Air-Sea Interaction at Wind Energy Site in FINO1 Using DCF (Lidar) Measurements from OBLEX-F1 campaign

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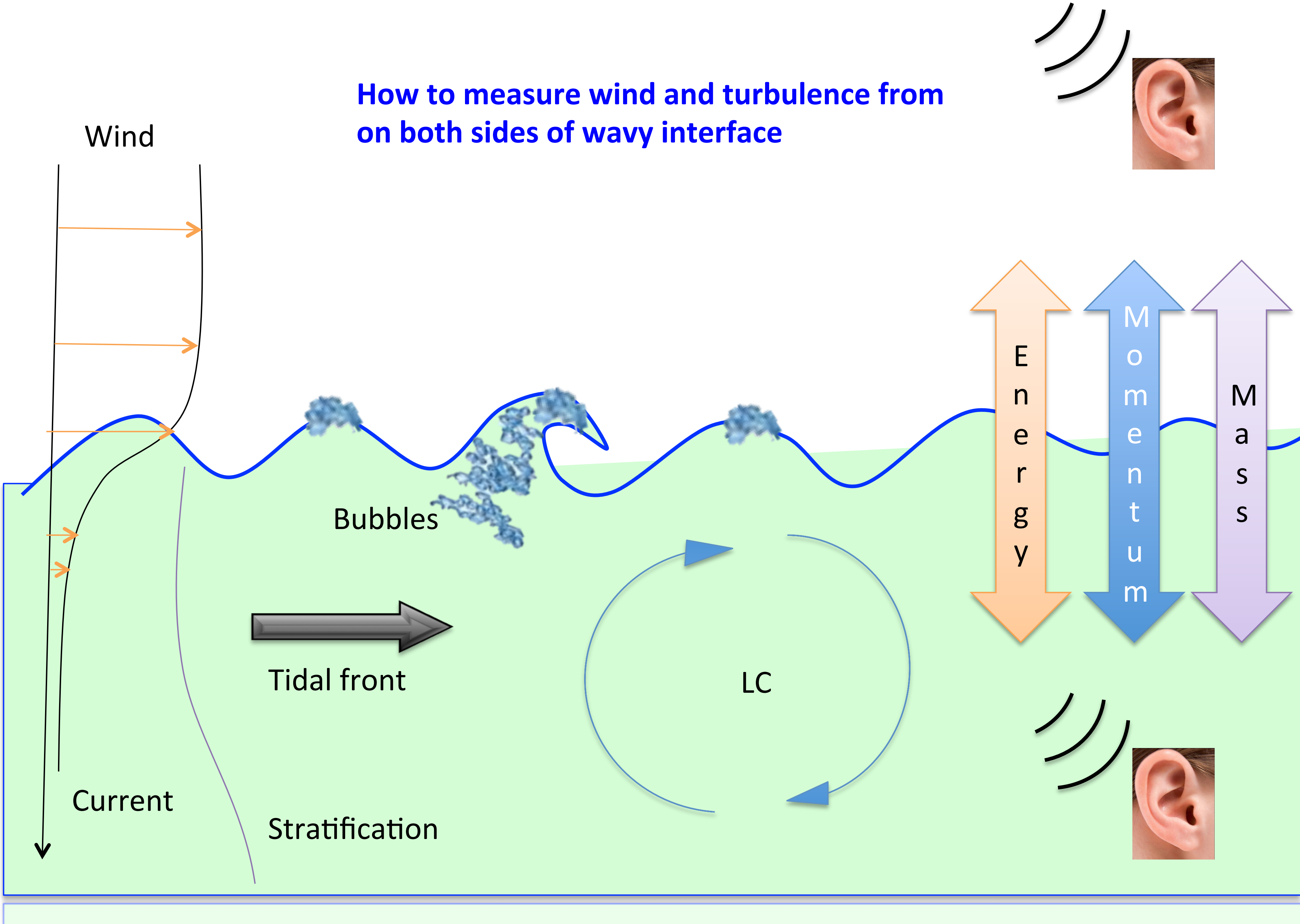
How to measure wind and turbulence from on both sides of wavy interface



Outline

- ➢ Measurement site (FINO1)
- ➢ Measuring techniques
- ➢ DCF systems and sea waves
- ➢ Wind-current interaction
- ➢ Conclusions

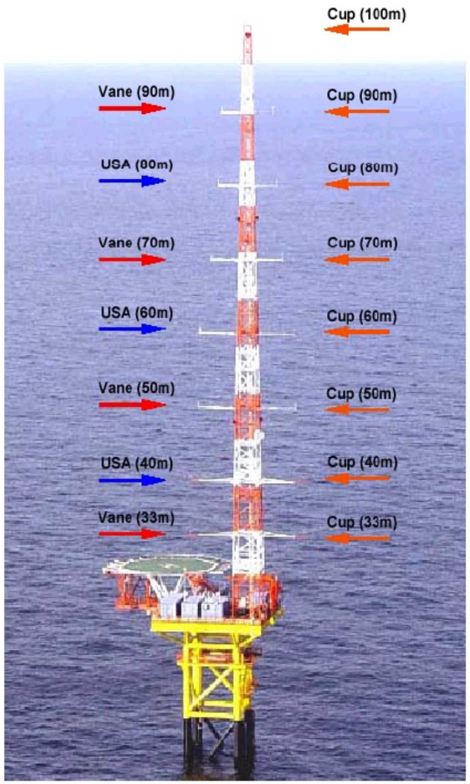


Fig.1: The FINO1 – Platform in the North Sea

In Fig. 1 the positions of the sensors for wind spe

Measurement site: FINO1

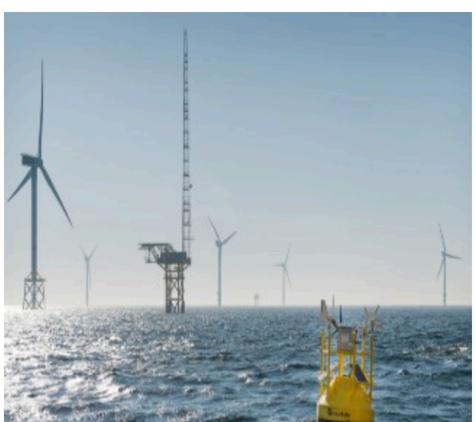
Offshore **B**oundary **L**ayer **Ex**periment FINO1 (OBLEX-F1)

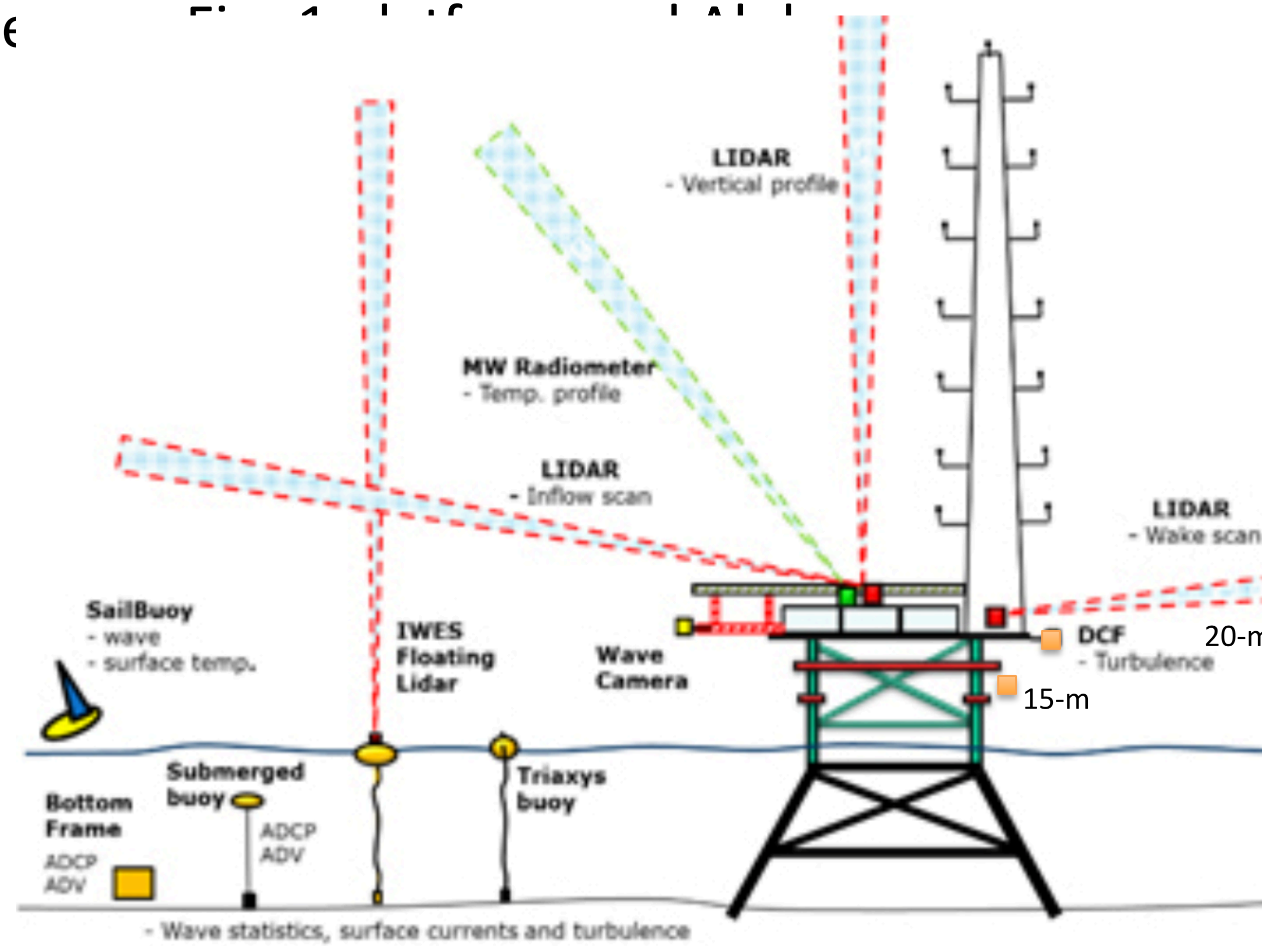
From June 2015 to September 2016.

Air-sea interaction processes in the presence of offshore platforms: Ge

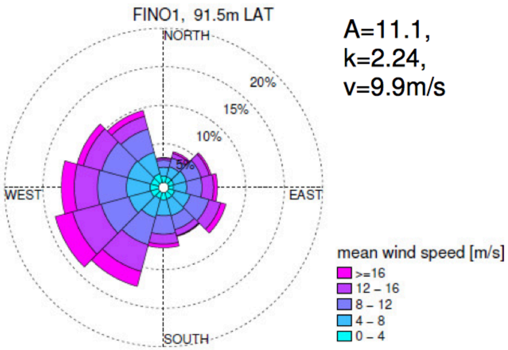
Ventus offshore wind

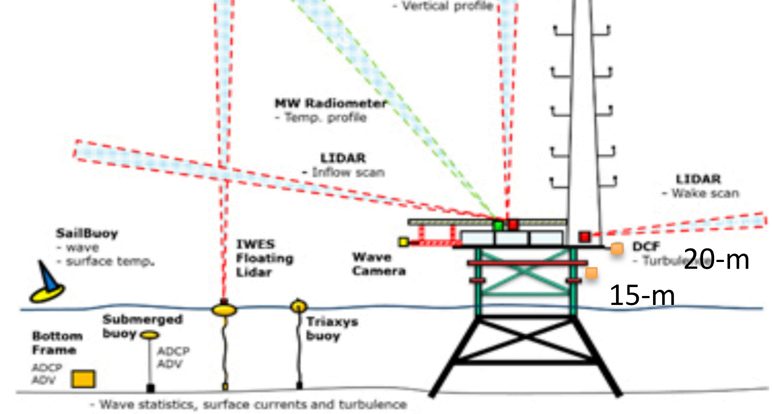
Oceanic field work:

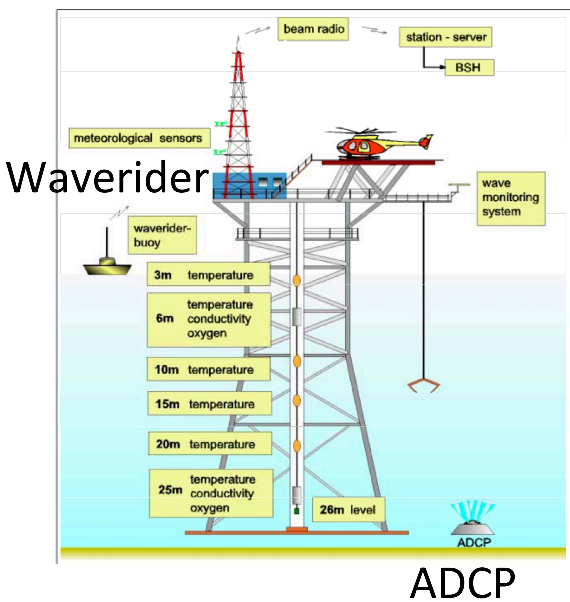


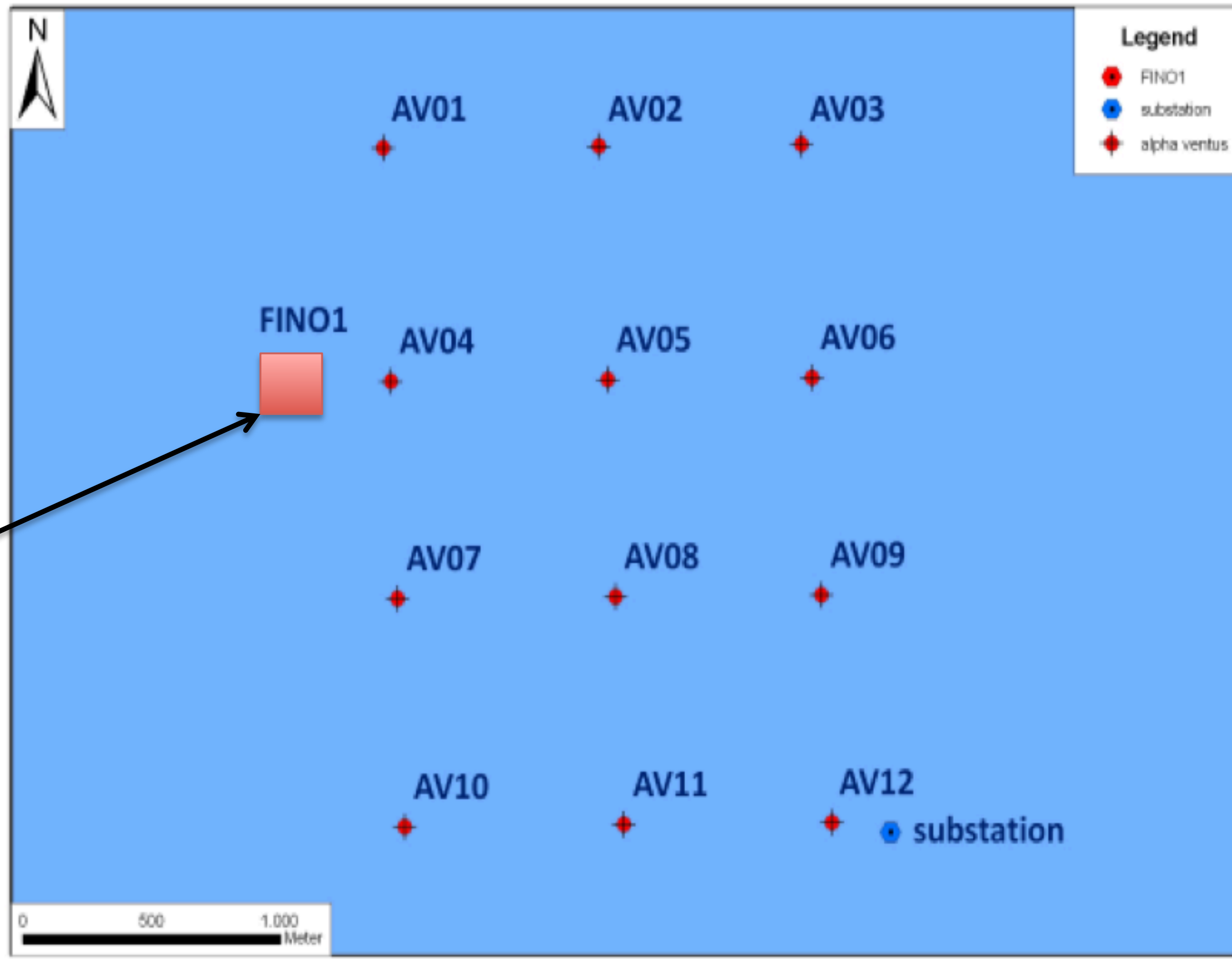


Deployment configuration







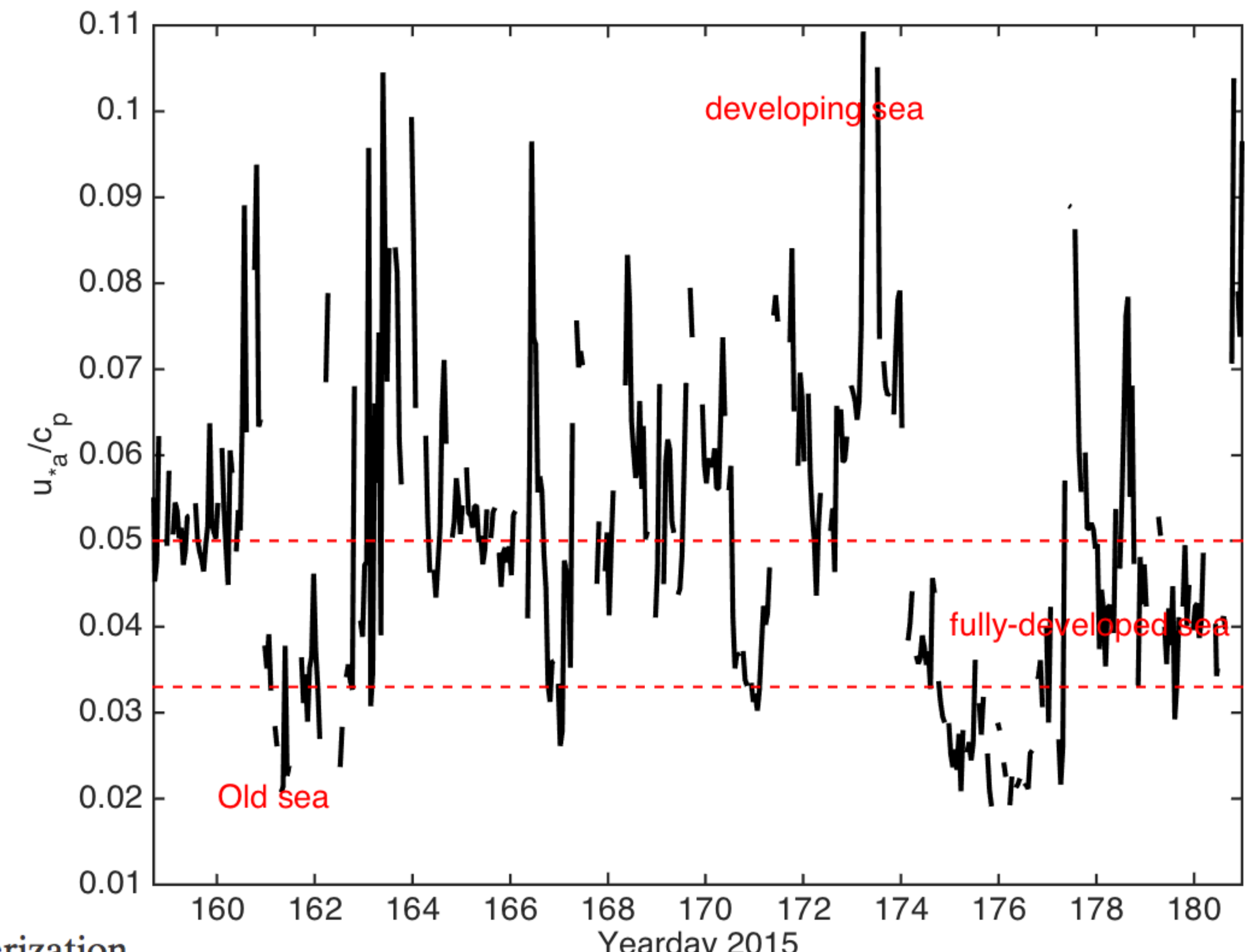


Environmental conditions

$$U_{10} = U(z_1) + \frac{u_*}{\kappa} \ln\left(\frac{10}{z_1}\right)$$

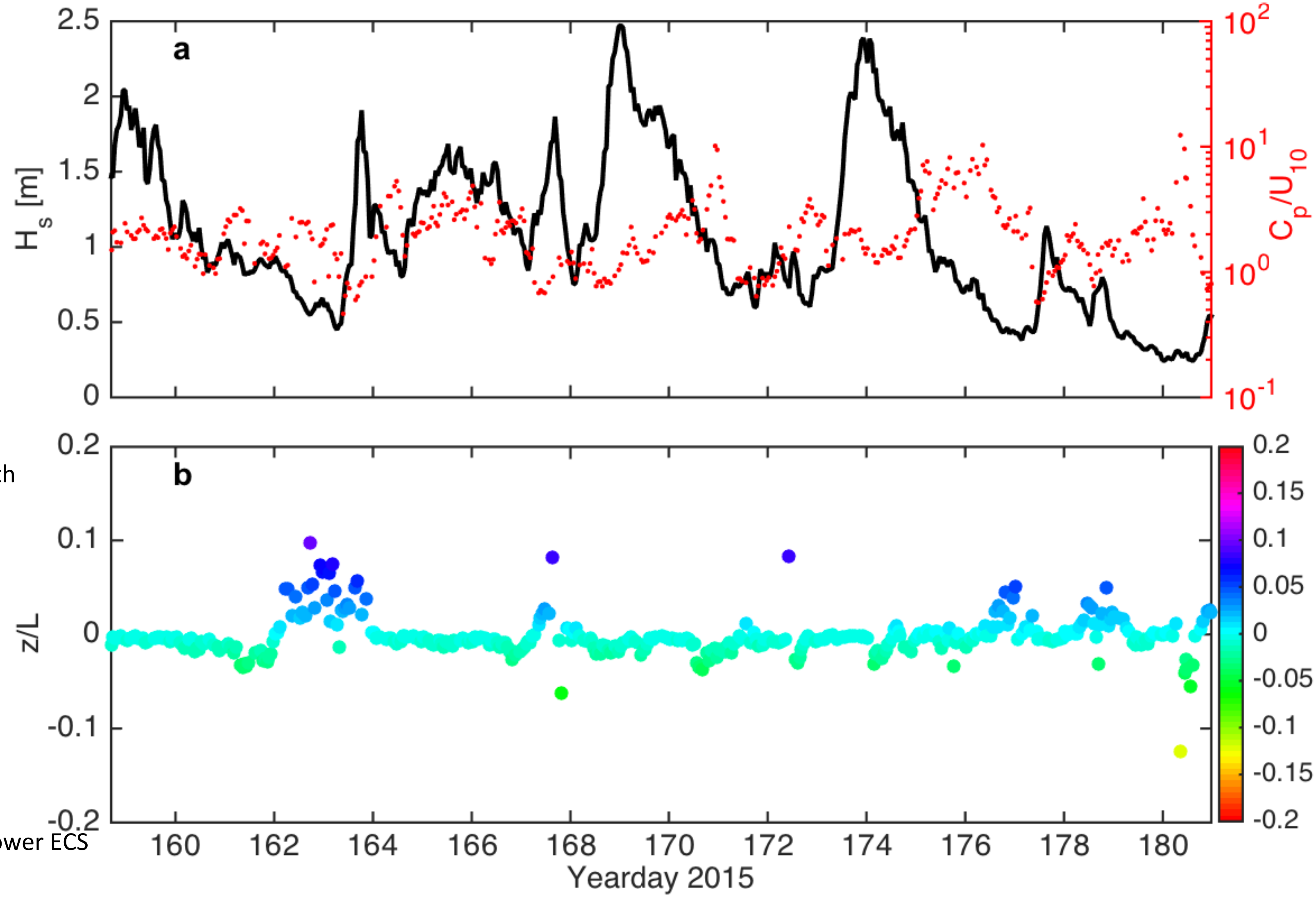
Here c_p is the phase speed of the surface waves at the spectral peak.

Friction velocity calculated from cup-anemometer at 33-m height.



TOGA COARE 3.0 parameterization

DCF system at 15-m



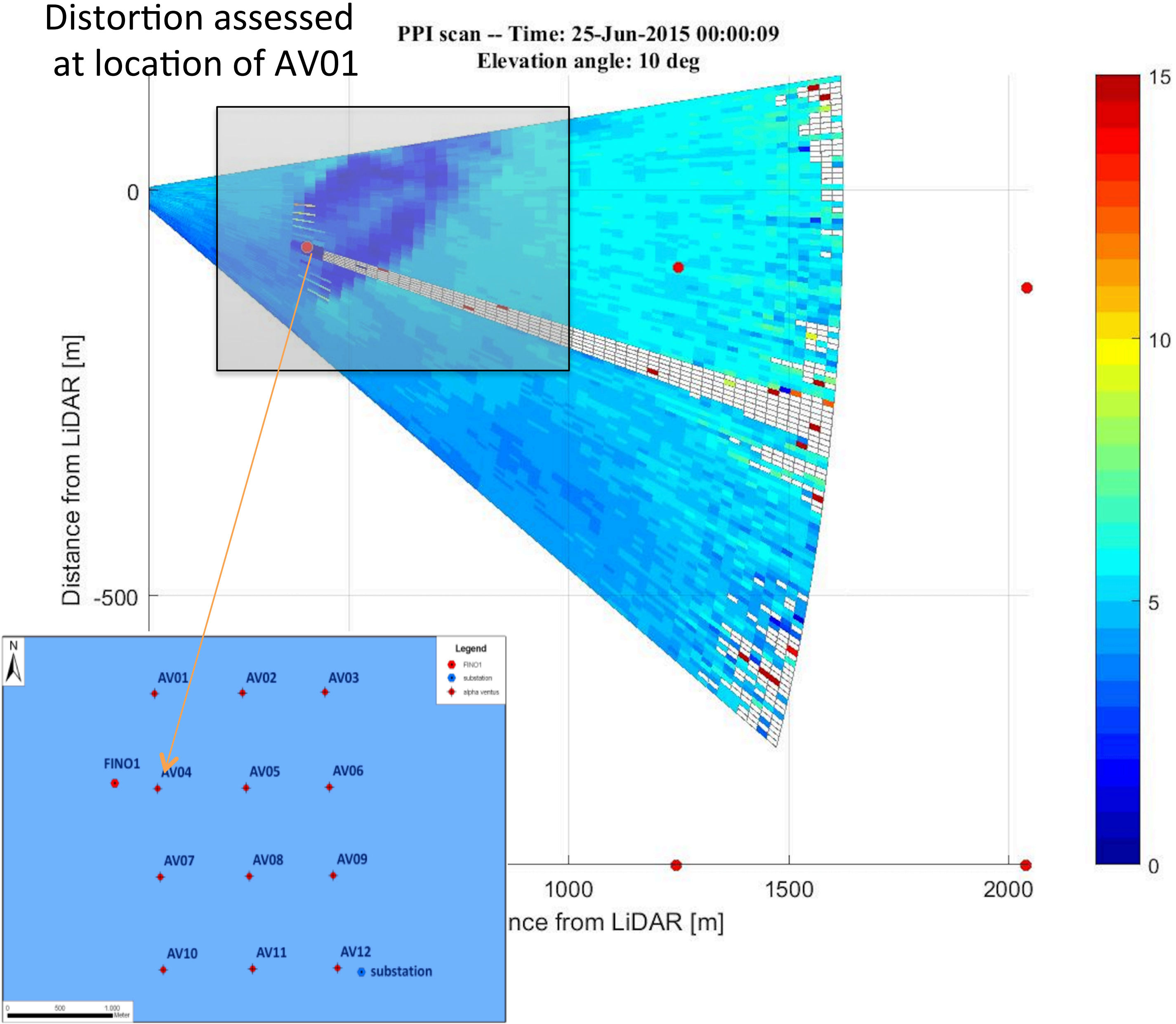
Monin–Obukhov length

$$L = -\frac{u_*^3 \bar{\theta}_v}{\kappa g \overline{w'\theta_v'}},$$

z is the height of the lower ECS

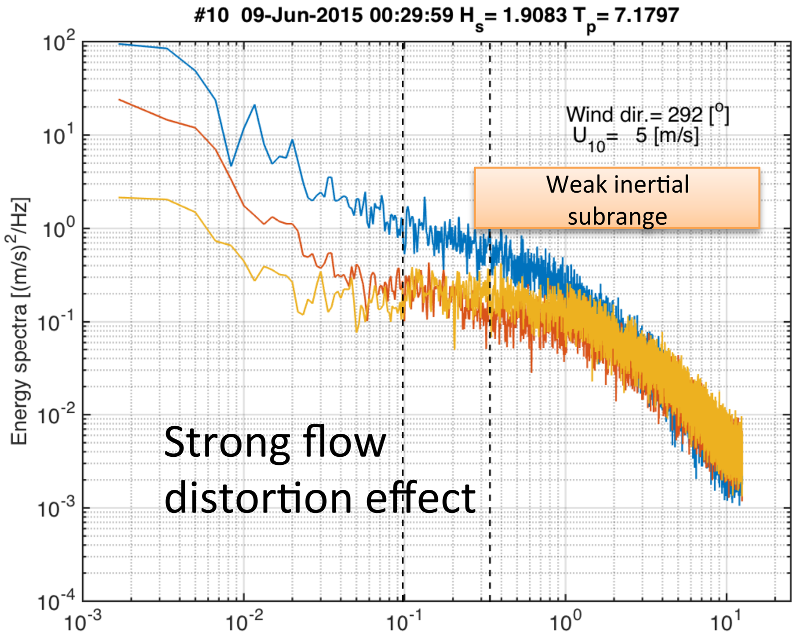
Wake characteristics: Lidar Data

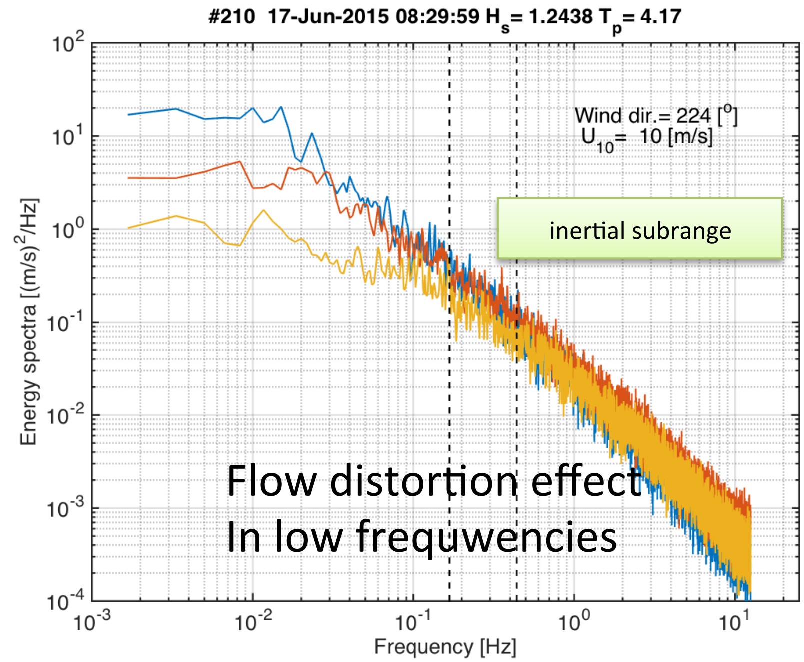
Distortion assessed at location of AV01

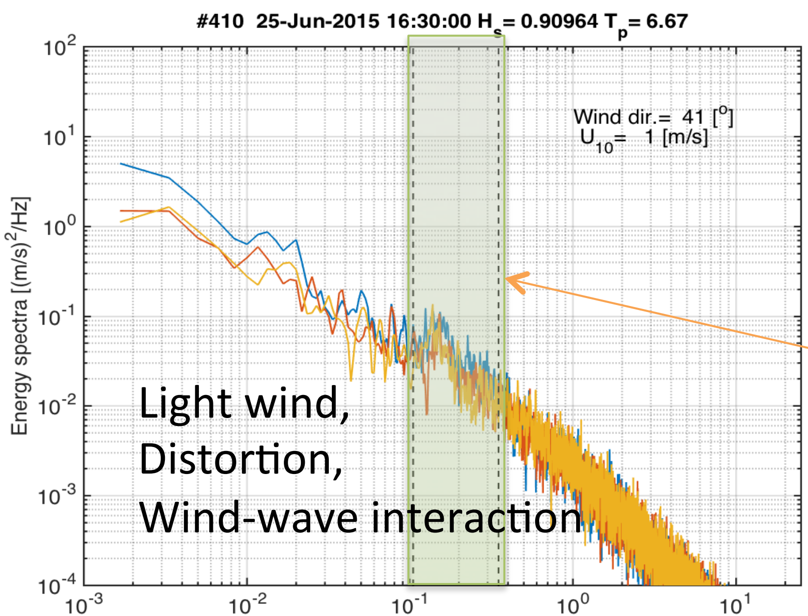


Windcub 100

DCF system at 15-m



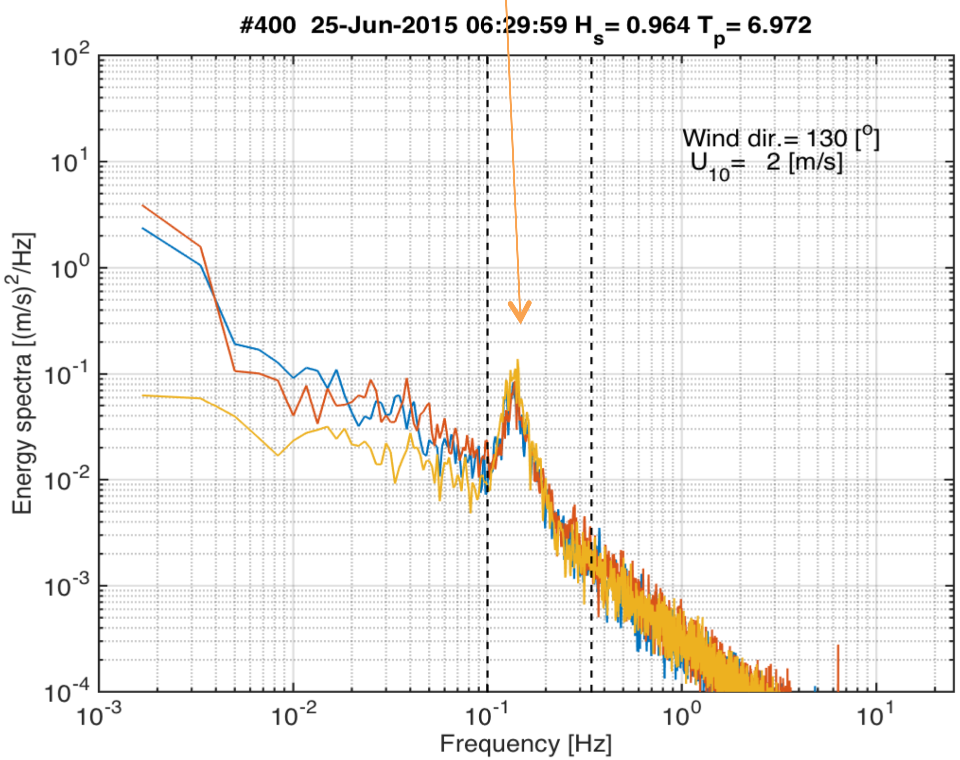




Wave affected frequency band calculated from Buoy data

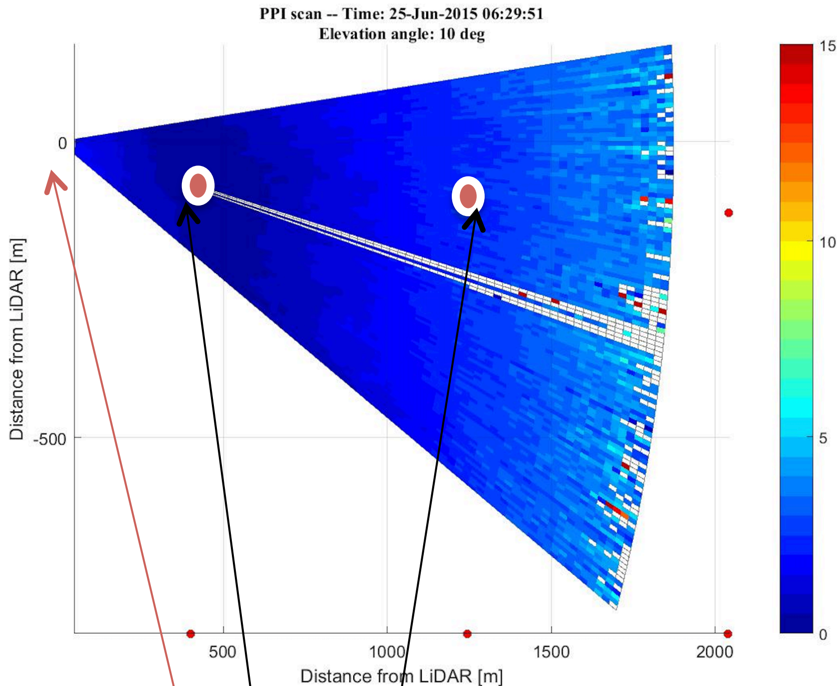
DCF system at 15-m

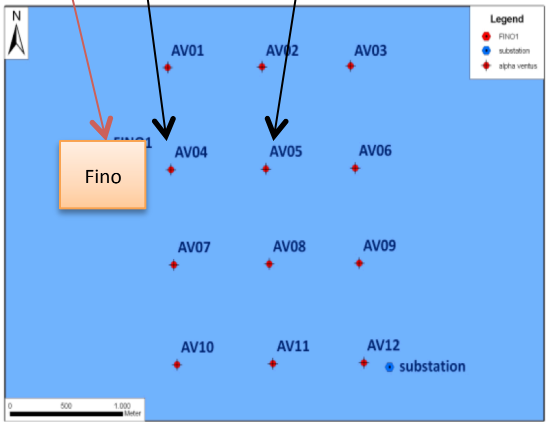
Wave-wind interaction



Less influenced by flow distortion.

Lidar data to check distorted
Flow characteristics





DCF system at 15-m: flow distortion

Effect of distortion on Friction velocity

$$|\tau| = \rho C_z (U_z - U_o)^2,$$

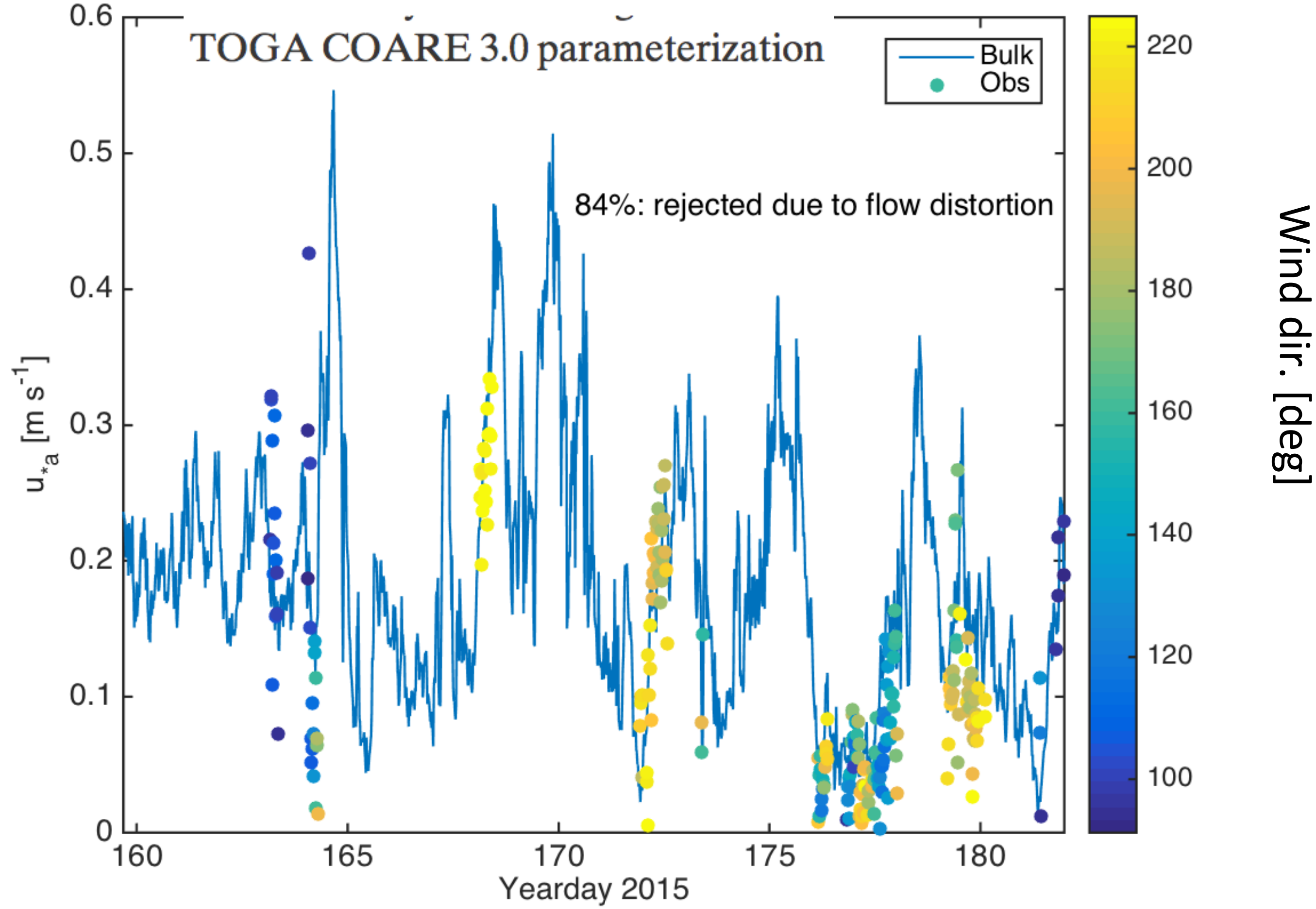
U_o the surface drift speed,

$$\tau = \tau_t + \tau_w + \tau_v.$$

turbulent

viscous

Wave-coherent

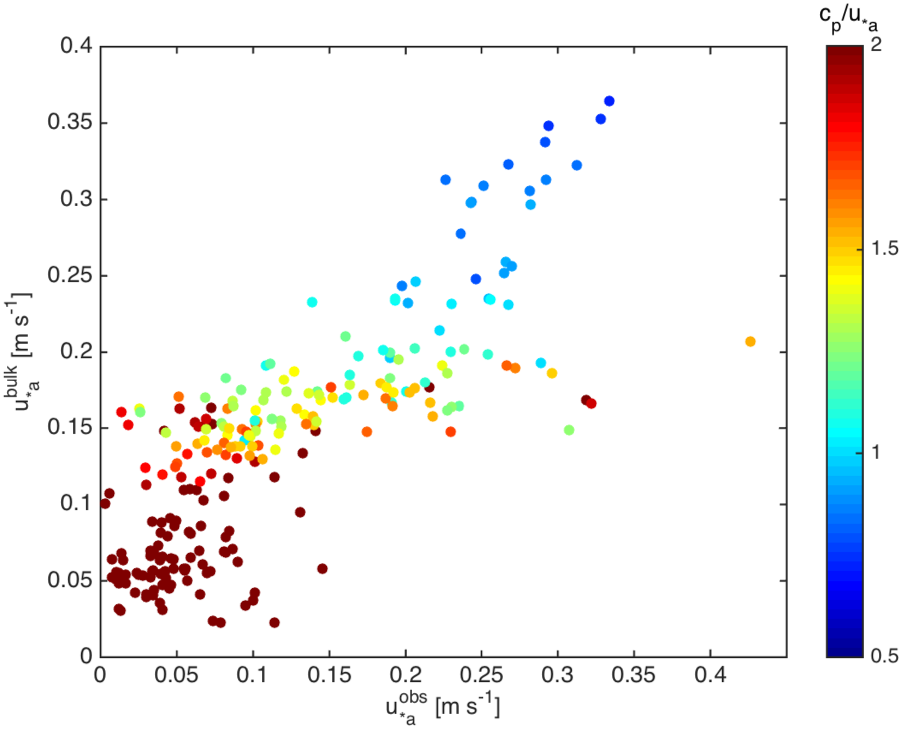


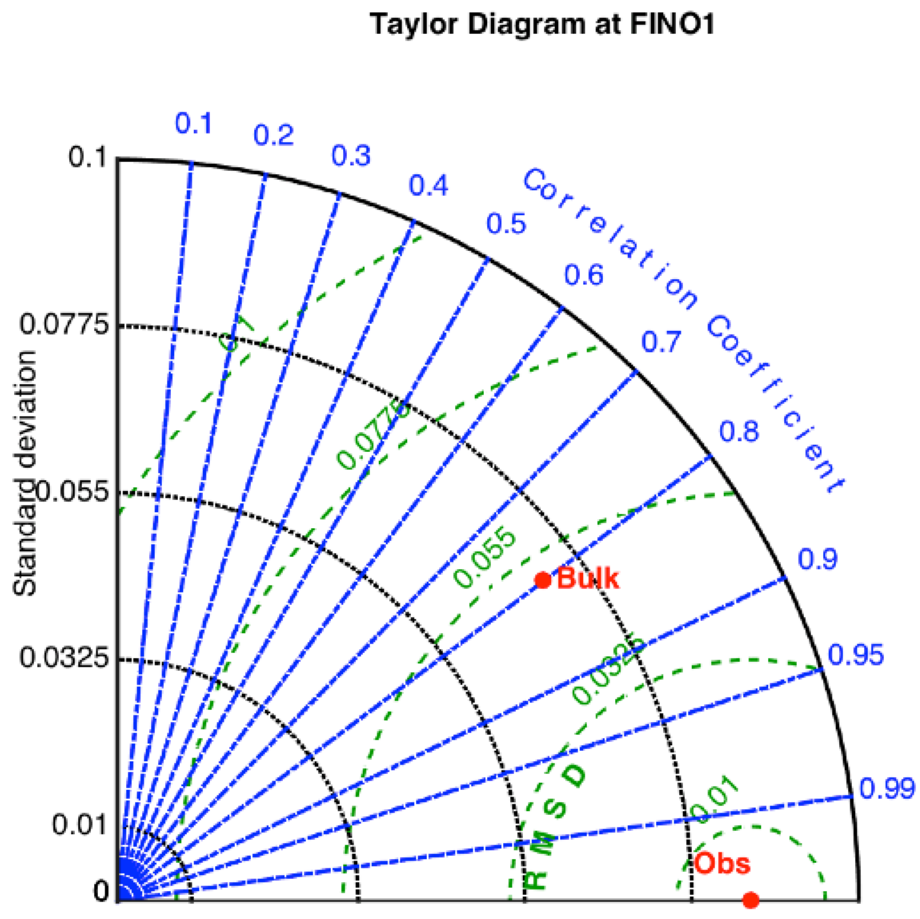
$u_* = (|\tau|/\rho)^{1/2}$ is the friction velocity,

DCF system at 15-m: friction velocity

$$\tau = -\rho\left(\overline{u'w'}\hat{i} + \overline{v'w'}\hat{j}\right),$$

$$u_* = (|\tau|/\rho)^{1/2}$$

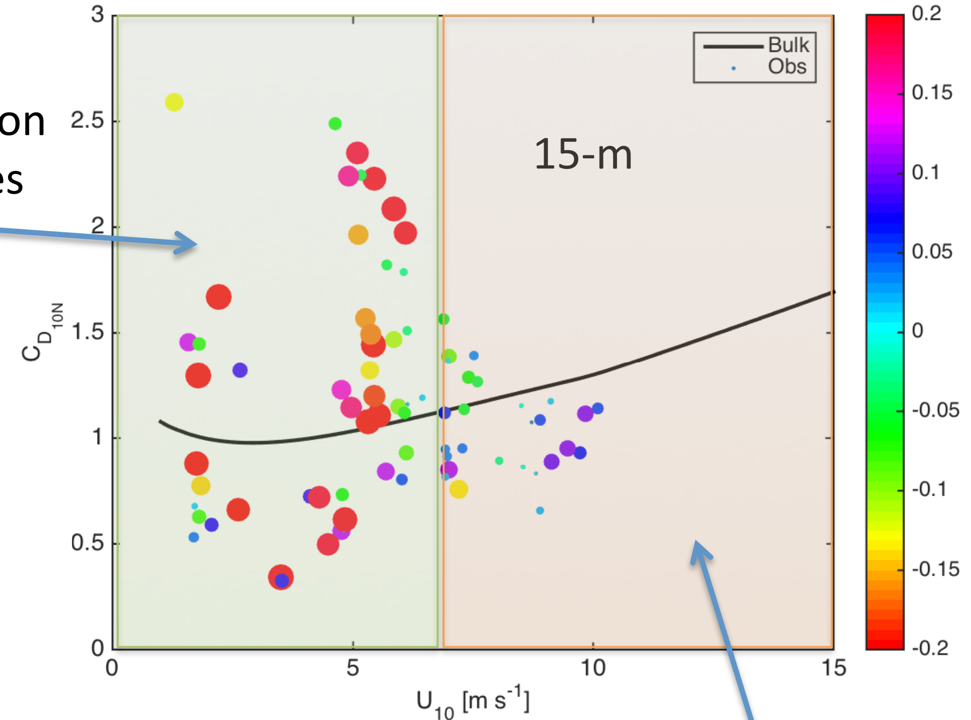


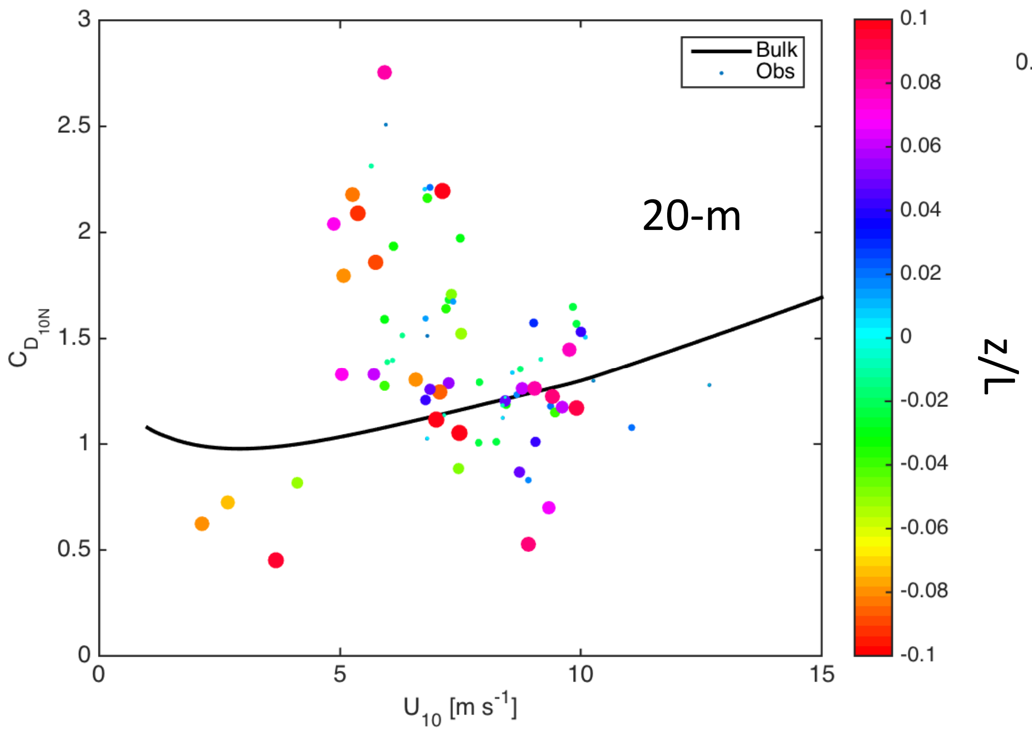


DCF systems: drag coefficient

$$C_{D_{10n}} = (u_*/U_{10n})^2,$$

Combined effects of
Incomplete flow distortion
Removal and swell waves



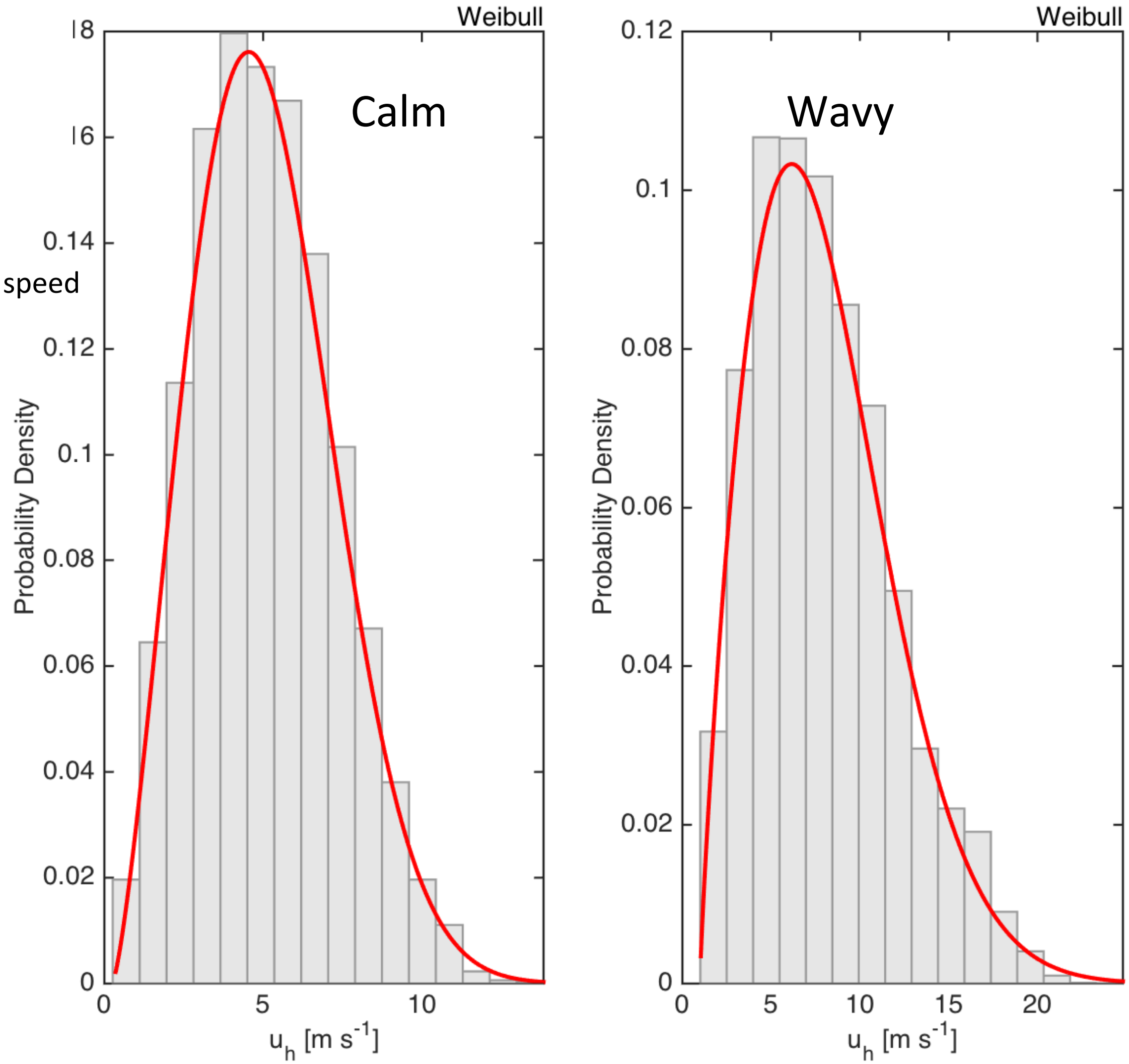


High-wind associated with
younger waves

DCF system at 15-m: some statistics

$$f(u_h; b; a) = \frac{a}{b}\left(\frac{u_h}{a}\right)^{b-1} e^{-\left(\frac{u_h}{a}\right)^b},$$

two-parameter Weibull distribution provides a reliable approximation to the probability density function of wind horizontal speed



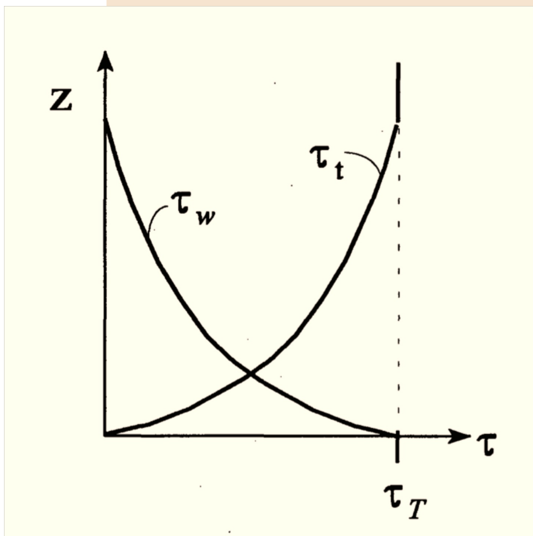
An analytic expression for the PDF is in Good agreement with the observed one By means of efficiently capturing the behavior of higher moments.

Bakhoday-Paskyabi 2017, under review, OMAE

DCF system at 15-m: wind-wave

horizontal momentum equation in the presence of waves

$$\left[\overline{\tilde{u}\tilde{w}} + \overline{u'w'} + \nu\frac{\partial \bar{u}}{\partial z}\right]_h = \underbrace{\boxed{\frac{1}{\rho_a}\overline{p_\eta \frac{\partial \eta}{\partial x}}}}_{\text{air pressure-wave slope correlation}} + \underbrace{\nu\overline{\left(\frac{\partial u}{\partial z}\right)_\eta} - \nu\overline{\left(\frac{\partial u}{\partial x_i}\right)_\eta \frac{\partial \eta}{\partial x_i}}}_{\text{viscous stress}}$$



Neglecting viscous terms

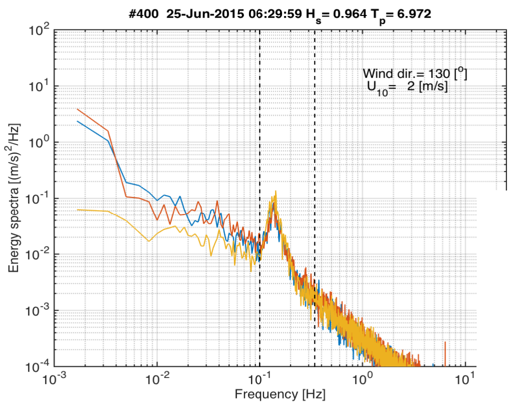
$$\rho_a \overline{\tilde{u}\tilde{w}}\,\big|_\eta = \overline{p_\eta \frac{\partial \eta}{\partial x}}$$

It is possible to use the wave-induced air pressure perturbation and wave slope in order to quantify the wave-induced momentum flux.

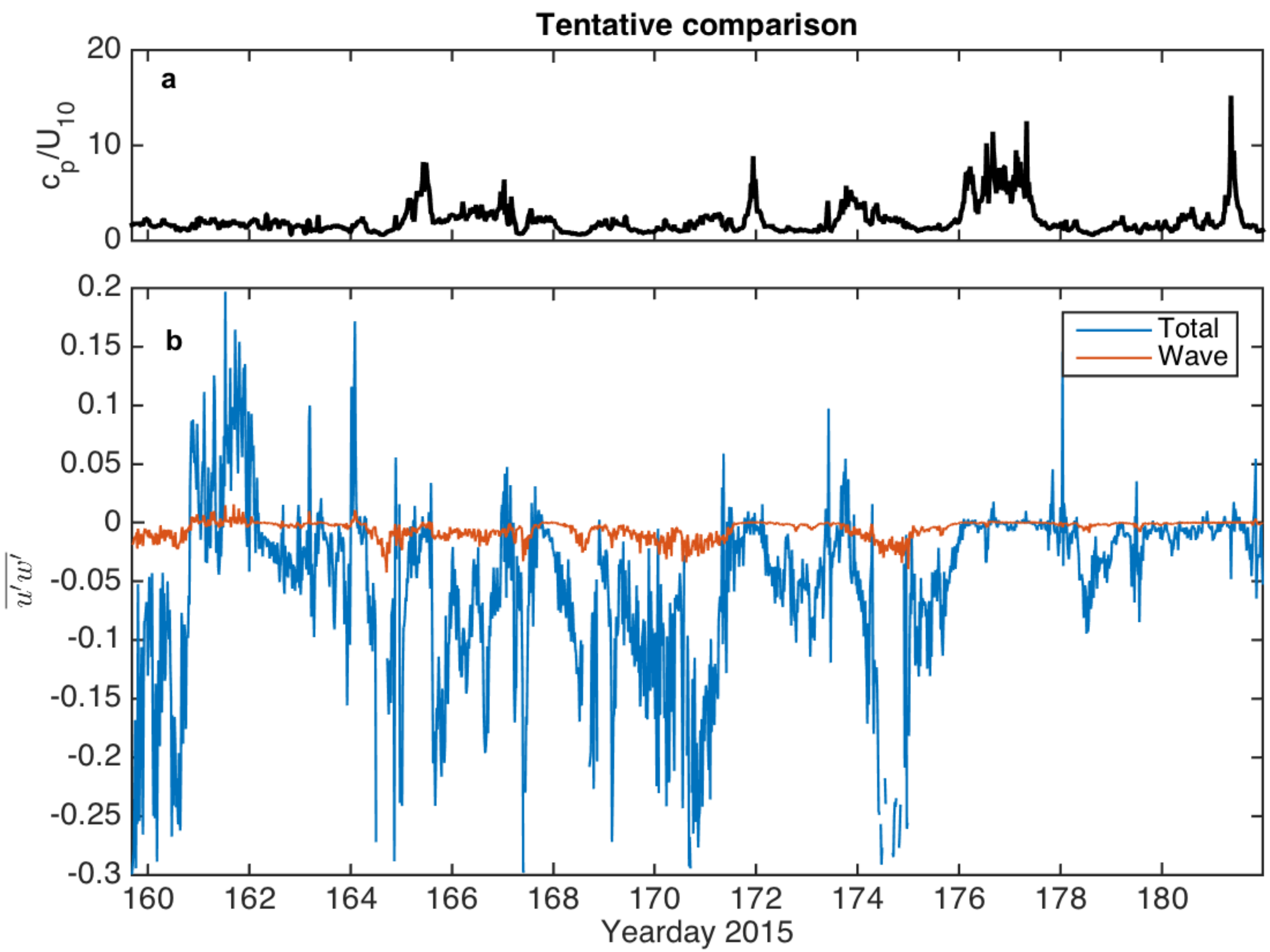
Due to the lack of sufficient knowledge about the structure of the wave-induced pressure field, we can use either parameterization or measured velocity spectra to estimate wave-induced stress.

Bakhoday-Paskyabi et al 2014
Wetzel 1996

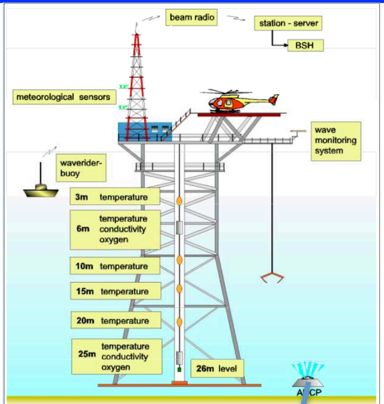
DCF system at 15-m: wind-wave



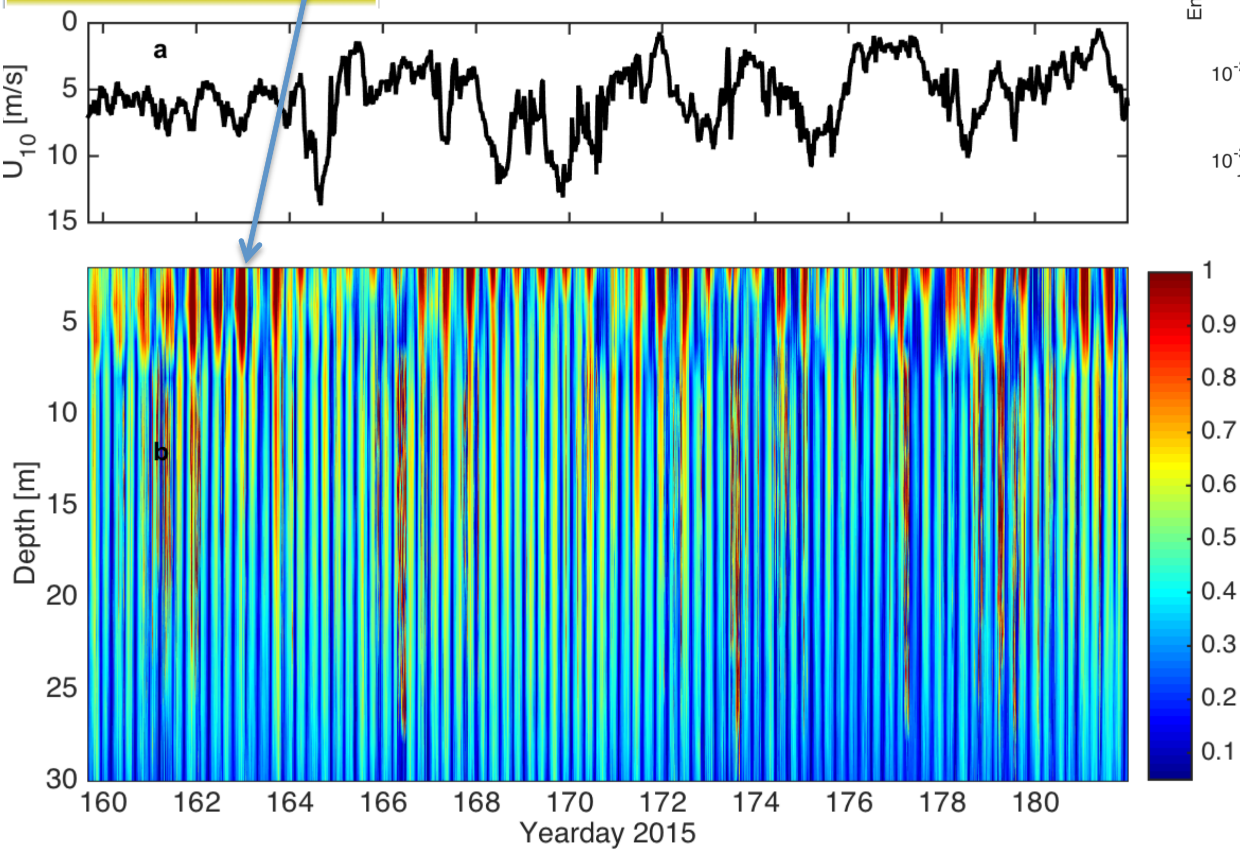
c/U_{10} for a fully developed sea is between 1.3 and 1.6.

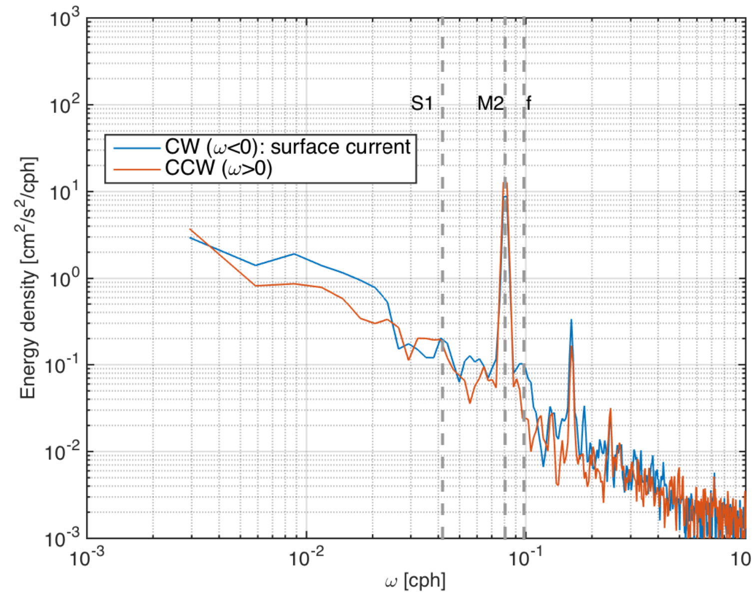


Ocean currents: uplooking ADCP



ADCP





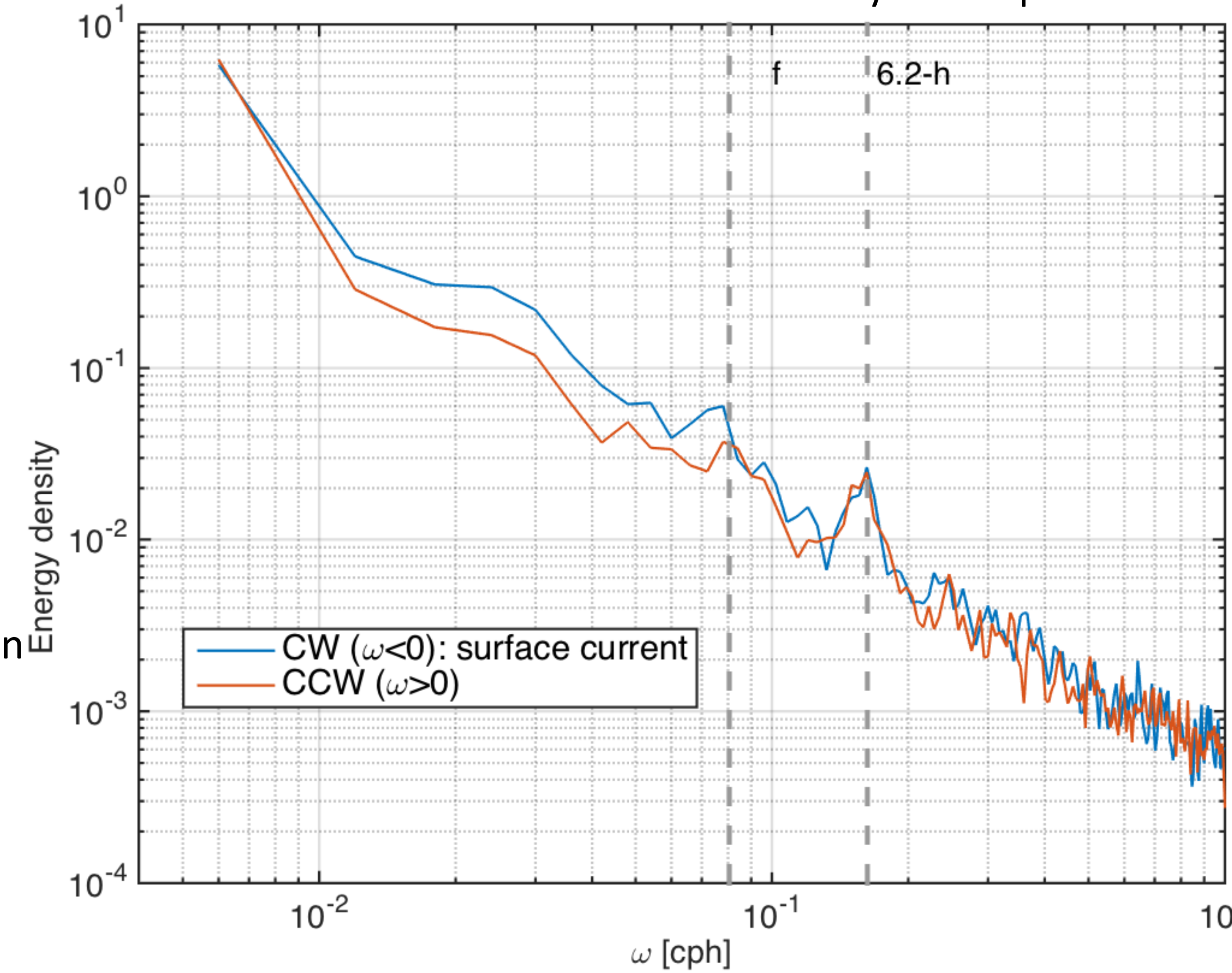
Bakhoday-Paskyabi et al 2017, under review ODY

Surface current and wind interaction

At low frequencies, the CW Component seems more energetic, in particular near the inertial frequency.

From rotary cross-spectra, It is possible to assess the phase characteristics between wind and waves and to measure the correlation amplitude.

the wind and surface current rotary cross spectra



Bakhoda-Paskyabi & Rohre 2017, under preparation

Conclusions

- There are significant scatters for light wind and swell wave conditions which might be explained by the residual effects of flow distortion.
- For high wind conditions, effects of wave-age is more pronounced in DCF measurements at 15-m height.
- Wave signature has been detected in measurements from ECF at 15-m height above MSL.
- Empirical expressions for the probability distribution is in good agreement with the observed ones for both calm and wavy sea-state conditions.
- There exist an almost large deflection angle between wind and surface currents for low frequencies (lower than 1/12 cph).
- All oceanographic data have been successfully analyzed and the first results with focus on processing and farm-wind-current interaction can be found in Bakhoday-Paskyabi et al (2017).

Thanks

Acknowledgment

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