Object-based (ensemble) verification of radar reflectivities on the convective scale

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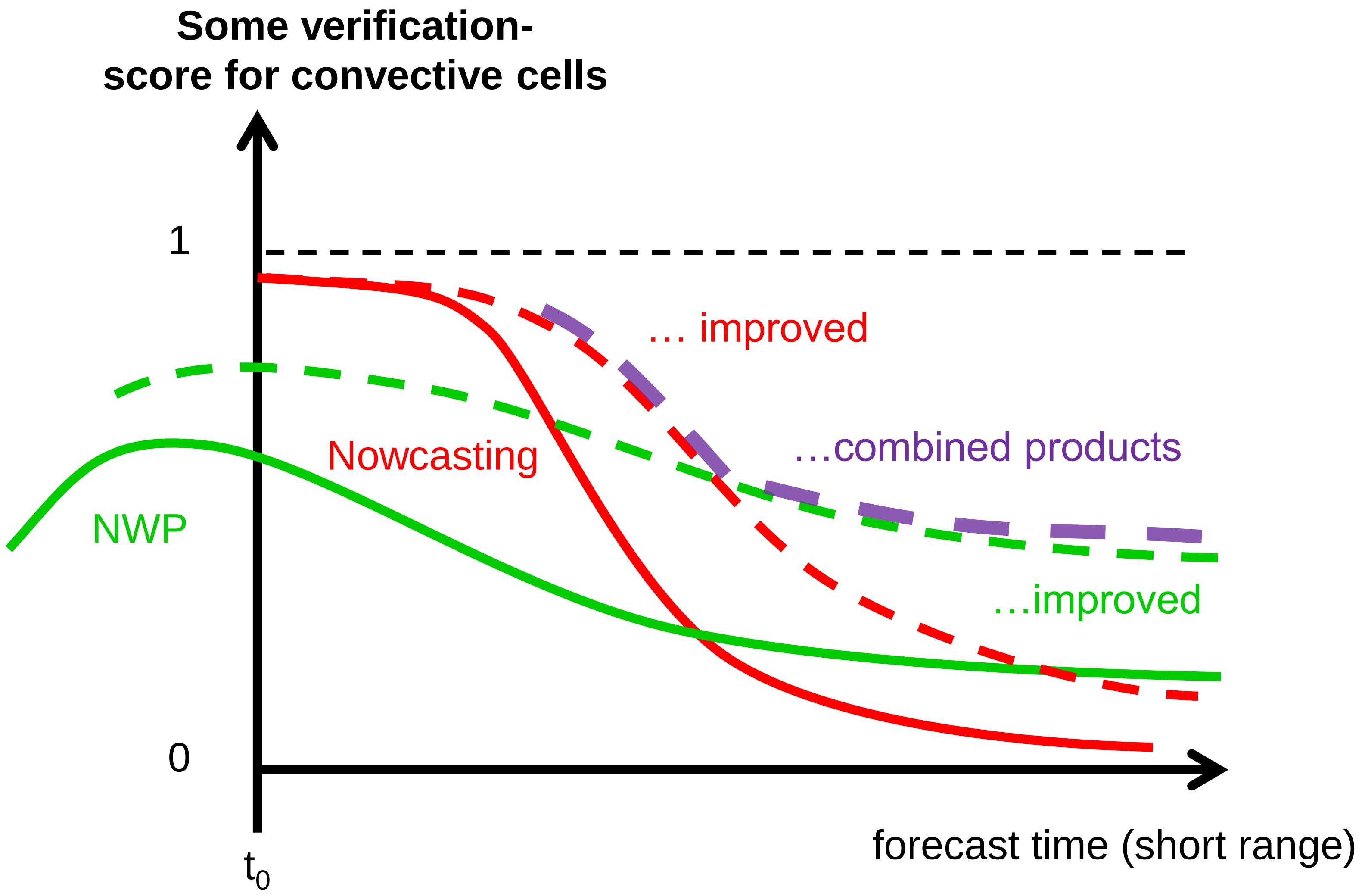
Basic Idea of SINFONY



Observation: 3D volume radar data

Radar network of DWD:

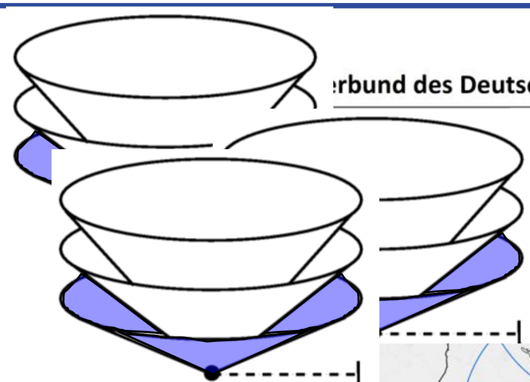
- ➔ 17 polarimetric Doppler C-Band radar systems
- ➔ temporal resolution:

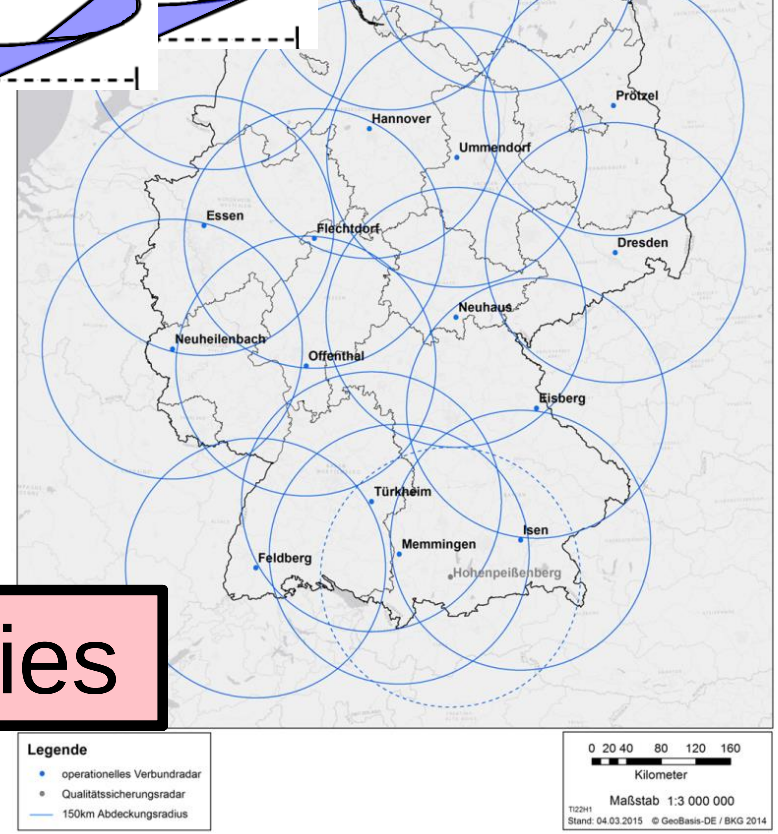
  volumescan every 5 min
- ➔ spatial resolution:

  1° azimuthal angle

  1 km radial resolution (up to 180 km)

  10 elevations (betw. 0.5° and 25°)





→ Grid based reflectivities

Current forecasting systems

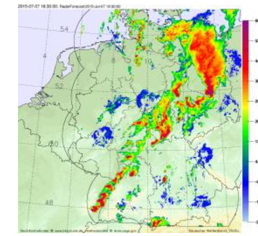
DWD uses different methods for nowcasting (0 – 2 h) and shortest-range NWP (2 – 12 h)

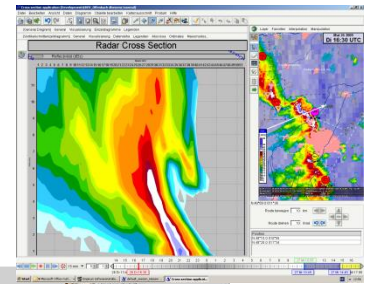
- ➔ **Nowcasting:**
  - ➔ purely deterministic
  - ➔ quite fast after initiation, forecasts every 5 min
- ➔ **Shortest-range NWP:**
  - ➔ deterministic and ensemble with 2.2 km mesh size (COSMO-D2 /- EPS)
  - ➔ new forecasts ~1 – 1,75 h after initiation, forecasts every 3h (1h data assimilation-cycle)

> - focus on radar reflectivities
> - NWP: radar forward operator EMVORADO simulates reflectivities on radar grid

Developments in nowcasting

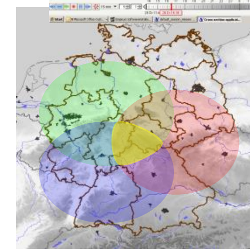
- Estimation of **uncertainty in nowcasting**
  - adapt ensemble concept in nowcasting (grid-based and object-based)
  - use of uncertainty information from NWP ensemble



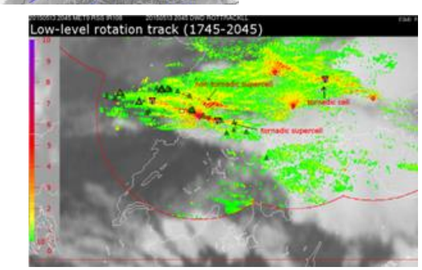


- earlier **detection of developments** of heavy thunderstorms
  - 3D detection and tracking of convective cells

KONRAD3D

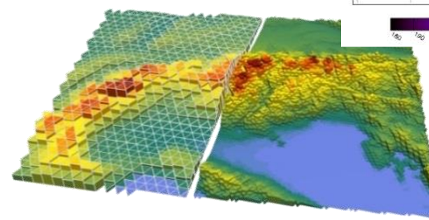


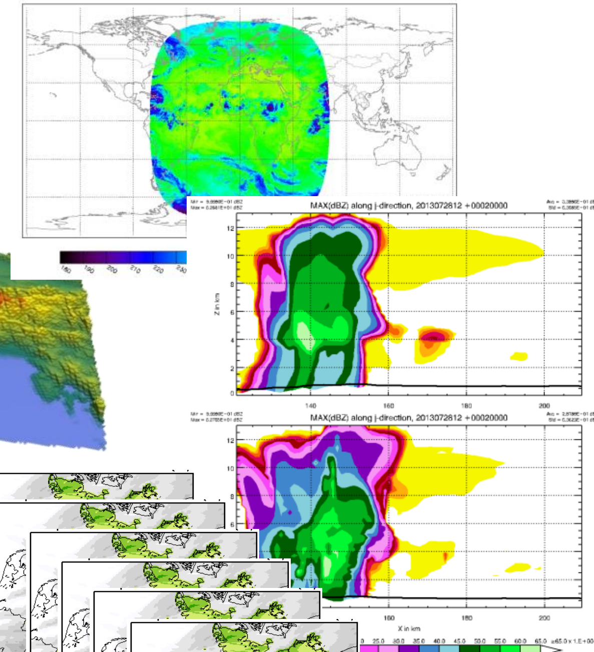
- Prediction of **development- and weakening tendencies**
  - life cycle of convective cells
  - use of information from NWP-RUC about environmental conditions



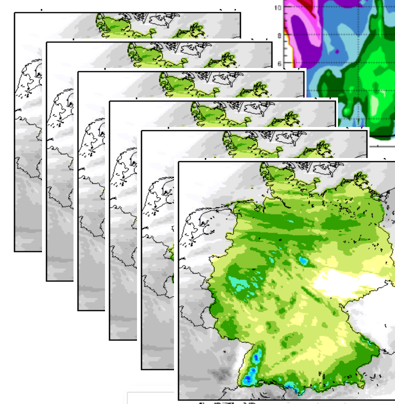
Developments in NWP

- Assimilation of **new observation types**
  - 3D-Radar-Volume data (radial wind, reflectivity)
  - Assimilation of (nowcast-) objects
  - SEVIRI-IR / -HRV
  - flash rate

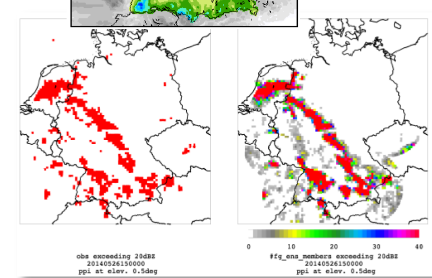




- development **of model physics / -dynamics**
  - Transition to ICON-LAM with mesh size ≤ 2.2 km
  - adjusted/ improved model physics (turbulence, cloud microphysics)



- Development of **„Rapid Update Cycle“ NWP**
  - hourly RUC ensemble-forecasts
  - algorithmic improvement in data assilimation



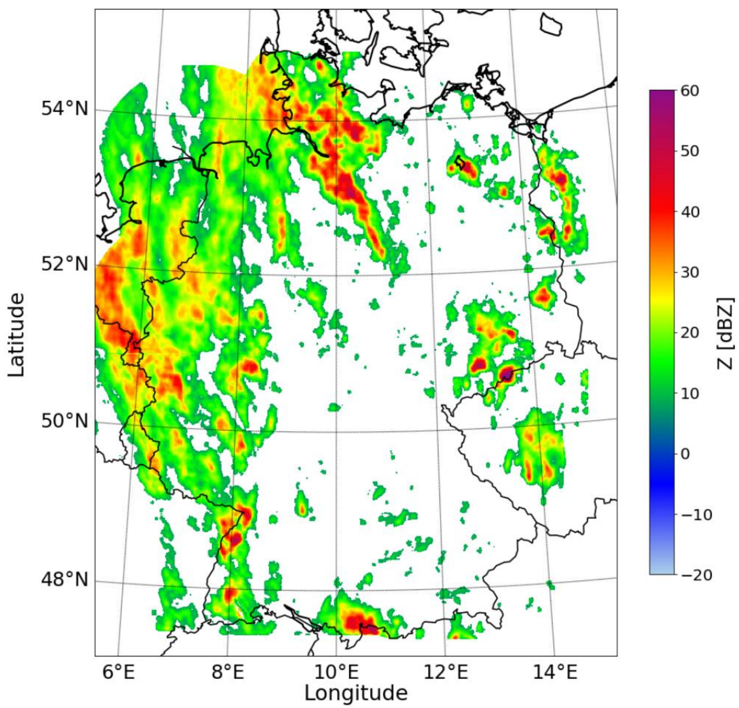
Combined products from NWP and NWC

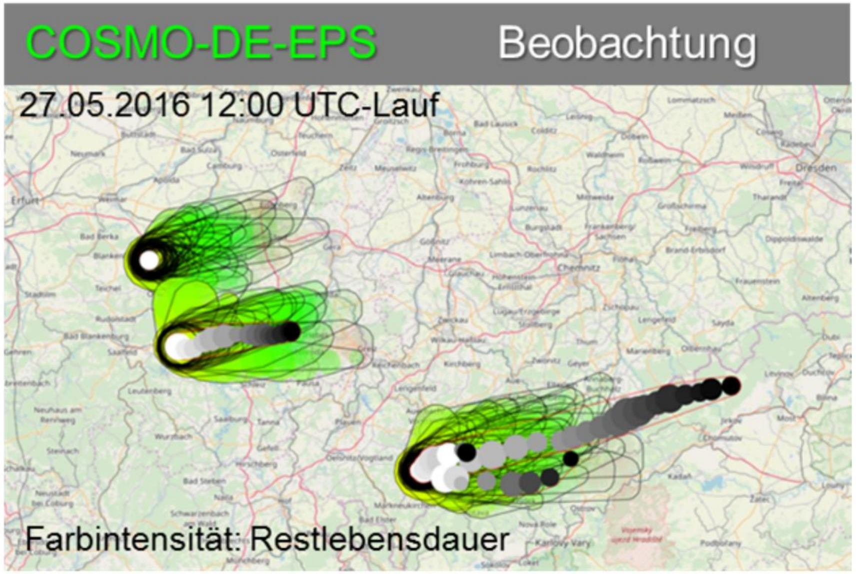
General meteorological situation
- consideration of the whole domain
- development tendencies of precipitation fields

→ *area-based approach*

Significant meteorological events
- consideration of convective cells (objects)
- tendency of object attributes

→ *object-based approach*





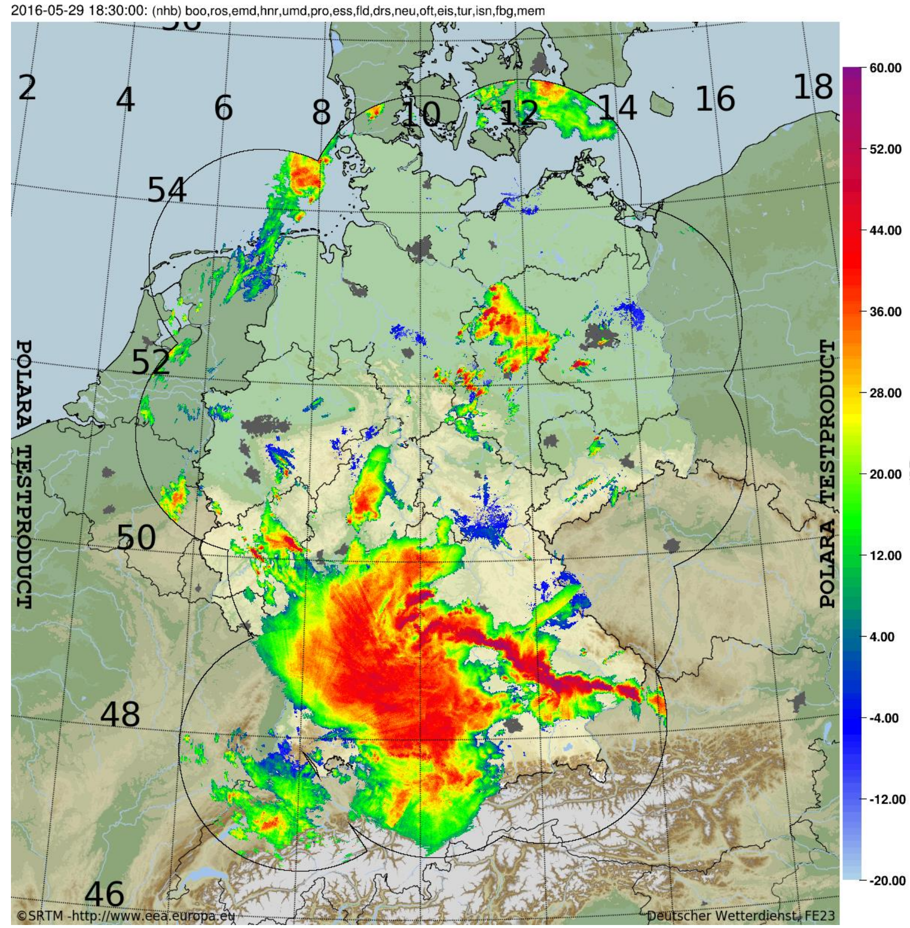
Which user we want to address?

➔ During SINFONY pilot project (setting up the system during first 4 years)

- ➔ verification information mainly used from **developers**.
- ➔ different setups depending on the users request, e.g. interested in intensity error? displacement error? etc. → respective score

Test case period 26.5. - 25.6.2016

- Time period with nearly permanent severe convective events
- Braunsbach- / Simbach floods: slow-moving intense convective systems, several fatalities, large damage to entire



How do we detect objects?

KONRAD3D cell detection

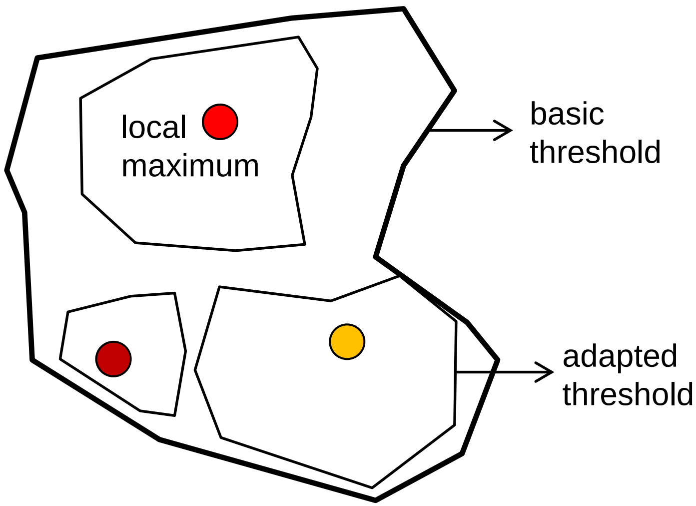


Figure 1: Adaptive thresholding procedure to extract 2D-cells in each radar sweep. First, a basic threshold is applied to extract intense regions. Within these regions, disjoint features around local maxima are extracted.

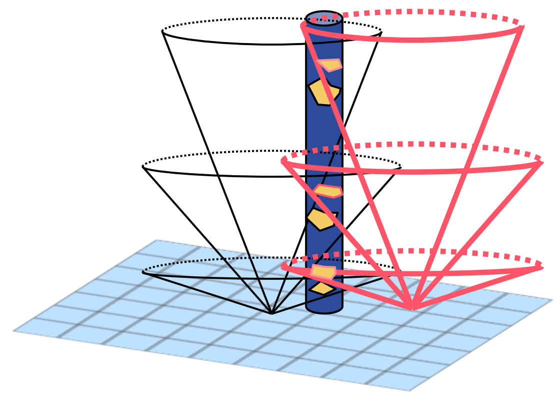


Figure 2: 2D-cells from different elevations from different radar sites grouped together to one 3D-cell.

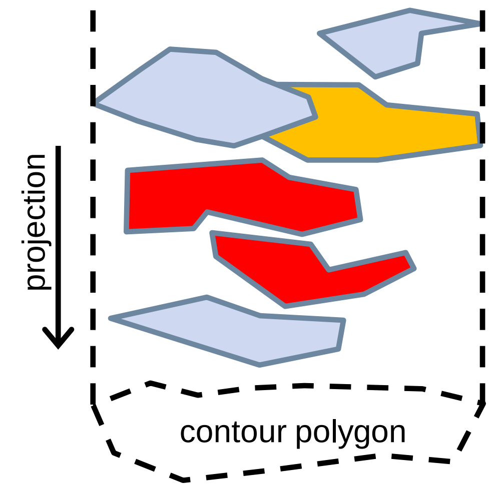


Figure 3: A projected contour polygon w.r.t. 2D regular grid is calculated.

Figures by Manuel Werner (DWD)

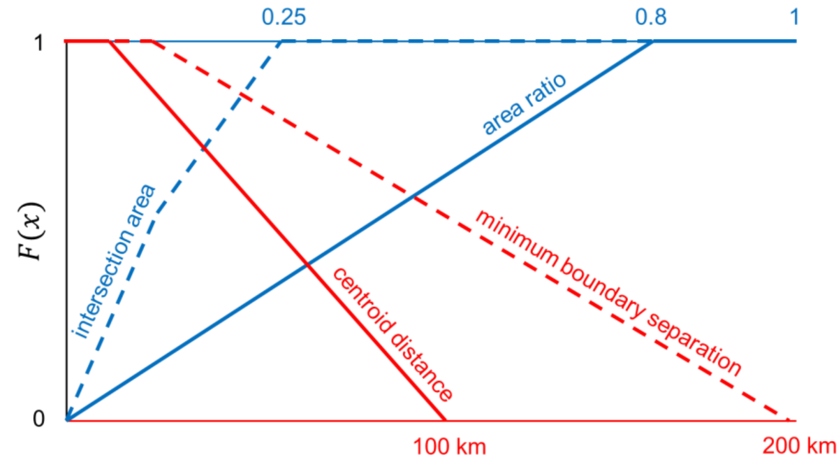
Median of Maximum Interest (MMI)

- Object-based score from MODE (Davies *et al.* 2009)
  - Fuzzy-Logic, takes several attributes between fcst and obs into account
  - should mimic the decision process of a forecaster

- What is an interest value?
  - given is an object pair *j*
  - interest value describes how similar both objects are
  - to evaluate this, one takes „*M*“ attributes into account

Median of Maximum **Interest**

Interester function *F*: includes limits for each attribute



Weight *w* of attributes:
cent.dist (28%),
minsep (40%),
area ratio (19%),
intersection ratio (13%)

$$I_{i,j} = c_i w_i F_{i,j} \;\; [0,1]\,, i = 1{:}M,\, M - \text{attribute}-\text{index}$$

Attributes *i*:
centroid distance,
minimum boundary separation,
area ratio,
intersection ratio

Correction factor c

Note: values taken from Davies et al., empirically optimized for US domain.

Median of Maximum Interest (MMI)

➔ sum up to „total interest“

$$TI_j = \frac{\sum_{i=1}^{M} c_i w_i F_{i,j}}{\sum_{i=1}^{M} c_i w_i}, \; [0,1]$$

F – Interest Function
w – weights
c – factor of attributes
M – number attributes
i – index interest function
j – index object pair

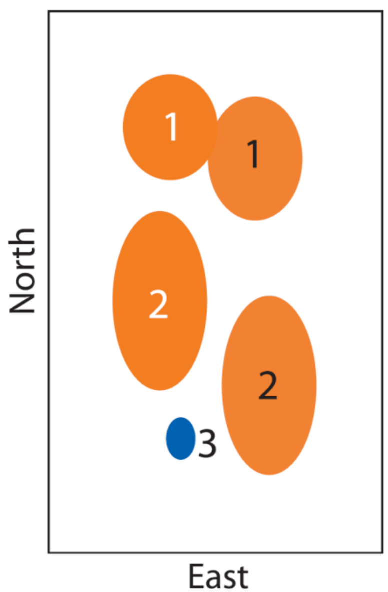


figure from Davies et al. (2009)

Interest Matrix

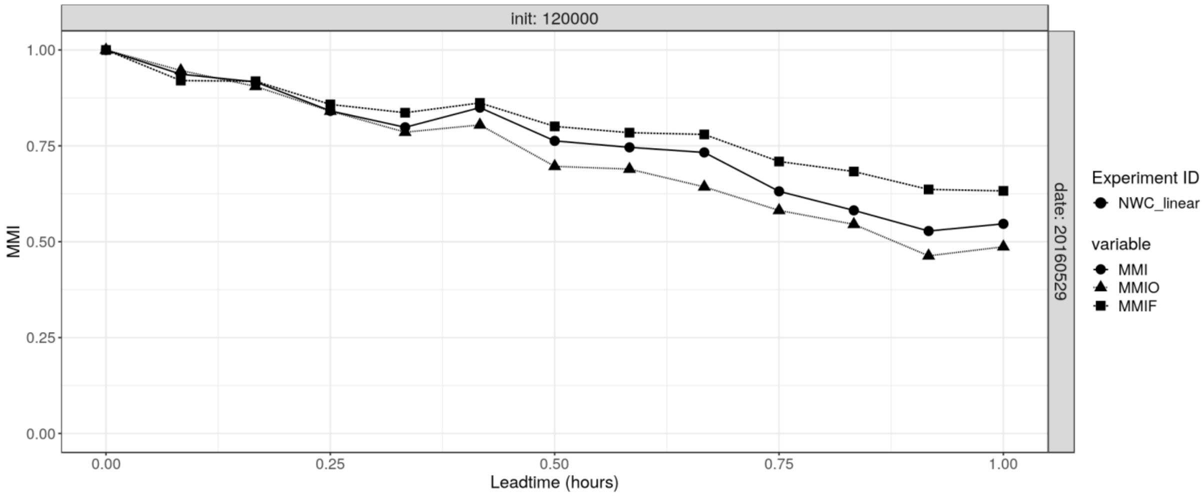
Forecast \ Observed	1	2	max:
1	0.90	0.75	0.90
2	0.50	0.80	0.80
3	0.40	0.55	0.55
max:	0.90	0.80	

Row maxima 0.90, 0.80, 0.55 → 0.80 (MMIF)

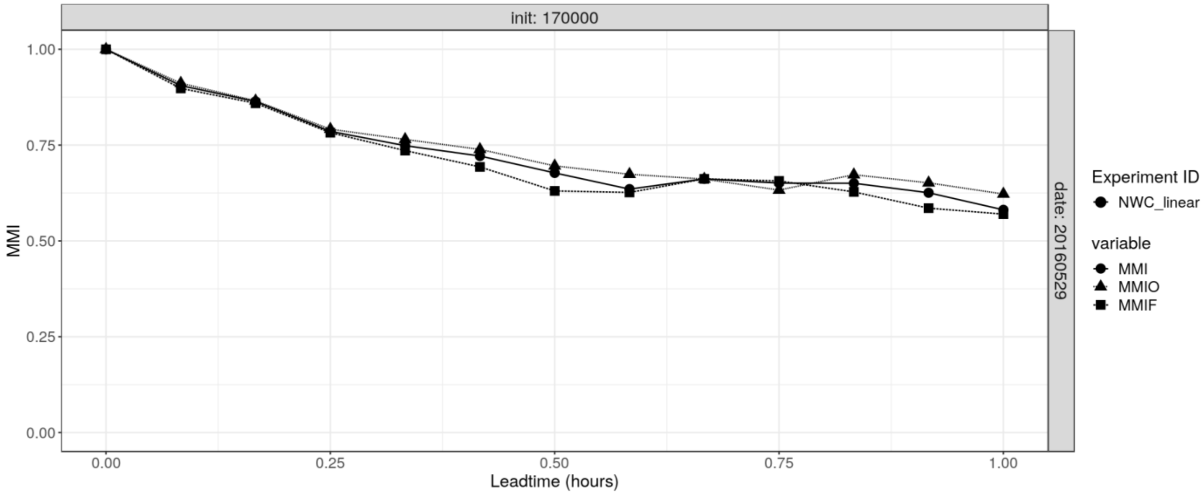
Column maxima 0.90, 0.80 → 0.85 (MMIO)

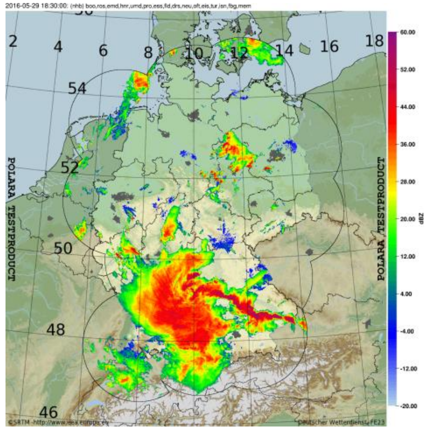
MMI – Median of all maximum interest values

object NWC - single event verification



	best		worst
cent.dist (28%):	9	..	25 km
min.sep (40%):	10	..	50 km
A-ratio (19%):	0.8	..	0
A-intersect (13%):	0.25	..	0





Median of Maximum Interest

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

MMI is good because…	However, …
• Matching not mandatory, but possible • (interactively) analysing multiple attributes simultaneously • Easy and fast to aggregate • summary Score for forecast quality • info about false alarms & misses	• **Appropriate choice of weights and limits** • **detailed statistical study necessary, to estimate parameters empirically** • Sensitive „matching“ behaviour, especially in case of many small objects (define clusters?!…)

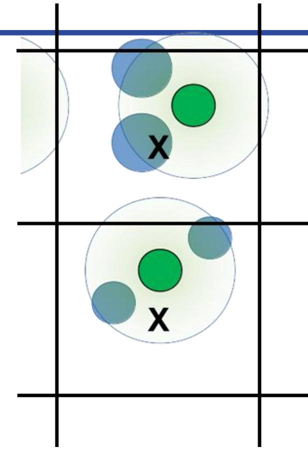
→ Any other shortcomings?

→ perhaps depending on specific weather situation?

→ e.g. how is the score working in case of convective events?

→ experiences?

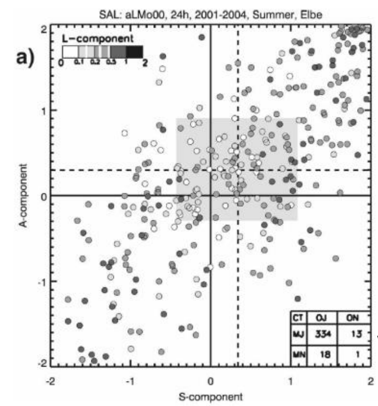
SINFONY



Other methods?

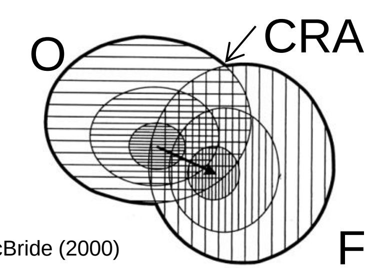
- “gridded objects” or “textures”

- Structure (Amplitude) Location
  - original data not available after Konrad3D detection
  - classical amplitude not possible,
  - alternative Location L1 necessary



Wernli et al. (2008)

- CRA?
  - matching could be difficult for convective events



Ebert & McBride (2000)

The biggest issue…

	Observation	Nowcast	NWV	Combined
Grid-based	radar composite	det + 40 members	det + 40 members	det + 40 members
Object-based	Konrad3D from volume scans	det + 40 members (Konrad3D)	det + 40 members (Konrad3D)	det + 40 members (Konrad3D)

- ➔ huge amount of data
- ➔ huge amount of identified objects
- ➔ big requirement on existing spatial verification methods
- ➔ **How to (spatially) verify multi-model ensemble forecasts?** (single member? Ok, but no real benefit)
- ➔ without increasing computing time too much (restrictions?)
- ➔ what about objects reaching the domain bounds? (large vs. small objects, domain size)
- ➔ also neighborhood…

Thank you for your attention!

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Appendix

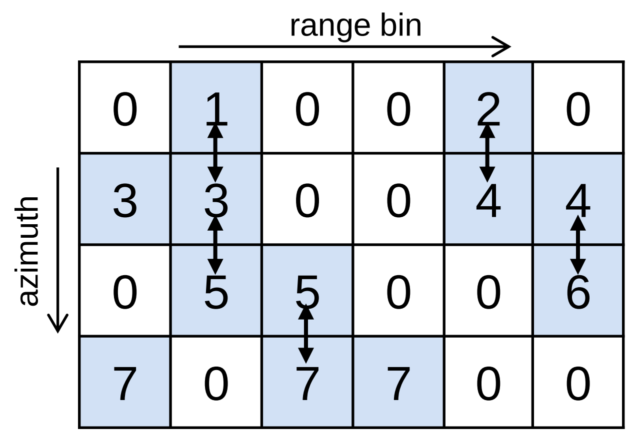
simple and multiple-thresholding method from SCIT

2D-cell detection from

Johnson, J. T., MacKeen, P. L., Witt, A., DeWayne Mitchell, E., Stumpf,G. J., Eilts, M. D., and Thomas, K. W. (1998*). The Storm Cell Identification and Tracking Algorithm: An Enhanced WSR-88D Algorithm.* Wea. Forecasting, 13:263–276.

Connected-component Labeling

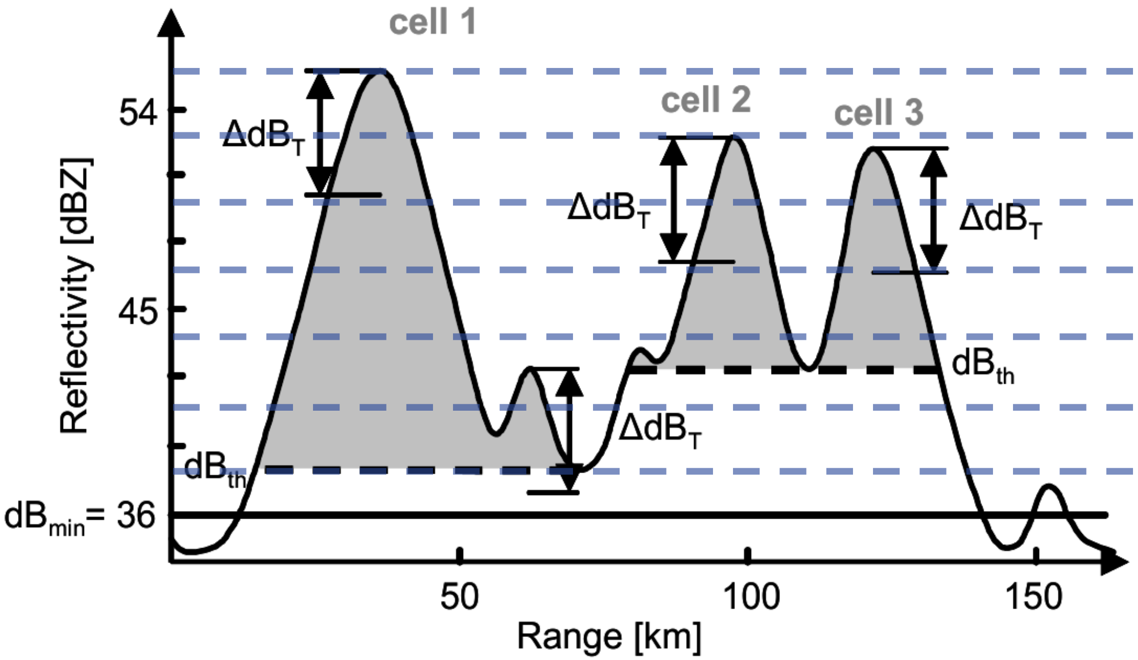
- ➔ row-wise determination of 1D features with soft threshold, i.e. slight shortfall is allowed for few pixels
- ➔ connection of 1D features for each pixels in between the rows with the help of adjacent matrix
- ➔ connected pixels define cells with new labels



Komponente	1D-Features
1	1, 3, 5, 7
2	2, 4, 6

Adaptive thresholding method (analog TRT, CONO, RDT)

1. Determination of region of intense precipitation through thresholding with dB_{min}
2. Determination of subcells and their maxima starting from global maximum followed by stepwise reduction of threshold. A subcell must have a max-min difference of at least ΔdB_T
3. For each maximum, a minimum threshold dB_{th} is determined so that subcell contains no more maxima

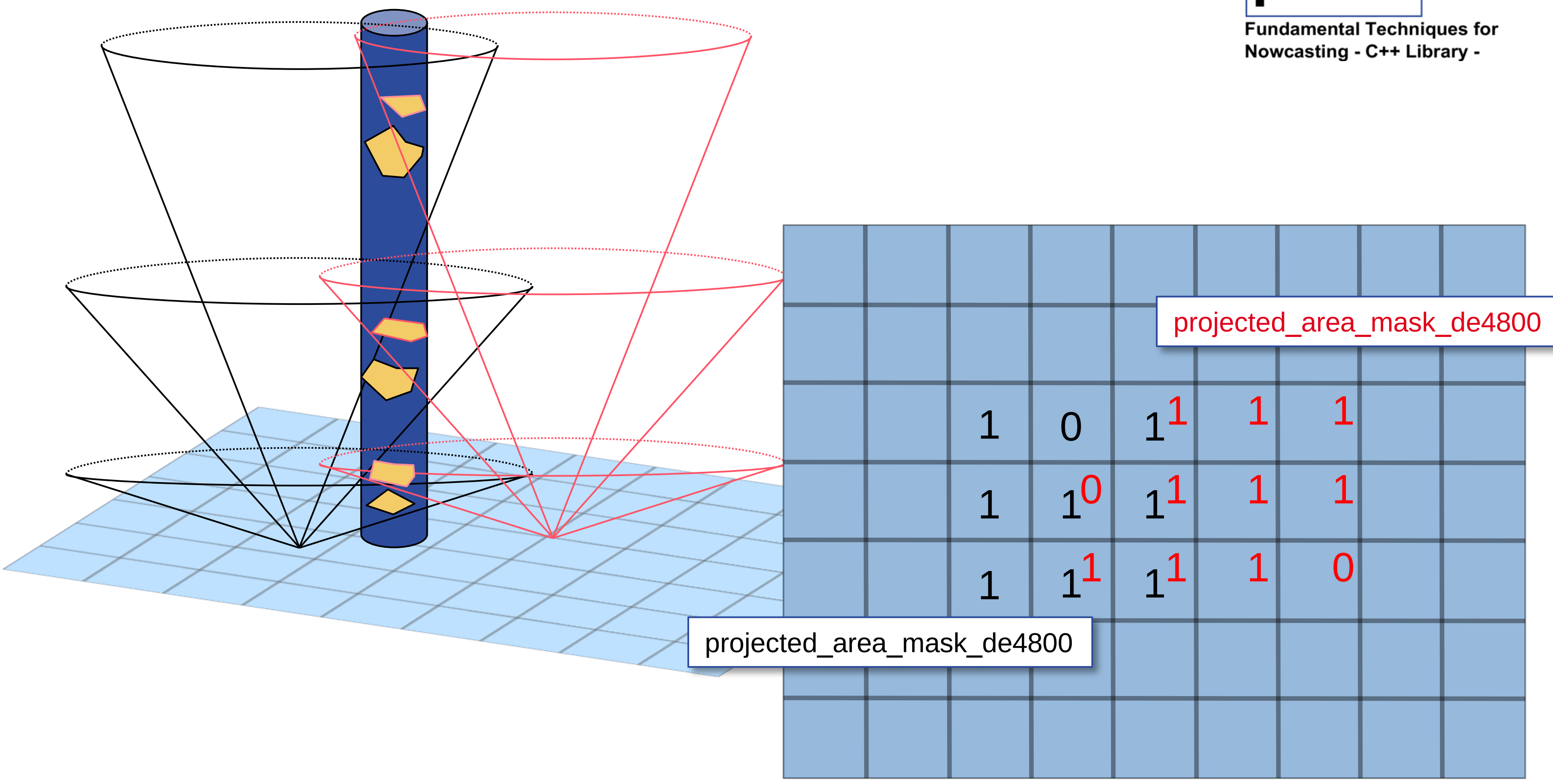


Hering, A. M., Morel, C., Galli, G., Sénési, S., Ambrosetti, P., and Boscacci, M. (2004). *Nowcasting thunderstorms in the Alpine region using a radar based adaptive thresholding scheme.* In Proc. 3rd Europ. Conf. On Radar in Meteor. and Hydrol., Visby,Sweden.

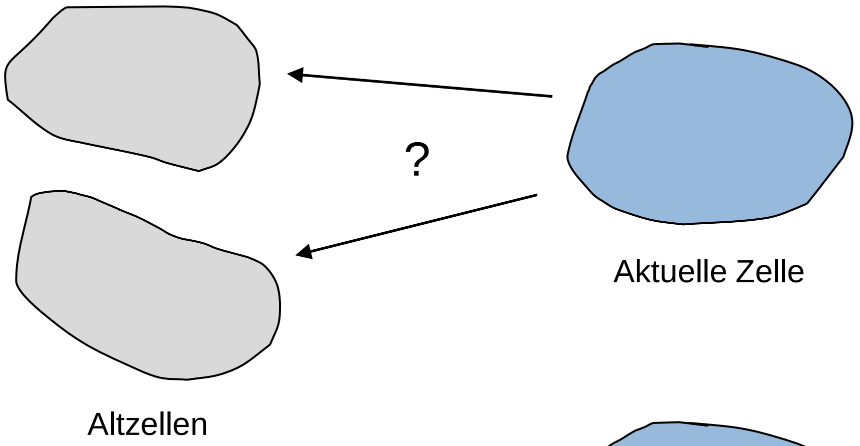
Grouping to 3D-cells

➔ Connected-component Labeling

Fundamental Techniques for Nowcasting - C++ Library -



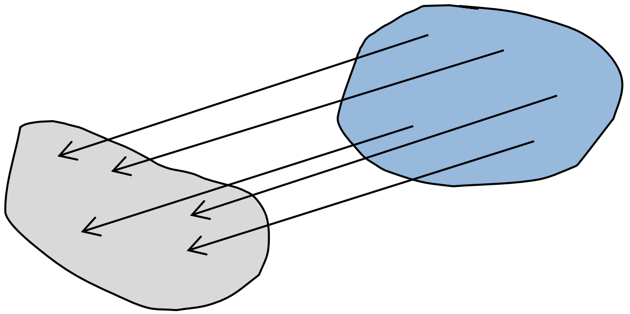
predecessor assignment



Tracking

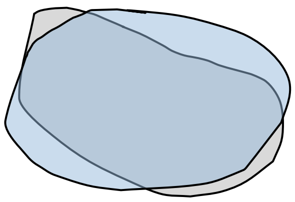
- ➔ assignment old cell to current cell
- ➔ cells change structure and position
- ➔ Splits and Merges

Standard-Algorithm



- ➔ Kuhn-Munkres-Method (Hungarian method)
- ➔ optimal match through minimization of sums of a cost function (here maximization)

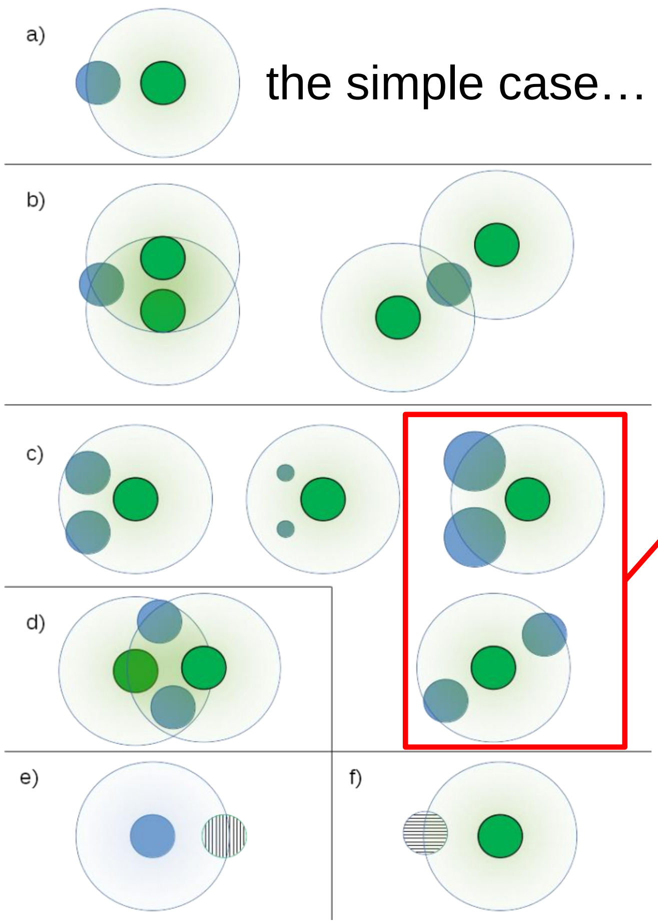
procedure

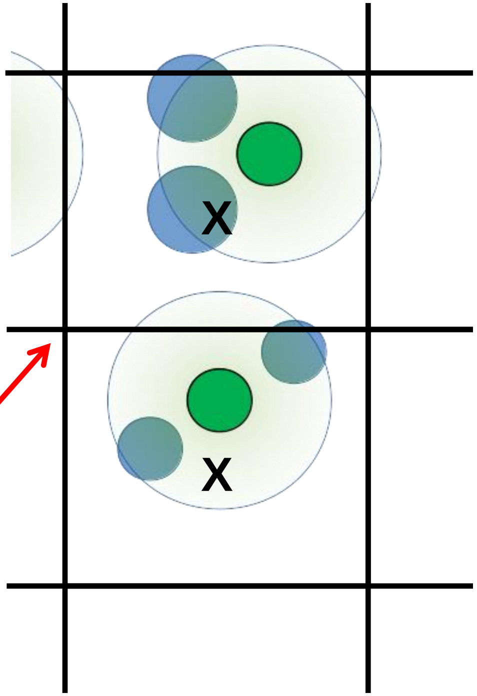


- ➔ actual cell is moved back with the help of displacement vectors
- ➔ Assumption: moved cell overlaps old cell
- ➔ cost function: Intersection-Over-Union = $\dfrac{\text{overlap area}}{\text{union area}}$

An alternative approach without matching…

For some situations, matching becomes a big problem:





- ➔ Determine object-related properties as „averages" in a local neighbourhood around a fixed location **X** in space
- ➔ e.g. #objects > thresh,

  area > thresh

  mean distance betw. obs & sim objects

  lightning activity

  Echo tops/base

- ➔ Do this both for **obs** and **simulations**
- ➔ verify this „gridded" information locally at **X**
- ➔ At the moment just an idea, we are currently starting with it.

Neighborhood verification (minor priority)

Neighborhood (minor priority)

Deterministic	Ensemble

• FSS
• Minimum Coverage
• Fuzzy Logic
• Fuzzy Logic with joint Probabilities
• Multi Event Contingency table
• Pragmatic approach
• Stein & Stoop cont. table
	• Single member verification (ok, but time consuming and no real benefit from using an ensemble)
	• Neighborhood Ensemble Probability (NEP; Schwartz et al. 2010)
	• In consideration: Spatial-Temporal FSS (LeDuc et al. 2013)
	  • Significant additional info?
	  • Difficult to summarise in meaningful plot, esp. for 5 minute data.
	• Other methods?