Extension of the regional climate model REMO by a 5-layer soil scheme

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Advanced Environmental Technologies via AI on the Web.

04.05.2020

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Motivation and Introduction

➢ Project aim:

- Create highly resolved climate projections for Lower Franconia, Bavaria, Germany
- Provide output data and indices to support decision-making by local actors in agriculture, forestry, and viticulture

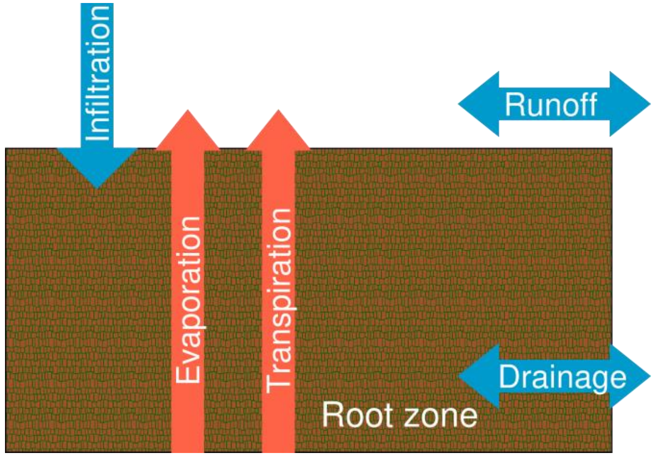
➢ Aim of model development:

- Improve subsurface hydrology by the introduction of a 5-layer soil scheme
- Further development of this scheme by the improvement of vertical subsurface flow and implementation of lateral subsurface flow

Soil moisture plays a key role for moisture and energy fluxes in the atmosphere and consequently shows a feedback with temperature and precipitation[1] . Thus, it is relevant for the occurrence of warm temperature extremes[2] and droughts[3]. Hence, realistic modelling of this variable is necessary, which requires a correspondingly good soil hydrological scheme.

Soil hydrology in REMO

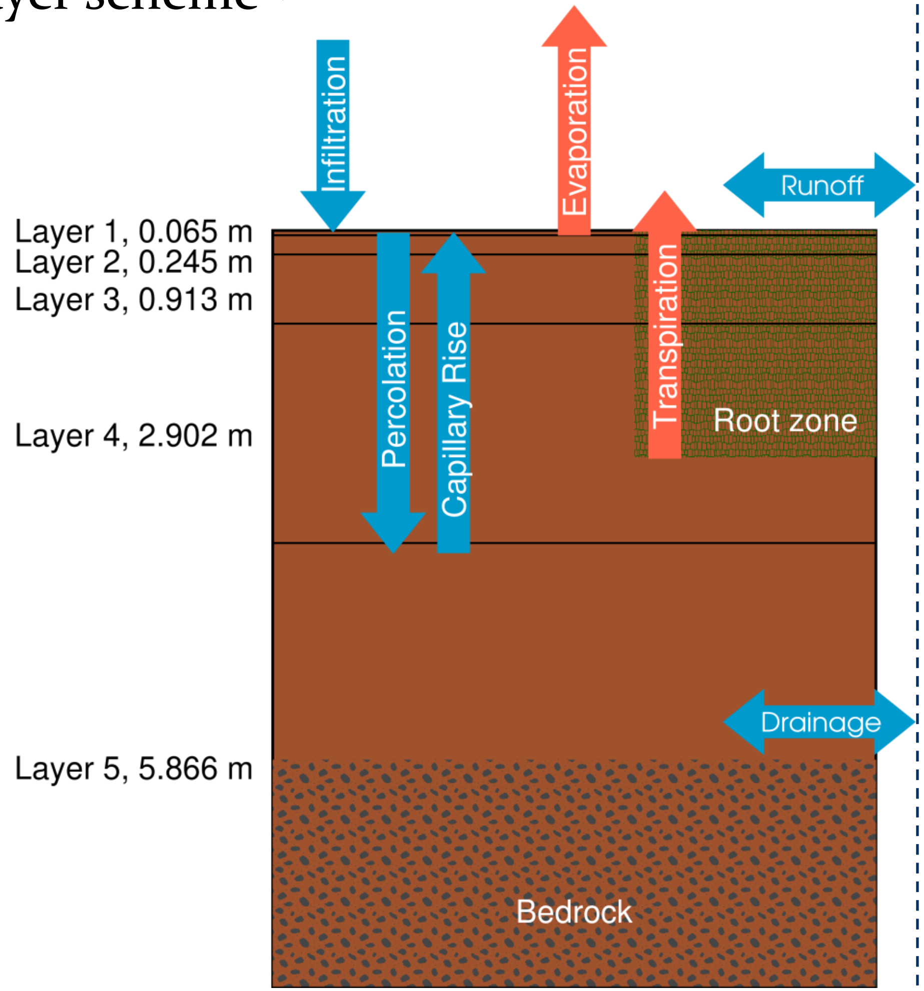
Old bucket scheme



- Depth is equal to rooting depth and strongly depends on land class
- Bare soil evaporation occurs from entire bucket

New 5-layer scheme[4]

- Depth is equal to bedrock depth or ca. 10m
- Percolation and diffusion between layers are possible (using moisture-based Richard's equation)
- Water below root zone is allowed
- Root zone can be refilled by diffusion from layers below
- Bare soil evaporation occurs solely from first layer



Test and model setup

- **Study area and resolution**: Extended German region, 0.11°: GER-11
- **Period**: 2000-2003, monthly

Data and setup	Original model ‚bucket‘	5-layer version 1.0 ‚5lay1.0‘	5-layer version 1.1 ‚5lay1.1‘
Topography	GTOPO (1 km)[5]	GTOPO (1 km)	
Soil properties	FAO (50 km)[6], soil textures	SoilGrids (1km)[7], using Pedo-Transfer Functions (PTFs) based on sand and clay content and organic matter[8]	
Handling of layer properties	-	Same value for all layers (weighted mean of 5lay1.1)	Individual values for each layer based on PTFs
Root depth	Estimated: $z_r = \frac{soil\ water\ holding\ capacity}{volumetric\ field\ capacity}$ [4]	Yang et al. 2016 (0.25°)[9]	
Bedrock depth	-	SoilGrids (1km)	
Saturated hydraulic conductivity	-	Montzka et al. 2017 (0.25°)[10]	

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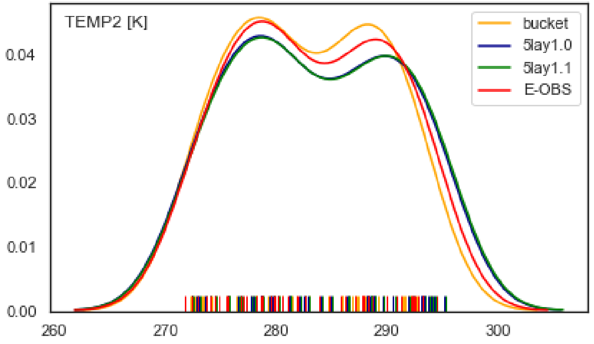
Results: Temperature, comparison with E-OBS[11]

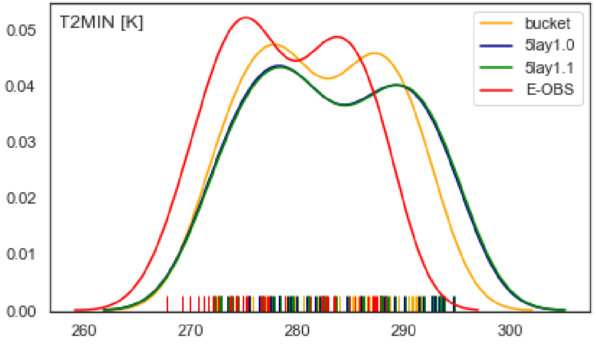
Kernel density estimation (KDE) of bucket and 5layer, GER-11, 48 months

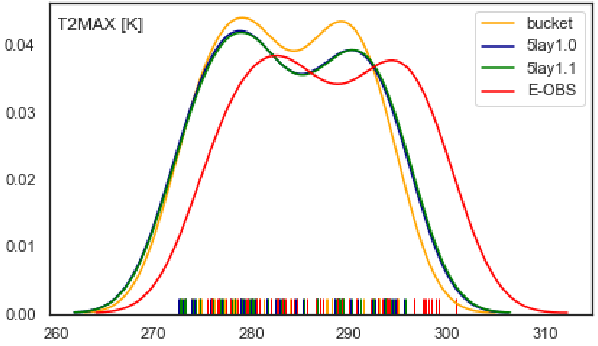
TEMP2 = mean 2 m-temperature

T2MIN = min. 2 m-temperature

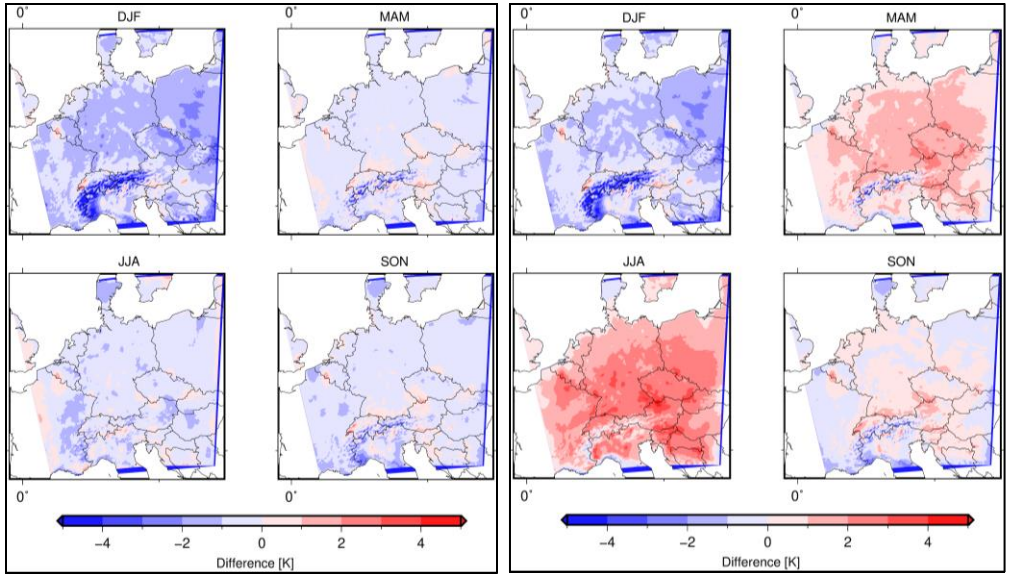
T2MAX = max. 2 m-temperature







Seasonal differences with E-OBS of 2m-Temperature (TEMP2) of bucket (left) and 5layv1.1 (right)



- The two 5layer-versions are very similar regarding the modeled temperature
- 5layer-versions show a higher range for temperatures compared to bucket

- 5layer tends to overestimate higher TEMP2 values
- Both model setups overestimate T2MIN and underestimate T2MAX
- Differences of T2MIN in 5layer increase compared to bucket, for T2MAX they decrease

- The seasonal consideration confirms the already indicated behavior, based on KDEs
- DJF and SON show similar results for bucket and 5layer compared to E-OBS
- 5layer is much warmer in MAM and JJA than E-OBS, bucket slightly underestimates TEMP2

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Results: Surface heat and evapotranspiration fluxes, comparison with GLEAM[12]

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Kernel density estimation (KDE) of bucket and 5layer, GER-11, 48 months

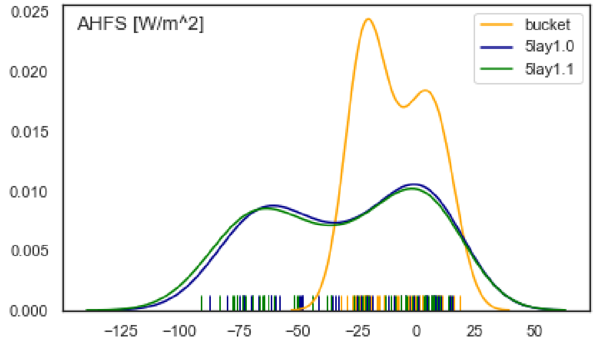
AHFL = latent heat flux

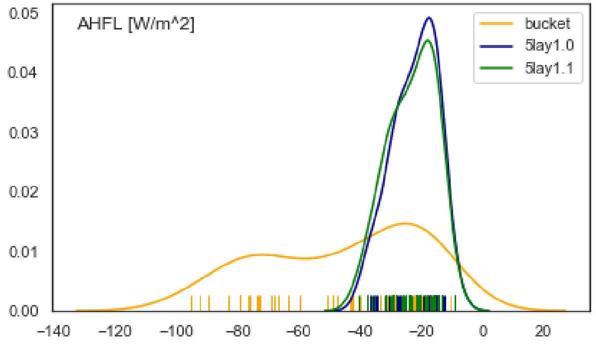
AHFS = sensible heat flux

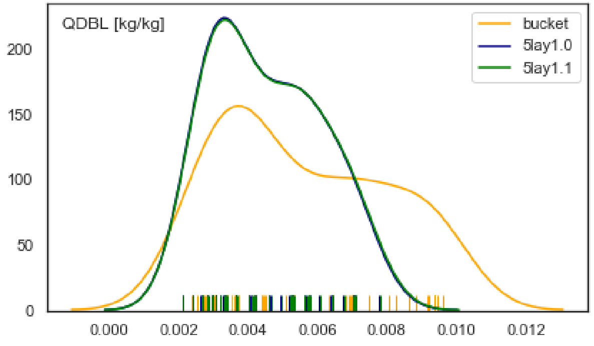
QDBL = relative moisture

ETRANS = transpiration

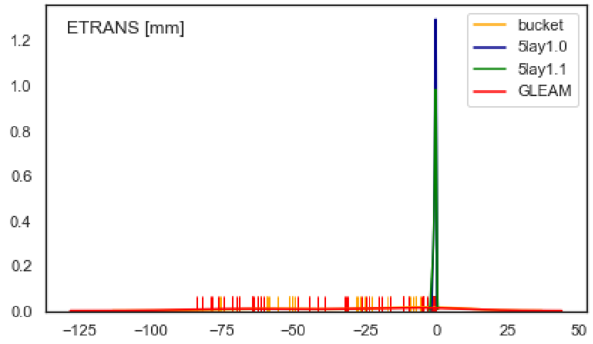
EBSOIL = bare soil evaporation

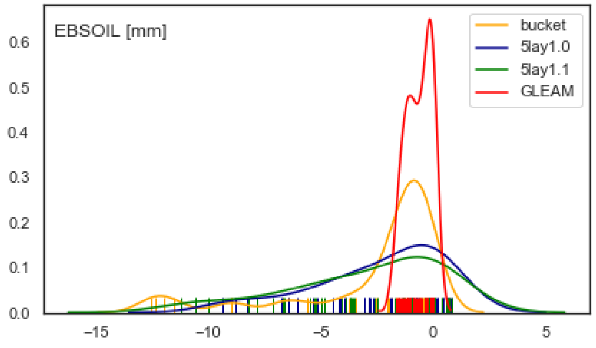






- In both 5layer-versions sensible heat fluxes increase and latent ones decrease compared to bucket
- This corresponds well to the observed temperature changes, especially during JJA
- Accordingly, the relative moisture decreases as well





- Transpiration and bare soil evaporation are compared with GLEAM data
- Transpiration shows a remarkable decrease compared to bucket and GLEAM
- Contrary, bare soil evaporation – already overestimated by bucket – further increases in the 5layer-versions
- In total, the 5layer shows lower evapotranspiration which leads to increased sensible heat fluxes and temperatures during JJA

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Results: Precipitation, comparison with E-OBS

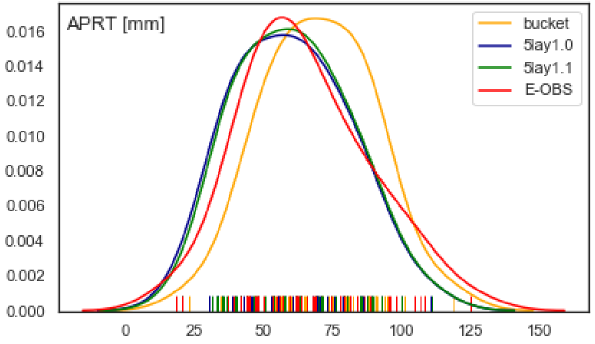
Kernel density estimation (KDE) of bucket and 5layer, GER-11, 48 months

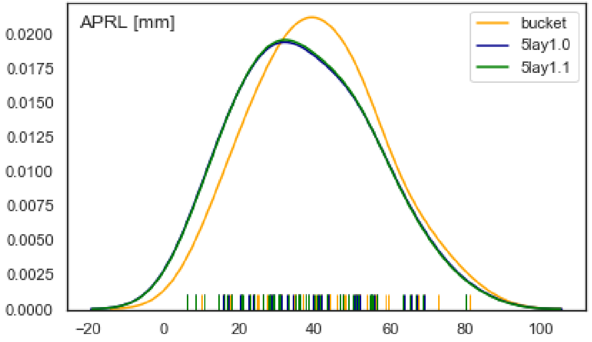
APRT = total precipitation

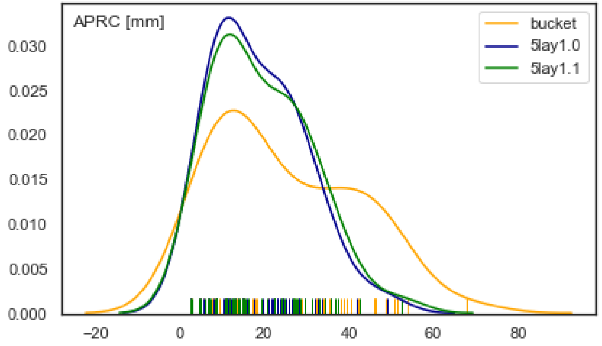
APRL = large scale precipitation

APRC = convective precipitation

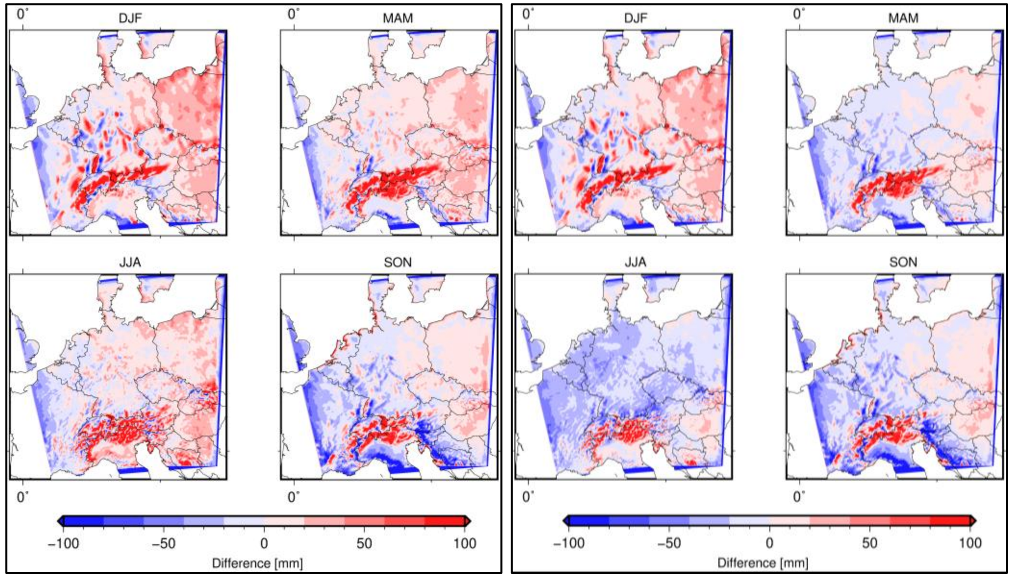
APRS = snowfall (not shown)







Seasonal differences with E-OBS of total precipitation (APRT) of bucket (left) and 5layv1.1 (right)



- 5layer-versions represent APRT (APRT = APRL + APRC + APRS) better but underestimate low precipitation amounts
- This is caused by a general decrease of APRL and especially of APRC

- DJF and SON show comparable differences of the model versions to E-OBS
- APRL differences to E-OBS are notable in DJF and in weaker form in MAM and SON where mountain ranges are highlighted
- In MAM and mainly SON, APRT is underestimated in the 5lay-versions which causes the better representation concerning the KDE
- Underestimation in JJA is mainly caused by a reduced APRC in summer

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Results: Hydrological variables and soil temperature

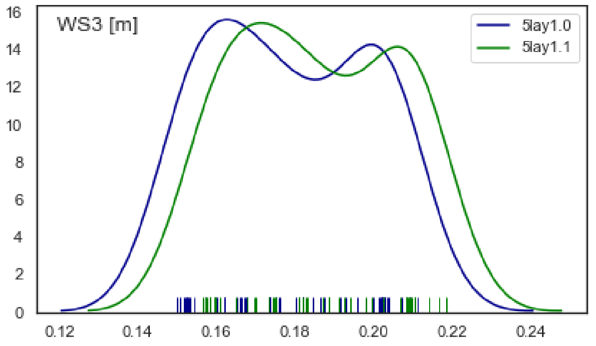
Kernel density estimation (KDE)
of bucket and 5layer,
GER-11, 48 months

WS3 = soil moisture in 3rd layer

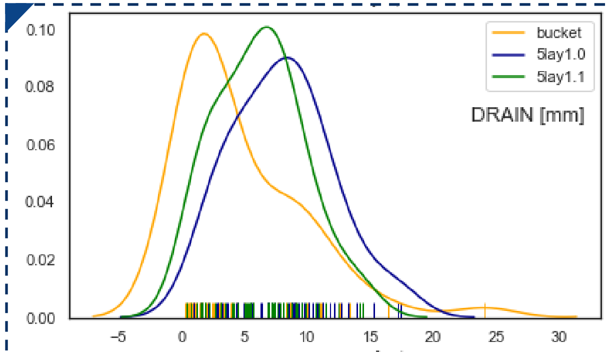
DRAIN = drainage

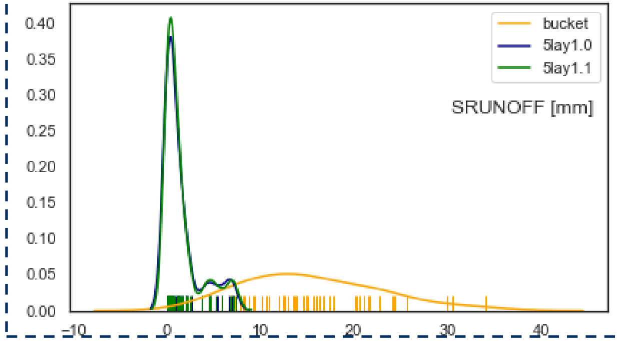
SRUNOFF = surface runoff

TDCL = soil temperature of 5th layer

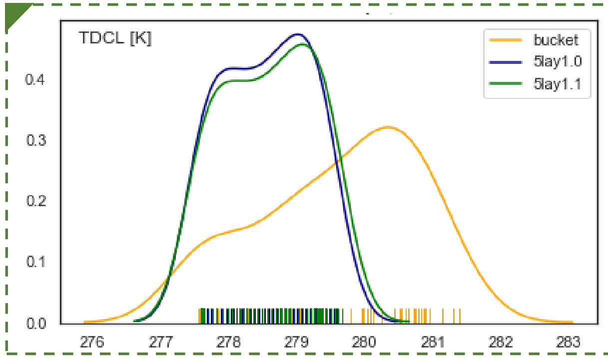


- Layered soil moisture only exists in 5layer-simulations. Further, the rooting depth on which the soil moisture in bucket is based, differs from the 5layer-rooting depth. Thus, a comparison to bucket is not possible.
- 5lay1.1 with individual soil properties for each layer tends to have higher soil moisture than 5lay1.0 in each layer (3rd layer is shown as an example)





- Drainage increases with 5layer compared to bucket, whereas 5lay1.0 shows the highest amounts
- Surface runoff decreases strongly in 5layer-versions
- This runoff behavior (drainage + surface runoff) might be explained by the (combined) effect of
  - the lower precipitation amounts, especially in JJA
  - the different definiton of lower boundary in the two schemes. The deeper soil of 5layer can store more water mainly in regions with shallow rooting dephts. This might decrease the surface runoff and increase drainage.



- Layer 1-3 (not shown) are more sensitive to surface energy fluxes and tend to be warmer mainly in summer in 5layer compared to bucket
- Layer 4 (not shown) and 5 of 5layer-versions show a smaller temperature range and are cooler than bucket which is more realistic for deeper soil temperatures

Conclusion

Main findings

- Mainly summer temperatures are overestimated by the new scheme
- Total precipitation is more realistic, whereas summer precipitation is underestimated
- Increasing sensible and decreasing latent heat fluxes explain the temperature findings
- According to the heat fluxes, evapotranspiration decreased. This decrease is mainly caused by very low amounts of transpiration which can not be compensated by a higher bare soil evaporation
- Surface runoff decreases in the new scheme, drainage increases
- Soil temperatures show more realistic behavior, especially deeper ones

- These findings may lead to the assumption that the vertical movement of water between the soil layers needs a revision. Water seems to infiltrate in and evaporate from the first layer. After percolation it might accumulate below the root zone and consequently transpiration is very low and water drains instead of transpirating.

- New soil temperature scheme is actually in the test phase and shows promising results to reduce the temperature overestimation

Further Investigations

- Revision of vertical water movement of the model which actually uses the moisture-based Richard‘s equation
  - Implementation of potential-based Richard‘s equation
  - Implementation of improved numerical solution (Crank-Nicholson scheme)
- Dealing with subgrid heterogeneity of topography and soil properties
- Implement lateral subsurface fluxes to deal with very high resolutions (3 km)
- Evaluation with runoff and streamflow data (on catchment scale)

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Thanks for your attention

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