Observation of the Vertical Wind by In-Situ and Remote Sensing Systems

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ABSTRACT

Vertical air speed plays an important role in several atmospheric processes e.g. like in turbulent transport and cloud formation. During the IMPACT campaign in May 2008 at Cabauw, the Netherlands, several systems were operated capable of sensing the vertical air speed with moderate to high temporal resolution [1]. Amongst these systems were 1) sonic anemometers mounted in a 200 m high meteorological tower, 2) a 1.55 µm Doppler wind lidar, and 3) a 35 GHz cloudradar. The Doppler lidar was operated during the campaign for a period of 7 days only. During this period some interesting cases for intercomparison were observed.

The sonic anemometer has the highest sampling rate. The data used here have a temporal resolution of 0.1 s. The Doppler lidar tracks mainly aerosols with diameter larger than 500 nm. The default operational mode of the lidar has a vertical resolution of 50 m, a time resolution of 10 s and the first gate at 100 m agl. The Doppler cloudradar typical measures the speed of cloud droplets and particulate matter suspended in air with a time resolution of approximately 15 s and vertical resolution of 90 m.

Here we focus on the vertical speed measured by these three systems on the 23rd of May. In section 2 measurements in a gravity wave that occurred shortly after midnight in a stable atmosphere are presented. In this period of very low turbulence the three systems show a good correlation. In section 3 measurements in an unstable condition, a convective boundary layer, are described. Under these turbulent conditions the correlation between the systems is much less. The specification of the three instruments is presented in section 1.

1. INSTRUMENTS SPECIFICATIONS

During the IMPACT campaign several instruments capable of measuring vertical air-speed were operated at the CESAR observatory. In reference [2] these systems are presented with the focus on the capabilities of the different systems. Here we limit the intercomparison to three different systems: 1) a Gill R3 sonic anemometer mounted at 180 m in the Cabauw tower, 2) a Doppler lidar system, the WindCube WLS70 and 3) a 35 GHz Doppler cloudradar. The latter two systems can only retrieve reliable measurements when sufficient particles to reflect the lidar or radar beam are present in the atmosphere.

1.1 Gill R3 sonic anemometer.

The Gill R3 sonic anemometer is located in the main tower at 180 m height on the south-east pointing boom (120^{o}) The Gill R3 is used to measure turbulent fluctuations of the three wind components [3]. The instrument is mounted on a thin vertical cylinder to avoid a too strong flow obstruction of the supporting boom. An inclinometer is mounted between the instruments and the boom. During May 23rd the main wind direction was also south easterly. Therefore any influence from the tower itself on the measurements can be neglected. The sampling rate of the Gill R3 is 50 Hz. The data used in the analysis have a time resolution of 0.1 s. Accuracy of the (vertical) wind speed measurement is <1% (RMS), with a resolution of 0.01 m/s. An azimuthal correction for the dependence of vertical speed on the mean horizontal wind speed has been determined.

Figure 1. A Gill R3 sonic anemometer mounted in the Cabauw Tower.

1.2 Windcube WLS70 lidar

The long range WindCube WLS70 infrared lidar transmits laser pulses at 1.55 µm. During the campaign the system was operated in vertical mode only. Data on the 23rd of May have been acquired with a 200 m vertical resolution and are averaged over a 10 s interval. Typical time spacing between the averaged profiles is 12 sec. The first gate is at 400 m agl. The lidar measures the vertical speed from the Doppler shift of the light backscattered by particles suspended in the atmosphere with diameter typical larger than 500 nm. The IMPACT campaign was one of the first field deployments of this system [4]. A low power version of the WindCube has been deployed more often, and was also successful operated next to Cabauw

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tower in august 2007. Accuracy of the (vertical) wind speed is < 0.2 m/s.

Figure 2. Left: WindCube WLS70 Doppler lidar with the Cabauw tower in the background, right: location of the remote sensing systems during the IMPACT campaign.

1.3 PDN100 Doppler Cloudradar

The 35 GHz KNMI cloudradar PDN100 is a vertical pointing Doppler radar. It has a peak power of 200 W, and has a user configurable measurement cycle. The vertical resolution is 89 m, and the lowest gate is located at 250 m and 320 m agl. for the uncoded and coded mode respectively. The normal operation cycle consists of 4 different data acquisition modes per measurement cycle. The total cycle time is approx. 15 sec. The cloudradar determines the vertical speed from particles suspended in the atmosphere like cloud droplets or so-called atmospheric plankton (i.e. insects or the remainder of it). The cloudradar is installed approximately 330 m south east of the Cabauw tower. During the IMPACT campaign the WindCube was installed within 10 meters next to the cloudradar container (see fig. 2b).

Figure 3. The 35 GHz Doppler Cloudradar PDN100.

2. GRAVITY WAVE CASE

In the night of 22nd/23rd of May 2008 a gravity wave was present above Cabauw. In the vertical velocity data from all three systems the typical wavelike velocity perturbation is clearly visible from shortly after midnight (UTC) till approximately 3 AM. In the first hour the velocity pattern is visible from 100 m agl. up to at least 1 km agl. (Fig. 4). Above 1 km the backscatter signal from both the lidar and cloudradar drop to values that too low for any signal detection. Gravity waves occur frequent in the stable atmosphere. E.g. in [5] a gravity wave in a shallow fog layer at Cabauw is described in detail. Also temperature, liquid water and humidity showed in this case oscillations associated with the gravity wave.

The typical oscillation period on the 23rd of May is approx. 10 minutes for the period between 1:15 and 2:00 UTC. Before 1:15 UTC the period is somewhat larger but the wave pattern seems also to be somewhat more complex with some small perturbations embedded in a longer wave.

For the intercomparison of the three systems the gravity wave has the advantage that local differences play a lesser role than in unstable turbulent conditions. Moreover the main vertical velocity field has a large extend, both in horizontal as in vertical direction. The typical well defined wavelike structure also allows a more reliable compensation for time offsets between the systems, either by clock offsets or by the physical distance between the systems.

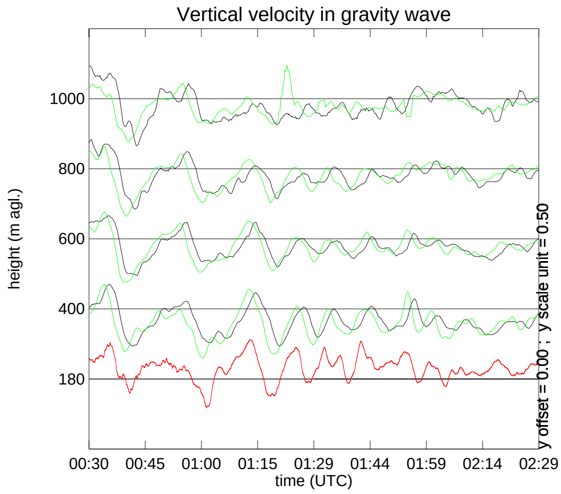

Figure 4. Typical vertical velocity pattern of the gravity wave measured by lidar (black), sonic anemometer (red) and cloudradar (green). Data are smoothed to show the oscillation pattern more clearly. Vertical velocity scale = 0.5 m/s per interval. Time and mean velocity offset corrections have not been applied here.

2.1 Data preprocessing

In order to compare the three systems we average and shift in time the sonic data from the 180 m level to fit the lidar data at 400 m. and cloudradar data at 390 m. respectively. The cloudradar data of the single pulse coded mode used here has an acquisition time interval of approximately 3 s.

To compensate for time offset differences between the systems due to clock errors and/or due to the distance between the tower and remote sensing systems of approximately 330 m., the three time series in fig. 5 were shifted visually for a minimum offset in the period between 1:15 and 2:00 UTC. We found a time shift between the sonic data and the lidar of 150 s, and between the sonic and the cloudradar of 40 s.

Especially the raw data of the cloudradar contained some spikes. These could be due to low signal strength, or perhaps active flying insects in the radar beam. To reduce the effect of these spikes on the intercomparison a 5 point median filter was applied to all raw data. Furthermore all three time series were smoothed with a moving average of 120 s. before the data were intercompared (fig 4).

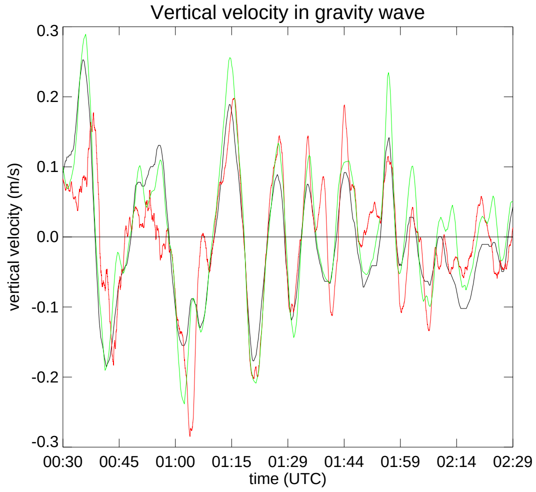

Figure 5. Smoothed time series of vertical speed of sonic at 180 m (red), lidar at 400 m. (black) and cloudradar at 390 m (green) resp. Time series of sonic and cloudradar have been shifted in time (see text), all series are shown with the mean subtracted.

2.2 Analysis results

The means (standard deviations) of the smoothed vertical speed time series in the period between 00:30 and 2:30 UTC are for: sonic +0.076 m/s (0.09 m/s), lidar -0.085 m/s (0.09 m/s), and cloudradar -0.107 m/s (0.10 m/s) resp.

The sonic at 180 m. has a small inclination offset. The bias in the vertical speed due to this offset is estimated from the mean wind speed and is on the average 0.072 m/s for this time period. A possible cause for the bias in the lidar and cloudradar data could be a small tilt of the vertical pointing beam. For the cloudradar the accuracy of the antenna beam direction is better than 0.1° at the antenna base. However in the antenna itself a sub reflector is mounted of which the pointing accuracy is not precisely known. The pointing accuracy of the lidar is not unknown.

An error in the beam pointing direction results in a contribution of the horizontal wind to the apparent vertical velocity. Assuming that the bias is caused by an error in the beam pointing only and an averaged wind speed of 8 m/s at 400 m. agl (from windprofiler observations) the beam pointing error in the main wind direction would be for the cloudradar 0.8° and for the lidar 0.6° resp. Comparison of more data is needed to confirm whether an error in the beam pointing is indeed contributing to the offset found here. The mean wind conditions didn't change significantly during the gravity wave period considered here. Therefore any dependence on wind speed and direction is impossible to assess for this period.

After correction for the time offset the sonic data have been averaged to create a collocated time series with both the lidar and cloudradar resp. The cloudradar have been interpolated to the lidar data. The scatter plots in fig 6 and 7 show the results and linear regression lines for the period 01:00 to 02:00 UTC. The slope of the regression line is 0.7 for lidar vs. sonic, 0.9 for cloudradar vs. sonic, and 1.3 for cloudradar vs. lidar resp.

The scatter between lidar and cloudradar is small but the slope of the regression line is rather high. This needs some further investigation. The scatter between the lidar/radar and sonic is larger although a reasonable correlation is still present. Also the difference in measuring volume, the height above surface and distance will add to the scatter between the lidar/radar on the one hand and the sonic on the other.

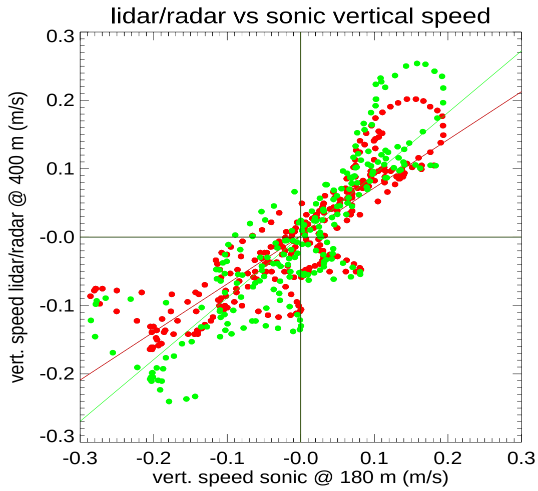

Figure 6. Scatter plot lidar vs. sonic (red) and cloudradar vs. sonic (green) for the period 01:00 to 02:00 UTC.

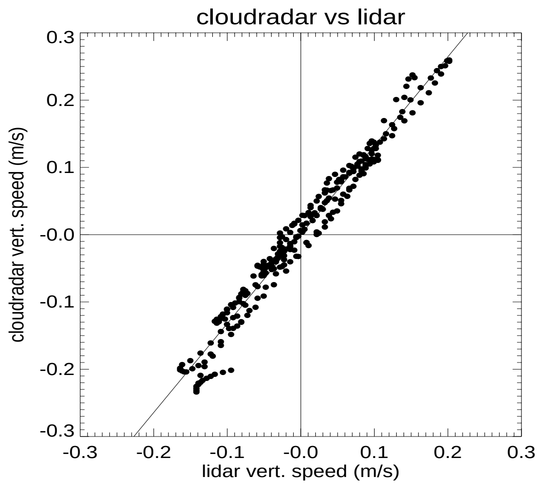

Figure 7. Scatter plot cloudradar vs. lidar for period between 01:00 and 02:00 UTC.

3. CONVECTIVE BOUNDARY LAYER CASE

In the day time of May 23rd a convective boundary layer developed. Measurements from the three systems have been processed in the same way as described for the gravity wave case. Except for the cloudradar only data from the non-coded mode are used now. The vertical velocities in the convective boundary layer are much higher than during the gravity wave event. The velocity range of the coded mode of the cloudradar is not large enough to sample these higher velocities accurately. Therefore only the non-coded mode with a much larger Nyquist velocity is used here.

The time period that we consider is from 10:30 to 14:30 UTC. Figures 8 and 9 show the results in the similar way as for the gravity wave. Note that the vertical scale has changed compared to fig. 4 and 5, and in fig. 5 we only show the period 12:00 to 13:00 UTC. Also the time shift between the sonic and the lidar is now set to 0 s instead of the 150 s in the gravity wave case.

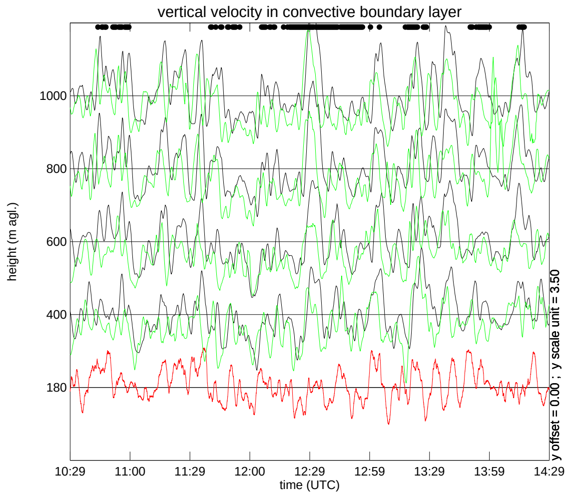

Figure 8. Typical vertical velocity pattern in the convective boundary layer measured by lidar (black), sonic anemometer (red) and cloudradar (green). Data are smoothed and vertical velocity scale = 3.5 m/s per interval. The black dots indicated when a cloud was detected by the CT75 ceilometer.

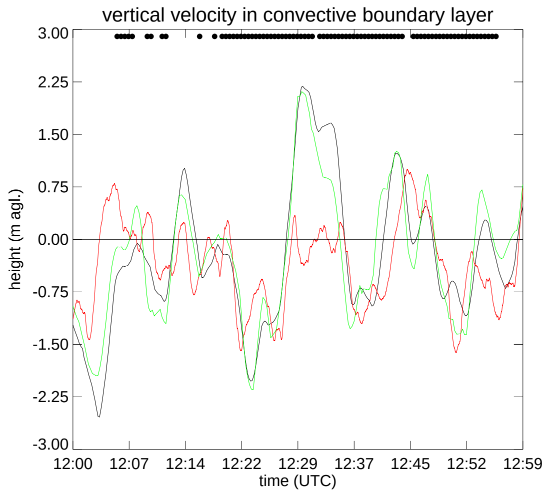

Figure 9. Smoothed time series of vertical speed of sonic at 180 m (red), lidar at 400 m. (black) and cloudradar at 430 m (green) resp. Time series of cloudradar has been shifted in time (see text), all series are shown with the mean subtracted.

From fig. 8 and 9 it is clear that the vertical velocities are much higher now, showing strong up- and downdrafts. Features with longer time scales are present in all the data but on the shorter time scales the correlation between the three signals is much less than in the stable atmosphere during the gravity wave event. Also we are not sure whether in these conditions the velocities derived from the backscatter signal from the cloudradar are still representative for the true vertical velocity. More insects might be flying which can introduce an offset in the velocity, and it is likely that the higher vertical speed also brings more and probably larger particles in to the atmosphere.

The mean and standard deviation of the smoothed time series have been calculated for the period 10:30 to 14:30 UTC. The mean (standard deviation) is for: sonic 0.11 m/s (0.74 m/s), lidar 0.02 m/s (0.96 m/s), and cloudradar -0.58 m/s (0.89 m/s) resp.

4. SUMMARY

Comparison of the vertical velocity measured by a sonic anemometer, a 1.55 µm Doppler lidar and a 35 GHz Doppler cloudradar show very comparable results in a gravity wave in a stable atmosphere. Both the structure and magnitude of the oscillations in the vertical speed compare reasonably well. The remaining small biases between the systems needs further investigation to assess if these can e.g. be attributed to a small offset in the beam pointing direction of the lidar and radar resp. Also the almost constant relative difference in vertical speed between the cloudradar and the lidar measurements needs further assessment.

Comparison of the three systems in a convective boundary layer shows much more scatter, although the main larger temporal components are still present in all observations.

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