Benefit of vertical localisation for sea surface temperature assimilation in isopycnal coordinate ocean model for climate reconstruction

Yiguo Wang[1,2], François Counillon[1,2,3], Sébastien Barthélémy[2,3], Alexander Barth[4]

1 Nansen Environmental and Remote Sensing Center, Norway
2 Bjerknes Centre for Climate Research, Norway
3 Geophysical Institute, University of Bergen, Norway
4 Université de Liège, Belgium

Manuscript under review in the journal *Frontiers in Climate*

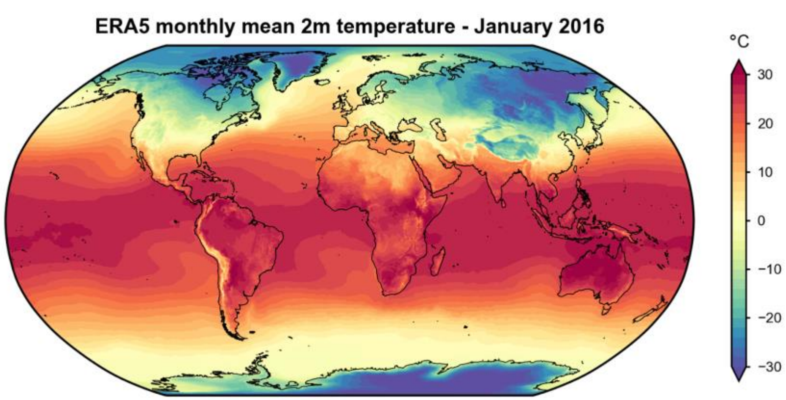
Bjerknes Climate Prediction Unit

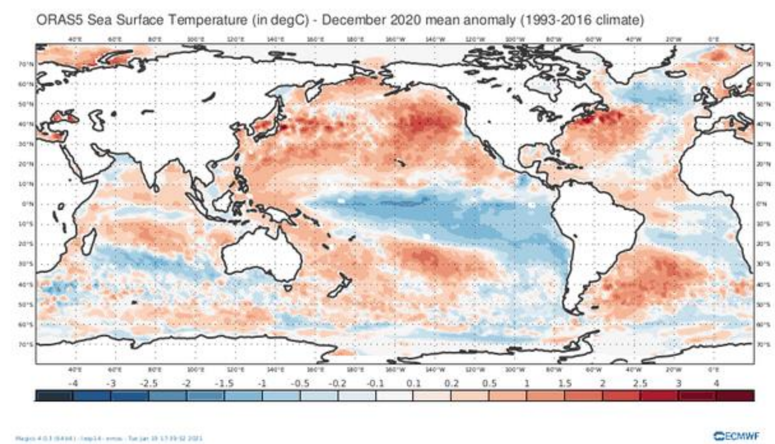
Outline

- Introduction
- Formulate tapering functions
- Experimental design
- Results
- Conclusions
- Future perspectives

Climate reanalysis

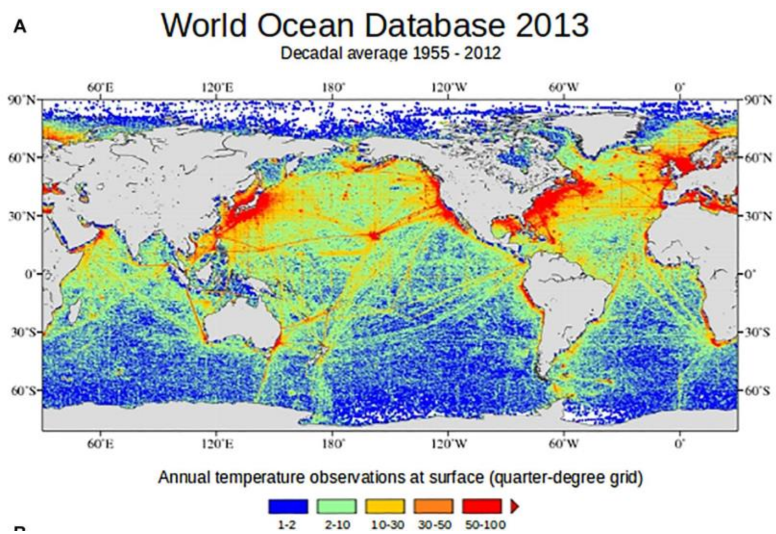
- Dynamically consistent reconstruction of the climate system
- Atmospheric reanalyses (ERA-Interim, Dee et al., 2011), ocean reanalyses (ORAS5, Zuo et al., 2019)
- Coupled reanalyses (Laloyaux et al., 2018, O’Kane et al., 2021)
- Understanding anthropologically driven global warming
- Studying climate variability and teleconnections
- Initialising climate predictions

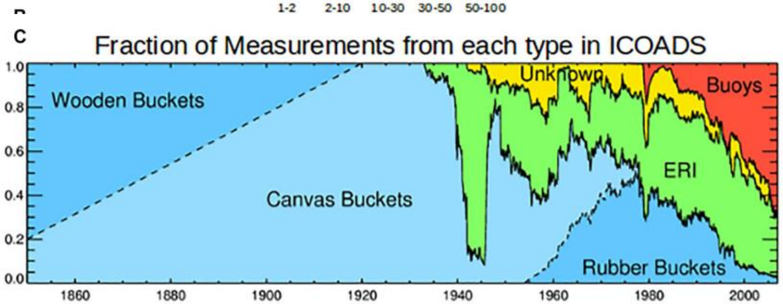




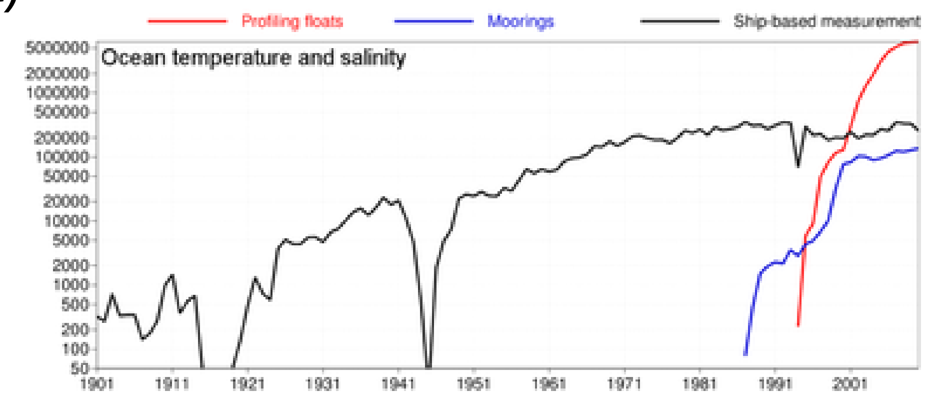
Sea surface temperature measurements

- The most primary instrumental oceanic measurements prior to satellite era
- Important oceanic data for long-term climate reanalysis (e.g., 1850-present)
- SST analysis products (gridded data)

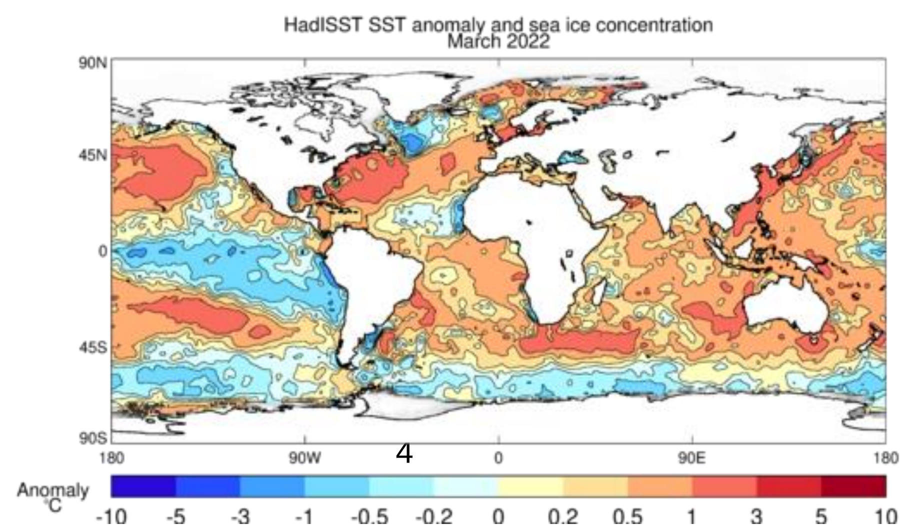




(O'Carroll et al. 2019)

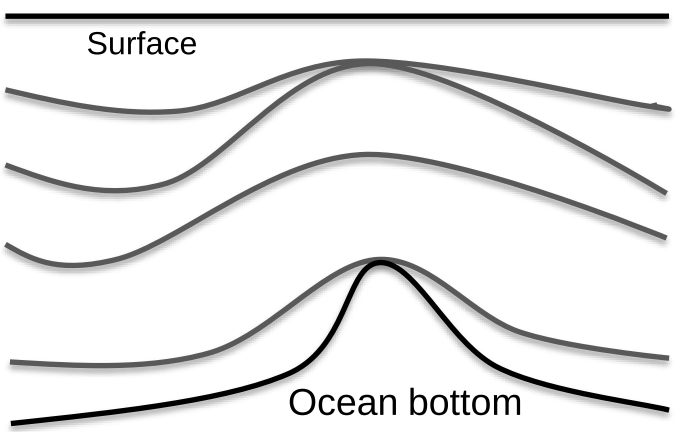


(Laloyaux et al. 2018)

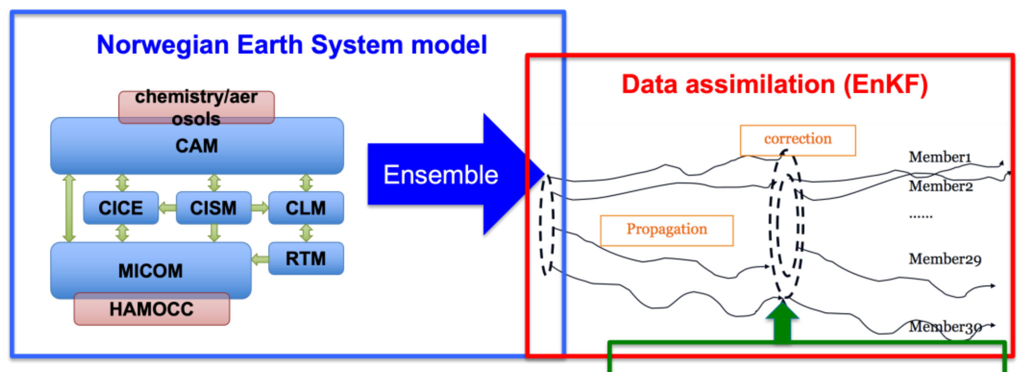


Isopycnal coordinate ocean models & DA

- Excellent conservation of water properties, e.g. heat and salt
- DA in isopycnal coordinate is efficient than in z coordinate (Gavart and De Mey,1997; Srinivasan et al. 2011; Counillon et al. 2016)
- Wang et al. (2016) alleviated the bias induced by SST assimilation
- But a slow drift in the ocean interior remains …

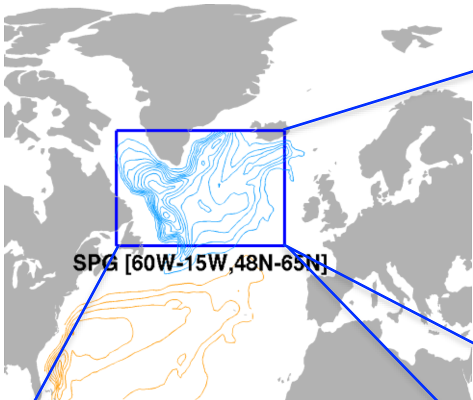


Norwegian Climate Prediction Model (NorCPM)

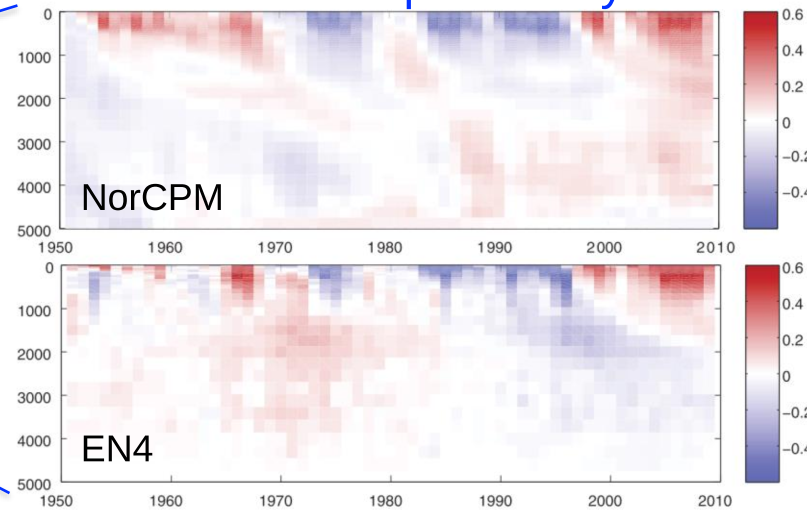


(Counillon et al. 2014; Bethke et al. 2021)

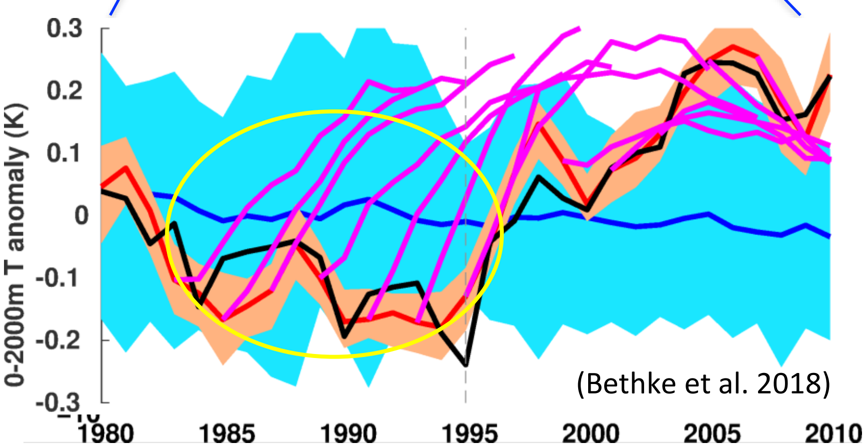
Our problem (examples)



SPG temp anomaly



(Counillon et al. 2014)

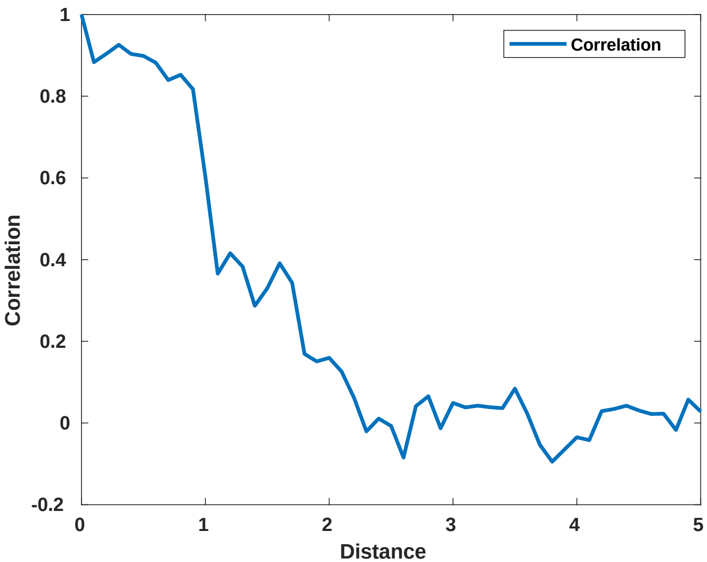


(Bethke et al. 2018)

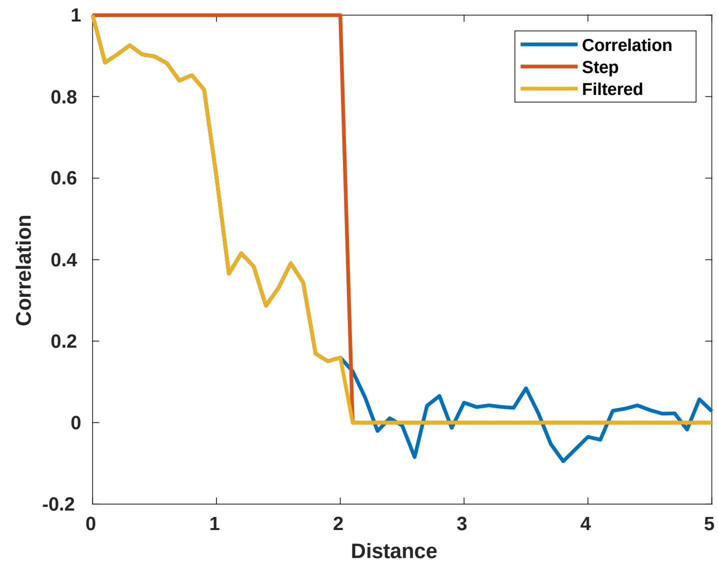
Initialization errors in subtropical heat content contribute to false SPG warmings (Bethke et al. 2018)

Localisation (ad-hoc technique)

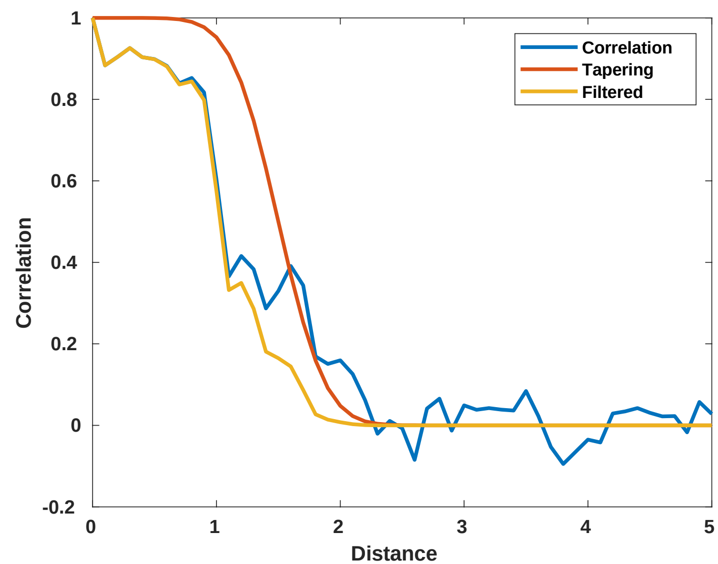
Sample correlation



Step function

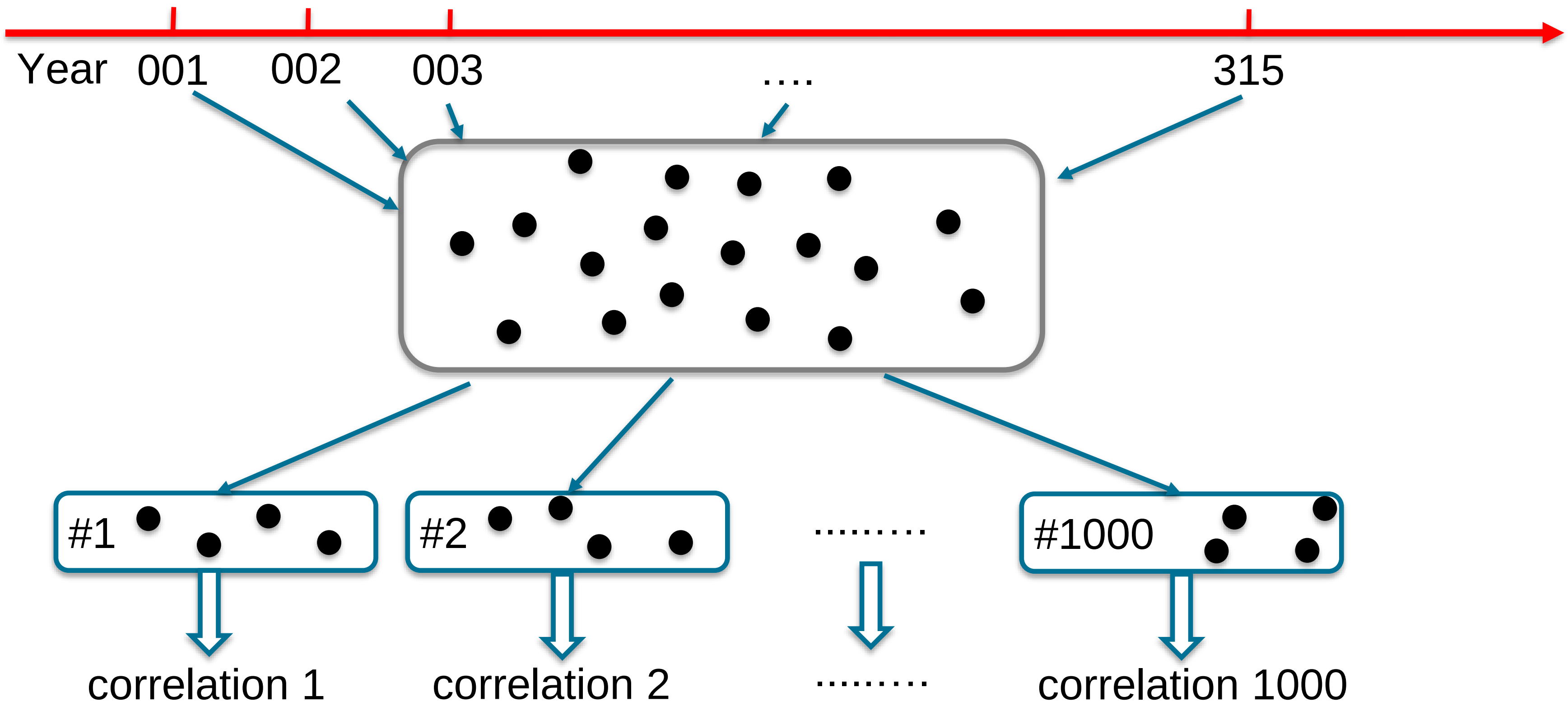


Smooth function



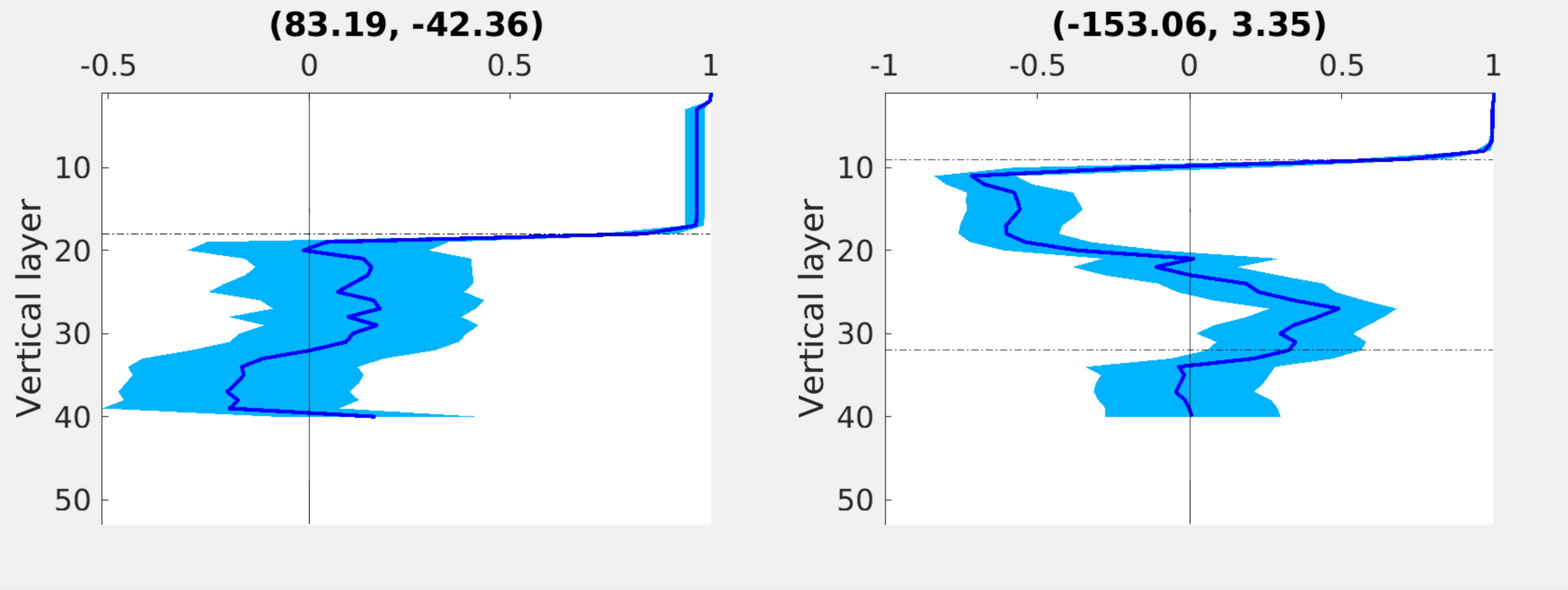
-The finite ensemble size (30 members in our case)
-Sampling noise on covariance can degrade the solution

Empirical methodology to formulate tapering functions



- NorESM pre-industrial run, save monthly outputs
- Large ensemble with 315 members for each calendrar month
- Bootstrap of 1000 ensembles with the size of 30 (i.e., current NorCPM ensemble size)
- Estimate correlation from each ensemble

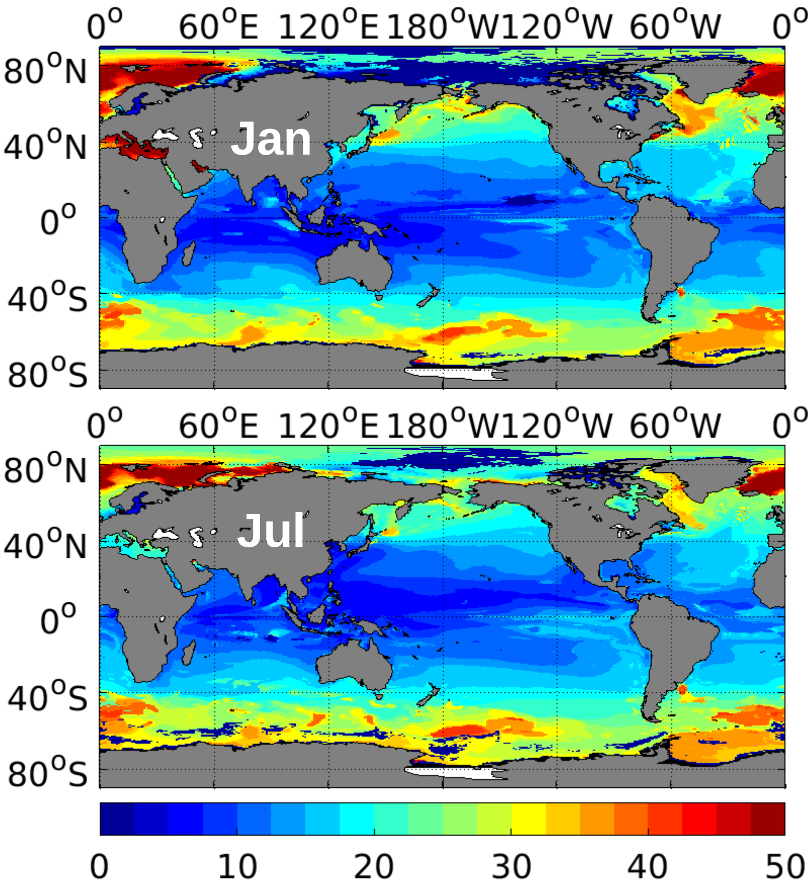
Step functions



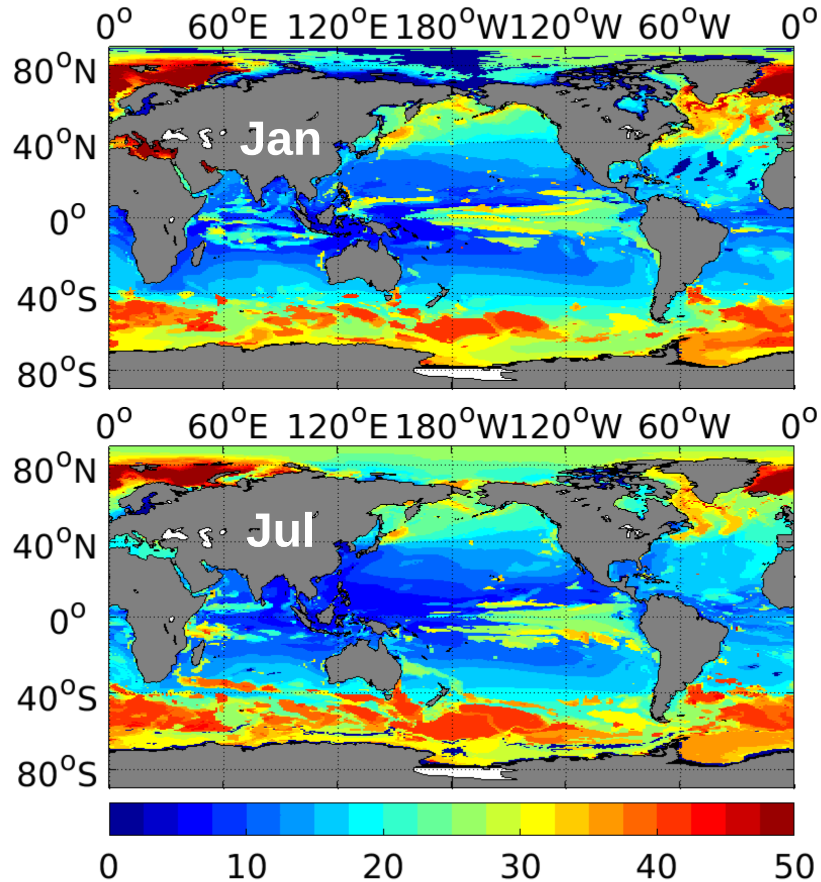
- Blue line: averaged correlation profile
- Blue shading: 5-95 percentile
- Dash line: threshold layer in step function

Step functions

Top threshold layer



Bottom threshold layer



Smooth tapering function

- Filtered matrix

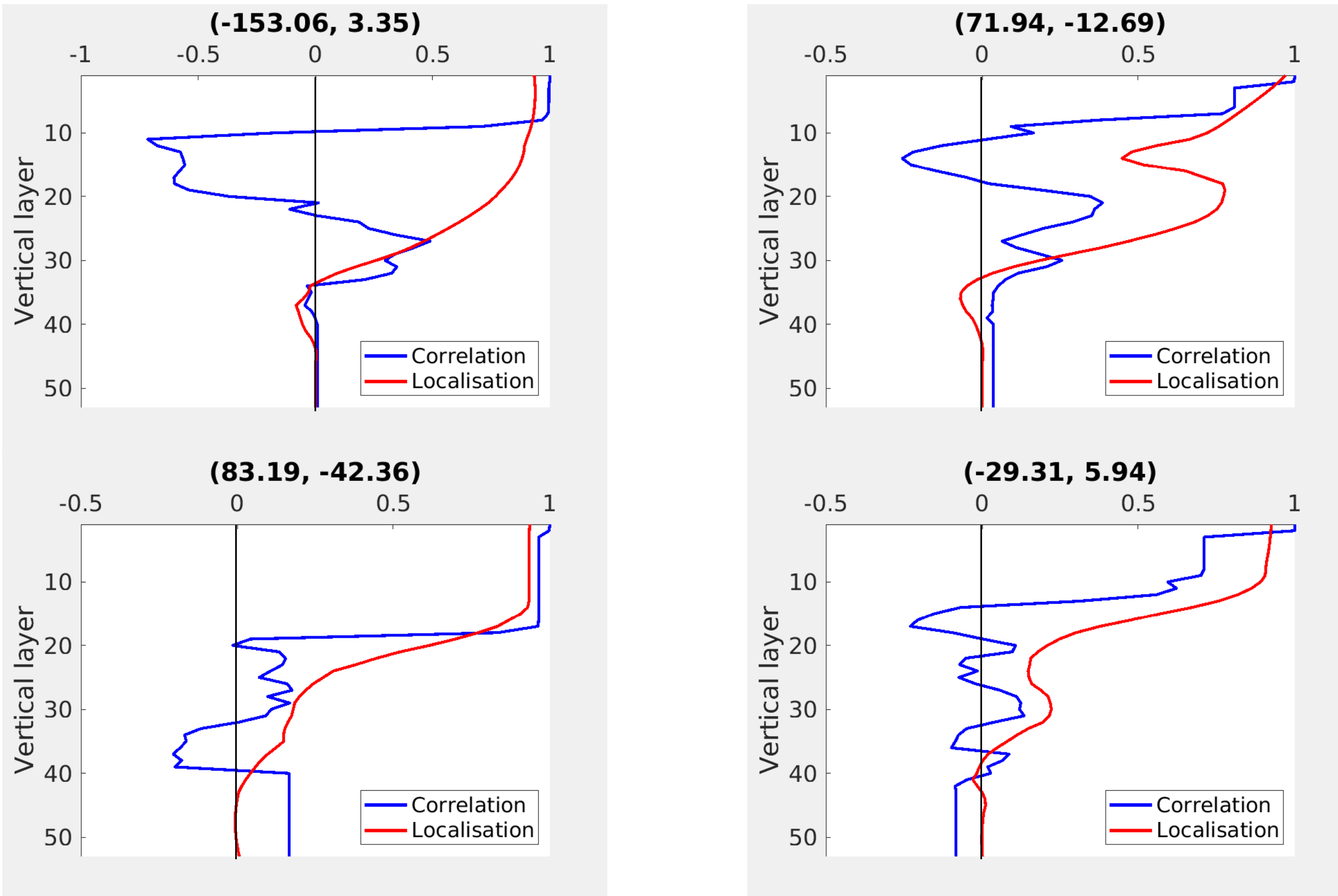
$$\widehat{\mathbf{P}} = \mathbf{L} \circ \mathbf{P}, \text{ where } \widehat{P}_{ij} = L_{ij}\, P_{ij}$$

- In Gaussian case,

$$L_{ij} = \frac{N-1}{(N+1)(N-2)} \left\{ (N-1) - \frac{\mathbb{E}(P_{ii}P_{jj})}{\mathbb{E}(P_{ij}^2)} \right\} \qquad (1)$$

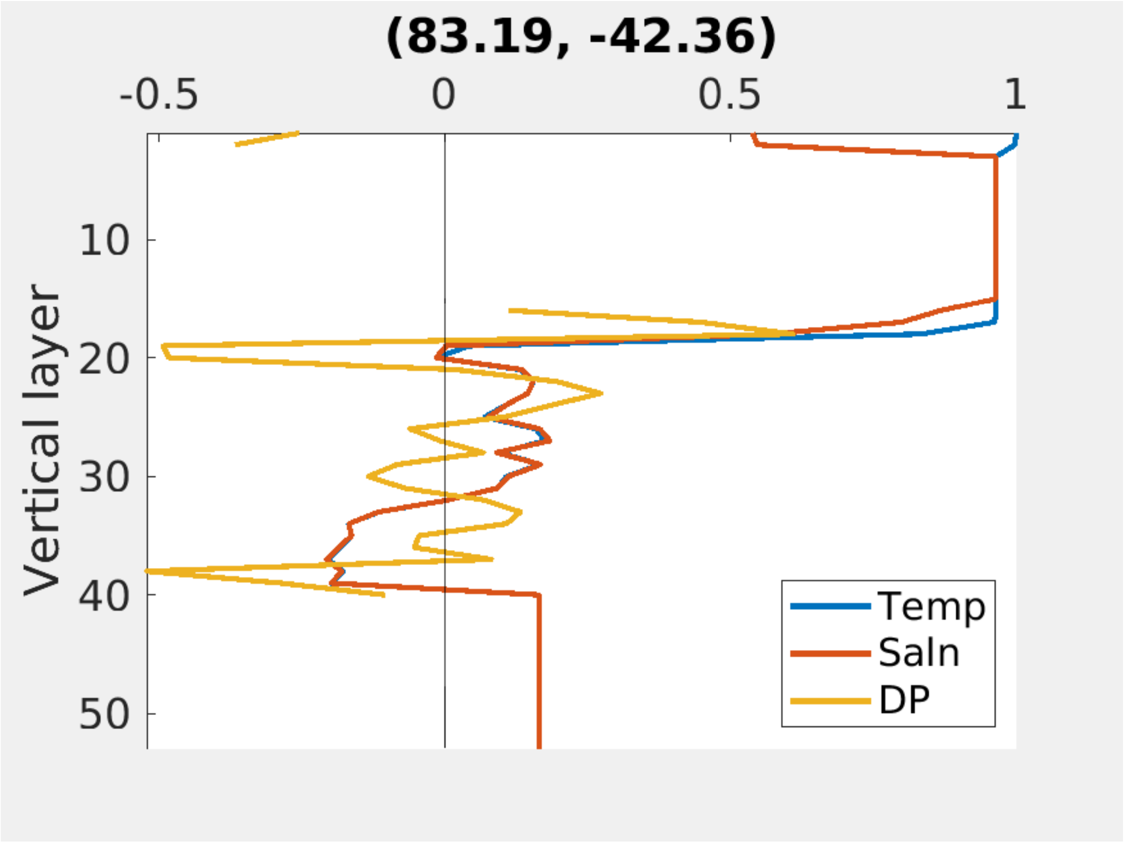
Ménétrier et al., 2015a: Linear Filtering of Sample Covariances for Ensemble-Based Data Assimilation. Part I: Optimality Criteria and Application to Variance Filtering and Covariance Localization, MWR.

Smooth tapering function



*Red line: smoothed from Eq (1) in previous slide

Multivariate consideration of tapering



-Sample correlations between SST and T, S or layer thickness (DP)
-Apply vertical localisation for TS but not for layer thickness (DP)

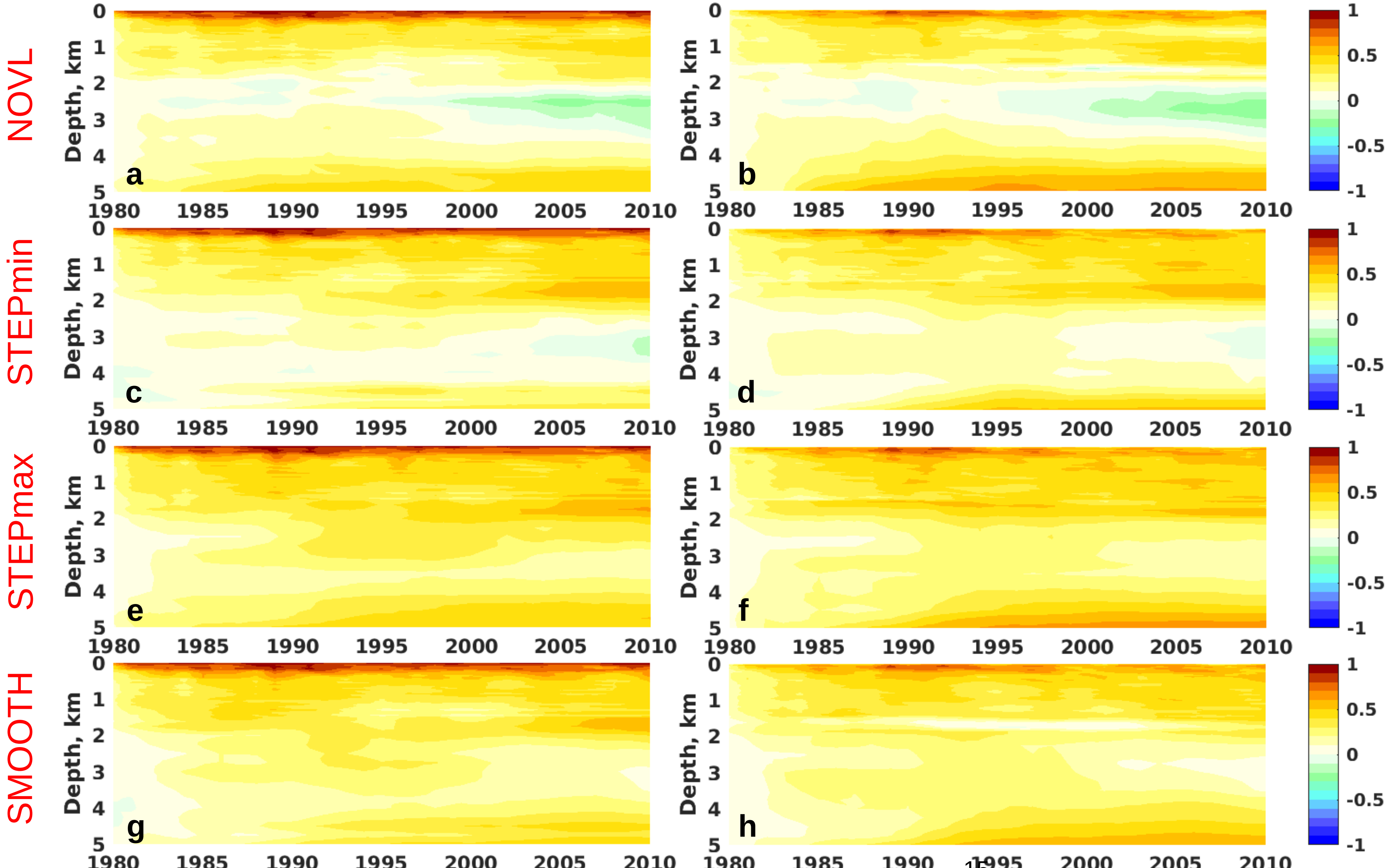
Twin experiments over 1980-2010

- **Free**: historical simulation with 30 members (NorCPM)
- **Truth**: member #1 of Free with perturbed SST in 1960
- **Obs**: SST from **Truth** with noise from HadISST2
- **NOVL**: reanalysis without vertical localisation
- **STEPmin**: step function with minimal support
- **STEPmax**: step function with maximal support
- **SMOOTH**: smooth step function (Ménétrier et al., 2015a)
- **Metrics**: ΔRMSE and Mean Squared Skill Score (MSSS)

$$MSSS = 1 - \frac{MSE\_a}{MSE\_f}$$

Bjerknes Centre for Climate Research

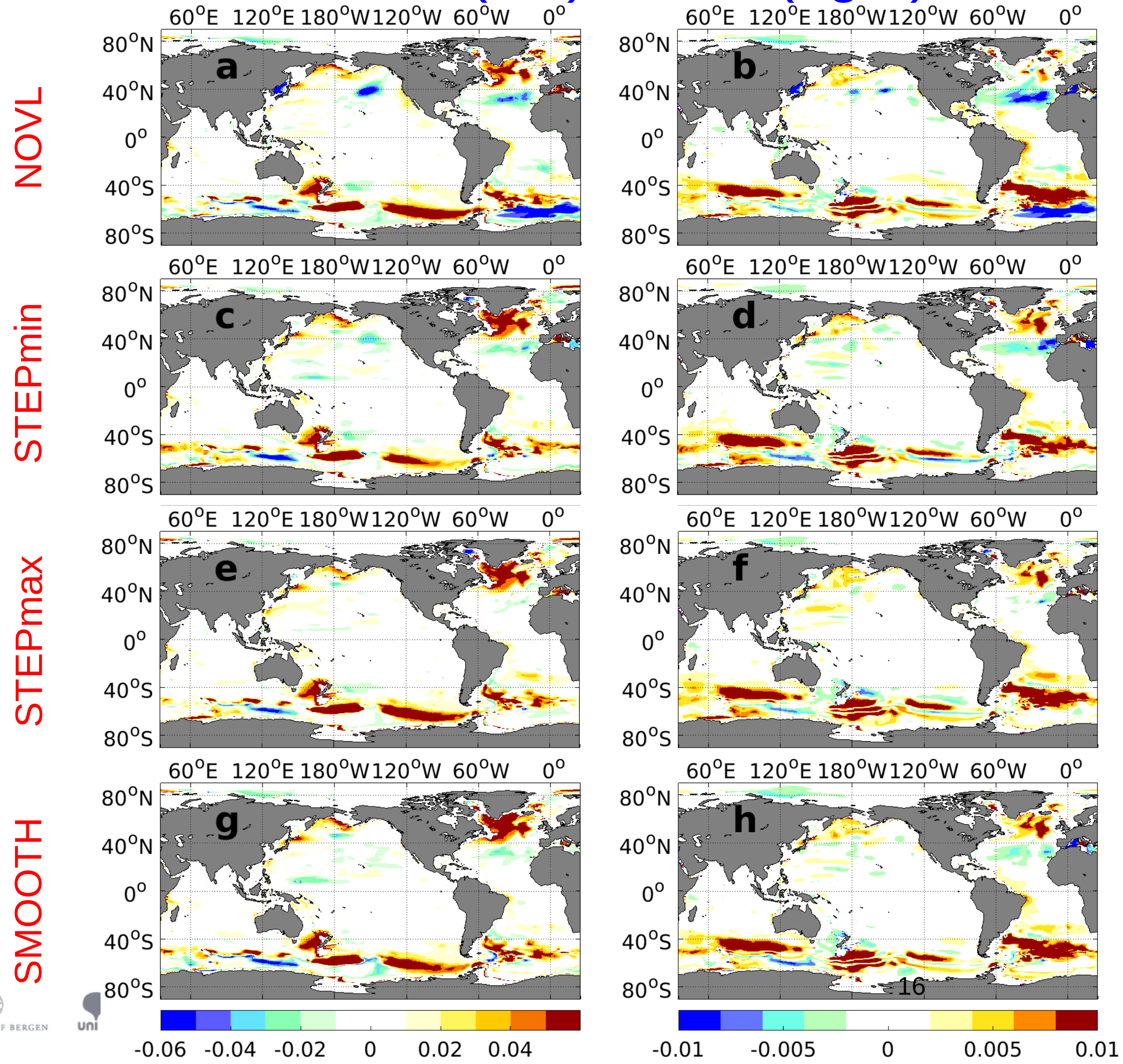
MSSS for T (left) and S (right) in depth



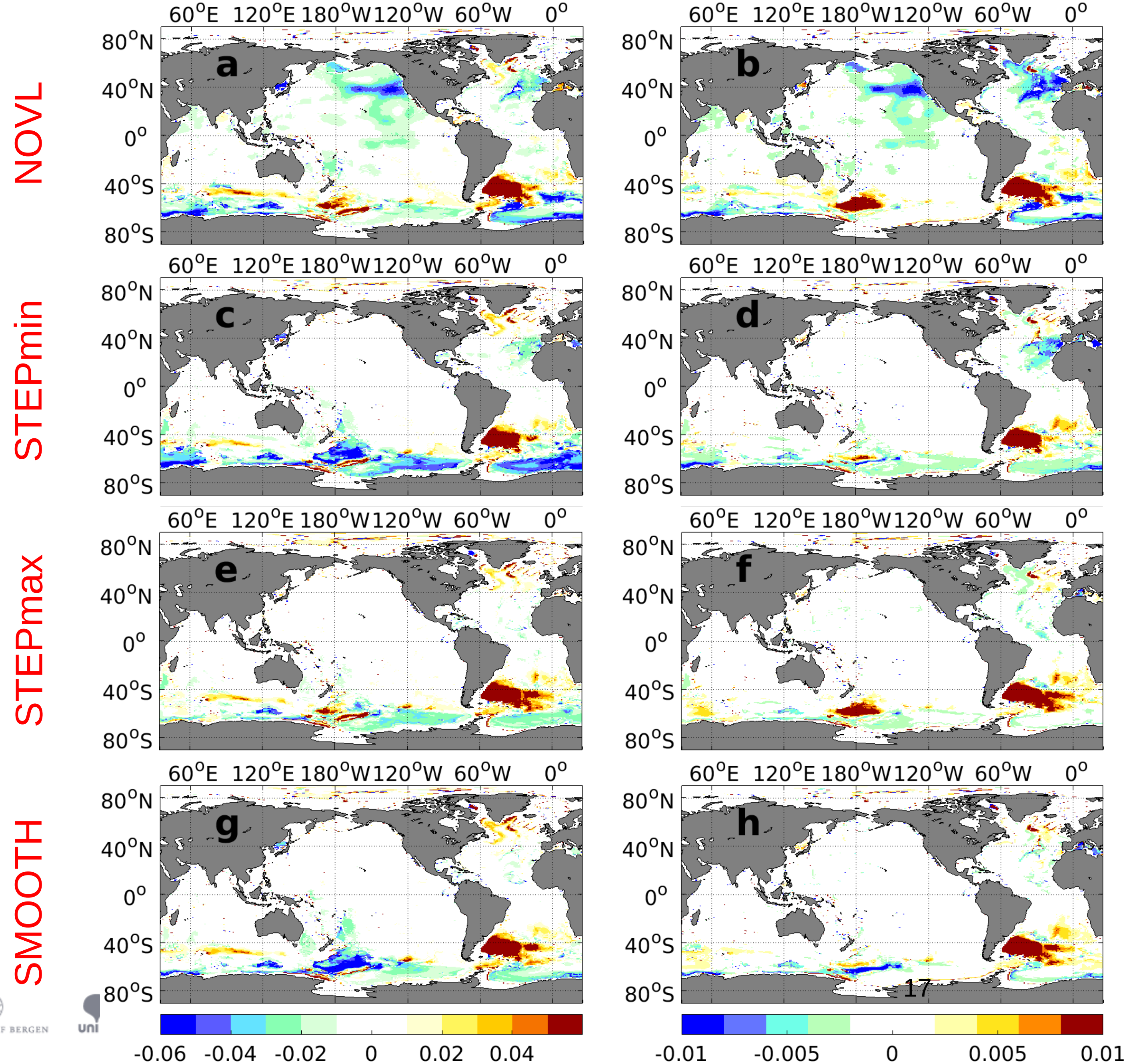
UNIVERSITY OF BERGEN
uni Research
NERSC Nansen Center, Bergen
HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH

Warm colours: improvement Cold colours: degradation

ΔRMSE for T (left) and S (right) in 1000-2000m



ΔRMSE for T (left) and S (right) in below 2000m



Take-home messages

- Vertical localisation in isopycnal coordinate ocean model
- Vertical localisation improves the performance of reanalysis
- Three schemes: two step functions and one smooth function
- The step function with large support outperforms the other schemes

Future perspectives

- Combine with hybrid-covariance (Ménétrier et al. 2015b, ongoing activity)
- Verify in the real framework
- Adapt for hydrographic profile
- Assess the impact of vertical localisation on decadal prediction skill (issue reported by Bethke et al., 2018)
- Multi-step function?

  ==>only consider the layers in which correlation is significant
- Apply to layer thickness and velocity?

  ==>apply vertical localisation on the baroclinic mode (not on the barotropic mode)

Bjerknes Centre for Climate Research

Thank you very much for your attention