Short-Period Oceanic Circulation: Implications for Satellite Altimetry

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Abstract

Atmospherically forced, high-frequency oceanic variability is investigated using different configurations of an ocean general circulation model. At periods of 20 days and shorter, the dynamic response of the sea surface to pressure loading exceeds that due to wind stress, and barotropic effects are much larger than baroclinic effects. Energy at these short periods aliases into satellite altimeter measurements of sea surface height (SSHT). The global variance of collinear (≈10 day) differences of this modelled aliased SSHT is between $(2\ \mathrm{cm})^2$ and $(3.5\ \mathrm{cm})^2$, depending on the model configuration used. The local variance can reach $(14\ \mathrm{cm})^2$ at some high latitude locations. We use the ocean model predictions to remove the high-frequency signals from Topex/Poseidon (T/P) observations, and obtain a global variance reduction in collinear differences of up to $(2\ \mathrm{cm})^2$, about 7% of the T/P signal, depending on the model and forcing configuration. Our model has difficulty in predicting the variability at very short periods (< 5 days).

Introduction

Forcing of the ocean by wind stress and pressure loading occurs over a broad range of frequencies. Analyses of ocean model output (*e.g. Fukumori et al.*, [1998], *Wahr et al.*, [1998]) suggest there is significant barotropic variability in the ocean at periods of 2-3 weeks and shorter. These disturbances can alias into satellite observations of the ocean because of the way a satellite ground track samples the earth's surface. The TOPEX/Poseidon (T/P) altimeter (and Jason, scheduled for a 2000 launch) has a ground track repeat period of 9.9156 days. Oceanic disturbances with periods shorter than twice this will alias into the altimeter sea surface height (SSHT) maps. Similarly, the GRACE gravity mission (a 2001 launch) will provide maps of sea floor pressure at intervals of ≈30 days. Disturbances in sea floor pressure at periods <60 days will alias into those maps.

The purpose of this work is to quantify the amplitude and spatial and temporal characteristics of this short-period oceanic signal, with emphasis on its possible aliasing effects on altimeter observations of SSHT. We extend the above studies by isolating the effects of wind and pressure (including both the barotropic and baroclinic components), by looking at the effects of different high-frequency filter widths, and by assessing model skill at these periods by removing the high-frequency model output from T/P observations and computing the resulting variance reductions (see also *Stammer et al.*, [1999]).

The ocean model

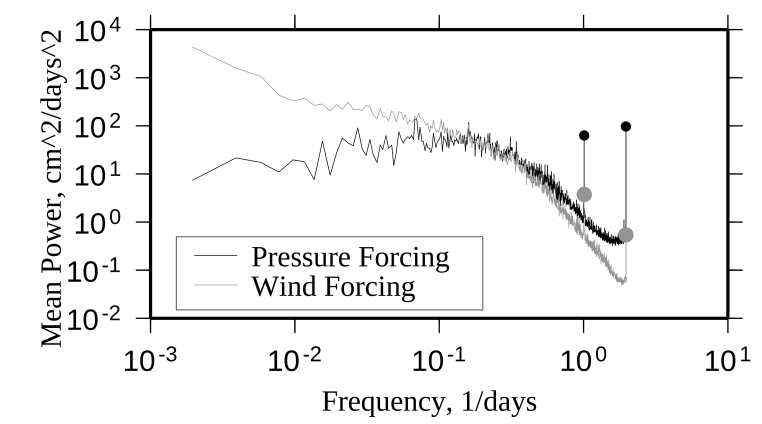
We use output from a free surface, primitive equation, global ocean general circulation model (POP) [*Dukowicz and Smith*, 1994] configured on a grid with average horizontal resolution of ≈150 km, and with 32 vertical levels separated by 25 m near the surface to 300 m in the deep ocean. We present results from two versions of the model: a baroclinic version in which the ocean temperature and salinity are free to evolve, and a barotropic version in which the temperature and salinity, and hence density, are held fixed to globally uniform constants. Horizontal dissipation is provided by a Laplacian form eddy viscosity with coefficients that vary linearly with grid cell area, ranging from 3×10^3 to $10\times10^4\ \mathrm{m}^4\ \mathrm{s}^{-1}$. Bottom friction is parameterized with a quadratic bottom drag with a coefficient of 1.225×10^{-3}. Vertical viscosity is parameterized following *Pacanowski and Philander* [1981] in the baroclinic cases and a constant value of $10^{-4}\ \mathrm{m}^2\ \mathrm{s}^{-1}$ in the barotropic cases.

The model is driven by operational 6 hourly surface winds and/or atmospheric pressure, generated by the European Centre for Medium-Range Weather For casts (ECMWF). For the baroclinic experiments the surface heat flux is prescribed by the linear bulk formulation of *Barnier et al.*, [1995], and surface salinity is forced through a Newtonian relaxation towards climatological monthly mean sea surface salinity [*Levitus et al.*, 1994]). Baroclinic experiments are initialized on Jan 1, 1986 with the equilibrium solution of an integration using repeating annual cycle forcing, and the barotropic experiments are initialized from rest on Jan. 1, 1995. In this study we use the model results for the 2-year period January, 1995, through December, 1996. When we refer to "wind forcing" in the baroclinic experiments below, we mean the combined forcing from winds and surface buoyancy fluxes.

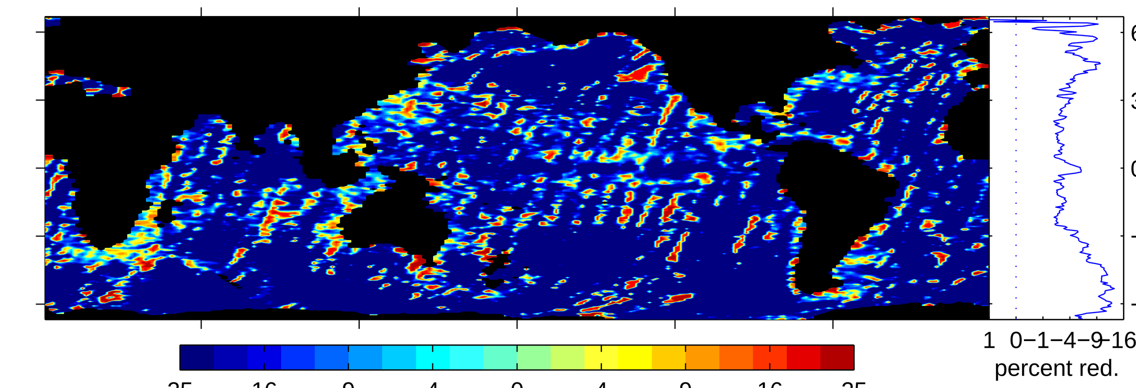
Table of variance reduction

Table 1: Variance reduction in collinear T/P differences after removing model output from several different model configurations and time-filter window widths. The table includes the varaince of the uncorrected T/P data. All results are global areal averages in cm^2.

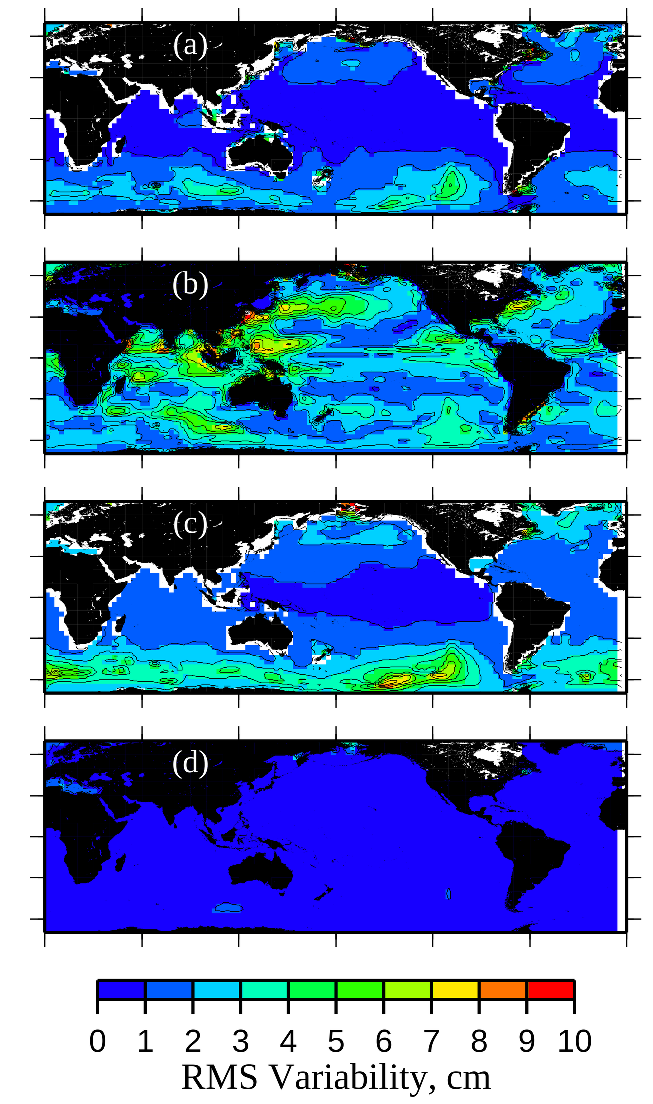
Model	Filter length	Global Variance	Model Variance	% Reduction
Uncorrected	—	59.9	—	—
Pressure - Barotropic	0-20 days	61.5	8.1	-2.6
	5-20 days	58.8	2.1	1.9
Wind - Baroclinic	0-20 days	57.3	3.7	4.3
	5-20 days	56.9	1.9	5.0
Wind & Pressure - Baroclinic	0-20 days	58.7	11.8	2.1
	5-20 days	55.7	3.8	7.1



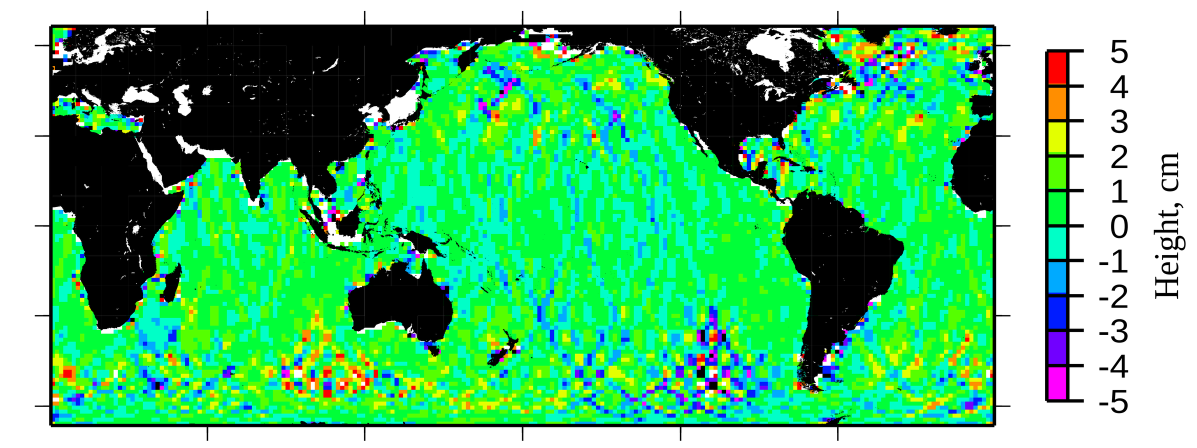
The power spectra at every grid point are averaged together to illustrate the variability as a function of frequency, for both the wind forced baroclinic and pressure forced barotropic model output. The diurnal and semi-diurnal amplitudes are marked with black and grey circles for the pressure forced barotropic and wind forced baroclinic cases, respectively.



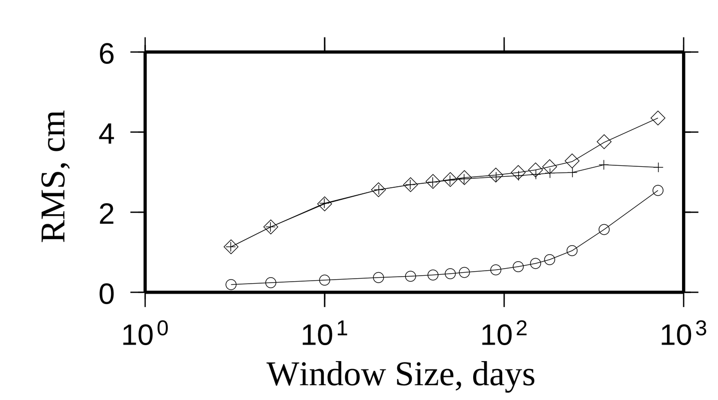
The change in variance of T/P collinear differences, in percent, averaged over 2 years, after removing the wind and pressure forced baroclinic model output filtered between 5 and 20 days. Blue shades imply a decrease in variance, red an increase in variance. The curve to the right of the map shows the zonally averaged percent variance change versus latitude.



The RMS of the high-pass filtered SSHT model output, for the wind forced baroclinic (a: high-passed; b: low-passed), and pressure forced barotropic (c: high-passed; d: low-passed) models. The low-passed pressure forced barotropic results are negligible at this scale.



The wind and pressure forced baroclinic model output, filtered between 5 and 20 days, sampled by the T/P ground track for cycle 88 (February, 1995), and binned into 1° boxes. Note the trackiness of this aliased short period signal.



The global RMS of the difference between the wind and pressure forced baroclinic and barotropic (marked with circles) model runs, and of the wind and pressure forced baroclinic (marked with diamonds) and barotropic (marked with plusses) models alone, as functions of filter width.

Conclusions

Short-period oceanic SSHT can be large, (as shown, for example, by *Fukumori et al.*, [1998]), particularly in the Southern Ocean and at high northern latitudes. Our model results suggest that RMS values at periods shorter than 20 days are on the order of 2.5 cm averaged over the globe, and can be as large as 10 cm at some locations. Contributions from the pressure-driven circulation tend to be larger than from the wind-driven circulation. Baroclinic effects are small at these short periods, although they can reach ≈1 cm at certain Southern Ocean locations. The high-frequency signal is aliased into analyses of T/P data due to the 9.9156-day altimeter sampling (unless large scale spatial averaging is involved), where it appears as trackiness: a signature similar to orbit error or improper removal of other fast effects on the altimeter. The magnitude of the signature is larger than several other corrections routinely applied to T/P data. When we use output from an ocean general circulation model to remove the high-frequency (5-20 day period) variability from T/P data, we obtain reductions of up to 7% in the global variance computed from collinear differences, depending on the model and forcing configuration. The variance reduction tends to be smaller when periods < 5 days are also included. The errors in the highest frequency (< 5 days) components of the model may be due to numerical issues (damping from implicit time steps [*Dukowicz and Smith*, 1994], treatment of bottom topography [*Pacanowski and Gnanadeskian*,1998]), inappropriate dissipation parameterizations, or errors in the forcing data. Further study is necessary to resolve these issues before model predictions can be used to routinely correct satellite observations of SSHT.

Acknowledgments

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