Responses to reviews on ‘Synoptic conditions and atmospheric moisture pathways associated with virga and precipitation over coastal Adélie Land in Antarctic’

Nicolas Jullien, Étienne Vignon, Michael Sprenger,
Franziska Aemisegger and Alexis Berne

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Dear The Cryosphere Editor,
Please find in this document our answers to the referees’ comments. We hope that our corrections to the manuscript will make it suitable for publication in The Cryosphere.

1 Review 1

The manuscript “Synoptic conditions and atmospheric moisture pathways associated to virga and precipitation over coastal Adélie Land in Antarctica” is a well-motivated study, which clearly presents different synoptic situations leading to virga or precipitation at Dumont d’Urville station (DDU). The paper is scientifically interesting, and provides very useful knowledge of those processes and related atmospheric conditions. The text is nicely written, and mostly easy to follow, although containing quite a lot of detailed information which makes the “main” story more challenging to follow. Anyway, this a paper that deserves to be published, after some minor revision.

Dear Referee,
Thank you very much for having carried out a thorough review of our paper and for supporting its publication after revisions. Please find below our responses to your comments.

General comments

I wonder do to pressure systems/fronts affect the strength of katabatic winds at DDU, or are they more or less constant. If the katabatic winds are affected, this might affect occurrence of virga... This could be discussed.

Cyclones and their fronts do affect the strength of katabatic winds at DDU. When they approach the station, the large scale pressure gradient between the continent and the ocean increases (see e.g. Parish and Bromwich, 1998, Papritz et al., 2015). Subsequently, the strength of the katabatic outflow increases as well. Regarding the three considered periods (pre-precipitation virga, surface precipitation and post-precipitation virga), the mean wind speed is generally higher when the cyclone is close to the station just off the coast, so during post-precipitation virga cases. In contrast to the wind speed, the wind direction remains easterly or south-easterly during the three phases. The sustained katabatic outflow during precipitation events is highlighted by lower than 100% near-surface relative humidity observed during surface precipitation periods. Therefore, snowfall is being sublimated over the duration of the three phases of precipitation events. This is illustrated with radiosonde measurements at DDU in the Fig 4 of Vignon et al. 2019b (see Fig. 1 in this document).
To clarify those points in the manuscript, we have renamed the subsection 4.2.1 as 'Extratropical cyclone position and effects on katabatic winds at DDU'. Moreover, we have modified the last paragraph of the subsection as follows:
'The cyclone transit not only affects the synoptic atmospheric circulation above Adélie Land but also strengthens katabatic winds by increasing the ocean-to-continent pressure gradient. 10-m wind measurements at DDU reveal that the wind speed is slightly lower during pre-precipitation virga cases (mean: 9.8 m s^{-1}) than during surface precipitation (mean: 13.6 m s^{-1} and post-precipitation virga (mean: 15.2 m s^{-1}) cases, i.e. when the low-pressure system is closer to the station. This finding is in agreement with other studies on the link between extratropical cyclones and the formation of cold air outbreaks from katabatic outflows from Antarctica (see e.g. Parish and Bromwich, 1998, Papritz et al., 2015). However, the regional low-level flow at DDU remains of continental origin (easterly or south-easterly direction) during both virga and surface precipitation cases. In addition, radiosoundings have further revealed that the lower troposphere remains under-saturated even during surface precipitation cases (see Fig. 4 of Vignon et al. 2019b). Therefore, the low-level sublimation is effective during the whole precipitation event.'

Specific comments

- Consider moving the content presented in the appendix to Supplementary material, as this information is not fundamental for the main manuscript.

Though not absolutely fundamental, we think that the three sections of the appendix significantly help to understand and justify our methodology and give additional - but necessary - information to discuss some of the main results of the paper. Moving the content of those three sections to an external document would make it less visible and could make the paper less easy to follow. That is why we prefer leaving it in the appendix of the main manuscript. We hope the reviewer concurs with our decision.

- Page 7, line 14: instead of "weaker", I recommend to use "lower".

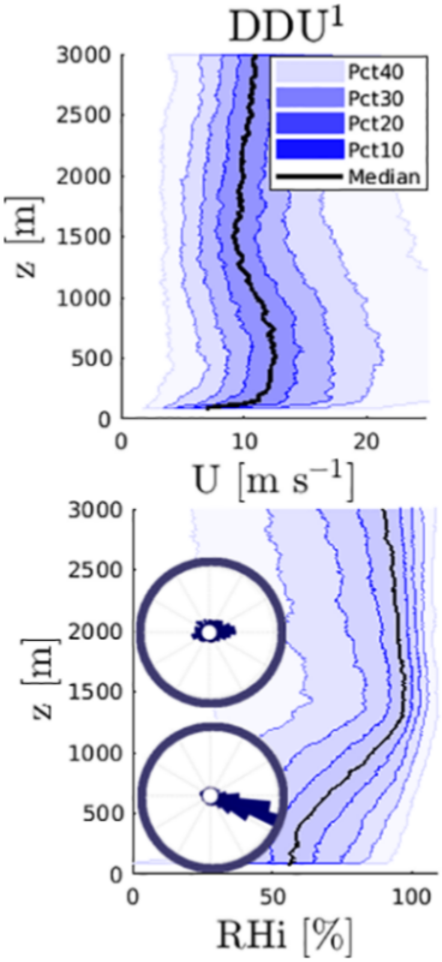

Figure 1: Part of Fig 4 from Vignon et al. 2019b. Vertical profiles of the wind speed (top row) and relative humidity with respect to ice (bottom row) from radiosonde measurements at DDU. Data sets are restricted to precipitation cases. Black lines are the medians, colored lines refer to the 10th, 20th, 30th, 40th, 60th, 70th, 80th and 90th percentiles. In the legend, "Pctx" refers to the shaded area that covers x percent of the data greater than the median and x percent of the data lower than it. The altitude z is above ground level. Wind roses (conditioned to precipitation events) at z = 500 and z = 2000 m are plotted in the lower row panels.

Pressure and geometrical height vertically vary in the opposite direction. Just using 'lower' might be confusing, as it may suggest a lower geometrical altitude. We have clarified as follows: "In agreement with MRR measurements, all the precipitating air parcels have an arrival pressure lower than 700 hPa, thus higher than ≈ 2500m a.s.l. (Fig. 3h)."

- Page 9, line 2: To me it seems that they are below 900 hPa ≈ 20 h before, and not 8 h before (if time 0 is the arrival time at DDU, and not 48 h).

It is indeed a mistake, thank you for pointing it out. We have corrected the text as follows: '30 hours before reaching the station, 8 out of 11 air parcels originate from a height below the 900 hPa level (cf. Fig. 3i).'

- Figure 2: Time of this cross section should be given in the caption. In addition, mark the DDU on the plot (instead of giving the latitude in the caption).

Thank you for these suggestions. We have modified the figure accordingly. (Fig.2)

- Figure 2: Instead of "randomly" multiplying the vertical wind component by 100, one could also scale it according to the geometry of the axes. Scaling factor of the horizontal wind vectors would be wind speed/distance of the whole x-axis in km (= 20 latitude degrees in km). Similarly, y-axis scaling factor would be vertical wind/altitude distance shown on the figure (=8 km). If you use these scaling factors to plot your results, they would show the vertical movement more realistically with respect to your potential temperature etc. fields.

We agree with your suggestion and we have changed the figure accordingly (Fig.2). The caption of the figure has been updated as follows: '*140.00°E meridional cross-section of the potential temperature (shading), meridional and vertical wind (black arrows), snow+ice water contents (white contours), cloud liquid water content (cyan contours) from ERA5 data on Feb 08 2017 00:00:00 UTC. Contour interval is* $5\ 10^{-5}$ kg kg^{-1}. *Wind vectors are scaled according to the spatial extent of the caption. DDU location is indicated by the red circle (140.00°E, 66.66°S).*'.

- Figure 3: This figure (especially in e, f, and g) contains a lot of information, almost too much. Especially, colors of trajectories (in e, f, g) are not visible enough. In addition, add date on the x-axis of (d) together with the time.

We agree with your point. Now trajectories in panels e, f and g are simply plotted in green and we have removed the information on their pressure. Following your recommendation, we have also added the date together with time on the x-axis of panel d. See Fig. 3

- Figure 6 has varying scale for y-axis due to different composite sizes. It would be clearer to divide the occurrence with the composite size and plot the fraction/percentage of occurrence. This would make the scale to be the same for all the variables and allow for direct comparison of the cases.

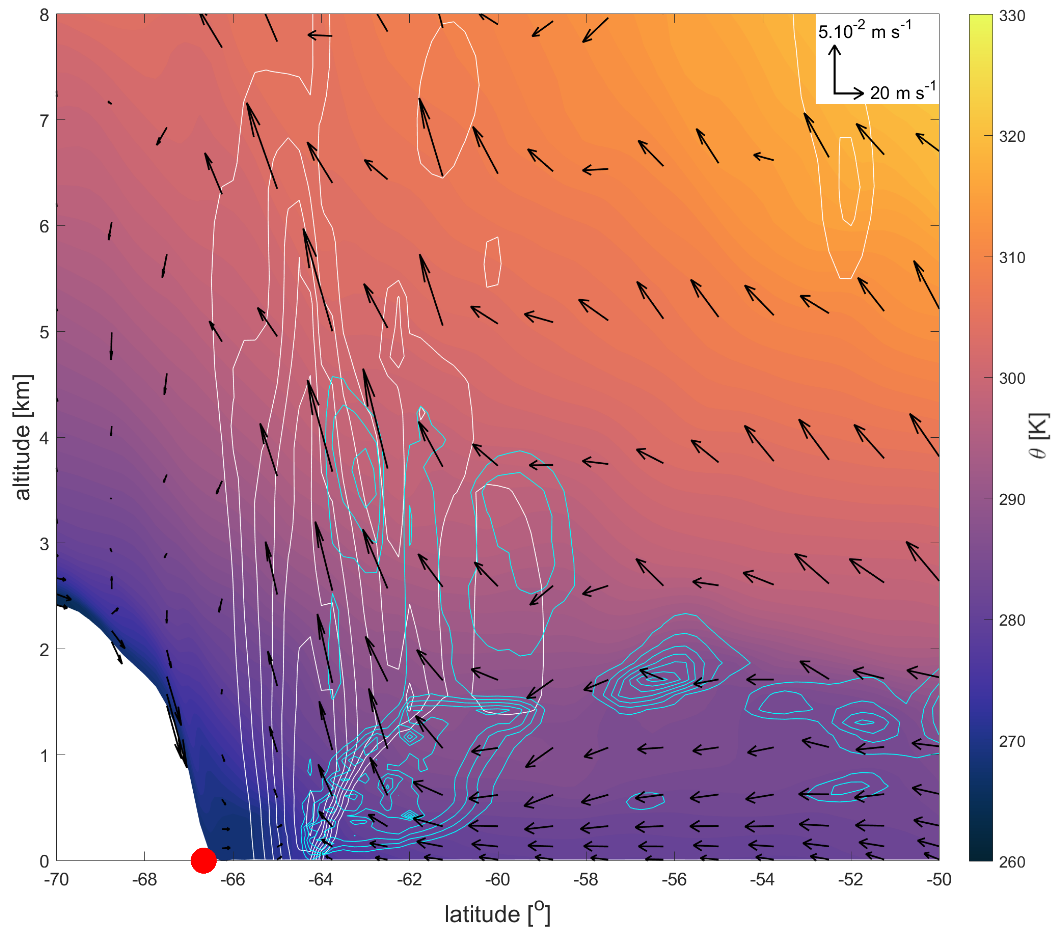

Figure 2: 140.00°E meridional cross-section of the potential temperature (shading), meridional and vertical wind (black arrows), snow+ice water contents (white contours), cloud liquid water content (cyan contours) from ERA5 data on Feb 08 2017 00:00:00 UTC. Contour interval is 5 10^{-5} kg kg^{-1}. Wind vectors are scaled according to the spatial extent of the figure. DDU location is indicated by the red circle (140.00°E, 66.66°S).

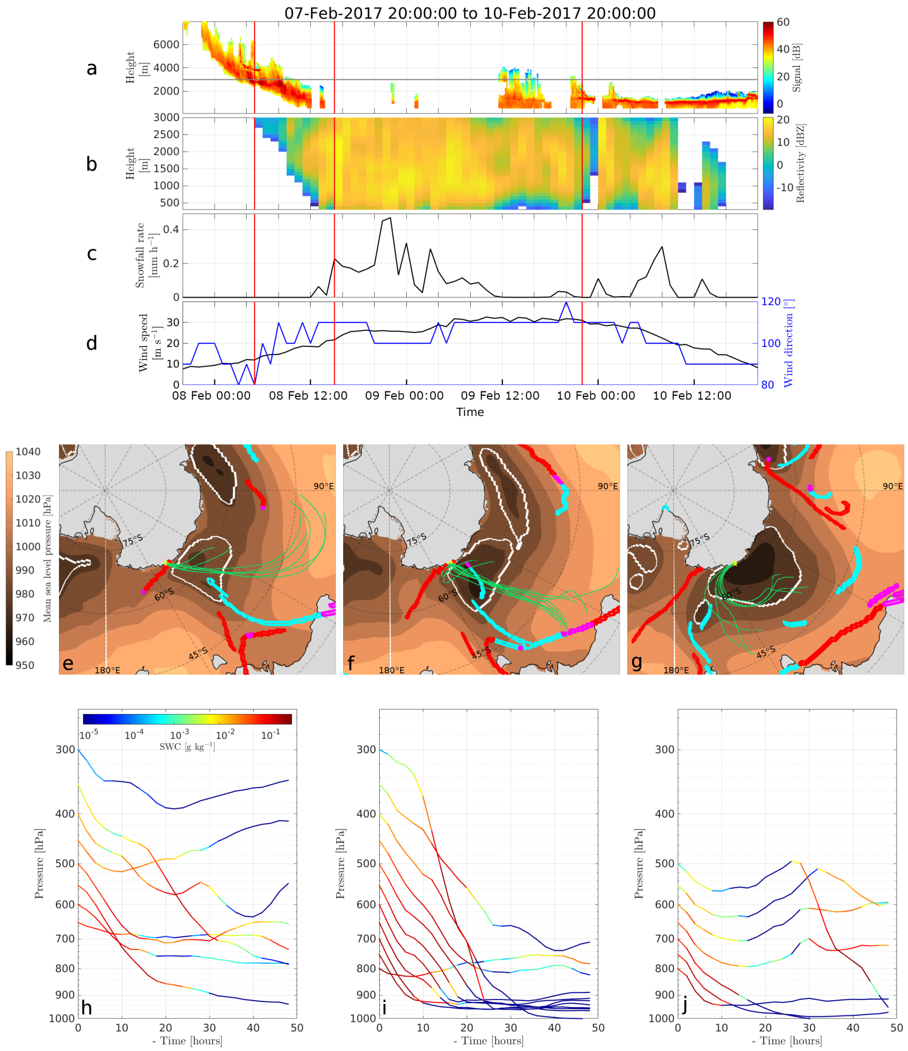

Figure 3: Case study of a precipitation event at DDU. Panel a shows a time-height plot of the lidar signal. The 3000 m MRR maximum height is highlighted with a grey line. Mind the lidar signal attenuation during precipitation periods. Panel b is a time-height plot of the MRR reflectivity. Panel c is the time series of the snowfall rate derived from MRR measurements. Panel d shows the time series of the 10-m wind speed and direction. Panels e, f and g show, for three different times indicated with red vertical lines in panels a-d, the sea level pressure (shading), the cyclone mask (white contours), the front lines (red for warm front, cyan for cold front, magenta for indefinite) as well as the 2-day back-trajectories of the precipitating air parcels (in green). The yellow star locates DDU. Panels h, i and j show the corresponding time evolution of the pressure along the back-trajectories. Colors indicate the SWC.

We agree with your point. We have changed the figure accordingly (cf. Fig. 4).

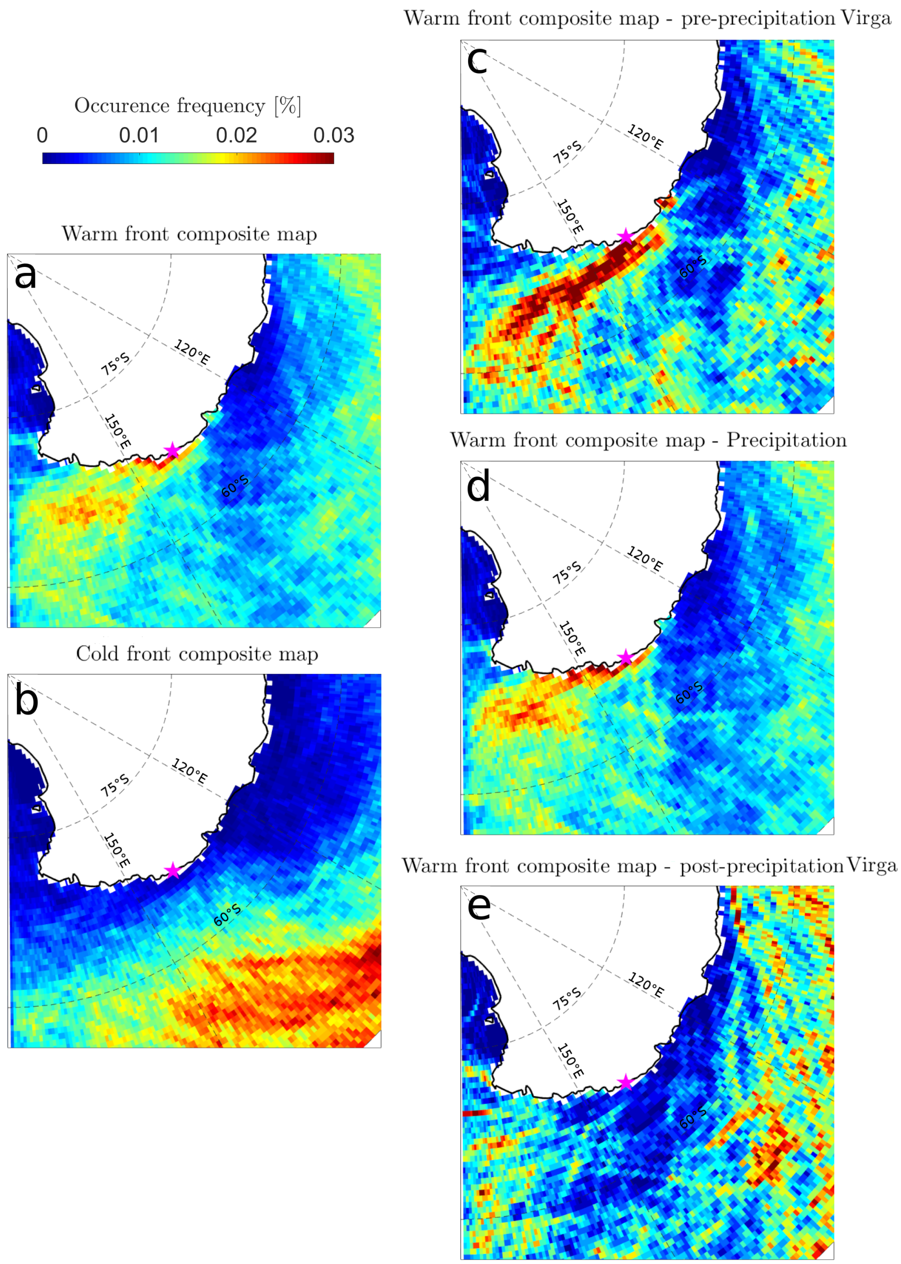

Figure 4: Statistical maps of front occurrences. Panels a and b shows the frequency of hourly occurrences of warm fronts (panel a) and cold fronts (panel b) during precipitation and virga cases at DDU. Panels c, d and e show the frequency of hourly occurrences of warm fronts for the pre-precipitation virga composite, surface precipitation composite, and post-precipitation virga composite respectively. The magenta star locates DDU. Note that fronts located above the Antarctic ice sheet (where the topography exceeds 100 m a.s.l.) have been removed