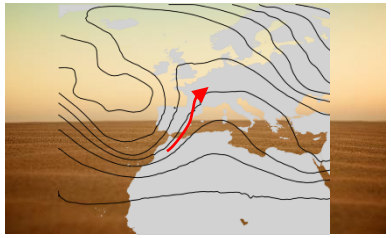
The project PerduS: Daily mineral dust forecasts with ICON-ART for NWP and the assessment of the related reduction of photovoltaic power generation

Photovoltaikertragsreduktion durch Saharastaub



4 years: 01.03.2016 – 29.02.2020

DWD: 3, KIT: 2 employees,
meteocontrol: 19,5 PM

Jochen Förstner, Vanessa Bachmann, Ali Hoshyaripour, Jonas Straub, Frank Wagner, Florian Filipitsch, Daniel Lassahn, Bernhard Vogel, Heike Vogel, Thomas Hanisch, Axel Seifert and Detlev Majewski

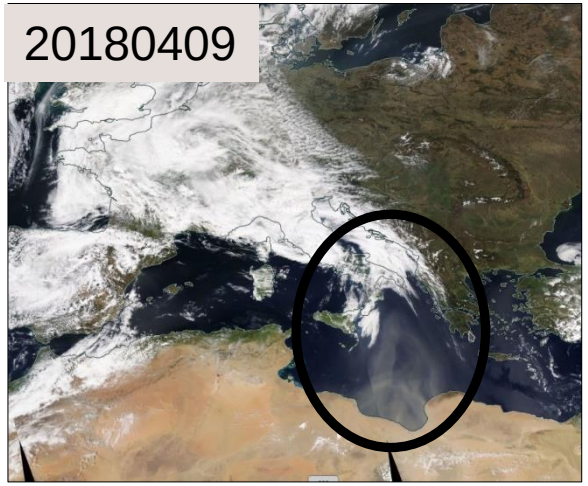
Saharan Dust: a challenge for the PV-power forecast

➔ NWP forecast errors:

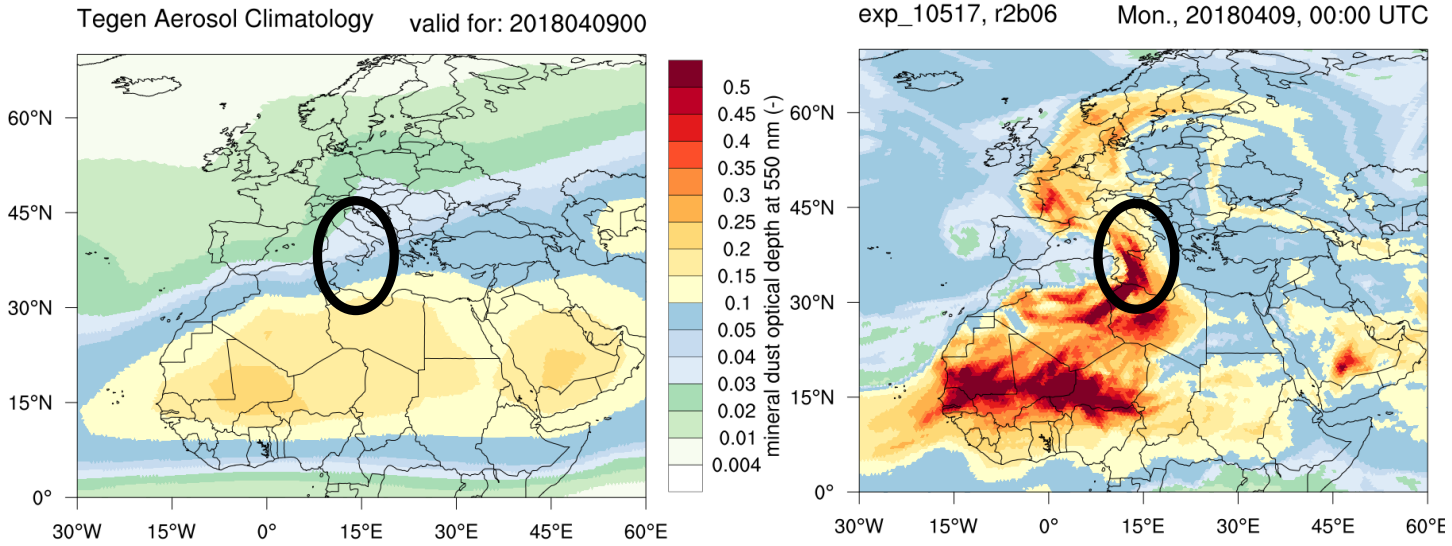
- direct, semi-direct,
- \+ indirect aerosol effects

PerduS

PermaStrom (since 05.2020)



Source: https://worldview.earthdata.nasa.gov/



Online-coupled mineral dust forecast with ICON-ART

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

ICON (ICOsahedral Nonhydrostatic) and **ART** (Aerosols and Reactive Trace gases)

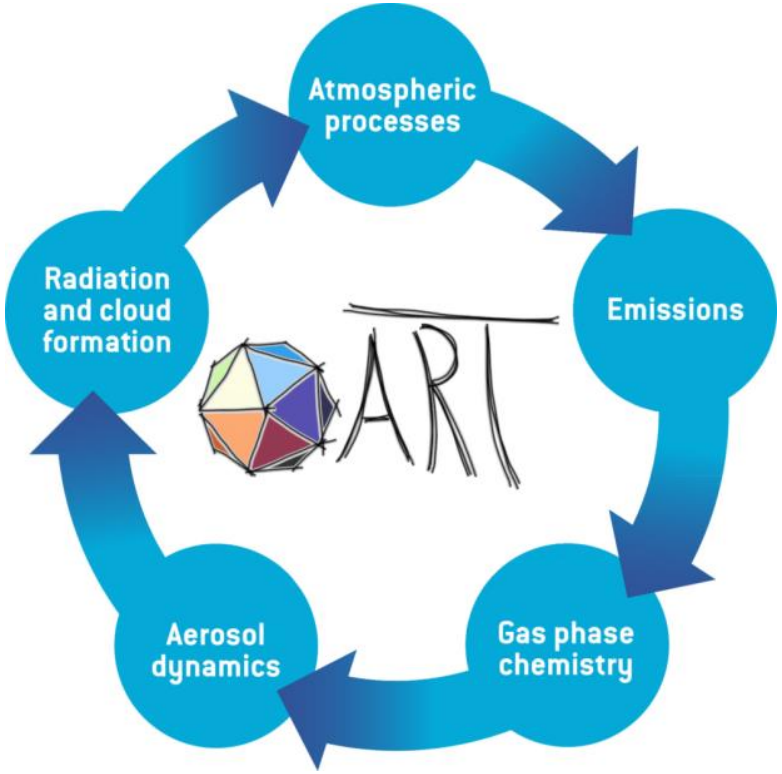
Max-Planck-Institut für Meteorologie

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Karlsruher Institut für Technologie

ICON (Zängl et. al. 2015)

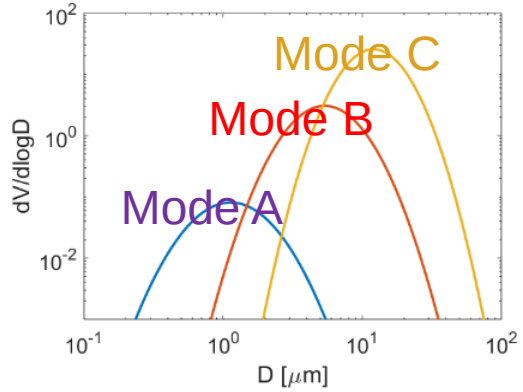
ICON-ART (Rieger et. al. 2015)



Representation of mineral dust in ICON-ART:

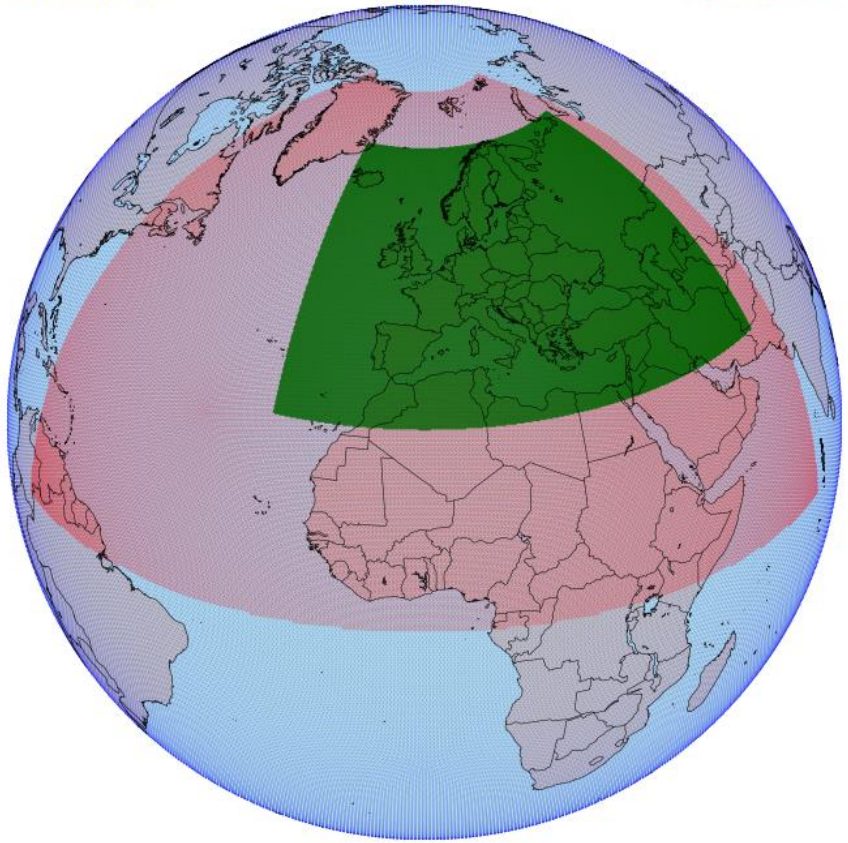
- 2 Moment-Aerosol-Microphysics (progn. number and mass concentration)
- Particle size distribution: 3 log-normal modes

➡ 6 progn. variables



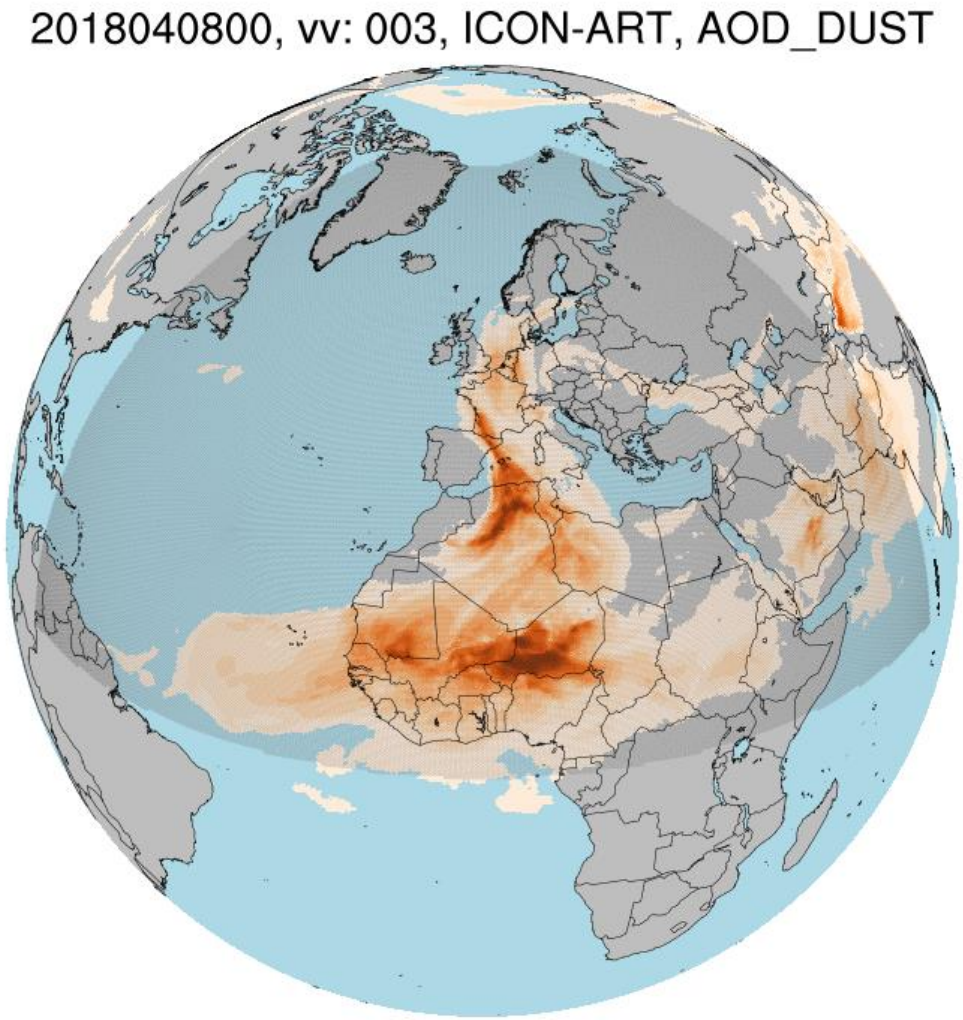
ICON-ART running in “EnVar” mode

40 km (13 km) 20 km
GLOBAL NEST ICON-EU (6.5 km)



➔ spatial resolution: 40 km (global)
20 km (nest)

ICON-ART running in “EnVar” mode



➔ spatial resolution: 40 km (global)
20 km (nest)

➔ since December 2017:

Daily 00 and 12 UTC forecasts up to +180 h (global), +120 h (nest)

➔ two long running experiments:

- **with prognostic mineral dust** (quasi-operational mineral dust forecasts)
- with Tegen*) dust climatology (control experiment, like operational ICON)

*) Tegen et al. (1997)

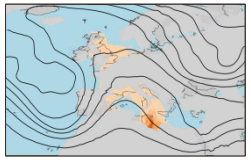
➔ data delivery to meteocontrol and KIT

ICON-ART running in “EnVar” mode

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

ICON-ART assimilation cycle

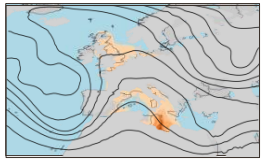
day X



analysis
with mineral dust

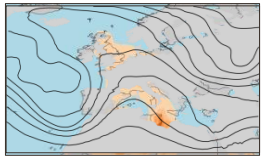
3 h ass. cycle

day X + 12 h



analysis
with mineral dust

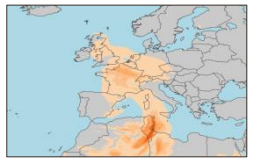
day X + 24 h



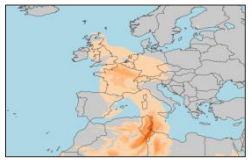
analysis
with mineral dust

...

ICON-ART forecasts



coupled weather- and
mineral dust forecast



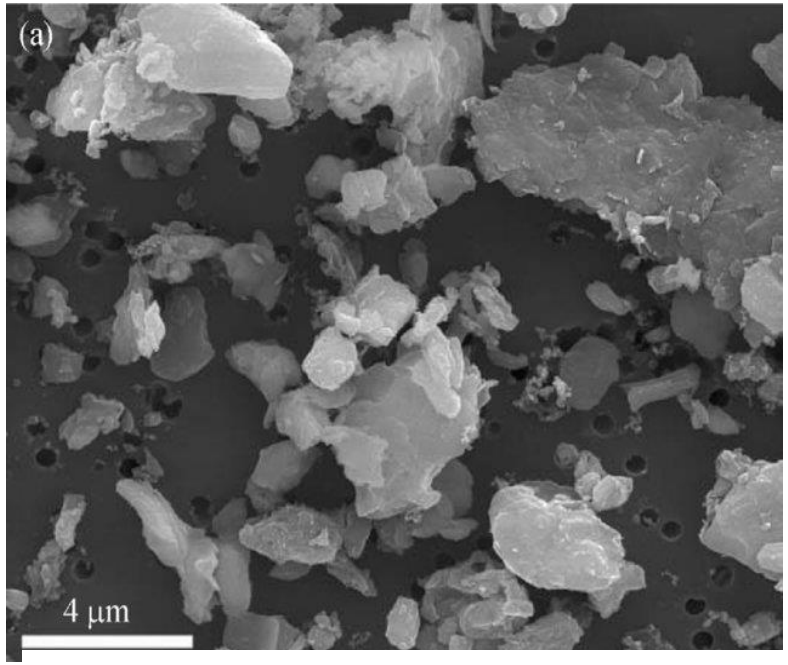
coupled weather- and
mineral dust forecast

...

first guess forecasts in the assimilation cycle are ICON-ART forecasts with prognostic mineral dust,
including aerosol-radiation feedback mechanisms

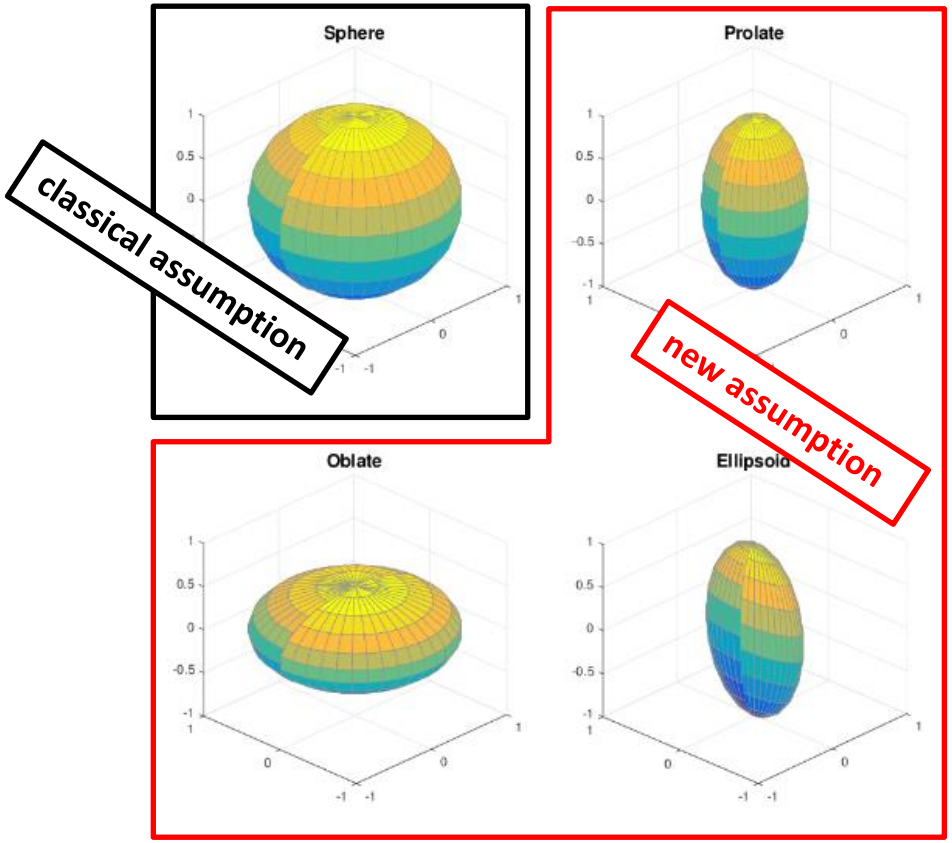
Shape of mineral dust particles

… under the microscope



Shao et al. (2007)

… in the model



Database of Meng (2010) with optical properties of non-spherical particles

new: mix of random orientated particles of different ellipsoidal shapes ➔ non-spherical ➔ improved optical properties of mineral dust

Sensitivity of backscatter with respect to particle shape

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

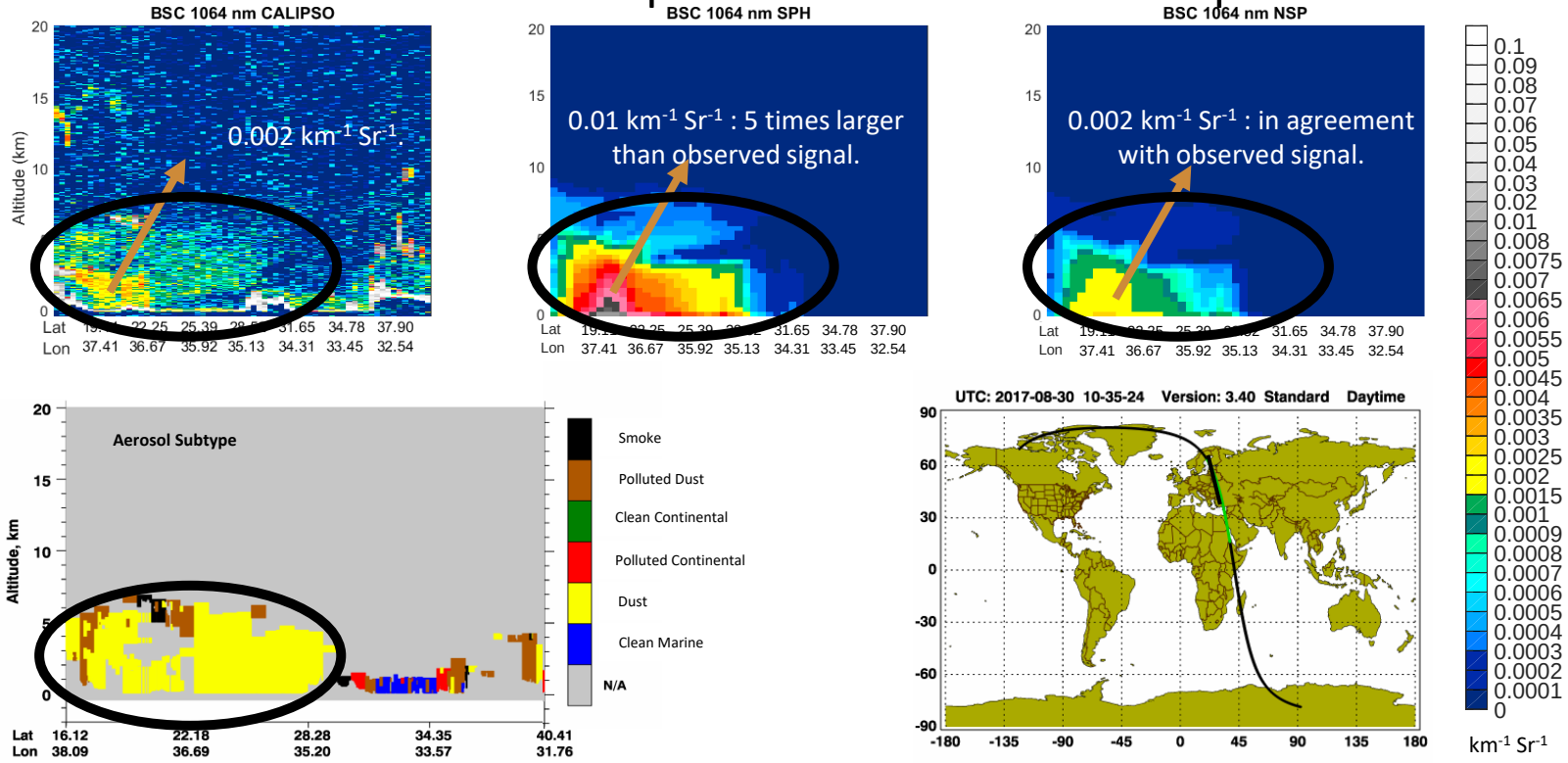
Ali Hoshyaripour, KIT

30.08.2017
10:35 UTC

Satellite CALIPSO

ICON-ART spherical

ICON-ART non-spherical



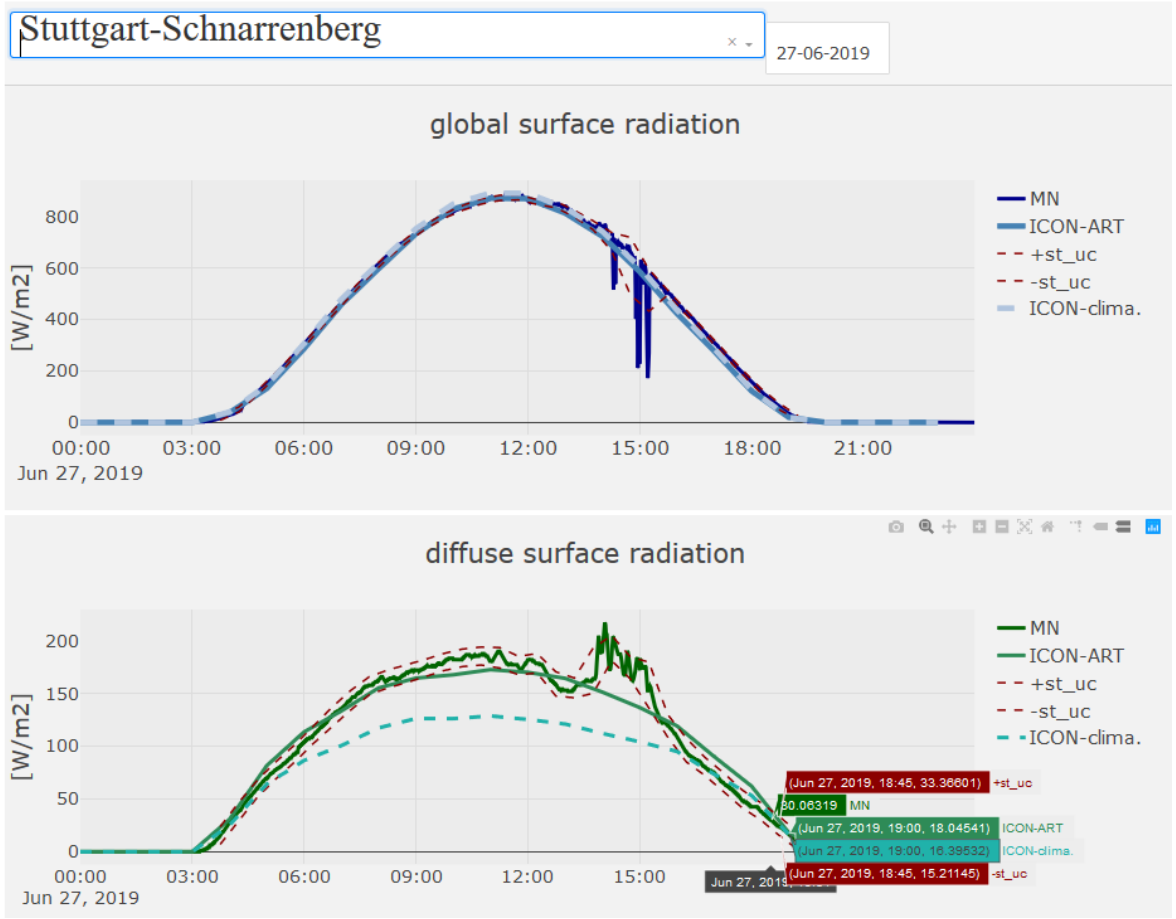
Hoshyaripour et al., 2019

➔ **Use of the optical properties of non-spherical particles leads to better agreement between model and CALIPSO**

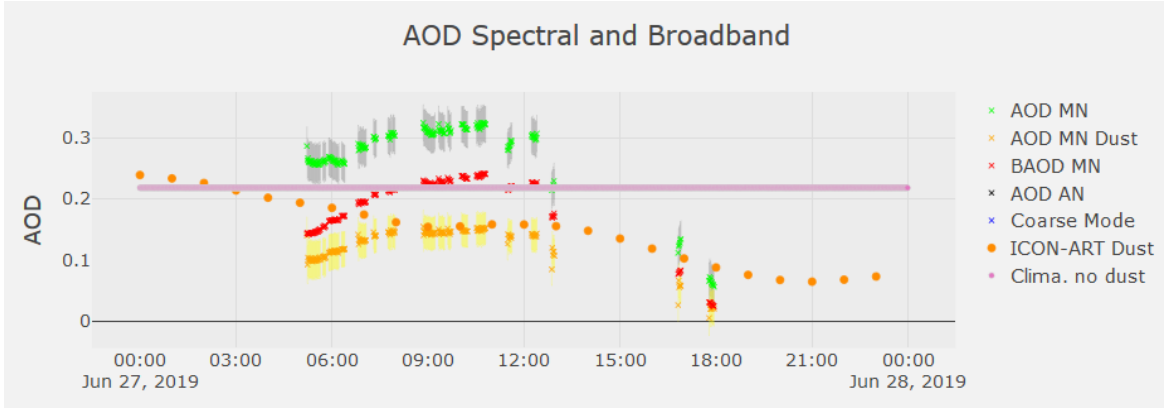
Processing, provision (dashboard) and evaluation of data from the DWD monitoring network

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Florian Filipitsch, DWD



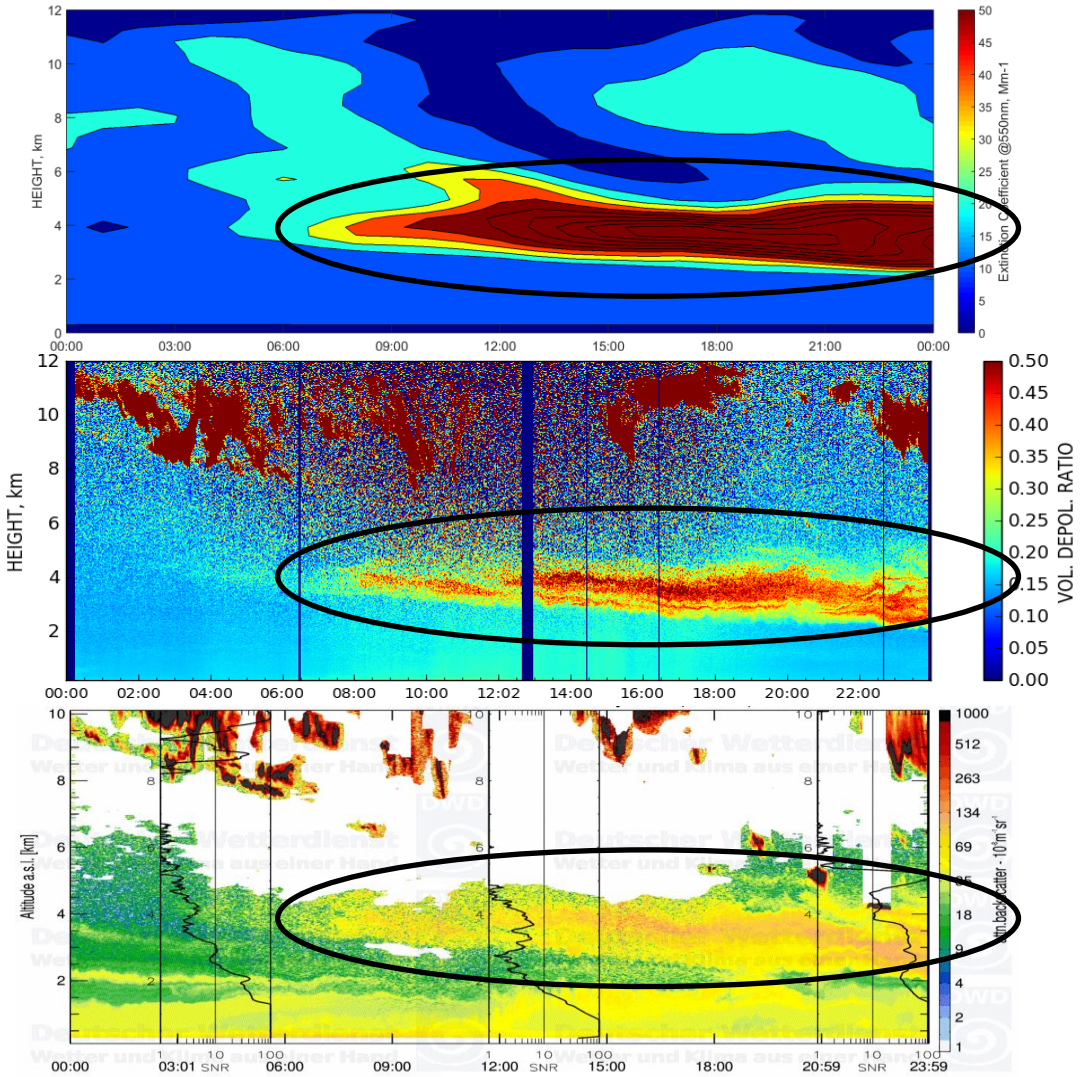
Saharan dust case 27.06.2019



➔ **Comparison of measurements with ICON-ART predictions difficult due to still used aerosol climatologies for other species than dust**

Model vs. Observation

26. Mai 2018
at KIT



ICON-ART

LIDAR
DEPOL

CEILOMETER

height
time

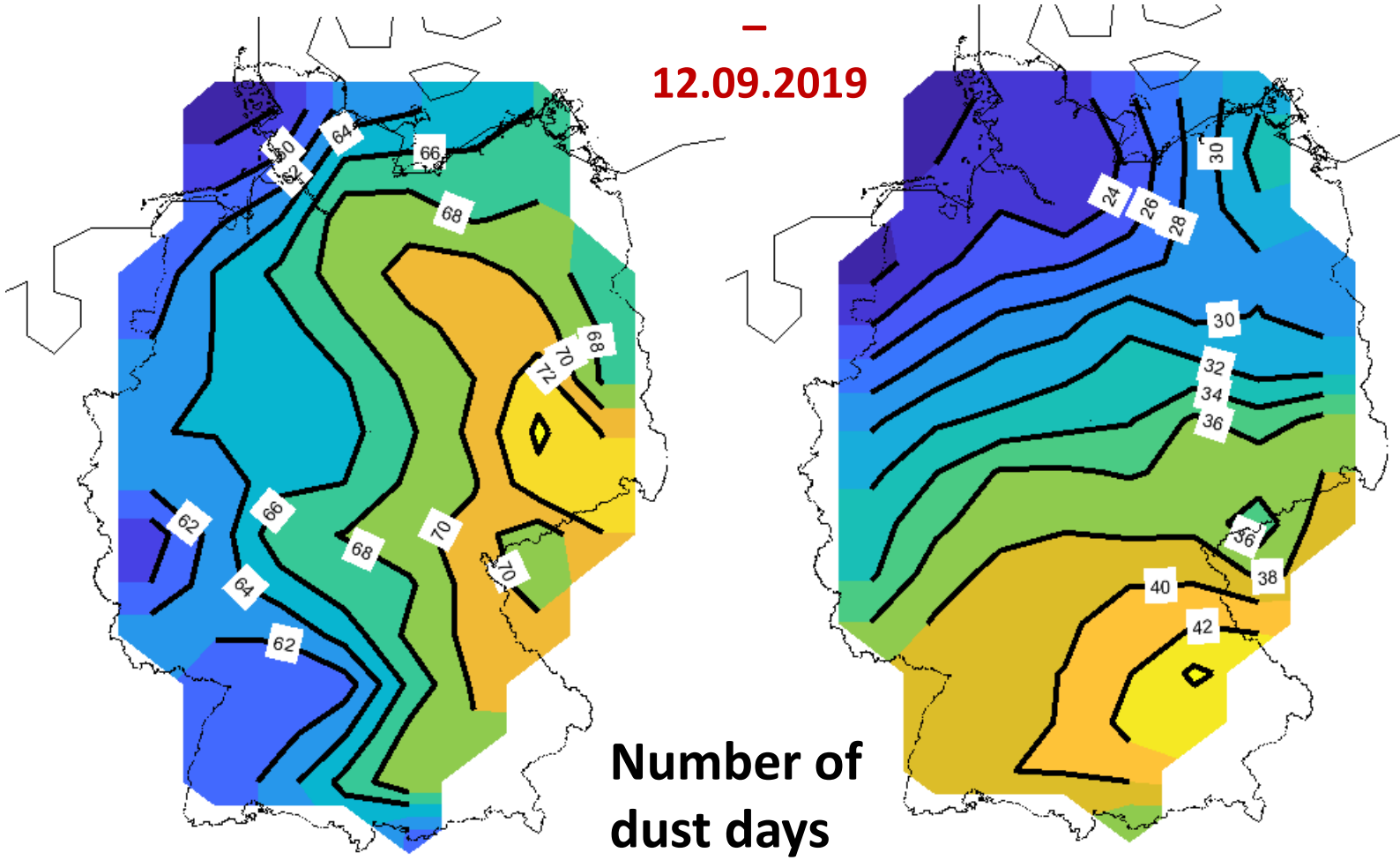
Mineral dust calendar based on ICON-ART

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

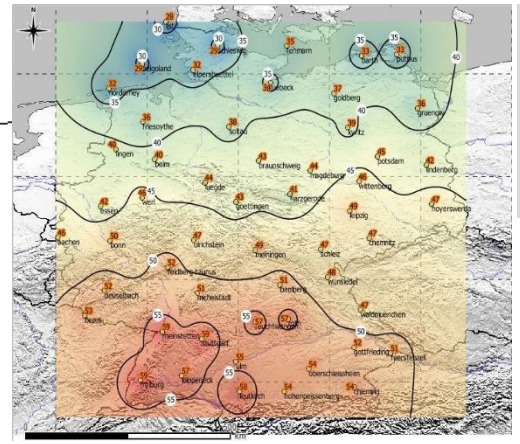
Frank Wagner, KIT

01.01.2018
–
12.09.2019

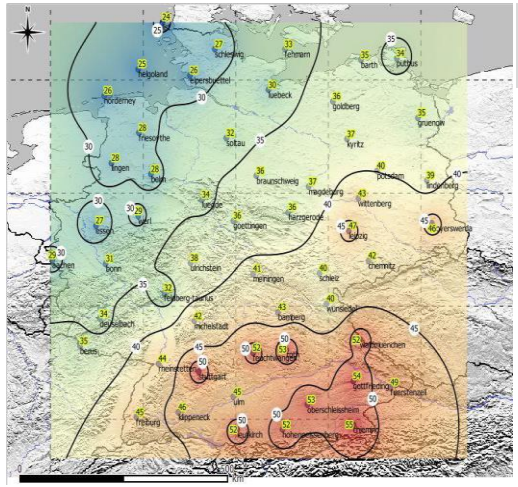
Colleagues at Hohenpeißenberg, DWD



Number of dust days



Jan 2014
–
Dec 2018



2018

Number of dust days, manual assessment using ceilometer measurements

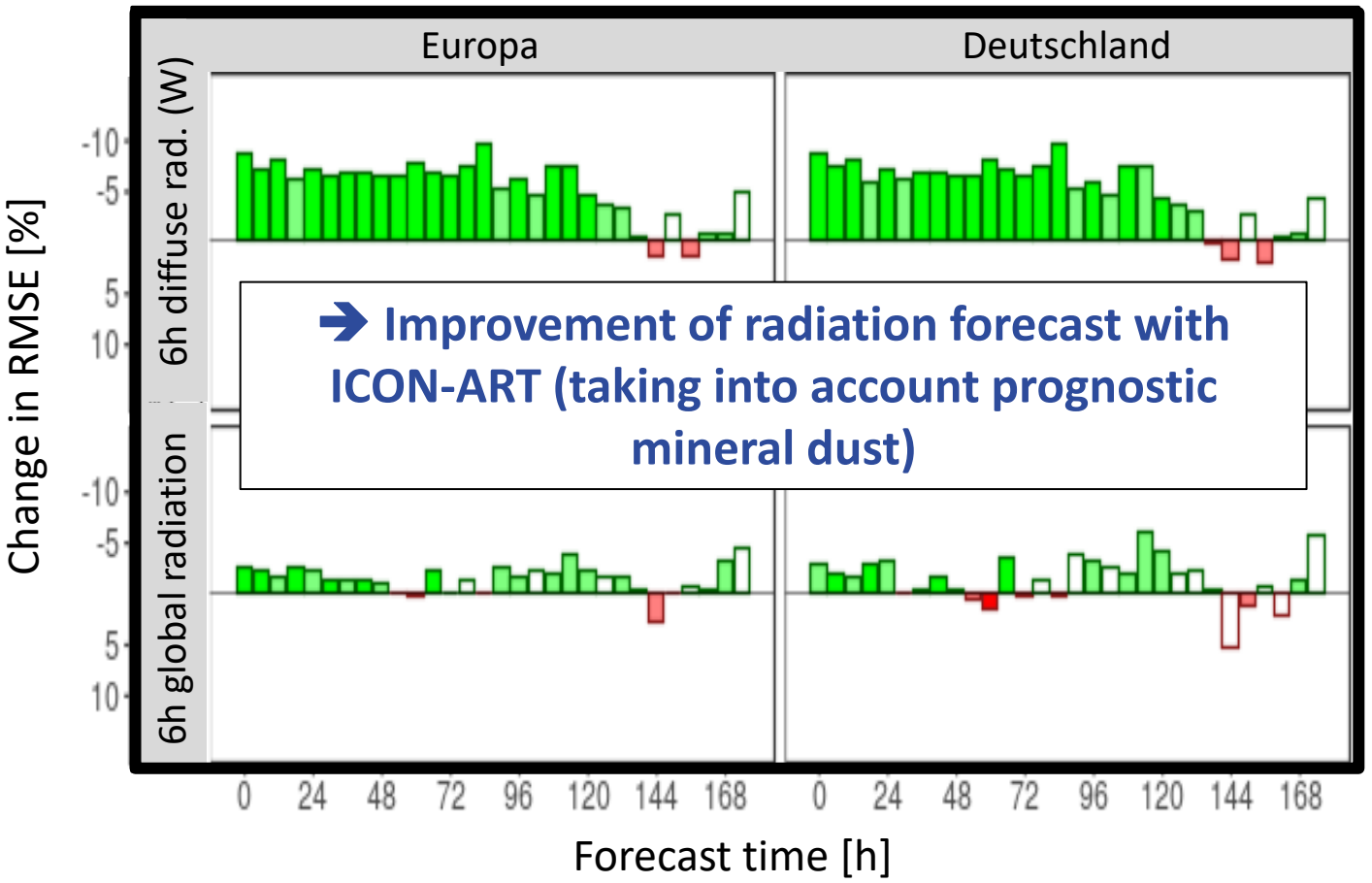
Threshold: AOD = 0.1 AOD = 0.14

Verification of radiation forecast

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Comparison of radiation forecast with SYNOP observations

June 2019



Experiments:

- with prognostic mineral dust
- with Tegen climatology for mineral dust (control exp.)

Treatment of prognostic mineral dust in the NWP leads to …

better radiation forecast

worse radiation forecast

Significance 0.00 0.25 0.50 0.75 1.00

ICON-ART
Radiation forecast

PV-power forecast
(meteocontrol GmbH)

Comparison of the PV-power predictions

Daniel Lassahn, meteocontrol

Investigation: Influence of improved radiation forecast on PV-power prediction

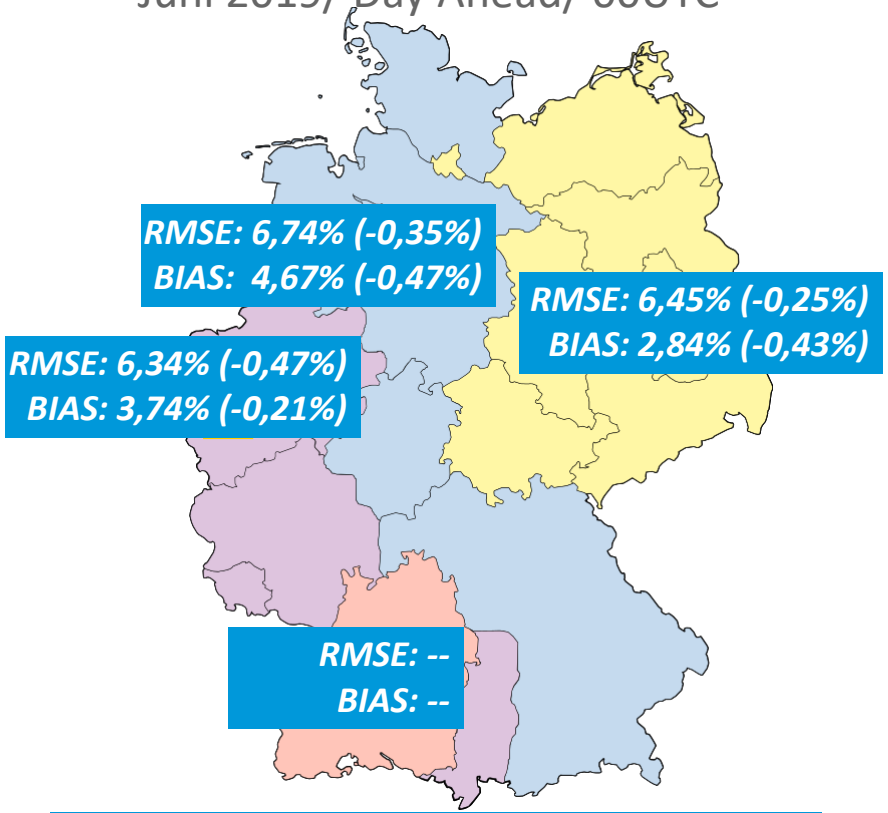
Assumption: only input from a single weather model

- **with Tegen mineral dust climatology (control exp.)**
- **with prognostic mineral dust**
  - The experiment with prognostic mineral dust is consistently better when measured on RMSE and BIAS.
  - Especially on radiation days in the presence of Saharan dust the improvement is even greater.
  - A reduction of these scores by approx. 0.4% points is a significant improvement for a forecasting service provider.

ATTENTION: here only single model PV prediction!

In reality: several models, learning methods etc.

Juni 2019/ Day Ahead/ 00UTC



Score with progn. mineral dust *(Difference to Tegen climatology)*

WMO SDS-WAS

(Sand and Dust Storm Warning Advisory and Assessment System)

Mineral Dust - Ensemble

ICON-ART as a new member of the WMO SDS-WAS Ensemble

(Sand and Dust Storm Warning Advisory and Assessment System)

➔ Link zur Homepage
(AEMet and BSC)

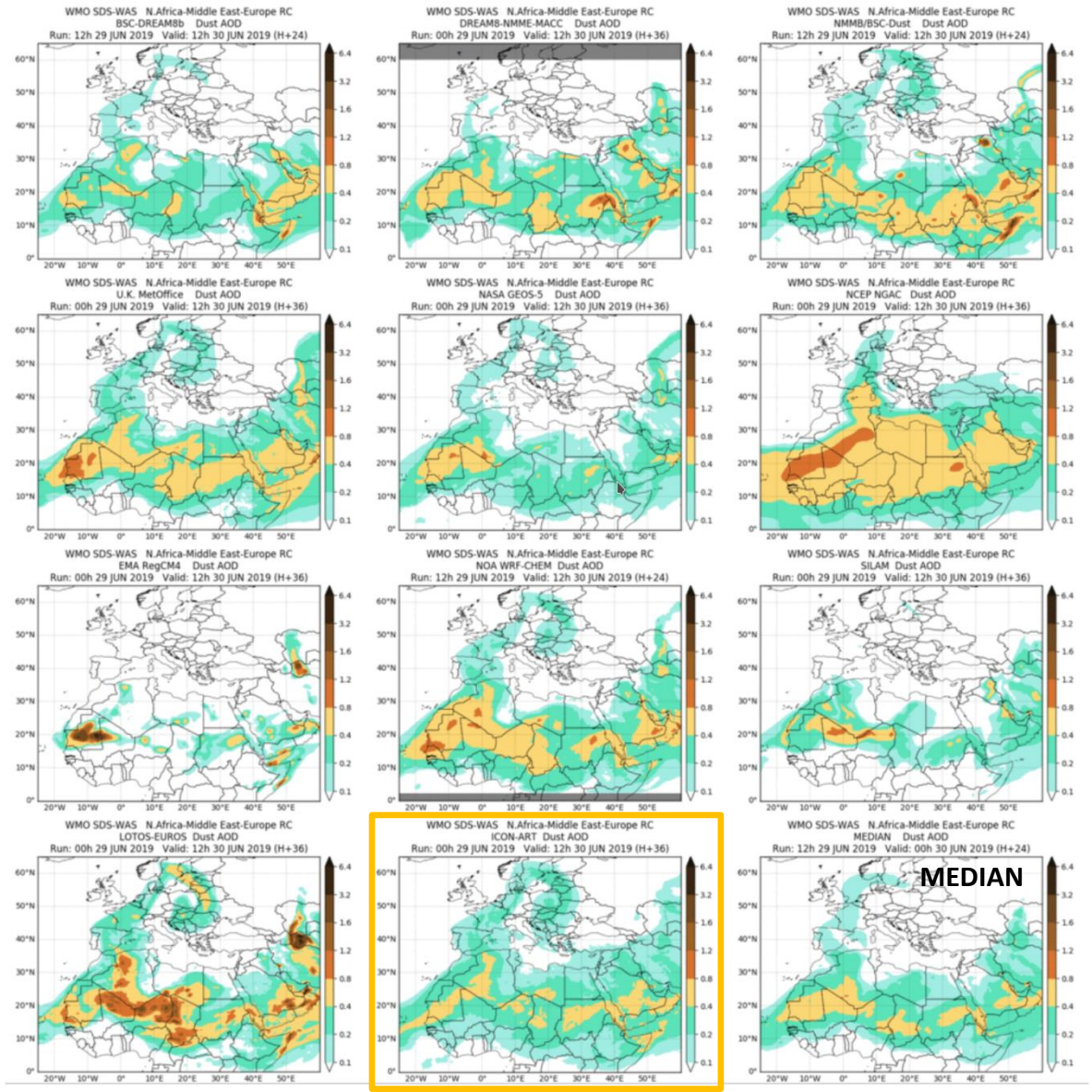
➔ ICON-ART forecasts
since 29.06.2019

➔ Products:

➔AOD Dust

➔Near surface
(lowest model layer)
mass concentration

Dust optical depth:



Summary PerduS

- Development of new analysis methods and model components
- Quasi-operational global mineral dust forecasts: twice a day for the next 7.5 days
- Daily preparation and provision of data (monitoring network and forecasts)
- Improved photovoltaic power forecasts for Germany at Saharan dust events

Photovoltaikertragsprognose zum besseren Management des Einflusses des atmosphärischen Aerosols auf die Stromnetze in Deutschland und Europa

(Photovoltaic power yield prediction for a better management of the influence of atmospheric aerosol on the power grids in Germany and Europe)

Motivation for PermaStrom from an NWP standpoint

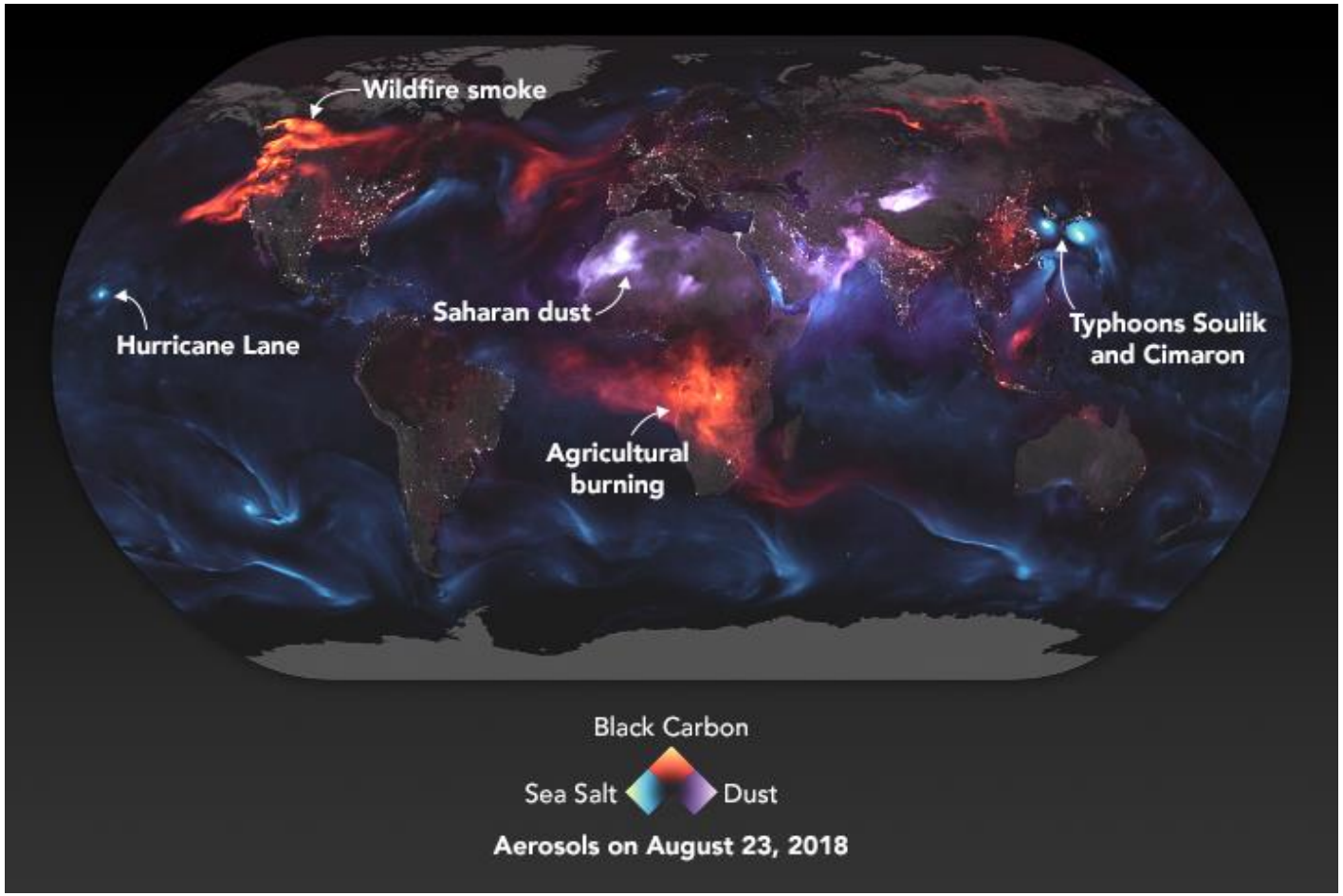
PerduS – „lessons learned“

- Comparison of forecasts with observations is difficult
  - remaining aerosol climatologies
  - influence on clouds (not or only partly considered)
  - few measurement stations
- Forecast subject to uncertainties

PermaStrom (since 05.2020)

- Extension:
  - mineral dust, sea salt, vegetation fire
  - influence on radiation and clouds (direct, semi-direct and indirect effect)
  - extensive validation with modern observation systems (area-wide)
- Consideration of prediction uncertainty (deterministic and ensemble prediction)

Aerosol variability due to mineral dust, sea salt and vegetation fires



https://earthobservatory.nasa.gov/images/92654/just-another-day-on-aerosol-earth

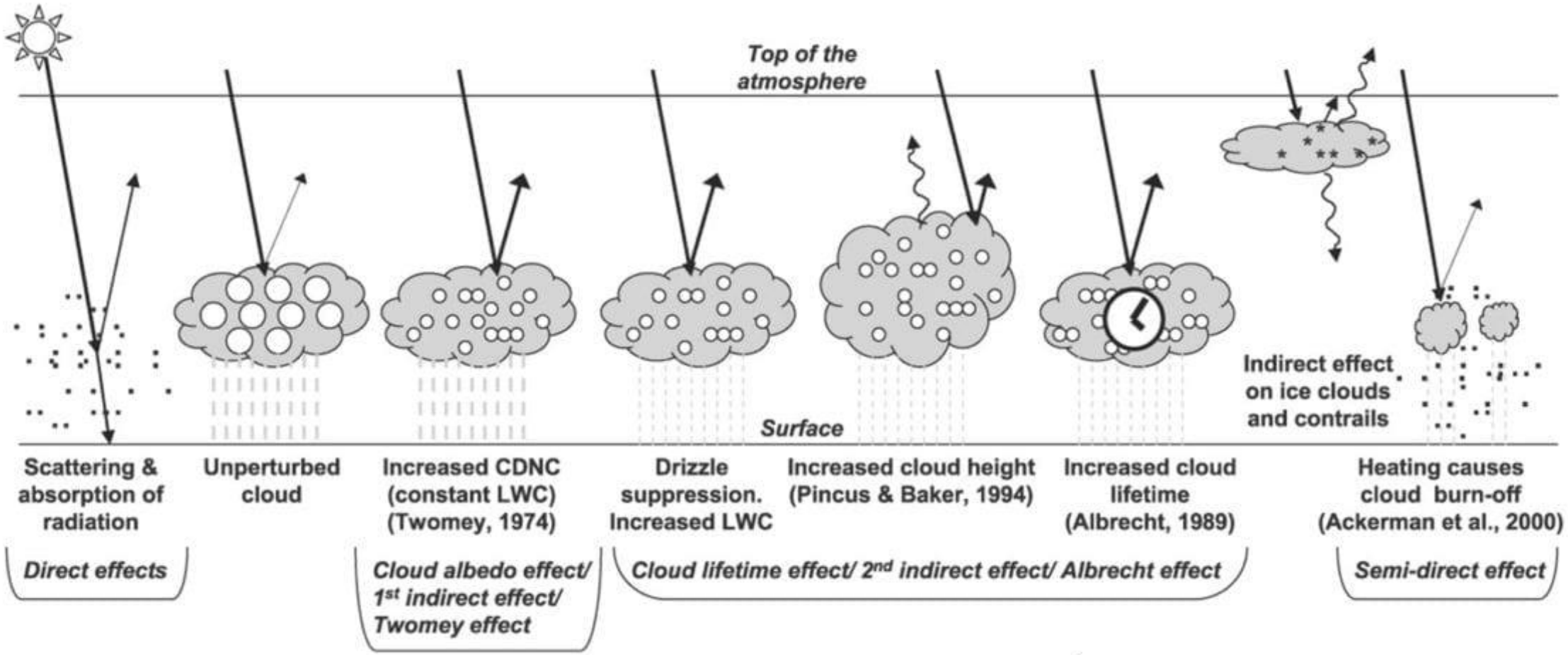
- Mineral dust (purple) from and above the deserts.
- Sea salt (blue) in the tropical and extratropical cyclones.
- Vegetation fire aerosol (red) over the continents.
- The variability is dominated by these 3 aerosol types.
- Without explicit aerosol modelling this leads to prediction errors.
- This is the American GEOS FP system, but we can do the same with ICON-ART!

New in PermaStrom: Vegetation fire aerosol / forest fires

ESA Sentinel, Forest fires in Greece

- Satellites show us in detail where and how much soot is released.
- ICON-ART can simulate the transport, aging and sedimentation of the forest fire aerosol.
- Beside the mineral dust events this is certainly another relevant special weather situation for the PV forecast.
- We plan to use the Copernicus Sentinel-3 NRT Fire Radiative Power product (1 km resolution). Alternative would be NASA MODIS FRP (daily).

Aerosol effects on clouds and radiation



IPCC Fourth Assessment Report (2007), Fig. 2.10

Prediction uncertainty and ensembles

- Aerosol predictions are uncertain. On the one hand, because the emissions and aerosol properties are not exactly known, on the other hand, it is difficult to correctly hit the often filament-like structures in space and time.
- Aerosols also cause uncertainty by acting on clouds and on the dynamics of the atmosphere.
- This motivates the use of an ensemble system to model the prediction uncertainties.
- In PermaStrom we will introduce an ensemble for the ICON-ART system.
  This ensemble will be small (~10 members), because ICON-ART is complex and expensive.
- Such a small ensemble is not necessarily stable. In this case an exchange of information with the operational ICON ensemble (~100 members) would be useful. The ICON-Ensemble could also use the information about aerosol variability from ICON-ART to increase the spread if necessary. These are current research topics in data assimilation and meteorological modeling.

Use of observational data

- In PerduS we have used especially station and LIDAR measurements to validate the aerosol and radiation predictions. This will be continued and extended, e.g. automatic classification of aerosol and cloud layers.
- The use of observational data is to be increasingly extended to the whole of Europe. For this purpose a comprehensive quality control is necessary.
- Furthermore, satellite data of aerosols and clouds shall be used more systematically for model development and validation, e.g. near-time CM-SAF products, which were not available 2-3 years ago.
- For case studies, special observations will also be used, e.g. vertical profiles of radiation fluxes in high fog situations with the ISOLDE system in Lindenberg. This is potentially very helpful for the understanding and validation of indirect aerosol effects.