The ground heat flux simulated by the COSMO land surface scheme TERRA

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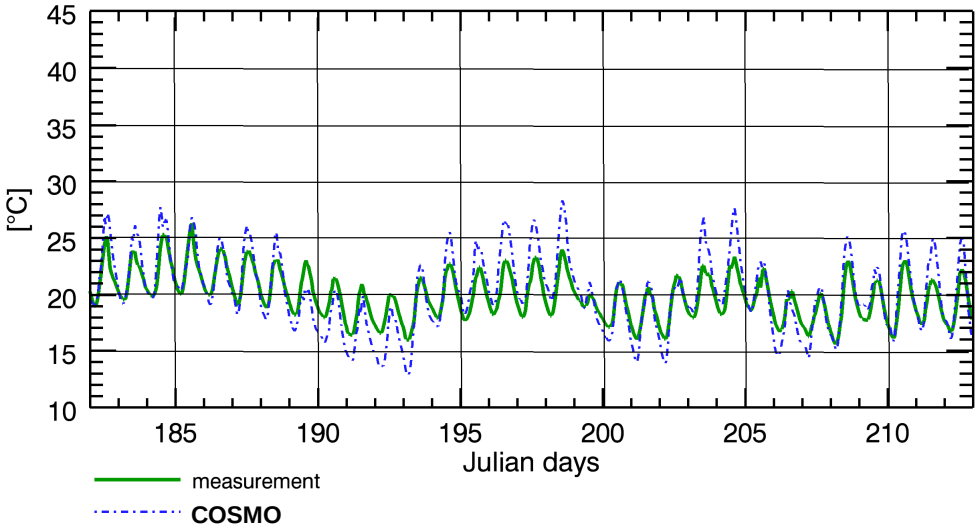
The problem …

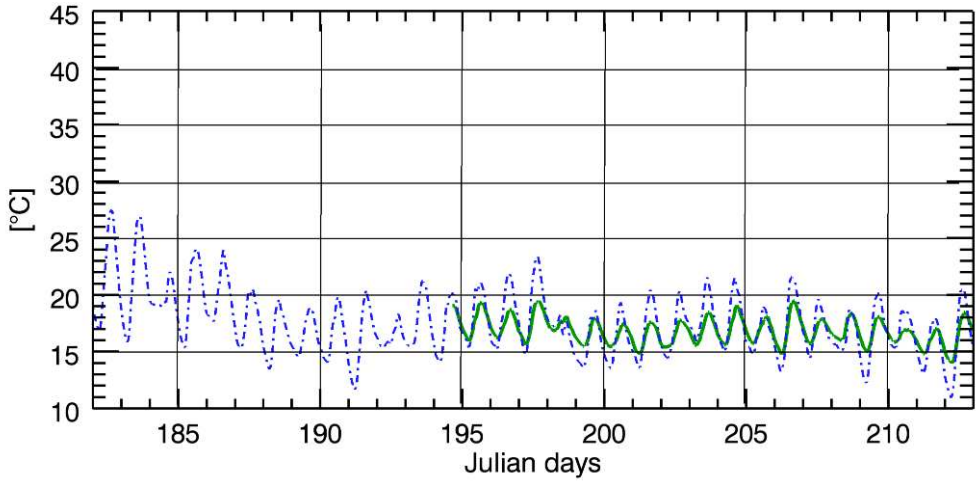
- The ground heat flux in the COSMO land surface scheme TERRA is systematically overestimated under dry conditions.
- Since this flux is part of the surface energy balance it affects the other components like the turbulent heat fluxes or the surface temperature.
- An overestimation of the ground heat flux during daytime leads to an underestimation of the other surface fluxes and a reduced surface warming.
- During afternoon and night this behaviour is reversed.

Soil temperature (-6 cm) : July 2009

Lindenberg (Falkenberg)



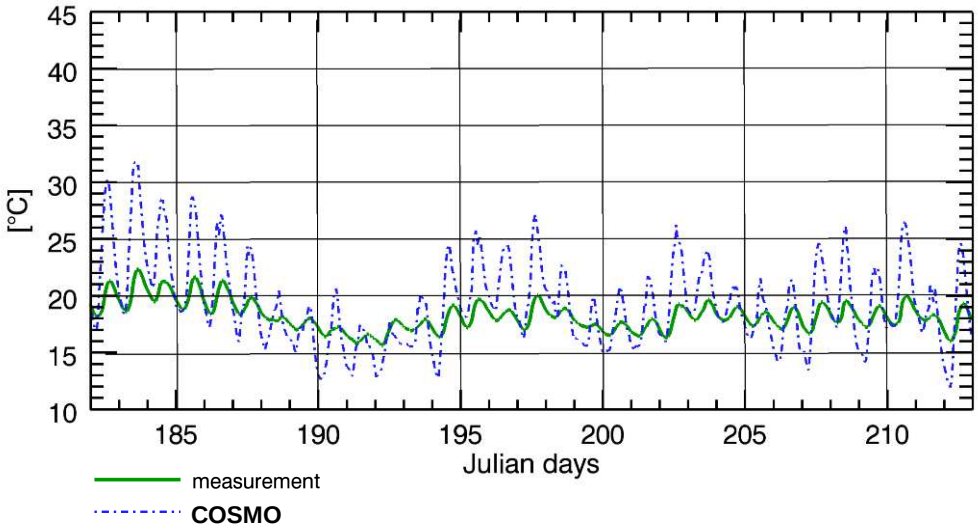
Cardington



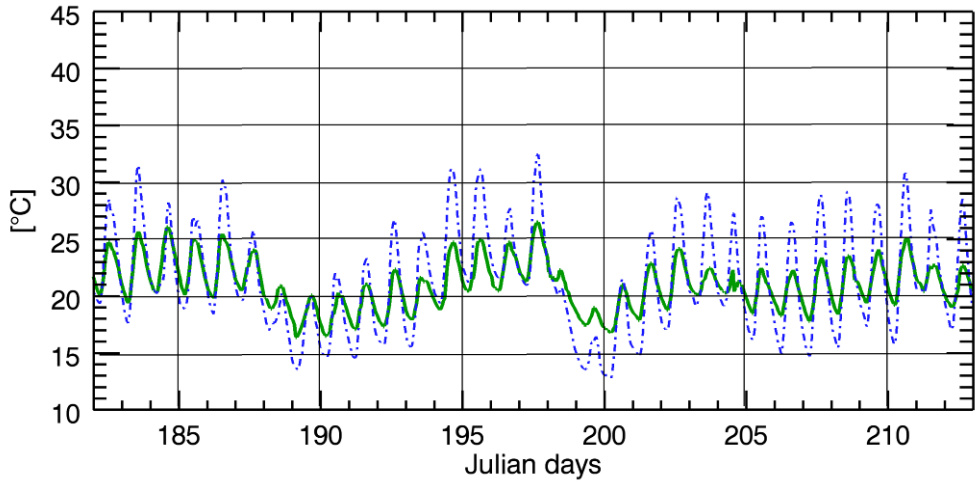
Observations from SRNWP data pool

Soil temperature (-6 cm) : July 2009

Cabauw



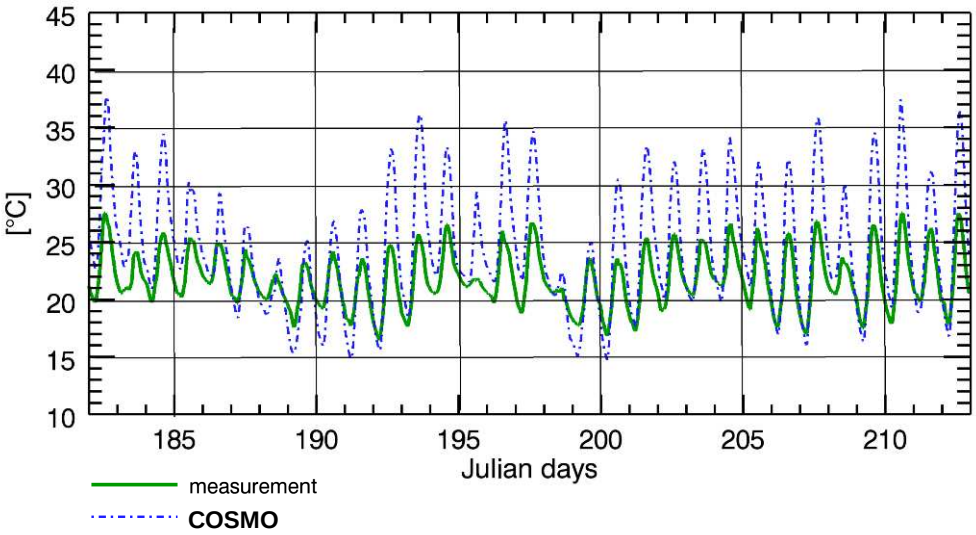
Payerne



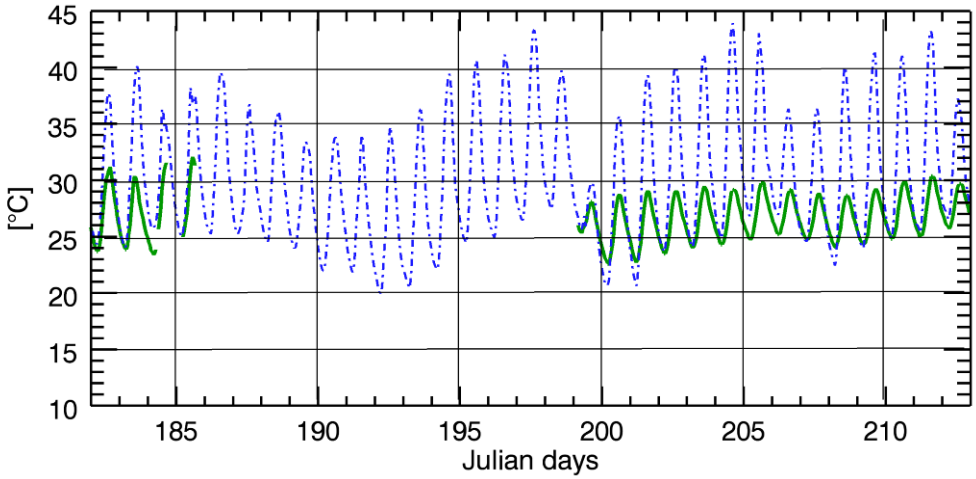
Observations from SRNWP data pool

Soil temperature (-6 cm) : July 2009

Toulouse (Fauga-Mauzac)



San Pietro Capofiume



Observations from SRNWP data pool

Hypothesis

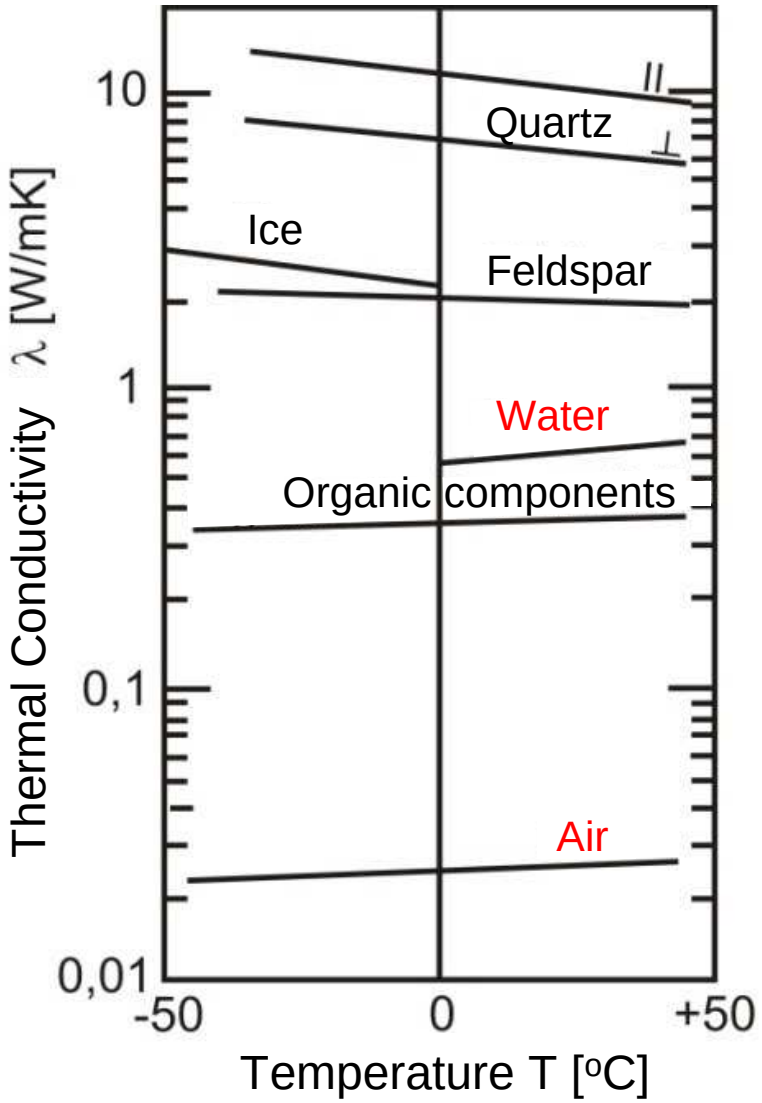
The ground heat flux in the COSMO model is systematically overestimated in summer. Main reasons:

- The shading effect of the vegetation is not represented in the model
- The thermal conductivity of the soil is too large in summer

Methodology

- Focus on thermal conductivity first
- Reduce the thermal conductivity of the soil in summer, by introducing its strong dependency on the soil moisture content

Thermal Conductivity



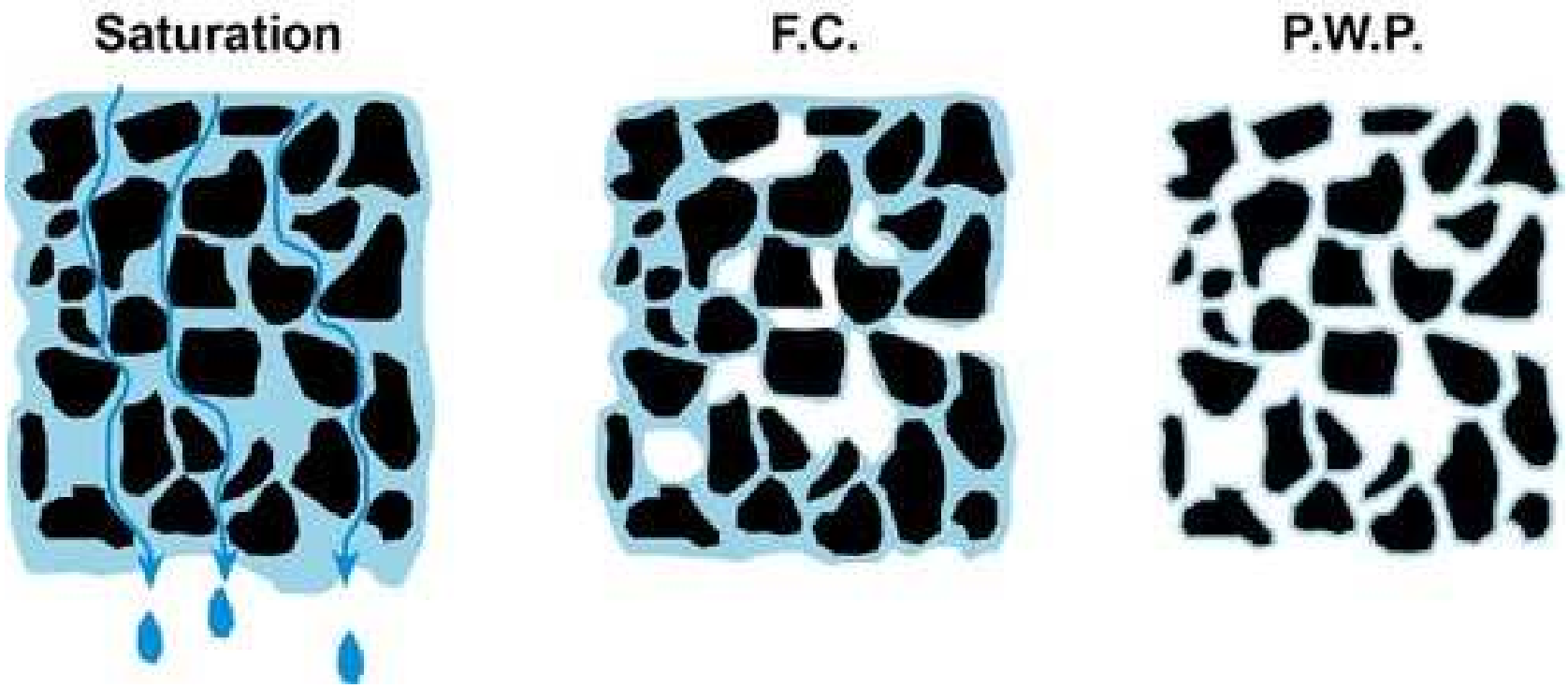
The thermal conductivity of water is about a factor of 25 larger than that of air!

This means, replacing the air in the pores of a soil by water increases the thermal conductivity of the soil system dramatically.

In other words:
A wet soil (in winter) has a much larger thermal conductivity than a dry soil (in summer).

Baier (2008), after Frivik (1981)

Thermal Conductivity depends on soil moisture



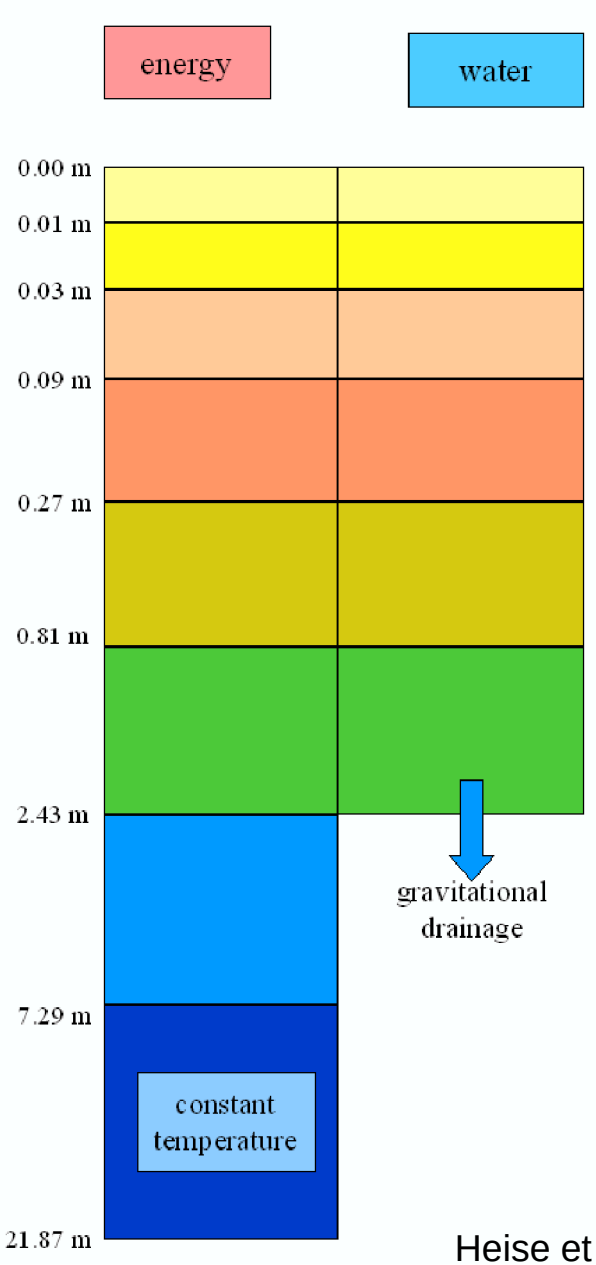
Saturation	All pores are filled with water	- thermal conductivity high!
Field capacity	Pores fill with air	- conductivity lower.
Permanent wilting point	Thin water films held by adhesion	- conductivity very low!

http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_water-soil_moisture_classification.html

Experiments

on soil thermal conductivity dependency on soil moisture content in

- Offline mode: Multi-layer land surface scheme TERRA
- NWP mode: COSMO-EU
- Climate mode: COSMO-CLM in Africa



Heise et al. (2006)

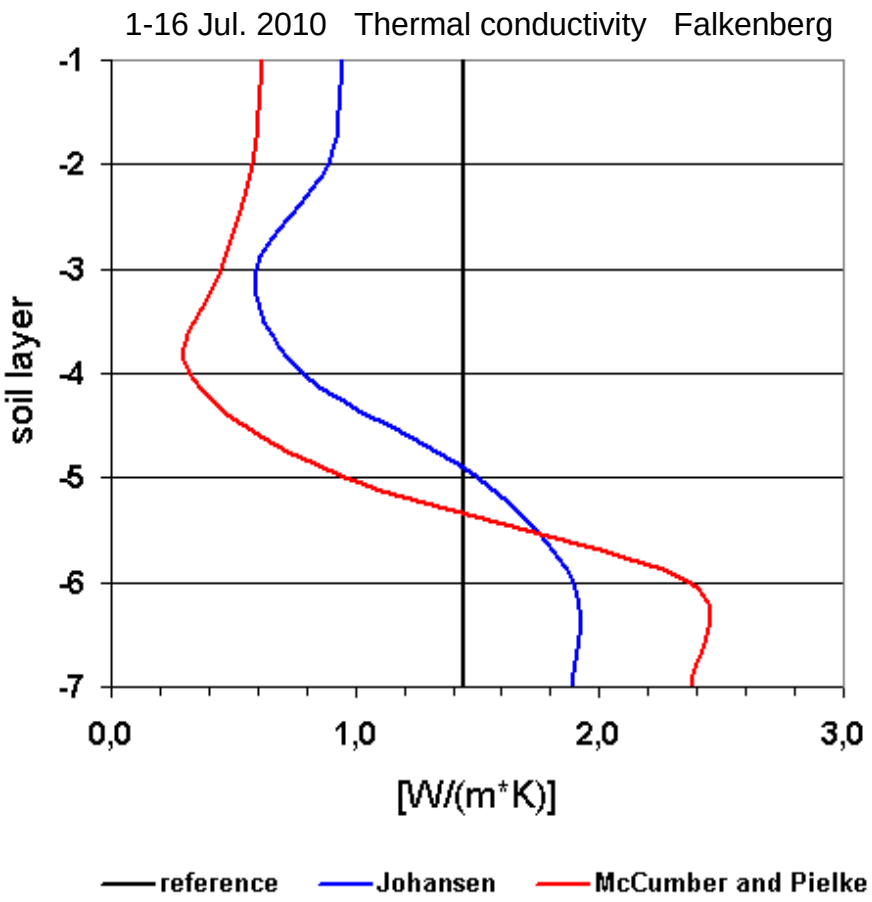
Land surface scheme TERRA

Layers for temperature and soil water content

Experiment 1:

- Use atmospheric forcing to run TERRA in offline mode
- Here, observed forcing from DWD observatory Lindenberg is used

Thermal Conductivity



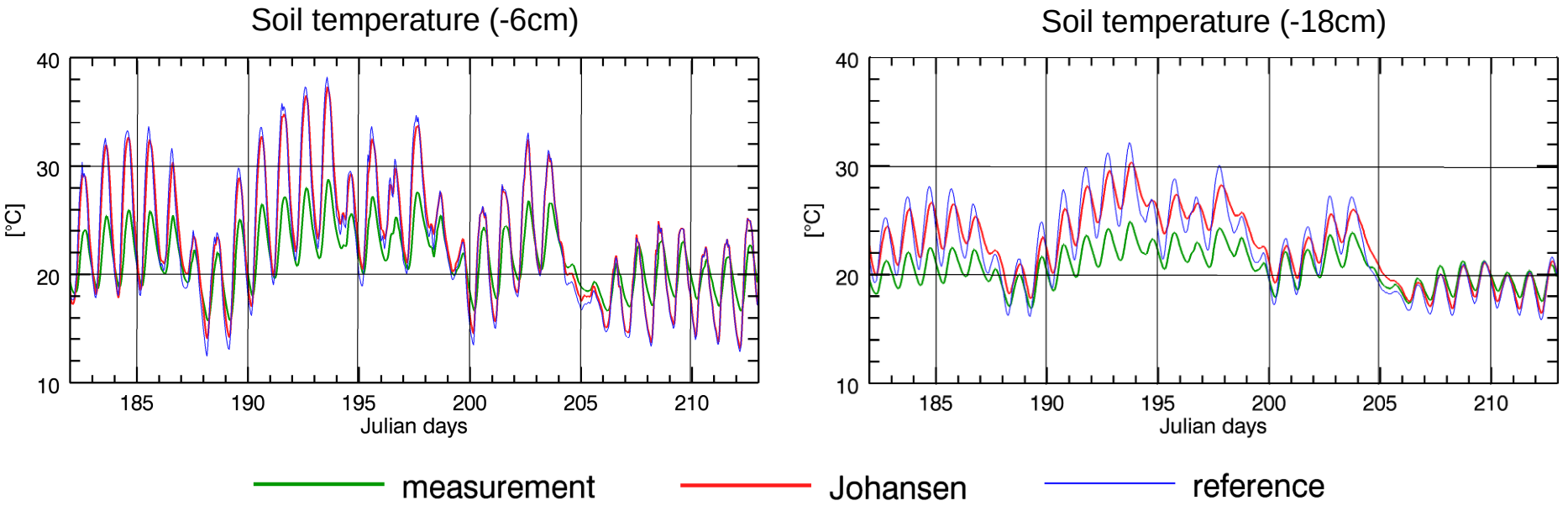
In the soil component of the COSMO model, the multi-layer TERRA scheme, the thermal conductivity is constant in time. It represents a medium soil wetness, shown by the **black line** in the figure.

The blue and red curve show two other approaches, relating thermal conductivity to soil water content:

- **Johansen (1975)**
- **McCumber and Pielke (1981)**

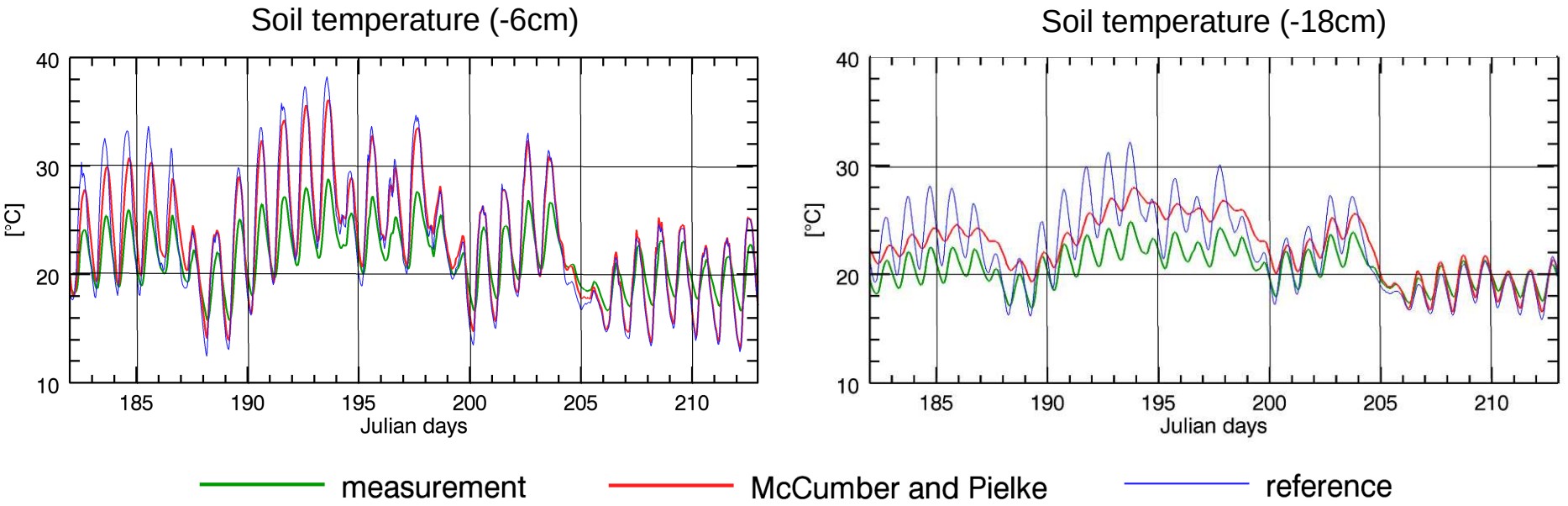
Curves were computed for the mean soil moisture profile for Falkenberg on 1-16 Jul. 2010 in offline TERRA.

Offline TERRA: Falkenberg July 2010
Thermal conductivity: Johansen
Grass land



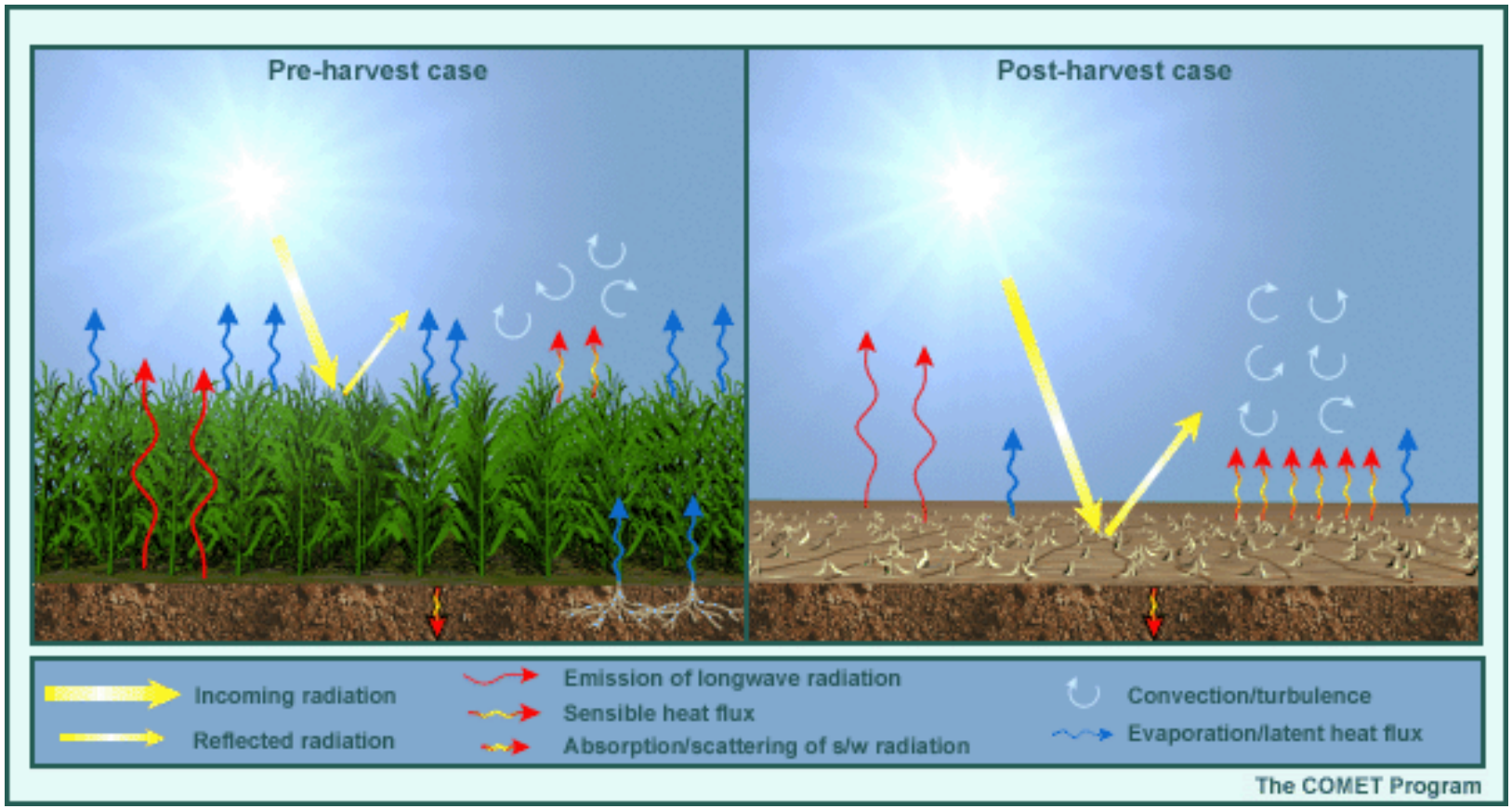
The diurnal cycles of the soil temperatures are reduced in the Johansen experiment and fit better to the observation.

Offline TERRA: Falkenberg July 2010
Thermal conductivity: McCumber and Pielke
Grass land



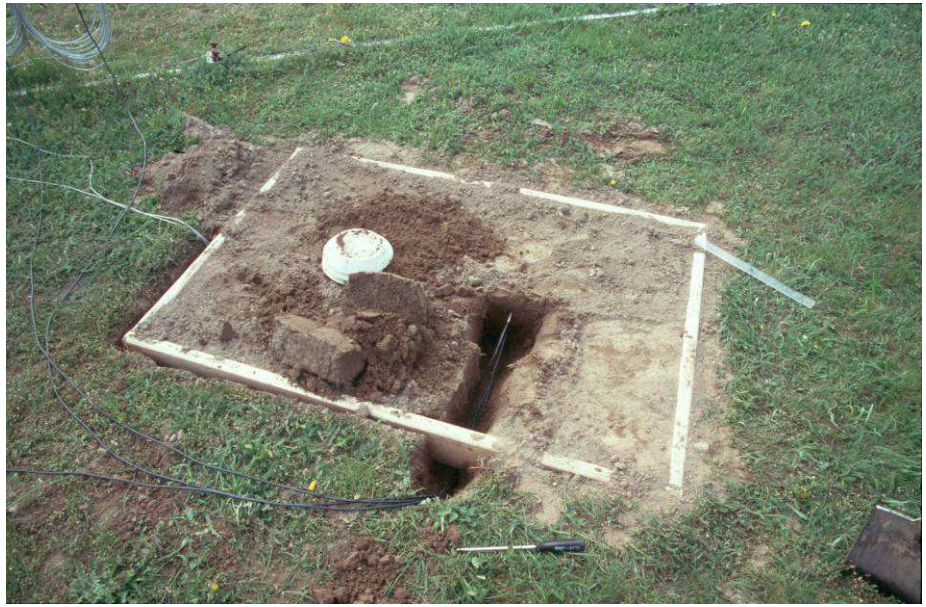
The diurnal cycles of the soil temperatures are too much reduced in the McCumber and Pielke experiment.

Shading



In TERRA the effects of shading of the sub-canopy land surface by the vegetation is not represented. The incoming solar radiation is directly used in the surface energy balance, modifying the other energy terms in an unrealistic way.

Falkenberg bare soil measurement site



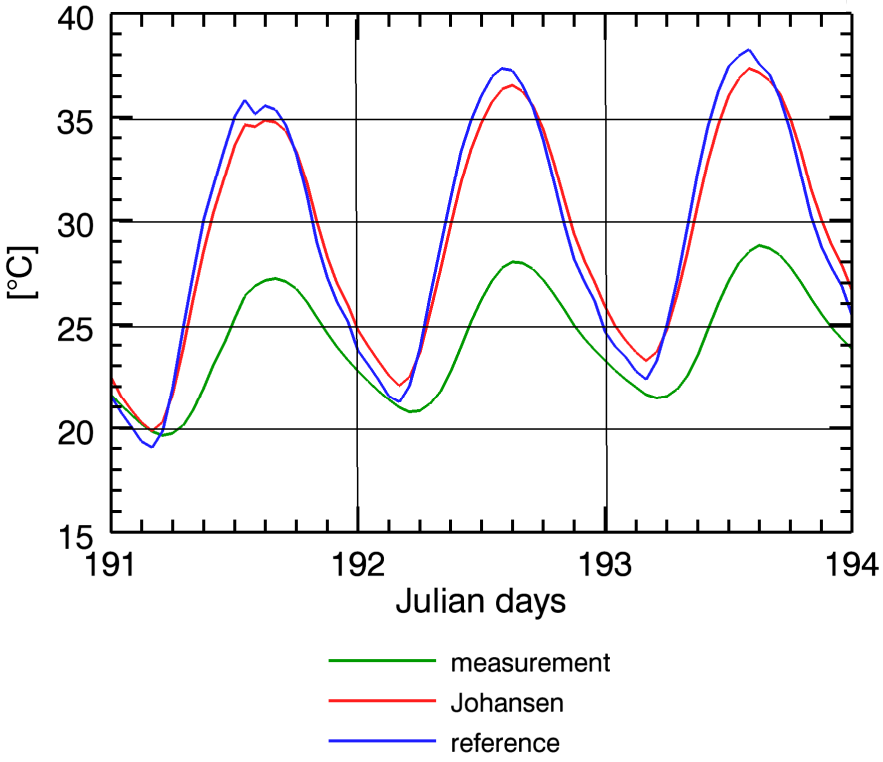
23 Apr.
2002

30 Apr.
2003

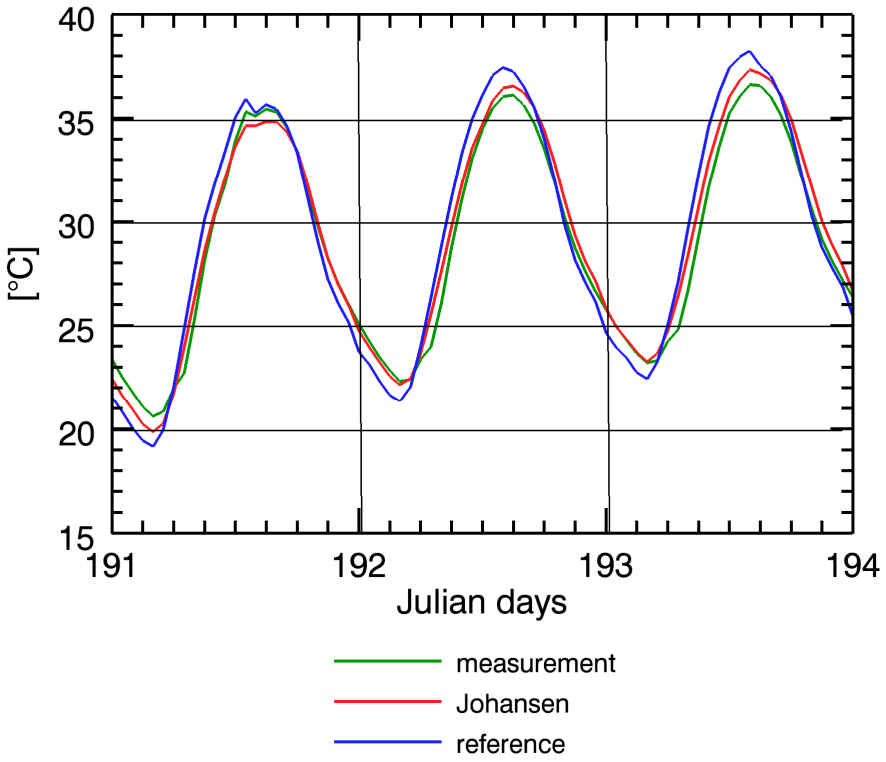
- Measurement of soil temperatures under bare soil
- Shading avoided
- About 1 m^2 in the middle of meadow ... okay, looks a bit small ...

Offline TERRA: Falkenberg 10-12 July 2010
Thermal conductivity: Johansen

Soil temperature (-6cm)



Bare soil temperature (-6cm)



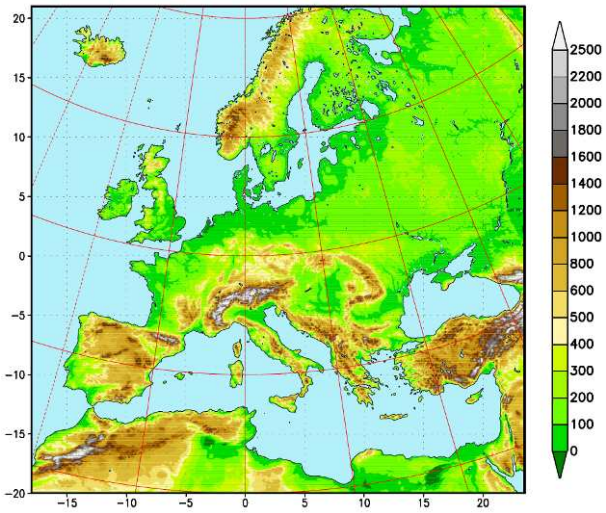
- Diurnal temperature range reduced by Johansen by about 2°C
- Compared to bare soil measurements this is very good
- Shading (even by grass) has a hugh effect

Experiment 2:

NWP mode: COSMO-EU

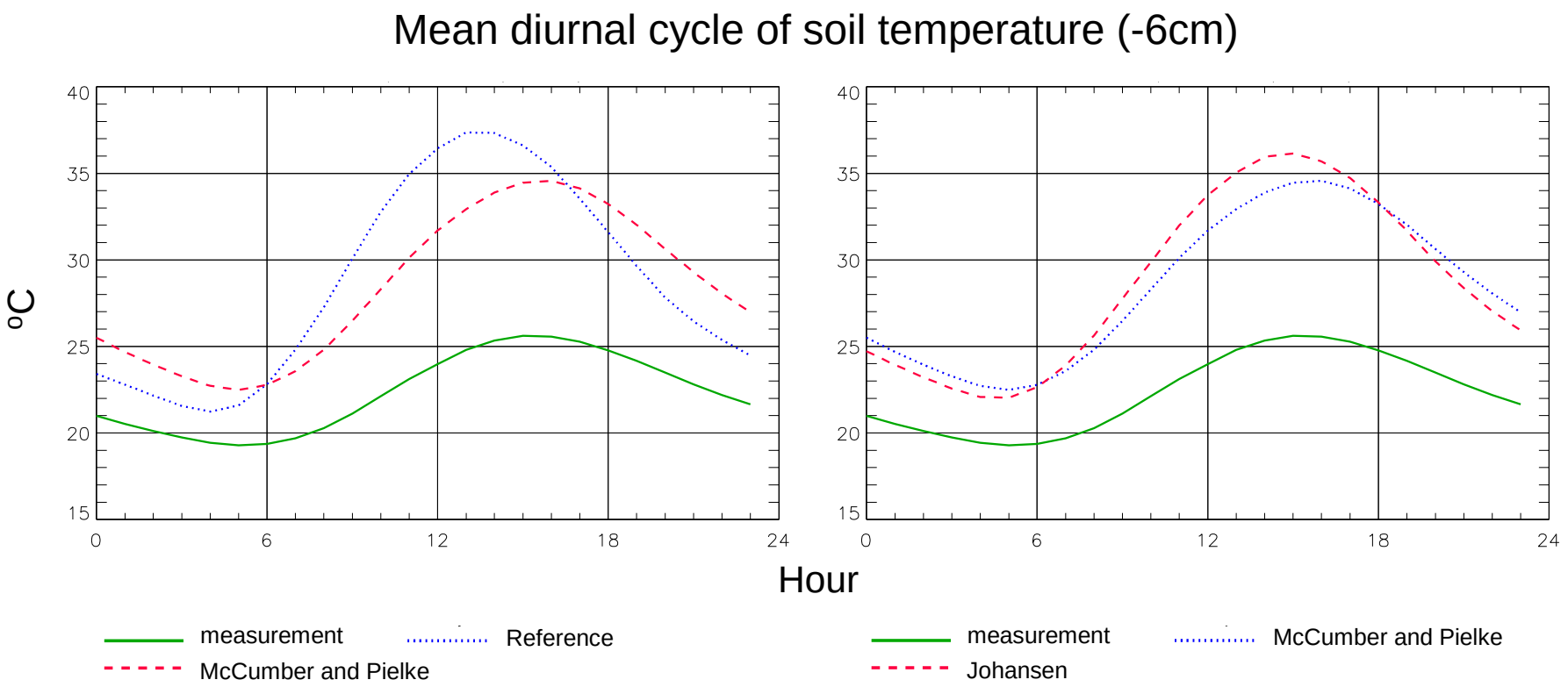
- Land surface scheme coupled to the atmosphere: allows for feedback
- Here, atmospheric variables are not part of a forcing, e.g. 2-m temperature can respond

Start of experiment: 1 July 2010 with 00 UTC forecasts
Verification period: 1 – 15 July 2010
Verification site: Lindenberg



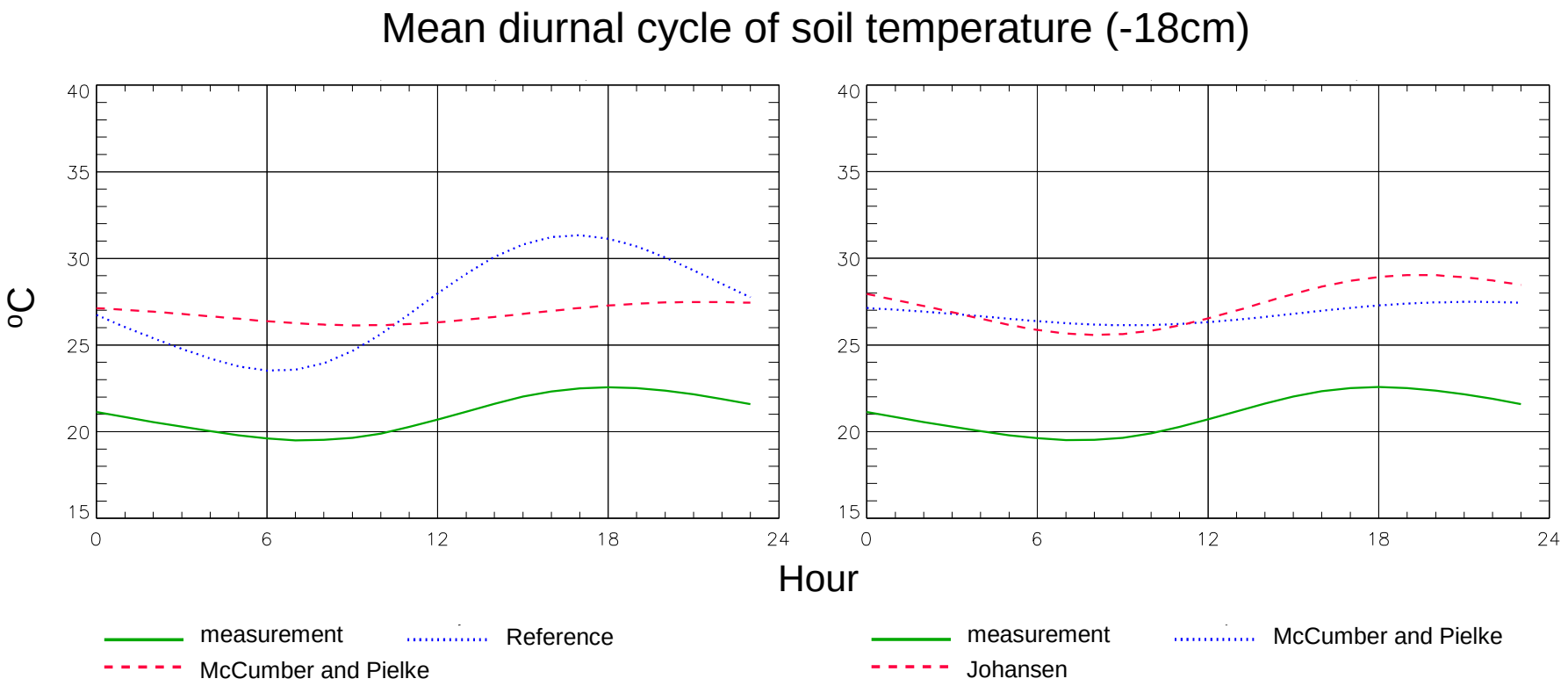
COSMO-EU: Falkenberg 1-15 July 2010

Thermal conductivity depending on soil moisture



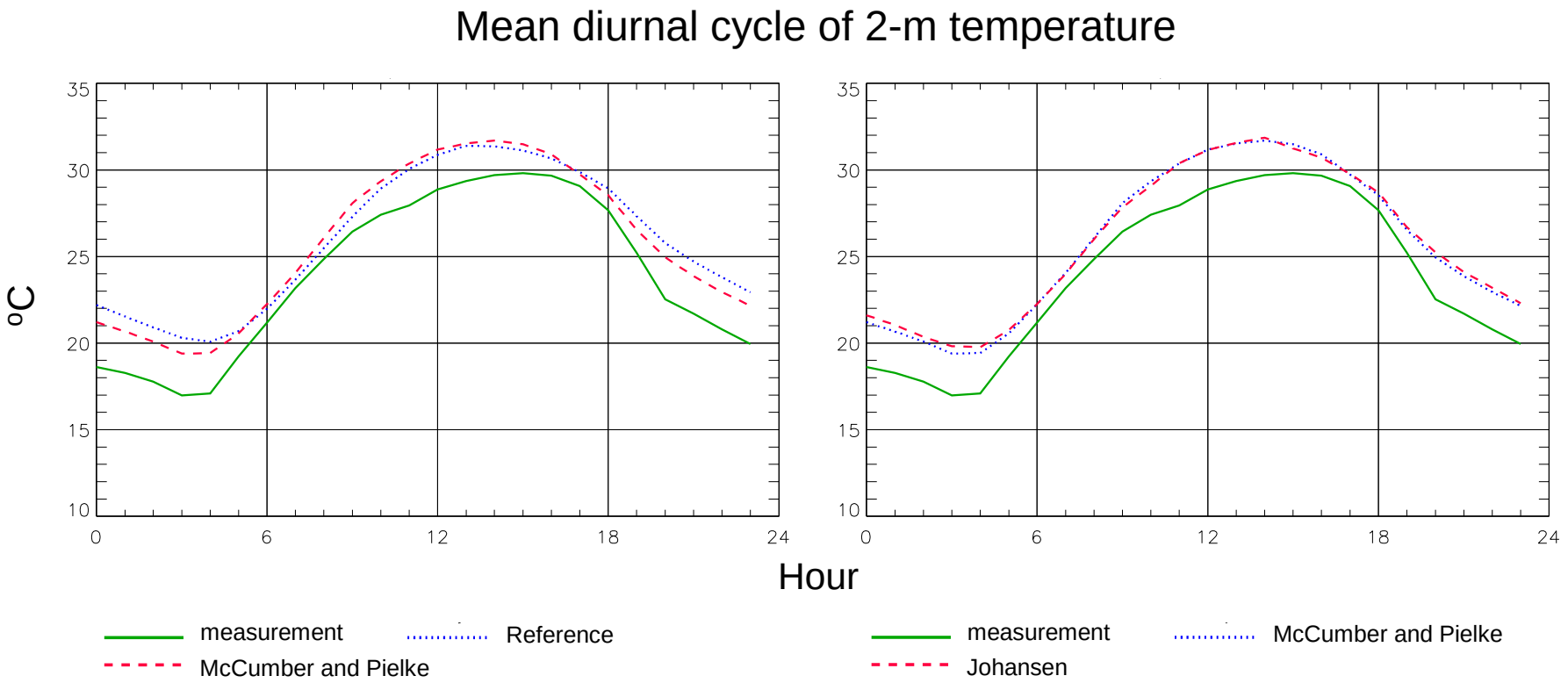
The diurnal cycles of the soil temperature are reduced in the experiments and fit better to the observation.

COSMO-EU: Falkenberg 1-15 July 2010
Thermal conductivity depending on soil moisture



The diurnal cycles of the soil temperature are much reduced in the experiments. McCumber and Pielke appears to overdo it, Johansen fits well to the observation.

COSMO-EU: Falkenberg 1-15 July 2010
Thermal conductivity depending on soil moisture



The diurnal cycles of the 2-m temperature are enhanced in the experiments and fit better to the observation. In particular, the cooling during the night is better simulated.

Experiment 3:

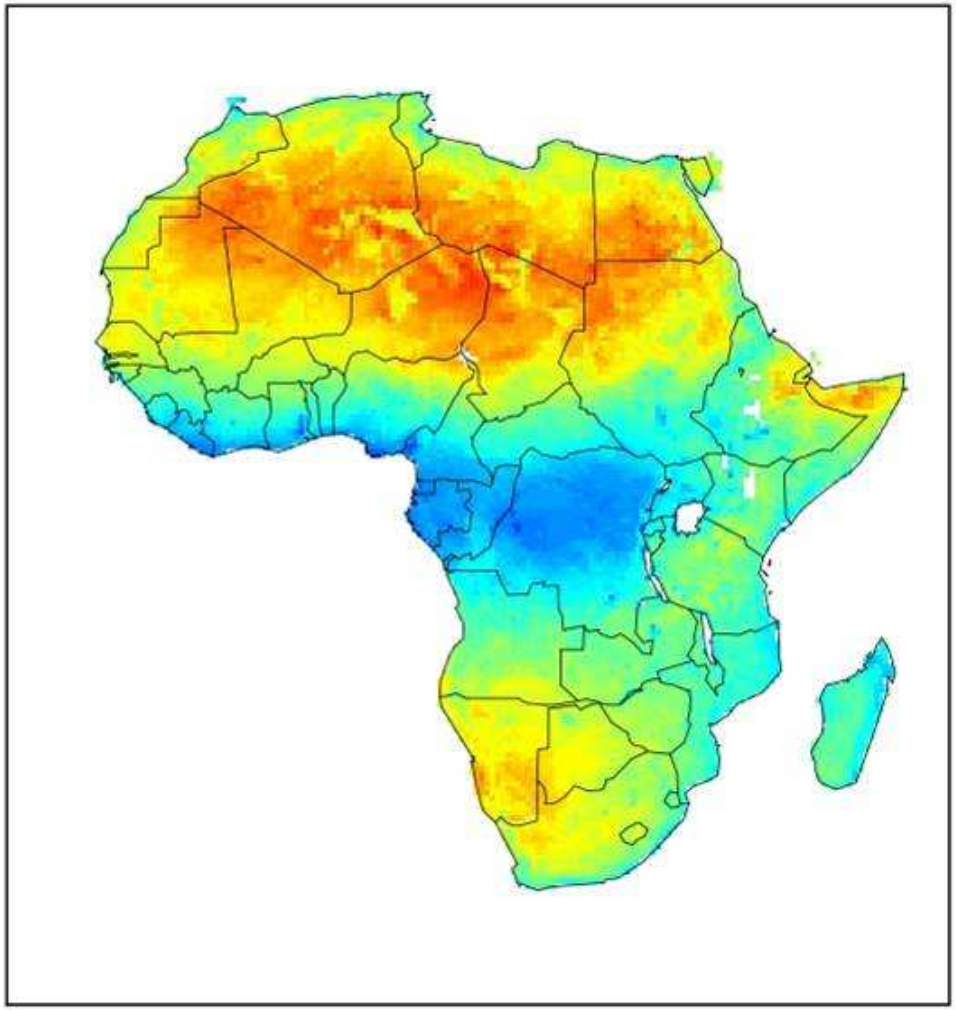
Climate mode: COSMO-CLM

Domain: CORDEX Africa
Horizontal resolution: 0.44°
Forcing: ERA-Interim
Simulation period: 2008 – 2010

- Climate more extreme in tropics/subtropics than in extra-tropics
- Large bare soil regions, e.g. Sahara

Average diurnal 2-m temperature range [ºC]

Observation



Observed ADTR:

-High in arid regions

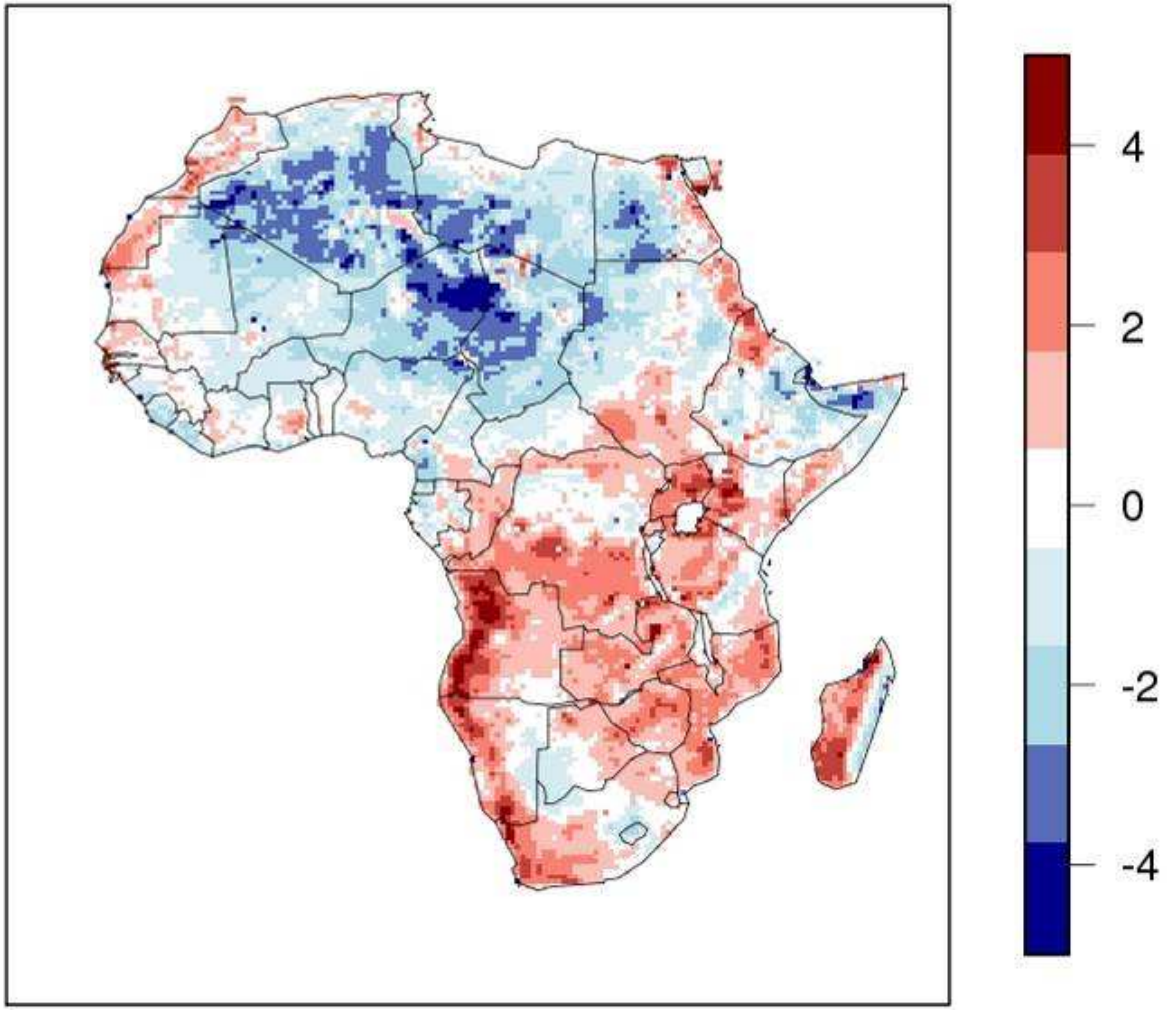
-Low in tropics

Role of cloud cover and vegetation.

Krähenmann et al. (2013)

Average diurnal 2-m temperature range [ºC]

COSMO-CLM (REF) - Observation



ADTR in COSMO-CLM reference:

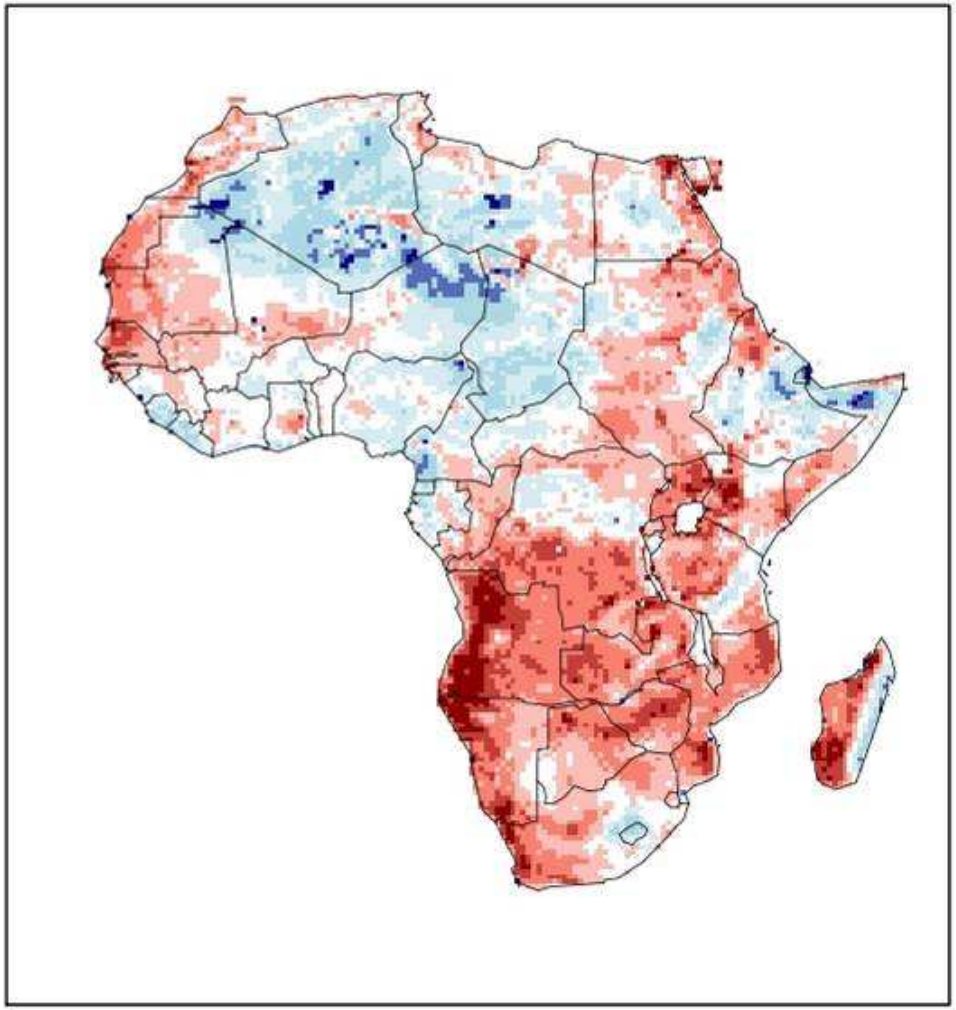
-Underestimated in arid or semi-arid regions by up to 4°C

-Overestimated in parts of tropics and southern Africa

Krähenmann et al. (2013)

Average diurnal 2-m temperature range [ºC]

COSMO-CLM (EXP) - Observation



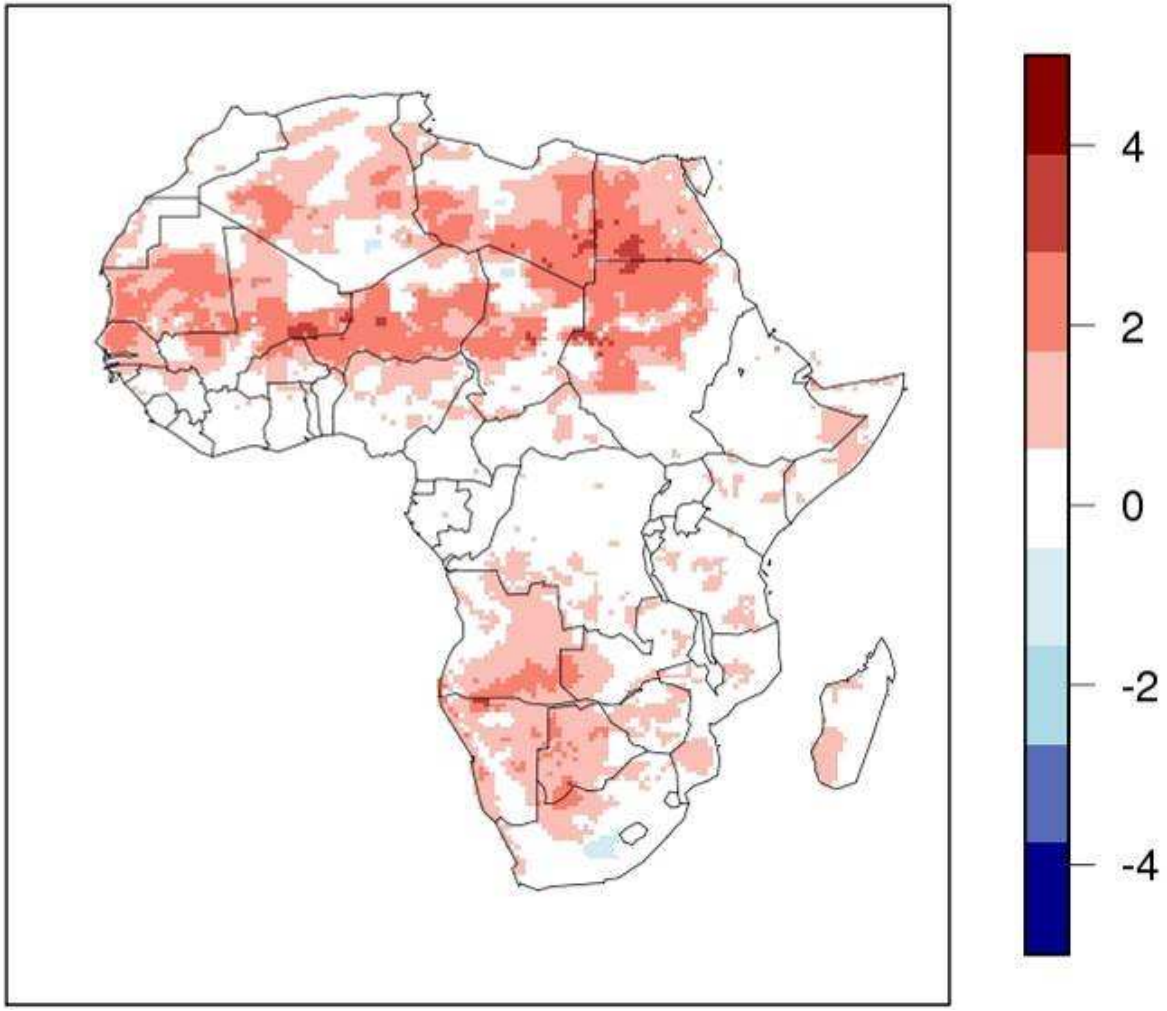
ADTR in COSMO-CLM experiment:

-Improvement in large parts of Sahara and Sahel

-Might improve simulation of convective systems during the West African Monsoon

Average diurnal 2-m temperature range [ºC]

COSMO-CLM: EXP – REF



ADTR in COSMO-CLM experiment:

-Increased in arid regions

Conclusions

- Ground heat flux in COSMO model is systematically overestimated under dry conditions.
- Affects other components of the surface energy balance like turbulent heat fluxes or surface temperature in terms of phase or amplitude of their diurnal cycles.
- Two approaches by Johansen (1975) and McCumber and Pielke (1981) for a soil thermal conductivity being dependent on soil moisture were tested.
- Improvements were achieved in offline, NWP and climate modes. The approach by Johansen (1975) appears favourable compared to the one by McCumber and Pielke (1981).

Thanks to Stefan Krähenmann and Steffen Kothe for assistance with COSMO-CLM Africa.