Explicit forecasting of deep convection with the operational convection-resolving model COSMO-DE

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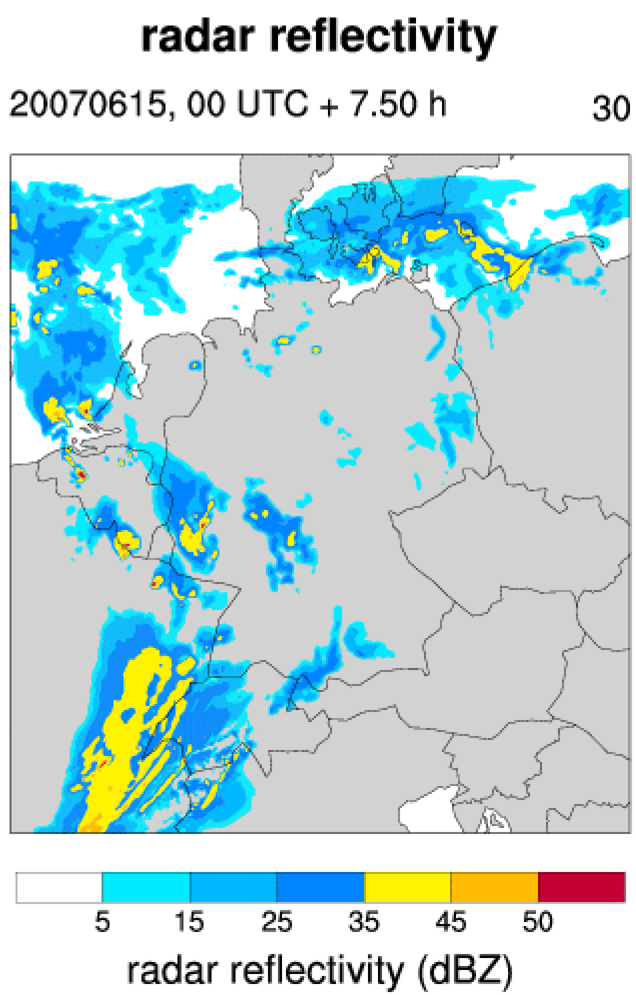
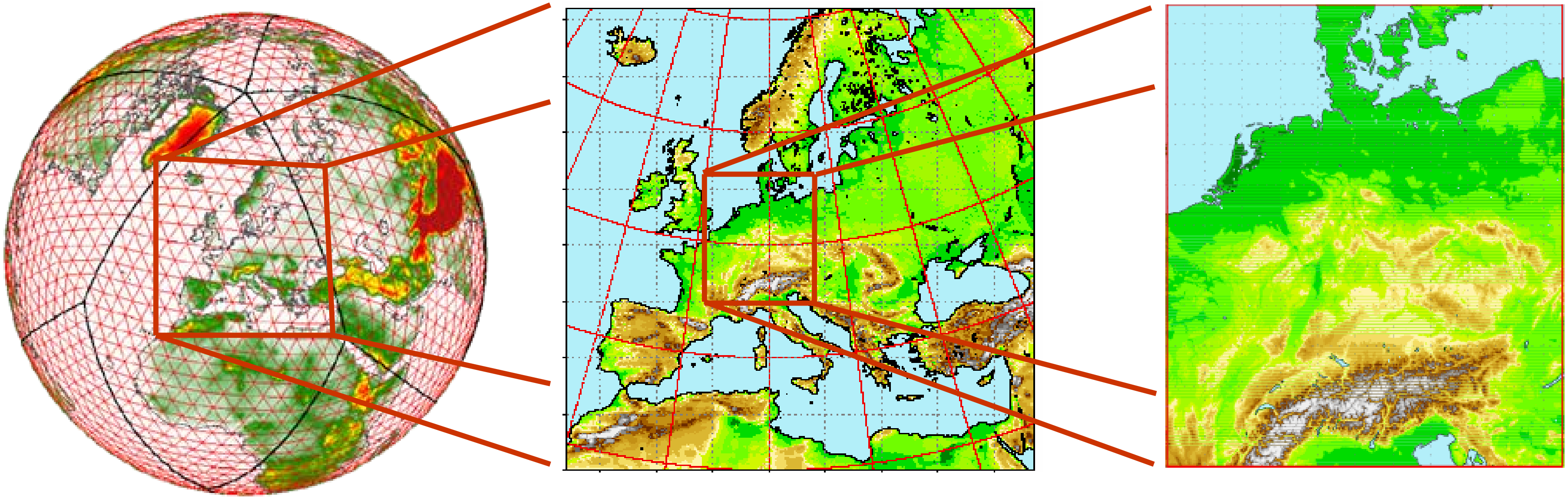


The operational NWP system at DWD

(since 16. April 2007)

GME 40 km | **COSMO-EU 7 km** | **COSMO-DE 2.8 km**

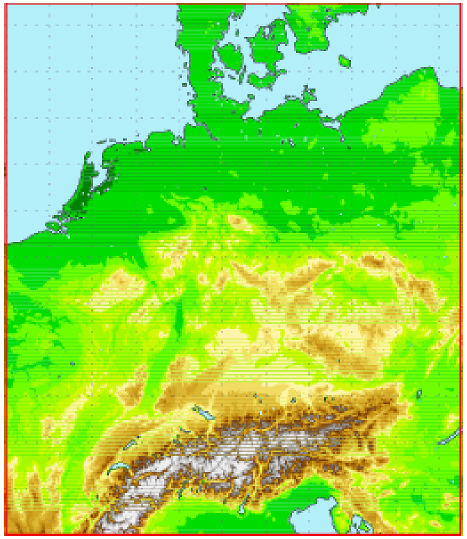


GME 40 km
- hydrostatic equations
- parameterized convection

COSMO-EU 7 km
- compressible equations
- parameterized convection

COSMO-DE 2.8 km
- compressible equations
- convection-resolving

Convection-resolving short-range model COSMO-DE

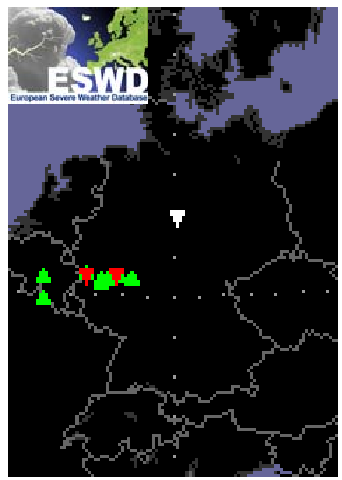


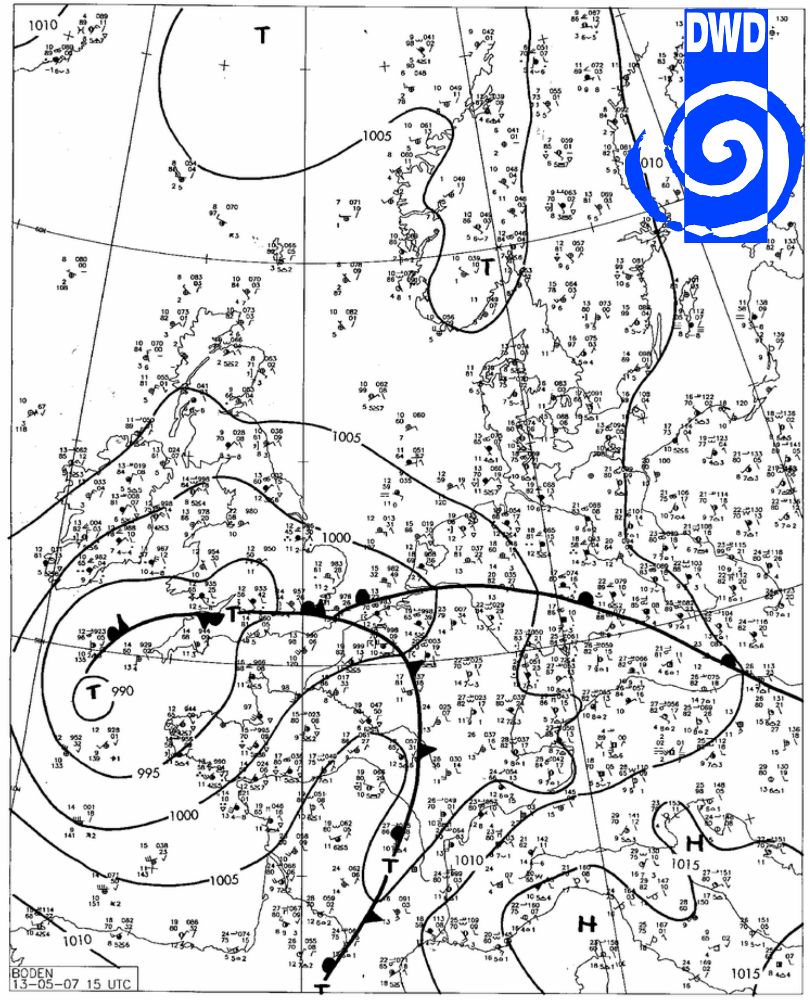
- Horizontal grid spacing: Δx = 2.8 km
- Vertical grid: 50 levels, starting at 10 m
- Domain: 1200 km x 1300 km (421 x 461 grid points)
- Timestep: Δt = 25 sec
- Runge-Kutta numerics (similar to WRF) with 5^{th} order horizontal advection
- Fully prognostic one-moment microphysics including graupel (similar to Lin et al. 1983)
- TKE-based 1D PBL scheme, Mellor-Yamada level 2.5
- Data assimilation using nudging, including radar data (latent heat nudging)
- Boundary data from 7-km COSMO-EU
- Rapid update cycle, 8 forecasts per day, but only 21h forecasts

Case study 13 May 2007:

In the evening of May 13 a cold front leads to the formation of a line of severe thunderstorms over Germany. According to the European Severe Weather Database the following events were observed:

- **F2 tornado near Kall-Sistig** at 19:15 UTC
- Possible **F0 tornado near Wirges** at 18:30 UTC
- Several reports of **large hail** up to 3 cm size in the area of Aachen/Koblenz





surface pressure, 13 May 2007 15 UTC

In addition, many reports of **observed supercells** from storm chasers.

The supercell detection index (SDI):

Following **Wicker, Kain, Weiss and Bright (2005),** who used this idea for the analysis of 4km-WRF forecasts during the SPC/NSSL Spring programm 2004, the supercell detection index (SDI) is defined as the correlation of vorticity and vertical velocity weighted by the mean vertical vorticity in an atmospheric column:

$$\boldsymbol{SDI_1} = \rho_{ij} \; \overline{\zeta}_{ij}$$

$$\rho_{ij} := \frac{< w' \zeta' >_{ij}}{\sqrt{< w'^2 >_{ij}} \sqrt{< \zeta'^2 >_{ij}}}$$

with < ... > = volume average (20 km * 20 km * [1.5..5.5 km])

$| SDI_1 | > 0.0003$ 1/s : minimum threshold for supercells

$| SDI_1 | > 0.003$ 1/s : significant signal for supercells

$SDI_1 > 0$: updrafts, $SDI_1 < 0$: downdrafts

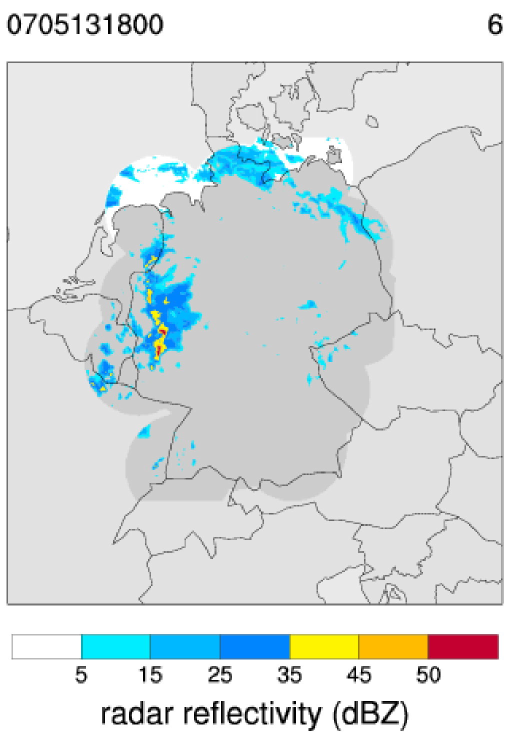
Wicker et al. (2005) define an $\mathbf{SDI_2}$ with:

$SDI_2 \neq 0$, only for w>0, i.e. only updrafts
$SDI_2 > 0$, positive (cyclonic) vorticity
$SDI_2 < 0$, negative (anti-cyclonic) vorticity

Case study 13 May 2007: Radar reflectivity

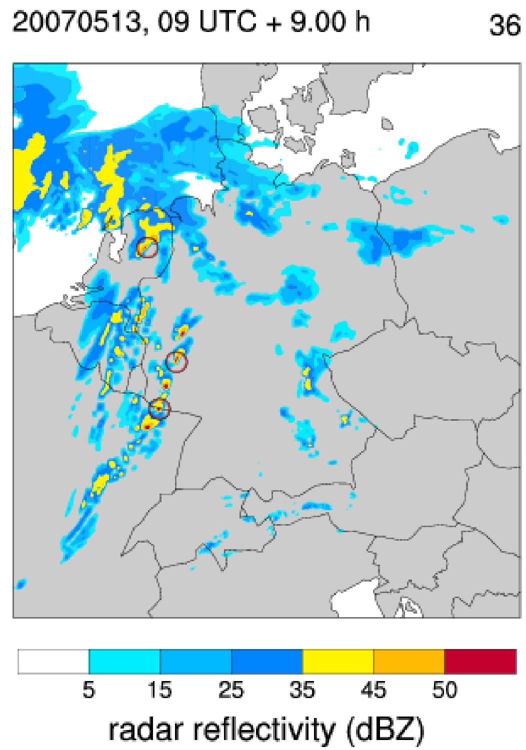
Base reflectivity

German composite



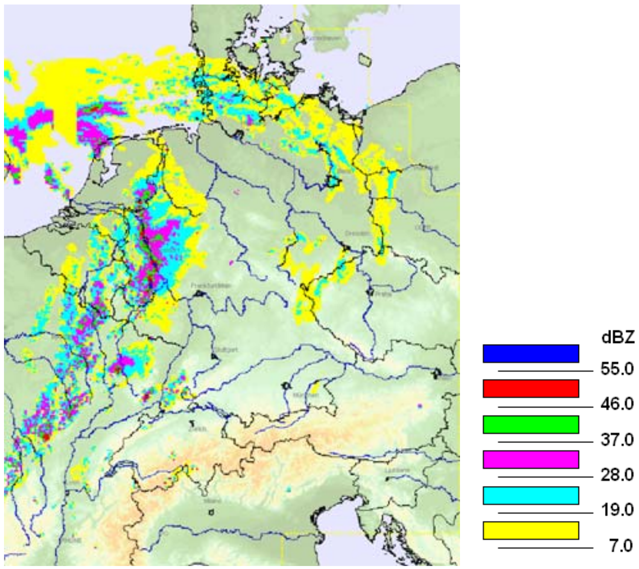
COSMO-DE

09 UTC model forecast



Base reflectivity

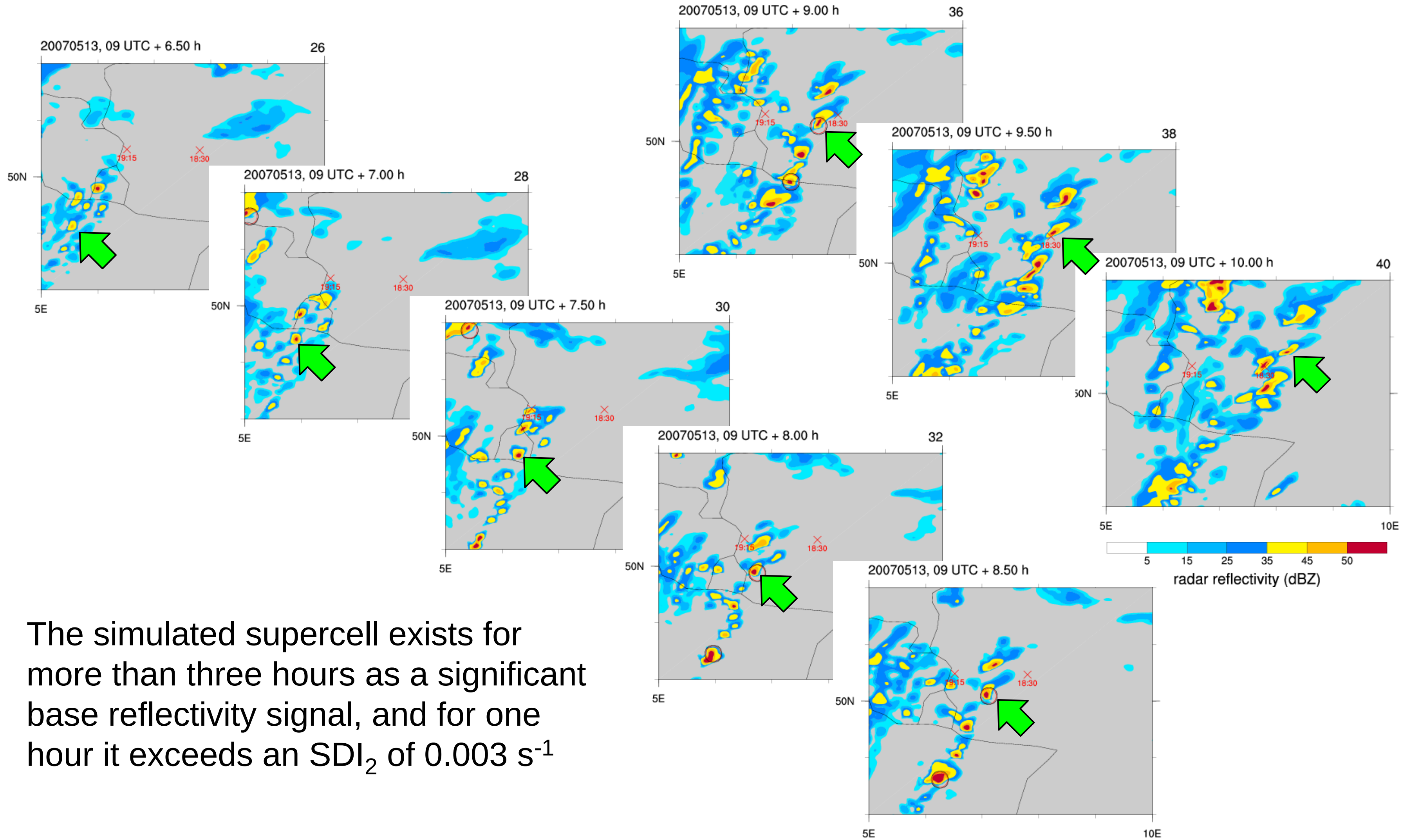
European composite



Convection-resolving NWP model COSMO-DE develops strong deep convection along the cold front, but more and smaller cells than observed.

Case study 13 May 2007: Supercells

COSMO-DE, 09 UTC model forecast, 6.50 h – 10.00 h

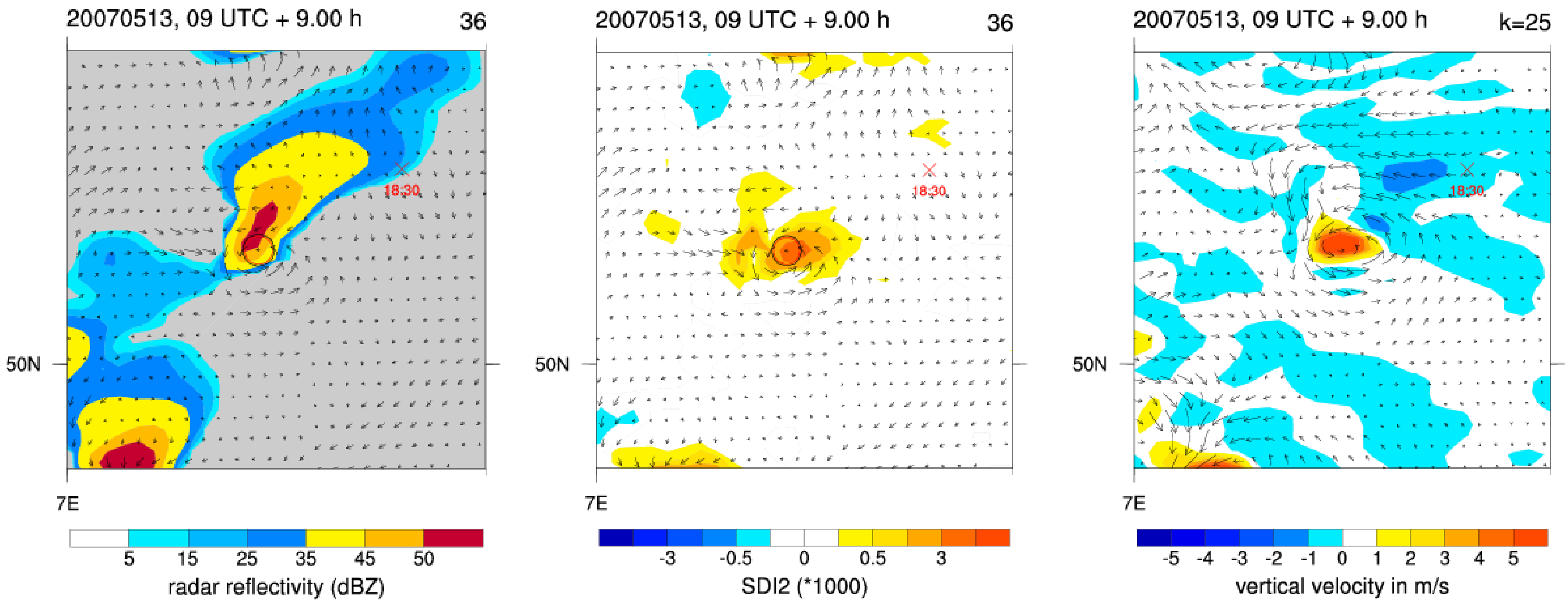


The simulated supercell exists for more than three hours as a significant base reflectivity signal, and for one hour it exceeds an SDI_2 of 0.003 s^{-1}

Case study 13 May 2007: Supercells

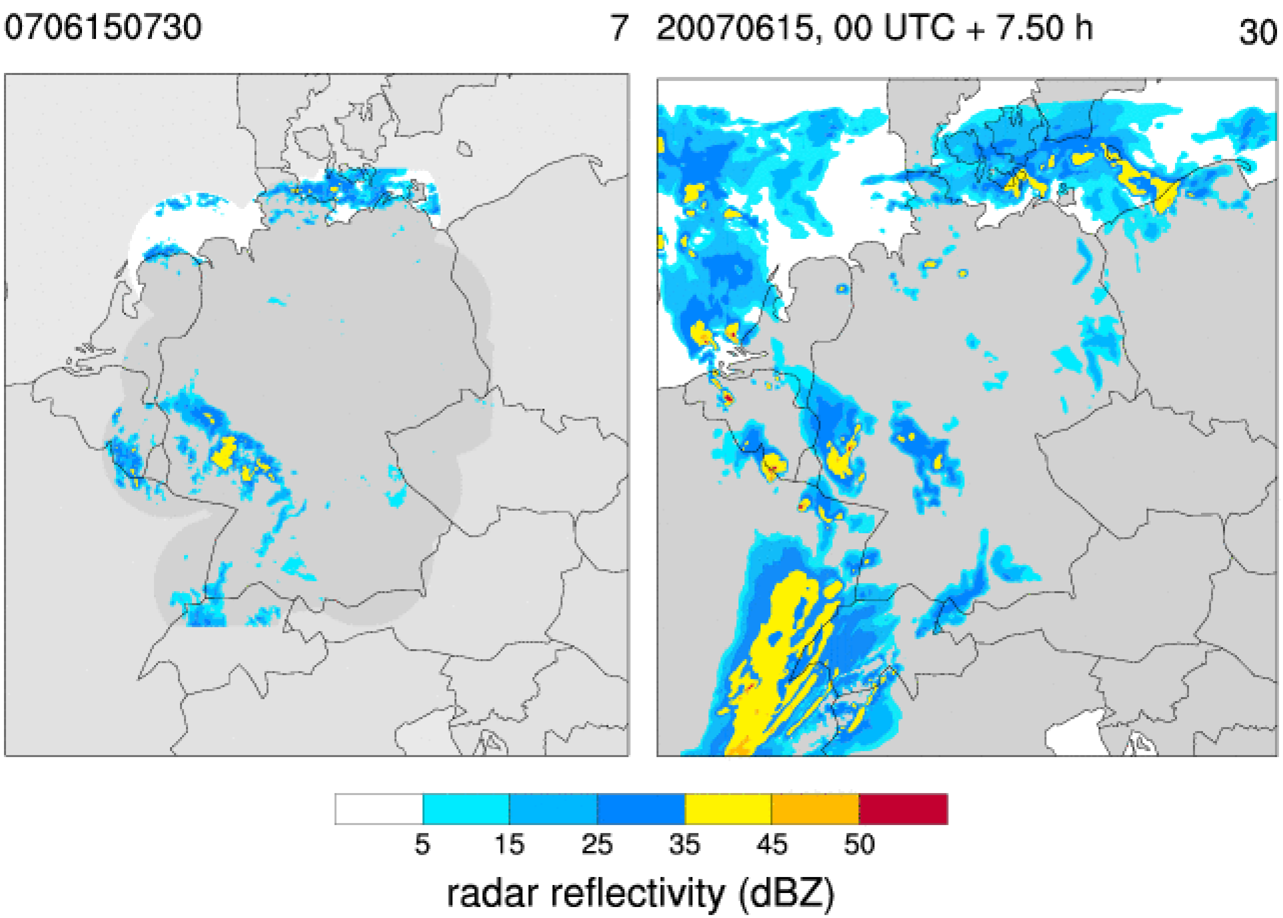
COSMO-DE, 09 UTC + 09 h model forecast

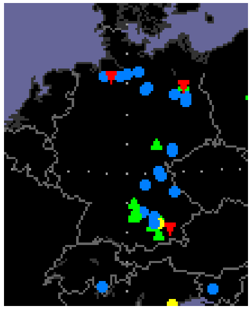
radar reflectivity | **supercell detection index** | **vertical velocity**



The model is indeed able to develop some significant mesocyclones!

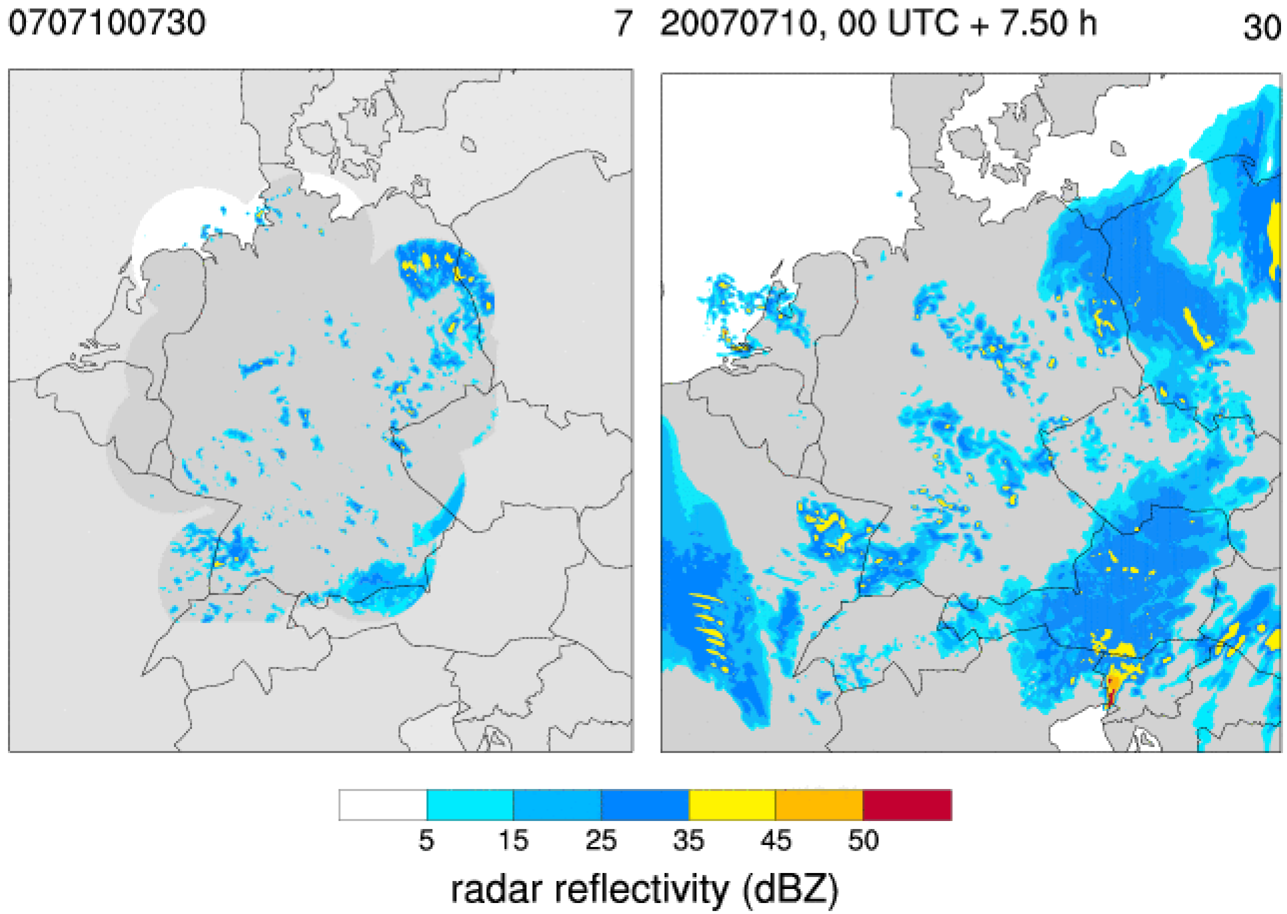
Radar composite and model reflectivity: 15 June 2007





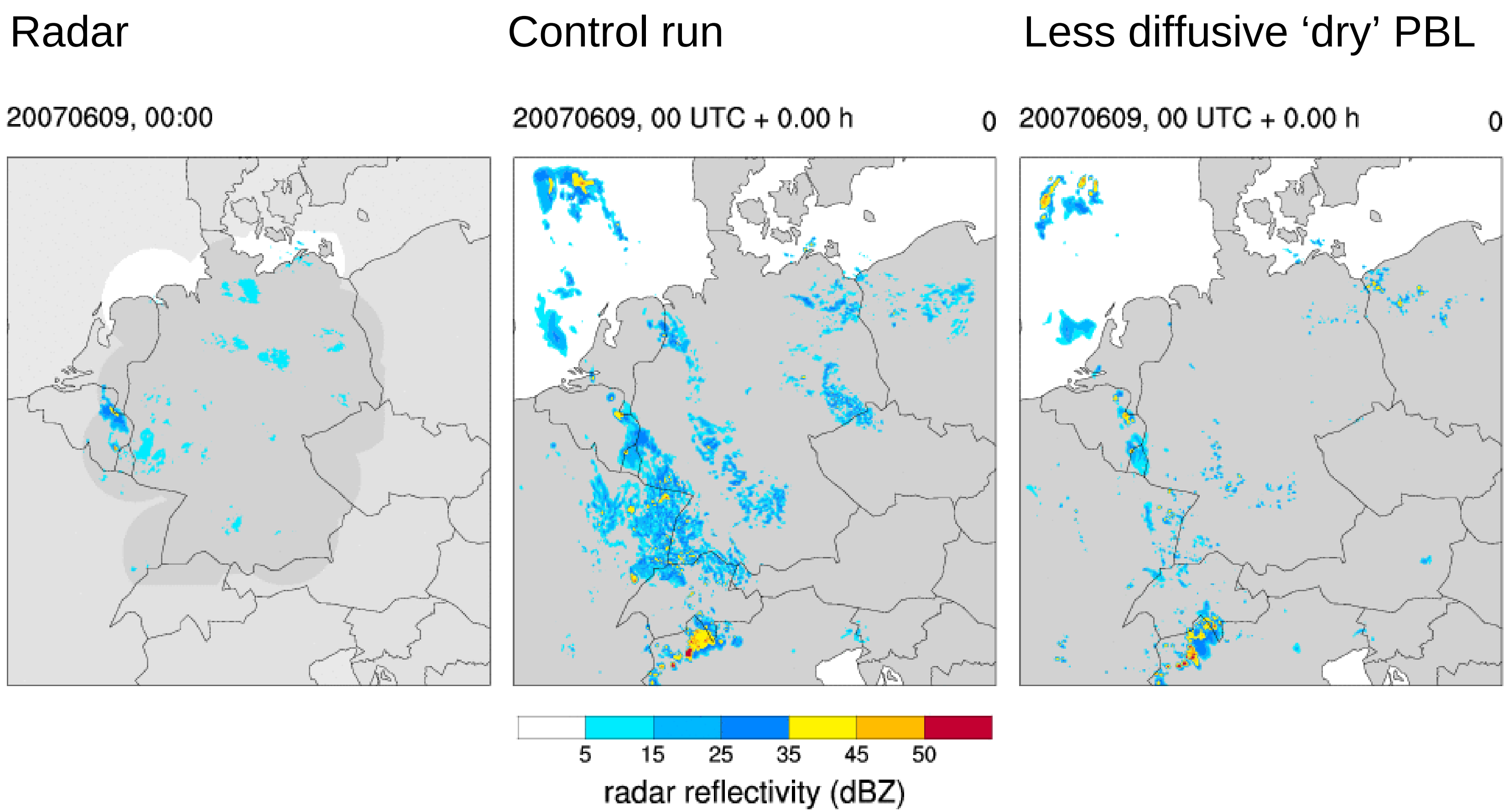
- The SDI identifies the squall line in Bavaria as being severe with many supercell structures, also other storms on that day are simulated as long-lived supercells.
- In fact a F1 tornado was reported in Bavaria, another F2 was observed north-east of Bremen and (maybe) a F1 near Berlin.

Radar composite and model reflectivity: 10 July 2007



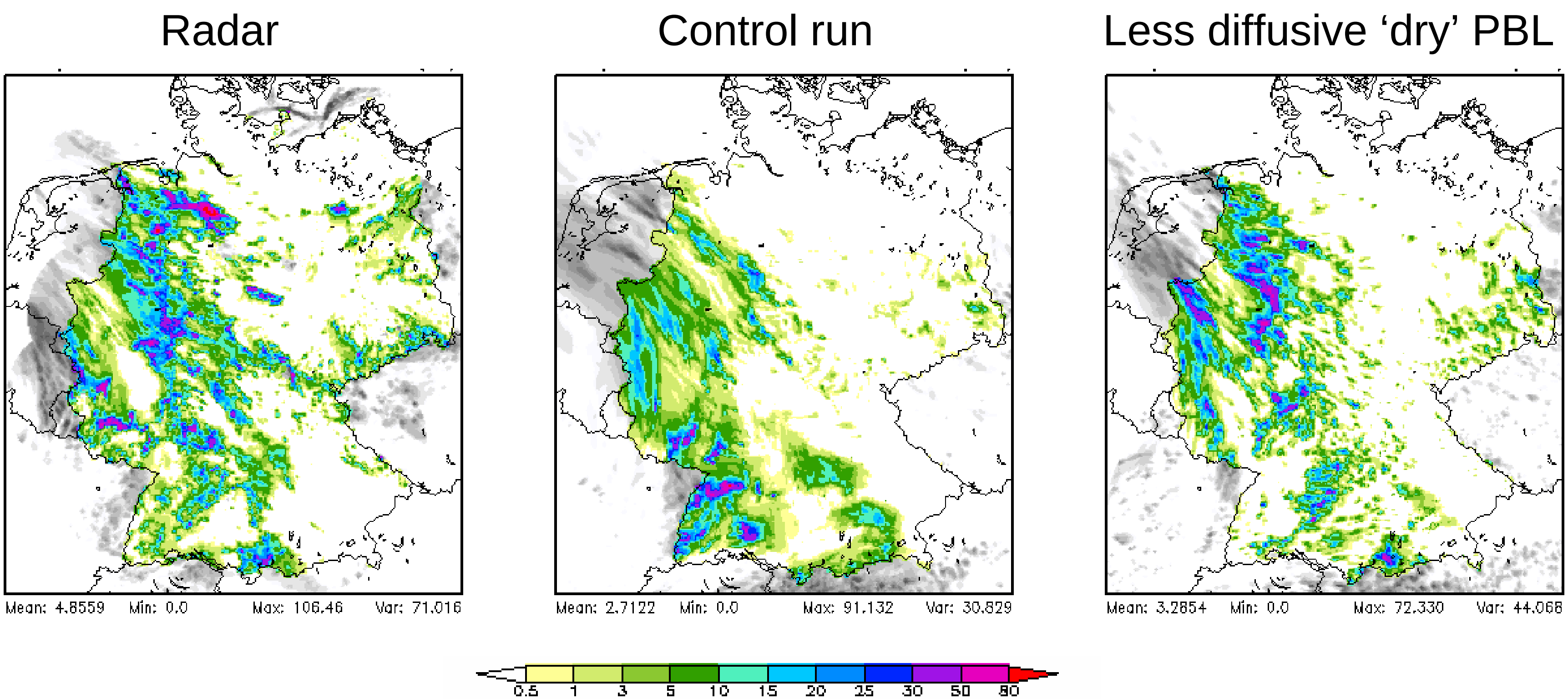
- Also for less organized small-scale short-lived convection the model works surprisingly well.

Sensitivity to PBL scheme: 09 June 2007



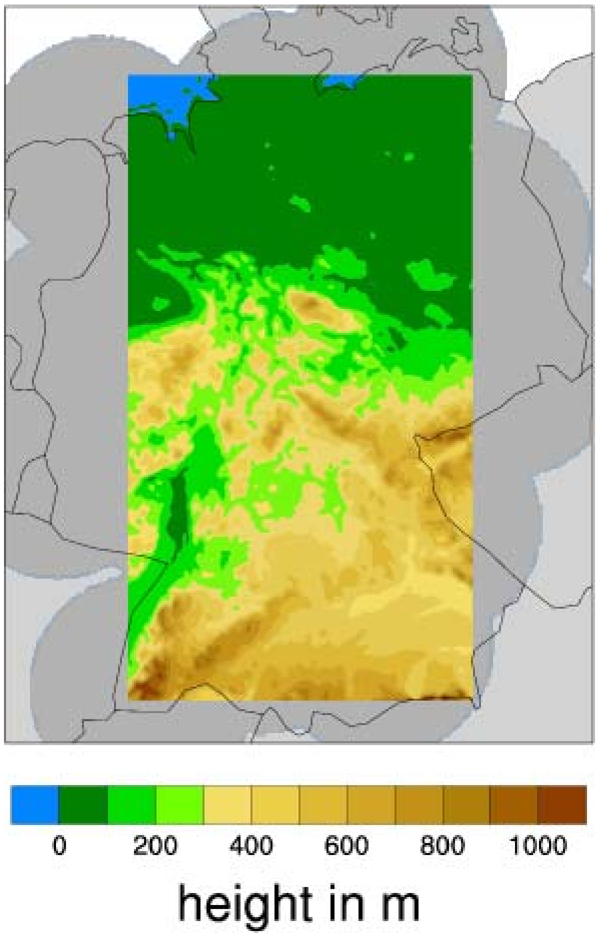
- Changing the PBL scheme, here using a smaller asymptotic Blackadar mixing length and 'dry' instead of 'moist' turbulence, has a quite large impact on the simulated deep convection and precipitation.

Sensitivity of QPF to PBL scheme: 09 June 2007

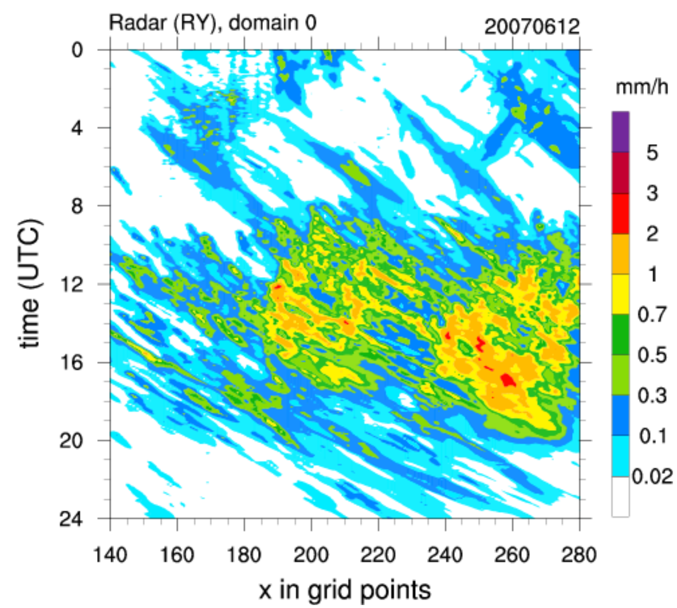


- Changing the PBL scheme significantly improves the QPF for this case
- Remaining underestimation is within the predictability limits and the uncertainty of the radar estimate

Hovmöller diagrams of precipitation (following Carbone et al. 2003)



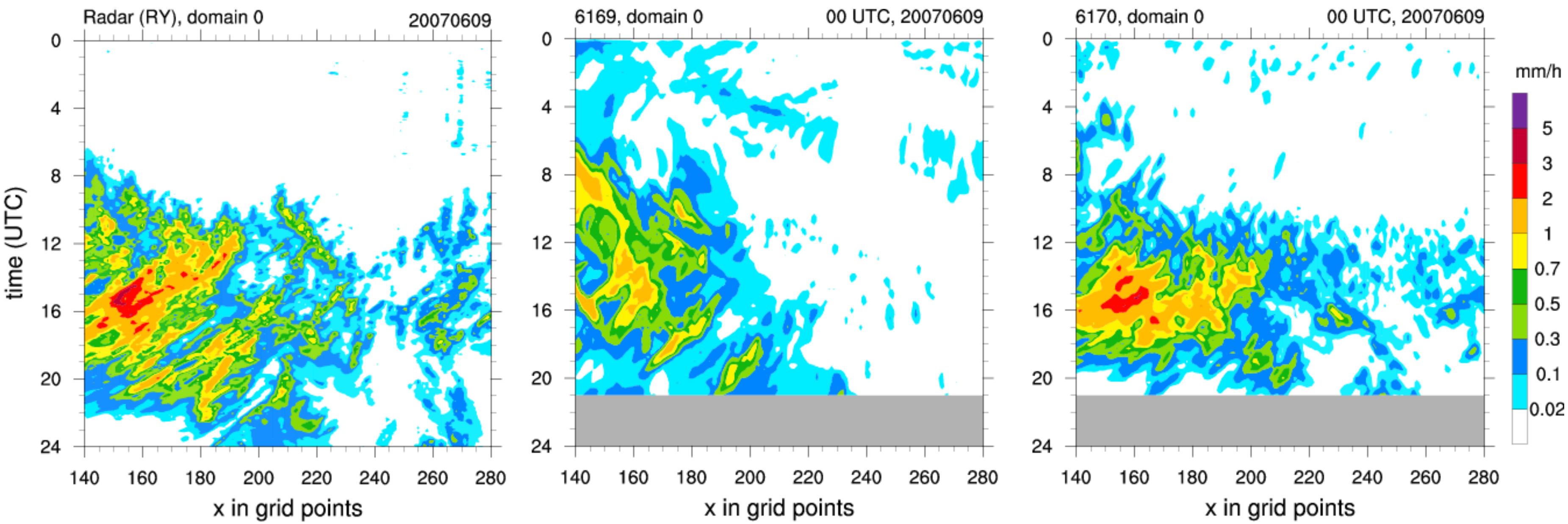
- Chose subdomain with full radar coverage
- Average the precipitation rate in north/south-direction
- Plot that average as a function of time and longitude (or ***x*** grid point)



Example: Radar-derived precipitation for 12 June 2007

Sensitivity to PBL scheme: 09 June 2007
Hovmöller diagrams of precipitation

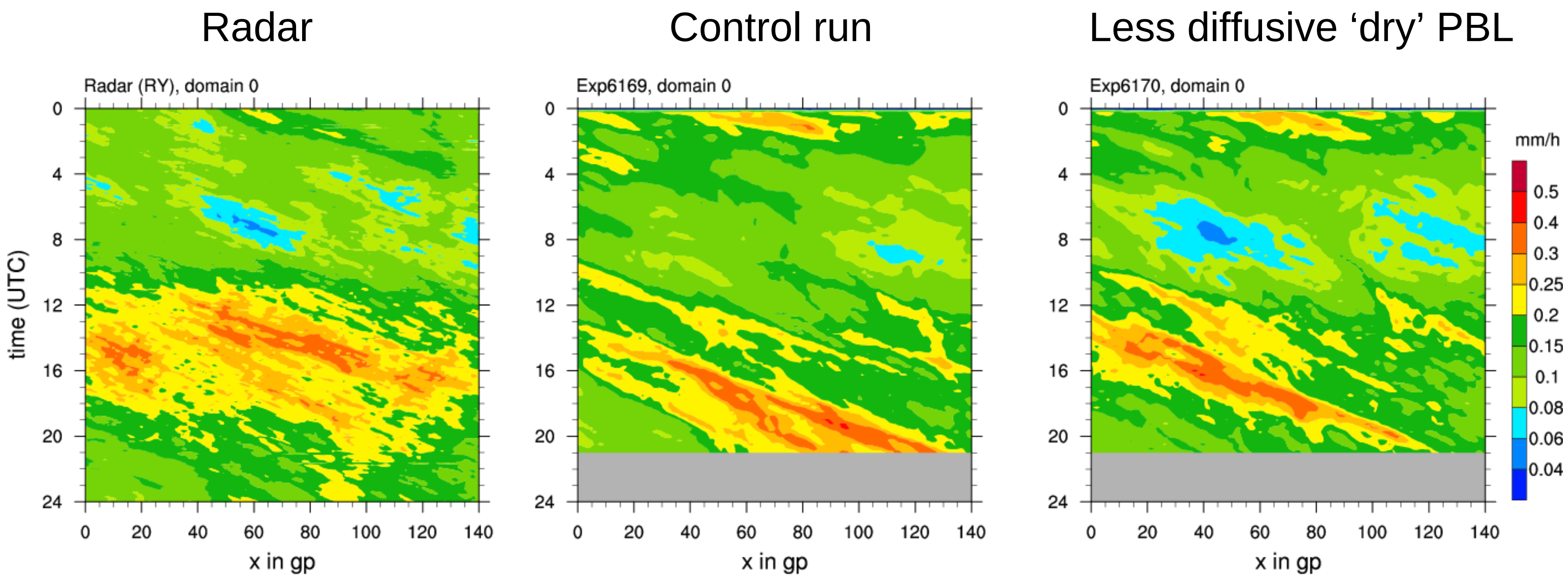
Radar | Control run | Less diffusive ‘dry’ PBL



- Changing the PBL scheme significantly improves timing and location of the precipitation forecast for this day.

Sensitivity of the diurnal cycle to PBL assumptions:

Precipitation average Hovmöller diagrams for Germany from 1 June to 21 July 2007

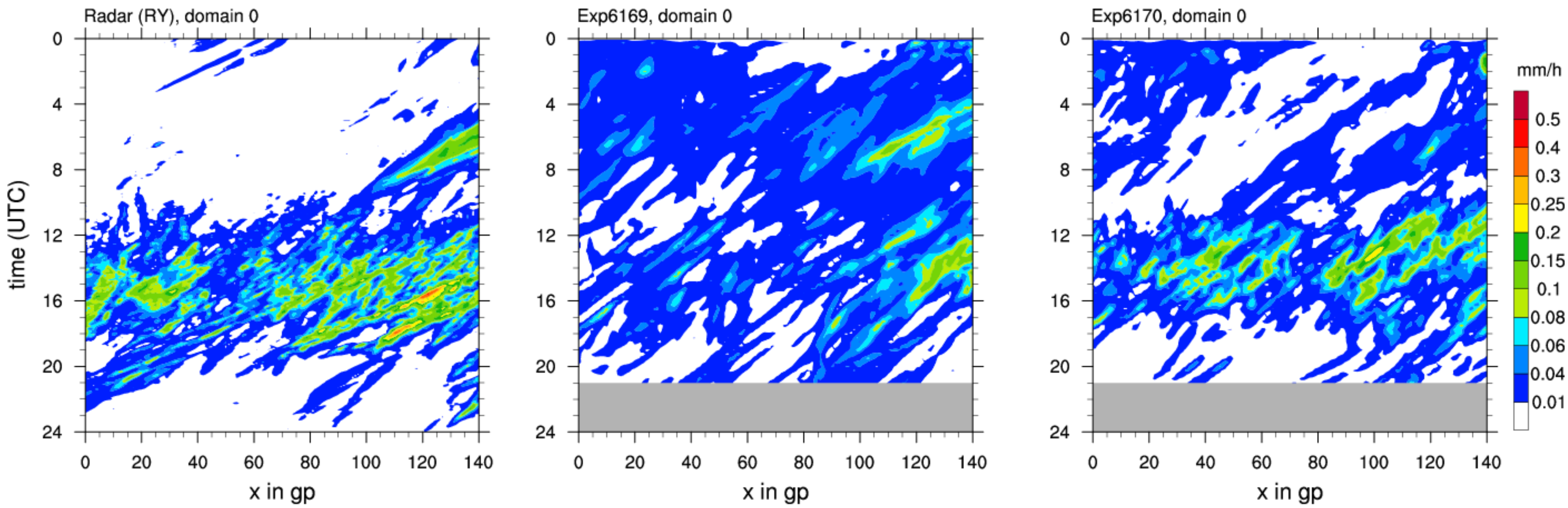


- The radar observations show a pronounced diurnal cycle
- The current version of COSMO-DE predicts the precipitation too late during the day
- The modified PBL scheme can help to get a little bit, but not as much as expected…

Sensitivity of the diurnal cycle to PBL assumptions:

Precipitation average Hovmöller diagrams for Germany from 2 June to 8 June 2007

Radar | Control run | Less diffusive 'dry' PBL

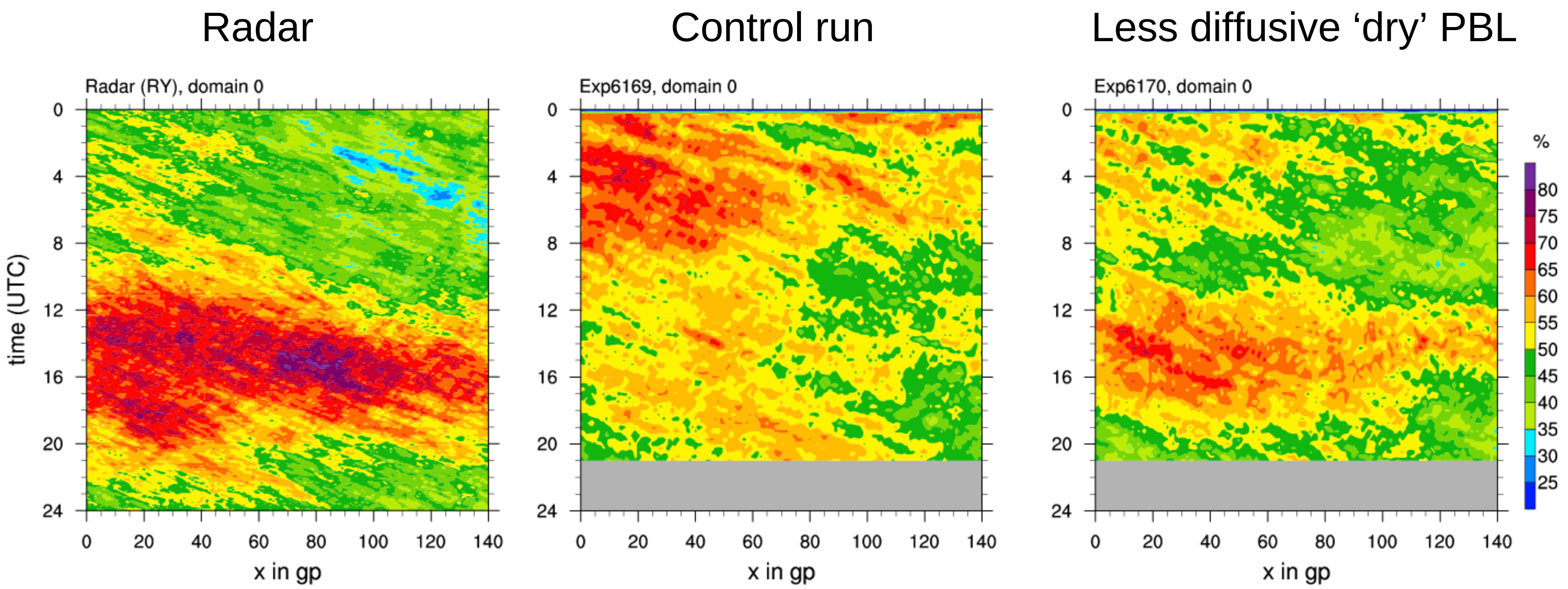


- This short period is dominated by air mass convection and orographic convection
- The current version of COSMO-DE has problems with these cases
- The modified PBL scheme does much better during that period

…. so, it depends on the choice of the period …. or we have to change the diagnostic…

Sensitivity of the diurnal cycle to PBL assumptions:

Precipitation frequency Hovmöller diagrams for Germany from 1 June to 21 July 2007

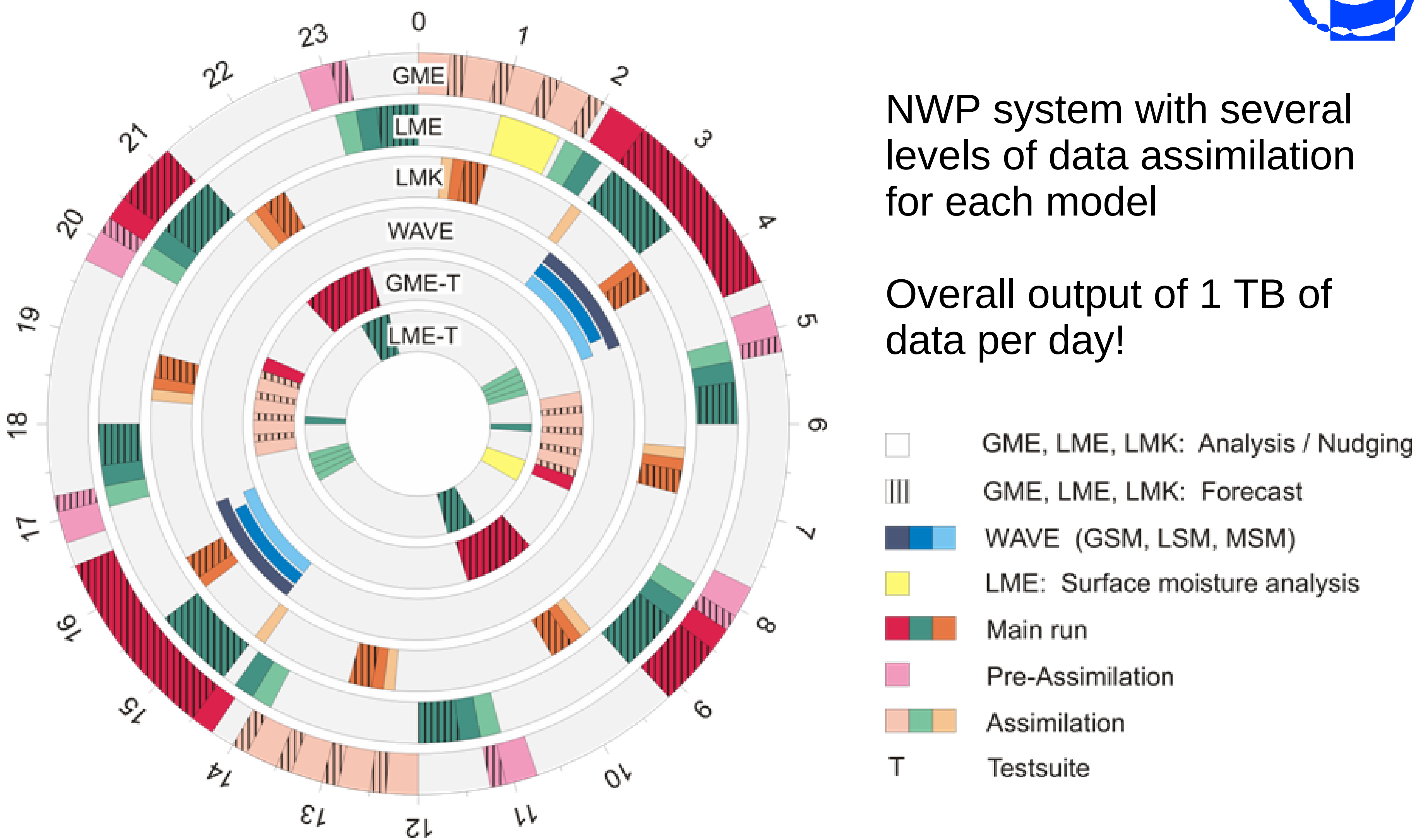


- Now the radar observations show an even more pronounced diurnal cycle
- The current version of COSMO-DE is not able to reproduce this diurnal cycle
- A modified PBL scheme can help to get the diurnal cycle even on a 2.8 km grid
- Obviously the mass average is dominated by larger-scale events, therefore the frequency diagram ist better for looking at the air mass / orographic convection which is weaker than the forced convection.

Summary, Conclusions and Outlook

- The NWP system at DWD has been extended towards the convection-permitting scale by the 2.8 km model COSMO-DE (formerly LMK).
- COSMO-DE is able to forecast severe convection, supercells and can provide an improved guidance for human forecasters in these situations.
- Forecasting convective precipitation is a challenge and improving the existing physical parameterizations is necessary
- Currently COSMO-DE has some problems with the diurnal cycle of small-scale convection. Experiments with a modified PBL scheme look promising, but more research is necessary. The PBL parameterization is obviously most important on that scale!

Operational timetable of the DWD forecast models

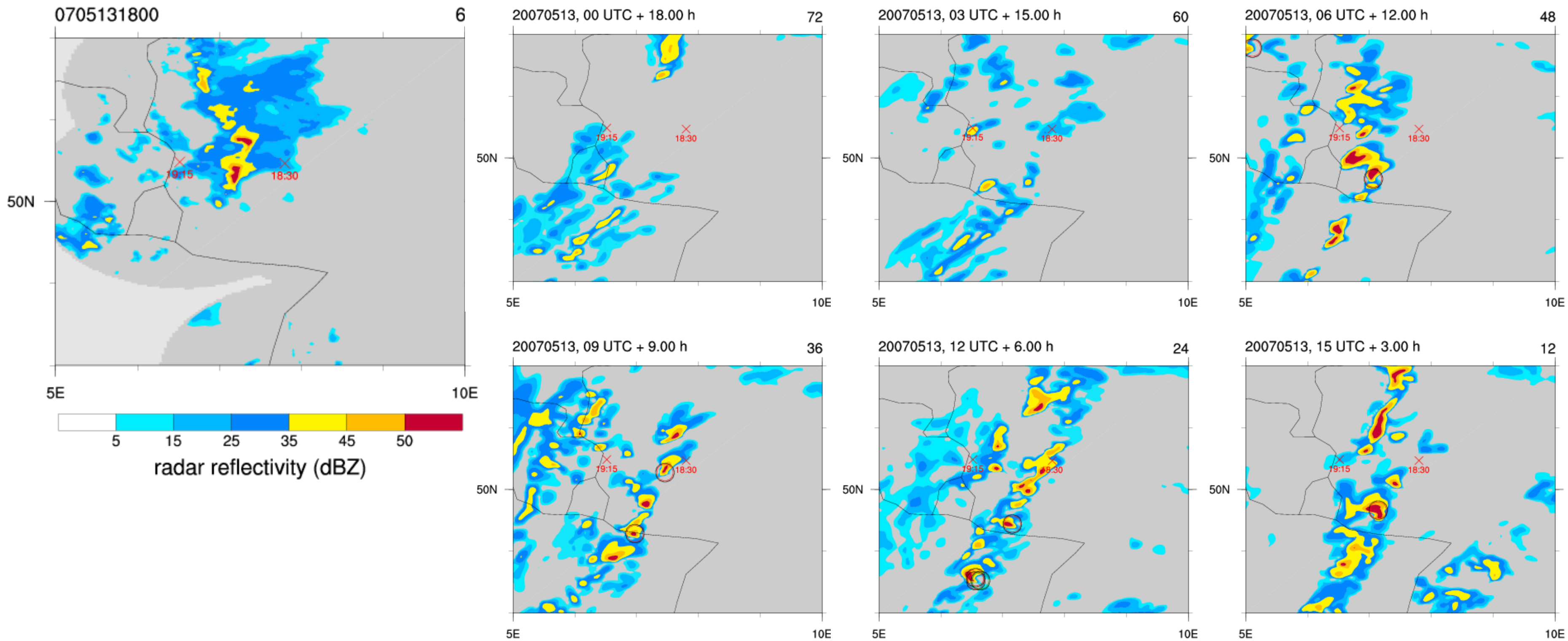


NWP system with several levels of data assimilation for each model

Overall output of 1 TB of data per day!

Case study 13 May 2007: Supercells

Radar and ... **COSMO-DE forecasts with different initial time**

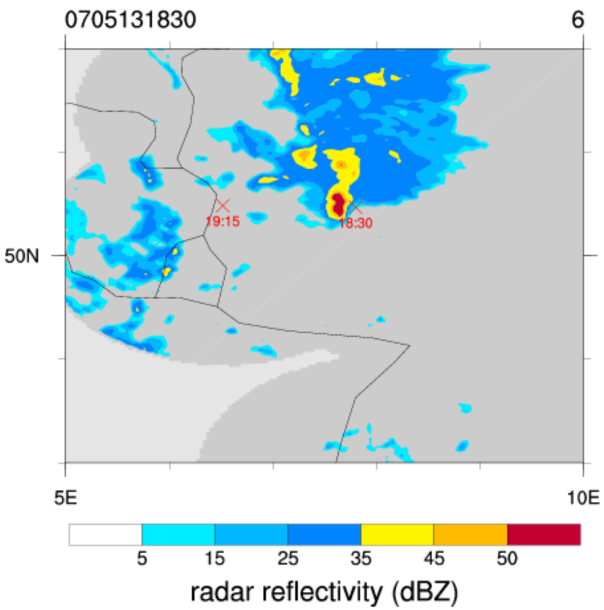


The general guidance is robust that supercells should be expected in that area. Starting with 06 UTC all forecasts show a line of severe convective storms. Individual cells are hardly predictable.

Case study 13 May 2007: Supercells

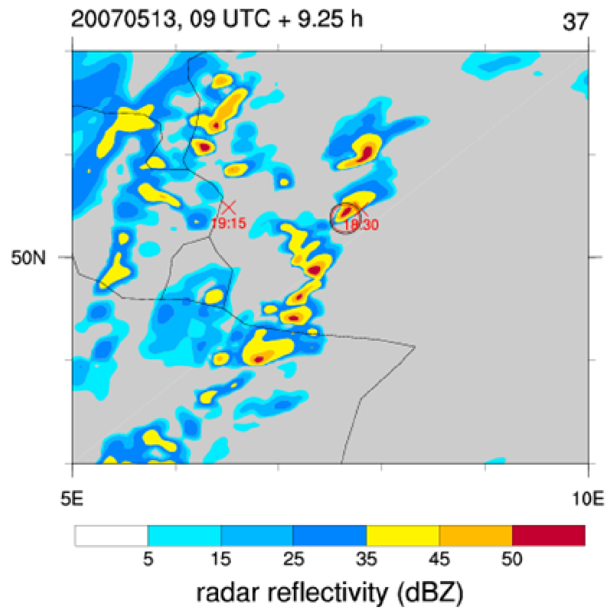
Base reflectivity

German composite



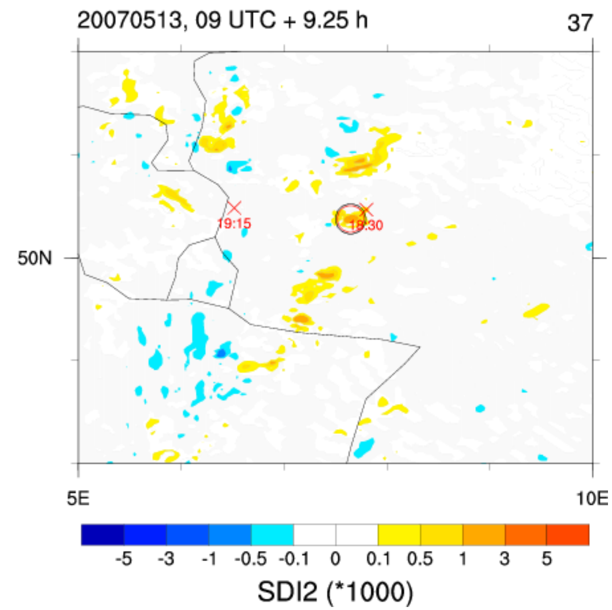
COSMO-DE

reflectivity



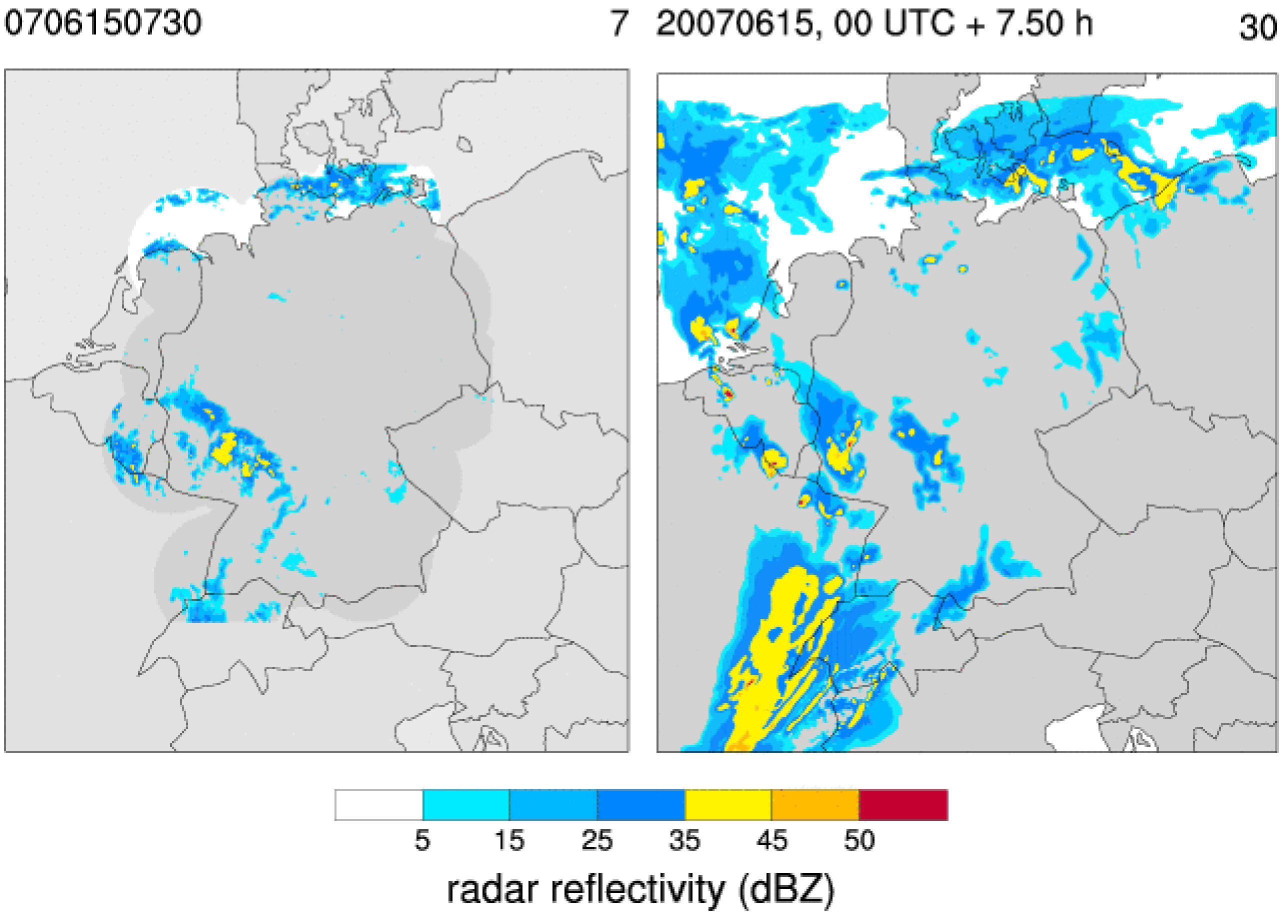
COSMO-DE

supercell detection index (SDI)



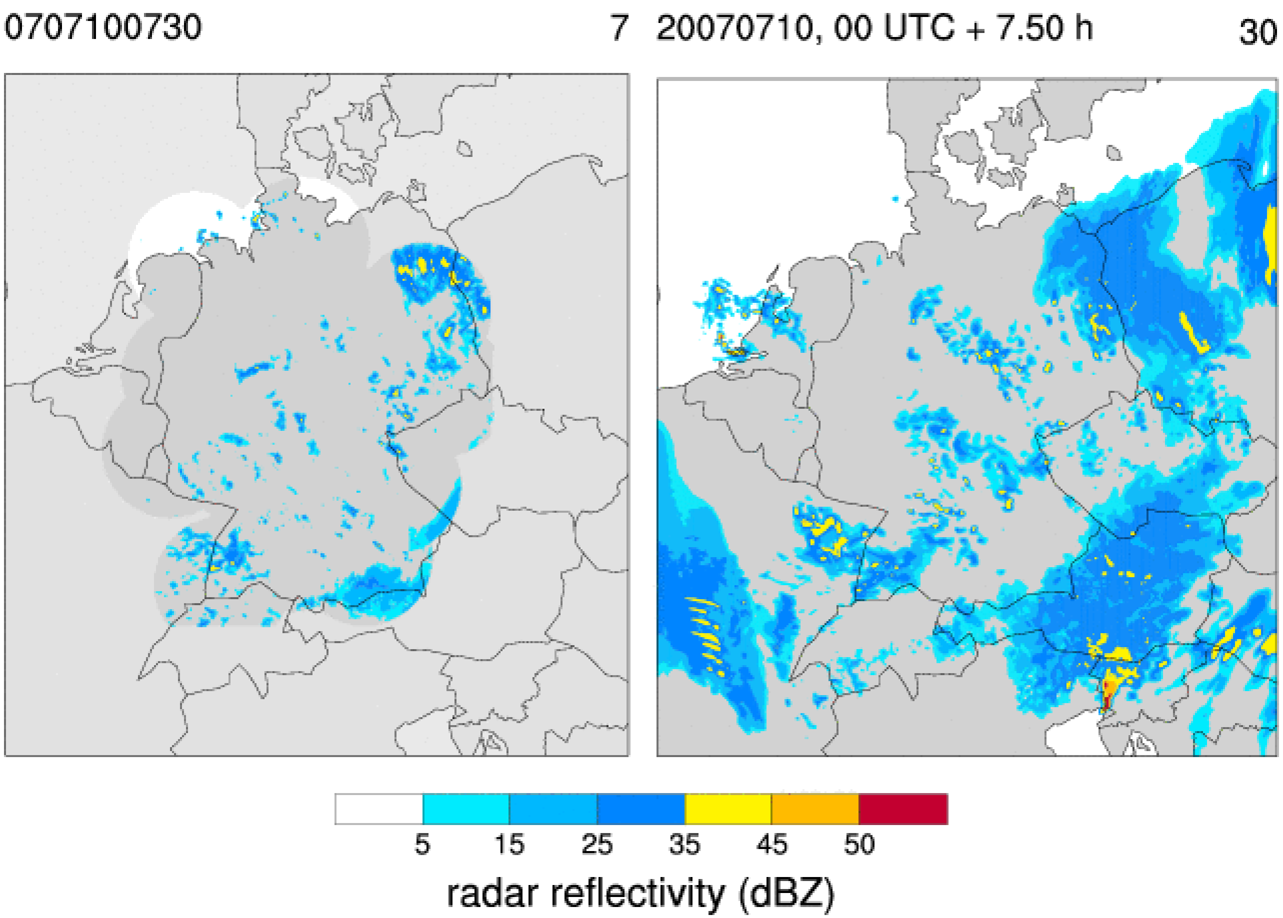
Most simulated cells in this convective line show some ‘supercellness’, but only one of them exceeds an SDI_2 of 0.003 s^{-1}

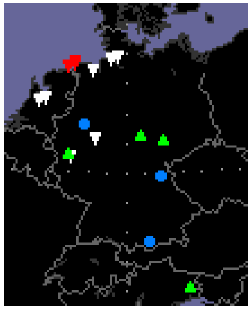
Radar composite and model reflectivity: 15 June 2007



- The COSMO-DE forecasts provides a good guidance where and when strong convection might develop.
- Exact deterministic forecasts cannot be expected on the convective scale

…. again using the SDI to identify severe storms:





- The model does not always produce supercell structures.
- On that day, two tornados where reported at the coastline of the North Sea