Internal Waves and Mixing in the Arctic Ocean

Ilker Fer[1], John D. Guthrie[2], and James H. Morison[2]

[1] Geophysical Institute, University of Bergen, Bergen, Norway
[2] Applied Physics Lab., University of Washington, Seattle, USA

Back-of-the-envelope calculations show that there is enough heat in Atlantic layer in the Arctic Ocean to melt the entire Arctic ice cover in four years, provided that all the heat reached the surface under the ice pack [*Turner*, 2010]. While the strongly stratified, cold halocline layer (CHL) of the Arctic Ocean is an efficient barrier for the vertical exchange of this heat [*Fer*, 2009], dramatically decreasing ice cover may lead to increased vertical mixing by allowing more wind energy into the ocean through, for example, near-inertial internal waves. The effect of decreasing ice cover on the internal wave energetics and mixing, however, is not well established. Here we report on observations of *i*) internal wave energy and mixing in the Arctic covering the recent 30 years [*Guthrie et al.*, 2013] and *ii*) near-inertial waves and mixing following a storm event in the central Arctic [*Fer*, 2013].

To determine whether deep background mixing has increased with the diminishment of the Arctic sea ice, we compare recent internal wave energy and mixing observations with historical measurements. Since 2007, the North Pole Environmental Observatory has launched expendable current probes (XCP) as part of annual airborne hydrographic surveys in the central Arctic Ocean. Mixing in the upper 500 m is estimated from XCP shear variance and CTD-derived Brunt-Väisälä frequency. Internal wave energy and average mixing estimates vary by an order of magnitude between surveys. All surveys are less energetic and show more vertical modes than typical mid-latitude Garrett-Munk model spectra. Comparisons of internal wave energy between modern and historical data, reanalyzed in identical fashion, reveal no trend evident over the 30-year period in spite of drastic diminution of the sea ice [*Guthrie et al.*, 2013]. Both mixing and internal wave energy in the Beaufort Sea are lower when compared to both the Central and Eastern Arctic Ocean, and expanding the analysis to moored profiler (MMP) data from the Beaufort Sea reveals little change in that area compared to historical results from AIWEX. The inferred eddy diffusivity (summarized in Figure 1 for all data sets) shows no clear temporal trend. We hypothesize that internal wave energy remains lowest in the Beaufort Sea in spite of dramatic declines in sea ice there, because increased stratification by melt water amplifies the negative effect of boundary layer dissipation on internal wave energy.

Dissipation in the under-ice boundary appears to be a dominant mechanism of internal wave energy loss where the energy following a single round trip to the seafloor is substantially absorbed. Approximately 4 -day long time series of horizontal currents, hydrography and shear microstructure, collected about 10 days after a storm event in April 2007, show near-inertial oscillations in the first half of the measurement period with comparable upward and downward propagating energy beneath a drifting ice camp in the central Arctic Ocean. The near-inertial frequency band is associated with dominant clockwise rotation in time of the horizontal currents, and elevated dissipation rates. Both the amplitude of the oscillations and the pycnocline-averaged dissipation rate gradually decay with time. Upward propagating inertial waves are dissipated when they contact the ice. The vertical profile of dissipation rate shows elevated values between the relatively turbulent under-ice boundary layer and deeper quiescent water column. The flux divergence between the wind work done beneath the ice and the downgoing energy flux below the pycnocline is approximately balanced by the depth integrated dissipation rate. Observations suggest that dissipation of near-inertial wave energy in the upper ocean is of crucial importance in the Arctic Ocean and can contribute to the irreversible vertical mixing in the crucial cold halocline layer.

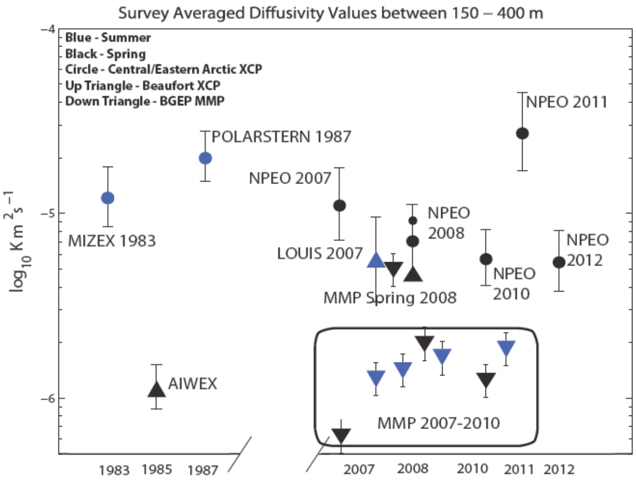

Figure 1. Survey-averaged mean diffusivity between 150-400 m. Black markers represent springtime surveys (March/April). Blue markers represent summertime surveys (June/July /August). Circles are Central/Eastern Arctic XCP data. Upward triangles are Beaufort Sea XCP data. Downward triangles are Beaufort Sea MMP data.

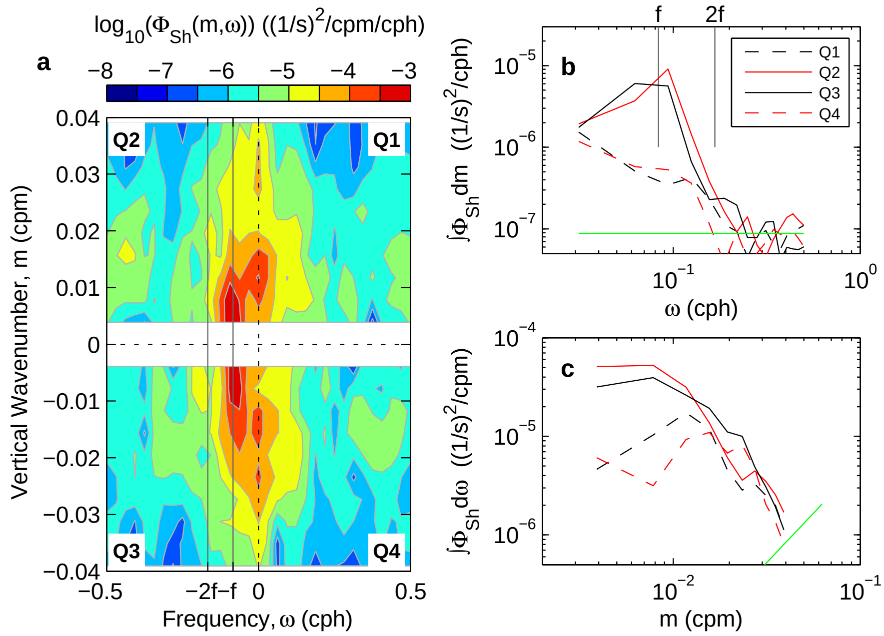

Figure 2. Frequency (ω) - vertical wavenumber (m) spectra of shear from ADCP measurements following a storm in the central Arctic. a) Four-quadrant, 2D spectra. Negative frequencies, quadrants Q2 and Q3 correspond to CW (anti-cyclonic) rotation, whereas the positive frequencies correspond to CCW rotation. Downward propagating energy corresponds to $\omega/m > 0$, i.e. Q1 and Q3, whereas upward propagating energy is in Q2 and Q4. Typically down-going near-inertial energy is expected in Q3. One-dimensional b) frequency and c) wavenumber spectra. The green lines indicate the shear noise spectrum.

References

Fer, I. (2009), Weak vertical diffusion allows maintenance of cold halocline in the central Arctic, *Atmos. Ocean. Sci. Lett.*, *2*, 148-152.

Fer, I. (2013), Near-inertial mixing in the central Arctic Ocean, *J. Phys. Oceanogr.*, in review.

Guthrie, J. D., J. H. Morison, and I. Fer (2013), Revisiting internal waves and mixing in the Arctic Ocean, *J. Geophys. Res.*, *118*, 10.1002/jgrc.20294.

Turner, J. S. (2010), The melting of ice in the Arctic Ocean: the influence of double-diffusive transport of heat from below, *J. Phys. Oceanogr.*, *40*, 249-256, 10.1175/2009jpo4279.1.