RPA-borne Measurements of Convective and Stable Boundary-Layers over the Near-Coastal North Sea during Strong Winds

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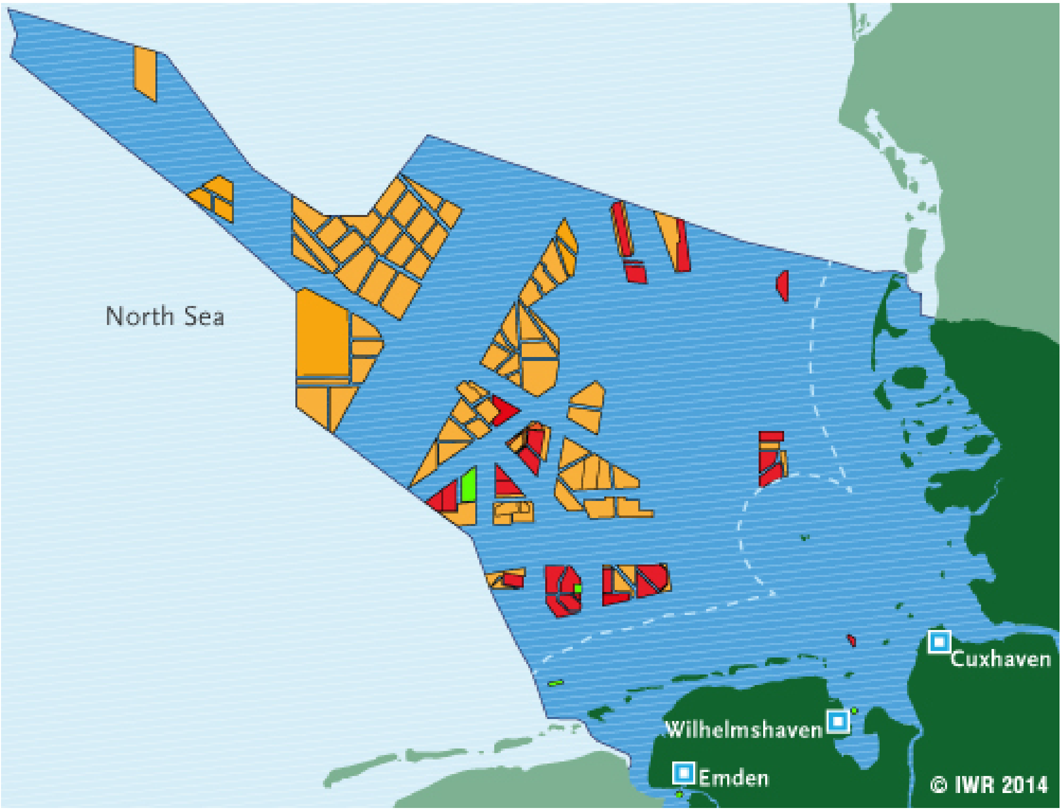
The OWEA LOADS project - motivation



Green: operating. Red: under construction. Orange: planned

- North Sea wind energy: operating 865 MW; under construction 2'400 MW; planned up to 40'000 MW
- Main objective: assess the structural loads borne by current and future offshore wind turbines, new generation up to 300 m ASL
- Role of Tubingen: obtain in-situ turbulent-scale measurements up to 500 m ASL
- Method: use of our Multiprobe Airborne Sensor Carrier (MASC). Cheap and easy to deploy.
- Status: three of five campaigns complete; two more before Christmas so feedback and discussion today is appreciated!

MASC: Multi-purpose Airborne Sensor Carrier

Operated by the **University of Tübingen**

(I told the designer, that I don't mind what colour, as long as it's well visible!)

wingspan:	2.7...3.5 m
total weight:	$<$ 6 kg
incl. sci. payload:	1.5 kg
cruising speed:	25 m/s
endurance:	$\approx$ 1 hour
electrical engine	
autopilot:	U Stuttgart

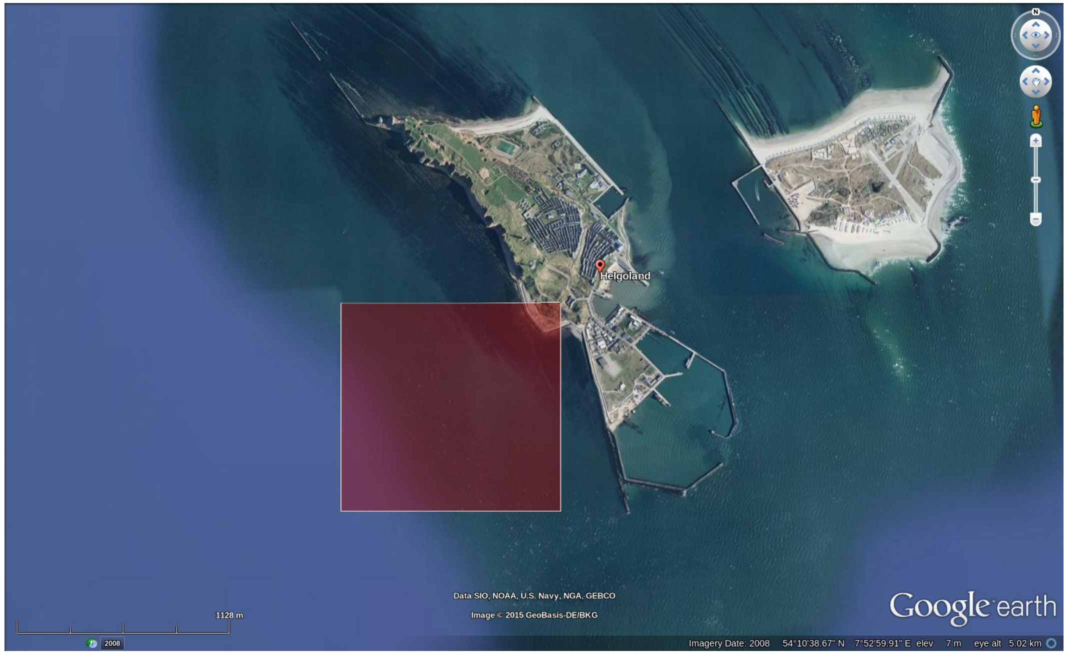
Measurements:

- 3D wind vector (30 Hz; 1 m)
- air temperature (30 Hz; 1 m)
- water vapour (not used here)

North Sea Region

Legal Requirement for line-of-sight

Helgoland



Permitted airspace highlighted, to the southwest of Helgoland

- Permitted airspace is 1 km square x 500 m ASL
- Probable flow distortion from 50 m cliffs, from 0-45 degrees
- Short fetch (50-150 km) flow from 90-225 degrees; thermal boundary layers from cold/warm air advection
- Long fetch (at least 500 km) 'open ocean' neutral conditions from 225-360 degrees: air and sea temperature in equilibrium
- So far... 40 flights conducted during Oct. 2014 and Feb. 2015. Several case studies of stable and convective boundary layers. Very recent Oct. 2015 data not ready for presentation

Typical flight strategy

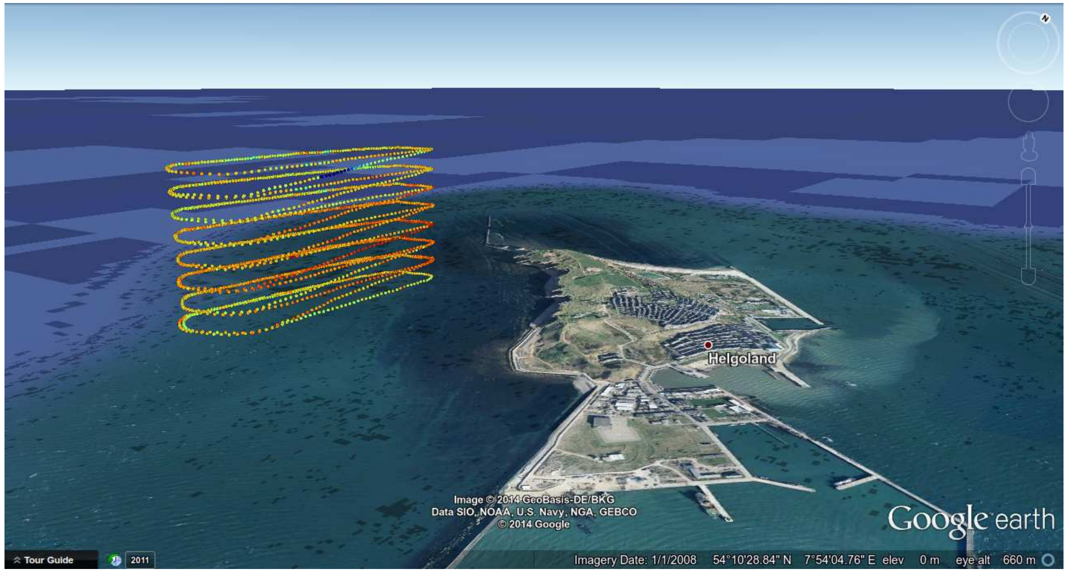
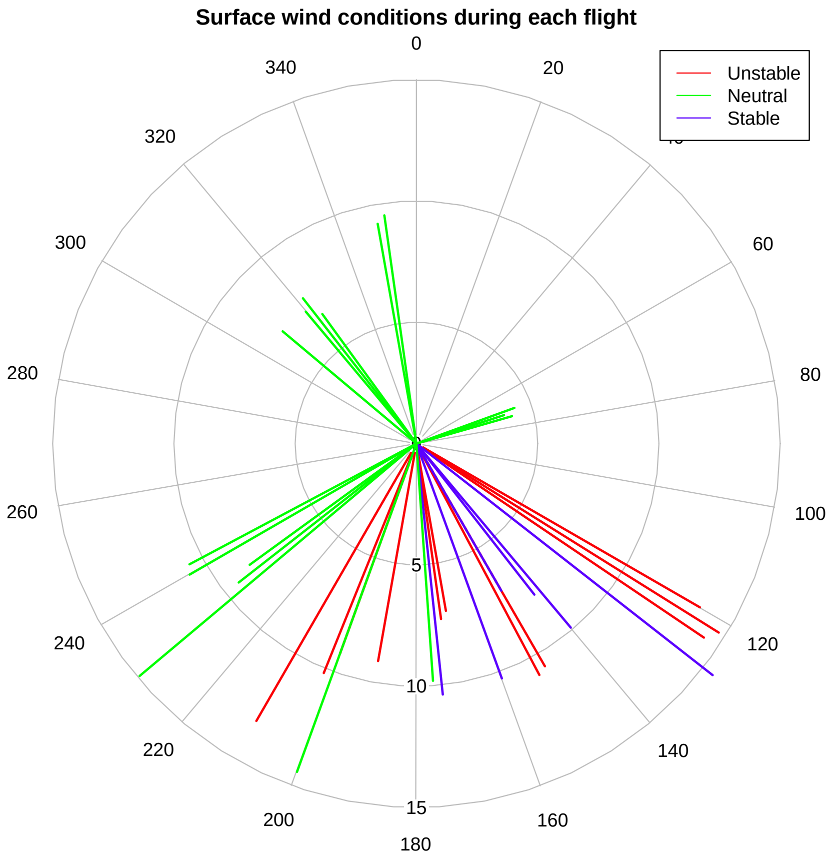


Image credit: Norman Wildmann

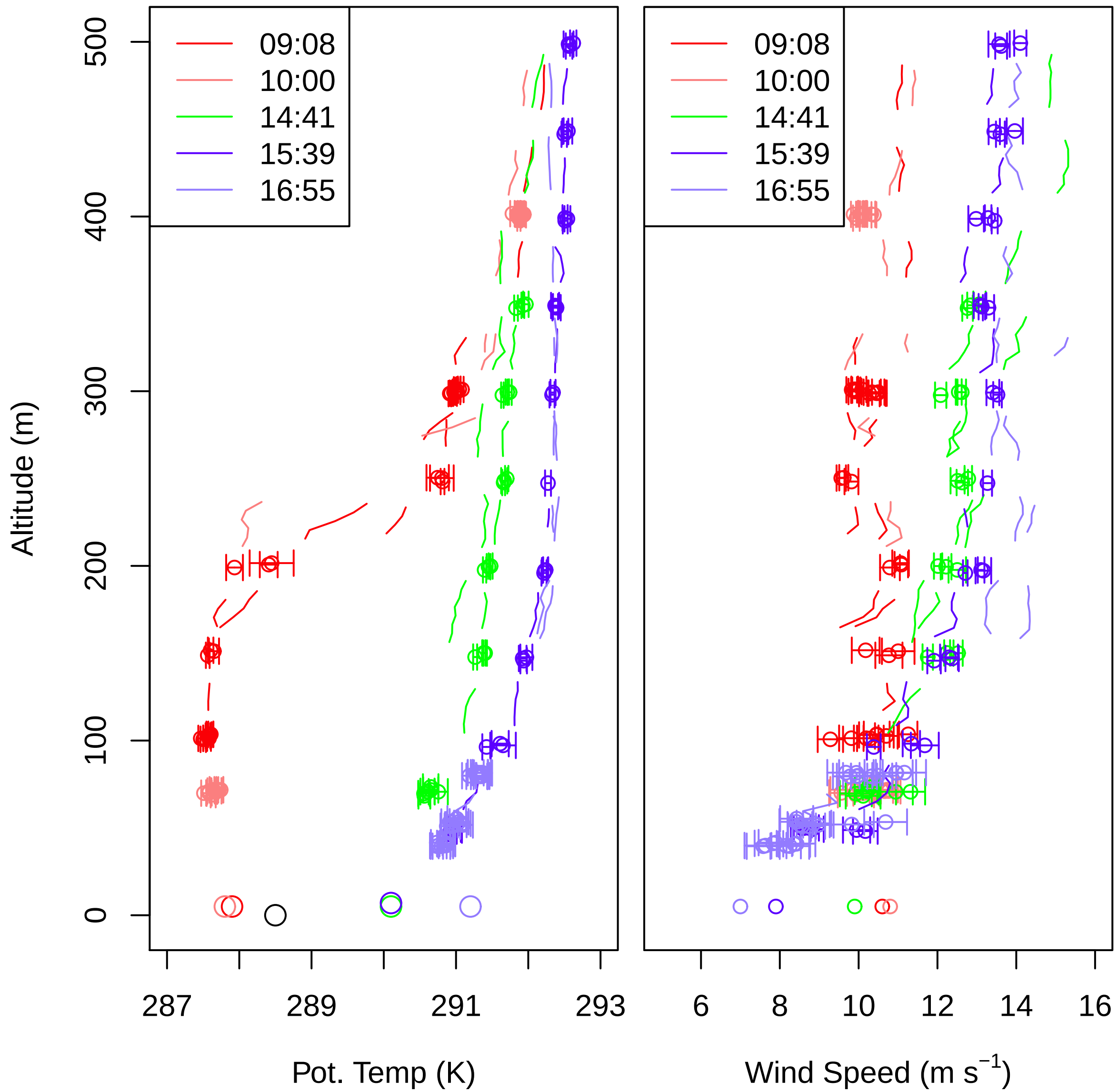
- Generally followed a 'racetrack' pattern, as straight legs are required for the wind measurement system
- Typically 90 minutes flying time during two or three hours, allowed 'case studies' to be developed. Conditions were not assumed to be constant, so each case study is demonstrated

Overview of flights



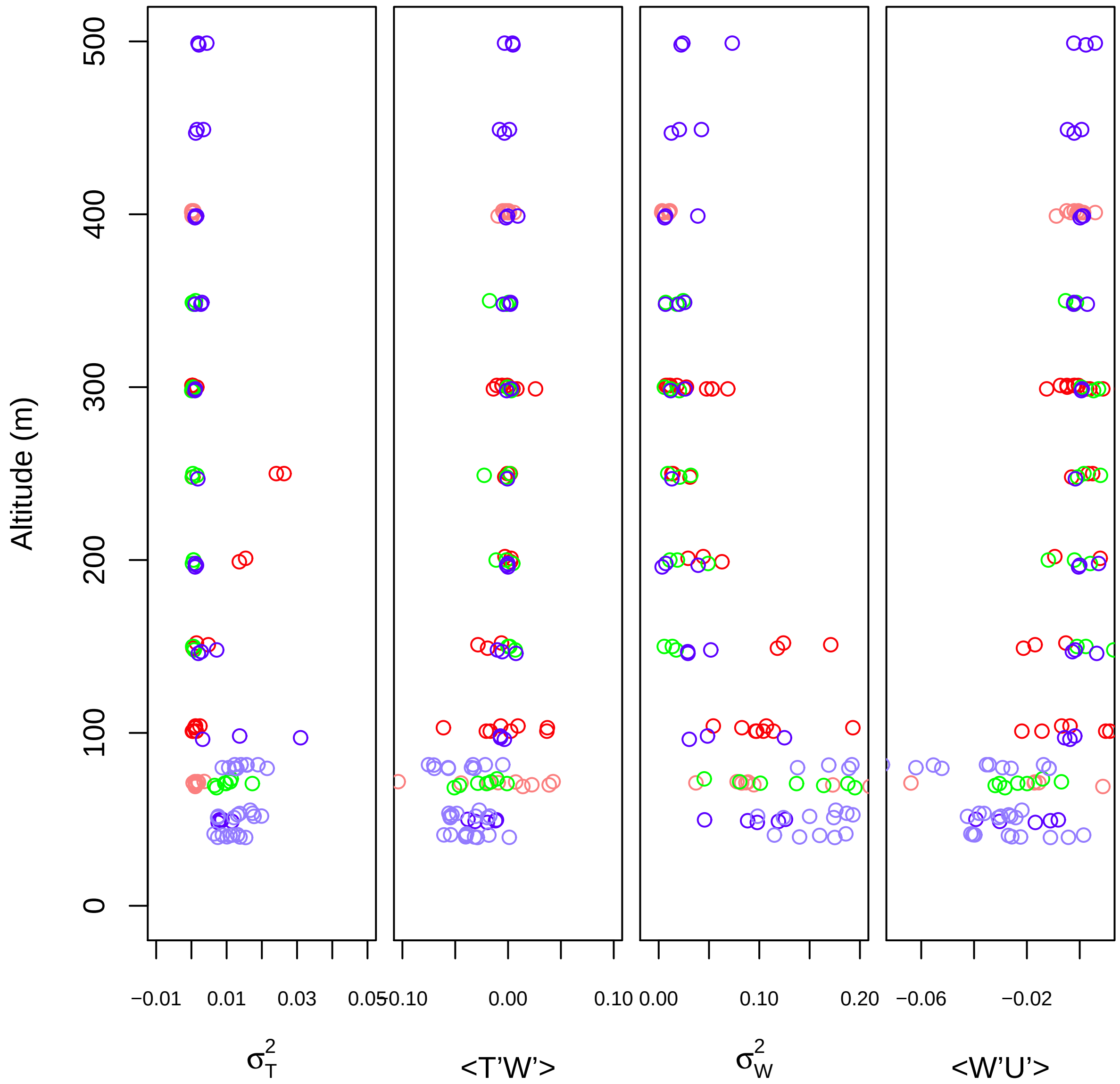
- Neutrally stable flow from the north and west. Stable and convective layers from the south, albeit some extremely weak
- Strong winds! Some near-surface wind speeds of 15 m s^{-1}, with a maximum recorded wind speed aloft of 23 m s^{-1}

4th Oct. 2014 - example of SBL and CBL



- During morning flights, stable cold nocturnal layer advected over warm sea, convective layer
- During afternoon flights, convective warm daytime layer advected over cool sea, stable layer
- Very clear differences in wind shear and turbulence intensity; an important diurnal cycle for wind power engineering

4th Oct. 2014 - Turbulent statistics



- For sensible interpretation, such plots must be normalised by the IBL height, and the surface fluxes
- Ideally we want several case studies of CBLs and SBLs with different heights and strengths, and normalised plots would converge perfectly and furthermore match the textbooks!
- So is this possible with what we have so far? No. But let's try anyway.

Research Questions

- Question 1: Can we make robust predictions of the IBL heights, and air-sea momentum and heat fluxes, using the experiment boundary conditions (e.g.: 10 m wind speed; fetch; air-sea temperature difference)?

There is a long history of published work here (e.g., Garratt (1990) review article), but we need more case studies to test these relations

- Question 2: Do turbulent statistics within different IBL cases converge, if normalised with the IBL heights, and the surface fluxes?

We need more case studies, and 50 m is too high to estimate surface fluxes. Need complementary sonic anemometer measurements
Update: campaign last week, we flew at 20 m ASL and deployed a sonic anemometer on the coast, so could get some exciting results soon

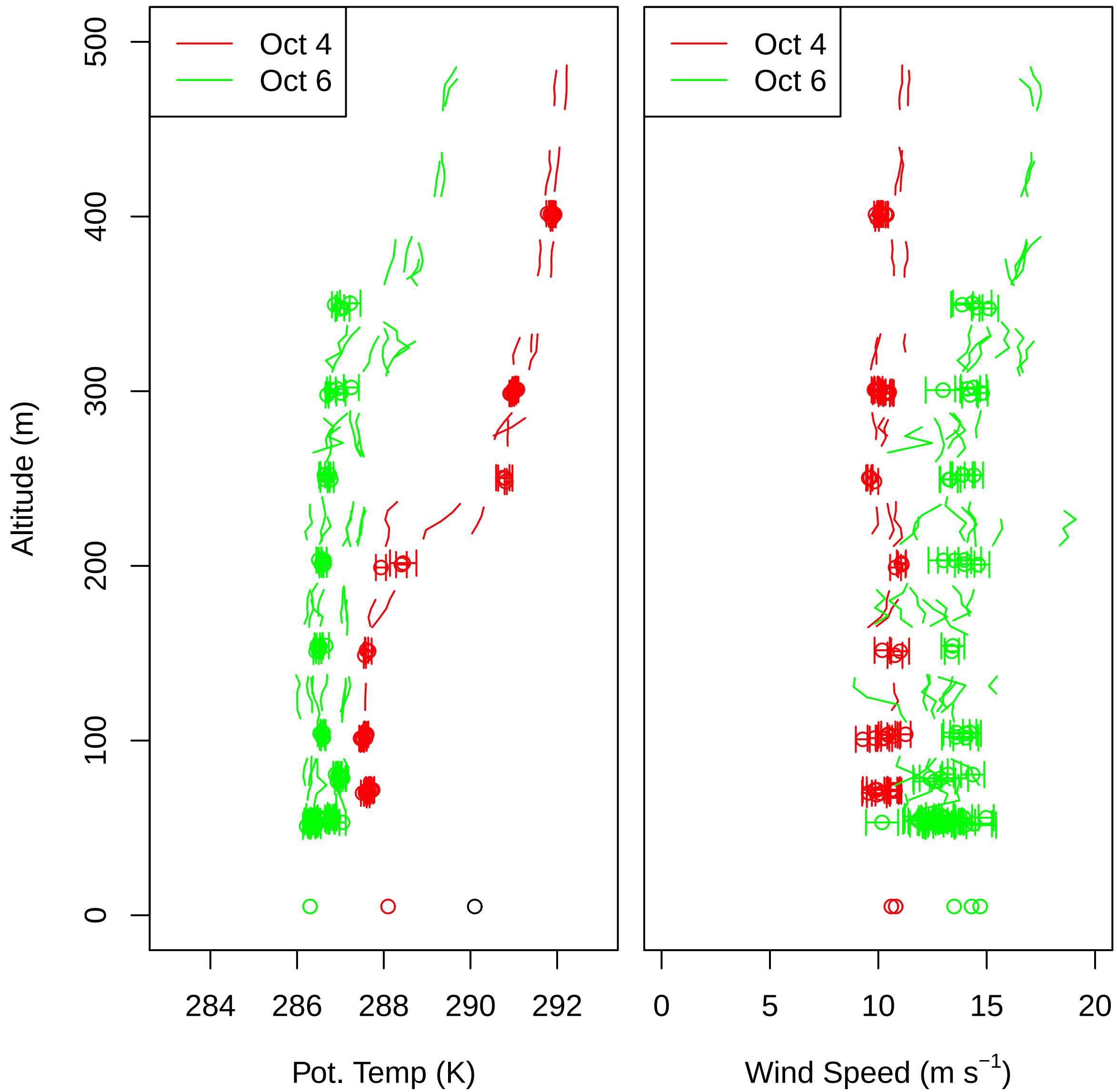
Preliminary results

- Presented are comparisons between two convective, two stable, and three neutral cases
- Problems 1 and 2: normalisation of turbulence plots requires IBL layer heights, and surface fluxes
- Problem 1 solved: We have direct high resolution measurements of the height of IBL layers
- Problem 2 we cannot solve: Direct flux measurements at 50 m ASL within a 100-300 m BL is well above the surface 'constant flux' layer

Surface flux estimates were therefore made using air-sea bulk transfer parameters (e.g.: Smith, 1980; Edson et al., 2013; Large and Pond, 1982)

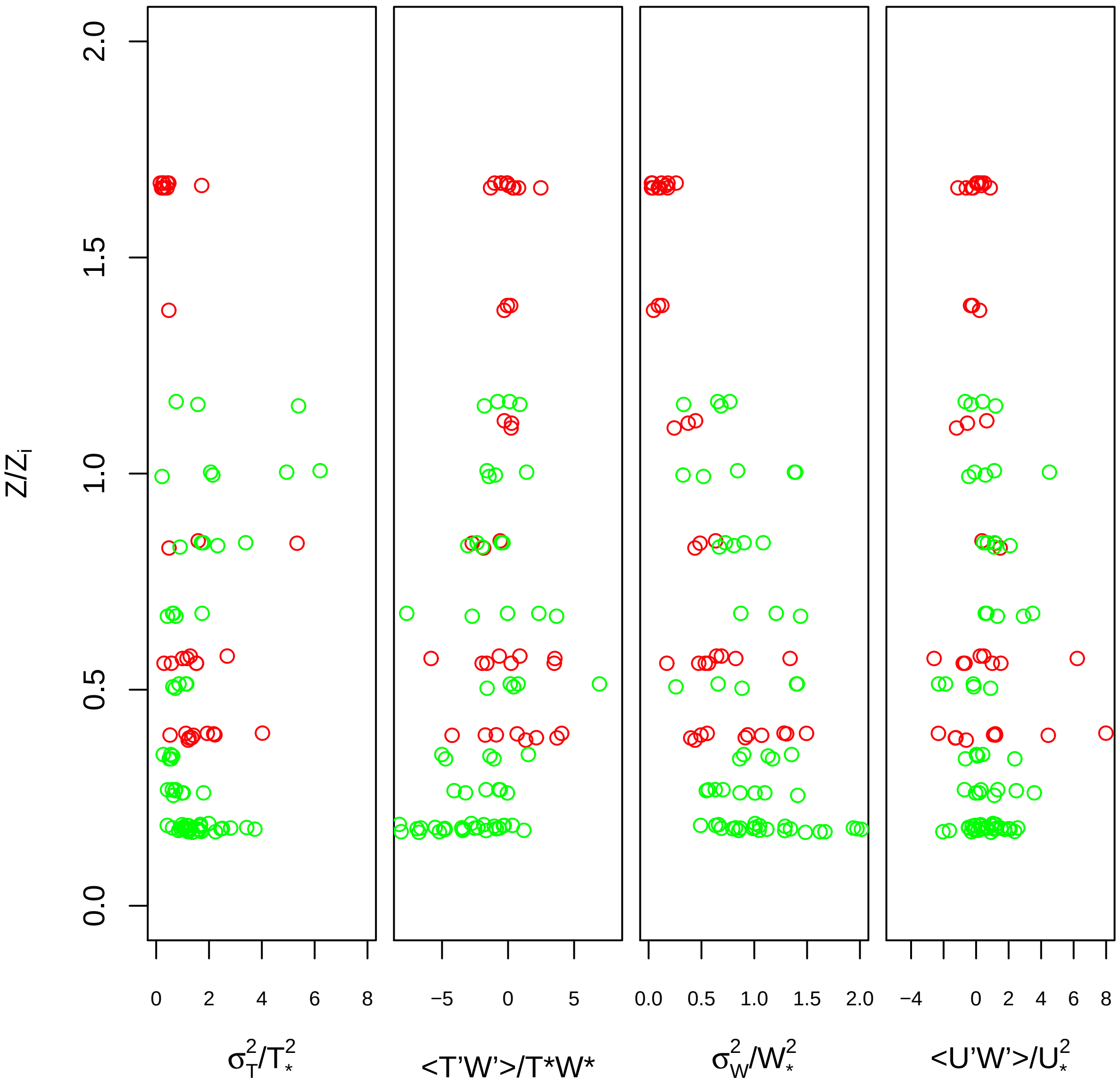
- Large errors (up to 100 percent?) expected: poor quality input bulk values, choice of parameterisation, coefficients not valid for IBLs... This is basically a rough guess, to allow some plots to be presented today, and not intended for publication

Two CBL comparison



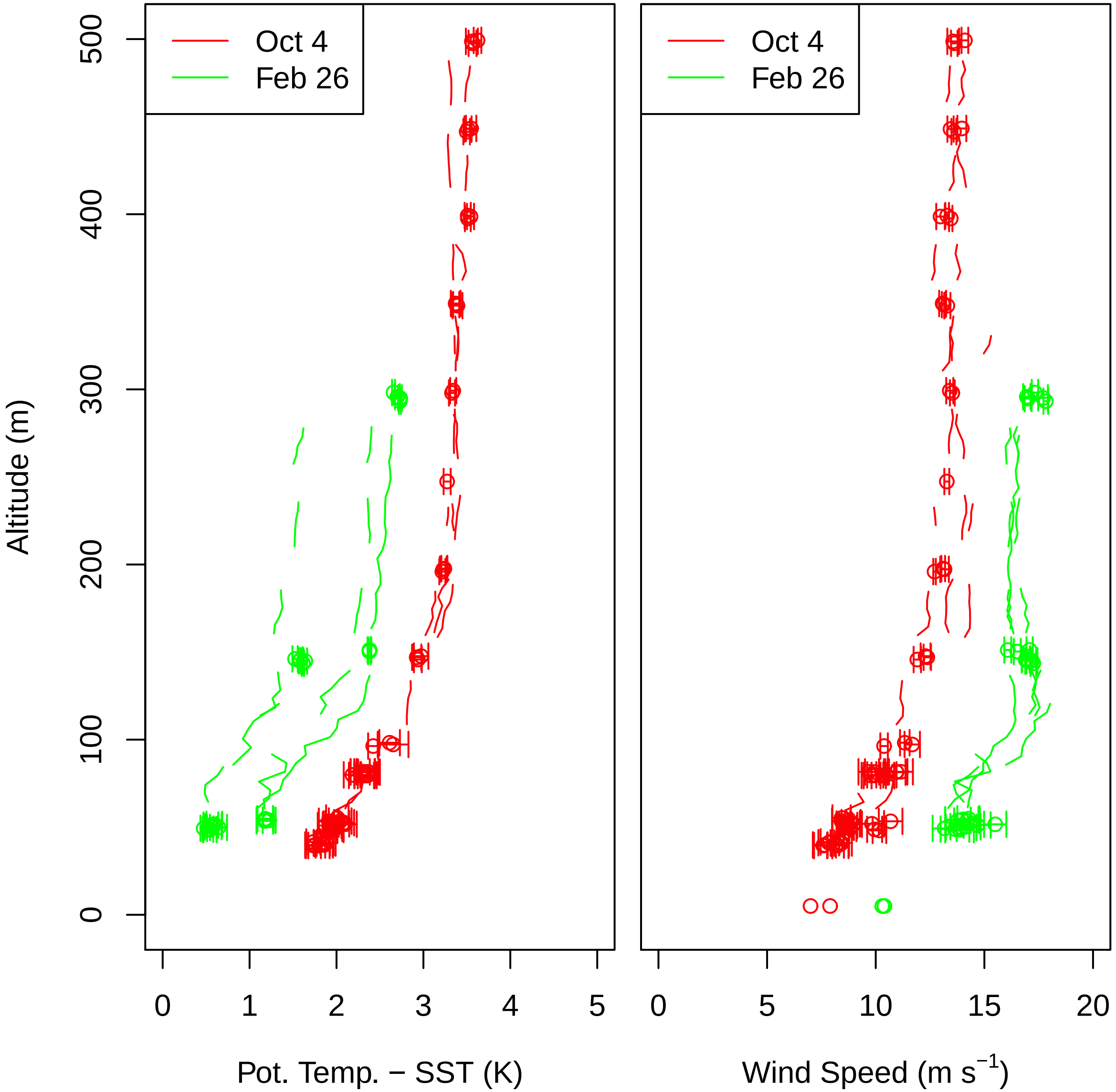
- Two CBLs at different stages of development, with clearly different forcing conditions
- Neither case had low cloud or other notable difference in forcings
- Recent flights (Oct. 2015; not presented) targeted the inversion, and included surface flux estimates

Two CBLs - Turbulent statistics



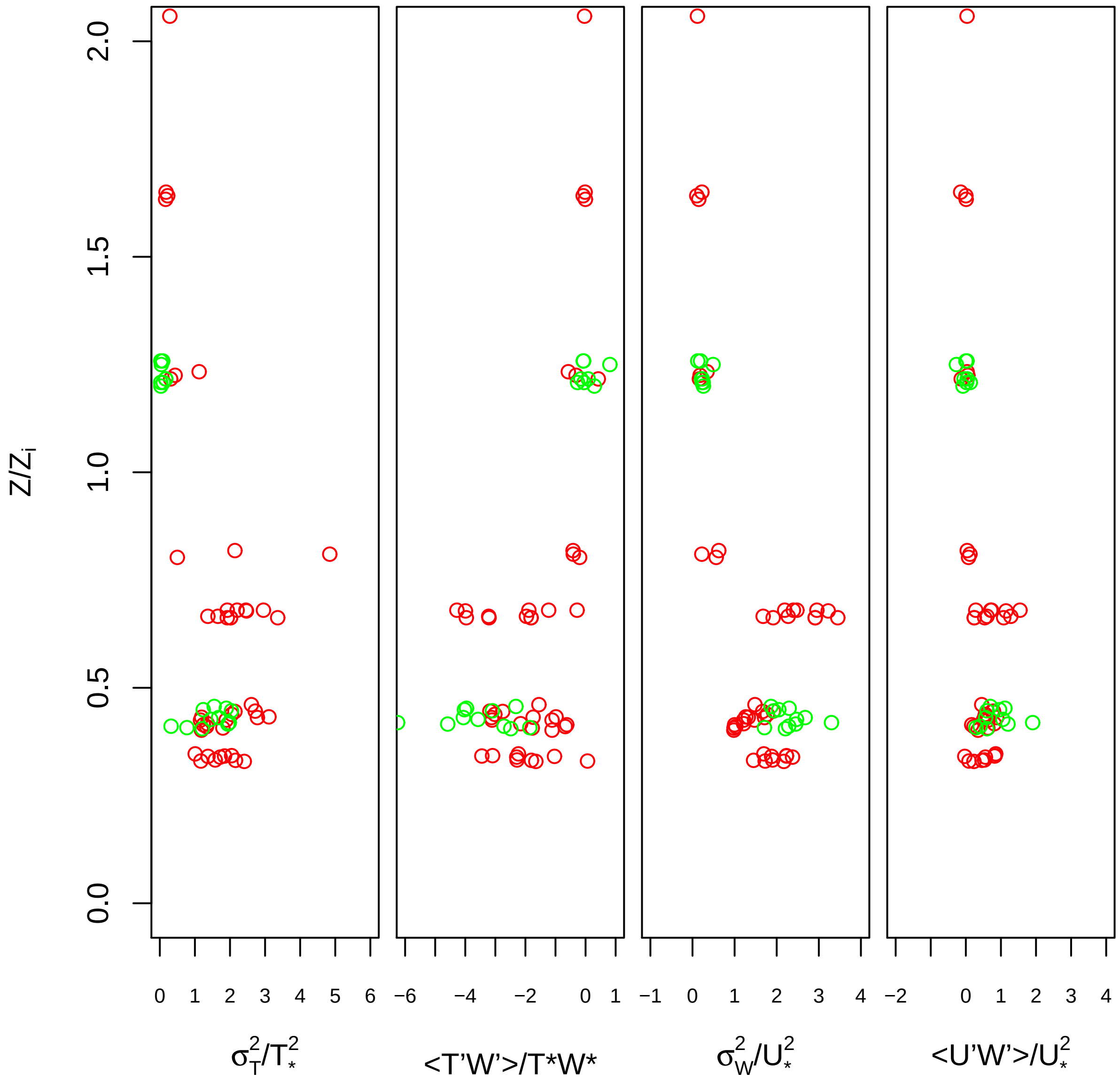
- T-variance: sensible form, potential for investigation
- T-flux: no conclusions
- W-variance: sensible form, potential for investigation
- momentum-flux: no conclusions

Two SBL comparison



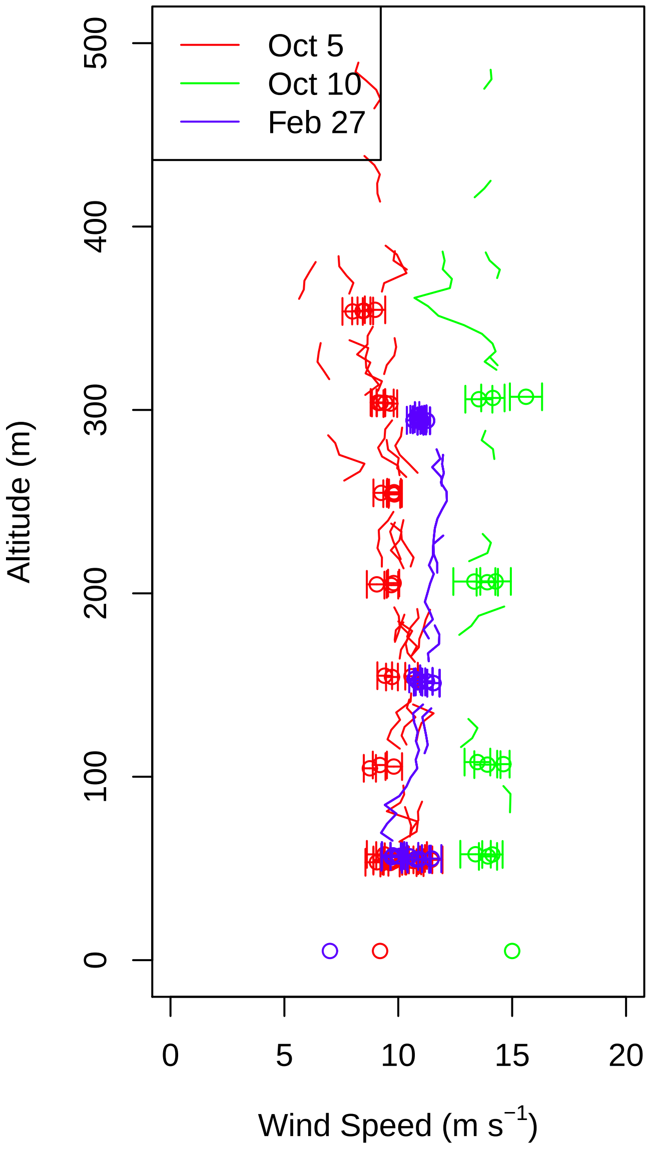
- Two SBLs, possibly different characteristics in mean profiles
- Sharp change in Feb. rather than more gradual in Oct.
- Feb. case merits closer study, low level wind maxima of 2 m/s, correlated to air temp. rise?

Two SBLs - Turbulent statistics



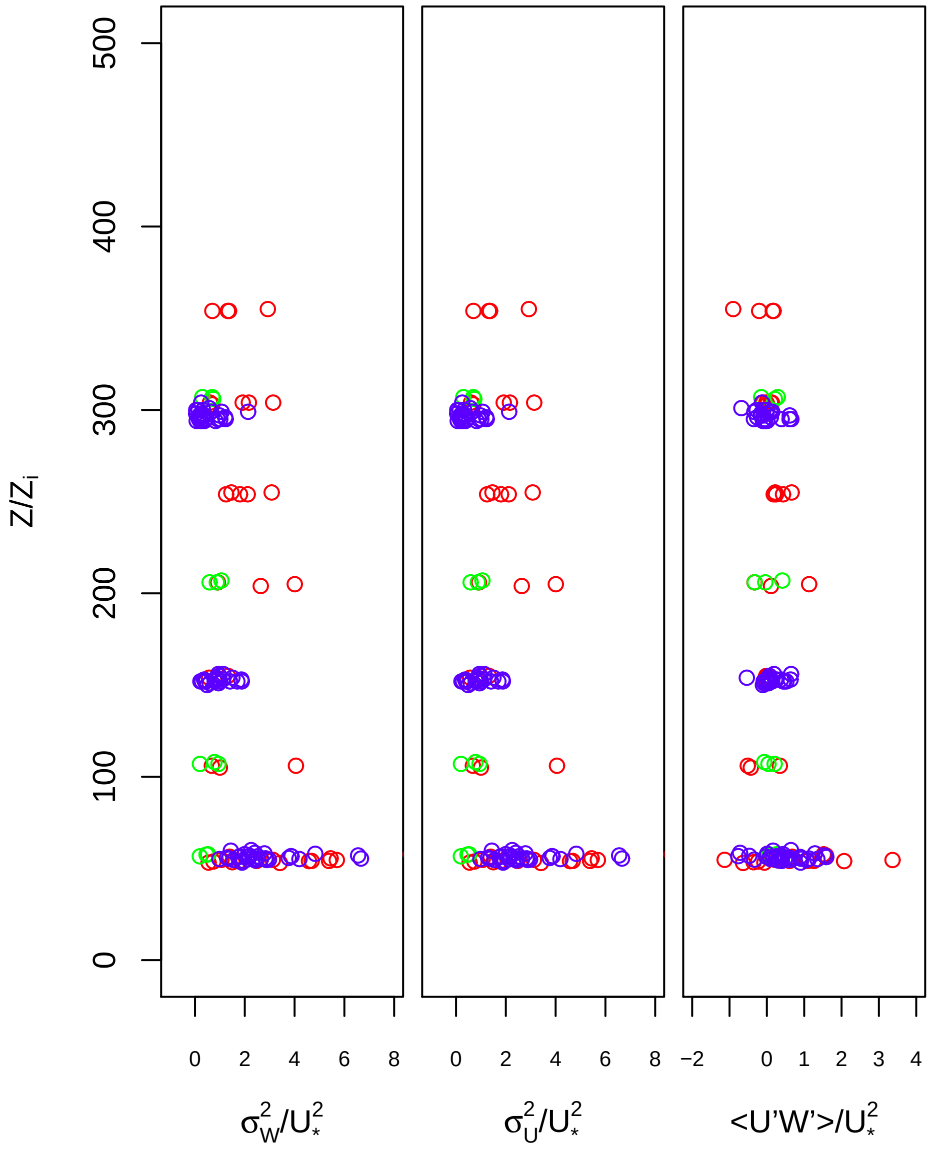
- Nothing groundbreaking, but at least we have order of magnitude agreement!
- Next campaigns, during SBLs, racetracks will be focussed on 20 m steps within the layer to obtain profiles with which to compare to other cases
- Unlikely to measure further SBLs this year, as the sea is relatively too warm with respect to the land-based boundary layer

Three NBL comparison



- No method to assess BL height, so no height normalisation
- Flux nomalisation via. bulk methods as before
- No consideration of temperature profiles or statistics

NBL - Turbulent statistics



- Oct. 5th (red), low cloud! Larger turbulent wind fluctuations
- Although no observed increase in momentum flux - wind shear is always small

Summary

- We have another 20 days flying this year from Helgoland - we are going for most of Novemeber
- After the analysis of the two campaigns so far, the research questions are clear
- The addition of near-surface flux measurements from a coastal sonic anemometer, and 20 m flight legs, are being analysed, a little too early for this conference