A Revisited Motion and Tilt Correction for Direct Air-Sea Flux Measurements

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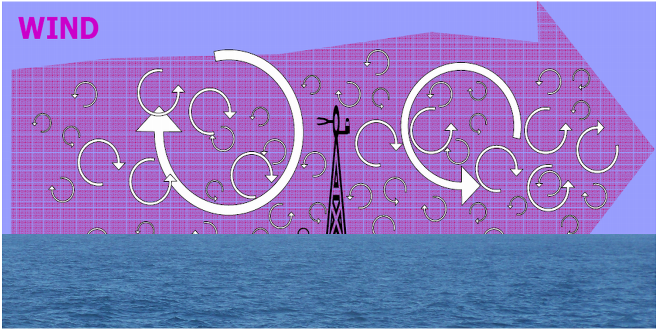
AirSea Lab

NUI Galway
OÉ Gaillimh

Eddy covariance principle



- The vertical flux of a quantity (x) can be measured directly as the covariance of the vertical wind speed (w) and x:

$$F_x = \langle wx \rangle$$

- The x can be anything, e.g.:
  - Horizontal wind speed (u) $\rightarrow$ momentum flux
  - Trace gases: CO_2, DMS, ...
  - Temperature, humidity, ...

Eddy covariance platforms

Buoys (un-manned) moored or drifting (photo WHOI).

Ships, e.g., R/V-*Saramiento de Gamboa* (photo Brian Ward).

+ Ships are the more convenient place to work at
+ Most trace gas flux measurements require a lot of power (pump) and maintenance (no off the shelf equipment)
– Distortion of the mean wind speed (can be corrected for)
– Distortion of the turbulent fluxes $\approx 15\%$ (no correction available)

Platform motion correction

From the measured 3D wind speed ($\mathbf{u}_{\mathrm{me}}$) to the true wind speed in natural coordinate system $\mathbf{u} = (u, v, w)$.

1. Correct for platform motion $\mathbf{v}_{\mathrm{ship}}$, calculated from 3D accelerations & rates, speed, course, and heading (e.g. Edson et al. 1998; Miller et al. 2010.)

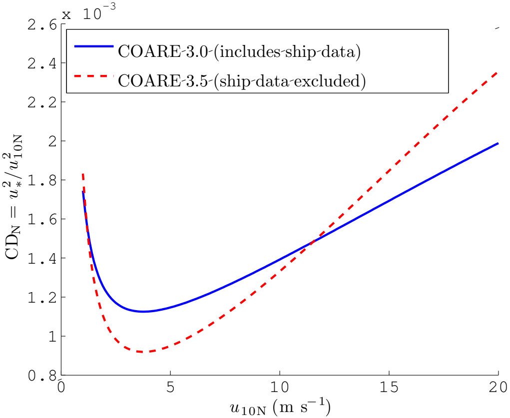
$$\mathbf{u}_{\mathrm{true}} = \mathbf{u}_{\mathrm{me}} + \mathbf{v}_{\mathrm{ship}}$$

2. Find the natural coordinate system using the double rotation method (DR), first yaw by ψ to get $\langle v \rangle = 0$, then pitch by θ to get $\langle w \rangle = 0$ (e.g. Anctil et al. 1994; Edson et al. 1998)

$$\mathbf{u} = \mathrm{DR}(\mathbf{u}_{\mathrm{true}})$$

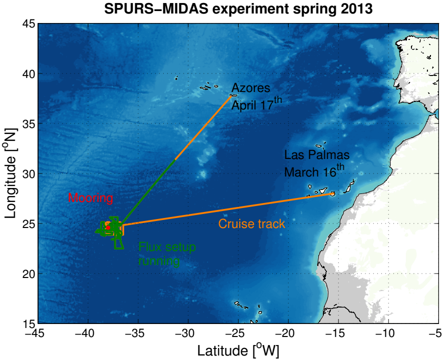
Air-sea momentum flux measured with eddy covariance

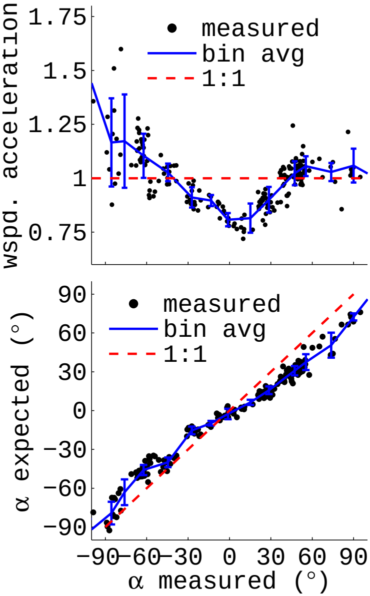
- Wind stress
  $\tau = \rho_{\mathrm{air}}(\mathbf{i}\langle wu\rangle + \mathbf{j}\langle wv\rangle)$
- Friction velocity
  $u_* = (\langle wu\rangle^2 + \langle wv\rangle^2)^{1/4}$
- Neutral drag coefficient
  $C_{\mathrm{DN}} = \frac{u_*^2}{u_{10\mathrm{N}}^2}$
- Ship borne EC fluxes typically higher than fluxes from moored platforms (Edson et al. 1998). Is this due to flow distortion?



Drag coefficient as function of the wind speed (normalized to 10 m height and neutral atmospheric conditions), based on Edson et al., 2013.

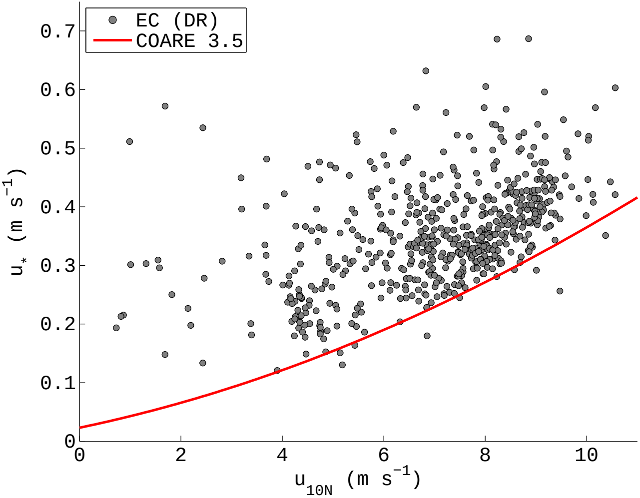
The SPURS MIDAS experiment





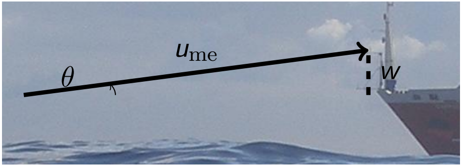
- "Calibration" of wind speed and wind direction (α) measured on board the R/V-*Saramiento de Gamboa* with the wind speed measured on the mooring.

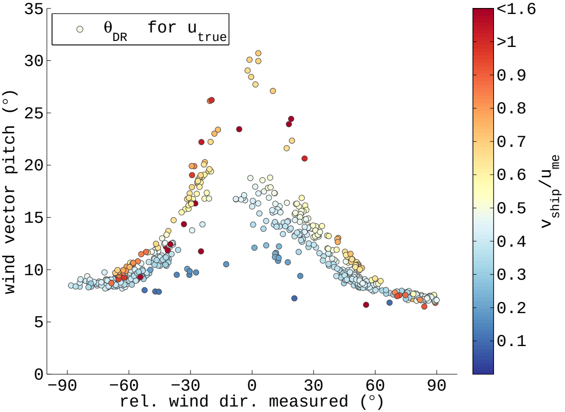
Initial u_* values from eddy covariance



- Friction velocity measurements and flow distortion corrected wind speeds don't match very well.
- Does flow distortion affect the u_* values?

A closer look at the tilt correction





- The wind vector is pitched when it passes the ship

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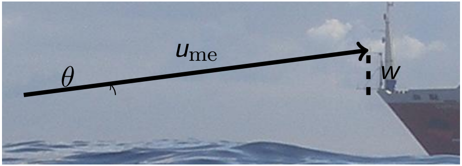

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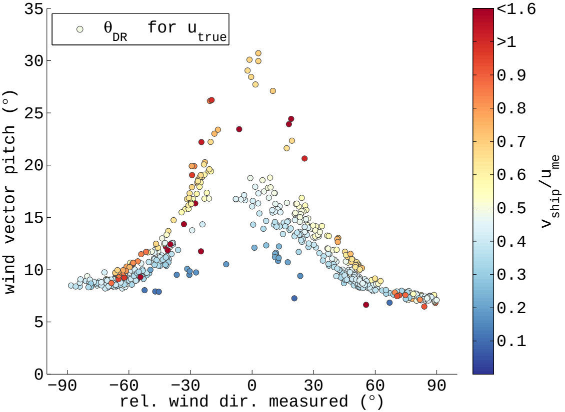

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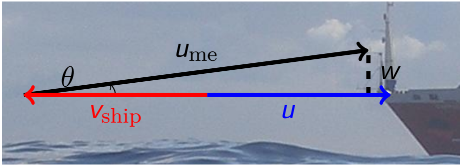

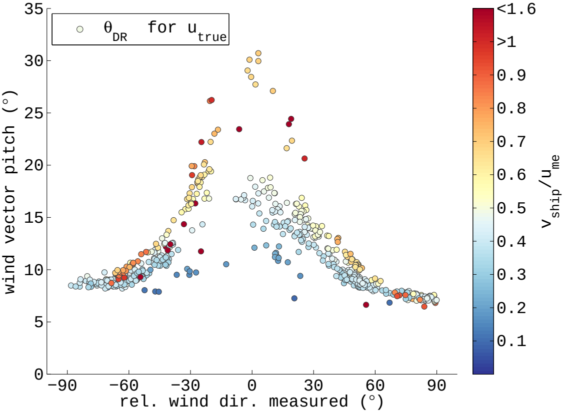

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  Pedreros 2003: $\frac{v_{\mathrm{ship}}}{u_{\mathrm{me}}} < 0.2$

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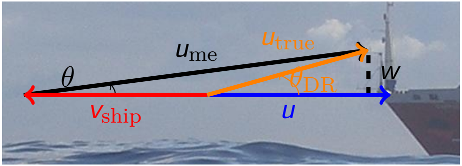

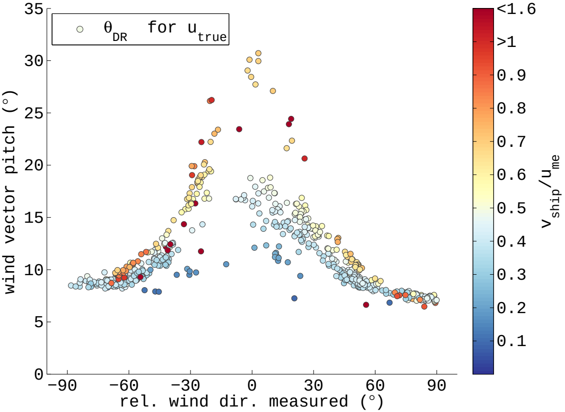

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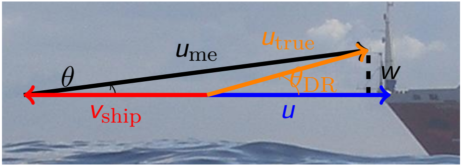

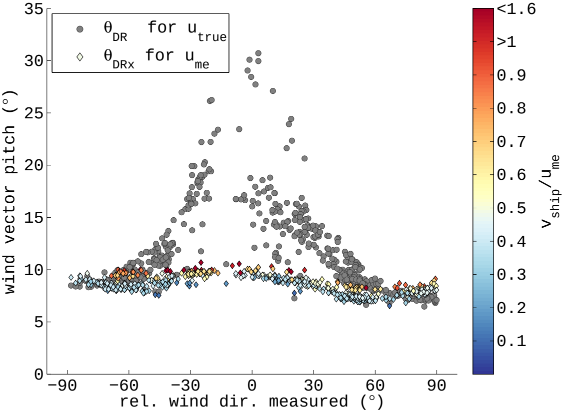

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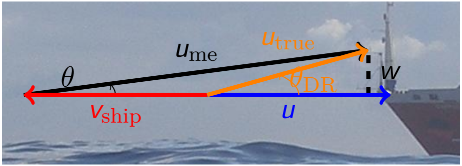

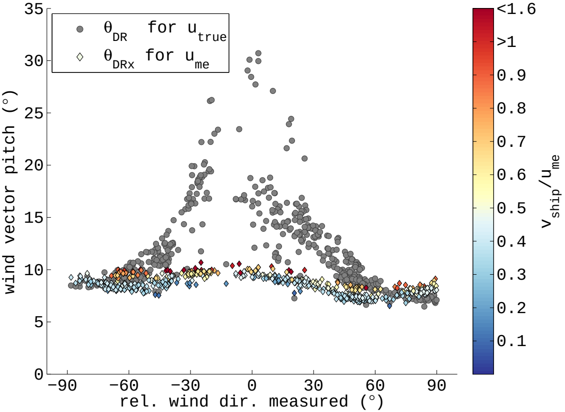

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- Double rotation of $\mathbf{u}_{\rm true}$ overestimates the pitch when $\langle v_{\rm ship} \rangle > 0$
- Better to use (DRx)
  $\mathbf{u} = \mathbf{DR}(\mathbf{u}_{\rm me} + \mathbf{v}'_{\rm ship})$
  $(\mathbf{v}'_{\rm ship} = \mathbf{v}_{\rm ship} - \langle \mathbf{v}_{\rm ship} \rangle)$

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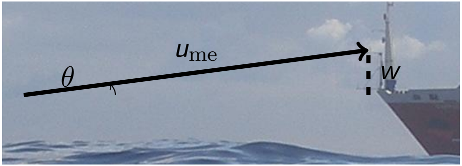

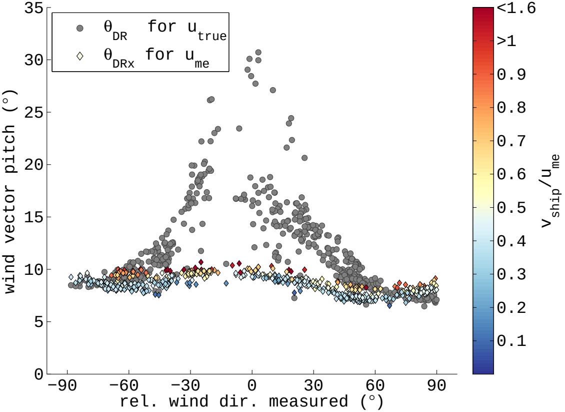

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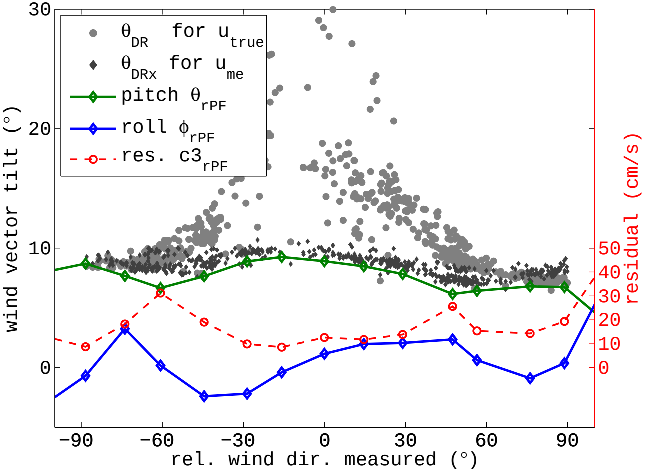
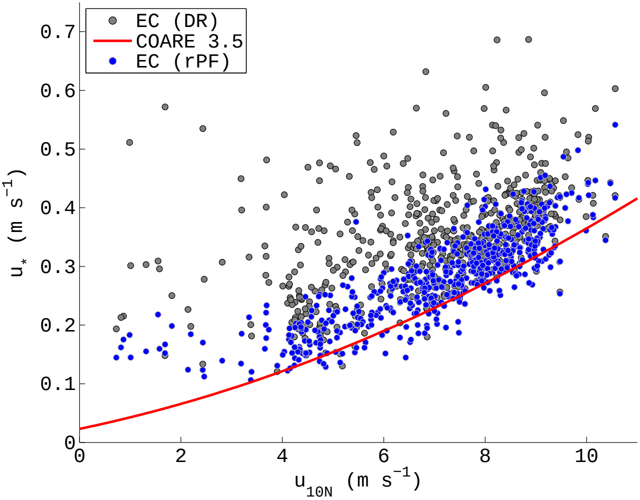
- Better to use (DRx)
  $\mathbf{u} = \mathbf{DR}(\mathbf{u}_{\mathrm{me}} + \mathbf{v}'_{\mathrm{ship}})$
  $(\mathbf{v}'_{\mathrm{ship}} = \mathbf{v}_{\mathrm{ship}} - \langle \mathbf{v}_{\mathrm{ship}} \rangle)$
- Individual θ_{DRx} still have high uncertainties

The radial planar fit method (rPF).



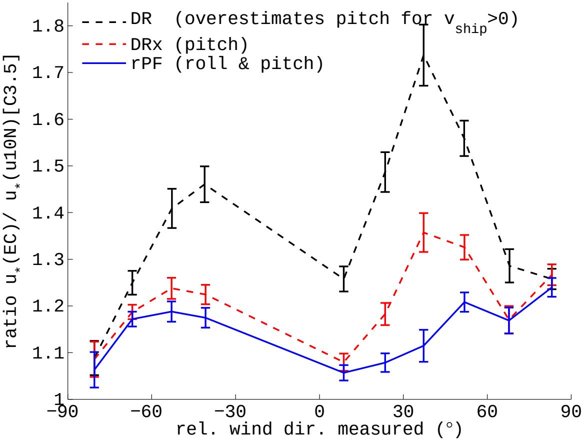
- Radial Planar fit over wind direction sectors (whole data set): $\langle w_{\mathrm{me}} \rangle = c_3 + \mathrm{atan}(\theta) \cdot \langle u_{\mathrm{mr}} \rangle - \mathrm{atan}(\phi) \cdot \langle v_{\mathrm{mr}} \rangle$
- First correct for $\mathbf{v}'_{\mathrm{ship}}$ then for pitch, roll (and yaw) then correct for $\langle \mathbf{v}_{\mathrm{ship}} \rangle$ (The rPF method)

Friction velocity and wind speed



- Using the rPF tilts significantly improves the correlation of u_* and $u_{10\mathrm{N}}$ when compared to classic DR method.

The three tilt-motion corrections and the flow distortion



- The rPF method significantly reduces the flow distortion effects when compared to the DR and DRx methods.
- The residual flow distortion increases with the relative wind direction. Potentially the effect of the large tower at the bow.

Conclusions

- Ships and buoys have different (dis)advantages for direct eddy covariance flux measurements
- The large structure of a ship leads to distortion of the air flow
- The classic motion-tilt correction over-estimates the tilt of the wind vector for ships under-way and leads to biased EC fluxes
- The radial planar fit method accounts for the flow distortion tilts (pitch and roll) and can significantly improve the quality of ship borne EC flux measurements

Landwehr, S., O'Sullivan, N. and Ward, B., 2014, Direct Flux Measurements from Mobile Platforms at Sea: Motion and Air Flow Distortion Corrections Revisited. *Journal of Atmospheric and Oceanic Technology*. (Revised).


Questions?