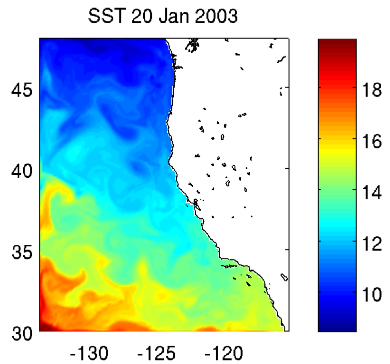
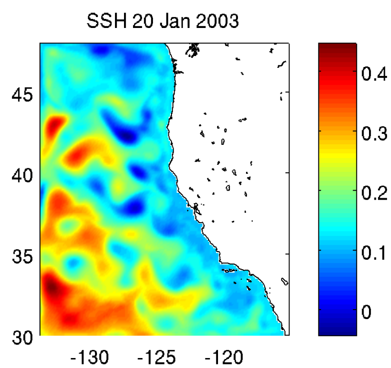
Lecture 4:
Observing System Simulation Experiments (OSSEs)

OSSE experiments to explore effects of:

- **number of outer-loops**
- **assimilation window length**
- **horizontal & vertical correlation lengths**
- **error models (incl innovation statistics)**
- **starting point**
- **errors in surface boundary conditions**
- **errors in open boundary conditions**
- **innovation pdfs**
- **independent obs**

Model Configuration





4D-Var

- **Dual**
- **B-preconditioned, Lanczos, RPCG**
- **Adjust i.c. only in most expts**
- **BGQC: ±3σ**

Nature run:

- **1999-2010 COAMPS**
- **Jan-Apr 2003**

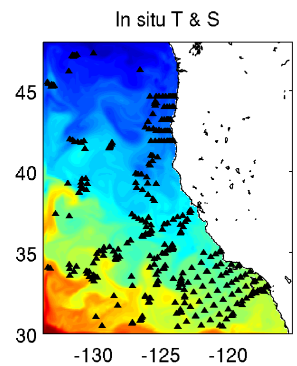
Observations:

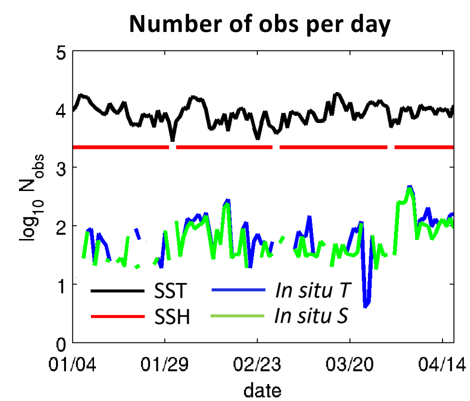
- **Satellite SST – daily (AVHRR, AMSR, MODIS)**
- **Aviso gridded SSH - daily**
- ***In situ* T & S profiles**
- **4 Jan – 18 April 2003**

First-guess:

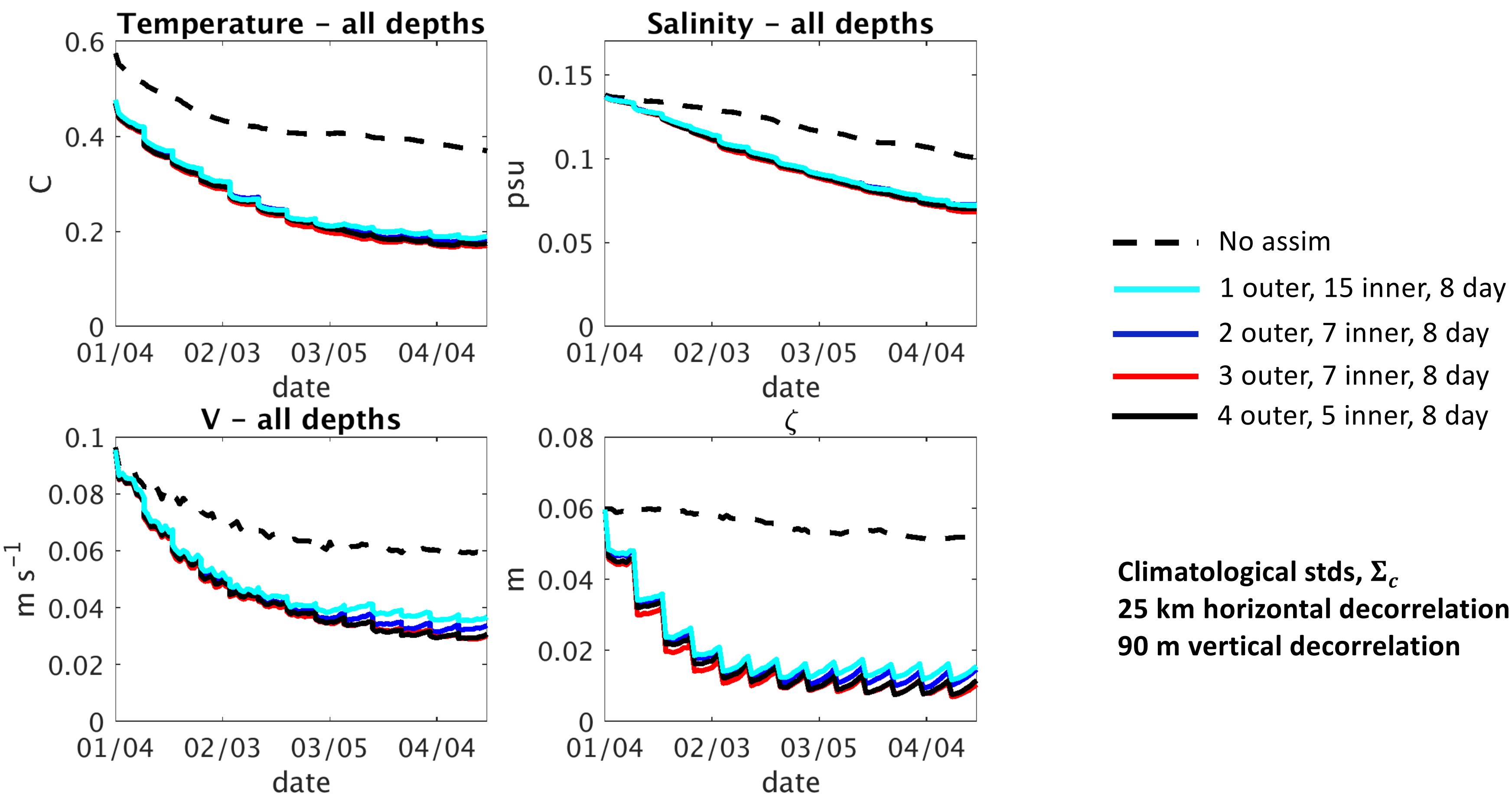
- **1980-2010 ERA+CCMP**
- **Reanalysis**

- 10km resolution. 42 σ-levels
- NRL COAMPS forcing
- SODA open boundary conds



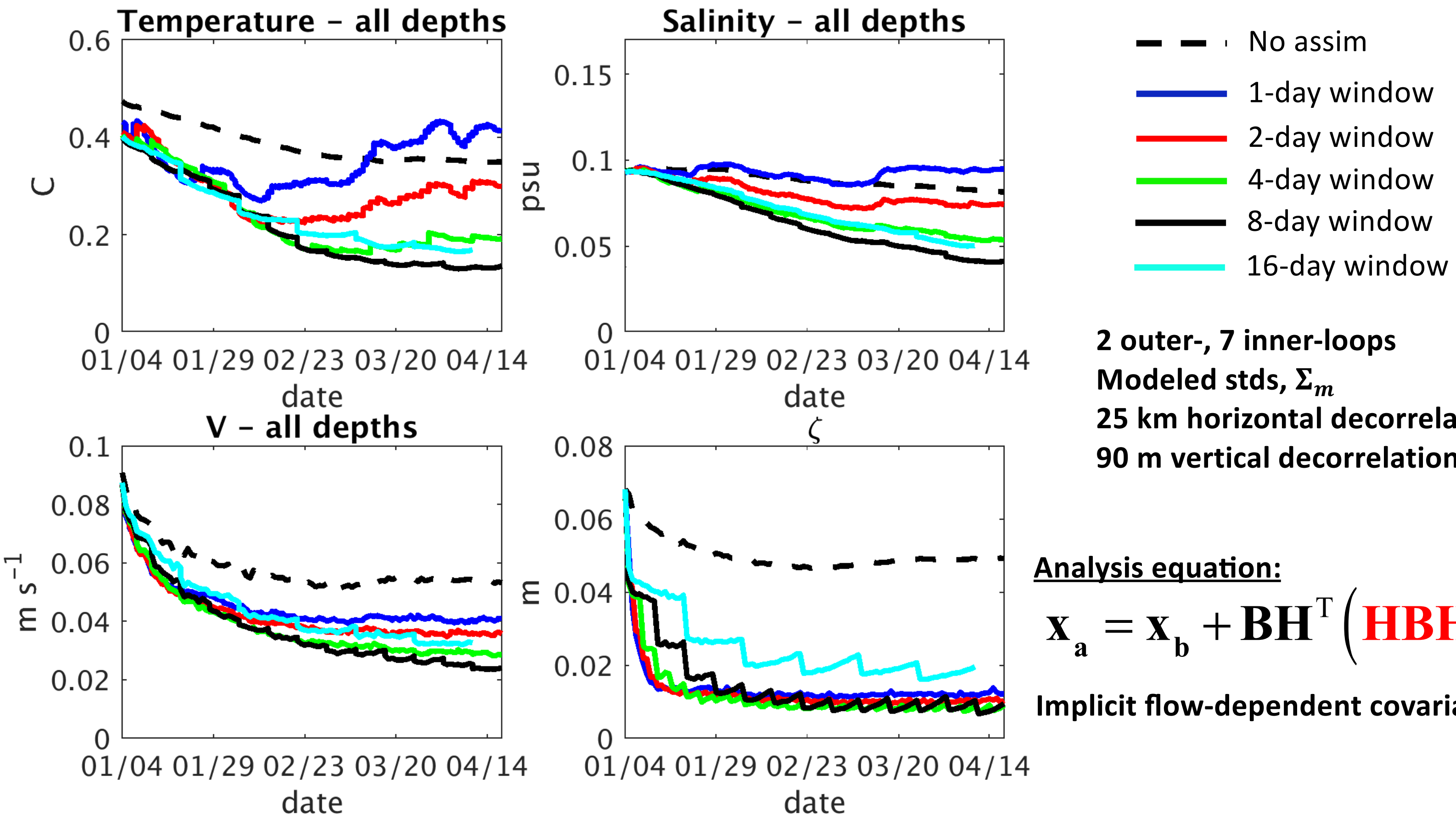


Impact of Outer-Loops



Climatological stds, Σ_c
25 km horizontal decorrelation
90 m vertical decorrelation

Impact of Assimilation Window Length



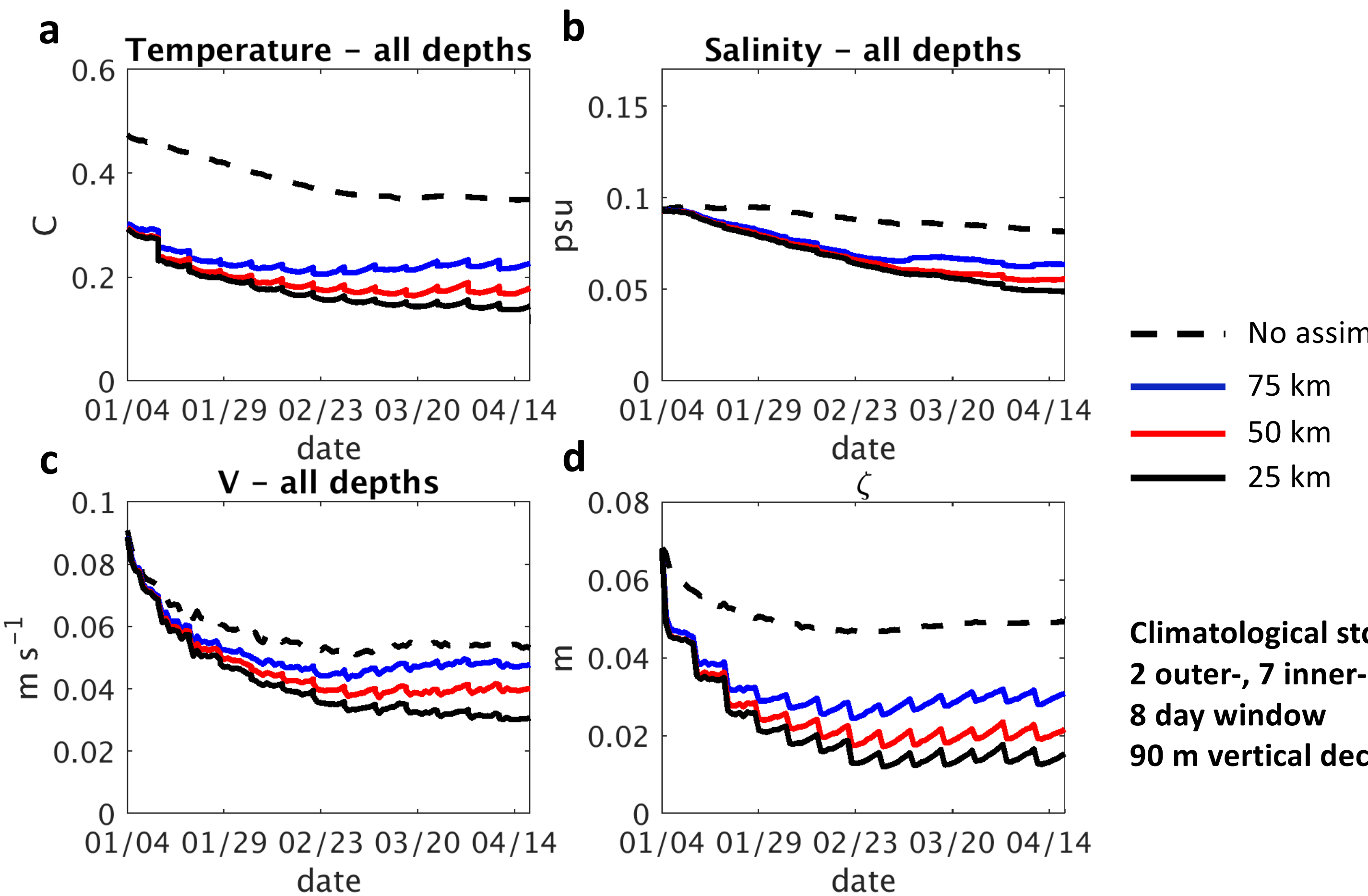
2 outer-, 7 inner-loops
Modeled stds, Σ_m
25 km horizontal decorrelation
90 m vertical decorrelation

Analysis equation:

$$\mathbf{x_a} = \mathbf{x_b} + \mathbf{BH}^{\mathrm{T}}\left(\mathbf{HBH}^{\mathrm{T}} + \mathbf{R}\right)^{-1}\mathbf{d}$$

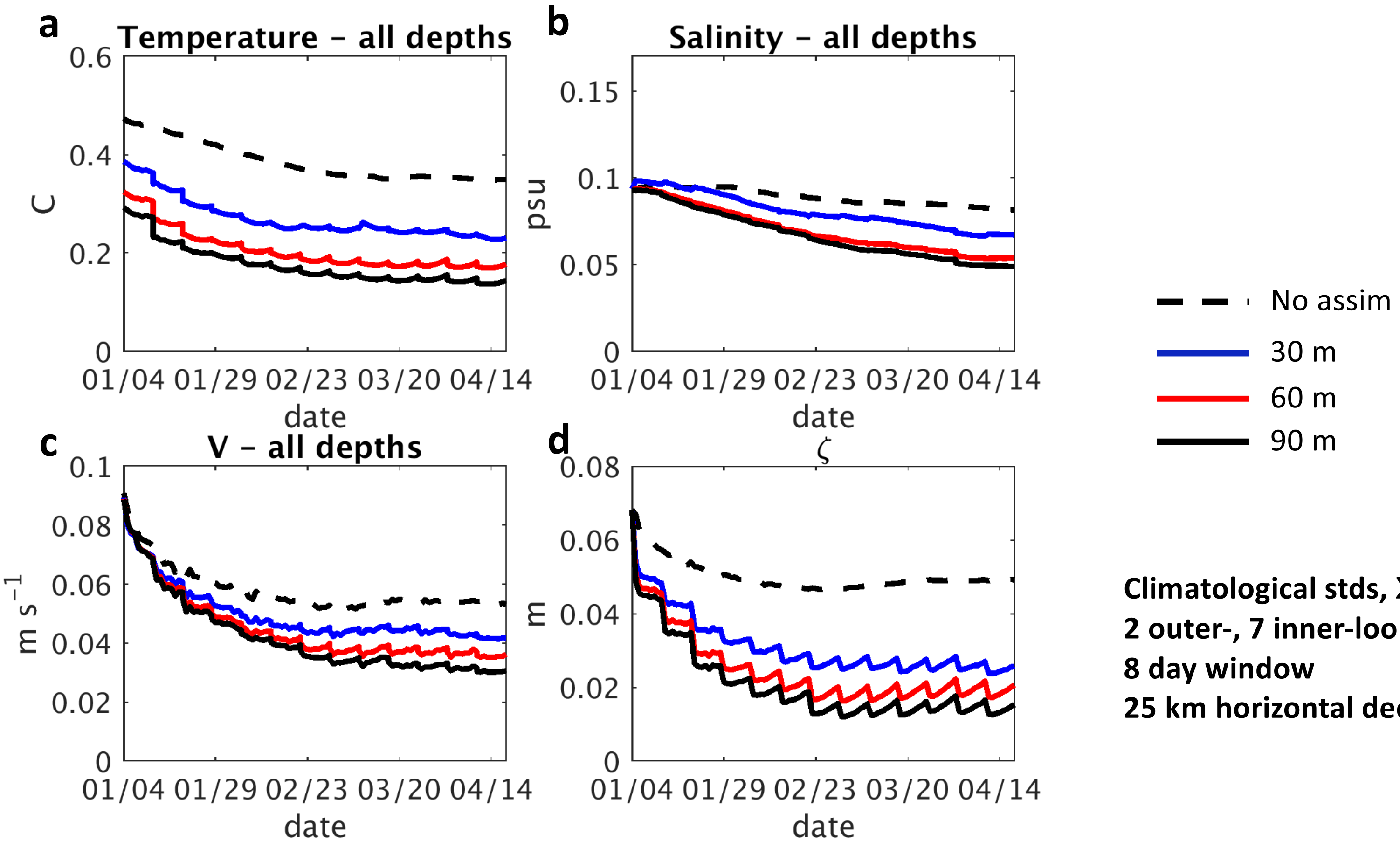
Implicit flow-dependent covariance

Impact of Horizontal Decorrelation Length



Climatological stds, Σ_c
2 outer-, 7 inner-loops
8 day window
90 m vertical decorrelation

Impact of Vertical Decorrelation Length



Climatological stds, Σ_c
2 outer-, 7 inner-loops
8 day window
25 km horizontal decorrelation

A Background Error Model

Assumption: The true value of T_t can be found in the vertical profile of the background T_b (Cooper and Haines, 1996; Mogensen et al, 2012).

$$T_t(z) = T_b(z+\delta z) \approx T_b(z) + (\partial T_b/\partial z)\delta z$$

The error in the background is therefore given by:

$$|T_t(z) - T_b(z)| \approx |(\partial T_b/\partial z)\delta z|$$

Choose:

$$\sigma \sim |(\partial T_b/\partial z)\delta z|$$

A Background Error Model

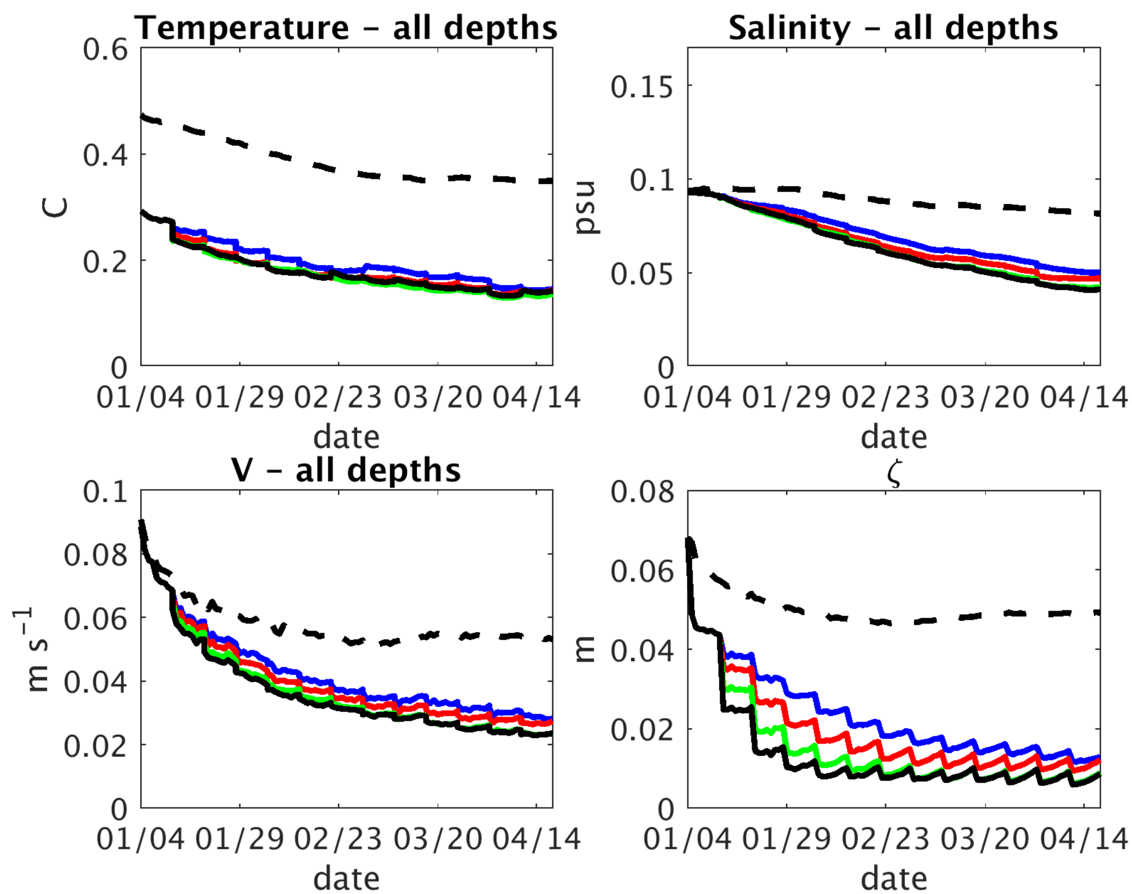
Suppose we apply this to *every* state-variable, φ , then using the formulation of Mogensen et al. (2012):

$$\sigma_\varphi = \begin{cases} max\left(\widehat{\sigma_\varphi}, \sigma_\varphi^{ml}\right) \; if \; z \geq -D_{ml} \\ max\left(\widehat{\sigma_\varphi}, \sigma_\varphi^{do}\right) \; if \; z < -D_{ml} \end{cases}$$

$$\widehat{\sigma_\varphi} = \min\left(\left|(\partial\varphi_b/\partial z)\delta z\right|, \sigma_\varphi^{max}\right)$$

The parameter σ_φ^{max} is the maximum value of σ_φ, while σ_φ^{ml} and σ_φ^{do} are the minimum values allowed in the mixed layer and deep ocean respectively. In ROMS, the mixed layer depth D_{ml} is computed using the method described by Kara et al. (2000).

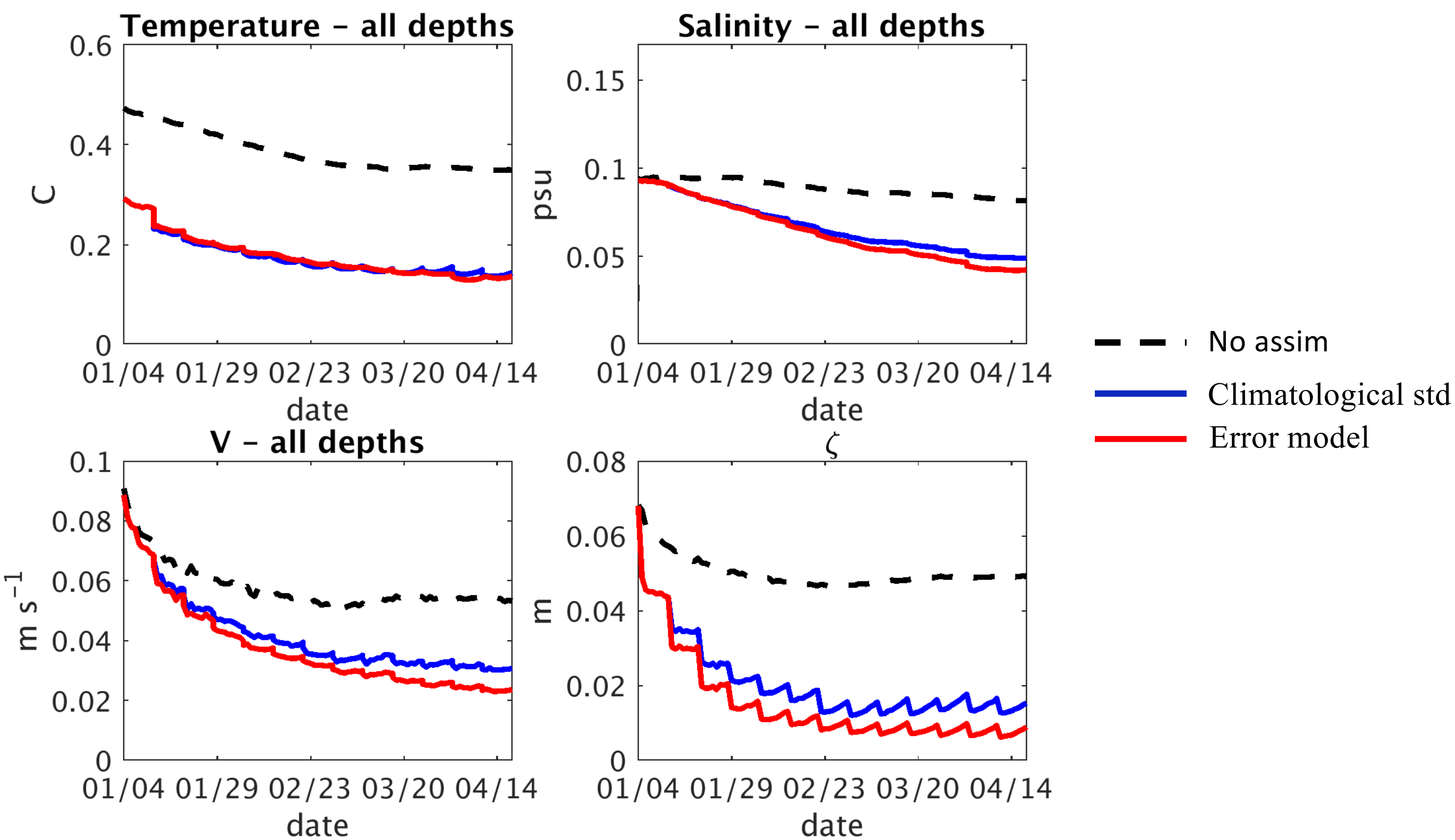
A Background Error Model



	σ^{max}	σ^{ml}	σ^{do}	δz
Temperature	0.66 C	0.1 C	0.04 C	40 m
Salinity	0.05	0.1	0.056	40 m
Velocity	0.12 ms^{-1}	0.1 ms^{-1}	0.04 ms^{-1}	500 m
SSH	0.05 m	-	-	-

α= scaling factor for all error model parameters (except δz)

A Background Error Model



Innnovation Statistics

Statistics of the innovation vectors following Desroziers et al (2005):

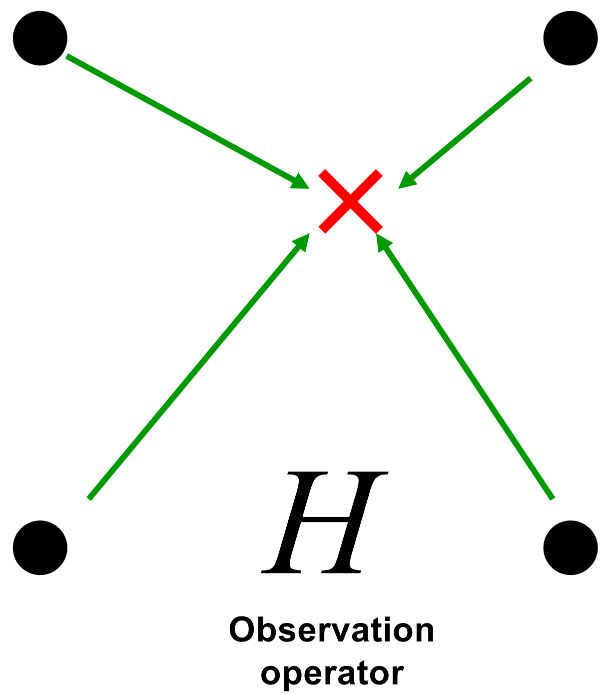
$$\mathbf{d} = (\mathbf{y} - H(\mathbf{x_b}))$$

$$\mathbf{d_a^o} = (\mathbf{y} - H(\mathbf{x_a}))$$

$$\mathbf{d_b^a} = (H(\mathbf{x_a}) - H(\mathbf{x_b}))$$

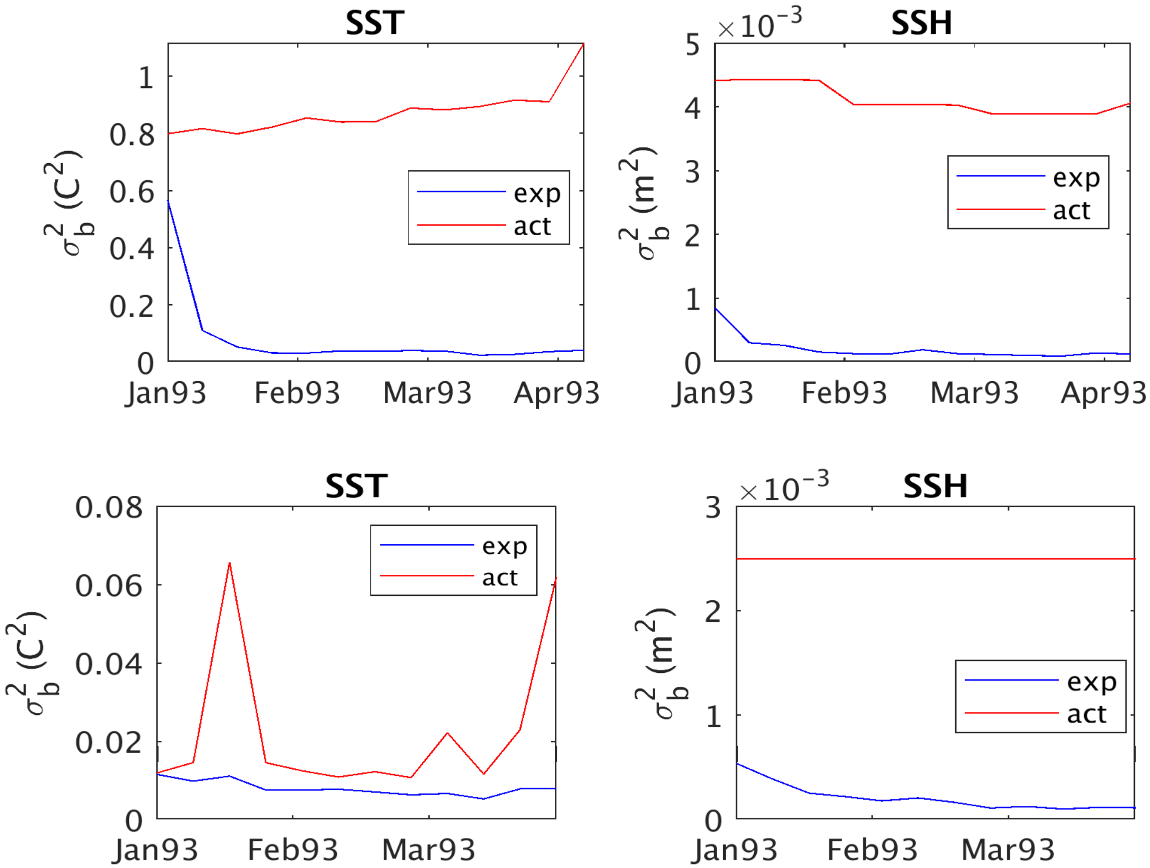
$$\tilde{\sigma}_b^2 = (\mathbf{d_b^a})^{\mathrm{T}} \mathbf{d} / p$$

$$\tilde{\sigma}_o^2 = (\mathbf{d_a^o})^{\mathrm{T}} \mathbf{d} / p$$



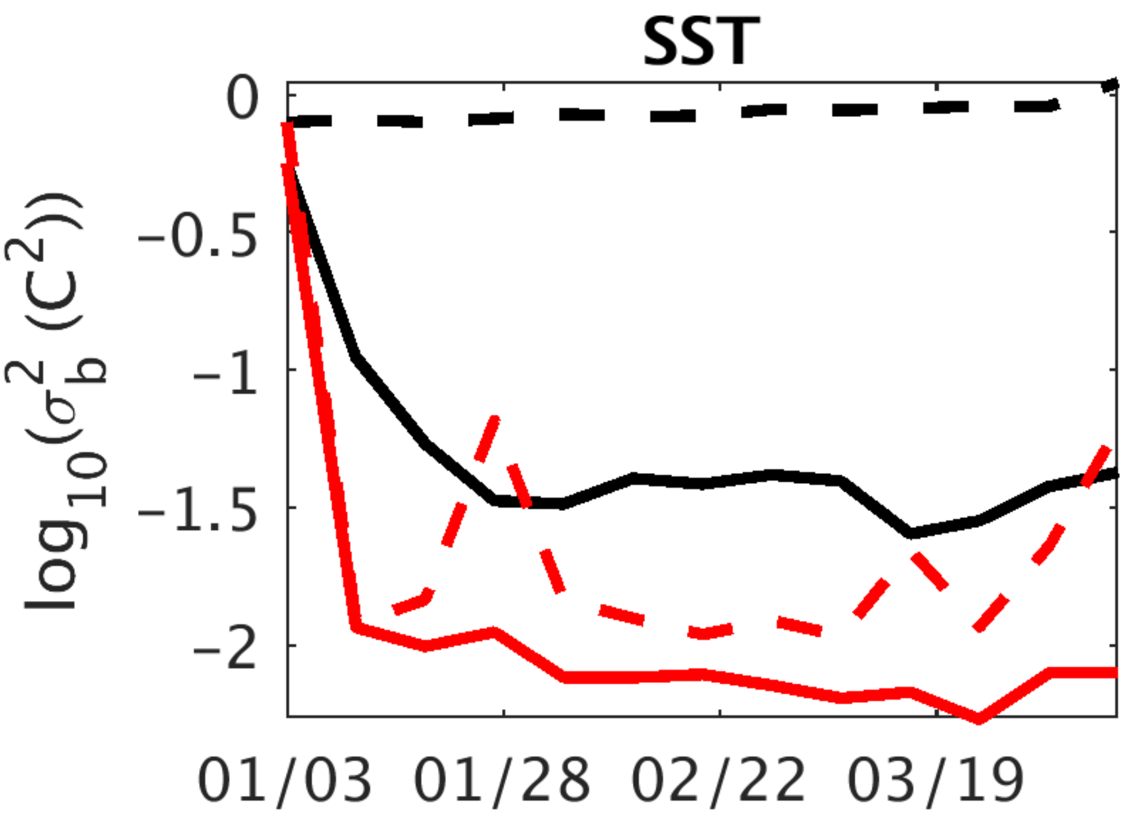
Compare $\tilde{\sigma}_o$ with σ_{o} & $\tilde{\sigma}_b$ with σ_{b}

REPLOT USING NEW RUN DATA

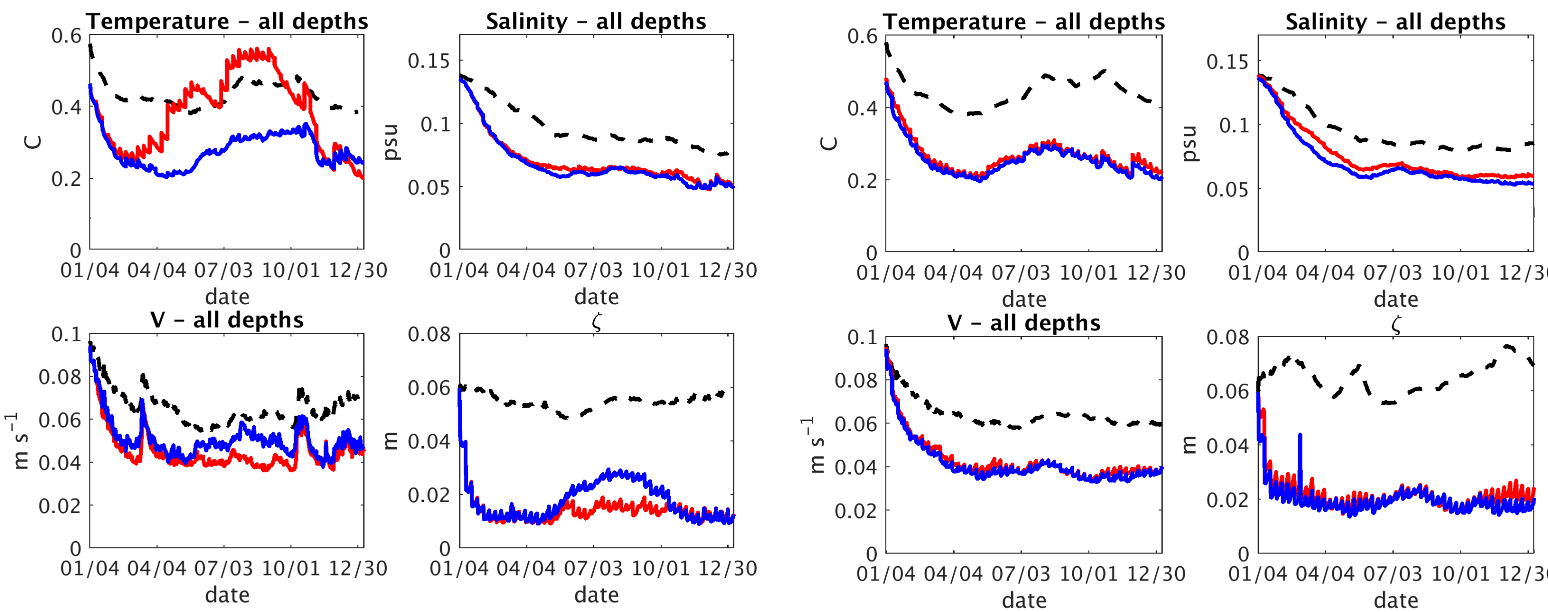


25km, 90m
(clim stds)

25km, 90m, α=1
(error model)


SST
0
-0.5
-1
-1.5
-2
log10(σb2 (C2))
01/03
01/28
02/22
03/19

Errors in Boundary Conditions



No assim
FRC ADJUST
IC only

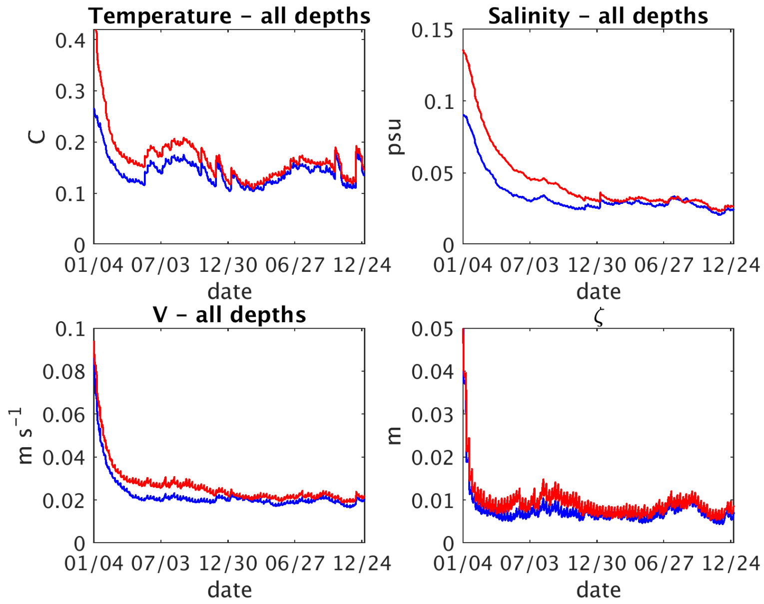
Errors in surface forcing

Errors in open boundary conditions

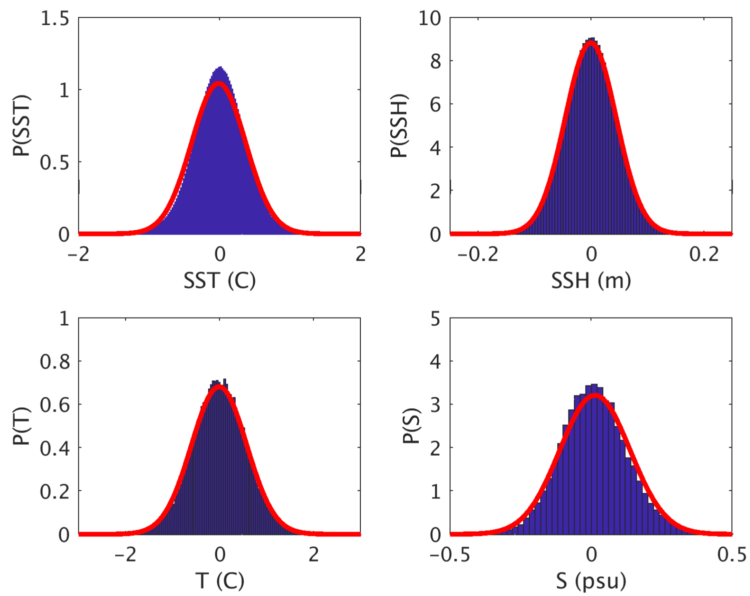
No assim
OBC ADJUST
IC only

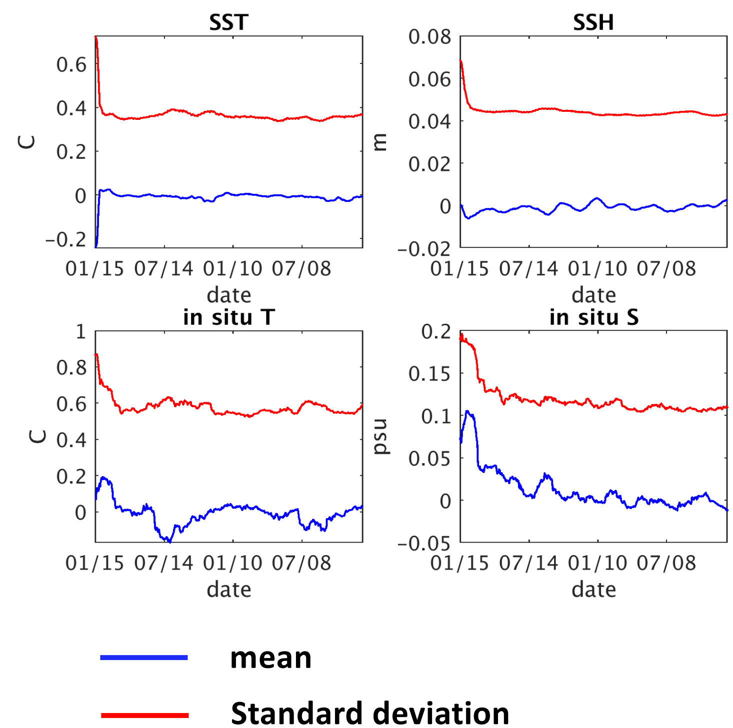
Starting Point

- We are solving a non-linear minimization problem using a truncated Gauss-Newton method.
- There is no guarantee that the problem will converge to a unique solution if multiple minima exist in the cost function.
- We can test this by solving the same minimization problem using different starting points.

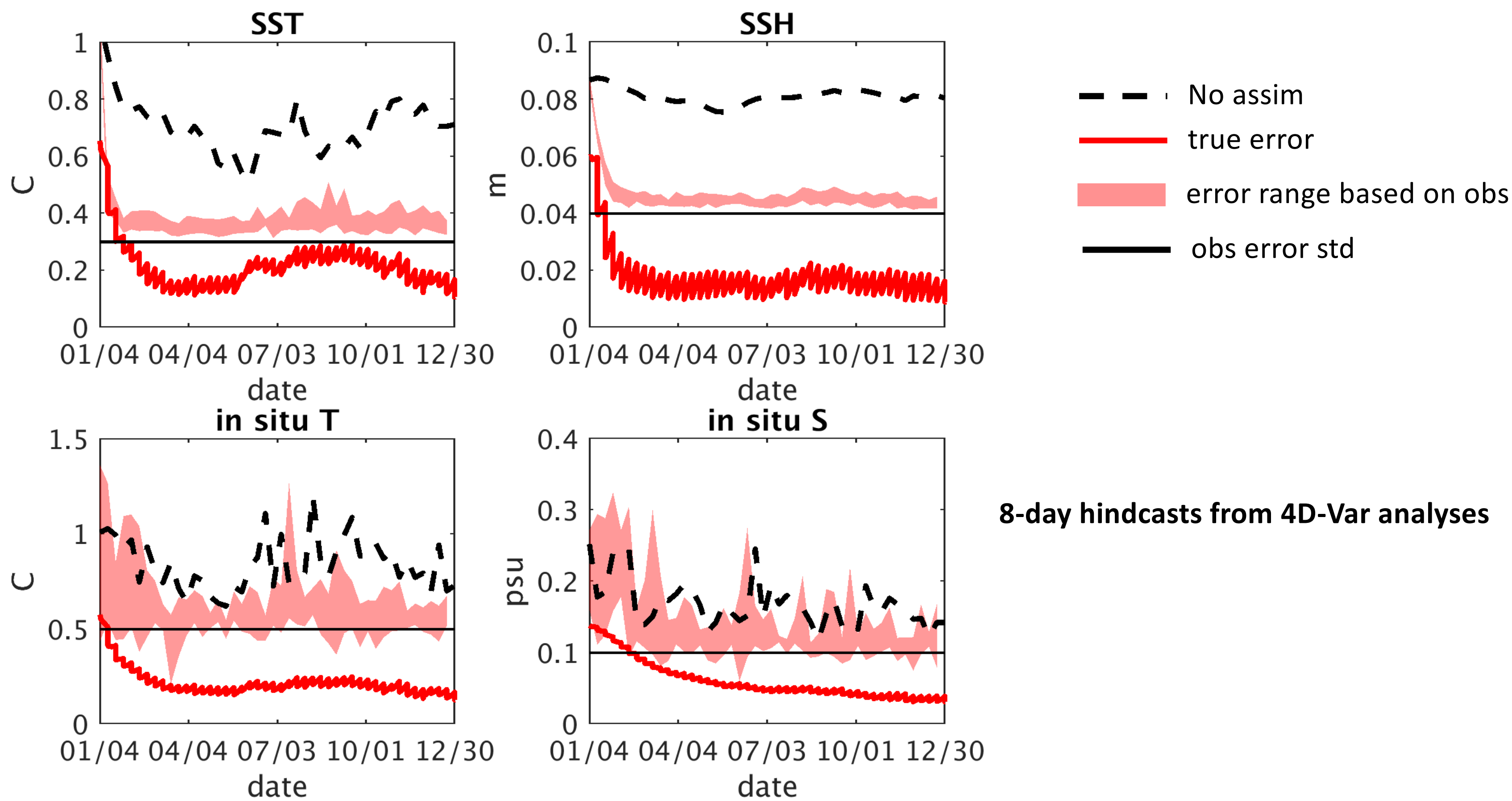


Innovation PDFs





Verification Against Independent Obs



8-day hindcasts from 4D-Var analyses

References

Cooper, M. and K. Haines, 1996: Altimetric assimilation with water property conservation. *J. Geophys. Res.,* **101**: 1059–1077.
Desroziers, G., L. Berre, B. Chapnik and P. Poli, 2005: Diagnosis of observation, background and analysis-error statistics in observation space. *Q. J. R. Meteorol. Soc*., 131, 3385-3396.
Kara, A.B., P.A. Rochford and H.E. Hurlburt, 2000: An optimal definition for ocean mixed layer depth. *J. Geophys. Res.*, **105**, 16,803-16,821.
Mogensen, K., M.A. Balmaseda and A.T. Weaver, 2012: The NEMOVAR ocean data assimilation system as implemented in the ECMWF ocean analysis for system 4. *ECMWF Technical Memorandum 668*, 59pp.