Impact of the soil hydrology scheme on soil moisture memory

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Soil Moisture memory

- Soil moisture-atmosphere feedback effects play an important role in several regions of the globe.
- For some of these regions, soil moisture memory may contribute significantly to the development of the regional climate.
- Identifying those regions can help to improve predictability in seasonal to decadal climate forecasts
- Adequate representation of soil hydrology is necessary to ably simulate soil moisture – atmosphere feedbacks.

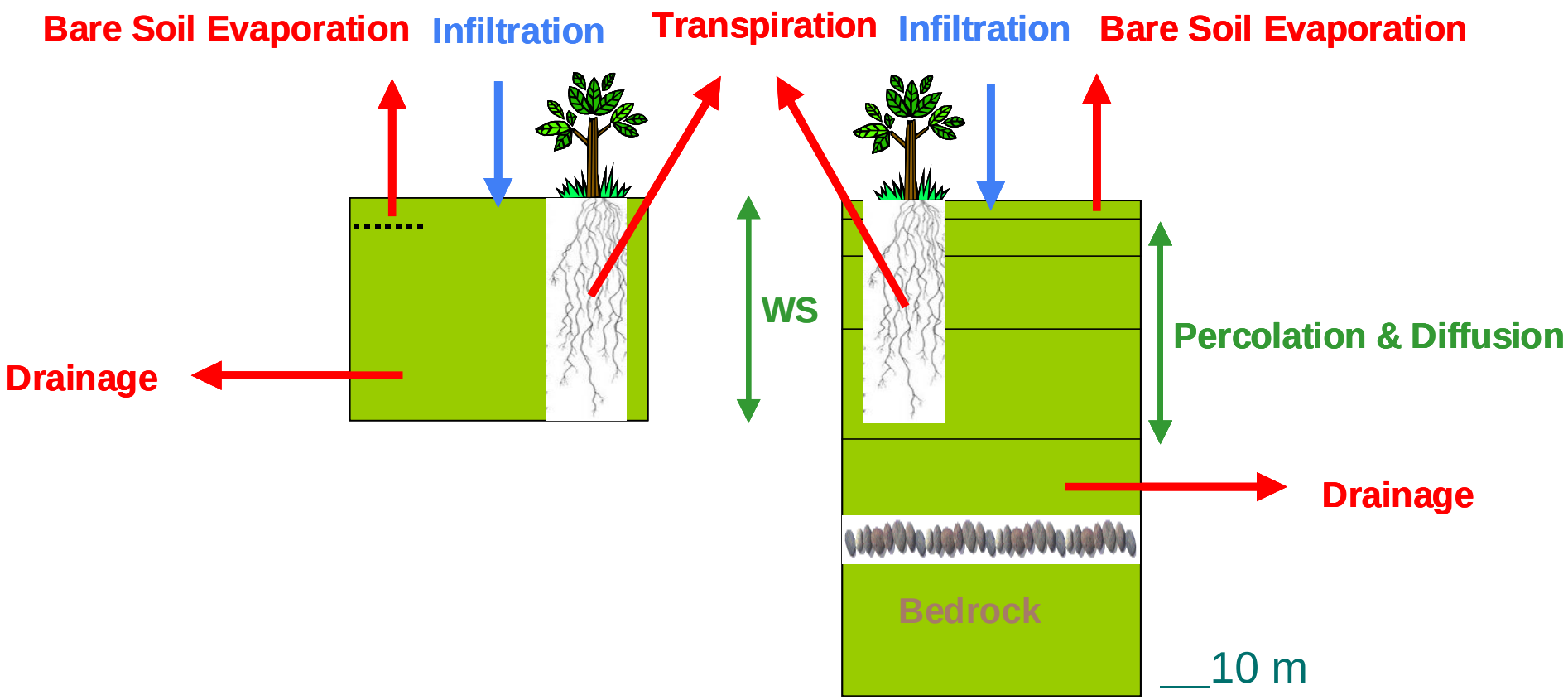
Overview

1. The old bucket and the new 5 layer soil hydrology scheme
2. Model experiments
3. Soil moisture memory
4. Conclusions

Implementation of a 5 layer soil hydrology scheme into JSBACH

Current single layer scheme

5 layer soil hydrology scheme



No water below the bedrock.

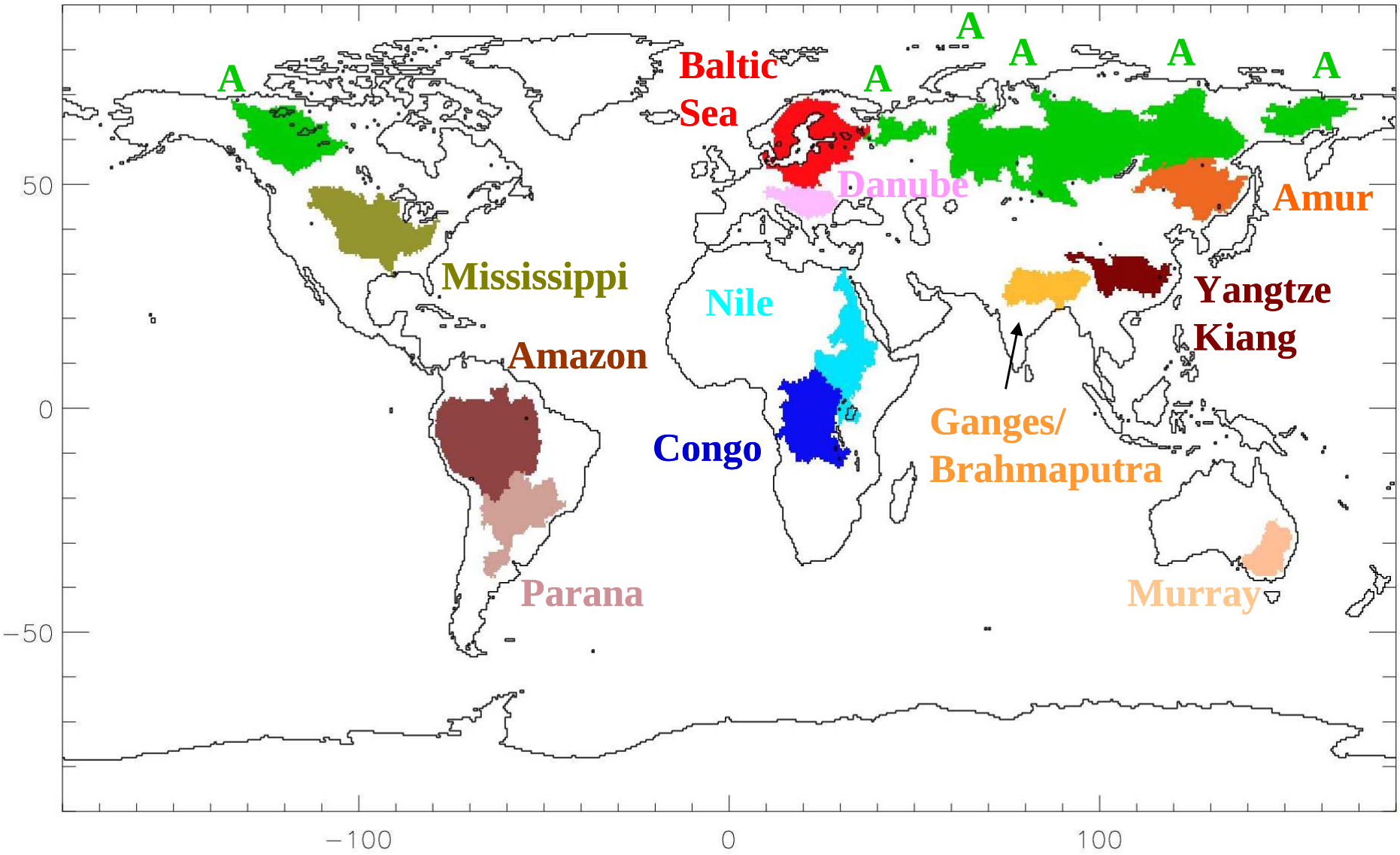
The previous bucket soil moisture **WS** now corresponds to the root zone soil moisture.

Simulation setup

- ECHAM6/JSBACH simulations conducted with AMIP2 SST forcing at T63L47 resolution: 1979-1999
  - **ECH6**: ECHAM6/JSBACH with bucket
  - **5LAY**: Initial 5-layer hydrology
  - **WsBs**: 5LAY + separate upper layer storage for bare soil part of gridbox
  - **WSMX**: New root zone soil water holding capacity (LSP3)

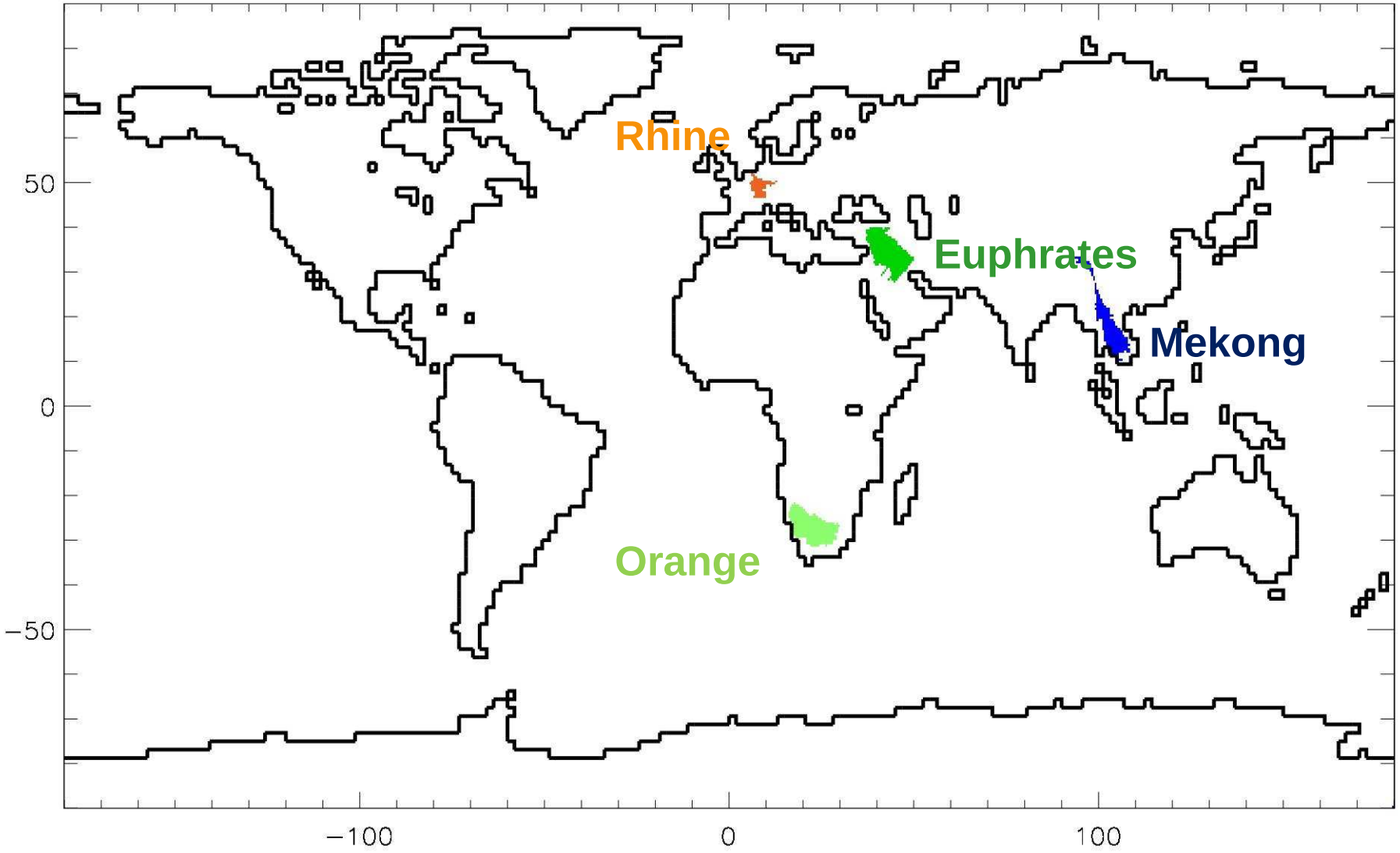
- Long-term spin-up of 5 soil layers before simulation started (1958-1978), ECH6: spin-up 1978
- The general climate does not change too much, with improvements in some areas, and larger biases in others.

Large catchments

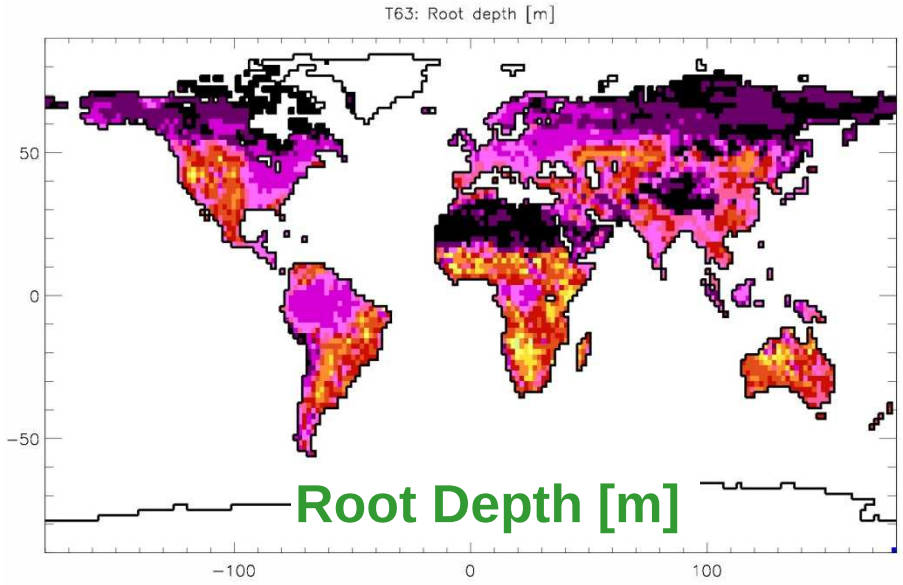


A = 6 largest Arctic Rivers = Mackenzie, N Dvina, Ob, Yenisey, Lena, Kolyma

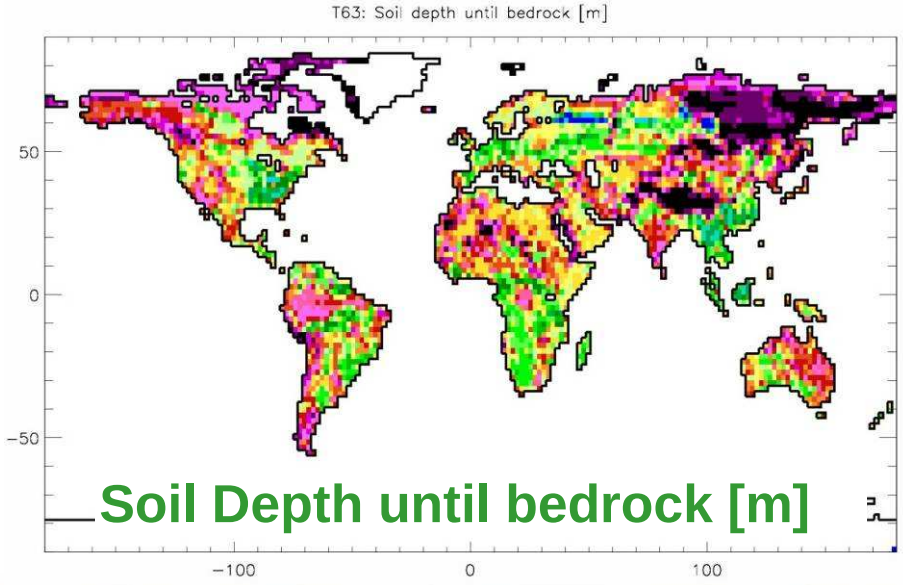
Large catchments



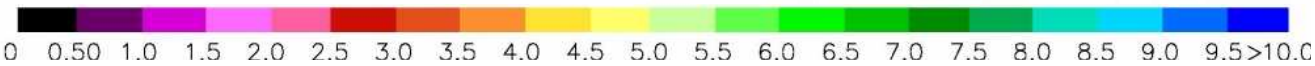
Implementation of a 5 layer soil hydrology scheme into JSBACH



Root Depth [m]

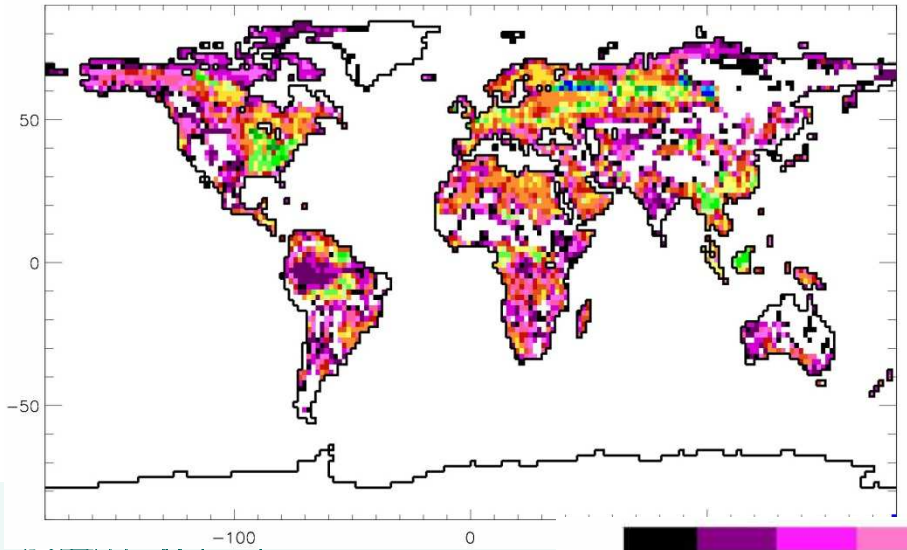


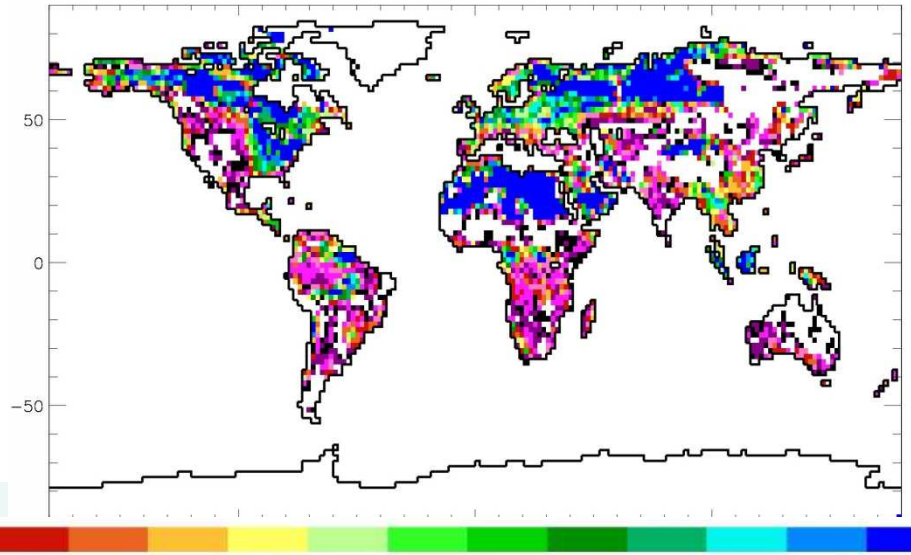
Soil Depth until bedrock [m]

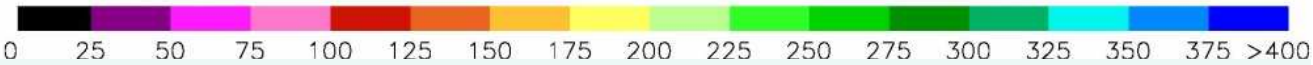


[m]

Difference between Soil Depth and root depth in [m] and [% of root depth]

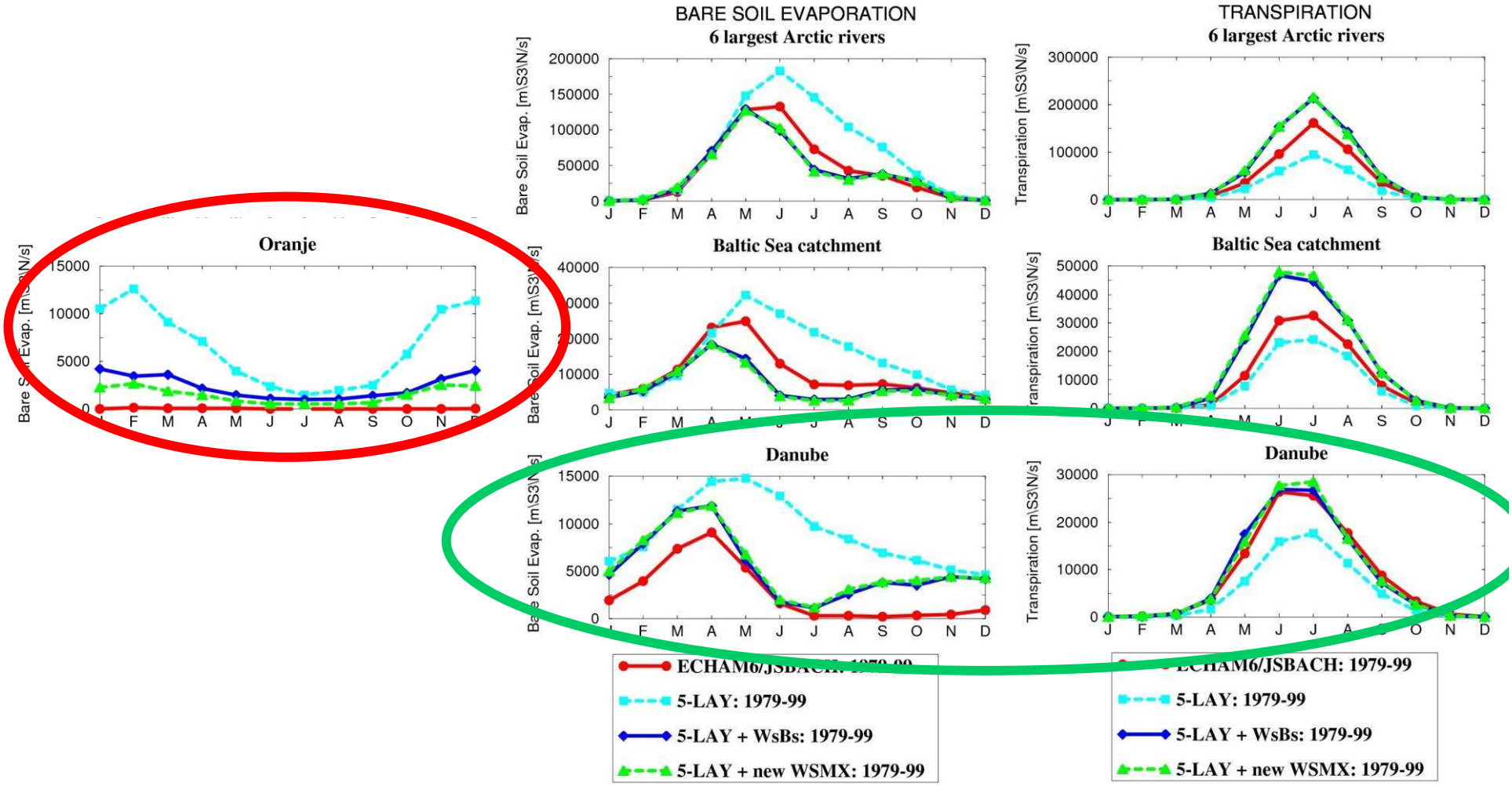




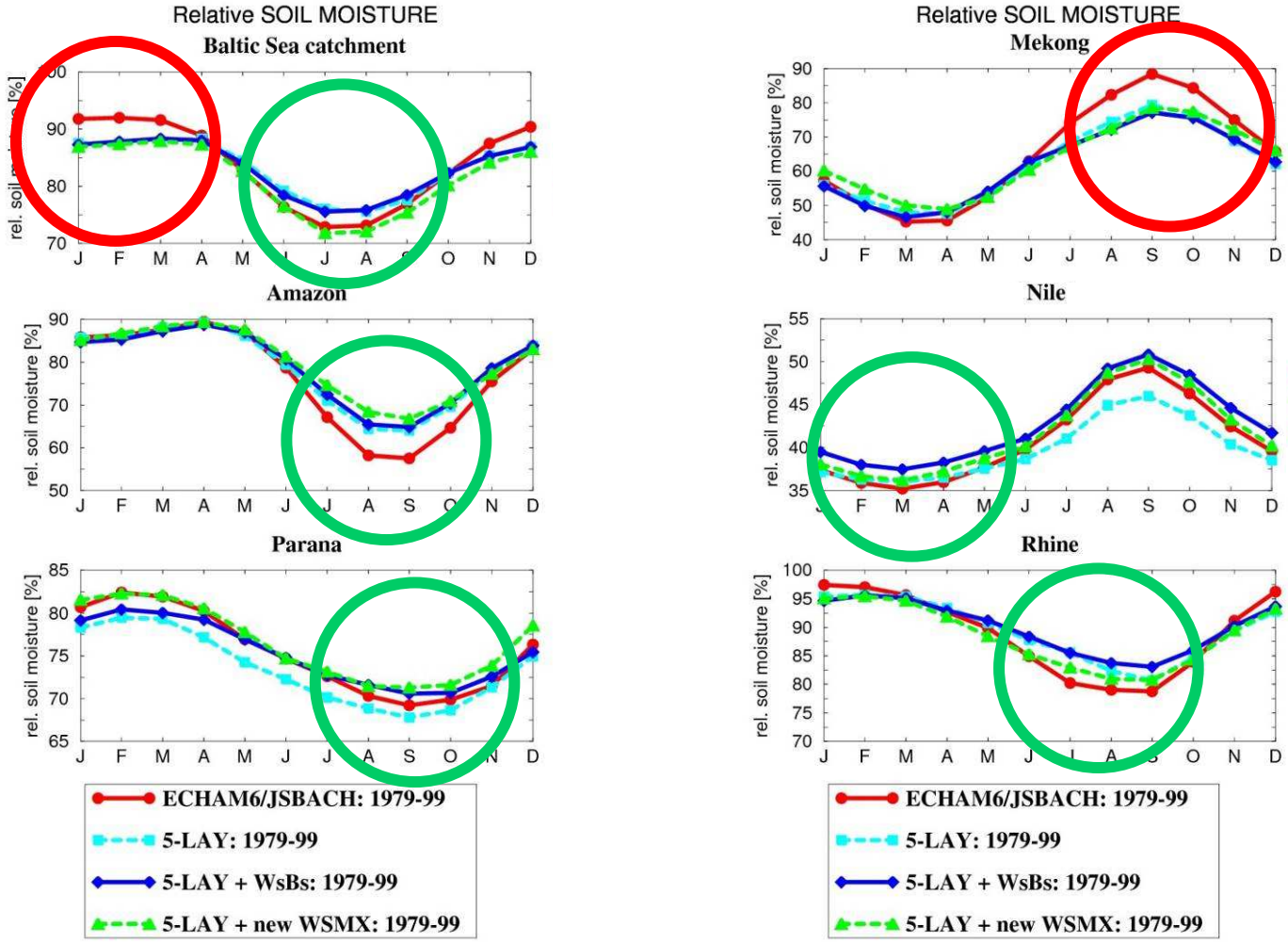


Bare Soil Evaporation

Transpiration



Relative Root Zone Soil Moisture

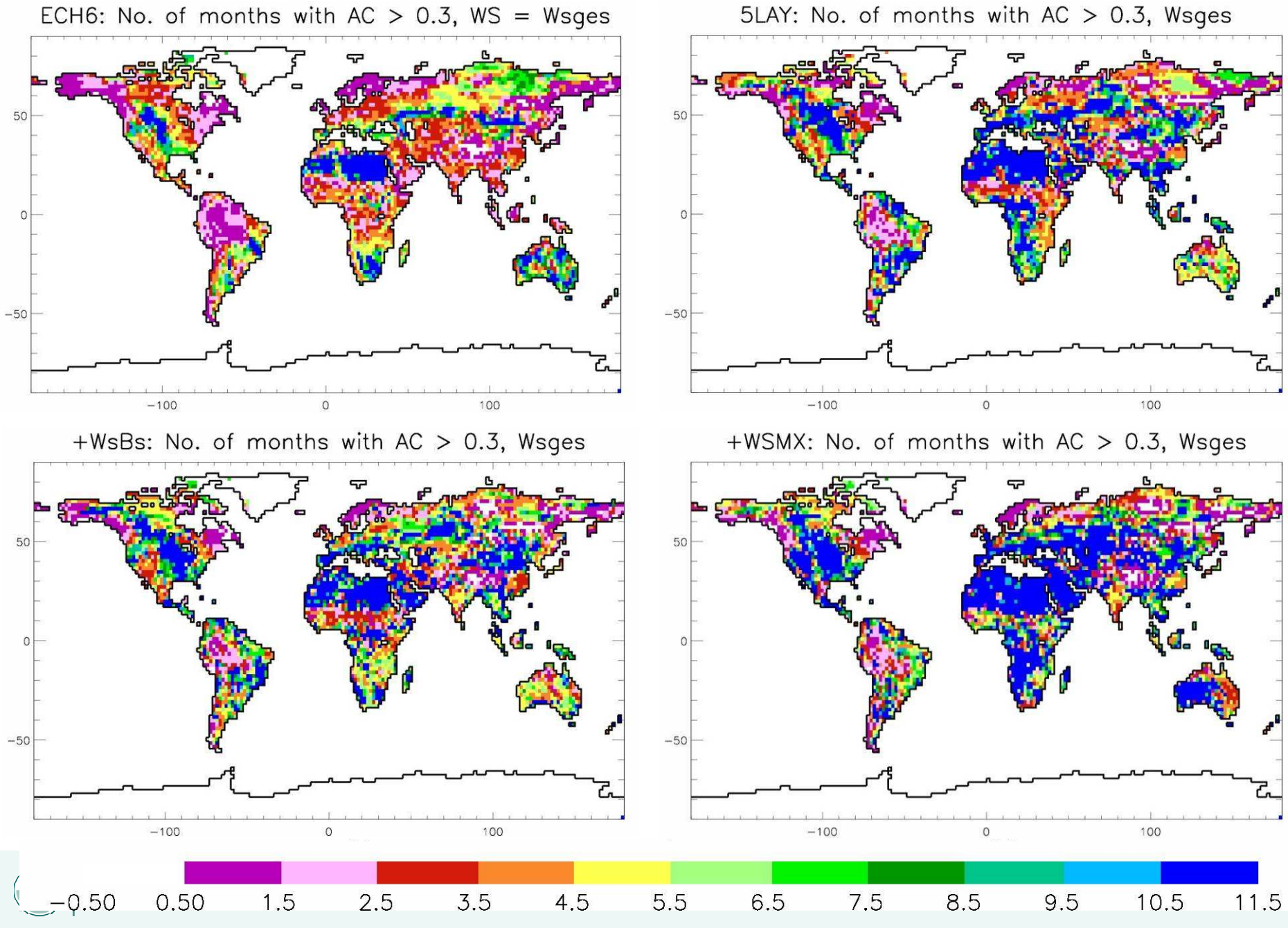


Soil moisture buffer below the root zone

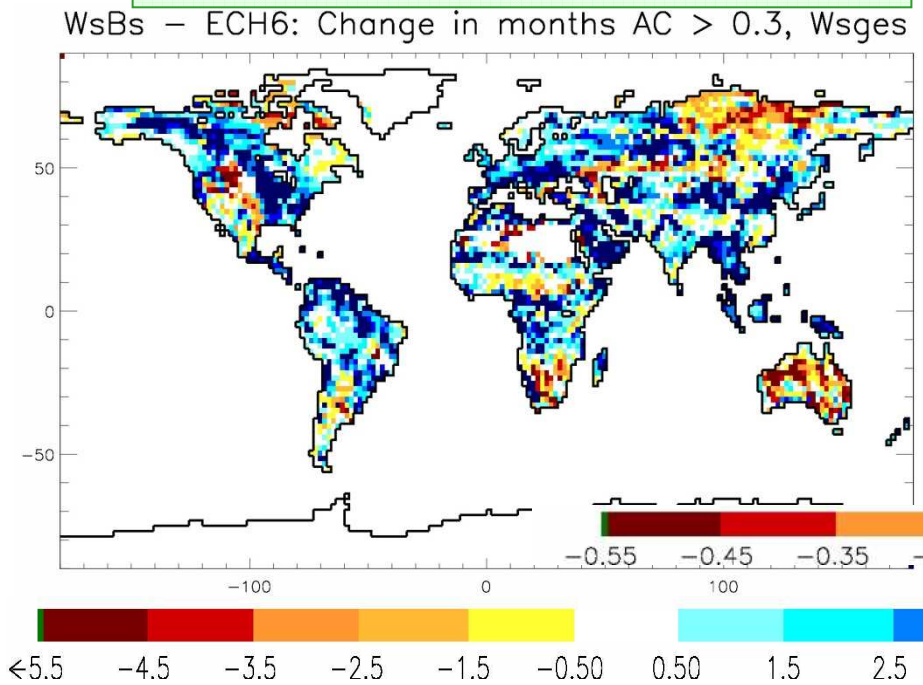
Soil Moisture memory

- Following Koster and Suarez (2001) and Seneviratne et al. (2006), soil moisture memory is indicated in regions where anomalies of soil moisture WS have a high autocorrelation.
- Areas, where the autocorrelation is continuously larger than 0.3 for several months, are considered to be potentially affected by soil moisture memory processes.

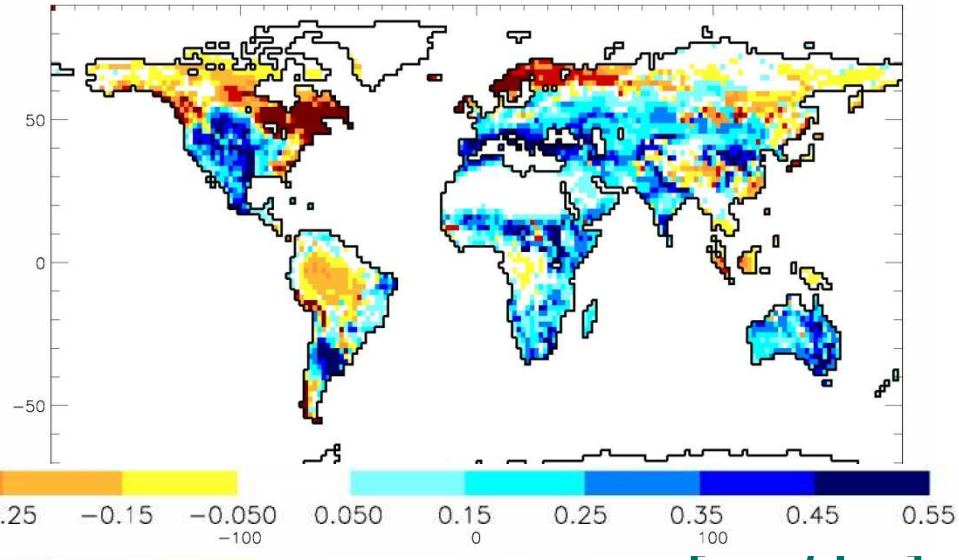
Number of months with WS autocorrelation continuously > 0.3



5LAY+WsBs – ECHAM6

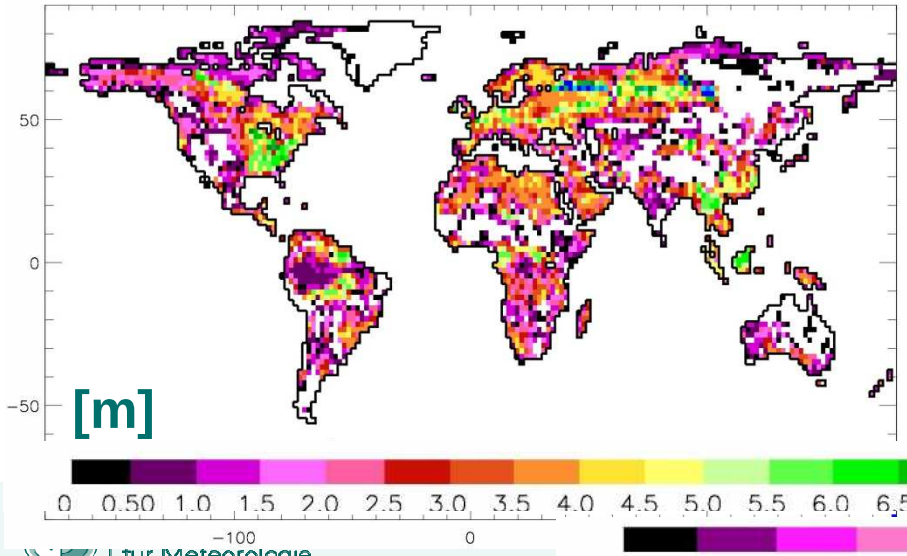


Bare Soil Evaporation change

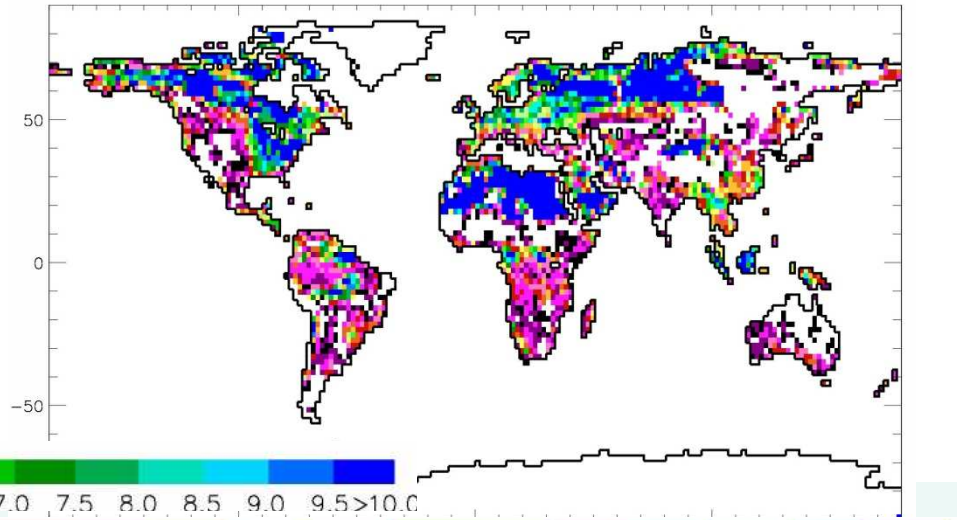


[mm/day]

Difference between Soil Depth and root depth in [m] and [% of root depth]



[m]



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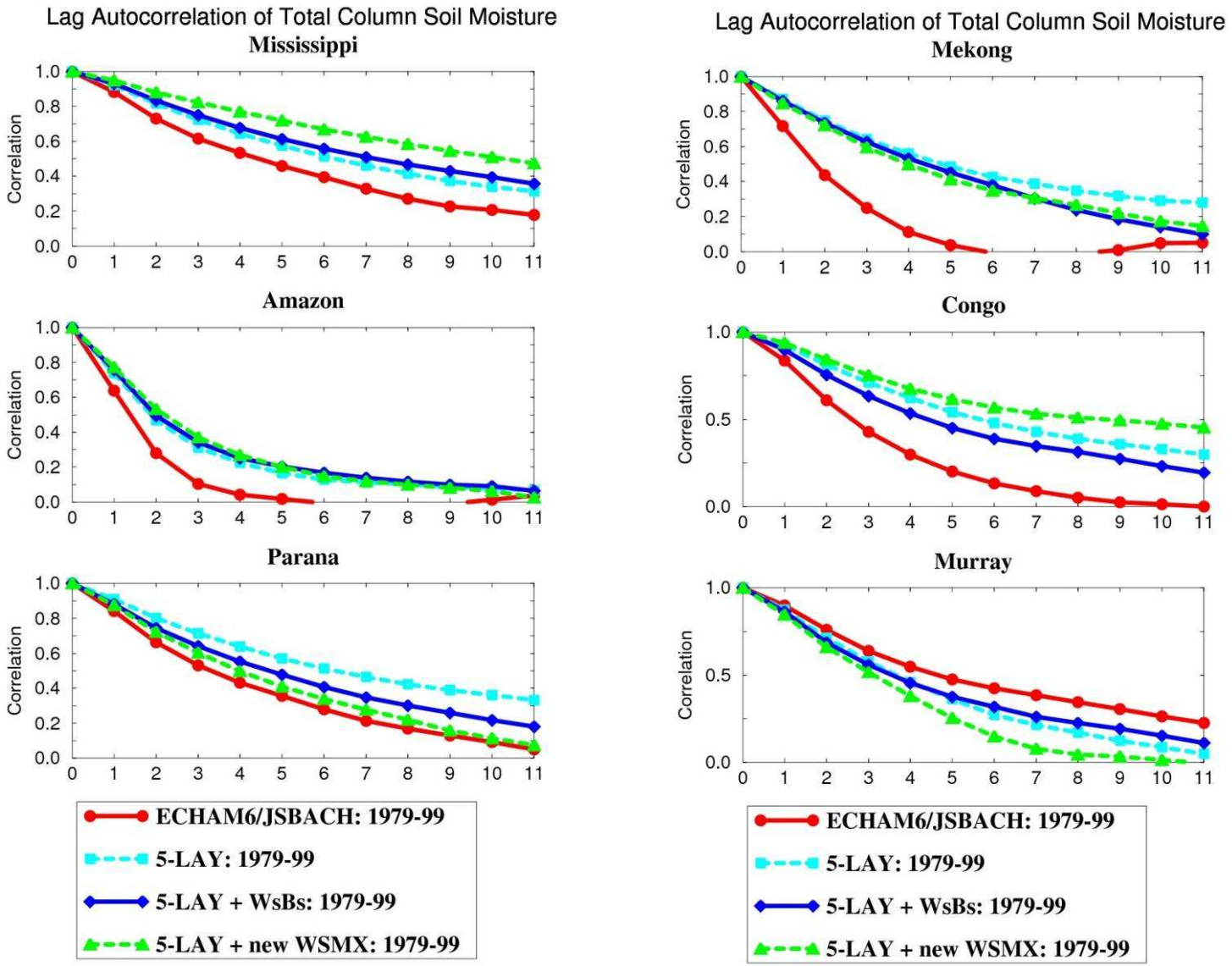
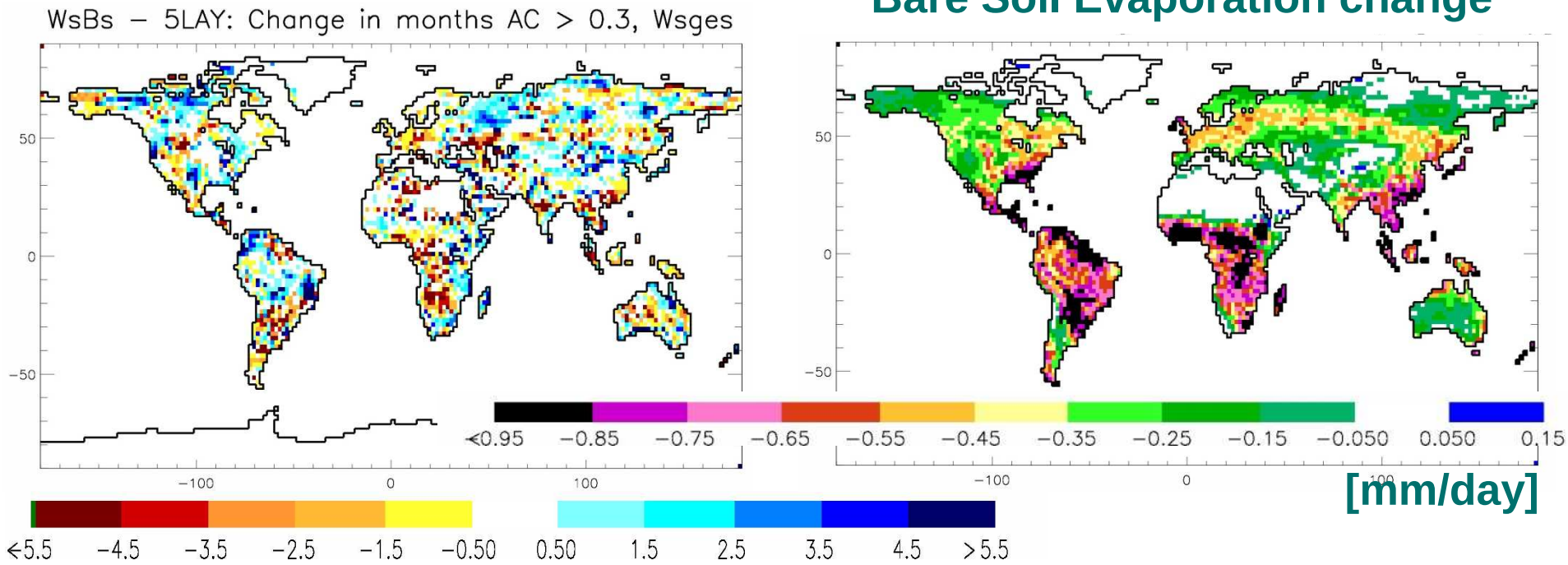
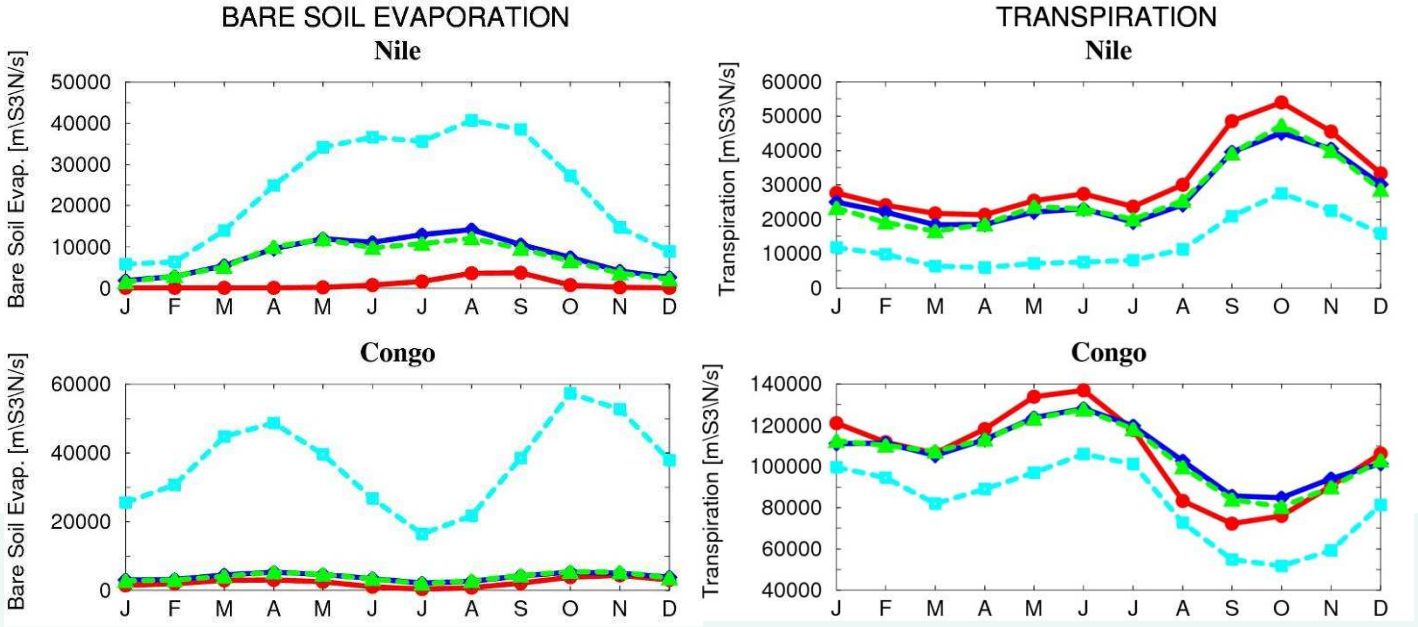
Total column soil moisture autocorrelation



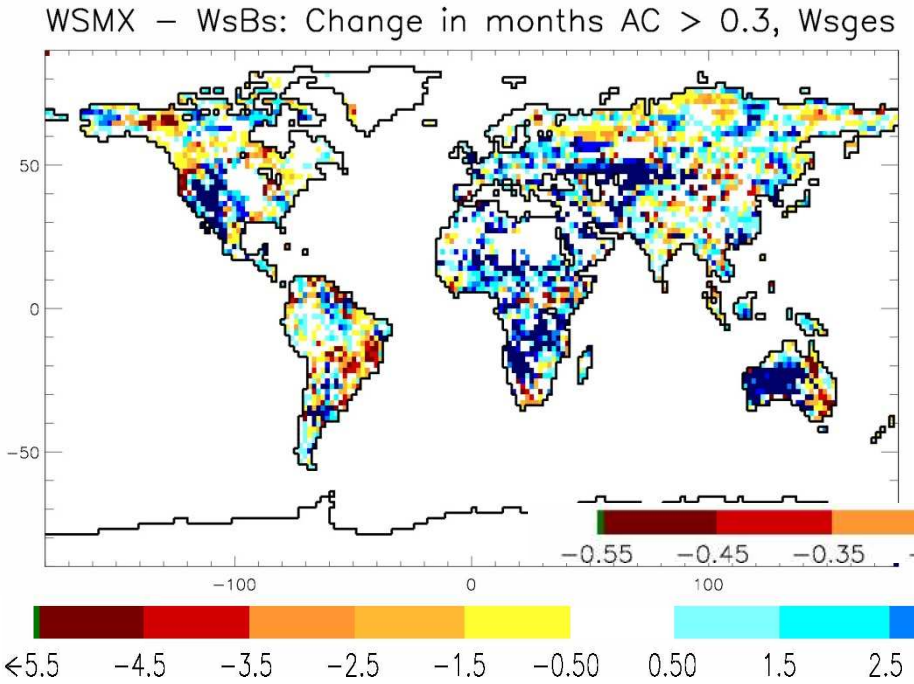
5LAY+WsBs – 5LAY

Bare Soil Evaporation change

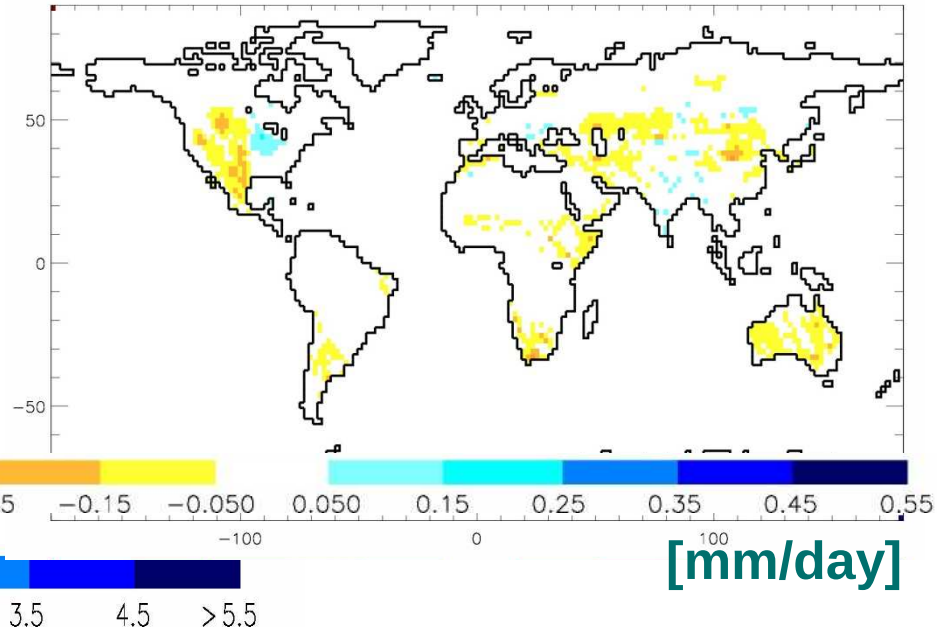




New WSMX – 5LAY+WsBs

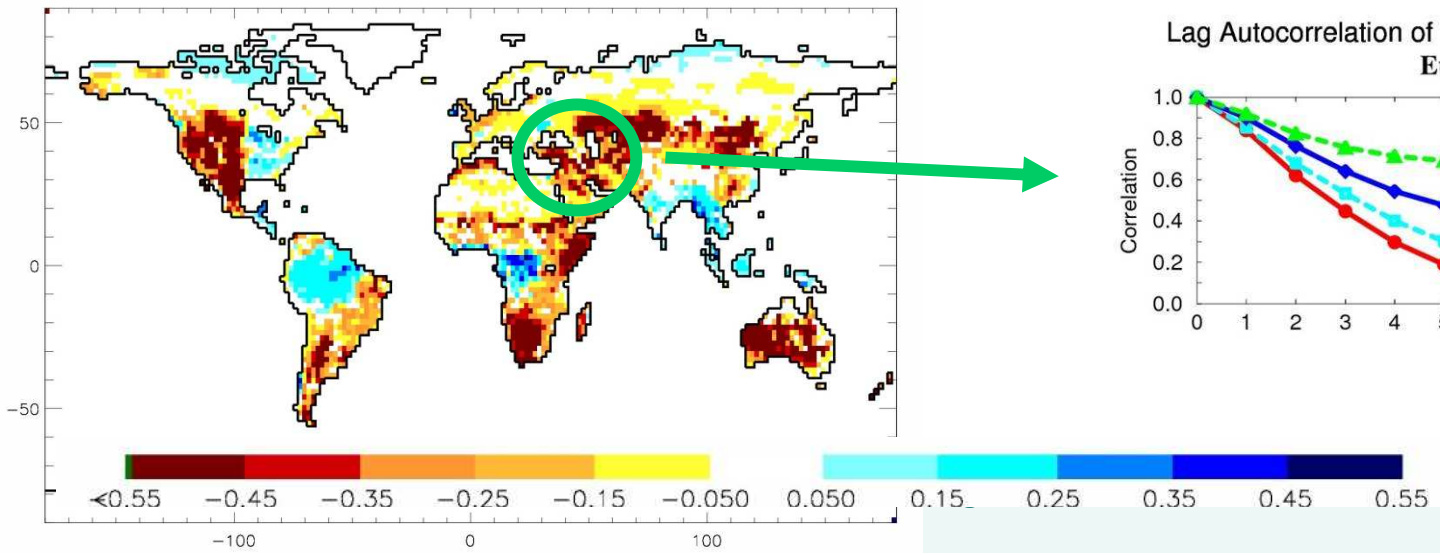


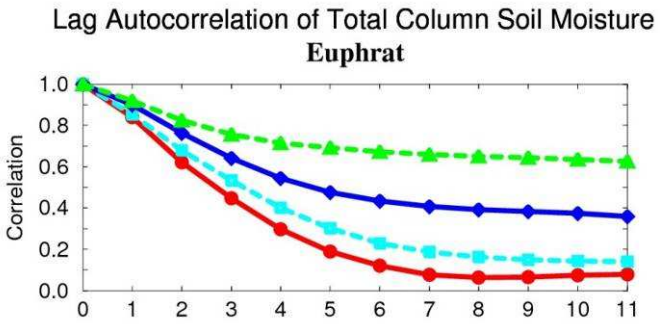
Bare Soil Evaporation change



[mm/day]

WSMX difference: New – LSP2

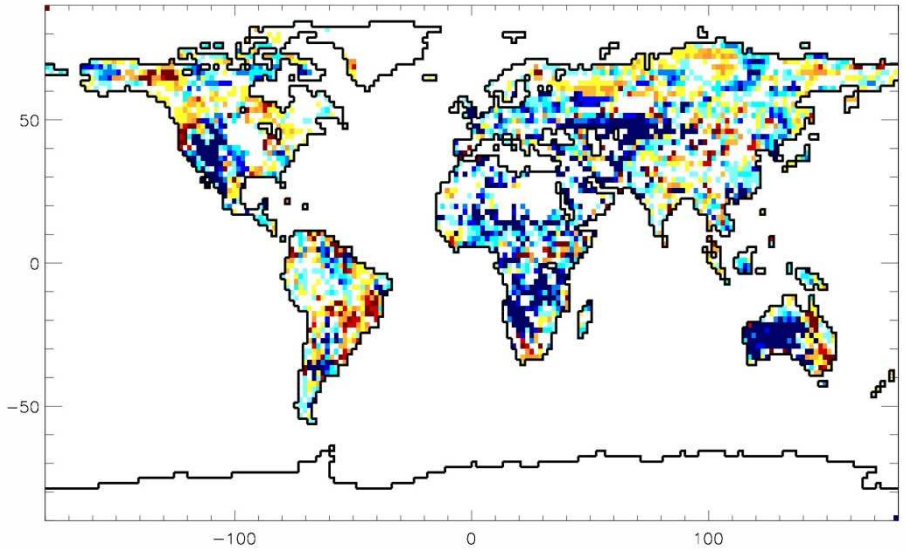




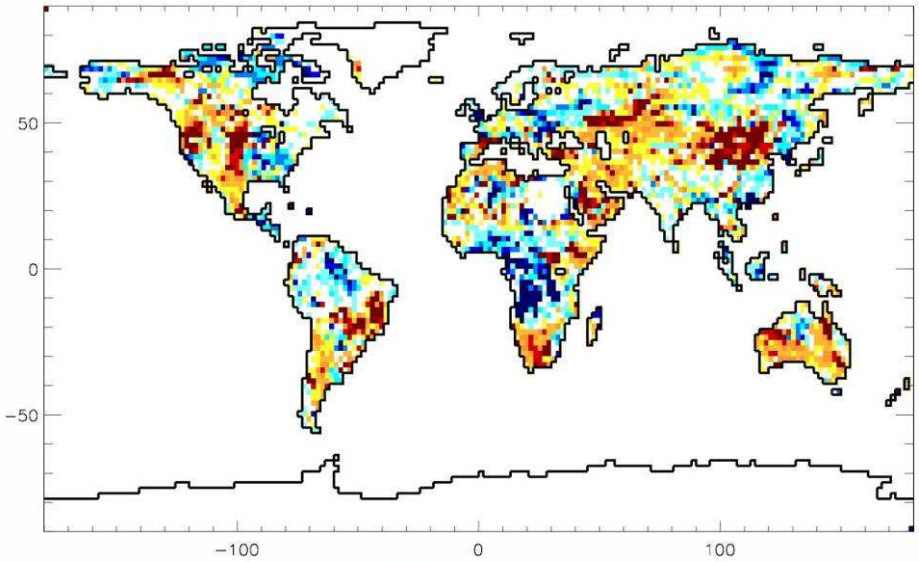
[m]

New WSMX – 5LAY+WsBs: No. of month with AC > 0.3

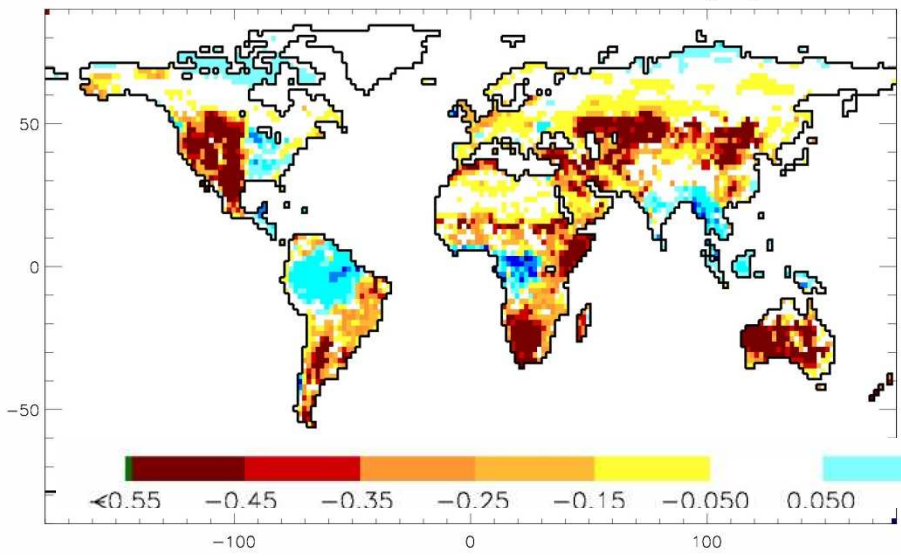
Total soil moisture WSges



Root zone soil moisture WS



WSMX difference: New – LSP2



[m]

Summary 1

- Simulated mean climate is largely kept with the new 5 layer scheme, showing slightly smaller biases in some variables and regions, somewhat larger in others
- Improved representation of soil hydrology processes:
  - Water available for bare soil evaporation.
  - Buffering effect of water storage below root zone
- For many catchments, such as, e.g. Baltic Sea, Nile, Rhine, the root zone becomes
  - drier in wet seasons, partially due to increased EBsoil
  - wetter in the dry season due to water supply from layer below root zone via diffusion.

Summary 2

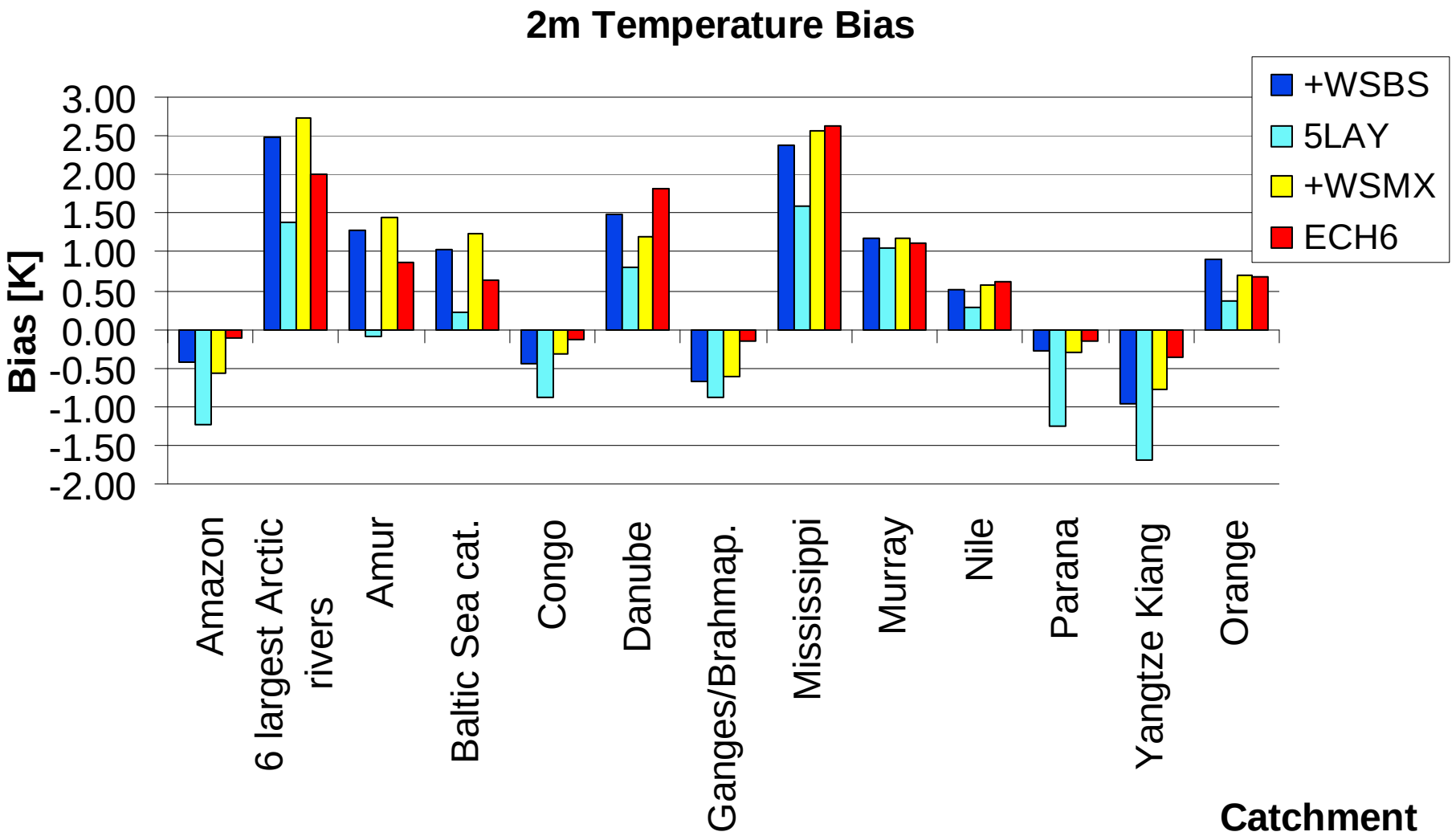
- Soil moisture memory effects of one season or more over many regions: US, southern South America (Parana) and Africa (Orange), Sahel, South and Central Europe (Danube), Australia, Kaukasus and West Siberia, Southern China and Indochine (Mekong).
- Memory diagnostics may be blurred in essentially dry (e.g. Sahara, Asian deserts, Australia) or continuously wet areas (Northern Siberia).
- The 5 layer scheme **increases (buffering effect) soil moisture memory** over large parts of N & S America, Europe, South Asia (esp. Mekong) and Central Africa. It **decreases memory (enhanced bare soil evaporation in less vegetated areas)** over Sahel, South Africa (Orange), Australia, Eastern US, Southern South America and Northern Siberia.
- Reduction in root zone soil moisture capacity (total capacity is kept constant) generally leads to increase in memory.

Outlook

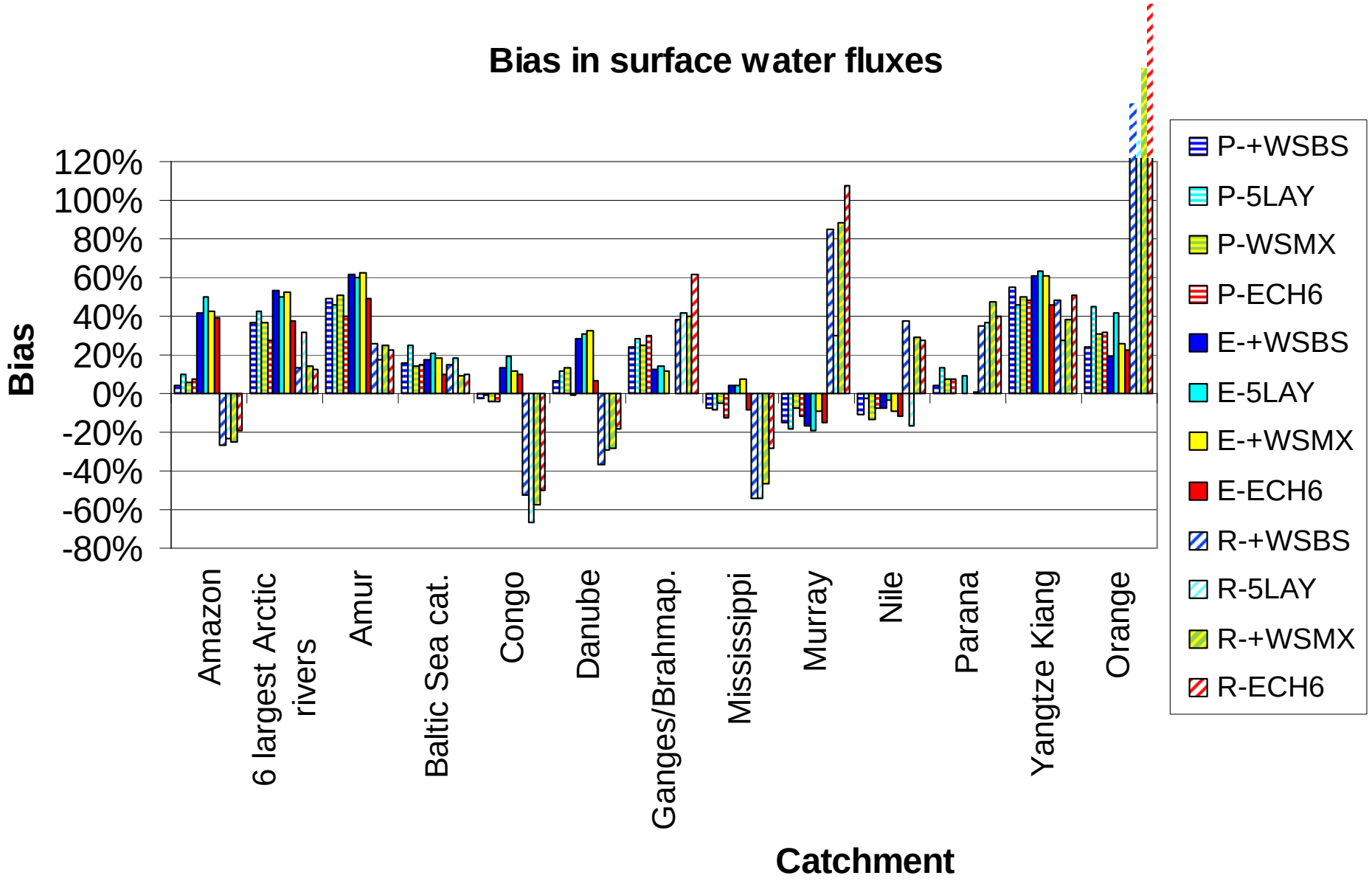
- Implement melting/freezing into JSBACH .
  - Cooperation MPI-BGC (Page21; Ekici et al. 2013, GMD)
- Investigate soil moisture memory effects in models and observations with respect to seasonal and decadal forecasts (MiKlip/ESA; Loew et al. 2013)

Thank you for your attention!

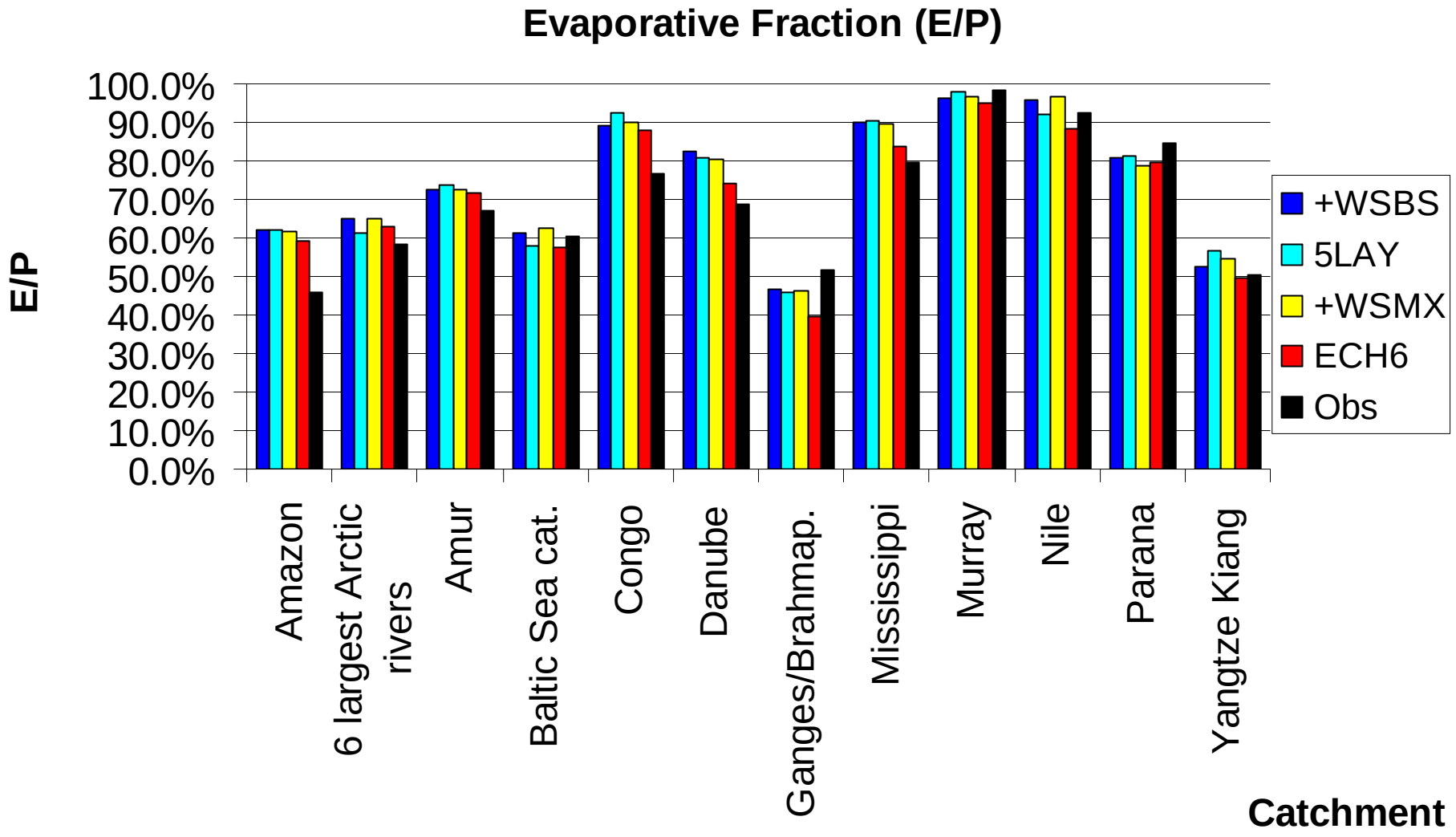
Biases 2m temperature: 1979-1999



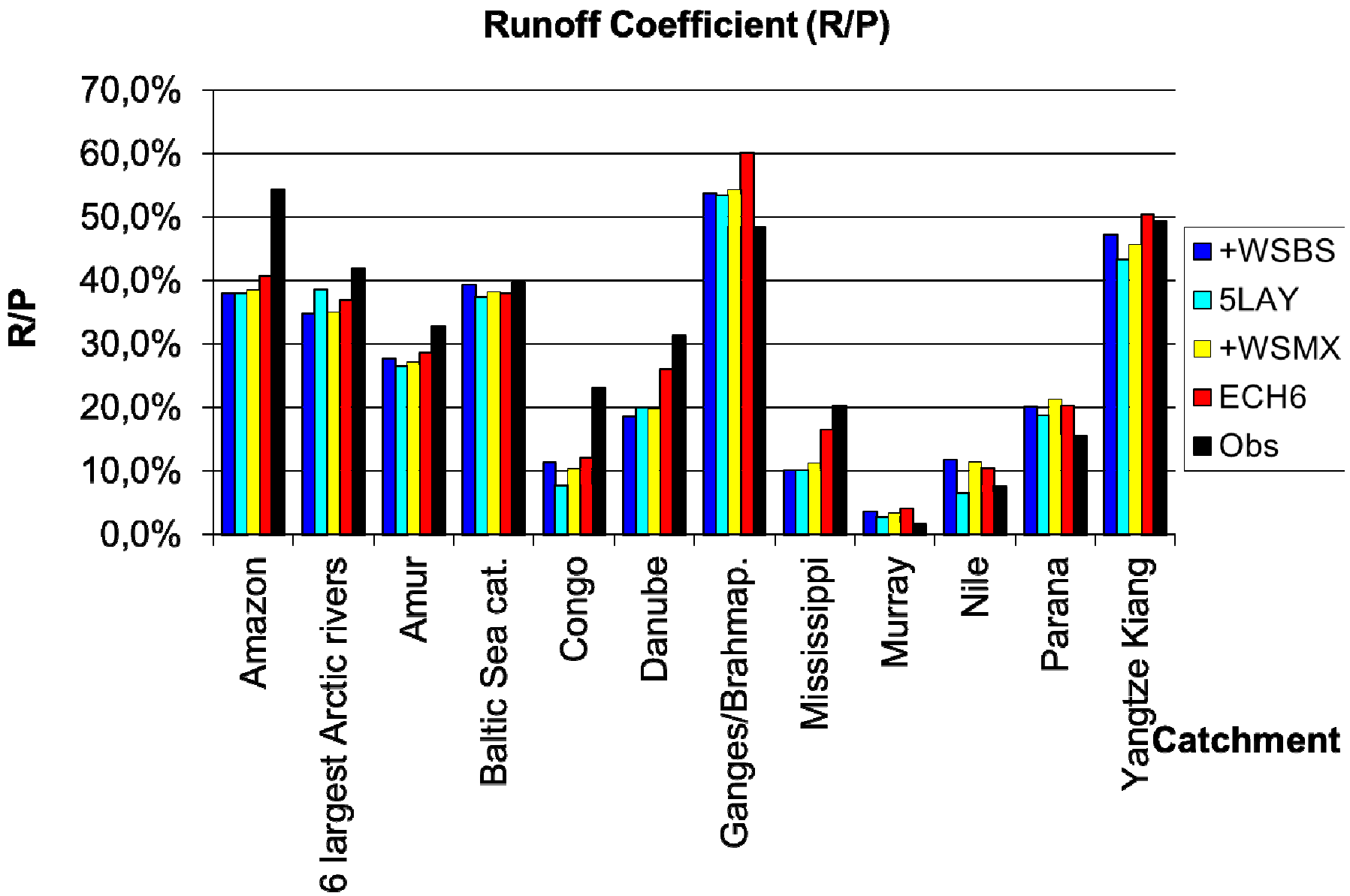
Biases in surface water balance: 1979-1999



Evaporative Fraction (E/P)



Runoff Coefficient (R/P)



Implementation of a 5 layer soil hydrology scheme into JSBACH

Current ECHAM6, JSBACH

Single layer (bucket) with spatially varying soil water holding capacity **WS_{max}**.

- ❖ No soil depth is allocated
- ❖ Processes of Infiltration, Transpiration and lateral drainage depend on bucket soil moisture **WS**
- ❖ Bare Soil Evaporation occurs only from the upper 10 cm of the bucket, i.e. if

$WS_{max} - 10\ cm < WS < WS_{max}$

Future JSBACH

5 layers with increasing thickness (0.065, 0.254, 0.913, 2.902, and 5.7 m), lower boundary at 10m depth

- ❖ Soil temperatures for each layer (such as before)
- ❖ Soil water content Ws_i of 5 layers: Ws_1, Ws_2, ..., Ws_5
- ❖ Bare Soil Evaporation occurs only from the first layer.
- ❖ Drainage (ECHAM4 formulation) may occur from each layer above the bedrock.

Percolation & Diffusion

The vertical movement of moisture θ can be characterized by the one-dimensional Richard`s equation. Here, the local change rate of moisture is related to diffusion and gravitational drainage. Both processes are considered separately in the 5 layer soil hydrology scheme.

Richards equation

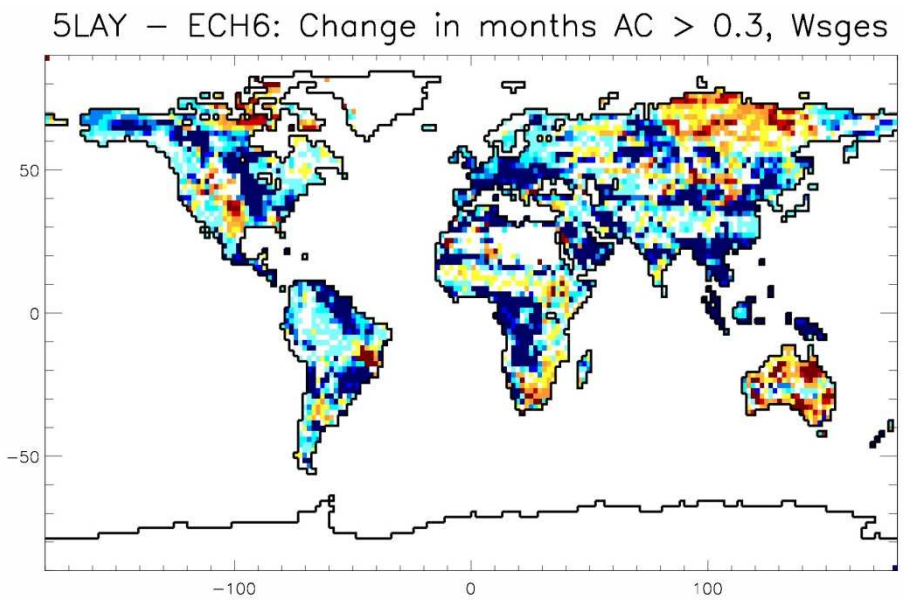
$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(D \cdot \frac{\partial \theta}{\partial z}\right) + \frac{\partial K}{\partial z} + S$$

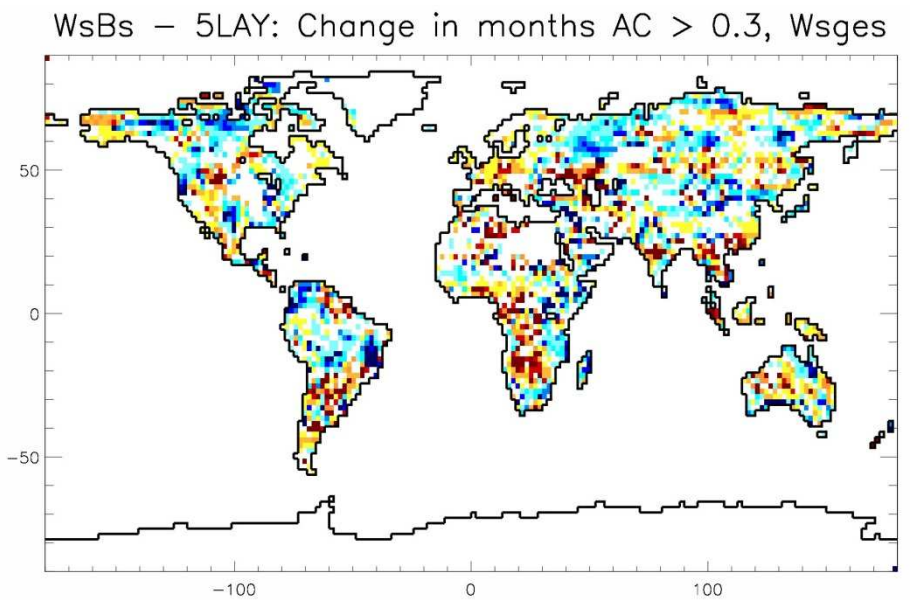
Diffusion

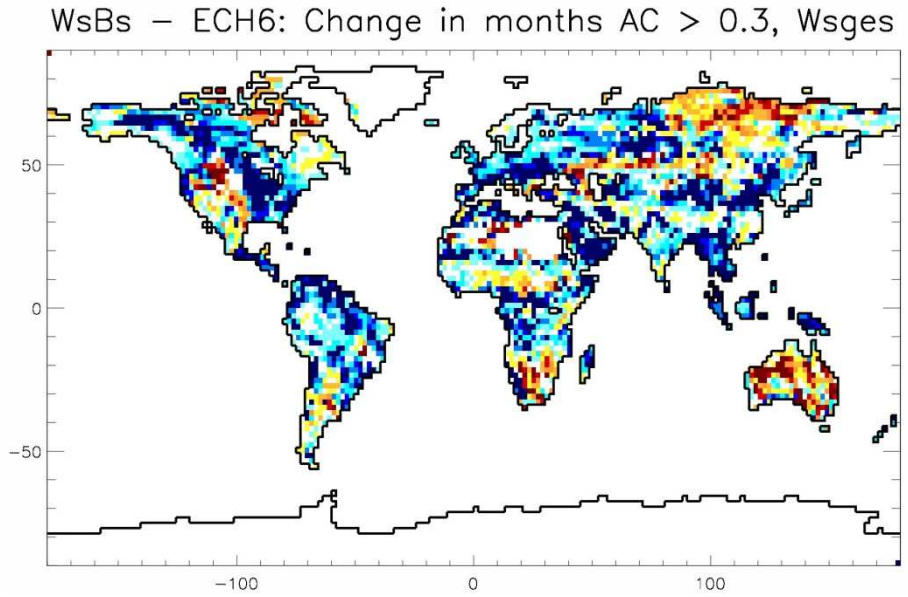
Gravitational drainage

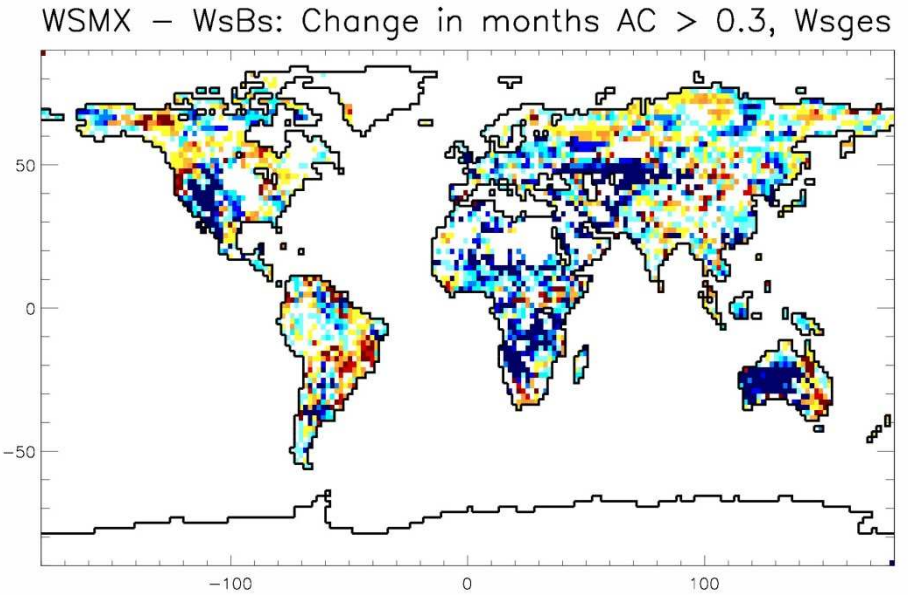
S = Source/Sink term related to infiltration, bare soil evaporation and transpiration

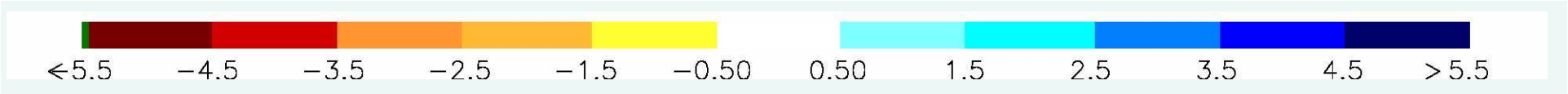
Change in number of months with WS autocorrelation > 0.3



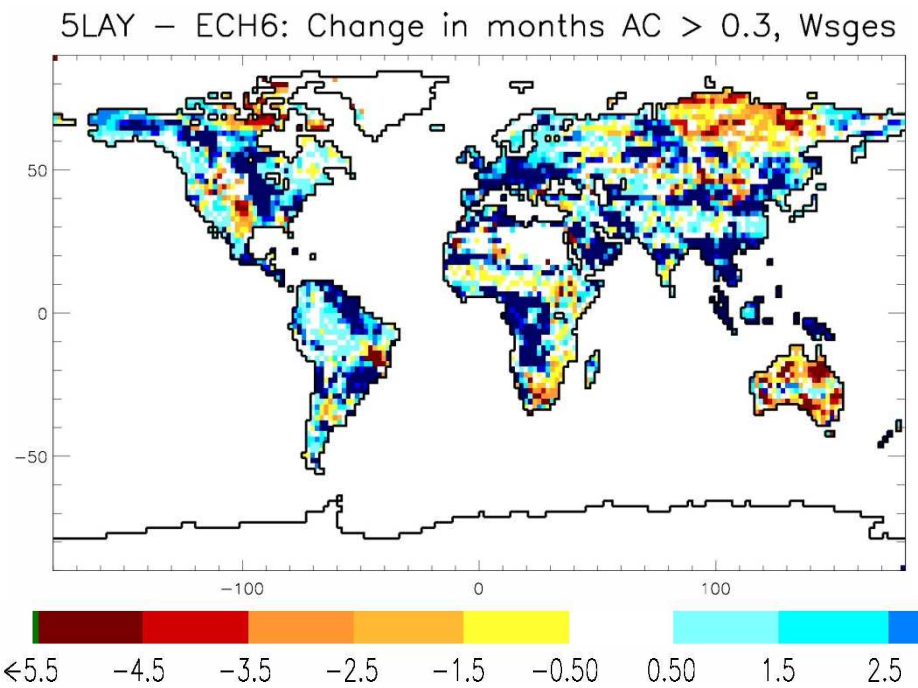


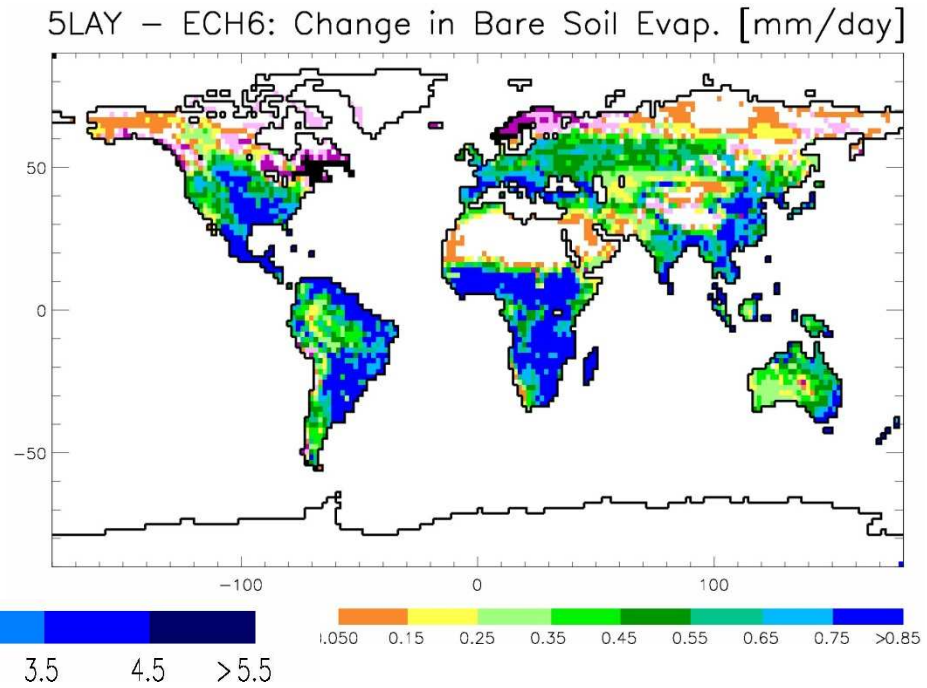


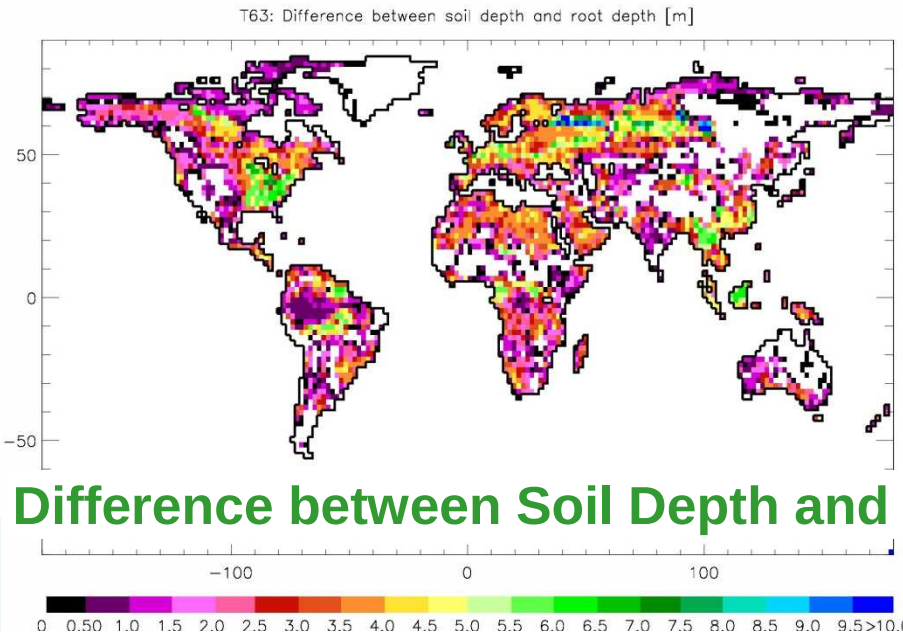


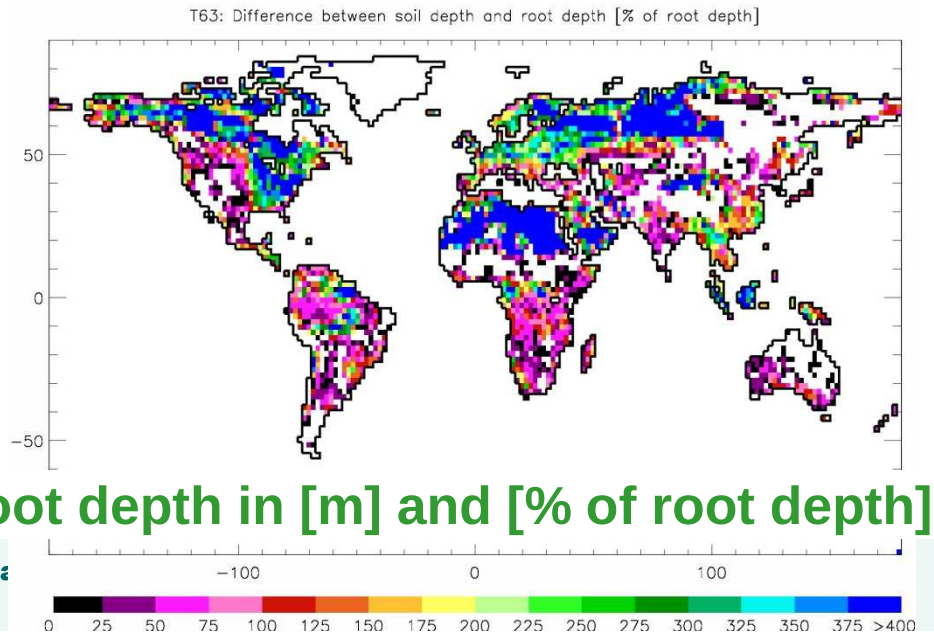


5LAY – ECHAM6



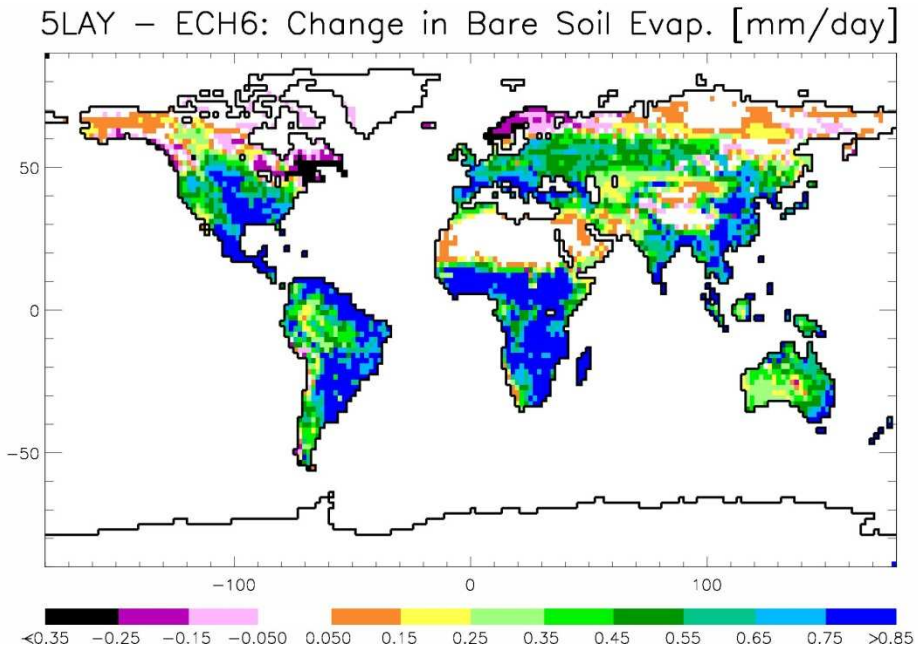


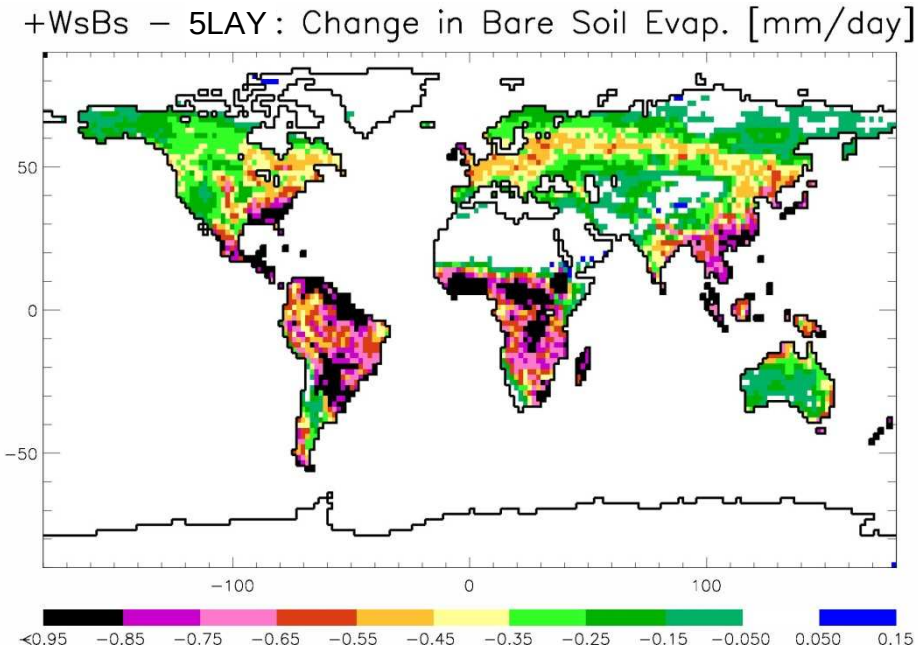


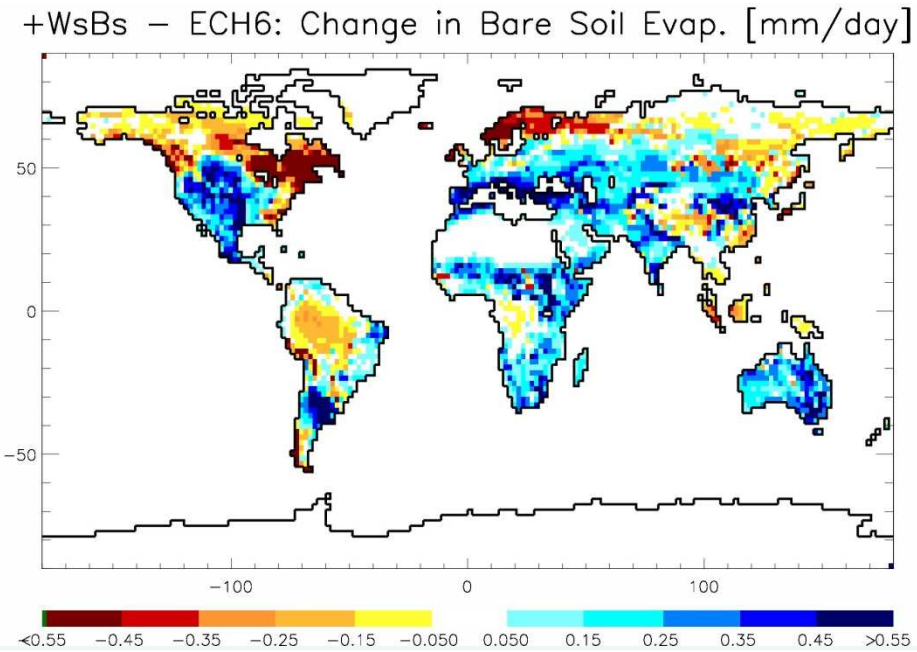


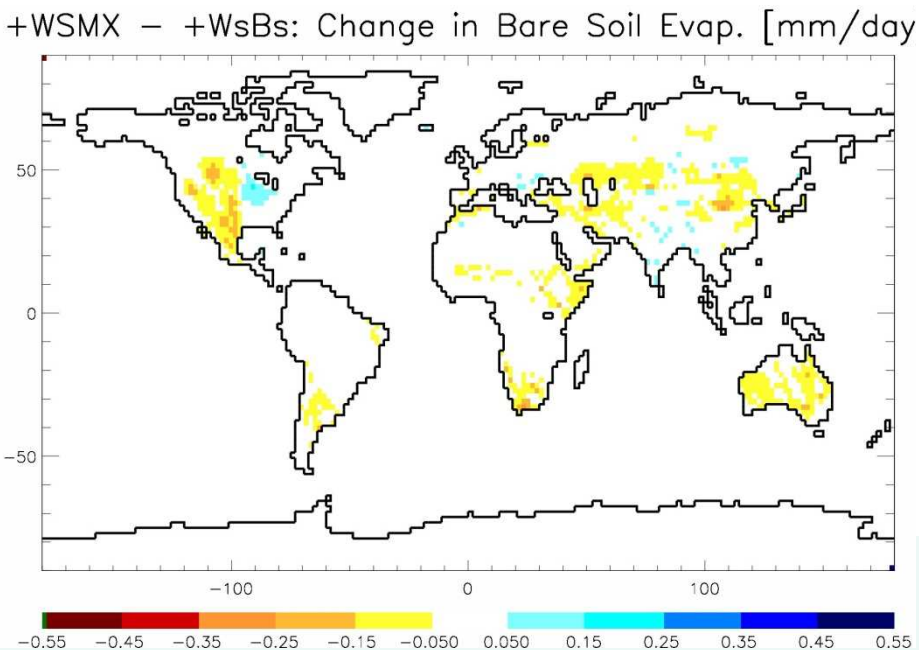
Difference between Soil Depth and root depth in [m] and [% of root depth]

Difference in Bare Soil Evaporation





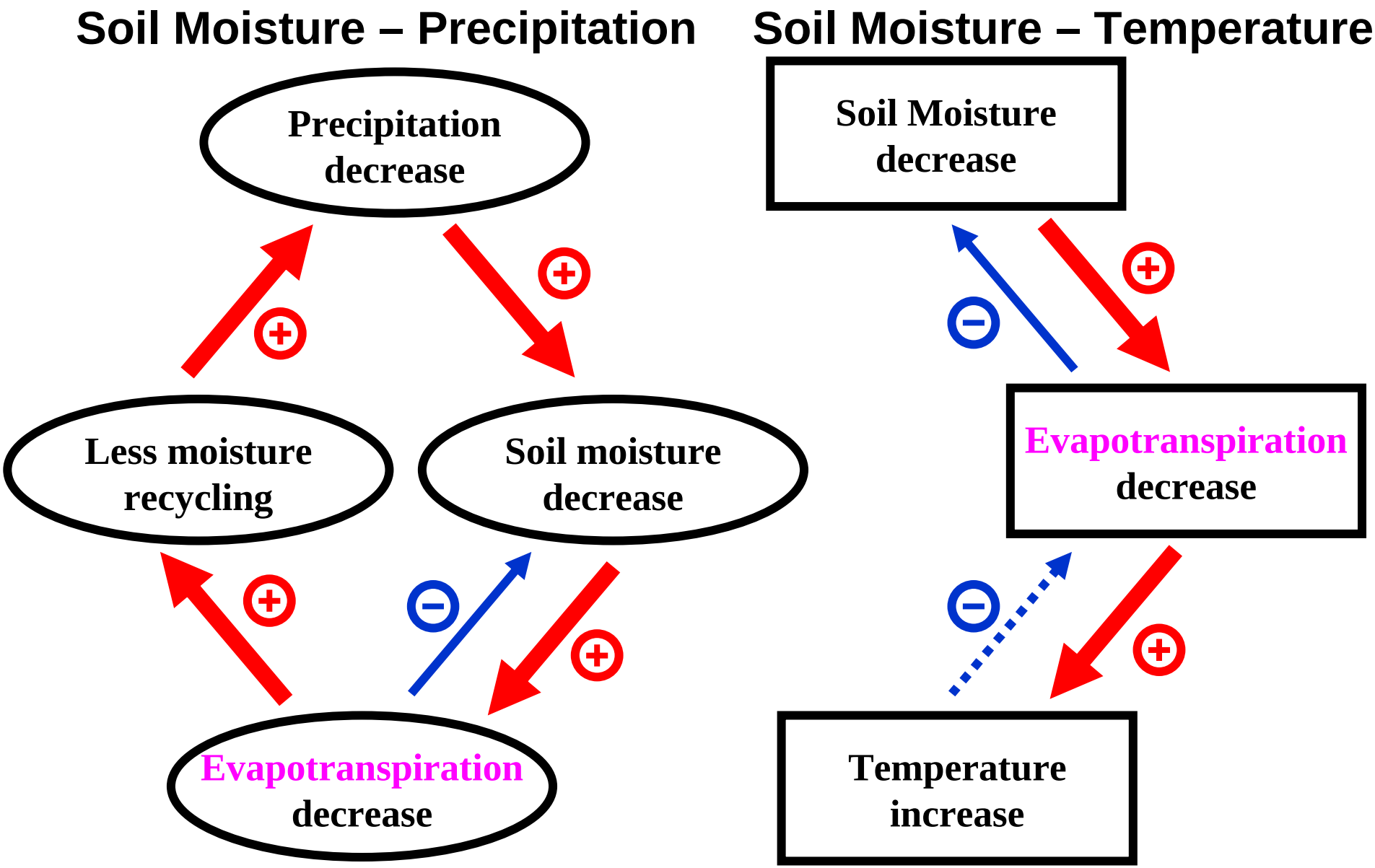




Percolation & Diffusion

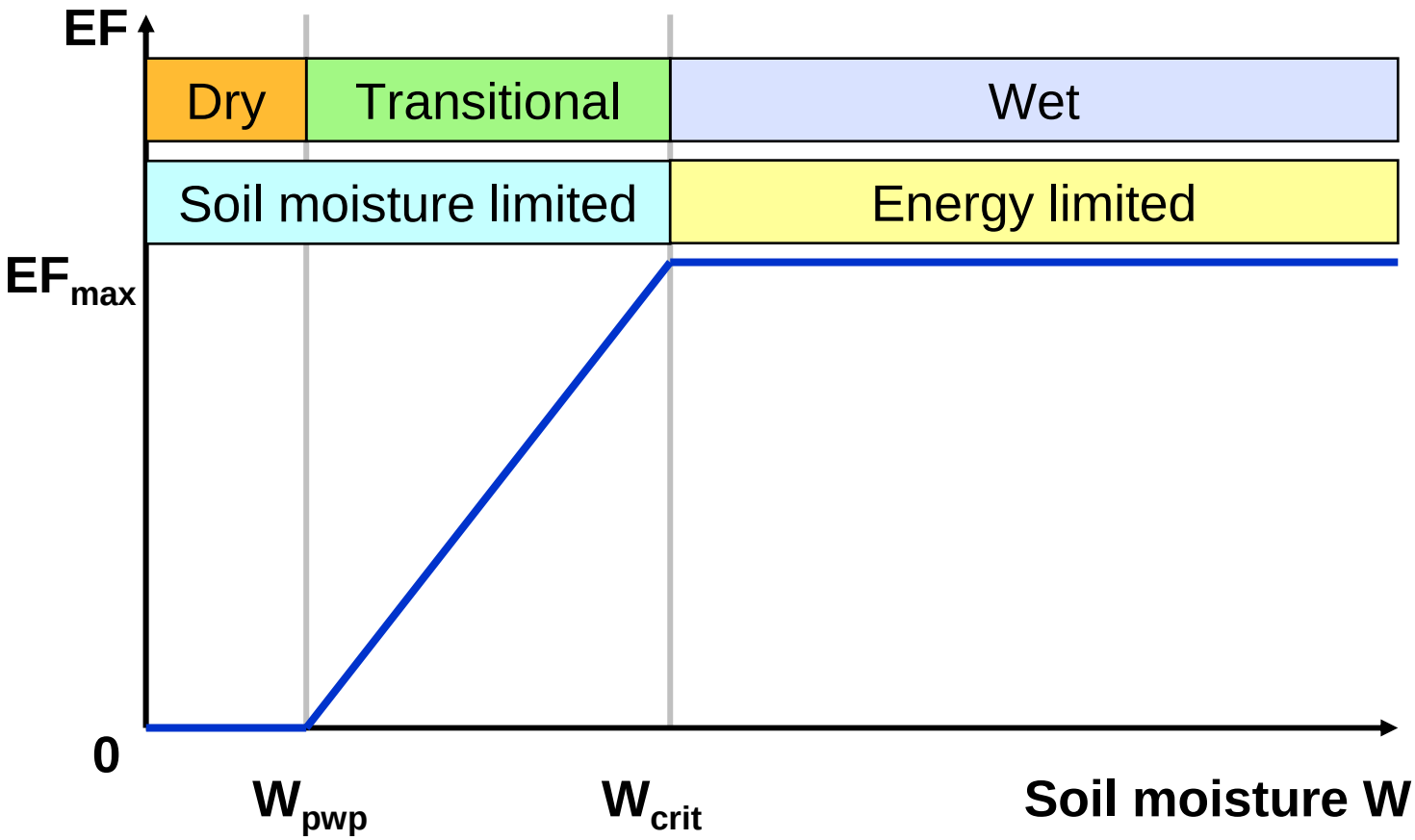
- Percolation by gravitational drainage: van Genuchten method proposed by Disse (1995).
- Soil water diffusivity of each layer: Clapp and Hornberger (1978).
- Diffusivity between two layers is calculated as average of both layer diffusivities.
- Soil water diffusion between the layers is calculated using the Richtmyer and Morton (1967) diffusion scheme.
- Soil parameter values for the different soil textures based on an improved FAO soil type datset (K. Dunne, pers. Comm.) are taken from various sources:
  - Volumetric soil porosity, saturated moisture potential, Saturated hydraulic conductivity: Beringer et al. 2001 (Peat: Letts et al. 2000)
  - Volumetric soil field capacity, wilting point - following Patterson 1990 (Peat: Letts et al. 2000)
  - Volumetric heat capacity and conductivty of dry soil, Exponent b in Clapp and Hornberger eq.: Beringer et al. 2001
  - Soil Pore size distribution index: William and Ahuja 2003 (Peat: Letts et al. 2000)

Soil Moisture Feedbacks



Evapotranspiration regimes

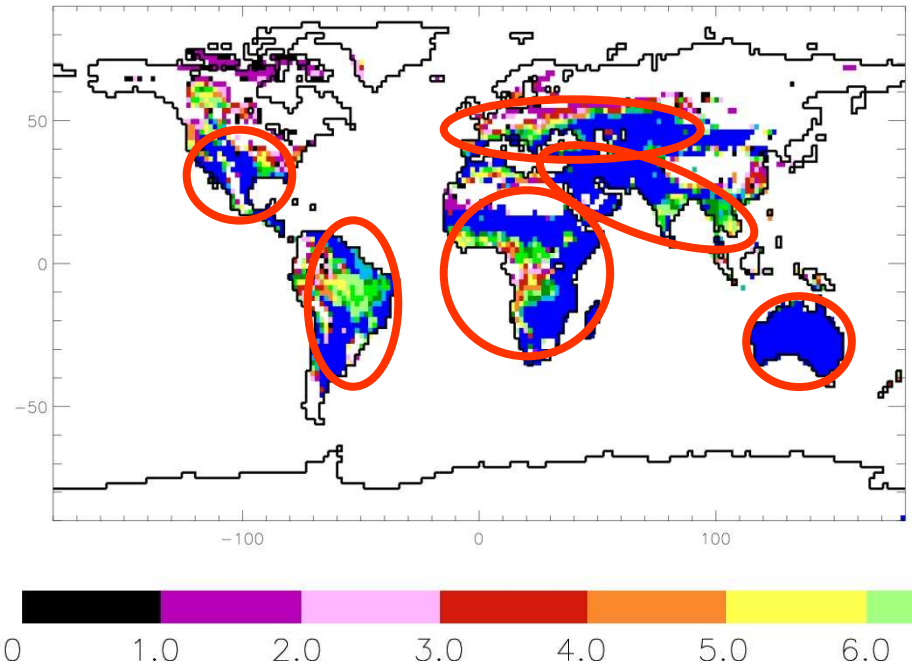
Soil moisture **W** coupling via evapotranspiration **E**
Evaporative Fraction **EF** = actual **E** / available energy

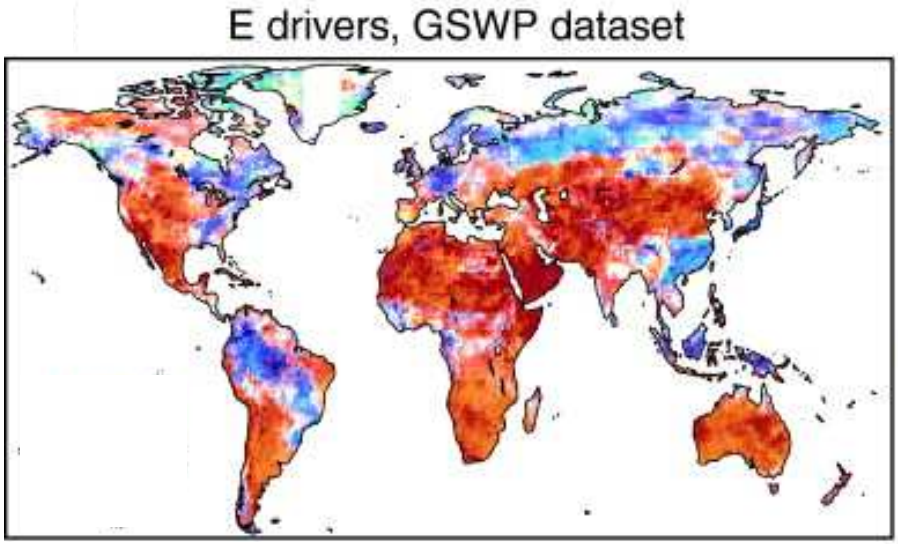


Review on soil moisture feedbacks: Seneviratne et al. (2010)

Transitional soil wetness WS

Number of months/year with $W_{pwp} < WS < W_{crit}$ from ECHAM5/MPIOM ensemble mean monthly climatology for 1961-1990





Teuling et al. (2009)

Driver of evapotranspiration E (**moisture** and **radiation**)

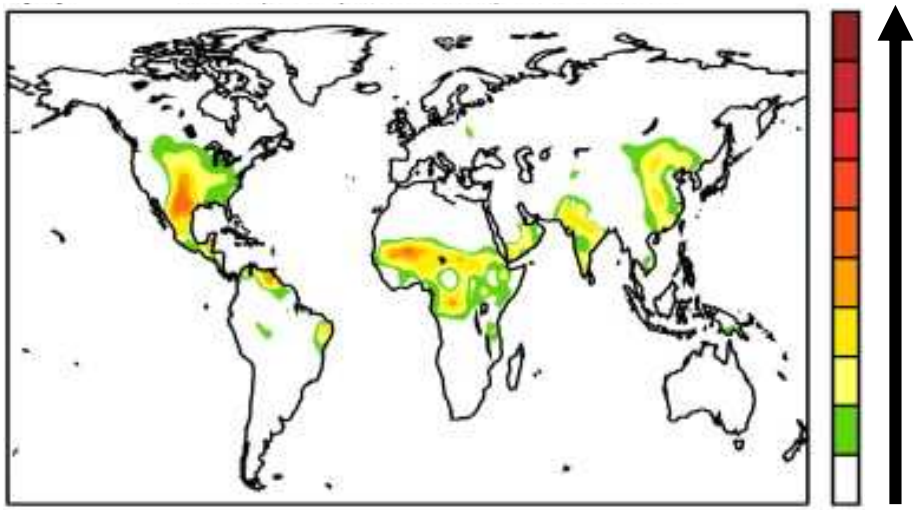
Estimation based on land surface **model** simulations

Yearly correlations of E with global radiation and precipitation.

Soil moisture coupling strength

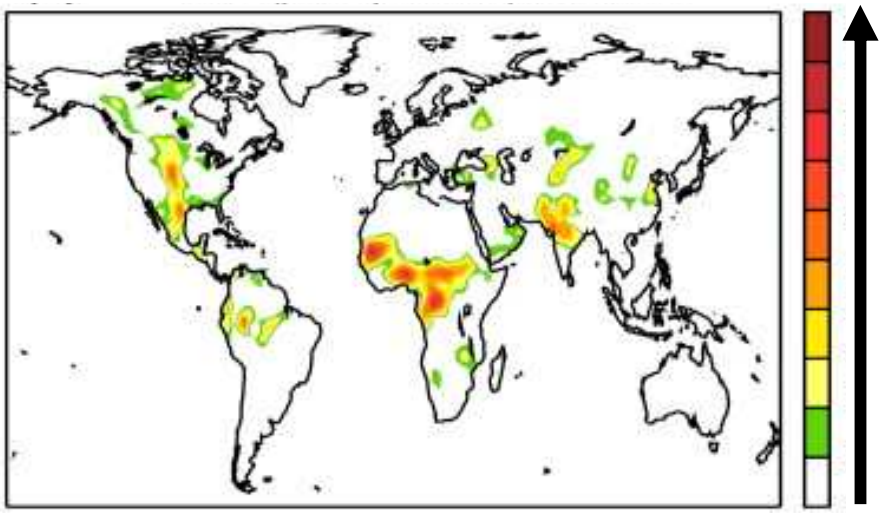
Derived from ensemble simulations of 12 GCMs
with and without prescribed soil moisture (WS) conditions

Temperature T



Koster et al. (2006)

Precipitation P



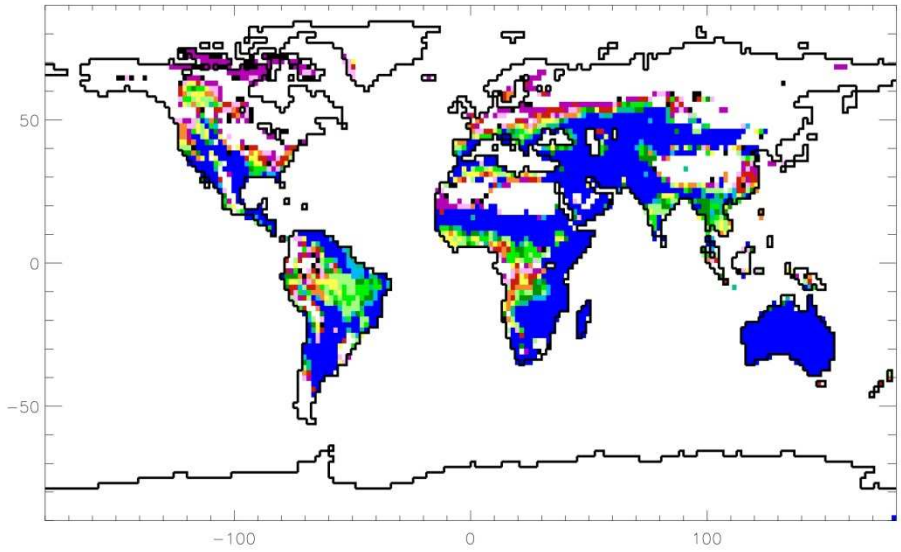
Koster et al. (2004)

Strong coupling: even smaller changes in WS may impact P & T

Transitional soil wetness WS

Number of months/year with $W_{pwp} < WS < W_{crit}$ from ECHAM5/MPIOM ensemble mean monthly climatology

1961-1990



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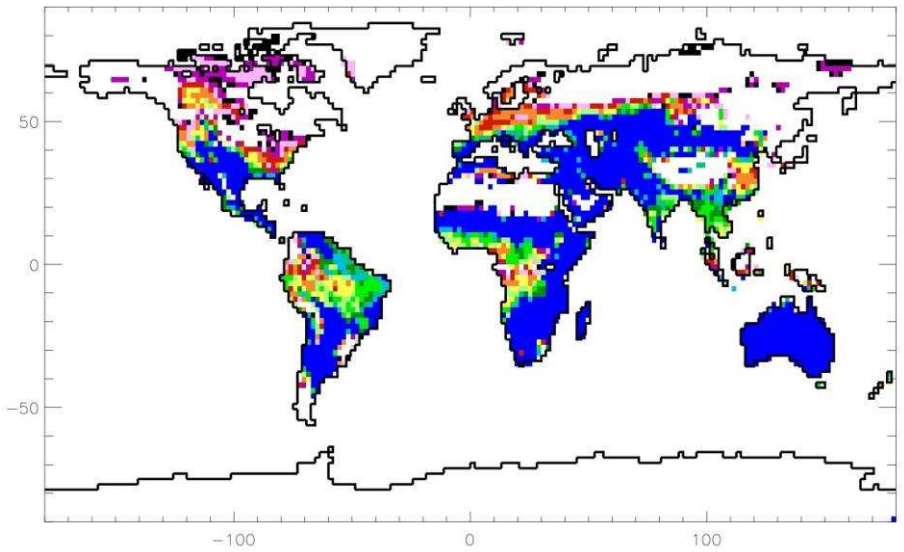

Similar patterns as E-T correlations of Seneviratne et al. (2006) obtained from three GCMs

WS autocorrelation – not the important AC