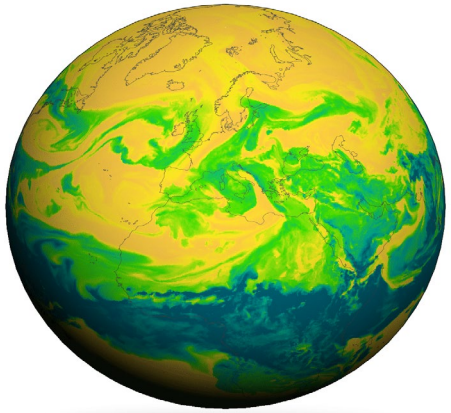
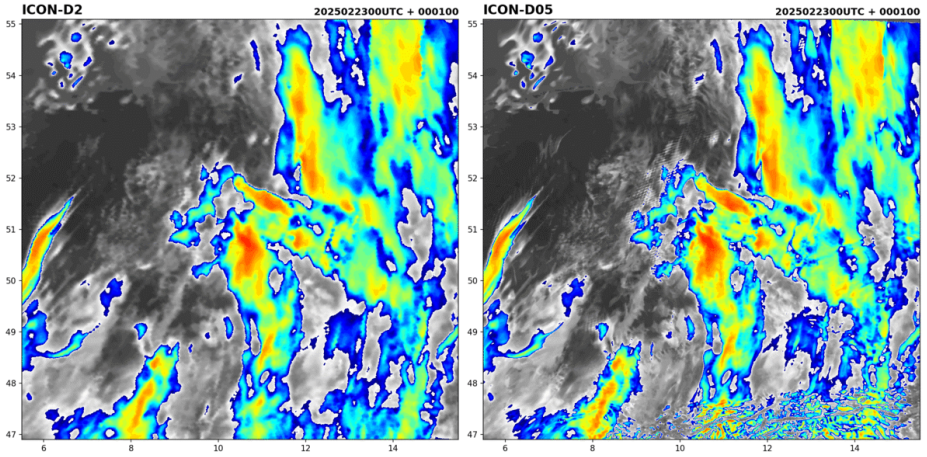
Data Assimilation Developments at DWD



Highlights and Activity

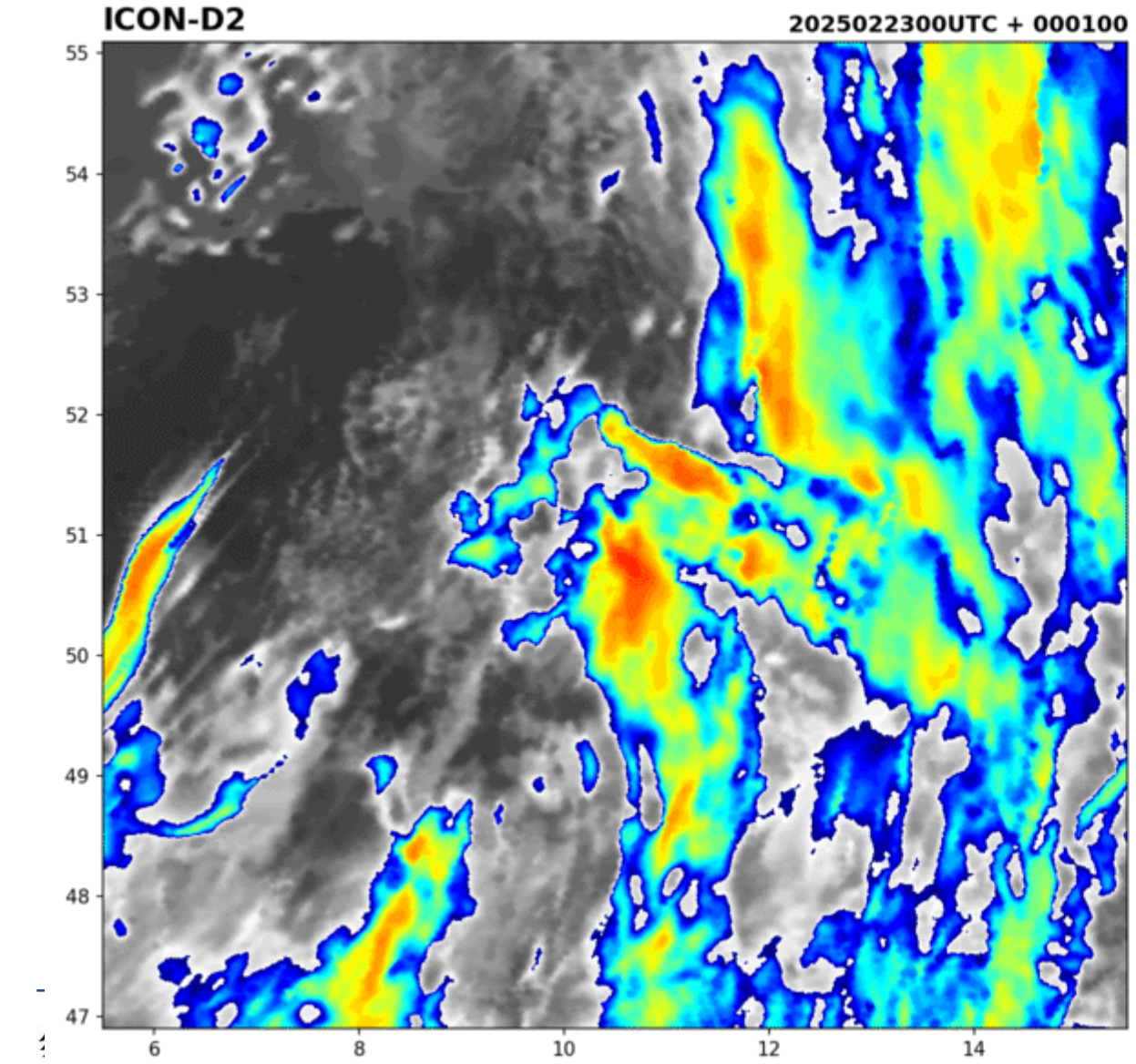


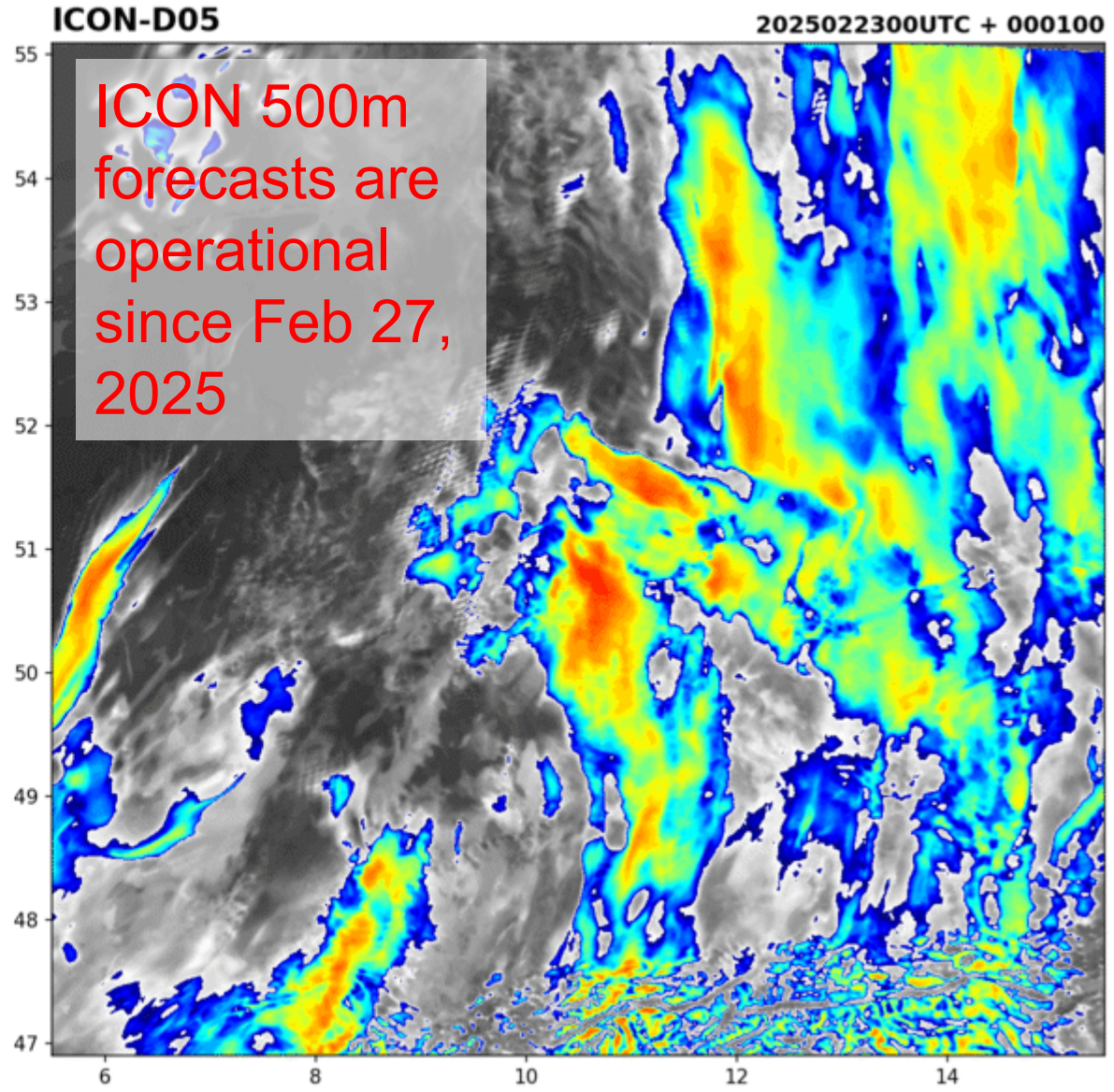
Christina Köpken-Watts, Stefanie Hollborn, Jan Keller, Günther Zängl, Christina Stumpf, … [many colleagues], Roland Potthast

- 500m ICON (D05)
- Operational Chain Evolving
- DestinE and GLORI
- Adaptive Parametertuning (APT)
- Climate-Neutral Flight
- GHG Data Assimilation and Inversion: ITMS
- Coupled Forecasts:
  - Atmosphere-Ocean ESM-W
  - Climate Forecast via ICON XPP
- ICON-WAVES
- Visible Reflectance & IR
- All-Sky Data Assimilation
- SINFONY
- AI-Var
- Particle Filters

500m ICON Operations

Deutscher Wetterdienst
Wetter und Klima aus einer Hand





ICON 500m forecasts are operational since Feb 27, 2025

Global to Regional ICON

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Global

ICON Global Non-Hydrostatic

Det **13 km** Resolution
EPS 26 km Resolution
120 level

40 member
Analysis every **3h**
EnVAR + LETKF

Forecasts
180h: 00,12 UTC, 120h: 06, 18 UTC, 51h: 03, 09, 15, 21UTC

EU

ICON-EU 2-way-nest

Det **6.5 km** Resolution
EPS 13 km Resolution
74 level

40 member
Analysis every 3h

EnVAR + LETKF
Forecasts
120 h: 00, 06, 12, 18 UTC, 51 h: 03, 09, 15, 21 UTC

D2 + D05

ICON D2 LAM Convective Scale

Det **2 km + 500m** Resolution
EPS **2 km** Resolution
65 level

40/20 member
Analysis every 1h

KENDA: 4D-LETKF
Forecasts
48h: 00, 03, 06, 09, 12, 15, 21 UTC

RUC

ICON-D2 RUC Convective Scale

Det **2 km** Resolution
EPS 2 km Resolution
65 level

40/20 member
Analysis every 1h

KENDA: 4D-LETKF
Forecasts
8h: 06, 07, 08, … 17, 18 UTC

ART

ICON ART Ensemble

26 km resolution

10 member

Analysis every 3h

EnVAR + LETKF

Forecasts 120h

K

Kangu

AI Forecast

Forecasts Every 3h

7 days

AICON

AICON

AI Forecast

Forecasts Every 3h

7 days

AICON-LAM

AI Forecast

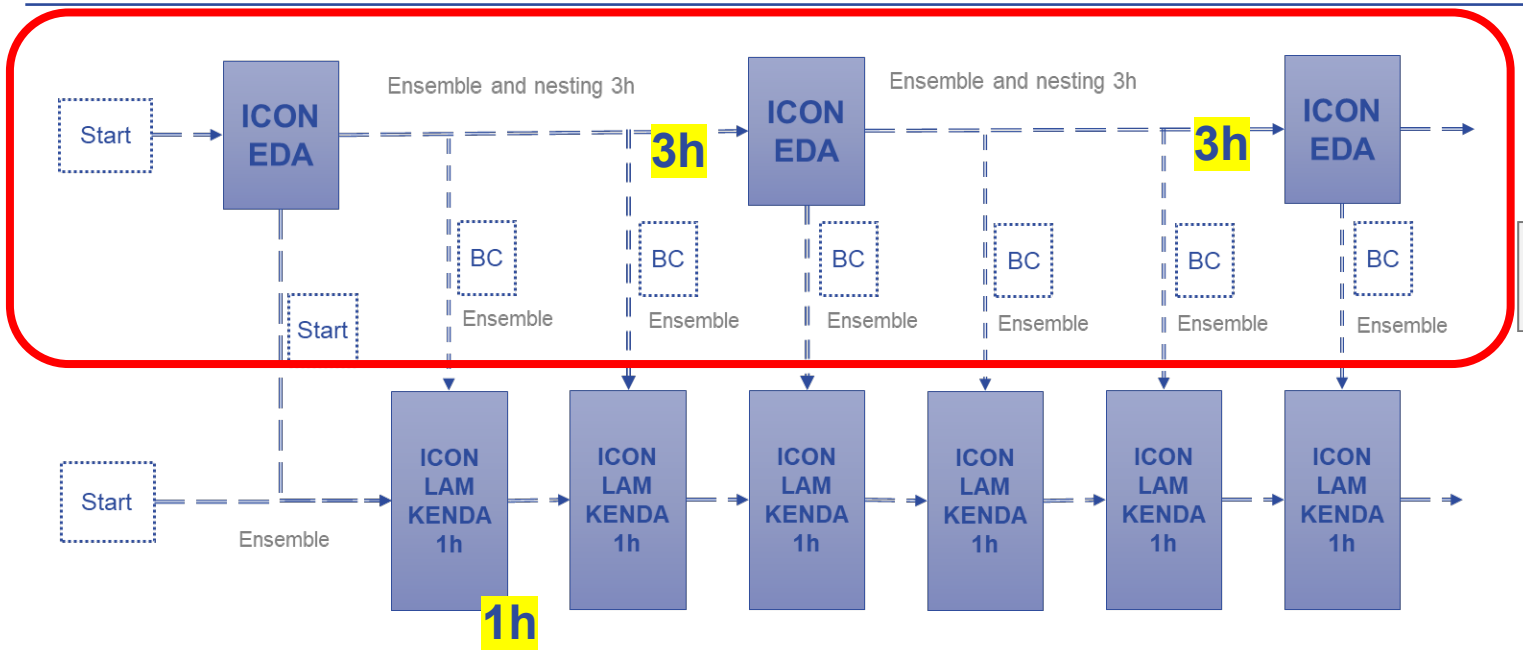
Forecast Every 1h

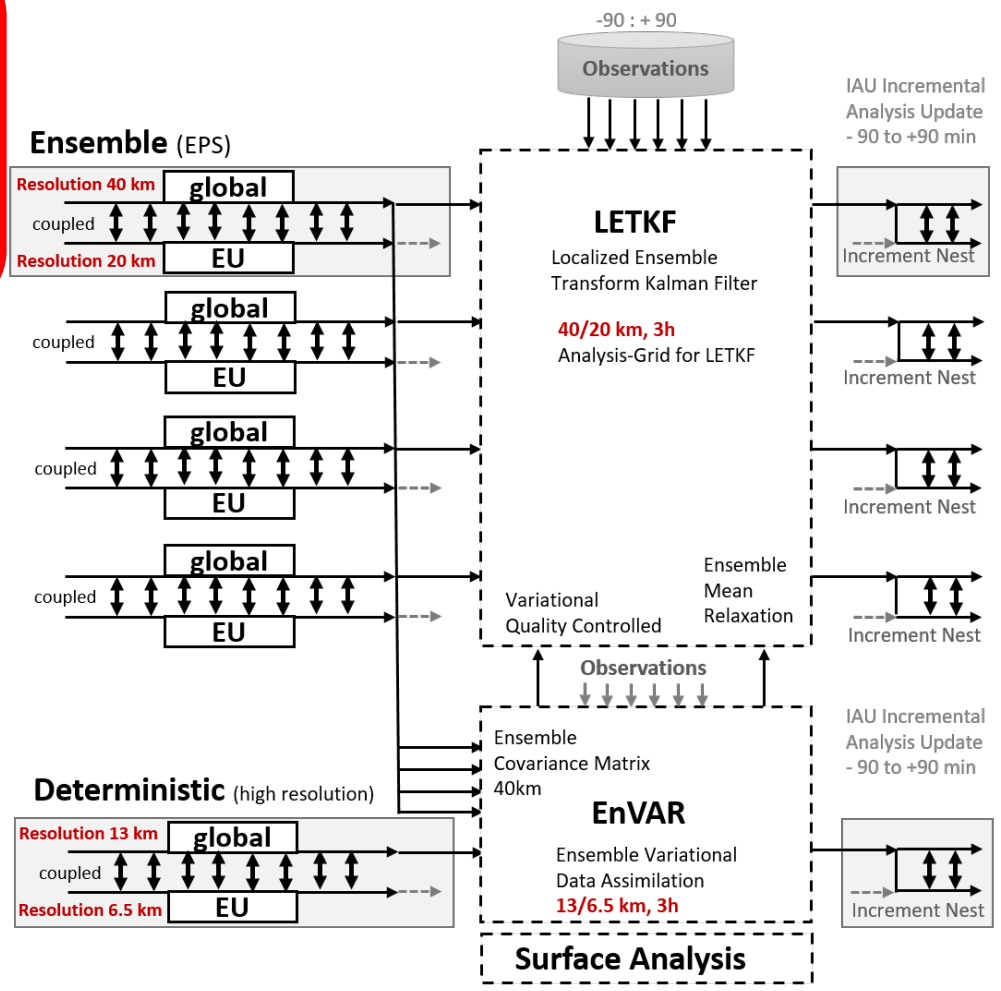
3 days

Operational Chain

GLORI = Global-to-Regional ICON Digital Twin

DA Hierarchy at DWD





Ensemble-Variational System

- 3-hourly Global+EU Analysis and Forecast Cycle, Different lead times, Deterministic plus EPS
- **2-Way Coupled Global + EU ICON Runs**
- High-Resolution Run 13/6.5 km
- Ensemble Resolution 26/13 km with 40 members
- Analysis Increments by **EnVAR** for High-Resolution Run
- Ensemble Generation by **LETKF (PF)**
- Ensemble **Mean Relaxation** towards High-Resolution
- Incremental Analysis Update (**IAU**)
- Portable Script Environment (**BACY**)

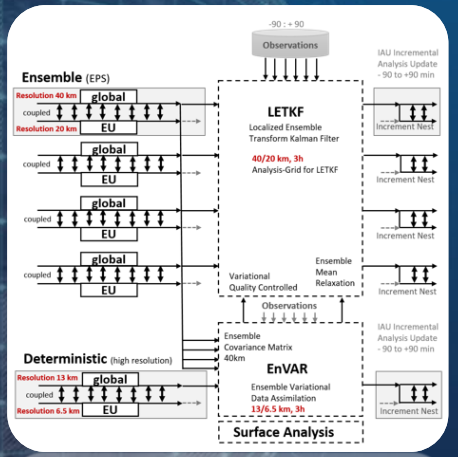
GLORI4DE

GLObal to Regional Icon for Destination Earth

Gabriella Scipione, Massimo Gisonni, CINECA
October 16th, 2024

Our Digital TWIN GLORI = Global to Regional ICON

Interoperable with the Destination Earth Initiative (DestinE)

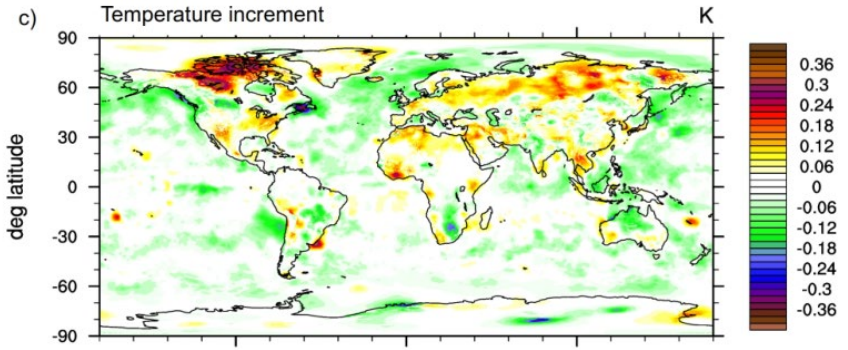


Twin includes **full scale EDA** globally and regionally

Funded by the European Union
Destination Earth implemented by ECMWF esa EUMETSAT
GLORI GLObal to Regional | ICON Digital Twin

Model-Data Assimilation Coupling

By Günther Zängl, DWD



- Adaptive surface friction
- Adaptive adjustment of soil and plant evaporation
- Adaptive adjustment of soil and snow properties
- Adaptive adjustment of the near-surface minimum diffusion coefficient

Model Analysis Increment → Filtered Increments → Adaptive Parameter Tuning

$$f_{sf} = \frac{1}{1 + 2.5 f_{ai} F F_{fi}}$$

$$f_{sf} = 1 - 2.5 f_{ai} F F_{fi}$$

Newtonian relaxation

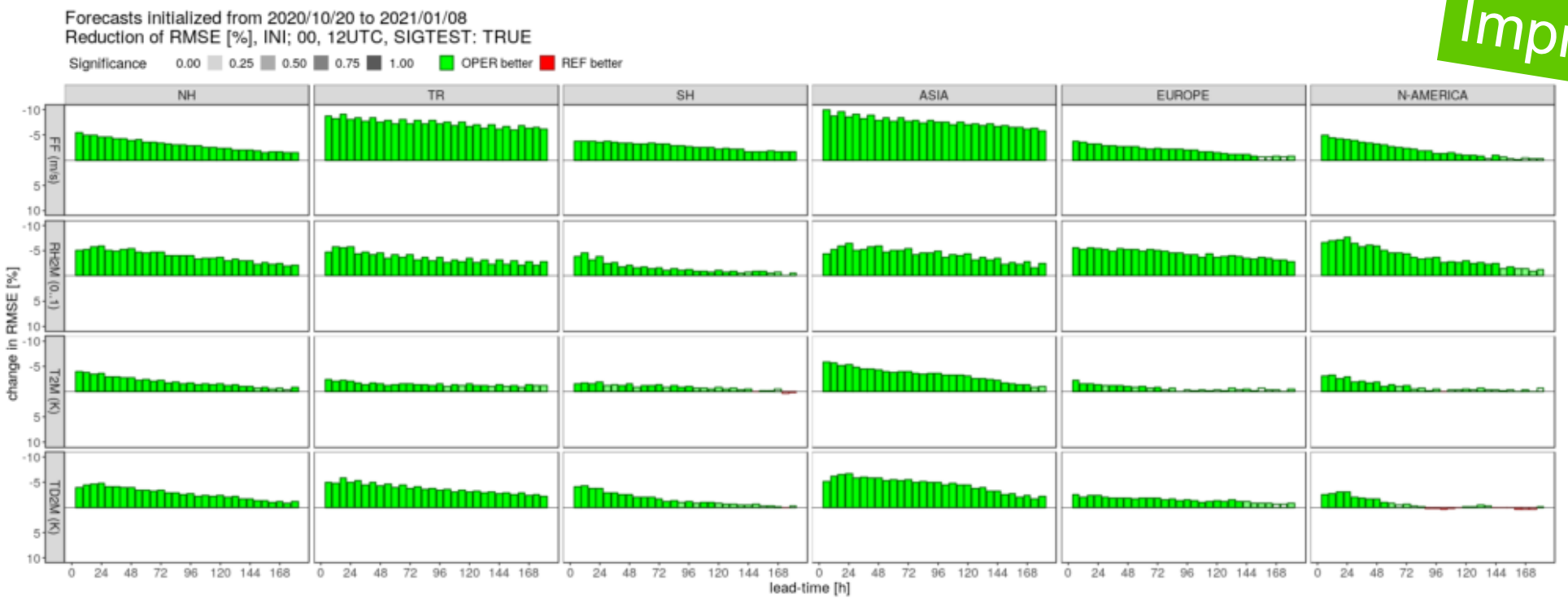
$$\psi_{fi}(t) = \psi_{fi}(t - dt_{ana}) + \frac{dt_{ana}}{dt_{filt}} \left(\psi_i(t) - \psi_{fi}(t - dt_{ana})\right)$$

$$T_{wfi}(t) = T_{wfi}(t - dt_{ana}) + \frac{dt_{ana}}{dt_{filt}} \left(T_i(t) \cos\left(\frac{2\pi}{86400} t_{loc}\right) - T_{wfi}(t - dt_{ana}) \right)$$

fi = filtered increments

Model-Data Assimilation Coupling

Strong Improvements



Wind

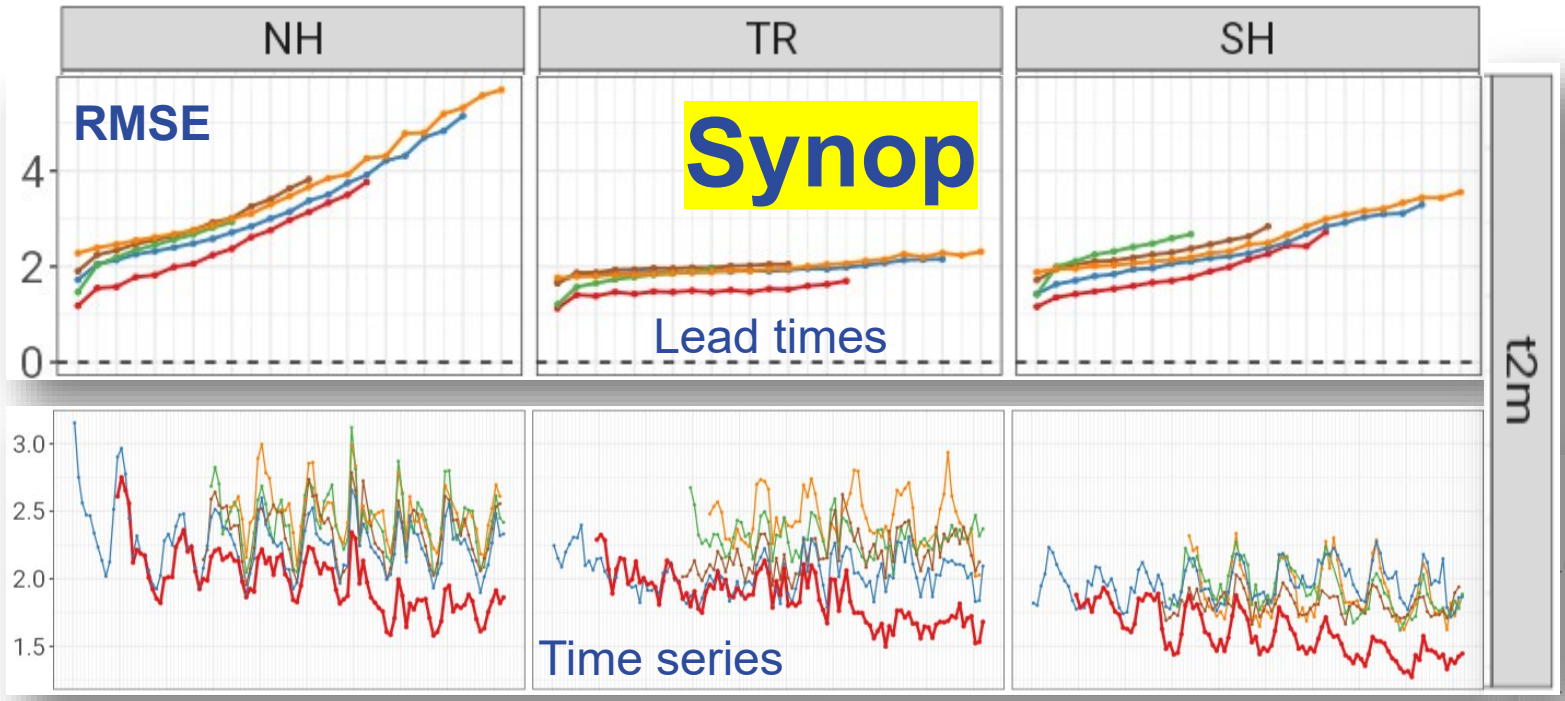
Humidity

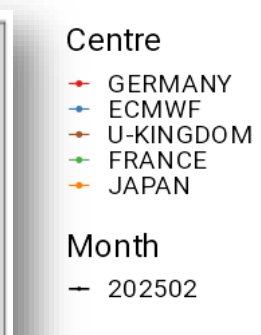
Temperature

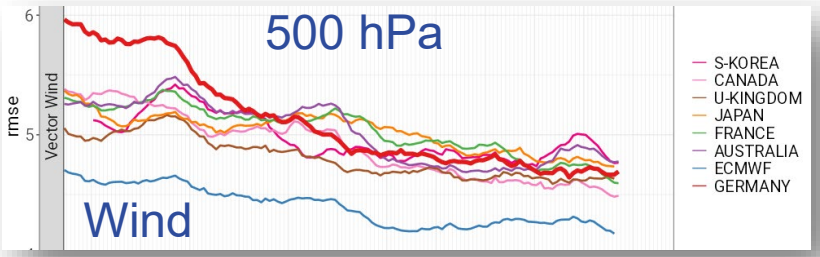
Dew Point

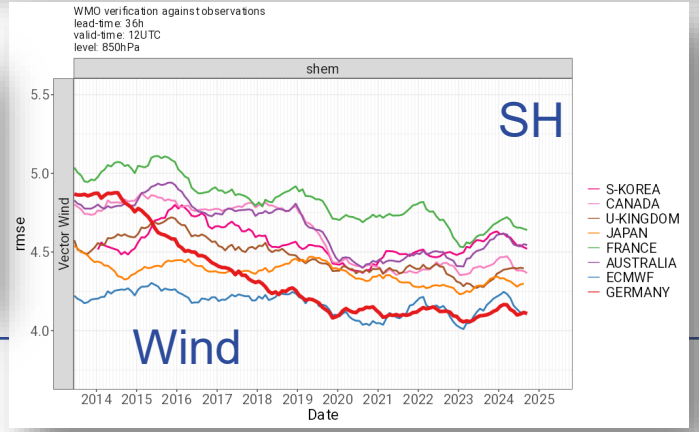
FIGURE 5 Scorecard for the verification against SYNOP stations, averaged over 00-UTC and 12-UTC forecasts of the full experiment period. Green (upward-pointing) bars indicate an improvement (reduction of RMSE) due to APT, filling indicates statistical significance at the 95% level. Regions are defined as follows: NH and SH (TR) poleward (equatorward) of 20 deg latitude, Europe 36°N–72°N, 10°W–40°E, Asia 20°N–75°N, 40°W–140°E, North America 20°N–80°N, 150°W–50°W.

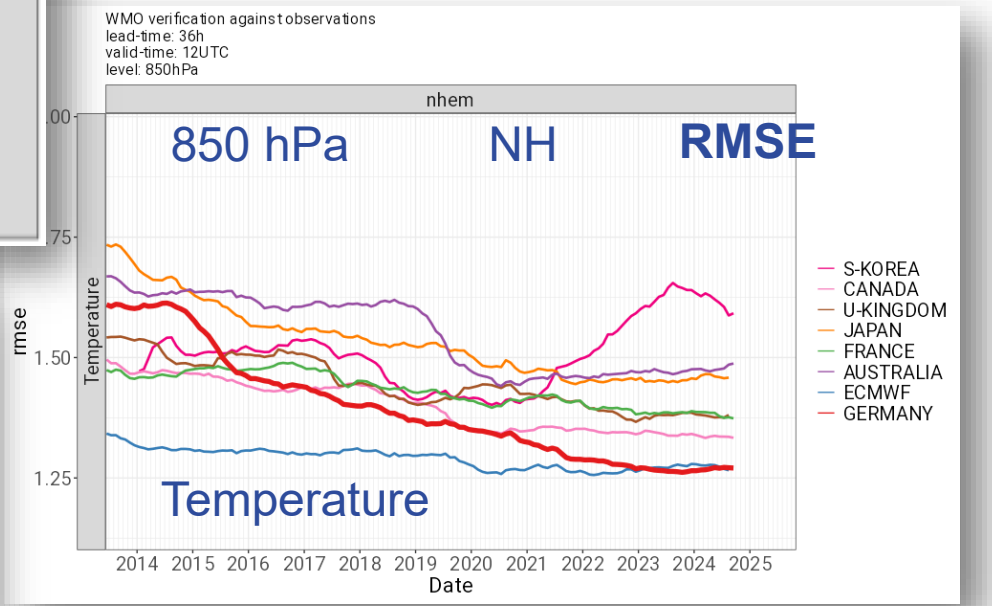
ICON Global Scores











DA for Weather to Climate

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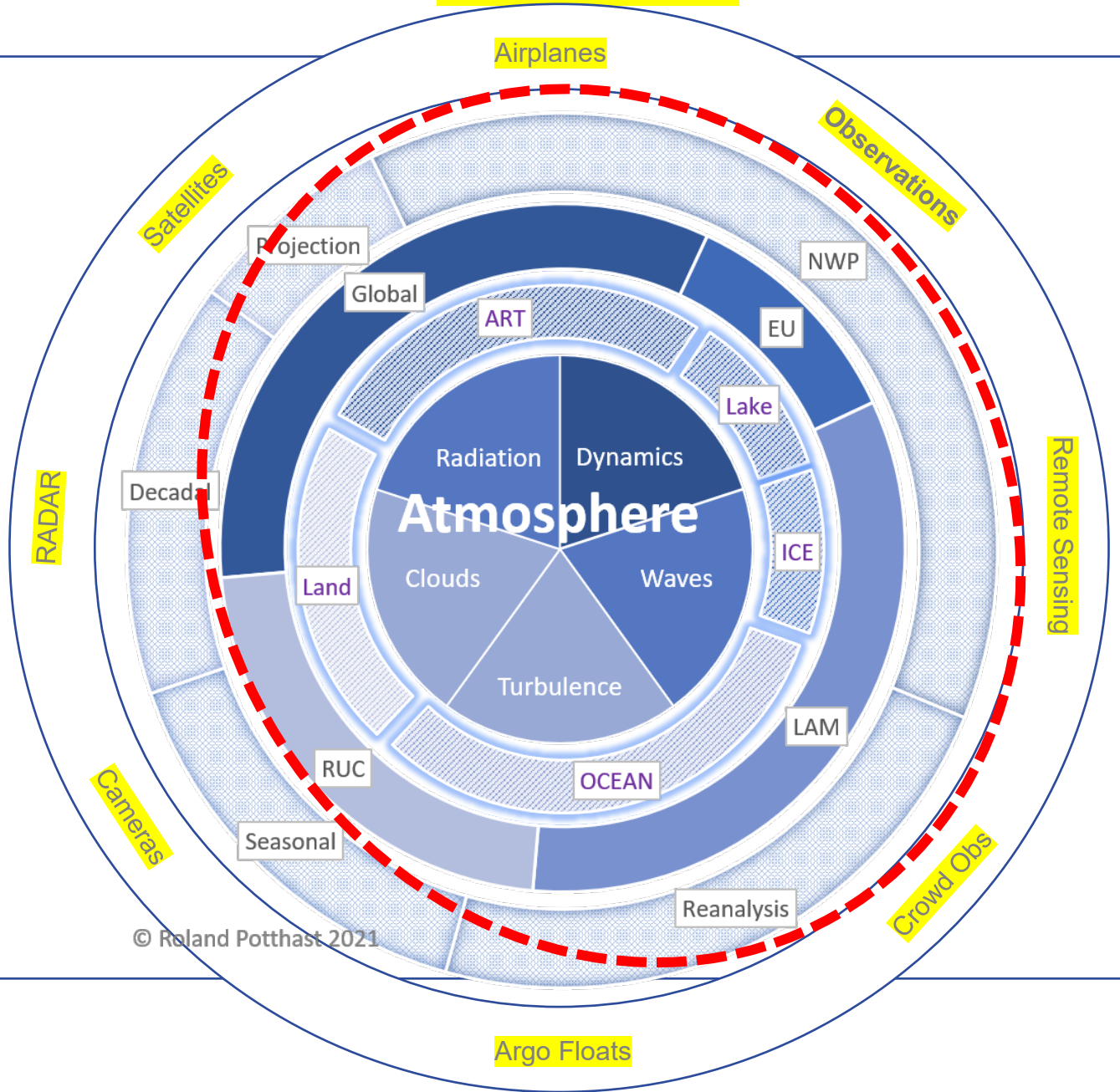
- **Seasonal**
- **Decadal**
- **Climate Projection**



Data Assimilation
Redesign

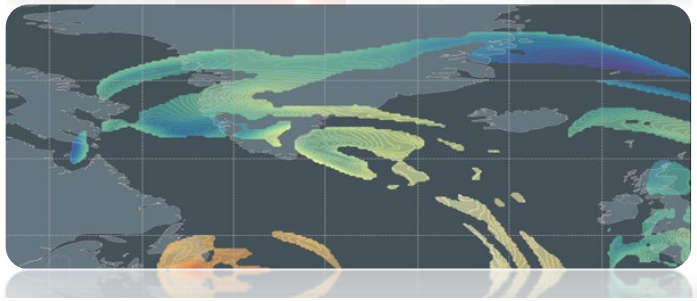
- **OCEAN & Coupled**
- **Surface**
- **Snow / ICE**
- **ART**
- **GHG**

GPUs

Artificial Intelligence
- Global
- LAM
- Components

Climate Friendly Flight

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

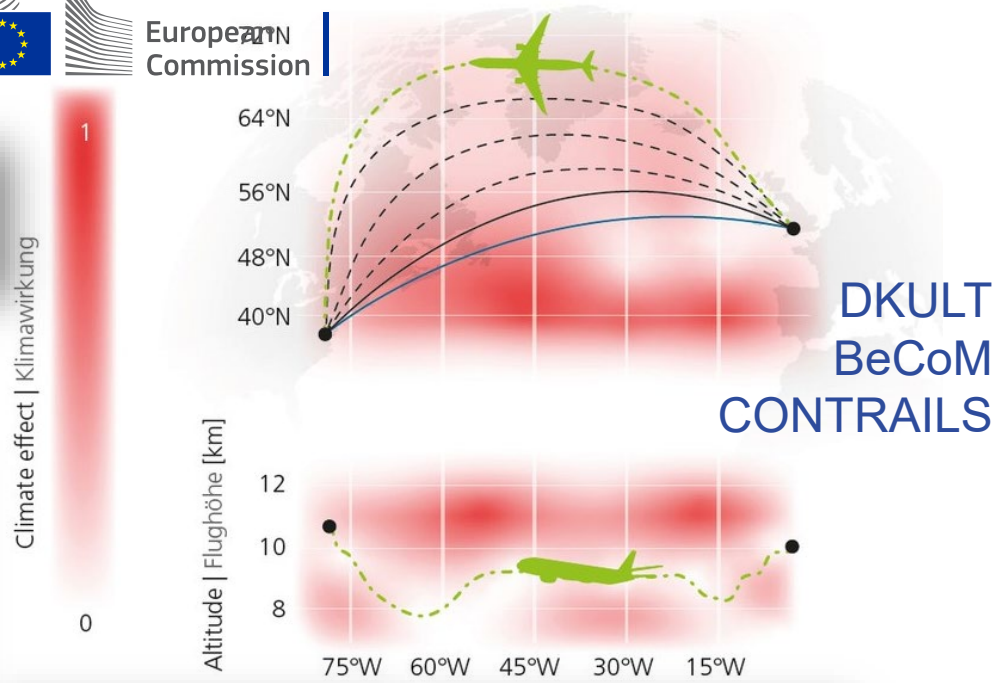


Ice Supersaturated Areas and Contrail Formation

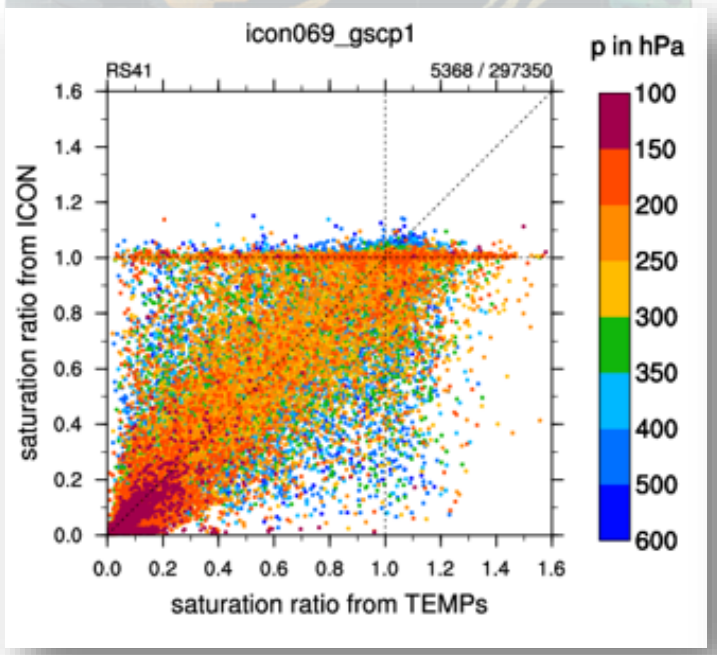
D-KULT

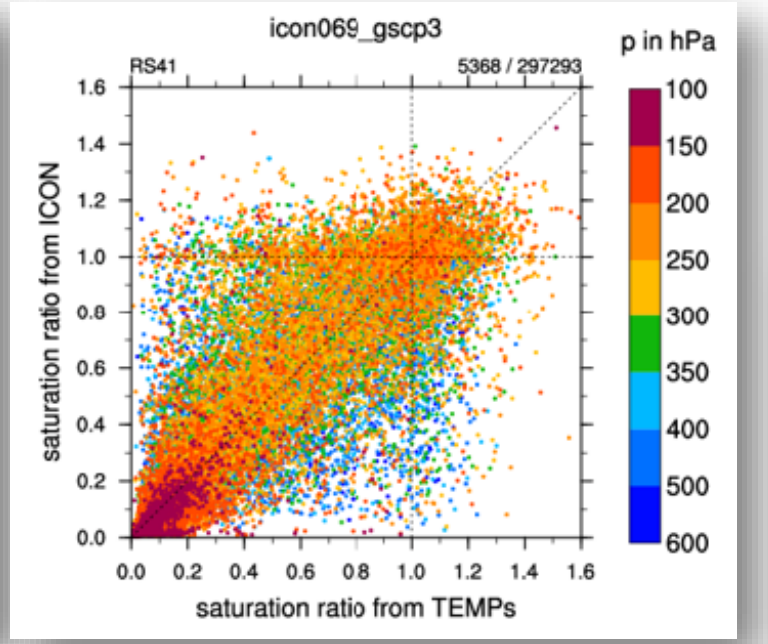
Green Flights

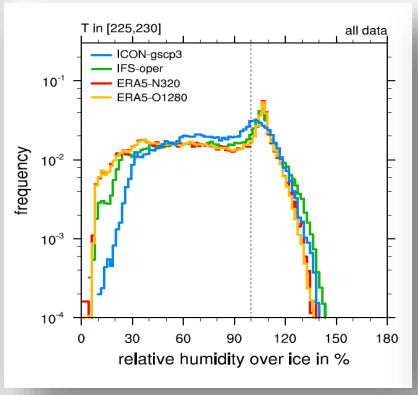
European Commission

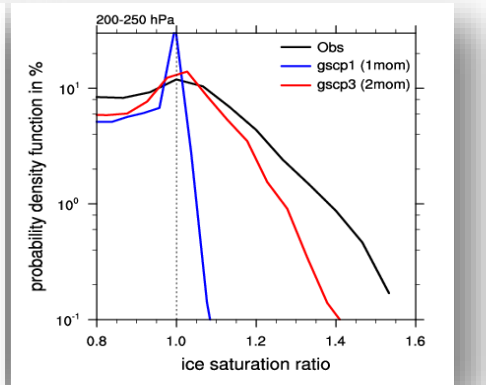


DKULT
BeCoM
CONTRAILS





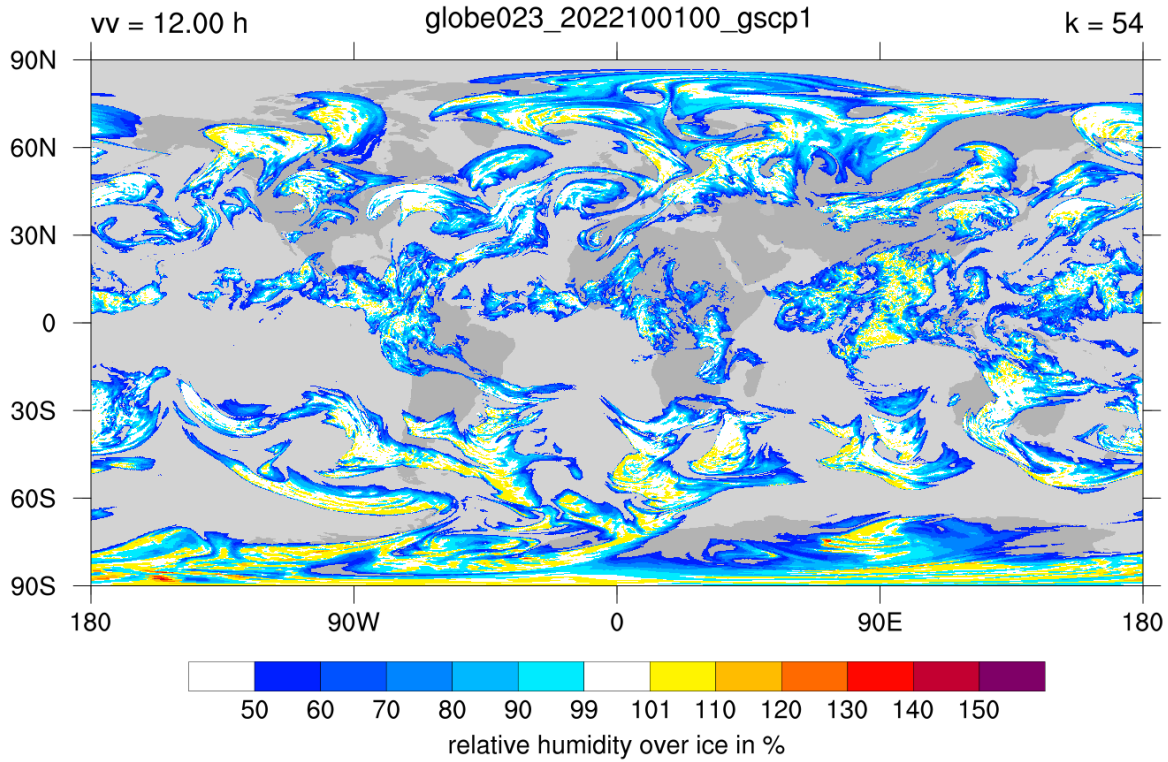




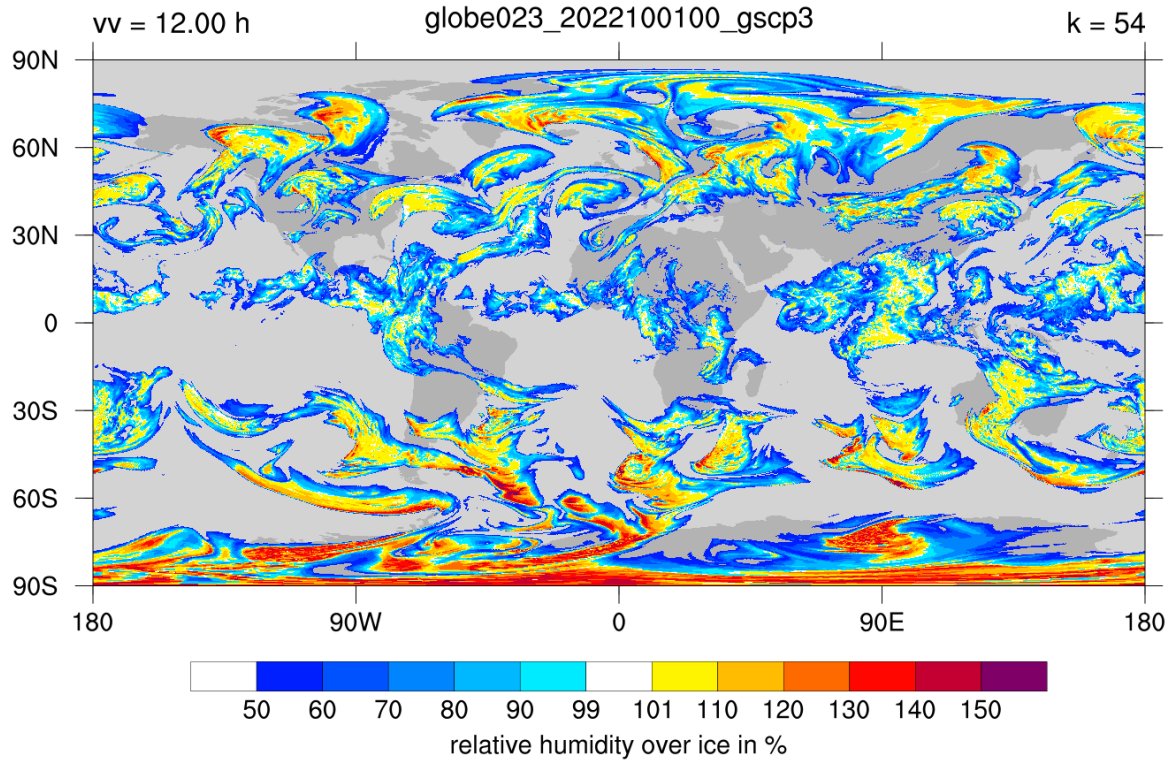
Ice Supersaturation

Contribution by Axel Seifert et al.

operational one-moment cloud ice



new two-moment cloud ice



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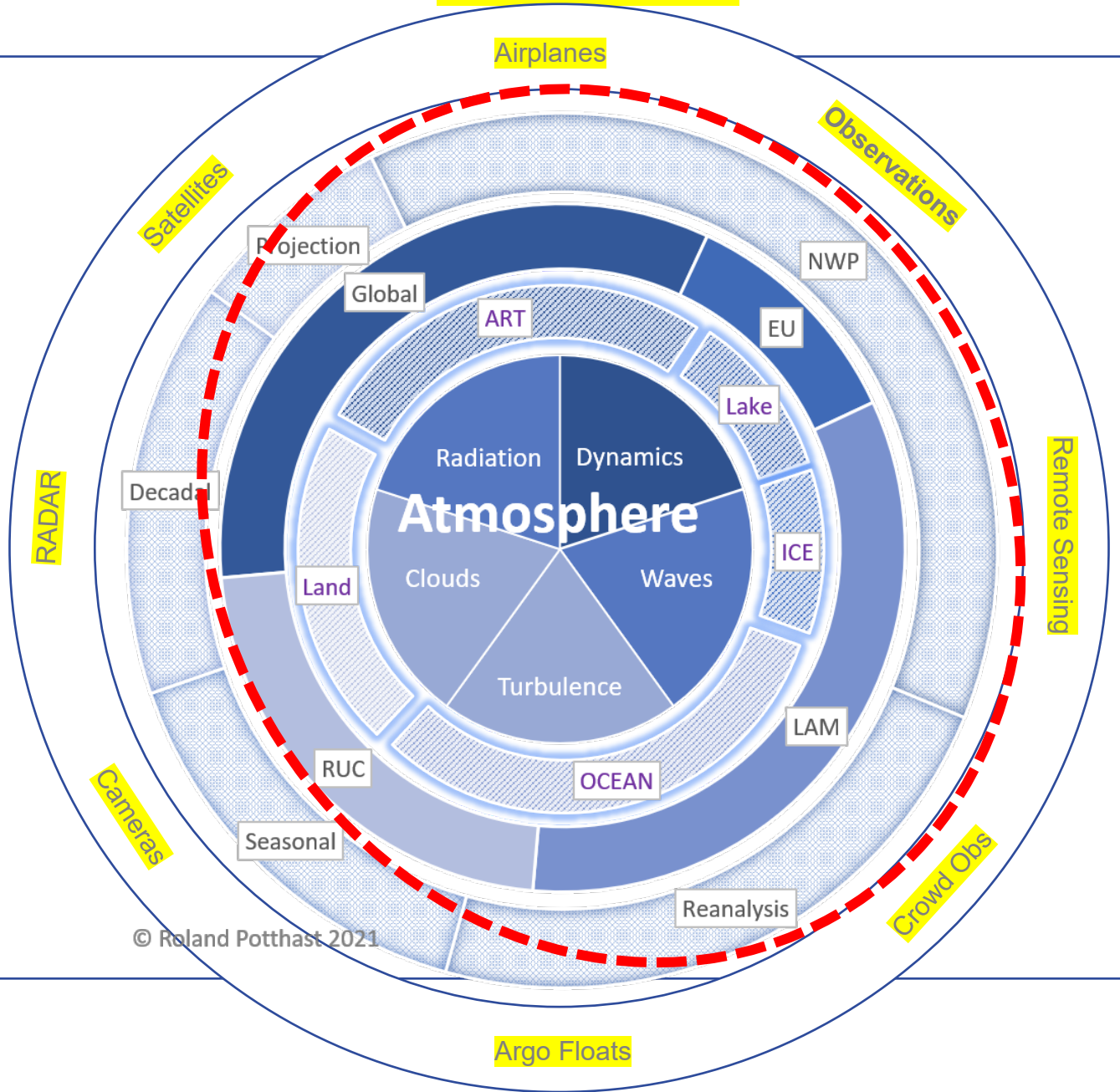

Data Assimilation
Redesign

- **OCEAN & Coupled**
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- **GHG**

GPUs

Artificial Intelligence
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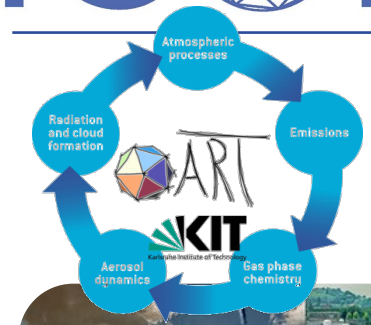
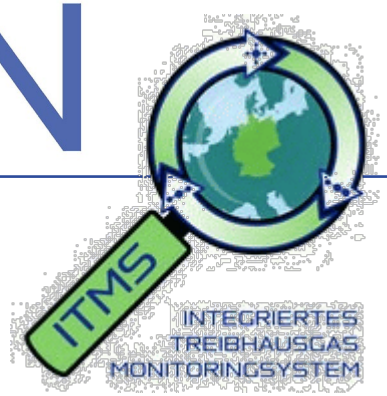
- Components

GHG Data Assimilation

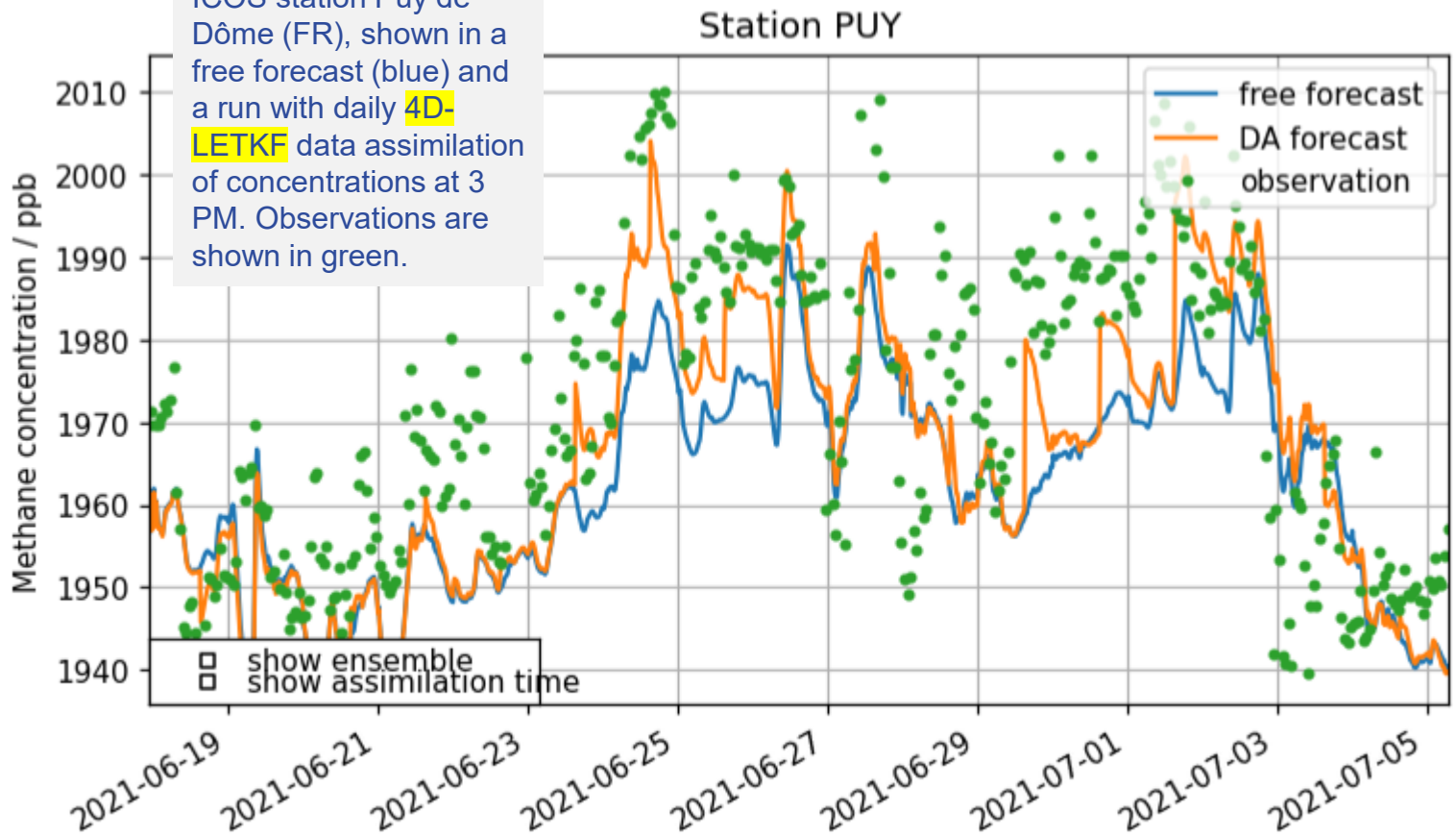
Deutscher Wetterdienst
Wetter und Klima aus einer Hand





KU22 + FEHP + FE1 + KIT

Methane levels at the ICOS station Puy de Dôme (FR), shown in a free forecast (blue) and a run with daily 4D-LETKF data assimilation of concentrations at 3 PM. Observations are shown in green.

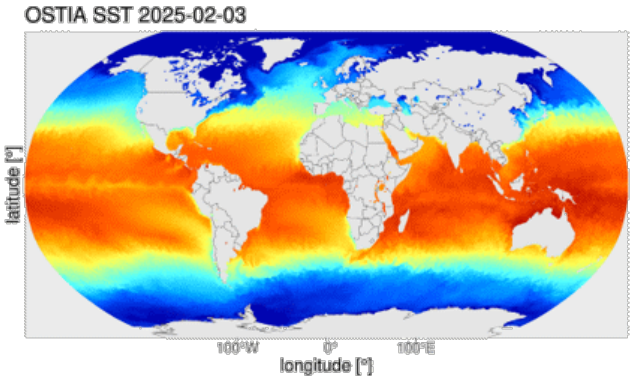


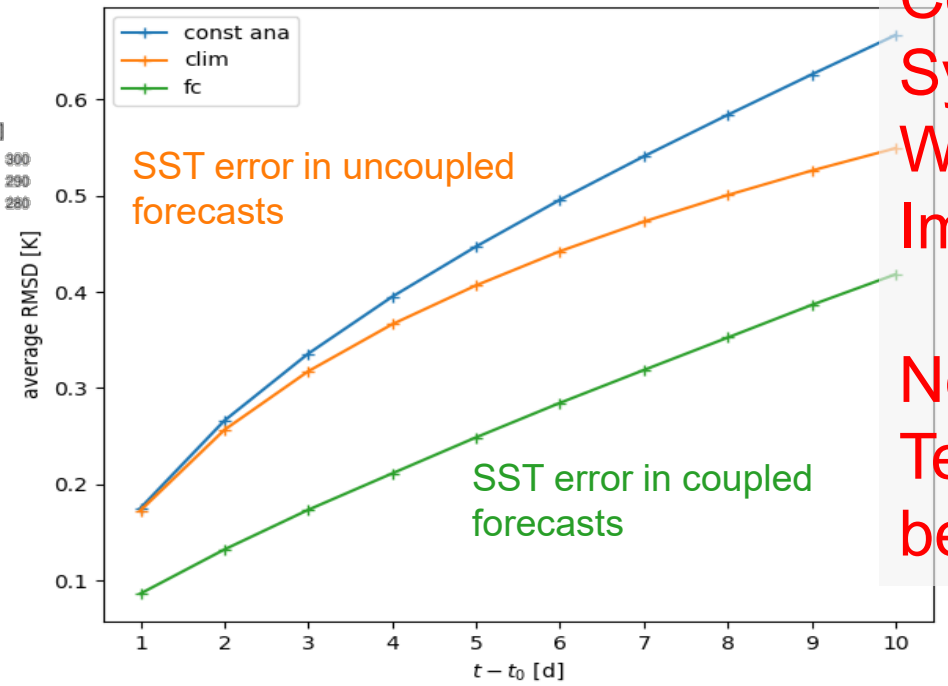
Data Assimilation with EnVAR and 4D LETKF implemented and being tested

Inversion being implemented

Coupled Forecasts A+O

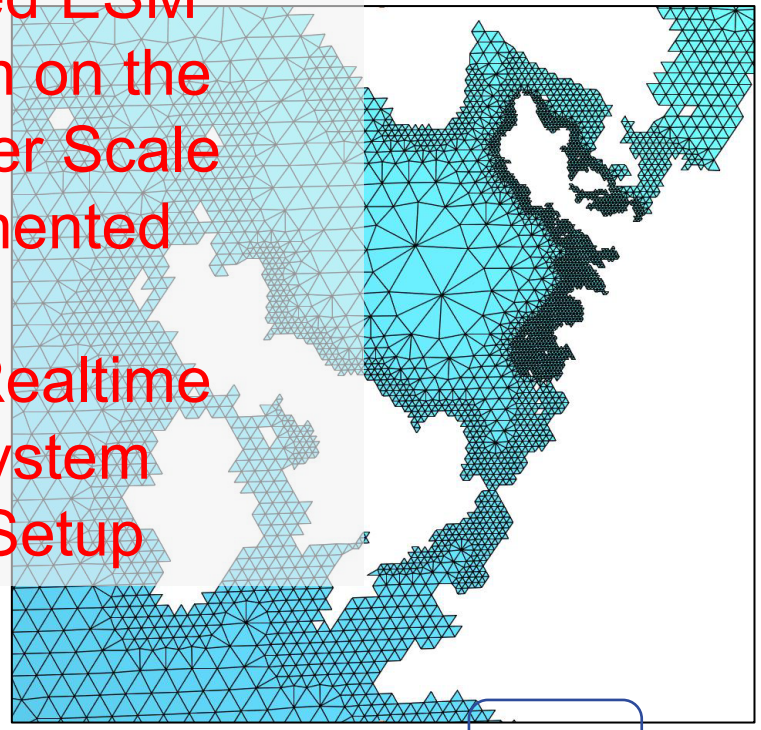
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

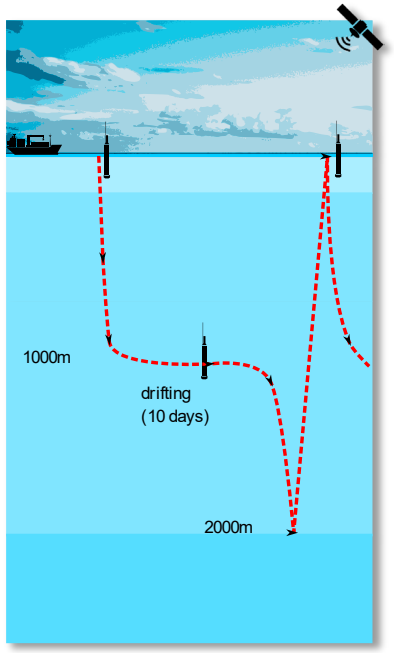


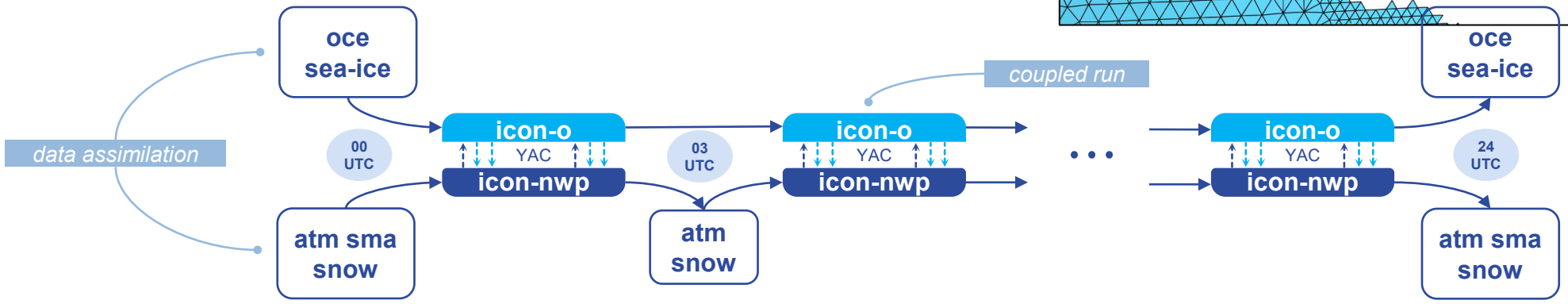


Coupled ESM System on the Weather Scale Implemented

Near Realtime Test System being Setup







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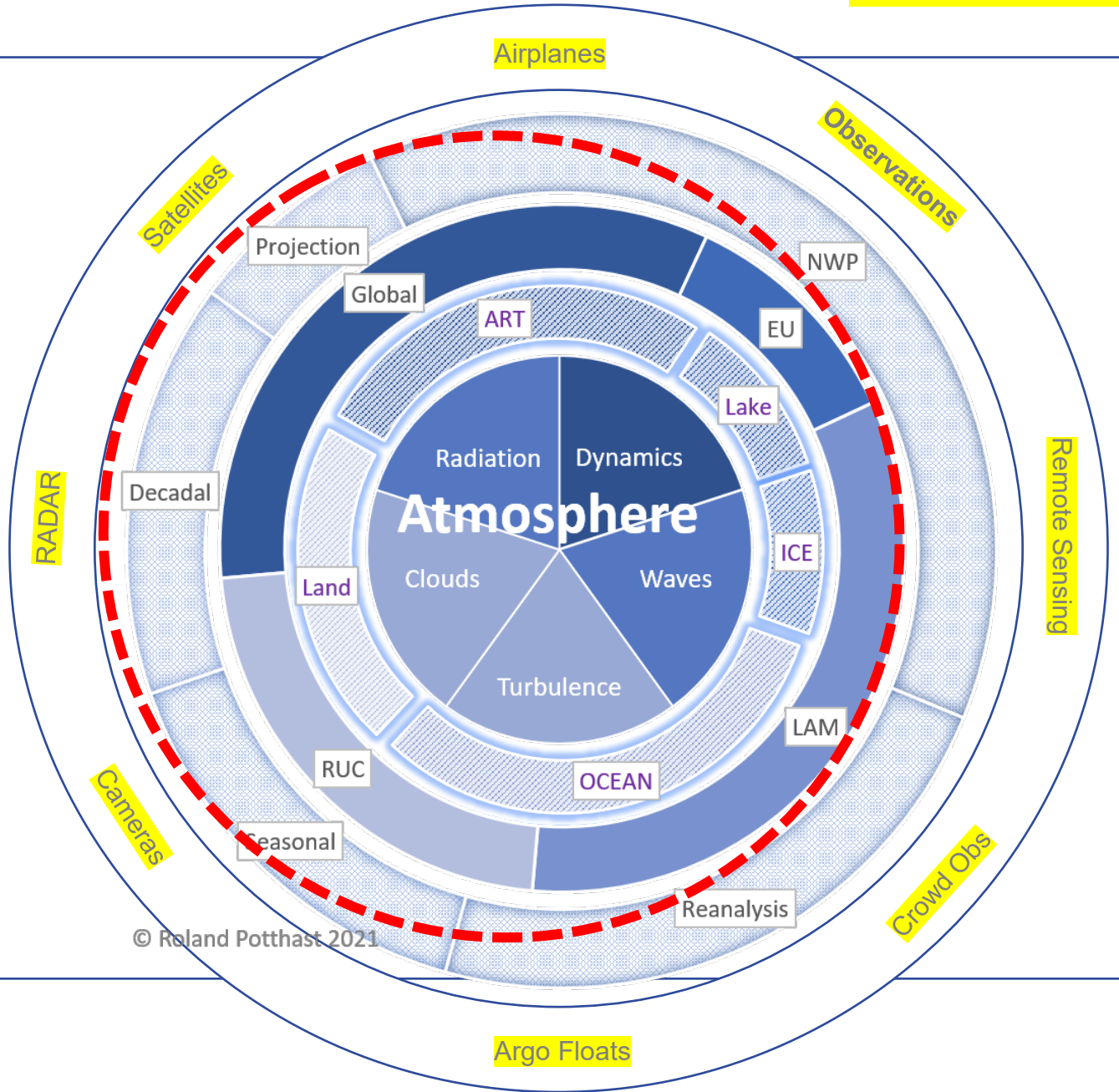

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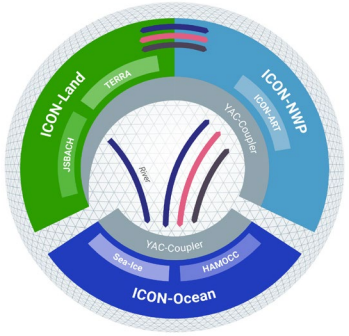
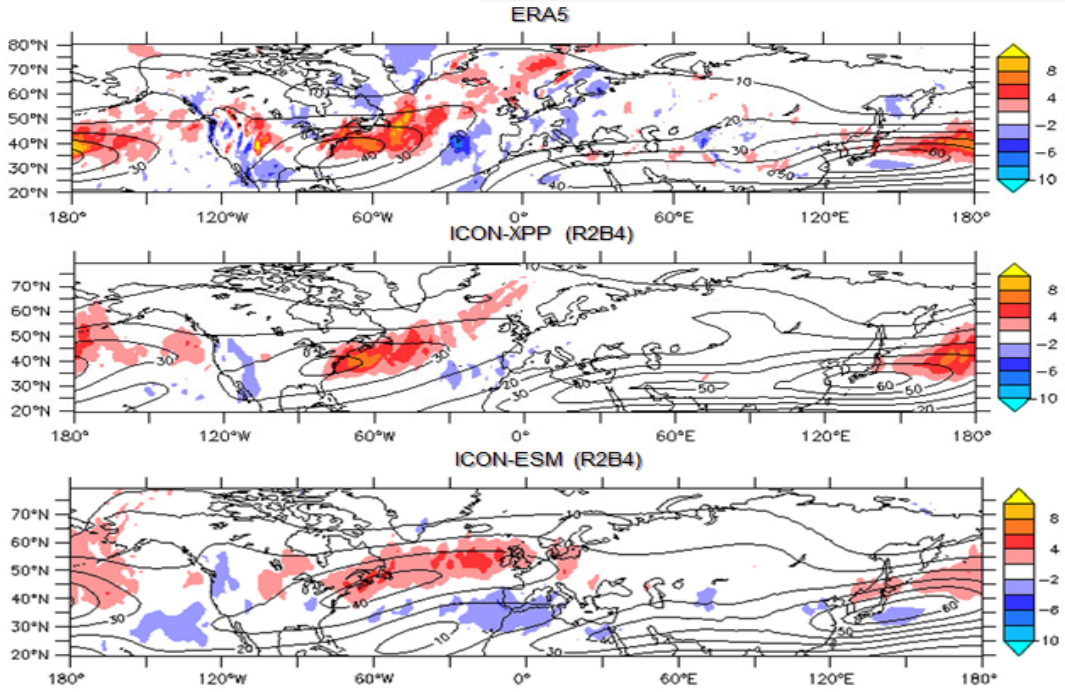
ICON Climate Forecasts XPP

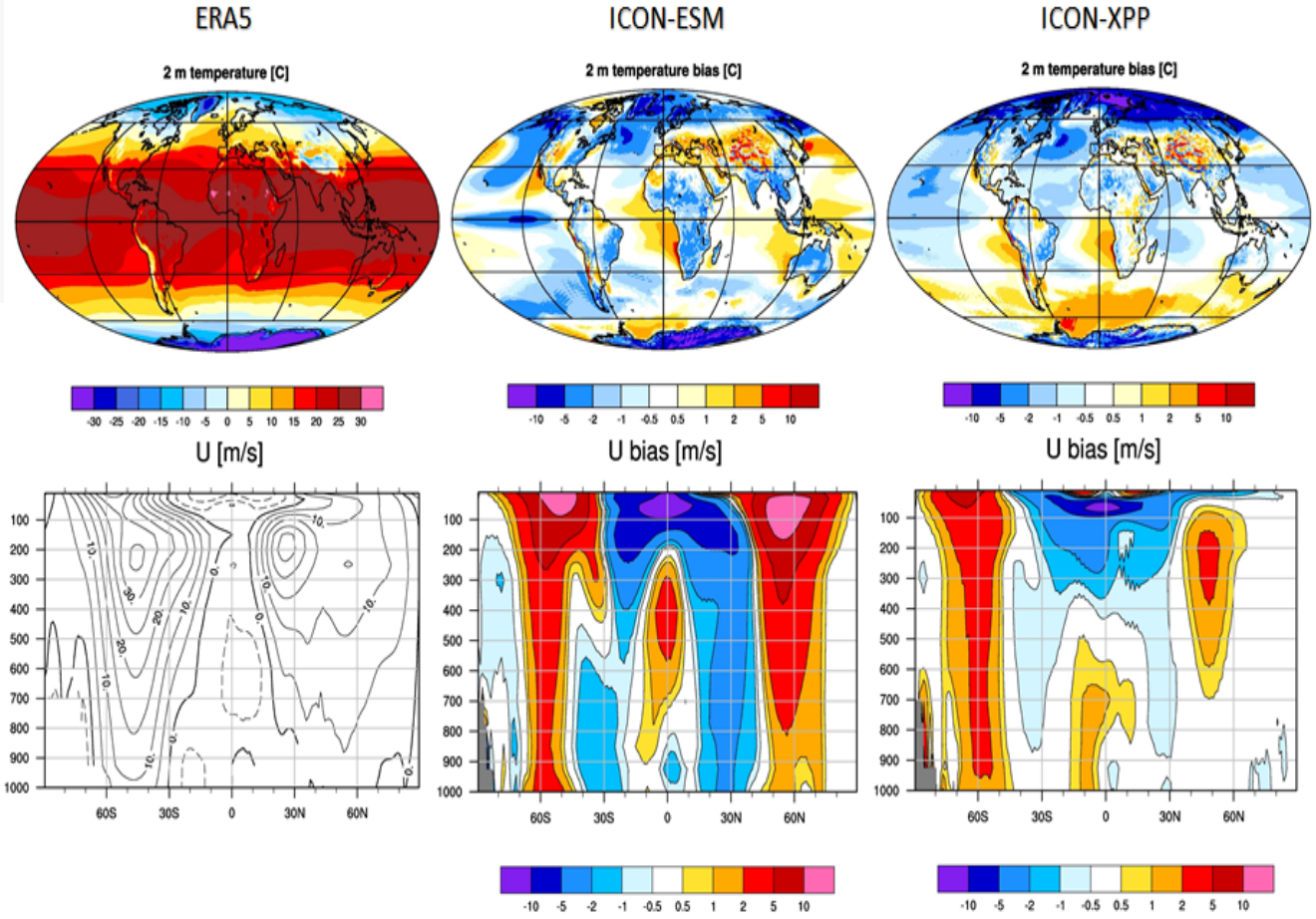
Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Coupled ICON XPP Climate Configuration

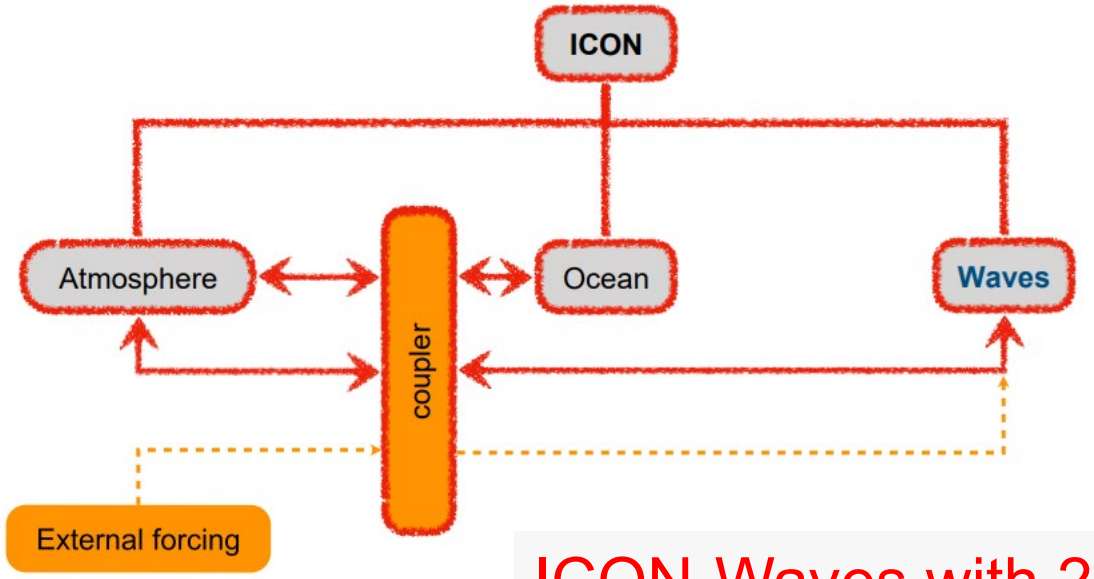
Open Source Release Available





https://doi.org/10.17617/3.UUIIZ8

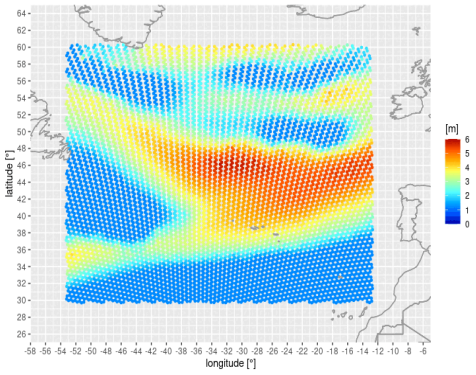
WAVE Model Coupling

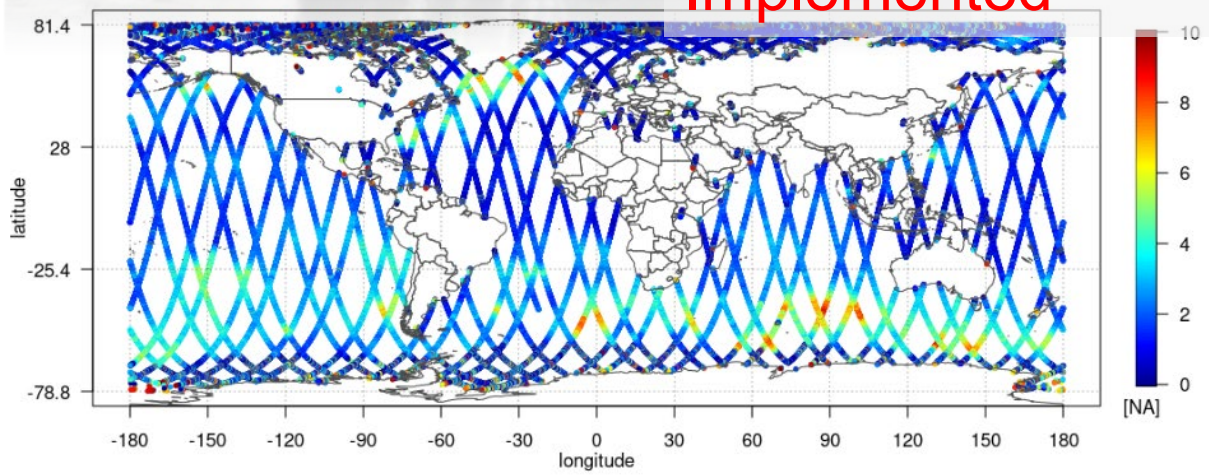


Variational
Data Assimilation
Implemented

ICON-Waves with 2-way online coupling implemented

ICON-Waves LAM implemented





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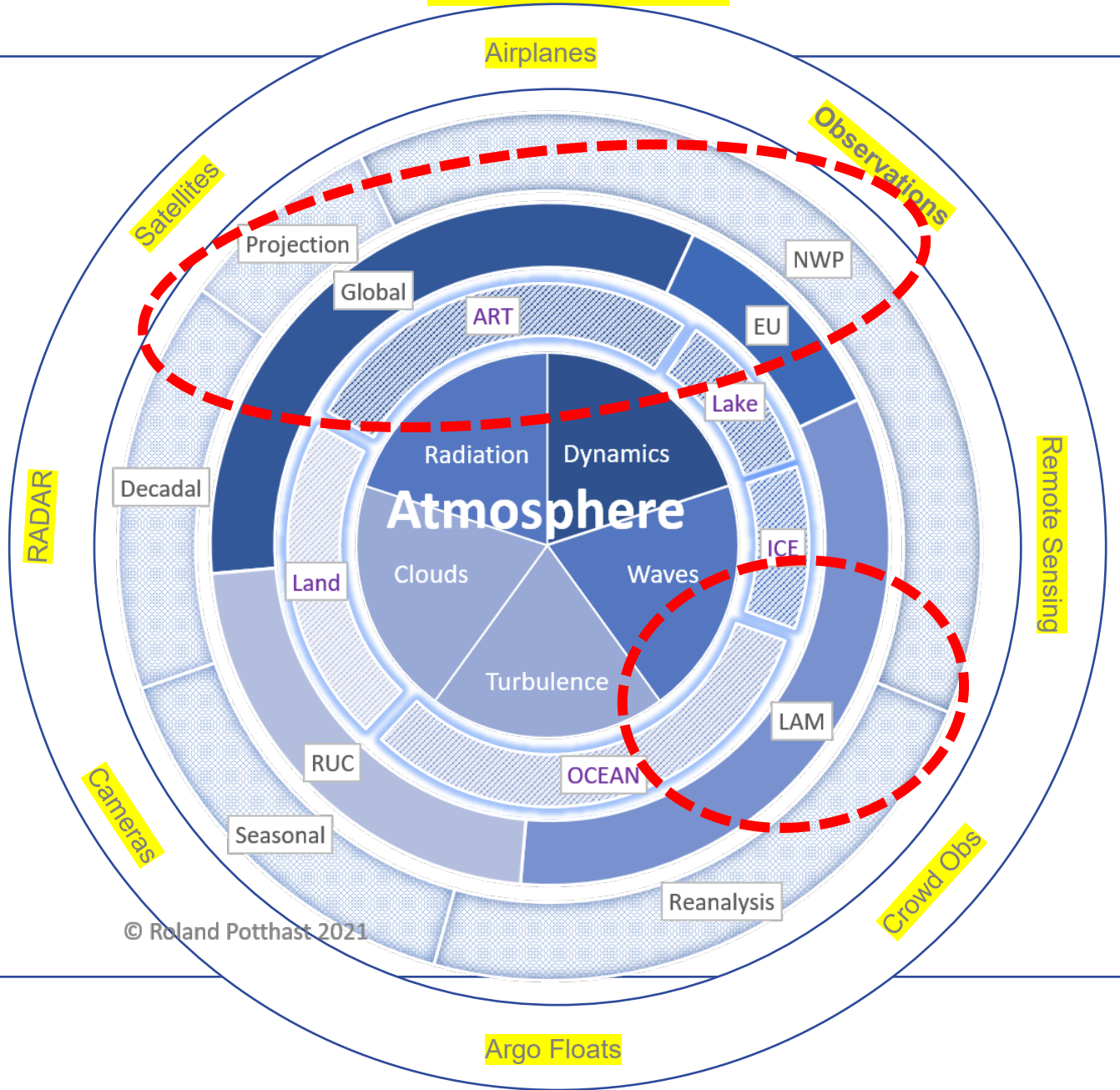

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Redesign

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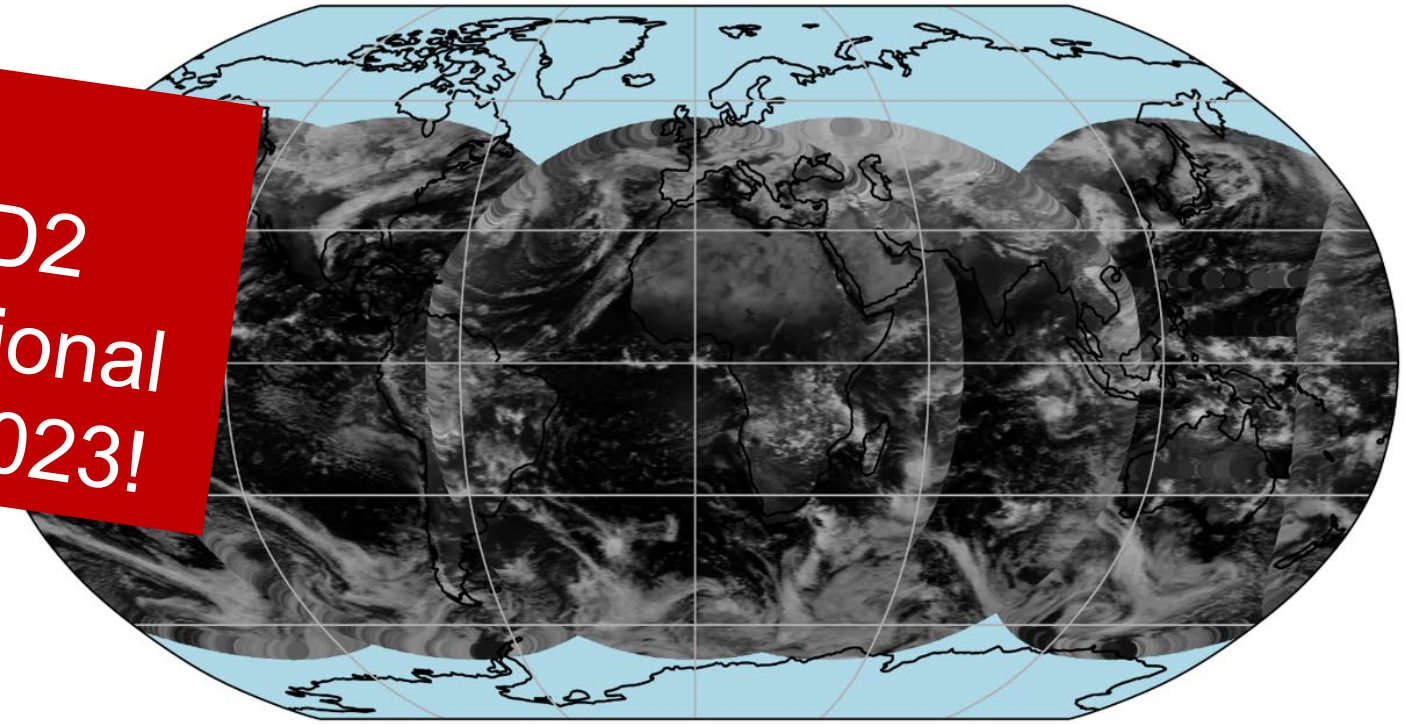
- Components

ICON and IFS model cloud evaluation using visible imagers on geostationary satellites

VIS in ICON D2 Operational since 2023!



Simulated SEVIRI RGB image generated from ICON forecast

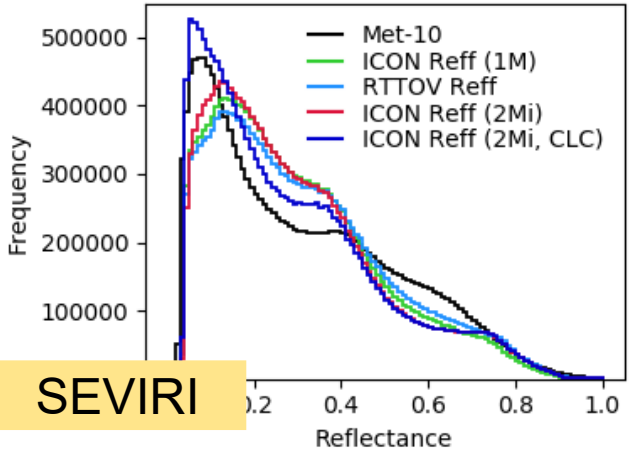
C. Stumpf, C. Köpken-Watts, R. Faulwetter, F. Baur, L. Scheck* (DWD, *HErZ)
C. Lupu, S. Quesada Ruiz, A. Benedetti, V. Firat, T. Necker, J. Schröttle (ECMWF)

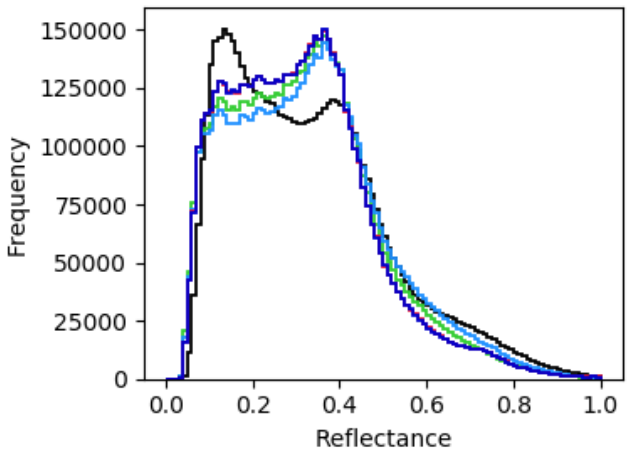
Refl. Histograms: different ICON cloud physics setups

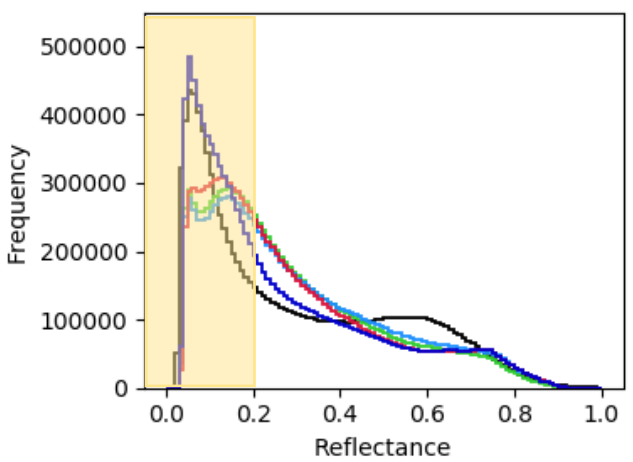
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Full disk | Land surfaces | Sea surfaces

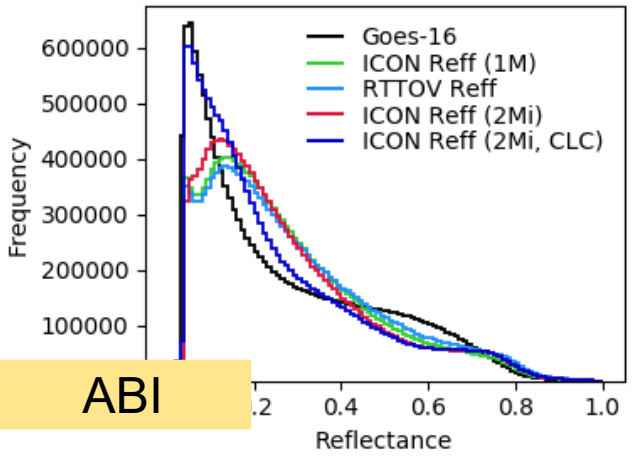
SEVIRI

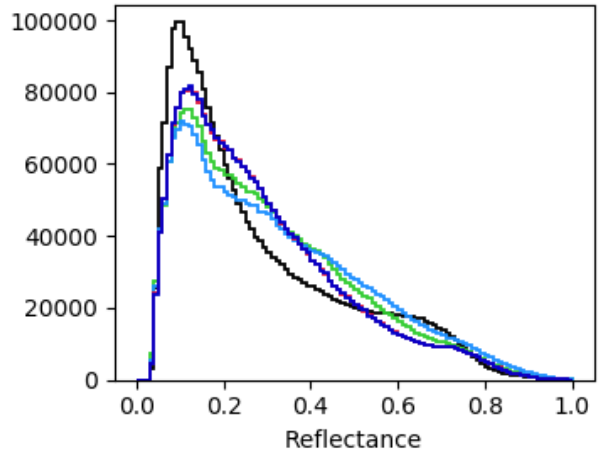


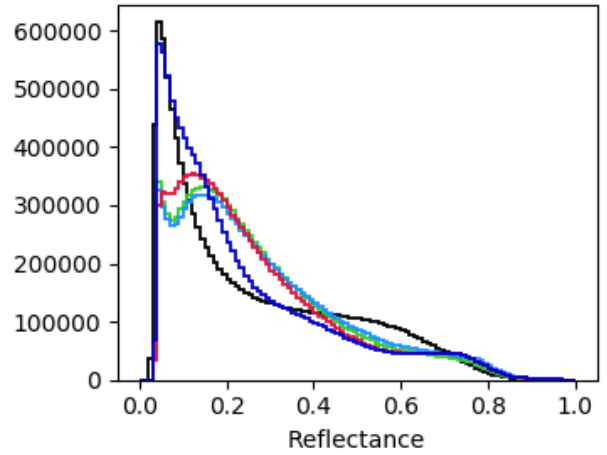




ABI







Overall structure of refl. histograms reproduced in sim.

Main difference: Peak at low reflectances due to too many thin model clouds in ICON (mainly oceans)

Little dependence on diff. radius param.s

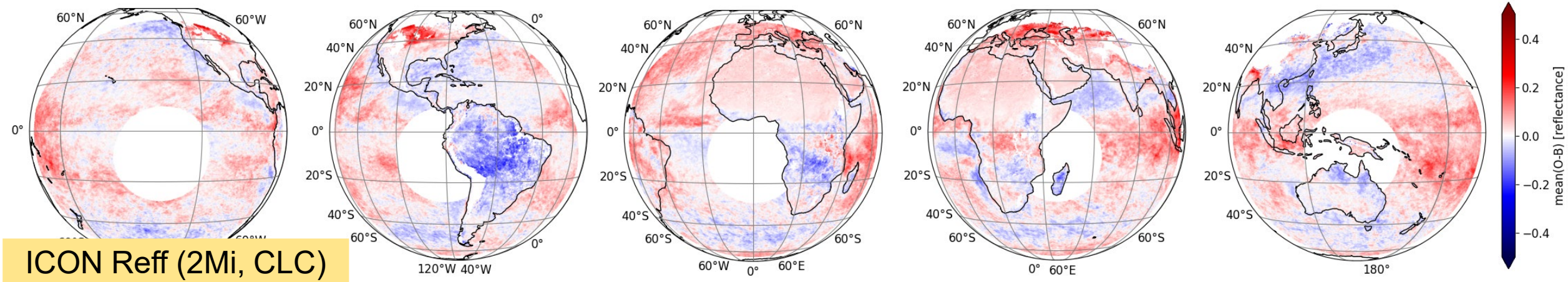
Cloud cover scheme modifications largely reduce diff.s at low reflectances (ICON)

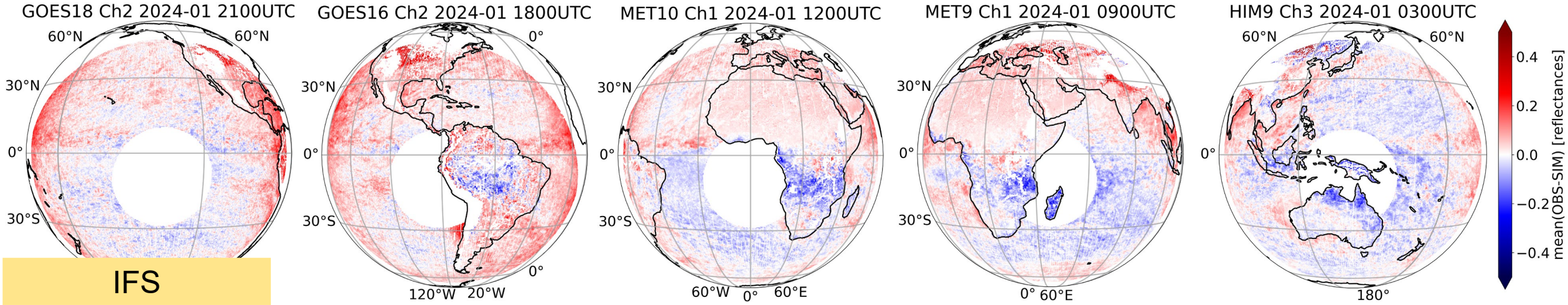
→ Poster ‘ICON and IFS model cloud evaluation using visible imagers on geostationary satellites’ by DWD and ECMWF

ICON vs. IFS: Monthly mean OmB (Jan 2024)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Goes-18 ch2 21 UTC	Goes-16 ch2 18 UTC	Met-10 ch1 12 UTC	Met-9 ch1 9 UTC	Him-9 ch3 3 UTC





Global All-Sky Data Assimilation

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

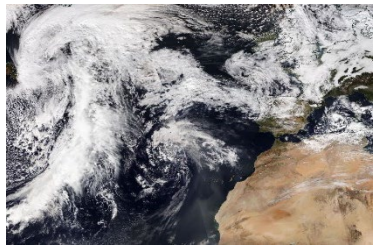
contrails

Satellite observation
REFL and BT

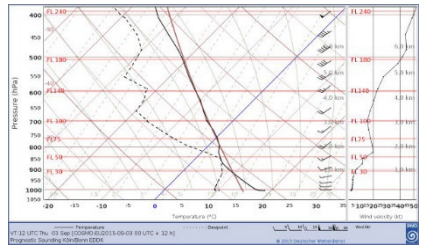
RTTOV-MFASIS

diagnosed

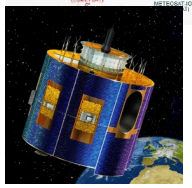
Large-scale water
and ice clouds



Solved NWP

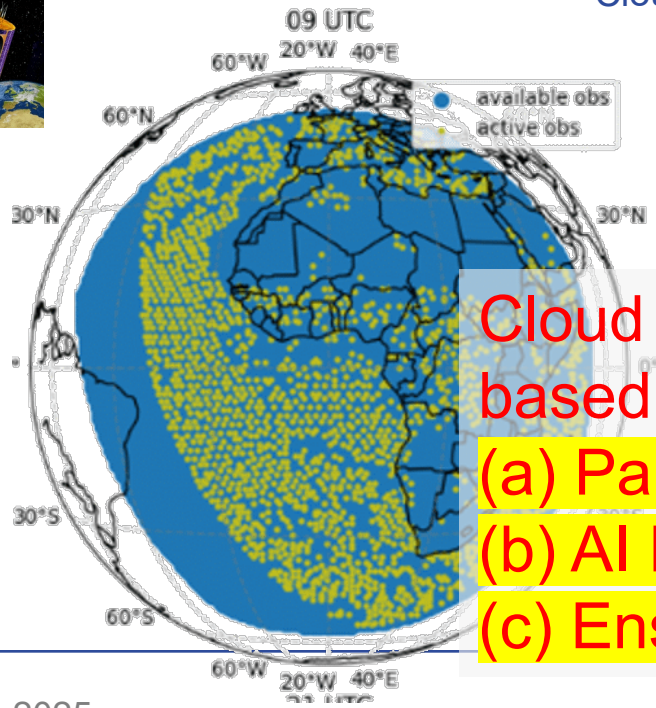


Linear operator developed
in the Contrails project



METEOSAT
second
generation

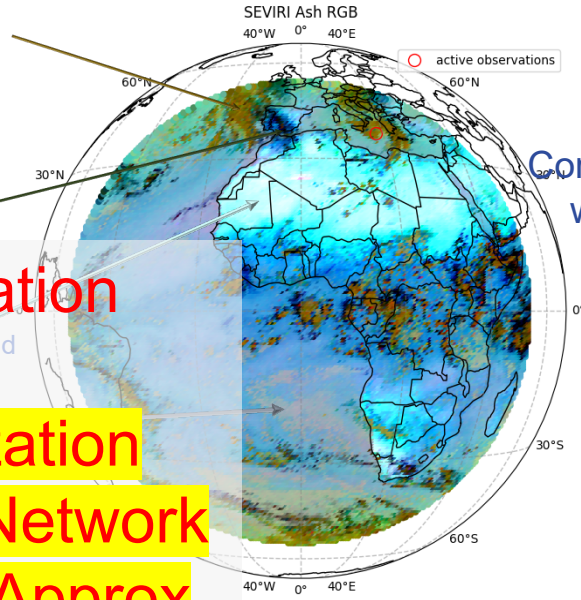
Cloud cover and small-scale clouds



Thick ice
cloud

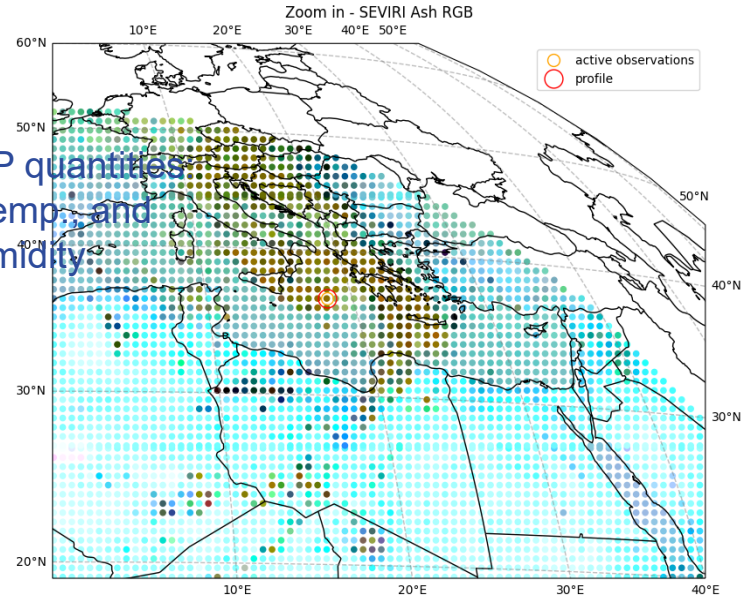
Thin ice cloud

Cloud free land



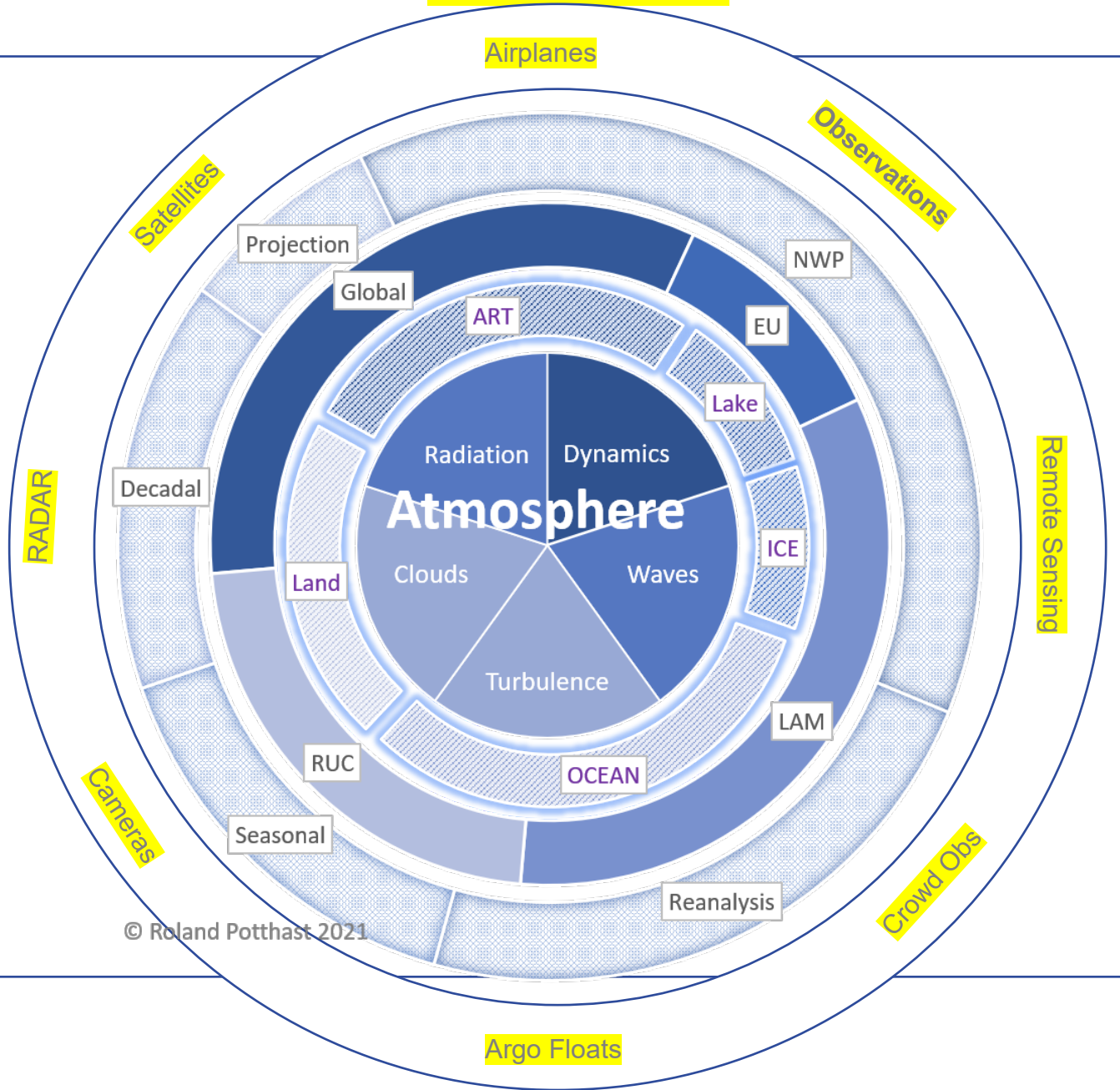
Cloud Assimilation
based on
(a) Parametrization
(b) AI Neural Network
(c) Ensemble Approx.

Core NWP quantities
wind, temp., and
humidity



DA for Weather to Climate

- **NWP Global, EU, LAM, RUC**
- **Digital Twins**
- **Climate Monitoring**
- **Seasonal**
- **Decadal**
- **Climate Projection**



Data Assimilation
Redesign

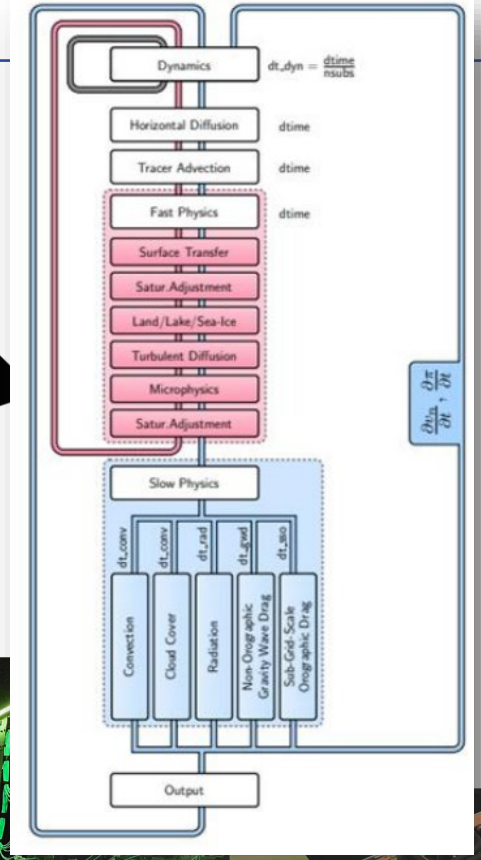
- ~~**OCEAN & Coupled**~~
- ~~Surface~~
- ~~Snow / ICE~~
- ~~ART~~
- **GHG**

~~GPUs~~

Artificial Intelligence
- Global
- LAM
- Components

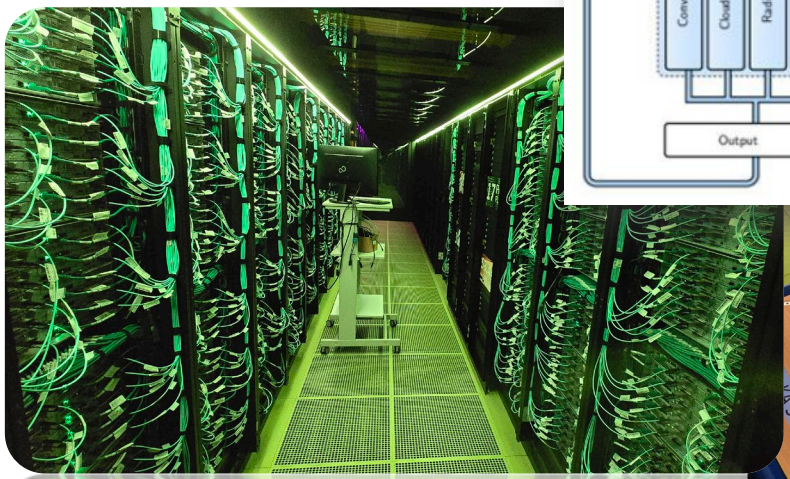
OpenICON & DA Redesign

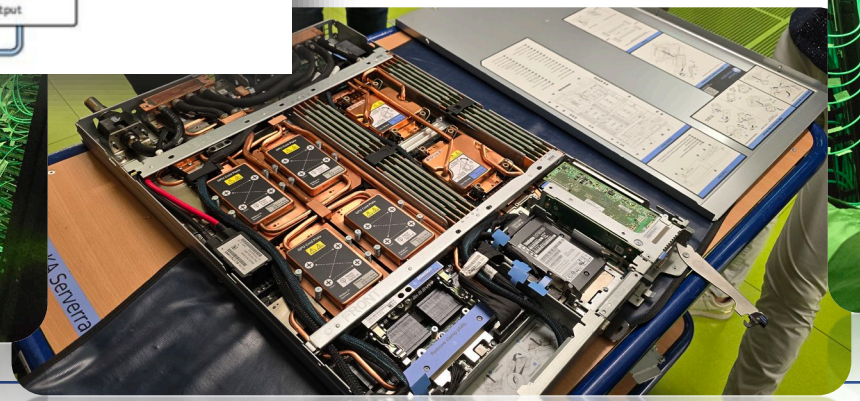
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

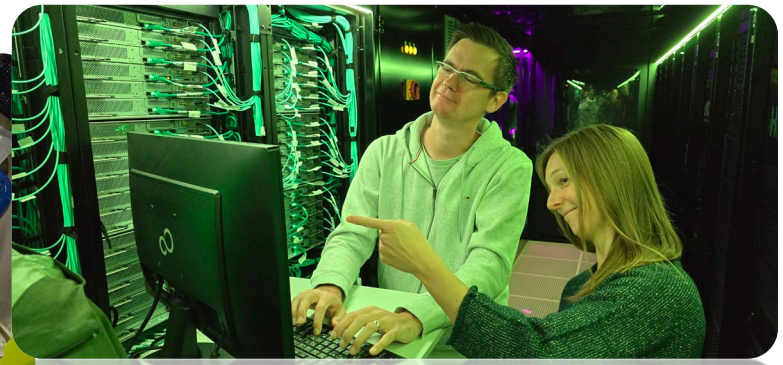


ICON modular, accessible, developing

- Granules
- Development
- Test Strategy
- Usability
- Computing Architectures
- Language Interoperability







DA for Weather to Climate

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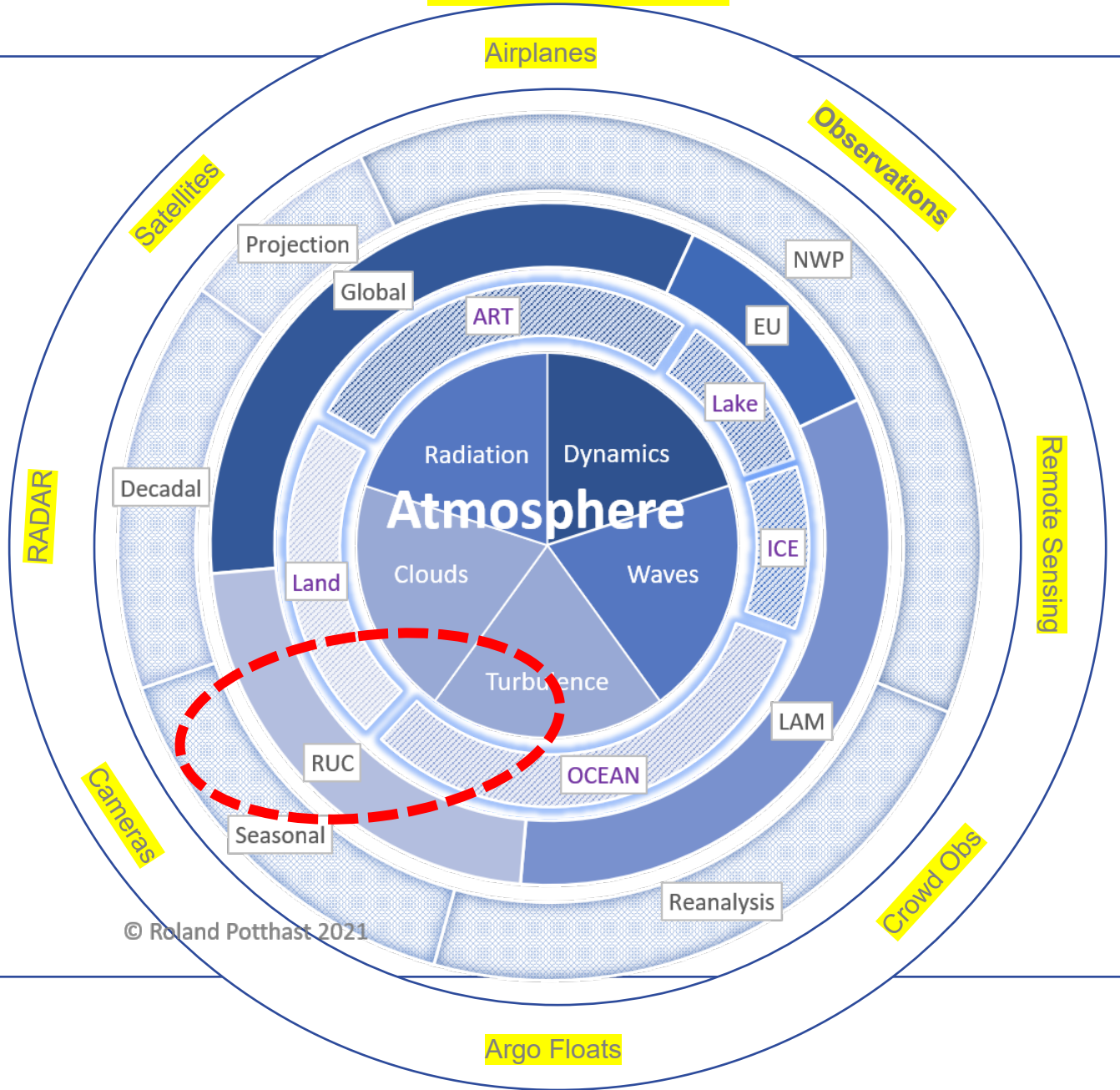


Data Assimilation
Redesign

- **OCEAN & Coupled**
- Surface
- Snow / ICE
- ART
- **GHG**

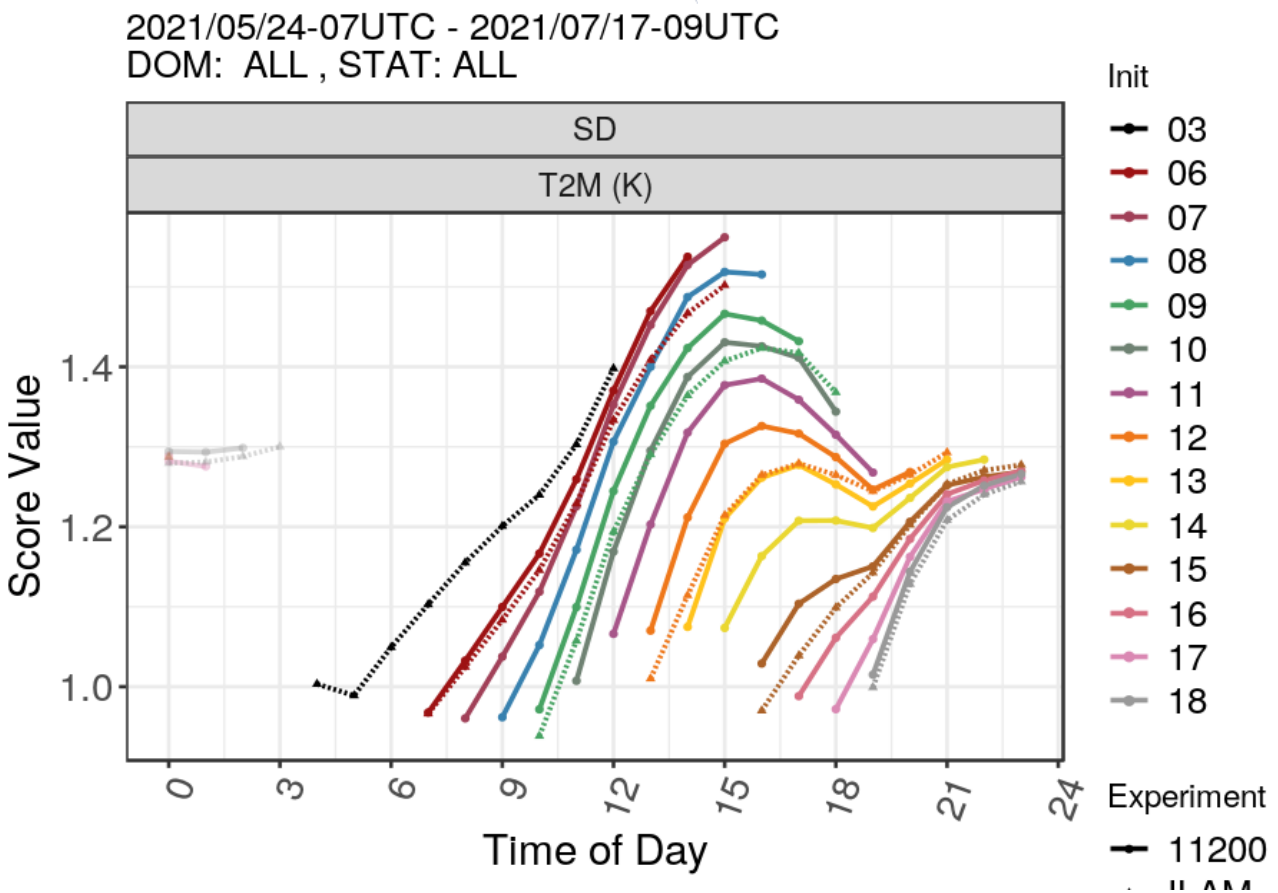
GPUs

Artificial Intelligence
- Global
- LAM
- Components

Advantage of timely EPS Initialization

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

45 minutes



Operational KENDA RUC System

- Hourly Initialization by EDA
- Hourly Forecast Runs
- Spin-off from classical cycle at 3 UTC
- **Younger Fast Initialization shows Best Scores** for several hours
- 3-hourly KENDA with **more observations** better after 5 hours

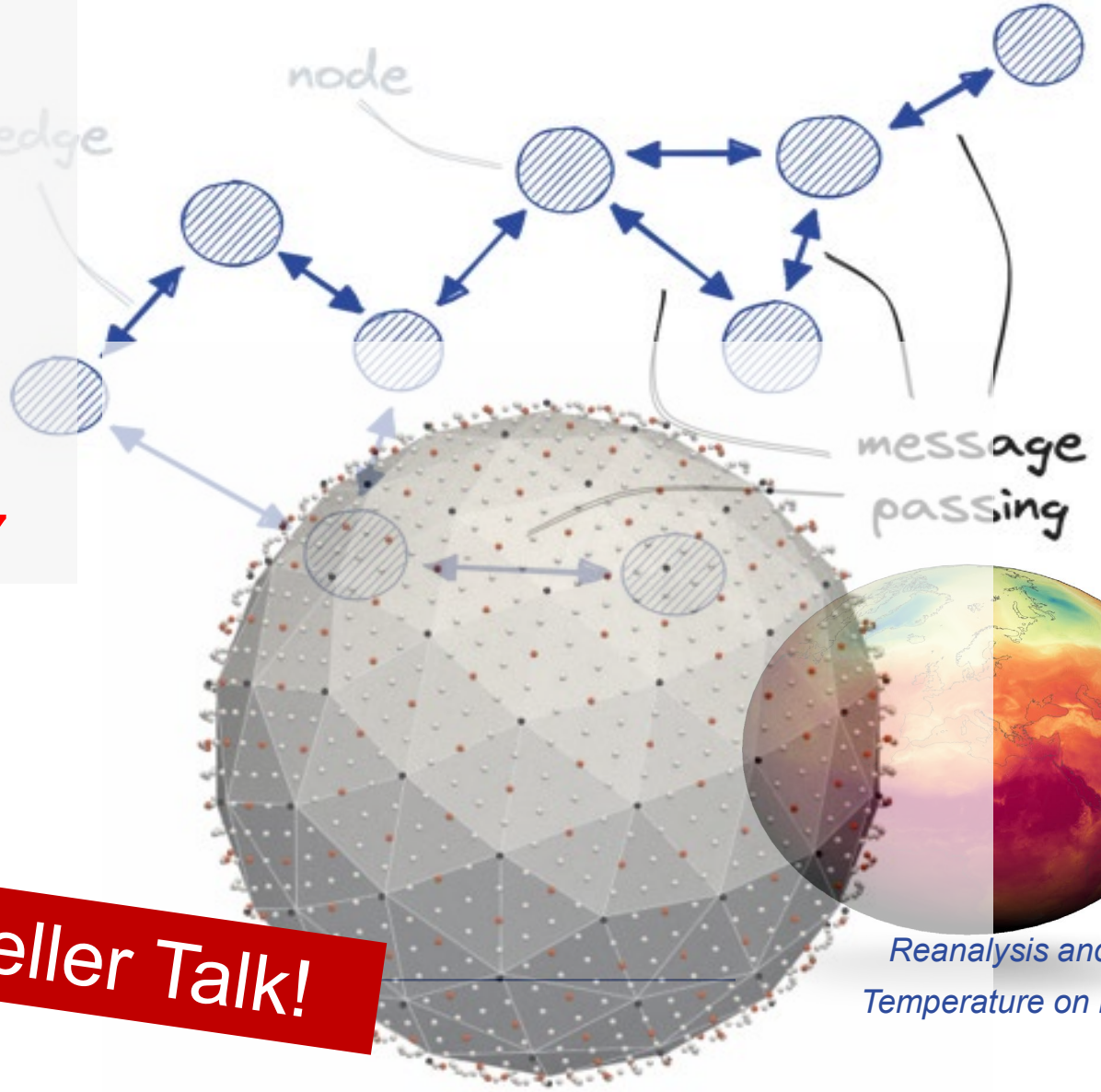
AICON and KANGU

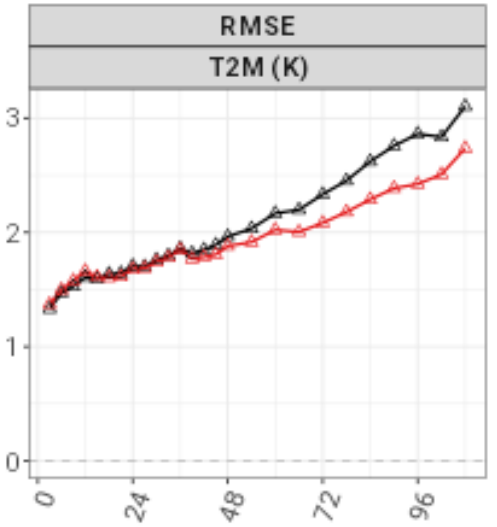
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

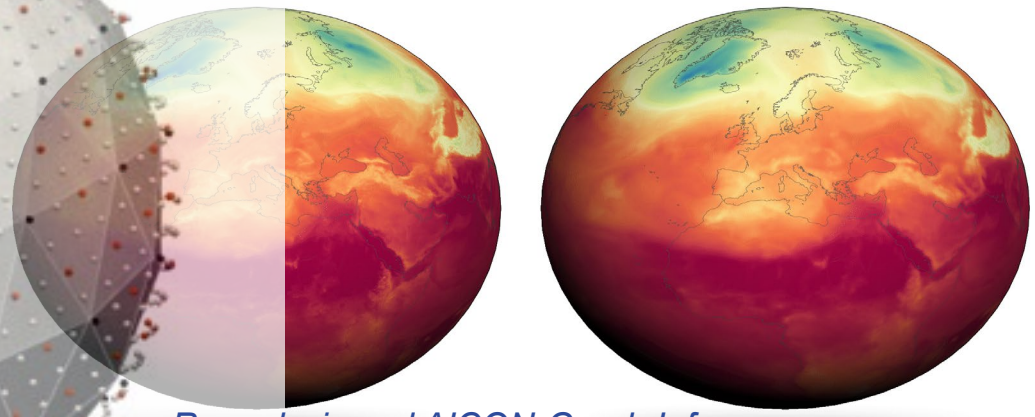
AICON
graph neural network
forecasting model

Implemented
Training ongoing

R3B5 -> R3B6 -> R3B7







Reanalysis and AICON-Graph Inference

Temperature on model level 101 (~700 hPa)

Jan Keller Talk!

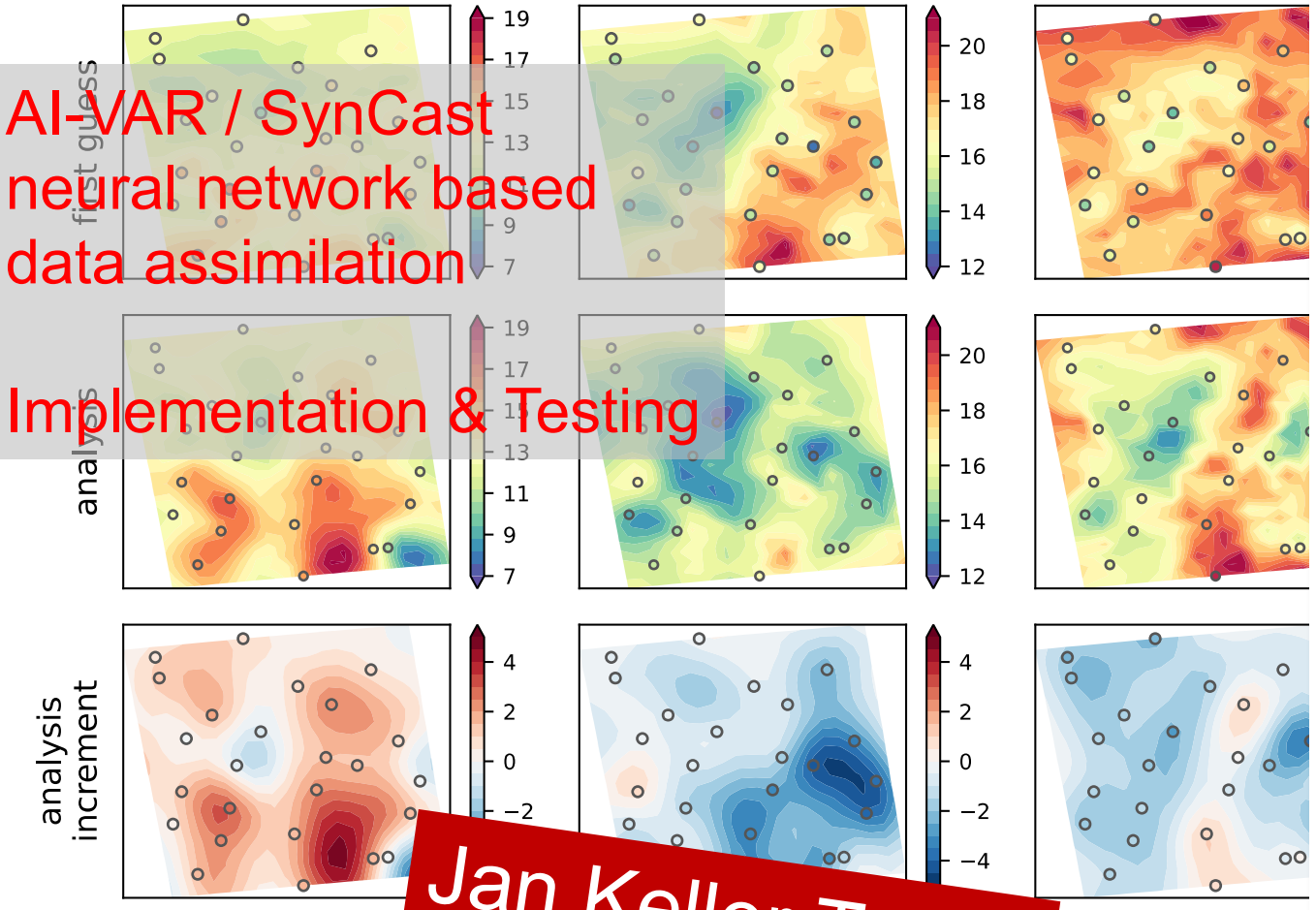
AI-VAR, SynCast, SINFONY

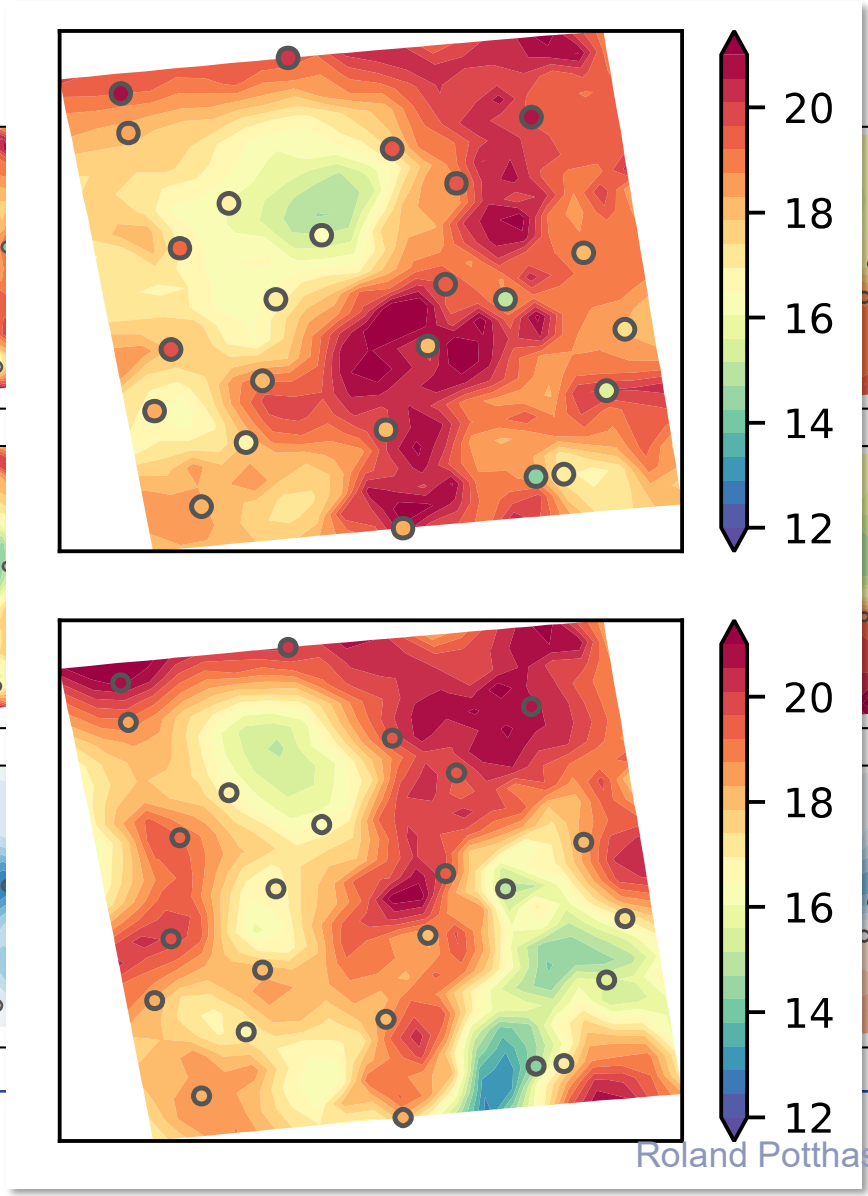
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

$$l = (\hat{\mathbf{x}} - \mathbf{x}^b)^T \mathbf{B}^{-1} (\hat{\mathbf{x}} - \mathbf{x}^b) + (\hat{\mathbf{y}} - \mathbf{y})^T \mathbf{R}^{-1} (\hat{\mathbf{y}} - \mathbf{y})$$

AI-VAR / SynCast
neural network based
data assimilation

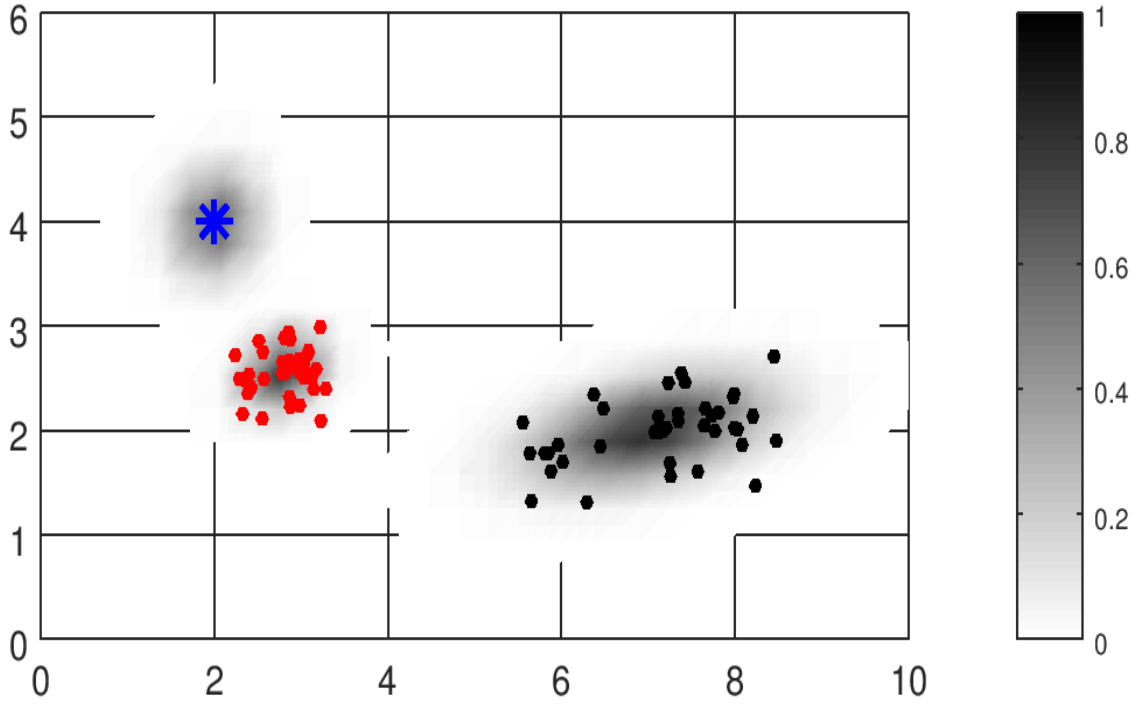
Implementation & Testing





Jan Keller Talk!

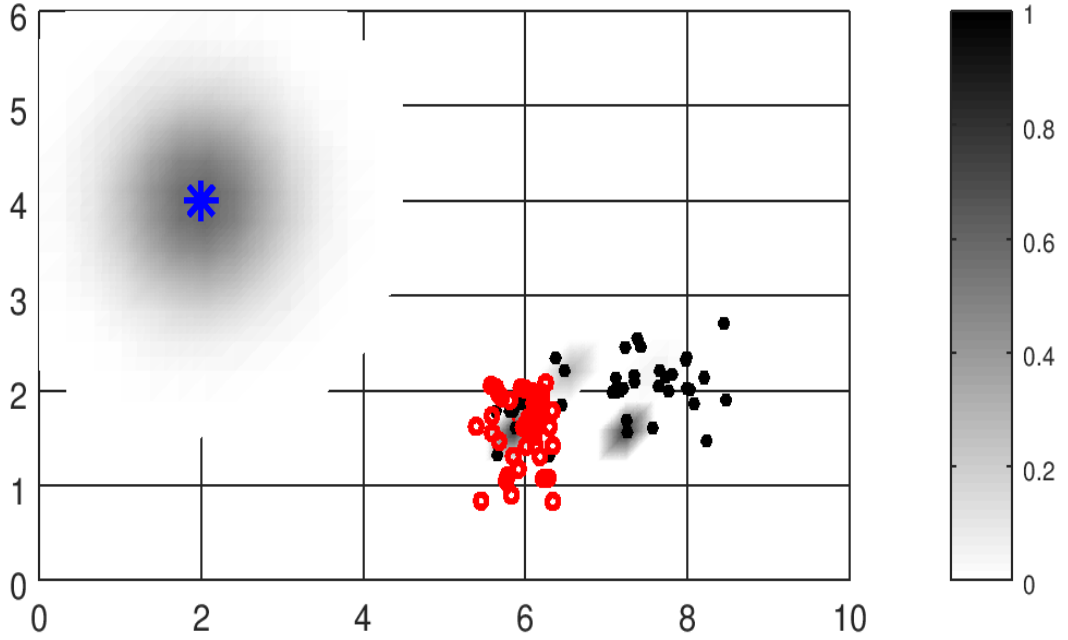
DA Algorithms at DWD



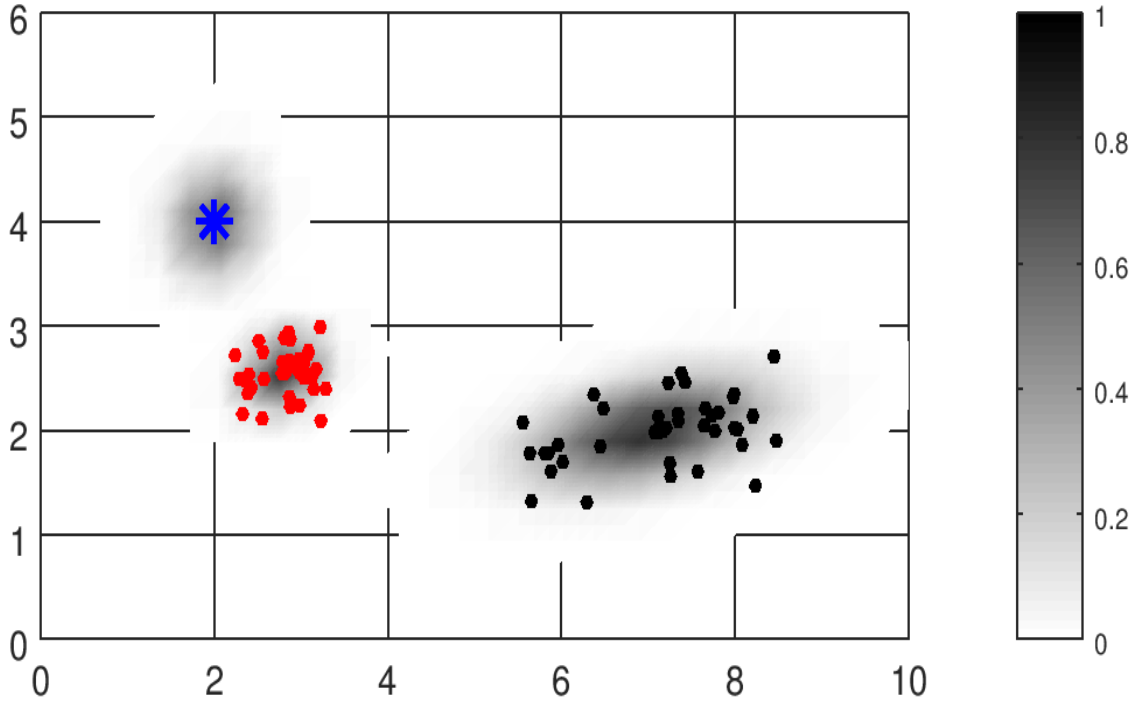
LETKF & EnVAR

Anne Rojahn, …

LPF

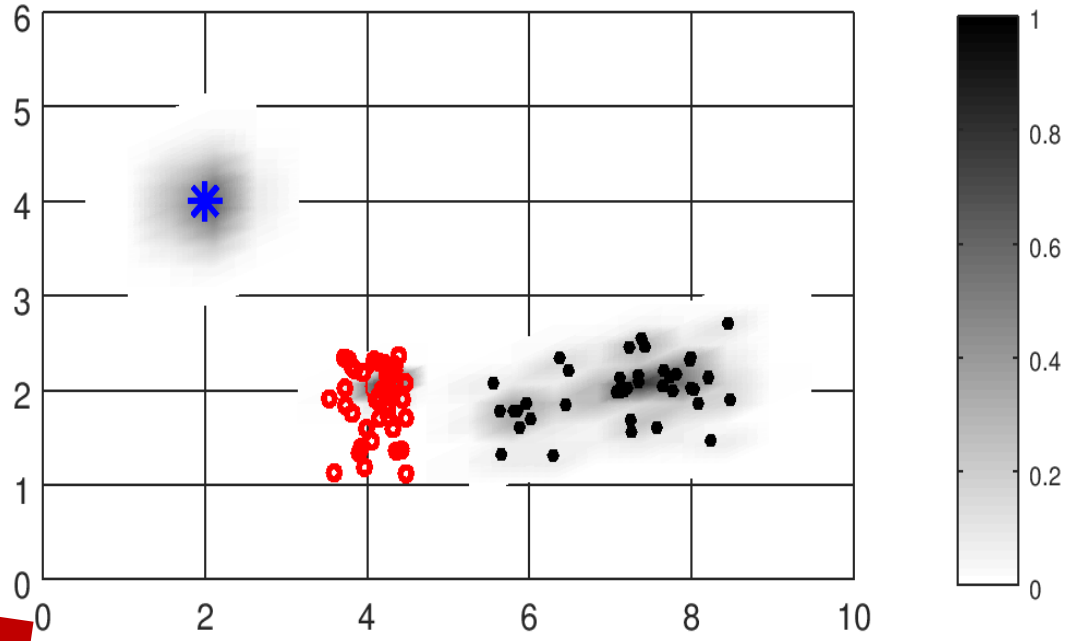


DA Algorithms at DWD



LETKF & EnVAR

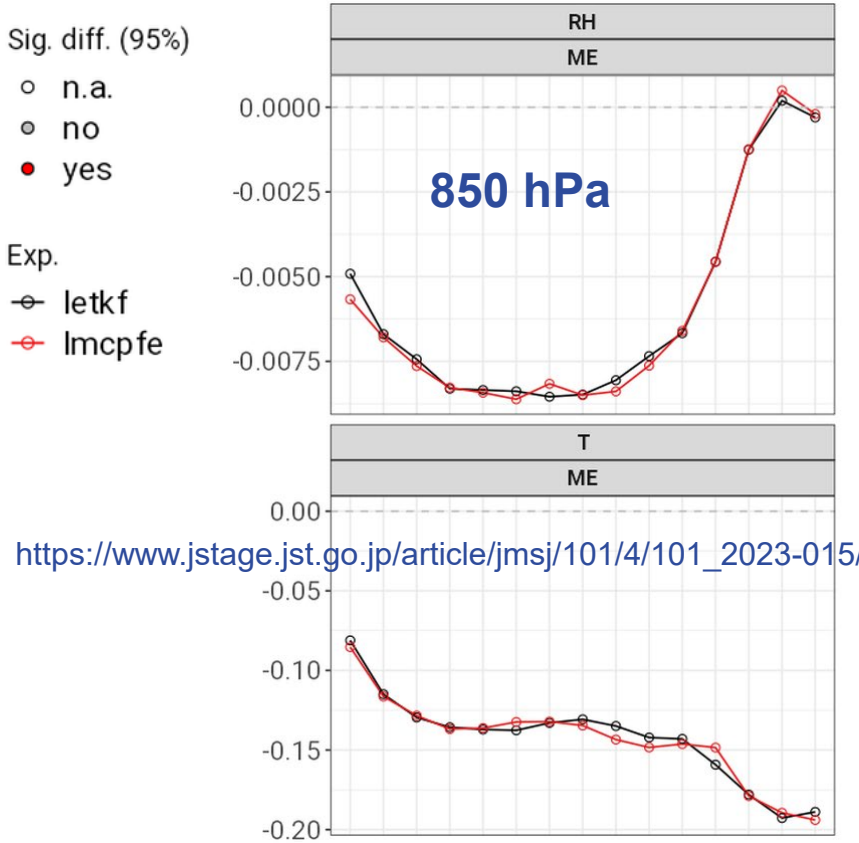
LMCPF & Gaussian Mixtures & IEWPF

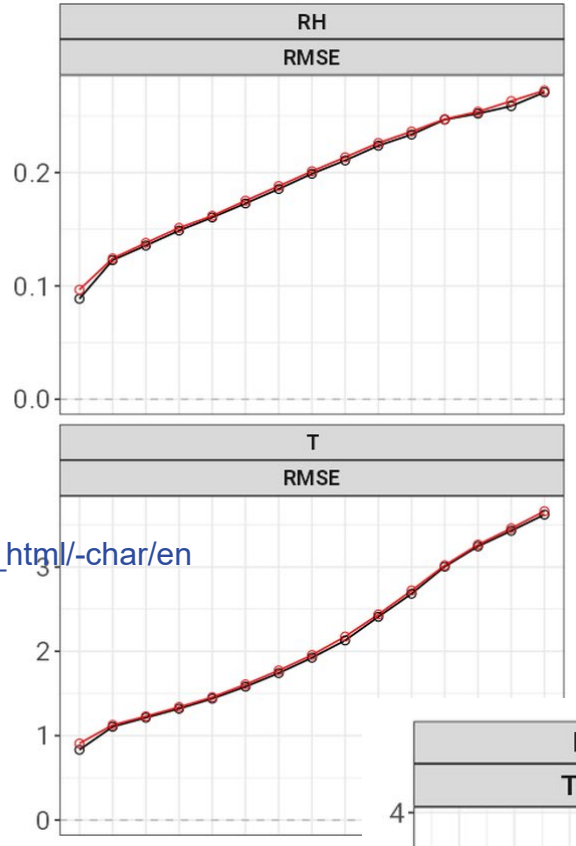


Anne Rojahn, …

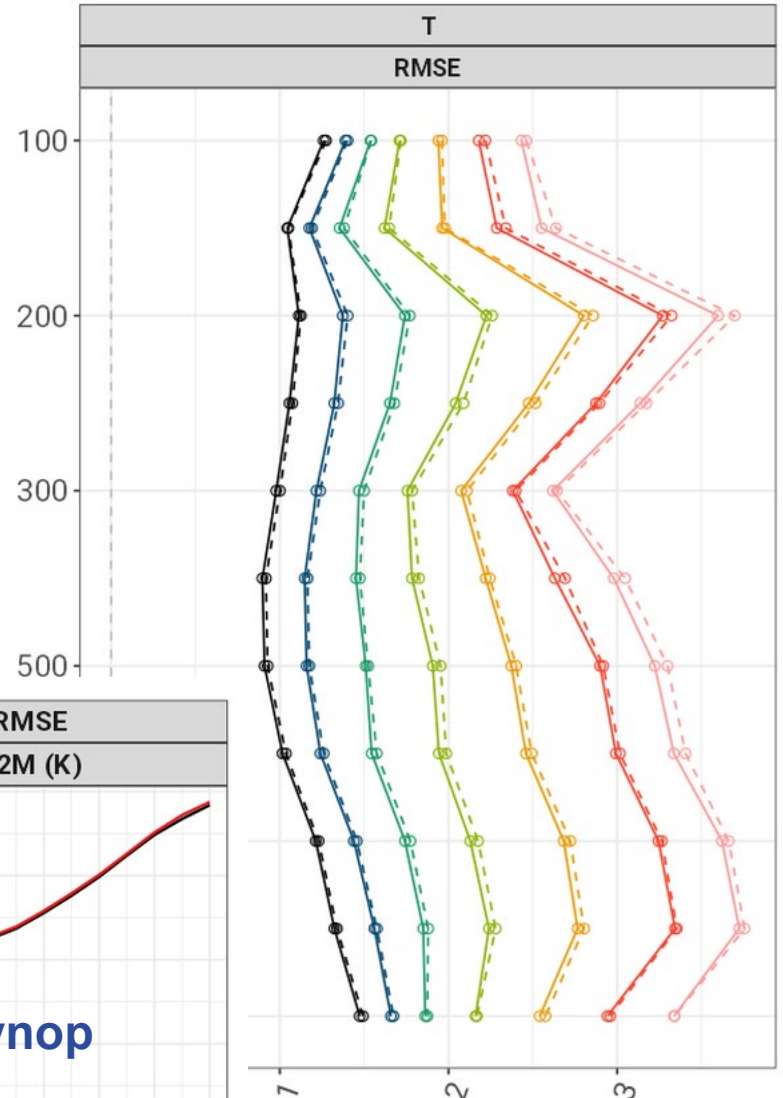
Particle Filters (LPF/LAPF/LMCPF)

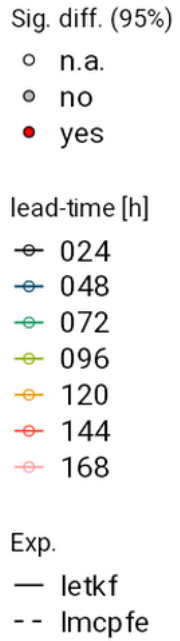
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

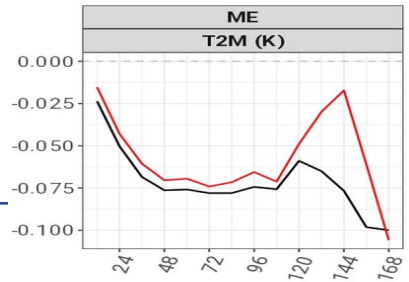


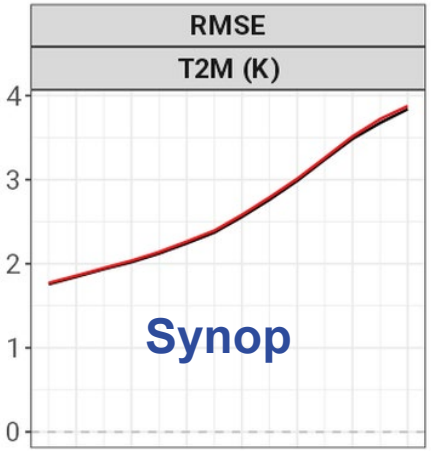


https://www.jstage.jst.go.jp/article/jmsj/101/4/101_2023-015/_html/-char/en









Article

Particle Filtering and Gaussian Mixtures – On a Localized Mixture Coefficients Particle Filter (LMCPF) for Global NWP

Anne ROJAHN, Nora SCHENK, Peter Jan VAN LEEUWEN, Roland POTTHAST

- 500m ICON (D05)
- Operational Chain Evolving
- DestinE and GLORI
- Adaptive Parametertuning (APT)
- Climate-Neutral Flight
- GHG Data Assimilation and Inversion: ITMS
- Coupled Forecasts:
  - Atmosphere-Ocean ESM-W
  - Climate Forecast via ICON XPP
- ICON-WAVES
- Visible Reflectance & IR
- All-Sky Data Assimilation
- SINFONY
- AI-Var
- Particle Filters

Many Thanks!