Ocean bottom pressure variability: Which part can be reliably modeled?

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Abstract

Ocean bottom pressure (OBP) variability serves as a proxy of ocean mass variability. A question how well it can modeled by the present general ocean circulation models on time scales of 1 day and more is addressed. It is shown that the models simulate consistent patterns of bottom pressure variability on monthly and longer scales except for areas with high mesoscale eddy activity, where high resolution is needed. The simulated variability is compared to a new data set from an array of PIES (Pressure - Inverted Echo Sounder) gauges deployed along a transect in the Southern Ocean. We show that while the STD of monthly averaged variability agrees well with observations except for the locations with high eddy activity, models lose a significant part of variability on shorter time scales. Furthermore, despite good agreement in the amplitude of variability, the OBP from the PIES and simulation show almost no correlation. Our findings point to limitations in geophysical background models required for space geodetic applications. We argue that major improvements in OBP modelling require data assimilation in order to increase the coherence between modelled and observed signals.

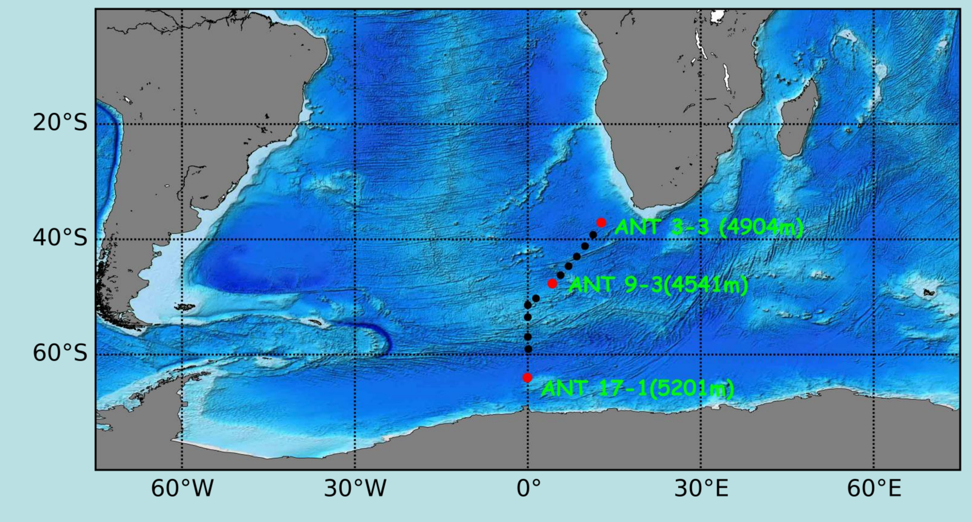

Fig. 1. Location of PIES stations. Red dots – PIES stations for analysis.

OBP variance

- We use the FESOM [1] (a locally eddy resolving (10 km in the Agulhas region) and coarse setups), and MITgcm (Massachusetts Institute of Technology General Circulation Model) [2] (18 km mesh).
- Mesoscale eddies and baroclinic waves contribute to the OBP variability. We study their signal by comparing simulations done with climate-type (coarse) and eddy resolving versions of models.
- In situ OBP measurements (Fig. 1) are used to judge about the realism of modelled variability.

The OBP variability on monthly timescales simulated on eddy resolving/permitting (upper panel) and coarse (lower panel) meshes differ in zones of enhanced eddy activity.

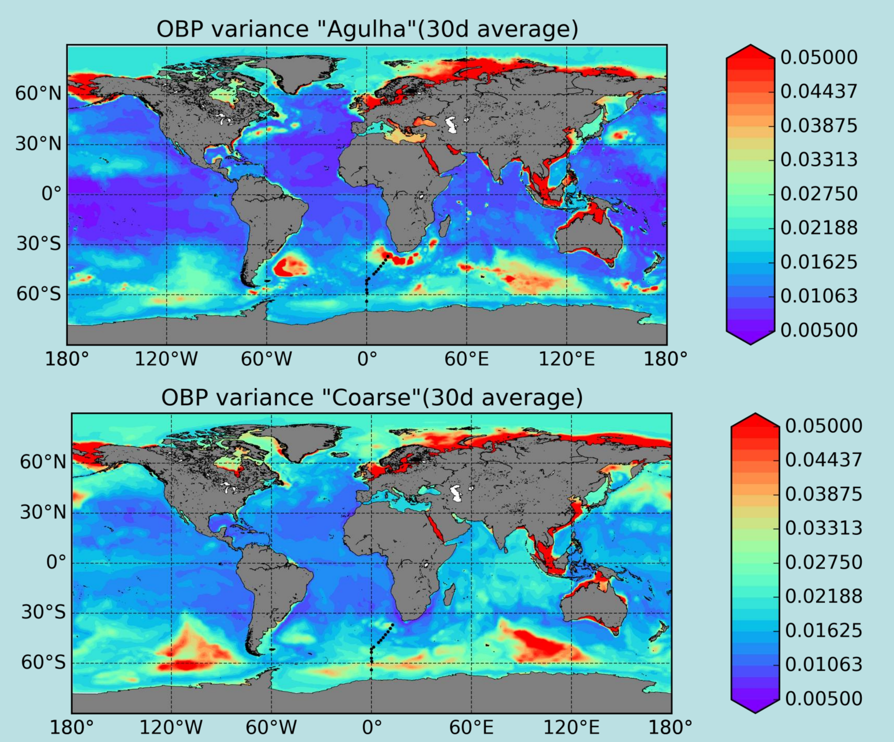

Fig. 2. OBP variance in cm for the period of 2000-2009 (monthly averages). Upper panel - FESOM Agulhas setup (CORE-II atmospheric forcing. Low panel - FESOM at coarse mesh (NCEP atmospheric forcing).

Comparison models results with observations - I

PIES observations are available for a four-year period from December 2010 [3]. They are compared with OBP simulated by FESOM-coarse and MITgcm, driven by the NCEP forcing.

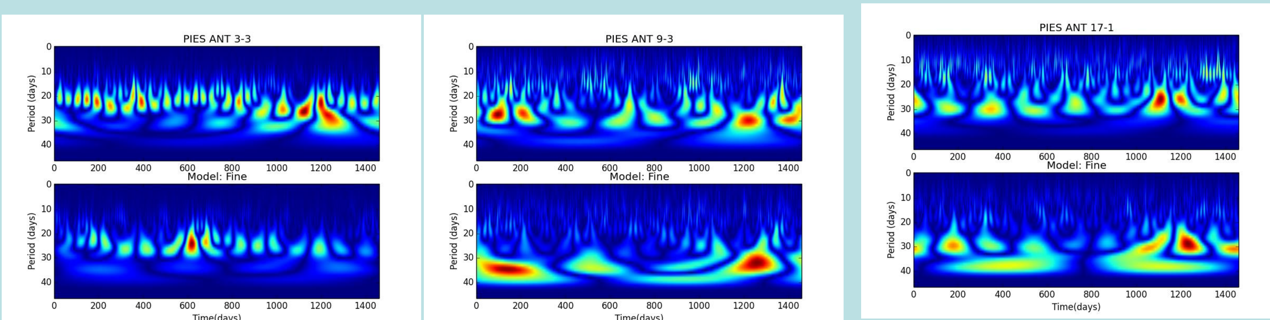

Fig. 4. Wavelet analysis (daily average). Upper row – PIES; bottom row – MITgcm model. Left column – PIES ANT 3-3; middle column – ANT 9-3; right column – ANT 17-1.

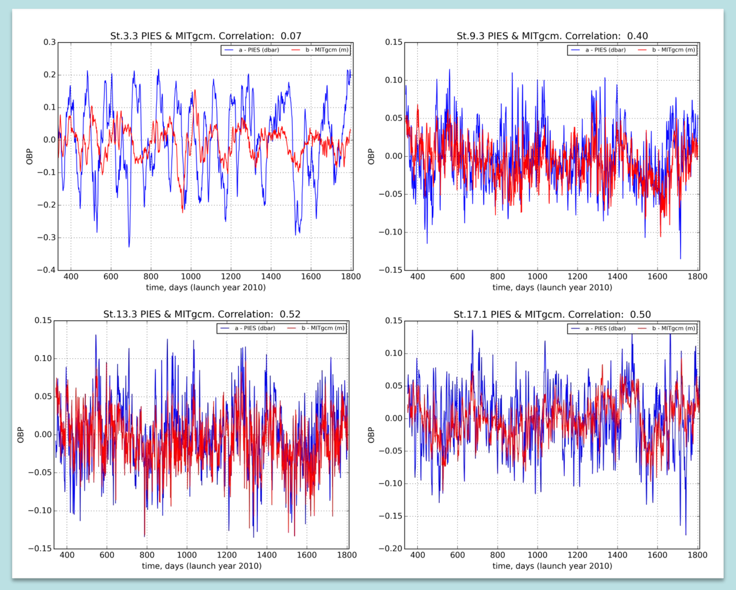

Fig. 3. Left upper panel: measured OBP (blue) and modelled values (red) at the station ANT3-3 in the Agulhas region. Right upper panel: same for station ANT9-3 in the centre of the ACC. Left lower panel: station ANT13-3 on the bottom sharp slope. Right lower panel: station ANT17-1 near the Antarctic coast.

A comparison of the one-day averaging of the OBP shows a fairly good agreement between models and observational data (Fig. 3) in almost the entire frequency range. Wavelet analysis (Fig. 4) indicates that the main frequency of the maximum signal is close to the sub-monthly signal. A significant part of variability is on periods around 20-30 days, which may lead to aliasing if monthly averaging is used. Wavelet analysis for monthly average output (Fig. 5) shows that both models reproduce only the seasonal or semi-annual cycle in the regions of weak eddy activity (PIES ANT 9-3, 17-1).

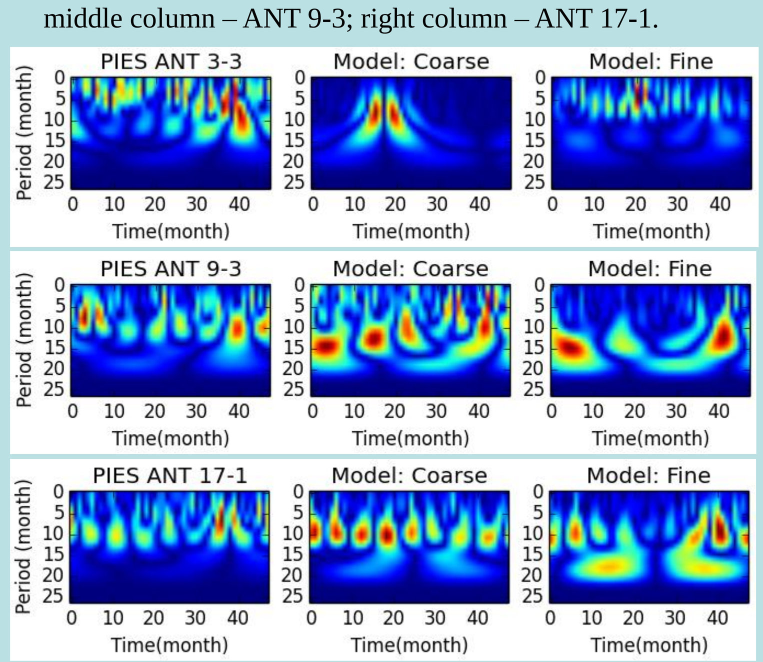

Fig. 5. Wavelet analysis (monthly average output). Upper row – station ANT 3-3; middle row – ANT 9-3; bottom row – ANT 17-1. Left column – PIES; middle column – FESOM-coarse; right column – MITgcm.

At locations eddy variability is high (PIES ANT 3-3), the coarse model does not reproduce the behaviour of OBP variability.

Comparison models results with observations - II

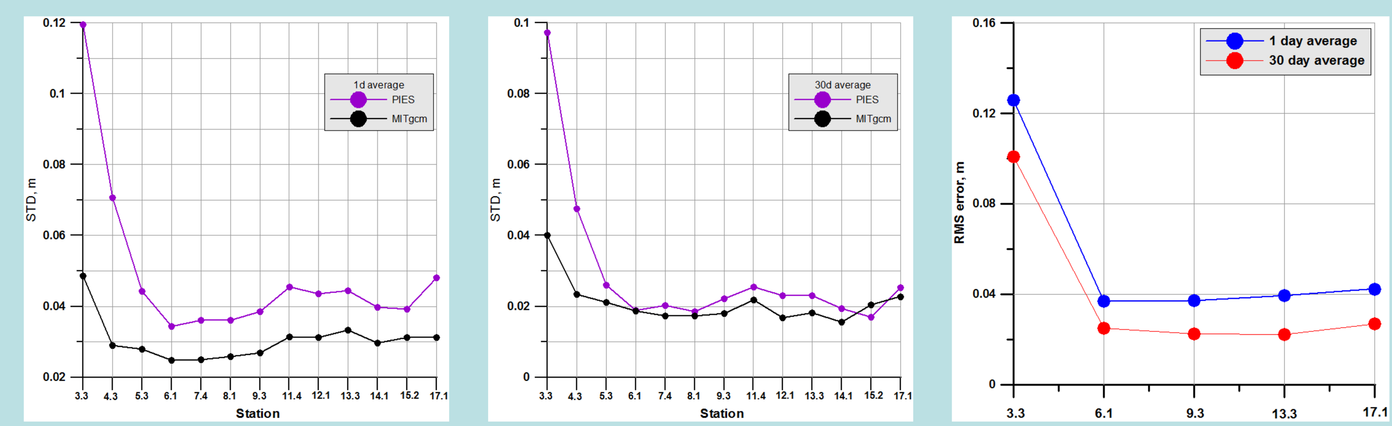

Fig. 6 Left panel: STD with 1 day data averaging; Middle panel: the STD with 30 day data averaging. Right panel: the RMS error between the simulated and observed values.

Middle panel (Fig. 6) presents comparison based on monthly averaging. The simulated STD agrees well with observations except for two stations that are close to the Agulhas retroflection region, where it is noticeably lower.

The simulated STD with a shorter window (1 day) is everywhere weaker than observed. The 6-hourly forcing used to drive the model is perhaps insufficient to properly excite high-frequency motions. Besides, global ocean circulation models commonly introduce some damping of surface gravity waves, which may be also playing the role here.

The right panel of Fig. 6 shows the RMS error between the model and observations.

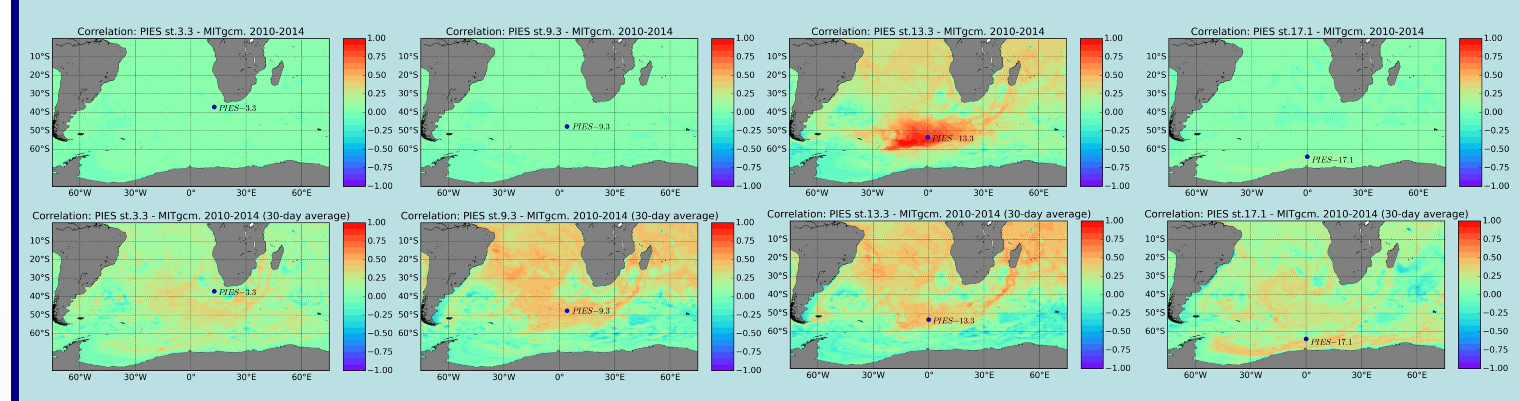

Fig. 7. Correlation between OBP from PIES with MITgcm; Upper panel - daily averages. Low panel – monthly averages. From left to right: Station 3.3, Station 9.3 , Station 13.3, Station 17.1.

The spatial correlation between model and PIES is shown in Fig.7. For daily averaging the noticeable correlation arises only at the station 13-3. For monthly averaging the correlation is significant outside eddy active regions.

Correlation between OBP and the residuals of the inversion

Figure 8 (left) shows remarkable correlations between modelled OBP and the GRACE-altimetry inversion residual: 19.3% of all correlations are higher than 0.5. Mass anomalies, expressed as water equivalent [m] were furthermore compared to *in situ* measurements. We present results for the eddy rich region in the Agulhas retroflection (ANT 3-3 right). The residuals of the inversion, derived from GRACE and Jason data correlate well with the in-situ data, which means that a great part of the residuals can be explained by a proper modelling of ocean bottom pressure. Current model results from MITgcm are shown in orange.

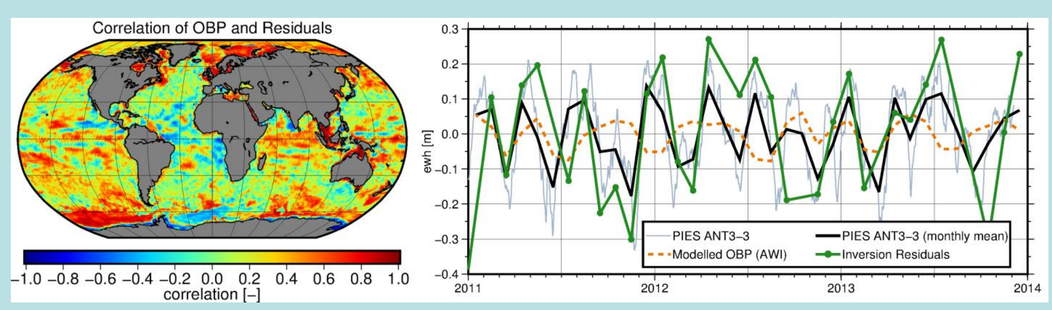

Fig.8. OBP from PIES ANT3-3 (right) in situ measurements compared to modelled OBP (MITgcm) and to the residuals of the inversion

Conclusions

- ✓ Modelling of OBP needs higher resolution. The intensity of eddies is underestimated in the Agulhas region and is marginally sufficient in the core of the ACC.
- ✓ A sub-monthly mode of OBP variability is observed in the period of PIES observations in the Antarctic region which may alias monthly-averaged signals.
- ✓ Simulated variability is consistent in magnitude, but is poorly correlated with the observed variability. It is likely that the ocean internal variability dominates the signal.

References

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2. Marshall, John; A. Adcroft; C. Hill; L. Perelman; C. Heisey (1997). A finite-volume, incompressible Navier Stokes model for studies of the ocean on parallel computers. *J. Geograph. Res.* v.102 (C3):, pp 5753–5766.
3. The Expedition PS89 of the Research Vessel POLARSTERN to the Weddell Sea in 2014/2015 Edited by Olaf Boebel with contributions of the participants. *Berichte zur Polar- und Meeresforschung Reports on Polar and Marine Research.*