Surface hydrology

Eleanor Blythe (CEH)

Soil moisture & temperature

Nic Gedney (Met Office)

JULES Science Meeting, 07-08 January 2008

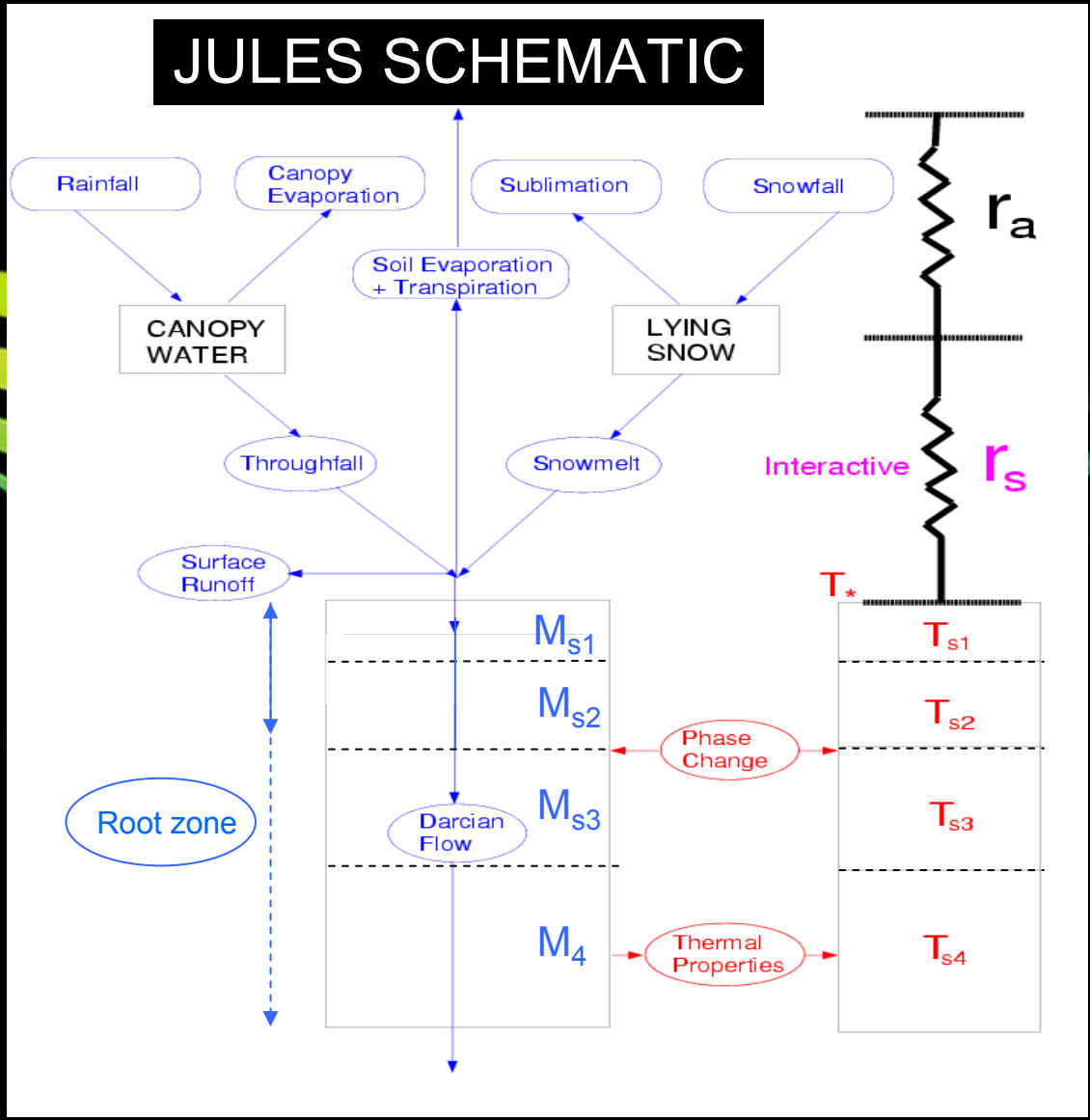
- Overview of JULES current formulation
  - Surface Hydrology
  - Soil Hydrology
  - Soil Hydraulic Parameters
  - Soil thermodynamics
- Current Limitations and Health Warnings
- Recent Developments
- Future Developments

JULES TILE SCHEME

Separate Surface Fluxes and Surface Layers for each Surface Type

Met Office
Hadley Centre

- 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 :

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

$\overline{R}$ = gridbox mean

ε = fraction of gridbox

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

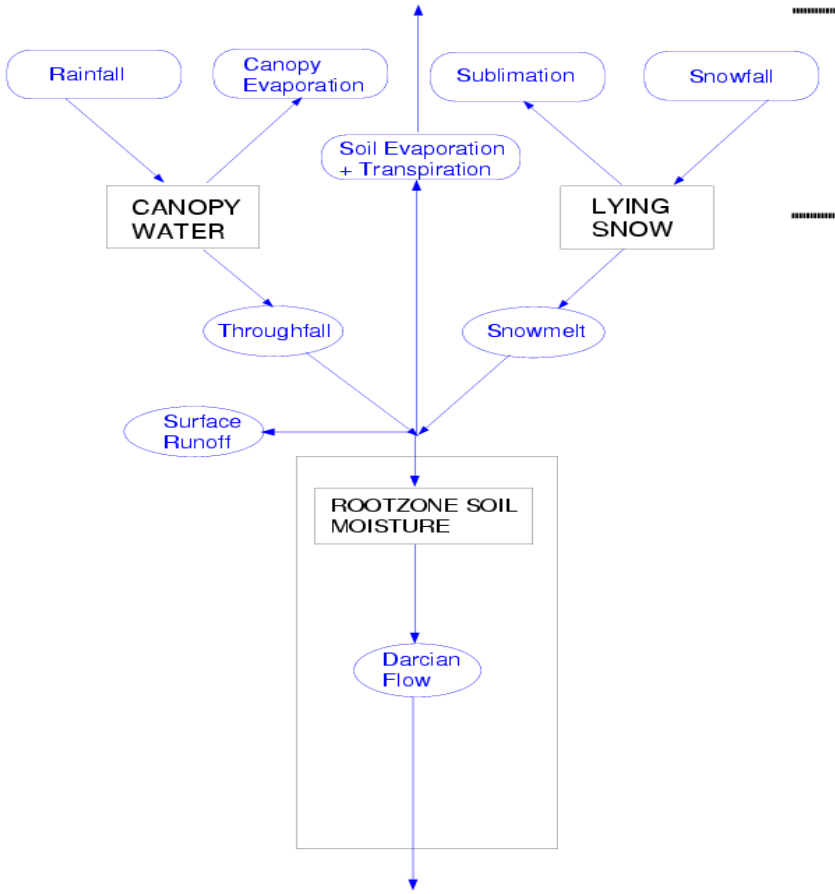
Local canopy water increases up to a maximum C_m.

Integrating gives the tile canopy throughfall :

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

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

Local surface runoff where T_F + Snowmelt > surface infiltration rate.



Soil Hydrology

Water fluxes given by Darcy's equation :

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

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

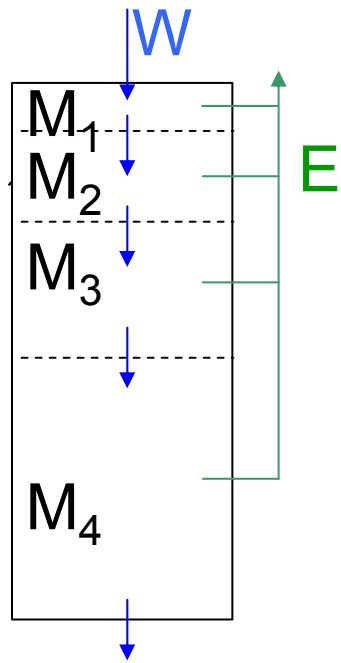
θ = volumetric soil moisture content

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 :

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

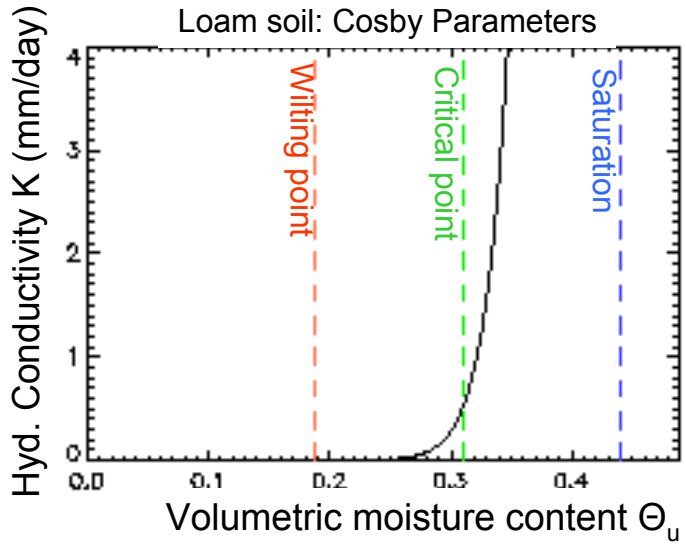
Canopy conductance is dependent on root weighted stress : $g_c \propto \tilde{\beta}$

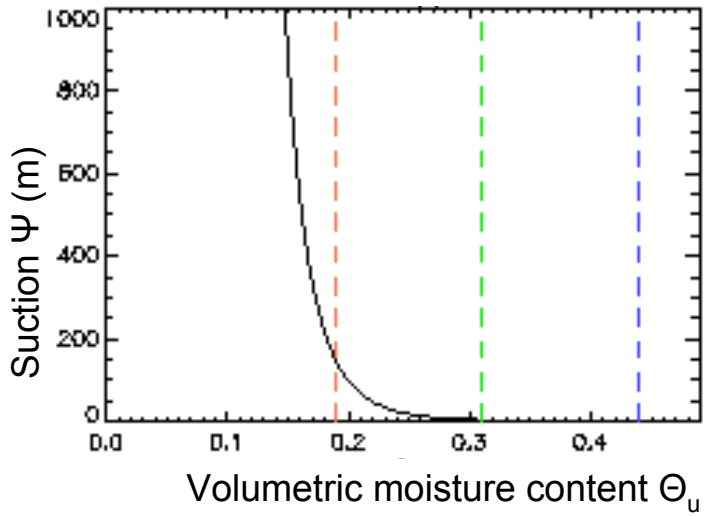
Soil : conductance, $g_{soil} = \frac{1}{100}\left(\frac{\theta_1}{\theta_c}\right)^2$

Soil hydraulic fluxes highly non - linear :

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

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



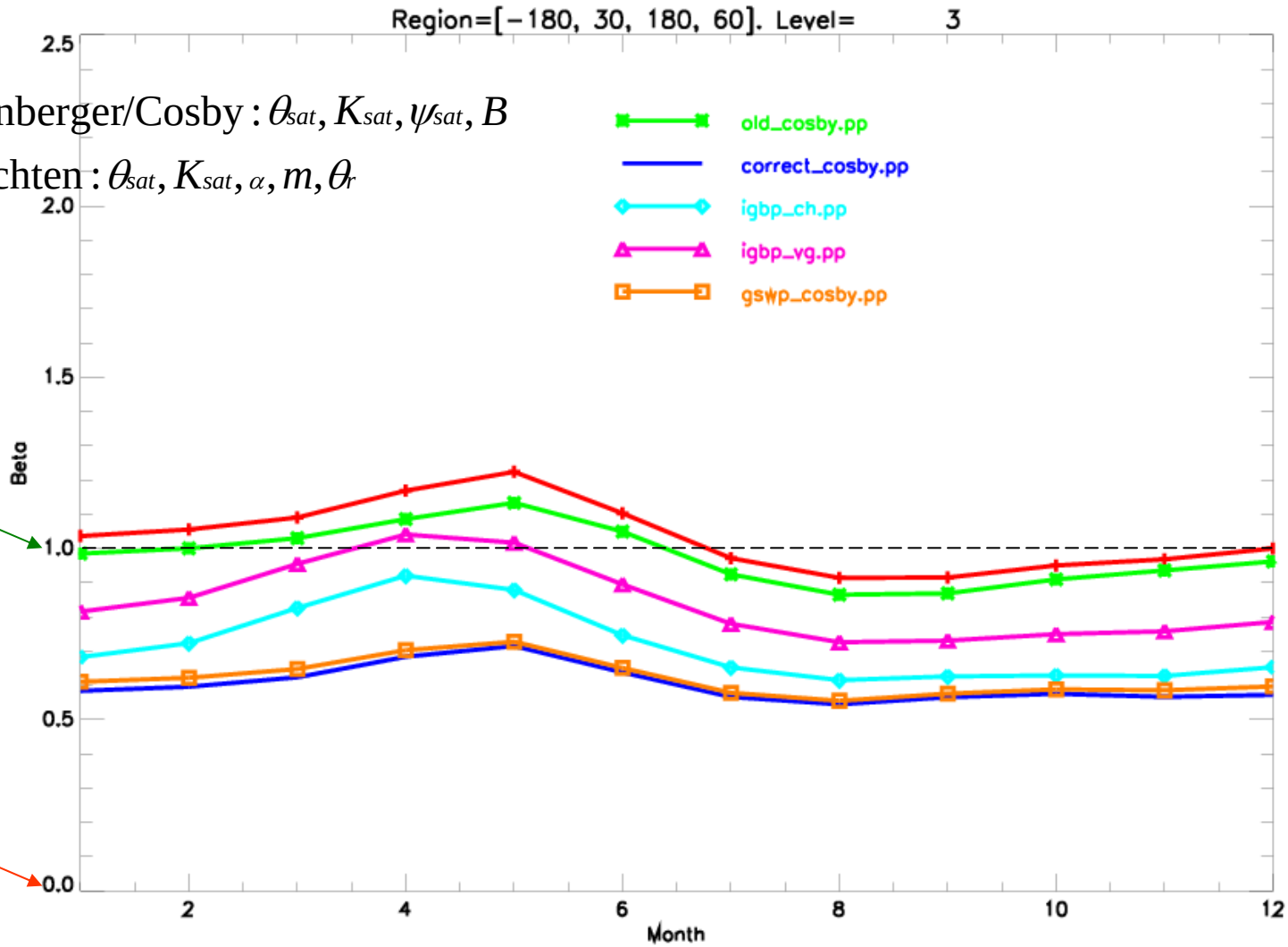


Effect of different soil property datasets on moisture stress: Northern mid latitudes

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

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

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



Critical point

Wilting point

Imtiaz Dharssi (2007)

Runoff

- Surface runoff if locally:

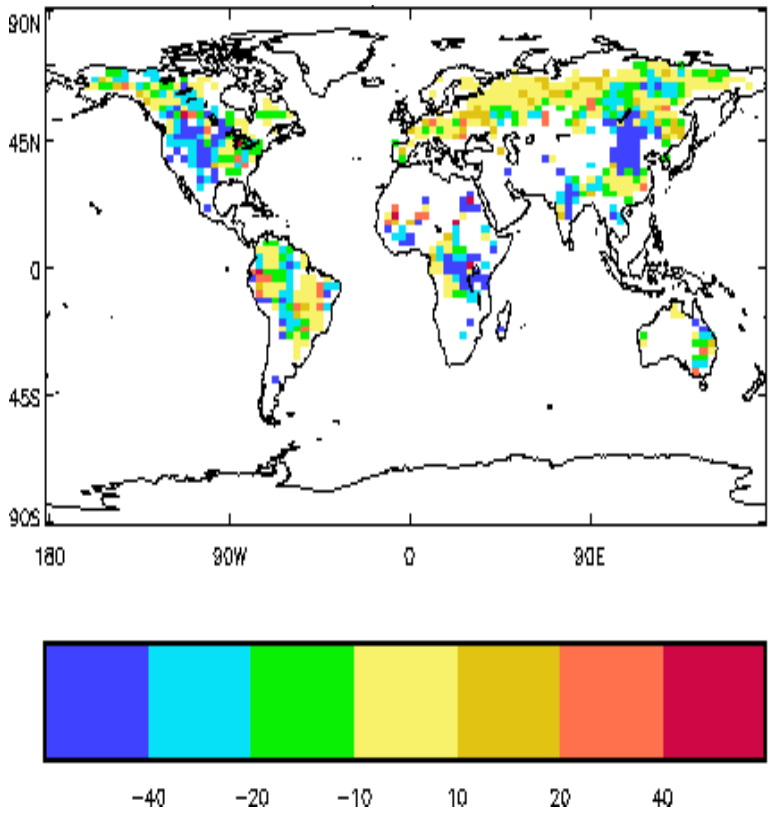
  throughfall + snowmelt>surface infiltration rate (βK_{sat}).

- Deep runoff: free drainage ($K(\theta_u)$).

- JULES: deep runoff>>surface runoff

  due to use of gridbox mean soil moisture & properties

Annual mean runoff/precip % Error



Soil Thermodynamics

Discretised heat diffusion equation :

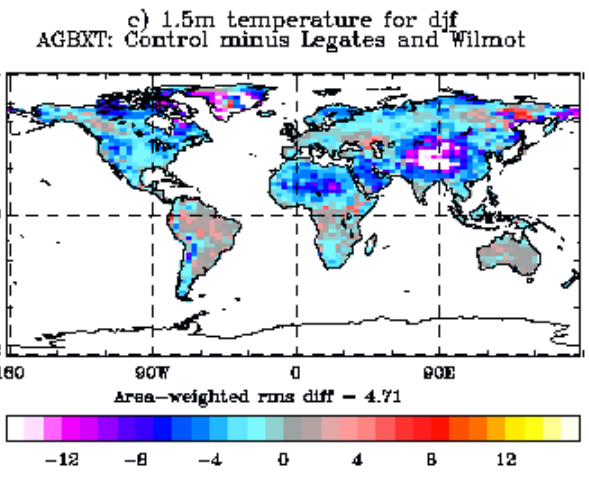
$$C_A \Delta z_n \frac{\partial T_n}{\partial t} = G_{n-1} - G_n - J_n \Delta z_n$$

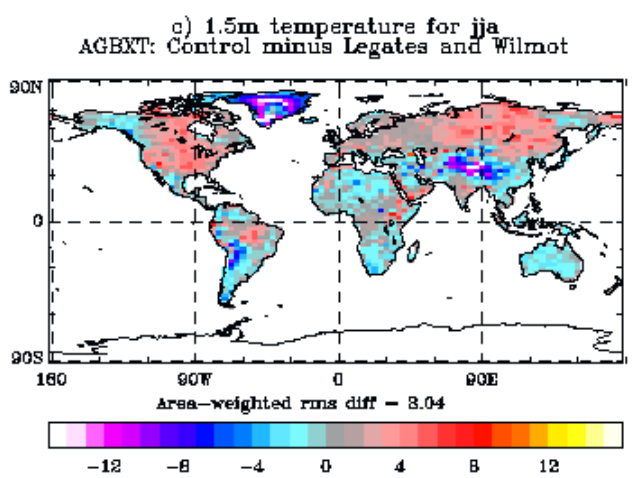
$$\text{diffusive flux} : G = \lambda_s \frac{\partial T}{\partial z} \quad \text{advective flux} : J = c_w W \frac{\partial T}{\partial z}$$

$$\text{Apparent vol heat capacity} : C_A = Fn(\theta_u, \theta_f, T)$$

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

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





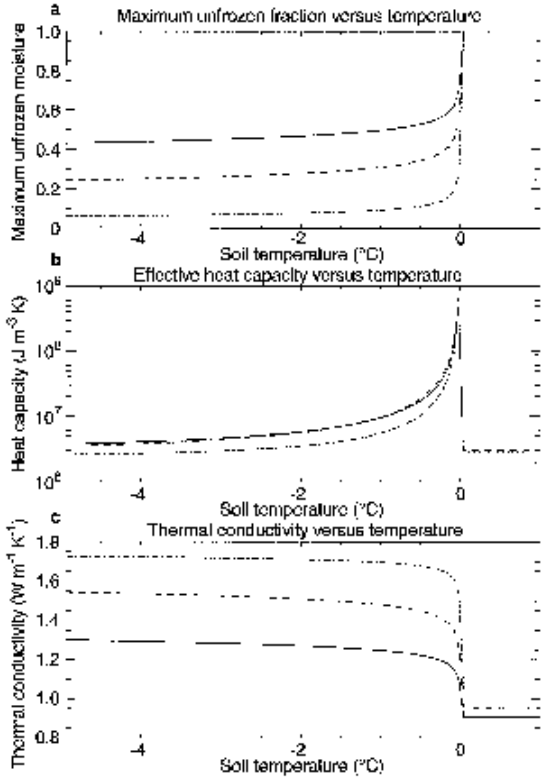


Fig. 3 a Maximum unfrozen soil moisture as a fraction of saturation, b effective heat capacity and c thermal conductivity versus soil temperature for the three soil textures used in MOSES: fine (*continuous line*), medium (*dashed line*) and coarse (*dot-dash line*).

HadGEM3 simulation

Current Limitations and Health Warnings

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

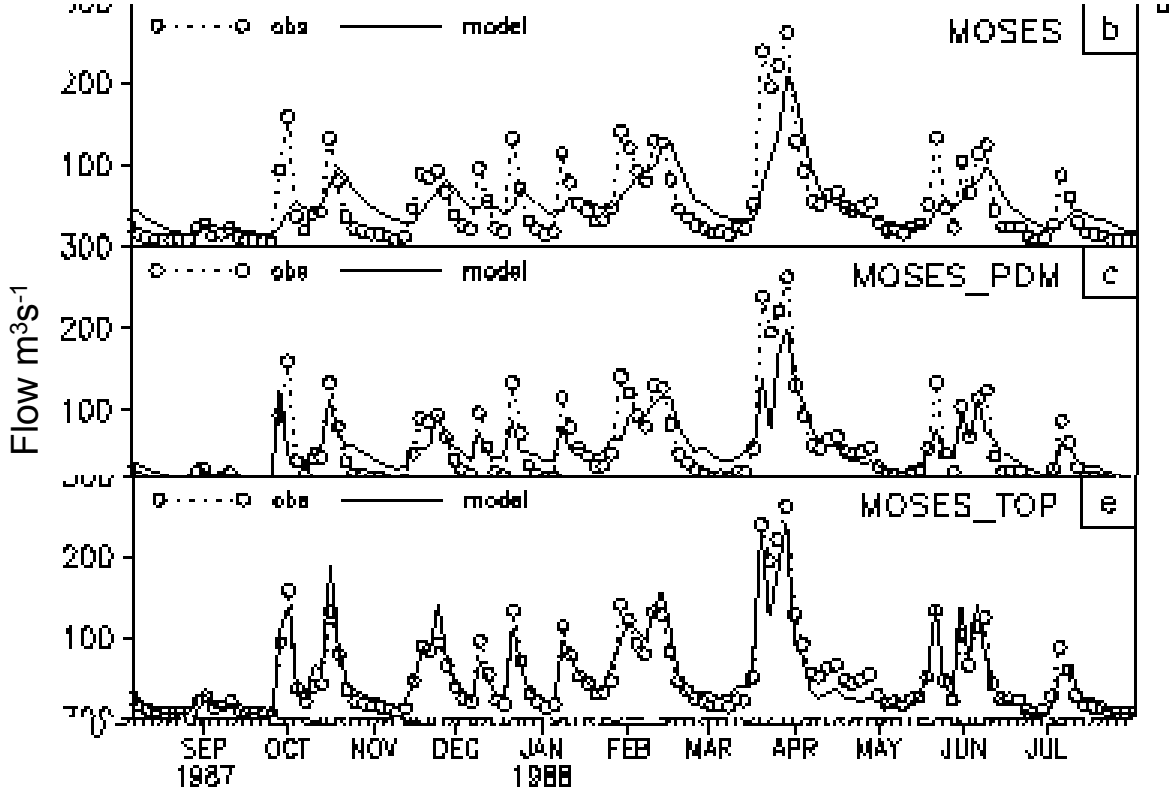
Met Office
Hadley Centre

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

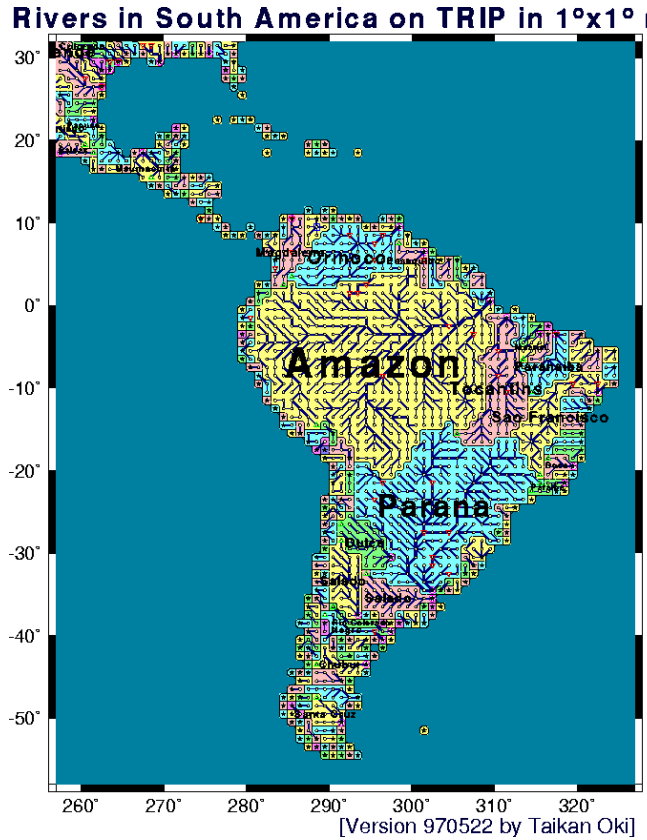
3-day average streamflow for the Ain Catchment (Rhone Basin)

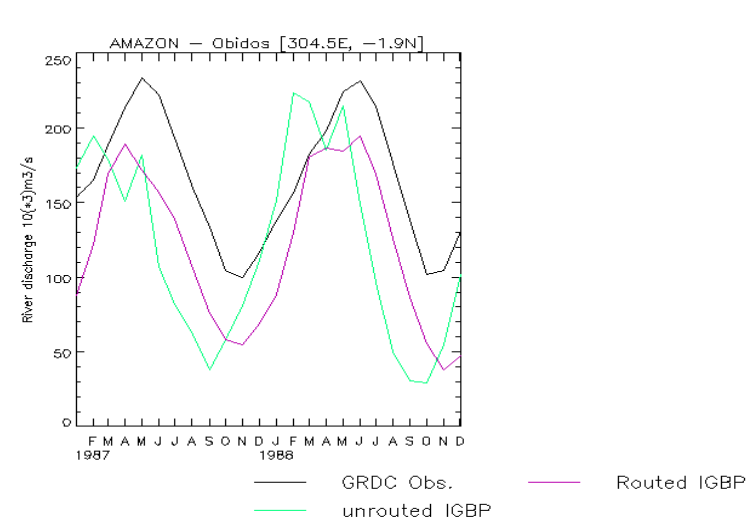


Clark & Gedney (in press)

River Routing

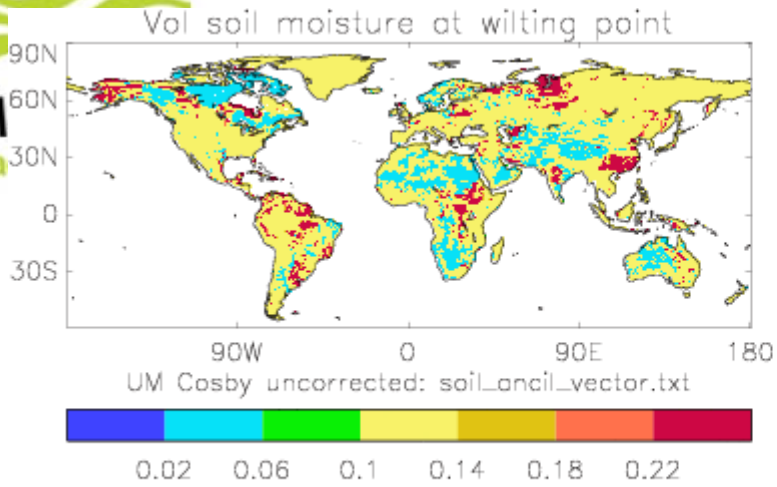
- TRIP
  - Global 1º resolution
- Grid2Grid:
  - UK 1km resolution
  - Europe 20km resolution

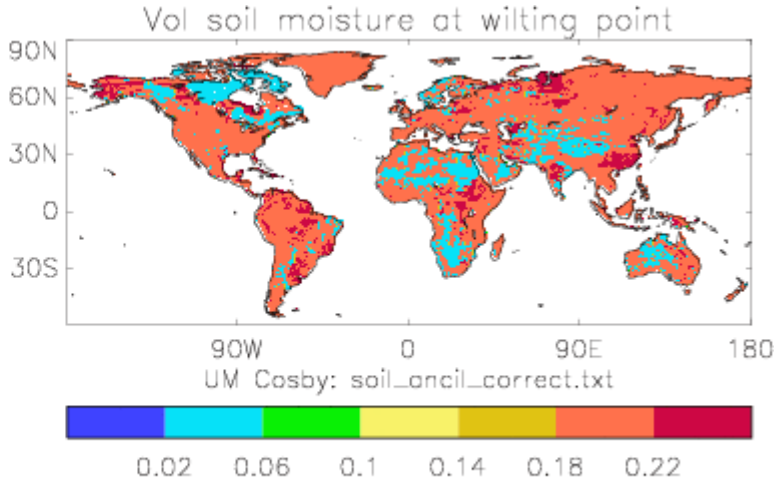


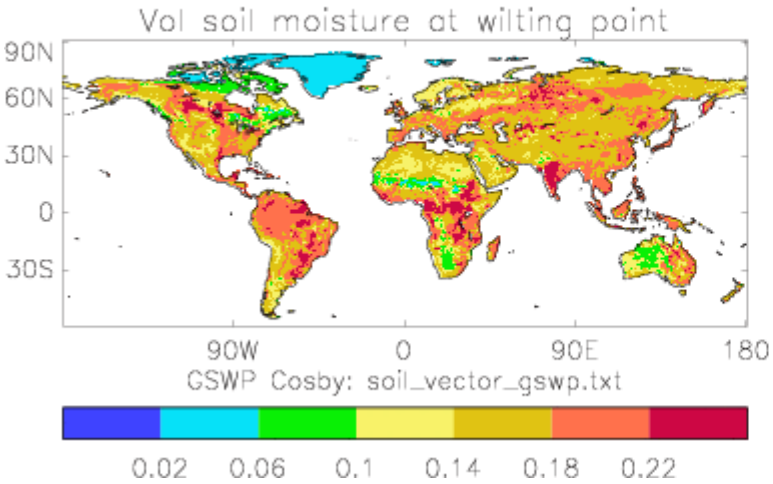


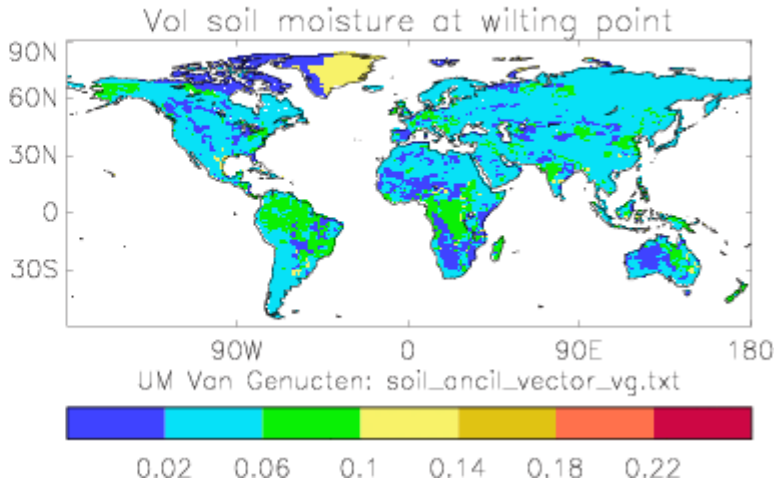
Future Developments

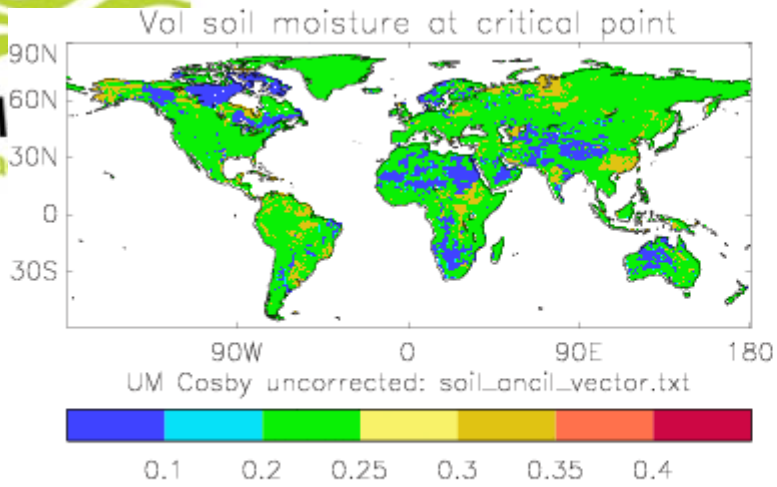
- Irrigation
- Groundwater
- Dams

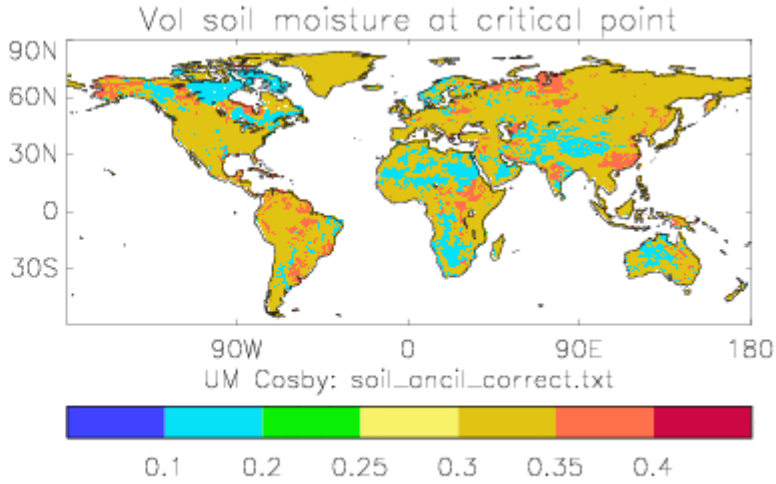


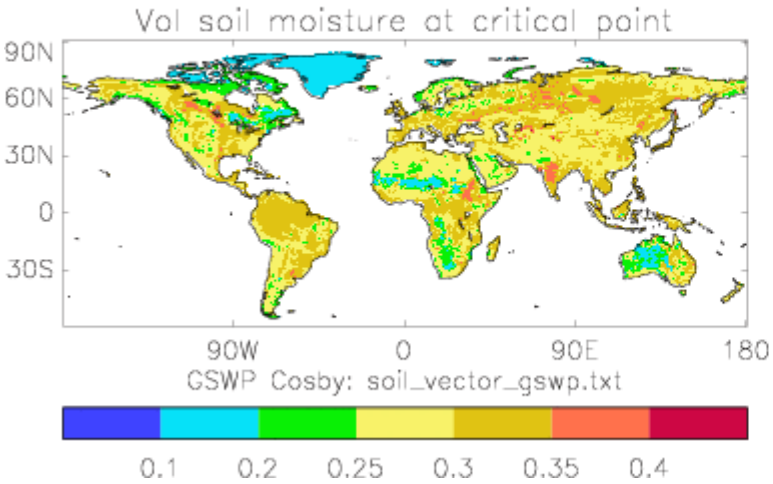


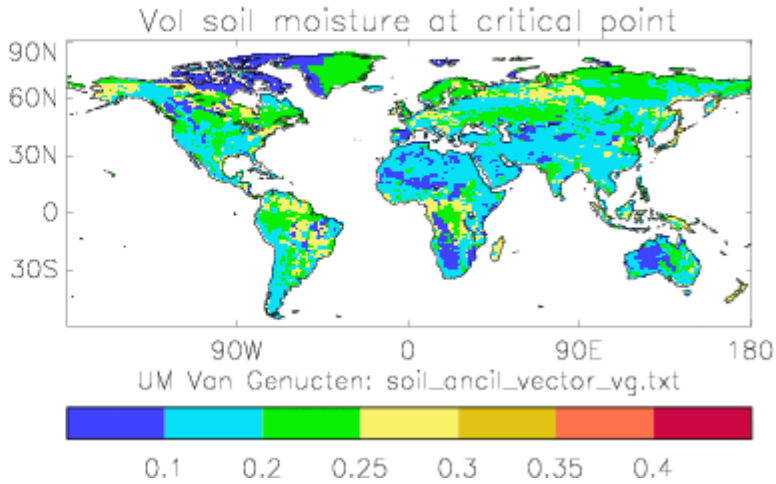


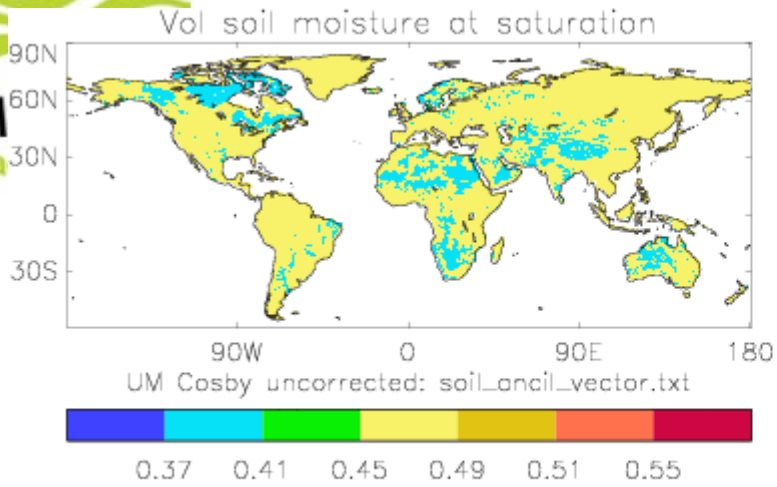


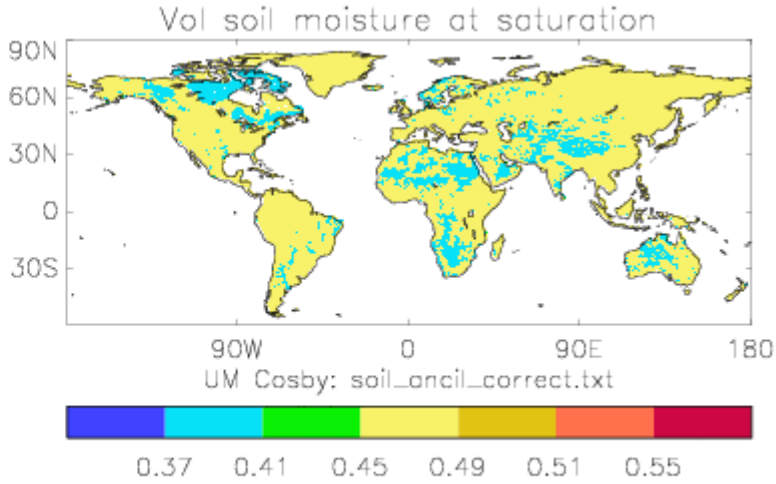


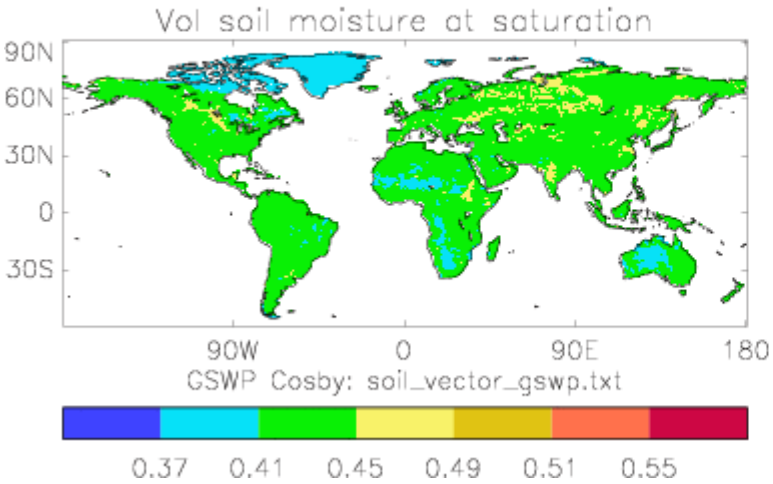


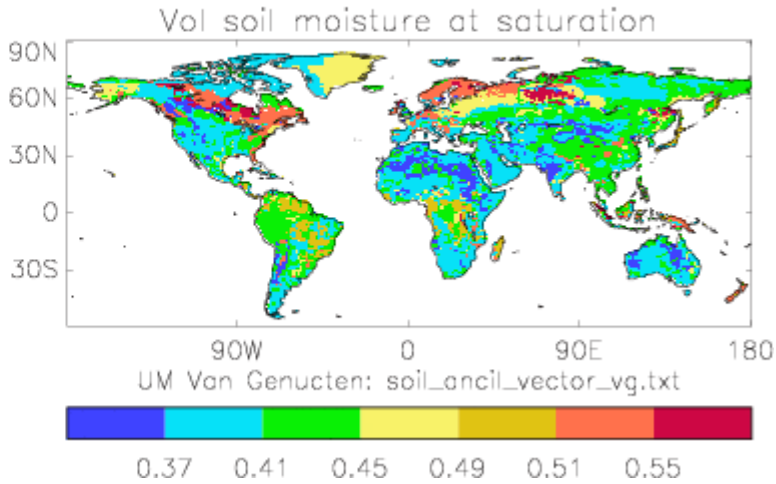


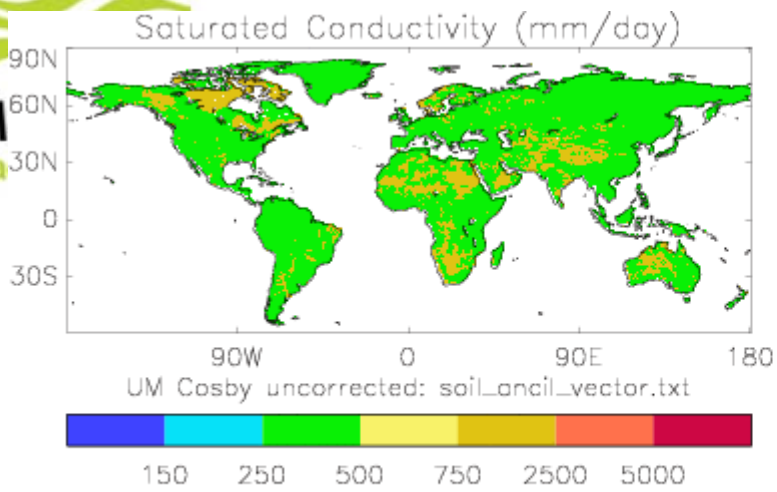


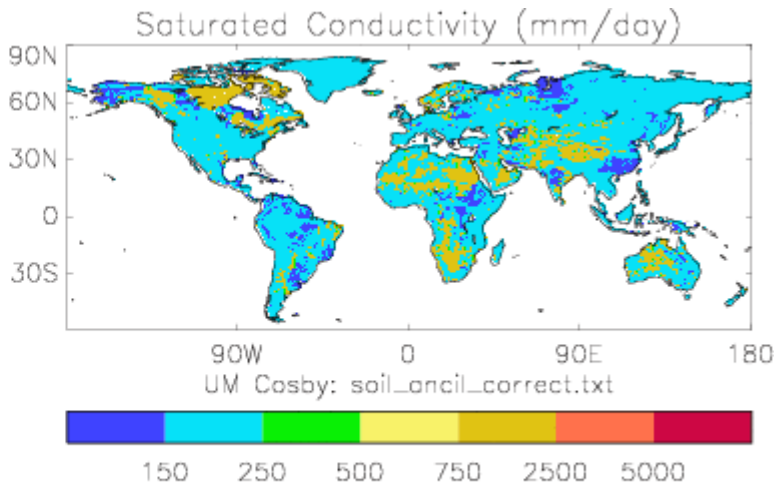


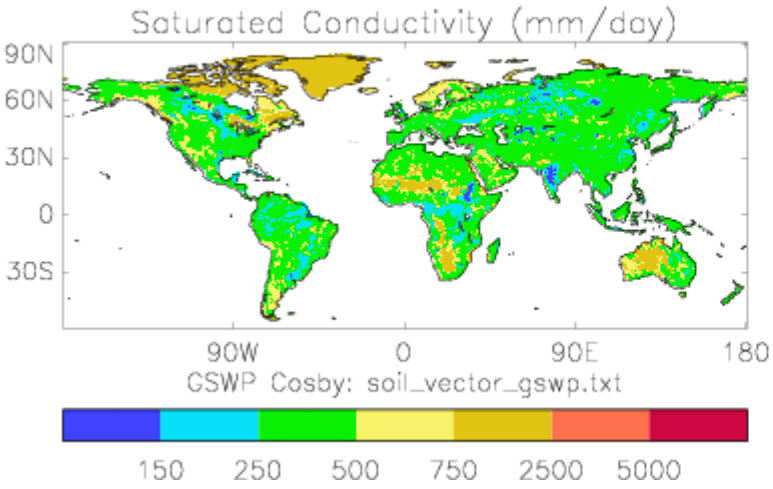


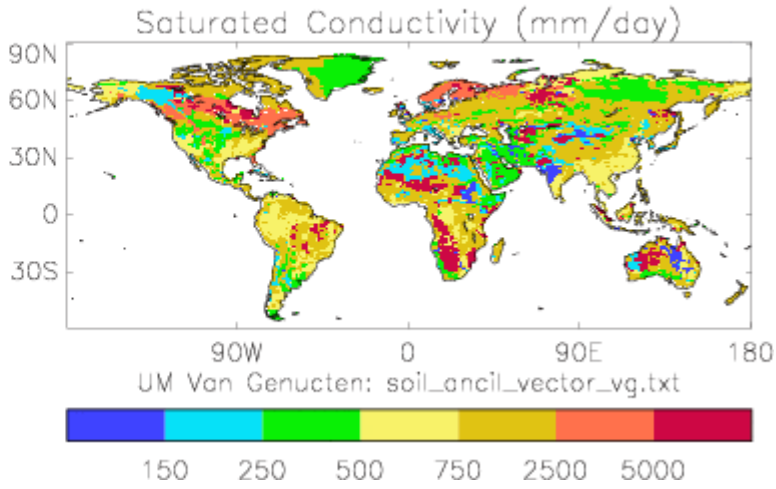


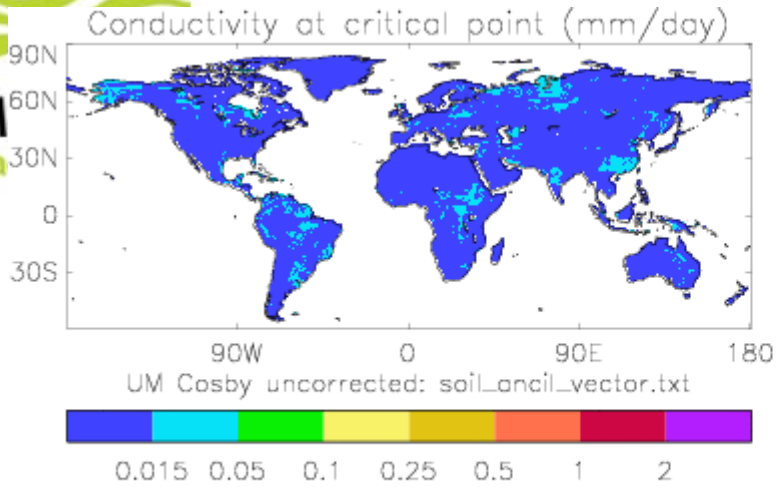


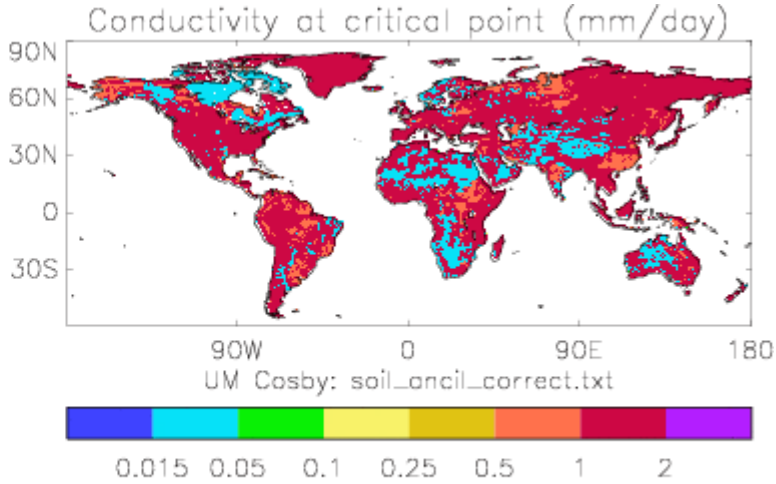


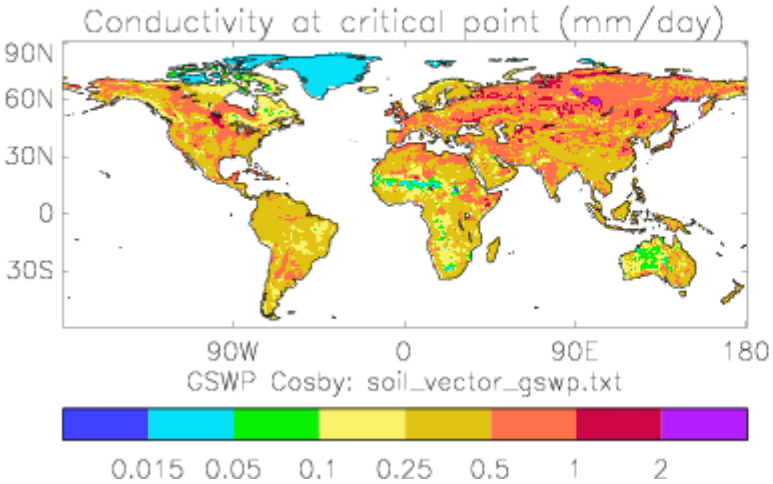


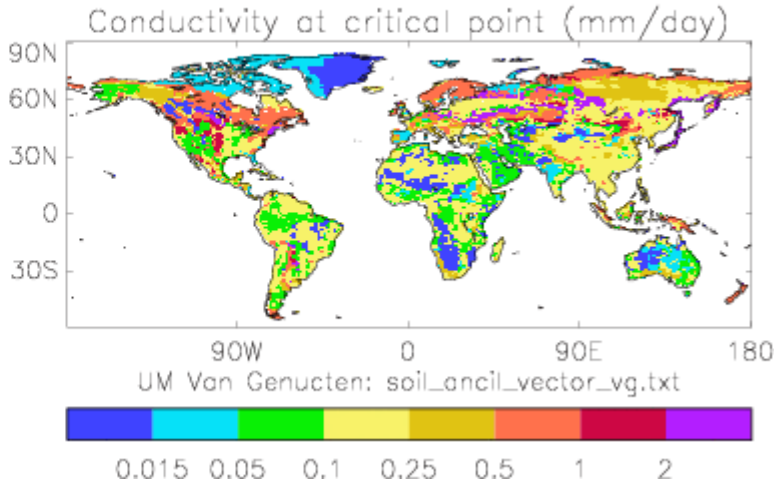












Impact of Improved Large-scale Hydrology on Simulation of Annual mean Runoff/Precipitation ratio

Met Office
Hadley Centre