Modelling soil heat and water flow as a coupled process

Raquel García González

Anne Verhoef

Pier Luigi Vidale

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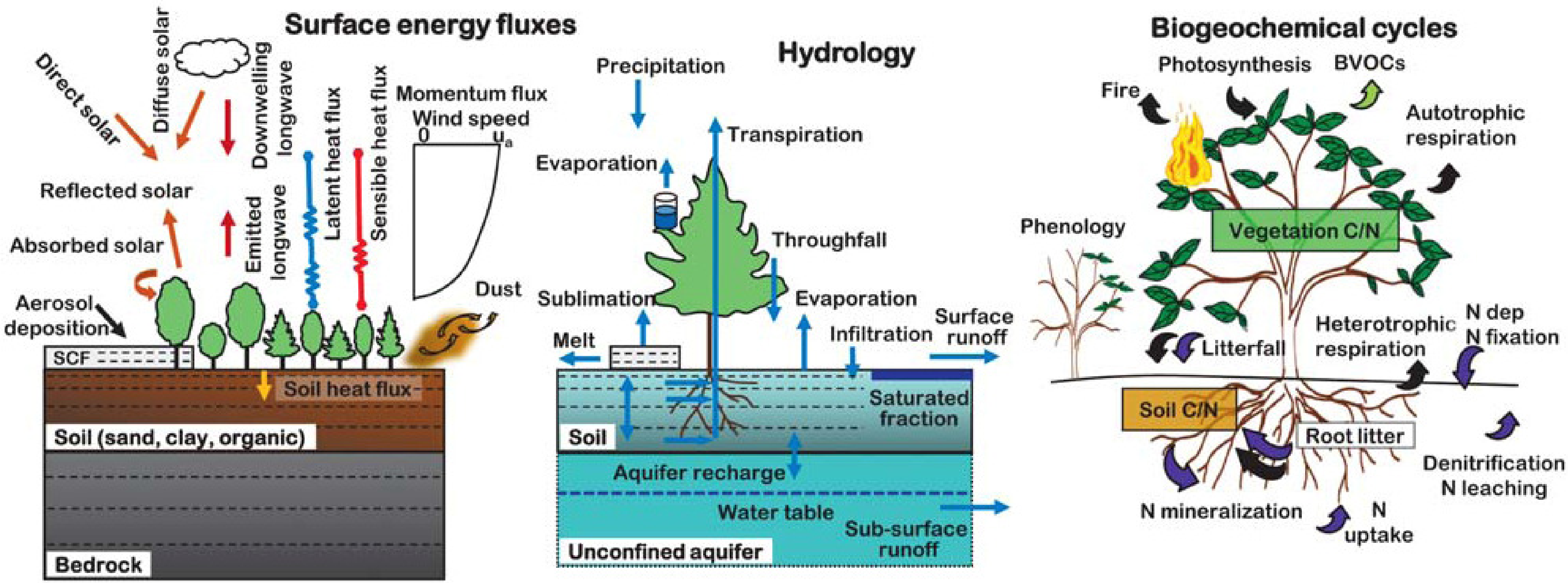
University of Reading

A complex environment

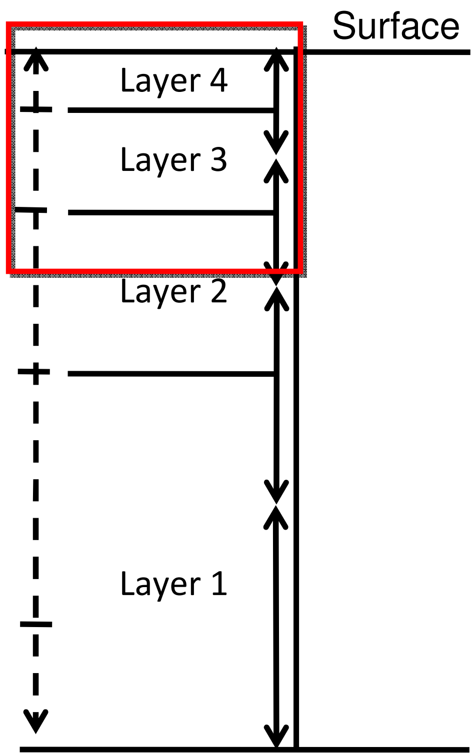


Schematic diagram of terrestrial processes represented in the National Center for Atmospheric Research Community Land Model (CLM4) (Source: Lawrence, 2010)

- “ALL MODELS ARE WRONG BUT SOME ARE USEFUL”
  George E.P. Box

- Need to understand the reasons of the considerable discrepancies found between models and experimental data
- Model-data inter-comparisons, as a benchmarking tool
  - Limitations of the measured data
  - Source of error in individual models
  - Reason for the variation among model simulations

Soil Heat & Water transfer in JULES



- Understand processes involved
- Identify neglected processes, i.e. water vapour flux
- Update multi-layer scheme
  - Soil water dynamics
  - Heat transfer
  - Soil-Vegetation-Atmosphere coupling

Focus: Combined effect of incorporating water vapour flux together with increasing the vertical soil resolution

Water vapour flux I

- Iso-thermal and thermal vapour fluxes in LSMs are neglected in LSMs and the simplified Richards equation is used instead
- Vapour transfer may affect the water fluxes and heat transfer in LSMs simulated for hydro-meteorological and climate studies [Bittelli et al., 2008]
- Processes occurring in the top-soil layers may affect water and heat flux dynamics in the deeper layers [Grifoll et al., 2005], as well as estimates of evapotranspiration, heterotrophic respiration and nitrogen cycling

Nomenclature:	4L- 4 layers only Liquid transfer 4LV- 4 layers with Liquid and Vapour flux 20LV – 20 layers with Liquid and Vapour flux

Water vapour flux in JULES II

Due to soil water potential (isothermal) and thermal gradients…

$$C_{h,i}\frac{\partial \psi_i}{\partial t}=\frac{\partial}{\partial z}\left(\left(K_i+D_{\psi,v,i}\right)\frac{\partial \psi_i}{\partial z}+D_{T,v,i}\frac{\partial T_i}{\partial z}+K_i\right)-E_i$$

Isothermal vapour conductivity → $D_{\psi,v,i}$

Thermal vapour diffusivity → $D_{T,v,i}$

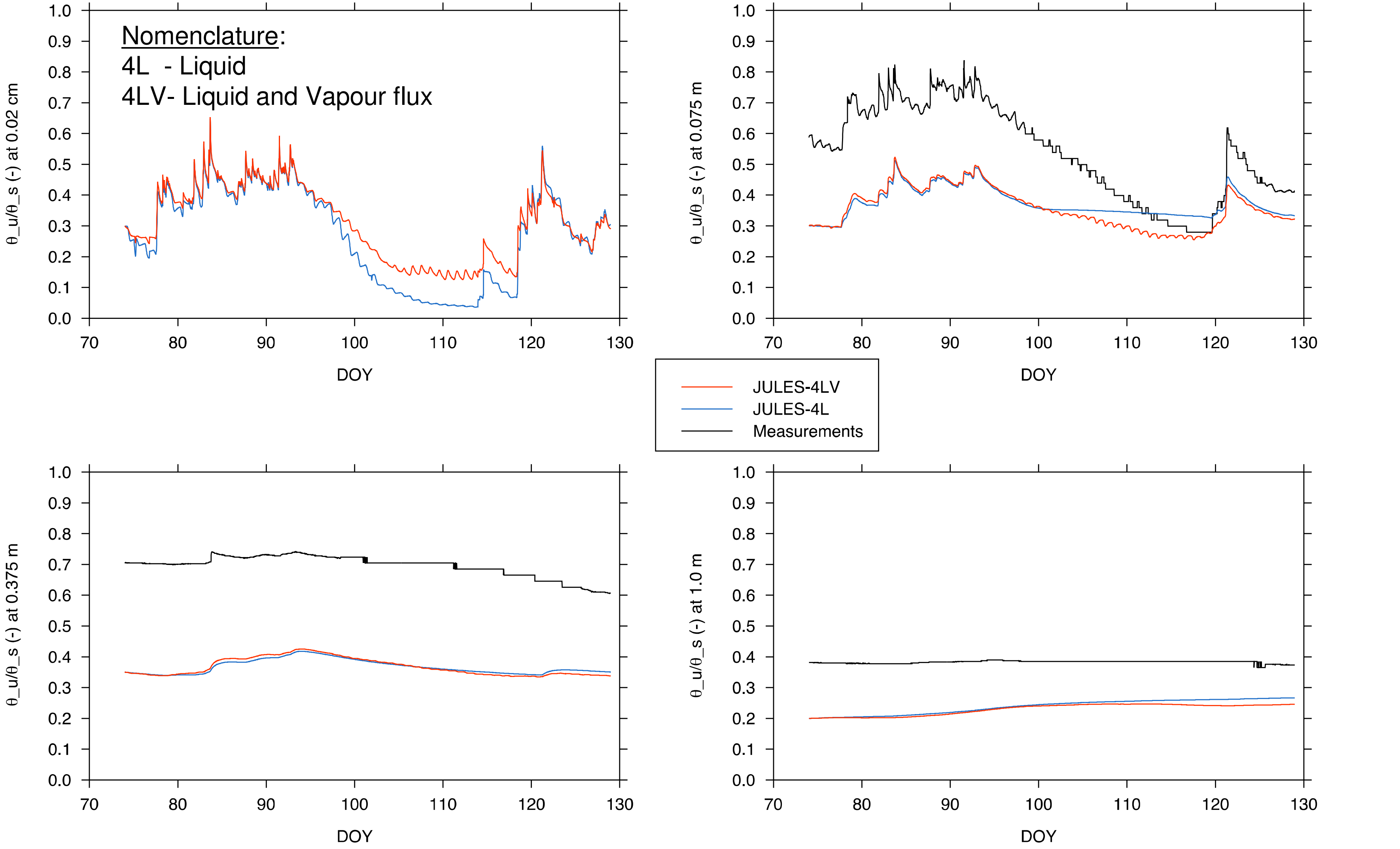
$$C_A\frac{\partial T_i}{\partial t}=\frac{\partial}{\partial z}\left[\lambda_i\frac{\partial T_i}{\partial z}+\rho_w L D_{\psi,v,i}\frac{\partial \psi_i}{\partial z}\right]-c_w W_{l,i}\frac{\partial T_i}{\partial z}$$

These gradients will induce soil moisture transport and affect soil moisture distribution, which in turn will affect heat flow

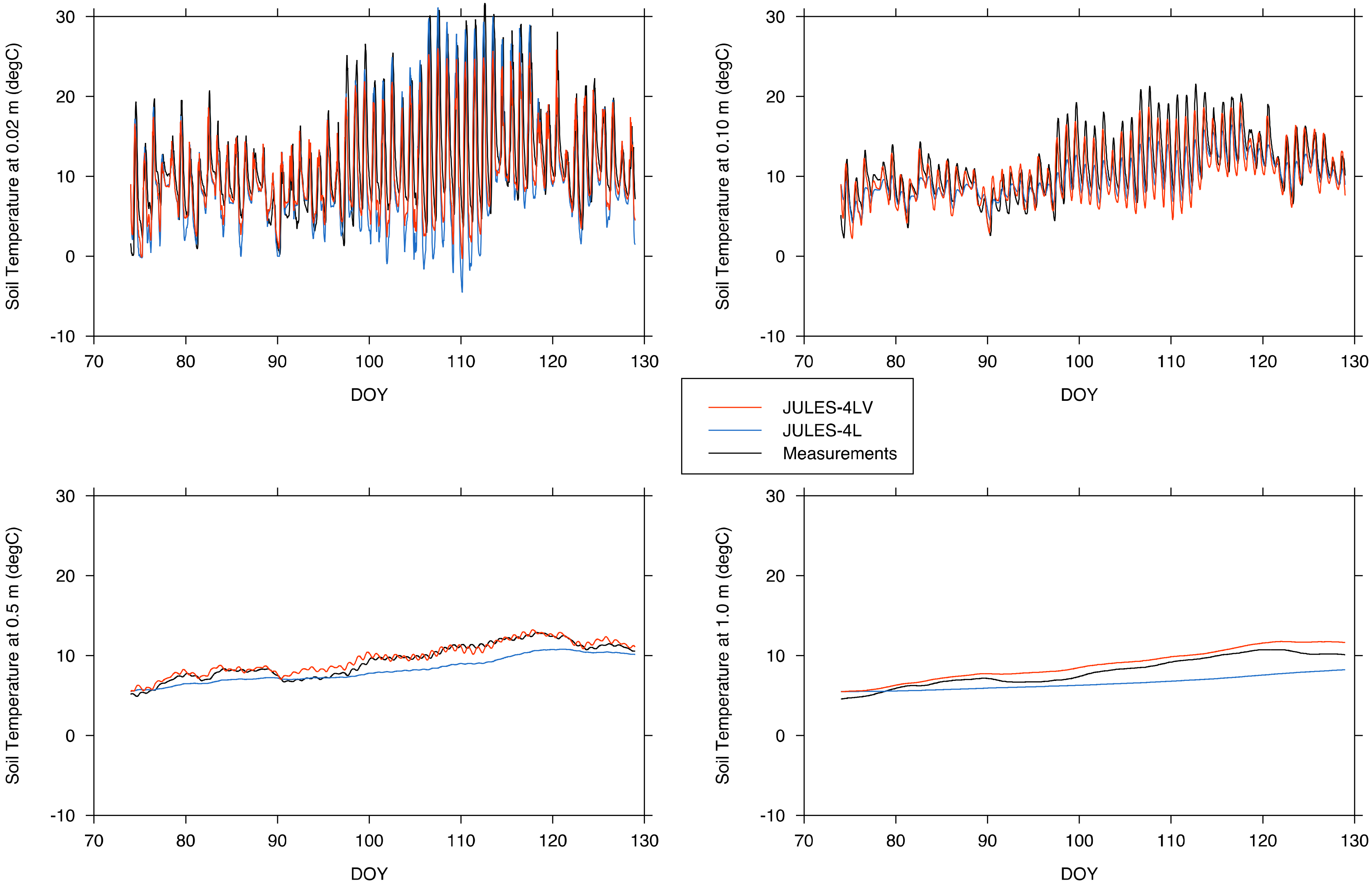
Milly, et. 1982, 1984

Site: Drayton St Leonard (Oxfordshire)

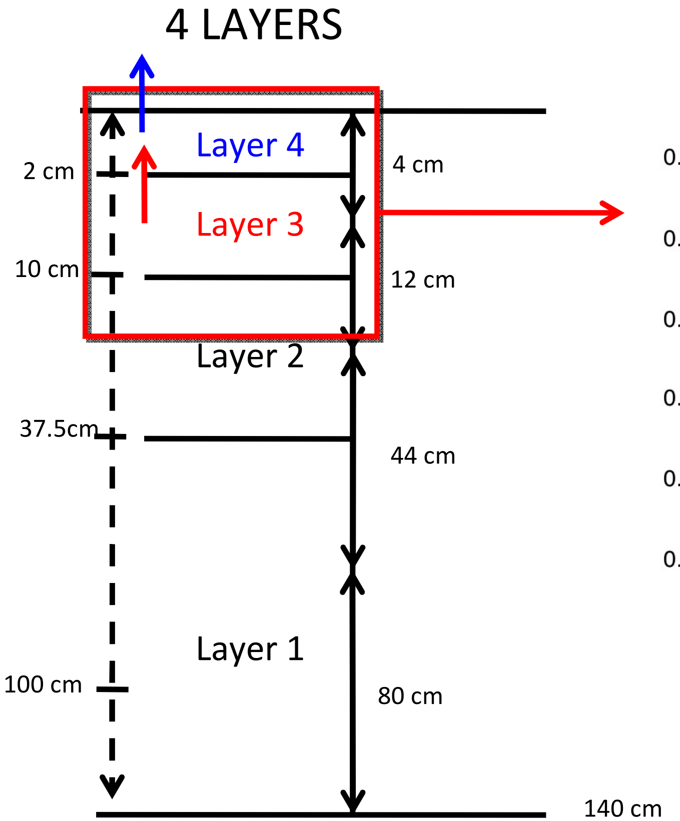
Results – Hydrology and heat transfer



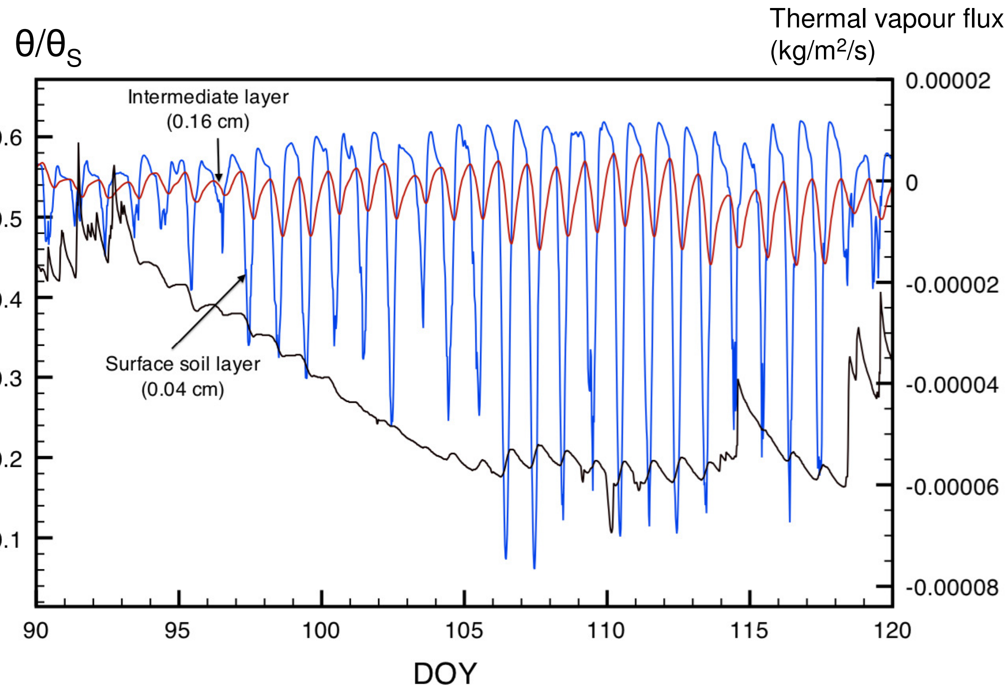
Results – Hydrology and heat transfer



Results - Contribution of water vapour fluxes



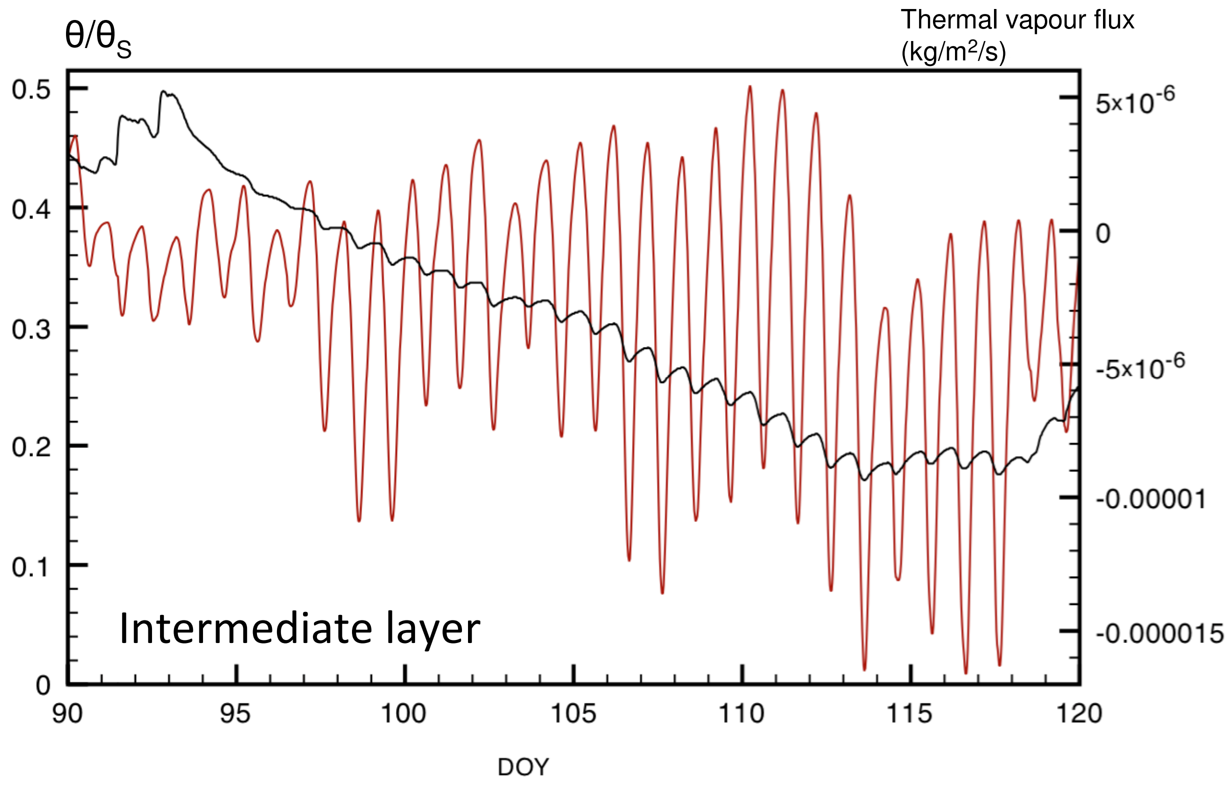
Downward fluxes are positive



Effective water vapour transfer in the first 20 cm top soil layer (for other sites could be up to 30 cm) >> as a result of different climate and soil properties

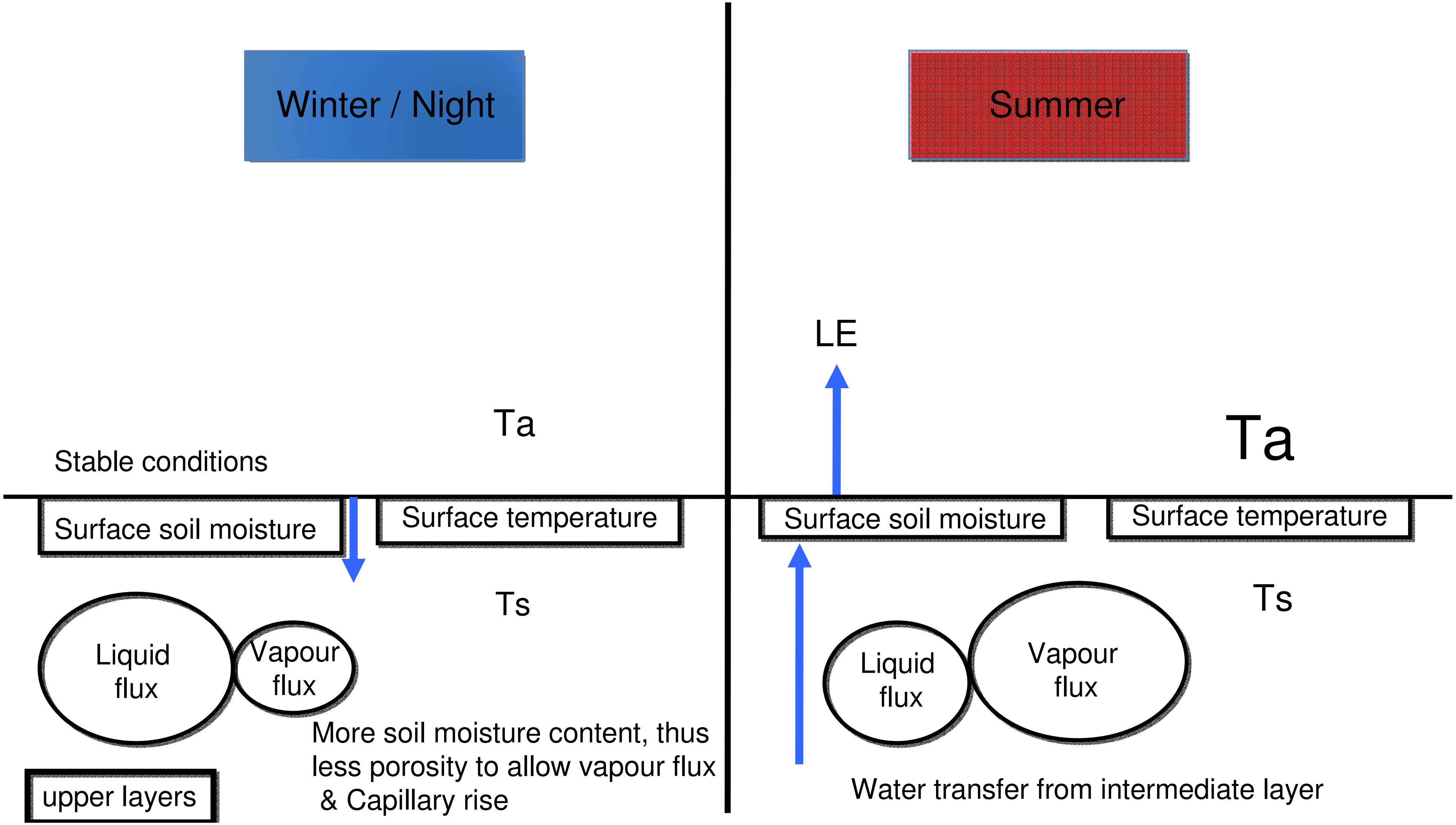
- Water transfer from layer 3 (intermediate) to upper layer 4 (surface layer) is mainly due to thermal vapour flux
- Liquid flux/Thermal Vapour flux ~ 10^{-4} kg/m²/s, Isothermal Vapour flux ~ 10^{-6} kg/m²/s

Results - Contribution of water vapour fluxes



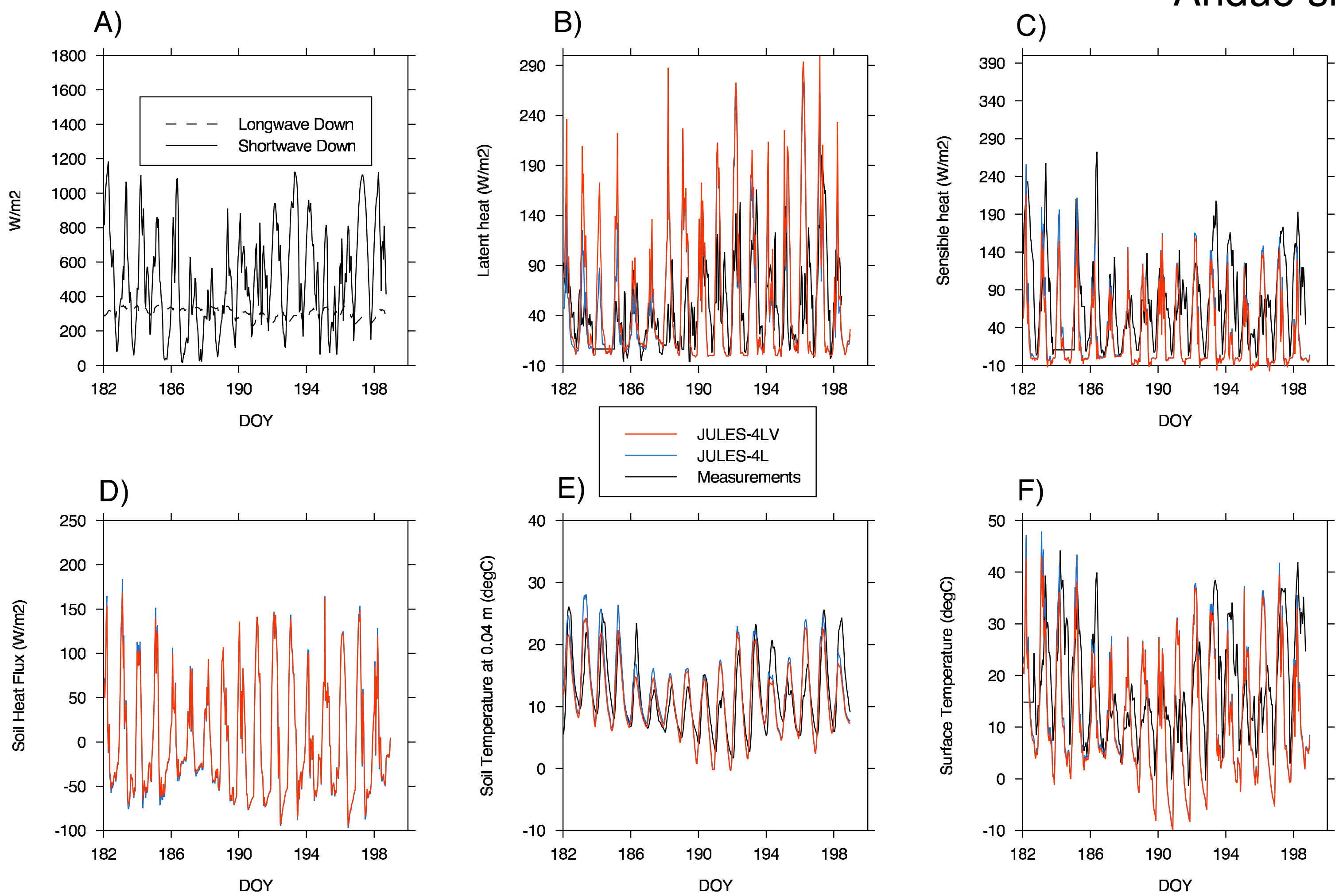
- Drying out the intermediate layer
- Increasing the soil moisture content in the surface layer
- Contribute to the total evapotranspiration – diurnal pattern
- So then upper boundary-energy balance feedbacks
- Cooling/warming the soil surface depend on the net flux

Soil-Atmospheric boundary conditions near the surface



Results – Effect on the energy balance and surface temperature

Anduo site



Conclusions

- Water vapour flux contributes significantly to the water and heat transfer in the upper soil layers mainly due to thermal vapour diffusion processes with a similar magnitude for the selected sites
- Water vapour flux is generally more effective in the first 20-30 cm top soil layer and under drier environmental conditions
- The effect of the inclusion of water vapour flux has introduced a diurnal pattern in the latent heat, soil moisture content and surface temperature
- An increase of vertical soil resolution improved water dynamics and soil temperature predictions; optimization issues
- Incorporation of water vapour flux into the model impacted on the water and energy balance of environments under a range of climatic conditions
- Incorporation of new processes and a more detail vertical soil resolution could improve the coupling between the upper soil layers and the atmosphere

Thanks!