IMPACT ASSESSMENT OF A DOPPLER WIND LIDAR IN SPACE ON ATMOSPHERIC ANALYSES AND NUMERICAL WEATHER PREDICTION

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ABSTRACT

Wind profiles from space would help to fill in data sparse areas over the oceans, the tropics, and the southern hemisphere. ESA has conducted a phase A study for the Earth Explorer Atmospheric Dynamics Mission (ADM). A polar satellite with a Doppler Wind Lidar (DWL) on board is proposed for this mission and which is described in this session by Ingmann. The DWL measures wind profiles in the troposphere and stratosphere up to 26.5 km height. Performance assessment studies have been performed for this system by simulation. In a statistical assessment it is investigated whether the DWL provides sufficient data quality in clear air, but also in cloudy regions. Obviously clouds are good scatterers, but could obstruct lower-lying air masses. We find that even in cloudy regions cloud penetration is sufficient to detect extreme tropospheric wind shear or the areas with large humidity flux in most cases. After the statistical assessment of performance an Observation System Simulation Experiment (OSSE) was performed. This experiment over a two-week period confirms earlier assessments that the ESA ADM will demonstrate the impact of space-borne DWL on atmospheric analyses, used for numerical weather prediction and climate analyses.

1. Introduction

ESA has recently approved a Doppler Wind Lidar (DWL) to fly on a free-flyer platform orbiting dawn-dusk at 400 km altitude. Rigorous trade-off studies during the Atmospheric Dynamics Mission (ADM) phase-A have resulted in the definition of a lidar concept, hereafter named ADM_UV, operating in the ultraviolet part of the spectrum at 355 nm laser wavelength. In order to guarantee the demonstration value of this mission for Numerical Weather Prediction (NWP) and in climate studies, extended atmospheric analyses and forecast runs are needed to better quantify this potential DWL impact and to address specific issues of concern during the ADM phase A study, such as profile quality and coverage.

The objective of this activity is demonstration of the impact on atmospheric circulation and on NWP of wind profiles from ADM_UV and comparison to the impact of conventional wind profiles (TEMP/PILOT) with respect to the existing Global Observing System (GOS). This demonstration is made by means of OSSEs (Observing System Simulation Experiments). It serves to consolidate the requirements for an operational mission by assessing the sensitivity of the impact of ADM_UV to key mission parameters to aid in the design of future operational missions, as well as to demonstrate the impact of the minimum useful requirements and performance of the Atmospheric Dynamics Earth Explorer Mission.

1.1 Background

The quality of state-of-the-art NWP is among other things determined by the availability and quality of meteorological observations. NWP models have improved much over the last decades, and advanced 4D-var techniques are now being used for the analysis. The spatial resolution of global circulation models has as well improved, which leads to a need for more observations on the sub-synoptic scales. On these scales the wind field, rather than the atmospheric temperature or humidity fields determines the atmospheric dynamics. Furthermore, the prime factor determining meteorological instability is vertical wind shear. In the tropics, for an accurate definition of the Hadley circulation, 3D wind information has been lacking. Conventional wind profile data lack coverage and a uniform distribution over the globe.

For the study of climate processes extensive reanalyses experiments are being conducted. These experiments use the technique of data assimilation, as used for NWP, to establish long time series of the weather in support of climate studies. In the OSSE evaluation we investigated extensively the analysis impact of wind profile data, thus supporting the climate application.

Recent OSEs (Observation System Experiments) by the European Centre for Medium-range Weather Forecasts (ECMWF) (Isaksen, 1998, and Kelly, 1997) have confirmed the relevance of tropospheric wind profile data for NWP. ECMWF tested this in a series of experiments where they excluded conventional wind profile observations (TEMP/PILOT), or parts thereof in the free troposphere, and compare to experiments where conventional (TEMP), or satellite (TOVS) temperature or humidity profile data, or single level observations, were excluded.

Complementary experimentation has been performed at the Deutcher Wetter Dienst (DWD) to test the impact of continental North American wind profile observations (Wergen, 1998). From these experiments, a few points are noteworthy. These experiments confirm largely the importance of wind profile data, compared to the importance of temperature/humidity data. Near-surface winds (PBL winds) seem less important than winds in the middle and upper troposphere. In the OSE experiments, a small number of (good quality) wind profiles already shows a positive impact on the quality of the NWP. TEMP/PILOT OSE work with the US National Center for Environmental Prediction, NCEP, NWP model confirms some of these conclusions. For these reasons, the ADM requirements have been focussing on quality rather than quantity over the last few years, in accordance with the WMO requirements. Moreover, past experience in data assimilation shows that quality can usually not be traded off against quantity without a degrading effect.

The results and conclusions of OSEs give an insight into the effect of a particular type of *existing* observation has in the *existing* data assimilation system. However, it is difficult to draw from this easily conclusions on the added value of supplementary measurements on the meteorological analyses and forecasts. This added value may be investigated through OSSEs. Météo France has made a first step. The work encompassed to run OSSE experiments with the French Arpege NWP model, in order to test the impact of the OSSE data base DWL wind profiles from a 10 micron laser attached to a free flyer satellite in a polar orbit (Cardinali et al, 1998). This scenario provided a wind profile density over the oceans comparable to the current density over land in the Northern Hemisphere. The assimilation experiments were performed with a low-resolution version of the NWP model (T42), and as expected the DWL impact could be well demonstrated.

DWL OSSEs performed in the United States indicate an impact even for low measurement accuracy. However, the forecast quality was almost exclusively based on DWL information from the Southern Hemisphere and therefore show obviously an improvement against the control analysis which did not contain relevant observations in this area.

For an operational system, the impact on NWP often depends on the skill of the data assimilation system used. Therefore it is worthwhile to perform an OSSE with the state-of-the-art ECMWF 4D-var system in order to consolidate the requirements for an operational mission. Based on past work (especially of ECMWF and Météo France, as well as preparatory work by KNMI), those additional questions have to be addressed. The main critical points to be considered are up-to-date model dynamics and resolution (desirable to have T319 L31), as well as the identification and consolidation of the driving key mission parameters.

1.2 Report outline

Chapter 2 discusses the general OSSE setup and required attributes. Most of necessary preparatory work to perform the OSSEs has been the result of many studies, started in the early 1990's (Stoffelen, 1994), (Becker, 1995), (Stoffelen and Marseille, 1998). The result of these studies is a database with simulated observations of conventional meteorological observation systems and three infrared lidar concepts that were proposed in the mid 1990's. The simulation of the ADM_UV concept is using the LIPAS simulation tool (Veldman, 1999). It includes simulation of data coverage according to the ADM user requirements and profile quality simulation according to expected instrument characteristics. Results of a pre-OSSE analysis to assess profile quality in clear air, *i.e*. without clouds, and the impact of clouds on atmospheric penetration are presented. Moreover shear and flux visibility are assessed in relation to clouds. After validation, the new concept is added to the OSSE database at ECMWF. Chapter 3 discusses results of the OSSEs performed to demonstrate the impact of the ADM_UV concept on NWP and atmospheric circulation analyses.

Table 1. MSE of analysis wind fields for the NoDWL and DWL experiments verified against the nature run. The mean is taken over 15 cases, i.e. analyses at 12 UTC from 19930206 until 19930220. The effective lidar impact (effect.) is defined as the difference of the MSE of the NoDWL and DWL experiment. The total lidar data impact equals the MSE of the differences of the analysed fields from the NoDWL and DWL experiments.

	500 hPa				200 hPa			
	NoDWL	DWL	effect.	total	NoDWL	DWL	effect.	total
Globe	20.98	12.52	8.46	14.11	27.88	15.78	12.10	18.86
N.Hemis	11.10	9.34	1.76	4.85	7.63	6.45	1.18	2.81
S.Hemis	31.73	14.75	16.98	25.58	40.61	16.63	23.98	32.20
Tropics	20.17	13.42	6.75	12.01	34.98	23.78	11.20	21.41
Europe	3.14	3.01	0.13	0.78	2.92	2.83	0.09	0.60
N.Atlantic	11.98	9.94	2.04	4.71	9.84	8.27	1.57	3.57
N.America	9.26	7.25	2.01	5.27	8.53	5.99	2.54	4.12

To compare the observational network as generated in Stoffelen et al. (1994) with the current operational network we compared the observation statistics of the OSSE with the operational observation statistics in the February period of 1999. The results are condensed in Table 2 and show that the OSSE uses more radiosondes (TEMPs), less AIREPs, less SATOBs and less DRIBUs.

Table 2. Global observation coverage and statistics of OSSE related to the operational system in 1999 for the same period, i.e. 5 February 18UTC to 16 February 12UTC. (o-b) Denotes the background departure and (o-a) the analysis departure.

	OSSE experiment			Operations 1999		
	NUMBER OF data	data RMS		number of data	data RMS	
		o - b	o - a		o - b	o - a
TEMP-wind[1] [m/s]	830,118	3.2	2.8	307,301	3.7	3.0
TEMP-T[1] [K]	400,290	3.8	3.7	402,404	3.0	2.8
TEMP-q[1] [kg/kg]	264,425	0.16E-2	0.15e-2	215,811	0.24e-2	0.23e-2
PILOT[1] [m/s]	328,870	3.2	2.8	241,334	3.7	3.0
AIREP-wind[1] [m/s]	100,060	5.8	5.3	920,698	4.3	4.0
AIREP-T[1] [K]	66,774	2.6	2.5	407,484	2.2	2.2
TOVS[1] [K]	0	-	-	2,347,298	6.5	5.0
LIDAR[1] [m/s]	532,992	4.2	3.4	0	-	-
SYNOPship-10U [m/s]	49,794	3.0	2.8	67,754	3.9	3.8
DRIBU-10U [m/s]	2,618	5.1	4.9	11,712	3.3	3.0
SCAT-10U[1] [m/s]	99,685	2.7	2.1	114,756	1.7	1.2
SYNOPland-2RH [%]	24,727	14.0	14.0	282,571	14.0	14.0
SYNOPship-2RH [%]	16,960	15.0	13.0	33,948	16.0	15.0
SATOB-wind [m/s]	37,576	4.3	4.1	981,886	5.3	5.2
PAOB (Pa)	3,255	229	207	3,353	307	273
RAOB-WIND [M/S]	1,183,830	3.9	3.5	855,975	5.2	4.6

[1] For instruments measuring profiles, the number of data equals the sum of data at all levels. The data RMS is an average over all levels.

[2] Only the closest 10m u-wind vector of the two available ambiguities is considered.

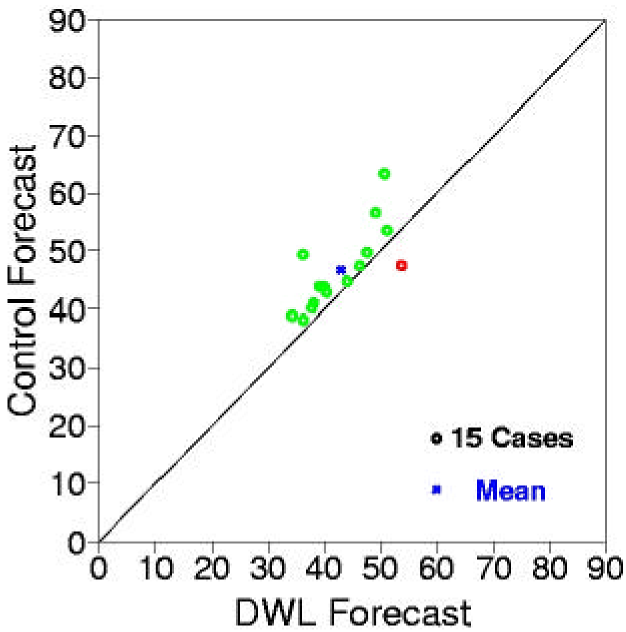

Figure 1. Comparison of control forecast and DWL forecast for 15 cases.

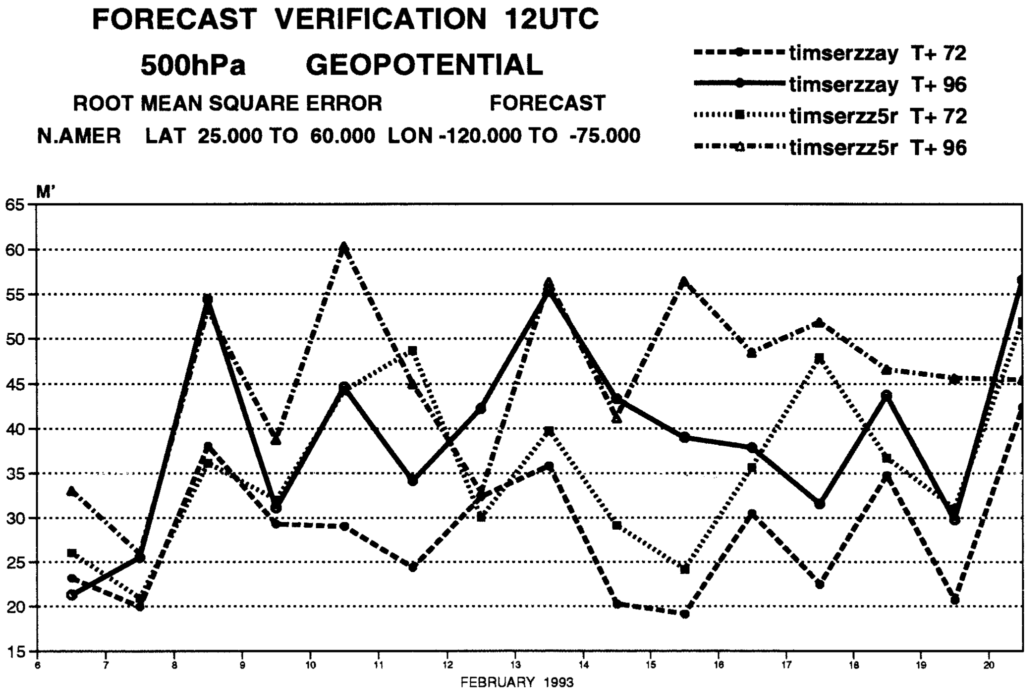

Figure 2. Comparison of reference run (NoDWL) with experiment run including lidar wind data. Analyzed period: 1993020512 – 1993022012, 6 hour assimilation window. Model: T319L31, no waves, no TOVS, no SSM/I, IFS cycle 21r1 + modification to allow the use of simulated HLOS winds form Doppler wind lidar data. 10-day forecasts were run once a day initiated with the analysis at 12 UTC.
az5r: Reference or control or NoDWL assimilation, no lidar winds.
zz5r: 10-day forecasts from az5r
azay: Same as az5r, including lidar wind data starting at 1993020518.
zzay: 10-day forecasts from azay

2. Observing System Simulation Experiments

This report addresses the use of OSSEs to assess the potential impact of the proposed ADM_UV DWL on atmospheric analyses and on NWP. More generally, OSSEs can be used to assess the potential impact of any new observing system. The basic elements of an OSSE are a state-of-the-art data assimilation system, a nature run “truth” and a database of simulated observations. The latter includes both simulated observations of conventional meteorological systems, covering a network similar to the operational network, and simulated observations of the new instrument to be assessed. Generation of the nature run and data base for conventional observation systems has been reported extensively in the past (Stoffelen et al, 1994), (Becker et al, 1995).

To build up a database of simulated observations one needs a description of the atmosphere over a certain time period. For this purpose, a “true” atmosphere is generated through a long integration period of a forecast model, initiated with an atmospheric analysis. This is called the “nature run”. The nature run we use in this study was the result of a 30-day integration, initiated on 5 february 1993 00 UTC and ended on 7 march 1993 00 UTC. Integration was performed with the operational forecast model at ECMWF in 1993, *i.e.* T213 horizontal and 31 levels vertical resolution (Stoffelen, 1994). Mean atmospheric characteristics during the OSSE assimilation period, *i.e.* 6 February 1993 12UTC until 20 February 1993 12UTC are displayed in figures 1 and 2.

3. Conclusions

In this study we realistically simulated the UV Doppler Wind Lidar as proposed for the ESA Core Explorer Atmospheric Dynamics Mission, ADM_UV. ADM_UV was simulated, validated, and added to ECMWF OSSE database. In particular, a closer look was given to the nature run clouds, but no serious deficiencies were found. The relative lack of PBL clouds over the oceans as compared to satellite observations may be improved. However, we found that in the PBL over the ocean, the DWL impact is very limited due to the presence of the ASCAT scatterometer.

ADM_UV has a clear and demonstrable positive impact on the analyses and forecasts in the northern hemisphere. In the tropics and southern hemisphere the impact is overwhelmingly positive, but here the OSSE observing system is not representative of the real world observing system. In particular in the southern hemisphere, the incapability to realistically use satellite temperature sounding measurements is regretful. However, based on current operational experience at ECMWF, this is of little limitation in the northern hemisphere.

The average benefit of lidar data on medium-range forecast in the OSSE was about 0.25 days in the northern hemisphere (above 20N). Local impacts varied and were up to 0.5 days, for example for Europe. To test the significance of our results we verified that time series of forecast impact showed sufficient variability. On the other hand, in a clear majority of cases was the DWL forecast better than the control.

Good quality ADM_UV wind observations have a clear and beneficial impact on the analyses. Some large and beneficial forecast impacts of ADM_UV can traced back to areas with large analysis impact.
However, inaccurate ADM_UV data causes locally negative impacts. This occurs probably because those observations are not properly weighted against the background model fields in the analysis. In the local absence of good quality observations the background error estimate becomes poor, probably frequently resulting in detrimental observation impacts in the analysis. In areas with extensive high-level cloud cover negative impacts were most frequent. We may conclude from this that:
The tuning of data assimilation systems is very important for achieving beneficial observation impact and OSSE could be used for this; Quality control on real observations is very important in cloudy regions.

Wind profile observations are of key importance to the GOS, as demonstrated here again. However, the operational profile network is expected to further decrease in the future. As an illustration of this fact we note that the conventional wind profile network in operations is much smaller than that used in the OSSE. This will result in a larger impact of satellite data in the future in the northern hemisphere, both for mass and wind observations. Moreover, the simulated quality in the OSSE data base was too optimistic for the conventional wind profiles. This somewhat reduces the improvements brought by ADM_UV in the OSSE. On the other hand, more AIREP are available nowadays, mainly resulting in tropopause flight level observations, but also some profiles near airports. We rigorously tested the presence of a so-called fraternal twin problem, but found no substantial evidence of such a problem.

4. Recommendations

Although we have verified in this study that ADM_UV is indeed capable of demonstrating the potential value of space-borne wind profile observations for improving atmospheric analyses and NWP, this study was of a limited nature and more experimentation is recommendable.
OSSEs for other and more periods would reveal more about the significance of the results that we have found here. A two-week assimilation period is generally though of as the minimum to be able to demonstrate impact with an OSE or OSSE.

Moreover, it will be useful to study several scenarios of ADM_UV, such as for example a best and worst case scenario based on different instrumental and sampling options, or for different ways of data processing, in particular to test quality control.

OSSE can be used to tune data assimilation systems.

Quality control is very important. In the OSSE low–quality ADM_UV observations showed often detrimental impact. LITE observations may be useful to investigate the interaction of a lidar with a cloudy atmosphere and to study quality control issues. Also air and ground measurements may help to verify processing schemes.

Where ADM_UV is designed to demonstrate the capability of a space-borne DWL, OSSE could be used to study scenarios for an operational meteorological mission to be implemented when ADM_UV has successfully flown. Options for targeting LOS profiles, multiple LOS or even multiple satellites could be tested.

To avoid the fraternal twin problem we recommend the use of a foreign model for the production of the nature run. These fields can then be interpolated and processed in any location to provide an OSSE data base in standard meteorological format. The ECMWF has a great capability to run OSSEs on such input.

OSSEs including TOVS data would be better capable of assessing the relative benefit of temperature and wind sounding in the southern hemisphere and tropics. Simulation of AIRS or IASI or other new observation systems is also worthwhile. However, we note that for these observations, cloud clearing is a major issue and consequently error properties are complex and more difficult to simulate realistically.

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