Simulating the Diurnal Cycle in Semiarid Regions

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10th May 2018

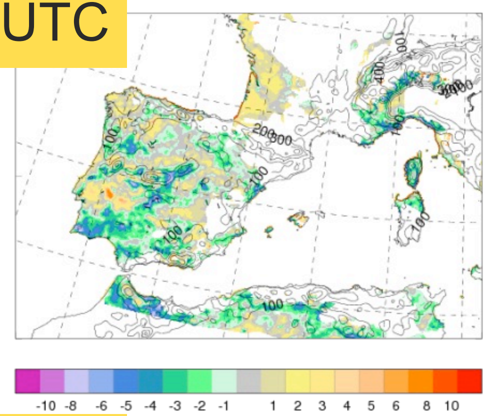
Outline

- Motivation
- Soil Physics in semiarid conditions
  - Three recent developments
    - Adsorbed water
    - Thermal Conductivity
    - The Surface resistance
  - Near-surface profiles of soil moisture and thermal conductivity -> parametrization
- Large-eddy simulations of the diurnal cycle over semiarid bare soil
  - MONC model with interactive land surface and radiation schemes

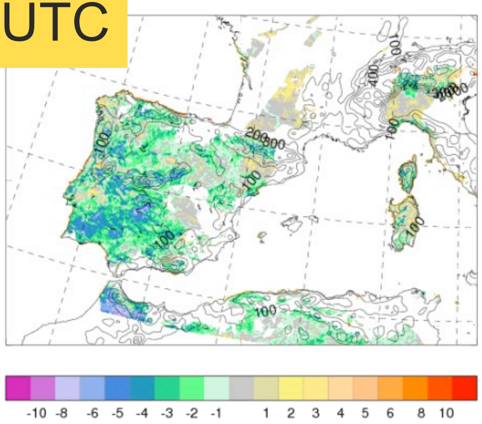
Motivation: Cold Bias in Land Surface Temperature

Errors in Land Surface Temperature vs. SEVIRI

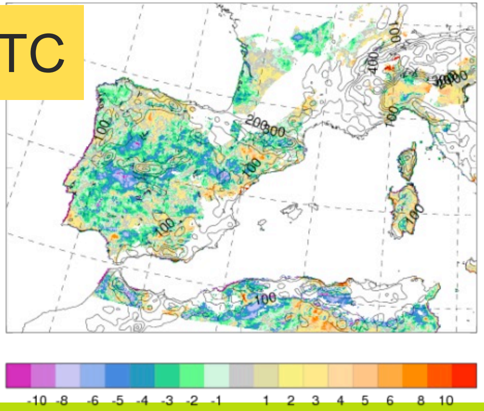
00 UTC



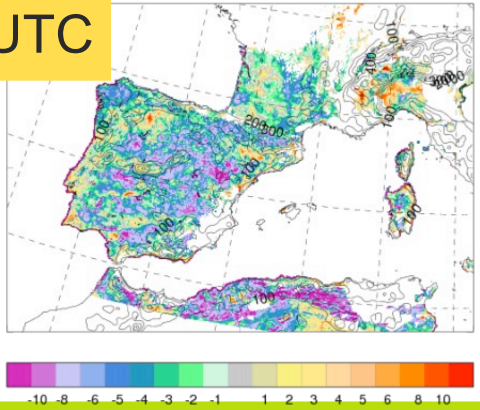
06 UTC



09 UTC



12 UTC



6th August 2016

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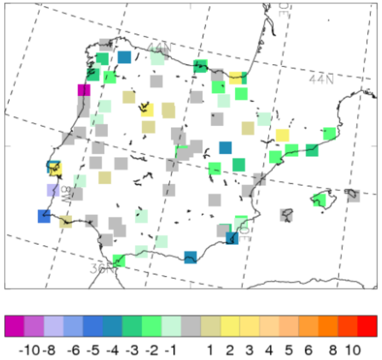
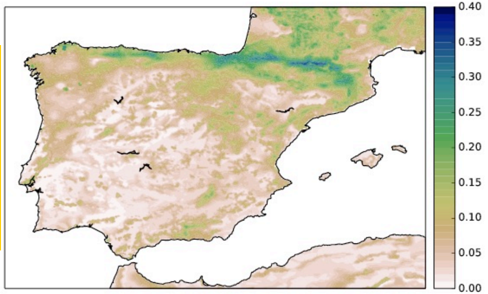
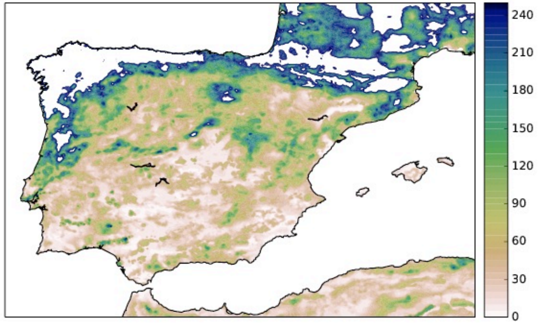
Error in T2m at 12 UTC



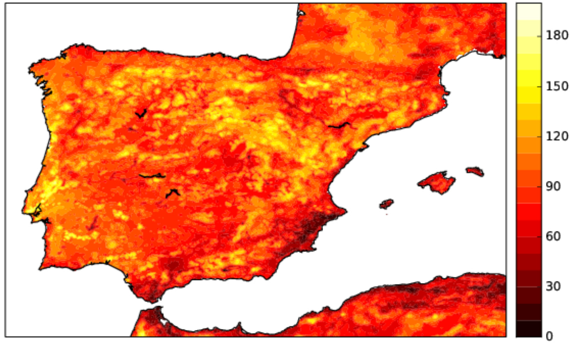
Volumetric Soil Moisture 0-10 cm - ASCAT assimilated



Latent Heat Flux at 12 UTC



Ground Heat Flux at 12 UTC



Modelling the Soil Surface

The Soil Surface in JULES

- Standard thicknesses of soil layers: Δ_i = **0.1 m**, 0.25 m, 0.65 m, 2 m
- Soil surface resistance to evaporation

$$r_s = 100[\theta_{FC} / \theta(\Delta_1 / 2)]^2$$

- Ground Heat Flux

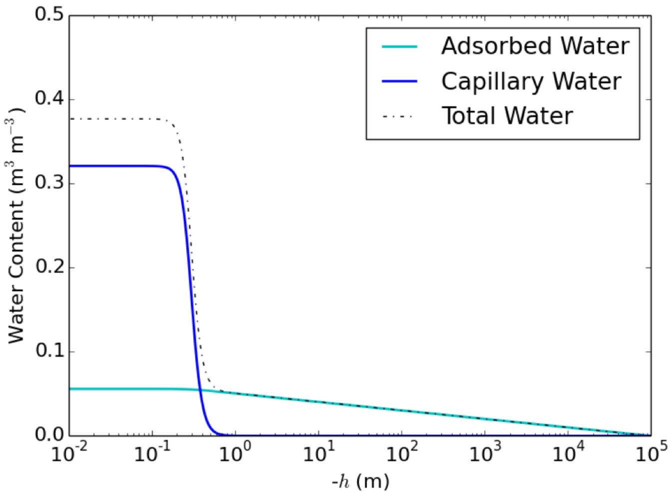
$$G = \lambda(\Delta_1 / 2) \frac{[T(0) - T(\Delta_1 / 2)]}{\Delta_1 / 2}$$

1. Adsorbed Water

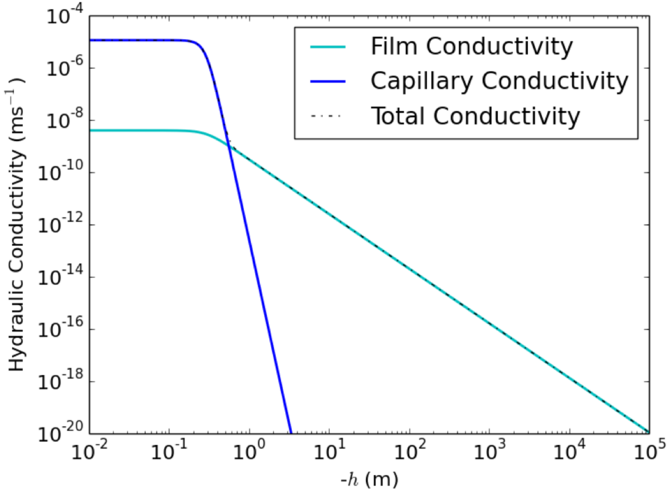
- Soil moisture and water fluxes
  - Flow of capillary water through soil pores: traditional soil hydraulics
  - Diffusion of vapour through air spaces
  - Flow of liquid in adsorbed films: not considered in typical LSMs
- Recent Work
  - **A Peters (2013), Water Resour. Res., 49, 6765**
    - Complete model for SWRC and hydraulic conductivity but contains unspecified parameters
  - **Rudiyanto et al. (2015), Water Resour. Res., 51, 8757**
    - Propose equations to infer missing parameters for adsorption from existing parameters for capillary water

Example: Tottori Dune Sand

Soil Water Retention Curve



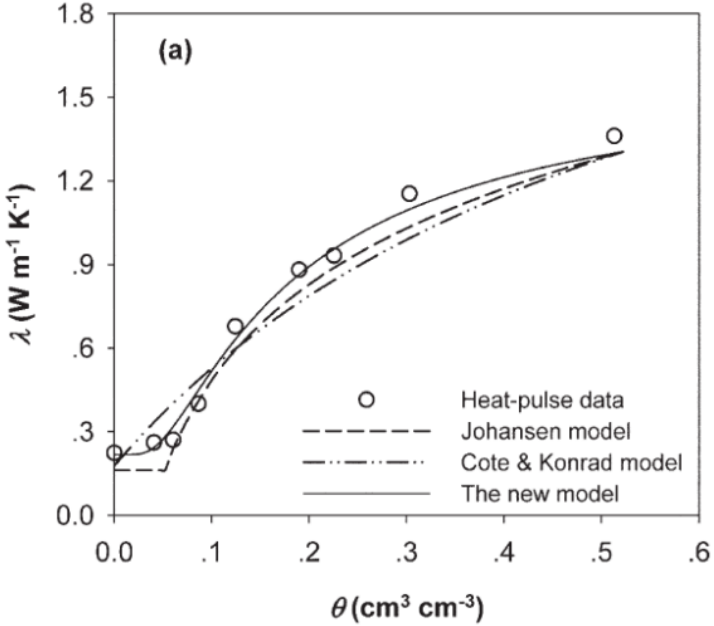
Hydraulic Conductivity



2. Thermal Conductivity λ

- λ increases with water content, but only slowly at first
- Parametrizations are somewhat uncertain in the dry region
- Resistivity may be more important in practice
  - Temperature difference across a constant flux layer

$$\Delta T = H \int_0^d \frac{1}{\lambda(z)} dz \equiv H \frac{d}{\boldsymbol{\lambda}_{\mathbf{eff}}}$$



Lu et al. (2007), Soil Sci. Soc. Am. J., 71, 8—14

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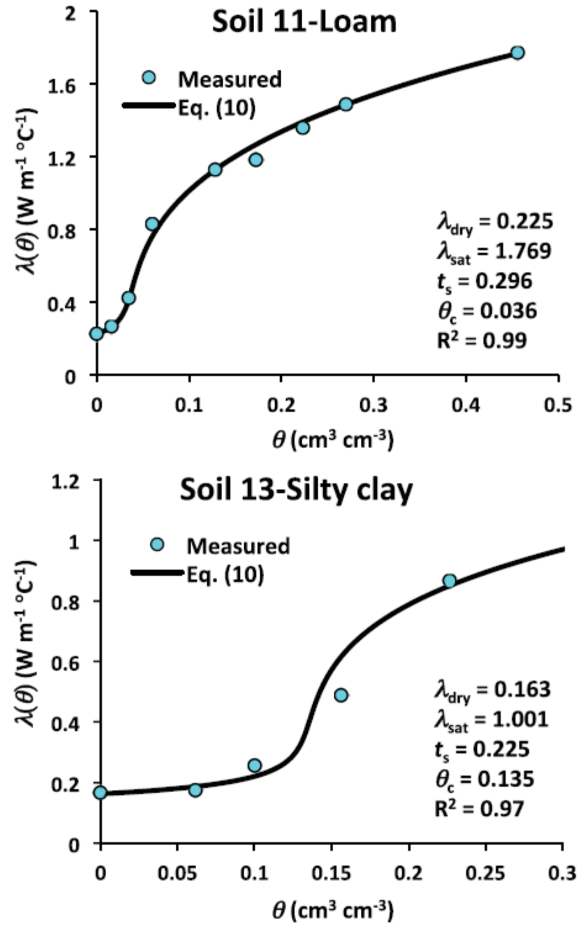
- Model impact of water on thermal conductivity as a process of percolation – **Ghanbarian and Daigle (2015), Water Resourc. Res., 52, 295**

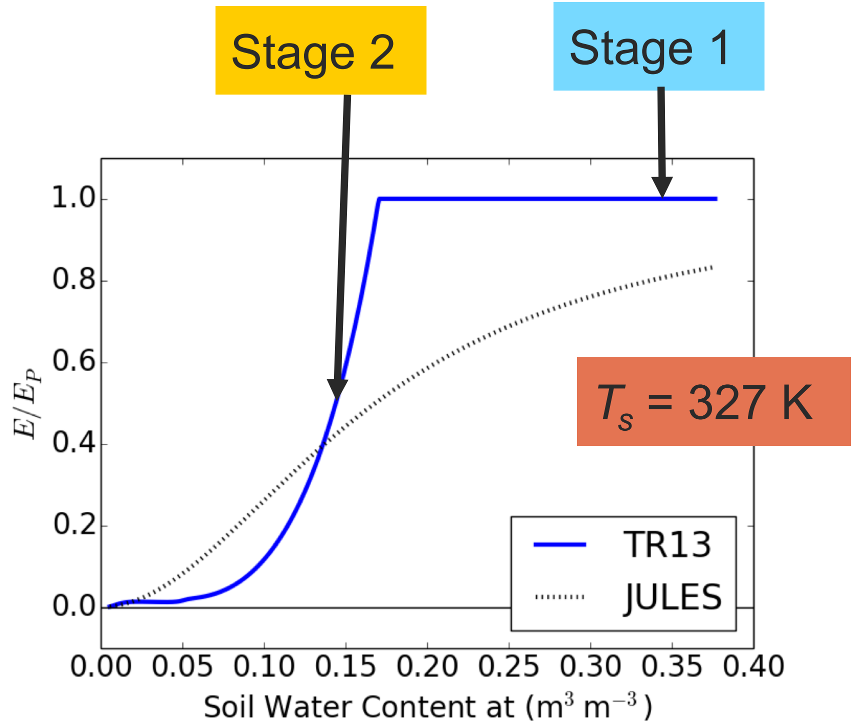
- Rapid increase in conductivity as domain-spanning threads of water appear

From Ghanbarian & Daigle Fig. 5



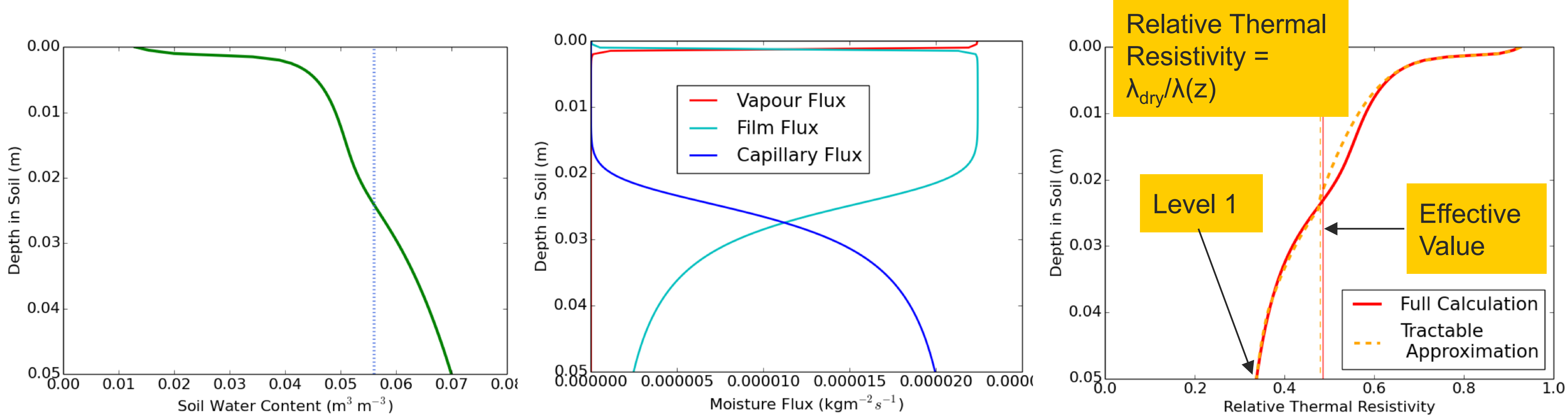
3. Evaporation at the Surface

- Standard surface resistance in JULES gives insufficient variation of evaporation with soil moisture
- Instead, follow **Tang & Riley (2013), Hydrol. Earth Syst. Sci., 71, 873**.
  - Constant flux layer for water in soil and air, including vapour and liquid
- Use hydraulics of Rudiyanto et al. in their scheme, but do not discretize derivatives in the soil as Tang & Riley do, so as to handle sharp gradients well
  - Get a continuous profiles of soil moisture etc.



Illustrative Example: Tottori Sand

- If SWC at 5 cm (level 1) is just above residual water content in Stage 2 we may expect:
  - A sharp gradient of SWC very close to the surface
  - Transport by vapour in the top few mm/cm of the soil
  - A zone of film flow
  - Effective thermal conductivity between surface and level 1 significantly less than local value at 5 cm

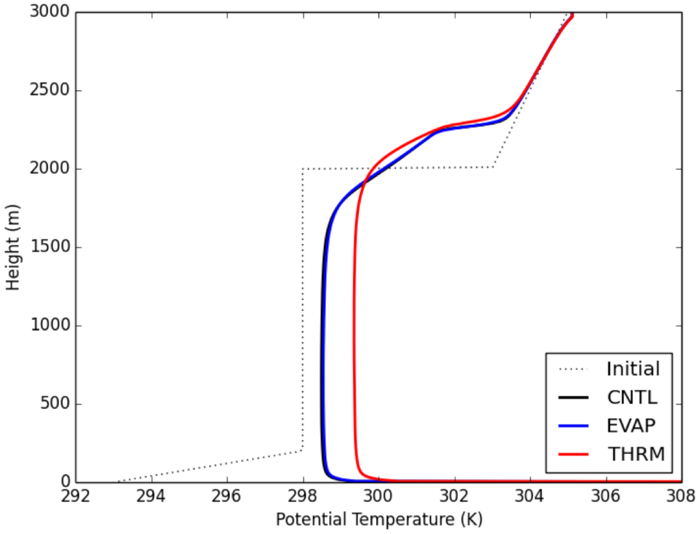


Large-Eddy Simulations

Diurnal Cycle in LES

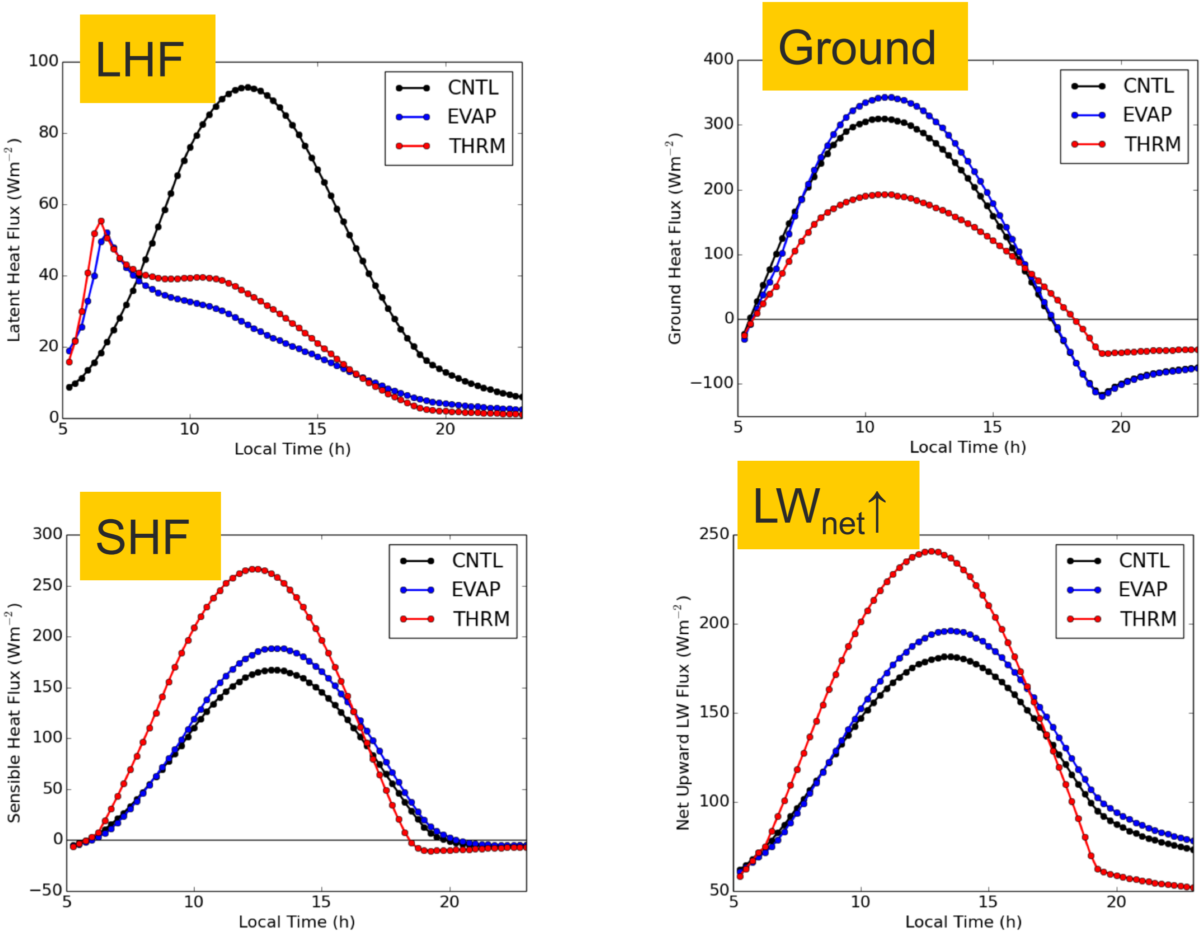
- Mid-June, 40º N, Clear-sky
- Initialized at dawn
  - SBL 200 m deep, Residual layer above, Strong capping inversion (dotted profile)
- Interactive Radiation and Land Surface
  - Soil based on Tottori Dune Sand with assumed thermal properties – 20 % saturated initially
- Domain: 5 x 5 x 3 km (128^2 x 256 pts)
- **Three Simulations:** 18 hours long
  - CNTL (standard r_s, λ at 5 cm)
  - EVAP (revised r_s)
  - THRM (revised r_s and thermal resistivity)

Profiles of Potential Temperature at 11 am



Surface Fluxes

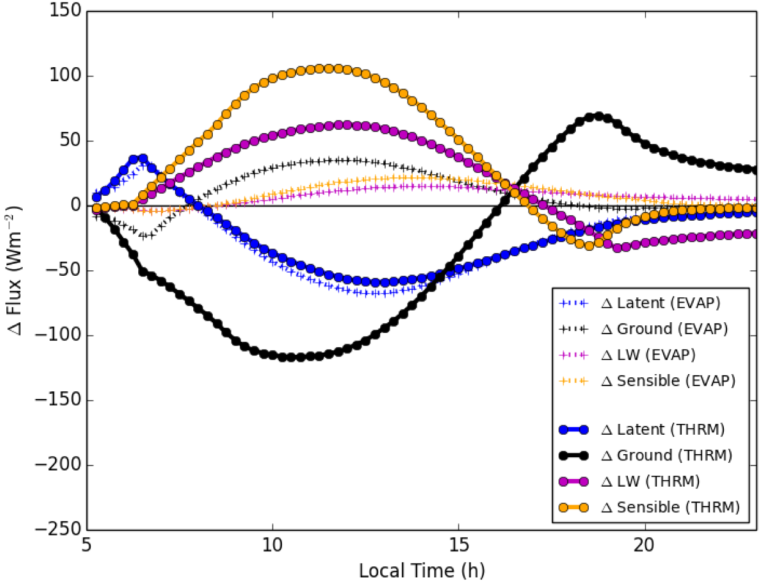
+ve away from surface



Change in Fluxes away from the Surface

More surface cooling

Less surface cooling

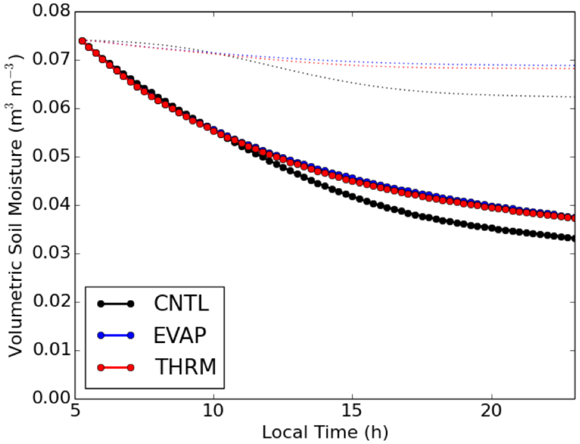


EVAP – CNTL
(*Dot-dashed*) =>
LH ↓
G, SH, LW_n ↑

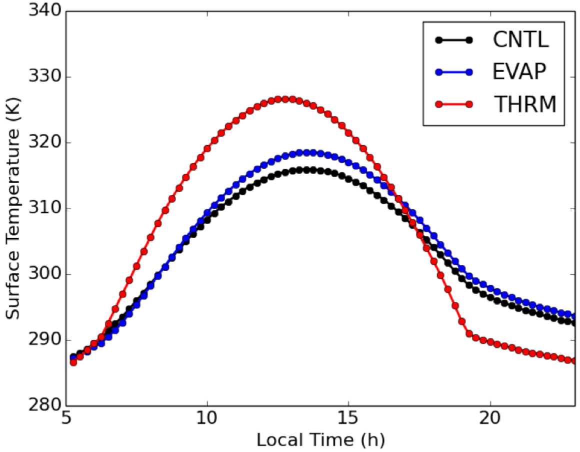
THRM - CNTL
(*Solid*) =>
LH, G ↓
SH, LW_n ↑

Soil Moisture and LST

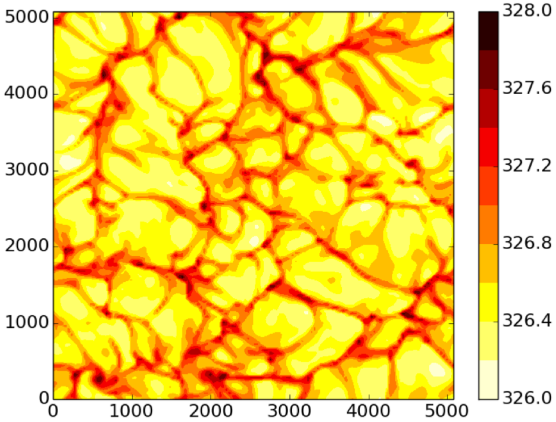
Soil moisture in level 1
Thick: Full incl. drainage
Thin: Evaporative part



Surface Temperature
Grid-box mean



Surface Temperature at peak of cycle



Conclusions

- Important to consider thermal and hydraulic properties of the soil together
  - Thermal **resistivity** in dry conditions is particularly important
- When near-surface soil moisture is close to residual value, models should represent zone of low thermal conductivity