70 Jahre
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Seamless Combination of Object-Based Probabilistic Nowcasting and NWP Ensemble of Convective Cells from KONRAD3D

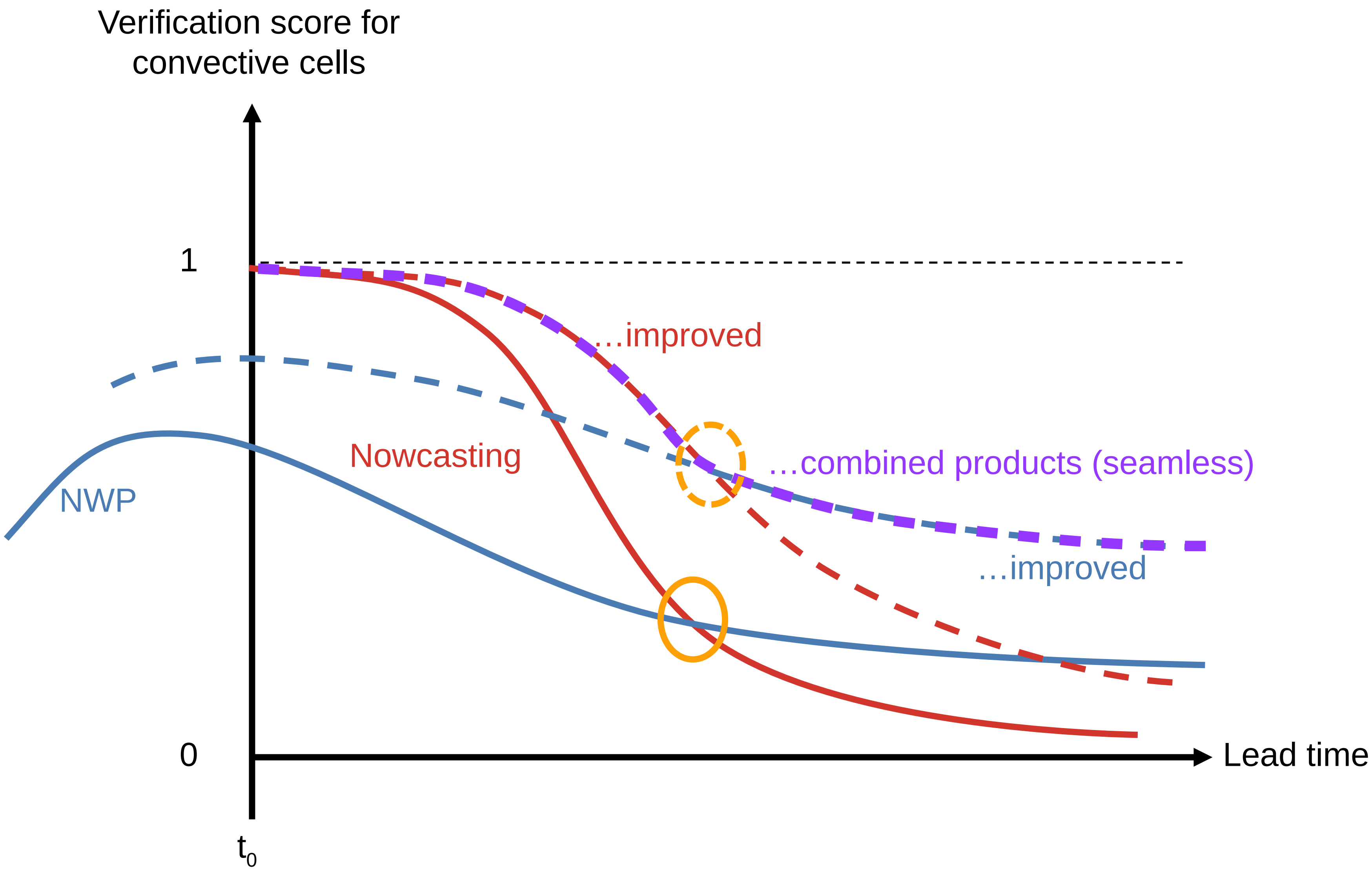
Lukas Josipović, Nora Strotjohann, Gregor Pante, Ulrich Blahak

PrePEP-Conference

March 19th, 2025

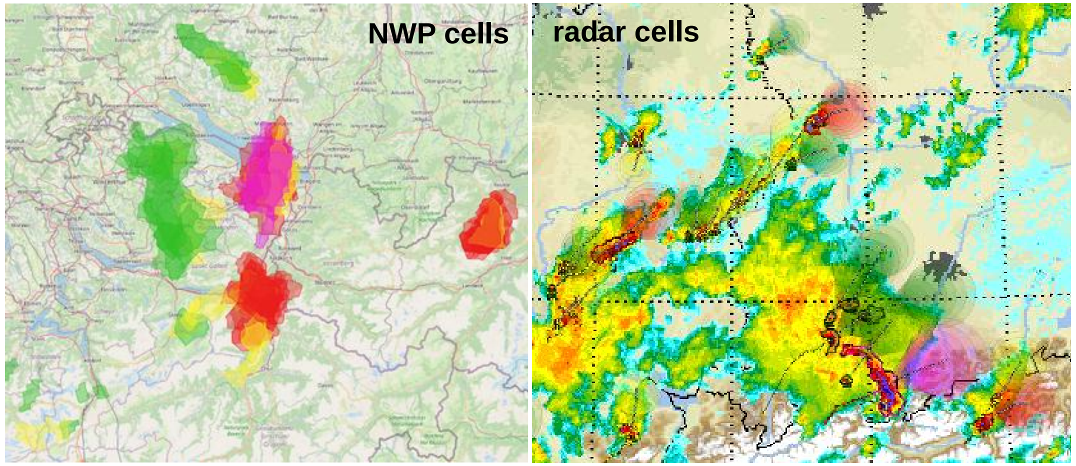
SINFONY

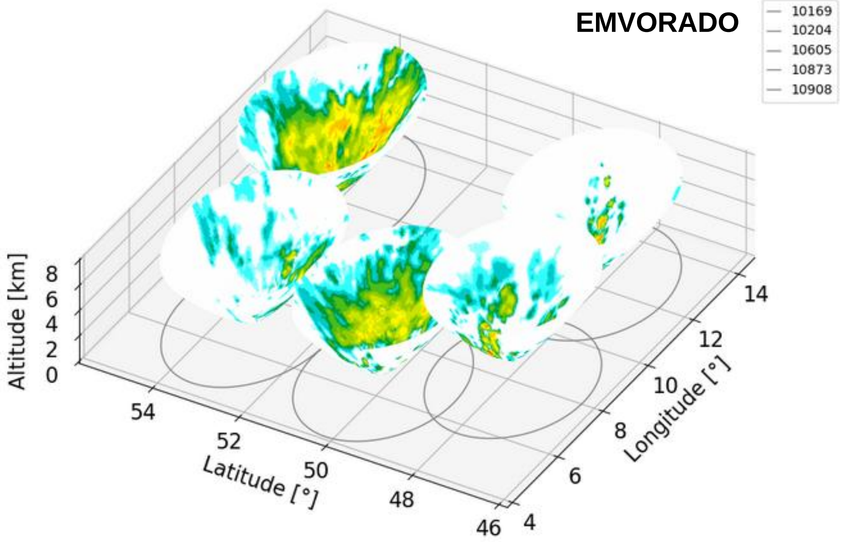
Motivation


Verification score for convective cells
1
0
t_0
Lead time
NWP
Nowcasting
…improved
…combined products (seamless)
…improved

Available KONRAD3D-Cells

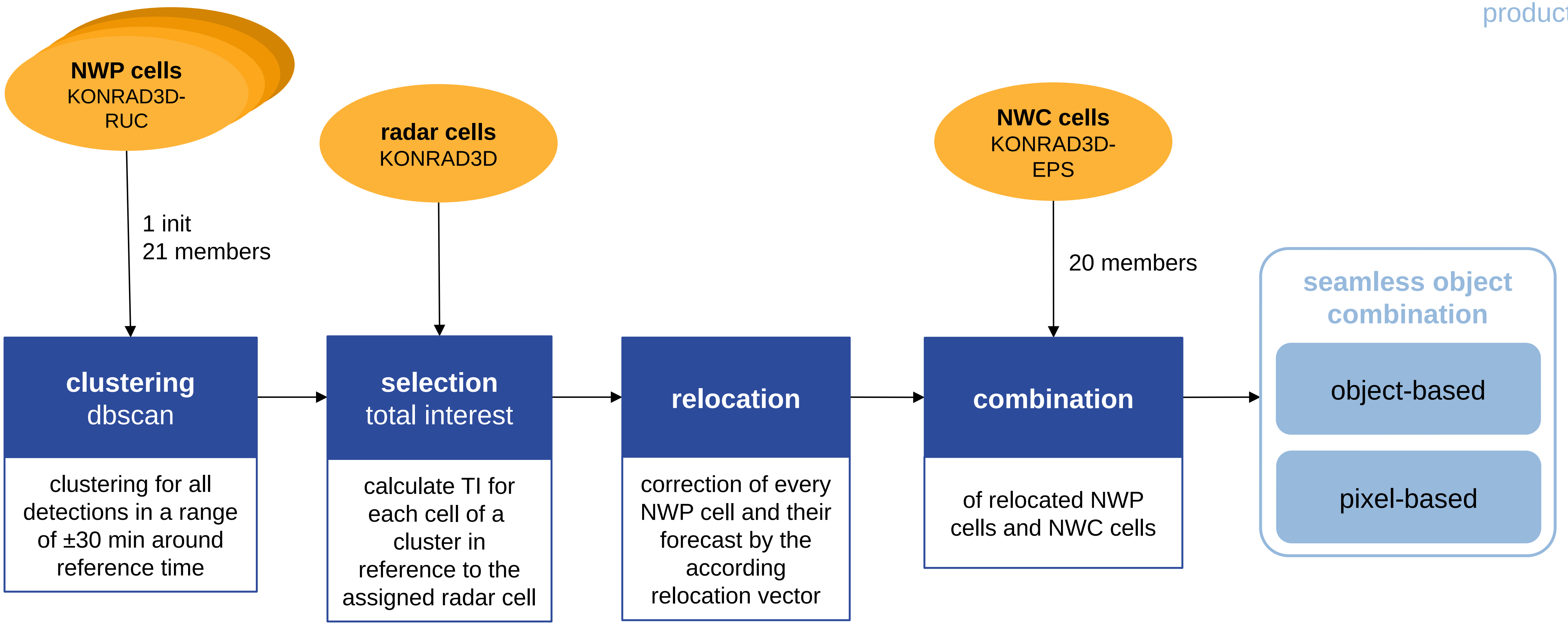
- KONRAD3D
  - detection, tracking and forecasting of convective cells at DWD
- Radar cells
  - available every 5 min
- Nowcasting cells
  - KONRAD3D-EPS based on radar cells
  - available every 5 min
  - 20 members
- NWP cells
  - ICON-D2-RUC + EMVORADO
  - 2-moment microphysics scheme
  - available every hour with a 5-min forecast step
  - forecast time of 14 h
  - 21 members





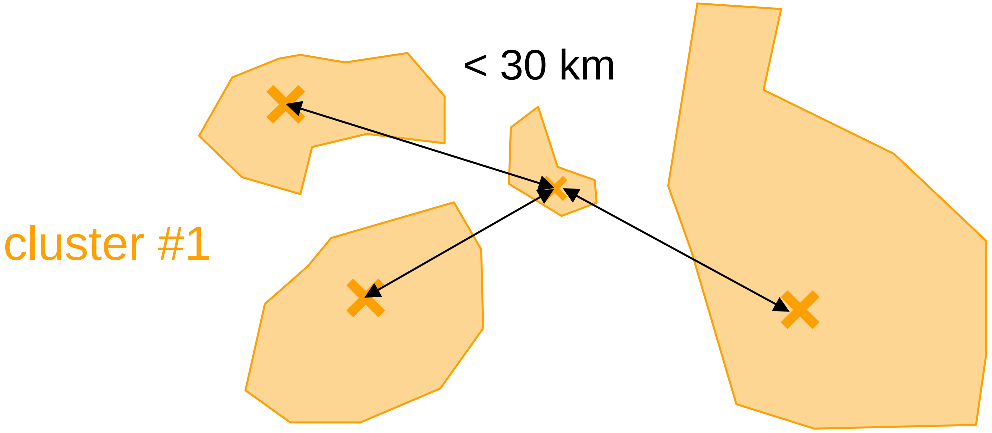
KONRAD3D-SINFONY Overview

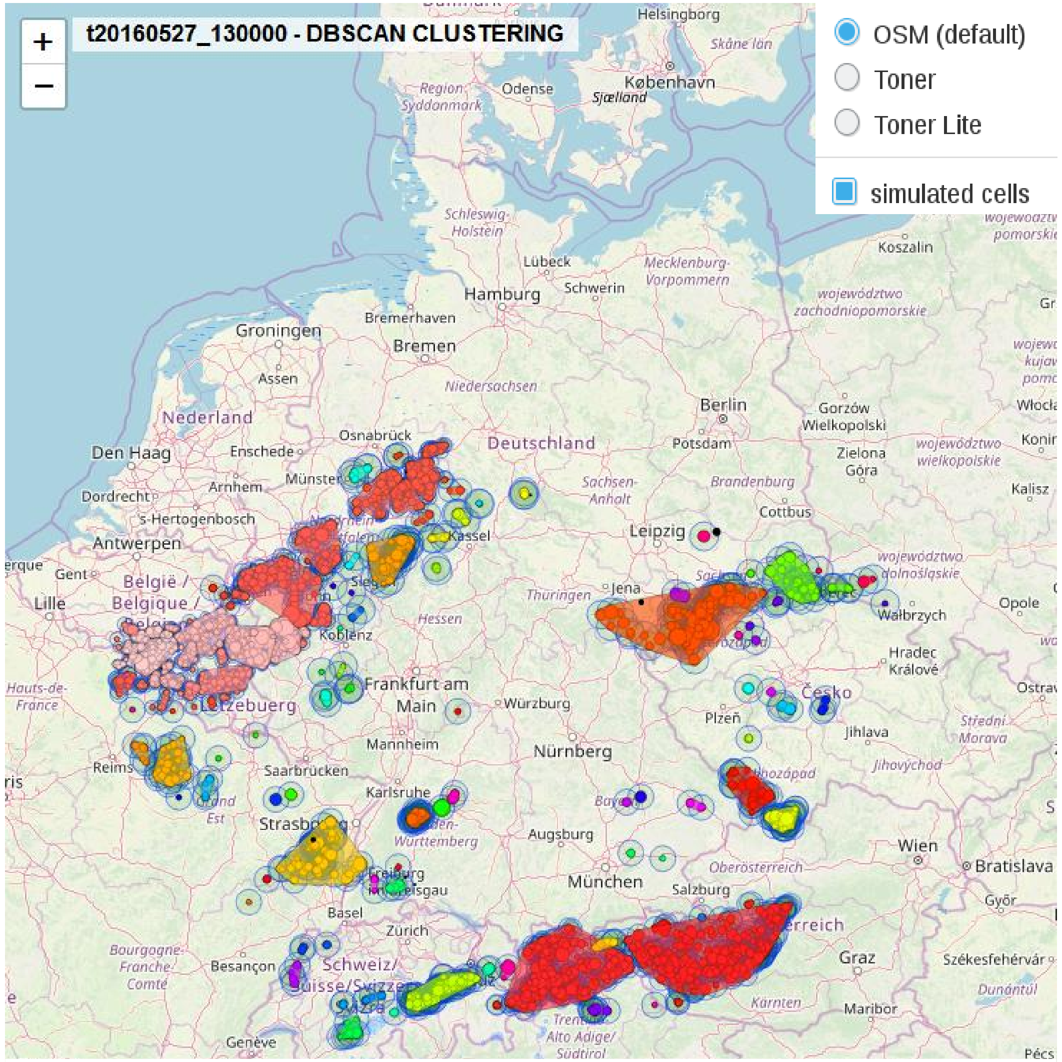
input data
algorithms
products



Clustering of NWP Cells

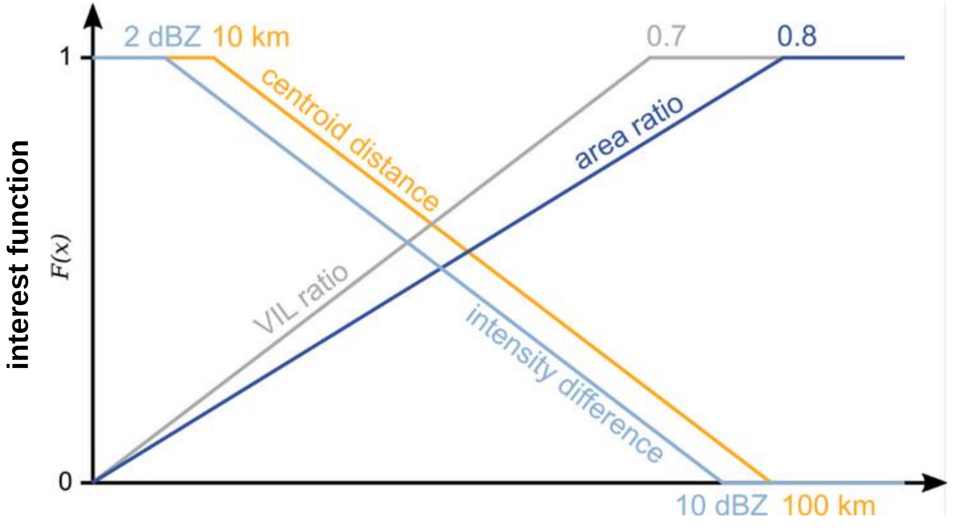
- spatial clustering of cell centroids using dbscan
  - neighborhood_distance = 30 km
- any number of clusters are possible
  - here 141
- discard short-living and single cells

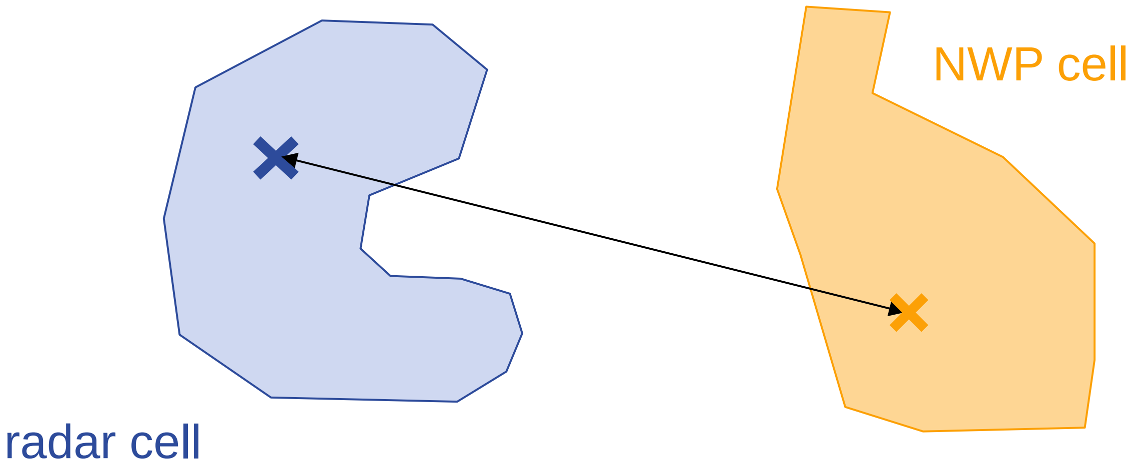




Selection and Relocation of Best NWP Cells

- KONRAD3D cell properties
  - centroid distance
  - area
  - VIL
  - max. reflectivity (intensity)
- **only cells with a TI > 0.85 are selected**





- interest I [0,1]
  - i attribute index
  - j object pair index
  - w weight of attribute
  - $F(x)$ interest function
- total interest TI [0,1]

$$\boxed{I_{i,j} = w_i\, F_{i,j}}$$

$$\boxed{TI_j = \frac{\sum_{i=1}^{M} I_{i,j}}{\sum_{i=1}^{M} w_i}}$$

Selection and Relocation of Best NWP Cells

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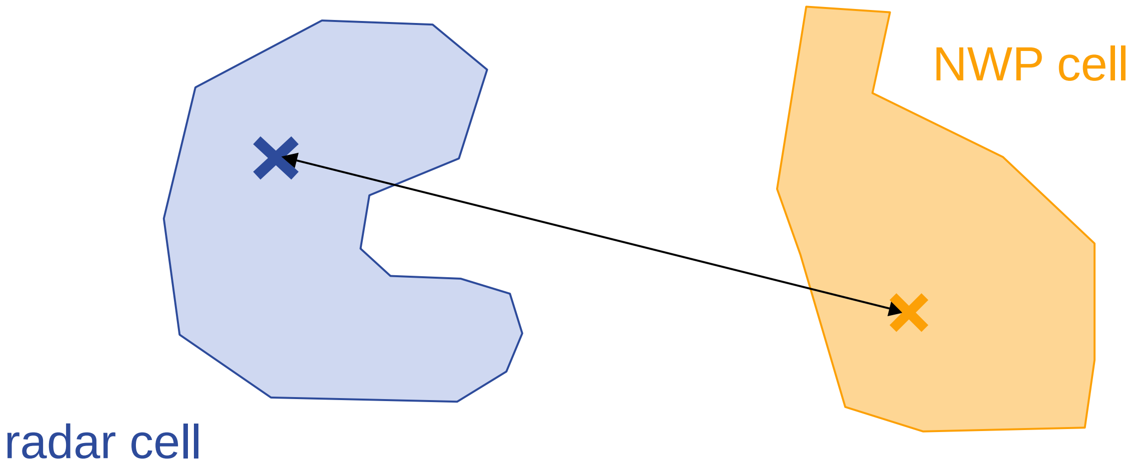
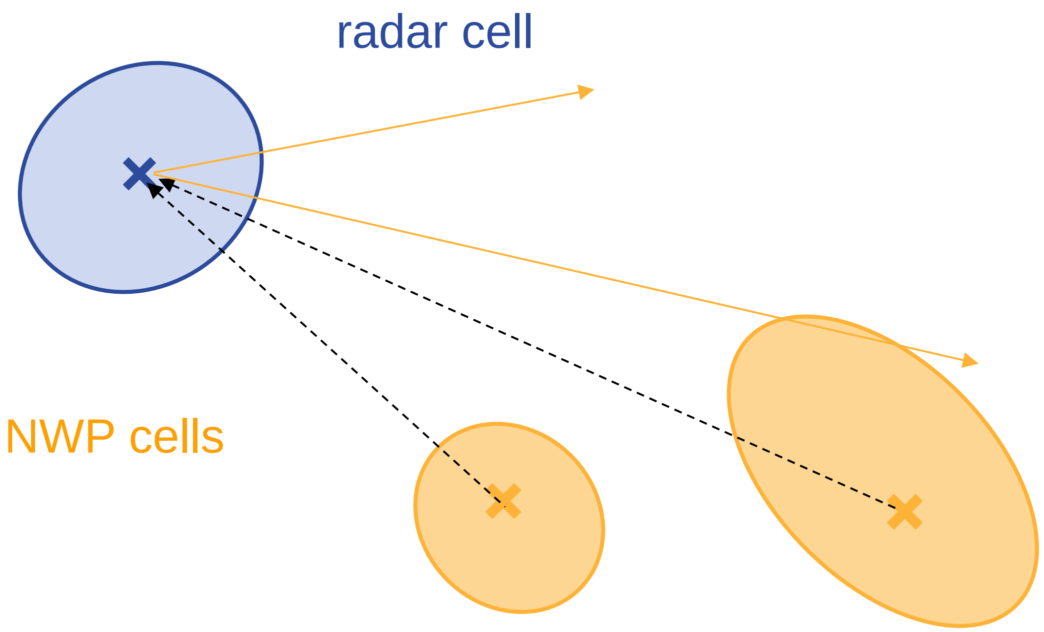




KONRAD3D-EPS overview

Objective

- Ensemble prediction of cell life cycles with regard to nowcast uncertainties in position, motion, intensity, and lifetime

Ensemble Initialization

- Cell position, motion, severity: KONRAD3D detected cells as mean + statistically tuned observation errors
- Lifetime, maximum expected severity: drawing from theoretical PDFs that were fitted to the corresponding observed distributions
- 20 members per cell

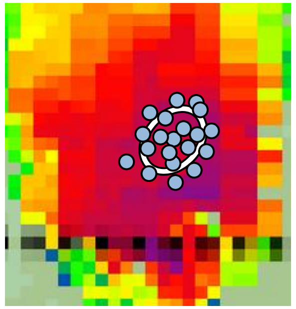
Prediction

- Constant cell speed and parabolic life cycle

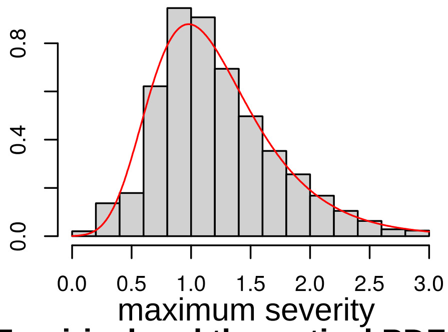
Correction of the Nowcast of Redetected cells

- Cell positions and speed: Ensemble-Kalman-Filter
- (Maximum expected) severity and lifetime:

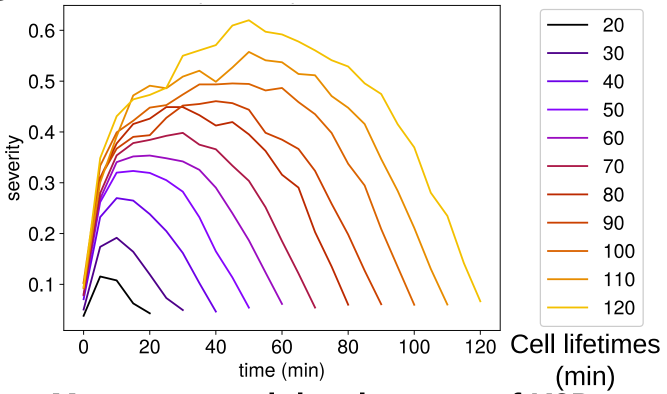
  fitting of cell parabolas to observed severity trend of last 15 min



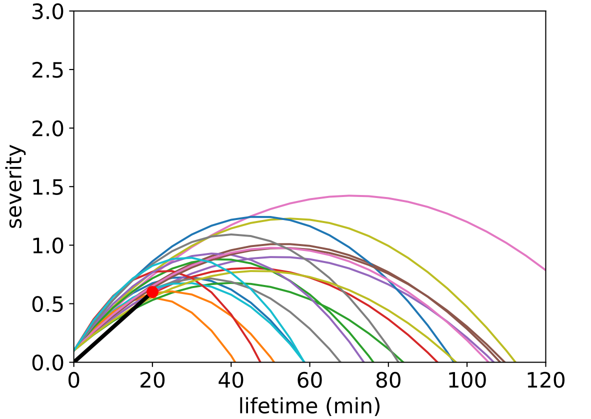
Stochastic ensemble of cell positions of a detected K3D cell.



Empirical and theoretical PDF of maximum expected severity.



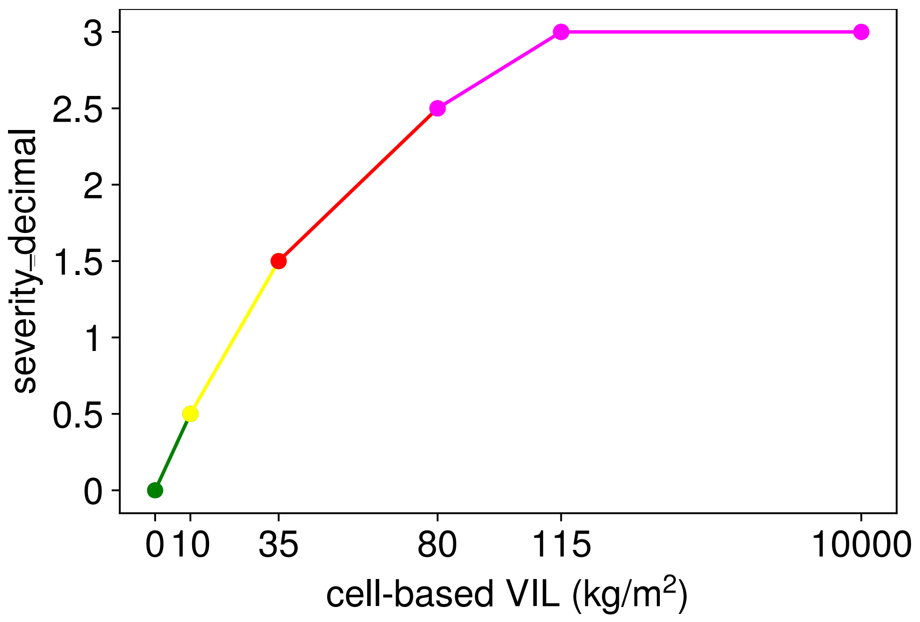
Mean temporal development of K3D cell severity from 04. to 09.2019.



Example of fitting parabolas to observed severity trend (black solid line.)

KONRAD3D: Cell Severity

- Function of 5 reflectivity-based cell attributes
- Piecewise linear function per predictand
- Weighted averaging
- Consolidation with warning flags for hail, heavy rain, gusts
- Cell category as round(severity)

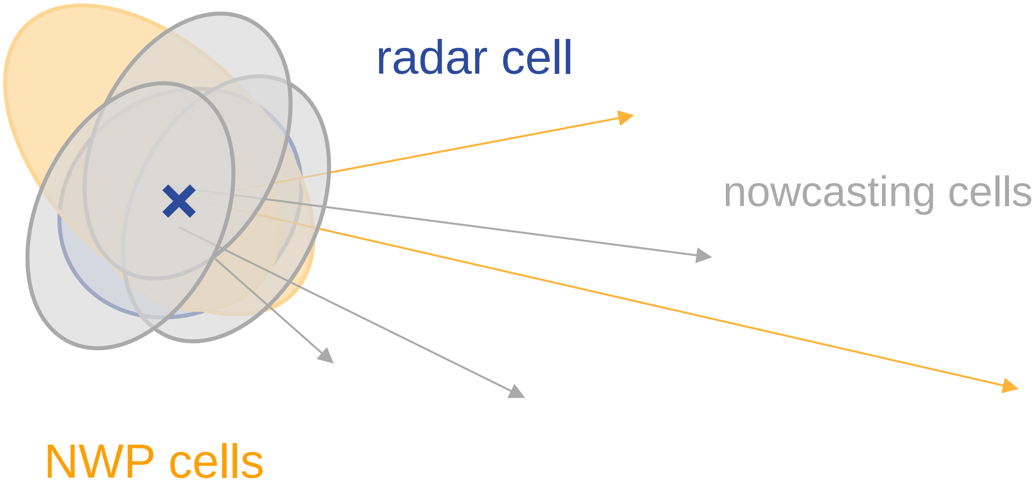


Piecewise linear function of VIL.

Severity	Meaning
0	weak
1	moderate
2	severe
3	extreme

Combination

- Fusion of KONRAD3D-EPS cells and selected NWP cells at time of observation
- Nowcasting cells die when their parabolic lifecycle is at the end
- Convective initiation is predicted using future NWP cells (also clustered using dbscan)
  - ➔ Seamless object-based forecast up to 12 h



t = 0

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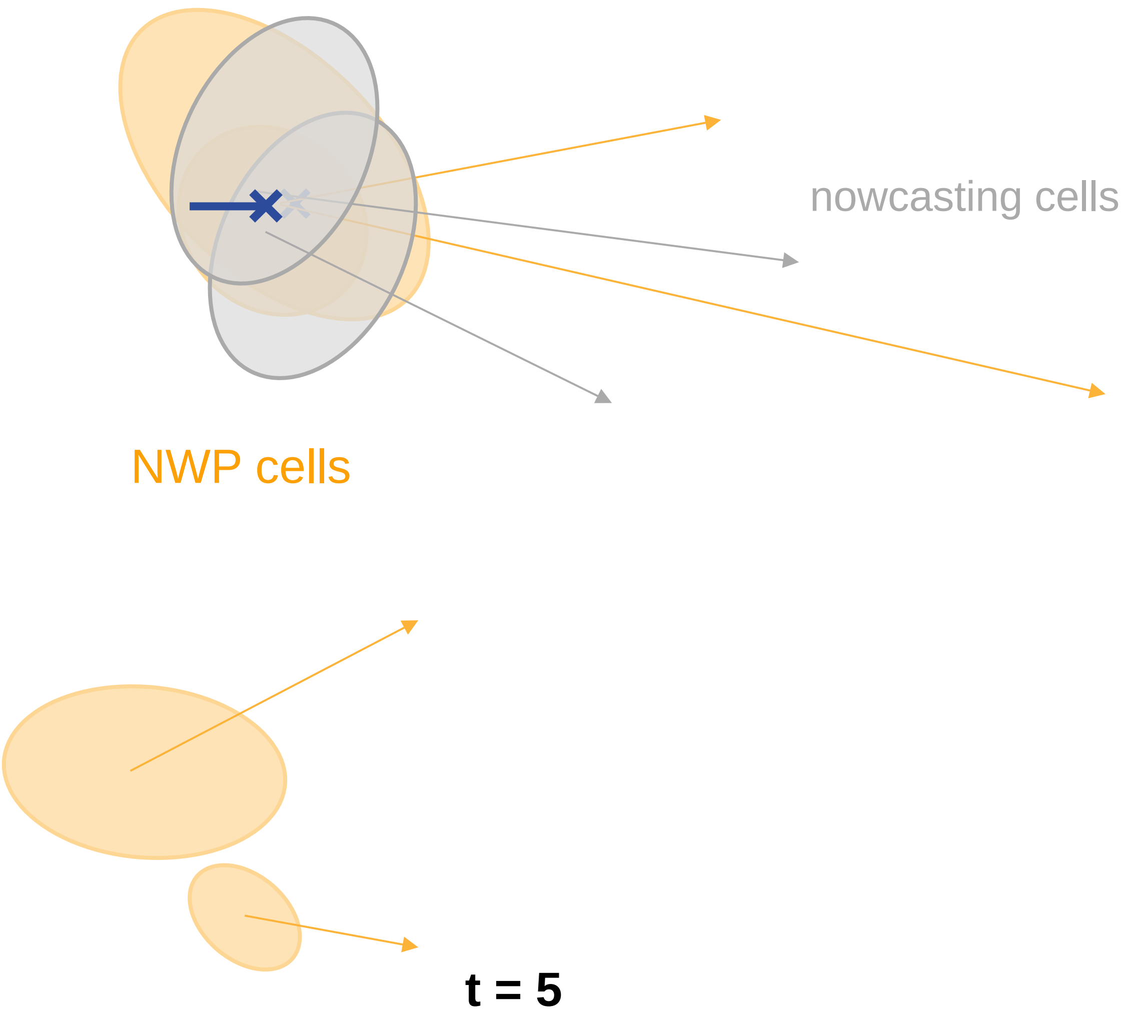

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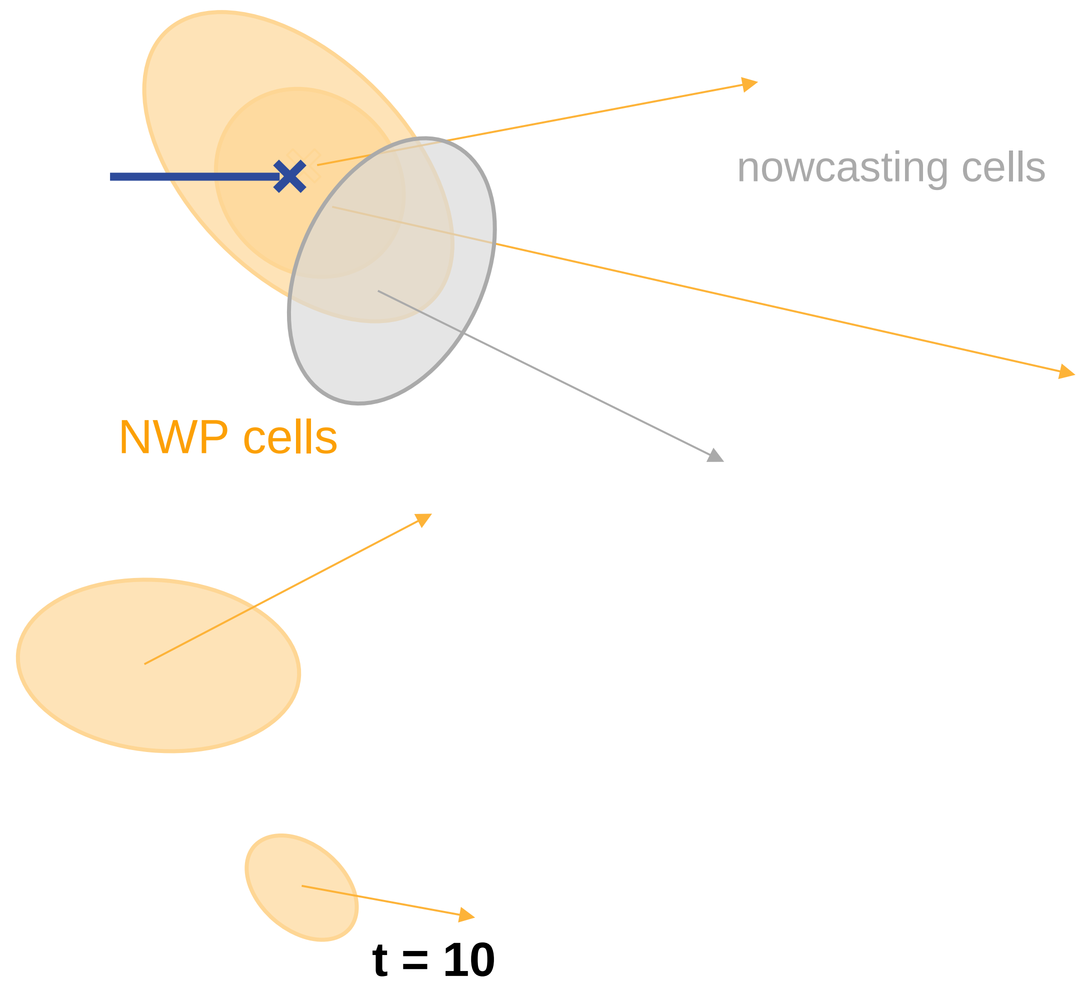

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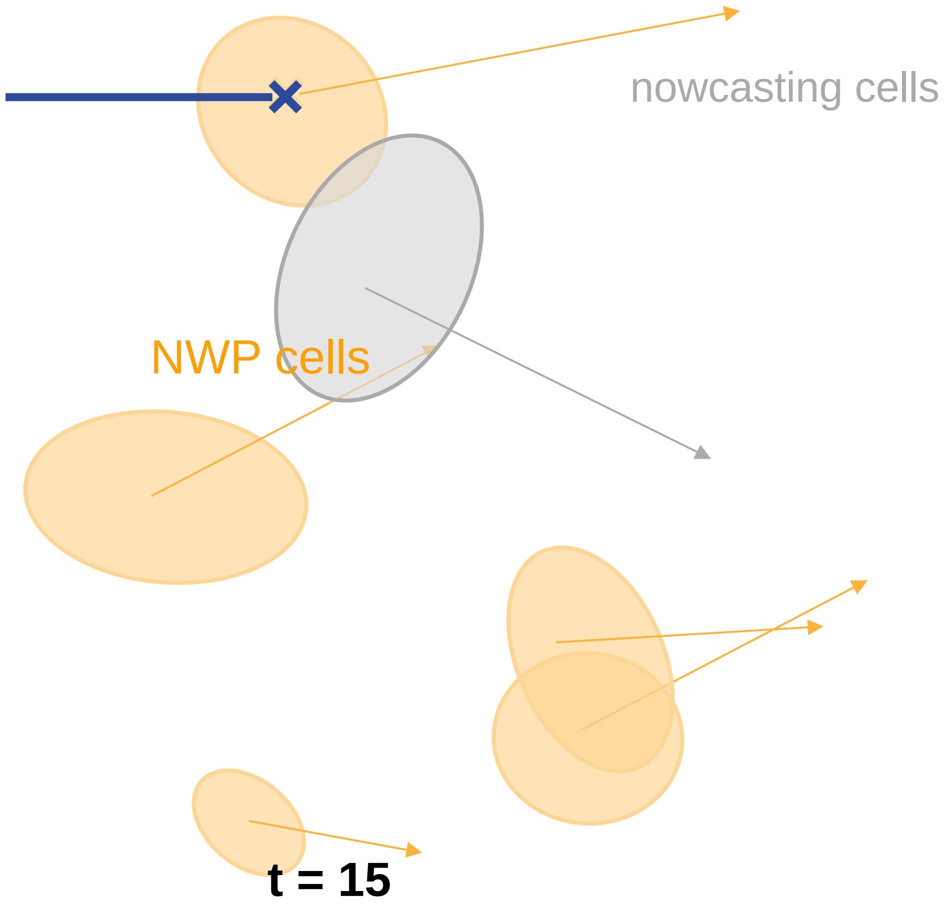

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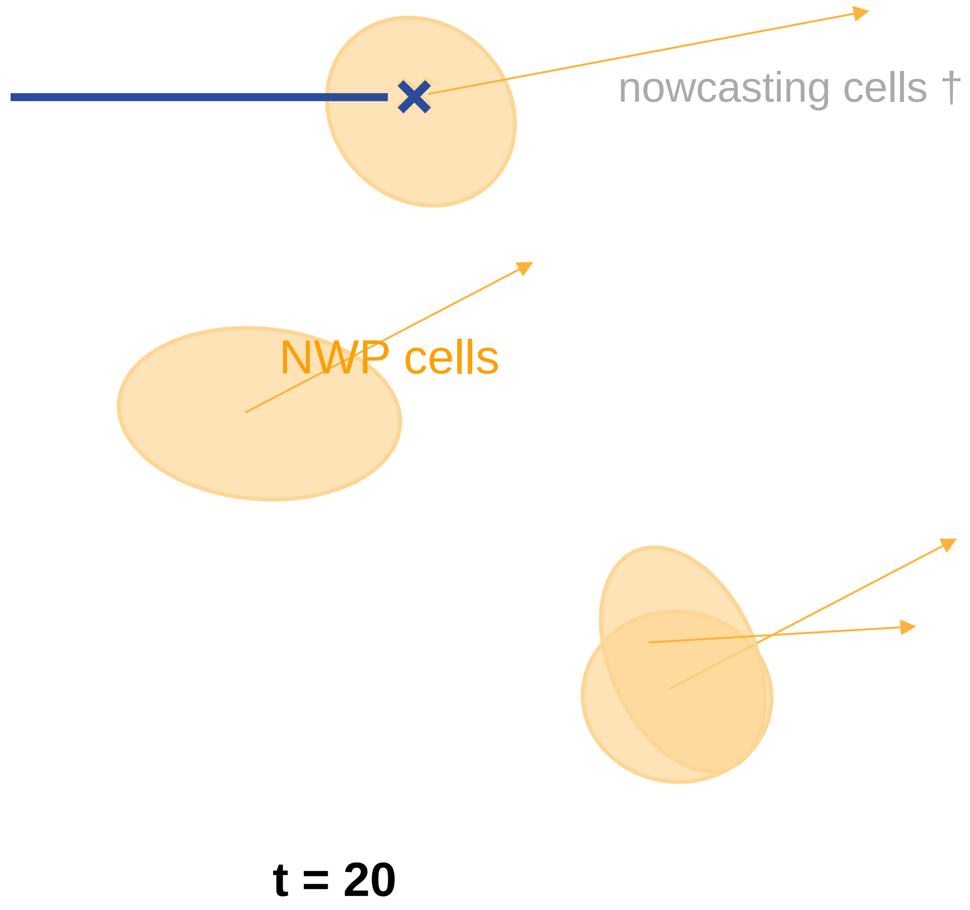

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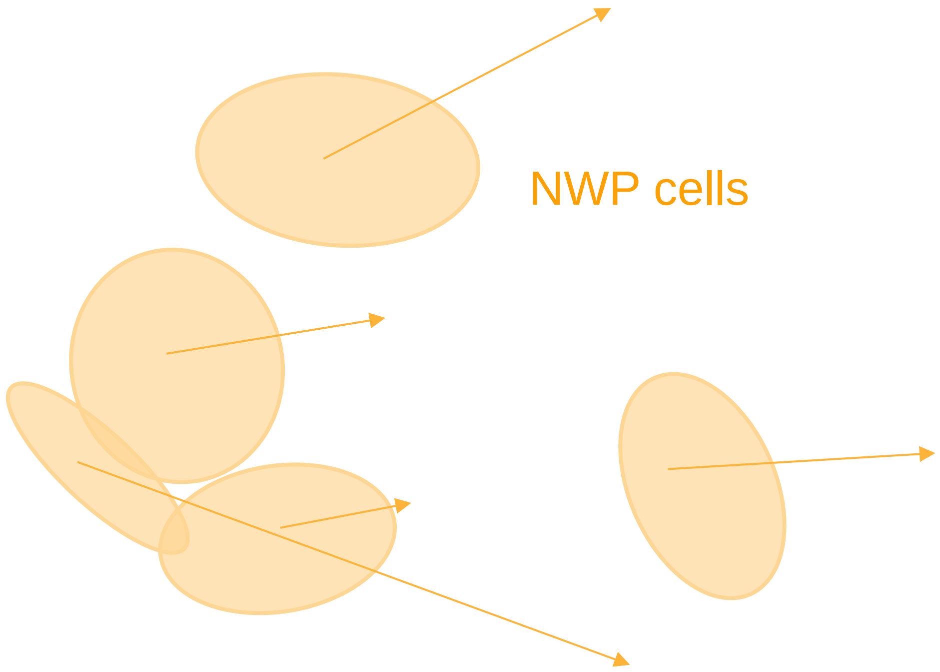
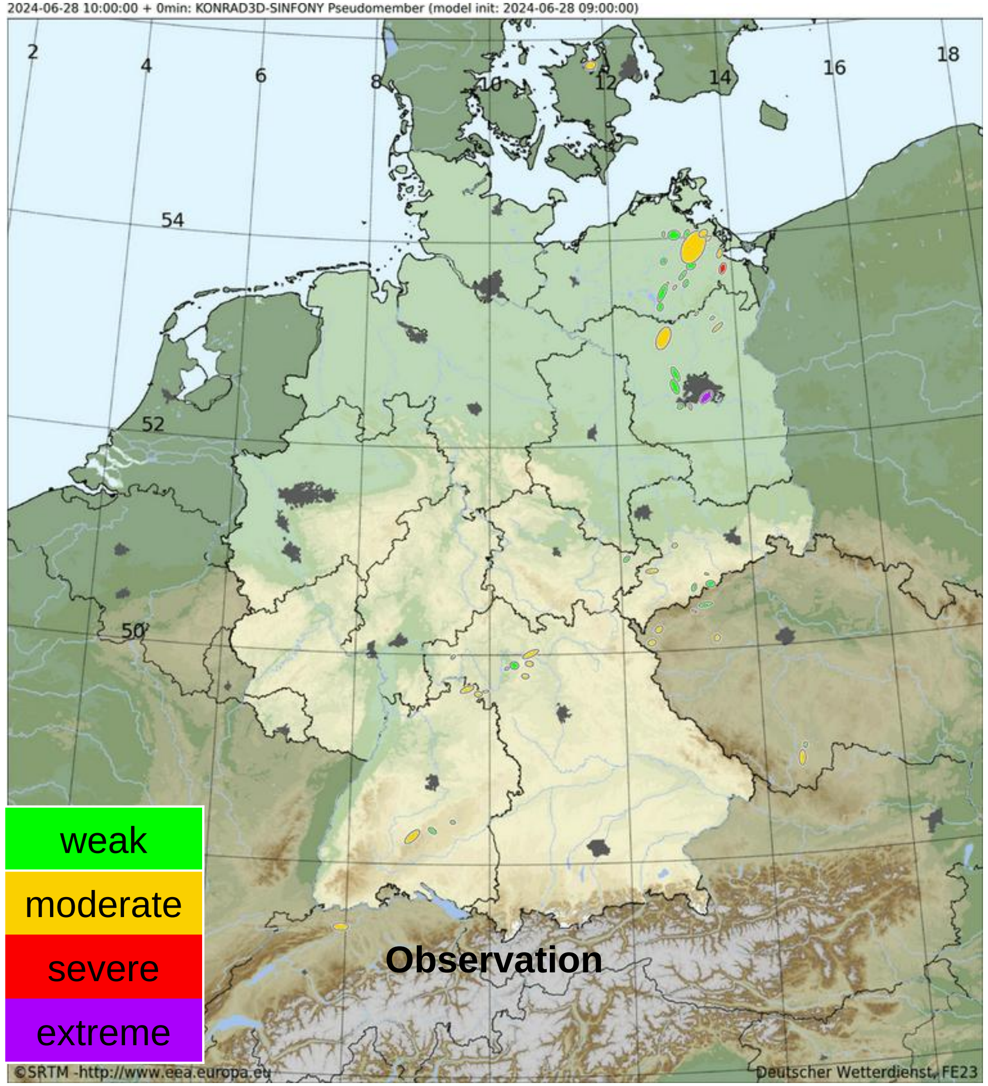
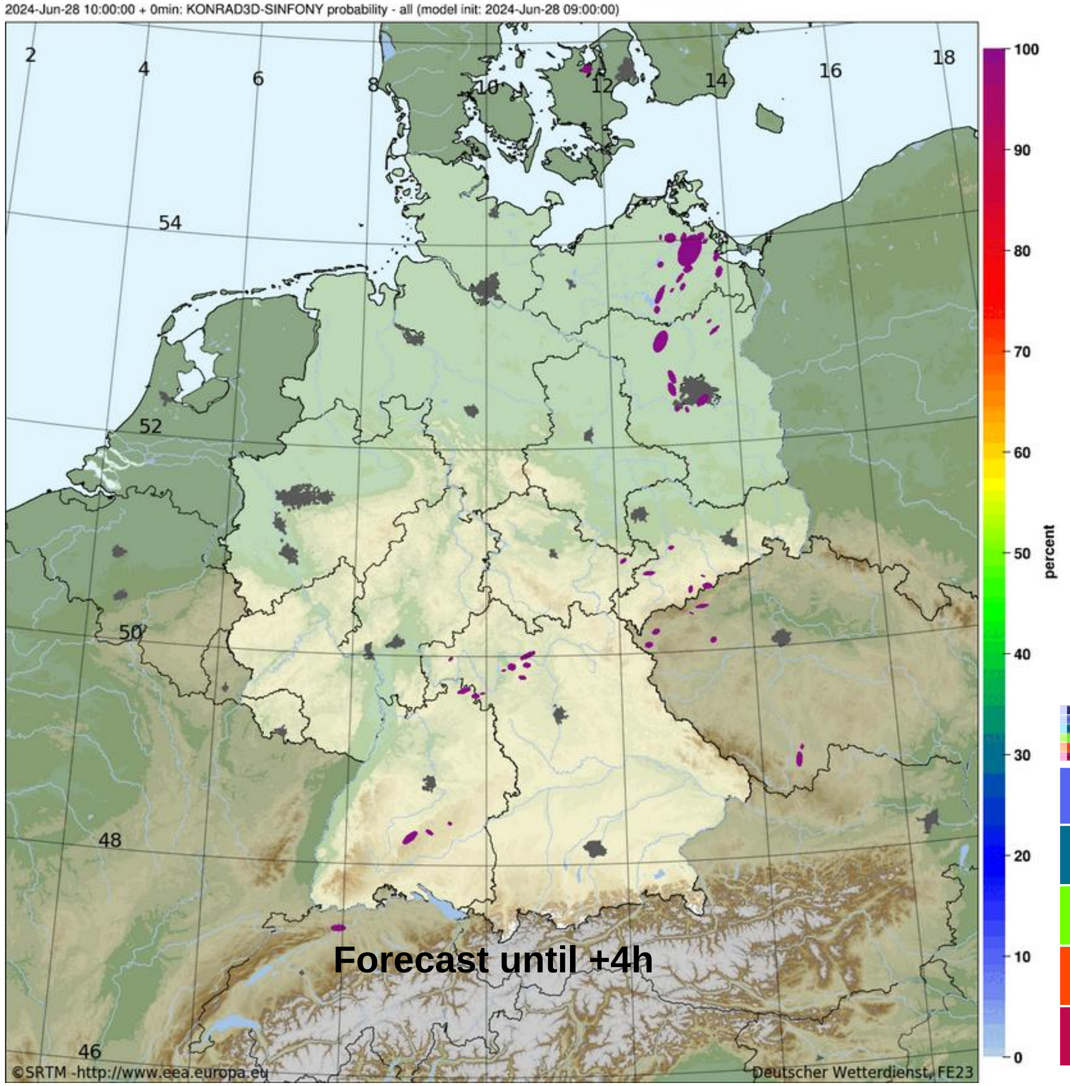


t = 25

Ensemble Probabilities of Convective Cells

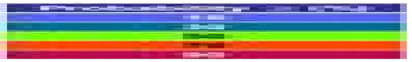




Probabilities derived by counting NO contributing members per pixel.

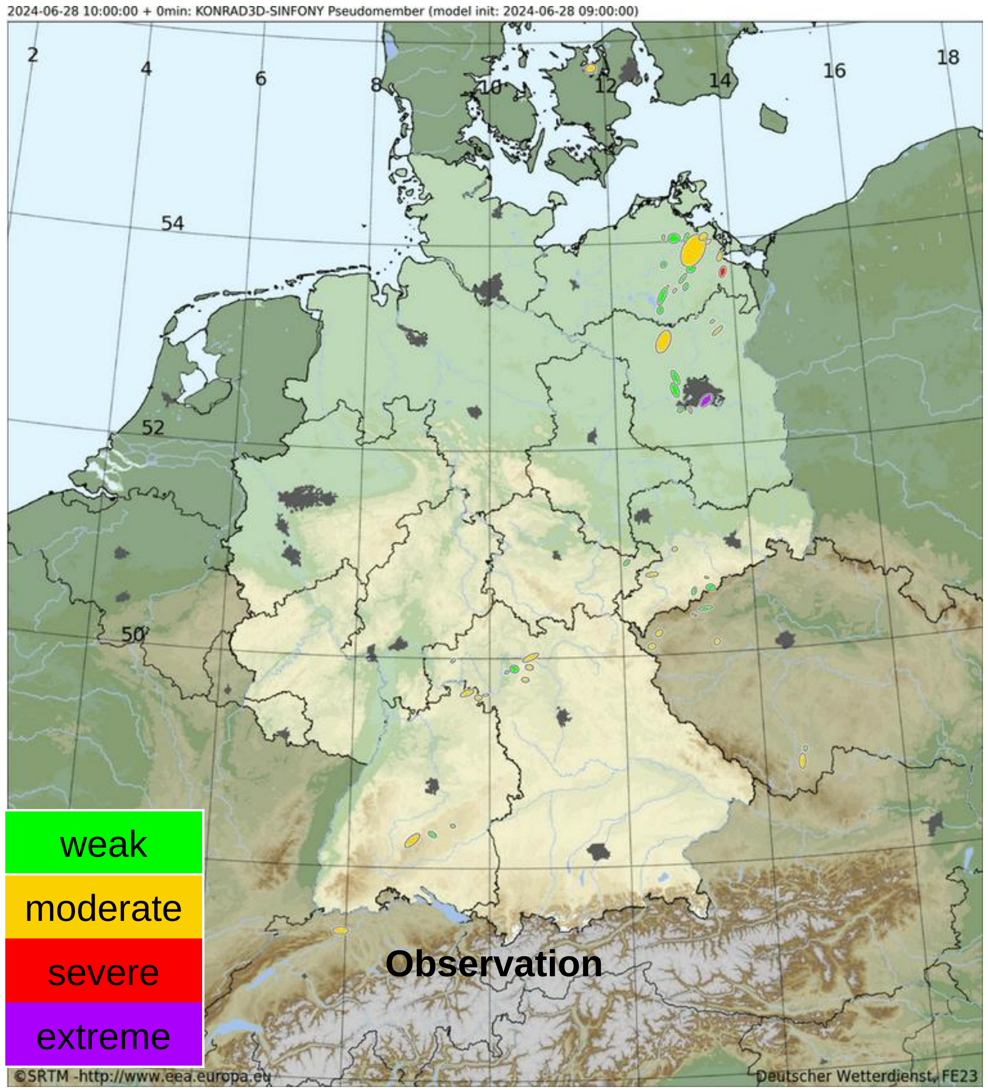
Here: probabilities for cells of <u>all</u> severities.

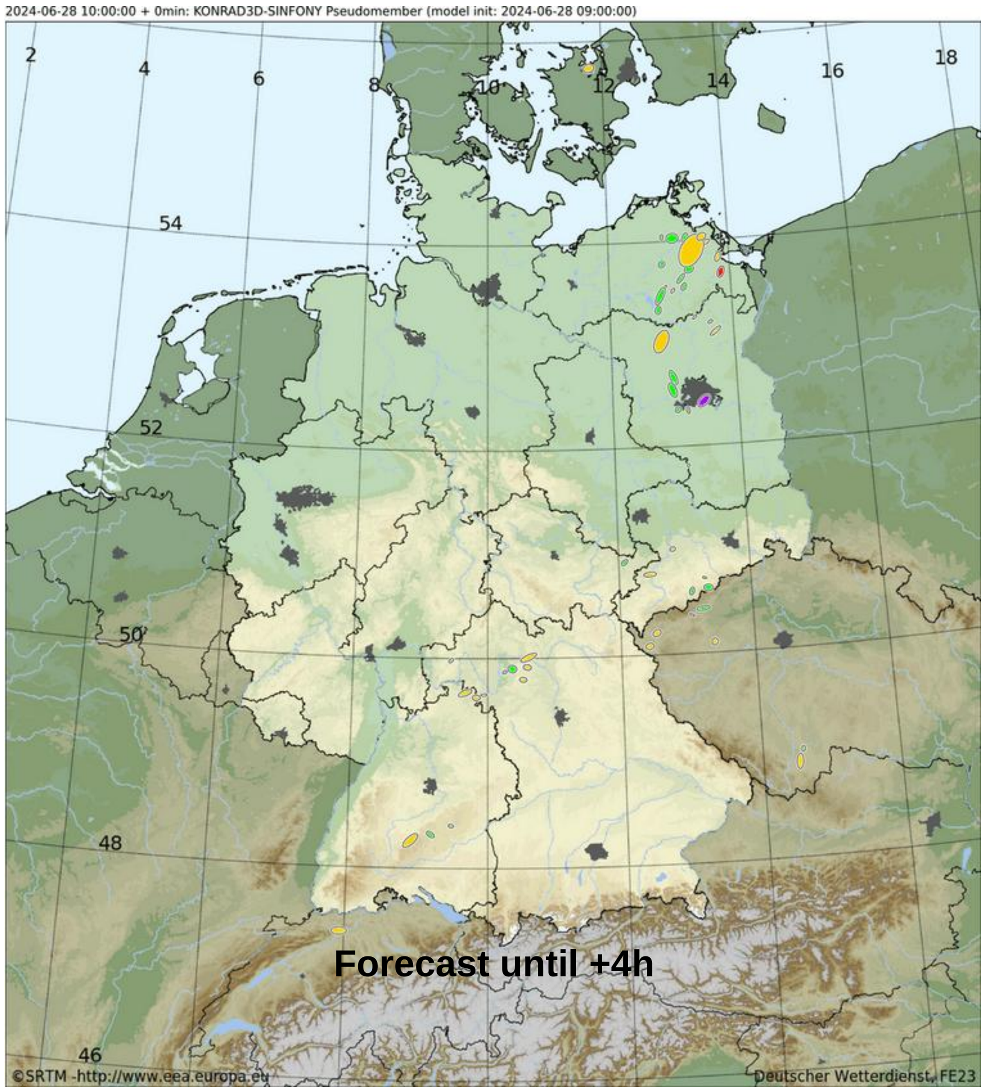
We provide exceedance probabilities for each severity category.



10
30
50
70
90

Calibrated Probabilities and Representative Cells





Work is still in progress!

Aim: get smoother visualization

By N. Strotjohann

10
30
50
70
90

Verification of Period May 26th to June 29th, 2016 with 1-hourly inits

KONRAD3D-EPS nowcasting:
ICON-RUC:
KONRAD3D-SINFONY:

70 Jahre
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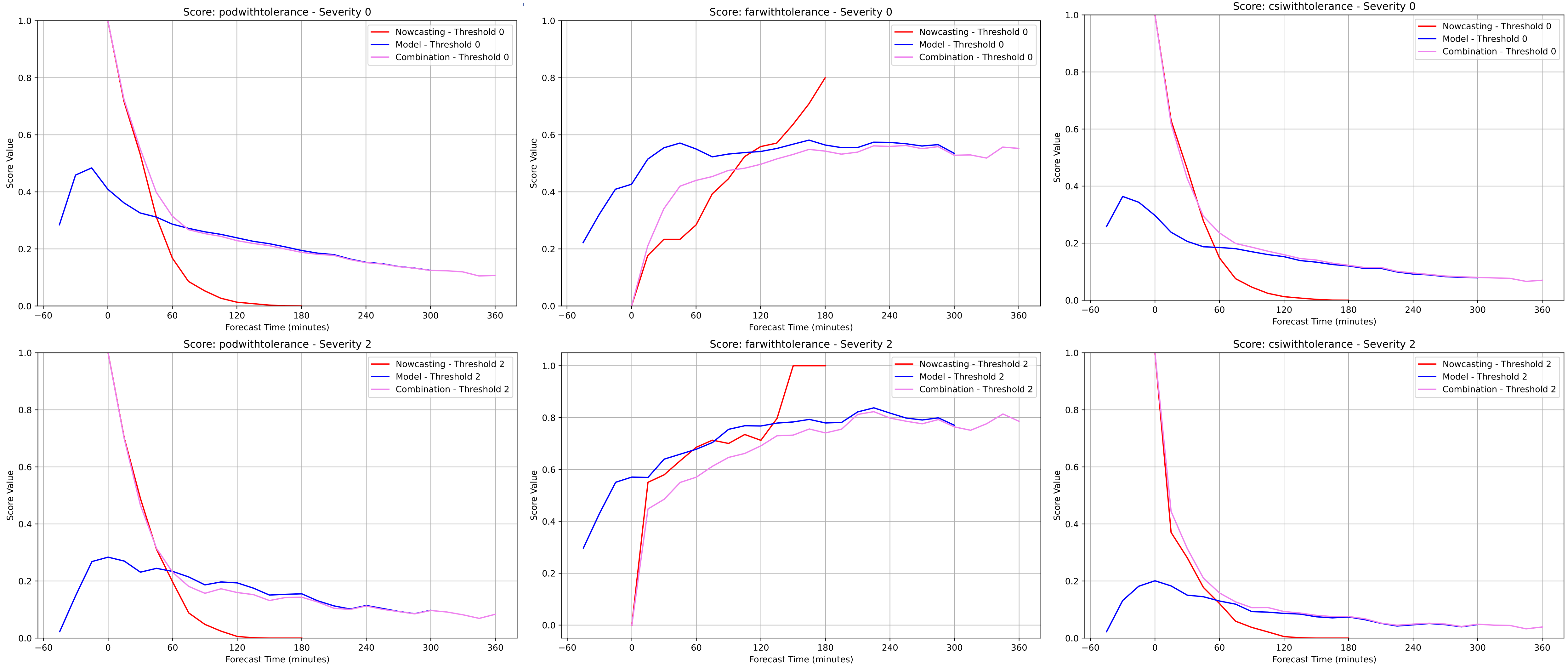

Box size: 31 km, probability threshold for a positive forecast: 25 %. Left: POD, center: FAR, right: CSI. Lead time: 6 h.

Current Status

- Real-time operations for tests and evaluation

- Derived ensemble products:
  - Exceedance probability fields for four different cell severity levels
  - Calibrated probabilities with representative cells

- Evaluation at ESSL Testbeds 2023 and 2024

- Maximum forecast time: currently 10 h, planned 12 h

- Update rate: 5 min (1 h for ICON-RUC cells)

Outlook and Future Plans

- Further tuning and verification
- Improvement of cell detection in simulated reflectivities
- Improvement of severity nowcast based on machine learning
- Development of probabilistic warning flags for gusts and hail based on machine learning
- Evaluation by DWD forecasters and at ESSL Testbed
- Deployment into operational service for automatic issuance of thunderstorm warnings

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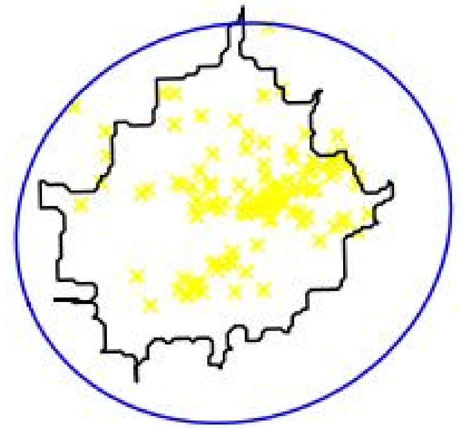


Supercell south from Offenbach, Germany, August 18th, 2019.

References

- **Johnson, A., X. Wang, Y. Wang, A. Reinhart, A. J. Clark, I. L. Jirak, 2020:** Neighborhood- and Object-Based Probabilistic Verification of the OU MAP Ensemble Forecasts during 2017 and 2018 Hazardous Weather Testbeds, Weather and Forecasting, 35, 169-191, doi: 10.1175/WAF-D-19-0060.1.

Backup

Postprocessing: Pseudomember

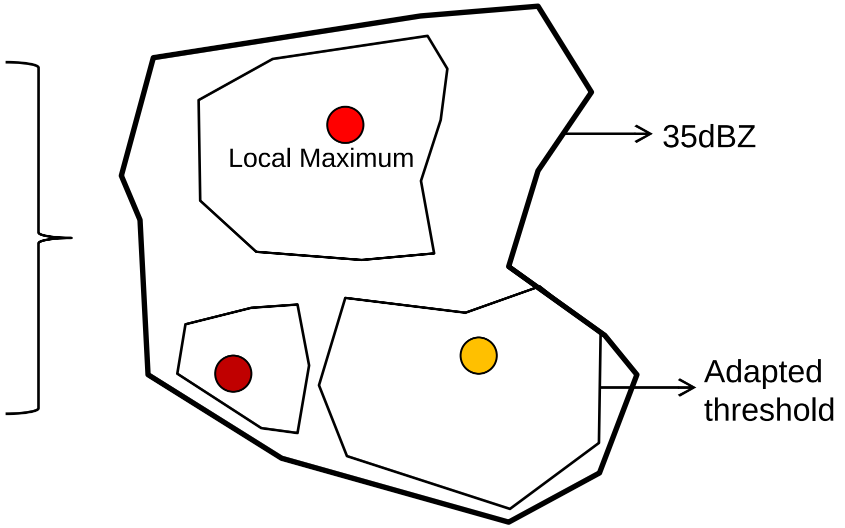
- ➔ Find representative member(s) by comparing all members with each other (Johnson et al., 2020)
- „similarity“ defined using interest functions analogous to selection step in KONRAD3D-SINFONY
- Motivation: condensation of information for visualization and verification

- Pseudomember algorithm delivers:
  - Pseudomember itself
  - Matching Members: members that are similar to pseudomember (in terms of pos., mot., sev., lifecycle)
  - Pseudomember probability: $\frac{\text{no(matching members incl. pseudomember)}}{\text{no(all members)}}$
  - Total Interest Mean: similarity score between pseudomember and matching members: $0 \leq \overline{TI} \leq 1$

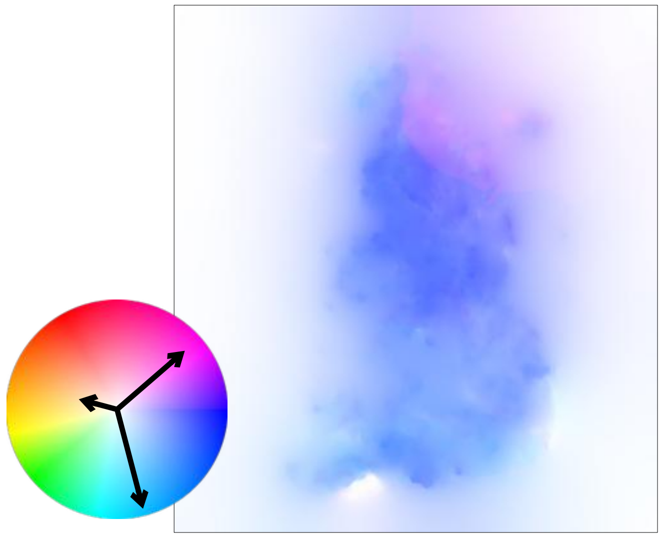
KONRAD3D: Cell Detection

Cell Detection

- **Adaptive thresholding** scheme in 2D radar sweeps
- Principle: Seek disjoint features around local maxima within regions of increased radar reflectivity (e.g. 35 dBZ)
- Formation of 3D features by spatial adjacency
- 2D cell polygons w.r.t associated regular grid **(250m x 250m)**



- **Optical Flow:** Via **OPENCV** library (Open Source Computer Vision)



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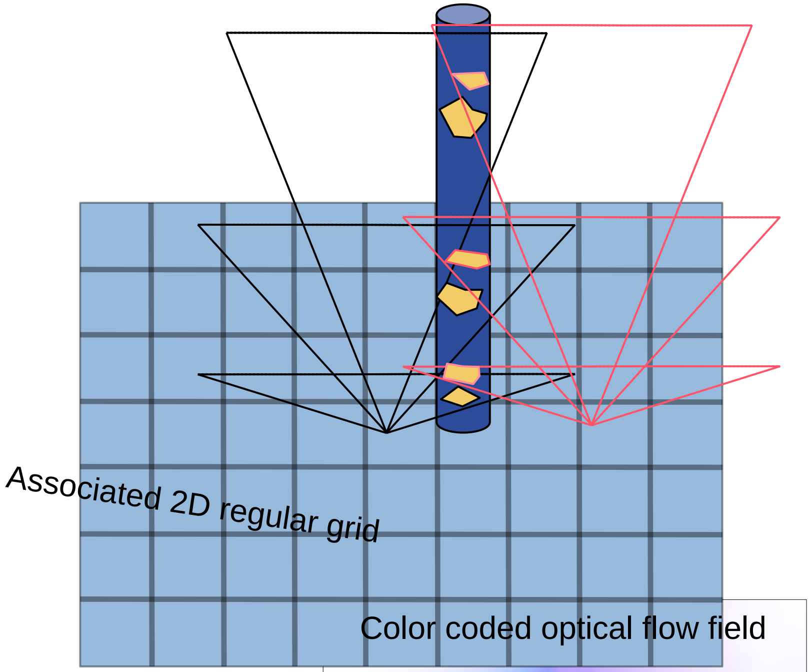

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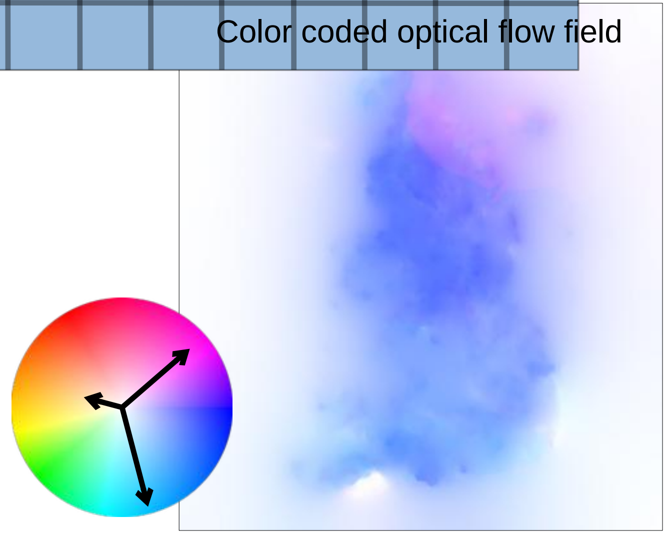


KONRAD3D: Convective Mask Principle

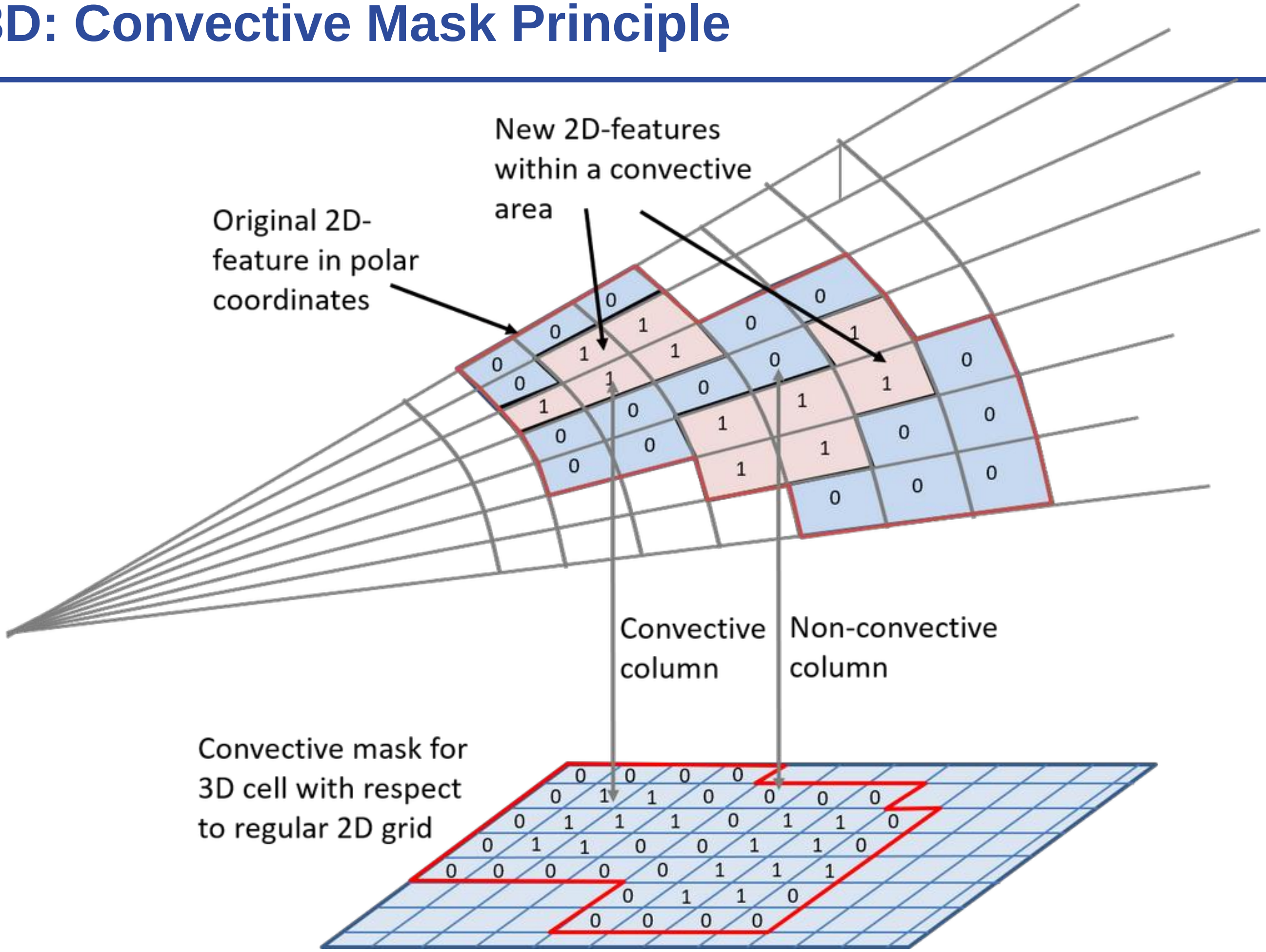


***Figure 7:** Imprinting “convective mask” from Step 2.c to 2D-features. New 2D-features arise from which new 3D cells are formed in d.*

KONRAD3D-EPS overview

Objective

- Ensemble prediction of cell life cycles with regard to nowcast uncertainties in position, motion, intensity, and lifetime

Ensemble Initialization

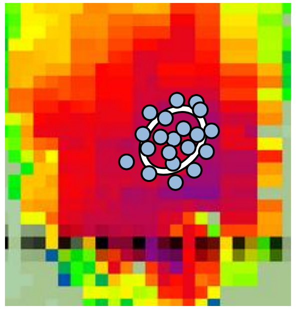
- Cell position, motion, severity: KONRAD3D detected cells as mean + statistically tuned observation errors
- Lifetime, maximum expected severity: drawing from theoretical PDFs that were fitted to the corresponding observed distributions
- 20 members per cell

Prediction

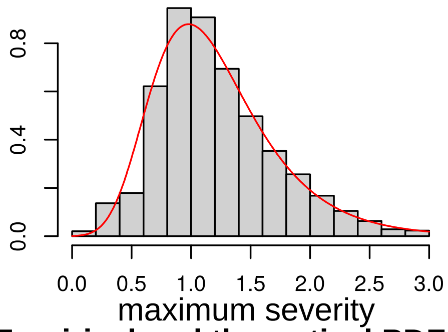
- Cells move with constant speed
- Life cycle of cell intensity is a upside down parabola

Correction of the Nowcast of Redetected cells

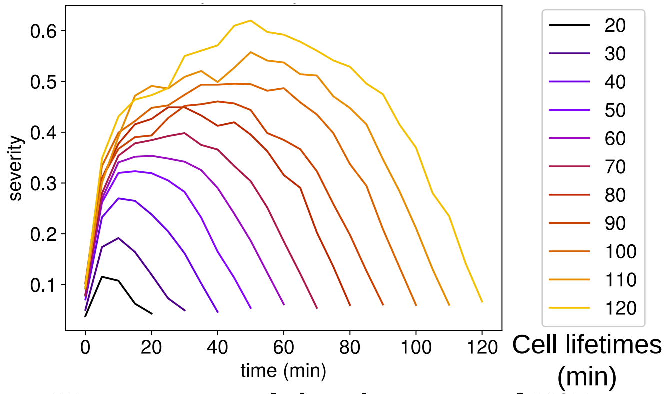
- Cell positions and speed: Ensemble-Kalman-Filter
- (Maximum expected) severity and lifetime: fitting of cell parabolas to observed severity trend of last 15 min
- Special treatment of long-living cells using lightning and mesocyclones



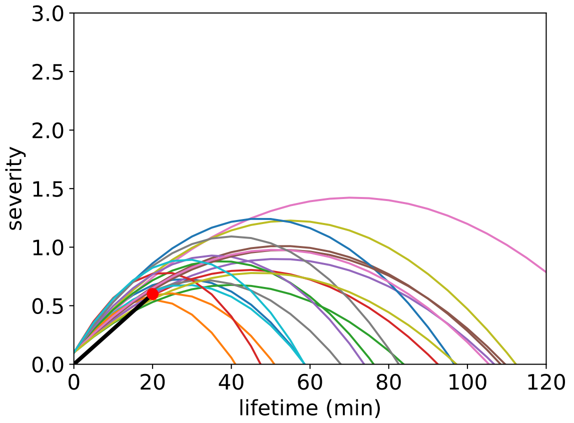
Stochastic ensemble of cell positions of a detected K3D cell.



Empirical and theoretical PDF of maximum expected severity.



Mean temporal development of K3D cell severity from 04. to 09.2019.



Example of fitting parabolas to observed severity trend (black solid line.)

KONRAD3D-EPS: Object-Based Nowcasting Ensemble

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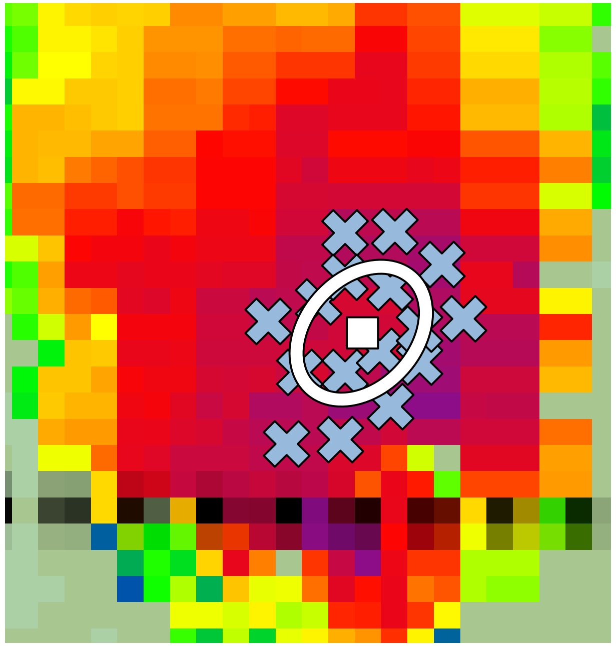
Objective

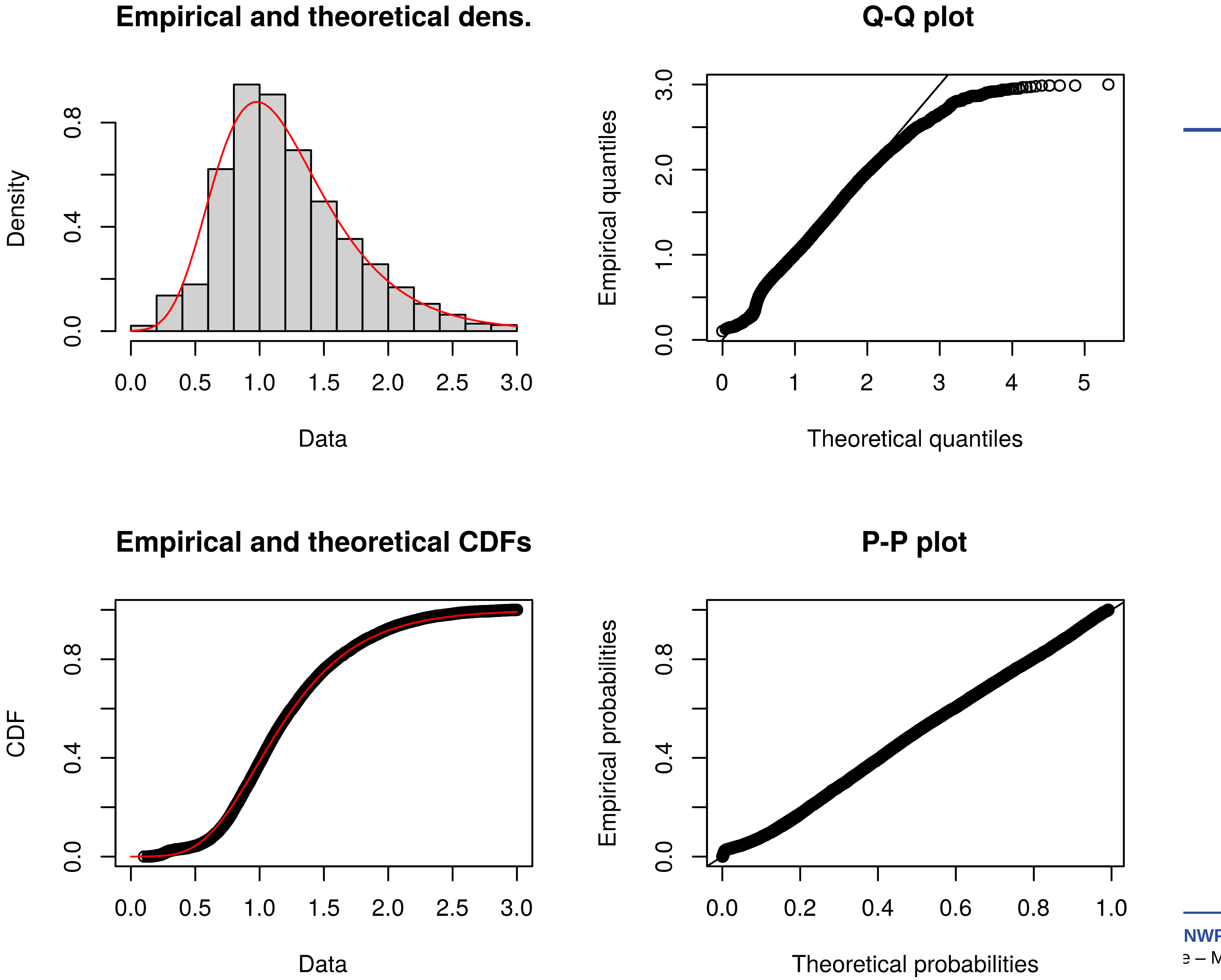
- Capture nowcast uncertainties
- Predict intensity changes

Concept

- Generate an ensemble with 20 members by:
  - KONRAD3D output as ensemble mean
  - Statistically calibrated errors of the observations
  - Statistical distributions of maximum severity and lifetime
- Predict cell parameters
  - Cell speed assumed to be constant
  - Severity show a parabolic behavior
- Apply an Ensemble Kalman filter to track cells



Ensemble of KONRAD3D cell centers



Observed maximum severities of KONRAD3D cells fitted to a Gumbel distribution.
Period: JJA 2021.

→ Used for initialization only!

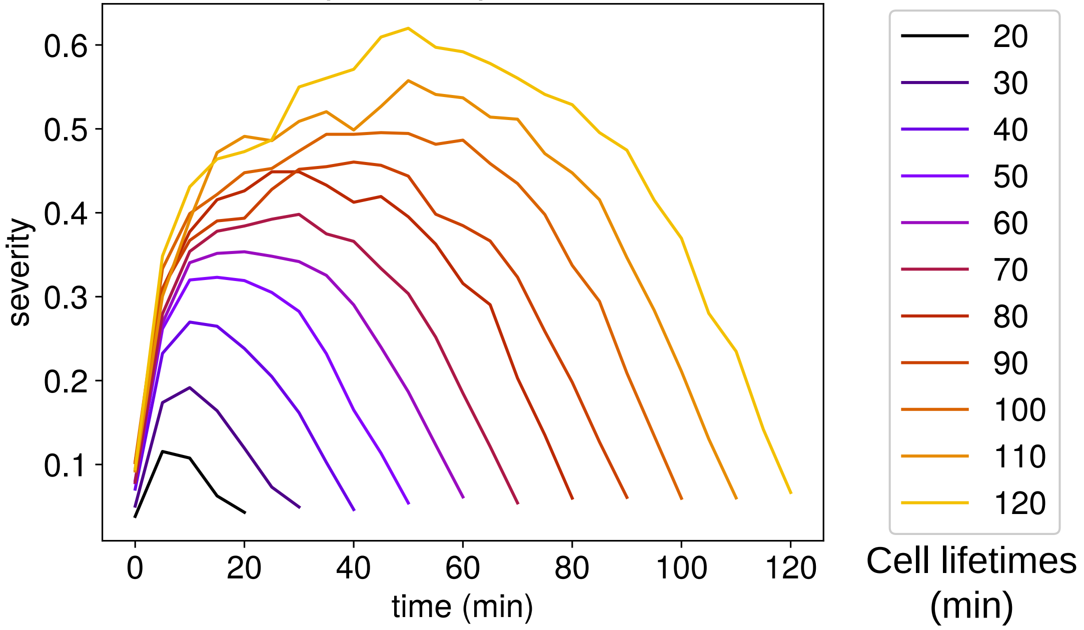
KONRAD3D-EPS: Severity Lifecycle Prediction

- Severity lifecycle prediction is main objective of KONRAD3D-EPS

- Severity S is parameterized as a parabola function of lifetime τ_l und maximum severity $S_{\max}$

$$S(t) = -4(S_{\max} - S_0)\left(\frac{t^2}{\tau_l^2} - \frac{t}{\tau_l}\right) + S_0$$

Mean temporal development of cell severity from April to September 2019



Severity	Meaning
0	weak
1	moderate
2	severe
3	extreme

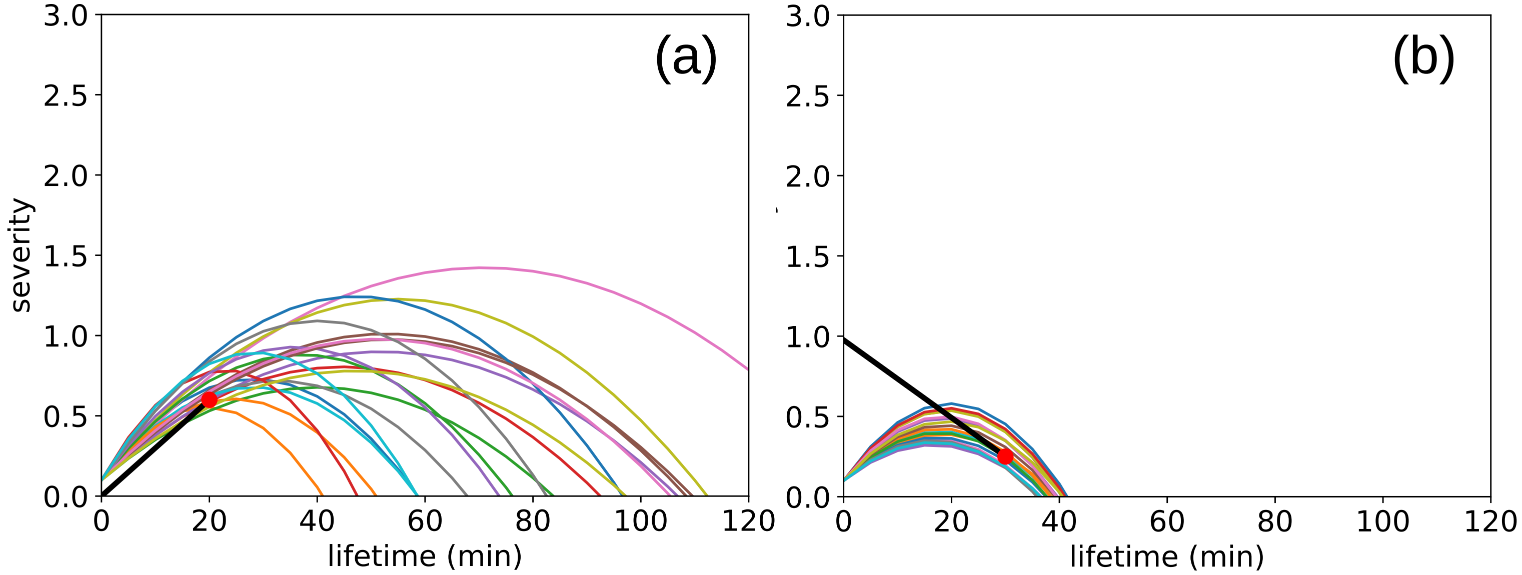
KONRAD3D-EPS: Correction

Cell Motion

- Ensemble-Kalman filter
- Application of covariance inflation if necessary

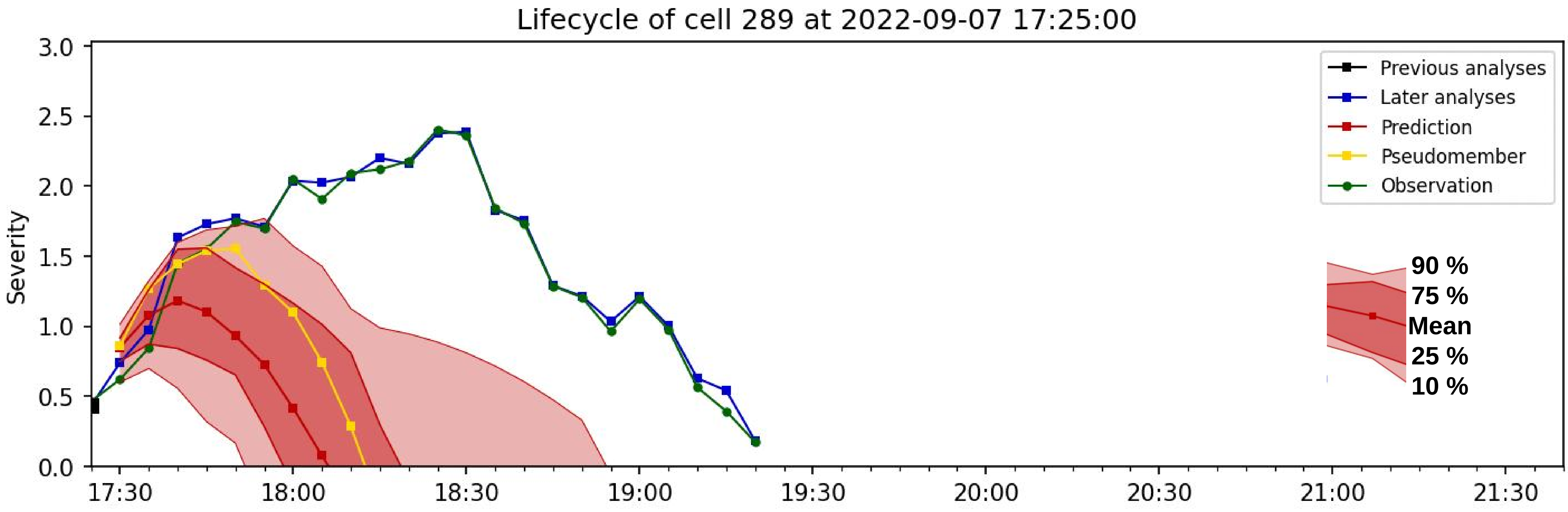
Cell Severity Parabolas

- Fit parabolas to the observed severity trend of the last 15 (configurable) minutes
- Error of fit determines parabola spread



Fitting severities to observed trends (black lines). Currently observed severity indicated by red dot. Examples for:
(a) intensification.
(b) weakening.

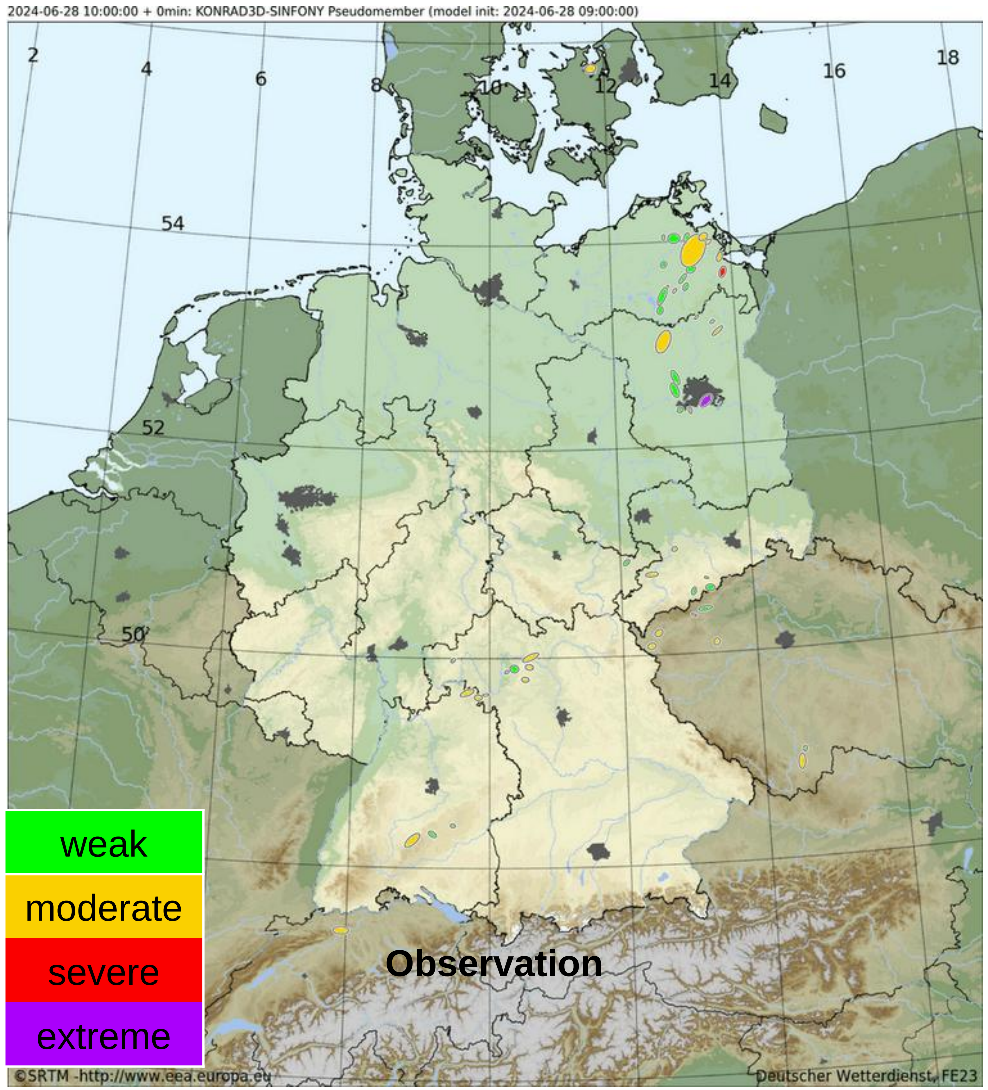
KONRAD3D-EPS: Lifecycle Visualization

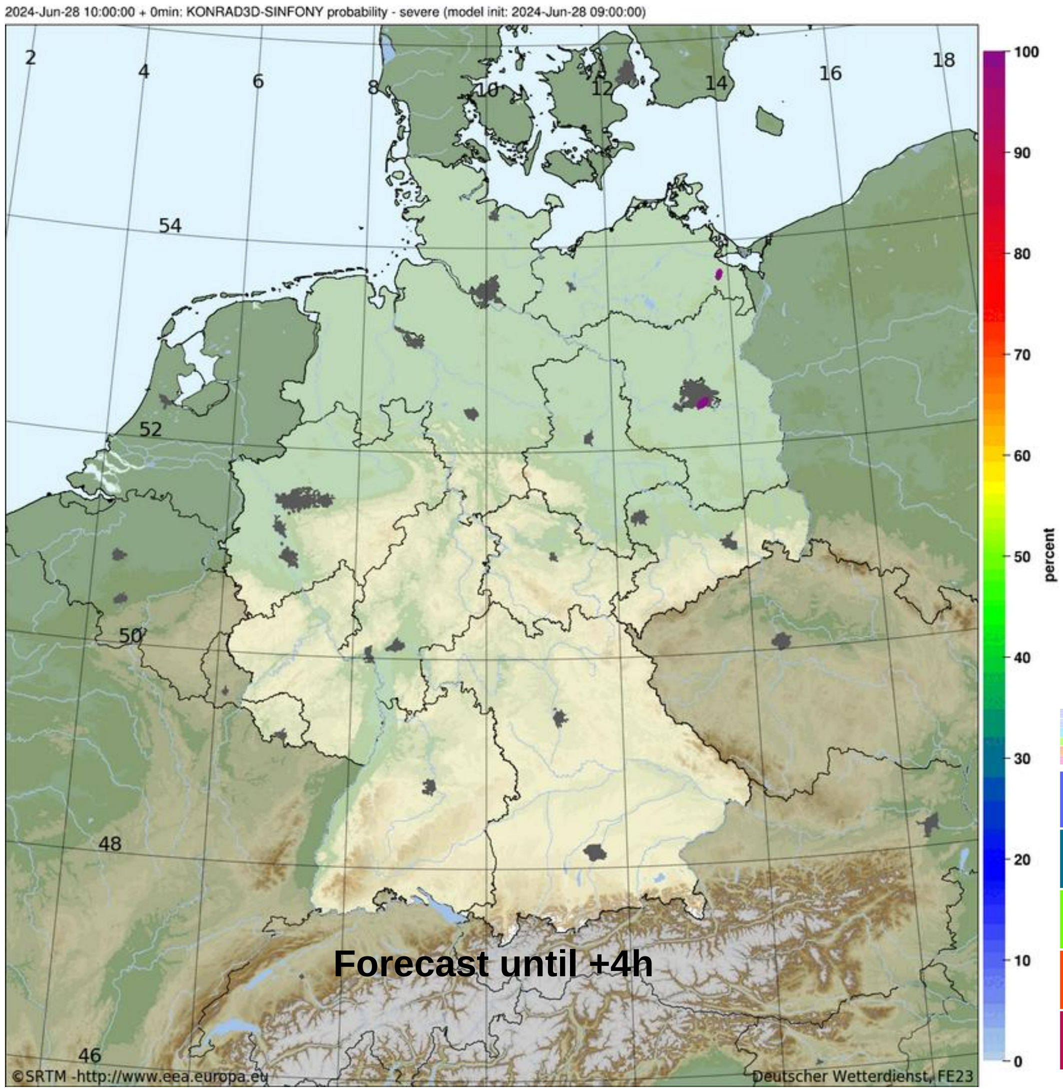


Ensemble prediction of a cell lifecycle.

Severity	Meaning
0	weak
1	moderate
2	severe
3	extreme

Ensemble Probabilities of Severe / Extreme Convective Cells





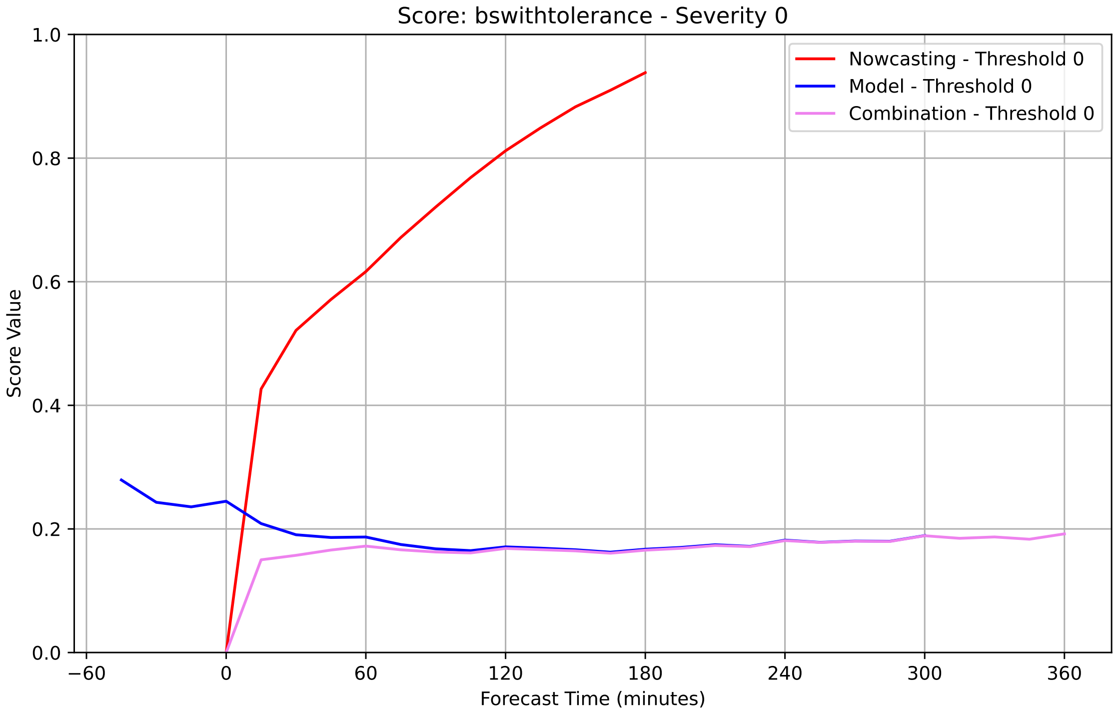
Probabilities derived by counting NO contributing members per pixel.

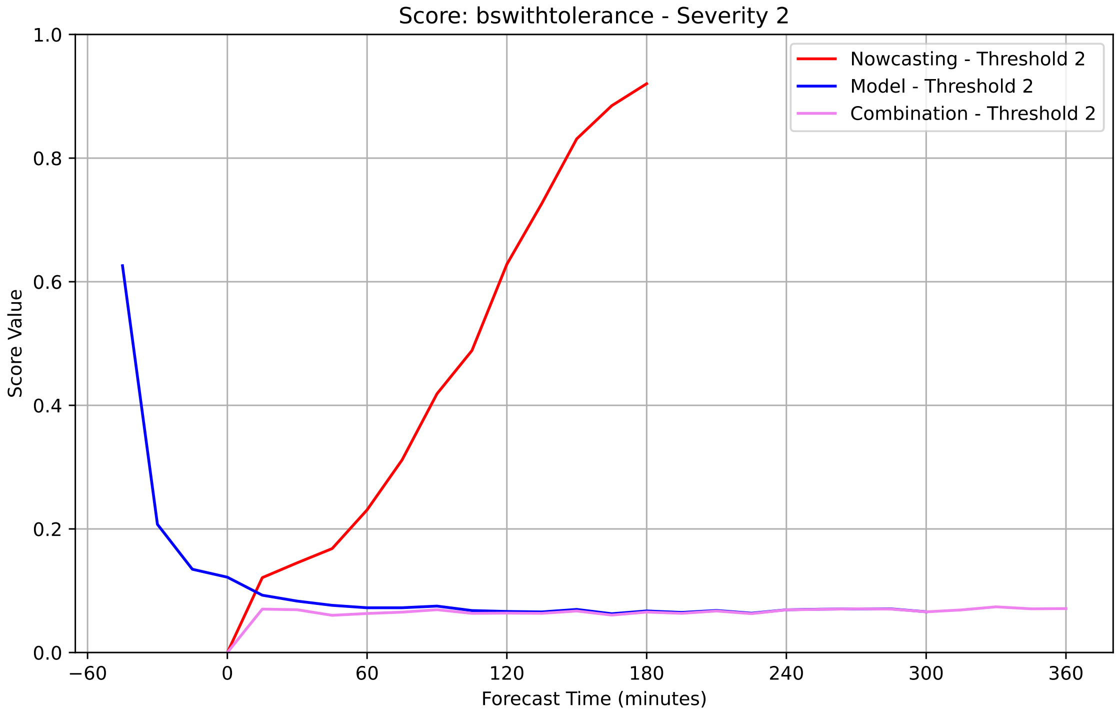
Here: probabilities for <u>severe + extreme</u> cells.

We provide exceedance probabilities for each severity category.

10
30
50
70
90

Verification: Brier Score

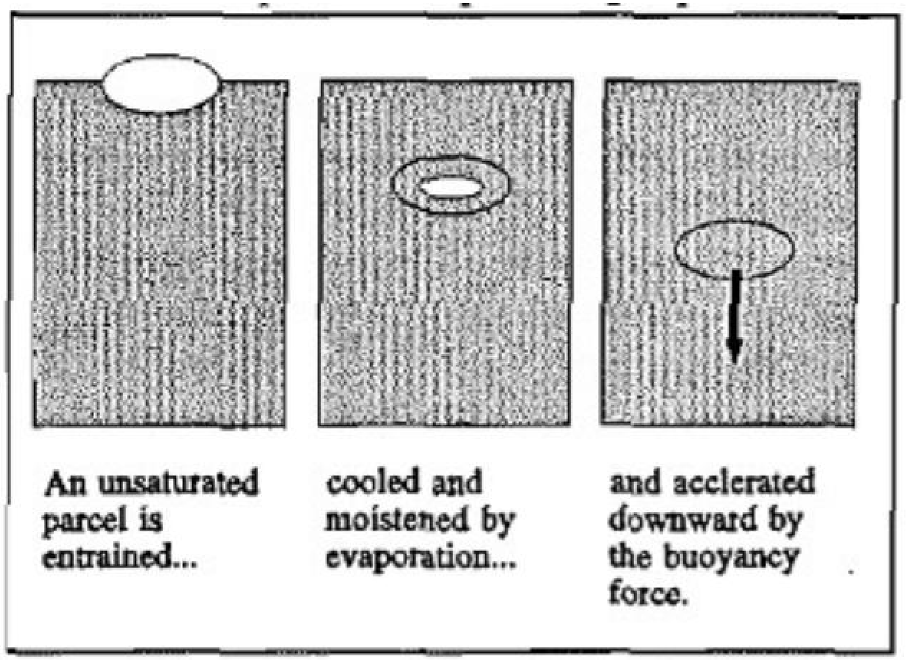




KONRAD3D: Gust Flag

General

- Based on „Cloud Top Penetrative Downdraft Mechanism“
- Aim: determine maximum expected gust category at the ground



Schematic of a dry air parcel (ellipse) that is mixed into a cloud (grey area) (Stewart, 1991).

Definition

Gust Flag	Wind Speed (km/h)	Beaufort
0	0 – 64	0-7
1	65 – 104	8-10
2	105 – 140	11-12
3	> 140	12

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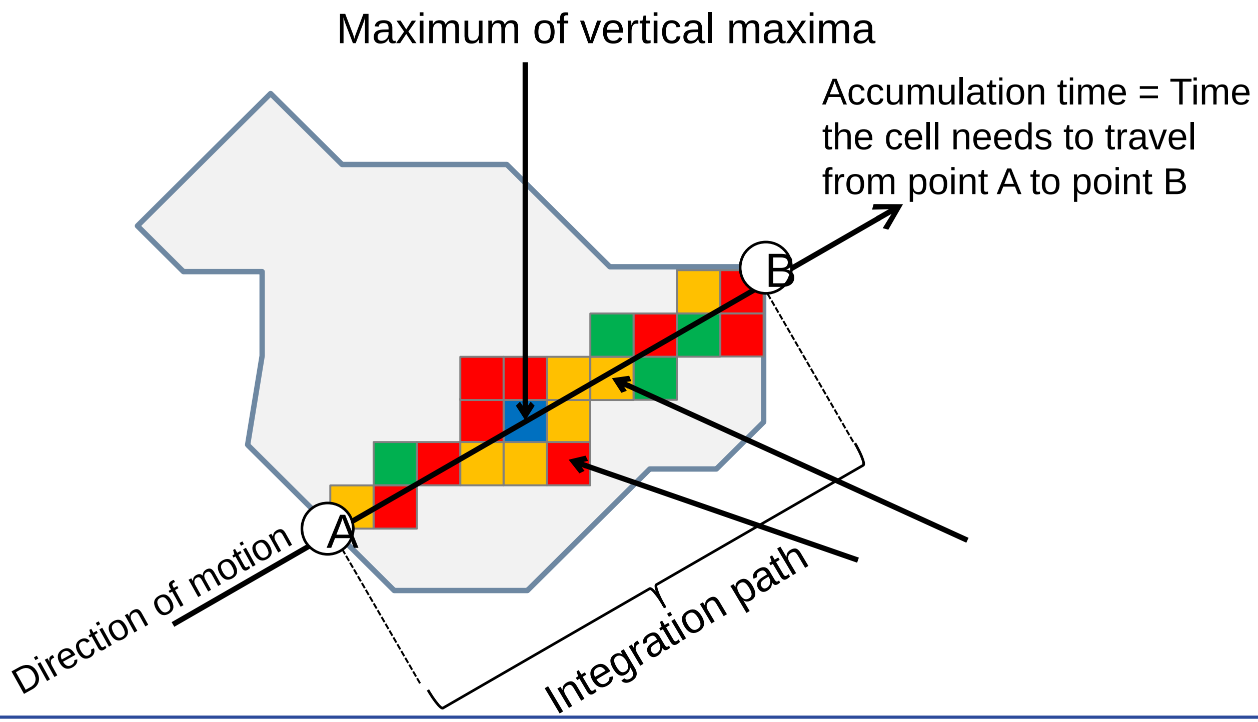
- **Approach (Stewart (1991))**
- $w = \sqrt{20.63 \cdot VIL - 3.125 \cdot 10^{-6} \cdot TOP^2}\,\frac{\mathrm{m}}{\mathrm{s}}$
- $v_{\max} = \left(w \cdot 3.6 + \frac{1}{6}c\right)\frac{\mathrm{km}}{\mathrm{h}}$
- w: maximum downdraft in m/s
- VIL: cell based VIL in kg/m^2
- TOP: echo-Top in m
- c: cell speed in km/h
- $v_{\max}$: maximum expected wind speed at the ground in km/h

KONRAD3D: Heavy Rain Flag / Potential

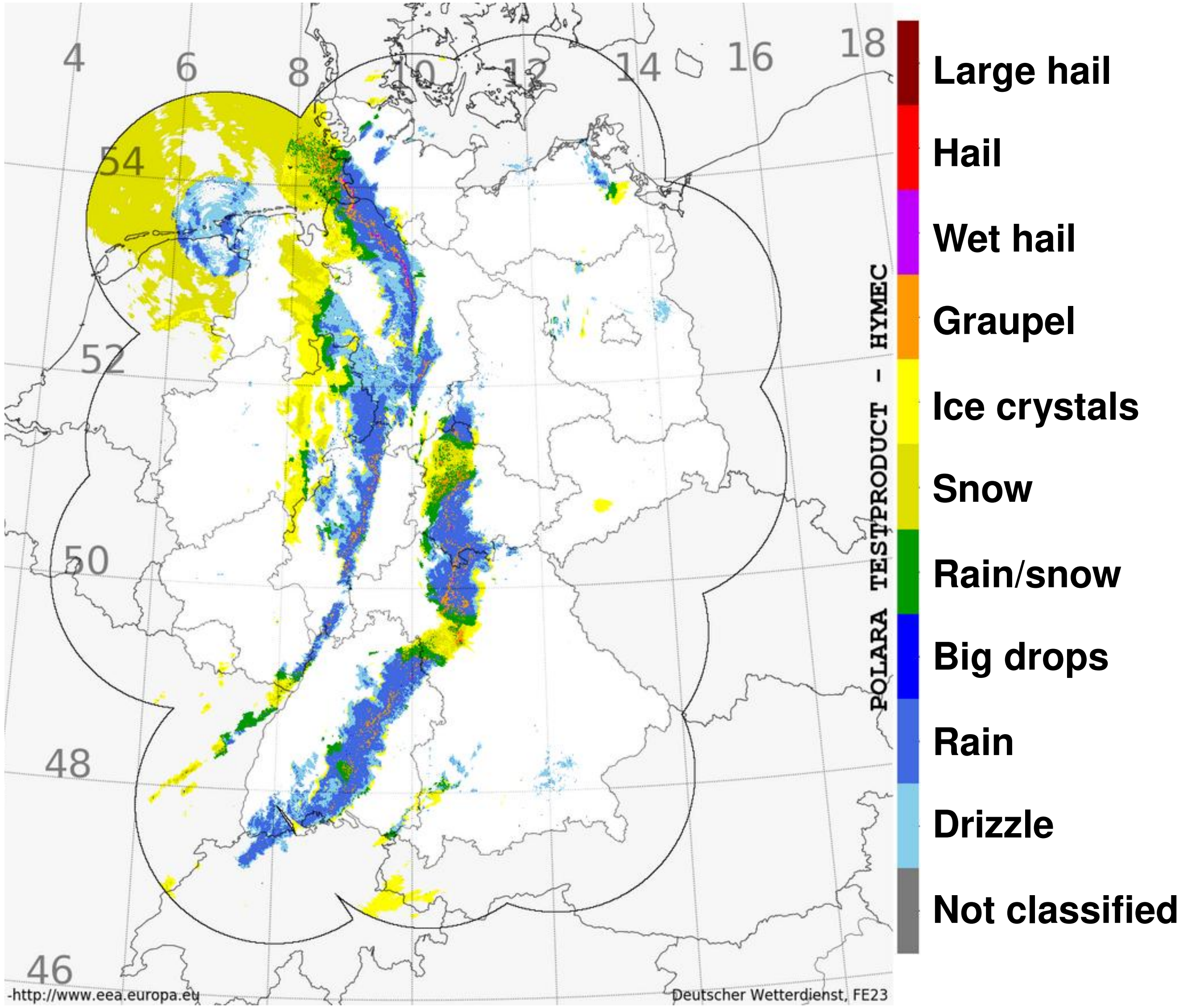
- Suppose, the most intense part of the cell passes over you. How many rain do you have to expect?
- Rain rate estimated by averaged reflectivities around cell core
- Rain accumulation along the line through most intense point in cell polygon in direction of motion.
- Current HRP = rain rate x accumulation time
- Include HRP history to estimate final HRP estimated by



HR Flag	Rain accumulation (mm)
0	0 – 15
1	15 – 25
2	25 – 40
3	> 40

HYMEC

- "**HY**dro**ME**teor **C**lassification"
- Algorithm developed by J. Steinert, M. Schultze
- Based on 3D polarimetric radar data and ICON D2
- Returns most likely hydrometeor class



HYMEC composite of Germany, October 18th, 2019, 13:30 UTC.

KONRAD3D: Hail Flag

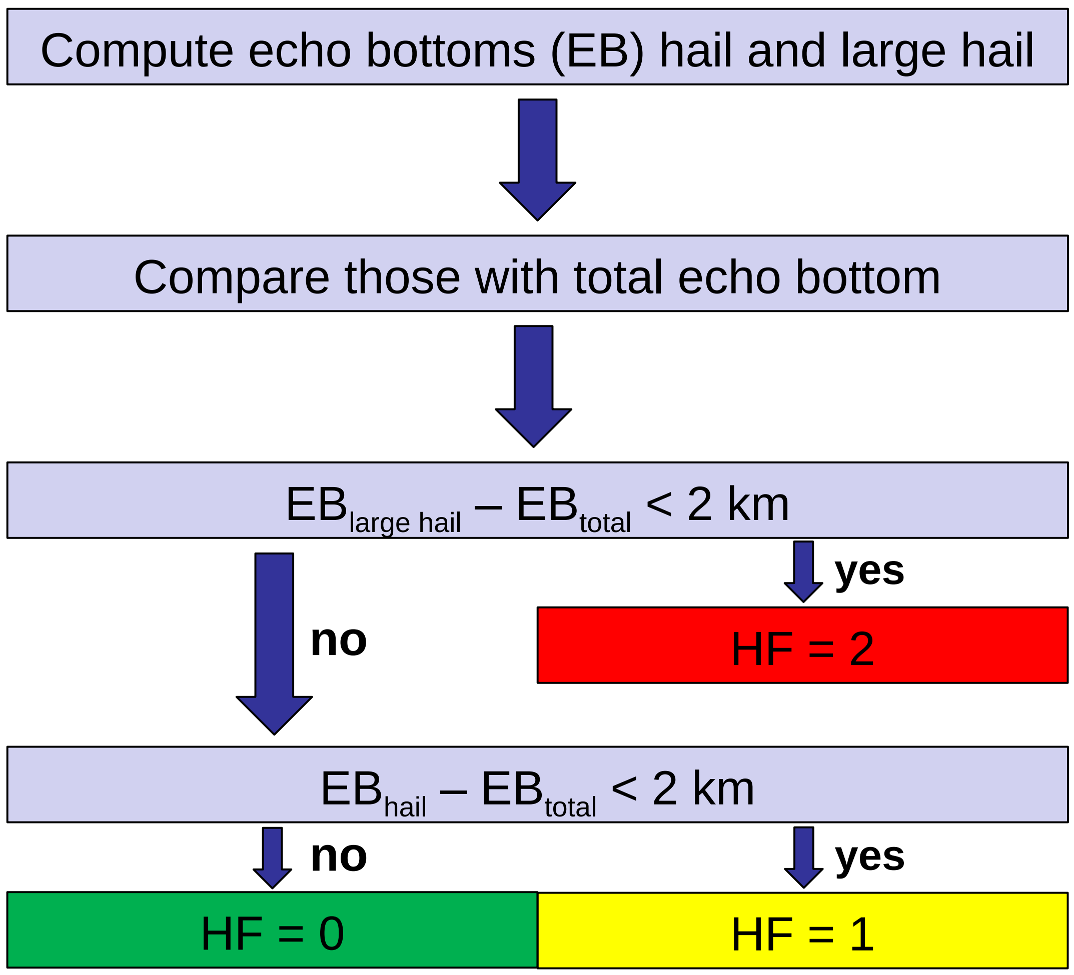
General

- Based on HYdroMEClassification classes “hail” and “large hail”
- Aim: determine whether a KONRAD3D cell *currently* contains near-surface hail

Definition

Hail Flag	HYMEC hail class	Meaning
0	None	No hail
1	Hail	Moderate hail
2	Large hail	Severe / extreme hail

Determination



KONRAD3D: overview of cell attributes

Geometry (horizontal + vertical extent, 3D centroid, topographic elevation at centroid, cells in neighborhood)

Intensity (severity, 3 warning flags, maximum reflectivity, cell areas and echo tops by reflectivity thresholds)

Hail (echo tops, bottoms, areas, and volumes of HYMEC's hail classes)

Lightning (lightning rate, density, lightning jumps)

NWP (CAPE, SHR, PPW, SRH, etc. from ICON-EU for different parcel curves)

Mesocyclone (intensity, horizontal and vertical extent) → new!

Tracking (cell speed, predecessor(s), splits, merges)

Forecast (predicted cell positions for next hour)