



Met Office
Hadley Centre

Surface hydrology

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Soil moisture & temperature

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JULES Science Meeting, 07-08 January 2008

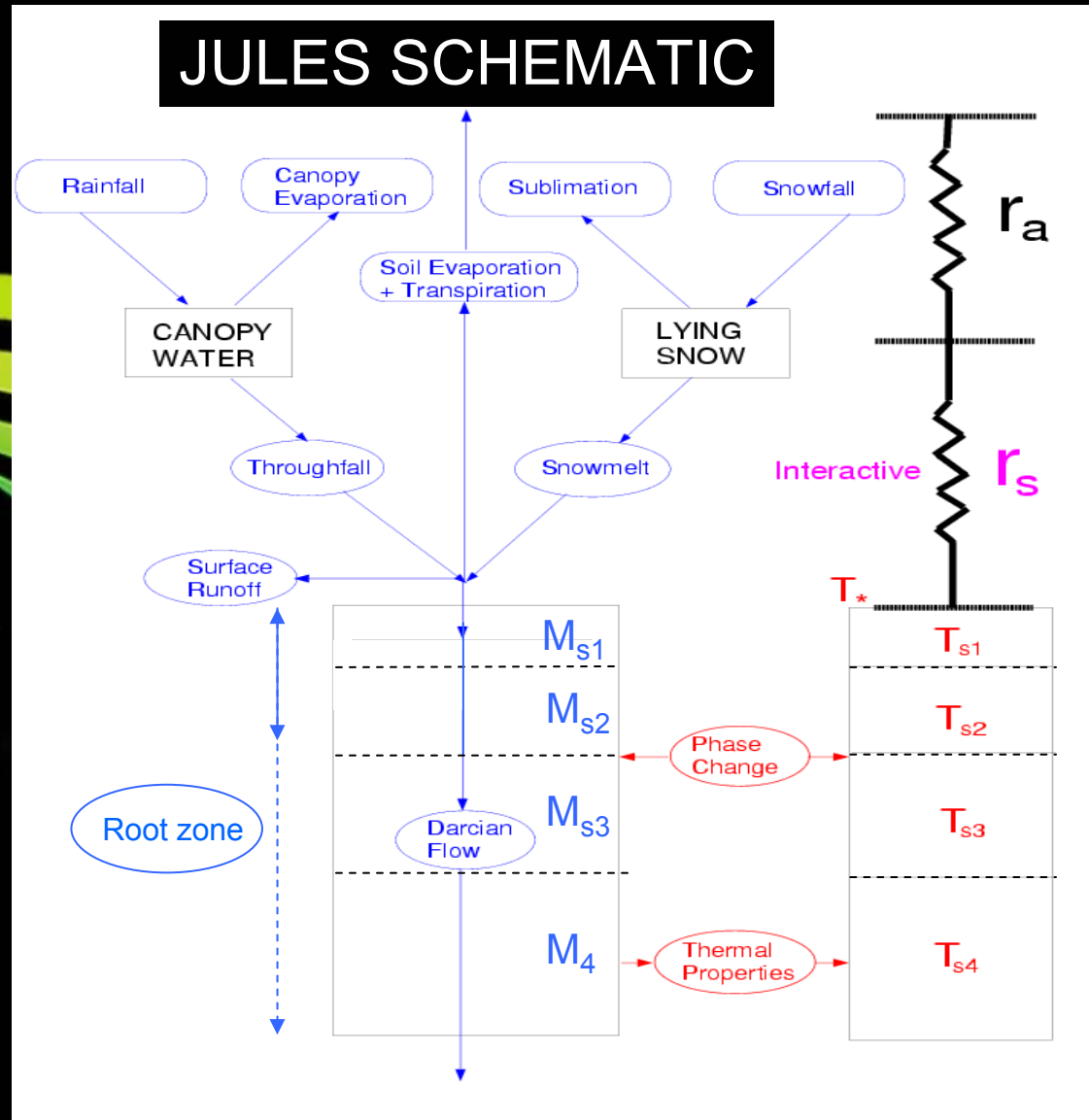
- Overview of JULES current formulation
 - Surface Hydrology
 - Soil Hydrology
 - Soil Hydraulic Parameters
 - Soil thermodynamics
- Current Limitations and Health Warnings
- Recent Developments
- Future Developments

JULES TILE SCHEME

Separate Surface Fluxes and Surface Layers for each Surface Type



- Grid box mean soil:
 - Parameters, T & M
- 4 soil layers
- Same layer depths for T & M



Surface Hydrology

Partitioning of precipitation into:
interception, throughfall, runoff and infiltration

Consider large - scale and convective rainfall and condensation over each tile.

Local water fall rate R_L distribution :

$$f(R_L) = \frac{\varepsilon}{\bar{R}} \exp\left(\frac{-\varepsilon R_L}{\bar{R}}\right)$$

\bar{R} = gridbox mean

ε = fraction of gridbox

R_L falls onto a canopy with tile mean water storage \bar{C} .

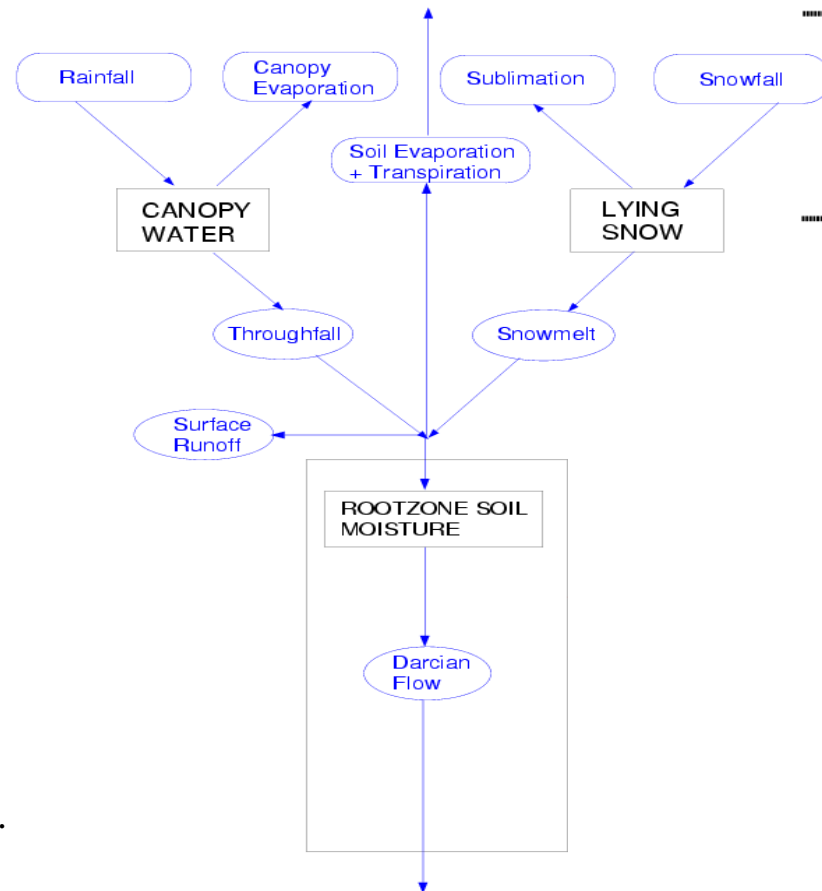
Local canopy water increases up to a maximum C_m .

Integrating gives the tile canopy throughfall :

$$\bar{T}_F = \bar{R} \left(1 - \frac{\bar{C}}{C_m}\right) \exp\left(-\frac{\varepsilon C_m}{\bar{R} \Delta t}\right) + R \frac{\bar{C}}{C_m}$$

$$\bar{C}^{(t+1)} = \bar{C}^{(t)} + (\bar{R} - \bar{T}_F) \Delta t$$

Local surface runoff where $T_F + \text{Snowmelt} >$ surface infiltration rate.



Soil Hydrology

Water fluxes given by Darcy's equation :

$$\frac{\partial M}{\partial t} = K(\theta_u) \left\{ \frac{\partial \Psi(\theta_u)}{\partial z} + 1 \right\}$$

$$M = \Delta z \rho_w (\theta_u + \theta_f)$$

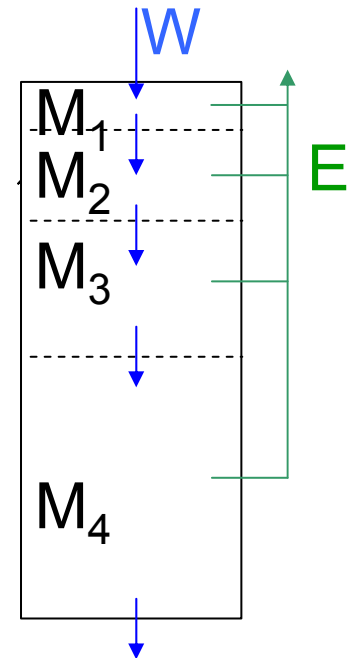
θ = volumetric soil moisture content

K = hydraulic conductivity

Ψ = soil water suction

Change in water content in a layer :

$$\frac{\partial M_n}{\partial t} = W_{n-1} - W_n - E_n$$



M ≠ reality → spinup

Evaporation dependence on soil moisture

Vegetation : soil moisture stress in each layer :

$$\beta_n = \frac{\theta_n - \theta_w}{\theta_c - \theta_w} \quad \text{where } \theta_w \leq \theta_n \leq \theta_c; \quad 0 \leq \beta \leq 1$$

Canopy conductance is dependent on

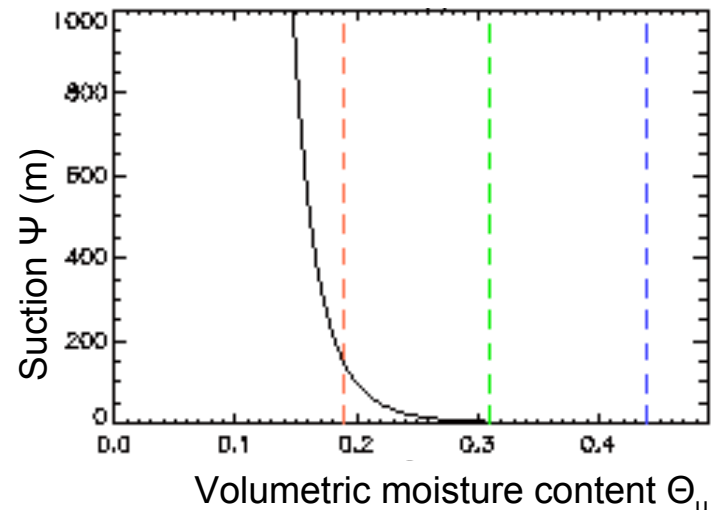
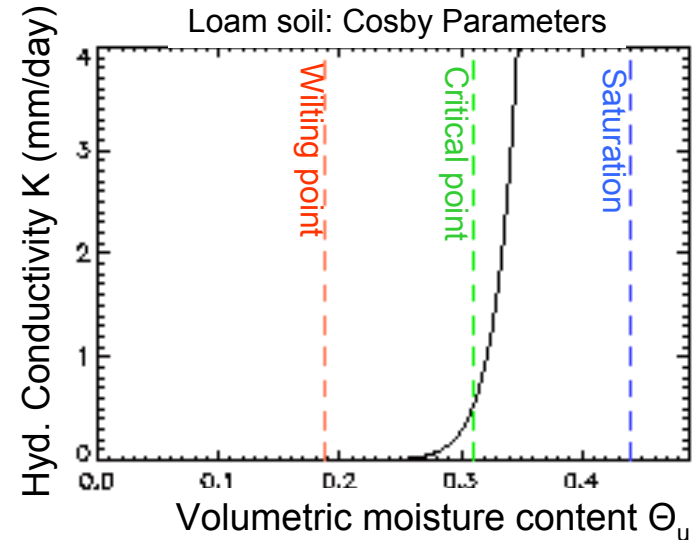
root weighted stress : $g_c \propto \tilde{\beta}$

Soil : conductance, $g_{soil} = \frac{1}{100} \left(\frac{\theta_1}{\theta_c} \right)^2$

Soil hydraulic fluxes highly non - linear :

$$K = K_{sat} \left(\frac{\theta}{\theta_s} \right)^{2B+3} \quad (\text{Clapp - Hornberger/Cosby params})$$

$\Rightarrow E, T_*$ etc dependent on soil properties



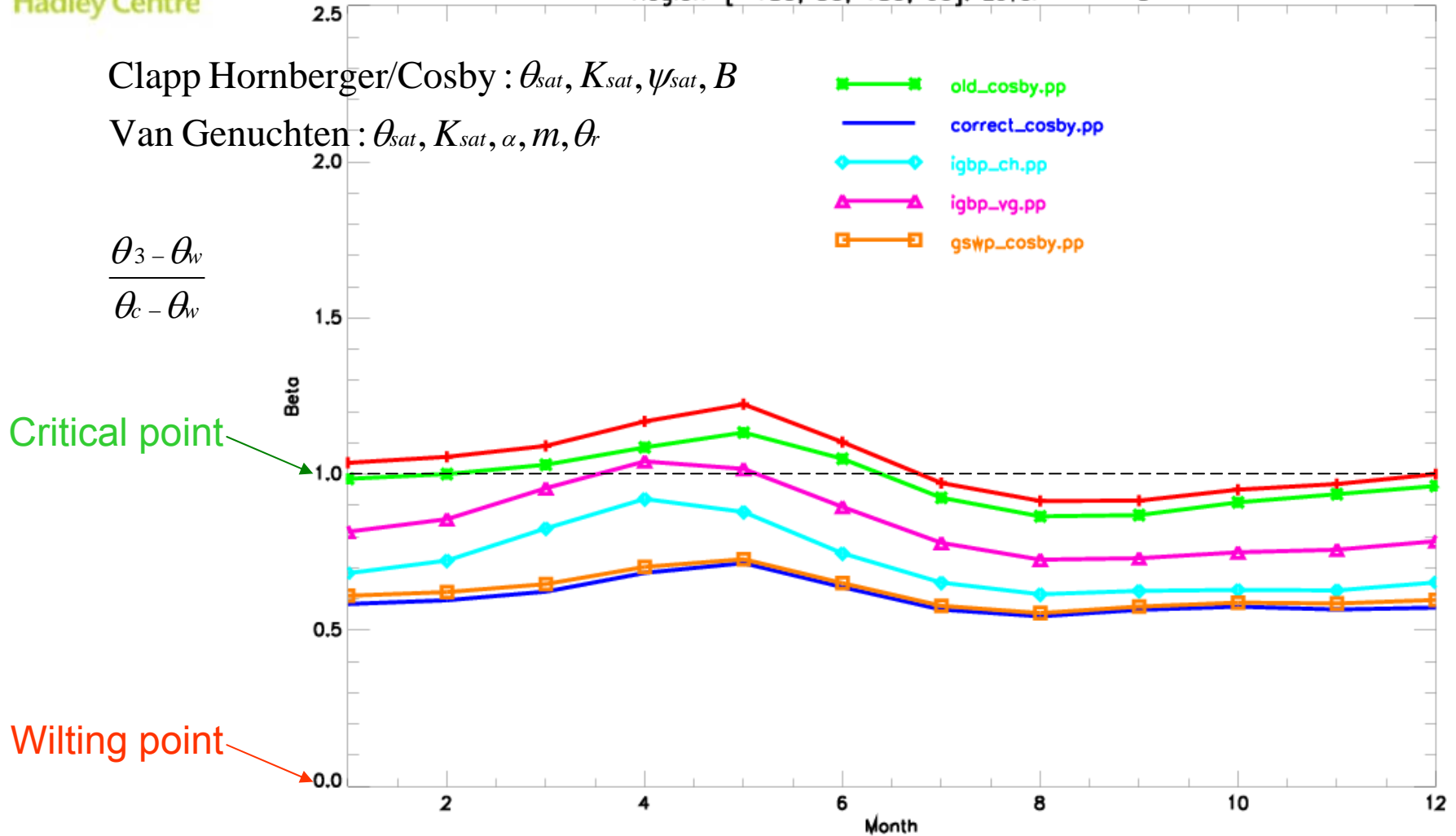
Effect of different soil property datasets on moisture stress: Northern mid latitudes

Region=[-180, 30, 180, 60]. Level= 3

Clapp Hornberger/Cosby : $\theta_{sat}, K_{sat}, \psi_{sat}, B$

Van Genuchten : $\theta_{sat}, K_{sat}, \alpha, m, \theta_r$

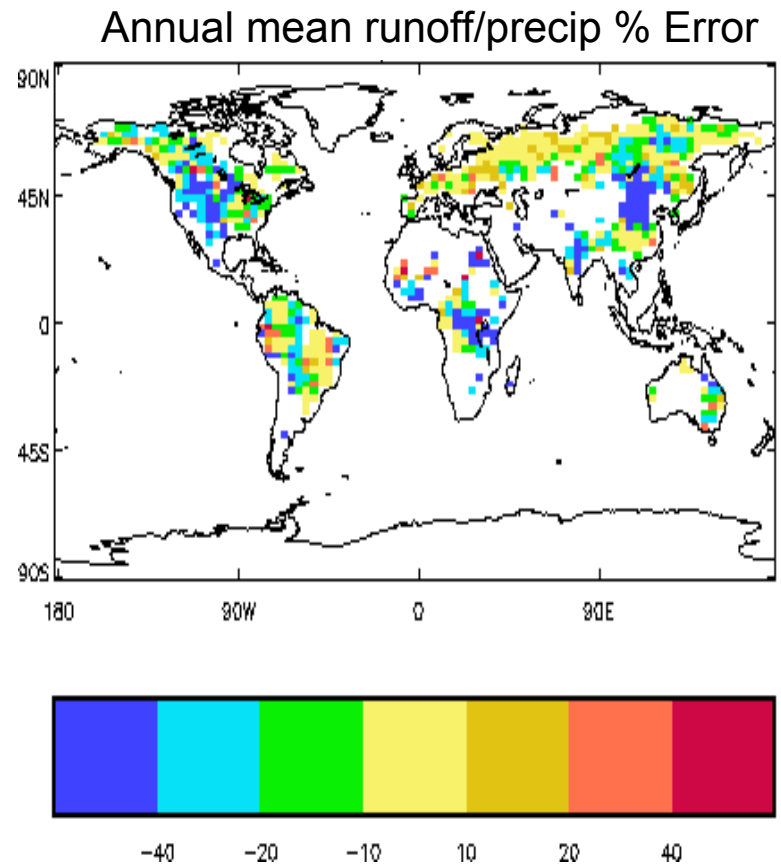
$$\frac{\theta_3 - \theta_w}{\theta_c - \theta_w}$$



Intiaz Dharssi (2007)

Runoff

- Surface runoff if locally:
throughfall + snowmelt > surface
infiltration rate (βK_{sat}).
- Deep runoff: free drainage ($K(\theta_u)$).
- JULES: deep runoff >> surface
runoff
due to use of gridbox mean soil
moisture & properties





Soil Thermodynamics

Discretised heat diffusion equation :

$$C_A \Delta z_n \frac{\partial T_n}{\partial t} = G_{n-1} - G_n - J_n \Delta z_n$$

diffusive flux : $G = \lambda_s \frac{\partial T}{\partial z}$ advective flux : $J = c_w W \frac{\partial T}{\partial z}$

Apparent vol heat capacity : $C_A = F_n(\theta_u, \theta_f, T)$

Thermal conductivity : $\lambda_s = \{ \lambda_{sat} - \lambda_{dry} \} \frac{\theta}{\theta_{sat}} + \lambda_{dry}$ (Farouki, 1981)

$\lambda_{sat}, \lambda_{dry}$ are functions of minerals, air, water and ice λ .

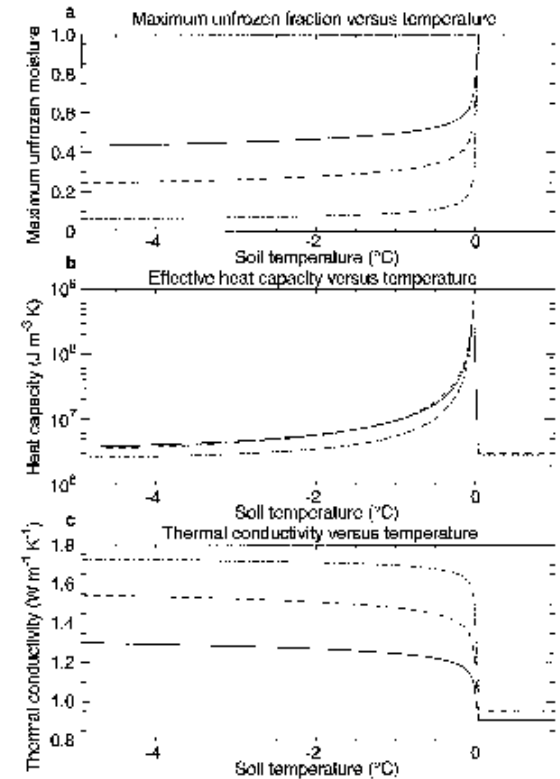
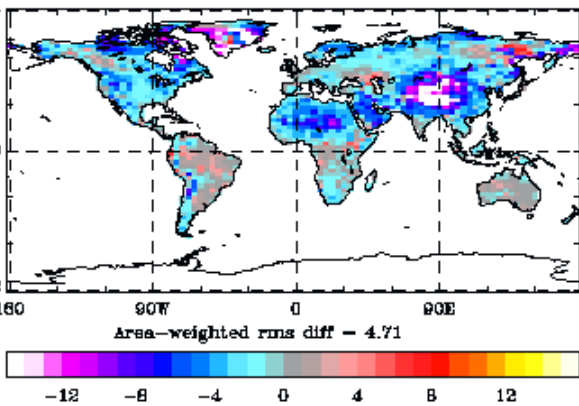
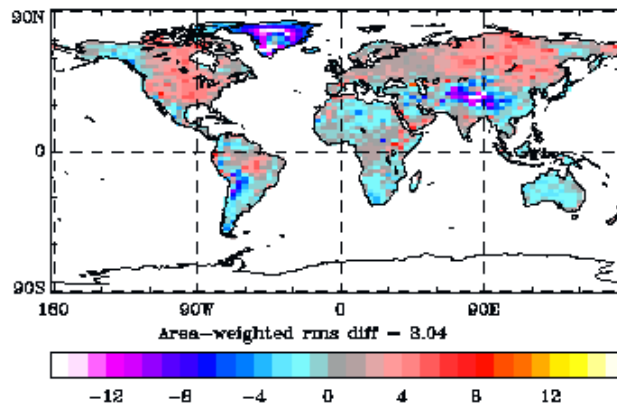


Fig. 3 a Maximum unfrozen soil moisture as a fraction of saturation, b effective heat capacity and c thermal conductivity versus soil temperature for the three soil textures used in MOSES: fine (cont. line), medium (dashed line) and coarse (dot-dash line).

c) 1.5m temperature for dif
AGBXT: Control minus Legates and Wilmot



c) 1.5m temperature for jja
AGBXT: Control minus Legates and Wilmot



HadGEM3 simulation

Current Limitations and Health Warnings

- Gridbox mean soil moisture and temperature
- → Runoff errors
- Parameter uncertainty
- Soil moisture \neq observations
- → spinup required (> 5years??)
- Soil layer thickness



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Recent Developments

Including sub-grid scale soil moisture heterogeneity

- PDM

- PDF of soil moisture storage capacity (Moore, 1985)

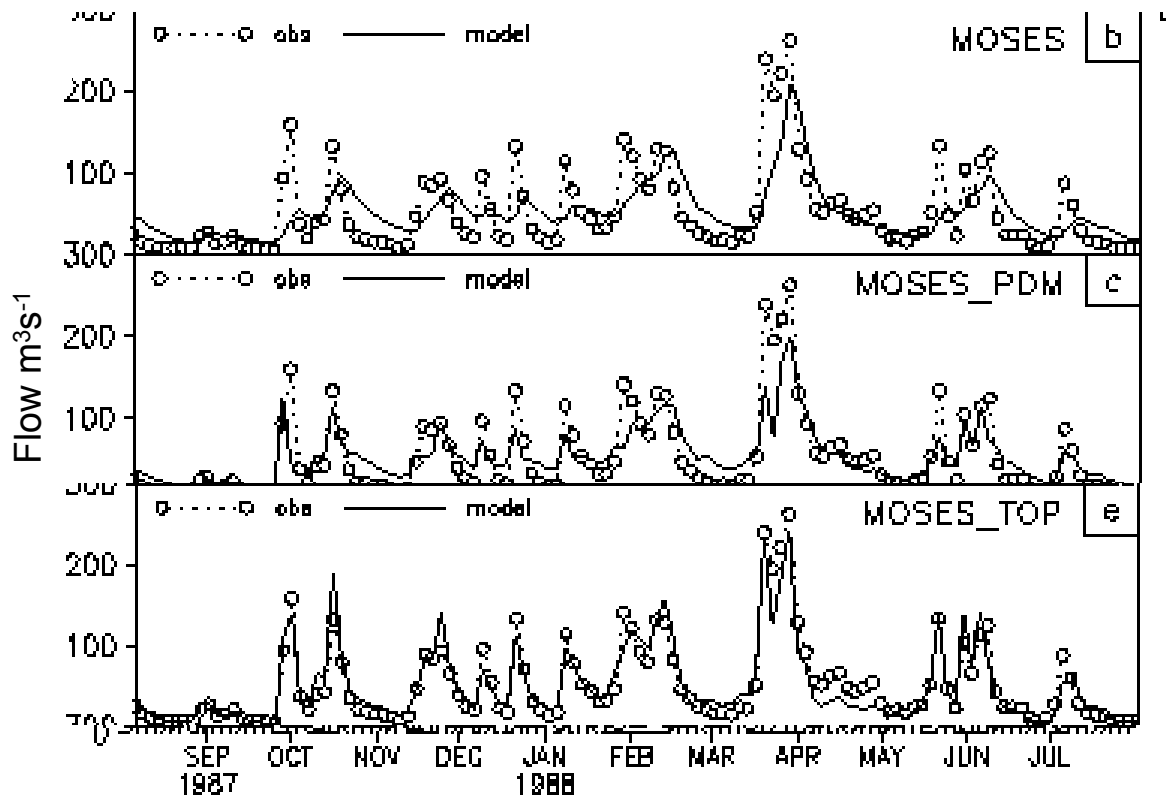
- TOPMODEL

- PDF of topographic index; Baseflow (Bevin & Kirkby, 1979)

- Issues

- Estimating parameter values
- Appropriate scales

3-day average streamflow for the
Ain Catchment (Rhône Basin)

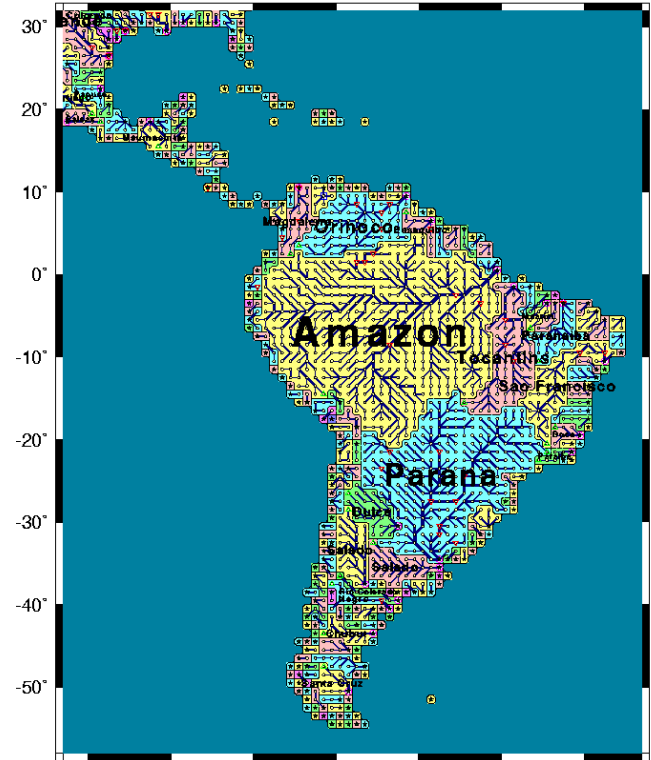


Clark & Gedney (in press)

River Routing

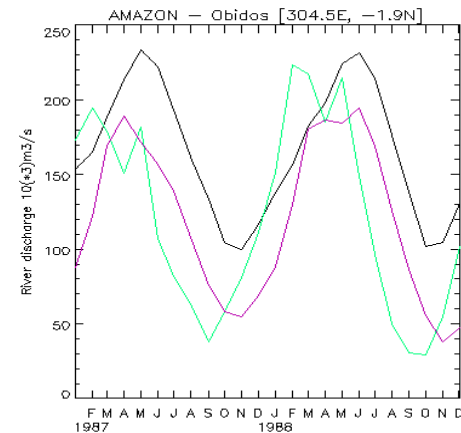
- TRIP
 - Global 1° resolution
- Grid2Grid:
 - UK 1km resolution
 - Europe 20km resolution

Rivers in South America on TRIP in 1°x1° mesh



[Version 970522 by Taikan Okij]

OBSERVATIONS and ROUTED and UNROUTED RIVER DISCHARGE

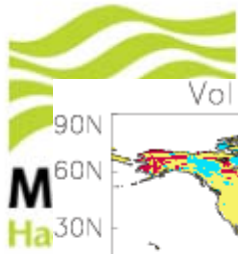


— GRDC Obs. — Routed IGBP
— unrouted IGBP

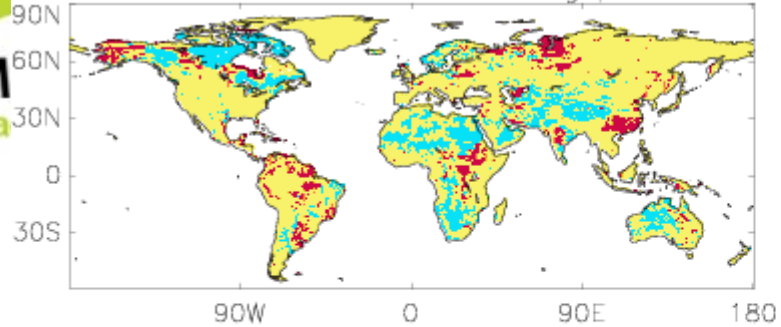


Future Developments

- Irrigation
- Groundwater
- Dams



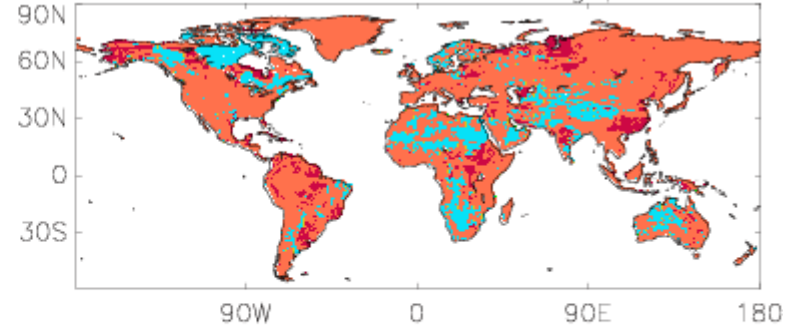
Vol soil moisture at wilting point



UM Cosby uncorrected: soil_ancil_vector.txt



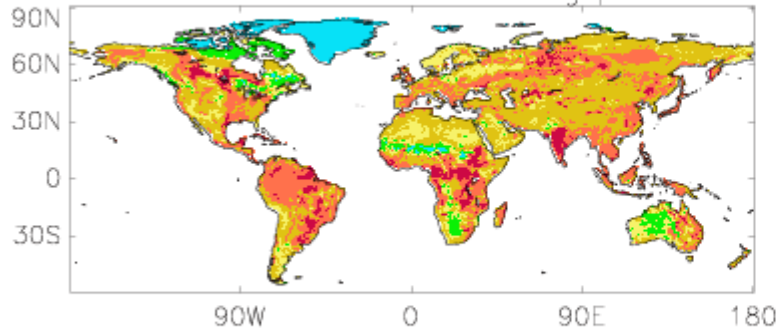
Vol soil moisture at wilting point



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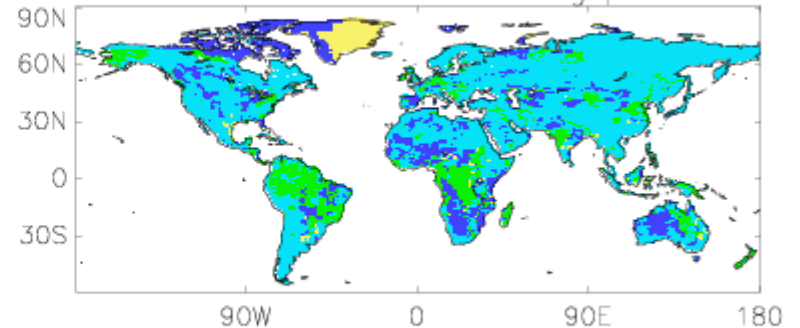
Vol soil moisture at wilting point



GSWP Cosby: soil_vector_gswp.txt

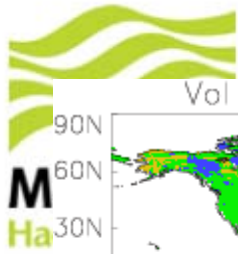


Vol soil moisture at wilting point

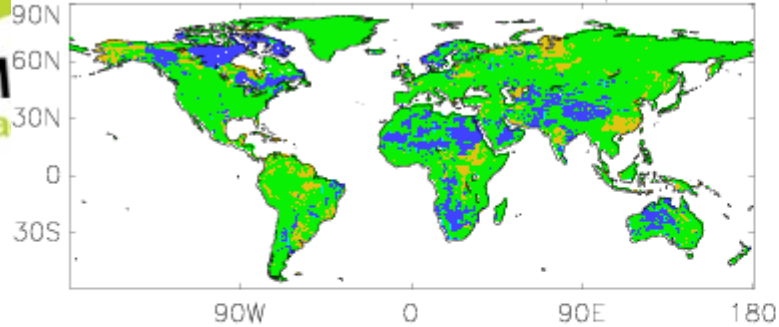


UM Van Genuchten: soil_ancil_vector_vg.txt





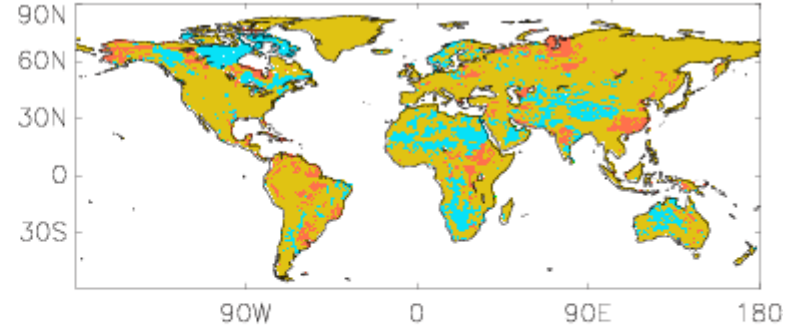
Vol soil moisture at critical point



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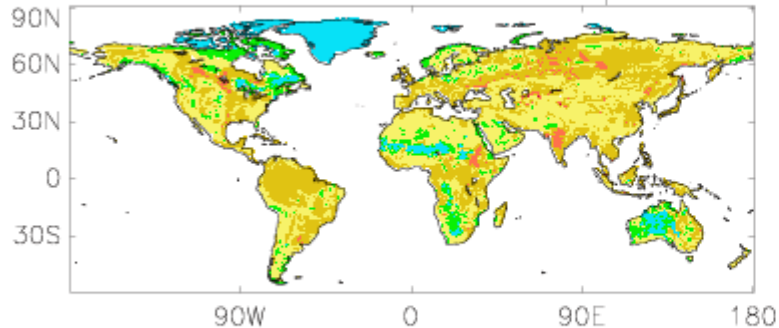
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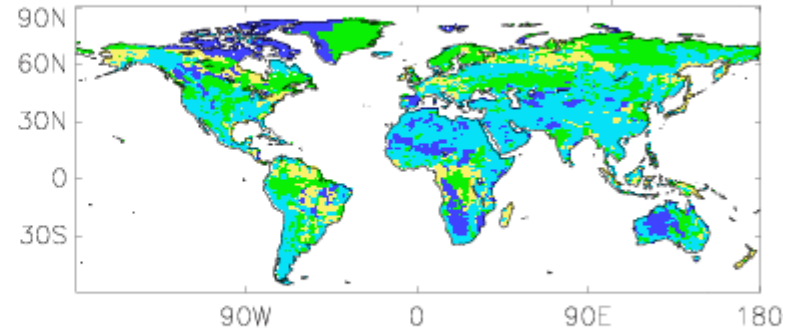
Vol soil moisture at critical point



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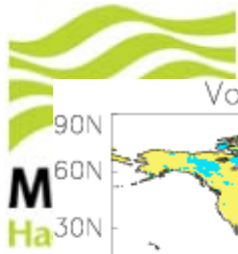


Vol soil moisture at critical point

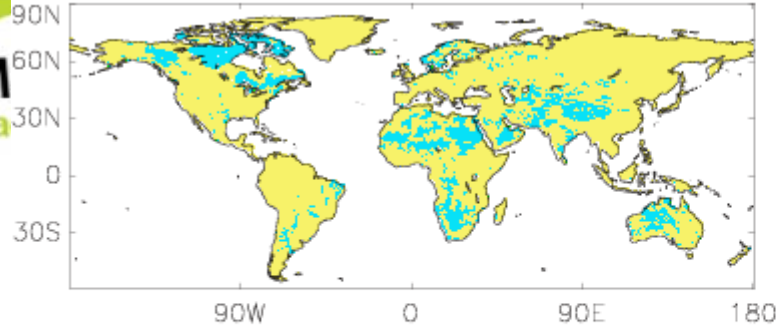


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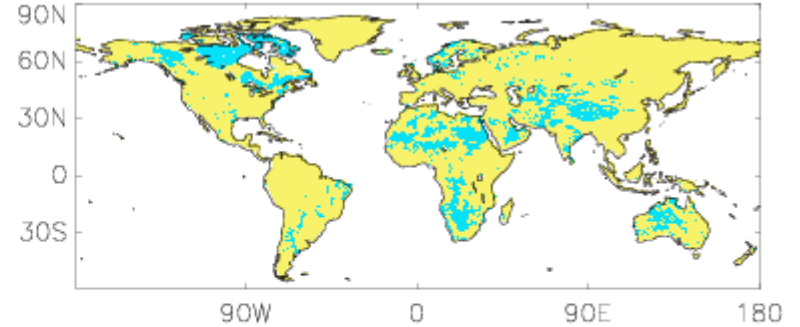
Vol soil moisture at saturation



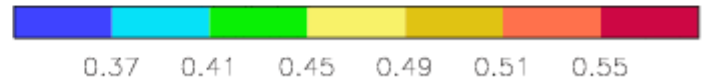
UM Cosby uncorrected: soil_ancil_vector.txt



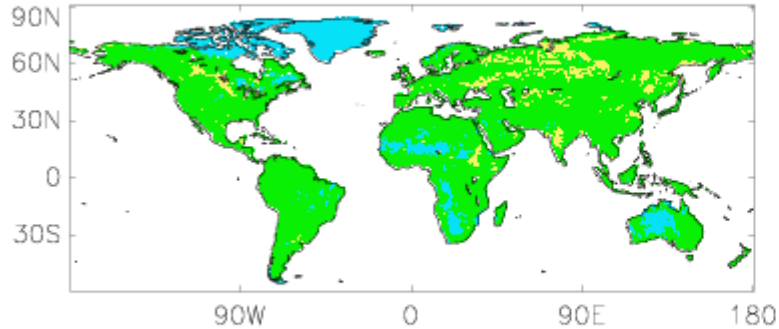
Vol soil moisture at saturation



UM Cosby: soil_ancil_correct.txt



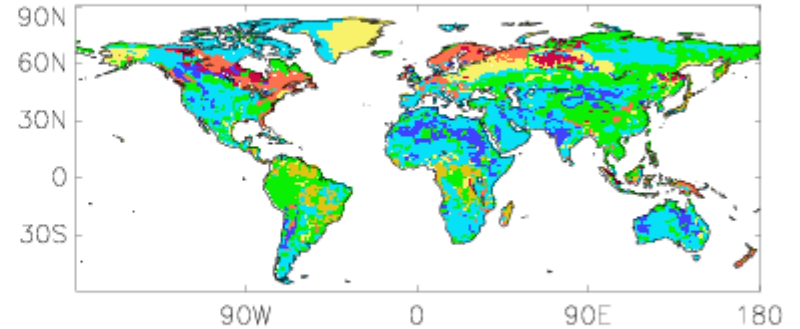
Vol soil moisture at saturation



GSWP Cosby: soil_vector_gswp.txt



Vol soil moisture at saturation



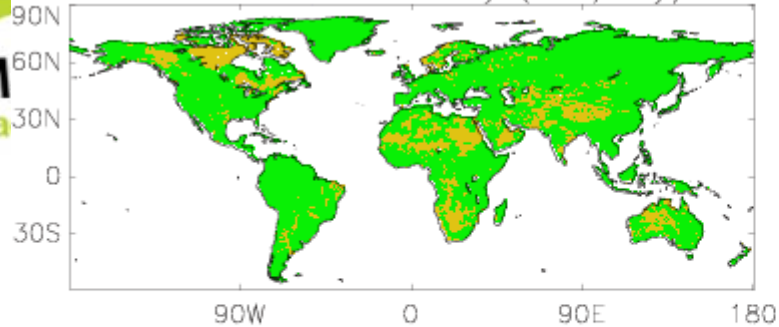
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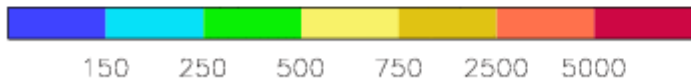


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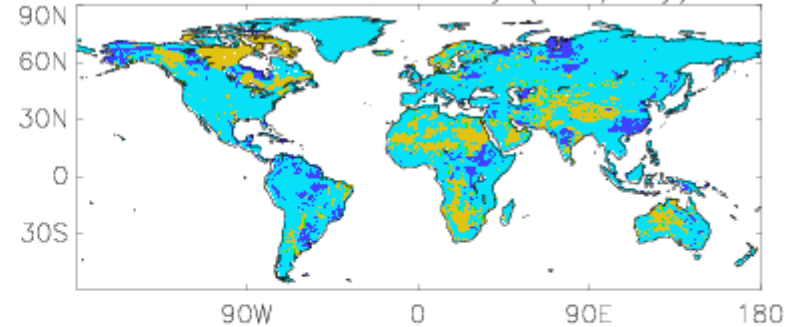
Saturated Conductivity (mm/day)



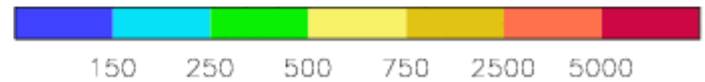
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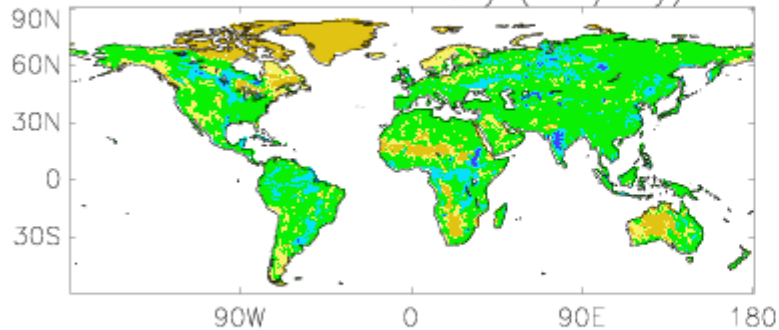
Saturated Conductivity (mm/day)



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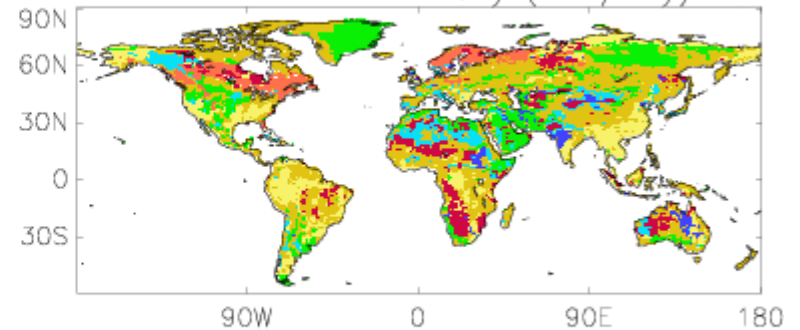
Saturated Conductivity (mm/day)



GSWP Cosby: soil_vector_gswp.txt



Saturated Conductivity (mm/day)



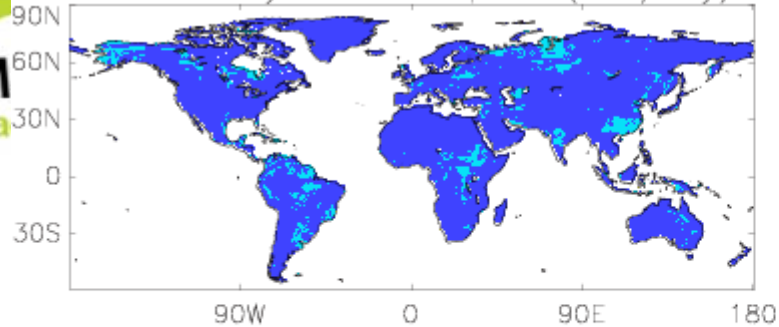
UM Van Genuchten: soil_ancil_vector_vg.txt





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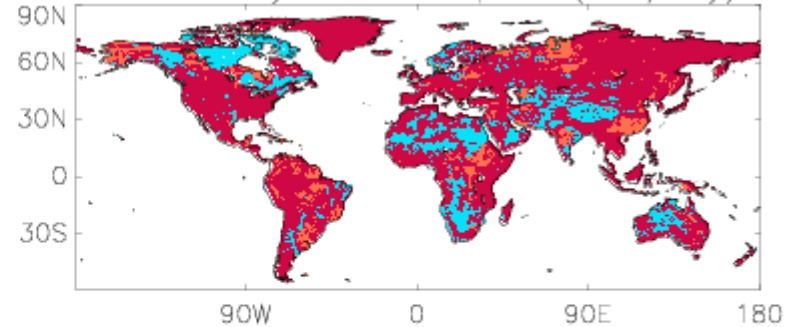
Conductivity at critical point (mm/day)



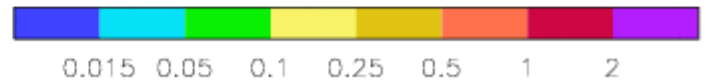
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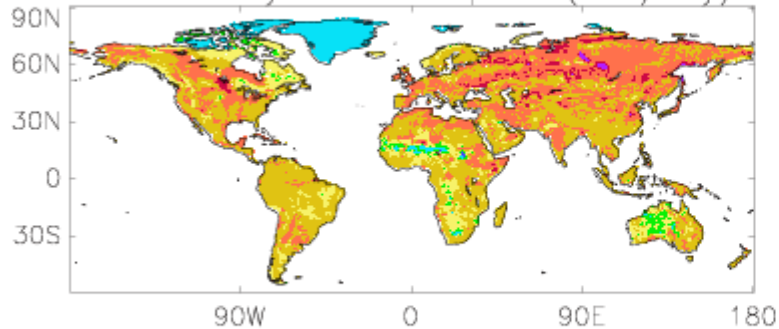
Conductivity at critical point (mm/day)



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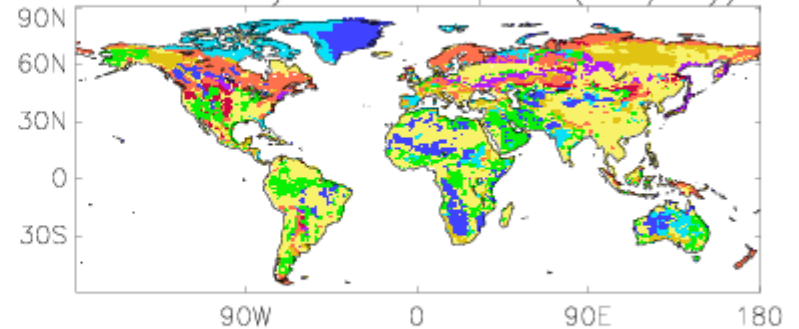
Conductivity at critical point (mm/day)



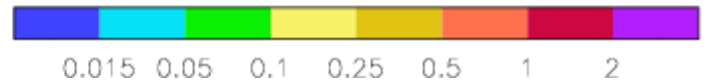
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Conductivity at critical point (mm/day)



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Impact of Improved Large-scale Hydrology on Simulation of Annual mean Runoff/Precipitation ratio

ratio
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