Reviewer:1

We thank Reviewer 1 for his/her constructive comments.
Our responses are given below in red.

Responses to the major comments:

1. The authors conducted two verification of a case study and a statistical examination.
The case study showed that the RASTA assimilation improved wind and rainfall fields, and the 3-h assimilation looked best. On the other hand, the statistical examination for the entire domain in Figure 1 illustrated that the RASTA assimilation mostly had no impact even on the wind field, and only the 1-h assimilation has some skill in rainfall forecasts. Since the RASTA data is limited in cloud region, the assimilation impact is also limited in time and space. I suggest that the statistical examination is re-conducted over a limited area, for instance, the Figure 2 area, or convective-system-related area, or RASTA-related area, since the inconsistent results between the case study and the statistical examination makes the readers confused.

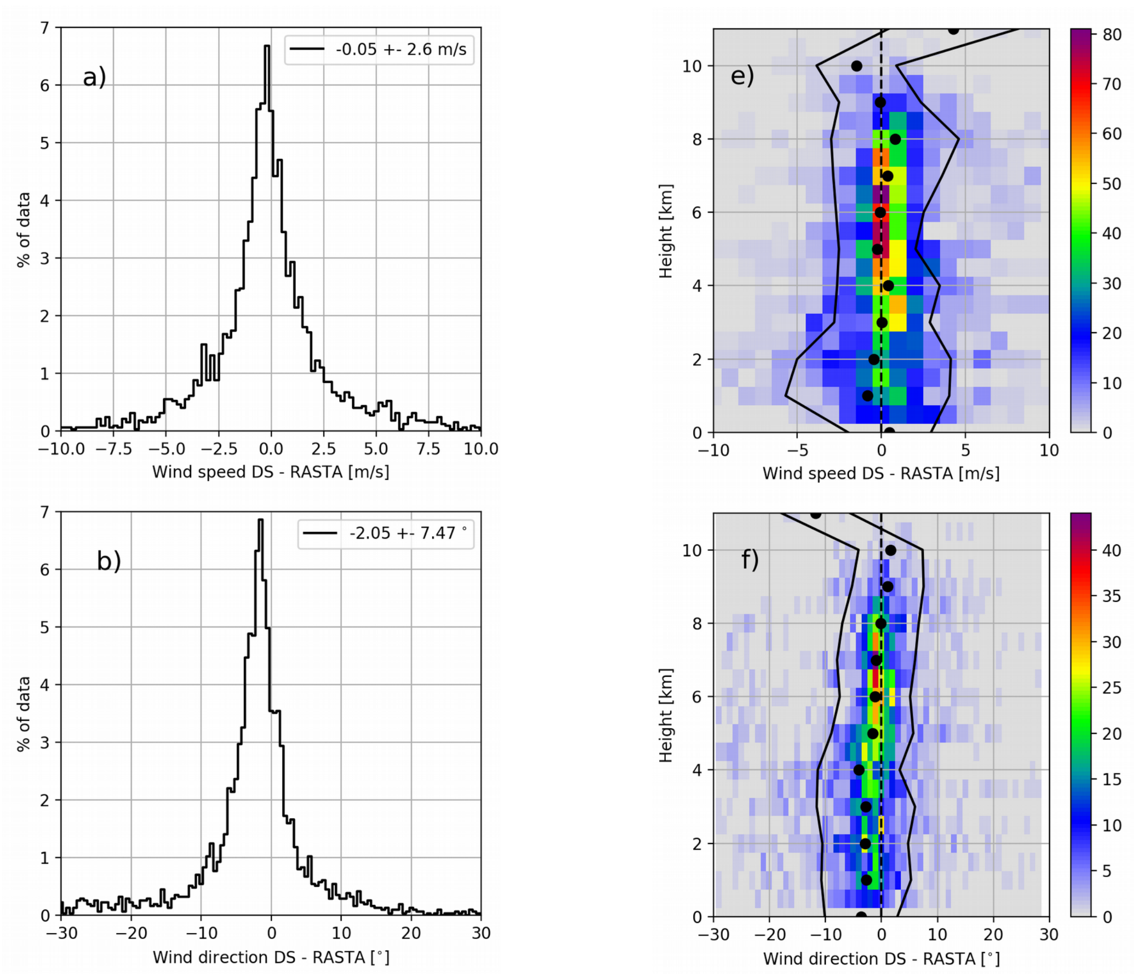
> The authors are grateful to Reviewer 1 for his comment because now we have a better consistency between the case study and the statistical examination. The statistical examination has been re conducted over a RASTA-limited area. This area contains the aircraft flight path +/- 0.5° both in longitude and latitude. The RASTA-limited validation domain is larger than the exact flight path because the increments are advected as the forecast term increases. The text has been modified in section 6.1.
>
> The comparison against conventional observations indicates similar results (see section 6.1 and Figure 9 of the revised version): generally the impact is slightly negative to slightly positive. Besides, the differences are less than 0.5 m/s, so the impact is neutral.
>
> The methodology employed to compute the scores against rain gauge measurements has been modified. In the RASTA-limited validation area, observations and model outputs are first averaged in boxes of 0.25°*0.25°, and then concatenated over the 35 assimilation cases. Bootstrap confidence intervals are calculated with these new sets of observations/model outputs. To avoid the spin-up problem, the first hour of rainfall accumulation has also been removed from the calculations.
>
> - The new results are more consistent with the case study: the best scores are reached with the largest assimilation windows (2h or 3h) and the most significant differences appear with the RASTA_3h and RASTA_2h experiments.
> - Generally, the impact is slightly positive to neutral. The use of the smallest assimilation window leads to the most neutral impact, which is also consistent with the IOP7a case study.
> - In the previous version of the paper, the differences between the CTRL experiment and the RASTA experiments appeared above approximately 25 mm. Now in Figure 9 (Figure 10 in the revised version) we can see differences above 10 mm.
> - Figure 9 has been modified (Figure 10 in the revised version), together with the text in sections 6.2, 7 and in the abstract.

2. I agree that Figure 6 implies a spin-up problem in forecast. For the reason of the spin-up, I doubt that the observational error of RASTA use in the present study would be smaller than appropriate value because it is the same with that of radiosondes. The error should be larger since RASTA includes much more sources of errors than radiosondes include.

> We are not sure that the observation error should be larger than the one used for radiosondes.
>
> Indeed, RASTA wind data during the HyMeX-SOP1 field campaign have been compared against ground-based Doppler radar by Bousquet et al. (2016). Results of their study show that “The low values of the bias error suggest that errors are close to Multiple-Doppler wind synthesis and should remain comprised <u>between 1 and 1.5m/s</u>” (see section 3.2, page 93).

These values are smaller than the radiosonde ones (between 1.8 and 2.52m/s). We added these values in section 4.2. *“Bousquet et al. (2016) demonstrated that the bias error of RASTA wind data is comprised between 1 and 1.5 ms −1 . In this study, it has been decided to use the same observation error as the one used for radiosondes, which increases with the altitude (from ≈ 1.8 ms −1 at 900 hPa to ≈ 2.52 ms −1 at 200 hPa).”*

RASTA wind data have also been evaluated during the NAWDEX field campaign which occurred in Iceland (http://www.pa.op.dlr.de/nawdex/). In the following figures, RASTA wind retrieval were compared against radiosonde measurements. These Figures demonstrate that the observational error for RASTA wind data is of the same order of magnitude as that of radiosondes.



Bousquet, O. , Delanoë, J. and Bielli, S. (2016), Evaluation of 3D wind observations inferred from the analysis of airborne and ground-based radars during HyMeX SOP-1. Q.J.R. Meteorol. Soc., 142: 86-94. doi:10.1002/qj.2710

3. I suggest that Figure 5, and explanations for Figures 4 and 5 will be modified. The increment in Fig. 5A is reflected the flight path of all observations, thus, all data points assimilated in this 3-h window should be presented in Fig. 5A. Moreover, the 1-h, 2-h, and 3-h assimilation window experiments include the observation until 0630, 0700, and 0730 UTC, respectively (L10 P7). I think that this different time limitations create the difference between panels in Figure 4 unlike the authors explanation on overpasses (L6-17 P8). Please exam and discuss this point of view.

Figure 5 (now Figure 6) has been modified: All the data that are assimilated in the RASTA_3h experiment are now shown. The explanations have also been modified. Fig 5a is first described is section 5.2:

"Figure 5A represents the wind speed increments at approximately 4 km of altitude (model level 30) between the RASTA_3h and the CTRL analysis. Wind directions are also indicated by the green (resp. black) arrows for the CTRL (resp. RASTA_3h) analysis. The data points assimilated in the RASTA_3h experiment until 07:30 UTC are also represented by the black data points.".

Then, Fig.5 B-D are explained at the beginning of section 5.2: *"Figure 5 (panels B to D) represents the wind speed differences of the RASTA_3 h 1-, 2- and 3-h forecasts and the CTRL ones. At each forecast term, the black data points indicate the different RASTA locations which are available during a 1-h time window centred on the forecast time (forecast term ± 30 minutes)."*

Reviewer 1 is correct, the different time limitations explain the differences in wind and direction in Figure 4 (now Figure 5). We added this explanation in the text.

4. It is amazing for me that RASTA_3h in Figure 4 improved the wind filed even at the end of the assimilation window because the experiment did not employ FGAT. Since the RASTA data only exist in cloud area, 3 hours seems too long to assimilate the data appropriately. I understand that this is the motivation of the authors to conduct three experiments. If they use FGAT, the 3-h experiment may significantly improve the result. I recommend the authors to conduct the FGAT experiment additionally if possible.

Reviewer 1 is right, FGAT is a way to improve the handling of the time dimension in a 3D-Var scheme as it allows to compute the innovations (i.e. the observation-guess differences) at the time of the observations for different times during the assimilation window. For the AROME model, the FGAT option has been evaluated by Brousseau (2012) for moving platforms, but without any positive improvement in the subsequent forecasts (Brousseau et al. 2016, section 2). For observations from static platforms, the 3DVar without FGAT only uses the observations performed at the middle of the assimilation window. The FGAT option allows to estimate innovations for sub-hourly data from the same instrument at the same location. More observations are assimilated, but the 3D-Var minimisation, without time dimension, uses these several innovations at the middle of the assimilation window. This leads to an averaging and a smoothing effect on these observations and a loss of information on the temporal details, which is not desirable in a convective DA system. Therefore, in this study we decided to use conventional 3DVar to assimilate all the different kinds of observations in the same way.

Brousseau, 2012: Propagation of observed information into the AROME data assimilation and atmospheric model, PhD thesis, Université de Toulouse III – Paul Sabatier

Brousseau, P. , Seity, Y. , Ricard, D. and Léger, J. (2016), Improvement of the forecast of convective activity from the AROME-France system. Q.J.R. Meteorol. Soc., 142: 2231-2243. doi:10.1002/qj.2822

5. The authors used the median value of observations in a grid box (L16 P5) for thinning. If observational data distribute followed the Gaussian PDF and their number are large enough, the median and the mean values are the same. Usually “super observations” are made by the “mean” method in order to reduce representativeness errors and avoid noises. Therefore, the authors should explain why they adopt the “median” method instead of the mean.

The two approaches have been tested by the authors. After the data processing described in section 2.1 (whose description has been enhanced in the revised version of the paper), some spurious data were still occasionally present. Using a median filter, instead of the mean filter, helps to reduce the weight that these spurious observations can have when we calculate the “Super-observations”. Besides, a median filter is also employed by Bousquet et al. (2016) and by Tabary et al. (2006) to calculate the “super observations” of ground-based radar Doppler velocity observations

Tabary, P., F. Guibert, L. Perier, and J. Parent-du-Chatelet, 2006: An Operational Triple-PRT Doppler Scheme for the French Radar Network. *J. Atmos. Oceanic Technol.*, **23**, 1645–1656, https://doi.org/10.1175/JTECH1923.1

Bousquet, O. , Delanoë, J. and Bielli, S. (2016), Evaluation of 3D wind observations inferred from the analysis of airborne and ground-based radars during HyMeX SOP-1. Q.J.R. Meteorol. Soc., 142: 86-94. doi:10.1002/qj.2710

6. English needs to be proofread by professional native speaker(s) with scientific background

The revised manuscript has been carefully copy-edited for English. Together with the copy-editing standard service offered by Copernicus, we believe that the English should be sufficiently polished in the final version of our manuscript.

Responses to the minor comments:

L23 P1: “To fill the gap in clear air condition” I suggest the authors to refer the following articles, because wind observations in clear air can be also provided by Doppler lidars (air-born and ground-based), and clear air echoes (insects) by Doppler radars.

[Ground-based lidar] Kawabata, T., H. Iwai, H. Seko, Y. Shoji, K. Saito, S. Ishii, and K. Mizutani, 2014: Cloud-Resolving 4D-Var Assimilation of Doppler Wind Lidar Data on a Meso-Gamma-Scale Convective System. Mon. Wea. Rev., 142, 4484–4498, doi: 10.1175/MWR-D-13-00362.1.

[Air-born lidar] Weissmann, M., R. H. Langland, C. Cardinali, P. M. Pauley, and S. Rahm, 2012: Influence of airborne Doppler wind lidar profiles near Typhoon Sinlaku on ECMWF and NOGAPS forecasts. Quart. J. Roy. Meteor. Soc., 138, 118–130, doi:10.1002/qj.896.

[Clear air echoes] Kawabata, T., H.Seko, K. Saito, T. Kuroda, K. Tamiya, T. Tsuyuki, Y. Honda, and Y. Wakazuki, 2007:An assimilation and forecasting experiment of the Nerima heavy rainfall with a cloud-resolving nonhydrostatic 4-dimensional variational data assimilation system. J. Meteor. Soc. Japan, 85, 255–276, doi:10.2151/jmsj.85.255.

The authors are grateful to Reviewer 1 for these references. We now refer to the suggested articles from L 23: “In clear air condition, wind observations can be provided by insect-derived Doppler radar measurements (Kawabata et al., 2007; Rennie et al., 2011) or by Doppler lidars (Weissmann et al., 2012; Kawabata et al., 2014).”

L19 P2: “has never been investigated” I did not understand what thing has never been investigated in the following “vertical profiles from Doppler W-band radar”. “vertical profiles from Doppler radar”? “W-band radar”? “vertical profiles” by W-band radar? (“horizontal” winds have been done)? Please clarify.

We meant “vertical profiles by W-band radar”. This has been rectified in the text (Doppler has been removed in the sentence).

L30 P2: “first” This is the same with the above. What is the first?

“First” means the assimilation of wind profiles measured by Doppler W-band radar. Since Doppler is redundant with “wind profiles”, we removed Doppler.

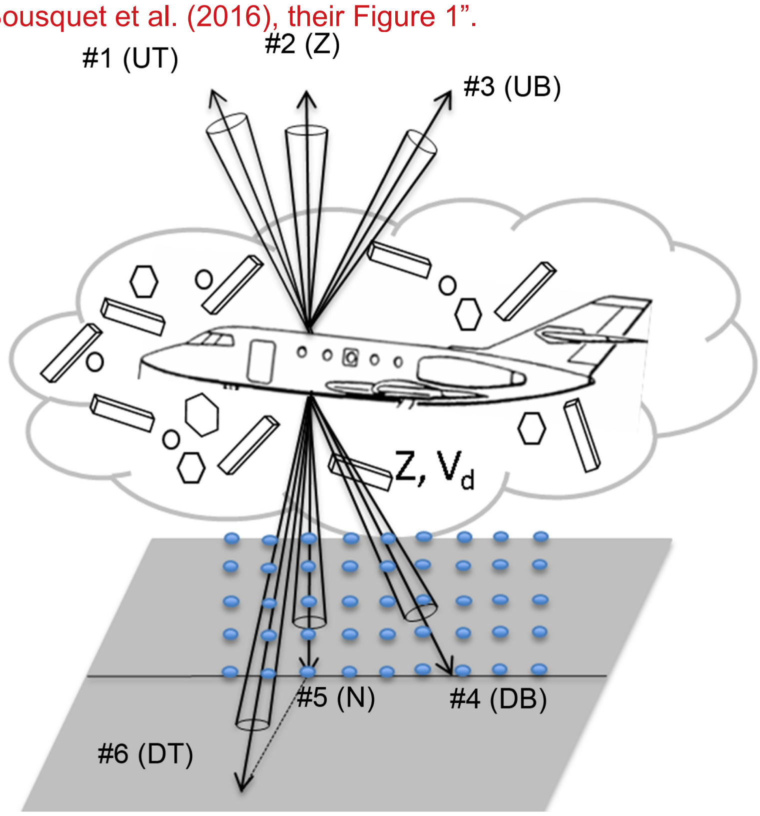
L8 P3: “HyMeX-SOP1” What is this? Spell out it and add explanation.

HyMeX (Hydrological cycle in the Mediterranean Experiment) aims at a better understanding, quantification and modelling of the hydrological cycle in the Mediterranean, with emphasis on the predictability and evolution of extreme weather events (Drobinski et al., 2014). The HyMeX first Special Observing Period (HyMeX-SOP1, Ducrocq et al., 2014) took place during a 2-month period during the autumn 2012. The main goal of the HyMeX-SOP1 was to document the heavy rainfall and flashflood events which regularly affect the mediterranean area.

We added some informations L35, page 2 about the HyMeX-SOP1. For further explanations, the reader can refer to Ducrocq et al., (2014).

L28 P3: “six Cassegrain antennas” How do these six antennas observe three directions above and below the aircraft? Add explanation and, if possible, a schematic figure.

RASTA configuration during the HyMeX-SOP1 is given by Bousquet et al. (2016) (Figure 1). The radar is equipped with 6 antennas pointing either upward (antennas 1-3) or downward (antennas 4-6). Labels 1-6 refer to the ‘upward transverse’ (UT), ‘zenith’ (Z), ‘upward backward’ (UB), ‘downward backward’ (DB), ‘nadir’ (N) and ‘downward transverse’ (DT) antennas, respectively.
In the text, we added “A schematic figure of RASTA configuration during the HyMeX-SOP1 is given by Bousquet et al. (2016), their Figure 1”.



L30 P3: “unambiguous distance” “unambiguous velocity” What are these? Observational range and available observations? But, in Figure 4, we see larger observations than 7.8 m/s.

Unambiguous distance is maximum range and unambiguous velocity is Nyquist velocity. The text has been rectified.

We see observations larger than 7.8 m/s because an unfolding algorithm is applied to the Doppler velocities. The algorithm is explained by Bousquet et al. (2016): “Radial velocities are processed by first removing the projection of aircraft ground speed along the six radar beams. Doppler observations are then unfolded by using an in situ wind sensor as a reference for the first valid gate and by applying a gate-to-gate correction for the next ones.”

We added more informations about RASTA data processing in section 2.1

L22 P4: “2.5 km x 2.5 km” Modify it to 2.5 x 2.5 km” and add the number of horizontal grids or the horizontal size of the domain.

The authors modified it, and added “It has 948 * 628 horizontal grid points, which is equivalent to a horizontal size of 2370*1570 km².”

L25 P4: “specially designed” What is the special in this study? Please clarify.

Please see comment n°2 of Reviewer 2. The AROME-WMED model was specifically designed for the HyMeX-SOP1 field campaign to support the instrument deployment. It is dedicated to the heavy precipitation events which regularly occur in the autumn.
The major differences between AROME and AROME-Wmed are:

- the AROME-Wmed domain has been extended and centred on our area of interest (the northwestern Mediterranean area)
- The background error covariance matrix
- The number of assimilated observations in the southern part of the domain.

We added more explanations in section 3.1

L7 P5: “GPS” Spell out it. GPS stands for Global Positioning System operated by U.S.A.. I guess the authors use other navigation satellite systems like Galileo and GLONASS. In this case, GPS should be replaced by “GNSS” (Global Navigation Satellite System).

The authors replaced GPS by GNSS.

L17-19 P5: “When the aircraft – removed from the interpolation.” It is hard to understand the situation and removed data. Did the authors remove the data only outside the grid box or the whole profile of the data? It should be better to show a schematic figure of the aircraft with the six radar antennas, and wind profiles in and out the grid boxes.

Only the data that are outside the grid box are removed. We added a schematic figure (Figure 2 in the new version) to explain this sentence.

L29 P6 and L10 P10 I suggest that the title of Section 5 and 6 as well as the examinations are named as “the case study” and “the statistical study” instead of IOP7a and HyMeX SOP1, respectively.

The titles of Sections 5 and 6 have been replaced by “Results on the case study” and “Statistical study”

L30, L31, L34 P9: “the maximum rainfall” Please show the exact maximum values in each experiment, not approximated values.

The exact maximum values are now shown in each panel.

L31-31 P10: “small number” From Figure 8, the numbers of observations are several thousands. These are not “small”.

We meant the number of observations in the area of interest. Following the suggestions of the major comment N1, Figure 8 (Figure 9 in the revised version) has been changed. The examinations are only conducted in RASTA-limited area (see major comment #1). Therefore, we only have hundreds of observations to evaluate the 3-h forecasts. Generally, the impact is neutral.

Figure 1 Add the explanation on the red box.

We added the following explanation in the caption: “The area surrounding the IOP7a case study is indicated by the red box.”

Figure 3 It is helpful for the readers if the authors add the information on flight level in this figure, for instance, by changing the size of circles as height, or by replacing the circles with triangles or rectangular or cross-marks as height.

To add an information on flight level, a circle has been set if the aircraft is below an altitude of 4km, a square if the altitude is between 4 and 6 km, a star if the aircraft is between 6 and 8 km, and a triangle if the aircraft is above 8 km. This new information is now written in the figure caption (now Figure 4).

Figure 4 Add (a), (b), (c) and etc. or figure titles to each panel to refer it easier.

We modified figure 4 (Figure 5 in the revised version) by adding A to a E for the wind speed and F to J for the wind direction. We now refer to the to A, B, etc. in the text.

Figure 7 Add the maximum rainfall amount values to each panel.

The maximum rainfall amount values are now displayed in each panel (now Figure 8).

Figure 8 I suggest that Figure 8 will be illustrated by the difference between CTRL and others, not each profile, in addition to the examination on the limited area (see the major comment)

Figure 8 has been modified (now Figure 9). It now illustrates the differences between the standard deviation of (OBS - CTRL) and the standard deviation of (OBS – Rasta experiment) on the Rasta-limited area. The text has also been modified in section 6.1. The results are still neutral