Thunderstorm forecasting by a fuzzy logic combination of model data

Martin Köhler, Arnold Tafferner
DLR Oberpfaffenhofen

7th Conference of Severe Storms
3 – 7 June, Helsinki, Finland

DLR

Motivation

Photo by Martin Köhler

Hazards:

- heavy rain
- hail
- lightning strokes
- turbulence
- downdrafts

Effects (air traffic):

- reduced safety
- reduced comfort
- increased fuel consumption
- redirections
- cancellations
- additional costs

→According to DFS (German Air Navigation Services) > **80 %** of summertime delays at Munich Airport are induced by thunderstorms!

→ **Demand** for thunderstorm forecasts up to several hours ahead in time which would enable decision makers to plan accordingly and to lessen the consequences

DLR

Data source: Output from COSMO-DE model

General notes:

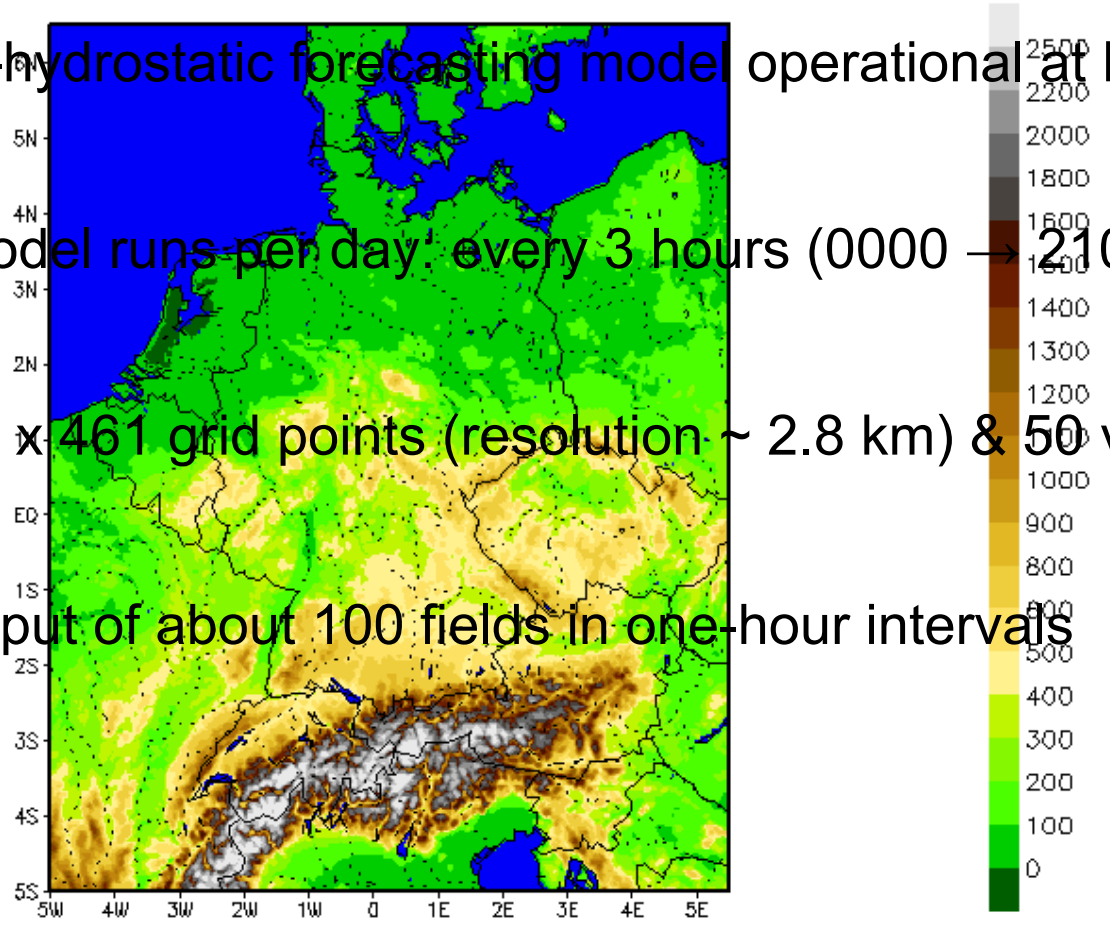
i) Non-hydrostatic forecasting model operational at DWD

ii) 8 model runs per day: every 3 hours (0000 → 2100 UTC)

iii) 421 x 461 grid points (resolution ~ 2.8 km) & 50 vertical levels

iv) Output of about 100 fields in one-hour intervals

v) Model area covers mainly Middle Euope



Source: http://www.cosmo-model.org/

DLR

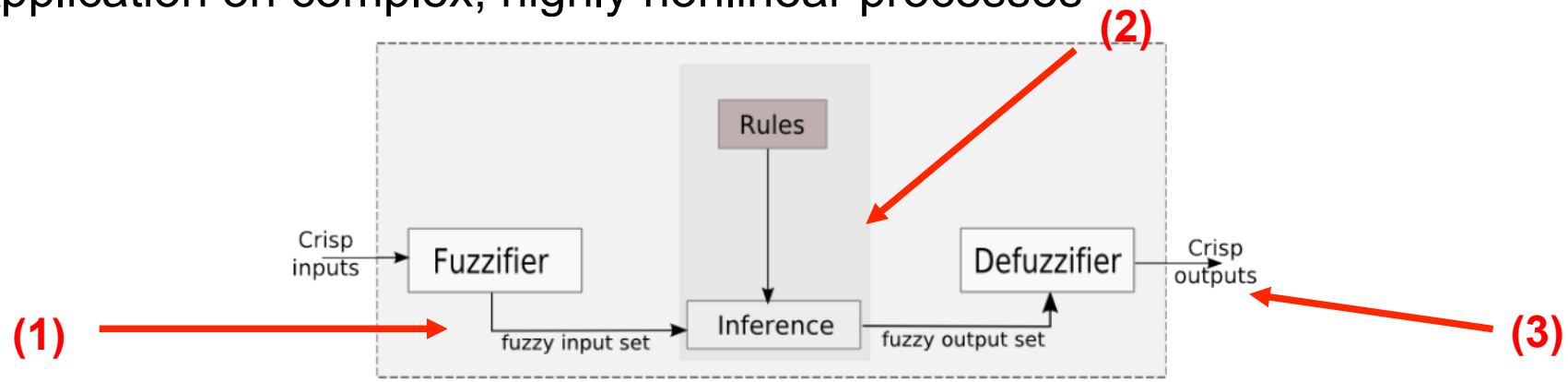
Overview of fuzzy logic

- **General notes:**

i) Capability to translate human reasoning based on imprecise data and fuzzy conception into mathematical decision making in a more appropriate way than binary logic

ii) Fuzzy logic can handle the concept of partial truth (rejection of the wrong or right (0 or 1) concept → smooth transition)

iii) Application on complex, highly nonlinear processes



DLR

New fuzzy logic forecasting system

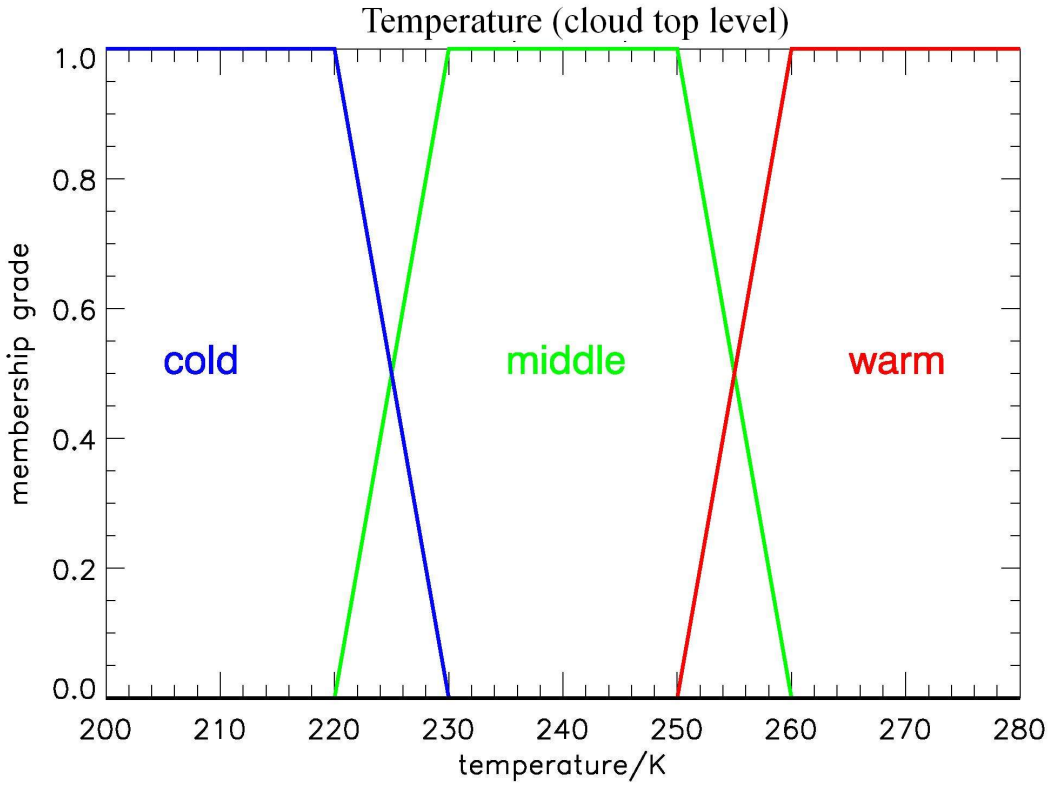
Step I: fuzzification → fuzzy input sets

i) CAPE

ii) Omega (500 hPa)

iii) Synthetic radar data

iv) Synthetic satellite data (IR 10.9)

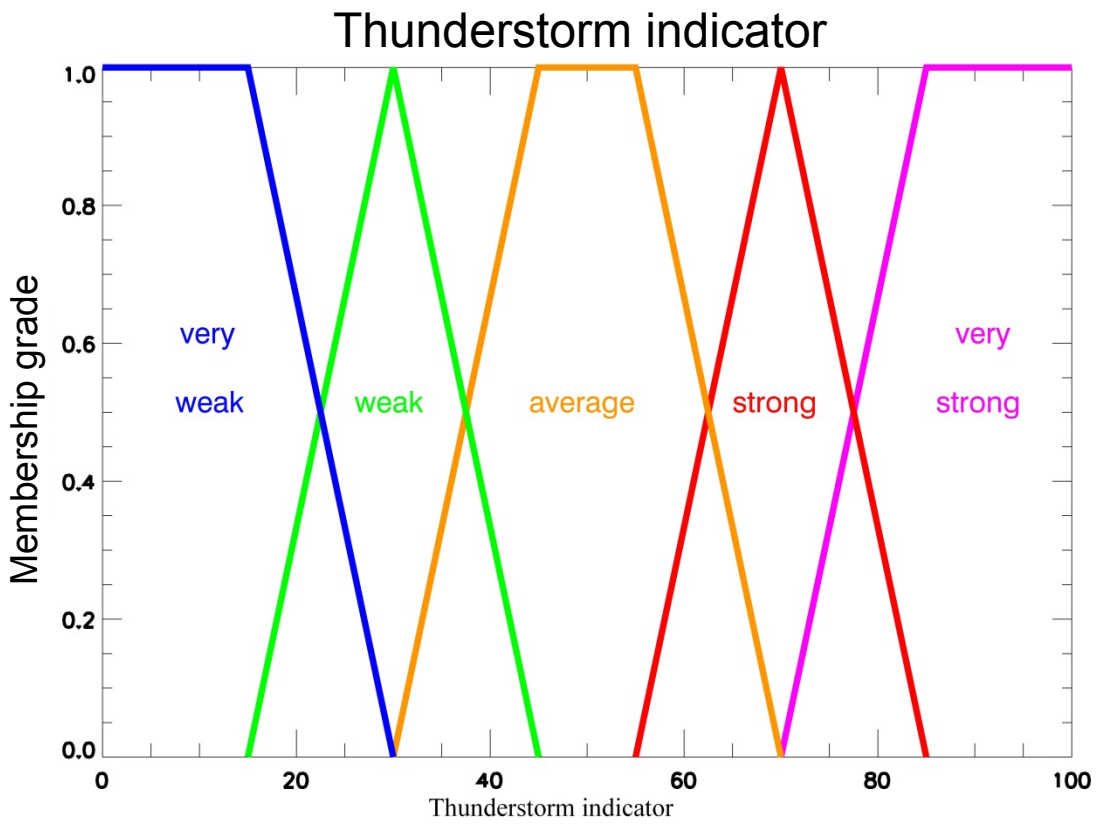


- 3 fuzzy input sets per parameter → derived from **meteorological knowledge**

DLR

New fuzzy logic forecasting system

Step III : defuzzification → fuzzy output sets



→ Transition from fuzzy input to fuzzy output sets with the **„rule base“ (step II)**

DLR

New fuzzy logic forecasting system

Step II: Rule base (If …. then decision rules)

→ **81 rules** (all possible combinations of the fuzzy input sets: 3^4)

- Each rule assigns a certain combination of the fuzzy input sets to a certain fuzzy output set → **„rule book“**

- Example: strongest rule

If **s**CAPE and **s**Radar and **s**Omega and **I**CTT then

very strong Thunderstorm Indicator

→ **Finally a symmetrical** assignment of the 81 rules to the five fuzzy output sets is chosen!

DLR

New fuzzy logic forecasting system

- **Next step:** calculation of the average weigth of all rules for each fuzzy output set → Weighting of each fuzzy output set

- Used method: **Root-Sum-Square (RSS)**

→ Formular RSS: $$Output = \sqrt{\left(\sum_i rule_i^2\right)}$$

- **Defuzzification (step III)**

→ Calculation of the averaged center of gravity of the weighted areas of the fuzzy output sets → x - value is used as the defuzzificated number **(„Output Crisp Number“)**

Method: **Center of Gravity** → weighted CoG = $$\sum_i \frac{\textbf{Center of gravity}_i \textbf{ x Area}_i}{\textbf{Area}_i}$$

DLR

New fuzzy logic forecasting system

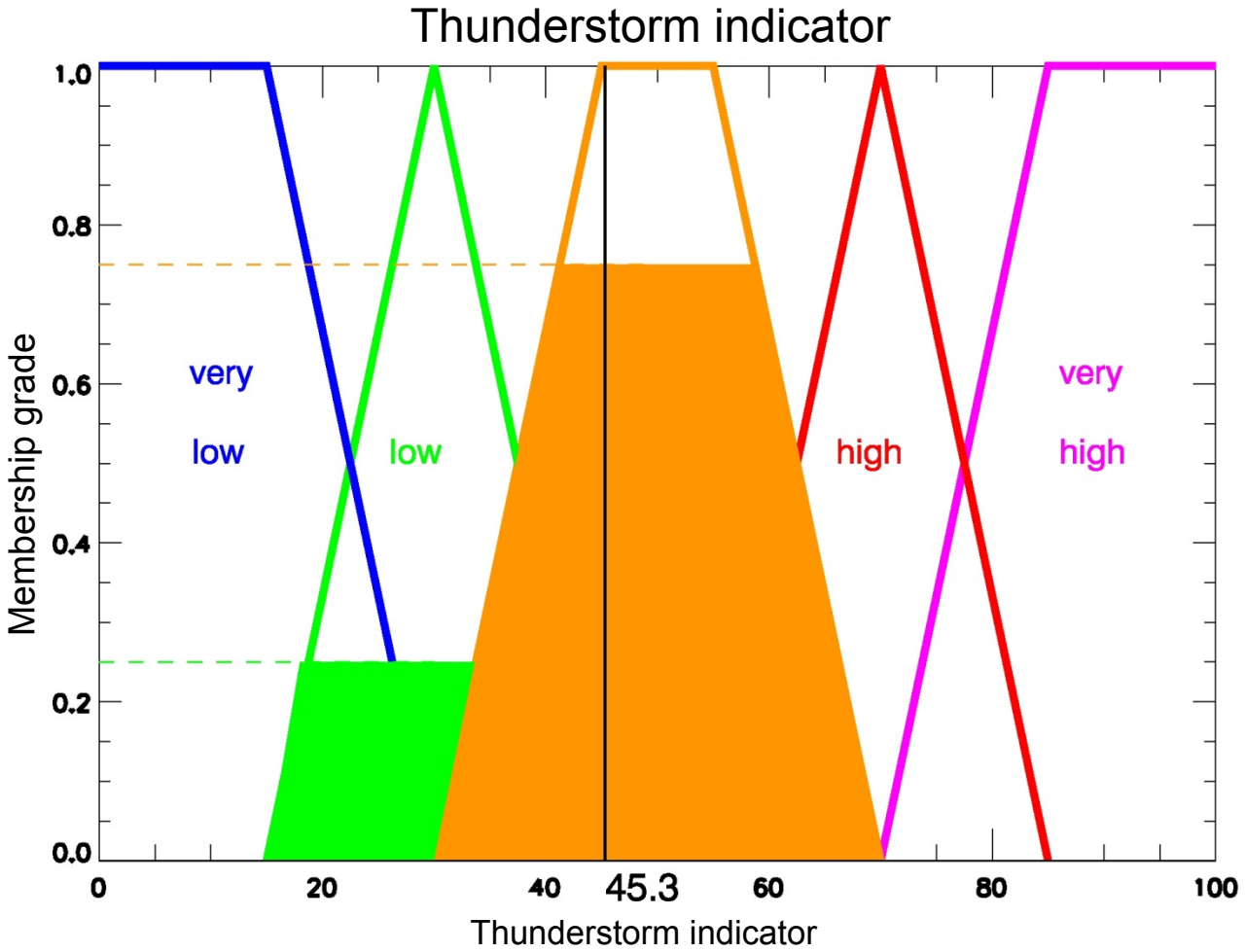
Example values:

CAPE: 450 j/kg

Omega: - 45 hPa/h

CTT: 232 K

Radar: 35 dBz



→ **Thunderstorm indicator:** 45.3

Example case: 22/06/2011

- Model run **1200 UTC** – forecast beginning at **1400 UTC** up to **1800 UTC**

- **Comparison:** fuzzy logic forecast ↔ COSMO - DE probability forecast*
  → shown as coloured surfaces

- Verification of the forecast with detected storms by **radar (Rad-TRAM**)**
  → shown as blue contours

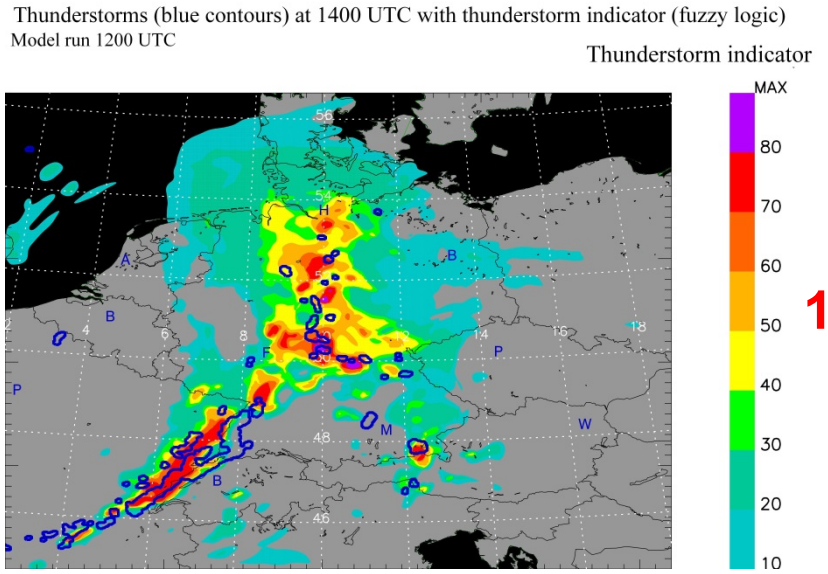
*neighborhood method
Theis et al. (2005)

Rad-TRAM = **Radar – **TR**acking **A**nd **M**onitoring
Kober & Tafferner (2009)

DLR

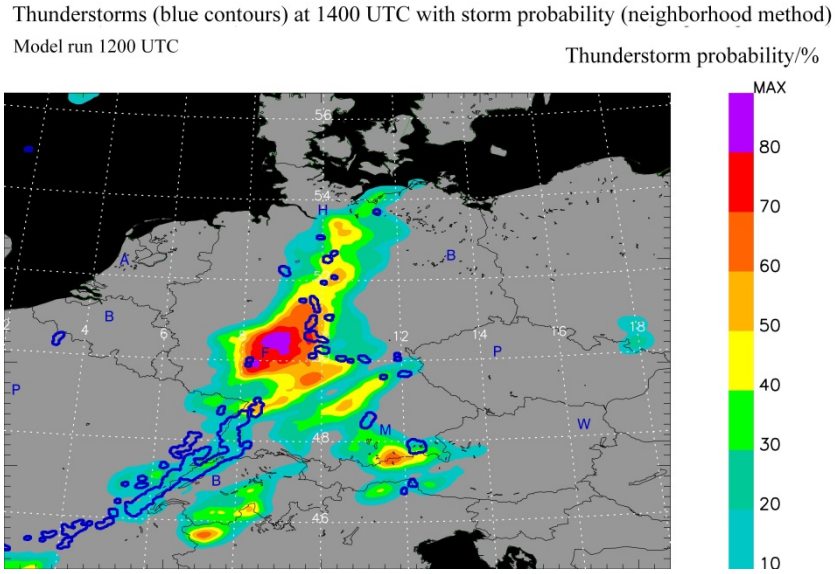
Example case: 22/06/2011

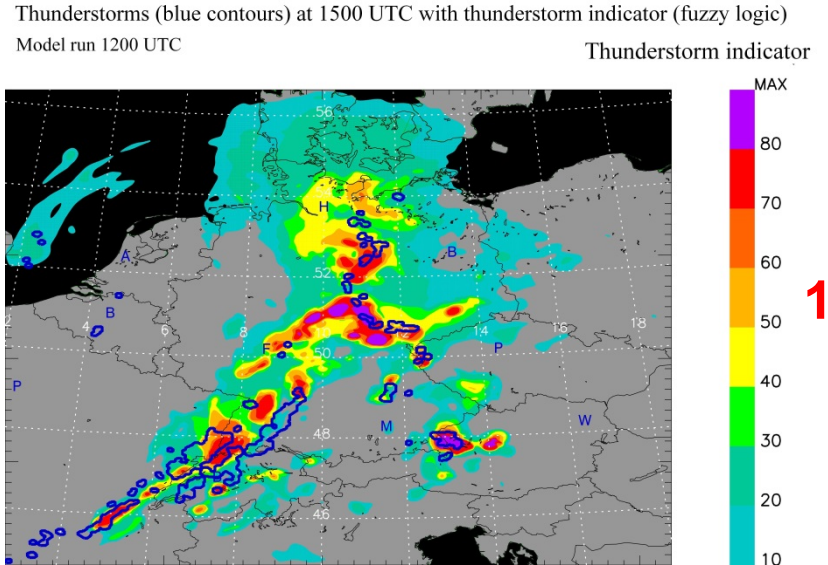
Fuzzy logic forecast



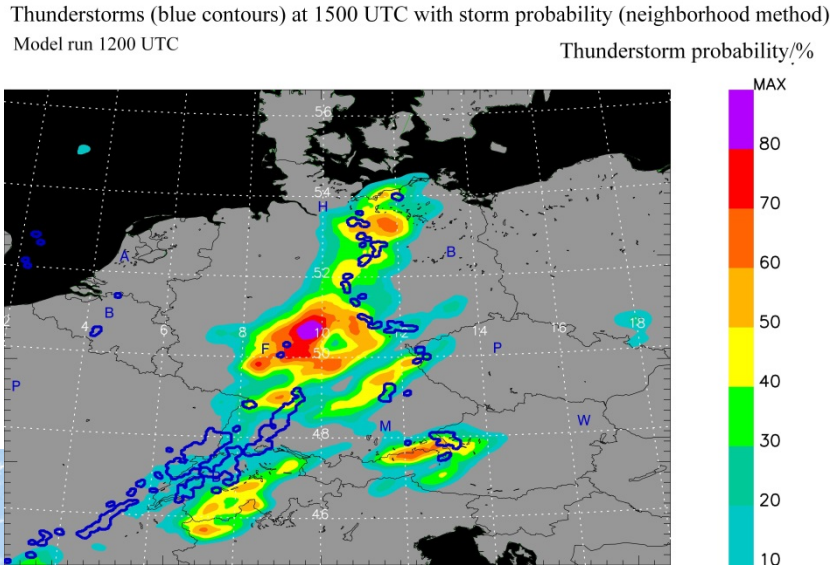
1400 UTC

COSMO – DE probability forecast



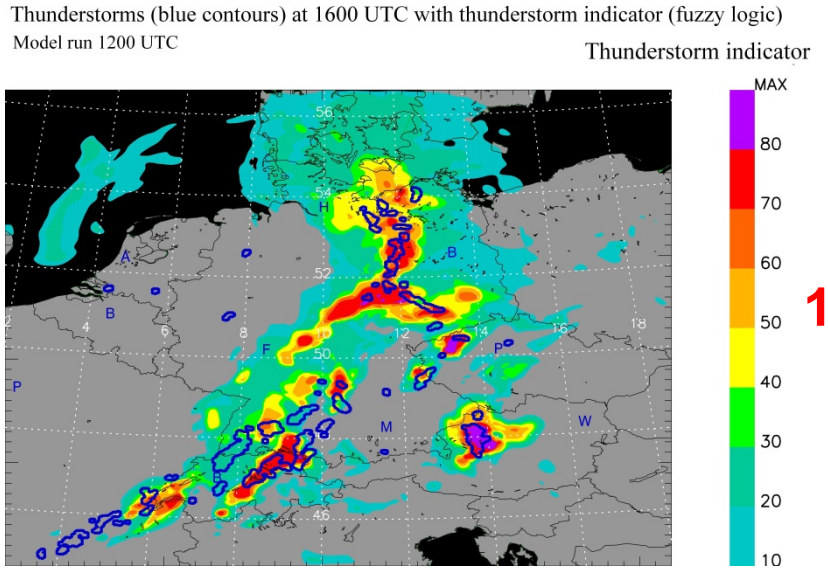


1500 UTC



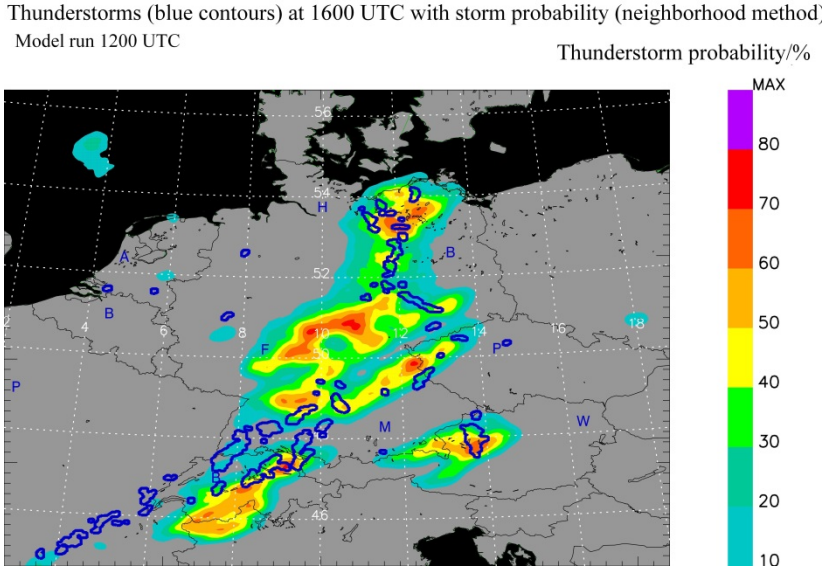
Example case: 22/06/2011

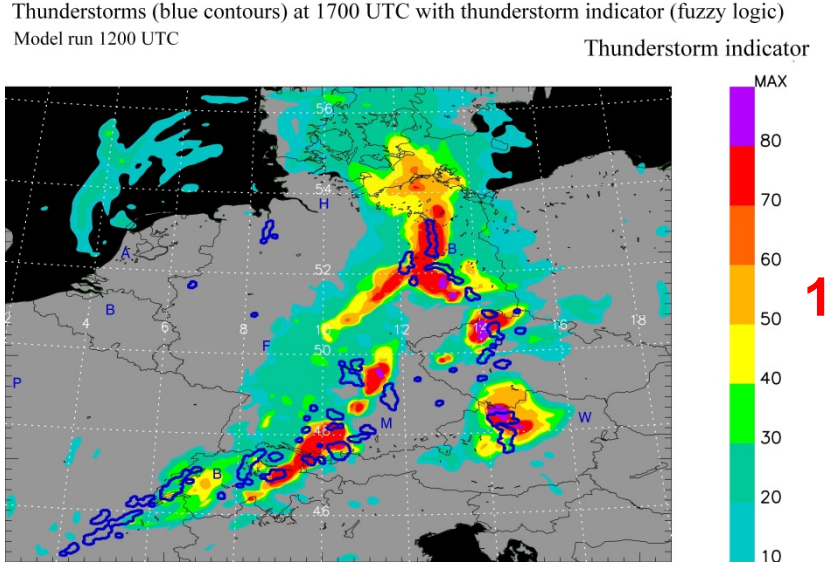
Fuzzy logic forecast



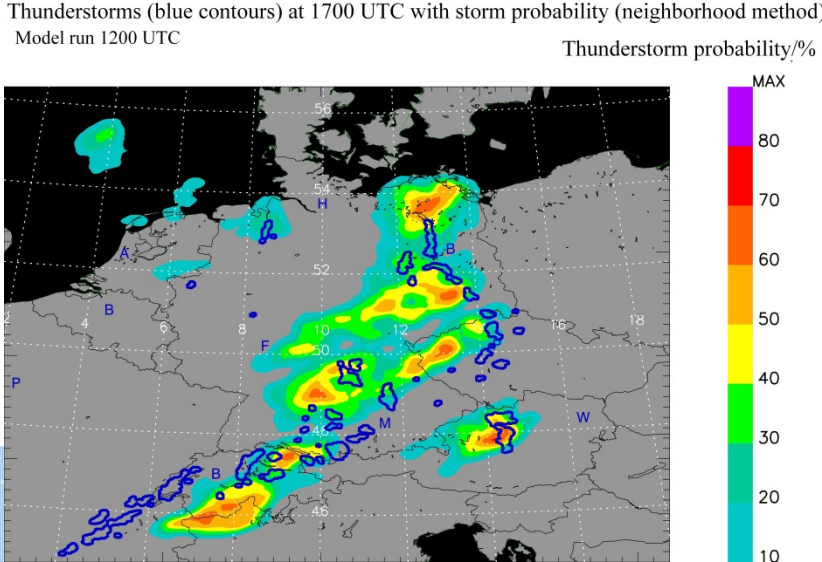
1600 UTC

COSMO – DE probability forecast



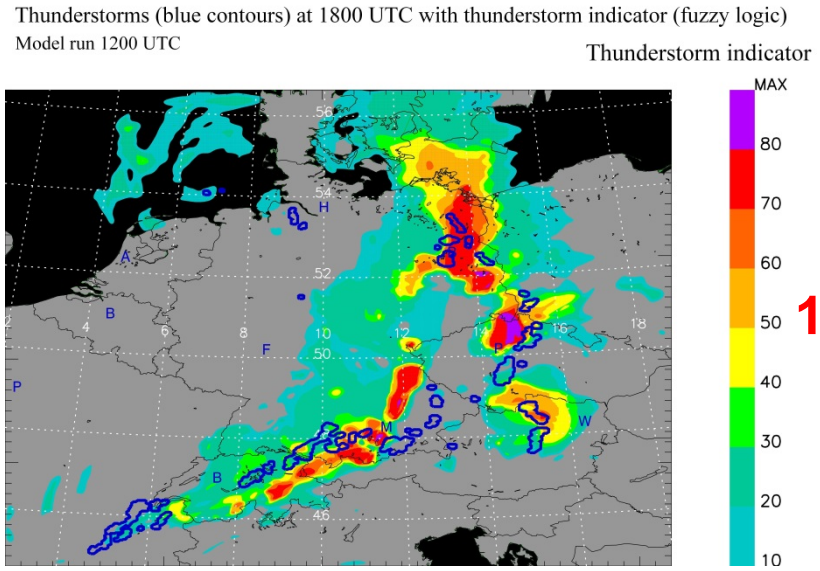


1700 UTC



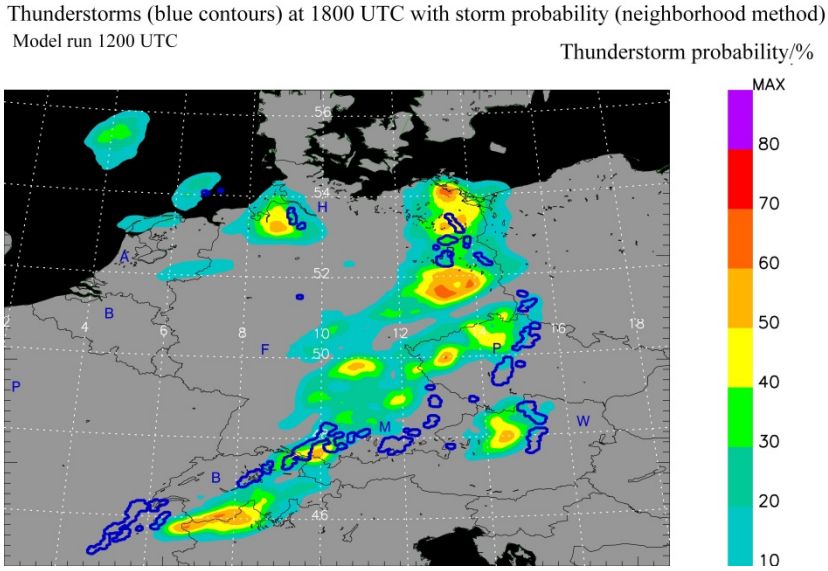
Example case: 22/06/2011

Fuzzy logic forecast



1800 UTC

COSMO – DE probability forecast



Conclusion:

i) new forecasting system works quite well

ii) fuzzy logic seems to better agree with the observations compared with the neighborhood method

DLR

Outlook

i) **Statistical analysis:** Currently running for summer period of 2012
→ Including object-based verification (lightning data)
→ Verification scores (POD, FAR...)

ii) **Operational application:** Since 03/06/13 provided at Munich Airport
→ Available: 6 hours of forecast (hourly update) on a separate homepage
→ Aim: feedback of users

iii) **Tuning of the approach:**
→ Weighting of the input parameters
→ Different fuzzy input sets (thresholds, overlaps)
→ Use of a best-time-member-ensemble

Thank you for your attention!

Contact: martin.koehler@dlr.de

DLR