Use of GOCE MDT and Error Information in NEMOVAR (a Variational Data Assimilation Scheme for NEMO)

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Introduction

The GOCE mission is now producing gravity information of useful accuracy for ocean data assimilation. We test a new GOCE based mean dynamic topography (MDT) along with a new online bias correction scheme, we developed for a 3D-Var assimilation system (NEMOVAR).

NEMOVAR is a multivariate assimilation scheme which assimilates sea level anomaly (SLA), remotely sensed and in-situ sea surface temperature, profile temperature and salinity data, and sea ice concentration data. Assimilating the SLA data requires a MDT to be provided. Currently in the Met Office's operational ocean forecasting system, FOAM, we use the CNES-CLS09 MDT which is a combination of GRACE data, and a synthetic MDT based on dynamic heights and velocities from insitu observations. As GOCE data is accurate to higher resolutions than GRACE this provides the opportunity to use a purely gravity based MDT, but allow a bias correction scheme running online in NEMOVAR to correct the smallest scales of MDT. The bias correction scheme is designed to focus the bias correction at shorter length scales less than 200 km where the MDT errors are known to be larger.

Results are presented from the new Met Office NEMOVAR system running a global at 1/4º resolution. Several experiments are performed testing different MDTs and bias correction schemes. We compare the bias corrected MDTs to alternative MDT products. At this stage, the results are mostly assessed by looking at the observation minus background errors.

Assimilation of MDT as a Sea level bias: Theory

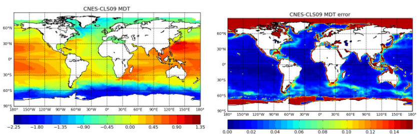
A key challenge is to separate the MDT and its errors in order to use the new GOCE data effectively. This is achieved using a 3D-Var approach which allows part of the Dynamic topography error to be identified as either model bias or observation bias. The observation bias is identified to be an unknown offset to the MDT which has a known error covariance and this bias is derived or forecast as the assimilation proceeds. The method relies on the model dynamic topography error having different space and time error covariances from that of the observations. (Drecourt et al 2006 and Lea et al 2008)

$J = (\mathbf{y}-\mathbf{H}(\mathbf{x}+\mathbf{b}))^{\mathrm{T}}\mathbf{R}^{-1}(\mathbf{y}-\mathbf{H}(\mathbf{x}+\mathbf{b}))$	Model data misfit
$+(\mathbf{x}-\mathbf{x}^{\mathrm{f}}+\mathbf{c})^{\mathrm{T}}\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^{\mathrm{f}}+\mathbf{c})$	Background constraint
$+(\mathbf{b}^{\mathrm{o}}-\mathbf{b})^{\mathrm{T}}\mathbf{T}^{-1}(\mathbf{b}^{\mathrm{o}}-\mathbf{b})$	Observation (MDT) bias constraint
$+(\mathbf{b}-\mathbf{b}^{\mathrm{f}})^{\mathrm{T}}\mathbf{O}^{-1}(\mathbf{b}-\mathbf{b}^{\mathrm{f}})$	Observation bias evolution constraint
$+(\mathbf{c}-\mathbf{c}^{\mathrm{f}})^{\mathrm{T}}\mathbf{P}^{-1}(\mathbf{c}-\mathbf{c}^{\mathrm{f}})$	Model bias forecast constraint

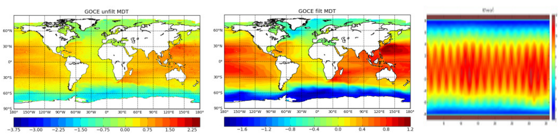
x – model state
y – observation
R – observation error covariance
B – background error covariance
H – observation operator

b – observation bias: Note we assume $\mathbf{b}^{\mathrm{o}}$ = 0 in this case
c – model bias
T – observation bias error covariance: **This is the MDT error covariance**
O – obs bias forecast error covariance
P – model bias forecast error covariance

Error covariance **O** should be small since the bias is slowly varying. It is assumed to be 0.01**T** the overall bias constraint.
Currently the model bias scheme is the pressure correction scheme. NEMOVAR is an incremental scheme and it is not clear how to implement the observation bias constraint term in incremental form so only the observation bias evolution constraint is currently used.



▲ **Figure 1:** (left) the CNES-CLS09 MDT (m); (right) the error variance (cm) (formal error times 5).



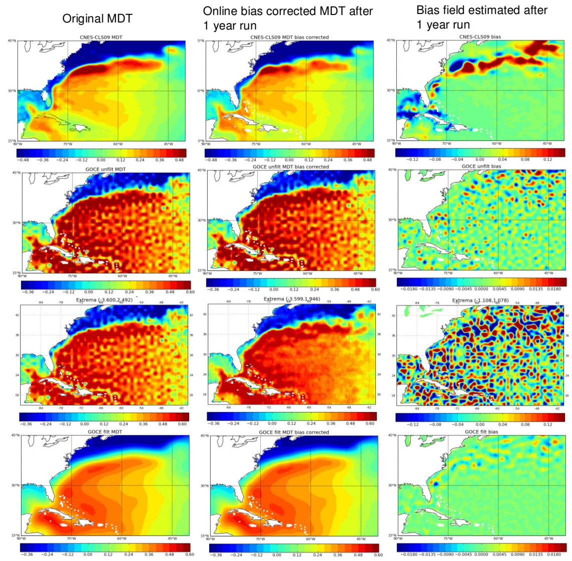
▲ **Figure 2:** (left) the GOCE MDT (m); (middle) filtered GOCE MDT; (right) the known error variance (cm). An estimate of the unknown small scale error is needed too for the bias correction.

Experiments

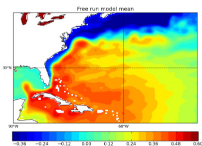
These are 1 year runs of ¼ degree 75 level (ORCA025L75) NEMO using NEMOVAR all starting with the same initial condition on 1 July 2010. The assessment period is the second half of the run – 1 Dec 2010 to 30 June 2011. ▼ **Table 1** for more experiment details.

	CNES-CLS09	GOCE unfilt	GOCE unfilt2	GOCE filt
	Combined MDT 5 years GRACE data Combined with a synthetic MDT based on in-situ data	Gravity based combined GOCE time-wise v3 and GRACE	Gravity based combined GOCE time-wise v3 and GRACE	Gravity based combined GOCE time-wise v3 and GRACE. 200km filter applied to MDT
Bias evolution (**O** = **T**/100) constraint error std dev	Formal error map times 5 / 10	Uniform 2 cm / 10	Uniform 2cm	Uniform 2 cm / 10
Bias length scale	40 km	40 km	40 km	40 km
Length scale of large scale bias removed	Large scale bias not removed	200 km	200 km	200 km

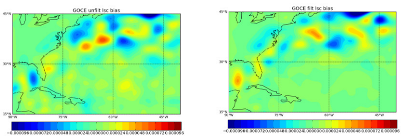
Results



▲ **Figure 3:** Original MDT for the three experiments in three rows (first column). The bias is estimated online which gives a corrected MDT (second column). The bias field is shown in the third column. The CNES-CLS bias correction scheme makes substantial changes in the Gulf Stream region. The GOCE data is spectral and when this is gridded there is significant small scale noise. GOCE filt smoothes the field (too much) with a 200 km diffusion filter. GOCE unfilt2 with an increased bias variance does a good job at correcting the small scale noise in the unfiltered MDT



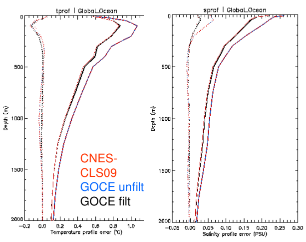
◄ **Figure 4:** Free running model mean for 1 year. The bias correction scheme may be causing the model to converge to its own MDT in the CNES-CLS09 run rather than perhaps the best one. For example, the eddy at the Gulf Stream separation appears in the bias corrected MDT. This motivates the use of the scale selective bias correction scheme – however some work is still needed to get this to function effectively.



◄ **Figure 5:** Large scale bias estimated in (left) the GOCE unfilt run and (right) the GOCE filt run

	CNES-CLS09 (b)	GOCE unfilt (b)	GOCE unfilt2 (b)	GOCE filt (b)
SSH /cm	7.3	12.5	8.2	8.4
Insitu SST /C	0.478	0.511	0.479	0.489
T	0.590	0.718	0.635	0.599
S	0.128	0.162	0.137	0.130

▲ **Table 2**: Summary RMS innovation (obs-bkg) statistics of the run. The lowest errors are found with in the CNES-CLS09 run. The highest errors are with the GOCE unfilt MDT. This is too noisy and the bias correction has not done enough to remove this. The GOCE filt field is appears too smooth (compared to the old MDT and a free running model mean) and produces slightly worse results than CNES-CLS09.



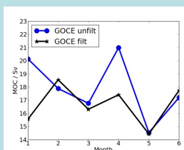
◄ **Figure 6:** The impact on other variables is important test of consistency of the MDT estimate. Here we show plots of the depth binned RMS (solid) and mean (dashed lines) temperature innovations for the three experiments. The red line is CNES-CLS09, blue is GOCE unfilt and black is GOCE filt. Clearly having a particularly noisy MDT is harmful to the fit to other variables.

Conclusions

Still some work to do to be able to use GOCE data effectively in FOAM.

To do

- Tune the errors in the bias correction to increase the size of the bias correction
- Perhaps, use optimally filtered the GOCE data. The unfiltered MDT may be too noisy and the filtered MDT is too smooth.
- Compare model to independent data e.g. drifters currents / MOC (see **Figure 7** ►: preliminary MOC results from Jan 2011 to June 2011).



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