Testing Ocean Models With Earth Rotation Measurements

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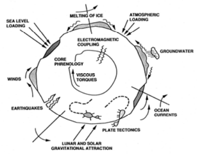
Abstract. Angular momentum is a fundamental conserved property of dynamical systems. It is an integrated measure of mass motion and redistribution and as such can be used to diagnose the oceans' changing general circulation. Furthermore, the angular momentum of the oceans is exchanged with that of the solid Earth causing the Earth's rotation to change. In fact, a number of studies have recently shown the importance of oceanic processes in causing Earth rotation changes, particularly in exciting polar motion, which is the motion of the rotation pole with respect to the Earth's crust. Because of this demonstrated importance of oceanic processes in exciting polar motion, polar motion observations have the potential to be used as a novel means of testing ocean models. Here, this potential is explored by computing the angular momentum from 15 different ocean model runs of the ECCO consortium that have been forced by surface fluxes from different sources and/or that have assimilated different types and amounts of oceanographic data. Comparing this suite of oceanic angular momentum series to polar motion excitation observations from which atmospheric and tidal effects have been removed shows that, as expected, the angular momentum series from the data assimilative runs are in closer agreement with the observed polar motion excitation series than are those from the runs that have not been constrained by data.

INTRODUCTION

- Recent studies using oceanic general circulation models (OGCMs) have shown that oceanic current and bottom pressure variations
  - Measurably change the length of the day
    - Marcus *et al.* (1998), Ponte and Stammer (2000), Gross *et al.* (2003a)
  - Are a major source of polar motion excitation
    - Ponte *et al.* (1998), Johnson *et al.* (1999), Gross *et al.* (2003b)
- Consequently, it has been demonstrated that
  - Current generation OGCMs can accurately model the angular momentum of the oceans
  - Earth rotation measurements are sensitive to changes in oceanic angular momentum
    - After accounting for other effects on the Earth's rotation such as those due to the atmosphere and tides
- This allows the possibility, which is explored here, of using Earth rotation observations to test ocean models
  - Compare oceanic angular momentum (OAM) to Earth rotation observations from which atmospheric and tidal effects have been removed
    - Compute OAM of 15 different model runs generated under different forcing conditions and/or which have assimilated different data sets
    - All model results used here have been obtained by the ECCO group at JPL

Earth Rotation Dynamics



Sources of Earth Rotation Variations

Earth's rotation is changing

Length of day by few milliseconds
Wobbles by few hundred milliarcseconds (10 meters at North Pole)
Nutation and precession

Earth rotation changes caused by

External torques — tidal phenomena
Angular momentum exchange with bounding fluids (atmosphere, oceans, core)
Internal deformation — postglacial rebound, earthquakes

Oceanic processes that influence Earth's rotation

Angular momentum carried by oceanic currents
Ocean-bottom pressure variations
Sea level rise from meltwater

OCEANIC ANGULAR MOMENTUM (OAM)

- Angular momentum of oceans changes due to:
  - Changes in strength and direction of oceanic currents
  - Changes in mass distribution of oceans (changes in ocean-bottom pressure)
- Under principle of conservation of angular momentum, the rotation of the solid Earth changes as OAM is exchanged with the solid Earth
- OAM can be computed from products of OGCMs by:
  - OAM due to ocean-bottom pressure changes (inertia tensor)

$$\mathrm{M}^p(t) = M_1^p(t) + i\,M_2^p(t) = -\int_{V_o} r^2\,\Omega\,\rho(\mathrm{r},t)\sin\phi\cos\phi\,(\cos\lambda + i\sin\lambda)\,dV$$

$$M_3^p(t) = \int_{V_o} r^2\,\Omega\,\rho(\mathrm{r},t)\cos^2\phi\,dV$$

  - OAM due to current changes (relative angular momentum)

$$\mathrm{M}^c(t) = M_1^c(t) + i\,M_2^c(t) = -\int_{V_o} \rho(\mathrm{r},t)\,r\,[\sin\phi\,u(\mathrm{r},t) + i\,v(\mathrm{r},t)]\,(\cos\lambda + i\sin\lambda)\,dV$$

$$M_3^c(t) = \int_{V_o} \rho(\mathrm{r},t)\,r\cos\phi\,u(\mathrm{r},t)\,dV$$

- OAM is related to polar motion excitation and length-of-day changes by:

$$\chi(t) = \chi_1(t) + i\,\chi_2(t) = \frac{1.61}{\Omega\,(C-A)}\left[\mathrm{M}^c(t) + \frac{\mathrm{M}^p(t)}{1.44}\right] \quad \text{(polar motion excitation)}$$

$$\Delta\Lambda(t) = \frac{\Lambda_o}{C_m\,\Omega}\left[M_3^c(t) + 0.756\,M_3^p(t)\right] \quad \text{(length-of-day changes)}$$

Oceanic Angular Momentum Series Studied

The oceanic angular momentum was computed from 3 series of 5 model runs
Each model run spanned 1993–2001

SERIES A :
- Forced by NCEP/NCAR reanalysis surface fluxes
- Topex/Poseidon data assimilated

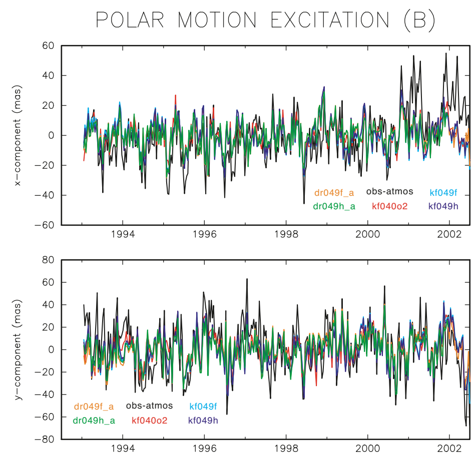
SERIES B :
- Tuned by a Green's function procedure developed by D. Menemenlis
- Topex/Poseidon and XBT data assimilated

SERIES C :
- Employs time-mean bias corrections of the forcing estimated by ECCO/Scripps group
- Topex/Poseidon and XBT data assimilated

SERIES A model runs :
kf035d2 : control run that assimilated no data
kf056 : Kalman filter run with data assimilated with respect to control mean
dr056a_a : smoothed-wind driven run corresponding to kf056
kf056b : Kalman filter run with data assimilated with respect to control trend
dr056b_a : smoothed-wind driven run corresponding to kf056b

SERIES B model runs :
kf040o2 : control run that assimilated no data
kf049f : Kalman filter run with data assimilated with respect to control mean
dr049f_a : smoothed-wind driven run corresponding to kf049f
kf049h : Kalman filter run with data assimilated with respect to control trend
dr049h_a : smoothed-wind driven run corresponding to kf049h

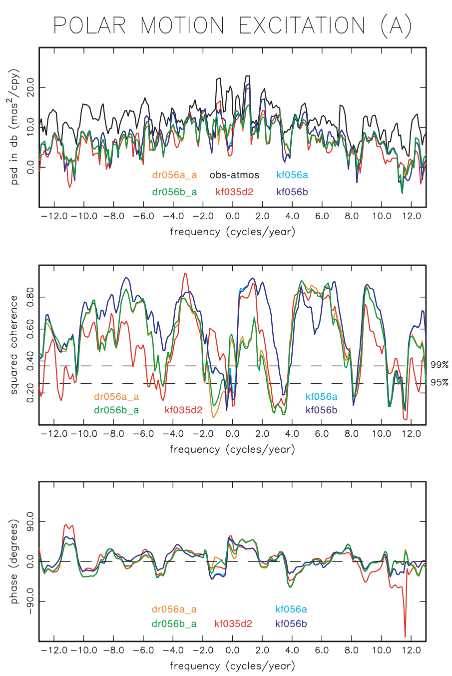
SERIES C model runs :
kf052a : control run that assimilated no data
kf052c : Kalman filter run with data assimilated with respect to control mean
dr052c_a : smoothed-wind driven run corresponding to kf052c
kf052d : Kalman filter run with data assimilated with respect to control trend
dr052d_a : smoothed-wind driven run corresponding to kf052d

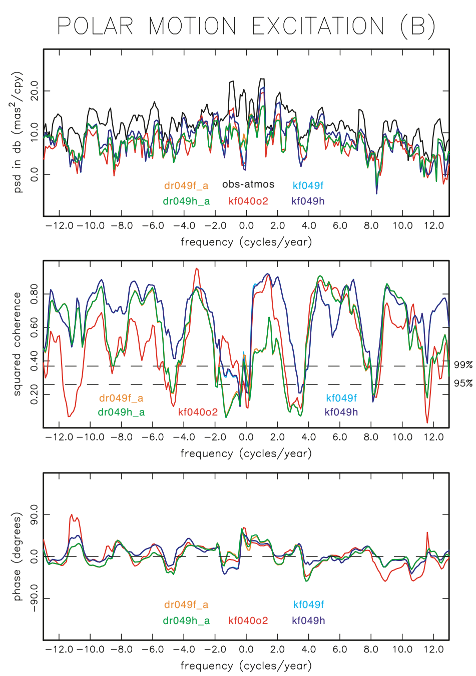


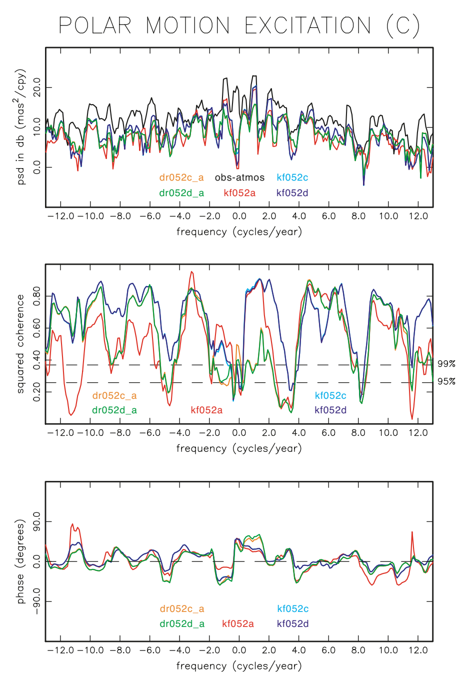
Agreement of OAM with polar motion excitation observations
(after removing effects of atmosphere from observations)

	Seasonal Component Included		Seasonal Component Removed	
	correlation	obs. variance explained	correlation	obs. variance explained
SERIES A				
kf035d2	0.6665	42.50%	0.6190	37.79%
kf056	0.7106	49.19%	0.7263	51.83%
dr056a_a	0.5989	34.57%	0.6219	38.64%
kf056b	0.7183	50.51%	0.7228	51.32%
dr056b_a	0.6134	37.35%	0.6199	38.39%
SERIES B				
kf040o2	0.6750	43.38%	0.6228	38.21%
kf049f	0.7092	48.39%	0.7231	51.36%
dr049f_a	0.6485	40.88%	0.6514	42.36%
kf049h	0.7224	50.31%	0.7181	50.65%
dr049h_a	0.6697	43.38%	0.6581	43.18%
SERIES C				
kf052a	0.6744	44.13%	0.6271	38.78%
kf052c	0.7102	49.07%	0.7226	51.39%
dr052c_a	0.6550	42.12%	0.6482	41.99%
kf052d	0.7220	51.08%	0.7199	50.97%
dr052d_a	0.6763	44.65%	0.6586	43.27%

within each series, the first results are for the control run, the second are for the Kalman filter run with respect to the control mean, the third are for the smoothed-wind driven results corresponding to this Kalman filter run, the fourth are for the Kalman filter run with respect to the control trend, and the fifth is its corresponding smoothed-wind driven run.







Summary. The correlations of the OAM series studied here with the observed polar motion excitation residuals range from a low of 0.60 to a high of 0.73, and the observed variances explained by the OAM series range from a low of 35% to a high of 52%. In general, the data assimilative runs are seen to agree better with the observed residual than do the control runs, particularly for nonseasonal excitation and at retrograde (negative) frequencies. The smoothed-wind driven results (those whose names begin with *dr*) do not agree as well with the observed residuals as do their corresponding Kalman filter runs. Based on these results, additional tests were performed (not shown here) which indicated that there may be problems with the smoother at high latitudes. These results demonstrate the value of using Earth rotation measurements, from which atmospheric and tidal effects have been removed, to test the fidelity of modeled oceanic angular momentum series.