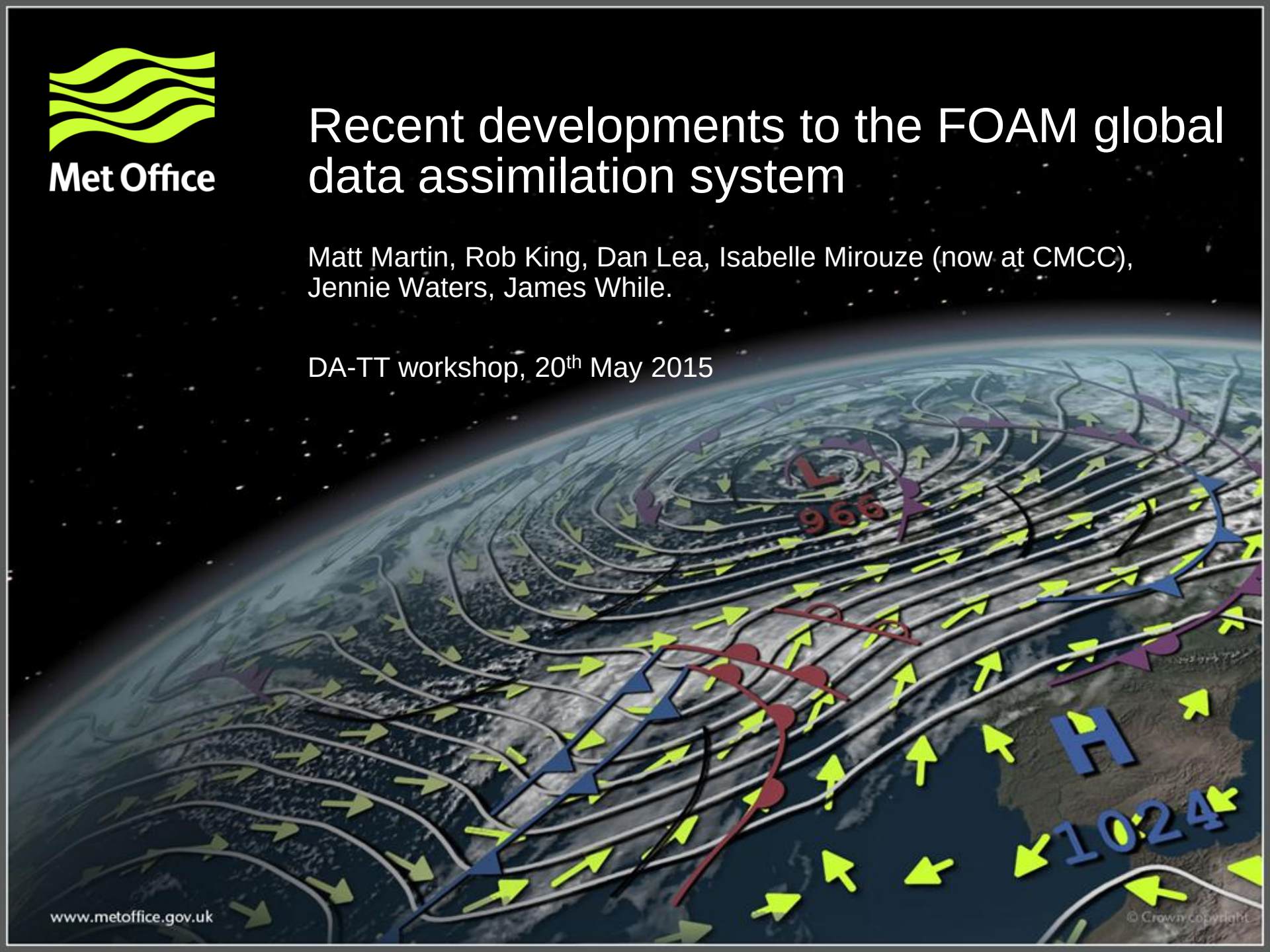
Recent developments to the FOAM global data assimilation system

Matt Martin, Rob King, Dan Lea, Isabelle Mirouze (now at CMCC), Jennie Waters, James While.

DA-TT workshop, 20th May 2015



Contents

1. Introduction

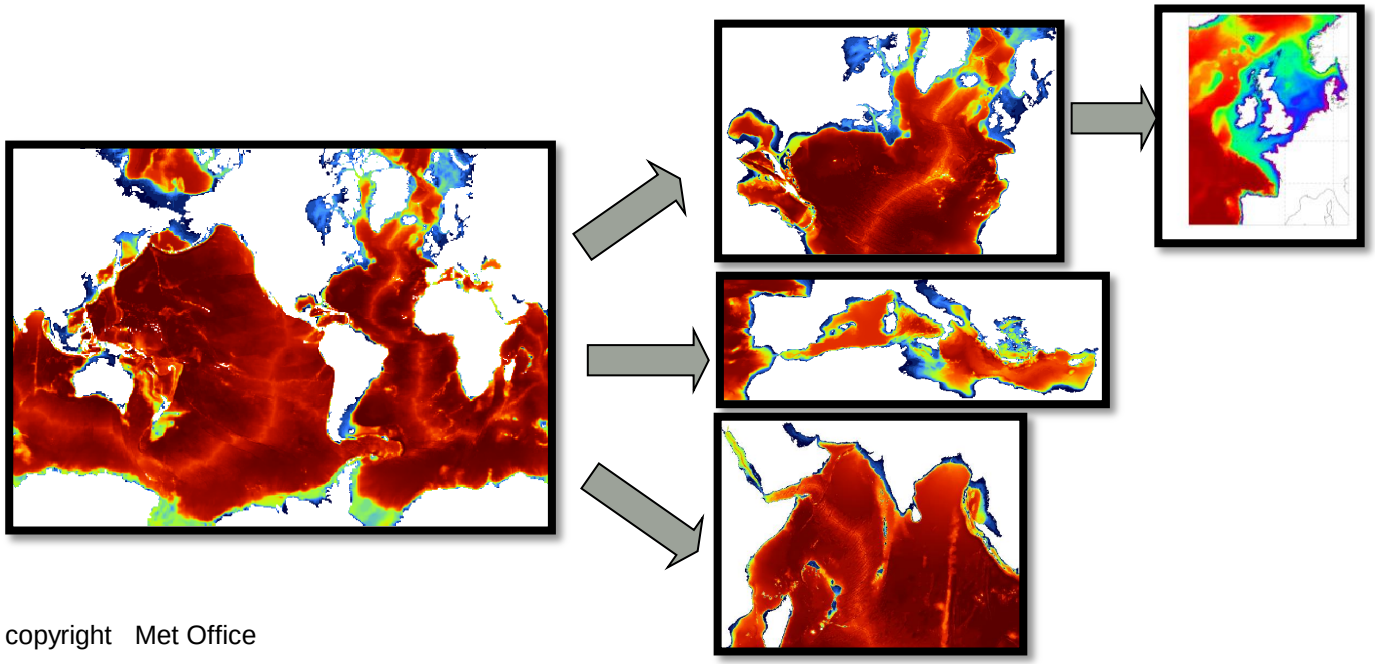
Introduction

Overview

FOAM system provides daily analysis and forecasts of the deep ocean and North-West European shelf-seas.

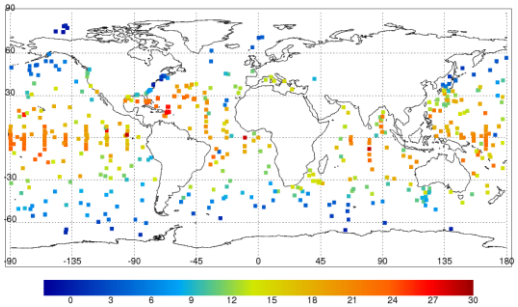
- Global ¼°system
- Nested regional 1/12°configurations in N. Atlantic, Med. Sea and Indian Ocean
- NWS model at 6km resolution includes tides and has different vertical coordinate.

All configurations based on NEMO vn3.4 and CICE (global and N. Atlantic).

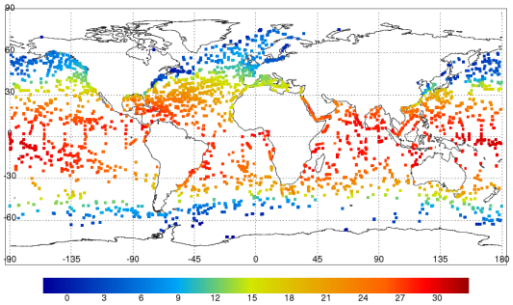


Introduction

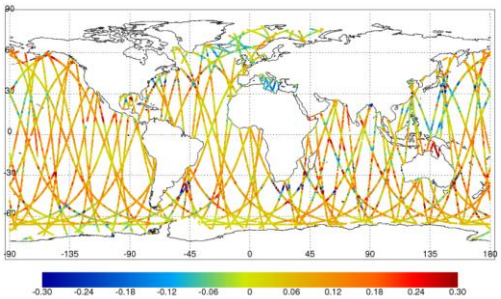
Observations assimilated



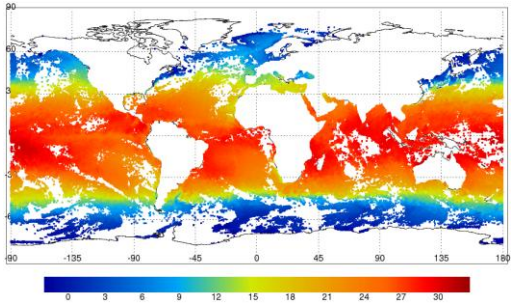
T and S profiles
(Argo, moored buoys, XBTs, CTDs, marine mammals, gliders)



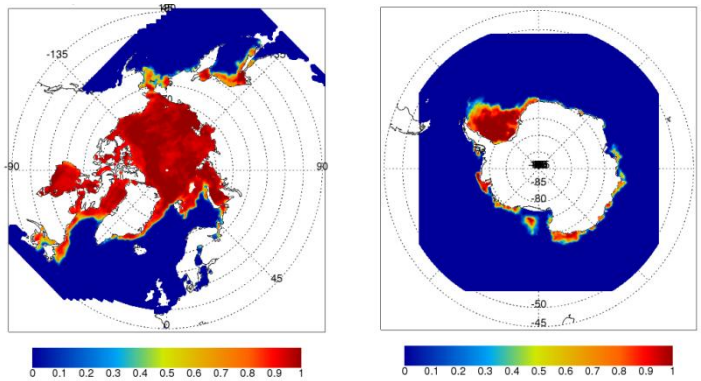
In situ SST data
(ships, moored and drifting buoys)



Satellite altimeter SSH data
(Jason-2, Cryosat, Altika)



Satellite SST data
(NOAA/AVHRR, MetOp/AVHRR)



Satellite sea-ice concentration data
(SSMI/S)

Introduction

Data assimilation in FOAM using NEMOVAR

- NEMOVAR scheme in 3DVar-FGAT mode.
- Uses 3x1D implicit diffusion operator to model the background error correlations (Mirouze and Weaver, 2010).
- Multivariate balance operator to transfer information between variables (Weaver et al 2005).
- Implementation of NEMOVAR in FOAM described in Waters et al. 2015:
  - Tuning of background error length-scales (based on Rossby radius) and standard deviations for ORCA025 configuration.
  - Particular attention to design flow-dependent (based on background MLD) vertical length-scales so that assimilation of swath SST data worked well.
  - Implementation of sea-ice concentration assimilation in NEMOVAR.
- The first NEMOVAR version of FOAM was called version 12, and went operational in January 2013.
- A new version (FOAM v13) was implemented operationally in February 2015 which included:
  - Model updates (vertical mixing improvements, sea-ice tuning)
  - Data assimilation improvements (2-lengthscale background error covariances)

2. Background error covariance developments

Isabelle Mirouze

Background error covariances

- In inter-comparisons organised through GOV IV-TT, the FOAM v12 system performed well for surface variables (particularly SST and SSH), but sub-surface profile statistics were not particularly good, especially in Southern Ocean.

- Salinity and sub-surface temperature fields not well constrained by the sparse data and small correlation scales, particularly at mid- to high-latitudes.

- Decided to implement a multiple length-scale correlation operator so that we can make better use of the profile data at higher latitudes.

Dual horizontal length scale formulation

- Correlation functions can be linearly combined to obtain correlation functions with more complex shape, *e.g.*

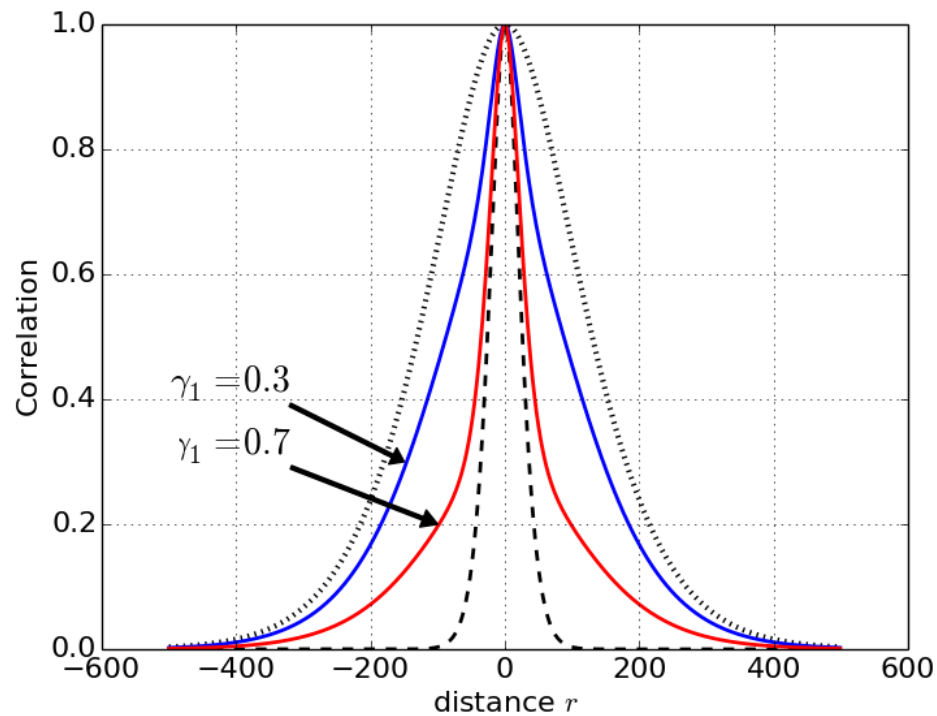
$$f = \gamma c_1 + (1-\gamma) c_2$$

- c_1 with mesoscale for internal dynamics errors
- c_2 with synoptic scale for errors arising from atmospheric forcing fields

- Each function is modelled by using a diffusion operator

- Documented in **Mirouze et al., 2015:**

  Mirouze, I, Blockley, E.W., Lea, D.J., Martin, M.J., Bell, M.J.: **A multiple length scale correlation operator with application to ocean data assimilation,** QJRMS (submitted), 2015

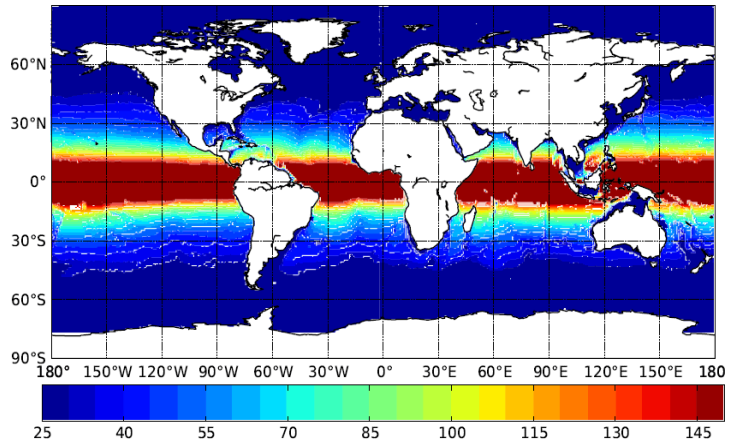


- - - L_1 = 10
….. L_2 = 50

Data assimilation upgrades at v13

Dual horizontal length scale formulation

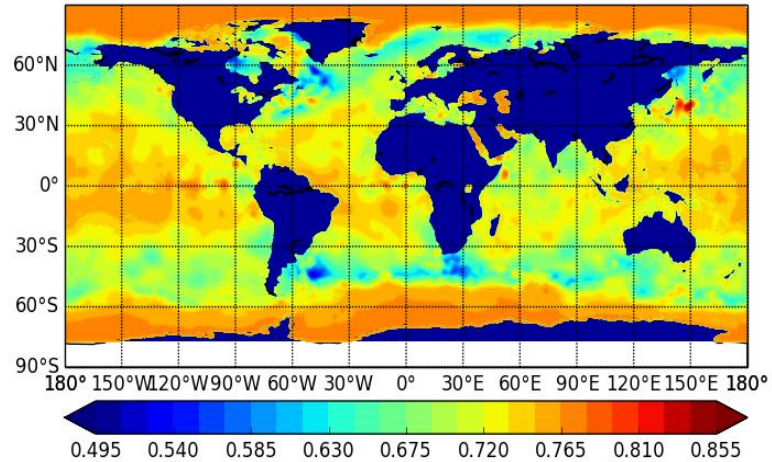
- The dual length scale formulation has been used for temperature and unbalanced salinity correlations



- Mesoscale: based on Rossby radius
- Synoptic scale: 400 km
- Vertical scales: depending on MLD

- γ : seasonal variances from V11 interpolated temporally

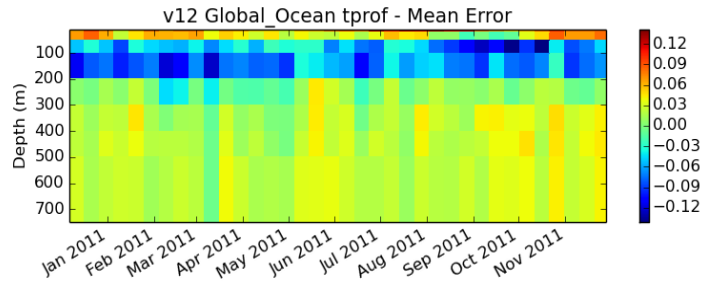
  e.g. surface temperature γ on 01/12



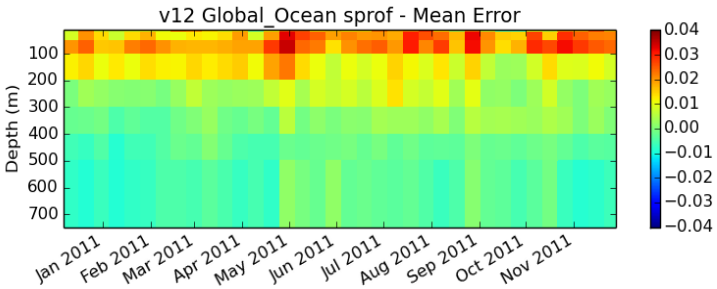
Improvements with FOAM v13:
Profile biases – calculated from innovations

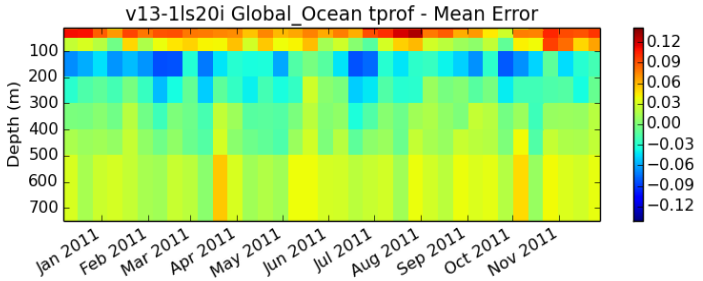
Temperature

Salinity

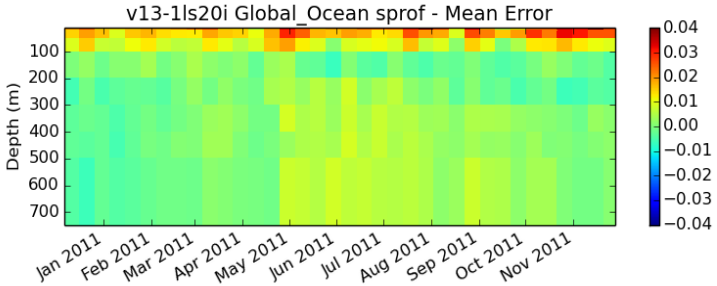


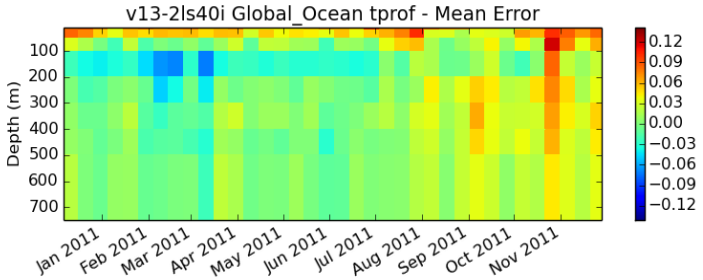
FOAM v12



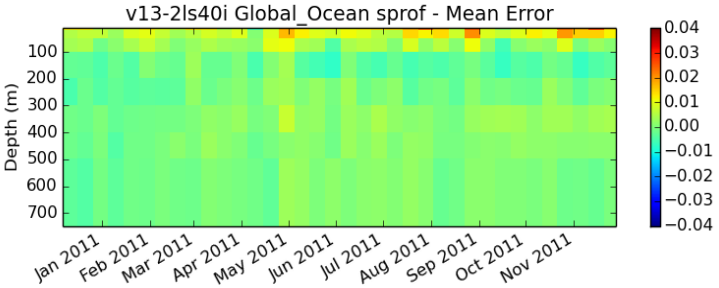


FOAM v12
+ model upgrades





FOAM v13
(model+DA
upgrades)



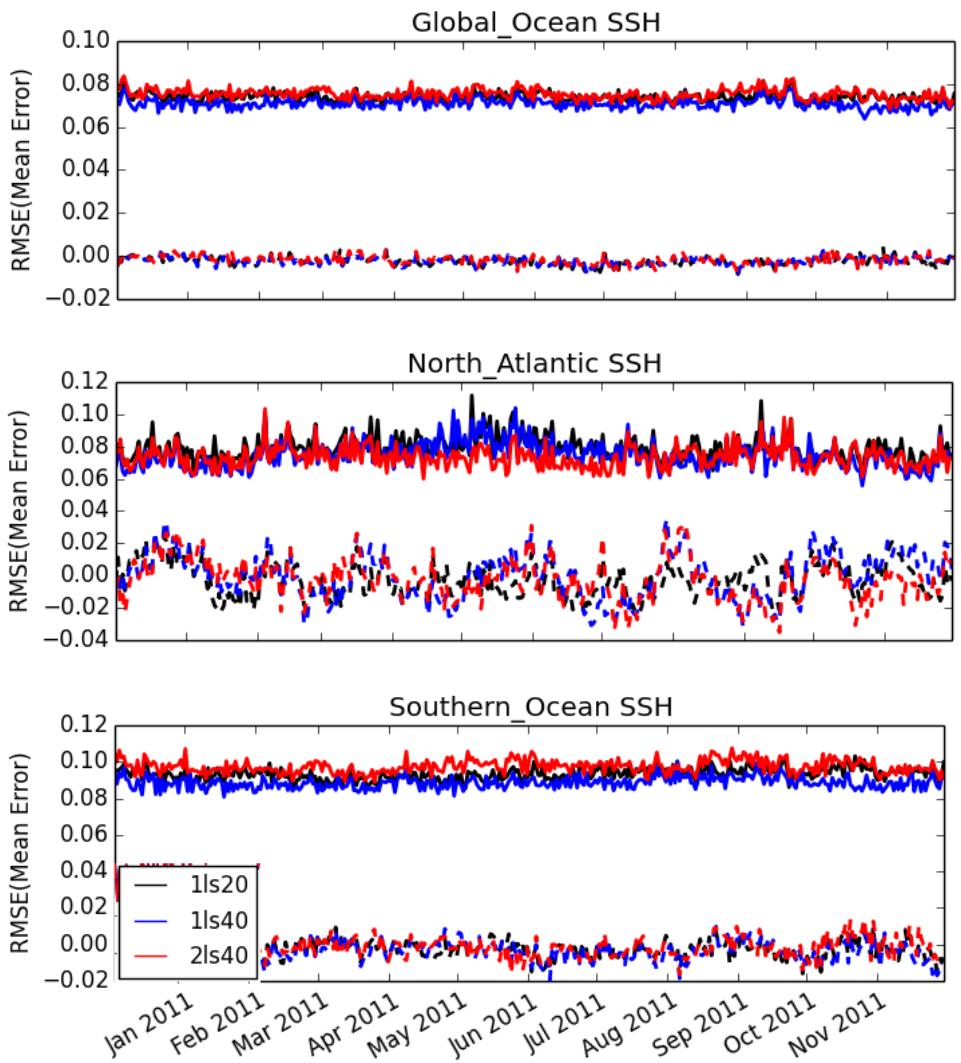
Two length-scale covariances

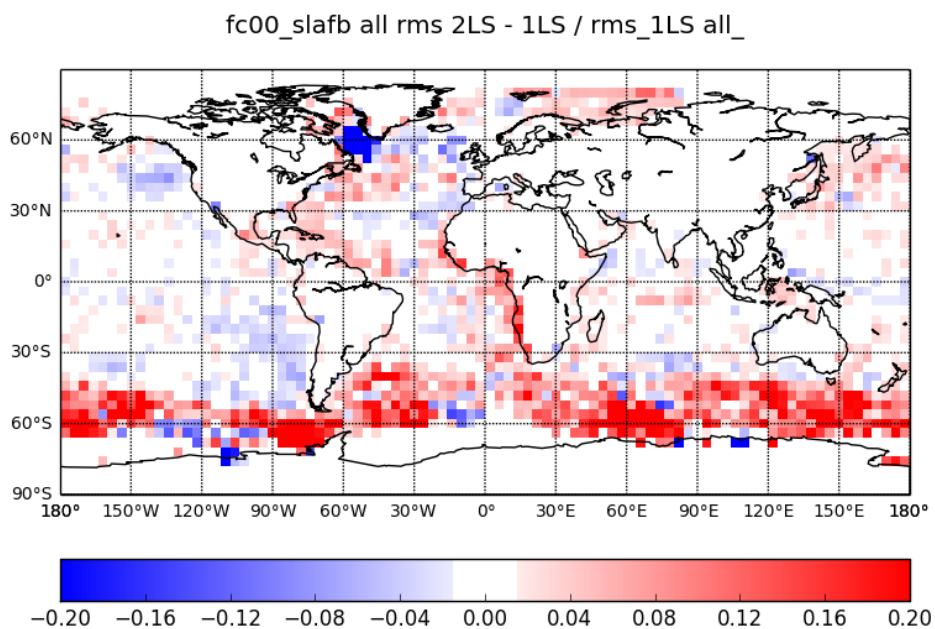
Impacts on the sea surface height

Blue => One length-scale

Red => Two length-scales

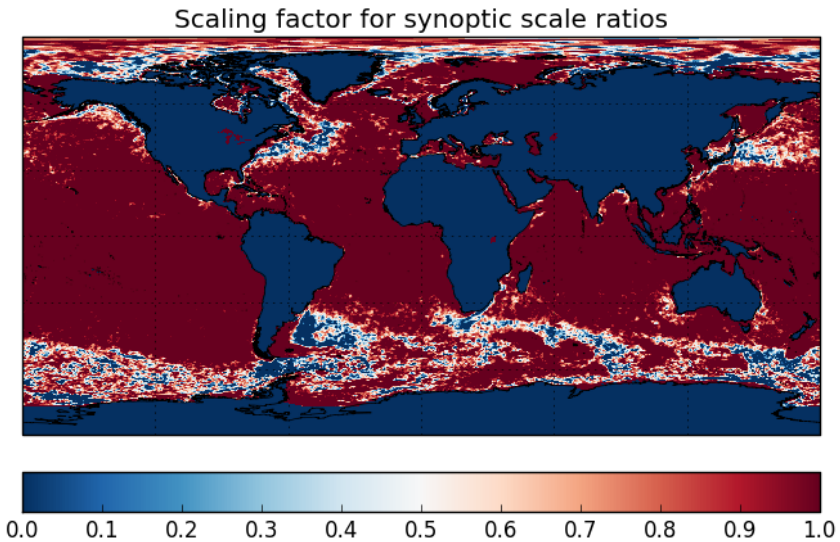
- 2-LS degrades RMS (0.071 to 0.075)
- Plot below shows where the degradation happens (2-LS worse in red)
- Mainly in S. Ocean and boundary currents





Two length-scale covariances

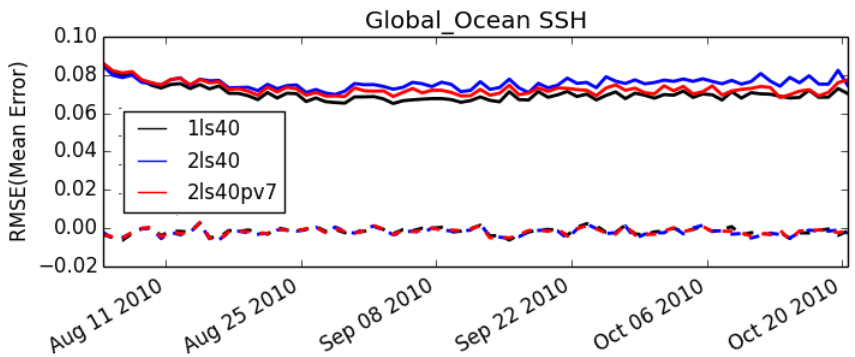
Constraining the synoptic scale using a PV barrier

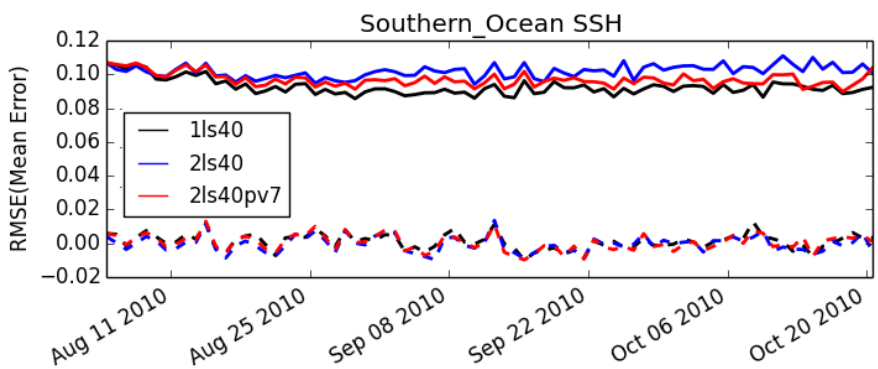


$$\Pi = \frac{\zeta + f}{\rho} \frac{\partial \rho}{\partial z}$$

ζ: Relative vorticity
f: Planetary vorticity
ρ: Density

Horizontal gradients of Π are calculated from the model background at each point and used to modify the longer length-scale

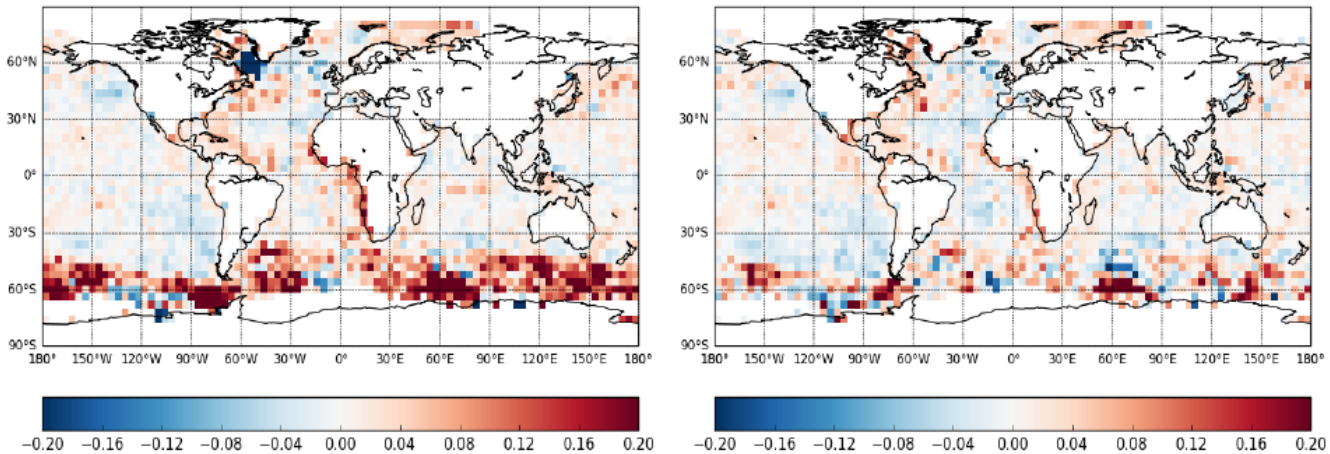




Two length-scale covariances

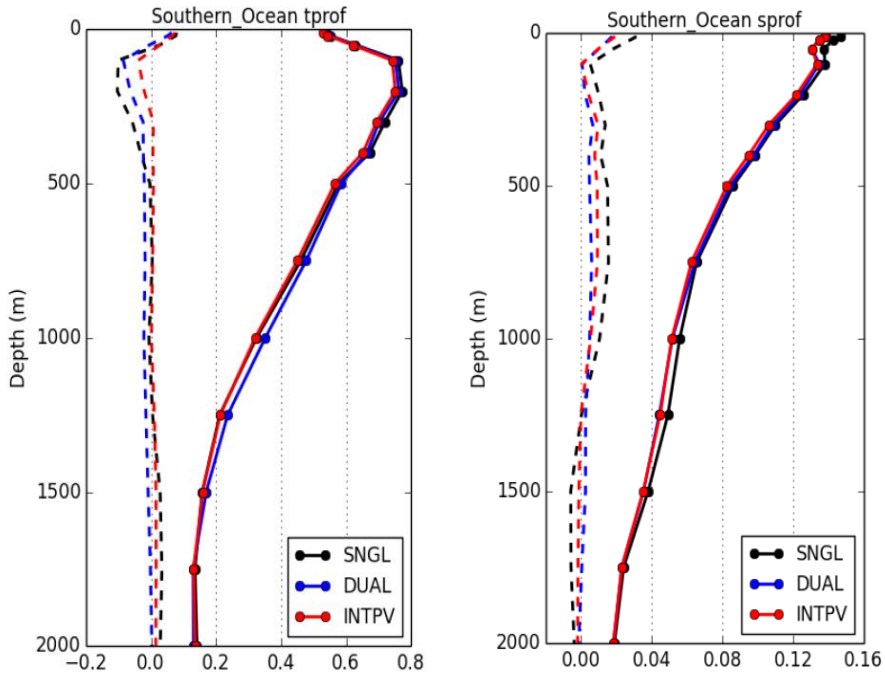
Results of using a PV barrier

SSH errors:
- blue => improved
- red => degraded



(a) (DUAL - SNGL) / SNGL RMS error (b) (INTPV - SNGL) / SNGL RMS error

- SSH in the Southern Ocean much improved by the use of the PV-gradient dependent length-scales
- Temperature also improved by this change.
- Salinity gives similar results.
- This scheme is expected to be implemented operationally in the next major FOAM upgrade.



3. Equatorial data assimilation

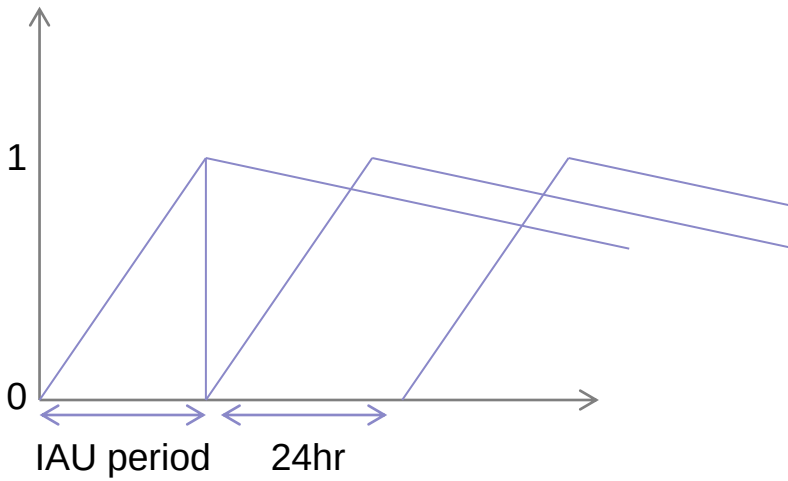
Jennie Waters

Improving equatorial data assimilation
Overview

- The main balance at the equator is between the wind stress and the sub-surface pressure gradients in the ocean.
- Physical data assimilation causes spurious vertical and horizontal circulations at the equator due to inconsistencies between the ocean observations and applied wind stress. Major problem for coupled physical-biogeochemical models.
- The pressure correction method (Bell et al, 2004) attempts to correct for long term biases (**here called "bias_pc")** in wind stress and the way the wind stress is applied in the model.
- The method calculates the pressure correction field by gradually accumulating the temperature and salinity increments over a long period.
- This correction is then applied in the momentum equations in NEMO. The corrections are applied to the ocean pressure fields as an alternative to directly correcting the wind stress. This correction removes the imbalance caused by the bias and as a result reduces the amount of work for the physical data assimilation.
- We have developed a new **instantaneous pressure correction ("inst_pc").** This aims to correct for the short time scale imbalances (or shock) caused by applying the increments. The instantaneous pressure correction can be viewed as an equatorial balance for the temperature and salinity increments.

The Instantaneous Pressure correction method

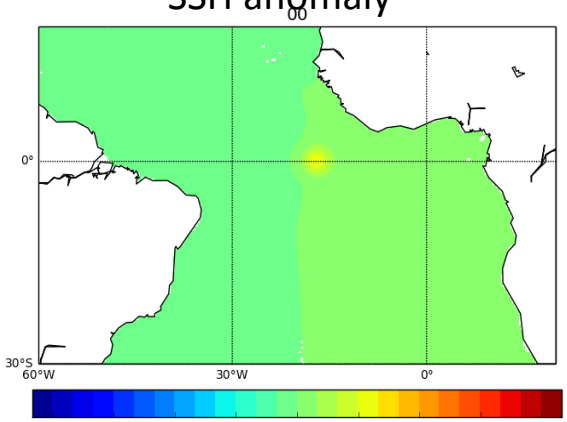
- As in the bias_pc method, a correction is still applied to the pressure gradients in the momentum equation.
- However, the inst_pc is accumulated at a rate proportional to the size of the temperature and salinity increments in the model.
- During the 24 hour IAU step the increments are applied at a rate 1/(total number of timesteps) per timestep.
- The instantaneous pressure correction is then gradually reduced over time in the forecast.
- We have chosen to reduce the correction by 0.9 in each 24 hour forecast.
- This scale was chosen through sensitivity experiments and could be interpreted as a timescale for the persistence of the increments.
- The scheme is only applied near the equator, and ramped down to the North/South in the same proportion as the geostrophic velocity balance is ramped up.



Impact of Inst pc on single observation experiments: SSH innovation of 10cm

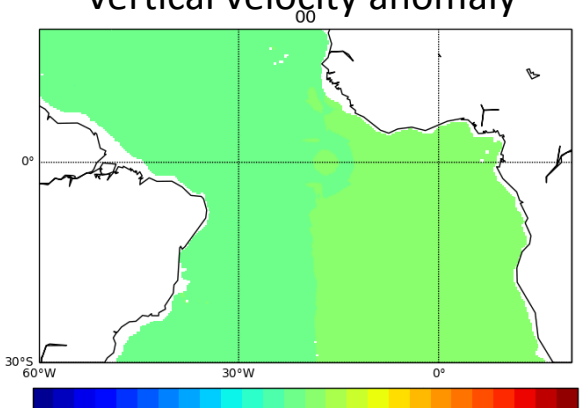
Original case

SSH anomaly



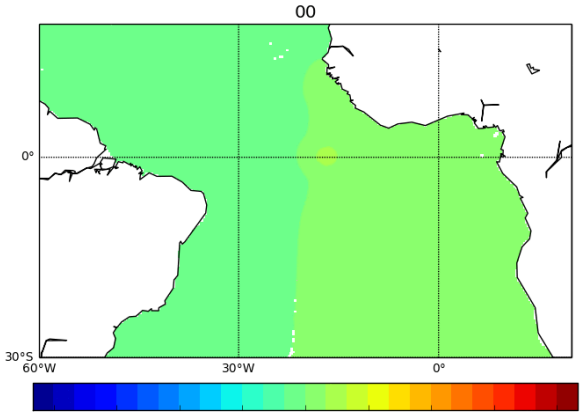
-0.01 0.01

Vertical velocity anomaly

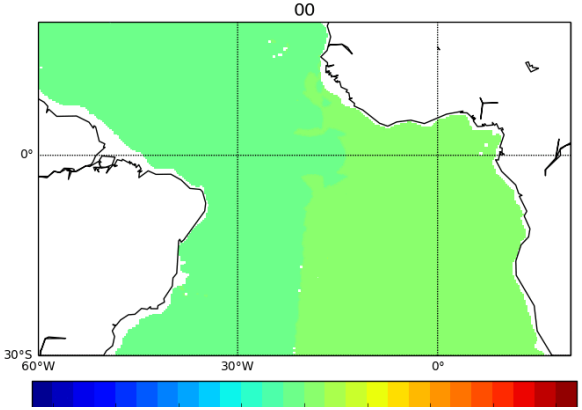


-0.00005 0.00005

Inst pc case



-0.01 0.01

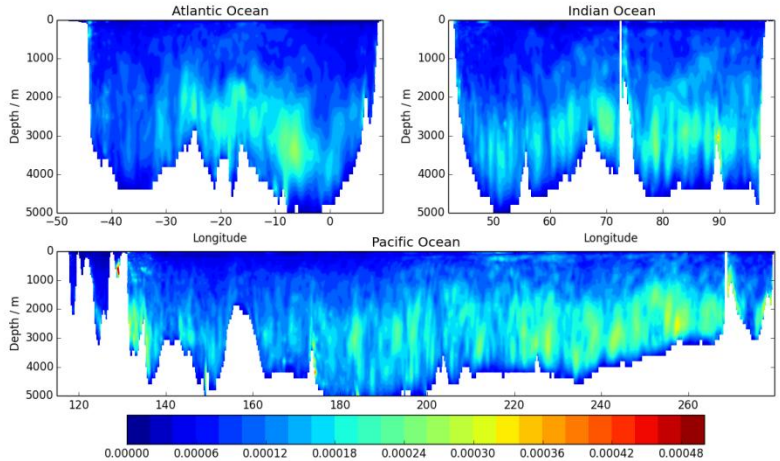


-0.00005 0.00005

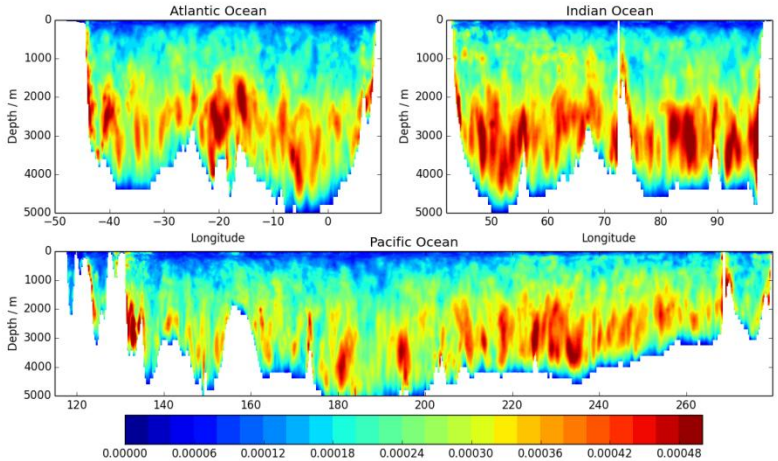
Results from reanalysis experiments: W monthly standard deviation for 12/2011

Experiments assimilating all data, starting in August 2010

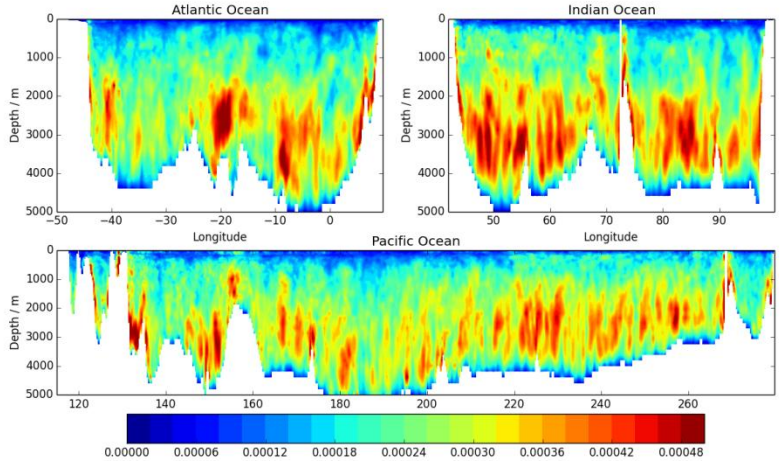
Free model run (no DA)



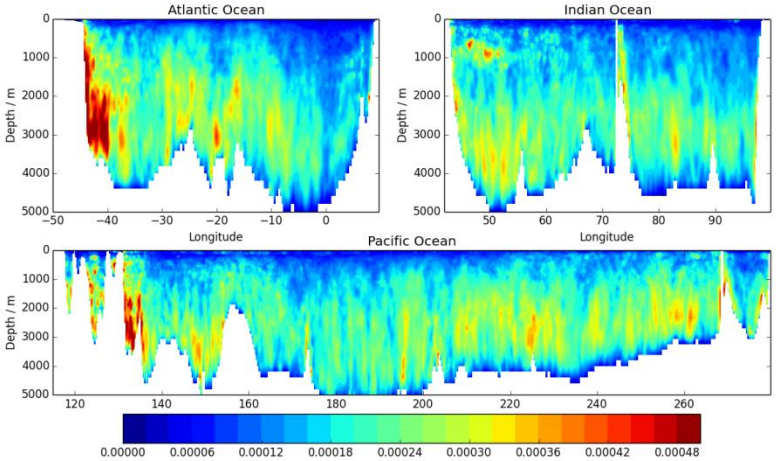
With DA, no pressure correction



With DA + bias_pc (existing system)



With DA + bias_pc + inst_pc



Mean vertical velocites (not shown)
are reduced by the bias_pc

5. Summary and future work

Summary

- A multiple length-scale error covariance model has been implemented in NEMOVAR:
  - Significant improvements to sub-surface biases in T and S.
  - Initial degradation in SSH in the Southern Ocean.
  - Implementing a PV-gradient based reduction in the length-scales leads to improvements in SSH in the Southern Ocean and further improvements to T and S there.

- Instantaneous pressure correction scheme to balance T/S/SSH increments at the equator reduces the spurious circulations generated by data assimilation.

- Next operational upgrade (expected in 2016) will include the new developments described here.

Future work

Various other developments are also being investigated:

- The use of even larger-scale error covariances based on EOFs to improve the use of NEMOVAR for running historical reanalyses when the observational coverage was much more sparse.
- Improve bias correction for SST assimilation (see James While's poster)
- Investigating the use of ensemble forecasting and whether to move to hybrid ensemble/variational DA.
- Improving the assimilation of data in the shelf-seas configurations: currently only SST data are assimilated in those configurations, and we plan to add in profile data and altimeter data.
- Possibly investigate assimilation of satellite SSS data (SMOS/Aquarius).
- Moving to higher resolution global ocean configuration at 1/12° resolution.
- Developing ocean/atmosphere coupled data assimilation systems.

Met Office

Thank you for listening.

Questions?