Testing the roughness sublayer in SURFEX: Implications for vegetation-atmosphere coupling in Harmonie-Arome

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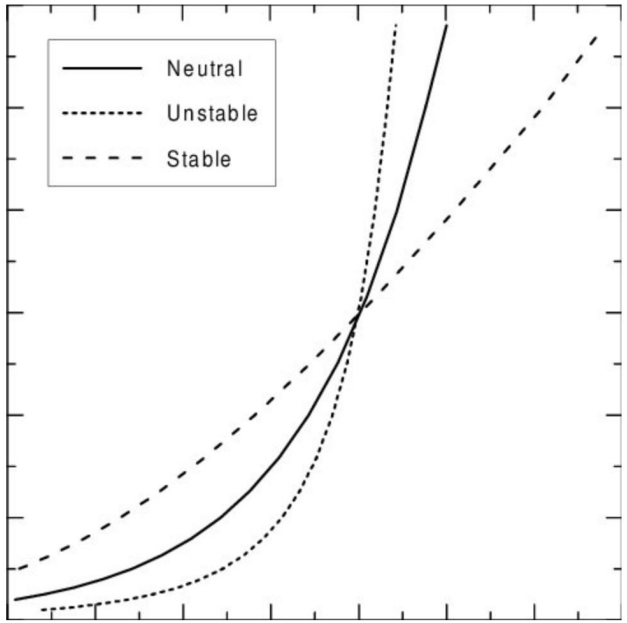
Outline

- MOST and RSL (Harman & Finnigan 2007) recap
- Methodology for RSL validation in SURFEX
- RSL validation in SURFEX OFFLINE
- RSL validation in coupled mode: Harmonie-Arome
- Summary and future work

Monin-Obukhov similarity theory (MOST)



$$\frac{kz}{\varphi_*}\frac{d\varphi(z)}{dz} = \phi_\varphi(\zeta)$$

Diagnostics

Fluxes

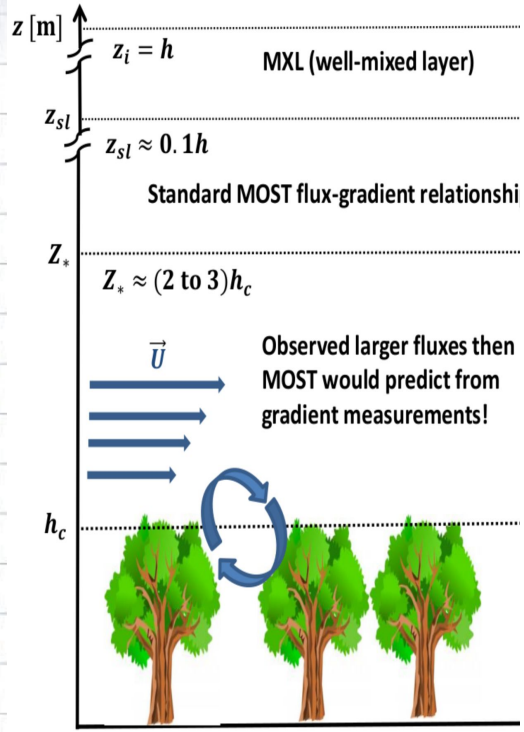
$$u_z = \frac{u_*}{\kappa}\left[\ln\left(\frac{z-d}{z_0}\right) + \psi(z, z_0, L)\right]$$

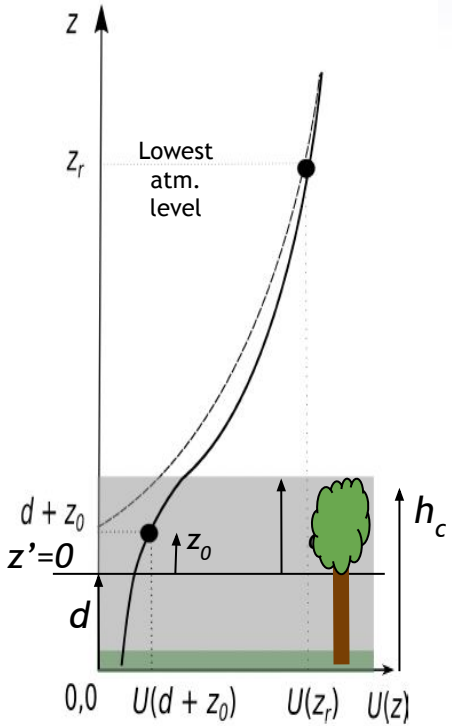
$$\tau_0 = \rho C_D U^2 = \rho k^2 [ln(z/z_0) - \psi_m(\zeta)]^{-2} U^2$$

$$H = \rho_a c_p C_H V_a (T_s - T_a)$$

- Simple and effective scaling law for the surface layer.
- Multiple purposes (NWP, climate modelling, etc):
  - Diagnostics / profiles of wind or scalars.
  - Evaluation of turbulent fluxes: SEB, etc.
- ϕ: universal *dimensionless gradients* in the surface layer, depend on the stability parameter $\zeta = z/L$, L=M-O length
- MOST is valid for heights larger than 2-3 times the canopy height
- With current vertical resolutions in NWP, the lowest atmospheric (coupling) level over tall canopies is often where MOST loses validity → **Need to represent the roughness sublayer (RSL) in land - surface modelling.**

Roughness sublayer (RSL) (Harman & Finnigan 2007, HF07)





$$\frac{kz}{\varphi_*}\frac{d\varphi(z)}{dz} = \phi_\varphi(\zeta)\,\hat{\phi}(\zeta, \delta_\omega)$$

- Original MOST flux-gradient relationships are modified by HF07 RSL functions ( ) to account for enhanced vertical mixing close to a (tall) canopy.
- RSL functions depend both on stability and canopy characteristics.
- d_t & z_0 (stability dependant displacement height and roughness lengths)
- RSL modifies drag coefficients in the surface layer (C_D,C_H,C_Q), which in turn modify turbulent momentum and heat exchanges with the atmosphere
- New T2m, Q2m, U10m interpolation considering *d* and using RSL-corrected dimensionless gradients:

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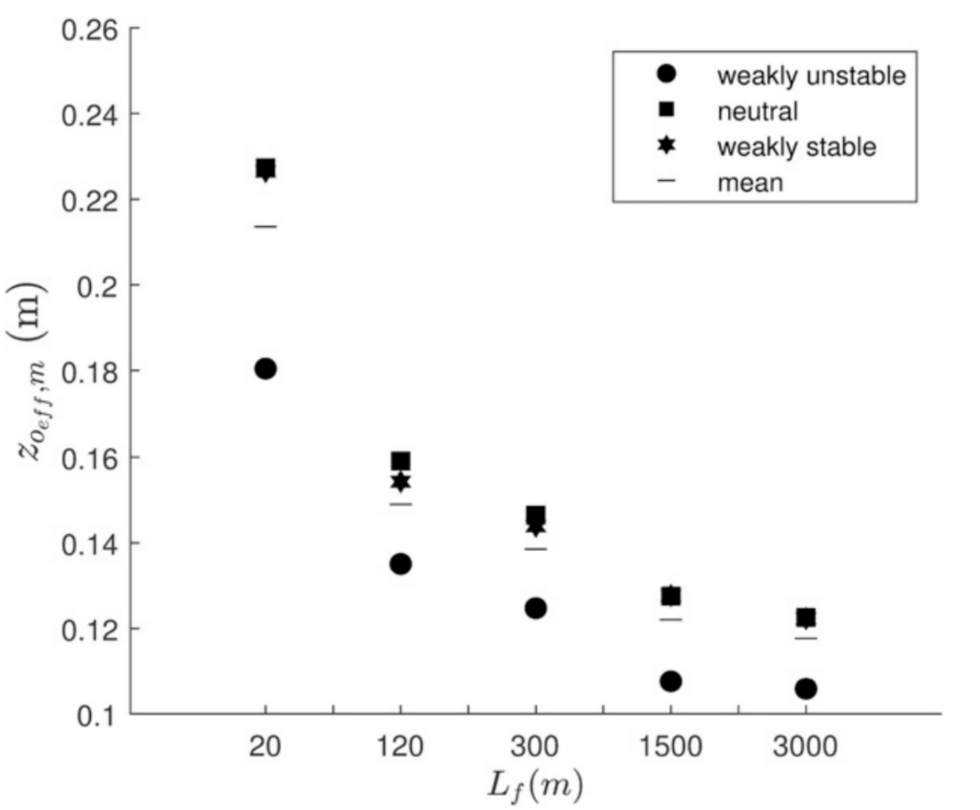

Janzon et al.(2023), J.Appl. Met. & Clim. 62(4),511-527

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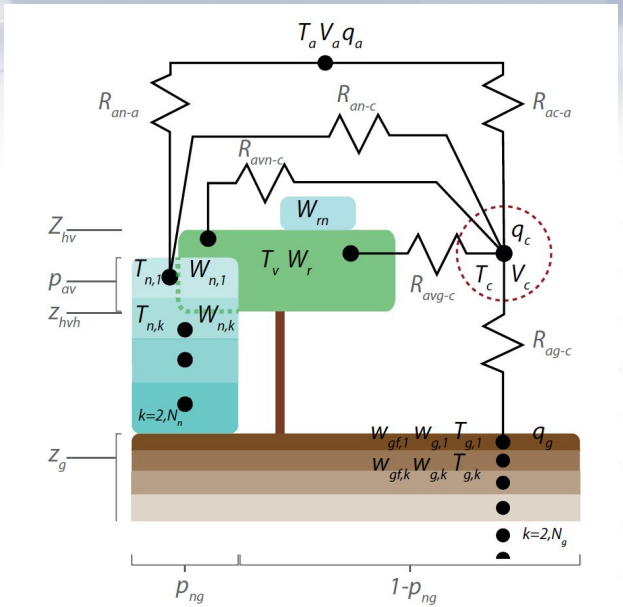
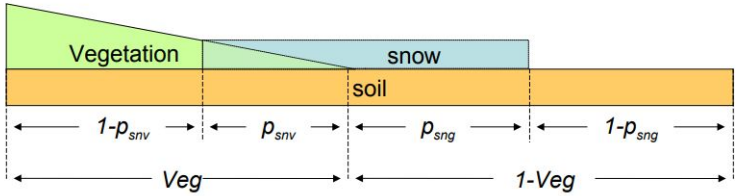
RSL in SURFEX

- **We implemented RSL in ISBA (land surface component of SURFEX), both for composite ISBA (traditional configuration) and ISBA-MEB**
- **We have tested it mainly in the forested tile (patch), but can also be activated in the low-vegetation patch.**



- ISBA: Single energy balance for the combined soil–vegetation surface system, and single composite surface temperature, no displacement height (*d*) considered
  FR: Force Restore approach, 3 layer soil.



- ISBA-MEB: Separate energy budgets for vegetation, soil & snow. Separate ground, canopy and snow temperatures, *d* considered
  DIF: Diffusive equations for (up to 14) soil layers.

Methodology for RSL validation in SURFEX

OBSERVATIONS: 4 Forest stations from the ICOS network: Temperature, Wind, humidity… + turbulent & radiation fluxes at different levels

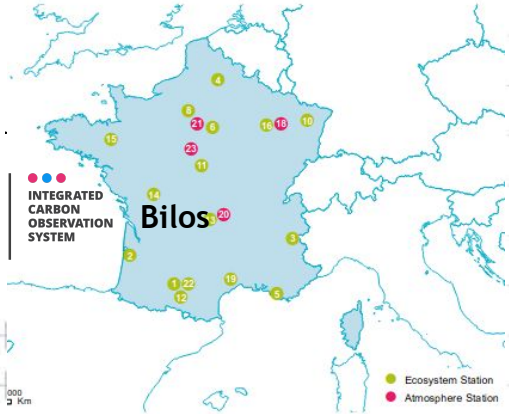
Common warm-up (15d) & simulation period: 15/08/2021 to 15/09/2021

OFFLINE RUNS

Model version: SURFEX8.1_NWP. Single point simulations.
Atmospheric forcing from the ICOS stations:
U,T at different forcing heights from 15.6 (Bilos) to 70m (Hyltemossa)
Physiography (tree height, LAI…) from ICOS metadata
FR_REF / FR_RSL= ISBA-FR, 1 single forest patch
MEB_REF / MEB_RSL = ISBA-DIF_MEB, 1 single forest patch

COUPLED RUNS

Model version: HAMONIE-AROME CY46, ISBA-DIF/MEB, no DA.
2 domains: Iberia & MetCoop,
2 patches: P1: bare soil/low veg, P2: forests
BCs: ECMWF (IFS). 65 vertical levels (coupling ~12-14m)
Physiography: ECOCLIMAP-SG
HAR_MEBREF / HAR_MEBRSL (RSL active in both patches)

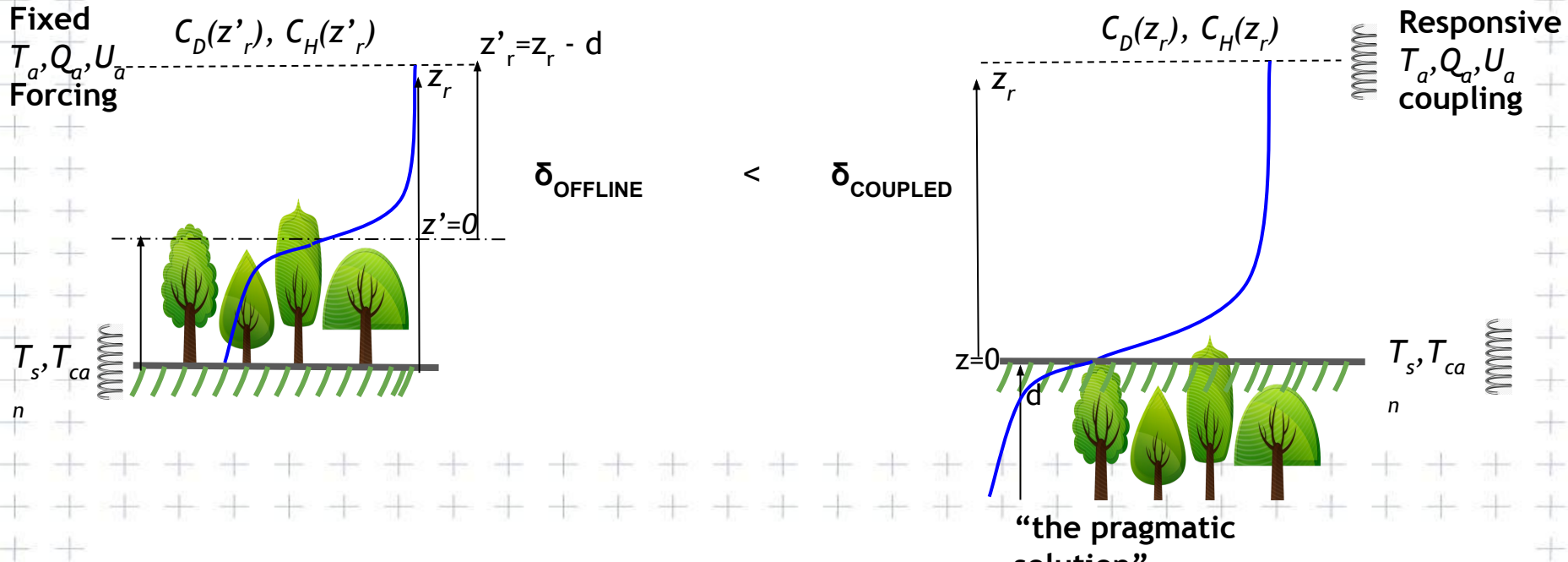


Analysis: Extract (offline runs) or interpolate (coupled runs) relevant SURFEX variables at the 4 ICOS sites. Compare the impact of RSL in average diurnal cycles of fluxes, diagnostics, stability parameters, etc. , and also plot some scatterplots

Surface coupling in surface layer schemes using *d*

OFFLINE: C_D, C_H evaluated for the *shifted* reference system z'_r.

COUPLED: C_D, C_H evaluated for reference system z_r.



RSL validation in SURFEX offline

OFFLINE RUNS

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Atmospheric forcing from the ICOS stations:
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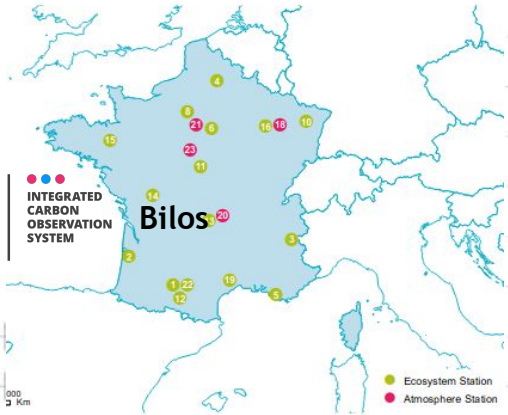
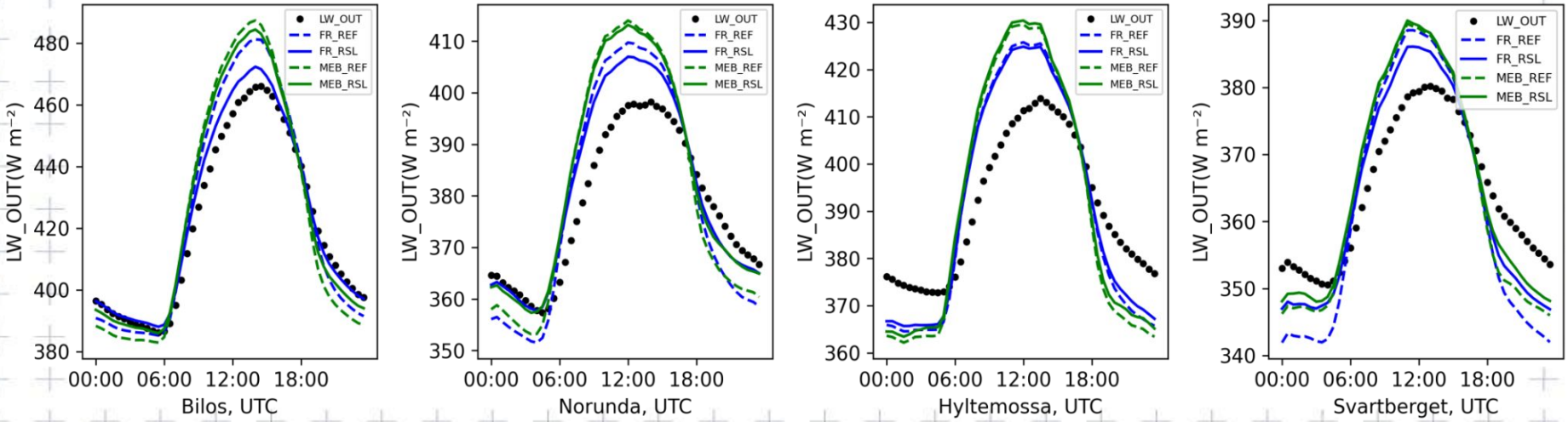
ICOS INTEGRATED CARBON OBSERVATION SYSTEM

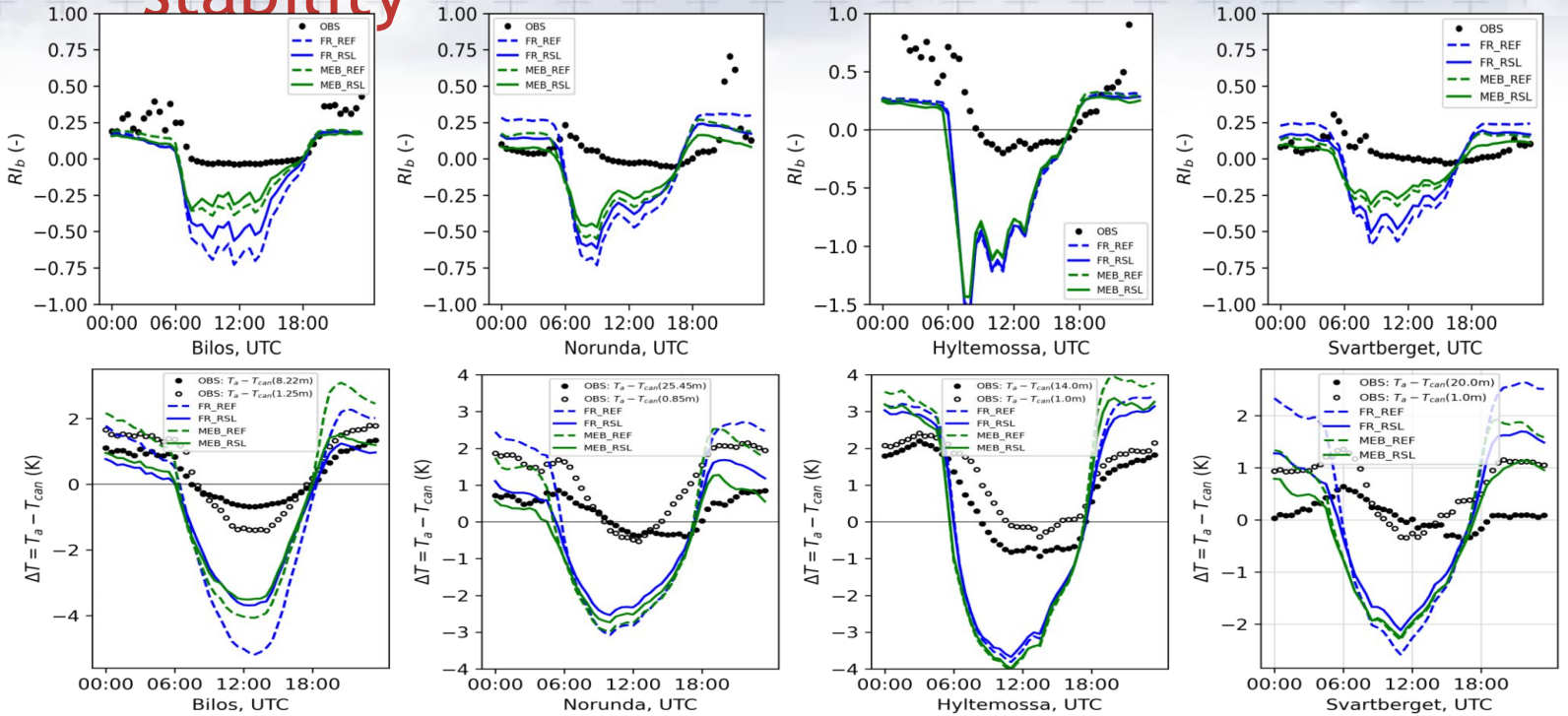


OFFLINE: Validation of radiation components

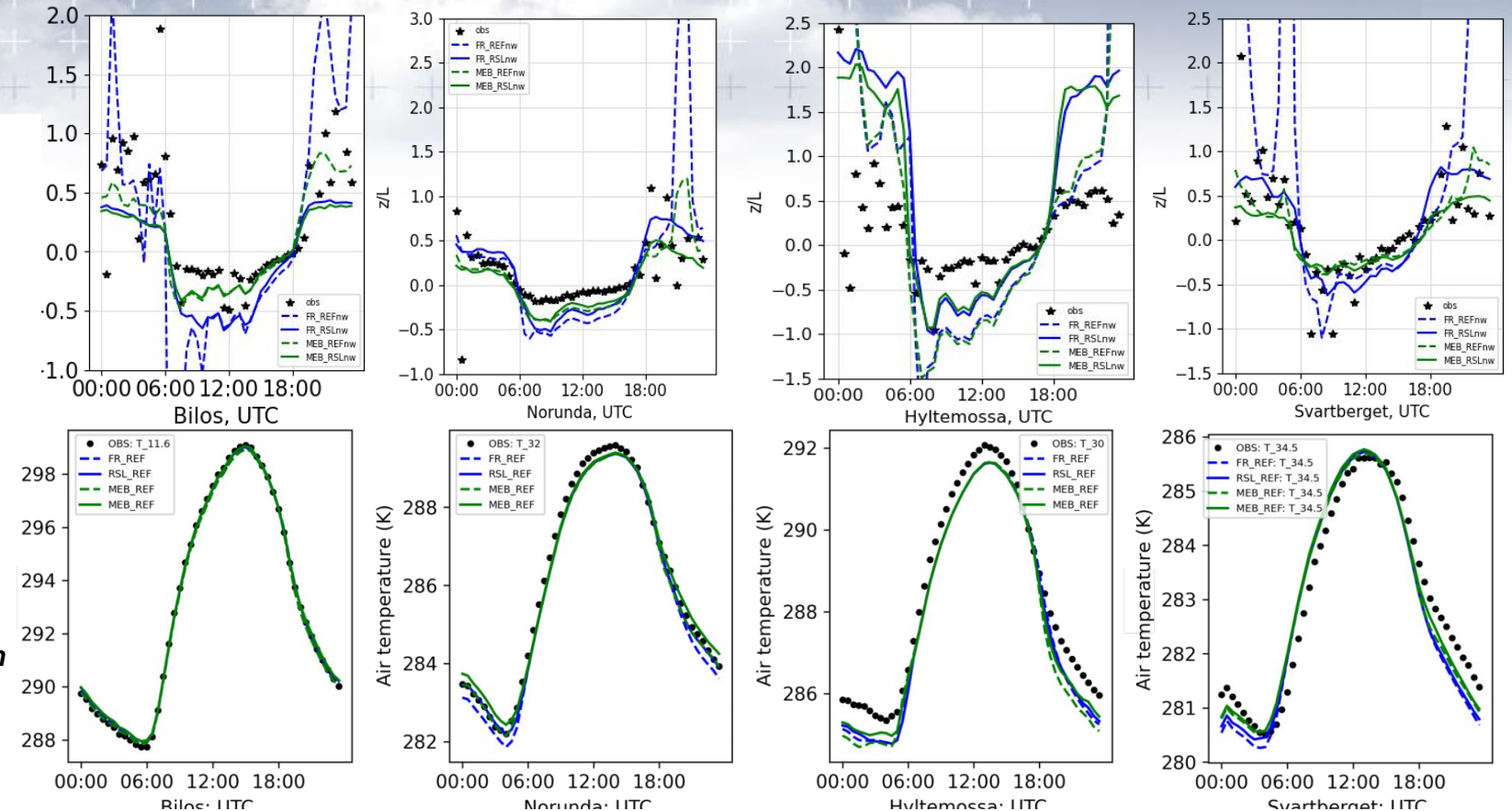
- SW_OUT (not shown) is well represented at all sites (surface albedo is prescribed from field data)
- LW_OUT improves consistently in **RSL** runs, indicating a better representation of surface temperatures, surface-atmosphere temperature gradient and the surface layer stability when **RSL** is active.



OFFLINE: Surface layer stability

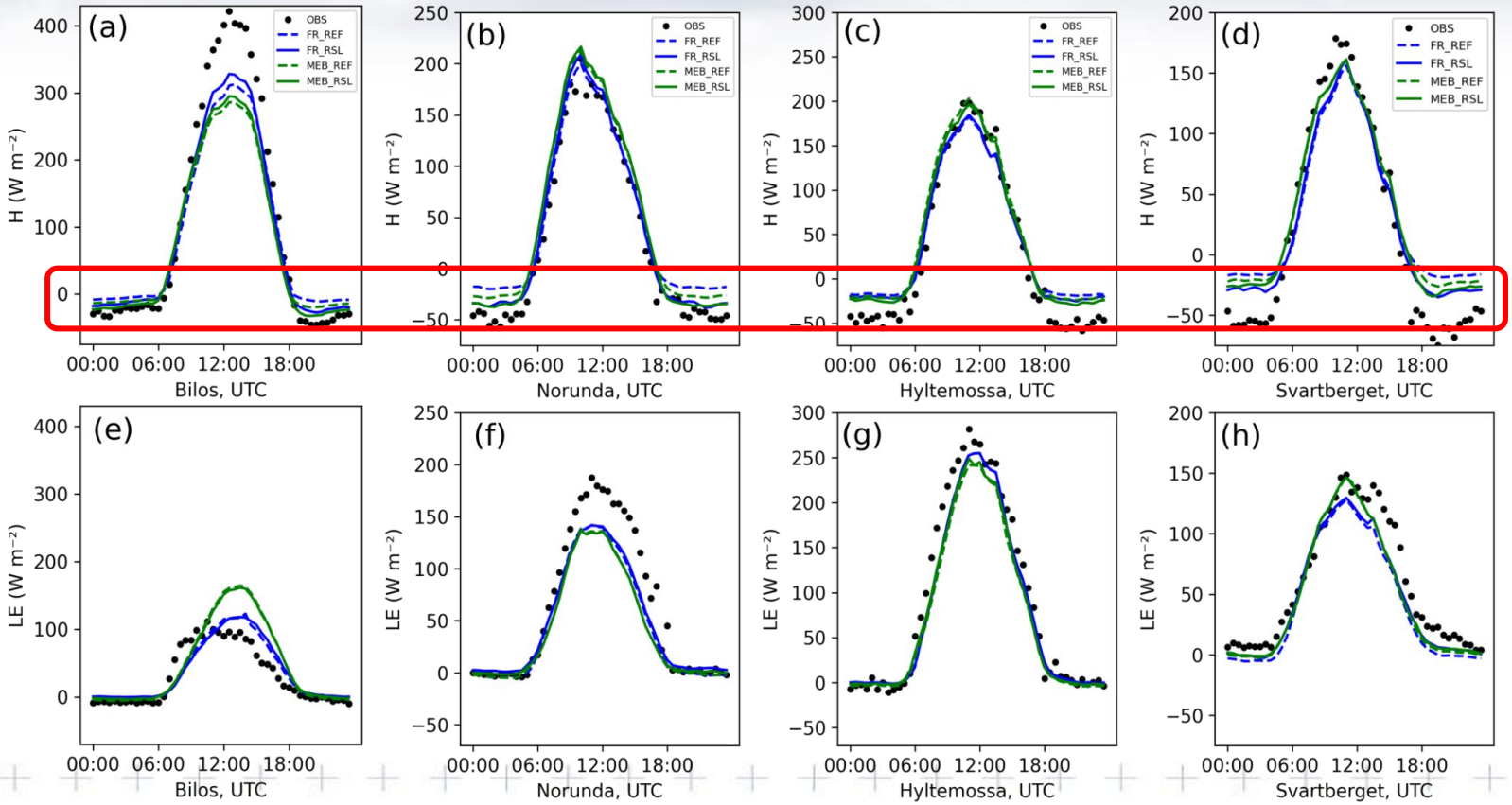


- Diurnal instability is overestimated at all sites.
- **RSL** runs improve canopy / surface temperatures at most periods and sites (specially daytime), leading to better *Ri* and outgoing longwave (previous slide)

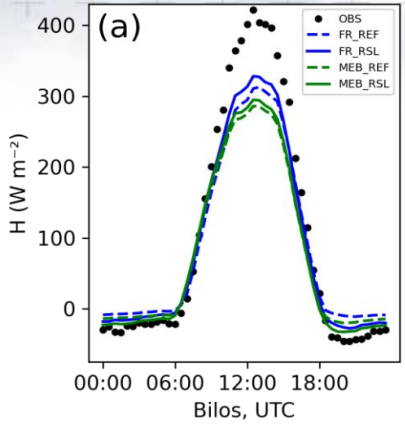


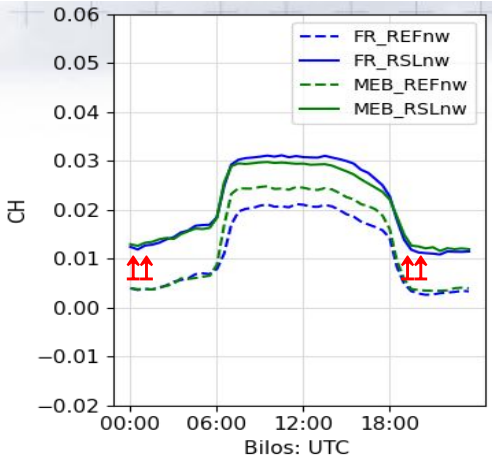
- z/L improves during daytime in RSL runs.
- Small or no impact in temperature diagnostics (in spite of improvement in T_s or T_{can})

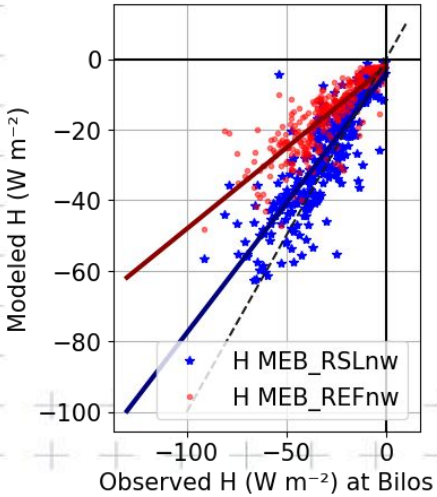
OFFLINE: sensible and latent heat fluxes

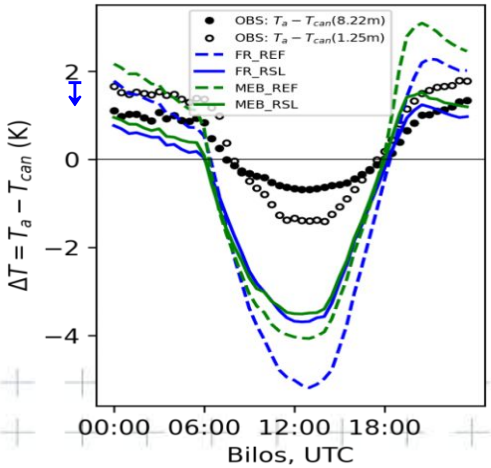


OFFLINE: Sensible heat flux





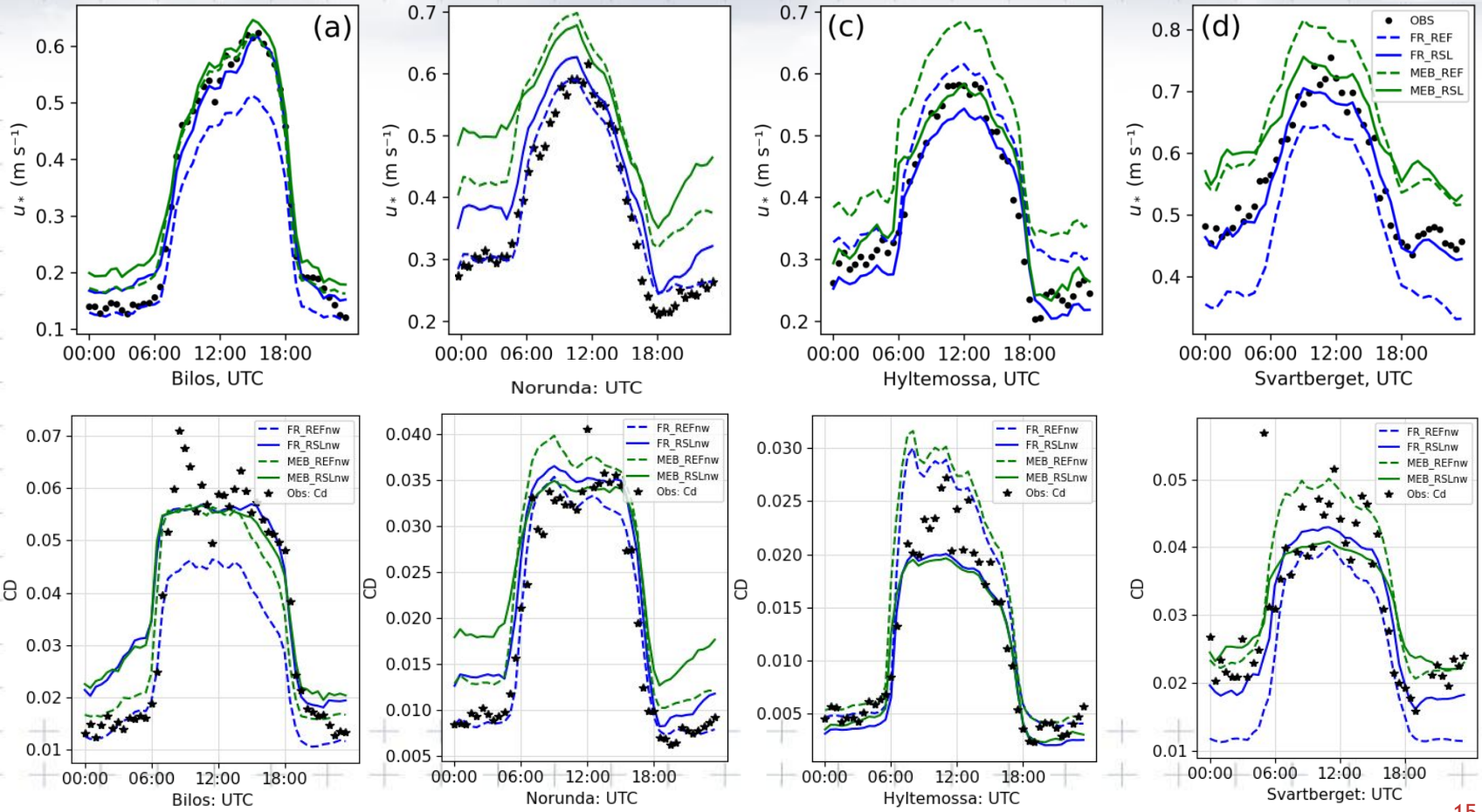




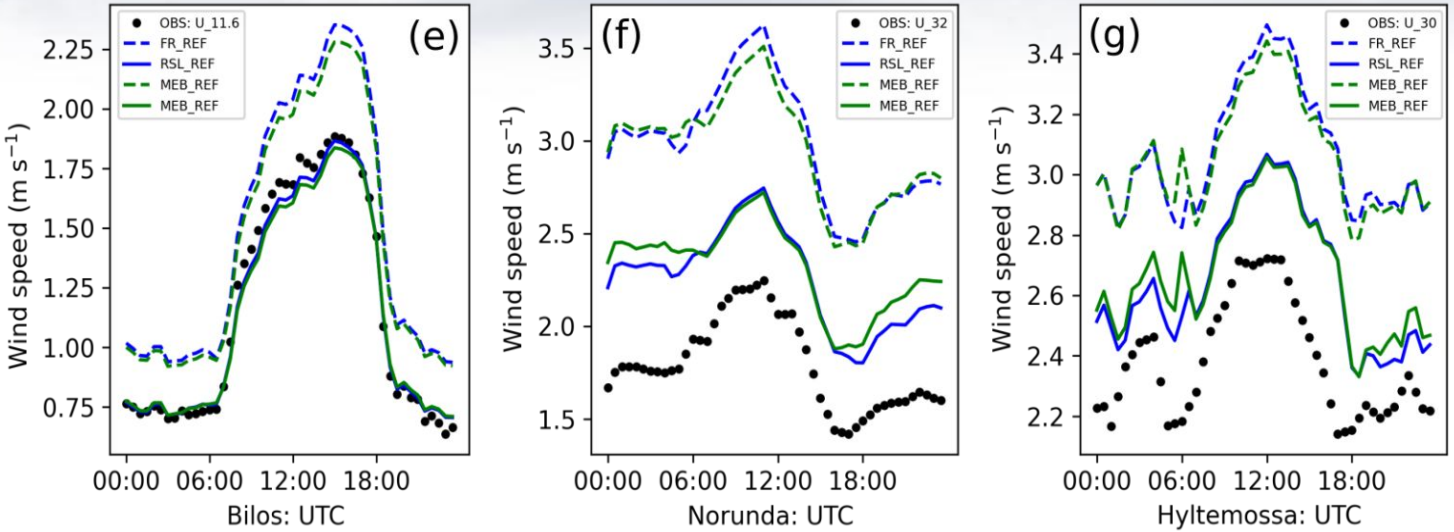
- The scatterplots show that at Bilos, the nighttime improvement of H is stronger.
- Forcing height at Bilos (15.6m) is closer to the canopy top (9.5m), i.e. **RSL** corrections are more important.
- C_h increase due to **RSL** is larger, which tends to decrease (T_s-T_a) gradient, but the increase in C_h prevails.

$$H = \rho_a c_p C_H V_a (T_s - T_a)$$

OFFLINE: C_D, U_*


(a)
(c)
(d)
OBS
FR_REF
FR_RSL
MEB_REF
MEB_RSL
u_* (m s^{-1})
Bilos, UTC
Norunda: UTC
Hyltemossa, UTC
Svartberget, UTC
FR_REFnw
FR_RSLnw
MEB_REFnw
MEB_RSLnw
Obs: Cd
CD
Bilos: UTC
Norunda: UTC
Hyltemossa: UTC
Svartberget: UTC
00:00
06:00
12:00
18:00

OFFLINE: Wind speed diagnostics



- As expected, increased mixing in the RSL decreases wind speed.
- Wind speed diagnostics improve significantly due to:
  - Corrected shape of similarity functions ($\phi_\varphi(\zeta)\ \hat{\phi}(\zeta, \delta_\omega)$) leading to better estimations of C_D and U_*
  - Use of displacement height *d* in the interpolation formulas.

Summary from offline runs

- The impact of RSL in *H* & *LE* is small, but there's a consistent relevant decrease in the nighttime bias of sensible heat flux
- U_* compares better with observations at all sites, due to the presence of the stability dependant *d* and z_0
- The RSL wind diagnostic above forests improve currently available diagnostics in SURFEX. Improvement in temperature diagnostic is more limited.
- Surface stability conditions and canopy/surface temperatures are also better represented with RSL scheme.

RSL validation in Harmonie - Arome

COUPLED RUNS

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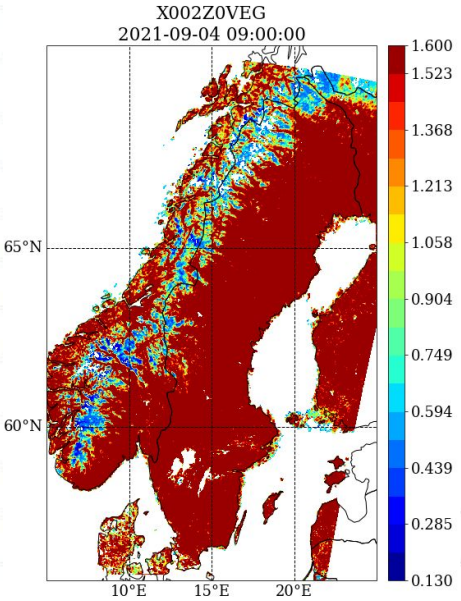
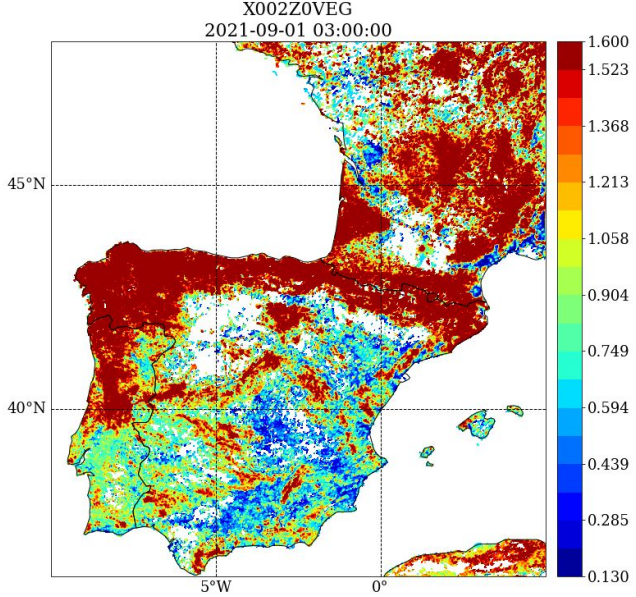
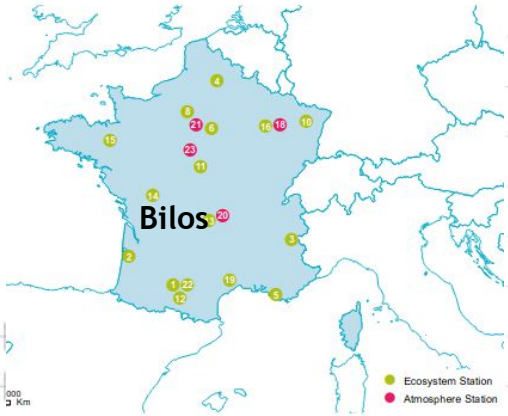
- 2 domains: Iberia & MetCoop,
- 2 patches: p1: bare soil + low veg, p2: forests
- BCs: ECMWF (IFS). 65 vertical levels (coupling ~12m)
- Physiography: ECOCLIMAP-SG
- HAR_MEBREF / HAR_MEBRSL (RSL active in both patches)







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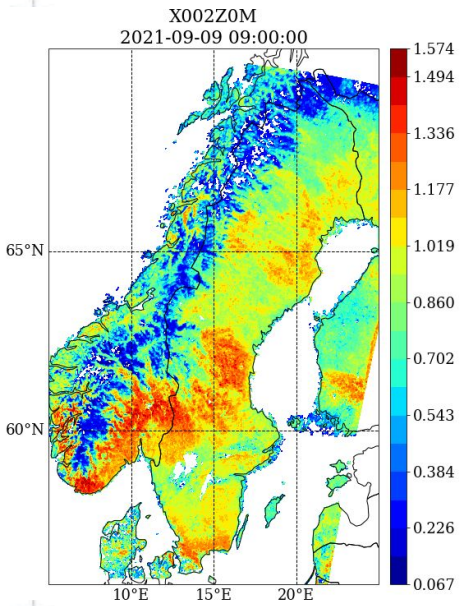
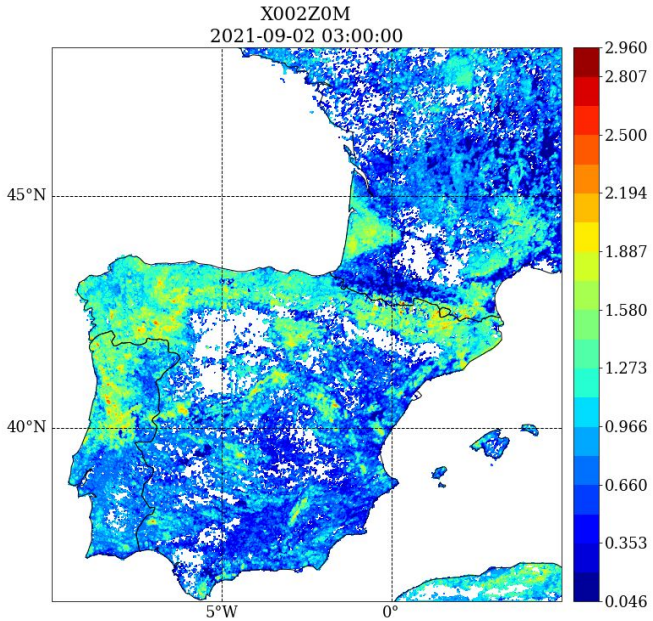
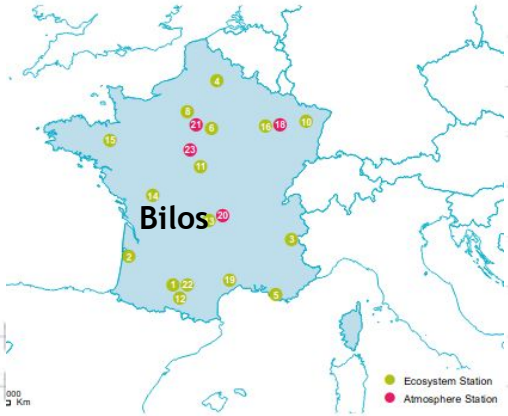
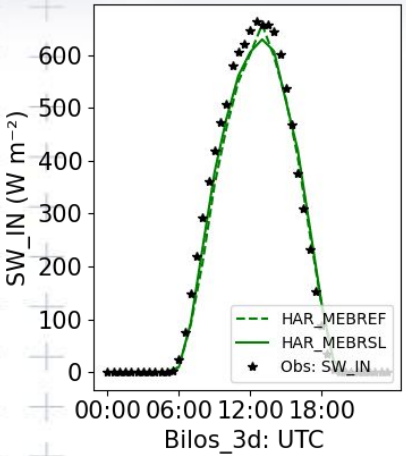
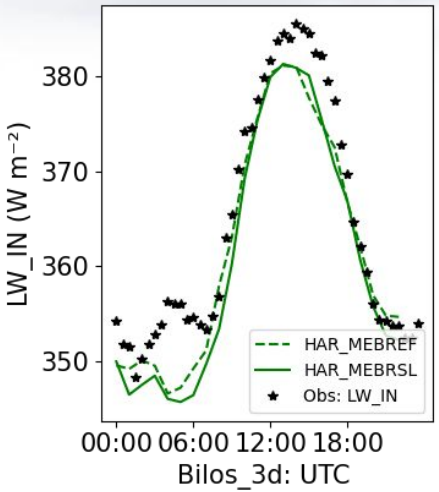


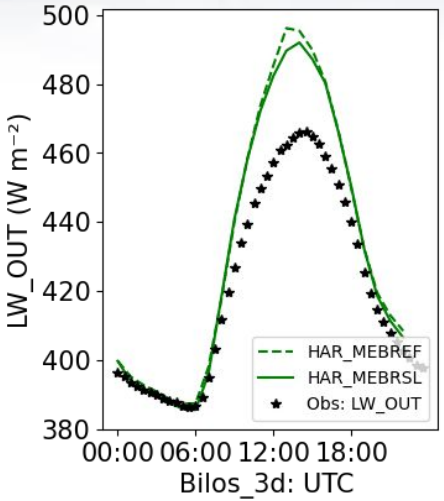


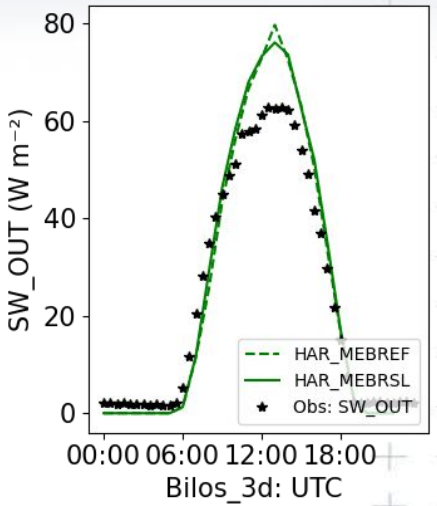


COUPLED:Validation of radiation components









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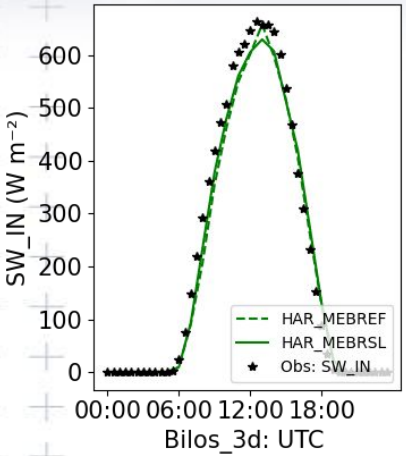
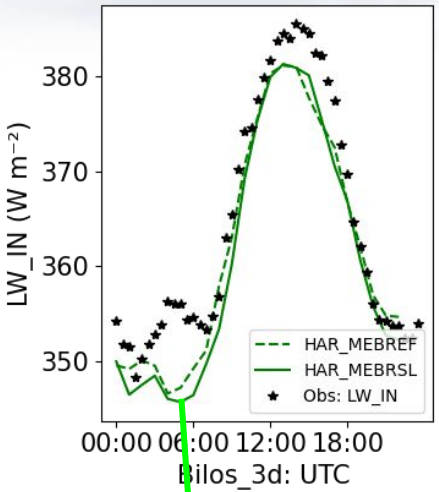
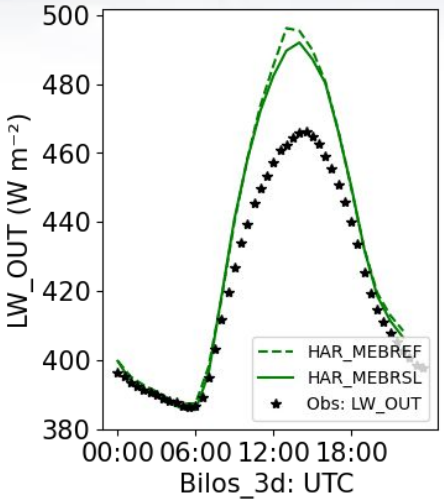
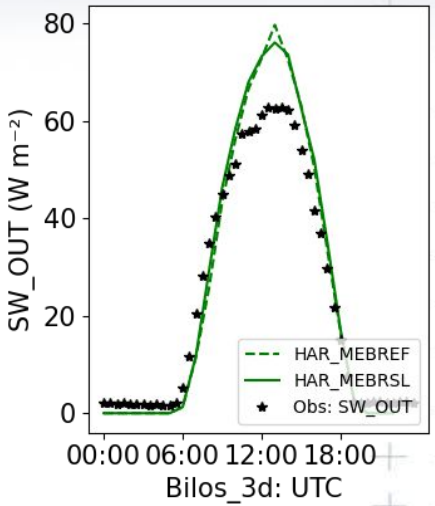
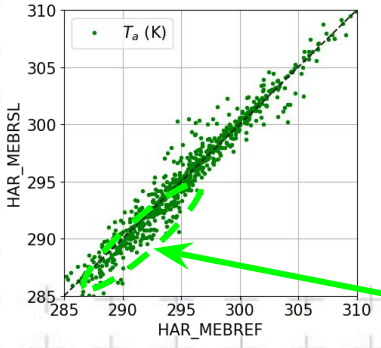
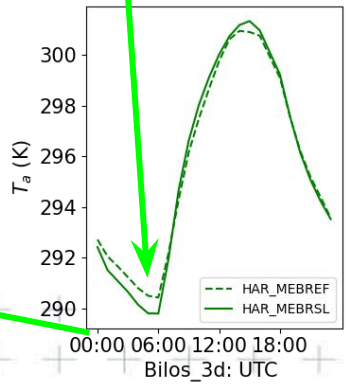






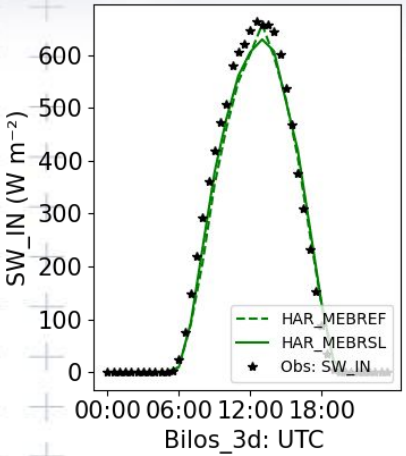


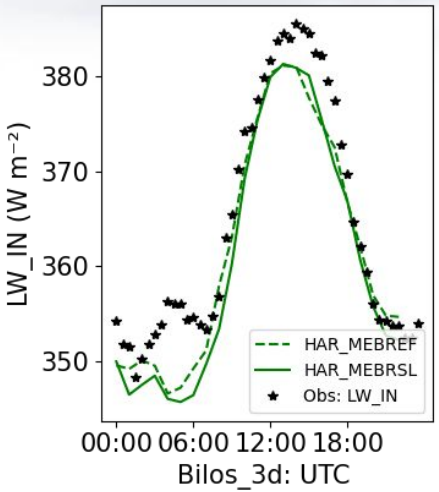


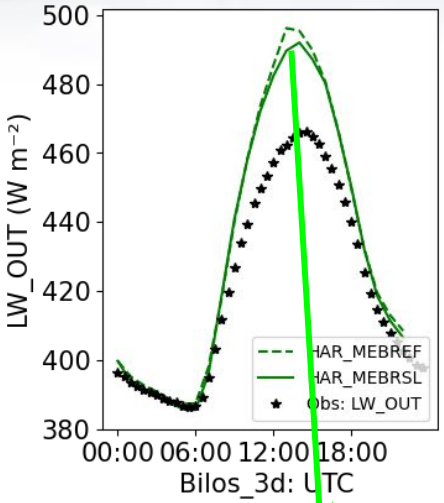


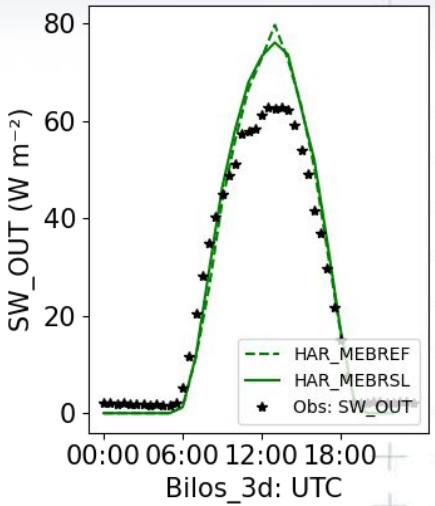
- **Nocturnal cooling in the lower atmospheric (coupling) level**

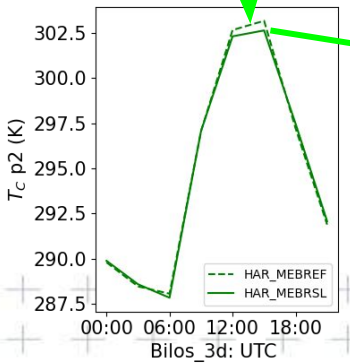
COUPLED:Validation of radiation components

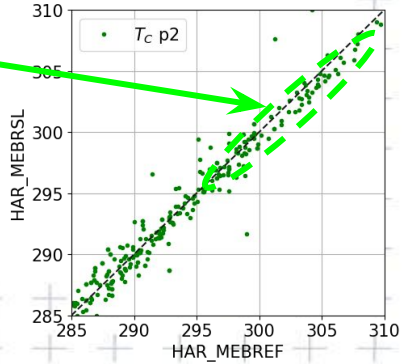






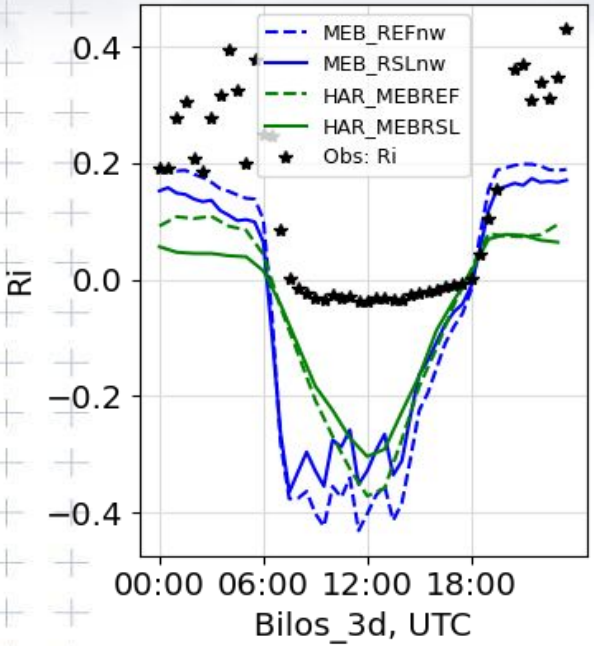


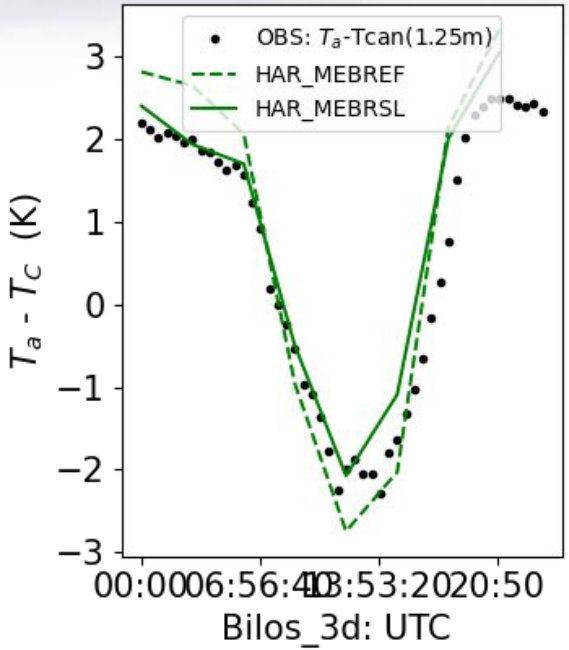


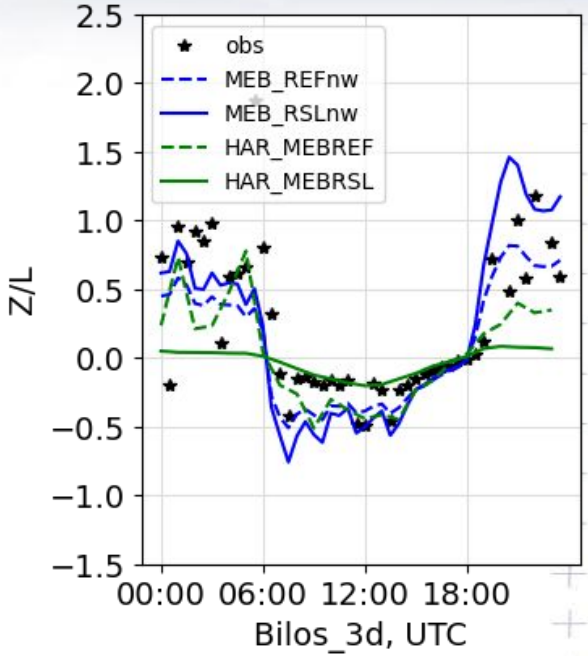


- **Diurnal cooling in canopy temperatures**

COUPLED vs OFFLINE: Surface layer stability

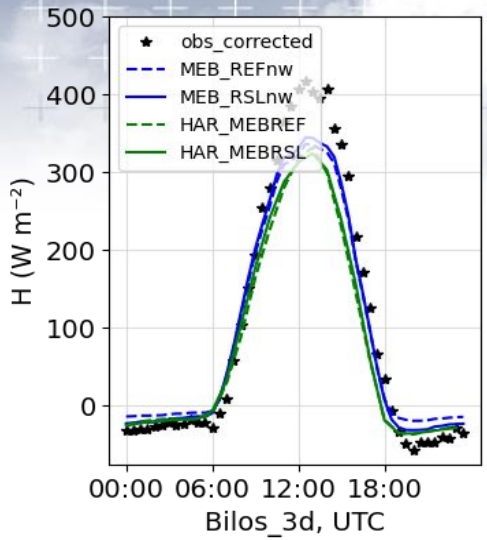


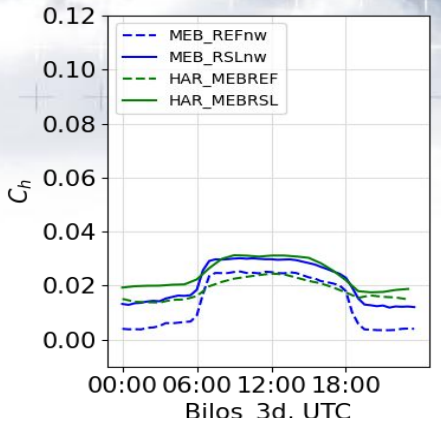




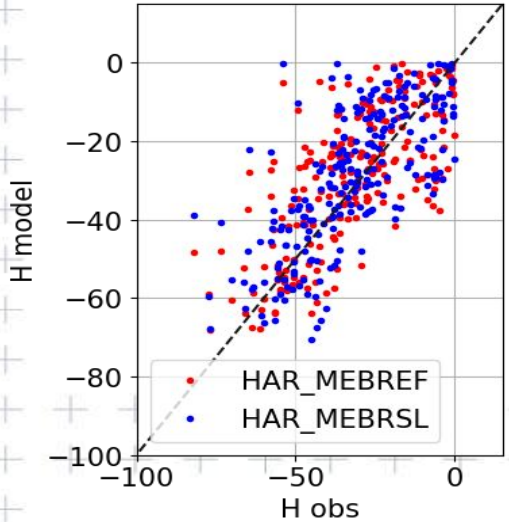
- Diurnal instability overestimated; **RSL** helps to compensate (*Ri* and *z*/*L* closer to observations)
- Issue with nocturnal period, where offline runs showed better results.

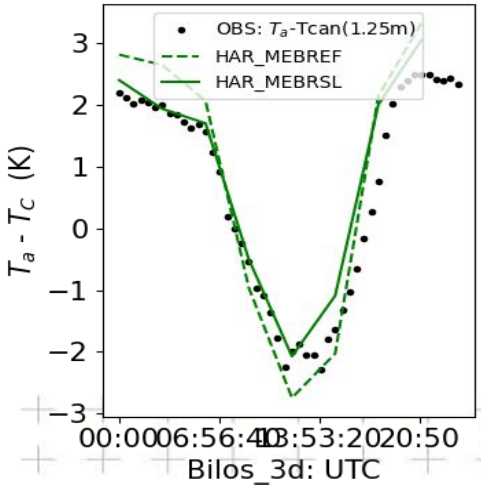
COUPLED: H





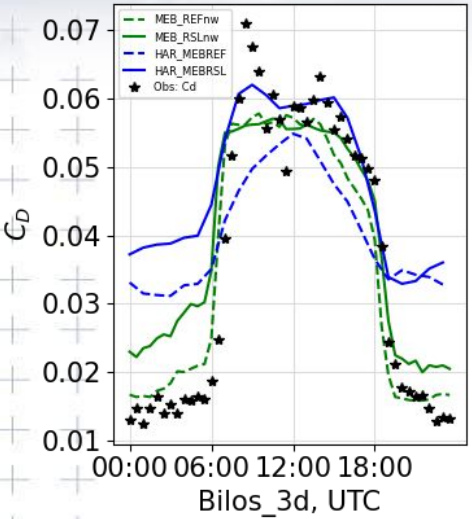
$$H = \rho_a c_p C_H V_a (T_s - T_a)$$

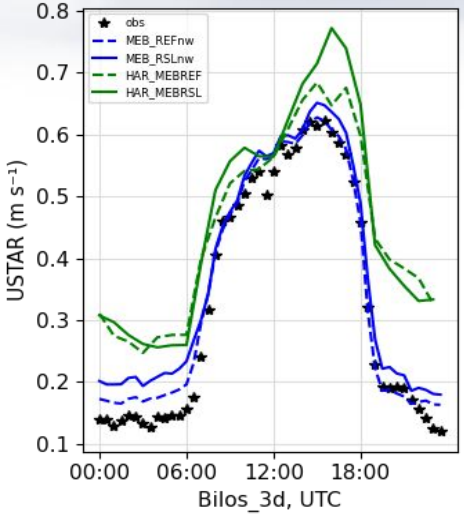


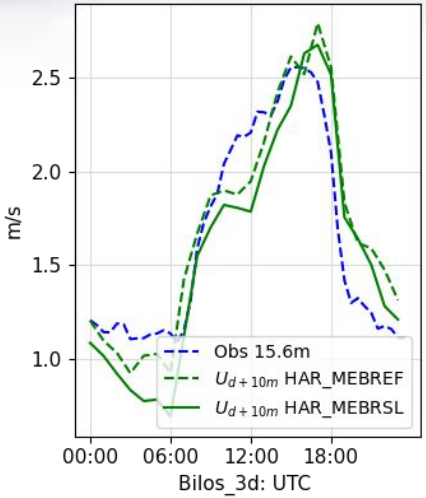


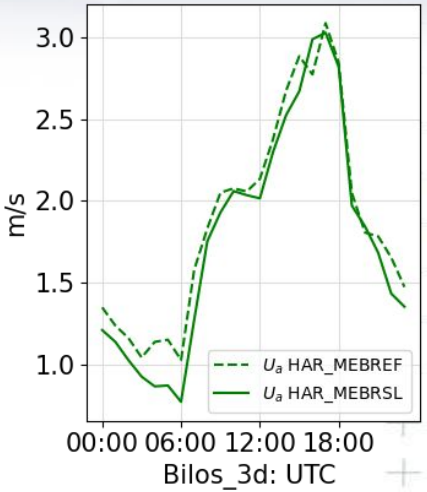
- Coupled runs shows no nighttime improvement of H at Bilos.
- In coupled mode, C_h increase is lower (and is compensated by decrease in $(T_s\text{-}T_a)$).
- This is related to the larger thickness of the coupling layer ($\delta_{COUPLED} > \delta_{OFFLINE}$), i.e. the lower atmospheric level is further away from the canopy top than in the offline run.

COUPLED: C_D, U_*, U_{d+10m}, U_a



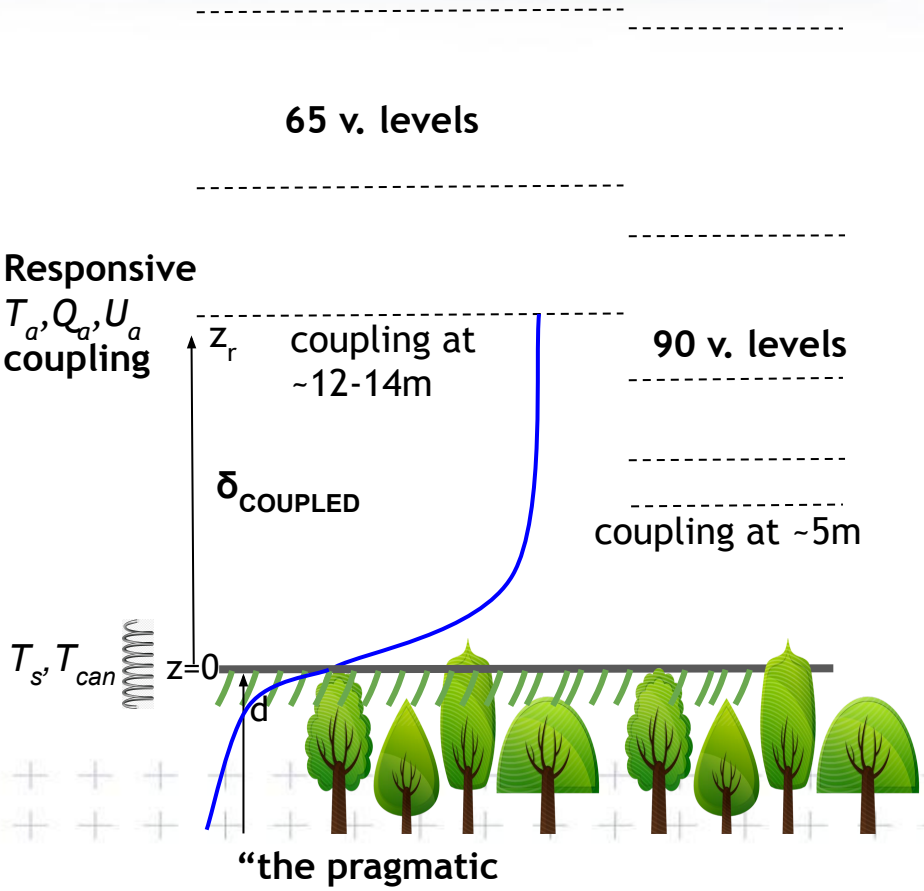






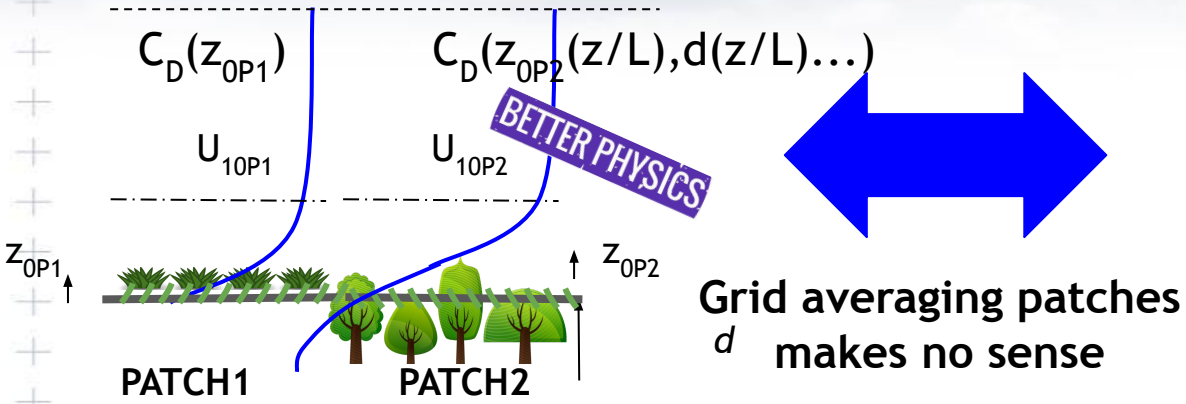
- RSL increases C_D as in OFFLINE, but this has less impact increasing U_*
- Also less impact in decreasing W_{10m} above canopy: interpolation profile without d.
- As with temperature, coupling wind is also affected by RSL.

Implications of increasing vertical resolution



- Currently the coupling height in Harmonie-Arome is ~12m (above *d*)
- How these results are affected by moving to higher vertical resolution (e.g. coupling layer at ~ 5m above *d*)?.

Adapting U_{10m}, T_{2m}, Q_{2m} diagnostics



Grid averaging patches d **makes no sense**

AWS are in clearings

- RSL makes **interpolation profiles are more realistic over forests**, but the grid averaging is still not well posed.
- <u>Efforts are planned at ACCORD level to adapt interpolation methods for current horizontal / vertical resolutions, i.e</u>:
  - "Blending height": Select and atm. level far enough from the canopy and interpolate U_{10m} considering z_0 for grassland.
  - Find a more clever way of averaging tiles in diagnostics (consider forest footprint, gridpoint heterogeneity, etc).

Summary & future work

- HF07's RSL fixes MOST over forests by accounting for the impact of tall canopies in the flow and the surface fluxes.

- Drag coefficients and diagnostics with HF07 RSL are evaluated from z/L instead of f(Ri); improves the flux-gradient relationships in stably-stratified conditions.

- Activation of RSL in SURFEX helps to better represent surface stability and canopy temperatures.

- OFFLINE runs show positive impact in drag coefficients, friction velocity, and specially sensible heat flux and wind speed diagnostics.

Summary & future work

- ONLINE coupling follows in general the behaviour of the OFFLINE control for Bilos, but improvements are smaller i.e. in coupling variables (fluxes).

- This is mainly explained by the different reference system, the increase in degrees of freedom in coupled systems (i.e. sfc-atm feedback), and dropping *d* out of the interpolation formulas.

- Next steps:
  - Continue online validations (Norunda, Svartberget), also over PATCH 1.
  - Tuning the scheme to compensate for decreased performance in ONLINE.
  - Tests with 90 level configurations.

Takk!

Forest next to Kerid volcanic crater, south Iceland