Evaluation of the ground heat flux simulated by a multi-layer land surface scheme using high-quality observations

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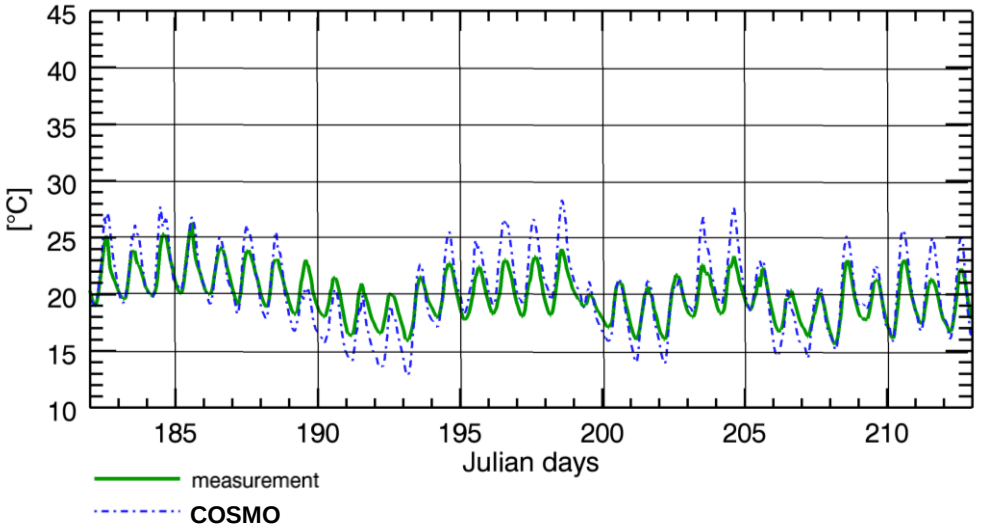
The problem …

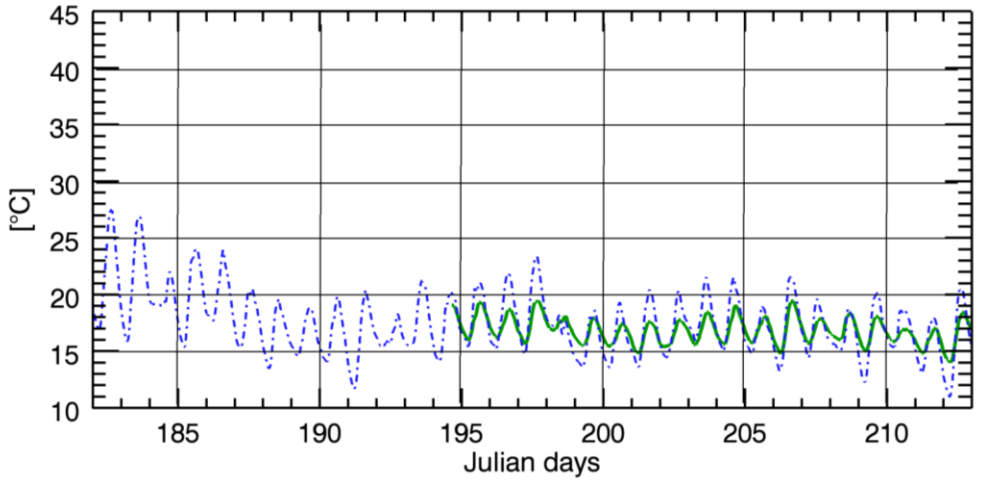
- The ground heat flux in the COSMO land surface scheme TERRA is systematically overestimated under dry conditions.
- Since this flux is part of the surface energy balance it affects the other components like the turbulent heat fluxes or the surface temperature.
- An overestimation of the ground heat 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)



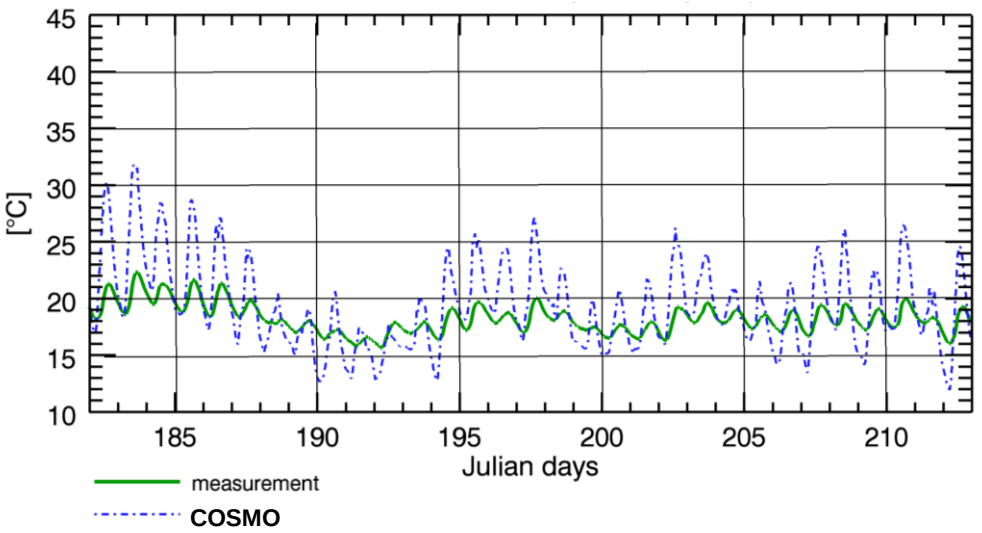
Cardington



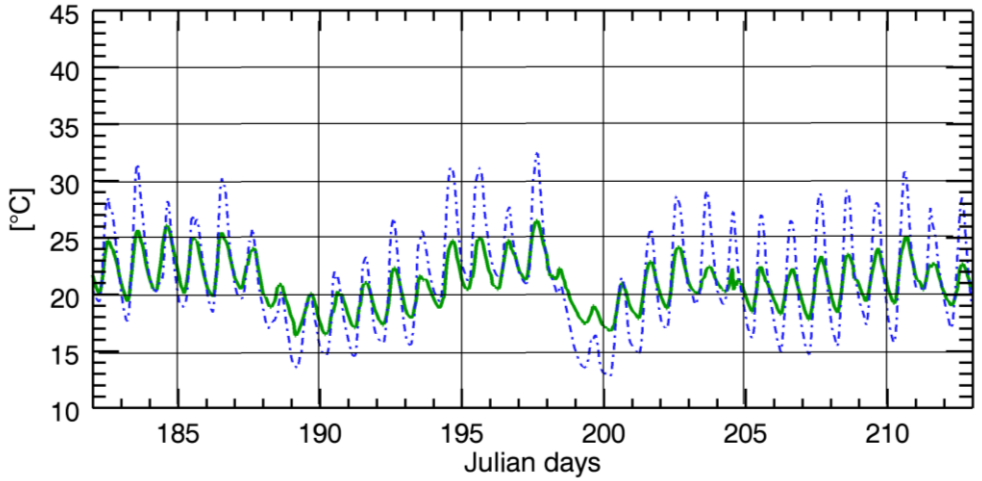
Observations from SRNWP data pool

Soil temperature (-6 cm) : July 2009

Cabauw



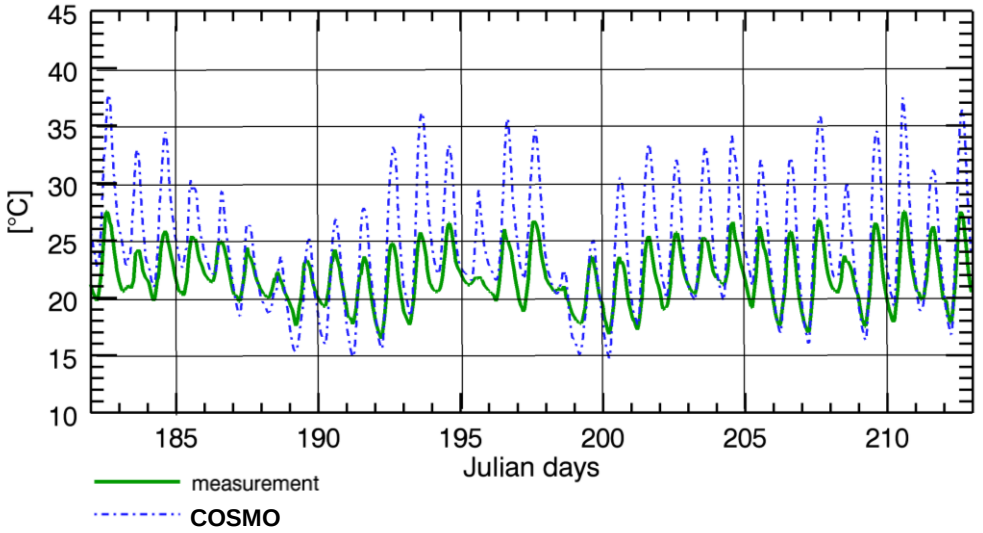
Payerne



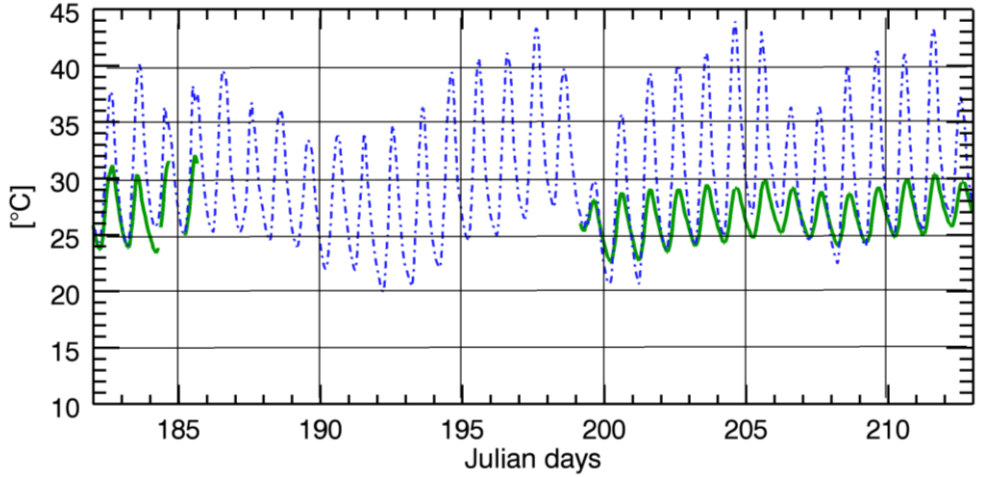
Observations from SRNWP data pool

Soil temperature (-6 cm) : July 2009

Toulouse (Fauga-Mauzac)



San Pietro Capofiume



Observations from SRNWP data pool

Hypothesis

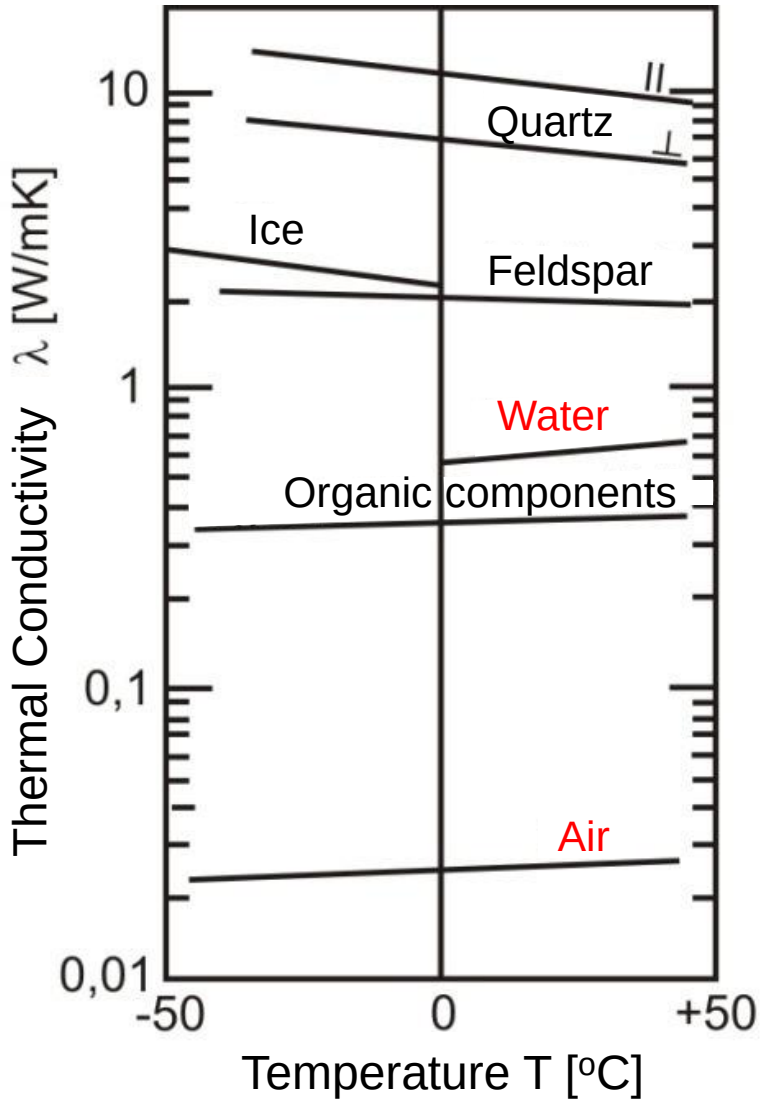
The ground heat flux in the COSMO model is systematically overestimated in summer. Main reasons:

- 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 dependence on the soil water content

Thermal Conductivity



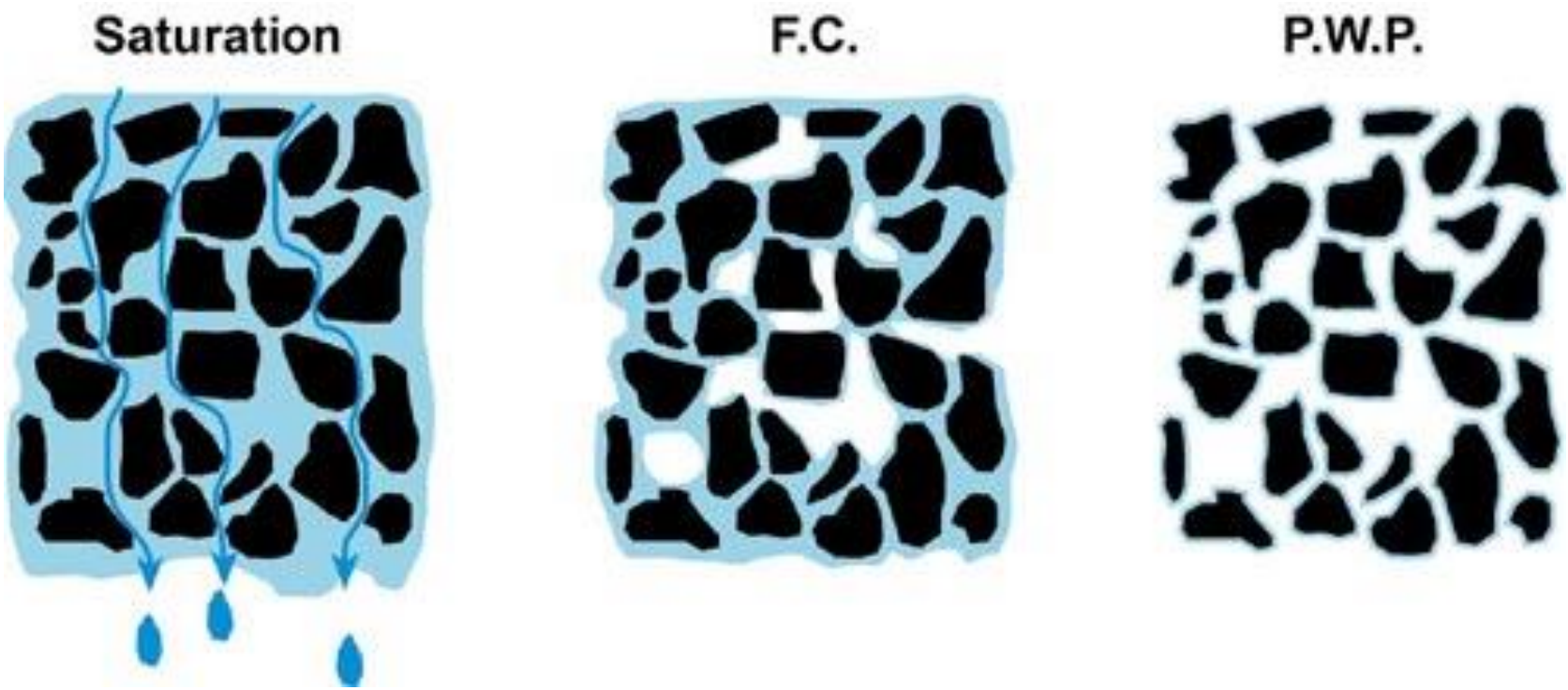
The thermal conductivity of water is about a factor of 25 larger than that of air!

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).

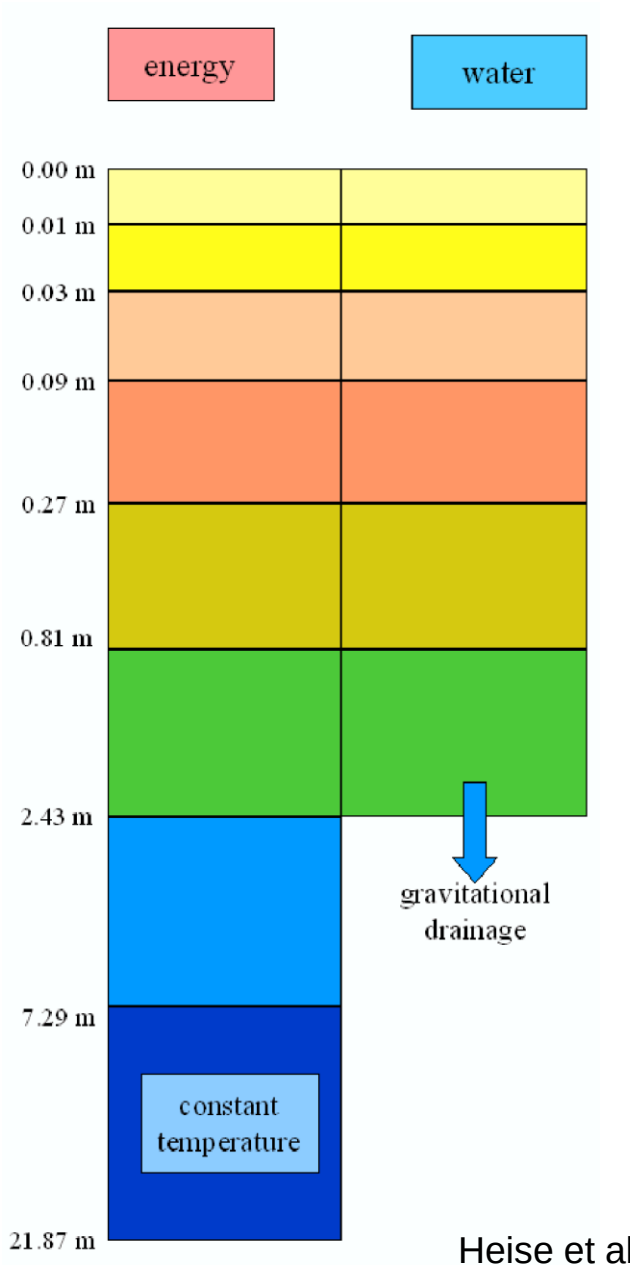
Baier (2008), after Frivik (1981)

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



Heise et al. (2006)

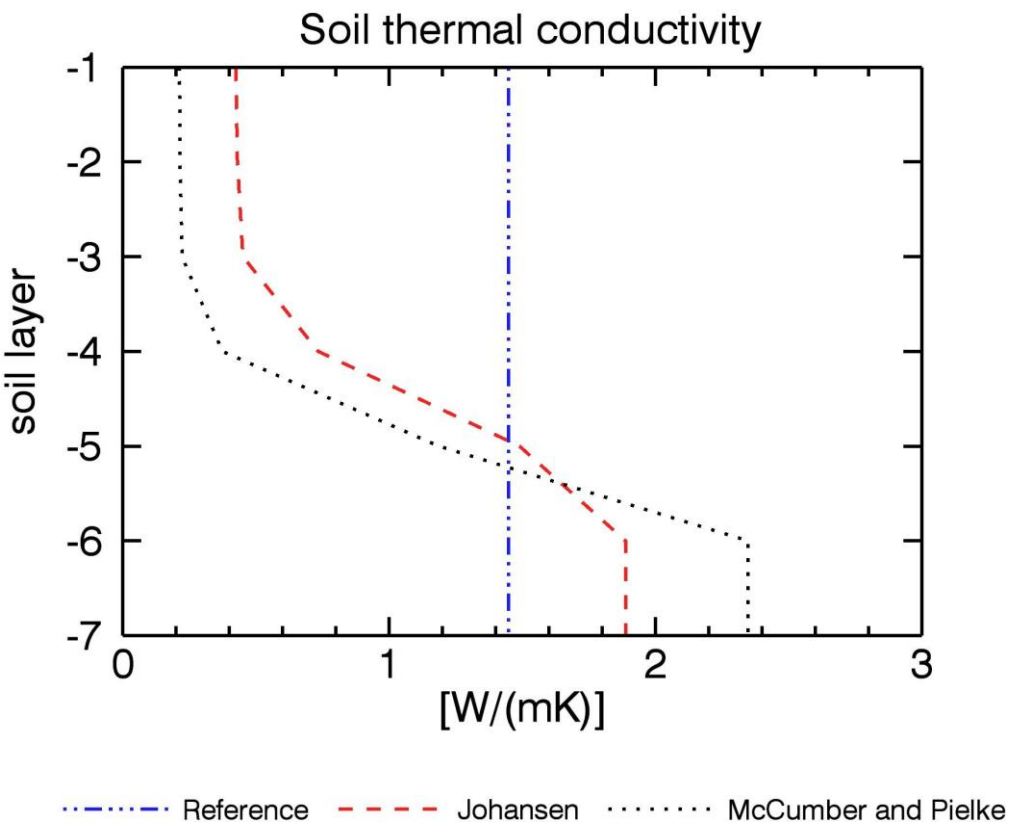
Land surface scheme TERRA

Layers for temperature and soil water content

Experiments:

- Introduce soil thermal conductivity dependence on soil water content
- Use atmospheric forcing to run TERRA in offline mode
- Here, observed forcing from DWD observatory Lindenberg is used (Falkenberg site)

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 **blue line** in the figure.

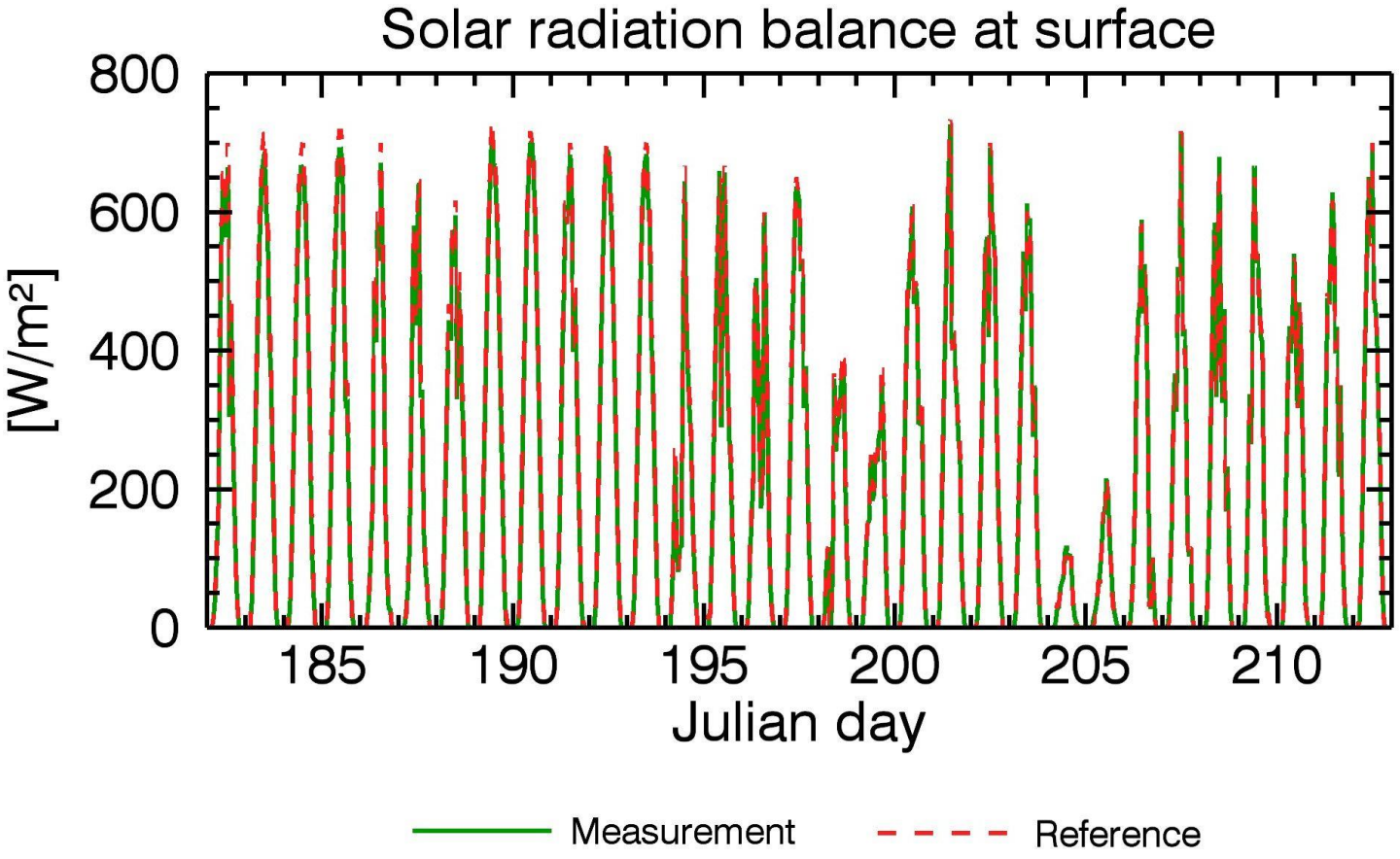
The red and black curve show two other approaches, relating thermal conductivity to soil water content:

- **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

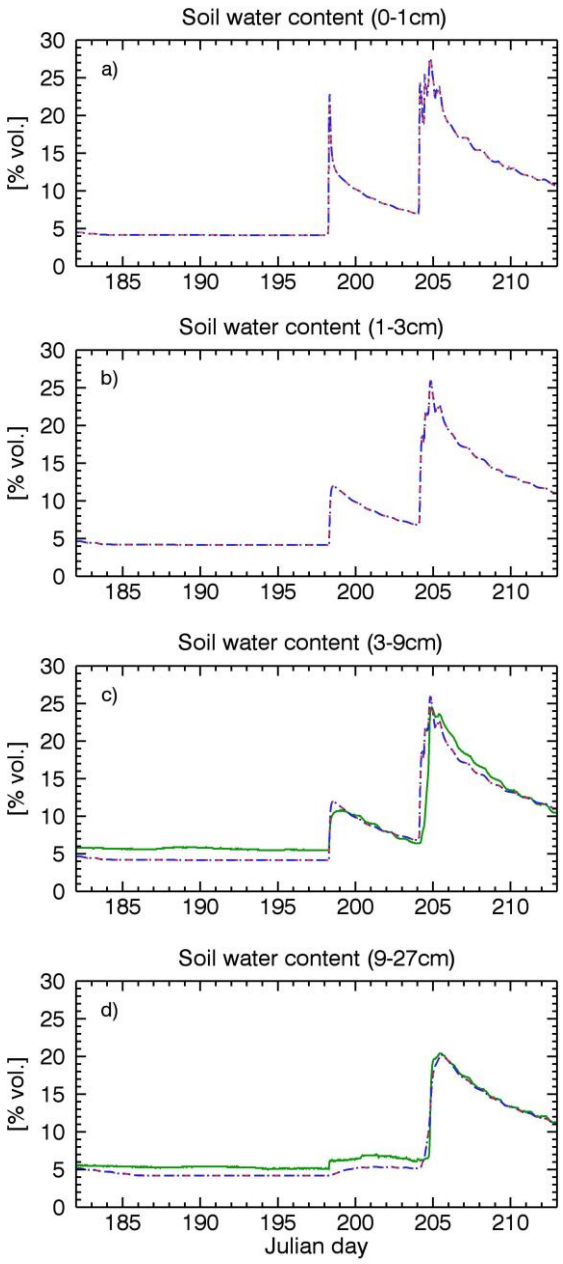
Grass land

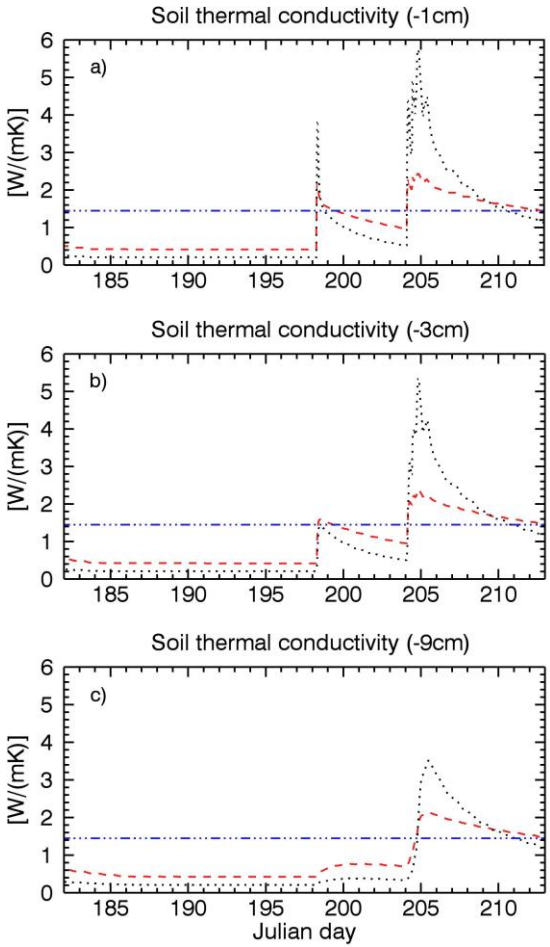


The simulated surface solar radiation balance agrees well with the observation (grass albedo = 0.18).

Offline TERRA: Falkenberg July 2010

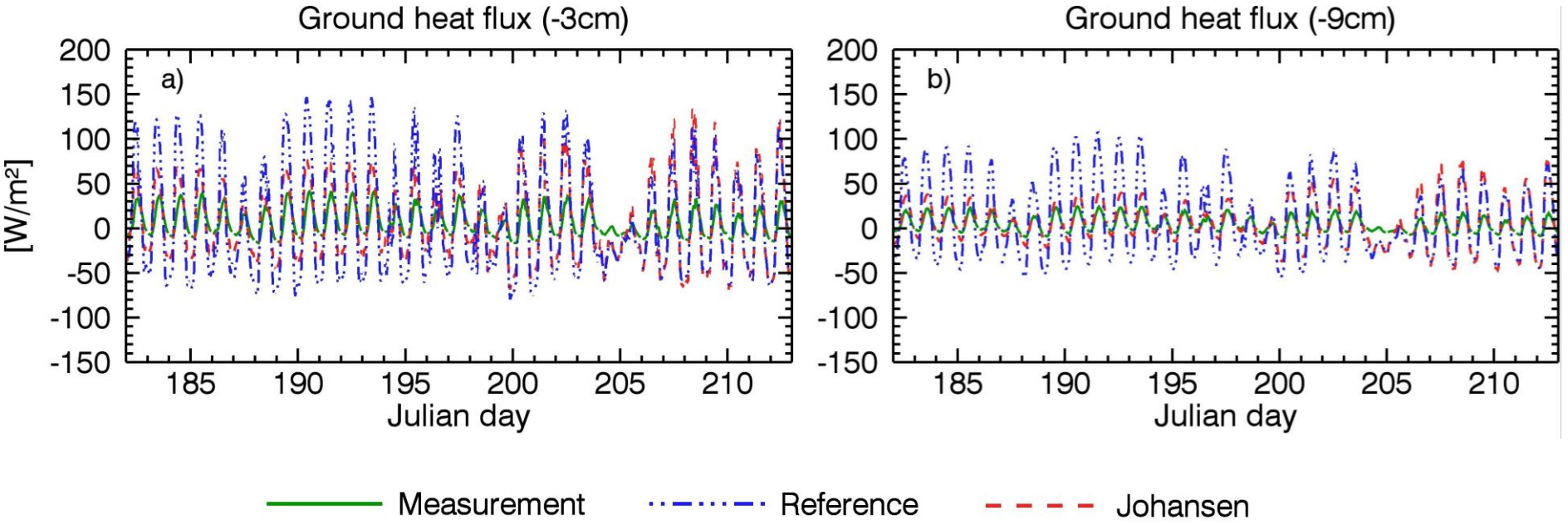
Grass land





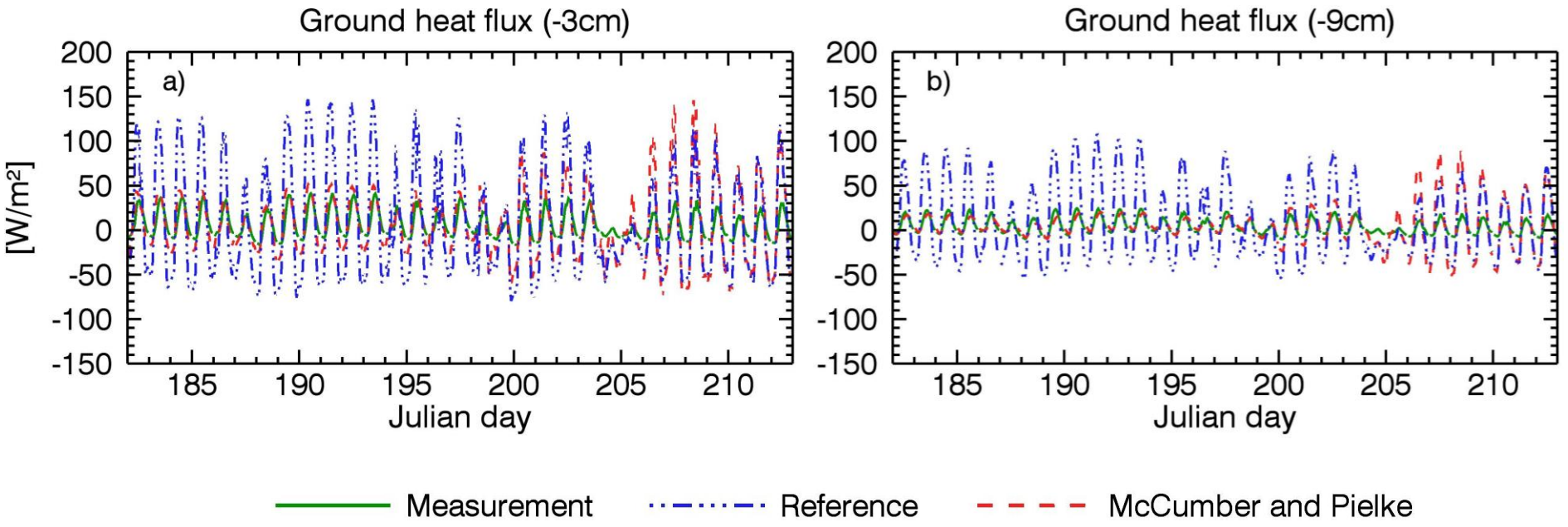
- First half of July 2010: Soil column very dry
- Two rain events in second half
- Changes in soil moisture are reflected in thermal conductivity

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



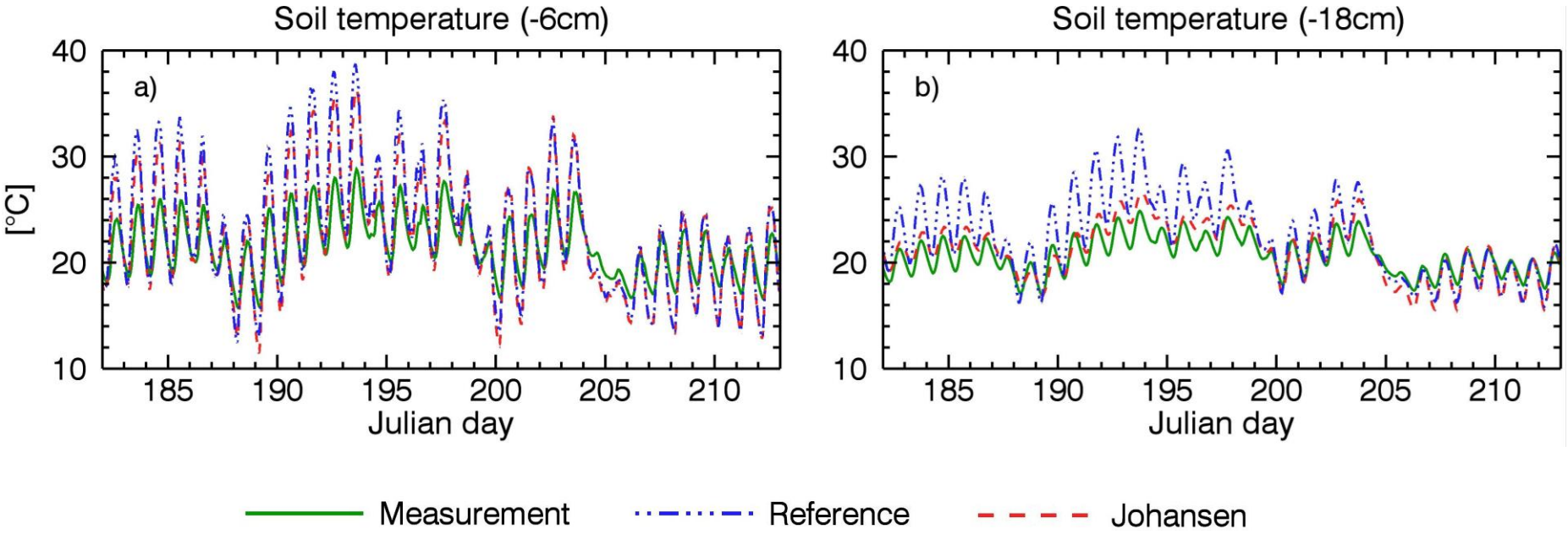
The diurnal cycles of the ground heat flux are reduced by Johansen under dry conditions and fit better to the observation.

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



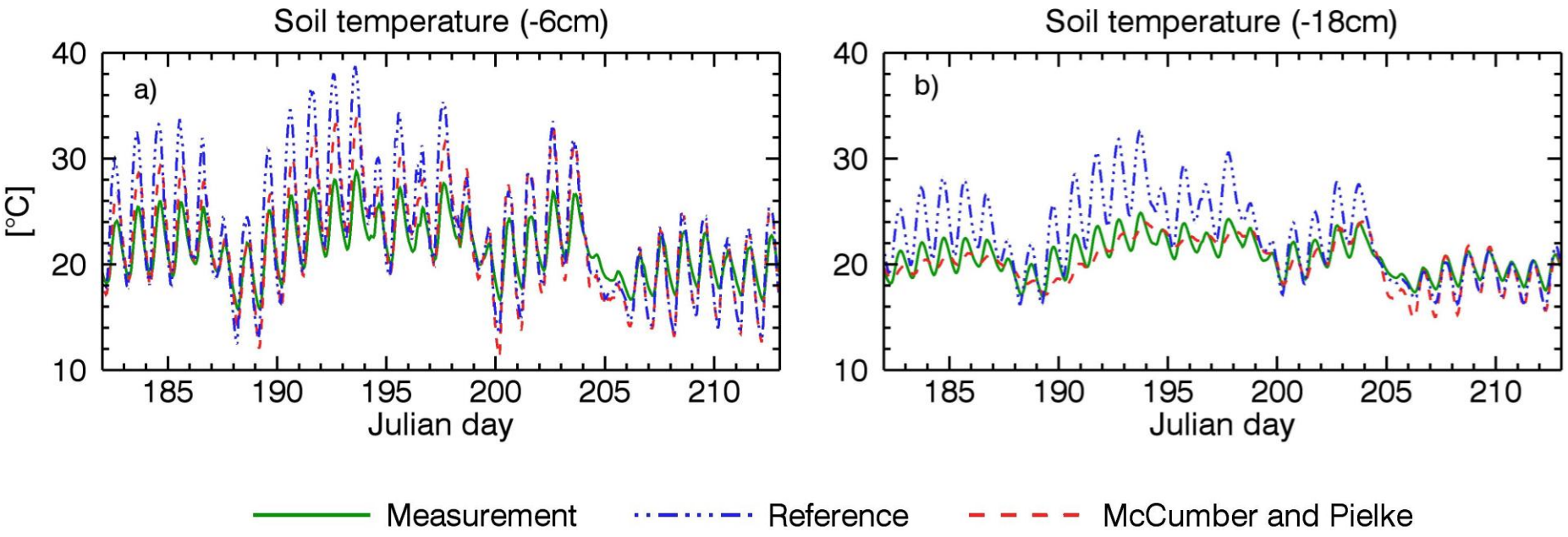
The diurnal cycles of the ground heat flux are even more reduced by McCumber and Pielke under dry conditions.

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



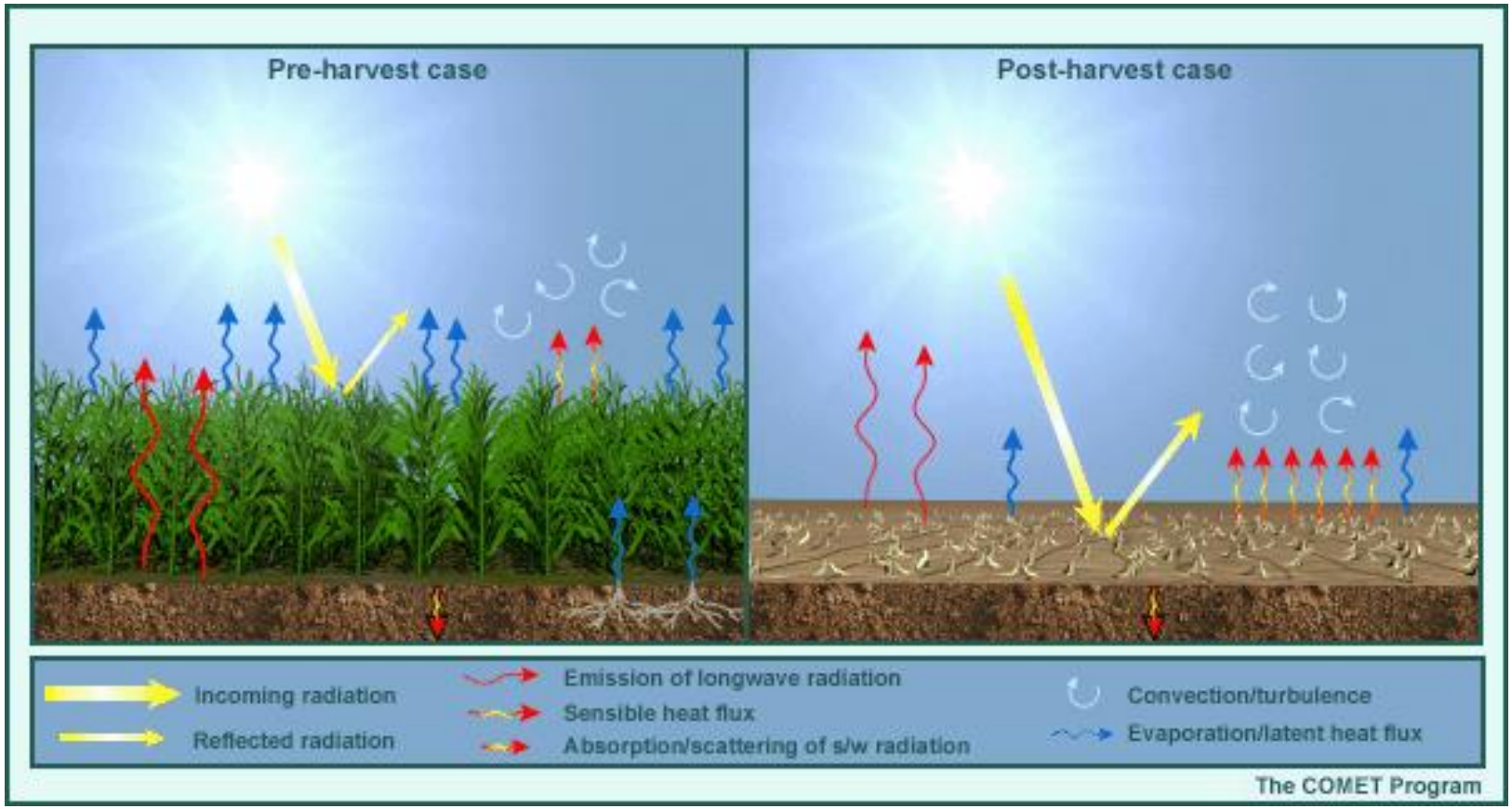
The diurnal cycles of the soil temperature are reduced by Johansen under dry conditions.

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



The diurnal cycles of the soil temperature are too much reduced by McCumber and Pielke under dry conditions.

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.

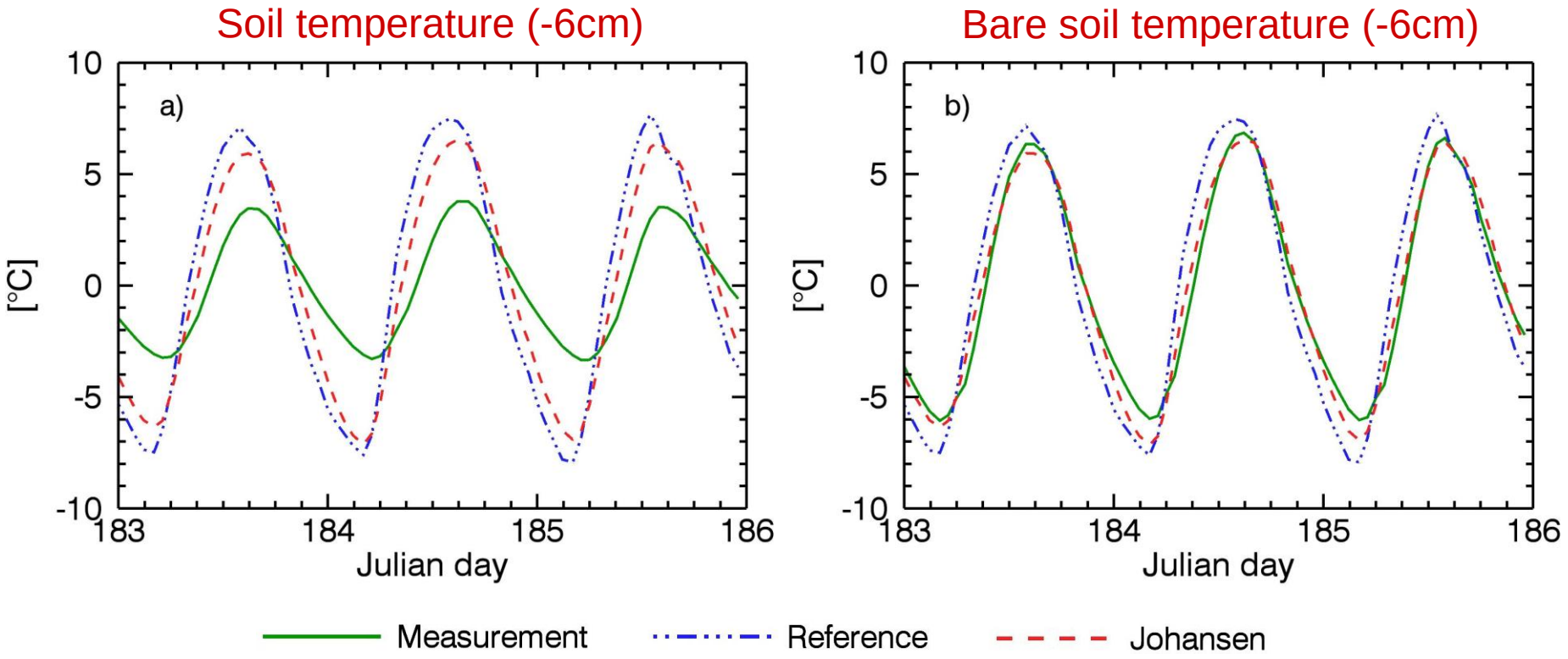
Falkenberg bare soil measurement site

23 Apr. 2002

30 Apr. 2003

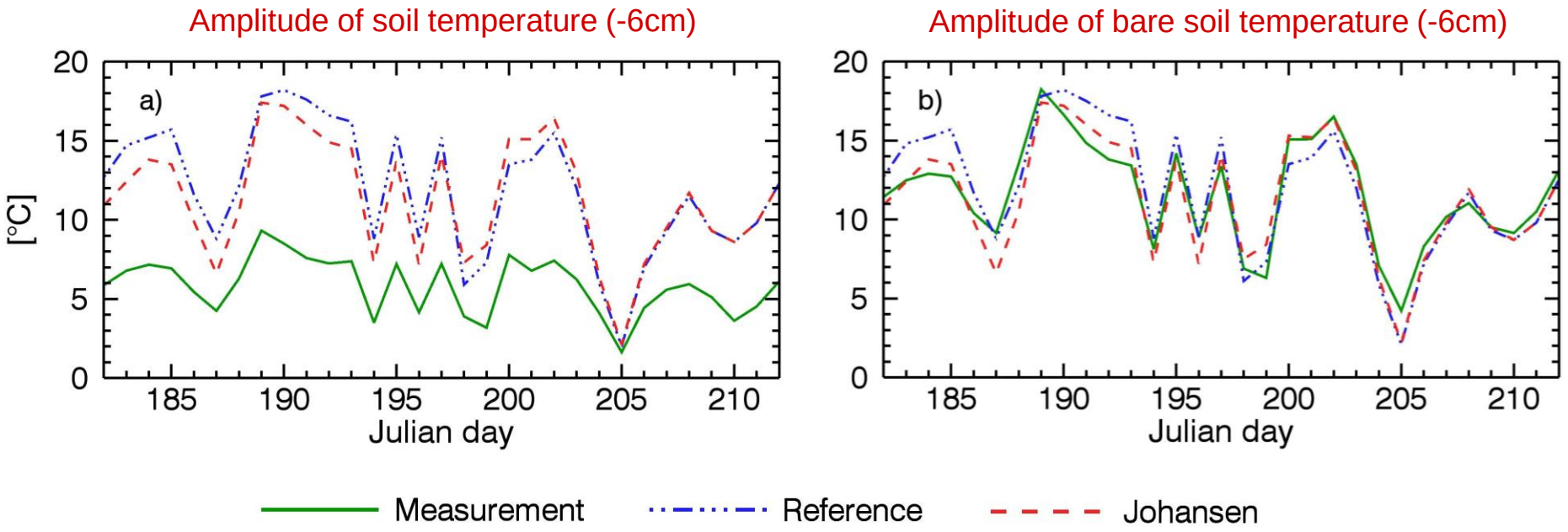
- Measurement of soil temperatures under bare soil
- Shading avoided
- About 1 m^2 in the middle of meadow
- Now comparison of temperatures under grass land and bare soil possible

Offline TERRA: Falkenberg 2 - 4 July 2010
Thermal conductivity: Johansen



- 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 huge effect

Offline TERRA: Falkenberg July 2010
Thermal conductivity: Johansen



- Measurements: Average diurnal temperature range (DTR) reduced by shading from 11.62°C to 5.84°C
- Day 182-197: Dry period, DTR reduced by Johansen by about 2°C
- Day 200-204: Soil column getting wet, DTR increased by Johansen by up to 2°C
- Beyond day 205: Wet period, both model versions and observation become similar

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. The first one leads to better results and appears to be favourable.
- A representation of the shading effect in the model needs further attention.