ENERGY REDISTRIBUTION THROUGH TIDAL AND INERTIAL WAVE INTERACTION

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION OF THE UNIVERSITY OF HAWAI'I IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

OCEANOGRAPHY

MAY 2009

By
Martin D. Guiles

Dissertation Committee:

Douglas Luther, Chairperson
Eric Firing
Mark Merrifield
Axel Timmermann
John Learned

Abstract

Evidence for an interaction between inertial internal waves and semi-diurnal internal tides is described from oceanic velocity records. The resulting motions at the difference frequency between M_2 and f, termed Internal Wave Induced Sub/Super-inertial Currents, or IWISC, are complicated structures whose existence suggests a new energy path from tidal and inertial internal waves directly to dissipative structures, independent of the assumed cascade of energy through the internal wave field from large to small scales.

We have observed an accumulation of energy in cyclonic rotary power spectral densities at the frequency of $M_2 - f$ (the IWISC frequency) over a broad range of depths and in numerous geographic locations throughout the worlds oceans. Poleward of the critical latitude (where $f = M_2/2$), IWISC is outside of the freely propagating internal wave band. Bulk observations of IWISC cyclonic energy poleward of the critical latitude show a positive correlation (though not strong, $R < .5$) with the corresponding anti-cyclonic $M_2 + f$ energy peak. The relationships between IWISC energy and the semi-diurnal and inertial interactant energies do not appear to be simple, since the correlations between IWISC and M_2 and f are small, although significant for the IWISC vs. inertial correlation.

IWISC energy in mid-latitude records exhibits a depth dependence, with normalized maximum energy above a mesoscale background occurring near 1500 meters depth. IWISC energy has been observed to vary considerably on quite small vertical scales, on the order of 30 meters. Even equatorward of the critical latitude, IWISC energy appears predominantly in the cyclonic component, commonly distorting the expected relationship between cyclonic and anti-cyclonic currents for free internal waves.

A significant focus in our study of IWISC is the differentiation between reversible vertical advection and irreversible non-linear interaction. A hierarchy of vertical advection models has been created to establish if, when, and how vertical advection is a satisfactory explanation of IWISC. A simple model of single sinusoid semi-diurnal internal tide displacement of an inertial internal wave, as is commonly employed in the literature, replicates properties of the Eulerian oceanic observations such as a power spectral density (PSD) peak at the IWISC frequency. However, this model always yields an additional PSD peak at the sum ($M_2 + f$) frequency. Such a tight correlation between PSD at IWISC and $M_2 + f$

frequencies is not commonly observed, as noted above. When we extended the displacement model to include multiple semi-diurnal vertical modes and frequency constituents, the result was a temporal and spatial variability of IWISC and $M_2 + f$ energies, which consequently decorrelated those energies. This result is consistent with observed variability.

Bispectra and bicoherence analysis were tested on the complex displacement model velocities to determine if these methodologies can distinguish between reversible vertical advection and energy exchanging non-linearity. In fact, they cannot. Due to the frequently short duration of the inertial wave energy and even the internal tide energy a wavelet rotary bispectral analysis technique was created in an attempt to improve the identification of interactions. While the methodology appears to have great promise, its utility for this problem has yet to be demonstrated.

An analysis of vertical profiles of horizontal currents from ADCP instruments deployed in the Hawaii Ocean Mixing Experiment revealed IWISC PSD peaks for both horizontal currents and their vertical shear. Semi-diurnal internal tide displacement was derived from the well-instrumented HOME mooring A2 ADCP vertical velocity record, after application of our new method for correcting for biases due to diel migrators. The semi-diurnal displacement was used to project the ADCP horizontal velocities into a semi-Lagrangian coordinate system. This Semi-Lagrange inversion revealed that there are depth ranges where interaction peak energy (at IWISC and $M_2 + f$) is diminished by the inversion, thus implying that those signals were dominated by reversible advection, and depth ranges where the energy peaks remained unaffected or were amplified. This leads to the conclusion that both periodic, reversible advection and other energy redistribution processes are present at this location. Bispectral and bicoherence analysis of the Semi-Lagrange inverted ADCP velocities suggests the presence of irreversible non-linear interaction at IWISC.