

Assessing the Quality and Biases of European Radar Radial Winds for Numerical Weather Prediction

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Radar observations Radars use electromagnetic waves to detect and measure the speed of moving objects. After the signal is sent, part of the energy reflected from the object is recorded. These reflections make it possible to measure the reflectivity and radial component of the wind, i.e. the speed of the object along the imaginary line between the radar and the target. The key variable in the case of assimilation of the radial component of the wind is the Nyquist velocity, which helps ensure that these measurements are reliable and accurate.

The data were first homogenized to ensure compatibility with the assimilation system. This step was critical because European meteorological services operate a diverse array of radar technologies, each with unique signal processing algorithms and scanning strategies. Such heterogeneity introduces varied observation errors and spatial biases.

The key to data analysis is to quantify the deviations between the observations y and the model state vector x , which is transformed to observation space with observation operator $H()$. This is given by the vector of departures at the observation points:

$$d = y - H(x)$$

The pre-selection of radars were under few criteria :

- 1) Radars provides datasets to EUMETNET Operational Programme on the Exchange of Meteorological Radar Information
- 2) Datasets contains information about radial wind, Nyquist velocity and reflectivity.
- 3) Radars are in model domain of ALADIN/CHMI

Figure 1: Spatial Distribution and Monitoring of the European Radar Network. The map displays radar locations within the ALADIN/CHMI domain. Radar stations are color-coded by their mean departure values, providing a spatial overview. The size of each point reflects the total observation count (Number of Obs), highlighting the density of data available for assimilation.



The **First Guess Check** is a critical step in the data assimilation pipeline. It determines the inclusion of an observation by comparing it directly to the model's background field. If the observations deviate significantly from the model equivalent, the observations are discarded to prevent the degradation of the subsequent analysis. A fundamental requirement for optimal data assimilation (such as 3D-Var) is that the observation errors must follow a Gaussian distribution.

The histograms below provided visualizes the distribution of radial velocity departures between observed and model background values. However, raw radar radial wind departures often exhibit "heavy tails"—extreme values that occur more frequently than predicted by a normal distribution. To rigorously examine the rejection limits and identify these non-Gaussian features, we employed the **Anderson-Järvinen method**. The left panels show the transformed histogram of observation departures for the background, which have been transformed according to the following equation:

$$f = \sqrt{-2 * \ln \frac{f}{\max(f)}}$$

where f is the amount of data in each bin of the histogram (marked as blue crosses) (Anderson, et al., 1999). The red/green line describes the Gaussian curve that corresponds to the mean and standard deviation of your data, for better match was the line set offset to get better visual match (green one is without offset).

The significant reduction in spread from 'All' to 'Active' data demonstrates effectiveness of the Quality Control (for Global monitoring). Only **8.2%** of observations passed the strict criteria, ensuring a high-quality increment for the Aladin/CHMI model.

From a visual comparison, the rejection limit can be set at a certain distance beyond the point where the values of the function f begin to deviate from the straight red/green lines. As seen in Figure 2 (middle, right), estimated deviations follow Gaussian behaviour up to $\pm 6-7$ m/s, but for higher values they form tails, indicating a non-Gaussian distribution. This is thought to be one of the reasons why the assimilation of radial velocity has had a detrimental effect on predictions (Ridal, 2023).

Figure 2: Statistical distribution of Radial Wind departures.

(Left) Comparison of the full dataset (gray) vs. active observations (blue) after quality control. The narrowed distribution of active data demonstrates the effectiveness of the first-guess check. (Middle) Breakdown of European radar network by country (Slovakia, Belgium). Each histogram is paired with an Anderson-Järvinen plot, used to assess Gaussianity. (Right) Detailed breakdown of national radar networks (SKJAV,SKKOJ,BEWID,BEJAB) also, with Anderson-Järvinen plot.

