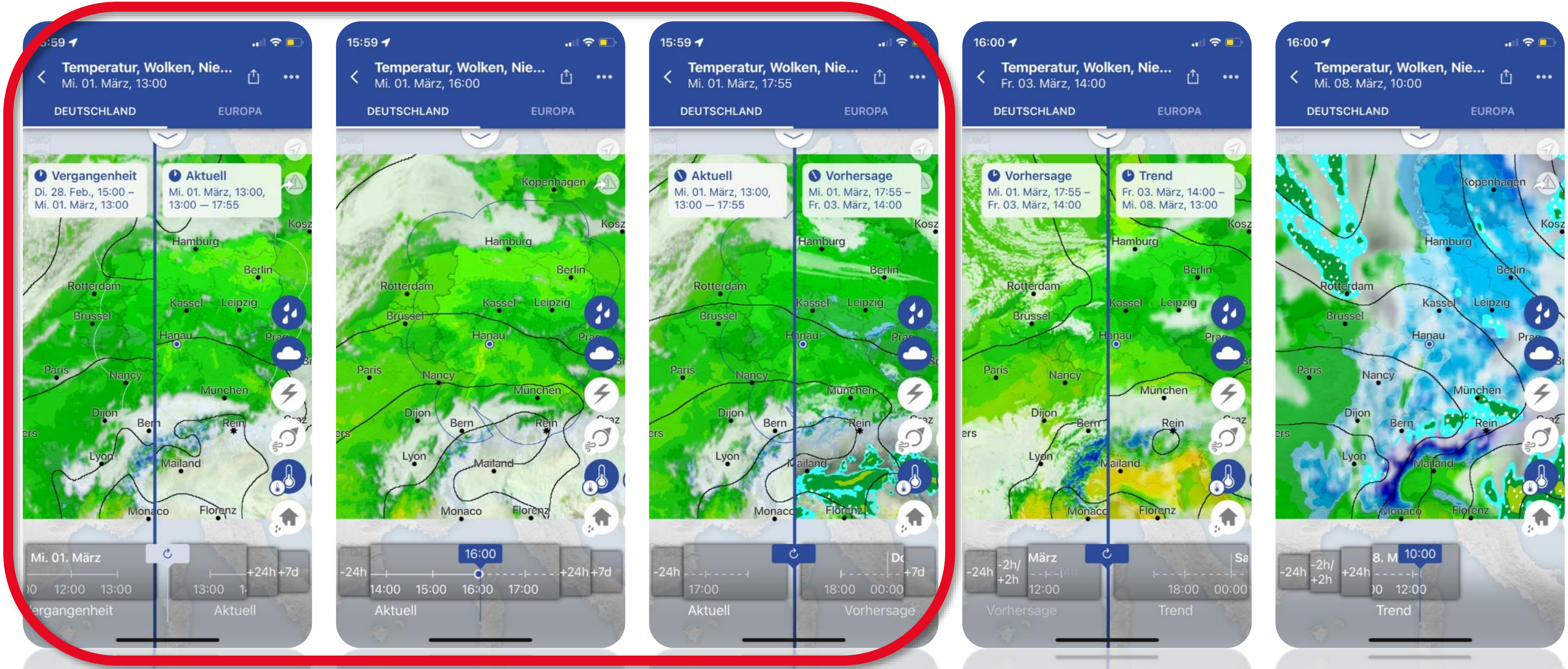
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Enhancing Numerical Weather Prediction with Opportunistic and Crowdsourced Observations:

Insights from NetAtmo and Microwave Link Assimilation

Stefanie Hollborn
FE12 – Observation Modelling and Verification
FE1 – Meteorological Analysis and Modelling

Range of DWD Weather Forecasts



NWP Model Chain

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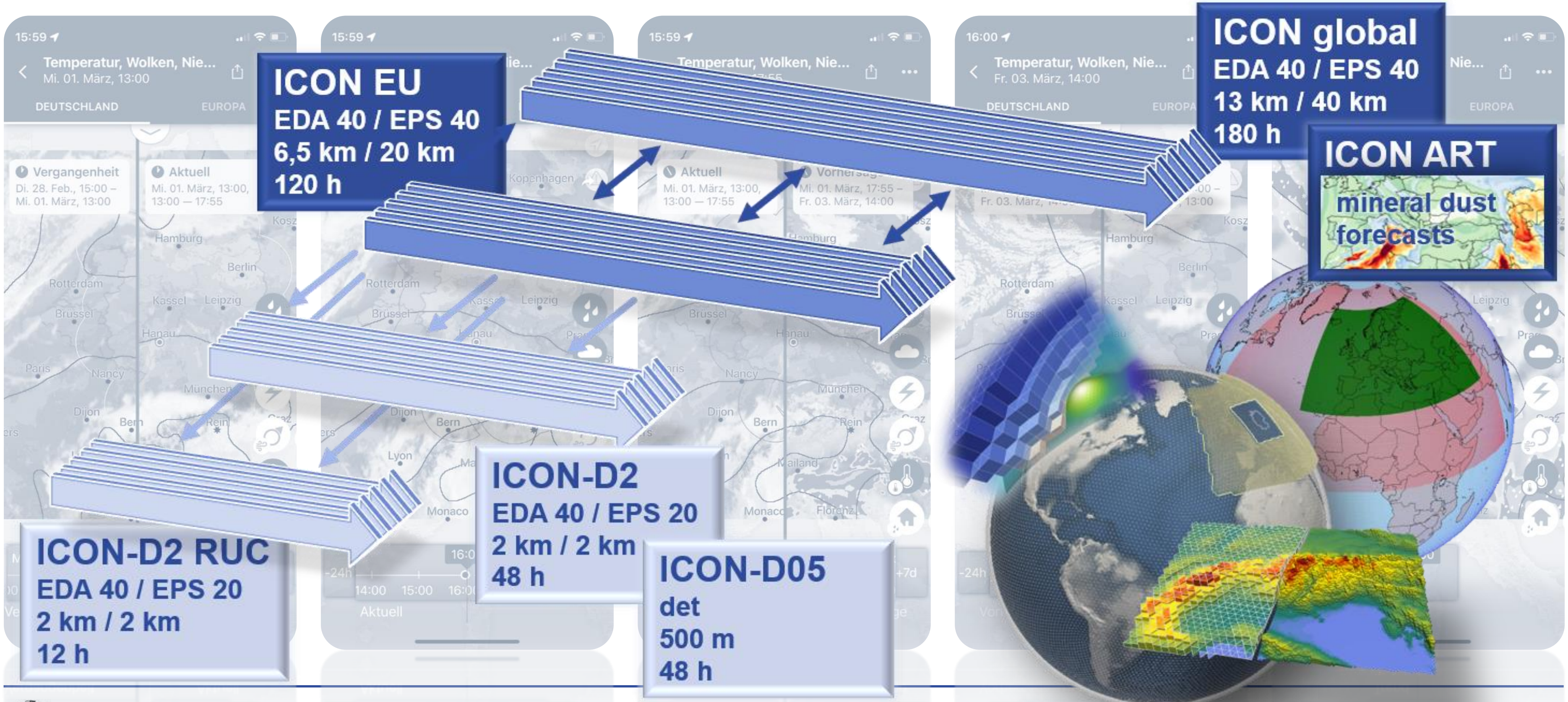
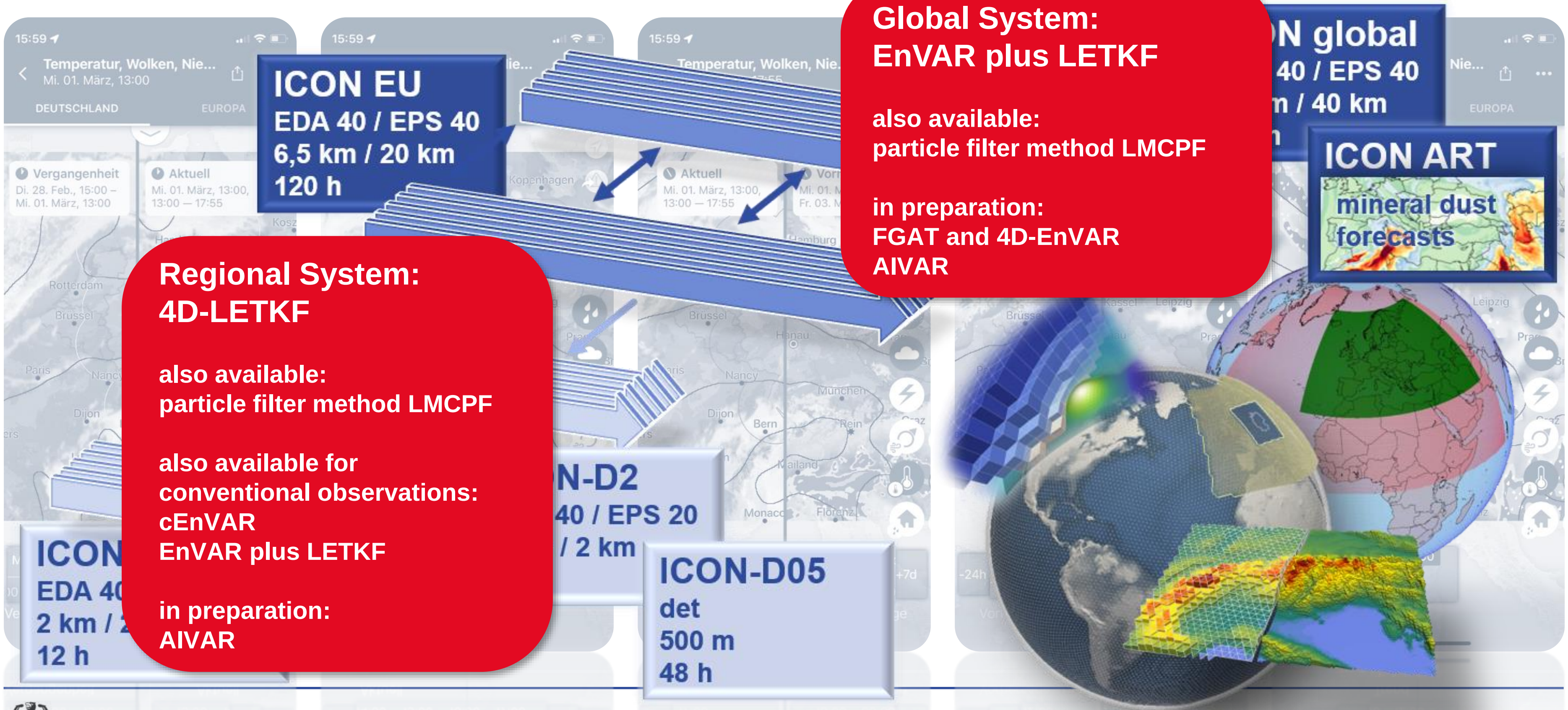


NetAtmo and CML Data Assimilation

NWP DA Methods



Global System:
EnVAR plus LETKF

also available:
particle filter method LMCPF

in preparation:
FGAT and 4D-EnVAR
AIVAR

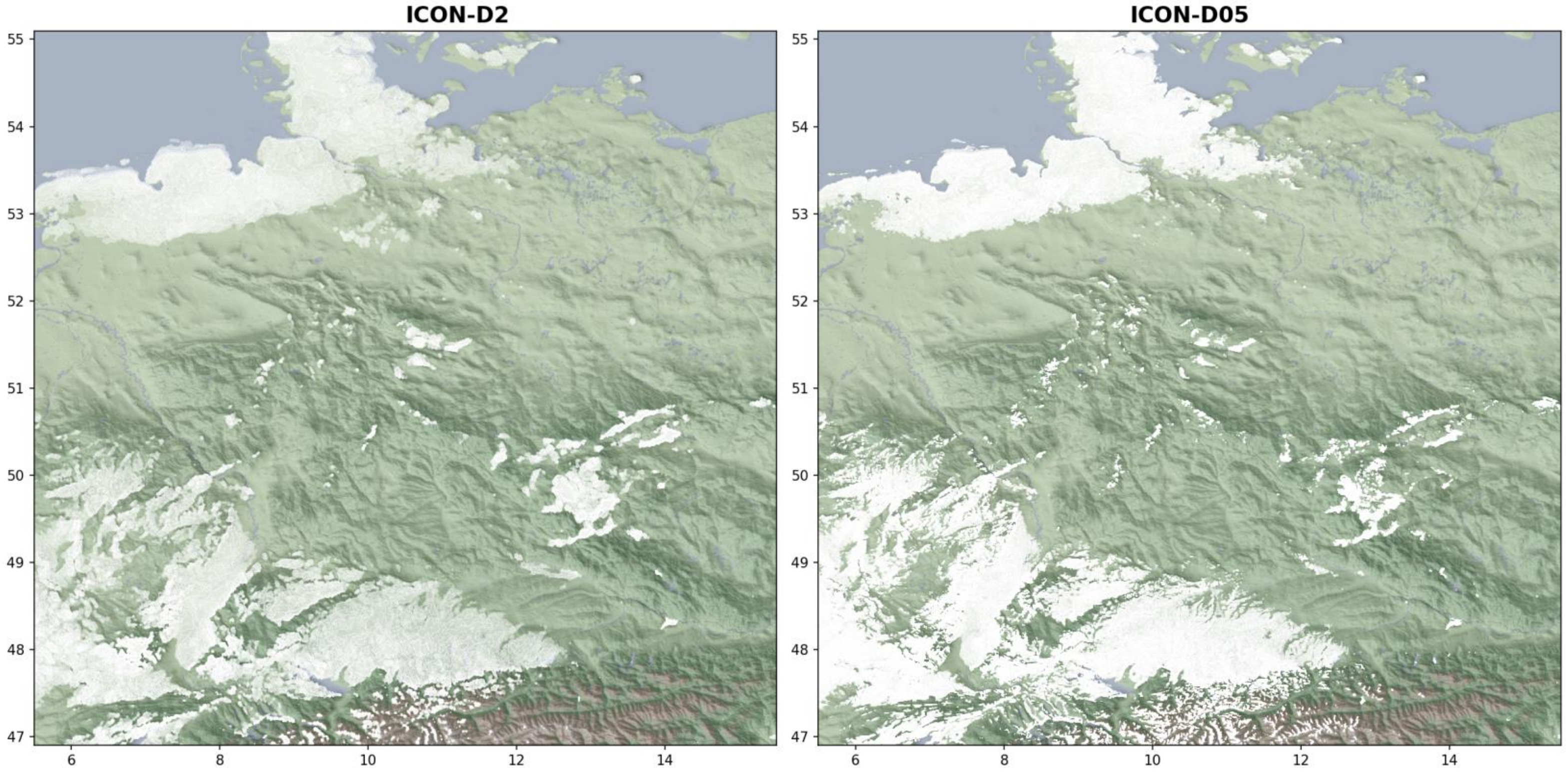
Regional System:
4D-LETKF

also available:
particle filter method LMCPF

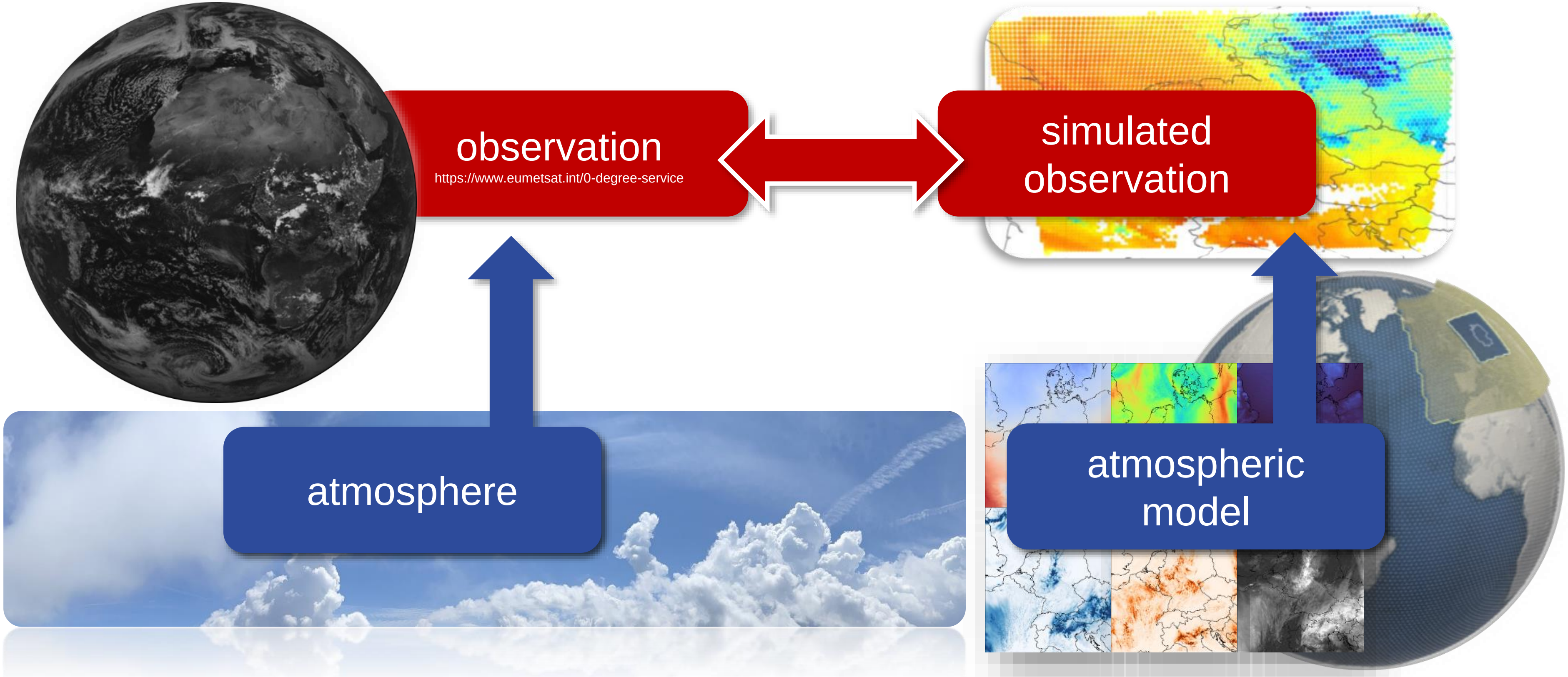
also available for conventional observations:
cEnVAR
EnVAR plus LETKF

in preparation:
AIVAR

NWP Model Chain



Observations and NWP Model



Operational Data Usage

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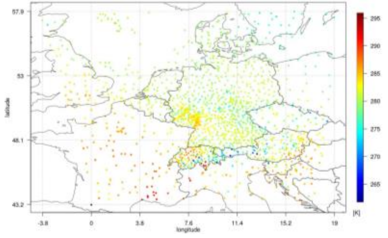
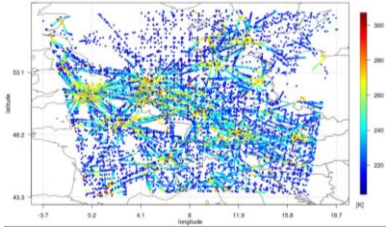
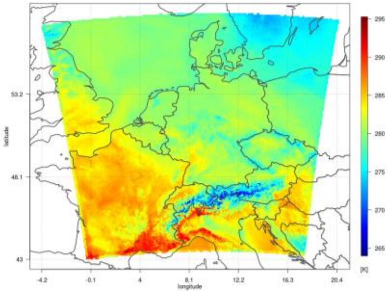
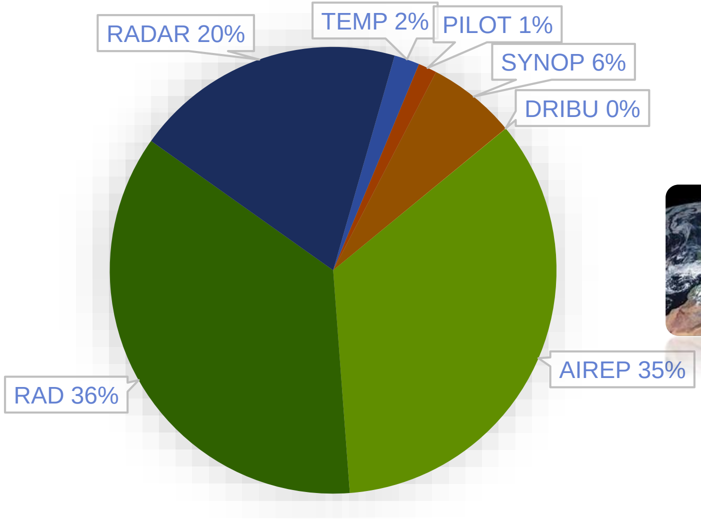
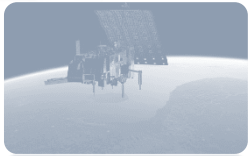






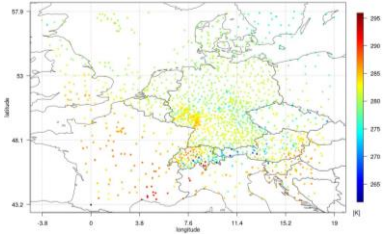


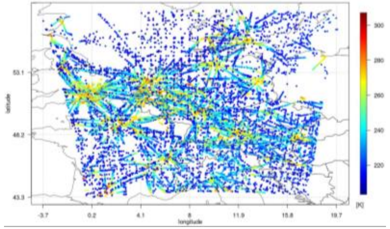


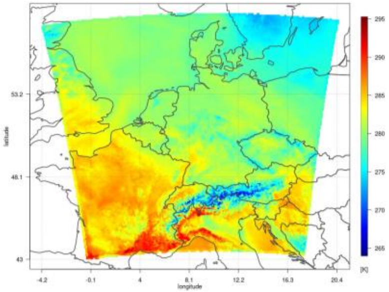
ICON-D2

- **operational monitoring:** ~ 10 M data per day (depends on weather)
- **used data:** ~ 2 M data per day

KENDA System

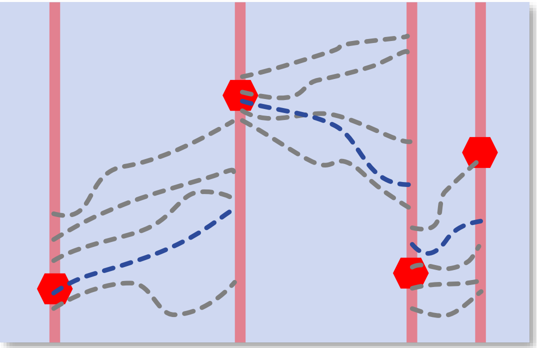






Observations and forecasts have systematic and random errors.

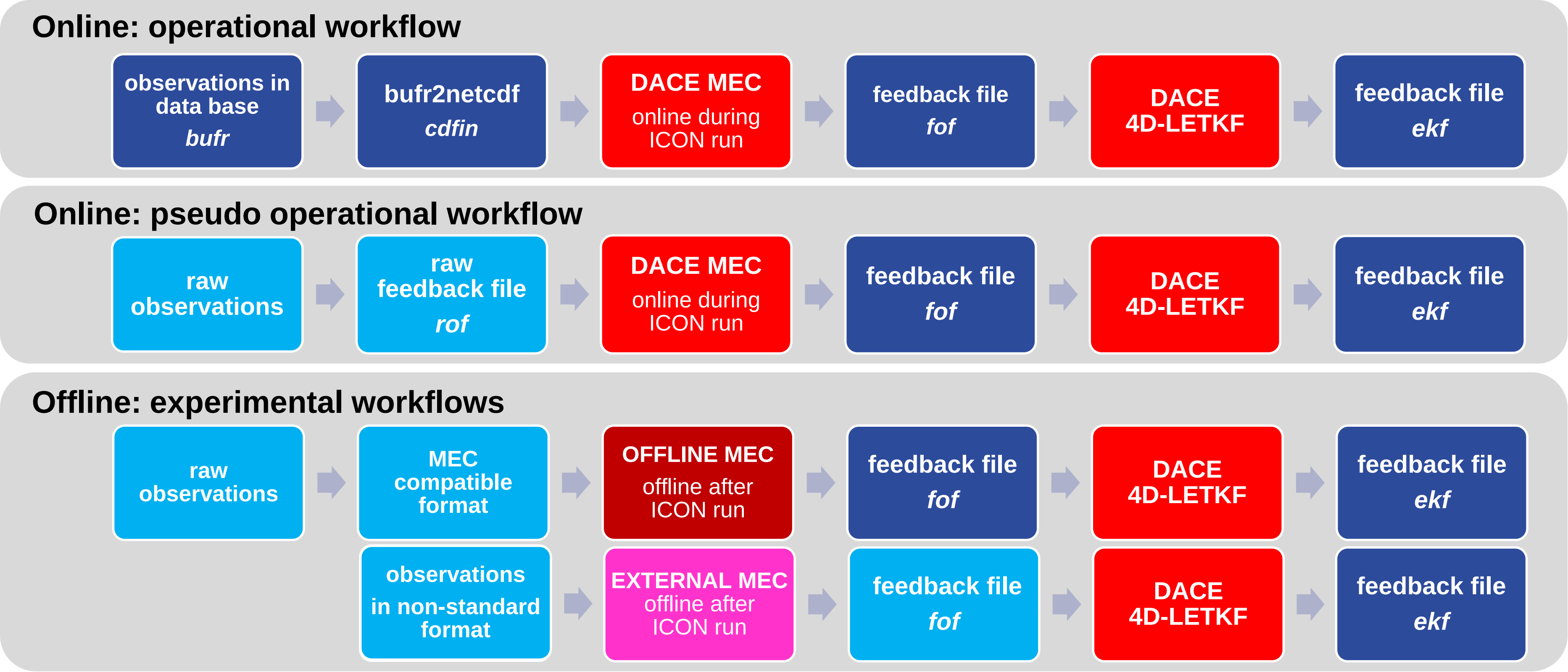
Localized Ensemble Transform Kalman Filter



- needs observations, observation equivalents, and mean deviation in observation space
- influence of observations is locally restricted
- basic observation operator:
  interpolation and variable transformation (NetAtmo)
- complex observation operator:
  EMVORADO (CML data)
- assumptions: observations are unbiased
  and have Gaussian observation error

Multiple forecasts (ensemble) provide information about the forecast accuracy (spread).

Observation Processing



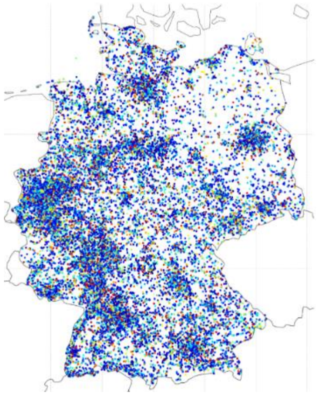
DACE: Data Assimilation Coding Environment at DWD
MEC: Model Equivalent Calculator – observation operator
feedback file: observation, model equivalents and meta data

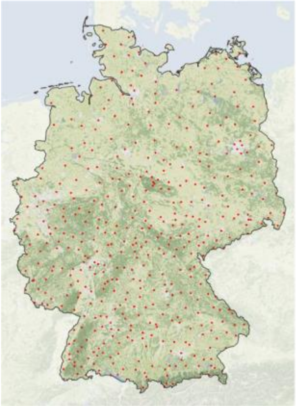
NetAtmo Data Assimilation

NetAtmo Project (2020-2021)

Comparision of the assimilation of SYNOP and NetAtmo stations

Christine Sgoff, Walter Acevedo,
Zoi Paschalidi, Sven Ulbrich,
Thomas Kratzsch, Roland Potthast





Data coverage

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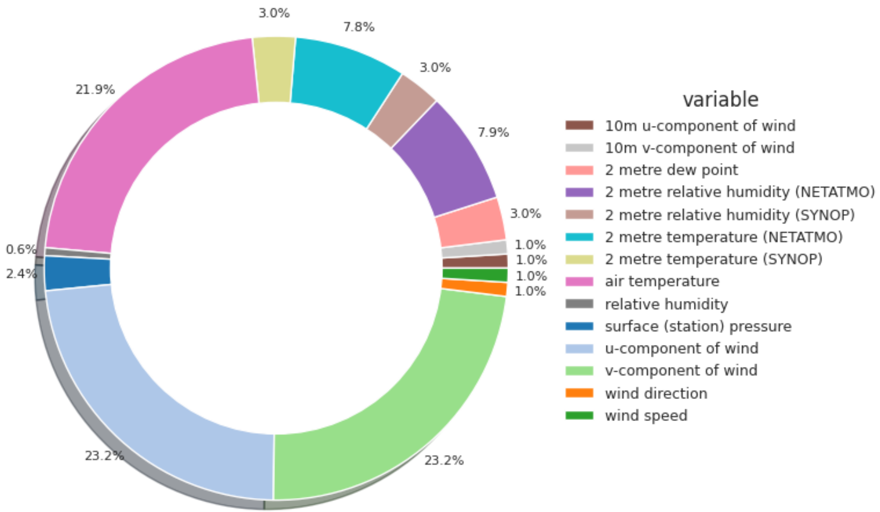
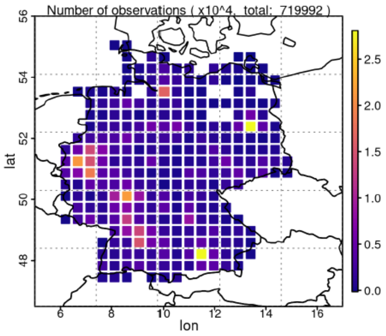
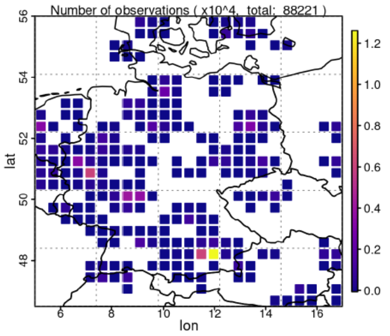
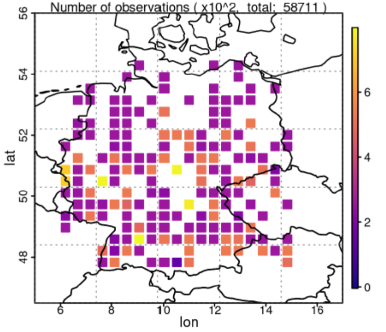


NetAtmo

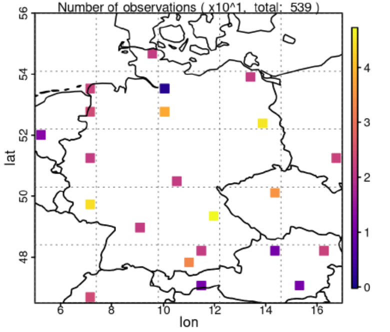


Aircrafts





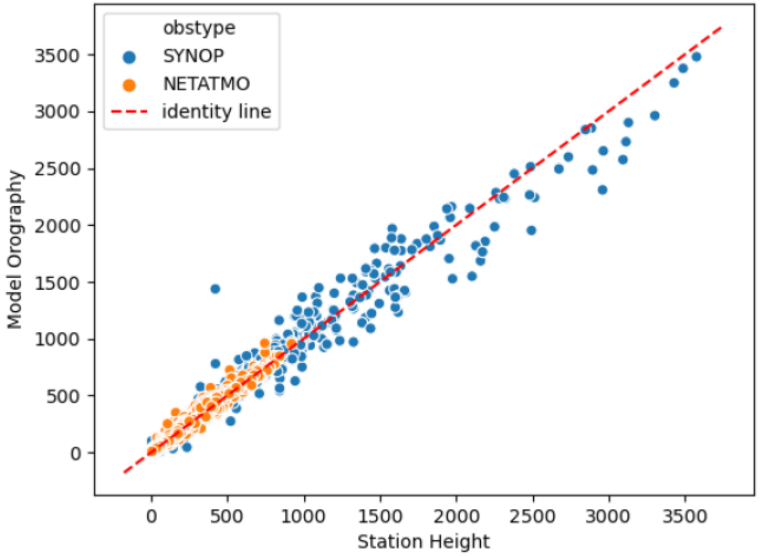
SYNOP

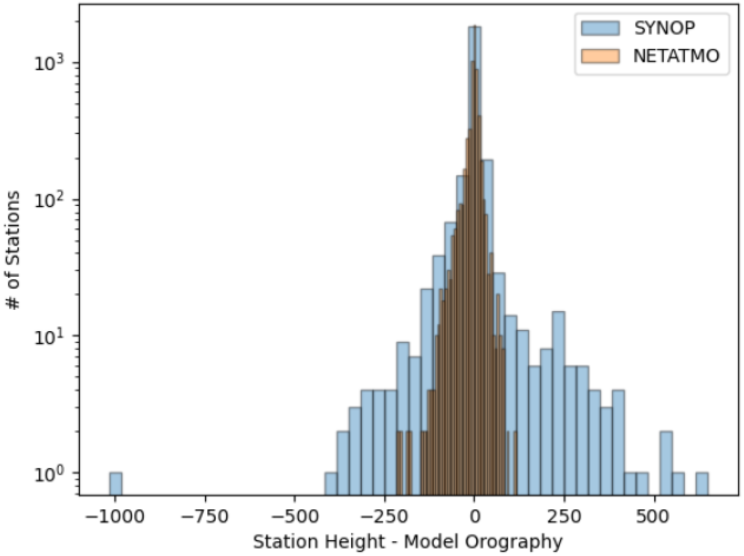


Radiosondes

The high density of NetAtmo stations requires spatial thinning.

NetAtmo – Data coverage





SYNOP stations are evenly distributed across Germany, whereas NetAtmo stations are mainly found in urban metropolitan areas. This poses challenges for both modeling and verification.

NetAtmo – Biascorrection

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Experimental period: 2 weeks in September 2018

Quality control:

preprocessing control (observations only)

- plausibility control (feasible variable range)
- double records control

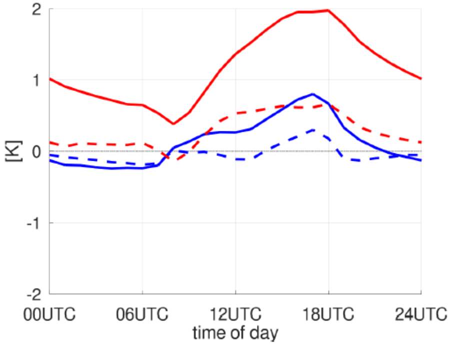
processing control (with ICON model data)

- first guess control
- modelling check (height control)
- error checks

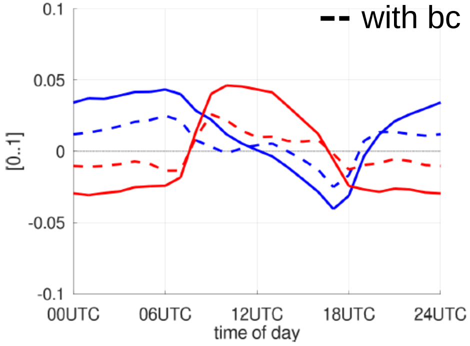
Bias correction

SYNOP
NetAtmo
— without bc
-- with bc

2m humidity



2m temperature



NetAtmo data have a significantly larger bias than SYNOP data.

An approriate bias correction attenuates the diurnal cycle.
input for NetAtmo: day time
input for SYNOP: day time and cloud cover

NetAtmo – Assimilation experiments

experiment name	assimilated observations	bias correction
REF	Conventional (the operational set up)	no
SNP	Conventional + synoptic T2M+RH2M	no
SNP_BC	Conventional + synoptic T2M+RH2M	yes
NTM	Conventional + NetAtmo T2M+RH2M	no
NTM_BC	Conventional + NetAtmo T2M+RH2M	yes

NetAtmo – SYNOP verification

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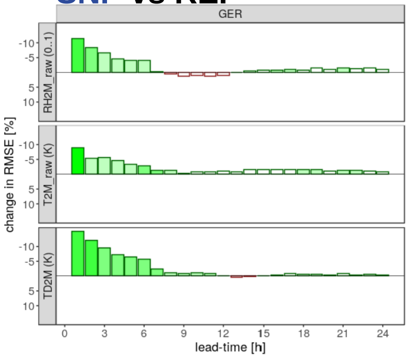
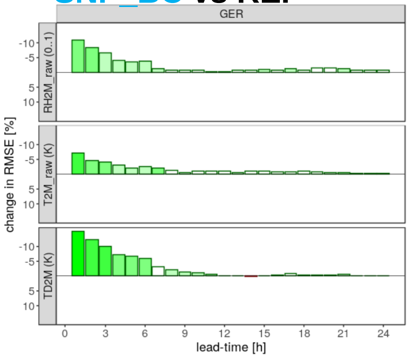
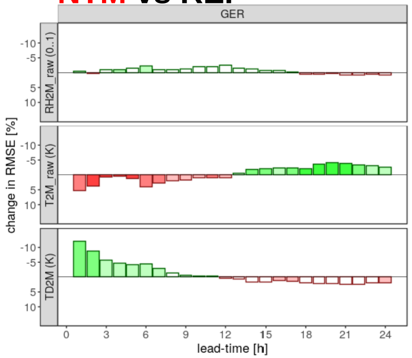
SNP vs REF



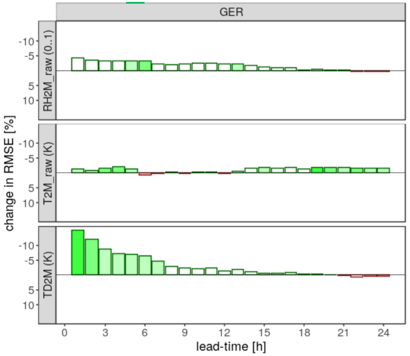
SNP_BC vs REF



NTM vs REF



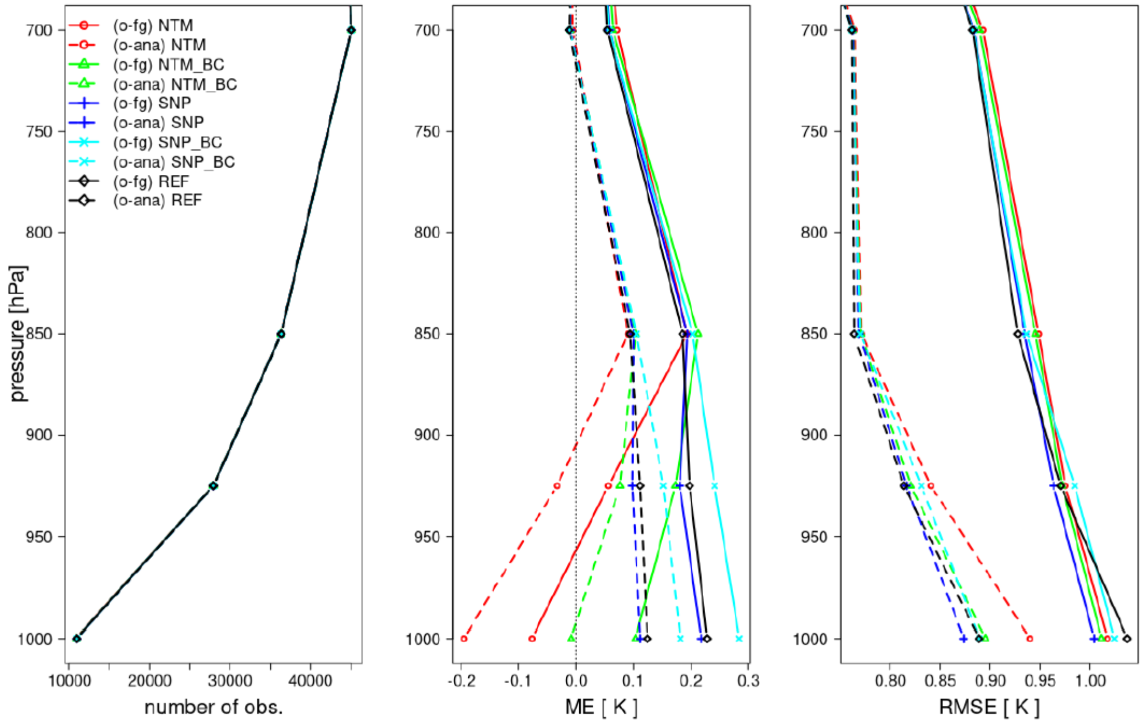
NTM_BC vs REF



name	observations	bias correction
REF	Conventional	no
SNP	Conventional + SYNOP	no
SNP_BC	Conventional + SYNOP	yes
NTM	Conventional + NetAtmo	no
NTM_BC	Conventional + NetAtmo	yes

NetAtmo – Upper air verification

Upper air temperature: Analysis and first guess



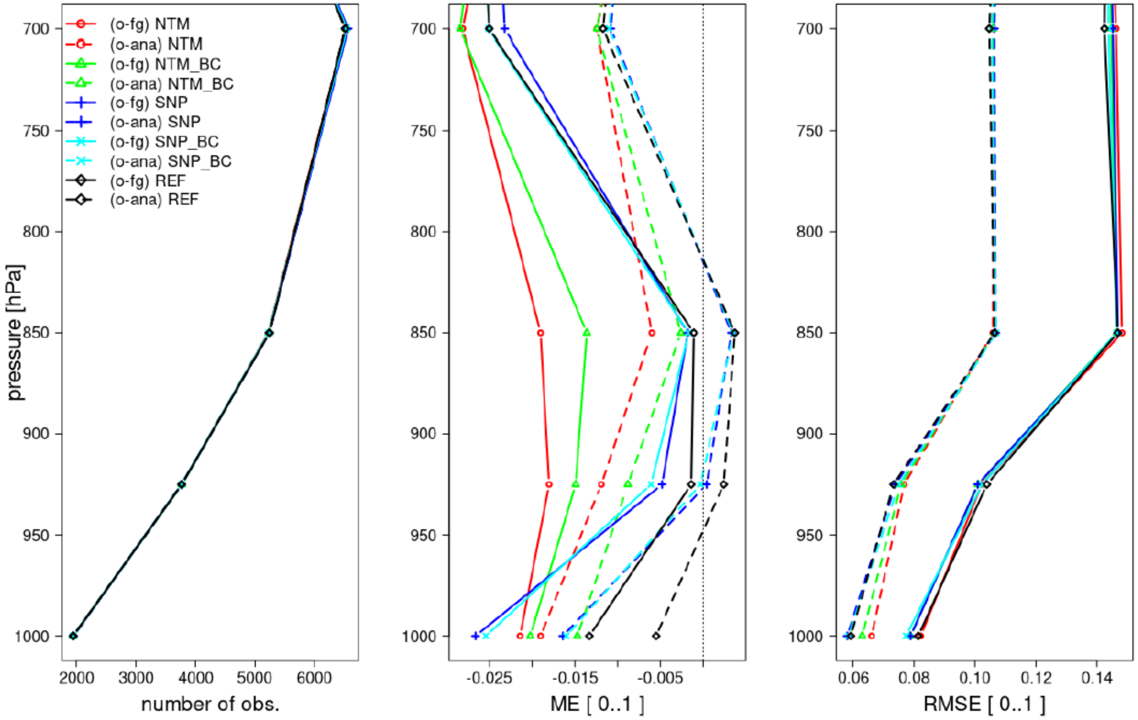
name	observations	bias correction
REF	Conventional	no
SNP	Conventional + SYNOP	no
SNP_BC	Conventional + SYNOP	yes
NTM	Conventional + NetAtmo	no
NTM_BC	Conventional + NetAtmo	yes

— first guess
-- analysis

NetAtmo – Upper air verification

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Upper air humidity: Analysis and first guess



name	observations	bias correction
REF	Conventional	no
SNP	Conventional + SYNOP	no
SNP_BC	Conventional + SYNOP	yes
NTM	Conventional + NetAtmo	no
NTM_BC	Conventional + NetAtmo	yes

— first guess
-- analysis

NetAtmo – Upper air verification

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DWD

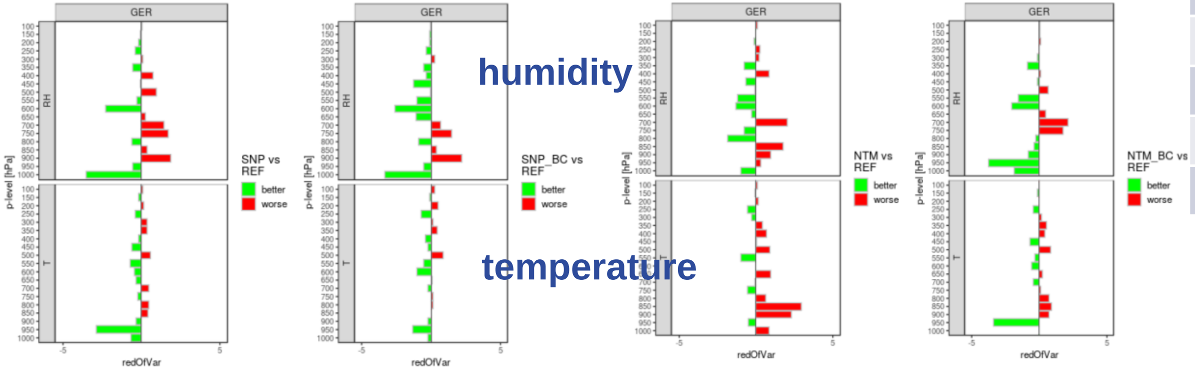
name	observations	bias correction
REF	Conventional	no
SNP	Conventional + SYNOP	no
SNP_BC	Conventional + SYNOP	yes
NTM	Conventional + NetAtmo	no
NTM_BC	Conventional + NetAtmo	yes

SNP vs REF **SNP_BC vs REF** **NTM vs REF** **NTM_BC vs REF**

radiosondes

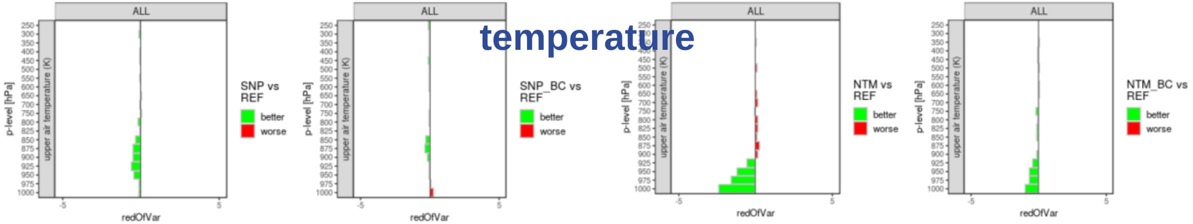
humidity

temperature

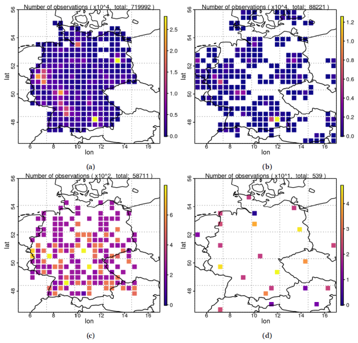


aircrafts

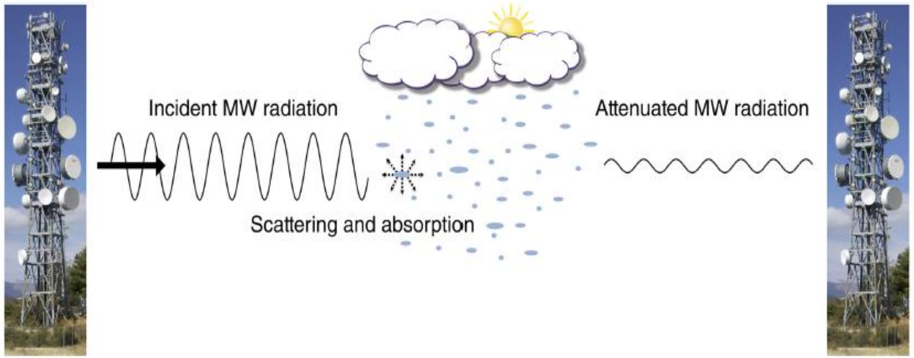
temperature



verification of 24h forecasts



CML Data Assimilation



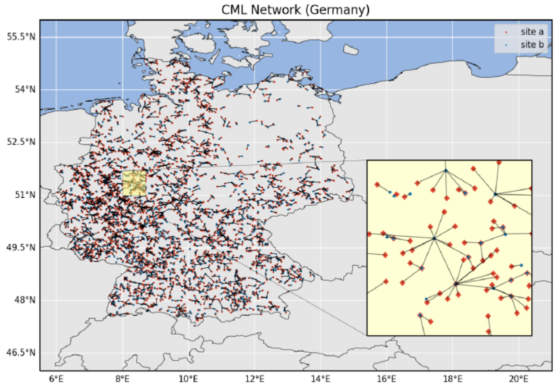
https://doi.org/10.1002/wat2.1337

RealPEP (2021-2025)
Commercial Microwave Link Data Assimilation with the LETKF

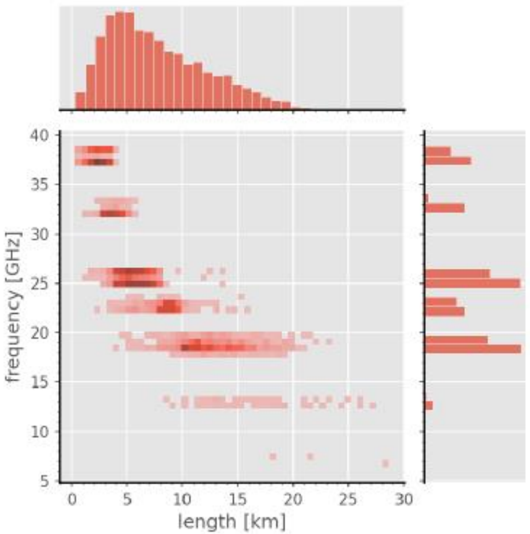
Klaus Vobig, Roland Potthast,
Christian Chwala, Julius Polz

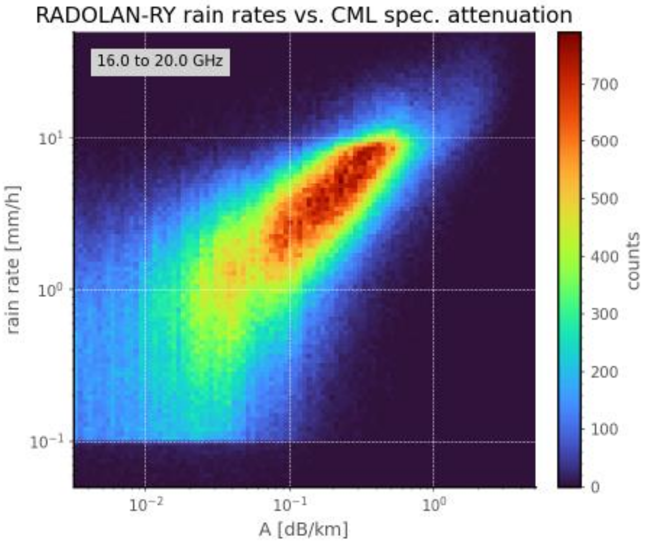
Commercial Microwave Links (CMLs)

- wireless communication connections between mobile phone towers that transmit data using microwave frequencies
- sensitive to atmospheric conditions, especially **rain**
- dataset of ~4000 CMLs (June 2019)
  one minute resolution



CML – Observations

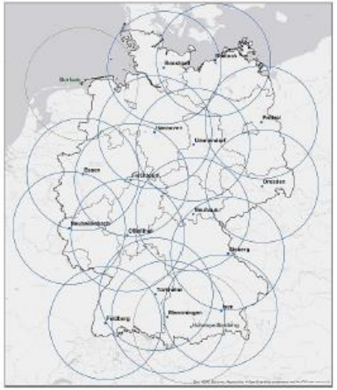


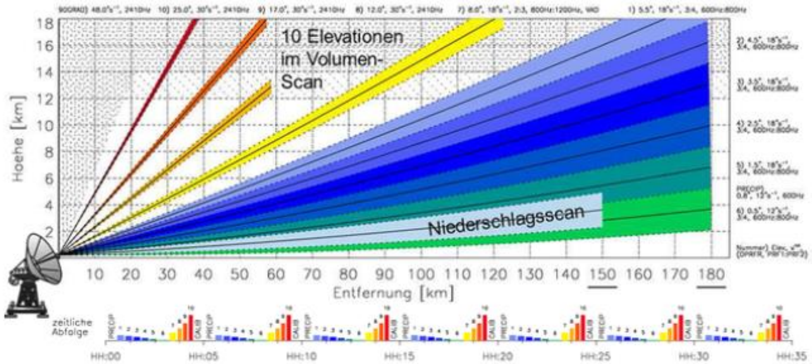


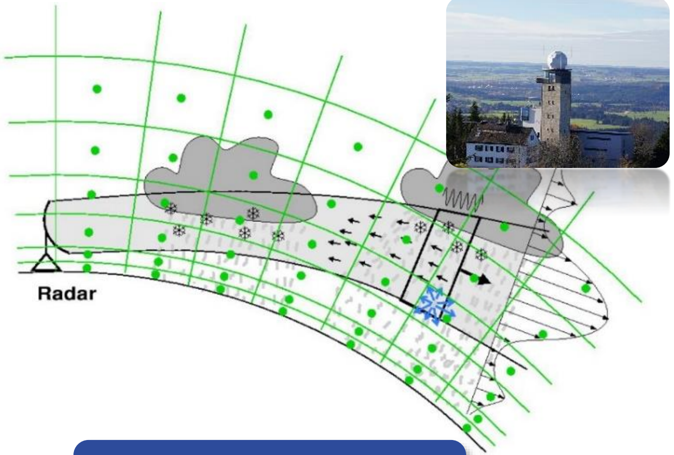
Commercial Microwave Links (CMLs)

- CML frequency between 10 and 40 GHz
- power law relation between rainfall rate and CML attenuation
- assimilation of path-averaged specific attenuations

Radar Operator EMVORADO





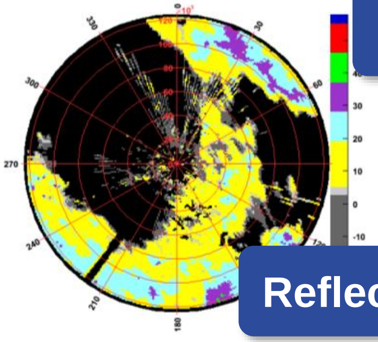


Efficient Modular Volume scan Radar Operator

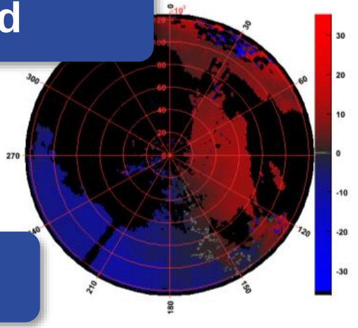
- framework for simulation of radar volume data of entire networks in a modular and highly configurable way
- computes reflectivities and attenuations

German Radar Network

- 17 dual-polarization C-band Doppler Radars
- reflectivity and radial wind assimilated in ICON_KENDA, and Latent Heat Nudging is employed



Reflectivity (3D)

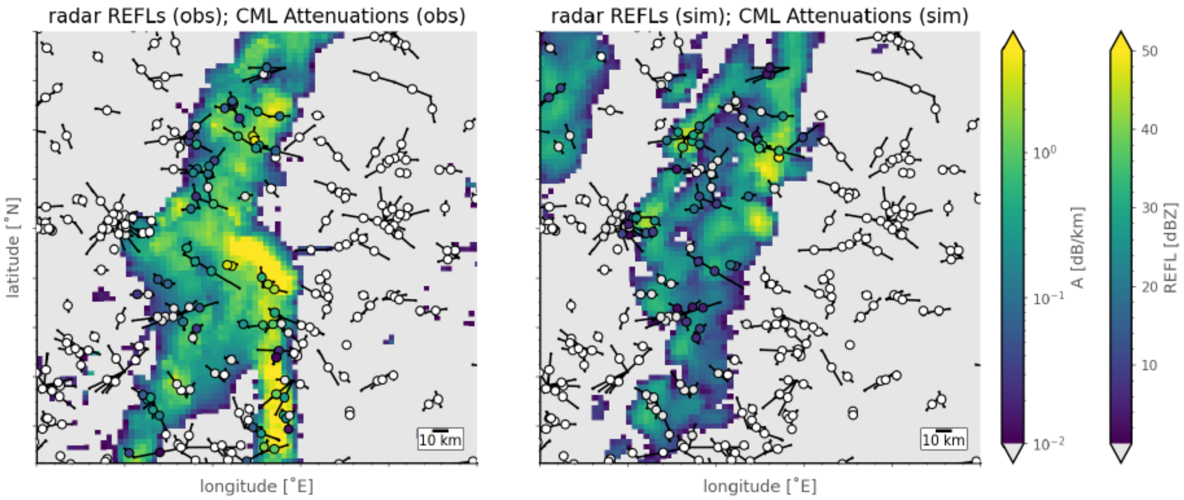


Radial wind

CML – Model equivalents

observations

simulations



Radar

- 17 stations, many azimuths for certain elevations
- fixed frequency (C-band, ~5 GHz)
- standard EMVORADO setting

CML

- 4000 stations, fixed individual azimuth and elevation
- individual frequencies (10-40 GHz)
- special EMVORADO setting to compute the path-integrated one-way attenuation
- experimental data assimilation workflow

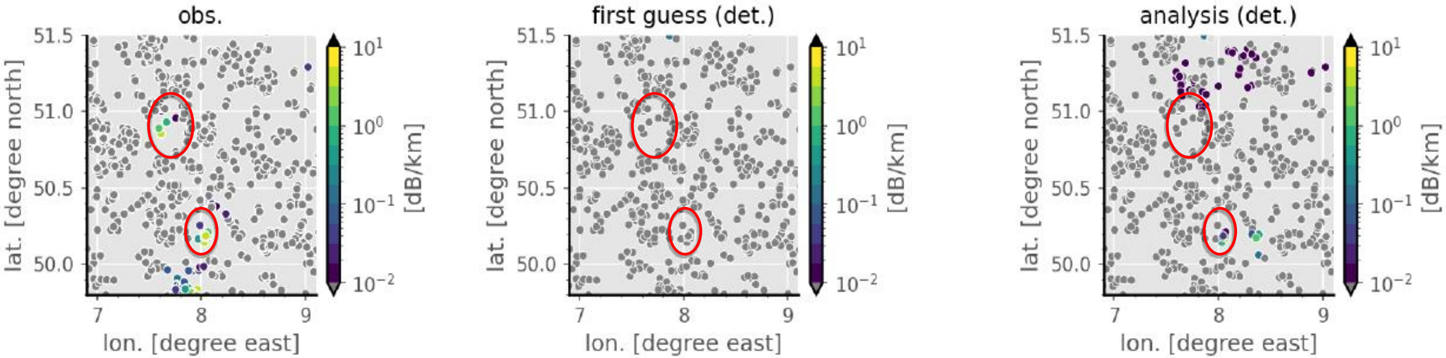
CML – Quality control

Single case studies

preprocessing control (observations only)
- temporal average over 10 min before assimilation time
- spatial assignment to the center of the link path

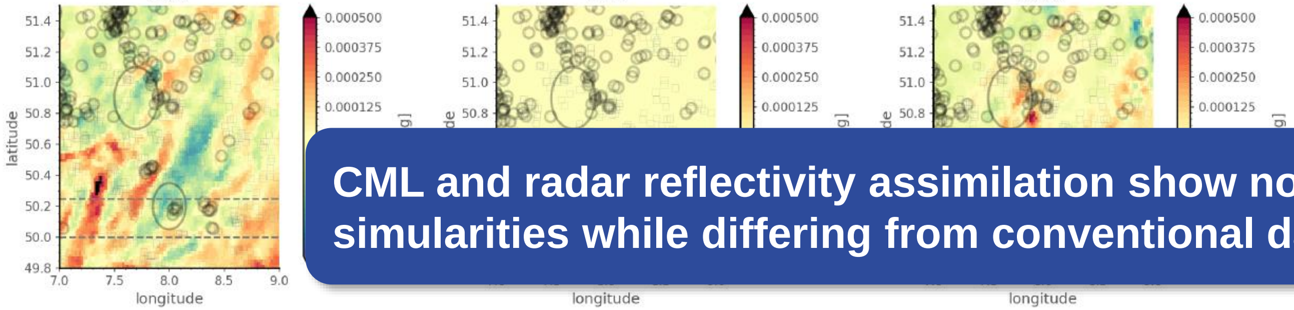
processing control (with ICON model data)
- range control (trim small values in observations and simulations)
- ensemble checks
- dynamic observation error (1 dB / path length)

CML – Single case study



humidity increments (vertically averaged) from different observing systems

conventional data **CML data** **radar reflectivities**



CML and radar reflectivity assimilation show notable simularities while differing from conventional data assimilation.

CML – Forecast impact

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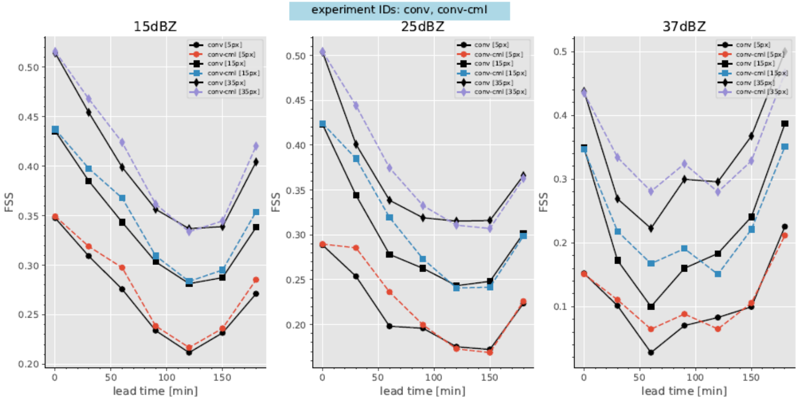
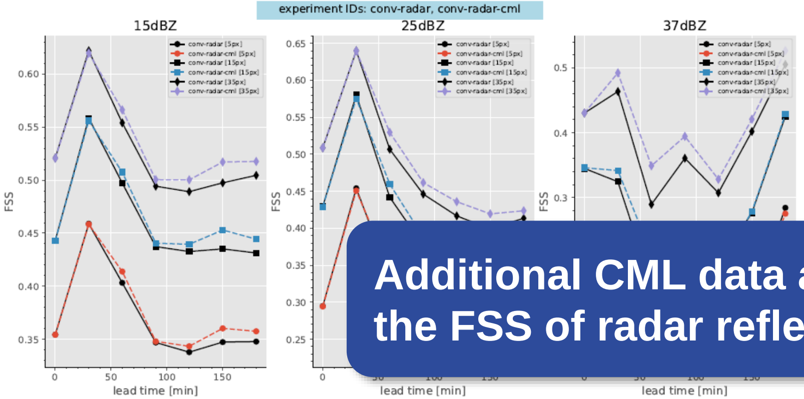


Conventional data only (black)
compared to
conventional and CML data
for different scales (different colors)



Conventional and radar data only (black)
compared to
conventional, radar, and CML data
for different scales (different colors)

Additional CML data assimilation is capable of improving the FSS of radar reflectivity forecasts.

Summary

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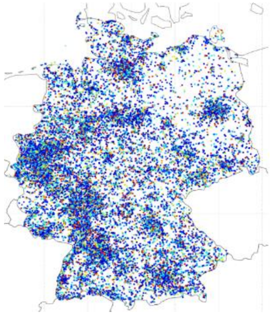
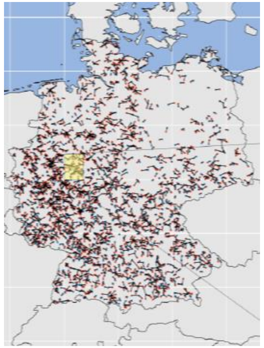
Crowdsourcing and opportunistic observations have the potential to enhance numerical weather prediction (NWP) within regional forecasting systems.



NetAtmo data

- Bias correction is essential.
- While the quantity of these observations may compensate for their lower quality compared to SYNOP data, this requires sophisticated treatment in the data assimilation (horizontal superobbing, horizontal observation error correlations)
- If implemented properly, NetAtmo data can provide a valuable densification of the observational network.



CML data

- CML data integration would require substantial and fundamental developments in observation modeling.
- CML data are likely redundant when compared to radar observations;
  however, CML data may be an adequate substitute where no radar data are available.

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Bibliography

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- RealPEP project: https://www2.meteo.uni-bonn.de/realpep/doku.php?id=home
- Klaus Vobig, Roland Potthast, Christian Chwala, Julius Polz: Commercial Microwave Link (CML) Data Assimilation with the LETKF, in preparation.