

A Consortium for CONvection-scale modelling
Research and Development

On the challenges of vegetation-atmosphere coupling in the roughness sublayer of a NWP system

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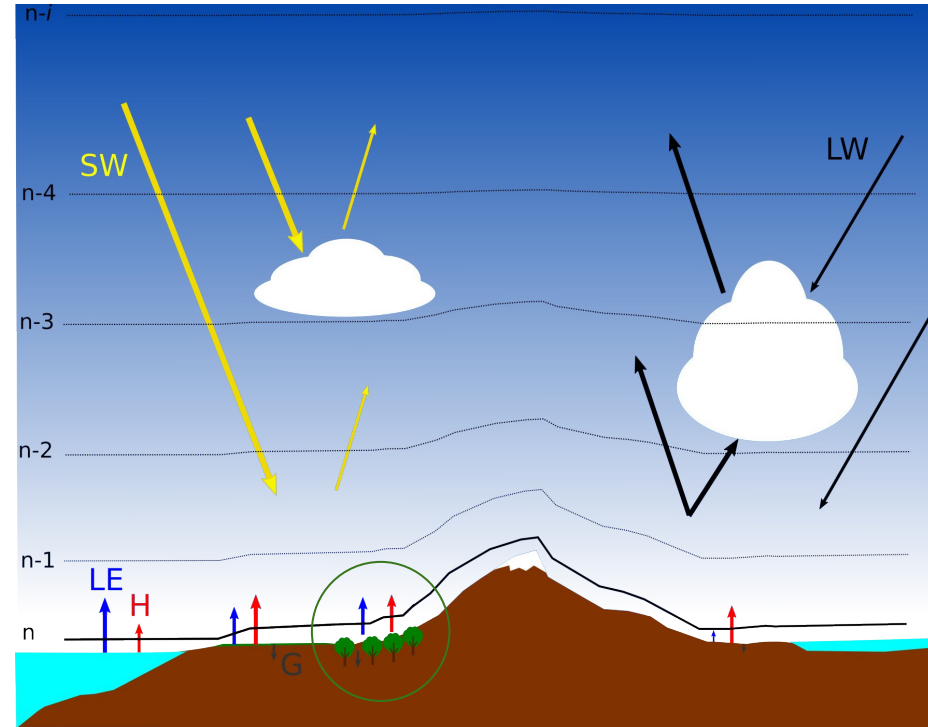
Why do we care about SURFACE and its heterogeneity?

- the atmosphere and the Earth surface exchange momentum, energy (heat, moisture), chemical compounds
- surface properties alter the exchange differently (soil/sand, grass, trees, urban, snow, ice, sea/lake, ...)
- ESM and NWP: lower boundary (forcing) in atmospheric models

$$\frac{\partial \bar{\theta}}{\partial t} = -\bar{U} \frac{\partial \bar{\theta}}{\partial x} - \frac{1}{\rho c_p} \frac{\partial H}{\partial z} - \frac{1}{\rho L_v} \frac{\partial LE}{\partial z} + \frac{1}{\rho c_p} \frac{\partial R_n}{\partial z}$$

- requirement for continuum in the surface-atmospheric coupling system (radiation and surface energy balance in coupling)

$$R_n = SW_{net} + LW_{net} = H + LE + G$$



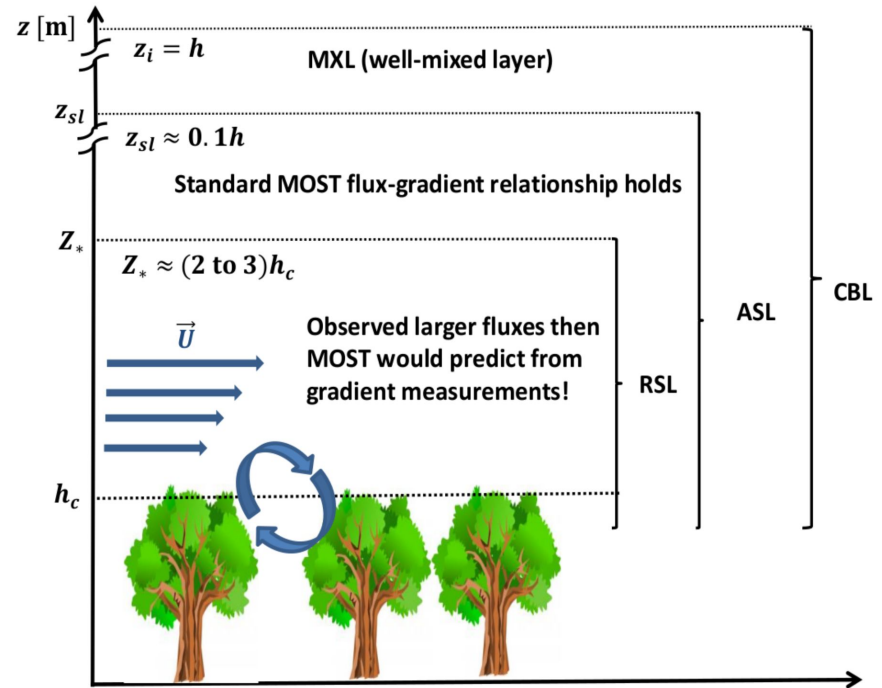
This presentation: vertical exchange between atmosphere and tall vegetation.

Roughness sublayer - RSL

RSL is a layer in the ASL formed above the (tall) vegetation due to the interaction between the atmospheric flow and the canopy elements.

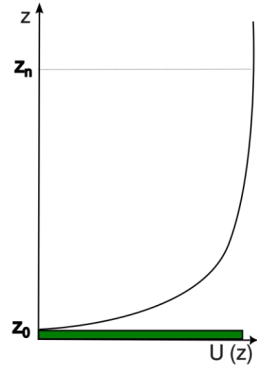
- due to the creation and dissipation of coherent structures at the canopy-atmosphere interface (Raupach et al. 1996).

A modification of the standard Monin-Obukhov similarity theory (MOST) in the RSL to account for the canopy-induced turbulent mixing.



Surface-atmosphere coupling: from low to tall vegetation

Low vegetation

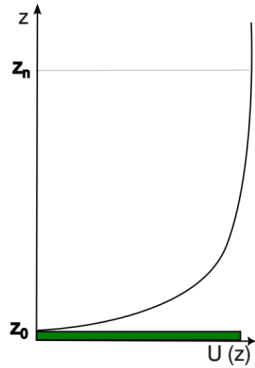


$$\zeta = \frac{z}{L}$$

$$\frac{kz}{u_*} \frac{du(z)}{dz} = \phi_M(\zeta)$$

Surface-atmosphere coupling: from low to tall vegetation

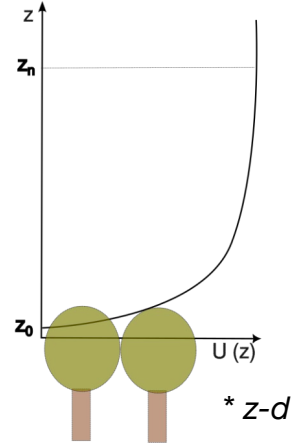
Low vegetation



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Tall vegetation/city



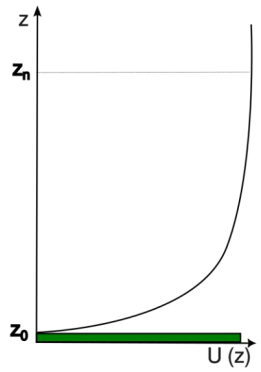
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The power of MOST - Monin-Obukhov Similarity Theory [1954]

Surface-atmosphere coupling: from low to tall vegetation

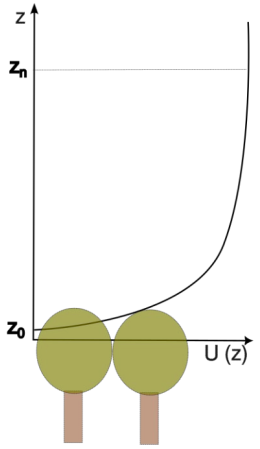
Low vegetation



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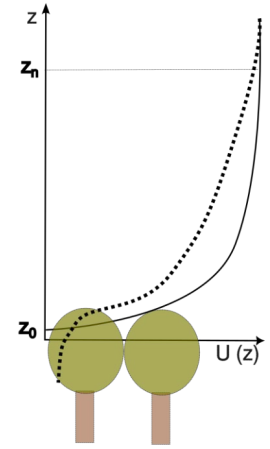
Tall vegetation



$$\zeta = \frac{z}{L}$$

$$\frac{kz}{u_*} \frac{du(z)}{dz} = \phi_M(\zeta)$$

RSL: tall vegetation/city



$$\zeta = \frac{z'}{L}$$

$$\frac{k(z')}{u_*} \frac{du(z')}{dz} = \phi_M(\zeta) \hat{\phi}(\zeta, \delta_\omega)$$

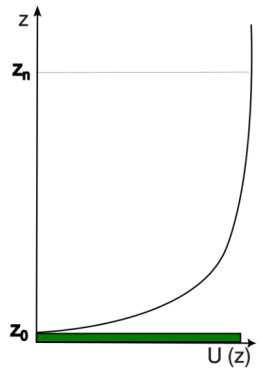
$\hat{\phi}(\zeta, \delta_\omega)$ - effects of canopy-induced turbulent mixing

$\delta_\omega = u/[du/dz]$ - vorticity thickness, controls the depth over which the organized motions impact the flow.

[Harman and Finnigan 2007, 2008, BLM]

Surface-atmosphere coupling: from low to tall vegetation

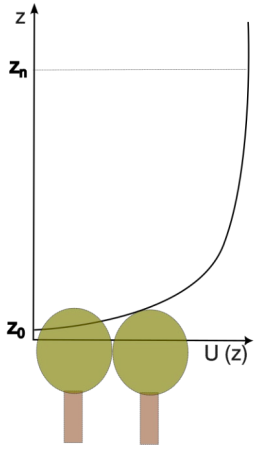
Low vegetation



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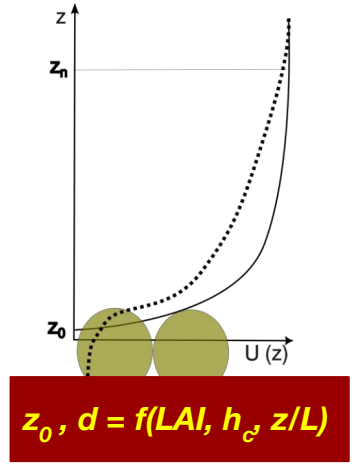
Tall vegetation



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RSL: tall vegetation/city



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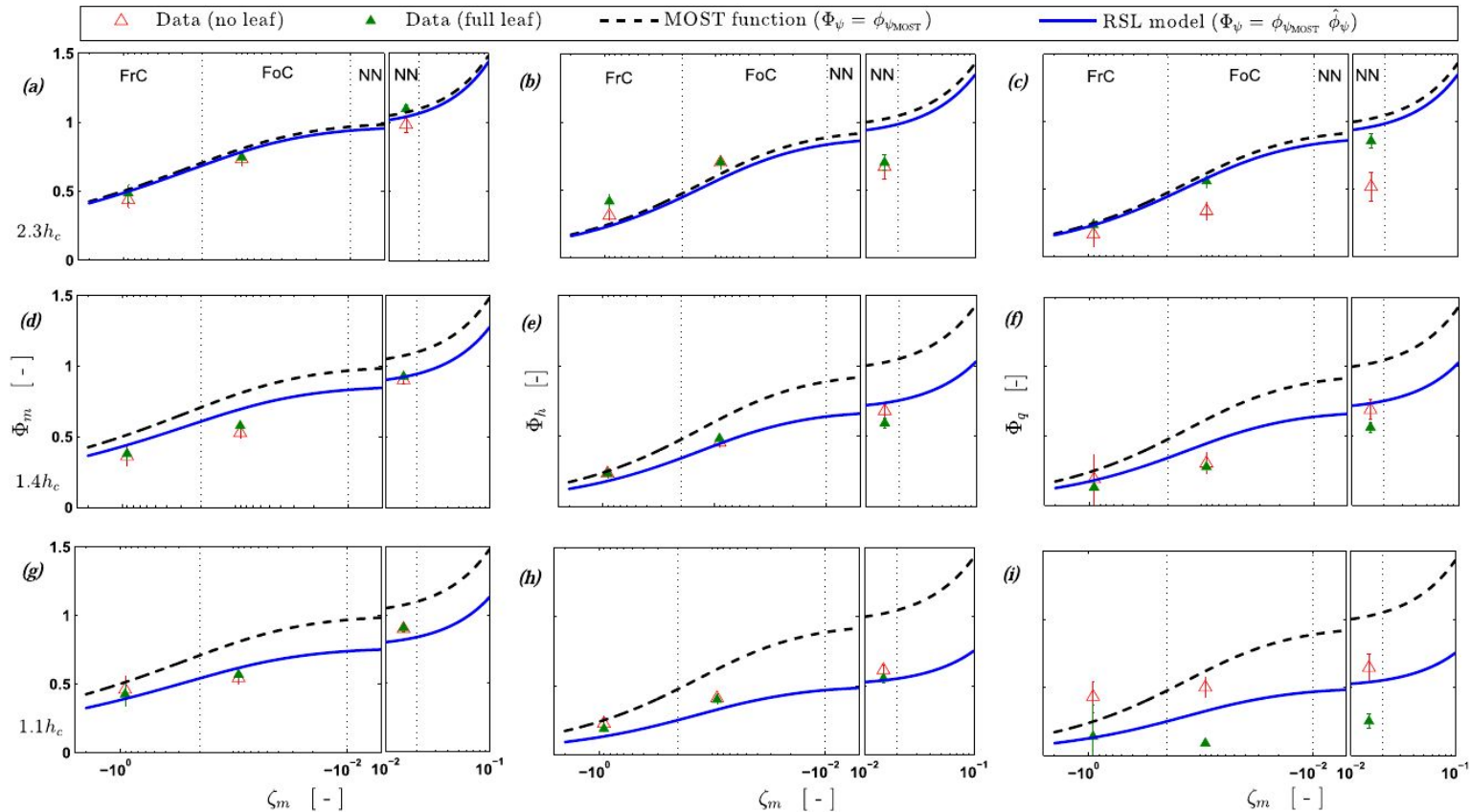
$$\frac{k(z')}{u_*} \frac{du(z')}{dz} = \phi_M(\zeta) \hat{\phi}(\zeta, \delta_\omega)$$

$\hat{\phi}(\zeta, \delta_\omega)$ - effects of canopy-induced turbulent mixing

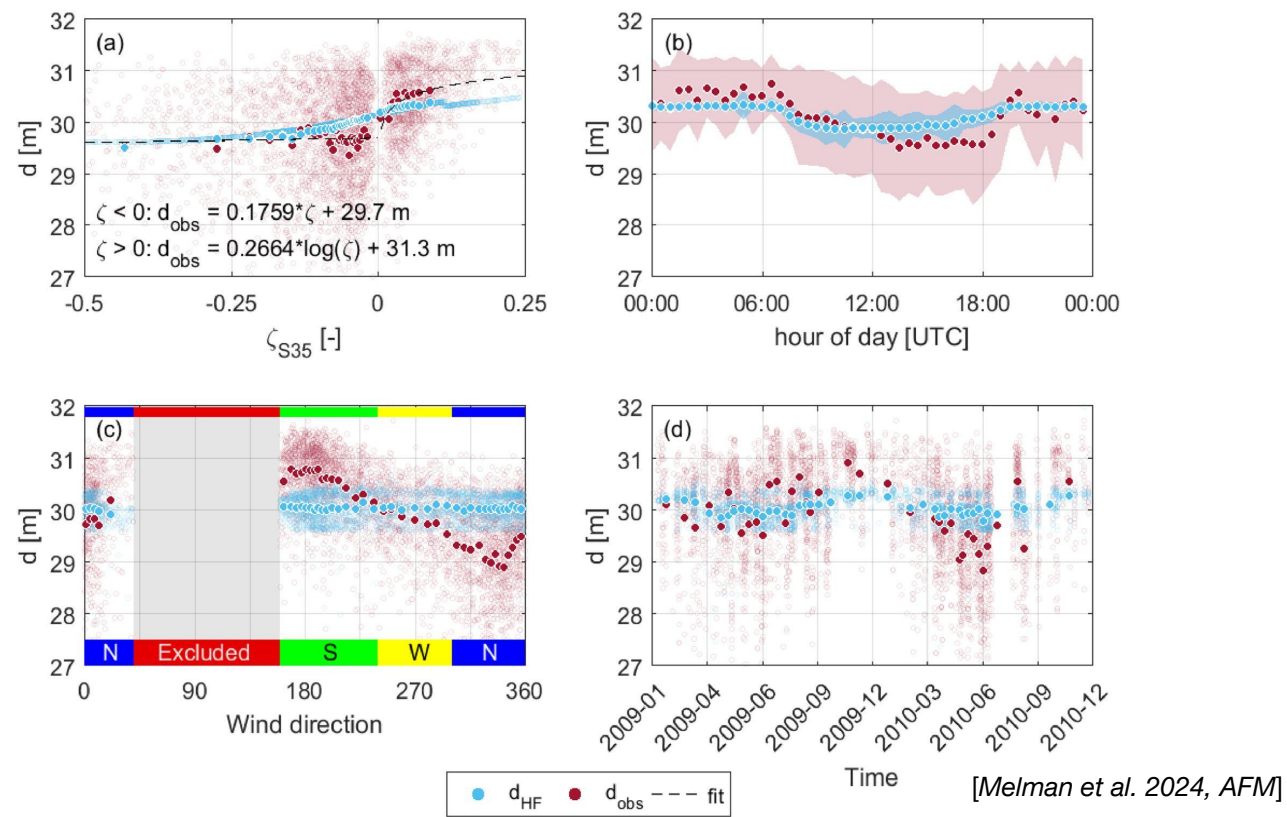
$\delta_\omega = u/[du/dz]$ - vorticity thickness, controls the depth over which the organized motions impact the flow.

[Harman and Finnigan 2007, 2008, BLM]

Dimensionless functions in the roughness sublayer



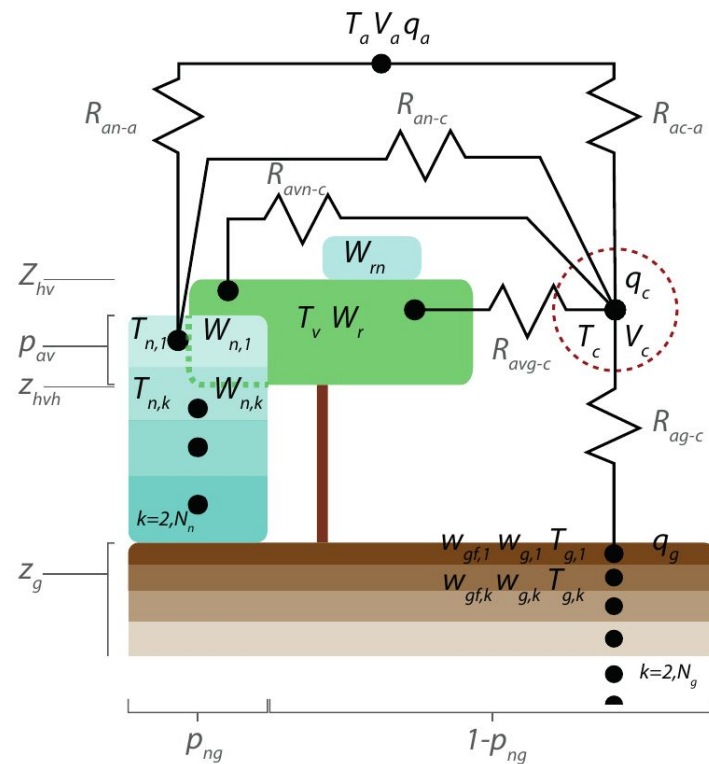
Accounts for vegetation seasonal variability



- **A prove** that the RSL parameterization [Harman and Finnigan 2007, 2008] can account for canopy seasonal changes

RSL parameterization in ACCORD NWP systems

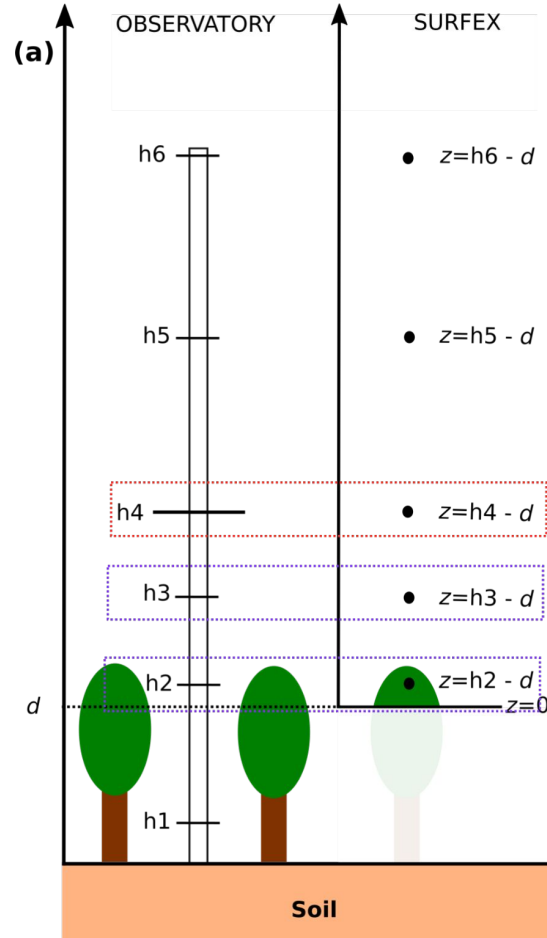
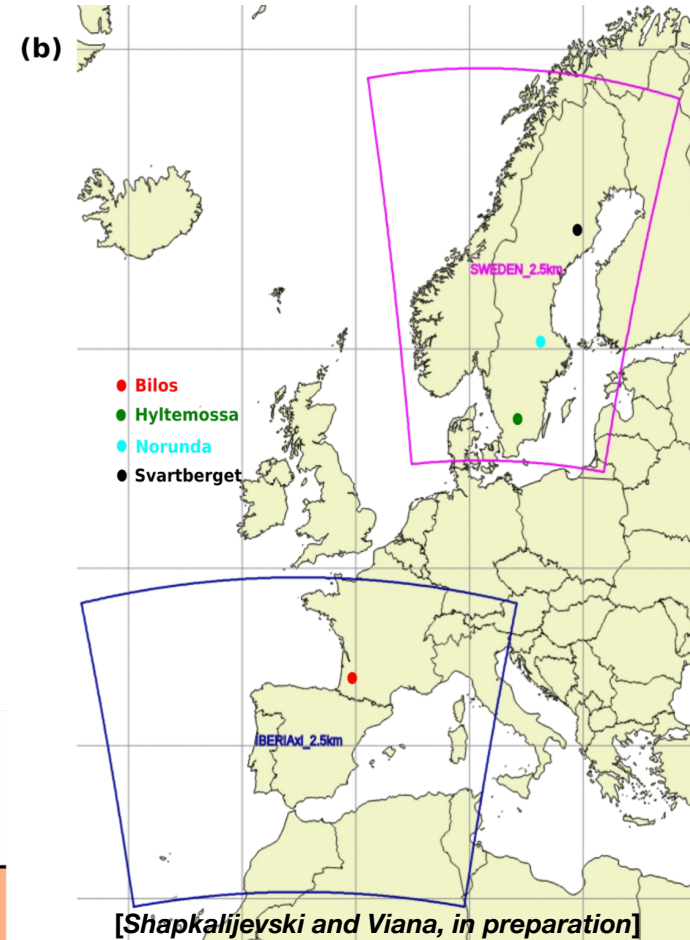
- Implemented via SURFEX offline (v8.1) in
 - ISBA-composite (force restore, FR)
 - ISBA-DIF/MEB
- Implemented via SURFEX inline in
 - HARMONIE-AROME CY46h1
 - PR -----> CY50T1



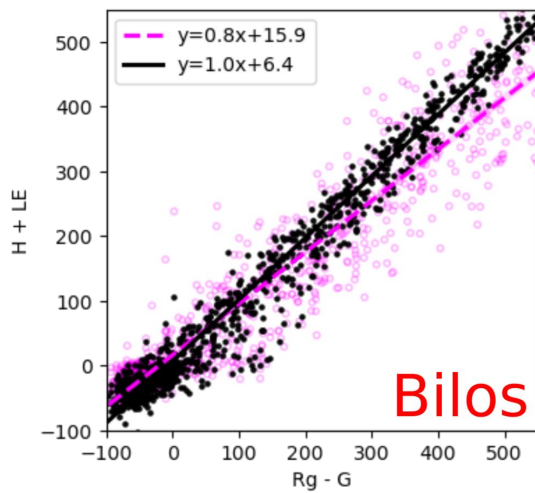
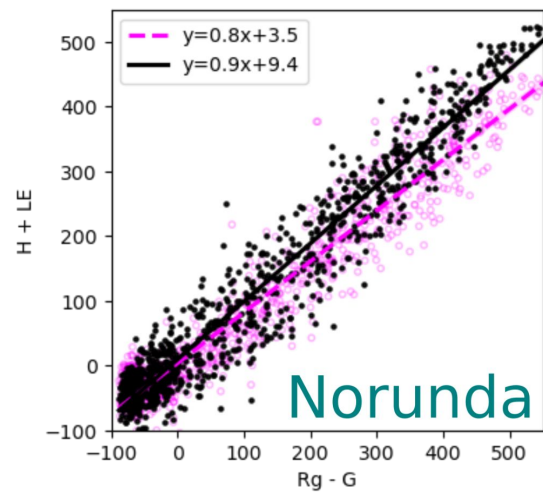
[DIF/MEB, Le Moigne 2018, Scientific doc.]

Validation and verification - methodology

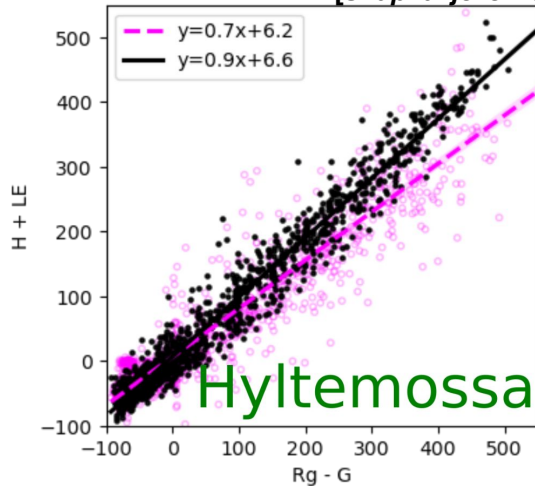
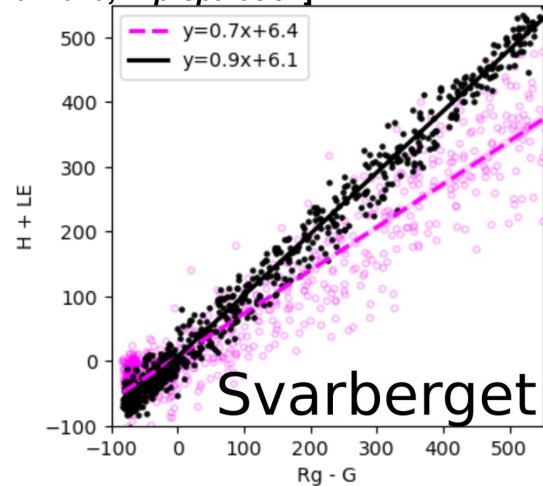
- Observations
 - 4 ICOS stations
- SURFEX 1-d offline
 - Controlled coupling (REF)
- SURFEX 3-d online
 - HARMONIE-AROME
 - Forcing at 12m a.m.g.s.
 - U10M, 2mT, 2mRH
- Observations and Simulations
 - 01.08.2021 - 15.09.2021
(including 15 days spin-up)



Surface Energy (Im)Balance

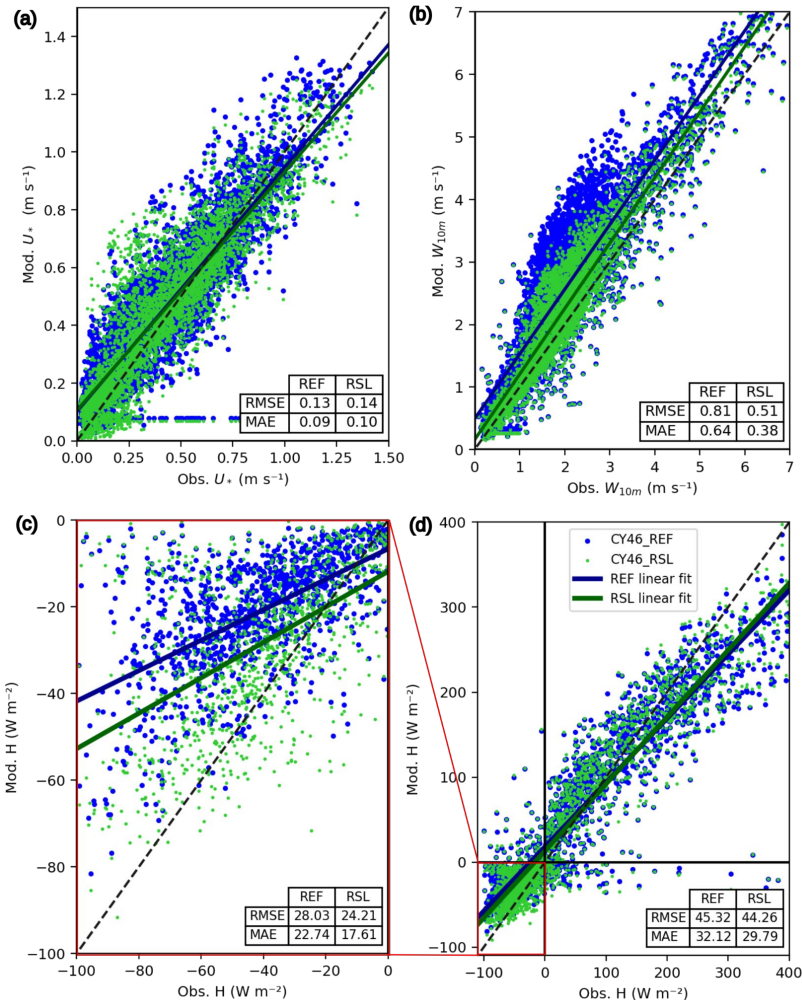


[Shapkalijevski and Viana, in preparation]



Validation and verification

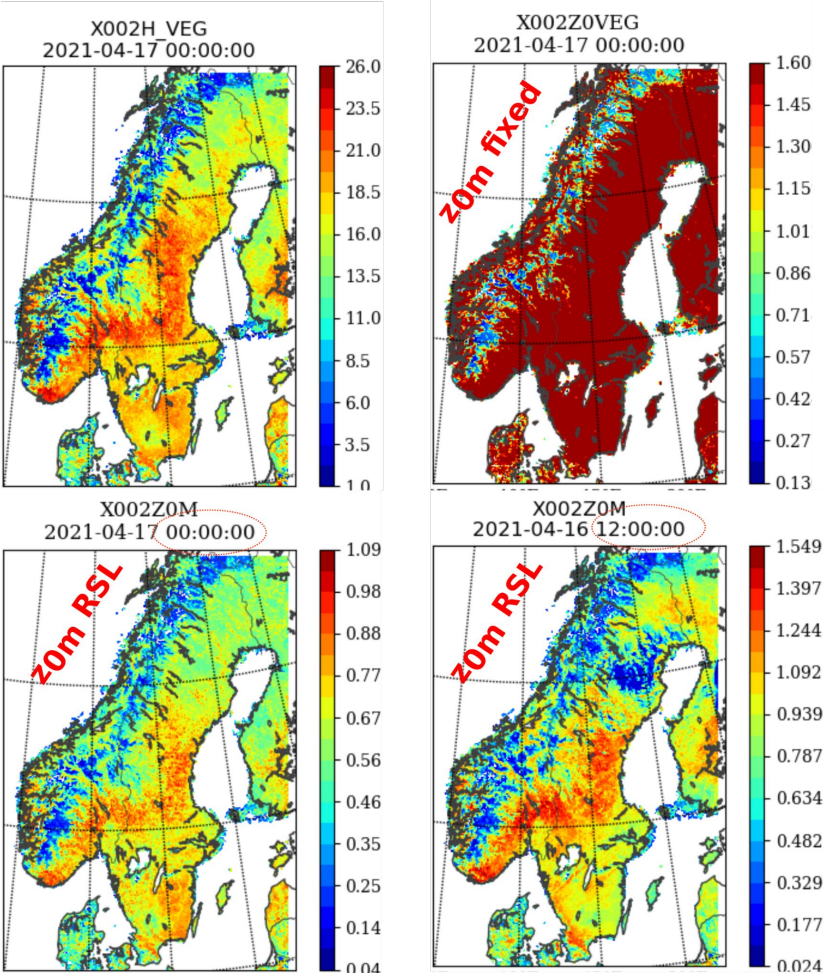
Overall and for all observatories systematically, largest improvements in wind diagnostics (10m wind speed) and nocturnal sensible heat flux and nocturnal 2mT (better surface cooling).



Validation and verification

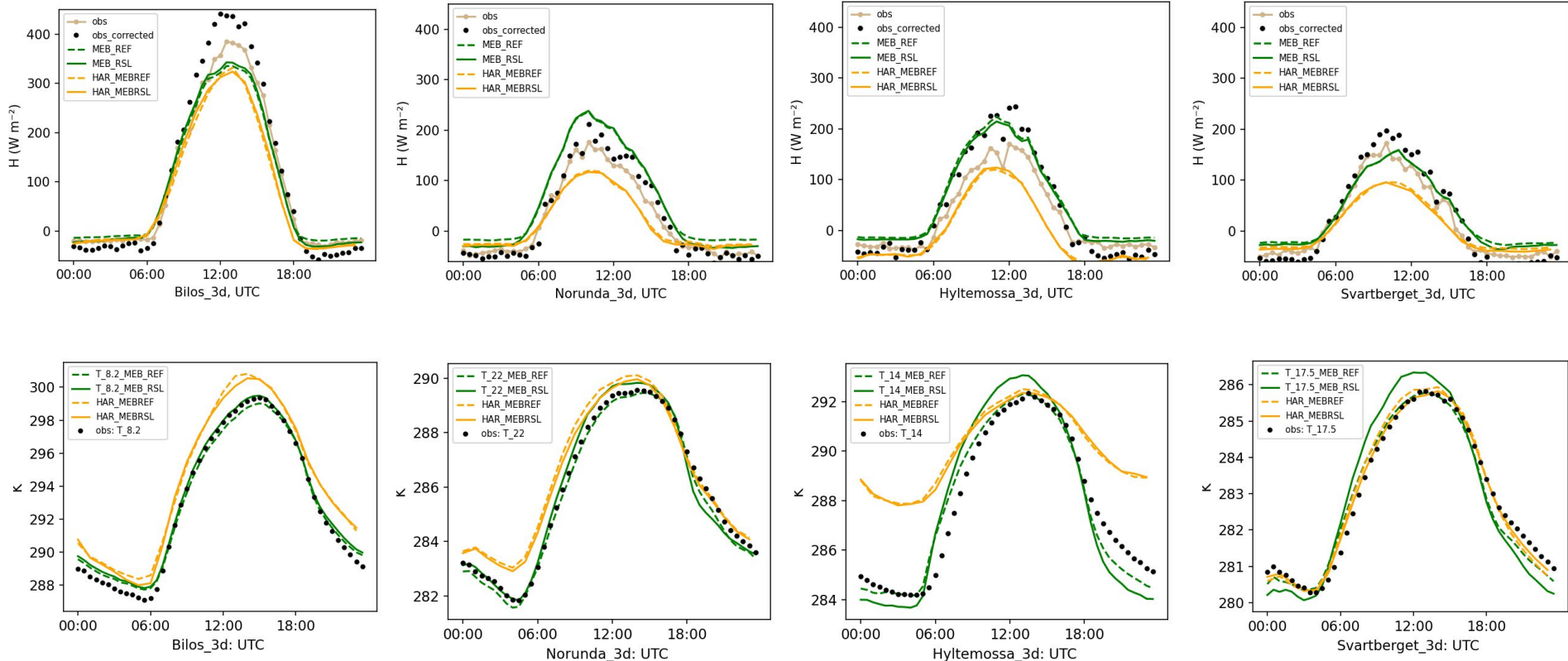
Overall and for all observatories systematically, largest improvements in wind diagnostics (10m wind speed) and nocturnal sensible heat flux and 2mT (better surface cooling)

Vegetation roughness length(s) more realistic and physically more sound



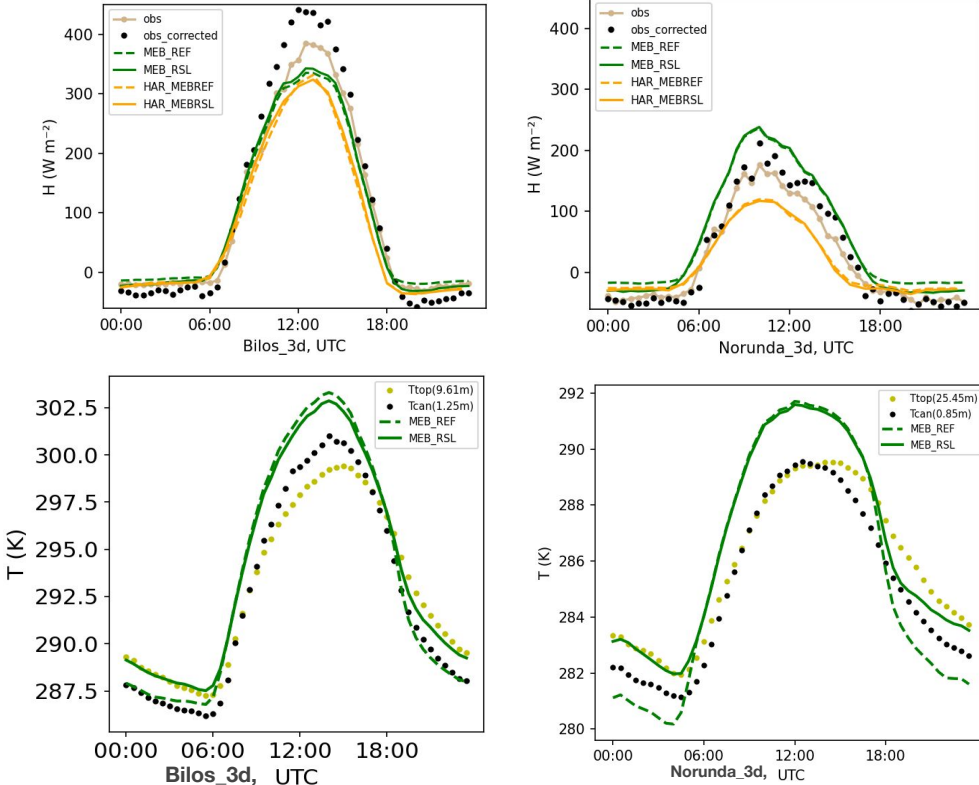
Challenges on the way

Differences between offline and online vegetation-atmosphere coupling vs. observations. Why?



Challenges on the way

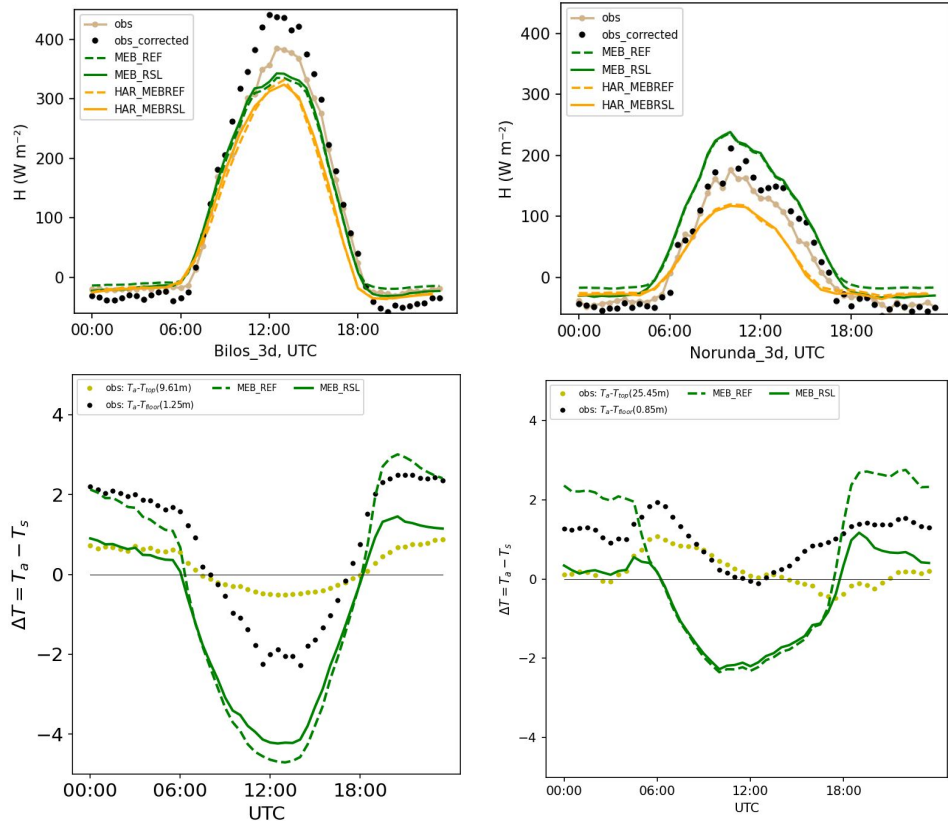
However, overall we see differences between offline and online vegetation-atmosphere coupling vs. observations



- Daytime **sensible heat flux systematically underestimated** by HARMONIE-AROME
- Canopy (skin) temperature overestimated during daytime; RSL well predicts the nocturnal canopy temperature

Challenges on the way

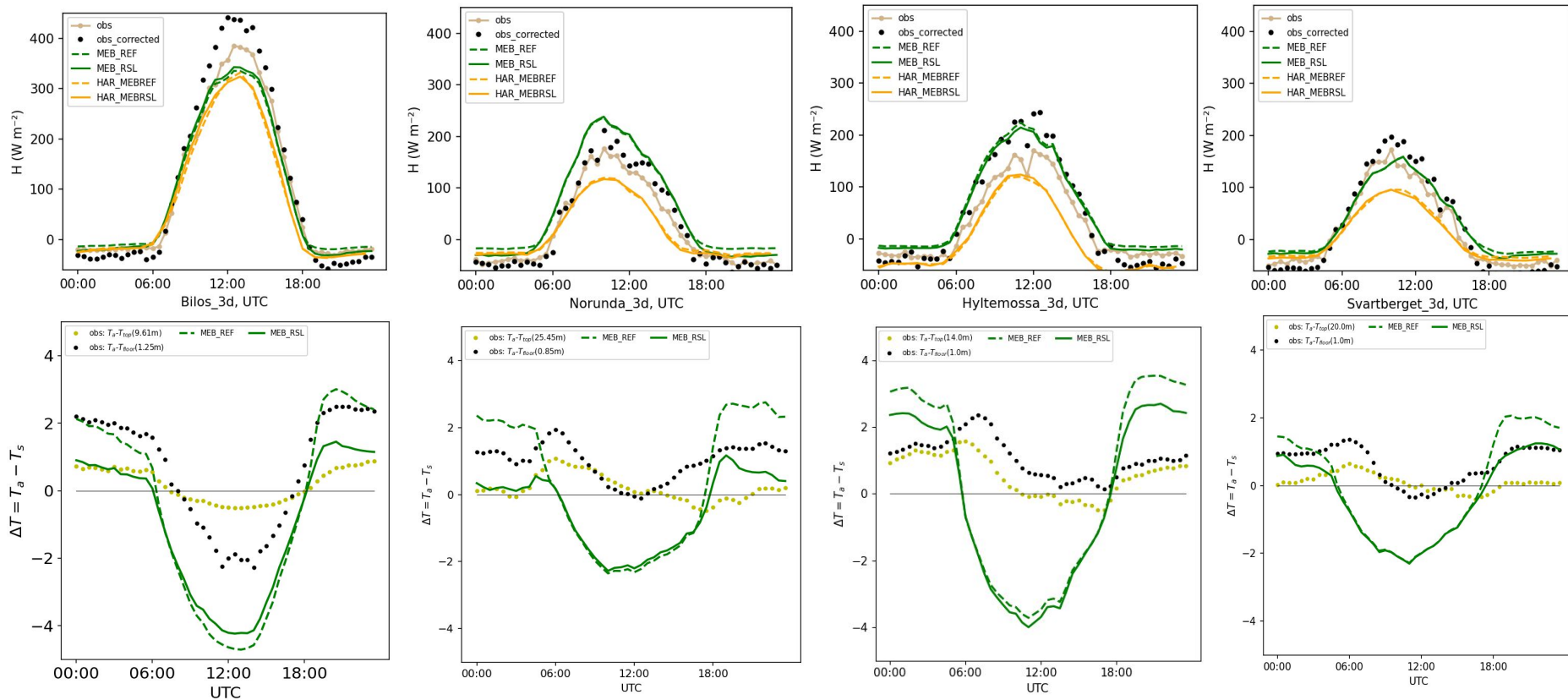
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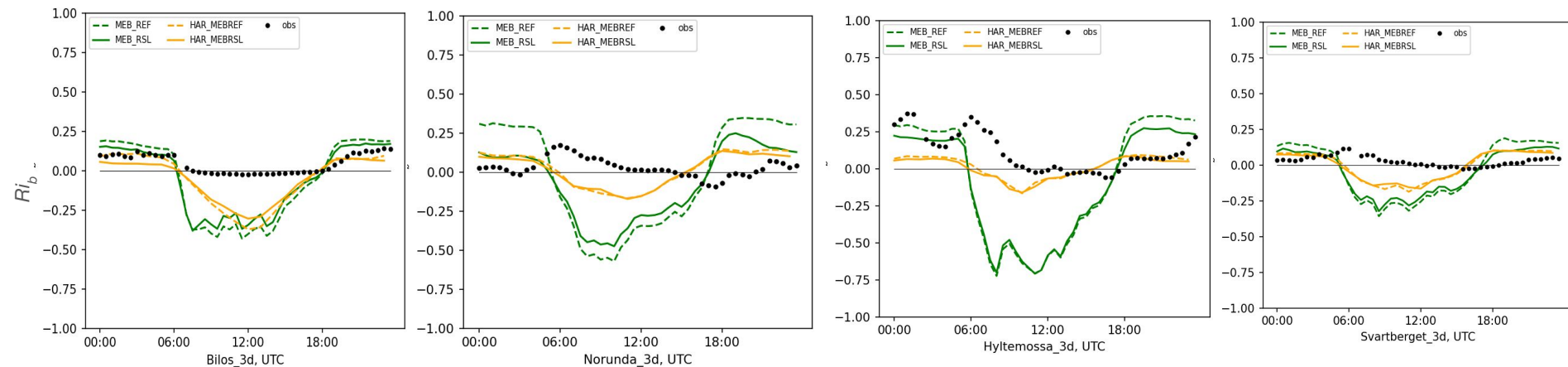
- Daytime **sensible heat flux systematically underestimated** by HARMONIE-AROME
- Canopy (skin) temperature overestimated; RSL well predicts the nocturnal canopy temperature
- SURFEX offline forced by observed quantities, so the scheme computes correct fluxes due to overestimation of temperature gradients (2-4 K)
- Observed temperature gradients over the Swedish observatories missing the clear diurnal cycle
 - counter-gradient flow often present
 - should we care?
 - effects on stability?

Challenges on the way

However, overall we see differences between offline and online vegetation-atmosphere coupling vs. observations

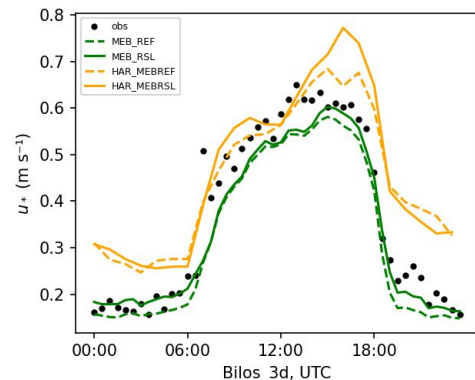
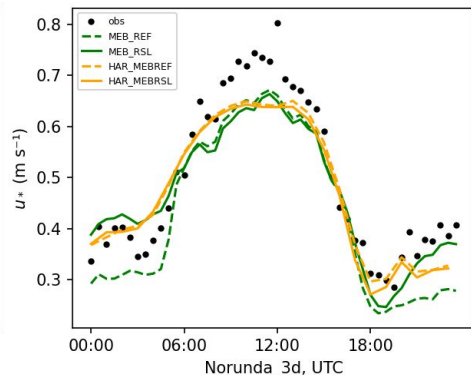
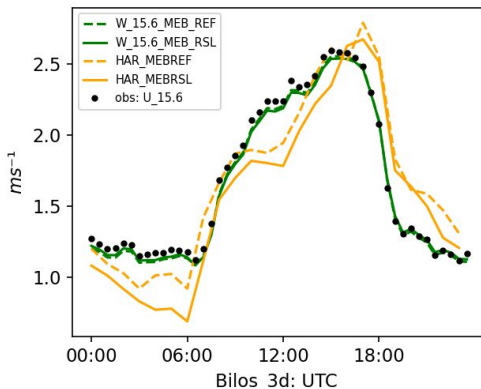
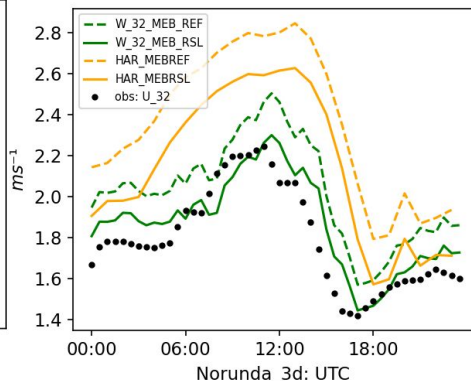


Challenges on the way



HARMONIE-AROME predicts closer to observations but maybe for a wrong reason (less sensible heat)?

Challenges on the way



➤ Momentum (friction velocity) and 10mWS predicted satisfactorily, but still some strange differences

- over(under)estimation of friction velocity
- over(under)estimated wind at 10m

➤ MEB and RSL sensitive to **LAI** and **tree height**

- SURFEX offline simulations use observed values
- HARMONIE-AROME uses **ECOSG**
- Any differences?

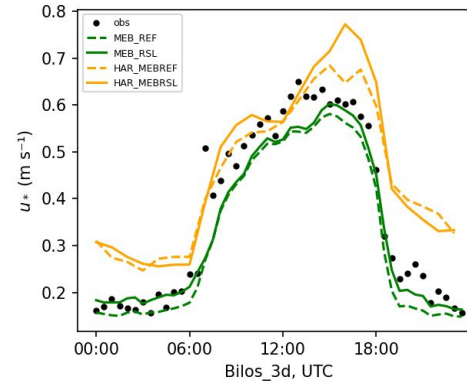
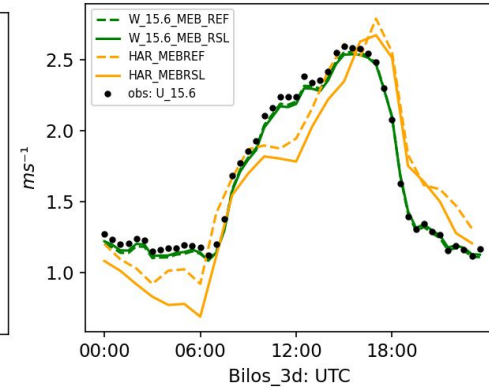
Challenges on the way

	Bilos	Norunda	Hyltemossa	Svartberget
ICOS_Tree h (offline surfex)	9.5	25	14.56	20
Harmonie Tree_height (ECOSG or max value: 12.3m)	12.3	20	10.0	20
ICOS LAI (offline SURFEX)	2.75	2.75	4.5	3.4
ECOSG 2.5km LAI for Aug,1 P2	2.2	3.5	3.0	2.9

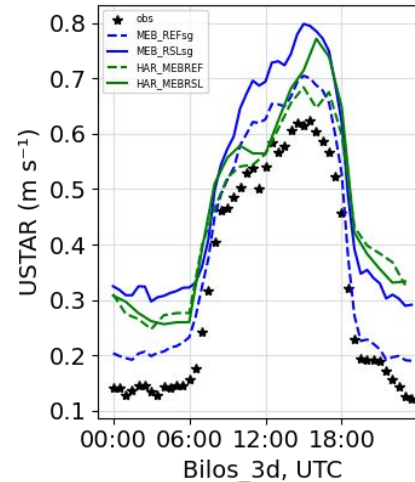
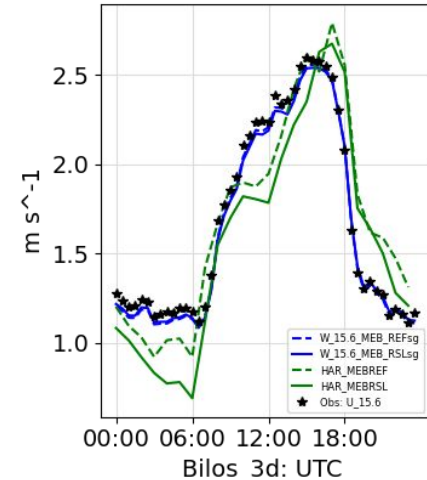
- Prove of the assumption: rerunning the 1-d offline simulations by using the wrong values from ECOSG

Challenges on the way

- Indeed, wind stays same (forcing), but momentum flux (friction) increases as in the online simulations



The rerun
(blue lines):



Summary and discussion points

- **By adding increased physical details in the classical similarity coupling scheme over a vegetated surface, the present work improves the surface-atmosphere coupling in HARMONIE-AROME**
 - Nocturnal H, 2mT, as well as 10mWS overall
 - Dynamical vegetation roughness (z_0 , d)
- **The study reveals a few important questions about the differences between the offline and online coupling due to:**
 - counter-gradient flow: we can ignore this process but it seems relevant
 - effects of inaccurate physiography data: presented were already some improvements on LAI

Acknowledgments

Thank you for your attention!

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