

AI Serving Weather Prediction

September 2026

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AI Technology Officer
E-AI Programme Coordinator

Formerly in *Research and Development*
Now in *Information Technology and Operations*

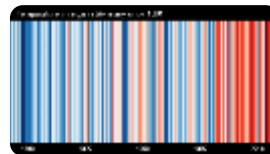
Marek.Jacob@dwd.de



Duties of the Deutscher Wetterdienst

The Deutscher Wetterdienst ...

- ... provides meteorological and climatological services.
- ... operates the measuring and observation systems.
- ... issues official warnings about weather phenomena.
- ... monitors the processes of the atmosphere.
- ... undertakes meteorological research.
- ... provides weather and climate predictions.
- ... operates necessary compute and HPC facilities.
- ... is under legislation of the Federal Ministry for Transport

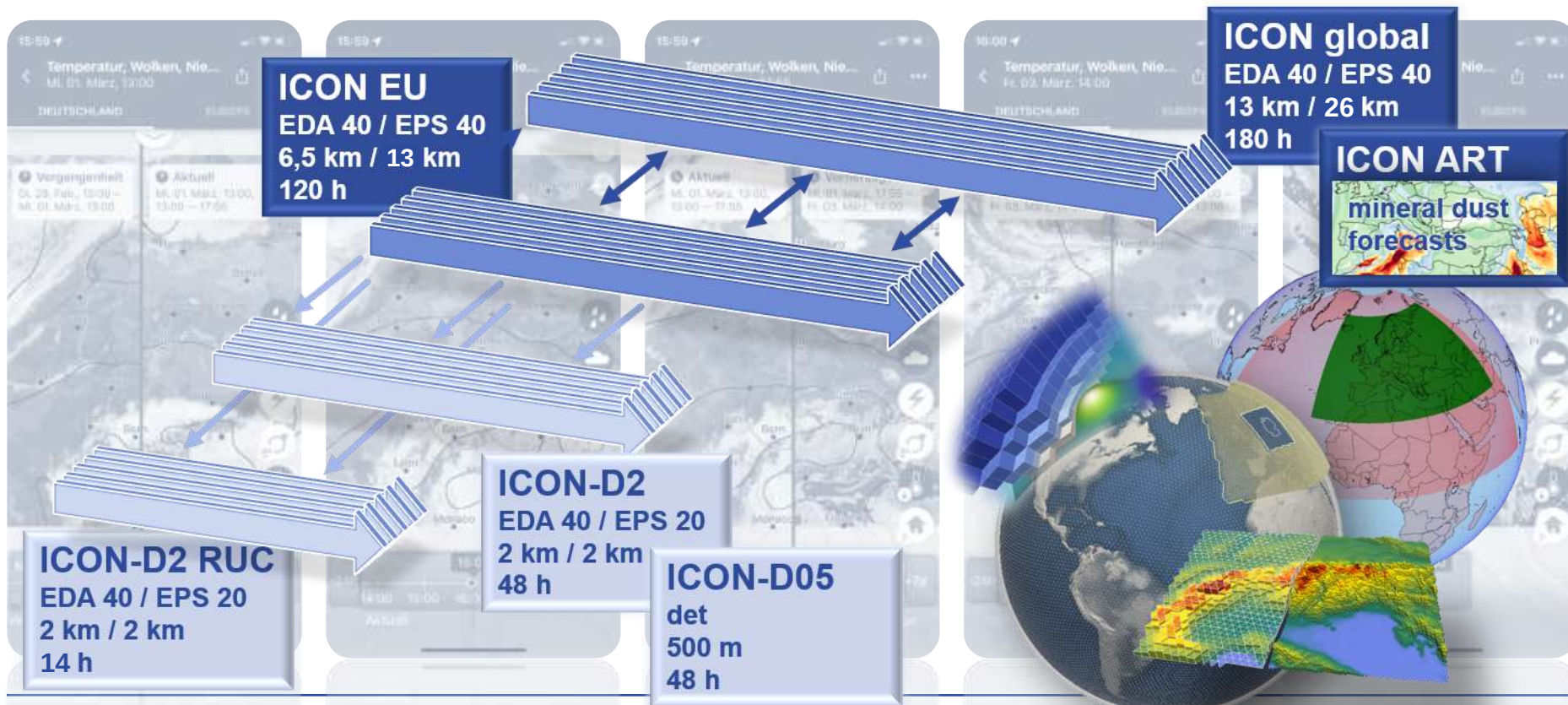


- Meteorology is a versatile discipline
- Big-Tech is not insuperable
- Public agencies and European Centres can enhance their collaboration by developing under open-source licences

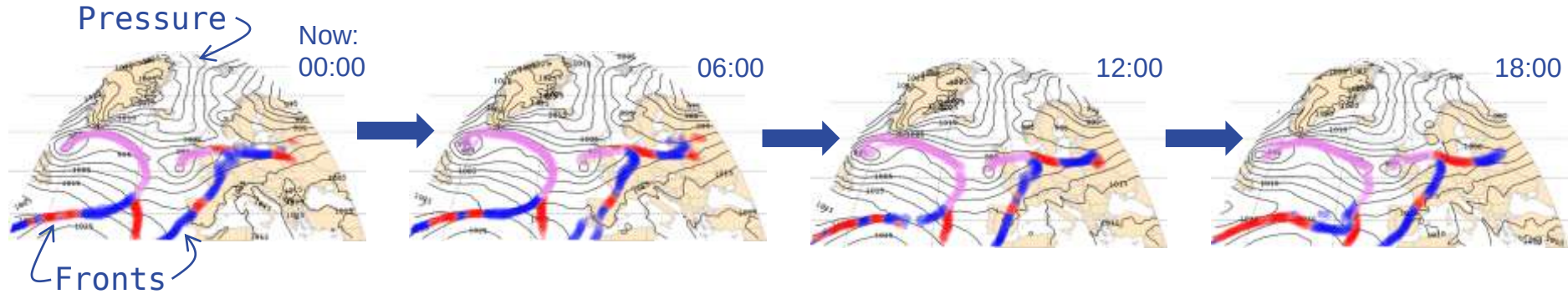
Seamless Weather Observation and Prediction



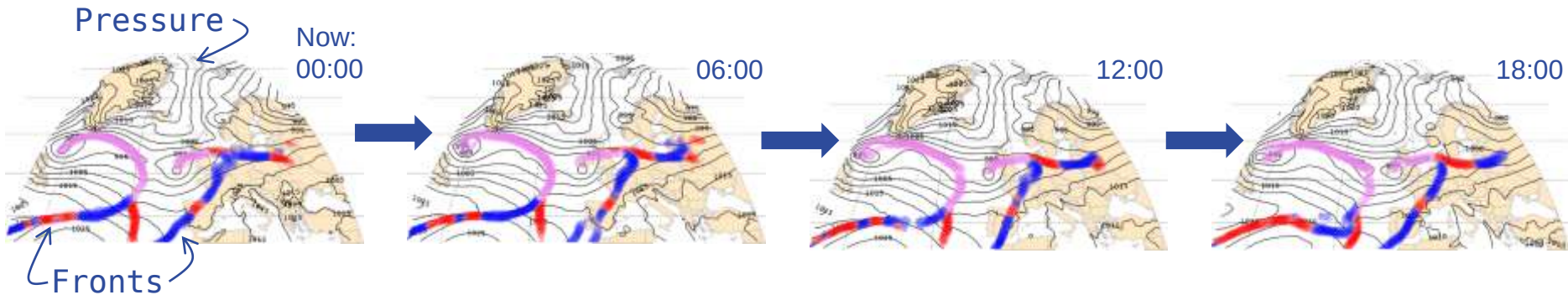
Numerical Weather Prediction Suite



Numerical Weather Prediction



figures: Felix Fundel (DWD)



- Description of the **state of the atmosphere**
 - Constrained by observations
- Physical model of the **motion and processes in the atmosphere**
 - Differential equations
 - Numerical solver for the equations
- A (super-)computer with corresponding infrastructure

$$\begin{aligned}\frac{\partial v_n}{\partial t} + (\zeta + f)v_t + \frac{\partial K}{\partial n} + w \frac{\partial v_n}{\partial z} &= -c_{pd}\theta_v \frac{\partial \pi}{\partial n} \\ \frac{\partial w}{\partial t} + \vec{v}_h \cdot \nabla w + w \frac{\partial w}{\partial z} &= -c_{pd}\theta_v \frac{\partial \pi}{\partial z} - g \\ \frac{\partial \rho}{\partial t} + \nabla \cdot (\vec{v}\rho) &= 0 \\ \frac{\partial \rho \theta_v}{\partial t} + \nabla \cdot (\vec{v}\rho \theta_v) &= 0\end{aligned}$$

Processes and Physical Model Elements that are Parameterized in NWP Models

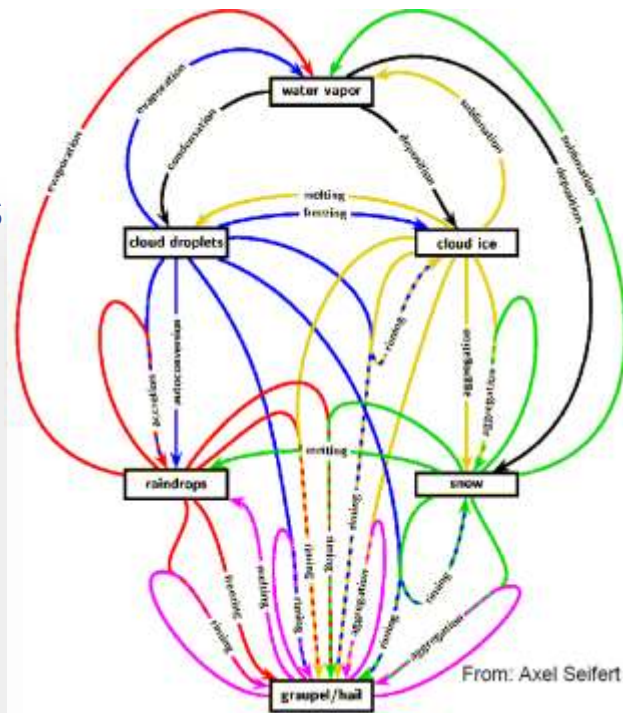


Example:
Processes in
cloud
microphysics

```

117  !SOMP      c_theta_tang_pi, c_theta_tang_i ICON_SMP_DEFAULT_SCHEDULE
118  DO jb = i_startblk, i_endblk
119
120      CALL get_indices_cip_patch( jb, i_startblk, i_endblk, &
121      i_startidx, i_endidx, ri_start, ri_end)
122
123      IF (listep == 1) THEN ! to be executed in predictor step only
124
125          !SACC PARALLEL DEFAULT(PRESENT) ASYNC(1)
126          !SACC LOOP GANG VECTOR COLLAPSE(2)
127          DO jk = 1, nlev
128
129              !SOMP
130              DO jc = i_startidx, i_endidx
131                  ! temporally extrapolated perturbation Exner pressure (used for horizontal gradients only)
132                  z_exner_ex_pr(jc,k,jb) = (1_wp + p_nhmwmetrics_exner_exfac(jc,k,jb)) * &
133                  (p_nhmwmetrics_exner_ref_m(jc,k,jb) - p_nhmwmetrics_exner_ref_m(jc,k,jb)) + &
134                  p_nhmwmetrics_exner_exfac(jc,k,jb) * p_nhmwmetrics_exner_ref_m(jc,k,jb)
135
136                  ! non-extrapolated perturbation Exner pressure, saved in exner_pr for the next time step
137                  p_nhmwmetrics_exner_pr(jc,k,jb) = p_nhmwmetrics_exner_exfac(jc,k,jb) * &
138                  p_nhmwmetrics_exner_ref_m(jc,k,jb)
139
140              ENDDO
141              !SACC END PARALLEL
142
143              ! The purpose of the extra level of exner_pr is to simplify coding for
144              ! jgradp_method=4/5, it is multiplied with zero and thus actually not used
145              !SACC KERNELS DEFAULT(PRESENT) ASYNC(1)
146              z_exner_ex_pr(:,nlev+1,jb) = 0_wp
147              !SACC END KERNELS
148
149          IF (jgradp_method == 3) THEN
150              ! Perturbation Exner pressure on bottom half (level)
151

```



Reliable Meteorological Products

Comparison of national forecast models

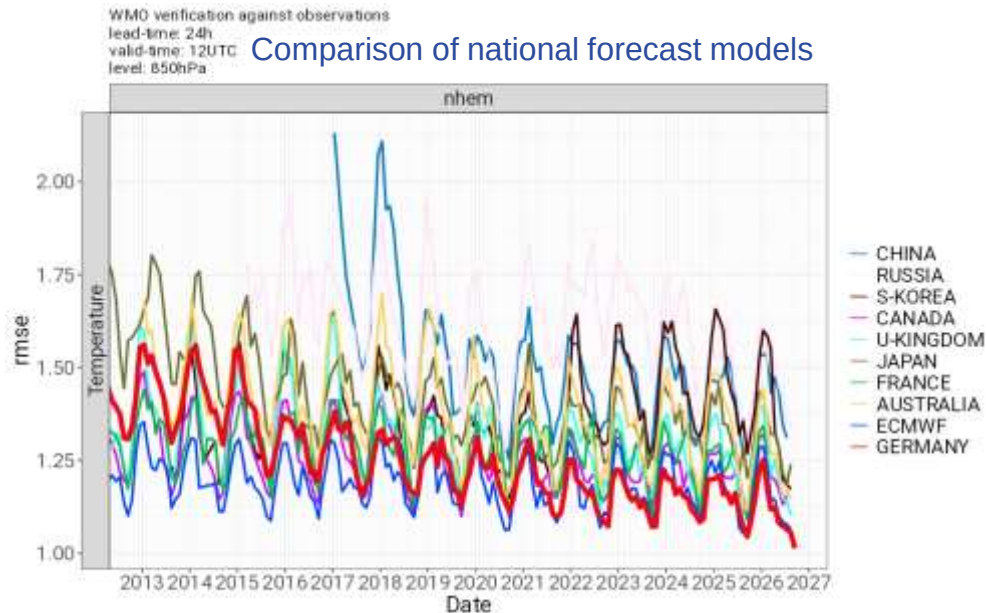


figure: Felix Fundel (DWD)



Informationssystem zur
Agrarmeteorologischen
Beratung für die Länder

DEUTSCHLANDÜBERSICHT

MEIN AGRARWETTER

ALLGEMEIN

Startseite > Deutschlandübersicht > Agrarwet. Gefahrenwarnung

Waldbrandgefahrenindex

Zeitraum

4. Folgetag

Waldbrandgefahrenindex (WBI)

Mo 21.09.25



Historischer Mittelwert (Jahre 1981-2010) 4.14 WBI
Datenquelle: DWD, Bundesamt für Naturschutz und Statistik (www.bund.de)

Grafik

Tabelle

isabel.dwd.de
www.agrowetter.de



The Revolution

AI in Meteorology: Data-Driven Forecasting

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Starting in 2022, substantial progress in the field of data-driven weather forecasting was demonstrated: *FourCastNet*, *Pangu-Weather*, *GraphCast*, *GenCast*, *Aurora* (NVIDIA/Huawei/Google Deepmind, Microsoft), ...

- ➔ Decision to enhance DWD numerical weather prediction:
Develop ML-based forecasting to complement the global and regional ICON model.



Numerical Weather Prediction

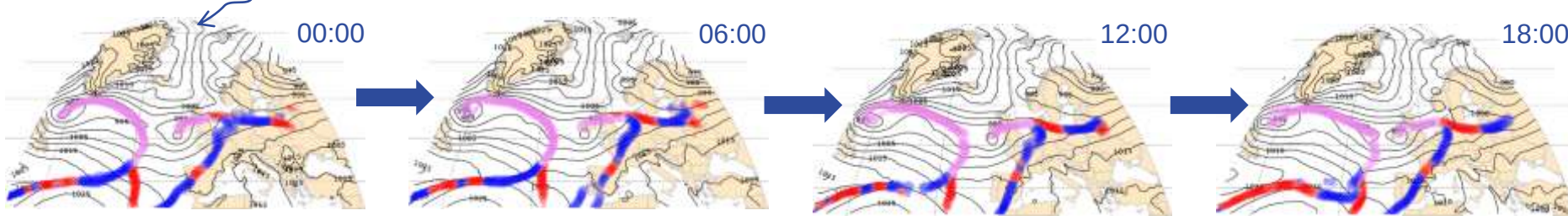
Surface Pressure

00:00

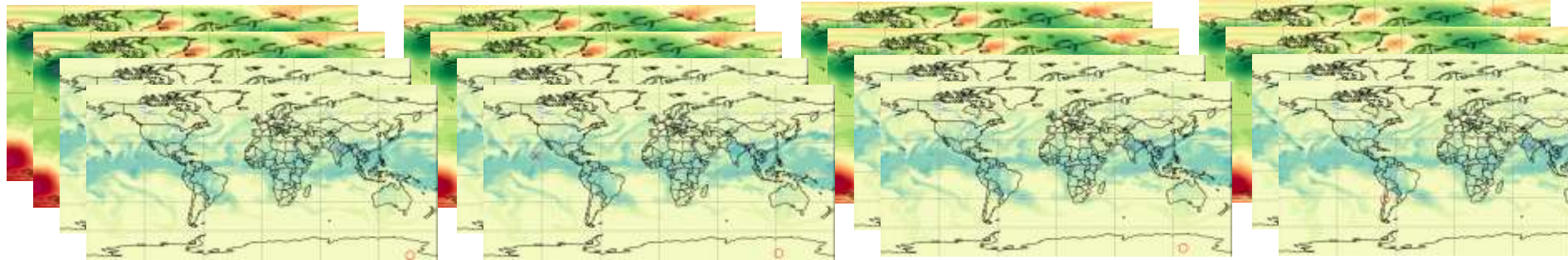
06:00

12:00

18:00

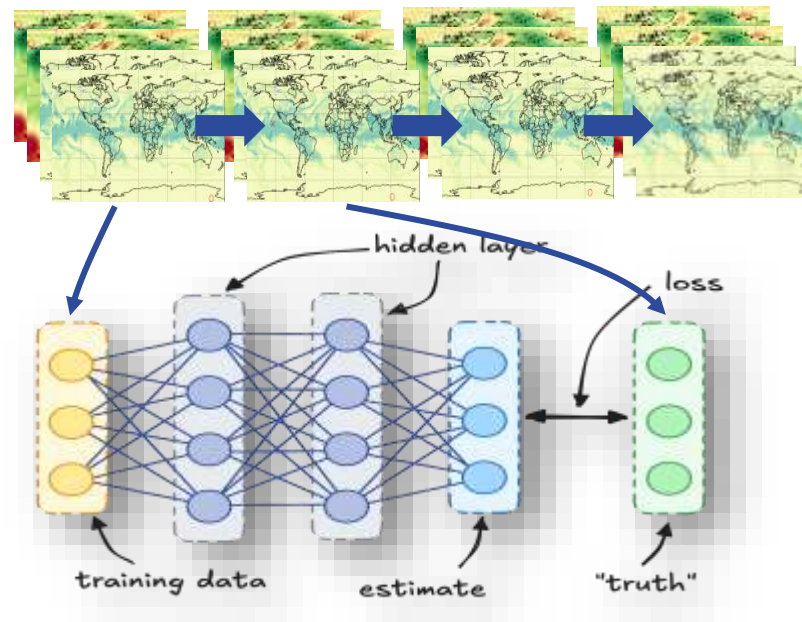


Further atmospheric variables: wind, temperature, pressure, density, moisture, clouds, soil properties, ...



figures: Felix Fundel and Helmut Frank(DWD)

- The Atmosphere is described by a set of 3D variable fields
- The changing of weather can be learned as a transformation of patterns in multi-channel images
- Multistep forecast with autoregressive rollout



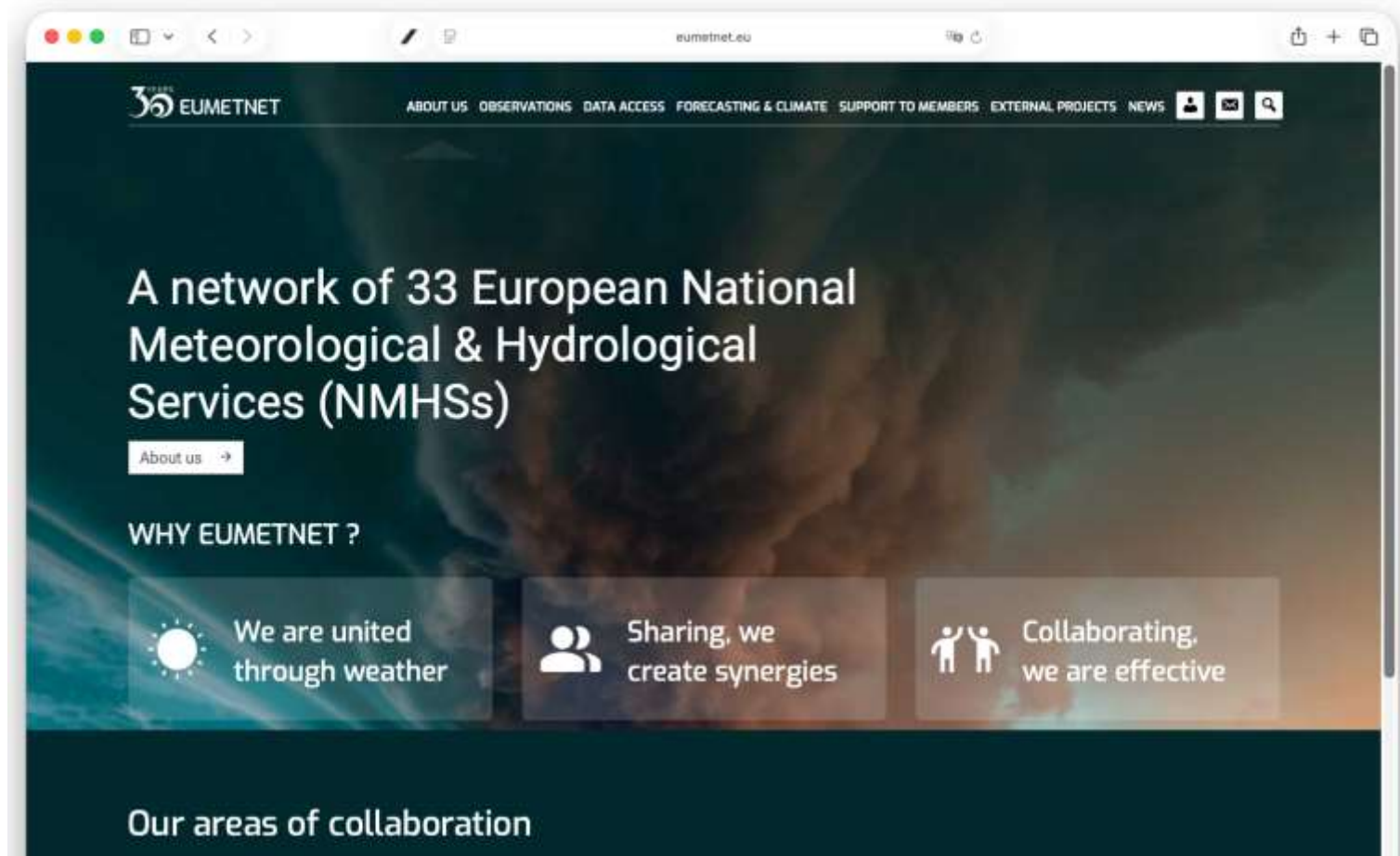
- ML models show better forecast scores
 - Worth almost a decade of NWP research
- Forecasting (Inference) is much cheaper and much faster
 - 10 minutes on 1 node instead of 45 minutes on 10 nodes
- ML models tend to produce smooth fields
- Uncertain behavior for extreme weather situation
- Trained on so called “Reanalysis Data”
 - Generated with traditional numerical models



Weather Service Activity

European Collaboration

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

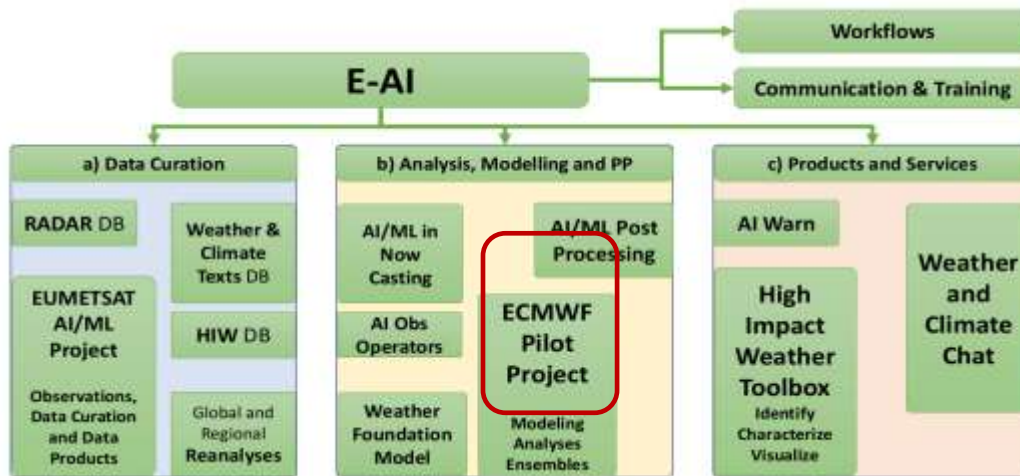


September 2026

Artificial Intelligence and Machine Learning in Weather, Climate and Environmental Applications

Objective: Enhance the collaboration of European National Meteorological Services (NMSs) and external partners in the area of AI/ML in weather, climate and environment.

- Programme Lead: Deutscher Wetterdienst
- Phase: 2024 – 2028
- Participating:
20 national meteorological Services,
EUMETSAT, ECMWF

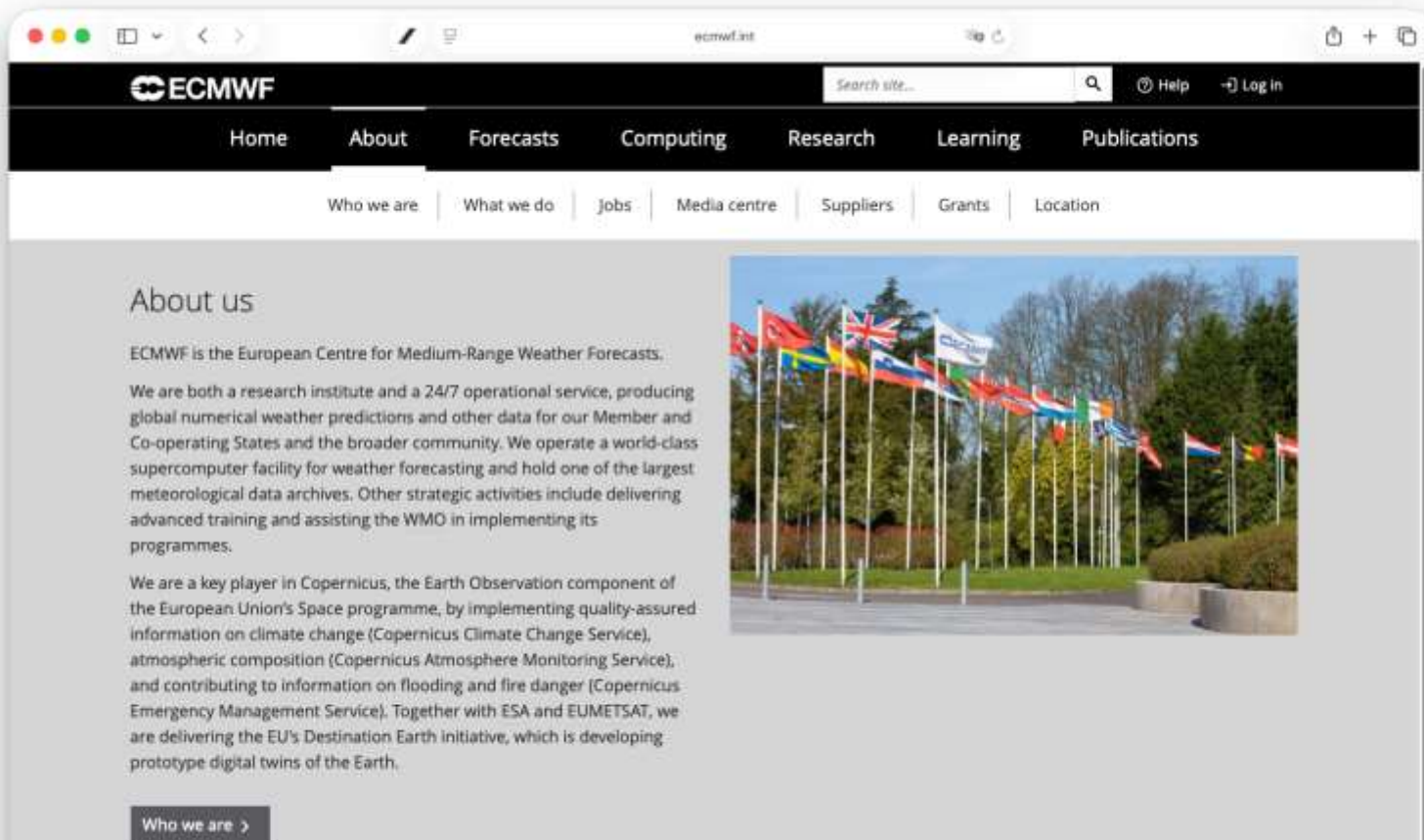


<https://www.eumetnet.eu/forecasting-and-climate/artificial-intelligence/>



Together with the European Centre

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



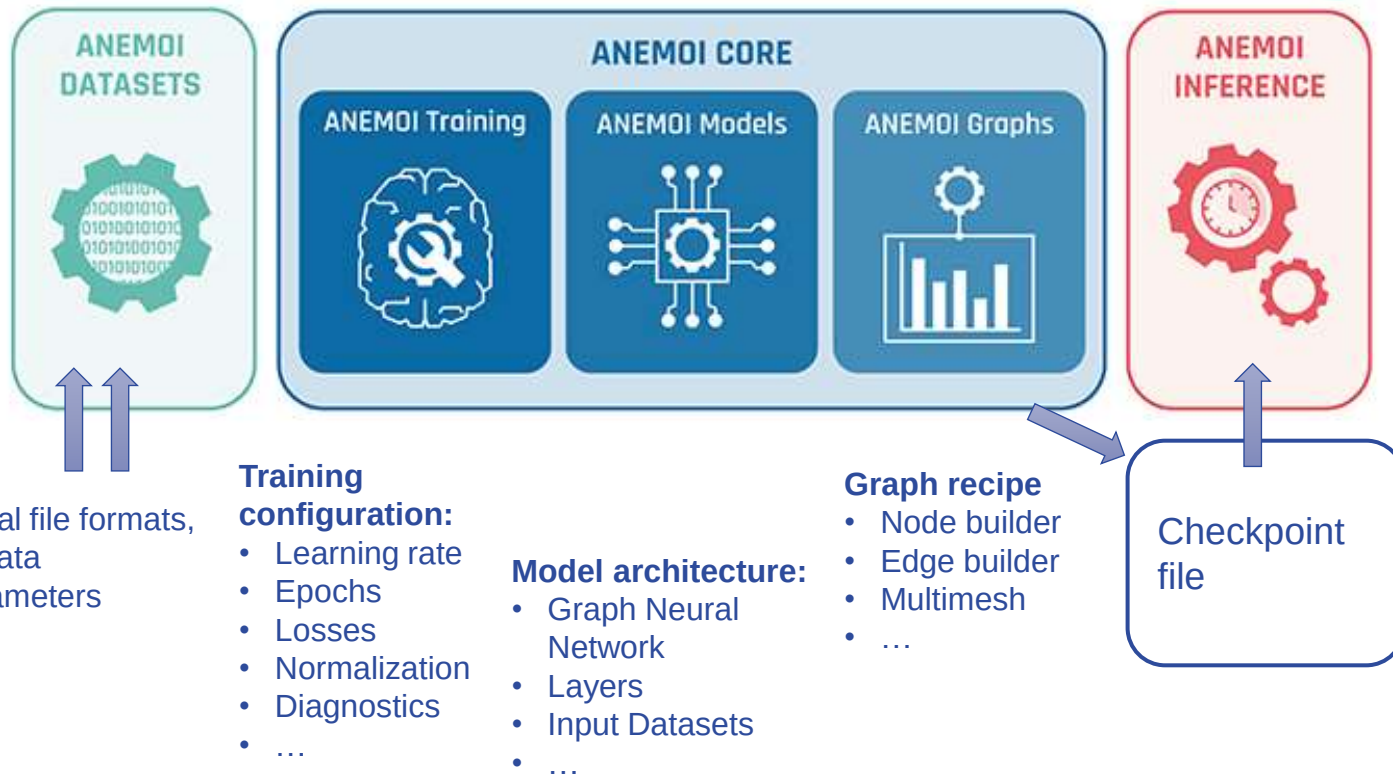
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ECMWF Machine Learning Pilot Project

Goal: Integrating machine learning (ML) into (numerical) weather prediction (NWP) at national weather services, based on the *Anemoi software ecosystem*

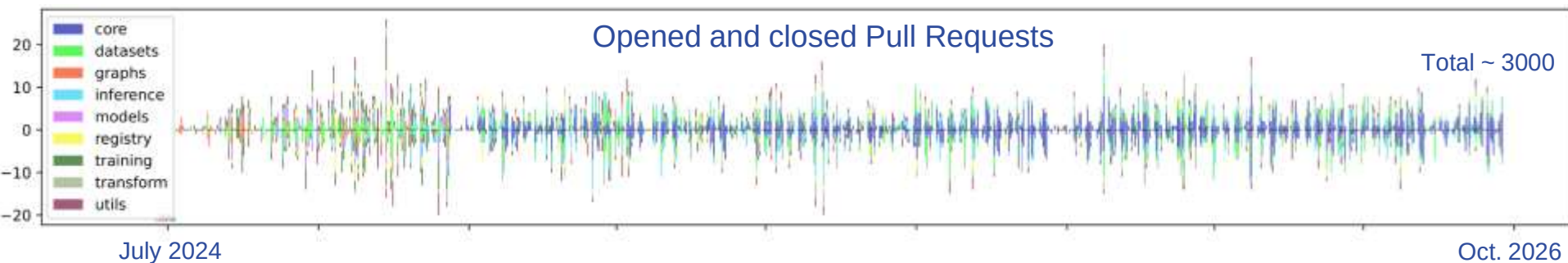
- Kicked off in June 2024
- 18 partners from 17 member states
- Funded by ECMWF, but driven by the partners
- Covers full forecasting chain: data-driven forecasting, ensembles, data assimilation, operations and infrastructure



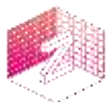


Joint Software Development

- Open-source Licence (Apache 2.0)
- <https://github.com/ecmwf/Anemoi>, <https://anemoi.readthedocs.io/>



Dependencies:
(selection)



Zarr



PyG



Numpy

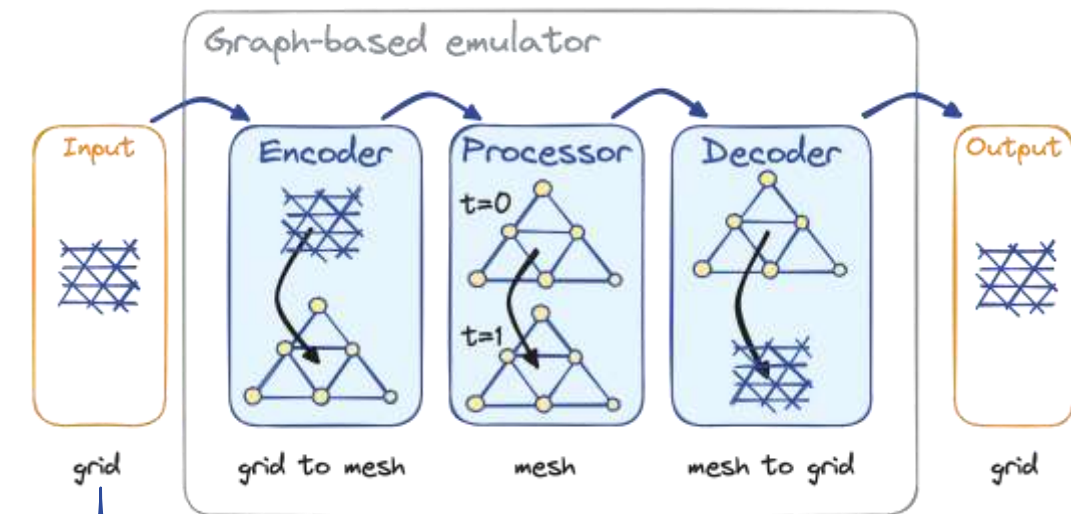


Pydantic

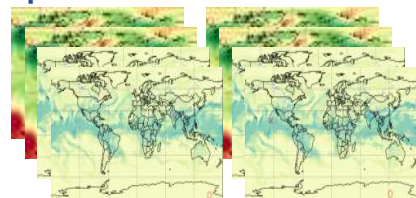


PyTorch Lightning

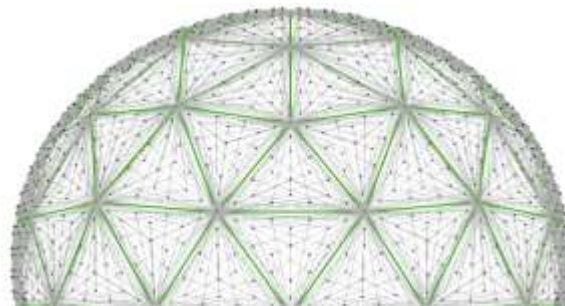
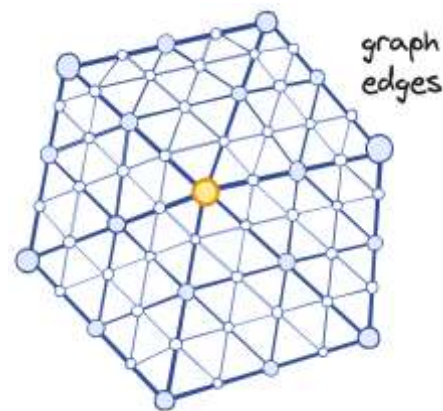
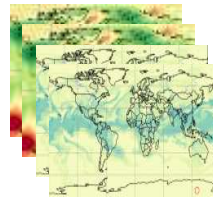
Typical Anemoi architecture: Graph neural network



past current

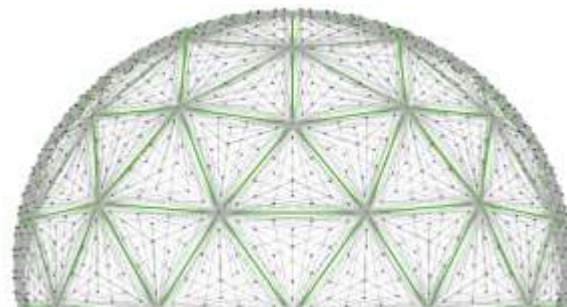
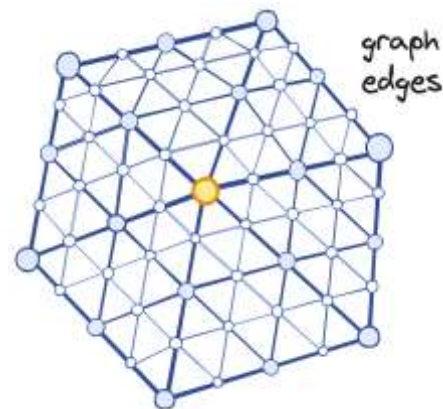
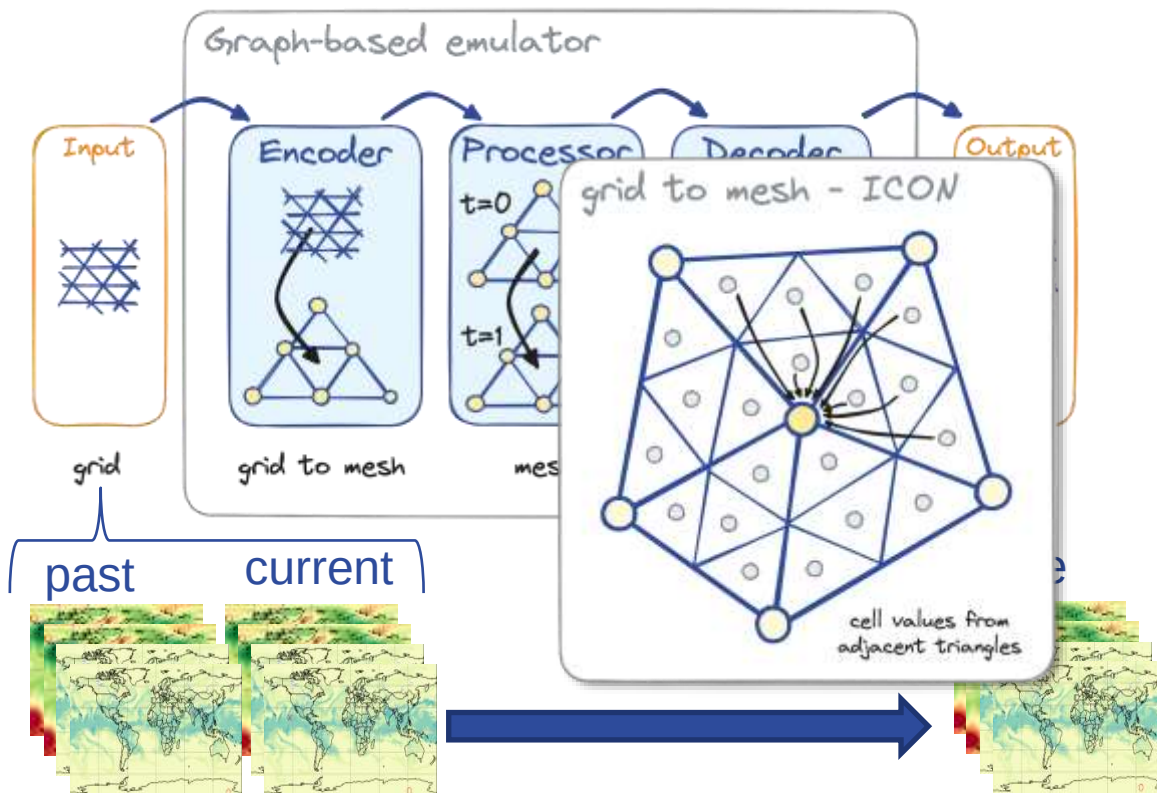


future



figures: Florian Prill, Jan Keller (DWD)

Typical Anemoi architecture: Graph neural network



figures: Florian Prill, Jan Keller (DWD)

- ML complement to ICON NWP
 - Model chain from global to regional
- National sovereignty
 - In-hose production of training data
 - Training on-premises
 - Inference/Forecast production in operational chain
- Leverage the community project
 - Software package
 - Training best practices
 - MLOps exchange

ICON-Global
(13km, up to 180h)

European-Nest
(6.5km, up to 120h)

ICON-D2/RUC
Regional Model
(2.2 km, 48h/14h)

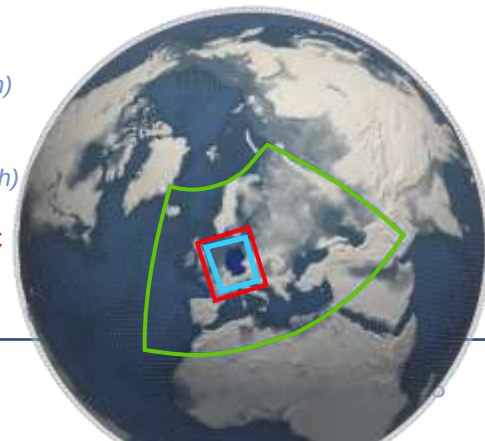
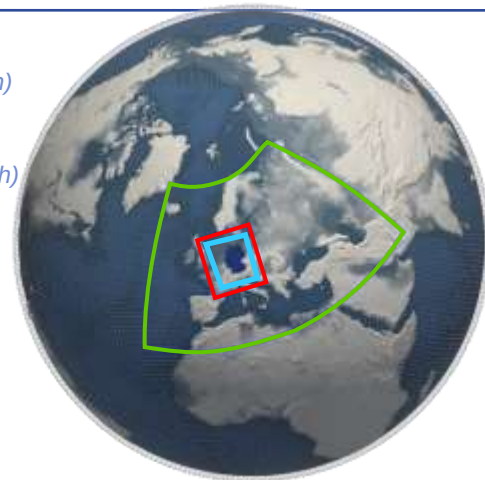
ICON-D05
(500m, 48h)

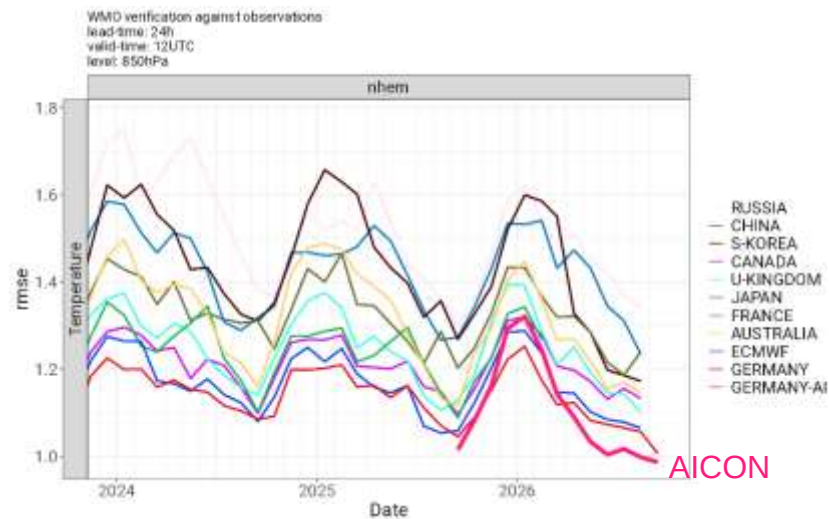


AICON-Global
(13km, up to 180h)

AICON-EU
(6.5km, up to 120h)

AICON-D2/RUC
Regional Model
(2.2 km, 48h/14h)



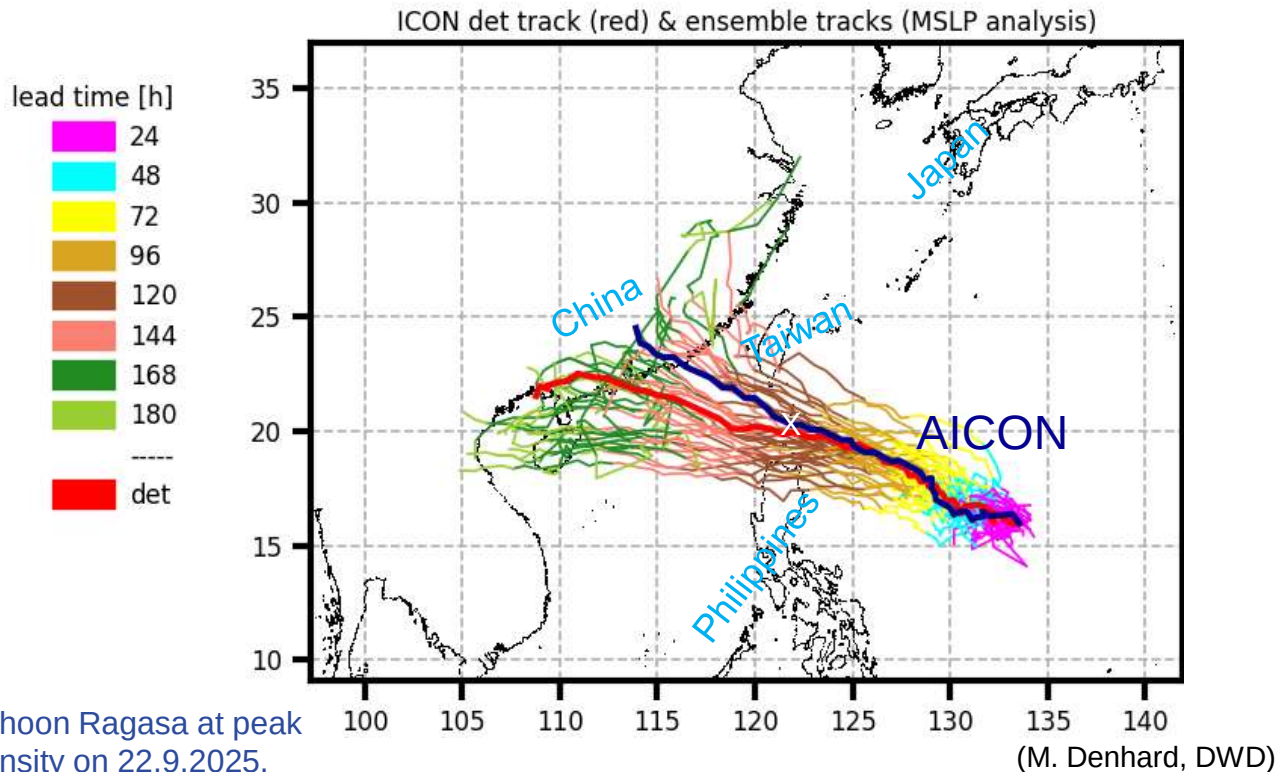


Typhoon Ragasa Init: 18.9.2025 00:00 UTC



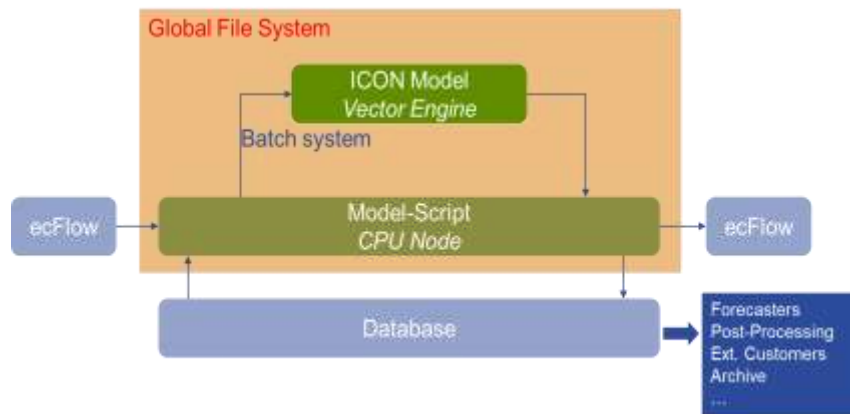
Typhoon Ragasa at peak
intensity on 22.9.2025.

NOAA satellite image

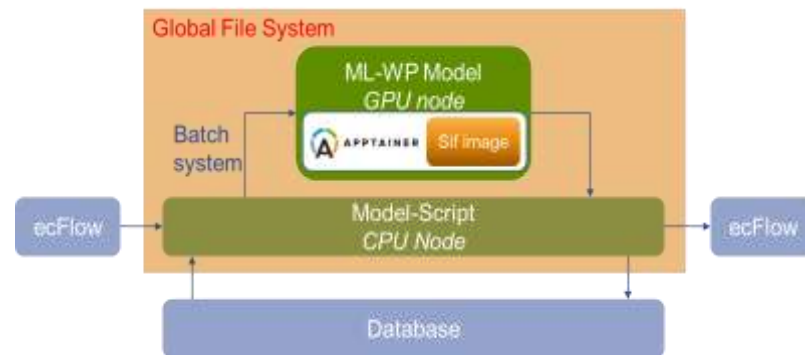


AICON fits seamlessly into the existing process chain of 24/7 numerical weather forecasting.

DWD classical NWP process chain



ML-model process chain



Containerized multi-GPU inference

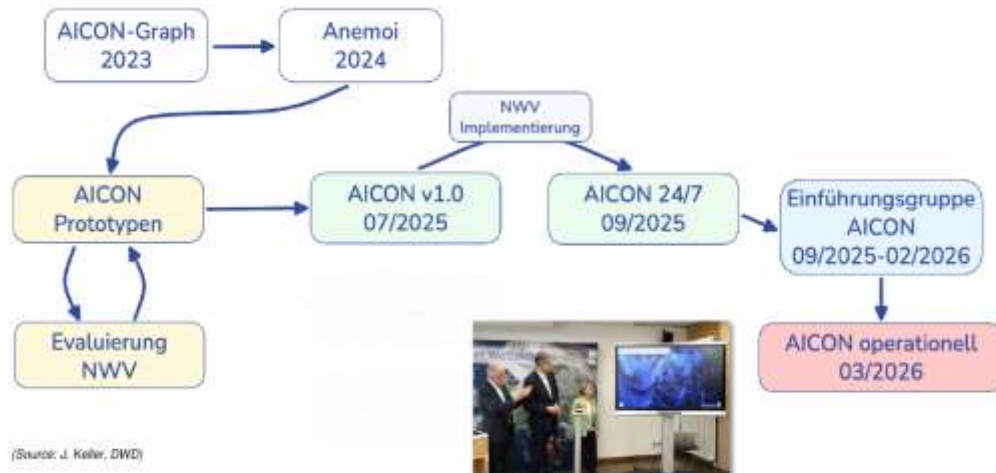
straight deployment into production environment: base layer for meteorological libraries

incl. pre-processing, post-processing (horizontal interpolation, clipping)

- ➔ AICON global became operational in March 2026
- ➔ 24/7 production
- ➔ Evaluated by forecasters

Now:

- ➔ AICON used by forecasters at work place
- ➔ Forecasts distributed to/used by customers
- ➔ Available on opendata.dwd.de for general public





anemoi

AICON

Pillars of AI software development at DWD



**Platform for
AI Language
Applications**



**Meteorological and
Climatological
AI Applications**



AICON

Pillars of AI software development at DWD

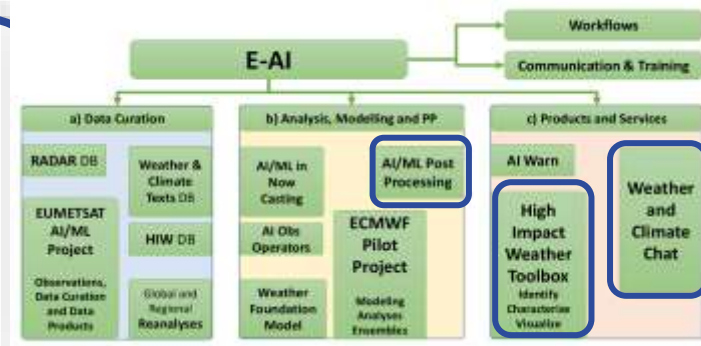
DWD AI Centre within E-AI.



Platform for
AI Language
Applications



Meteorological and
Climatological
AI Applications



Goals of DWD's AI Center

- A **uniform, easy-to-maintain** software architecture for AI/ML
- Implement **sustainable AI solutions** along the entire value chain
- **Coordinate AI developments** and resources within DWD
- Network with national and international **partners, esp. E-AI**



DWD
AI

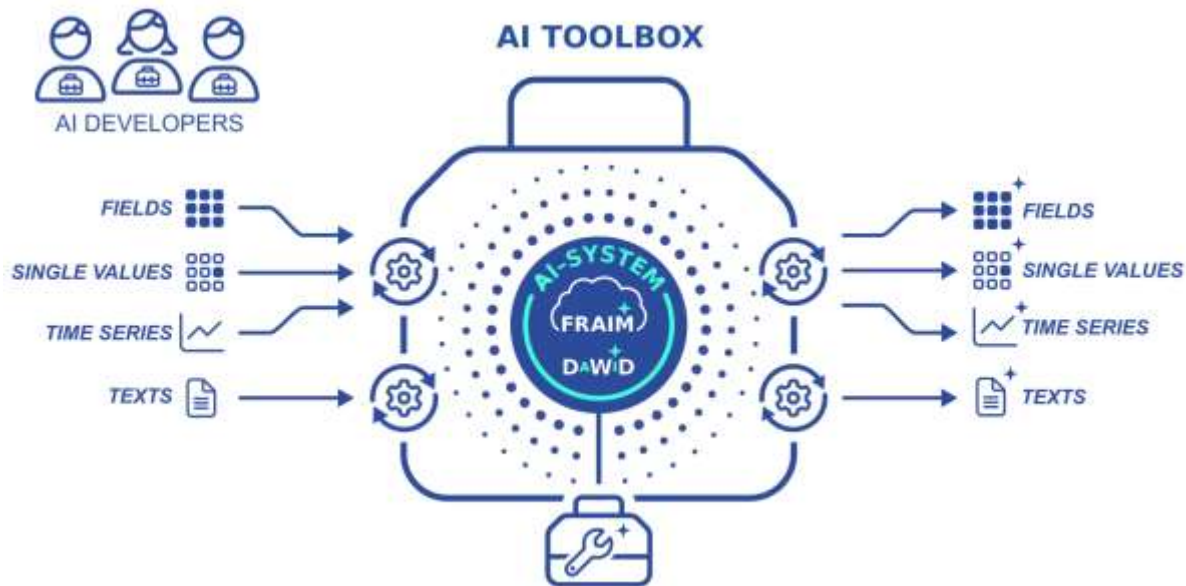
Modular AI toolbox for sustainable AI development

- Focus on **data and data formats** used at DWD
- Focus on **flexibility** and **maintainability** for applications
- Documentation and **knowledge** management
- Close cooperation between **AI and domain experts**



FRamework for
AI in
Meteorology

Goals and Approach



FRAIM

development is use case driven.

Selection of current use cases

- SMAI (Soil Moisture with AI)
- road weather forecasts,

data curation
and organisation

AI models and
training

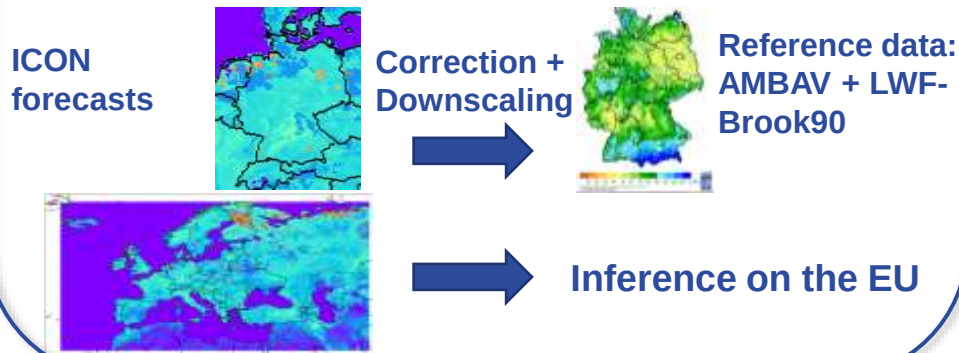
data output
and evaluation

SMAI (Soil Moisture with AI)

Project Goal: High-resolution (hourly, 1x1 km grid) and improved soil moisture forecasts for Germany and the EU

Previously: Forecasts from the DWD's Agricultural Meteorology were available only for Germany and individual stations (AMBAV + LWF-Brook90)

Target product for the EU: Correction and spatial downscaling (from 13 km to 1 km) of the ICON soil moisture forecast



Reference data:

- For agricultural land: **AMBAV** (Agricultural Meteorological Model for Calculating Actual Evaporation)
- For forests: **LWF-Brook90**
 - Soil-Vegetation-Atmosphere Models
 - 1x1 km grid, 10 cm layers at depths of 0–2 m
 - Input: soil parameters
 - Input: meteorological data: SYNOP
 - Modeling evapotranspiration, soil water balance, percolate, and runoff
 - Parameterized for various crop types



Current statistical approach



The new method developed at the DWD's AI Centre provides high-resolution weather information along the entire road network.



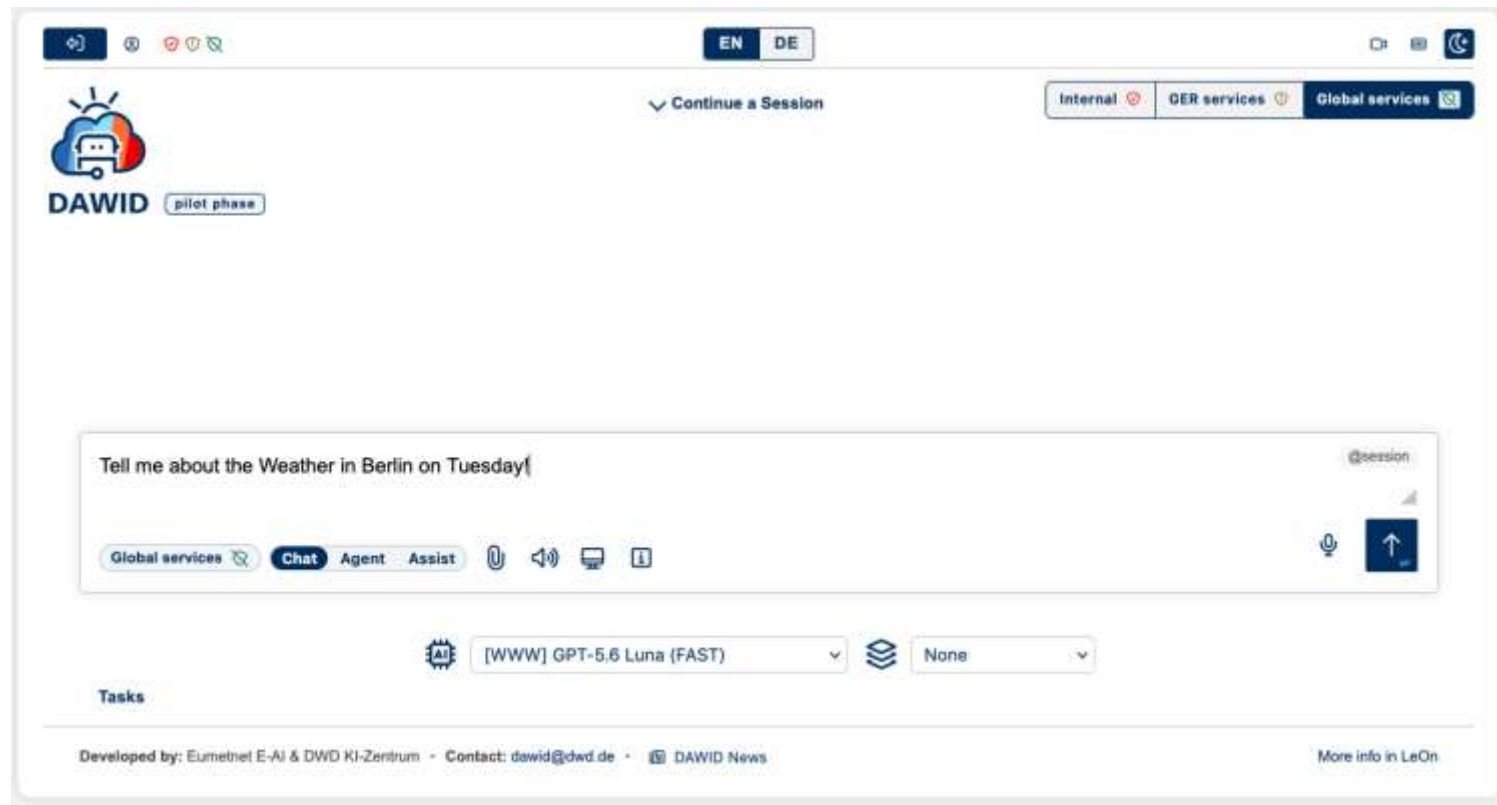
work by Sebastian Brune, Matthias Mages, and Felix Strnad (DWD)

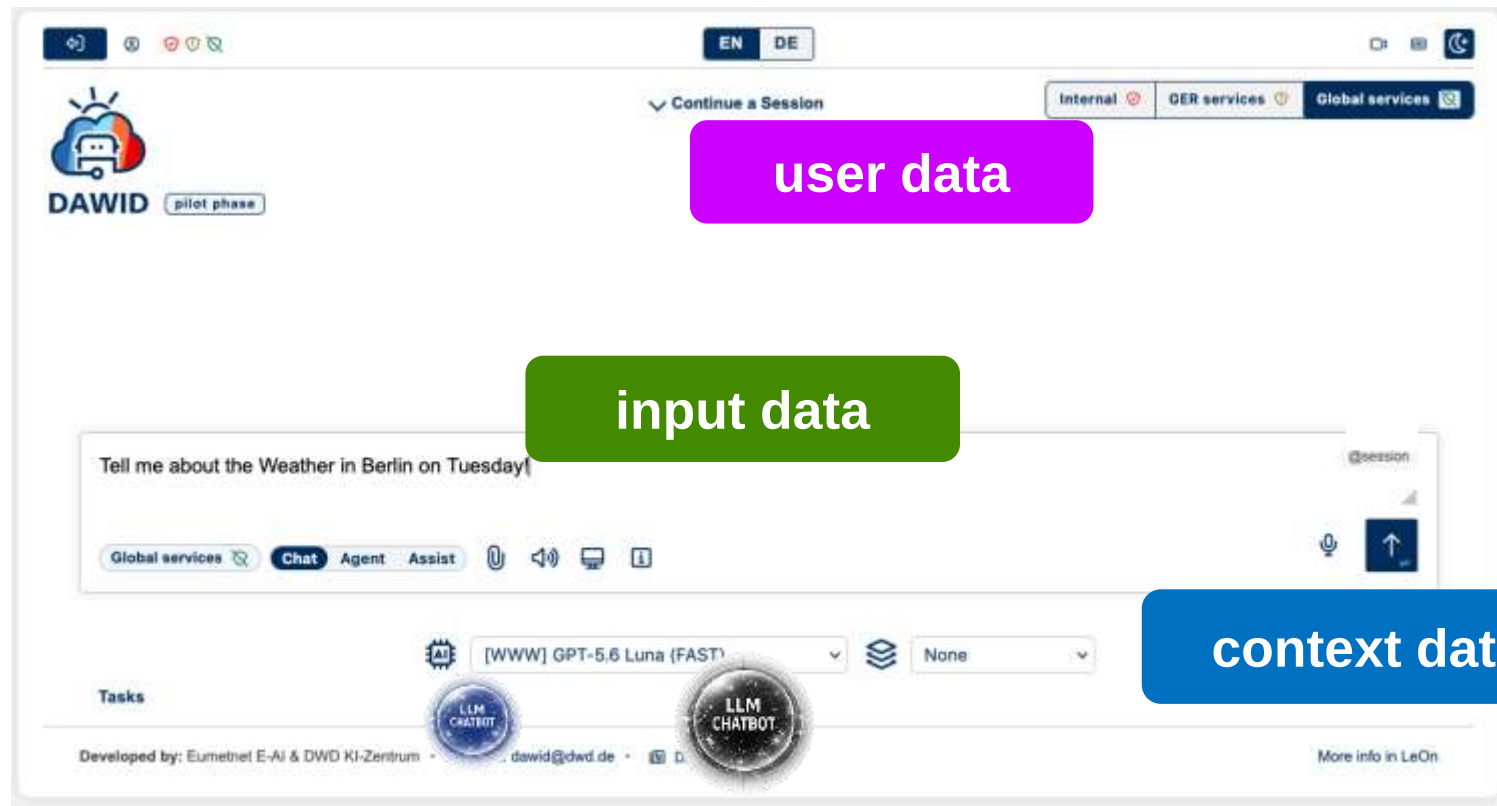


**Platform for
AI Language
Applications**

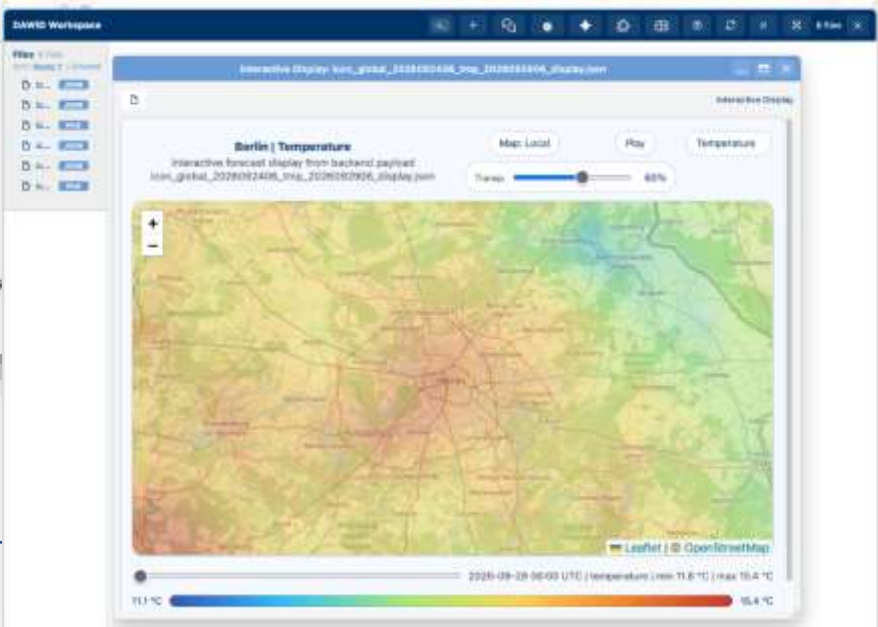
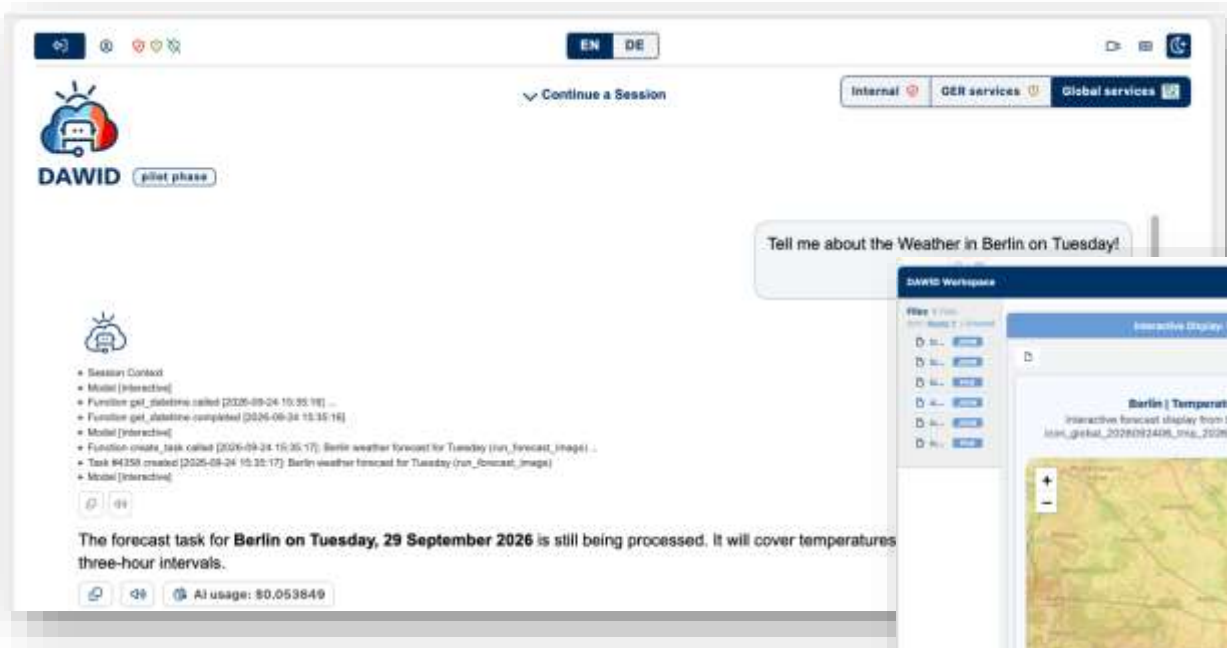
- What is DAWID?
- How is it different from any other chat bot?

Design and Functionality

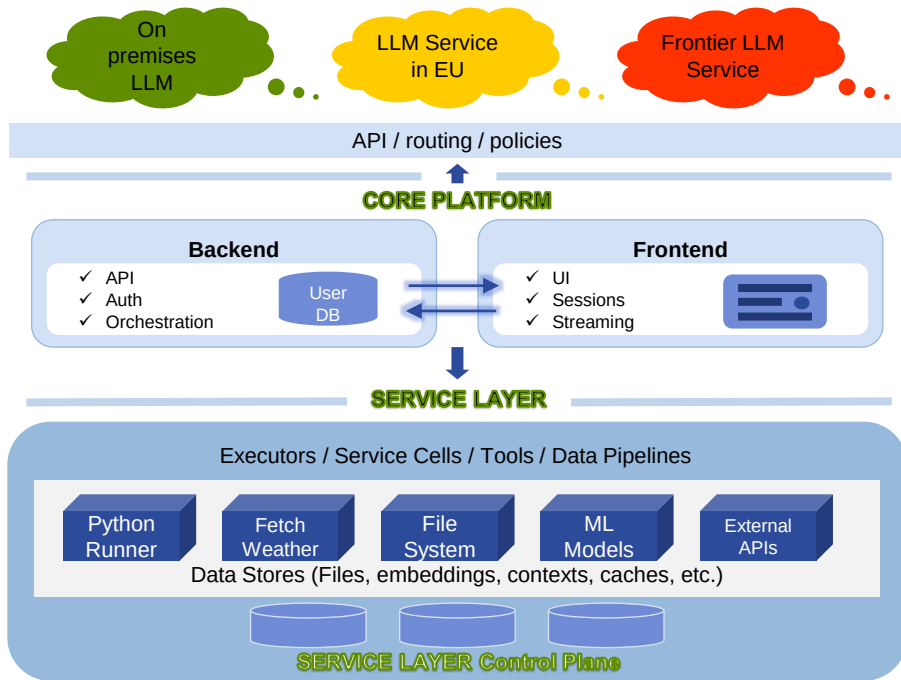




Example Meteorological Data

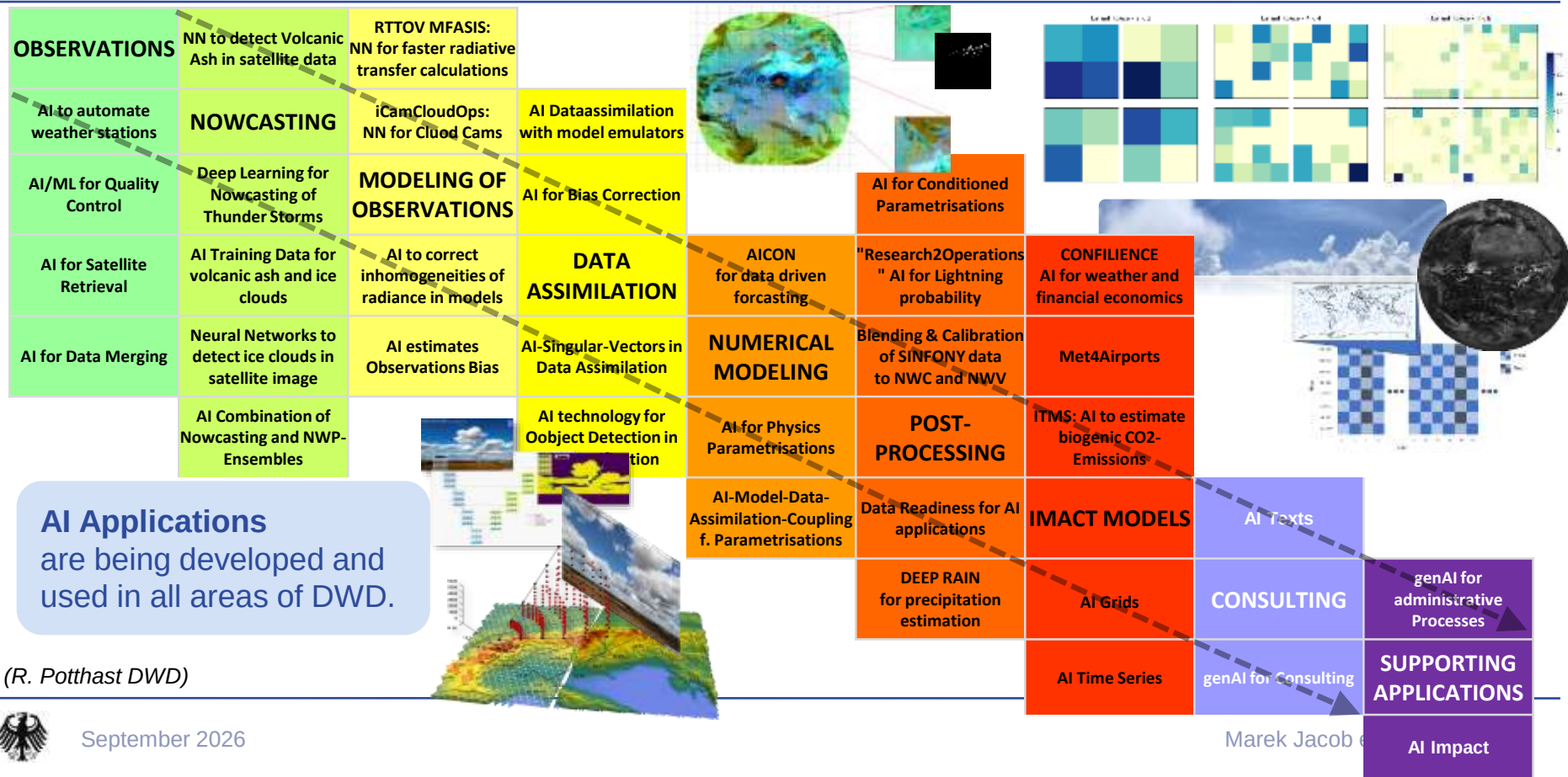


Architecture of DAWID

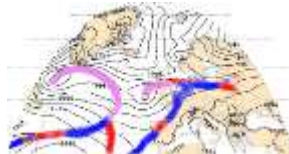


DAWID assistant system architecture with the LLM layer (top), the service layer (bottom), and the core platform layer (middle), which orchestrates the interaction between the two layers.

AI all along the value chain



- ML-Weather Prediction and AICON
- DWD is developing a modular AI toolbox for sustainable AI development
- DWD leverages generic LLMs for customized internal AI agents



- Big-Tech is not insuperable



- Public agencies and European Centres can enhance their collaboration by developing under open-source licences

Thanks for your attention 😊