Improvements on the Assimilation of radar reflectivities (P3)

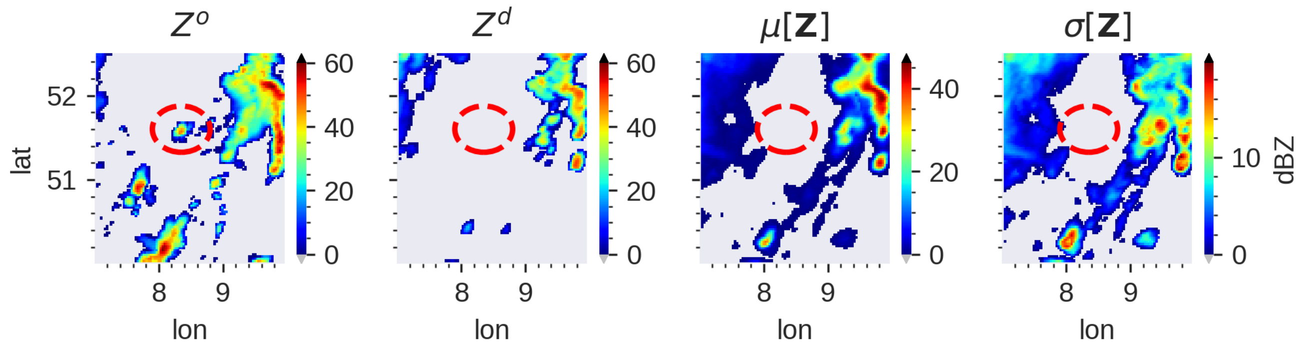
R. Potthast, K. Vobig

RealPEP

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

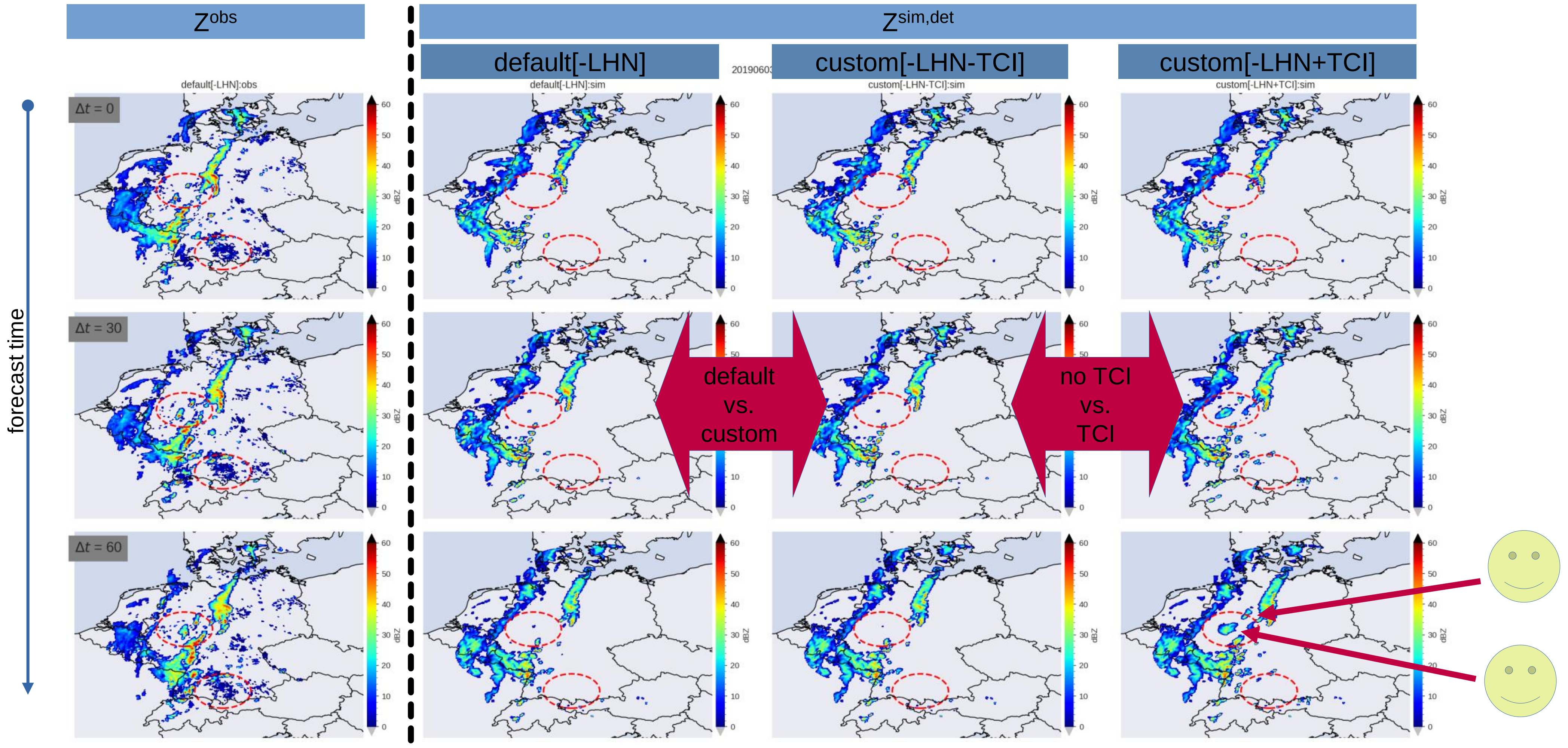
DWD

TCI: Motivation & Recap

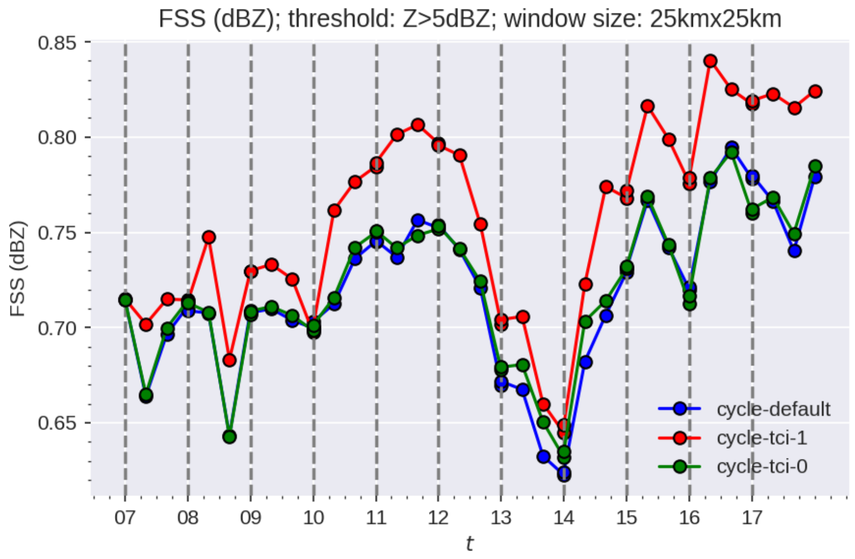


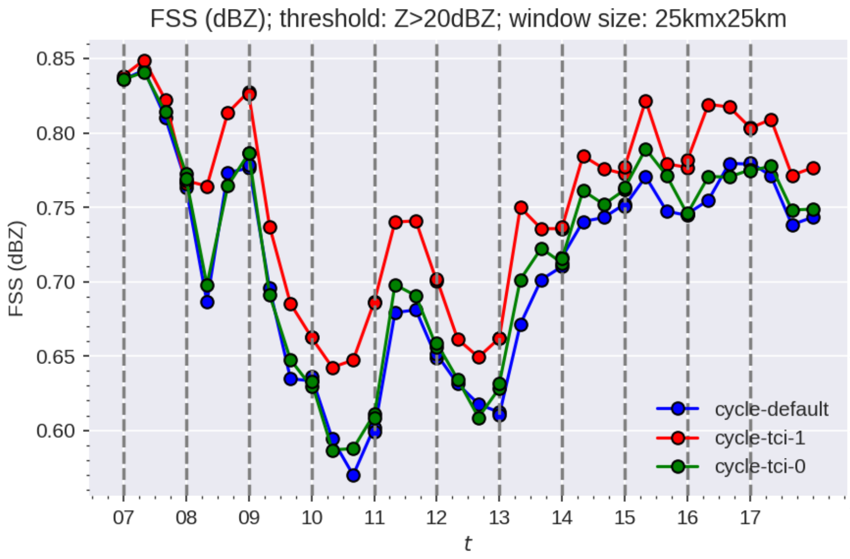
- even for large discrepancies between obs./sim. REFL LETKF might give small increments due to very small ensemble spread σ[**Z**]≪1
- approach: increase spread via (additive) targeted covariance inflation (TCI) based on correlations between Z and QV
- overall, TCI results are promising
  - production of “new” REFL cells (consistent with observations)
  - positive impact on fractional skill score (w.r.t. REFL)

Evolution of REFL



Verification: Fractional Skill Score





default[+LHN]
custom[+LHN+TCI]
custom[+LHN]

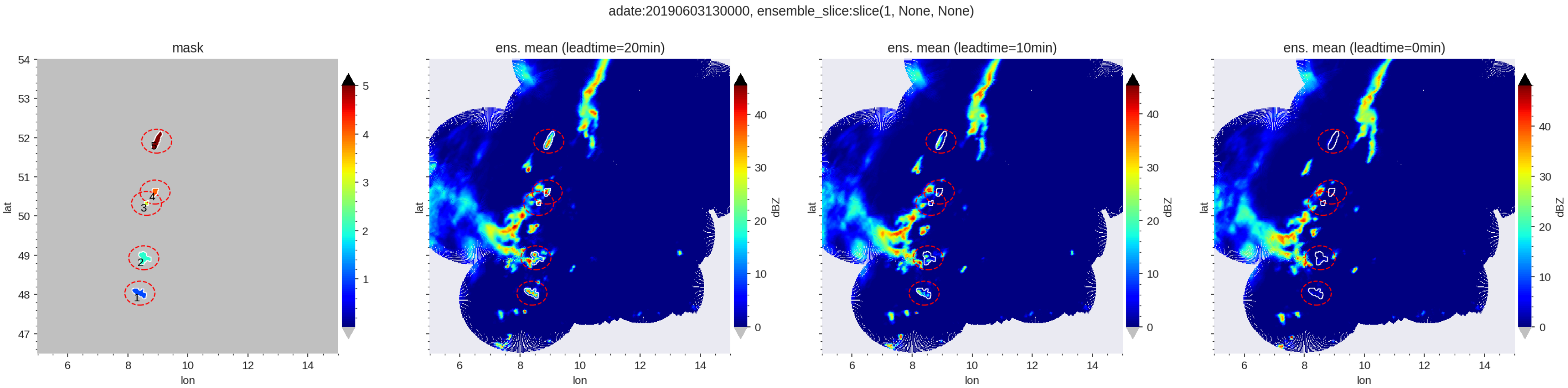
- performing cycle starting at 7 UTC
- TCI applied at each assimilation (hourly)
- FSS for two dBZ thresholds shown

positive impact of TCI on FSS

TCI: New Developments

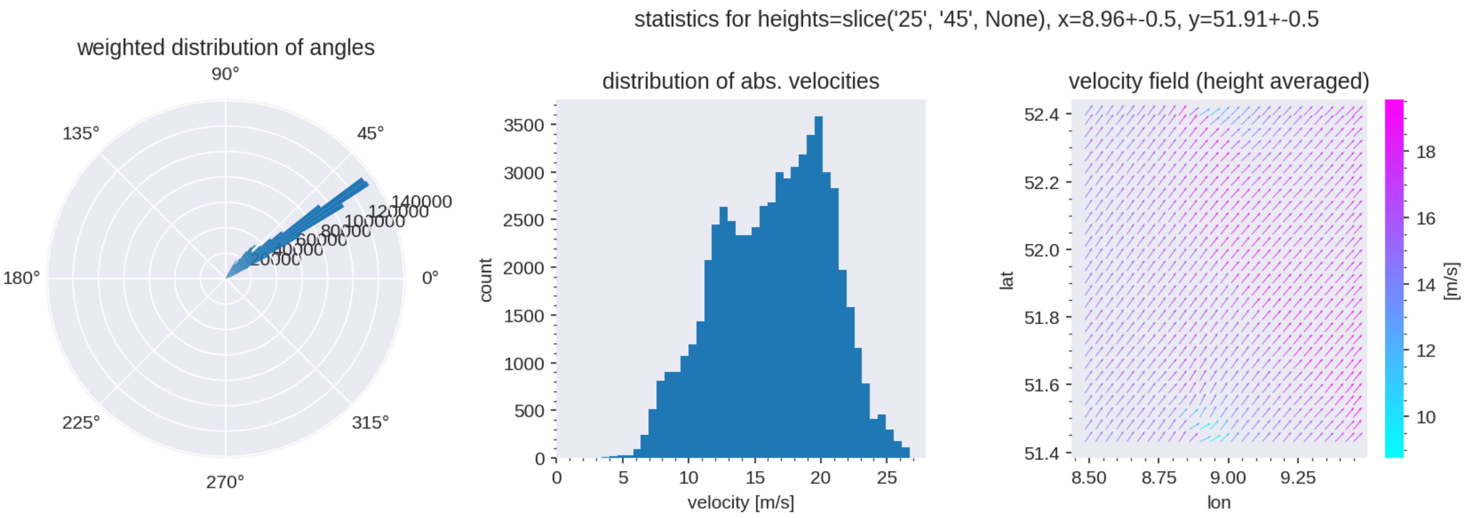
- AIREP/TEMP observation error statistics for humidity:
  - negative impact of TCI
  - contribution (positive/negative) to statistics highly time/location dependent
  - time/spatial/process dependence of correlations
- optimize the capturing and use of correlations of TCI method
  - better data filtering/pre-processing necessary
  - towards more “process-aware” TCI
  - first step here: only include data associated with new emerging cells for correlation analysis

Cell Detection



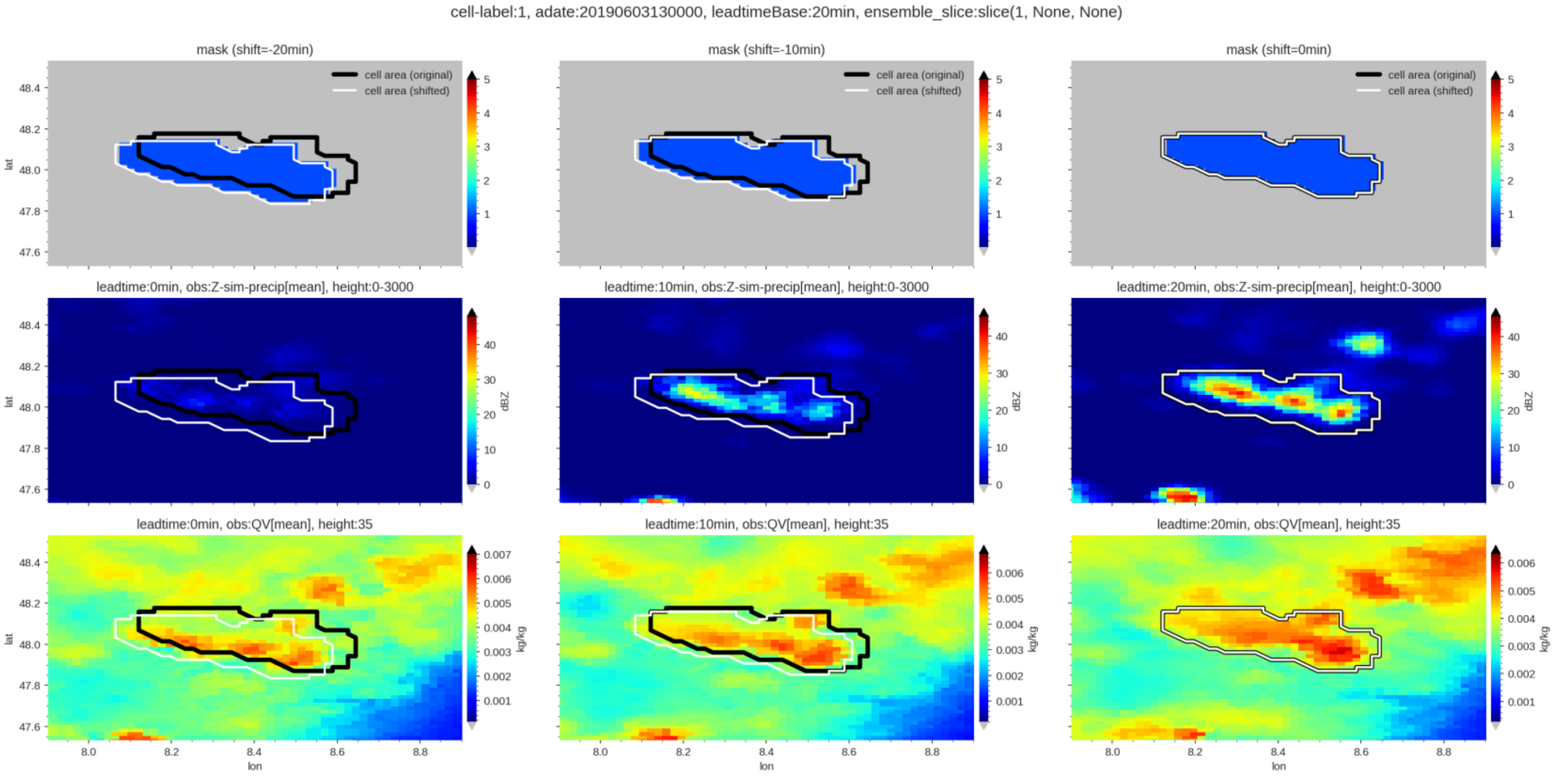
- Implemented simple algorithm for the detection of new cells
- employs time series of (binned) Radar data at 0-3000m
- gives area of new cells at certain leadtime
- here: ‘mask’ shows area of 5 new cells detected for 20min leadtime

Cell Drifting: Statistical Basis



- using statistical analysis of wind fields for obtaining dominant angle and velocity of horizontal wind in region of detected cells
- next: shift area associated with each cell using the corresponding wind field information → "backward propagation in time" / obtain environment cell eventually originated from

Cell Drifting: Application



- zoom into the area of one of the detected cells
- assumed drift seems to match “real” drift of structure in QV field

Correlation Calculation: Procedure

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- previous plot already hints at relationship between Z "now" and QV at an earlier time (contained within shifted area)
- use the previously shown cell areas (for each time t and cell c) $A_{c,t}$ for calculating spatial mean of ensemble perturbations $dQV_{e,h}$ and dZ_e (for each ICON level h and ensemble member e) yielding $dQV_{e,h,c,t}$ and $dZ_{e,c,t'}$
- given t, t', h the correlation $corr_{t,t',h}$ is then based on the dataset $\{(dQV_{e,h,c,t}\ ,\ dZ_{e,c,t'})\ |$ all members e and all cells c$\}$
- perform this correlation calculation for several t, t' and all ICON levels h

Z-QV Correlation

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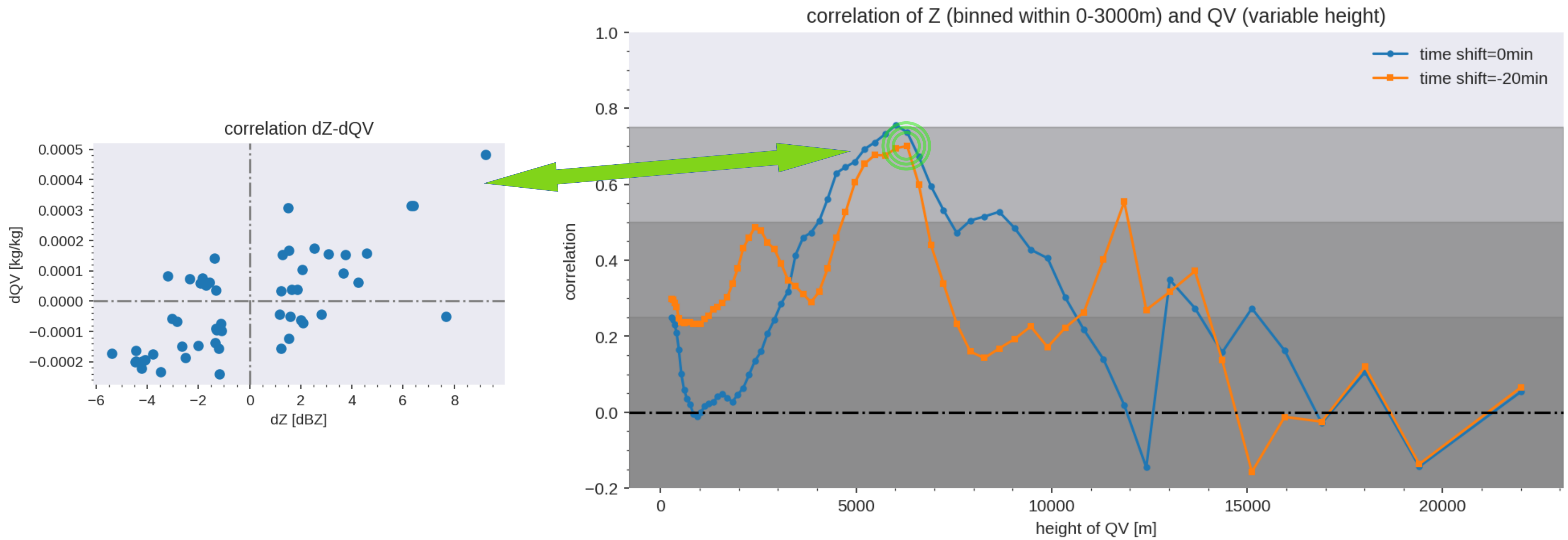

- depiction of correlation between Z and QV (at variable height)
- QV shifted against Z by 0min or -20min
- clear maximum at around 6000-7000m height for QV

TCI: Next Steps

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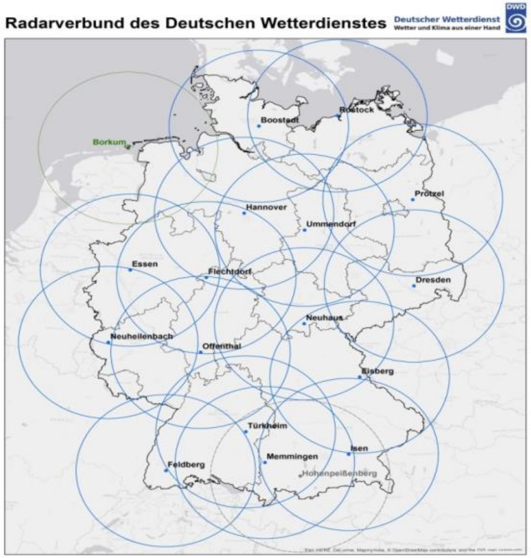
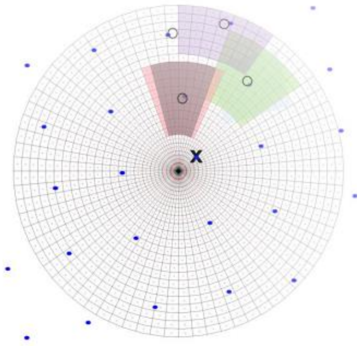
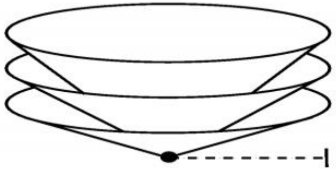
- further optimize the process/data-filtering
- use these “process-aware” correlations as a basis for the TCI approach
- for the application of these correlations (within the TCI approach) the procedure for their extraction is basically inverted:
    - check if discrepancies exist between obs./sim. REFL
    - check if spread for sim. REFL is vanishing
    - check if (obs.) cell has just emerged
    - use tailored Z-QV correlations for these regions

OLD

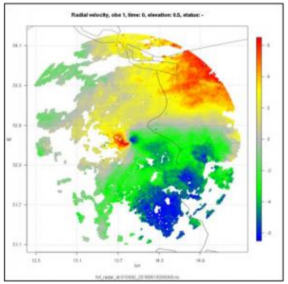
Radar Network of the DWD



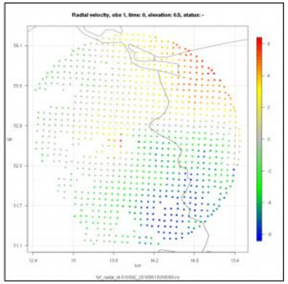




Radar network of DWD (left); generation of superobservations (upper right); volume scan modus (lower-right)



Original Data



Superobing (~ 10 km)

- 16 **Dualpolarization Radars** with 3D-Volume scans every 5 minutes
  - radial winds (**RW**)
  - reflectivities (**REFL**)
  - dual polarization moments (**DP**)
- generation of **superobservations**
  - average over specific volume
  - makes handling of large data sets feasible

Radar-related Projects at DWD

- assimilate **2D REFL** based on **latent heat nudging** ✔
- assimilation of **3D-Volume** Radar data via LETKF and EMVORADO (by Blahak and Zheng)
  - assimilation of Radar **RW** ✔
  - assimilation of **REFL** ✔
- assimilation of Radar-derived **objects** and seamless integration of Radar objects into nowcasting and short-range NWP
- **Jana Mendrok** works on extending EMVORADO to simulate **DP** (✔)
  - enables **direct** assimilation of DP
  - alternatively: "indirect" assimilation of DP via derived hydrometeor mixing ratios (→Lucas Reimann)

Radar-related Projects at DWD

RealPEP — Deutscher Wetterdienst — Wetter und Klima aus einer Hand — DWD

- assimilation of nowcasted information[1]
    - tested assim. of nowcasted information via LETKF
      (based on oscillator model / Lorenz 63 model system)
    - positive impact of assimilating nowcasted information demonstrated
    - first tests assimilating nowcasted states (REFL) with KENDA
- overall topic here: improve assimilation of REFL
  via targeted covariance inflation[2] (TCI)

- [1]: R. Potthast et al., MWR, (2022), accepted for publication
- [2]: K. Vobig et al., https://doi.org/10.1002/qj.4157, (2021)

TCI – Motivation & Basics

TCI: Motivation

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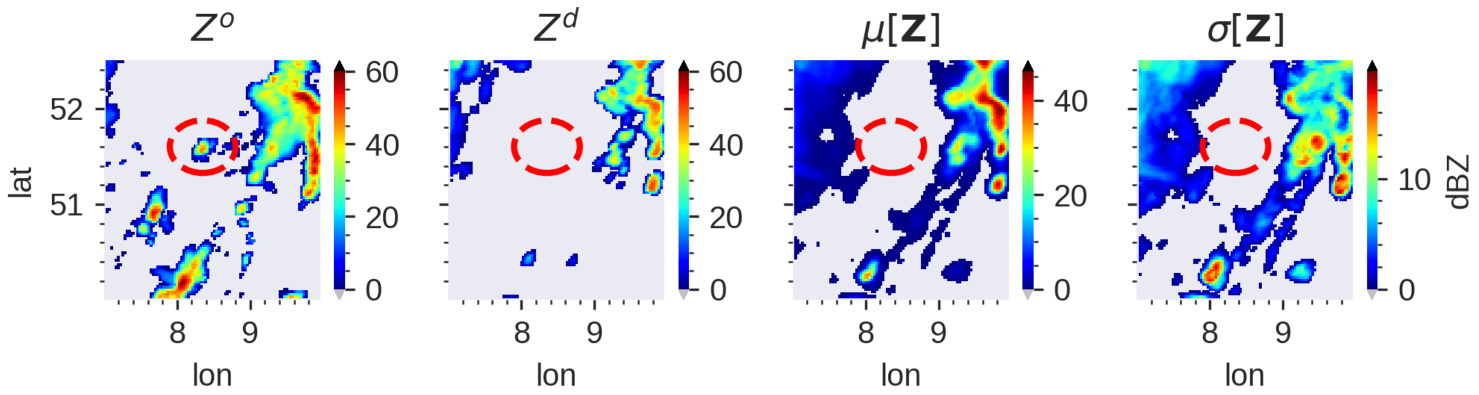


- even for large discrepancies between observed/simulated REFL LETKF might still produce small increments
- problem: very small ensemble spread σ[**Z**]≪1
- approach: increase spread via (additive) targeted covariance inflation (TCI)

TCI: Basics

RealPEP Deutscher Wetterdienst Wetter und Klima aus einer Hand DWD

- assume correlation of Z with model variable Ψ

$$Z_i'(\mathrm{r}) = Z_i(\mathrm{r}) + \alpha_{\mathrm{TCI}} \left(\Psi_i(\mathrm{r}) - \mu[\Psi(\mathrm{r})] \right)$$

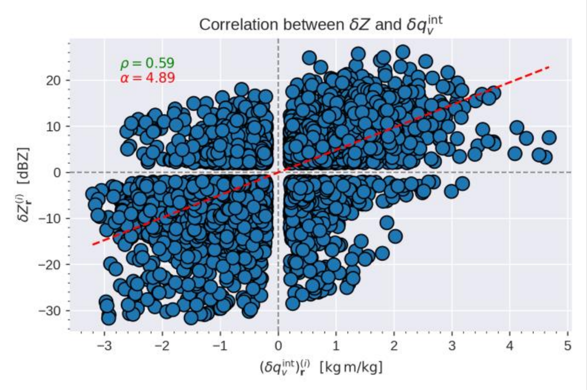
- α_{TCI} serves as scaling factor for “strength” of TCI
- us

$$q_v^{\mathrm{int}}(\lambda, \mu, l_0, l_1, \beta) \equiv \int_{\mathcal{A}} \mathrm{d}\lambda' \mathrm{d}\mu' \; f_\beta(\lambda' - \lambda, \mu' - \mu) \int_{h(l_0)}^{h(l_1)} q_v(\lambda', \mu', h) \mathrm{d}h$$

- overall idea:
  - spread of q_v “imprinted” onto spread of Z
  - assim. “favors” members with more humidity: additional q_v (q_r,q_s,...) increments via corr.
  - model generates reflectivity (possibly ...)

integral details

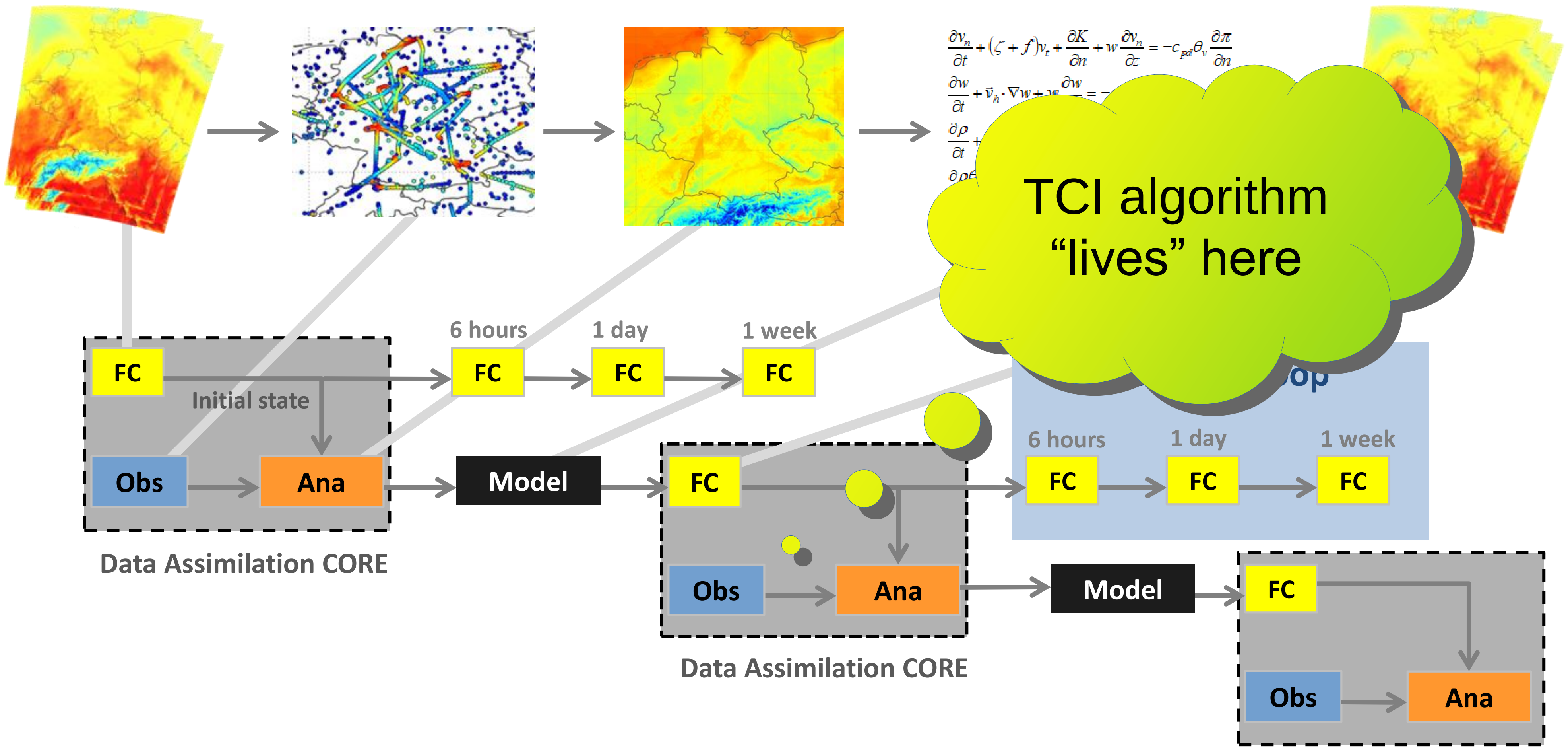
- β: strength of running mean factoring in time uncertainty
- l_0, l_1, β determined via optimization of corr. coefficient



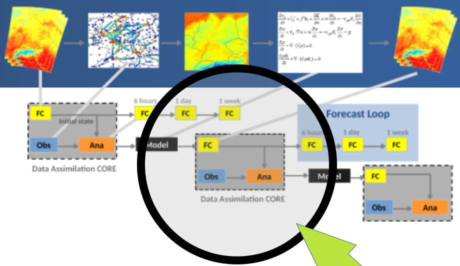
corr. coefficient

- several thresholds for data filtering and process determination
- α_{TCI} ⇝ “slope” of correlation

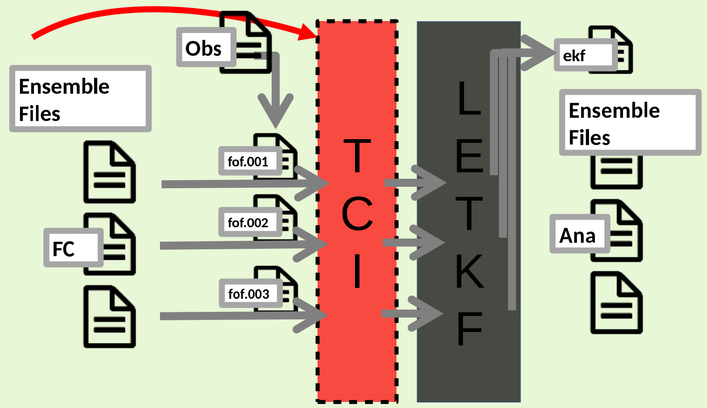
NWP: Assimilation Cycle



TCI: Technical Steps



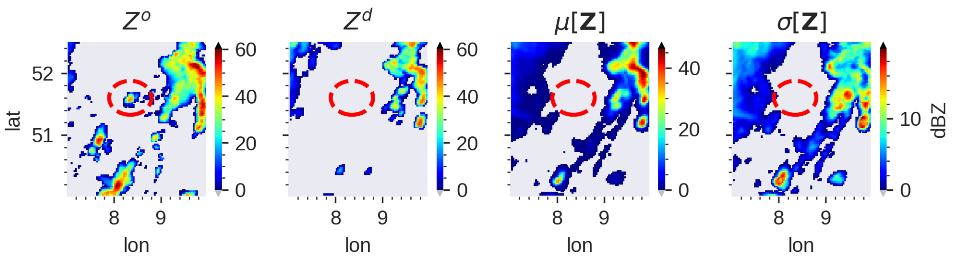
- implemented via **pre-processing feedback (fof) files** before entering the **LETKF**
- apply TCI algorithm and **alter simulated Z** in feedback files
- each member processed separately
- use altered feedback files as input for LETKF



- fof.*: sim. + obs. quantities of ens. members → enter LETKF
- LETKF produces increments depending on innovations + Kalman gain

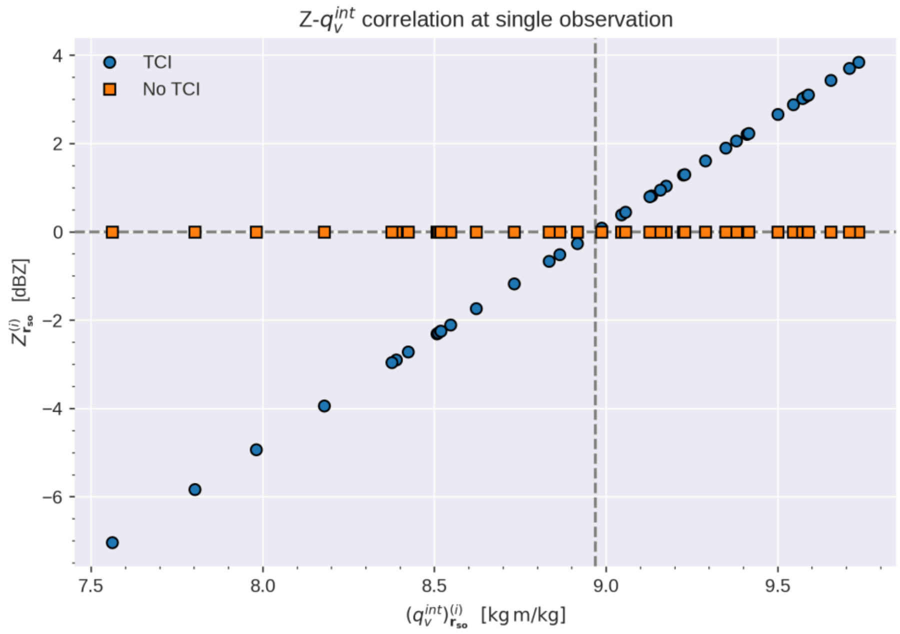
TCI – Single-Observation Experiments

Single-Observation Experiment



- study effects of TCI in single-observation (SO) experiment
  - assimilating only single reflectivity at (51.60°,8.35°,1035m) for 2019-06-03 at 12 UTC
  - data from Radar station Flechtdorf at elevation angle 0.5°
  - other observation set to 'passive' within feedback files
- relevant changes to "default" BACY settings
  - obs. error reduced to 2 dBZ
  - vertical localization increased to v_{loc}=10.3
  - no multiplicative cov. inflation / no relaxation to prior perturbation

SO Exp.: Correlations and Increments



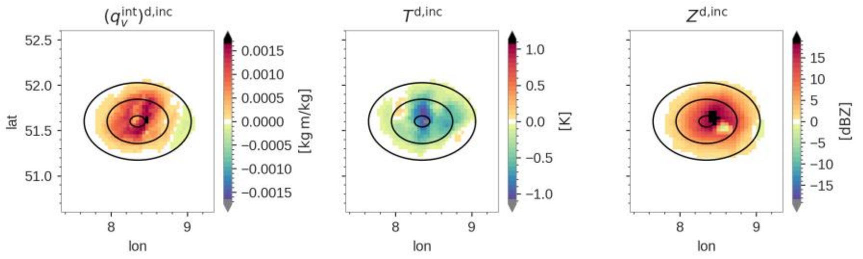
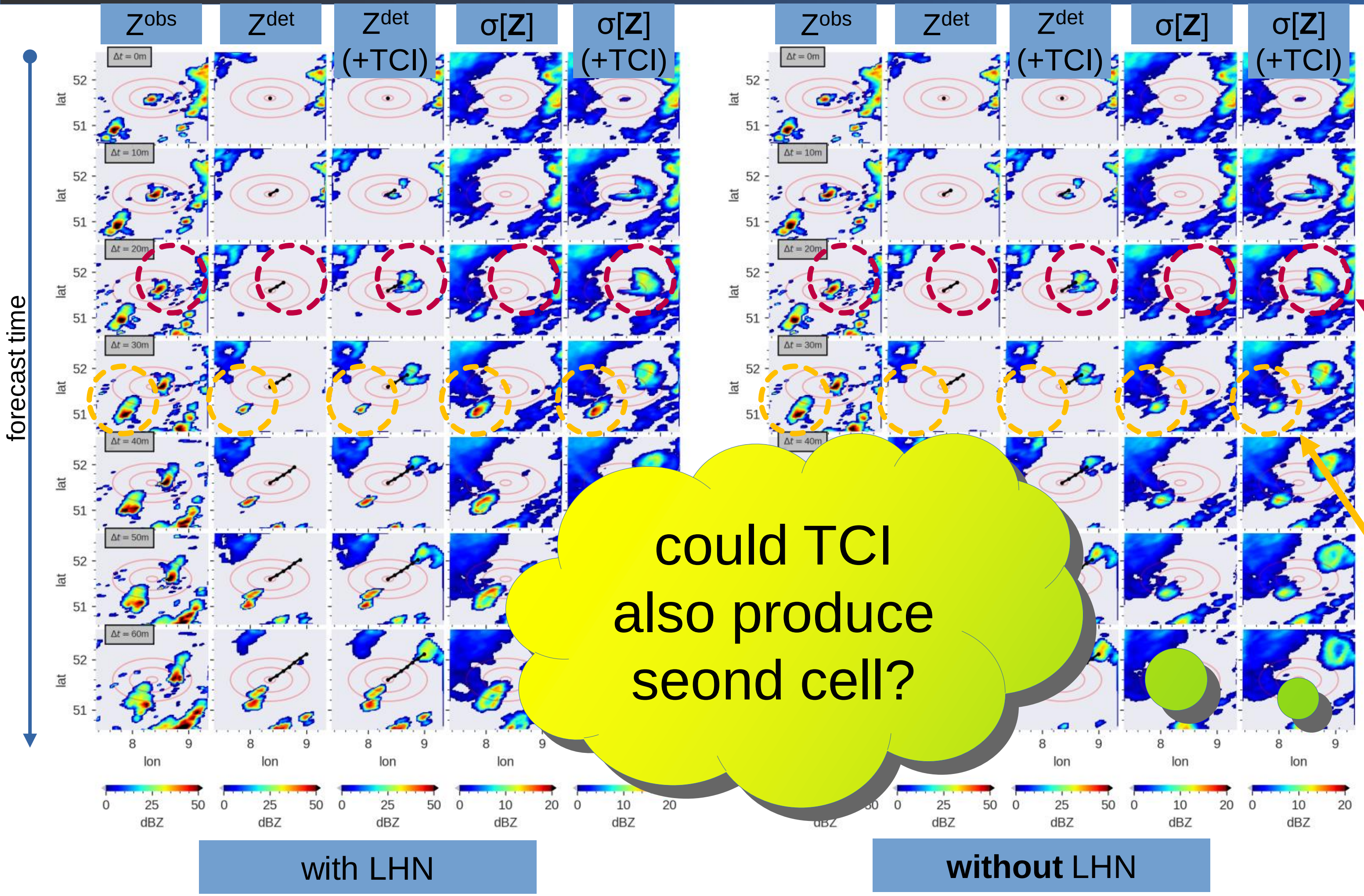


FIG: Increments at ICON-D2 layer 35, concentric circles indicate location of single observation

- without TCI: no spread in Z at single observation at all
- with TCI: spread in Z is produced
  - result: analysis produces increments for Z (linearized) and q_v

SO Exp.: Evolution of REFL



- ass. at 12 UTC followed by 1h free forecast
- “new” cell emerges consistent with observed cell
- second cell only with LHN (out of spatial reach of TCI)

TCI – Beyond Single-Obs Exps.

Multi-Observation TCI

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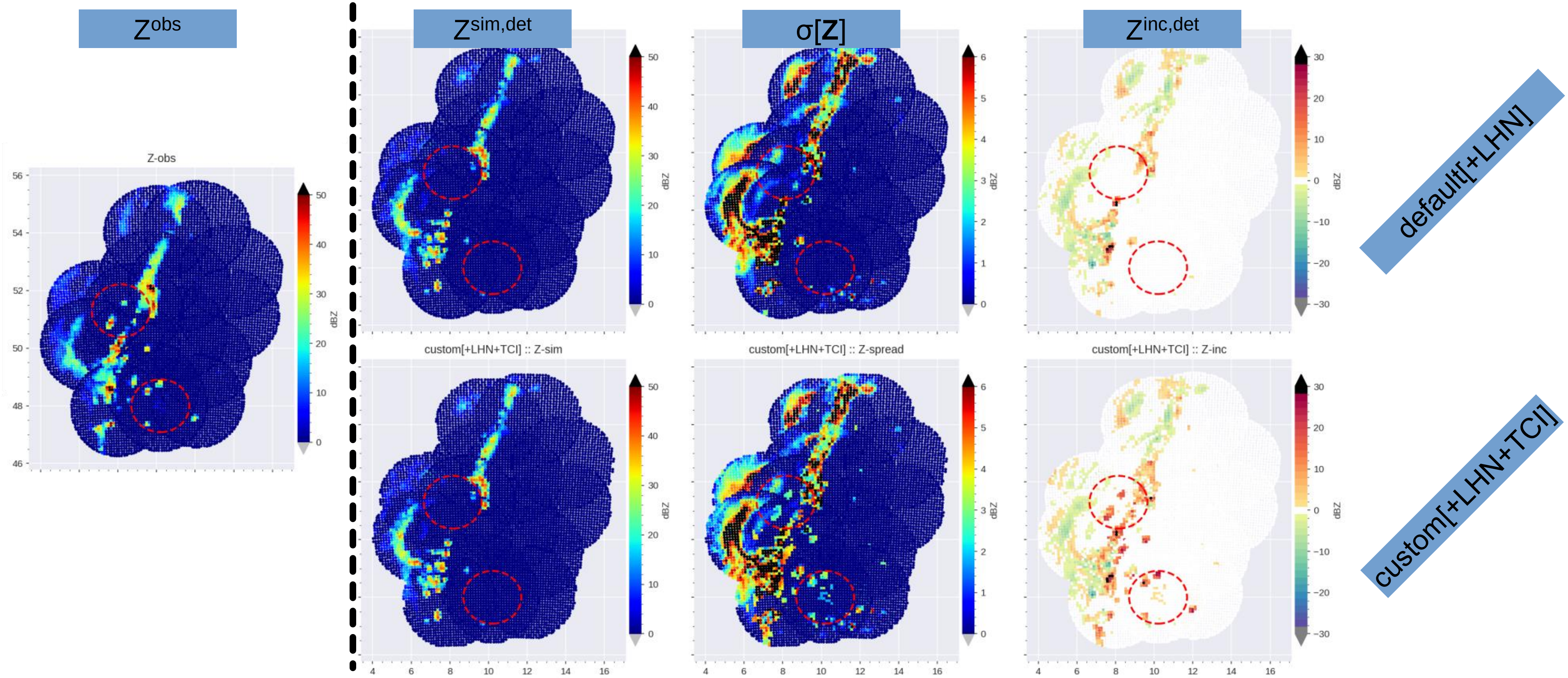
- previously: studied effects of TCI in SO experiments
- now: study effects of TCI applied to all radar data
- as before: TCI is applied via modification of feedback files before entering LETKF machinery
- prerequisites and effects of TCI application at **r**:
  - discrepancy between observed/simulated REFL
  - small ensemble spread
  - modify Z for all ensemble members via integrated q_v correlation

BACY Configurations

- “default”: (mostly) default BACY configuration
  - assimilation of conv. data and REFL (at several elevations)
  - LHN may be turned on/off [±LHN]
  - assimilation takes place on 2019-06-03 at t0 = 12 UTC
- “custom”: minor changes w.r.t. default configuration
  - serves as reference for assessing direct impact of TCI
  - increased first-guess check for REFL
  - TCI may be turned on/off [±TCI]

REFL: Assimilation



- TCI produces spread → additional increments for REFL

Evolution of REFL (with LHN)

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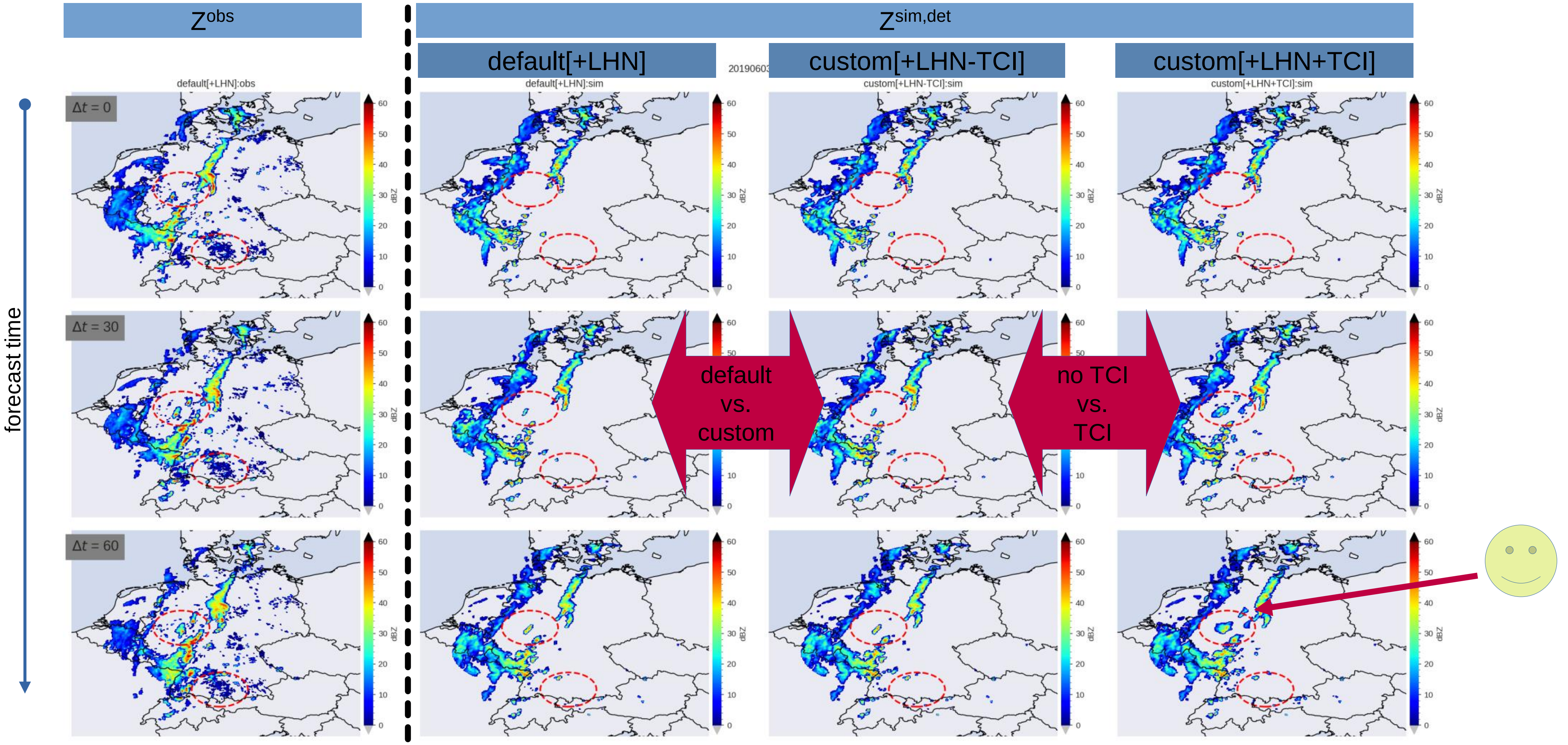

Evolution of REFL (without LHN)

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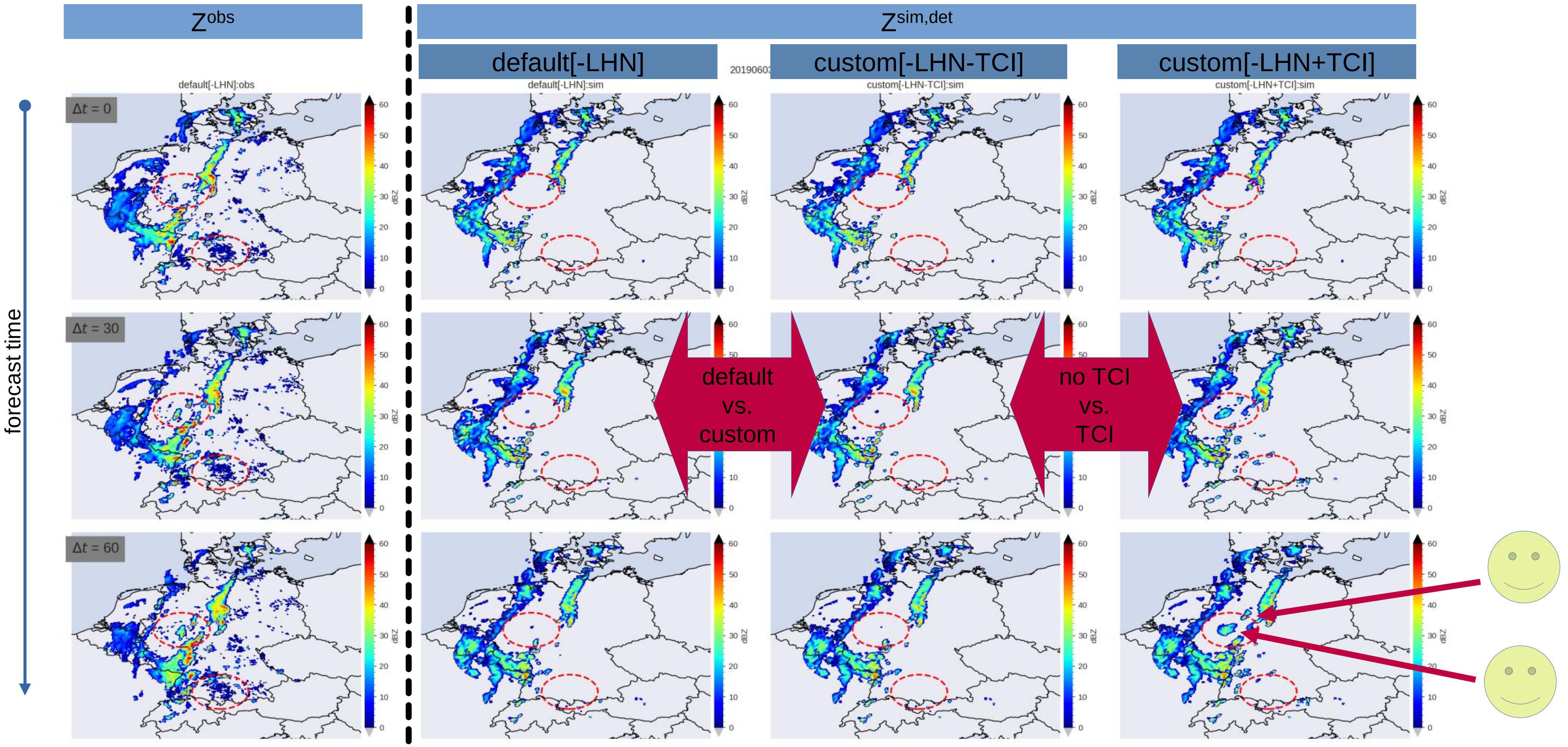
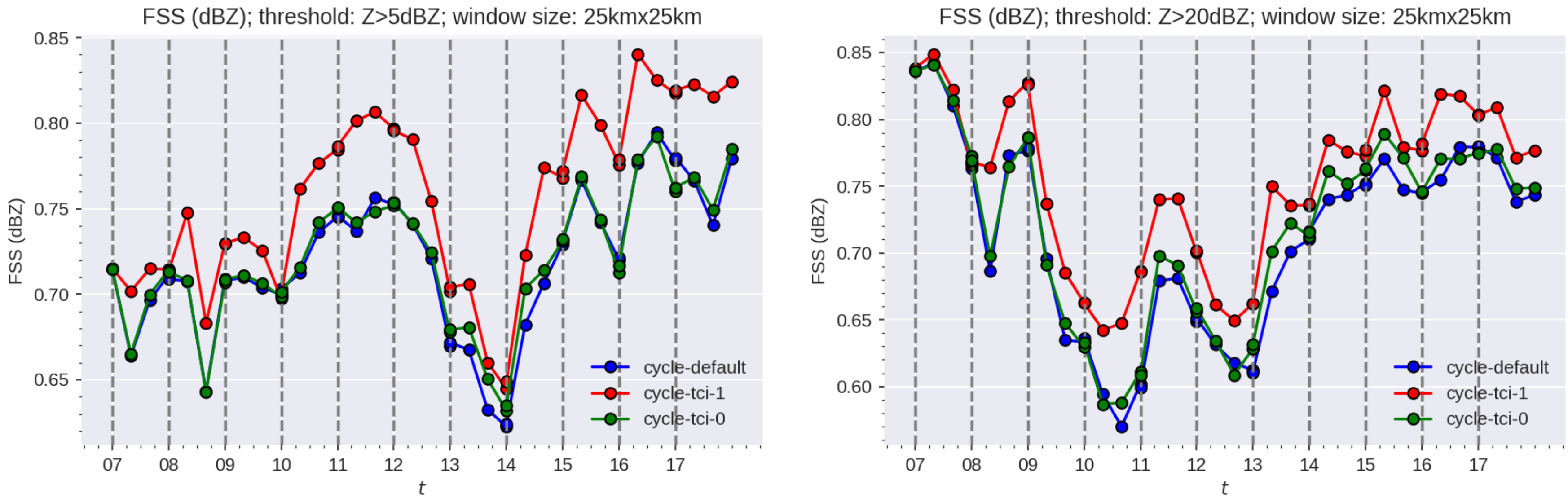


Verification: Fractional Skill Score



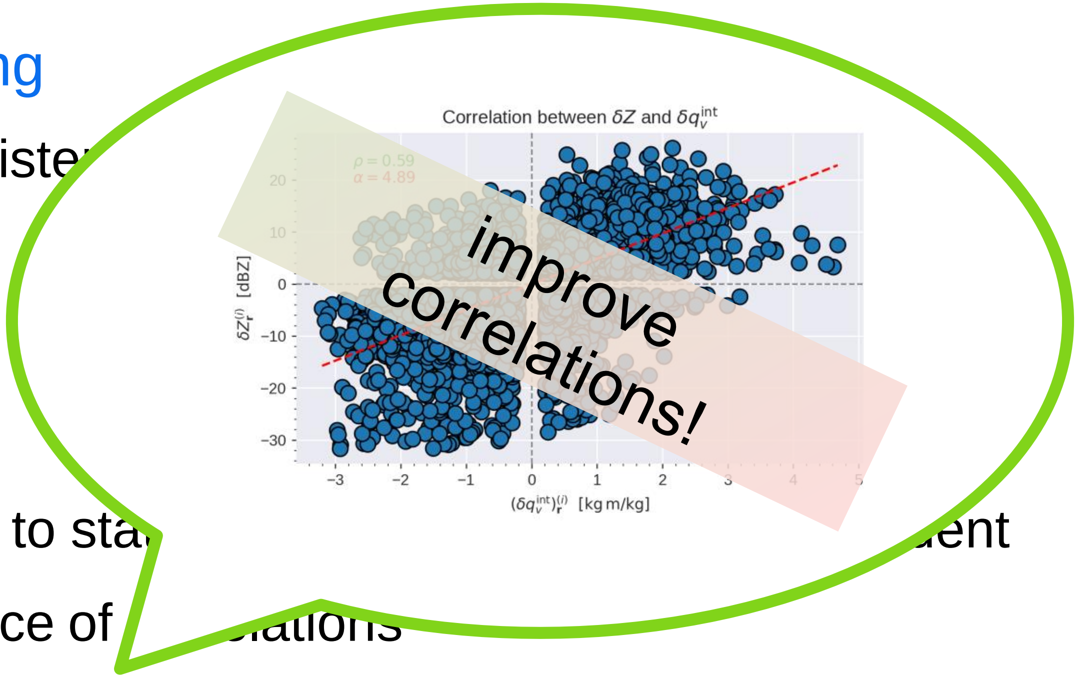
default[+LHN]
custom[+LHN+TCI]
custom[+LHN]

- performing cycle starting at 7 UTC
- TCI applied at each assimilation (hourly)
- FSS for two dBZ thresholds shown

positive impact of TCI on FSS

Summary and Outlook

- overall, TCI results are promising
  - production of “new” cells (consiste
  - positive impact on FSS
- AIREP/TEMP observation error
  - negative impact of TCI
  - contribution (positive/negative) to sta ent
  - time/spatial/process dependence of lations



- optimize the capturing and use of correlations of TCI method
  - better data filtering/pre-processing necessary
  - towards more “process-aware” TCI

Outlook

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- assim. of information on convective initiation
  - employ total column water vapor obtained from satellite data
  - also apply TCI-like approach (?)
- assim. of data from Commercial Microwave links (CMLs)
- assim. of nowcasted states
  - employ advanced nowcasting for assim. nowcasted states (REFL) with KENDA

Thank you for your attention!