PerduS: Photovoltaikertragsreduktion durch Saharastaub

(Reduction of Photovoltaic Power Generation due to Saharan Dust)

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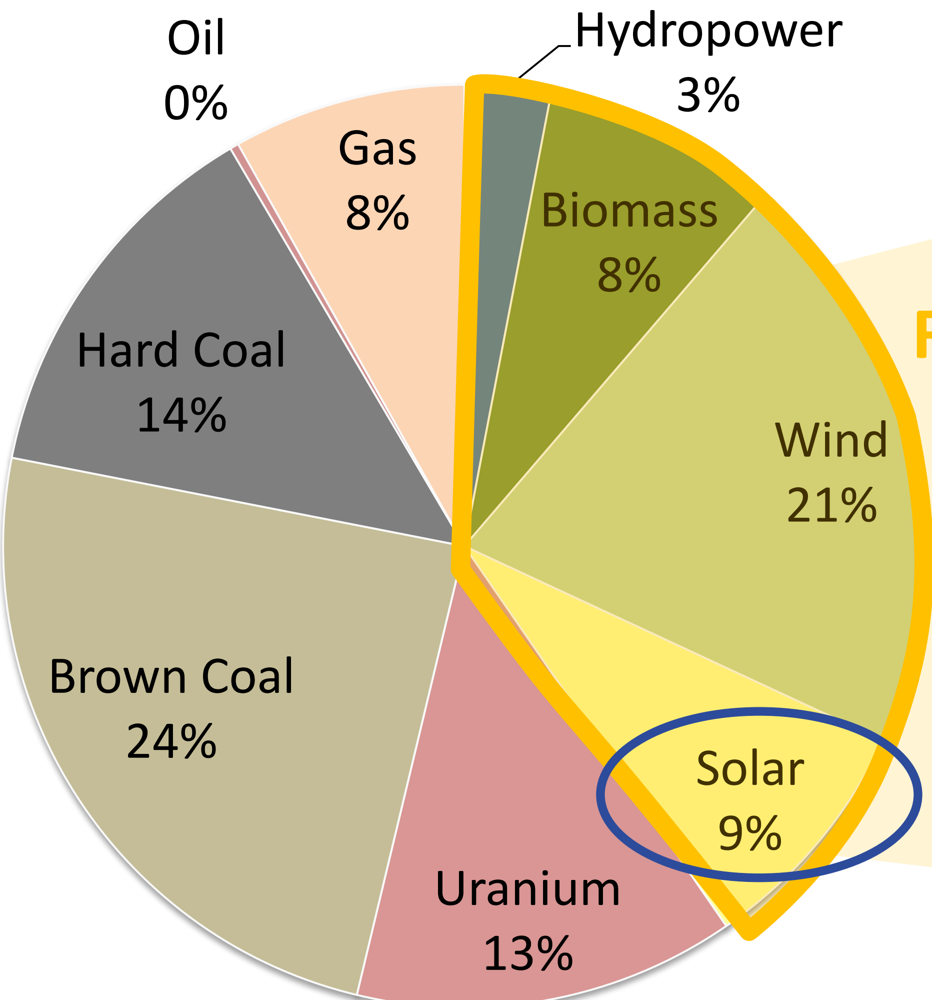
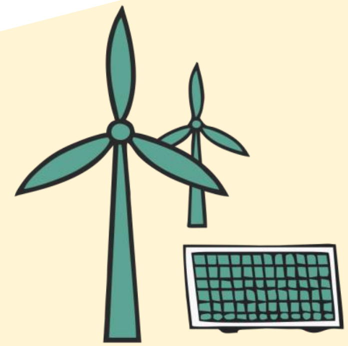
Gefördert durch: Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages

Net Power Production, Germany 2018





Installed Capacities of VREs*):

→ ca. 51 GW Wind onshore
→ ca. 6 GW Wind offshore
→ ca. **43** GW Photovoltaic

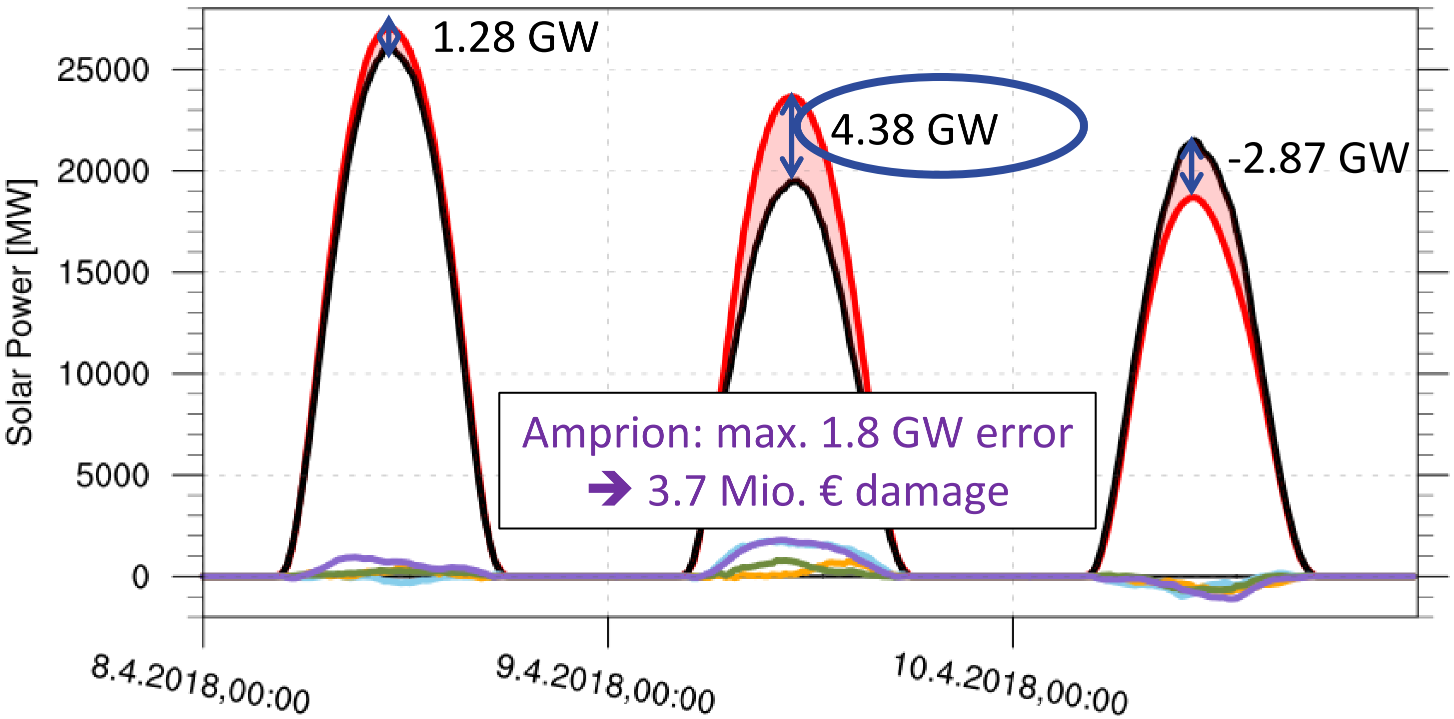
*) VRE: variable renewable energy

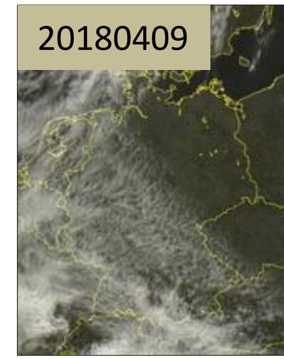
Data source: https://www.energy-charts.de/

Case example April 2018

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

solar power day-ahead forecast and observation for Germany





TSOs

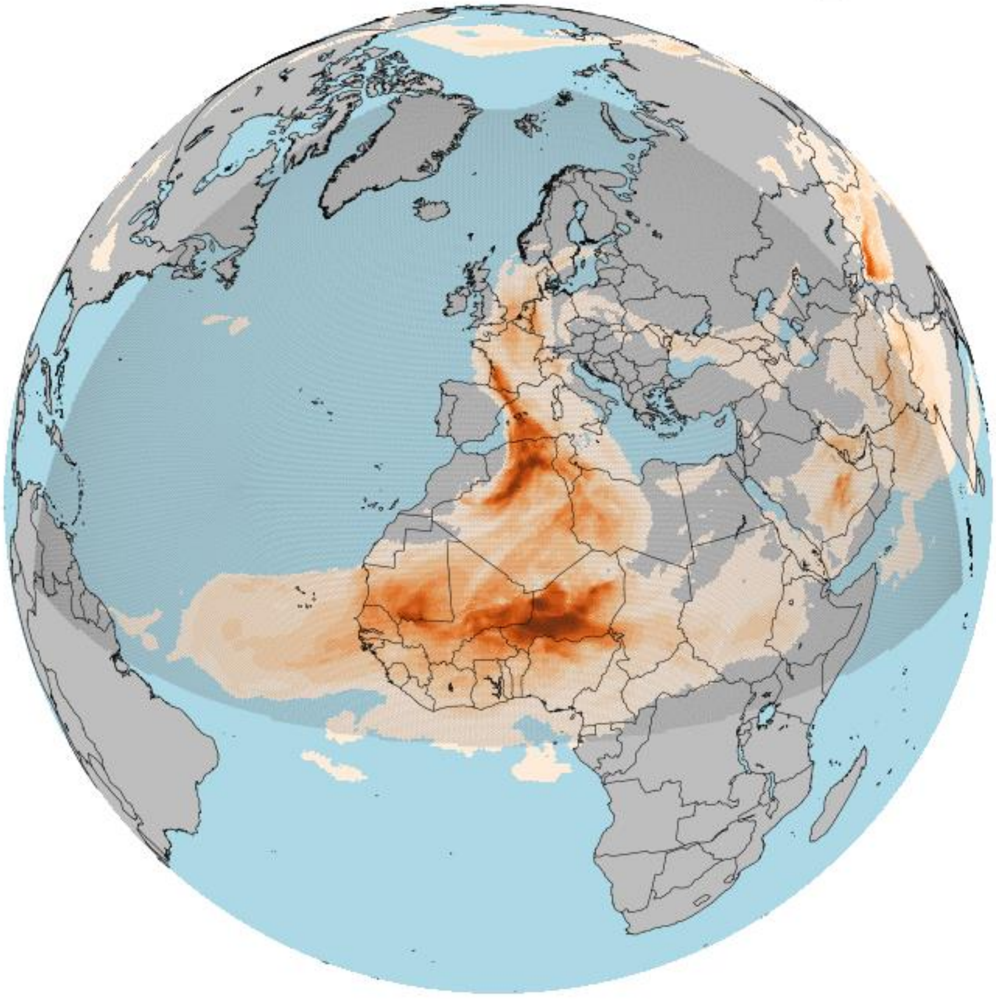
Typical Nuclear Power Plant: 1 GW Power

➔ PV power was overestimated (cloud cover underestimated)

➔ Transmission system operators (TSOs) ensure grid stability

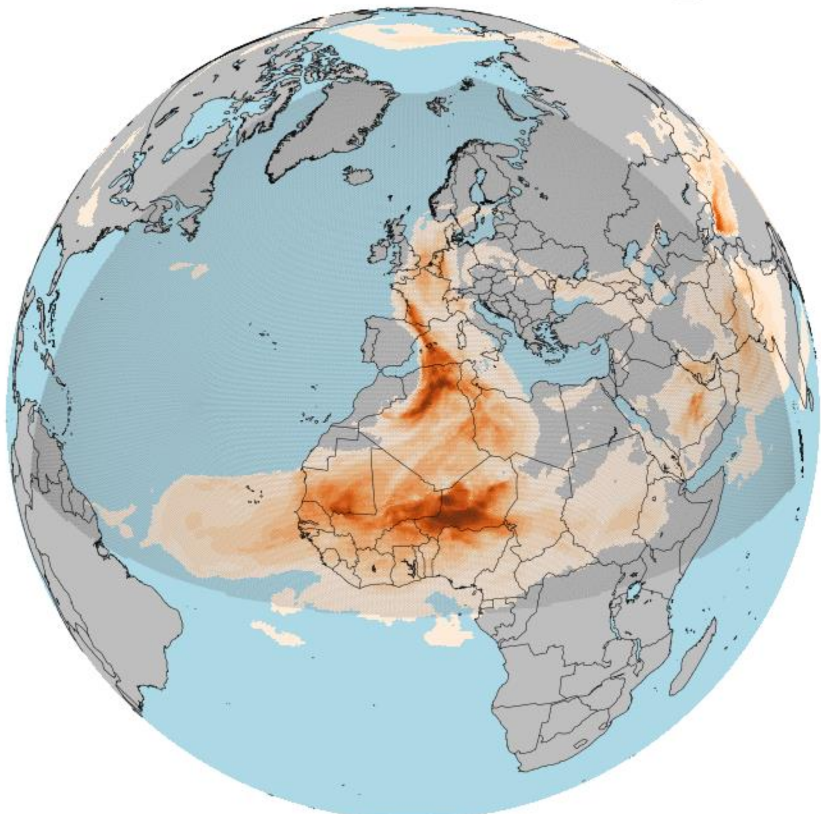
ICON-ART 20180408 +72h

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



ICON and ART (Aerosols and Reactive Trace Gases)

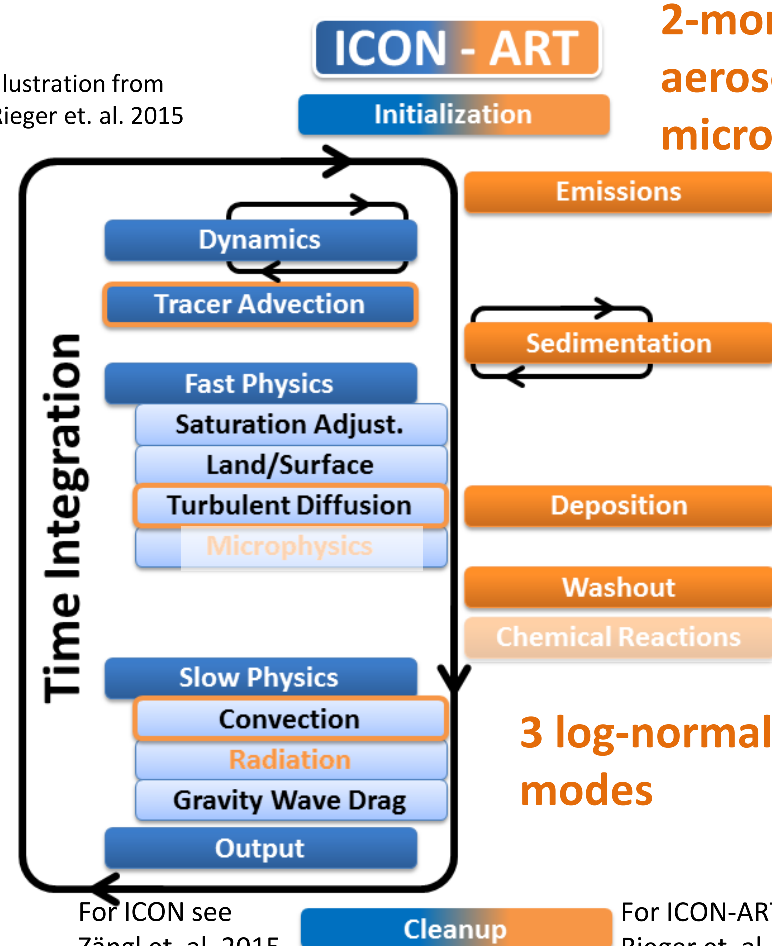
2018040800, vv: 003, ICON-ART, AOD_DUST



→ Online-coupling of **ICON** and the **ART-Modules**

2-moment aerosol microphysics

Illustration from Rieger et. al. 2015



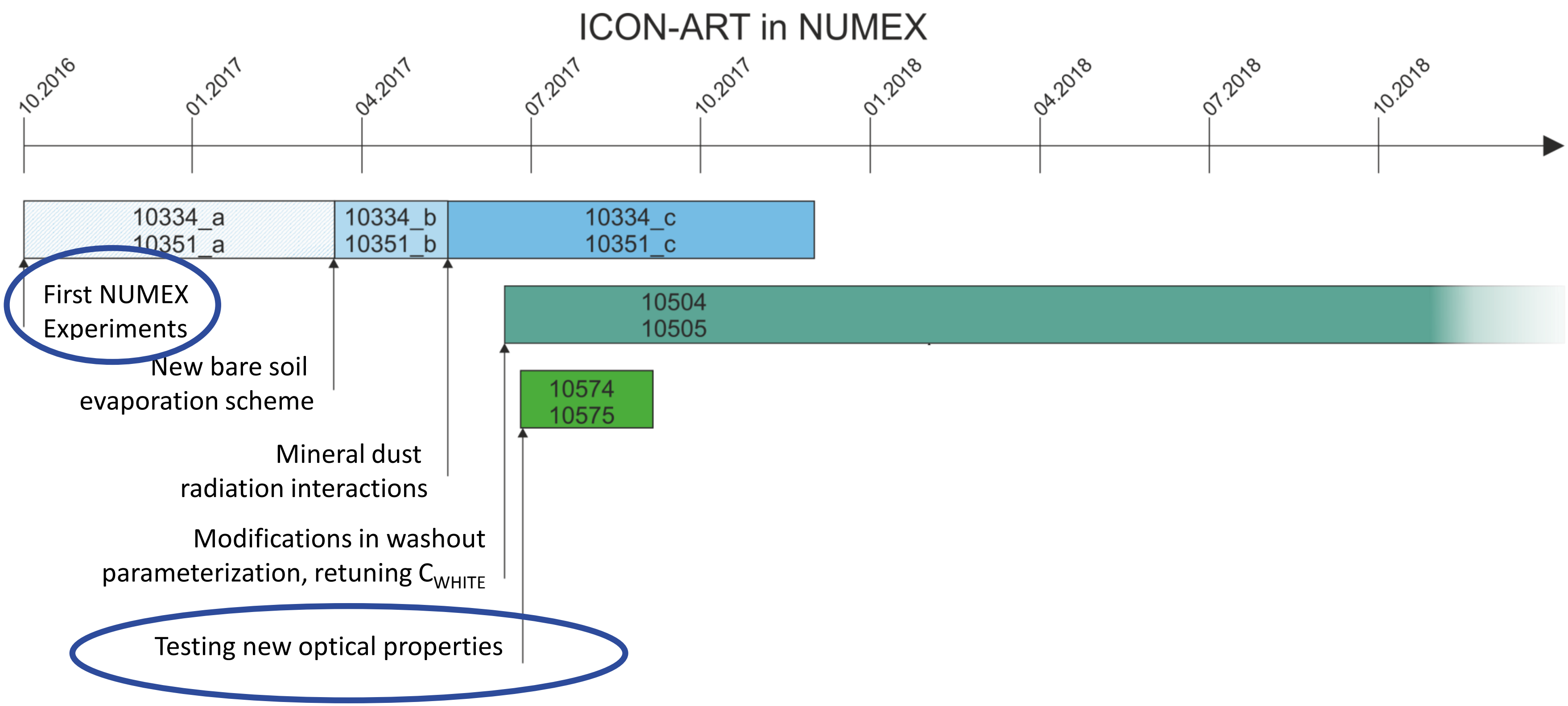
3 log-normal modes

For ICON see Zängl et. al. 2015

For ICON-ART see Rieger et. al. 2015

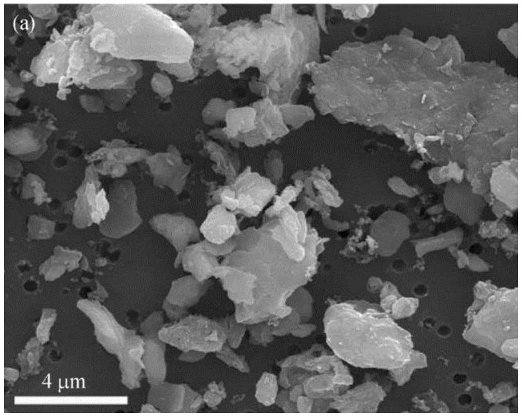
ICON-ART in NUMEX

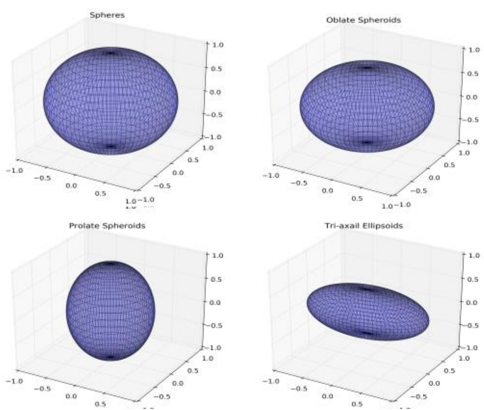
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



New optical properties

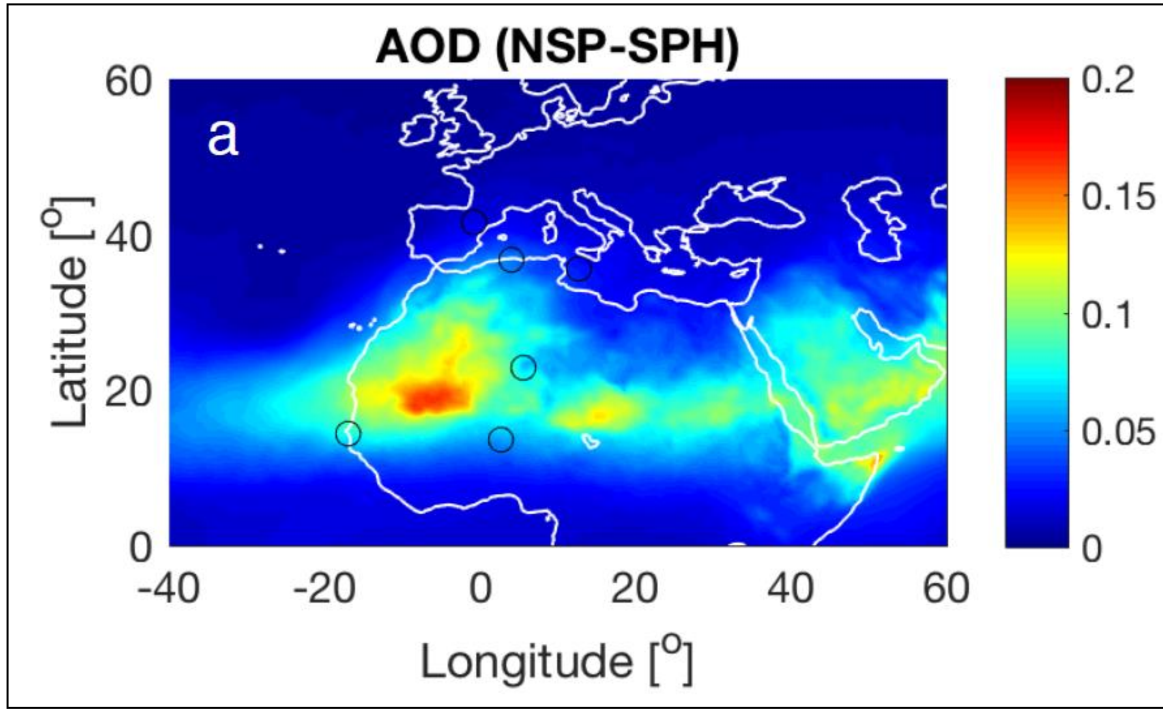
Shao et al. (2007)





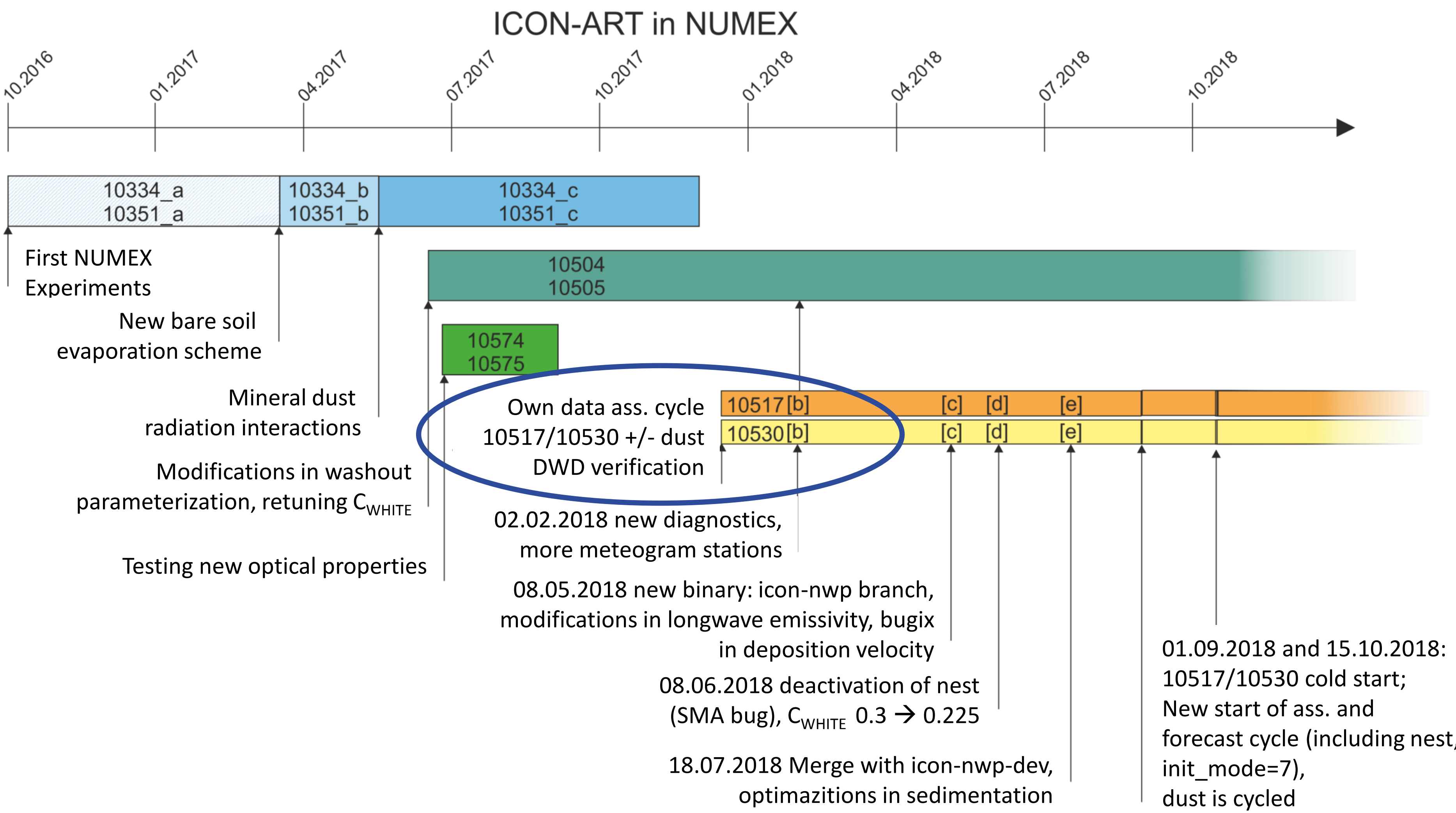
Data bank of optical properties of non-spherical particles (Meng, 2010)

©Project colleague Ali Hoshyaripour, KIT



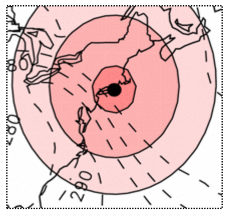
→ Non-spherical dust particles increase the optical depth by up to 28% (Hoshyaripour et al., 2018 in review)

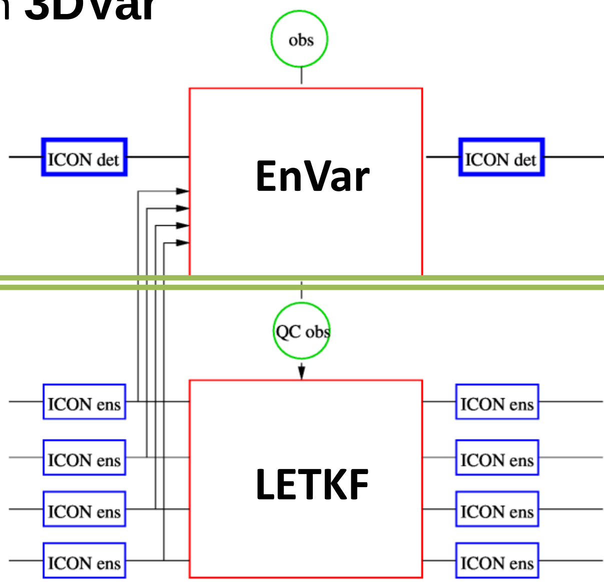
ICON-ART in NUMEX



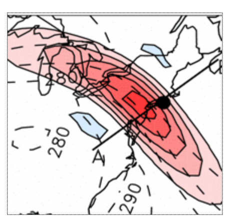
EnVar

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





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



3DVar/EnVar:

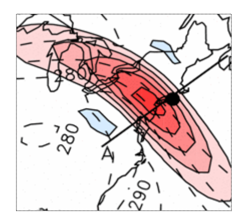
$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{W}(\mathbf{y}_0 - H(\mathbf{x}_b))$$

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

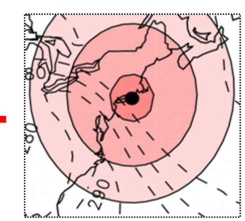
3DVar ⟷ EnVar
ensemble background error covariance matrix in a variational context:

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

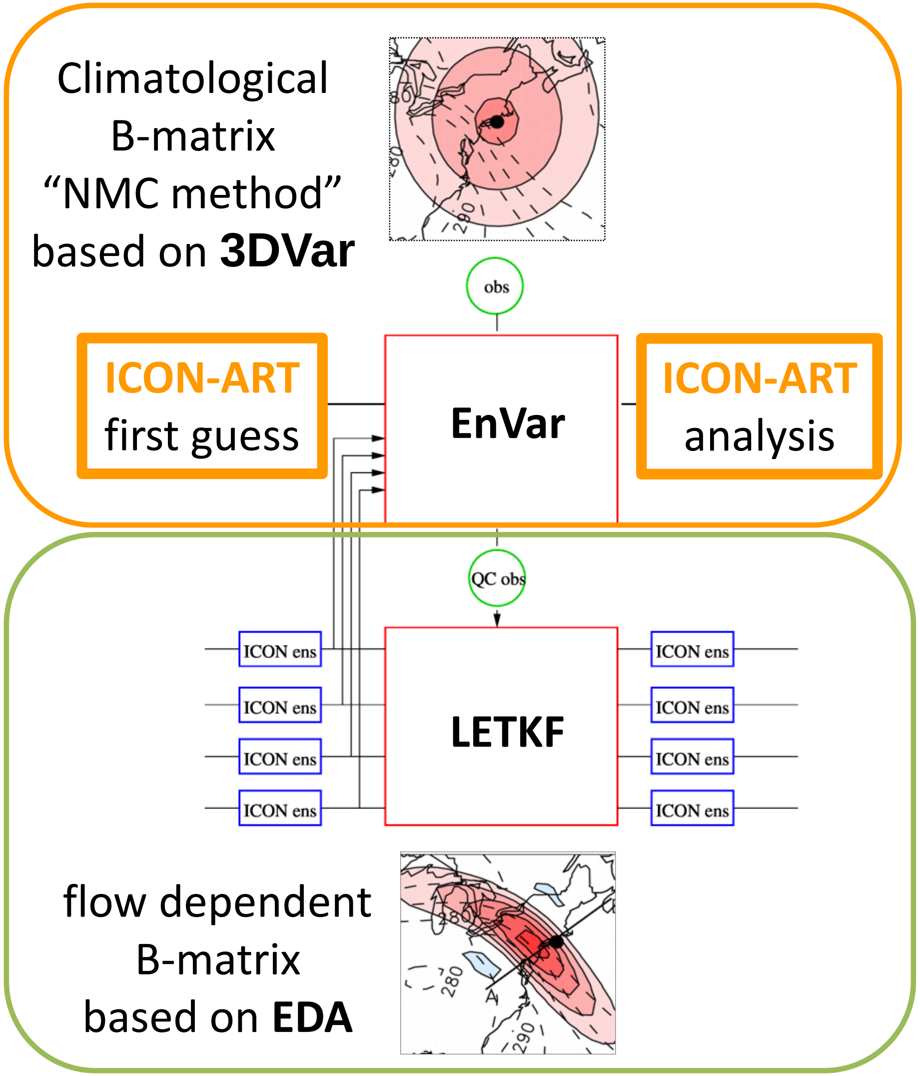
$\alpha = 0.7$
$\beta = 0.3$



+



EnVar with dust



3DVar/EnVar:

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

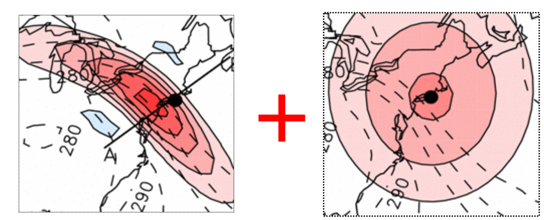
first guess

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

3DVar ⟷ EnVar
ensemble background error covariance matrix in a variational context:

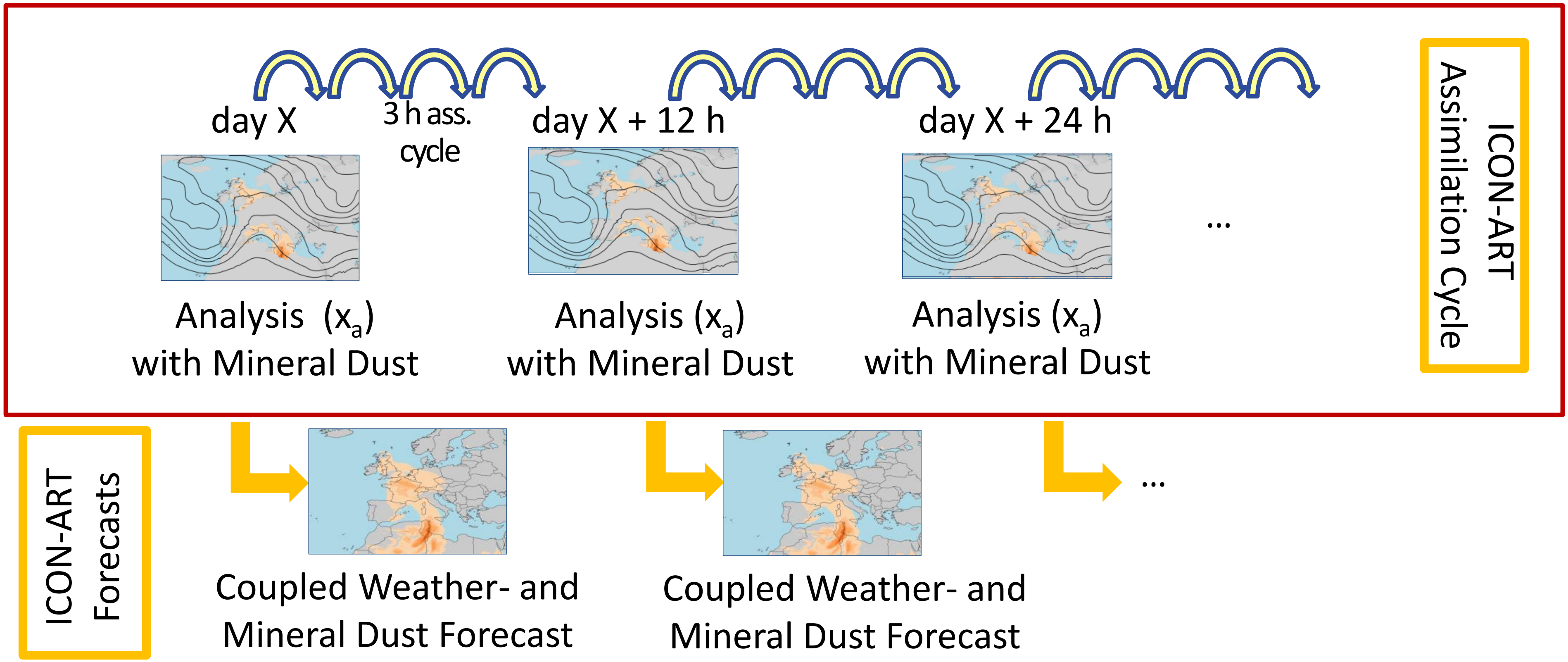
$$\mathbf{B}_{hybrid} = \alpha\,\mathbf{B}_{EnKF} + \beta\,\mathbf{B}_{3DVar}$$

$\alpha = 0.7$
$\beta = 0.3$



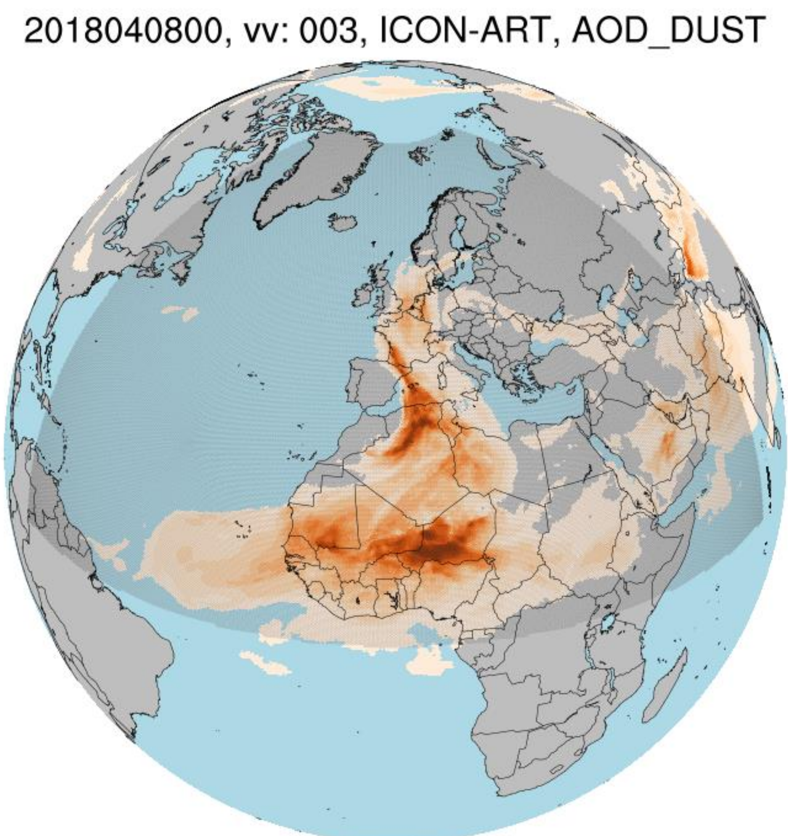
ICON-ART in “EnVar” Mode

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



First Guess forecasts (x_b) in the assimilation cycle are ICON-ART forecasts with prognostic mineral dust, including aerosol-radiation feedback mechanisms.

ICON-ART in “EnVar” Mode



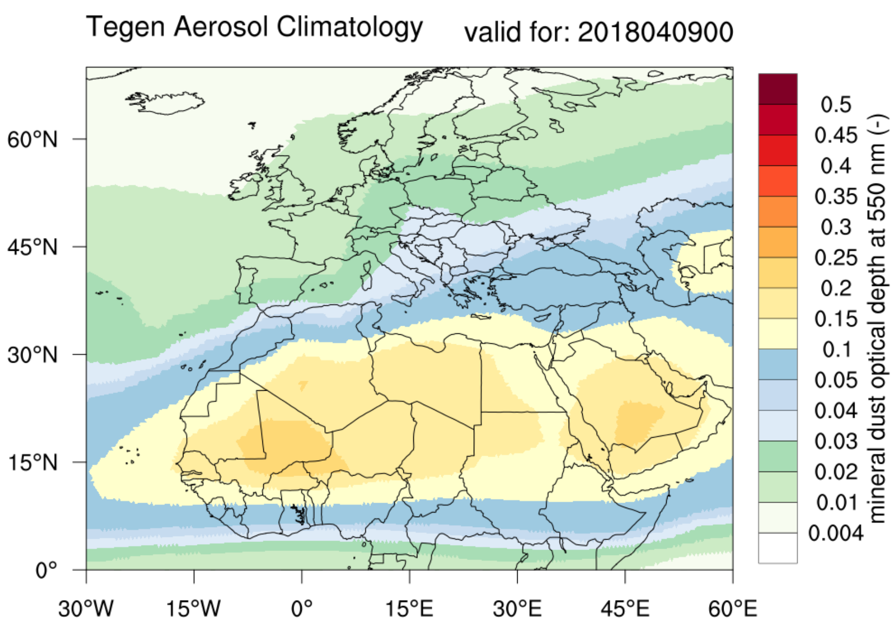
- Daily 00 and 12 UTC forecasts up to +180 h (global), +120 h (nest)
- Resolution: 40 km (global) 20 km (nest)
- Experiments with (10517) and without (10530) prognostic mineral dust
- **How does the prognostic mineral dust distribution differ from the operationally used Tegen aerosol climatology*)**

*) Tegen et al. (1997)

Aerosol-Radiation Feedback

➔ Dust Optical Depth τ at 550 nm for 09/04/2018:

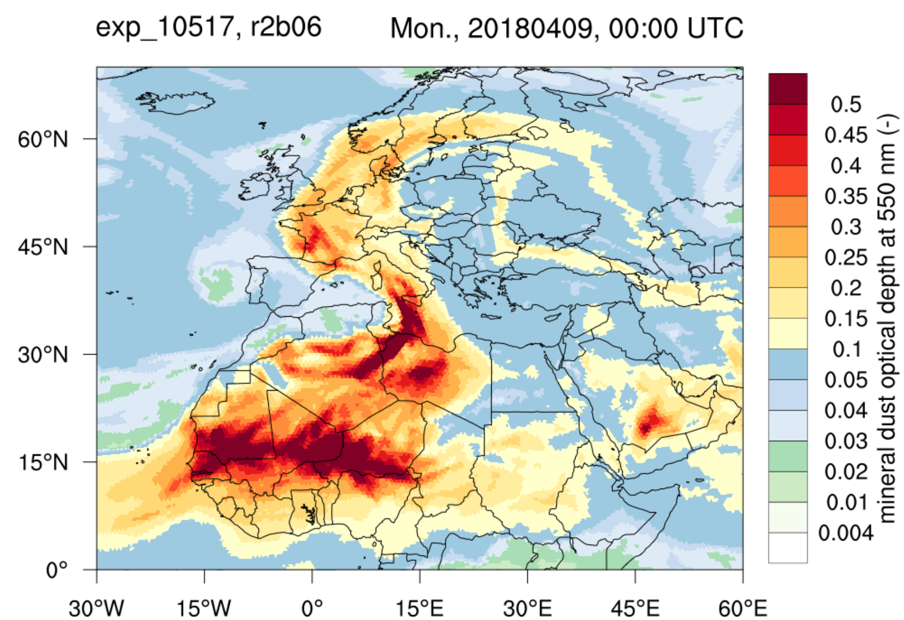
Tegen Climatology



mean: 0.08, max: 0.24, std: 0.06 (plot)

mean: 0.03, max: 0.37, std: 0.04 (global)

ICON-ART



mean: 0.14, max: 1.56, std: 0.13 (plot)

mean: 0.04, max: 1.56, std: 0.07 (global)

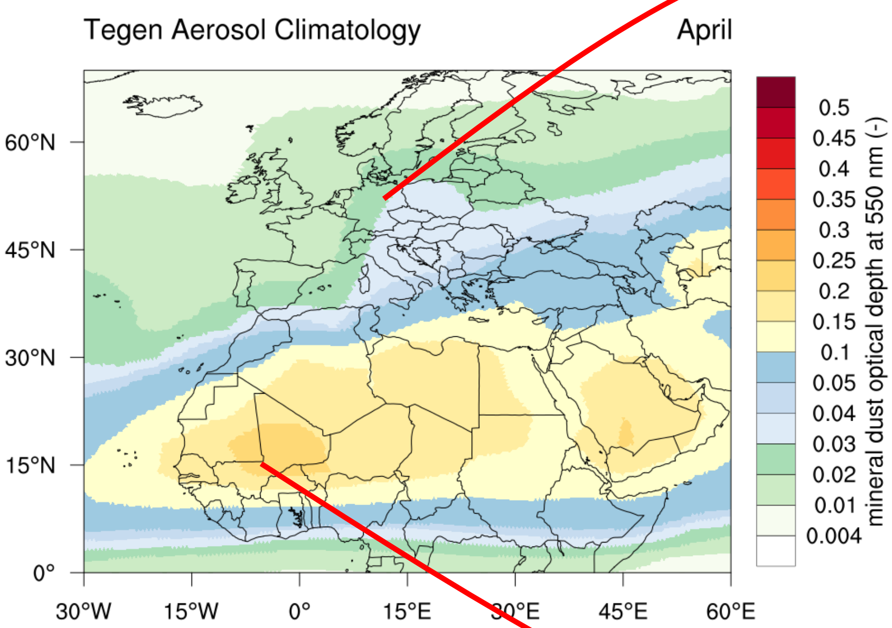
$$I(\lambda) = I_0 e^{-\tau(\lambda)} \quad \text{for } \lambda = 550 \text{ nm}$$

Aerosol-Radiation Feedback

→ Dust Optical Depth τ at 550 nm for 04/2018:

0.02 vs 0.05

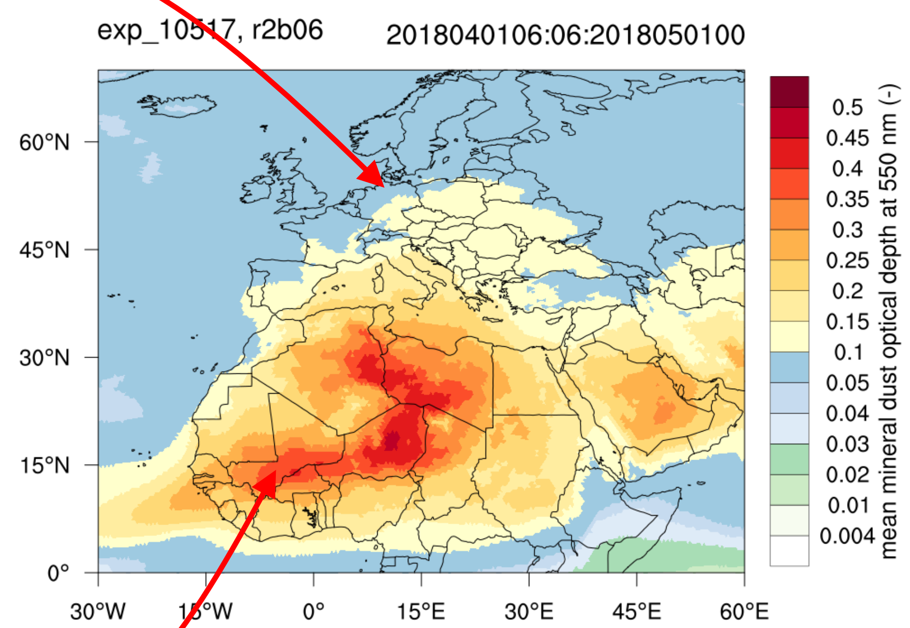
Tegen Climatology



mean: 0.08, max: 0.24, std: 0.06 (plot)

mean: 0.03, max: 0.43, std: 0.04 (global)

ICON-ART



mean: 0.15, max: 0.49, std: 0.09 (plot)

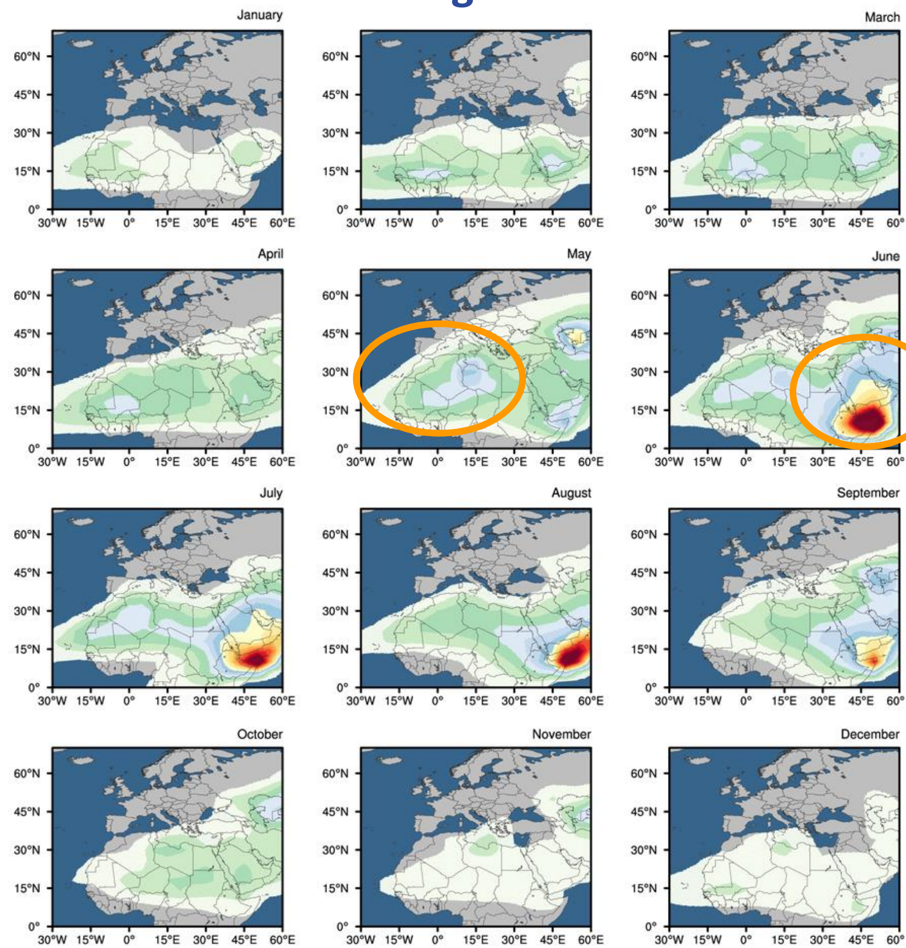
mean: 0.05, max: 0.49, std: 0.06 (global)

0.2 vs 0.4

$$I(\lambda) = I_0 e^{-\tau(\lambda)} \quad \text{for } \lambda = 550 \text{ nm}$$

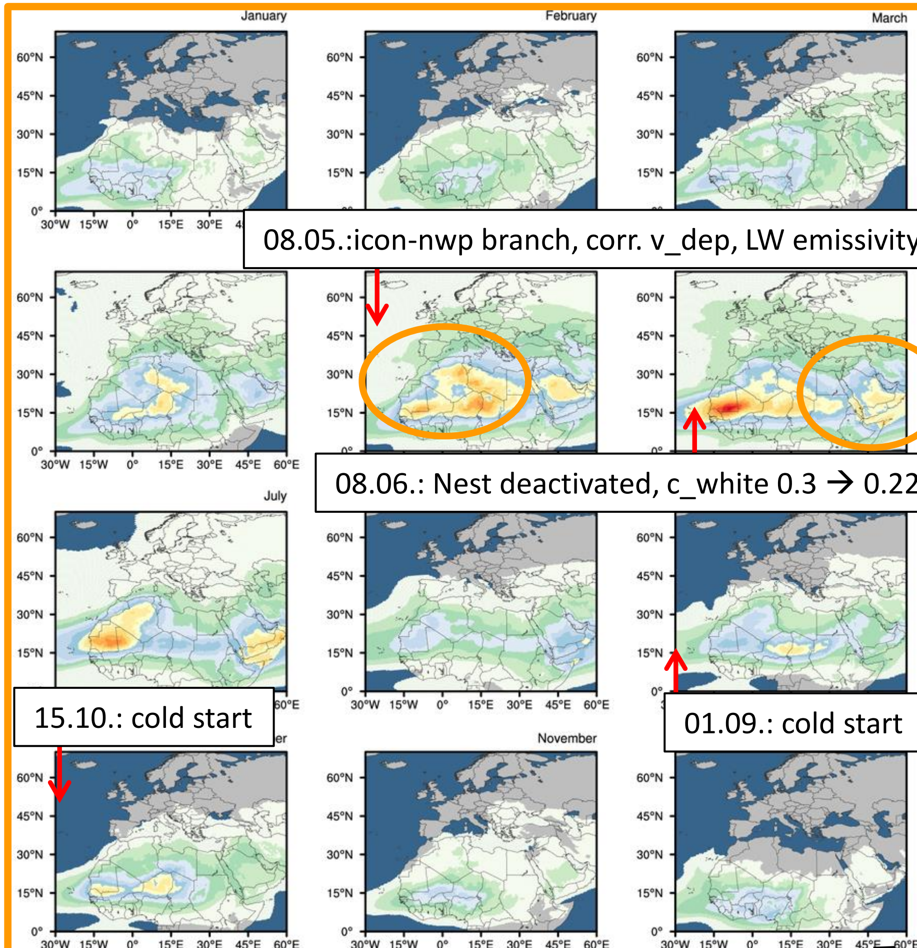
Monthly mean AOD Dust in 2018

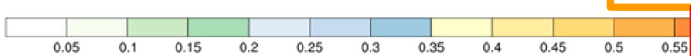
Tegen



ICON-ART

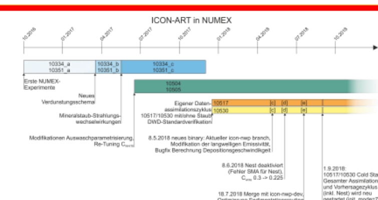
Exp. 10517, r2b06





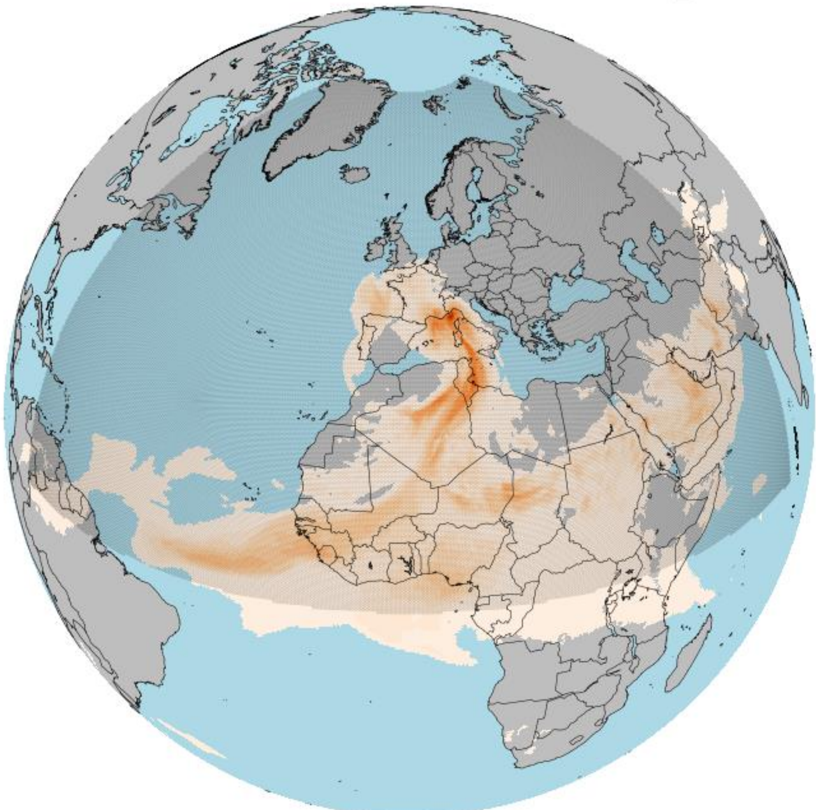
Mineral optical depth at 550 n

Ongoing developments!



ICON-ART in “EnVar” Mode

2018010800, vv: 012, ICON-ART, AOD_DUST

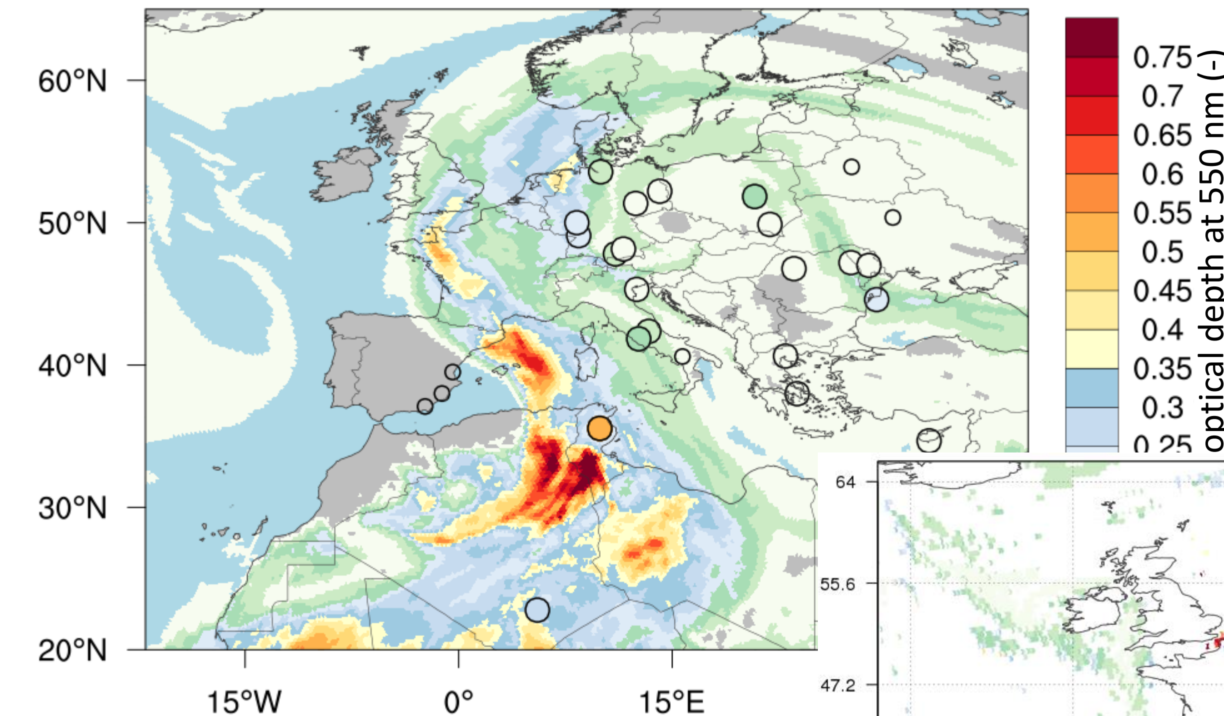


- Daily 00 and 12 UTC forecasts up to +180h (Nest: +120h)
- Experiments with (10517) and without (10530) prognostic mineral dust
- How does the prognostic mineral dust distribution differ from the operationally used Tegen aerosol climatology*)
- **How good are our dust forecasts?**

*) Tegen et al. (1997)

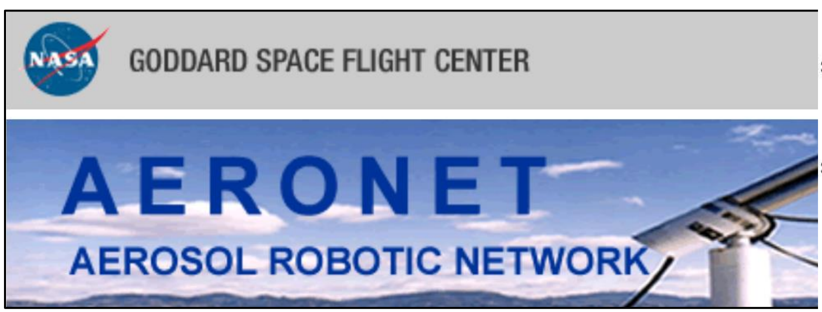
Comparison Model vs. AERONET / MODIS

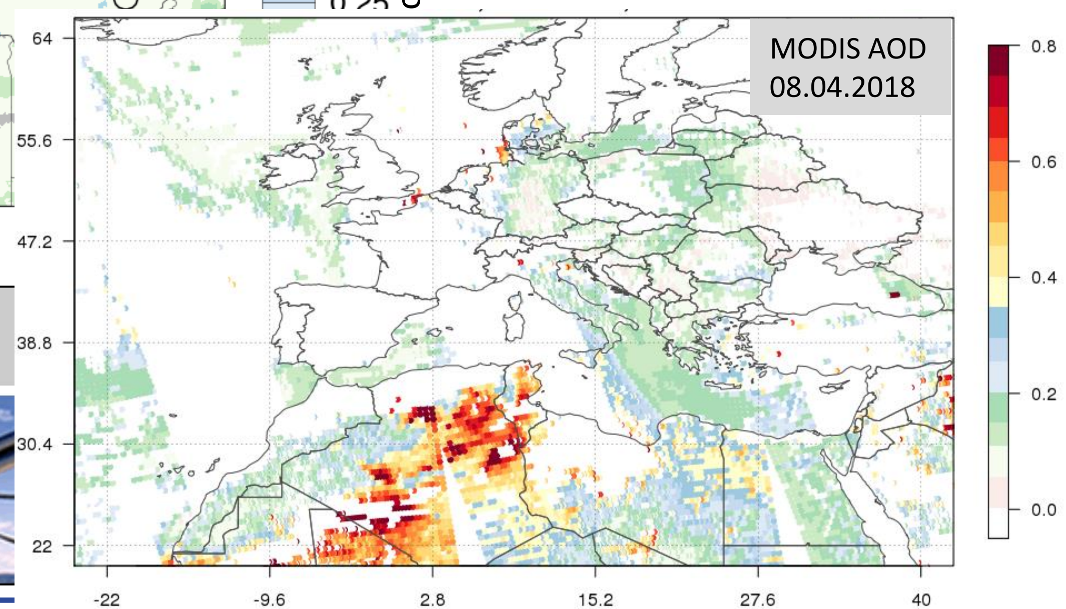
2018040800 vv: 12, ICON-ART-EUNA2_10517 , vertically integrated



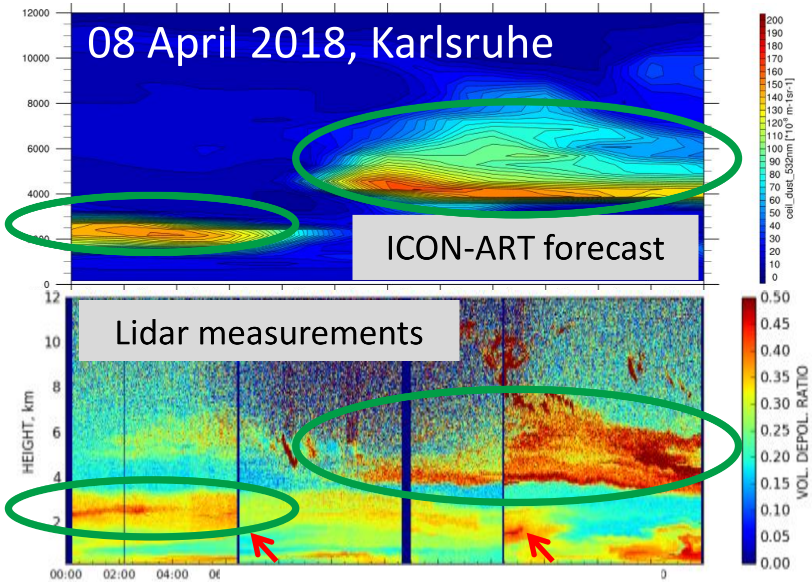
AERONET
(AErosol RObotic NETwork)

groundbased
sun photometer

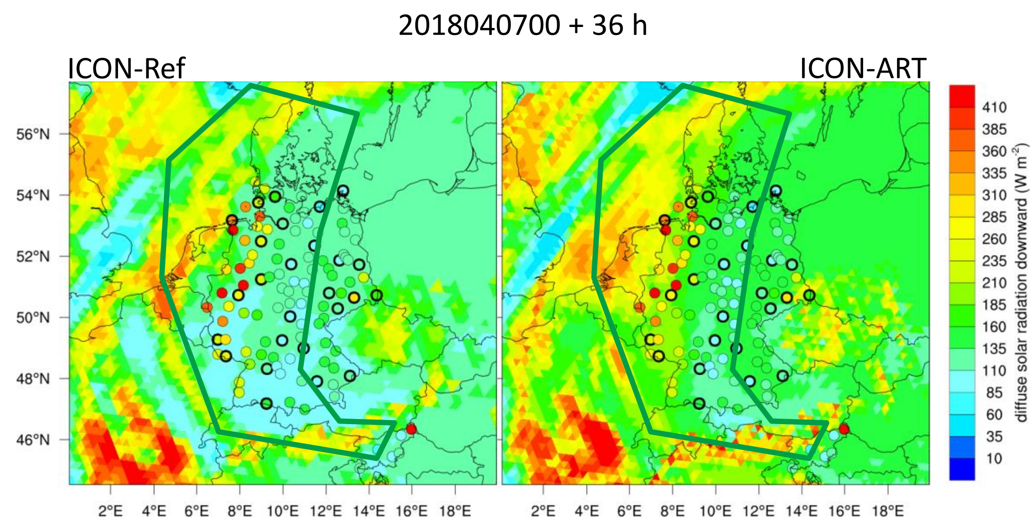


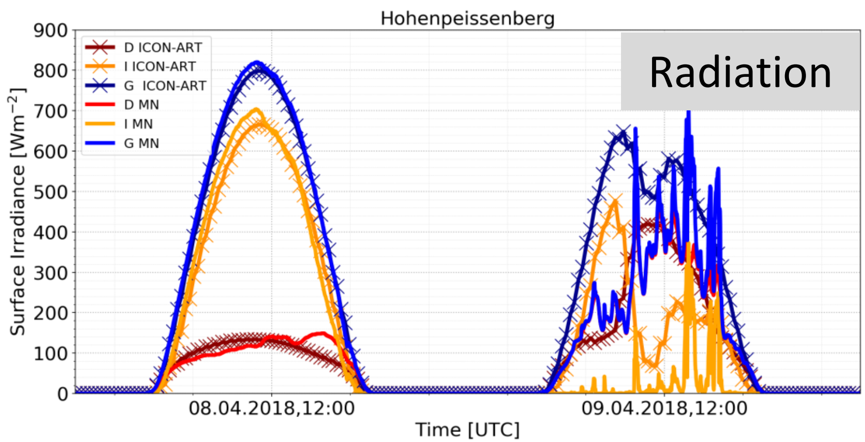


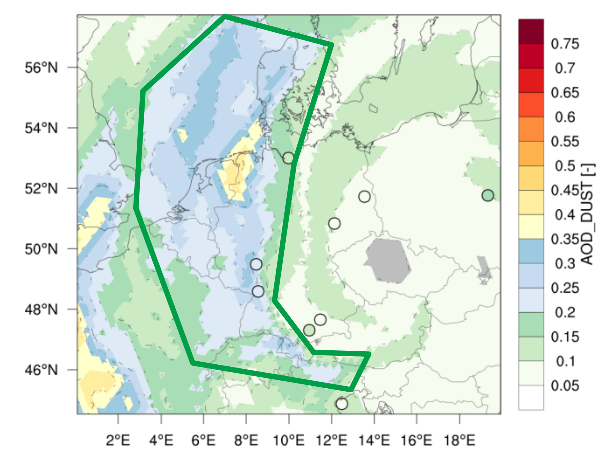
Examples of Observational Data



changings in configuration





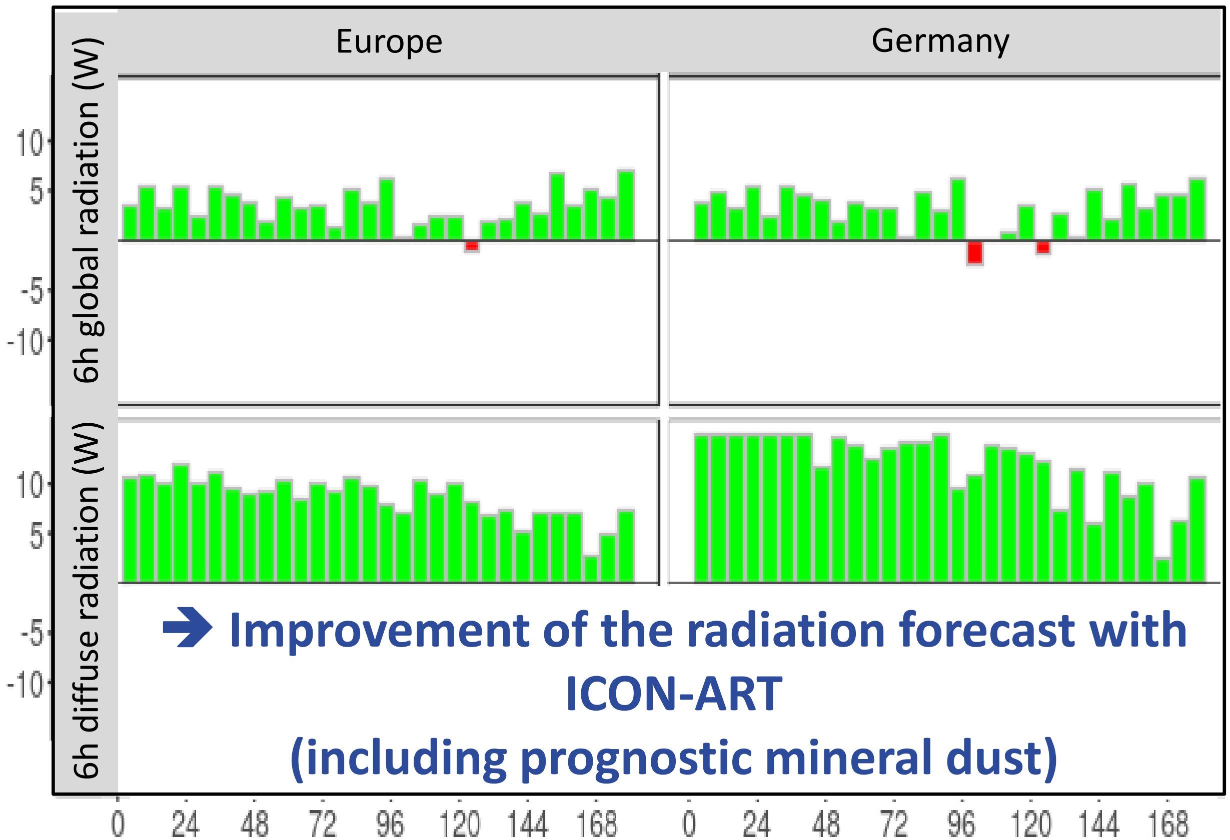


Comparison of the Radiation Forecast

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Comparison of the irradiance at the surface – verification against SYNOP observations

April 2018



➔ **Improvement of the radiation forecast with ICON-ART (including prognostic mineral dust)**

Experiments with (10517) and without (10530) prognostic mineral dust

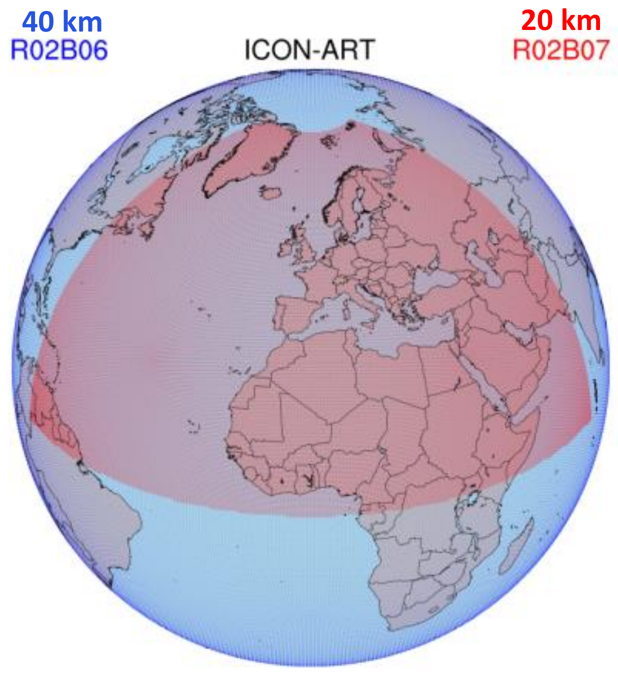
Inclusion of prognostic mineral dust in NWP

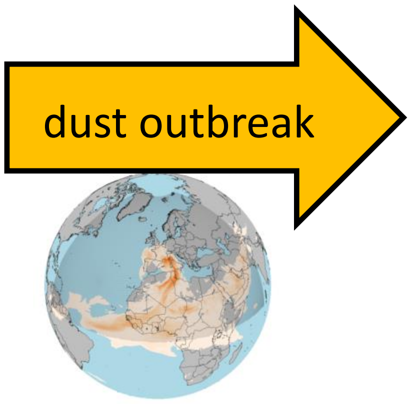
leads to an …

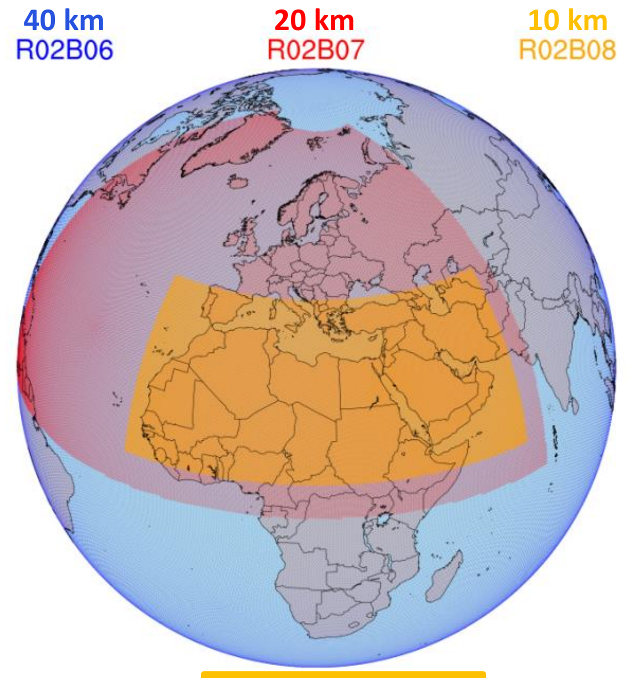
improved radiation forecast

worse radiation forecast

? ICON-ART configuration in dust case ?







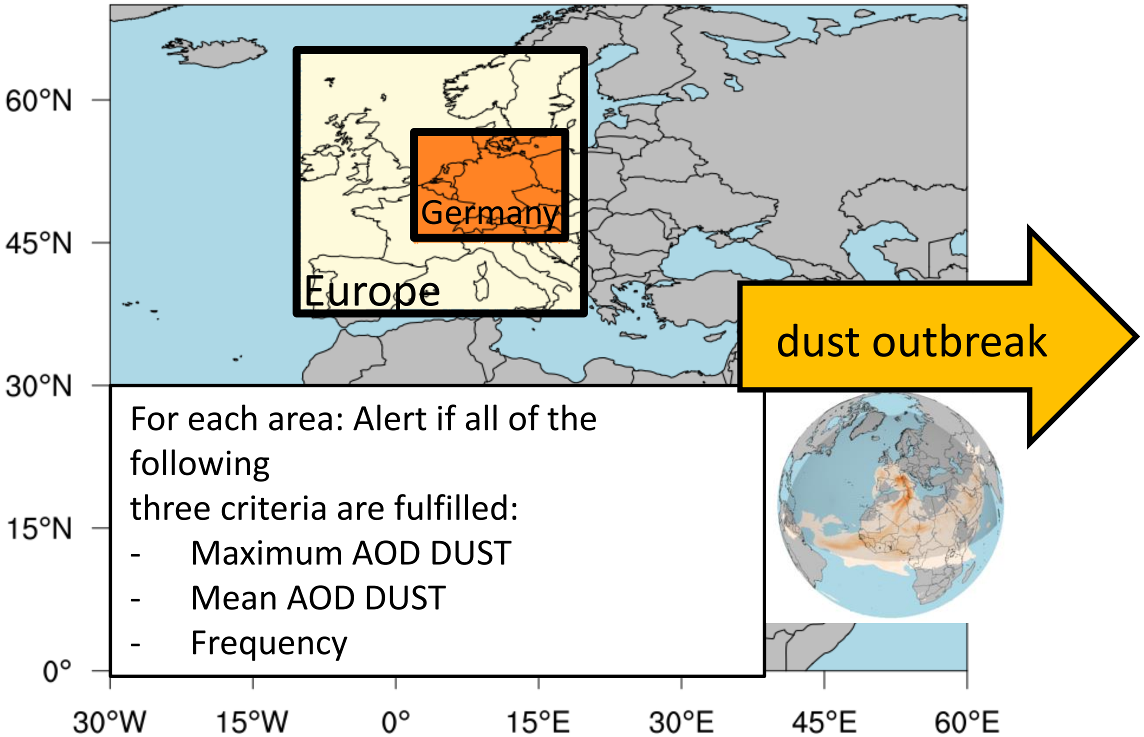
dust emission is resolution dependent

additional nest on demand

On demand: additional nest in forecasts

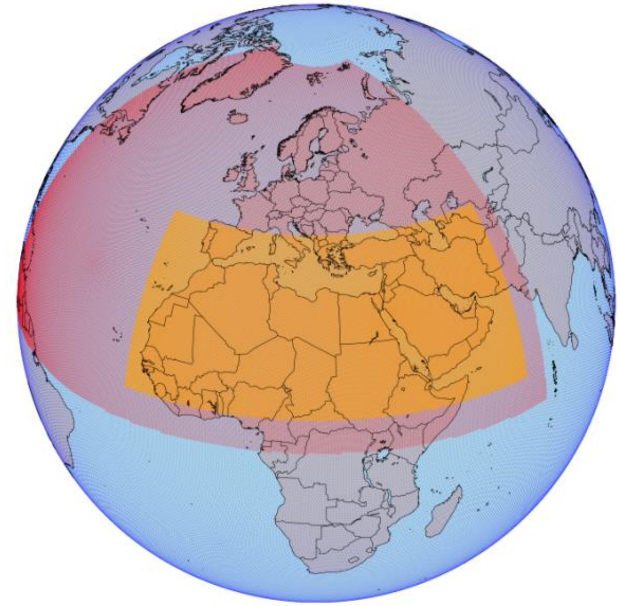
+ Higher resolution in emission area → More realistic dust emission (long term study)
+ Influencing the DA cycle (2-way-nesting)
+ no interpolation necessary

? ICON-ART configuration in dust case ?



For each area: Alert if all of the following three criteria are fulfilled:

- Maximum AOD DUST
- Mean AOD DUST
- Frequency



additional nest on demand

On demand: additional nest in forecasts

+ Higher resolution in emission area → More realistic dust emission (long term study)
+ Influencing the DA cycle (2-way-nesting)
+ no interpolation necessary

Thank you!

➔ Question: Trigger similar to dust warning mails?

Literatur

➔ 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, 2017

➔ Rieger, D., Bangert, M., BischoffGauss, I., Förstner, J., Lundgren, K., Reinert, D., Schröter, J., Vogel, H., Zängl, G., Ruhnke, R., and Vogel, B.: ICON–ART 1.0 – a new online-coupled model system from the global to regional scale, Geosci. Model Dev., 8, 1659–1676,doi:10.5194/gmd-8-1659-2015, 2015.

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➔ Hoshyaripour, G. A. , Bachmann, V. , Förstner, J., Steiner, A., Vogel, H., Wagner, F., Walter, C. and Vogel, B.: Accounting for Particle Non-Sphericity in a Dust Forecast System: Impacts on Model-Observation Comparison, in review, 2018.