Observation of interior and boundary-layer mixing processes due to near-inertial waves in a stratified basin without tides

Eefke M. van der Lee[1] and Lars Umlauf[1]

[1]Leibniz Institute for Baltic Sea Research Warnemünde, Germany

Leibniz Institute for Baltic Sea Research Warnemünde

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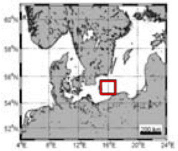
Introduction & Methods

Many mixing processes occur in the Baltic Sea (Fig. 1). Here we compare internal wave mixing processes in the interior of a stratified basin to those occurring on the sloping boundaries in order to later estimate their importance to basin-wide mixing. In the virtually tideless Baltic Sea we can isolate the effect of near-inertial waves that is otherwise (often) overshadowed by internal tides.

The measurements presented here were obtained from a research cruise in the Bornholm Basin in September 2008 (Fig. 2). They consist of a moored ADCP in the centre of the basin (at station S1) and ADCP cross-slope transects (at transect T1), both combined with densely spaced shear-microstructure profiles (Fig. 3).



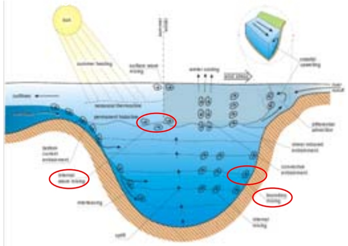


Figure 1: Diagram of mixing processes in the Baltic Sea (from Reissmann *et al.*, 2009)

Figure 3: Diagram of shipborne instruments: the microstructure profiler and two ADCPs

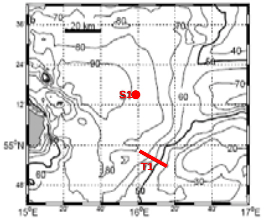


Figure 2: Bornholm Basin station S1 and transect T1

Vertical modes

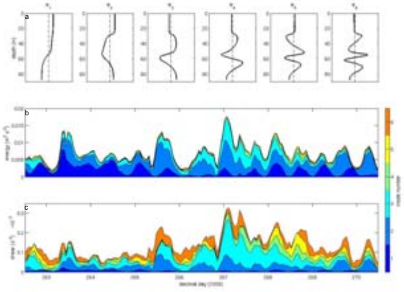


Figure 5: Of the first 6 vertical modes (a) the vertical structure, the stacked histograms of energy (b) and shear variance (c)

- Vertical structure of the first 6 vertical normal modes (Ψ) calculated from the mean profile of the stratification N^2 (Fig. 4b, Eq. 2)
- Because of the three-layer system Ψ_2 dominates in energy variance
- Although low modes contain more energy, higher modes contribute more to shear variance
- The distribution of energy and shear variance of the internal wave field is not fixed among modes and changes significantly over time

$$\frac{d}{dz}\left(\frac{1}{N^2}\frac{d\Psi_n}{dz}\right)+\frac{1}{c_n^2}\Psi_n=0$$

Equation 2

Boundary layer mixing

- Velocity composites from ship (Fig. 7a,b) ADCP (above black line) and "flying" ADCP (below black line)
- The velocity direction changes sharply at the thermocline causing shear and a considerably increased buoyancy flux (Fig. 7c) at the interface
- Near-bottom currents oscillating with near-inertial frequency trigger a periodic near-bed dissipation rate signal and a growing and decaying BBL thickness
- Near-bottom buoyancy fluxes can dominate over interior mixing (Fig. 7d) if the BBL is highly turbulent
- Cross-slope velocity strains lateral density gradients, therefore mixing is rather efficient and contributes significantly to the basin-scale mixing

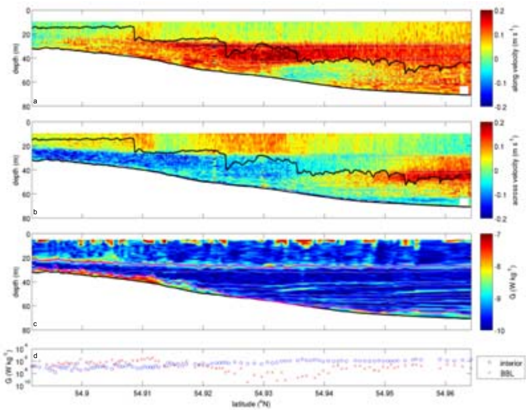


Figure 7: Transect T1/4 (a) along slope velocity and (b) across slope velocity (c) buoyancy flux with the boundaries of the interior and BBL regions and (d) integrated buoyancy flux

Interior mixing

- Summer stratification: a three-layer density structure (Fig. 4c,d) with a thermocline and deeper halocline
- A short wind event (Fig. 4a) excited downward energy propagation
- Near-inertial oscillations in the surface and middle layers and near-inertial waves in the bottom layer (Fig. 4b)
- These motions caused shear and, with it, turbulence (ε) (Fig. 4e) and a buoyancy flux (*G*) (Eq. 1, Fig. 4f) especially at the interfaces between layers
- The buoyancy flux (*G*) is defined as a mixing efficiency (γ) times the dissipation rate (ε), where γ varies as proposed by Shih *et al.* (2005)
- Separating the water column into surface layer, interior and bottom boundary layer (BBL) and integrating the buoyancy flux it can be seen that ∫*G* is of order 10^{-6} W kg^{-1} in the interior and much lower, of order 10^{-8} W kg^{-1}, in the BBL (Fig. 4g)

$$G=-\gamma\cdot\varepsilon$$

Equation 1

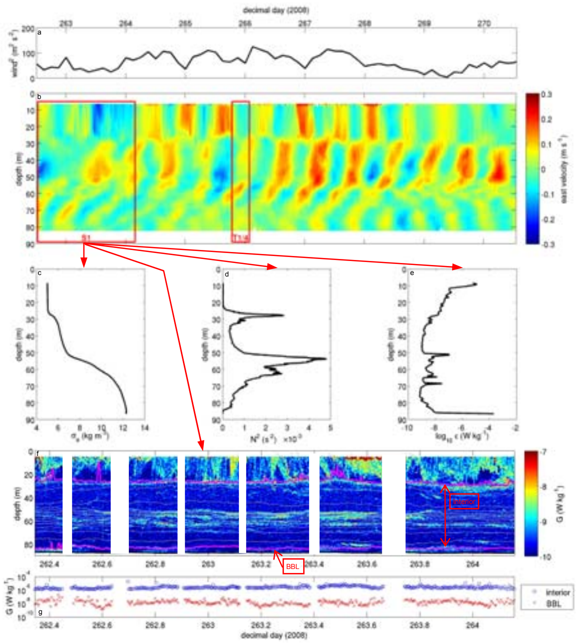


Figure 4: Station S1 (a) wind velocity squared and (b) east velocity over 8 days and mean profiles of microstructure potential density (c), buoyancy frequency (d) and dissipation rate (e) as well as (f) buoyancy flux with the boundaries of the interior and BBL regions and (g) integrated buoyancy flux

Parameterisation of the dissipation rate

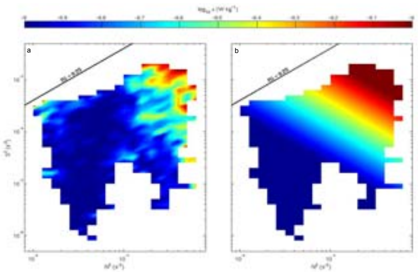


Figure 6: Measured dissipation (a) v. MacKinnon and Gregg scaling (b)

- Open ocean internal wave parameterisations of the dissipation rate (ε), in terms of shear (S^2) and stratification (N^2), assume a fixed energy distribution among modes; this assumption does not hold for our data (Fig. 5)
- MacKinnon and Gregg (2003) propose an alternate scaling for the Atlantic shelf (Eq. 3), where ε increases with increasing N^2
- Measured dissipation rates in bins of N^2 and S^2 were averaged (Fig. 6a) and the ε_0 value was set to 4.67x10^{-12} in the scaling (Fig 6b) for equal ε averages in the two plots.

$$\varepsilon=\varepsilon_0\left(\frac{N}{N_0}\right)\left(\frac{S}{S_0}\right)$$

Equation 3

Conclusions

- The strain and shear of internal waves caused patches of high dissipation rates and buoyancy fluxes in the interior region, with high modes contributing most to the shear variance even though containing less energy
- At the central station mixing in the interior was more important than BBL mixing and followed the parameterisation of MacKinnon and Gregg well (although the model constant had to be changed substantially)
- At the sloping boundaries high near-bed velocities caused increased mixing in the BBL which could equal or dominate over interior mixing

References

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