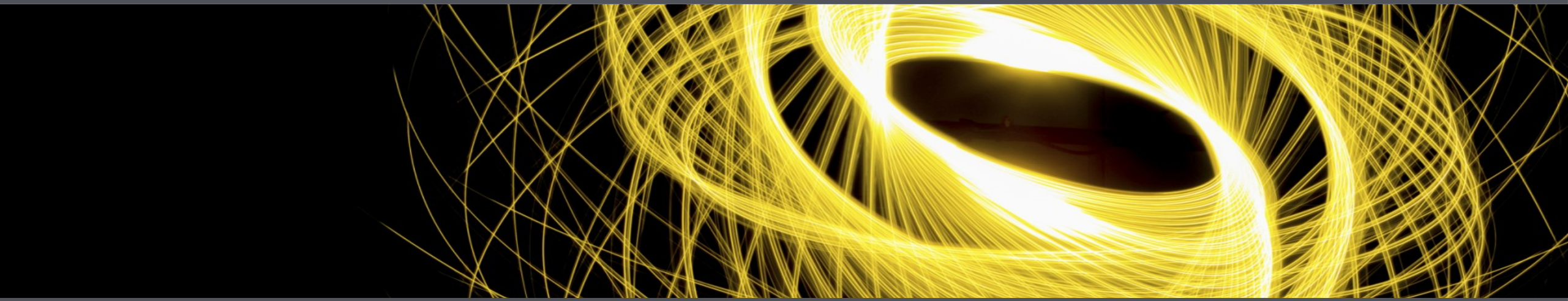
Department of Meteorology
Data assimilation research centre (DARC)

A post-process smoother for improving the past reanalyses with sparse observations



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Joint CP-TT/DA-TT Workshop

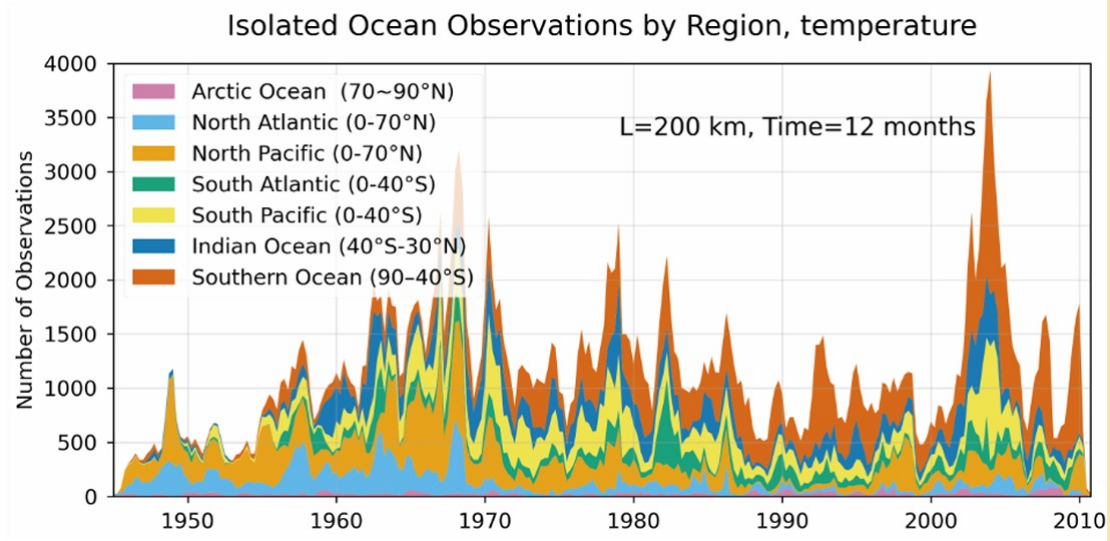
29 Oct 2026

https://github.com/yumeng...

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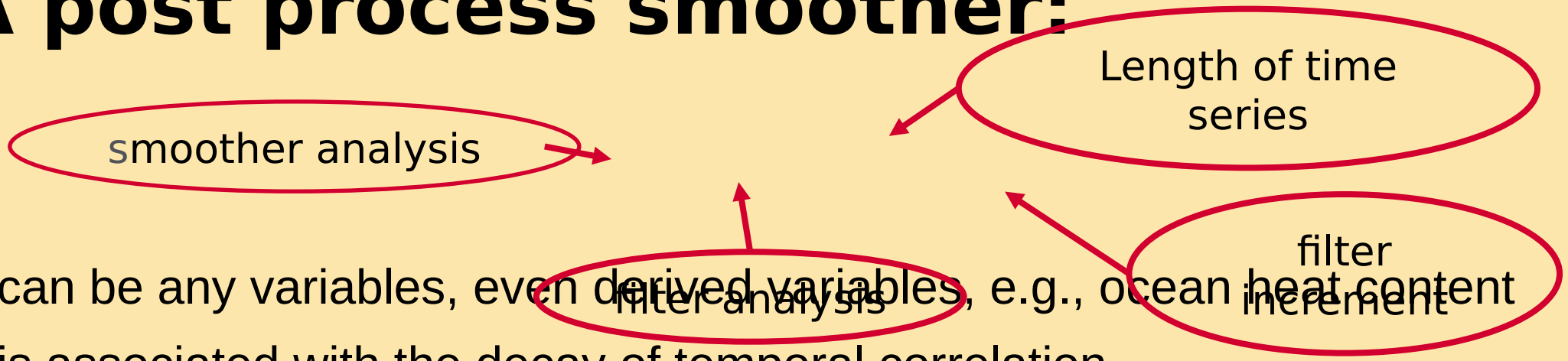
- Ocean observation network went through various periods
  - ship-based, buoys
  - Sea ice and SST from satellite
  - Satellite altimetery
  - Argo data
- Many ocean processes have very long memory and are sources of predictability
  - (Most) reanalyses use filter-type DA approaches or relatively short DA windows
  - A cheap post-process smoother can be a flexible alternative to constructing a new DA system

Credit: Sukun Cher



Number of future observations (after 12 months) available at locations without current observations in CIGAR reanalyses

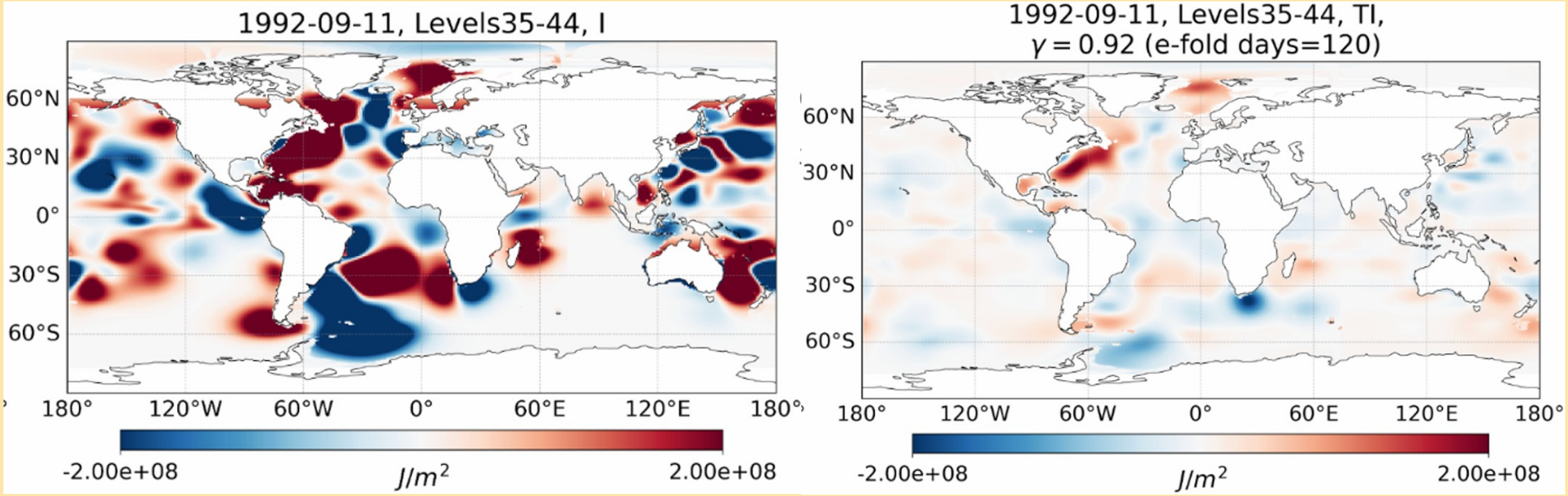
A post process smoother:



- can be any variables, even derived variables, e.g., ocean heat content
- is associated with the decay of temporal correlation
- Relation to fixed-lag (Kalman) smoother: or

Dong et al., 2021, 2023

•Reducing large unphysical temporal oscillations



Credit: Sukun Cheng

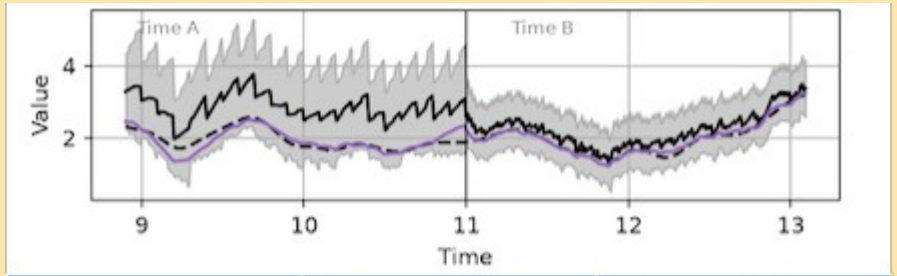
- Very large-scale increments due to background error covariances
- Large swings in estimated ocean heat content
- Smoother reduces the increments and large swings

Bias correction

Credit: Alison Fowler

- Assume reanalyses have
  - no observation biases
  - constant biases over smoothing period

  - is bias in background
  - To make zero bias in smoother analysis
    - -- is the degrees of freedom for signal (DFS)
    - DFS can be estimated by Desroziers' type of diagnostics



	Time period A	Time period B
Ob sampling	Err var=2, dt=10,dx=1	Err var=1, dt=2, dx=1
Bias in EnKF	0.835	0.244
γ_{DFS}	0.961	0.791
Bias in smoothed analysis	-0.108 (87% reduction)	0.01 (97% reduction)

Time series of filter (black solid line) and smoother analysis (purple line) in a
Lorenz 96 model compared with truth (dashed line)

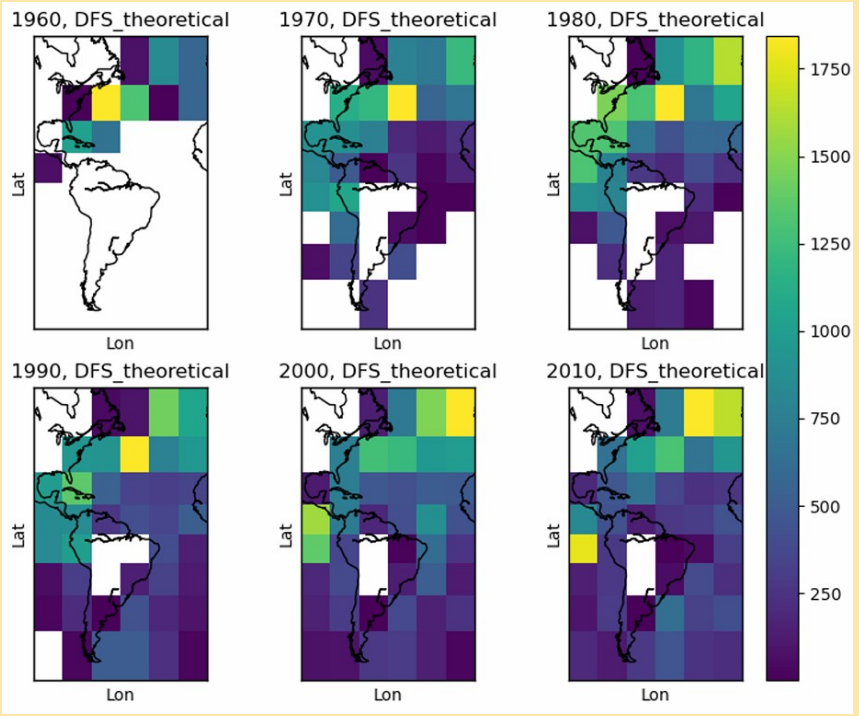
Fowler et al., 2020; Fowler et al., 2026 (in

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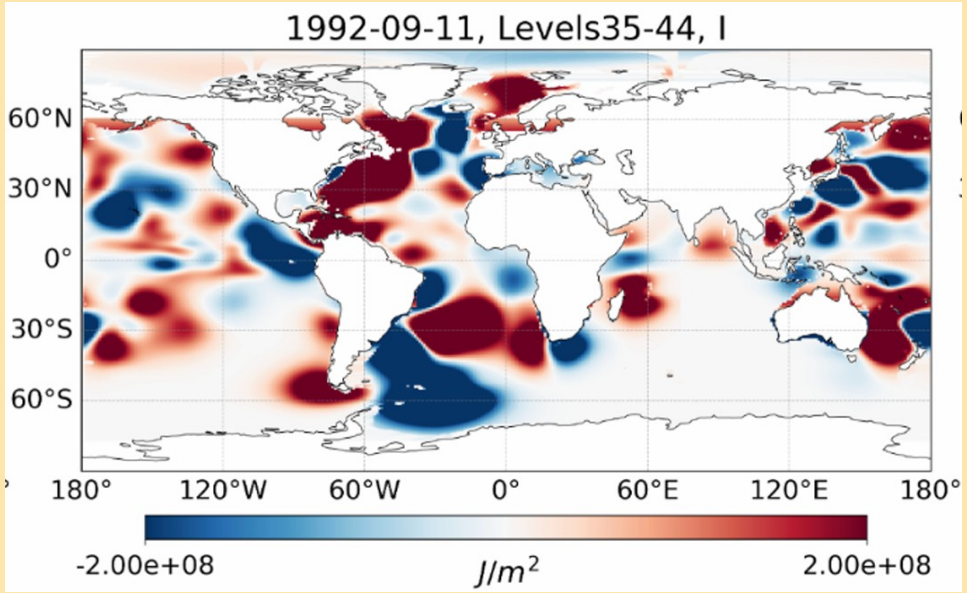


DFS for CIGAR reanalysis computed for temperature across depths 300-800m and 15° by 15° bins in the Atlantic

Fowler et al., 2020; Fowler et al., 2026 (in

Dynamical consistency?

- With sparse observations, filter reanalysis can have large temporal swings due to large increments
- Large temporal oscillatory means that it deviates from the model/true trajectory
- Will reanalysis from smoother better follow the model/true dynamics?



$$d_k^{obs} = \frac{1}{L'+1}\sum_{l=0}^{L'} ¿\left(\frac{1}{N_y}\left(\mathbf{y}_{k+l} - \mathscr{H}\circ\mathscr{M}_{k:k+l}\left(\mathbf{x}_k^s\right)\right)^T \mathbf{R}^{-1}\left(\mathbf{y}_{k+l} - \mathscr{H}\circ\mathscr{M}_{k:k+l}\left(\mathbf{x}_k^s\right)\right)\right)^{\frac{1}{2}} - 1\vee,$$

Observation space

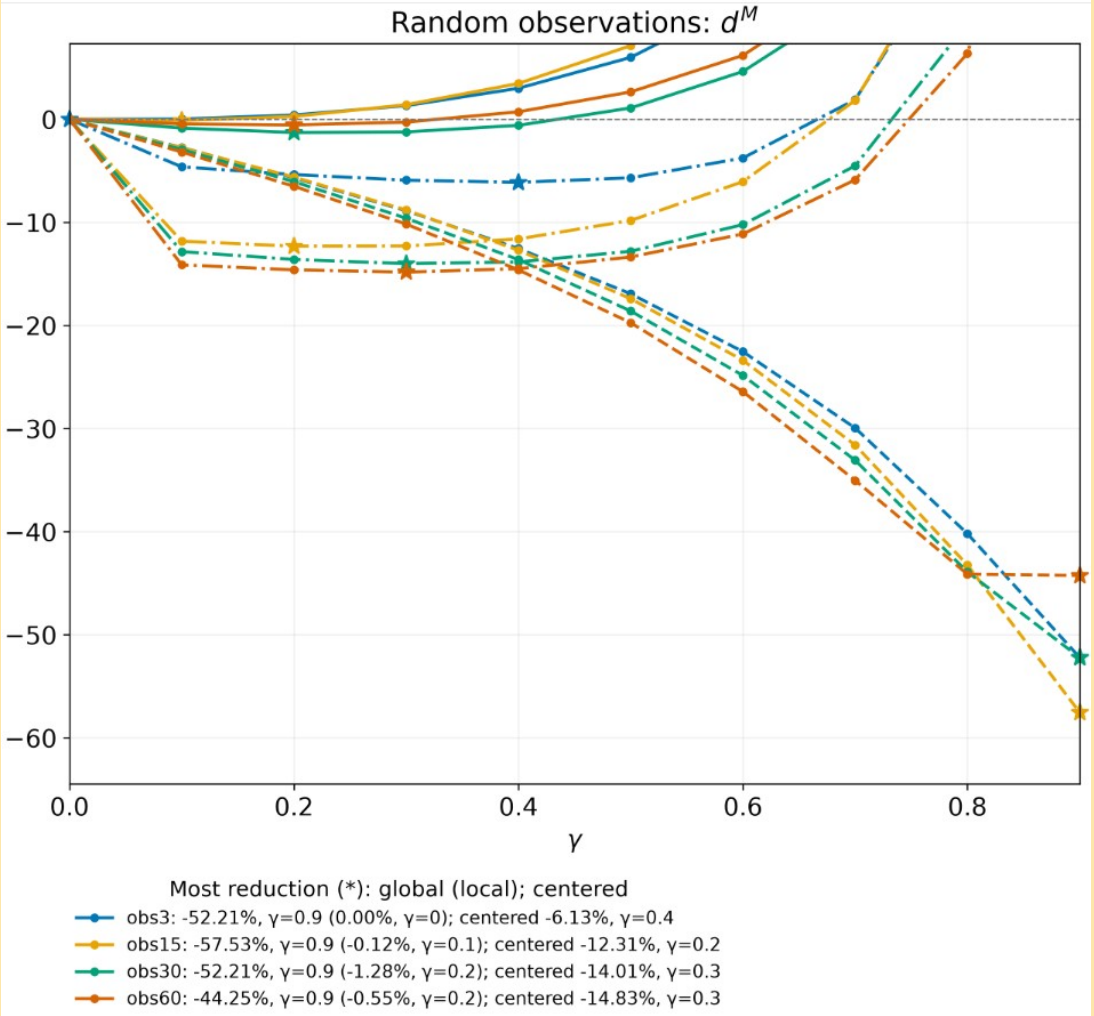
$$d_k^M = \frac{1}{L'}\sum_{l=1}^{L'}\left(\frac{1}{N_x}\left(\mathbf{x}_{k+l}^s - \mathscr{M}_{k:k+l}\left(\mathbf{x}_k^s\right)\right)^T\left(\mathbf{x}_{k+l}^s - \mathscr{M}_{k:k+l}\left(\mathbf{x}_k^s\right)\right)\right)^{\frac{1}{2}}$$

Smoother trajectory fits model trajectory

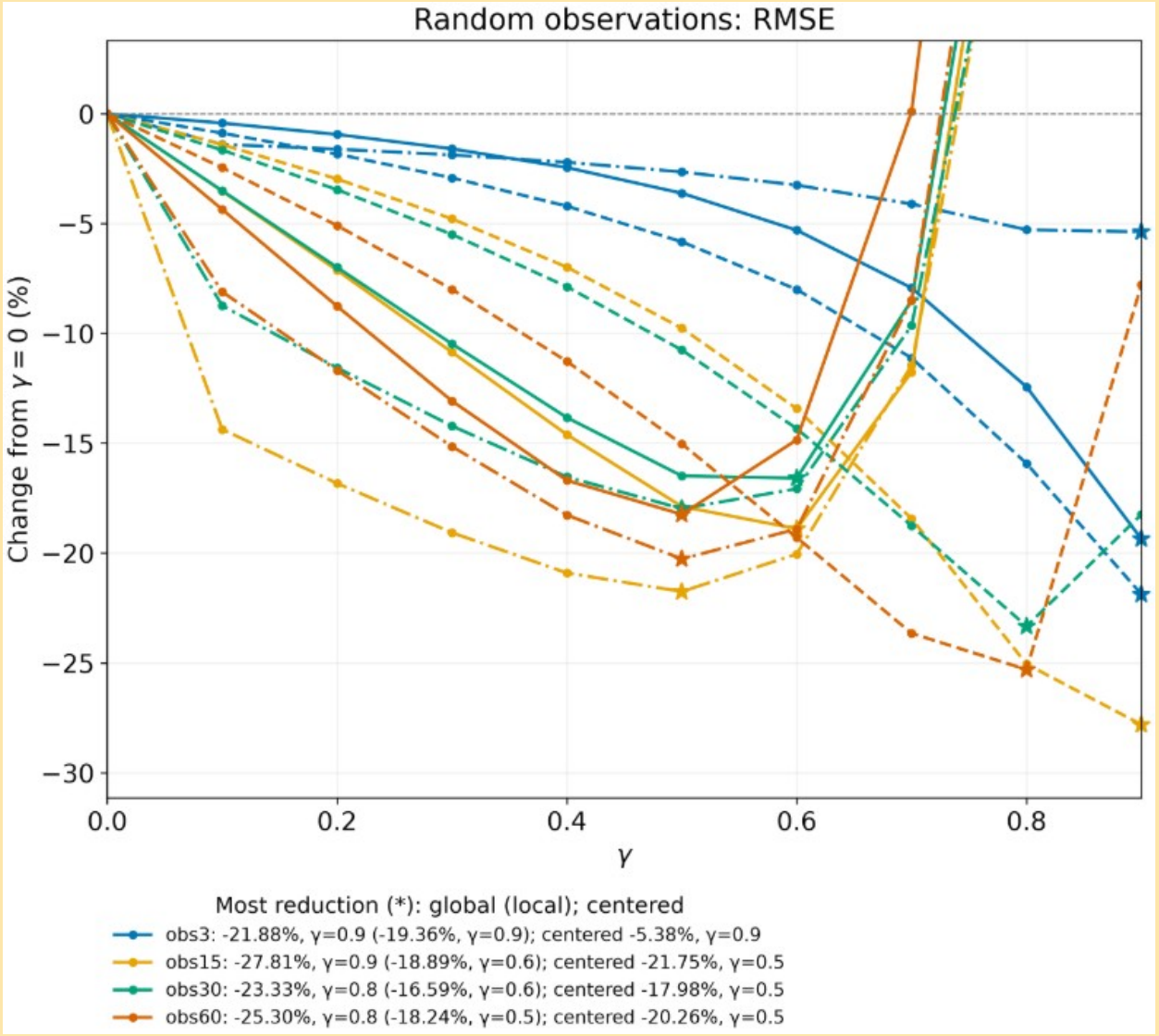
Idealised experiment

- The Modular Arbitrary-Order Ocean-Atmosphere Model: MAOOAM
- Ocean temperature observations
- State vector: ocean temperature and streamfunction
- Global filter better than local filter
  - Low wavenumbers configuration
  - Sufficient ensemble members
- Implemented by pyPDAF (a poster)

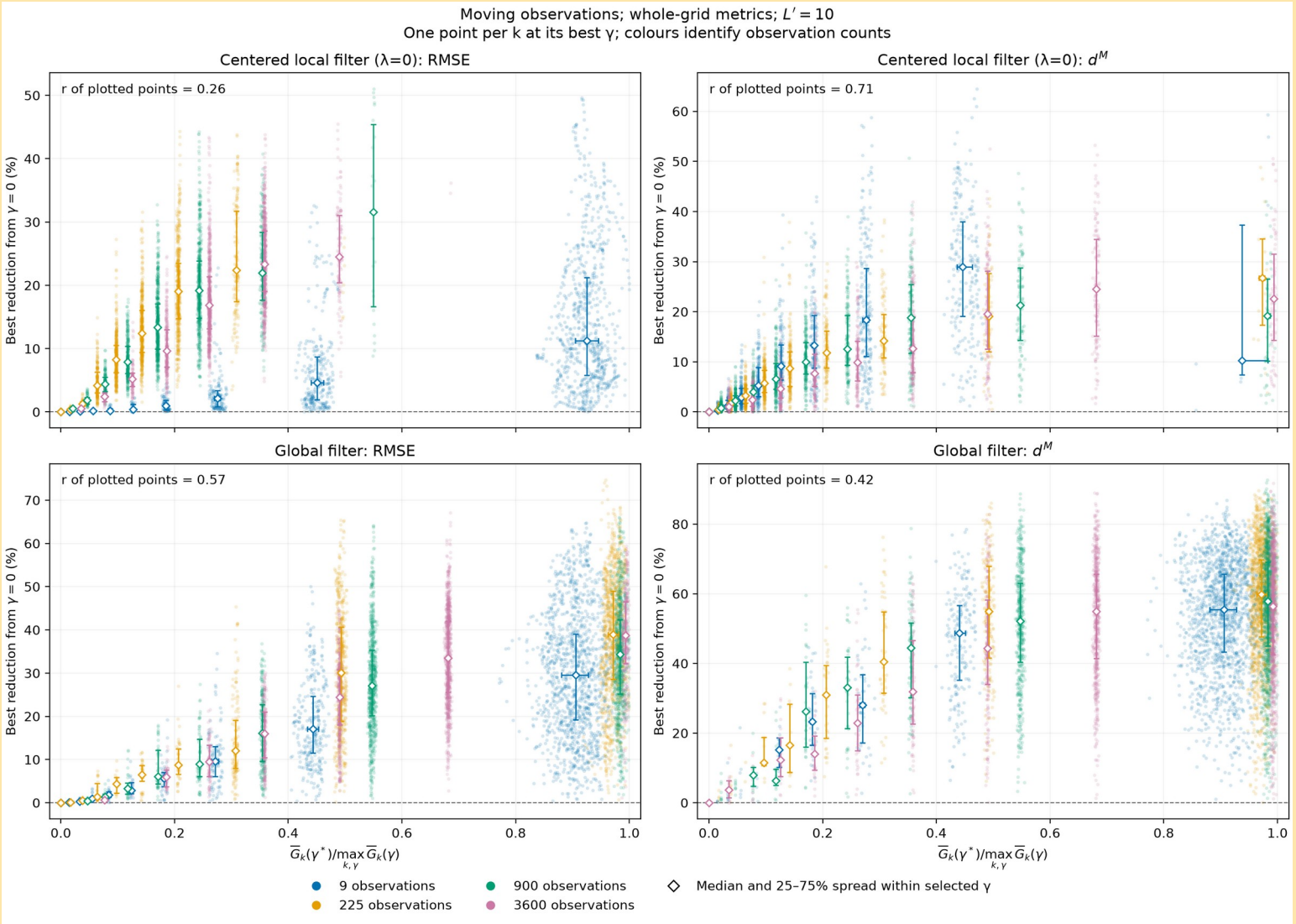
https://github.com/yumengch/pyPDAF



- Different observation density with location changes in time (like a random walk ship)
- Localisation impacted the stream function estimate leading to persistent large increments
- The local filter with 9 observations does not converge but post-process smoother still gets improved
- Dynamical consistency only get improved after removing those persistent increments
- Global filters (more optimal in this case) can use very strong smoothing



- Removing the persistent increments has no obvious impact on RMSE and choice of
- In the case of non-optimal filtering analysis, the best dynamical consistency does not mean the minimum RMSE as the corresponding differs



- X-axis: amount of future observation information at locations without observations at filter time
- Better improvements with selected and more observation information
- The improvements are still observation density dependent

Summary

- Post-process smother can
  - improve the RMSE and dynamical consistency of the filter analysis
  - reduce biases
  - perform gap filling for sparse observations
- Best RMSE, dynamical consistency and minimum biases may not coincide with each other reflected by different optimal smoother parameters
- It can improve the filter results even if the filter is not fully optimised, e.g., problematic B matrix or localisation radius
  - Removing persistent increments (bias) helps dynamical consistency but not necessarily RMSE

EGU Session

- **OS4.6: Data assimilation in the ocean and coupled components**
  - **Convener: Yumeng Chen, Lars Nerger, Anna Teruzzi, Ali Aydogdu**

References

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