IMPACT OF AIRBORNE AND FUTURE SPACEBORNE WIND LIDAR OBSERVATIONS OF ADM-AEOLUS ON WEATHER PREDICTION SKILLS

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ABSTRACT

Measurements of winds throughout the atmosphere are crucial for both numerical weather prediction NWP and climate studies. Nevertheless observations of height profiles of the global wind field are outstanding and profile measurements of wind are prioritized by WMO Expert Teams for global NWP.

Recently the positive impact of airborne wind lidar observations from the Atlantic THORPEX Regional Campaign on numerical weather prediction was demonstrated. For the first time airborne wind lidar observations were assimilated into a global model at ECMWF. These results give further confidence in the importance of wind profile observations and support the high expectations on ESA’s wind lidar mission ADM-Aeolus, which will be the first lidar mission to sense the global wind field from space.

The results of the impact studies for airborne wind lidar observations on ECMWF model analyses and forecast skills will be presented. The conclusions from the assimilation experiments with real airborne observations add further confidence to the impact studies using simulated ADM-Aeolus wind lidar observations. The findings from these ADM-Aeolus impact studies will be discussed.

1. INTRODUCTION

Global observations of wind profiles at all levels are recognized as the number one priority for global numerical weather prediction from World Meteorological Organization WMO expert teams during recent years [1]. The wind profile is still poorly observed globally, because the majority of the satellite sounding instruments provides mass rather than wind information. Global satellite wind observations are obtained from scatterometers for the sea-surface and for atmospheric motion vectors and cloud-drift winds from imaging instruments.

The measurement of the wind vector profile by airborne Doppler lidar with conical scanning was first demonstrated in 1999 [2]. These airborne lidar instruments were used since then during field experiments for process and case studies of mesoscale phenomena [e.g. 3,4]. Targeted observations with an airborne Doppler lidar were performed in 2003 for the first time with the purpose to extend the scope of the previous field campaigns towards assimilating the lidar measurements directly into numerical weather prediction models.

2. IMPACT OF AIRBORNE WIND LIDAR OBSERVATIONS

During the Atlantic THORPEX Regional Campaign A-TReC (THORPEX: The Observing System Research and Predictability Experiment) in autumn 2003, the airborne 2-µm coherent Doppler lidar of DLR was used to observe the wind in predicted sensitive regions of the North Atlantic [5,6]. During 8 flights a total of 1600 wind profiles were obtained and assimilated into the global model of the European Centre for Medium-Range Weather Forecasts ECMWF (version T511L60, 12-h 4D-VAR). It was the first time that wind lidar observations were assimilated into a global model [7,8], in contrast to one earlier assimilation study with water vapor observations and a global model [9, 10]. It could be shown that airborne wind lidar observations have a significant impact on the analyses as well as on forecast skills due to their high accuracy, high spatial resolution, and low representativity error. The instrumental error of the lidar was assessed by comparison with 33 collocated dropsondes, yielding a negligible systematic error and a random error between 0.75-1.0 m/s [5]. A low representativity error is obtained with airborne lidar observations due to the applied conical scanning technique, which samples the atmospheric volumes much better than dropsondes or radiosondes. Thus the total wind lidar observation error was only 1-1.5 m/s, compared to 1.8-3 m/s for dropsondes and radiosondes, or 2-5.7 m/s for satellite cloud-drift winds [8].

The measurements reduce the errors of the 1-4 day forecasts of geopotential height (Fig. 1), wind and humidity over Europe throughout the troposphere. On average the forecast error is reduced by 3% (Fig.2) corresponding to 1 m for the 3-day forecast. The observational impact per observation is about 40% higher for lidar than for a dropsonde, yielding to a 3 times higher information content of the lidar data, taking into account the higher number of lidar observations.
Figure 1. Impact of airborne wind lidar observations for the 4-day forecast during A-TReC in November 2003; color-coded is the difference of root mean square error in geopotential height at 500 hPa between lidar and control experiment; green values indicate reduction of forecast error (from [7]).

Figure 2. Relative reduction of errors of geopotential height at 500 hPa over Europe for different experiments for lidar observations (yellow, light blue, green, red) and dropsonde observations (blue) during A-TReC in November 2003 (from [7]).

Furthermore the dataset was also used to assess the structure of key analysis errors by comparing it with the analysis departures of the wind lidar observations [11]. The total deployment time of the airborne lidar during A-TReC covers a period of 2 weeks and a total duration of 28.5 flight hours, which is rather limited for an impact assessment of an observation system. The next targeted observation experiment in the Pacific – named THORPEX Pacific Asian Regional Campaign (T-PARC) – offers the opportunity to extend the observational dataset significantly. It is planned that the DLR Falcon aircraft equipped with a wind and water vapor lidar and a dropsonde unit will be operated from Japan from end August to begin October 2008 with a total amount of about 100 flight hours [12]. Objectives of the Falcon flights are the study of extra-tropical transition of tropical cyclones and the targeting of typhoons. In addition the Naval Research Laboratory NRL P-3 aircraft will be operated during T-PARC with a wind lidar, the Doppler radar ELDORA (ELectra DOppler RAdar) and a dropsonde unit.

3. IMPACT OF SPACEBORNE WIND LIDAR OBSERVATIONS OF ADM-AEOLUS

In 1999 the European Space Agency ESA decided to establish a Doppler wind lidar mission named Atmospheric Dynamics Mission ADM-Aeolus. The mission will provide profiles of one component of the horizontal wind vector from ground up to the lower stratosphere (20-30 km) with 0.5-2 km vertical resolution and a precision of 1-3 m/s depending on height above ground. A line-of-sight LOS wind profile will be obtained every 200 km with a horizontal averaging length of 50 km [13, 14]. About 3000 wind profiles will be obtained per day, which is a factor of 3 times higher than the number of radiosonde profiles. In contrast to the airborne lidar, which measures profiles of the horizontal wind vector with a vertical resolution of 100 m every 4-10 km, the profiles from ADM-Aeolus will be provided for one component of the horizontal wind vector with a coarser vertical resolution and a larger horizontal averaging length. ADM-Aeolus will provide global horizontal coverage up to altitudes of 20 km (or even 30 km) with about 2 times more profiles on 1 day compared to all profiles of the airborne experiment during the 2 weeks in November 2003. The instrument on ADM-Aeolus called ALADIN (Atmospheric LAser Doppler Instrument) is based on a direct-detection wind lidar transmitting at 355 nm, while the airborne observations were derived from a 2-µm coherent lidar. ALADIN will provide wind profiles throughout the whole troposphere and lower stratosphere due to its two receivers for molecular and aerosol/cloud backscatter, while the 2-µm wind lidar is only sensitive to aerosol backscatter. The achieved instrumental error for the airborne wind lidar observations (< 1 m/s) is about half the requirement for ALADIN in the troposphere (< 2 m/s).

Numerous studies were performed in the past, showing the impact on forecast skills of space-based wind lidar observations using simulated data [15-20] or through data denial experiments [21]. Results with a data assimilation ensemble technique at ECMWF show that ADM-Aeolus will provide benefits comparable to the
radiosonde and wind-profiler network with analysis impact particularly over oceans and the tropics until 5 days [15]. An Observing System Simulation Experiment OSSE for ADM-Aeolus [16] shows an average improvement of the 500 hPa wind forecast for 5 days of 0.25 days (Northern Hemisphere) and 0.5 days (Europe). It is worth noting in this context that the typical advancement of weather forecast skills on the medium-range is in the order of 1 day during 10 years resulting from improvements in the numerical model, observing system and computing power [22]. An impact assessment for operational wind lidar missions post ADM-Aeolus consisting of a network of up to 3 satellites to achieve higher horizontal coverage and/or a second line-of-sight components were performed using a Sensitive Observing System Experiment SOSE [18]. The study shows that a constellation of 3 satellites would double the impact of ADM-Aeolus with 1 satellite.

SUMMARY AND OUTLOOK

For the first time airborne Doppler wind lidar observations were assimilated into a global model. A significant positive impact on analysis and forecast skill scores of the ECMWF global model was achieved. The mean reduction of the 2-4 day forecast error of the geopotential height over Europe was around 3 %. The information content of the wind lidar observations was 3 times higher than of dropsondes, released during the same flights. These results support the high expectations for the future satellite wind lidar on ADM-Aeolus.

Already in summer 2008 the THORPEX Pacific Regional Campaign T-PARC offers the opportunity to extend the basis of the wind lidar impact studies significantly. Two aircrafts – the NRL P-3 and the DLR Falcon – will be equipped with a wind lidar, dropsondes, a water vapor lidar (only Falcon), and a Doppler radar (only P-3). The DLR Falcon will be based in Japan for a period of 6-weeks with a total of 120 flight hours (including transfer), which is 4 times higher than during the earlier North Atlantic campaign.

ADM-Aeolus will provide wind profiles for a 3-year period starting about 2010. An operational follow-on wind mission from US or European agencies might not be in place within the next decade, although efforts are ongoing to close the gap between the end of ADM-Aeolus and a possible operational wind lidar mission. One interesting possibility to obtain wind profiles at least over some parts of the globe might be the deployment of several wind lidars on commercial aircrafts. These wind lidars could sense the wind vector profile below air traffic corridors like the North Atlantic or Northern Pacific.

REFERENCES


[12] DLR 2008: THORPEX Pacific Asian Regional Campaign T-PARC Website: http://www.pa.op.dlr.de/tparc/


