

IS DEEP-OCEAN MIXING DUE TO THE DECAY OF SEMIDIURNAL TIDES?

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Internal waves represent a ubiquitous and permanent “inner unrest” in the ocean; in particular, they play a pivotal role in deep-ocean mixing, a crucial chain in maintaining the large-scale meridian overturning circulation. The recent analytical and numerical modelling presented here has advanced the understanding of internal wave induced mixing, by studying the generation of internal waves at small scales of high shear. The model results are compared with observations from the Canary Basin, one of the LOCO-sites, both of which show a strong latitudinal variation in internal wave energy.

The internal-wave spectrum is usually dominated by two kinds of frequencies: the inertial frequency (i.e. at frequency f , the Coriolis parameter, which is proportional to the sine of latitude) and the tidal frequencies (semi-diurnal and, to a lesser extent, diurnal). Both are low frequencies, implying that Coriolis effects play a major role. In standard theory and models, the Coriolis force is taken into account in a simplified form, the so-called “traditional approximation”.

Theoretical work (in collaboration with V.I. Shrira of Keele University, U.K.) has now shown the importance of including the Coriolis force in its full form. When this is done, two new elements appear in the behaviour of near-inertial waves, both of which are of high relevance to vertical mixing processes in the ocean.

It appears that near-inertial waves ultimately become shorter as they propagate pole ward (in contrast to the traditional theory, where they become longer). The tendency to short scales makes them particularly susceptible to

wave-breaking and hence increased mixing at high latitudes. It furthermore appears that they tend to be ‘locked up’ in regions of weak stratification, such as the abyssal ocean; in other words, their energy is pushed into the seabottom, precisely where enhanced mixing is needed in view of the large-scale ocean circulation!

The division made above between near-inertial and tidal fre-

quencies is not always appropriate. For example, diurnal internal tides are nearly inertial at the latitude of 30° North and South. Theoretically, one can expect to find enhanced inertial energy at this latitude. Our ongoing measurement programs carried out as part of the NWO-large investment project Long-term Ocean Current Observations (LOCO) near Great Meteor Seamount are intended to provide

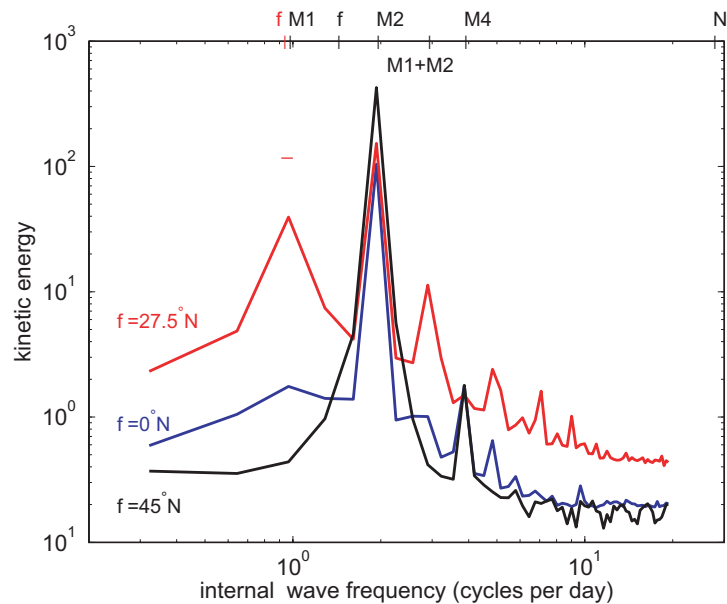


Fig. 1. Kinetic energy spectra from numerical internal wave model above a continental slope for different latitudes 0°N (blue; f is infinitely small and not shown), 27.5°N (red) and 45°N (black).

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field evidence for this theoretical increase.

Diurnal internal tides can be created directly by diurnal barotropic tides, but also by instability of semi-diurnal tides (subharmonic resonance). Numerical model calculations (in collaboration with C. Staquet, LEGI, Grenoble, and P. Bouruet-Aubertot, LOCEAN, Paris) have now provided evidence of such a transfer in a reasonably realistic setting. Here internal tides are forced at the semi-diurnal lunar frequency (M_2), but near 30°N one finds an additional spectral peak at the diurnal frequency M_1 (Fig. 1) and motions at smaller vertical scales (Fig. 2), due to subharmonic resonance. This provides an extra source of near-inertial energy. However, the above model found such an extra source only very close to the continental slope, being the source of internal tides.

Further spectral analysis of historic and new long-term data sets over a period of more than 7

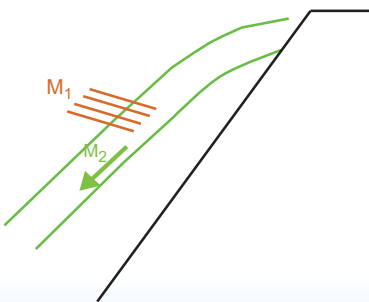


Fig. 2. Sketch of model results showing a change in slope and vertical scale from large-scale, steep sloping semidiurnal tidal motions in a beam emanating from the continental shelf break, to small-scale diurnal tidal motions.

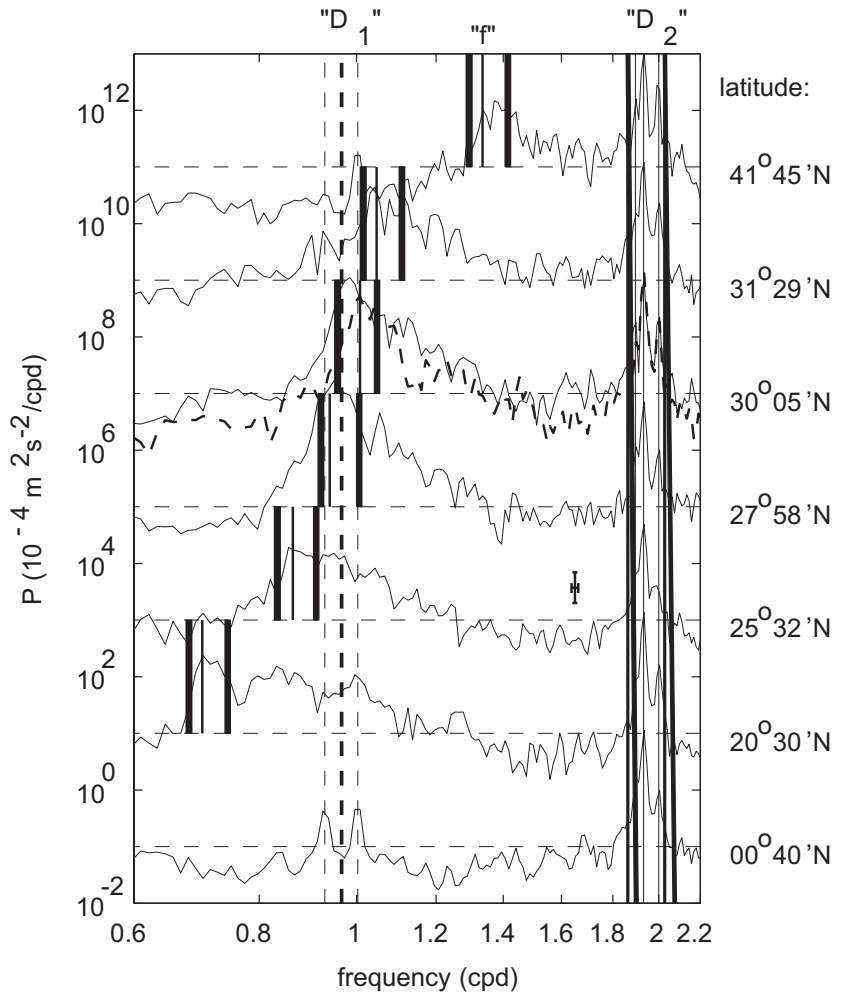


Fig. 3. Kinetic energy spectra from 8 current meter records between 1000-2000 m at different latitudes as a function of frequency (in cycles per day, cpd). Spectra are offset by two decades, except those from the two moorings near 30°N ($30^\circ 11' \text{N}$ is dashed). Vertical dashed lines indicate diurnal (D1) frequencies O1, M1 (heavy dashed) and K1 (l-r). Semi-diurnal frequencies (D2) include N2, M2, S2. Note that the f-band varies with latitude (equal to D1 at $28\text{--}30^\circ$).

months from the Canary Basin showed even stronger changes in diurnal/inertial and semidiurnal tidal energy (Figs. 3 and 4) than the model results predicted, and these observations were all from the open ocean, far away from topography such as the continental slope or seamounts. The spectra showed an energy loss by about 50% of M_2 at $25\text{--}28^\circ\text{N}$, but a nearly fivefold increase in inertial energy at 30°N . The enhancement

could be the result of subharmonic instability, although systematic enhancement of precise diurnal tidal frequencies, notably M_1 , was not observed, and the latitudes of low D2-energy and high f-energy did not coincide. This could be due to a mix of coupled and independent waves, whilst the pole-ward trapping of sub-f Coriolis energy suggested the occurrence of non-traditional effects.

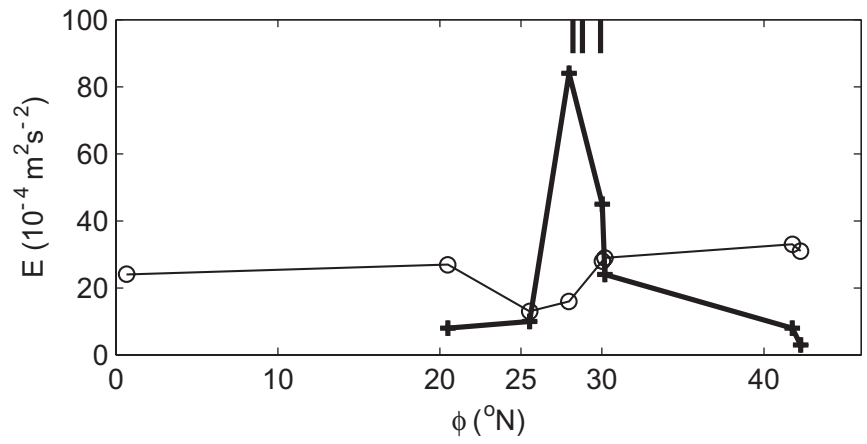


Fig. 4. Summed energies E observed between 1000-2000 m for the inertial (+) and semi-diurnal band (o) as a function of latitude ϕ . Short lines indicate critical diurnal latitudes N1, M1 and S1 (l-r).