ATMOSPHERIC FLOW ANALYSES FOR CLIMATE STUDIES AND NUMERICAL WEATHER PREDICTION

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ABSTRACT

Accurate analyses of the atmospheric flow and circulation are the basis for studies of the basic processes determining the distribution of energy and matter in the earth climate system, and at the same time provide initial conditions for numerical weather prediction (NWP). In fact, atmospheric re-analysis projects are being carried out in order to provide 15- or 40-year long time series of the atmosphere for climate studies, by using NWP data assimilation systems. The large-scale motion of the atmosphere is determined by the temperature and pressure fields, but for smaller scales of motion the wind field is the most relevant. As such, to improve our knowledge of the climate system, or to improve NWP, observations of the wind field are essential. ESA has recently approved the Atmospheric Dynamics Mission (ADM), called Aeolus, to bring a Doppler Wind Lidar (DWL) in space. The objective of this mission is to provide atmospheric wind information to demonstrate improvements in atmospheric analyses and weather forecasts. The ADM DWL will provide good accuracy profiles rather than a large coverage. The coverage requirement is based on the required ability to demonstrate impact of the ADM DWL in atmospheric analyses and forecasts. In an end-to-end simulation to test the assimilation of ADM DWL wind profiles in a state-of-the-art Observing System Simulation Experiment (OSSE) the anticipated improvements were found. It is believed that the impact results in the northern hemisphere are indicative of the expected impact of adding ADM DWL data to the Global Observing System as foreseen in 2006 and beyond.

1 THE NEED FOR WIND PROFILES

The quality of state-of-the-art atmospheric analyses is among other things determined by the availability and quality of meteorological observations. For the study of climate processes extensive re-analyses 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. Climate studies are concerned with a broad range of time scales and the cycling of heat, water, aerosol, ozone and other trace gases through the atmosphere (ESA, 1999). Most of these components affect the earth radiation balance in a poorly understood, but non-negligible way. General atmospheric Circulation Models (GCMs) have improved much over the last decades, and advanced 4D-var techniques are now being used for the analysis (e.g. Courtier et al, 1999). Nontheless, large discrepancies remain between analyses of different centres, indicating large uncertainty in the atmospheric flow (see e.g. figure 1).

The spatial resolution of GCMs is continuously being improved as the availability of computational resources increases, which leads to a need for more observations on the sub-synoptic scales. On these smaller scales of motion the wind field, rather than the atmospheric temperature or humidity fields determines the atmospheric dynamics, as depicted in Figure 2. 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, and are particularly needed over the oceans, in the tropics, and southern hemisphere (see also ESA, 1996, 1999).

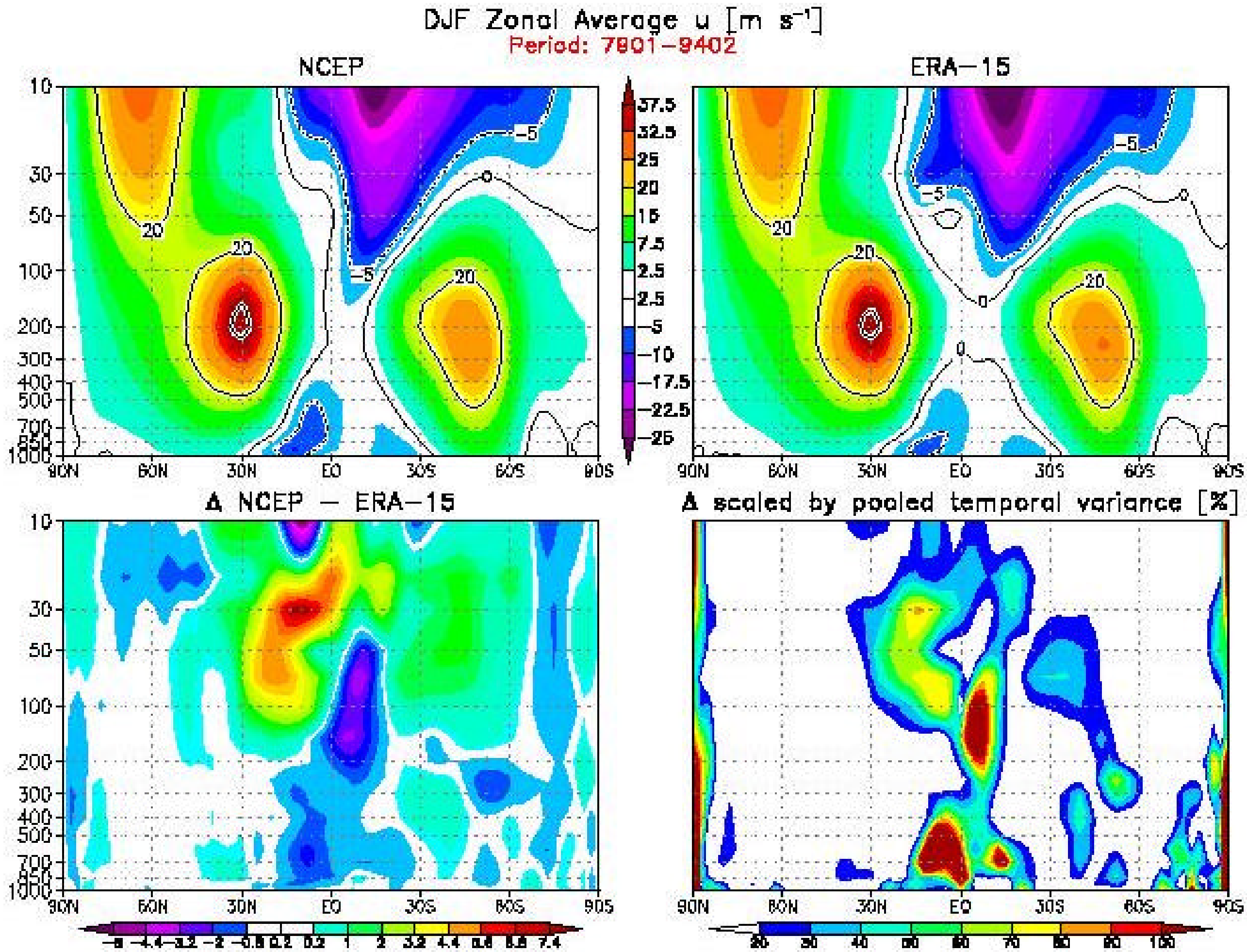


Figure 1: December-January-February zonal average of the west-east component of the wind over the years 1979-1994 as re-analysed by the US National Centre for Environmental Prediction (NCEP) at the top left, and by the European Centre for Medium-range Weather Forecasts (ECMWF) at the top right. The difference is plotted at the bottom left, and after scaling by the temporal variance at the right (Courtesy M. Fiorino). The long-term seasonal differences as high as the temporal wind variance indicate a poor understanding of the atmospheric flow, in particular in the tropics.

For NWP, the prime factor determining meteorological instability is vertical wind shear. Recent OSEs (Observation System Experiments) by the European Centre for Medium-range Weather Forecasts (ECMWF) (Isaksen, 1998, and Kelly, 1997) at the Deutcher Wetter Dienst (DWD; Wergen, 1998) have confirmed the relevance of tropospheric wind profile data for NWP. In more recent experiments (Kelly, 2000) TEMP/PILOT wind profile observations seem to have less impact, probably because of the gradually decreasing number of TEMP/PILOT, and because of the increasing amount of aircraft wind profile reports over the land areas where TEMP/PILOT are launched. In the OSE experiments, a small number of (good quality) wind profiles already shows a positive impact on the quality of atmospheric analyses and NWP. TEMP/PILOT OSE work with the US National Center for Environmental Prediction, NCEP, NWP model confirms some of these conclusions. In line with this, the ADM requirements have been focussing on quality rather than quantity over the last few years, in accordance with the WMO (1998) 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 that a particular type of existing observation has in the existing data assimilation system. However, it is more difficult to draw conclusions on the added value of supplementary measurements on the meteorological analyses and forecasts based on OSE. This added value may be investigated through

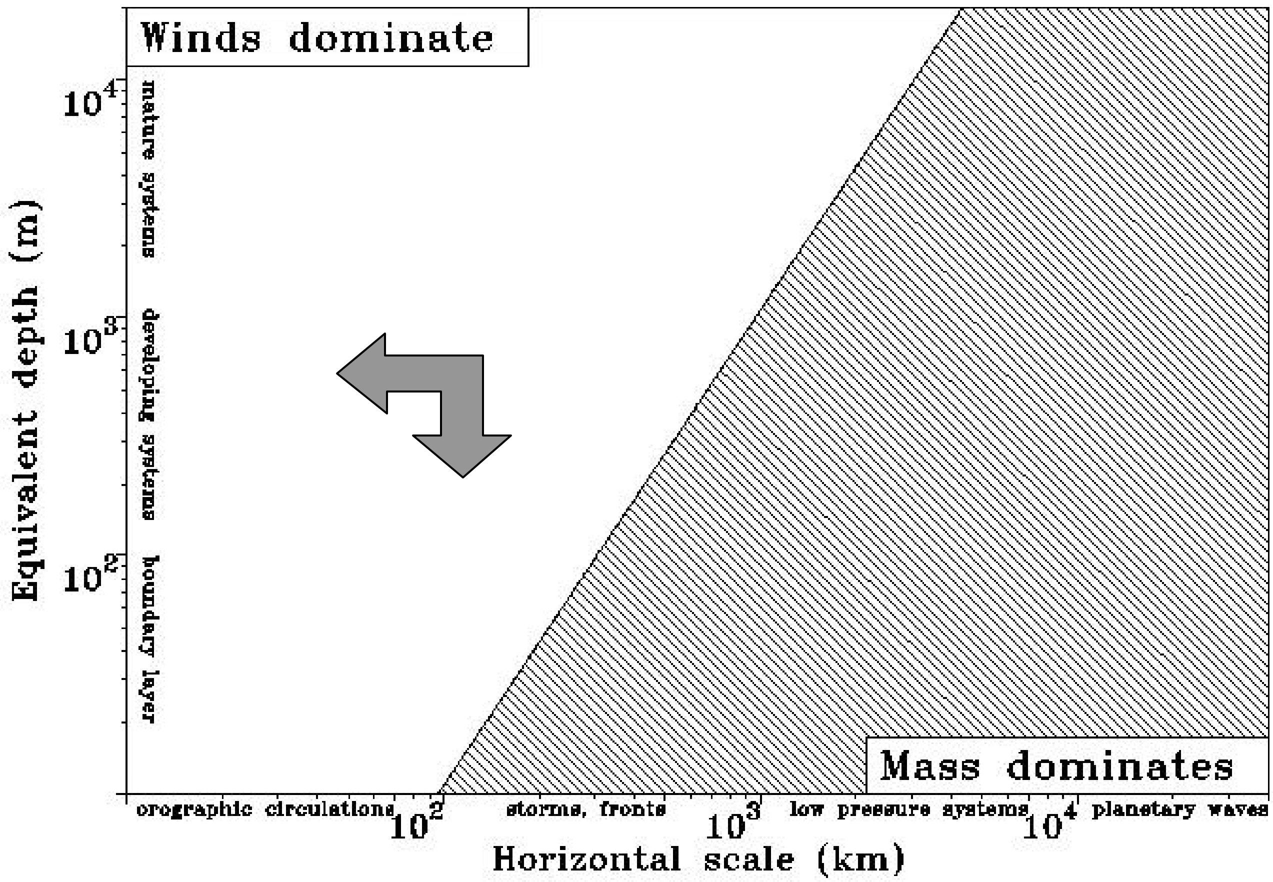
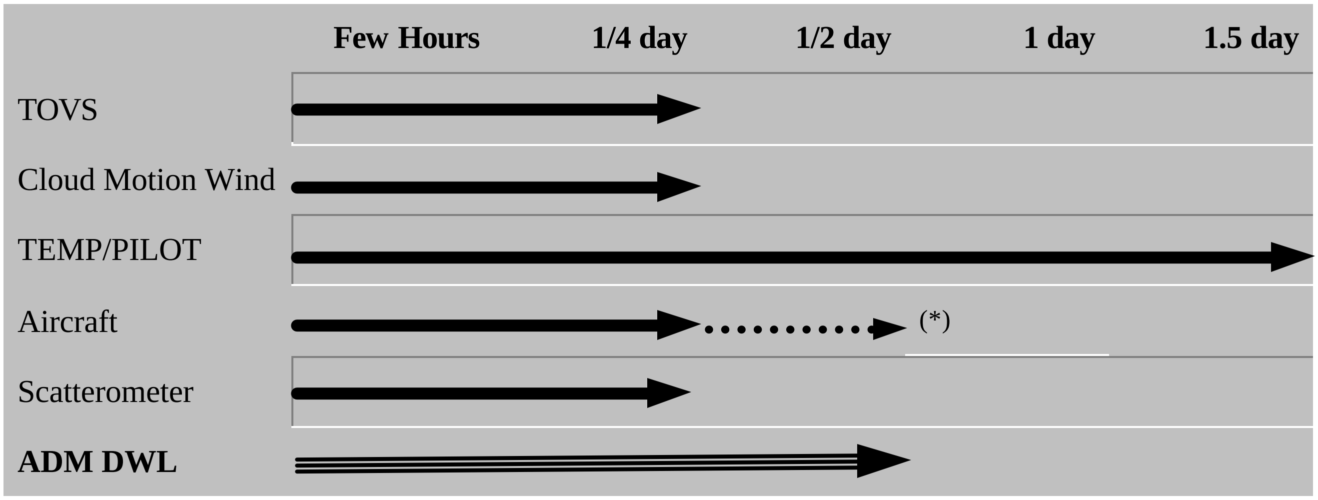


Figure 2: Scales of motion in the atmosphere. The diagonal line depicts the so-called Rossby radius of deformation at a latitude of 45 degrees; modes of motion to the right are best described by their associated temperature and pressure fields, whereas smaller scales of motion to the left of this line are mainly determined by their associated wind field (ESA, 1999). The grey arrow indicates state-of-the-art resolution and the direction of progress. The direct measurement of wind is fundamental for improving atmospheric flow analyses.

simulation by OSSEs. For an operational system, the impact on NWP often depends on the skill of the data assimilation system used. Therefore, an OSSE with the state-of-the-art ECMWF 4D-var system was conducted for ADM-Aeolus in order to consolidate the requirements for a DWL demonstration mission.

2 THE ATMOSPHERIC DYNAMICS MISSION - AEOLUS

ESA has recently approved a Doppler Wind Lidar (DWL) to fly on a free-flyer platform orbiting dawn-dusk at 400 km altitude (see Ingmann et al in this volume). 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. Detailed assessments of the science objectives, requirements, design, and expected performance of this mission can be found in ESA (1999). In Stoffelen and Marseille (1998) and Veldman et al (1999) detailed user assessments of the performance of a DWL are reported. Their analysis concerns both the performance in clear air and in cloudy conditions. The clear air performance of ADM_UV fulfills the user requirements, but also in conditions with broken cloud they find that still many useful wind profiles can be obtained.



(*) Impact only locally

Table 1: Extension of northern-hemisphere forecast skill by satellite temperature sounding (TOVS), imagery-derived winds (Cloud Motion Wind), conventional profilers (TEMP/PILOT), aircraft reports, and scatterometer data, as reported in WMO (1997), complemented with the first OSSE assessment of the extension of forecast skill by the ADM DWL. The addition of DWL wind component profiles over the oceans provides a demonstrable impact on NWP.

3 OBSERVING SYSTEM SIMULATION EXPERIMENT

Most of necessary preparatory work to perform the OSSEs has been the result of many studies, started in the early 1990's (Stoffelen and Becker, 1994), (Becker et al, 1995). Stoffelen and Marseille (2000) provide a first report of the ADM DWL OSSE results. Table 1 provides a summary of their finding that ADM_UV, as anticipated, will demonstrably improve atmospheric analyses and NWP. The improvement in the analyses is notable in those areas where conventional wind profile observations are absent, i.e. the northern hemisphere oceans, tropics and southern hemisphere. Due to the density of the meteorological observing system in the northern hemisphere, the impact of an additional observing system such as a DWL is most difficult to demonstrate here. However, as anticipated, the quality and coverage of ADM_UV is sufficient to improve the analyses over the northern hemisphere oceans and, consequently, improve the short- and medium-range weather forecasts over Europe and other continental areas.

4 CONCLUSIONS

The meteorological community requires wind profile data for meteorological analyses used for climate studies and NWP. The requirements set up for the ADM exceed the WMO minimum requirements for wind profiling in order to obtain a clear beneficial impact on state-of-the-art atmospheric analyses. The ADM_UV meets the performance requirements in clear and in cloudy scenes it will further provide useful wind profile information as verified statistically and in OSSE. The DWL community can look forward to a space mission that demonstrates the scientific and technical feasibility of operational missions. More detailed studies are needed to exploit the full potential of DWL for the scientific and operational meteorological communities.

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