PO.312

Fluxes estimation and the derivation of the atmospheric stability at the offshore mast FINO1

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Introduction

Knowledge of vertical momentum/heat exchange processes over the sea is relevant for a better understanding of the Marine Boundary Layer (MBL) and essential to improve parameterizations used in atmospheric numerical models which are a basis to understand and predict wind conditions for wind energy applications.

In the present study, the methodology used to estimate momentum/heat fluxes is presented where the optimum average time is investigated. The study is based on a long period of fast-response measurements collected at the offshore mast FINO1 during 2010. Fluxes of momentum and heat are determined by using the so called eddy-covariance method. From fluxes calculation the derivation of the atmospheric stability is performed and the resulting statistics of the atmospheric stratification is analyzed.

Measurement campaign

Figure 1 FINO1 research platform.

Location: Offshore platform FINO1 [1] (lat. 54°0.86'N, long. 6°35.26'E).
Period: January-December 2010.
Wind sector: (240°-360°] ⇒ Open sea conditions.

Table 1 Measurements used in this study.

Parameter	Sensor (accuracy)	Height [m] LAT
Sonic anemometer	SOLENT 1210R3-50 (< 1 % rms)	41.5, 61.5, 81.5
Sea Temperature	Wavec datawell buoy (± 3 %)	SST
Air Temperature	Pt-100 (± 0.1°C)	41.5, 51.5, 71.5, 101.5
Air Pressure	Barometer, Vaisala (± 0.03 hPa)	22.5, 91.5
Air Humidity	Hygrometer, Thies (± 3 % RH)	34.5

Methodology

The so-called Eddy-Covariance method is applied to determine turbulent fluxes of momentum and heat from direct calibrated sonic data. A two-fold rotation was applied after which the x-axis is aligned with the mean wind vector and the mean vertical component is removed. The measurements were compared to allowable upper and lower limiting values based on instrument manufacturing specifications and the prevalent weather over the North Sea. Values exceeding those thresholds were discarded as instrumental errors. Furthermore, unreasonable peaks (unrealistically large or small values) associated with non-meteorological events in the data were removed. Mean values were corrected from mast shadowing by using uniform ambient flow mast correction scheme, UAM, developed by DEWI [2].

Choose of the averaging period:
An optimum value of the averaging time should be used in order to include the low frequency contribution to the fluxes and to fulfill the steady state condition (requirement of the eddy-covariance method). Spectral analysis was used to determine an optimum averaging period. The Ogive $Og_{x,w}(f_i)$, is the integral of the co- spectra between the frequency f_i and the Nyquist frequency,f_N:

$$Og_{x,w}(f_i) = \int_{f_N}^{f_i} Co_{x,w}(f)\,df \qquad (1)$$

To illustrate the influence of the atmospheric stability, the Ogive function for <u'w'> is shown in Fig. 2 for stable and convective conditions.

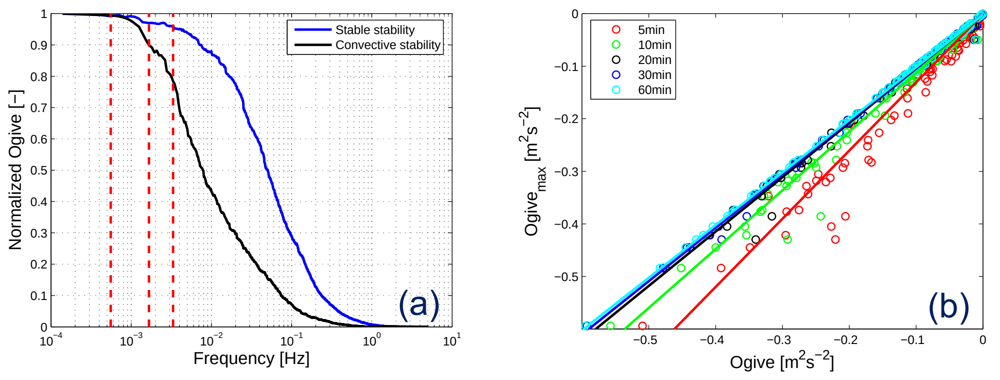


Figure 2 (a) Normalized Ogive function. Dashed lines indicate 30min, 10min and 5min, from lower to higher frequencies. (b) Sensivility test: Ogive values for different averaging times vs maximum Ogive.

In Fig.3 the error distribution (estimated flux - maximum of the Ogive) due to the choice of time averaging is presented. From these results a 30min averaging time is found to be appropriate to compute the fluxes at FINO1.

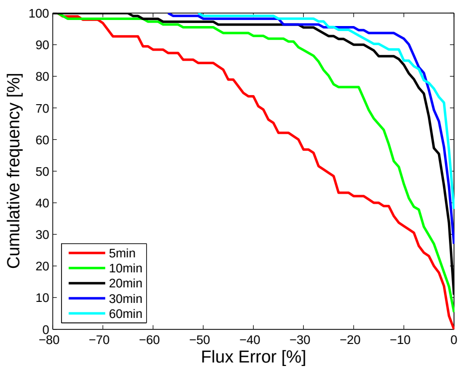


Figure 3 Error distribution as a function of time averaging.

Turbulent Fluxes

Sensible heat flux: In order to obtain the fluctuations of the actual temperature instead of the fluctuation of the sonic temperature, the humidity effect was corrected based on [3]:

$$< w'\theta' >_{sonic} = < w'\theta' > + 0.51\theta < w'q' > \qquad (2)$$

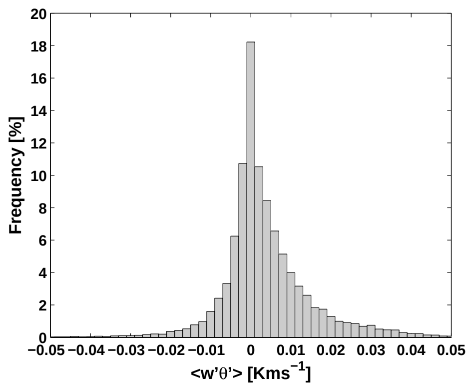


Figure 4 Probability distribution function of corrected <w'θ'>.

In absence of fast humidity response sensors at FINO1, a bulk formulation was used as first approximation to determine the second term on the right side in Eq. (2). If the humidity flux is included, the pdf distribution of heat flux is shifted towards unstable conditions. Crosswind contamination is internally corrected by the type of sonic used.

Momentum fluxes: In Fig. 5, the mean covariences of <u'w'> and <v'w'> are plotted as a function of wind speed at 41.5m LAT. After the alignment with the mean wind, <v'w'> stays around zero whereas <u'w'> shows the expected dependency with wind speed.

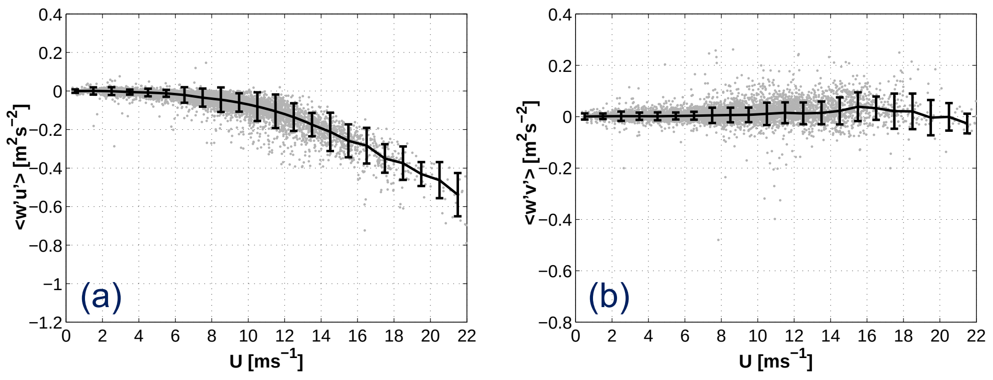
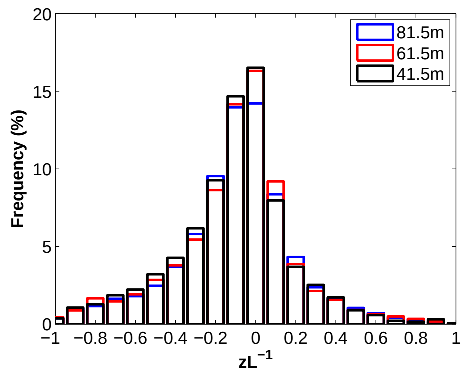


Figure 5 Mean momentum covariances: (a) along wind direction, (b) crosswind direction. The solid lines show the bin-averaged values and bars denote one standard deviation.

Atmospheric Stability

Once turbulence fluxes of heat and momentum are calculated, the atmospheric stability as described by the Monin-Obukhov similarity theory (MOST) was computed based on Eq. 3. The zL-1 pdf's at the three heights show a good agreement among them.



$$zL^{-1} = -\frac{g\kappa < w'\theta' > z}{\theta_z {u_*}^3} \qquad (3) \text{ with}$$

$$u_* = (< w'u' >^2 + < w'v' >^2)^{1/4}$$

Figure 6 Probability distribution of flux-based zL^{-1} at all the sonic heights.

Comparison of stability methods: sonic versus bulk method
Since sonic anemometry is not routinely used in wind energy, an alternative way (Bulk Richardson number) to estimate the atmospheric stability based on local gradient of mean meteorological measurements is computed and compared to the flux-based zL^{-1} parameter (Eq.3).

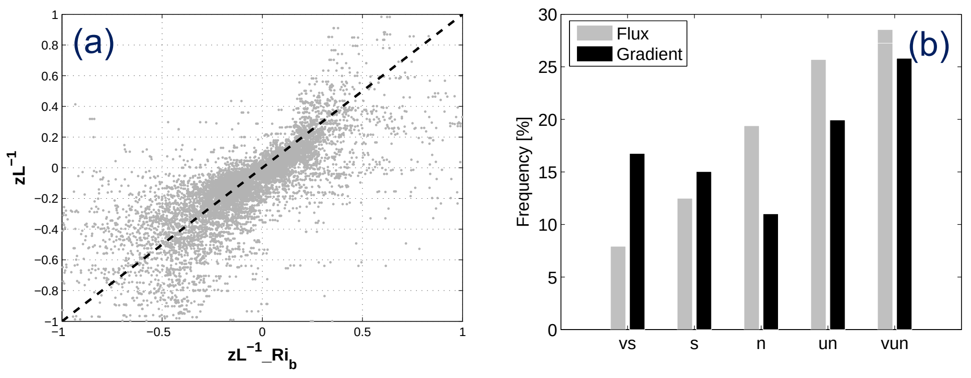
Bulk Richardson number: $Ri_b = -\frac{gz}{T_{air}} \frac{\Delta\theta_v}{{U_{air,z}}^2}$
(gradient-based)

$$\Delta\theta_v = \Delta\theta + 0.51 T_{air} \Delta q$$

Conversion into zL^{-1} [4] ⇒

$$\begin{cases} zL^{-1} = 10 Ri_b & Ri_b < 0 \\ zL^{-1} = \dfrac{10 Ri_b}{1 - 4.5 Ri_b} & 0 \le Ri_b \le 0.2 \end{cases} \qquad (4)$$

Δθ and Δq denote the potential temperature and specific humidity differences between air (41.5 m) and sea surface (SST). For 2010, $\Delta\theta_v \approx \pm 2.9$K and $\Delta q \approx \pm 4 10^{-3}$kgkg^{-1}.



Stability class	zL^{-1}
Very stable (VS)	$0.2 < zL^{-1} < +\infty$
Stable (S)	$0.04 < zL^{-1} < 0.2$
Near neutral (NN)	$-0.04 < zL^{-1} < 0.04$
Unstable (U)	$-0.2 < zL^{-1} < -0.04$
Very Unstable (VU)	$-\infty < zL^{-1} < -0.2$

Table 2 Stability classification.

Figure 7 (a) Scatter plot of flux-based (zL^{-1}) versus gradient-based (zL^{-1}_Ri_b) stability parameter at 41.5m LAT. (b) Histogram by stability classes.

The relatively large scatter could be associated to the complex interplay of different parameter involved in the calculations and to the different uncertainties of the different methods and sensors. The gradient-based method tends to produce more stable conditions than the sonic one. Nevertheless, the overall agreement between both sets of data is rather good.

Conclusion

In this study, a detailed data analysis was presented focusing on turbulent fluxes calculation under offshore conditions.

A time average of 30-min interval was found, by means of an Ogive analysis, to be adequate to estimate the turbulent fluxes at FINO1.

The stability parameter (zL^{-1}) was computed using both flux and gradient based methods. Despite of the relatively large scatter in the comparison, an overall good agreement was found. Further investigation are needed to confirm these results.

Atmospheric stability is very sensible to humidity changes, this is important especially offshore. In this study a bulk approximation was used to estimate humidity fluxes, however a deeper study of humidity effects on the stability is foreseen in the new TUFFO project [5].

FINO1 mast provides high-quality data which can be used to check modeling results and obtain a more detailed picture of the physical processes in the MBL (see poster PO.394 [6]).

Acknowledgements:

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References:

[1] FINO: Forschungsplattformen in Nord- und Ostsee, www.fino-offshore.de.
[2] A. Westerhellweg, V. Riedel, T. Neumann: Comparison of Lidar- and UAM-based offshore mast effect corrections, EWEA 2011, Brussels.
[3] P. Schotanus, F. T. M. Nieuwstadt, and H. A. R. De Bruin,2004: Temperature measurement with a sonic anemometer and its application to heat and moisture fluxes. Boundary-Layer Meteorology, 26(1): 81–93.
[4] Grachev, A. and C. Fairall, 1996: Dependence of the Monin-Obukhov stability parameter on the bulk Richardson number over the ocean. J. Appl. Meteorol., 36, 406–414.
[5] TUFFO Project. Erfassung und Bewertung des Einflusses turbulenter Feuchteflüsse auf die Turbulenzintensität in Offshore Windparks. Part of RAVE project (www.rave-offshore.de).
[6] D. Muñoz-Esparza, B. Cañadillas, T. Neumann, J. van Beeck. WRF mesoscale modelling and LiDAR measurements of tall wind profiles at FINO1. **PO.394**. EWEA OFFSHORE 2011, Amsterdam, The Netherlands.

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