# Characterization of wind and wind-shear profiles from high-resolution radiosondes and ECMWF model

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## ABSTRACT

Global high-resolution radiosonde profiles are collected to characterize the atmospheric variability of wind and wind-shear in the vertical. Such characterization is important for the preparation of the European Space Agency Atmospheric Dynamics Mission, Aeolus, wind profiling mission, in which the launch of a Doppler Wind Lidar (DWL) is planned in 2011. The analysis is performed over different climate regions and over a period of 10 years. Moreover, the radiosonde observations were collocated and compared with independent European Centre for Medium-range Weather Forecast (ECMWF) wind fields. The results from both datasets will be presented and the differences in wind and shear variability will be highlighted. ECMWF wind and shear has a typical resolution of about 1.7 km in the free troposphere and the ECMWF wind-shear variability is generally about a factor of 2-3 smaller than the shear variability in the radiosondes. The difference in variability between land and sea and the diurnal changes in variability were investigated. These wind and shear differences and changes are mainly apparent in the lowest 2 km of the atmosphere and limited elsewhere. Our results will be used to set the vertical sampling of the Aeolus DWL.

## 1. INTRODUCTION

With the increase of interest on high-resolution modelling in numerical weather prediction and climate research [6&7], a more detailed description of the atmosphere dynamics and optics propreties is highly needed. The determination of the mean state and variability of the atmosphere can be based on measurements or on models. Currently, many of NWP and climate models may generally offer a global coverage of the atmospheric state but still at coarse resolution, contrary to the observations which may offer a more accurate representation with very fine-resolutions, but remain very limited in spatial coverage [12]. Hakansson [5] described a global wind statistics utilizing 31 ECMWF model levels of analysis fields and low-resolution radiosondes observations, reported only at standard and some significant levels where he showed similarity in the wind and shear statistics for both data sets. It is however important to mention that these results of modelled and observed wind are not compared at grid-points collocated with observation sites. The aim of this study is to statistically describe the climatology wind and wind-shear characteristics of the first 30 km above the earth surface. This is done by collocating the ECMWF short-Range forecast model (ECMWF-SRF) with high-resolution radiosondes observations. The effect of the vertical scaling on wind and shear variability are both investigated, where the effective ECMWF model resolution is determined. The differences in wind and shear are also highlighted for land-sea and dawn-dusk cases. ADM-Aeolus measurements will focus mainly on the continuous observations rather than fine resolutions, since the vertical ranges bin-resolution is limited to 24 for both type of channels, dedicated for Mie and Rayleigh scatterings [9]. In this context, the distribution of these vertical bins should be optimized by conducting simulations on Aeolus-DWL vertical sampling in realistic and global atmospheric conditions, i.e. with considering the complex optical and dynamical heterogeneities of the atmosphere [11]. Thus, by characterizing the climate wind dynamics from model and observations, one may build more realistic and global atmospheric database needed for Aeolus-DWL simulations (For more issues about this ESA's Aeolus mission, See Ad Stoffelen, Gert-Jan Marseille and Jos de Kloe contributions)

## 2. DATA AND METHODS

92 stations of 6 seconds high-resolution radiosondes data over 10 year period from 1998 to 2007 available through SPARC project website [8], were fully exploited to characterize the atmospheric wind dynamics. The most continuous 2006 radio-soundings data from the British Atmospheric Centre (BADC), African Multidisciplinary Monsoon Analysis (AMMA) and De Bilt at Royal Netherlands Meteorological Institute (KNMI, Netherlands.), are also selected to be analysed separately (Results from the 3 last sub-datasets are not shown). The spatial coverage is shown in the map of figure 1. One year SPARC 2006 totalling 85 stations for both 12 UTC and 00 UTC are first collocated with ECMWF-SRF model fields, for a better comparison between model and observations. The spatial collocation is performed according to the radiosonde launch ground-locations, i.e. model wind fields are extracted from the ECMWF archive (MARS) and interpolated to the ground-location (lat, lon) of the radiosonde launch (not following the radiosondes trajectory). The temporal collocation is done with the 12-hour model forecasts (SRF) i.e. a radiosonde launched for instance at 12UTC (00UTC) is thus compared with a SRF initiated at 00UTC the same day (12UTC the day before). However, the forecast model is used rather than the analyses in order to avoid what called generally "incestuous" comparison between model and observations, since the analyses model fields contain already these radiosondes observations. 7 climate zones are defined according to the latitude as follow: Northern/southern Hemisphere polar (70-90°), Northern/Southern Hemisphere Mid-latitude (40-70°), Northern/Southern Hemisphere Subtropics (20-40°) and Tropics (20-20°). The radio-sounding stations are thus distributed over these climate regions as follow: 9 tropical, 37 subtropical, 38 mid-latitudes and 1 polar.

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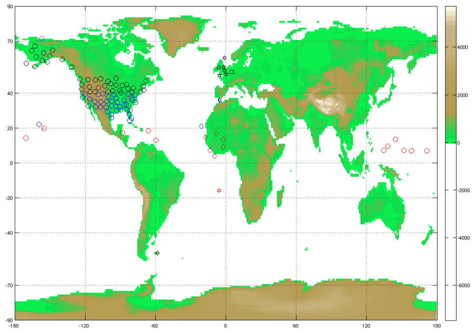


Figure 1.*The geographical locations of analyzed high-resolution radiosondes data-sets: SPARC (circles), BADC (hexagrams), AMMA (diamonds) and De Bilt (Square) as function of climate regions, successively for the tropics (red), Subtropics (blue), mid-latitudes (black) and Polar (magenta). Note the orography (brown). The right legend from zero meter and up indicate the altitude of the earth surface from the sea-level; and down is the ocean depth which is masked here.*

## 3. RESULTS AND DISCUSSIONS

### 3.1 Collocated radiosondes-model wind and wind-shear profiles

An example of single wind and wind-shear profiles of a high-resolution radiosonde at 6 seconds (~30 m) collocated with an independent ECMWF short-range forecast is shown in figure 2.

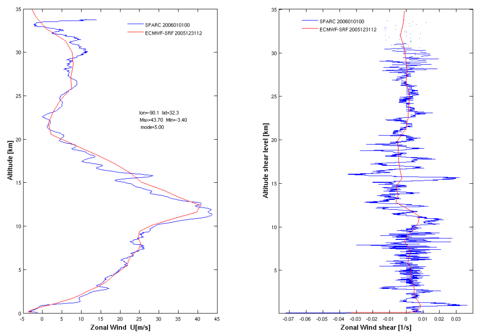


Figure 2. *Zonal wind (left) and wind-shear (right) collocation of the hi-res resolution radiosonde from the SPARC data-set (blue) with the ECMWF 12-hour forecast (red). The vertical resolution of the radiosonde here is 30m. 2005123112 means that the 12h forecast was initiated at 12 UTC on 31 December 2005. Verification time is 00 UTC on 1 January 2006, i.e. the radiosonde launch time.*

The spatial resolution value between parentheses is given as a rough guide, considering that the mean ascent rate of the balloon is about 5m/s, which is generally the case [4]. The ECMWF model profile shown here is from the L60 model version which has an irregular vertical resolution, as its successor, the L91 model version, which is operational since January 2, 2006. Clear differences may be seen between profiles in both wind and shear, particularly in the vertical structure. Though the smooth ECMWF profiles espouse well in shape the radiosonde profile, the vertical variability of the horizontal wind is large for a typical high-resolution radiosonde ascent comparing to the ECMWF-model, as seen in this example at 90.10W 32.3N on 1 January 2006 at 00UTC.

### 3.2 Zonal/meridional wind, wind-shear and balloon drift statistics

Statistics of zonal wind from radiosonde and model show a clear resemblance while for wind-shear statistics are different. This finding is observed in all climate regions; e.g. subtropics case in figure 3a. This difference in wind-shear is due in particular to the limited effective vertical resolution of the ECWMF. It is however shown [10] that the power spectra of this model drops for a wavelength below 250 km, leaving thus all the atmospheric processes occurring below this scale unresolved. One may note the highest order of values of wind and shear in the subtropics and mid-latitudes

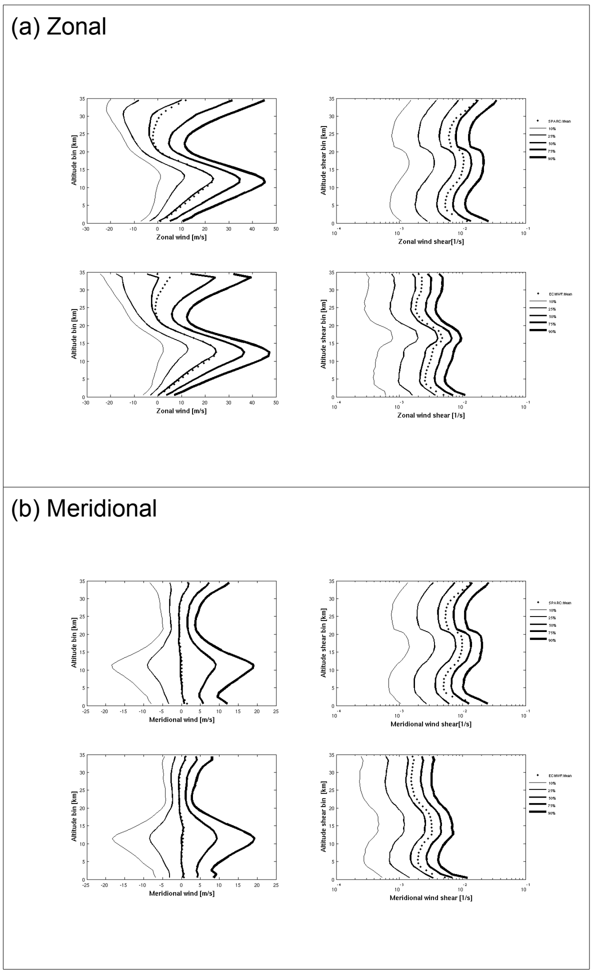



Figure 3. *(a) Zonal wind and wind-shear statistics for the subtropics case based on high-resolution 12s (~60 m) SPARC radiosondes (top) collocated with ECMWF-SRF model (bottom): mean (dots) and percentiles (successively from left to right: 10, 25, 50, 75, 90%). The statistics are performed at each 1km level bins from one year 2006 SPARC radiosondes and ECMWF model data-sets. (b) similar than (a) for meridional wind.*

Similar remarks may be made about meridional wind and wind-shear statistics, but with smaller order of magnitude of wind, e.g. subtropics case (figure 3b).

The high values observed occur mainly around the tropopause (from 9 to 15km) near the jet stream, which is associated with high wind values exceeding 55 $ms^{-1}$ , and in the stratosphere.

The radiosonde balloon drift (figure 4) is usually below 100 km and which remain largely smaller than the ECMWF model effective horizontal resolution (250km). Thus, we conclude that the comparison between the radiosondes and model, just by applying a simple col-location according the ground-location is valid and consistent. The drift is computed, at each layer level $z_N$ , from the successive horizontal position of the balloon with the altitude. This is done by accumulating successive horizontal distances made by the balloon, as given by equation (1)

$$Drift(z_N)=\sqrt{\left(\sum_{i=1}^{i=N} dx_i\right)^2+\left(\sum_{i=1}^{i=N} dy_i\right)^2} \quad , (1)$$

where $dx_i=0.5(u_i+u_{i+1})dt$ and $dx_i=0.5(v_i+v_{i+1})dt$ , are the zonal and meridional distances traveled by the radiosonde balloon from one atmospheric layer level i to another i+1. $z_N$ is the level heights, where N indicates the level number starting from the first to the last available data level.

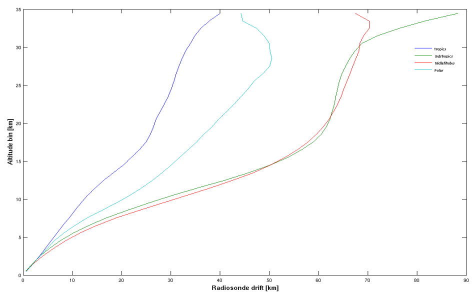



Figure 4. *Means of radiosondes drift over the different climate regions as shown by the legend, established from one year 2006 SPARC data.*

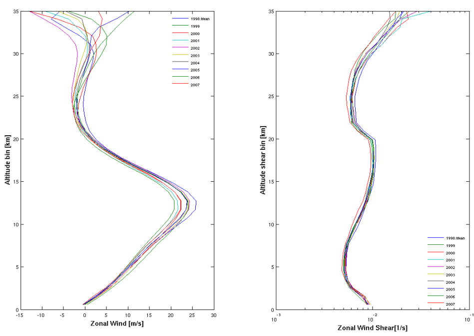



Figure 5. *Inter-annual variability of wind and wind-shear for ten years period 1998-2007, e.g. subtropics.*

Results from new generation and more accurate radiosoundings (BADC, AMMA and De Bilt; described in section.2) (not shown) and as well as the processing of 9 years additional SPARC data (1998-2007) show comparable wind and wind-shear statistics for a given specific climate region. The 10 years SPARC data statistics show similar order of values of wind and shear from year to another for this subtropics case (figure 5). Apart some differences related to the temporal variability, e.g. the Quasi-biannual Oscillation (QBO) in the tropics [1], similar results are observed for the others climate regions.

### 3.3 Effect of vertical resolution on the wind-shear statistics: Effective model resolution

To measure the degree in the difference of observed and modelled wind-shear variabilities, ratios of wind-shear statistics are computed at each level bin for successive degraded vertical-resolutions of radiosondes and the ECMWF model, see equation (2). Only the means and medians profiles of zonal and meridional wind-shears are used (means ratios shown here).

$$Rsh_m(z)=\frac{|Vsh_{dz}(z)|_{RS}}{|Vsh(z)|_{EC}} \quad , \qquad (2)$$

$Vsh_{dz}$ denote the wind-shear for the different spatial-resolutions "dz".of the radiosondes.

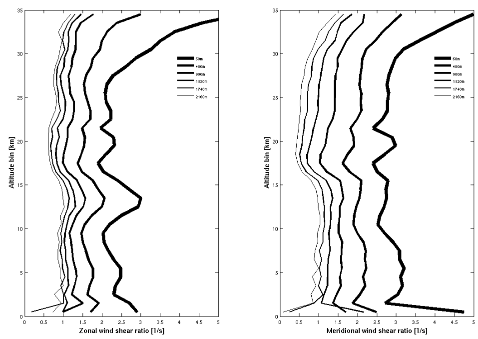



Figure 6. *Zonal (left) and meridional (right) wind-shear ratios of a series of successive degraded resolutions radiosondes and the ECMWF model. This example is from the subtropics. Similar results are found for the other climate regions.*

The means-profiles ratios of SPARC and ECMWF are close to 1 for a radiosonde resolution of about 1.7km (figure 6), at least in the free troposphere. Considering the zonal and meridional results, we conclude that the vertical ECMWF effective resolution is typically 1.7 km. In the stratosphere the effective resolution of the ECMWF in the vertical seems large (>2km) mainly because the coarse model bin-resolutions in this part of the atmosphere. This is also probably amplified by the measurements errors in the horizontal winds due the gravity waves effects [2], combined with the less accurate wind-finding system, the radio-theodolite. In the planetary boundary layer (PBL) where the vertical bin–resolution of the ECMWF is very enhanced, the effective vertical resolution is clearly improved, where one may see particularly the wind-shear ratios drop below the profiles 1.7 km. Essenwanger and Reiter [3] demonstrated by using military wind rocket, the existence of a power law between the wind-shear and shear interval (dz) which explains this dependence of the wind vertical variability (shear) with the spatial vertical resolution .

### 3.4 Sea-Land and dawn-Dusk comparison

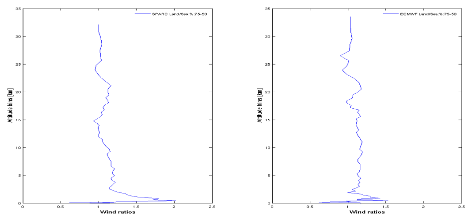
The difference in wind variation between Land and Sea, and dawn (6AM) and dusk (6PM) is demonstrated by computing the following quantities, Land-Sea and Dawn-Dusk Profiles (LSP and DDP):

$$\mathrm{LSP}(z)=\frac{\left[p_{75}(z)-p_{50}(z)\right]\Big|_{\mathrm{Land}}}{\left[p_{75}(z)-p_{50}(z)\right]\Big|_{\mathrm{Sea}}} \quad (3)$$

$$\mathrm{DDP}(z)=\frac{\left[p_{75}(z)-p_{50}(z)\right]\Big|_{\mathrm{Dawn\,(6AM)}}}{\left[p_{75}(z)-p_{50}(z)\right]\Big|_{\mathrm{Dusk\,(6PM)}}} \quad (4)$$

$p_{75}$ and $p_{50}$ are successively the third quartiles and the medians of the wind or wind shear.

(a) Zonal wind



(b) Zonal wind shear

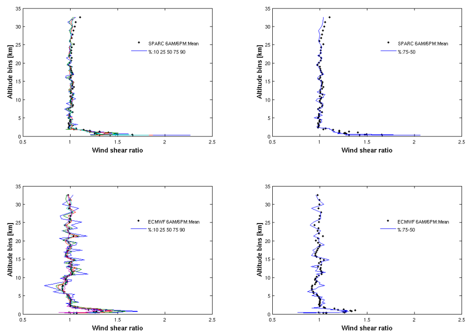


Figure 7. *Land–Sea difference in the subtropics zonal wind (a) and shear (b) statistics from both radiosondes (12UTC) and ECMWF independently (wind-shear LSP (b-right), and means and percentiles(10,25,50,75,90%) ratios profiles (b-left)).*

### 4. CONCLUSION

The horizontal wind representation from both model and observations are complementary, since they reproduce a pretty similar averages (means/medians) state and horizontal wind variability at different levels of the atmosphere and over the various climate regions. But the vertical variability of ECMWF model wind (shear) is underestimated with a factor of about 2.5 (zonal wind) to 3 (meridional wind). It is thus demonstrated that the effective vertical resolution of the model is typically 1.7km. From the radiosondes drift statistics, we conclude that the comparison between the ECMWF model and the radiosondes observations is valid and consistent. Moreover, the statistics from a new generation wind-finding systems (LORAN and GPS) and from inter-annual variability, shows a large consistency of the annual climate. The difference in variability between land and sea and the diurnal changes in variability is more pronounced in the lowest 2 km of the atmosphere. Besides the importance of this study for NWP and the climate modelling, it is used as an immediate application in the framework of ESA's ADM-Aeolus, to investigate the optimal vertical sampling of the Aeolus Doppler Wind Lidar (DWL). Aeolus DWL has a limited number of vertical range gates or levels (24) that need to be distributed vertically in an optimal way such that the maximum information content on wind and shear may be obtained from the atmosphere by the mission. This study is thus exploited to build a global and dynamically and optically realistic atmospheric database. For more details, see Stoffelen et al [11].

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