ETH zürich

IAC Institute for Atmospheric and Climate Science

A modified slope-dependent formulation for groundwater runoff in a regional climate model

Linda Schlemmer, Christoph Schär, Daniel Lüthi, Lukas Strebel
Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

Motivation

- Soil moisture influences the state of the atmosphere by regulating the partitioning of the available energy into sensible and latent heat fluxes
- The water transport and ground-water runoff in the soil are often handled in a very crude way in many weather and climate models
- Many global and regional climate models (RCMs) show an unrealistically large drying of the soil during summer and fall.
- This summer-drying is suspected to support too warm summer temperatures in climate simulations (e.g. Vidale et al., 2007, Christensen and Boberg 2012)

In this study:

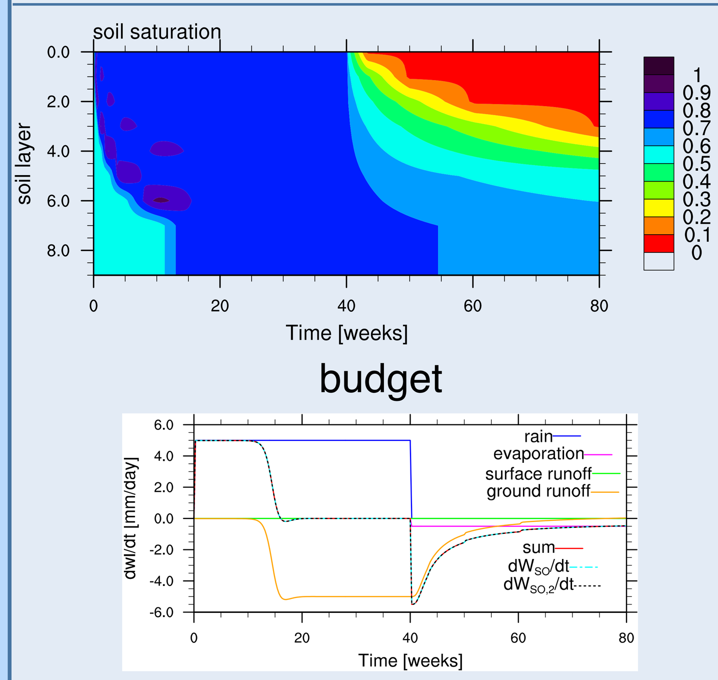
Take a heuristic approach that extends the Richards-equation formulation for soil-water transport:

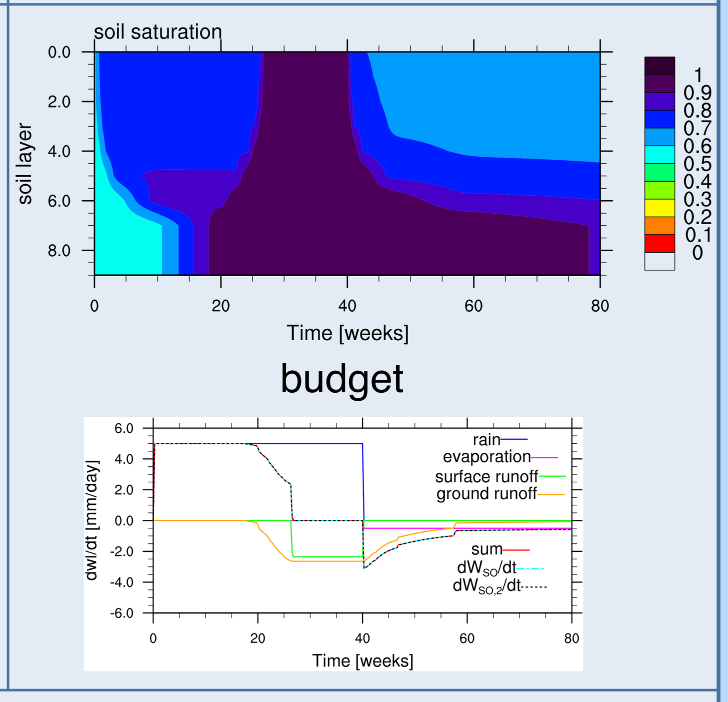
- Introduce limiters to the soil-water fluxes
- Implement a modified formulation for ground-water runoff
- Implement the new approach into the land-surface model TERRA_ML of the RCM COSMO-CLM

Idealized, stand-alone (offline) single column model

TERRA_ML: 40 weeks constant rain, 40 weeks constant evaporation from soil

old (default)	new



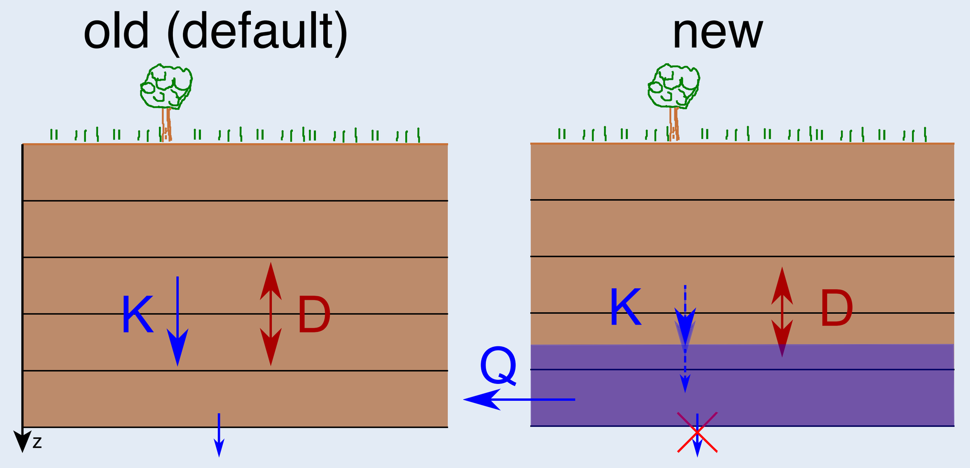


- Ground water can build up in the modified formulation ⟶ water storage
- Larger soil-water content after the 40-week evaporation period in the new formulation.

Conclusions

- A new formulation for vertical ground-water transport and runoff has been developed and implemented both in an idealized, and a regional climate model (RCM).
- The new formulation enables the buildup of ground-water storage.
- The ground-water runoff depends on the slope of the underlying orography.
- The idealized test case shows a physically meaningful behaviour of the soil water
- RCM simulations show very promising results, especially:
  - A reduction of a long-standing warm-temperature bias in the Mediterranean and Eastern European region.
  - A more realistic distribution of the soil-moisture content with altitude.
- High-resolution climate simulations (Δx=12km, 2km) show an improvement using the modified formulation (not shown).

Model Formulation



Soil-water fluxes *F*:

The vertical flux *F* of soil water is governed by the Richards Equation:

$$F = -\rho_w \cdot \left[-D(\theta)\frac{\partial \theta}{\partial z} + K(\theta) \right]$$

ρ_w: density of water, θ: volumetric water content, *D*: diffusivity, *K*: conductivity.

- In the standard formulation of TERRA_ML a free drainage condition is implemented at the lower boundary. This prohibits the buildup of ground water in the soil ⟶ no-flux lower boundary condition.
- The Richards equation computes the fluxes based on *D* and *K*. If *θ exceeds* the porosity *η* the fluxes must be limited to ensure mass conservation.

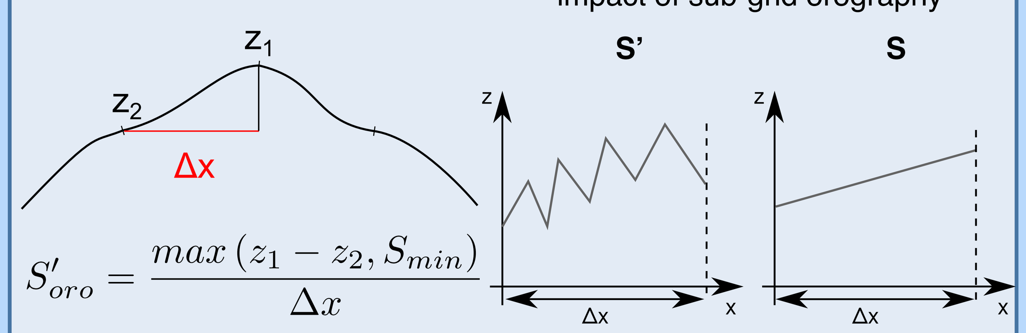
Ground water runoff *Q*:

Q is computed diagnostically:

$$Q = \gamma \cdot K_0(k) \cdot S_{oro} \cdot h_{wt}(k)$$

γ: tuning constant
K_0: saturated hydraulic conductivity
S_{oro}: gradient of (sub-grid) orography
h_{wt}: depth of groundwater table
k: soil level

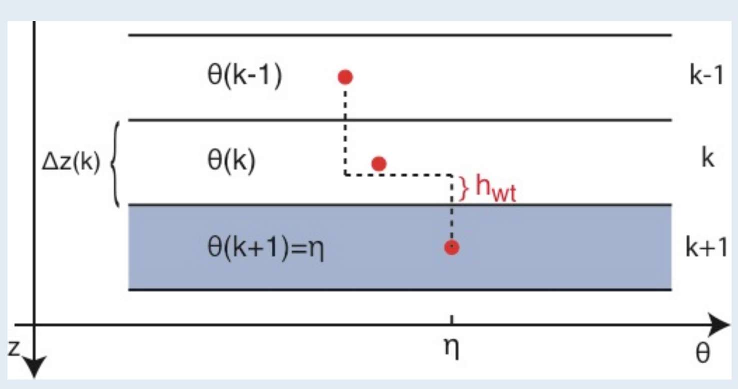
impact of sub-grid orography



$$S'_{oro} = \frac{max\,(z_1 - z_2, S_{min})}{\Delta x}$$

S_{min}=1‰ (runoff in flat areas)

$$S = \overline{S'}$$



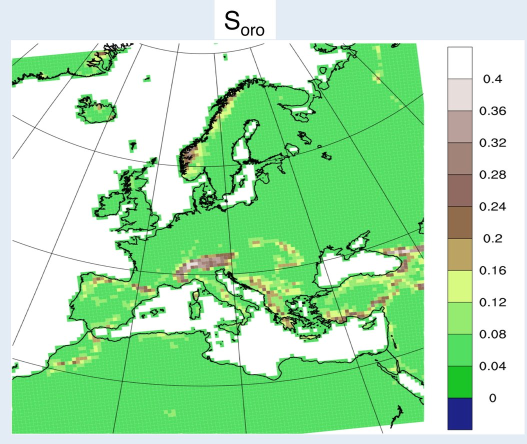
h_{wt}: continuous function for water table depth

CCLM regional climate simulations

COSMO5.0_CLM6 using **TERRA_ML** as land-surface model

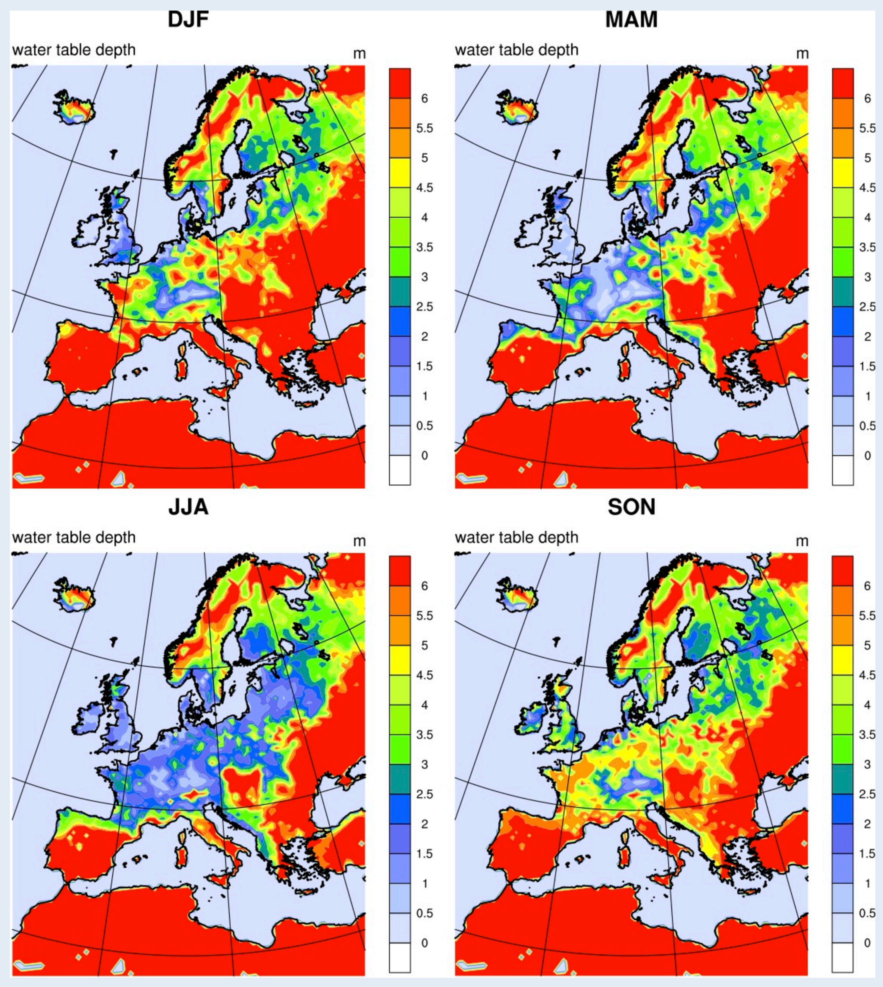
- CORDEX-EU 0.44°, dt=300 s
- ERAInterim driven
- Tegen Aerosol Climatology
- 1979-1985
  (1981-1985 for evaluation)
- 10 soil layers, down to 11.5 m
- 9 active layers
  (larger dynamical range)
- Decharme formulation for hydraulic conductivity (Decharme et al., 2006) (Jürgen Helmert), only in modified TERRA_ML:
- $K_0(k) = K_{0,d} \cdot \exp(-2.0(z(k) - rd))$
  rd: root depth

S_{oro}

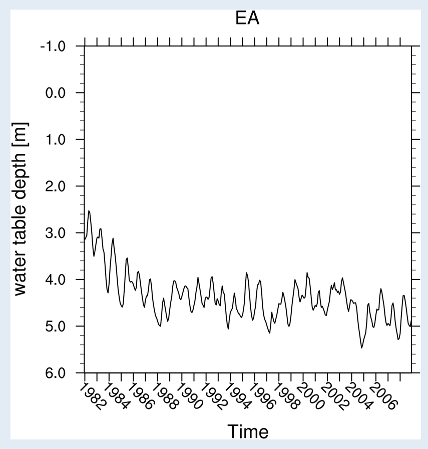


S_{oro} for the simulations on the 50 km grid.

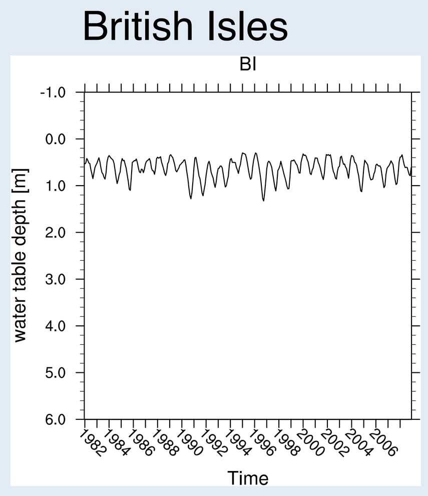
depth of water table



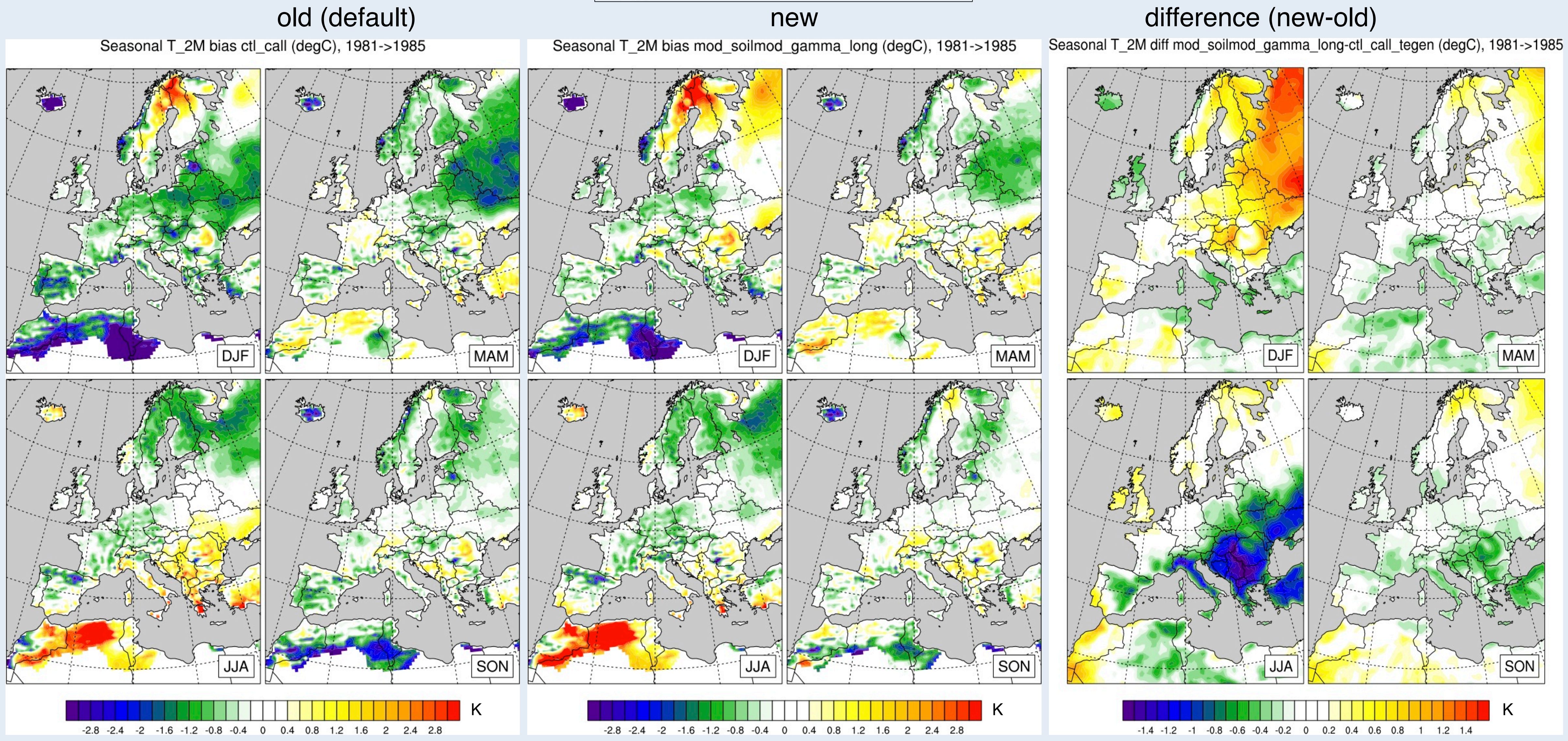
Eastern Europe



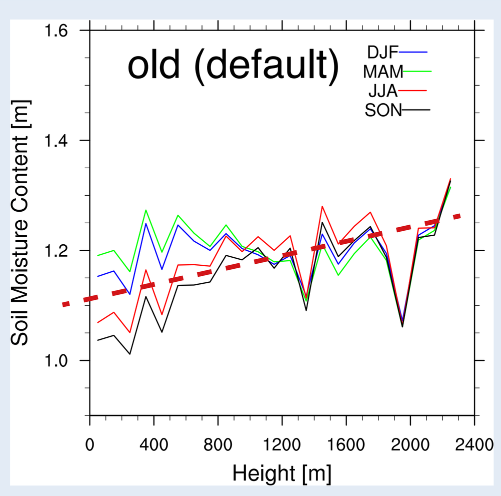
British Isles

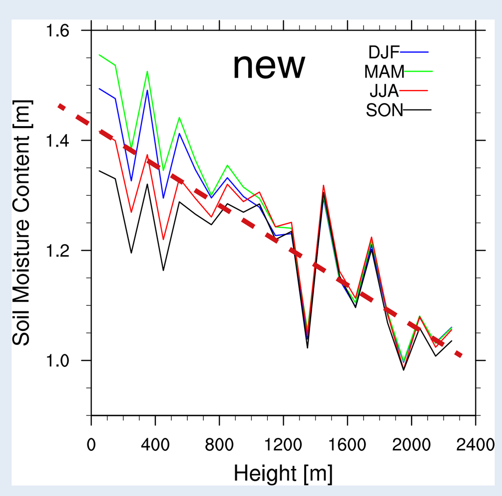


T_{2m} bias (model - EOBS)



Elevation dependence of soil-moisture content





Soil-moisture content (m) binned by the surface height of the underlying orography for the Alpine Region for the different seasons.

References:
Vidale, P. L., D. Lüthi, R. Wegemann, and C. Schär, 2007: European summer climate variability in a heterogeneous multi-model ensemble. *Clim. Change*, **81**, 209-232.
Christensen, J. H., and F. Boberg, 2012: Temperature dependent climate projection deficiencies in CMIP5 model. *Geophysical Research Letters*, **39 (24)**, doi: 10.1029/2012GL053650.
Décharme, B., H. Douville, A. Boone, F. Habets, and J. Noilhan, 2006: Impact of an Exponential Profile of Saturated Hydraulic Conductivity within the ISBA LSM: Simulations over the Rhone Basin. *Journal of Hydrometeorology*, **7 (1)**, 61-80, doi: 10.1175/JHM469.1.