Response to Anonymous Referee #2:

We would like to thank the referee for their comments and suggestions. Thanks to their suggestions, we have improved the manuscript and corrected some errors. In the following we have reproduced the referee's comments in italics and provided our response in bold text. Where necessary we provide the text we have used in the revised manuscript.

Referee: *"Figure 1: Add Auroral zone and polar vortex extents locations approximation."*

We have done this, by including dashed lines indicating the variable location of the edge of the vortex, and another shaded region showing an approximate auroral oval for quiet to moderate geomagnetic activity.

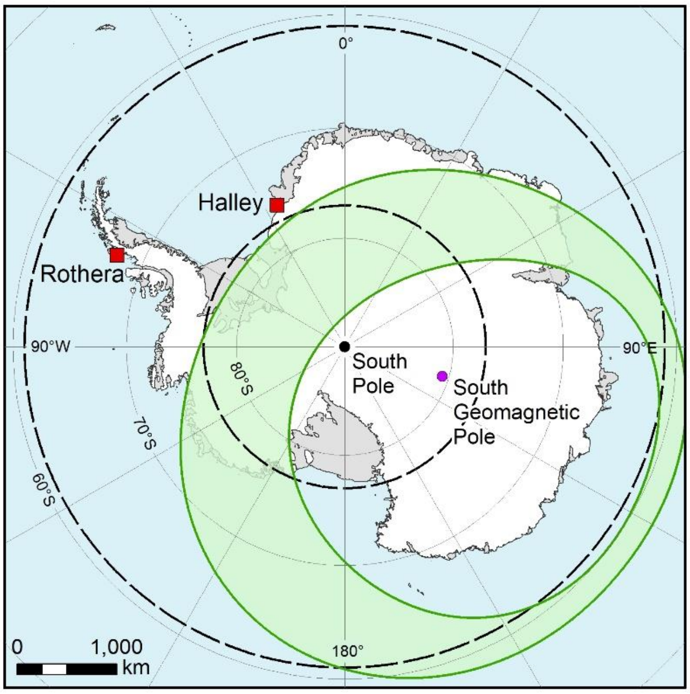

Figure 1: Location of the two MF radars used in this study (Halley and Rothera) marked as red squares, with the locations of the geocentric (black) and geomagnetic (purple) south poles. The dashed black lines give estimates of the extent of the polar vortex from May (inner) to August (outer). The green shaded region shows the statistical location of the auroral oval for quiet (Kp=3) geomagnetic activity.

Referee: "*Line 96 : "An oscillating signal can be seen, most strongly in panel (b) then (c)" We can't see any oscillation on (c) picture due to missing data. I guess the authors wanted to mention (e). Additionally, to highlight the semi-diurnal oscillation mention, it could be interesting to add on the plot the estimated oscillation (sliding-median or least-square adjustment). It could be also interesting to have the meridional in the same plots (in red for example)."*

The text should have read 'most strongly in panels (b) and (e); this has been corrected. We think that adding both a line to show the oscillation AND the meridional data makes the plot too busy. Therefore, we have included just the meridional data since the identification of the tide is not actually important for the paper at this stage and the Halley data actually makes it stand out more clearly.

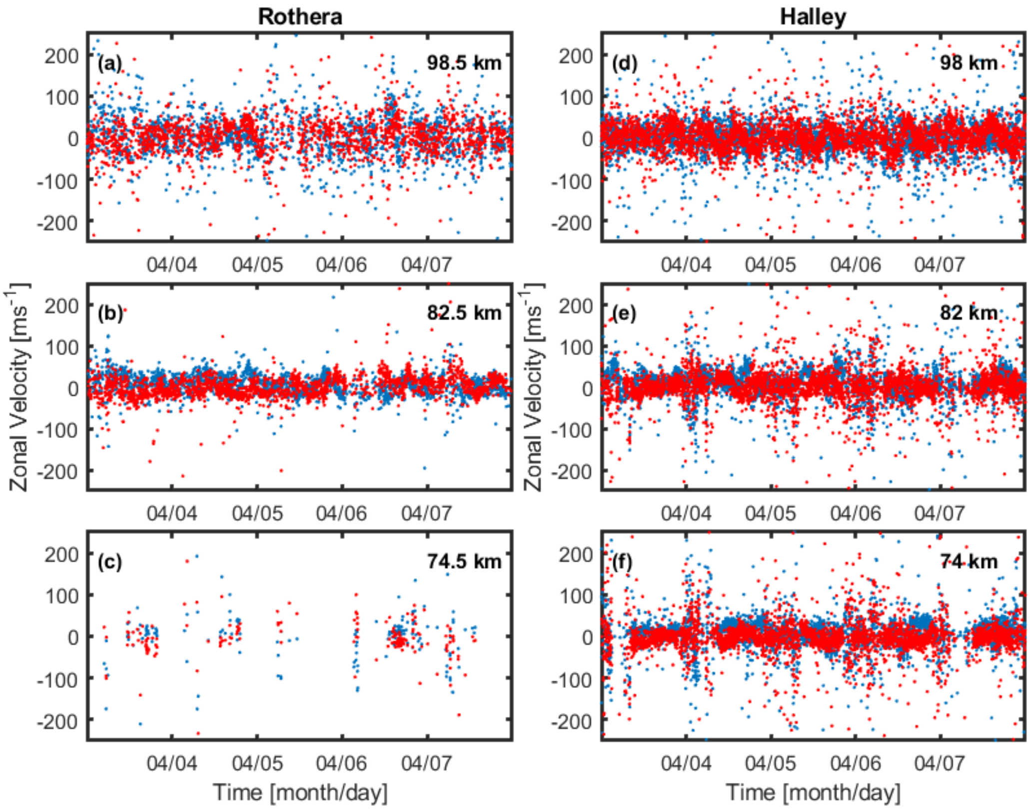

Figure 2. Sample data from the Rothera (left) and Halley (right) radars for three comparable heights from 3-7 April 2013. Blue dots represent zonal winds, red dots represent meridional winds. Large variability can be seen in each plot. At the lowest altitude, Rothera (c) is experiencing a loss of scatter due to a weaker (than Halley (f)) returned signal.

Referee "*Fig 3 : is it based on the entire data set or only on the 5 days in April 2013. Can you explain the larger wind speed in Halley compare to Rothera.* "

This is based on the entire data set (though Halley has a lot less data than Rothera), we have made this clear in the figure caption and the text. However, the wind speed is not appreciably larger in Halley than at Rothera according to the figure (speed is on the x-axis). Actually the wind at Rothera is slightly faster than at Halley (particularly close to 50-100 m/s). We wonder if the referee means why the humps of the distributions are larger in Halley than in Rothera? This is simply the reverse of the effect we just described: Rothera has proportionally faster wind than Halley.

"Figure 3. Panel (a): probability distribution function of the combined (zonal and meridional) wind velocities at Halley (red) and Rothera (blue), for the entire data set. The double hump is due to the tidal influence over the winds. Panel (b): The same distributions plotted on a log-log scale to illustrate the long tails of the distributions, with a Lorentz distribution (b = 5.7) fitted to the data beyond ~300 ms^{-1} (yellow)."

Referee: *"Line 134-136 : "The data in fig. 3 are from all altitude ranges from the Rothera radar: the relationship between velocity and axial ratio appears to be independent of altitude for the range of heights that the radars measure." I don't understand this statement as fig 3 (nor fig 4) is dependent on the altitude. Could the authors explain a little bit more on this point?"*

Yes, this was a mistake, there should have been a line explaining that we had performed the analysis behind figure 4 (and figure 3) for limited altitude ranges and it had no significant effect on the result (apart from those height ranges where there was insufficient data).

"The data in fig. 4 are from all altitude ranges from the Rothera radar. Limiting the altitude range produces the same results indicating that the relationship between velocity and axial ratio appears to be independent of altitude for the range of heights that the radars measure. The pattern remains the same when data from Halley are used."

Referee: *"Line 146, 147,...: Replace H2 by 2.H or something similar instead of H2 which is confusing."*

This was a mistake in the formatting – H2 should have been H^2. This has been corrected.

Referee: *"Figure 6 and associated discussion: What is the period of time taking into account to produce this plots (especially the black circles). Is it years, month or a typical day or hour? I suppose that the variance at a certain altitude "varies" with time, seasons,.... If not, could you add a sentence on this for a non-expert."*

The following lines are included in the text:

"For each altitude simulated data was generated from equation 7 (w where i = 1 million and is the length of the simulated time series) and the mean variance for velocities below 150 ms^{-1} measured using a monte-carlo method with 100 iterations."

"The observed variance and axial ratio are averages of the hourly means that were calculated from data with wind speed < 150 m/s."

Referee: *"L233 : "This is interpreted as a response to the changing levels of ionisation". In the ionosphere, we call it Weddell Sea Anomaly, which corresponds to a maximum of electron density at local midnight during summer season. This paper "Chang, L. C.,Liu, H., Miyoshi, Y., Chen, C., Chang, F., Lin, C., Liu, J. and Sun, Y. (2015), Structure and origins of the Weddell Sea Anomaly from tidal and planetary wave signatures in FORMOSAT/COSMIC observations and GAIA GCM simulations. J. Geophys. Res. Space Physics, 120: 1325– 1340. doi: 10.1002/2014JA020752." This could be interesting to discuss in the paper to make the link between neutral and ionised atmosphere. In theory is that the maximum electron density at local midnight is due to thermospheric winds. "*

We disagree with the referee. The Weddell Sea Anomaly, as indicated in the paper they provide is predominantly an F-region phenomenon, occurring at altitudes above 200 km. The radar is

responding to changes in ionospheric density in the D region (below 100 km), where according to the figures in the recommended paper, the density perturbation from the tides is close to zero at the magnetic latitude of Rothera. The response of the variance in panel (b) of Figure 7 follows the change in solar elevation angle without needing to invoke the anomaly. The ionisation changes at those altitudes are predominantly dependent on solar illumination: the greater the amount of illumination (high elevation) the lower the variance and the vice versa.

Referee*: "Fig 8 and corresponding discussion: The solar Zenith Angle (SZA) stands generally for the angle between the zenith of the location considered and the sun angle with respect to this zenith. So 0◦means at the Zenith, and +/-90◦at the horizon. The authors should adapt the figure and the caption with respect to this rule as they mention that "the solar zenith angle (90 – solar elevation angle)" while from figure 7 top, the SZA should be in between 90-40=50◦and 90-(-5) = 95◦. I suggest the author to SZA for zenith = 0◦and below the horizon + or - 90◦and + corresponding to the sunrise and sunset respectively".*

This is a mistake in the labelling that has carried over from an older version of the plot. We switched to using solar elevation angle so as to be consistent with the other figures and forgot to alter the caption and label. The correct x –axis label should be 'solar elevation angle' where 0 degrees represents the Sun's apparent position at the horizon, negative values indicate the sun is below the horizon and positive that it is above the horizon.

Referee: *"Figure 10: Do you observed the same patterns above Halley? It could be interesting to have both in case they behave in different ways."*

We do see a similar pattern at Halley. This is now shown as a separate panel in the figure. There are some differences, which we discuss. We also have cut the plots off at a slightly higher altitude due to the paucity of data at the lower range gates (which is seasonal) particularly at the lower power Rothera radar.

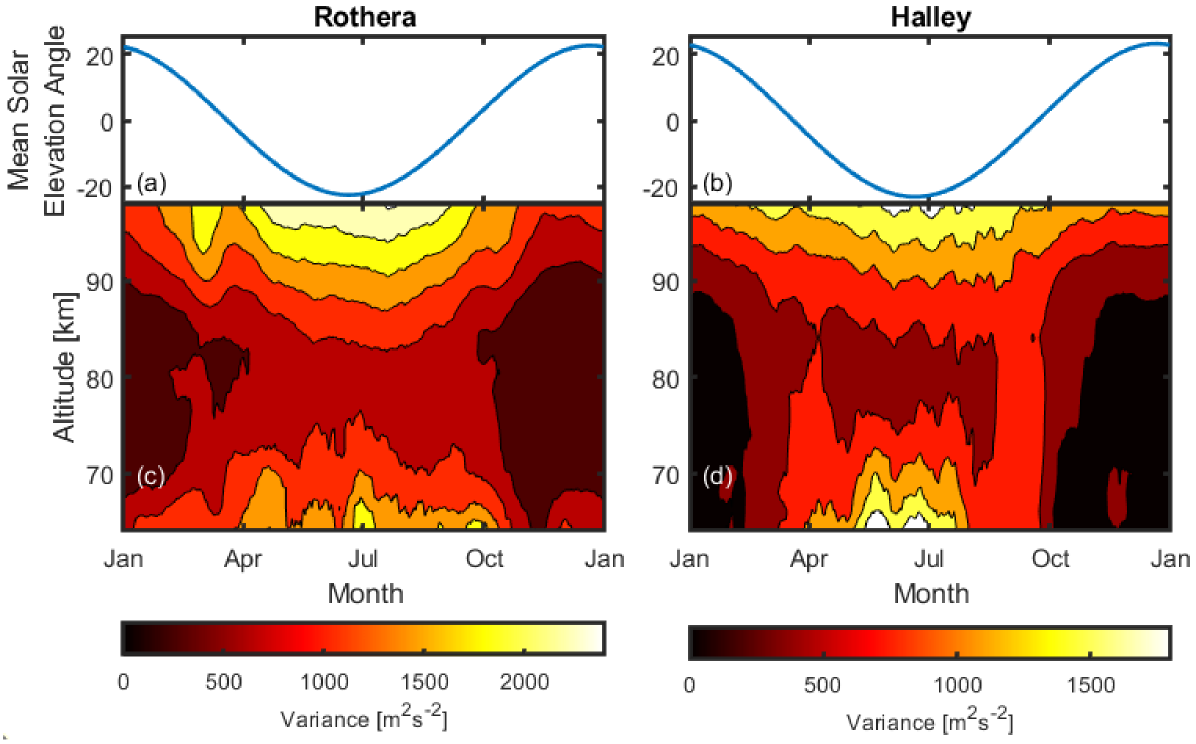

Figure 10. Trends in variance over the course of the year at Rothera (c) and Halley (d) with the daily mean angle of the sun above the horizon ((a) and (b)). Mean variances were calculated for each day and the result smoothed using a 15-day running mean. Note the difference in colour scale between the two plots.

Referee: *"AE comparison with zonal wind variance: this part is interesting in terms of climatology (seasonal correlations) but also in term of altitude impact. However, the correlations ranged between 0 and +/-0.2 which is really small. The authors should explain how we can be sure about the conclusions with small correlation coefficients."*

We have increased the discussion about the correlation between AE and the radar data and we have changed the analysis slightly to remove the distracting daily variations that is not important for the paper.

"To probe this relationship the Auroral Electroject (AE) index is used as a measure of geomagnetic activity. This index is derived from geomagnetic variations in the horizontal component of the magnetic field observed by 10 to 13 stations in the auroral zone in the northern hemisphere. The AE index is the difference between the largest and smallest values detected by these stations, produced at 1-minute resolution. It responds most strongly to the substorm cycle, where energy is loaded in the magnetotail from the solar wind, and then released earthward generating the auroral electroject and auroral displays. Although there can be quite drastic differences in the local scale structure, magnitude and positioning of auroral forms (and the underlying magnetic topology), between the poles, in a statistical sense the AE index will still be representative of geomagnetic activity in the south.

Figure 11, panel (a), shows the cross correlation between the hourly maximum AE index and the hourly zonal wind variance measured at Halley at three altitudes: 90 km, 80 km and 70 km the meridional winds show the same results). Each of the data sets have been normalized such that their autocorrelations equal one at the zero lag and lie between 1and -1. At each altitude there is an annual cycle in the correlation, though the value of the coefficient is relatively small (<0.2). This cycle is due to the seasonal variations of both the variance and the AE index; the variability of the AE index is driven by changes in solar wind activity, but the coupling to Earth's magnetic environment has a seasonal component known as the Russell-McPherron effect, whereby the coupling maximises around the equinoxes. Figure 10 illustrated that there is a seasonal pattern in the variance, which matches the level of solar illumination.. Panel (b) of fig. 11 shows the cross correlation for 40 days around the zero lag; there is a clear positive correlation at the zero lag for 90 km and a smaller negative correlation for 70 km. Variances at 80 km show little evidence of a relationship with geomagnetic activity.

These observations can be explained as follows: During periods of high geomagnetic activity, there is an influx of high-energy particles into the mesosphere (e.g. Brasseur and Solomon, 2005). This means that at lower altitudes, where there is normally very little ionisation, the ionisation levels increase, and partial reflection of radio waves is stronger. As we have already seen, measured wind variance is related to the scatter quality, so an increased scatter quality corresponds to a lower measured variance at 60 km.

Increased ionisation levels at the lower altitudes also have the effect of absorbing radio waves that pass through, meaning that the quality of signal for radio waves partially reflected at higher altitudes is diminished. Thus, we see the inverse effect for data from 90 km: periods with increased geomagnetic activity correspond to an in- crease in measured variance at higher altitudes, as the amount of data decreases. The correlations seen at 70 and 90 km decay with lag times of about 5-10 days, suggesting that this is the time scale over which the ionisation levels return to normal after a geomagnetic event. This would be in line with studies of energetic precipitation driven by solar wind transients such as high speed solar wind streams (e.g. Kavanagh et al., 2012). This reflects the pattern of SNR seen in (Kavanagh et al 2018) at Rothera in response to increased precipitation where there is a reduction in data at high altitudes due to signal loss and a gain in data at the lower altitudes. This hints at an underlying relationship between variance and data quality (in terms of the amount of data seen)."

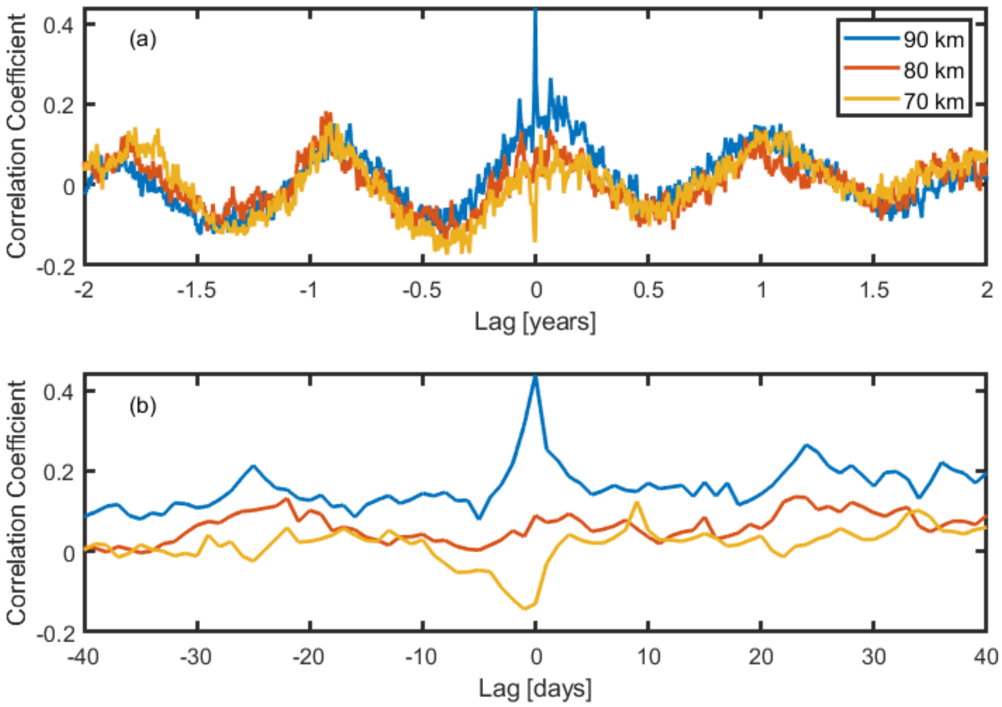

Figure 11. Correlation coefficients between maximum AE index in each hour and zonal wind variance observed at Halley shown at a range of lag times. Panel (a) shows the long term correlation: the sinusoidal nature of the correlation shows a seasonal cycle. Peaks are seen at zero lag at 70 and 90 km, suggesting a relationship beyond the seasonal variations. In panel (b) the central peaks are shown A distinct correlation at zero lag is seen for some altitudes, positive at 90 km and negative at 70 km. The same result is found for meridional winds.