Understanding the influence of wind pumping on temperature profiles in the topsoil

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Using (distributed) temperature observations to quantify soil heat flux and soil moisture

Understanding of land-atmosphere exchanges is of great importance in the study of the global energy and water cycle. Land-atmosphere exchanges of water and energy are mainly controlled by soil moisture and temperature, vegetation type and meteorological forcing. The dependence on soil characteristics, vegetation and meteorology means that land-atmosphere exchanges are characterized by patterns that vary at different spatial and temporal scales. The motivation for this study is to develop a new technique based on Distributed Temperature Sensing (DTS) to observe the spatiotemporal variability of land surface-atmosphere exchange of water and energy from micro- to meso-scale.

Heat transfer in the shallow subsurface is particularly crucial for understanding land- atmosphere exchanges; the difference between surface temperature and air temperature largely determines the sensible heat flux. Furthermore, recent and imminent satellite missions to observe land surface characteristics rely on radiative transfer schemes to relate satellite observations to surface characteristics such as soil moisture and vegetation. These schemes are particularly sensitive to skin temperature estimation.

Heat transfer models are necessary to relate temperature, moisture content and fluxes in the shallow subsurface. Heat transfer in the shallow subsurface is poorly understood, because of complex interaction between soil and atmosphere, biological activity and the high heterogeneity of this zone. The objective of this research is to increase understanding of heat transfer mechanisms in the shallow subsurface and the relation between heat transfer, temperature profiles and moisture conditions.

Steep temperature gradients → ***Hypothesis:*** *evaporation* → **Enhanced vapour transport**

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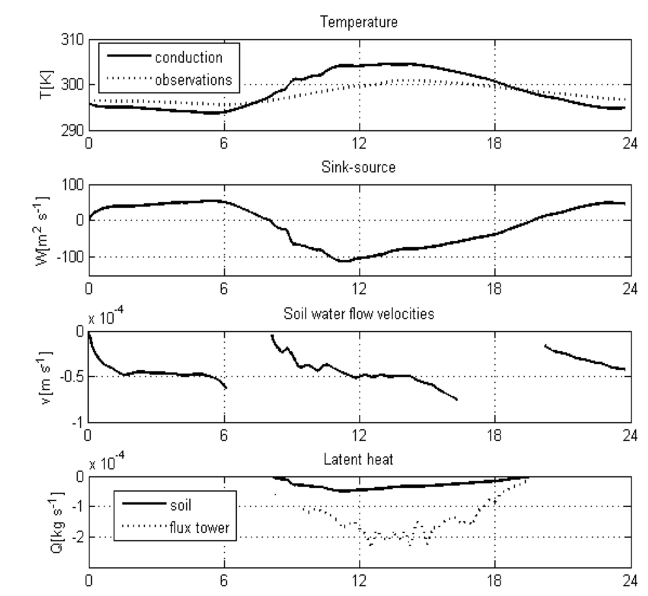
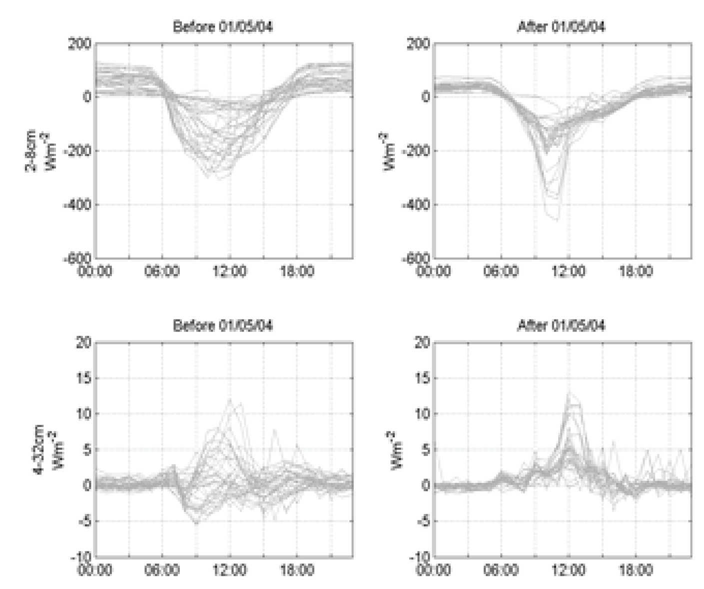
Heat diffusion models

Commonly used models based on full partitioning at the surface and heat conduction perform well when applied to deep soil layers, but result in errors when applied to the shallow subsurface. The figure below show an example using soil moisture and temperature data collected during MicroWEX-2 experiment in Florida. We found that temperature gradients in the shallow subsurface could not be explained by conduction. Sinks and sources of energy in each soil layer were quantified using an inversion approach to the heat equation.



Heat balance computations for the 27th of May 2004. The plots show from top to bottom temperature, sink, the equivalent of the sink in soil water velocities and the equivalent of the sink phase change and at a depth of 4 cm (Rutten et al. 2010).



Diurnal pattern of source/sink term in the top soil (Rutten et al. 2010).

We investigated the extent to which the sinks and sources could be explained by advection and phase change. From our analysis (partly shown in the figure above), it seems that, for dry days, advection is a comparatively minor contributor to heat transfer and that phase change plays a more significant role.

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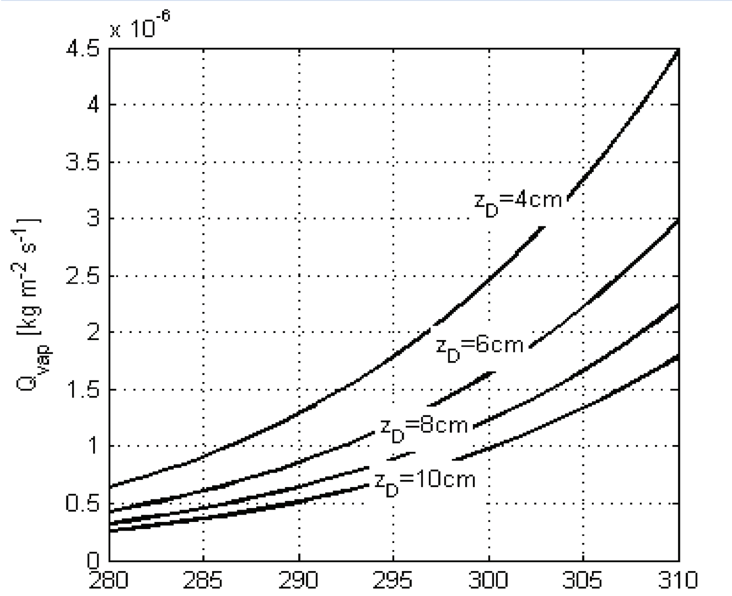
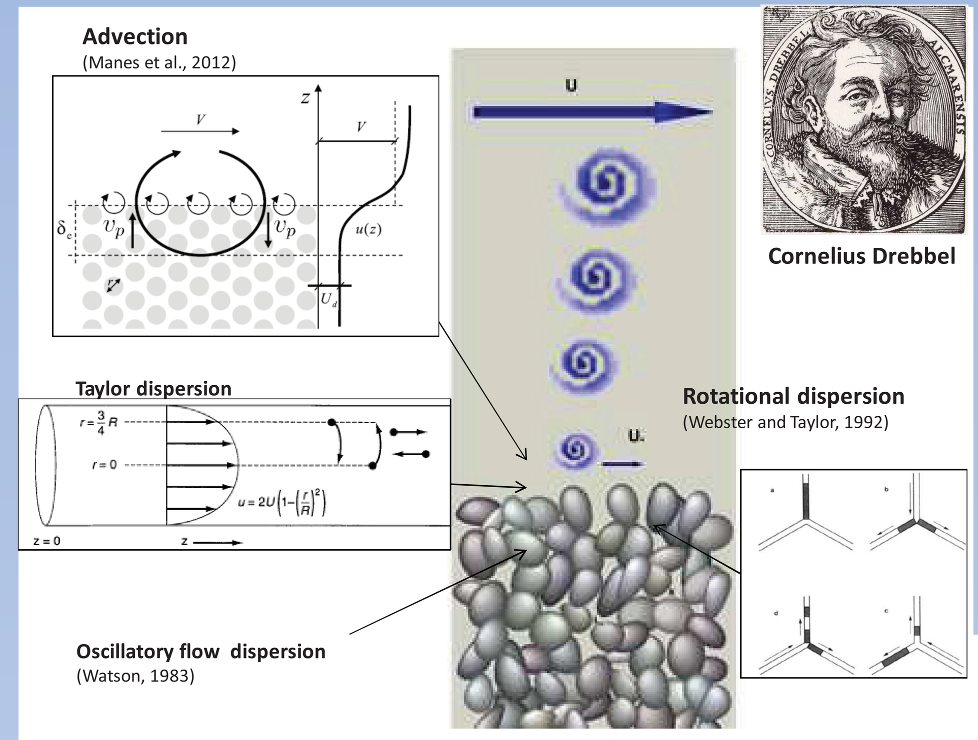
Vapour diffusion models

We compared vapor diffusion rates, required for sustaining phase changes, large enough to explain the sinks and sources, to plausible values of molecular vapor diffusion in soil. Rates were beyond the plausible range and enhancement of molecular diffusivity seems necessary to the explain sinks and sources.



Estimates of vapor diffusive flux for different temperatures and depths over which diffusion occurs. The air at depth z_D is assumed saturated and the relative saturation at the top is 0.5. It is assumed that the gas pore fraction (n-) is 0.3 (Rutten et al. 2010).

Hypothesis A: *enhancement by wind pumping*

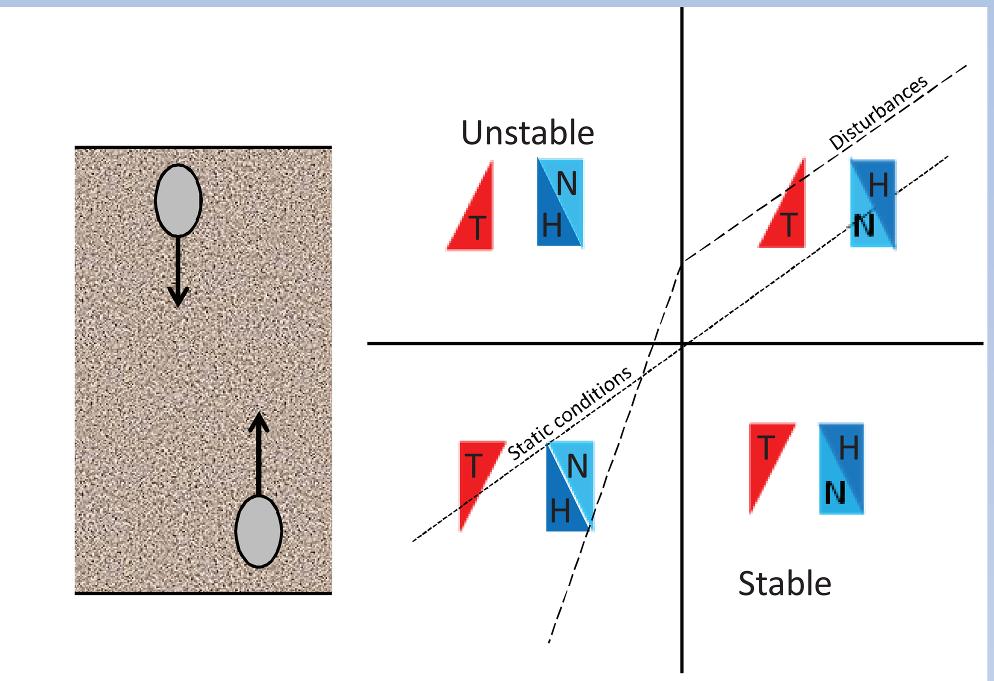


Sketch of wind pumping effect on vapor transport in the soil. Picture in the upper right corner shows one of the early investigators of this phenomenon.

The transport of vapor may be enhanced by advection and dispersion due to surface air pressure fluctuations.
We reviewed studies on this wind pumping mechanism. There are many modeling studies compared to experimental studies. In the few experimental studies enhancement factors (apparent diffusion coefficient over effective molecular diffusion coefficient in soil) from 1-5 are reported for soil. Enhancement factors in experimental studies range from 1-100 for soil. Crude and influential assumptions for boundary condition at the soil-atmosphere interface and dispersion coefficients explain major part of the found discrepancy. Current work focusses on improving understanding of the boundary condition and dispersion processes.

Hypothesis B: *enhancement by buoyancy*

We investigated conditions for which buoyancy can enhance evaporation. For the case that temperature decreases with depth, buoyant instability is only possible if the virtual temperature increases with depth. A second prerequisite is that diffusivities of heat and water vapor are sufficiently different. First results show instabilities may occur in permeable soils with relatively high heat diffusivity. Current work focusses on the quantification of this effect on vapor transport.



Sketch of buoyant instabilities giving rise to double convective diffusion in soil. For certain gradients in temperature (T) and vapor concentration (H), it is possible to trigger convective instabilities.

Hypothesis X (please add):

Combination

Rutten, M. M., S. C. Steele-Dunne, et al. (2010). "Understanding heat transfer in the shallow subsurface using temperature observations." Vadose Zone Journal **9**(4): 1034-1045.

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