# Achievements of the CoRea Project in Coupled Climate Reanalysis


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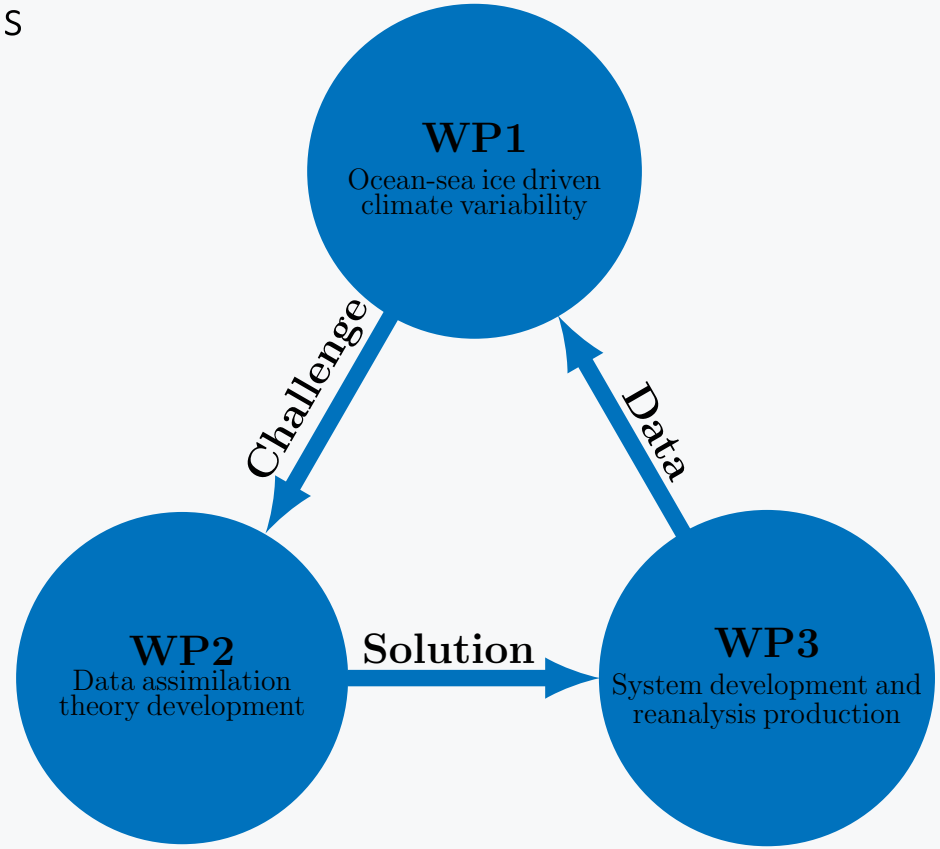
NERSC
STIFTELSEN NANSEN SENTER FOR MILJØ OG FJERNMÅLING
NANSENSENTERET · BERGEN · NORGE

CoRea

Bjerknes Centre for Climate Research

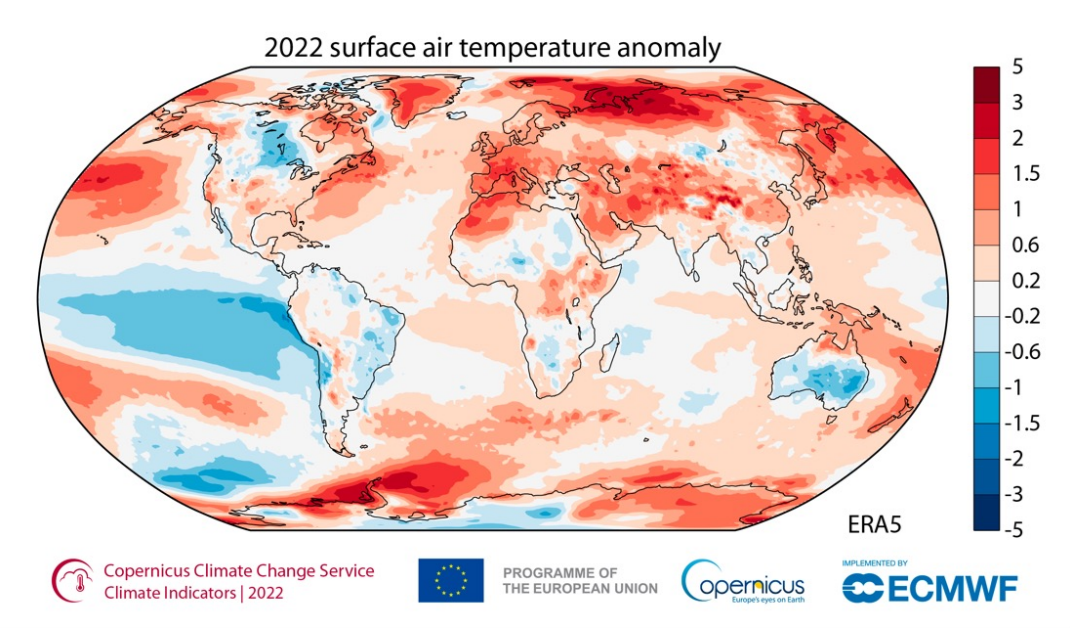
# What's CoRea?

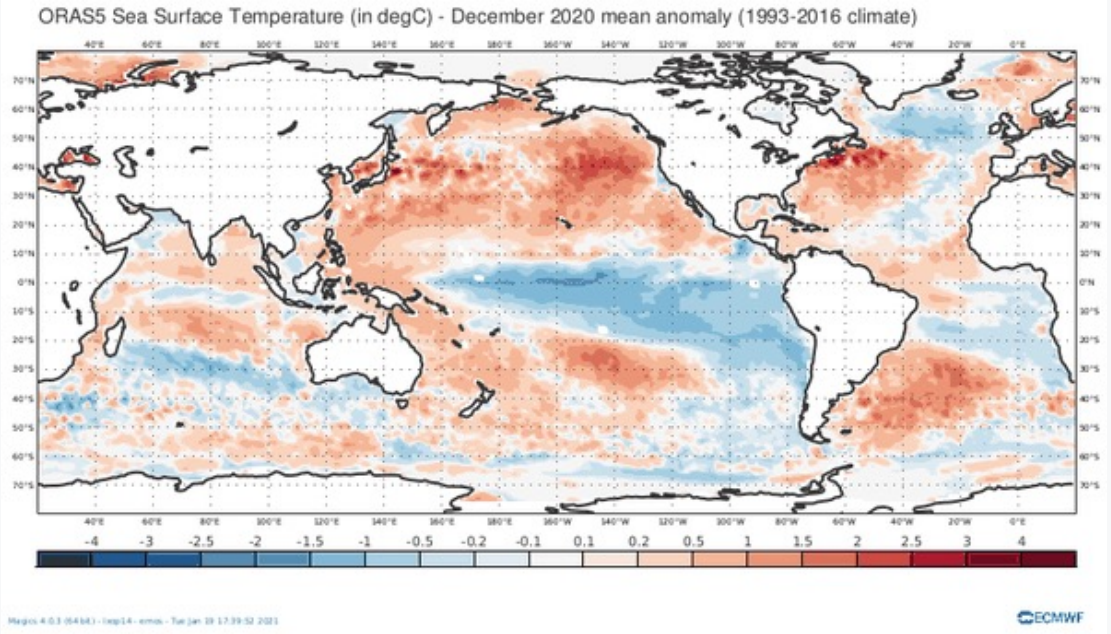
- Partners: NERSC (Yiguo, Francois), UiB/GFI (Sebastien), NORCE (Patrick Raanes), ENPC (Marc Bocquet), ECMWF (Patrick Laloyaux)
- Period: 10.2020 - 06.2025
- Overall objective: produce a reliable three-dimensional coupled reanalysis of the climate from 1850 to present for studies on the role of the ocean in the climate system and climate variability at decadal to multi-decadal timescales



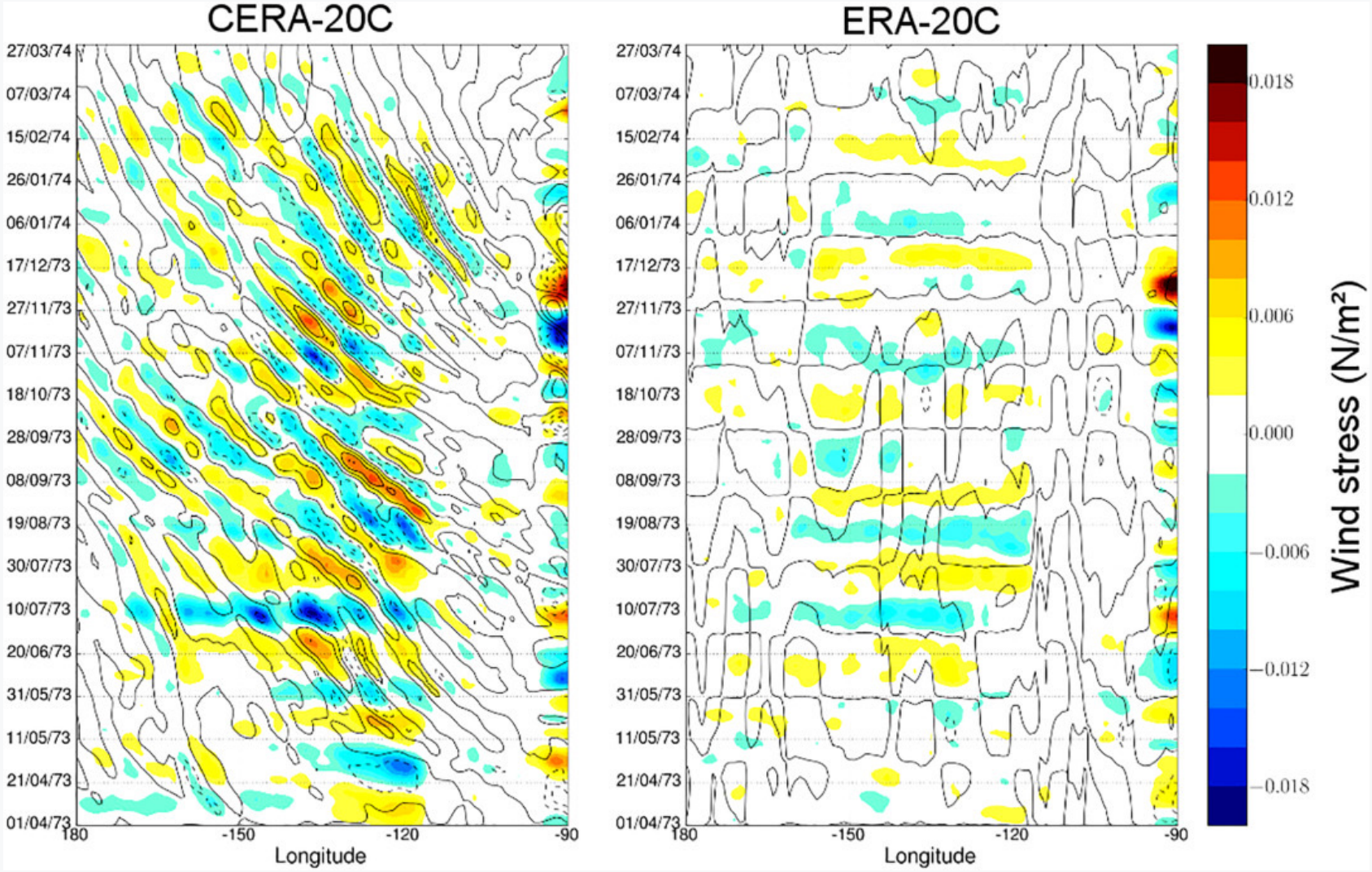
# What's reanalysis?

- Dynamically consistent reconstruction of the climate system:
  - reanalysis = dynamical model + observations + data assimilation
- Understanding anthropologically driven global warming
- Studying climate variability and teleconnections
- Initialising climate predictions
- Atmospheric reanalyses (ERA-Interim/ERA5, Dee et al., 2011), ocean reanalyses (ORAS5, Zuo et al., 2019)
- Coupled reanalyses (Laloyaux et al., 2018, O'Kane et al., 2021)



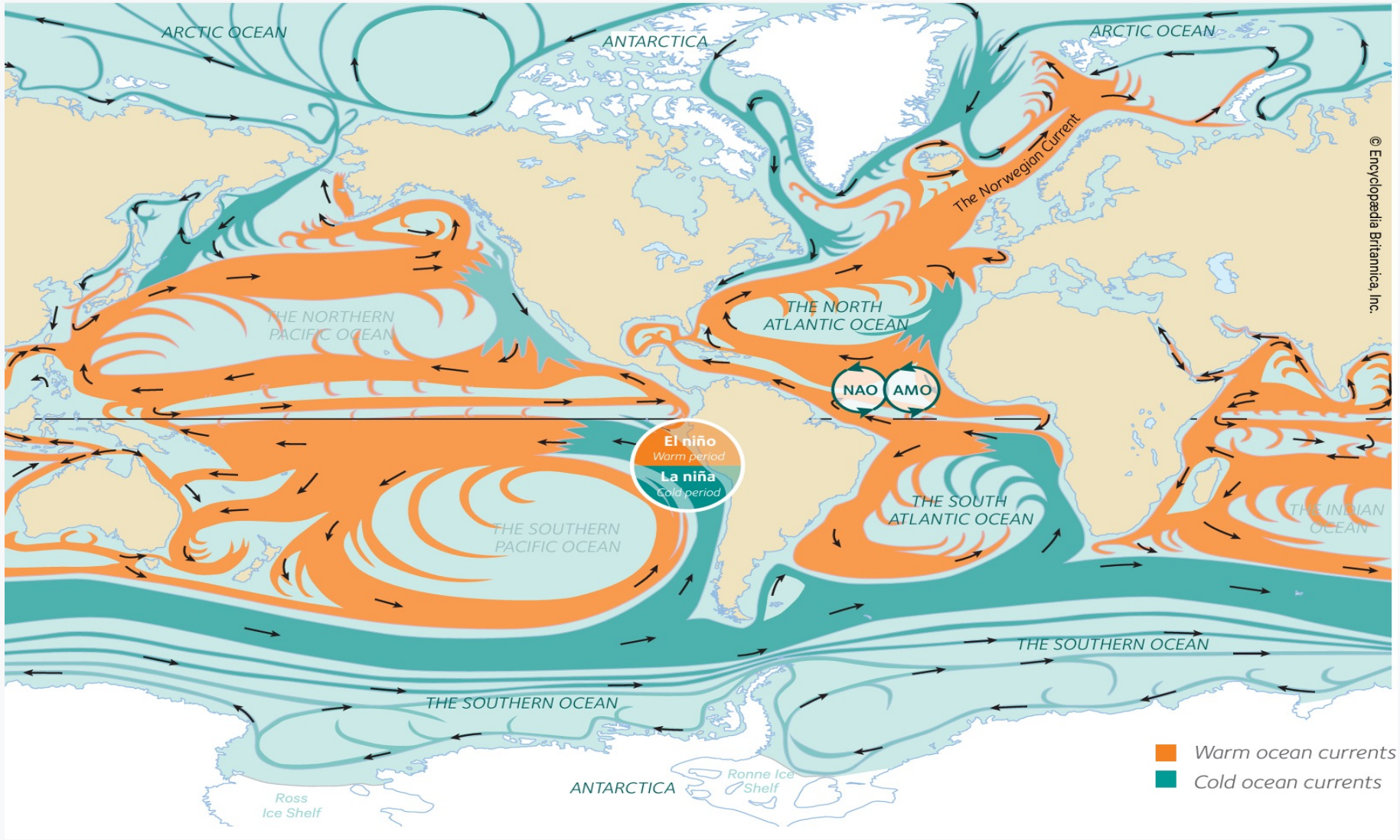
# 1st motivation: coupled processes




Hovmoller time series of spatially high-passed filtered SST (contours) and wind stress (shading) at 1°N in the eastern Pacific from April 1973 to April 1974.

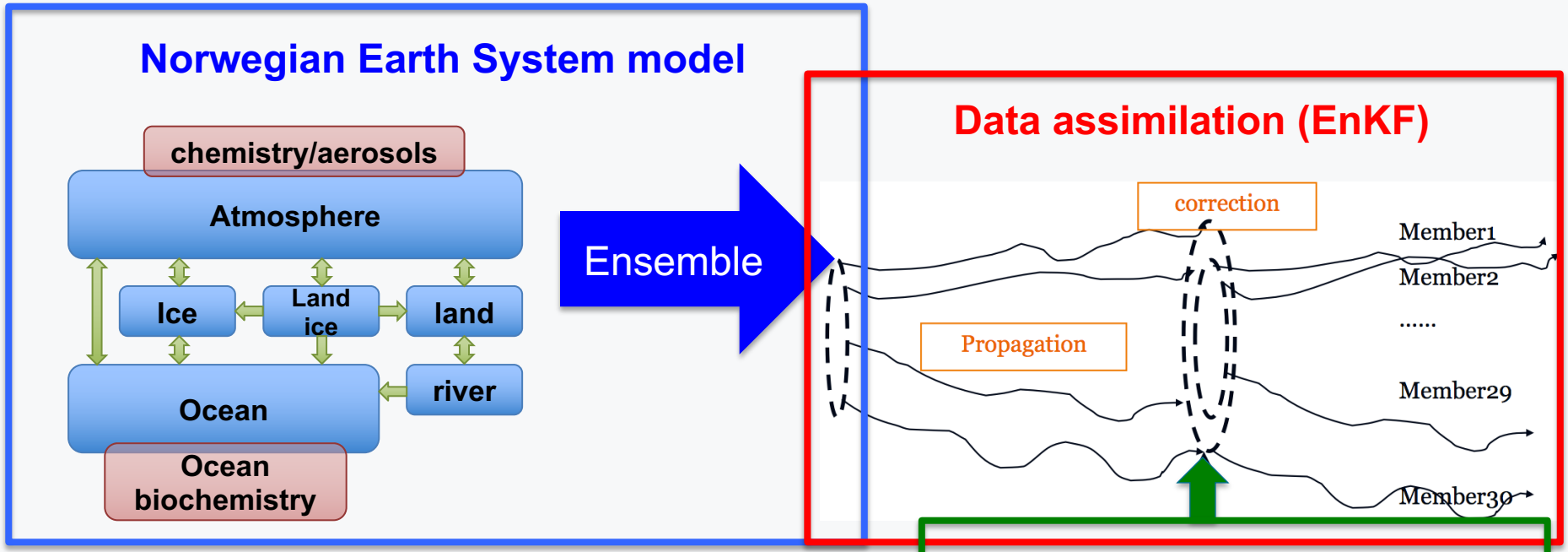
(Laloyaux et al., 2018)

# 2nd motivation: ocean's role in climate variability




Global heat budget Global water budget Global carbon budget (Schmitt, R.W. 2018)

# Norwegian Climate Prediction Model (NorCPM)




**Objectives:**

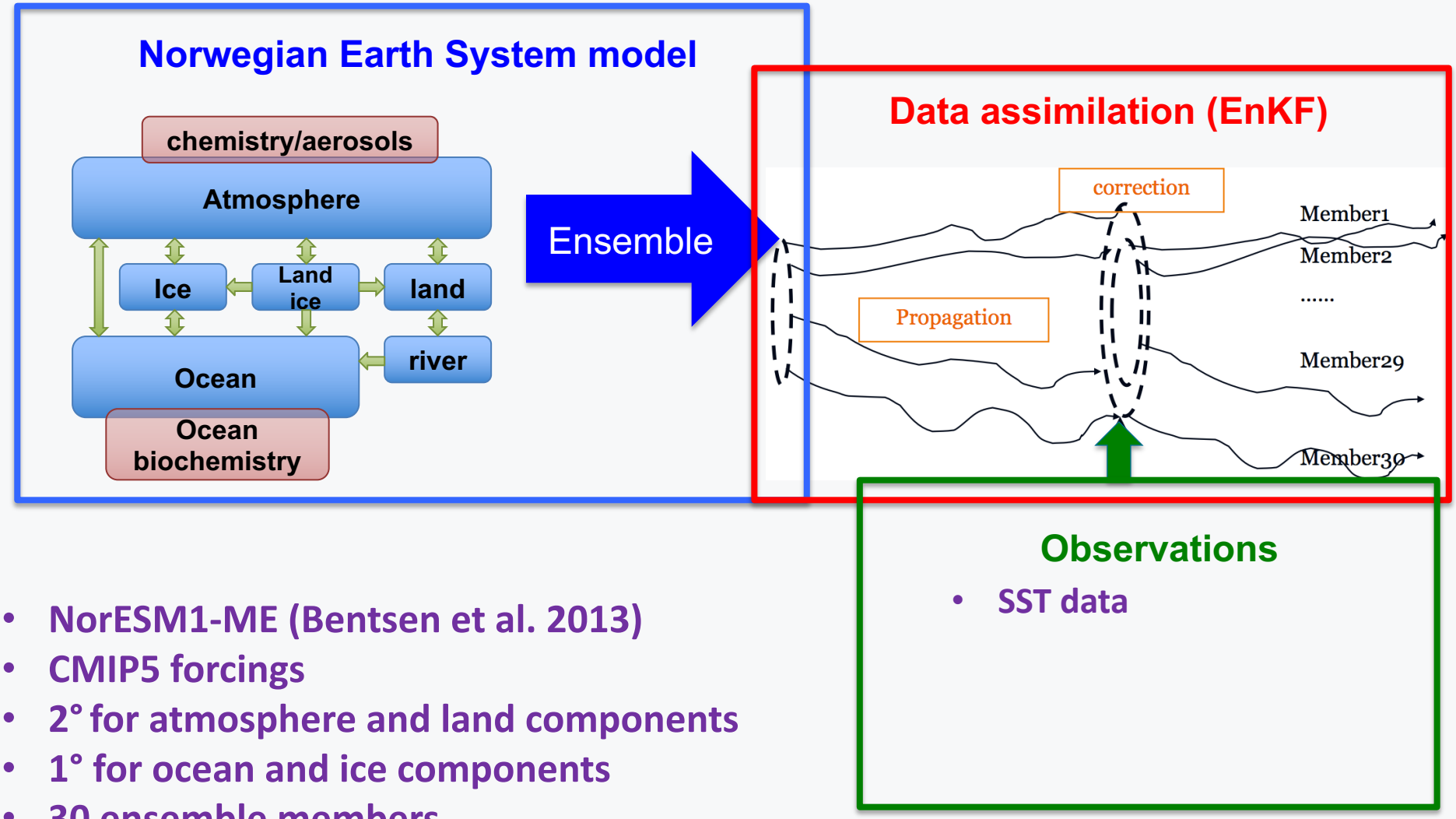
- **Climate prediction**
  - Seasonal time scale (SFI Climate Futures, SIPN)
  - Annual-to-decadal time scale (CMIP6 DCPP, WMO-ADCP)
- **Long climate reanalysis**
  - Instrumental (from 1850, CoRea)
  - Paleoproxy (last millennium, PARCIM)

**Observations**

- **OCN data**
- **ICE data**
- **Land data**
- **ATM data**

(Counillon et al. 2016; Bethke et al. 2021)

# Norwegian Climate Prediction Model (NorCPM)

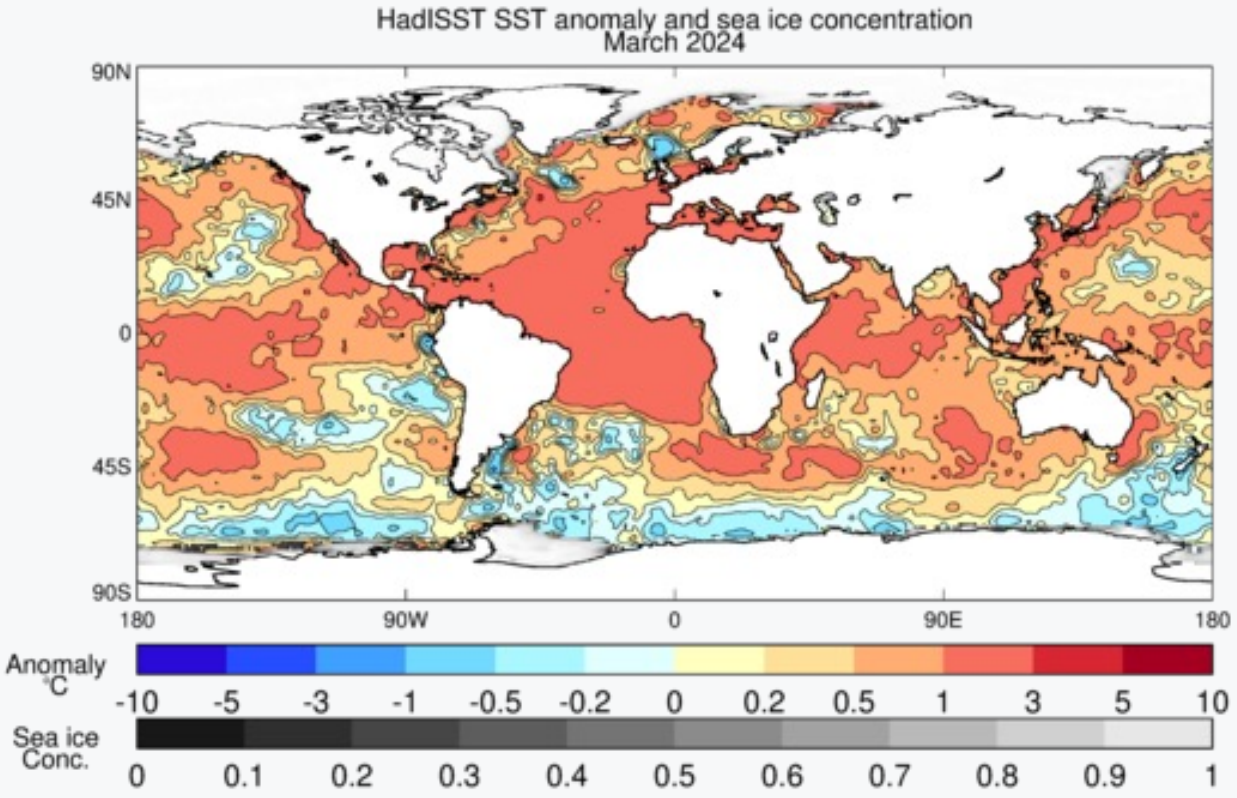


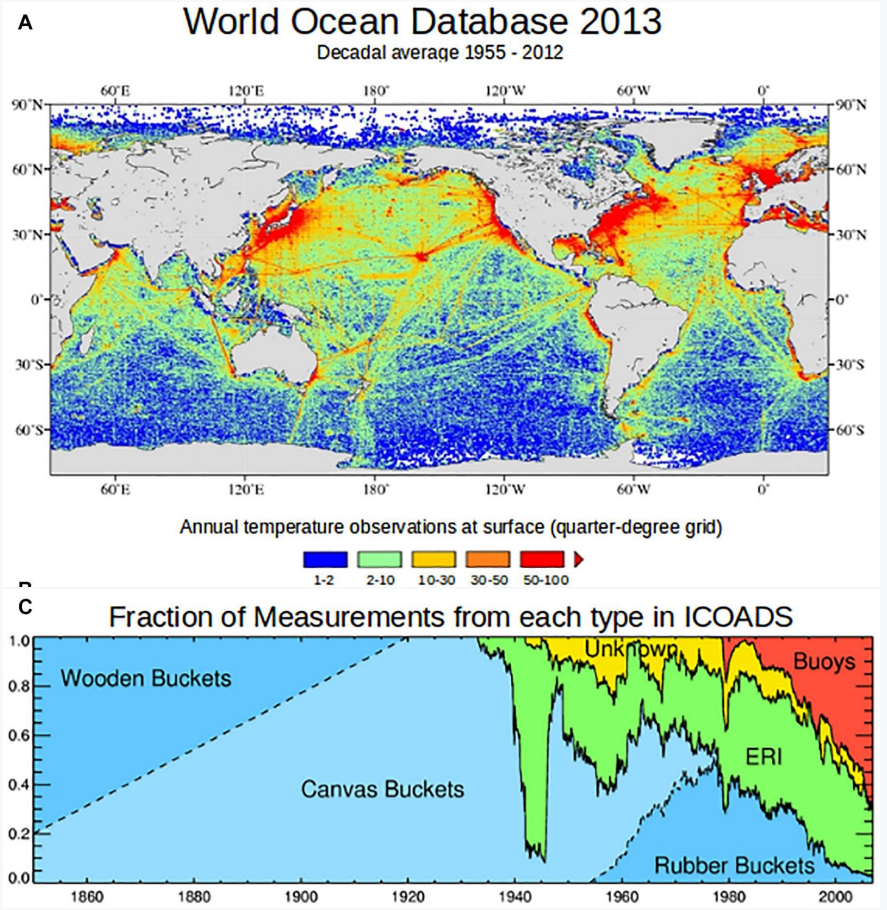

- NorESM1-ME (Bentsen et al. 2013)
- CMIP5 forcings
- 2° for atmosphere and land components
- 1° for ocean and ice components
- 30 ensemble members

(Counillon et al. 2016; Bethke et al. 2021)

# Why we assimilate solely SST in CoRea1860+?

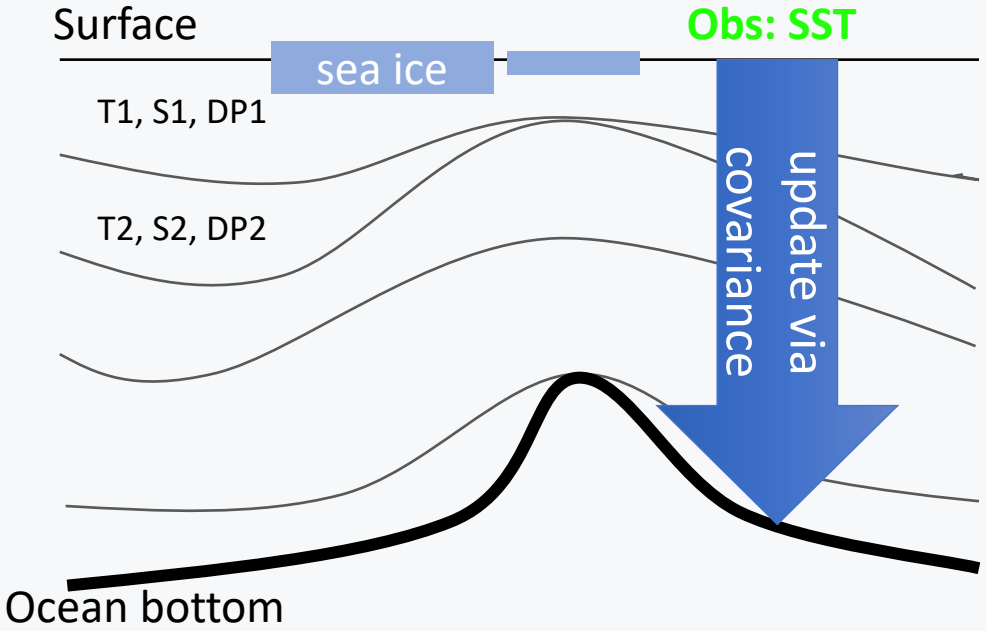
- SST data is the most primary instrumental data prior to the satellite era
- The use of new data in the course of the reanalysis introduces discontinuity
- The HadISST2.1 product (accounts for bias between measurements and provides a good uncertainty estimate) from 1860 to 2010
- OISSTV2 from 2011 onward

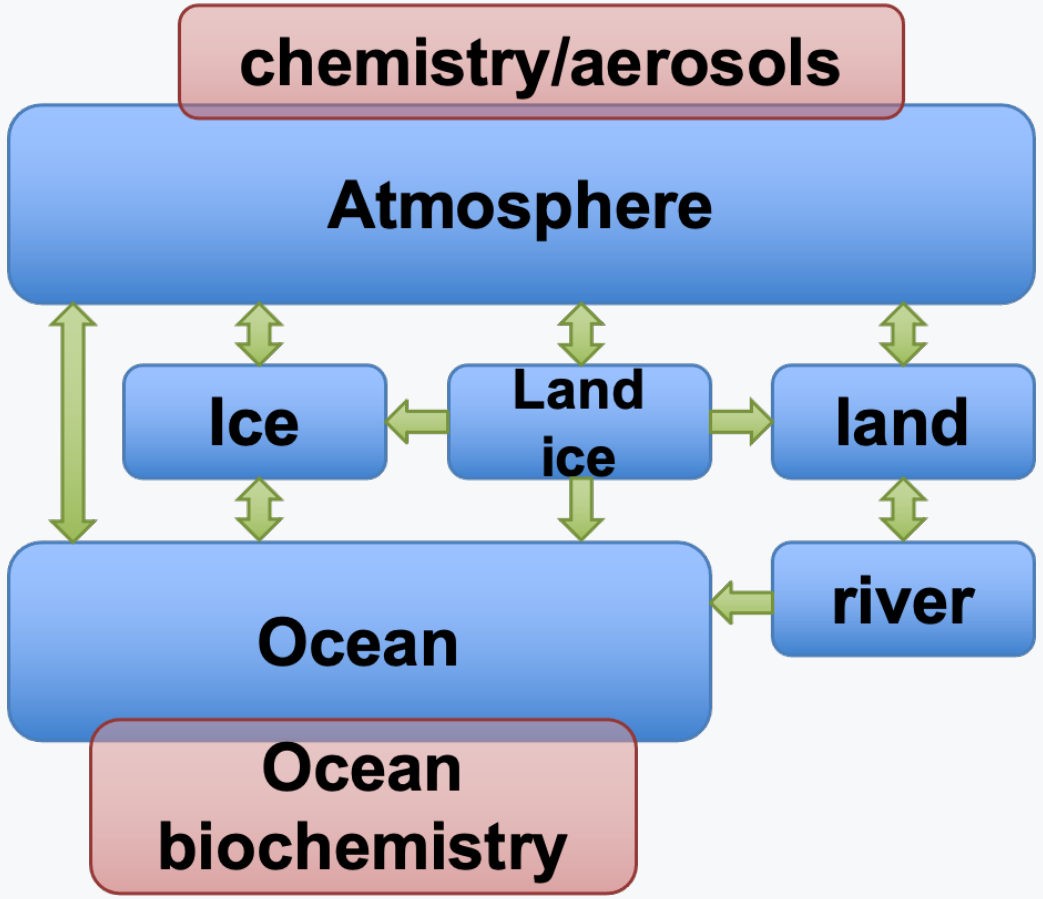



(O'Carroll et al. 2019)

# How are the other components updated?




Atmosphere and land components are updated via model integration.

# Error reduction ratio for T (left) and S (right)

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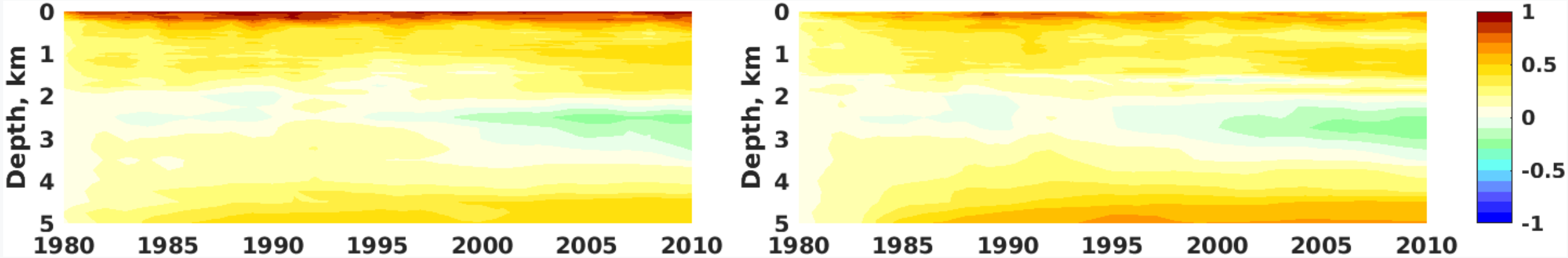
NOVL




JAMES | Journal of Advances in Modeling Earth Systems

Research Article | Open Access

**Adaptive Covariance Hybridization for the Assimilation of SST Observations Within a Coupled Earth System Reanalysis**

Sébastien Barthélémy, François Counillon, Yiguo Wang

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ORIGINAL RESEARCH article

Front. Clim., 15 December 2022
Sec. Predictions and Projections
Volume 4 - 2022 | https://doi.org/10.3389/fclim.2022.918572

This article is part of the Research Topic
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**Benefit of vertical localization for sea surface temperature assimilation in isopycnal coordinate model**

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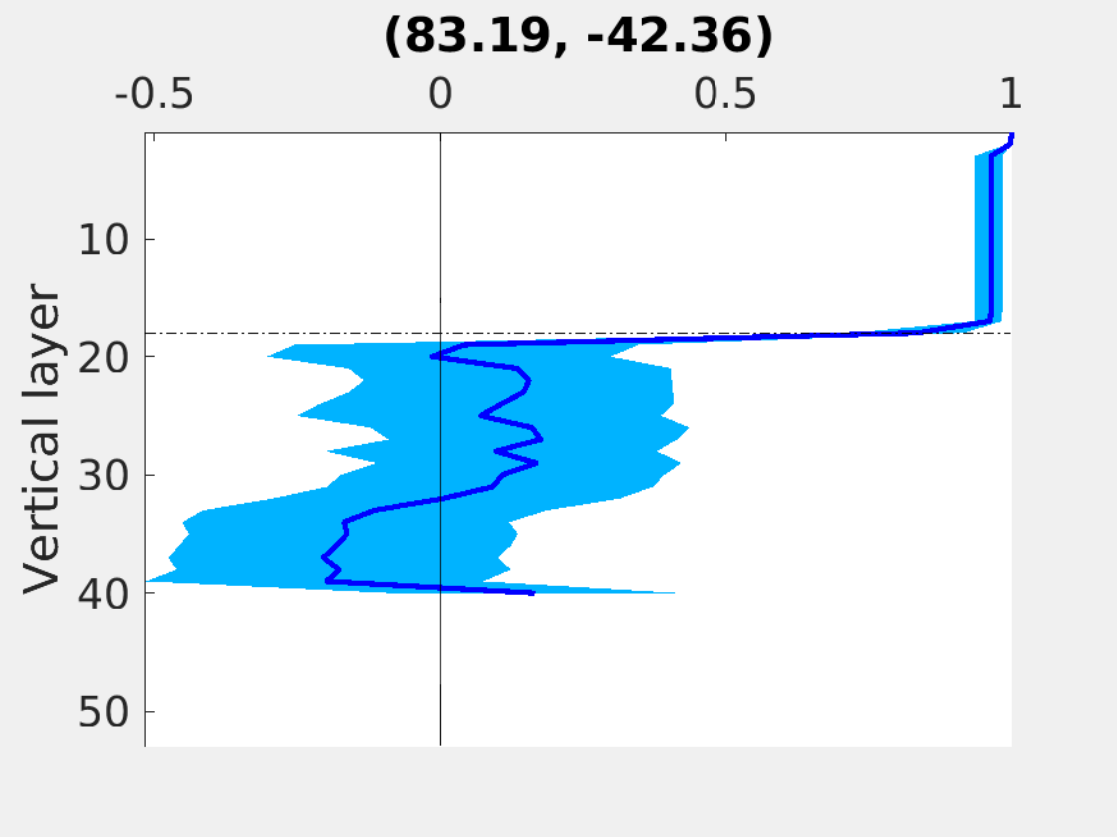
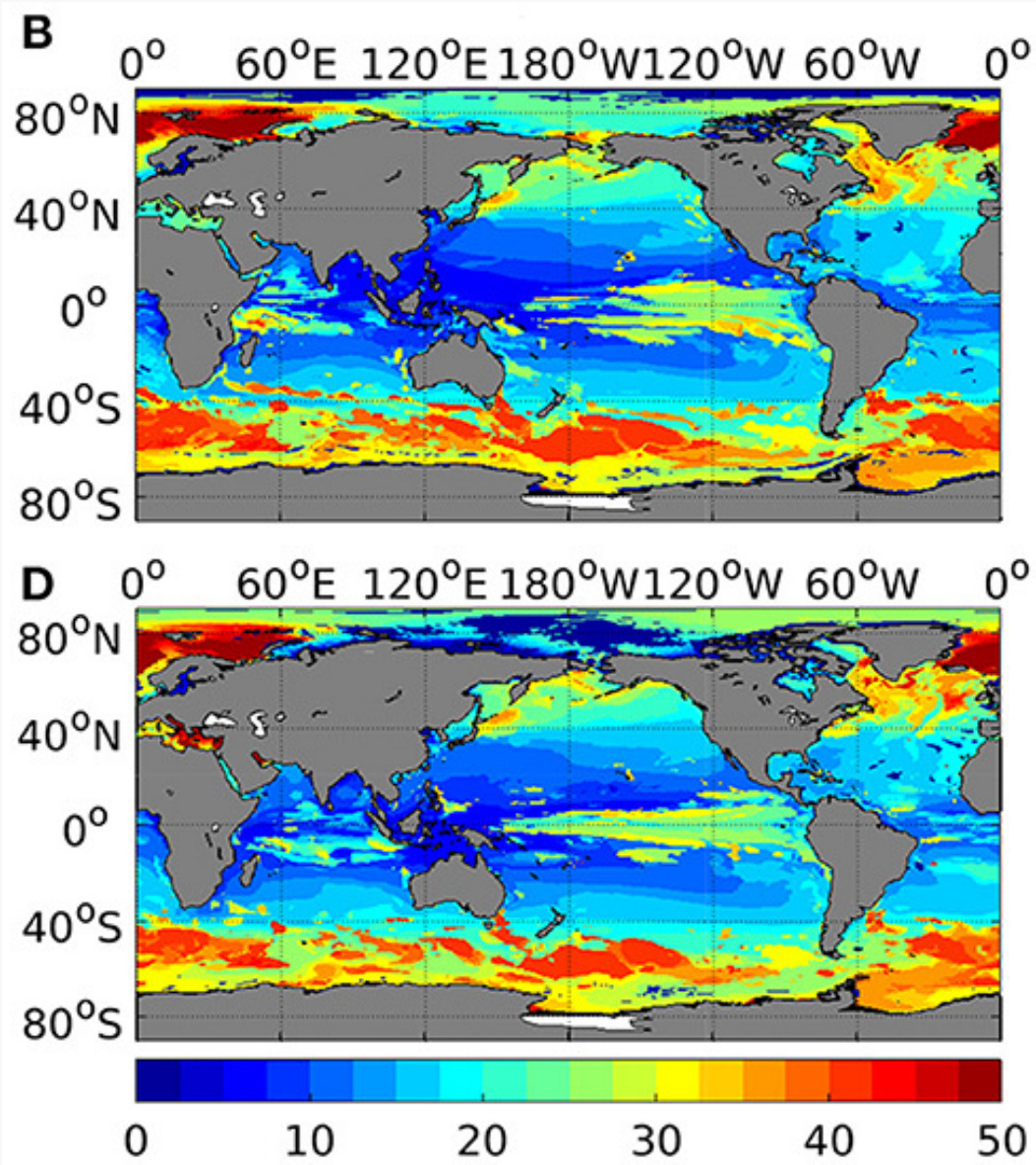
(Barthélémy et al., 2024; Wang et al., 2022)

# Vertical localisation




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




June

Dec

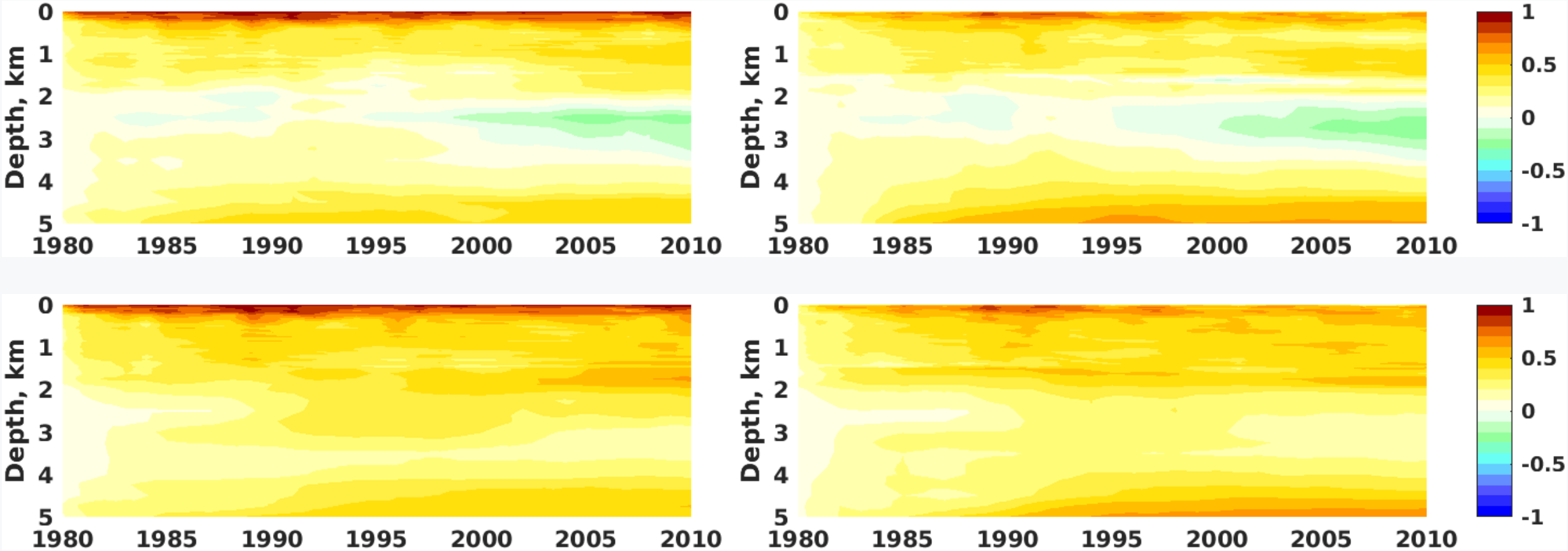
(Wang et al., 2022)

# Error reduction ratio for T (left) and S (right)

NERSC

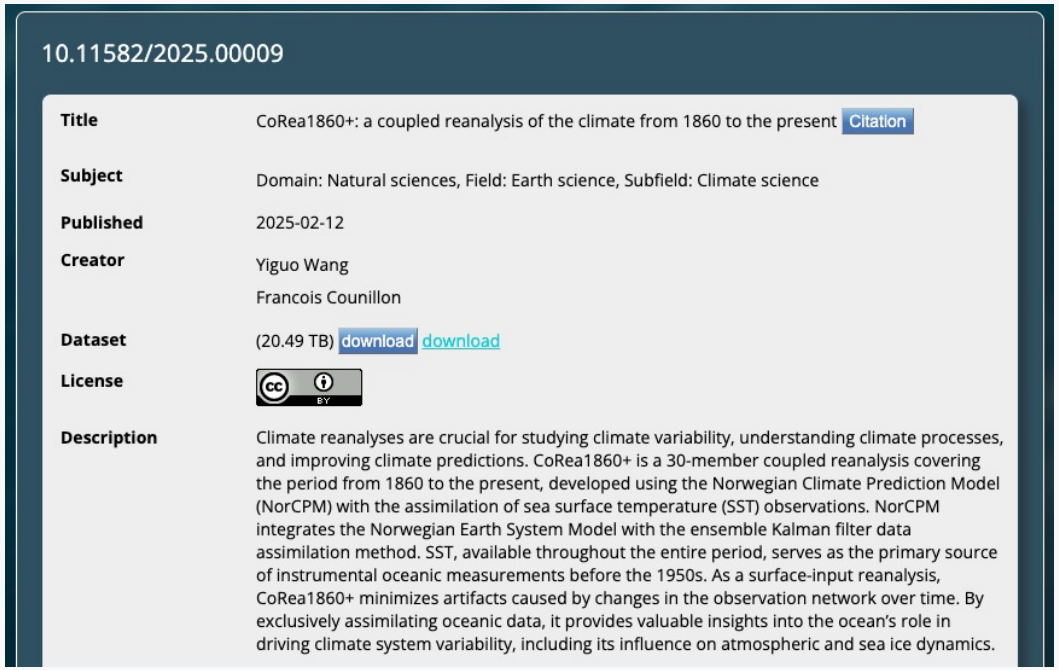
NOVL

VL




(Wang et al., 2022)

# CoRea1860+: a long dataset

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**Accepted**

Earth System Science Data

## An ensemble-based coupled reanalysis of the climate from 1860 to the present (CoRea1860+)

Yiguo Wang[1], François Counillon[1], Lea Svendsen[2], Ping-Gin Chiu[2], Noel Keenlyside[2], Patrick Laloyaux[3], Mariko Koseki[2], and Eric de Boisseson[3]

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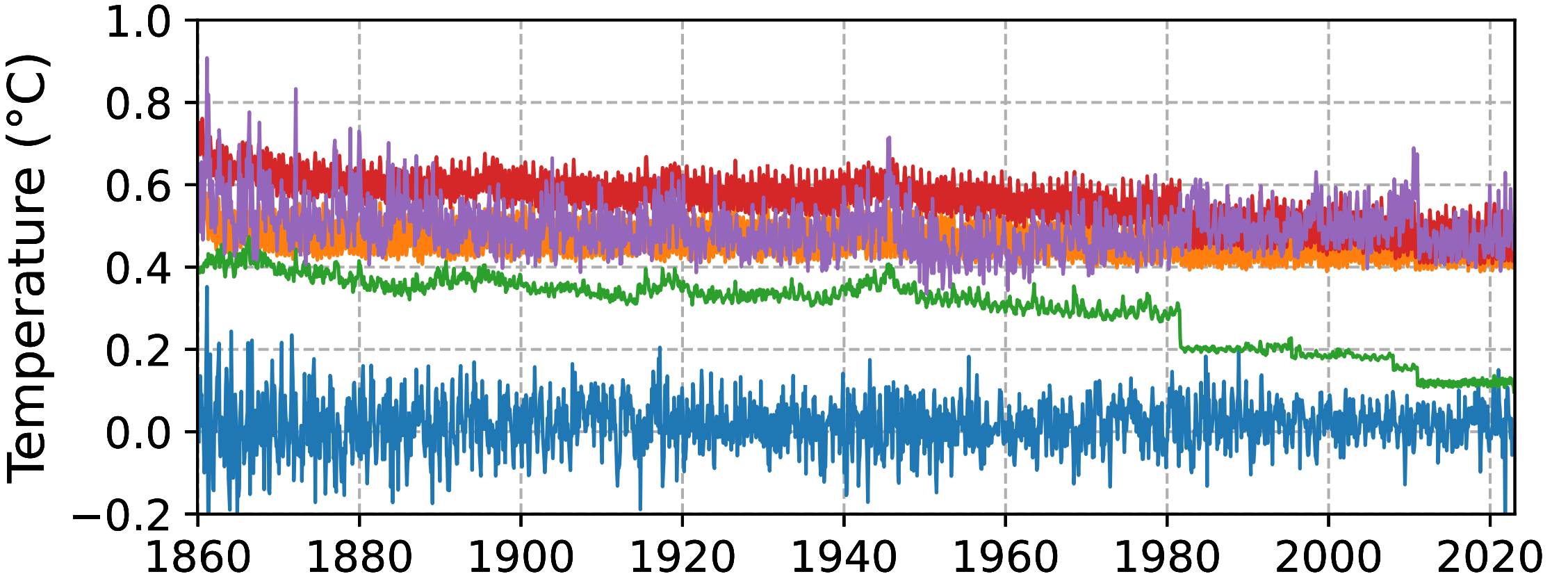
**Correspondence:** Yiguo Wang (yiguo.wang@nersc.no)

(Wang et al., 2025; Wang and Counillon, 2025)

# Reliability: ensemble can quantify the error?



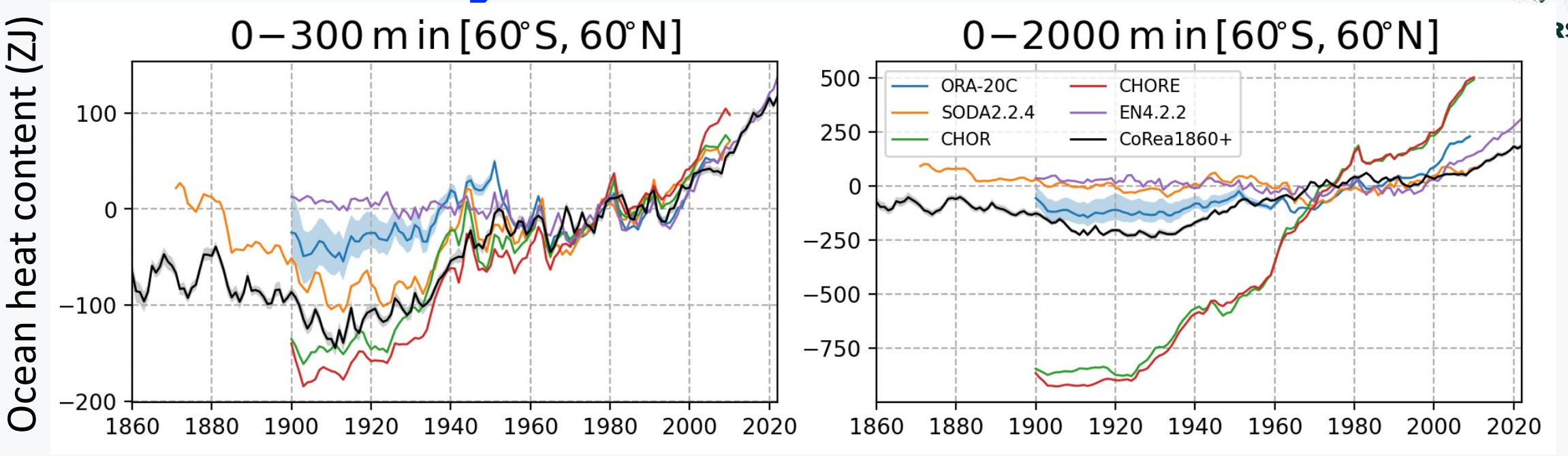

mean difference  model ensemble spread  observation uncertainties

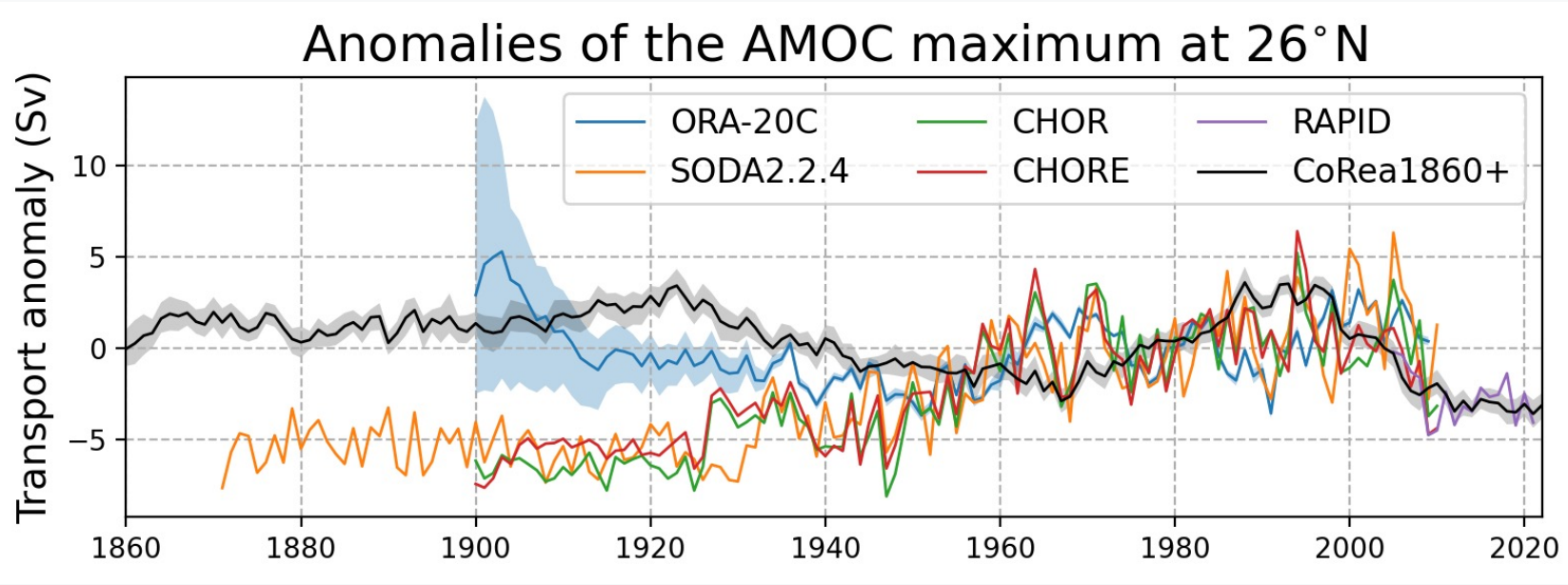
total error  RMSE

(Desroziers et al., 2005)

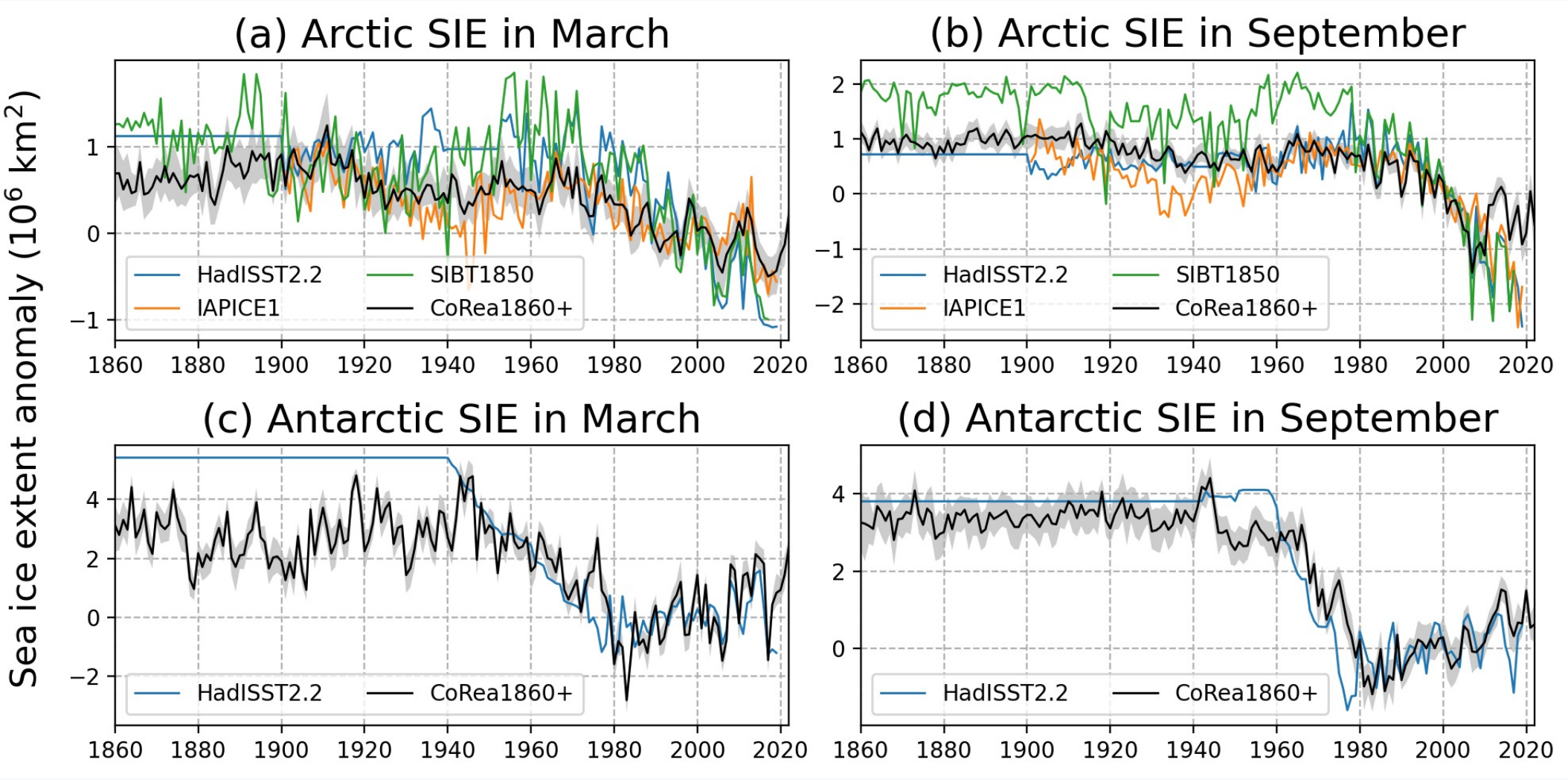
**The system is reasonably reliable!**

# Ocean variability



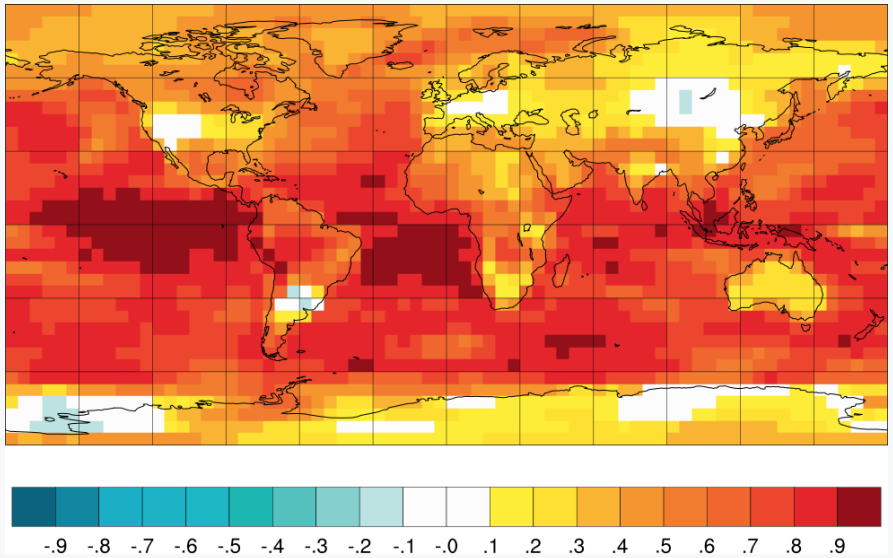
# Sea ice extent variability



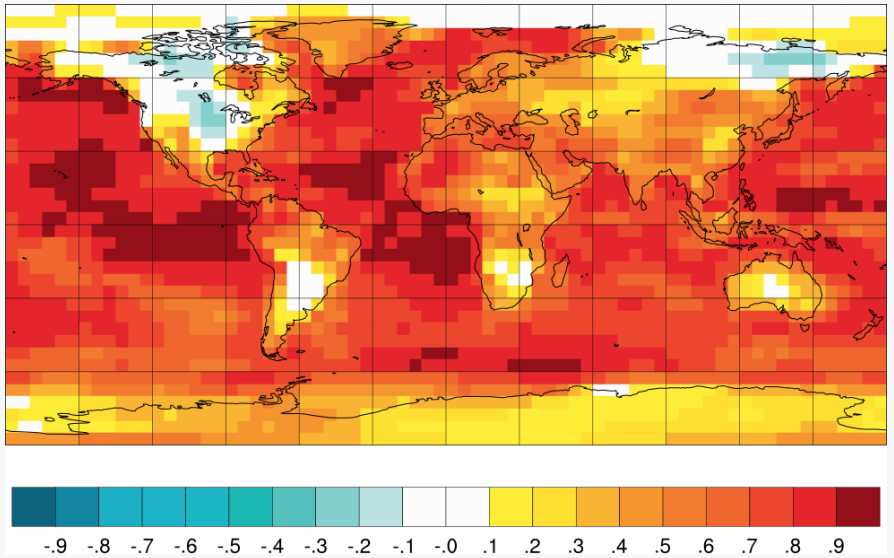

**Decline from 1940 to 1980 is consistent with previous studies (e.g., Fogt et al., 2022; Dalaiden et al., 2023; Goosse et al., 2024; Divine et al., 2024).**

# Air surface temperature and sea level pressure

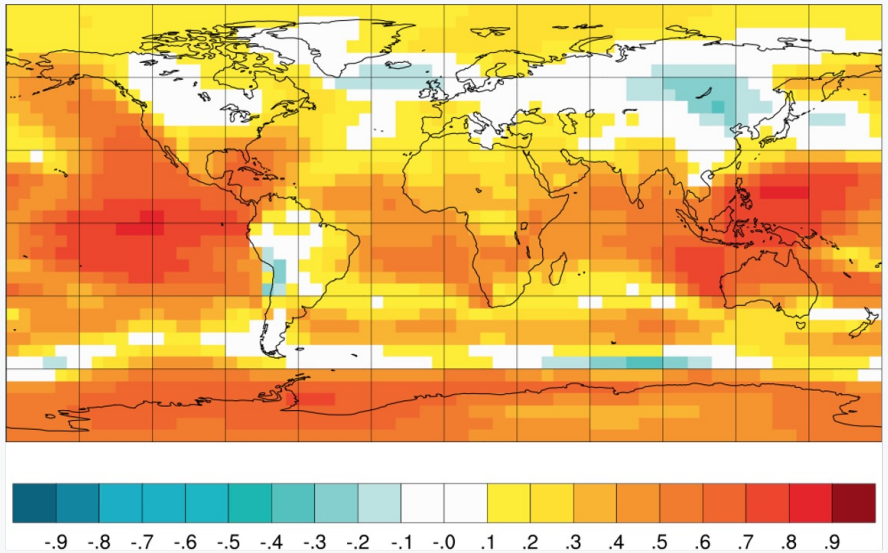
ACC(CoRea1860+, ERA-20C) (DJF)



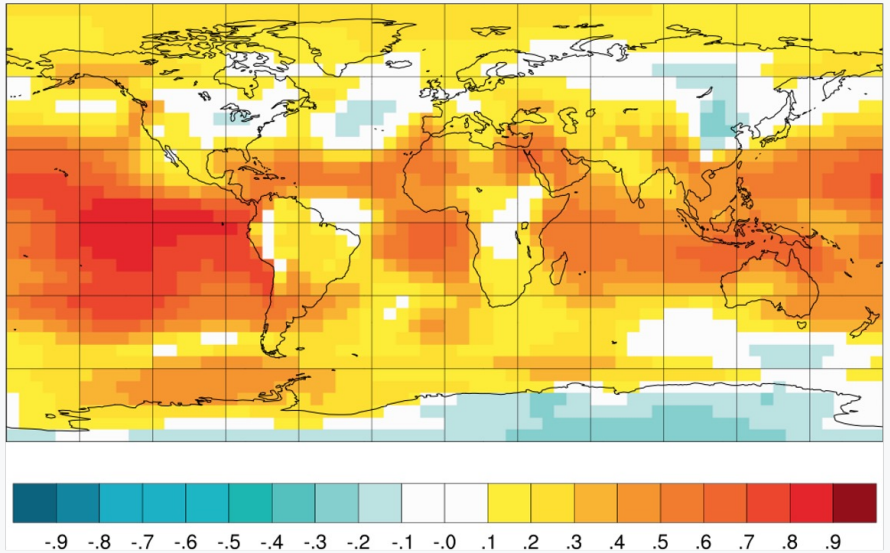

ACC(CoRea1860+, ERA-20C) (JJA)



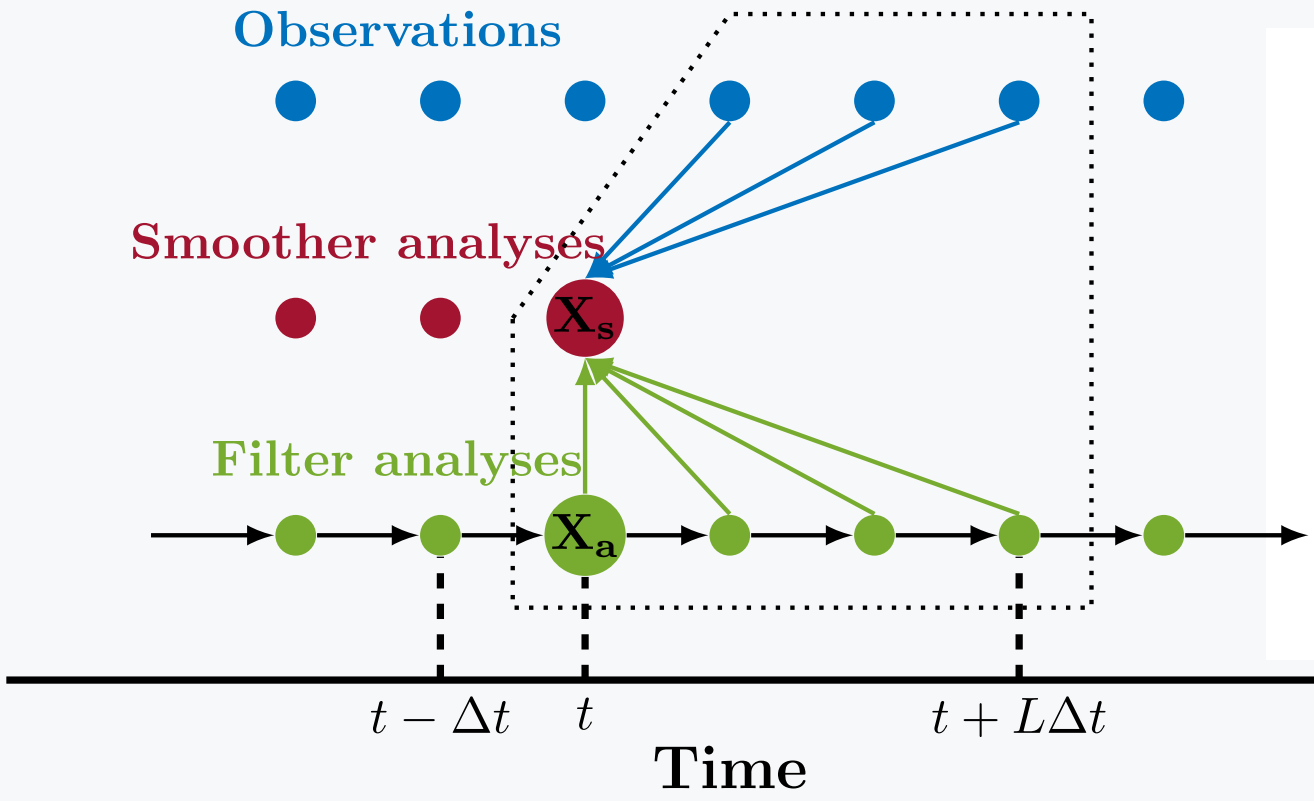

(e) ACC(CoRea1860+, ERA-20C) (DJF)

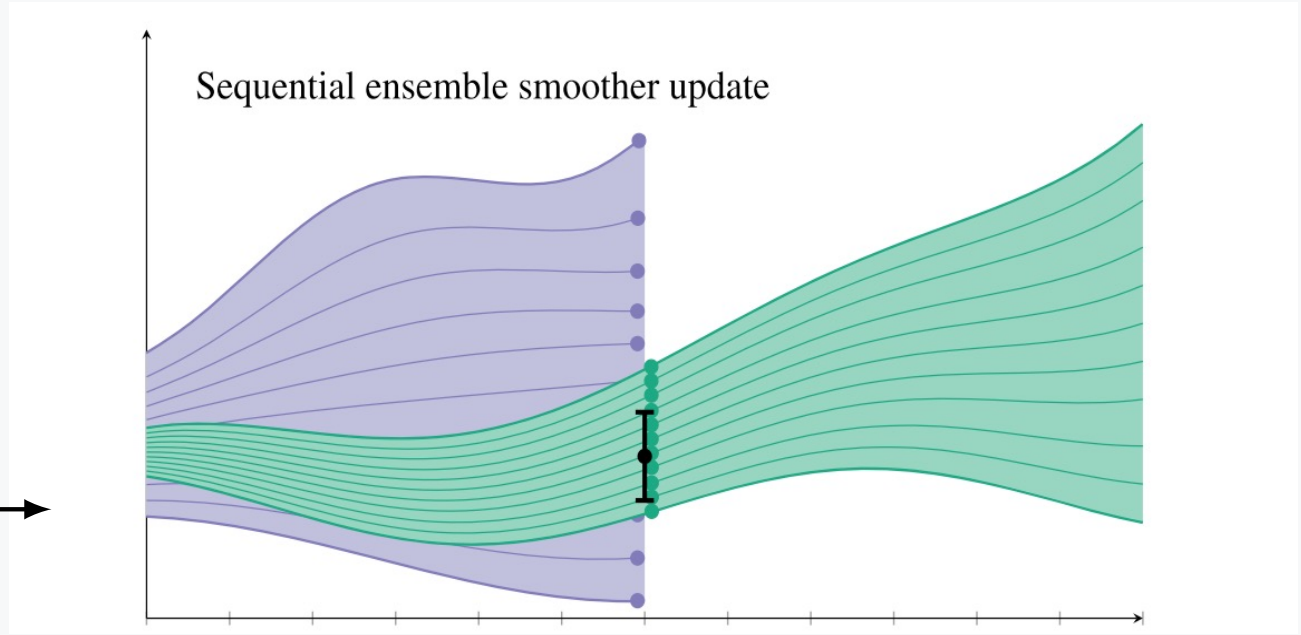



(f) ACC(CoRea1860+, ERA-20C) (JJA)



# Offline EnKS



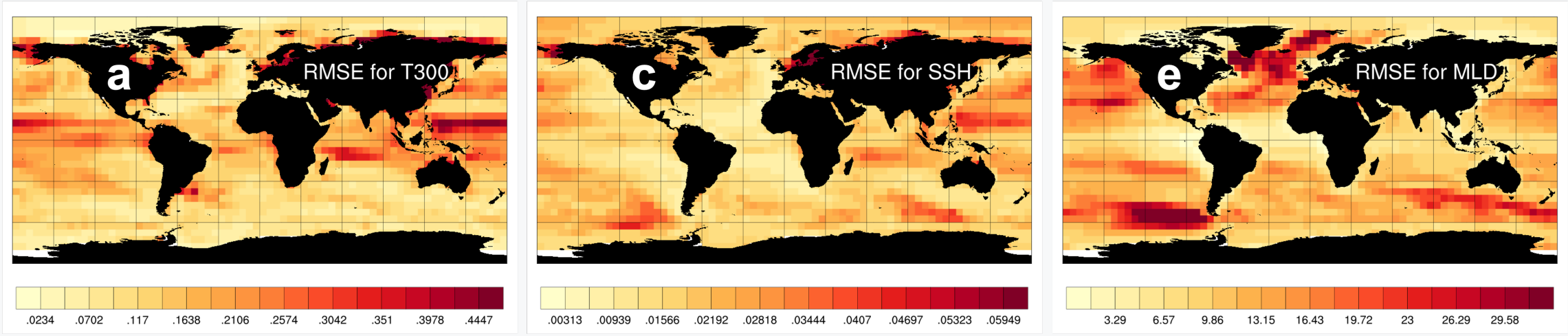

(Evensen et al., 2022)

- Past and present observations as ensemble filter
- Future observations via cross-time error covariances
- Numerically cheap
- Tested in Lorenz 1963 (Dong et al., 2023)
- Investigate whether the offline EnKS as post-processing approach can improve long-term climate reanalyses

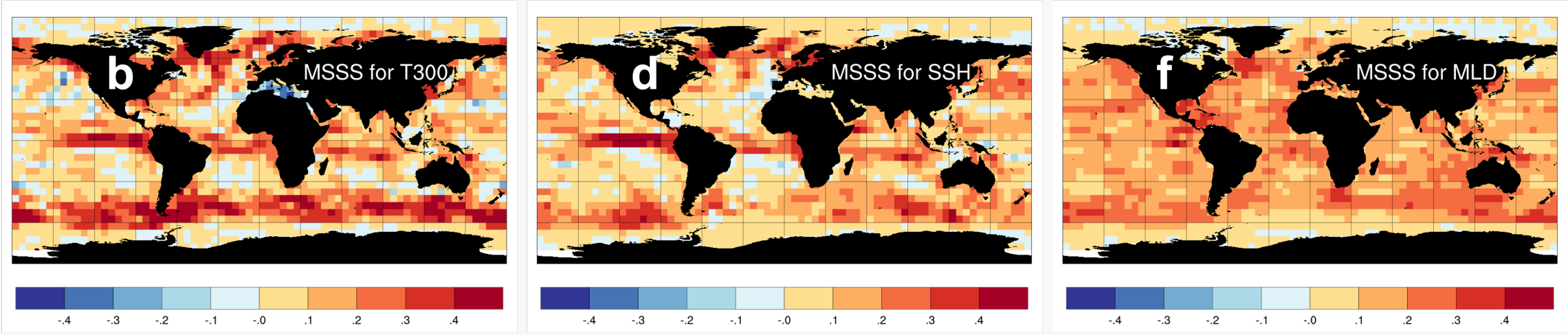
# Twin experiments: monthly T300, SSH and MLD

NERSC

RMSE

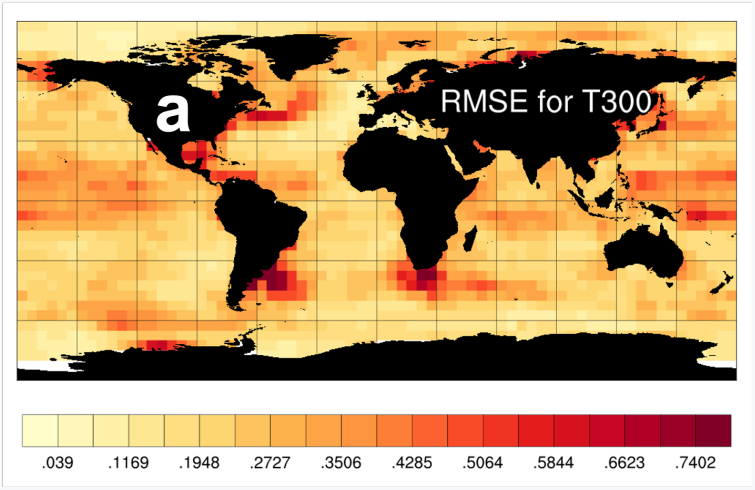


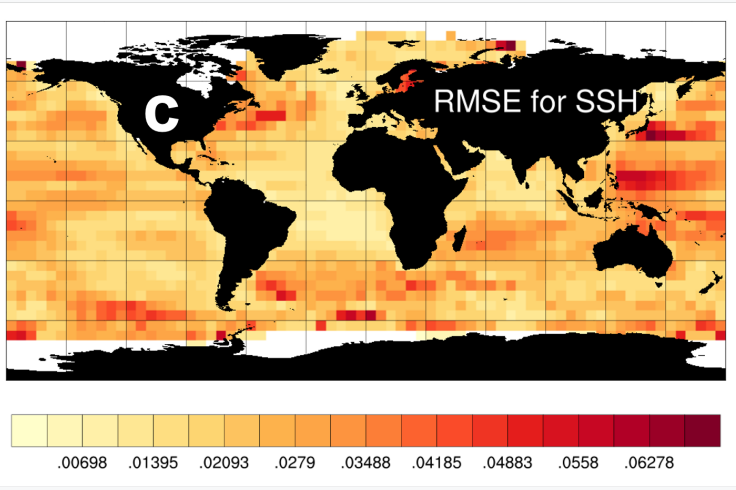

MSSS

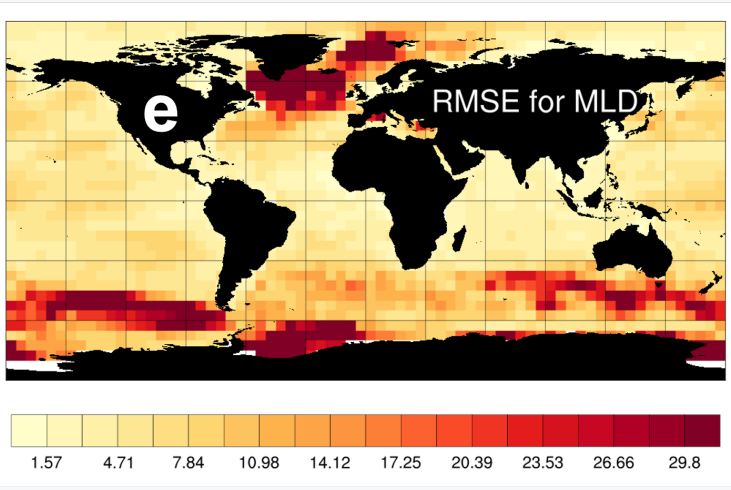


# Real experiments: Yearly T300, SSH and MLD

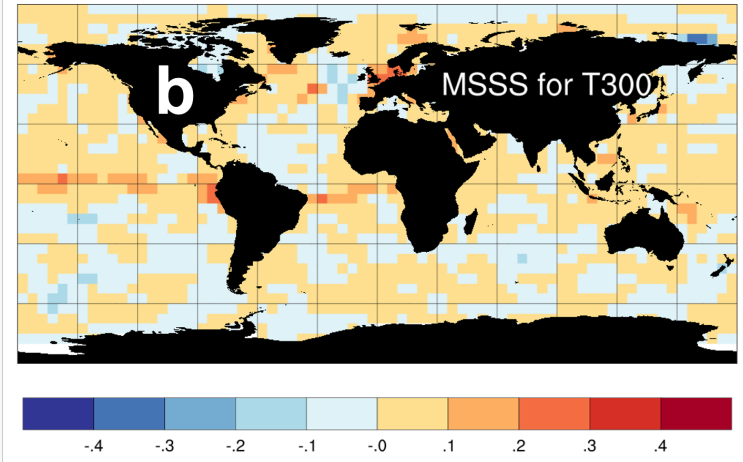
RMSE

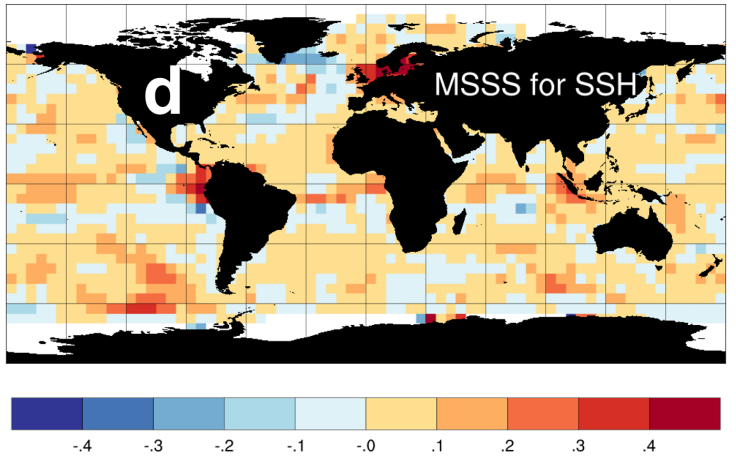


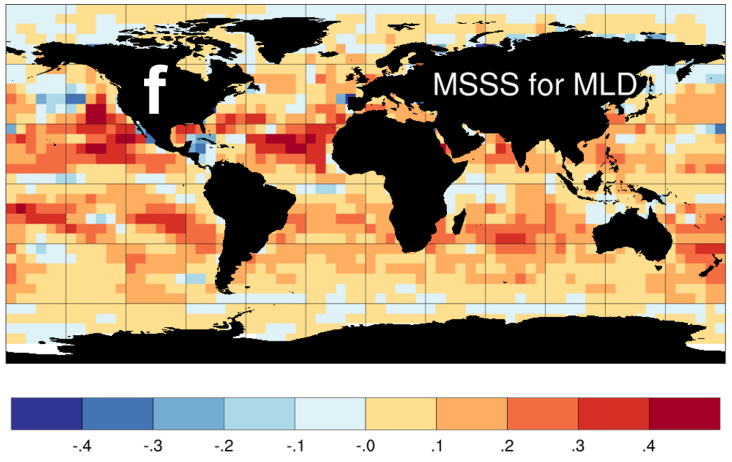



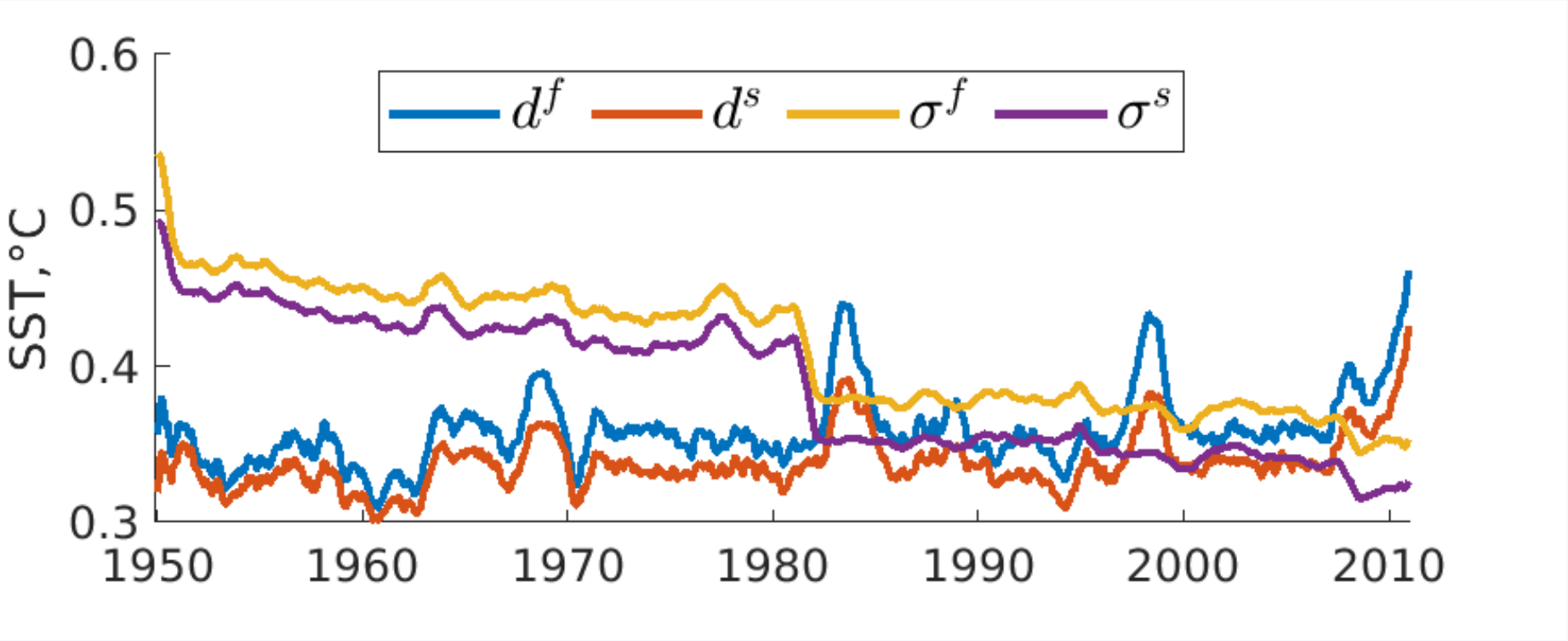

MSSS



# Real experiments: reliability (Desroziers et al. , 2005)




$$d = \sqrt{\sum_i w_i d_i^2},$$

$$\overline{\sigma^r} = \sqrt{\sum_i w_i \left(\sigma_i^r\right)^2},$$

$$\overline{\sigma^o} = \sqrt{\sum_i w_i \left(\sigma_i^o\right)^2},$$

$$\sigma = \sqrt{\left(\overline{\sigma^r}\right)^2 + \left(\overline{\sigma^o}\right)^2},$$

- **Smoother reduces both RMSE and total error (i.e., combination of obs and background errors)**
- **Reliability is not significantly change**

# Take-home messages

- Vertical localisation improves the performance of reanalysis
- CoRea1860+:
  - + coupled, stochastic (30 mems), continue (one stream, SST assimilation), …
  - - no atmospheric data assimilation, coarse resolution, model bias,…
  - + reliability, and ocean, sea ice and atmosphere variability
- An offline EnKS technique is cheap and seems promising to improve the accuracy of the reanalysis.