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Improvement of the simulation of the water and energy cycle using Multiscale Parameter Regionalization (MPR)

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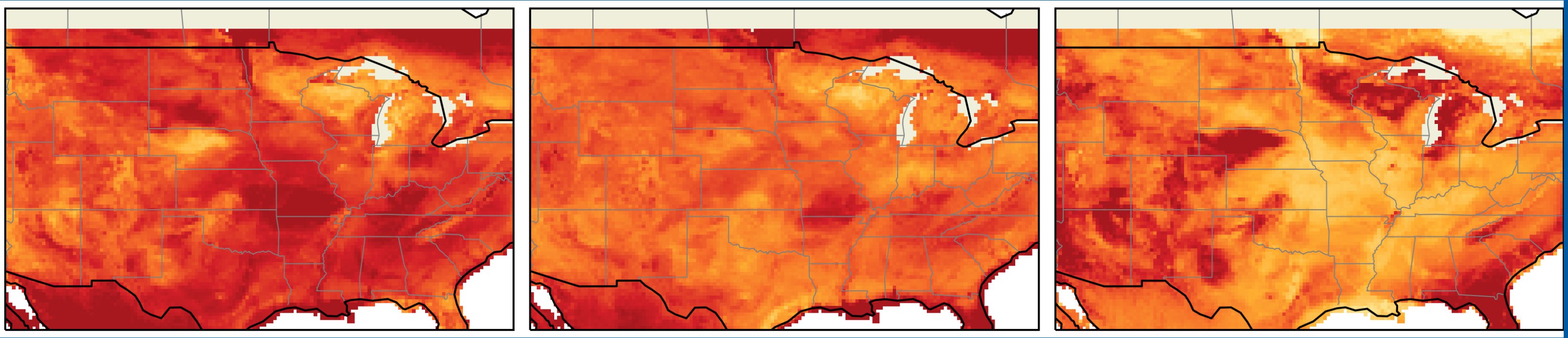
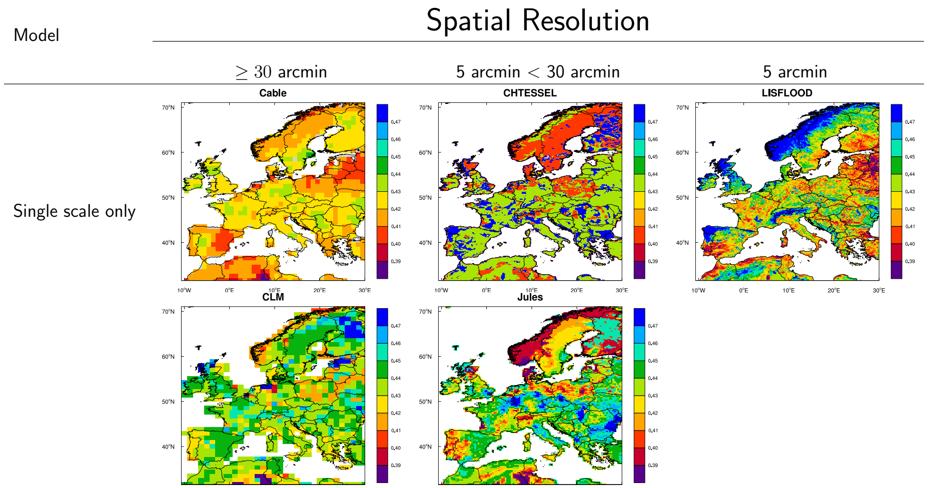


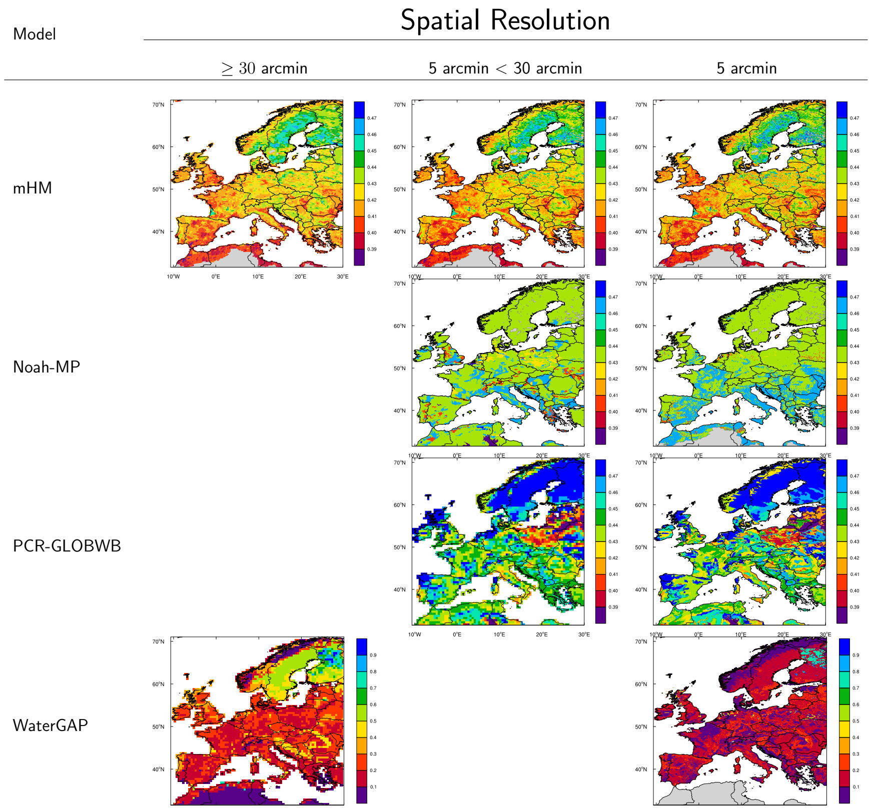
Virtual EGU, 8th May 2020

Introduction

Model parameters such as soil porosity often change with model and spatial modelling resolution (Samaniego et al., 2017). To use environmental models for purposes such as infrastructure planning and weather forecasting, it is crucial to accurately estimate parameters consistently (for each computational unit / grid cell). The dimensionality of the parameter space increases linearly by the number of grid cells, which hampers efficient parameter estimation. The Multiscale Parameter Regionalization (MPR) is a promising approach to solve this problem by regularizing the parameter space.



Soil porosity up to a depth of 2 m for five land-surface models (Samaniego et al. (2017, HESS)).



Soil porosity up to a depth of 2 m for four land-surface models at different spatial resolutions (Samaniego et al. (2017, HESS)).

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Multiscale Parameter Regionalization (MPR)

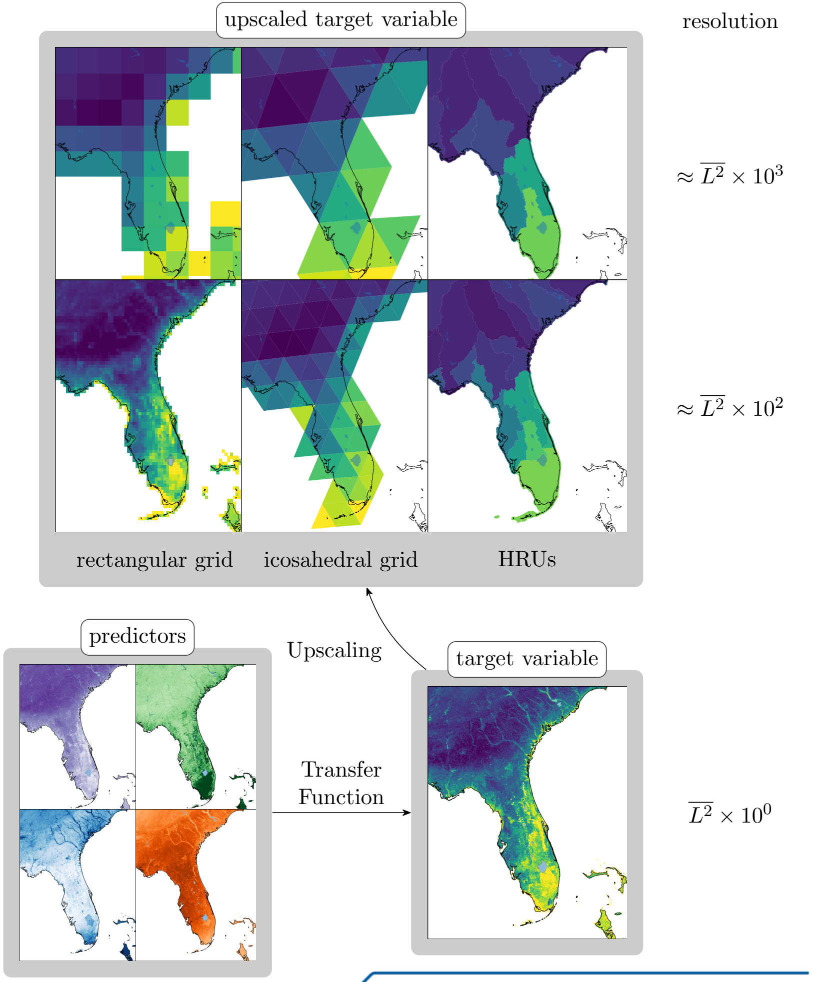
MPR has been developed for the mesoscale Hydrologic Model (mHM, Samaniego et al. 2010) and is now available as a stand-alone tool for applications to other models.
The Multiscale Parameter Regionalization (MPR) uses high-resolution geophysical attributes to estimate model parameters at any spatial resolution and grid type. The Multiscale Parameter Regionalization (MPR) is a modular, stand-alone software that allows to make use of high- resolution data sets for parameter estimation. It consists of two steps:

1. the use of transfer functions to translate high-resolution predictors into high-resolution model parameters,

2. upscaling of high-resolution model parameters to the scale at which the model is applied.

The transfer function and upscaling operator can be freely chosen as a text string in a configuration file (see Appendix). Supported grid types in the upscaling are:

1. Regular rectangular grids,
2. Icosahedral grids,
3. Irregular grids (e.g., Polygons, HRUs).



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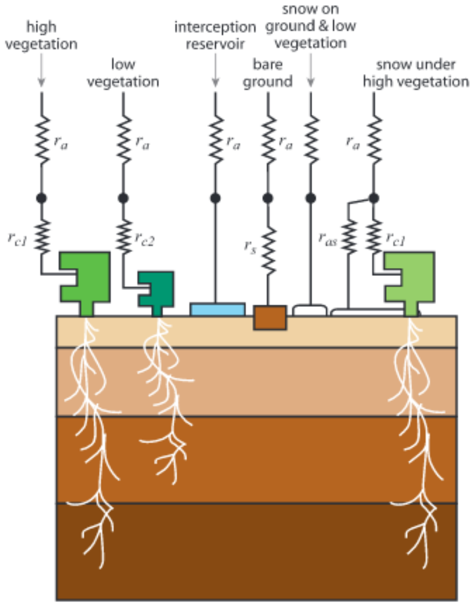
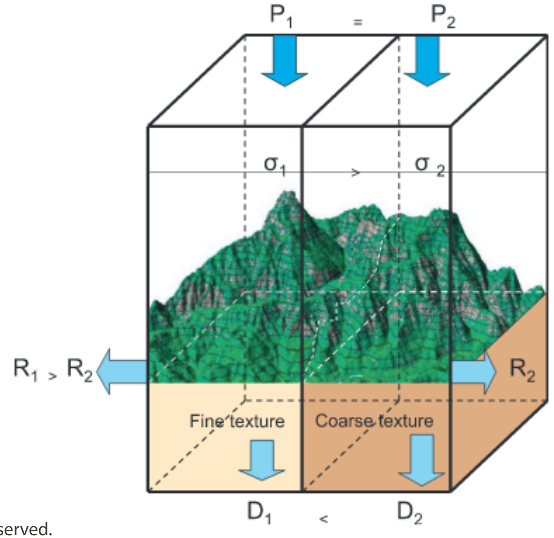
Land-surface model HTESSEL

HTESSEL (Balsamo et al. 2009) is the land-surface scheme used within integrated forecasting system developed at the ECMWF (European Centre for Medium-Range Weather Forecasts). It calculates water, energy and carbon fluxes and storages at the land-surface. HTESSEL uses a tiling approach to represent different land covers within one model grid cell. It uses 20 plant functional types to describe vegetation and constant soil properties throughout the soil column. The soil has a standard depth up to 2.89 m.

In an ongoing effort, we identify hard-coded parameters within the model source code and allow to set them at run time via configuration files (see example for snow density below).





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surf/module/srfsn_lwimp_mod.f90
Use parameters in calculation

```
      ! NEW DENSITY
      PRSN(JL)=ZRSTAR+ZRSTAR*ZRSNDT*PTMST
      PRSN(JL)=MIN(RHOMAXSN_NEW,PRSN(JL))
      PRSN(JL)=MAX(RHOMINSN,PRSN(JL))
```

surf/module/srfsn_lwimp_mod.f90
Use hard-coded value in calculation

```
      ! NEW DENSITY
      PRSN(JL)=ZRSTAR+ZRSTAR*ZRSNDT*PTMST
      PRSN(JL)=MIN(450._JPRB,PRSN(JL))
      PRSN(JL)=MAX(RHOMINSN,PRSN(JL))
```

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Experimental setup

This study focuses on two river basins that cover each a wide hydro-climatic gradient. These are the Mississippi and the Danube river basin.

Danube River Basin

https://commons.wikimedia.org/wiki/File:Danube_basin.png

Mississippi River Basin

https://commons.wikimedia.org/wiki/File:Mississippiriver-new-01.png

Model setup:

- Spatial resolution: 0.25°
- Meteo forcing: ERA5 dataset (C3S, 2017)

Default setup: seven soil types based on FAO soil map (Balsamo et al. 2009).

- MPR setup:
  - We used MPR to calculate spatially distributed soil parameters for the Van Genuchten water retention curve (Genuchten (1980)), saturated hydraulic conductivity, porosity. These parameters affect hydraulic conductivity (eq. 1) and soil saturation (eq. 2) below.
  - We used two transfer functions: these are Zacharias et al. (2007) and Weynants et al. (2009).

Eq. 1: $$\gamma = \gamma_{\text{sat}} \frac{[(1+(\alpha h)^n)^{1-1/n} - (\alpha h)^{n-1}]^2}{(1+(\alpha h)^n)^{(1-1/n)(l+2)}}$$

Eq. 2: $$\theta(h) = \theta_r + \frac{\theta_{sat} - \theta_r}{(1+(\alpha h)^n)^{1-1/n}}$$

MPR setup — transfer functions

The HTESSEL model parameters γ_{sat} is the saturated hydraulic conductivity (eq. 1) and θ_{sat} is the soil porosity (eq. 2). The α, l, and n are the Van Genuchten (1980) soil parameters. These are calculated with the following pedo-transfer functions.

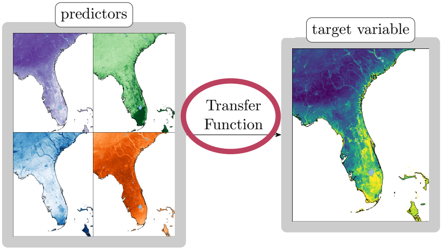
MPR setup for Weynants et al. (2009) PTF

$$\gamma_{sat} = exp(-1.8642 - 0.1317\ c + 0.0067s),$$
$$\alpha = 100\ exp(-4.30 - 0.01c + 0.01s - 0.1o),$$
$$n = exp(-1.01 - 0.02c - 0.01s + 0.0001s^2) + 1,$$
$$l = -1.86 - 0.13c + 0.01s,$$
$$\theta_{sat} = 0.64 + 0.001c - 0.16\rho$$

where c - clay content, s - sand content, o - organic matter content, ρ - bulk density. These soil texture properties have been obtained from the SoilGrids database (Hengl et al. (2016)).

MPR setup for Zacharias et al. (2007) PTF

$$\gamma_{sat} = exp(-0.884 + 0.0153s),$$
$$l = -1,$$
$$if(s < 66.5)$$
$$\alpha = exp(-0.648 + 0.023s + 0.044c - 3.168\rho),$$
$$n = -1.392 - 0.418s^{-0.024} + 1.212c^{-0.704},$$
$$\theta_{sat} = 0.788 + 0.001c - 0.263\rho,$$
$$else$$
$$\alpha = exp(-4.197 + 0.013s + 0.076c - 0.276\rho),$$
$$n = -2.562 - 7e - 9s^{4.004} + 3.75c^{-0.016},$$
$$\theta_{sat} = 0.890 - 0.001c - 0.322\rho$$



$\overline{L^2} \times 10^0$

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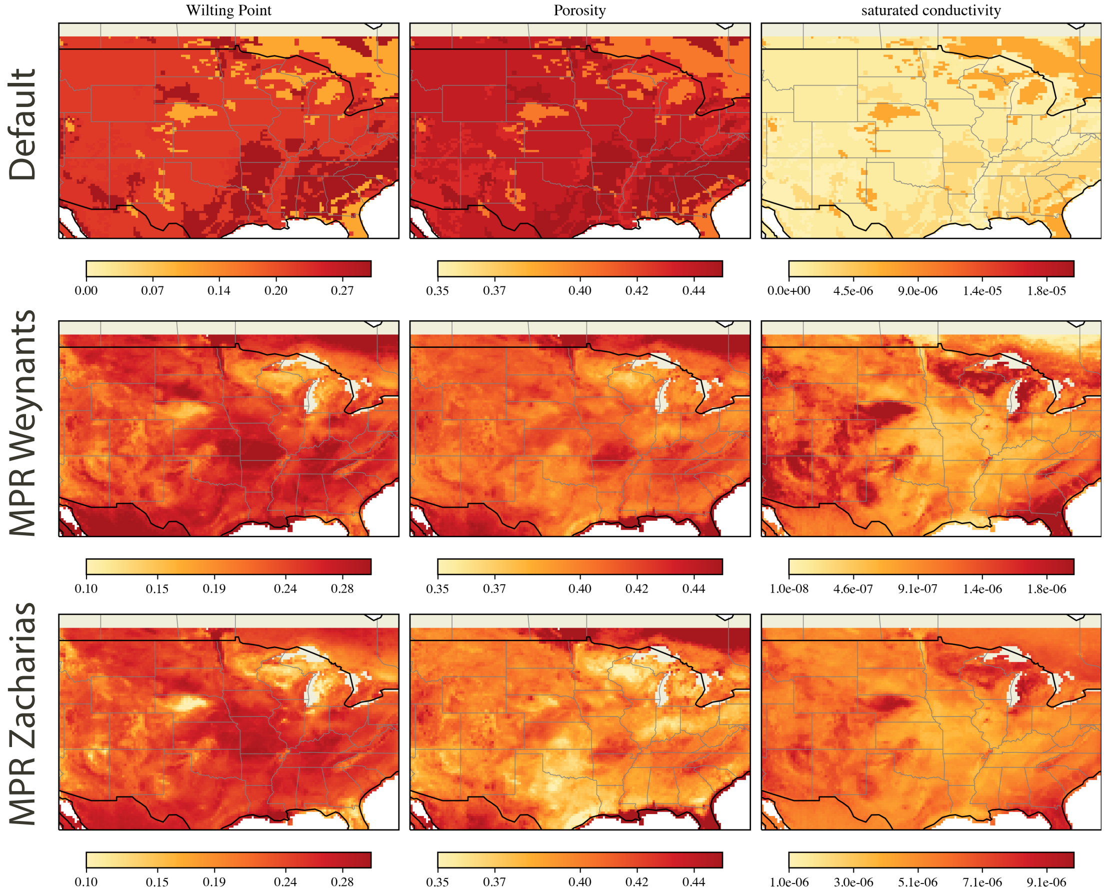
Mississippi river: MPR setup — results

Default setup:
Based on seven soil types:
Five are used in the modelling domain. No continuity of values as in the case using MPR.

MPR setup for Weynants PTF
Wilting point is higher, porosity is lower and saturated conductivity is higher compared to the default case.

MPR setup for Zacharias PTF
Similar to Weynants, but with a higher spatial variability.



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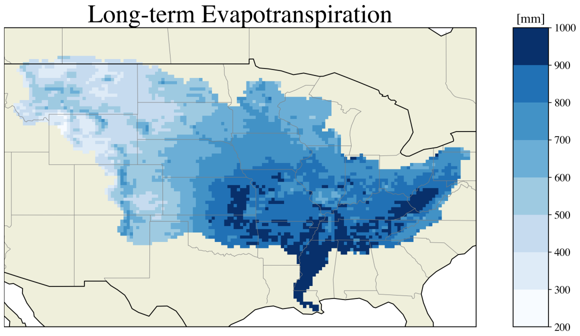
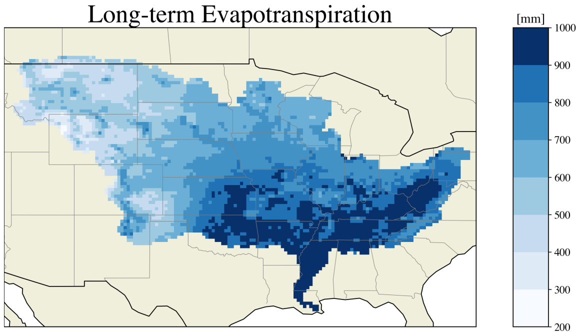
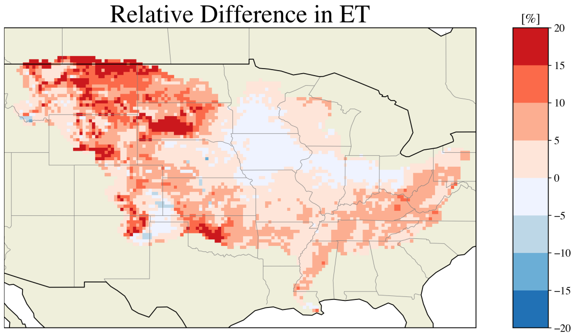
First results HTESSEL/MPR — atmospheric fluxes

Default

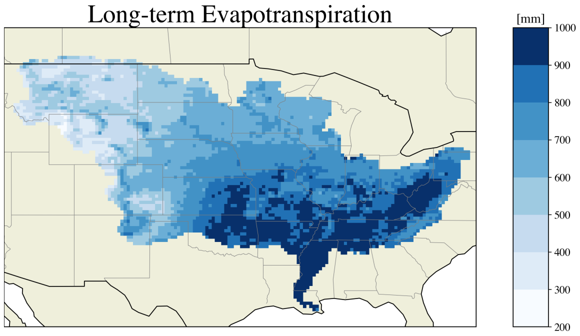


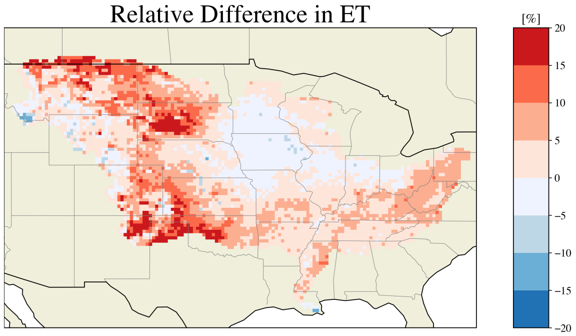
MPR Weynants





MPR Zacharias





The spatial pattern of long-term ET is comparable for all three setups, but setups using MPR lead to higher ET fluxes. Differences between the two transfer functions used are negligible.

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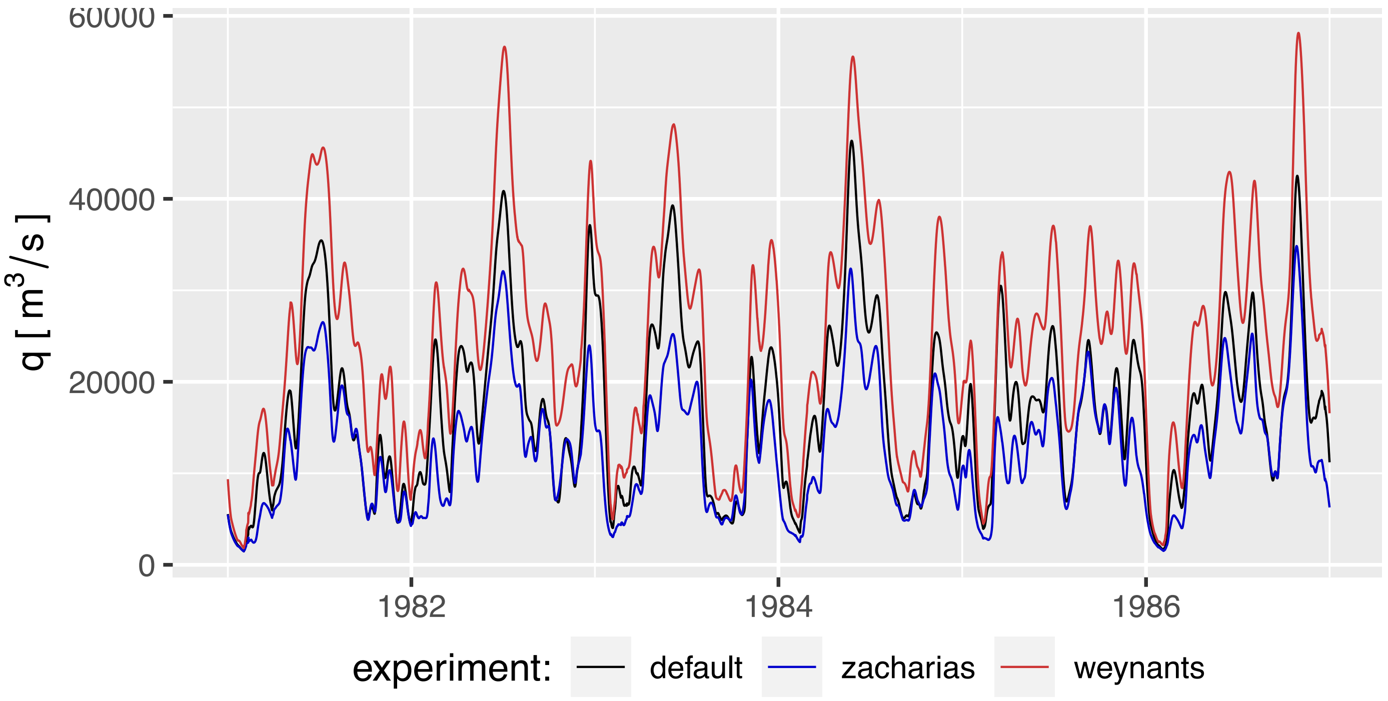
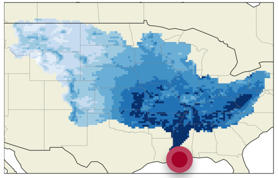
Mississippi river: First results HTESSEL/MPR — streamflow

The dynamics and long-term value of streamflow depend on the model setup. The MPR setup using the Weynants transfer functions leads to more streamflow than the default setup. The MPR setup using the Zacharias transfer function leads to less.





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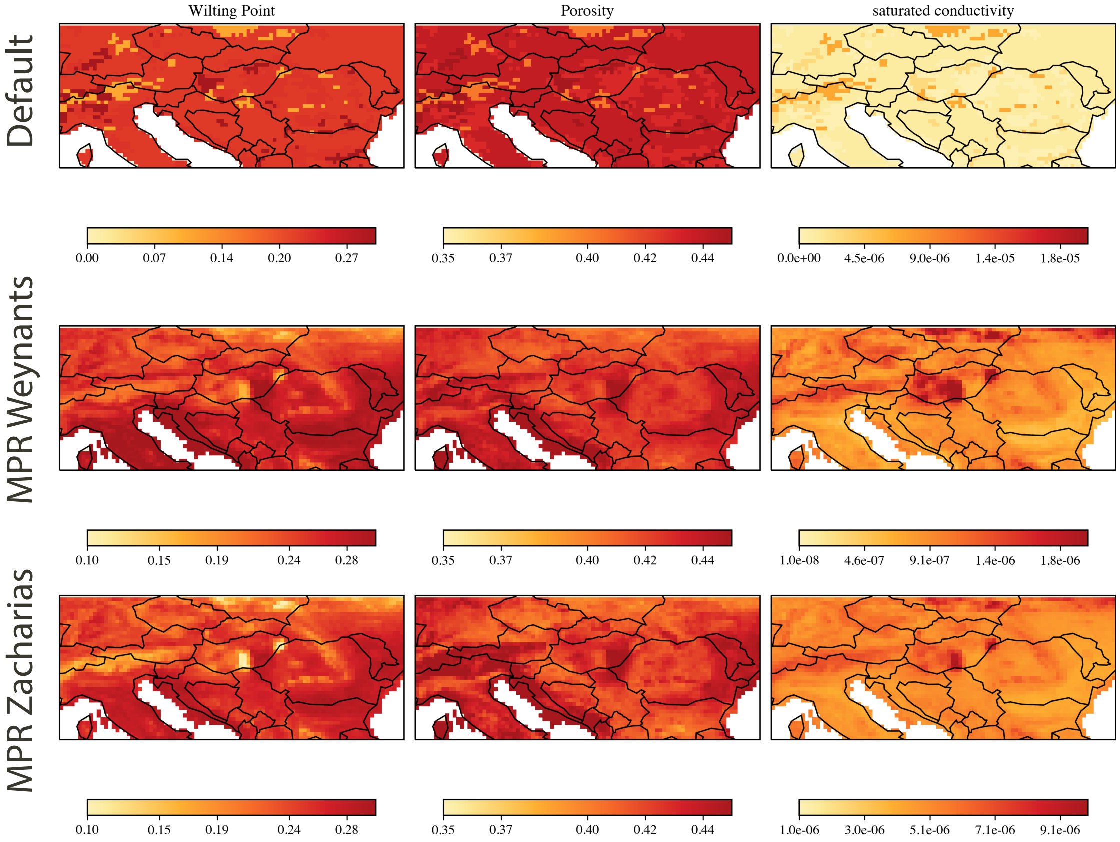
Danube river: MPR setup - results

Default setup:
Based on seven soil types:
Five are used in the modelling domain. No continuity of values as in the case using MPR.

MPR setup for Weynants PTF
Wilting point is higher, porosity is lower and saturated conductivity is higher compared to the default case.

MPR setup for Zacharias PTF
Spatial fields are comparable to those using the Weynants PTF.



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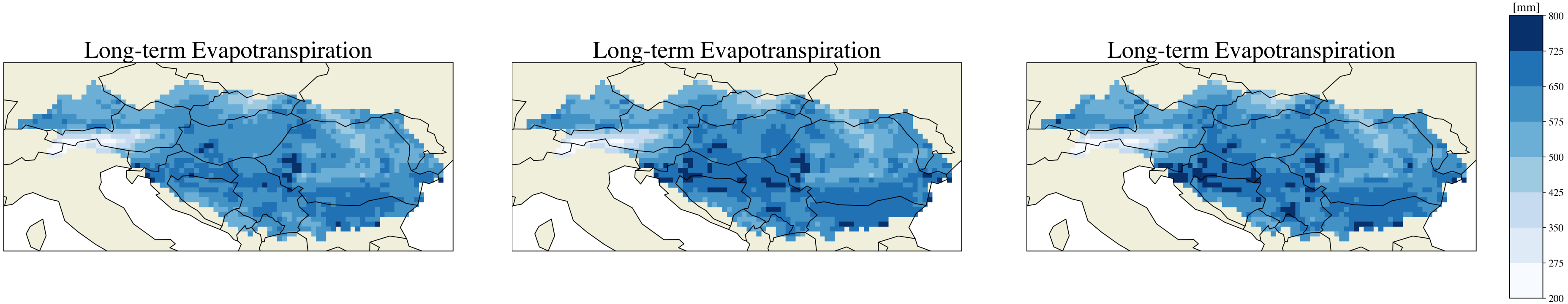
First results HTESSEL/MPR — atmospheric fluxes

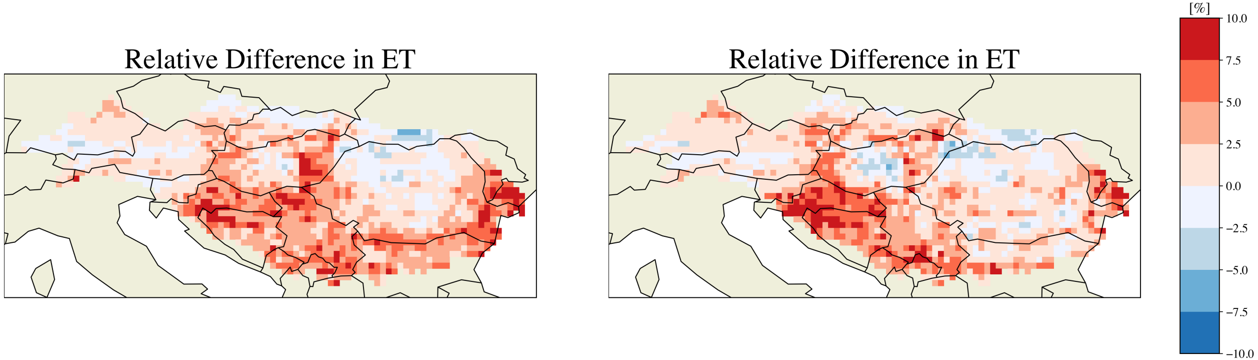
Default

MPR Weynants

MPR Zacharias



The spatial pattern of long-term ET is comparable for all three setups with differences between the setups being in general less than 10% in magnitude.



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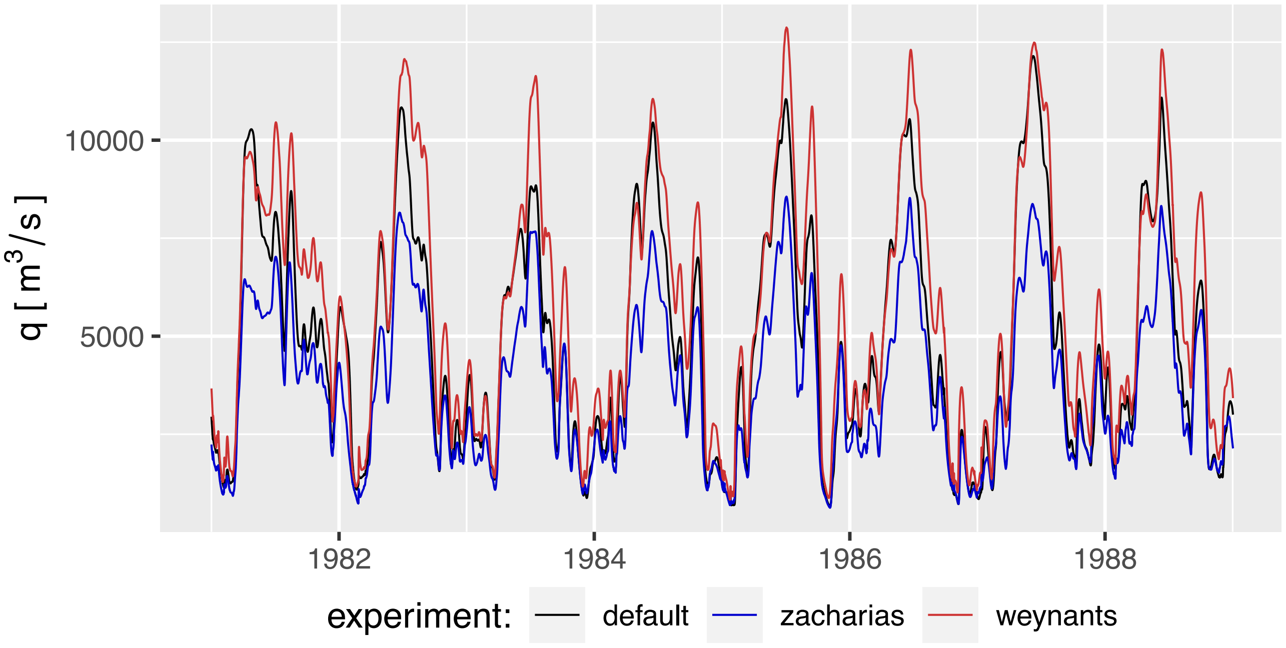
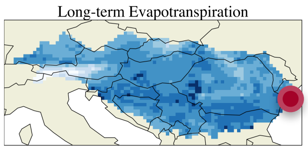
Danube river: First results HTESSEL/MPR — streamflow

Long-term value of streamflow depend on the model setup. The different temporal dynamics for the different setups highlight the non-linear relationship between soil parameters and model behaviour.





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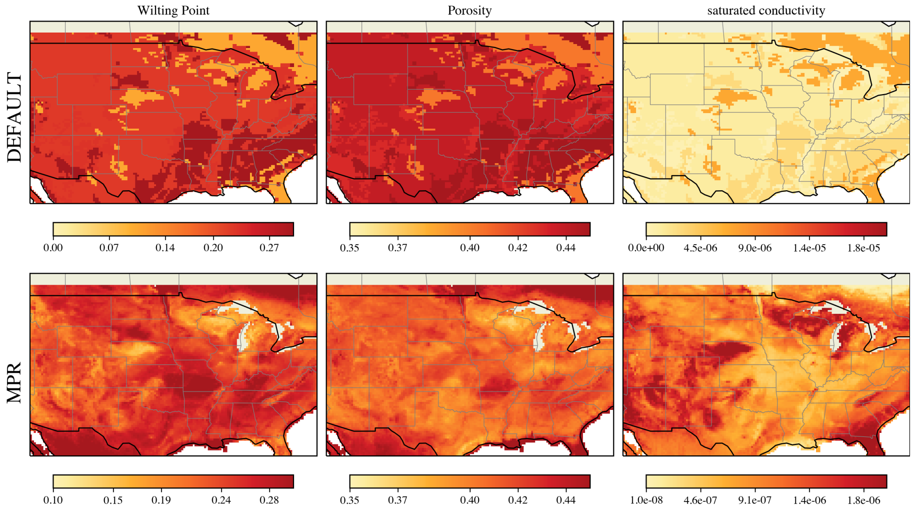
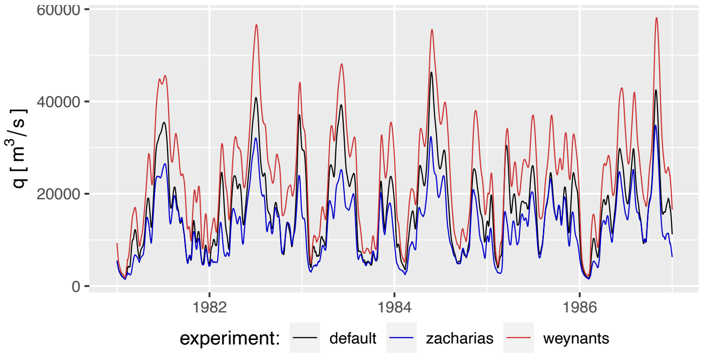
Conclusions

1. Refactored HTessel source code provides more flexibility for global parameters and spatially distributed parameters.
2. Simulated atmospheric (i.e., Evapotranspiration) and lateral (i.e., streamflow) show high sensitivity to soil parameters in HTessel that have been fixed before.
3. The choice of transfer function in MPR has a large impact on the simulated streamflow in HTessel.





Outlook

1. In the next steps, transfer function parameters in MPR will be calibrated to improve performance of HTessel for simulating streamflow.
2. MPR will be applied to other models and spatial grids to gain understanding how transfer functions affect simulated hydrologic fluxes across models and scales.

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Appendix

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Multiscale Parameter Regionalization — configuration file

On the right, an example namelist is shown that configure MPR to estimate hydraulic conductivity for the SoilGrids Dataset (Hengl et al., 2017) using the transfer function from Weynants et al. (2009).

The first block defines all data arrays. Data arrays can be read from file as is the case for the first three data arrays or be derived from other data arrays via transfer functions.

The second block defines all parameters that are used in the processing.

The third block defines all coordinate dimensions that are used within the upscaling.

The fourth block contains information on which coordinate variables describe the same dimension and the output file.

```
&Data_Arrays
  ! predictor variables
  name(1) = 'sand'
  from_file(1) = './input/sand_content.nc',
  name(2) = 'om'
  from_file(2) = './input/organic_matter.nc',
  name(3) = 'bd'
  from_file(3) = './input/bulk_density.nc'
  transfer_func(3) = 'BLDFIE_M / unit_conversion_1',
  ! target variable
  name(4) = 'k_zero'
  from_data_arrays(1:3,4) = 'sand', 'clay', 'bd'
  transfer_func(4) = 'exp(a5 + c5 * sand + d5 * bd + e5 * om) /
      unit_conversion_2'
  target_coord_names(1:2,4) = 'soil_layers', 'target_grid'
  upscale_ops(1:2,4) = '-1.0', '1.0'
  to_file(4) = .true.
/
&Parameters
  ! unit conversion constants
  parameter_names(1:2) = 'unit_conversion_1', 'unit_conversion_2'
  parameter_values(1:2) = 1000.0, 8640000.0
  ! global parameters
  parameter_names(3:6) = 'a5', 'c5', 'd5','e5'
  parameter_values(3:6) = 1.9582, 0.0308, -0.6142, -0.1566
/
&Coordinates
  ! specifications for the vertical target coordinate
  coord_name(1) = 'soil_layers'
  coord_from_values(1:4,1) = 0.1, 0.4, 1.0, 2.0
  coord_cell_reference(1) = 'end'
  coord_from_values_bound(1) = 0.0
  ! specifications for the horizontal target coordinate
  coord_name(2) = 'target_grid'
  coord_from_file(2) = './input/target_grid.nc'
  coord_sub_dims(1:2,2) = 'x', 'y'
/
&Main
  coordinate_group(1:3,1) = 'x', 'lon', 'target_grid'
  coordinate_group(1:3,2) = 'y', 'lat', 'target_grid'
  coordinate_group(1:3,3) = 'z', 'depth', 'soil_layers'
  out_filename = '/OutputPath/OutputFile.nc'
/
```

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