Recent and ongoing coherent Doppler lidar measurements at DLR

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Overview

In the past the coherent Doppler Lidar of DLR was used both onboard the Falcon research aircraft and ground based in a 20 ft container. At the ground based measurements mainly wake vortex of aircrafts were investigated but there was also one campaign with observations at a wind energy power plant. At airborne campaigns the 3 dimensional wind field was the main interest. However having a lidar available at sudden events like the Eyjafjallajökull eruption on Iceland has opened an opportunity for measurements where normally another Lidar with shorter pulse and depolarization channel would have been chosen if available in this moment. This paper will report about the following campaigns:

2009: Wind energy Bremerhafen. Measurement of the flow before and after a wind power plant

2010: Eyjafjalla volcanic ash: This was an ad-hoc campaign to make some statement to volcanic ash content over Europe.

2012: Wake vortex reference measurements Belgium. Here the DLR System was used as a “reference” for a recently developed direct detection lidar.

2013: Saltrace/Volcats: Current campaign at the Cape Verde Islands and Antigua in order to trace Sahara dust outbreaks.

Wind energy Bremerhaven

In 2009 a lidar campaign in Bremerhaven was organized in collaboration with the University of Stuttgart. In this campaign two Doppler lidar were involved. A short range lidar of the University of Stuttgart mounted on the gondola of a wind power plant looking in the direction of the incident wind. With this lidar the optimization of the pitch angle of the rotor blades was investigated. The long range Doppler lidar of DLR installed in a 20 ft. container was located 1.8 km away from the power plant looking through the rotor blades in order to measure simultaneously the incident wind together with the “exhaust” of the power plant. With this data the velocity deficit was calculated. Here the later measurements are presented. Measurements took place at various atmospheric conditions. Especially the convection induced turbulence varied over a wide range at measurements at noon compared to the set obtained at night. This measurement at night turned out to be the most interesting case especially as the wind direction did nearly match the LOS direction of the lidar. At this configuration the in- and outflow of the wind turbine was obtained with a single scan. Figure 1 shows one result of this measurement configuration.

Interesting are also the layers with different wind speed and how those layers become mixed up by the rotor of the power plant. Even the horizontal length of the wind deficit can be estimated roughly by eye out of the measurements. On the other hand in this configuration small variations of the wind direction can have a huge influence on the overlap between outflow and line of sight direction of the Doppler lidar. This effect has to be considered careful in the data evaluation to avoid an underestimation of the horizontal length of the velocity deficit. Further investigations on this data include the influence of turbulence (Eddy dissipation rate) on the size of the velocity deficit. From the measurements shown in figure 1 it can be deduced that a distance 6-8 times the rotor diameter is enough that the velocity deficit of the power plant is greatly reduced even at stable atmospheric condition. The reason for this rather fast decay may be found in the turbulence introduced by the power plant itself that helps to dissipate the velocity deficit quickly into the surrounding atmosphere.

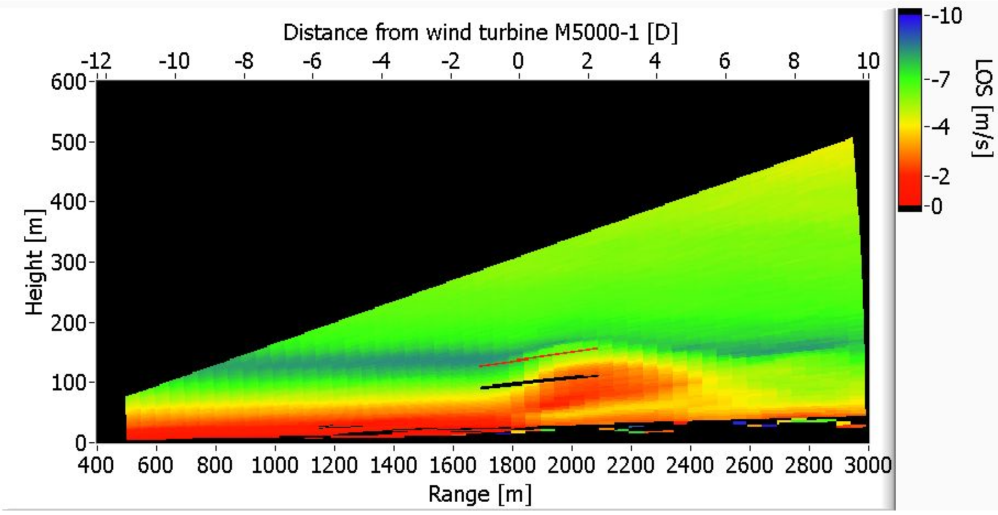

Figure 1: simultaneous in- and outflow measurement of a wind power plant at night.

Eyjafjallajökull volcanic ash measurement onboard the DLR Falcon research aircraft

On April 14, 2010 the Eyjafjalla volcano at Iceland started an intensive eruption episode where a lot of volcanic ash was thrown as high as 9 km into the atmosphere. This ash cloud was then transported by the wind towards Europe where it arrived at April 15 and here it caused extended closures of the air traffic due to the safety regulation this time that no aircraft is to be operated inside a volcanic ash laden air volume. The principal motivation of these measurement flights was to provide as fast as possible airborne measurements of volcanic ash properties over Central Europe. The data acquired in these flights was intended to provide information useful to assess the volcanic ash load predictions, which were used in the decisions on air space closure over Central Europe. In order to investigate the ash cloud the DLR research aircraft was equipped with as much in-situ instruments as possible. E.g. particle counter, trace gas sensors, but also the 2 micron Doppler lidar as only remote sensing instrument. During this campaign the DLR Falcon was operated as state aircraft which allowed it to operate in otherwise closed airspace. The first flight over Germany was already performed on April 19, 2010.

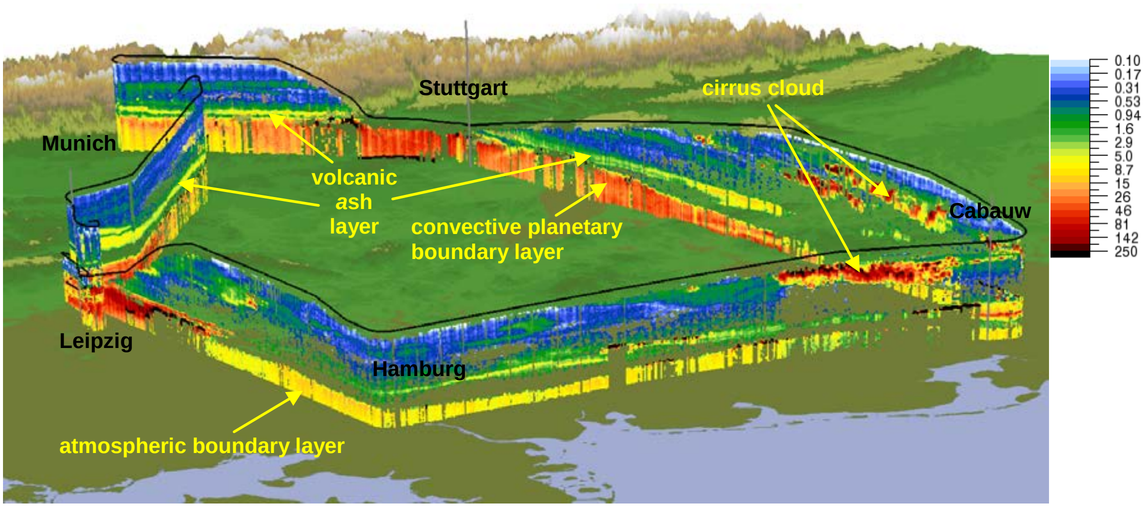

Figure 2: Lidar range corrected backscatter beneath the flight path over Germany and the Netherlands, with various aerosol and ash layers and cities identified, 19 April 2010

Given the fact that this campaign was not planned or foreseen at all it can be considered to be realized pretty quickly. Between 19 April and 18 May 2010, 17 flights with a total of 34 ash plume penetrations were performed. Right after each flight the aircraft engines were thoroughly examined for any sign of volcanic ash

induced degradation. The measurements were supported by satellite data, numerical volcanic ash predictions, and weather forecasts. Flight panning can be considered to be very crucial at this campaign. At first there had to be identified the regions with ash-contamination. But the humidity respectively the water vapor content inside the predicted ash layer was also very important because with the given sensors it was not possible to distinguish in a quantitative way between ash and water or ice particles.
Although this lidar is not the optimal instrument to detect ash clouds due to comparable long pulse width and without depolarization channel, it was the only one that was available airborne in this time. Even with the lack of a depolarization channel and a rather long pulse width it was useful for the detection of the ash clouds. The measurement strategy was to investigate those areas having a forecast for ash content from above, check by lidar if in those regions there is any significant backscatter, perform then altitude profile and gather information of the ash aerosols by the in-situ sensors, mainly particle counters, gain altitude again and investigate the lateral extension of the cloud again from above. Under the assumption that the particle size distribution does not vary significantly within the cloud it was even possible to use the range corrected lidar signal with a sort of in-situ "calibration" at the altitude profile as an estimate for the mass content across the ash cloud. As the ash clouds over Europe had a significant total age of at least several days the assumption of a comparable particle size distribution across one ash cloud was somehow realistic. During this campaign several flights over Europe were done as well as a trip to Iceland to obtain some lidar measurements directly from the source. After May 19 the Eyjafjalla volcano showed a rapidly decreasing activity and also the weather respectively the wind situation changed so that there was no further effect on the air traffic over Europe.

Wake vortex reference measurement at Belgium

At the EU founded project GREENWAKE the potential of an incoherent Doppler lidar for inflight detection and classification of wake vortices wind shear and clear air turbulence was to be investigated. Near the end of this project a ground based campaign on an airport was planned in order to test the incoherent Doppler lidar developed by Hovemere against the DLR coherent Doppler lidar. As the range of the incoherent Doppler lidar was limited to something between 100 and 200 m this system had to be placed very near to the glide path of the incoming traffic. Fortunately the airport at Charleroi sometime referred as Brussels South agreed to host this campaign. The main (only) traffic on this airport is from Ryan air, who have a very homogeneous fleet of Boing 737-800 only. This turned out to be a big advantage because all of the lidar measurements became comparable without sorting the aircraft type. This means as all of the measured wake vortex are generated by the same type of aircraft the only parameter left was the landing weight (unfortunately unknown) and the atmospheric condition. Over one day of measurements it was possible to obtain e.g. 50 landing aircraft which gave within this single day a good reasonable basis for statistical evaluation under comparable atmospheric conditions. Even at a big airport like Frankfurt or Munich with much more traffic it is very unlikely to obtain this number of landings of one specific aircraft type within a single day. One conclusion of this campaign was that with one single aircraft type it may be possible to test a new lidar even without a reference because within the first 30 seconds of vortex age the vorticity is known with a sufficient accuracy of +/- 15%. Figure 2 shows the results of one measurement day with strong cross wind.

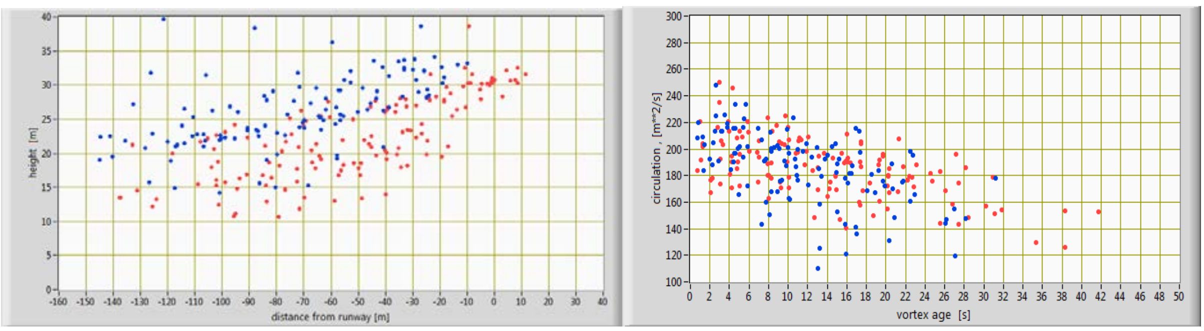

Figure 3: Circulation (right) and location of one measurement day at Charleroi. Red dots correspond to the left vortex and the blue ones to the right vortex.

Saltrace / Volcats campaign

Based on the positive experiences of the volcanic ash measurements a similar campaign will start in June 2013. Here two interconnected campaigns take place on the Cape Verde Islands and in Barbados. Objective is to measure and quantify the transport of Saharan dust over the Atlantic Ocean. With this data a better understanding of the interaction of mineral dust with water vapor and its influence on weather and climate will be gained. SALTRACE stands for Saharan Aerosol Long-range Transport and Aerosol-Cloud-Interaction Experiment. SALTRACE continues the work started with the Saharan Mineral dust Experiment (SAMUM; 2004-2011) and will help to close open gaps in the understanding of mineral dust in the climate system. Interesting on those two campaigns is the huge area that is planned to be covered with the planned measurement flights. Under good conditions measurements near the source of dust outbreaks will be obtained as well as data from far away areas like Barbados. The timeline for the airborne measurements is June, 9 to July 16. One week on the Island Sal followed by 4 weeks in Barbados. The strategy for a single measurement flight is to fly in high altitude to an area with a Saharan dust layer indicated by numerical models. During this flight lag a conical scan pattern will be applied in order to obtain a wind profile beneath the flight path. When an interesting layer is identified there will be on more lag well above the dust layer with a downward looking lidar beam to investigate the structure of the dust layer as good as possible followed by a descent into the layer to get in-situ information about the dust. The flight back will be in low altitude. During the last two sections of a measurement flight the lidar data are expected to be of minor interest, especially at the flights near Barbados where the dust layers are expected to be at a pretty low altitude. But beside the pathfinder task for dust/aerosol layers the measurement of the wind profile during the three ferry flights Germany – Sal (Cape Verde Islands) – Barbados – Germany will be a highlight of the campaign as a comparable huge area is covered. Quite impressing satellite photos of those dust outbreaks can be found on Wikipedia “Saharan dust”. Further information about the campaign can be found on: http://www.pa.op.dlr.de/saltrace/index.html .

Acknowledgements

The measurement campaigns with the synergy between several different sensors and with those results were only possible by the work of quite a lot of people from different institutes and companies as there are:
J. Trujillo, M. Kühn, A. Rettenmeier, R. Simmet, Y. Kaesler, O. Reitebuch, D. Heimann, U. Schumann, B. Weinzierl, H. Schlager, A. Minikin, C. Foster, R. Baumann, T. Sailer, K. Graf, H. Mannstein, C. Voigt, M. Scheibe, M. Lichtenstern, P. Stock, H. Rüba, D. Schäuble, A. Taverner, M. Rautenhaus, F. Holzäpfel, T. Gerz, H. Ziereis, M. Krautstrunk, C. Mallaun, D. Rees, S. Lugan, I. Smalikho et al.

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