Leibniz Institute for Baltic Sea Research Warnemünde

Energetics of mixing in a stratified basin without tides

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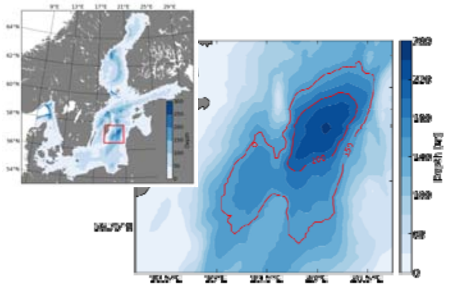
Motivation/Baltic Tracer Release Experiment

Gotland Basin (GB)

- largest Basin in the Baltic



Natural laboratory to study

- wind induced mixing (no tides)
- barotropic contribution to mixing
- near inertial wave contribution to mixing
- boundary/interior mixing

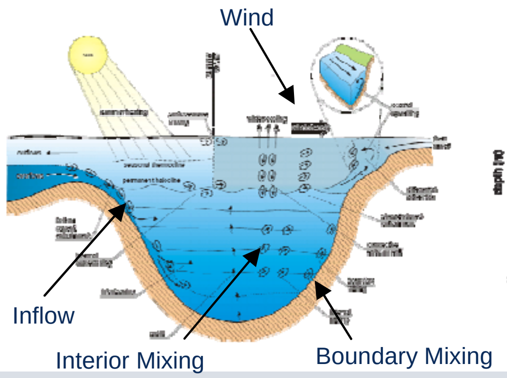
→ Mixing in the GB defines the residence time of water in the central Baltic Sea

BaTRE

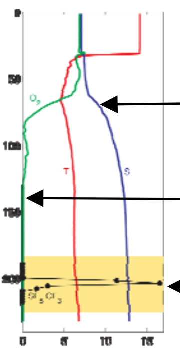
combined approach of

- long time moorings (Temperature, Salinity, Currents)
- tracer release (~1kg SF_5CF_3)
- microstructure measurements (MSS-90)

Processes



Hydrography



CTD cast 2 weeks after the tracer release

Halocline in ~ 80 m.
Salinity defines stratification

Anoxic deep water

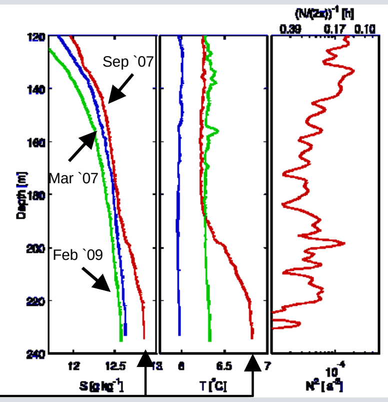
SF_5CF_3 Tracer concentration two weeks after the release

Inflow just before the tracer release

- Inflow ~ April 2007
- Tracer Release Sep. 2007

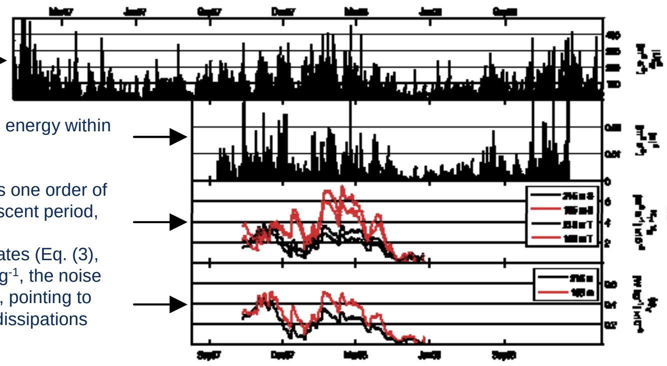
Deep water weakly stratified, compared to the surface water, but strong compared to ocean basins
- Santa Monica Basin ~ 1 h
- Santa Cruz Basin ~ 2 h

Inflow replaces deep water with warm and salty water



Seasonality of mixing

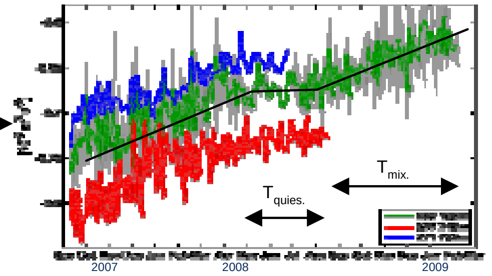
- Seasonality of momentum input through wind
- Same seasonality in the kinetic energy within the basin
- Diffusivity (Eq. (1), (2)) changes one order of magnitude between mixing/quiescent period, storm events are resolved
- Volume averaged dissipation rates (Eq. (3), (4)) are in the order of 10-9 W kg^{-1}, the noise level of the microstructure probe, pointing to boundary mixing, where higher dissipations were measured



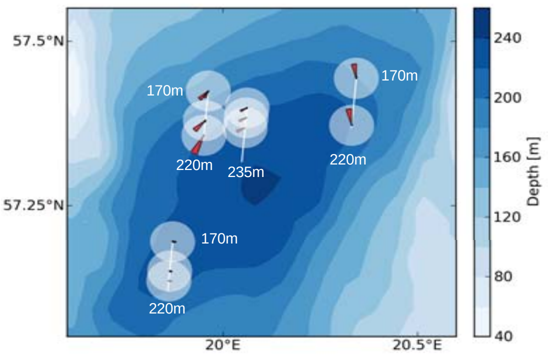
Effects of mixing: Buoyancy

change of buoyancy over time
- strong seasonality of the change

→ mixing period T_{mix}
→ quiescent period. T_{quies}.



Ring current

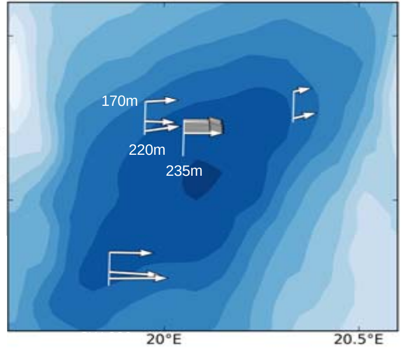


Ring current

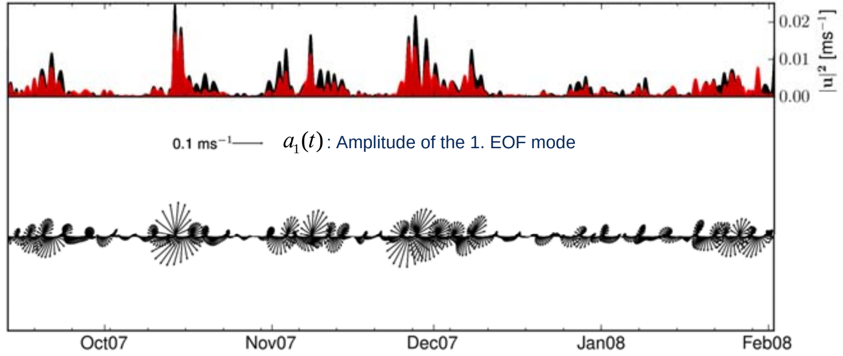
- permanent current
- motions with periods below 15 days
- counter clockwise (see trajectory plot above)
- decreasing to the centre and the south rim, strongest on the north rim
- currents O(0.03 m s^{-1})
- mixing/quiescent period seasonality
- driving processes not clear

Empirical Orthogonal Functions

Eigenvectors of the 1st EOF mode (sub inertial)



|U|² of the sub inertial motions (black) and the contributions of the 1st EOF mode (red), SW station



Sub inertial Motions

- „barotropic“ motions from the bottom up to 80 m (above unknown)
- contribute 64% to the kinetic energy
- motions in the 3 day period are coherent and counter clockwise
- 1st mode of EOF

→ explains 73% of the sub inertial motions
→ shows coherence via the same direction of the Eigenvectors (Figure above)

- Highly intermittent

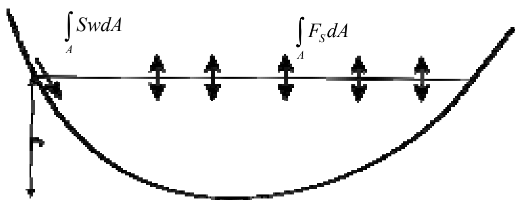
Ideas about the nature of motions

- coherence of motions larger than the internal Rossby radius (~5 km)
- excludes Kelvin waves (diameter of GB >> 5 km)
- excludes Baltic Sea eddies (Beddies)
- possibly Topographic waves (period fits ~ 72 hours) but the velocity should show two counter clockwise rotating gyres, the role of stratification is unclear. Numerical modelling should shed some light on the question

Description of the currents using EOFs:

$$\vec{u}(t,\vec{x}) = \sum_n a_n(t)\vec{\Psi}_n(\vec{x}) \quad (0)$$

Budget Methods



Diffusivity

The turbulent diffusivity is calculated by measuring the change of Salinity/Temperature over time and the assumption that advective fluxes are zero or neglegible:

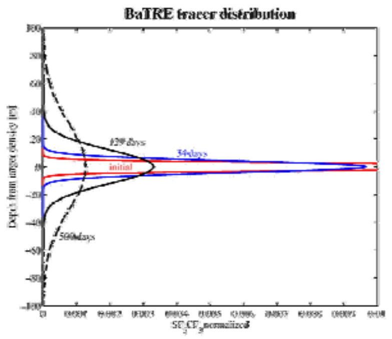
$$\frac{d}{dt}\int_V SdV = -\int_A SwdA - \int_A F_S dA \quad (1) \qquad \langle F_S \rangle_A = -\kappa_S \frac{\partial \langle S \rangle_A}{\partial z} \quad (2)$$

Dissipation rate

The volume averaged dissipation rate is calculated via the change of the potential energy in an fixed volume and the assumption of no advective fluxes:

$$\frac{d}{dt}\int_V E_P dV = -\int_V bwdV - \int_V \langle w'b' \rangle dV \quad (3) \qquad \gamma\varepsilon = -\langle w'b' \rangle \quad (4)$$

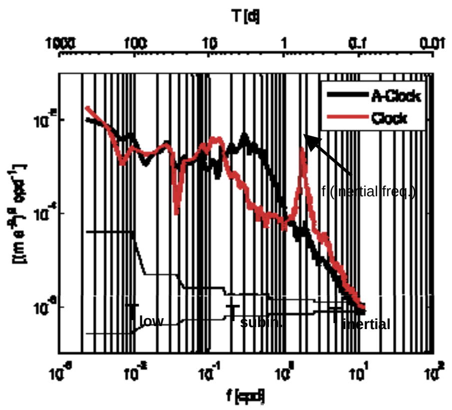
Tracer Analysis



SF_5CF_3 Tracer Injection

first sole injection of SF_5CF_3
- injected in a depth of ~ 190 m
- horizontally never homogeneous
- fitted to Gaussian curve
- Diffusivities in the same order of magnitude as computed with budget methods
- needs further analysis

Available Energy



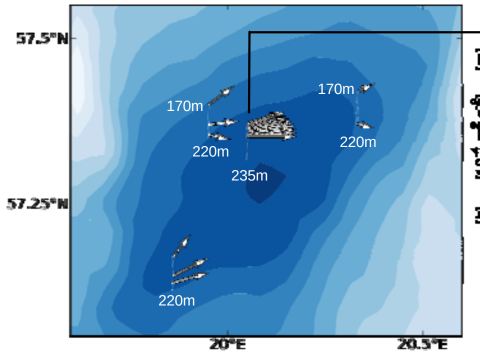
Rotary spectrum

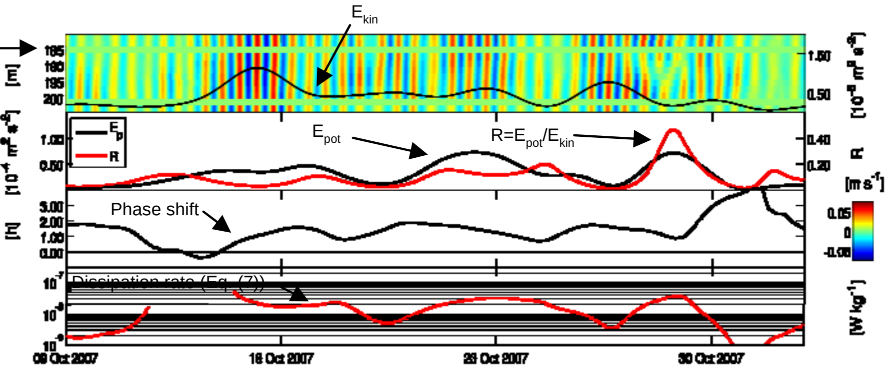
- Inertial (T < 1 day)
  - Clockwise, mostly inertial/near inertial internal waves
- Sub inertial (15 days > T > 1 day)
  - Highest contribution to the total energy
  - Counter clockwise
- Low (T<15 days)

Energy	T_{low}	$T_{subinertial}$	$T_{inertial}$
%	9	64	27

Vertical Energy Flux of Internal Waves

Eigenvectors of the 1st EOF mode (inertial)





Near inertial wave energy flux

- measurable phase shift
- Near inertial internal waves R<<1
- frequencies are not well known, broadband peak around the inertial frequency
- circumvent unknown frequency via function G (Eq. (6)) and the well known phase shift
- Energy is expressed via the dissipation rate (Eq. (7)), this can be compared with the budget methods and the microstructure measurements

Energy flux calculation via the phase velocity

$$F_z = c_{g_z} E \Rightarrow F_z = c_z GE \quad (5)$$

$$\frac{c_{g_z}}{c_z} = G\left(\frac{E_{pot}}{E_{kin}}\right) \quad (6)$$

$$\langle \varepsilon \rangle = F_z A V^{-1} \quad (7)$$

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