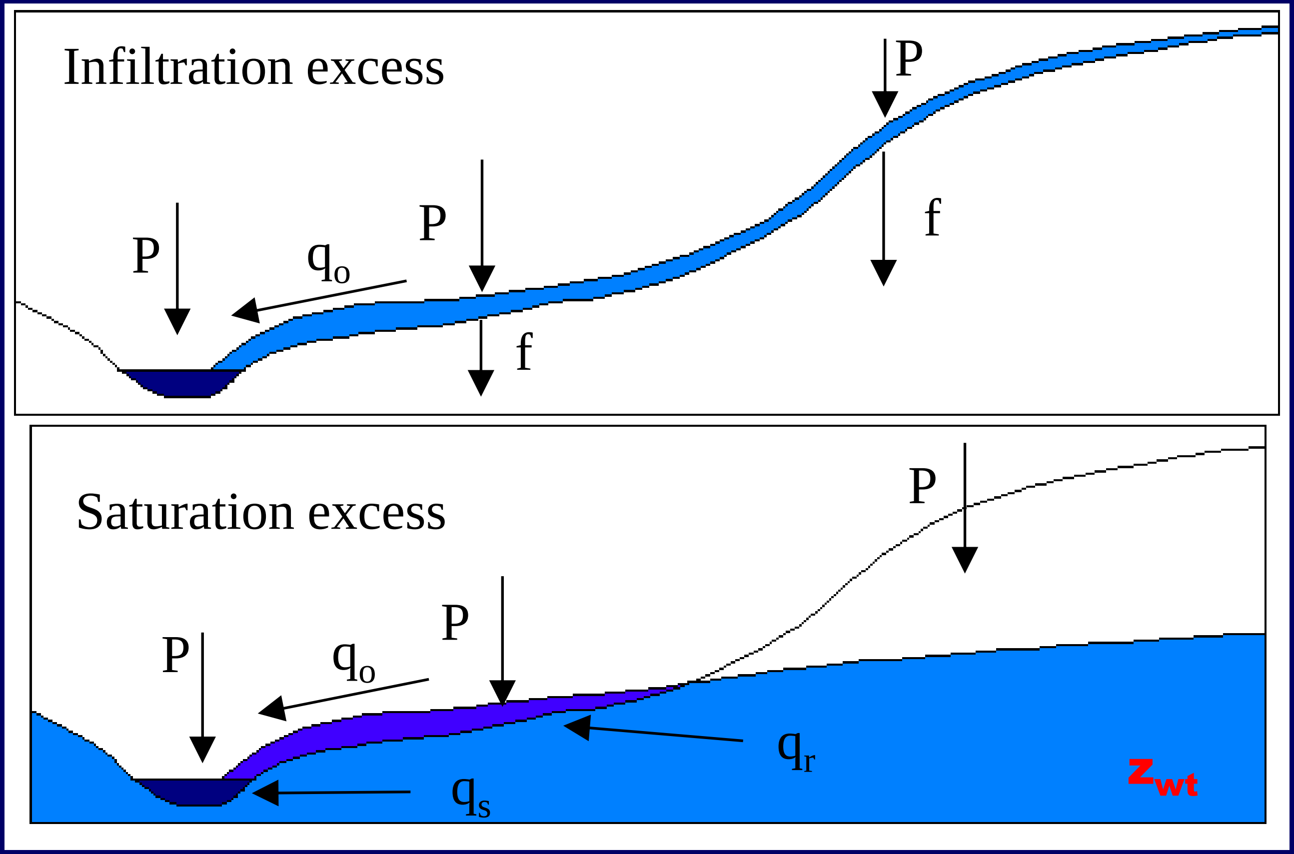
Chapter 12:

Watershed Hydrology

Acknowledgement: Guo-Yue Niu

The Processes to Generate Surface Runoff

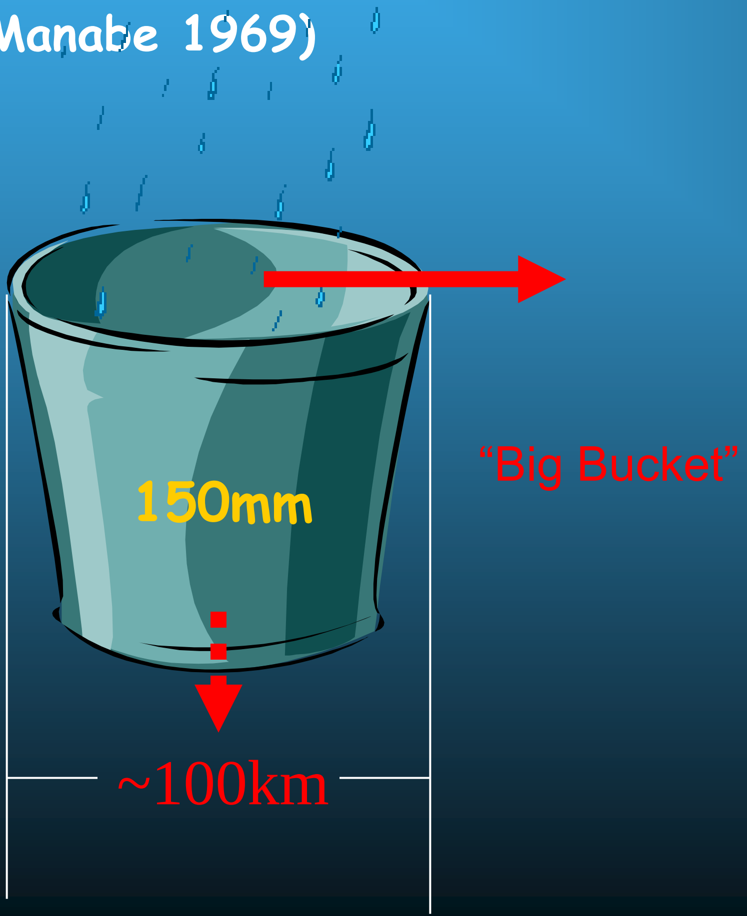


Urban area
Frozen surface
Severe storms

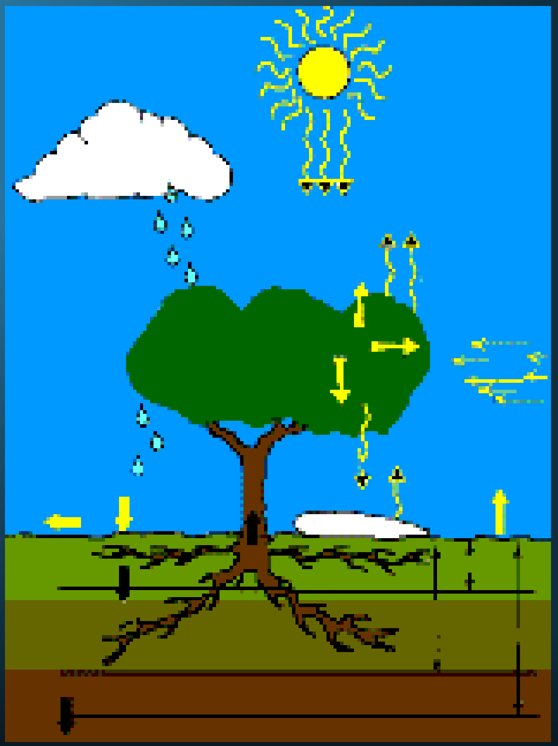
Dominant
contributor

History of Formulating Runoff in Climate Models

Bucket or
Leaky Bucket Models
1960s-1970s
(Manabe 1969)



Soil Vegetation Atmosphere
Transfer Schemes (SVATs)
1980s-1990s
(BATS and SiB)



"Big Leaf"

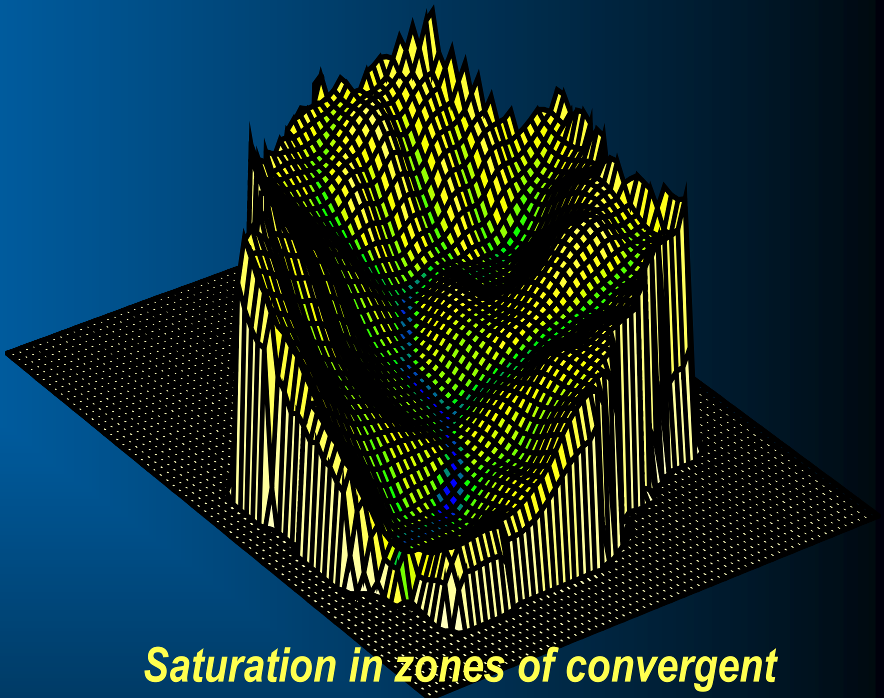
Recent Developments in Modeling Runoff in GCMs – TOPMODEL concepts

1. Representing topographic effects on subgrid distribution of soil moisture and its impacts on runoff generation

   (Famiglietti and Wood, 1994; Stieglitz et al. 1997; Koster et al. 2000; Chen and Kumar, 2002, Niu and Yang, 2003; Niu et al., 2005)

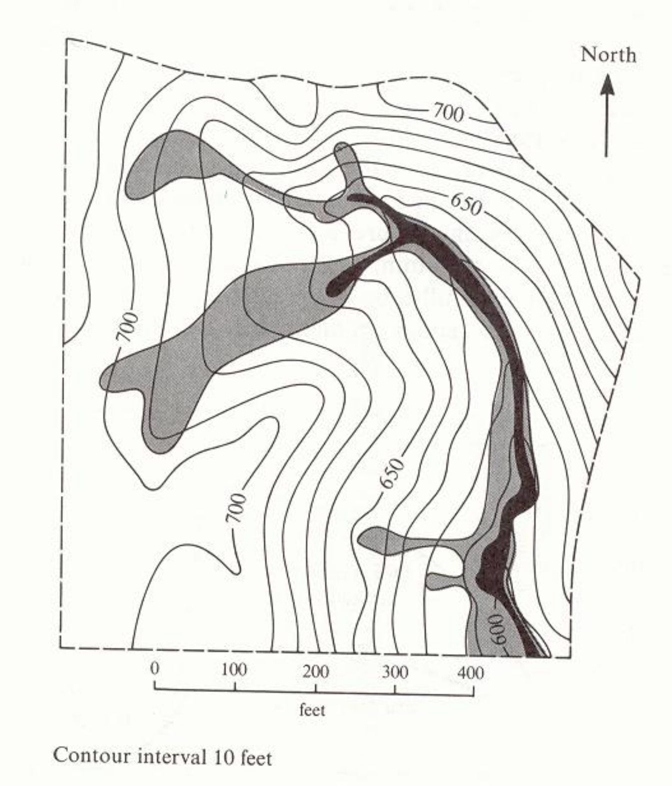
2. Representing groundwater and its impacts on runoff generation, soil moisture, and ET

   (Liang et al., 2003; Maxwell and Miller, 2005; Yeh and Eltahir 2005; Niu et al., 2007; Fan et al., 2007)

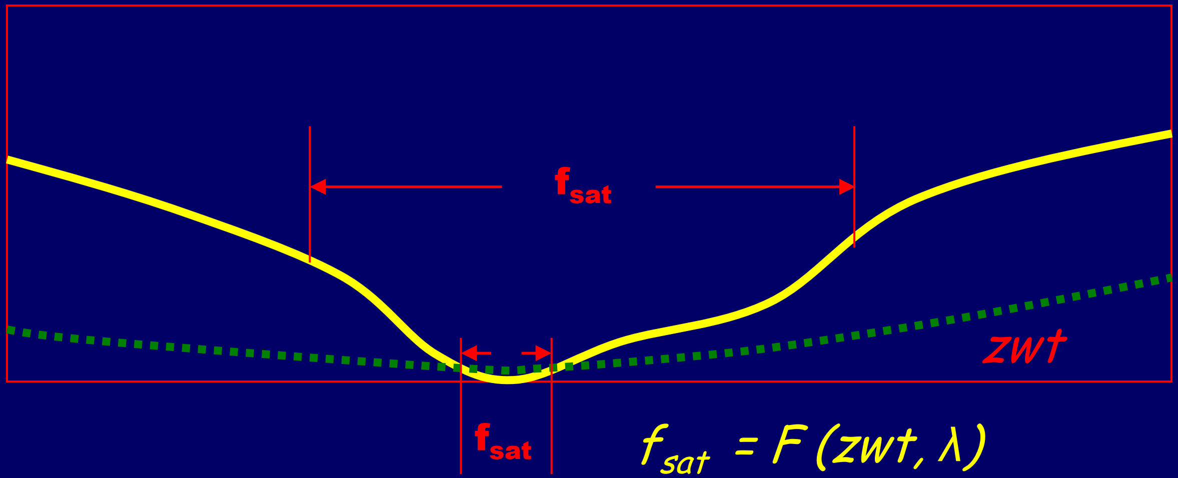


Saturation in zones of convergent topography

Relationship Between the Saturated Area and Water Table Depth



The saturated area showing expansion during a single rainstorm. [Dunne and Leopold, 1978]

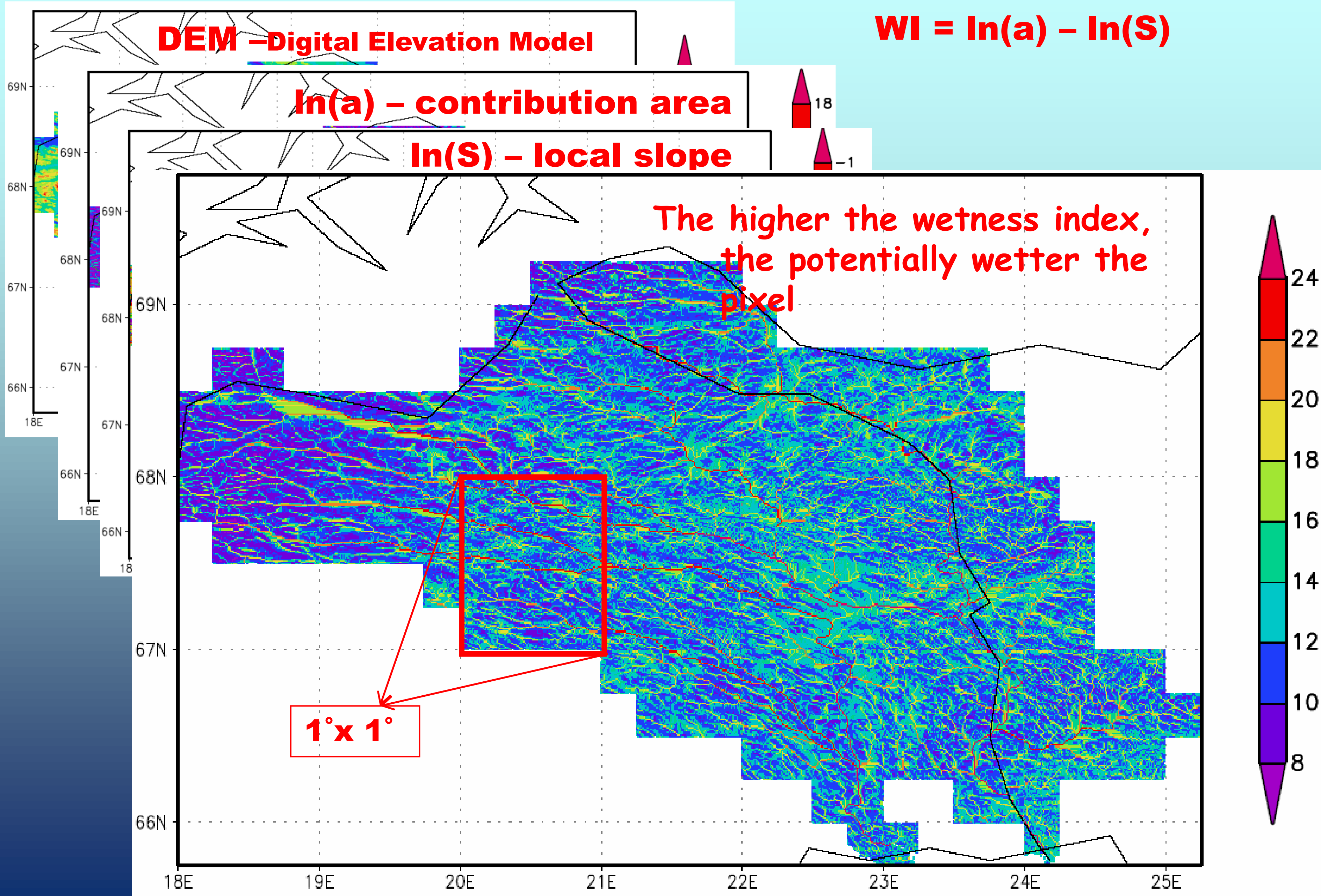


$$f_{sat} = F(zwt, \lambda)$$
$$= F_{max}(\lambda)\, e^{-0.5\, f\, zwt}$$

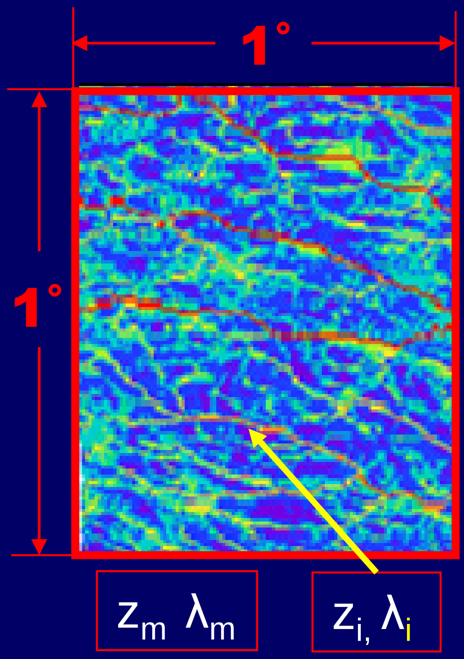
λ – wetness index derived from DEM

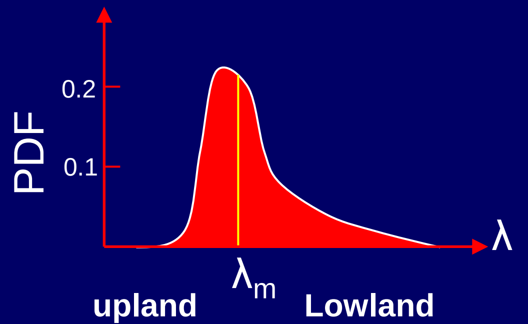
DEM (1km) to Wetness Index (WI)

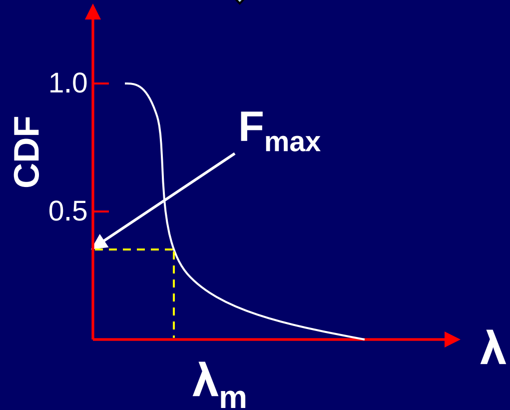
$$WI = \ln(a) - \ln(S)$$



Surface Runoff Formulation







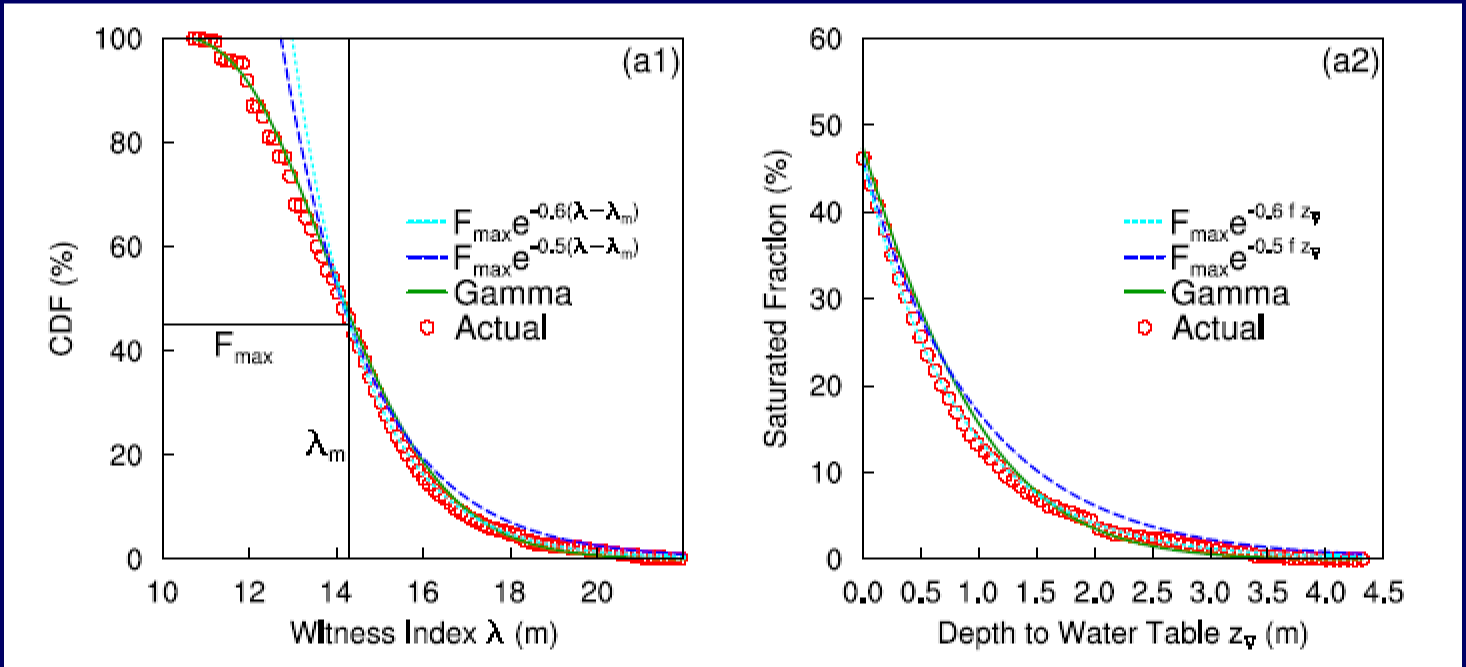
$\lambda_i - \lambda_m = f * z_m$ TOPMODEL
(Beven and Kirkby, 1979)

The Maximum Saturated Fraction of the Grid-Cell:

$$F_{max} = CDF \{ \lambda_i > \lambda_m \}$$

Surface Runoff Formulation

A 1 °x 1° grid-cell in the Amazon River basin



Both Gamma and exponential functions fit for the lowland part ($\lambda_i > \lambda_m$)

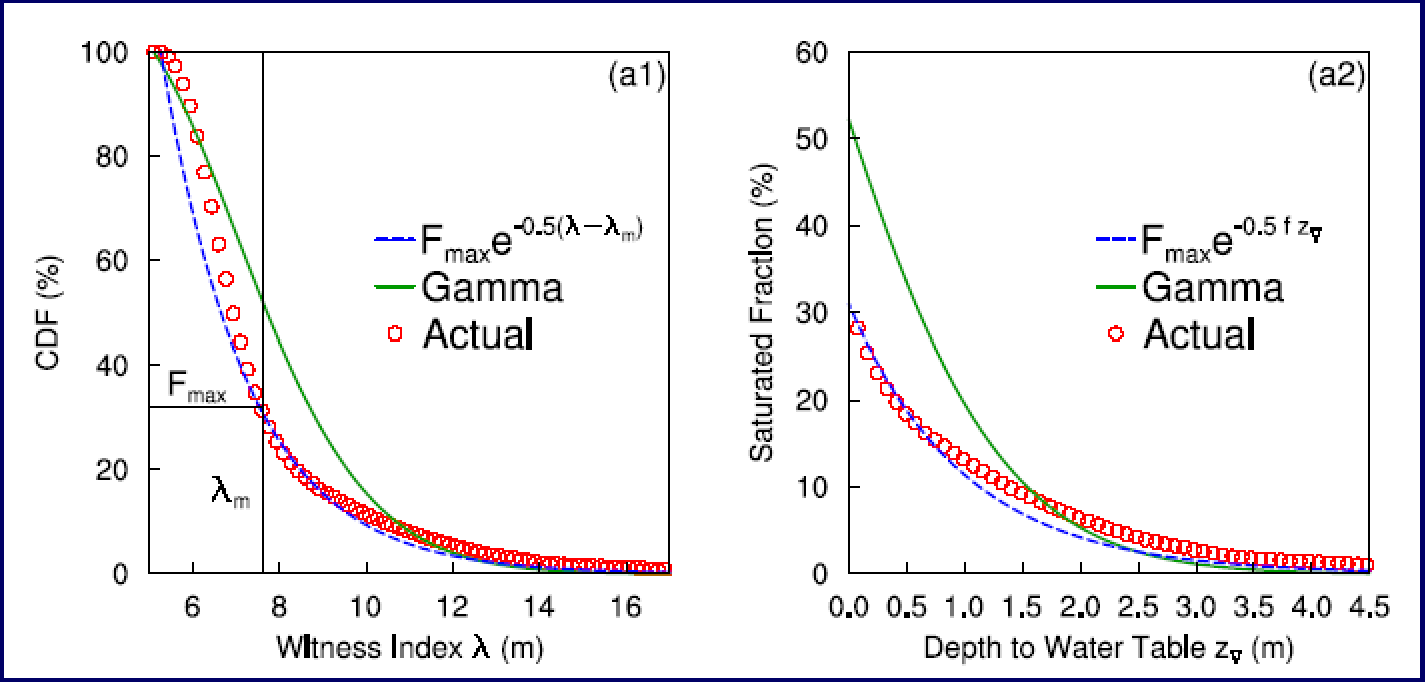
$$f_{sat} = F_{max}e^{-C(\lambda i - \lambda m)} \rightarrow f_{sat} = F_{max}e^{-C f zwt}$$

$F_{max} = 0.45;\ C = 0.6$

$\boxed{\lambda_i - \lambda_m = f * zwt \quad TOPMODEL}$

Surface Runoff Formulation

A 1 °x 1° grid-cell in Northern Rocky Mountain

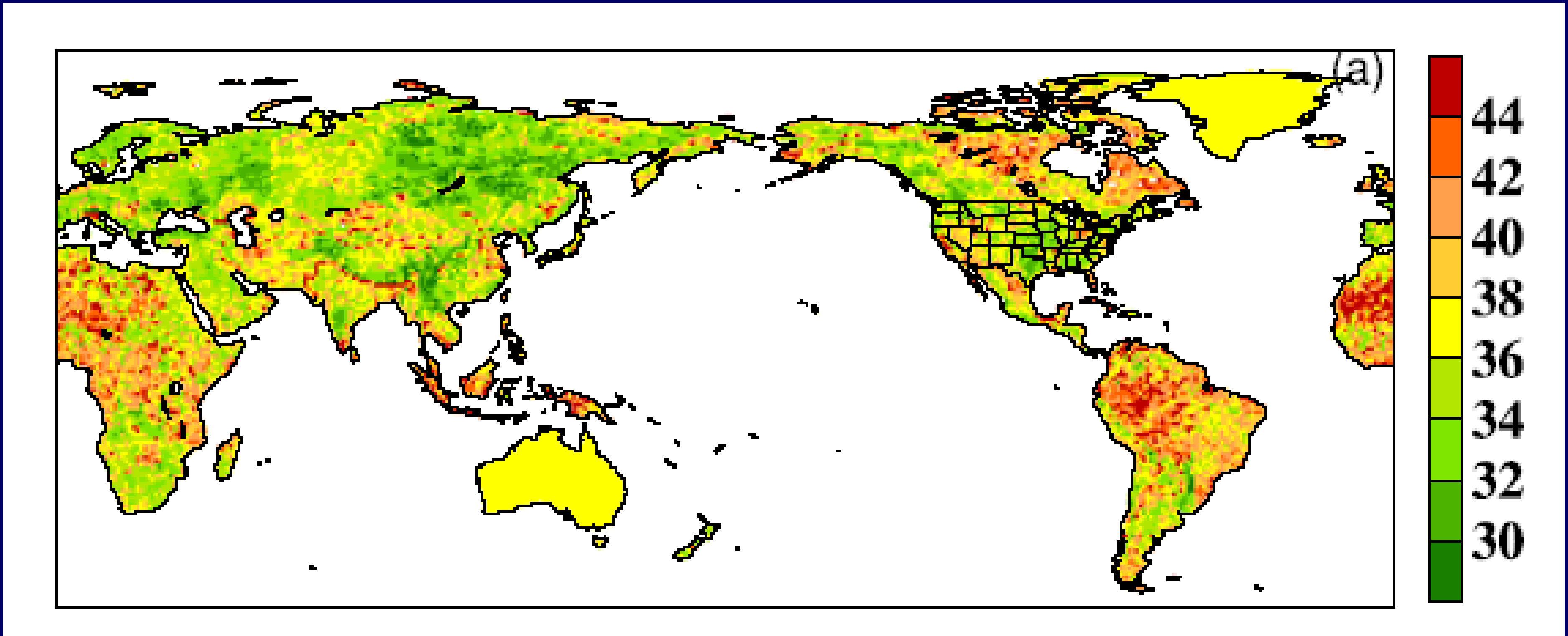


Gamma function fails, while exponential function works.

F_{max} = 0.30; C = 0.5

$$f_{sat} = F_{max} e^{-C f zwt}$$

Fmax derived from Hydro1k data



$f_{sat} = F_{max} e^{-C f zwt}$

(Niu et al., 2005)

Runoff Scheme for Climate Models

Runoff = $Q_s + Q_{sb}$

Surface Runoff : $R_s = P\,F_{max}\,e^{-C\,f\,zwt}$

p = precipitation

zwt = the depth to water table

f = the runoff decay parameter that determines recession curve

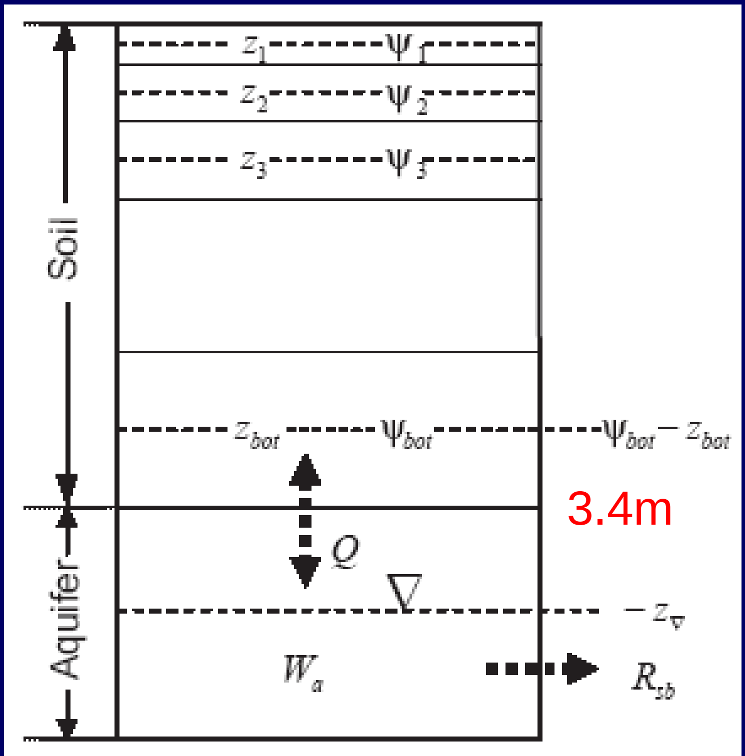
Subsurface Runoff : $R_{sb} = R_{sb,max}\,e^{-f\,zwt}$

$R_{sb,max}$ = the maximum subsurface runoff, which is related to lateral Ksat of an aquifer and local slopes ($e^{-\lambda}$) .

Parameters:

Two calibration parameters $R_{sb,max}$ (~10mm/day) and f (1.0~2.0)
Two topographic parameters F_{max} (~0.37) and C (~0.6)

Prognostic Water Table depth: A Simple Groundwater Model *(Niu et al. 2007 JGR)*



Water storage in an unconfined aquifer:

$$\frac{dW_a}{dt} = Q - R_{sb}$$

$$z_\nabla = W_a / S_y$$

Recharge Rate:

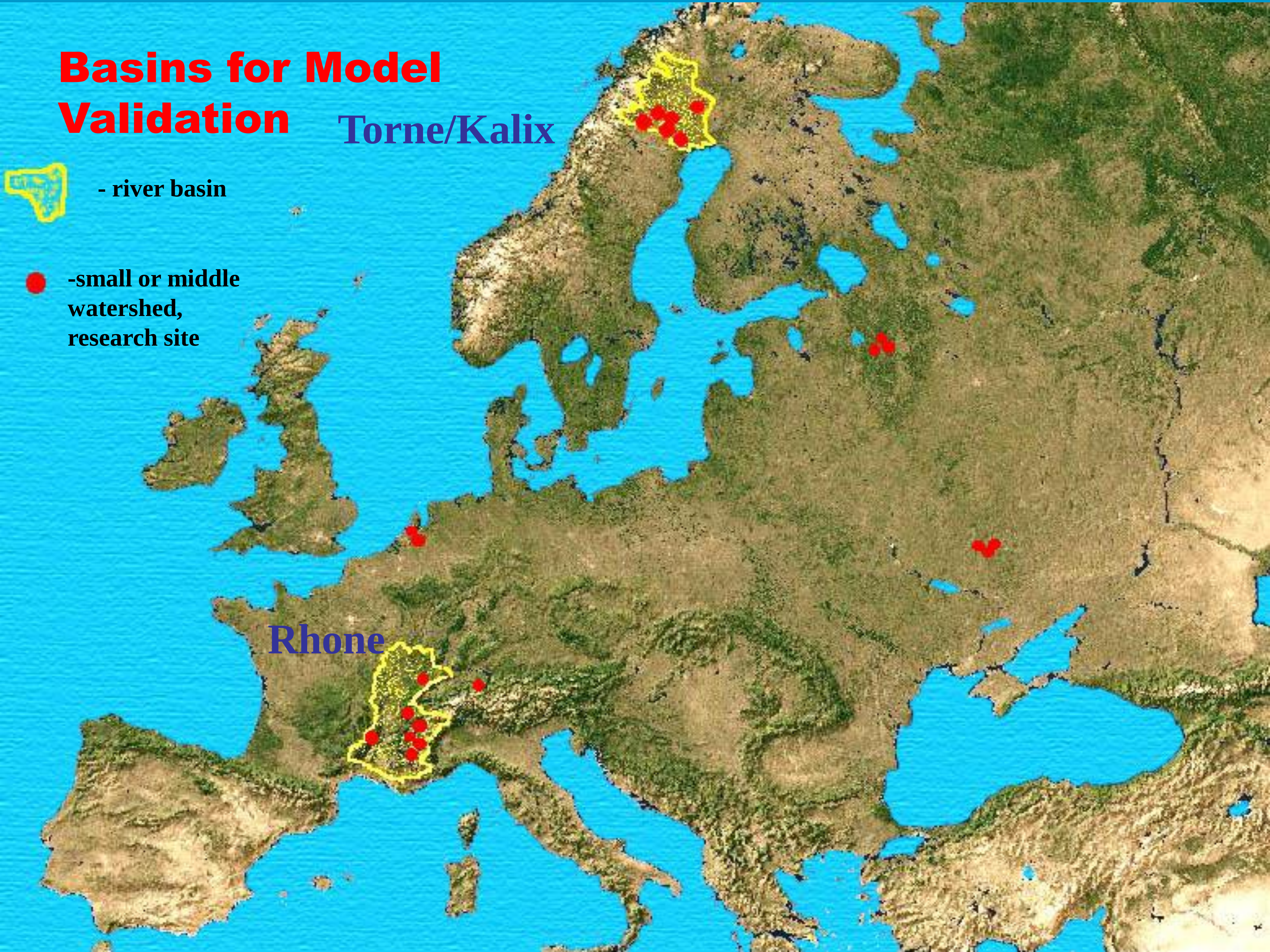
$$Q = -K_a \frac{-z_\nabla - (\psi_{bot} - z_{bot})}{z_\nabla - z_{bot}}$$

$$= K_a \left(1 + \frac{\psi_{bot}}{z_\nabla - z_{bot}}\right)$$

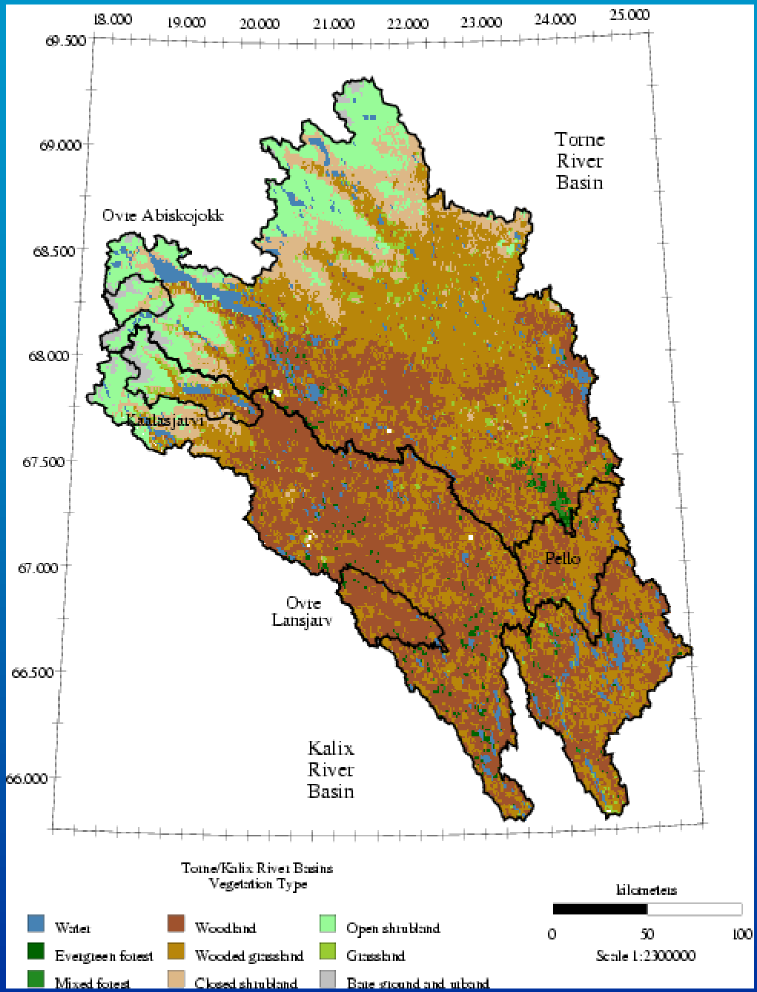
Buffer Zone

Gravitational Drainage

Upward Flow under capillary forces

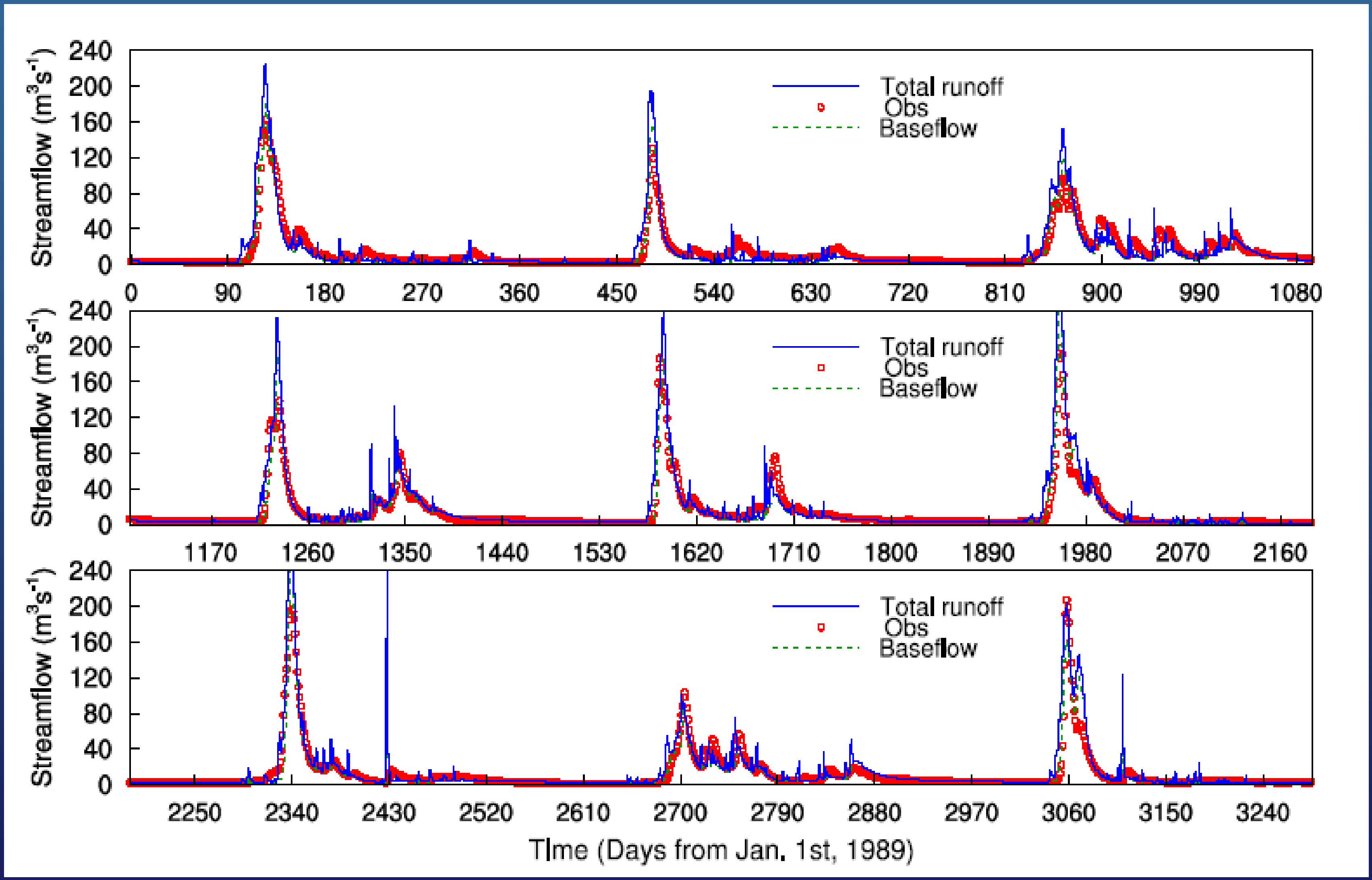

Basins for Model Validation
Torne/Kalix
- river basin
-small or middle watershed, research site
Rhone

Torne/Kalix Rivers, Sweden and Finland (58,000 km^2)



- 20-year (1979-1998) meteorological forcing data at hourly time step
- 218 grid-cells at 1/4 degree resolution

Modeled Runoff in Comparison with Observed Streamflow



Model intercomparison:

- 20 models from 11 different countries (Australia, Canada, China, France, Germany, Japan, Netherlands, Russia, Sweden, U.K., U.S.A.)

VISA – Versatile Integrator of Surface and Atmospheric processes

Table 1
Model groups, names, and identifiers (see also Table 6 in Bowling et al., 2003a-this issue)

Group	Model Name	Model Identifier
Group 1	SPONSOR	A
	RCA	B
	IHAS	C
Group 2	SEWAB	D
	ISBA	E
	NSIPP	F
	CLASS	G
	IBIS	H
	CHASM	I
	VIC	J
Group 3	MATSIRO	K
	HY-SSiB	L
	VISA	M
	SAST	N
	MECMWF	O
	NOAH	P
	SWAP	Q
Group 4	SSiB	R
	ECMWF	S
	MOSES	T
	MOSES-CEH	U

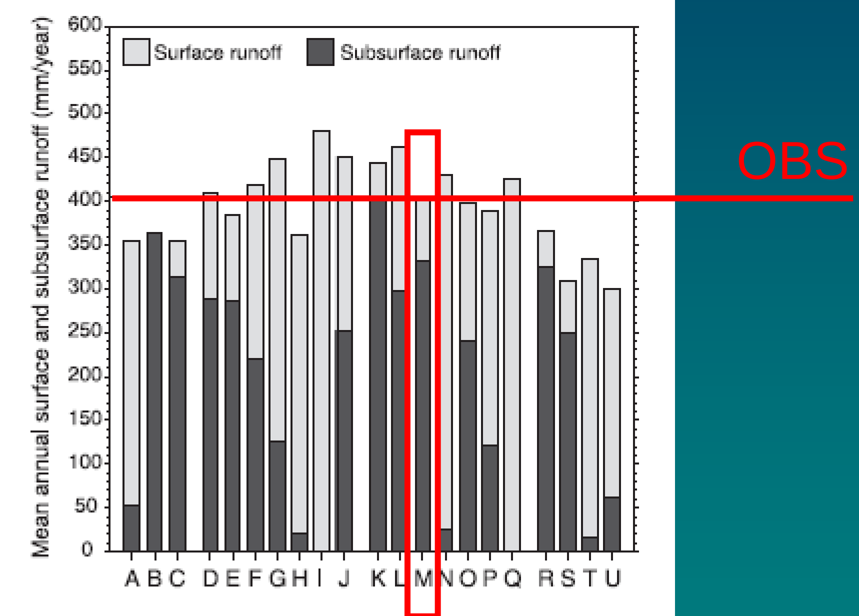
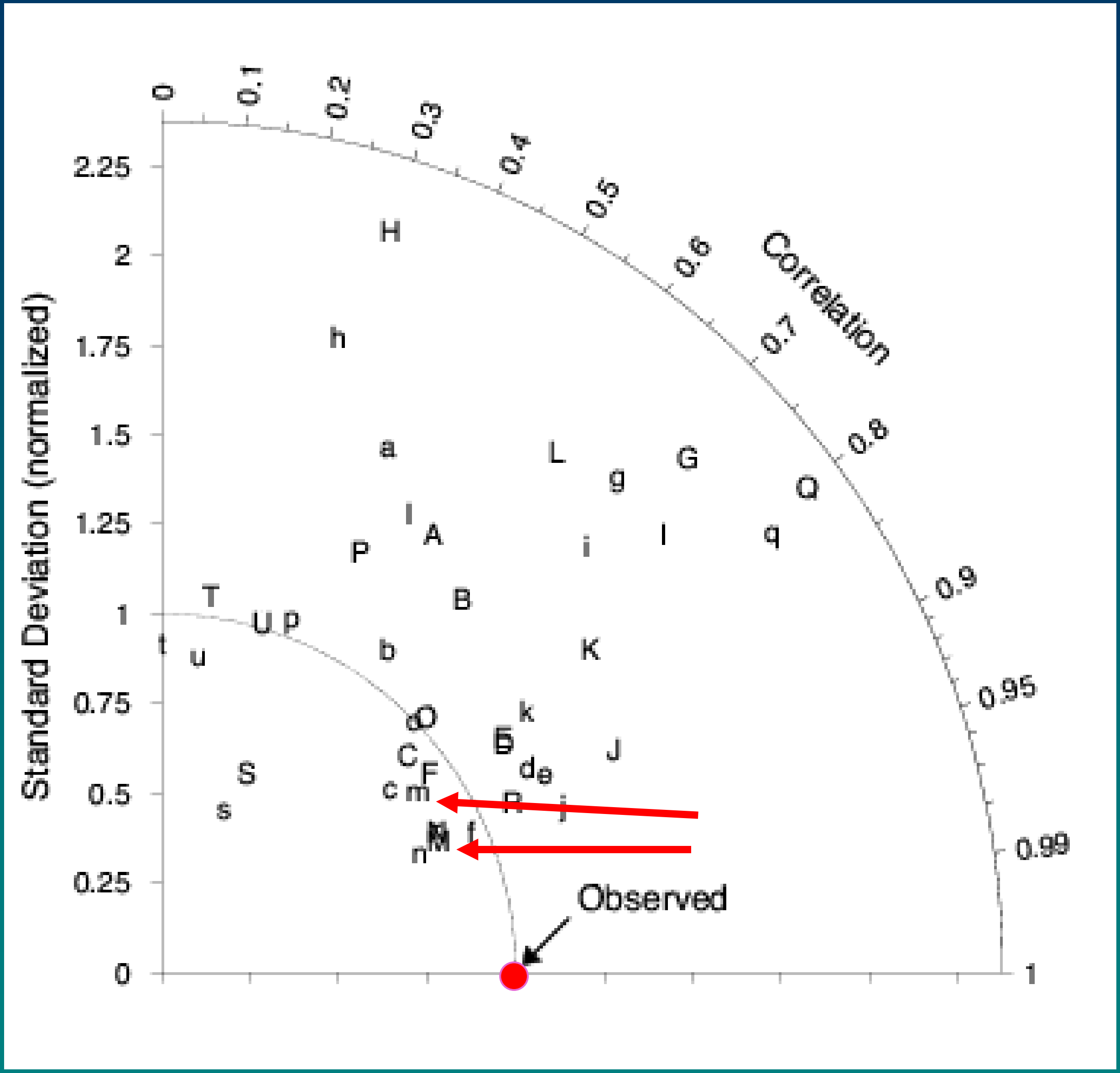


Fig. 16. Total basin mean annual surface and subsurface runoff. The dashed horizontal line represents mean annual runoff at the mouths of the Torne and Kalix Rivers combined.

From Bowling et al. (2003)

Model Intercomparison:

Nijssen et al. (2003)



Outline

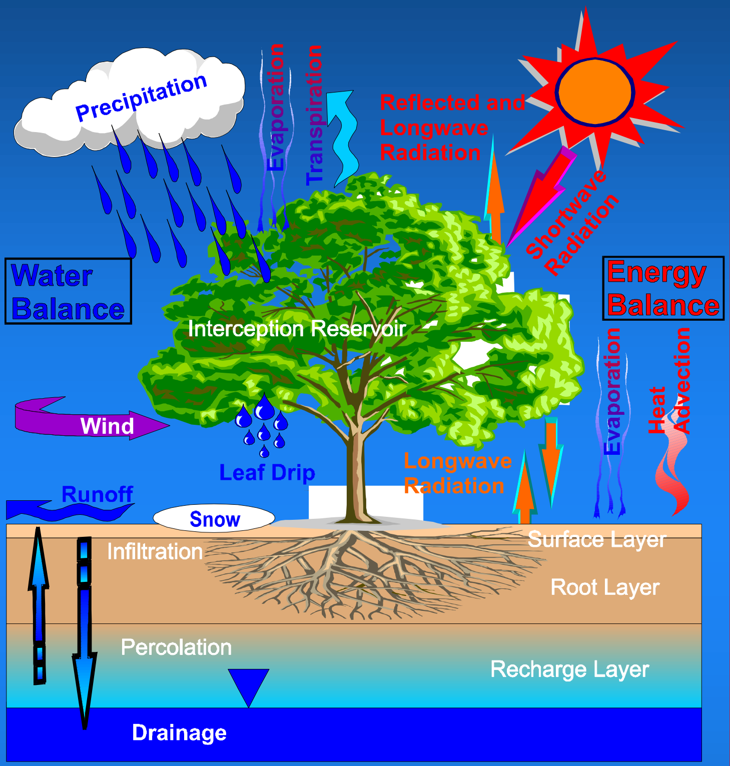
- Global water storages and fluxes
- Tools for prediction
- Precipitation
- Evapotranspiration (ET)
- Surface water, groundwater, and runoff
- Land surface modeling
- International water programs

Inputs & outputs

Inputs

Forcing Data
- Precipitation
- Radiation
- Wind
- Humidity
- Air Temperature

Parameters
- Soil Properties
- Vegetation Properties



Outputs

Water storage (soil moisture, snow mass, GW, etc.)

ET (evaporation & transpiration)

Runoff (surface & groundwater discharge)

Energy fluxes (heat & radiation)

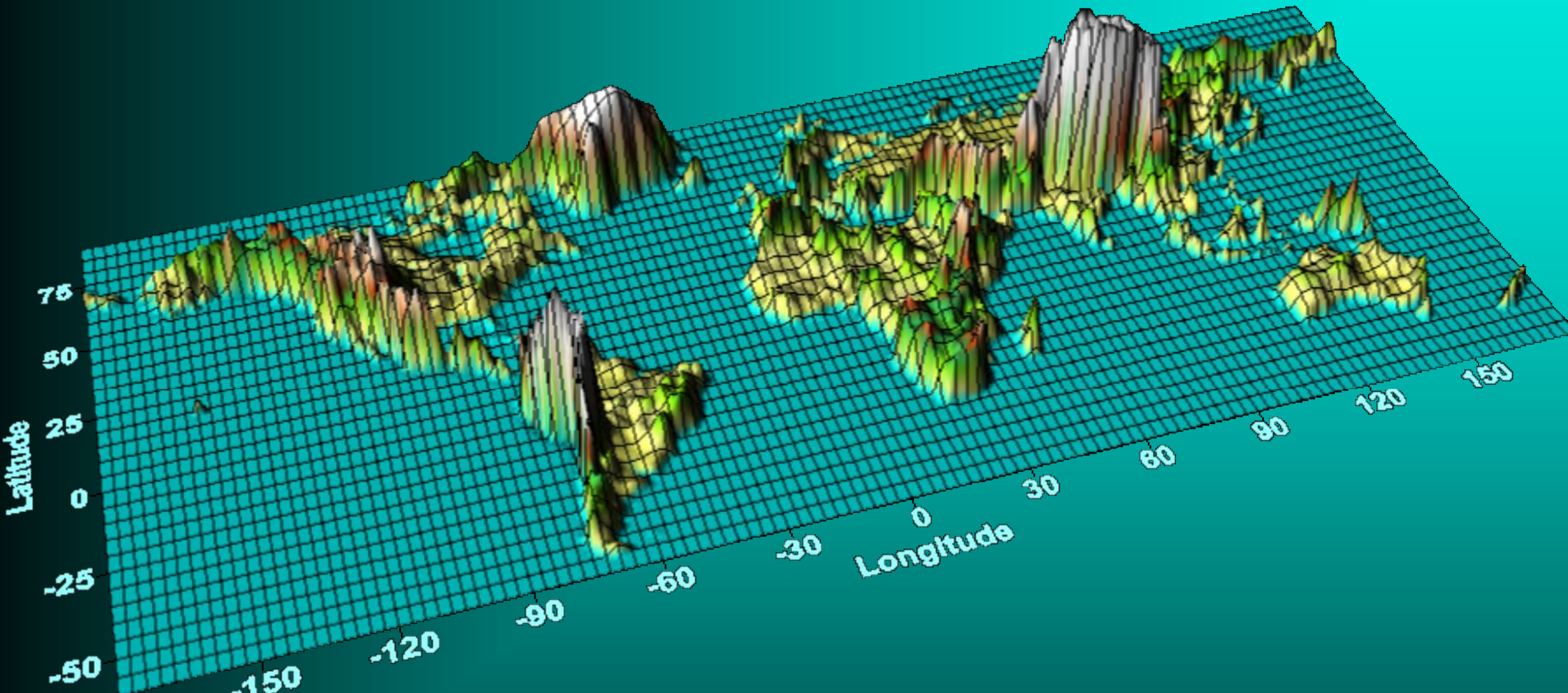
Temperature

Carbon fluxes (CO2 & BVOC, GPP, NPP etc)

Carbon storage (veg. & soil)

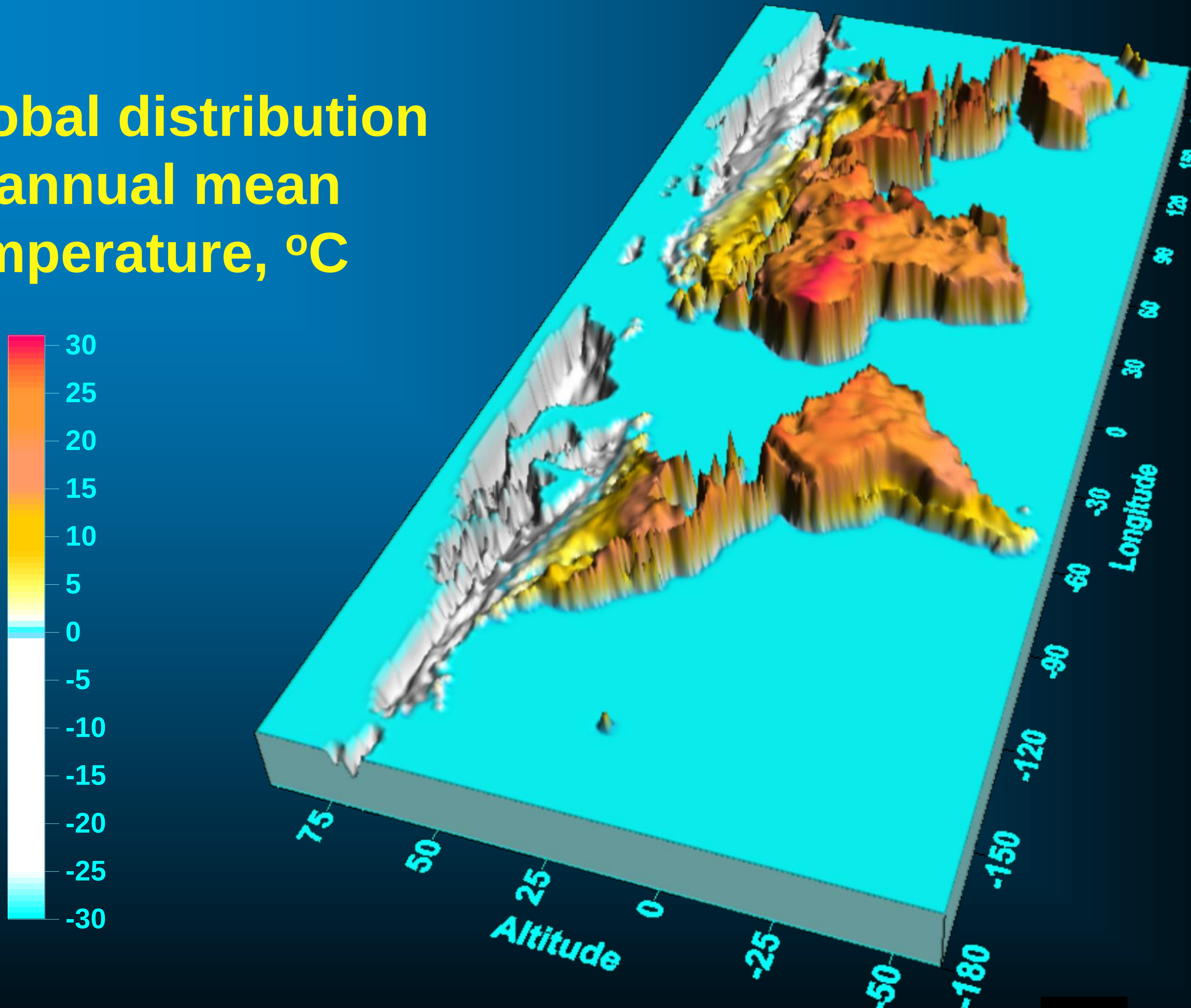
Spatial-Scales : Point, Catchment, Regional, or Global
Time step: 30 mins to 3 hours
Online: coupled with atmospheric models
Offline: decoupled; forcing data; testing model

Global Off-Line Application
(Decoupled from the Atmospheric Model)



15,238 grid-cells over land at
1 degree spatial resolution
GSWP 2 (Global Soil Wetness Project)
13-year (1983-1995) 3-hour forcing data **(50G)**

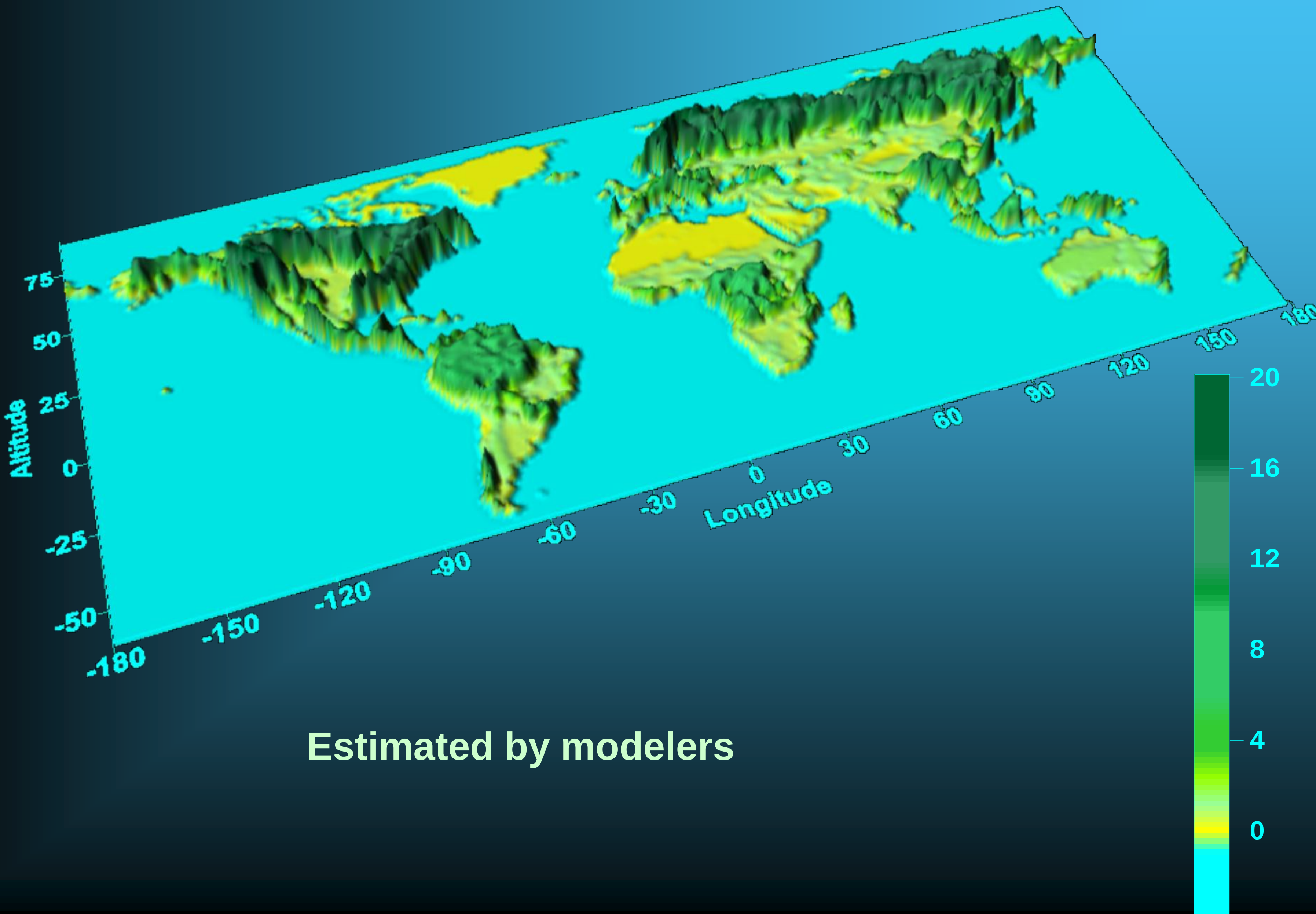
Global distribution of annual mean temperature, ºC



Vegetation parameters

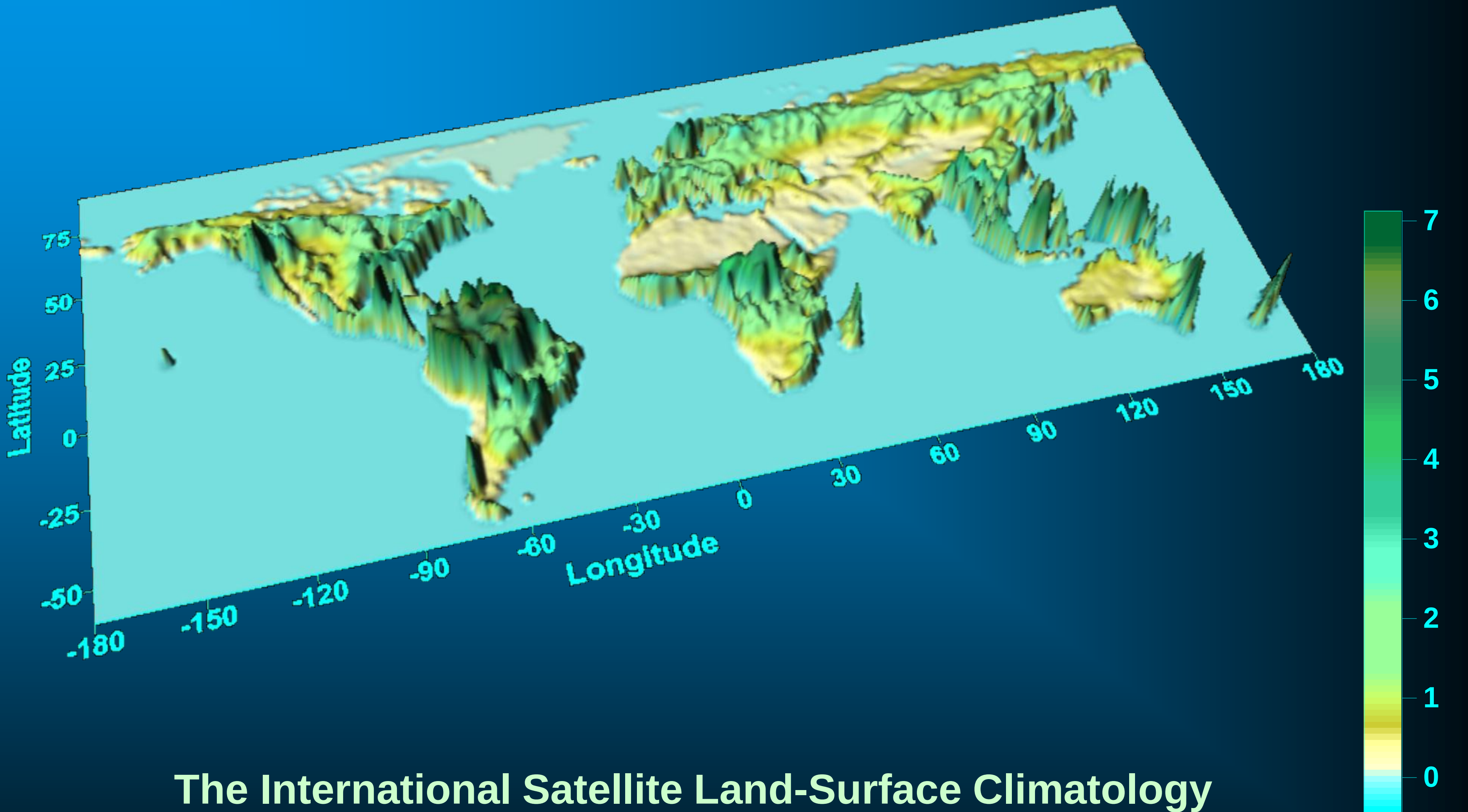
- **VegClass** — Vegetation type
- **LAI** — Leaf area index
- **VegHeight** — Vegetation height
- **vegFrac** — Vegetation cover fraction
- **classFrac** — Fraction of each VegClass
- **Albedo** — Snow-free albedo
- **RootDepth** — Root depth
- **Rs_min** — Minimum stomatal resistance

Global distribution of vegetation Height, m



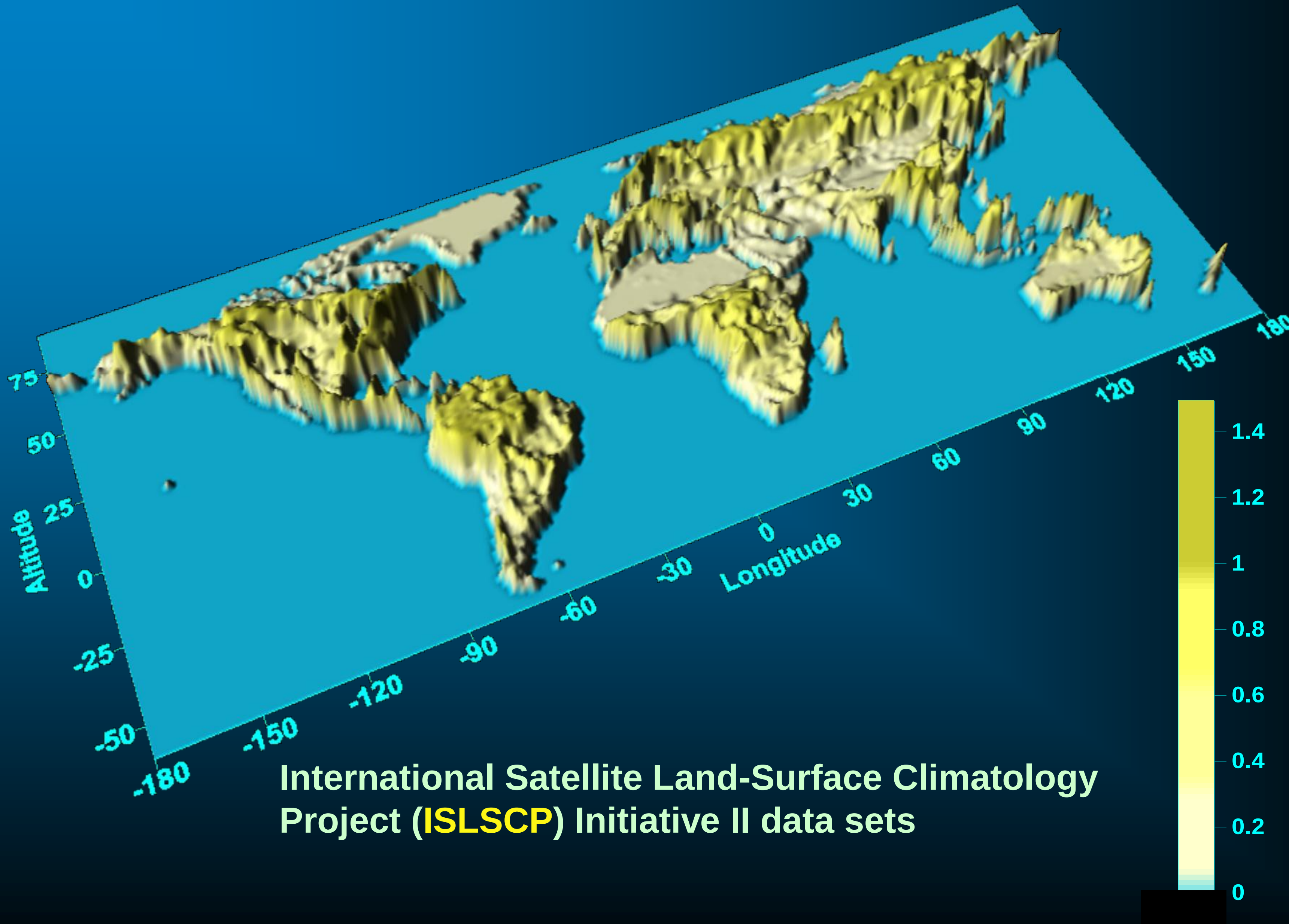
Estimated by modelers

Global distribution of the many-year averaged leaf area index (LAI)



The International Satellite Land-Surface Climatology Project (ISLSCP) Initiative II data sets

Global distribution of the root depth, m



International Satellite Land-Surface Climatology Project (ISLSCP) Initiative II data sets

Soil parameter data:

Soil texture (IGBP: Global Soil Data Task, 2000)

Clay / Sand / Silt / Organic

Wilting point
Porosity
Saturated hydraulic conductivity
Saturated matric potential

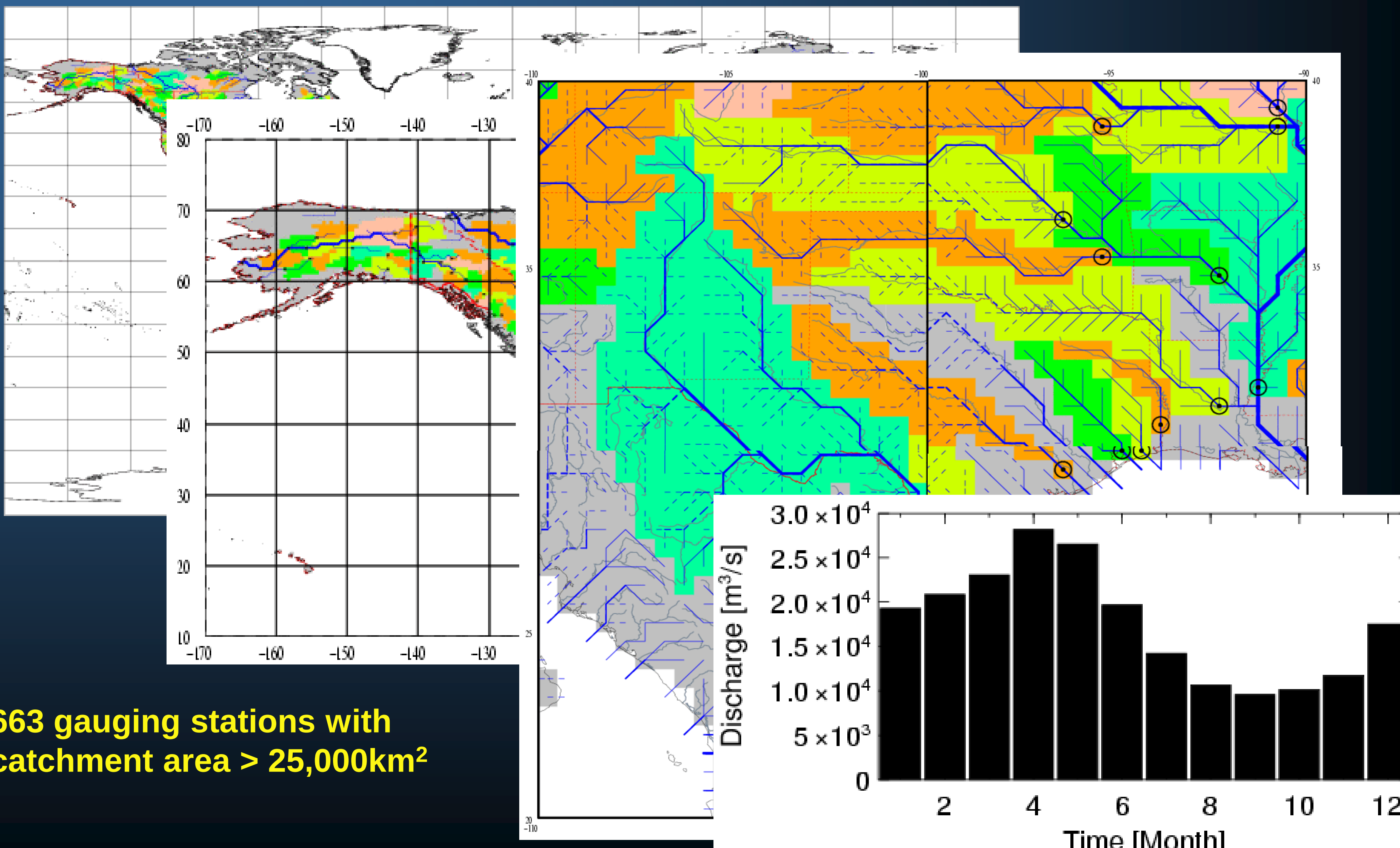
Soil color index (Zeng et al. 2002) satellite data

Visible albedo of soil
Near-infrared albedo

GRDC (Global Runoff Data Center) Estimated Runoff

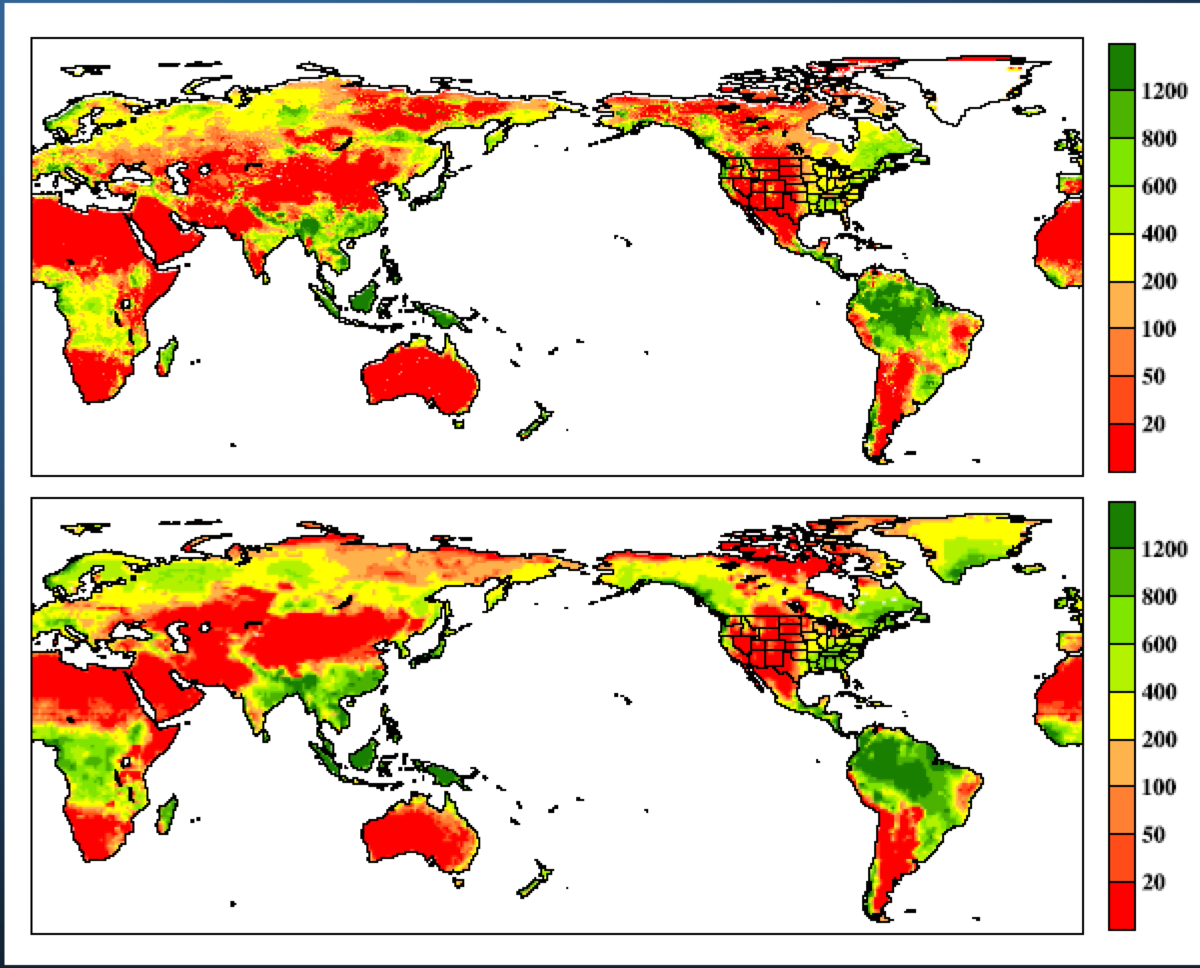
http://www.grdc.sr.unh.edu/html/station.html

Please select a continent



663 gauging stations with catchment area > 25,000km²

Global distribution annual runoff, mm/year



GRDC:

295.65 mm/year

Model:

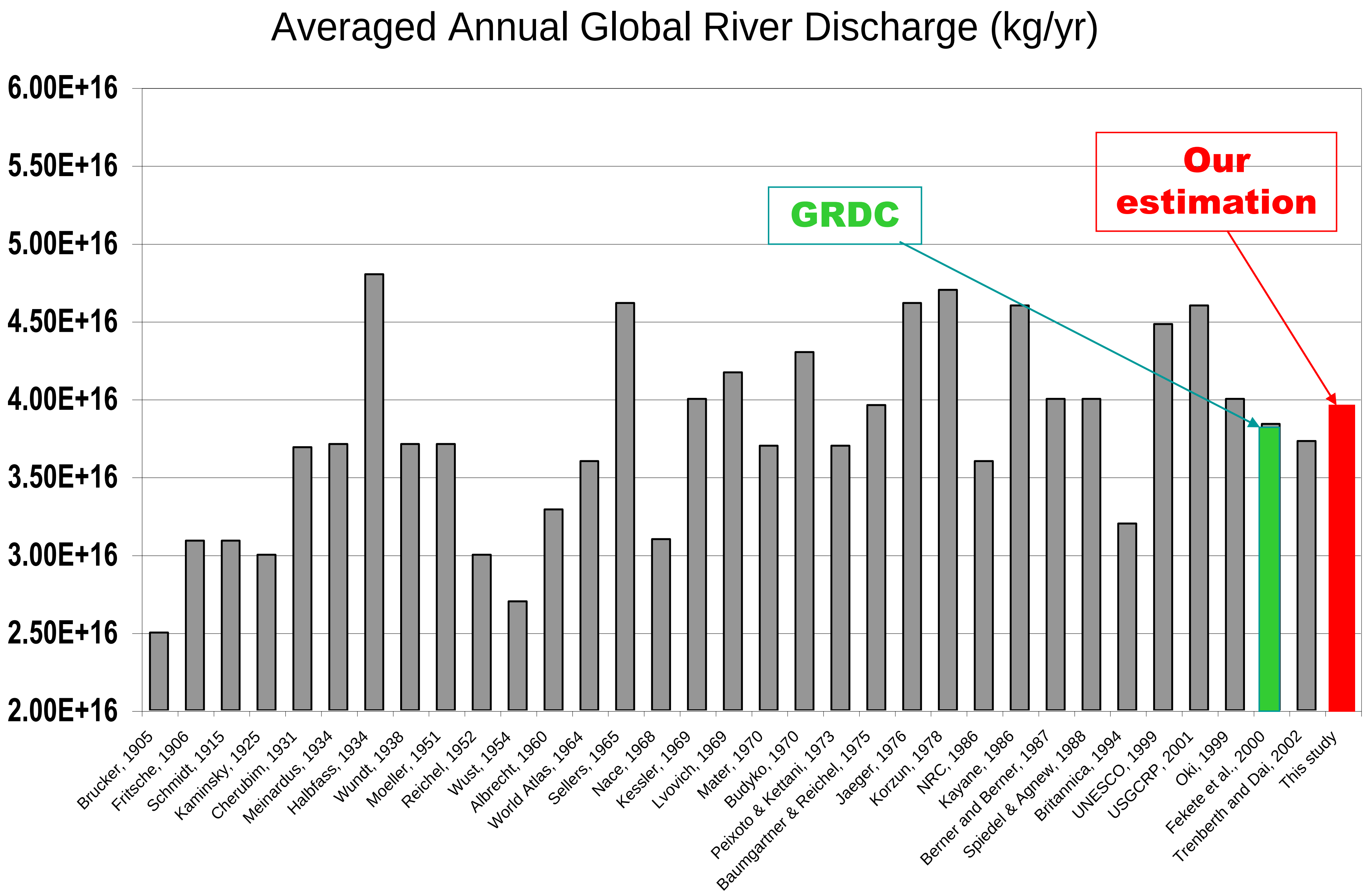
328.50 mm/year

42% of P

Our model produces 10% more than GRDC

1) GRDC did not include smaller basins; 2) vegetation parameters used in this study need to be refined; 3) The precipitation used in this study is larger.

Global River Discharge (kg/year)



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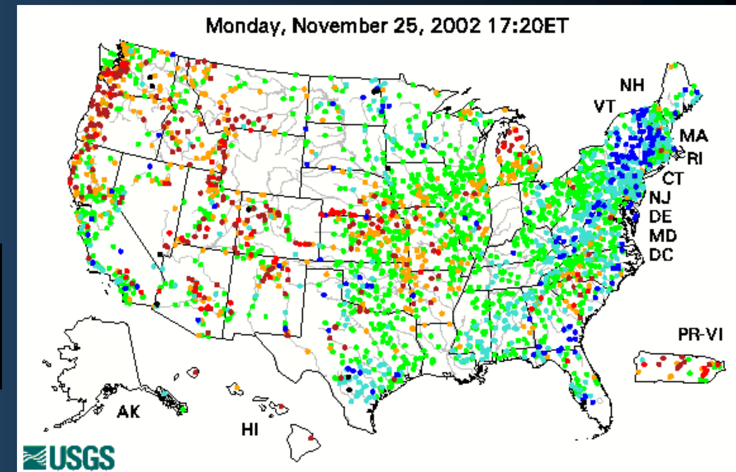
Agencies Involved in the Water Cycle Program

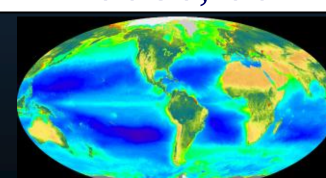


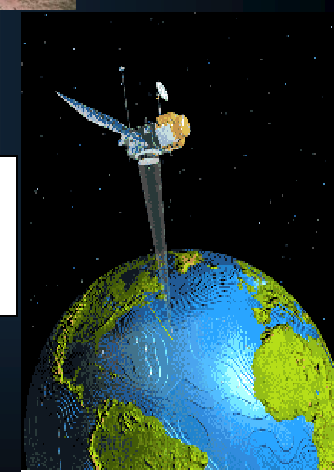
UNDERSTANDING
NSF, NASA, DOE

USDA
USGS
APPLICATIONS
EPA BoR
USACE

PREDICTION
NOAA, DOE, **NASA**

OBSERVATIONS
NASA, NOAA (DOE, USGS, USDA)



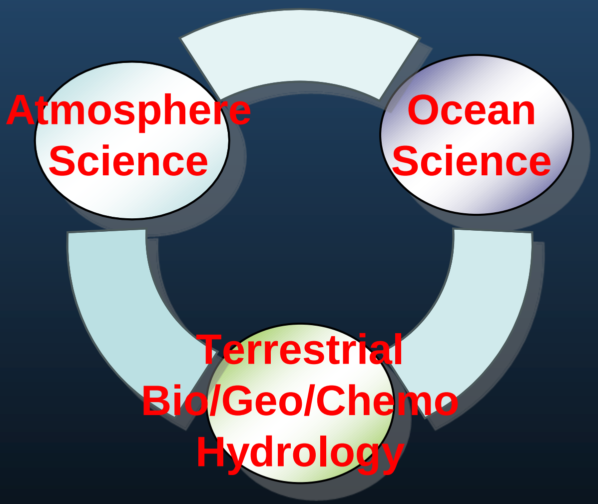


TOPEX/Poseidon Satellite

Water Research Plans

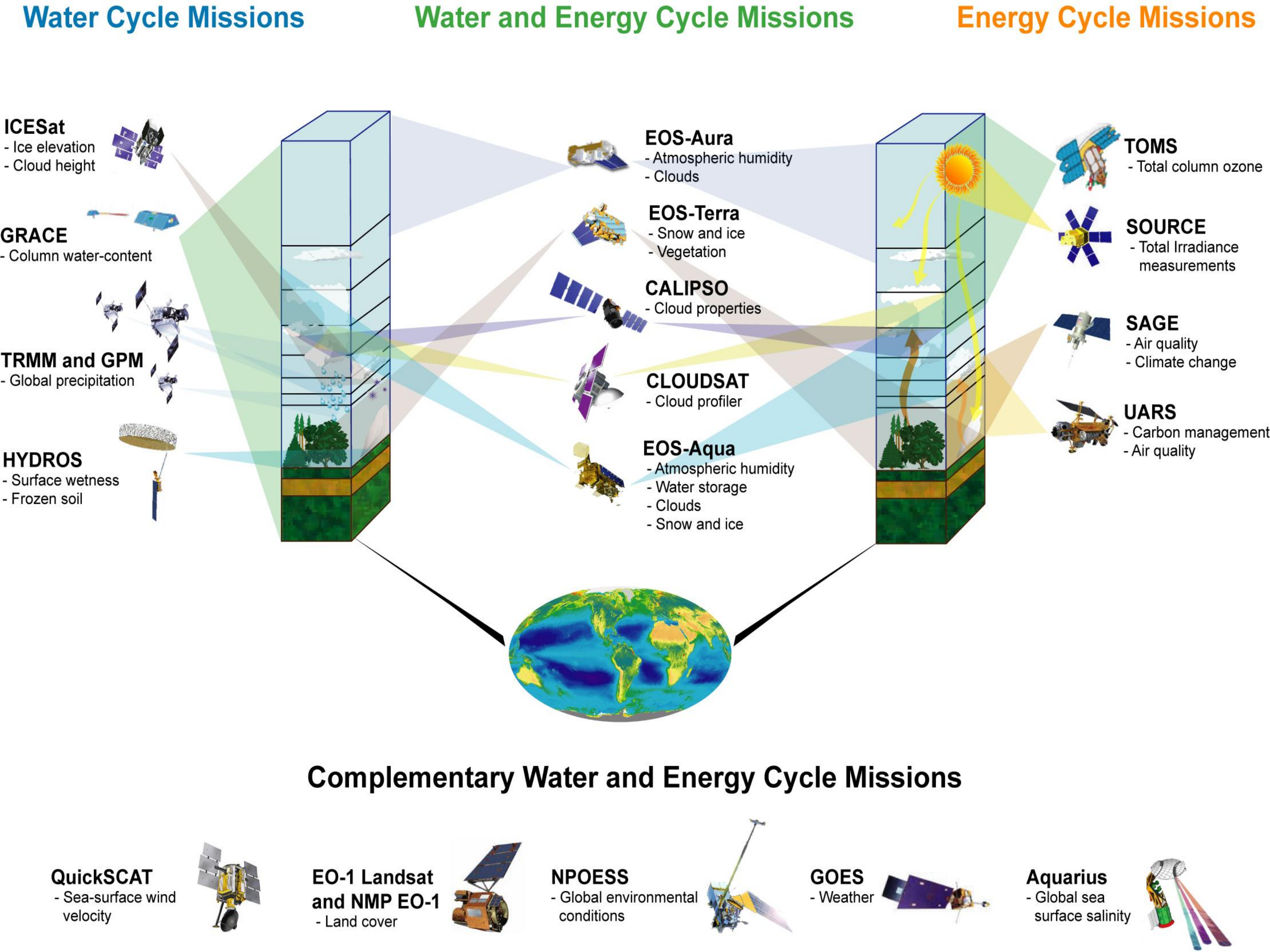
- What are the causes of water cycle variations?
- Are variations in the global and regional water cycle predictable?
- How are water and nutrient cycles linked?

Interdisciplinary Research

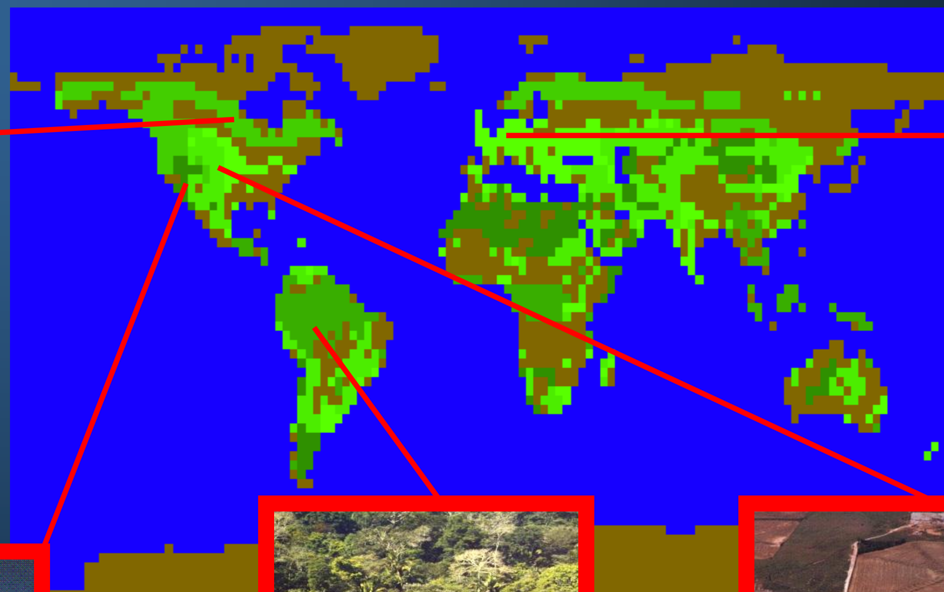


Interdisciplinary Linkages:

- **Aerosols:** *link to precipitation development, interaction with energy/radiation cycles*
- **Carbon:** *link to transpiration and radiation absorption*
- **Weather and Climate**: *water and energy are at the heart of weather and climate physics*
- **Modeling, Assimilation, and Computing**: *essential tools for integration and prediction*
- **Technology**: *development of new observation technology*
- **Applications**: *consequences of change delivered through water & energy cycle*


Water Cycle Missions
Water and Energy Cycle Missions
Energy Cycle Missions
ICESat
- Ice elevation
- Cloud height
GRACE
- Column water-content
TRMM and GPM
- Global precipitation
HYDROS
- Surface wetness
- Frozen soil
EOS-Aura
- Atmospheric humidity
- Clouds
EOS-Terra
- Snow and ice
- Vegetation
CALIPSO
- Cloud properties
CLOUDSAT
- Cloud profiler
EOS-Aqua
- Atmospheric humidity
- Water storage
- Clouds
- Snow and ice
TOMS
- Total column ozone
SOURCE
- Total Irradiance measurements
SAGE
- Air quality
- Climate change
UARS
- Carbon management
- Air quality
Complementary Water and Energy Cycle Missions
QuickSCAT
- Sea-surface wind velocity
EO-1 Landsat and NMP EO-1
- Land cover
NPOESS
- Global environmental conditions
GOES
- Weather
Aquarius
- Global sea surface salinity

Some Examples of Field Programs



BOREAS (NSA-OJP)
- Type: Evergreen Needleleaf
- Cover: 6.5%
- Precip: 242 mm
- Data : Jan 94 - Dec 96

Cabauw
- Type: Short Grass
- Cover: 16.6%
- Precip: 776 mm
- Data : Jan 87 - Dec 87

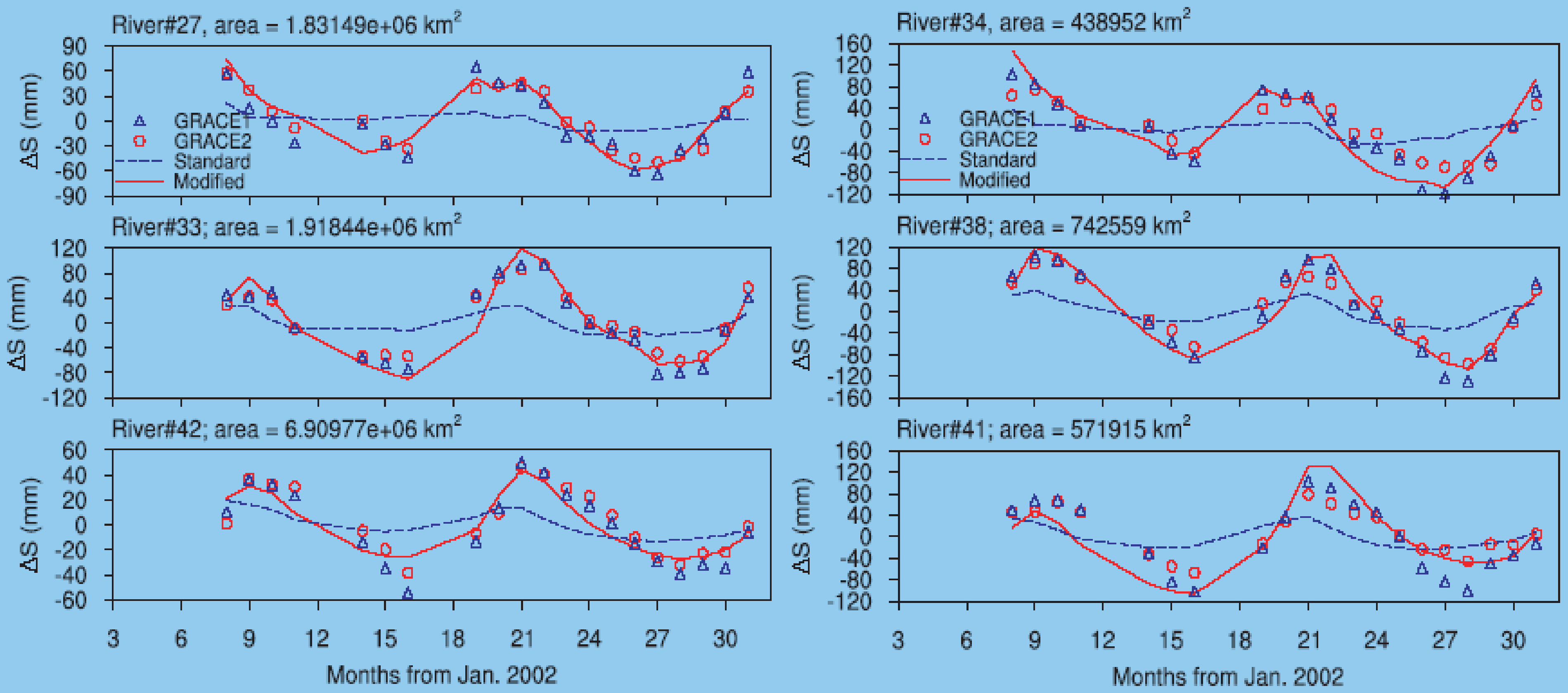
Tucson
- Type: Semi-Desert
- Cover: 9.2%
- Precip: 275 mm
- Data : May 93 - Jun 94

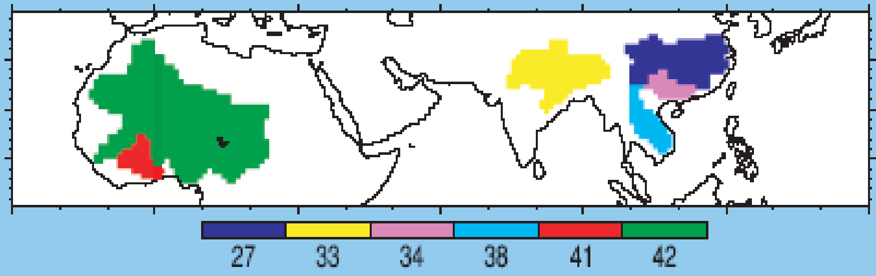
ABRACOS (Reserva Jaru)
- Type: Evergreen Broadleaf
- Cover: 9.7%
- Precip: 1600 mm
- Data : May 92 - Dec 93

ARM-CART (E13)
- Type: Mixed Crop / Farm Land
- Cover: 8.1%
- Precip: 600 mm
- Data : Apr 95 - Aug 95

Terrestrial Water Storage Change

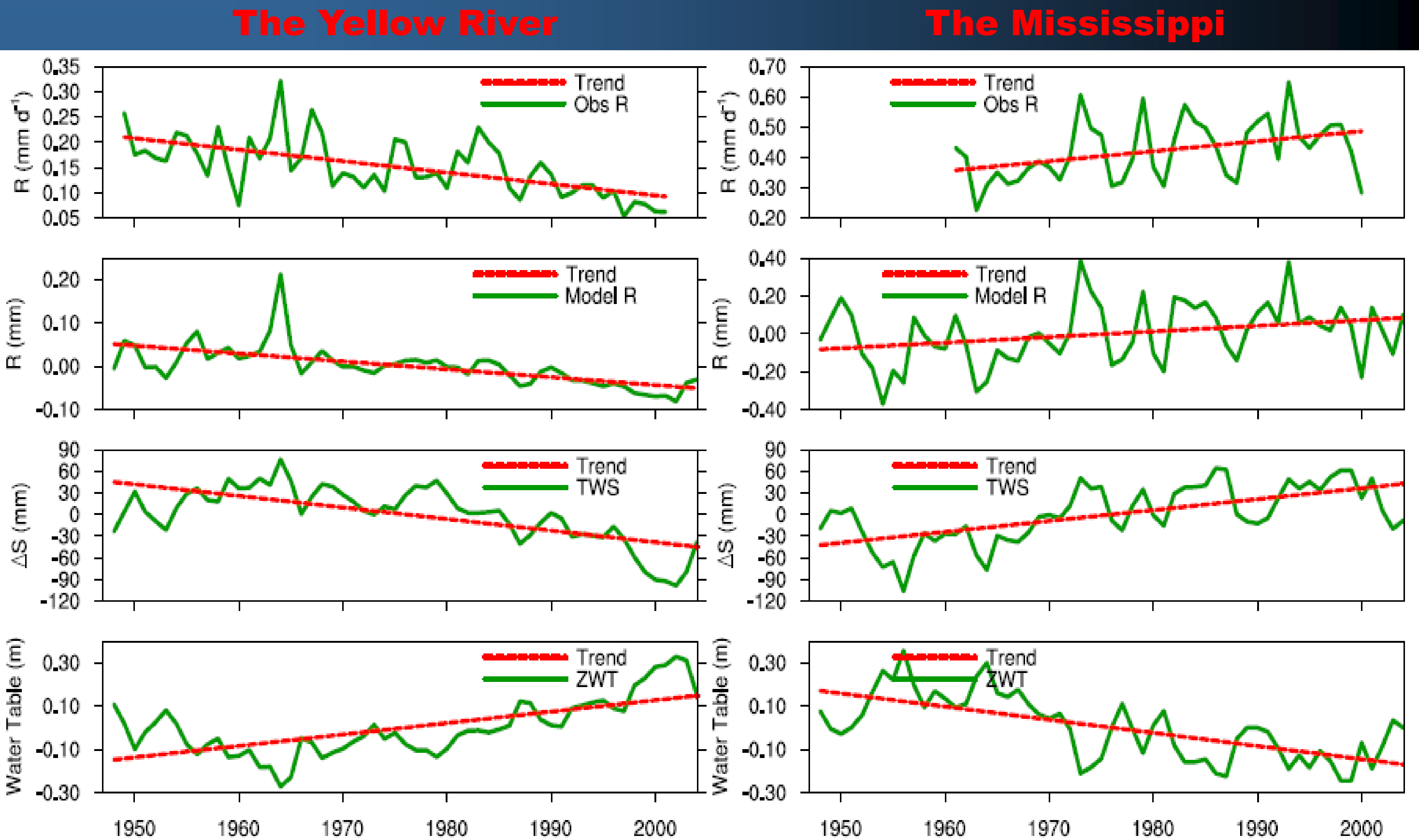
Use GRACE (2002- now) to validate and calibrate model





TWS Change

Use model to retrieve historical changes



Prediction ?

Regional Environmental Model System –

An Integrated Framework for modeling and Assessment