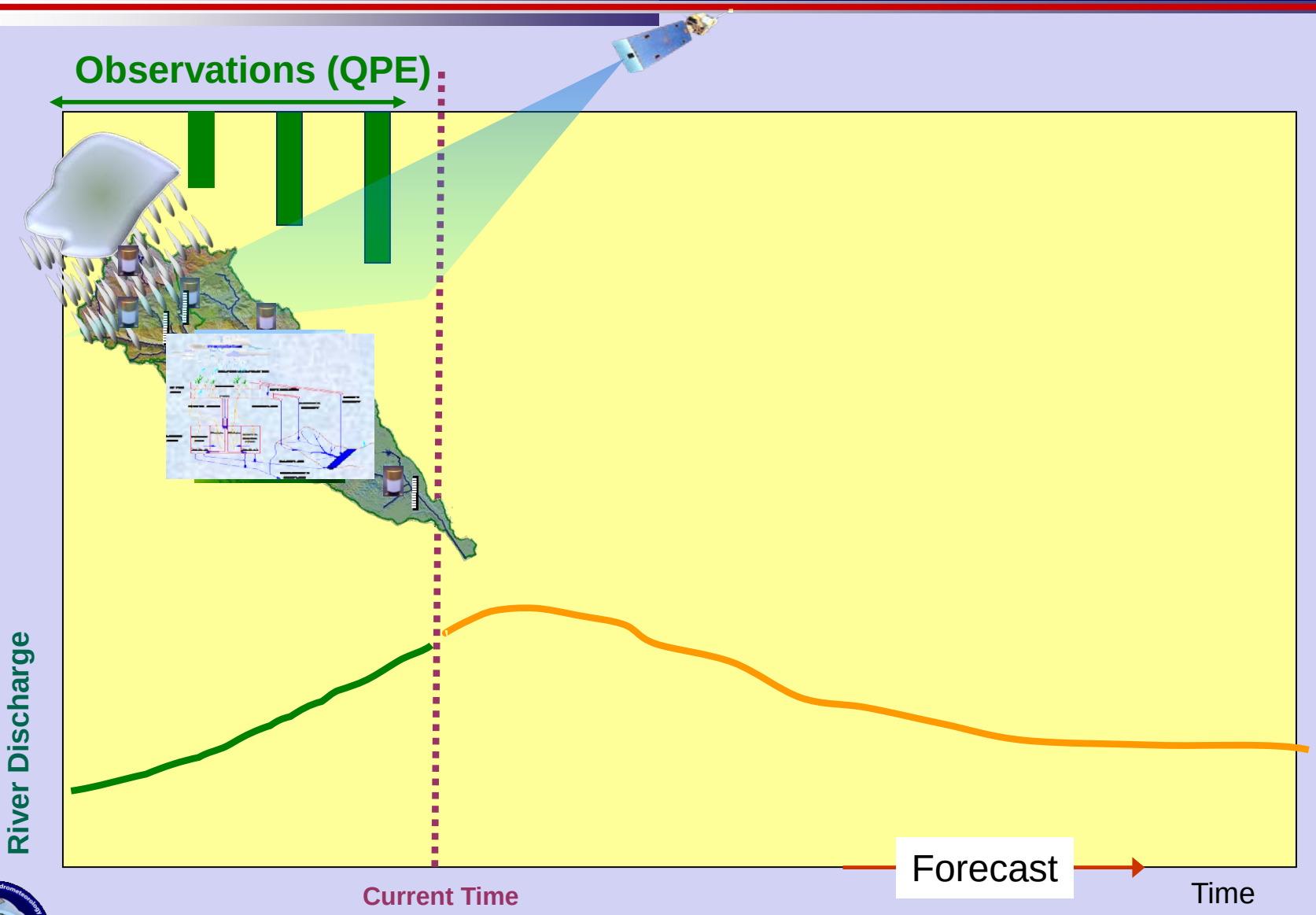
Spring River Flow Forecasts

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

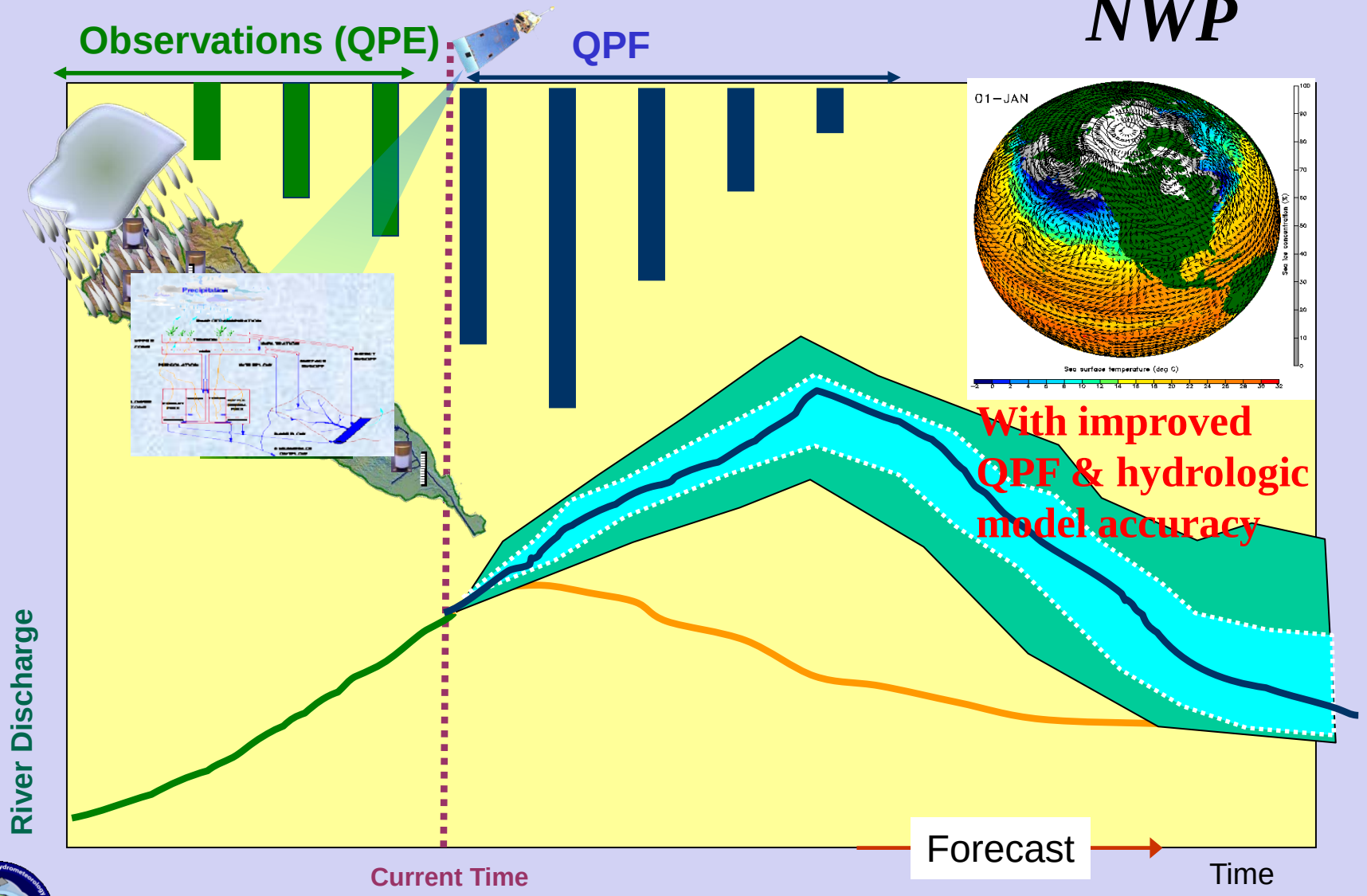
Extending the Short-term flood Forecasts

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

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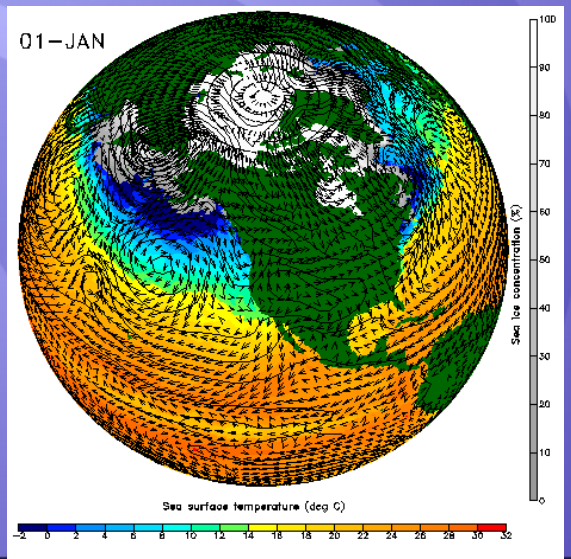
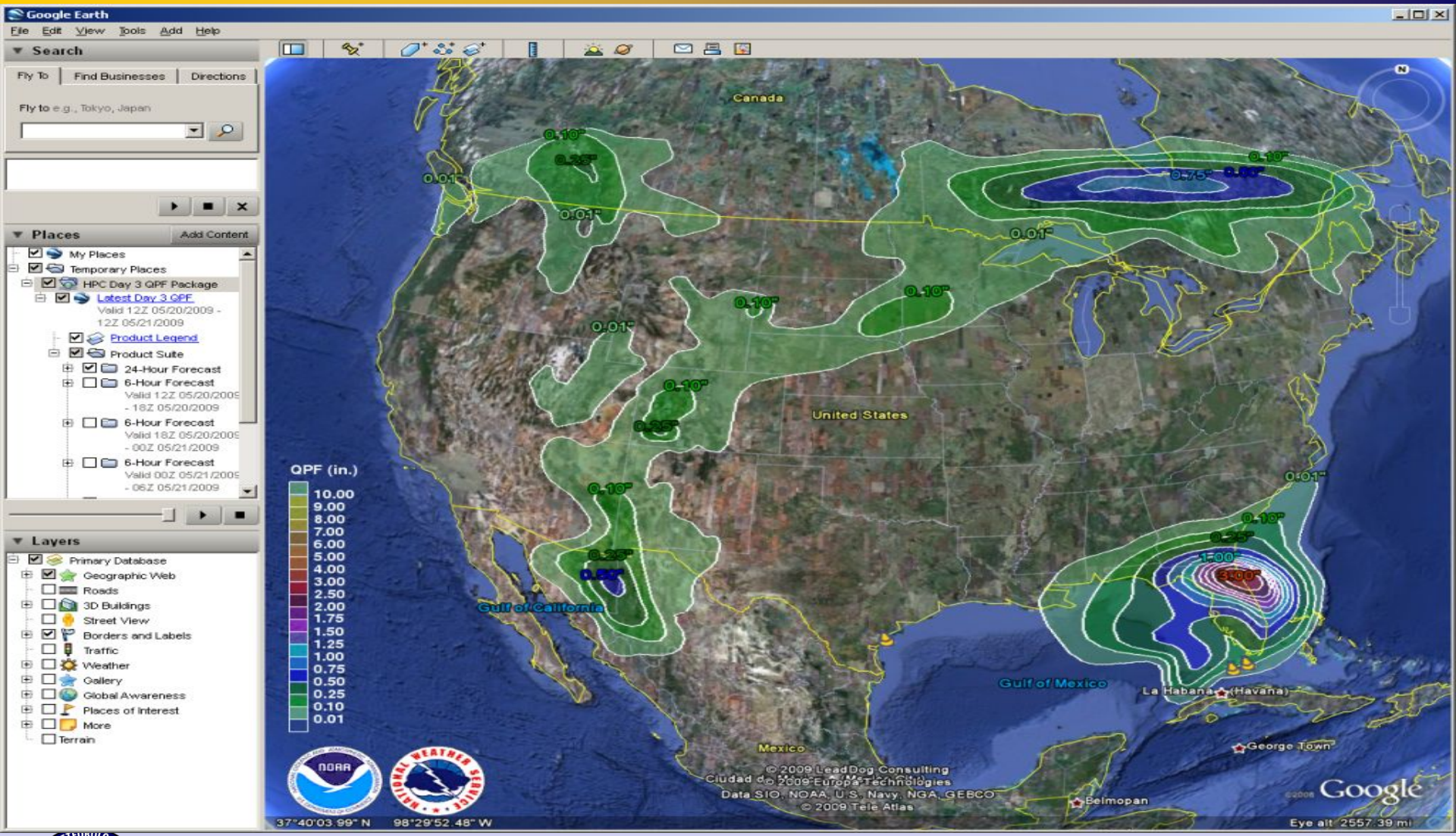
Progress in QPF to extend the lead time of hydrologic forecasts

NWP



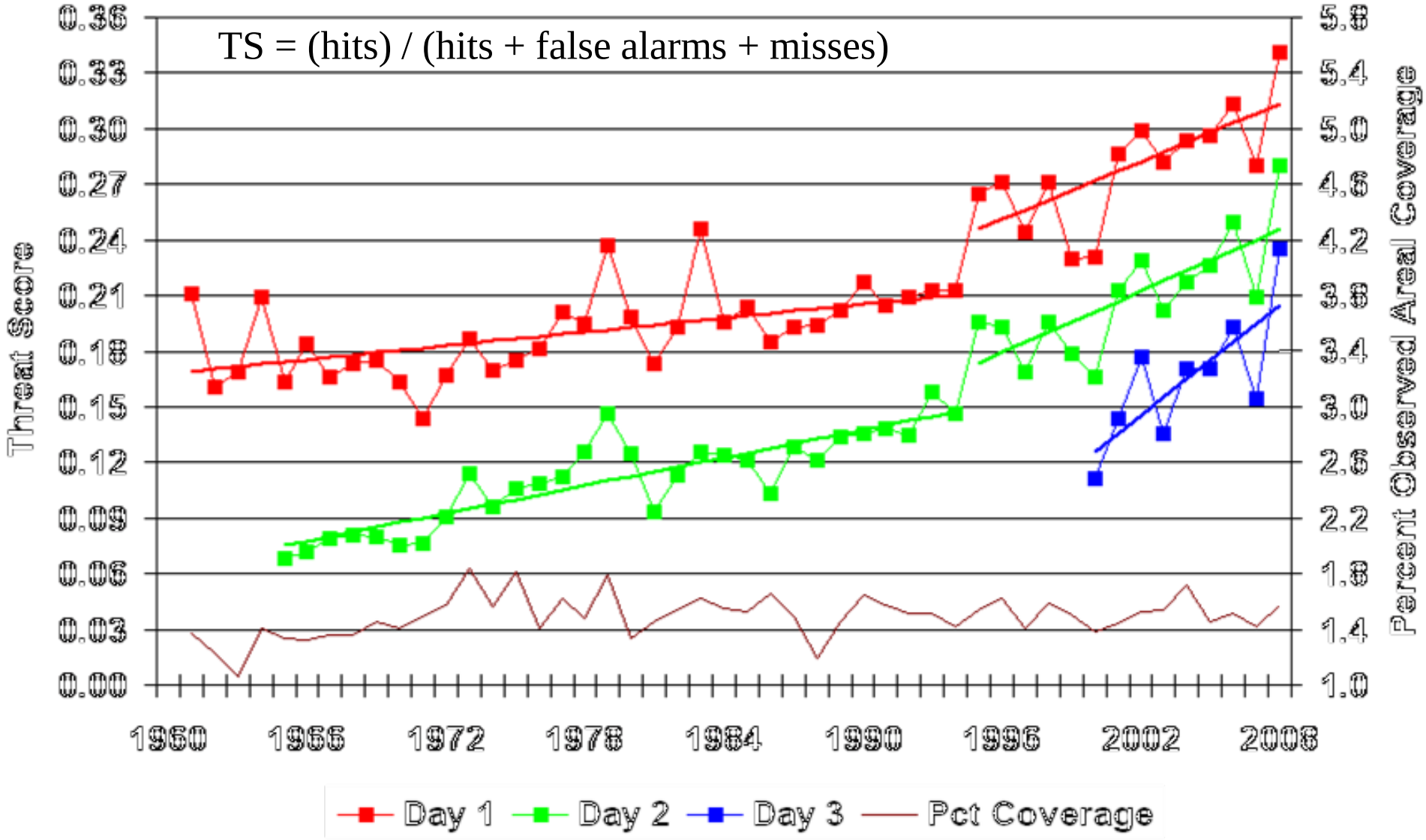
Quantitative Precipitation Forecast (QPF)



Source: NWS-WPC website

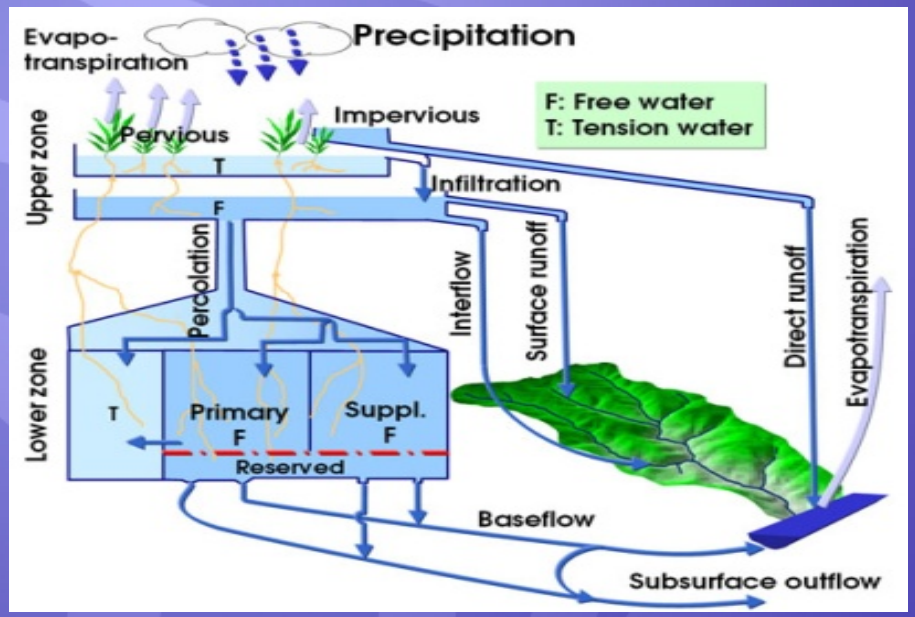
Provided by: J. Hoke

HPC QPF verification
1-inch threat score



SAHRA

Progress in hydrologic modeling



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Brief Review of Rainfall Runoff modeling:

Progress in Hydrologic Modeling

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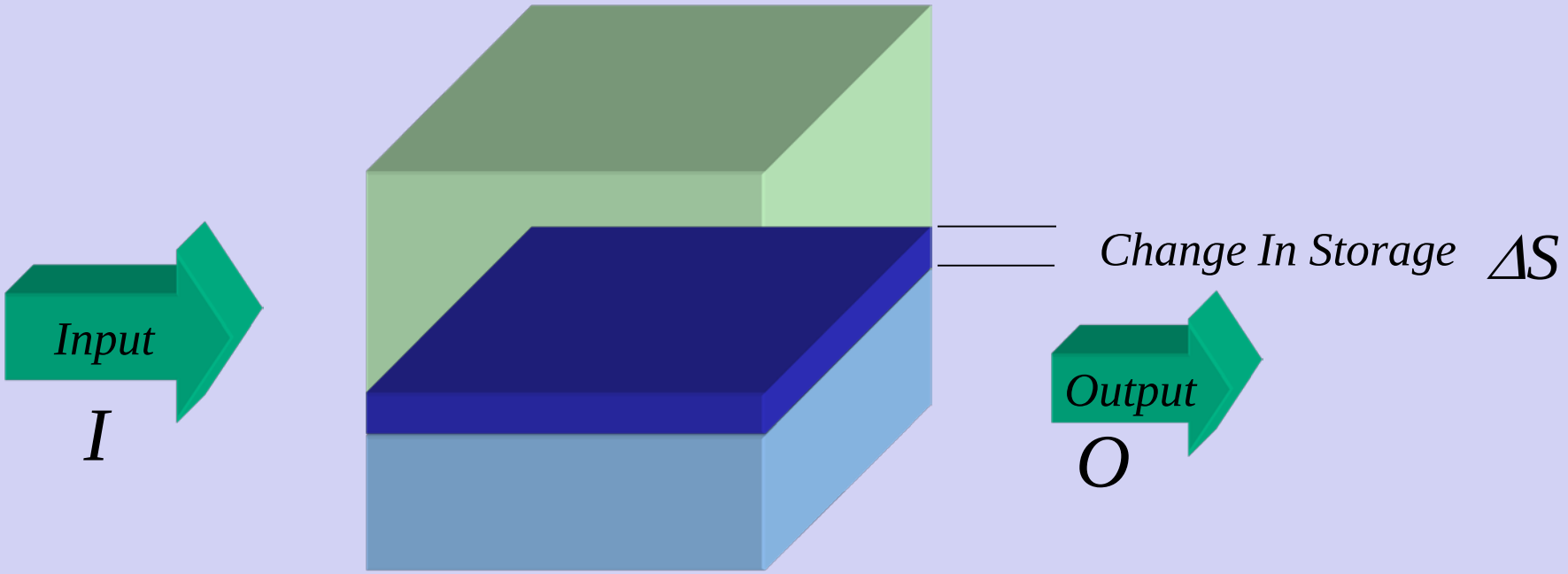
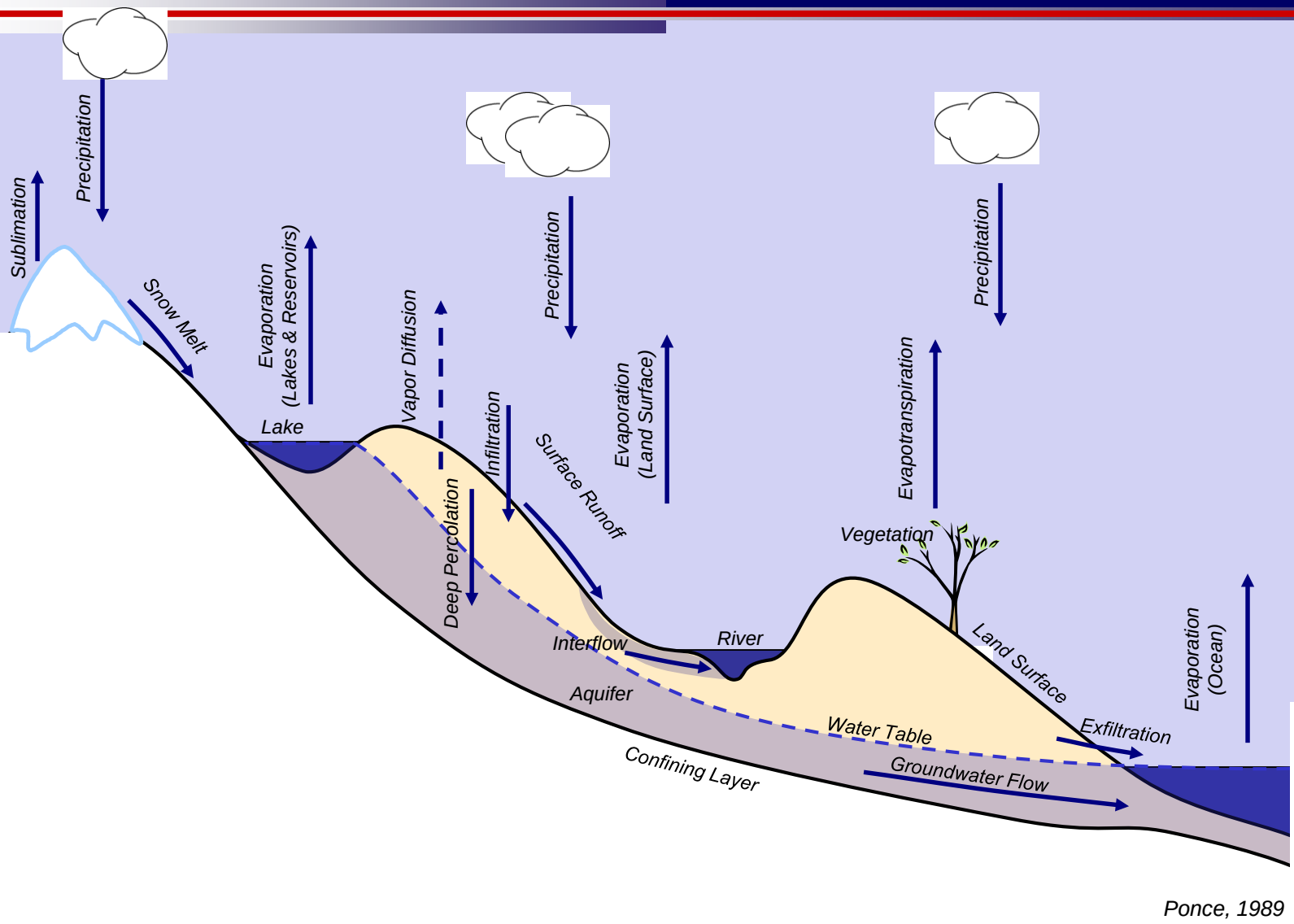
Fundamental Law

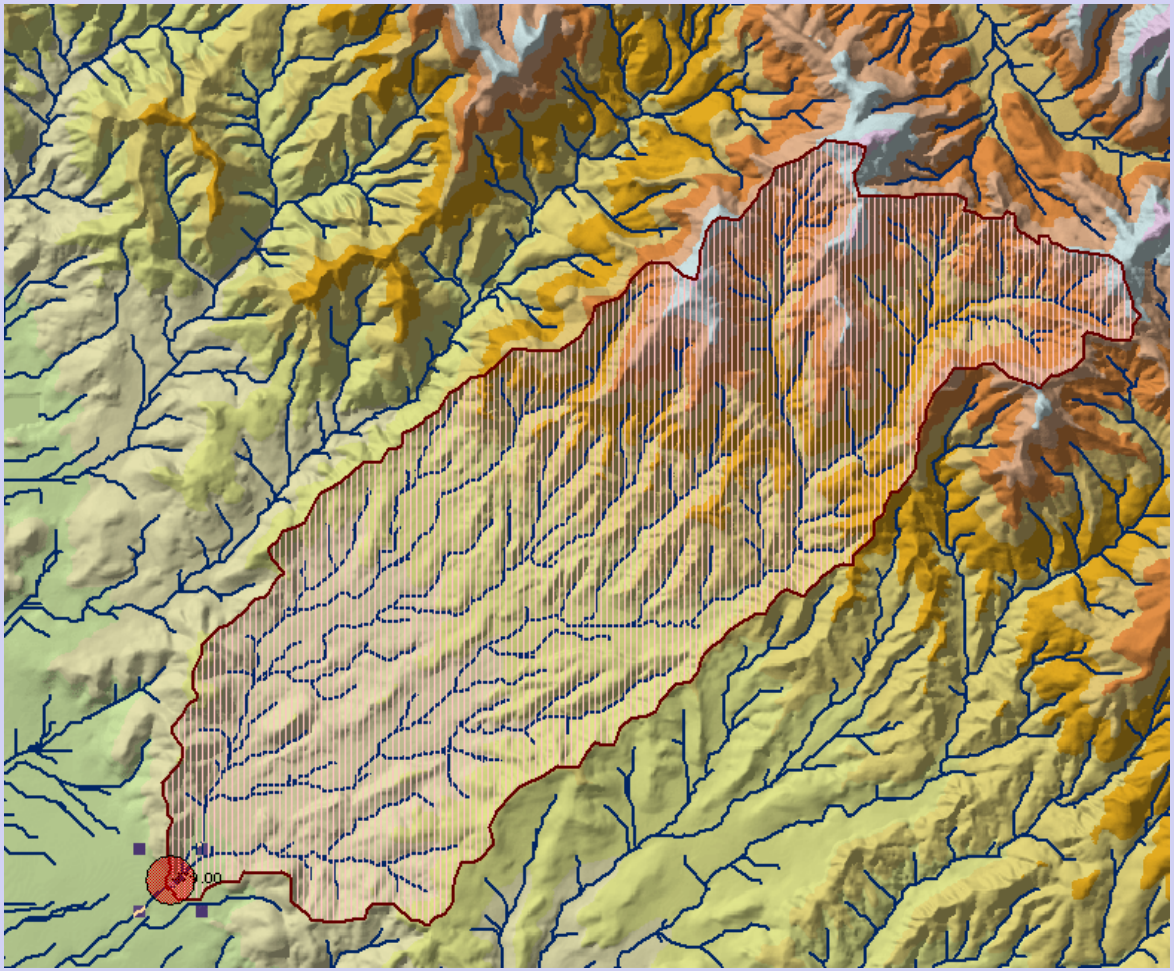


$$I - O = \Delta S$$

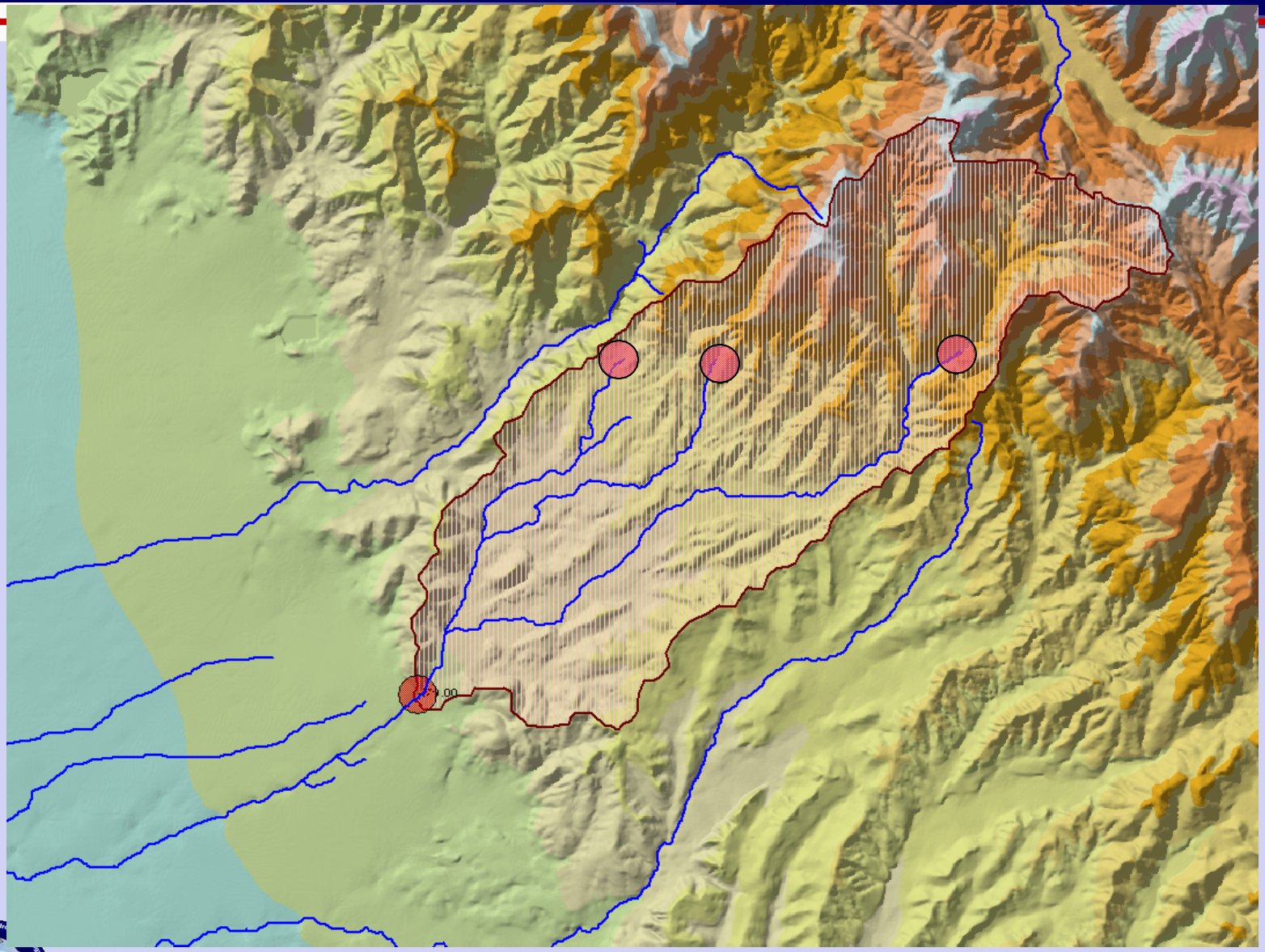

Precipitation
Sublimation
Snow Melt
Evaporation (Lakes & Reservoirs)
Lake
Vapor Diffusion
Infiltration
Deep Percolation
Surface Runoff
Precipitation
Evaporation (Land Surface)
Evapotranspiration
Vegetation
Precipitation
Interflow
River
Land Surface
Evaporation (Ocean)
Aquifer
Water Table
Exfiltration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

The Watershed

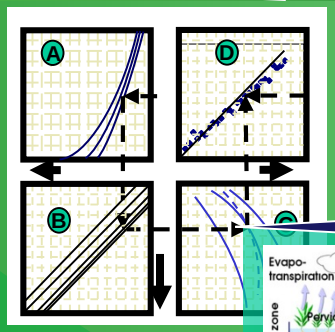
Area km2	12.78
Perimeter km	19.344
Min Elevation m	478.00
Max Elevation m	1756.00
Mean Elevation	930.34
Max Flow Length	8.878



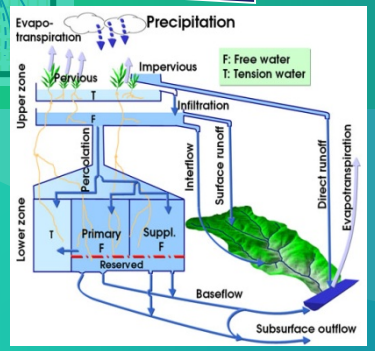
Trace The Water Drop



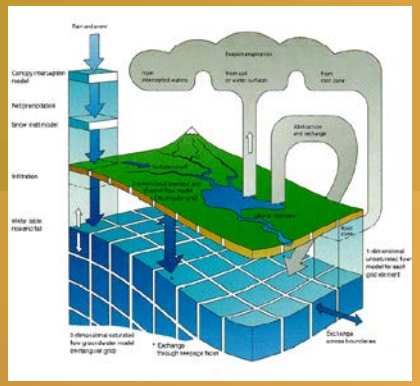
Evolution of Hydrologic R-R Models



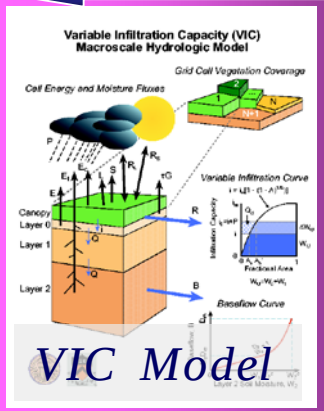
API Model



Lumped Conceptual



Distributed (Mike SHE)



VIC Model

Lumped "Simple"

Time

Distributed

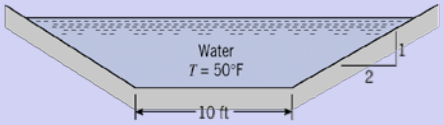
Physically-based

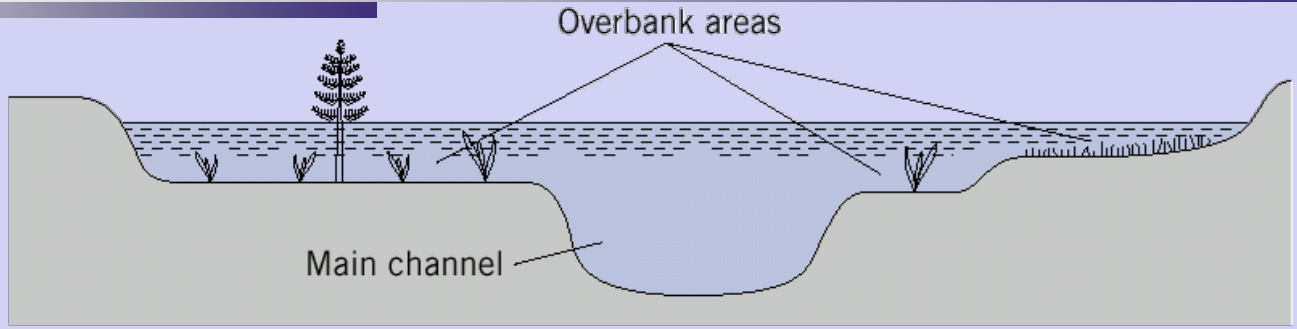
Hydrologic Modeling: 3 Elements!

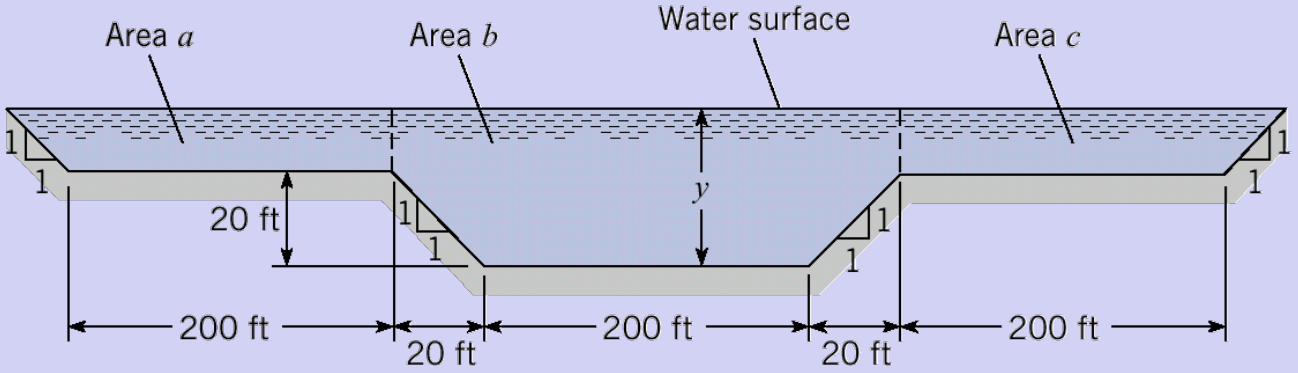
If the "World" of Watershed Hydrology Was Perfect!

Flow in Channels: How far can we go simplifying?

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

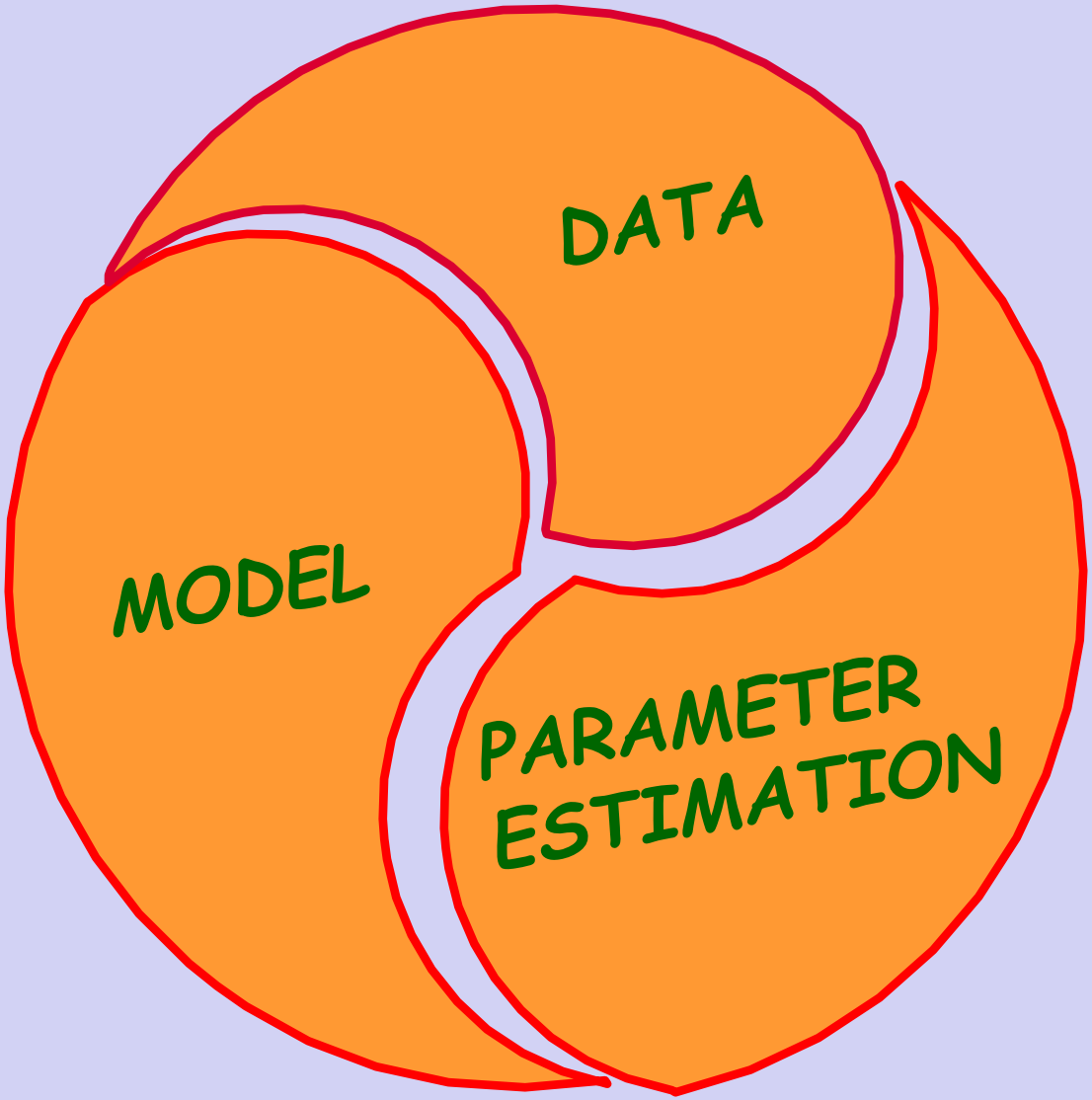




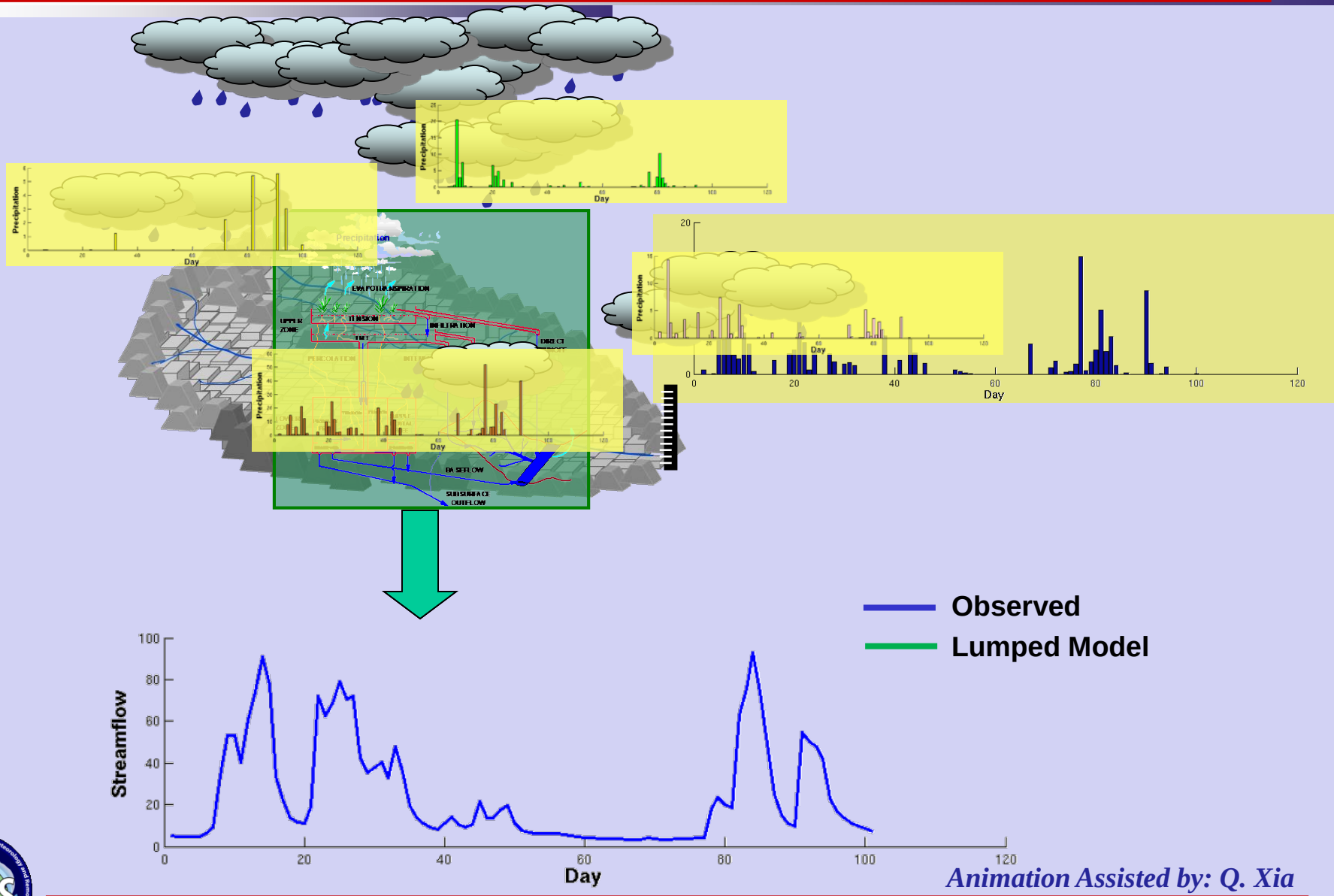


n – Manning Coefficient
R – Hydraulic Radius
S – Energy Slope

Hydrologic Modeling

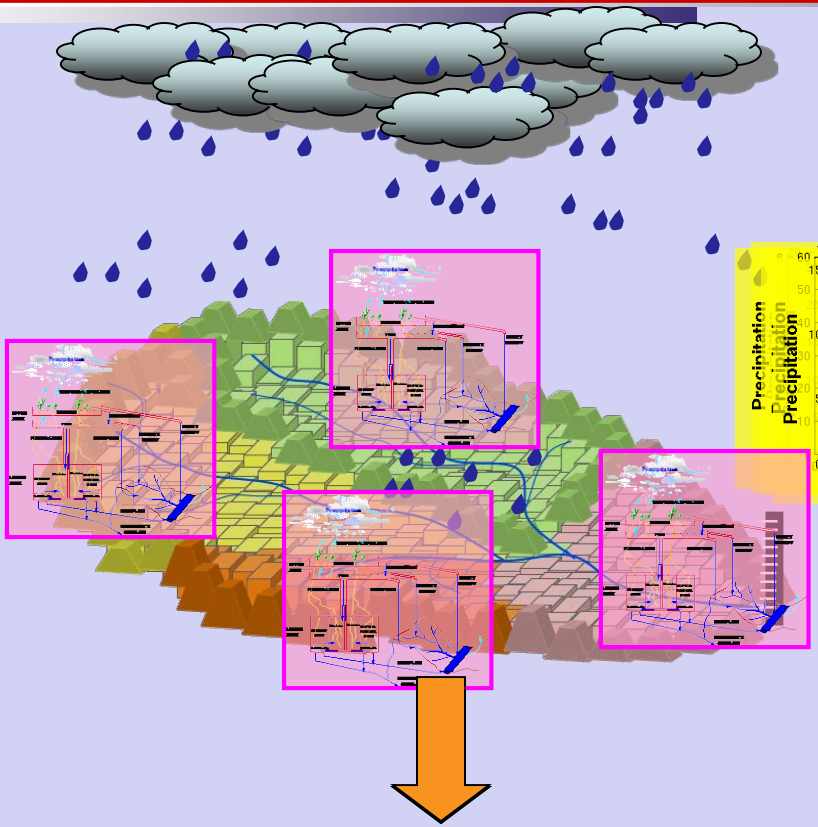


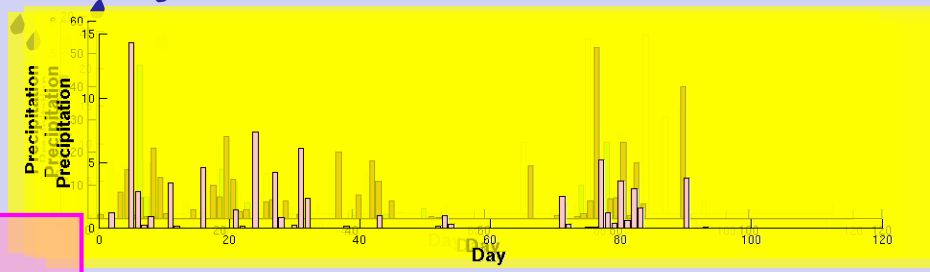
Hydrologic Modeling: "Lumped"

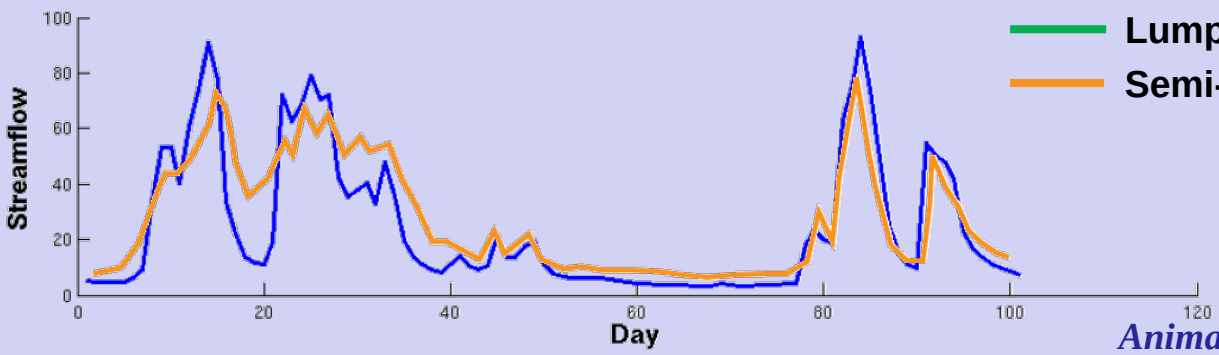


Animation Assisted by: Q. Xia

"Semi-distributed" Hydrologic Models

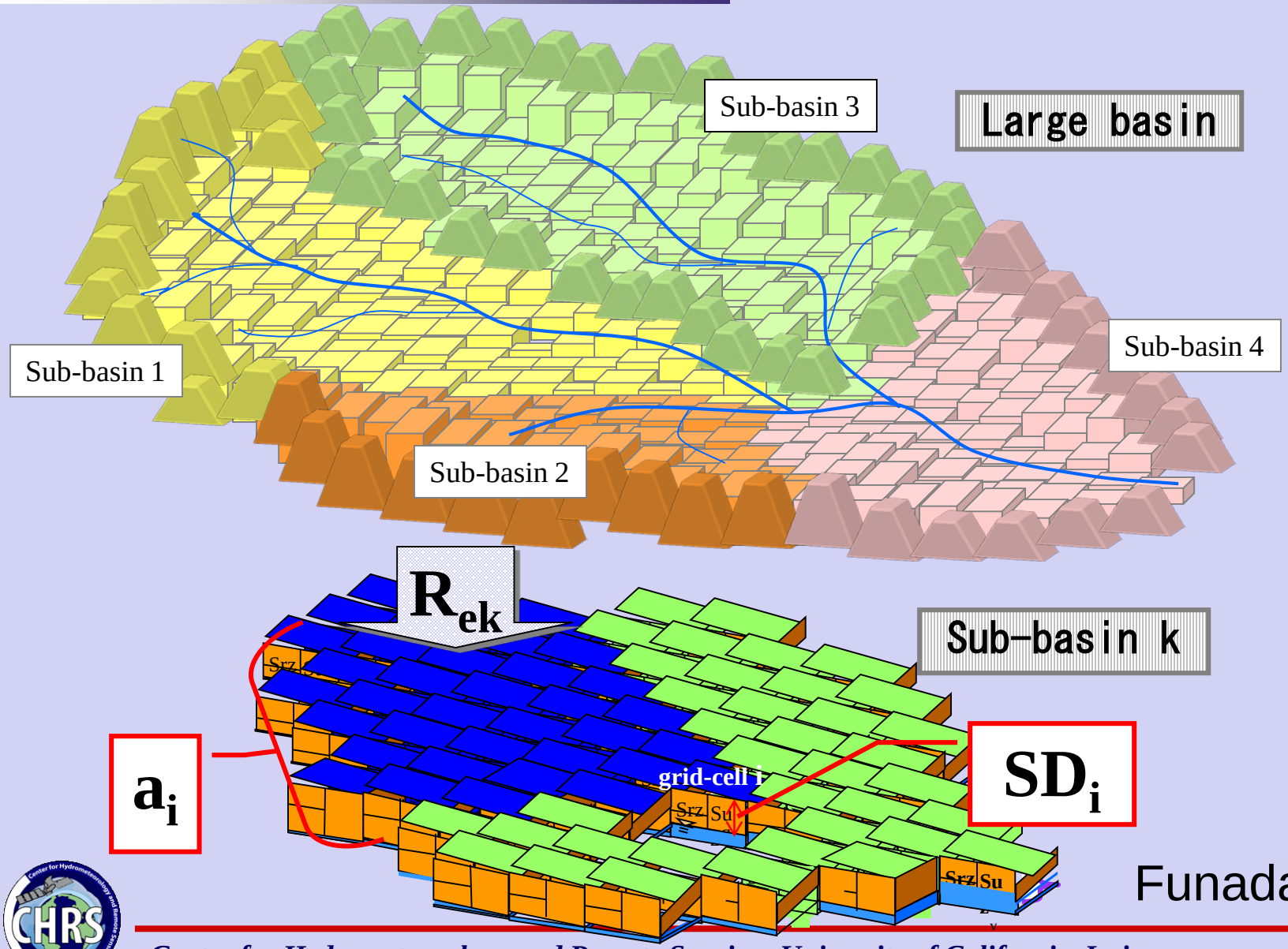






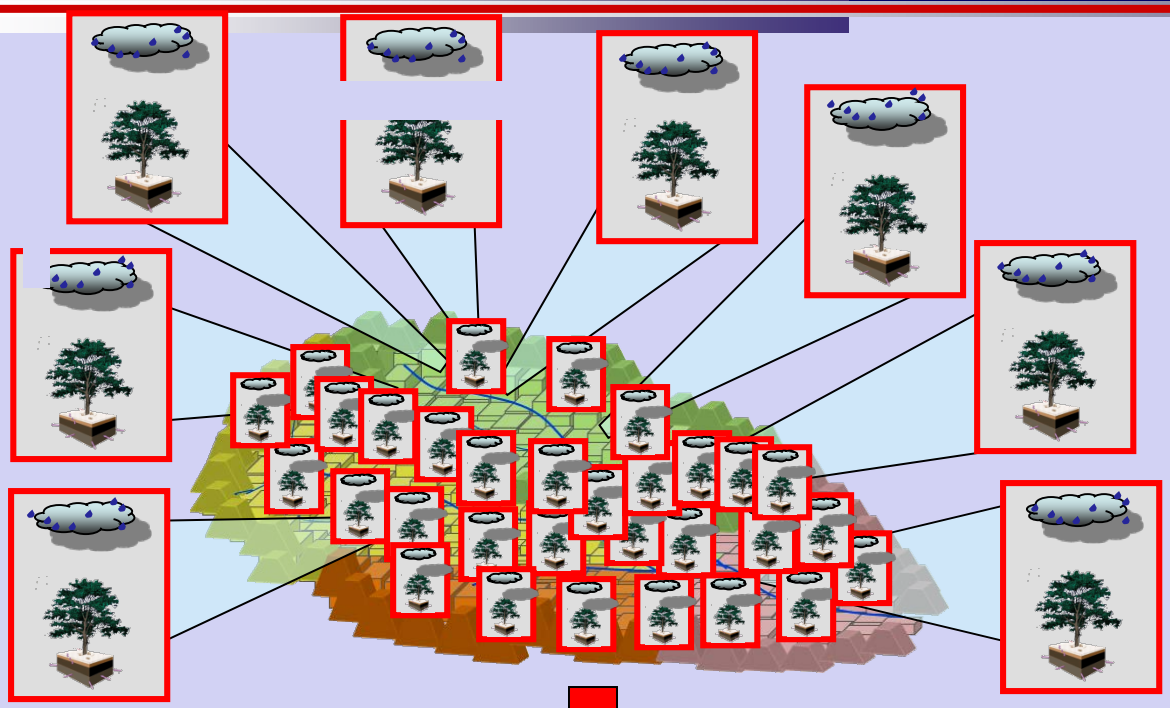
Animation Assisted by: Q. Xia

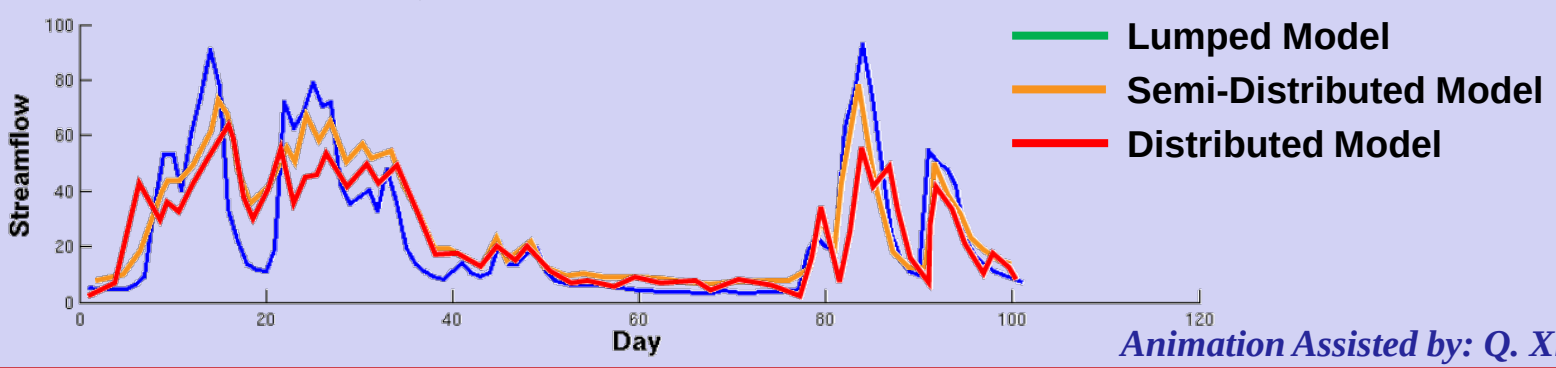
Example of Distributed Model Appl. in large Basins



Funada, 2004

Example of Distributed Model

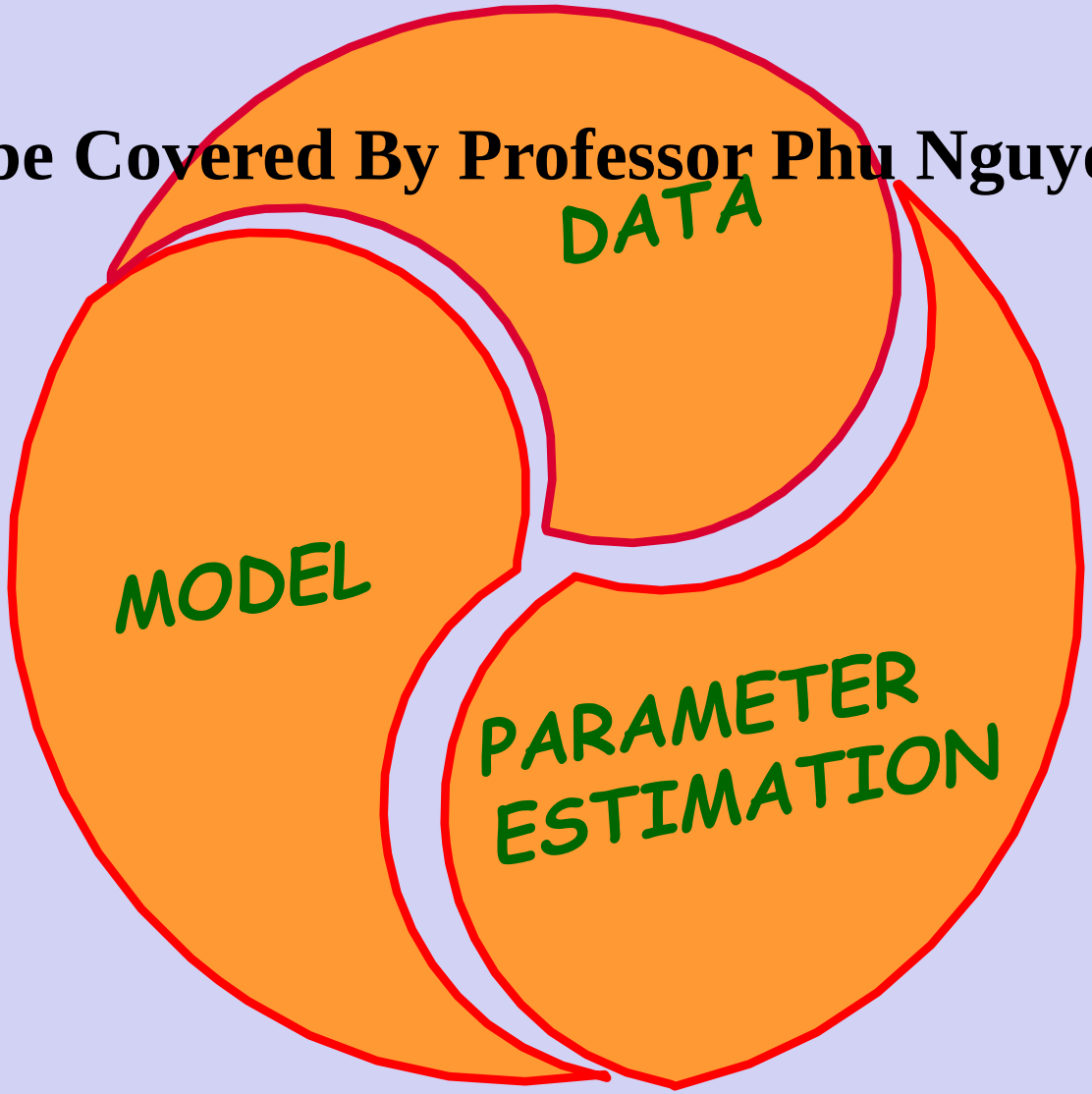




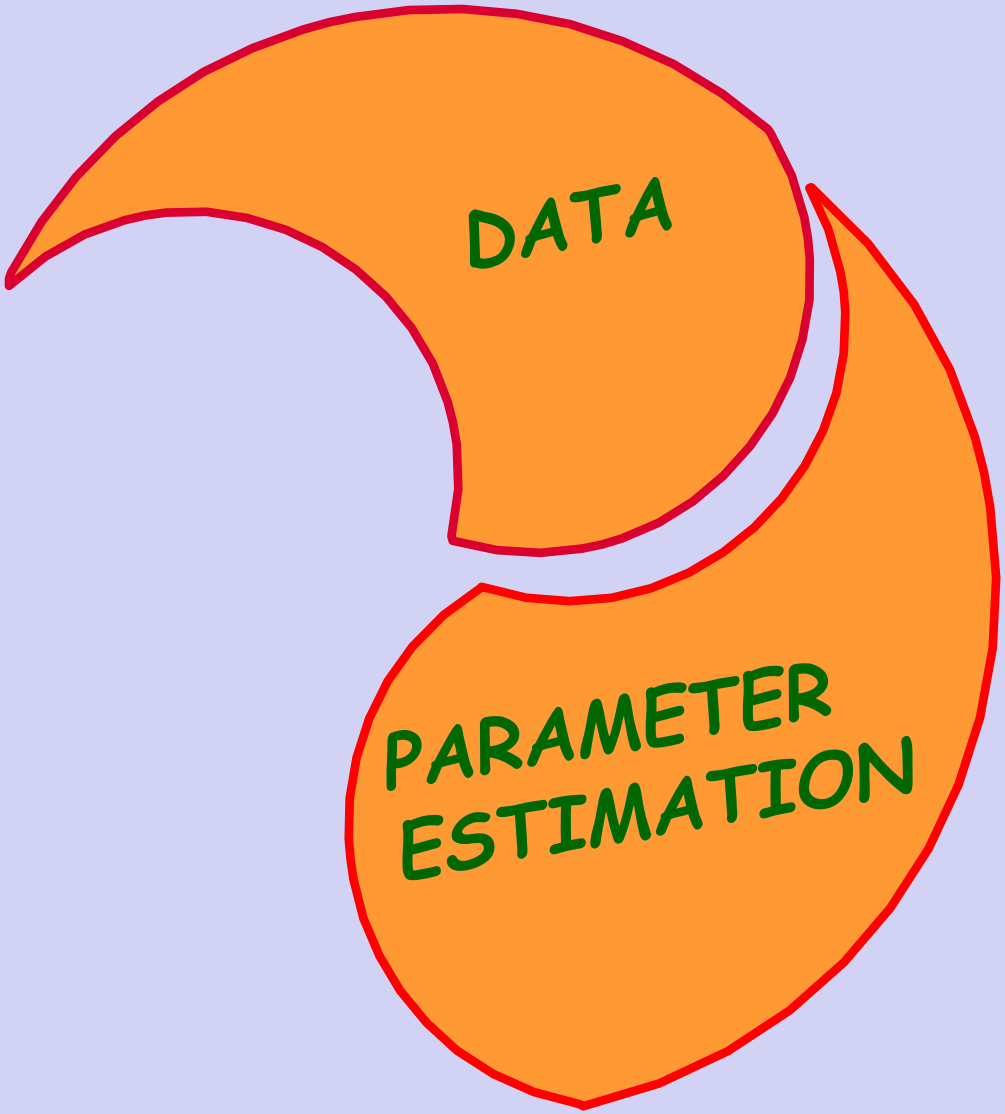
Animation Assisted by: Q. Xia

Hydrologic Modeling

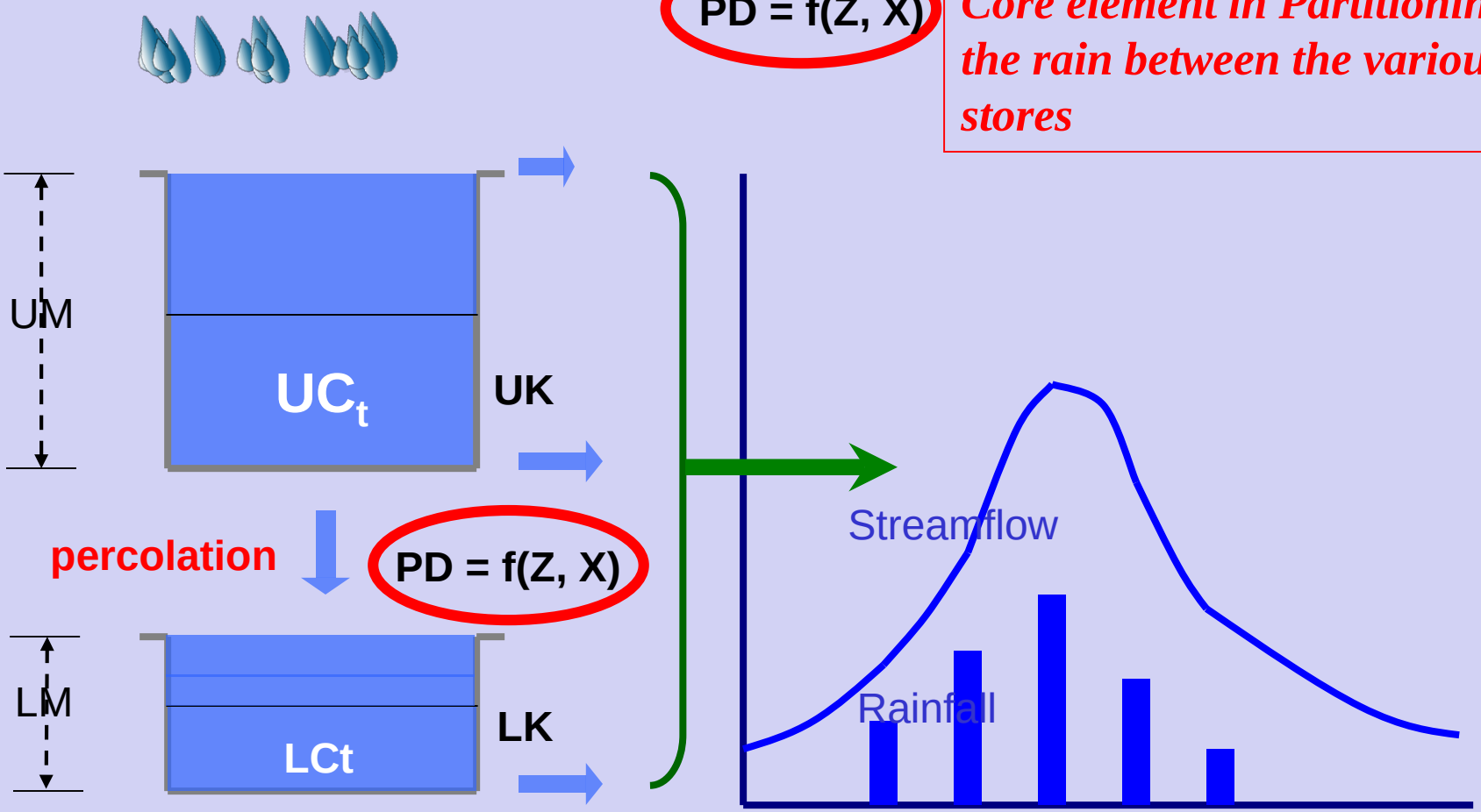
Will be Covered By Professor Phu Nguyen



Model Calibration



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



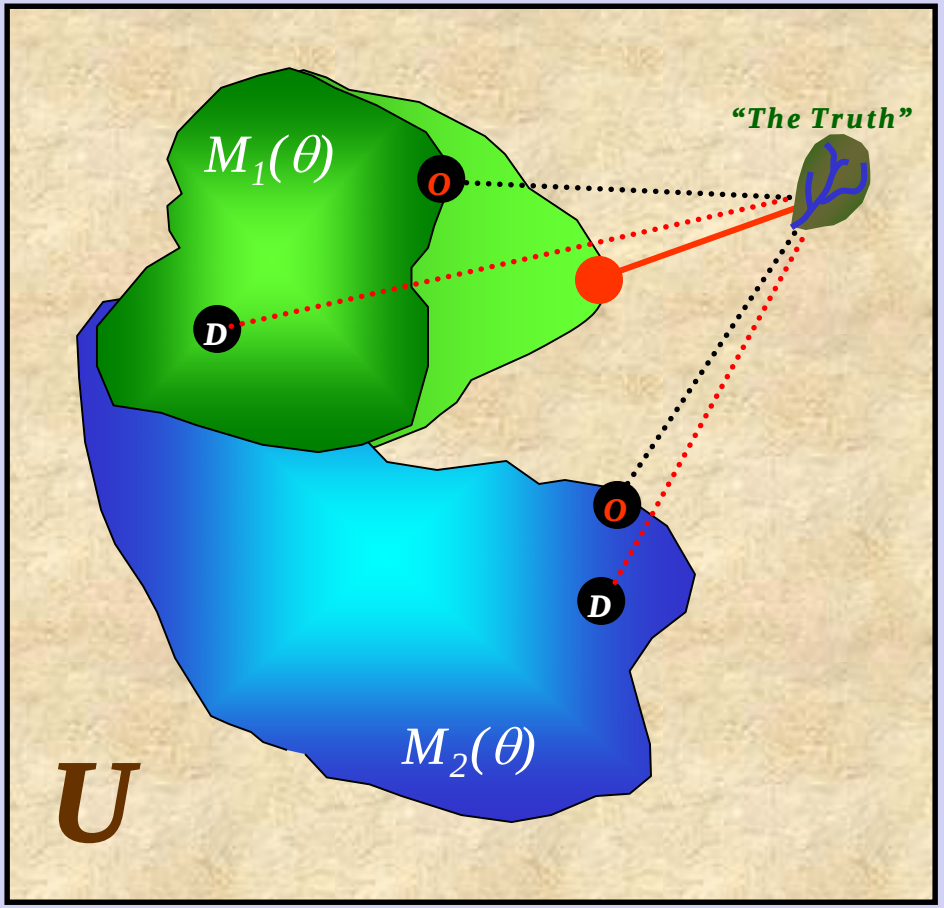
The Identification Problem

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

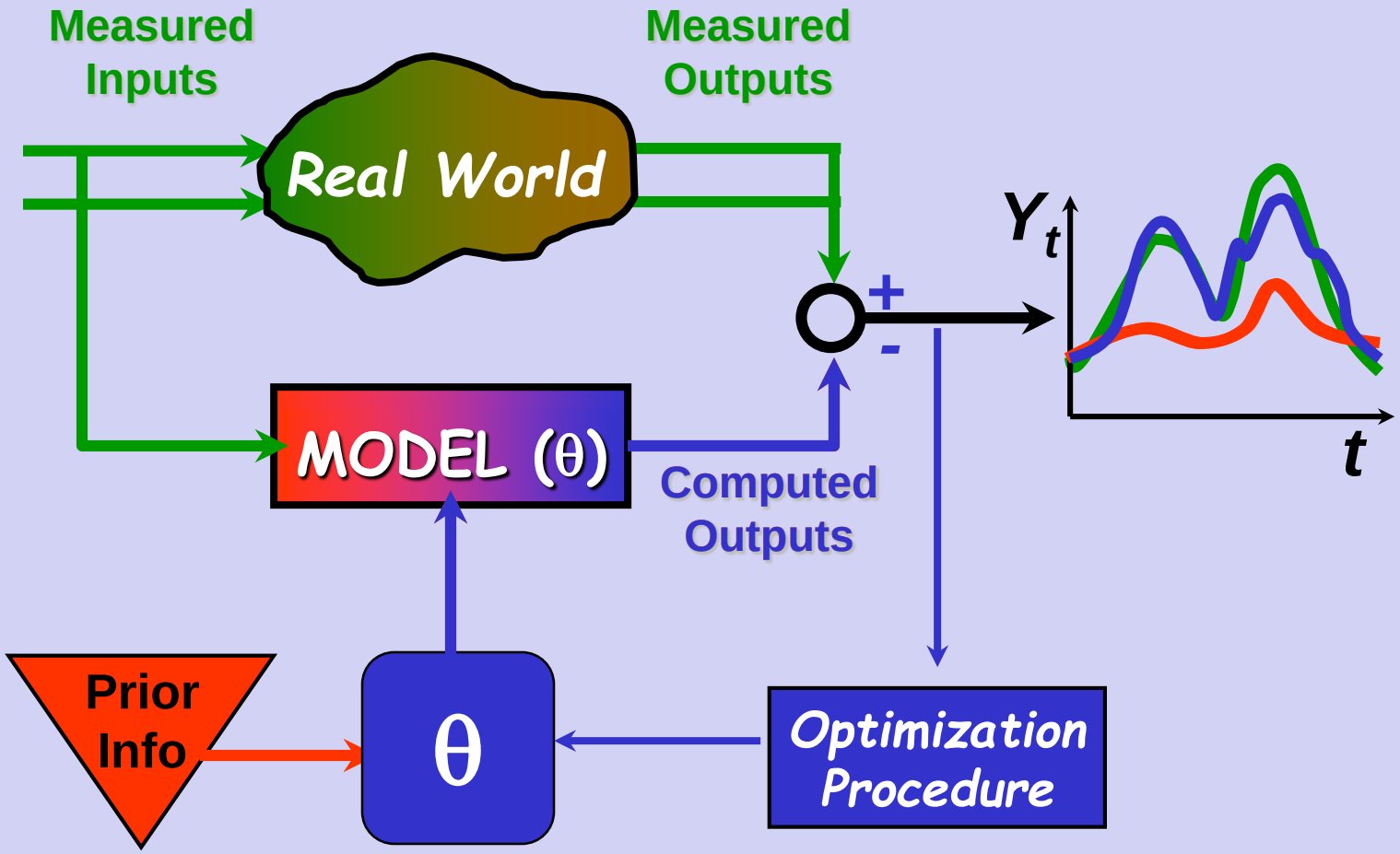
U – Universal Set

B - Basin

$M_i(\theta)$ – *Selected Model Structure*



The Concept of Model Calibration



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

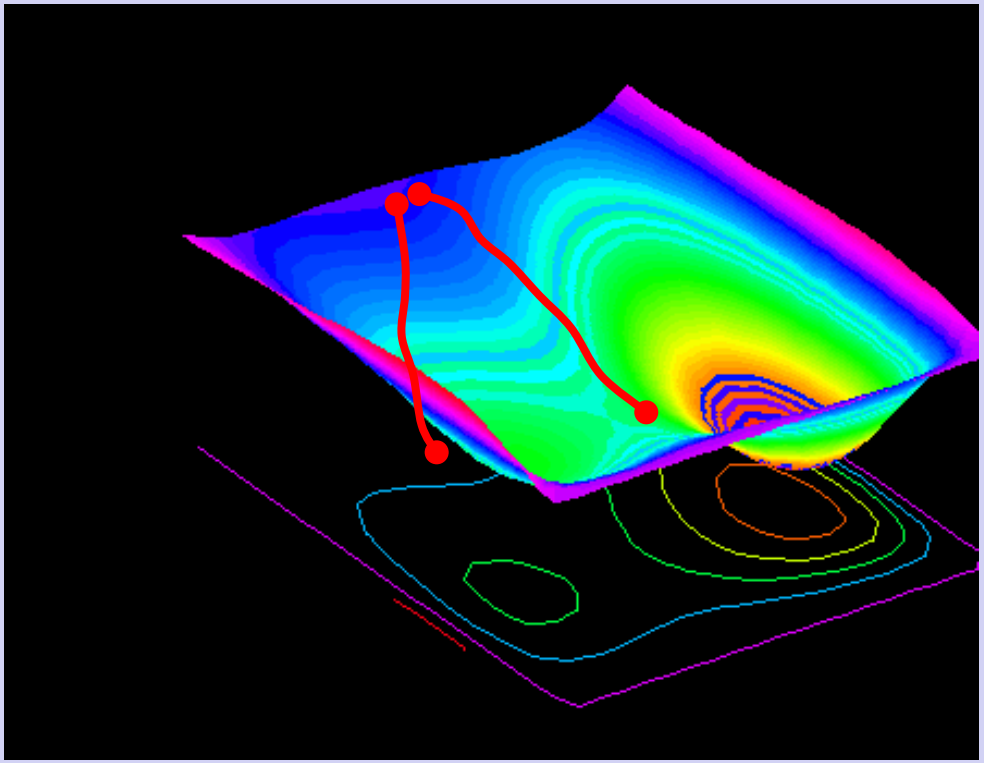
The Automatic Calibration Approach

Calibration components

Objective Function

Search Algorithm

Sensitivity Analysis



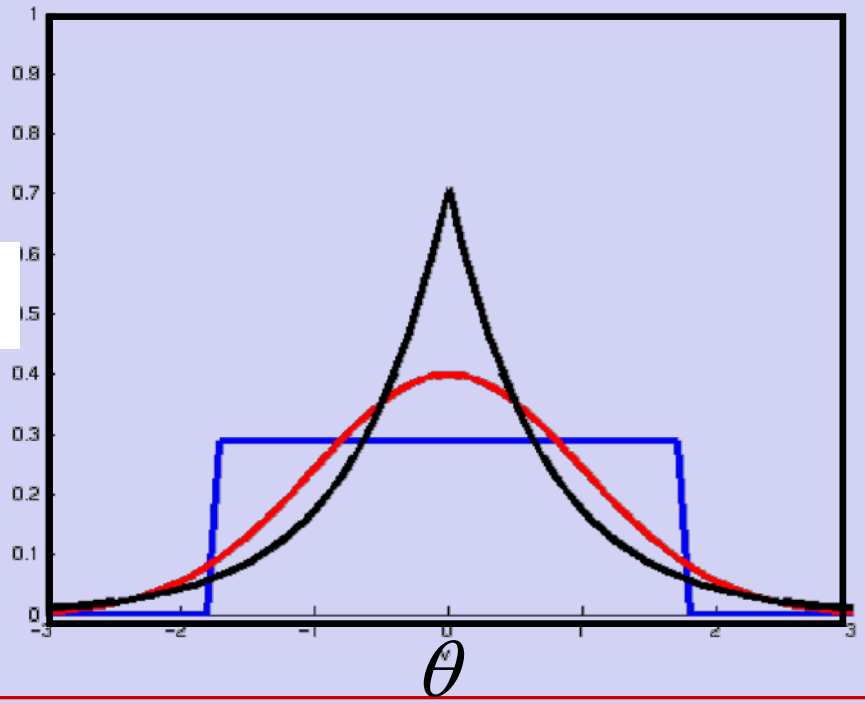
Problems with identifiability

Calibration Criterion

[General Exponential Power Density]

(Posterior Parameter Probability Distribution Function)

$$p(\theta_i \mid \mathbf{y}, \gamma) = \left[\frac{\omega(\gamma)}{\sigma}\right]^N \exp\left[-c(\gamma)\sum_{j=1}^{N}\left|\frac{e(\theta_i)_j}{\sigma}\right|^{2/(1+\gamma)}\right]$$

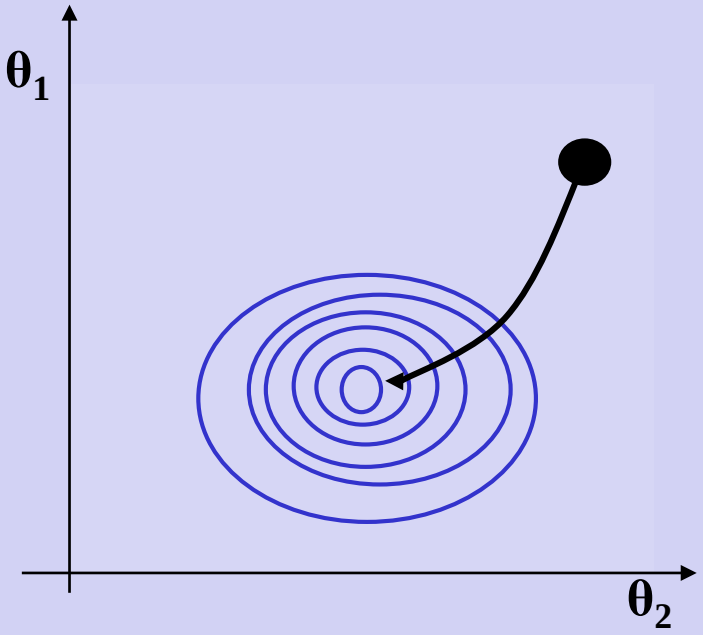


Uniform $\gamma \to (-1)$

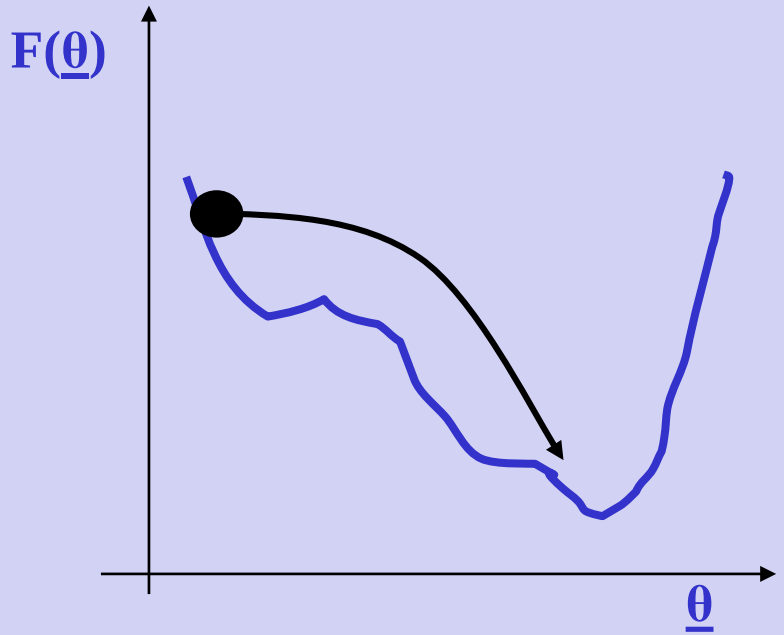
Normal $\gamma = 0$

Exponential $\gamma = 1$

Objective function Parameter Space

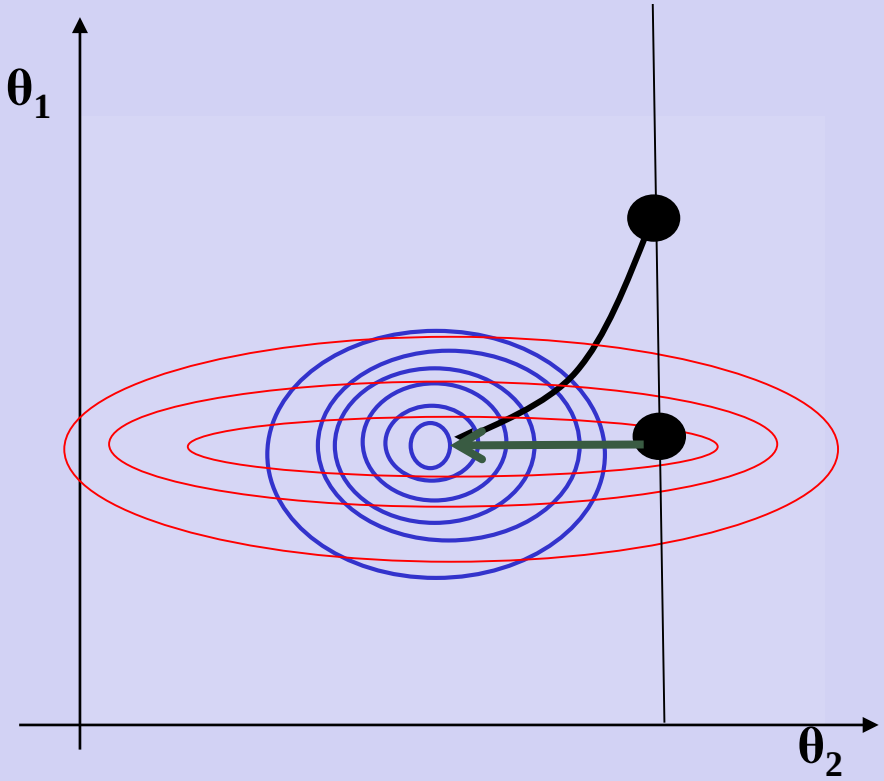


Parameter Space



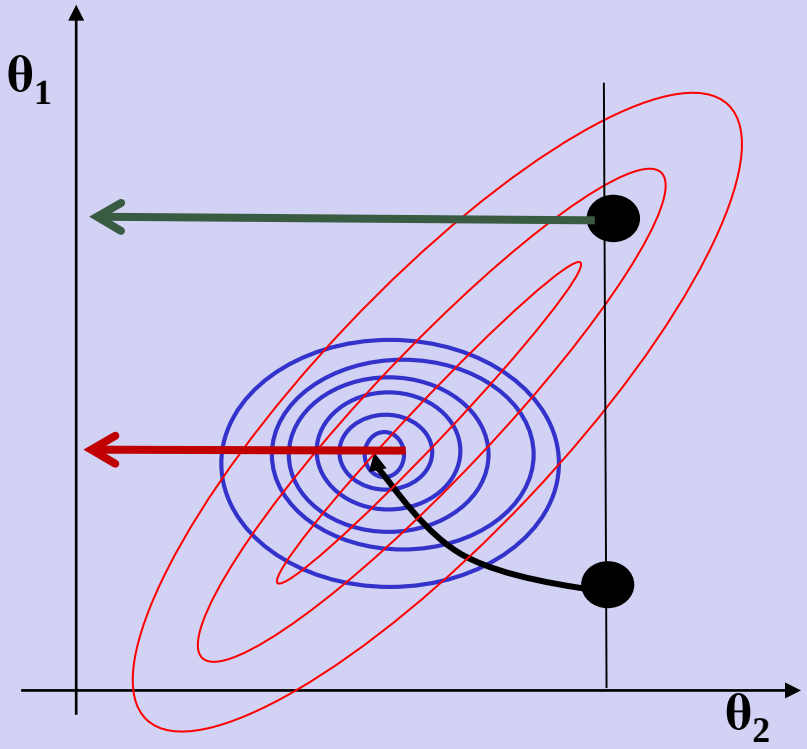
Objective Function Space

Parameter Sensitivity



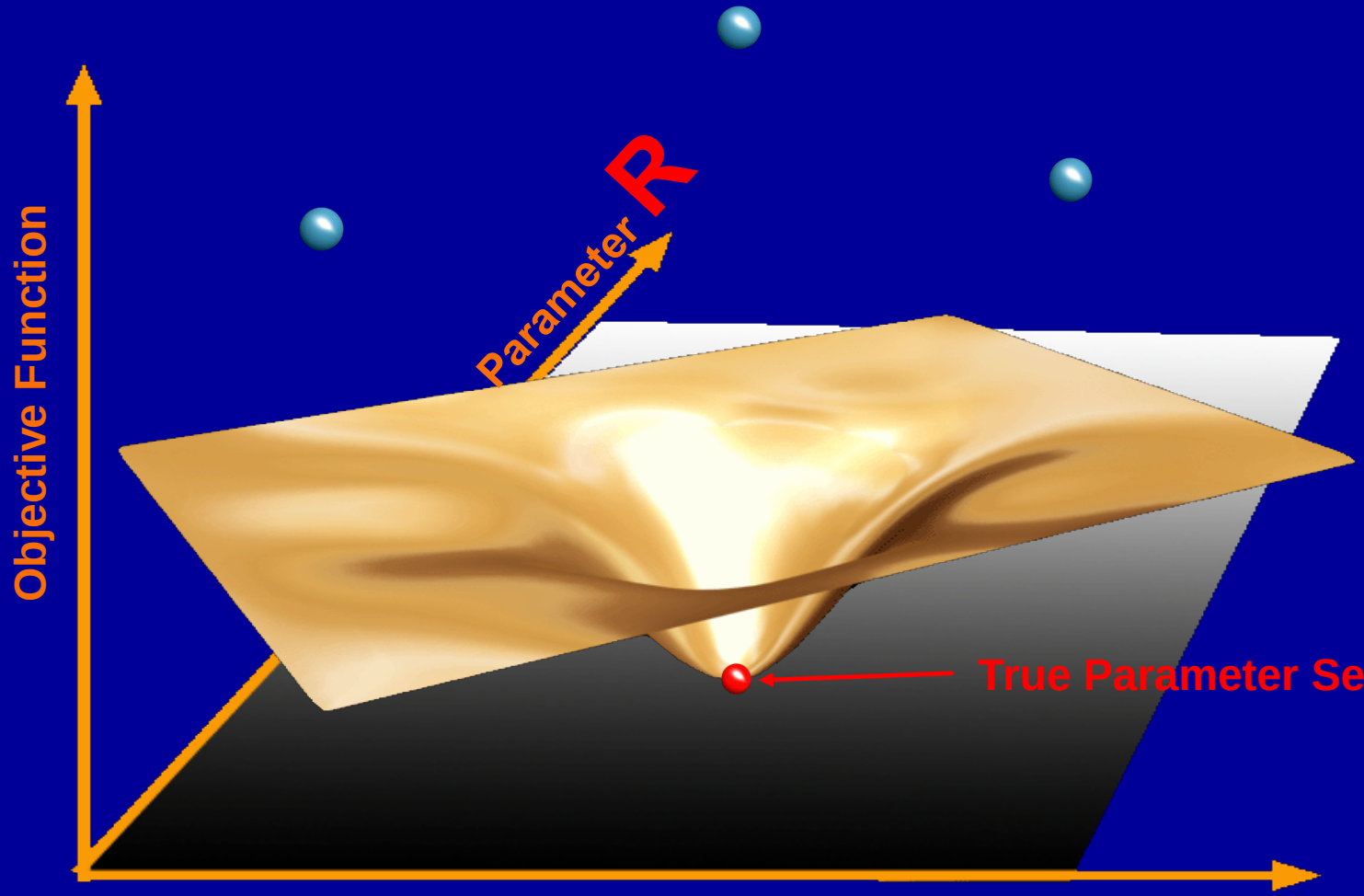
Parmeter Space

Parameter Sensitivity



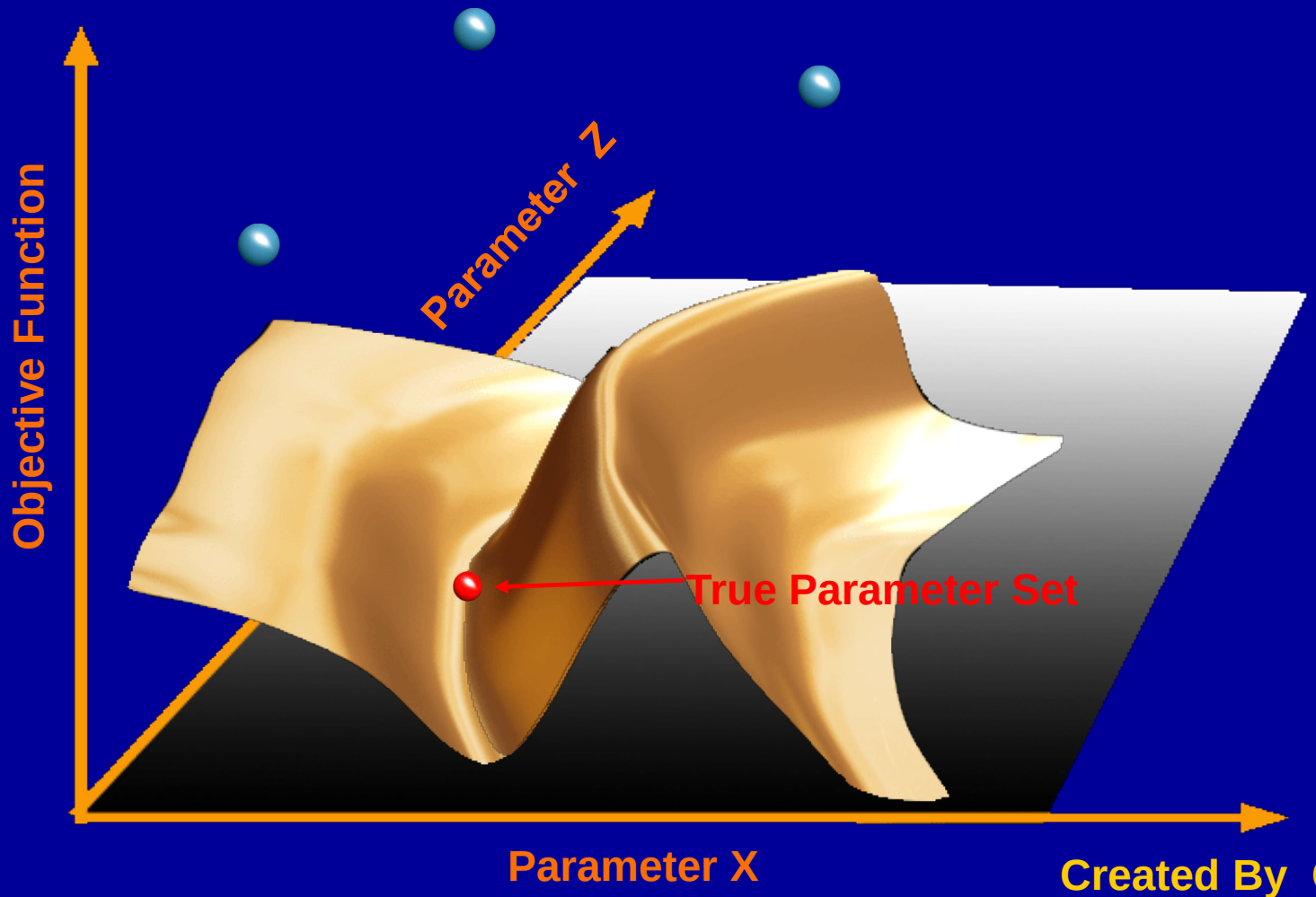
Parameter Space

The Ideal case: Convex Optimization



Created By G-H Park

Difficulties in Global Optimization



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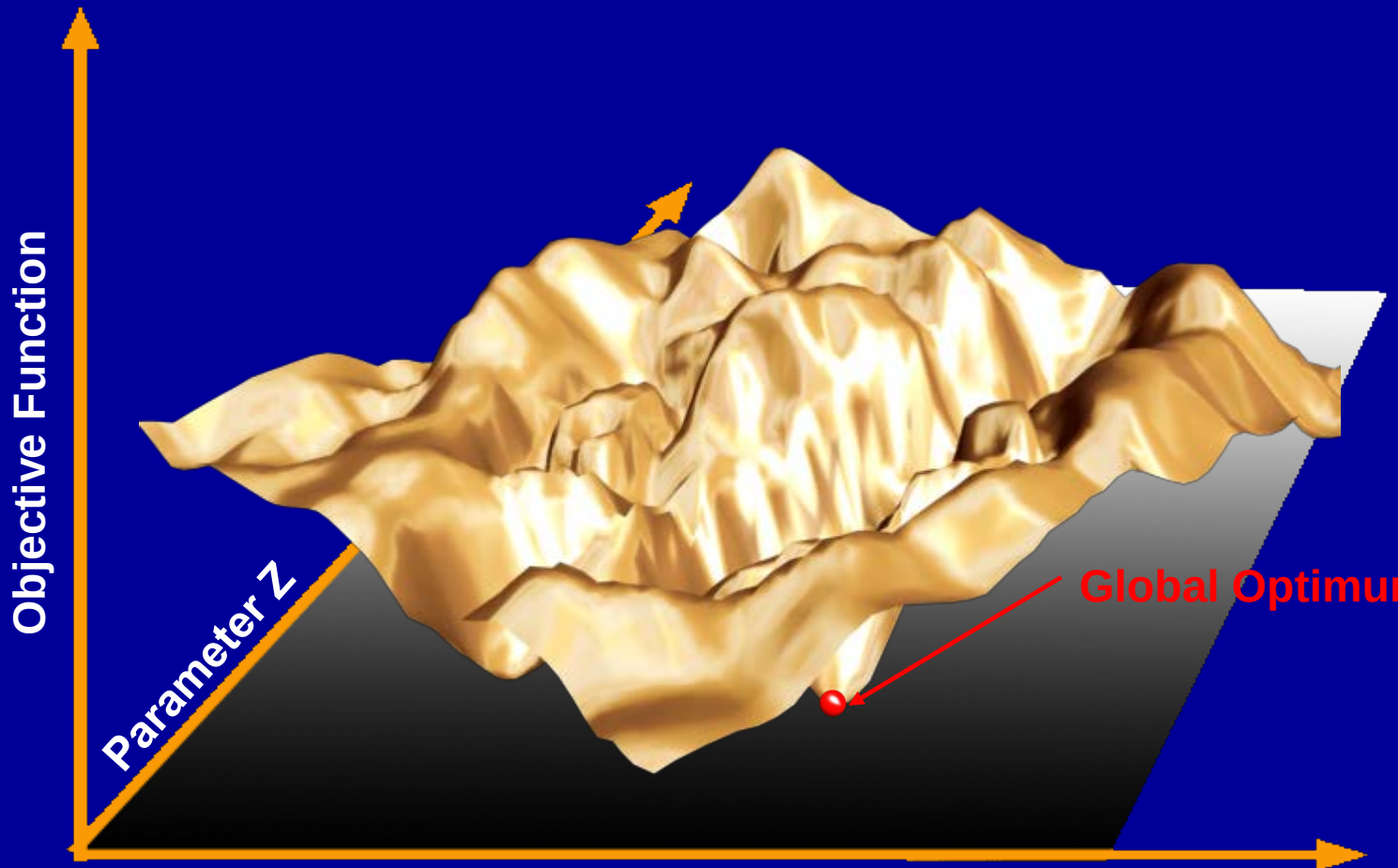
Parameter Estimation (non-convex, multi-optima)



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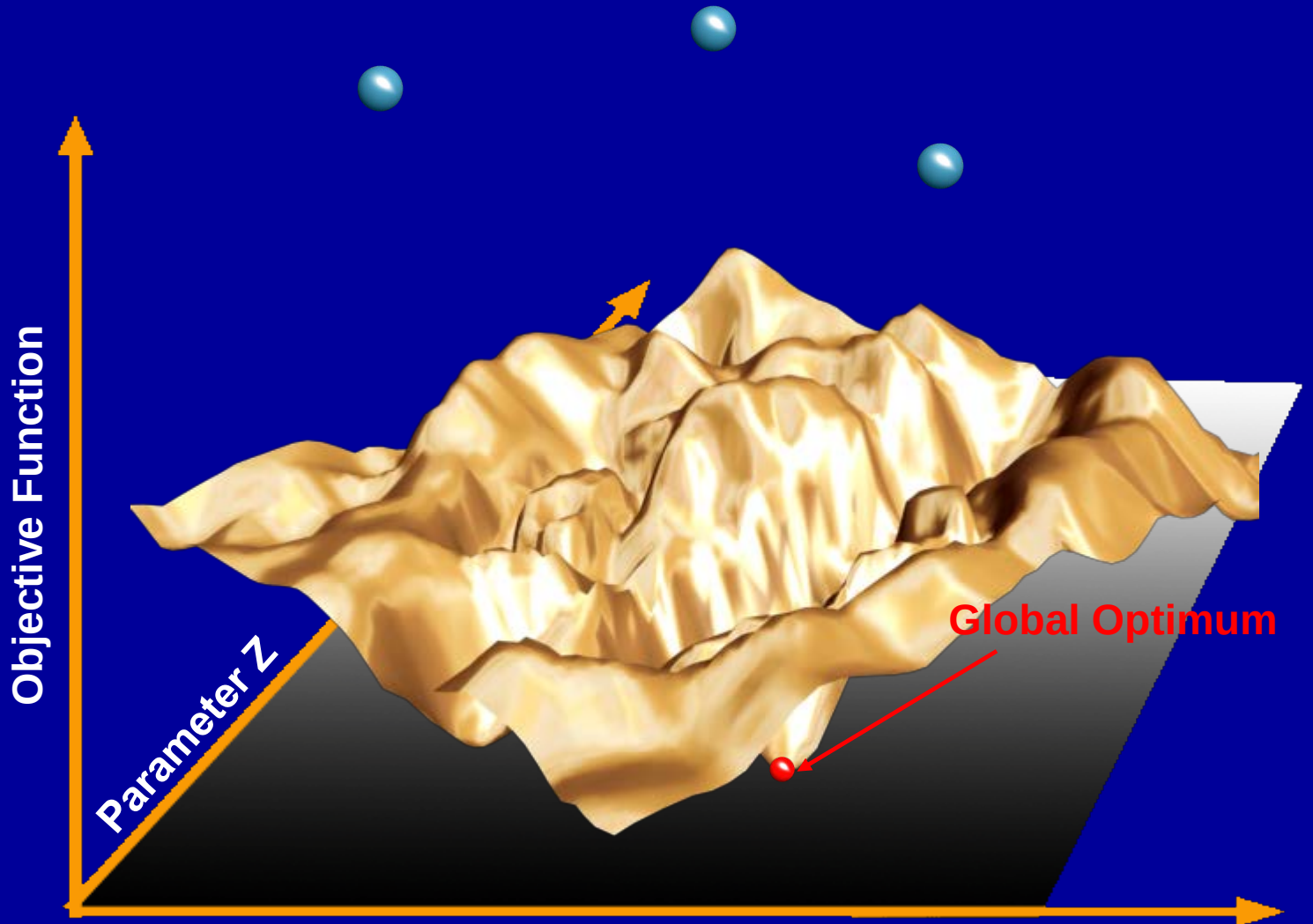
Parameter Estimation (non-convex, multi-optima)



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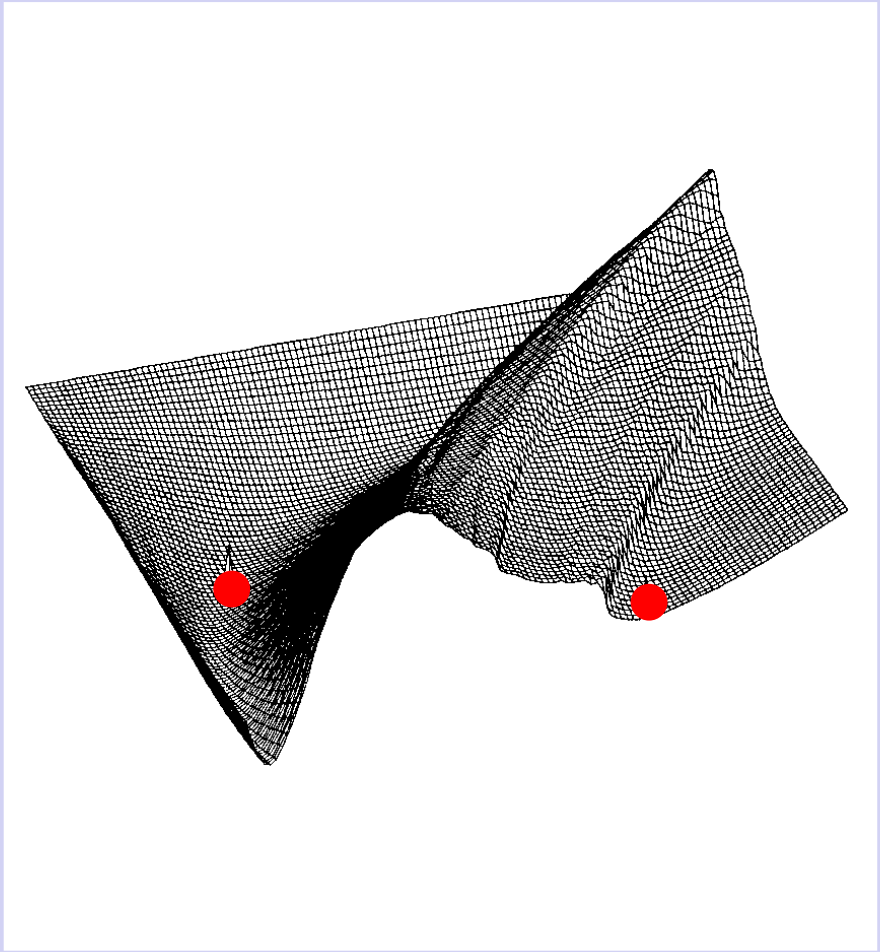
Difficulties in Optimization

1.- Regions of Attraction

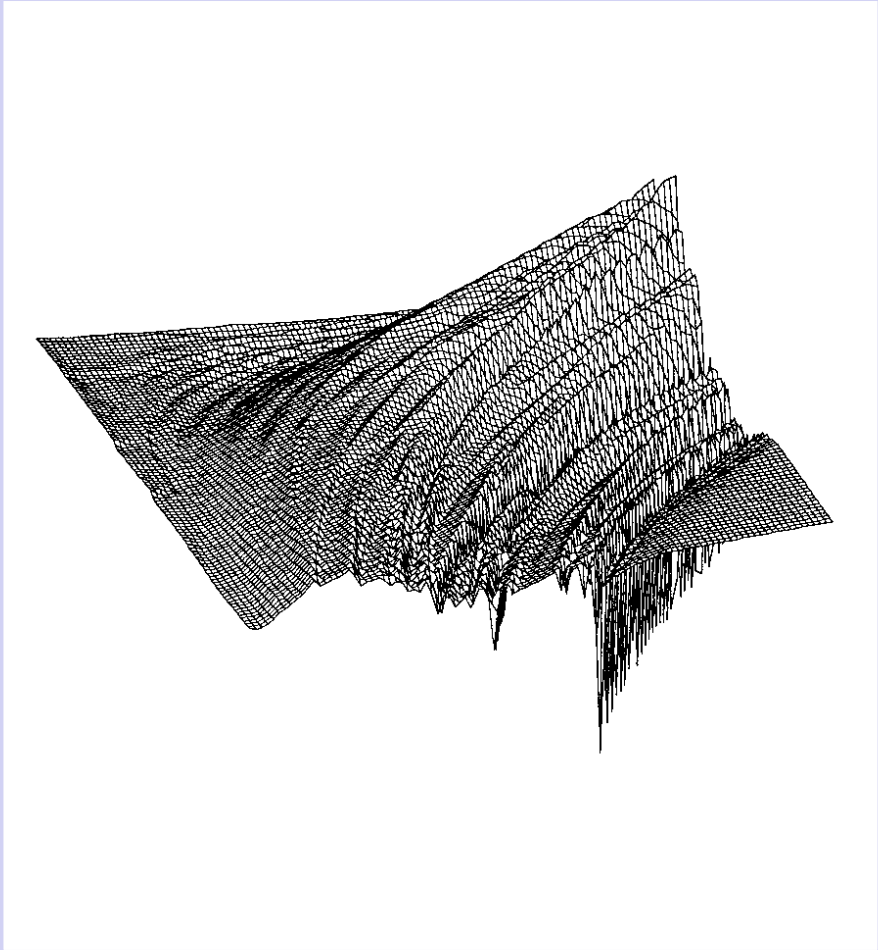
More than one main convergence region



Duan, Gupta, and Sorooshian, 1992, WRR

Difficulties in Optimization

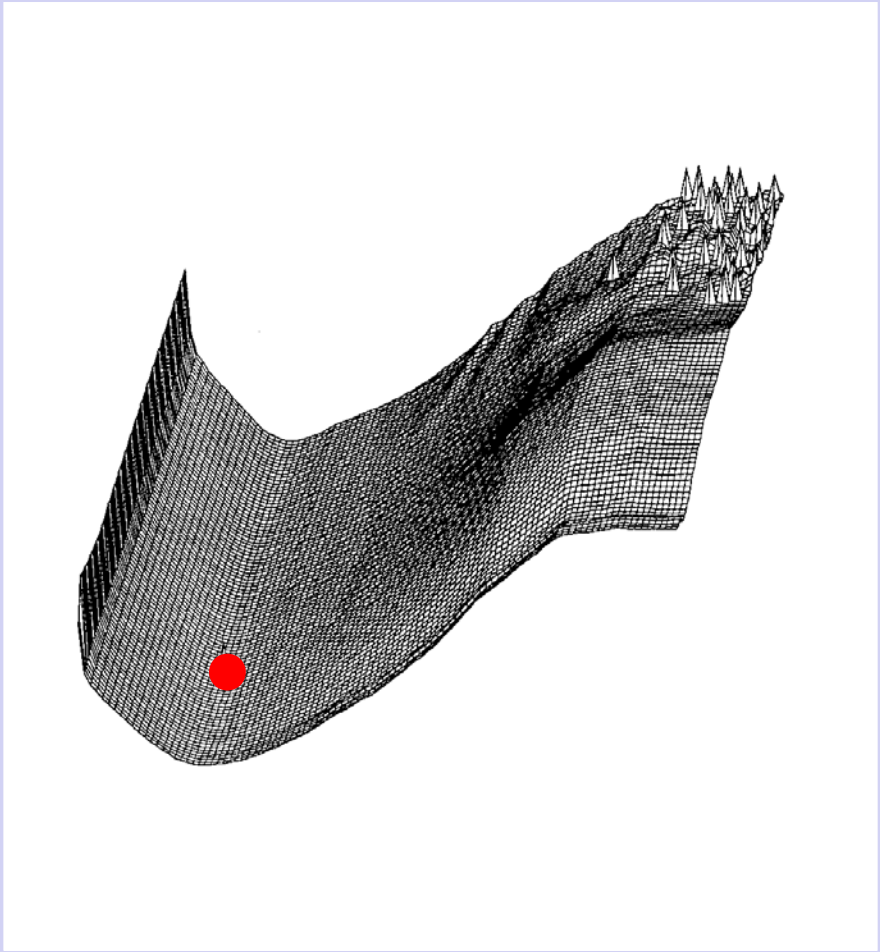
1.- Regions of Attraction	*More than one main convergence region*
2.- Local Optima	*Many small "pits" in each region*
3.- Roughness	*Rough surface with discontinuous derivatives*



Duan, Gupta, and Sorooshian, 1992, WRR

Difficulties in Optimization

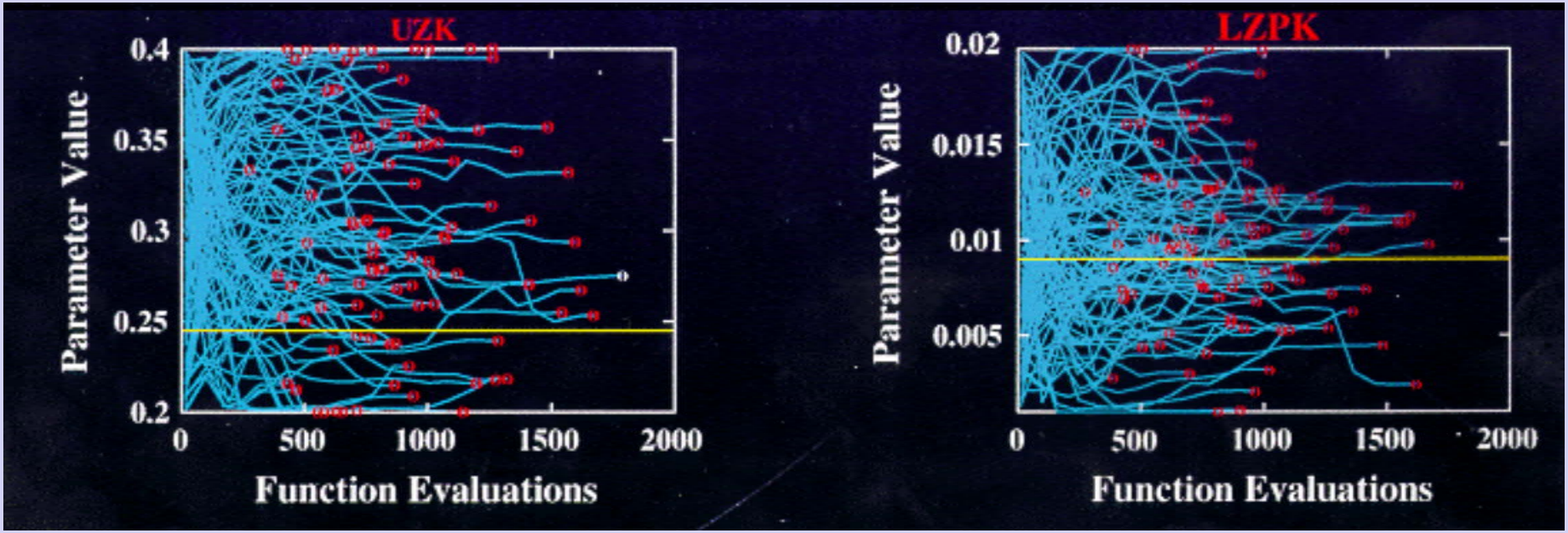
1.- Regions of Attraction	*More than one main convergence region*
2.- Local Optima	*Many small "pits" in each region*
3.- Roughness	*Rough surface with discontinuous derivatives*
4.- Flatness	*Flat near optimum with significantly different parameter sensitivities*



Duan, Gupta, and Sorooshian, 1992, WRR

Optimization Strategy – Local Direct Search

Calibration of the Sacramento Model
Downhill Simplex Method, *Nelder & Mead, 1965*



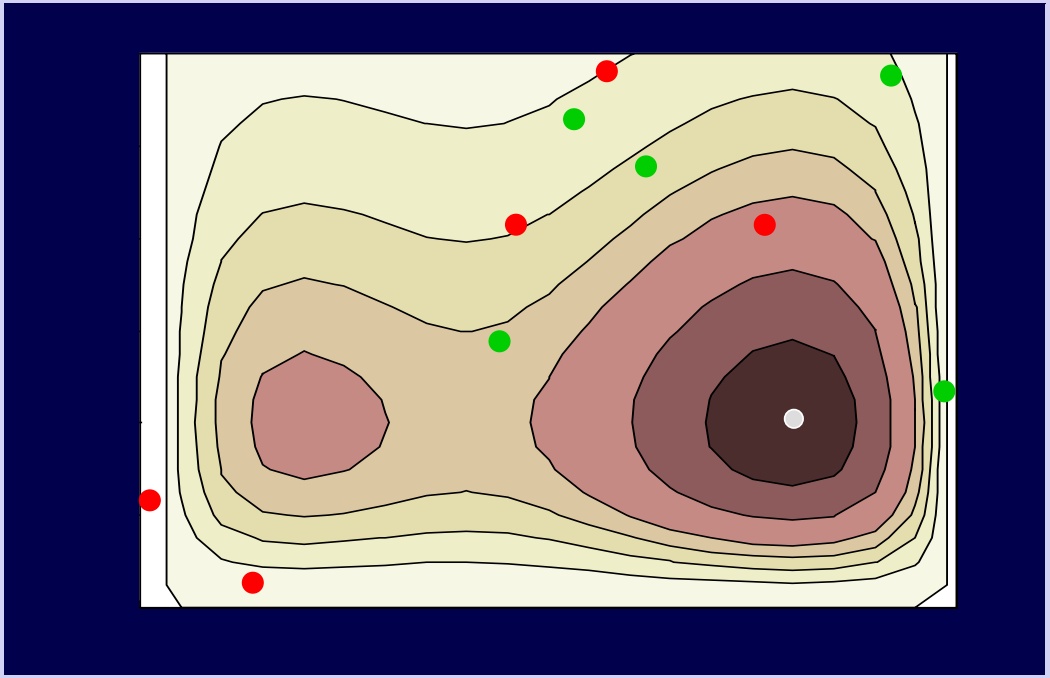
Duan, Gupta, and Sorooshian, 1992, WRR

The SCE-UA *Algorithm …*
(1992)

Duan, Gupta, and Sorooshian, 1992, WRR

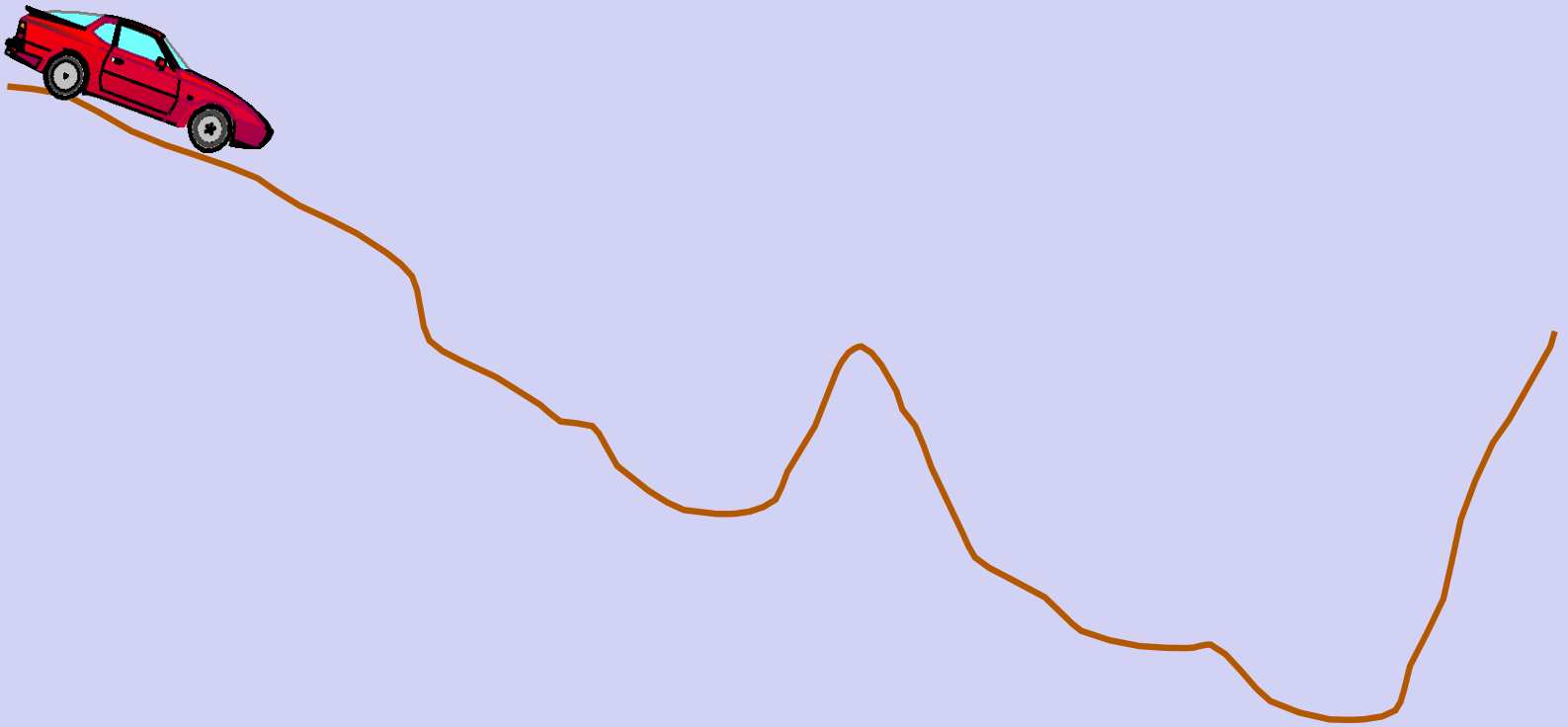
The Shuffled Complex Evolution Algorithm

The SCE-UA *Algorithm …*

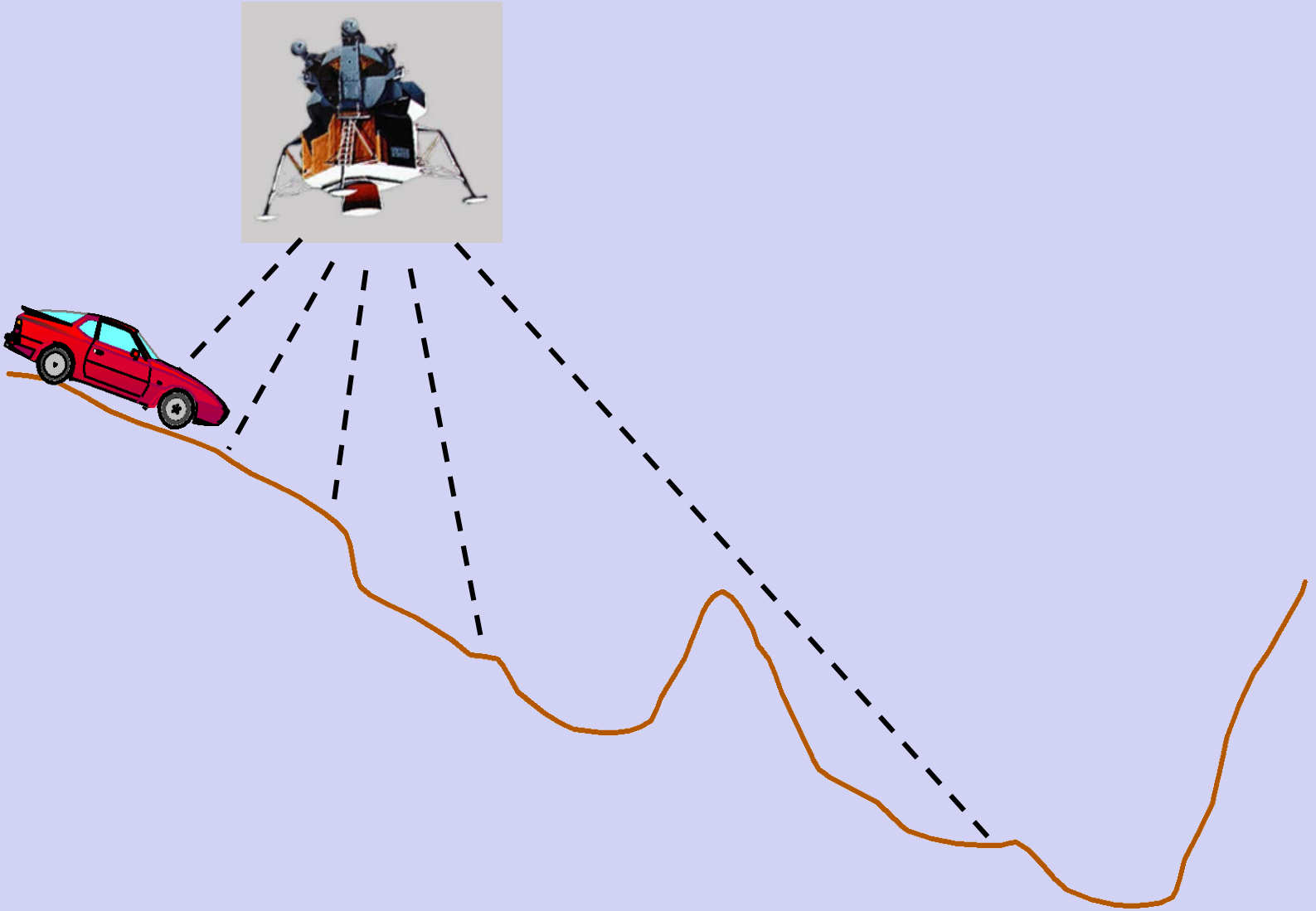


Duan, Sorooshian, and Gupta 1992, WRR

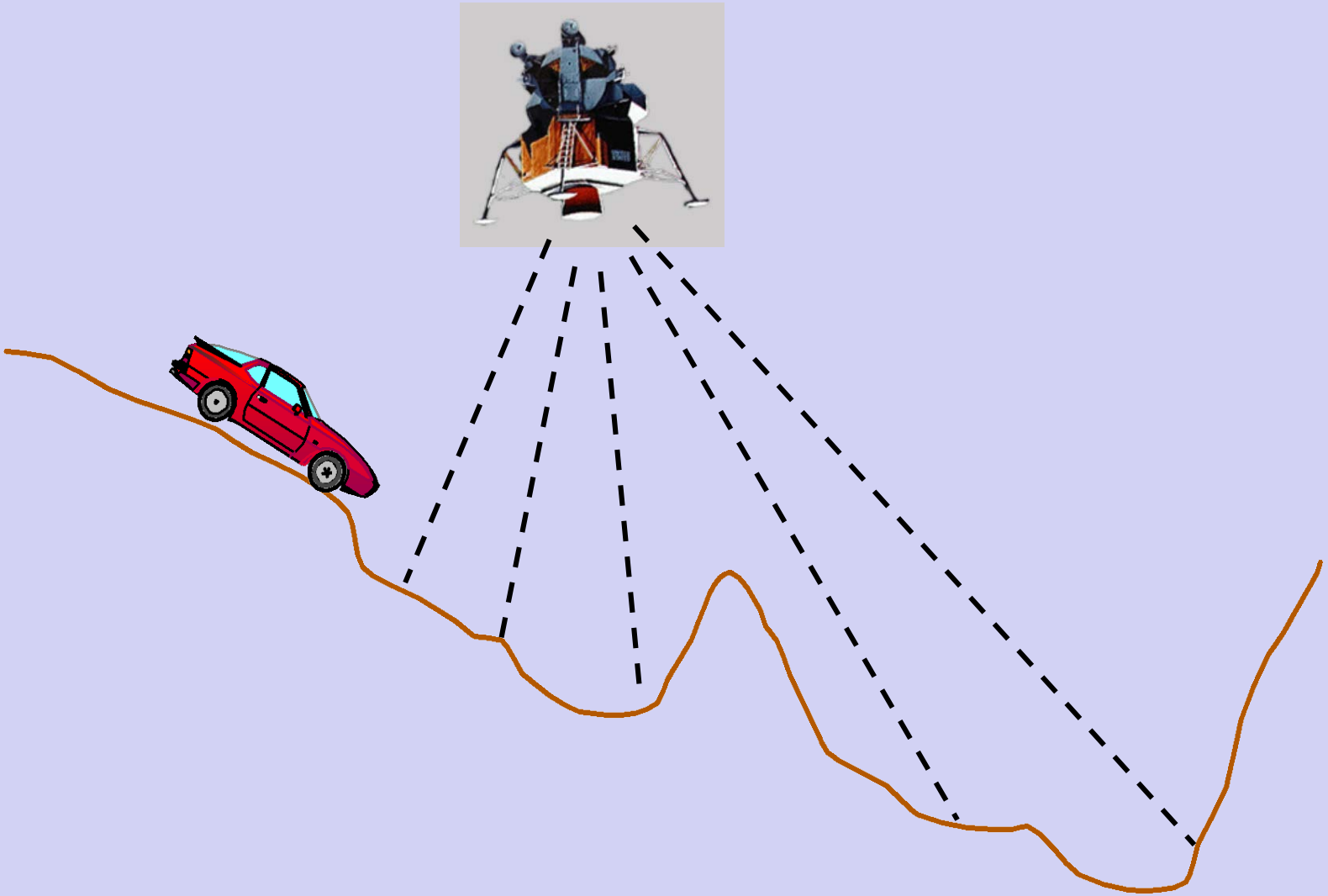
The Concept Behind SCE Method



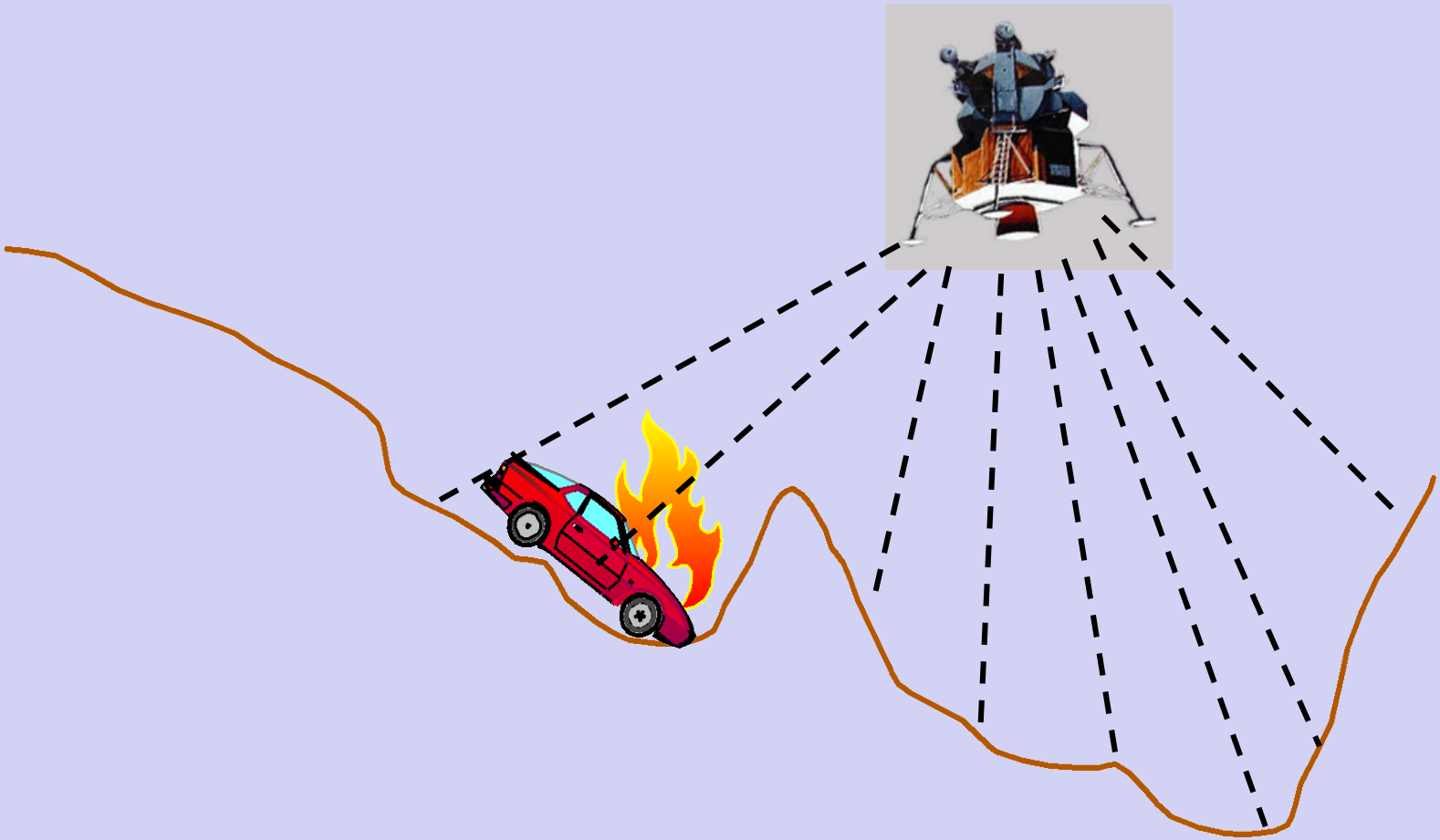
The Concept Behind SCE Method



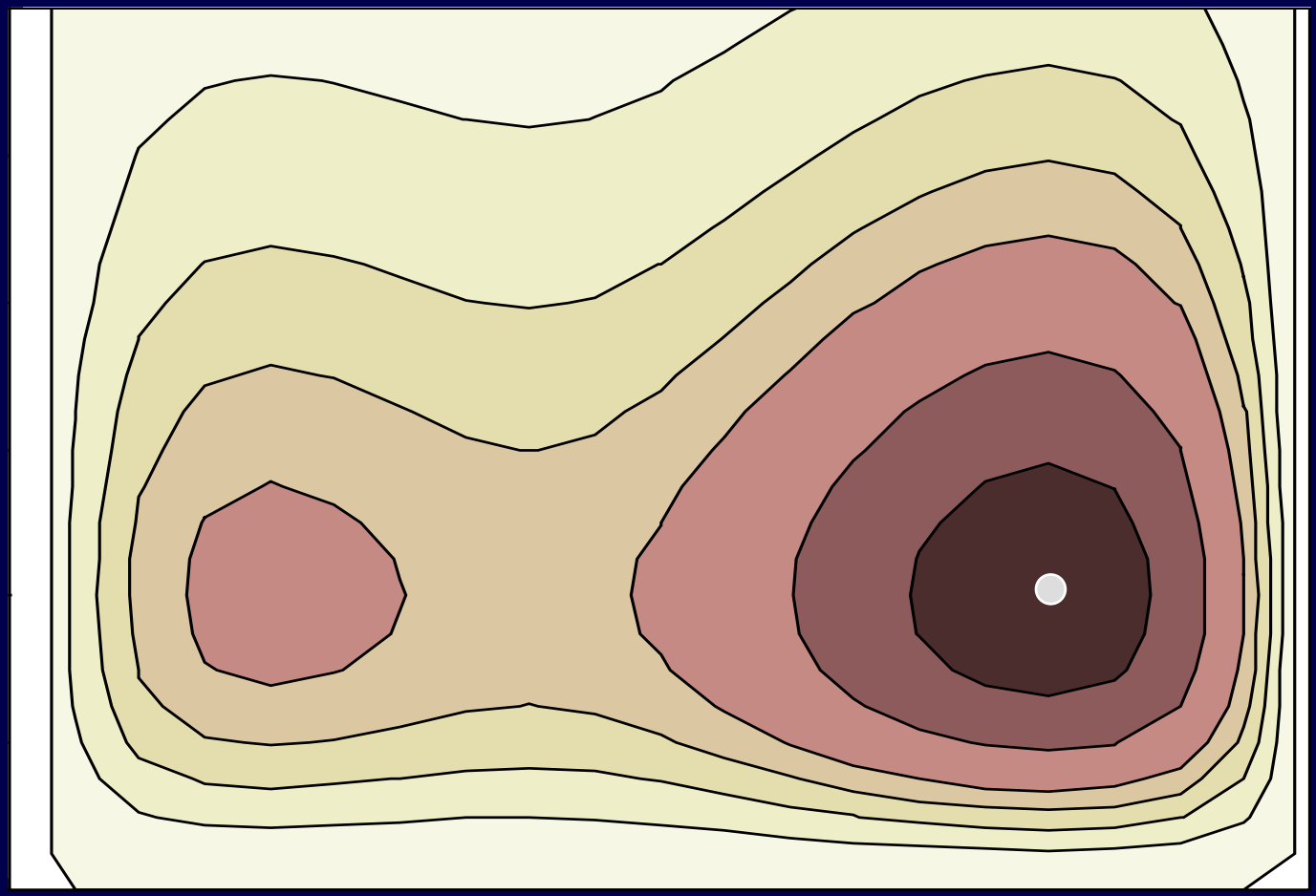
The Concept Behind SCE Method



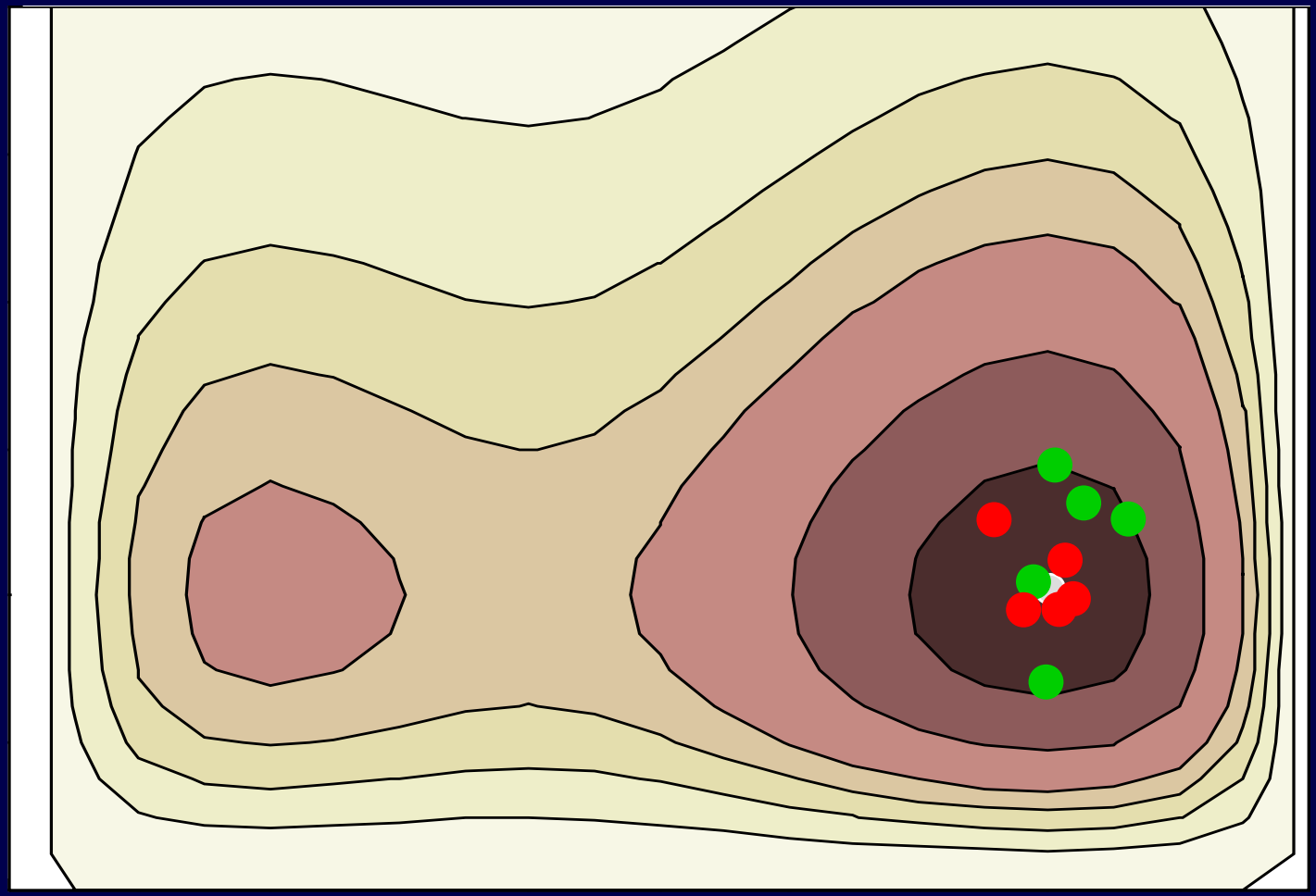
The Concept Behind SCE Method



SCE Method – How it works …



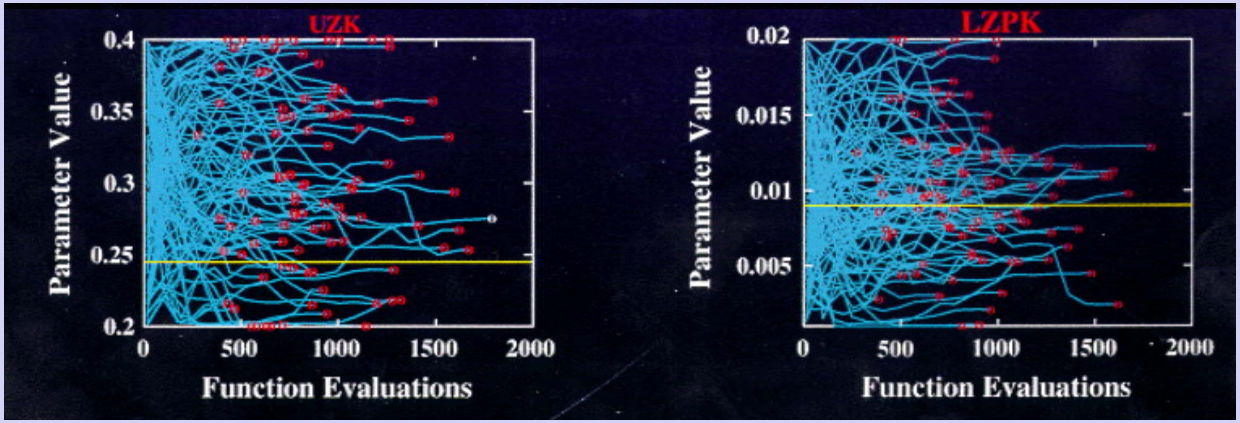
Shuffled Complex Evolution (SCE-UA)



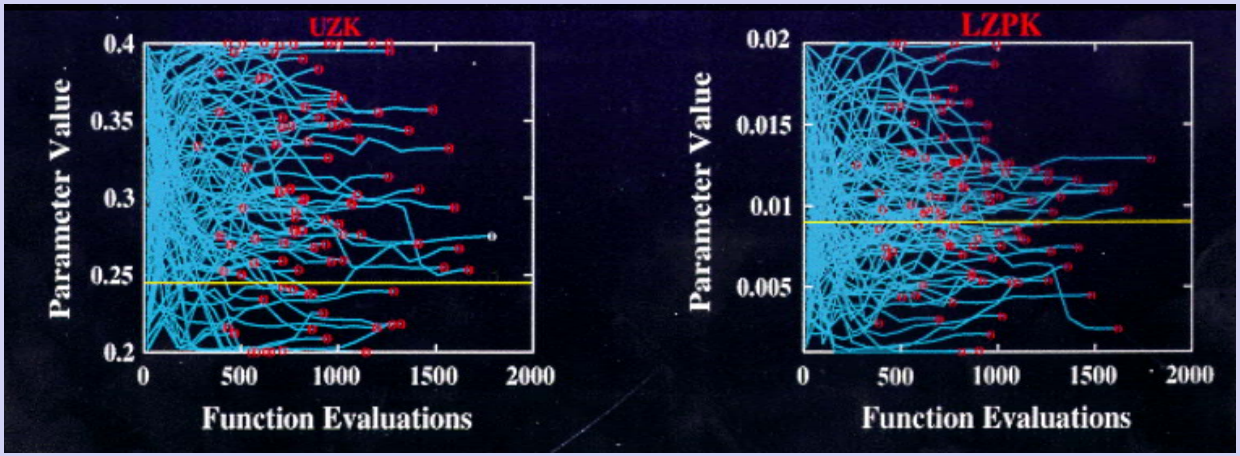
Global Optimization – The SCE-UA Algorithm

Duan, Gupta & Sorooshian, 1992, WRR

Simplex Method



Shuffled Complex Evolution (SCE-UA)



AGU Monograph – Now Available