# Vertical wind velocities observed from the Cabauw tower

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## Eddy correlation technique

The vertical turbulent flux of an arbitrary quantity $\phi$ is calculated from

$$\overline{w'\phi'} = \frac{1}{N}\sum_{i=1}^{N}(w_i - \overline{w})(\phi_i - \overline{\phi})$$

If the sampling time is sufficiently long, it is typically assumed that the mean vertical velocity is zero,

$$\overline{w} = \frac{1}{N}\sum_{i=1}^{N} w_i = 0$$

This research investigates the validity of the zero vertical velocity assumption.

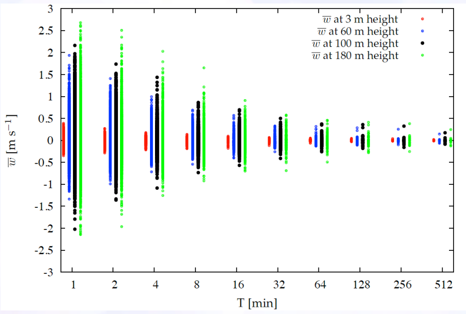
## Tower observations

Gill R3 sonic anemometers are installed at 60, 100 and 180 m on beams pointing south east from the Cabauw tower. An additional sonic anemometer is positioned at 3 m height about 200 m north of the main tower. The measurement frequency is 10 Hz.

Wind tilt corrections were calculated on the basis of measurements collected from 1 June 2007 until 31 May 2008 and were done for 18 wind direction sectors, covering 20° each.

The results presented here were collected during daytime between 3 and 13 May 2008 and represent clear convective conditions.

## Observed mean vertical wind velocities



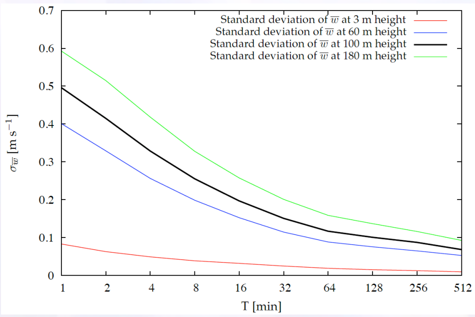




**Fig 1: Temporal averaged vertical wind velocities at four different heights plotted against the averaging time (top). The lower plot indicates the standard deviation of the temporal averaged vertical wind velocities displayed in the upper plot. The averaging times vary from 1 minute to 8 hours and 32 minutes (512 minutes).**

It is clear from Fig. 1 that even for averaging times $T$>30 min the mean vertical velocities deviate significantly from zero. Neglecting this non-zero vertical velocity leads to a systematic bias in the flux (Kanda et al., 2004; Steinfeld et al., 2007; Huang et al., 2008). If data are sampled at a fixed point in the domain of a large-simulation model similar results are found.

## Conclusion: the flux imbalance problem

A systematic error is introduced if a non-zero mean value for the vertical velocity is neglected in the calculation of the flux from the eddy-correlation technique. This so-called 'flux imbalance' effect was discussed by Mahrt (1998) and was demonstrated from Large-Eddy Simulation (LES) results by Kanda et al. (2004). To mimic observations collected in field experiments Kanda et al. sampled data at a fixed point in the LES domain. In an LES model the spatial mean vertical velocity is zero, whereas this will not be the case for the temporal mean value of the vertical velocity at any arbitrary point in space. The reason is that a quasi-stationary eddy may dominate the measurements collected at a local, fixed point. These Turbulent Organized Structures (TOS) are structures in which the air rises at specific positions and goes down at other specific positions, even if averaged over a longer time (Steinfeld et al., 2007; Huang et al., 2008).

Therefore the flux imbalance problem is due to sampling data at a fixed location. The observations show that the temporal mean value for the vertical velocity is rather large above the surface layer.

## References

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