Hydrology in the Community Land Model

Sean Swenson
Terrestrial Sciences Section

U.S. DEPARTMENT OF ENERGY

NSF

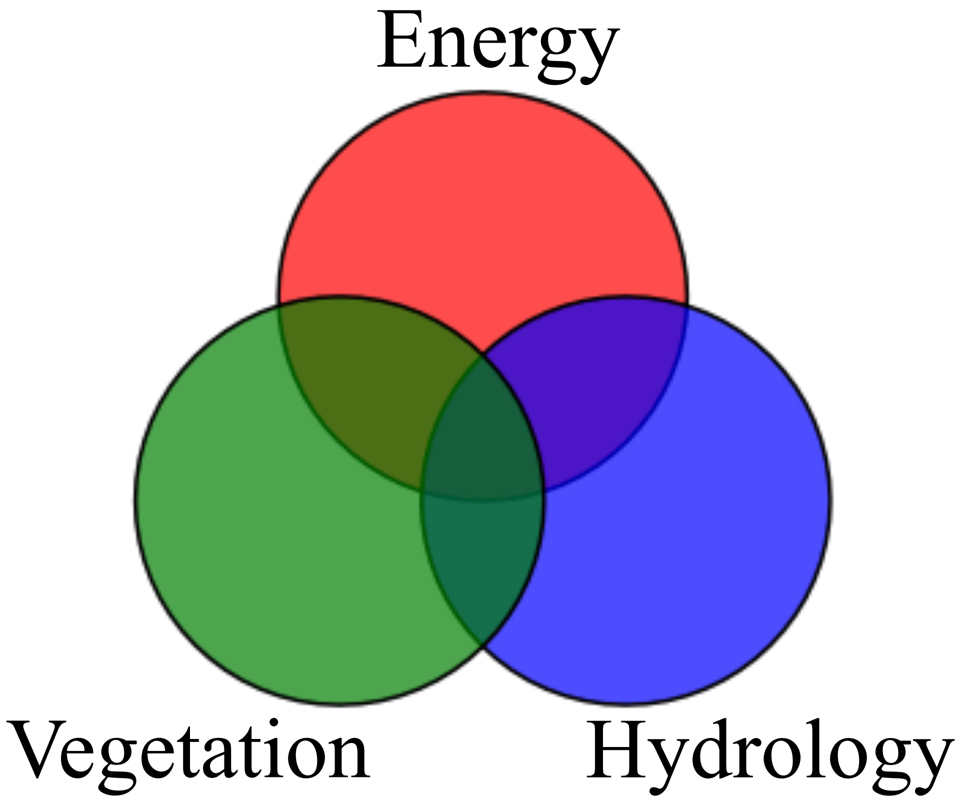
The **Community Land Model** is a... ?

a) Hydrology model

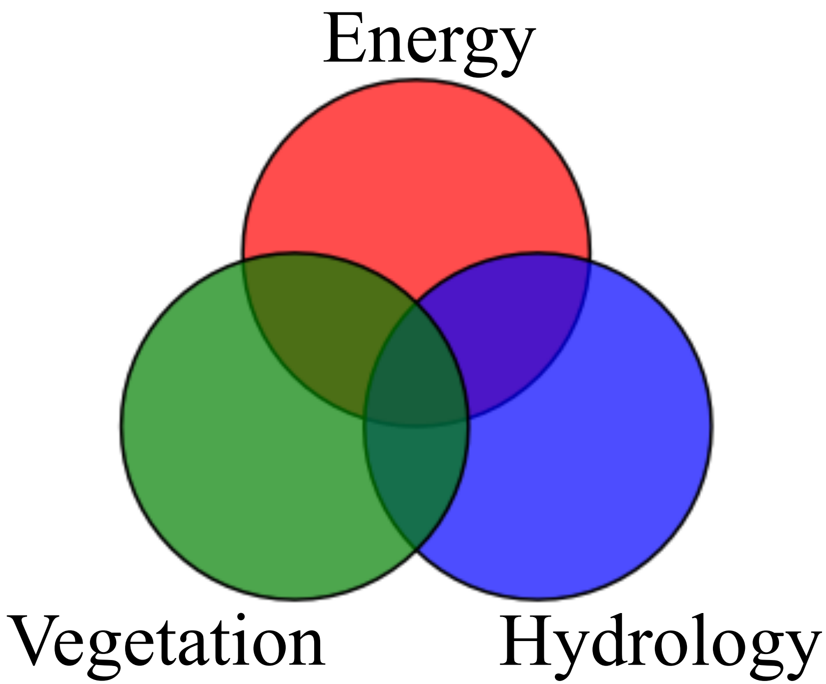
b) Land Surface model

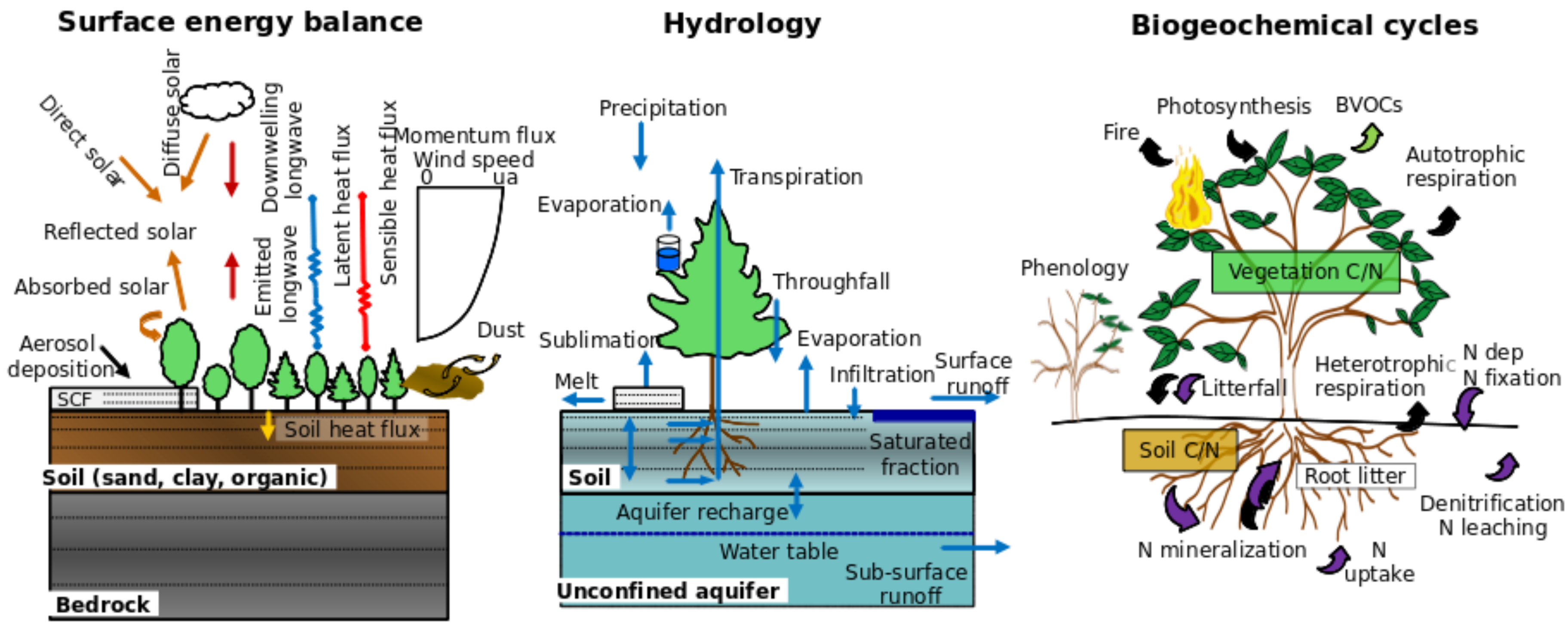
c) Terrestrial Processes model

The movement of **water** is inextricably linked to the flow of **energy** and the life cycle of **vegetation**



The ***modeling*** the of movement of water is inextricably linked to the ***modeling*** of the flow of energy and the ***modeling*** of the life cycle of vegetation




Surface energy balance
Hydrology
Biogeochemical cycles
Direct solar
Diffuse solar
Downwelling longwave
Latent heat flux
Sensible heat flux
Momentum flux
Wind speed
0
ua
Reflected solar
Absorbed solar
Emitted longwave
Aerosol deposition
Dust
SCF
Soil heat flux
Soil (sand, clay, organic)
Bedrock
Precipitation
Transpiration
Evaporation
Throughfall
Sublimation
Evaporation
Infiltration
Surface runoff
Melt
Saturated fraction
Soil
Aquifer recharge
Water table
Sub-surface runoff
Unconfined aquifer
Photosynthesis
BVOCs
Fire
Autotrophic respiration
Phenology
Vegetation C/N
Litterfall
Heterotrophic respiration
N dep
N fixation
Soil C/N
Root litter
Denitrification
N leaching
N mineralization
N uptake

The Water Balance

$$P = E + R + \Delta S$$

P = Precipitation
E = Evapotranspiration
R = Runoff
S = Storage

Different Models, ***Different Foci***

Flood Forecasting $\Rightarrow$ **R**

NWP, Climate Prediction $\Rightarrow$ **E**

Drought Monitoring, Groundwater $\Rightarrow$ **S**

Different Foci, *Different Models*

1-D ⇒ Darcy Flow (Infiltration/Recharge)

2-D ⇒ River Routing

3-D ⇒ Saturated Flow (Groundwater)

CLM is tasked with simulating ***all*** of these phenomena...

...therefore, ***trade-offs*** will be made.

CLM Water Balance Operations

Precipitation

⇒ Partitioning between rain and snow, or between stratiform and convective

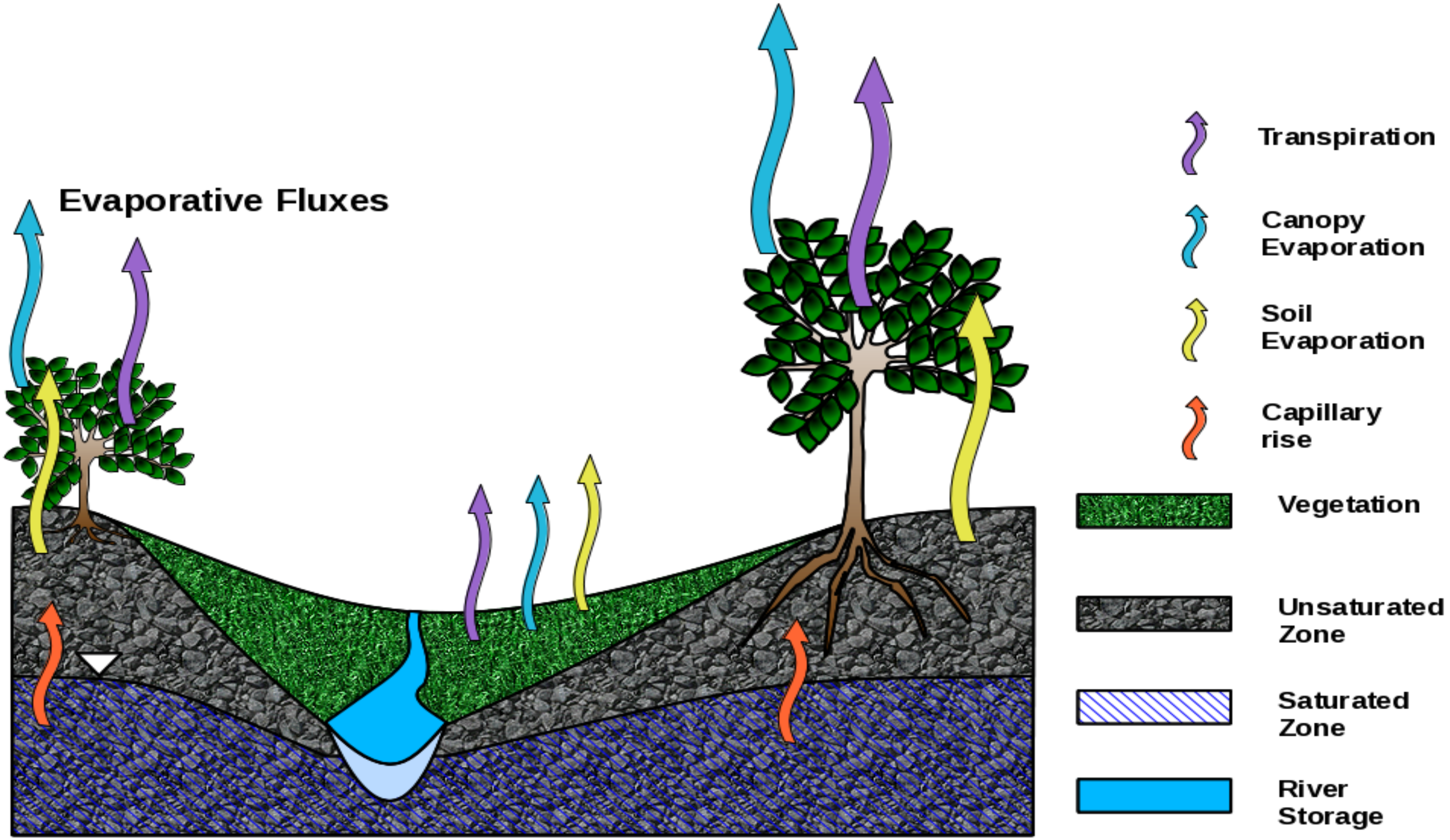
⇒ Canopy interception, storage, and throughfall

CLM Water Balance Operations

Evaporation

⇒ Evaporation from Soil / Canopy / Snow / Surface Water

⇒ Transpiration from vegetation


Evaporative Fluxes
Transpiration
Canopy Evaporation
Soil Evaporation
Capillary rise
Vegetation
Unsaturated Zone
Saturated Zone
River Storage

CLM Water Balance Operations

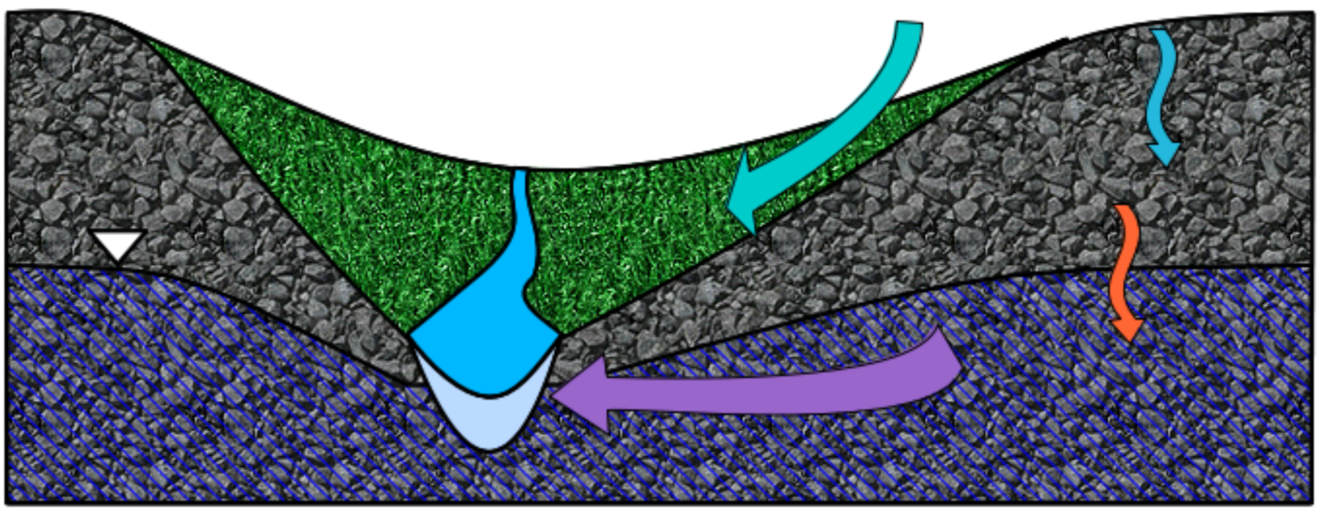
Runoff

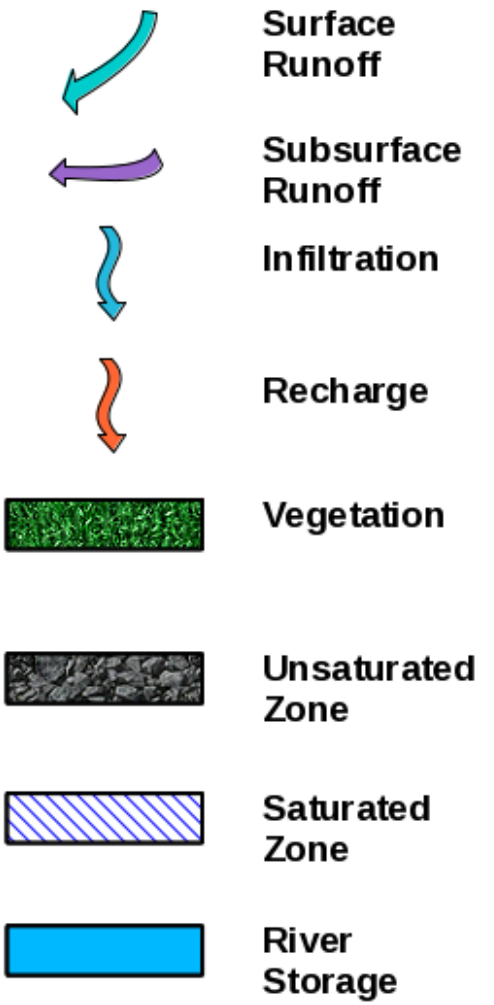
⇒ Surface Runoff (Infiltration and/or Saturation Excess)

⇒ Subsurface Runoff (Baseflow)

⇒ River Routing

Runoff Generation and Infiltration



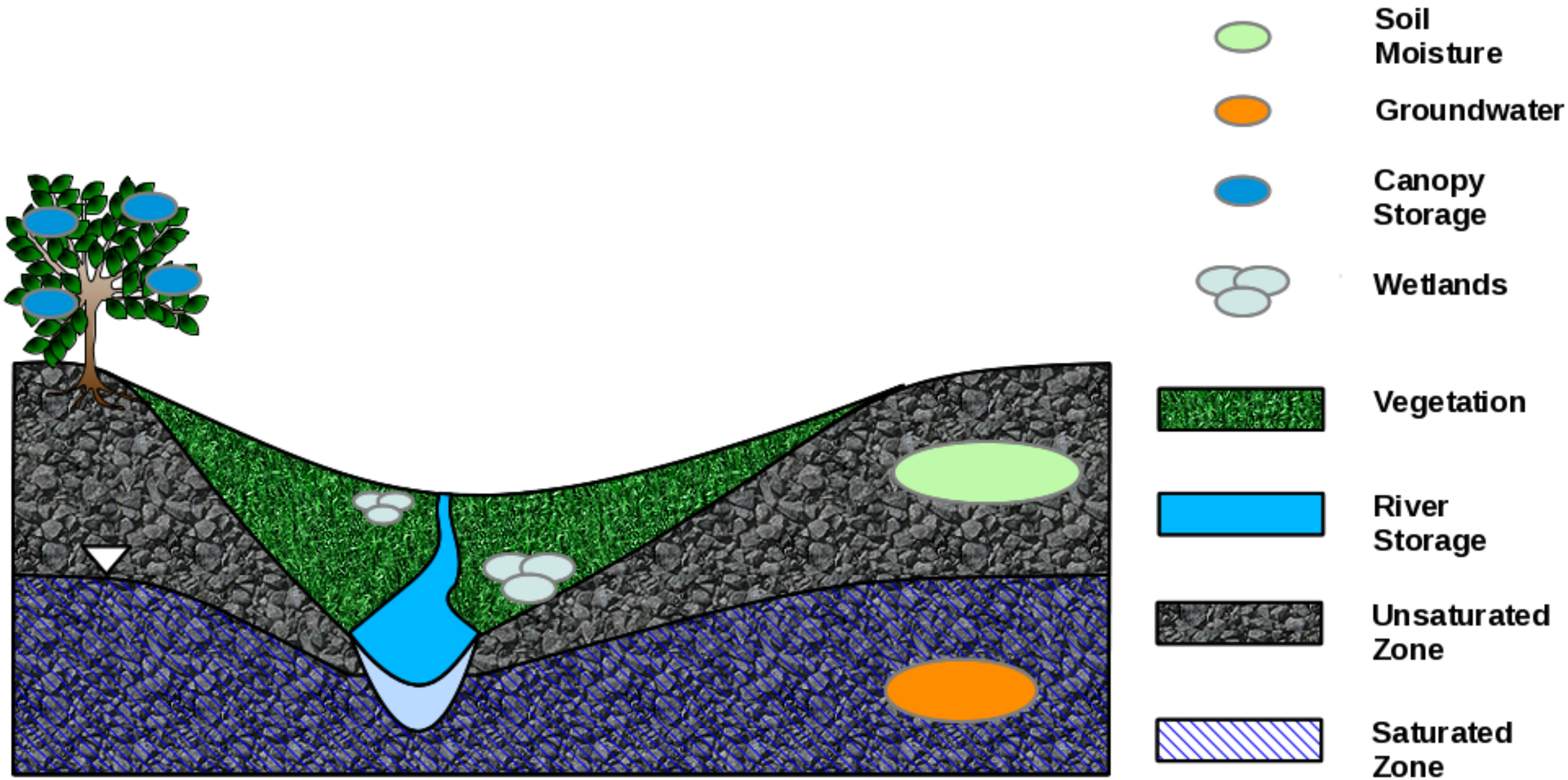


CLM Water Balance Operations

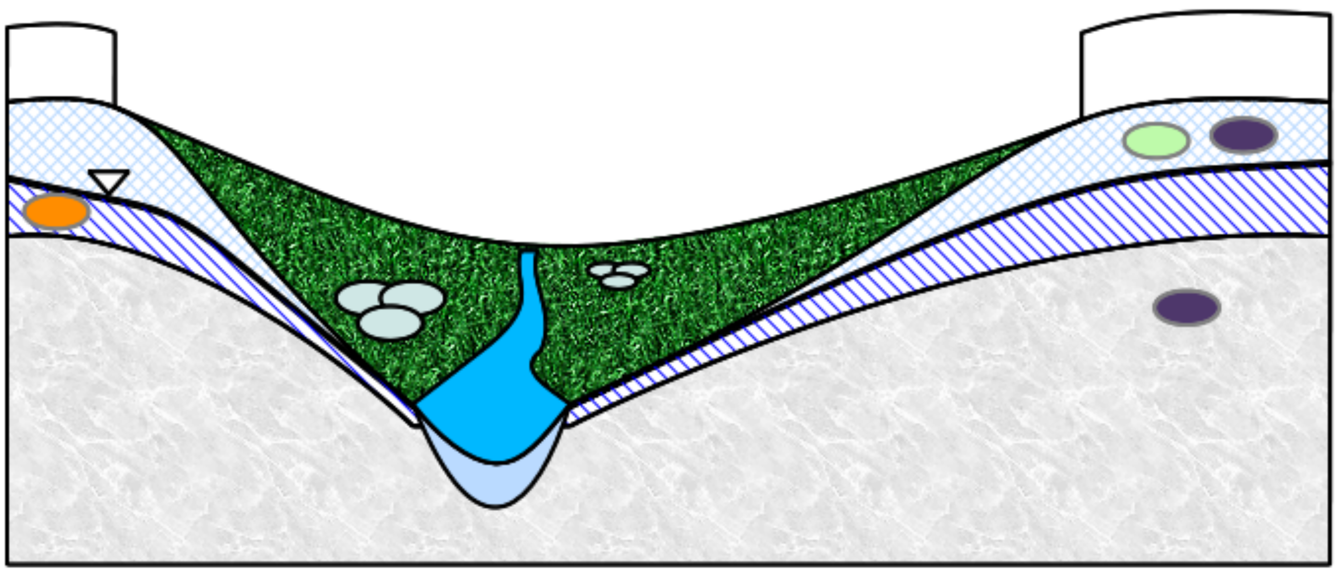
Storage

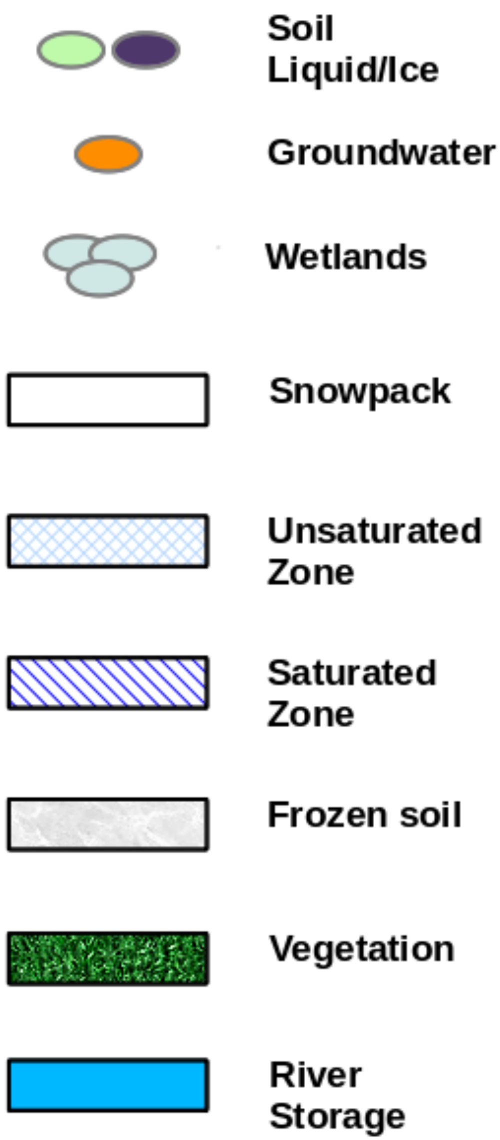
- ⇒ Soil Moisture
- ⇒ Groundwater and water table depth
- ⇒ Perched water table
- ⇒ Canopy water
- ⇒ Surface water
- ⇒ Snow

Storage Components



Cold Region Storage Components





CLM Submodels

- Soil hydrology and thermodynamics model
- Snow model
- Photosynthesis model
- Radiation and albedo model
- River Transport model
- Lake model
- Urban model
- Vegetation dynamics model
- Carbon and nitrogen cycle model
- Volatile Organic Compound emissions model
- Dust emissions model

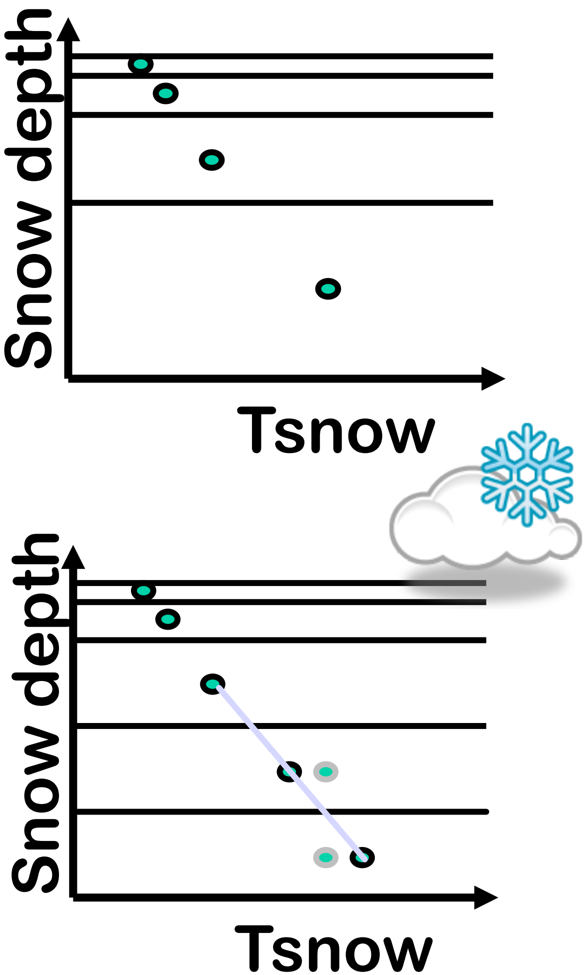
Snow model

Treats processes such as:

- Accumulation
- Snow melt and refreezing
- Snow aging
- Water transfer across layers
- Snow compaction:
  - destructive metamorphism due to wind
  - overburden
  - melt-freeze cyclesI

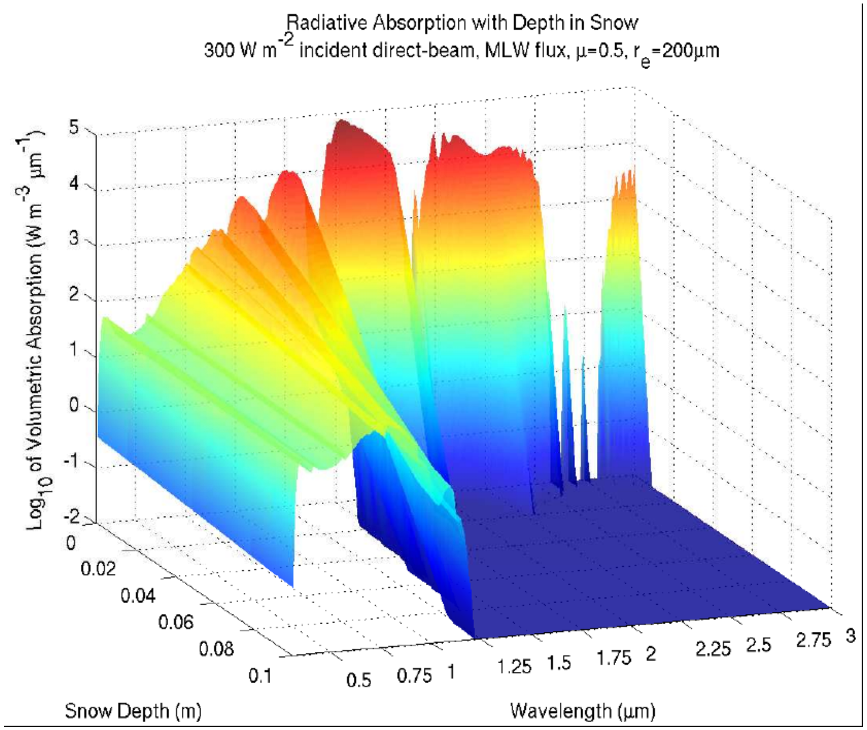
- Sublimation
- Aerosol deposition

Up to 5-layers of varying thickness



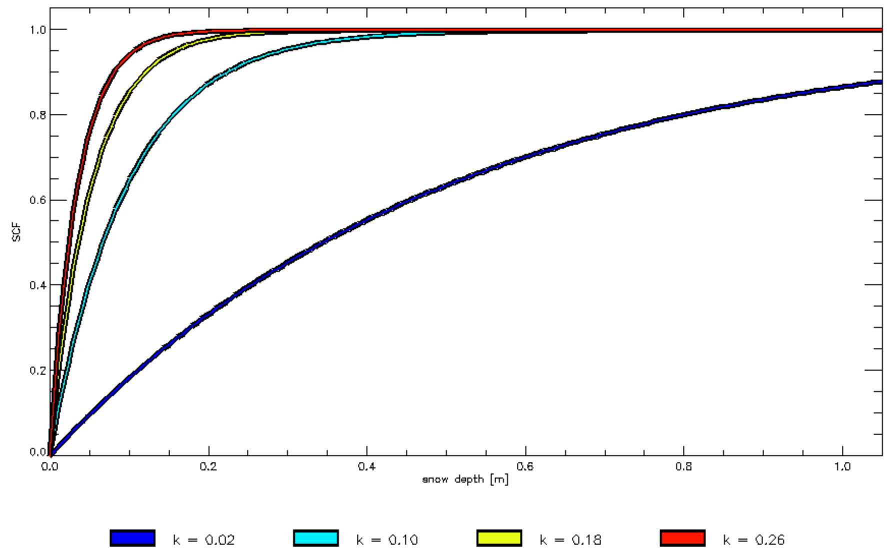
Snow Radiative Transfer (SNICAR)

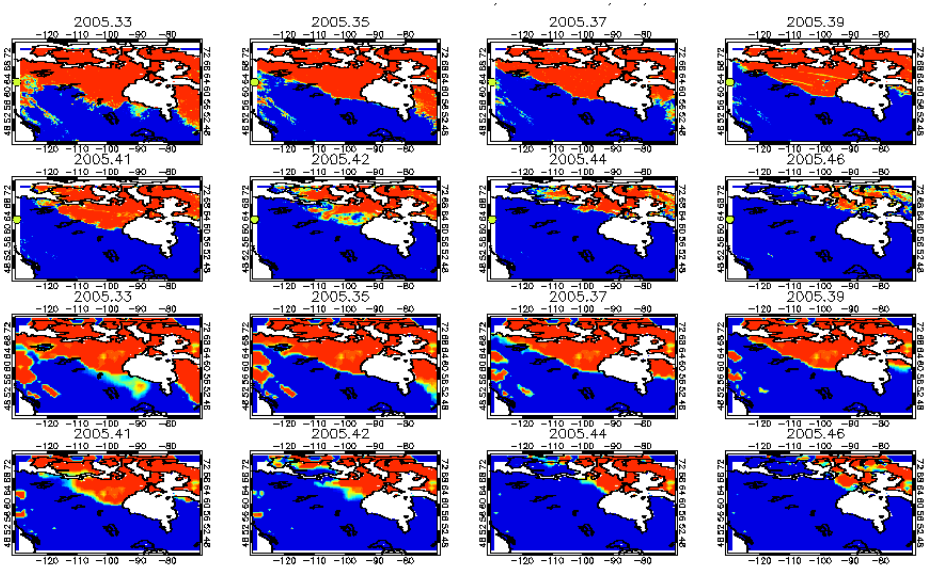
- Snow darkening from deposited black carbon, mineral dust, and organic matter
- Vertically-resolved solar heating in the snowpack
- Snow aging (evolution of effective grain size) based on:
  - Snow temperature and temperature gradient
  - Snow density
  - Liquid water content and
  - Melt/freeze cycling

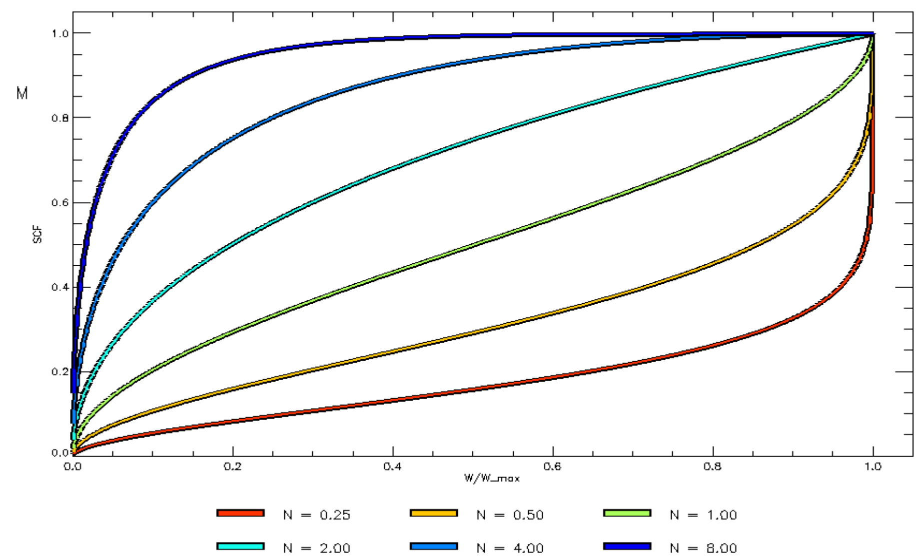


Fractional Snow Covered Area

- Describes sub-gridscale snow cover
- Based on snow water equivalent (SWE)
- Dependent on snow history
- Dependent on snow trajectory







Soil model

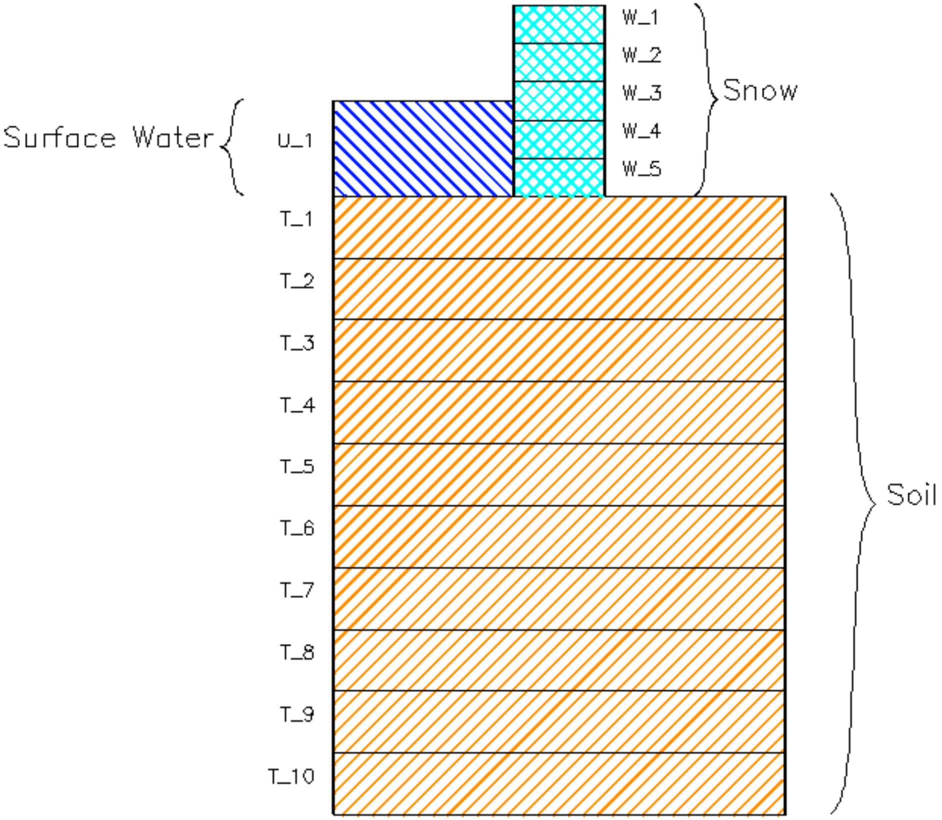
Treats processes such as:

- Soil moisture redistribution
  - Infiltration
  - Darcy flow
  - Recharge

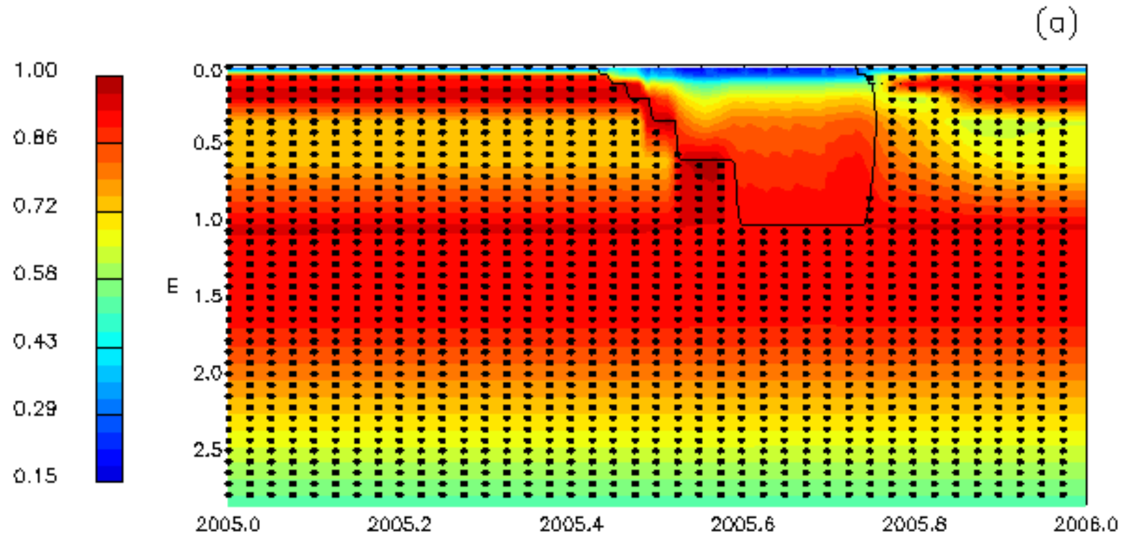
- Soil moisture phase change
- Soil temperature redistribution

Default structure has 10 layers of variable thickness, spanning nearly 4 meters depth

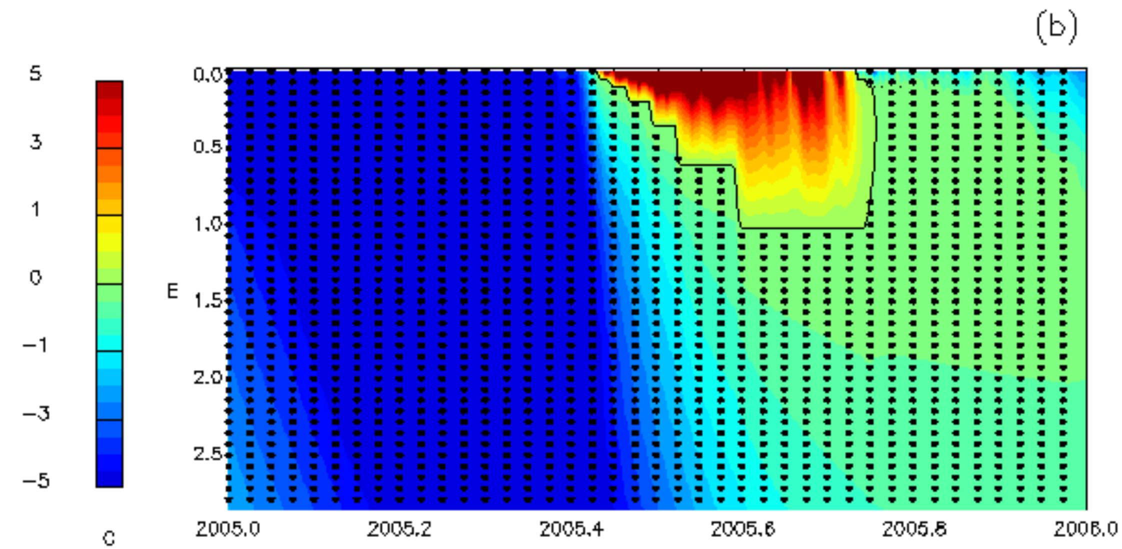
- Thermal calculations use additional deep layers



a) Soil moisture (% saturation)



b) Soil temperature (◦C)



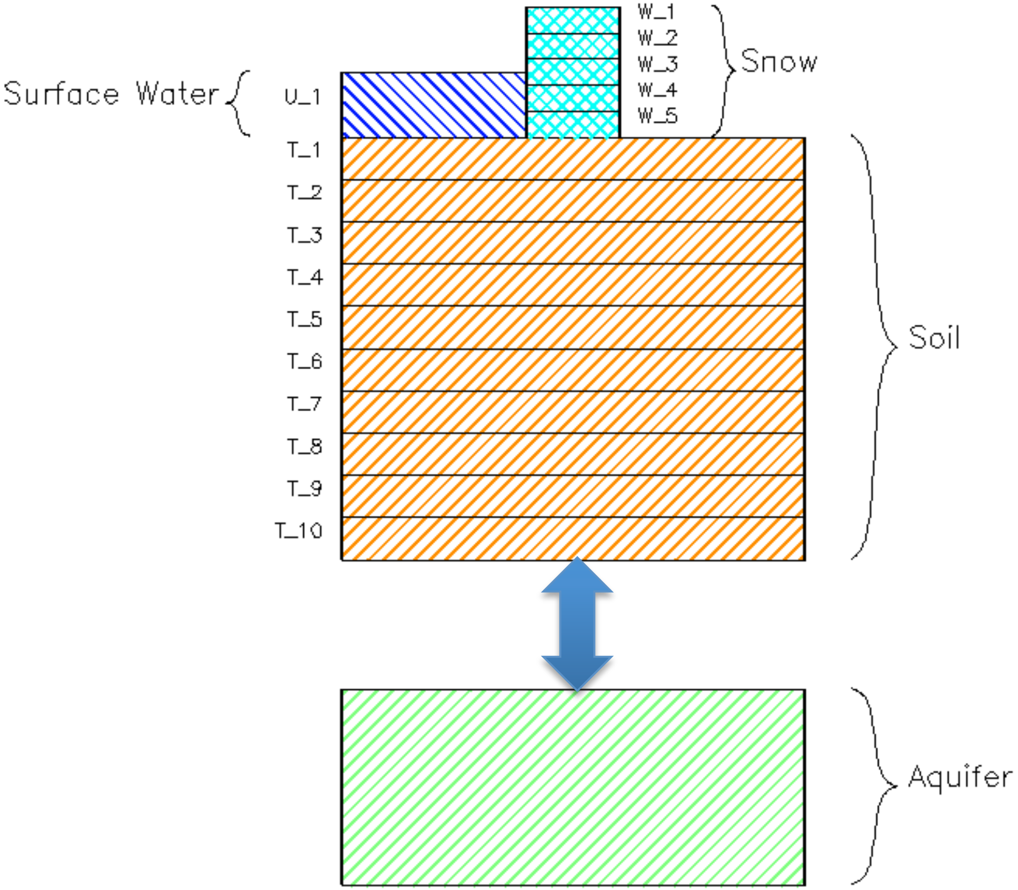
Stippling indicates frozen soil

Groundwater model

• Provides bottom boundary condition to soil column

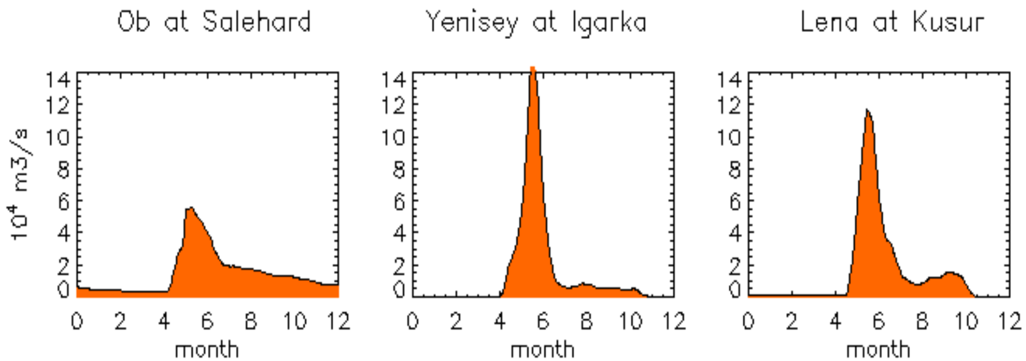
• Groundwater storage increased by recharge, decreased by subsurface flow and exfiltration

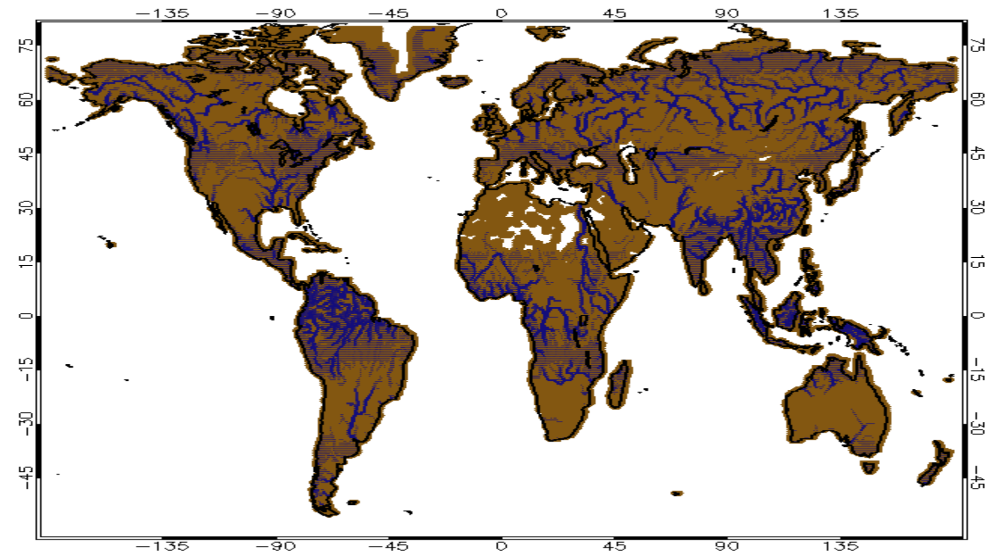
• Calculates water table depth



River model

- Routes runoff to the oceans
- Flow directions are obtained from an input dataset
- Calculates water volume and discharge





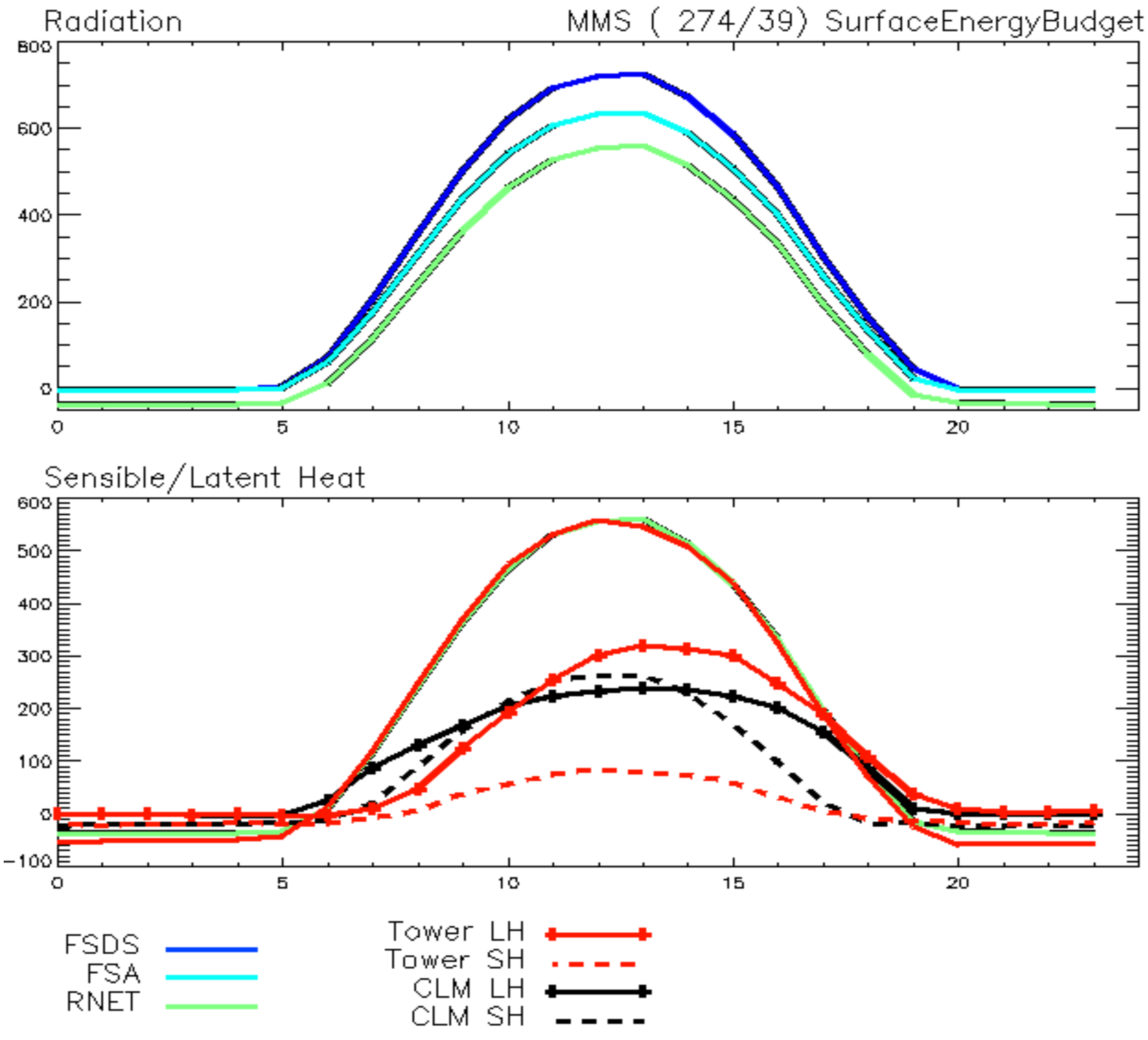
Model Validation Tools

Ideally, should be:

- Global
- Directly comparable to modeled process/state/flux
- Same spatial / temporal scale
- High accuracy
- Long record

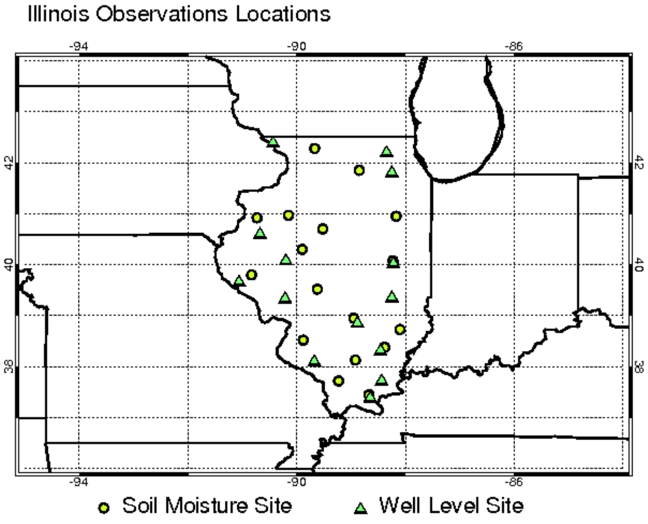
In reality, no datasets meeting these criteria exist...

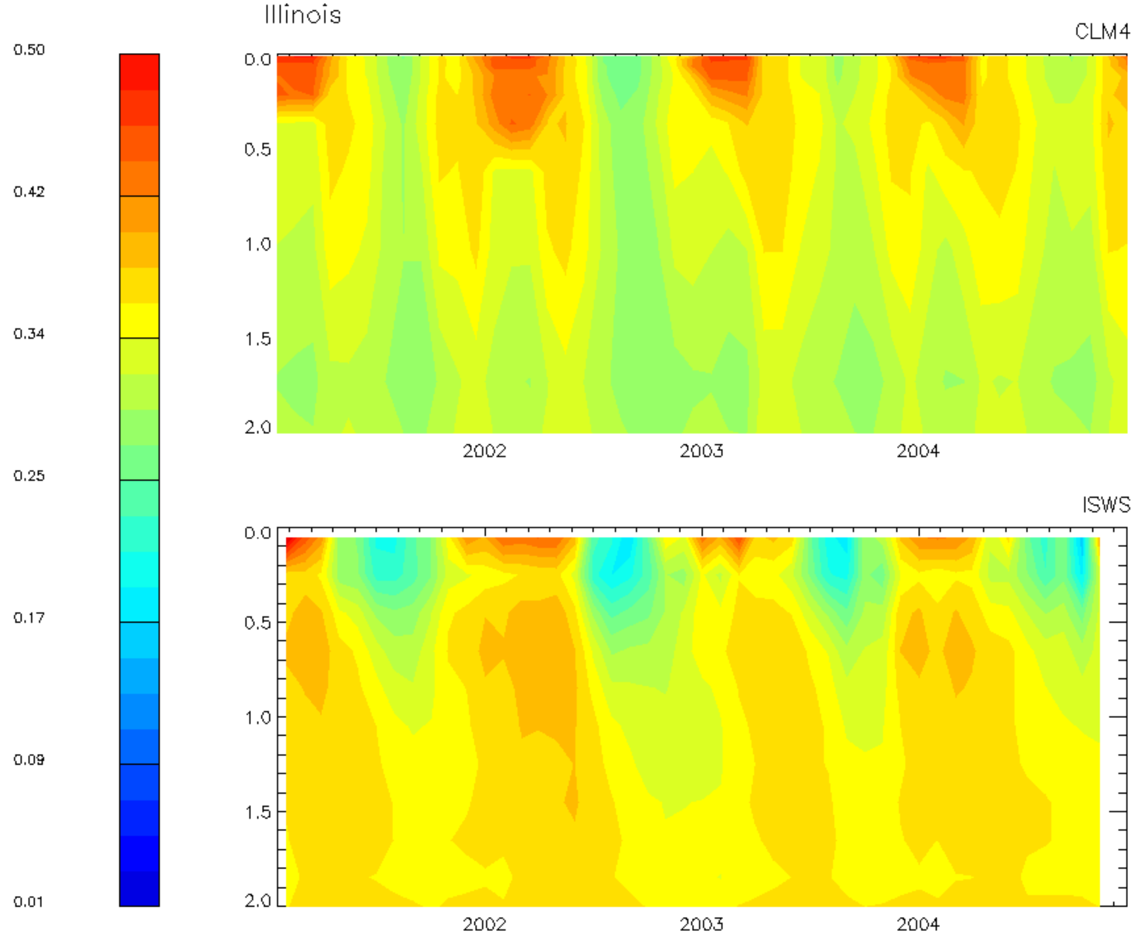
Flux Towers



Radiation
MMS (274/39) SurfaceEnergyBudget
800
600
400
200
0
0
5
10
15
20
Sensible/Latent Heat
600
500
400
300
200
100
0
−100
0
5
10
15
20
FSDS
FSA
RNET
Tower LH
Tower SH
CLM LH
CLM SH

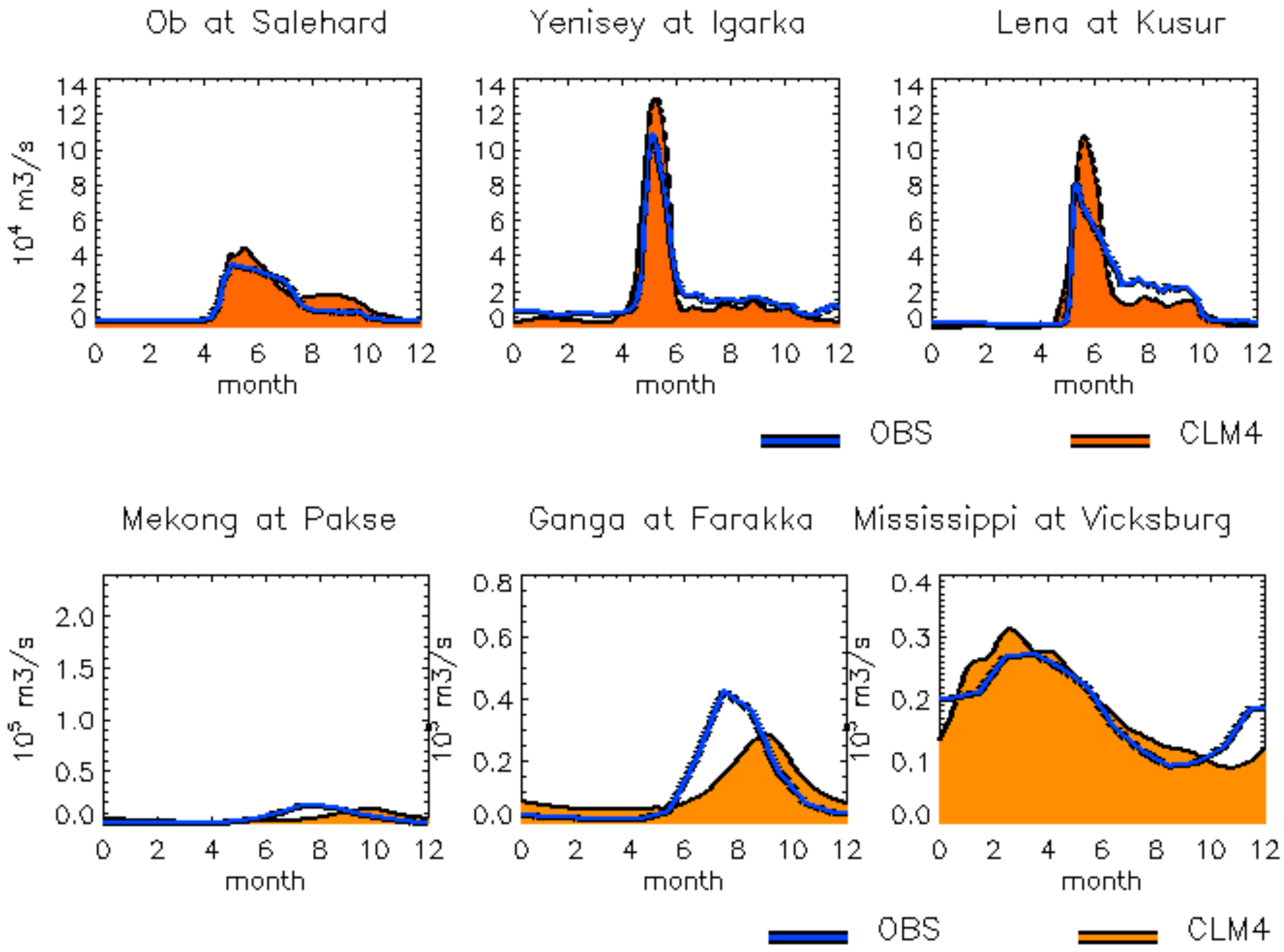
Soil Moisture Networks





Top panel: CLM soil moisture
Bottom: Observed soil moisture

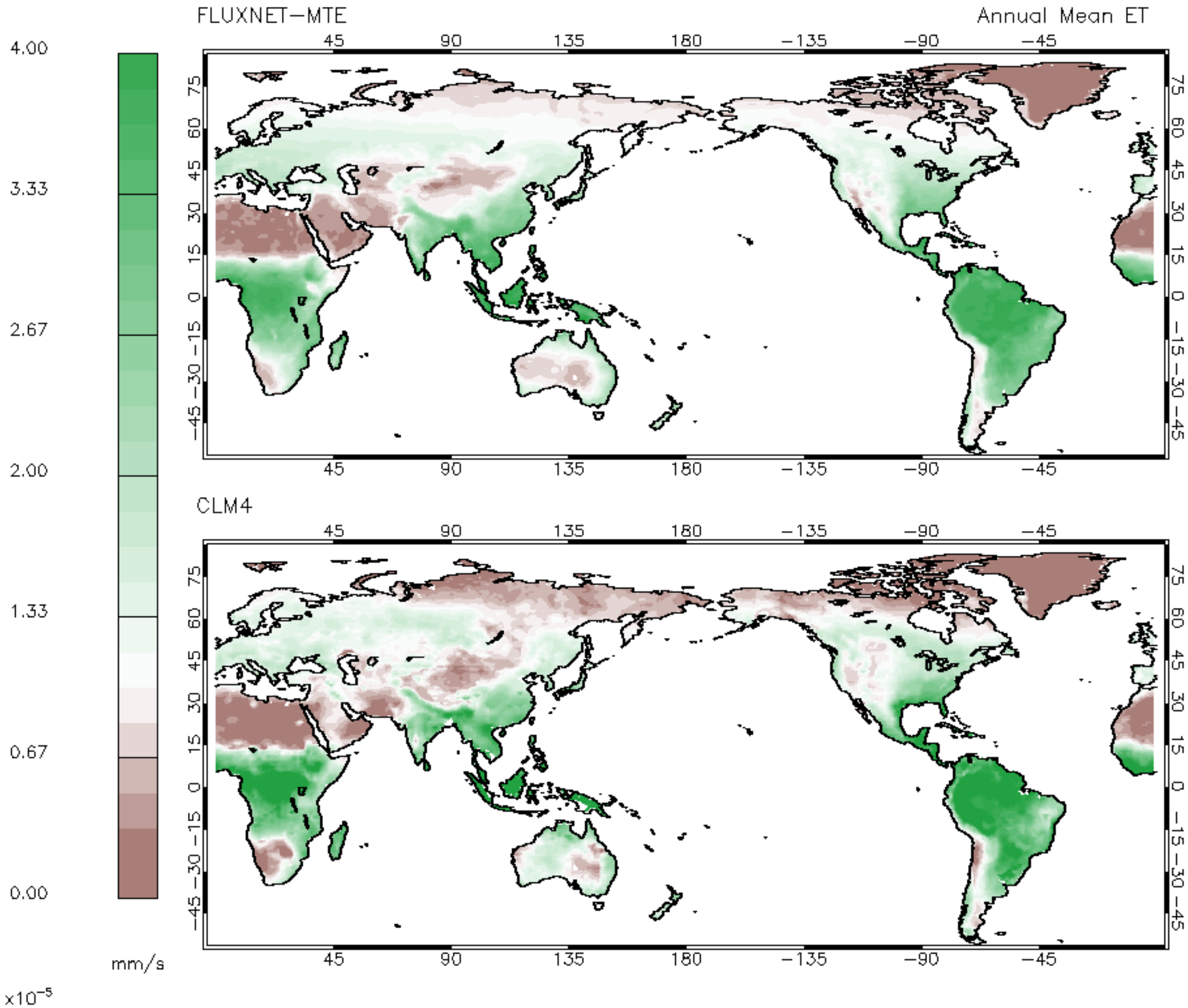
River Discharge



FLUXNET-MTE

Annual Mean Evapotranspiration

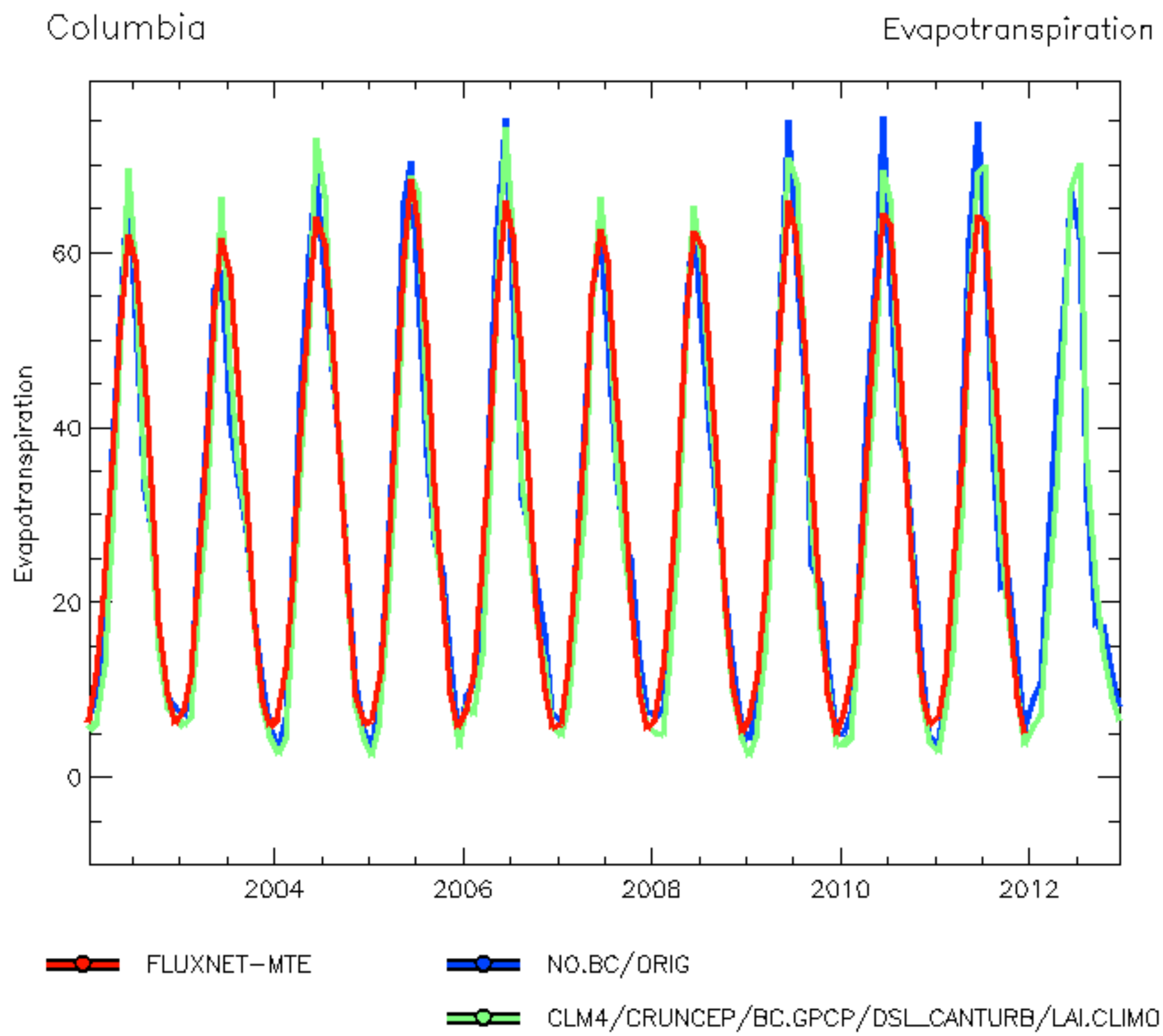
Top panel: FLUXNET-MTE
Bottom: CLM



FLUXNET-MTE

Columbia River Basin
Evapotranspiration

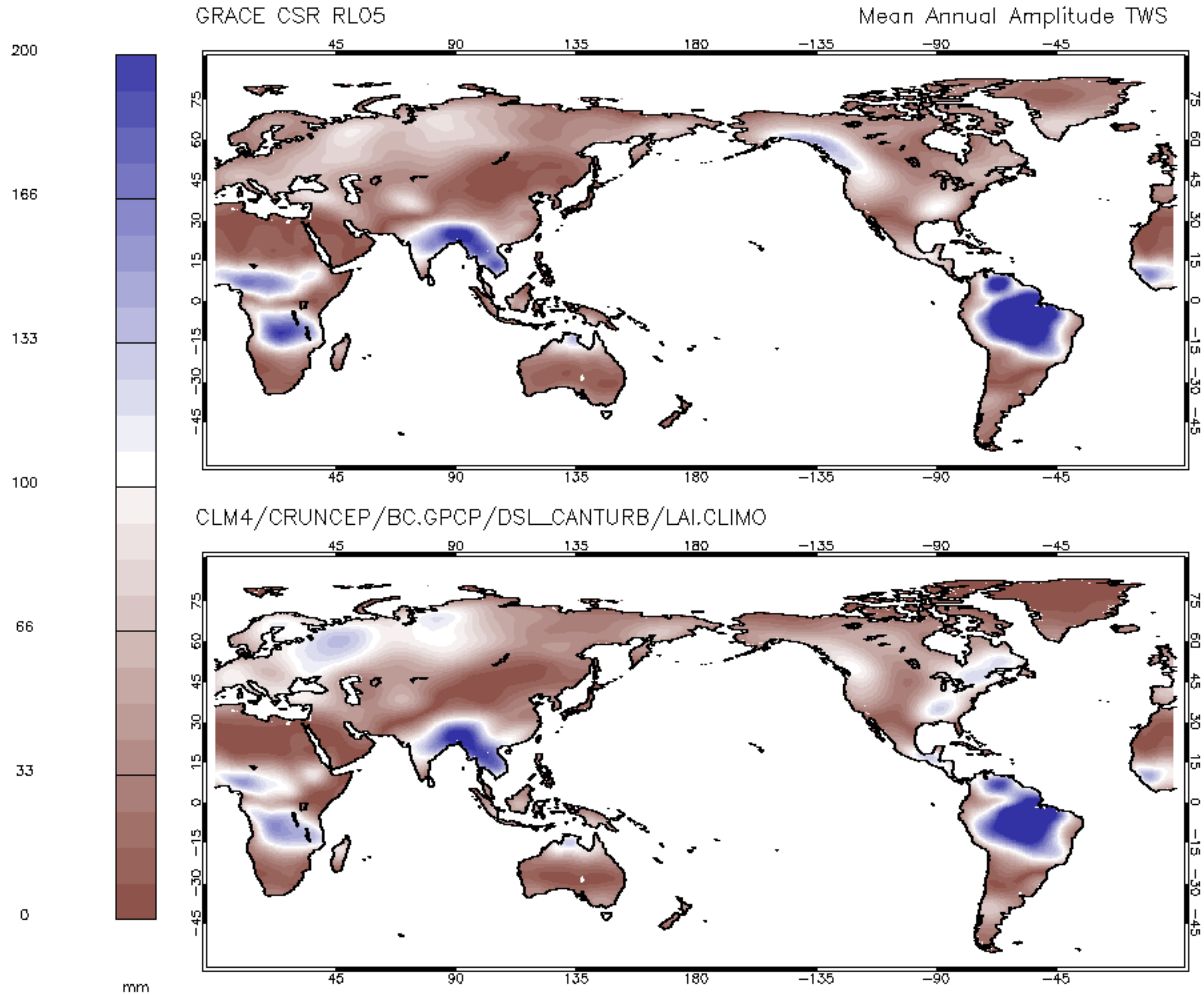
Red: FLUXNET-MTE
Blue/Green: CLM



GRACE Total Water Storage

Mean Annual Amplitude of Total Water Storage

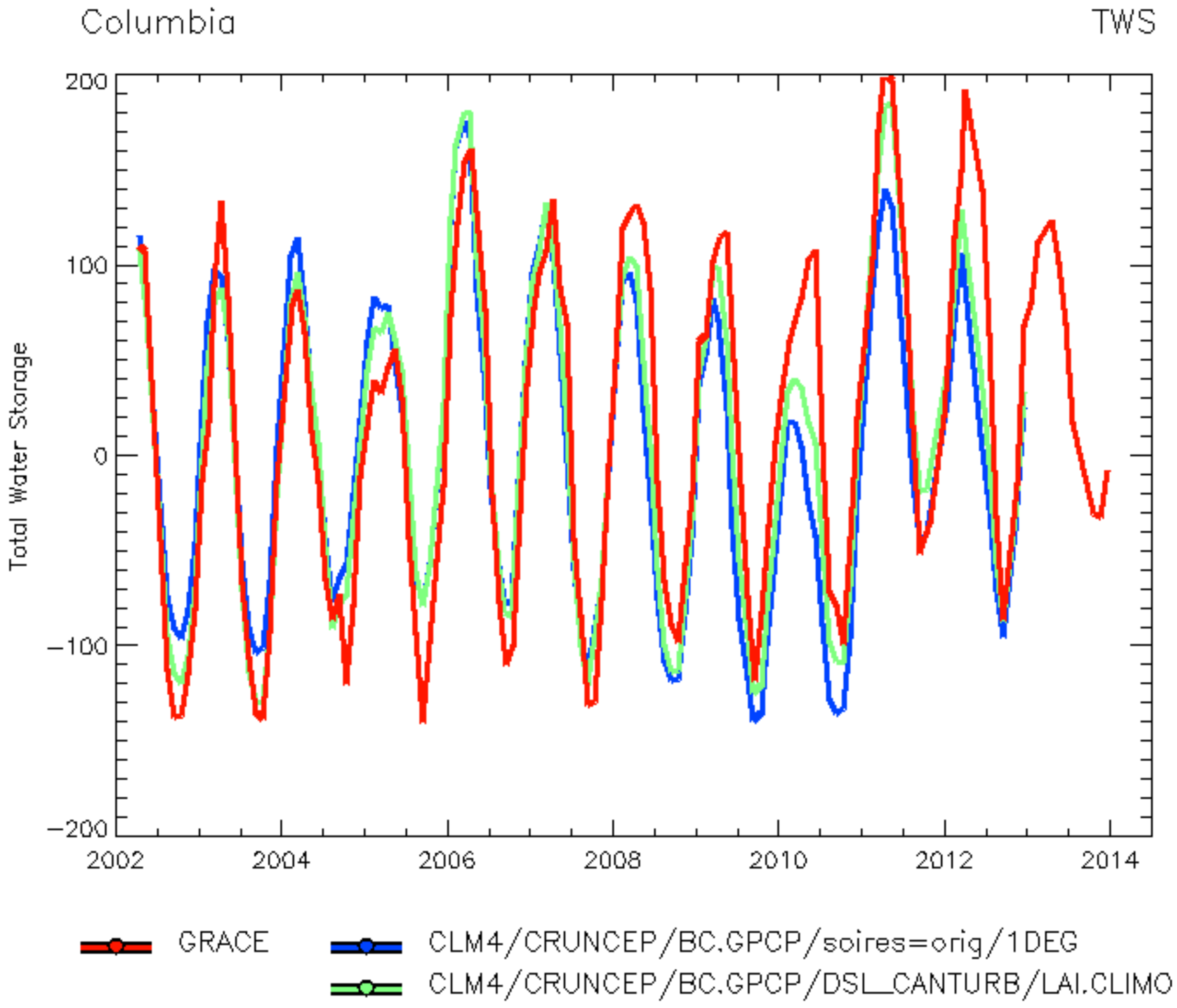
Top panel: GRACE
Bottom: CLM



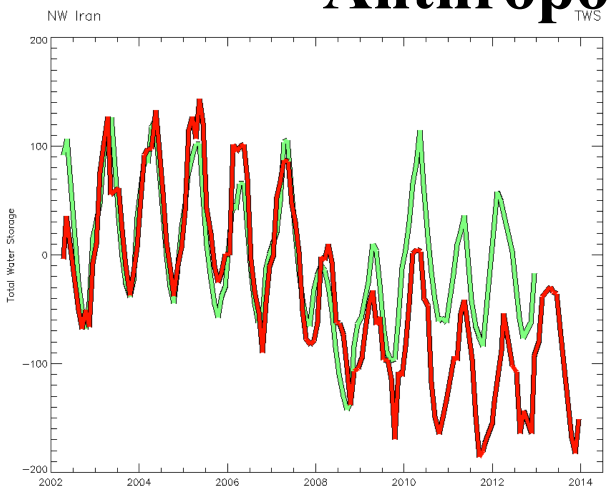
GRACE Total Water Storage

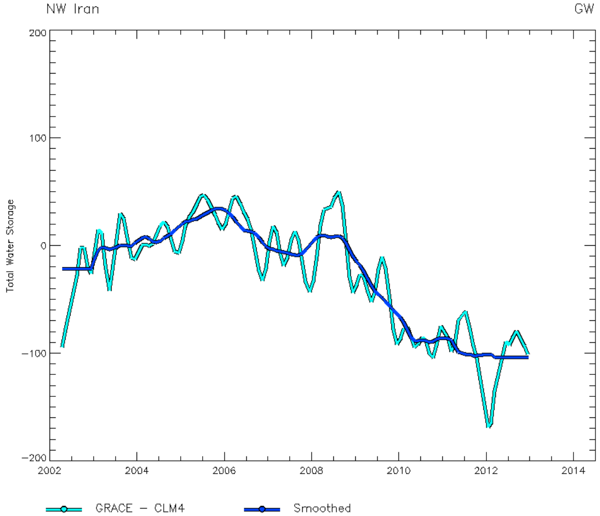
Columbia River Basin
Total Water Storage

Red: GRACE
Blue/Green: CLM



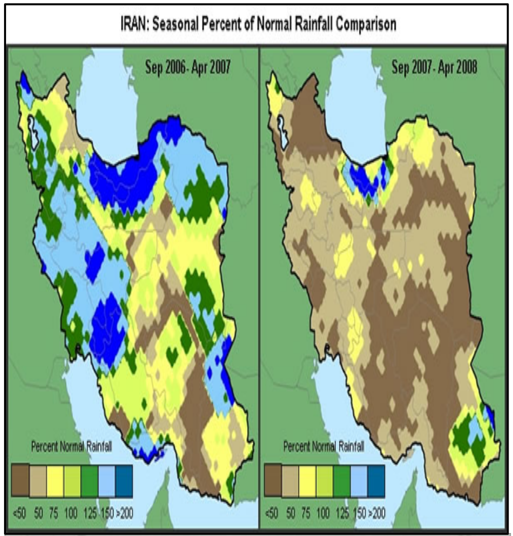
CLM Application Example: Anthropogenic Groundwater Withdrawal



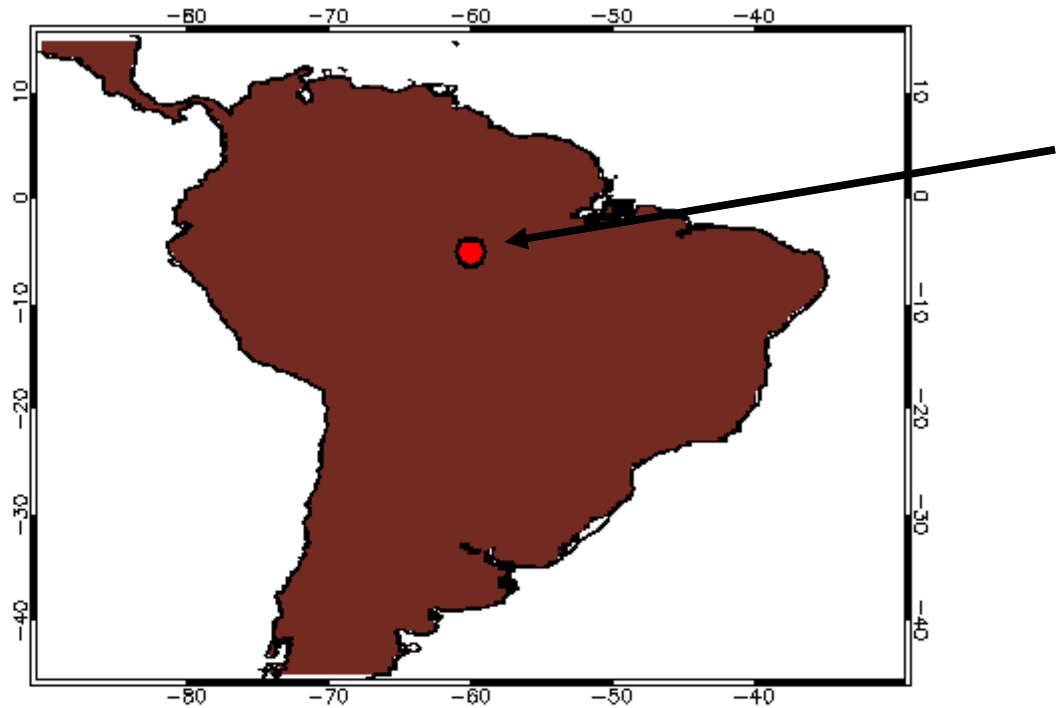


Human-induced groundwater changes can be estimated by removing the CLM estimate of TWS from the GRACE estimate of TWS

- GRACE TWS
- CLM TWS
- Groundwater

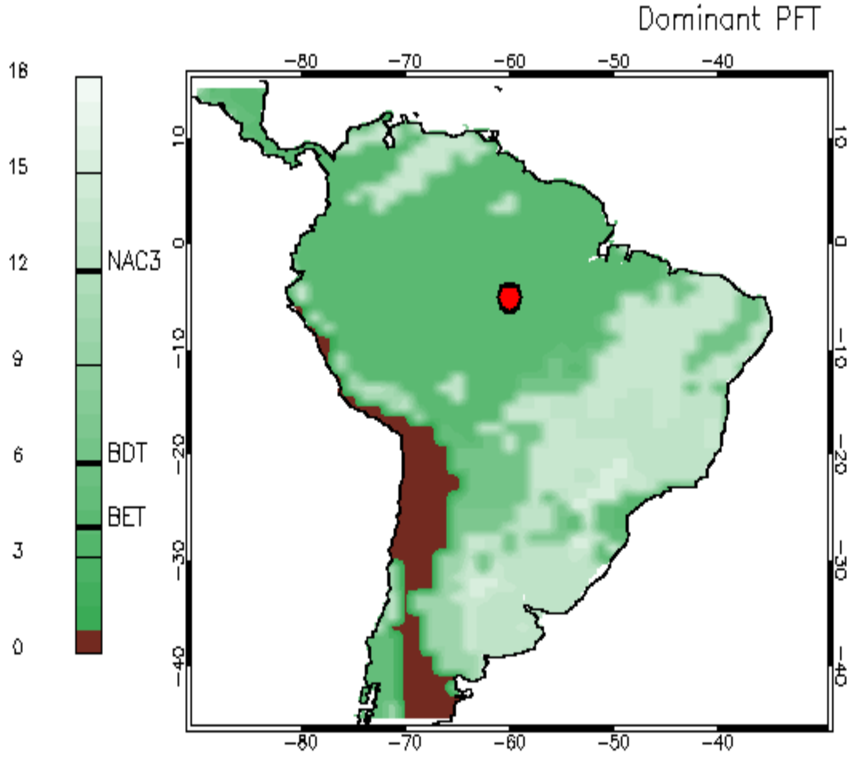


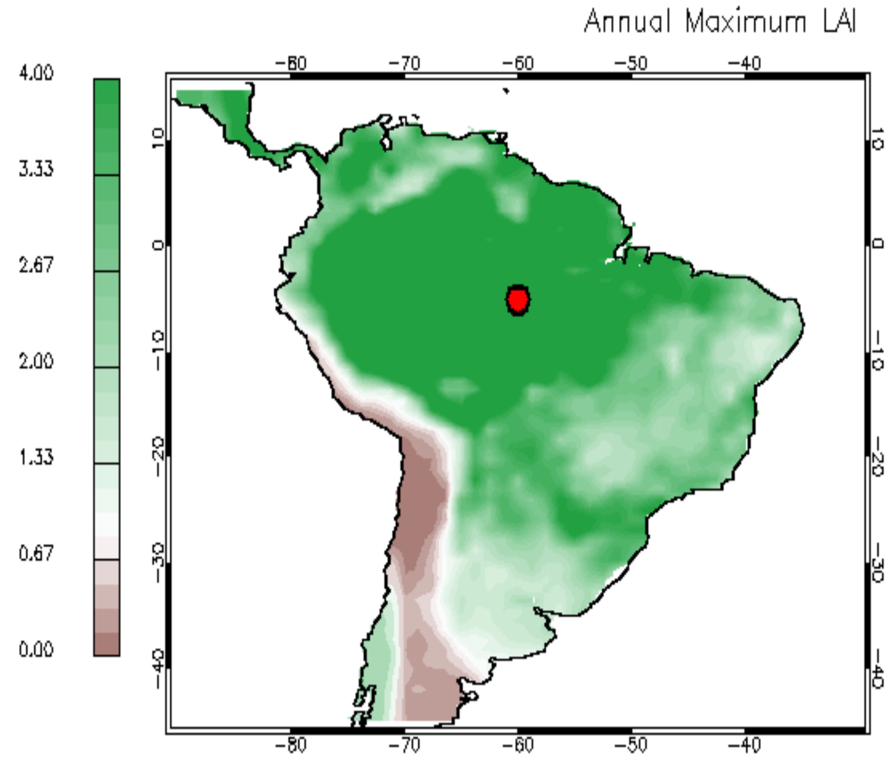
Simulation Examples I: Tropical



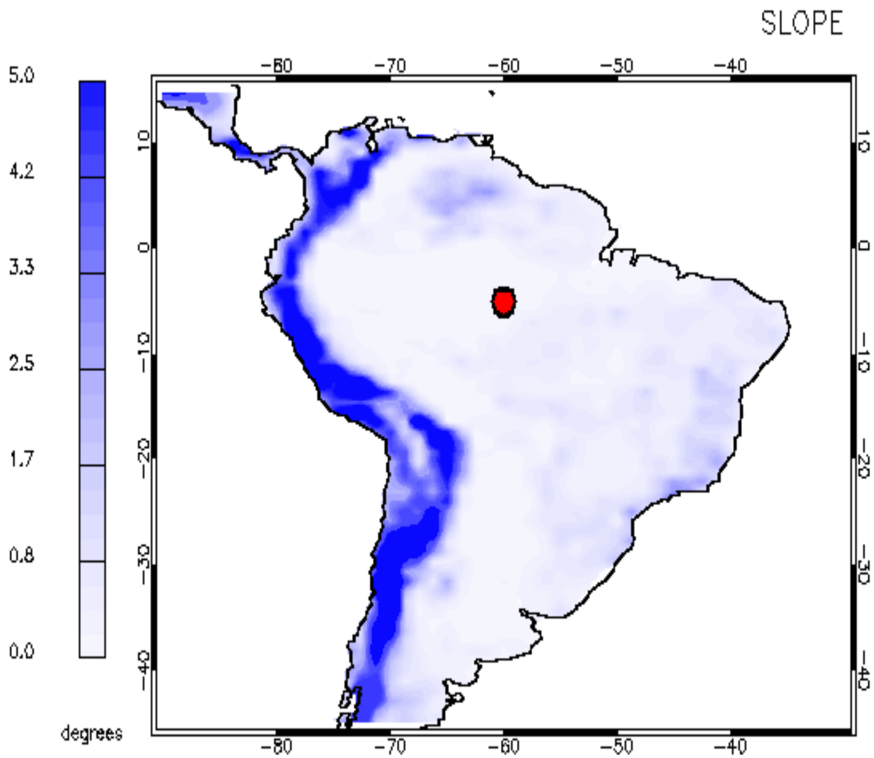
60W / 5S

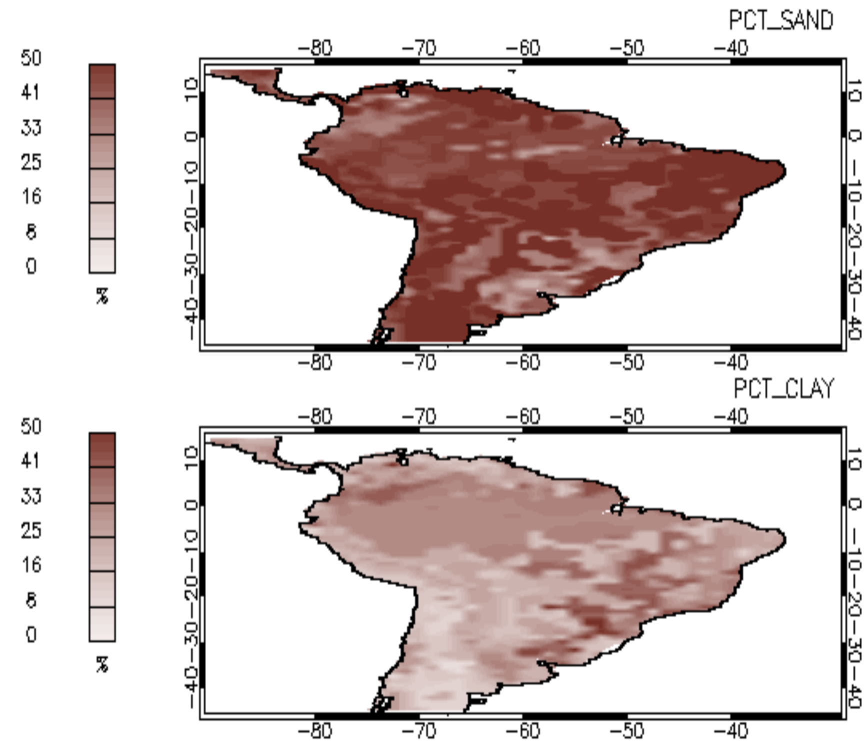
Hydrologically Relevant Surface Data



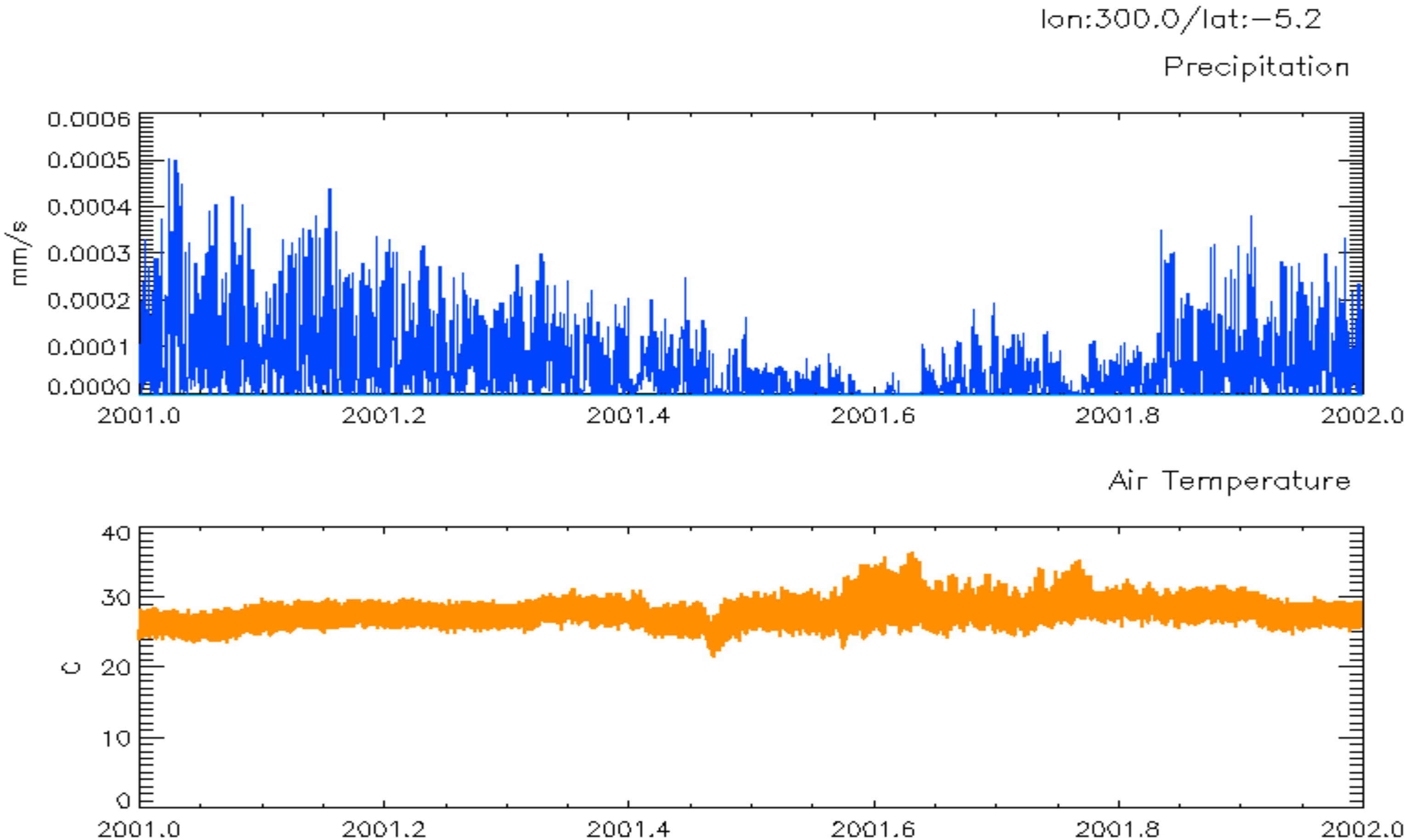


Hydrologically Relevant Surface Data





Time Series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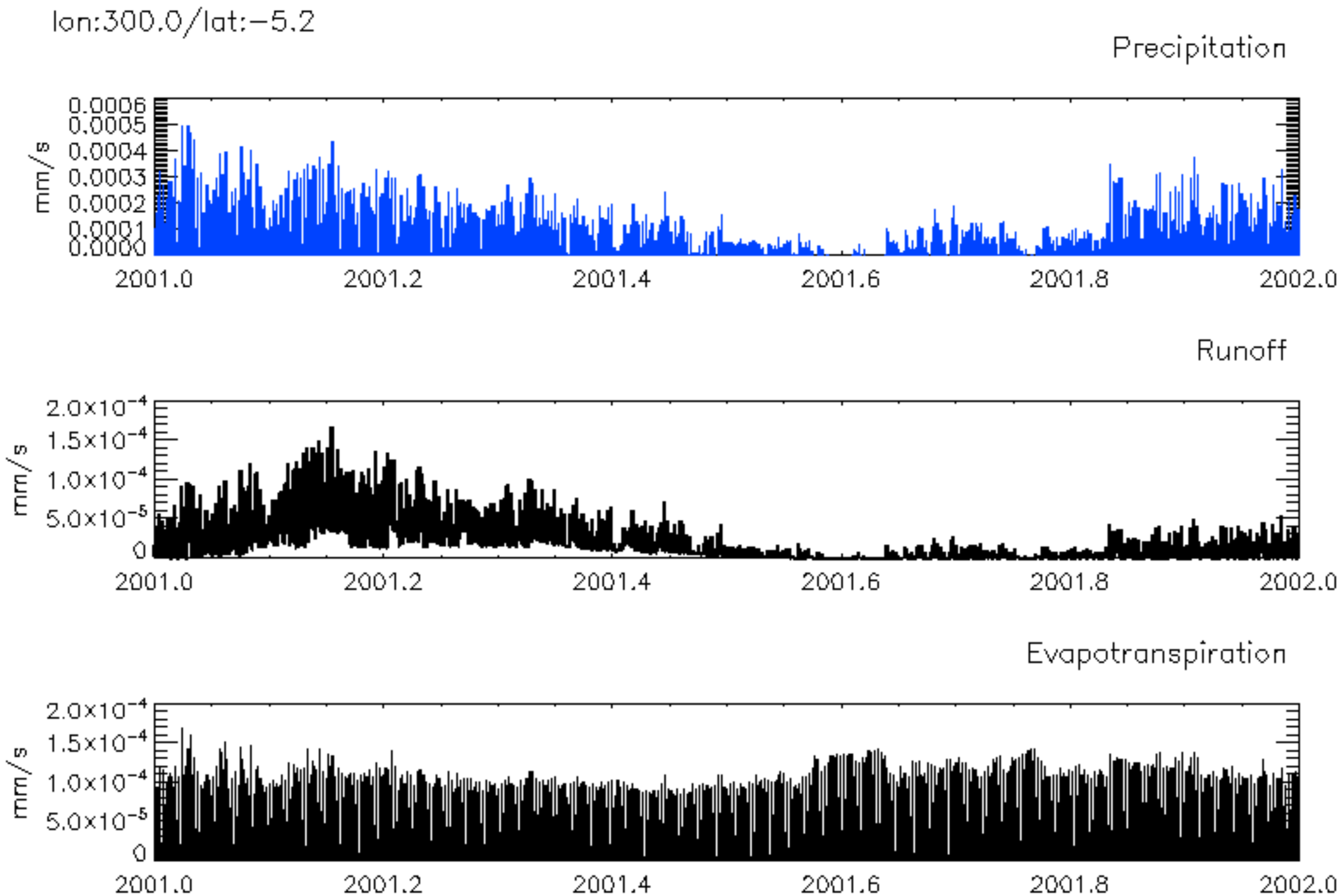
Precipitation
mm/s
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Air Temperature
C
40
30
20
10
0
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0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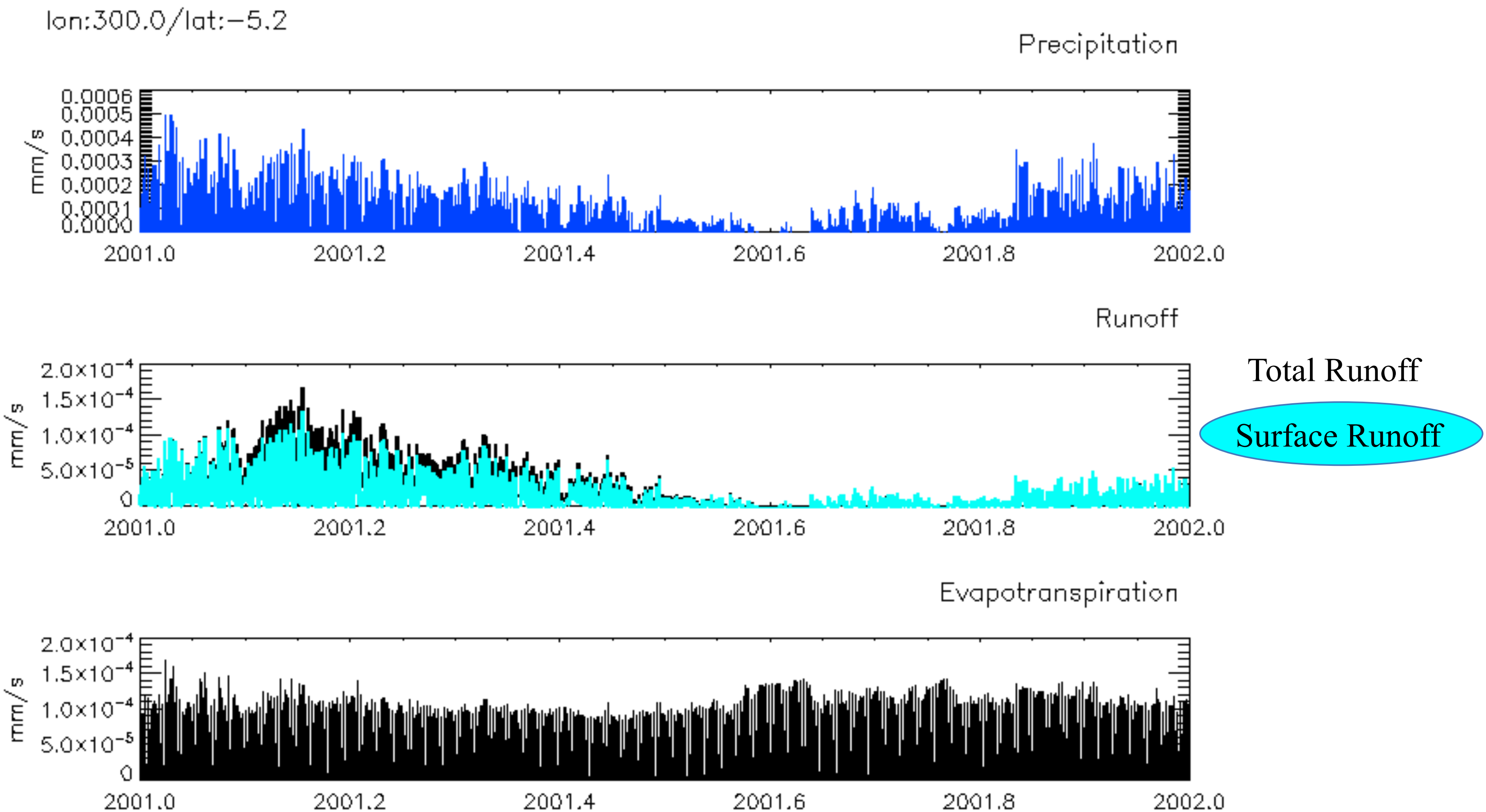
Precipitation
mm/s
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Runoff
mm/s
2.0x10^-4
1.5x10^-4
1.0x10^-4
5.0x10^-5
0
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Evapotranspiration
mm/s
2.0x10^-4
1.5x10^-4
1.0x10^-4
5.0x10^-5
0
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0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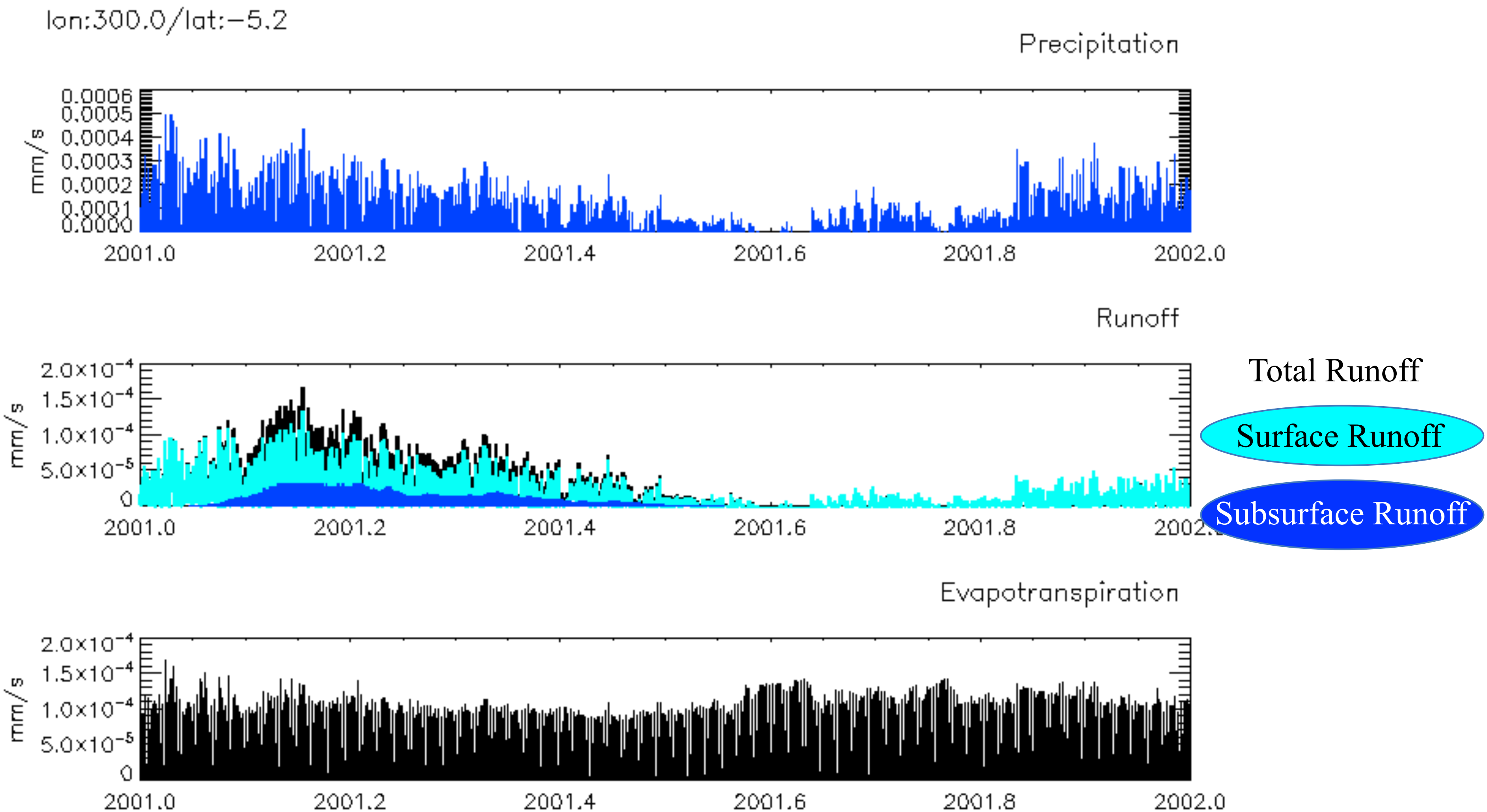
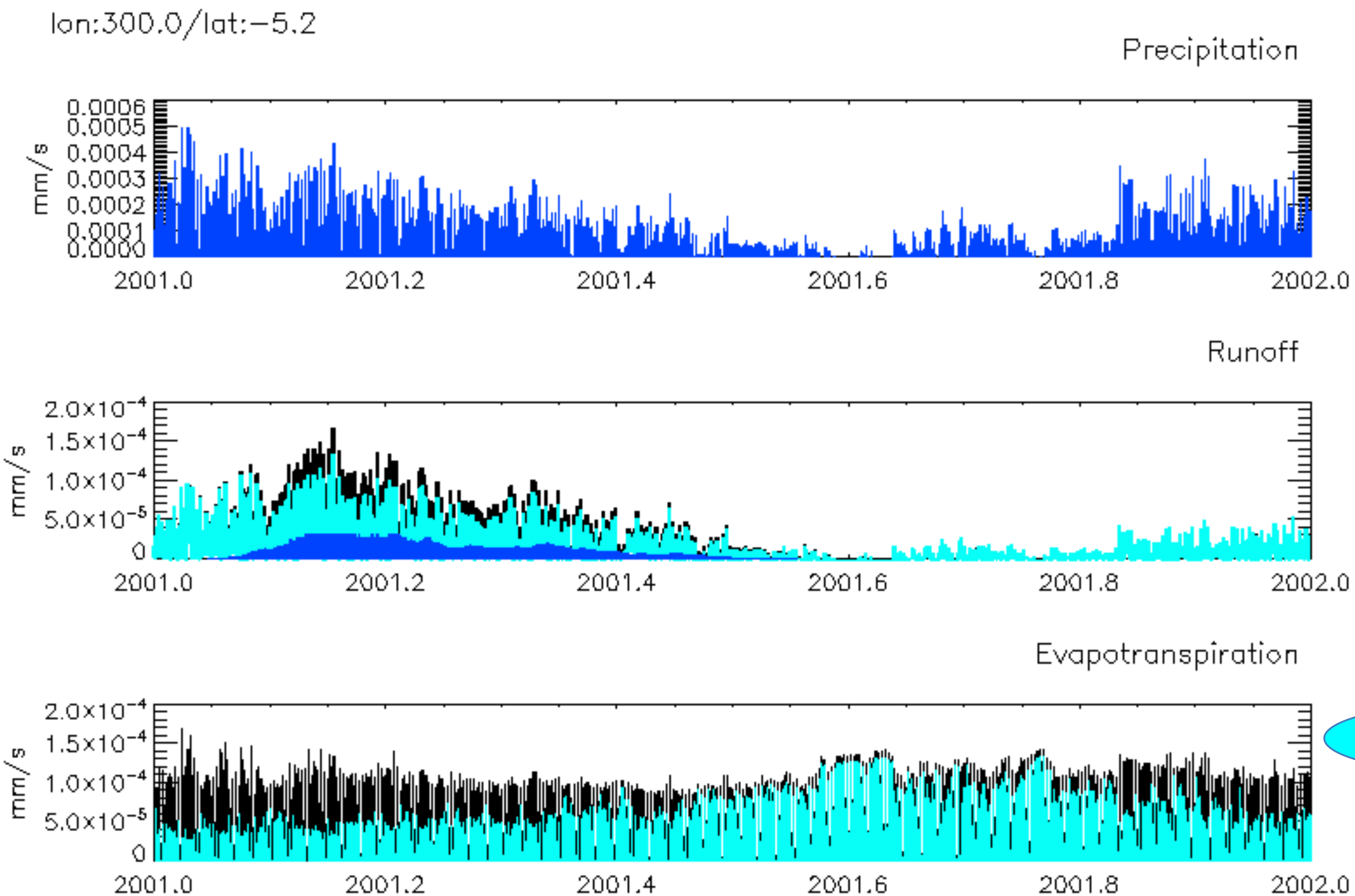
Precipitation
mm/s
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Runoff
mm/s
2.0x10⁻⁴
1.5x10⁻⁴
1.0x10⁻⁴
5.0x10⁻⁵
0
Total Runoff
Surface Runoff
Evapotranspiration
mm/s

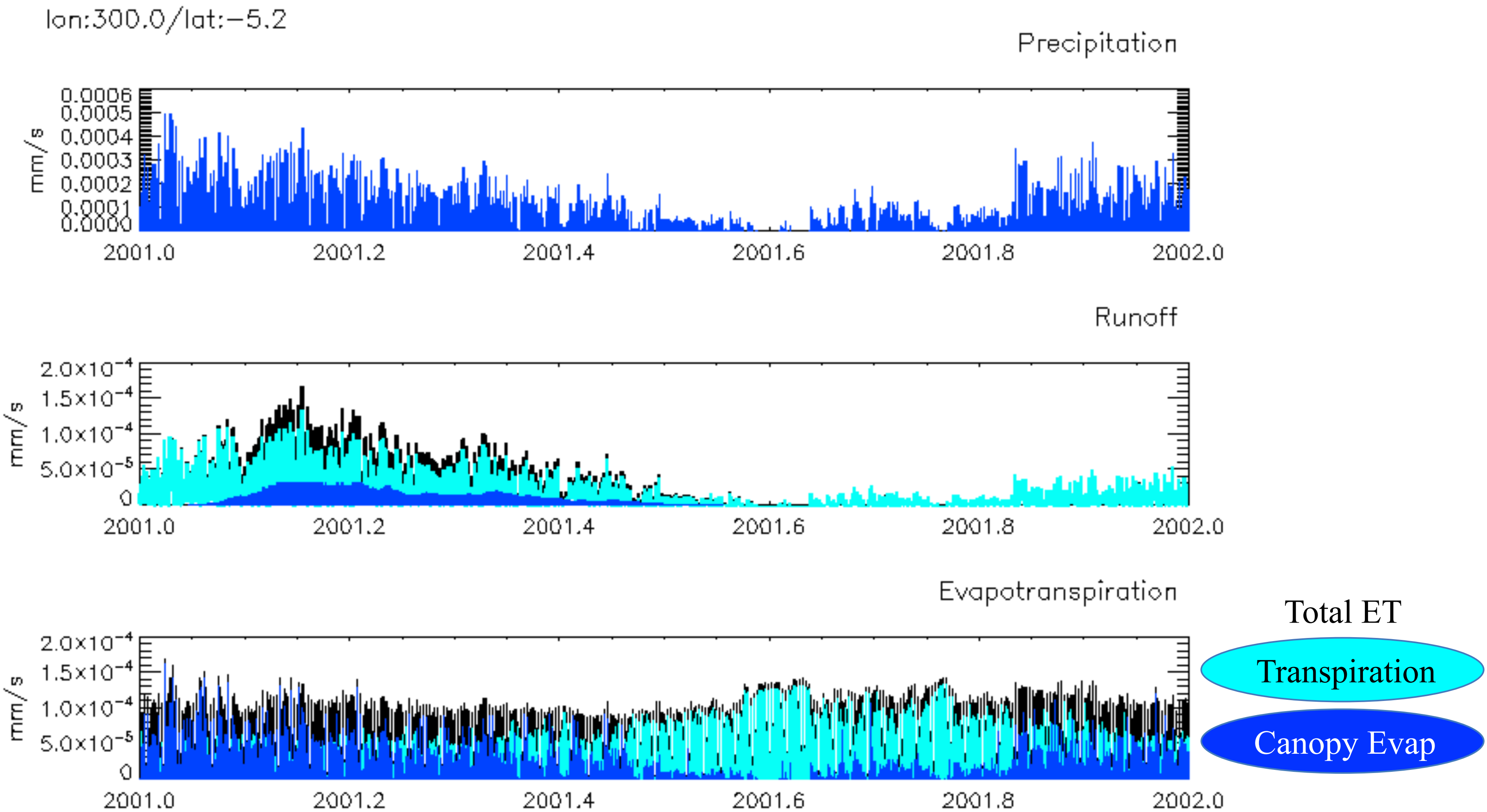


lon:300.0/lat:-5.2
Precipitation
mm/s
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Runoff
Total Runoff
Surface Runoff
Subsurface Runoff
2.0x10⁻⁴
1.5x10⁻⁴
1.0x10⁻⁴
5.0x10⁻⁵
0
Evapotranspiration



Total ET

Transpiration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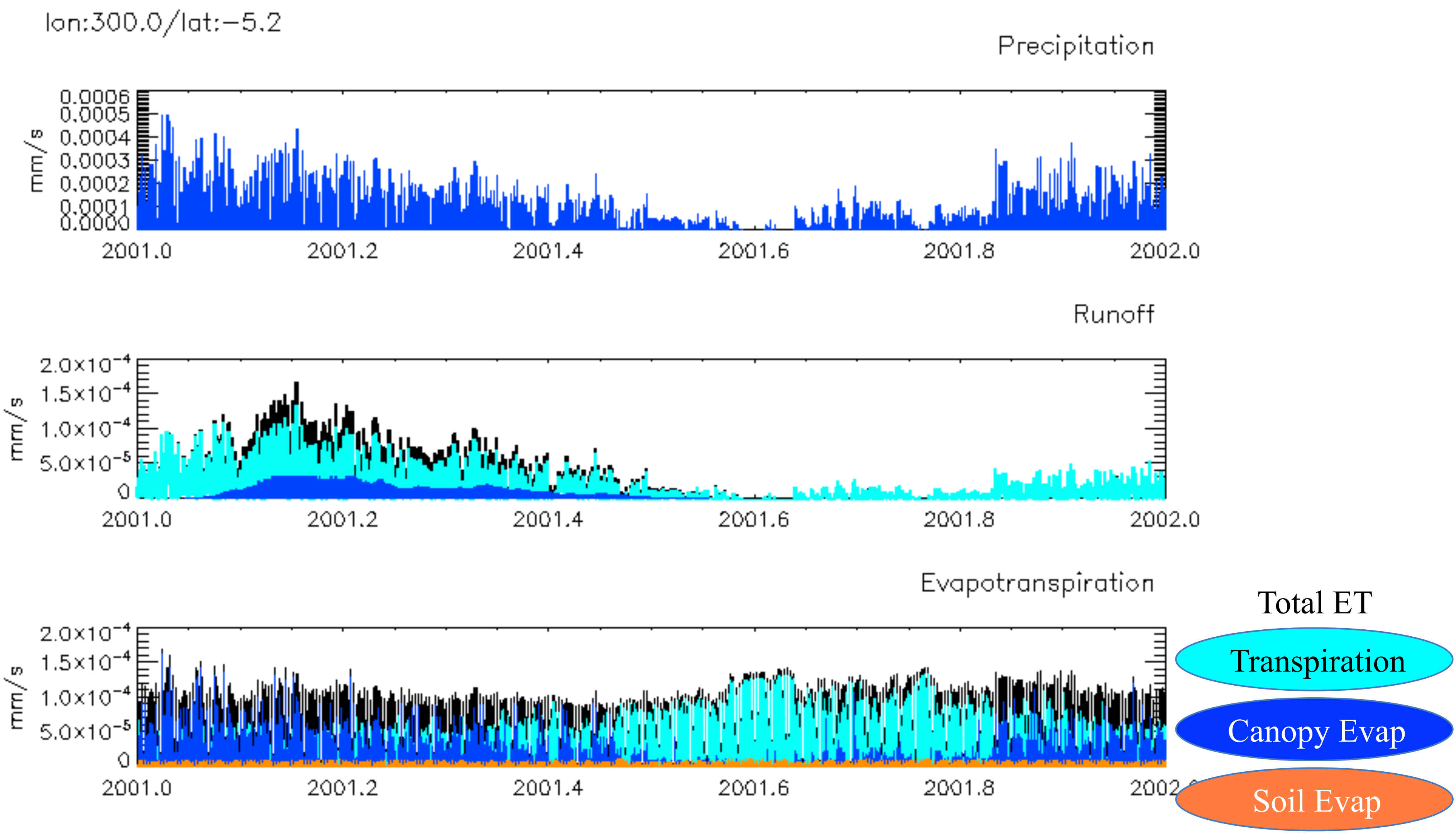
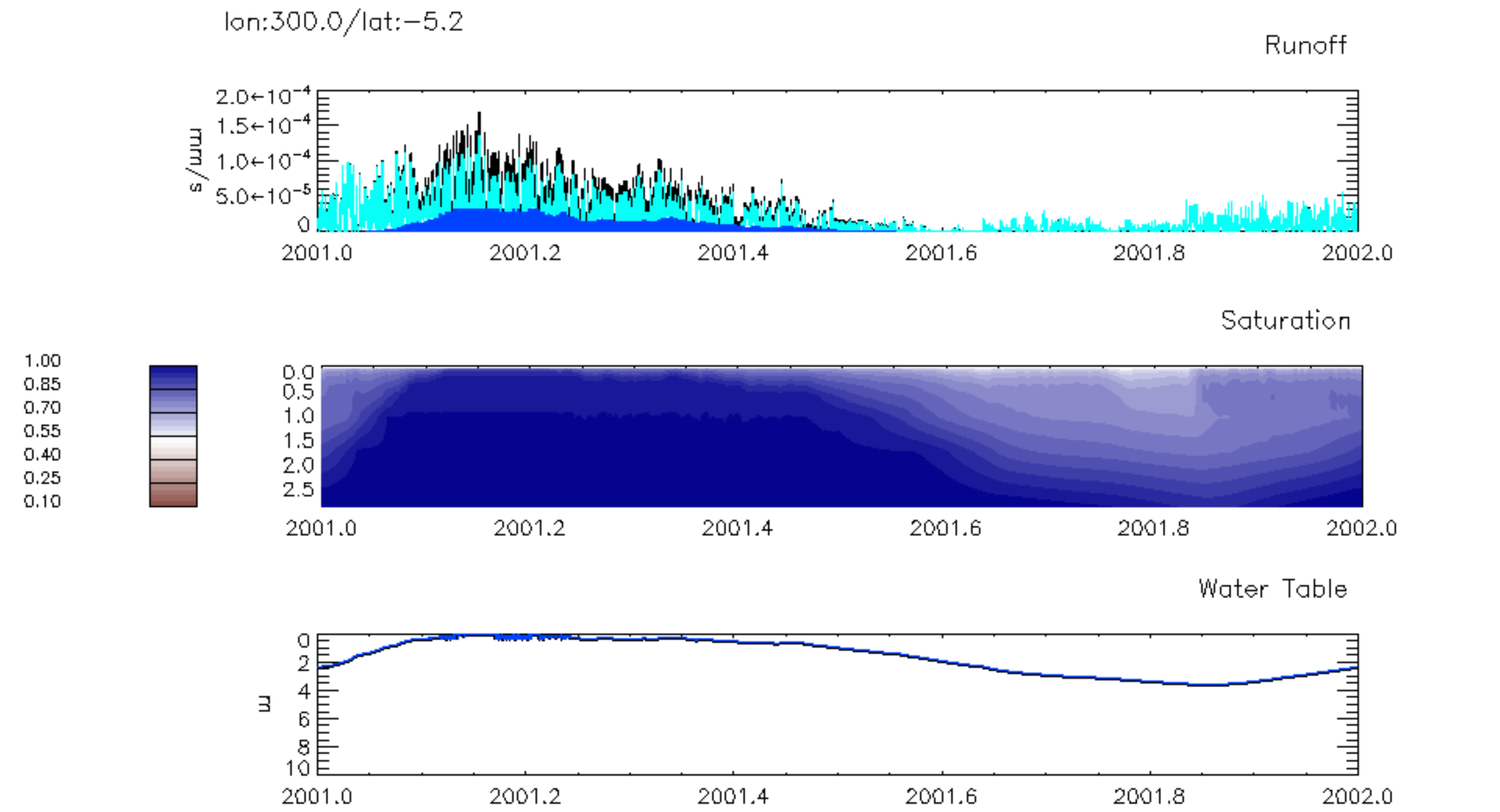
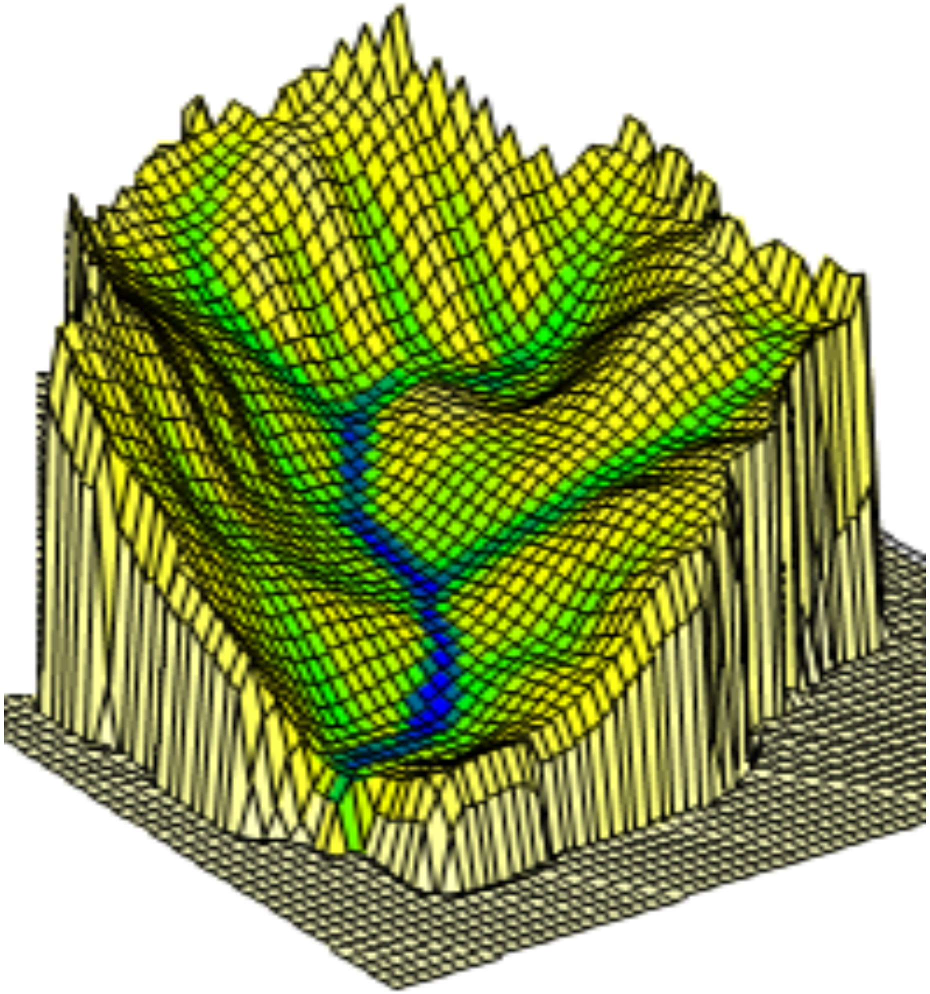
Precipitation
mm/s
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Runoff
mm/s
2.0x10−4
1.5x10−4
1.0x10−4
5.0x10−5
0
Evapotranspiration
Total ET
Transpiration
Canopy Evap



lon:300.0/lat:−5.2
Precipitation
mm/s
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Runoff
mm/s
2.0x10−4
1.5x10−4
1.0x10−4
5.0x10−5
0
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Evapotranspiration
mm/s
2.0x10−4
1.5x10−4
1.0x10−4
5.0x10−5
0
2001.0
2001.2
2001.4
2001.6
2001.8
Total ET
Transpiration
Canopy Evap
Soil Evap



lon:300.0/lat:-5.2
Runoff
mm/s
2.0×10^-4
1.5×10^-4
1.0×10^-4
5.0×10^-5
0
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Saturation
1.00
0.85
0.70
0.55
0.40
0.25
0.10
0.0
0.5
1.0
1.5
2.0
2.5
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Water Table
m
0
2
4
6
8
10
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0



The water table determines the fraction of the area that is saturated

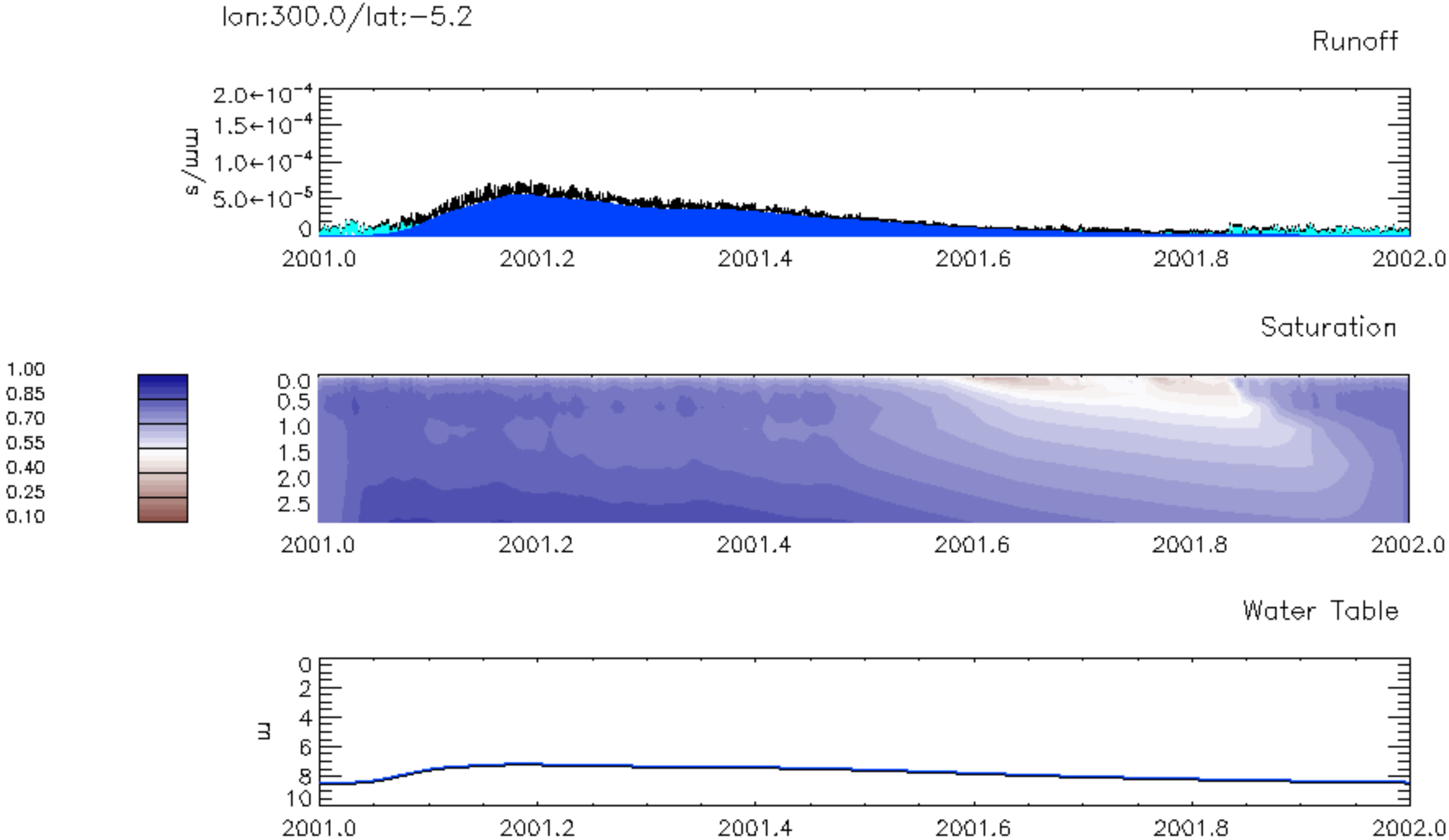
Saturated areas produce surface runoff

Example: Effects of Modifying the Water Table

$$\Delta Z_{WT} = Q_{drainage} - Q_{recharge}$$

$$Q_{drainage} = A \exp(-f\ z)$$

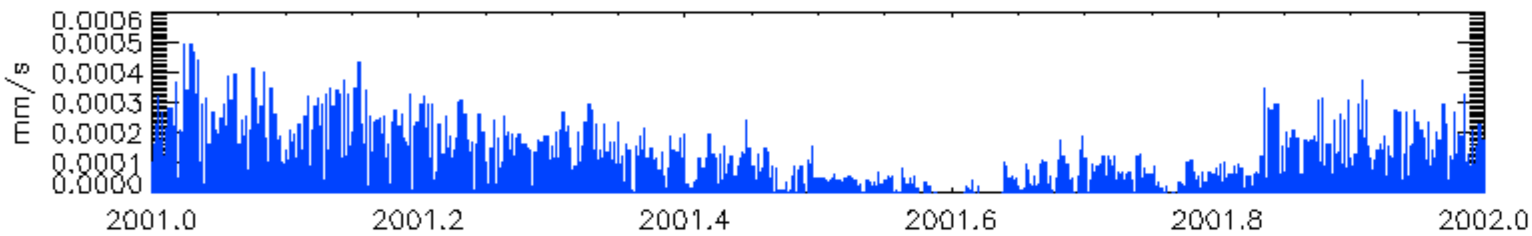
$$Q_{surface} = F \exp(-g\ z)\ {}_{Pthroughfall}$$



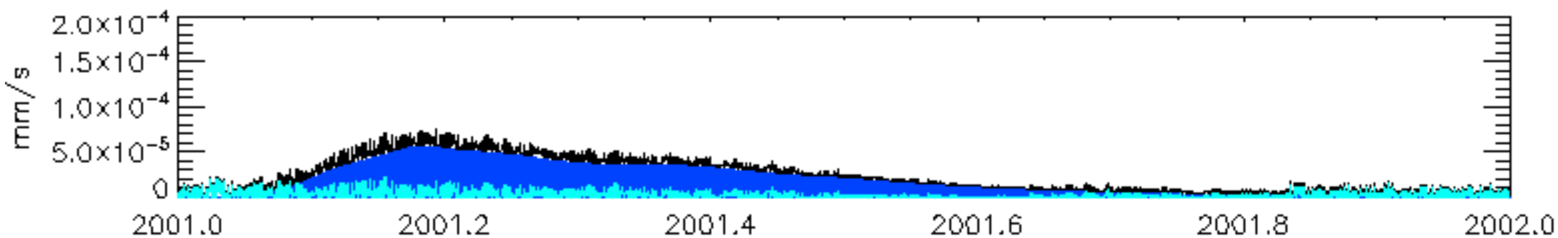
lon:300.0/lat:-5.2
Runoff
mm/s
2.0←10⁻⁴
1.5←10⁻⁴
1.0←10⁻⁴
5.0←10⁻⁵
0
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Saturation
1.00
0.85
0.70
0.55
0.40
0.25
0.10
0.0
0.5
1.0
1.5
2.0
2.5
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0
Water Table
m
0
2
4
6
8
10
2001.0
2001.2
2001.4
2001.6
2001.8
2002.0

lon:300.0/lat:−5.2

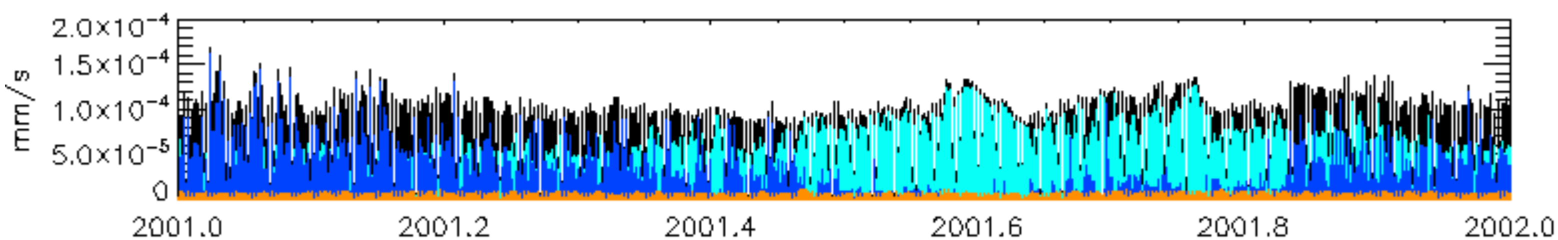
Precipitation



Runoff



Evapotranspiration



Current and Future Challenges

- Subgrid heterogeneity and covariance of vegetation, soil moisture, surface water and snow
- Within-canopy turbulent fluxes
- Human management and withdrawals
- Variable soil depths
- Canopy storage
- Hydrological response to land cover change