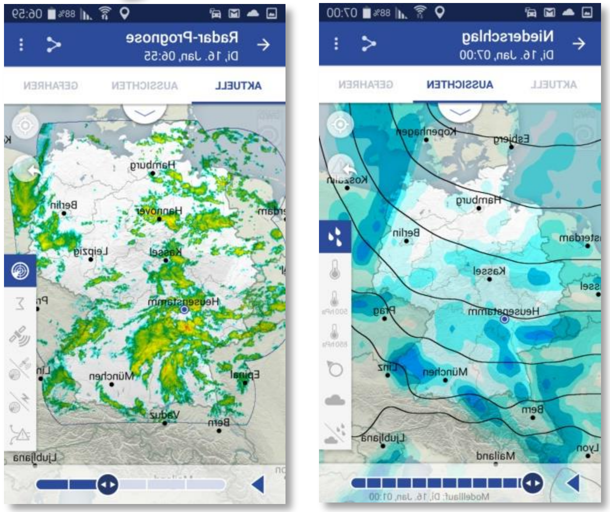
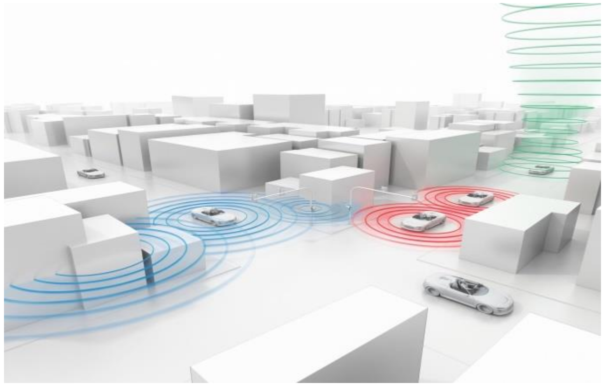
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Data Assimilation
From Minutes to Days

Roland Potthast
NWP @ DWD





Roland Potthast, Uli Blahak and Team, Febuary 9, 2018 at RIKEN Data Assimilation Seminar

Contents

1. Classical **Data Assimilation**

2. **SINFONY Project**: NWC + NWP Ensemble Prediction Systems, RADAR and Rapid Update Cycles (RUC)

3. **Real Time Weather** (Ultra Rapid Data Assimilation) based on the LETKF

Contents

Numerical Weather Prediction
Framework

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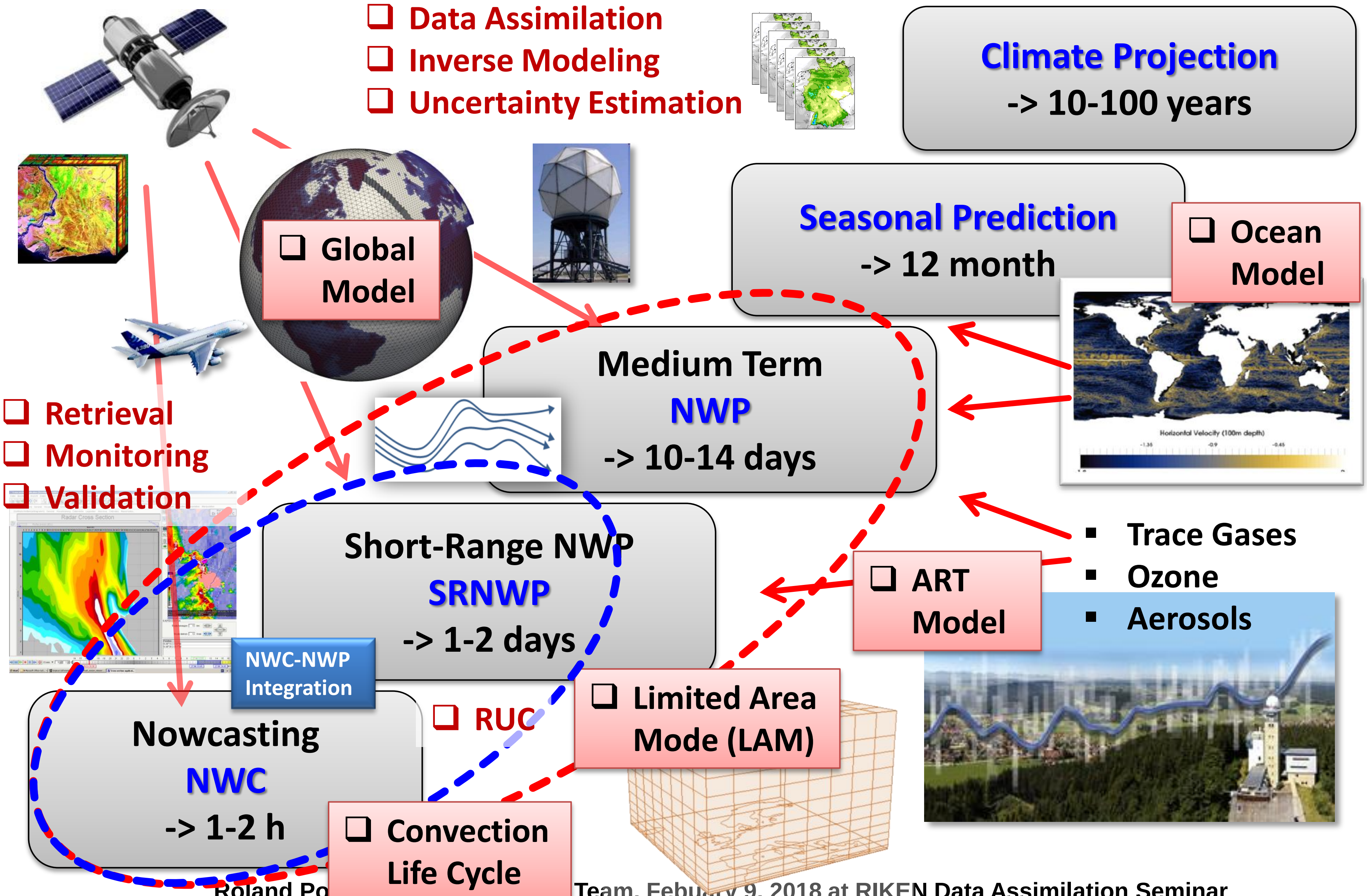

Operational NWP

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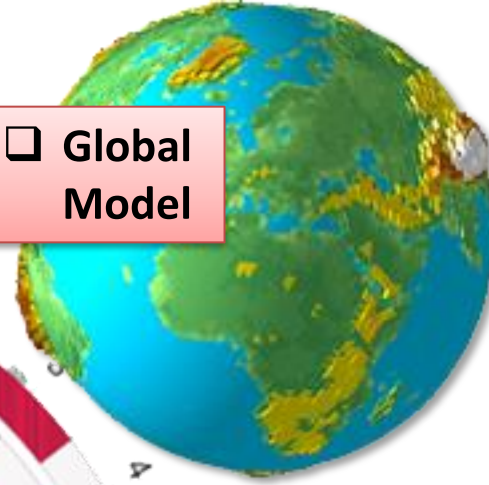
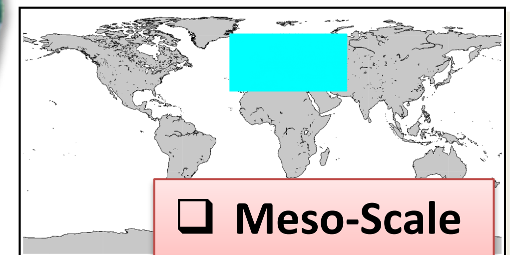
DWD

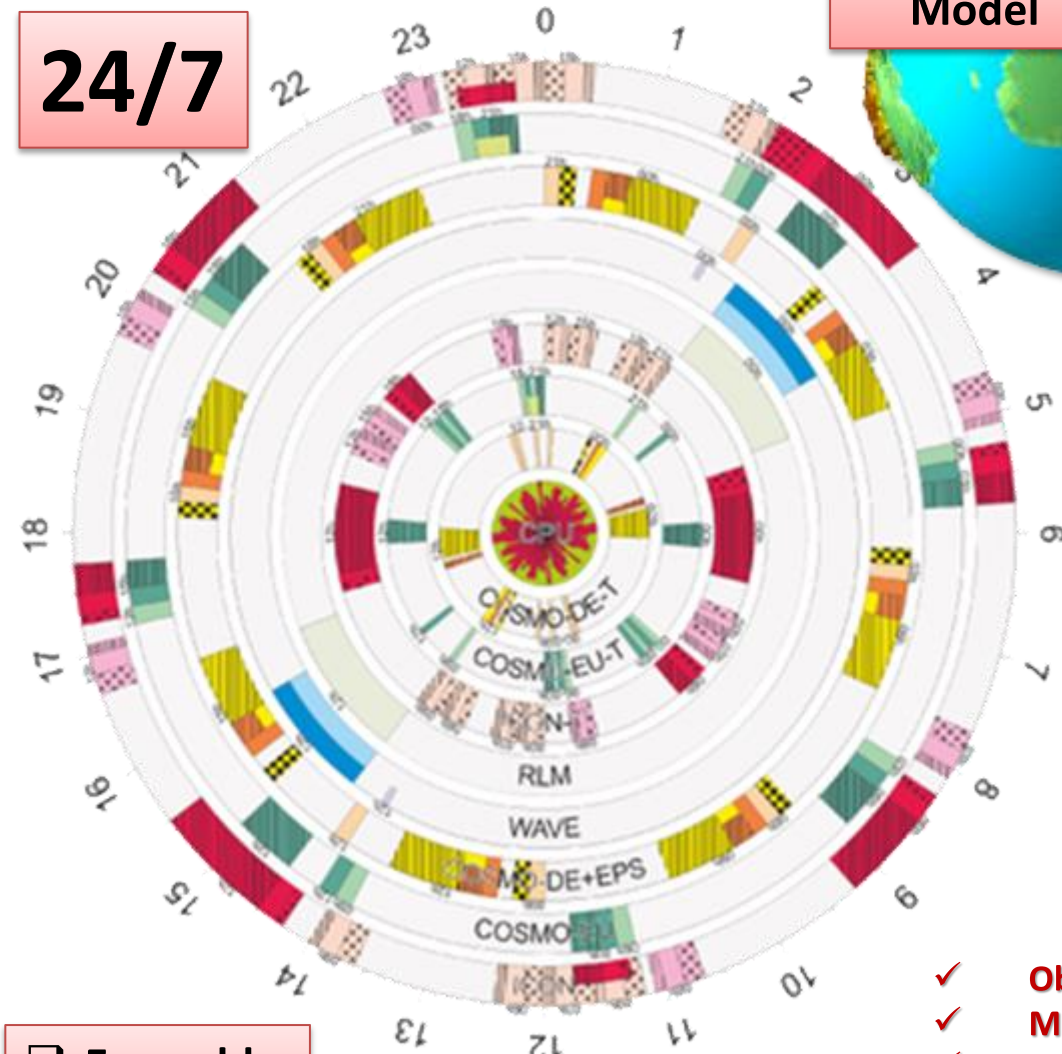


- ❑ Global Model

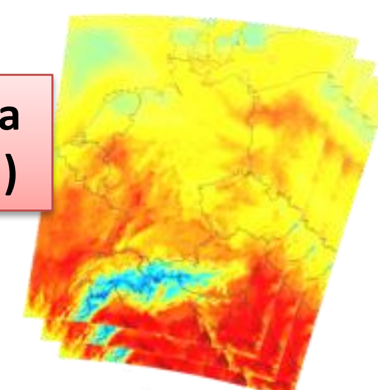


- ❑ Meso-Scale Model

24/7



- ❑ Limited Area Mode (LAM)



- ✓ Observe
- ✓ Monitor
- ✓ Model
- ✓ Warn
- ✓ Predict

- ❑ Ensemble Prediction

Typical DA Cycles

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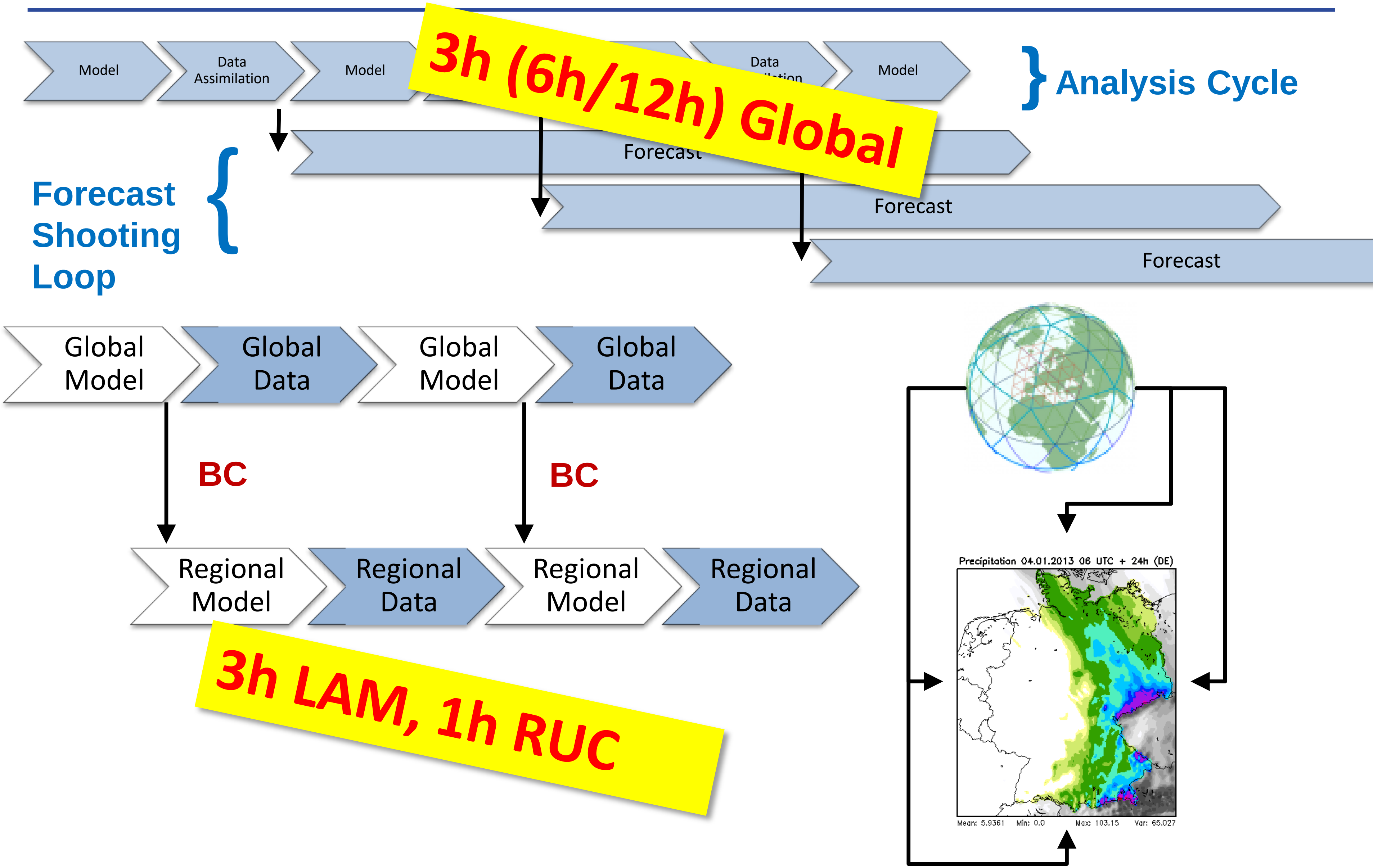


Ensemble DA on all Scales

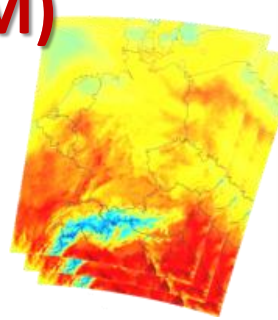
Global (13 km)

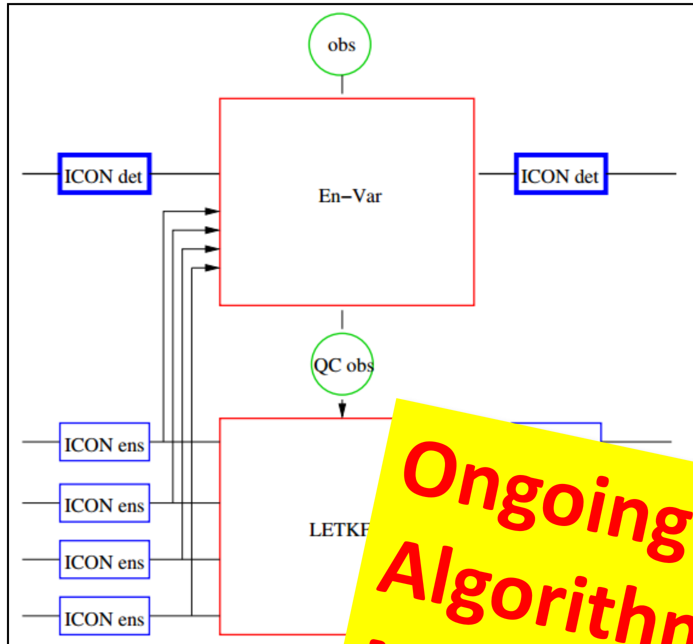
+ Mesoscale Nest (6.5 km)

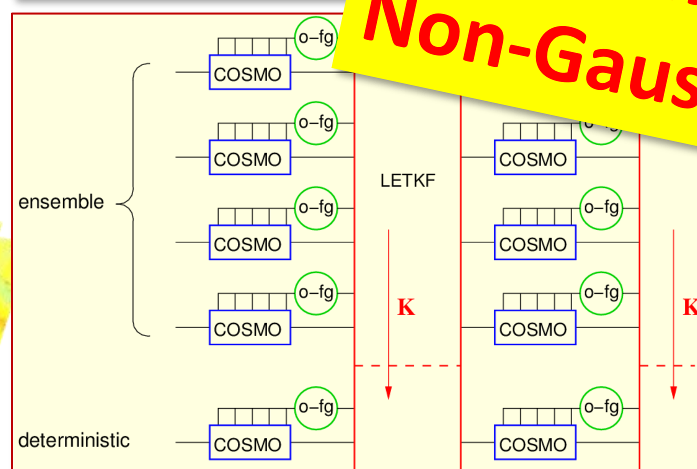
BC

Convective Scale (LAM)

(2.2 km/ 1km)







Ongoing Work on Algorithms and Non-Gaussianity

EnVAR

+

LETKF

(3h cycle)

4D-LETKF

(1h cycle)

Observation Systems

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Forecast Scores

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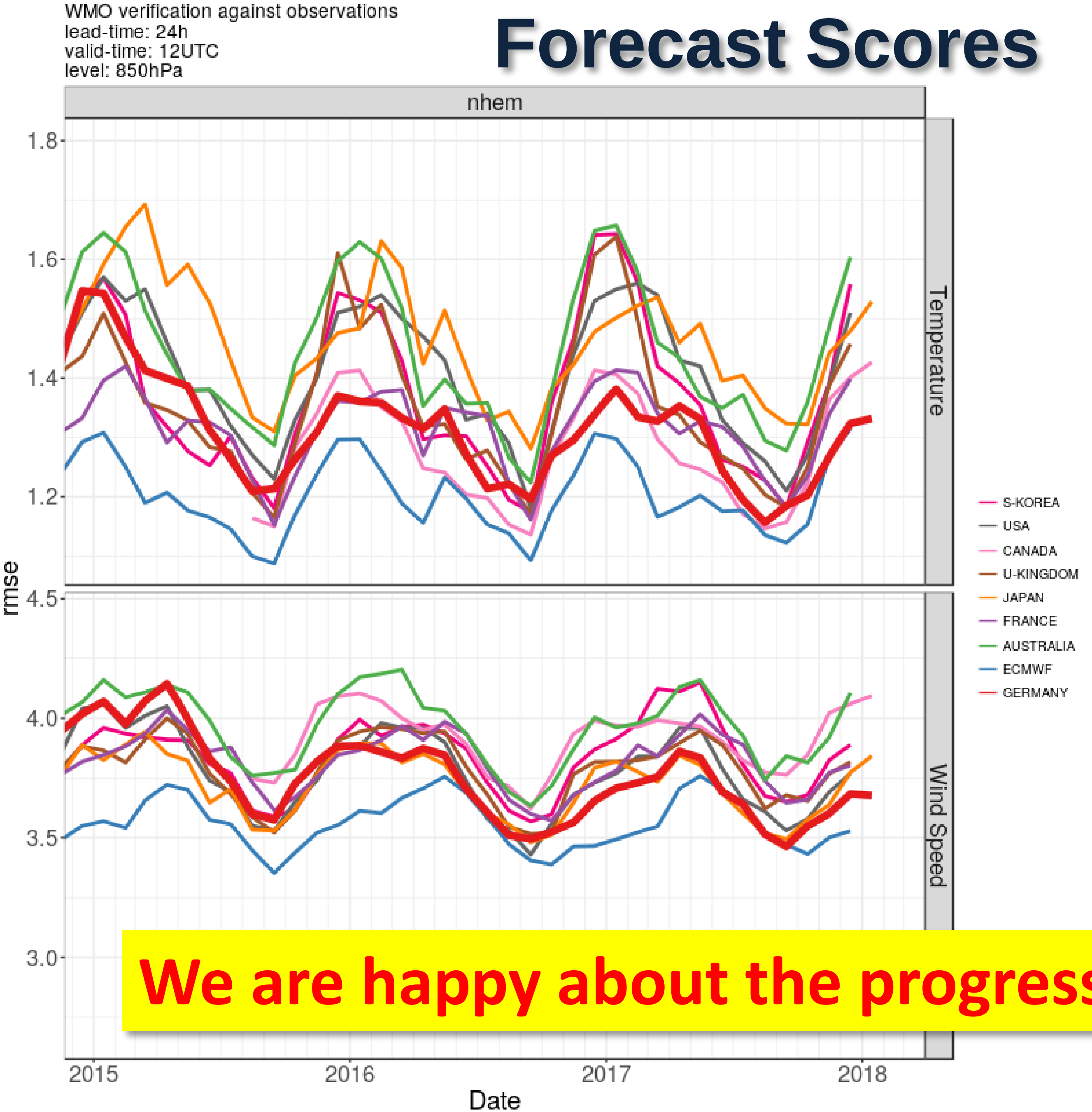
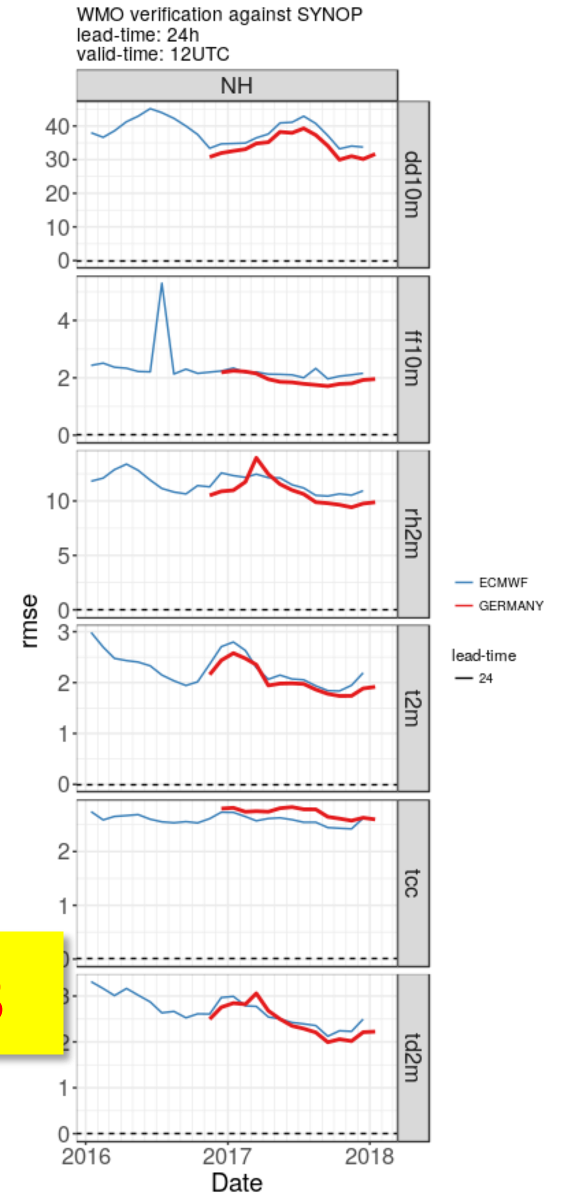
Wetter und Klima aus einer Hand





We are happy about the progress

Roland Potthast, Uli Blahak and Team, Febuary 9, 2018 at RIKEN Data Assimilation Seminar

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SINFONY

Development of a new **Seamless Integrated Forecasting System** for very short range convective-scale forecasting at DWD

Project team: Ulrich Blahak, Kathrin Wapler, Roland Potthast, Kathleen Helmert, Alberto De Lozar, Axel Seifert, Elisabeth Bauernschubert, Christian Welzbacher, Manuel Werner, Robert Feger, Rafael Posada Navia Osorio, Lilo Bach, Michael Hoff, Martin Rempel, Markus Junk, Lisa Neef, Kathrin Feige, Markus Schultze, Felix Fundel, Christoph Schraff, Michael Buchhold, Marcus Paulat

NWC+NWP Integration

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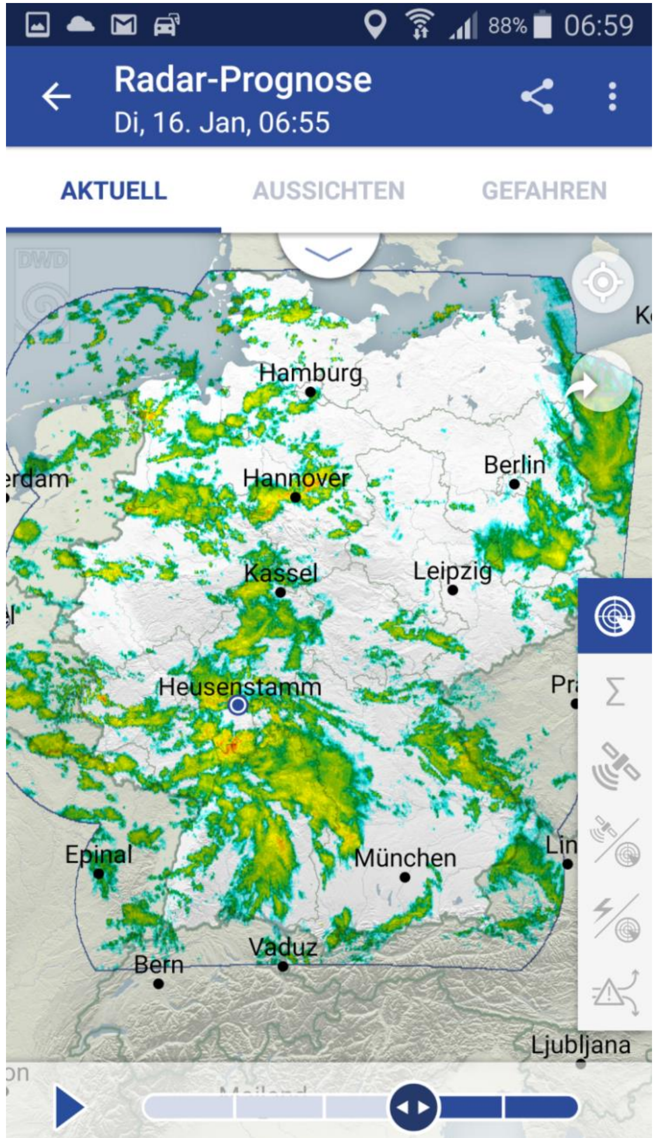
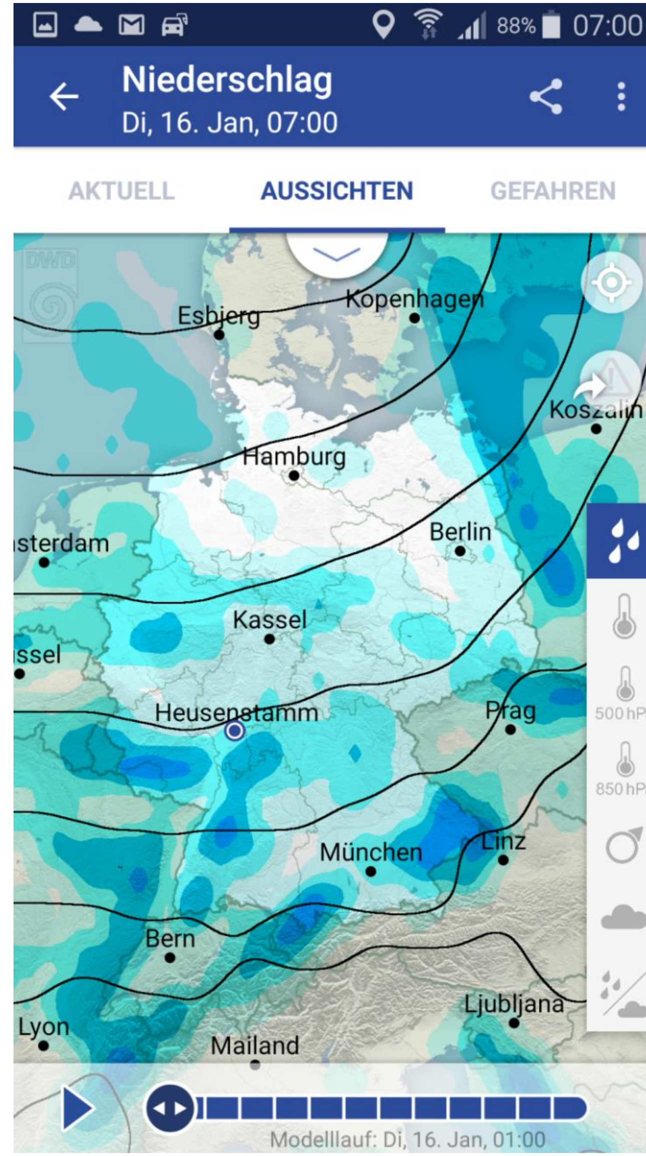
DWD SINFONY Project

NWC= Nowcasting

NWP= Numerical Weather Prediction





Motivation: NWC vs NWP

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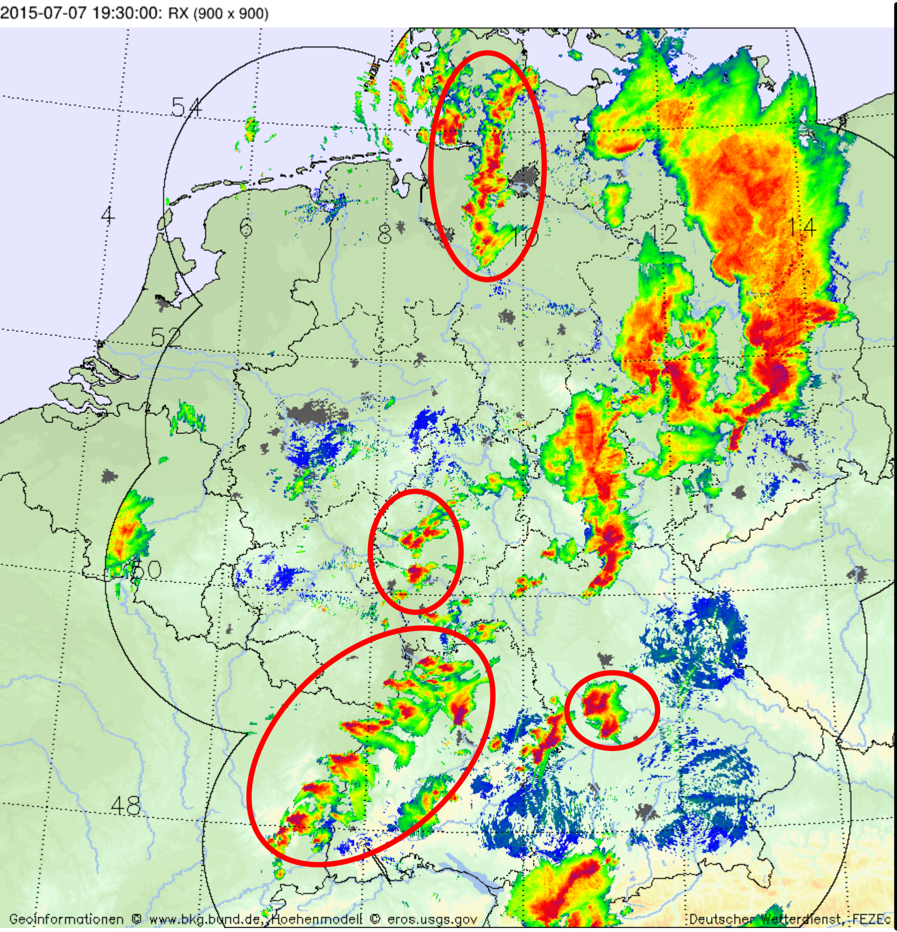
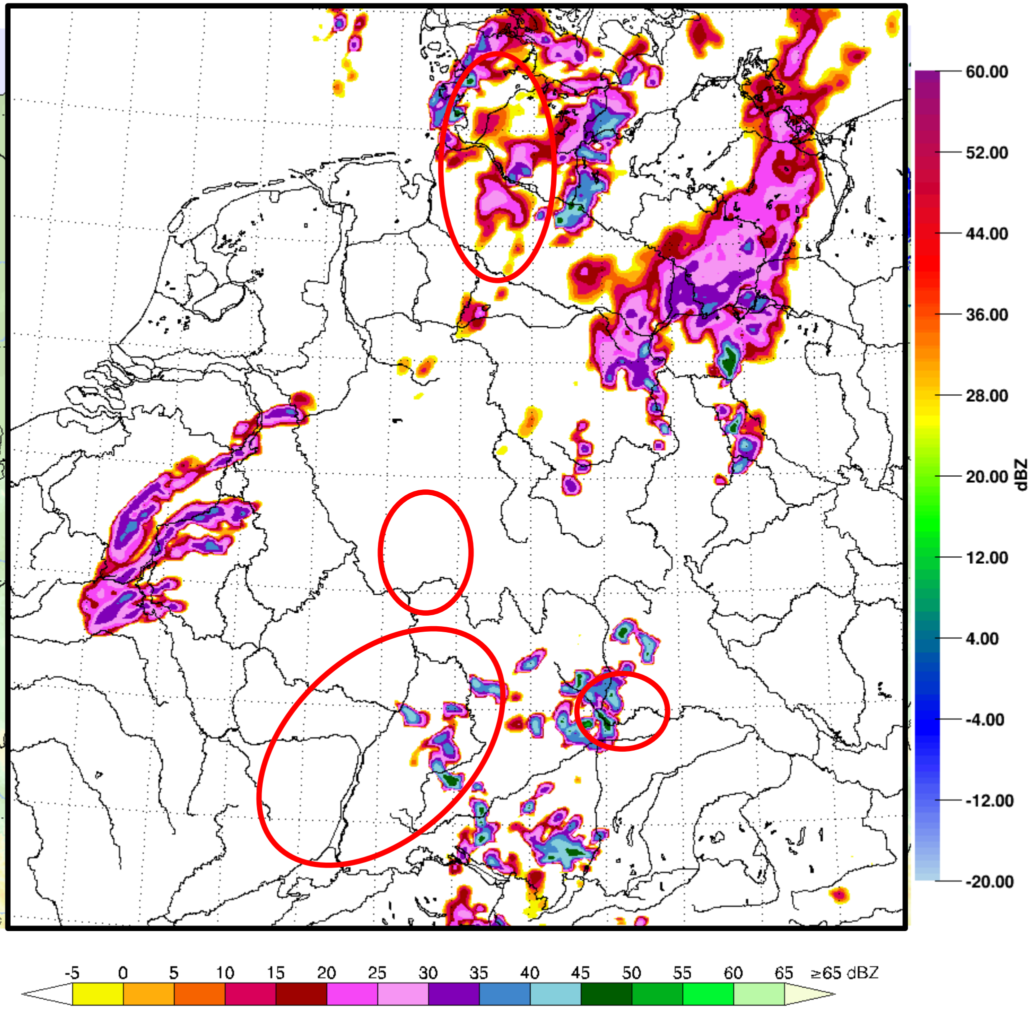
Wetter und Klima aus einer Hand

Measured Cells @ **19:30**



Model **for 19:30** **from 15:00**



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Usual methods of forecasting

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Very different methods for nowcasting (0 – 2 h) and very-short-range NWP (2 – 6 h):

- **Nowcasting:**
  - Based on structures in observation data, e.g. cell detection in radar images, estimation of displacement vectors, more or less „linear“ extrapolation of the tracks of structures/objects into the future. „Deterministic“ only.
  - Very fast, available very soon after the actual date, updates every 5 min
- **Very-short-range NWP:**
  - Model-based, analysis of the initial state using observation data. Solving the hydro-dynamic equations on a high-resolution 3D-grid in the atmosphere and in the soil.
  - New forecasts available ~1 – 1.25 h after the actual date, updates every 3 h (2.8 km resolution, deterministic and ensemble)

- **up to now mostly separated**
- **both with certain problems**
- **no common products**

Basic Idea of SINFONY

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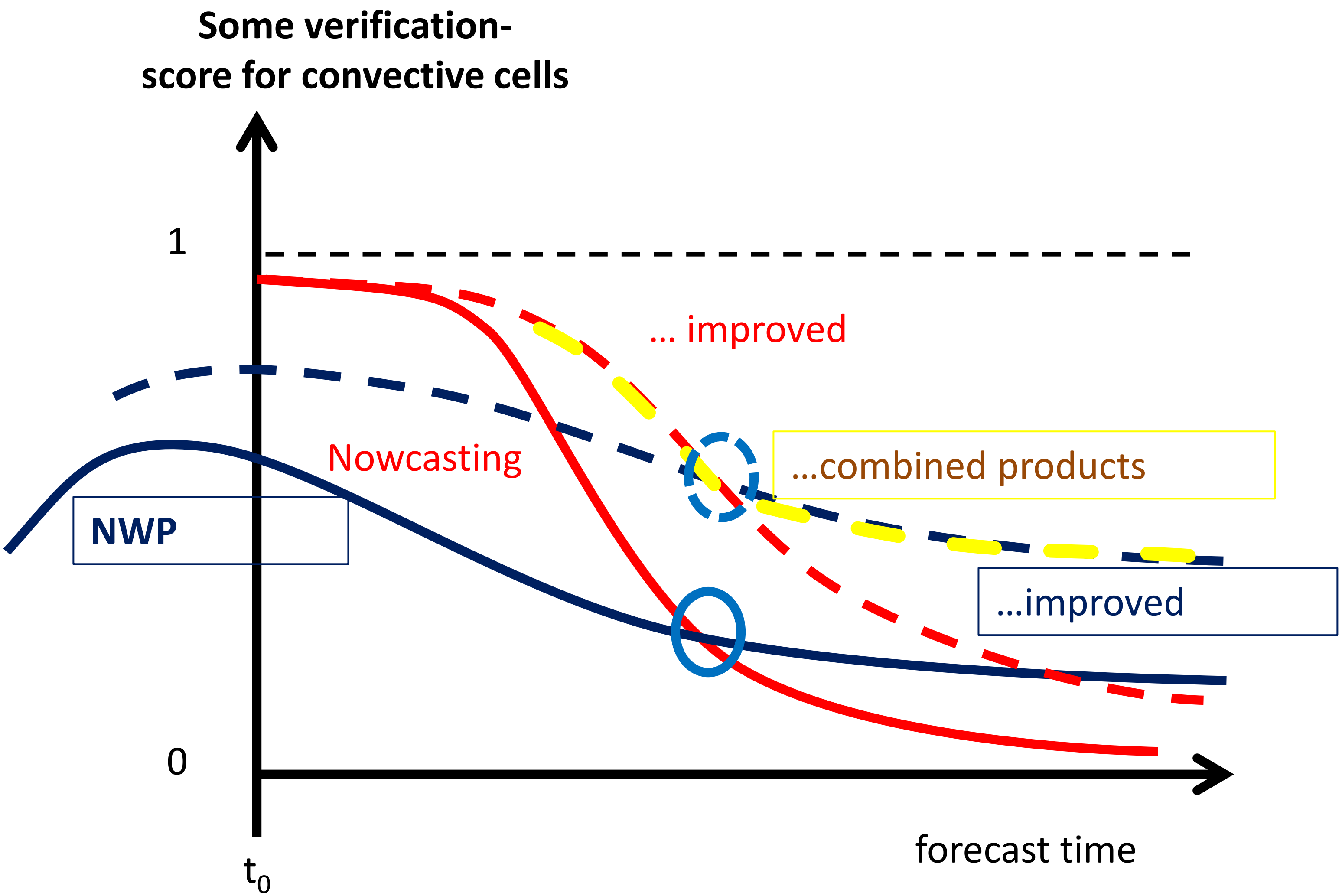
Wetter und Klima aus einer Hand

„Seamless Integrated Forecasting System" (SINFONY)

Goal: Complement, further develop and interlock products of Nowcasting and NWP in such a way that a seamless representation of the atmospheric state and weather phenomena from now until +6/+12 h possible

- **Ingredients:**
  - Probabilistic methods for the detection and Nowcasting of dangerous weather phenomena **(„Ensemble-Nowcasting"),**
  - Methods of ensemble based numerical data assimilation and very-short-range forecasting **(RUC),** simultaneous use and assimilation of all available **observations** and remote sensing data.
  - **Interlocking** of both methods in such a way, that mutual information exchange leads to quality enhancements of the „other" methods (z.B. Informations on the uncertainties and the spread of NWP-ENS winds and environmental conditions in Nowcasting; **Nowcasting-"objects" in NWP-data assimilation**)

Basic Idea of SINFONY



Tools 1: Numerical Model

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- Up to now: **COSMO***-model (non-hydrostatic, dynamics similar to WRF-ARW)
- Soon: **ICON-LAM** (ICOsahedral Nonhydrostatic, Limited Aera Mode)
- Options for microphysics
  - „standard“ 1-moment scheme including graupel
  - Seifert-Beheng 2-moment scheme including graupel and hail
- Need to work on setup of turbulence and microphysics for the km-scale
- **Goal: $\Delta x \leq 2$ km, hourly Rapid Update Cycle (RUC) ensemble (LETKF)**

* COSMO = COnsortium for Small scale MOdeling www.cosmo-model.org

(Baldauf et al, 2011: Operational convective-scale numerical weather prediction with the COSMO model: Description and sensitivities. Mon. Wea. Rev., **139**, 3887-3905)

(Gebhardt et al., 2011: Uncertainties in COSMO-DE precipitation forecasts introduced by model perturbations and variation of lateral boundaries. Atmos. Res., doi: 10.1016/j.atmosres.2010.12.008)

(Zängl et al, 2014: The ICON (ICOsahedral Non-hydrostatic) modelling framework of DWD and MPI-M: Description of the non-hydrostatic dynamical core. Q. J. R. Meteorol. Soc. **141**, 563-579, doi:10.1002/qj.2378)

Possible SINFONY NWV-RUC Ensemble starting 2020/2021 on „full“ new HPC

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DWD

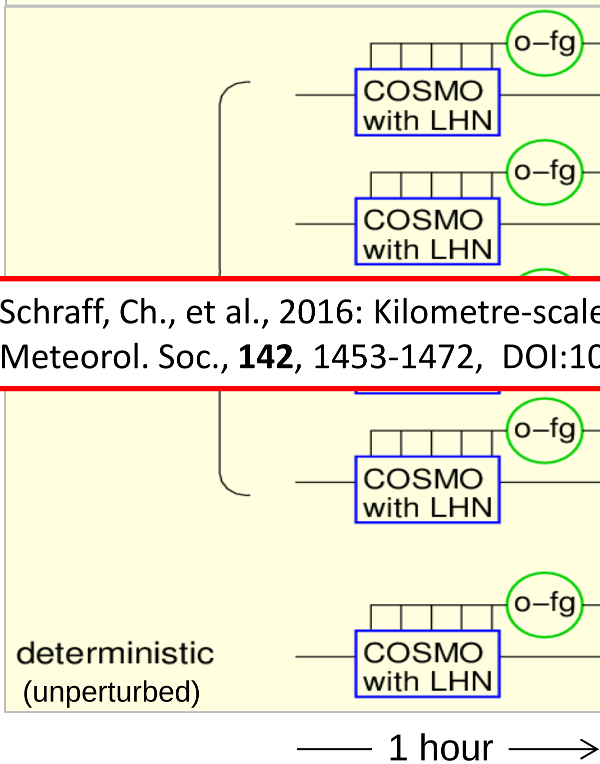
ICON-LAM ensemble, ~40 members, 1-h forecasts

Δ ~ 2.08 km 2-way-nesting to Δ ~ 1.04 km

(D. Majewski)

Tools 2: Km-Scale Ensemble Data Assimilation

KENDA: 4D-LETKF (Local Ensemble Transform Kalman Filter after Hunt et al., 2007)



o Observation
fg „First guess“ (simul. obs in short forecasts)

Schraff, Ch., et al., 2016: Kilometre-scale ensemble data assimilation for the COSMO model (KENDA), Q. J. R. Meteorol. Soc., **142**, 1453-1472, DOI:10.1002/qj.2748

K = Kalman gain for ensemble mean

Model state x → Observation-Operator **H**(x,t) → **Obs-space {o-H(x,t)}**

Tools 3: Remote Sensing Data and Forward Operators

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- **German (European) Radar Network**
  - Germany: 16 C-band dual-pol Doppler radars
  - **EMVORADO** (Efficient Modular VOlume scanning RADar Operator)

    (Zeng et al., 2016: An efficient volume-scanning radar forward operator for NWP models: description and coupling to the COSMO model, QJRMS, **142**, 3234-3256, doi:10.1002/qj.2904)

Radar Forward Operator EMVORADO

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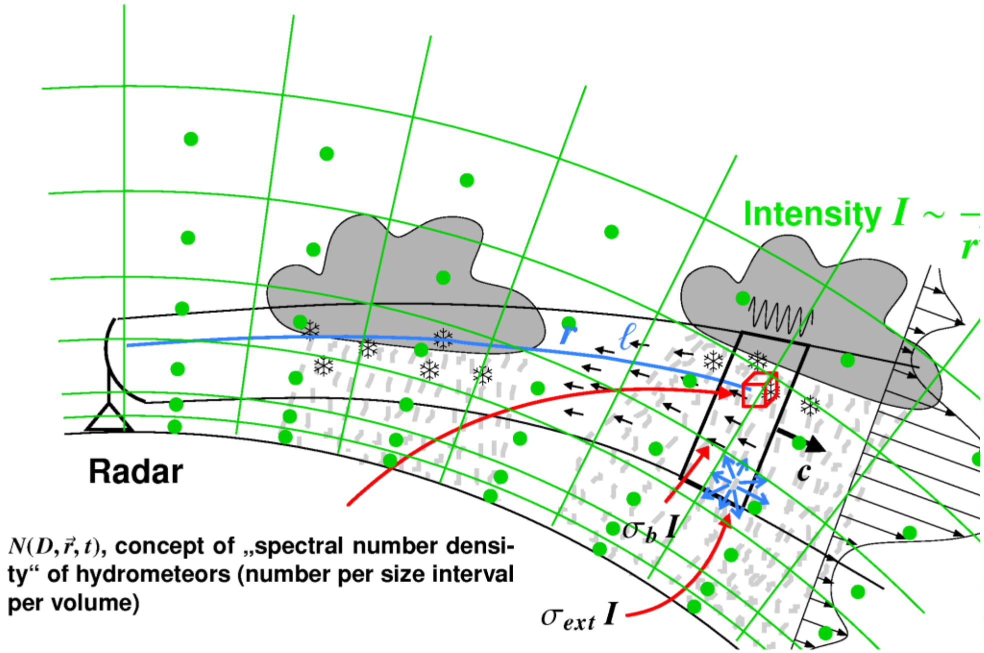
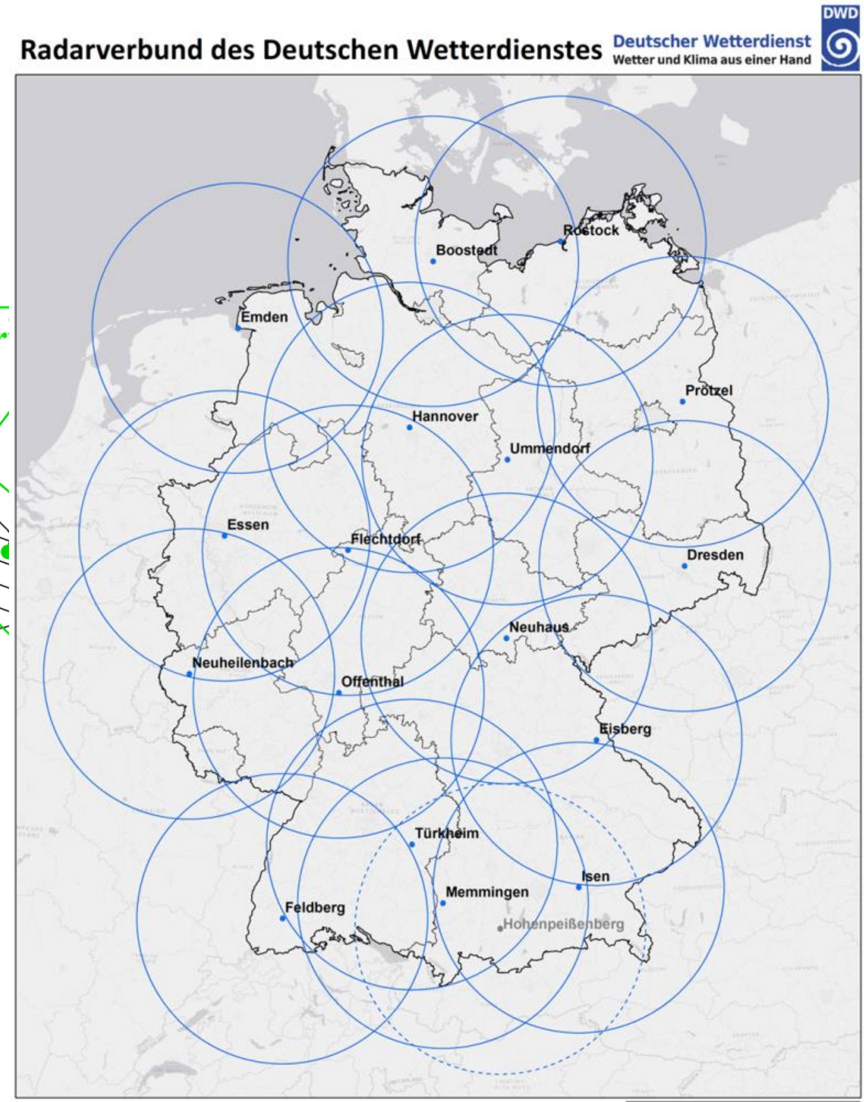
Model grid and weather radar





Simulated moments on radar grid:

- ➔ **Z** (Mie incl. melting effects, optionally consider attenuation, beam broadening)
- ➔ **V_r** (optionally Z-weighted beam broad.)
- ➔ Optionally detailed beam propagation

Example of simulated volume scan (dBZ)

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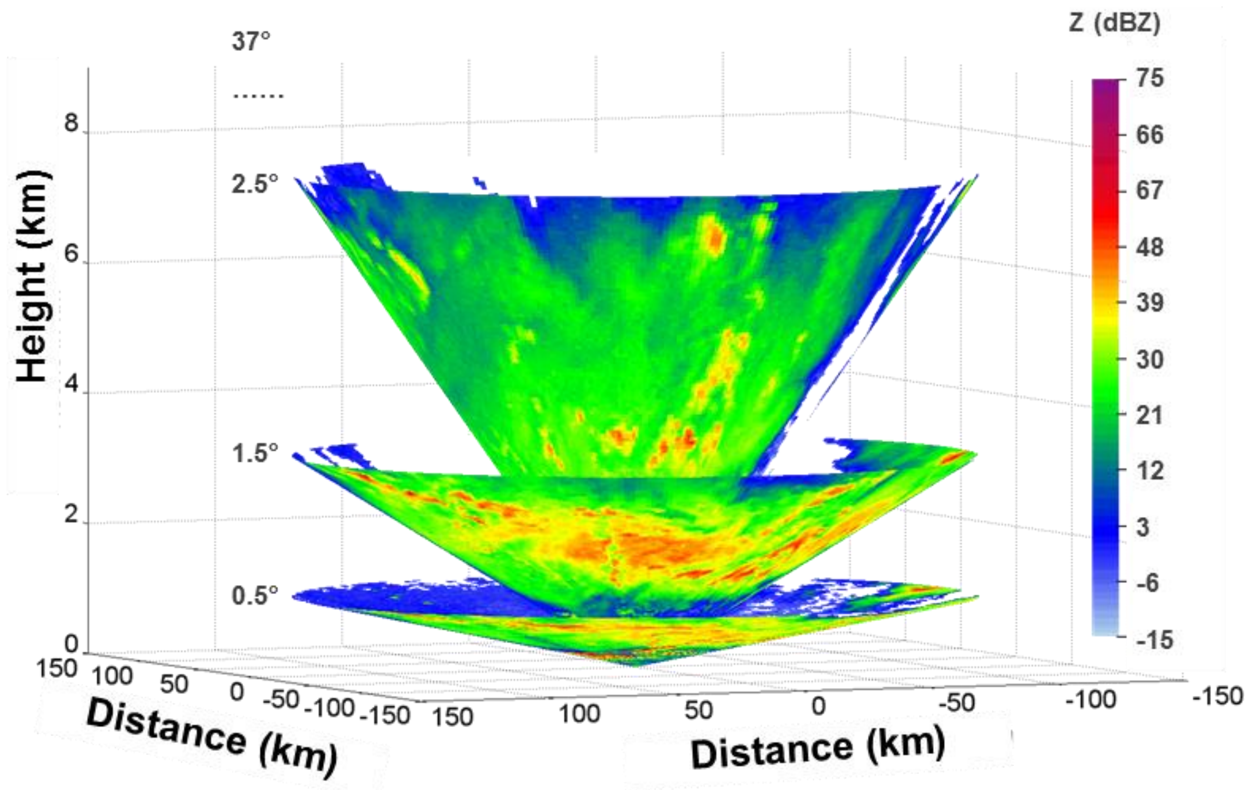

(From D. Zhang, personal comm.)

Observed vs. Simulated Volume Scans:
… *comparing apples to apples*

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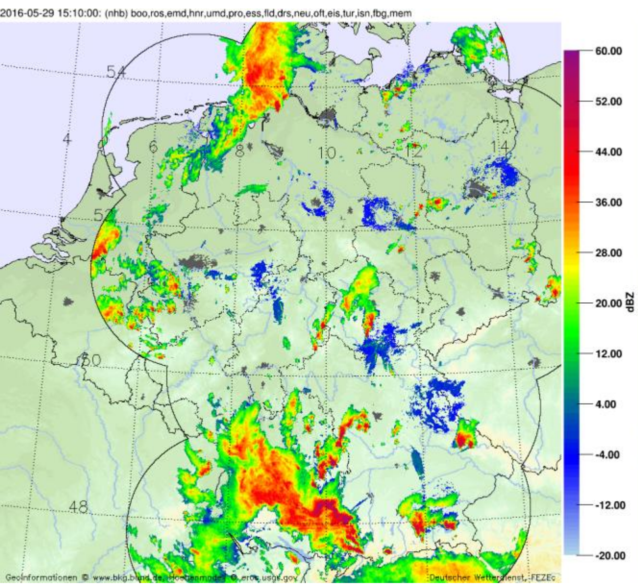
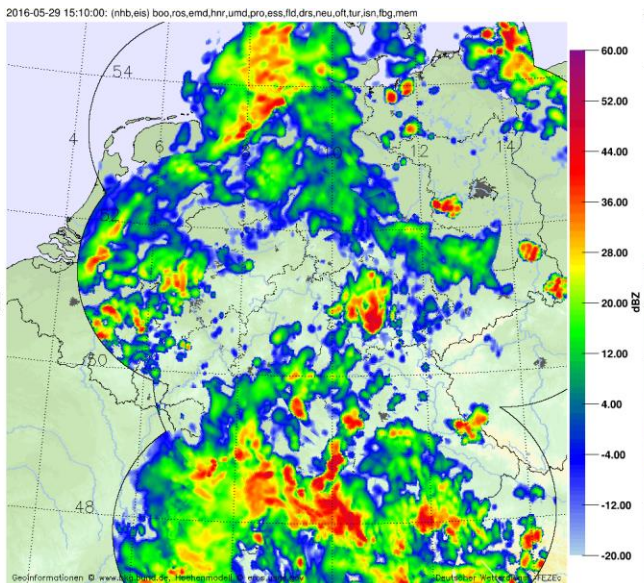
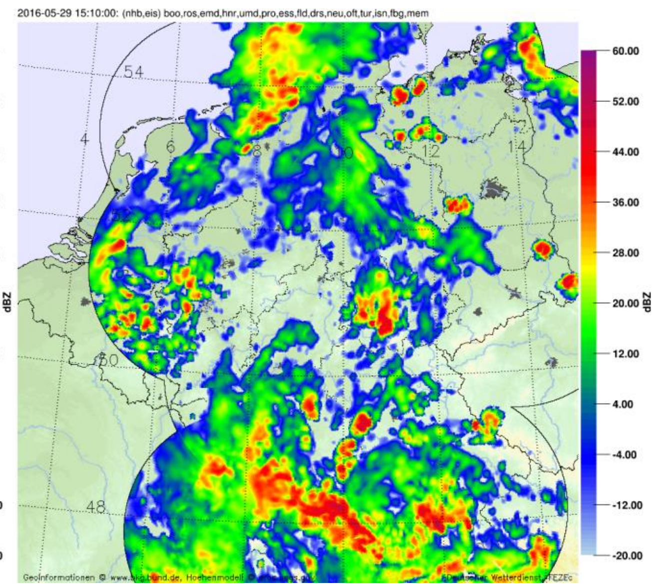
Wetter und Klima aus einer Hand

Example here: „RX Composite“ in DWD‘s POLARA software

OBS COSMO-DE-EPS (+10 min fcst) **det** **memb 3**







Tools 3: Remote Sensing Data and Forward Operators

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Geostationary Satellite Data (Meteosat **SEVIRI** IR and VIS)

- For IR: „RTTOV" from **NWP-SAF** (brightness temperature, radiances)
- For VIS: „**MFASIS**" from Uni Munich (reflectance)
- DWD (A Fernandez) is integrating MFASIS into RTTOV

(Scheck, L., et.al., 2016: A fast radiative transfer method for the simulation of visible satellite imagery, J. Quant. Spectr. Rad. Transf., **175**, 54-67, DOI:10.1016/j.jqsrt.2016.02.008)

Tools 3: Remote Sensing Data and Forward Operators

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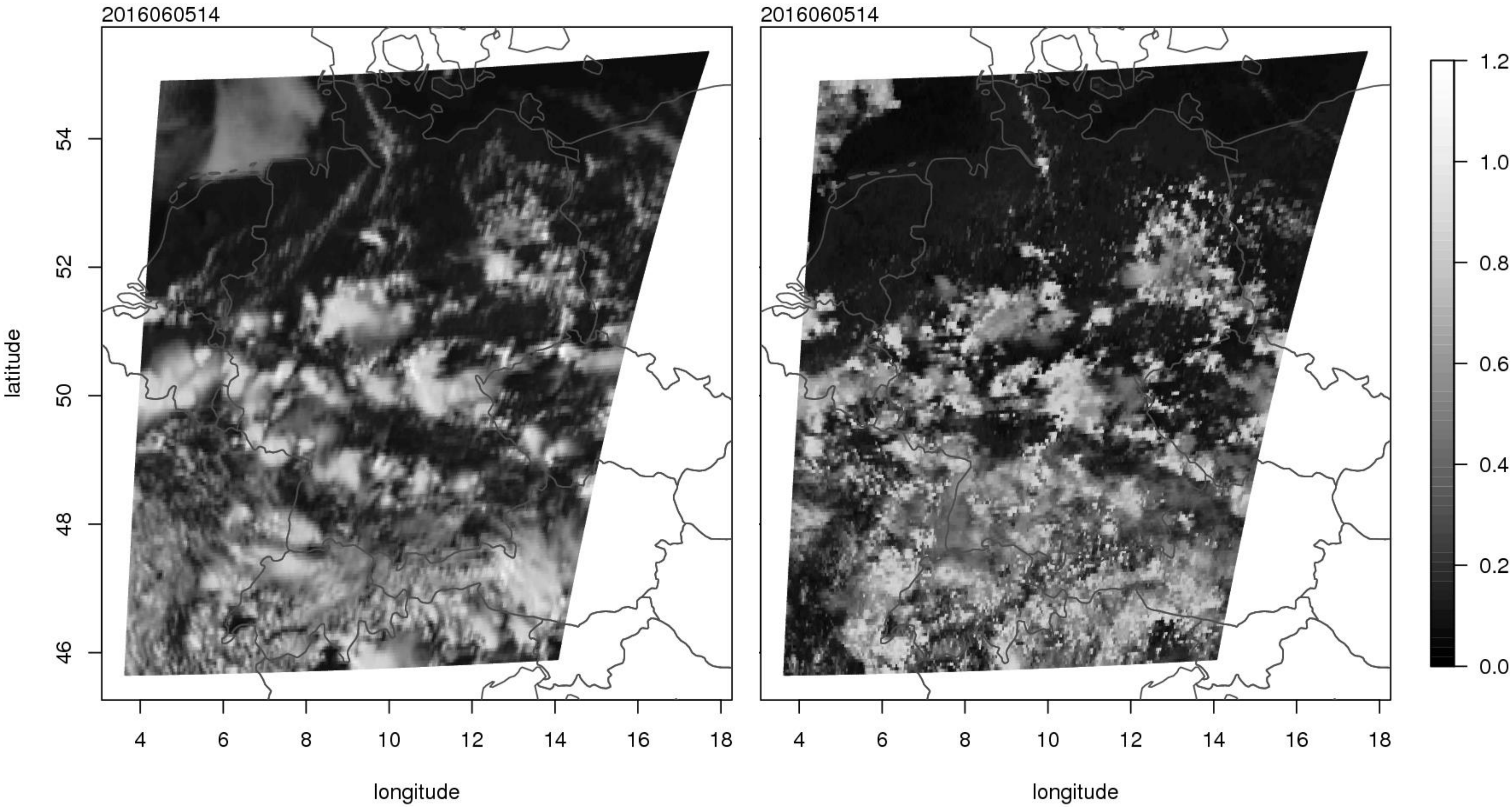
Obs (visible reflectance) Simul. (COSMO 2.8 km +MFASIS)



L. Bach, C. Schraff, U. Blahak, R. Potthast, C. Köpken-Watts, …

Tools 3: Remote Sensing Data and Forward Operators

- **Lightning strokes** (European LINET network)
- **Lightning potential index** (LPI) following Lynn et al., (2010)

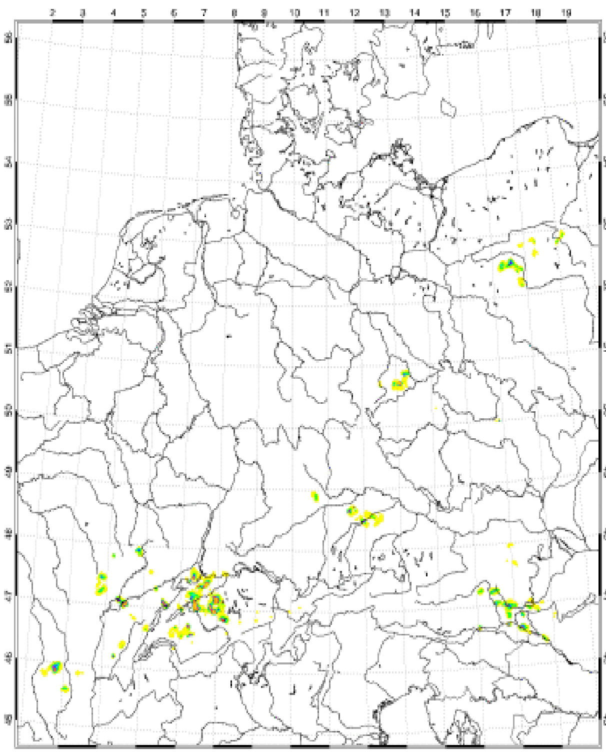
  (Lynn, B., and Y. Yair, 2010: *Prediction of lightning flash density with the WRF model*, Adv. Geosci., **23**, 11-16)

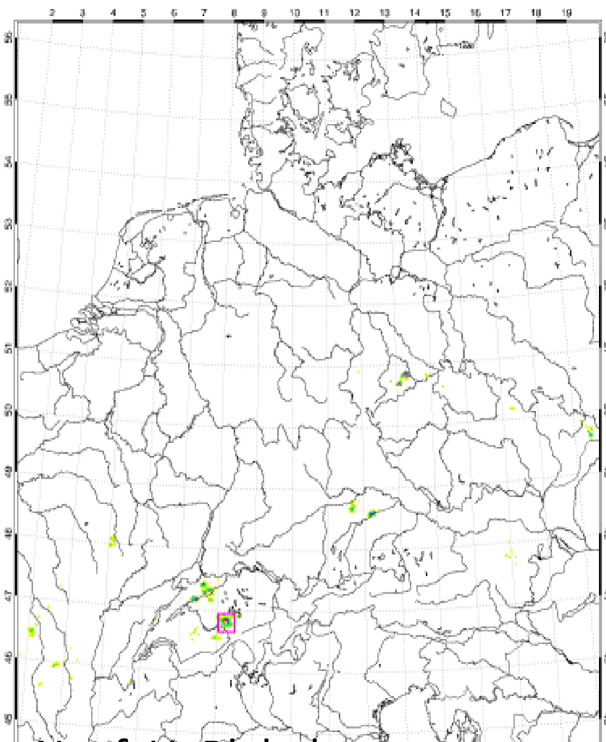
- Detects **pre-conditions for charge separation** in each model grid column depending on W and simulated hydrometeors (supercooled water, graupel, ice)

  L. Neef, U. Blahak, A. Rhodin, R. Potthast, C. Schraff, …

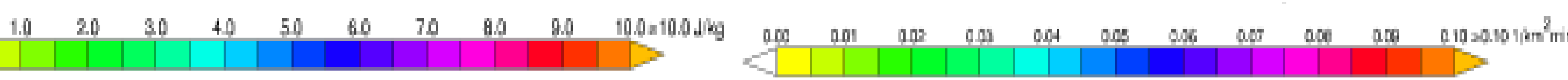
- **Lightning strokes** (European LINET network)

im. LPI (COSMO 2.8 km) obs. FLR t +- 7.5 min obs.





L. Neef, U. Blahak, …



Tools 4: Nowcasting

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- **Optical-flow** nowcasting (see earlier „Motivation“ slide)
- **Object-based** nowcasting (KONRAD-3D)
- Need to construct ensembles of both:
  - **Uncertainties** of optical flow field and cell identification/tracking
  - Information on **wind** and its uncertainty from NWV-ENS
  - Uncertainties of **life cycle**

KONRAD3D Object Nowcasting: Tornado Kürnach, 09.03.2017

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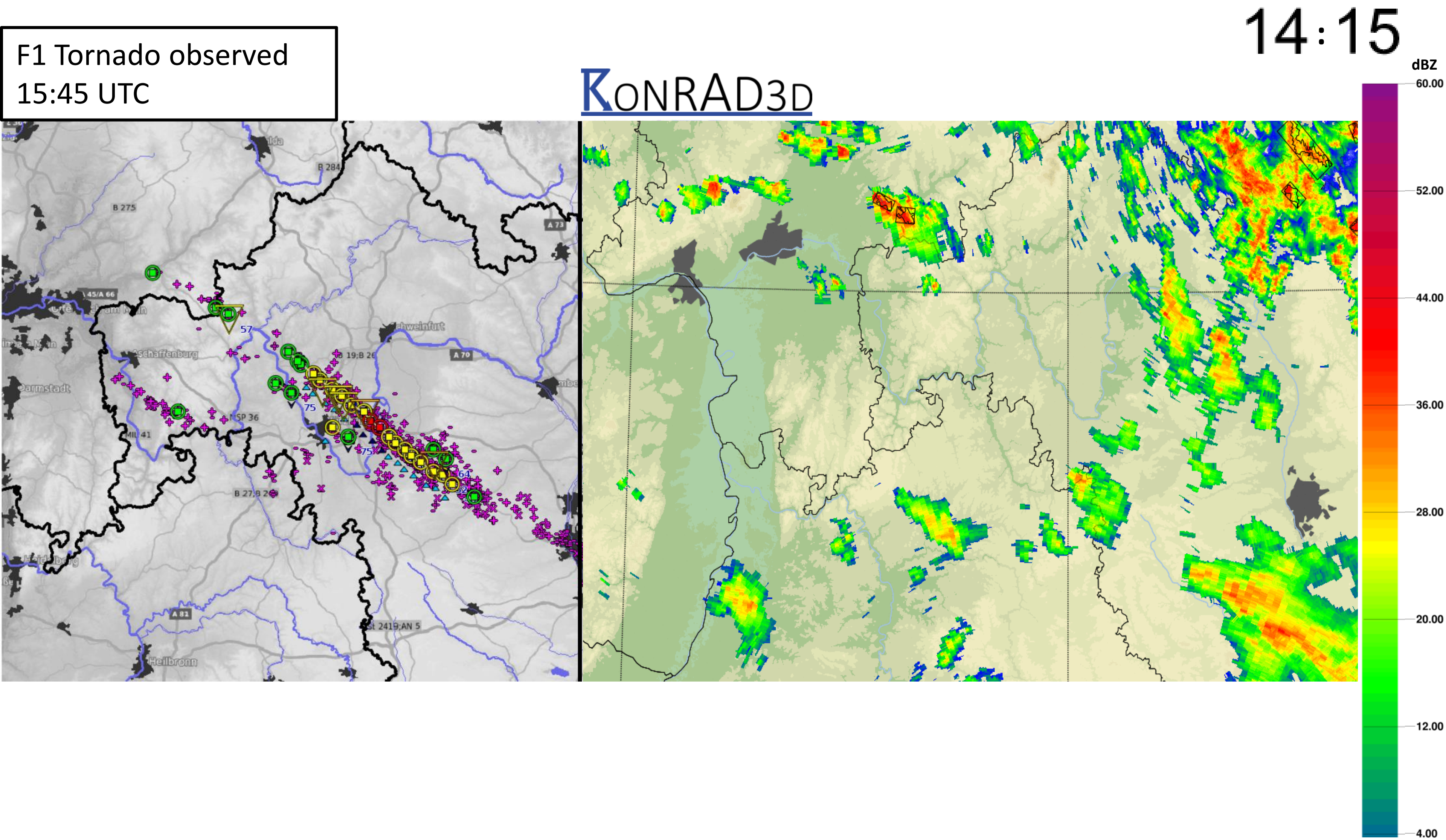
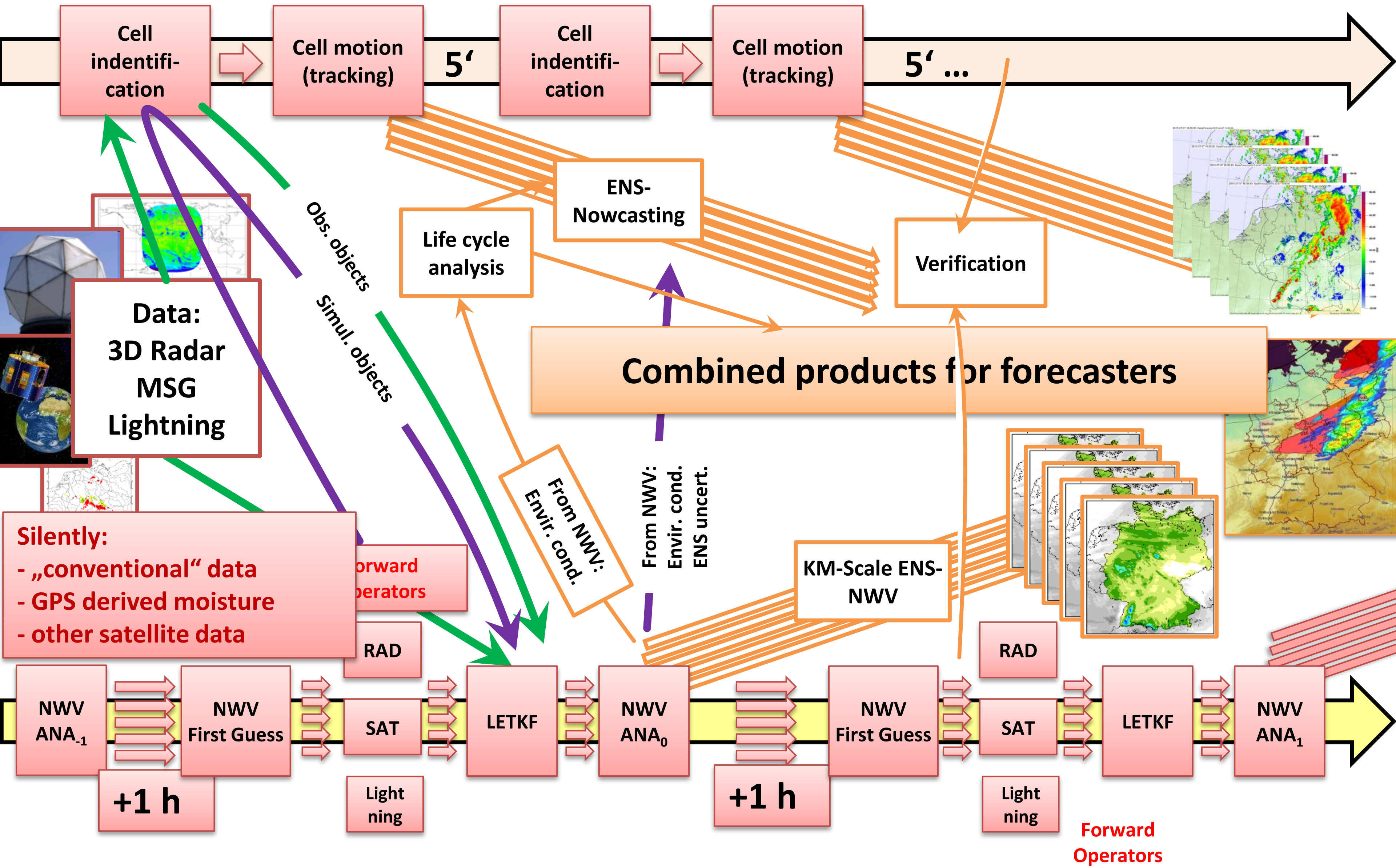


Manuel Werner, German Weather Service

Concept of SINFONY

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



NWP Case Study: cell with large hail

Deutscher Wetterdienst
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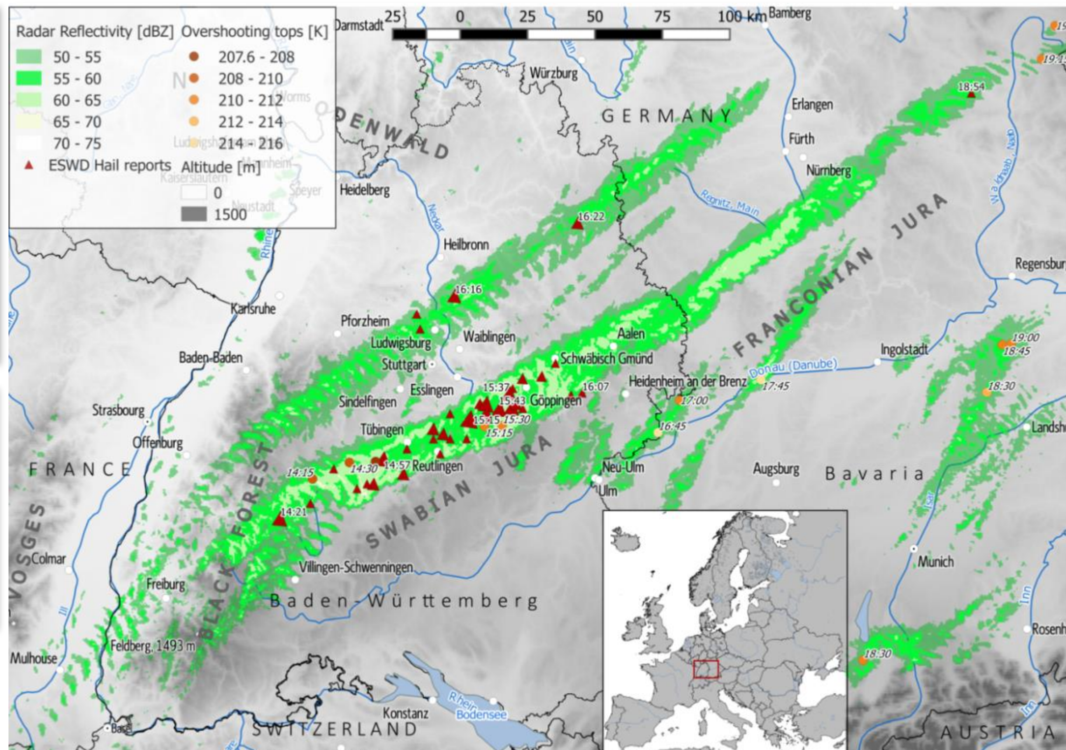
- 28.07.2013 supercell in Southern Germany, pre-frontal, insured losses of ~ 3 Billion €, togehter with another supercell the day before in N. Germany

- Large damages, maximum observed hail diameter > 10 cm



Kunz, M., et al, 2017: The severe hailstorm in Germany on 28 July 2013: Characteristics, impacts and meteorological conditions, QJRMS, submitted

NWP Case Study COSMO 2.8 km

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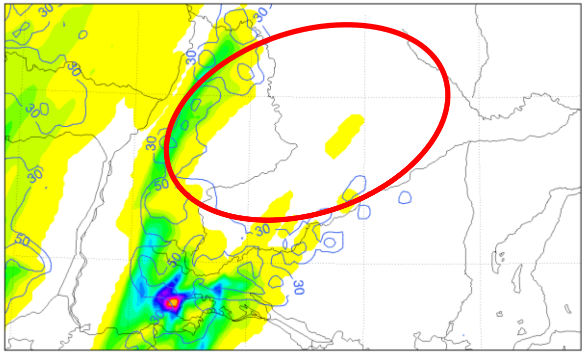
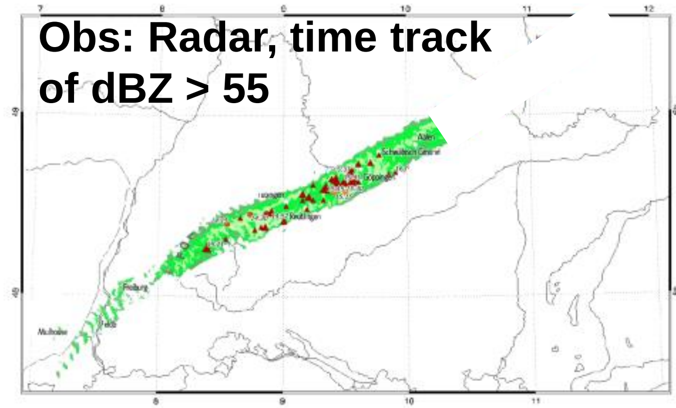
Standard model setup



COSMO
2.8 km



16 UTC
COSMO

Accumulated precipitation

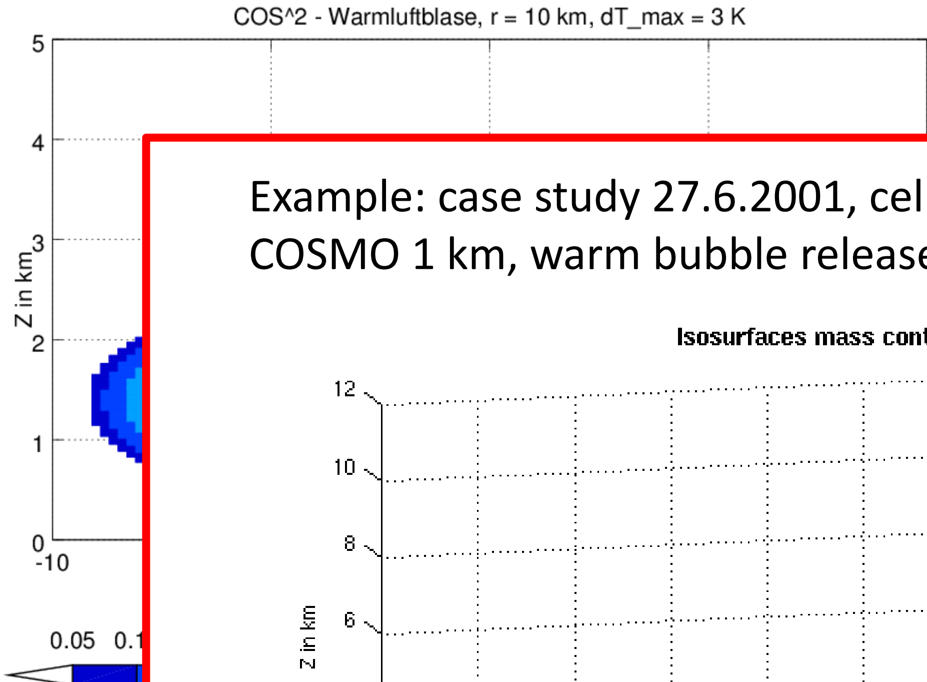
0 10 20 30 40 mm

Current problems of NWP:
- Triggering of convective cells
- LHN for radar data assimilation not always optimal
- Update only every 3 h with ~1-1.5 h delay (data collection, computing)

Kunz, M., et al, 2017: The severe hailstorm in Germany on 28 July 2013: Characteristics, impacts and meteorological conditions, QJRMS, submitted

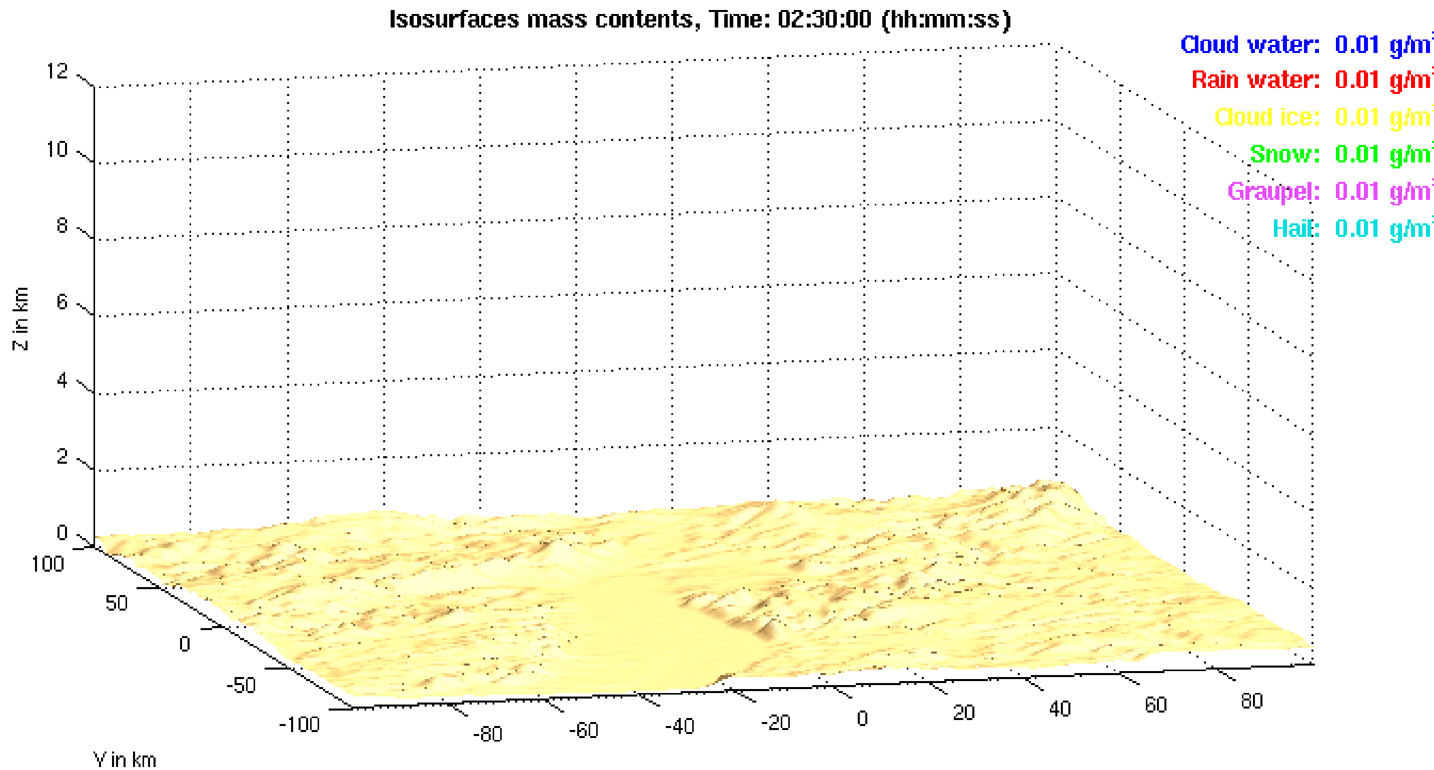
Adding Artificial „Warm Bubble“: A proxy for „ideal“ data assimilation

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

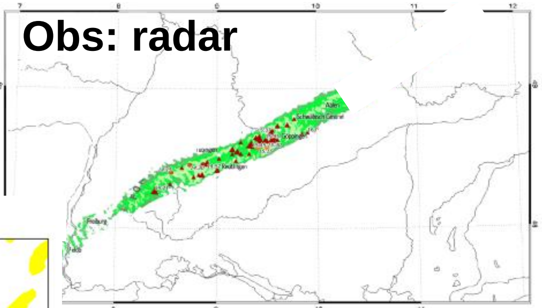


(similar to Weisman & Klemp, 1982)

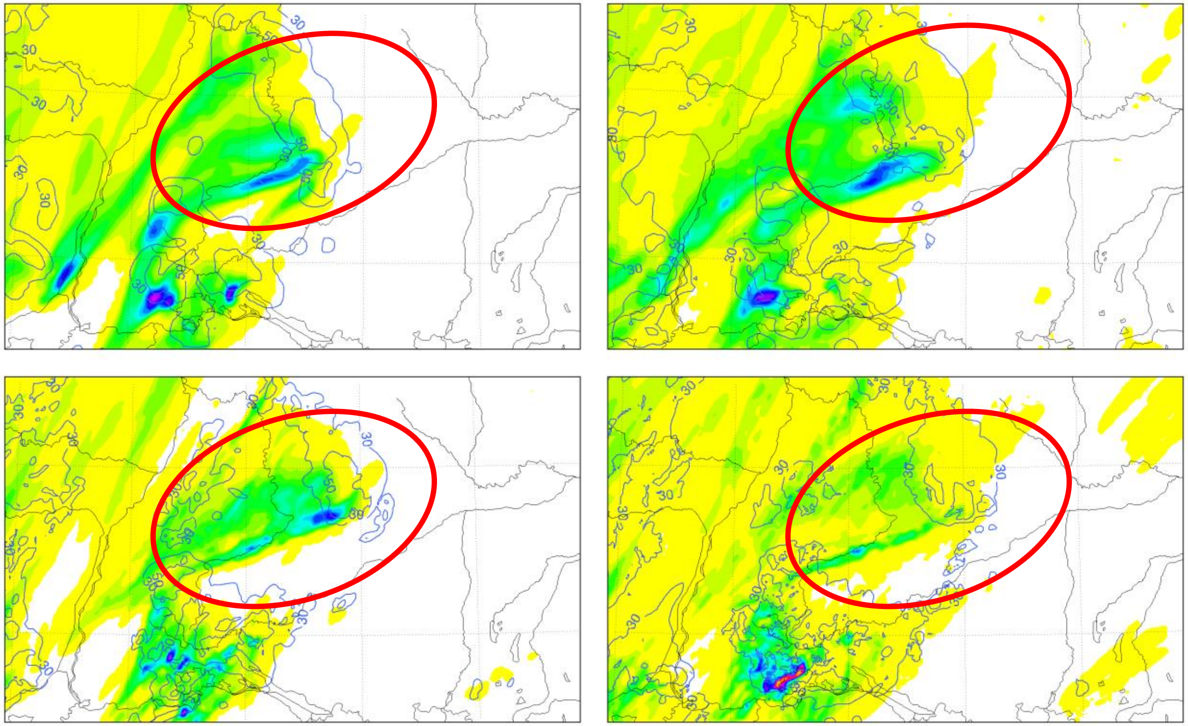
Example: case study 27.6.2001, cell near Mannheim, Germany
COSMO 1 km, warm bubble released at 2.5 h



COSMO + „Warm Bubble“



Standard model setup | 2-moment microphys.



COSMO
2.8 km

1.1 km

16 UTC

COSMO 1.1 / 2.8 km

Accumulated precipitation

0 10 20 30 40 mm

„Warm bubble“:
- D ~ 20 km, ΔT ~ 3 K, in PBL
- Proxy for „ideal“ data assimilation

Kunz, M., et al, 2017: The severe hailstorm in Germany on 28 July 2013: Characteristics, impacts and meteorological conditions. QJRMS, submitted.

1.1 km, 2-mom. microph., „warm bubble“: obs. and sim. dBZ (PPI 0.5°)

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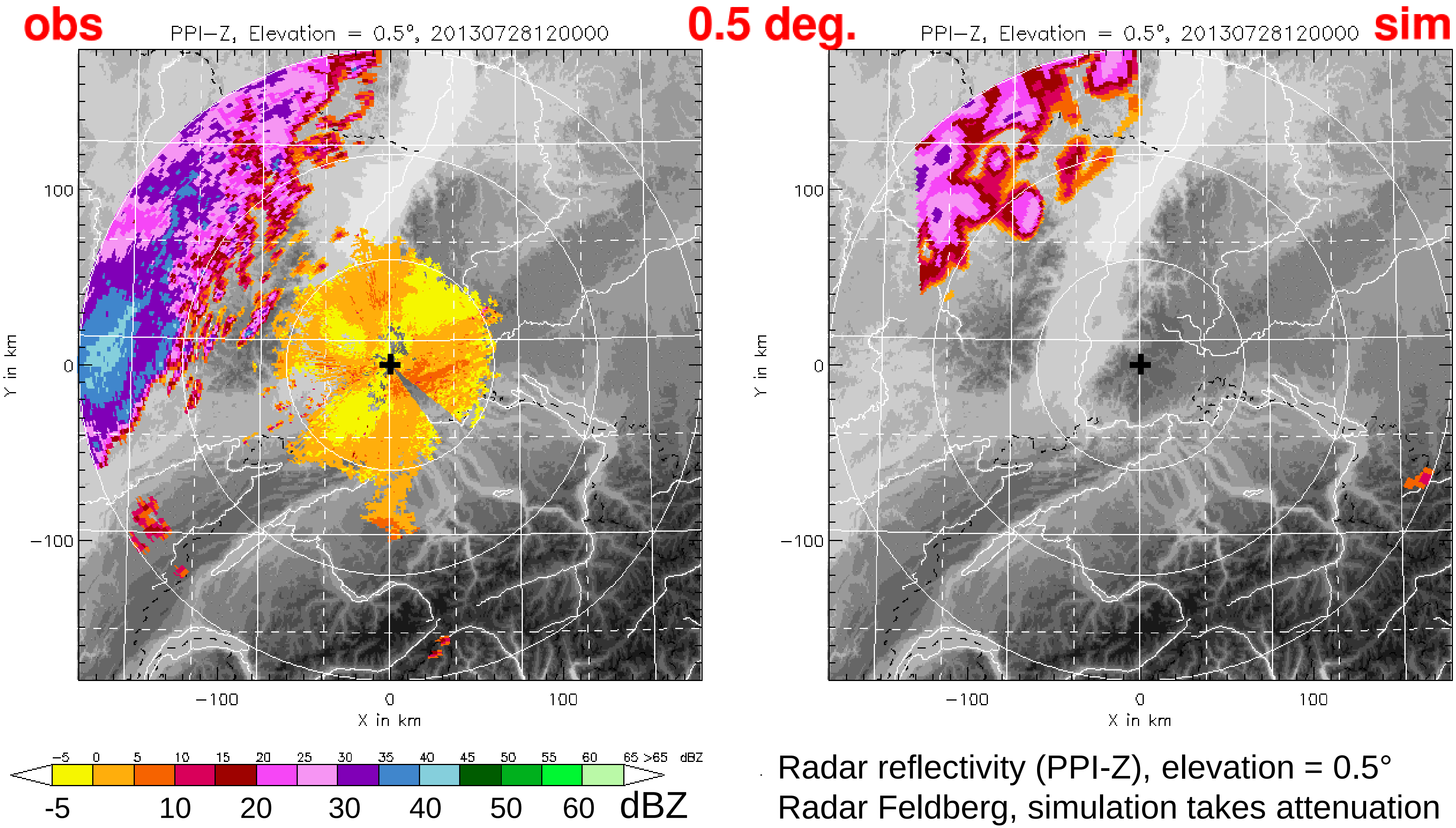
Wetter und Klima aus einer Hand

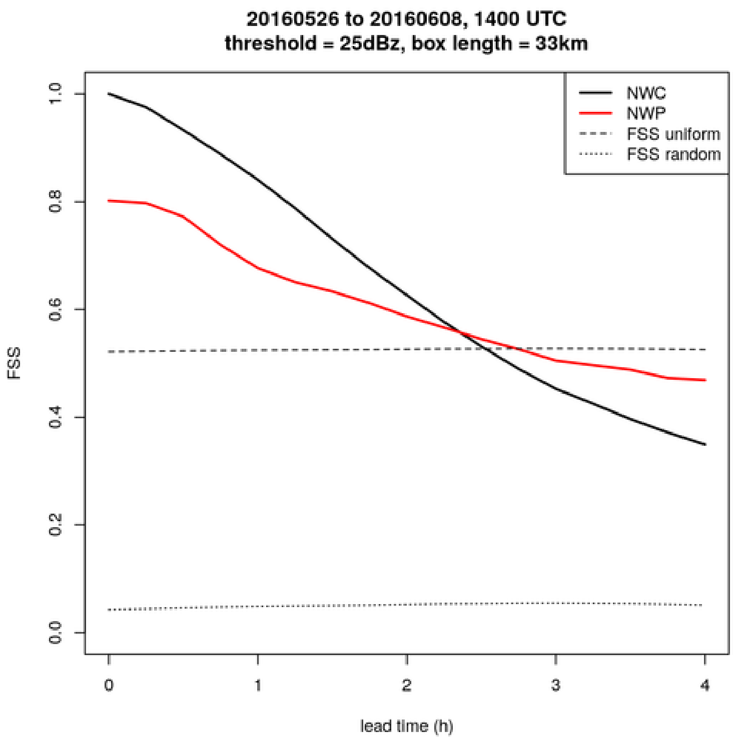


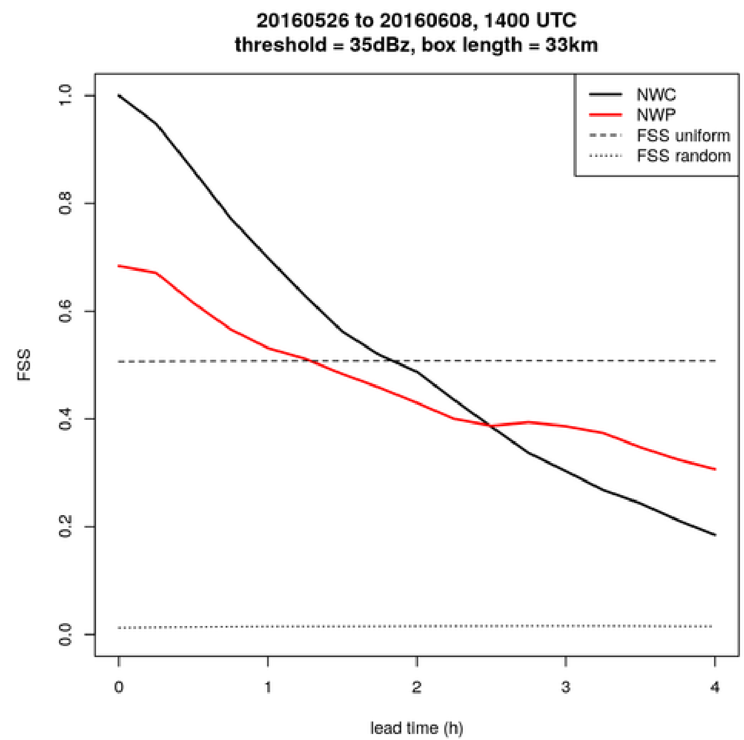
Radar reflectivity (PPI-Z), elevation = 0.5°
Radar Feldberg, simulation takes attenuation into account

First Results 1: Comparison of Current Operational Nowcasting and NWP-Ensemble

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- Optical-Flow Nowcasting / COSMO-DE-KENDA forecast experiment (determ. memb)
- FSS (fraction skill score) @ scale 33 km, thresholds 25 and 35 dBZ





(Michael Hoff)

Recalling LETKF before coming to „First results 2“:

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Wetter und Klima aus einer Hand

Some basics about the LETKF:

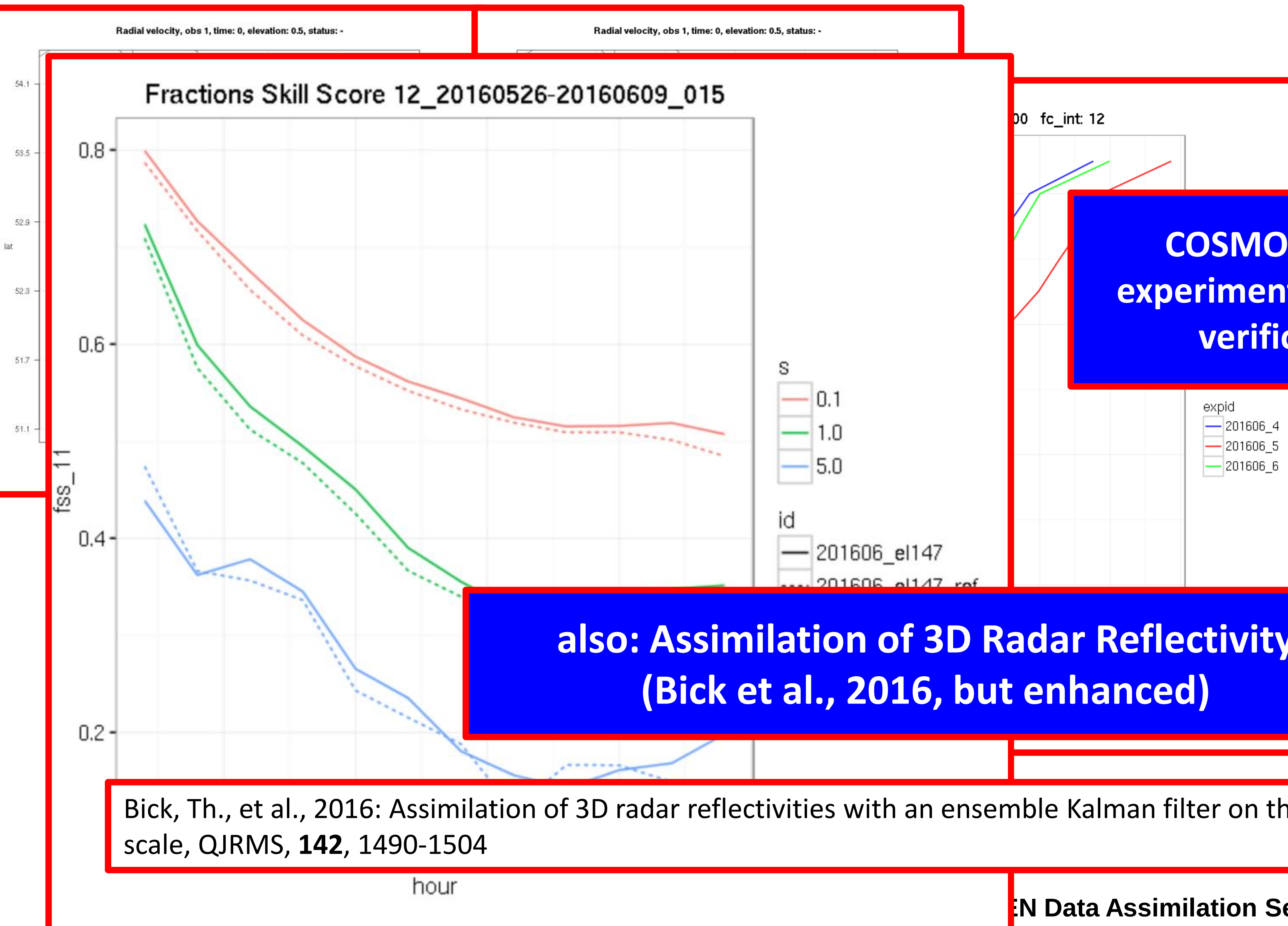
- New members (analysis) = local **linear combinations** of fg-members
- Combination weights determined by local **o-fg** difference:
  small difference = high weight   and   vice versa.
- Weights from maximum likelihood based on **assumed Gaussian distributions** of the o-fg differences.
- Weights take into account **local correllations** inbetween the prognostic model variables via a cross-correllation matrix called „B“-matrix . This B-matrix is computed from the actual state of the ensemble (**fg EPS**).

  Example:

  – Reflectivity Z projects directly onto hydrometeors: Z = fct(qr, qs, qg, …) (our „H(x)“ in this case)

  – Hydrometeors correllate with moisture, so a reflectivity difference to the observation can affect moisture.

First Results 2: Assimilation of RADAR Radial Winds



COSMO-DE-EPS experiments, forecast verification

also: Assimilation of 3D Radar Reflectivity (Bick et al., 2016, but enhanced)

Bick, Th., et al., 2016: Assimilation of 3D radar reflectivities with an ensemble Kalman filter on the convective scale, QJRMS, **142**, 1490-1504

But: Some Problems in Assimilation

- Especially for convective cells: Structures („cells“) **very localized** and intermittent **(Scale Problem)**
- Need small superobservation regions (~5x5 grid points) and localization radii
- LETKF has problems when no spread in ensemble, e.g., all members have 0 reflectivity but obs is > 0 at a location.
  In this case, data assimilation does nothing!
- **„Double penalty“** in case of spatial shifts of cells relative to the observations
- Removing **spurious convection** can be a problem

There is much to improve!!!

„Double penalty“

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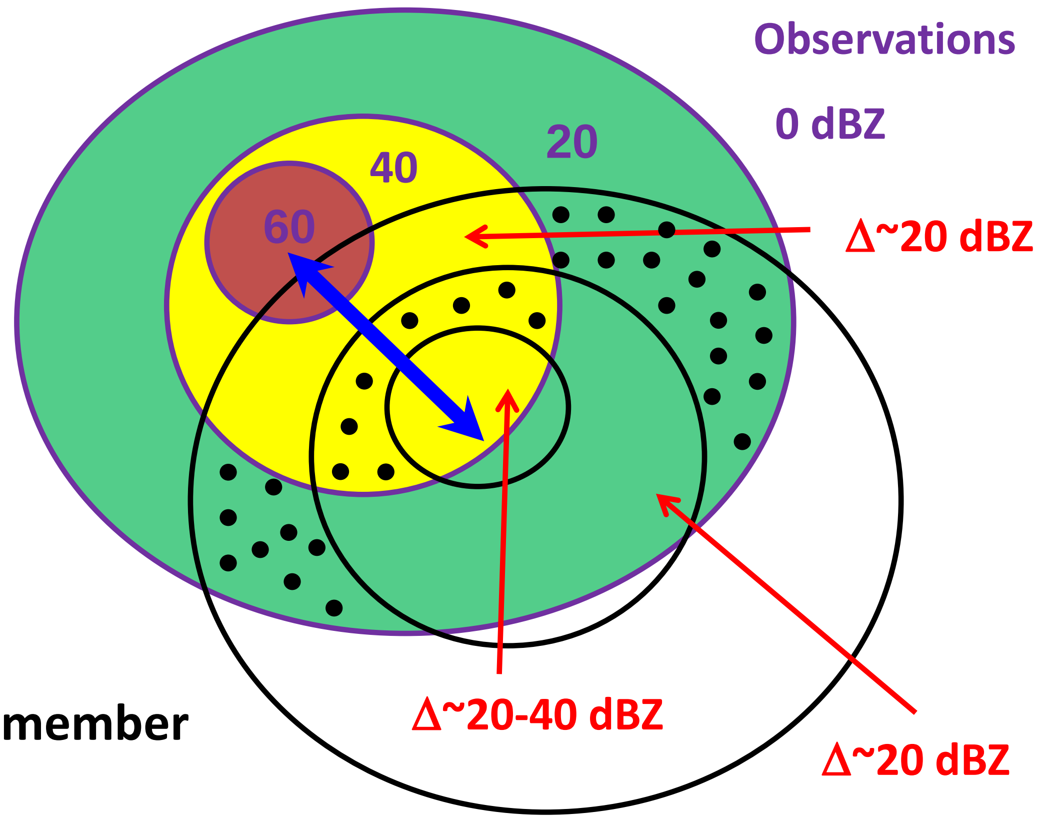
- „Double penalty“ when doing LETKF-DA pointwise
- If no other member „hits“ the reflectivity core:
  - DA would suppress modeled core
  - DA would not create observed core



• = „good“

Model ENS member

What can we do?

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- Increase **number** of ensemble members N:
  - Benefit: the „forecast quality" scales like $\sim 1/\sqrt{N}$
- Artificially increase ensemble **spread** by adding **noise** to the system:
  - Can be at various stages
  - Noise can be „clever" by obeying certain spatial and intra-variable correllations
- Artificially increase **number of members** for the assimilation step:
  - Clone existing members and add some „noise" in a clever way
- **Mix B-matrix** from LETKF with „climatological" B-matrix
  - In this way, enforce „physically known" correllations in case the actual ensemble does not cover them (limited ensemble size etc.)
  - Example: correllation of hydrometeor contents and moisture

What can we do?

- **Physically „force“** the ensemble members towards the observations during the first guess runs:
  - „Continuous“ latent heat/moisture nudging
  - Locally more isolated and forceful **convection triggering** („warm bubbles“)

Forcing the Model by „Warm Bubbles“

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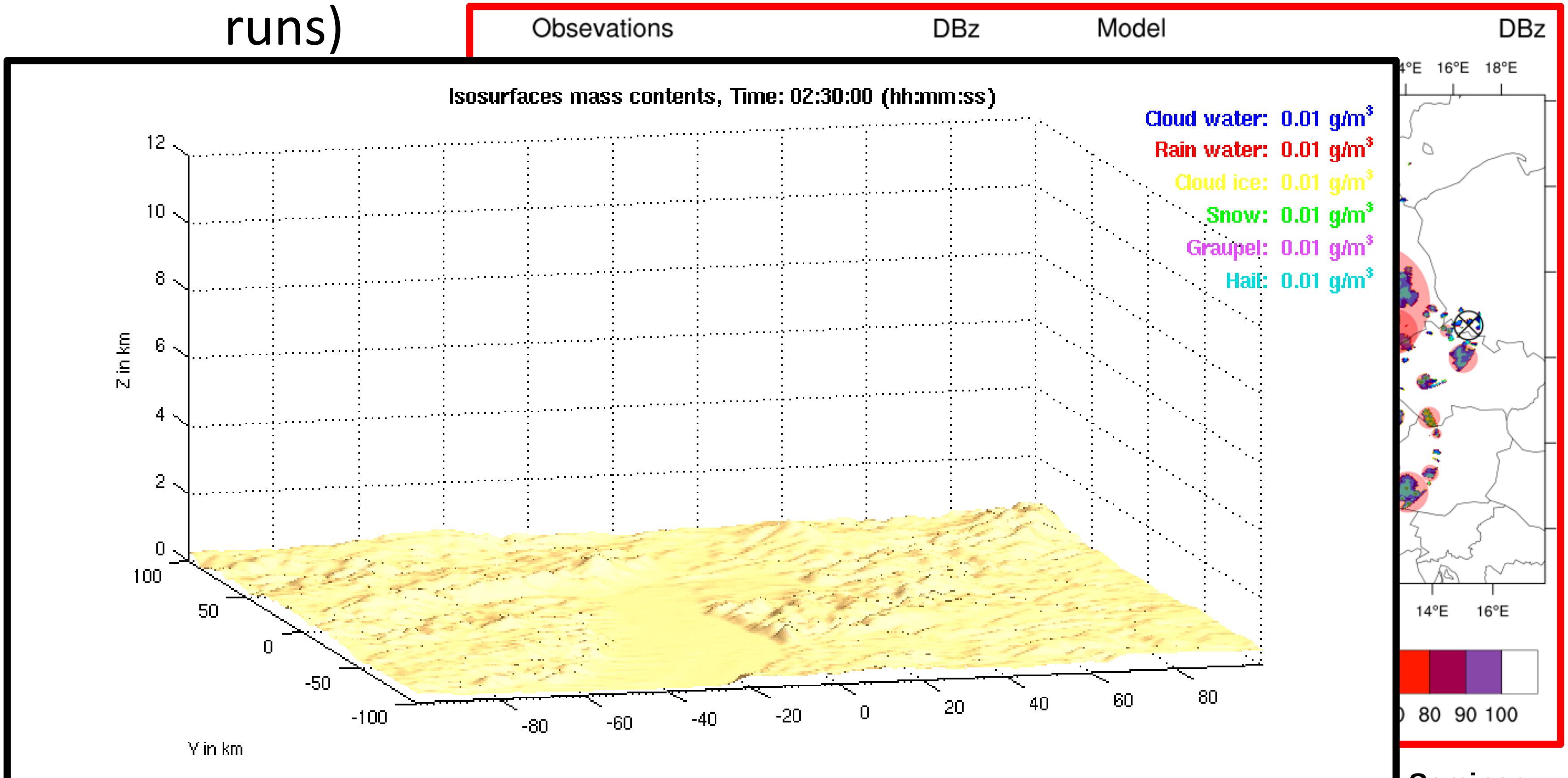
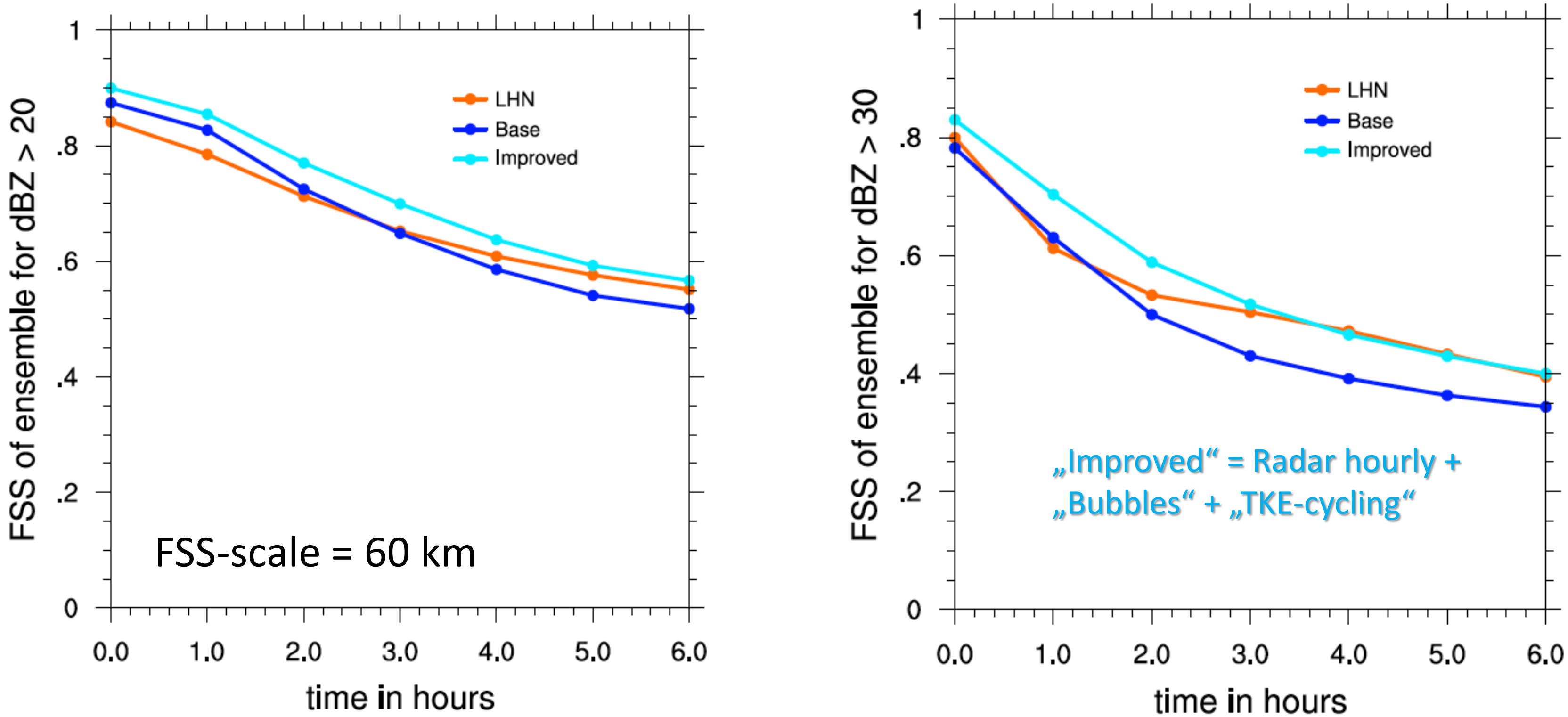
- LETKF has problems when no spread in ensemble, e.g., all members have 0 reflectivity but obs is > 0:
  - Automatic bubble generator every 15‘ in the model (fg-runs)



LHN versus Radar-LETKF

- Experiment COSMO-DE 2.8 km, hourly RUC (KENDA-DA), 27.5.-29.5.2016



1-Mom.-Scheme + **LHN**

1-Mom.-Scheme + **3D dBZ-DA (**first try)

1-Mom.-Schema + **3D dBZ-DA** (improved)

(Alberto De Lozar)

But High Reflectivities still not good (!)

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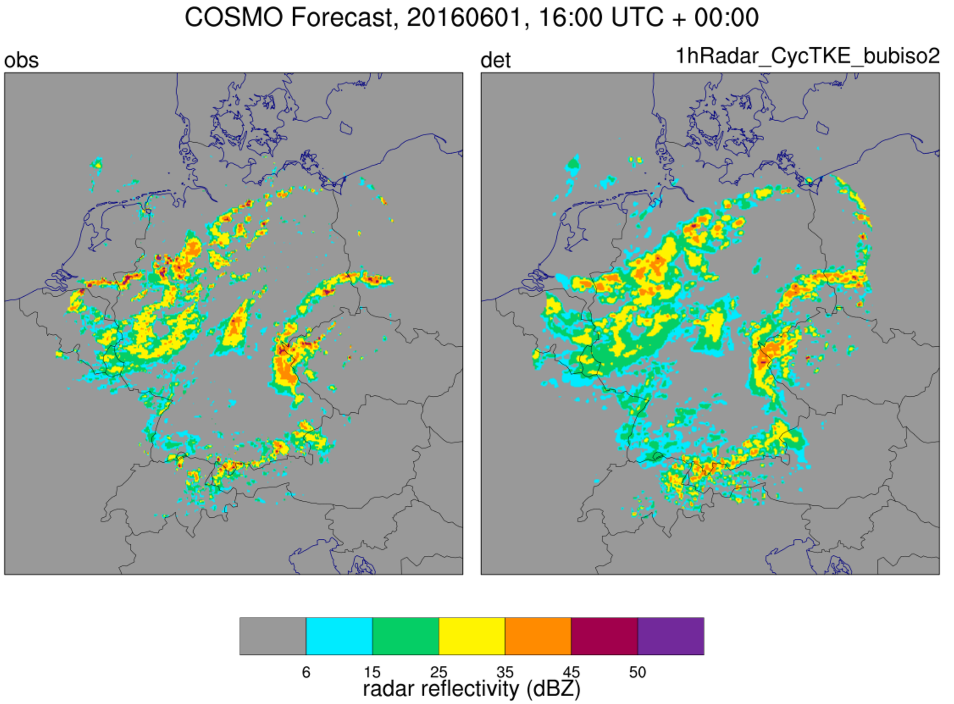

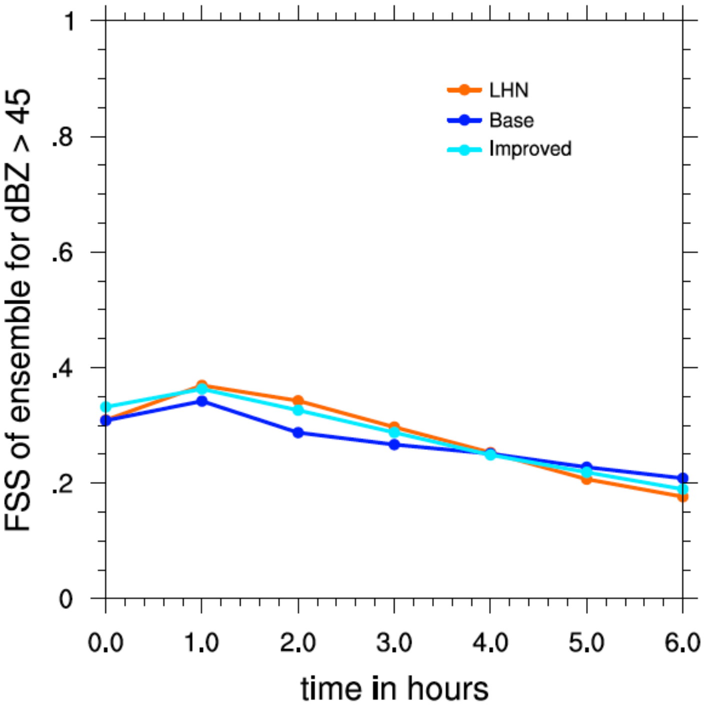

- A problem related to model microphysics:
  - COSMO 1-moment microphysics not aware of hail and not tuned to produce large graupel
  - Therefore too low reflectivities, especially above 0°-C-level

(Alberto De Lozar)

Try 2-moment-Scheme:

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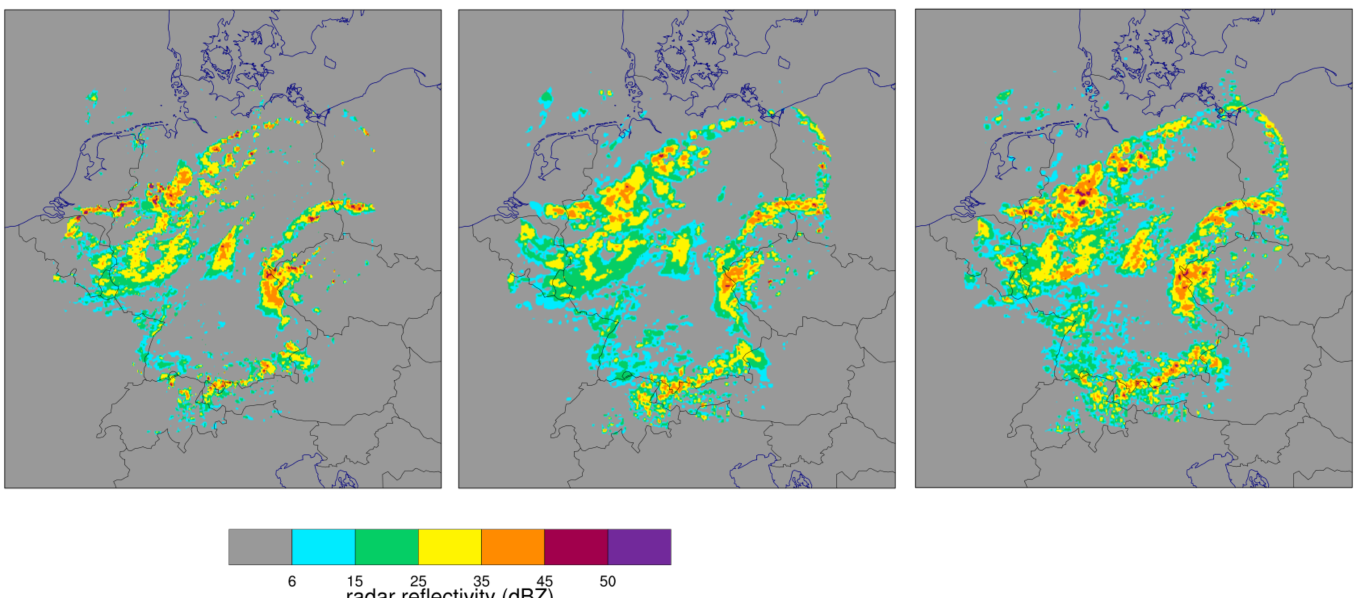
We test the 2-moment-scheme of Seifert and Beheng (2006) with additional hail class by Blahak (2008) and Noppel et al. (2010)

- Additional prognostic number concentrations
- More realistic particle sizes
- Additional hail class allowing for large hail particles
- But computationally more expensive!

Observation 1-moment 2-moment



(Alberto De Lozar)

2-Moment-Scheme gives better dBZ-scores

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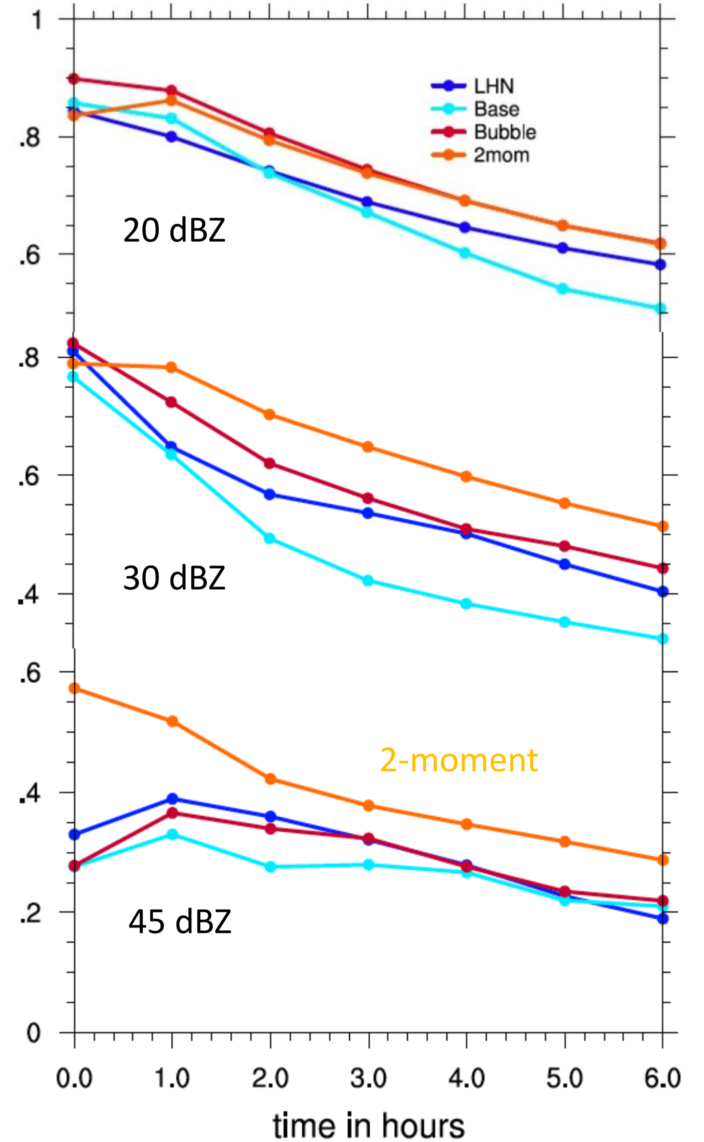
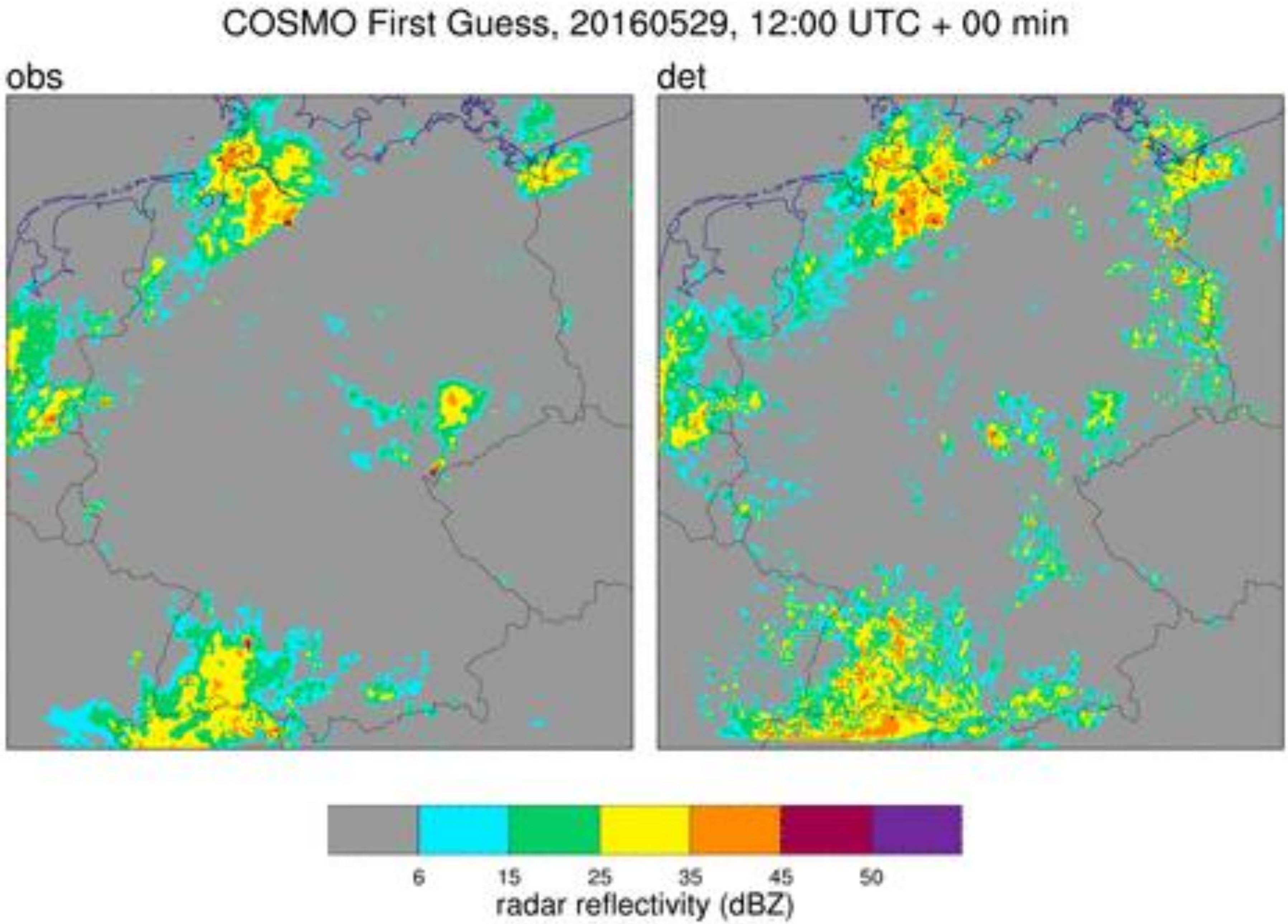
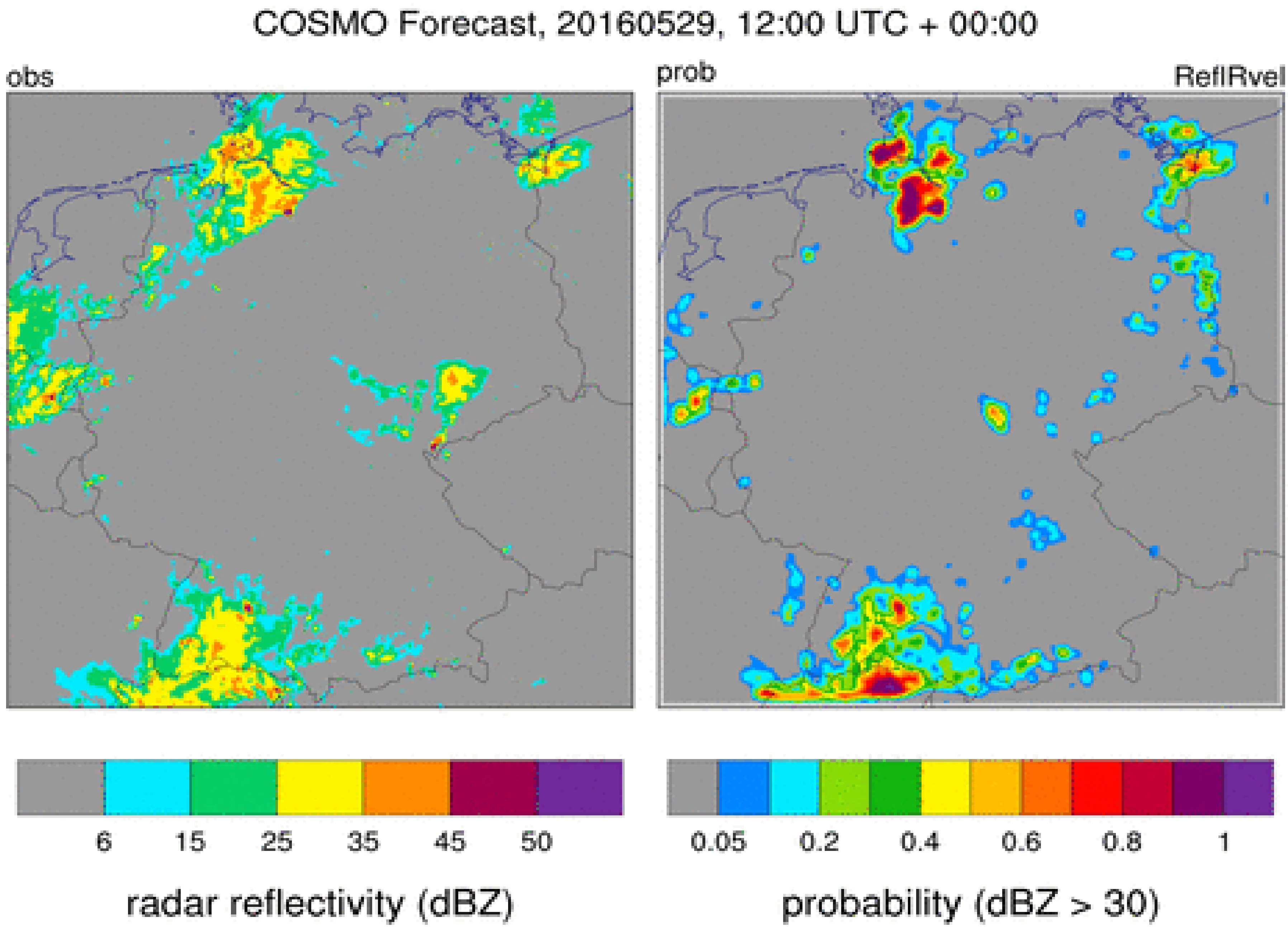
- 2-Moment-Scheme leads to better scores for higher reflectivities
- Scheme is not extensively tuned yet, large potential for improvements
- However, **worse scores for temperature and precipitation** at the moment! The rest of the COSMO-model is tuned to perform well with the 1-moment scheme!



(Alberto De Lozar)



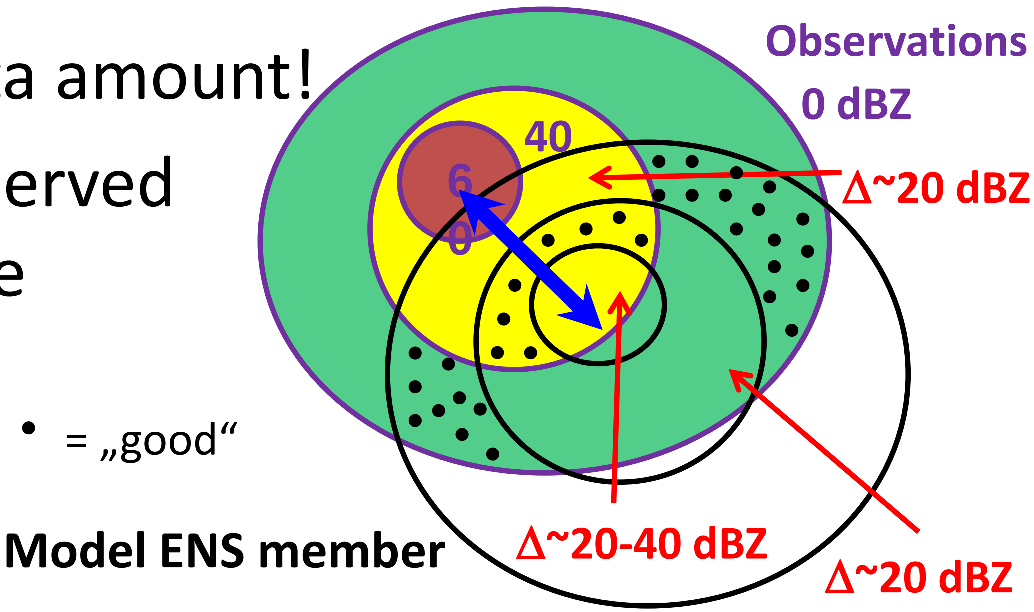
COSMO-KENDA-EPS (1.1 km, 2-mom) + Assim. dBZ, V_r (3D)



COSMO-KENDA-EPS (1.1 km, 2-mom) forecast

Why using (RADAR) Objects?

- „Double penalty“ when doing LETKF-DA pointwise
- Objects would allow **centroid distance** as quality measure
- Also: amplitude, lightning activity, core height, other object properties
- And: reduction of data amount!
- Objects based on observed and simulated volume scan composites



Be Careful !!! Don‘t mess up.

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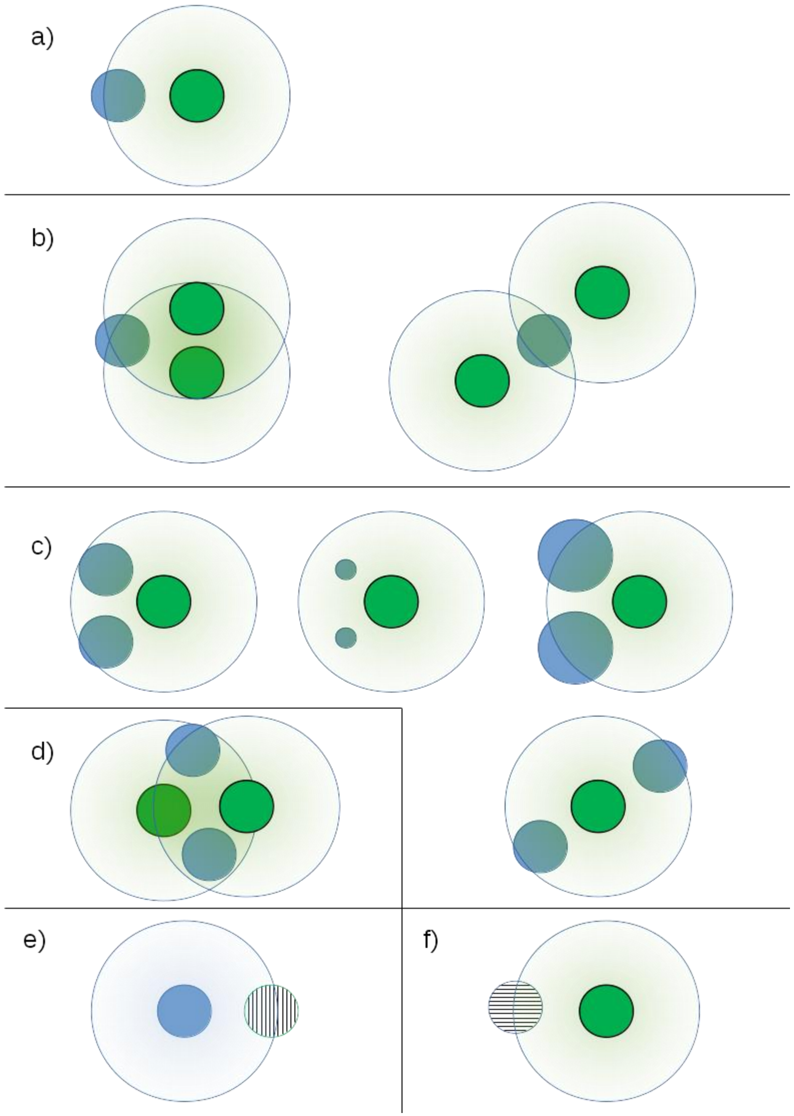
- **Matching:** Each object in obs and simul. ensemble member needs mutual counterpart!
- Easy if obs and sim have only 1 object each.
- But complex if not!
- In practice very difficult if not impossible at the moment!



Feasible Approach

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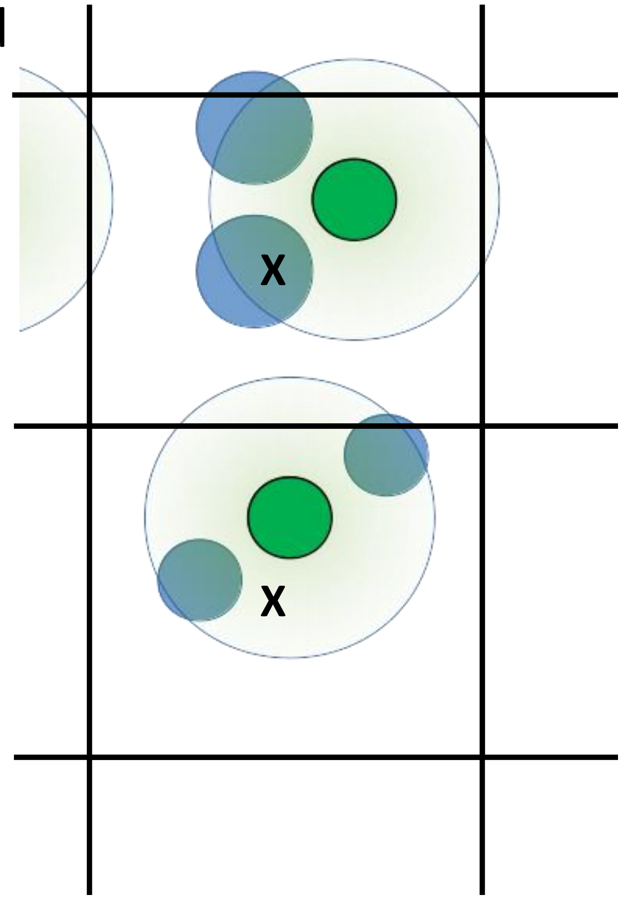
- Determine **object-related properties** as „averages" **in a local neighbourhood** around a fixed location **X** in space
  - Number of objects > threshold
  - Area > treshold
  - Mean distance obs – sim objects
  - Lightning activity
  - Echo tops, echo base …
- Do this both for **obs** and **simulations**
- Assimilate this „gridded" information locally at **X**
- At the moment just an idea, we are currently starting with it.



Further Parts of SINFONY

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- **Combined products:**
  - probabilistic ensemble NWC-NWV-object-based products
  - Ensemble NWC-NWV-derived probabilities of events in certain areas
  - Pseudo-deterministic product, e.g., automatic best member selection in forecast ensembles using most recent remote sensing data
- **Verification methods for NWC- and NWV-RUC ensembles:**
  - Object based
  - Reflectivity-based spatial and probabilistic verification
  - Comparing NWC and NWV

Contents

Real Time Weather and Ultra Rapid Data Assimilation (URDA)

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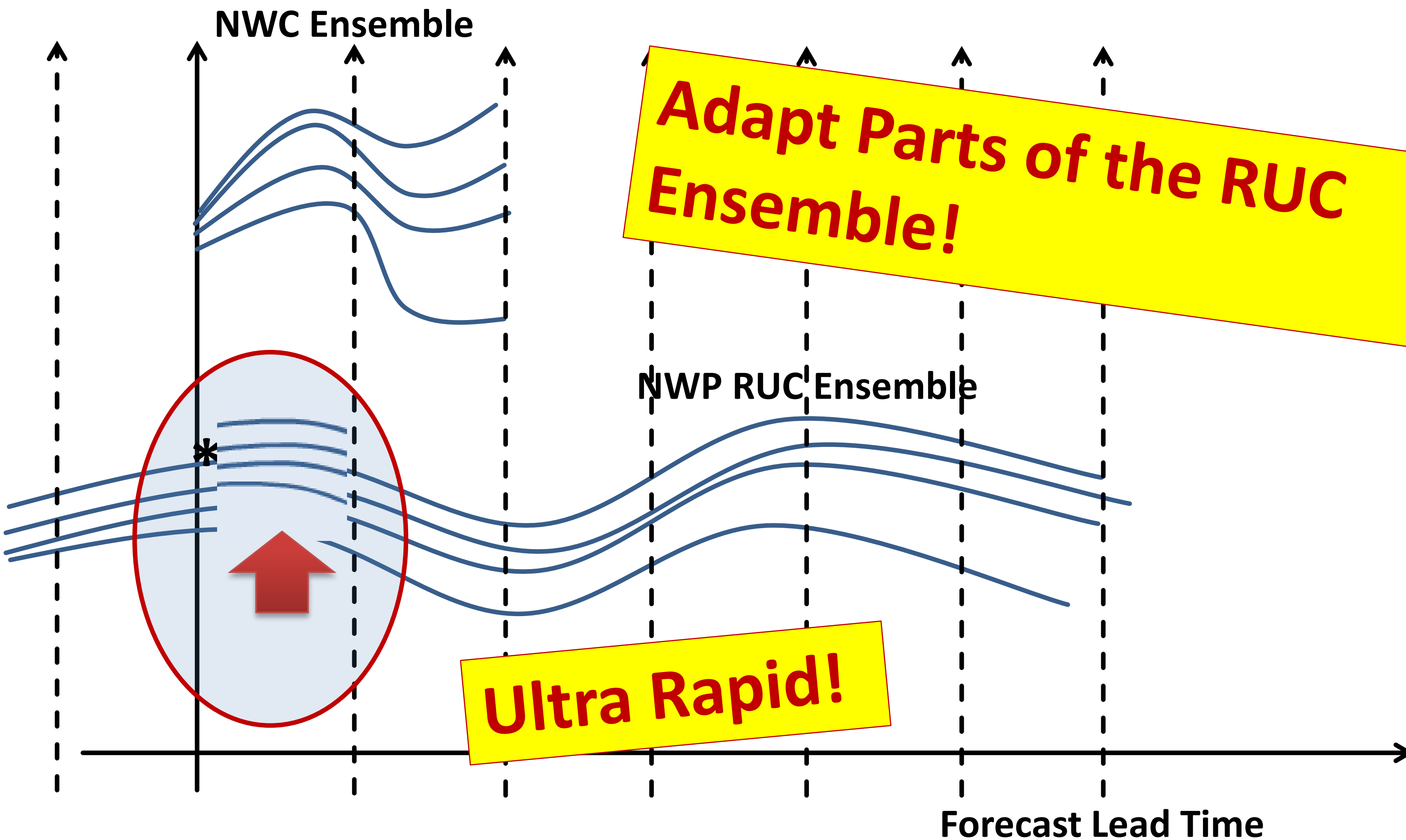

Zoi Paschalides, Walter Acevedo, Roland Potthast, Christian Welzbacher

Real Time Weather and Ultra Rapid Data Assimilation (URDA)

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Sensors + Nowcasting based on NWP-EPS, Real Time Weather for a Time Horizon of 5-60 Minutes

Real Time Weather and Ultra Rapid Data Assimilation (URDA)

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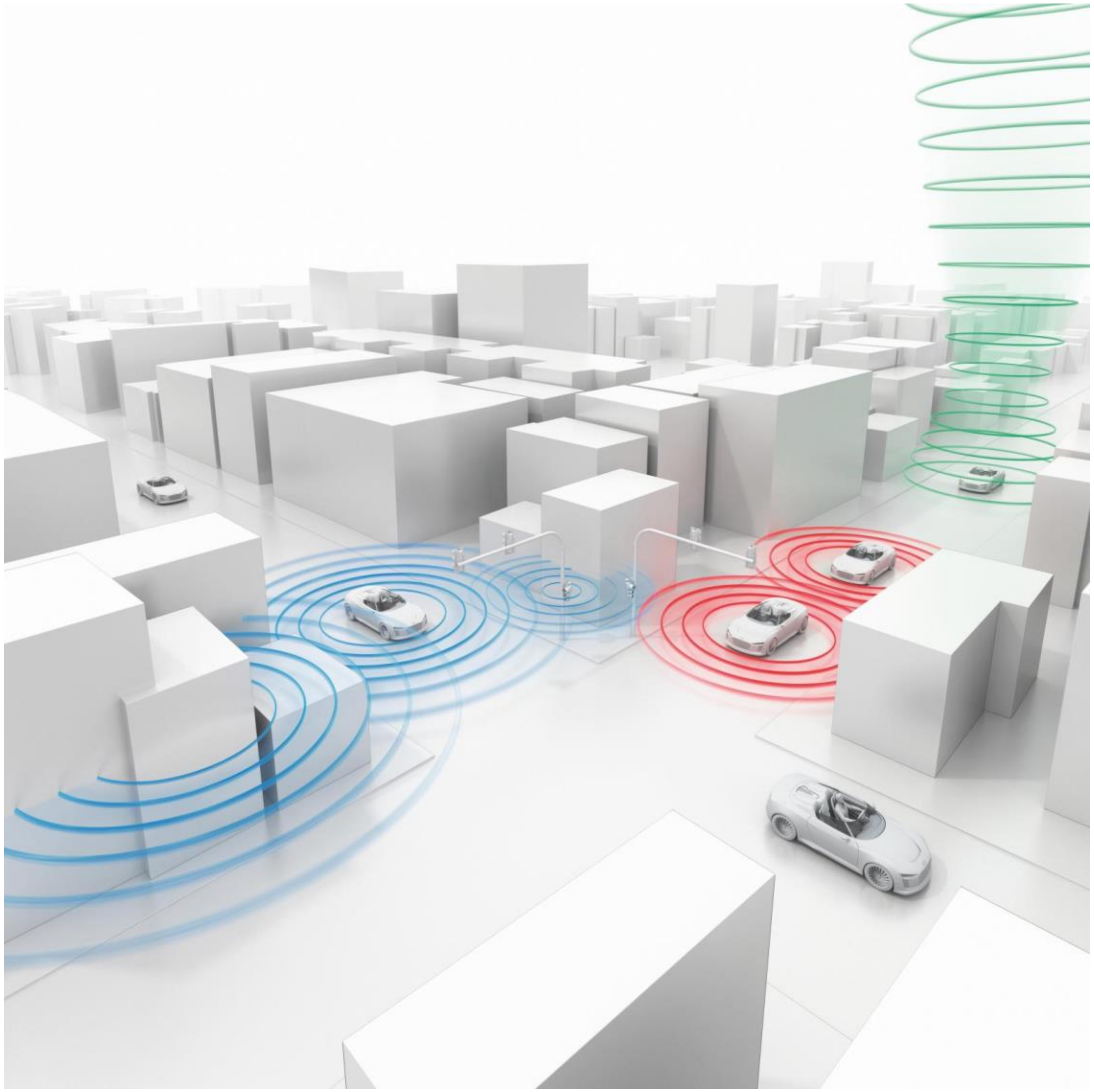

Updating **parts** of

- the **state x^a** and
- the **forecast x^f**

for the next **5-60** minutes by an ensemble DA step on the RUC EPS

✓ **LETKF based!**

First URDA Results …

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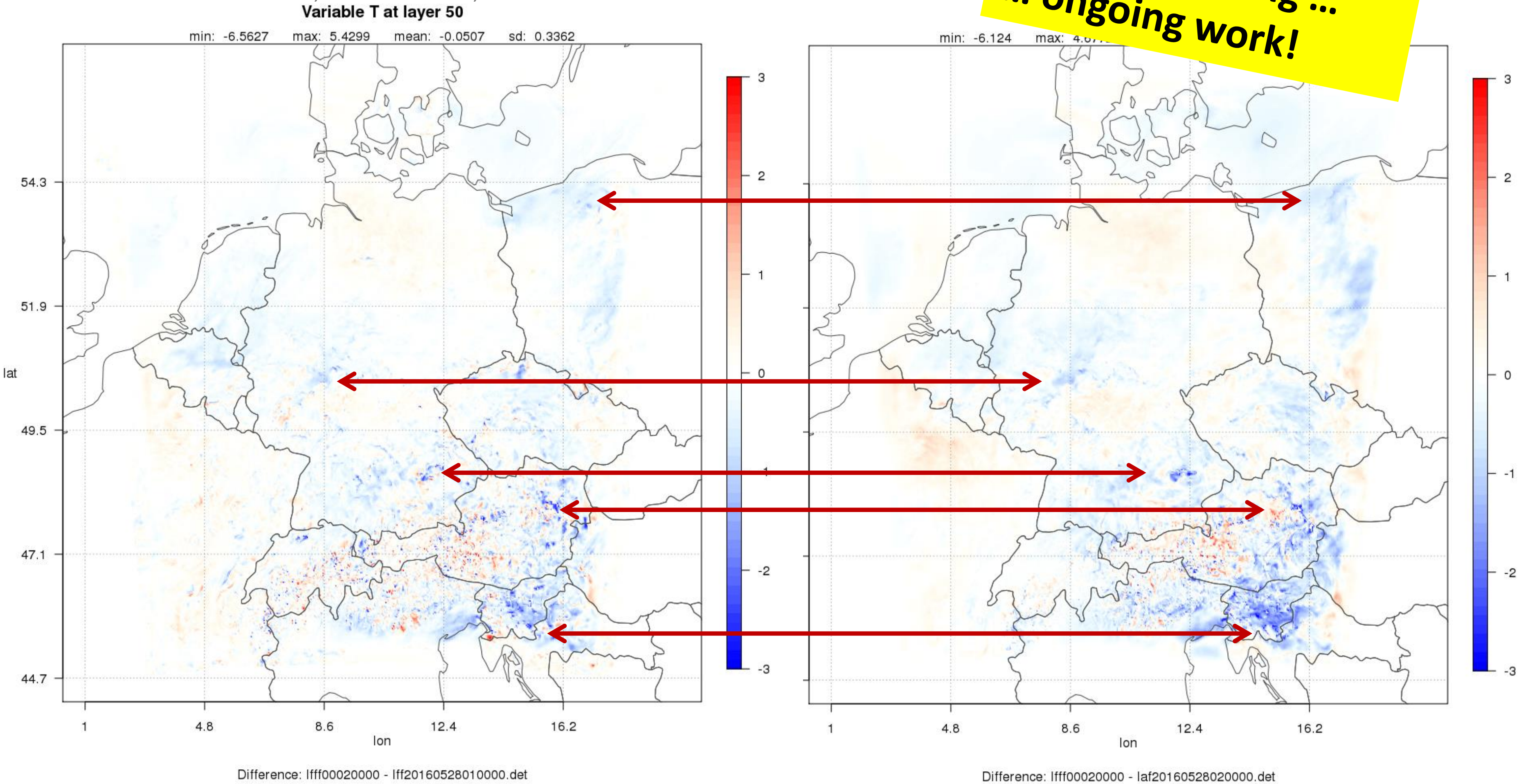
Zoi Paschalides, Walter Acevedo, Roland Potthast, Christian Welzbacher,
Elisabeth Bauernschubert, Hendrik Reich, Andreas Rhodin

Looks Promising …
… ongoing work!



Increments of Classical 1h forecast based on LETKF versus free 2h run

Increments of URDA forecast versus free 2h run

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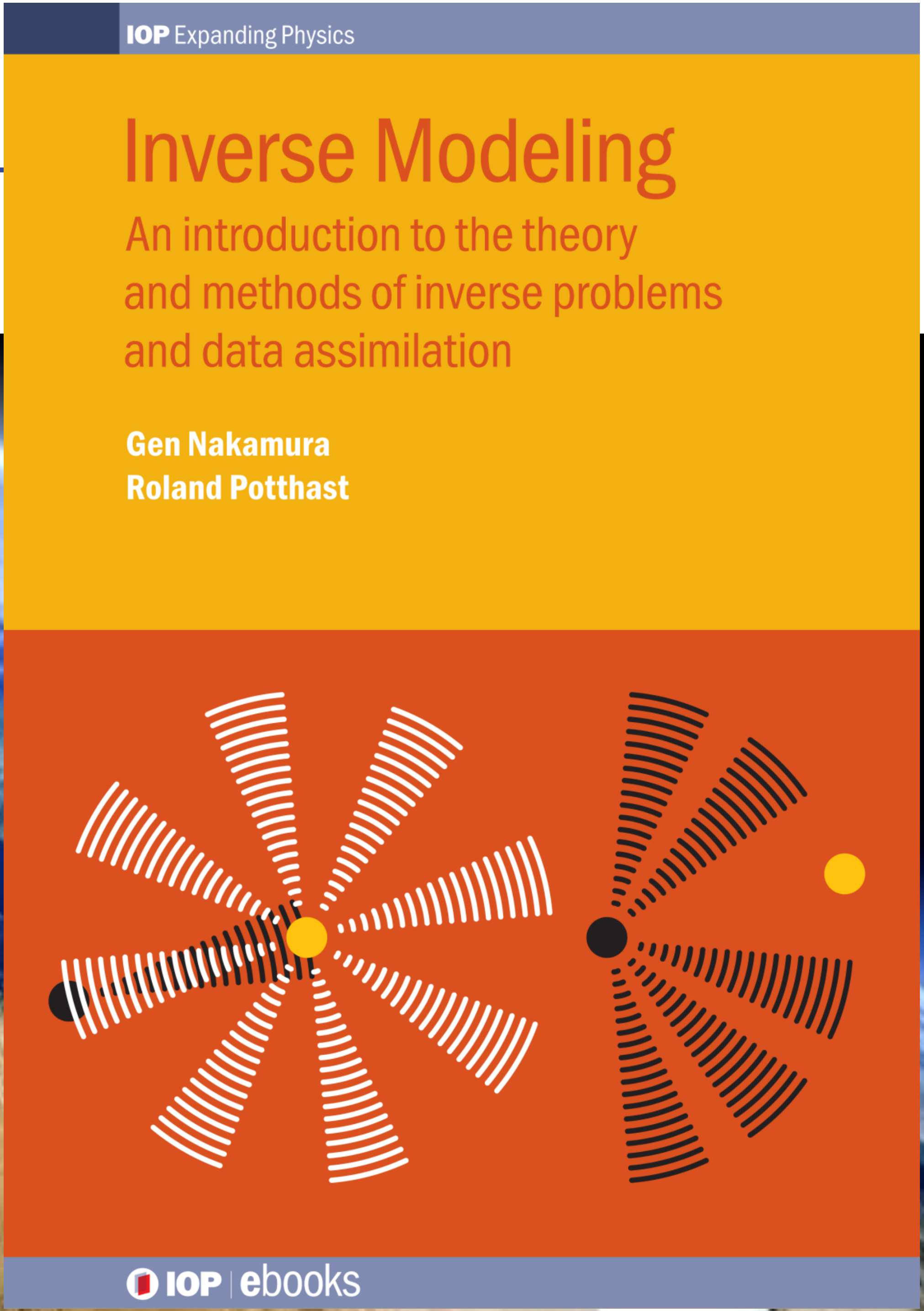
Many Thanks!



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