New Developments in Spectral Nudging

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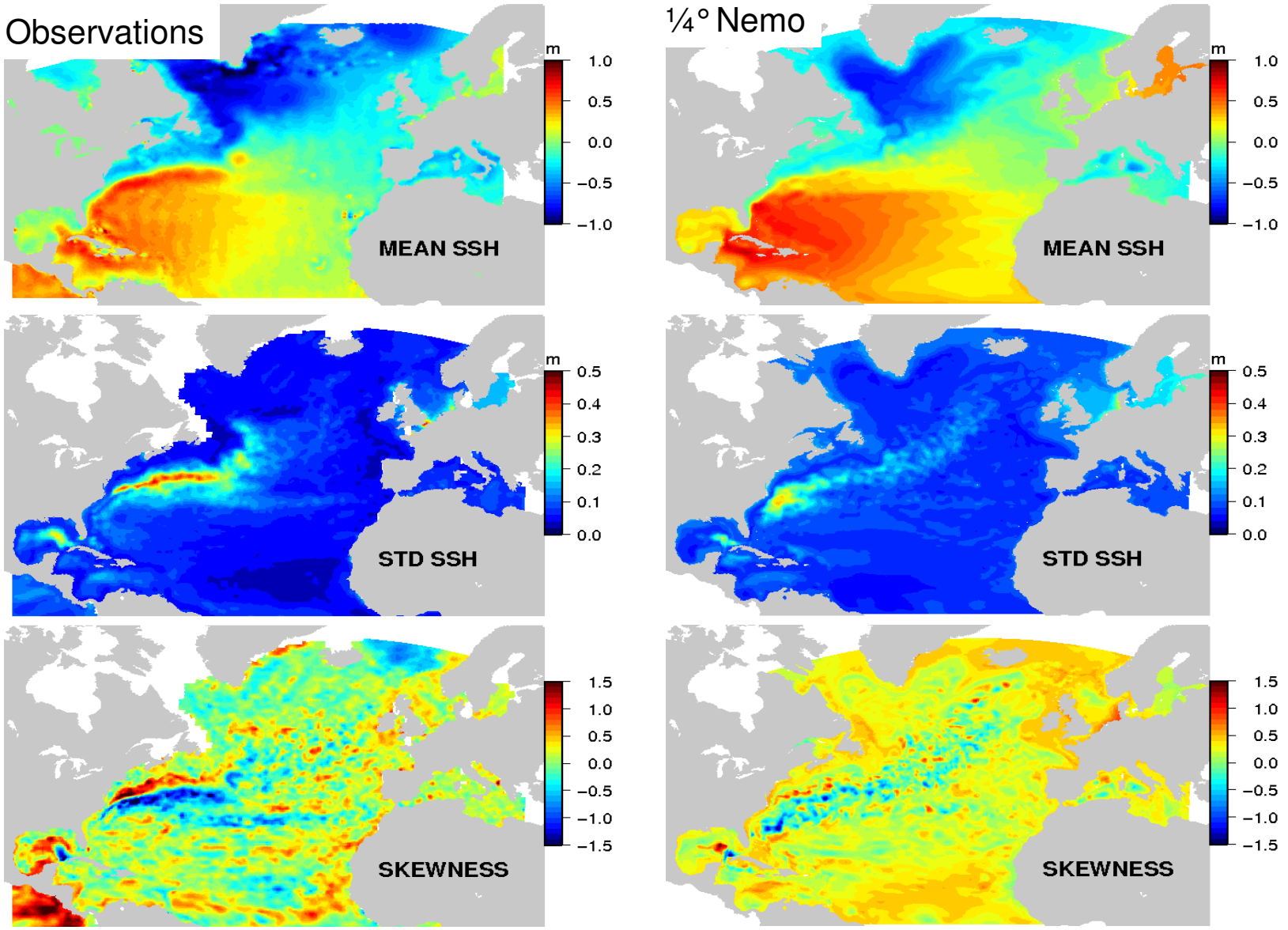
The success of spectral nudging depends on the climatology that you nudge towards.

But the climatology may be flawed.

We consider options to reduce related problems.

Review: Observations vs standard ¼° Nemo



Basics of Spectral Nudging

$$\frac{\partial T}{\partial t} + \cdots = \langle N_T \rangle \qquad N_T = \frac{1}{\tau}\langle T^{obs} - T \rangle$$

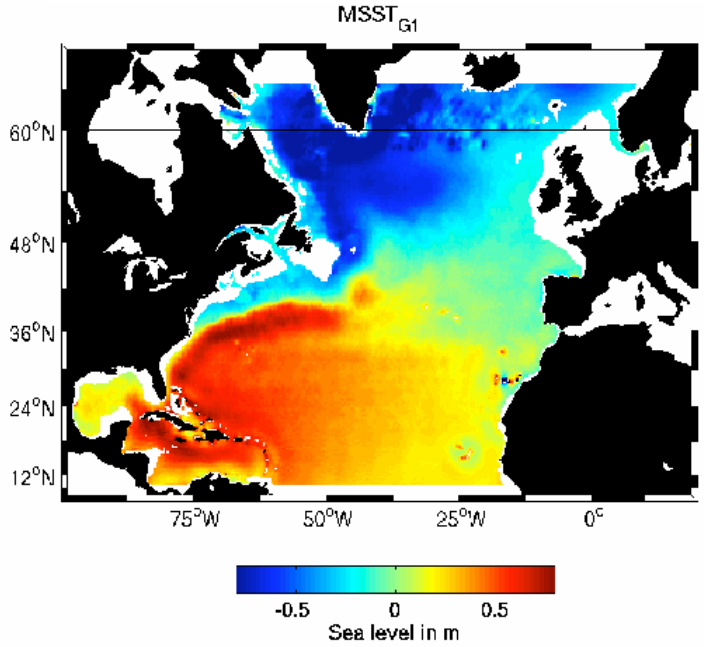
$$N_{n+1} = \boxed{T_c}\, N_n + \boxed{K}\,\boxed{[y_{n+1} - H\, T_c\, N_n]}$$

Transition matrix advances fit of mean and annual cycle

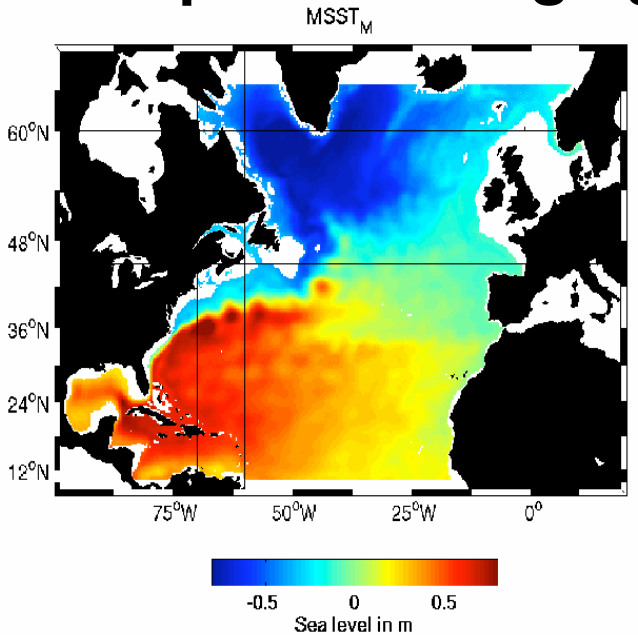
Gain factor: reduce magnitude to narrow the bandwidth

Deviation from the fit of mean plus annual cycle

Satellite-based Estimate of Mean Sea Level



Previous model result with Spectral Nudging



Two choices are considered to remove anomalies:

(i)Reduce the influence of uncertain aspects of the climatology

(ii)Reduce eddy effects in the climatology

Option 1: Reduce the influence of “eddy scales” that are in the climatology

We just want to increase the spatial smoothing but it’s not totally trivial.

- Definitely doable but filters are non-trivial near boundaries and you need to watch out for “leakage” across land boundaries. Details can get messy and expensive.

Fortunately, there is an interesting approach that avoids both CPU expense and leakage across land barriers.

Recursive Spatial Smoothing

We simply apply a weak spatial filter to the nudges every time step and allow the effects to accumulate. Note the recursive nature.

$$N_{n+1} = T_c\, \varphi(k, l) N_n + K\,[y_{n+1} - H\, T_c\, \varphi(k, l) N_n]$$

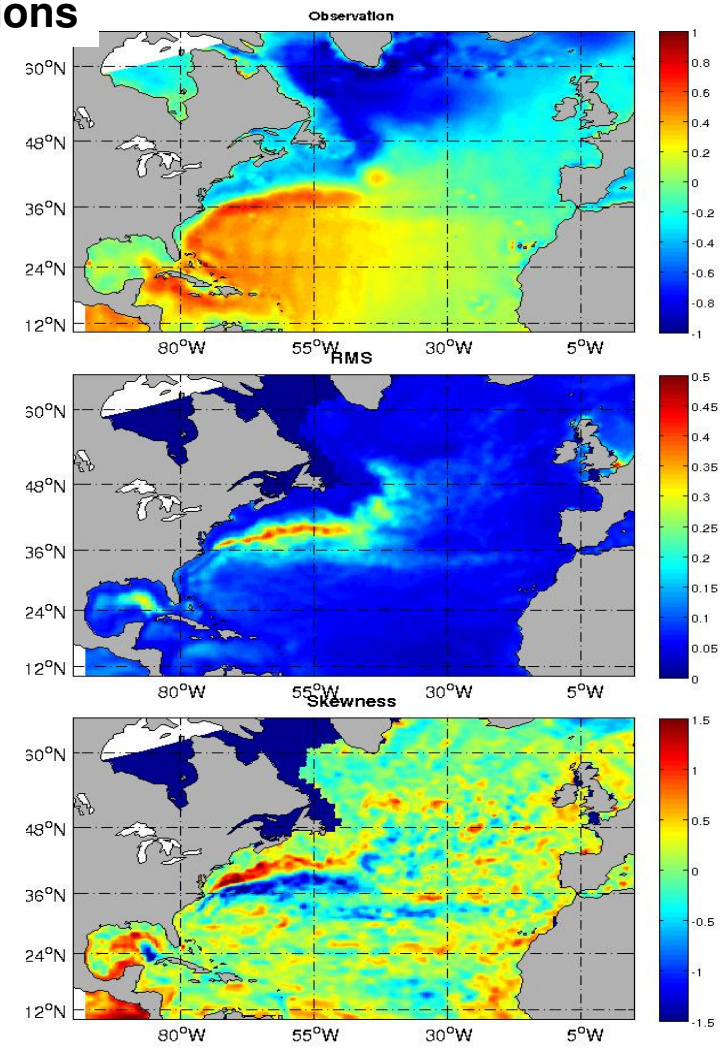
If $\omega_c = 0$, $\omega\Delta t << 1$ and $\varphi(k,l) = 1 - \varepsilon$ with $\varepsilon << 1$

then $$\Gamma = \frac{1}{1 + 0.5(\varepsilon + i\omega\Delta t)/\kappa\Delta t}$$

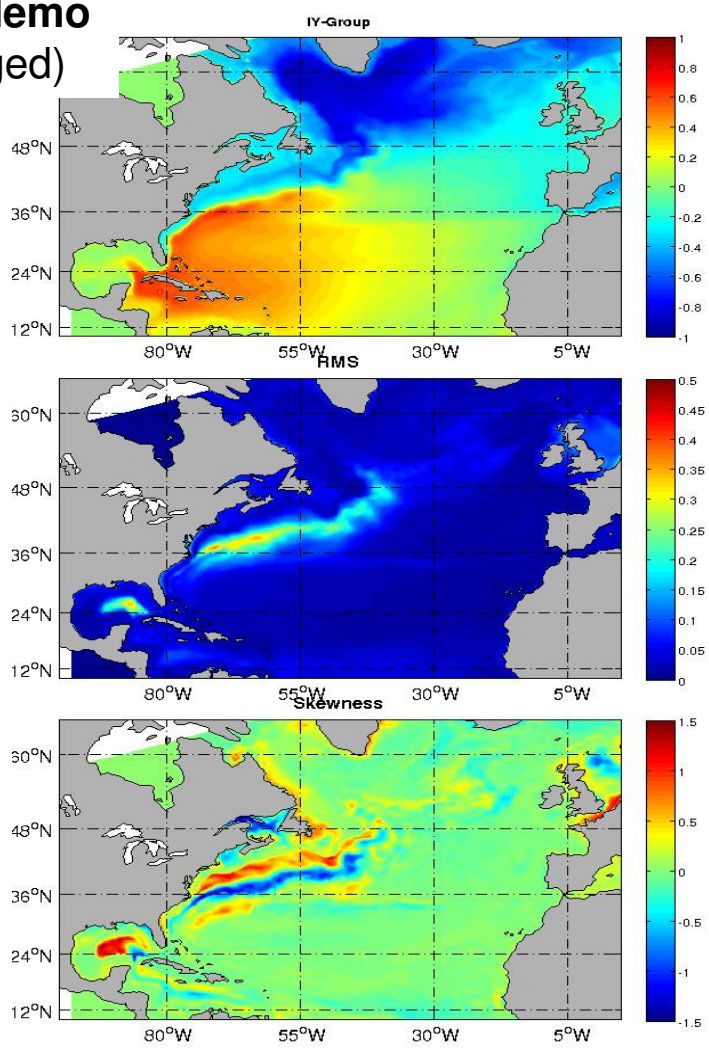
with $\varepsilon = 0.25\alpha[(k\Delta x)^2 + (l\Delta y)^2]$ for our choice of filter.

Results for a dozen different runs all look so similar that we can summarize with a single figure in which the results are averaged together. I.e., our results are **not** sensitive to details of filter bandwidth, spatial smoothing or restoring time.

Observations

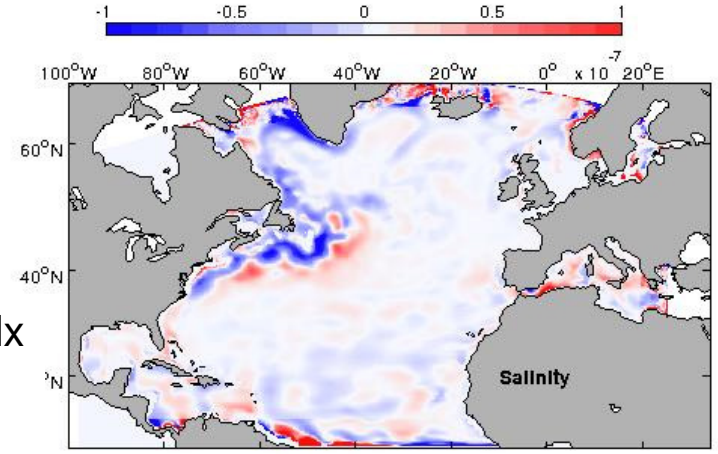


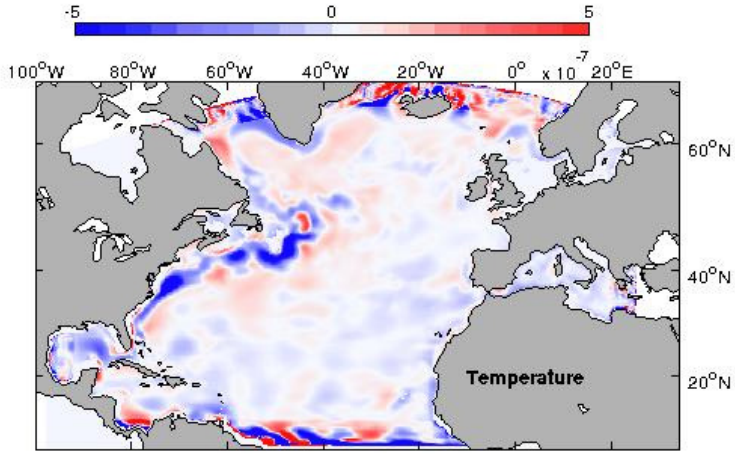
¼ ° Nemo (nudged)



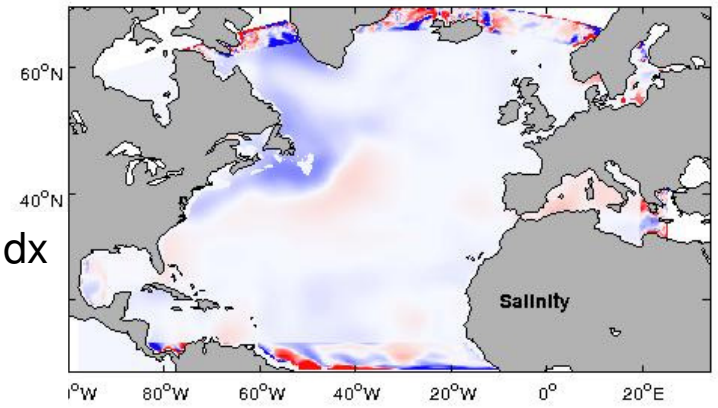
Note that the statistics of model results are not sensitive to details of nudging parameters, but the nudges themselves are strongly influenced.

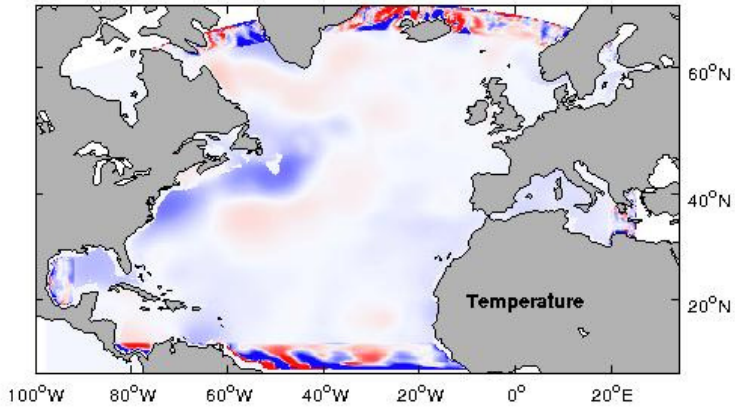
Filter 2 dx from the nudges





Filter 20 dx from the Nudges

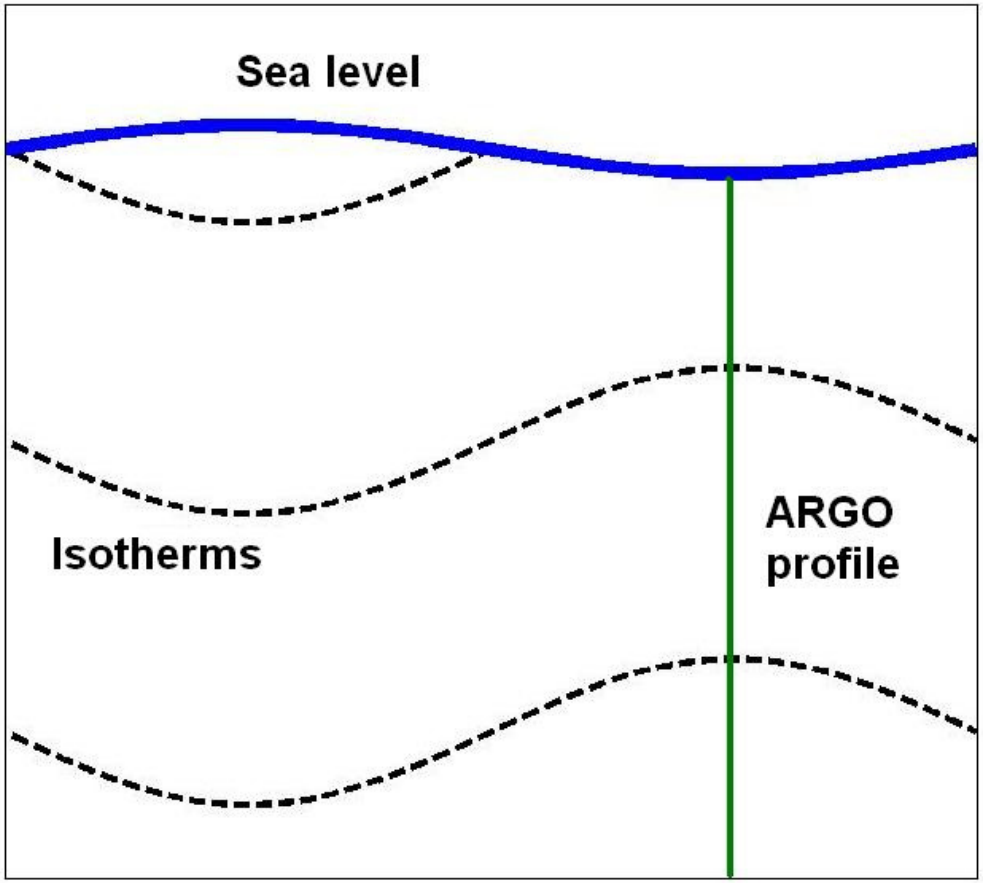




Restoring strength, time filtering, spatial filtering, climatology, surface forcing and open boundary conditions all influence details of the nudges but model results are not strongly affected if choices are “reasonable”.

Correcting Climatologies For Eddies

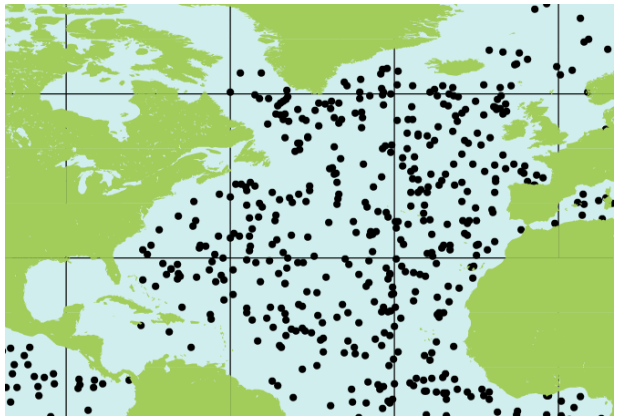
- Argo profiles provide unprecedented data, but it has not been available long enough to average out the effects of eddies on T and S.
- Fortunately, altimetry is available during the Argo period.



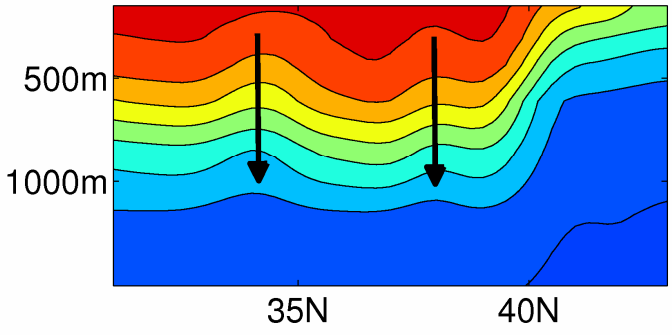
- **Thompson, Higginson and Liu use the Cooper & Haines assimilation technique to remove (some of) the effect of eddies on T and S**
- **Individual profiles are lifted or depressed by an amount dependent on the altimeter measurement of sea surface height**

Argo-period climatology

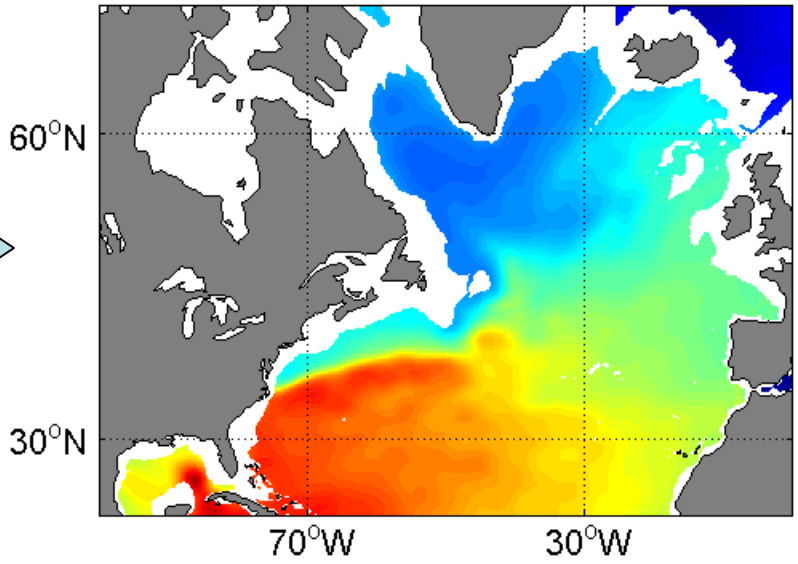
TS observations from Argo:



Observations de-eddied using altimeter sea surface height anomalies:



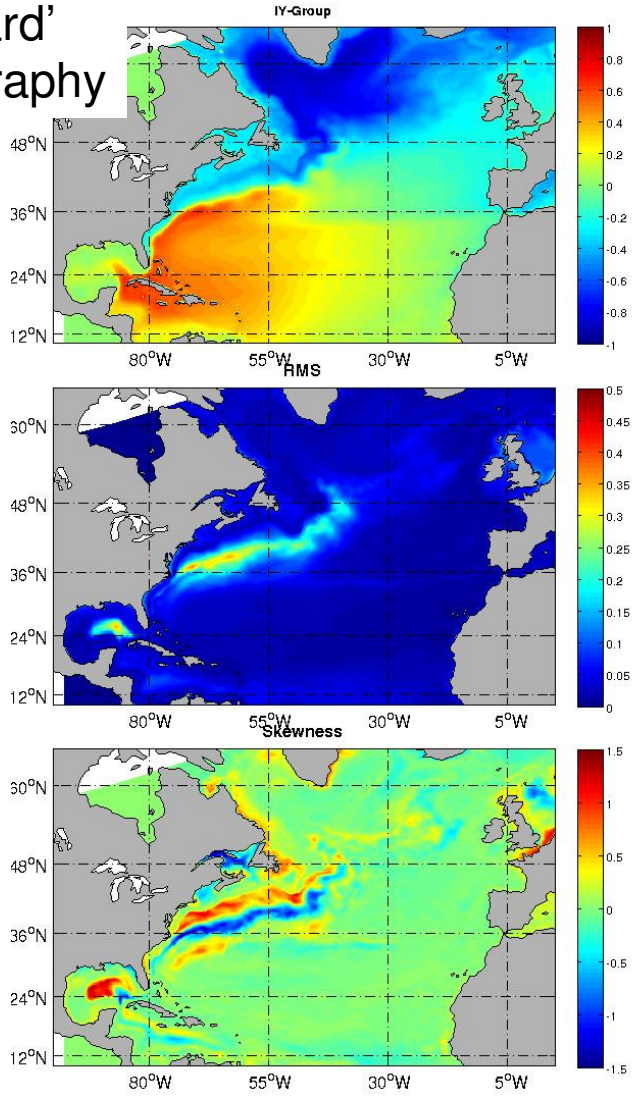
Mapped using OI to produce a new climatology:



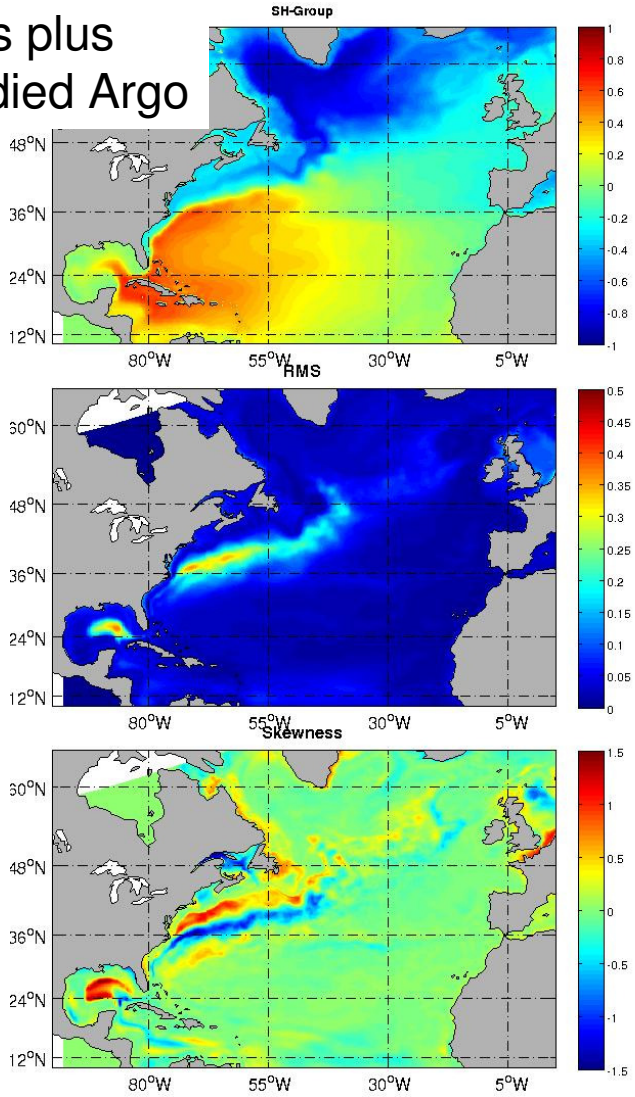
(Dynamic height shown here)

When the spatial smoothing is significant, the results are not sensitive to the climatology – that's good!

'Standard' hydrography



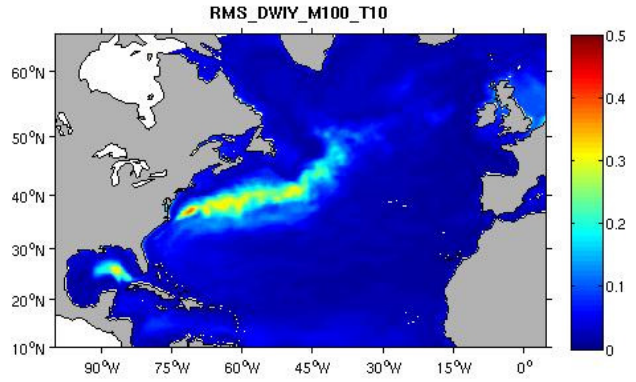
Levitus plus de-eddied Argo



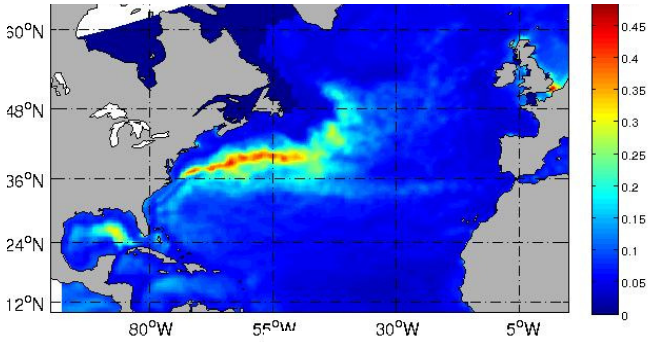
What is modified by using the new climatology?

Differences become apparent when we strongly constrain the model to agree with the observations.

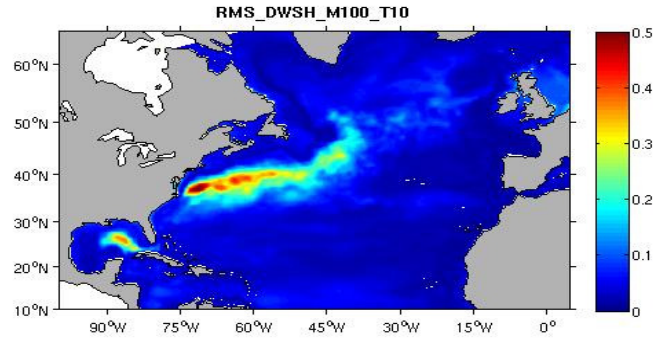
Results here show rms sea level based on a restoring time of just 10 days.



Old climatology

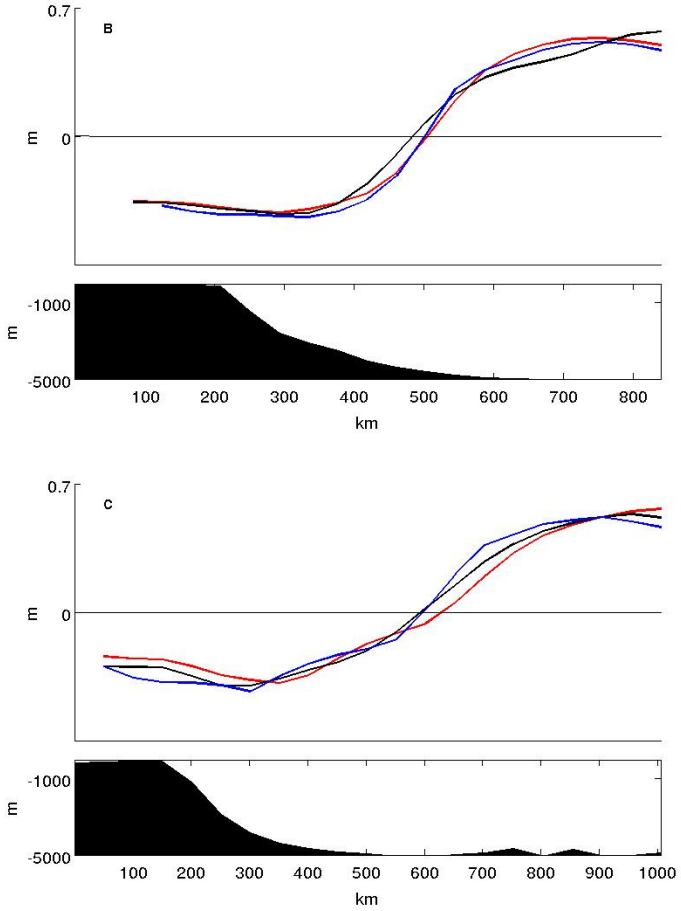


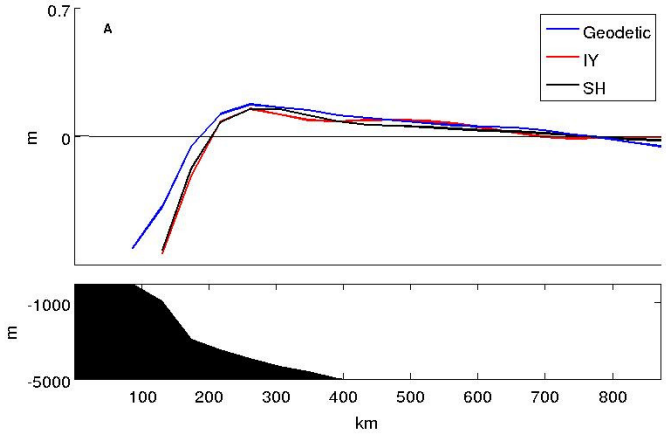
Observed

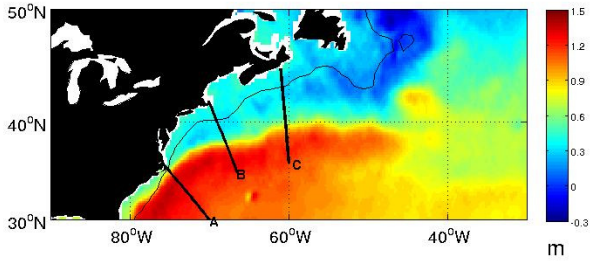


New climatology

Did the mean flow get stronger?

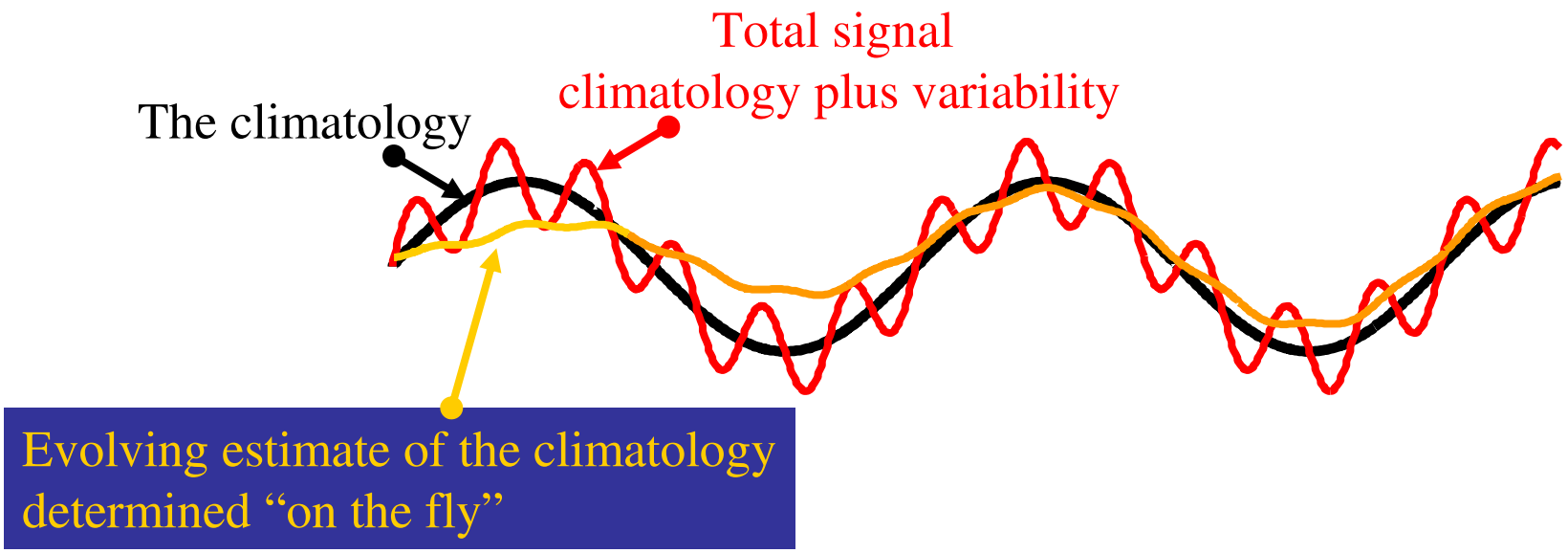






Summary

- A very efficient and versatile spatial smoother is available for use with spectral nudging.
- Model results with nudging are robust. They depend on large scale features in the nudges, not details.
- The improved climatology permits stronger constraints to be applied and results in improved representation of eddy variability with the NEMO model.


Total signal
climatology plus variability
The climatology
Evolving estimate of the climatology
determined “on the fly”

Let's look a bit closer at the model-data comparison