Quality of weather radar wind profiles at ARPA Emilia-Romagna

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1. Introduction

Retrieved radar wind profiles are widely used in weather services for monitoring purposes and are commonly assimilated into numerical weather prediction models. For these reasons they should be carefully verified in order to assess their reliability.

After the upgrade of Emilia-Romagna radar network a quality control of retrieved wind profiles has been required.

To calculate wind profiles the local wind field is approximated by a linear model. This hypothesis could not be verified far from the radar site, or in case of strong updrafts or downdrafts and it follows that retrievals can be affected by errors. This is more true if low elevation angles are considered. By means of this study, in particular for the velocity-azimuth display (VAD) technique (Lhermitte and Atlas, 1961) and (Browning and Wexler, 1968), the possibility to use profiles derived from low elevation angles wants to be established. For this reason the validation is performed independently for each scan elevation angle.

The advantage of having reliable profiles coming from different elevation angles should reside in a more detailed structure of wind in the lowest atmosphere levels. In this case profiles should be more suitable, for example, for environmental studies of polluting dispersion and for applications in the planetary boundary layer.

In this study, taking radiosonde data as reference, the verification of VAD technique is assessed over an eight month period. Moreover VAD profiles produced for monitoring purposes are compared with those obtained using volume velocity processing (VVP) technique (Waldteufel and Corbin, 1979). A preliminary analysis of distribution of wind speed and direction against the high resolution COSMO NWP model forecasted winds is shown.

2. Radar network and acquisition scheme

Emilia-Romagna network is formed by two polarimetric doppler C-band radars sited in San Pietro Capofiume (44.655°N, 11.624°E, and 11 m MSL) and in Gattatico (44.791°N, 10.499°E, and 40 m MSL). Due to the collocated radiosonde station, only data from San Pietro Capofiume radar are considered in this study.

After the upgrade of radar systems in the last years, different types of scans were tested. To have a consistent set of data, the period selected for the determination of the quality of wind radar profiles is reduced from October 2013 to May 2014. Finally for the wind profiles production, the scanning strategy is designed to have, every 15 minutes, a detailed volume of data over 11 elevations. Radial wind measurement is made for each elevation applying the dual pulse repetition frequency technique with an unambiguous velocity interval and measurement range that change as reported in Table 1. Please note that since an alternate polarization scheme used Nyquist velocity is half of its nominal value.

Table 1: Acquisition scheme for San Pietro Capofiume radar.

Elevation [degree]	PRF1 [Hz]	PRF2 [Hz]	V_{nyq} [m/s]	Maximum Range [km]
0.5	702	526.5	28.2	214
1.4	702	526.5	28.2	214
2.3	900	675	36.2	167
3.2	1200	900	48.2	125
4.2	1200	900	48.2	125
5.0	1200	900	48.2	125
7.0	1350	1012.5	54.2	111
9.5	1500	1125	60.3	100
13.0	2000	1500	80.4	75
18.0	2000	1500	80.4	75
25.0	2000	1333.3	53.6	75

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3. VAD and VVP algorithms

An exhaustive description of VAD and VVP retrieval methods and of the several sources that affect the quality of the wind profiles is given in Holleman (2005). VAD and VVP algorithms used in this study are implemented by the manufacturer. Some constraint are present and only few parameters can be changed in order to approximate Holleman (2005) recommendations.

Actually at ARPA Emilia-Romagna VAD profiles are produced operationally for monitoring purposes using only the highest elevation angle, while VVP profiles are in a pre-operational test.

For verification purposes, VAD profiles are calculated independently for each elevation. For low elevation angles data are very dense because VAD retrieval is performed at each range gate that have small vertical displacement (Table 2).

Table 2: Approximate layers thickness in the VAD algorithm.

Elevation	1	2	3	4	5	6	7	8	9	10	11
Vertical resolution [m]	3	7	10	14	18	22	30	42	56	78	104

The entire vertical extension of these profiles is limited to few kilometers above ground. Reminding that highest data are taken over a long range and that under this condition the hypothesis of linearity of the wind field cannot be longer verified, results should be analysed critically. For higher elevations the vertical extension increases greatly reaching heights over 7000 km above ground losing, at the same time, in vertical layers resolution. On the other hand underneath assumptions can be more easily attained.

Starting from the complete volume of data, the used VVP method computes winds at vertical heights regularly spaced. The vertical resolution, the maximum range and minimum elevation angle considered in the retrieval can be chosen by the user. In this study the vertical resolution has been set approximatively to the one set by the VAD highest elevation angle, making products directly comparable. Three different configurations have been chosen changing the maximum range and the minimum elevation angle.

4. Wind profiles verification

Two different kinds of verification has been carried out to assess the quality of radar retrieved wind profiles. Because VAD algorithm gives the possibility to use profiles derived from low elevation angles, in the first part the validation is performed independently for each scan elevation angle against observed wind profiles. The aim is to estimate the quality of retrieved profiles in terms of availability and reliability. Then wind profiles coming from VAD technique are compared to those deriving from VVP technique trying to know which technique gives better results. In the second section, observed profiles are verified against estimated wind profiles from radar and numerical weather prediction model. The issue is to understand if radar wind profiles could be relevant into assimilation cycles.

Over the selected time interval, verification dataset comprises all of radar acquisitions coincident with high resolution radiosondes data. At San Pietro Capofiume radiosondes launches are mostly once a day at 23 UTC. Some further launches at 11 UTC were made during observational campaign in October 2013, February and May 2014. Data from radiosondes are then interpolated over retrieved profiles in order to have data directly comparable.

4.1. Validation of VAD against radiosonde wind profiles

Before the comparison with radiosonde profiles, over the same set of data, a preliminary analysis of root mean square errors (RMS hereafter) related to retrieved radar velocity is exploited.

As expected higher RMS errors are associated to low and very high level winds. In both cases one of the causes resides in the poor samples of data over which retrieval is performed. This means that the fitted curve is associated to a great uncertainty. For first levels above ground another cause of these limited results resides in the measurements contamination due to clutter and side lobes.

The first elevation angle, mostly affected by clutter, presents noisy outcomes for the entire vertical extension. Boxplots exhibit large distributions with a high variability of the median value. Distributions become narrower with a more stable median as elevation angle increase. For example, to display the tendency of the RMS distributions with highest errors below 1 km and above 5 km, boxplots from the 9^{th} elevation are shown (see Fig. 1). For the eleventh elevation, considering all of the errors, between first and third quartiles, excluding the first 600 m above ground, errors associated to velocities are less than 2 m/s and in the layer between 1 and 4 km are smaller than 1 m/s.

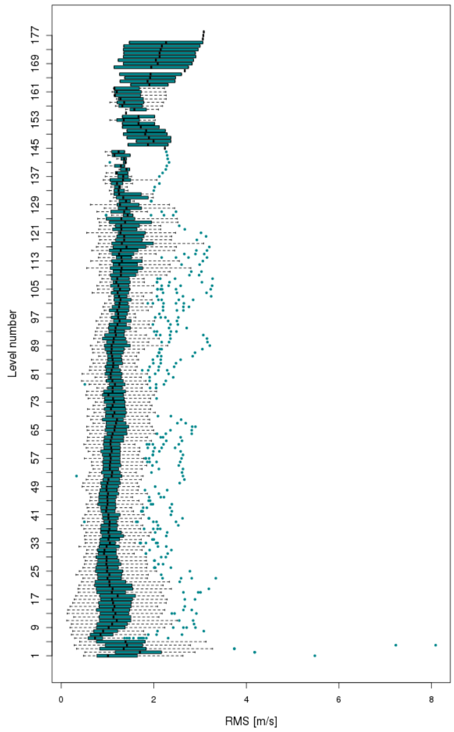

Figure 1: Distribution of RMS errors as function of height for the 9^{th} elevation angle.

Differences of radar profiles with respect to radiosondes were verified by means of bias and root mean square error as a function of height (see Fig. 2). Considering wind speed, RMS errors decrease as radar elevation angle increases. In particular, results from first and second elevations are very noisy over their whole vertical extension. Due to the fact that this behaviour is reflected also over the bias these data should not be considered at all. Errors near surface for all of elevations are greater than those of following levels.

The third elevation shows a general positive bias with the lowest RMS error between 100 e 500 m. Above this height, RMS values increase quickly becoming very noisy. As previous elevations the trend becomes unstable at higher levels. From the 4^{th} elevation angle a common feature can be distinguished: the RMS error increases from the first layer for about 4/5 levels and, then, tends to descrease. The tendency of error profiles is more continuous and less oscillating starting from the 7^{th} elevation. Elevations 7 and 8 are rather similar (only the 8^{th} is plotted) for all of the vertical extension. In the first kilometre above surface, better scores between highest three elevation angles are shown by the 9^{th} elevation, while higher RMS belongs to the 10^{th}. Over this height behaviour of 8^{th} and 9^{th} elevations are comparable, on average. 10^{th} has lowest RMS error values between 800 and 1600 m and later on it improves respect to the previous elevation. Values for the highest elevation angle reside below 4m/s up to 1500 m and then they decrease between 1500 and 3500 m, then they increase again. Over the 1800 m, the 11^{th} elevation gives the most reliable results.

For lowest elevation angles, the bias tends to overestimates observed wind speeds. This overestimation which is however lower than 5 m/s below 2500 m and decreases toward zero as elevation angle increases. A small underestimation can be noticed up to 1km height for elevations above 7 degrees. This underestimation is larger for the latest three elevation angles.

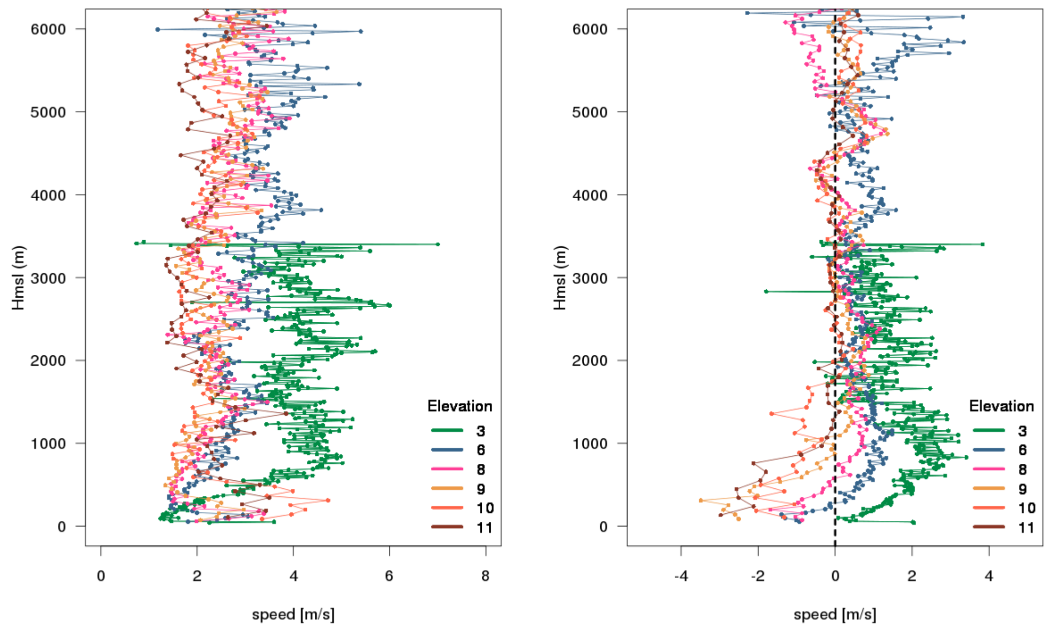

Figure 2: Differences between radar retrieved and radiosonde wind speed in terms of RMS error (left) and bias (right) as function of height.

For wind direction, only the bias between radar retrieved and radiosonde profiles has been analysed (see Fig. 3). Until the 5^{th} elevation, bias values show a noisy behaviour that makes trend evaluation impossible. Bias has negative sign firstly between the surface and 500 m and then between 1500 m and 4000 m. In the other vertical intervals it has a zigging behaviour across the zero. As a general results, it shows values below 20 degrees for the latest 3 elevations.

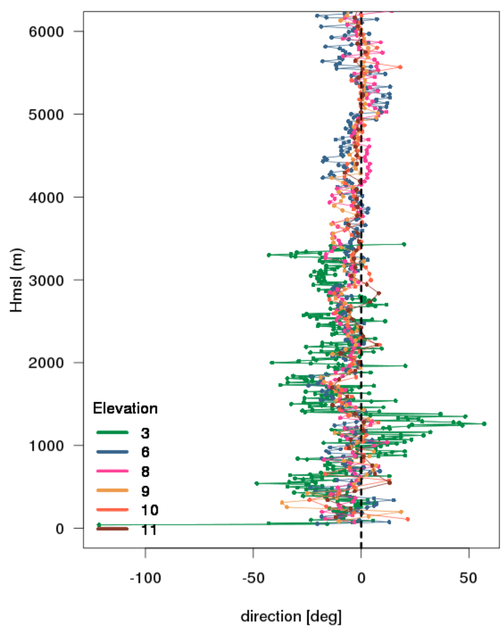

Figure 3: Differences between radar retrieved and radiosonde wind direction in terms of bias as function of height.

The investigation over radar retrieved wind profiles has been extended using also the VVP technique. As a first test, the vertical resolution of layers is set equal to the same derived by VAD using the 11^{th} elevation. Evaluations are made using three different configurations:

- VVP1: all of the elevation with a maximum range of 50 km;
- VVP2: all of the elevation with a maximum range of 20 km;

- VVP3: elevation angle above 5 degrees and a maximum range of 20 km.

Differences between VVP configurations are less than 1m/s for wind speed RMS error and less than 2 m/s for bias (see Fig. 4). As a term of comparison, profiles of bias and standard deviation from the verification of VAD at the 11^{th} elevation against radiosonde are plotted over the same graph. Up to 1000 m VVP1 and VVP2 are coincident, then between 1000 and 4000 m VVP1 have lower RMS error than VVP2. The trend inverts above 4000 m. The VVP3 configuration, which consider a reduced volume of data, has a more linear tendency between 1000 and 4000 m, with better scores respect to the other configurations between 1000 and 3000 m results. In the first layers high RMS values can be due to the fact that only elevation above the 5^{th} are considered. This means that first elevation angles gives useful information in retrieving wind profiles. Over 4500 m, the better scores of VVP1 configuration are due to the greater volume of data considered. As for RMS, bias tendency for VVP1 and VVP2 is the same in first levels. Under 1000 m, as for VAD outcomes, retrieved profiles underestimates observed ones. Above this height, configurations VVP2 and VVP3 show, on average, a smaller bias than VVP1.

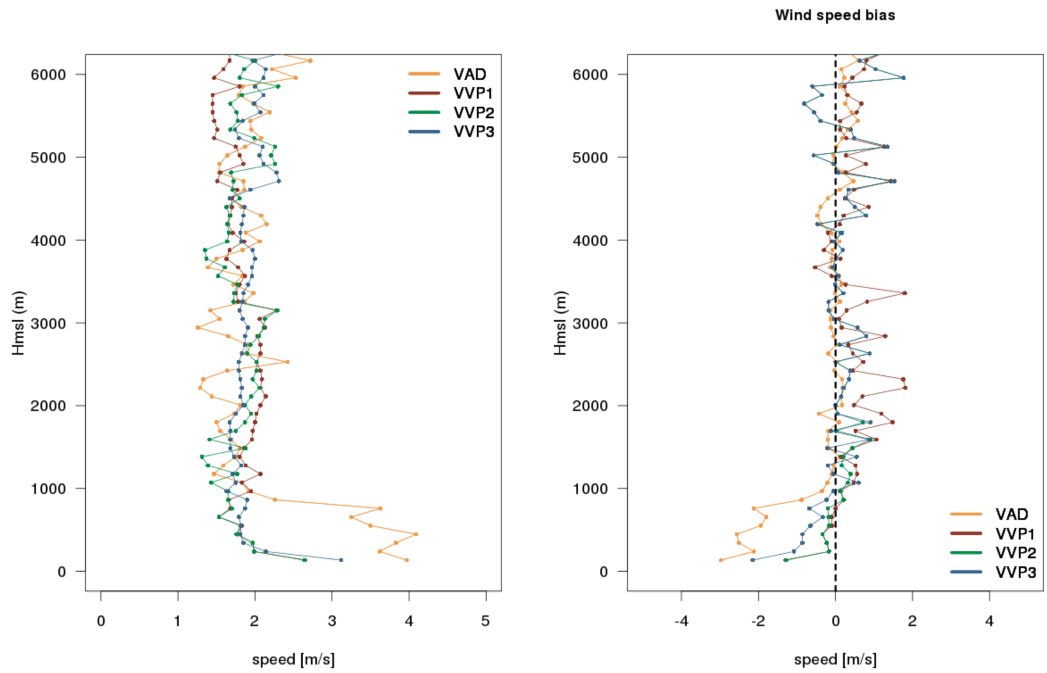

Figure 4: Differences between radar retrieved (VAD and VVP techniques) and radiosonde wind speed in terms of RMS error (left) and bias (right) as function of height.

As a general result,up to 1000 m, RMS errors derived from the verification of VVP technique against radiosondes outperform ones from VAD method, while bias is comparable (not shown). As expected, the VVP better performance in first layers is due to the bigger portion of data used in the retrieval. For higher heights, results are quite similar, even if VVP profiles are characterized by a less variability along the vertical.

4.2. Validation of different wind profiles sources against NWP model

Before the assimilation of retrieved wind profiles into the high resolution COSMO NWP model, a statistical analysis of differences between analysed COSMO model wind profiles and VVP profiles is accomplished. As reference also radiosonde data, that are regularly assimilated into COSMO model, are taken into account. The issue is to understand if distributions of wind speed and direction are similar between the different sources. This statistical analysis is carried out over two seasons (winter and spring 2014).

Stored COSMO model analyses at 00 UTC, located over San Pietro Capofiume, are extracted and winds along the vertical are linearly interpolated over the same levels of VVP profiles.

As expected, wind distribution for spring and winter differs both in speed and direction. Differences in direction reside mostly in seasonal weather regimes (not shown). In the winter, VVP distributions of wind speed show small differences in first four levels respect to the others (see Fig. 5). For higher layers, RSD and VVP distributions are quite similar. Model distributions are to some extent wider both in winter and in spring. In the spring panel, wind speed distributions show ah higher variability in particular with respect to the median value.

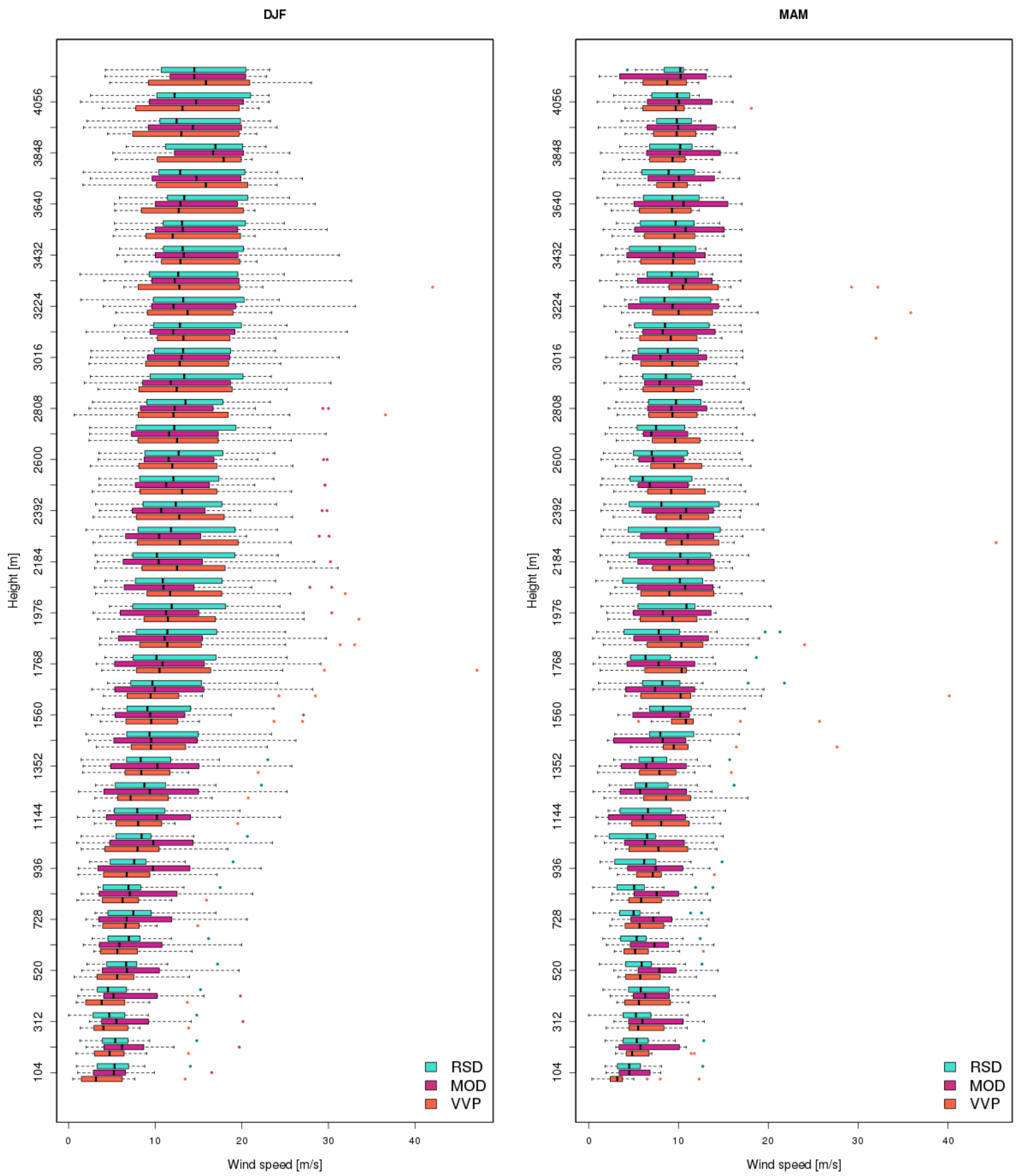

Figure 5: Distributions of COSMO model, VVP and radiosondes wind speed below 5000 m for winter (left) and spring (right).

5. Conclusions

In the presented analysis radar derived wind profiles show a good performance in the comparison against radiosonde data. In particular VVP technique outperforms VAD results in the first kilometre. Due to the improved reliability in first levels above surface, the overall conclusion is that for monitoring purposes the actual profiles used at ARPA Emilia-Romagna should be substituted by those retrieved by the VVP technique.

Due to the high RMS of VAD profiles near the surface for the highest elevations and in order to have better quality profiles near the surface, VVP technique will be tested also with higher vertical resolution.

The quality of profiles above 1 km height allows the assimilation of profiles into the COSMO model. In the future, an analysis of COSMO forecasts against coincident VVP profiles will be assessed in order to understand the extent to which the retrieved profiles could affect the assimilation cycle.

Next, an intensive analysis will be accomplished to define a climatology of retrieved profiles also from the other radar of Emilia-Romagna radar network. Due to their different location into Emilia-Romagna region radars are prone to different local wind regimes. The aim of this additional work is also to define if a correlation between the quality of retrieved profiles and weather regimes exists.

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References

K. A. Browning and R. Wexler, "The determination of kinematic properties of a wind field using doppler radar," *J. Appl. Meteor.*, vol. 7, pp. 105–113, 1968.

I. Holleman, "Quality control and verification of weather radar wind profiles," *J. Atmos. Ocean. Tech.*, vol. 22, pp. 1541–1550, 2005.

R. M. Lhermitte and D. Atlas, "Precipitation motion by pulse doppler radar," in *Preprints, 9^{th} Conf. on Radar Meteorology*. Kansas City, KS: Amer. Meteor. Soc., 1961, pp. 218–223.

P. Waldteufel and H. Corbin, "On the analysis of single doppler radar data," *J. Appl. Meteor.*, vol. 18, pp. 532–542, 1979.