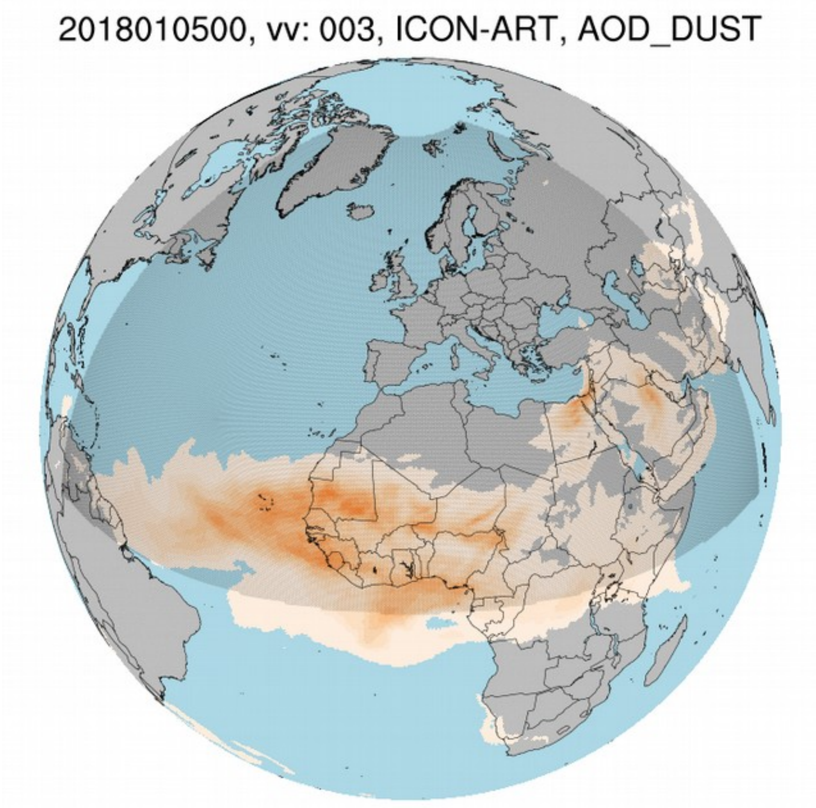
ICON-ART: Verification of the EnVar mode, N-African biases and runtime optimizations

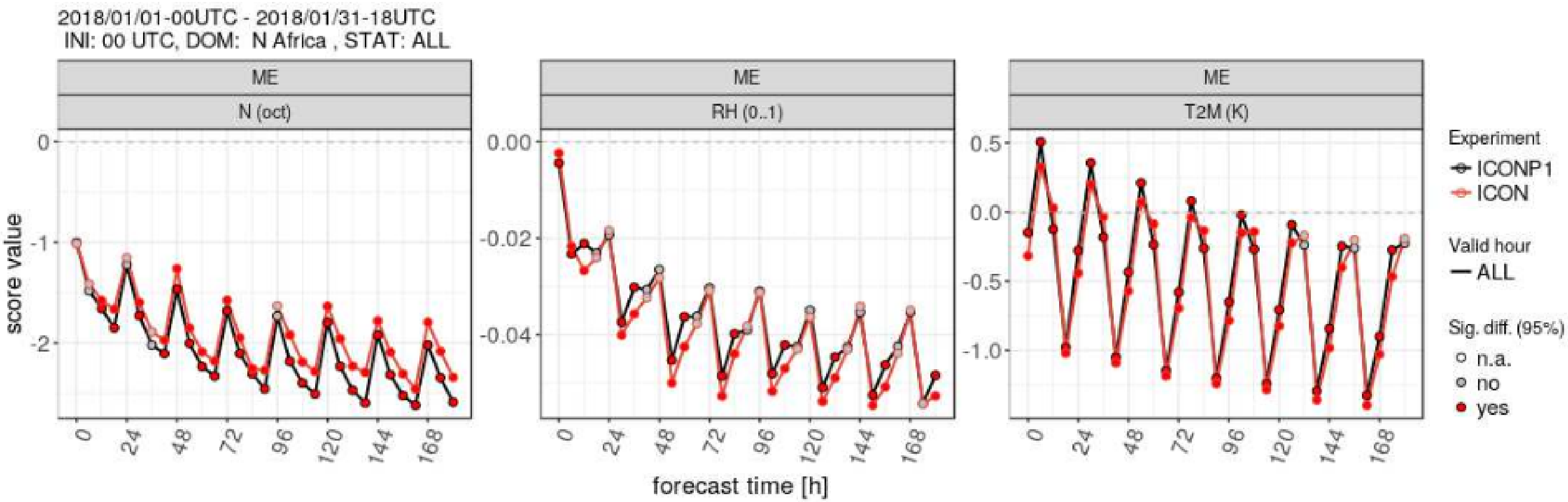


Jochen Förstner,
Andrea Steiner,
Vanessa Bachmann,
Günther Zängl,
Richard Müller,
Daniel Rieger,
Bodo Ritter

ICON ReSQME Task Force: T-Bias N-Africa

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

➔ **Bias in N-Africa: too few clouds, too dry, too cold…** ©Günther Zängl

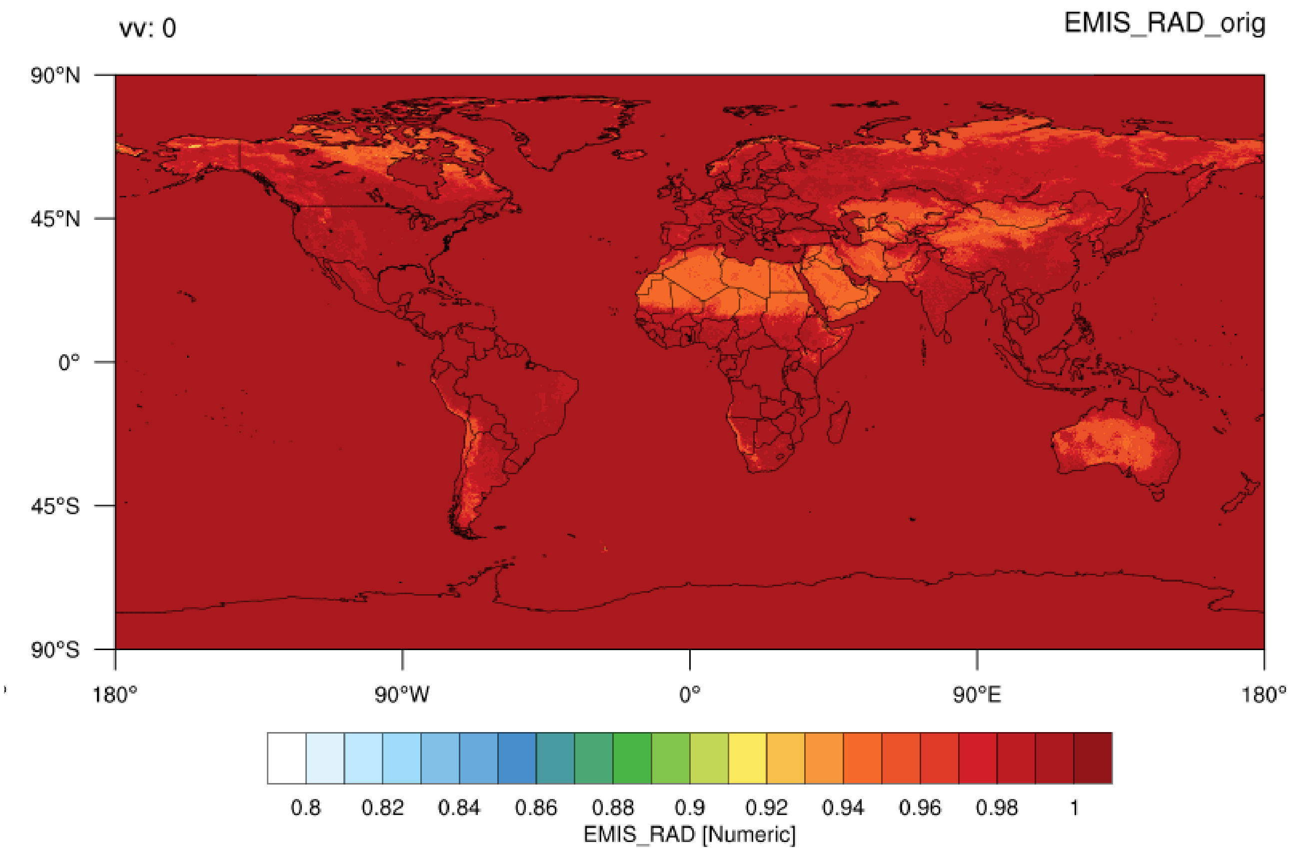


➔ **…despite artificial tunings: reduced Albedo in Saharan region, increased LW-absorption of mineral dust, head conductivity of sand tuned to reach highest values from literature**

➔ **Such an error correlation contradicts a positive radiation balance in this region.**

➔ **What's going on here?** **Discussion with Richard Müller (FE23)**

Longwave Emissivity (orig)



➔Operationally used in ICON at DWD:

EMIS_RAD = 0.95 for land use classes „bare soil“ and „sparse vegetation“

Longwave Emissivity (observed)

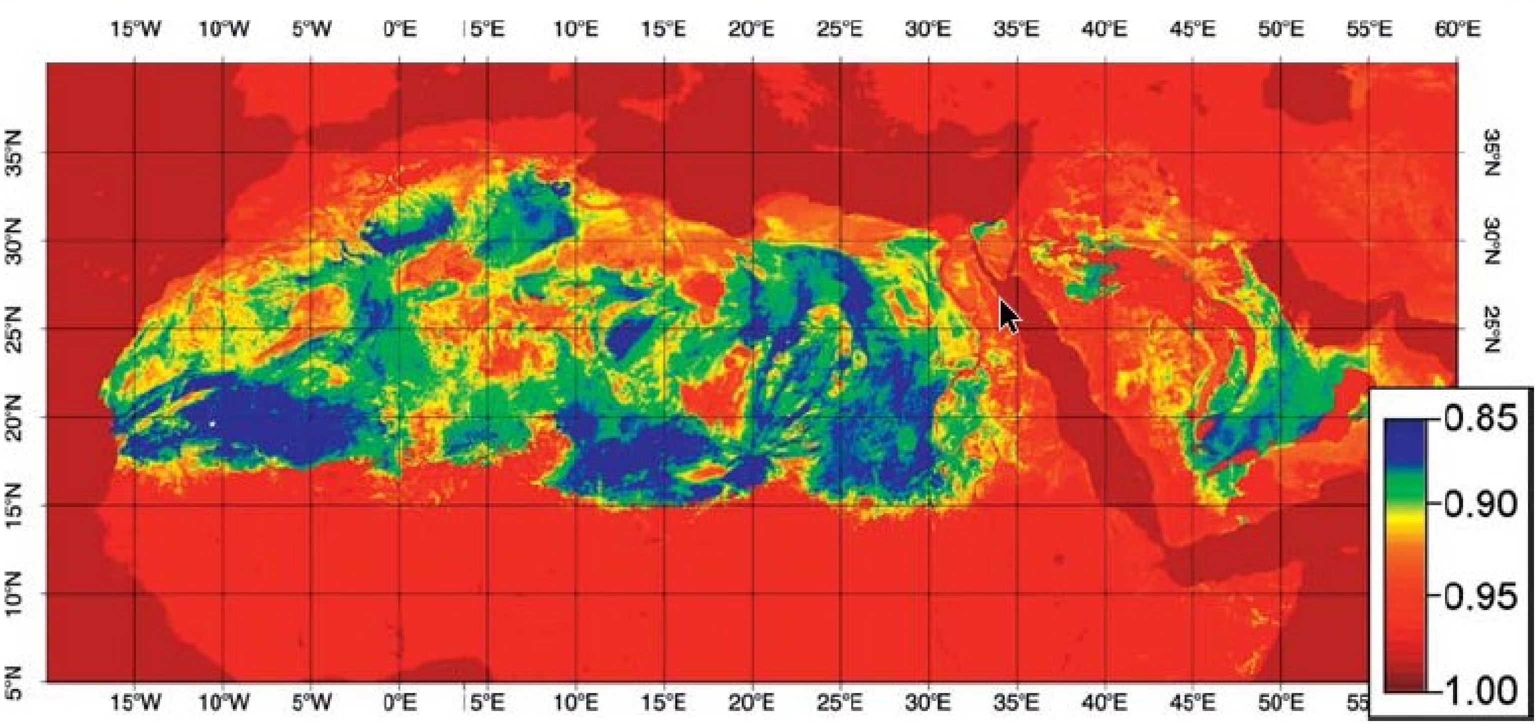
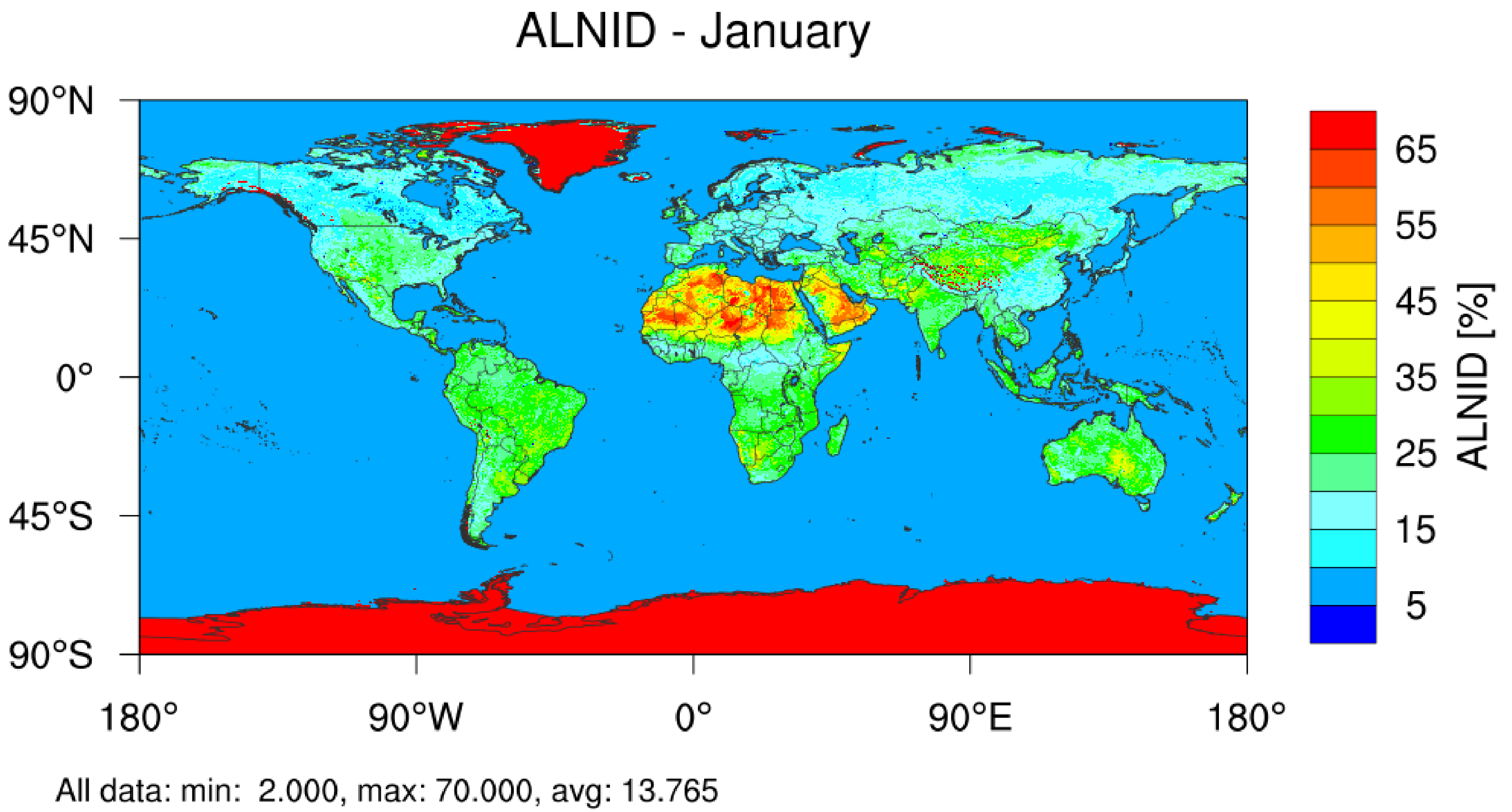


Figure 6. The broadband emissivity map of the Sahara Desert derived from the regressions. Water and vegetated area are masked using a land-cover map by USGS and given fixed values.

Source: K. Ogawa and T. Schmugge (2004). Mapping Surface Broadband Emissivity of the Sahara Desert Using ASTER and MODIS Data. *Earth Interactions, 8(7):1–14.*

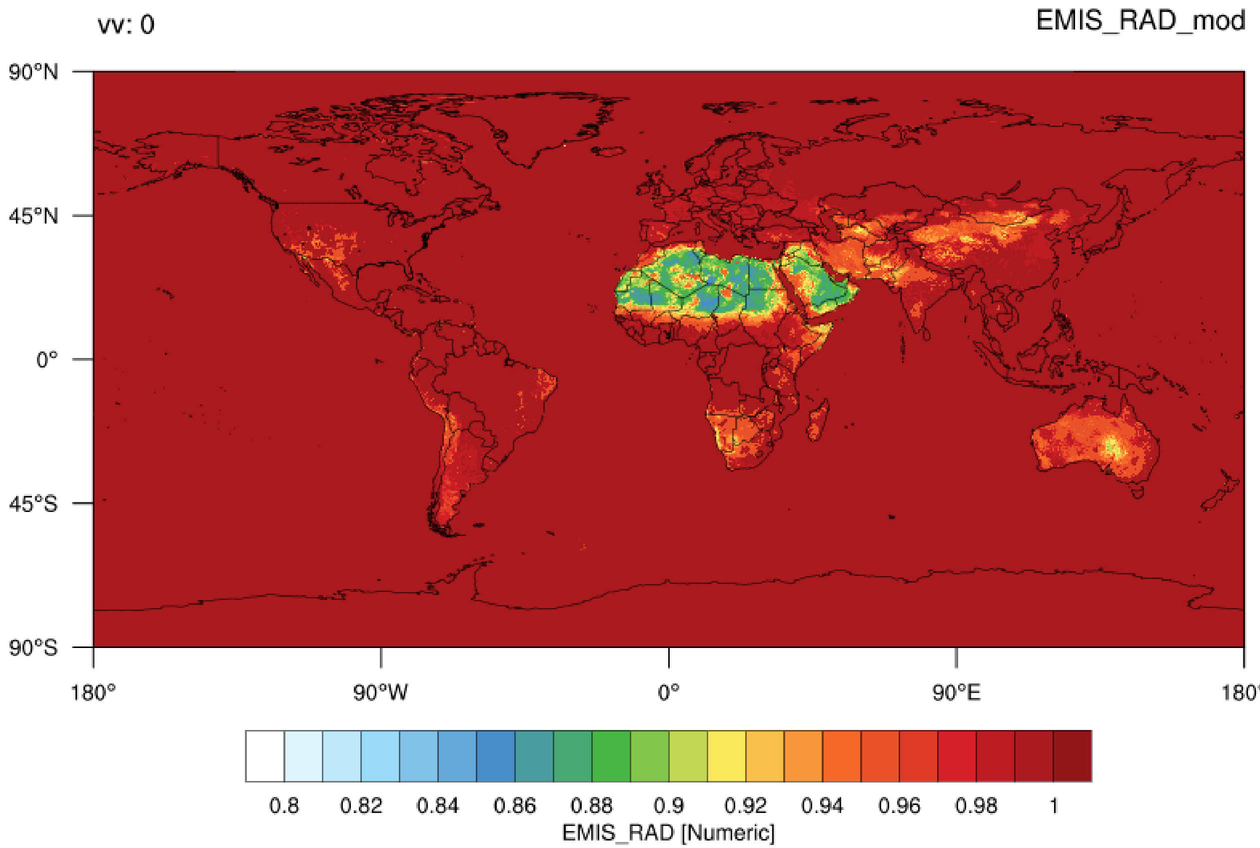
MODIS Near Infrared Broadband Albedo

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



- ➔ Similar structures in Saharan region and Arabian Peninsula as for observed LW Emissivity
- ➔ 1st Test: use ALNID to reduce LW Emissivity in N-Africa, Arabian Peninsula

Longwave Emissivity (mod)



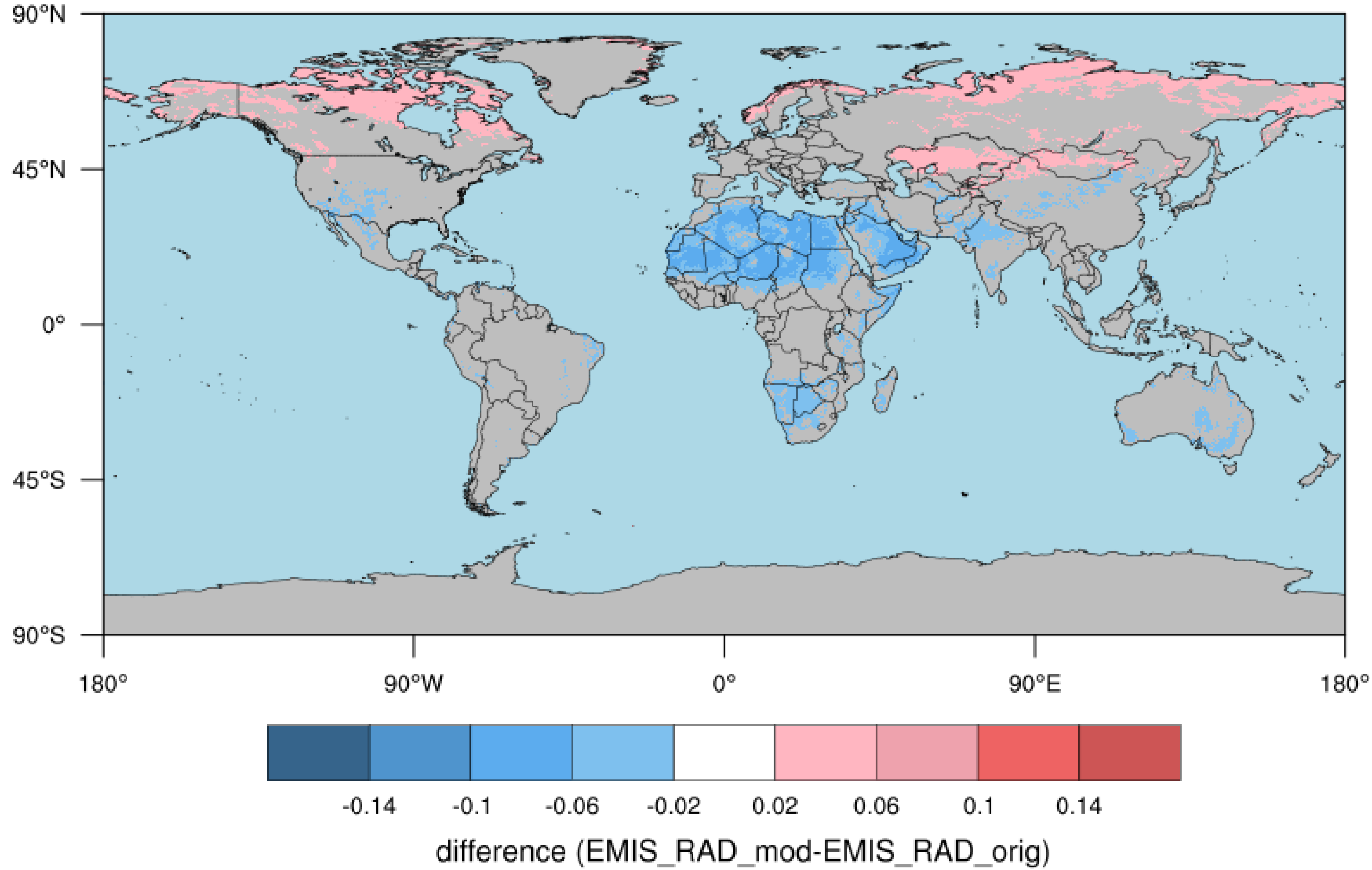
$$IF \;\; albni > 0.25 \;\; .AND. \;\; albni < 0.699 \;\; .AND. \;\; plcov < 0.5 \;\; .AND. \;\; soiltyp /= 1 \;\; THEN$$

$$lw\_emiss = MIN(lw\_emiss, 0.96 - (0.5 - plcov) * (albni - 0.25)/1.5)$$

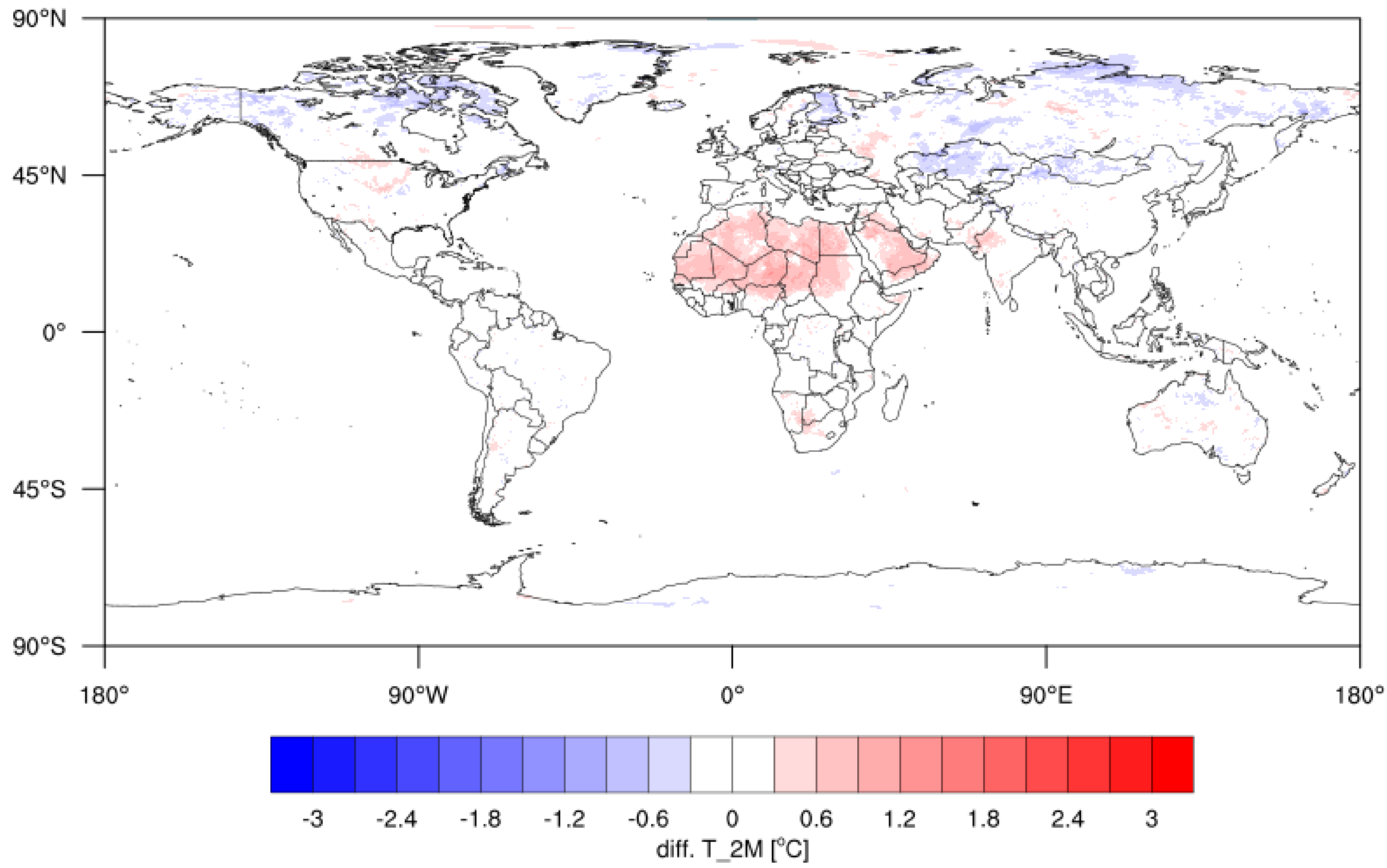
$$ENDIF$$

$$lw\_emiss = (1 - snowfrac) * lw\_emiss + (1 - 10^{-3} * gz0) * snowfrac$$

Longwave Emissivity (mod-orig)

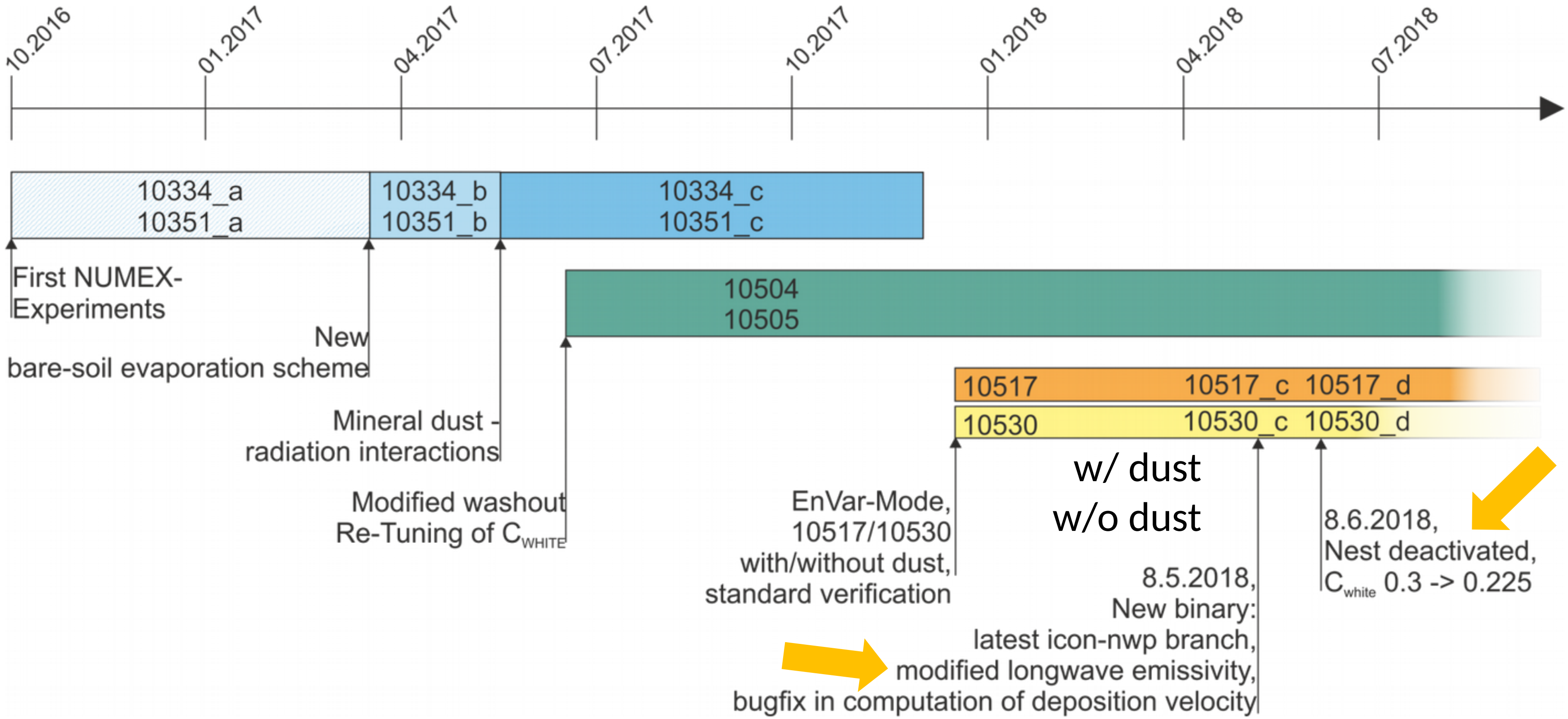


2m-Temperature (mod-orig)



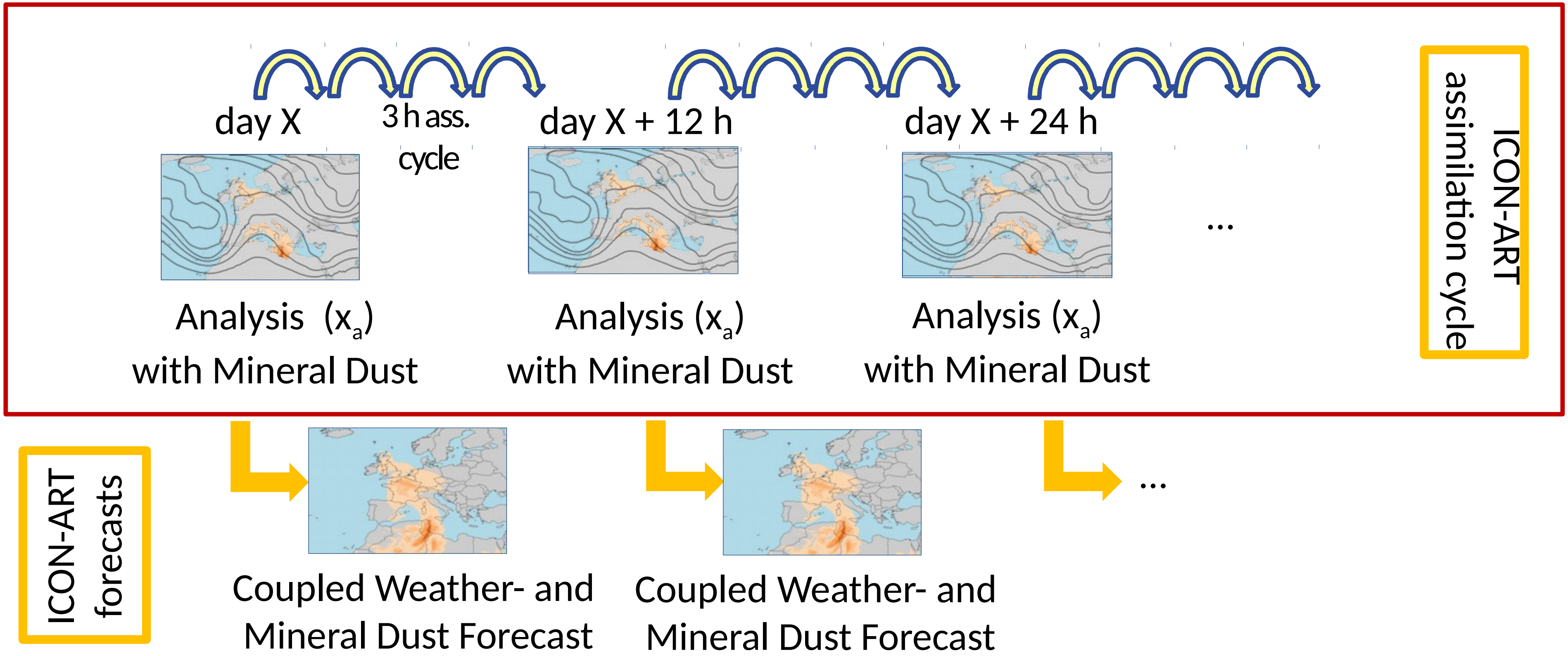
Mean over all +168 h (+7 d) forecasts from 31 forecast runs in January 2018, 00:00 UTC

PerduS - milestones



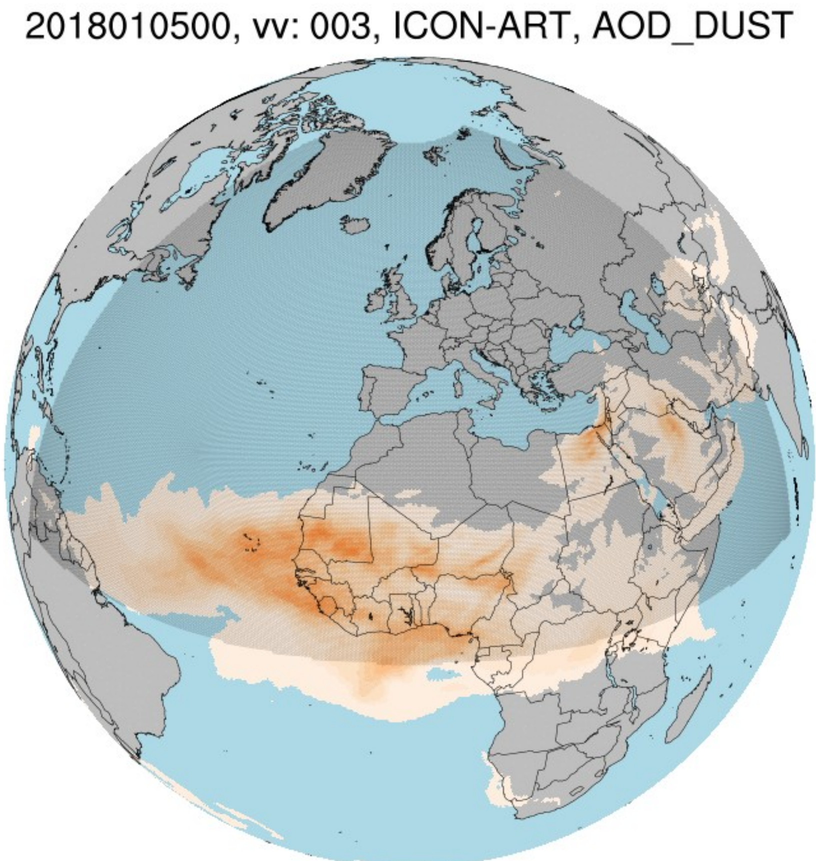
ICON-ART in EnVar mode

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Take home message: First guess forecasts (x_b) in assimilation cycle are ICON-ART forecasts with mineral dust, including aerosol radiation interactions

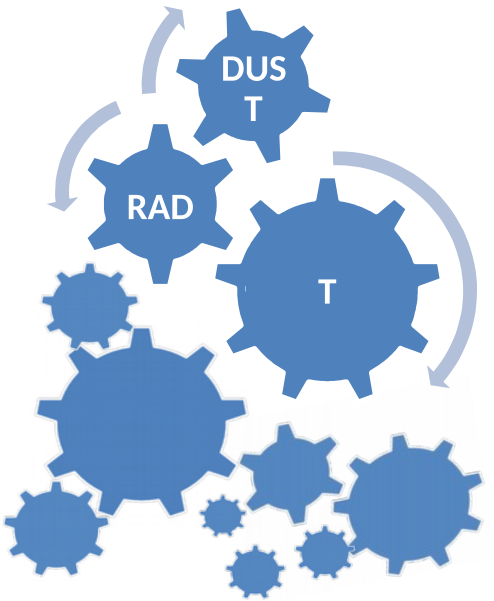
ICON-ART in EnVar mode



- ➔ Daily 00/12 UTC forecast runs with a lead time up to +180h (Nest: 120h)
- ➔ With / without prognostic dust
- ➔ How good is the NWP forecast with prognostic dust-radiation interactions?
- ➔ How does the forecasted mineral dust compare with the used Tegen climatology*) for mineral dust?

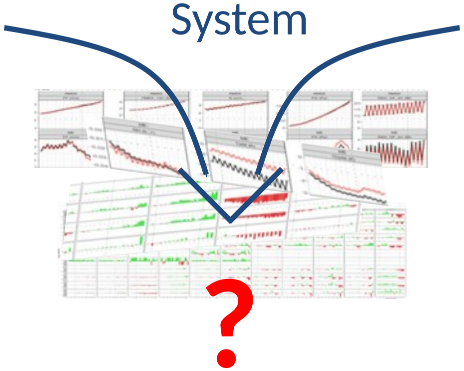
*) Tegen et al. (1997)

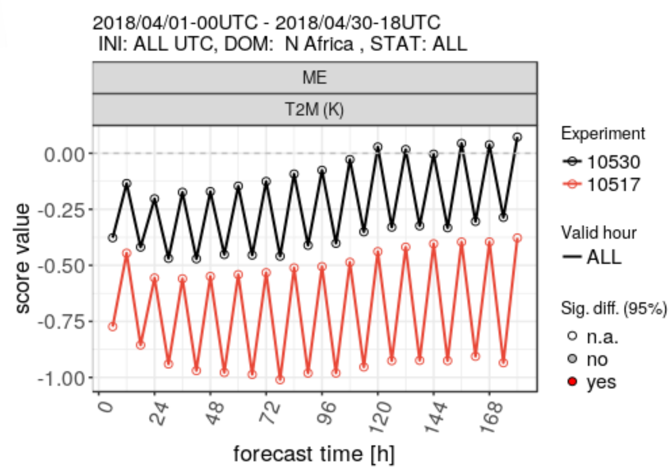
Verification



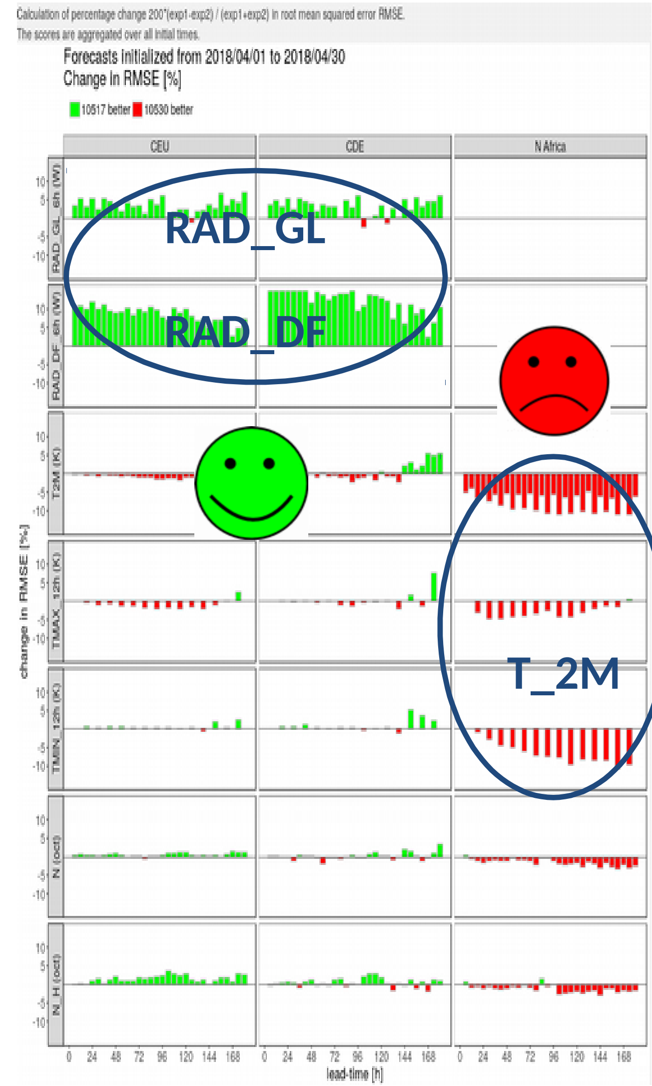
- ➔Improved
  DE/EU scores
- ➔**BUT:**
  Significant deterioration of negative Temperature Bias in N-Africa

Automated Verification System

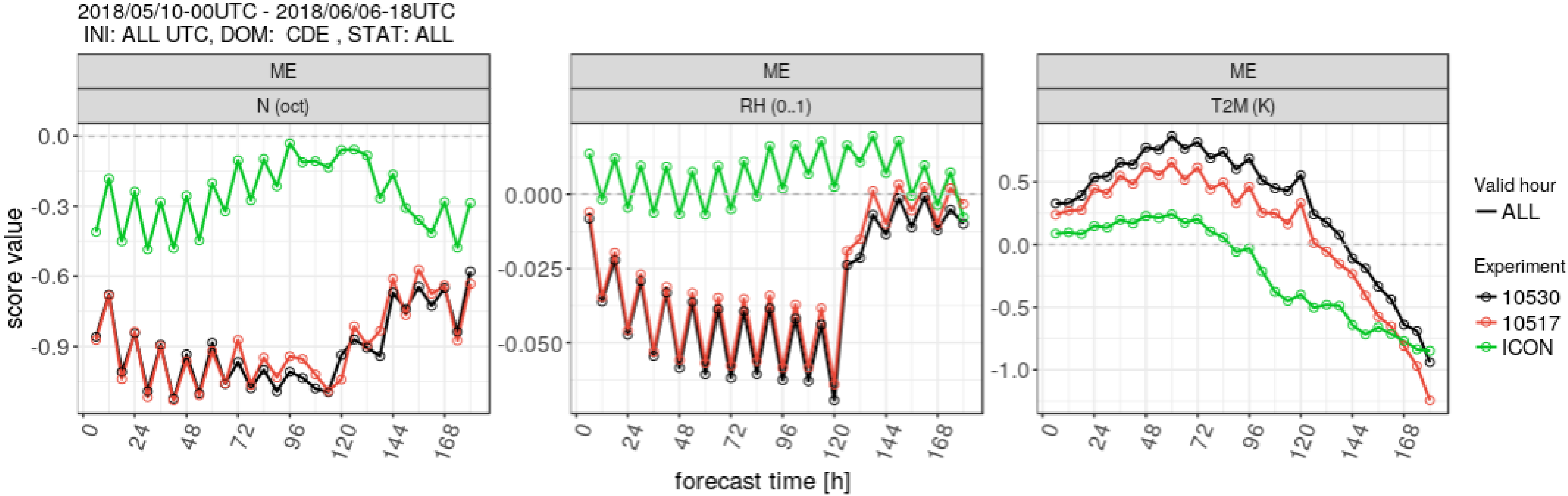




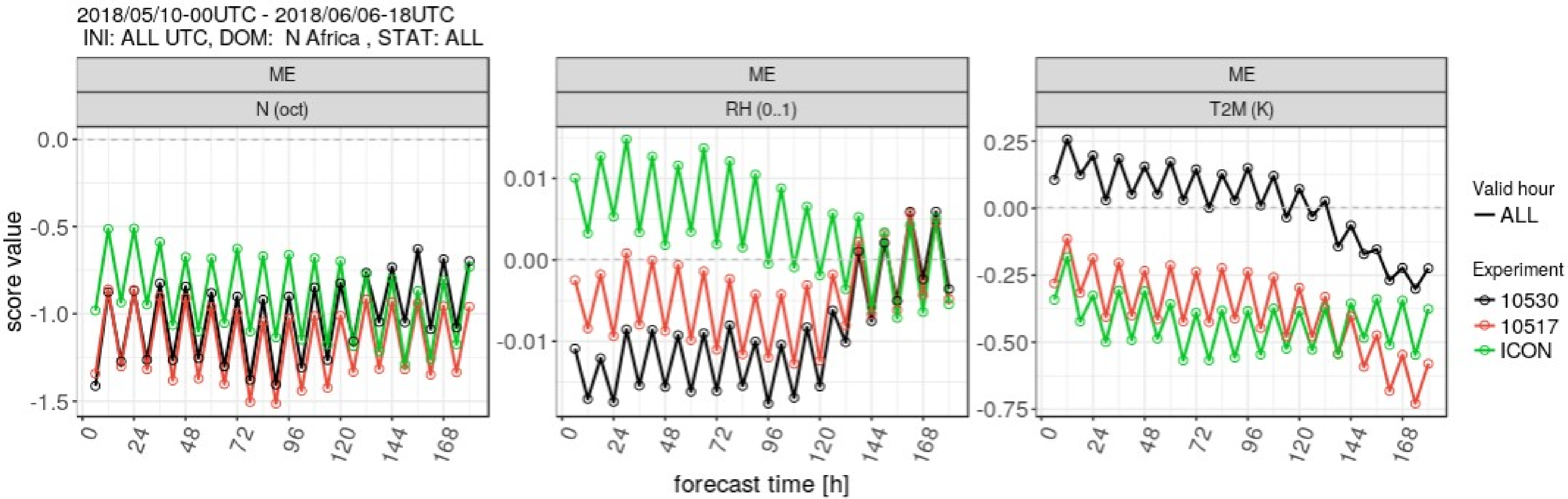
with, without prog. dust



Domain: CDE



Domain: N Africa

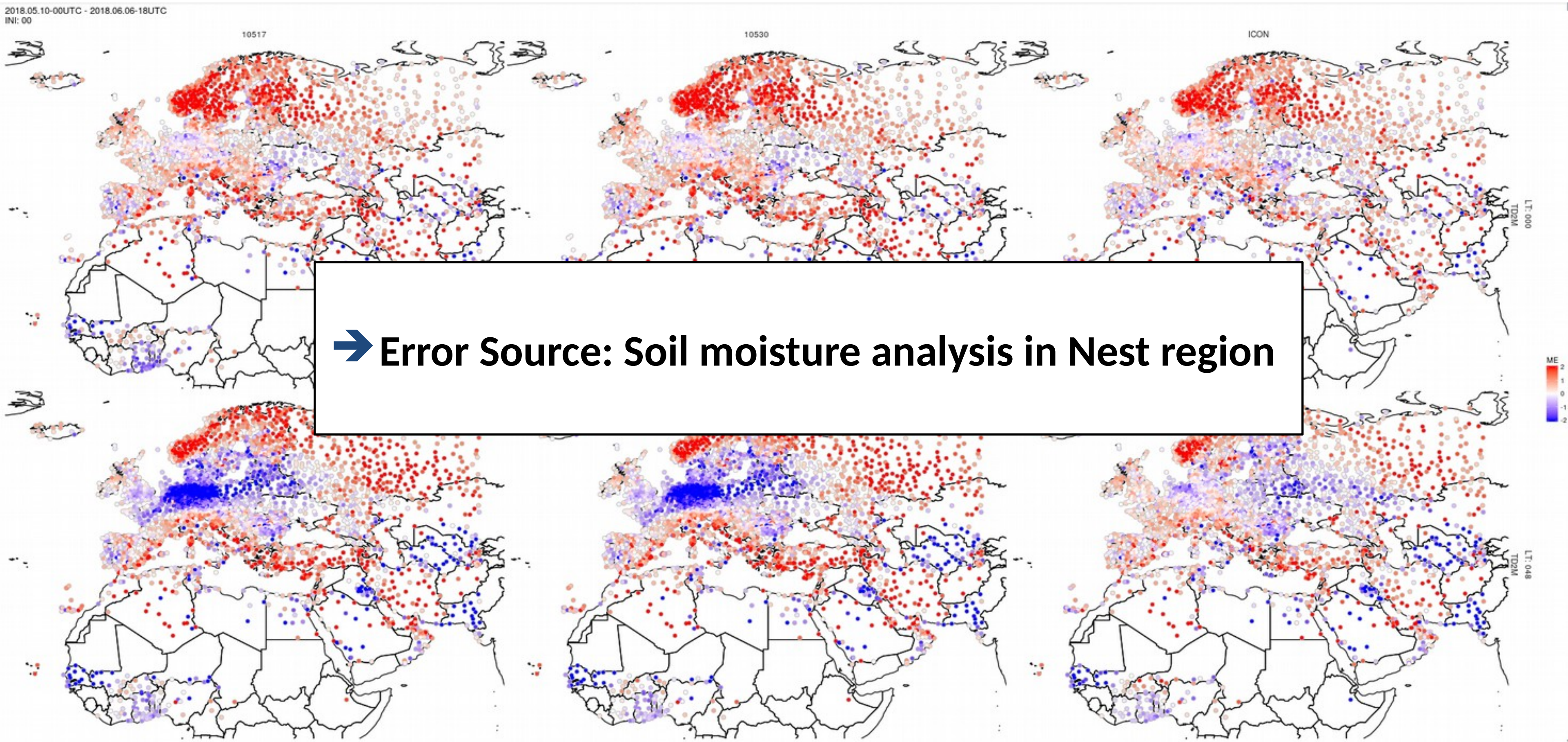


Bias 2m-Dew Point

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

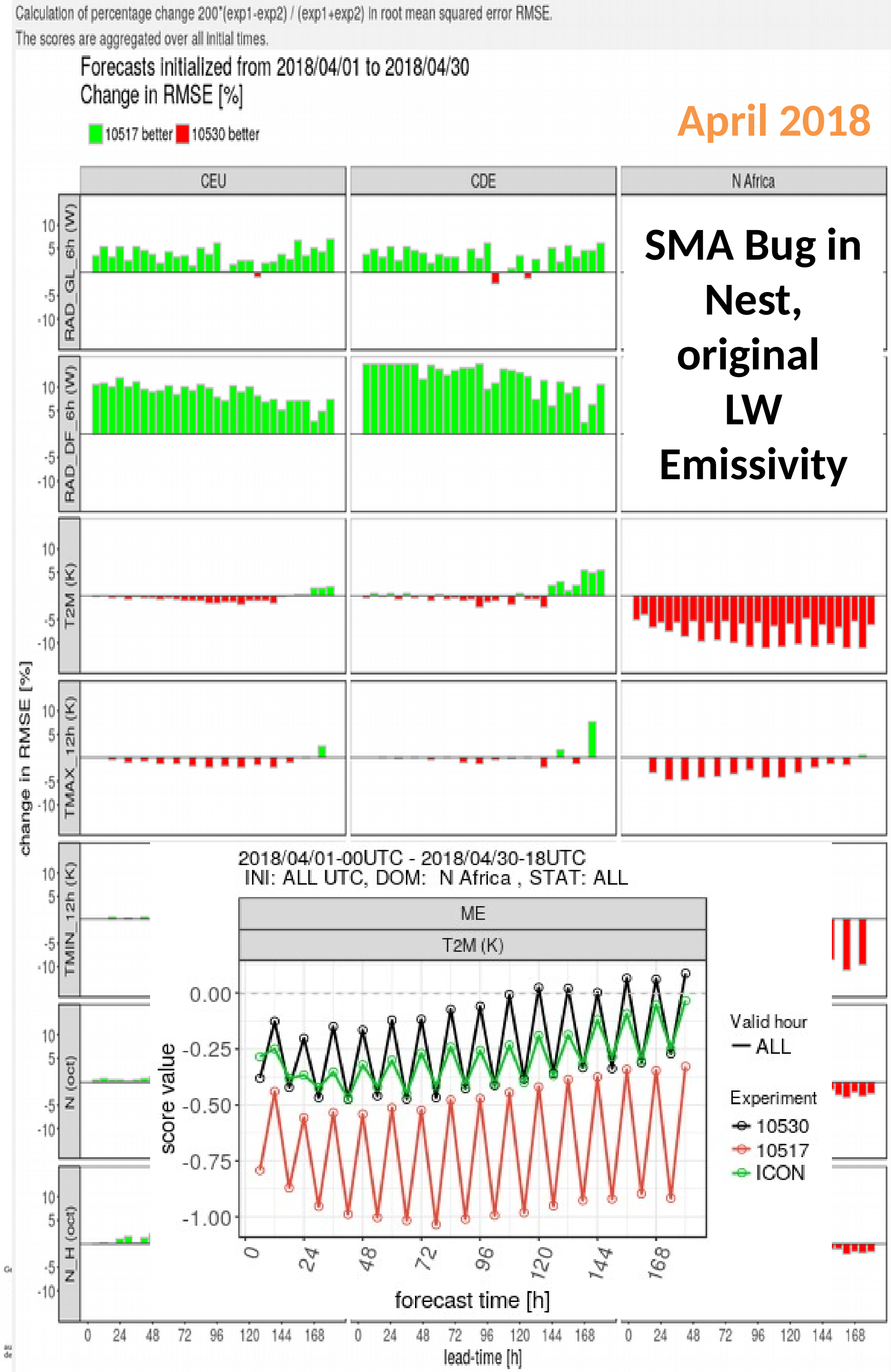
ICON-ART (10517) R2B06 **Referenz (10530) R2B06** **ICON R3B07**

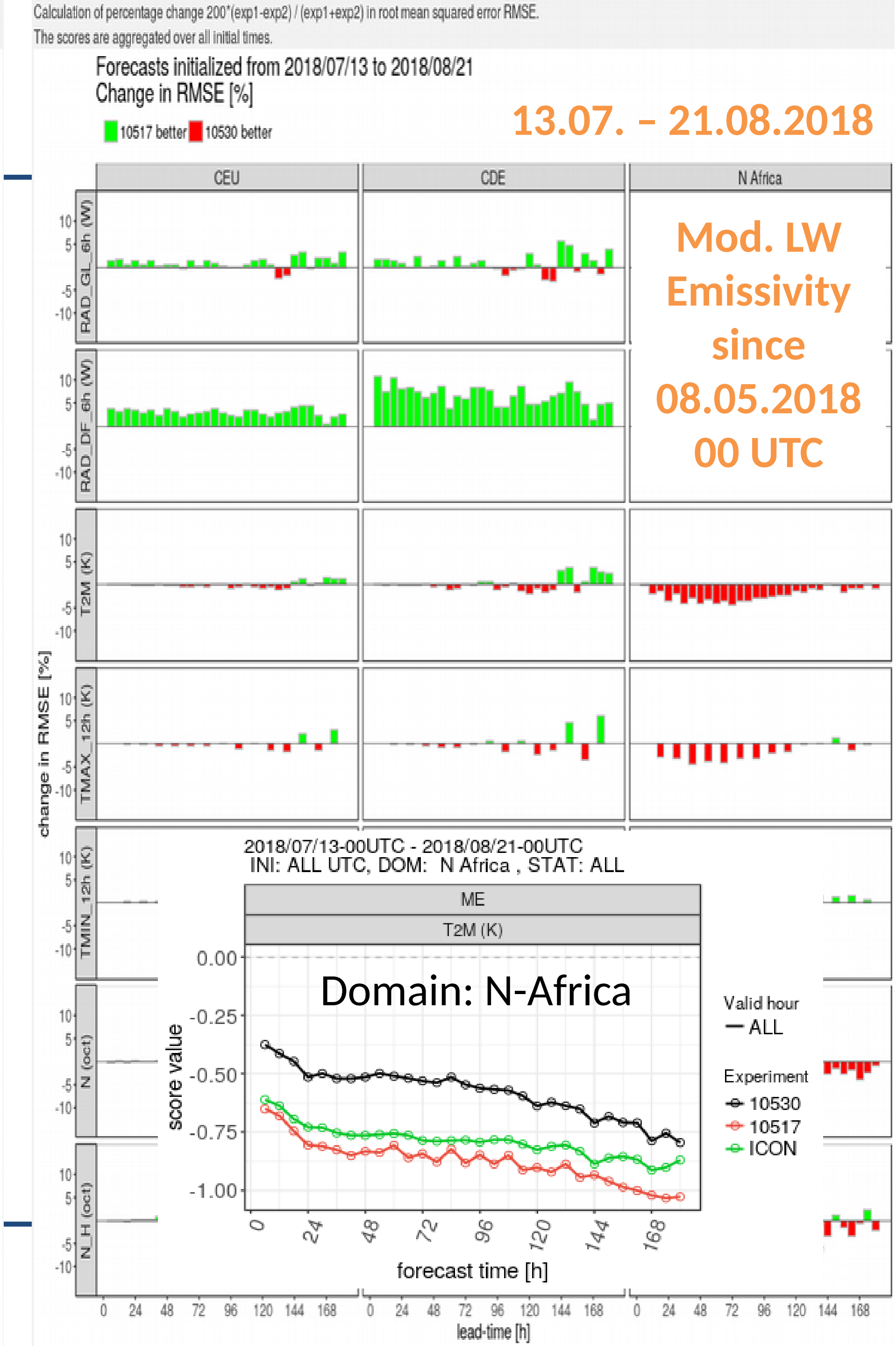
Lead time 0



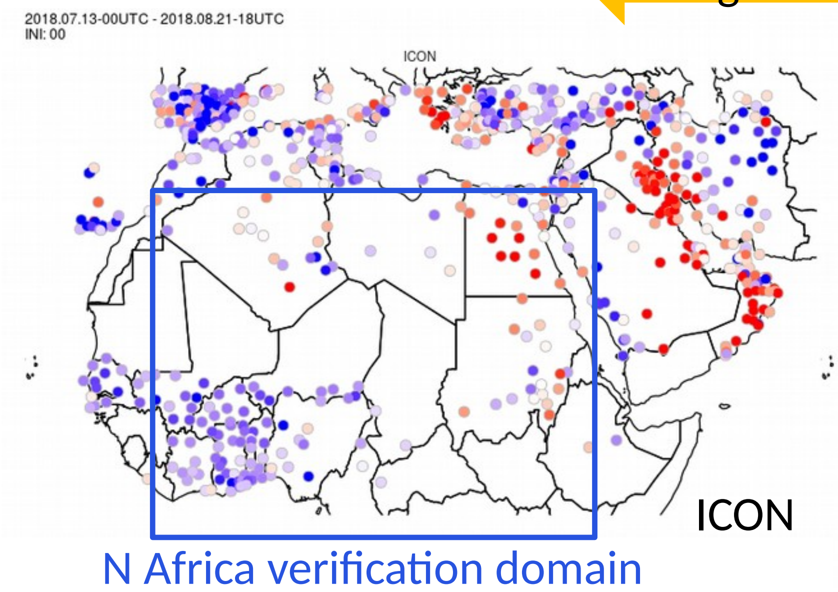
➔ Error Source: Soil moisture analysis in Nest region

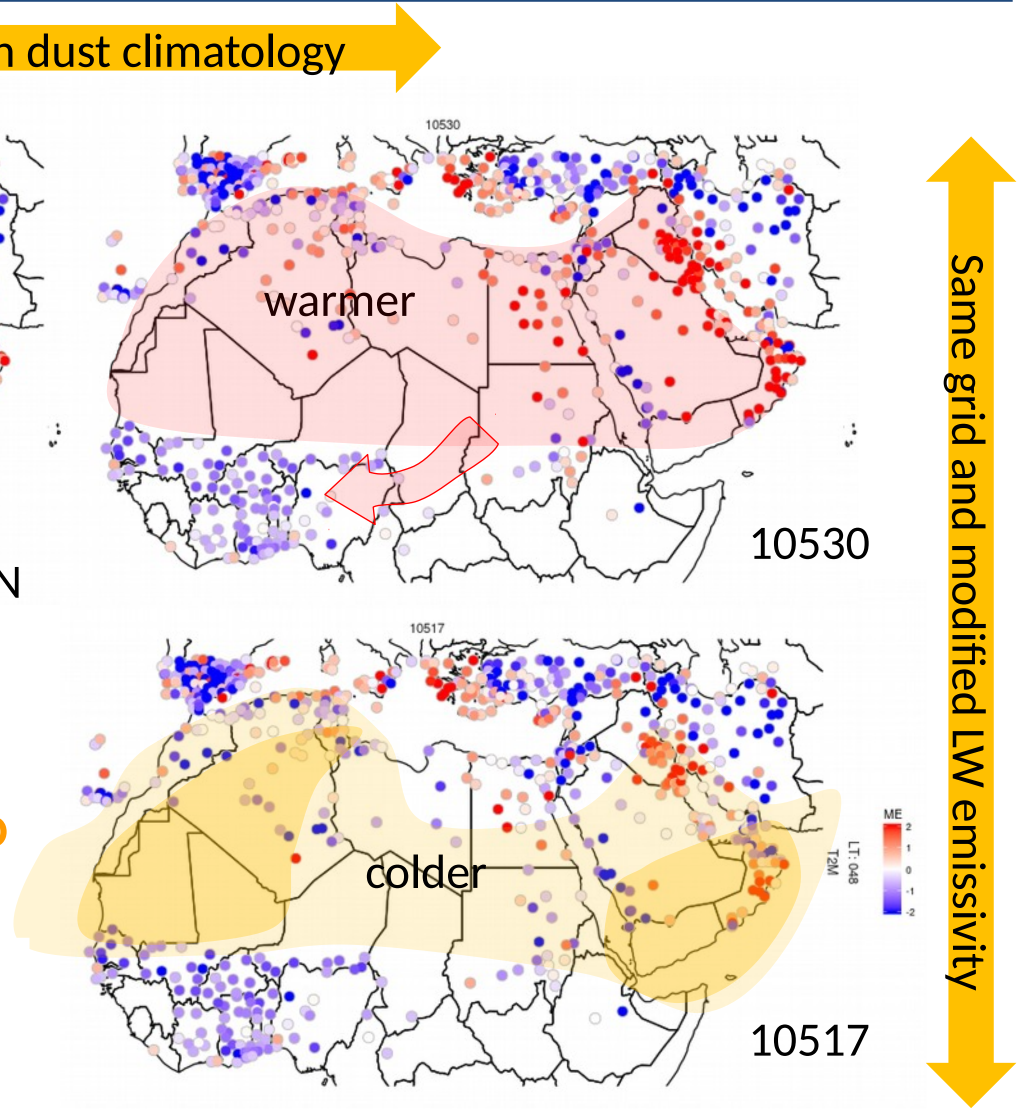
Lead time 48


Calculation of percentage change 200*(exp1-exp2) / (exp1+exp2) in root mean squared error RMSE.
The scores are aggregated over all initial times.
Forecasts initialized from 2018/04/01 to 2018/04/30
Change in RMSE [%]
10517 better
10530 better
April 2018
CEU
CDE
N Africa
SMA Bug in Nest, original LW Emissivity
RAD_GL_6h (W)
RAD_DF_6h (W)
T2M (K)
TMAX_12h (K)
TMIN_12h (K)
N (oct)
N_H (oct)
change in RMSE [%]
lead-time [h]
2018/04/01-00UTC - 2018/04/30-18UTC
INI: ALL UTC, DOM: N Africa , STAT: ALL
ME
T2M (K)
score value
forecast time [h]
Valid hour
ALL
Experiment
10530
10517
ICON


Calculation of percentage change 200*(exp1-exp2) / (exp1+exp2) in root mean squared error RMSE.
The scores are aggregated over all initial times.
Forecasts initialized from 2018/07/13 to 2018/08/21
Change in RMSE [%]
10517 better
10530 better
13.07. – 21.08.2018
CEU
CDE
N Africa
Mod. LW Emissivity since 08.05.2018 00 UTC
RAD_GL_6h (W)
RAD_DF_6h (W)
T2M (K)
TMAX_12h (K)
TMIN_12h (K)
N (oct)
N_H (oct)
change in RMSE [%]
lead-time [h]
2018/07/13-00UTC - 2018/08/21-00UTC
INI: ALL UTC, DOM: N Africa , STAT: ALL
ME
T2M (K)
Domain: N-Africa
score value
forecast time [h]
Valid hour
ALL
Experiment
10530
10517
ICON

Bias 2m-Temperature





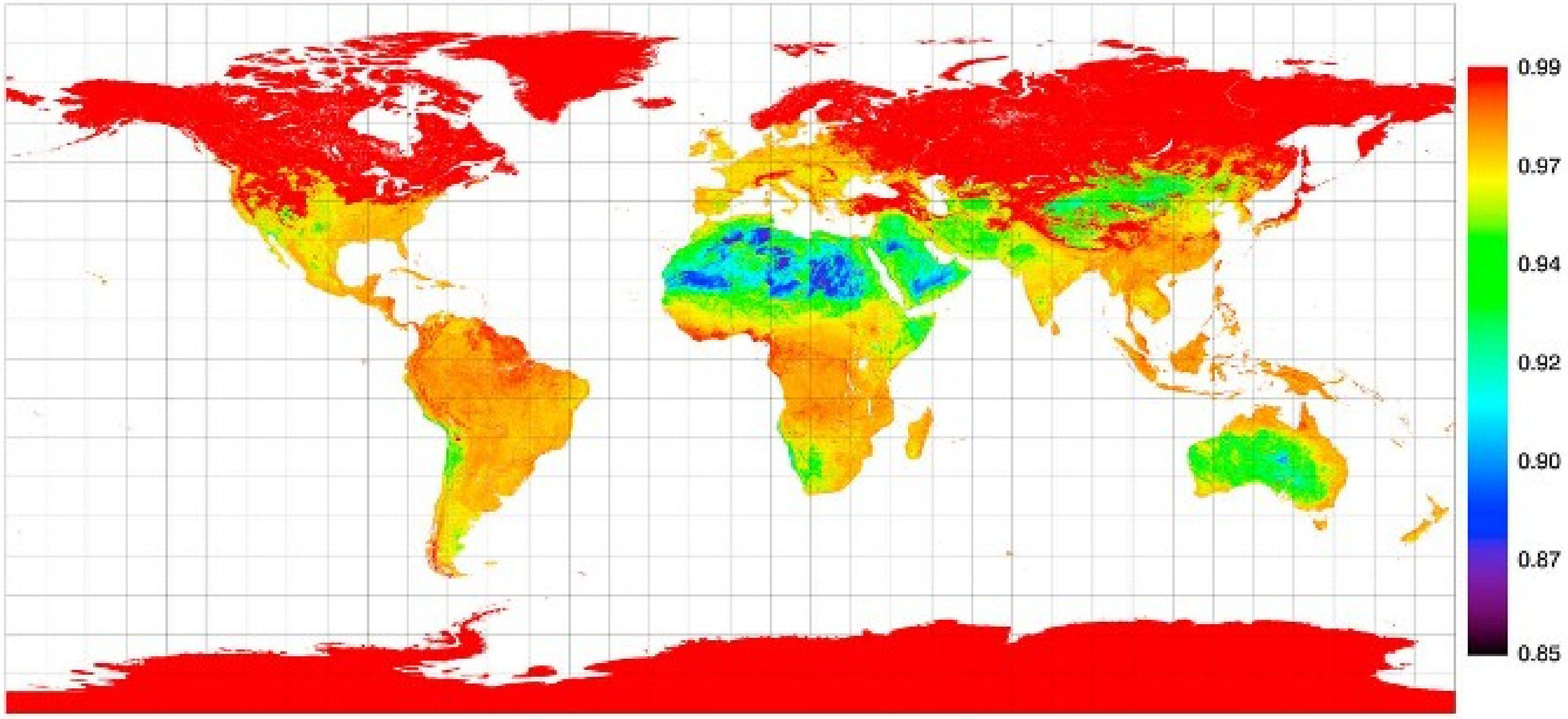
Changed LW-Emissivity

Regions with high Dust AOD

→ Cold Bias in **South-West** Africa; needs further investigation

Longwave Emissivity (obs)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



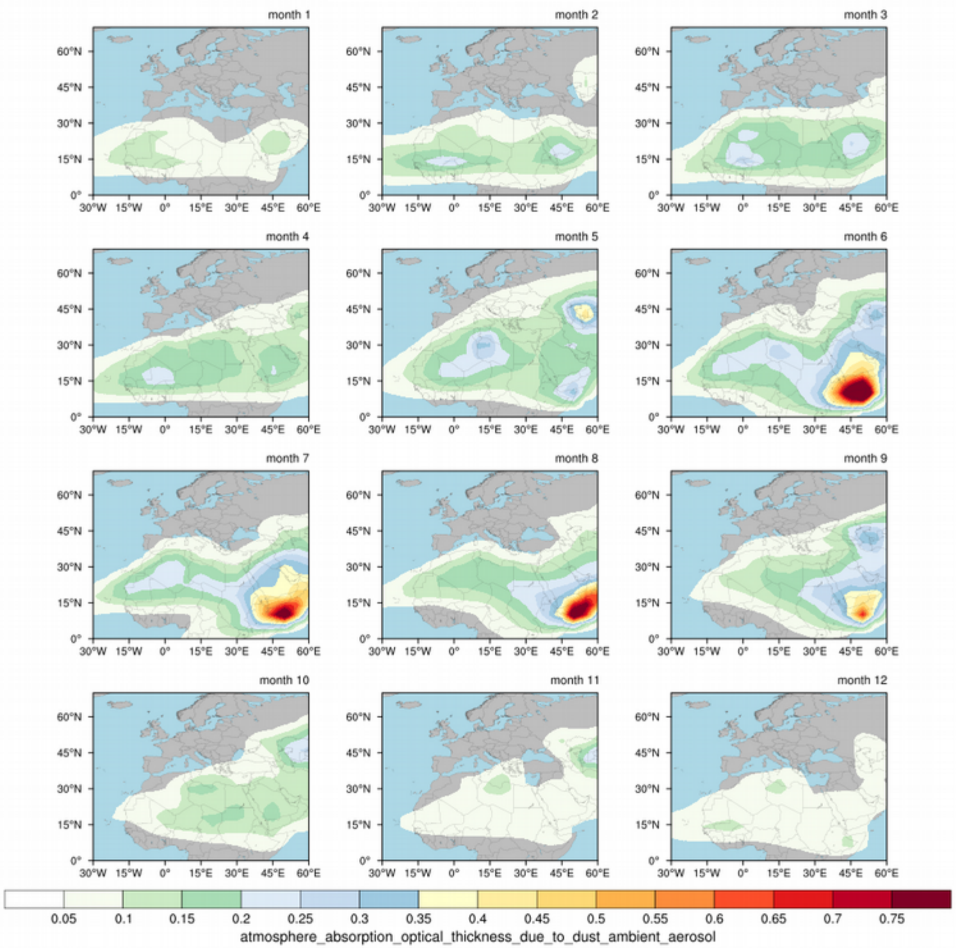
➔Planned: provide new external dataset of LW Emissivity for operational ICON
e.g.: after Cheng and Liang (2014)

Cheng, J. and S. Liang (2014). Estimating the broadband longwave emissivity of global bare soil from the MODIS shortwave albedo product. *Journal of Geophysical Research: Atmospheres, 119(2):614–634*.

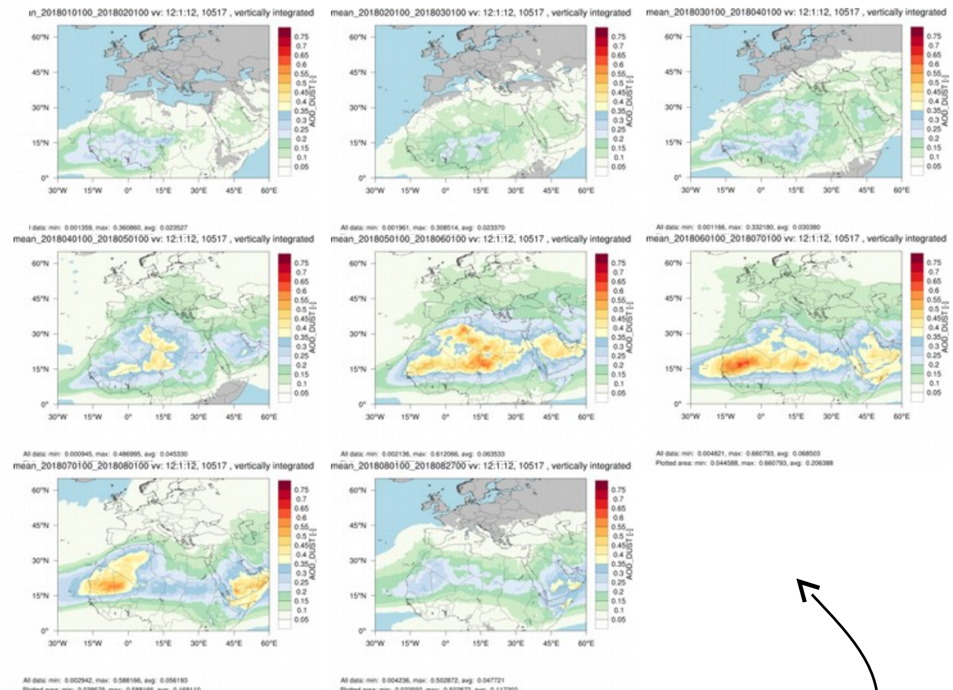
Monthly mean Dust AODs

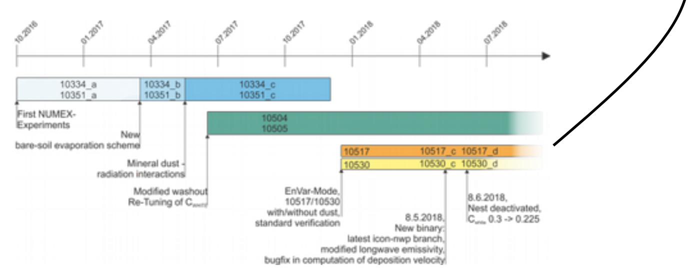
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Tegen



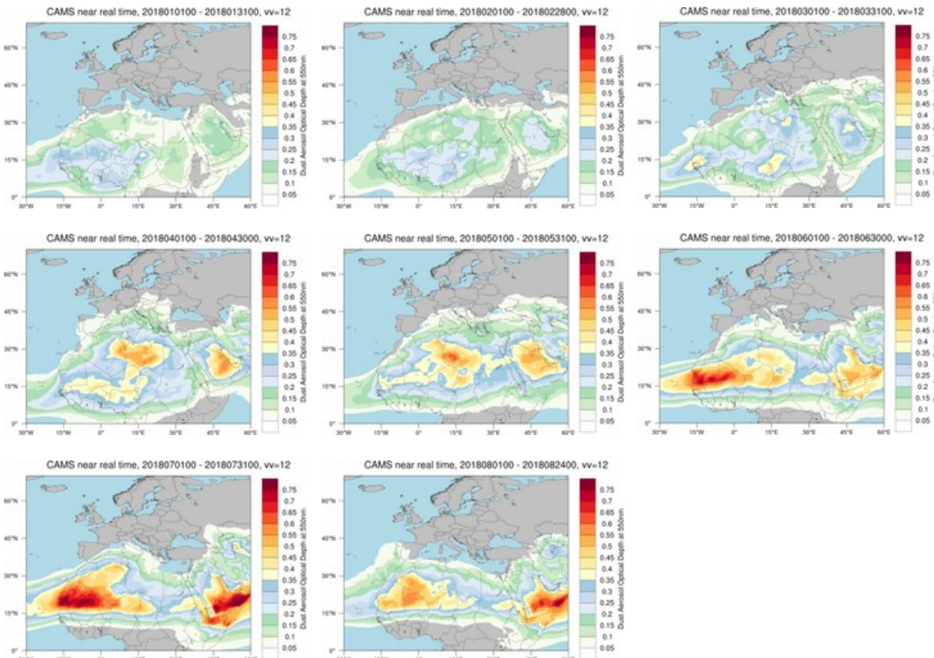
ICON-ART



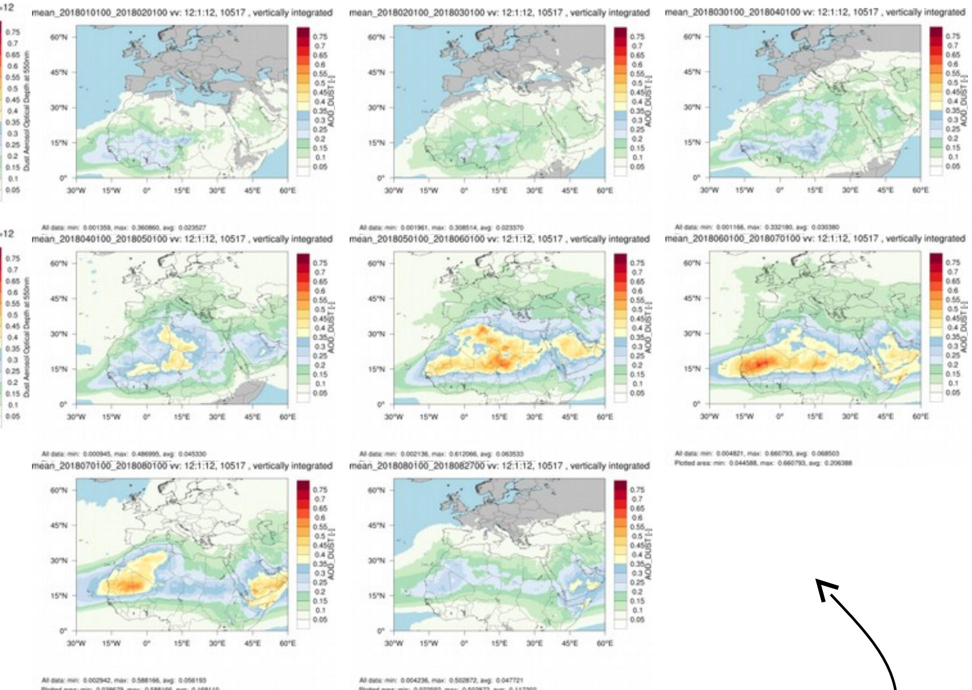


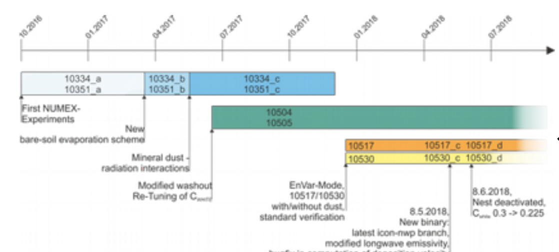
Monthly mean Dust AODs

CAMS



ICON-ART





ICON-ART Runtime optimizations

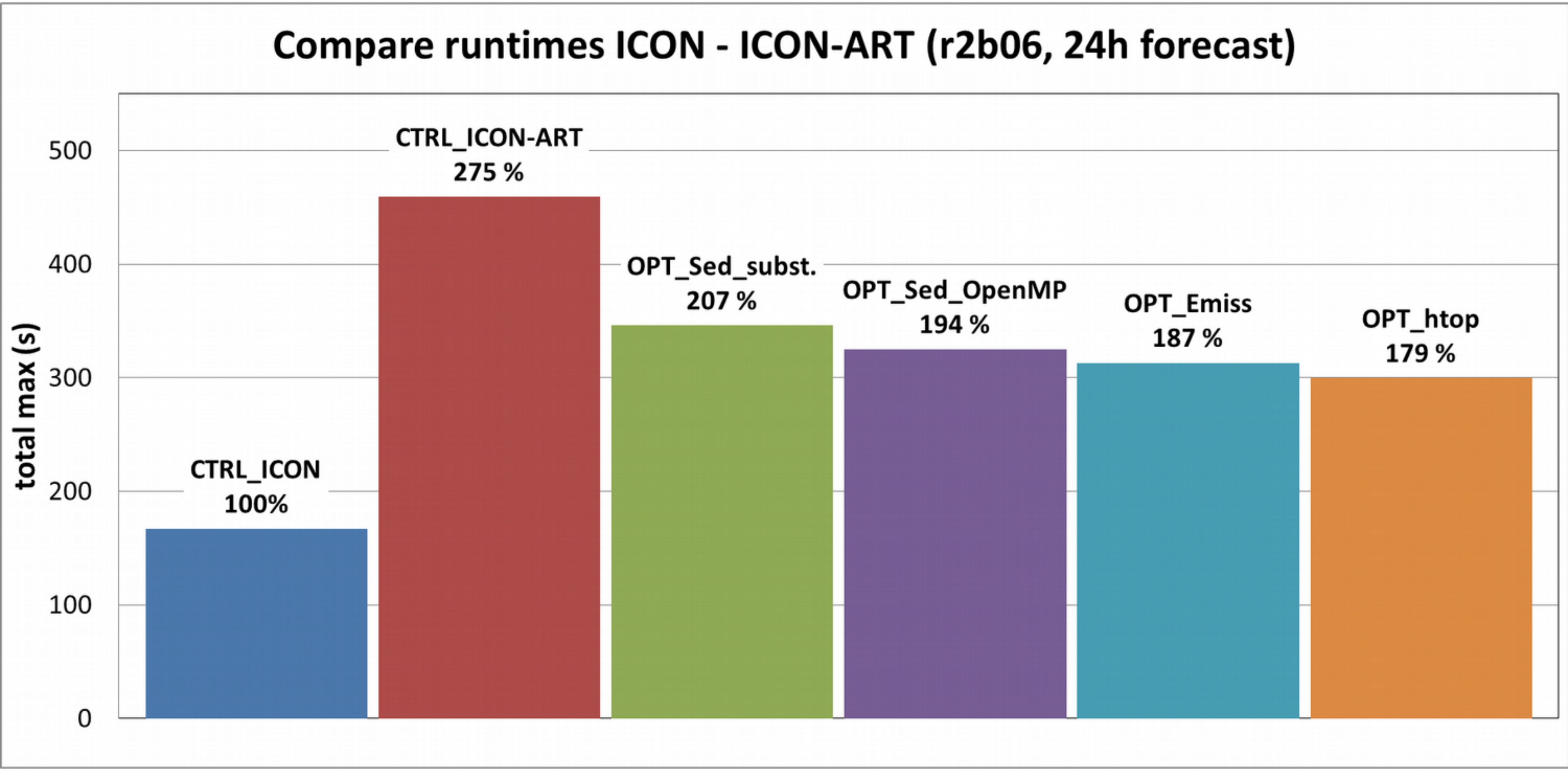
Compare runtimes of:

- ICON(-ART) R2B06, +24h

Name	Time	Short Description
CTRL_ICON-ART lart=.false.	100 %	
CTRL_ICON-ART	275 %	
OPT_Sed_substepping	207 %	substepping for flux calculation only, nart_substeps_sedi=2
OPT_Sed_OpenMP	195 %	OpenMP parallelization in sedimentation routine
OPT_Emiss	187 %	Precalculations outside soil type loop and smart formulae implementation
OPT_htop	179 %	Consider art-transport & physics only up to htop_art_poc (cf. htop_moist_proc)

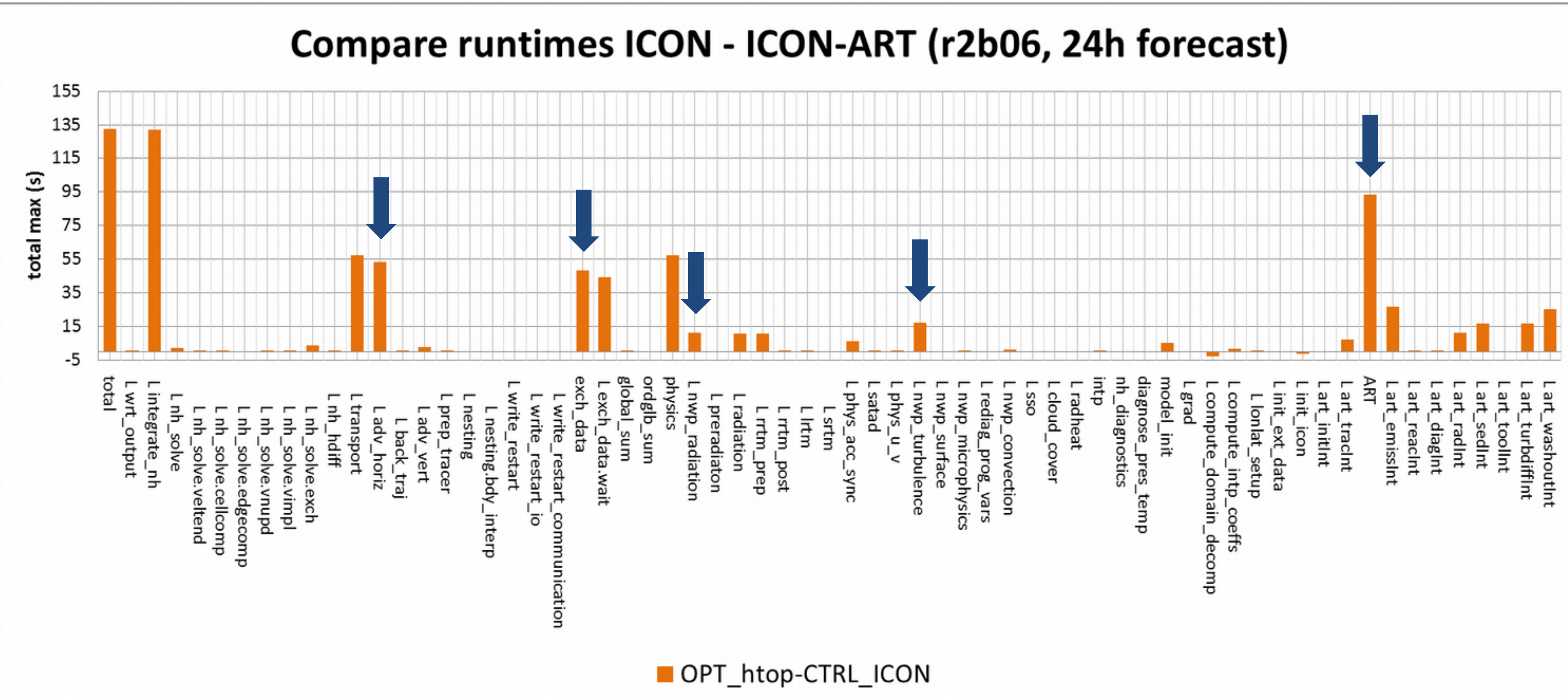
ICON-ART Runtime optimizations

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Increments due to ART modules

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

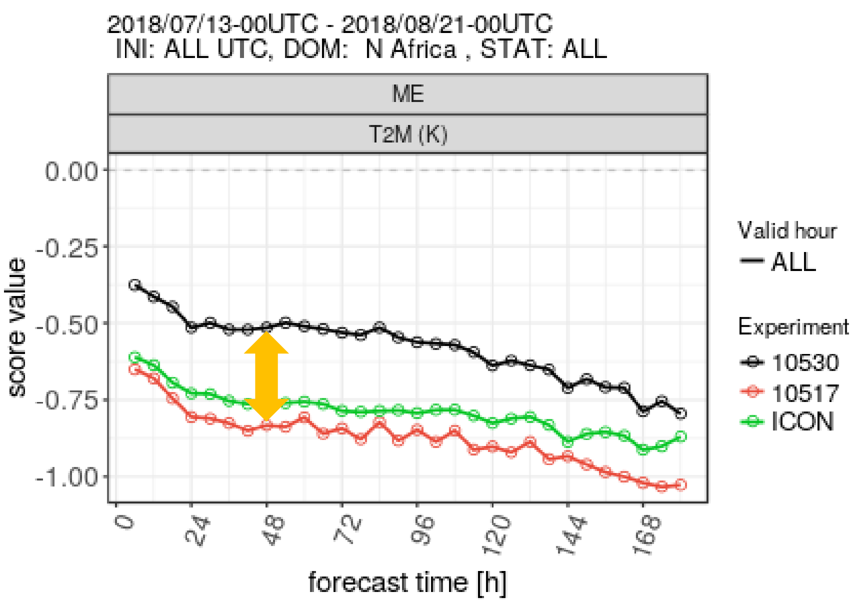


ART-related processes with largest impact on runtime:

- ➔ Horizontal transport
- ➔ Exchange data
- ➔ Turbulence
- ➔ Radiation
- ➔ Additional ART modules

Summary

- ICON-ART runtime optimizations (275% □ 179%)
- Bug in SMA has been recognized and has just been fixed
- ReSQME – T-Bias in N-Africa:
  - Modified LW Emissivity reduces negative Temperature Bias in N-Africa (ICON vs **10530**), T-Bias in SW-Africa needs further investigation



T-Bias in N-Africa in Dust Experiment:

- Dust Optical Properties under revision
- Dust Size Distribution under revision
- Tuning of Dust Emission
- … these modifications will likely worsen the Temperature Bias in N-Africa (?)
- How accurate is the moisture content in the atmosphere? (but: upper air verification shows already a positive rel. Humidity Bias)

Other ideas?

Literature

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

→ Gasch, P., Rieger, D., Walter, C., Khain, P., Levi, Y., Knippertz, P., and Vogel, B.: Revealing the meteorological drivers of the September 2015 severedust event in the Eastern Mediterranean, *Atmospheric Chemistry and Physics*, 17, 13573–13604, doi: https://doi.org/10.5194/acp-17-13573-2017

→Rieger, D., Bangert, M., Bischoff Gauss, I., Förstner, J., Lundgren, K., Reinert, D., Schröter, J., Vogel, H., Zängl, G., Ruhnke, R., and Vogel, B., 2015: ICON–ART 1.0 – a new online-coupled model system from the global to regional scale, Geosci. Model Dev., 8, 1659–1676

→ Rieger, D., Steiner, A., Bachmann, V., Gasch, P., Förstner, J., Deetz, K., Vogel, B., and Vogel, H.: Impact of the 4 April 2014 Saharan dust outbreak on the photovoltaic power generation in Germany, *Atmospheric Chemistry and Physics*, 17, 13391 – 13415, doi:10.5194/acp-17-13391-2017

→ Tegen, I., Hollrig, P., Chin, M., Fung, I., Jacob, D., and Penner, J. et al., Contribution of different aerosol species to the global aerosol extinction optical thickness: Estimates from model results, *J. Geophys. Res.*, 1997, 102, 23895–23915

→ K. Ogawa and T. Schmugge 2004: Mapping Surface Broadband Emissivity of the Sahara Desert Using ASTER and MODIS Data. *Earth Interactions, 8(7):1–14.*

→ Cheng, J. and S. Liang 2014: Estimating the broadband longwave emissivity of global bare soil from the MODIS shortwave albedo product. *Journal of Geophysical Research: Atmospheres, 119(2):614–634*.

ICON-ART in EnVar Mode

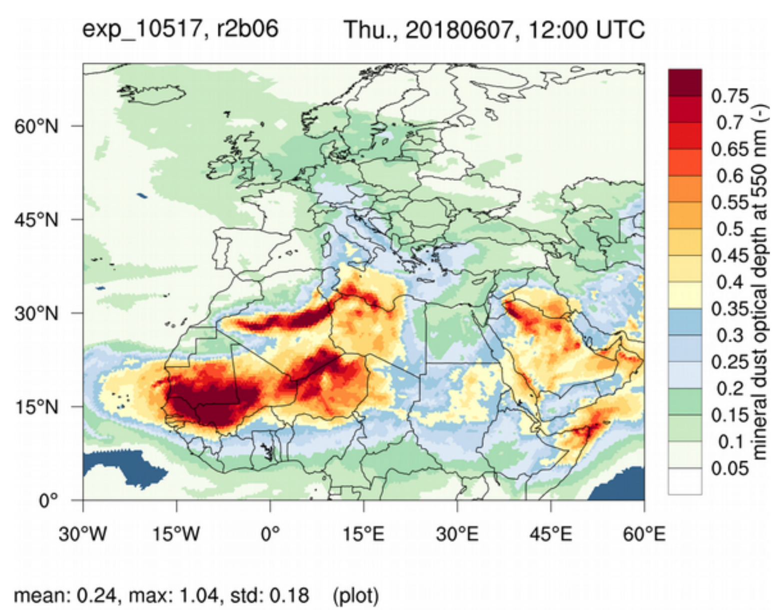
Changes since 8 May 2018

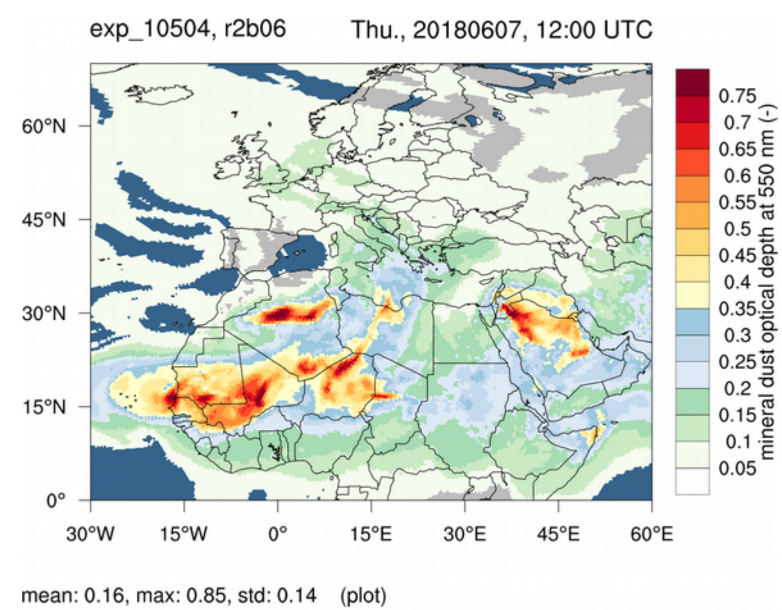
➔ Modified LW Emissivity

➔ ICON-ART binary is based on icon-nwp-dev branch (not anymore on icon-kit-dev), this includes namelist-settings of operational NWP routine

➔ „Double Counting“ for sedimentation removed

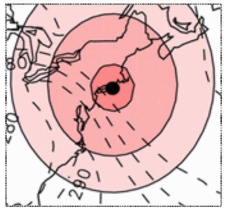
$$\hat{v}_{\mathrm{dep},k} = \left(r_a + \hat{r}_{d,k} + r_a \cancel{\hat{r}_{d,k}} \hat{v}_{\mathrm{sed},k}\right)^{-1} + \cancel{\hat{v}_{\mathrm{sed},k}}$$

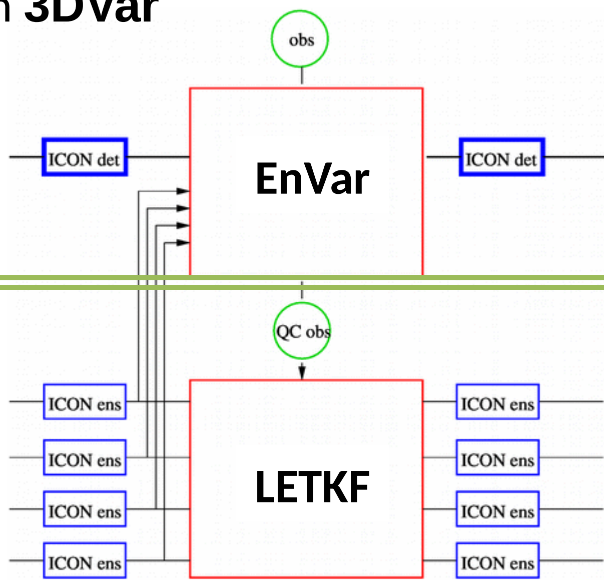




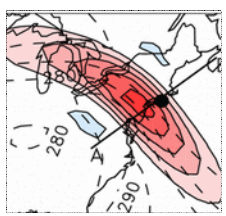
EnVar

Climatological B-matrix "NMC method" based on **3DVar**





flow dependent B-matrix based on **EDA**



3DVar/EnVar:

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{W}\left(\mathbf{y}_o - H\left(\mathbf{x}_b\right)\right)$$

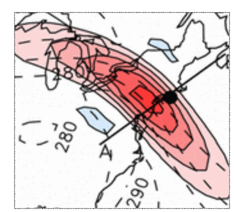
$$\mathbf{W} = \mathbf{B}\,\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$$

3DVar <— EnVar

ensemble background error covariance matrix in a variational context:

$$\mathbf{B}_{hybrid} = \alpha\,\mathbf{B}_{EnKF} + \beta\,\mathbf{B}_{3DVar}$$

α = 0.7
β = 0.3



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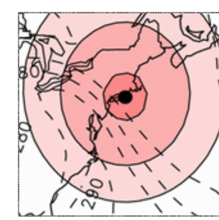
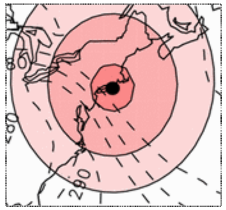
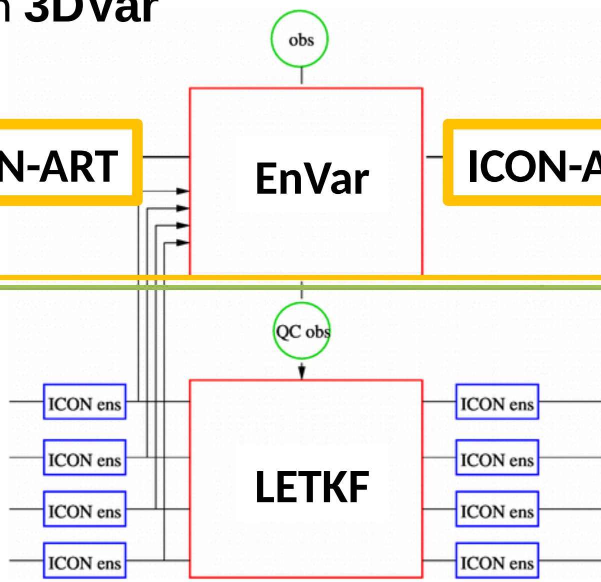


EnVar with dust

Climatological B-matrix “NMC method” based on **3DVar**

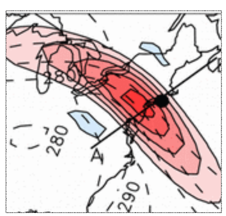




ICON-ART

ICON-ART

flow dependent B-matrix based on **EDA**



3DVar/EnVar:

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{W}(\mathbf{y}_0 - H(\mathbf{x}_b))$$

First guess

$$\mathbf{W} = \mathbf{B}\,\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$$

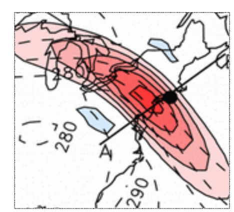
3DVar ⟷ EnVar

ensemble background error covariance matrix in a variational context:

$$\mathbf{B}_{hybrid} = \alpha\,\mathbf{B}_{EnKF} + \beta\,\mathbf{B}_{3DVar}$$

$\alpha = 0.7$

$\beta = 0.3$



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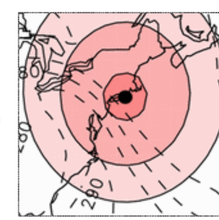


Verifikation

➔ **ICON (operationell) in Sahararegion:**

zu sonnig, zu trocken, zu kalt

➔ **Erwartung / Hoffnung:**

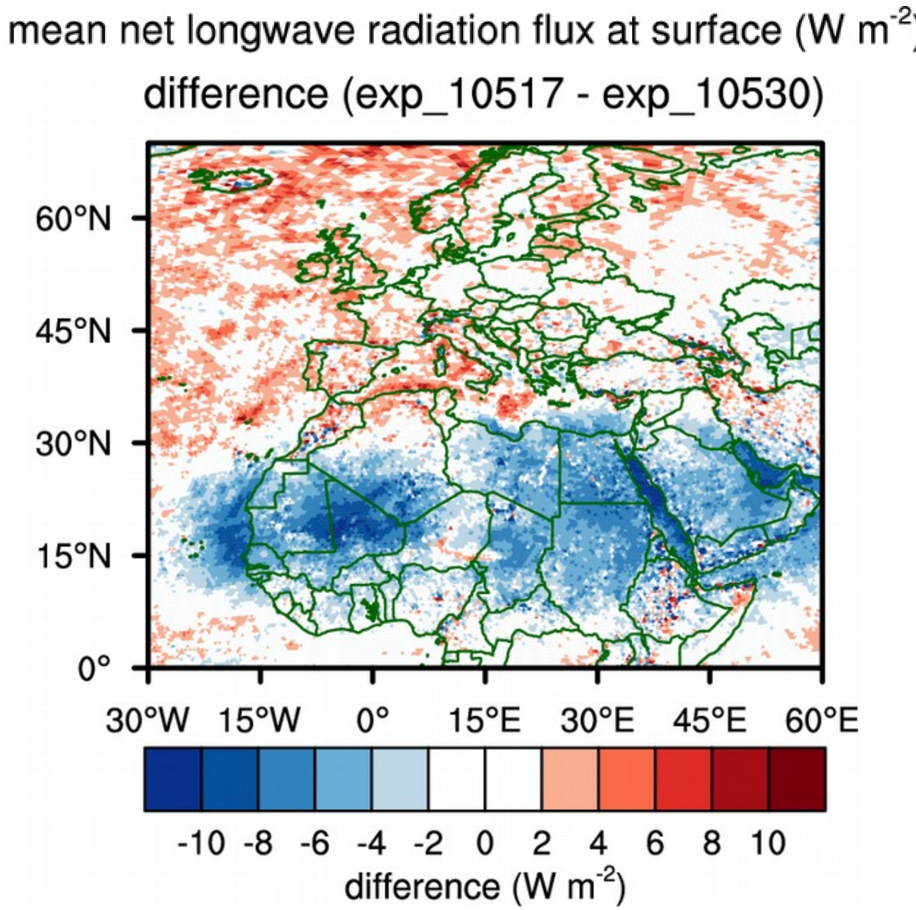
Langwellige Strahlungsheizung durch erhöhte Staubkonzentration reduziert den negativen Temperatur Bias in N-Afrika (wie in Fallstudien gezeigt z. B. Gasch et al., 2017)

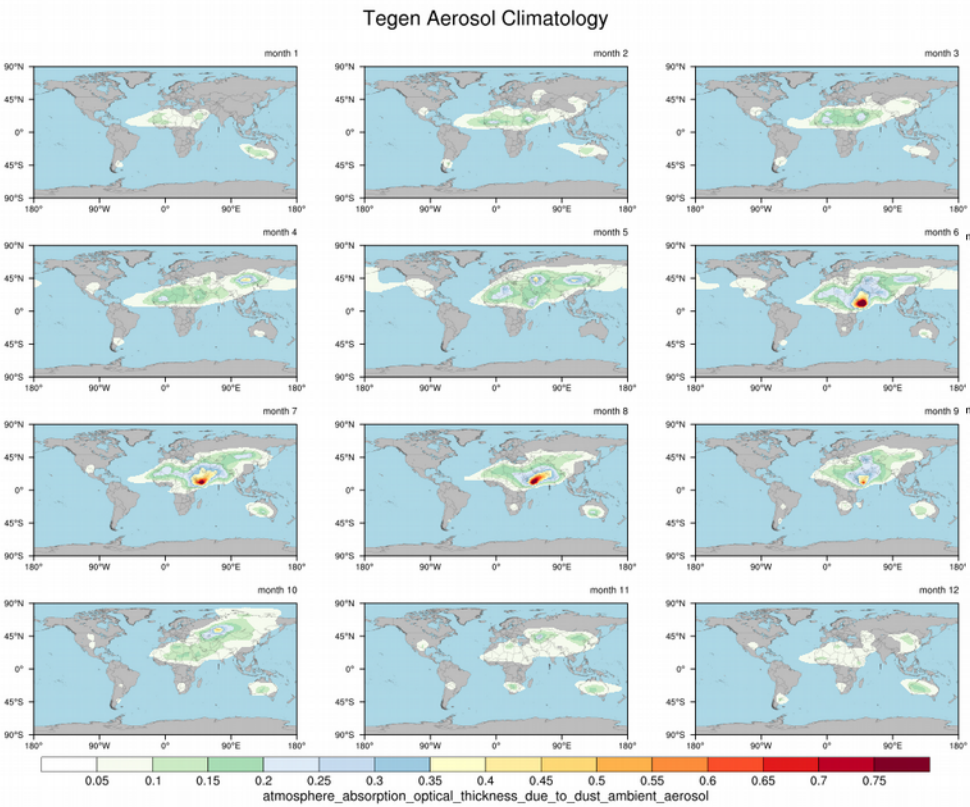
➔ **ABER:**

Im Mittel:

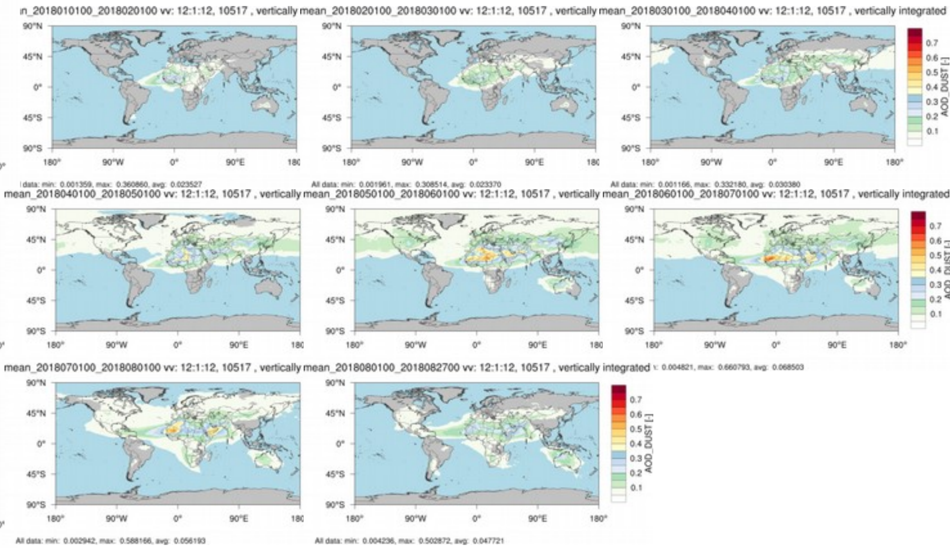
kurzwelligen Strahlungseffekte > langwelligen Strahlungseffekte durch erhöhte Staubkonzentration

2018/04, 21 UTC – 3UTC



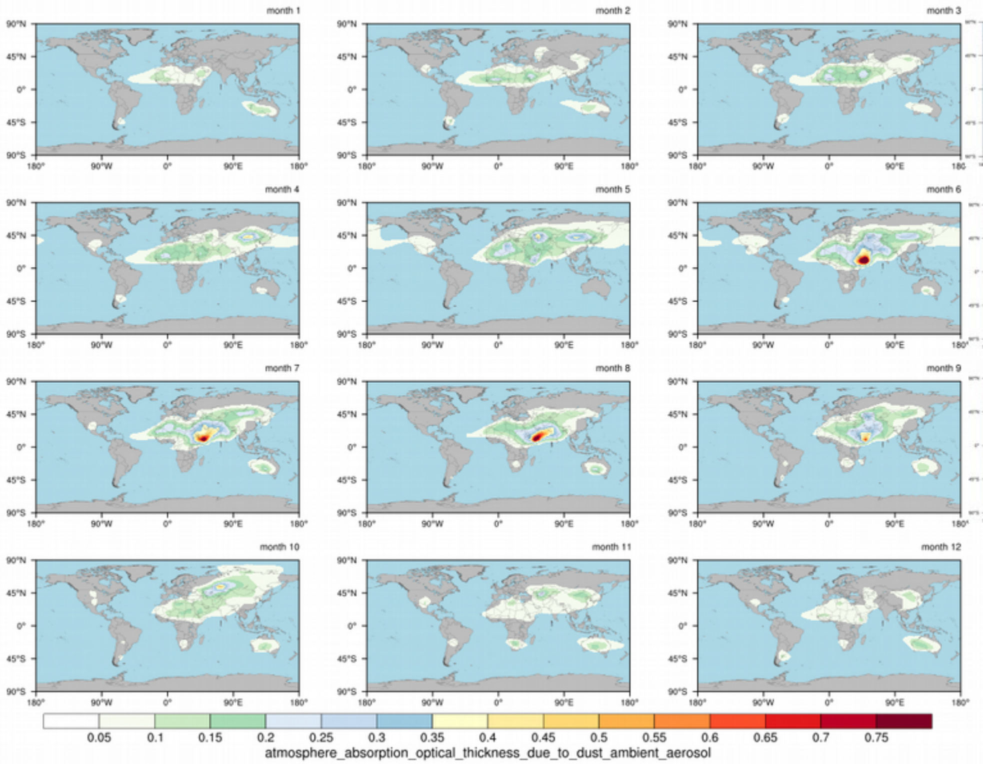


ICON-ART

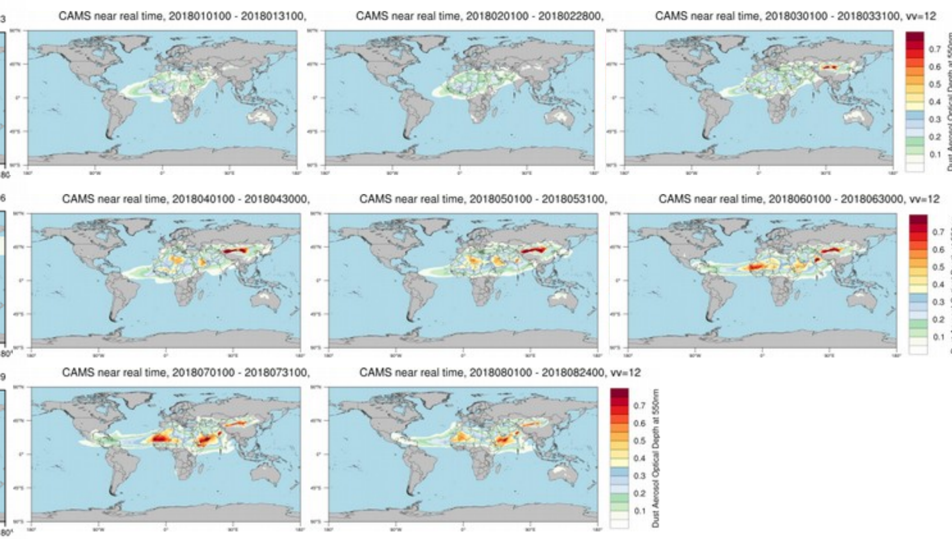


Too less dust emission from desert Gobi in ICON-ART ?

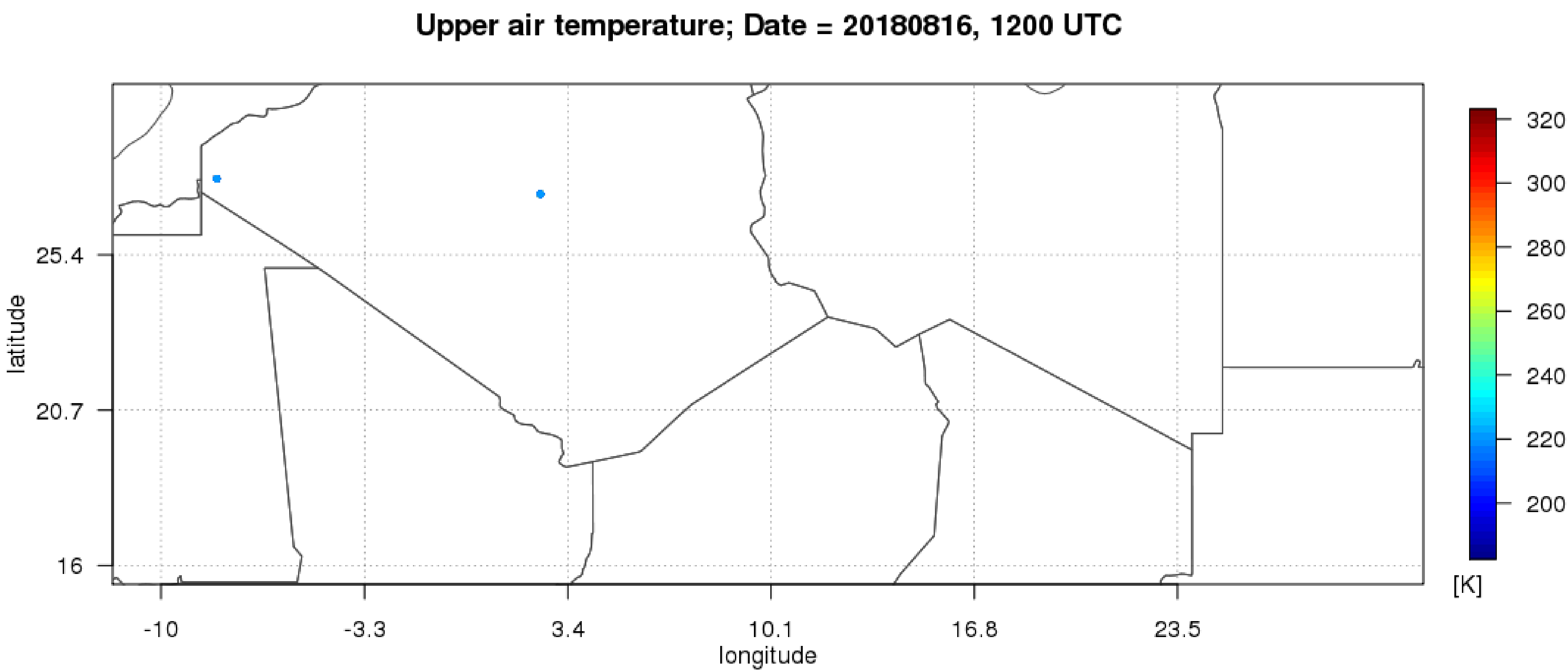
Tegen Aerosol Climatology



CAMS



Nordafrika

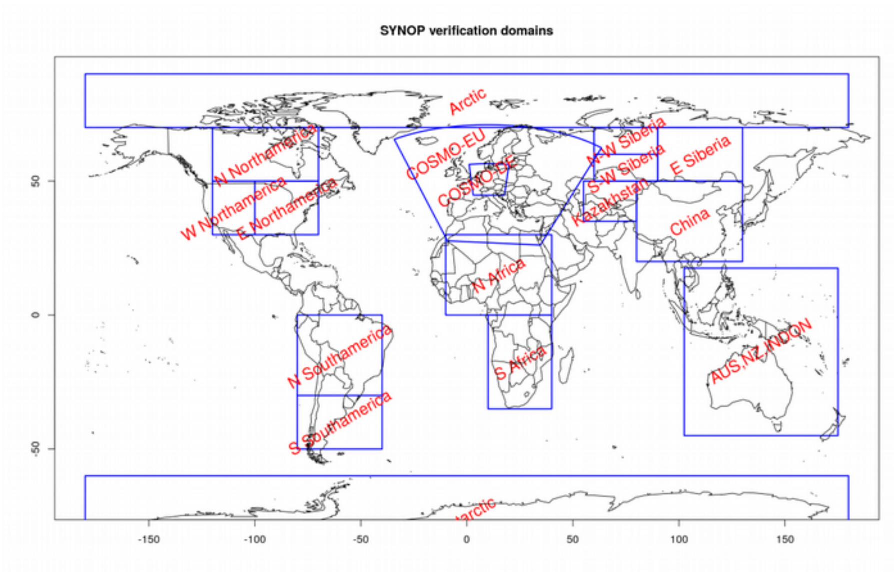


Upper air temperature; Date = 20180816, 1200 UTC
latitude
25.4
20.7
16
-10
-3.3
3.4
10.1
16.8
23.5
longitude
320
300
280
260
240
220
200
[K]

DWD Standard Verification

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

SYNOP Verification Domains



Radiosonde ("Temp")-Observation Domains