Multi-scale Localization in Ensemble-based Data Assimilation

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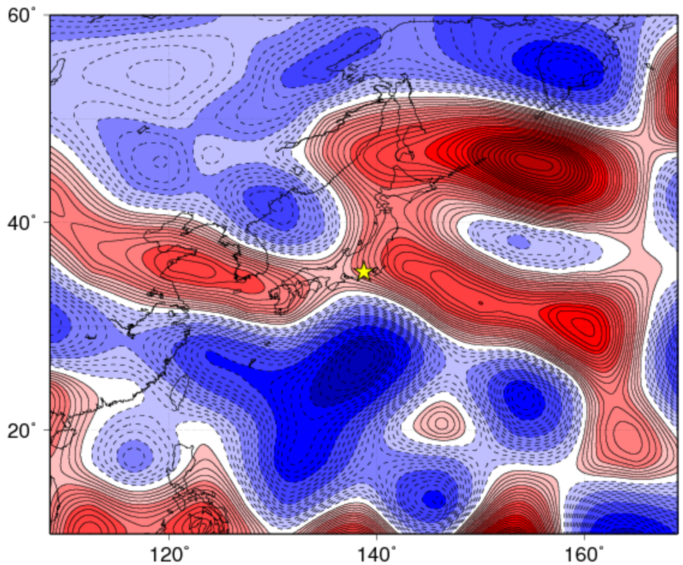
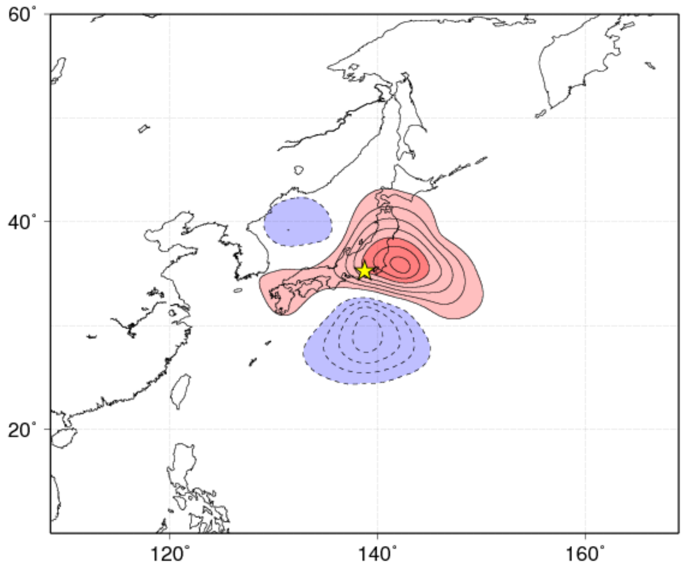
Motivation

- Due to the limited ensemble size, sampling error may be problematic.
- Localization plays an essential role.
  - Distance-dependent localization is applied to error covariance and reduces the sampling errors.

No localization



Localized



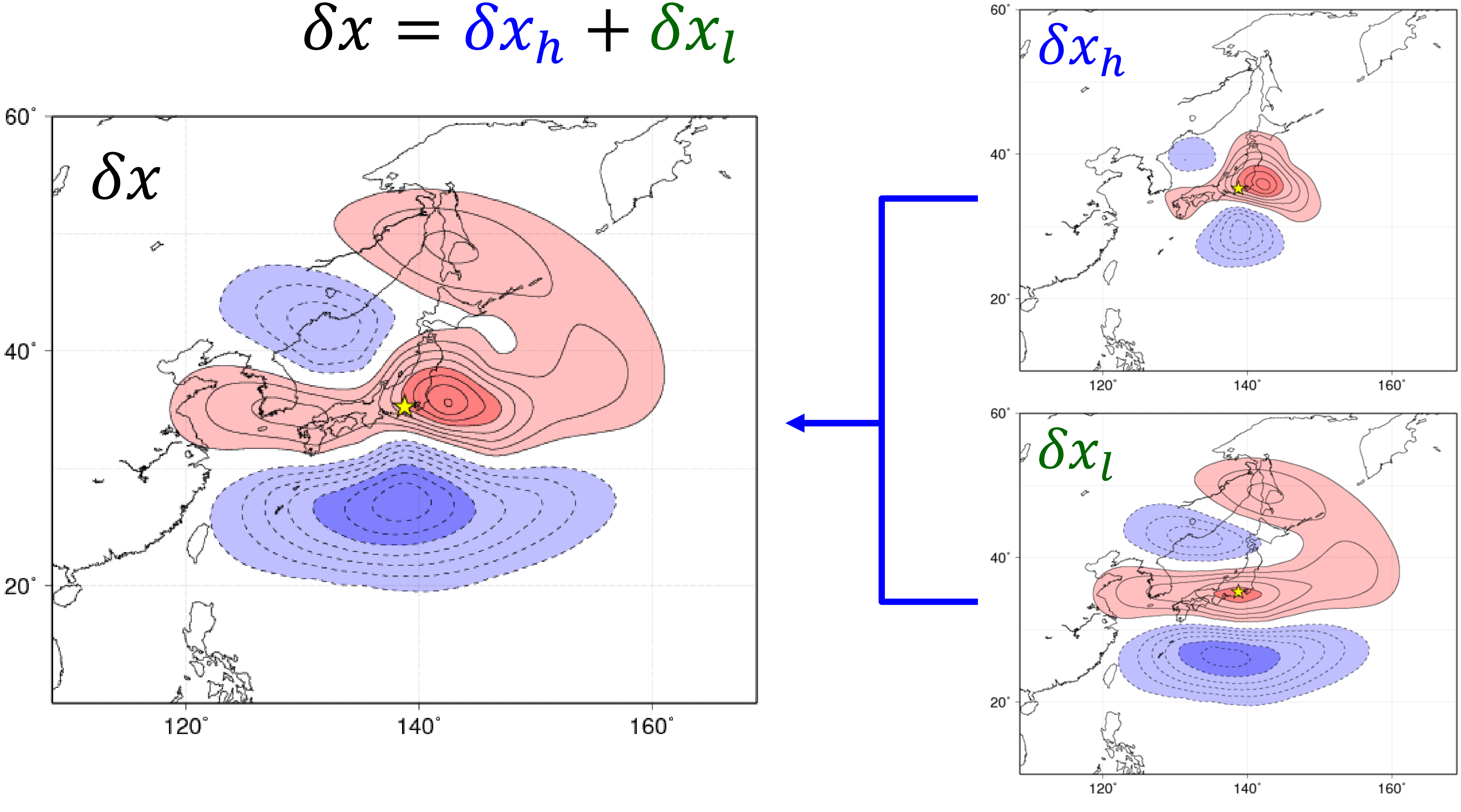
Analysis increments from a single profile observation (20 members)

- Higher resolution models require narrower localization which limits the influence of observations.

Approach

○ Motivated by Buehner (2012), we construct analysis increments as a sum of high- (h) and low- (l) wavenumber components.

$$\delta x = \delta x_h + \delta x_l$$

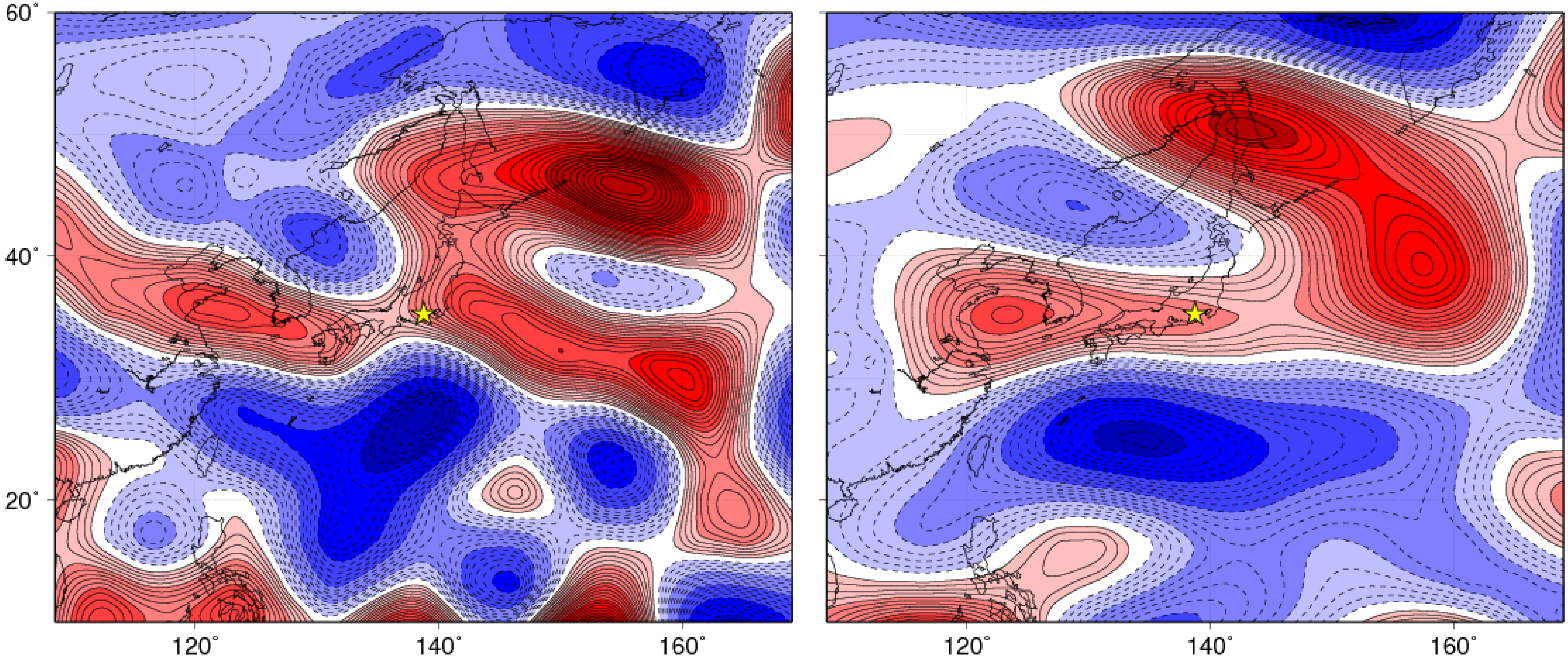


Longer-range covariance

- We apply spatial smoothing to the ensemble perturbations to reduce noise in longer-range covariance.

Full-range (T30) analysis increment

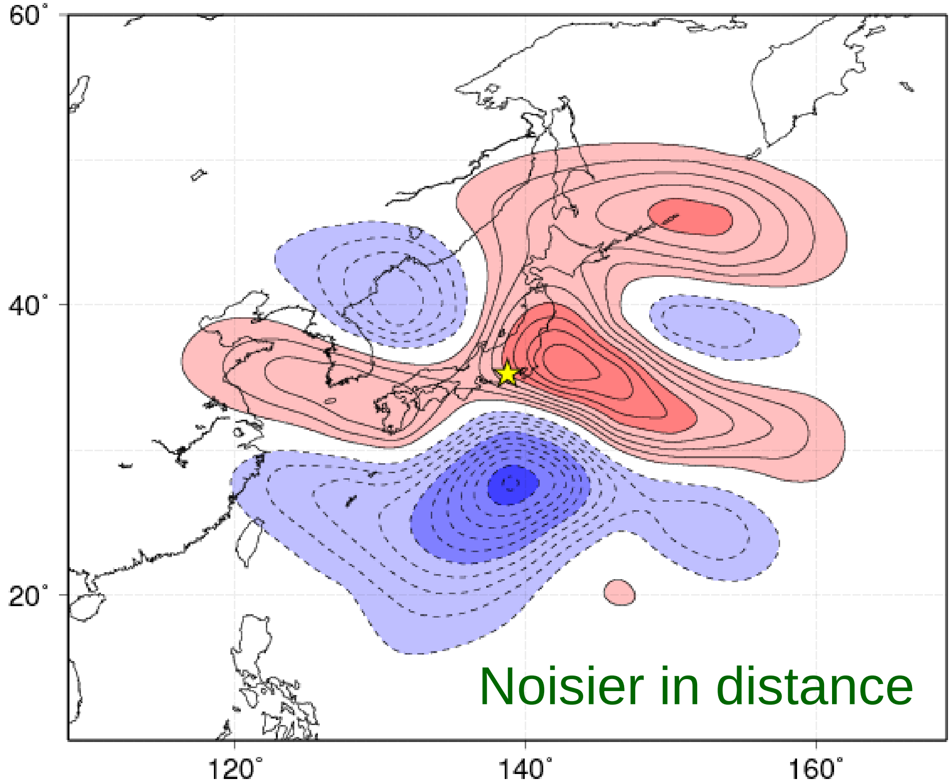
Analysis increment from reduced-resolution (T21) ensemble perturbations



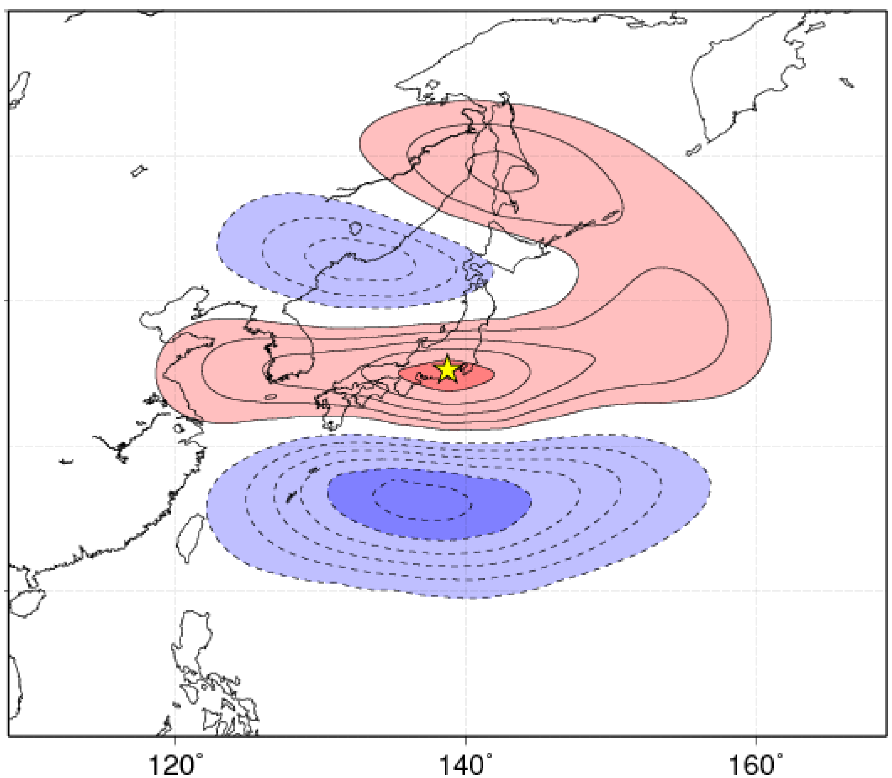
Larger-scale localization

- ○ Applying a 1000-km (larger scale) localization.

Full-range (T30) analysis increment



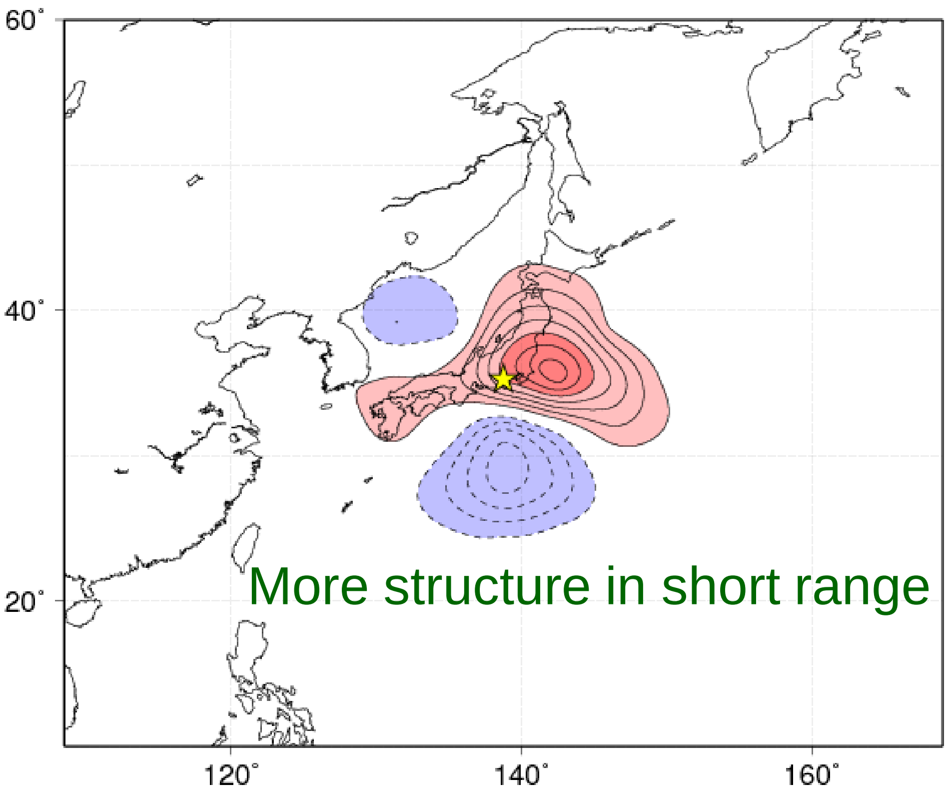
Analysis increment from reduced-resolution (T21) ensemble perturbations



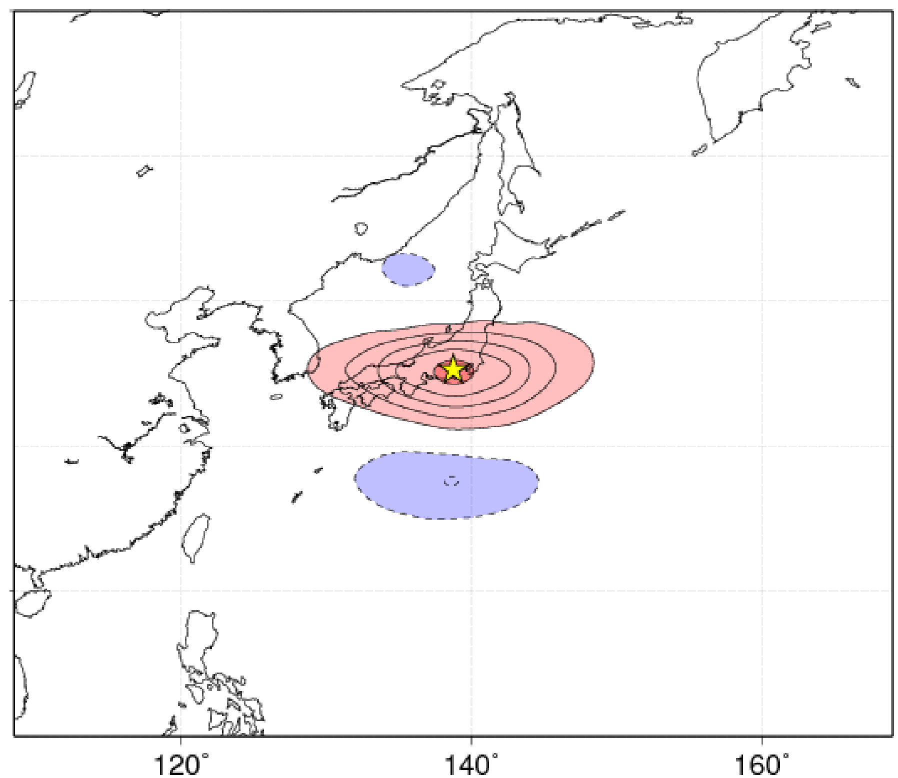
Smaller-scale structure

○ Applying a 500-km (smaller scale) localization.

Full-range (T30) analysis increment

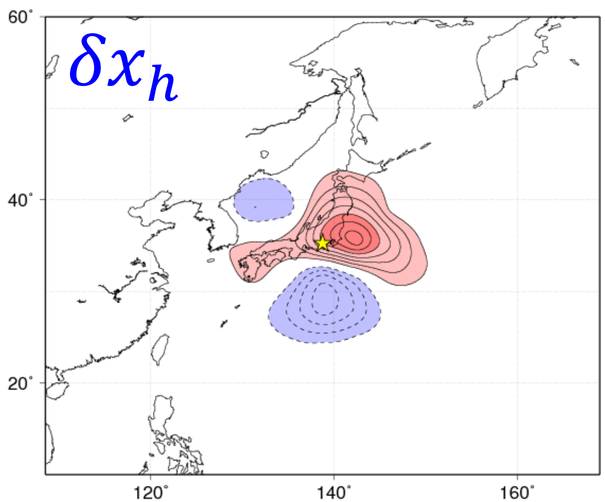


Analysis increment from reduced-resolution (T21) ensemble perturbations



Merging the two scales

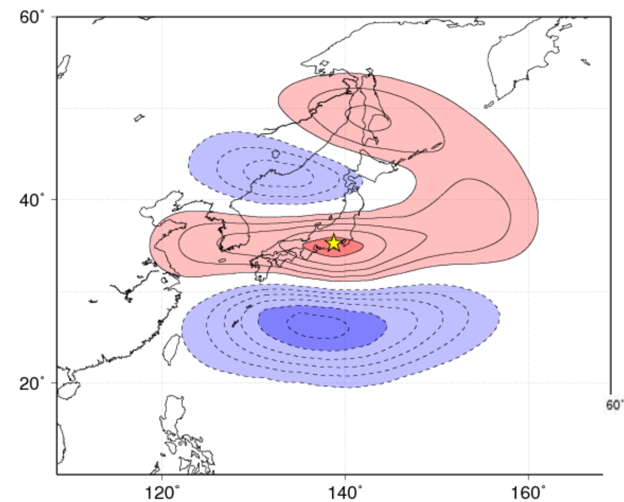
Original covariance with 500-km (smaller scale) localization

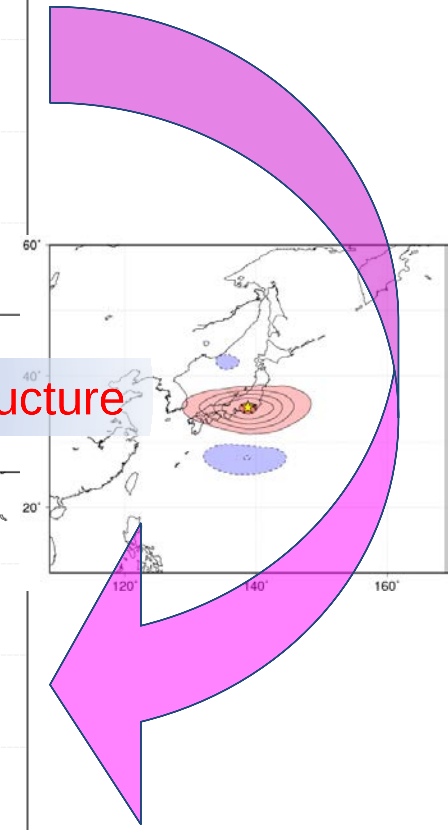


Preserve the smaller-scale structure in short range

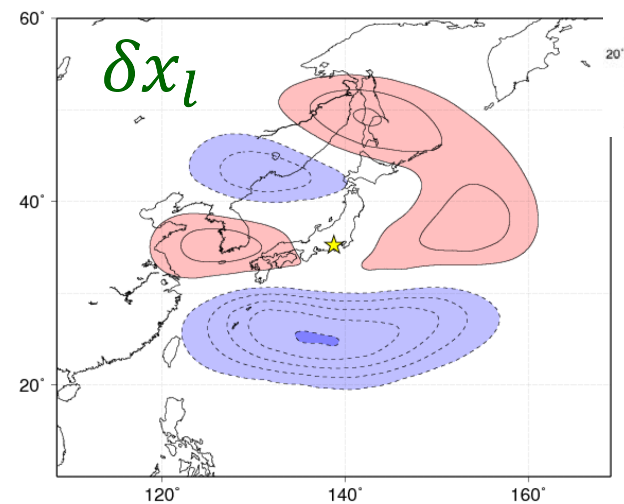
$$\delta x = \delta x_h + \delta x_l$$

Large-scale covariance with 1000-km (larger scale) localization





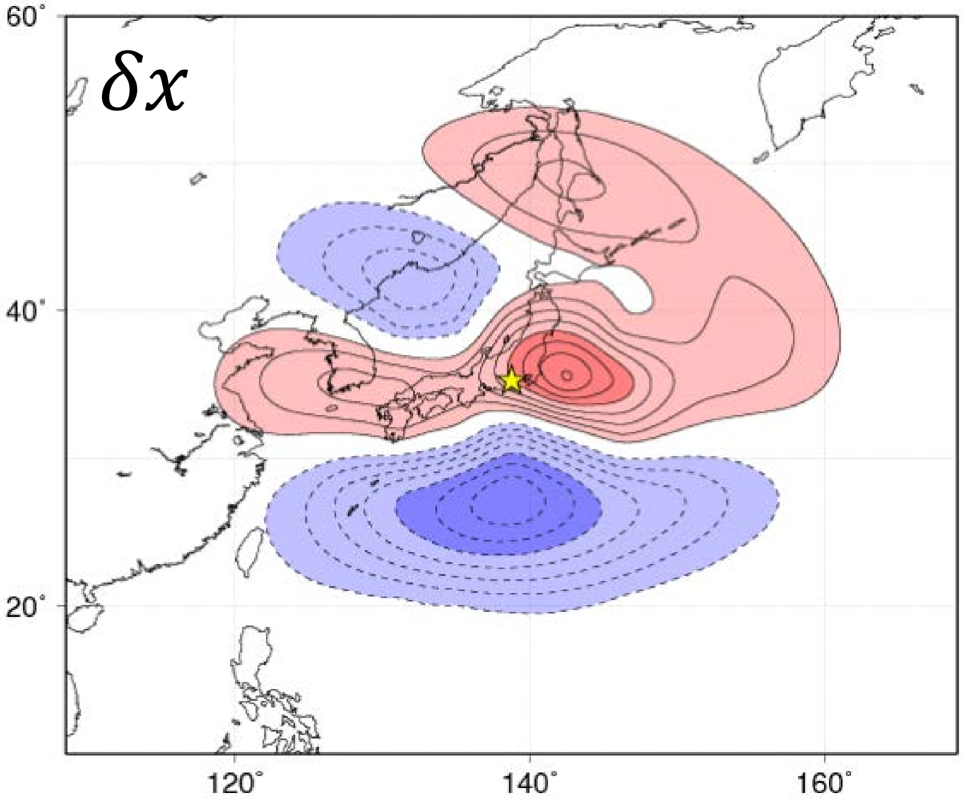
Removing the short-range structure

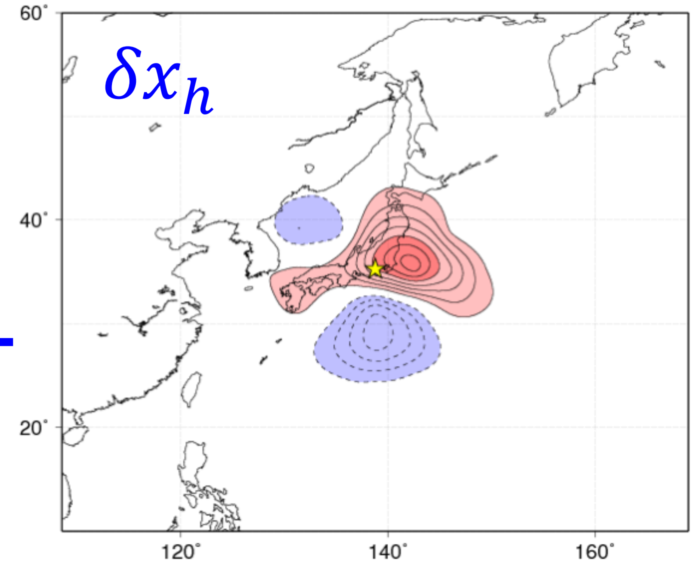


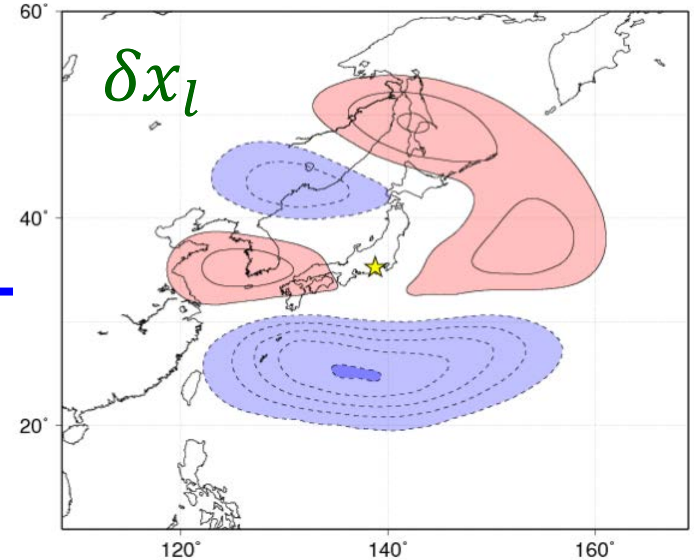
Merging the shorter and longer ranges

○ We merge the high (h) and low (l) wavenumber components.

$$\delta x = \delta x_h + \delta x_l$$

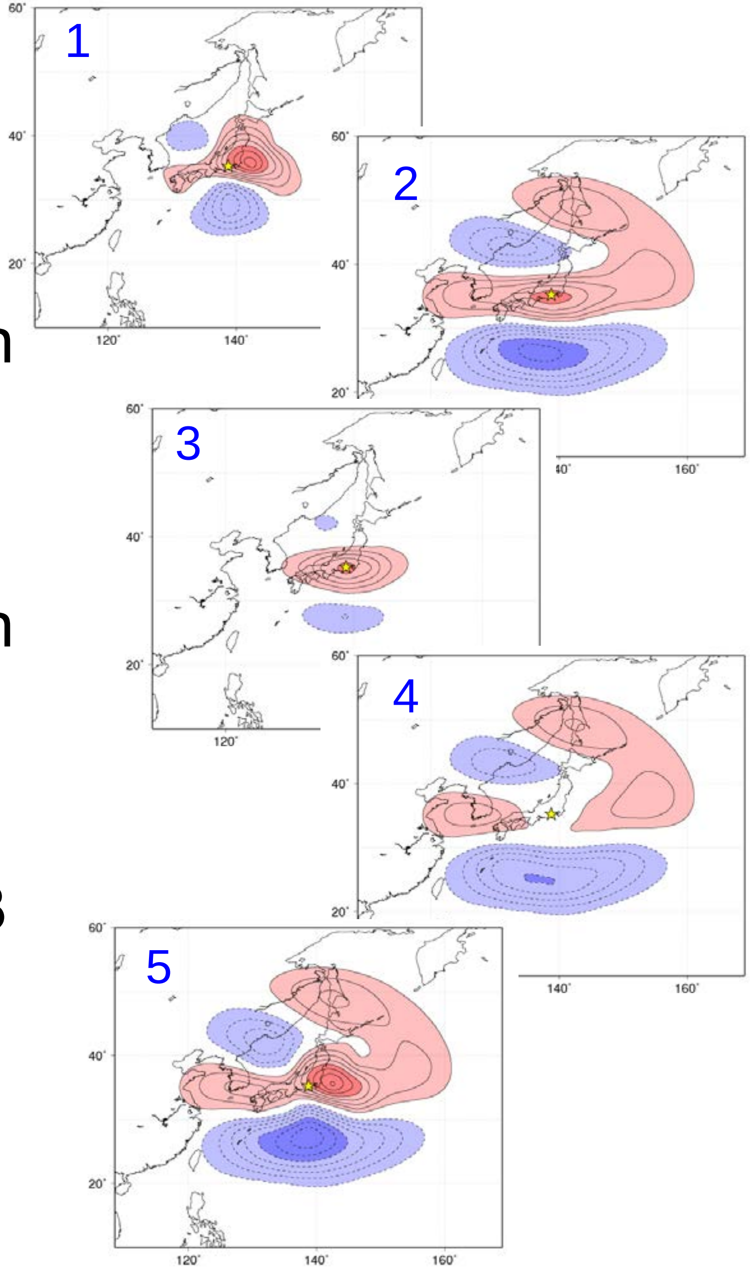






Summary of the algorithm

1. Compute the analysis increment regularly
   (with smaller-scale localization)
2. Compute the analysis increment with smoothed ensemble perturbations
   (with larger-scale localization)
3. Compute the analysis increment with smoothed ensemble perturbations
   (with smaller-scale localization)
4. Take the difference between 2 and 3
5. Add 1 and 4



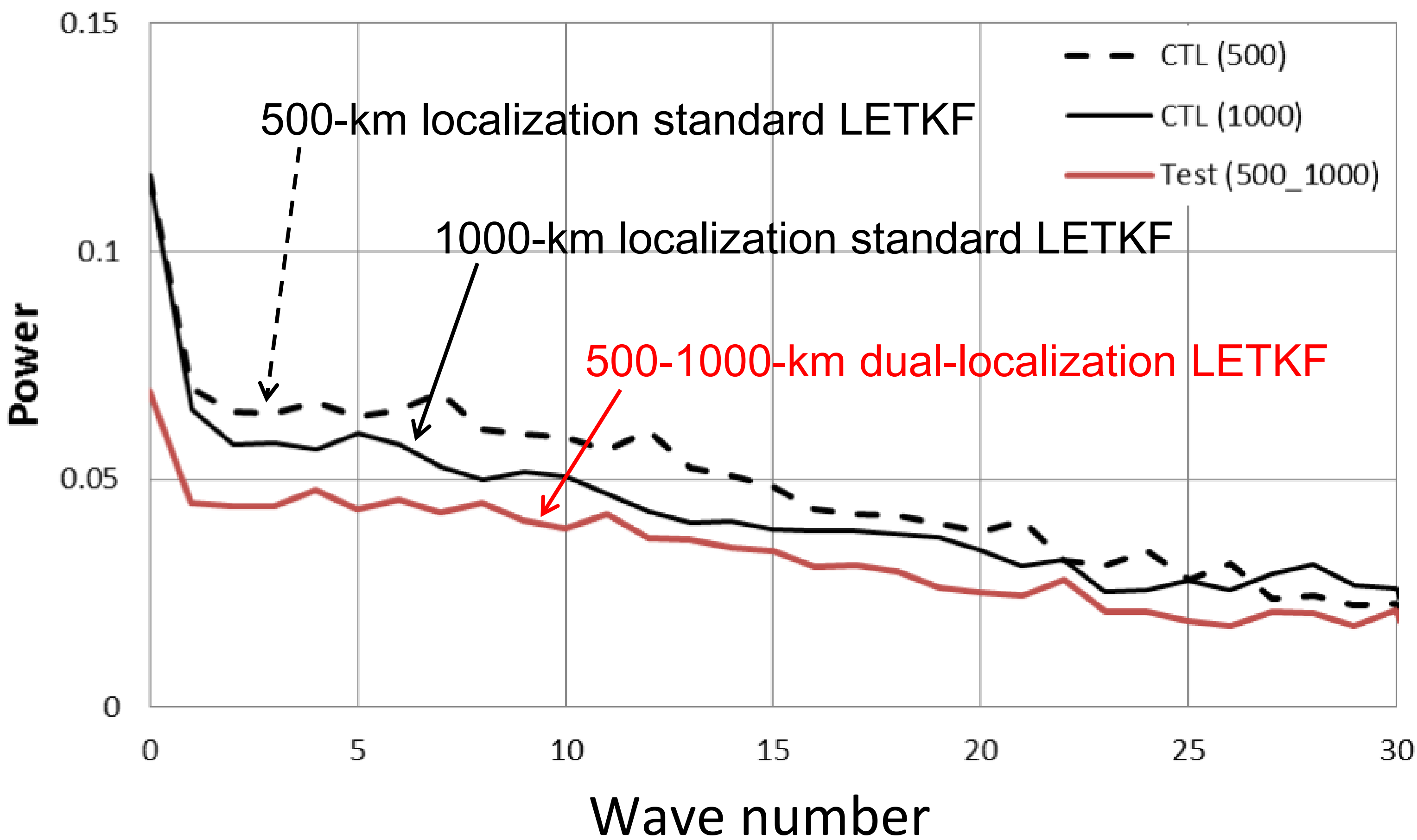
Settings of perfect model experiments

	CTL(L=500)	CTL(L=1000)	Test
Model	SPEEDY, T30L7 (Molteni 2003)		
Observation	Radiosonde-like		
Ensemble size	20		
Localization scale	**500 km** (small)	**1000 km** (large)	**500 km** **1000 km**

○ Test experiment: Dual Localization LETKF

RMSE (Q, Z=1) at each wavenumber

23-month average global analysis error power spectrum.



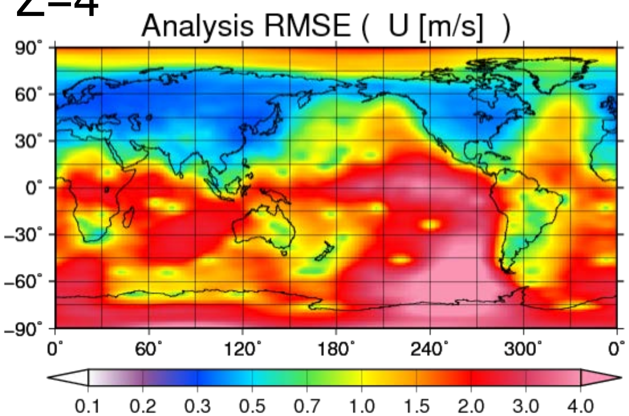
○ Successfully reducing the errors at all scales.

General improvements for mid-level U

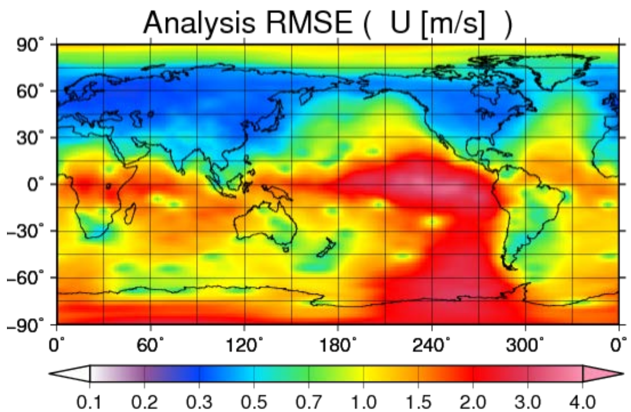
23-month average RMS errors

Z=4

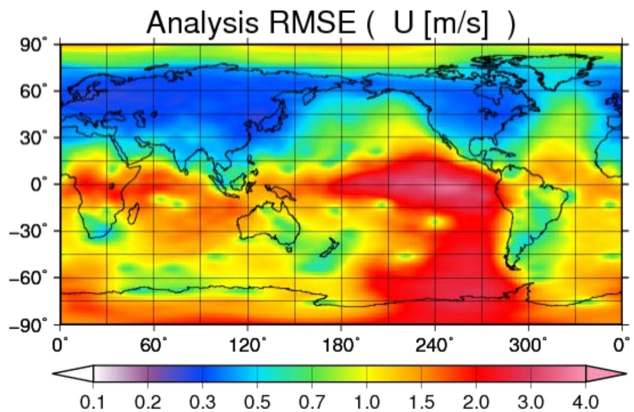
500-km regular



1000-km regular

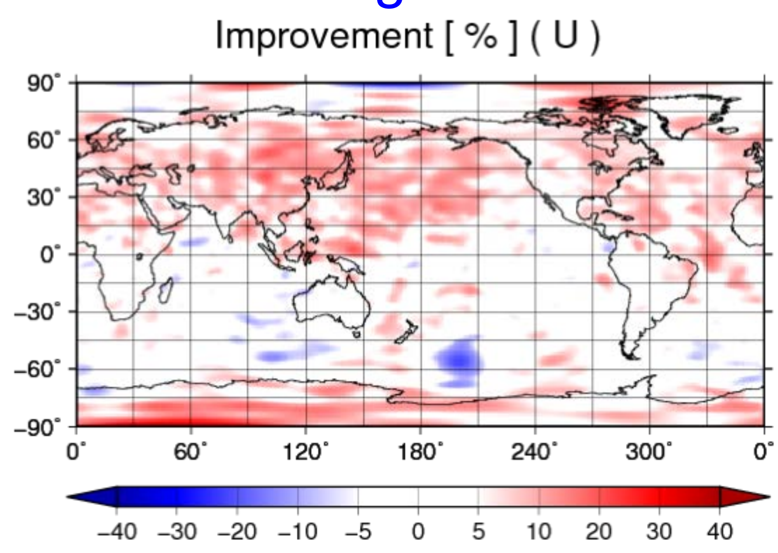


500-1000-km dual



- ○ Successfully improving analysis RMS errors in the Northern Hemisphere.

1000-km regular vs. dual

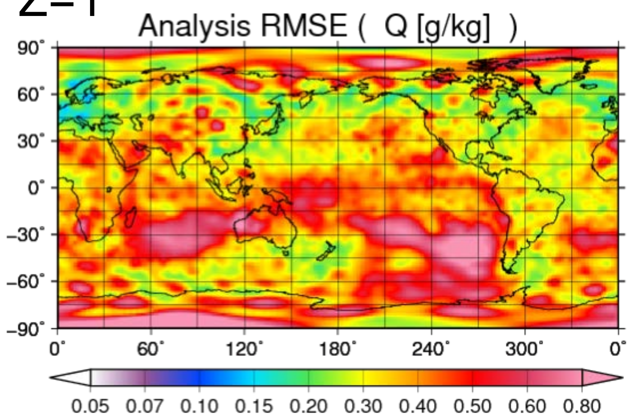


Impressive improvements for low-Q

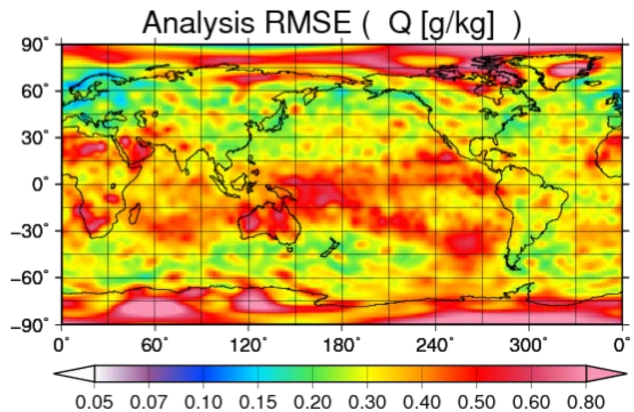
23-month average RMS errors

Z=1

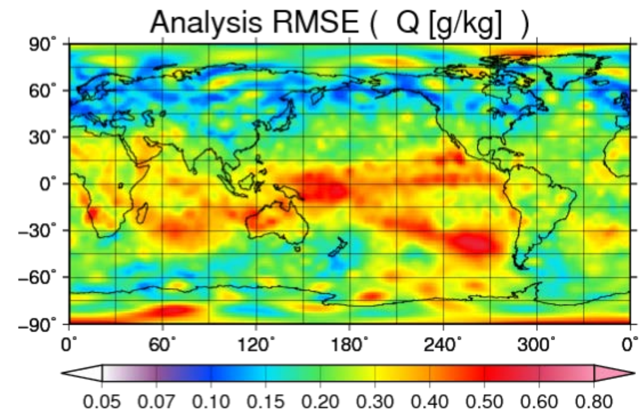
500-km regular



1000-km regular

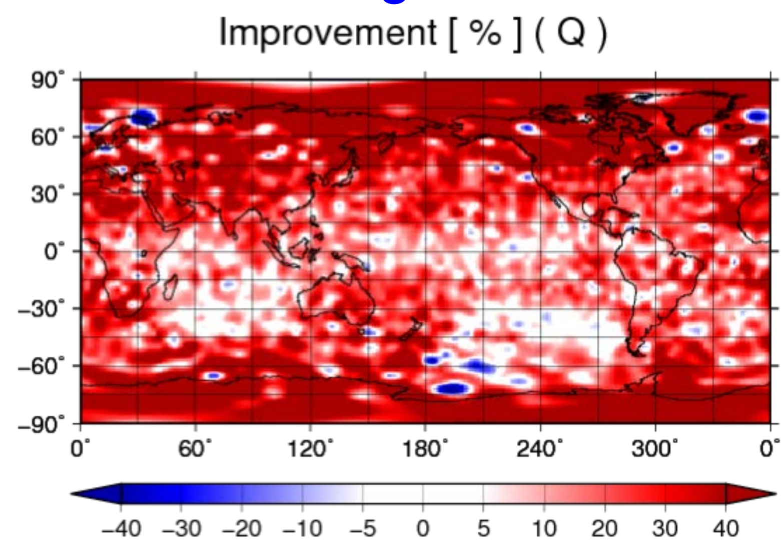


500-1000-km dual



- Greatly improving analysis RMS errors almost everywhere.

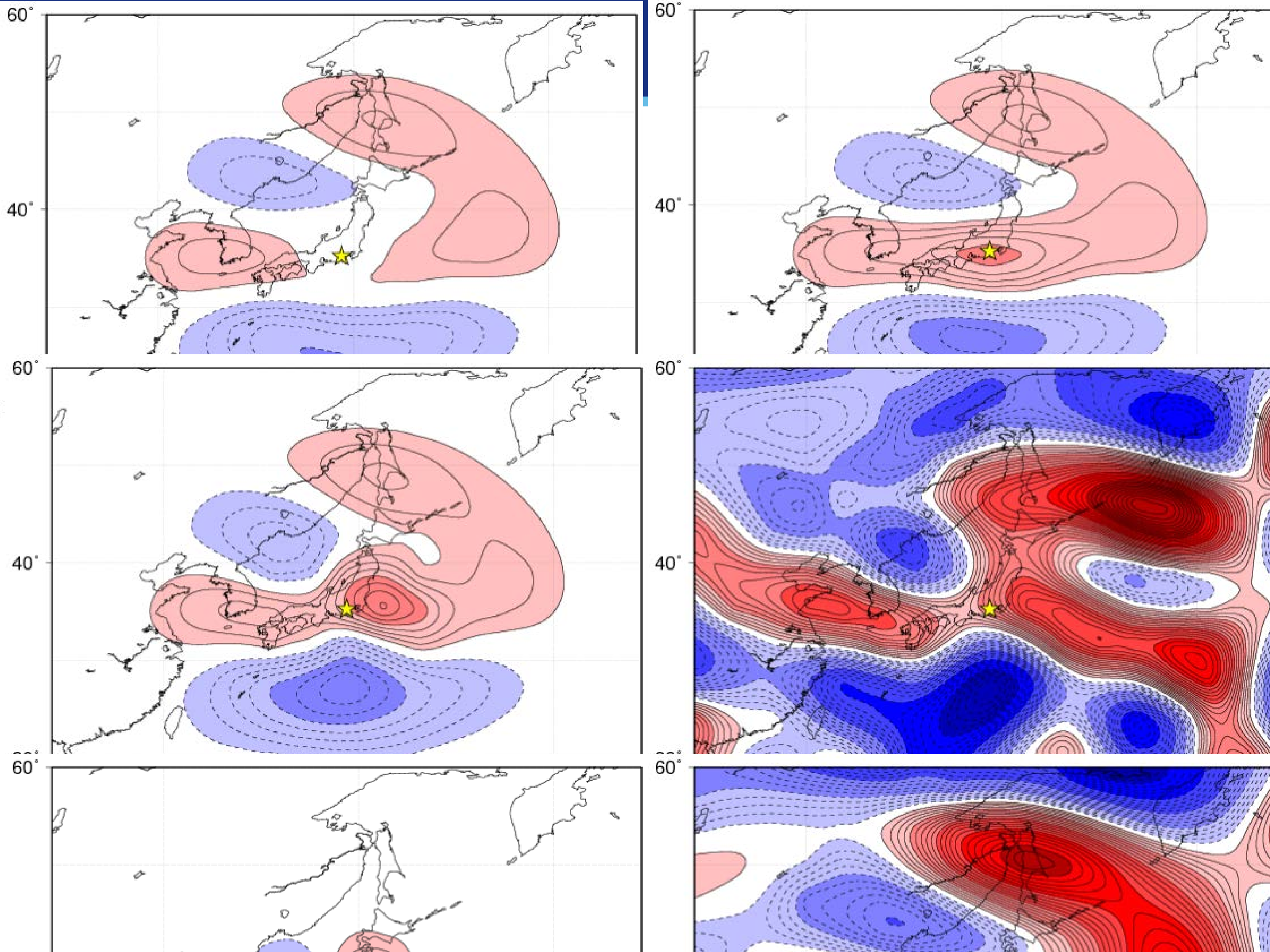
1000-km regular vs. dual



Summary

- Dual-localization LETKF analysis showed promising results.
  - Improvements at almost all scales
  - Improvements almost everywhere for all variables
  - Impressive improvements for humidity
- Drawback: LETKF computations are tripled.
- Future plans
  - Improving the algorithm for saving computations.
  - Applying to higher-resolution models
    - Multi-scale considerations are more important with higher resolutions.

Thank you for your attention !


60˚
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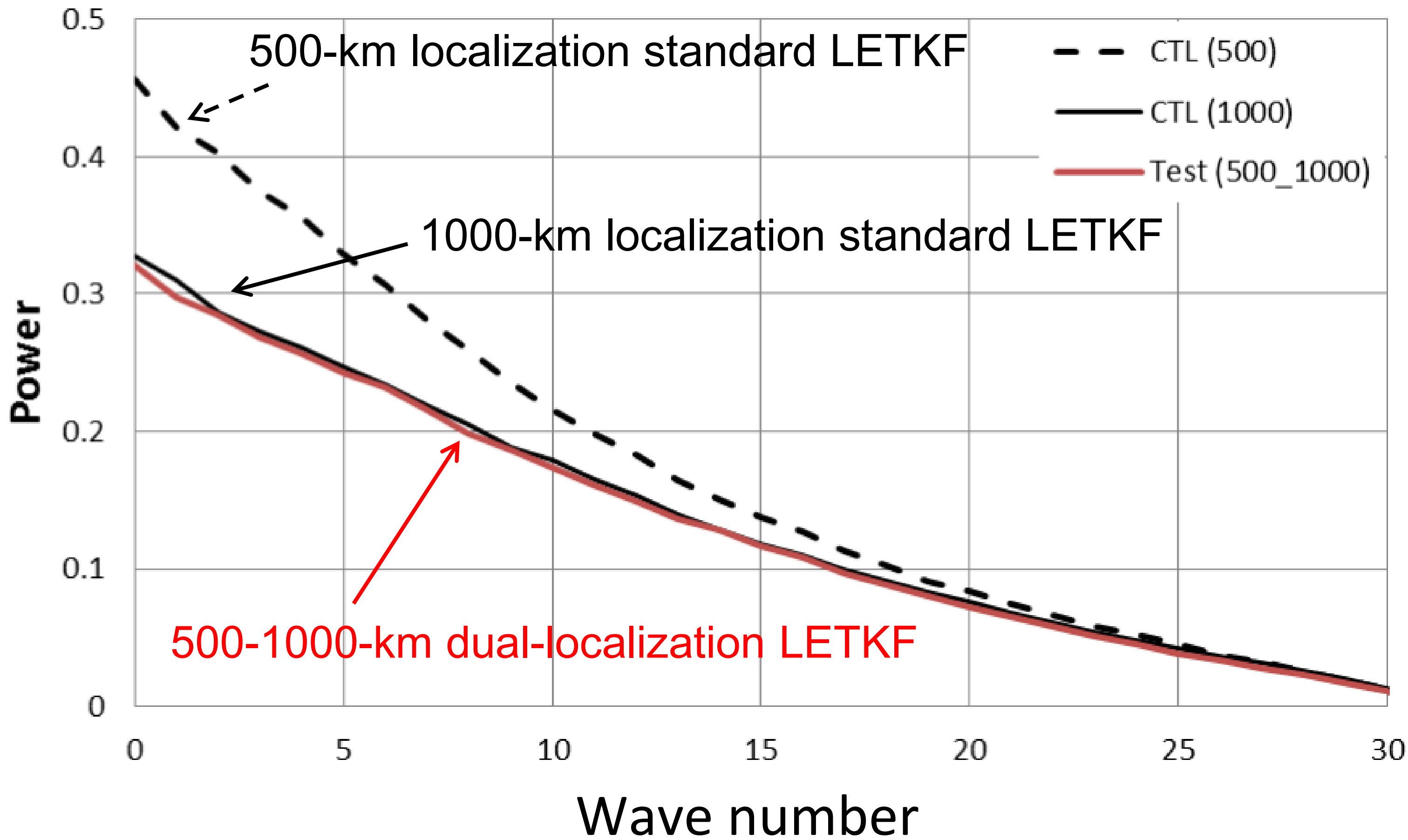
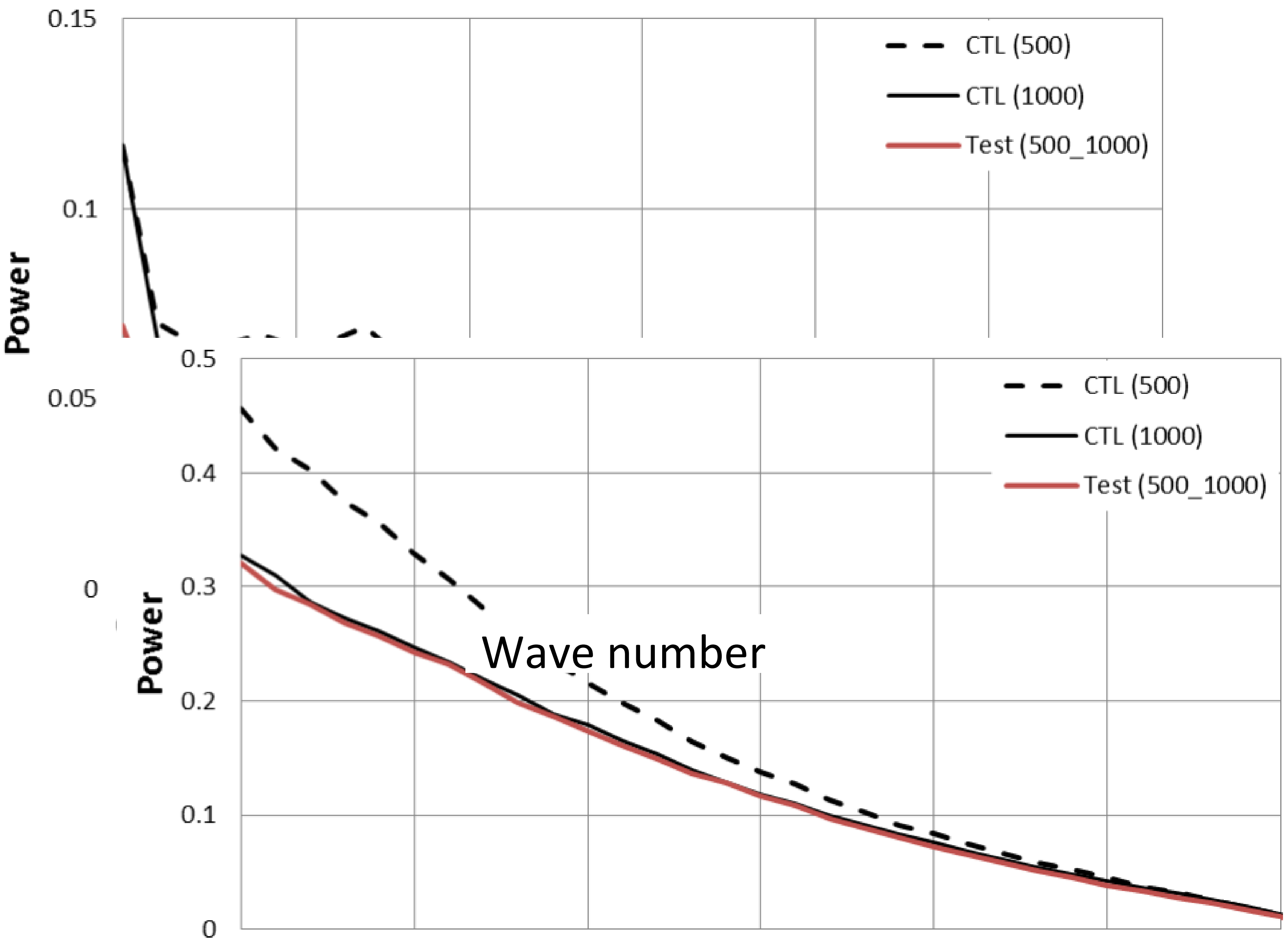
Power spectrum (U, Z=4)

23-month average global analysis error power spectrum.



○ Successfully reducing the errors slightly.

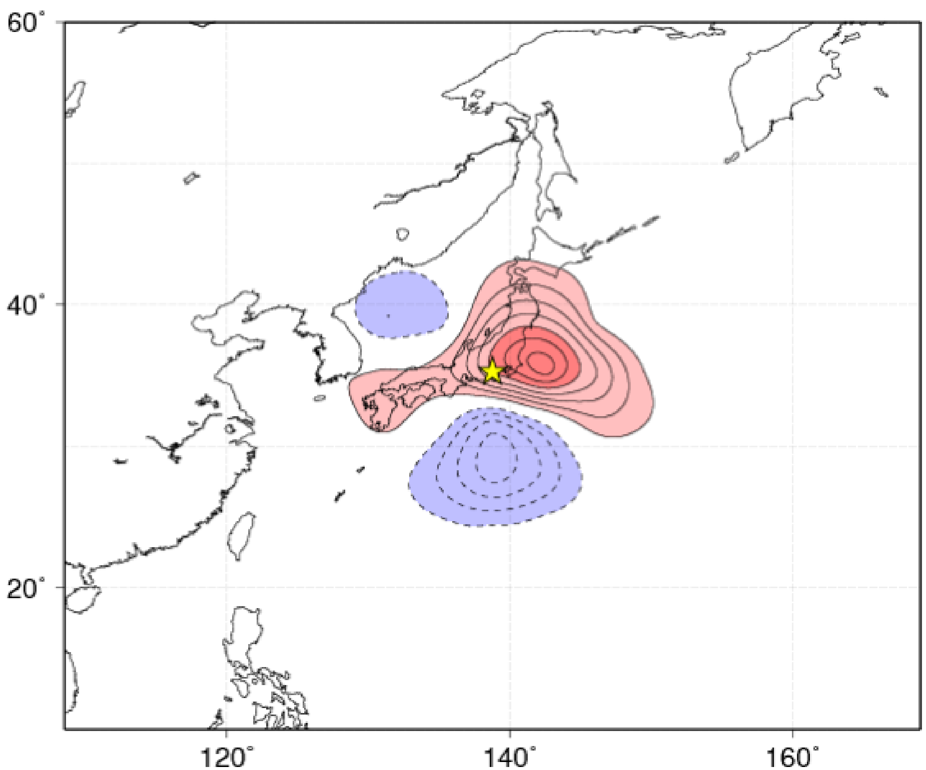
Power spectral



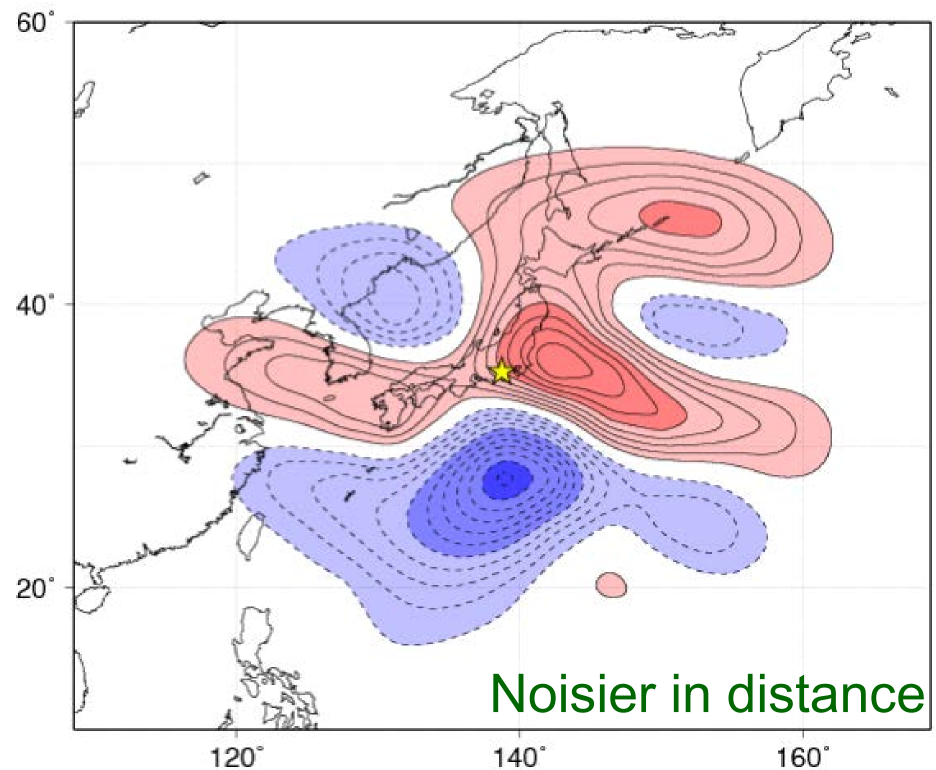
Small and large scale localization

- Regular analysis increments at the full resolution (T30) with two different localization scales:

Small scale localization



Large scale localization

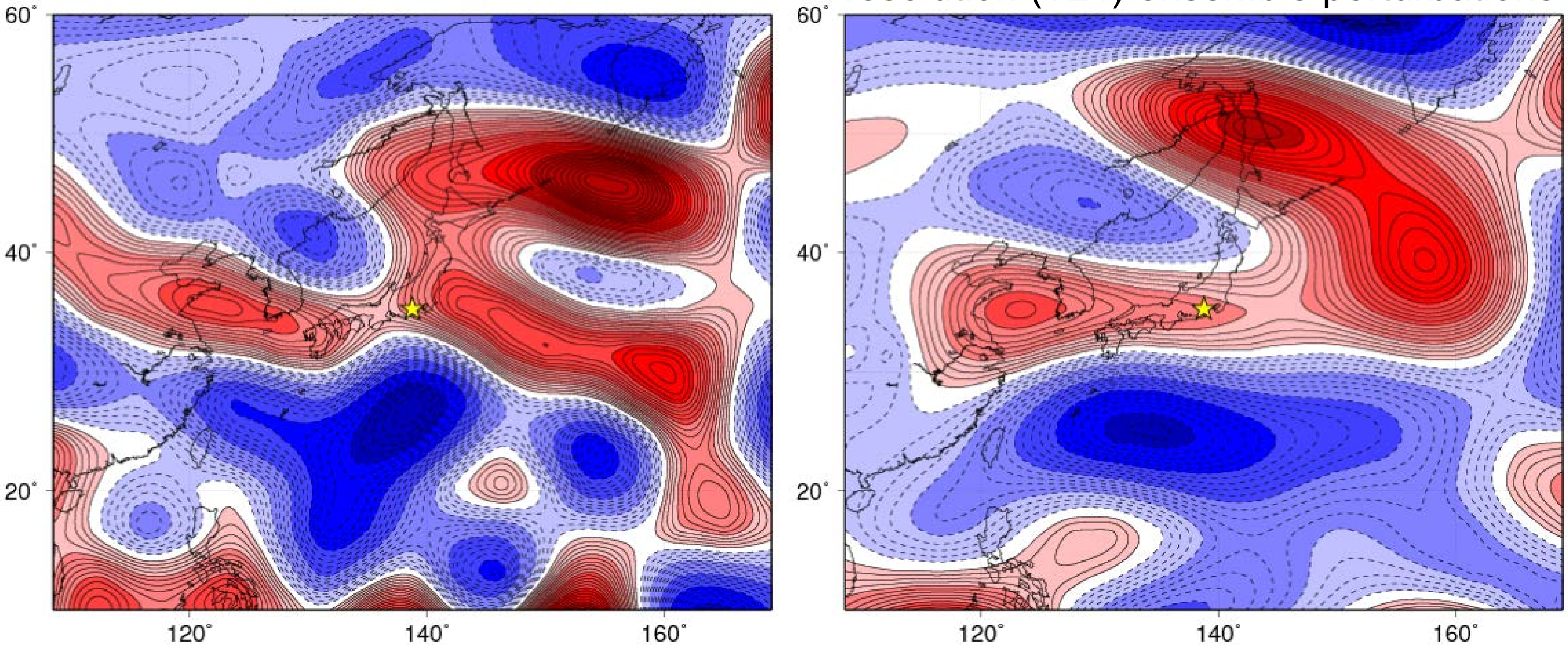


Reducing sampling noise in a longer range

- We apply spatial smoothing to the ensemble perturbations to reduce noise in longer-range covariance.

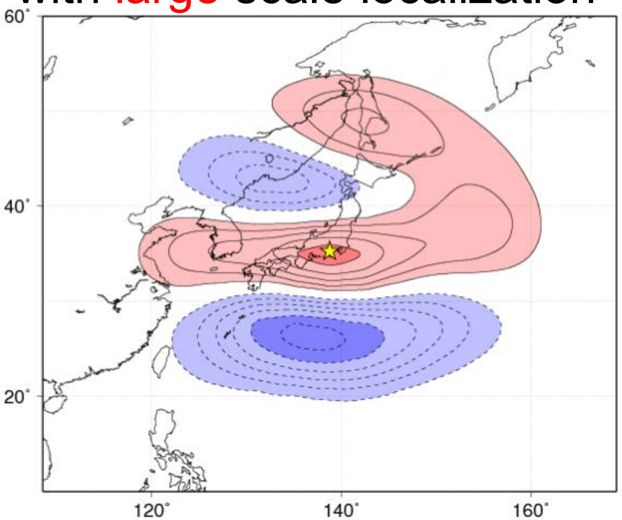
Full-range (T30) analysis increment

Analysis increment from reduced-resolution (T21) ensemble perturbations

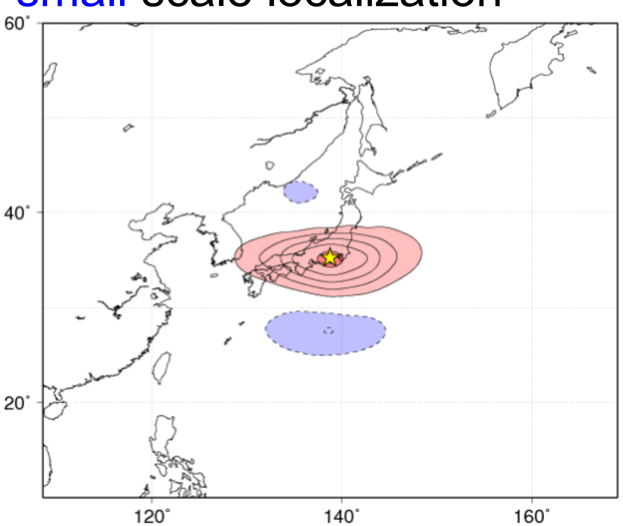


Longer-range component

Reduced-resolution (T21) perturbations with large scale localization



Reduced-resolution (T21) perturbations with small scale localization



Removing the small scale structure