# Profiles of the Turbulent Humidity Flux: from Measurement to Water Budget

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## 1. Introduction

Water vapor in the convective boundary layer (BL) has three main sinks or sources: evapotranspiration at the surface ($F_{srf}$), detrainment into the free troposphere ($F_{top}$) above, and horizontal transport (advection). Over the time they determine whether the BL becomes drier or more humid and thus influences whether clouds can form or not. The fluxes $F_{srf}$ and $F_{top}$ are the endpoints of the flux profile which should depend linear on height if the BL is well mixed.

Turbulent fluxes in the BL have been measured in-situ since the 60'es with sensors mounted on airplanes. Lenschow et al (1994) have shown that it is necessary to fly several ten kilometers to reduce statistical uncertainty and get reliable fluxes from these airborne measurements.

Technical development in Laser and receiver technology in the recent years led to LIDAR systems which allow remote sensing of turbulence in the BL. The advantage is clear: logistical effort is much smaller and the system can provide continuous data over space and time. But in contrast to an airplane a remote sensing system relies on the wind to pass by a sufficient large volume to derive reliable fluxes.

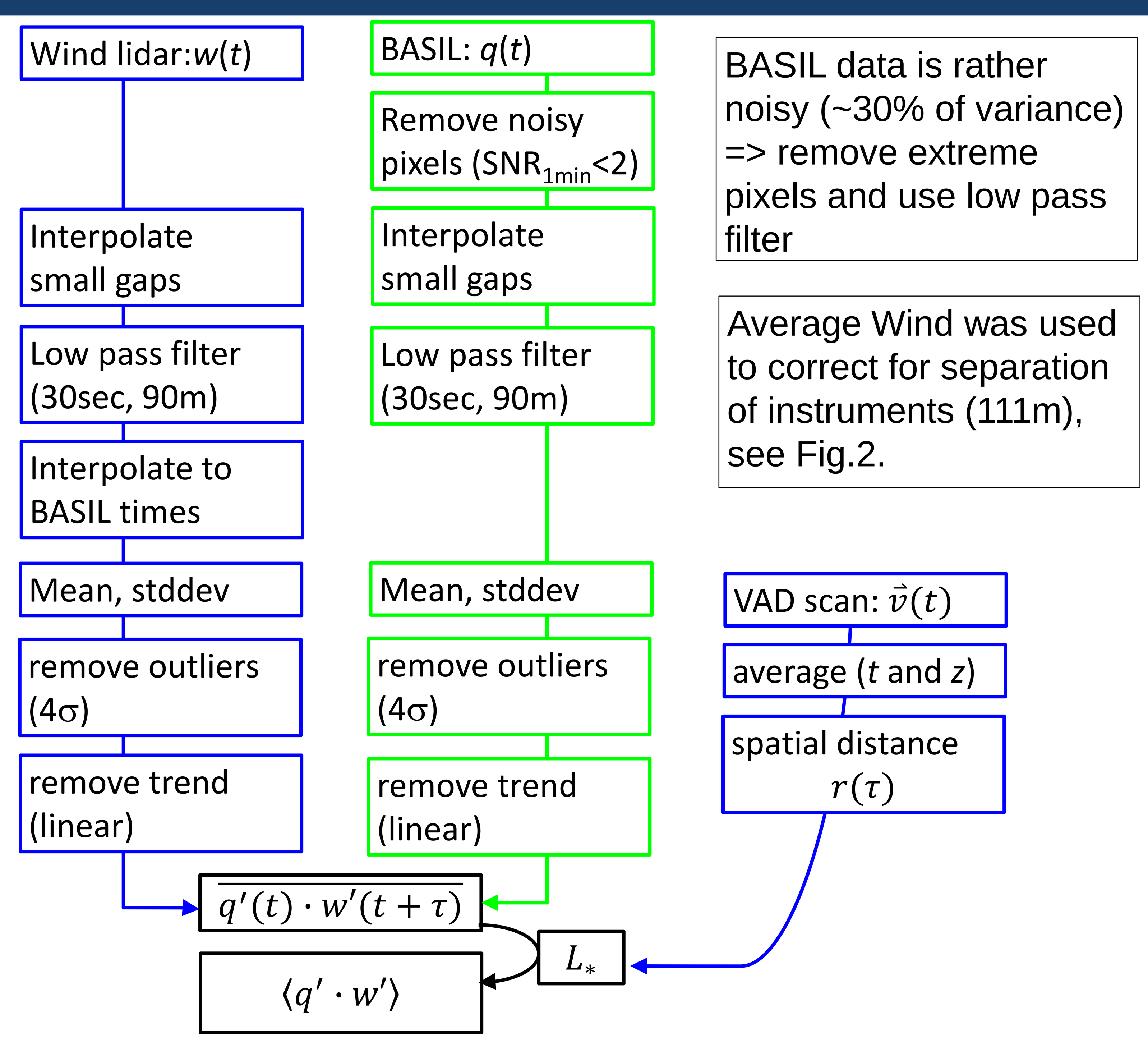
## 2. Instruments

During the HOPE campaign the '*University of BASILicata UV Raman lidar system*' (BASIL) was installed close to the *HALO photonics Streamline* Doppler Wind Lidar of the Juelich observatory for cloud evolution (JOYCE). Originally it was planned to work with 1sec temporal resolution but this was to ambitious for the Raman technique. To estimate the advection the wind Lidar performed every hour a VAD scan to provide wind profiles. Additionally the passive microwave radiometer HAPTRO performed every 6 minutes a scan to derive the humidity gradient (Schween et al. 2011). Technical specifications are as follows:

BASIL:
- 3 Wavelengths (355, 532, 1064nm), 7Channels, Raman technique
- $\Delta$t=10s $\Delta$z=30m
- continously

Doppler Wind Lidar:
- 1.5$\mu$m, multi pulse Doppler heterodyne technique,
- $\Delta$t=1s $\Delta$z=30m
- Interrupted every hour for ~2min by a VAD wind scan

## 3. Data processing




## 4. Results

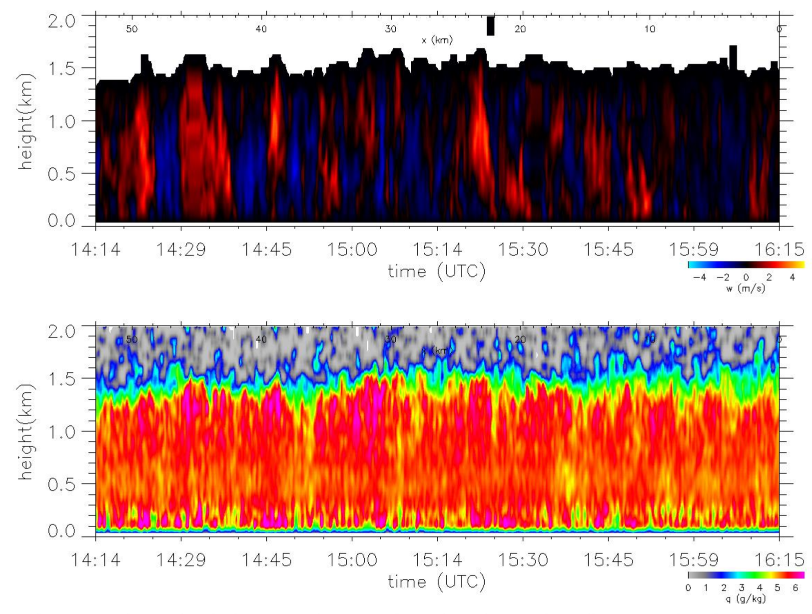



***Fig. 1**: Time height sections of w (top) and q (bottom) after filtering*

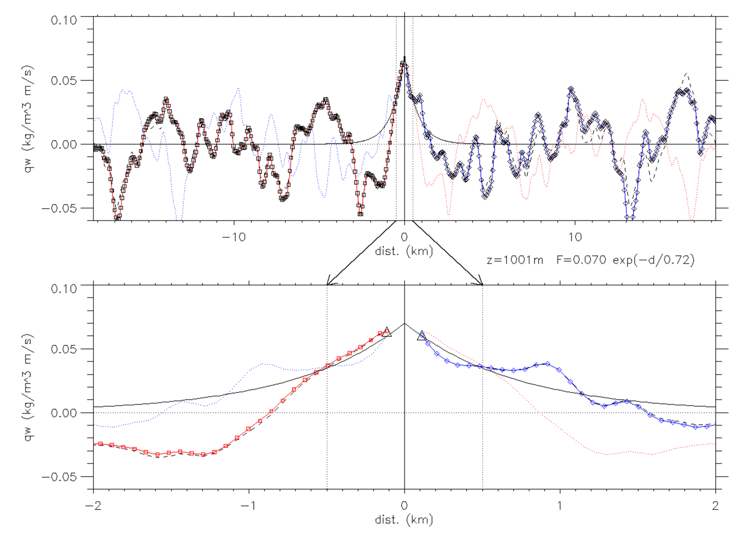


***Fig. 2**: Cross-covariance $\overline{qw}$ as a function of distance and extrapolation to zero distance.*

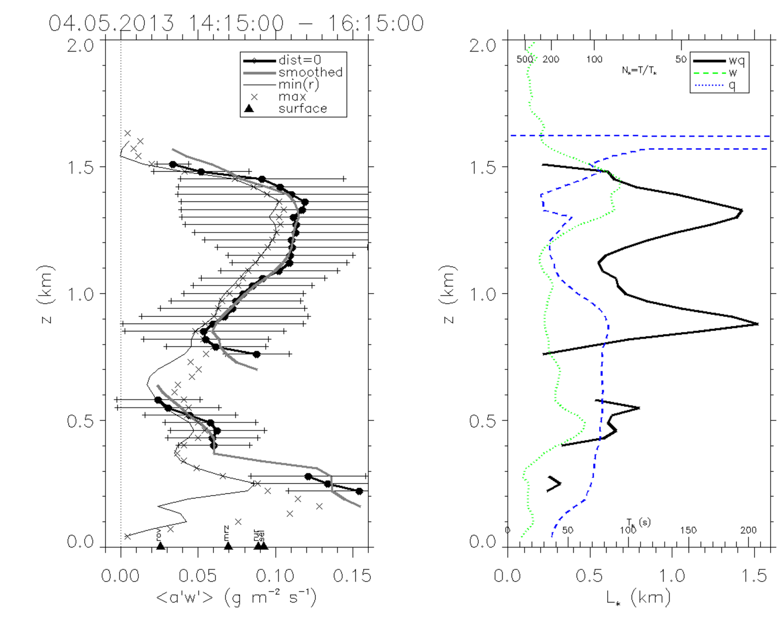



***Fig. 3**: Profiles of turbulent flux <aw> (left) and correlation length (right). Uncertainty ranges are calculated from the length scale following Lenschow et al (1994).*

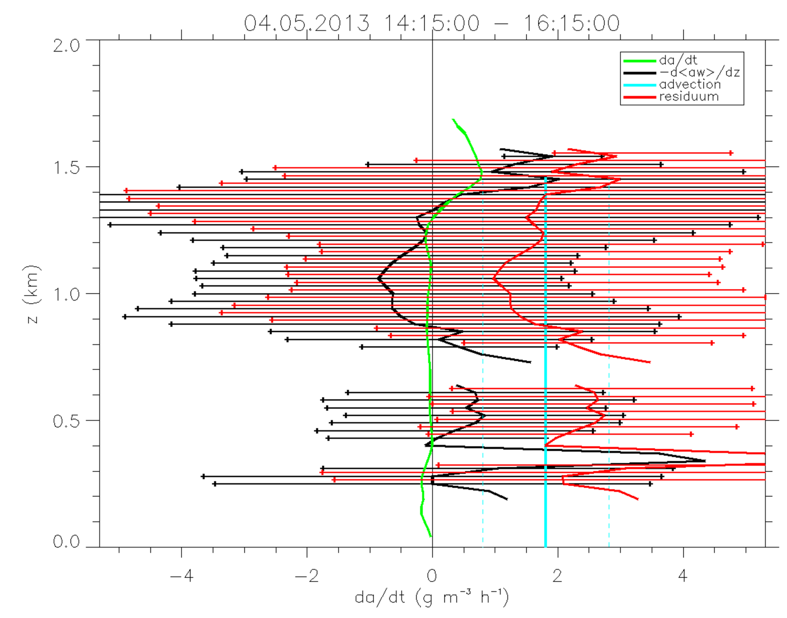



***Fig. 4**: Terms of the budget equation.*

Budget equation for vapor concentration $\bar{a} = \bar{\varrho}\cdot\bar{q}$:

$$\frac{\partial \bar{a}}{\partial t} = -\frac{\partial}{\partial z}\overline{w'a'} - \vec{\bar{v}}_h \circ \vec{\nabla}_h \bar{a} \qquad (1)$$

More:

## 5. Discussion

As a sample data set was selected May 4, 2013, 14:15-16:15 UTC: it was cloud free, showed a constant boundary layer height and constant turbulent properties (Fig.1). Wind speeds in the BL were rather high with values around 8m/s. During the 2 hours 8 strong updrafts can be identified clearly. Specific humidity is in these updrafts enhanced but shows much more fine scale structures which seem not to be related to the updrafts. Statistical analysis (Lenschow et al. 2000) gives for *q* and *w* similar integral length scales around $T_*$=60sec or $L_*$=450m which would mean that about $N_*$=120 independent samples have been taken.

The flux profile (Fig.3) shows at least above 500m a plausible form with a linear increase which indicates detrainment into the free troposphere. The integral length scale for *<aw>* is in the order of 950m or 130sec giving $N_*$=60. As according to Lenschow et al. (1994) the random error is proportional to $1/\sqrt{N_*}$ this results in rather large uncertainties for the flux.

These large uncertainties are further enhanced when we calculate the vertical divergence of the flux for the water vapor budget (Fig.4, equ.1). We must conclude that the flux divergence does not differ significantly from zero and also the rather large residuum is within uncertainty equal to zero.

This is of course not a satisfying result. The large uncertainties are not result of noisy measurements but instead due to the large integral length scales which result even for a 2 hour sampling period in rather large statistical uncertainty. Even doubling the averaging period will not overcome the problem: On the one hand we will run into the evening hours with decaying turbulence and all problems related to instationary conditions. On the other hand this will reduce the uncertainty only by a factor of $1/\sqrt{2} = 0.7$.

We thus must conclude that it is in general difficult to derive turbulent fluxes from remote sensing instruments fixed on the ground.

**References:**

Lenschow, D.H., Mann, J., and Kristensen, L., 1994: 'How long is long enough when measuring fluxes and other turbulence statistics?'. Journal of Atmospheric and Oceanic Technology, 11, 661-673.

Lenschow, , D. H., Wulfmeyer, V., and Senff, C 2000.: 'Measuring second- through fourth-order moments in noisy data', J.Atmos. Ocean. Tech., 17/10, 1330–1347

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