Wind-driven Radiation of Internal Gravity Waves from the Surface Mixed Layer

Philipp Jurgenowski[1,3], Dirk Olbers[2] and Carsten Eden[1]

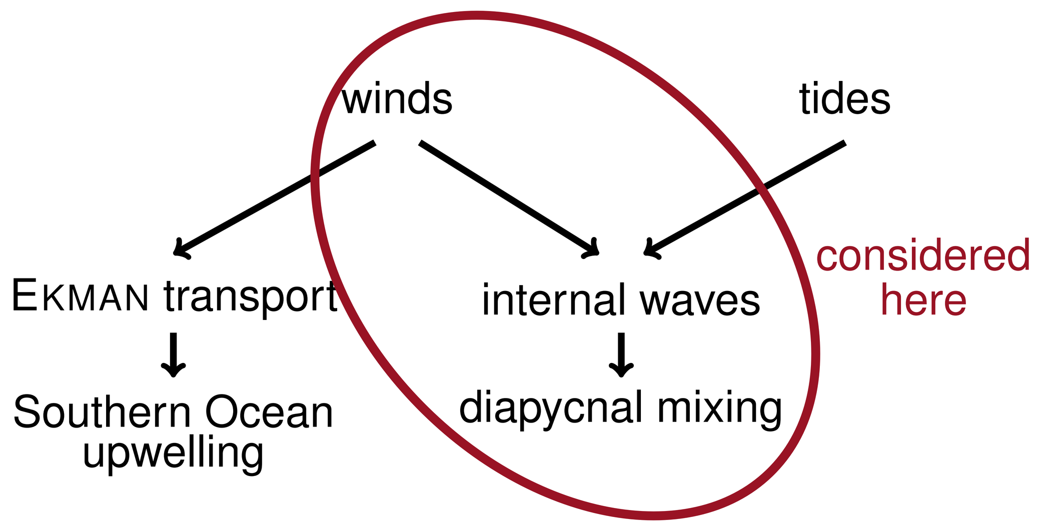
[1]: Universität Hamburg; [2]: Alfred-Wegener-Institut, Bremerhaven; [3]: philipp.jurgenowski@uni-hamburg.de

DFG

Background

(i) Drivers of the MOC

- the meridional overturning circulation (MOC) plays a key role in governing the climate of the Earth, *e.g.* by a poleward heat transport $\mathcal{O}(1\ \mathrm{PW})$, by influence on ocean's carbon dioxide storage ability *etc.*
- the MOC needs to be sustained against frictional effects by some external energy source
- major driving mechanisms:



(ii) Excitation of near-inertial waves by the wind: Common models

- slab ocean model after POLLARD and MILLARD [1970] already predicts resonance in $u + iv$ at frequencies near local CORIOLIS frequency, but lacks distinction between surface mixed layer and deep ocean
- [GILL, 1984]-model establishes central role of vertical "pumping" velocity with frequency near f at mixed layer base, but includes forcing in initial state only and no friction

A spectral model

- OLBERS and EDEN [2015] introduce a simple analytical model for the ocean surface mixed layer
- in particular, it yields an energy balance which can be used for estimating the amount of energy which is (i) provided by the windstress and (ii) transferred to the deep ocean:

$$\frac{\partial}{\partial t}\mathcal{E} = -2r\mathcal{E} - \mathcal{D} + \boldsymbol{u}\cdot\boldsymbol{\tau}|_{z=0} + wp|_{z=-d}$$

  with kinetic energy $\mathcal{E}$ and dissipation due to vertical stress $\mathcal{D}$ (horizontal mechanical energy flux up is neglected)
- the equations of motion (not shown) are solved after FOURIER-transformation (*i.e.* in spectral space)
- main outcome: energy flux at mixed layer base $S_{wp}(k,\omega) = F(k,\omega,f,N,r)S_\tau(k,\omega)$

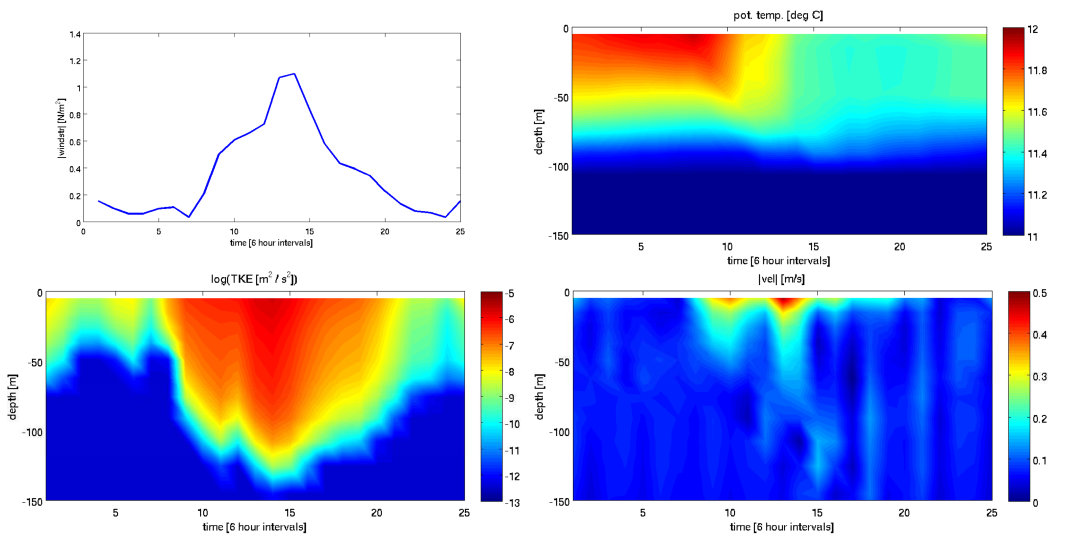


Figure 1. Time evolution of characteristic quantities during a storm (simulated with MITgcm). Shown are windstress $|\boldsymbol{\tau}_0|$, potential temperature θ, turbulent kinetic energy E_{tk} and horizontal velocity $|\boldsymbol{u}|$ in the days of a specific storm event over the North Atlantic (03-09 January 2004, $47°\mathrm{N}, 37°\mathrm{W}$). Evident is mixing of the surface layer, a burst of turbulent kinetic energy and near-inertial oscillations of velocity.

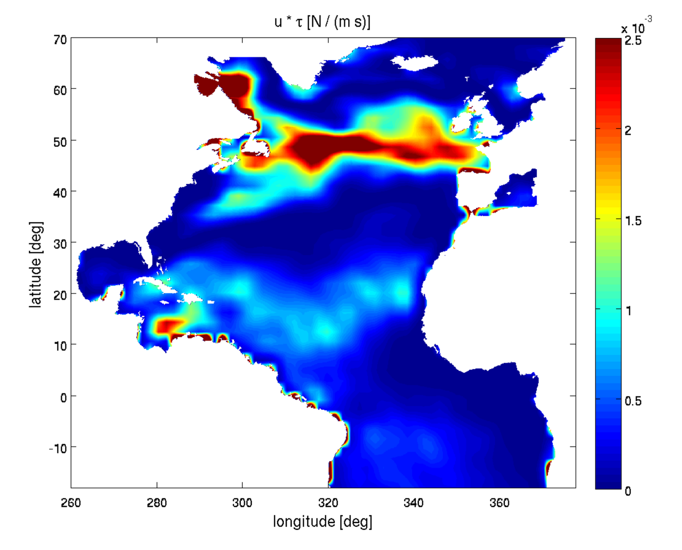


Figure 2. Shown is the energy flux $\boldsymbol{u}\cdot\boldsymbol{\tau}_0$ at the ocean surface, *i.e.* the energy input by windstress into the surface mixed layer. The mean over one year is taken. Clearly seen is the storm track region over the North Atlantic.

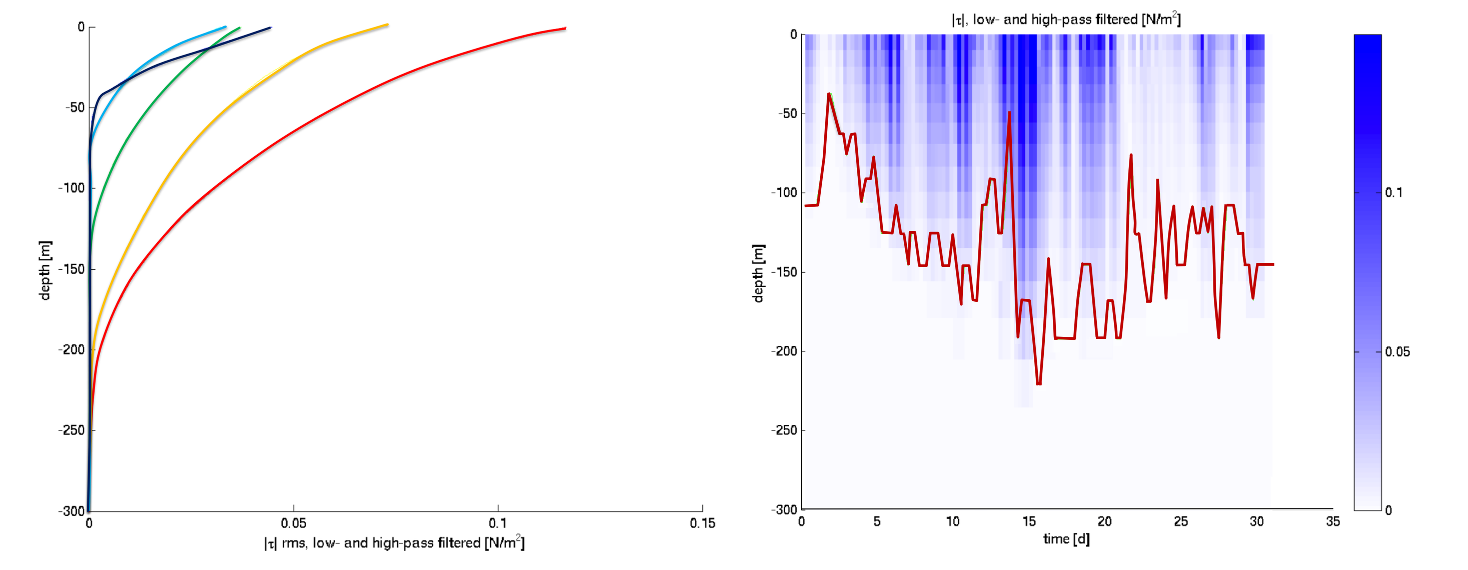


Figure 3. Typical stress profiles. Left: Temporal variance (root-mean-square) after band-pass filtering to the near-inertial frequency interval. Colours denote different latitudes (dark blue: $10°\mathrm{N}$, ..., red: $50°\mathrm{N}$ in equal steps). Right: Time-series of band-pass filtered stress profile; the red line denotes the mixed-layer depth diagnosed from a turbulent kinetic energy criterion. In particular, one can see that the depth of the mixed layer coincides quite well with the depth at which the stress $\boldsymbol{\tau}$ vanishes, as is assumed for the spectral model.

Questions

- What is the vertical structure of the ocean's response to windstress, in particular: how does the stress $\boldsymbol{\tau}$ and its derivatives at surface and mixed layer base behave (important for certain simplifications of the model)?
- Is the simple spectral model able to describe certain basic properties of the relevant energy terms, that is, can the model's predictions for the power law exponents be confirmed by numerical experiments?

Numerical approach

- We choose a numerical FLAME-type experiment using MIT general circulation model (MITgcm) at resolution of 1/12°, including the mixed layer scheme following GASPAR *et al.* [1990], six-hourly NCEP/NCAR reanalysis windstress data and high-frequency output. The model's response to a single storm event is shown in **Figure 1**. The average energy input by the windstress is shown in **Figure 2**.
- The general shape of the stress profiles, which is of importance for the formulation of the analytical model, is shown in **Figure 3**. In particular, the derivative at the ocean's surface is much larger than the one at the mixed layer base. Furthermore, the depths (i) at which the mixed layer ends and (ii) where the stress vanishes coincide quite well, as is assumed for the spectral model.
- Based on the assumption of a frequency spectrum $\sim\ \omega^{-2}$ of the windstress itself, the analytical model predicts power laws for the flux of mechanical energy wp at the mixed layer base of ω^{-6} and for the corresponding (horizontal) kinetic energy of ω^{-8}. These power law exponents are roughly confirmed by our numerical calculations, as can be seen in **Figure 5**. In this respect at least, the simple model seems to capture the relevant physics of the mixed layer.

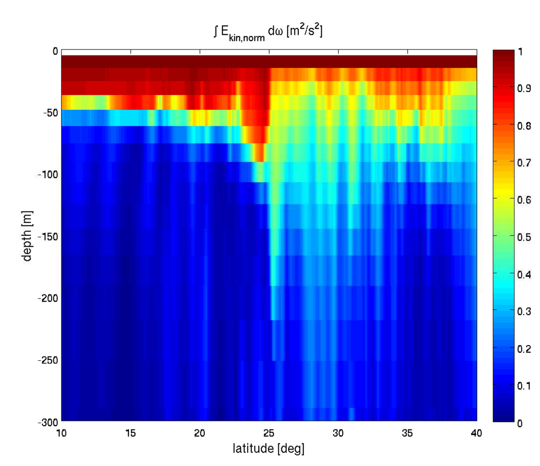


Figure 4. Near-inertial kinetic energy as function of latitude and depth (winter conditions).

Outlook

- Besides the spectral shape, also the absolute level of the near-inertial energy terms will be studied and compared to other models/observations in order to (i) check the descriptive power of the simple spectral model and (ii) assess the importance of the wind-provided energy for the sustainment of the MOC.
- In our group a non-hydrostatic model of the mixed layer is developed whose response to a storm event is planned to be used for comparison.

References P. GASPAR, Y. GRÉGORIS and J.-M. LEFEVRE: A Simple Eddy Kinetic Energy Model for Simulations of the Oceanic Vertical Mixing, J. Geophys. Res. 95:16179 (1990). || A.E. GILL: On the Behavior of Internal Waves in the Wakes of Storms, J. Phys. Oceanogr. 14:1129 (1984). || D. OLBERS and C. EDEN: Revisiting the Generation of Internal Waves by Resonant Interaction with Surface Waves, in press. || R.T. POLLARD and R.C. MILLARD: Comparison between Observed and Simulated Wind-generated Inertial Oscillations, Deep-Sea Res. 17:813 (1970). || J.-S. VON STORCH, H. SASAKI and J. MAROTZKE: Wind-Generated Power Input to the Deep Ocean: An Estimate Using a 1/10°General Circulation Model, J. Phys. Oceanogr. 37:657 (2007).

Acknowledgment This work was supported by the Deutsche Forschungsgemeinschaft (DFG).

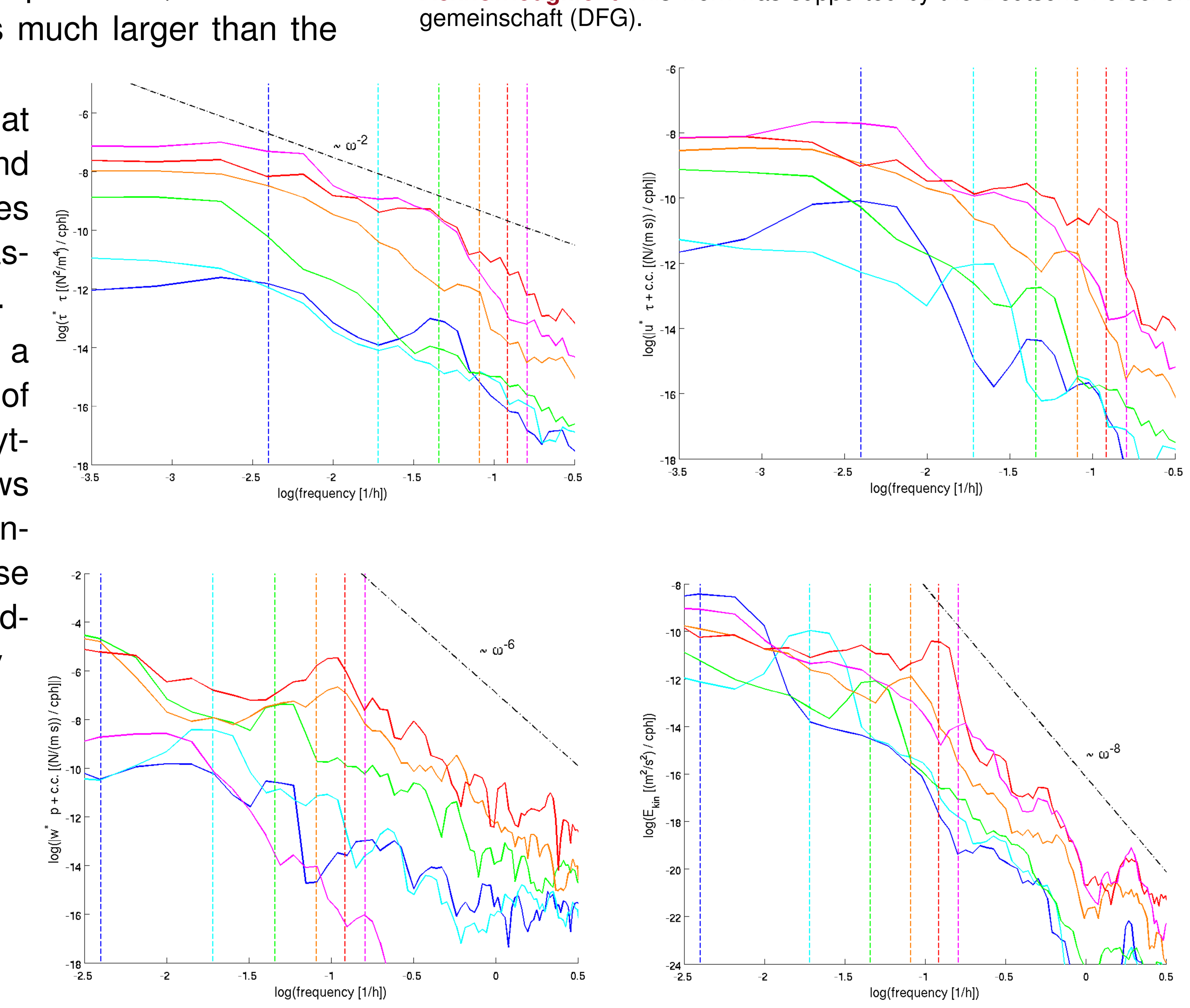


Figure 5. Frequency spectra of relevant quantities. Shown are the (absolute value of the) windstress itself, the energy term $\boldsymbol{u}\cdot\boldsymbol{\tau}_0$ at the ocean surface, the flux wp at the mixed layer base and (horizontal) kinetic energy. Colours denote different latitudes, vertical lines the local inertial frequency. Black lines represent the spectral shape of the quantities which is predicted by the analytical model and matched well by the general circulation model. Note the near-inertial peaks of the kinetic energy spectrum (lower right).