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Measuring and modelling the frictional velocity u*, turbulence and heat fluxes above the North Sea

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In this study, we analyse the frictional velocity u*, drag coefficient, vertical wind speed and turbulence profiles observed at different met-masts in the German North and Baltic Sea. We present an analysis of different models for the frictional velocity u* in convective, neutral and stable thermal stratification of the atmosphere. Atmospheric turbulent momentum and heat flux measurements performed with ultra-sonic anemometers are compared to profile-derived values and a bulk Richardson number formulation of the atmospheric thermal stability.

Modelling:
An improved approach to model the vertical wind speed profile is presented and compared against meso-scale model results (WRF, COSMO): Bye-Ekman-Coupling (BEC) describes the flux of momentum from the Ekman layer of the atmosphere through the Prandtl layer down to the air-sea interface by a modified wave boundary layer with enhanced Charnock dynamics (Bye et al. 2010).
The BEC model is based on the coupled pair of similarity relations for “aerodynamically rough flow” in both fluids (air and sea). The derived drag law is of Charnock form, almost independent of the wave age and consistent with the transfer of momentum to the wave spectrum – which takes place in the smaller rather than the dominant wavelengths.

Measurements:
It was found that the frictional velocity u* is considerably smaller than predicted by conventional approaches using the Charnock relation: For wind speeds between 10 m/s and 15 m/s at 40 m height above the sea surface, u*(observed) is 14% smaller than u*(Charnock).
Most important, we found unexpected, strong and obviously artificial distortions concerning the three wind speed components in the 10Hz data of the three ultra-sonic anemometers at the offshore met-mast FINO1 at 40 m, 60 m and 80 m height. The pattern of these distortions is independent from different post-processing procedures (planar-fit etc.). We anticipate that these artefacts imply severe problems for the eddy covariance technique. Moreover, these artefacts may be relevant in other (previous and on-going) ultra-sonic measurement campaigns where turbulent parameters such as u* and heat fluxes are derived.
A simple, but innovative analysis is proposed to check ultra-sonic measurements with respect to these artefacts, using the original temporal 10Hz resolution of the data: The instantaneous vertical wind speed component w is analysed versus the instantaneous wind direction (called wind.dir in the following), computed from the instantaneous horizontal components u and v. The observational density is then plotted in the (w; wind.dir)-space. We found a pattern of stripes of very strong densities for specific wind direction bins, which are thinner than 1° and which cannot be attributed directly to the geometry of the anemometer (transducers, physical structure etc.). The source of this artificial pattern is still unclear and open for discussion.

References:
Bye JAT, Ghantous M, Wolff J-O (2010) On the variability of the Charnock constant and the functional dependence of the drag coefficient on wind speed. Ocean Dynamics 60(4) 851-860