The eddy covariance method applied from a tethered-balloon

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CONTEXT

Turbulent processes of Atmospheric Boundary Layer contributes the most to transfers between the surface and the atmosphere. Typically turbulent boundary layer parameters are measured by sonic anemometer on masts and by research aircraft. To describe the evolution of the convective boundary layer between the surface and its top these two methods have several disadvantages, as for example, the elevation of the mast which is the greater part of the time less than 100 meters or the cost of deploying a research aircraft for a few hours of observation. This is to measure *in-situ* turbulent parameters in the Planetary Boundary Layer (PBL) at altitudes above 50 meters that our team have developed a system under tethered balloon since 2010. This system composed of a sonic anemometer and an inertial motion sensor has been validated during three campaigns, one dedicated and two of opportunity with different convective boundary layer conditions.

INSTRUMENTATION USED & DEVELOPMENT

The turbulence tethersonde :

The instrument package was built around a commercial sonic anemometer (Gill windmasterpro model) which provides measurements of three-dimensional wind and sonic-temperature at 10 Hz.

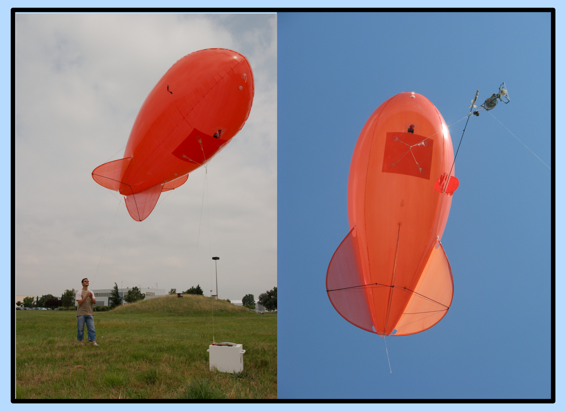
An off-the-shelf coupled inertial-GPS motion and attitude sensor (Mti-G from Xsens) was added in order to correct the anemometer movements.

A fast-response thin wire allows the measurement of air temperature fluctuation, and standard pressure and temperature sensors provide "slow" reference measurements.

Data was logged aboard on 2 SD cards by custom designed and built control electronics.

The total mass of the system is around 2 kg.

← The turbulence tethersonde: sonic anemometer + inertial motion sensor (zoom ↓) + electronic system(house-made)



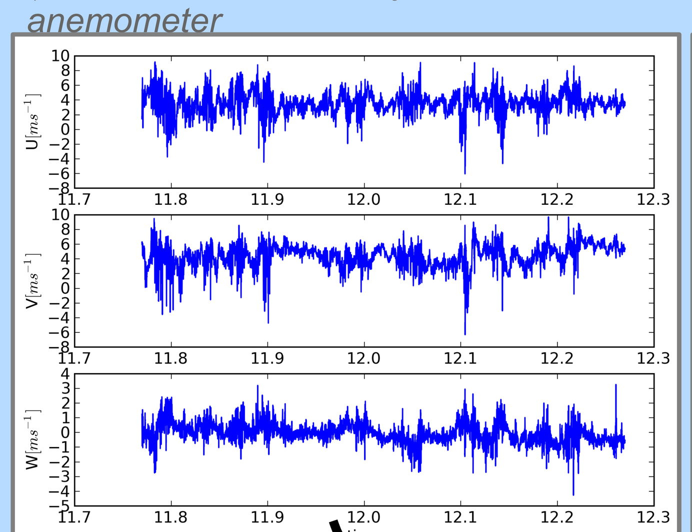
The tethered balloon : Tethered-balloon (Vaisala 7 m3 inflated with He) and tether line are used for the operations. The gondola is suspended 5 m below the balloon. The system was flown up to 700m above ground.

The 1Hz tethersonde: a Vaisala tethersonde (Vaisala Tethersonde TTS111, DIGICORA system) was also mounted on the cable. It measures temperature, humidity, pressure, wind speed and direction, and is capable of transmitting 1Hz data to ground using a radio link. This probe is mainly used to monitor the wind at flight altitude.

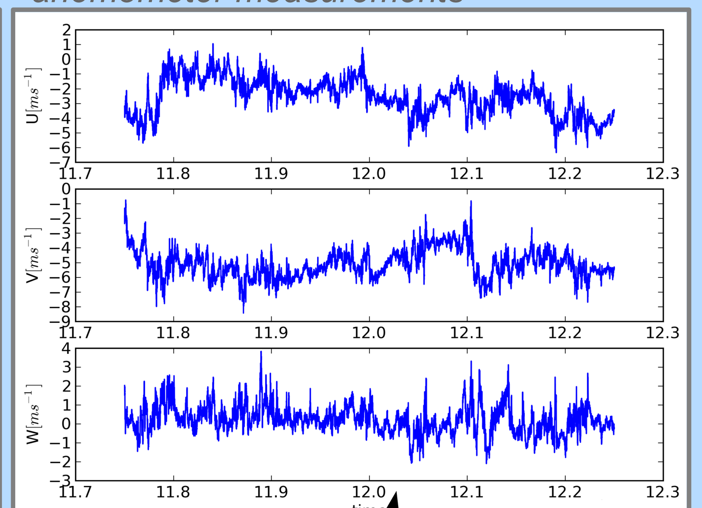
DATA PROCESSING & MOTION CORRECTION

Sensor synchronisation, motion composition and rotation to the local geographic frame allow the restitution of high-frequency wind comparable to the measure of fixed instruments.

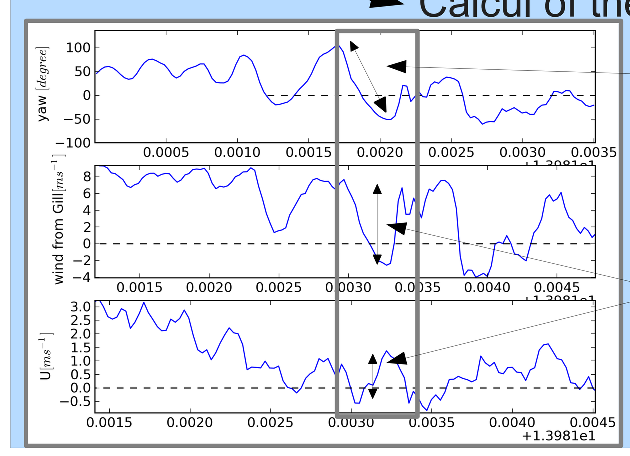
↓ Raw data measured by the sonic anemometer



↓ Corrected data from the sonic anemometer measurements



Calcul of the velocity composition



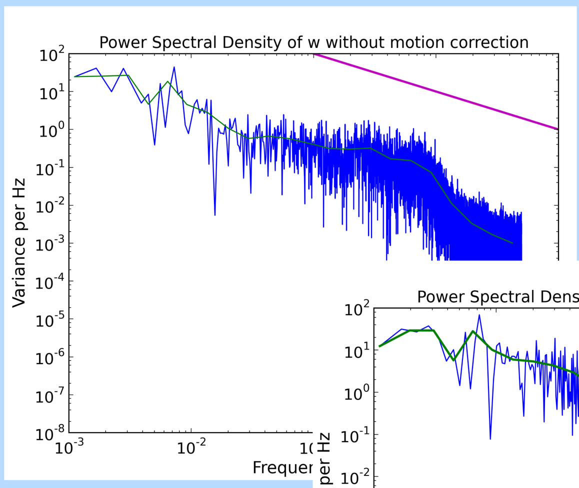
The gondola makes a half turn (~150 degree)

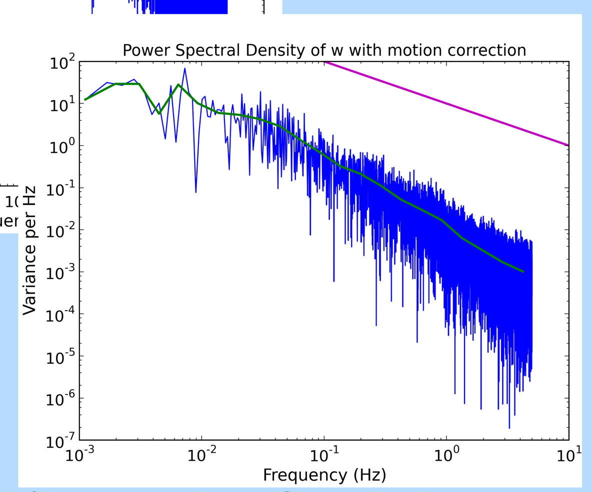
←This figure shows a zoom on ten seconds of the yaw angle, the apparent wind (one component) measured by the sonic anemometer and the U component of the wind after the motion correction.

The U component of the apparent wind changes of sign during the half turn with a strong amplitude (~10 m.s^{-1}). Whereas the magnitude of the corrected data (around 2-3 m.s^{-1}) is more consistent with the atmospheric conditions.

↓ The figure below shows the power spectra density (PSD) for wind in the w direction recorder from the turbulence tethersonde with and without correction for motion.

A feature center on 0.3Hz is observed in the uncorrected data. The feature is significantly decreased by the motion correction.

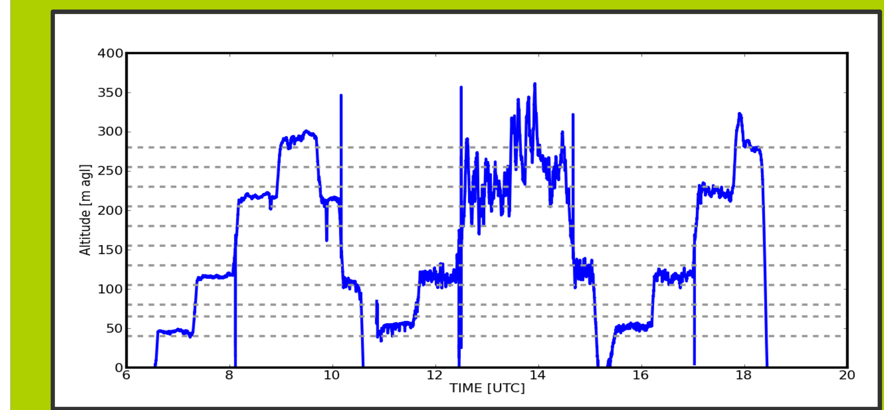




After motion correction, the power spectral of w present a inertial domain which obey at -5/3 power law from kolmogorov theory for homogenous and isotropic turbulent flow.

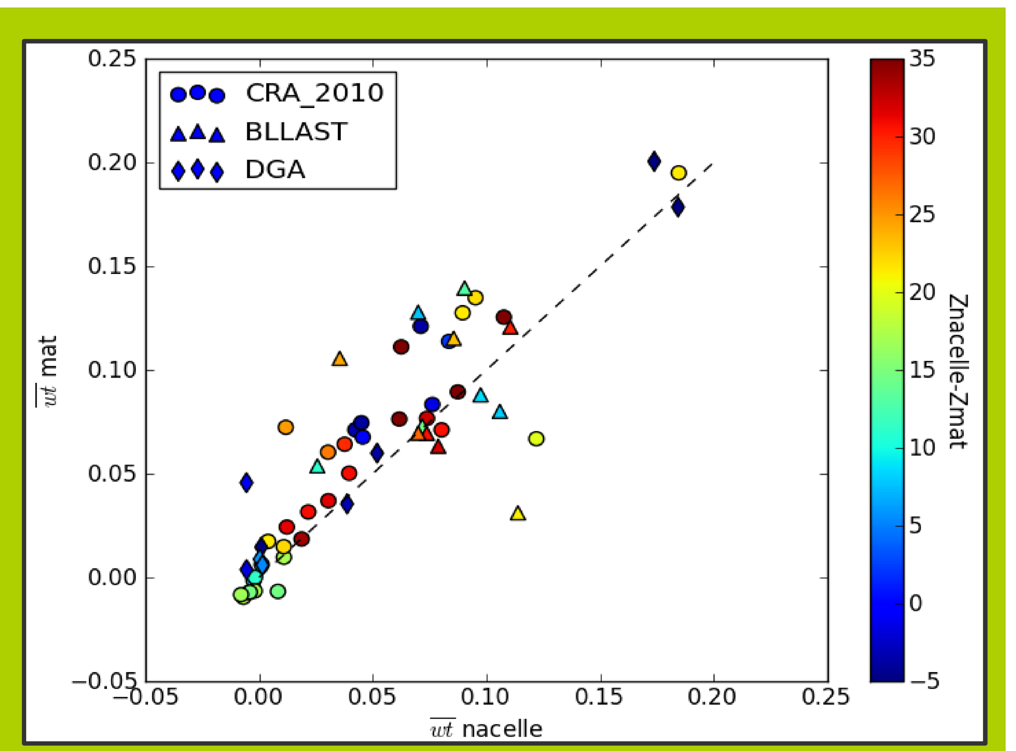
VALIDATION

In order to check the validity of the tethersonde sensible heat flux estimates, they are compared with those determined from similar Gill sonic anemometers mounted at 30 m, 40 m and 60m, on meteorological towers installed during three experimental campaigns in 2010, 2011 and 2013. Each times the met tower was located at 200-500 m from the balloon launch site. All data points included in this comparison (figure on the right) are for the tethersonde at altitudes within 30 m of the tower-mounted anemometers. The general correspondence of turbulence tethersonde and tower-derived sensible heat fluxes is good with a correlation coefficient of 0.86.



To estimate the heat fluxes with the turbulence tethersonde we try to keep the balloon at constant altitude during at least 20 minutes because we use this time period to calculate the heat flux.

← Altitude of the tethered balloon during the flight, example during one day of the 2013 field campaign

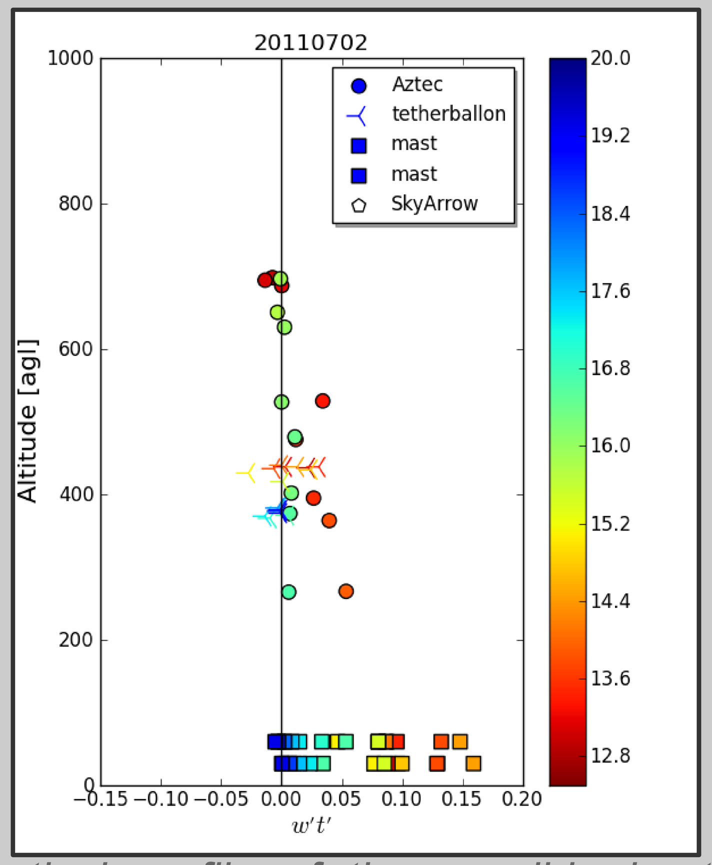


↑ Comparison between the sensible heat flux measured by turbulence tethersonde and by fixed sonic anemometers on meteorological mast during 3 field campaigns (differents symbols). The colors represent the altitude difference between the balloon and the fixed sonic anemometer.

USE

Study the vertical turbulence structure of the PBL

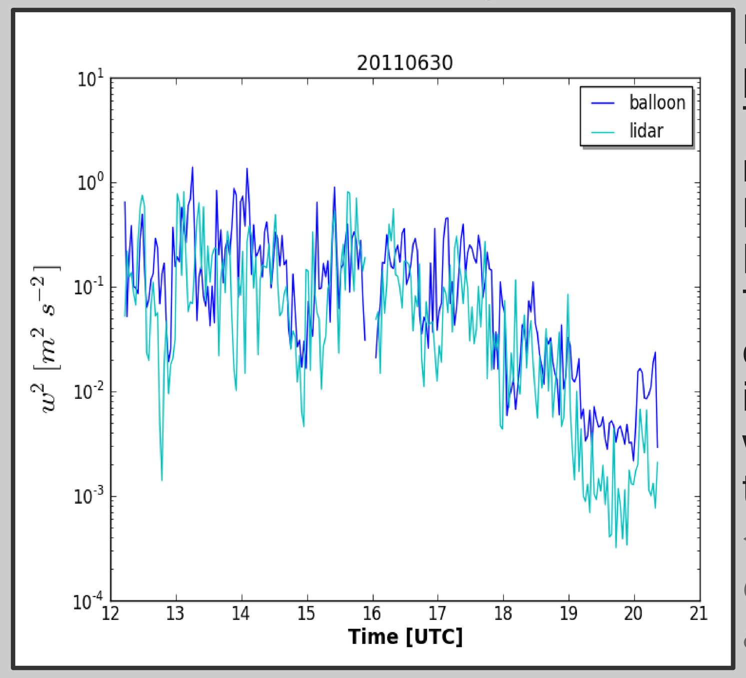
The turbulence tethersonde explores the middle of the PBL. It is a complementary tool to measure turbulence from mast or research aircraft. We can estimate the variance of the 3 wind components, the TKE (Turbulent Kinetic Energy), the dissipation rate of TKE and the sensible heat flux.



↑ Vertical profile of the sensible heat flux estimate with (■) sonic anemometer on the mast,(-<)the turbulence tethersonde and (o) the research aircraft during BLLAST experiment.

Evaluate & validate other estimates of turbulence

✱ Remote sensing



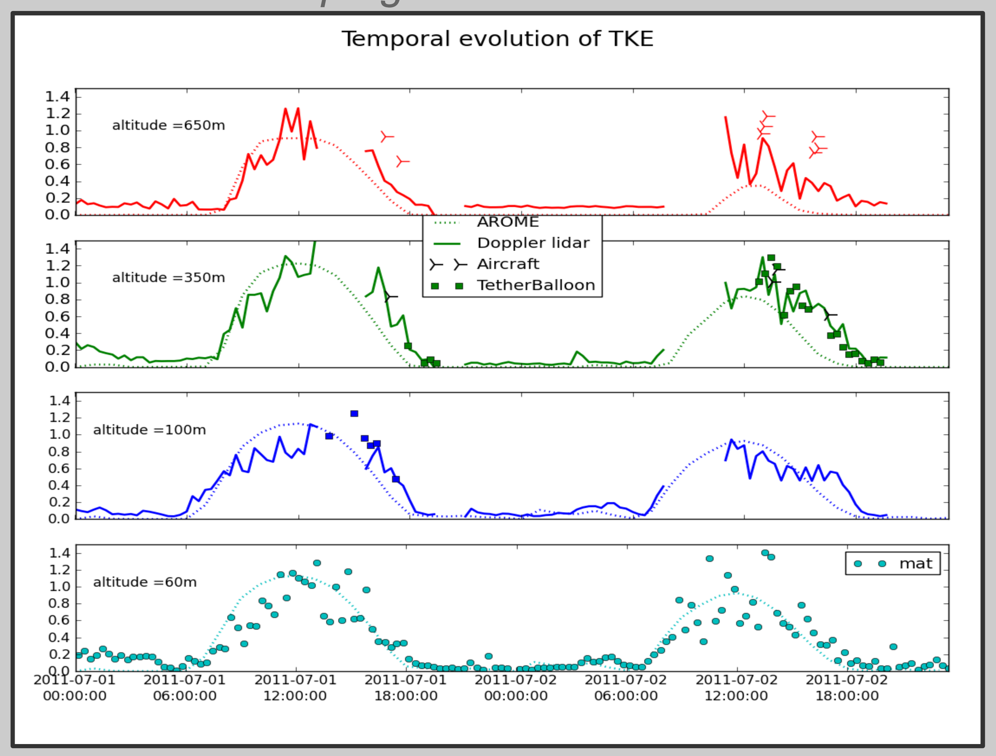
During 2 field campaigns we compared turbulent parameters (standart deviation of 3 wind components, TKE) obtained by turbulence tethersonde and those return by Doppler lidar (Windcube, manufactured by Leosphere, french company). The frequency of the Doppler Lidar was 0.25Hz.

The diurnal cycle of the turbulence linked at the convection is well capted by the both tools. The intensity of the variances of the 3 components of the wind is similar between the Doppler lidar and the turbulence tethersonde.

← Temporal evolution of the variance of w' estimated with (dark blue) turbulence tethersonde and (light blue) Doppler lidar during one day of BLLAST field campaign.

✱ Atmospheric models

Temporal evolution of TKE at 4 differents levels (60m, 100m, 350m and 650m) in the PBL during 2 consecutives days of BLLAST experiment. The figure presents the comparison between numerical weather prediction model (French model called AROME) and observations. →



Most of the case study (9 days in total) shows that TKE by numerical model is smaller than TKE provided by instruments.

This new system developped at Météo-France presents several advantages:

- explore vertical turbulence at the low part of the PBL at altitudes where the research aircrafts encounter some difficults to fly
- estimate or assess the quality of turbulent parameters at the middle of PBL at lower costs

Ongoing works & development :

- explore the posibility to estimate vertical profile of the dissipation rate of TKE without made severals stacked legs
- load off the system to add a fast humidity sensor to measure in-situ the latent heat flux
- deploy the system simultaneously with other instruments (particles counter, O3-CO2 probes,...) to better understand the link between microphysics and atmospheric turbulence like for example in fogs.

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