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MEASURES OF IMBALANCE IN CONVECTIVE-SCALE DATA ASSIMILATION

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1) 2) 3)

What is imbalance?

Example:

Real World

Measure water level

Model

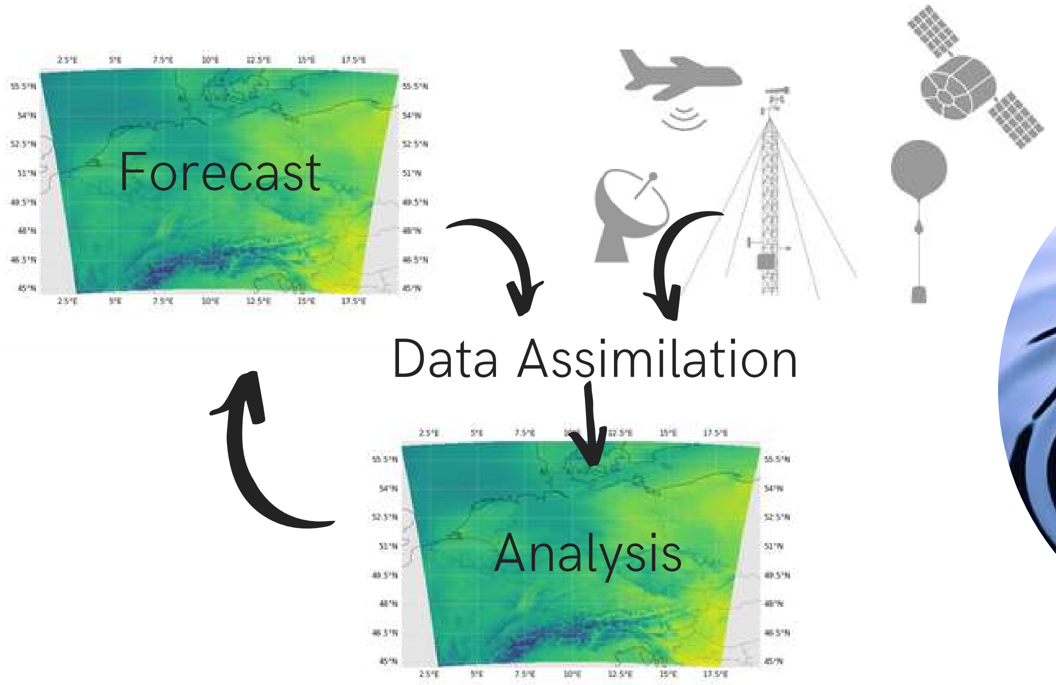
Update water level

Different ways to update the water level:

- Pour the water in all at once.
- Pour the water in slowly such that the water level adjusts gradually.
- Pour the water in drop by drop.

The way the model state gets updated influences the spin-up of the model and the effectiveness of the data assimilation.

- Goal of data assimilation is to combine a background forecast and observations in an optimal way.
- Data assimilation causes spurious gravity wave noise that has the potential to influence the model dynamics and degrade the forecast.



Goals of this project: Measure the imbalance produced in a convective-scale DA system.

- Measure imbalance with three different types of diagnostics:
  - Surface pressure tendencies (classic way)
  - Vertical velocity variance in the vincinity of the convection (Lange et al., 2017)
  - Deviations from the weak temperature gradient approximation (Craig and Selz, 2018)

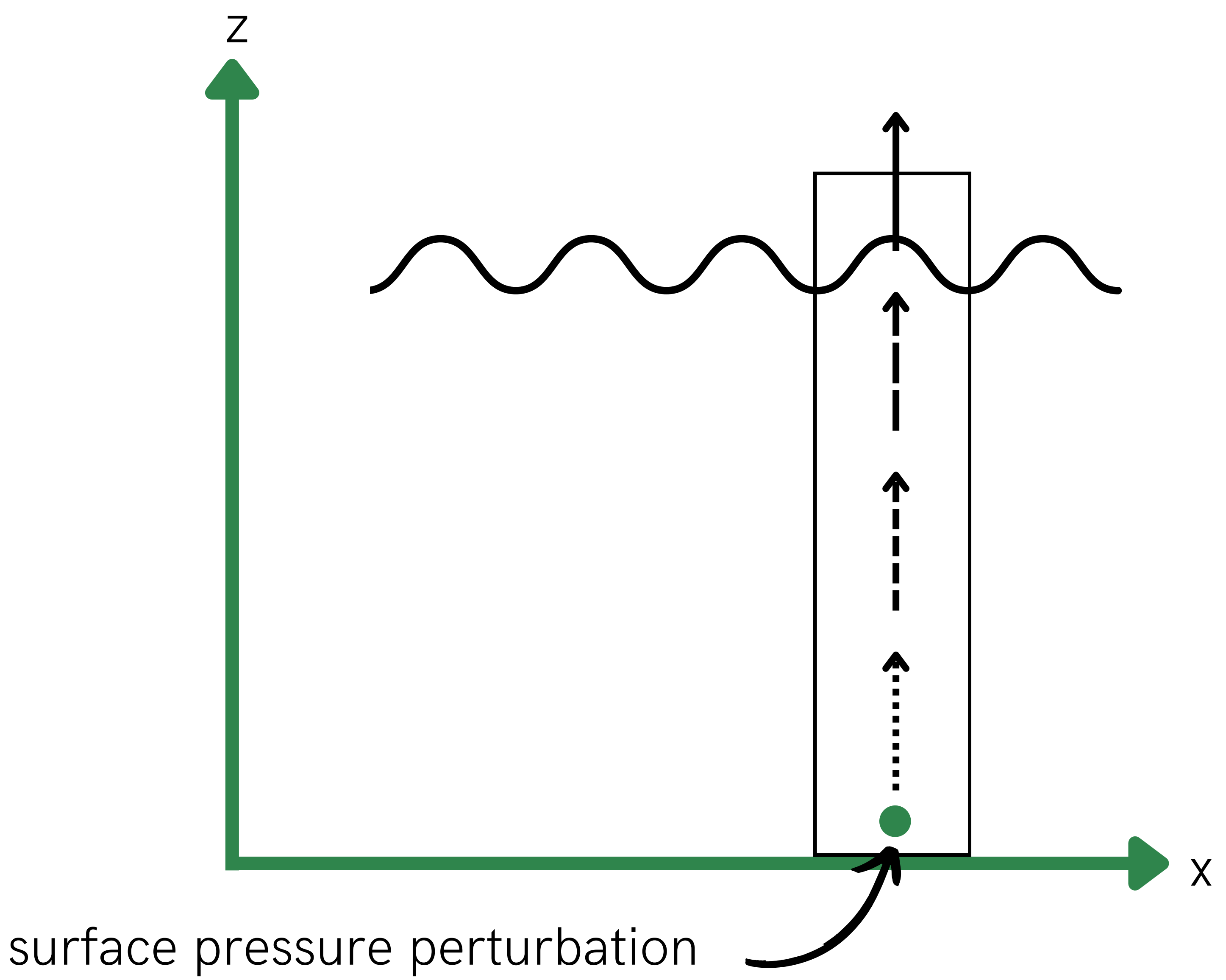
- Strategy:
  - Use different data assimilation techniques to produce a set of analyses.
  - The data assimilation techniques are chosen such that we expect different degrees of imbalance in the analyses.

- Research Questions:
  a. Do the different diagnostics measure the same kind of imbalance?
  b. Do they measure differences in the performance of data assimilation methods?

Imbalance metrics: Detection of noise in the surface pressure

Surface Pressure Tendencies (classic way, Lynch and Huang, 1992)

- Assumption: Deviations within the atmospheric column are measurable at the ground (hydrostatic balance)
- Domain integrated absolute mean (DPSDT)

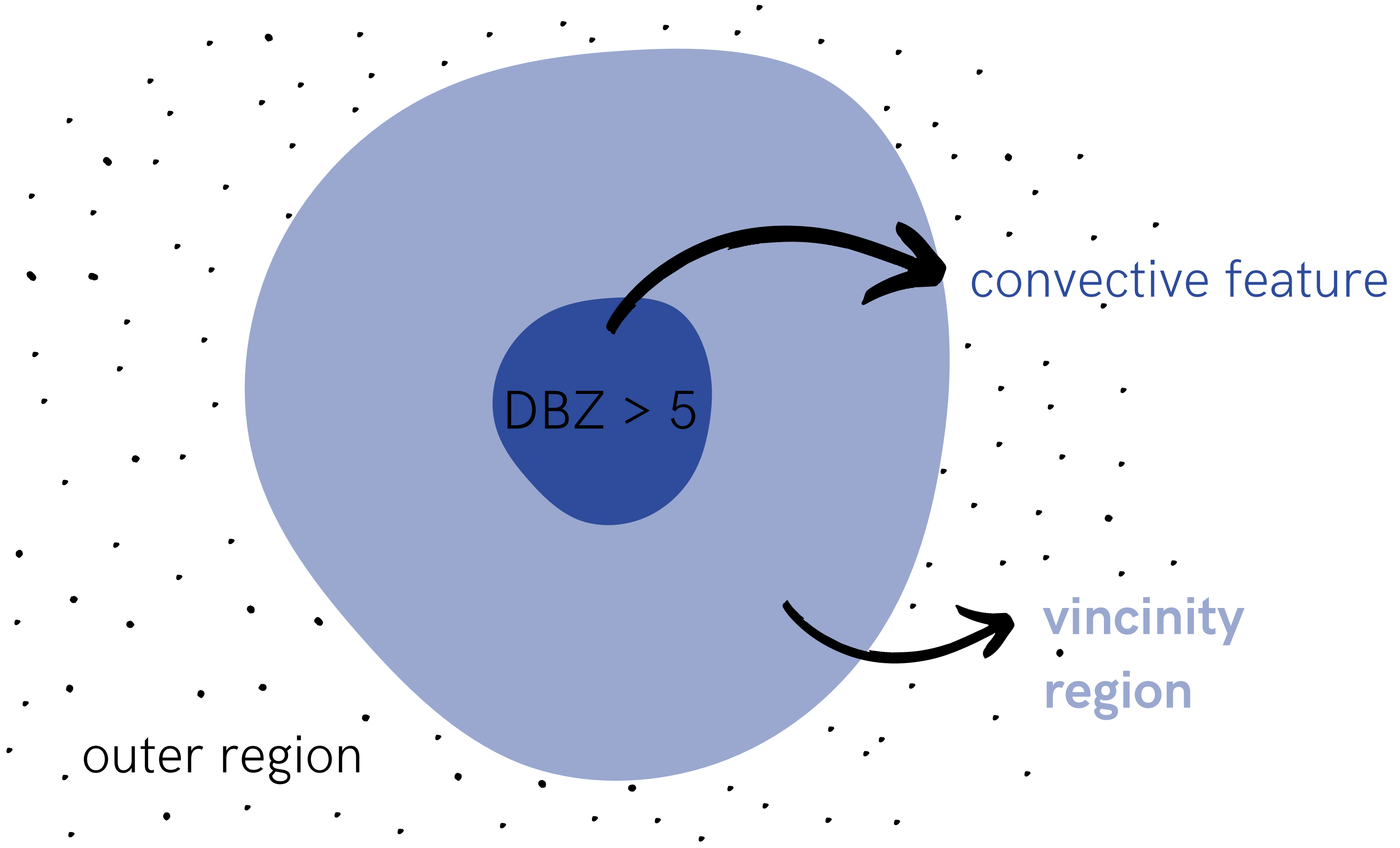


- Works well on the synoptic scale, where hydrostatic balance holds.
- On the convective scale non-hydrostatic (internal) gravity waves play an important role.
- Are they detectable in the surface pressure?

Imbalance metrics: Abundance of vertical velocity in the vincinity of convection

Vertical motion diagnostic (Lange et al., 2017):

- Hypothesis: Enhanced vertical velocity variance in the vincinity of the storms is an indication of gravity wave noise.
- Masking algorithm based on DBZ threshold values
- Detect abundance of w in near convective environment
- Partitioned variance of vertical velocity in the different masking regions



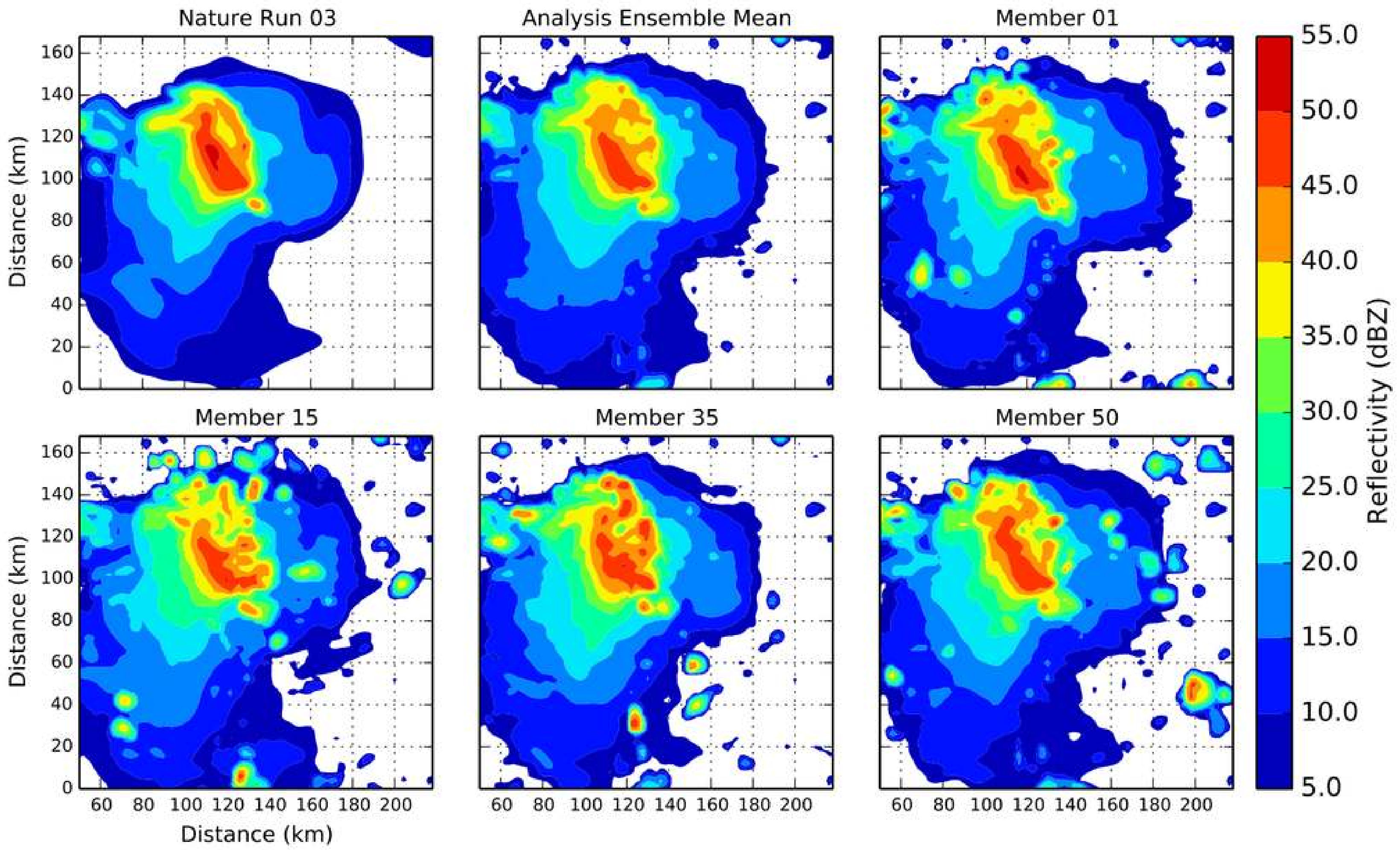


Figure: Radar reflectivity, idealized experiment from Lange et al., 2017

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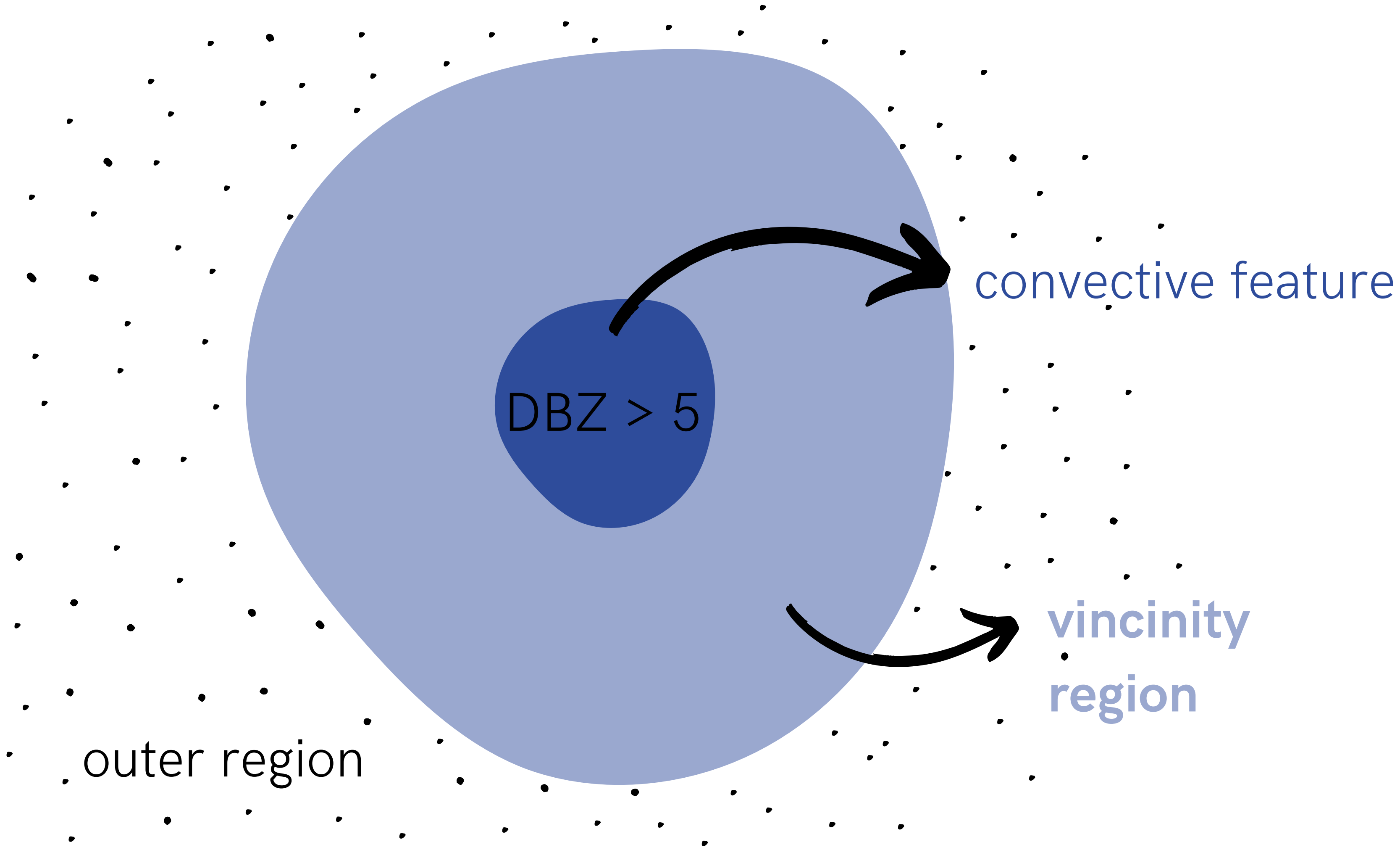
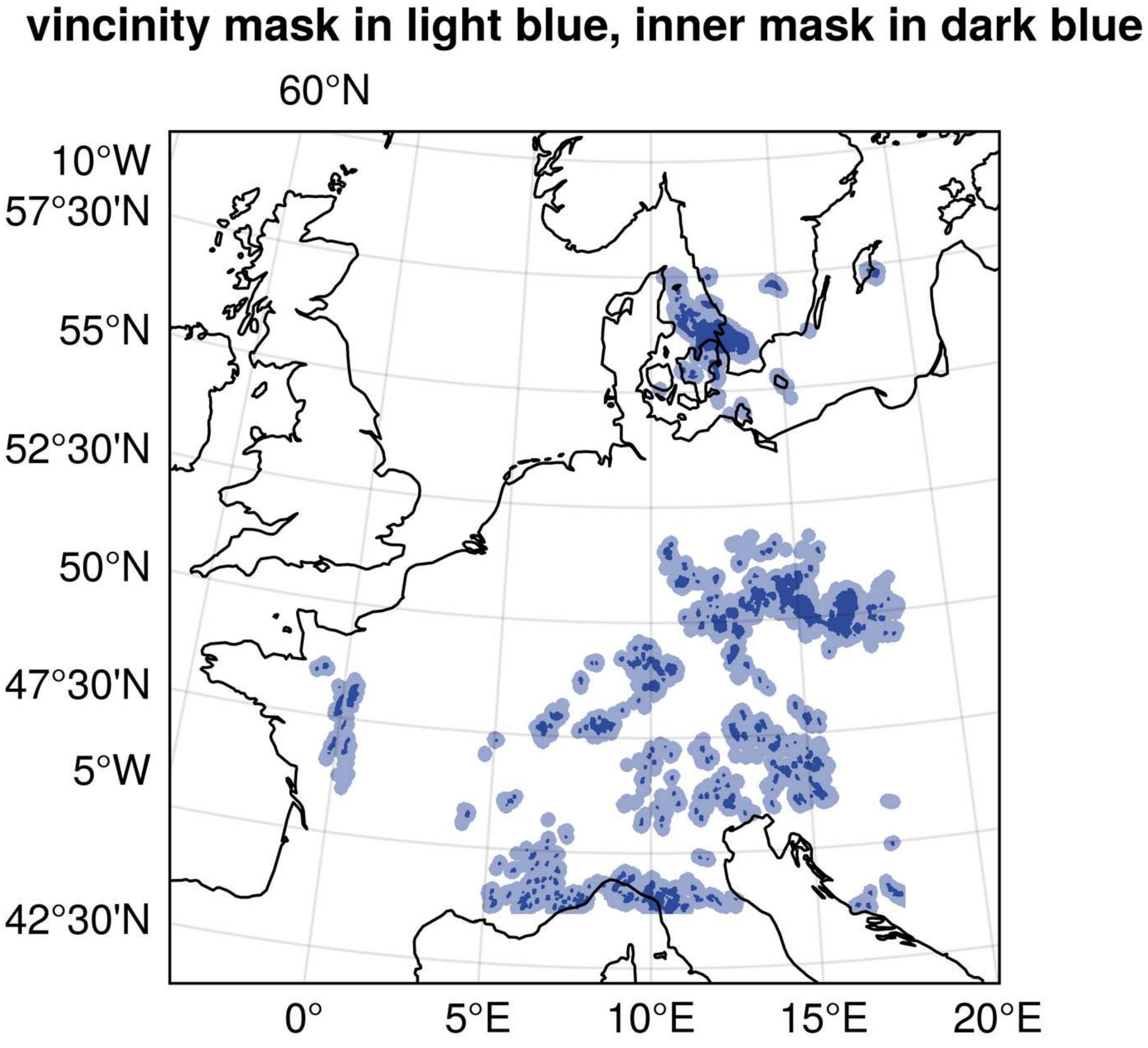




Imbalance metrics: Departures from the weak temperature gradient balance

Weak temperature gradient (WTG) balance:

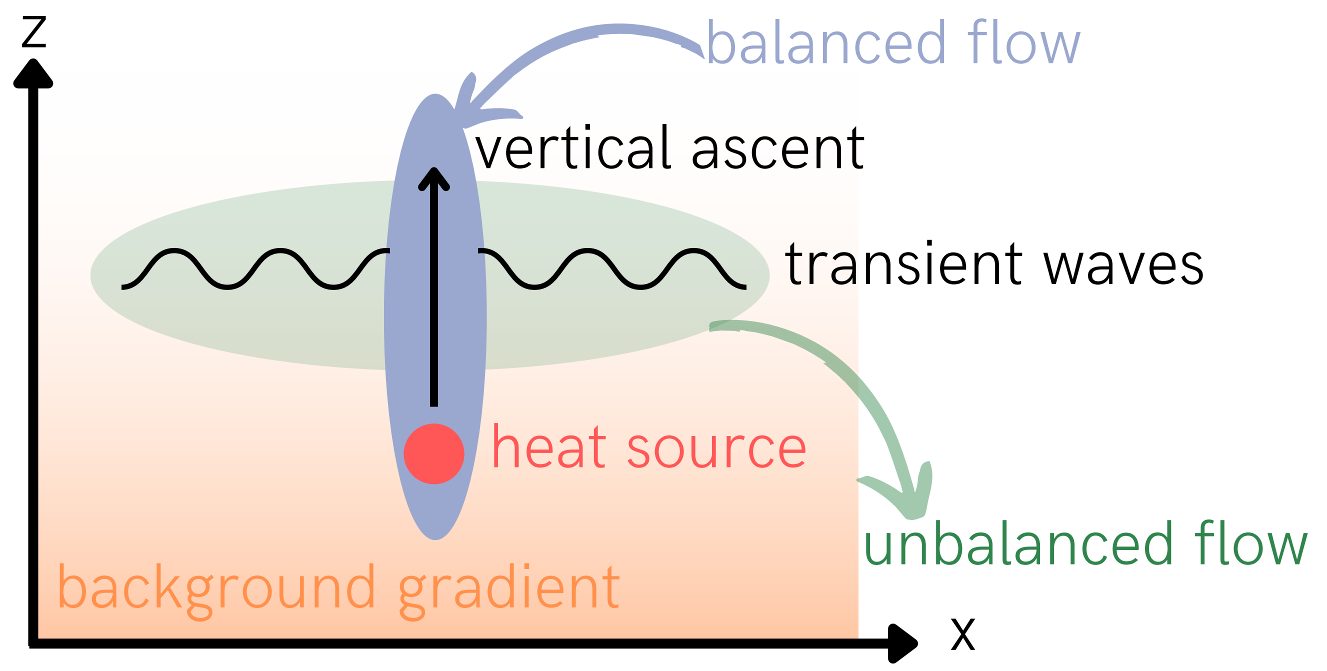
$$w_{WTG} = \frac{q_\theta}{\partial_z \theta_0} = \frac{\text{"diabatic heating"}}{\text{"vertical gradient of potential temperature"}}$$

- The response to a diabatic heat source is vertical ascent.
- Widely used in the tropics.
- Approximately valid in the mid-latitudes. (Klein, 2010; Craig and Selz, 2018)

Departures from WTG balance indicate transient motions:

$$w_{res} = w_{WTG} - w$$

Domain integrated mean absolute value of w_{res}



Experimental set-up: ICON-KENDA simulations, near-operational set-up

Two case studies: weak synoptic forcing strong synoptic forcing

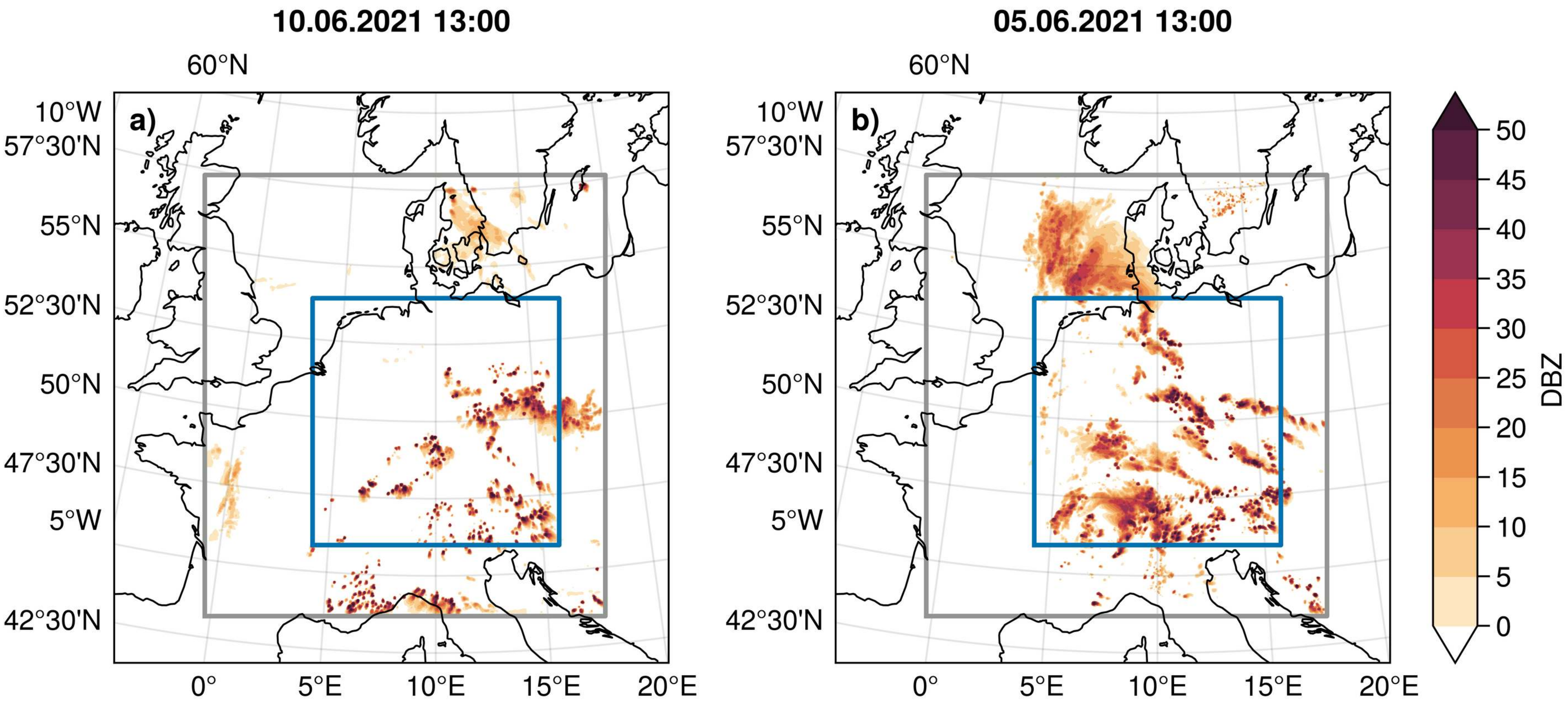
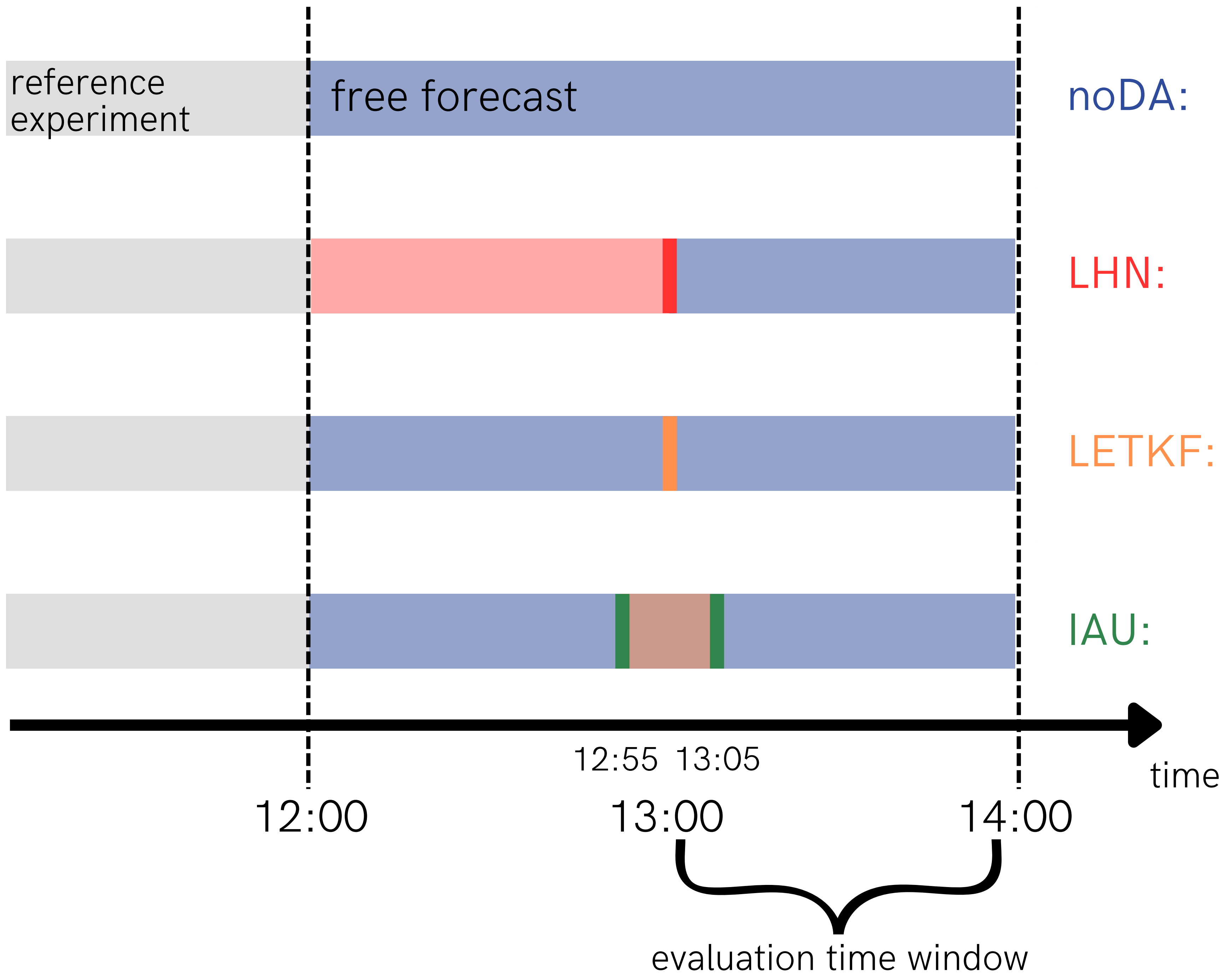


Figure: Model data, column maximum radar refelctivity, grey box: model domain, blue box: evaluation domain

Experimental set-up: ICON-KENDA simulations, near-operational set-up

Data assimilation experiments: starting from reference experiment with hourly cycling, assimilation of conventional obs, radar, and visible satellite images, latent heat nudging, 2 km resolution.



noDA: Control run, no data assimilation between 12:00 and 14:00 UTC

LHN: Latent heat nudging from 12:00 to 13:00 UTC, switched off at 13:00

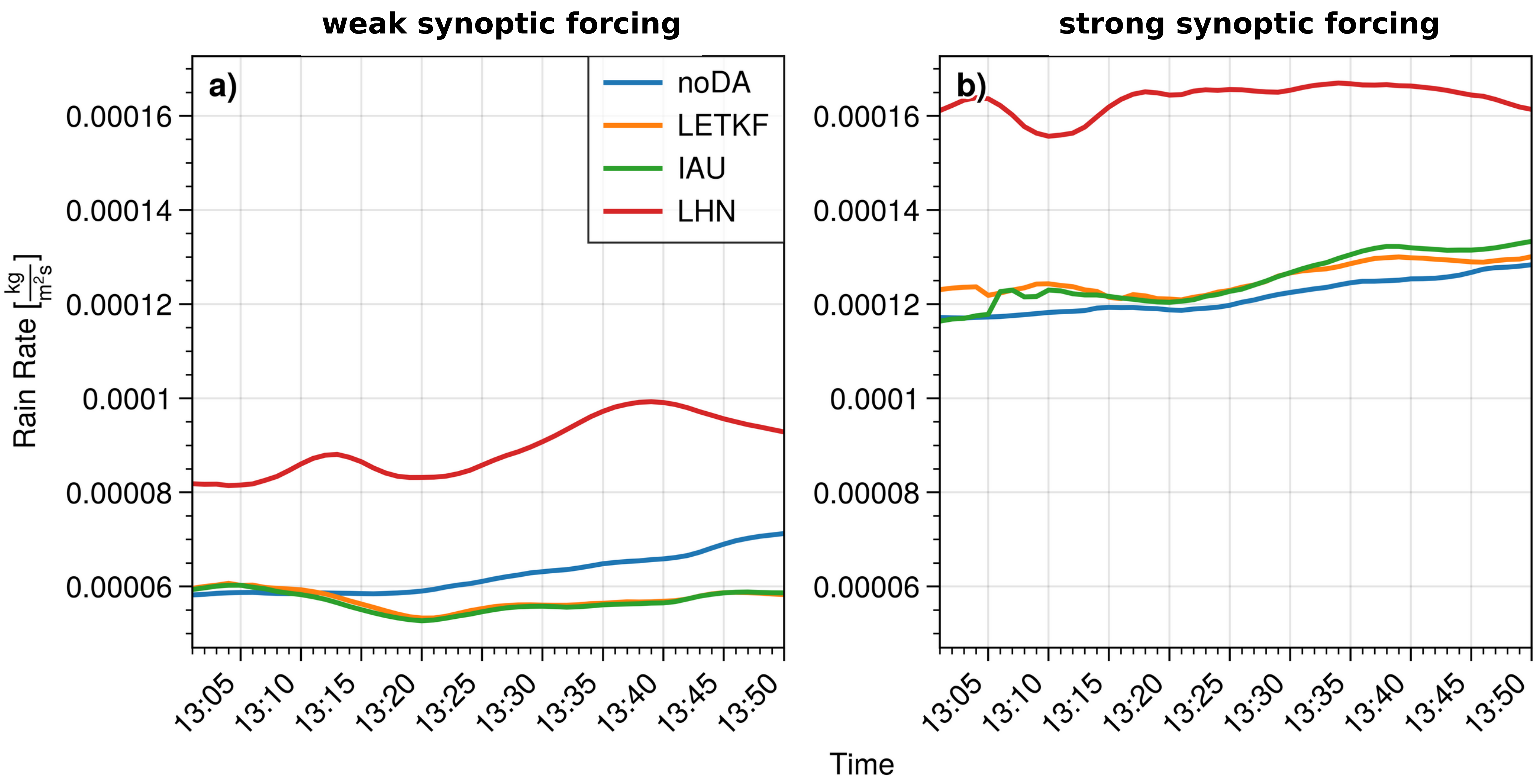
LETKF: LETKF at 13:00 UTC

IAU: LETKF with incremental analysis update (IAU)

Simulation has 10 ensemble members.
Results are shown for the first ensemble member.

Rain rate in the experiments

- Enhanced rain in the LHN experiment
- Spin-up after LETKF DA is visible in the LETKF and IAU experiments.



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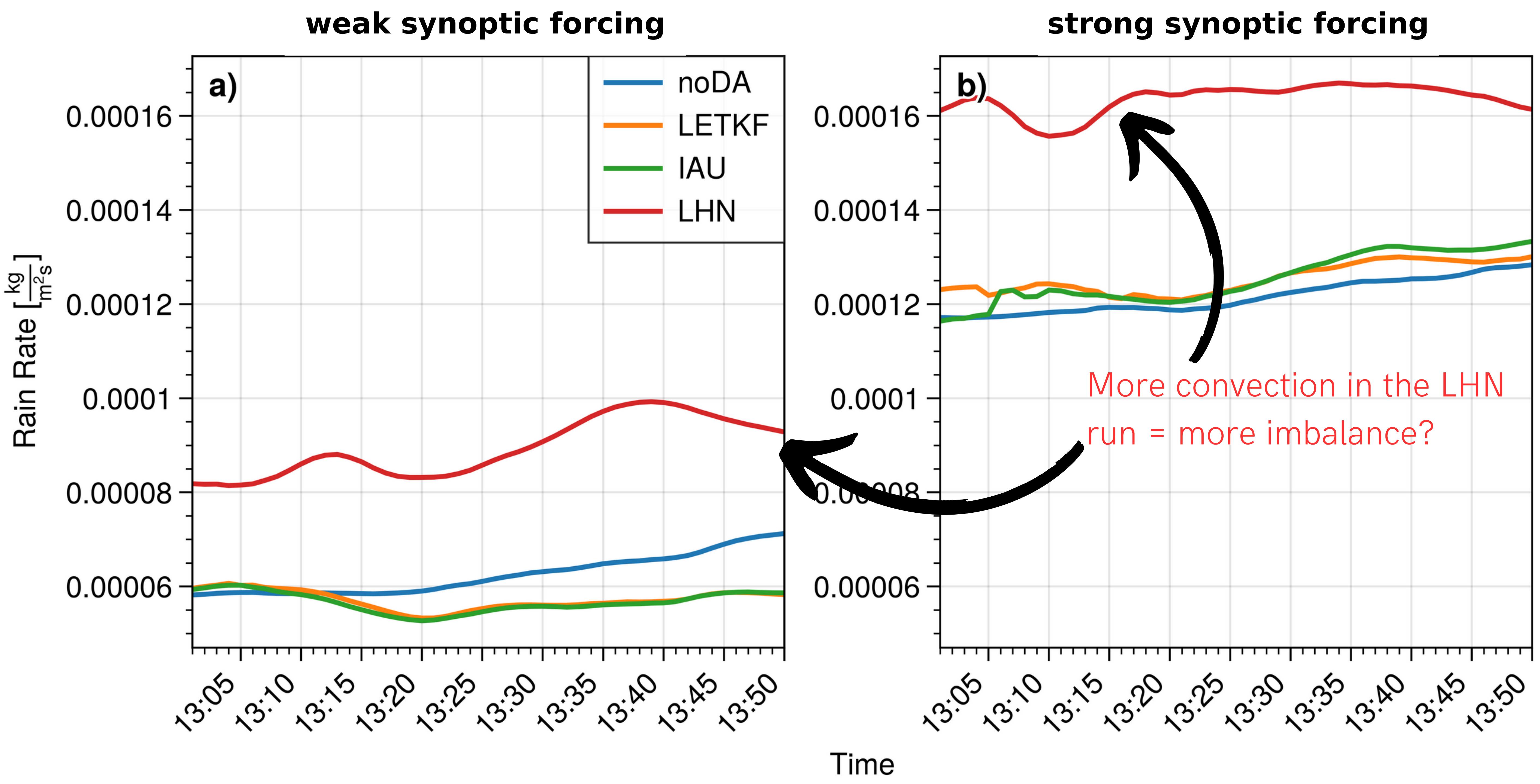
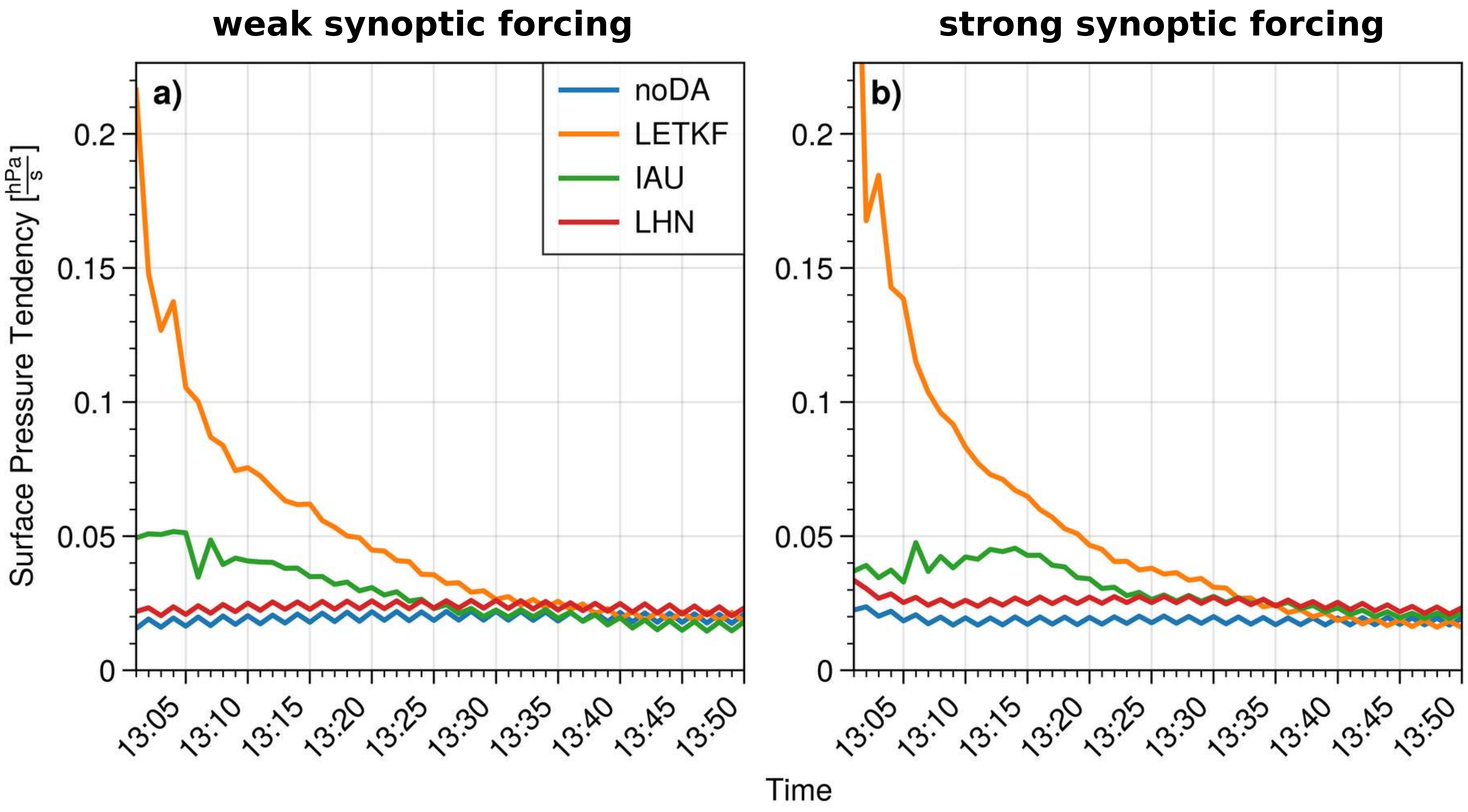


Surface pressure tendencies: Domain absolute mean (DPSDT)

- Biggest response in LETKF run
- IAU reduces the initial peak
- LHN is only slightly increased as compared to the control run



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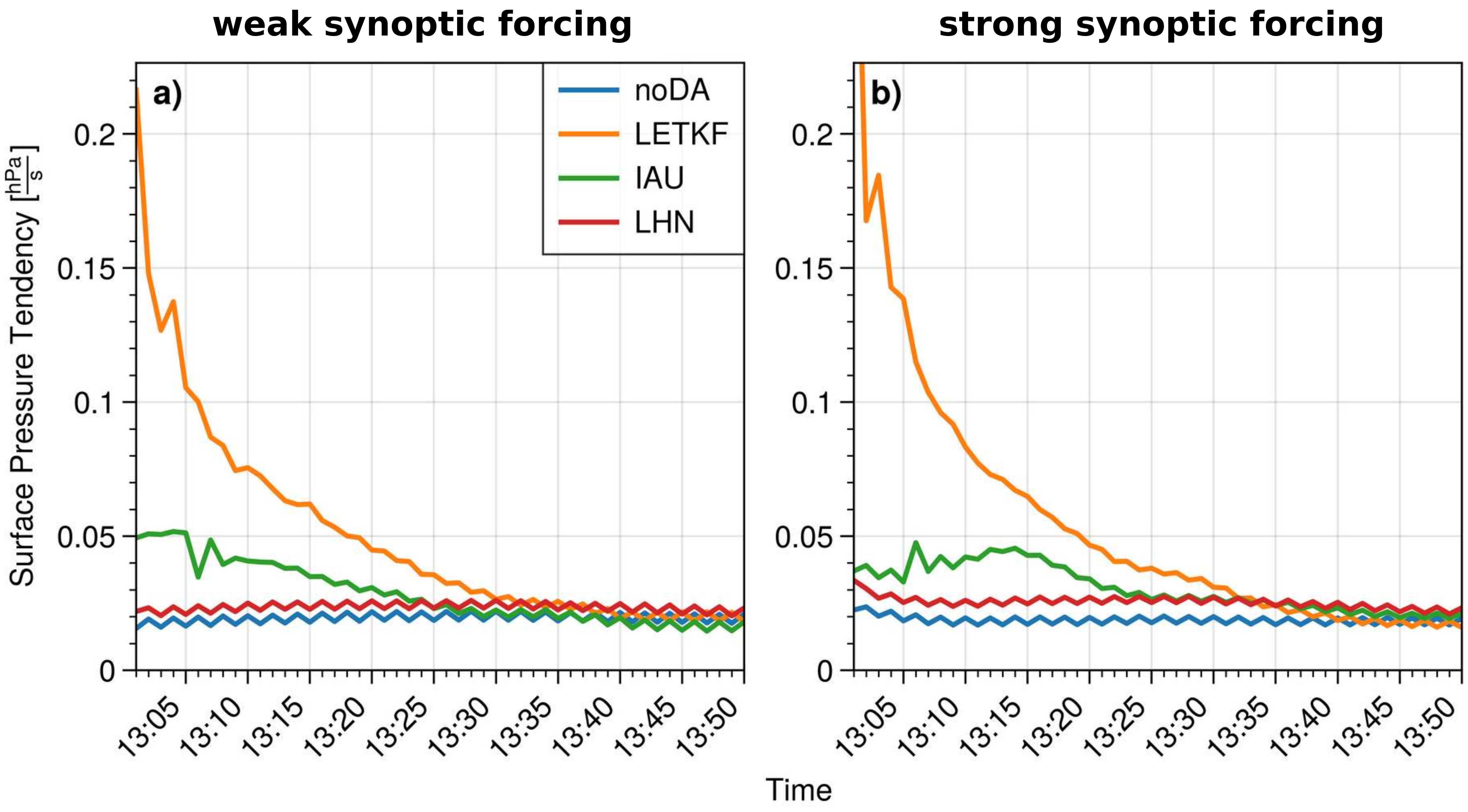
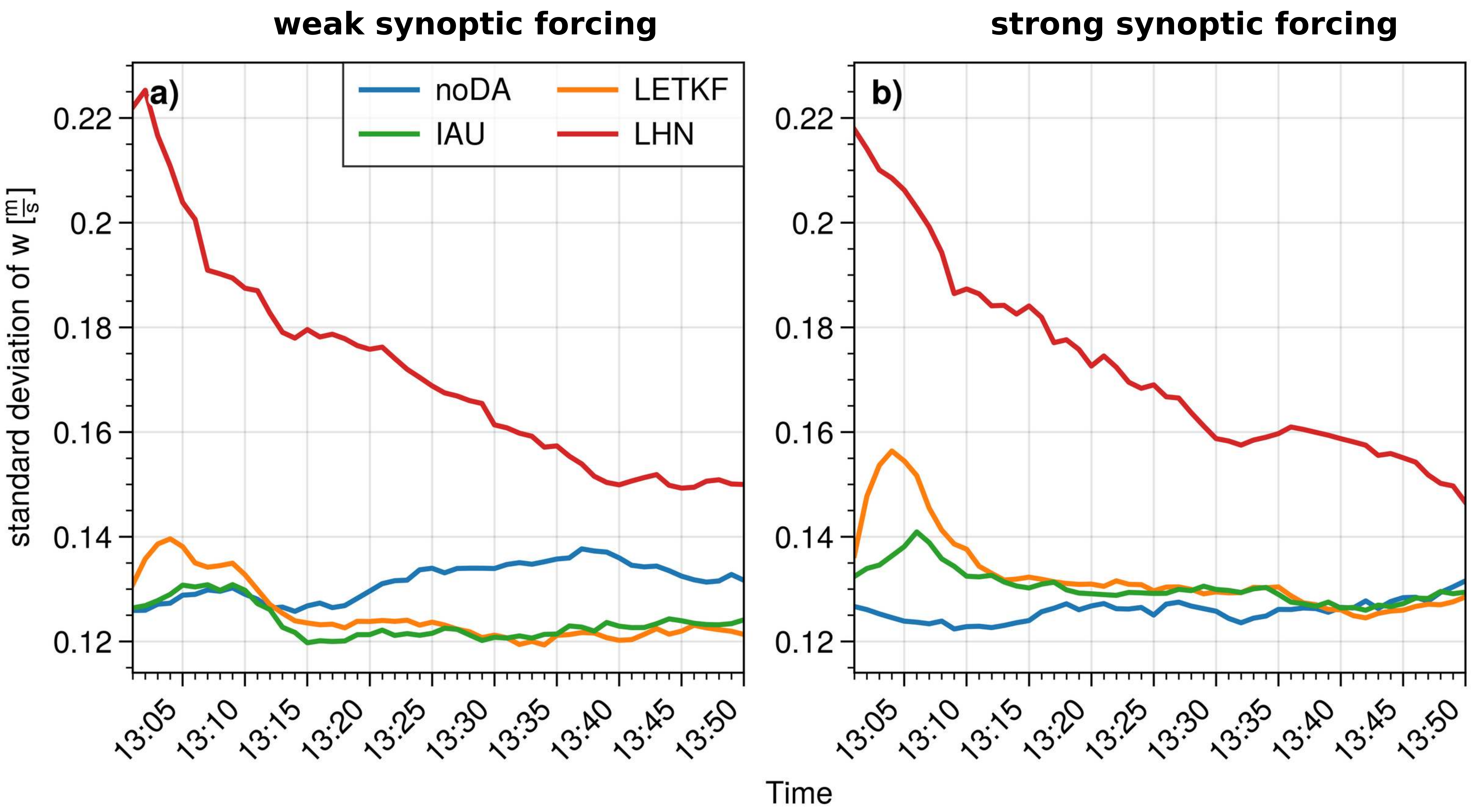
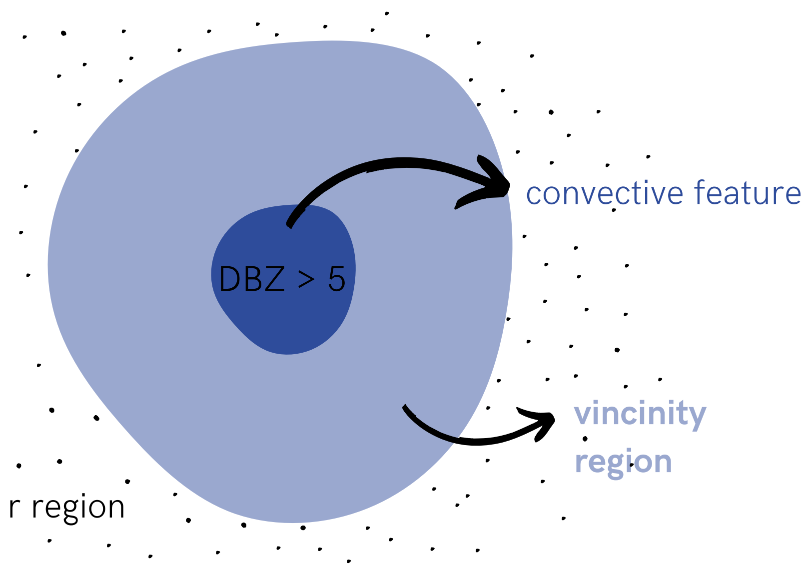


LHN more in balance than LETKF?

Vertical motion diagnostic – vincinity mask

- LHN highest standard deviation of w in the vincinity
- Model spin-up is visible in the vincinity mask for LETKF and IAU.





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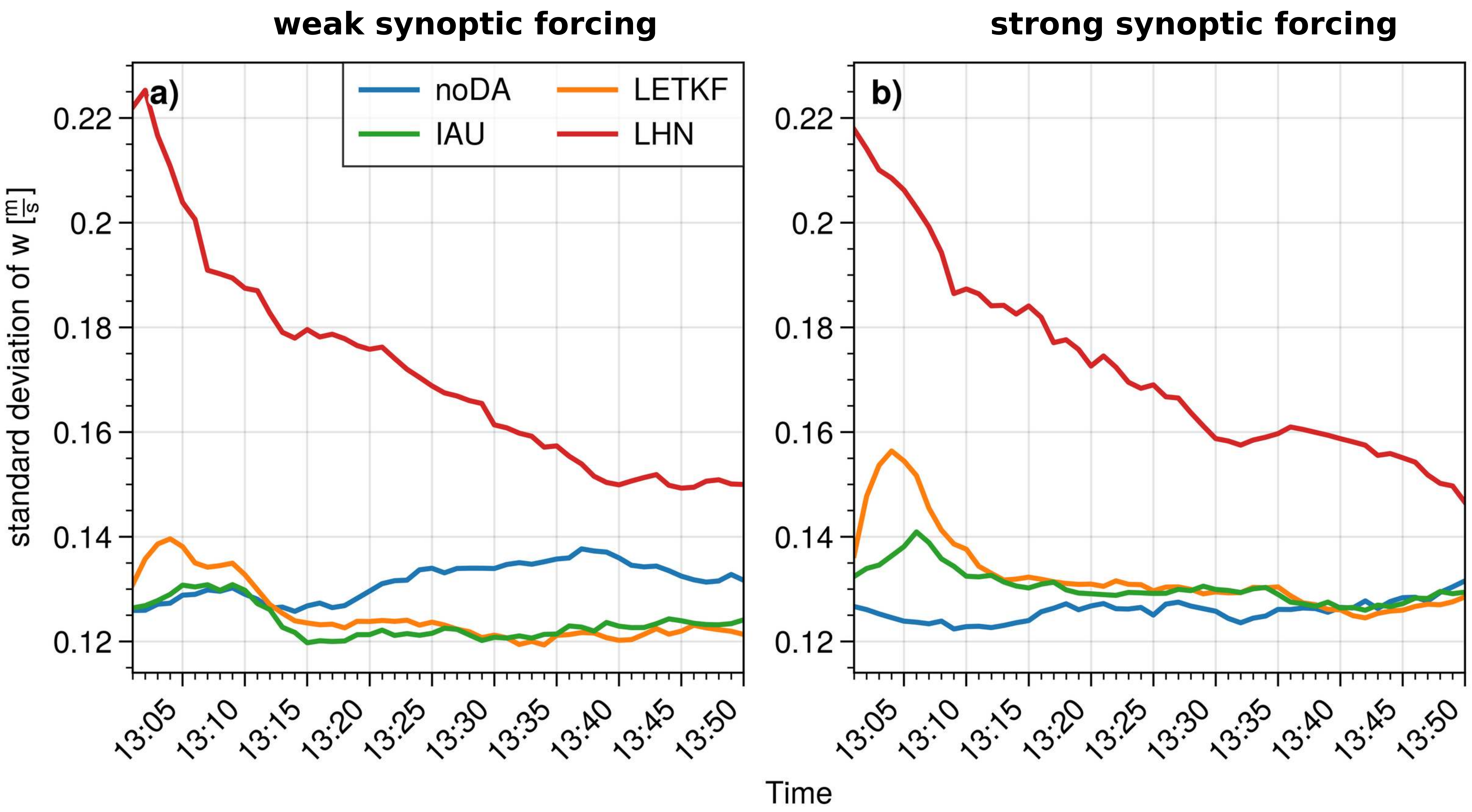
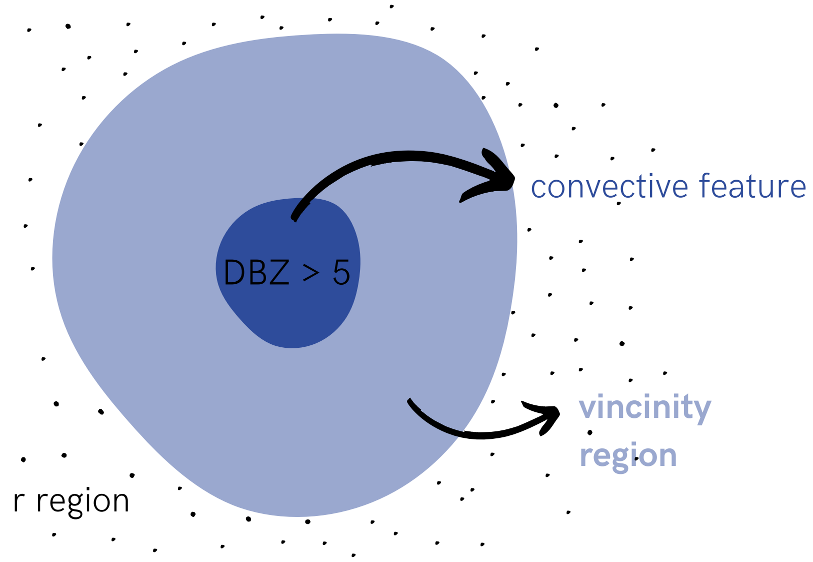


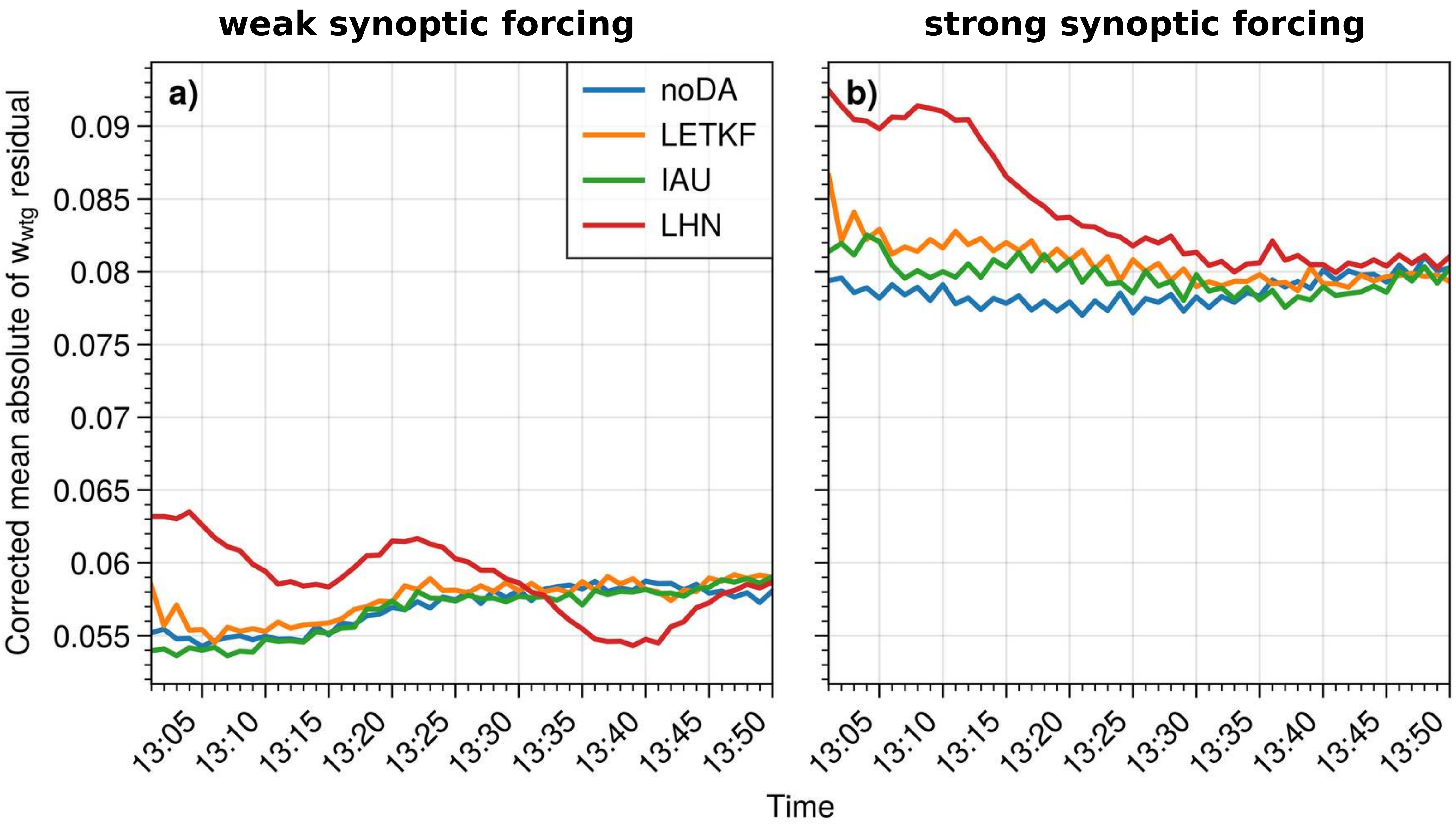
LHN less in balance than LETKF?



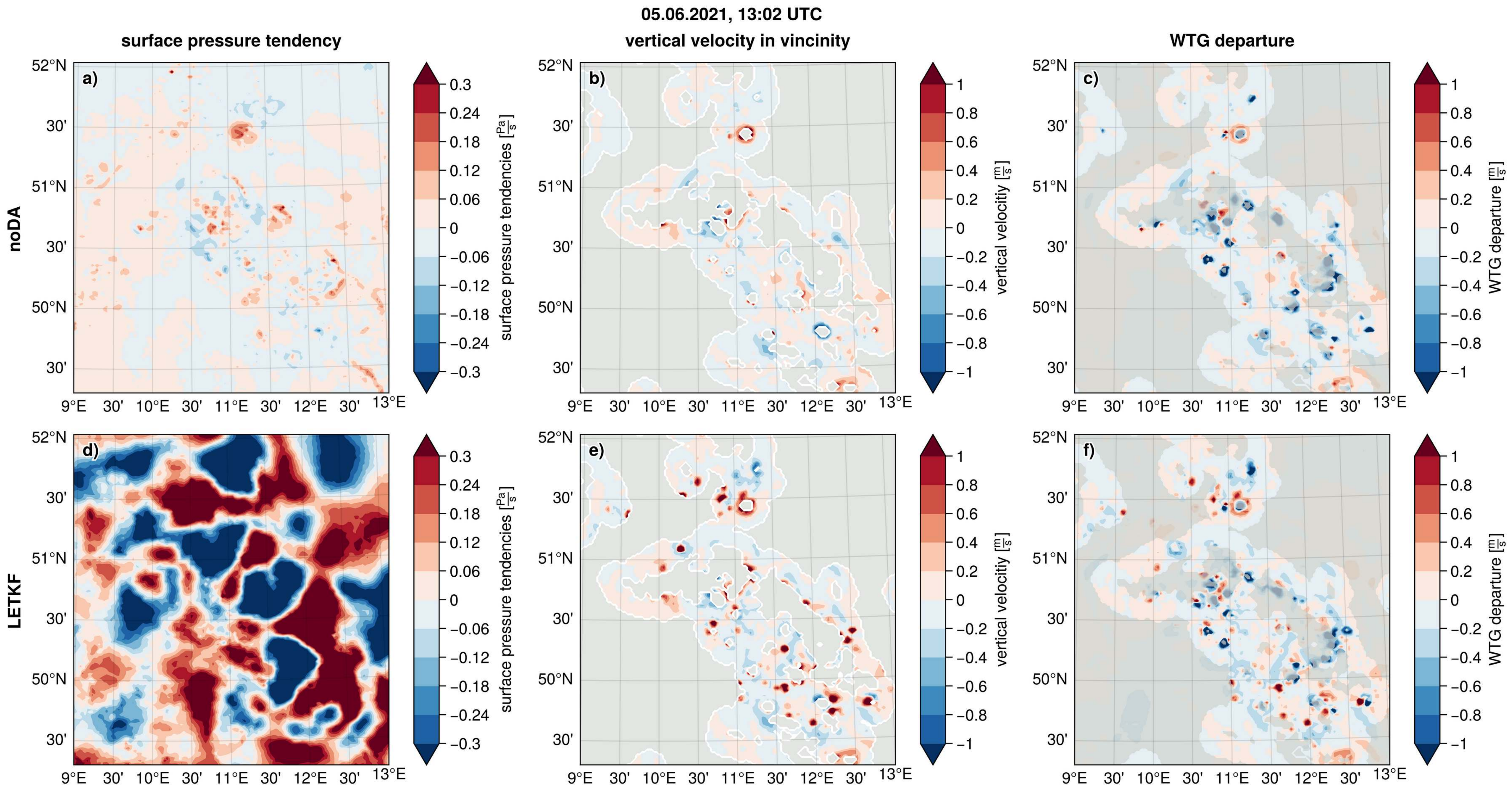
Weak temperature gradient diagnostic

- LHN highest departures from the WTG vertical velocity
- Model spin-up is visible in the departures for LETKF and IAU (strong forcing).
- Linear correlation between the amount of rain and WTG departures? Linear correction for the amount of precipitation

Results are very similar to VMD results in the vincinity mask.



Relations of the different methods



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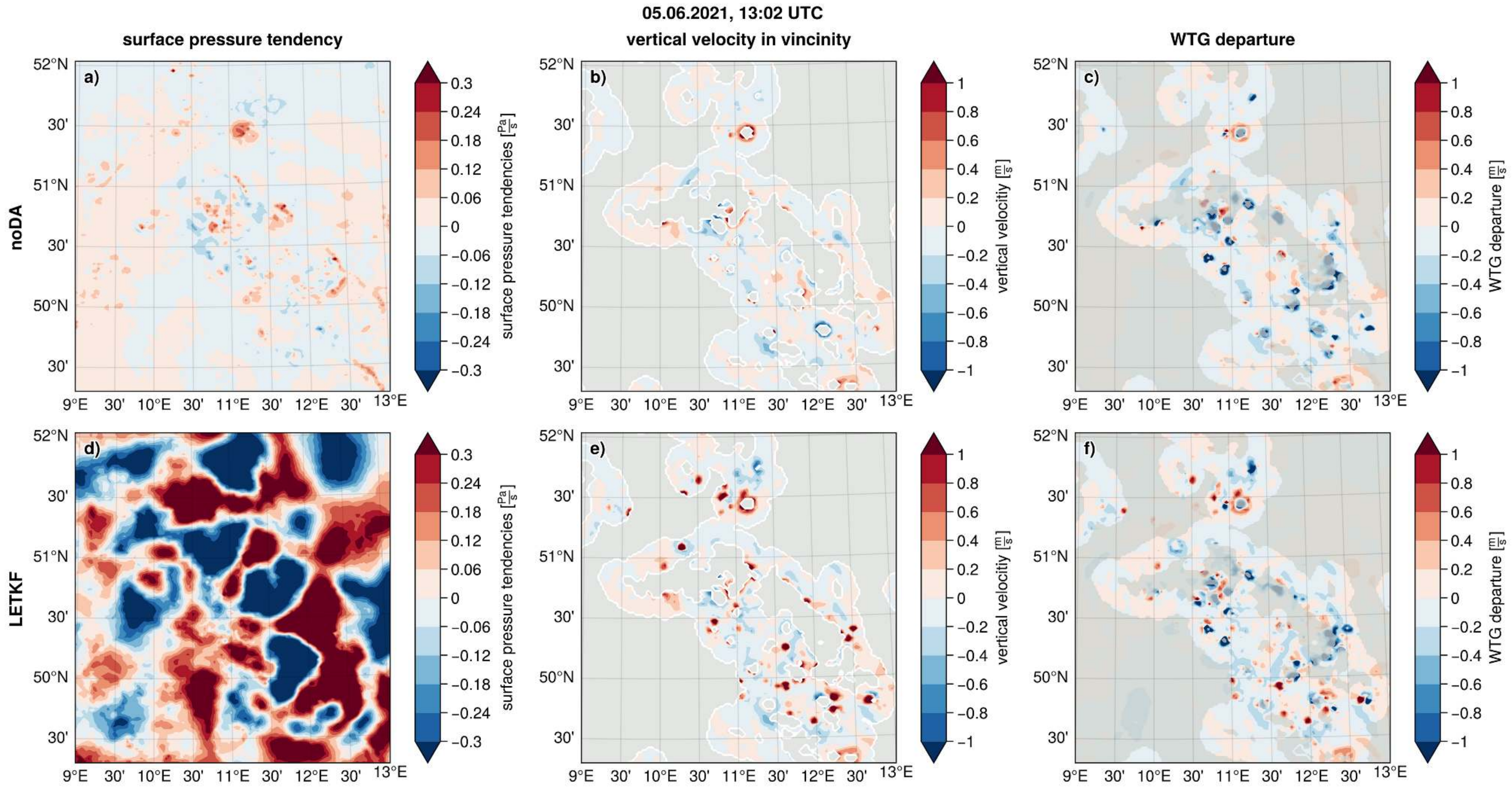


very different spatial pattern

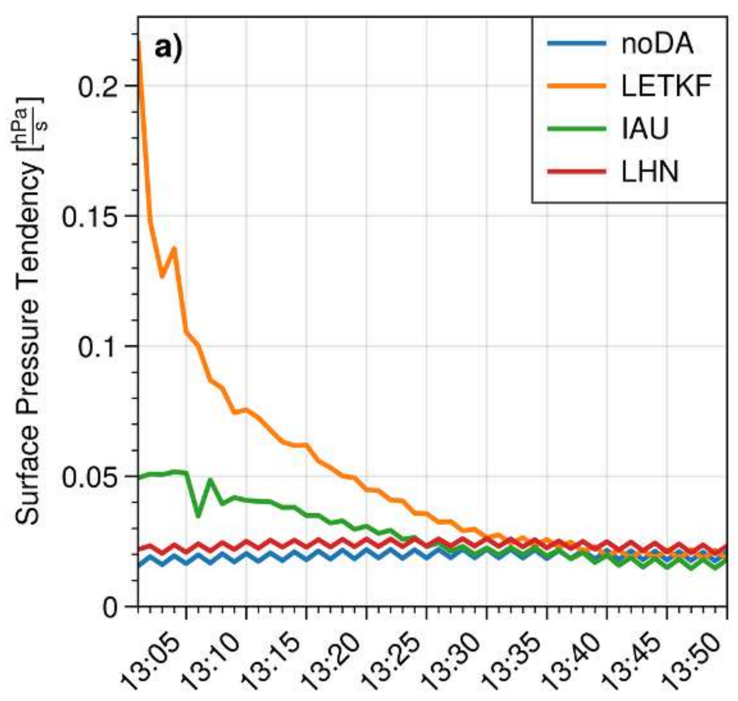
noise in the vincinity

biggest WTG departures (noise) in the vincinity

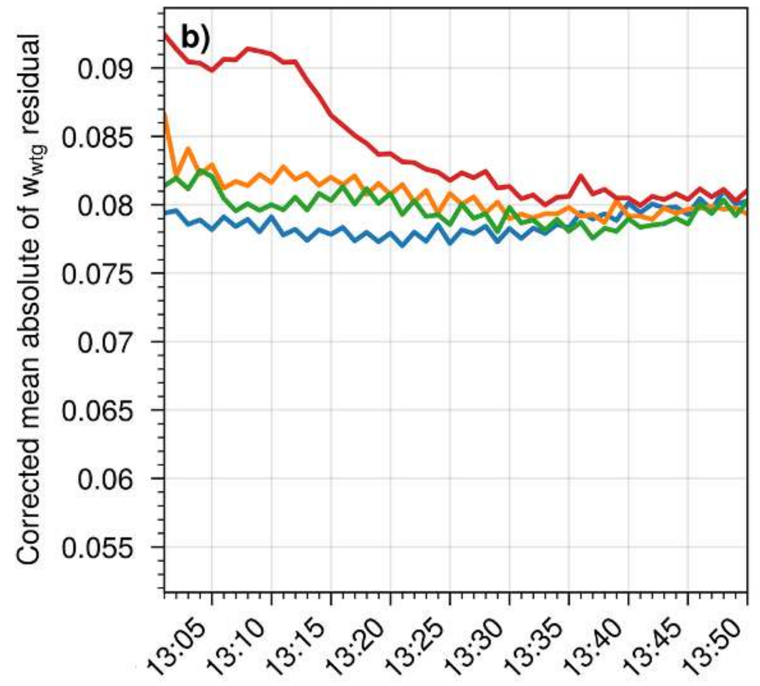
Summary

- Systematic difference between LHN and LETKF imbalance (expected)
- Surface pressure tendencies more sensitive to the inital shock of the LETKF update
- Weak temperature gradient departures largest for LHN (consistent with vertical motion diagnostic)

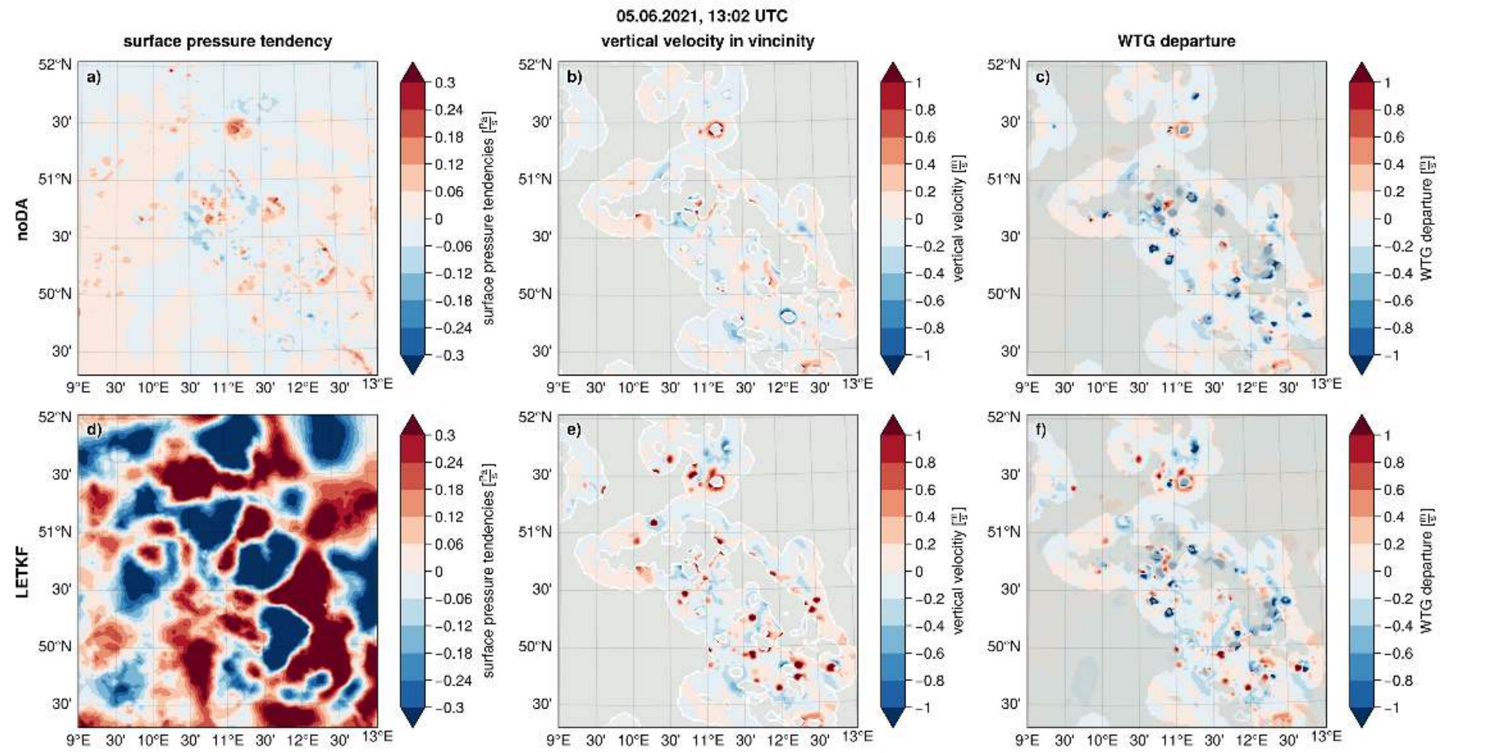
Surface Pressure Tendency



Weak Temperature Gradient Departure



Surface pressure tendencies seem to measure a **different kind of imbalance** than the weak temperature gradient diagnostic or the vertical velocity masking.



What does this imply for practical data assimilation?

Appendix

Resources

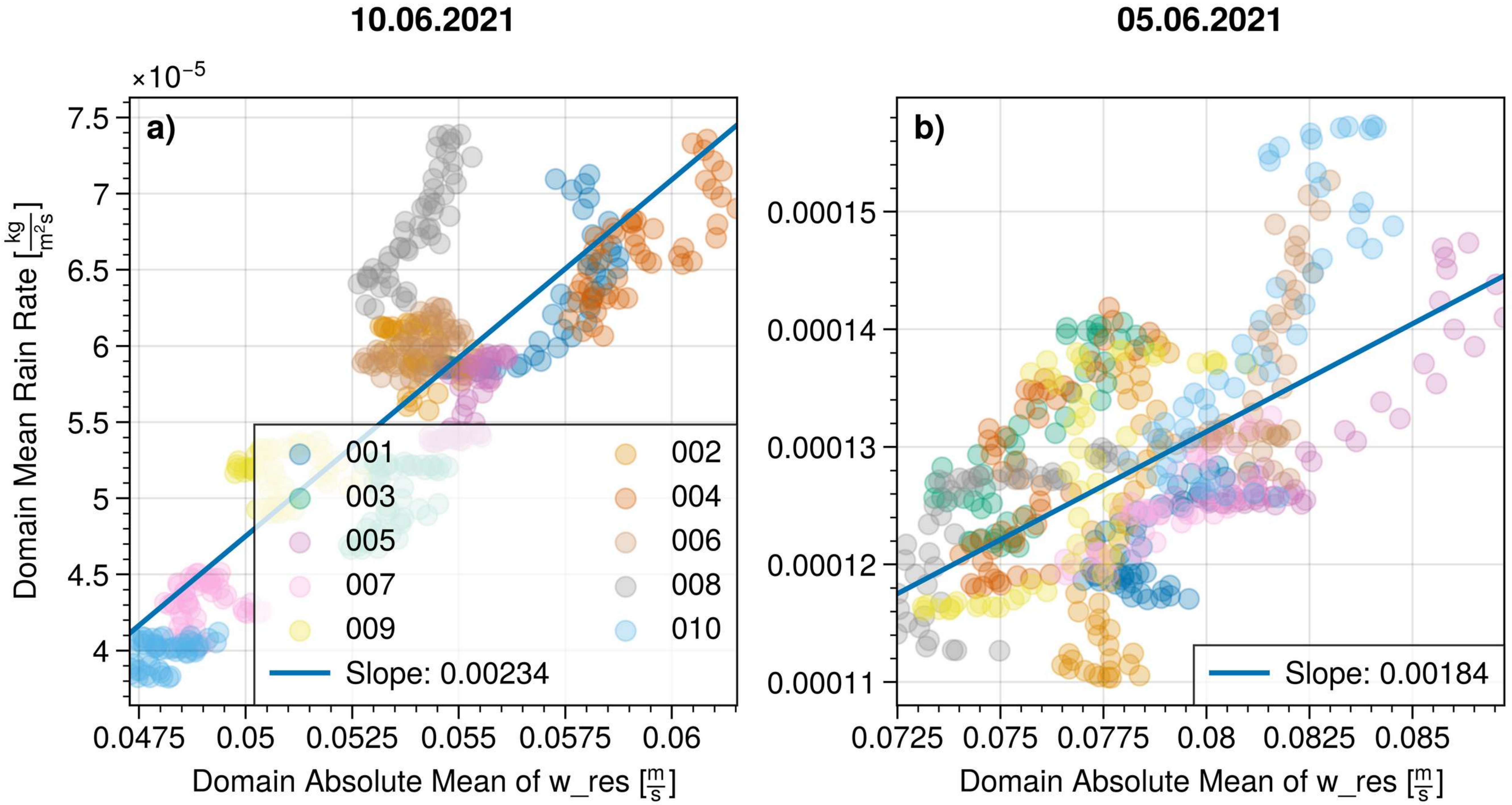
G. C. Craig and T. Selz. Mesoscale dynamical regimes in the midlatitudes. Geophysical Research Letters, 45(1):410–417, 2018. doi: 10.1002/2017gl076174. URL https://doi.org/10.1002/2017gl076174.

H. Lange, G. C. Craig, and T. Janjić. Characterizing noise and spurious convection in convective data assimilation. Quarterly Journal of the Royal Meteorological Society, 143(709):3060–3069, 2017. doi:10.1002/qj.3162. URL https://doi.org/10.1002/qj.3162.

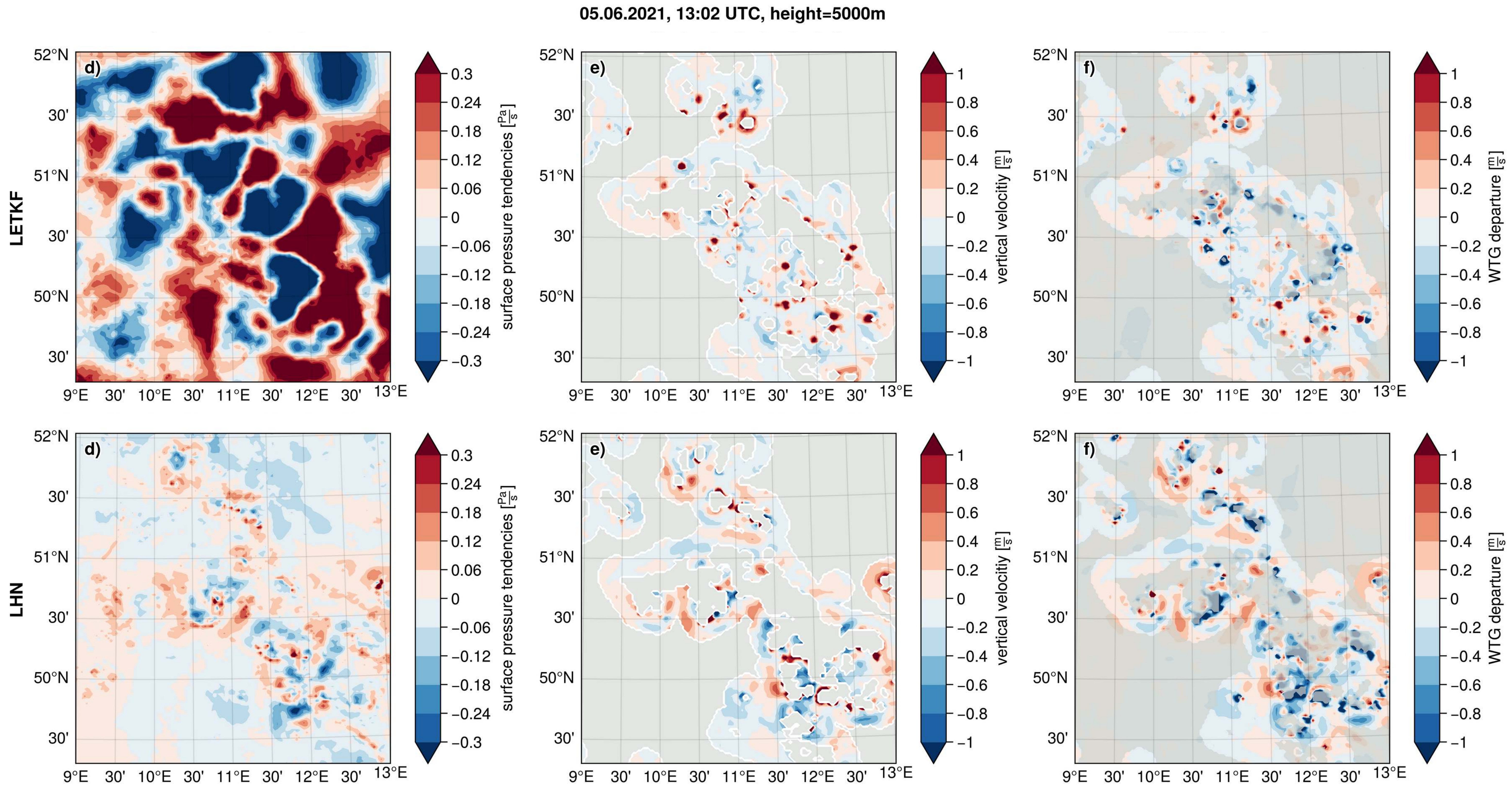
P. Lynch and X.-Y. Huang. Initialization of the hirlam model using a digital filter. Monthly Weather Review, 120(6):1019 - 1034, 1992. doi: https://doi.org/10.1175/1520-0493(1992)120<1019:IOTHMU>2.0.CO; 2. URL https://journals.ametsoc.org/view/journals/mwre/120/6/1520-0493_1992_120_1019_iothmu_2_0_co_2.xml.

Appendix: Linear relation: precipitation vs. wres

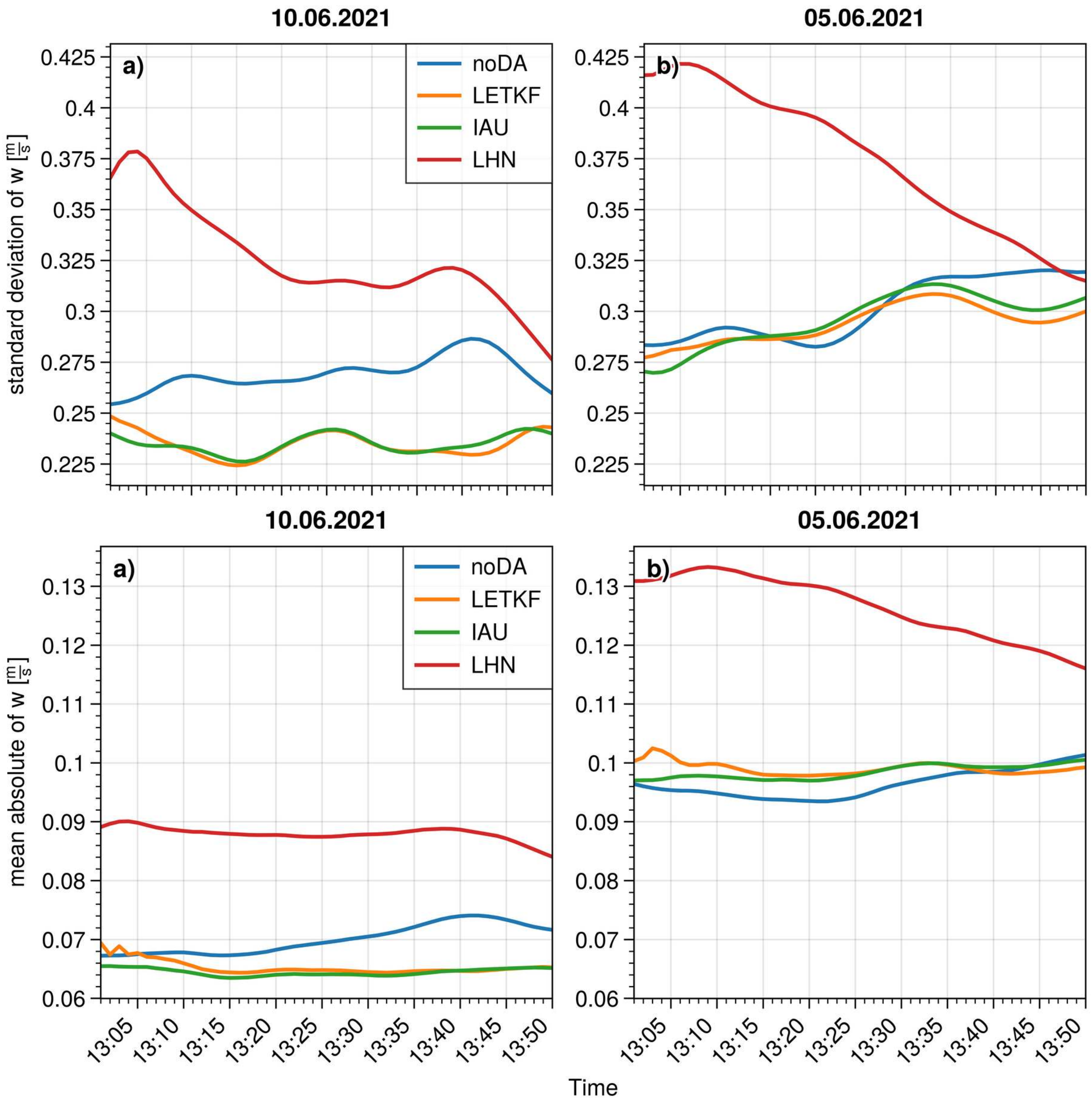
$$w'_{res} = w_{res} - y(precip_{exp} - precip_{noDA})$$



Relations of the different methods – LETKF vs LHN



Appendix: Vertical motion diagnostic

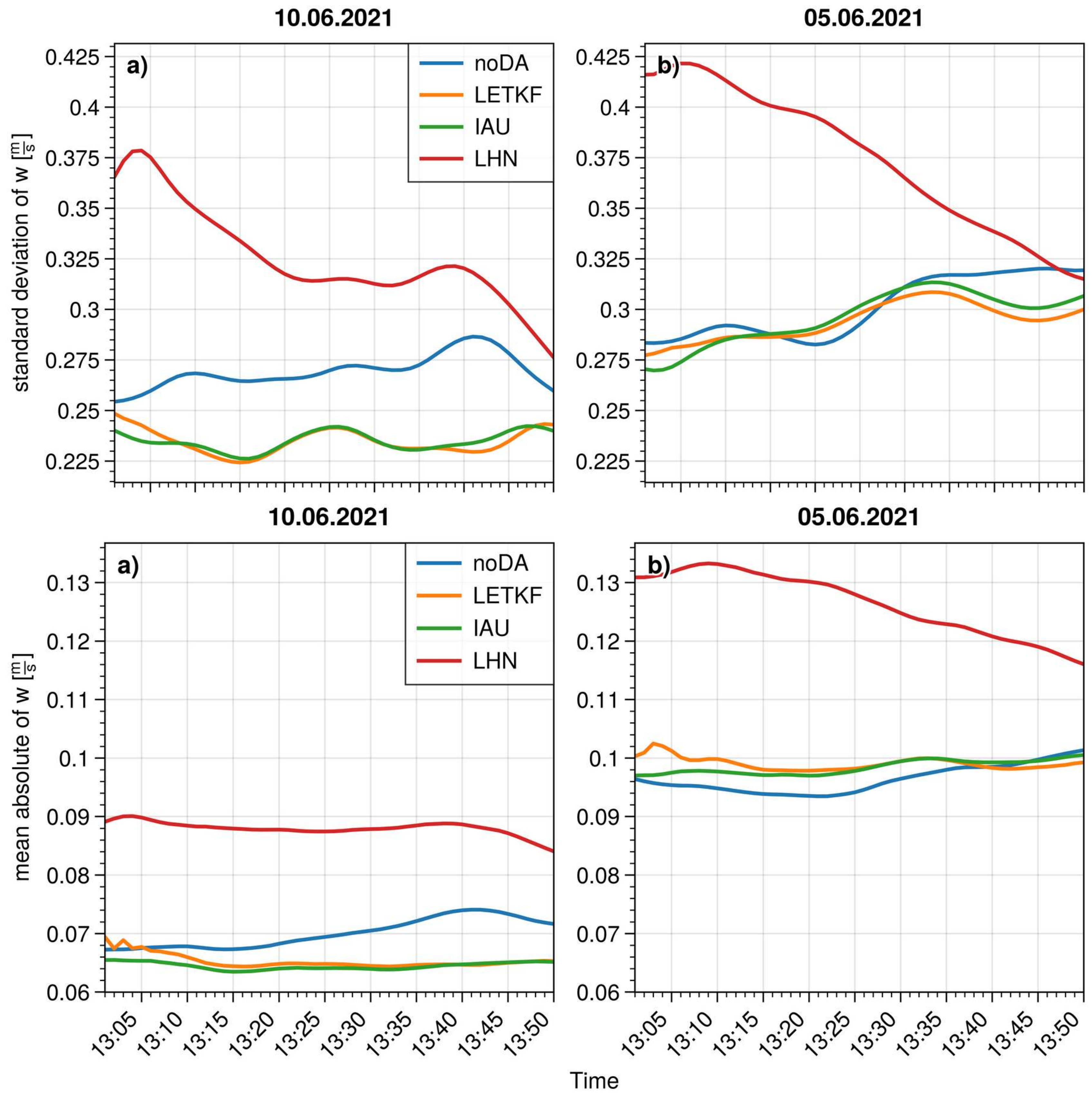


- No masking in these plots
- Upper row: standard deviation of w in the domain
- Lower row: mean absolute of w in the domain
- In contrast to DPSDT, LHN shows the highest values

- Standard deviation: LETKF decreases w.r.t control run
- Mean absolute: LETKF increases the w.r.t control run (strong forcing case)

- Quadratic norm: higher weighting of high values, strong updrafts inside the convection.
- Linear norm: equal weighting of low and high values of w.

Appendix: Vertical motion diagnostic



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- Quadratic norm: higher weighting of high values, strong updrafts inside the convection.
- Linear norm: equal weighting of low and high values of w.

LETKF weakens the convective updrafts?
LETKF creates noise in the vincinity of the convection?