Expectations for Space-based Wind Profiling

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ABSTRACT

Wind profiles over the ocean, tropics and southern hemisphere are largely lacking. ESA is planning to launch a direct-detection high-spectral resolution Doppler Wind Lidar (DWL) in 2011 in the Atmospheric Dynamics Mission (ADM), called Aeolus. Aeolus is expected to provide unique data of great value to the meteorological community, as has been verified in several Numerical Weather Prediction (NWP) impact experiments and will be illustrated at the conference. Following requirements for space-based wind profiles from the World Meteorological Organisation, WMO, the European Organisation for the Exploitation of Meteorological Satellites, EUMETSAT, recognizes wind profiles as high priority for the "post-EPS" programme (2020). Moreover, a DWL may be combined with an aerosol and cloud profiling lidar. There is however at present no funded programme to provide wind profile data between the end of life of Aeolus and the post-EPS era. An affordable post-Aeolus option has been sketched by ESA that has been tested to provide beneficial NWP analysis and forecast impact, and that has support from several NWP centres. The requirements and expectations from the above wind lidar missions will be elaborated at the meeting.

1. THE GLOBAL OBSERVING SYSTEM

Reliable instantaneous global analyses of winds are needed to improve the understanding of atmospheric dynamics and climate processes, and also to improve the quality of NWP models. Indeed there is a synergy between advances in climate-related studies and those in NWP, as climate studies are increasingly using analyses of atmospheric (and other) fields from data assimilation systems designed originally to provide initial conditions for operational weather forecasting models. These scientific applications are severely limited by the lack of direct three-dimensional wind information over the oceans, the tropics and the southern hemisphere, where radiosonde observations are scarce. A wide variety of observation types are currently available routinely for assimilation in NWP systems. They constitute the Global Observing System (GOS), at the basis of operational weather forecasting and climate studies and coordinated by WMO [1]. Despite the sophistication of modern data assimilation methods [2], large uncertainties remain in some wide areas of the globe, especially for the wind field (figure 1). Over the oceans the upper-air wind analysis relies mainly on space-borne radiance observations, which, when coupled with accurate surface pressure information and geostrophic adjustment theory, can provide some information, indirectly, also on the wind field. In the tropics the geostrophic assumption is not valid, and direct measurements of the wind are required to produce accurate analyses of the atmospheric flow. The wind information is essential in the tropics as it governs the dynamics. In the extra-tropics, wind data are the primary source of information for small horizontal scale features. It is only for the large horizontal scale features that the wind field can be derived from the mass field in the assimilation process with reasonable accuracy (see figure 2). A space-based DWL provides wind profile information globally, which is of value particularly in the tropics and over the oceans where such observations are otherwise lacking [3]; see also figure 1.

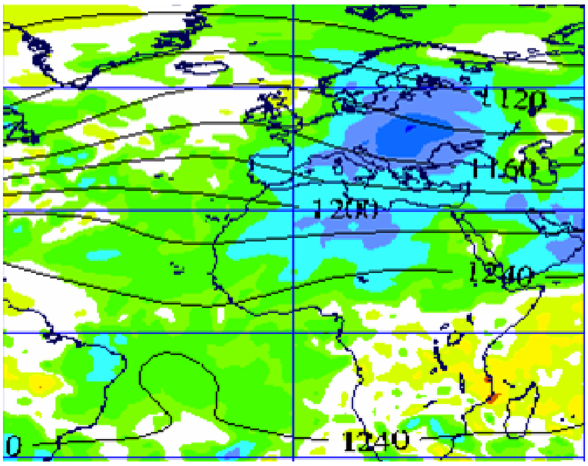

Figure 1. *Spread ratio in a 2-week ensemble of short-range (12 hour) ECMWF NWP forecasts at a pressure level of 200 hPa (tropopause), depicting the error reduction due to the use of available wind profile observations [10]. Note the lack of improvement in coastal Europe and the concentration of impact in central Europe due to the relatively high density of wind profile observations in Europe.*

2. REQUIREMENTS

The WMO assesses capabilities of the GOS and uses a rolling requirements review for different meteorological applications and its observables [1]. This includes nowcasting (e.g., extreme weather), NWP and climate. Satellite agencies use these reviews to specify requirements for their missions and satellite programmes, such as in case of ESA's ADM-Aeolus or EUMETSAT's follow-on programme for their Polar System (post-EPS) [3,4,5]. Satellite wind profiles are a prime WMO requirement for the GOS [1].

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3. EXPECTATIONS FROM AEOLUS

ESA is currently implementing the Doppler Wind Lidar (DWL) mission 'ADM-Aeolus' in its Living Planet Programme. The mission is a demonstrator for future operational missions providing vertical profiles of the tropospheric and lower stratospheric wind field for the improvement of numerical weather prediction (NWP) and atmospheric research; see [3,6,7] for more details. The quality of the ADM-Aeolus wind component profiles is benchmarked on the quality of radiosonde winds. ADM-Aeolus winds are expected to improve atmospheric analyses in the Southern Hemisphere, in the tropics, over the oceans, in Polar regions, and in other areas where conventional wind profiles and aircraft wind profiles (ascents/descents) are sparse. ADM-Aeolus would make the distribution of wind profile observations more uniform. In turn the improved analyses are expected to lead to improved NWP forecasts and climate analyses [3,5,6,7,8,10,11,12,13].

Simulation studies reveal that ADM-Aeolus may have an impact on forecast quality comparable to that of radiosondes. Moreover, studies in THORPEX (THe Observing system Research and Predictability EXperiment) with a very limited amount of aircraft DWL observations in the North Atlantic showed a substantial forecast impact in Europe [14]. Based on these experiences, most benefit from ADM-Aeolus for regional forecasting over Europe would be achieved by i) better boundary conditions provided by global NWP models, such as the European Centre for Medium-range Weather Forecasts (ECMWF) and ii) when Aeolus wind profiles would be made available in quasi real time (QRT), such that most ADM-Aeolus wind profiles may be timely to be incorporated in the NWP data assimilation cycles (with short cut-off times down to 30 minutes).

Preparations for ADM-Aeolus include the building of a simulation data base, an end-to-end simulator, and processors of the Aeolus data [9,15,16,17]. KNMI is particularly involved in considering heterogeneous atmospheric cases with small-scale wind, aerosol, and cloud variability, which need particular care in the Aeolus processing and sampling [18,19].

4. POST AEOLUS EXPECTATIONS

One important aspect to be considered for NWP is the detectability of precursor features. Atmospheric structures that are precursors to the development of extra-tropical cyclones can often be identified in areas where cyclogenesis takes place. In such baroclinic zones is the vertical wind shear the main variable. Even at very short range, NWP models can be hit by severe failures, which, although it cannot be always proven, are suspected to be due to a lack of meteorological observations in precursor areas, which are critical for the initial state of these models. One example are the “Christmas” storms in December 1999, which deepened very quickly in the middle of the Atlantic Ocean just before Christmas 1999, then hit France. Studies have been performed to determine the potential of a tandem ADM-Aeolus DWL mission in such cases, showing good impact for this particular problematic extreme forecasting case (see table 1), but also good impact in other severe weather cases [20].

Table 1 *ECMWF ensemble of 50 members of 54-hour forecasts for 00Z 28 December 1999 in an observation sensitivity experiment (SOSE) for a simulated truth (bottom), an experiment with a tandem Aeolus DWL added (middle), and a normal ECMWF forecast top; NoDWL). With standard verification criteria of storm occurrence of i) wind speed above 10 Beaufort and ii) mean sea level pressure (PMSL) below 980 hPa, the tandem DWL gives rise to a substantial increase in forecast ensemble members with a storm.*

Verification *00 Z 28 Dec 1999* *+54-h forecasts*	# Members of 50 Wind > 10 Bft or PMSL < 980 hPa
NoDwl	5
DWL	15
Pseudo-truth	38

Different follow-on scenarios have been studied, for example as depicted in figure 3 [21,22]. Figure 3 illustrates that wind component profile coverage was found more important than measuring both wind perspectives, zonal and meridional, in the extratropics. In the tropics, however, there is a slight preference two measure both perspectives [23]. By measuring the two perspectives along different ground tracks, the advantages of multiperspective and maximum coverage may be combined.

After these tests and other experiments showing beneficial NWP analysis and forecast impact, e.g., in the tropics, an affordable post-Aeolus option has been sketched by ESA and that has support from several NWP centres. There is however at present no funded programme to provide wind profile data between the end of life of Aeolus and the post-EPS era.

5. POST-EPS

ADM-Aeolus is a demonstration mission that set out to demonstrate the feasibility to measure high-quality wind profiles from space and demonstrate the beneficial impact of these data on NWP analyses for NWP and climate applications. Even if well prepared and with a launch date in 2011, such demonstration will not be feasible before 2012. The first slice of the EUMETSAT Post-EPS constellation is currently in a pre-design phase in order to meet the planned 2019 launch date [4].

Moreover, a space-borne DWL such as ADM-Aeolus requires a low earth orbit at about 400 km height, preferably flying in dawn-dusk conditions. These conditions are not compatible with other Post-EPS instruments, such that a DWL may be considered as a separate and technically independent slice of the Post-EPS programme.

Note that besides wind, post-EPS DWL concepts may be well combined with an aerosol and cloud profiling lidar capability, thus extending the successful CALIPSO mission.

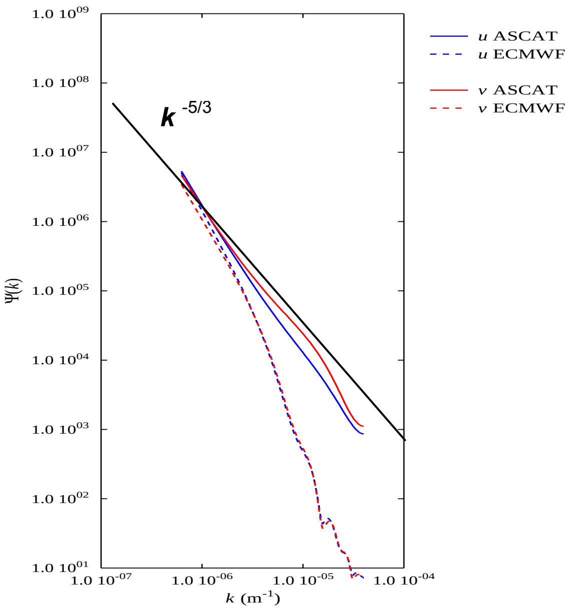

Figure 2. *Wind covariance spectra over the global oceans for a week of collocated EPS ASCAT scatterometer (solid) and ECMWF model (dashed) wind components u (eastward) and v (northward). The straight line ($k^{-5/3}$) denotes the expected and verified spectral shape due to 3D turbulence. At scales of 500 km and lower, the ECMWF model contains substantially less wind variance than the scatterometer observations, even an order of magnitude at the 100-km scale, and deviates from a $k^{-5/3}$ spectral shape. Similar deficiencies occur at other vertical levels [24].*

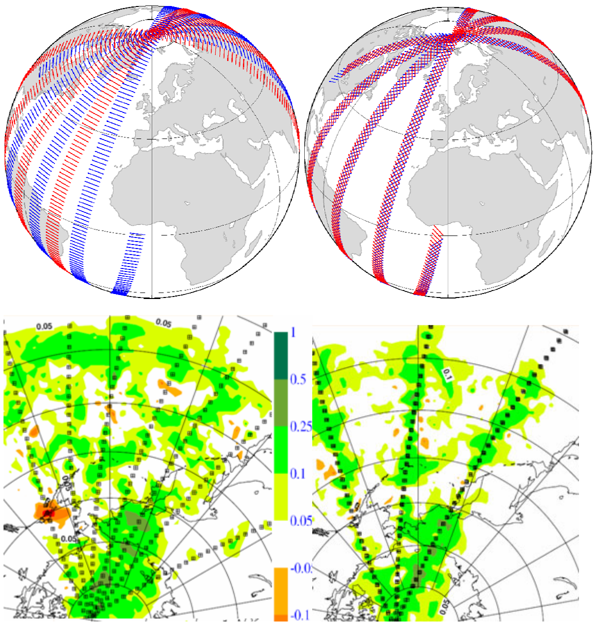

Figure 3. *.Top: tandem Aeolus coverage with left interlaced tracks and right a single track, but now measuring both wind vector components. Bottom: Corresponding simulated analysis wind vector improvement in m/s over 84 cases at the 500 hPa pressure level for both tandem scenarios, respectively left and right. The left scenario provides more beneficial impact and also more homogeneously spread over the ocean area (Pacific).*

6. CONCLUSIONS

Wind profiles over the ocean, tropics and southern hemisphere are largely lacking and a prime WMO requirement. As such, Aeolus is expected to provide unique data of great value to the meteorological community for NWP and climate applications, as has been verified in several Numerical Weather Prediction (NWP) impact experiments and related climate studies. Following requirements for space-based wind profiles from the WMO, EUMETSAT recognizes wind profiles as high priority for the “post-EPS” programme. Moreover, a DWL may be combined with an aerosol and cloud profiling lidar. The successful demonstration of the ADM-Aeolus DWL, after its launch foreseen in 2011, will provide further impetus for the implementation of an operational DWL mission under EUMETSAT responsibility.

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