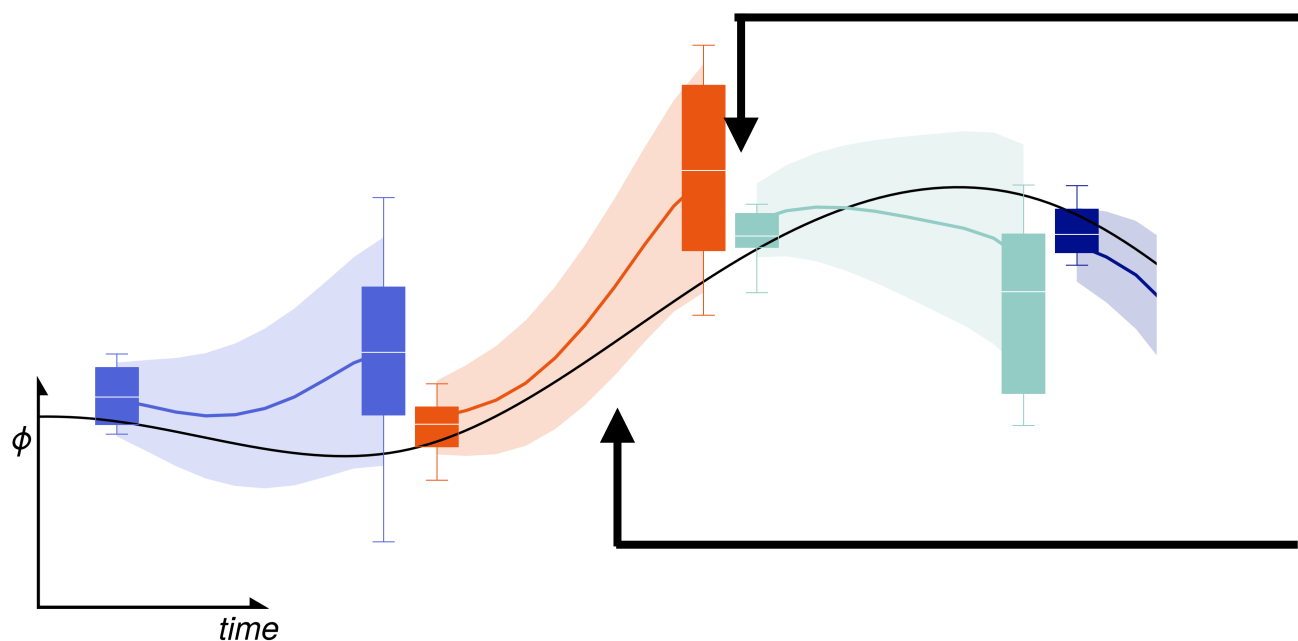


A Variance Budget to quantify the Growth and Interaction of Uncertainties on Convective Scales

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Model errors in ensemble DA



► Relaxation approaches in DA:
RTPP, RTPS, random noise,
warm bubbles, ...

► Perturbation approaches in
forecasts:
Multi-physics, SPPT, SPP, PSP,
SKEB, ...

► “It is surprisingly hard to improve upon additive inflation by replacing it with SKEB” (Whitaker and Hamill 2013)
and confirmed by follow-up studies (e.g. Ha et al. 2015).

Model errors in convective-scale DA and forecasts

- ▶ Combining the PSP scheme had little effects on RMSE compared to the effects of additive noise (Zheng et al. 2020).
- ▶ When multiple uncertainty schemes are combined, the net variance increase is much smaller than the simple sum of their variances.
e.g. Hermoso et al. 2021(multi physics, SPPT and MPRP), Frogner et al. 2022 (IBC and SPPT),
Chen et al. 2024 (PSP and SPPMP)

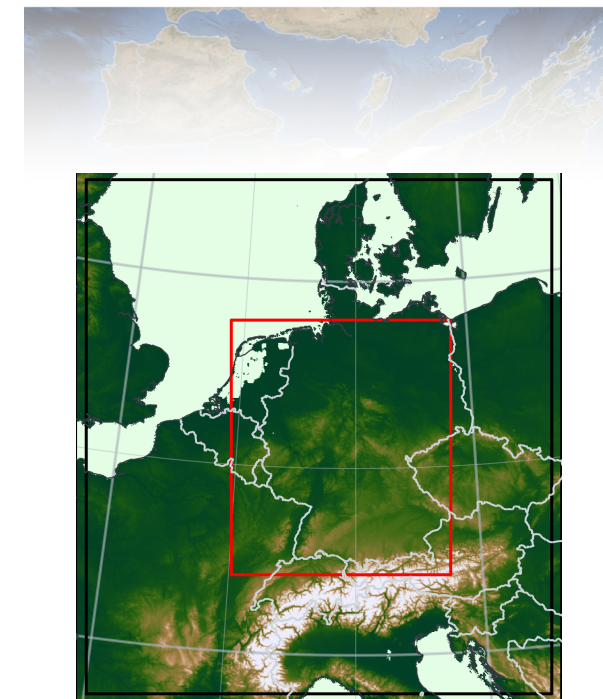
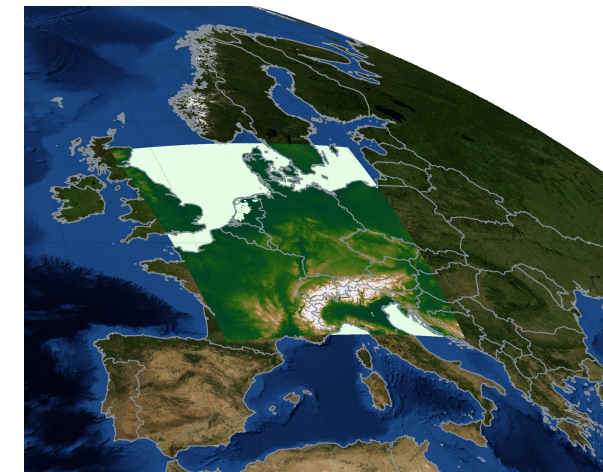
Q: When, where, and how do perturbations from different sources interact?

- in a forecast mode
- with 2 model uncertainty schemes
- for convective precipitation events over Germany

Model: ICON-D2

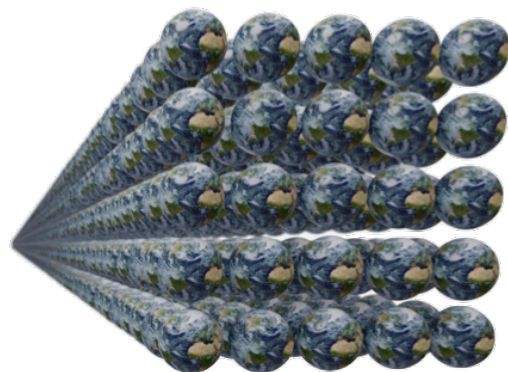
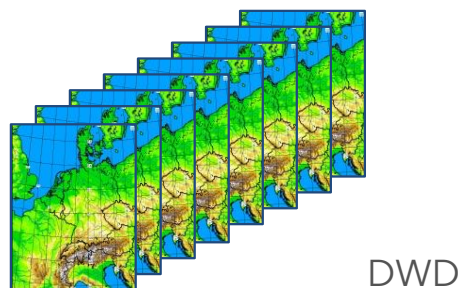
Operational at DWD since Feb. 2021

Model	Based on ICON-LAM (driven by externally supplied boundary conditions)
Resolution	2 km horizontal grid spacing 65 vertical levels up to 22 km agl
Microphysics	Two-moment scheme (Seifert and Beheng 2006)
Initialisation and forecast length	8 convective days from June 2021 and Aug. 2022, from 00 UTC up to 24h
Initial and Boundary conditions	20 ICs from KENDA (Schraff et al. 2016) 20 LBCs from ICON-EU-EPS

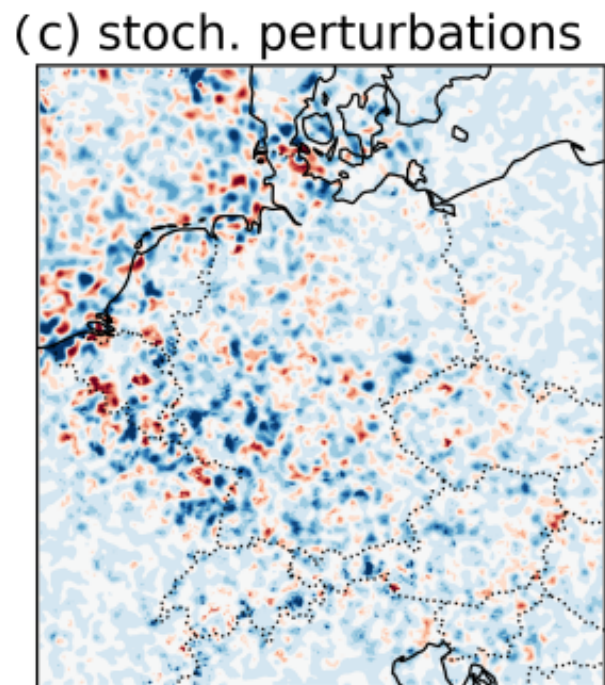


Uncertainty representations (schemes)

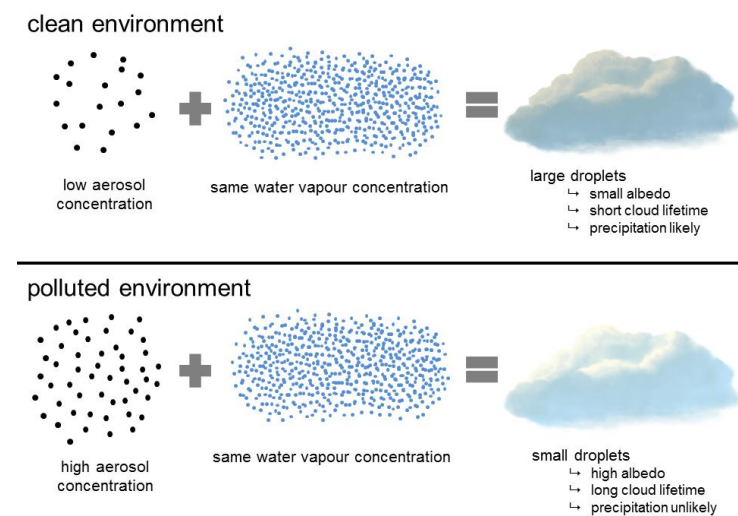
I: Initial + boundary conditions



P: PSP scheme



M: microphysical PP



Paranomov (2015)

Hirt et al. (2019)

Model Uncertainty representations

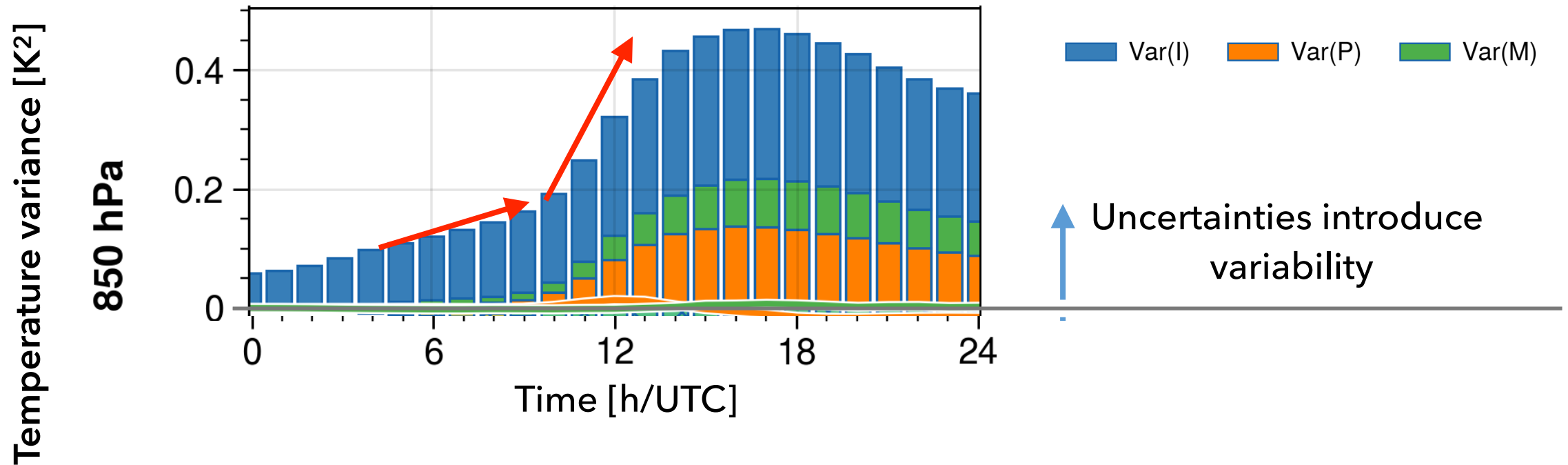
Variance budget: variance decomposition

$$\text{Var}(x'_{ipm}) = \underbrace{\text{Var}(x'_i) + \text{Var}(x'_p) + \text{Var}(x'_m)}_{\text{Variance due to a single source}} + \underbrace{2(\text{Cov}(x'_i, x'_p) + \text{Cov}(x'_i, x'_m) + \text{Cov}(x'_p, x'_m))}_{\text{Interaction between sources}}$$

When the interaction terms are zero, the total variance becomes equal to the sum of Vars.

-> Impacts are orthogonal and there is no redundancy.

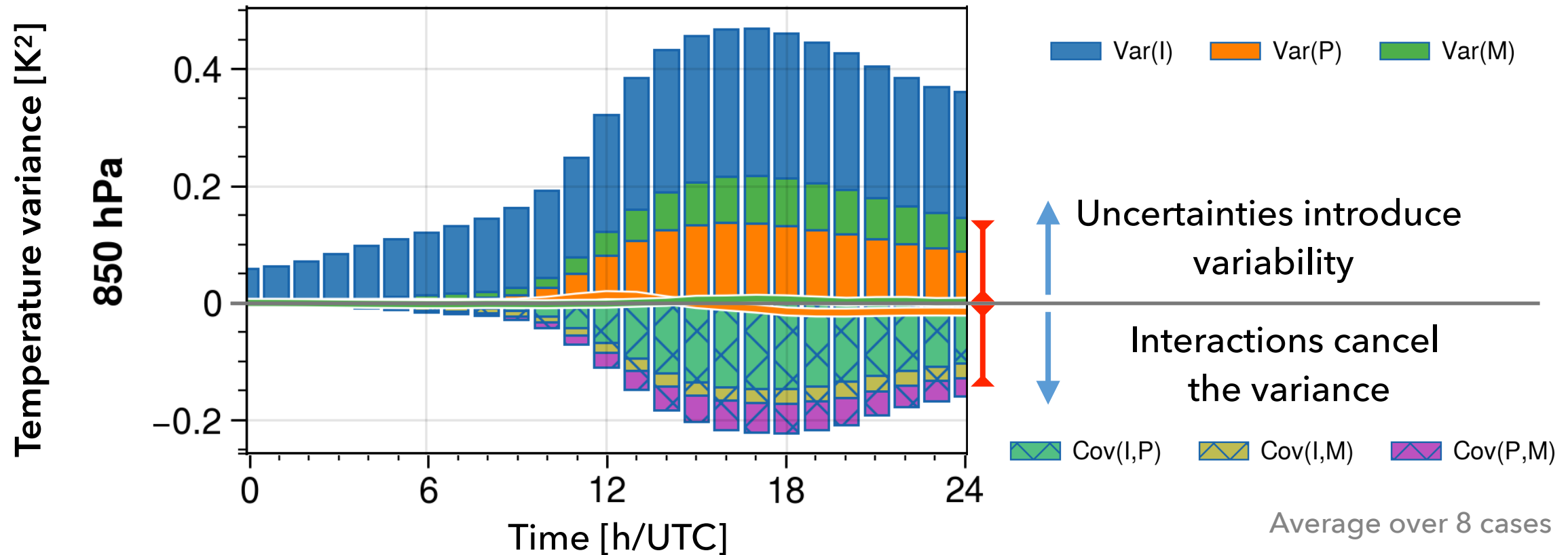
Evolution of variances and interactions



Average over 8 cases

- Model uncertainties grow quickly after convection initiation.

Evolution of variances and interactions



- Model uncertainties grow quickly after convection initiation.
- but mostly cancelled out by the interaction terms.

Overlapped variance distributions

IBC

PSP

MPP

Hourly precip.

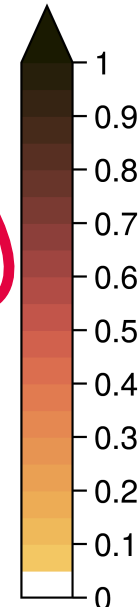
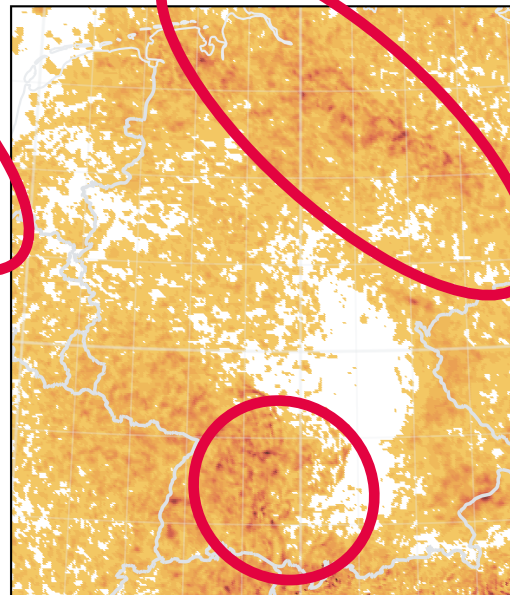
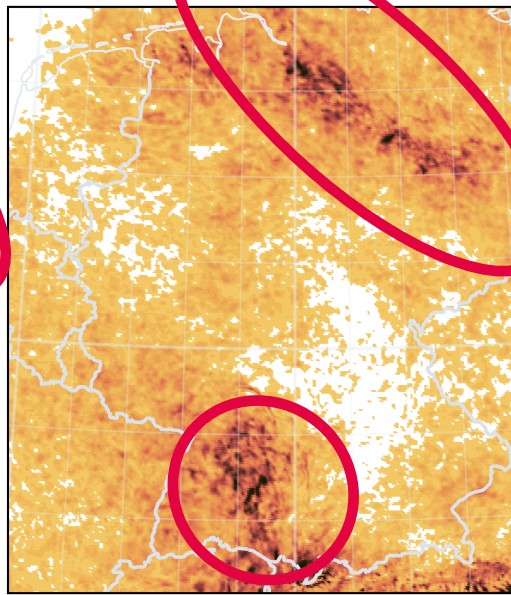
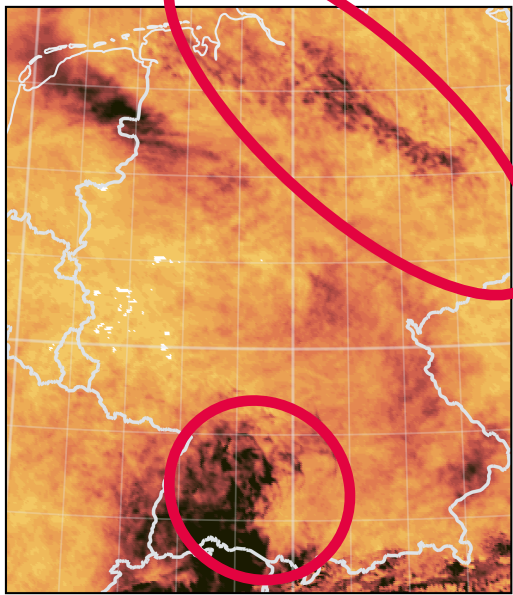
Variance TEMP (850 hPa) at 15 August 2022 00 UTC (+16h)

(a) Var(I)

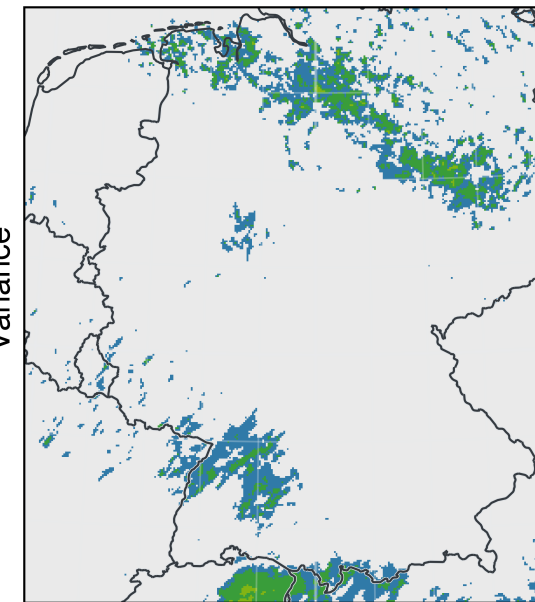
(b) Var(P)

(c) Var(M)

(d) Precipitation



Variance

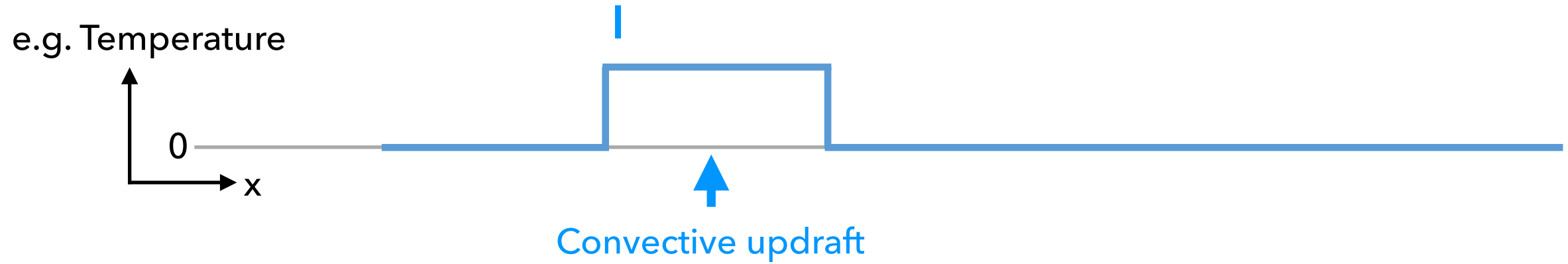


Precipitation

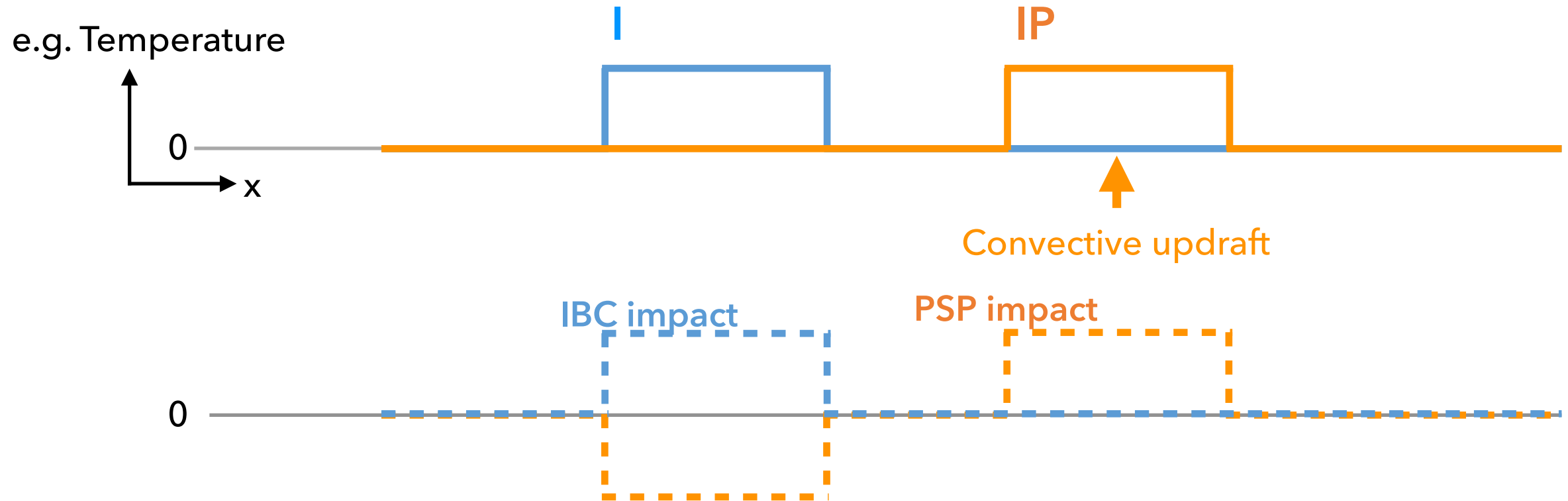
Snapshot

- MU variance are concentrated in convective regions, part of IBC variance.

Impact under high dimensionality



Impact under high dimensionality

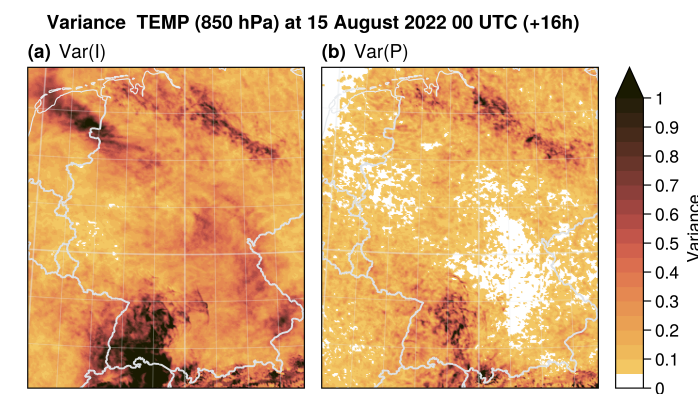
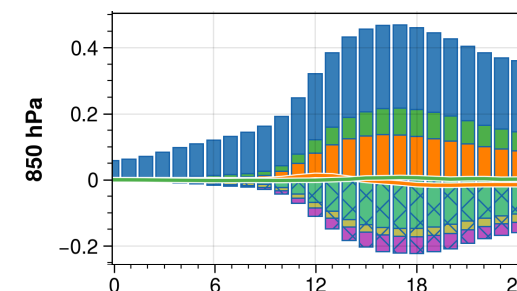


- Anti-phase relationship between impacts due to displacements
- Tiny added information in terms of energy

Summary

Q: When, where, and how do perturbations from different sources interact?

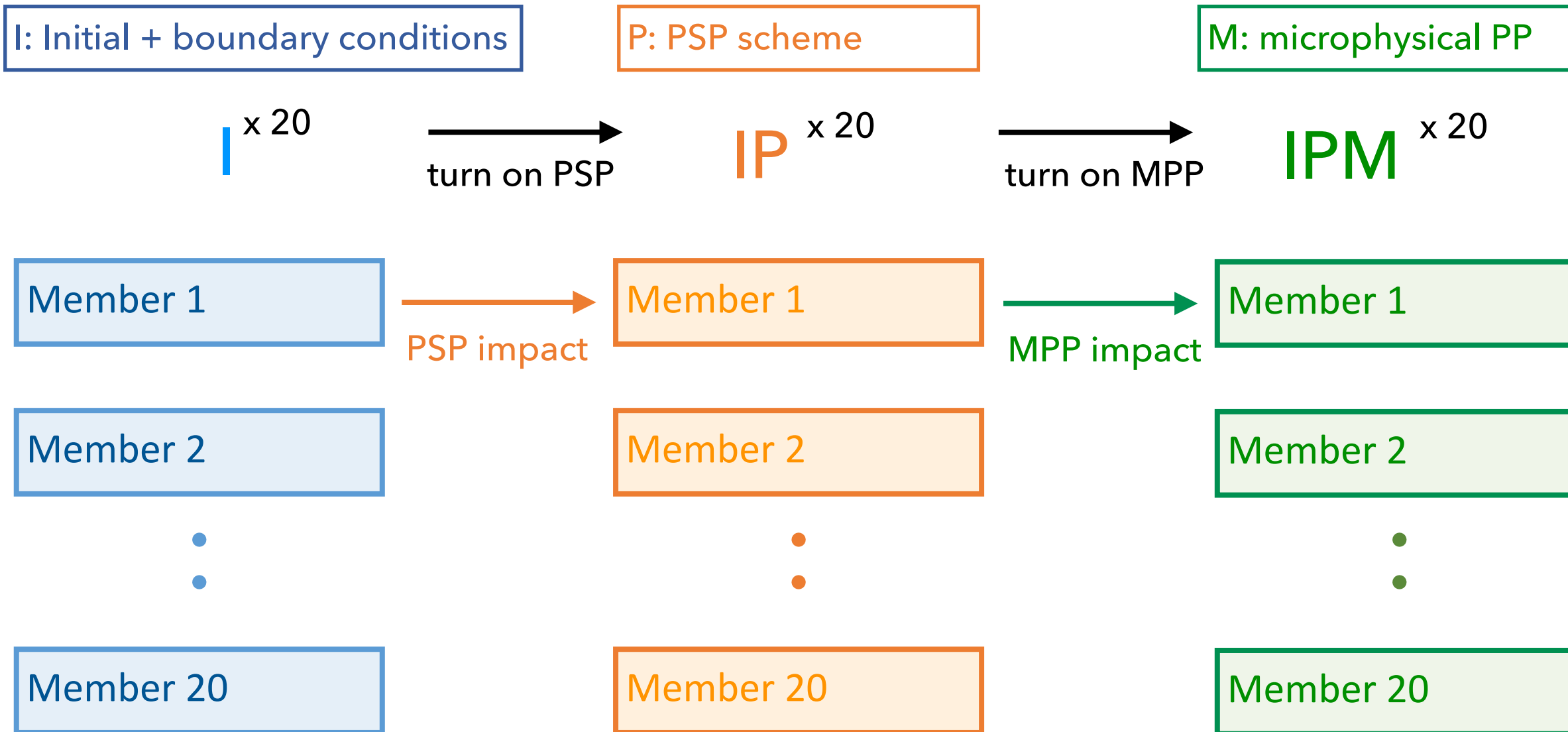
- MU schemes introduce variance, but mostly cancelled out by the interactions. Quick MU variance growth where convection is active. The region is part of the IBC variance.
- MU variances arise largely from displacements. Overlap effect of perturbation methods on average



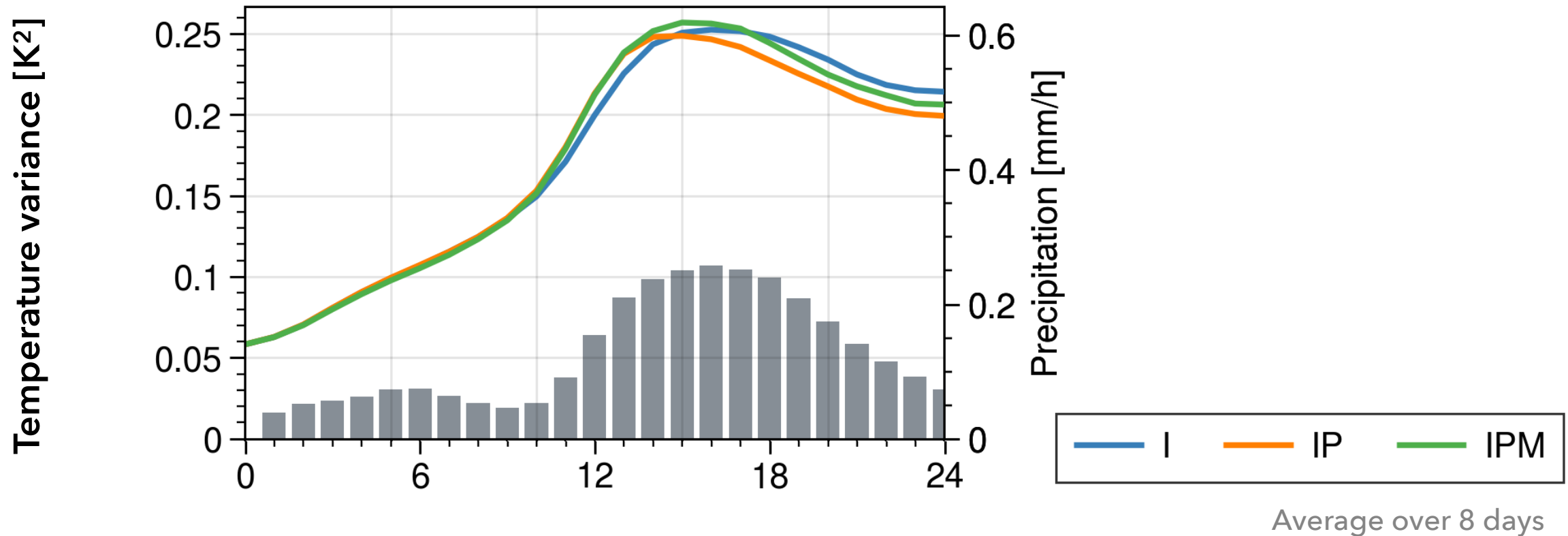
Next step: model uncertainty impact over ETKF cycles

- Similar overlap?
- Scale-dependent interactions?
- Which is more important:
changes in first guess distributions or subsequent error
covariances?
- Are they correlated?
- How sensitive to the diurnal cycle?

Variance budget: impact sampling



Evolution of variances and interactions



- Variance growth driven by convective activity
- Slight increase by PSP at 12 UTC, followed by increase by MPP

Variance budget: variance decomposition

$$\begin{aligned} \text{Var}(x'_{ipm}) = & \text{Var}(x'_i) + \text{Var}(x'_p) + \text{Var}(x'_m) \\ & + 2(\text{Cov}(x'_i, x'_p) + \text{Cov}(x'_i, x'_m) + \text{Cov}(x'_p, x'_m)) \end{aligned}$$

$$\text{Cov}(x'_i, x'_p) = \sqrt{\text{Var}(x'_i)} \sqrt{\text{Var}(x'_p)} \text{Corr}(x'_i, x'_p)$$

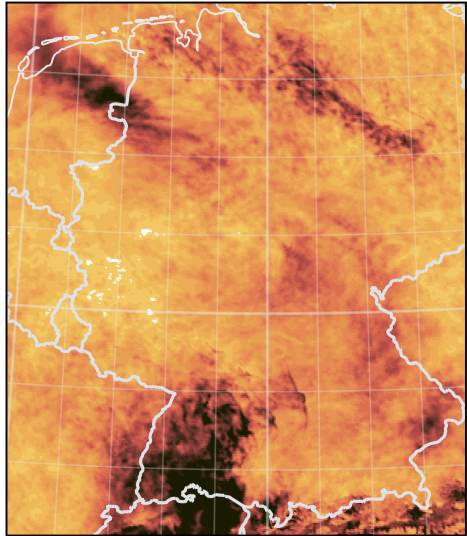
Pearson correlation coefficient

- We can quantify:
 - variability from individual sources
 - their interactions in a form of correlation

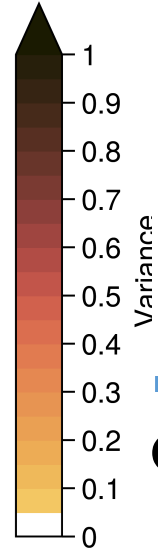
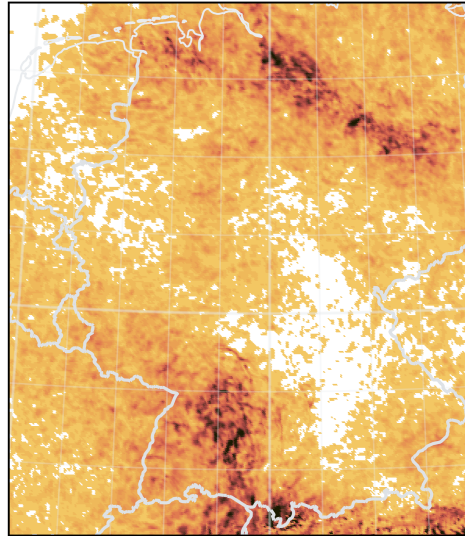
Convection correlates impact (IBC x PSP)

Variance TEMP (850 hPa) at 15 August 2022 00 UTC (+16h)

(a) Var(I)



(b) Var(P)

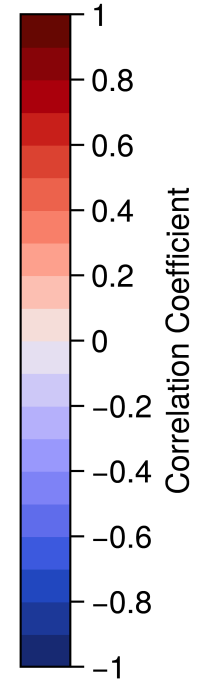
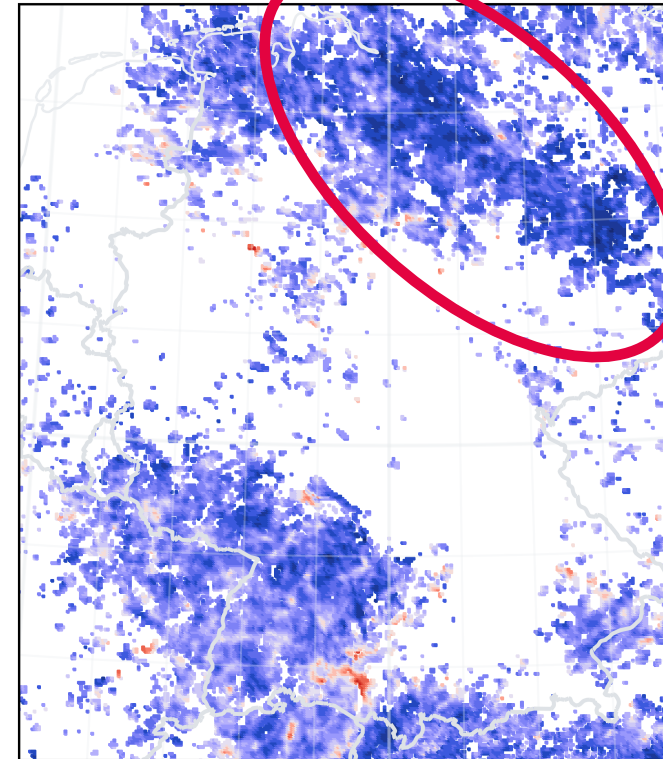


Correlation

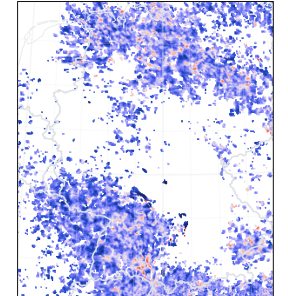
Corr(IBC, PSP)

(a) Corr(I,P)

-0.449



(c) Corr(P,M) -0.403



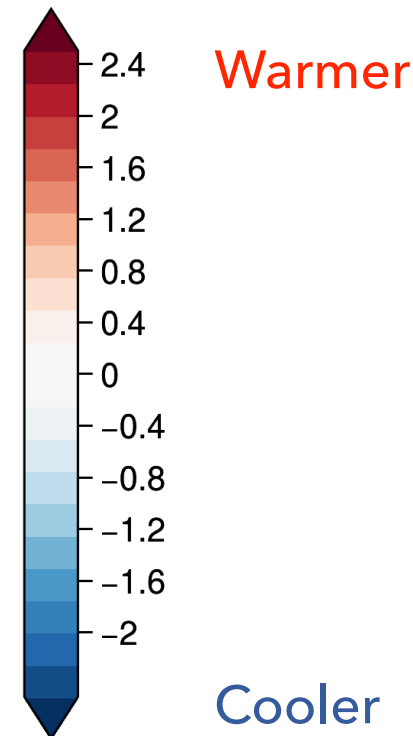
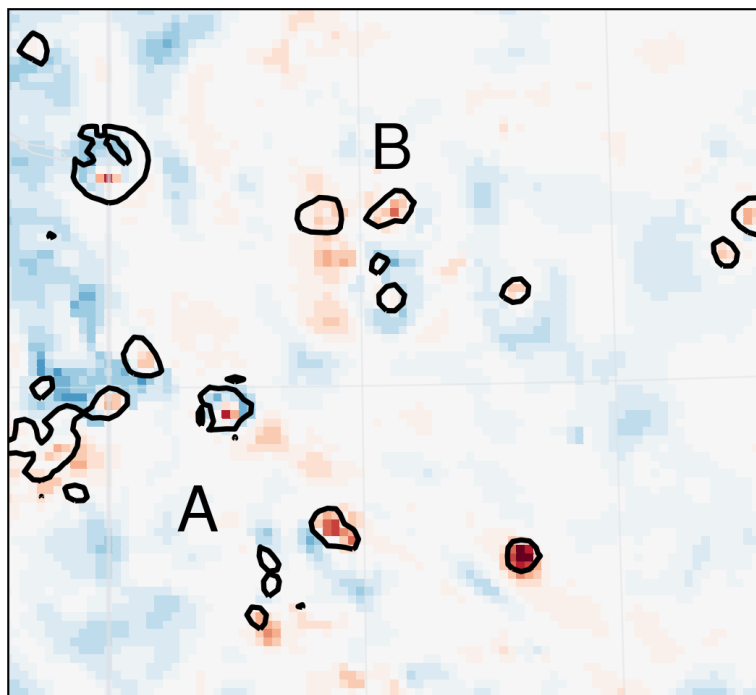
- Negatively correlated.
- Strong correlation with local convection.

Warm temperature associated with convective heating

Temperature deviation from mean (1 member)

(a) IBC impact

Updraft
in I



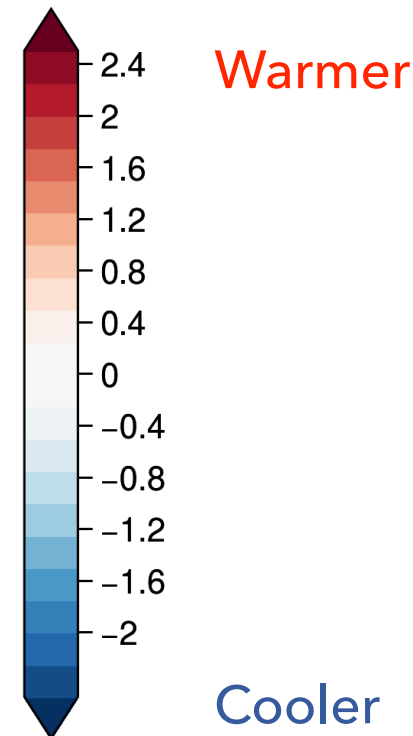
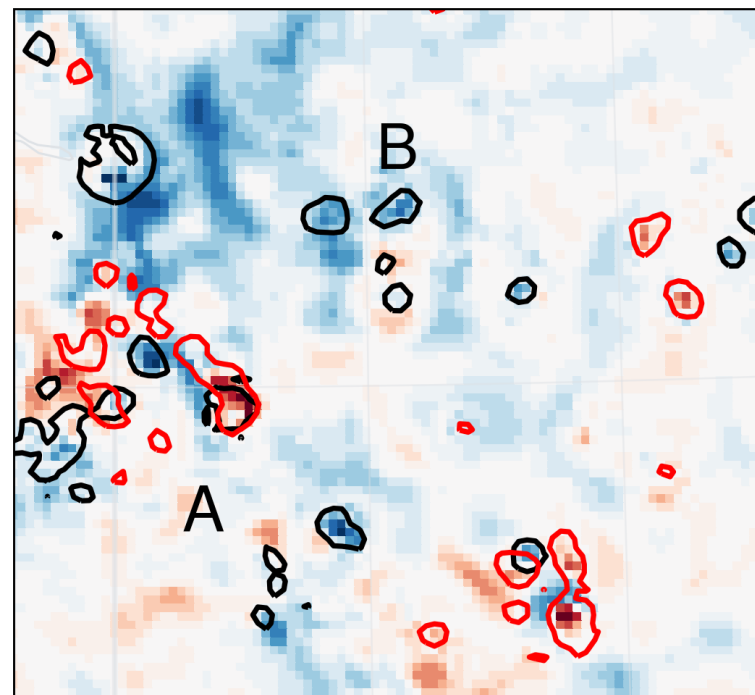
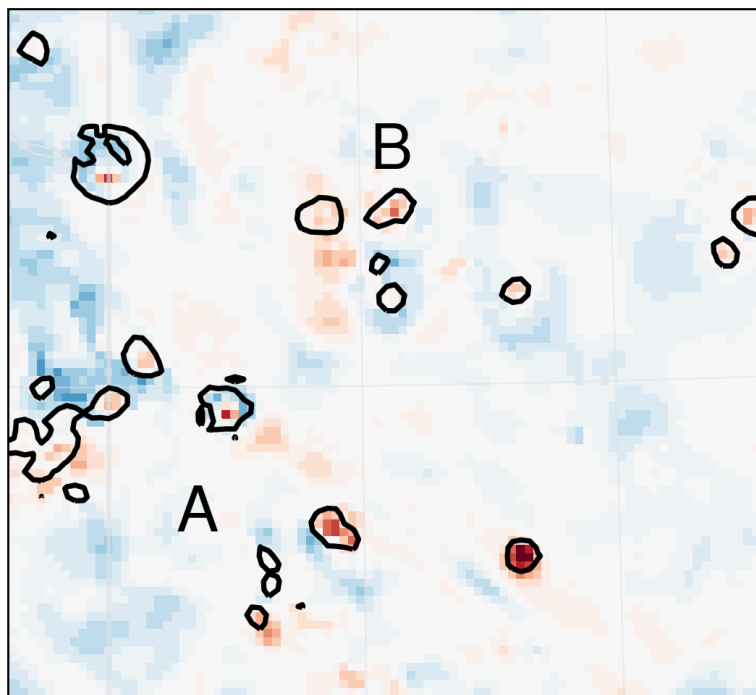
- Convective updraft leads to strong warm temperature deviations.

Displacement of convective cells drives negative corr.

Temperature deviation from mean (1 member)

(a) IBC impact

(b) PSP impact



- Displacements of convection in IP result in negative PSP impact.
- New convection in IP produces positive PSP impact.