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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Knowledge of internal waves and ocean mixing is important for advancing the performance of operational and climate models, as well as for understanding local problems such as pollutant dispersal and biological productivity. Consequently, a long-term goal of the oceanographic community has been to develop a global internal wave prediction system analogous to systems already in place for surface waves. Early steps have been accomplished with simulations of internal tides at basin and global scale (Niwa and Hibiya 2001; Simmons et al. 2004; Simmons 2008) and near-inertial waves (Zhai et al. 2007). However, near-inertial waves and mesoscale variability have not been studied carefully in the context of global simulations. This project takes another step toward this larger goal. Our objectives were to:

- Understand the generation mechanisms and subsequent propagation of near-inertial waves in an eddy-resolving global model.
- Validate model predictions with historical and new datasets and determine improvements.

15. SUBJECT TERMS

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FINAL TECHNICAL REPORT

Near-inertial Wave Studies Using Historical Mooring Records and a High-resolution General Circulation Model

Performance Period: 12/4/08 -12/31/10

ONR Award number N00014-09-1-0401

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ABSTRACT

Knowledge of internal waves and ocean mixing is important for advancing the performance of operational and climate models, as well as for understanding local problems such as pollutant dispersal and biological productivity. Consequently, a long-term goal of the oceanographic community has been to develop a global internal wave prediction system analogous to systems already in place for surface waves. Early steps have been accomplished with simulations of internal tides at basin and global scale (Niwa and Hibiya 2001; Simmons et al. 2004; Simmons 2008) and near-inertial waves (Zhai et al. 2007). However, near-inertial waves and mesoscale variability have not been studied carefully in the context of global simulations. This project takes another step toward this larger goal. Our objectives were to:

- Understand the generation mechanisms and subsequent propagation of near-inertial waves in an eddy-resolving global model.
- Validate model predictions with historical and new datasets and determine improvements.

Our approach was to force Simmons' eddy-resolving GOLD numerical model with wind and tides, and to examine the spatial scales and dynamics of near-inertial waves (NIW, hereafter) in it. Model output has been compared to historical moorings.

WORK COMPLETED

The GOLD model was spun up for 6 years using the Large and Yeager (2004) climatology that includes wind forcing from the NCEP climatology. This climatology has been tuned to produce plausible air-sea fluxes that repeat annually, but retain realistic storm propagation, taken from a particular year, 1995. After the six-year spin-up, the simulation was continued for an additional year, archiving surface values of currents and fluxes hourly and the full three-dimensional model state every two hours. Significantly, the wind forcing was changed during the data-archiving year to the NOGAPS dataset for the year 2007. The NOGAPS winds have considerable advantages with regard to spatial and temporal resolution (Figure 1), both of which are important for accurate representation of near-inertial waves; the NOGAPS product is 3-hourly and 0.5 degree resolution, vs 6-hourly and 1.875 degree resolution for NCEP. The large scale spatial structures and amplitudes are very similar, but the temporal and spatial resolution are significantly improved in the NOGAPS simulation. Preliminary analysis and early results are discussed below.

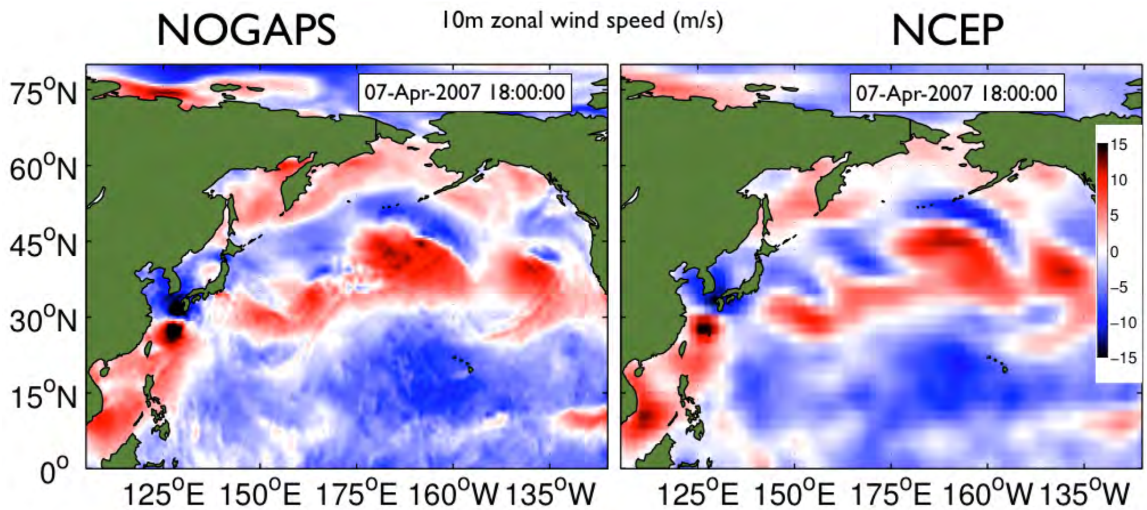

Figure 1 ***Left panel: NOGAPS wind product with 0.5 degree spatial resolution and 3-hourly temporal resolution. Right Panel: NCEP reanalysis winds with 1.875 degree and 6-hourly resolution.***

RESULTS

The model resolves many familiar features of the ocean general circulation-- unstable, highly nonlinear western boundary currents, tropical instability waves, a highly turbulent Antarctic Circumpolar Current, et cetera (Figure 2). We have focused our analysis on the high-frequency (near-inertial and higher) response. The high-frequency response of the ocean is quite striking, with clear evidence of basin-scale propagation of highly coherent NIW wave trains (Figures 3 and 4).

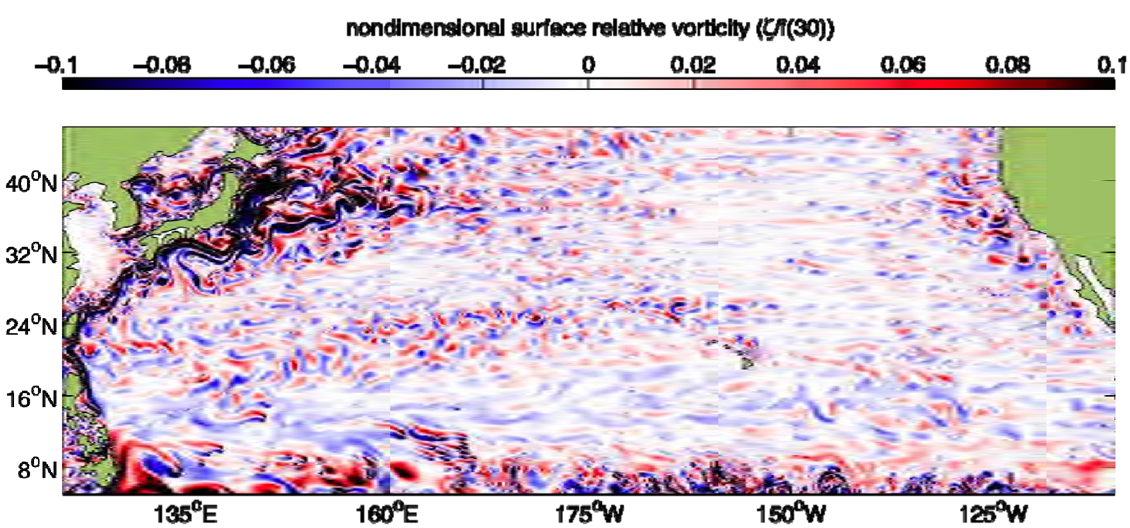

Figure 2. Surface relative vorticity at year six of the simulation.

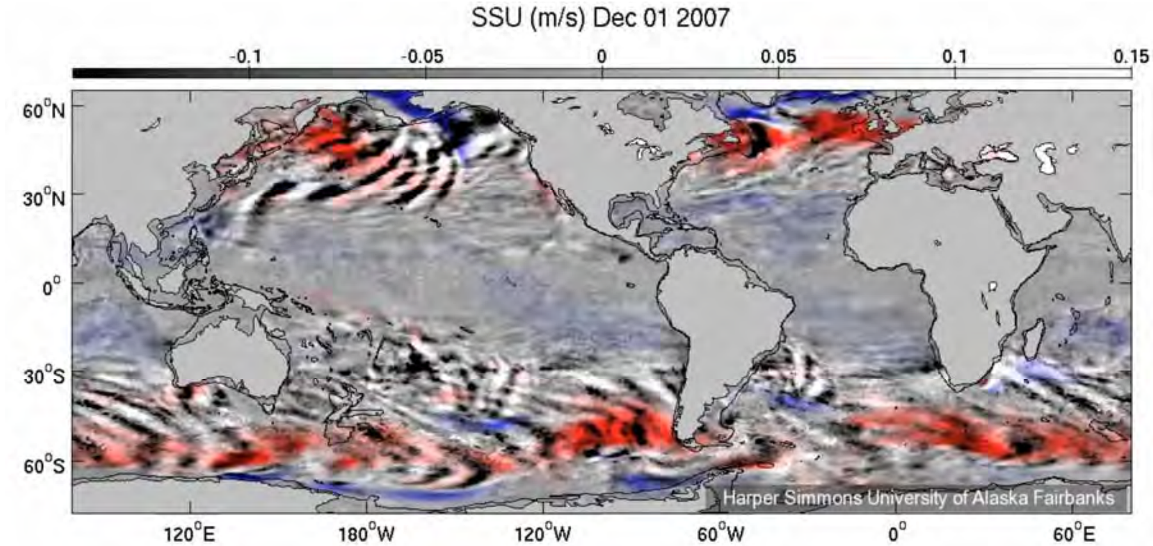

Figure 3 Gray shading represents meridional sea surface currents ("SSU") bandpassed around the local inertial band. Red-blue shading overlaying the currents indicate the meridional wind stress applied to the ocean surface.

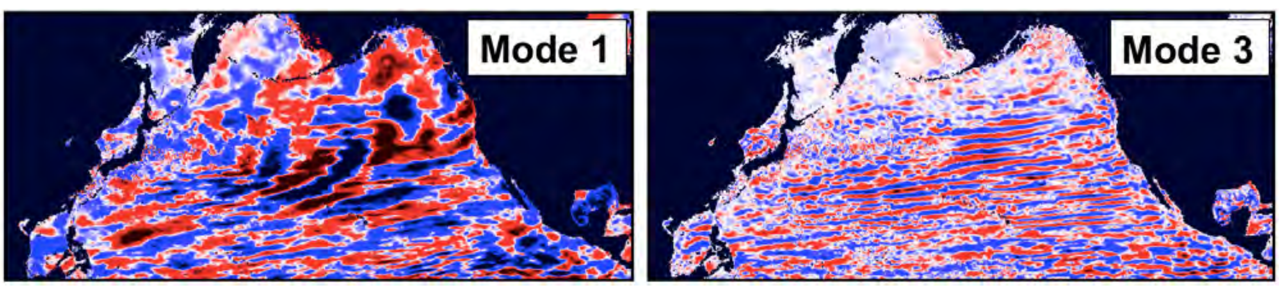

Figure 4: Red-blue shading represents the magnitude of the modal fit of baroclinic currents to mode 1 (left panel) and mode 3 (right panel).

We found that the adoption of the NOGAPS wind product doubled the predicted total energy transfer to the ocean relative to preliminary simulations using the NCEP reanalysis. The total work increased from 0.16 TW to 0.30 TW.

We have computed the rotary spectra of the thermocline-to-surface velocity shear, a proxy for first the first baroclinic mode. Figure 5 (LHS) shows the latitudinally averaged spectra of clockwise and counter-clockwise velocity shear, revealing the strong near-inertial and internal tide response, suggesting that the model is carrying importance energy sources for internal wave spectrum. It must be stressed however that the model internal wave spectrum is much too blue, with most of the simulated internal wave energy trapped at only a few frequencies, as can be seen from a comparison between the model predicted internal wave spectrum in the Ocean Storms region, and that from current meter records from that experiment (D'Asaro 1995), (Figure 5, RHS), though the energy in the inertial and semidiurnal tidal band compares favorably.

We compared the large scale pattern of near-inertial energy flux to moored estimates (80 moorings, modes I&II) and the results are encouraging (Figure 6). We have found near-inertial wind work of 0.3 TW, which is comparable with other estimates. Modal analysis reveals highly coherent motions that propagate equatorward. Flux magnitudes and direction agree well with the moorings. Modeling an ocean internal wave field/spectrum is in its early days, but we conclude that these preliminary efforts provide insights into the global energy budget.

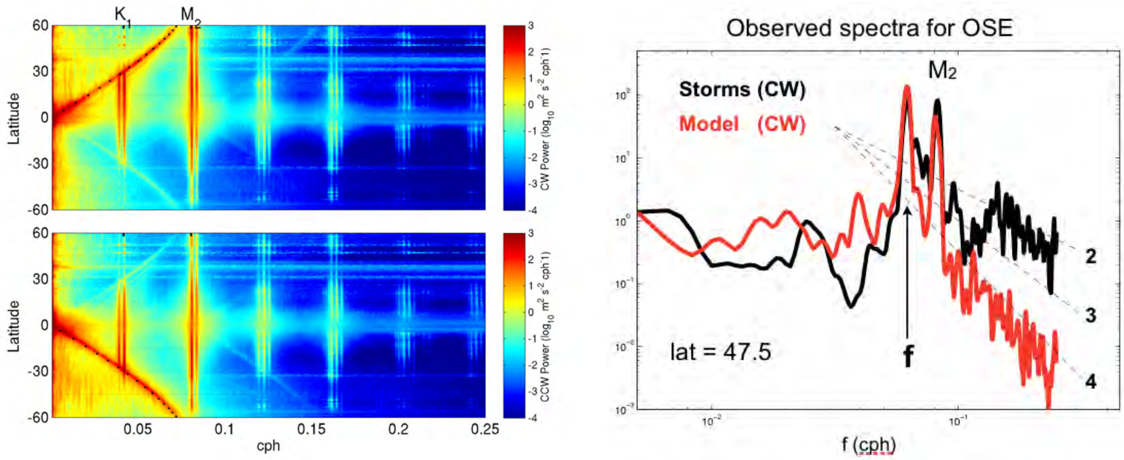

Figure 5. Left Panel: Rotary spectra of surface-to-thermocline velocity shear, averaged across each latitude in the Pacific. The diagonal signal originating from the equator, marked by black dots, is the near-inertial response. The K1 and M2 tidal frequencies are indicated. Right panel: Model versus observed spectra for the Ocean Storms experiment region. Note that Ocean Storms data was gathered in the fall and winter of 1989, whereas our model prediction is for February 2007, so the comparison is qualitative.

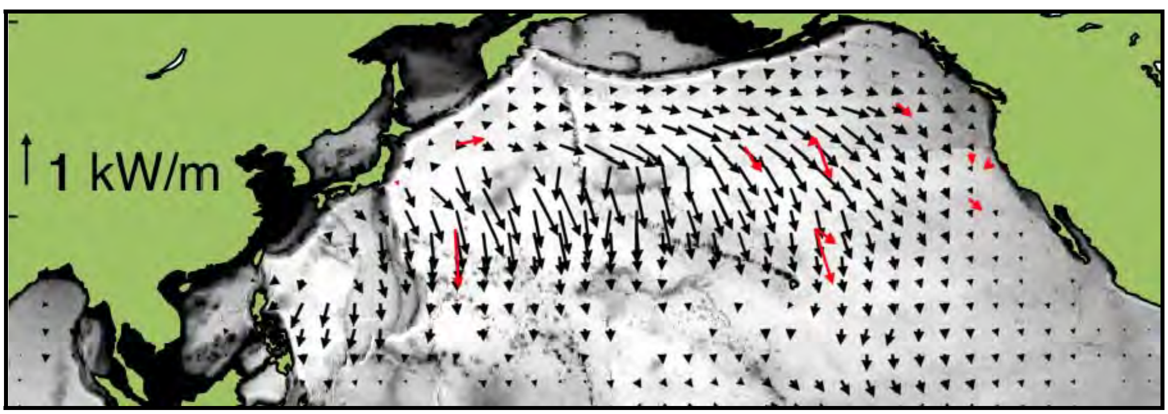

Figure 6. Depth-integrated baroclinic energy fluxes, averaged over the month of February (black arrows) and Alford's calculations from historical mooring data (red arrows). For clarity, the model data was smoothed over 32 grid points (nominally 4 degrees), and every 16th vector (nominally 2 degrees) is plotted.

RELATED PROJECTS

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PUBLICATIONS

A manuscript describing the work is in preparation:

Simmons, H. and M. Alford. Basin-scale radiation and beta-dispersion of near-inertial waves -- a modal perspective. To be submitted to *Ocean Modelling.*