Color code :

Comments from Referee 1 (RC2) (italic and blue)

Comments from Referee 2 (RC1) (italic and red)

Changes we propose (magenta)

Referee 1 (RC2) comments:

"The authors present and discuss a technique for retrieving vertical humidity profiles from both UHF radar measurements and radiosonde measurements. The general approach is well known and has been documented in several journal papers published during the last 30 years or so. The retrieval technique relies on quite a number of nonrigorous physical and meteorological assumptions and simplifications and is known to be not as robust as, e.g., the retrieval of wind velocities and of the refractive-index structure parameter. Improvements in our ability to retrieve humidity profiles from clear-air radar observations have been incremental, and a fundamental breakthrough is not to be expected.

The manuscript is much too long in comparison to its scientific content. If the paper contains results that might be worthy of publication, they are well hidden under a large amount of unnecessary material. The figure captions are not self-explanatory. The abstract does not state the underlying physical hypotheses, assumptions, simplifications, and approximations, and it contains no information about the precision or accuracy of the retrieved humidity profiles. The conclusions section is much too long and does not present hard conclusions in a compelling and concise manner.

I recommend to reject the paper."

Reply to Referee 1 (RC2)

Despite the Referee's final recommendation to reject the paper , we have decided to move forward and proceed with the submission of a revised version of the manuscript. There are two main motivations behind this decision.
First of all, we have contacted the Associate Editor for an advice, and the Editor has encouraged us to submit a revised version of our manuscript. The Editor believes that the comments from both Referees can help us to improve the manuscript and has invited us to take them all under serious consideration and move forward in the process, which is what we are presently doing.
Second motivation: we have the impression that the final evaluation from the referee (rejection) is somewhat conflicting with the reminder part of the reviewer evaluation. In fact, besides some preliminary statement on the originality of the paper ("The general approach is well known and has been documented in several journal papers published during the last 30 years or so.") and the considered assumptions ("The retrieval technique relies on quite a number of non-rigorous physical and meteorological assumptions and simplifications"), the reviewer is stating that: ... "The manuscript is much too long in comparison to its scientific content. If the paper contains results that might be worthy of publication, they are well hidden under a large amount of unnecessary material." T**his is indeed an aspect that we can easily address by shortening and partially reshuffling the paper, that is what we are decided to do and are presently doing.** The reviewer is also stating that: ..."The figure captions are not self-explanatory." Again, **this is an aspect we can easily address and we actually already did it in the revised version of the paper**. The reviewer adds: ... "The abstract does not state the underlying physical hypotheses, assumptions, simplifications, and approximations, and it contains no information about the precision or accuracy of the retrieved humidity profiles. Again, **we added all** this **missing information in the revised version of the Abstract**. And again: ... "The conclusions section is much too long and does not present hard conclusions in a compelling and concise manner." **In the revised version of the paper, the conclusions have been shortened and the**

text has been partially rewritten in order to present the conclusions in a compelling and concise manner.
To summarize, **we believe that all issues raised by the Referee can be addressed (and have actually already been addressed in the revised version of the paper that we are in the process to submit)** and, consequently, the statement "I recommend to reject the paper" is somewhat conflicting with the specific points raised by the Referee, which can indeed be addressed.
With this premise, we would like to address (below) the different issues raised by the Referee, hoping that our replies can make him/her re-consider his/her judgment on the manuscript publication.

1 - *"The general approach is well known and has been documented in several journal papers published during the last 30 years or so.* […] *Improvements in our ability to retrieve humidity profiles from clear-air radar observations have been incremental, and a fundamental breakthrough is not to be expected."*

We do not claim that this research is new and we agree with the comment from Referee 2, who underlined that *"The technique itself is not new, and the development presented in the current manuscript is incremental rather than fundamental."* We insisted on this point in the manuscript by quoting the authors who proposed or used the method and we made this clear in page 4, lines 12-13: 'Following Tsuda et al. (2001), Furumoto et al. (2006), Klaus et al. (2006) and Imura et al. (2007) also used Eq. (12) to compute humidity profiles. We use this equation in the present work.'
Nevertheless we point out that most research efforts that were carried out on this subject indicated that the method was promising for an operational use, although, to our knowledge, no work had been presented yet for such an application (page 1, line 23: 'However, as far as we know, no successful attempt to apply this method to operational observations has been reported in literature.'). That is why our aim was to check whether an operational application could be implemented or not. We tried to do so, improved the algorithm (by introducing the use of a transition level and a calibration process that varied with time and height) and obtained mildly encouraging results. Our objective was to honestly present the encountered difficulties and provide conclusive statements on the applicability of the method. This seems to have been appreciated by Referee 2, who wrote: "It is good that the authors have acknowledged instances where the technique does not produce reliable results."

2 - *'The retrieval technique relies on quite a number of nonrigorous physical and meteorological assumptions and simplifications and is known to be not as robust as, e.g., the retrieval of wind velocities and of the refractive-index structure parameter.' […]*

We agree with you on the lack of robustness of the considered retrieval technique, and we propose to highlight the difficulties in the abstract by writing: **"The retrieval of humidity profiles from wind profiler radars has already been documented in the past 30 years and is known to be neither straightforward nor as robust as the retrieval of wind velocity, which exploits a physical property of electromagnetic waves (i.e. the Doppler effect). The main constraint to retrieve the humidity profile is the necessity to combine measurements from the wind profiler and additional measurements (such as observations from radiosoundings at a coarser time resolution). Furthermore, the method relies on some assumptions and simplifications that restrict the scope of its application. The first objective of this paper is to identify the obstacles and limitations and try to solve them, or at least define the field of applicability of the method. To improve the method, we propose to use the radar capacity to detect transition levels, such as the top level of the boundary layer, marked by a maximum in the radar reflectivity and to use this level as a new constraint for the algorithm** which reduced the error affecting the specific humidity profile retrieval, with the mean bias never exceeding 0.25 g kg-1. **The second objective is to explore the capability of the**

algorithm to retrieve the humidity vertical profiles for an operational purpose by comparing the results with observations from a Raman lidar."

3 - *The abstract does not state the underlying physical hypotheses, assumptions, simplifications, and approximations, and it contains no information about the precision or accuracy of the retrieved humidity profiles.*

The Abstract has been modified in the direction to include the limitations of the approach used in the paper. The following new sentences have been introduced: "The retrieval of humidity profiles from wind profiler radars has already been documented in the past 30 years and is known to be neither straightforward nor as robust as the retrieval the wind velocity. The main constraint to retrieve the humidity profile is the necessity to combine measurements from the wind profiler and additional measurements (such as observations from radiosoundings at a coarser time resolution). Furthermore the method relies on some assumptions and simplifications that restrict the scope of its application. **The first objective of this paper is to identify the obstacles and limitations and try to solve them, or at least define the field of applicability of the method.**" An estimate of the accuracy of the retrieved humidity profiles has also been introduced, the corresponding sentence of the Abstract now reading: " … **and to use this level as a new constraint for the algorithm** which reduced the error affecting the specific humidity profile retrieval, with the mean bias never exceeding 0.25 g kg-1. "

The conclusions section is much too long and does not present hard conclusions in a compelling and concise manner.

As explained above, one of the paper aims is to point out these hypothesis, assumptions and simplifications, but they can hardly be summarized in the Abstract. Instead, we propose to be more concise in the conclusion (39 lines instead of 62), and to quote there the main restrictions that are highlighted in the manuscript:

"We demonstrated in the first four sections of this paper that, although WPRs, with their first three moments, measure essential parameters for the determination of the vertical humidity gradient of, radar data cannot be used to retrieve the vertical profiles of humidity independently from other sensors' data. To obtain the profiles, we applied a method already proposed by Tsuda et al. (2001), which consists in using a combined retrieval algorithm exploiting WPR measurements supported by RS observations at a coarser frequency. This algorithm is based on several approximations and assumptions that proved to be appropriate since the accuracy of the results we obtained did not exceed 0.3 g/ kg (mean bias between q radar and q RS). To obtain these results, we improved the algorithm proposed by Tsuda et al. (2001), by using a key parameter from the radar, which is the level of the reflectivity peak value, Hlim, allowing to split the calculations in two parts, with two different calibration coefficients accounting for two distinct vertical regions with different turbulence characteristics. The introduction of this level also mitigated the errors by replacing a long integration by two shorter ones.

After assessing the algorithm at the time of the RS observations, we applied it between two RS profiles, to obtain humidity profiles at a finer time resolution and to check the performance of the combined algorithm with respect to a simple RS time interpolation. We used, when available, simultaneous lidar data to assess the results. The set of data that enabled this comparison was collected during a period seldom characterized by the presence of clear-sky conditions, while cloudy conditions were prevailing (HYMEX SOP1). In the presence of clouds, the lidar beam is rapidly attenuated above cloud base, so that the assessment can only be made in the lower portion of the profiles.

We obtained some satisfactory results, provided that the time separating the two boundary RS did not exceed 12 h. However we also met some hindrances that make the method hard to apply in an

entirely automatic way, due to the assumptions we made. These difficulties are summarized below:

- **The most restrictive issue is the one associated with the border conditions (bottom and top). The method assumes that they vary linearly between the two RSs which is not always true. If the border conditions are not well defined (for instance at a moisture inversion level), the error may propagate and become large at the Hlim level. Additionally, the resulting profiles can easily move apart, towards the two constraining borders: either towards 0 g/kg as the minimum value, or towards the saturated moisture content as the maximum value.**

- **Although pressure and temperature are secondary parameters in the algorithm, so that they do not require to be as accurate as the border conditions, the profiles for these parameters have to be provided. These two parameters are also used to constrain the computed humidity values to the saturation q. We used a linear interpolation of the two border RS profiles to get the intermediate P and T profiles. Alternatively, these profiles could be provided by models, which are usually more reliable for pressure and temperature than they are for humidity.**

- **The constraint on the sign of the humidity gradient is also an issue that can hardly be solved by a simple interpolation or a continuity constraint in time. Some authors constraint their results with GPS measurements of integrated water content. This approach failed with our data set.**

- **We highlighted the necessity of calibrating the vertical gradient of radar refractivity, with calibration coefficients likely to vary in time and space. This revealed to be helpful, but also in this case, a simple interpolation between the initial and final coefficients could be too large an approximation. However, the detection of the transition level between the boundary layer and the free troposphere was definitely helpful.**

Finally, we demonstrated that the combined RS-radar algorithm used to retrieve the humidity profiles outperforms a simple interpolation of the RS observations. The radar is especially skilled at determining the evolution of the transition layers, which is usually an issue when using other remote-sensing measurements such as, for example, radiometer measurements. However, the present method should be used with caution, and is probably more adequate in post-processing a dataset for scientific purpose than for a blind use in an automatic platform."

4 - *The manuscript is much too long in comparison to its scientific content. If the paper contains results that might be worthy of publication, they are well hidden under a large amount of unnecessary material.*

We could shorten the manuscript by removing several parts and shortening others. Specifically, we could remove the:

- description of case studies and the associated figure (4) : section 4.2, page 13, lines 10 -34 + page 14, lines 1-22
- discussion of the BLLAST upper layer: page 15, lines 3-10
- discussion on the use of a constant calibration coefficient: p 17, lines 13-17
- last case study in section 5.2 : p 21, lines 19-34 and p 22, lines 1-12 and Fig. 12.
- Fig. 6 and 7 could be presented in one single Fig (with two parts). Total number of Fig. would be 9.

Additionally, we reshuffled the conclusion as proposed in point 3.

5 - *The figure captions are not self-explanatory.*

As suggested by the reviewer, we tried to improve figure captions in order to make them self-explanatory.

The caption of figure 1 now reads: "Vertical profiles of refractivity gradient (panels (a) and (b)) and humidity (panels (c) and (d)) using a systematic negative sign for M (panels (a) and (c)), or after assigning to M the sign of M provided by the RS observations (panels (b) and (d)). RS values (q-RS) are red solid lines and radar values (q-Radar) are black solid lines. The thin red lines (int-q-RS) identify the humidity profiles retrieved from the integration of M_{RS} after averaging the RS observations by slices of 75 m, to match the vertical resolution of the radar. The red dashed line (qsat-RS) is for the saturated humidity profile. The horizontal dashed line delineates Hlim, the transition level used to separate the upper and lower part of the profile. The two values of α^2 (calibration coefficients), over or below Hlim are also indicated."

The caption of figure 2 now reads: "Radar turbulence structure parameter Cn^2 (panels (a) and (d)) and humidity profiles (same details as in Fig. 1 (c)) for different Hlim levels. Panels (b) and (e) illustrate the WPR specific humidity profile (q-Radar) obtained considering the value of Hlim corresponding to the dominant Cn^2 peak observed in panels (a) and (d), respectively. Panels (c) and (f) illustrate the WPR specific humidity profile obtained considering the value of Hlim corresponding to a different relative maximum of the Cn^2 profile. In panels (b), (c), (e) and (f) the RS specific humidity profile (q-RS), the saturation specific humidity profile (qsat-RS) obtained from RS pressure and temperature profiles, and the saturation specific humidity profile (int-q-RS) obtained by integrating RS vertical gradient of refractivity (M_{RS}) are also indicated. Panels (a), (b) and (c) are for the high mode (vertical resolution 375 m, interpolated every 150 m), while panels (d), (e) and (f) are for the low mode (vertical resolution 150 m)."

The caption of figure 3 now reads: "Specific humidity profiles obtained: i) using an automatic detection of the initial specific humidity value (q_o) at the level z_o where the integration is initialized (panels (a) and (c)); ii) through an adjustment of q_o (panels (b) and (d)) for two different profiles from the BLLAST data set. The vertical resolution is 75 m. Same details as in Fig. 1 (c).

The caption of figure 4 now reads: "Panels (a), (c), (e) and (g) : scatterplots of radar versus RS specific humidity during June and July 2011 (BLLAST), September 2012n(HyMeX SOP1), October 2012 (HyMeX SOP1) and February 2013 (HyMeX SOP2), respectively, with the linear regression line (in red) and the 1:1 slope line (in black). The R^2 correlation coefficient of the regression is also specified. Panels (b), (d), (f) and (h) : Deviation profiles between the RS specific humidity measurements and radar-based estimate for the above specified data sets ± the standard deviation. The mean bias and standard deviation values for the whole dataset are reported, along with the maximum standard deviation value (g kg^{-1}).