Overview of the DLR 2 micron Doppler lidar campaigns with emphasis on possibilities and limits of signal processing

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Abstract: In the past three years several airborne campaigns all over the world with the DLR two micron Doppler lidar installed onboard the Falcon F20 research aircraft were performed. The scientific goals of these campaigns reached from the study of transport phenomena of Saharan dust over the Atlantic Ocean (SALTRACE) to gravity wave measurements in Sweden (GWLCYCLE) and New Zealand (DEEPWAVE). A comparison campaign with the ADM direct detection lidar on Iceland (WindVal) together with the NASA DC8 was also performed. This paper will give a brief overview of the campaigns and then focuses on the data processing. The accumulation of all LOS spectra of a VAD scan into one Spectrum in order to improve the coverage is presented. Furthermore the challenge of extracting a wind vector out of a set of LOS estimates of a VAD scan in the presence of gravity waves will also be addressed.

Keywords: Airborne Doppler lidar, VAD scan, GWLCYCLE, SALTRACE, DEEPWAVE, WindVal

1. Overview of campaigns

SALTRACE 2013: Saharan Aerosol Long-range Transport and Aerosol-Cloud-Interaction Experiment. Lagrange measurement of the transport of Saharan dust over the Atlantic Ocean. First time of the 2 micron Doppler lidar providing “calibrated” backscatter measurements [1, 2].
Location: Cape Verde islands and Barbados
Web: http://www.pa.op.dlr.de/saltrace/index.html

GW-LCYCLE I 2013: First Gravity wave experiment in December 2013 in Sweden with several wave events.
Location: Kiruna, Sweden
Web: http://www.pa.op.dlr.de/gwlcycle/

DEEPWAVE 2014: “Deep Propagating Gravity Wave Experiment” over New Zealand together with NOAA. At this campaign there was a constant struggle with clear air / low backscatter as there is nearly no background aerosol.
Location: Christchurch, New Zealand
Web: www.pa.op.dlr.de/deepwave/ ; https://www.eol.ucar.edu/field_projects/deepwave

WindVal 2015: Campaign together with ADM Aeolus instrument on Falcon and with DAWN Coherent Doppler Lidar [3], TWILITE direct detection Doppler lidar [4] and dropsonde unit onboard NASA DC-8.
Location: Keflavik, Iceland
Web: http://blogs.esa.int/campaignearth/2015/05/20/windval-petta-reddast/ and:
http://www.dlr.de/pa/en/desktopdefault.aspx/tabid-2342/6725_read-43282/

GW-LCYCLE II 2013: Most recent gravity wave campaign. Due to very calm weather only two wave events.
Location: Kiruna / Sweden
Web: http://www.pa.op.dlr.de/gwlcycle2/news.html

2. Increased coverage by new accumulation algorithm

The DLR two micron Doppler Lidar usually applies a conical step and stare scan with 20° off nadir and 18 stare positions. Accumulation time for a single LOS is usually 1 second that is approx. 500 laser shots. Usually the processing strategy is to accumulate all shots of one stare position and then estimate the peak power spectral density PSD from the accumulated spectrum. The result are 18 Doppler shift estimates that can then be used to evaluate the 3 dimensional wind vector assuming a constant wind field across the scanning volume. In the case of poor backscatter conditions this method is suffering from low SNR because of limited accumulation time. When the peak of the backscattered Doppler signal is near the noise floor there is no reliable estimate possible anymore. Another approach is to accumulate all Doppler spectra of a scan into one resulting spectra with an accumulation time in this case of 18 s. In order to do so a wind field is assumed and the spectra of the different LOS positions are shifted according to this wind field and projected to the LOS direction before accumulation. By varying the wind field over all realistic values one gets a set of accumulated spectra. The idea is now that with the right wind field the power spectral density (PSD) of the accumulated spectra becomes maximal. This approach is already described by Smalikho [5] and the performance is assessed by Weissmann [6]. In theory the possible improvement is square root of the number of LOS positions. In practical tests it is lower due to atmospheric turbulence that causes a spectral broadening of the resultant PSD.

It was found empirically that this "accumulation algorithm" may be improved by not only looking at the maximum PSD but the quotient of PSD and vertical wind. This causes some underestimation of the vertical wind speed. To avoid this effect and to reduce processing time the approach is done in two steps. A coarse variation of the wind assumption in steps of 2 m/s followed by the above mentioned selection of the PSD and vertical wind. This first approach is followed by a fine variation of the wind assumption around the previous wind estimate with a selection of the most likely wind by using the PSD alone.

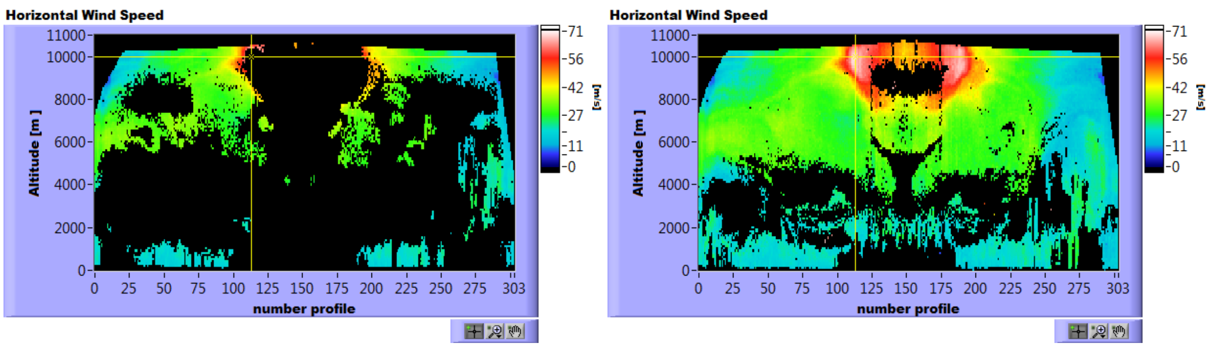

Figure 1: Example of increased coverage with the modified accumulation algorithm (right) compared to standard LOS inversion algorithm (left).

The improvement in coverage by this algorithm depends strongly on the backscatter distribution in the atmosphere. In case of a moderate reduction of the backscatter coefficient e.g. in a jet stream the coverage can be enhanced significantly like shown in Figure 1. On the other hand the r-square dependence of the lidar signal or a significant drop in backscatter cannot be compensated by this algorithm. Longer accumulation times e.g. several scans show the limits of this technique as there are some EMI peaks (e.g. from computer) buried in the noise, that make problems if the accumulation time gets too long.

3. Vertical winds causing trouble in 3D wind vector estimation

The processing step from the LOS estimates of a scan to a three dimensional wind vector seems to be straight forward. It only uses the assumption that the wind field is constant over the scanning volume. At the ADM Aeolus mission with only one LOS direction there is the even more rigid assumption, that the average vertical wind is zero over the accumulated volume. In most cases those assumptions are justified. However under special conditions like gravity waves or frontal ascend processes this may lead to dramatic errors in the estimated 3D-wind vector. The general reason for the sensitivity to a variation of the vertical wind is a small off nadir angle of the conical step and stare scan. In case of the DLR airborne 2µm Doppler lidar this off nadir angle is 20°. According to $v_{LOS} = v_{hor} \sin(20°)$ and $v_{LOS} = v_v \cos(20°)$ any error respectively variation in the vertical velocity is multiplied by up to a factor of nearly 3 and added to the horizontal wind speed! To make things even more complicated are the measurement volumes varying with altitude. Figure 2 gives an overview of the measurement volumes of the 2 µm Doppler lidar over altitude.

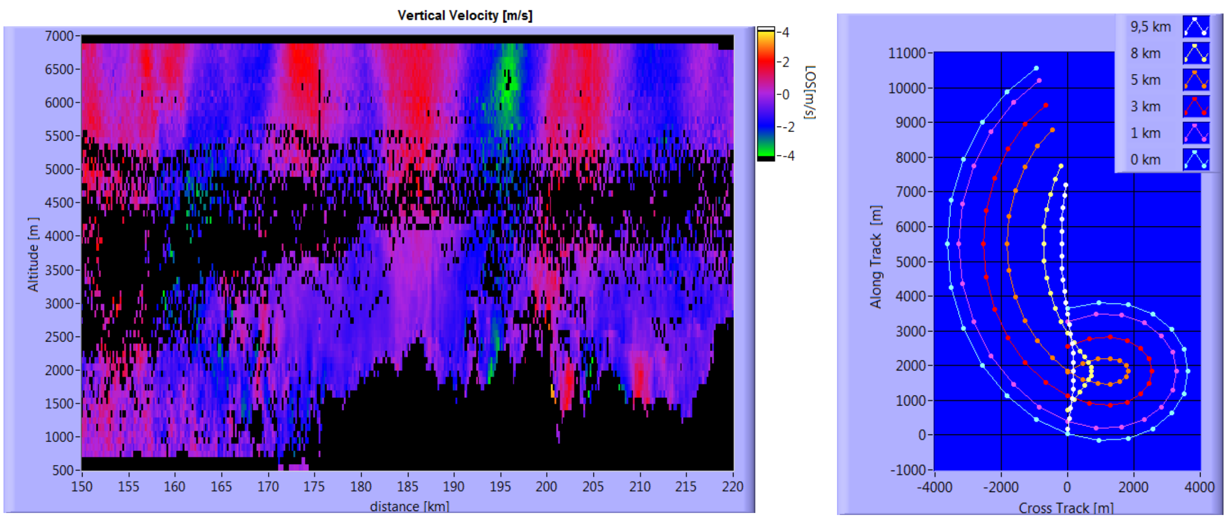

Figure 2: Example of vertical wind due to gravity waves (left) compared to the footprint of a conical scan

At the gravity wave experiments in Kiruna / Sweden and Christchurch / New Zealand several flight lags were performed two times once with conical step and stare scanning and next with fixed nadir looking LOS. The time difference between those two lags was only about 30 minutes at nearly unchanged wind situation. At those examples it was found that at areas with strong gravity waves the 3D wind estimation gets complicated and unstable. The amplitude of those gravity waves was up to 3 m/s! Consequently the observed uncertainty / variation of the estimates of the horizontal wind have been up to 9 m/s. Both the conventional “inversion” algorithm as well as the previously described “accumulation” algorithm showed similar variations. Unfortunately the geometric wavelength of the gravity waves and the scanning volume of the lidar were about the same size so that the wave had a maximum influence on the estimation of the horizontal wind estimate. However even with less LOS positions there will remain some influence from the gravity waves. With the existing scan pattern an elimination of the influence of those gravity waves seems to be impossible. For future experiments it is planned to add several nadir looking LOS directions to each scan in order to be able to subtract the vertical wind from the LOS estimate before calculating the inversion matrix. Or if this does not eliminate the gravity waves at least a warning can be generated that the resultant wind estimate may be corrupted.

4. Conclusion

Although airborne Doppler lidar measurements are well established for several decades there are still issues to be addressed at data processing. It has been shown that some improvements are still possible. On the other hand some atmospheric issues still have to be considered for an acceptable accuracy of the final wind estimates.

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