Response to reviews

Review n°3

Dear Referee,

Thank you very much for your review of our paper. You will find herebelow our responses to your comments.

General Comments:
This a comprehensive and well executed paper of low-level radiosonde observations along the East Antarctic coast. In general, the coast is a region of sharp changes in topography and atmospheric conditions. The horizontally varying nature of the katabatic winds across the coast needs to be emphasized (e.g., Parish and Bromwich 2007).
In addition, the manuscript already discusses the impact of the free-flying radiosonde balloons being advected away by the wind. The results one gets from radiosonde observations will depend on their launch locations. The discussion in this manuscript would be improved by systematic review of the station location characteristics and local meteorology. Halley and Neumayer are located on ice shelves. Dumont D'Urville is on an offshore island. McMurdo sits on the southern end of the mountainous Ross Island. Mawson is located at the base of the coastal slopes. Casey is on the west side of local Law Dome. Davis is on the western side of the Bunger (?) Oasis in the Vestfold Hills. Mario Zucchelli sits in Terra Nova Bay region and is affected by katabatic flows from Reeves and Priestley Glaciers and their modification by local mountains. More generally, how the coastal katabatic winds behave could be very localized in regions of complex topography. The International Antarctic Weather Forecasting Handbook, available online, provides information about many of these locations and should be consulted for a more refined interpretation of your results.*

Thank you for this very relevant comment and for your suggestions of description. Following your recommendation and those from another reviewer, we have added this paragraph in Sect. 2.1 for the description of the station location characteristics:
"McMurdo station lies on the southwestern edge of the Ross Island, close to the interface between the Ross ice shelf - that extends over 900 km to the south with a slight rise in elevation - and the Ross sea to the north. The topography of the Ross Island region is complex with steeply rising terrain corresponding to the two main mounts: the Mount Erebus and the Mount Terror. Black Island and White Island with respective maximum elevation of 1040 m and 740 m are located 30 km south of McMurdo. The Transantarctic Mountains whose altitude can exceed 2000 m are located west of Ross island at a distance of about 80 km.
About 350 km north of McMurdo, MZ is located on the coast of Terra Nova Bay, at the northeastern side of the confluence zone of the Prietsley and Reeves glaciers and at the south of an orographic jump of more than 1200 m associated to the abrupt slopes of the Transantarctic Mountains Range. Mawson station is situated on the coast of an isolated horseshoe-shaped rocky area. The ice sheet surface steeply rises from the coastal ice cliffs surrounding the station toward the Plateau. Davis is a coastal base that lies to the east of the Amery ice shelf in the Vestfold Hills, the largest coastal ice-free area of Antarctica. The land rises progressively to the south-west towards the Plateau and a ridgeline in the ice topography is located around 60 km to the northeast of the station (Alexander and Murphy, 2015).
Casey station is located on the coast of the Wilkes Land, at 12 m of altitude. The Law Dome, which lies to the east of Casey and which rises to an altitude of 1395 m, shields the base from the easterly winds that predominate in the region. DDU station is located at 41 m of altitude on the Petrels

Island, approximately 5 km off Adélie Land and the ice sheet proper. The climate at the station is very influenced by strong katabatic winds blowing from the interior of the ice sheet.
Neumayer station lies on the Ekström ice shelf, at a few kilometers from the shore line. The shelf extends more than 100 km to the south with an inclination of approximately 1 ‰. Halley station is situated towards the seaward edge of the Brunt Ice shelf, Coats Land, on the southeastern shore of the Weddell Sea at about 30 m of altitude. The Brunt ice shelf extends to the south-east of the station for over 40 km, and the uniform surface rises very gradually over this distance until the hinge zone where the land steeply rises up to the continental plateau.
Unlike all the other stations of interest here - that are located close to the coast and near sea-level - PE is 220 km far from the coast at 1382 m of altitude. The station has been built on a small granite ridge just north of the Sør Rondane Mountains in the Dronning Maud Land and it is located at approximately 1 km north of the Utsteinen Nunatak that culminates at an elevation of 1564 m."

Then, we have added a few elements of discussion about the local meteorology when we present the radiosonde profiles in the "results" section.
In particular, about MZ station we now state:
'At MZ station the observed profiles are often the results of the confluence of katabatic flows from the Reeves and Priestley glaciers affected by local mountains (Bromwich et al 1993).'

We have also added a Table in the supplementary materials (Tab 1) that summarizes the exact location, elevation and terrain-type characteristics in the ERA5, ERA-I and Polar WRF grid points (and we refer to it in the main text) :

Table 1. Geographical characteristics of the stations (indications in black font). Green, cyan and red indications correspond to the location and mean altitude of the nearest grid point in ERA5, ERA-I and in the Polar WRF simulation respectively. In the last column, the distance from the station to the nearest coast is indicated in black font and the percentage of 'land-type' surface (excluding sea-ice) is indicated for the nearest mesh in ERA5, ERA-I and Polar WRF.

station name	longitude (°)	latitude (°)	altitude (m)	distance to the coast (km) or % of land
Halley	-25.80, -25.8, -25.5, -26.00	-75.61, -75.5, -75.8, -75.68,	30, 25, 207, 74	15, 76 %, 77 %, 91%
DDU	140.00, 140.0, 140.3, 139.9	-66.66, -66.8, -66.8, -66.67	41, 302, 532, 260	0, 75%, 59%, 56%
McMurdo	166.67, 166.8, 166.5, 166.6	-77.85, -77.8, -78.0, -75.74	10 , 138, 239, 1	0, 48%, 84%, 29%
Neumayer	-7.74, -7.8, -7.5, -8.00	-70.63, -70.8, -70.5, -70.82	17, 58.18, 7, 86	5, 75%, 43%, 100%
Mawson	62.87, 62.8, 63.0, 62.75	-67.60, -67.5, -67.5, -67.62	15, 91.25, 383.4, 313	0, 21%, 52%, 69%
Casey	110.52, 110.5, 110.3, 110.7	-66.28, -66.3, -66.0, -66.32	30, 100, 109, 249	0, 36%, 22%, 73%
Davis	77.97, 78.0, 78.0, 78.42	-68.58, -68.5, -68.3, -68.47	18, 45, 142, 200	0, 27%, 24%, 69%
MZ	164.11, 164.0, 164.3, 164.40	-74.39, -74.5, -74.3, -74.67	15, 531, 828, 163	0, 88%, 81%, 62%
PE	23.35, 23.3, 23.3, 23.33	-71.95, -72.0, -72.0, -71.86	1382, 1515, 1518, 1269	220, 100%, 100%, 100%

This review was prepared without consulting previous comments on the manuscript.

Specific Comments:
1. Page 1, line 21: Douglas is not the right reference. It should be Mawson, D., 1915: The Home of the Blizzard. Vols. 1 and 2, William Heinemann, 687 pp. Similarly, an important relatively contemporary reference for the extreme winds affecting Adélie Land (Cape Denison, in particular) is Parish, T.R., and R. Walker, 2006: A re-examination of the winds of Adélie Land, Antarctica. Aust. Meteor. Mag., 55, 105–117. 2.

Thank your for pointing this mistake in the citation, it has been corrected. Thank you also for proposing this additional reference that has been added in the introduction.

Page 2, line 5, Loewe's phenomenon. This clearly does apply/happen along many parts of the coast of East Antarctica. There is abundant direct evidence that is rarely important in the Ross Sea sector, see for example: Parish, T.R., and D. H. Bromwich, 1989: Instrumented aircraft observations of the katabatic wind regime near Terra Nova Bay. Mon. Wea. Rev., 117, 1570-1585, doi: 10.1175/1520-0493(1989)117<1570:IAOOTK>2.0.CO;2. 3.

Thanks a lot for this clarification. We have reformulated as follows:
'This accumulation of cold air is responsible for a pressure gradient force opposing the katabatic wind that is particularly intense under weak synoptic forcing (Van den Broeke et al., 2002; Van den Broeke and Van Lipzig, 2003). In some regions of the ice sheet like in Adélie Land or in Coats Land, the flow regime transition can be abrupt (Pettré and André, 1991; Gallée et al., 1996; Gallée and Pettré, 1998; Renfrew, 2004) and is therefore interpreted as a hydraulic jump, often referred to as a katabatic jump or Loewe's phenomenon. Such jumps are however rarely important in other sectors of the Antarctic periphery like at Terra Nova Bay (Parish and Bromwich, 1989).'

Page 2, forcing of the katabatic wind regime, the following paper provides an insightful analysis: Parish, T.R., and J. J. Cassano, 2003: The role of katabatic winds on the Antarctic surface wind regime. Mon. Wea. Rev.,131, 317–333. 4.

Thank you for this relevant reference. It has been added in the text.

Page 2, line 18: Spelling of "Weddell" should be corrected. Several other places in the manuscript, including Figure 1. 5.

This has been corrected throughout the manuscript and in the figures.

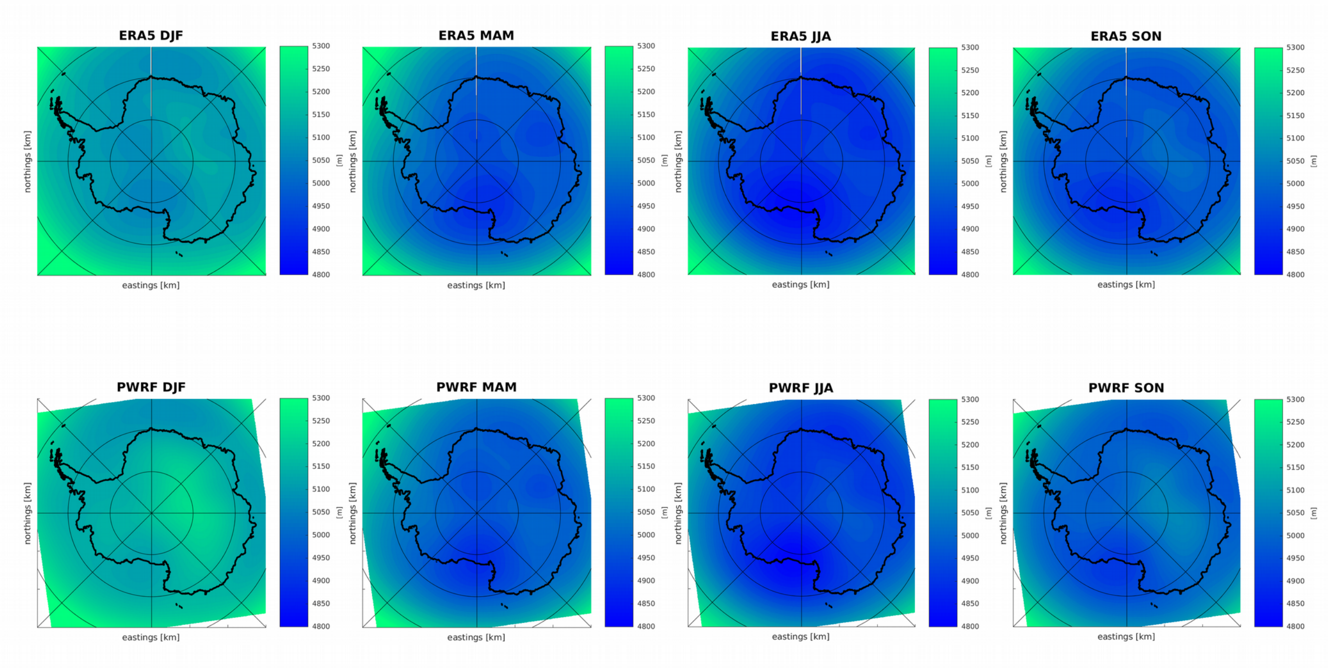
Section 2.3 Polar WRF Simulations. Suspect for this large grid you did not do any nudging at upper levels to ERA-Interim (for large spatial scales). If not, you probably would have gotten better results for the Polar WRF downscaling with nudging, especially as it appears you ran continuously for 8 years. (See Glisan, J. M., W. J. Gutowski, J. J. Cassano, and M. E. Higgins, 2013: Effects of spectral nudging in WRF on Arctic temperature and precipitation simulations. J. Climate, 26, 3985–3999, doi:10.1175/JCLI-D-12-00318.1).

We fully agree on the fact that nudging at upper levels may improve the scores of our Polar WRF simulations. In particular we believe that the free evolution of the model will partly remove the actual interannual variability and potentially degrades the direct comparison with observations.
However, note that in this paper we analyse statistics calculated over a 8-year period (sufficiently long to smooth out part of the interannual variability) regardless of the time evolution of the profiles.
The two main reasons why we preferred not nudging the model at upper levels are the following:

* First, the upper level circulation over Antarctica closely interacts with the low-level flow (e.g., James 1989, Egger 1991). A potential 'constraint' on the high tropospheric circulation may thus have a direct impact on the surface drainage flow and affects the statistics. When leaving the model 'free' i.e. creating its own circulation (and interactions between katabatic winds and the upper circulation as well as between katabatic winds and weather systems), we therefore evaluate the reproduction of the low-level continental circulation and its feedbacks on the larger scales.

* Second, we look at stations in regions of complex topography (McMurdo and Mario Zucchelli), where the way the nudging is applied may have large impacts on the simulation and can even be detrimental due to damping of high-resolution features.

In any case, we have checked that the large scale mean circulation patterns in the free Polar WRF simulation are reasonably reproduced. This is visible in the following figure that compares the seasonally mean geopotential height at 500 hPa in ERA5 and in Polar WRF:



The pixel-to-pixel correlation coefficient between the two data sets equals 0.67 (resp. 0.80, 0.70, 0.71) for the DJF (resp. MAM, JJA, SON) mean.

Note also that adding a nudging to the simulations would require many additional sensitivity tests and a specifically dedicated discussion, which is beyond the scope of the present paper. However, we fully agree that this aspect warrants further research, for instance the framework of the Antarctic CORDEX project.
As we restrict the analysis to a free running Polar WRF simulation - in which the interactions between the low-level flow over the ice sheet and the large scale circulation are fully consistent -, we prefer not confusing the reader with an additional discussion on a potential nudging in the manuscript. We thank you for your relevant and useful remark and we will more thoroughly investigate the effect of upper-level nudging in our future studies on the Antarctic surface mass balance using Polar WRF, following e.g., Glisan et al 2013 and van den Berg and Medley 2016.

James, I. M. (1989), The Antarctic drainage flow: implications for hemispheric flow on the southern hemisphere, Antarct Sci, 1, 279–290.
Egger, J. (1991), On the mean atmospheric circulation over Antarctica, Geophys. Astrophys. Fluid Dynamics, 58, 75–90.
van de Berg and Medley 2016, Brief Communication: Upper-air relaxation in RACMO2 significantly improves modelled interannual surface massbalance variability in Antarctica
The Cryosphere, 10, 459–463, doi:10.5194/tc-10-459-2016

It is appropriate to remember that, when comparing data sets, the Polar WRF results are from free running forecasts whereas the ECMWF reanalyses are tightly constrained by frequent 4DVAR assimilation of observations.

This information was written in Sect 2.2 (presentation of the reanalyses):
'It is worth mentioning that radiosonde data at all the considered Antarctic sites - except PE - have been assimilated by the IFS model to make both ERA-I and ERA5. The reanalysis data sets are therefore not purely independent from radiosonde data.'

and at the beginning of Sect. 3.2 (Evaluation of the vertical profile statistics in ERA-I, ERA5 and Polar WRF):
'It is worth remembering that unlike Polar WRF, ERA-I and ERA5 are not fully independent from radiosoundings since they assimilate them at low vertical resolution (except at PE station).'

We have slightly reformulated the latter sentence to make it even clearer:
'It is worth remembering that unlike the free running Polar WRF simulation, ERA-I and ERA5 reanalyses are not fully independent from radiosoundings since they frequently assimilate them at low vertical resolution (except at PE station).'

Figures 2-4 Can only see 3 colored lines plotted on each side of the median, not 4.

Thanks for raising this point. Actually, four percentiles above and below the median are plotted but the color associated to the extreme percentiles is too light to be clearly visible. We have increased the contrast in the figures to make them more readable.

** Bromwich et al. 1993: Spatial and temporal variations of the intense katabatic winds at Terra Nova Bay, Antarctica. Antarctic Meteorology and Climatology: Studies Based on Automatic Weather Stations, Amer. Geophys. Union, 47-68.*

We thank you again for your thorough review. The corrections following your comments have improved the quality of the paper.

The authors of "*On the fine scale vertical structure of the low troposphere over the coastal margins of East Antarctica*"