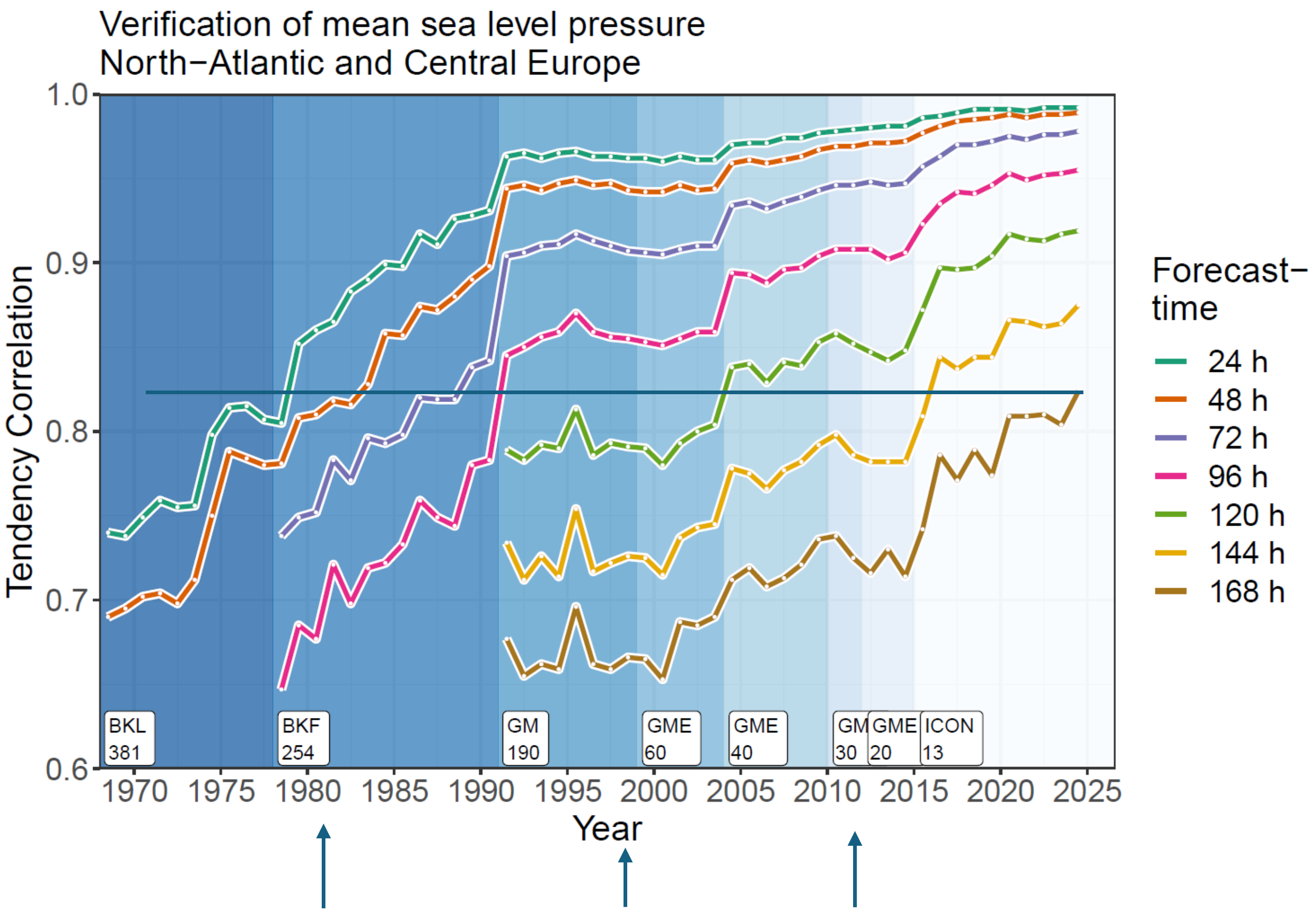
Following 50 Years of the Evolution of Numerical Weather Prediction from my personal perspective

Gerhard Adrian

My career in Meteorology / Development of NWP scores of the German Weather Service (DWD)



1981
Meteorology Diploma

1999
joined DWD

2010-2023
PR with WMO

Where did our predecessors come from?

- V. Bjerknes (1904): Das Problem der Wettervorhersage betrachtet vom Standpunkt der Mechanik und der Physik. Met. Zeitschr. 21 (1-7)
  - *The problem of weather forecasting as a problem in mechanics and physics (Translation by Y. Mintz. Los Angeles 1954)*
- Necessary and sufficient conditions for the rational solution of forecasting problems:
  1. A sufficiently accurate knowledge of the state of the atmosphere at the initial time
  2. A sufficiently accurate knowledge of the laws according to which one state of the atmosphere develops from the other

Open question: How to reduce the complexity of the problem of weather forecasting?

Bjerkness‘ approach (1911): graphical methods on the basis of approximations of the Navier-Stokes equations (synoptic meteorology)

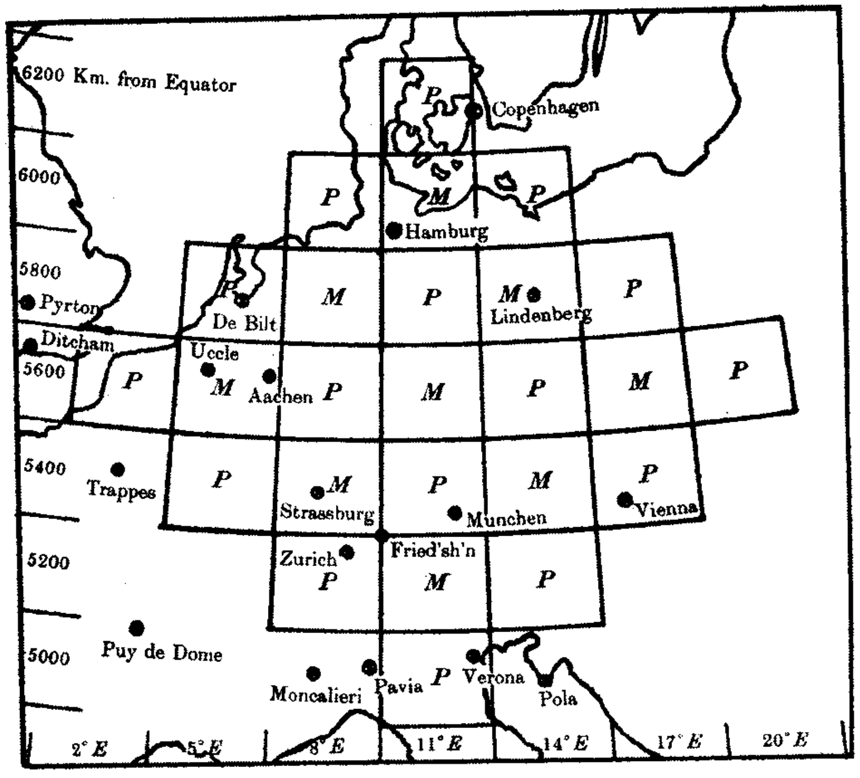
- Weather charts on main pressure levels
- Adaptation of the global observing system to this concept

Richardson‘s approach (1922): numerical approximation of the differential equations

- Noise filter to reduce the stability constraints (still actual discussion)
- Choice of variables (momentum versus angular momentum)
- Numerical approximations

The beginning of NWP

- L. F. Richardson (1922) Weather prediction by numerical process. Cambridge University Press
- IMO established an International Commission on Scientific Aeronautics (ICSA) on its Conference 1896 in Paris with the task
    - *To co-ordinate regular upper air observations on „international aerological days“ (one day per month)*



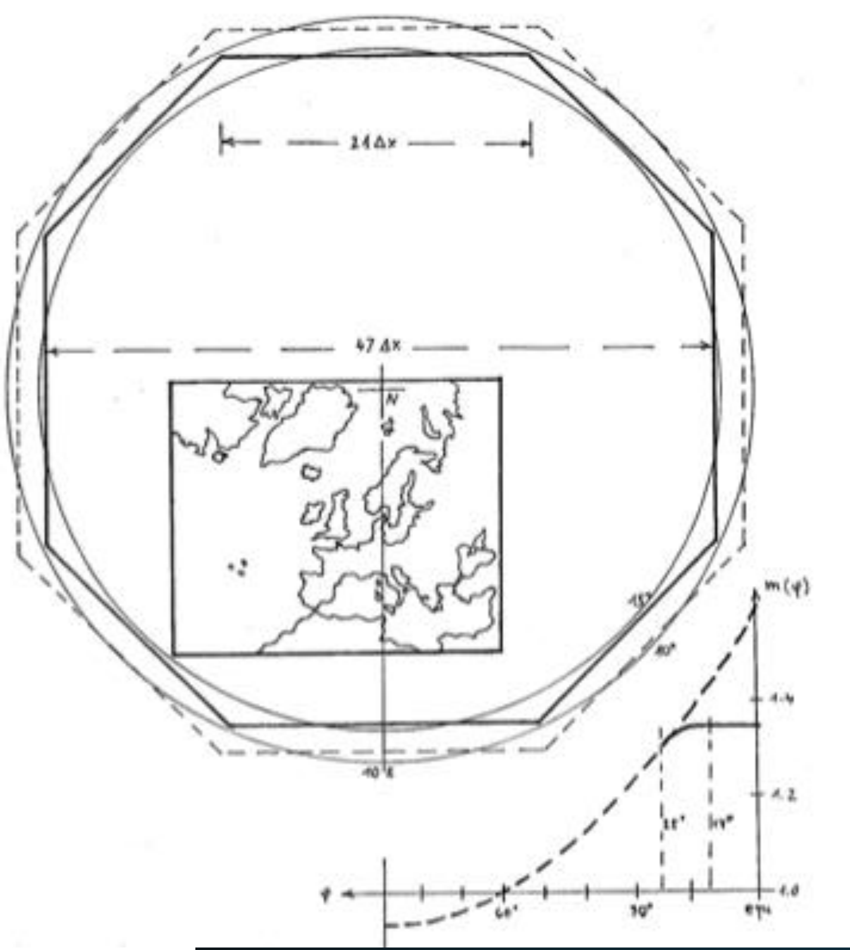
Richardson‘s model formulation

- three dimensional numerical model
- Hydrostatic filtered
- Primitive variables
- Pressure as the vertical coordinate
- Flow dependent turbulence parameterization („Richardson number“)

First barotrope and barocline models in DWD (1966-1990)

- Hemispheric model
- Barotrope model
  - 381 km grid size
  - Forecast range 48 hours
- Barocline model from 1978
  - with moisture and orography
  - 254 km grid size and 6 layers

(H. Reiser 2000)



1990-1999 nested NWP system GM, EM, DM

Global spectral model from ECMWF

- Challenged the available human ressources for maintenance (200 km horizontal grid size)

Limited area, hydrostatic model EM/ DM

- EM („european model“) grid size 55 km

DM („Deutschland model“) grid size 14 km

SM - Fruitful co-operation with Meteo Swiss

EM/DM was later migrated also to „PC“-based computing systems under the name „High Resolution Model“ HRM and offered to NMHs of developing coutries

New demands on the NWP system

Most severe weather phenomena are often caused by deep convection

- Simulation of deep convection

New computer architecture from shared memory systems to massive parallel systems with distributed memory

- Impact on internal data structures

Reduction of maintenance costs

- From three nested forecast systems to two

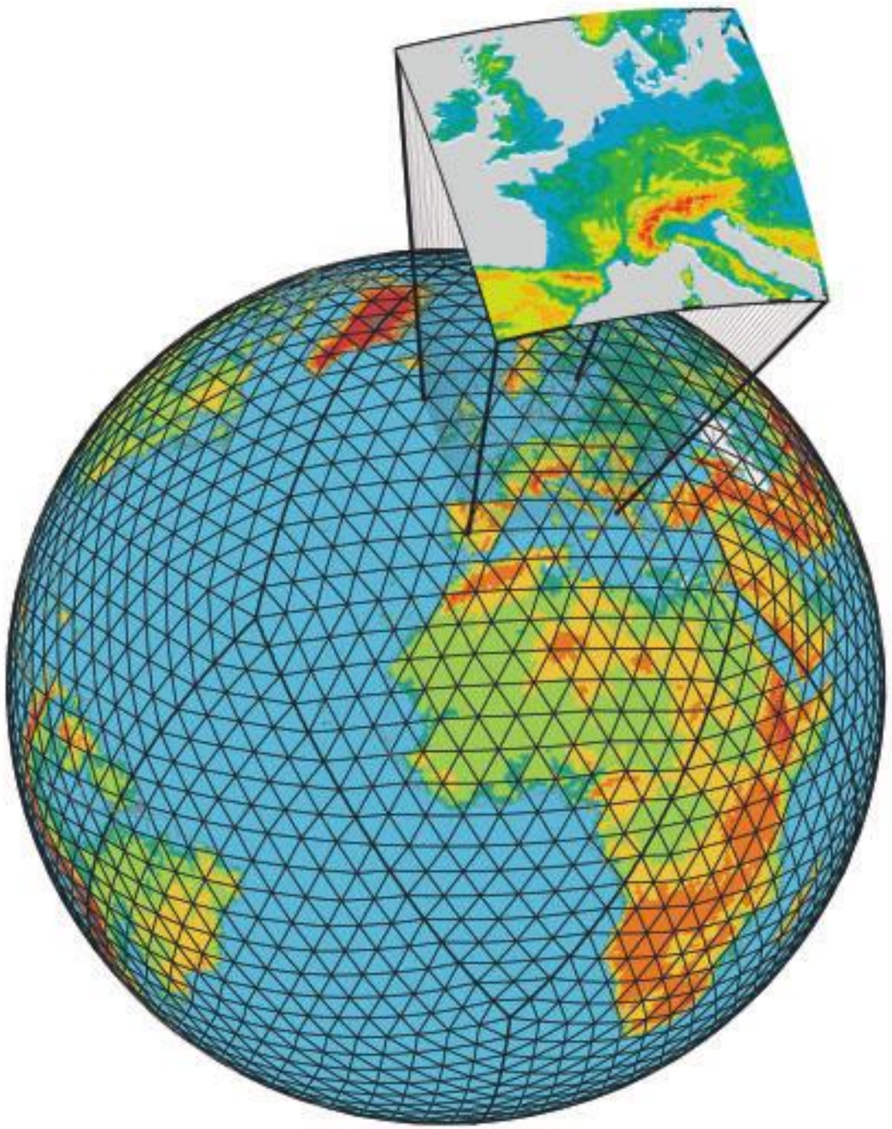
Decision to develop a hydrostatic global model and a non-hydrostatic limited area model

The NWP Systems GME and LM (1999)

- GME to replace the global model with the grid size of the previous limited area model EM

- A new nonhydrostatic „Local Model“ LM allowing direct simulation of deep convection

- The system became operational on 1st December 1999, 24 days before the disastrous winter storms causing severe damages in France and Germany



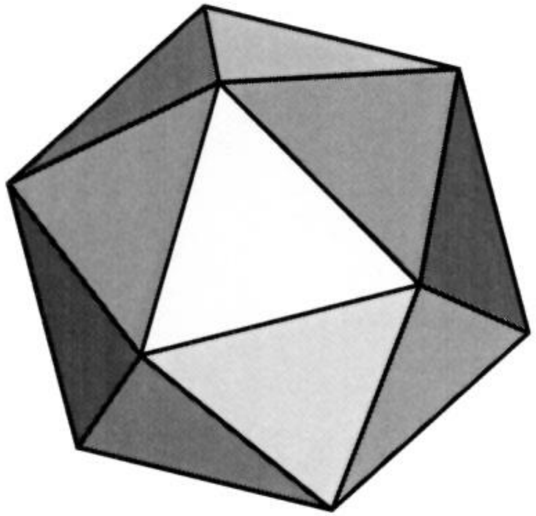
The global model GME

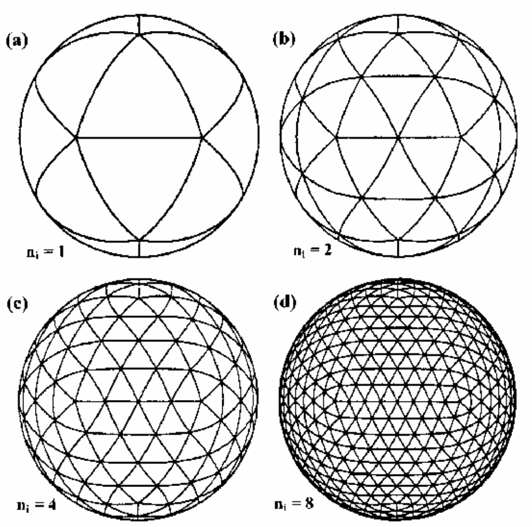
- Icosahedral grid
- Hydrostatic model

- Finite differences/volumes formulated on the hexagons and 12 pentagons

- Flexibal configuration of the data structures in the code

- high scalability on massive parallel computers.

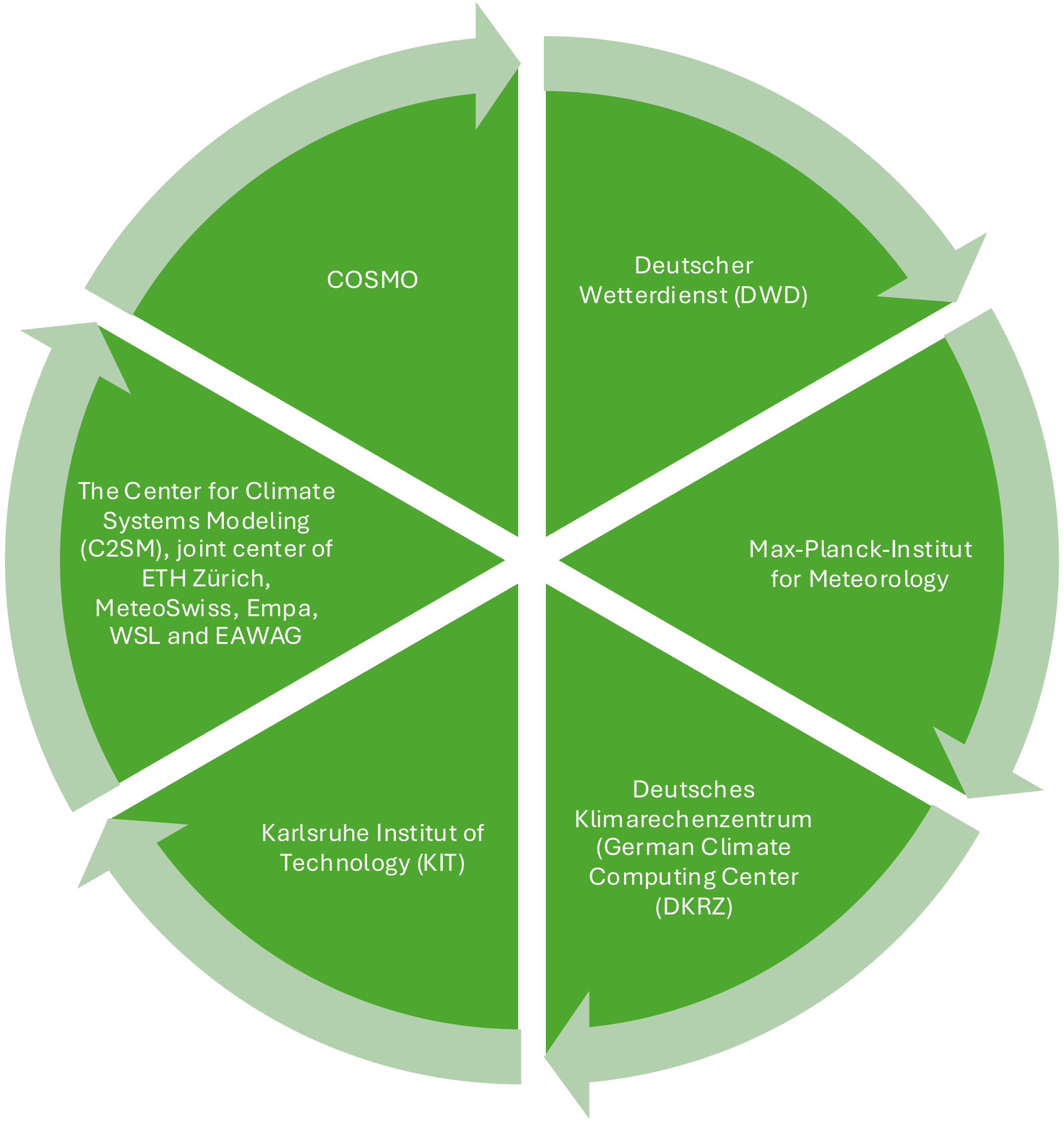




The ICON (ICOsahedral Non-hydrostatic) modelling framework

- Co-operation between DWD and MPI for Meteorology
- Unified system for NWP and climate modelling
- Exact local mass conservation
- Mass-consistent tracer transport
- Flexible grid nesting capability
- Non-hydrostatic equations
- available under a permissive open source licence (BSD-3C)
- https://icon-model.org

ICON Partners



Open Source

ICON is available under a permissive open source license (BSD-3C) (https://icon-model.org)

ICON is used

for global and regional weather forecasts, climate prediction

for research by many academic and operational partner organisations contributing

- Ocean, cryosphere, carbon cycle, air chemistry, air pollution as part of the release
- Standardized Community Interface for additional plug-ins
- ICON-LAM is used by 10 NMHS for operational services

ICON Partners

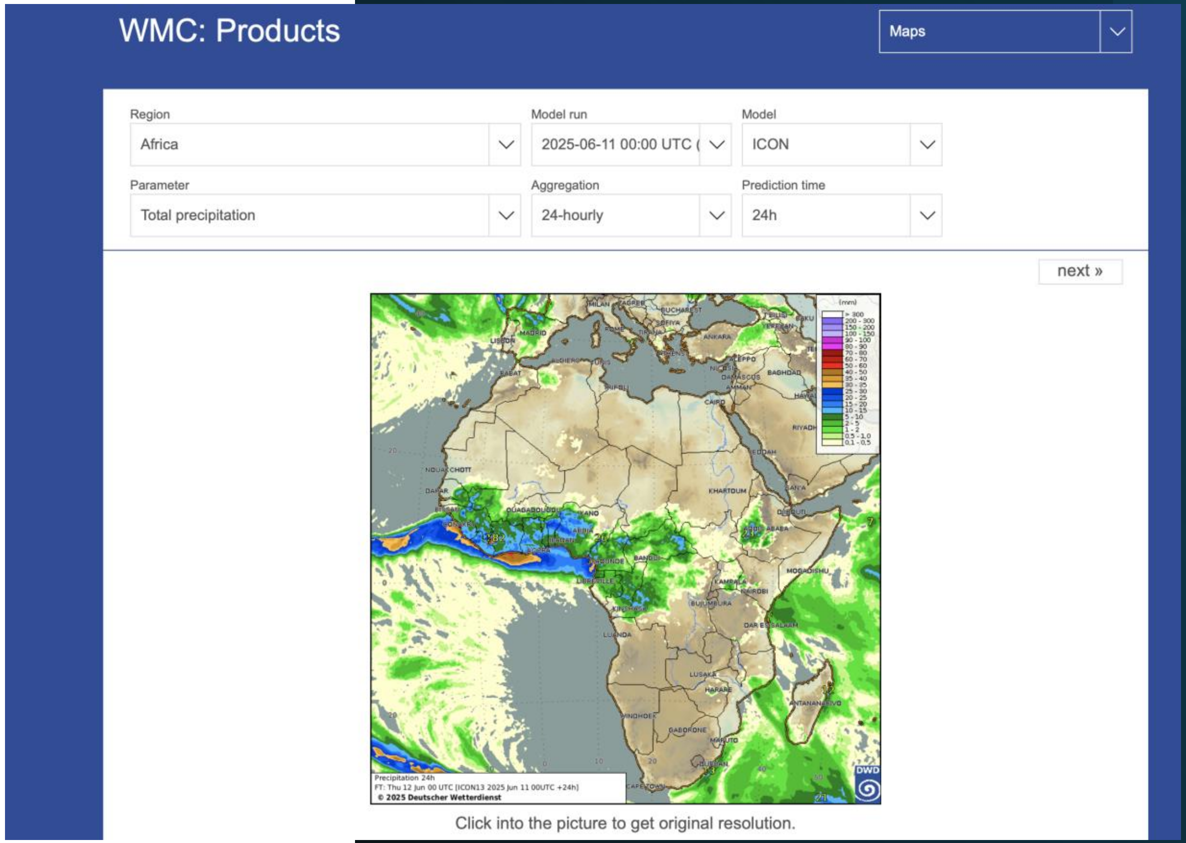
DWD, Max Planck Institut for Meteorology, German Climate Computing Centre,, Karlsruhe Institute for Technolgy, Center for Climate System Modeling

provide various tutorials, training courses and material online

COSMO Partners are offering support, additional software (verification, data assimilation) and services (initial and boundary data) for national meteorological and hydrological services (NMHS) to run ICON-LAM

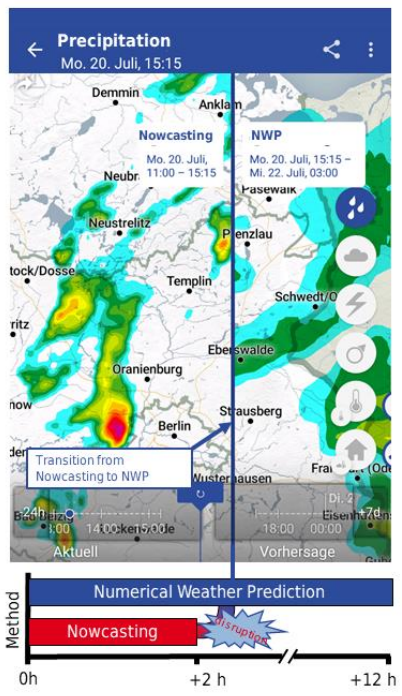
Open Data

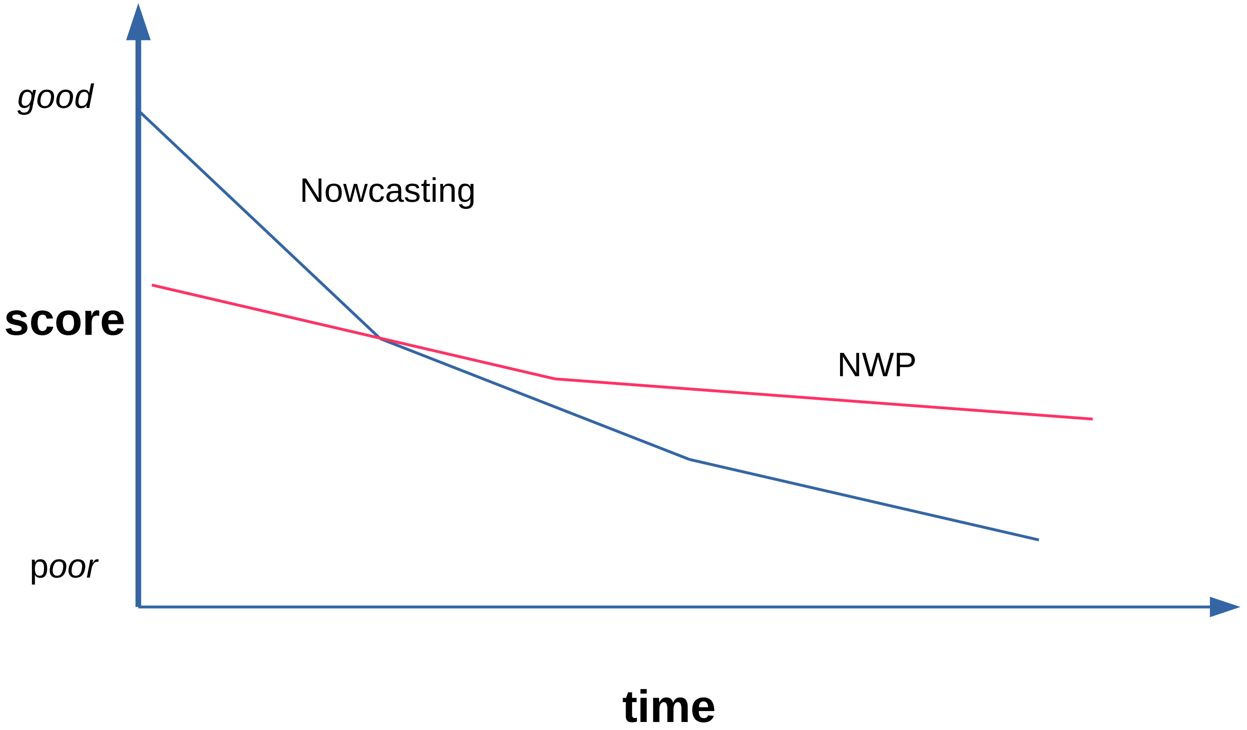
- “Provision of spatial data and spatial data services of DWD are free of charge … “(DWD Act section 6(2a) 2024) (https://opendata.dwd.de)
- DWD is committed as WMO World Meteorological Center (https://www.dwd.de/WMC)



Integration of NWP into the Weather Forecasting Process

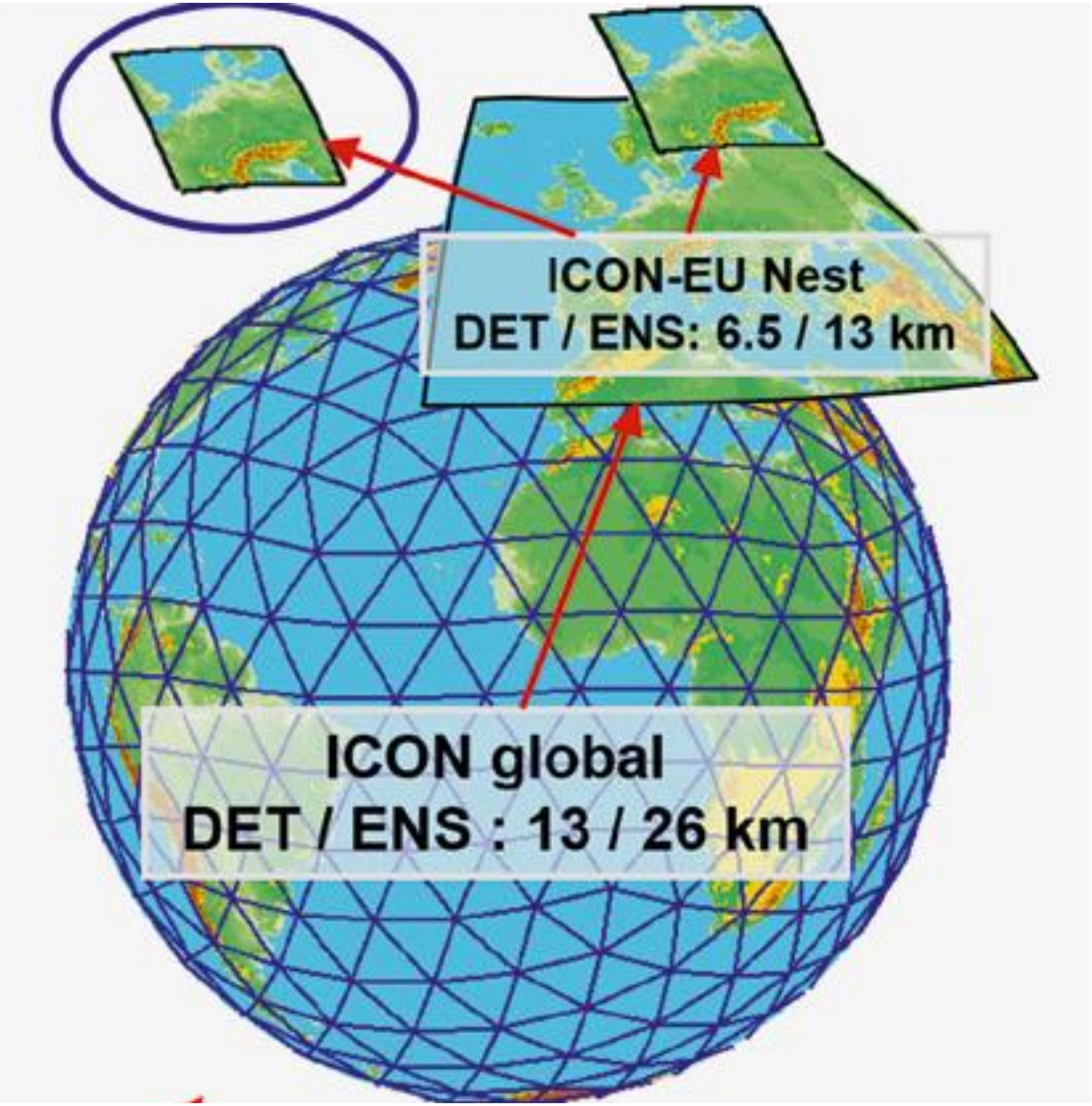
Challenge to avoid the discontinuity between Nowcasting and NWP forecasts





SINFONY (Seamless INtegrated FOrecastiNg sYstem)
(U. Blahak)

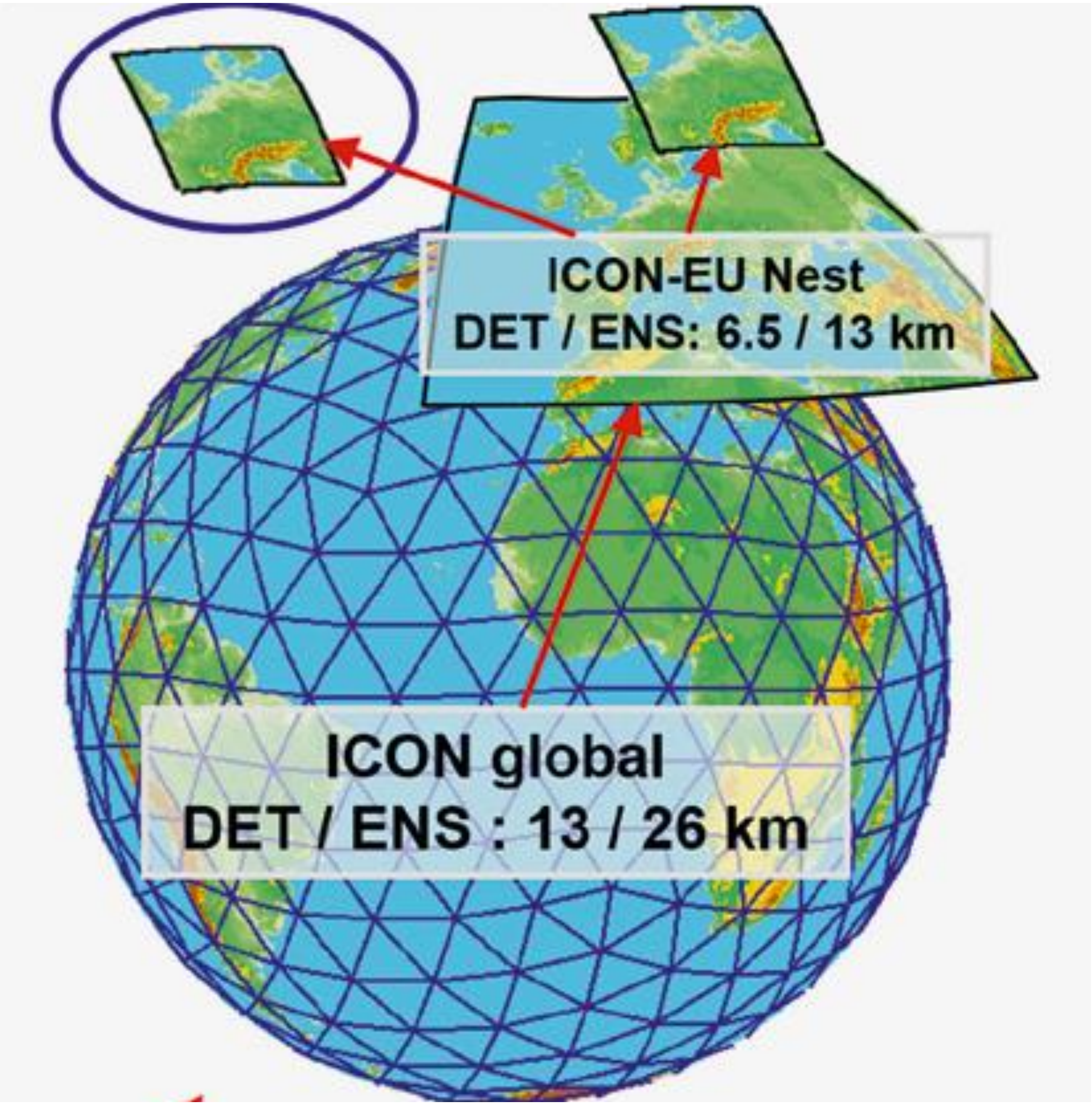
- The challenge from the NWP perspective
  - The NWP is older than the Nowcasting
    - Time for delivering the final NWP products to the users 2 hours,
    - Production cycle 3 hours
  - The NWP uses different (older) observations



ICON in a Rapid Update Cycle (RUC)

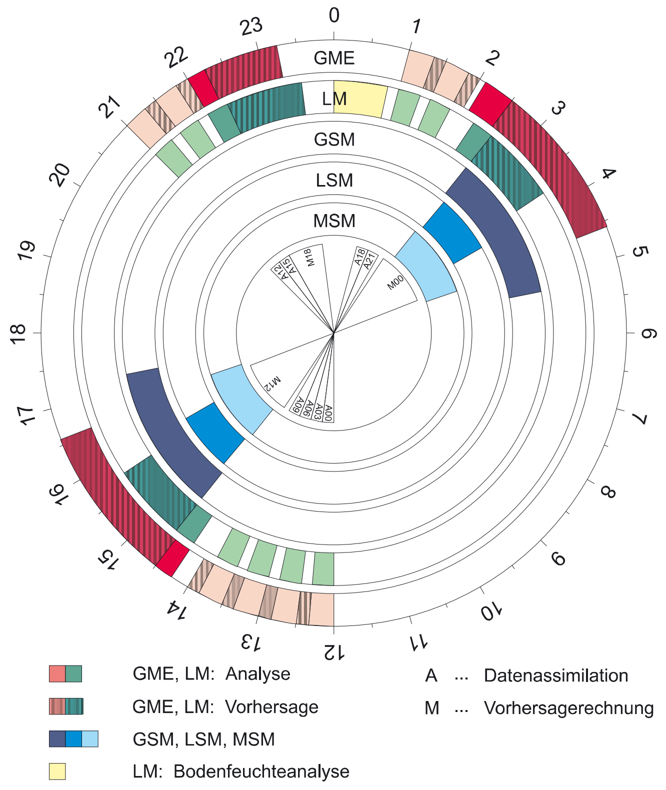
- Grid size 2 km
- Ensemble 20 members (40 for data assimilation)
- Forecast range 14 hours
- 1 hour cycle
- Products available to users after 40 min

- Remote sensing observations
    - Radar volume scans wind, reflectivity
- Satellite data
    - MSG-SEVERI
        - 0,6 µm water- and ice clouds
        - 2 IR channels water vapour and clouds
- Foreward operators also used for visualisation

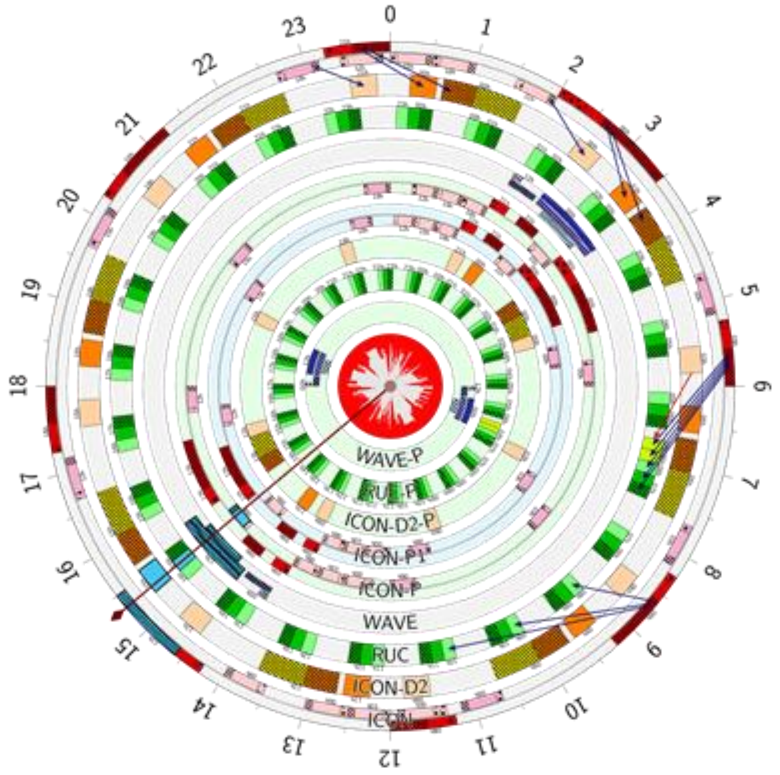


Operational schedule

2022



2025



RAINBOW (K. Feige)
Risk-based, **A**pplication-oriented and **I**ndividualizable of **O**ptimized **W**eather warnings

Seamless warnings, from immediate to a warning trend covering up to 7 days

Communication of forecast uncertainty

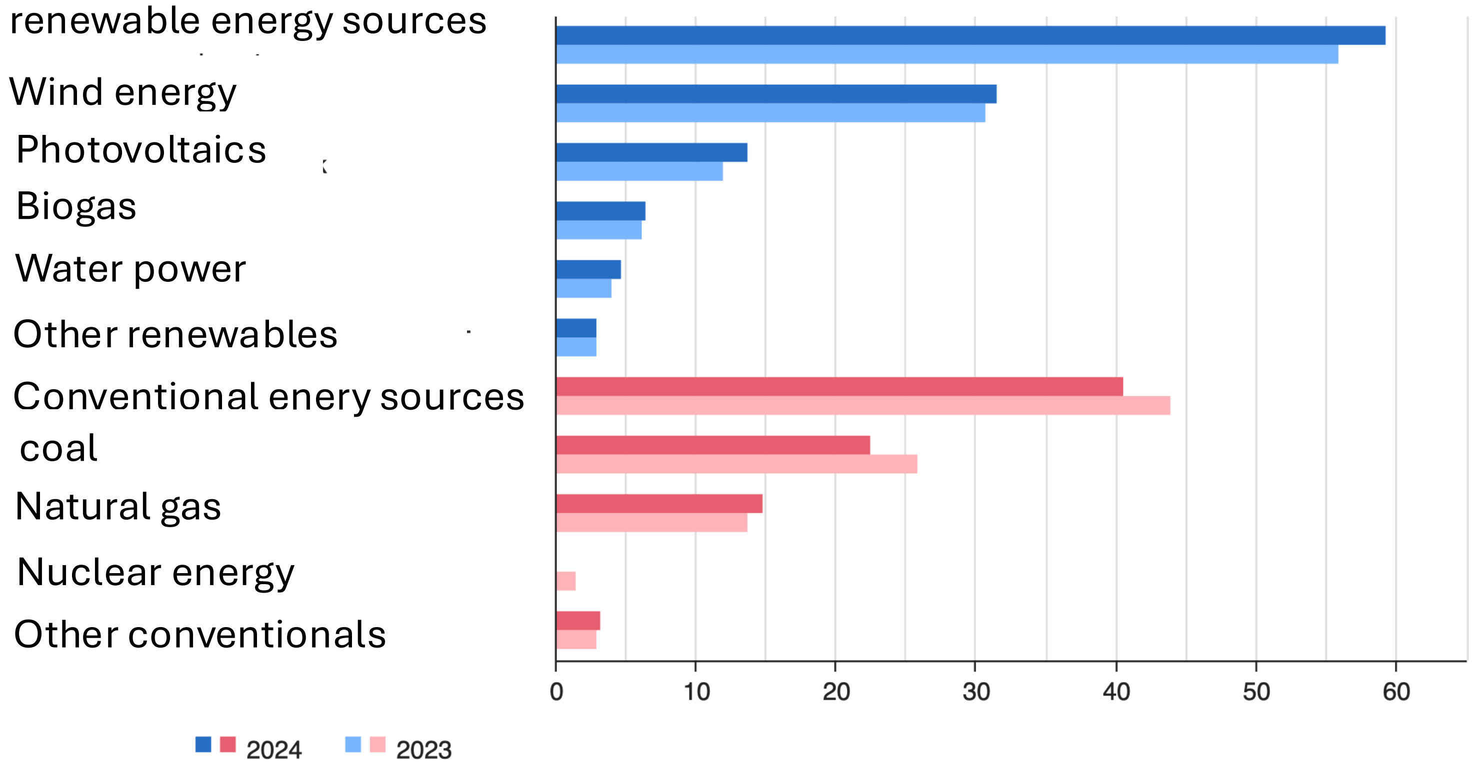
Interactive configuration of warning profiles depending on users‘ applications

- Disaster management, road maintenance, industry, infrastructure institutions, water management and flood forecasting, …

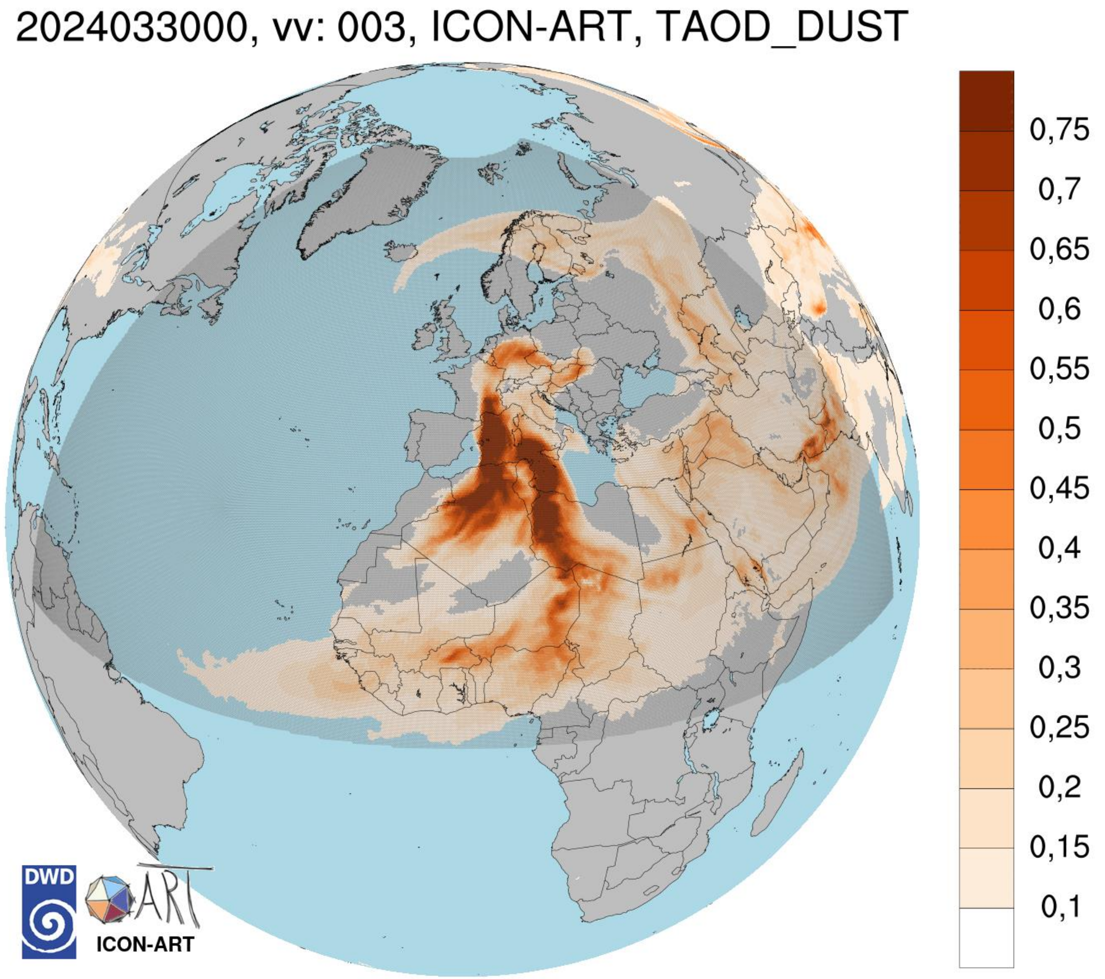
Electric power supply in Germany in 2024

- 59,4% (256 TWh) from renewables
- 31,5% (136 TWh) Wind
- 10,4% (59,5 TWh) Photovoltaic

Electric power supply by renewable and conventional energy sources in %

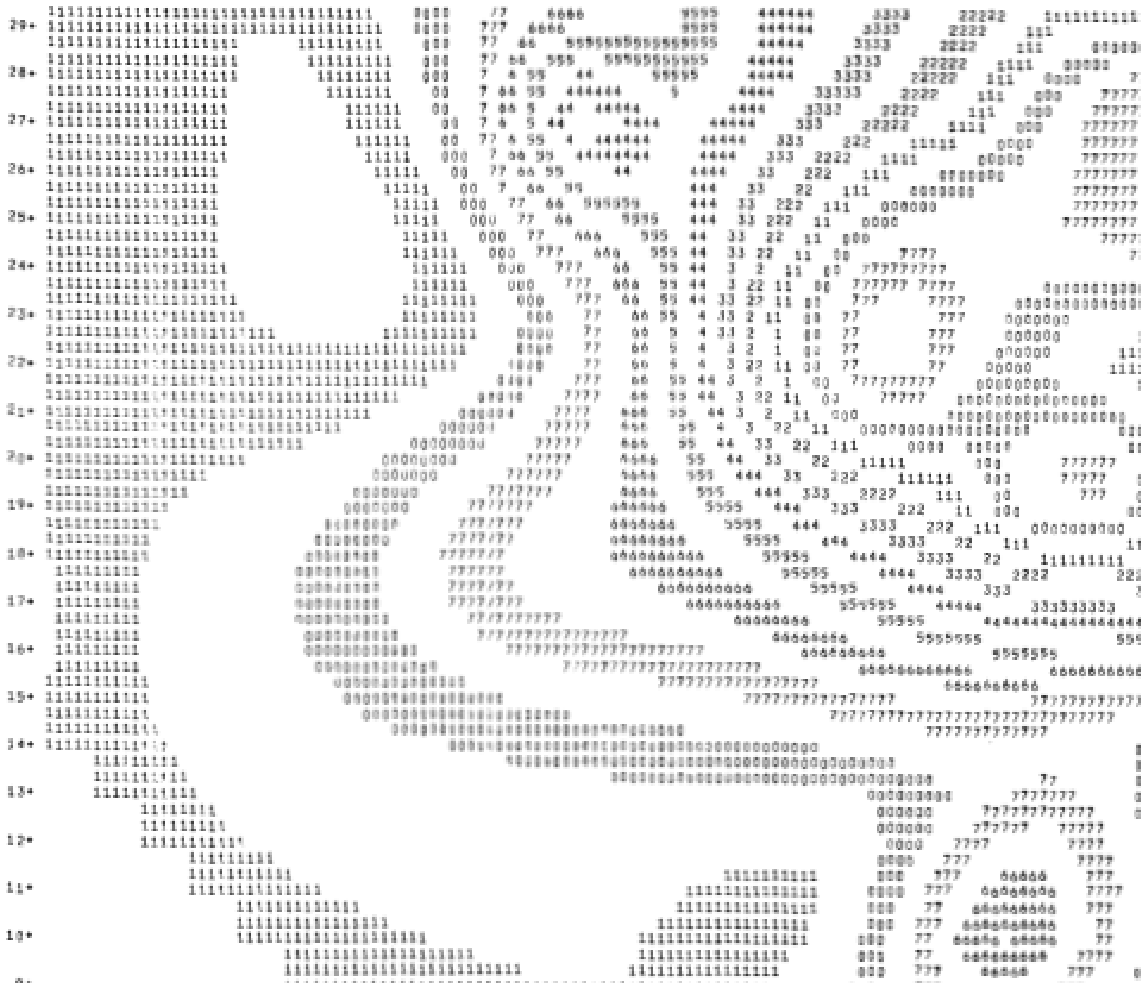


Forecast of Saharan dust (U. Blahak)



Factors of success

1975



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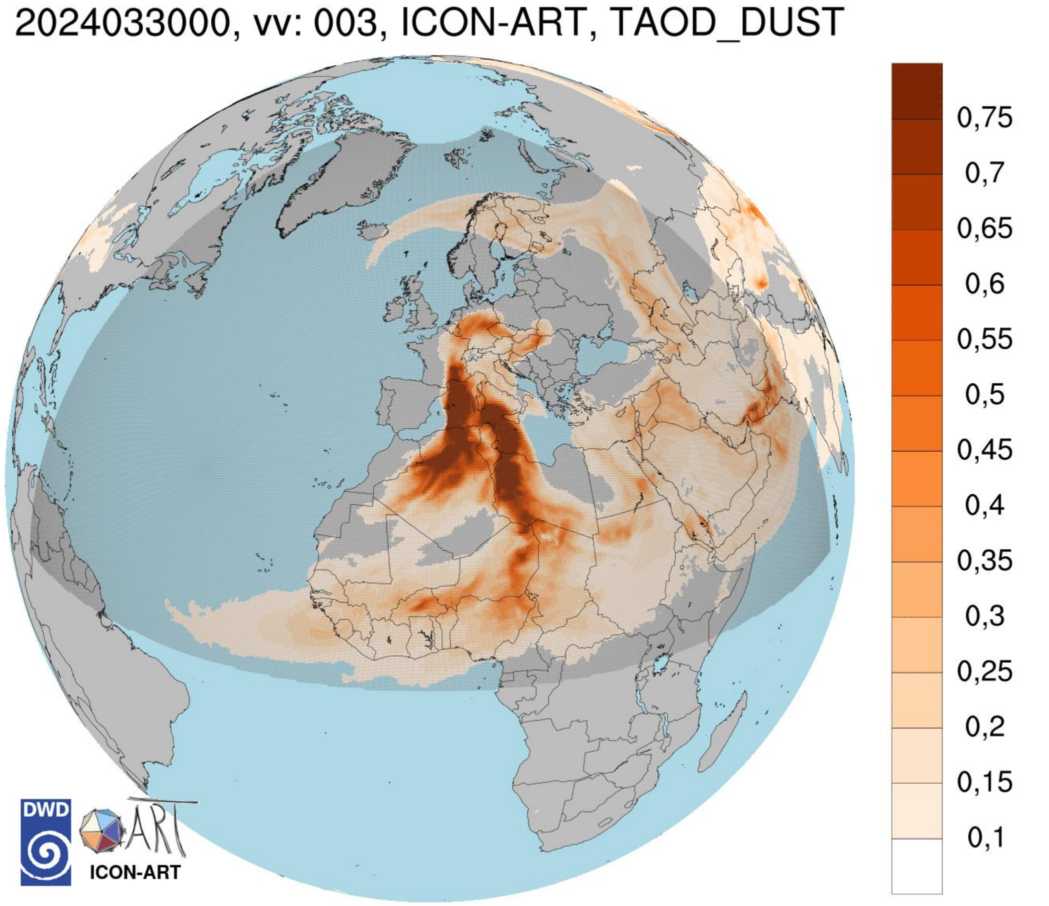

Success Factor WMO

A globally co-ordinated observing system (World Weather Watch)

- Resolution 2 (Cg-Ext(2021)) Global Basic Observing Network (GBON)
- Resolution 3 (Cg-Ext(2021)) Systematic Observations Financing Facility (SOFF)

Free and open international exchange of data

- Resolution 1 (Cg-Ext(2021)) WMO Unified Policy for the International Exchange of Earth System Data

Necessary standards and infrastructure for observations and data exchange (WIS, WIGOS, WIPPS)

Success Factor – international and national collaboration

Collaboration between NMHSs and their national partners

- Making ICON available under open source has opened partnerships with an growing interdisciplinary community

Collaboration with intergovernmental organisations

- ECMWF with 23 member states (established in 1973)
- EUMETSAT with 30 member states (established in 1986)
- EU (Copernicus Program)

Thank you to all who supported me during the last 50 years