The Role of Soil Moisture in Land-Atmosphere Interactions

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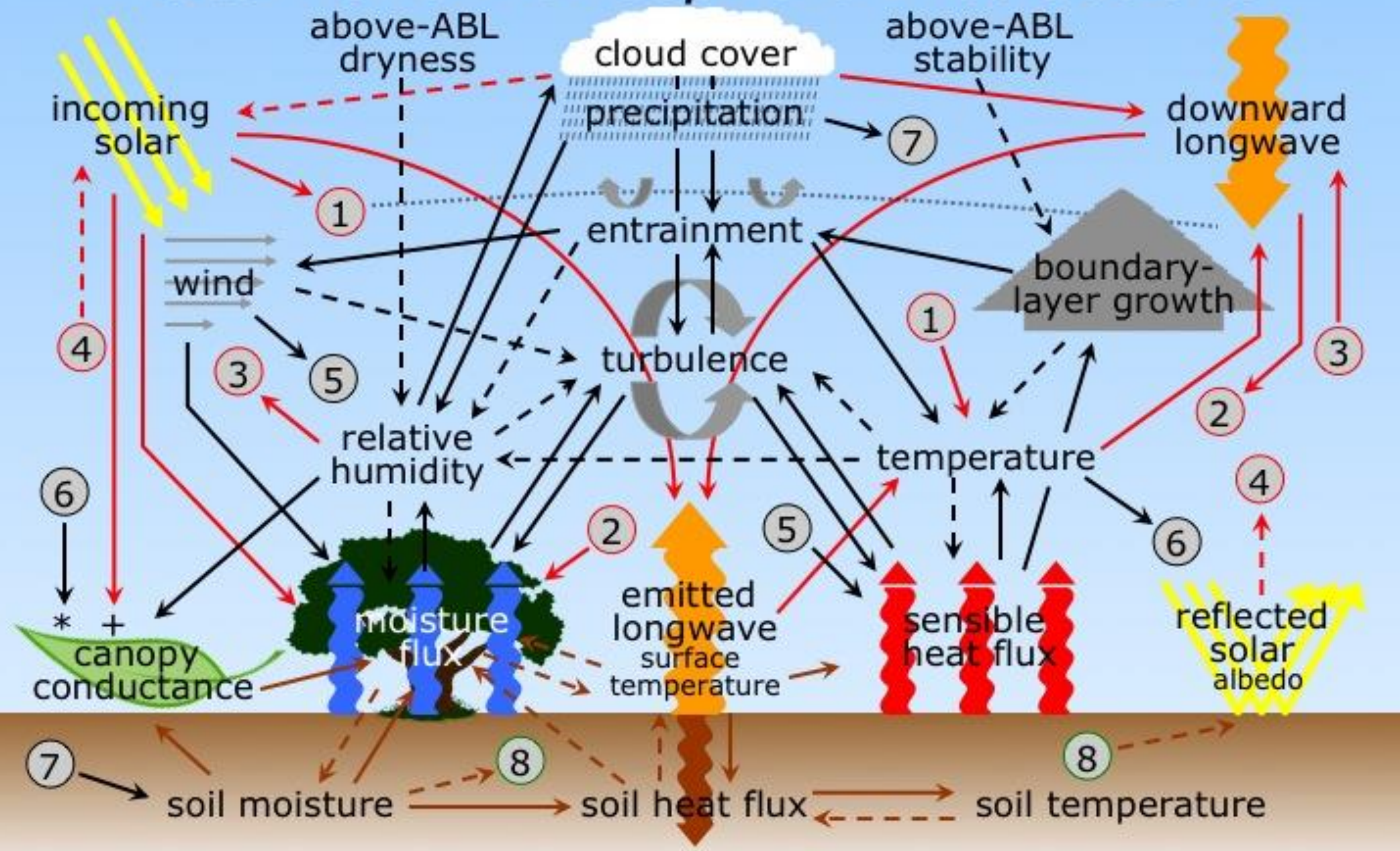
in collaboration with: P. de Rosnay, G. Balsamo, Y. Ma, J. Wen, M. Ek

Local Land-Atmosphere Interactions



→ radiation → surface layer & ABL → land-surface processes

feedbacks:

→ **positive**

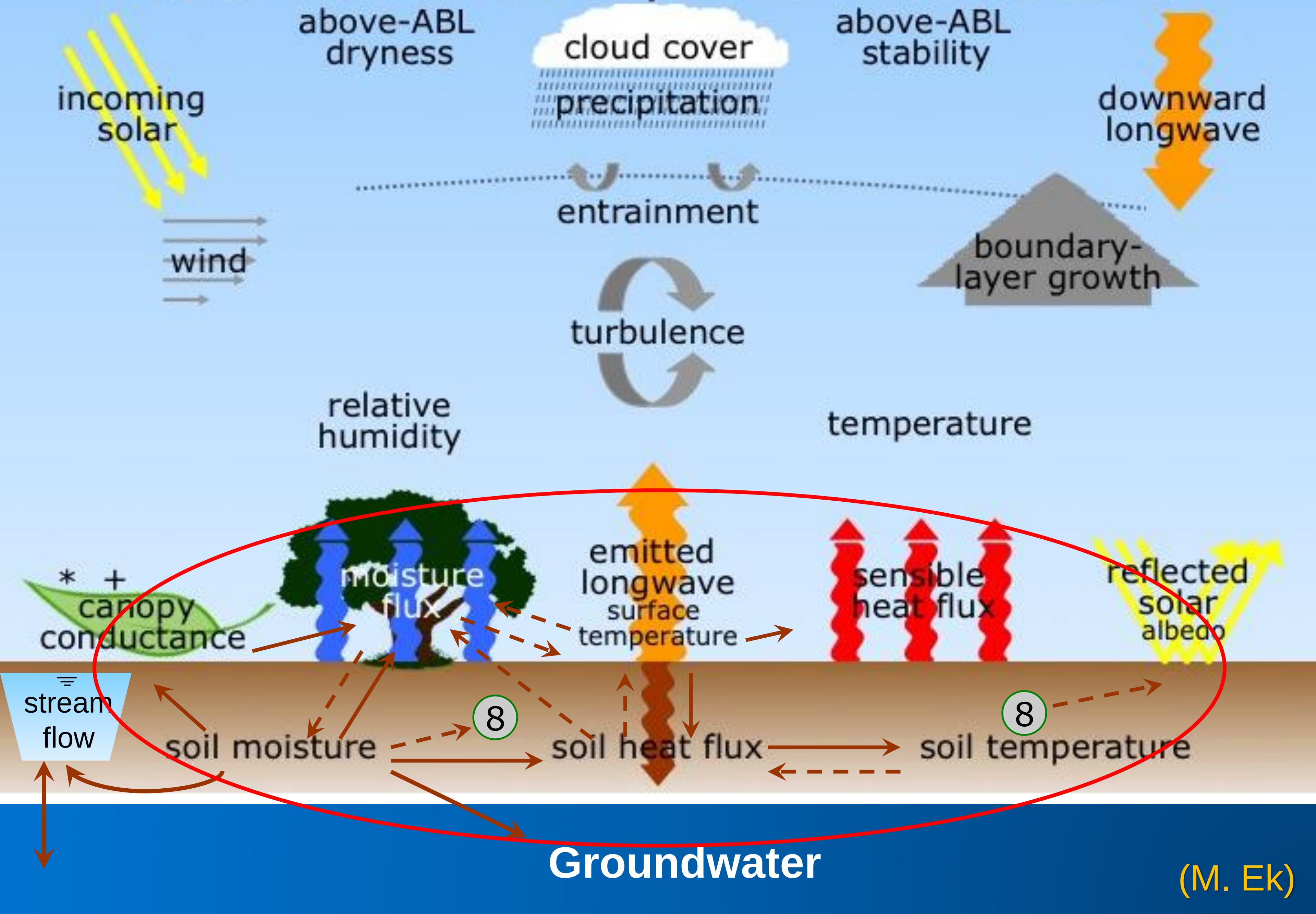
- - → **negative**

+positive feedback for C3 & C4 plants, negative feedback for CAM plants

****negative feedback above optimal temperature***

(M. Ek)

Local Land-Atmosphere Interactions



incoming solar

above-ABL dryness

cloud cover

precipitation

above-ABL stability

downward longwave

wind

entrainment

boundary-layer growth

turbulence

relative humidity

temperature

* +

canopy conductance

moisture flux

emitted longwave

surface temperature

sensible heat flux

reflected solar

albedo

stream flow

soil moisture

8

soil heat flux

8

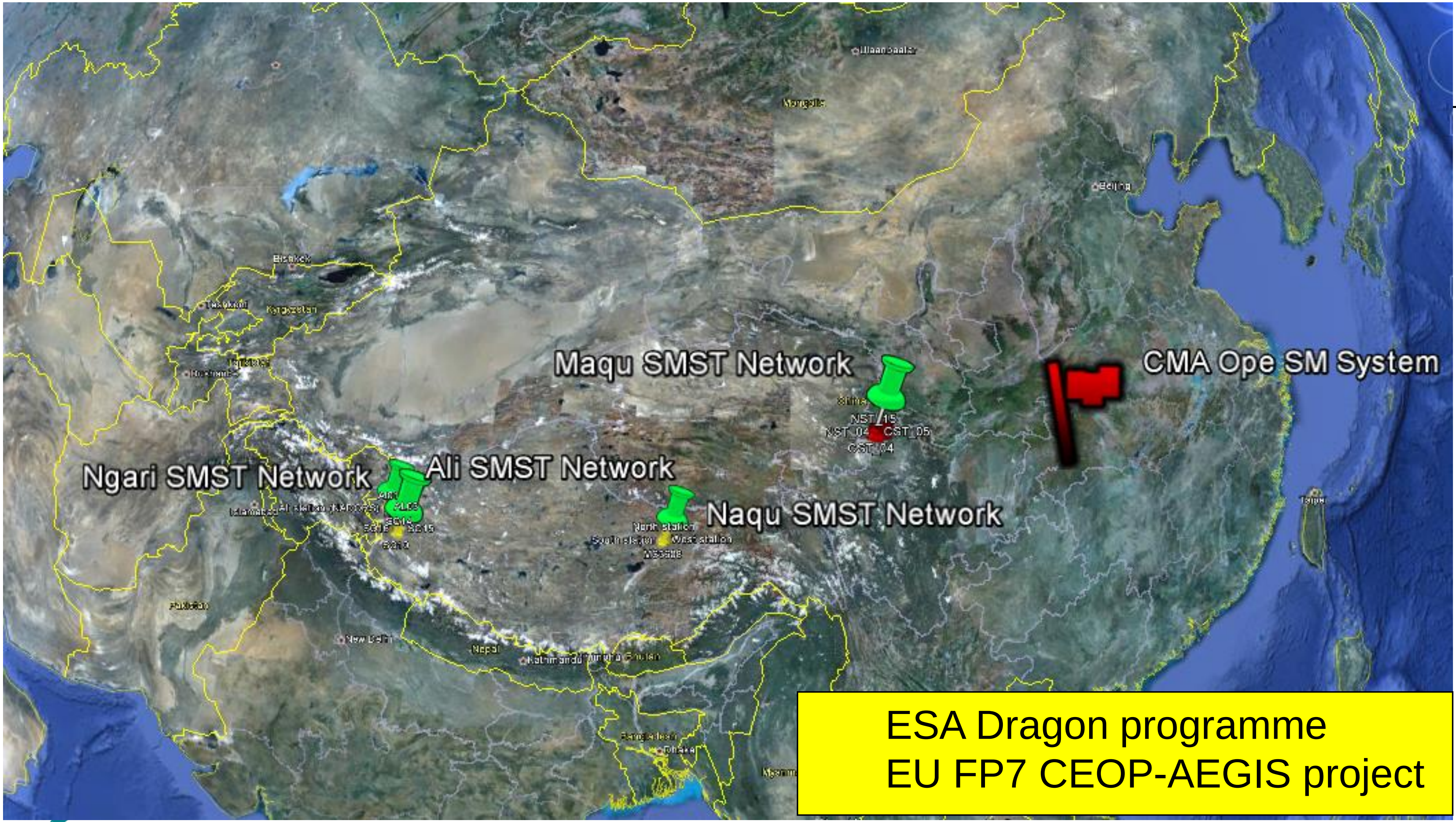
soil temperature

Groundwater

(M. Ek)

ITC GEO Soil Moisture Soil Temperature Networks

Tibetan Plateau observatory of plateau scale soil moisture and soil temperature (Tibet-Obs)



ESA Dragon programme
EU FP7 CEOP-AEGIS project

(Su, Z., et al. 2011, HESS)

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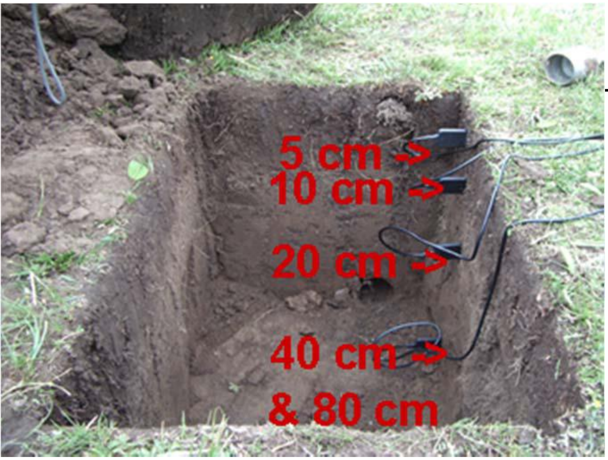
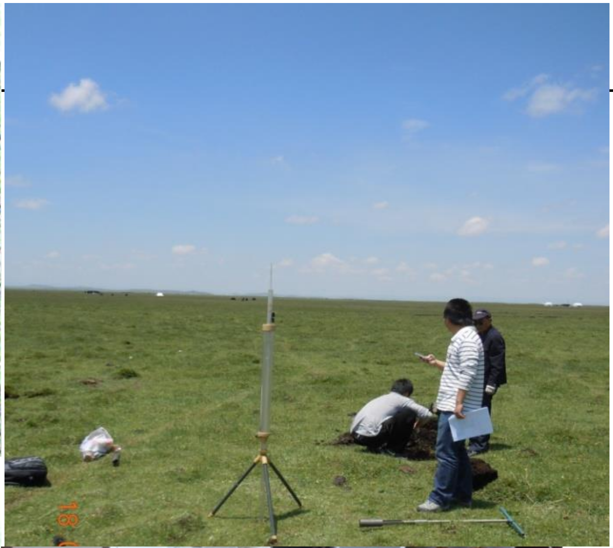
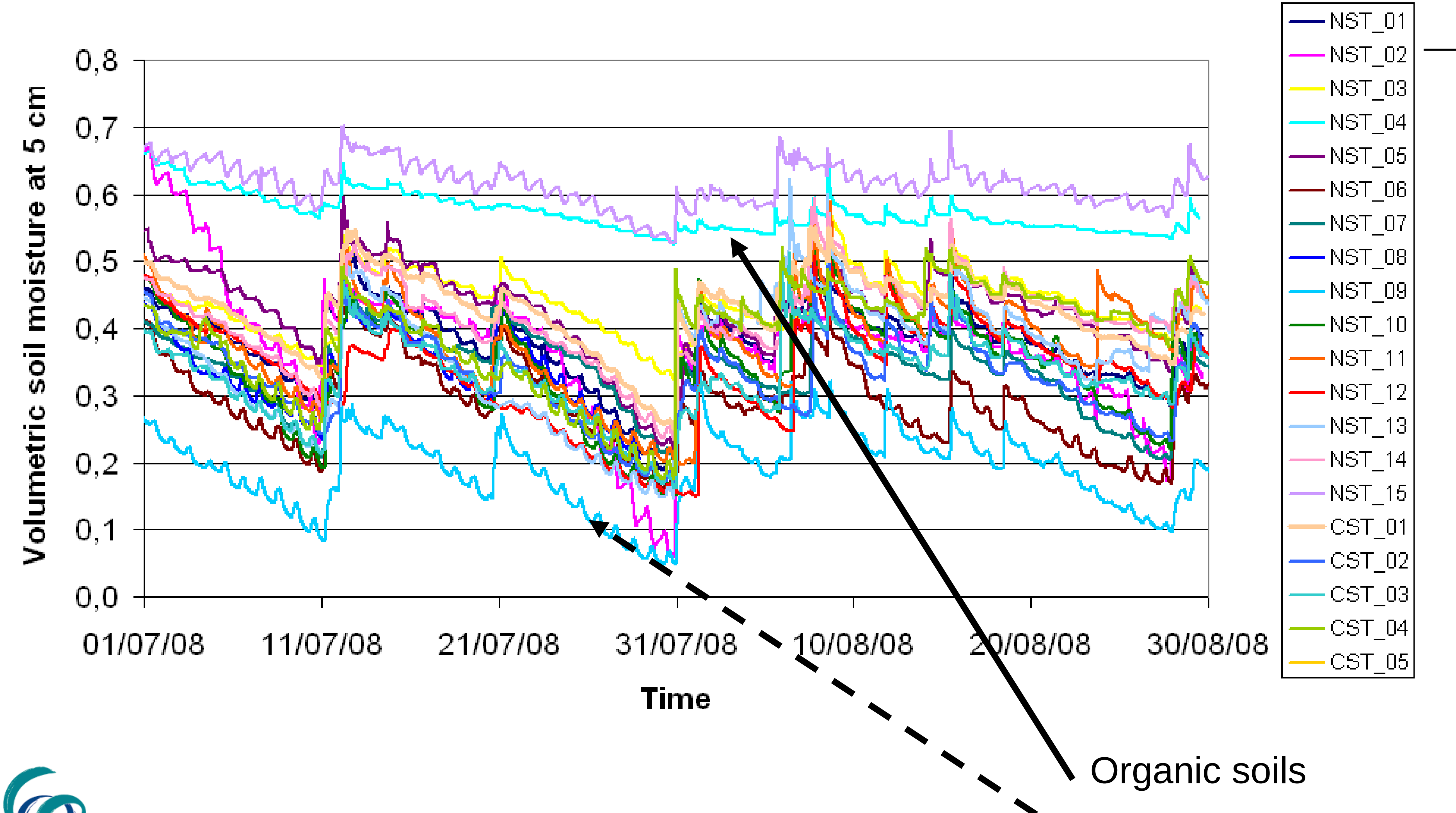
Maqu Station: Field Site and Experiment





Maqu: Soil moisture at 5 cm depth



Organic soils

Sandy loam soil

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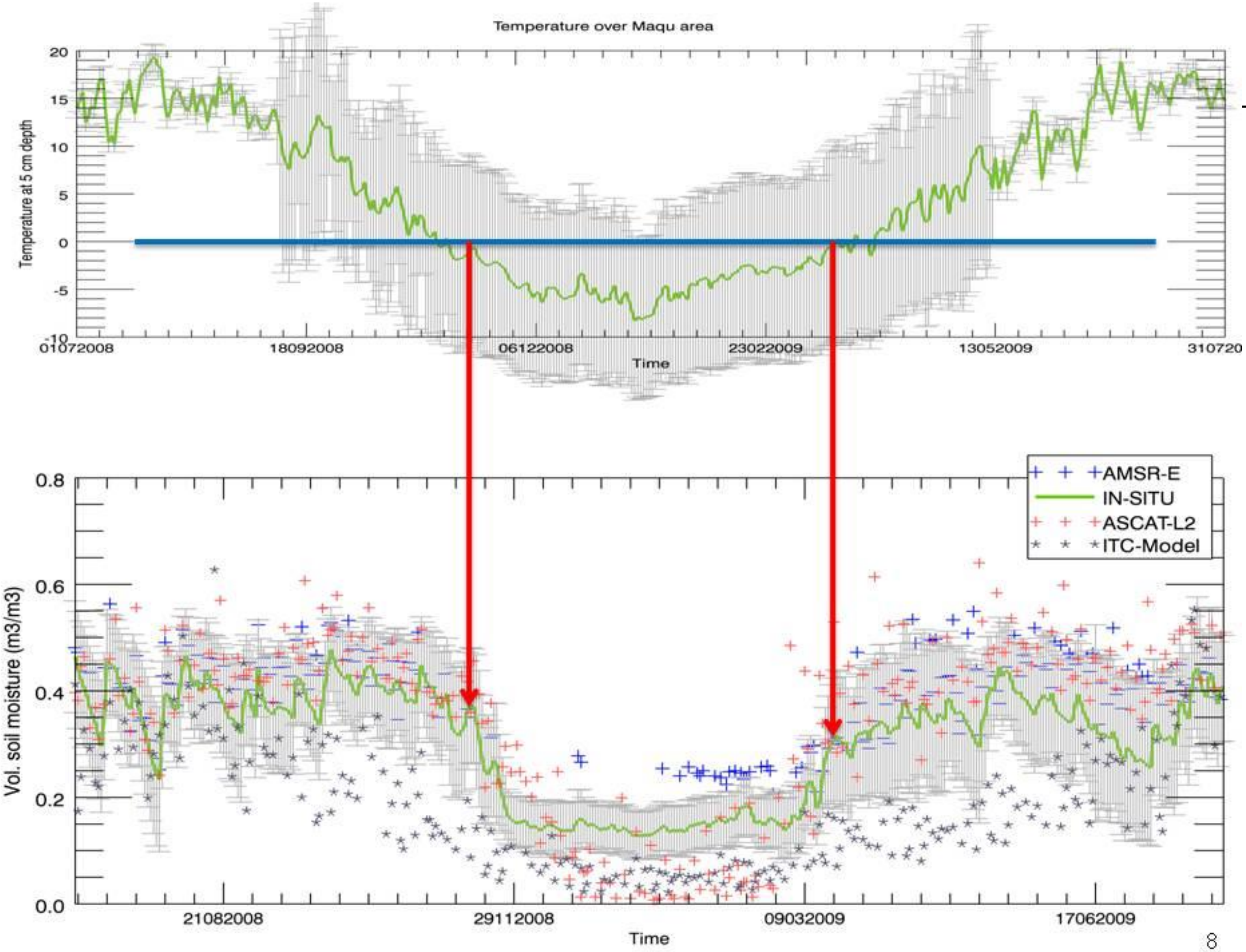
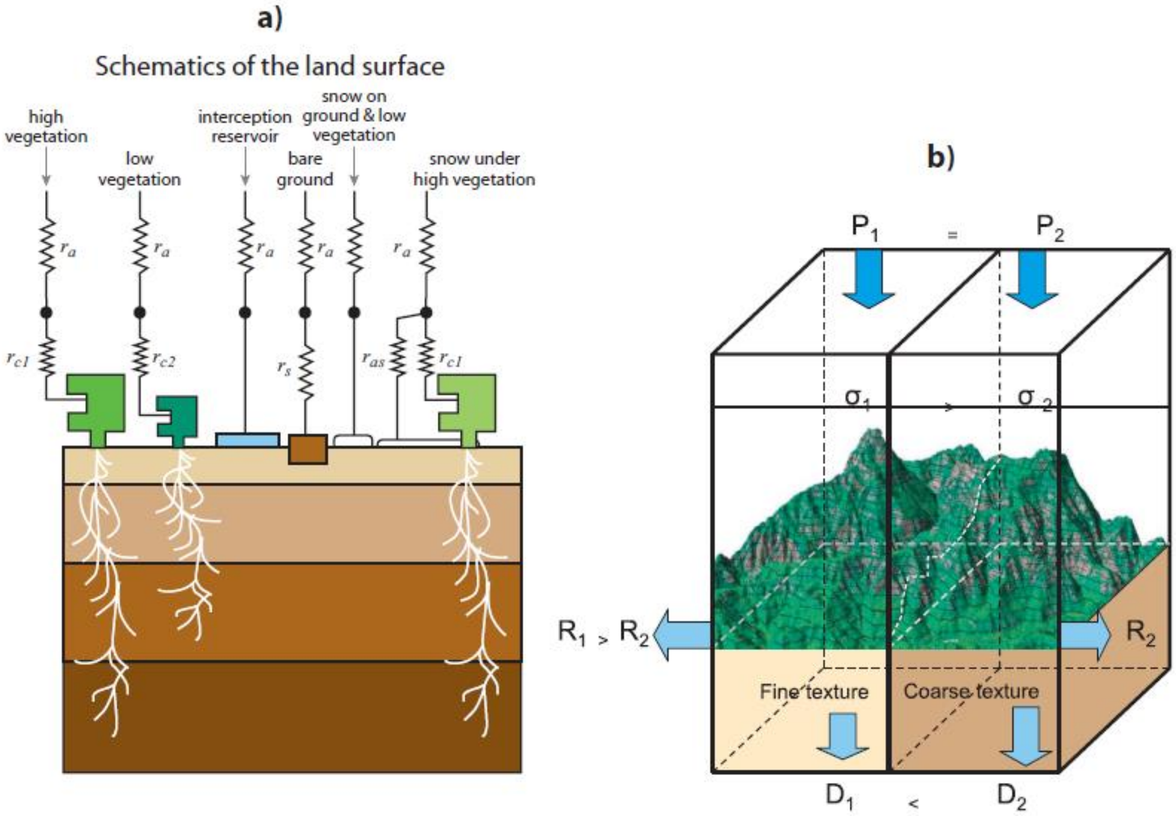
Quantification of uncertainties in global products

(Su, et al., 2011, HESS)



The Tiled ECMWF Scheme for Surface Exchanges over Land (TESSEL) & the HTESSEL (Hydrology TESSEL)

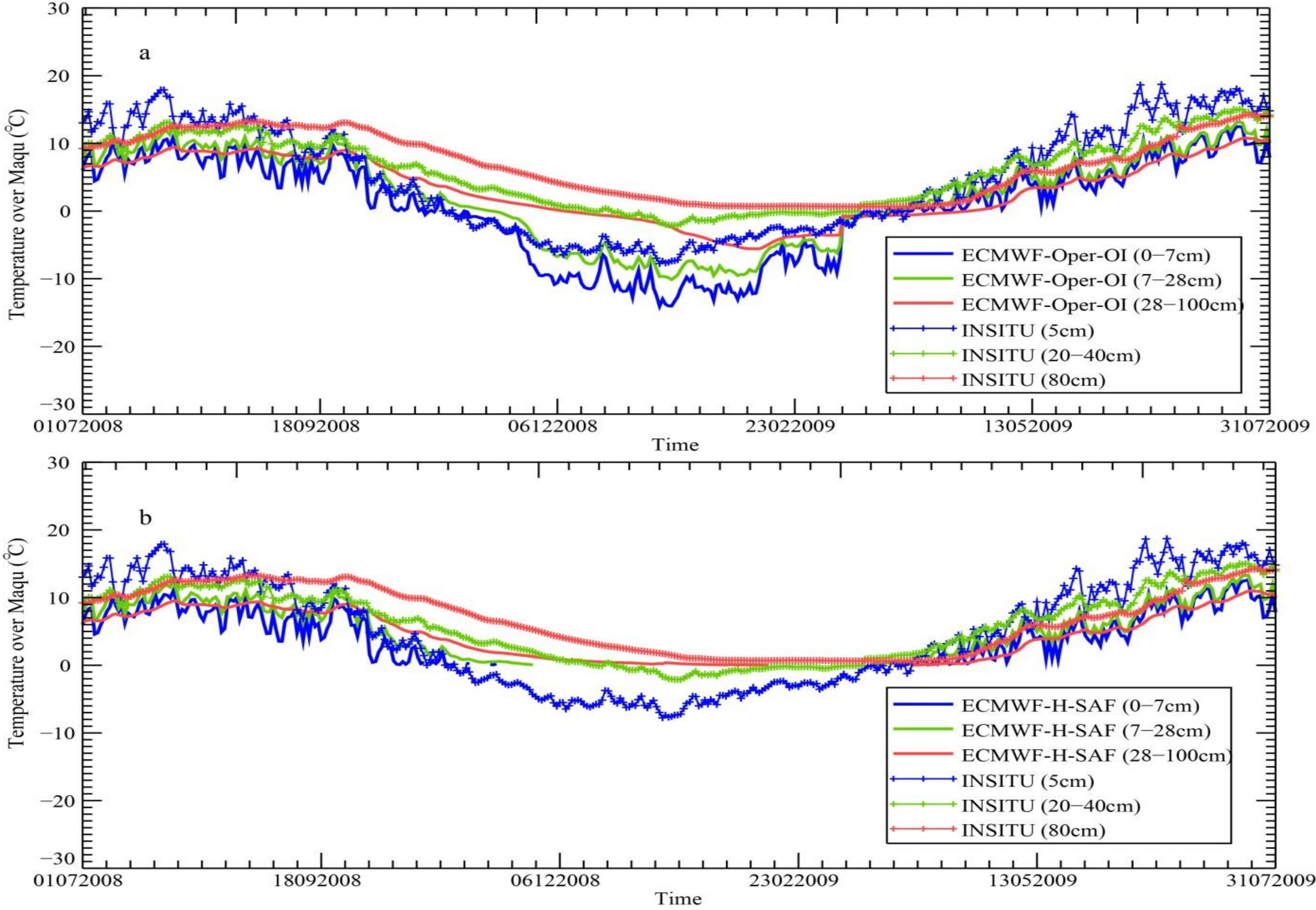


(a) TESSEL land-surface scheme, (b) spatial structure in HTESSEL

(for a given precipitation P1 = P2 the scheme distributes the water as surface runoff and drainage with functional dependencies on orography and soil texture respectively) (Balsamo et al., 2006)

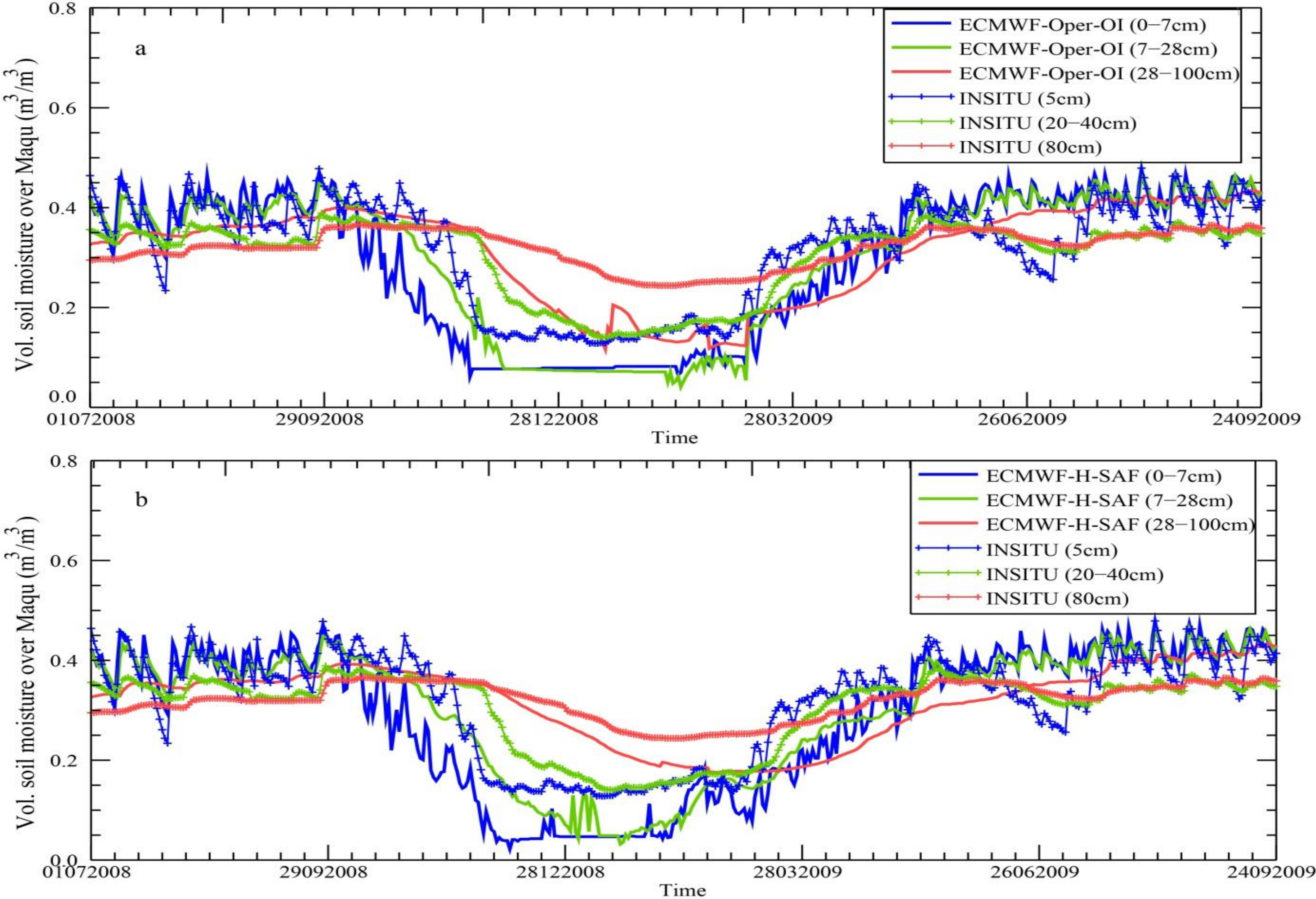
How good is soil temperature simulation/analysis?

(Su & de Rosnay, et al. 2013, JGR)

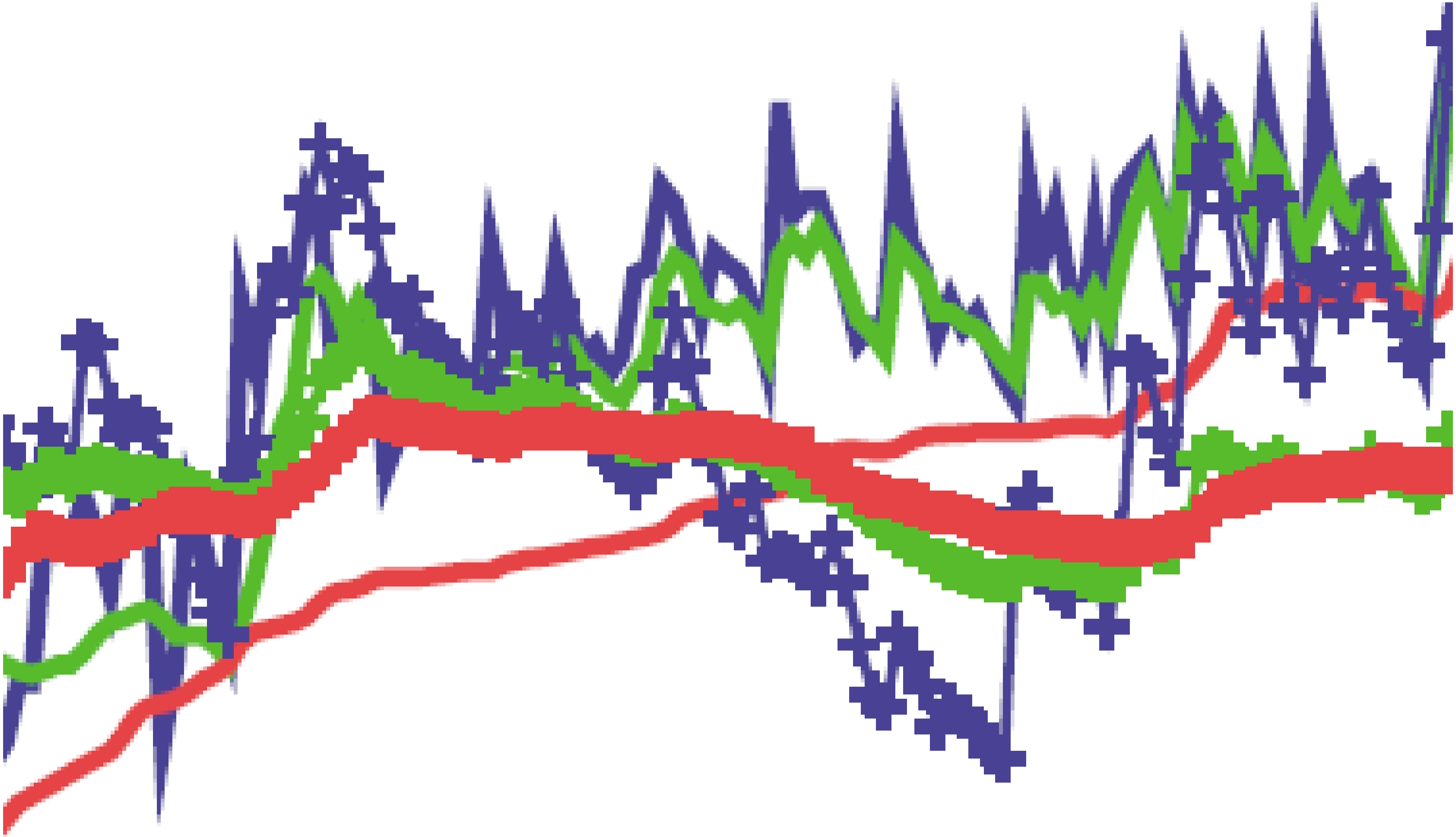


How good is soil moisture analysis/assimilation?

(Su & de Rosnay, et al. 2013, JGR)



How good is soil moisture assimilation?



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(Su & de Rosnay, et al. 2013, JGR)

Noah LSM

N: National Centers for Environmental Prediction (NCEP)
O: Oregon State University (Dept of Atmospheric Sciences)
A: Air Force (both AFWA and AFRL - formerly AFGL, PL)
H: Hydrologic Research Lab - NWS (now Office of Hydrologic Dev -- OHD)

Noah LSM provides a complete description of the physical processes with a limited number of parameters.

- Soil water flow;
- Soil heat flow;
- Heat exchange with the atmosphere;

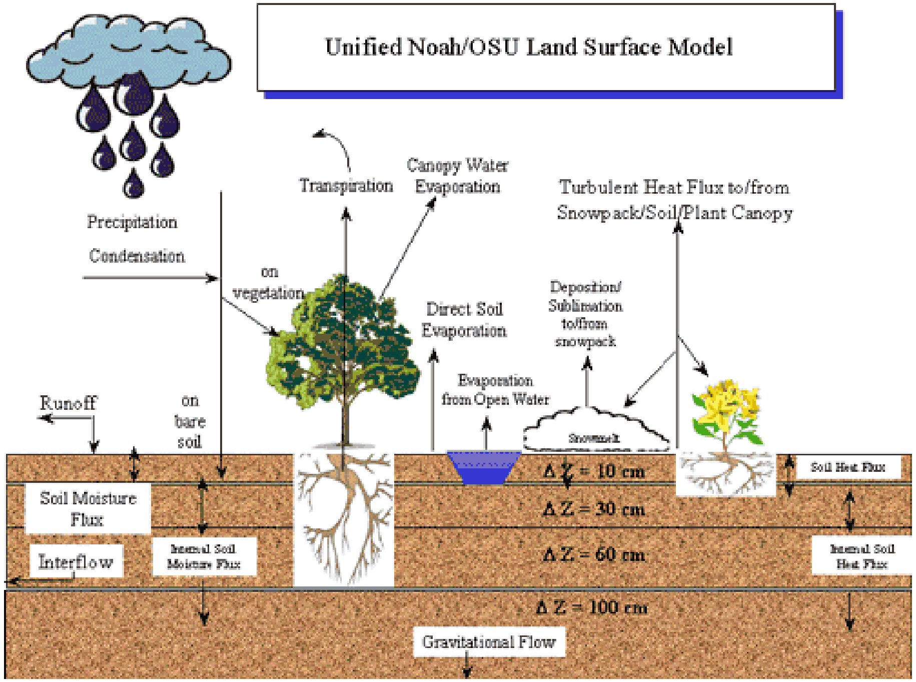
(Zheng et al., 2013, JHM; Zheng 2014a,b in review.)

- Snow pack.

(Malik et al., 2012, JHM; JGR, 2013; RSE, 2011)

- Frozen soil; ???

(NWO SMAP project)



AUGMENTATIONS TO NOAH SOIL WATER FLOW MODEL PHYSICS

i) Impact of organic matter considered on the soil water retention curve via the additivity hypothesis,

ii) Saturated hydraulic conductivity (*Ks*) implemented as an exponentially decaying function with soil depth,

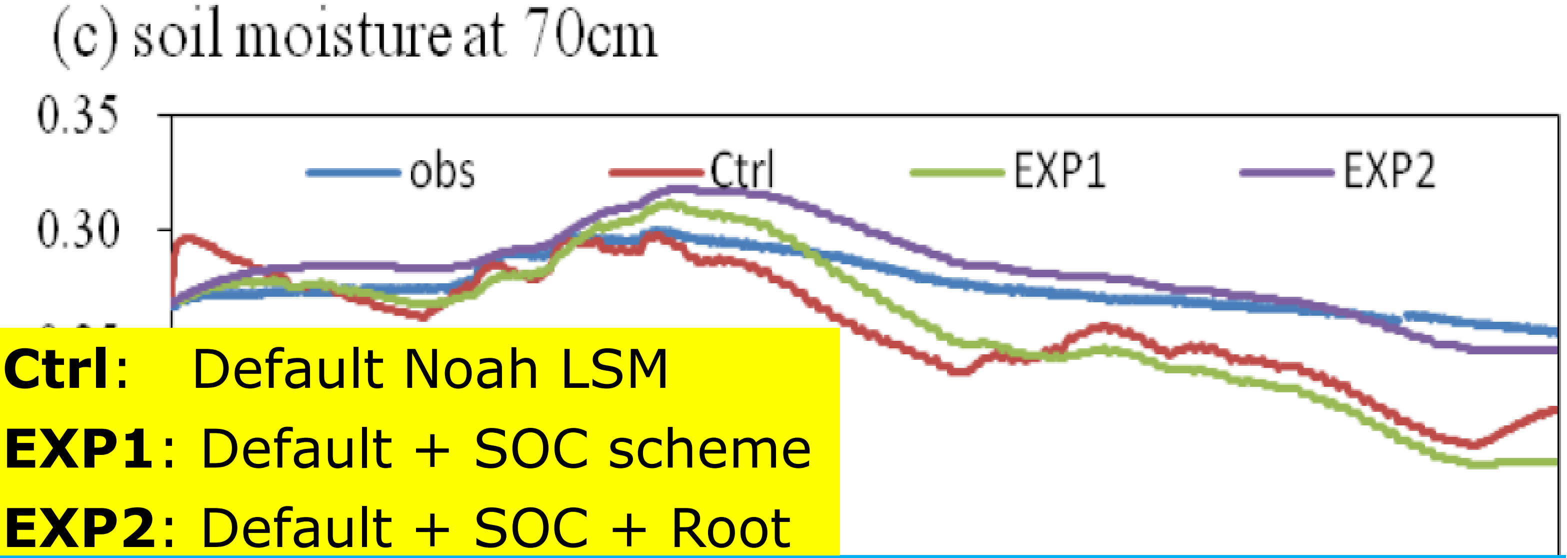
iii) Vertical root distribution modified to better represent the Tibetan alpine grassland conditions (abundance of roots in the top soil layer).

(Diffusivity form of Richards's equation revised to allow the simulation of the soil water flow across soil layers with different hydraulic properties).

Three numerical experiments:

- **Ctrl**: a Noah control run with default model structure,
- **EXP1**: a Noah run with modified soil hydraulic parameterization,
- **EXP2**: a Noah run with modified soil hydraulic parameterization and vertical root distribution.

Augmentations to Noah soil water flow model physics


(c) soil moisture at 70cm

- **Ctrl**: Default Noah LSM
- **EXP1**: Default + SOC scheme
- **EXP2**: Default + SOC + Root

- Ctrl **underestimates** the of top layer soil moisture under wet conditions, **overestimates** it during dry-down episodes, and **systematically underestimates** it in the deeper soil layers.

- EXP1 **resolves** the soil moisture underestimation in the upper soil layer under wet conditions, but the overestimation during dry-downs remains.

- EXP2 **captures** the soil moisture dynamics of the upper layer under dry conditions and **improves** the simulations of the deeper layers.

(Zheng et al., 2014a, JHM)

AUGMENTATIONS TO NOAH TURBULENT HEAT FLUX AND SOIL HEAT TRANSPORT MODEL PHYSICS

Four numerical experiments:

- **Ctrl**: a Noah control run with default model structure,
- **EXP1**: a Noah run after removing vegetation muting effect,
- **EXP2**: a Noah run with *βveg* as function of the *LAI* and *GVF*,
- **EXP3**: a Noah run Zilitinkevich’s coefficient, *Czil*, parameterized as an indirect function of canopy height via *z*0m,

Results: Heat Flux Simulation with Noah

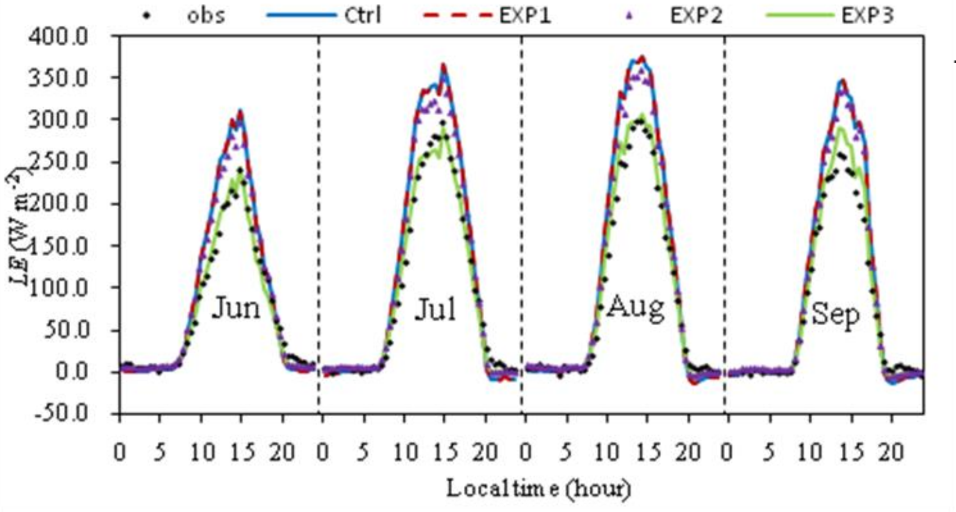
- **Numerical Experiments**

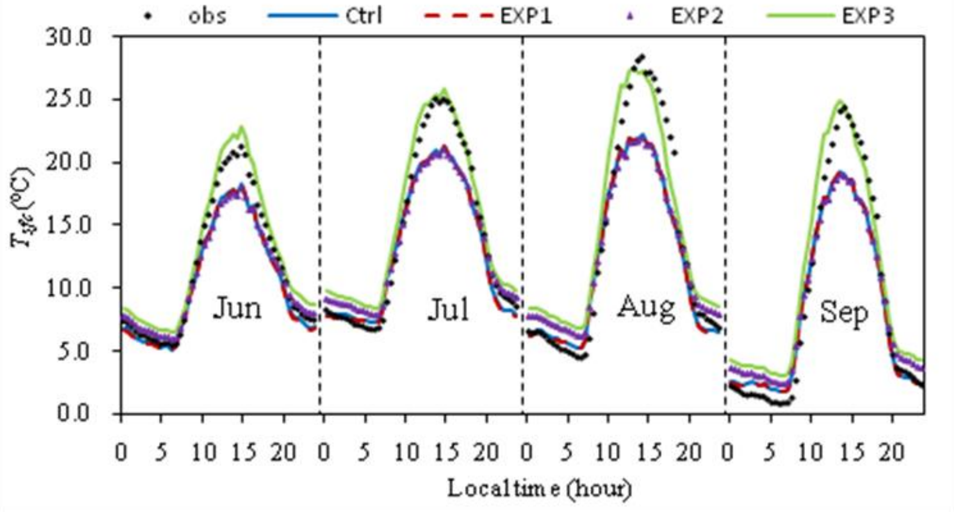
Ctrl: Default Noah LSM

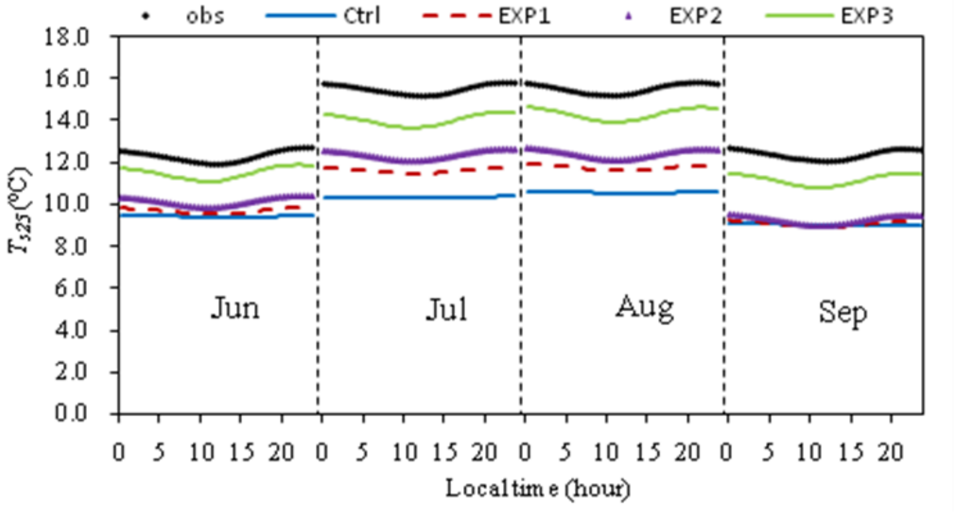
EXP1: Default + k_h

EXP2: Default + k_h + β_{veg}

EXP3: Default + k_h + β_{veg} + z_{0h}


(a)latent heat flux


(b)surface temperature

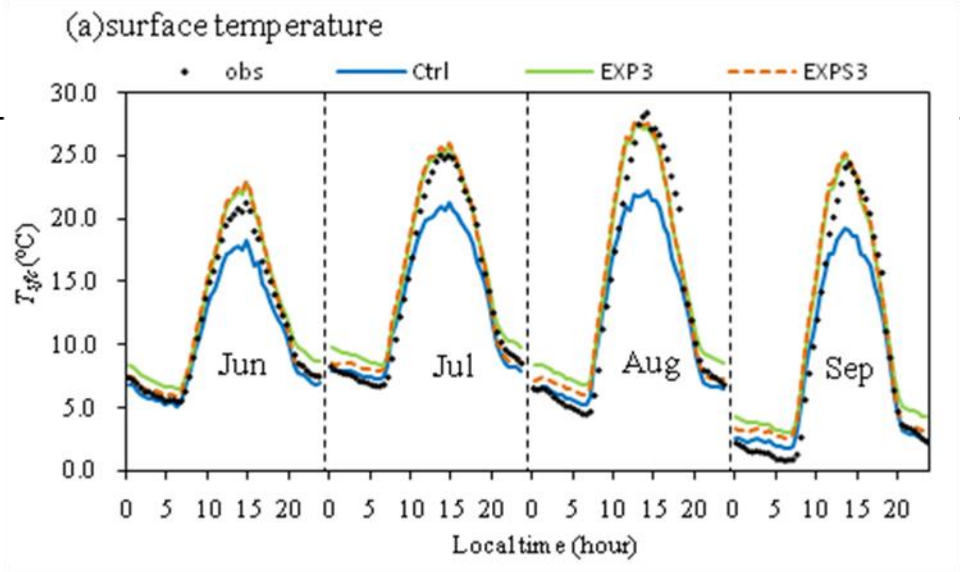

(c)soil temperature at 25cm

Improvement in Nighttime Surface and Soil Temperatures

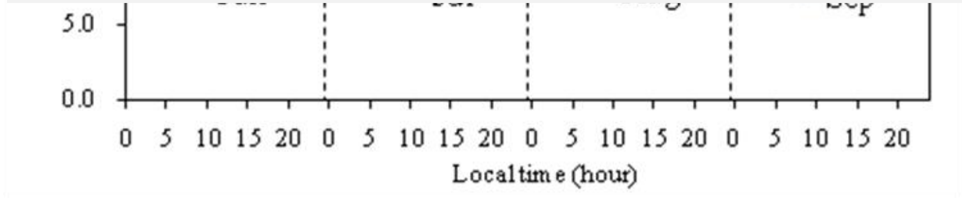
$$G_0 = \kappa_{h0} \frac{T_{sfc} - T_{s1}}{\Delta z_1}$$

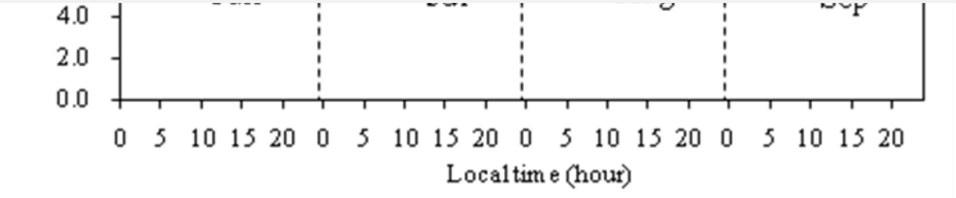
$$\kappa_{h0} = \kappa_h(\theta_1) \cdot \exp(-\beta_{veg} GVF)$$

$$\beta_{veg} = \begin{cases} 0.5LAI/GVF\,, & daytime \\ 2.0\,, & nighttime \end{cases}$$



Surface energy budget calculations by physically based LSMs can only be ameliorated if the water budget is well treated.



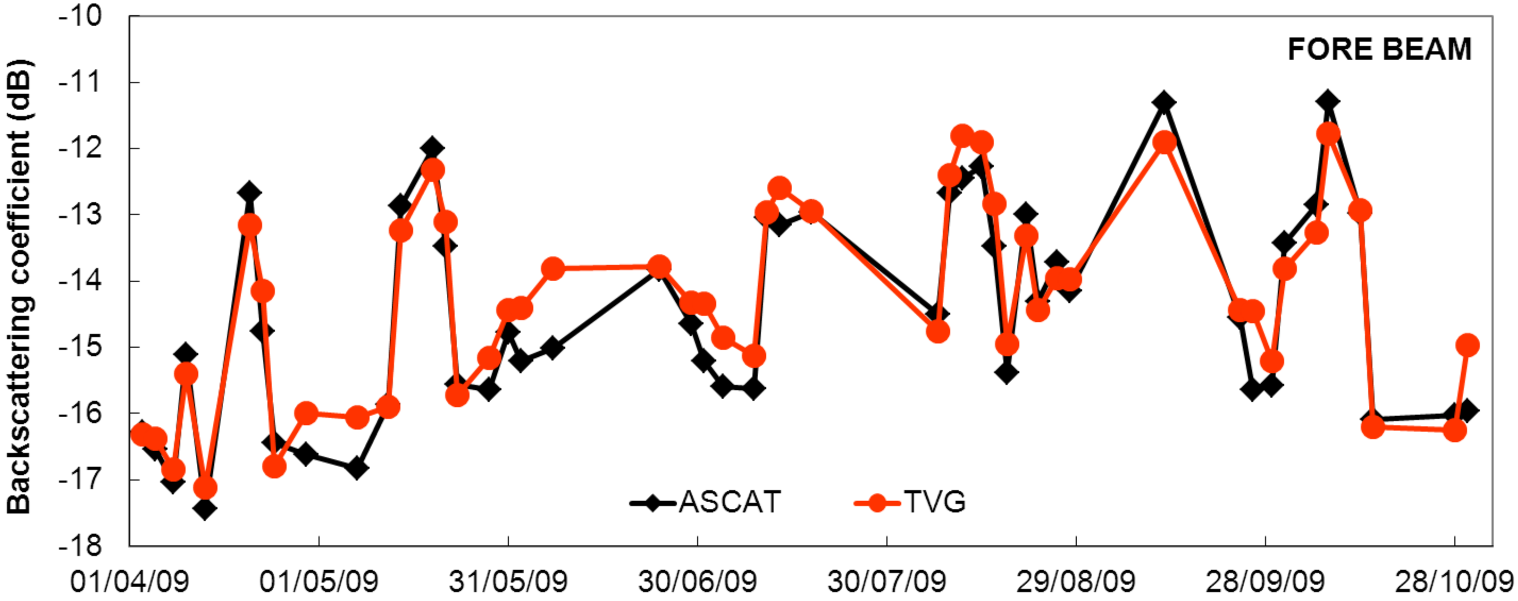


Tor Vergata Model – Simultaneous Modeling of Active And Passive Microwave Signatures

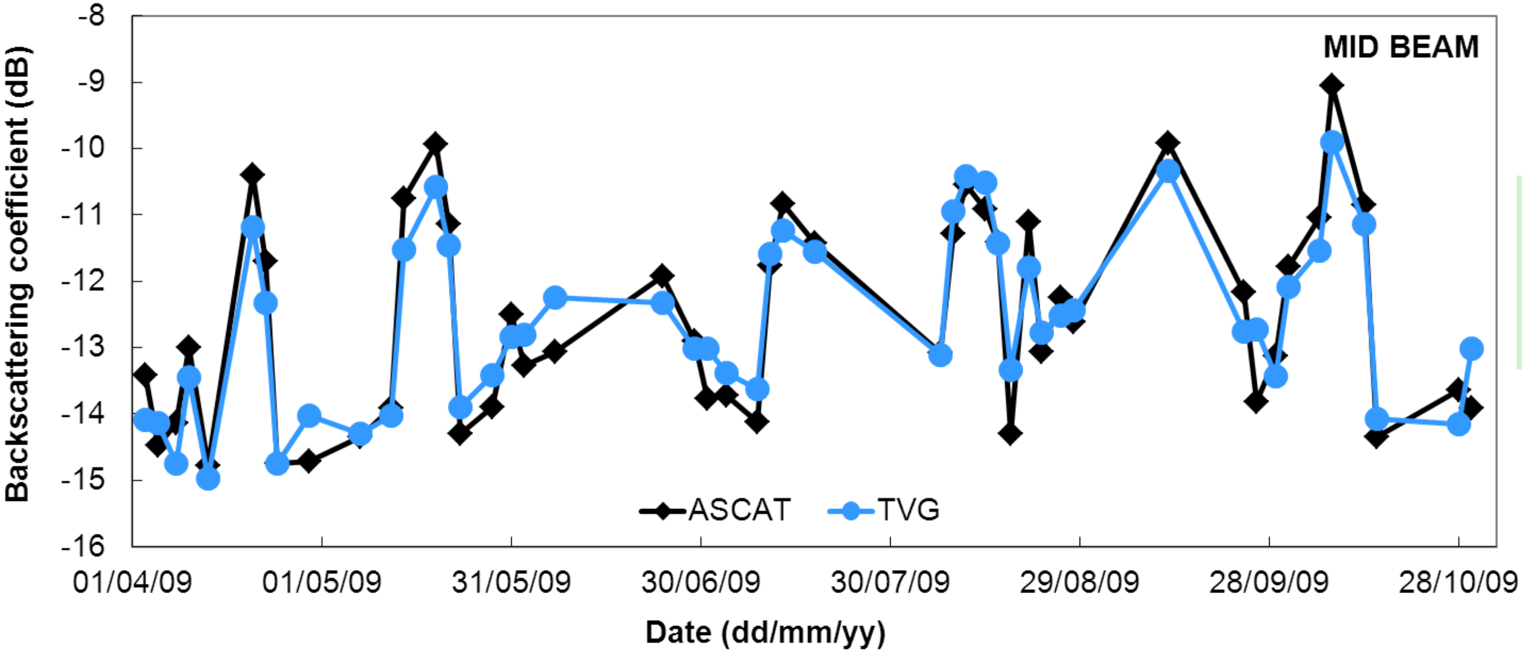
- To use a single discrete scattering model to simulate both emission and backscattering, with a unique set of input parameters
- To combine the use of active and passive microwave satellite signatures to constrain the model
- To improve the modelling and understanding of microwave emissivity and backscattering coefficient over grassland with litter
- To contribute to an optimal use of SMAP-like data
- To improve the soil moisture retrieval

L. Dente, P. Ferrazzoli, Z. Su, R. van de Velde, L. Guerriero, 2014, Combined use of active and passive microwave satellite data to constrain a discrete scattering model, RSE.

RESULTS: MODEL CALIBRATION (2009) – ACTIVE CASE

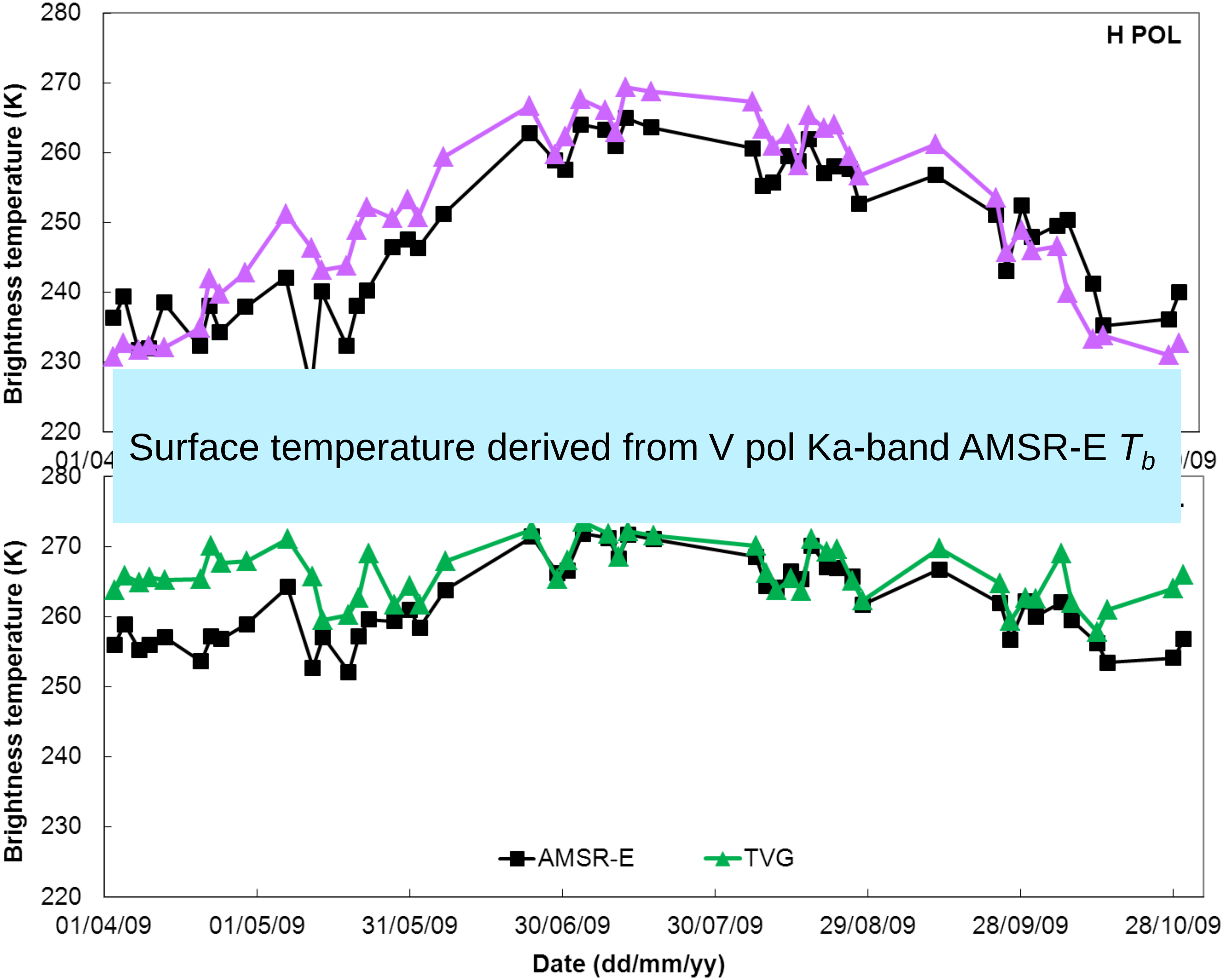


R^2 = 0.9
rmse = 0.5 dB
bias = 0.2 dB



R^2 = 0.9
rmse = 0.5 dB
bias = -0.04 dB

RESULTS: MODEL CALIBRATION (2009) – PASSIVE CASE

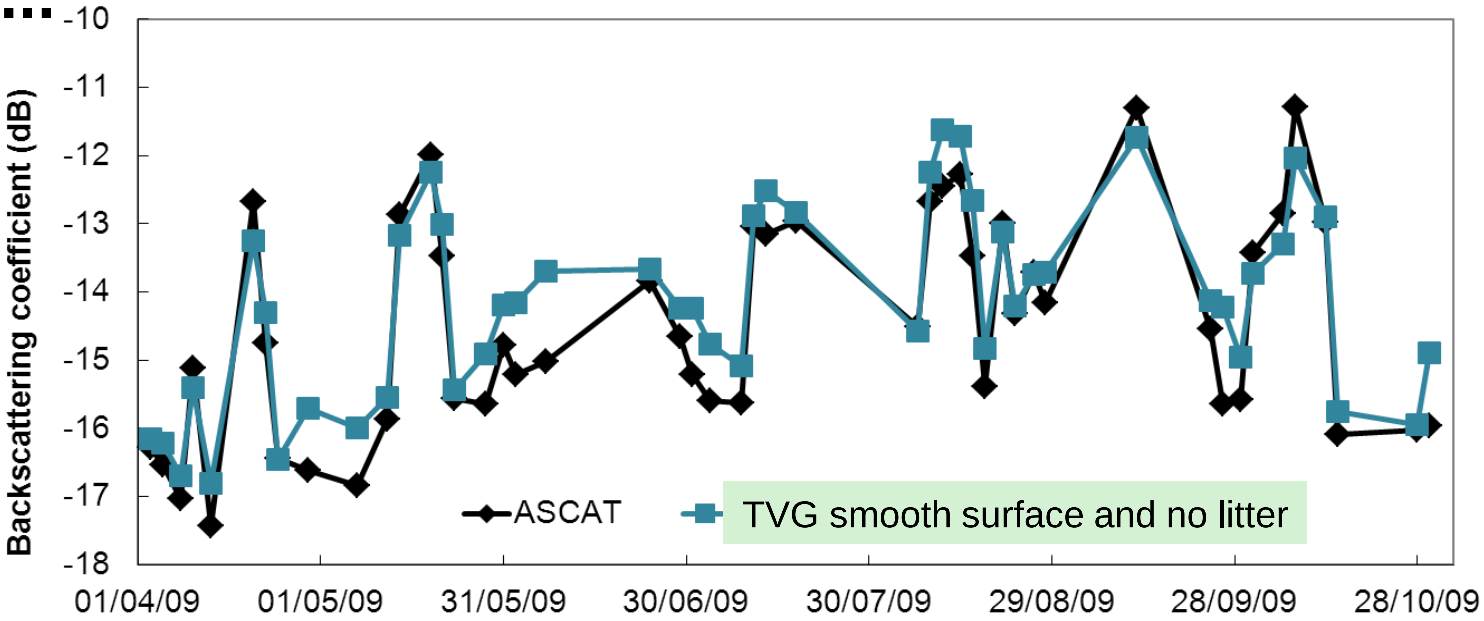


Surface temperature derived from V pol Ka-band AMSR-E T_b

R^2 = 0.8
rmse = 6.3 K
bias = 2.7 K

R^2 = 0.5
rmse = 5.9 K
bias = 4.3 K

IF ONLY THE ACTIVE MICROWAVE DATA WERE USED …



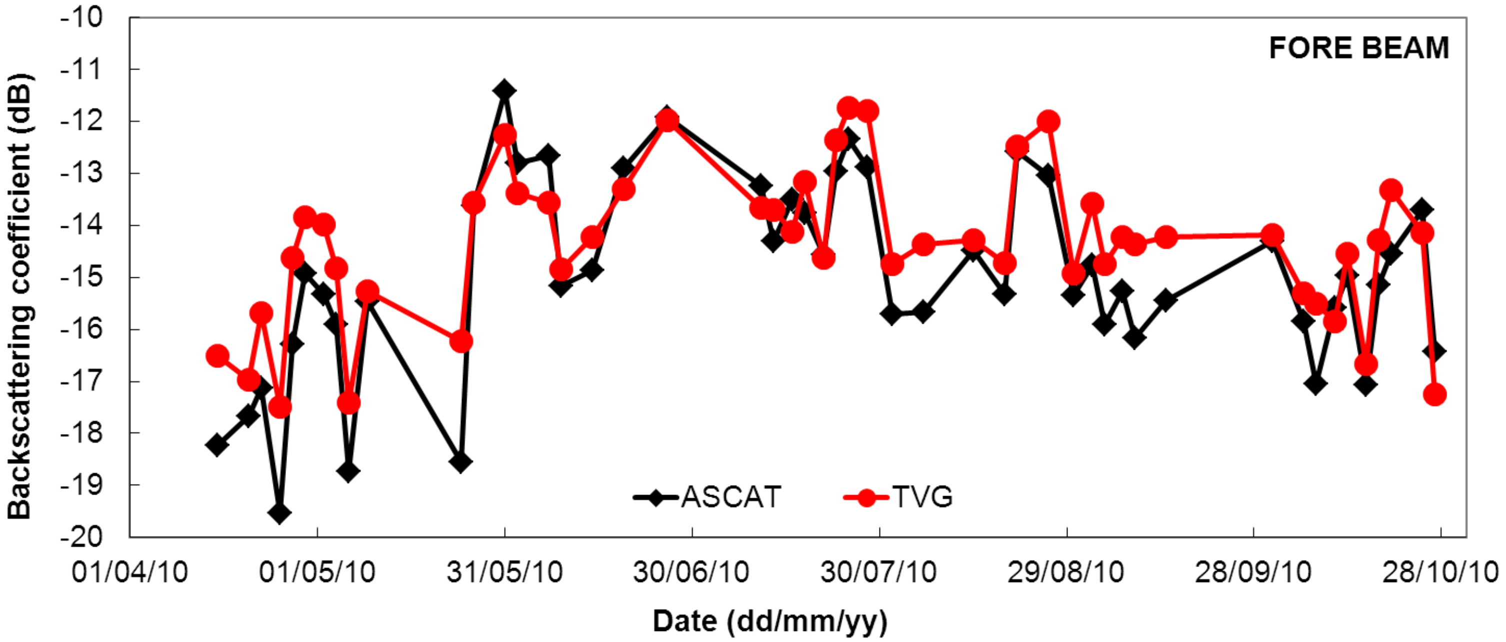
… a good match with ASCAT observations was possible with unrealistic assumptions:

-absence of litter

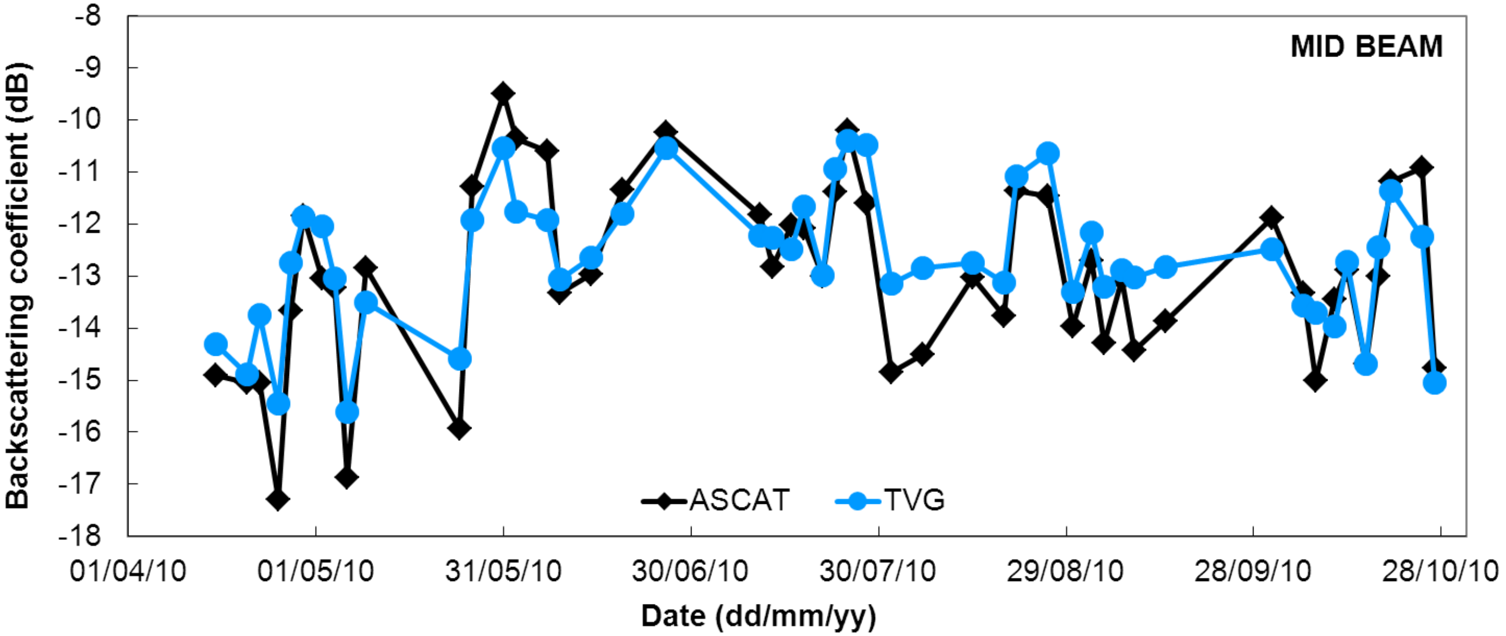
-smooth surface

However, the same assumptions led to a large underestimation of T_b!

RESULTS: MODEL VALIDATION (2010) – ACTIVE CASE

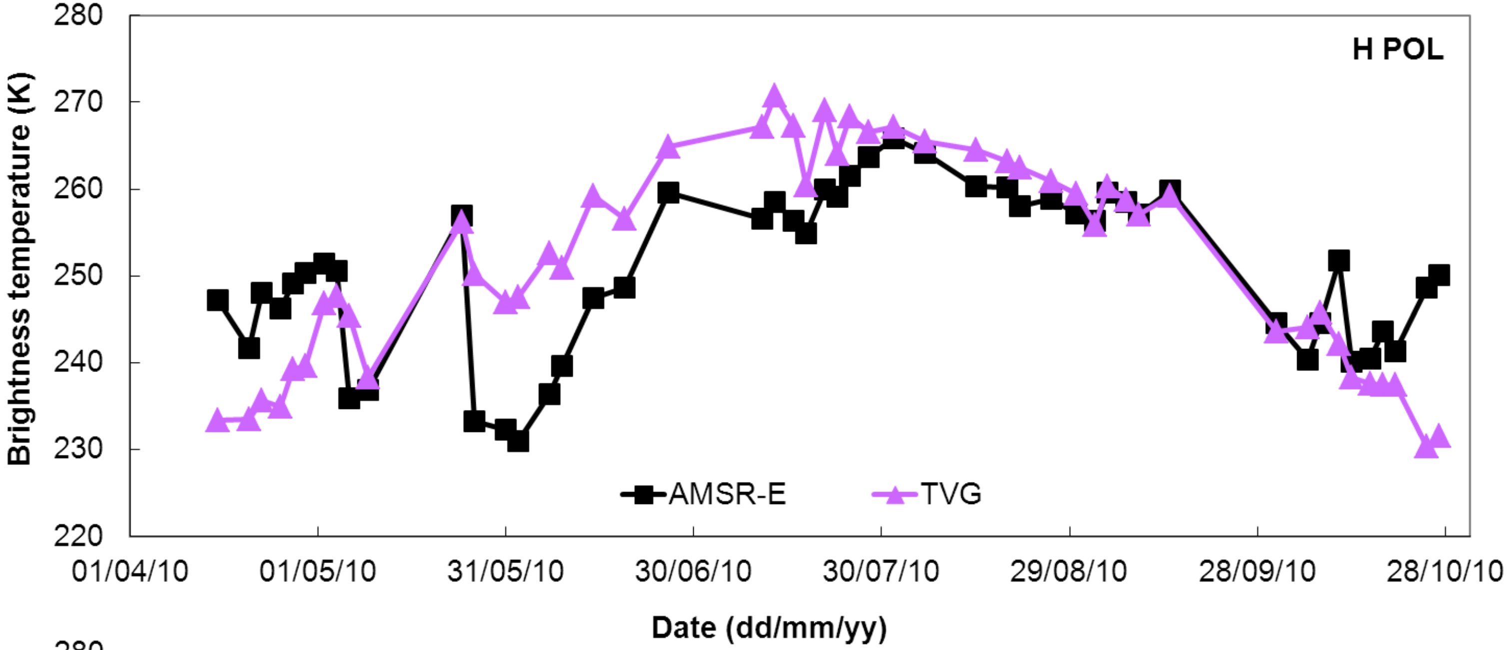


R^2 = 0.8
rmse = 1 dB
bias = 0.6 dB

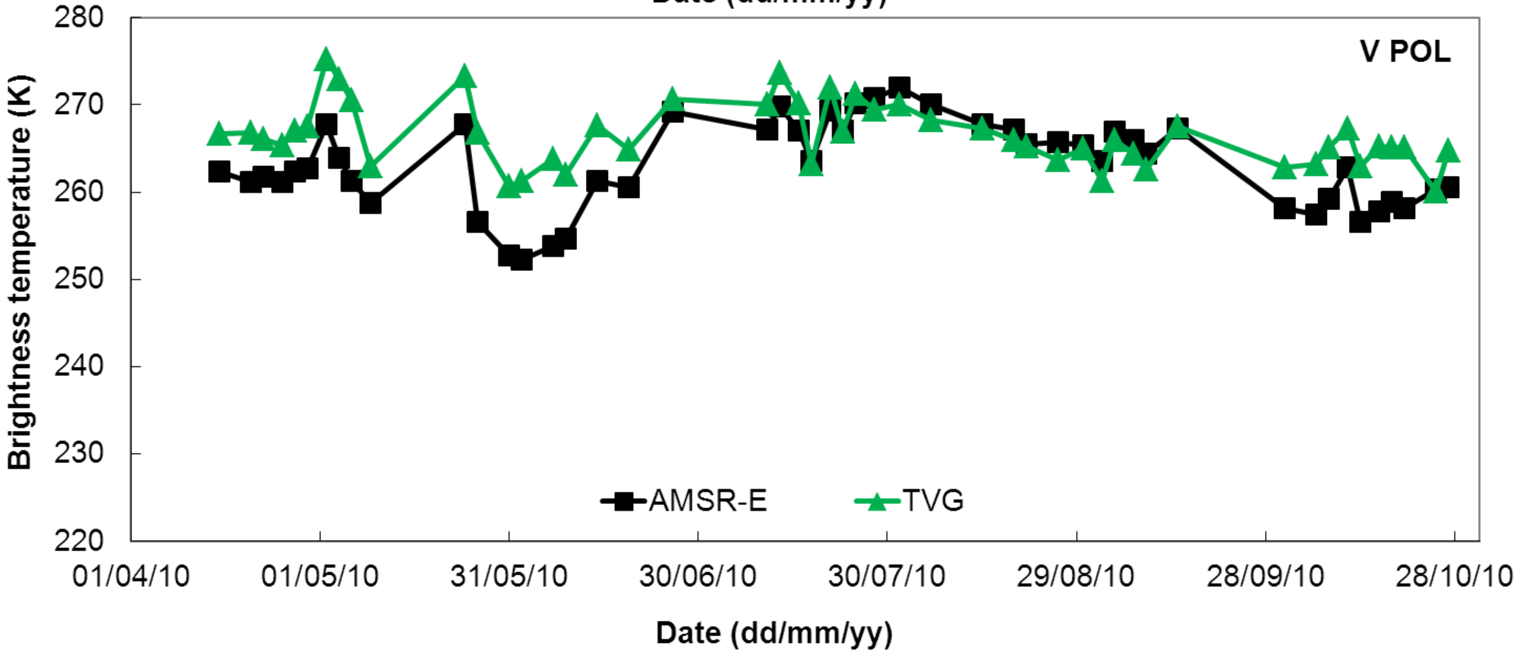


R^2 = 0.8
rmse = 0.8 dB
bias = 0.3 dB

RESULTS: MODEL VALIDATION (2010) – PASSIVE CASE



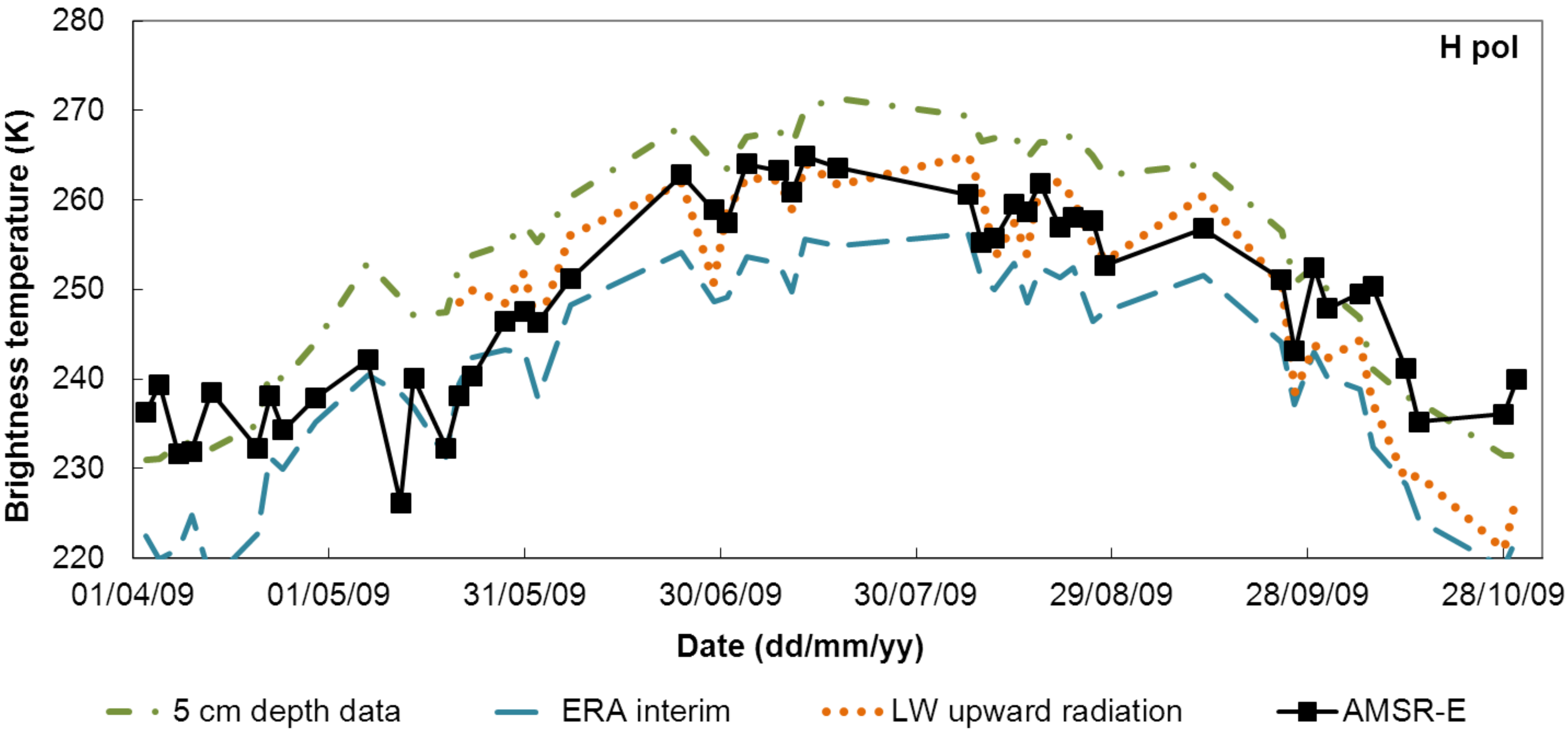
R^2 = 0.5
rmse = 8.7 K
bias = 1.3 K



R^2 = 0.5
rmse = 5.0 K
bias = 3.4 K

WHAT IF SURFACE TEMPERATURE IS NOT SIMULTANEOUSLY OBSERVED

… when a different surface temperature is used.



R^2 = 0.8
rmse = 8.2 K
bias = 5.1 K

R^2 = 0.8
rmse = 9.7 K
bias = -7.8 K

R^2 = 0.7
rmse = 6.2 K
bias = -1.7 K

R^2 = 0.8
rmse = 6.3 K
bias = 2.7 K

An Improved Two-layer Algorithm for Estimating Effective Soil Temperature using L-band Radiometry

$$T_B = \varepsilon T_{eff}$$

(Lv et al., 2014, RSE)

$$T_{eff} = \int_0^\infty T(x)\alpha(x)\exp\left[-\int_0^x a(x')dx'\right]dx$$

(Ulaby et al. 1978; 1979)

$$\alpha(x) = \frac{4\pi}{\lambda}\varepsilon''(x)\Big/ 2[\varepsilon'(x)]^{\frac{1}{2}}$$

(Wilheit 1978)

A two-layer system:

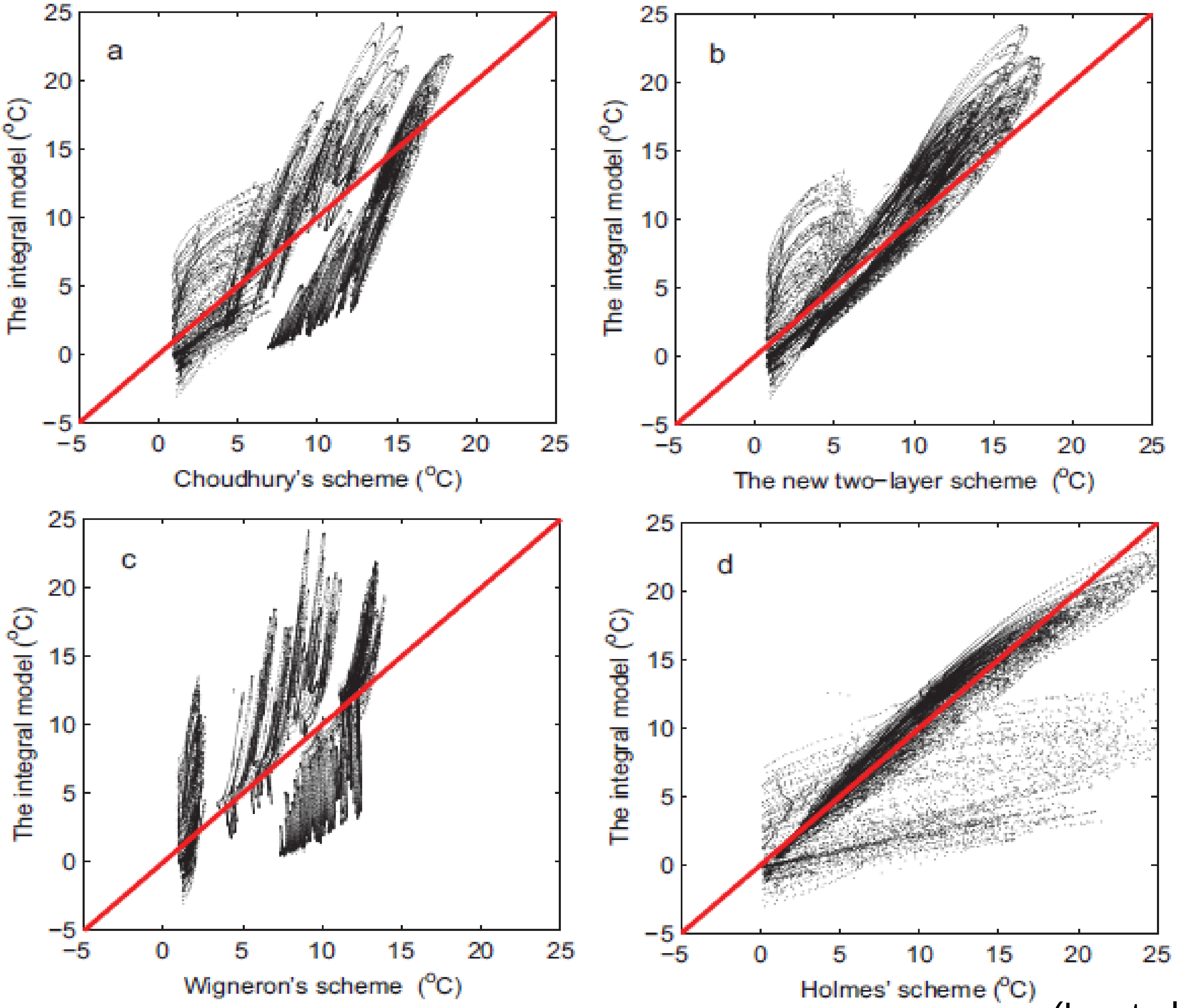
$$T_{eff} = T_0\left(1 - e^{-B_0}\right) + T_\infty e^{-B_0}$$

$$B_0 = \alpha_1 x_1$$

$$B_0 = \Delta x \cdot \frac{4\pi}{\lambda} \cdot \frac{\varepsilon''}{2\sqrt{\varepsilon'}}$$

$$\begin{aligned} C &= 1 - e^{-B_0} \\ &= 1 - \exp(-\Delta x \alpha_1) \\ &= 1 - \exp\left(-\Delta x \cdot \frac{4\pi}{\lambda} \cdot \frac{\varepsilon''}{2\sqrt{\varepsilon'}}\right) \end{aligned}$$

The weight function C is a parameter affected by wavelength (a), soil moisture (b), sampling depth (c), and soil temperature (d)



(Lv et al., 2014, RSE)

Can we infer what is below the surface?
Numerical Analysis of Air-Water-Heat Flow in the Unsaturated Soil: the role of Air Flow in Land Surface Models?

a Two-phase Heat and Mass Transfer Model (STEMMUS)

Zeng, Y., Su Z., Wan, L. and Wen, J., 2011, Numerical Analysis of Air-Water-Heat Flow in the Unsaturated Soil - Is it Necessary to Consider Air Flow in Land Surface Models. Journal of Geophysical Research – Atmosphere, 116(20), D20107, doi: 10.1029/2011JD015835.

Zeng, Y., Su, Z., Wan, L. and Wen, J., 2011, A simulation analysis of the advective effect on evaporation using a two-phase heat and mass flow model. Water Resources Research, 47(10), W10529, doi: 10.1029/2011WR010701.

A two-phase numerical model: governing equations (Zeng et al., 2011)

Soil Moisture Equation

$$\frac{\partial}{\partial t}(\rho_L \theta + \rho_V \theta_a) = -\nabla q_m$$

$$q_m = q_{Lh} + q_{La} + q_{LT} + q_{Vh} + q_{Va} + q_{VT})\frac{\partial T}{\partial z} + K_{Lh}]$$

q_{Lh} & q_{Vh} (kg m^{-2} s^{-1}) is the isothermal liquid and vapor flux;

ficient for

q_{LT} & q_{VT} (kg m^{-2} s^{-1}) is the thermal liquid and vapor flux;

Flow due to

Gradient

q_{La} & q_{Va} (kg m^{-2} s^{-1}) is the convective liquid and vapor flux due to air pressure gradient.

Dry Air Equation

$$\frac{\partial}{\partial t}[\varepsilon \cdot \rho_{da}(S_a + H_c S_r)] = -\nabla q_a$$

$$q_a = q_{ah} + q_{aT} + q_{aa} \cdot \rho_{da}\frac{S_a k_g}{\mu}\frac{\partial P_g}{\partial z} - D_{Vg}\underbrace{\frac{\partial \rho_{da}}{\partial z}}_{\text{spersion}} + \underbrace{H_c \rho_{da}\frac{q_L}{\rho_L}}_{\text{Dissolving}}$$

q_{ah} (kg m^{-2} s^{-1}) is the isothermal air flux;

q_{aT} (kg m^{-2} s^{-1}) the thermal air flux; q_{aa} (kg m^{-2} s^{-1}) the convective flux.

Energy Equation

$$\frac{\partial}{\partial t}[(\rho_s \theta_s c_s + \rho_L \theta c_L + \rho_{da}\theta_a c_a + \rho_V \theta_a c_V)(T - T_r) + \rho_V L_0 \theta_a] - \rho_L \boxed{W}\frac{\partial \theta}{\partial t}$$

Differential Heat of Wetting

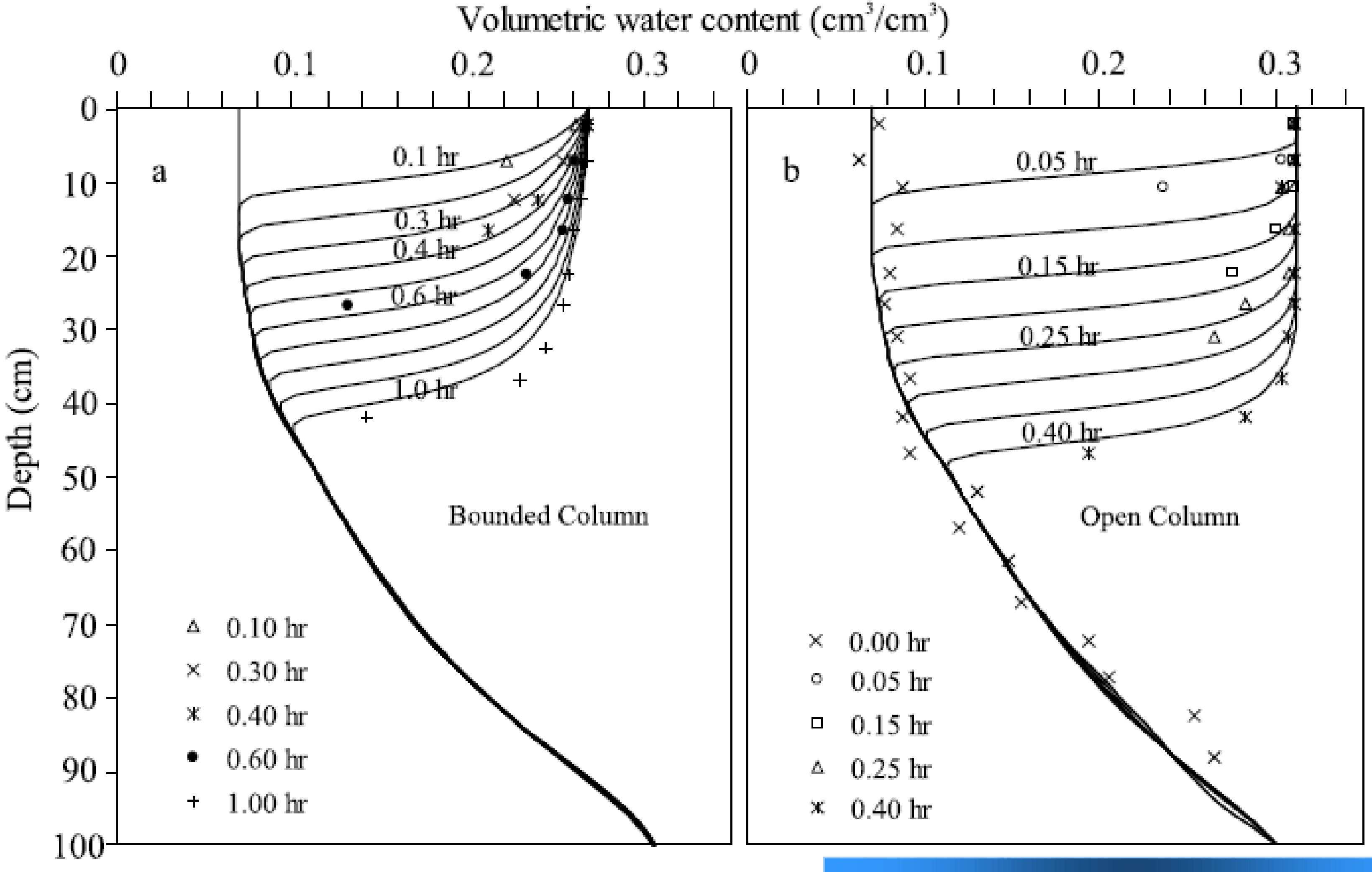
$$= \frac{\partial}{\partial z}(\lambda_{eff}\frac{\partial T}{\partial z}) - \frac{\partial}{\partial z}[\boxed{q_L c_L \cdot (T - T_r)} + \boxed{q_V (L_0 + c_V \cdot (T - T_r))} + \boxed{q_a c_a \cdot (T - T_r)}]$$

(Zeng et al., 2011)

STEMMUS: Ponding water exp.

Ponding Water

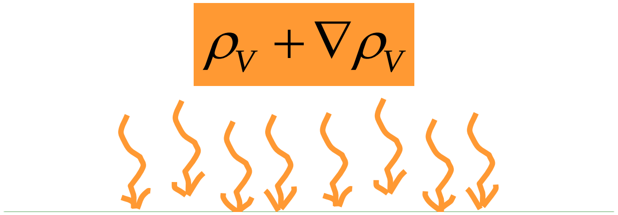
Ponding Water



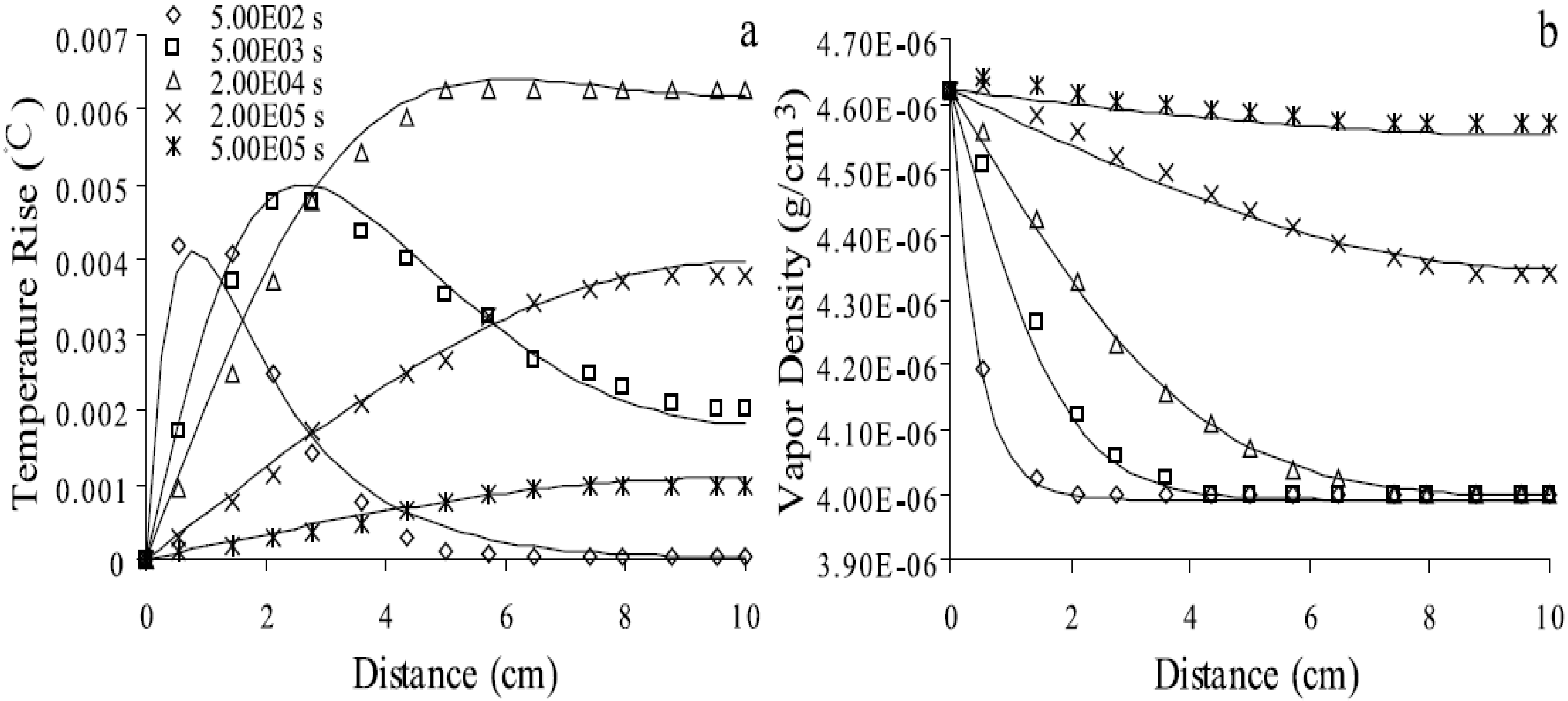
(Zeng, Su, et al. 2011, JGR)

STEMMUS: Soil Moisture and Heat Flow Exp.

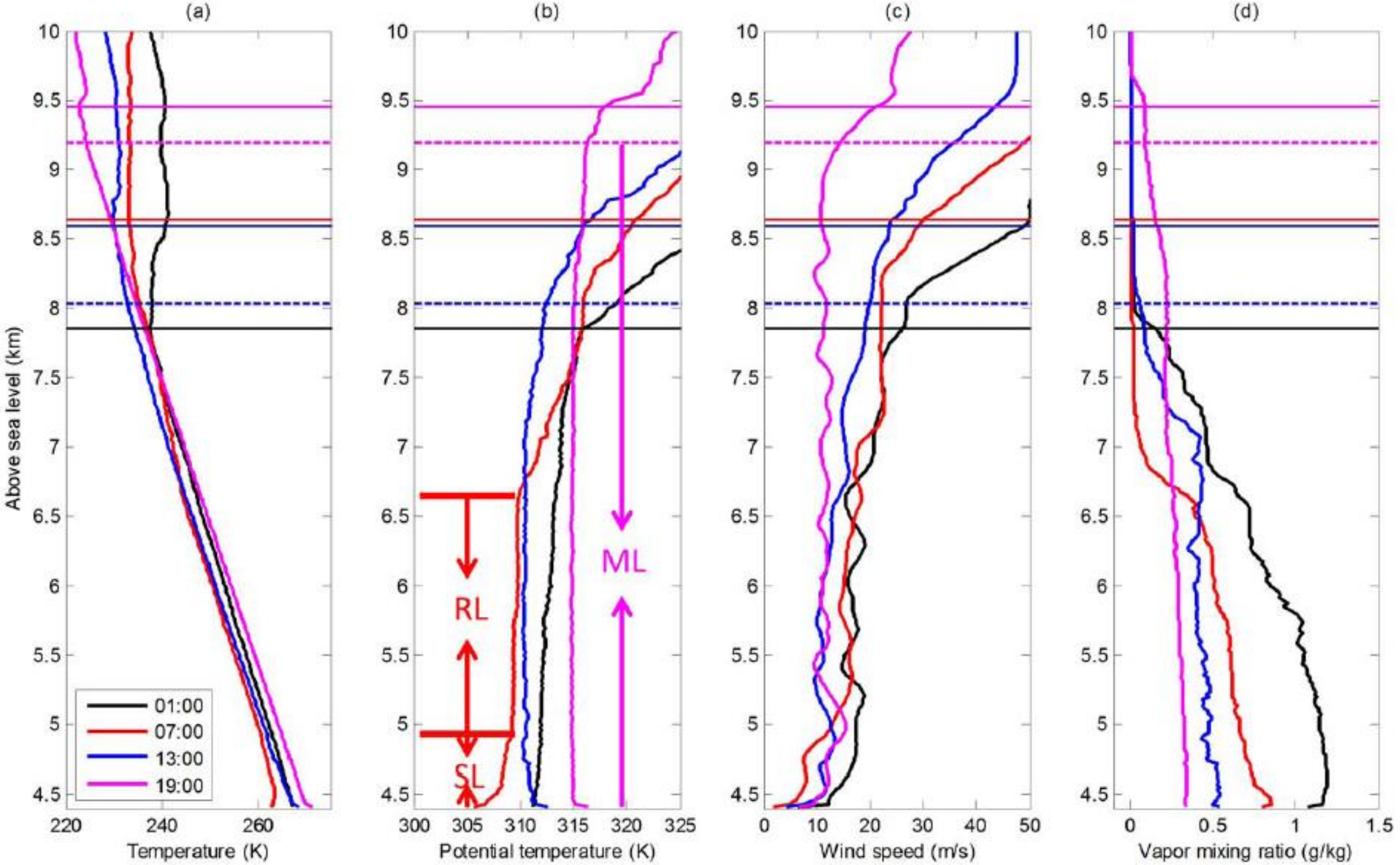
(Zeng, Su, et al. JGR, 2011)



$\rho_V + \nabla\rho_V$



What causes the high PBL on Tibetan Plateau?



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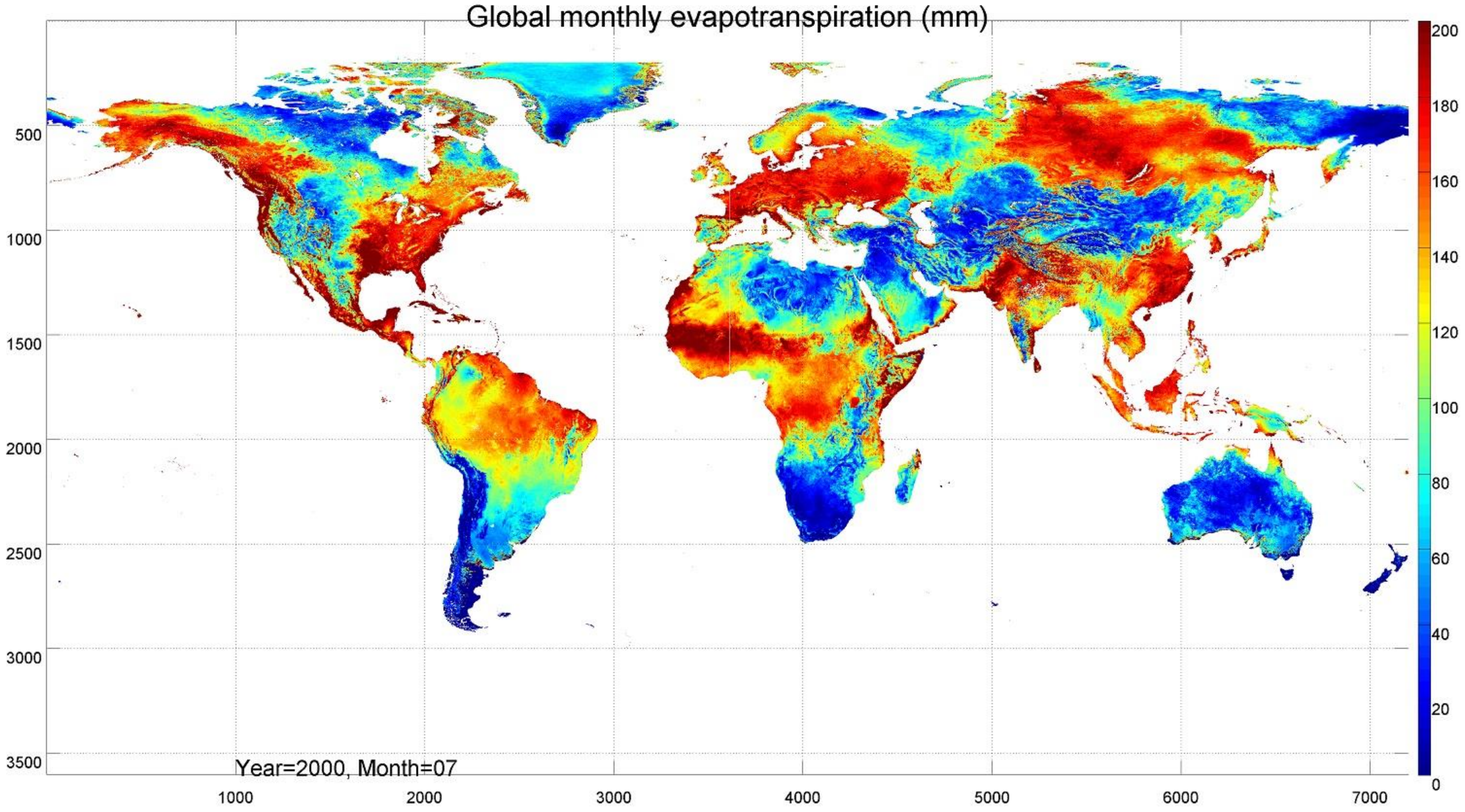
(Chen et al., 2013, PLOSone)

ITC SEBS DERIVED GLOBAL ENERGY & ET FLUXES

(2000 to present at 5 km*5 km spatial resolution), data access: linkendin SEBS group



(Chen et al., 2014, ACP)

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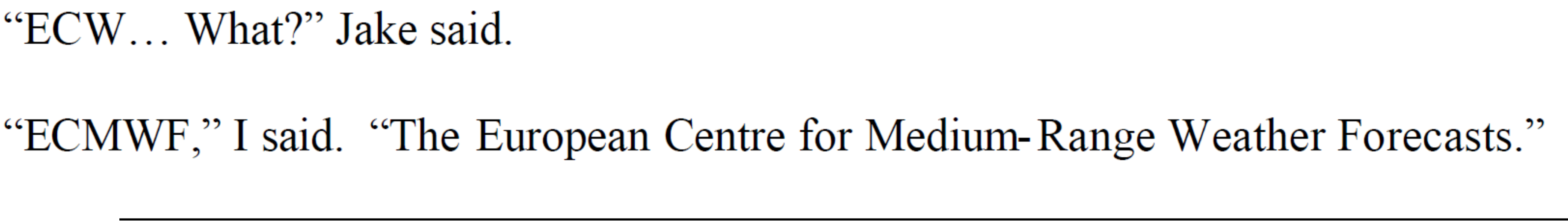
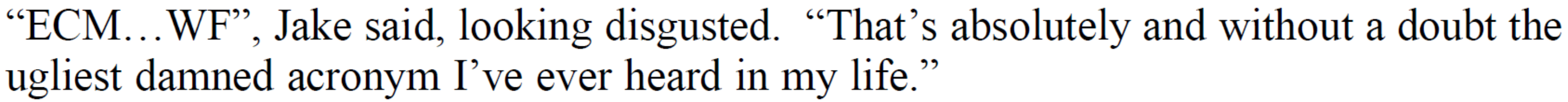


"ECW… What?" Jake said.

"ECMWF," I said. "The European Centre for Medium-Range Weather Forecasts."



"ECM…WF", Jake said, looking disgusted. "That's absolutely and without a doubt the ugliest damned acronym I've ever heard in my life."

From 'THE SWENSON CODE
A Land Surface Modeling Thriller
by R. Koster'

Is this why the bus stop is called the "Weather Centre" ?

Thank you very much!