First Airborne Doppler Lidar Observations of the Wind Field during MAP-SOP: Validation Results in the Vicinity of a High Altitude Jet.

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Abstract

First observations of the wind field have been performed with the new airborne Doppler lidar WIND during the MAP-SOP on October 11 and 12, 1999, just before IOP-6. The system has been developed in French-German cooperation of CNRS/CNES and DLR within the projekt WIND (Wind Infrared Doppler Lidar). It is the first airborne Doppler lidar for atmospheric research to retrieve the whole tropospheric wind profile between ground and flight level. Flying on board DLR Falcon 20, it is able to retrieve the three-dimensional wind vector with a vertical resolution of 250 m along the flight track.

The dynamics in the vicinity of a high altitude jet could be studied during a flight from Munich to Berlin. Wind velocities up to 50 ms^{-1} in 10 km altitude could be observed. Simultanuous measurements of the windprofiler radar of the German Weather Service in Lindenberg are in agreement within 1.8 ms^{-1} and 5 ° for the horizontal wind vector. Strong spatial gradients of the wind velocities on a scale of 200 km were observed while flying south. Measurements of WIND will be presented and compared with profiler data as well as with simulation results from mesoscale models (DWD *Lokal Modell*, French *meso-NH* model).

WIND Instrument

A pulsed airborne Doppler lidar with conically scanning technique has been developed within the scope of the French-German project WIND (Wind Infrared Doppler Lidar) conducted jointly by DLR (Deutsches Zentrum für Luft- und Raumfahrt), CNES (Centre National d'Etudes Spatiales) and CNRS (Centre National de la Recherche Scientifique). To our knowledge, WIND is presently the first airborne Doppler lidar for atmospheric research, capable of retrieving wind profiles to the ground by using nadir conical scanning. In contrast to airborne Doppler radar measurements, which could yield information only inside cloud and precipitation areas, airborne Doppler lidar measurements have the potential to sense clear air and partially cloudy atmosphere.

WIND measures the three-dimensional wind field from the ground to 500 m below the flight level with a vertical resolution of 250 m. The wind-profile is obtained by a Velocity Azimuth Display VAD technique (Browning and Wexler 1968). This is done by conically scanning around the vertical axis with an angle of 30 ° from nadir within 20 s. Combined with the movement of the aircraft, this results in a cycloid scanning pattern. WIND is a 10µm-heterodyne Doppler lidar consisting of a pulsed CO_2 and a continuous-wave CO_2 laser, a telescope, an optical mixing unit and a scanning device (Werner et al. 2001). It has been designed for installation on board the DLR Falcon 20 aircraft (Fig. 1). A major part of the whole system is a pulsed transverse-excited (TE) CO_2 laser emitting at 10.6 µm with a pulse repetition frequency of 10 Hz, an output energy between 100 mJ and 200 mJ and a length of 1 µs to 3 µs. It is sent out via the same telescope that is used as a receiver, and a Germanium scanner and Germanium window in the aircraft fuselage. The light is backscattered by naturally occuring aerosol particles in the diameter range of a few µm. The aerosols within this size range are advected by the mean wind and therefore the backscattered light is frequency-shifted due to the Doppler effect. The received signal intensity depends strongly on the aerosol loading of the atmosphere. Strong signals are received within the atmospheric boundary layer, whereas the signal is usually weak in the free troposphere where low aerosol concentrations exist.

WIND measurements during MAP-SOP

First observations of the wind field have been performed with WIND during the two flights on board the Falcon 20 aircraft on October 11 and 12, 1999, just before IOP-6. The scientific objective for a participation of WIND was to document flows above the Brenner pass and the atmospheric boundary layer organisation in the Italian Po valley. For the purpose of validation, a flight around the windprofiler radar WPR of the German Weather Service at Lindenberg near Berlin was conducted on 12 October 1999 (Reitebuch et al. 2001). The dynamics in the vicinity of a high altitude jet could be studied during this flight. The result of the validation is reported here, whereas the measurements over the Brenner Pass are presented by elsewhere (Dabas et al. 2001).

The synoptic condition on October 12, 1999 is characterised by a low pressure region over the eastern baltic sea and a high over the British Islands. The winds over Southern Germany and the Alps were quite low, but strong windgradients were dominant towards the Northeast. The horizontal wind velocity over Europe retrieved from the *Lokal Modell* of the German Weather Service shows strong northwesterly winds with a maximum up to 60 ms^{-1} in the upper troposphere over Northern Germany and Denmark. The investigated area around Lindenberg was just at the southern edge of a strong jet stream. Cirrus and cumulus clouds could be observed, during the flight above the area.

The flight track around the WPR is shown in Fig. 3. The Falcon was flying several rectangular boxes centered at Lindenberg, Germany (52.21N, 14.13E) in a height of 11.3 km. Comparisons of wind profiles taken during flights from East to West (flight track 1, 13:35 UTC) and North to South (flight track 2, 13:40 UTC) are made with the windprofiler radar WPR (Steinhagen et al. 1998) and the *Lokal Modell* LM of the German Weather Service (DWD 1999). Measurements of the WIND Doppler lidar were obtained by averaging data over five scanner revolutions (100 s), which corresponds to a width of the swath at ground of 13 km and an along-track resolution of 20 km. Measurements of the WPR are averaged over 25 minutes. Data from LM were calculated for a time of 13:30 UTC with a prognostic run beginning at 12:00 UTC.

Results

A comparison of the profiles for the horizontal wind vector is shown in Fig. 4 for the East-West flight track 1. Profiles of the horizontal wind velocity show a remarkable wind shear from 10 ms^{-1} near ground up to 50 ms^{-1} at 10 km height. The correspondence among the measurements from WIND Doppler lidar, WPR and the 1.5-hour prediction of *Lokal Modell* LM is excellent, except in a region from 4 km to 6 km during flight track 1, where SNR was very low. A closer look at the height 8 km to 10 km from profiles of flight track 1 and 2 shows a small decrease in wind velocity of 2 ms^{-1} for the WIND and LM data. This is due to the horizontal wind gradient on a scale of 50 km and demonstrates the capabilitiy of WIND to resolve small changes of wind velocity. A statistical comparison has been performed although it is only limited to a small number of data on the two flight tracks. The comparison of the WIND and WPR measurements yield a standard deviation of 1.8 ms^{-1}, a bias of -0.7 ms^{-1} and a relative standard deviation of 6 %; the corresponding values for the WIND and LM comparison are a standard deviation of 1.5 ms^{-1}, a bias of -0.5 ms^{-1} and a relative standard deviation of 6 %. The result of this comparison are quite remarkable, taking into account that the calculated values for standard deviation includes statistical errors from both sources.

While flying south from Berlin to Munich strong spatial gradients of the horizontal wind speed could be observed. Fig. 4 shows the WIND measurements, while flying from southwards for 250 km in the vicinity of the jet-stream beginning at the Northern side of the rectangular box (Fig. 2). An overall of 11 wind vector profiles with a separation of 25 km were obtained, when averaging over 5 scanner revolutions. Mesoscale simulations from the non-hydrostatic model *meso-NH* (Lafore et al. 1998) with a horizontal resolution of 10 km are compared to measurements of the WIND system for the same slice through the atmosphere (Fig. 5). Simulations are performed for 14:00 UTC, based on an initialisation on the 12:00 UTC analysis of ARPEGE or ECMWF. The agreement between the *meso-NH* and WIND measurements is good in all levels. A significant difference could be observed for the higher wind speeds in the jet-level between the initialisation with ARPEGE and ECMWF. The simulation output initialised with ARPEGE, which is slightly higher than ECMWF, corresponds better to the WIND measurements with a bias of 0.3 ms^{-1} and a standard deviation of 1.9 ms^{-1}.

Conclusion

The first conical scanning Doppler lidar on airborne platform has been successfully developed in the scope of the French-German WIND project. First flights in 1999 did demonstrate the excellent capability for measuring the whole wind profile between ground and flight level with a nadir pointing conical scanning lidar. Comparisons with windprofiler radar measurements of the German Weather Service showed an correspondence within 1.5 ms^{-1} and 5 ° for the horizontal wind vector. The agreement between WIND measurements and mesoscale models models (DWD *Lokal Modell*, French *meso-NH* model) in the vicinity of a high altitude jet is remarkable. Further improvements have to be implemented. The source of systematic errors in the determination of the vertical aircraft speed has to be identified to extract vertical wind velocities. There is strong need to improve the horizontal resolution of the system, which requires to retrieve the wind field within only one instead of five scan revolutions. Simulations indicate that this could be achievable by increasing the laser energy. The modular concept of the WIND system allows the application of new scan techniques with minor modifications. Foreward-afterward scanning while looking downward could be used to resolve horizontal wave-like structures in the atmosphere in a vertical plane (Drobinski et al. 2001).

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References:

Browning, R. A., R. Wexler, 1968: The determination of kinematic properties of a wind field using Doppler radar. J. Appl. Meteor., **7**, 105-113.

Dabas, A., Ph. Drobinski, O. Reitebuch, P. Delville, R. Benoit, P. Flamant, and Ch. Werner, 2001: The wind field over the Brenner pass viewed by the airborne Doppler lidar WIND. MAP newsletter no. 15, this issue.

Deutscher Wetterdienst, 1999: Quarterly Report of the Operational NWP-Models of the Deutscher Wetterdienst, No. **21**. [Available from Deutscher Wetterdienst, Frankfurter Str. 135, D-63067 Offenbach/M., Germany]

Drobinski, Ph., J. Perin, A. M. Dabas, P. H. Flamant, and R. A. Brown (2000): Simulation of the retrieval of a two-dimensional wave-like structure in the atmospheric boundary layer by an airborne 10.6 µm-heterodyne doppler lidar. Meteor. Zeitschrift, **9**, 329-338.

Lafore, J. P., J. Stein, N. Asencio, P. Bougeault, V. Ducrocq, J. Duron, C. Fischer, P. Héreil, P. Mascart, V. Massson, J. P. Pinty, J. L. Redelsperger, E. Richard, and J. Vilà-Guerau de Arellano, 1998: The Meso-Nh Atmospheric Simulation System. Part I: Adiabatic Formulation and Control Simulation. Ann. Geophys., 16, 90-109.

Reitebuch, 0., Ch. Werner, I. Leike, P. Delville, P. H. Flamant, A. Cress, and D. Engelbart, 2001: Experimental validatioin of wind profiling performed by the airborne 10µm-Heterodyne Doppler Lidar WIND. J. Atmos. Ocean. Tech., in print.

Steinhagen, H., J. Dibbern, D. Engelbart, U. Görsdorf, V. Lehmann, J. Neisser, and J.W. Neuschaefer, 1998: Performance of the first European 482 MHz Wind Profiler Radar with RASS under operational conditions. Meteorol. Zeitschrift, N.F. **7**, 248-261.

Werner, Ch., P. H. Flamant, O. Reitebuch, C. Loth, F. Köpp, P. Delville , J. Streicher , Ph. Drobinski, S. Rahm, B. Romand, E. Nagel, Ch. Boitel, M. Klier, D. Bruneau, H. Herrmann, A. Dabas, and P.H. Salamitou, 2001: Wind infrared Doppler lidar instrument. Optical Engineering 40 (1), 115-125.

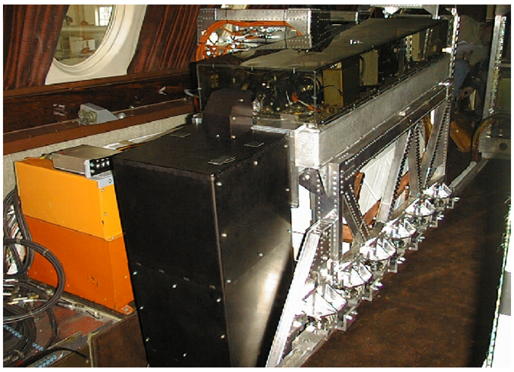

Fig. 1. Photo of Doppler lidar WIND inside DLR Falcon 20 aircraft with telescope (black), optical bench and TE CO_2 laser (white) inside aluminium frame.

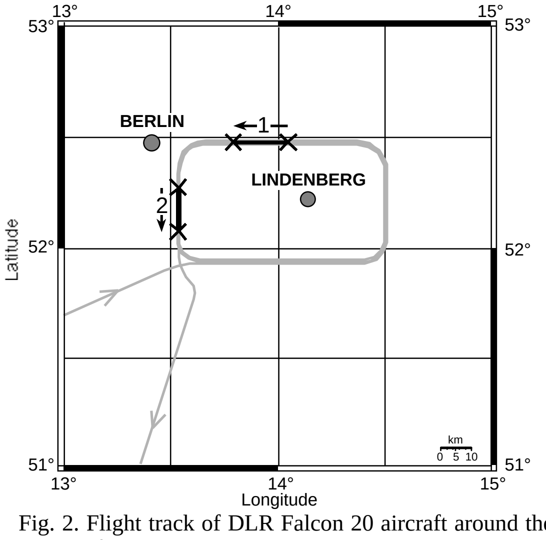

Fig. 2. Flight track of DLR Falcon 20 aircraft around the windprofiler radar WPR at Lindenberg, Germany on October 12, 1999; East-West track 1 and North-South track 2 are indicated.

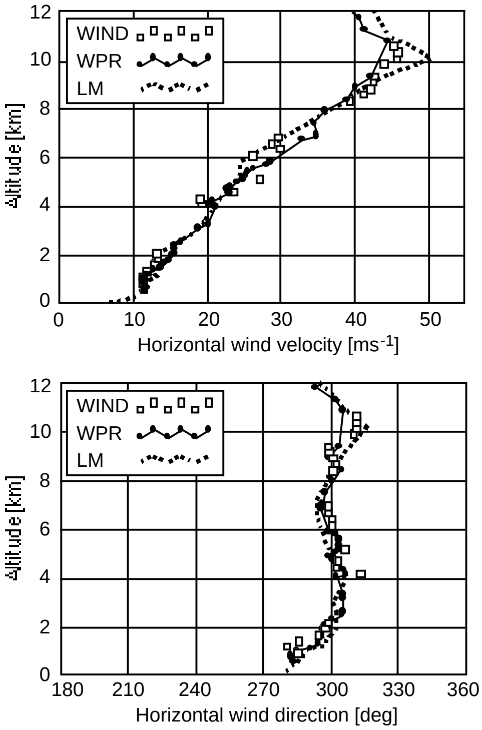

Fig. 3. Profiles of horizontal wind velocity (top) and direction (bottom) from Doppler lidar WIND (open squares), windprofiler radar WPR (full circles) and *Lokal Modell* LM (dashed line) on October 12, 1999 on East-West flight track 1; WIND at 1335 UTC (averaging time 100 s); WPR from 1335 UTC to 1400 UTC; LM at 1330 UTC.

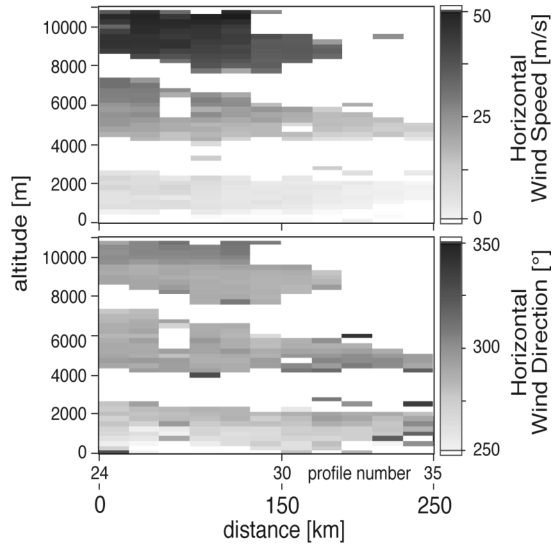

Fig. 4. Measurements of the WIND system on October 12, 1999, flying from North to South in the vicinity of a high altitude jet, white areas: no reliable data.

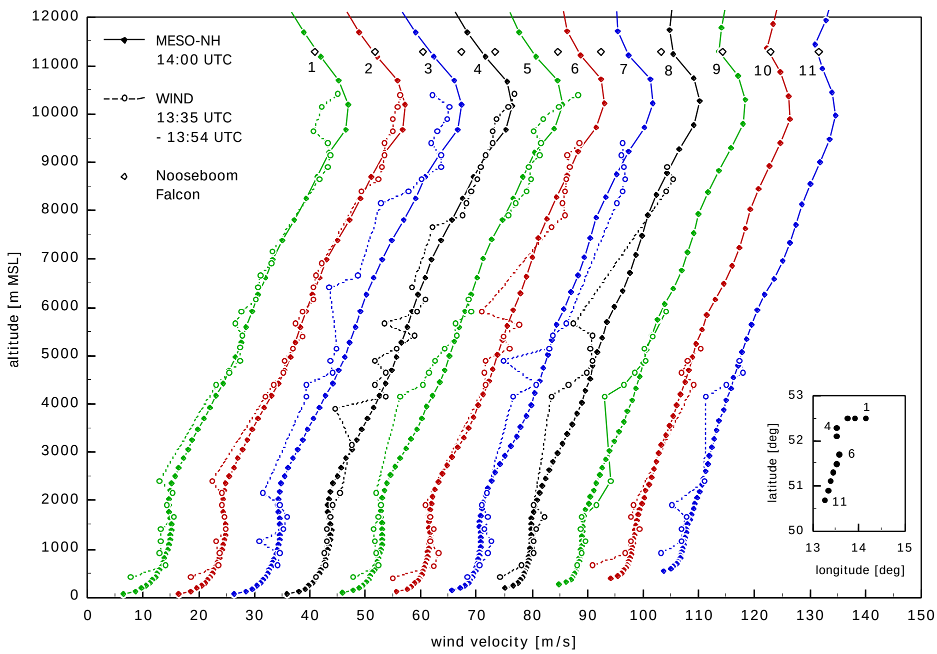

Fig. 5. *Meso-NH* simulations (solid), WIND measurements (dashed) and Falcon in-situ measurements from the nooseboom (diamond); October 12, 1999 for North to South flight track; successive profiles are separated by adding 10 ms^{-1}.