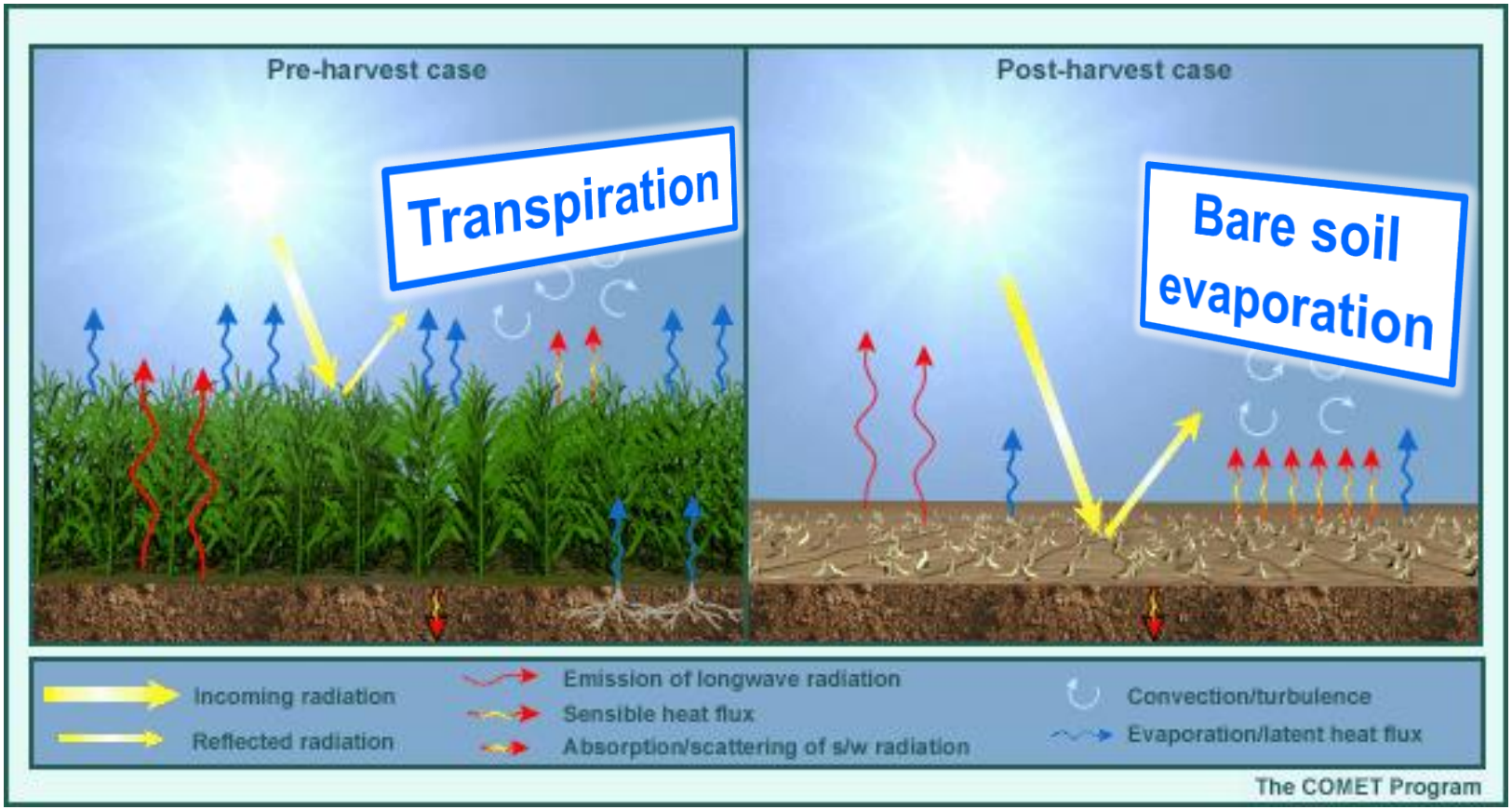
Improved processes in the land surface model TERRA: Bare soil evaporation und skin temperature

Jan-Peter Schulz[1] and Gerd Vogel[2]

[1]Deutscher Wetterdienst, Offenbach, Germany
[2]Deutscher Wetterdienst, Lindenberg, Germany

41st EWGLAM and 26th SRNWP Meeting, 30 Sep. - 3 Oct. 2019, Sofia, Bulgaria

What is bare soil evaporation?



The problem …

- The bare soil evaporation in TERRA is systematically overestimated under medium-wet to wet conditions.
- This creates a
  - dry bias in the soil,
  - moist bias of near-surface humidity,
  - cold bias of near-surface temperature (daytime),
  - reduced diurnal near-surface temperature range.
- The bare soil evaporation in TERRA is systematically underestimated under medium-dry to dry conditions.

Bare soil evaporation

based on the Biosphere-Atmosphere Transfer Scheme (BATS; Dickinson, 1984)

$$E_{bs} = \rho_w C_k D \frac{s_t}{(z_u z_t)^{1/2}}$$

ρ_w: density of water

s_u : average soil water content in upper $z_u = 0.09$ m

s_t : average soil water content in upper $z_t = 0.81$ m

Bare soil evaporation

based on the Biosphere-Atmosphere Transfer Scheme (BATS; Dickinson, 1984)

where C_k is calculated by

(11.18)

(11.19)

(11.20)

m and the fraction
depend on the soil

(11.21)

B_f is given by

$$B_f = 5.5 - 0.8B \left[1 + 0.1(B-4) log_{10} \frac{K_0}{K_R}\right] \quad , \qquad (11.22)$$

with $K_R = 10^{-5} m/s$.

The scheme was adapted, or tuned, to the two-layer land surface scheme (Jacobsen and Heise, 1982) of the former model generation. Apparently, this can not directly be transferred to the current multi-layer land surface scheme.

ρ_w: density of water

s_u : average soil water content in upper $z_u = 0.09$ m

s_t : average soil water content in upper $z_t = 0.81$ m

Bare soil evaporation

based on a resistance formulation analogue to Ohm´s law (for a review see e.g. Schulz et al., 1998)

$$E_{bs} = \rho \frac{1}{r_a + r_s} (q_v - q_{sat})$$

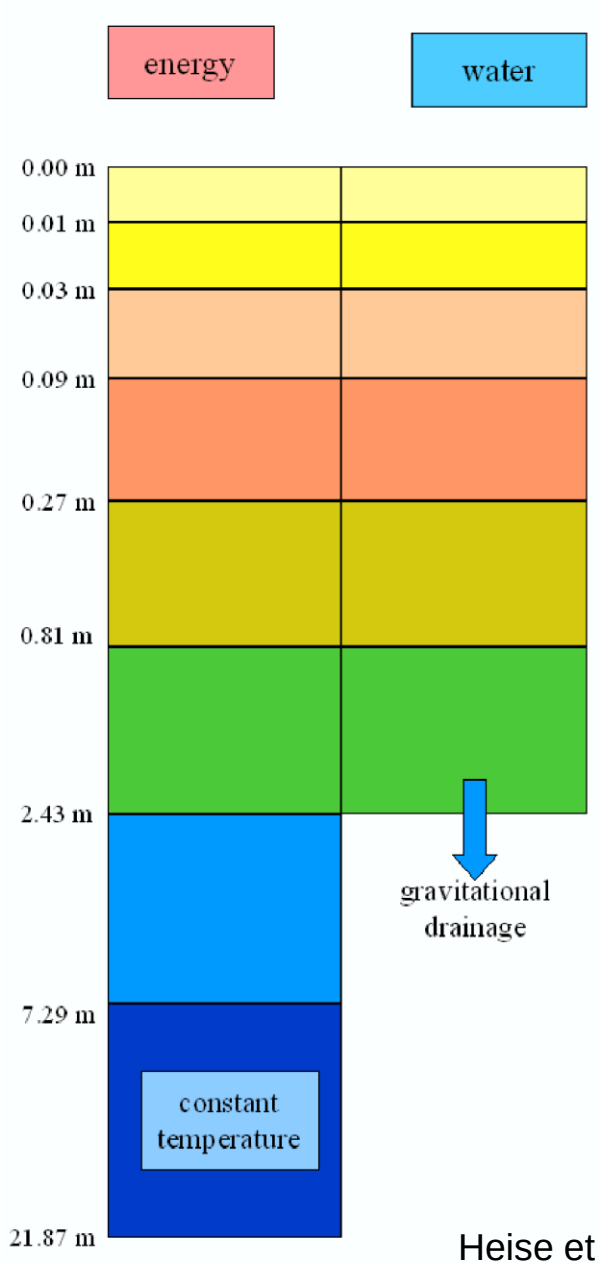
$$r_s = r_{s,\min} \left(\frac{\theta_1 - \theta_{\min}}{\theta_{\max} - \theta_{\min}} \right)^{-1}$$

ρ : density of air

q_v, q_{sat} : specific humidity of air, and saturation specific humidity at surface

r_a, r_s, $r_{s,\min}$: aerodynamic resistance, soil resistance, and minimum soil resistance

θ_1, $\theta_{\min}$, $\theta_{\max}$: volumetric soil water content of top layer, min. and max. value of θ



Heise et al. (2006)

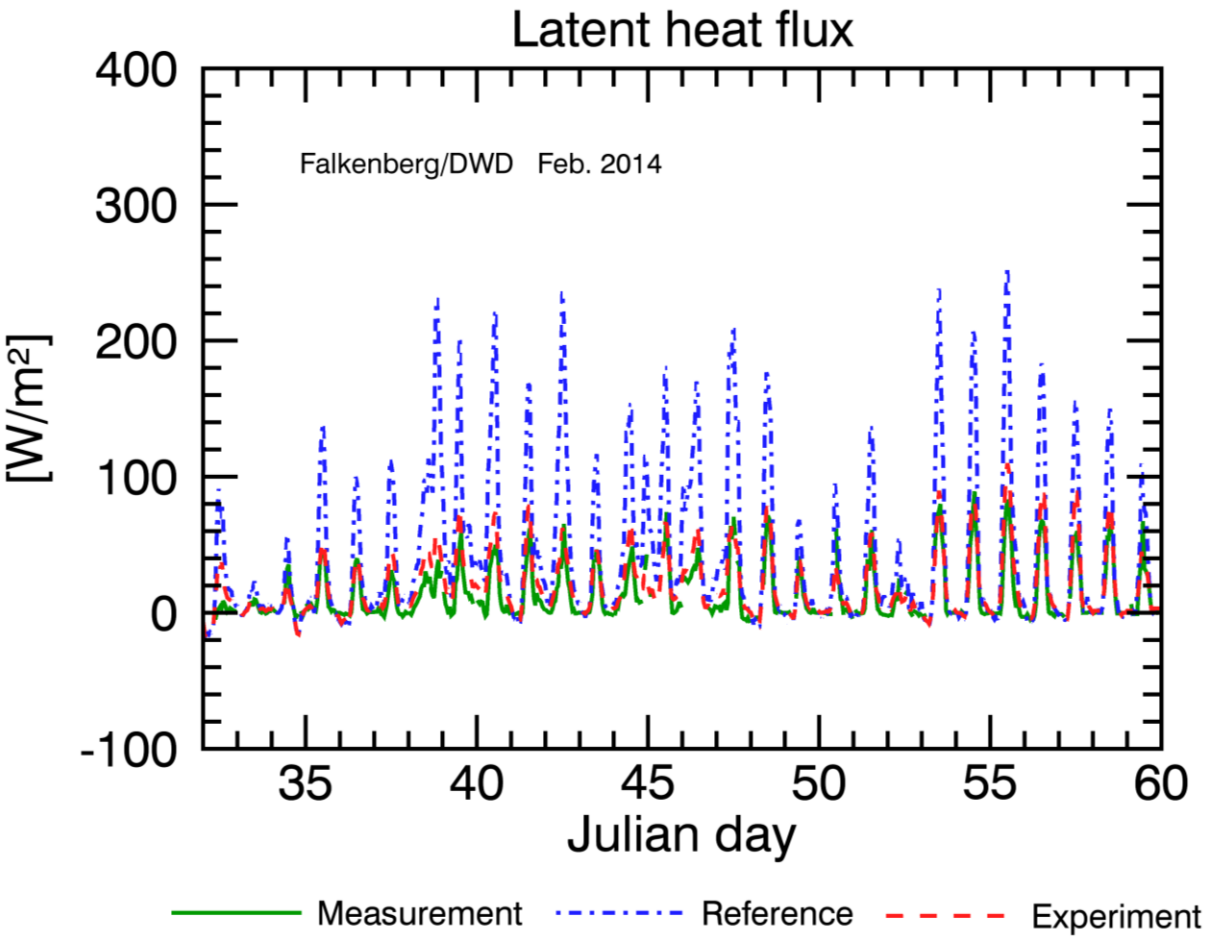
Land surface scheme TERRA

Layers for temperature and soil water content

Experiments:

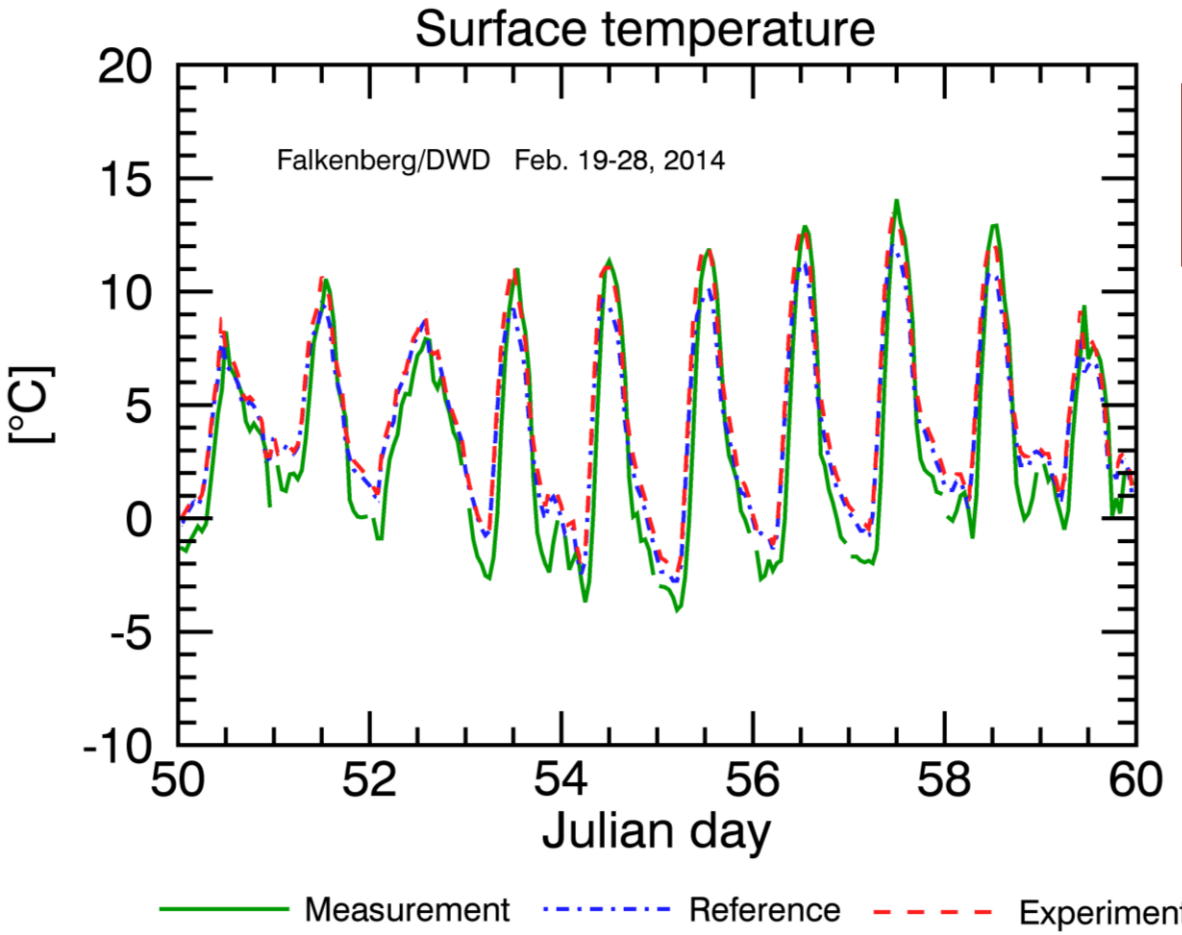
- Use atmospheric forcing to run TERRA in offline mode
- Here, observed forcing from DWD observatory Lindenberg is used (Falkenberg site)

- Reference : BATS
- Experiment : Resistance



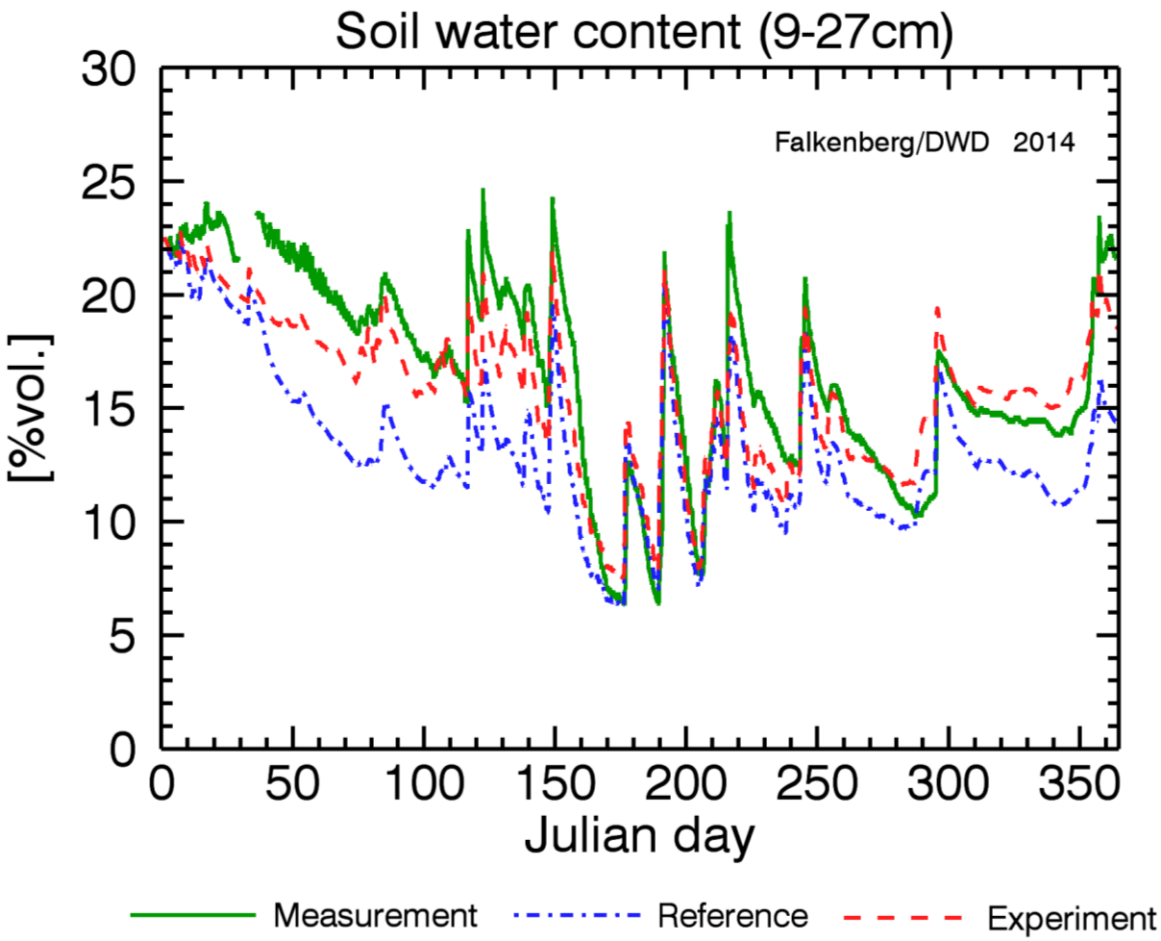
Feb. 2014

Reduced bare soil evaporation simulated by resistance method improves the total latent heat flux substantially compared to BATS



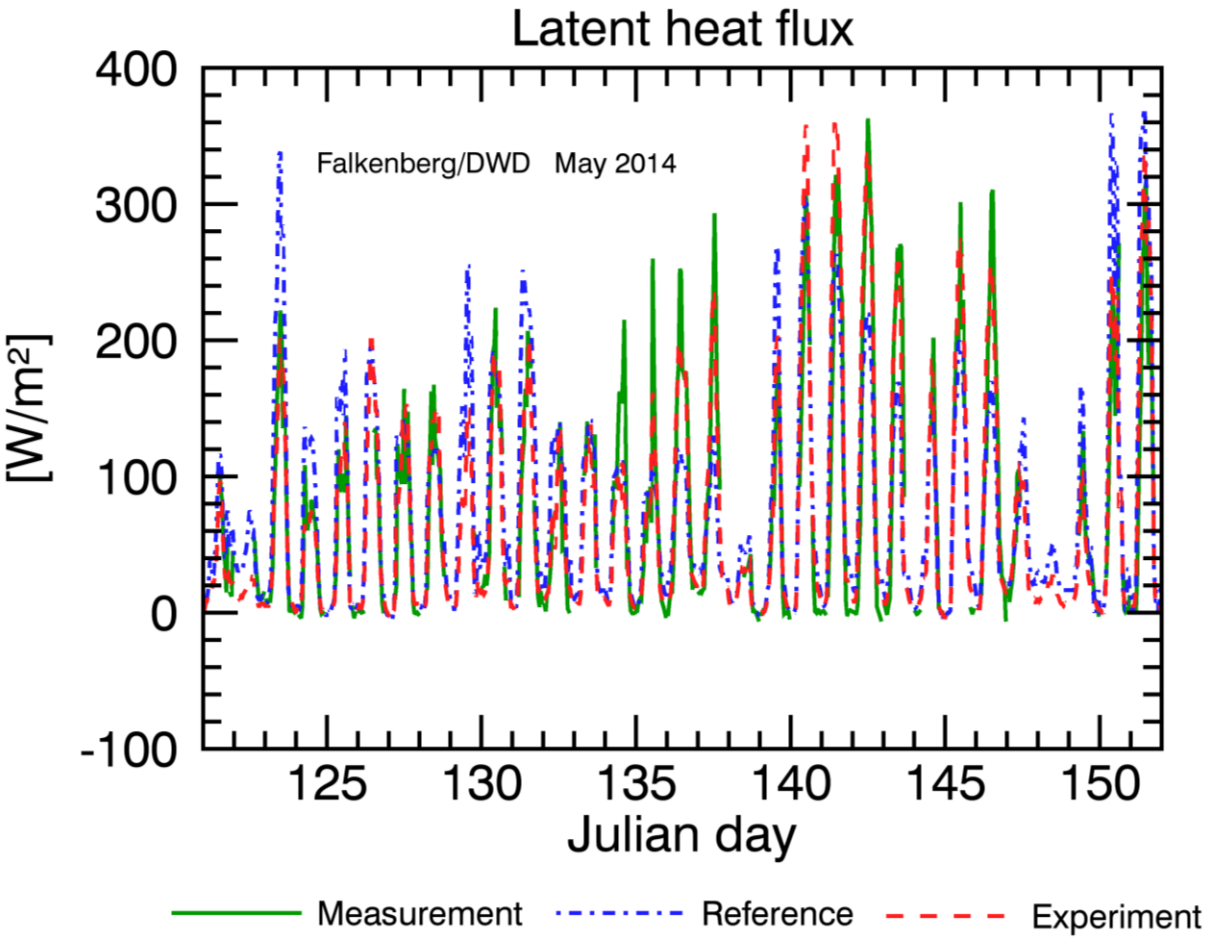
19-28 Feb. 2014

Reducing latent heat flux by the resistance method increases daily maximum surface temperatures, correcting for a cold bias by BATS



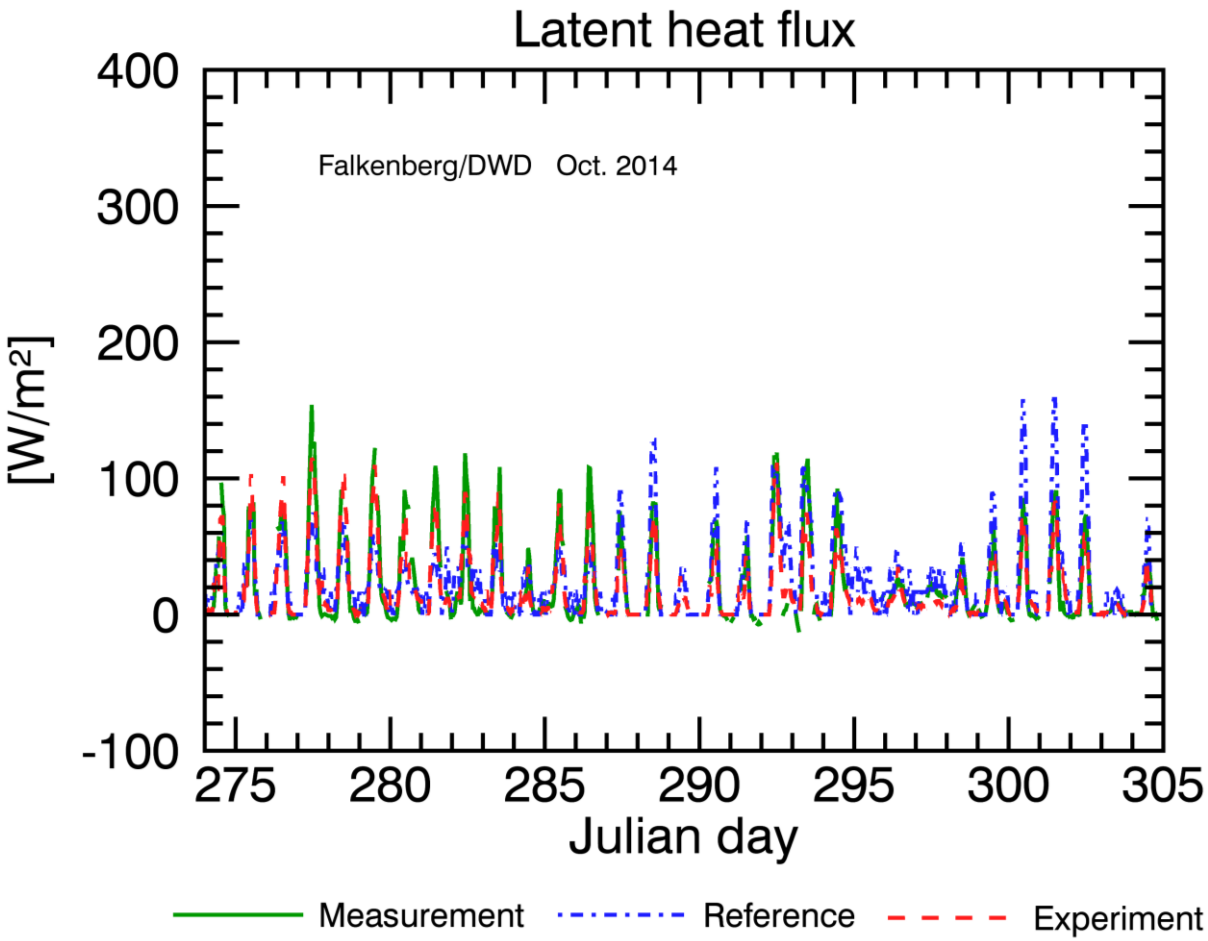
2014

Reduced bare soil evaporation simulated by resistance method reduces drying of the soil considerably, annual cycle of soil moisture much improved compared to BATS



May 2014

Latent heat flux improved by resistance method both under wet conditions (reduced) as well as under dry conditions (increased) compared to BATS

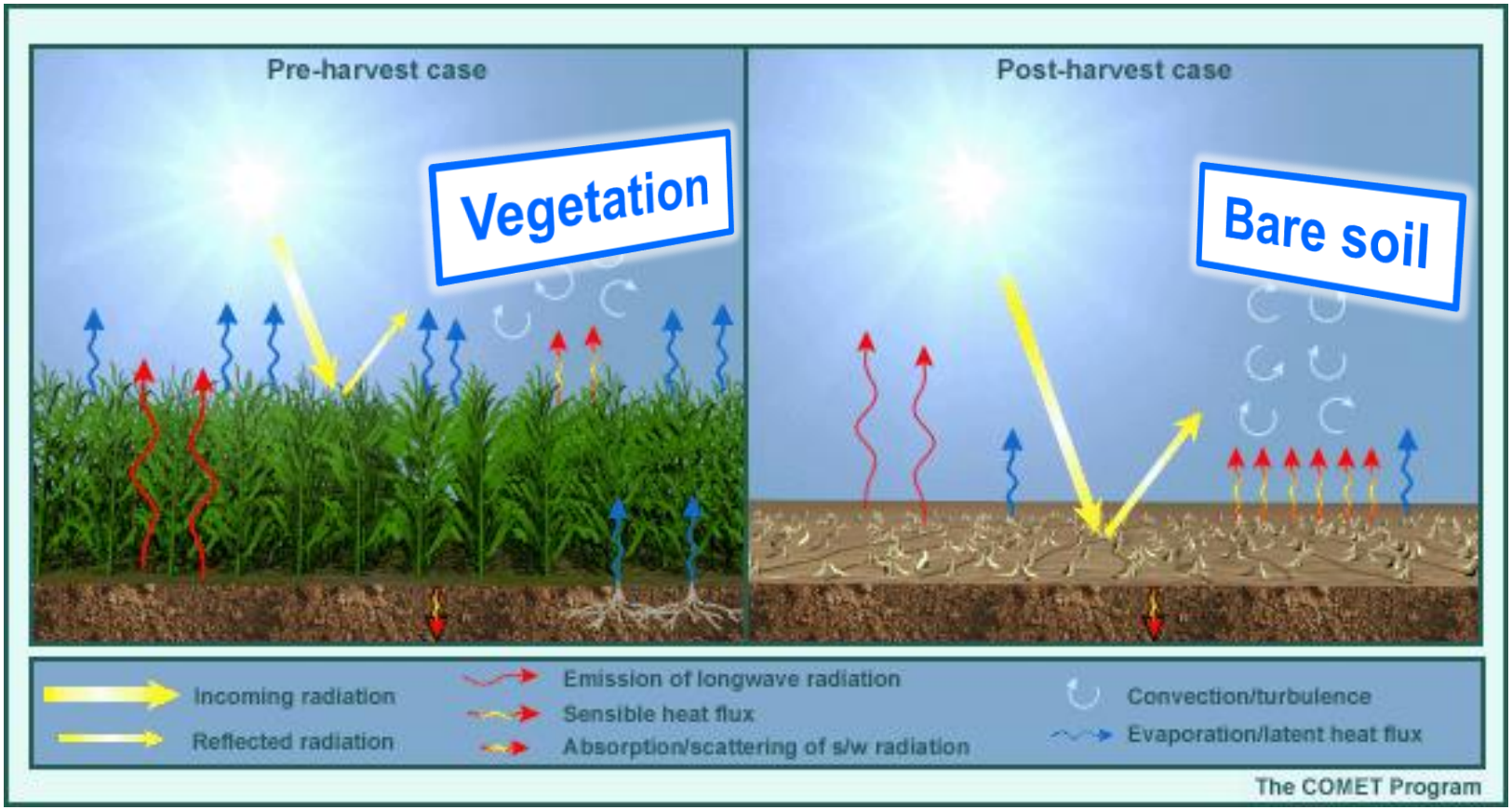

Latent heat flux
Falkenberg/DWD Oct. 2014
[W/m²]
400
300
200
100
0
-100
275
280
285
290
295
300
305
Julian day
Measurement
Reference
Experiment

Oct. 2014

Conclusions

- The bare soil evaporation in TERRA, simulated by the BATS scheme, is systematically overestimated under medium-wet to wet conditions. This behaviour is reversed under medium-dry to dry conditions.
- An overestimated evaporation and latent heat flux, respectively, lead to a dry bias in the soil, moist and cold biases in the near-surface atmosphere, and an underestimated diurnal near-surface temperature range.
- A new formulation of the bare soil evaporation, based on the resistance method, was developed and implemented in TERRA. Experiments in offline mode, utilizing measurements of the Lindenberg/Falkenberg site, show substantial improvements with respect to moisture and temperature errors.
- Experiments in coupled mode, with ICON, show improvements as well.

What is the surface temperature in TERRA?



The problem …

- The amplitude of the diurnal cycle of the surface temperature in TERRA is systematically underestimated.
- The amplitudes of the diurnal cycles of the soil temperatures in TERRA are systematically overestimated.
- In TERRA, there is no representation of the vegetation in the surface energy balance. This means, there is no energy budget including a temperature for the vegetation layer (canopy temperature missing).
- The insulating effects by the vegetation at the sub-canopy level are missing.
- Including these two effects in TERRA can improve the simulation of surface and of soil temperatures (see e.g. Deardorff 1978, Schulz et al. 1998, or Vogel et al. 2015).

Surface temperature in TERRA

(Doms et al. 2011)

$$C_s \frac{\partial T_s}{\partial t} = R_{SW} + R_{LW} + LE + H + G$$

T_s : surface temperature
C_s, t : heat capacity per unit area, time
R_{SW}, R_{LW} : net shortwave radiation flux, net longwave radiation flux
LE, H, G : latent heat flux, sensible heat flux, ground heat flux

Skin temperature in IFS

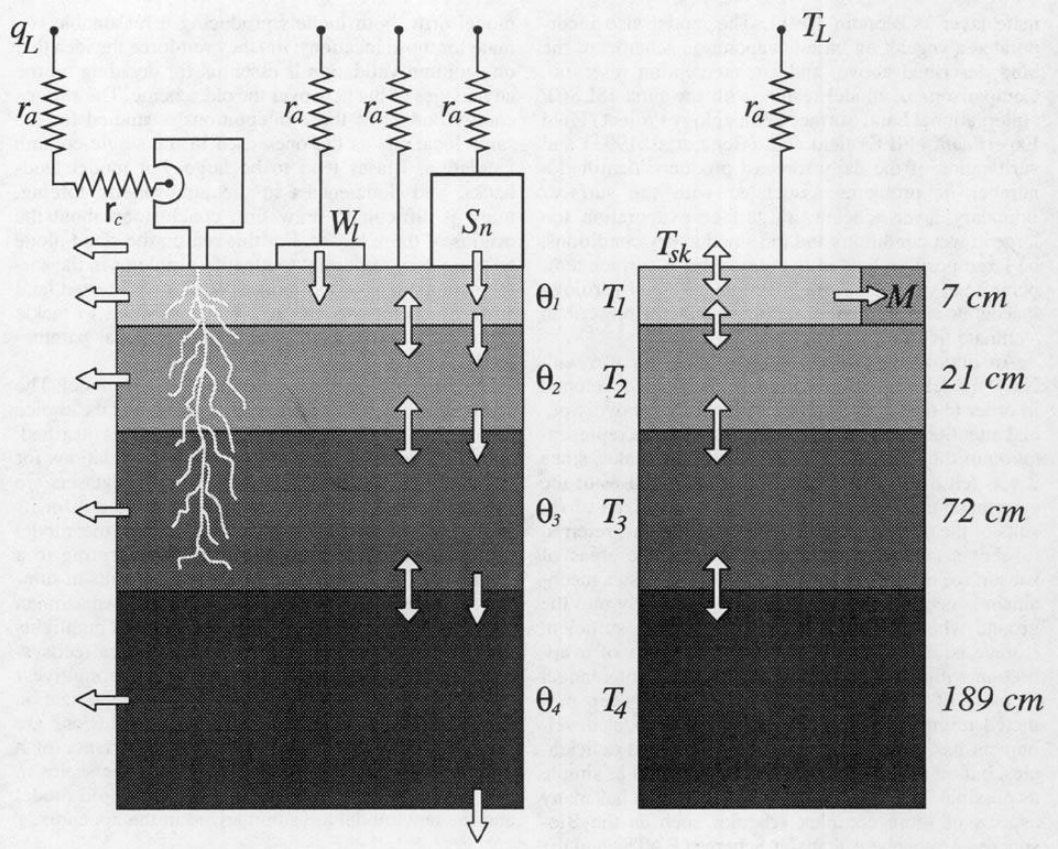
(Viterbo and Beljaars 1995)

$$\Lambda_{sk}(T_{sk} - T_s) = R_{SW} + R_{LW} + LE + H$$

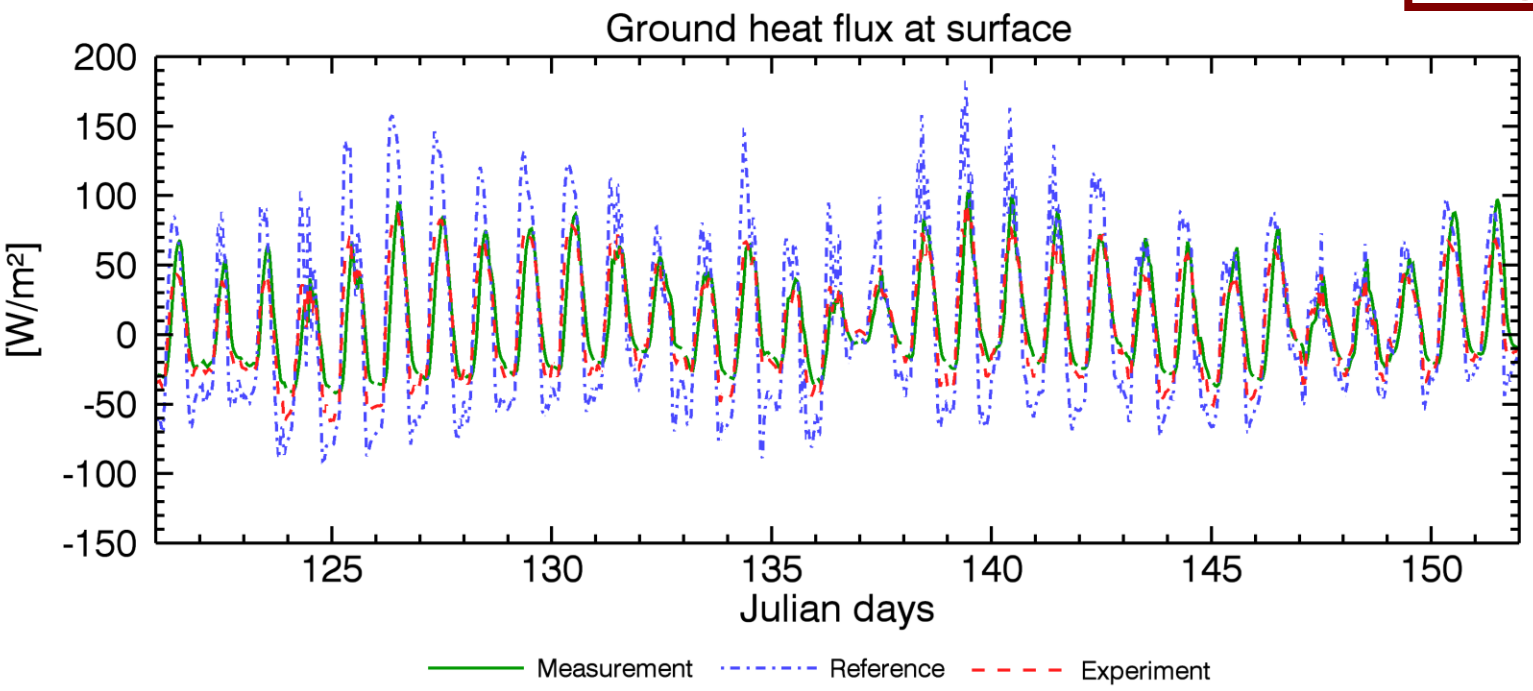
T_{sk}, T_s : skin temperature, surface temperature
Λ_{sk} : skin layer conductivity
R_{SW}, R_{LW} : net shortwave radiation flux, net longwave radiation flux
LE, H : latent heat flux, sensible heat flux

Skin temperature in IFS

(Viterbo and Beljaars 1995)

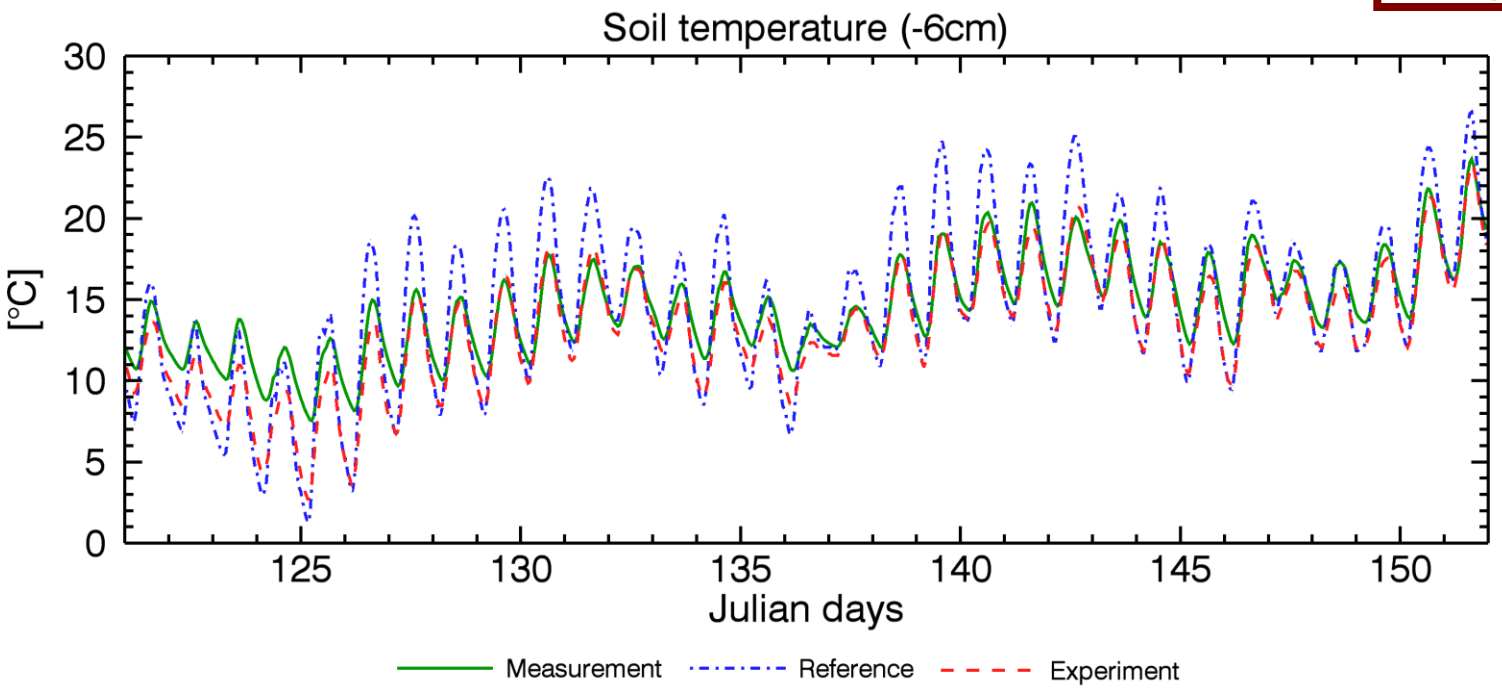


May 2011



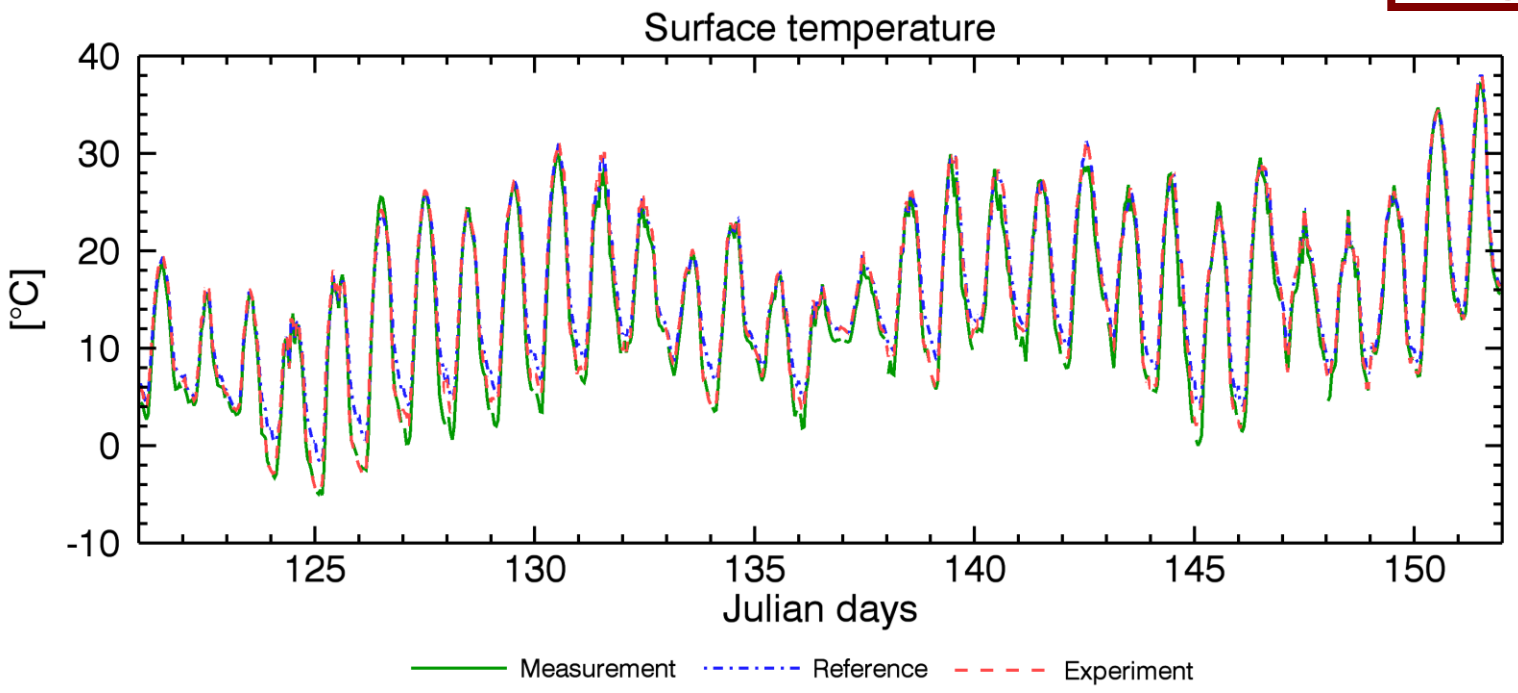
Ground heat flux substantially overestimated by TERRA, with the skin temperature formulation it is significantly reduced and much closer to the measurements

May 2011



Amplitudes of the diurnal cycles of the soil temperatures in TERRA are systematically overestimated, with the skin temperature formulation they are considerably reduced and therefore improved

May 2011



Amplitude of the diurnal cycle of the surface temperature in TERRA is systematically underestimated (clear nocturnal warm bias), with the skin temperature formulation it is substantially increased and much closer to the measurements

Conclusions

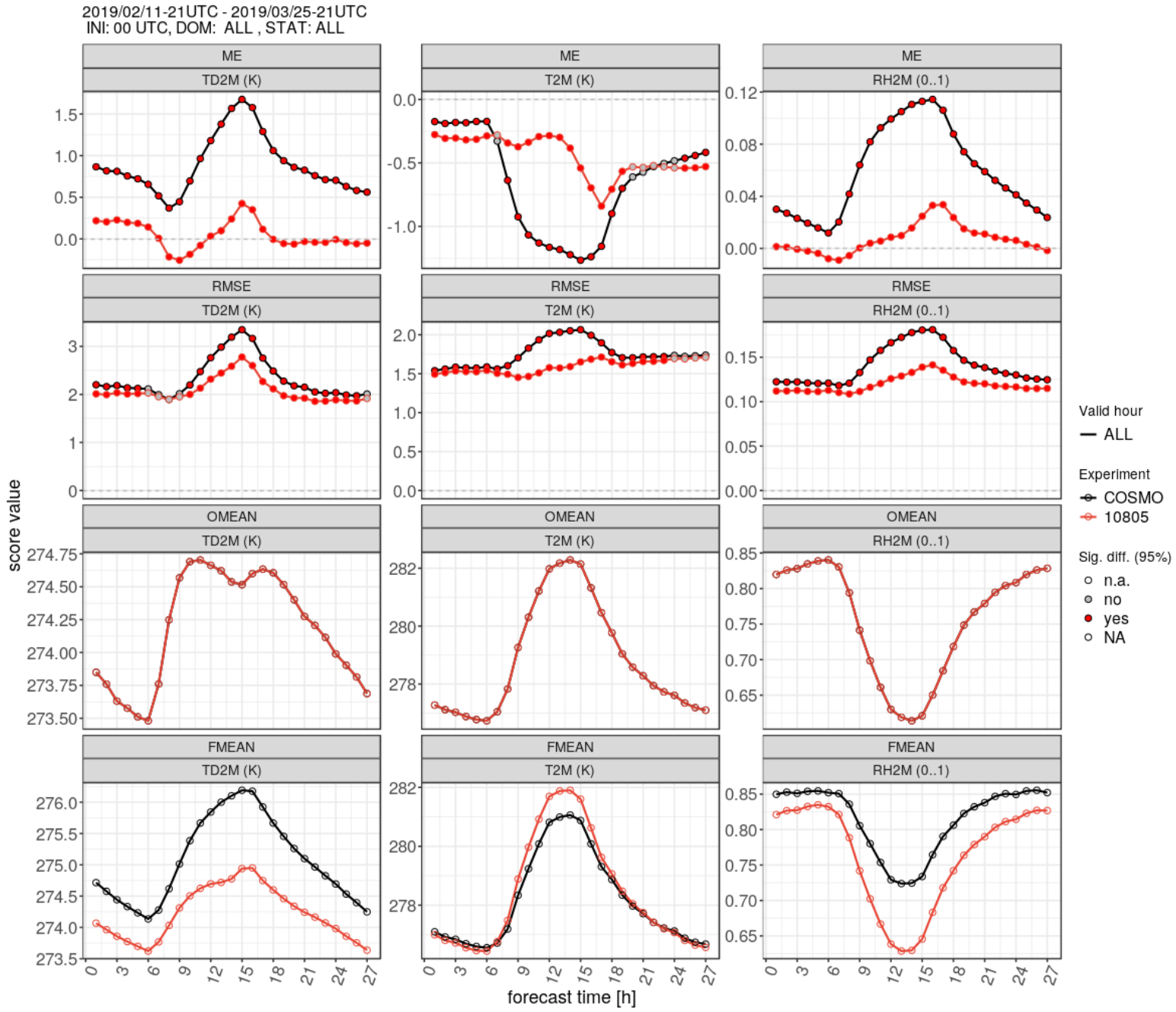
- The amplitude of the diurnal cycle of the surface temperature in TERRA is systematically underestimated.
- The amplitudes of the diurnal cycles of the soil temperatures in TERRA are systematically overestimated.
- The IFS skin temperature formulation was adapted and implemented in TERRA. It provides an additional energy budget for and insulating effects by the vegetation. Experiments in offline mode show substantial improvements with respect to temperature and heat flux errors.
- Experiments in coupled mode (ICON, COSMO-D2, COSMO-CLM) show improvements as well.

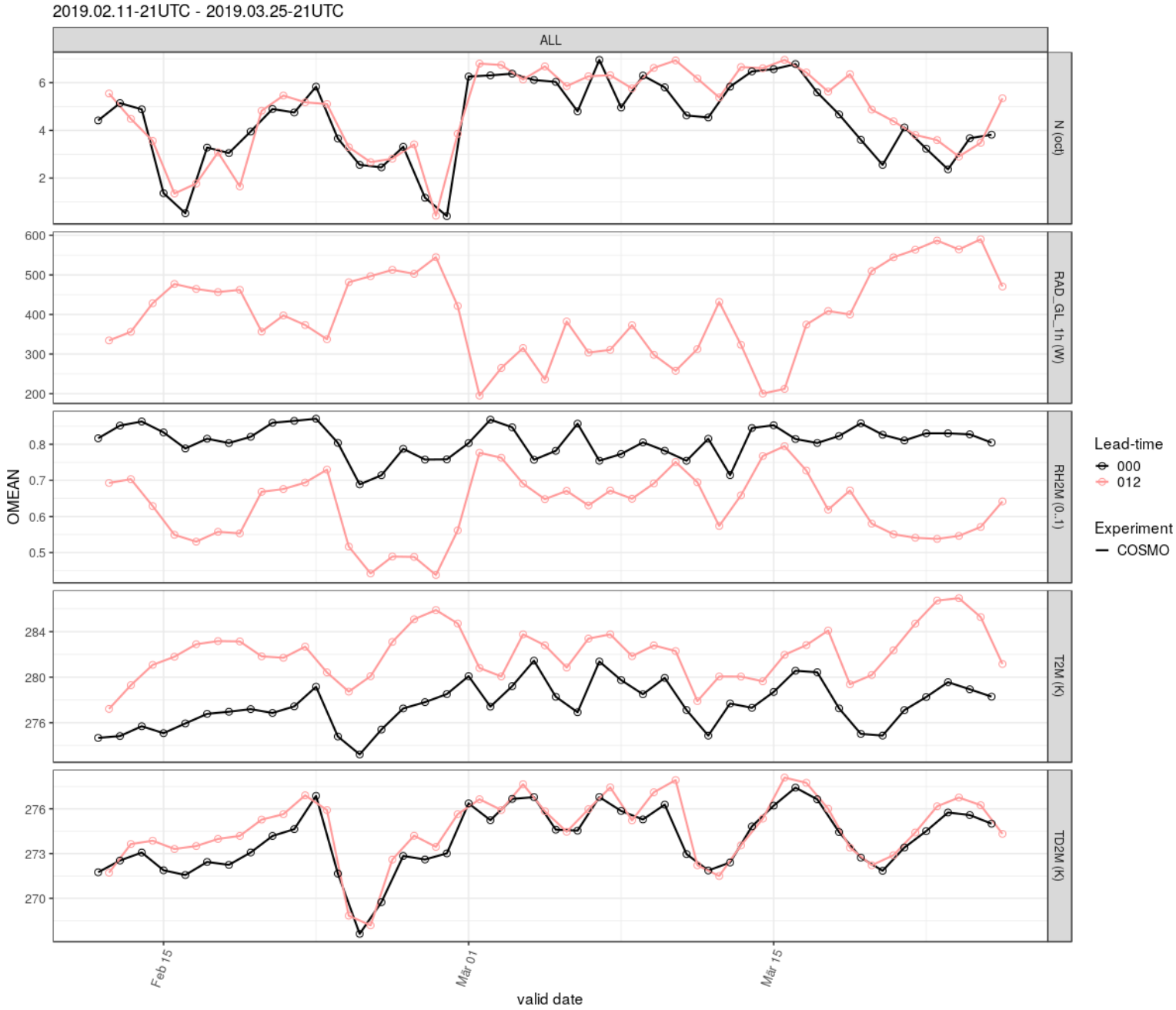
COSMO-D2 experiment 10805

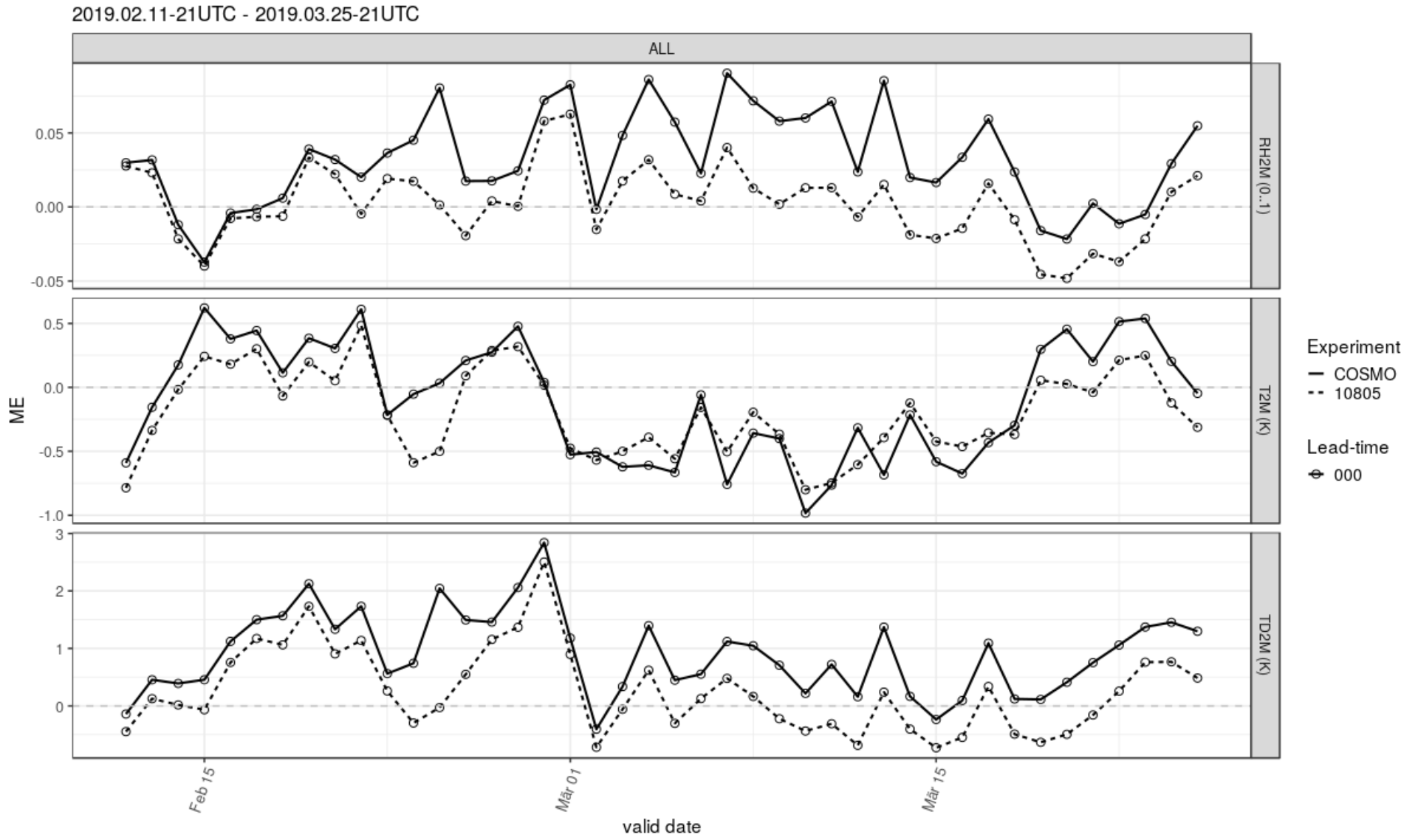
Simulation period: 11 Feb. – 25 Mar. 2019 (six weeks)

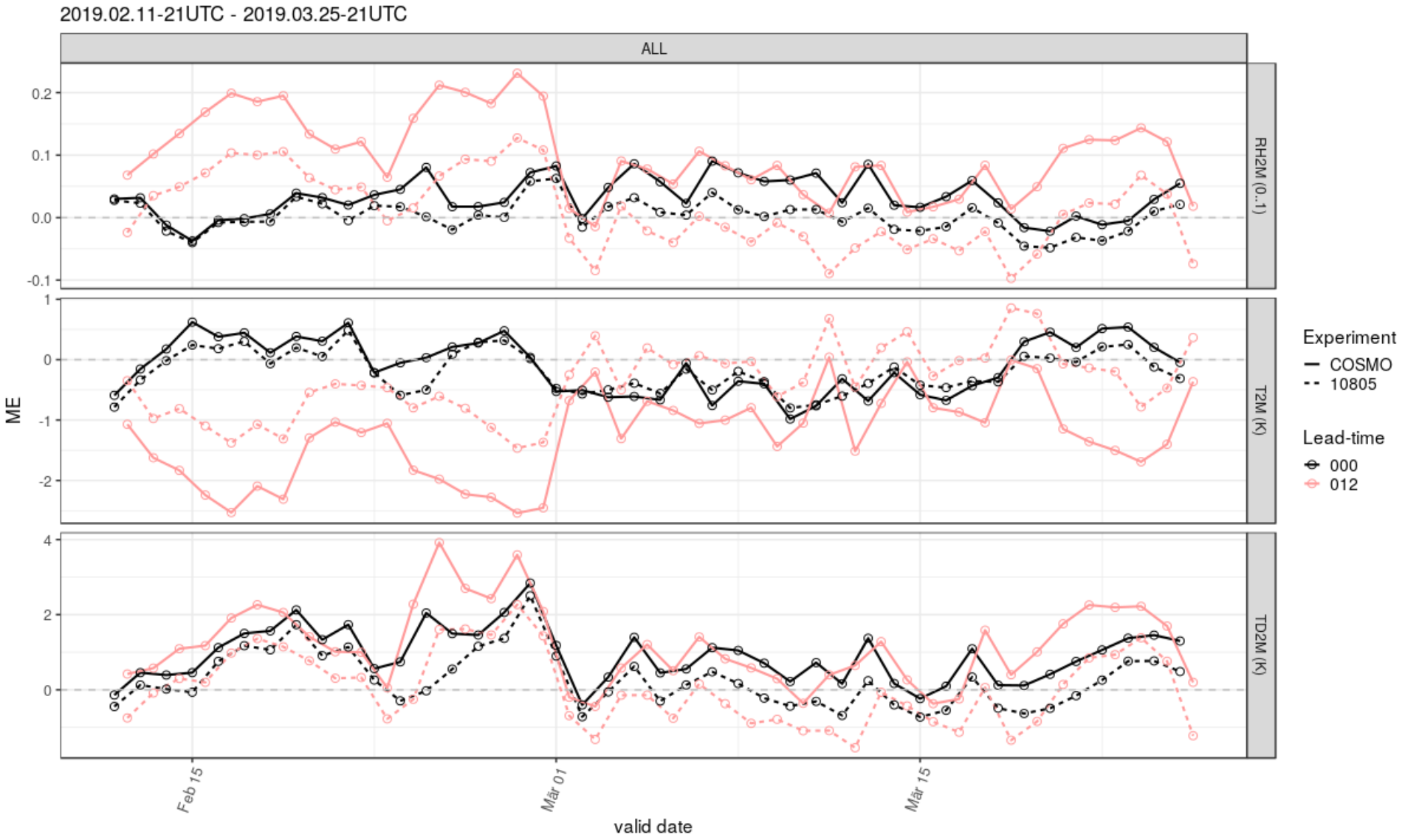
Namelists as in operational COSMO-D2, except for (in PHYCTL):

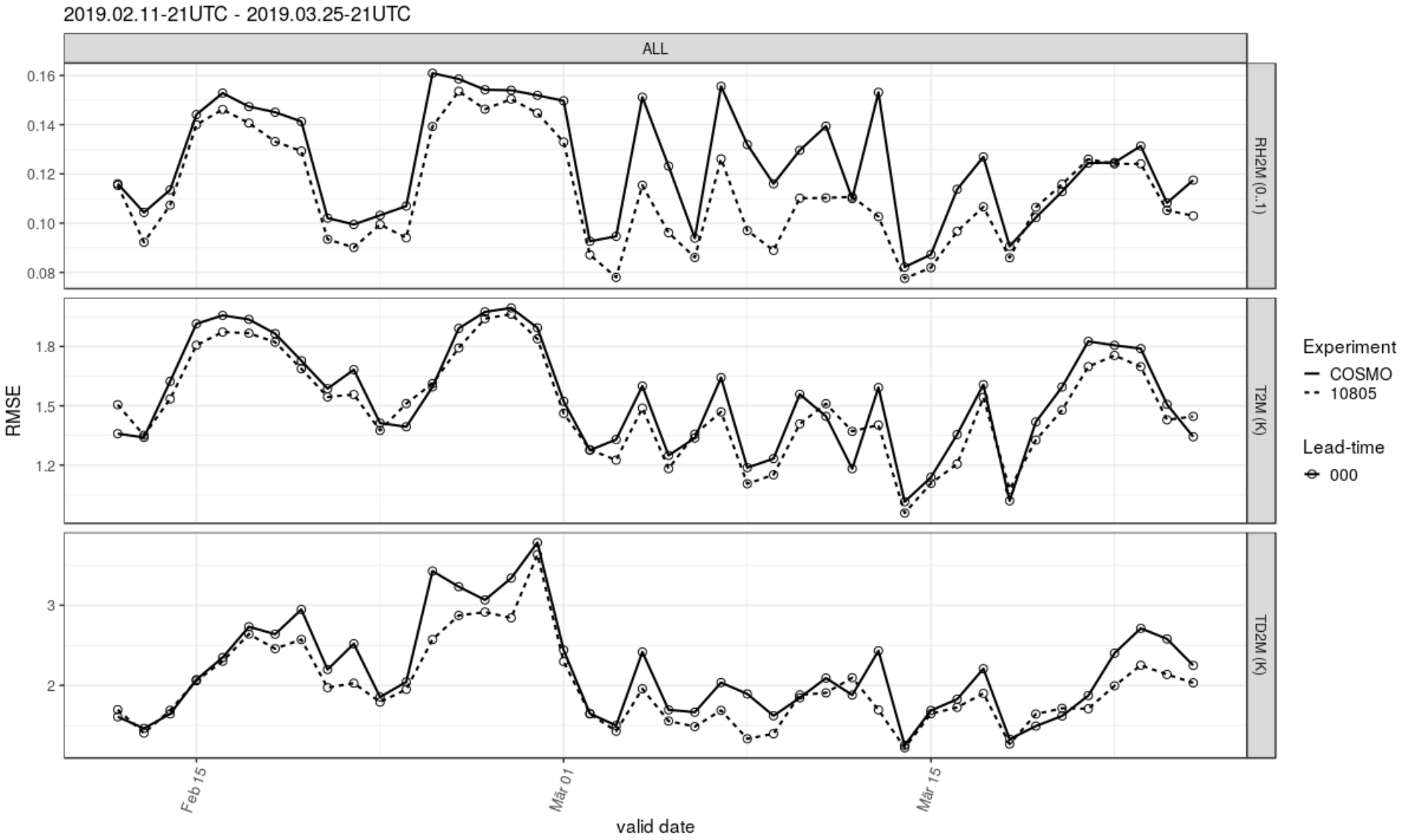
- itype_evsl = 4 : New bare soil evaporation
- itype_root = 2 : Exponential root profile
- cwimax_ml = 0.0005 : Interception reservoir activated
- itype_heatcond = 3 : Soil thermal conductivity dependent on moisture
- itype_canopy = 2 : Skin temperature

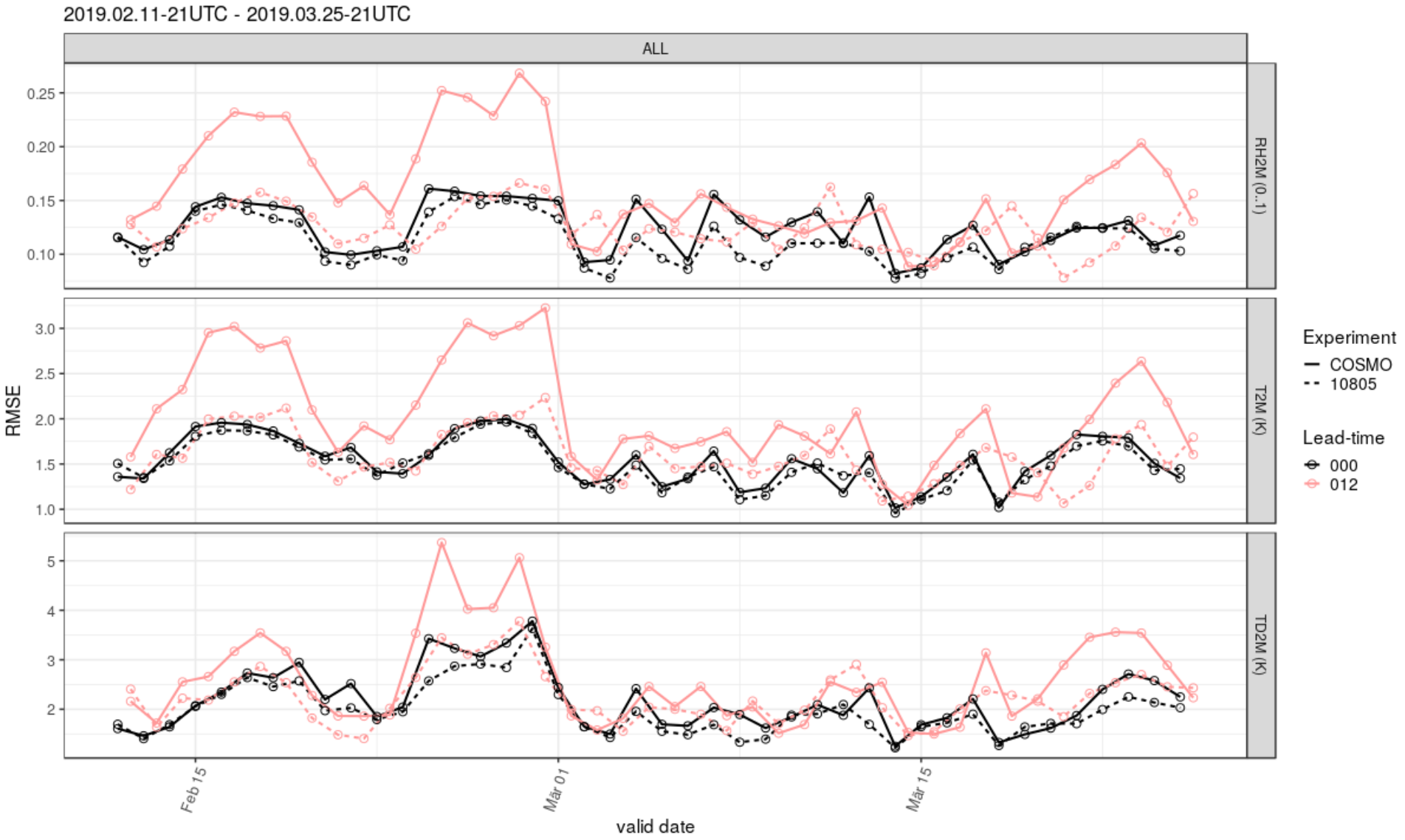

2019/02/11-21UTC - 2019/03/25-21UTC
INI: 00 UTC, DOM: ALL , STAT: ALL
ME
TD2M (K)
T2M (K)
RH2M (0..1)
RMSE
OMEAN
FMEAN
score value
forecast time [h]
Valid hour
ALL
Experiment
COSMO
10805
Sig. diff. (95%)
n.a.
no
yes
NA

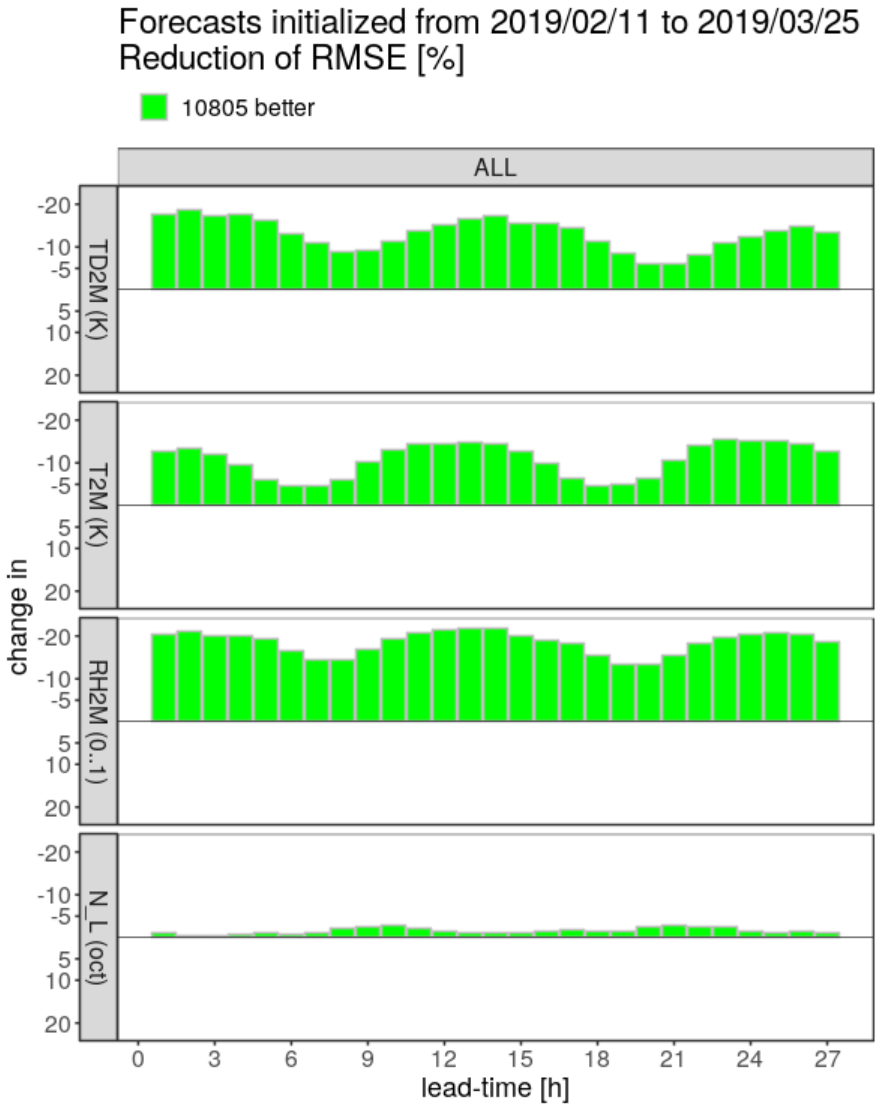

2019.02.11-21UTC - 2019.03.25-21UTC
ALL
N (oct)
RAD_GL_1h (W)
RH2M (0..1)
T2M (K)
TD2M (K)
OMEAN
valid date
Feb 15
Mär 01
Mär 15
Lead-time
000
012
Experiment
COSMO

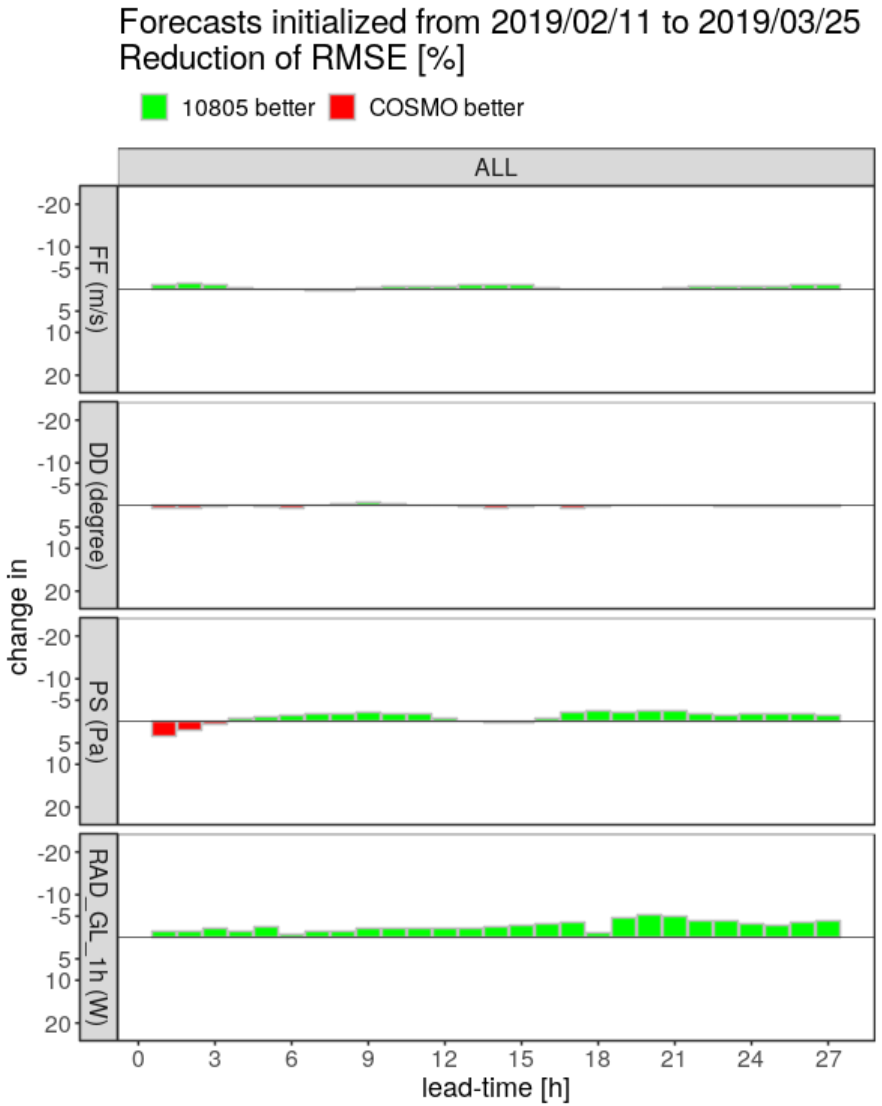

2019.02.11-21UTC - 2019.03.25-21UTC
ALL
RH2M (0..1)
T2M (K)
TD2M (K)
ME
0.05
0.00
-0.05
0.5
0.0
-0.5
-1.0
3
2
1
0
Feb 15
Mär 01
Mär 15
valid date
Experiment
COSMO
10805
Lead-time
000

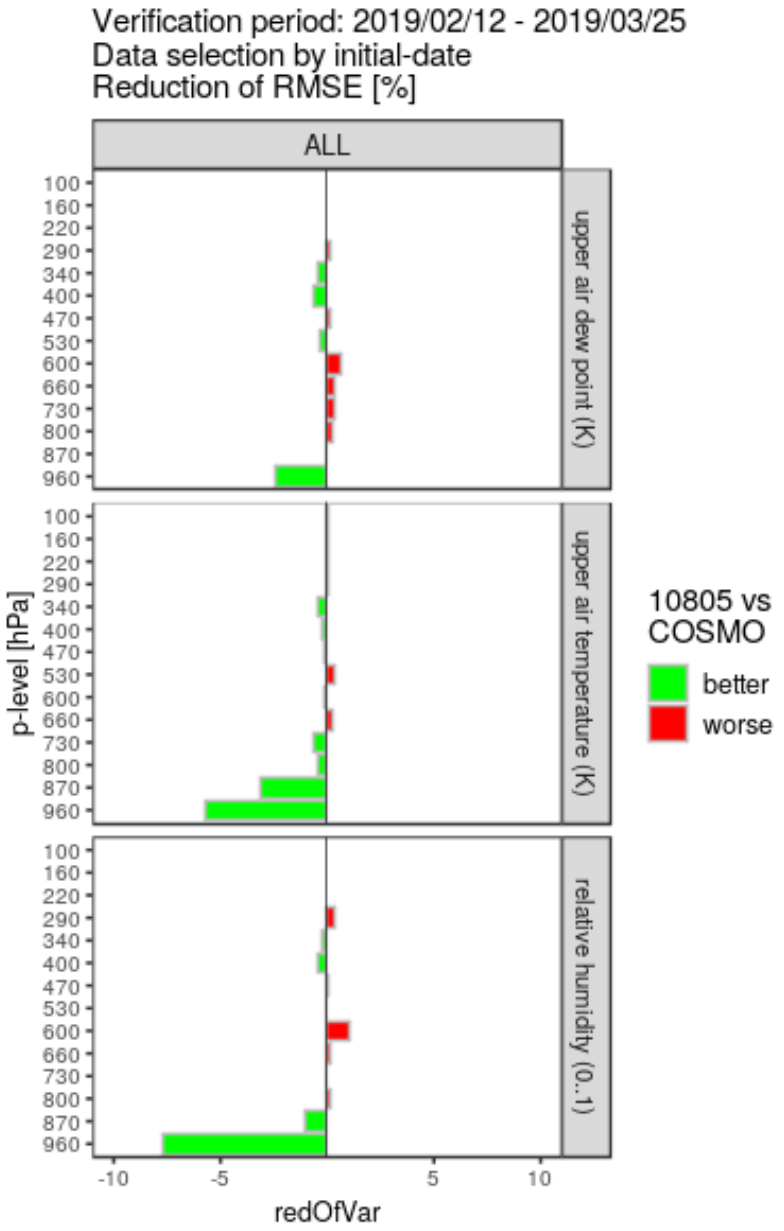

2019.02.11-21UTC - 2019.03.25-21UTC
ALL
RH2M (0..1)
T2M (K)
TD2M (K)
ME
0.2
0.1
0.0
-0.1
1
0
-1
-2
4
2
0
Feb 15
Mär 01
Mär 15
valid date
Experiment
COSMO
10805
Lead-time
000
012

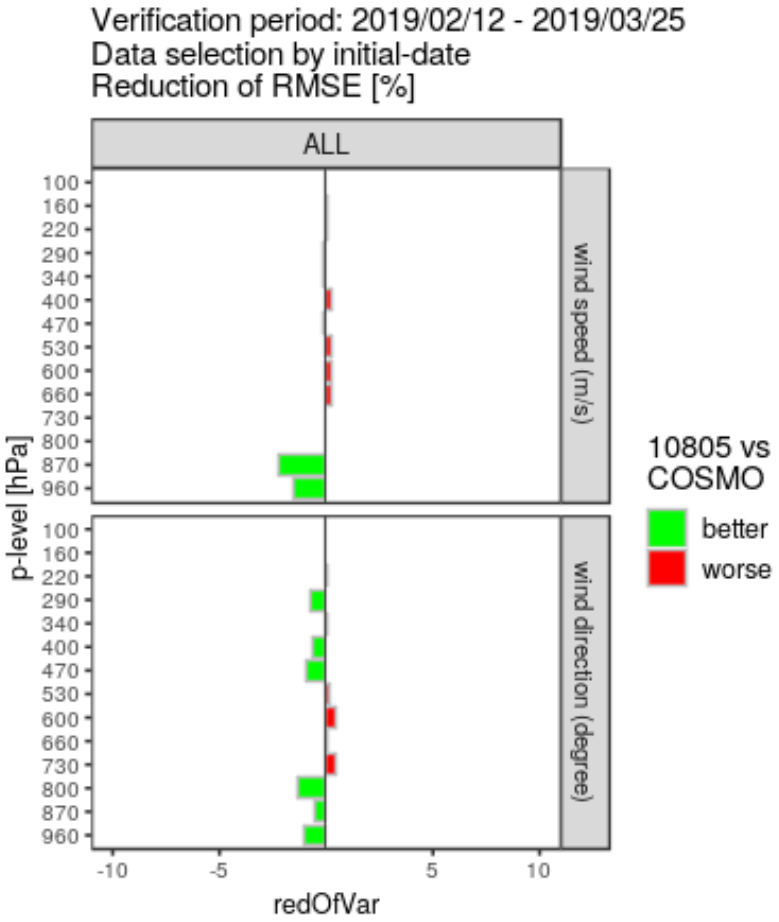

2019.02.11-21UTC - 2019.03.25-21UTC
ALL
RH2M (0..1)
T2M (K)
TD2M (K)
RMSE
0.16
0.14
0.12
0.10
0.08
1.8
1.5
1.2
3
2
Feb 15
Mär 01
Mär 15
valid date
Experiment
COSMO
10805
Lead-time
000


2019.02.11-21UTC - 2019.03.25-21UTC
ALL
RH2M (0..1)
T2M (K)
TD2M (K)
RMSE
0.25
0.20
0.15
0.10
3.0
2.5
2.0
1.5
1.0
5
4
3
2
Feb 15
Mär 01
Mär 15
valid date
Experiment
COSMO
10805
Lead-time
000
012


Forecasts initialized from 2019/02/11 to 2019/03/25
Reduction of RMSE [%]
10805 better
ALL
TD2M (K)
T2M (K)
RH2M (0..1)
N_L (oct)
change in
-20
-10
-5
5
10
20
0
3
6
9
12
15
18
21
24
27
lead-time [h]

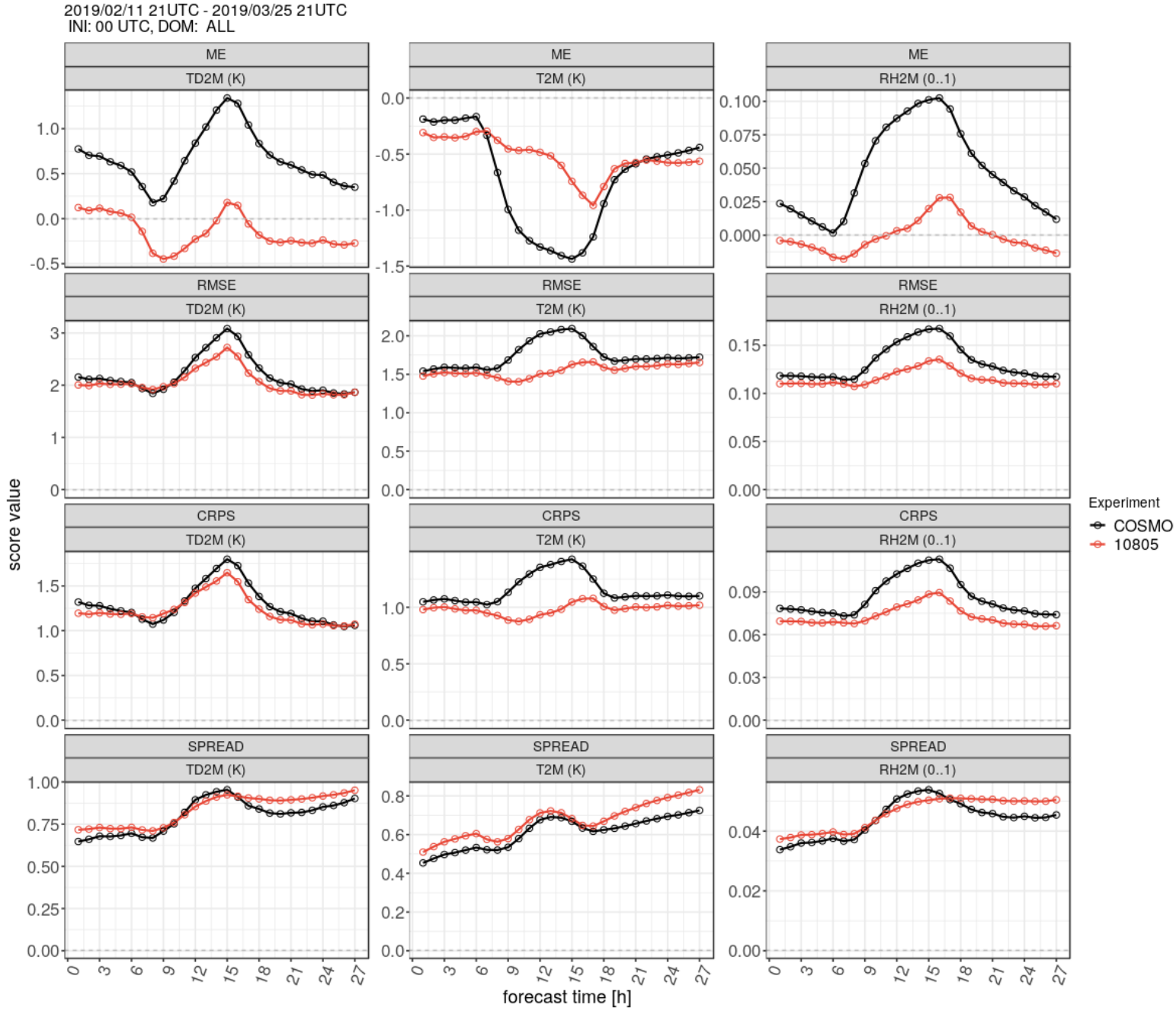

Forecasts initialized from 2019/02/11 to 2019/03/25
Reduction of RMSE [%]
10805 better
COSMO better
ALL
FF (m/s)
DD (degree)
PS (Pa)
RAD_GL_1h (W)
change in
-20
-10
-5
5
10
20
0
3
6
9
12
15
18
21
24
27
lead-time [h]


Verification period: 2019/02/12 - 2019/03/25
Data selection by initial-date
Reduction of RMSE [%]
ALL
upper air dew point (K)
upper air temperature (K)
relative humidity (0..1)
p-level [hPa]
100
160
220
290
340
400
470
530
600
660
730
800
870
960
-10
-5
5
10
redOfVar
10805 vs COSMO
better
worse

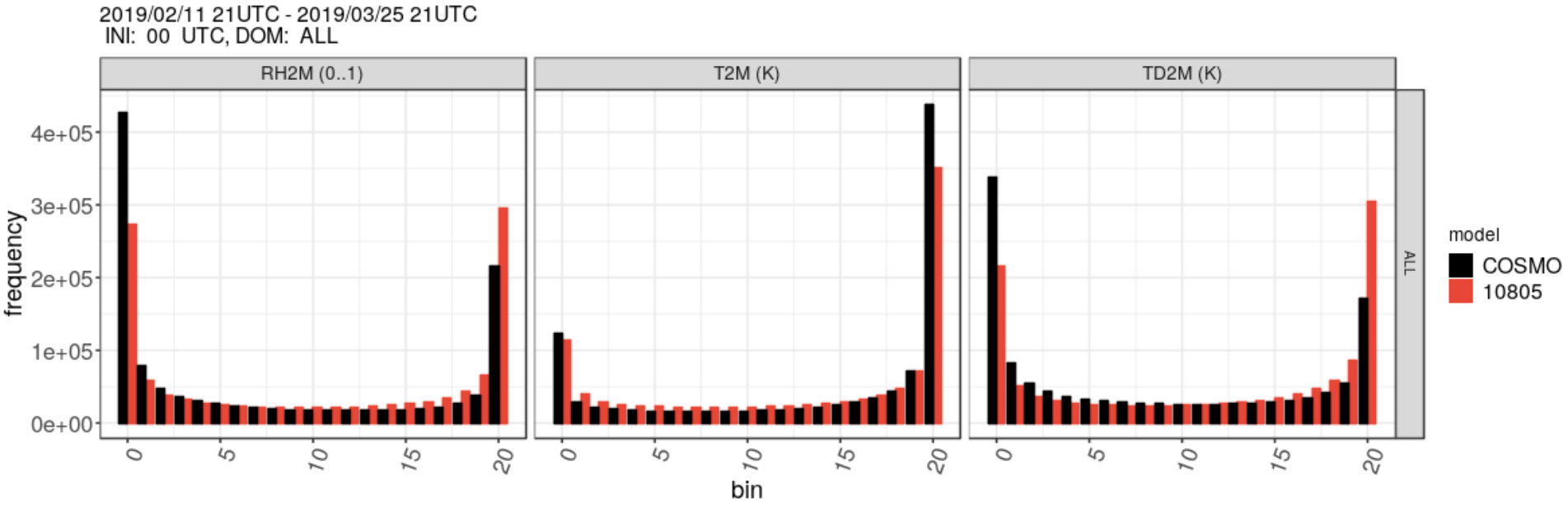

Verification period: 2019/02/12 - 2019/03/25
Data selection by initial-date
Reduction of RMSE [%]
ALL
wind speed (m/s)
wind direction (degree)
p-level [hPa]
100
160
220
290
340
400
470
530
600
660
730
800
870
960
-10
-5
5
10
redOfVar
10805 vs COSMO
better
worse

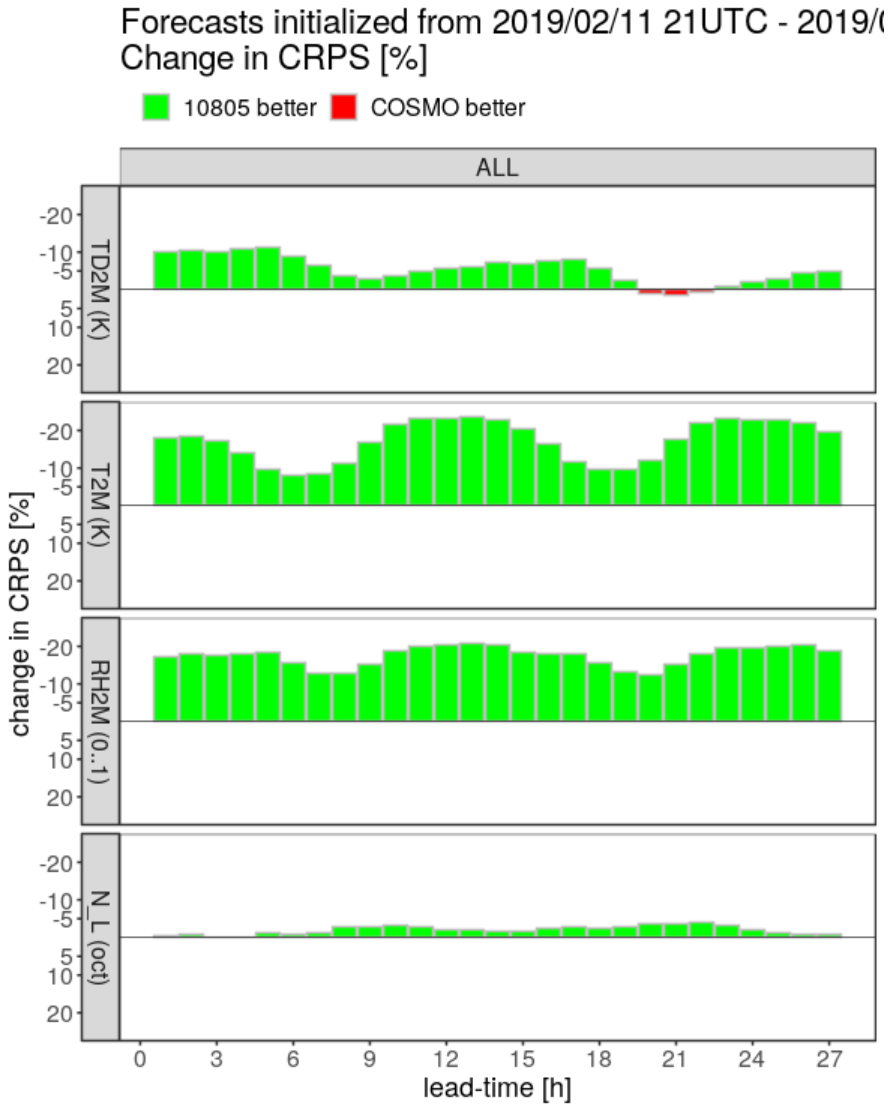
Conclusions

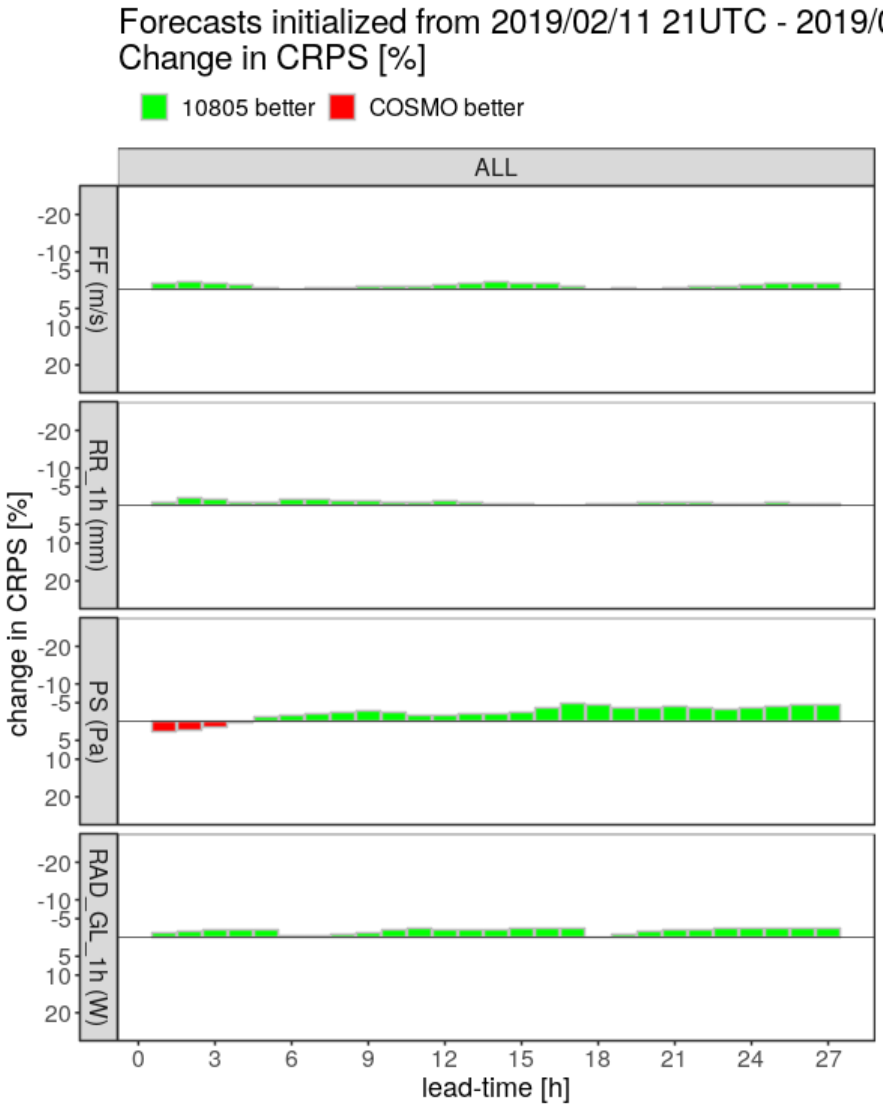
- The new formulations of bare soil evaporation and skin temperature were tested in COSMO-D2.
- The biases and RMSE's of near-surface humidity and temperature are substantially reduced.
- It is proposed to test and eventually introduce these improvements in the different domains of the COSMO partners.


2019/02/11 21UTC - 2019/03/25 21UTC
INI: 00 UTC, DOM: ALL
ME
TD2M (K)
ME
T2M (K)
ME
RH2M (0..1)
RMSE
TD2M (K)
RMSE
T2M (K)
RMSE
RH2M (0..1)
CRPS
TD2M (K)
CRPS
T2M (K)
CRPS
RH2M (0..1)
SPREAD
TD2M (K)
SPREAD
T2M (K)
SPREAD
RH2M (0..1)
score value
forecast time [h]
Experiment
COSMO
10805

Talagrand diagrams




Forecasts initialized from 2019/02/11 21UTC - 2019/(
Change in CRPS [%]
10805 better
COSMO better
ALL
TD2M (K)
T2M (K)
RH2M (0..1)
N_L (oct)
-20
-10
-5
5
10
20
change in CRPS [%]
0
3
6
9
12
15
18
21
24
27
lead-time [h]

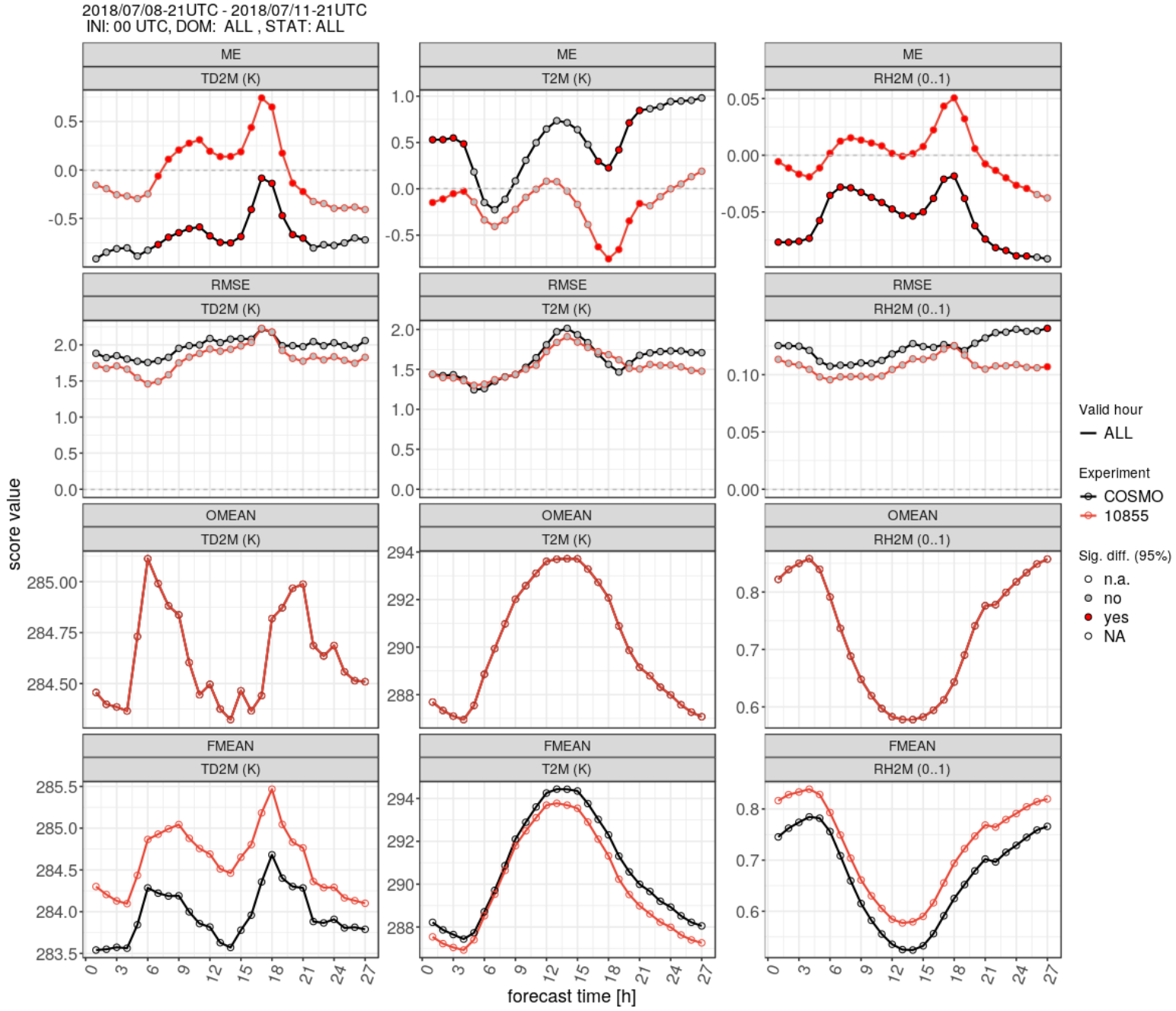

Forecasts initialized from 2019/02/11 21UTC - 2019/(
Change in CRPS [%]
10805 better
COSMO better
ALL
FF (m/s)
RR_1h (mm)
PS (Pa)
RAD_GL_1h (W)
-20
-10
-5
5
10
20
change in CRPS [%]
0
3
6
9
12
15
18
21
24
27
lead-time [h]

COSMO-D2 experiment 10855

Simulation period: 8 – 11 Jul. 2018 (three days)

Namelists as in operational COSMO-D2, except for (in PHYCTL):

- itype_evsl = 4 : New bare soil evaporation
- itype_root = 2 : Exponential root profile
- cwimax_ml = 0.0005 : Interception reservoir activated
- itype_heatcond = 3 : Soil thermal conductivity dependent on moisture
- itype_canopy = 2 : Skin temperature


2018/07/08-21UTC - 2018/07/11-21UTC
INI: 00 UTC, DOM: ALL , STAT: ALL
ME
TD2M (K)
T2M (K)
RH2M (0..1)
RMSE
OMEAN
FMEAN
score value
forecast time [h]
Valid hour
ALL
Experiment
COSMO
10855
Sig. diff. (95%)
n.a.
no
yes
NA