Improving high-resolution ocean reanalyses using a smoother algorithm

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Motivation

- Long memory and sparse observation of the ocean
  – use “future” data to improve historical state estimate

- Operational Ocean Forecasting is sequential (**only using past data**), e.g., 3DVar-FGAT. Same method used for Reanalysis! =>**Future data not being used**!

- **Increments** from reanalysis are archived.

- Smoother uses increments for smoothing in future data.

Simple smoothing algorithm

Smoothing **S**, of Analysis **A** + Increments **I**; Time decay γ where $\gamma < 1$

$$S_{t=0} = A_{t=0} + \gamma\, I_{t=1} + \gamma^2 I_{t=2} + \gamma^3 I_{t=3} + \gamma^4 I_{t=4} + \ldots\ldots$$

$$S_{t=1} = A_{t=1} + \gamma\, I_{t=2} + \gamma^2 I_{t=3} + \gamma^3 I_{t=4} + \gamma^4 I_{t=5} + \ldots\ldots$$

$$S_0 = A_0 + \gamma[S_1 - A_1 + I_1]$$

Smoother Analysis Smoother increment

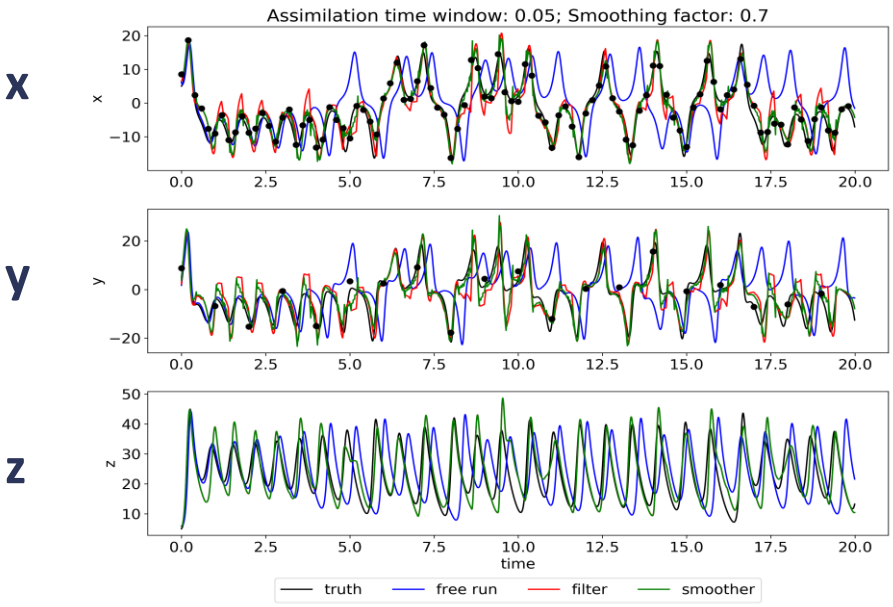
Recursive relationship: Start at latest time t and work backward through reanalysis

- Decay timescale $\tau = -1/\ln(\gamma)$ *e.g., ~3 days for* $\gamma = 0.7$
- Variations in γ(x,y,z) possible

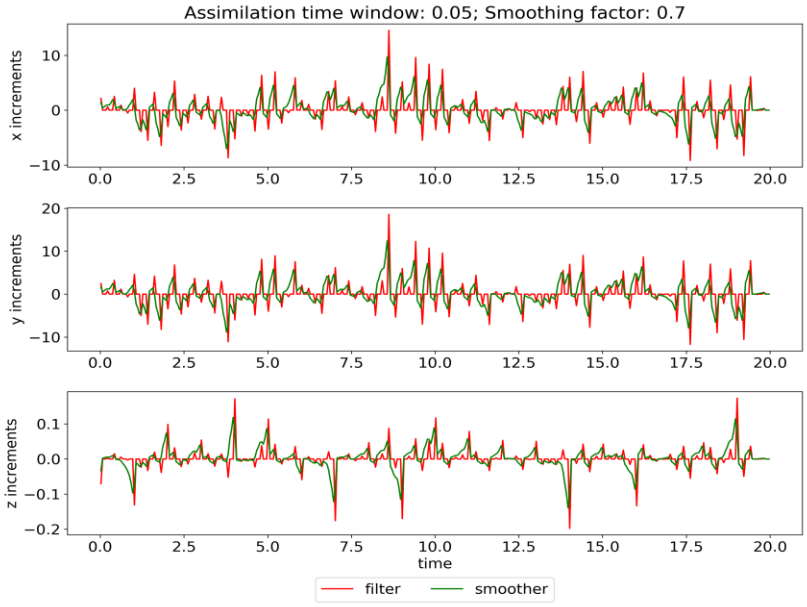
Lorenz 1963 twin

x observation frequency 20 timesteps
y observation frequency 100 timesteps
no z observation
Analysis time window 5 timesteps using 3DVar-FGAT

Truth, **free model run**
Analysis and **Smoother** solutions



Increments: **Analysis** vs. **Smoother**



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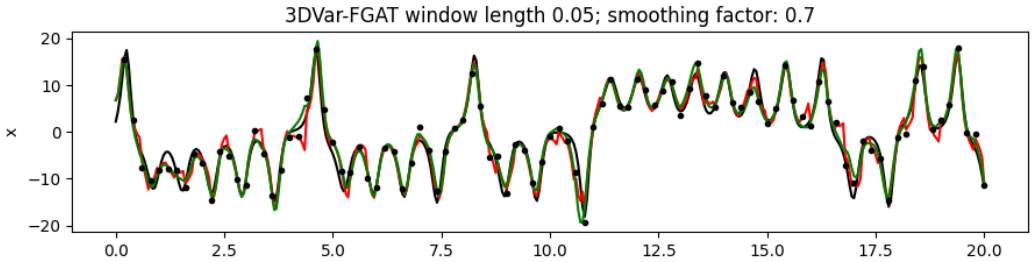
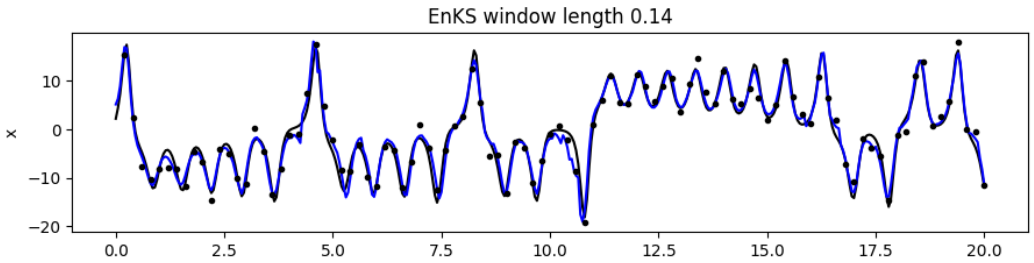
Compare ocean smoother with EnKS

Truth
Analysis
Smoother

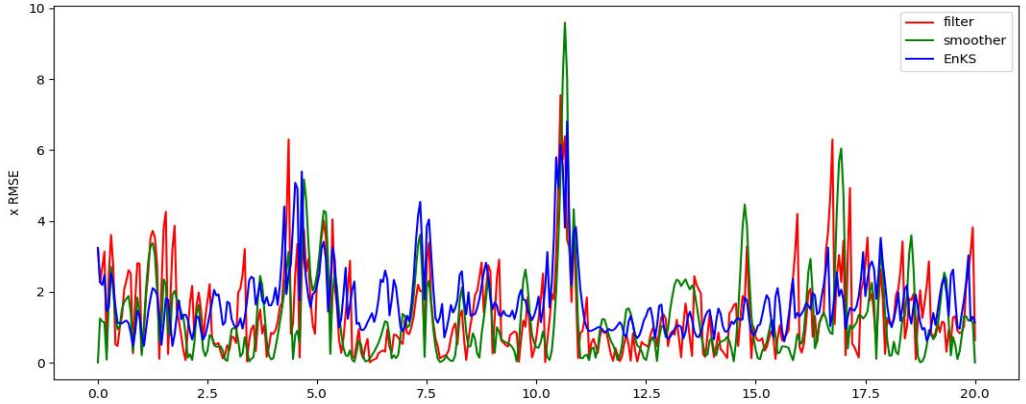


EnKS



- Ensemble size 100
- Lag = 14 timesteps (~2.8 window)

ensemble RMSE



Mean RMSE

Analysis – 1.73
EnKS – 1.69
Smoother – 1.36

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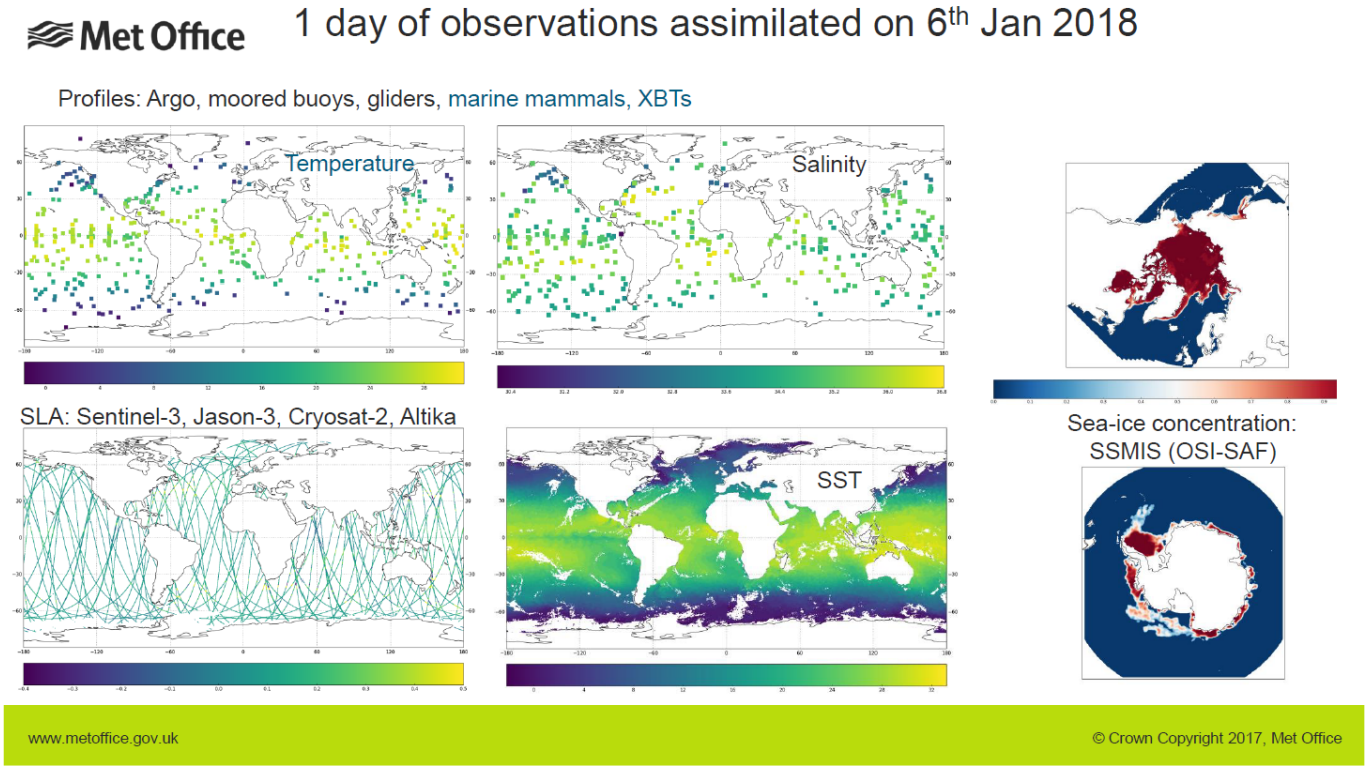
Smoother for GloSea5 (FOAM) ocean reanalysis

- Smoother increment added on T and S fields.
- SSH and U,V increments are in geostrophic balance with the density field increments



- Forecasting Ocean Assimilation Model (FOAM) version 14 ocean reanalysis, global ¼° resolution
- Daily Incremental 3DVar-FGAT
- Incremental analysis update (IAU): assimilation increments are added evenly in the 1-day window during analysis run

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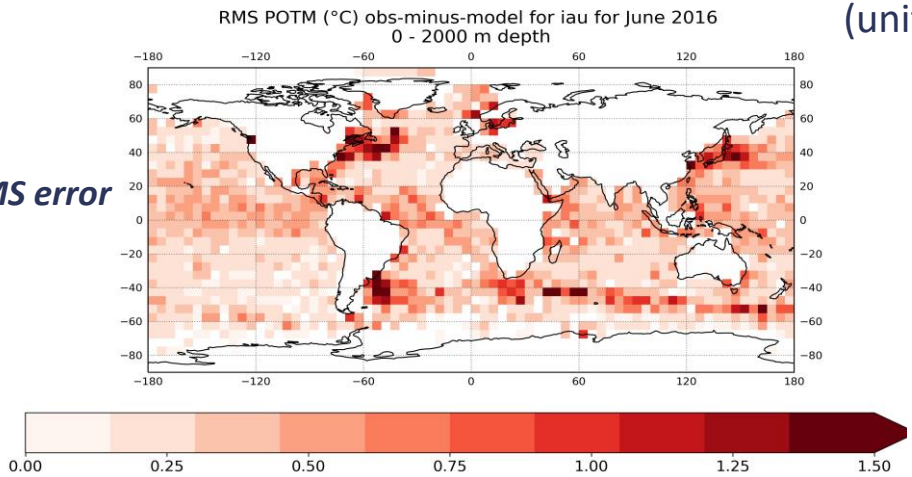
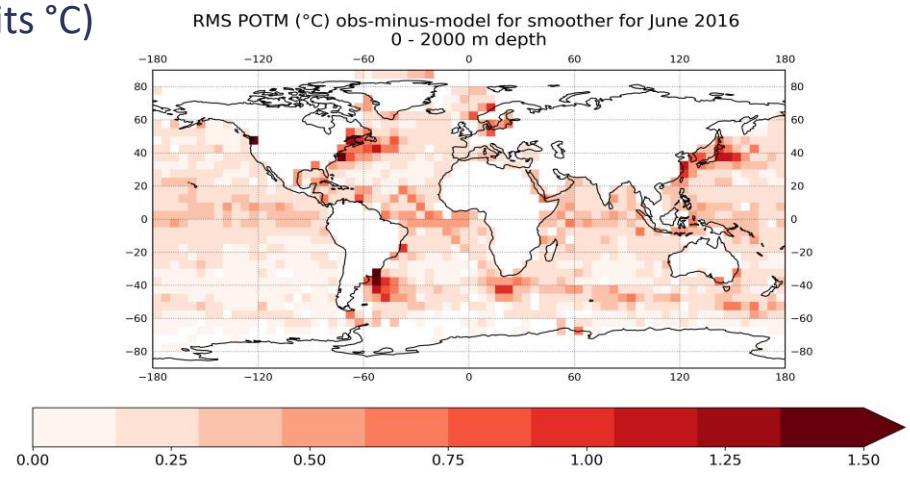
Temperature errors against Argo Observations - June 2016

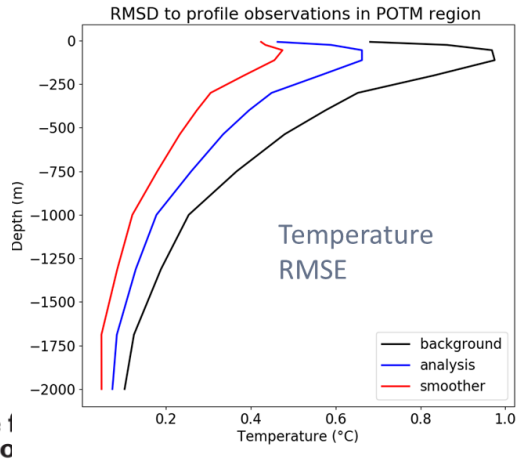
FOAM Analysis (units °C) ***Smoother***

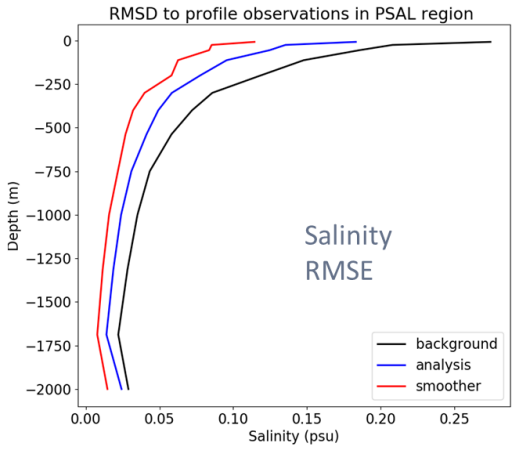
RMS error





Global mean RMS differences





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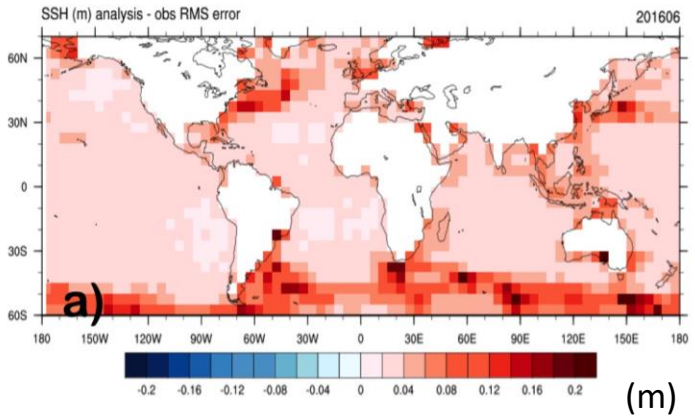
RMS SSH errors against Altimeter Observations

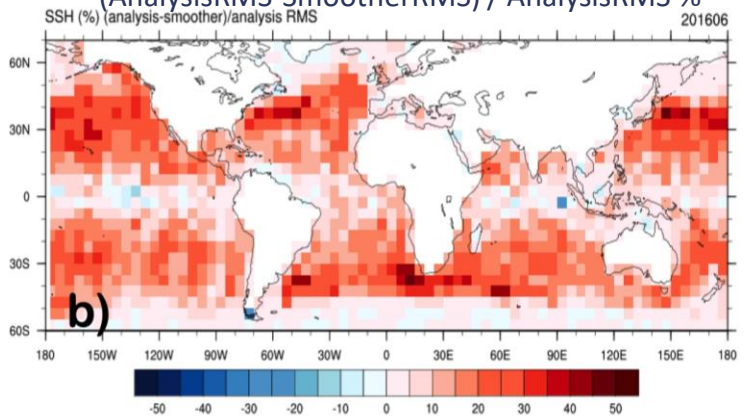
FOAM SSH Analysis errors



(m)

Smoother % SSH error reduction vs. Analysis

(AnalysisRMS-SmootherRMS) / AnalysisRMS %

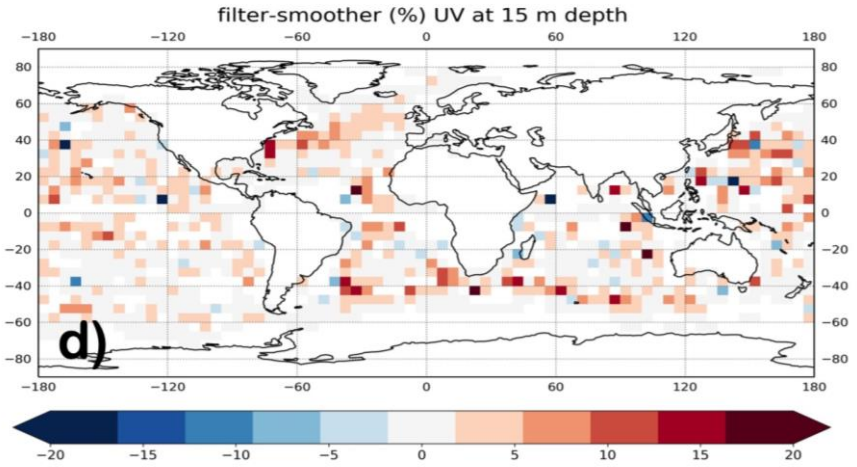


SSH error reduction in smoother is up to 50% compared to FOAM analysis

RMS velocity errors against 15m Drifters

Smoother % U,V (15m) error reduction vs. Analysis

Independent Drifter Comparison



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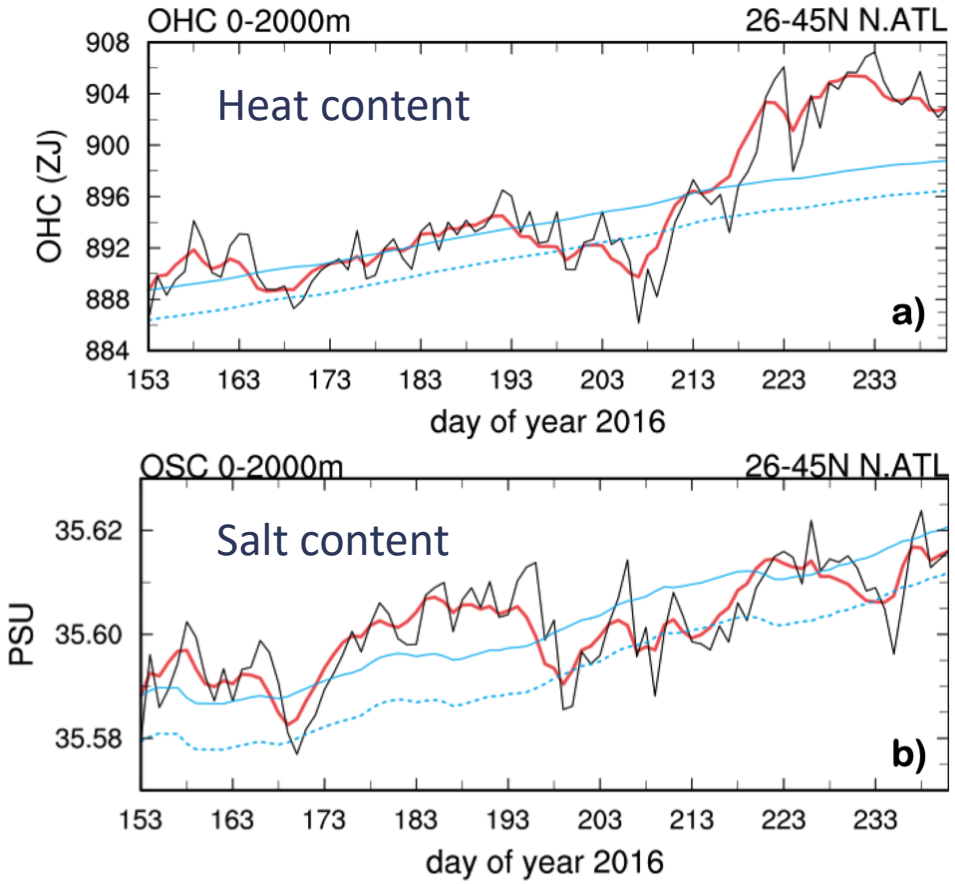
Smoothed Regional Ocean Heat & Salt content

North Atlantic



Smoother vs. Analysis

Artificial free model run: stringing together OHC 1-day tendencies from the *background* runs

High frequency changes taking place in the analysis run are coming directly from the DA

Summary

- Ocean smoother performs well in Lorenz 63 and FOAM models
- Only future increments are smoothed – internal high frequency variability is retained
- Inexpensive to run! -- advantage over 4DVar and Kalman smoother in global high resolution model.
- Works effectively where
  - observations made in new regions which were not available at all in the forward pass
  - the system evolution is relatively slow so that error covariances do not evolve rapidly