Anonymous Referee #1

This manuscript intends to study of cold weather conditions (over Antarctica). It focuses on clouds and diamond dust, and various observational platforms and model simulations over more than 1 month of observations. There are several issues with this manuscript and need to be improved significantly before goes to publication.

Because of above I see that paper needs to be improved significantly before making a decision if it is appropriate for this ACP.

→ Specific changes have been made in response to the reviewers' comments and are described below.

Major/minor issues:

1. Objectives are not clearly set up. Lots of information but nothing to do with objectives.
→ We have clarified this crucial point. The objectives of the paper are mainly to investigate the processes that cause the presence of thick cloud and diamond dust/ice fog episodes above the Dome C station based on observations and verify whether operational models can evaluate them. The title has been modified accordingly into "Genesis of Diamond Dust, Ice Fog and Thick Cloud Episodes observed and modelled above Dome C, Antarctica"

2. Diamond dust definition is not right. See Gultepe et al. AMS Bulletin/Atmos Res for ice fog, also diamond dust definitions. DD is not suspending in the air but ice fog it does. DD has large particles and usually plates which shines as diamond.
→ Consistent to the definitions listed in Gultepe et al. (2014), we present below the definition of "diamond dust" and "ice fog" taken from the National Snow and Ice Data Center (NSIDC) on their site *http://nsidc.org/cryosphere/glossary*:

Diamond dust: a type of precipitation composed of slowly falling, very small, unbranched crystals which often seem to float in the air; it may fall from a high cloud or from a cloudless sky, it usually occurs under frosty weather conditions (under very low air temperatures).

Ice fog: a suspension of numerous minute ice crystals in the air, reducing visibility at the earth's surface; the crystals often glitter in the sunshine; ice fog produces optical phenomena such as luminous pillars and small haloes.

From Girard and Blanchet (2001), ice fog is distinguished from diamond dust by the high concentration of ice crystal of smaller diameters. Ice fog, ice crystals are generally closer to spherical shape and their number concentration exceeds 1000 L^{-1} while their mean diameter is below 30 μm. From Walden et al. (2003), the atmospheric ice crystals over the Antarctic Plateau in winter is mainly constituted of three major types: diamond dust, blowing snow and snow grains. When sorted by number, Lawson et al. (2006) attribute 30% of the crystals recorded at the South Pole Station to rosette shaped (mixed-habit rosettes, platelike polycrystals, and rosette shapes with side planes), 45% to diamond dust (columns, thick plates, and plates), and 25% to irregular. By mass, the percentages are 57% rosette shapes, 23% diamond dust, and 20% irregular. In conclusion, in the literature of the ice crystals over Antarctica and particularly over the Antarctic Plateau, there is little mention of ice fog except some studies performed in the coastal areas of e.g. McMurdo in Lazzara (2010). Based on Gultepe et al. (2015) and Arctic studies, the maximum size for ice fog crystals is about 200 µm with diamond dust ice crystal sizes greater than 200 µm.

We have thus modified the paragraph in L. 418 related to the diamond dust and inserted a discussion on ice fog.

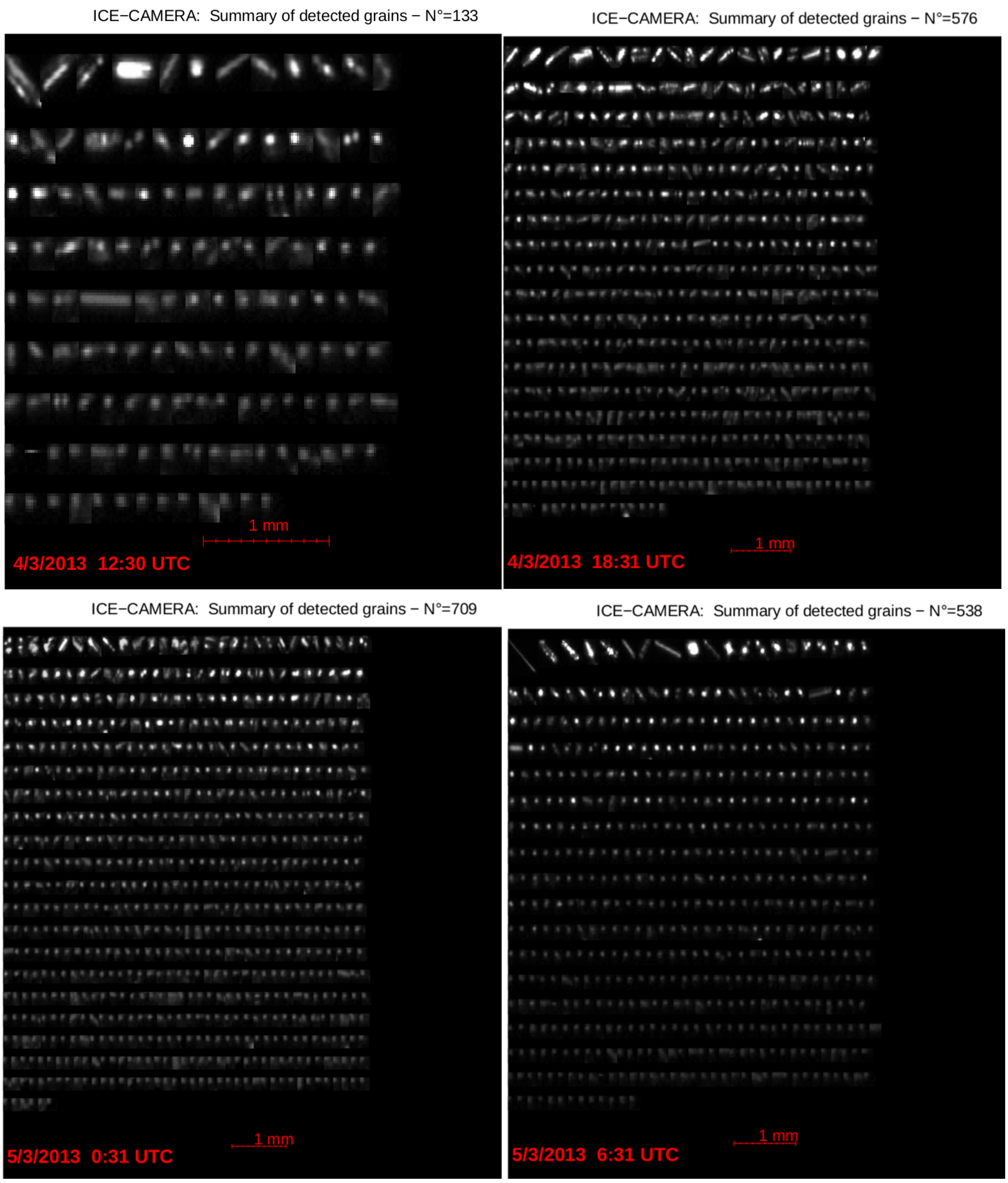
At Dome C, in 2013, an ICE-CAMERA was installed by Dr M. del Guasta on the roof of the shelter where both the HAMSTRAD and the aerosol Lidar were set up. This camera was able to take on an hourly rate a picture of the ice crystal grains deposited at the surface of the camera.

The ICE-CAMERA (http://lidarmax.altervista.org/englidar/_Antarctic%20Precipitation.php) is equivalent to a flatbed scanner. It was built in order to operate unattended in Polar Regions for the study of precipitating ice grains. Precipitation is collected on a glass plate, where it is photographed with 5 um resolution hourly. After each scan, the glass plate is electrically-heated in order to sublimate the ice grains. Image-processing software is used for the automatic characterization and counting of grains. A sub-section has been inserted in the new version of the manuscript.

> 2.6. The ICE-CAMERA
> At Dome C, in 2013, an ICE-CAMERA was installed on the roof of the shelter where both the HAMSTRAD and the aerosol Lidar were set up. This camera was able to take on an hourly rate a picture of the ice crystal grains deposited at the surface of the camera. The ICE-CAMERA (http://lidarmax.altervista.org/englidar/_Antarctic%20Precipitation.php) is equivalent to a flatbed scanner. It was built in order to operate unattended in Polar Regions for the study of precipitating ice grains. Precipitation is collected on a glass plate, where it is photographed with 5 um resolution hourly. After each scan, the glass plate is electrically-heated in order to sublimate the ice grains. Image-processing software is used for the automatic characterization and counting of grains.

The distinction between ice-fog and diamond dust is quite recent. In the past, the two phenomena were completely confused at least in Antarctica. We often have "frozen low clouds/fogs" in Concordia showing little evident precipitation on the glass plate of ICE-CAMERA, and other cases with bigger ice crystals. Of course particles from (high) clouds are bigger, while in-situ formed ones are smaller, and this, regardless of their classification into ice-fog and/or diamond dust. In fact, the use of the Lidar instrument actually shows the region of formation, a point indirectly assessed in the ref. papers suggested by the referees, and under this point of view, we can distinguish between cloud-originated particles (precipitation) and locally formed particles (ice fog and diamond dust). In the ICE CAMERA, very small particles (less than 20 um diameter) are not detected nor counted. About the form of the crystals, for focusing reasons before 2014, their appearance is sub spherical.

Figure R1 shows, as an example for episode 2 in 2013, the warm period on 4 March and the beginning of the cold period of 5 March: a) 4 March at 12:31 UTC; b) 4 March at 18:31 UTC; c) 5 March at 00:31 UTC; d) 5 March at 06:31 UTC and e) 5 March at 09:31 UTC. The 1-mm scale is indicated on each frame. The camera stopped functioning after 5 March at 09:31 UTC. From the images taken on 4 and early on 5 March, we can see that crystals are mainly constituted of elongated columns and/or plates, at least the bigger ones. From Figure R1, the size of the bigger crystals is about 300-400 um on 4 March and about 400-600 um on 5 March. From the literature, it seems that on 4 March, the size and form of the crystals are consistent with blowing snow. On 5 March at 09:30 UTC, we are slightly before the period of diamond dust that is to say after 12:00 UTC. On 5 March, the crystals seem to be bigger in size than on 4 March, elongated, but far much bigger that they should be from literature if they were only labelled as diamond dust but again we are few hours before the diamond dust period. Note the differences in the detection of ice grains due to the focus device present on 13 March 2011 (Fig. R2) and absent on 4 March 2013 (Fig. R1).



<u>Figure R1.</u> (From top to bottom and from left to right) Pictures taken from the ICE-CAMERA installed on the roof of the shelter where the HAMSTRAD and the aerosol Lidar are installed showing grains of ice crystals deposited over one hour on the surface of the camera in 2013 on: a) 4 March at 12:31 UTC; b) 4 March at 18:31 UTC; c) 5 March at 00:31 UTC; d) 5 March at 06:31 UTC and e) 5 March at 09:31 UTC. The 1-mm scale is indicated on each frame.

<u>Figure R2.</u> Example of a picture taken from the ICE-CAMERA on 13 March 2012 when the autofocus was active.

We also present the histograms for the "lengths" (major axis of the ellipsoid fitting the particle shape) for 4 and 5 March 2013 (Fig. R3). Until 2014, the image processing was relatively inadequate for the absence of autofocus, and also for the excess of heating of the collecting plate. The device was replaced with the actual one on 2014. As a result the 2013 histograms show always small particles with comparison with what observed later on.

Two histograms of particle lengths for the whole March 2013 and the whole March 2015 are also shown in Figure R4. The crystal lengths in 2015 are apparently much longer than in 2013. For this reason, as the "threshold" size of particles for fog ice is approx. 200 µm (following the literature suggested by the referees) for 5 March 2013, we would be on the "ice fog" side, rather than the diamond dust side. But this choice would be caused by an underestimation of the particle size resulting when following literally the ICE-CAMERA data of that period. As explained earlier, data recorded in 2013 are not quantitatively reliable until 2014.

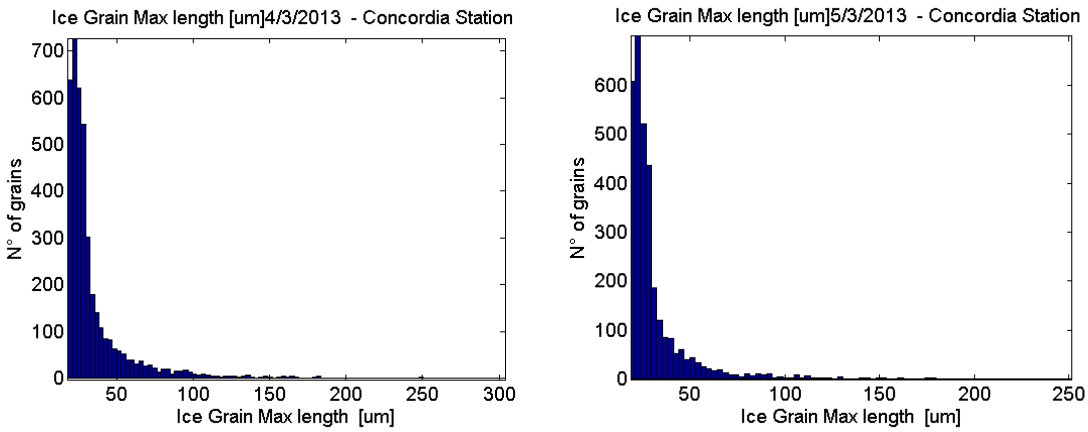


Figure R3. *Ice grain size distribution measured on 4 March (left) and on 5 March (right) 2013 at the Dome C station by the ICE CAMERA.*

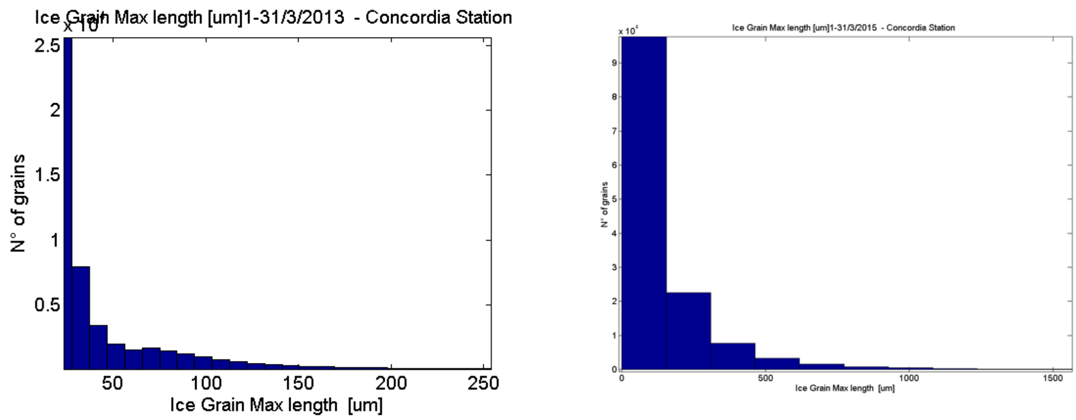


Figure R4. *Ice grain size distribution measured in March 2013 (left) and in March 2015 (right) at the Dome C station by the ICE CAMERA.*

When looking at the ICE-CAMERA photos for several years, plates are relatively scarce in all the observed Concordia crystals. Also ice rosettes, columns, etc. shine in the sun like diamonds, and the diamond dust brilliancy is not due to plates only. This is just atmospheric optics. In addition, Gultepe et al. (2014) worked in the Arctic, whilst our study refers to the Antarctic in Concordia.

In conclusion, we cannot confirm or infirm that the low level ice crystals observed at Dome C are diamond dust or ice fog. So, we prefer keeping these two terms in the title and in the discussion of the revised manuscript.

References:

Girard, E. and Blanchet, J. P.: Microphysical parameterization of Arctic diamond dust, ice fog, and thin stratus for climate models. J. Atmos. Sci., 58, 1181-1198, 2001.

Gultepe, I., Kuhn, T., Pavolonis, M., Calvert, C., Gurka, J., Heymsfield, A. J., Liu, P. S. K., Zhou, B., Ware, R., Ferrier, B., Milbrandt, J. and Berstein, B.: Ice fog in Arctic during FRAM-ICE Fog project: Aviation and Nowcasting Applications, Bull. Am. Meteor. Soc., 95, 211-226, 2014.

Lawson, R. P., Baker, B. A., Zmarzly, P., O'Connor, D., Mo, Q., Gayet, J.-F. and Shcherbakov, V.: Microphysical and optical properties of atmospheric ice crystals at South Pole Station, J. Appl. Meteor. Climatol., 45, 1505-1524, 2006.

Lazzara, M.: Diagnosing Antarctic fog, 5th International Conference on Fog, Fog Collection and Dew, Münster, Germany, 25-30 July 2010. Vol. 1, p. 150. (http://meetingorganizer.copernicus.org/FOGDEW2010/FOGDEW2010-150.pdf)

Walden, V. P., Waren, S. G. and Tuttle, E.: Atmospheric ice crystals over the Antarctic Plateau in winter, J. Appl. Meteor., 42, 1391-1405, 2003.

3. Better to have results on 1) clouds and 2) DD, then fill up with your knowledge/observations.
→ We have 2 distinct periods in 2011 and 2013 covered by 2 different operational models showing both thick clouds and diamond dust/ice fog episodes. We investigate the processes that drive these observed episodes and check whether the operational models can or cannot detect them.

We have entirely restructured the revised manuscript focussing on clouds and diamond dust/ice fog based on observations, then evaluated by the operational models, followed by the evolution of meteorological parameters (radiation, temperature and water vapour) during these episodes. We finally discuss the processes that contribute to the presence of these episodes: origin of air masses, integrated water vapour and temperature/water vapour budgets.

Figure 12 (Figure R5) have been modified in order to highlight the impact of the presence of the thick cloud and of the diamond dust/ice fog episodes on the net irradiances. Over the period 1-8 March 2013, considering clear sky days (excluding 4 and 5 March), the net irradiance between 14:00 and 17:00 UTC is –30.55 W m^{-2} whilst on 4 March (thick cloud episode) the net irradiance has increased to –16.75 W m^{-2} and on 5 March (diamond dust/ice fog episode) the net irradiance has decreased to –45.52 W m^{-2}.

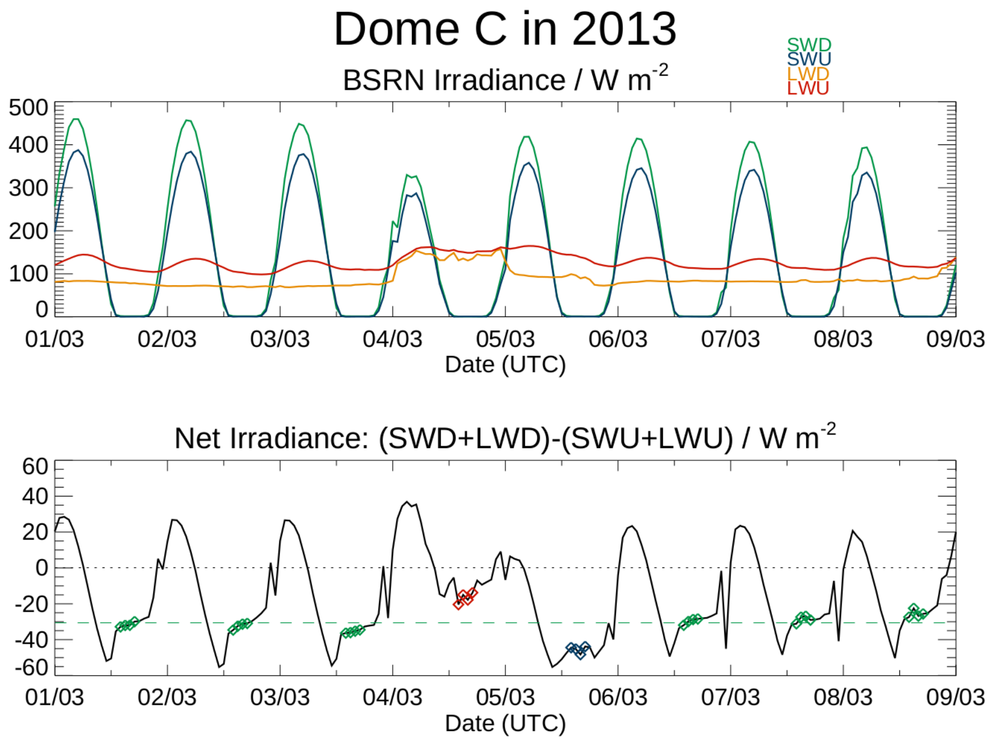


Figure R5: (Top) Time evolution of downward shortwave radiation (SWD, green line), upward shortwave radiation (SWU, blue line), downward longwave radiation (LWD, orange line), and upward longwave radiation (LWU, red line) from 1 to 9 March 2013 above Dome C as measured by the BSRN instruments. (Bottom) Net irradiance (SWD+LWD-SWU-LWU) as measured by the BSRN instruments. The horizontal green dashed line represents the net irradiance averaged between 14:00 and 17:00 UTC (represented by green diamonds) from 1 to 8 March excluding 4 and 5 March. The red and blue diamonds represent the net irradiances measured between 14:00 and 17:00 UTC on 4 March (thick cloud episode) and 5 March (diamond dust/ice fog episode), respectively.

Figure 12 has been replaced by Figure R5 in the new version of the manuscript.

4. What is the method here? We know that all these observations are important. How do you come up with conclusions? I don't see clear conclusions???? What are the issues with models? for these conditions?

→ In general, in the lower troposphere, ARPEGE and HAMSTRAD temperature datasets are very consistent to each other (see Fig. 10 of the first submitted manuscript). If we now consider into detail the evolution of the vertical temperature structures during the 2 episodes, using also radiosondes measurements at 12:00 UTC, interesting conclusions can be deduced from Figure R6. During the warm episode (thick cloud) on 4 March, there is a sharp positive vertical temperature gradient at 12:00 and 18:00 UTC within the first 100-200 m altitude layer in the planetary boundary layer from a very cold surface of about 230 K reaching a maximum of about 240-242 K. Above, the atmosphere is rather isothermal and starts cooling around 400-800 m. All the datasets are very consistent to each other. During the cold episode on 5 March, the lower troposphere is generally colder that during the warm episode, but at 12:00 UTC there is no such a stable planetary boundary layer as observed a day before since the vertical gradient is only of a 3 K over 500 m altitude instead of 20 K over 200 m during the warm episode. Radiosonde, ARPEGE and HAMSTRAD profiles are consistent to each other. At 18:00 UTC, in the core of the diamond dust/ice fog episode, the vertical structure of the temperature observed by

HAMSTRAD showing a positive gradient (218 to 227 K from 100 to 500 m) is opposite to the negative gradient of ARPEGE temperature (228 to 226 K from the surface to 400 m). Consistent with Figure 12 (Figure R6), the radiative impact of the thick cloud is to enlarge the net irradiance by about 15 W m^{-2} thus to locally increase temperature as measured by HAMSTRAD and calculated by ARPEGE whilst the radiative impact of the diamond dust/ice fog is to reduce the net irradiance by about 15 W m^{-2} thus to locally decrease temperature as measured by HAMSTRAD but not calculated by ARPEGE.

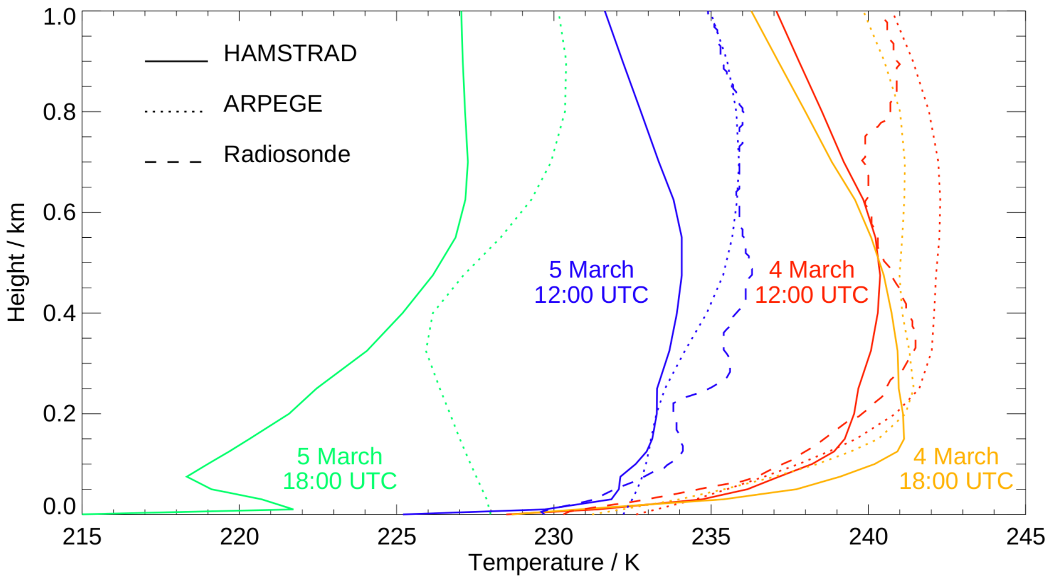


Figure R6: Vertical distribution of temperature measured by HAMSTRAD (solid line), and radiosondes (dashed lines) and calculated by ARPEGE (dotted lines) on 4 March 12:00 UTC (red line) and 18:00 UTC (orange line) and on 5 March 12:00 UTC (blue line) and 18:00 UTC (green line). Note radiosondes are only available at 12:00 UTC.

Figure R6 has been inserted in the new version of the manuscript together with this new paragraph in section 4.4.

We have inserted this new paragraph as a synthesis together with this new reference in section 4.4:

> The operational models take into account interactions between liquid and solid water phases but are enable to actually simulate the number of droplets that depends on their sizes. Consequently, models can estimate the presence of thick clouds but cannot reproduce diamond dust/ice fog episodes. A more sophisticated cloud microphysics such as a two-moment scheme as LIMA (Liquid Ice Multiple Aerosols) scheme (Vié et al., 2016) and an explicit aerosol scheme (Girard et al., 2001) would favour the local production of ice crystals in the planetary boundary layer.

Vié, B., Pinty, J. P., Berthet, S., & Leriche, M. : LIMA (v1. 0): A quasi two-moment microphysical scheme driven by a multimodal population of cloud condensation and ice freezing nuclei. Geosci. Model Dev., 9, 567-586, 2016.

7. Manuscript should be reduced, using with tables and focusing with objectives

→ The manuscript has been considerably shortened (1 page) and reorganized (see point 3). 3 Figures have been removed (Figs. 1, 3 and 4), 2 new Figures have been inserted (Figs. R6 and R7), and 1 Figure has been upgraded (Fig. 12 or Fig. R5). 5 new references have been inserted.

8. Scientifically is a poor paper, no new ideas or relate objectives to new instrumental platforms or models.

→ The new version of the manuscript replies to the main concerns of the reviewer.