THE ATMOSPHERIC DYNAMICS MISSION

P. Ingmann and J. Fuchs (*)

and the members of the ADMAG[1]

(*)ESA/ESTEC, P.O. Box 299, NL-2200 AG Noordwijk, The Netherlands

ABSTRACT

The primary aim of the Earth Explorer Atmospheric Dynamics Mission is to provide improved analyses of the global three-dimensional wind field by demonstrating the capability to correct the major deficiency in wind-profiling of the current GOS and GCOS. The ADM will provide the wind-profile measurements to establish advancements in atmospheric modelling and analysis. There is an intimate link between progress in climate modelling and progress in numerical weather prediction (NWP) as our understanding of the atmosphere is largely based on the experience of operational weather centres. Long-term data bases are being created by NWP data assimilation systems to serve the climate research community. It is widely recognised therefore that the impact of a new global atmospheric observing system on our understanding of atmospheric dynamics should be evaluated primarily in the context of operational weather forecasting.

New insights into the atmosphere through the provision of wind profiles are expected for NWP but also for climate research. The ADM is addressing one of the main areas discussed under Theme 2 of the 'ESA Living Planet Programme' (ESA, 1998). Although there are several ways of measuring wind from a satellite, only the active Doppler Wind Lidars (DWL) has the potential to provide the requisite data globally. It is the only candidate so far that can provide direct observations of wind profiles. In addition, a DWL will not only provide wind data but also has the potential to provide ancillary information on cloud top heights, vertical distribution of cloud, aerosol properties, and wind variability as by-products.

1. Introduction

The 'ESA Living Planet Programme' (ESA, 1998) describes the plans for the Agency's new strategy for Earth Observation in the post 2000 time frame. It marks a new era for European Earth Observation based on smaller more focused missions and a programme that is user driven, covering the whole spectrum of interests ranging from scientific research-driven Earth Explorer missions through to application-driven Earth Watch missions. The user community is therefore now able to look forward to a programme of more frequent but very specific missions directed at the fundamental problems of Earth system sciences.

Out of the nine Earth Explorer core missions identified in ESA SP-1196 (1-9), four core missions were selected for in-depth study, namely: the Land-Surface Processes and Interactions Mission (LSPIM); the Earth Radiation Mission (ERM); the Gravity Field and Steady-State Ocean Circulation Mission (GOCE); and the Atmospheric Dynamics Mission (ADM). In autumn 1999, GOCE and ADM were selected for implementation.

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[1] The members of the Atmospheric Dynamics Mission Advisory Group (ADMAG) were:
P. Flamant/LMD, L. Isaksen/ECMWF, E. Källén/MISU, J. Pailleux/Météo France,
A. Stoffelen/KNMI, M. Vaughan/DERA, W. Wergen/DWD

The primary aim of the Earth Explorer Atmospheric Dynamics Mission is to provide improved analyses of the global three-dimensional wind field by demonstrating the capability to correct the major deficiency in wind-profiling of the current Global Observing System (GOS) and Global Climate Observing System (GCOS). The ADM will provide the wind-profile measurements to establish advancements in atmospheric modelling and analysis. There is an intimate link between progress in climate modelling and progress in numerical weather prediction (NWP) as our understanding of the atmosphere is largely based on the experience of operational weather centres. Long-term data bases are being created by NWP data assimilation systems to serve the climate research community. It is widely recognised therefore that the impact of a new global atmospheric observing system on our understanding of atmospheric dynamics should be evaluated primarily in the context of operational weather forecasting.

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2. Global Wind Profile Measurements for Climate and NWP

Reliable instantaneous analyses and longer term climatologies of winds are needed to improve our understanding of atmospheric dynamics and the global atmospheric transport and the cycling of energy, water, aerosols, chemicals and other airborne materials. However, improvement in analysing global climate, its variability, predictability and change requires measurements of winds throughout the atmosphere. In order to do so, it is a pre-requisite to improve NWP, as progress in climate-related studies is intimately linked to progress in operational weather forecasting. The World Meteorological Organisation (WMO) states in their recent evaluation of user requirements and satellite capabilities that for global meteorological analyses measurement of wind profiles remains most challenging and most important (WMO, 1998).

After several decades of observations from space, direct measurements of the fully global, three-dimensional wind field are still lacking. Deficiencies, including coverage and frequency of observations, in the current observing system are impeding progress in both climate-related studies and operational weather forecasting while there is a clear requirement for a high-resolution observing system for atmospheric wind profiles.

At present, our information on the three-dimensional wind field over the oceans, the tropics and the southern hemisphere is indirect. It is severely limited by having to rely on mainly space-borne observation of the mass field and geostrophic adjustment theory. Improvements in the available wind data are needed urgently if we are to exploit fully the potential of recent advances in climate prediction and NWP and continue to make significant progress in the field, e.g. 4-DVAR assimilation.

The different types of observations currently available and constituting the Global Observing System (GOS) are documented in full detail in ESA (1996). They can be classified in the following way:

- *Surface data* – they are the synoptic reports from land stations and ships, the (moored and drifting) buoys, and also the scatterometer winds from satellites (such as ERS). They are all single level data, and cannot provide any information on atmospheric profiles.
- *Single-level upper-air data* – mainly aircraft reports and cloud motion winds derived from geostationary satellite imagery. More and more aircraft observations (wind and temperature) are

being made during ascent and descent phases, thus tending to become ‘multi-level’. Their main deficiency is the poor data coverage.

- *Multi-level upper-air data* – mainly the radiosondes (Fig. 1) and the polar orbiting sounder data. Satellite sounders provide global coverage with radiance data, which can only be used indirectly for the definition of the mass field (temperature and humidity). Radiosondes are the only current observing system providing vertical profiles of the wind field, but they are available mainly from the continents in the northern hemisphere.

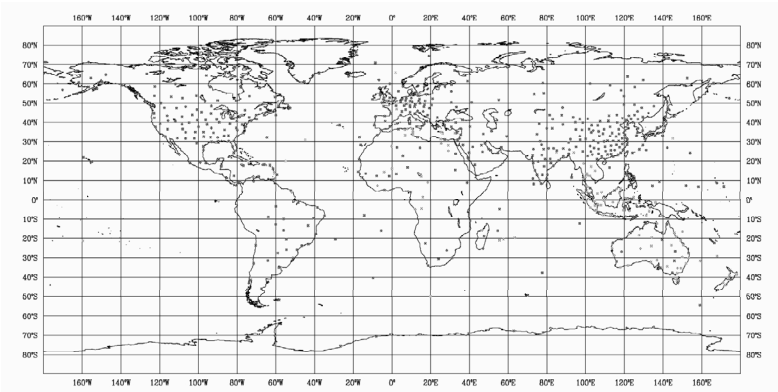

Figure 1. The radiosonde network – radiosonde/pilot ascents containing wind profile information that were available for the 6-hour time window centred around 12 UTC on 28 April 1999. Wind profile information is generally lacking over all ocean areas.

3. OSE and OSSE: Principles, Limitations and Some General Results

In order to assess the impact of wind profile data on NWP in a more quantitative way, Observing System Experiments (OSE) and Observing System Simulation Experiments (OSSE) have been run in NWP for at least twenty years. OSE are impact studies carried out with existing observations: two parallel data assimilations are carried out, with and without the observing system to be evaluated; resulting analyses and subsequent forecasts are then compared. OSSE are similar to OSE except the observations to be tested are simulated rather than real: simulated observations are produced from an NWP model integration assumed to be the ‘known truth’ and usually called the ‘nature run’. For a quantitative assessment of a non-existing observing system like the global wind profiles, which may be produced by a space Doppler lidar in the next decade, OSSE are required.

In a recent OSSE performed in Germany it was shown that a system providing only a small number of wind profiles in place of the conventional wind observations over North America would recover more than half of this forecast degradation. Figure 2 (from the same study) illustrates that even at forecast range 0 (model initial state), systematically removing the North-American wind profiles produces wind uncertainties over almost the entire tropical area, indicating that the tropical flow is rather uncertain. This experiment provides a rough estimate of the potential impact of wind profile data available in a data sparse area of the size equivalent to North America. Forecasts started from the degraded analysis reduced the operational medium-range forecast skill by 20 hours.

Another interesting OSE was carried out by Isaksen (Ingmann et al., 1999) with the 1997 ECMWF global data assimilation and forecasting system. It evaluates the impact of all the radiosonde wind profiles above the planetary boundary layer (PBL) versus the impact of the radiosonde mass profiles (geopotential height), and also the impact of all available radiosonde information. The impact is found to be much larger than the impact of any single-level data observing system and equivalent to a big portion of the total radiosonde network impact which includes temperature and humidity information.

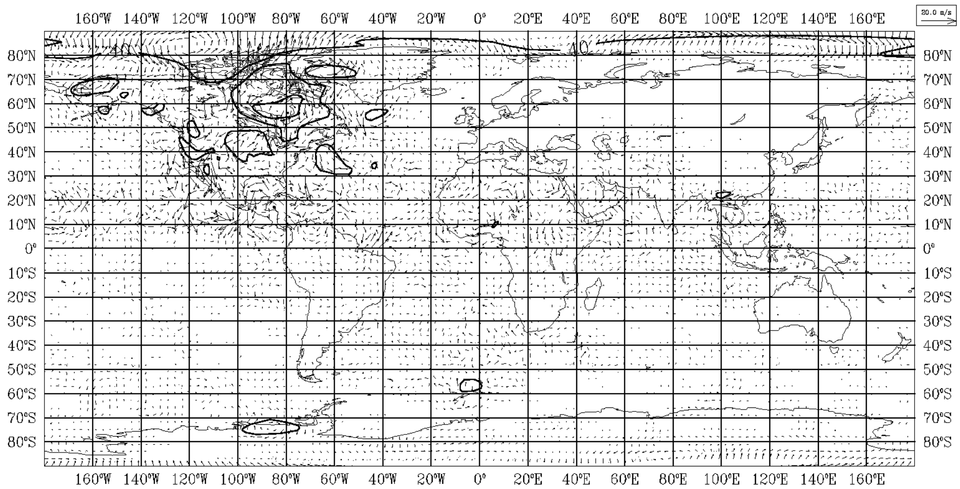

Figure 2. Degradation of the global wind field – analysis of differences in the geopotential height and wind field at 500 hPa between an 11 day long assimilation not using wind profile observation from radiosondes, pilots and aircraft over the United States and Canada and the control assimilation using all observations. The difference is valid for 30 January 1998, the contour interval for the height field is 20 m (from Cress, 1999).

4. The Need for Atmospheric Wind Fields for Climate Studies

Climate-change issues have received substantial attention in recent years due to the increasing awareness that human activities may substantially modify the future climate of the Earth. The globally averaged temperature has increased by about 0.6 degrees Celsius over the past hundred years and 1998 was the warmest year recorded on instrumental temperature record covering the last 150 years. These facts and other pieces of evidence suggest that an increased greenhouse effect due to human activities is starting to influence the global climate system. A very important question is thus to assess how a further future increase in greenhouse gases may affect this system. The most effective tools available to answer such questions are global and regional climate models, which to a very large extent resemble the corresponding NWP models. All the benefits of wind data discussed in the previous section relating to NWP models are also relevant to circulation models used for climate studies as both model types are based on the same physical and numerical principles. An illustration of the uncertainties involved in climate-change scenarios can be seen in Figure 3.

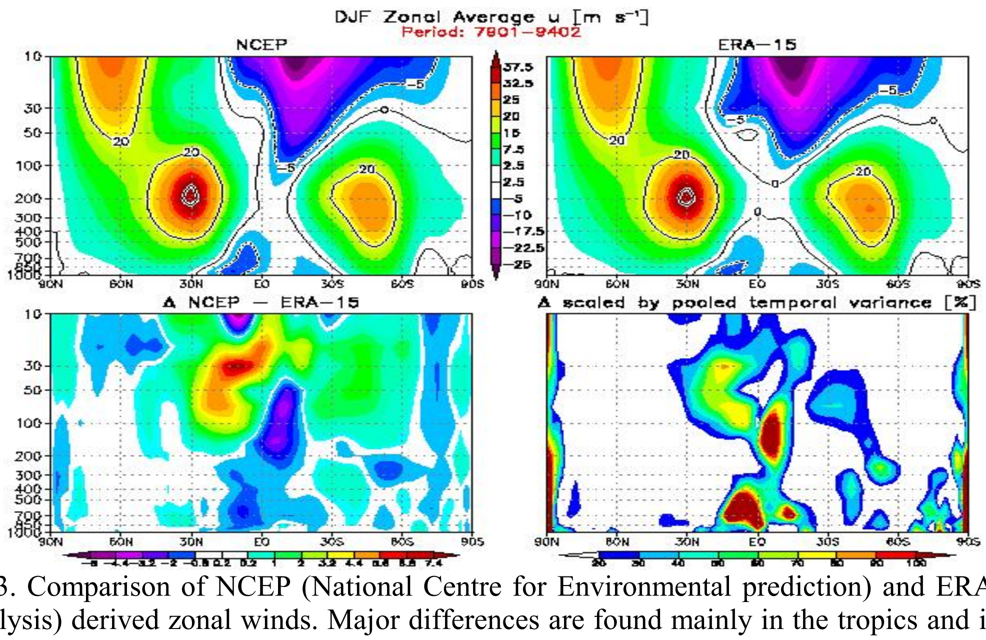

Figure 3. Comparison of NCEP (National Centre for Environmental prediction) and ERA (ECMWF Re-Analysis) derived zonal winds. Major differences are found mainly in the tropics and in the lower stratosphere.

5. Observational Requirements

Existing and planned systems will not meet the requirements for better wind profiles. In order to meet the numerical weather prediction, climate and atmospheric research objectives, an observing system is needed that provides three-dimensional winds over the globe. This means that it is essential to put significant effort into the development of a space-based system.

The WMO recognises the prime need for wind-profile data (WMO, 1998) and has defined a set of optimum wind-profile measurement requirements (WMO, 1996). User requirements for synoptic use are as or more stringent than those for climatological use. Quoting from WMO (1996): 'Various statements of requirements have been made, and both needs and capability change with time. The statements given here were the most authoritative at the time of writing, and may be taken as useful guides to development, but are not fully definite'. The WMO assigns great importance to wind-profile measurements. The realisation of their requirements would represent a major step forward in improving the quality of atmospheric flow analyses.

Current satellite capabilities for wind profiles consist of image-derived cloud motion winds (CMWs). However, it should be noted that in the absence of any appreciable wind-profiling capability, the current satellite winds mainly improve wind analysis in the tropics (e.g. Kelly, 1997, or Kållberg and Uppala, 1999), and thus do not at all meet the objectives. In order to give better guidance to developers of observation systems, the WMO has used the current satellite capability (i.e. CMW) to set a threshold below which no impact is expected from additional wind measurements.

Table 1. Observational requirements for an Atmospheric Dynamics Demonstrator Mission.

		Observational Requirements		
		PBL	Troposph.	Stratosph.
Vertical Domain	[km]	0-2	2-16	16-20
Vertical Resolution	[km]	0.5	1.0	2.0
Horizontal Domain			global	
Number of Profiles	[hour^{-1}]		100	
Profile Separation	[km]		> 200	
Temporal Sampling	[hour]		12	
Accuracy (Component)	[m s^{-1}]	2	2-3	3
Horizontal Integration	[km]		50	
Error Correlation			0.01	
Reliability	[%]		95	
Timeliness	[hour]		3	
Length of Observational Data Set	[yr]		3	

For a mission intended to demonstrate the feasibility of a full-scale spaceborne wind observing system to improve global atmospheric analyses, the requirements on data quality and vertical resolution are the most stringent and most important to achieve. Under this assumption, the horizontal density of observations is of the lowest priority amongst the requirements discussed in this chapter. The derivation of the coverage specification is supported by weather-forecast-impact experiments, which included the inputs of the conventional wind-profile network that is thin and irregular but of key importance. Moreover, the coverage specification reflects the WMO threshold requirements. Table 1 specifies the principal parameters for wind-profile observations that have been extracted from the above-mentioned WMO requirements and capabilities documents in view of demonstrating the capabilities.

6. The Technical Concept

The mission requires the measurement of horizontal wind velocity components from the lower part of the troposphere to the lower part of the stratosphere (up to 20 km altitude). The observation of a single component of the horizontal wind velocity is required to ease the instrument design since it has been shown to be adequate for the ADM. Furthermore, there is no particular requirement on the direction of the wind component to be measured.

The required instrumental accuracy for any horizontal line-of-sight (HLOS) wind component has been translated from the mission accuracy requirement of 2-3 ms^{-1}. The background representativeness error for a line-averaged wind component measurement has been quadratically subtracted from the mission accuracy requirement, yielding an instrumental accuracy requirement of 1-2 ms^{-1} for the HLOS wind component. It has to be noted that this representativeness error includes the contribution from the vertical wind component.

Stringent requirements on both wind accuracy and large vertical domain (up to 20 km) lead to consider an instrument concept relying on molecular backscatter at high altitude, where background aerosols become rare (Vaughan et al., 1999), and on aerosol backscatter at lower altitude. Figure 4 shows the baseline measurement profile.

The main characteristics of the proposed system feature a satellite flying in a Sun-synchronous dawn-dusk orbit of 400 km altitude, carrying a continuously operated lidar instrument

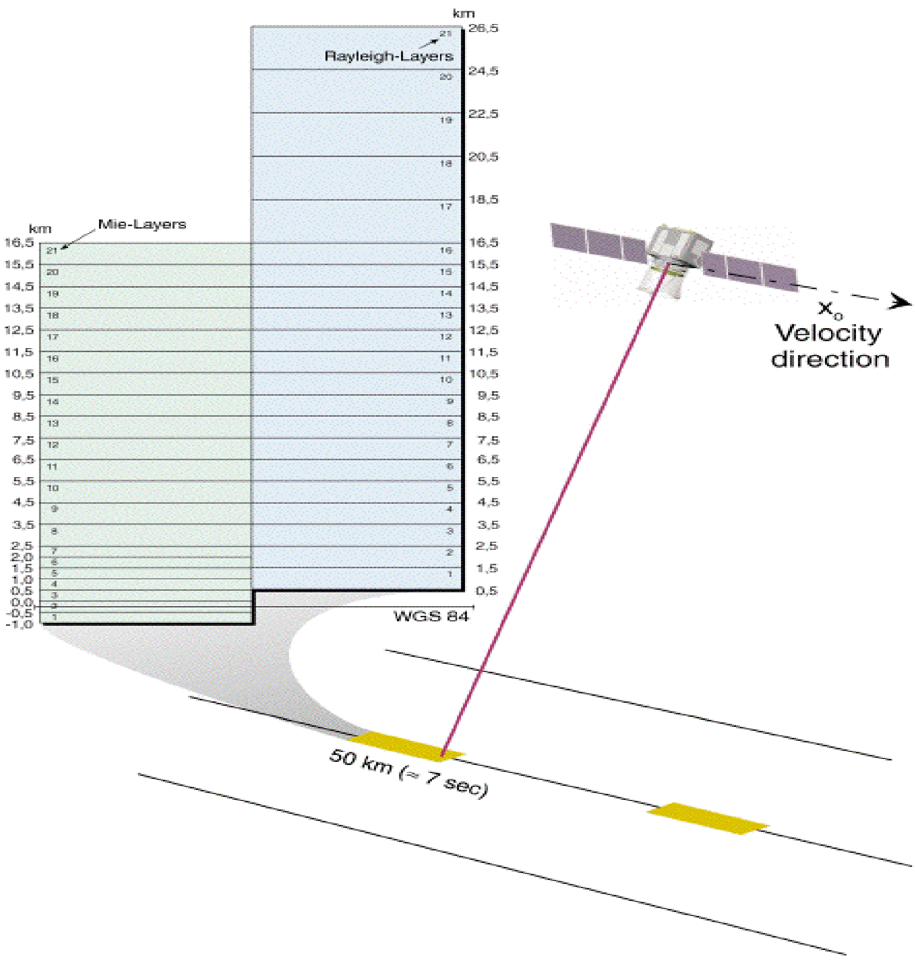

Figure 4. The baseline measurement profile depicting the mapping of atmospheric heights to layers measured by the detector. (ALADIN) whose main field of view is 35° off nadir and points to the anti-Sun side of the satellite track.

The performance requirements of the instrument require that an optical aperture of 1.1 m is needed, resulting in an outer diameter for the protecting baffle of about 1.2 m diameter, which dictates to some extent the dimensions of other satellite elements. A further consequence of the measurement performance requirements is the need to provide an excellent thermal stability, which affects the distribution of the units in the satellite. The baseline satellite configuration is shown in figure 5.

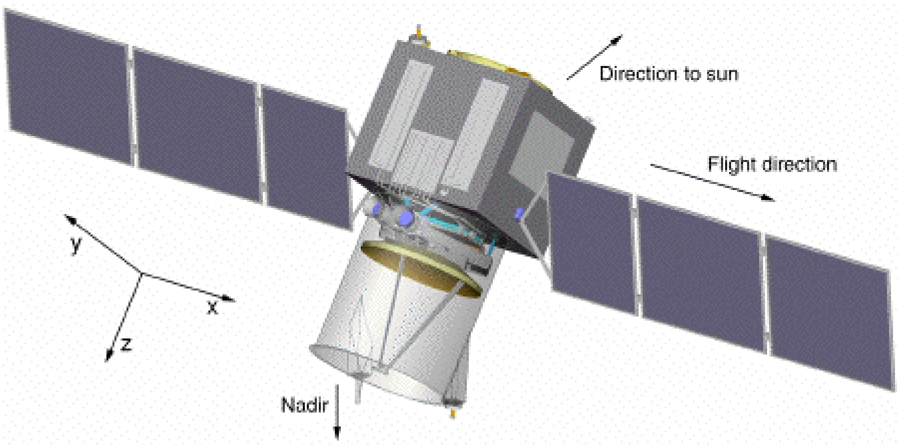

Figure 5. ADM baseline satellite configuration.

7. Programmatics

The US started with activities targeted at a DWL. The original concept was the LAWS (laser atmospheric wind sounder) concept. After refinement it was planned to embark a DWL on a shuttle for technology demonstration in 2001. However, this project was discontinued in 1999. In the context of the IPO (Integrated Program Office) NPOESS programme there are plans to embark an operational instrument in the 2007/8 time-frame. In Japan there are similar plans for a DWL called JLAWS (Japanese LAWS).

In the context of the European Space Agency's future Earth Observation *Living Planet Programme* (ESA, 1998) the Atmospheric Dynamics Mission is one of the two missions selected for implementation with a target launch date of 2006.

8. Conclusions

The Atmospheric Dynamics Earth Explorer Core Mission will for the first time provide direct observations on a global scale of atmospheric wind profiles over the depth of the atmosphere, a notable deficiency of current observing systems. These data will find wide application in advancing the performance of numerical models used in weather forecasting as these are suffering increasingly from the lack of such data. With these data it will also be possible to increase understanding of atmospheric processes occurring in tropical regions to the point where it will be possible to take proper account of them in climate models. The proposed concept meets the requirements of growth potential which is relevant in view of a future operational mission.

More detailed information on the scientific context and the mission implementation can be found in ESA (1999).

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