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Assessing tidal turbine performance and the relationship between the turbine output power and turbulence in a tidal estuary

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PRO-TIDE
FINDING POWERFUL SOLUTIONS

Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
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INTERREG IVB

Motivation

"Pro-Tide" (*www.pro-tide.eu*) focuses on
Developing, Testing and Promoting Tidal Energy in coastal and estuarine zone in the NW Europe

Special focus on innovative systems:
small differences in tidal level and/or low flow rate

Specific actions:

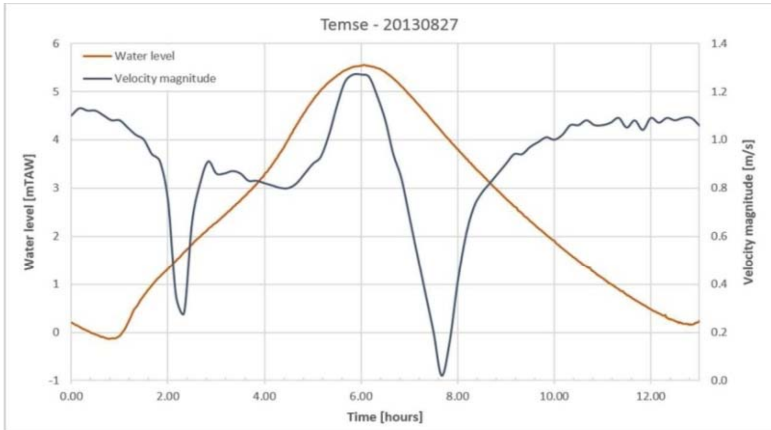
- turbine tests and *in situ* measurements in the Sea Scheldt
- analysis of flow variability and power generated by tidal turbines

Water2Energy (W2E, NL)

Aquascrew (BE)

Blue Energy Canada (BEC)

Experimental site – Sea Scheldt, Temse (BE)



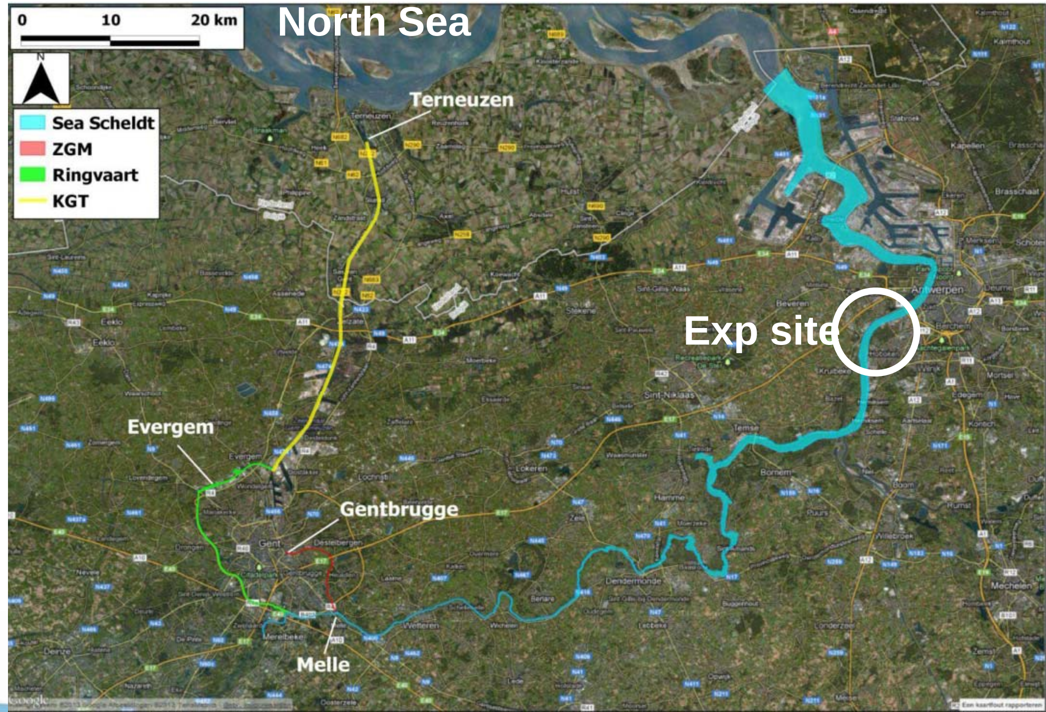
Major characteristics

Tidal estuary with daily flow: 2 x 70 million m^3

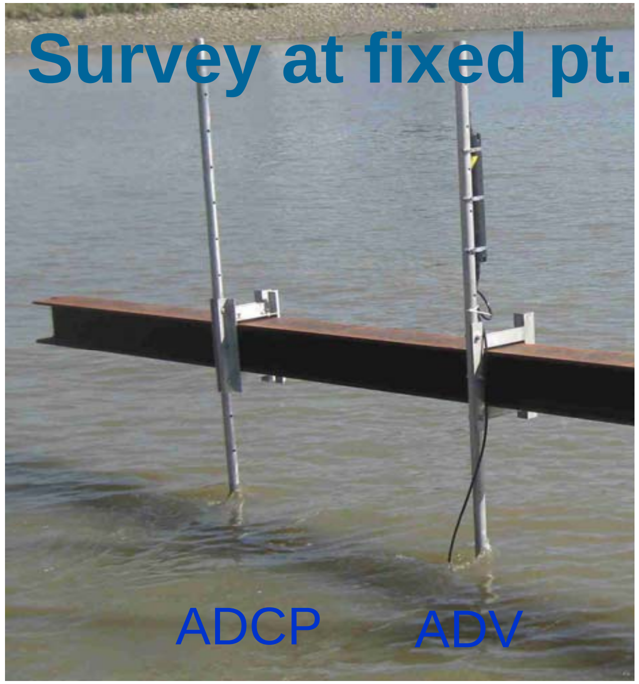
Width: ~ 300 m

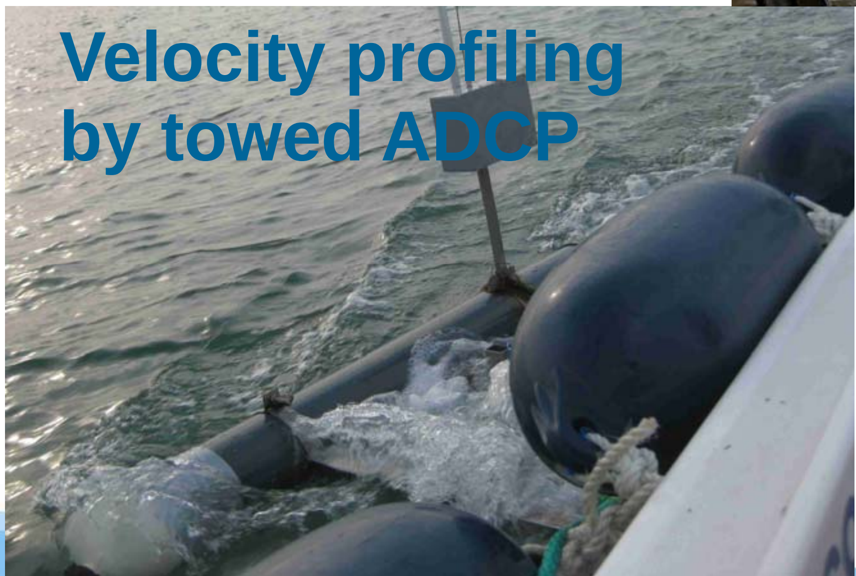
Mean tidal range: 5 m

ebb/flood flow max speed: 1.0 – 1.8 m/s

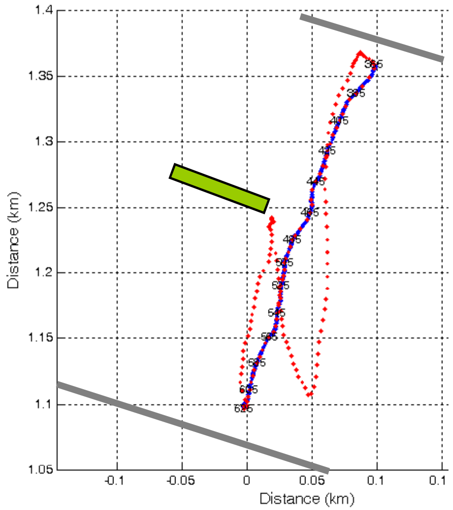


Experimental settings



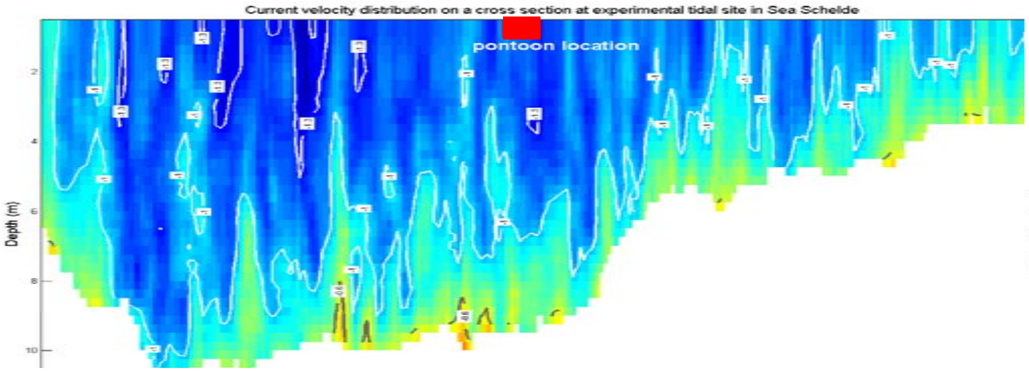


Current profiling, mapping, resource assessment



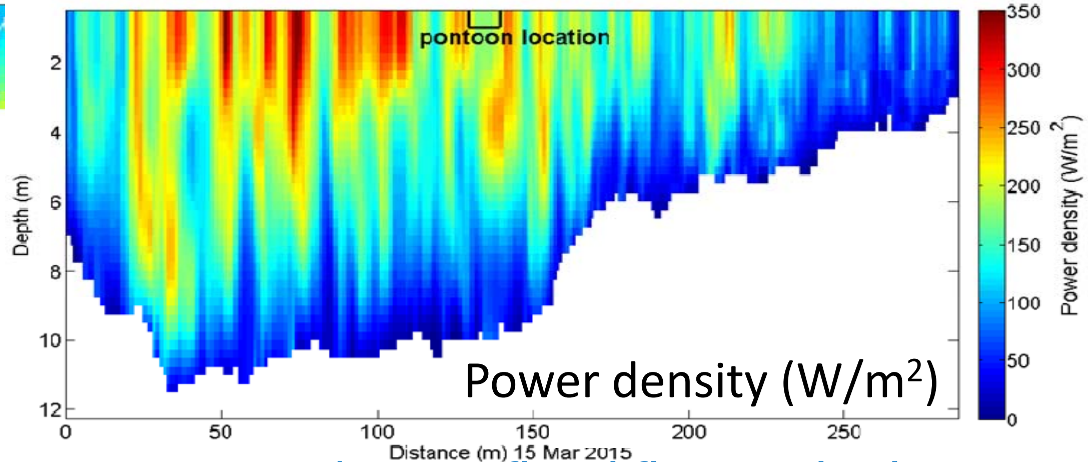
Velocity profiling by towed ADCP across the Sea Scheldt on flood flow (18/03/2015)

Streamwise velocity (m/s)



Current speed > 1m/s at the pontoon location (red)
Velocity is higher (>1.3m/s) 50 m northward

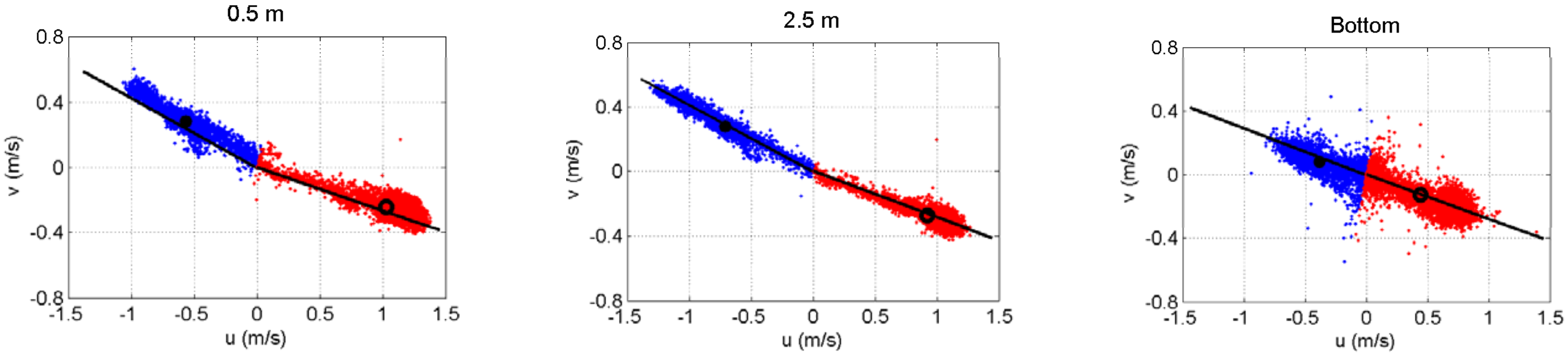
Bridge piles



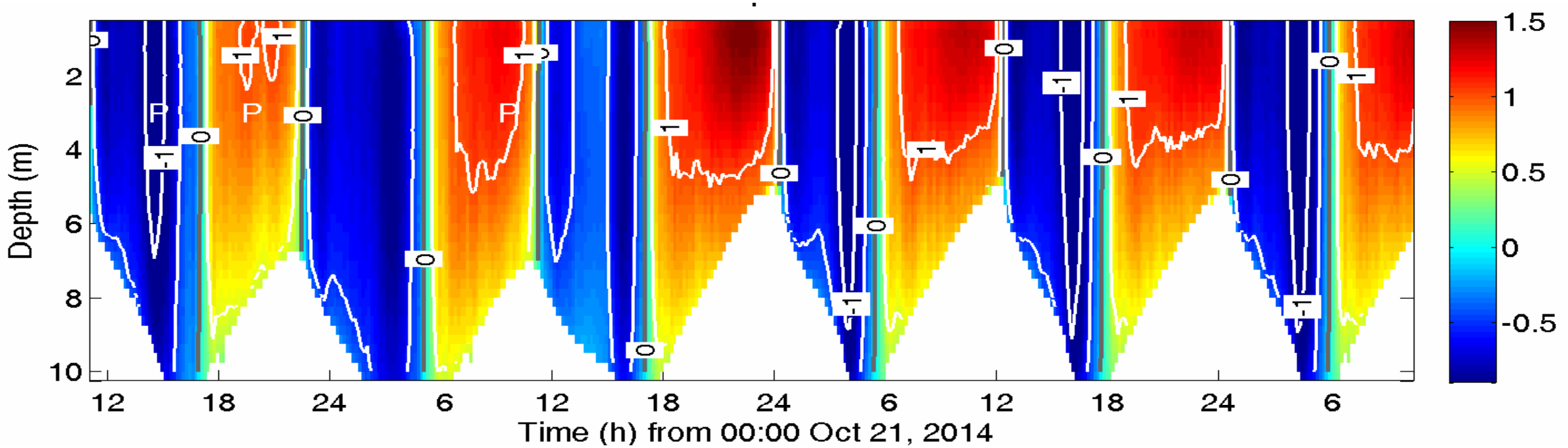
- *P ≈200-250 W/m2 on flood flow on both sides of the pontoon*
- *Patchiness in power distribution (effect of piles)*

Space-time variability of the flow

Current ellipses at different depth levels – a small misalignment in the surf layer



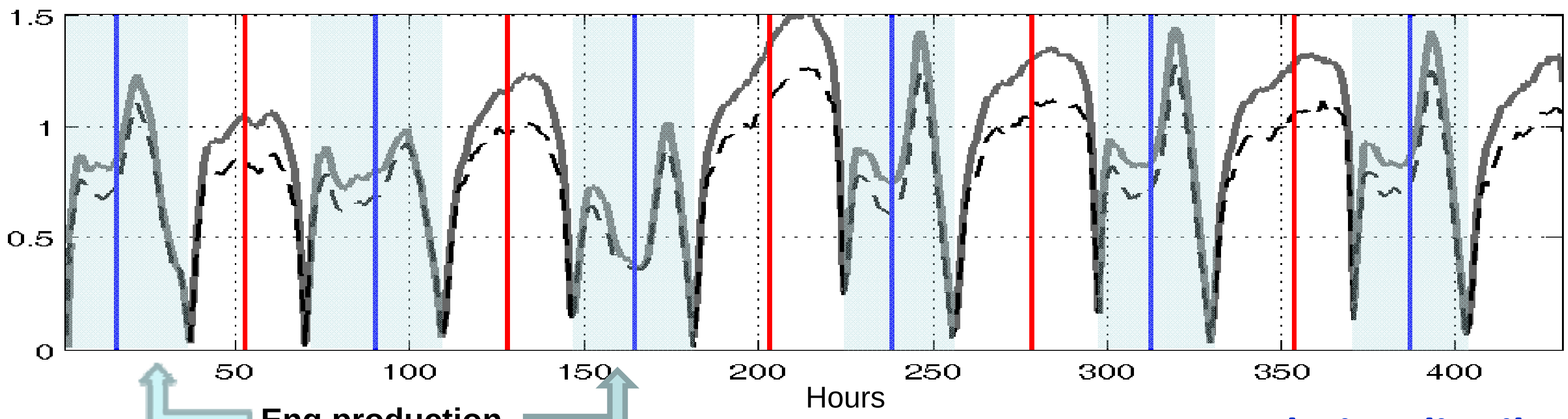
Streamwise velocity in Oct 2014 (10 min averaged)



Ebb tide velocities > flood tide velocities

Mean flow properties

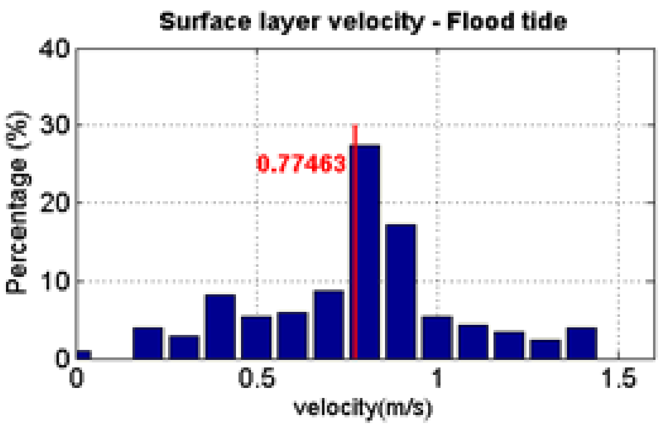
Depth averaged (dashed line) and surface layer (1.5 m thick) velocity (grey line). Red/blue lines – EbbFlood flow mid-time

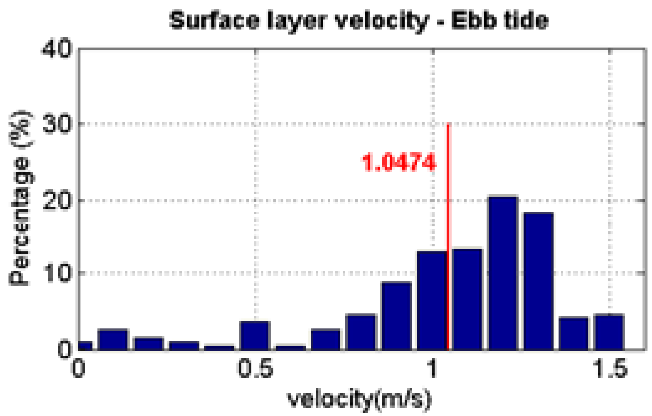


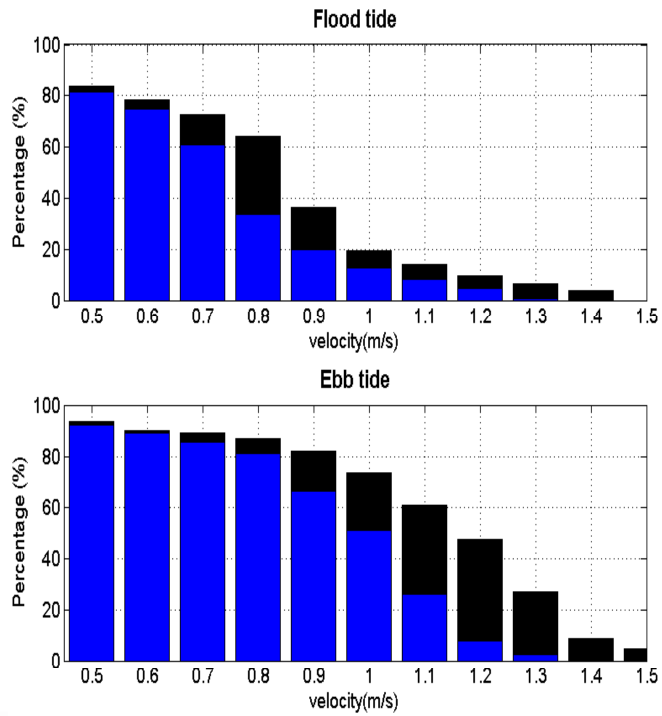
Eng production

Cumulative distribution of V

Hist of velocity distribution: ebb/flood flow



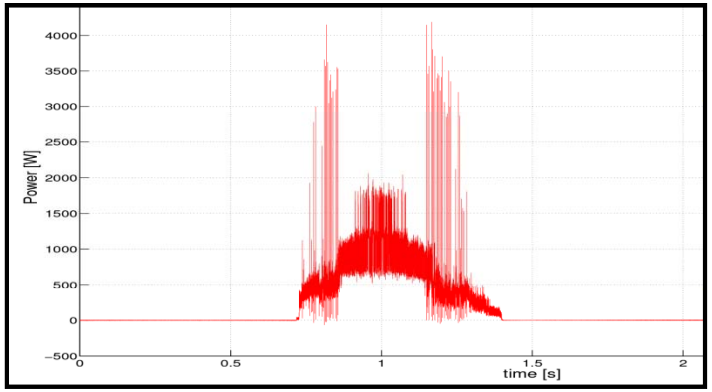




Ebb flow velocity is 30 % higher than flood flow velocity in the surface layer. The choice of tidal period for power production by W2E turbine is not justified

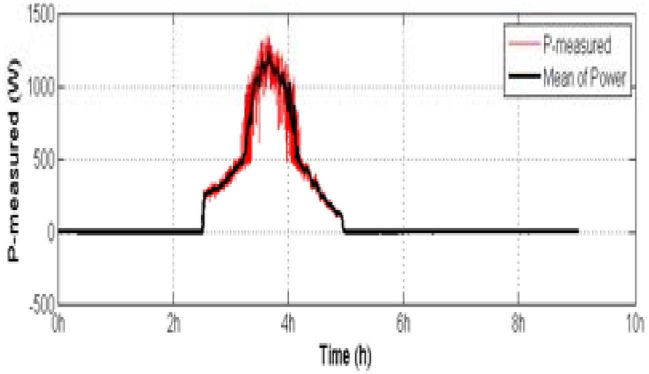
Assessment of the W2E turbine performance

Power: example of the raw data

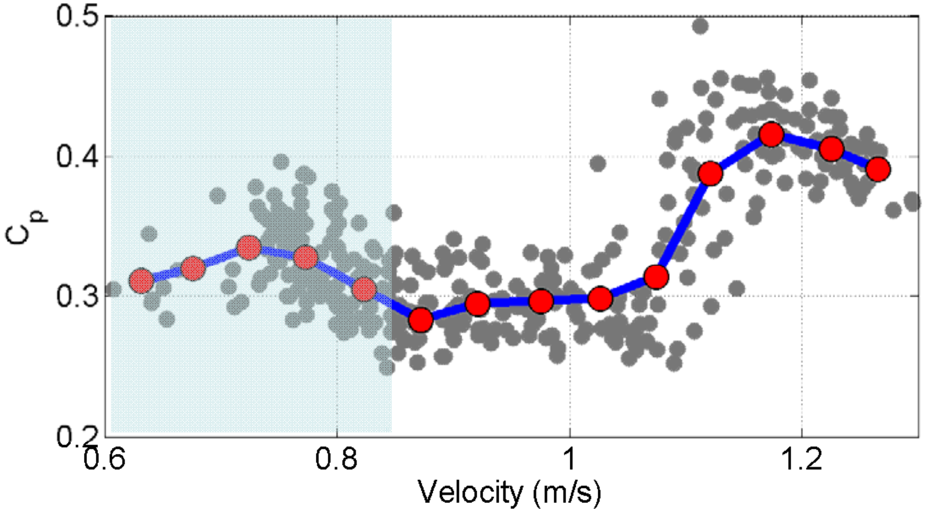


Power recording unit

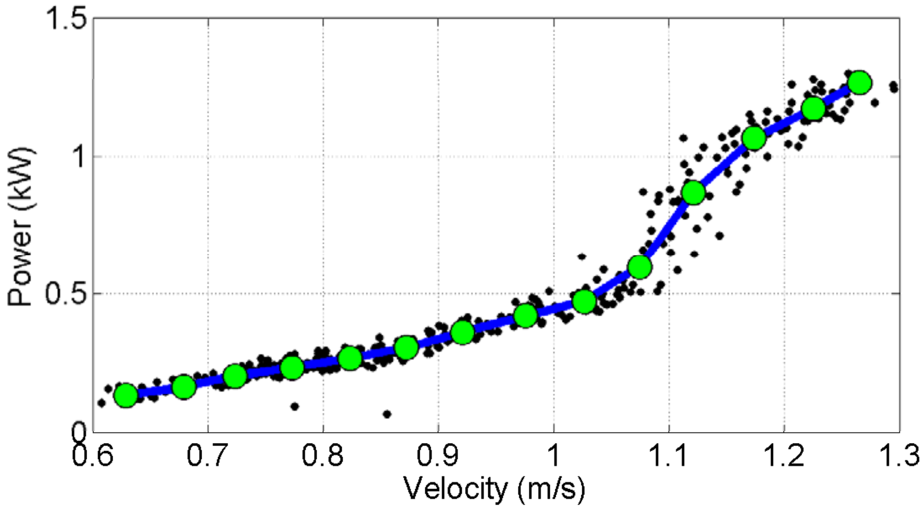
***P* after spike removal (<5%)**



Power coefficient



Power curve

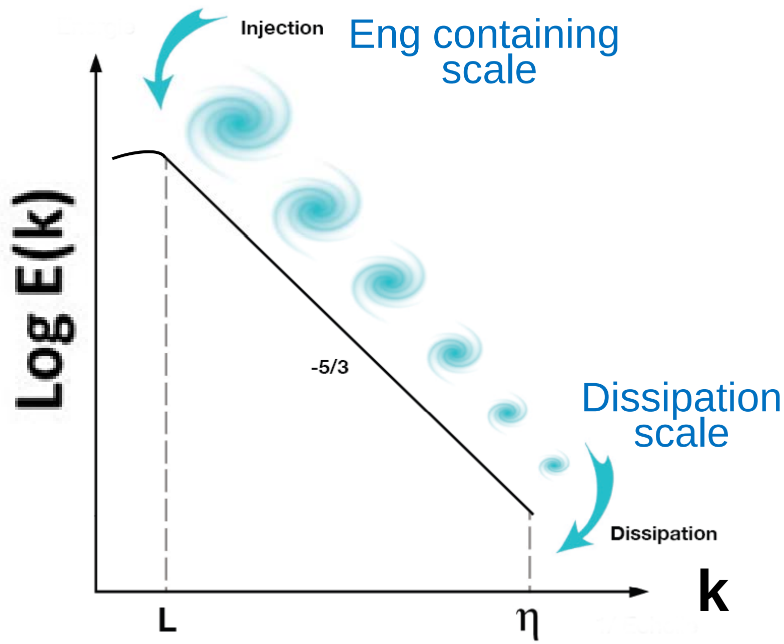


Cp	0.32	**0.30**	**0.39 - 0.42**
Vel. range (m/s)	0.6 – 0.8	0.8 - 1.1	1.1 – 1.3

Intermittency in a tidal river turbulent flow

We seek to verify the hypothesis of Kolmog-Obukhov's cascade and to estimate some major parameters of the turbulence

$$E(f) = C_0 f^{-\frac{5}{3}}$$



Methodology

Obukhov'41 law: Energy in turbulent flow, cascade, dissipation

$$E(k) = C\,\varepsilon^{2/3}\,k^{-5/3}$$

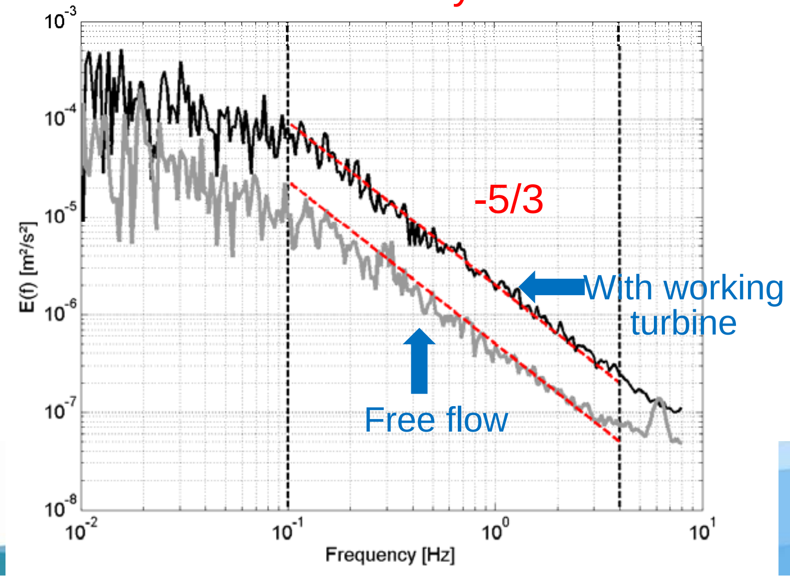
With $k = 2\pi f / U$, $C = 1.5$, U the mean velocity of the flow, and C_0 derived from the best fit of $E(f) = C_0\, f^{-5/3}$, the dissipation rate can be estimated:

$$\varepsilon = (C_0/C)^{3/2}(2\pi/U)^{5/2}$$

Energy containing scale (integral scale) $L = \sigma_u^{3}/\varepsilon$,

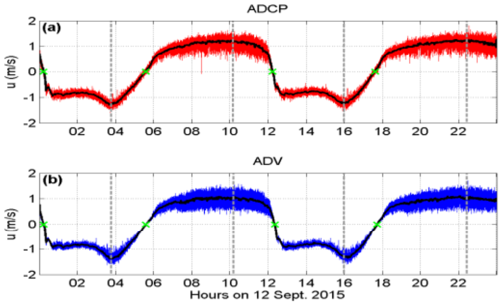
Kolmogorov scale (dissipation scale) $\eta = (\nu^3/\varepsilon)^{1/4}$

PSD of flow velocity from ADV



Scaling properties and turbulence intensity

Velocity monitoring by ADCP (1Hz) & ADV (16/32 Hz)

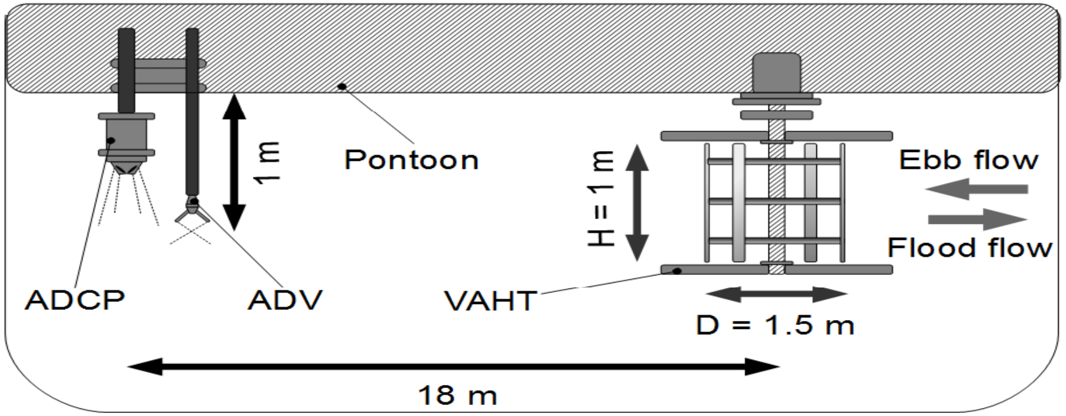


Intensity I_u

	w/o turbine		with turbine	
Td stage	flood	ebb	flood	ebb
ADV	4.5	5.5	5.0	16.0
ADCP	6.0	7.0	6.5	12.0

- Larger is the sampling interval – higher is the intensity (effect of vel evolution)
- ADCP provides good estimates for low I_u
- ADCP underestimates I_u for higher level
- I_u level is very high at 12D !

Experimental settings



Scaling properties of the flow

	ε (m^2s^{-3})	L (m)	η (mm)
w/o turbine	2.10^{-4}	1.7	0.3
with turbine	5.10^{-3}	0.8	0.2

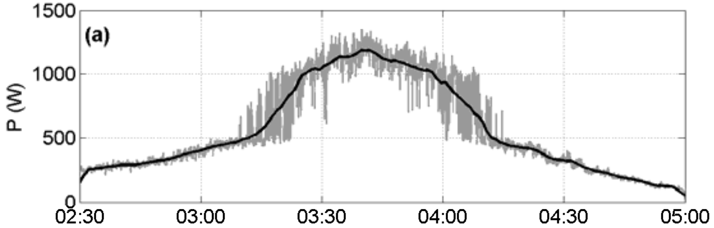
- The working turbine increases dissipation (x 25)
- It breaks turbulent eddies

The turbine considerably affects turbulence in the downstream flow at far ranges (> 12D)

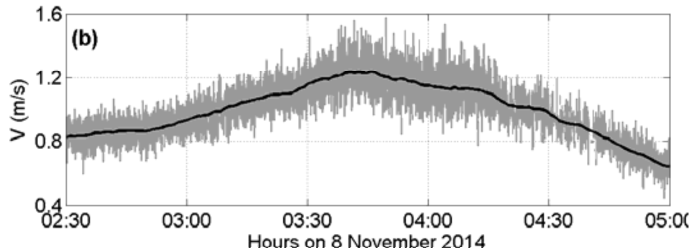
Turbulence and power

Does the ambient (upstream) turbulence affect the turbine?

Output power



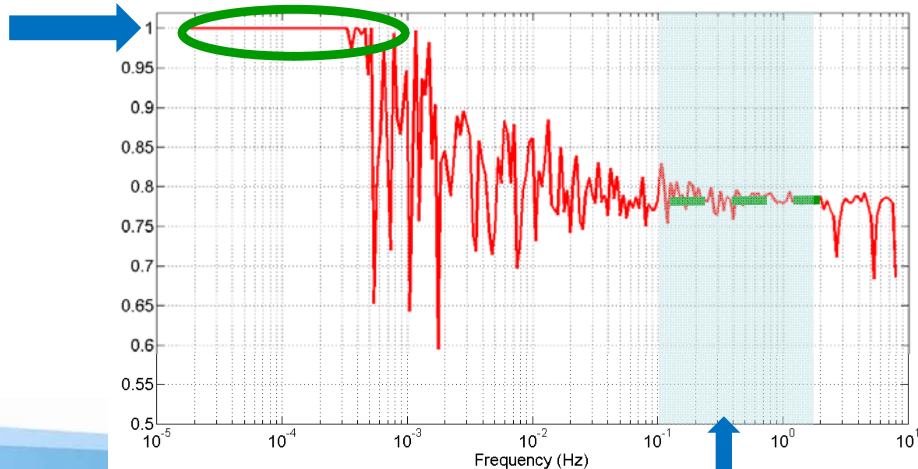
Current velocity



Coherency spectrum

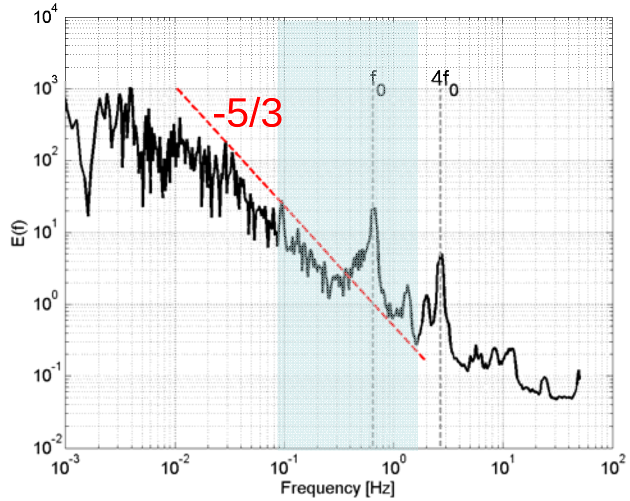
$$H_{xy}(f) = \frac{E_{xy}(f)}{\sqrt{E_x(f)E_y(f)}}$$

***H* = 1 in low-freq band: High coherency**

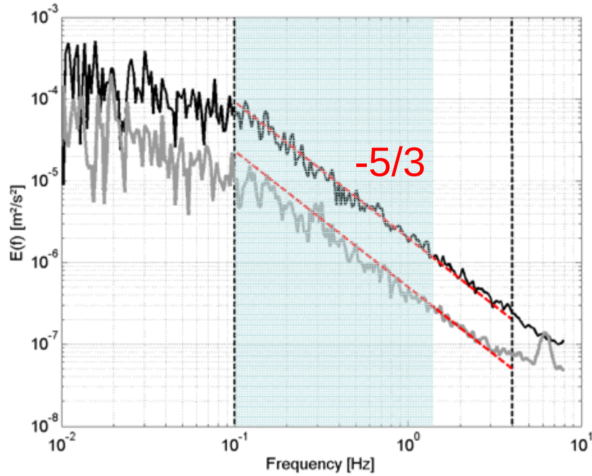


Coherency is stable and high … in the inertial sub-range

PSD of output Power



Spectra for current velocity



Conclusion

Field studies are necessary for assessing the flow potential and finding the best location for energy conversion devices

Measurements provided reliable estimates of the mean flow and turbulence properties in real conditions – of primary importance for turbine test.
Turb estimates are sensitive to averaging interval. How to define it?

The W2E tidal turbine performance is evaluated with high degree of confidence (Cp ~0.40)

Scaling properties allow to characterize turbulence in a tidal flow. They show a considerable effect of turbine on the background turbulence level

High turbulence intensity (15%) is found at a large distance (12D) downstream the turbine. *How far it remains high*?

In the inertial sub-range, the output power fluctuations are found tightly related with turbulent pulsations of the current velocity.
How to reduce this effect? New design? Concept?

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Thank for your attention

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