Response to Anonymous Referee #2

We appreciate the comprehensive, practical, and instructive comments of referee #2. They have helped us improving the paper. We are responding to the comments in the following way:

Unfortunately, the analysis is somewhat limited. For example, the authors only perform back-trajectory modeling for less than half their dataset, which limits their ability to interpret the data. Some of the more interesting features – such as a secular trend in the d data – are not addressed. The reader is left with very little new insight in what type of dynamical processes may be driving the isotopic trends.

We thank the referee for this helpful advice and have now expanded all analyses to the reported full measurement period of two years. Furthermore, we added a new subsection named "Diurnal cycle" to the paper (revised manuscript, Subsection 3.5) and discussed it in the "Discussion" section. The method to find extreme *d* has been improved and the link between extreme *d* values and the origin of the water vapour is better evaluated in the revised manuscript, Subsection 4.2. Generally, we have substantially improved the manuscript based on the specific comments of this referee and of two other anonymous referees.

-*I am not a meteorologist, but it appears there are some shortcomings in the interpretation of the various weather data (as noted in the detailed comments below). The paper would benefit from being read/reviewed by an expert on Antarctic meteorology. Very few, if any, papers on this topic are cited. Various meteorological observations must be placed in a broader context of such observations, and the correct interpretations must be given.*

For the interpretation of the weather data, we have asked a colleague at our institute, who has worked as a meteorologist at Neumayer Station for several years (Schmithüsen. et al, 2019), for help. Furthermore, we have now included the results of several studies related to the Neumayer Station and Antarctica meteorology:

<u>Revised manuscript, Subsection 2.1, line 93:</u>

Like most coastal Antarctic stations, weather and climate at Neumayer Station are characterized by relatively high wind speeds, with an annual mean value of 8.7 $m.s^{-1}$ (1-sigma standard deviation of calculated mean value from daily values: ±5.7 $m.s^{-1}$). Large wind direction and wind speed variations at Neumayer Station reflect complex dynamical processes resulting from travelling cyclones around the station and katabatic winds (Kottmeier and Fay, 1998). There are two main wind directions. The prevailing wind direction is from east, caused by the passage of cyclones north of the Antarctic coast in the circumpolar trough. These low-pressure systems move toward west around Antarctica. Easterly storms are common, with wind speeds up to approx. 40 $m\ s^{-1}$. The second, less frequent, typical wind direction is south to south-west, caused by a mixture of weak katabatic and synoptic influence, with typical wind speeds below 10 $m\ s^{-1}$ (König-Langlo and Loose, 2007; Rimbu et al., 2014).

Revised manuscript, Subsubsection 3.2.1, line 265:

Daily temperature and $\delta^{18}O$ values in summer are less fluctuating than in the other three seasons (revised manuscript, Fig. 4). This might be explained by a weaker temperature inversion, lower sea ice variability, and stronger sublimation and snowmelt in summer.

Hudson and Brandt (2005) showed that the temperature inversion strength variations in winter are one reason for the large day-to-day variability of 2-meter temperature in Antarctica. In winter, clouds can be much warmer than the surface, which leads to a strong temperature inversion. However, changes in wind speed and direction might change the cloud cover and thereby weaken or destroy the inversion layer, in short time. Due to these processes, stronger temperature inversions can lead to higher temperature variability in winter.

As sea ice can strongly limit the heat flux between a relatively warm ocean and the atmosphere, sea ice coverage variations close to Antarctica's coastal stations can primarily affect the near-surface temperature at the stations (Turner et al., 2020). Decreasing sea ice variability close to the Neumayer Station in summer compared to other seasons, which is true for most other coastal stations in Antarctica, may also lower the temperature variability.

Another reason for the reduced temperature variations in summer can be a stronger heat loss, which prevents temperatures above zero. At Neumayer Station, the largest sources of heat loss in summer are sublimation and snow melting (Jakobs et al., 2019). The sublimation is primarily temperature-controlled and is only significant at Neumayer station in summer. About 19 % of the annual snowfall at this location is removed by sublimation (van den Broeke et al., 2010). The second source of heat loss at the station is snow melting. In summertime, when the air temperature can rise above 0°C, the surface snow will reach its melting point and start to melt. For the melting process, the incoming radiative energy is partly used for latent heat uptake, keeping the near-surface temperature close to the melting point.

These three phenomena might explain the detected cut-off at 0°C of the 2-m temperature (Fig. 4). They could also partly explain the lower correlation coefficient between the 2-m temperature and $\delta^{18}O$ in summer, as upper air temperatures most likely control the latter.

Revised manuscript, Subsubsection 3.2.1, line 286:

At Neumayer Station, the specific humidity is highly correlated with temperature (Jakobs et al., 2019), as expected from the general Clausius-Clapeyron relation between both quantities. As a consequence, the $\delta^{18}O$ values of water vapour at Neumayer Station are strongly correlated not only to temperature, but also to specific humidity (r = 0.85).

Revised manuscript, Section 1, line 32:

The fundamental physical processes, which link the isotopic fractionation processes during precipitation formation in clouds, the condensation temperature, and the surface temperature at the precipitation location, are well understood (Jouzel and Merli- vat, 1984). However, in the interior of Antarctica, up to 60% of annual precipitation can be diamond dust or so-called clear-sky precipitation, and hoar frost, which are not related to clouds (Walden et al., 2003; Stenni et al., 2016).

The back-trajectory provides the most meaningful and relevant data analysis tool in the paper, but it is only used very summarily. First, I would encourage the authors to run the back-trajectory on the full data period. Second, I would encourage the authors to provide more in-depth analysis of what the back-trajectories mean.

In the revised manuscript (Subsection 3.3), we have now expanded the FLEXPART analysis for the whole two-years period. Furthermore, the analyses of this back-trajectory analysis have been enhanced:

Revised manuscript, Subsection 3.3, line 308:

For further understanding of the seasonal different relations between $\delta^{18}O$, δD, Deuterium excess, and the meteorological variables, we analyse potential seasonal differences in the main moisture uptake areas for vapour transported to Neumayer Station for years of 2017 and 2018, as simulated by FLEXPART (Fig. 5 in the revised manuscript). Moisture uptake coming to Neumayer Station depends on different factors such as sea ice extent, the Southern Hemisphere semi-annual oscillation (SAO), and absolute temperature. As Fig. 5 shows, the sea ice prevents evaporation from the ocean. In the areas with ice coverage more than 90 %, the moisture uptake is minor. The SAO is the main phenomenon that affects surface pressure changes at the middle and high latitudes of the Southern Hemisphere (Schwerdtfeger, 1967). It means the twice-yearly contraction and compression of the pressure belt surrounding Antarctica as a result of the different heat capacities of the Antarctic continent and the ocean. The SAO leads to a clear half-yearly pressure wave in surface pressure at high latitudes and modifies the atmospheric circulation and temperature cycles (Van Den Broeke, 1998).

Revised manuscript, Subsection 3.3, Figure 5:

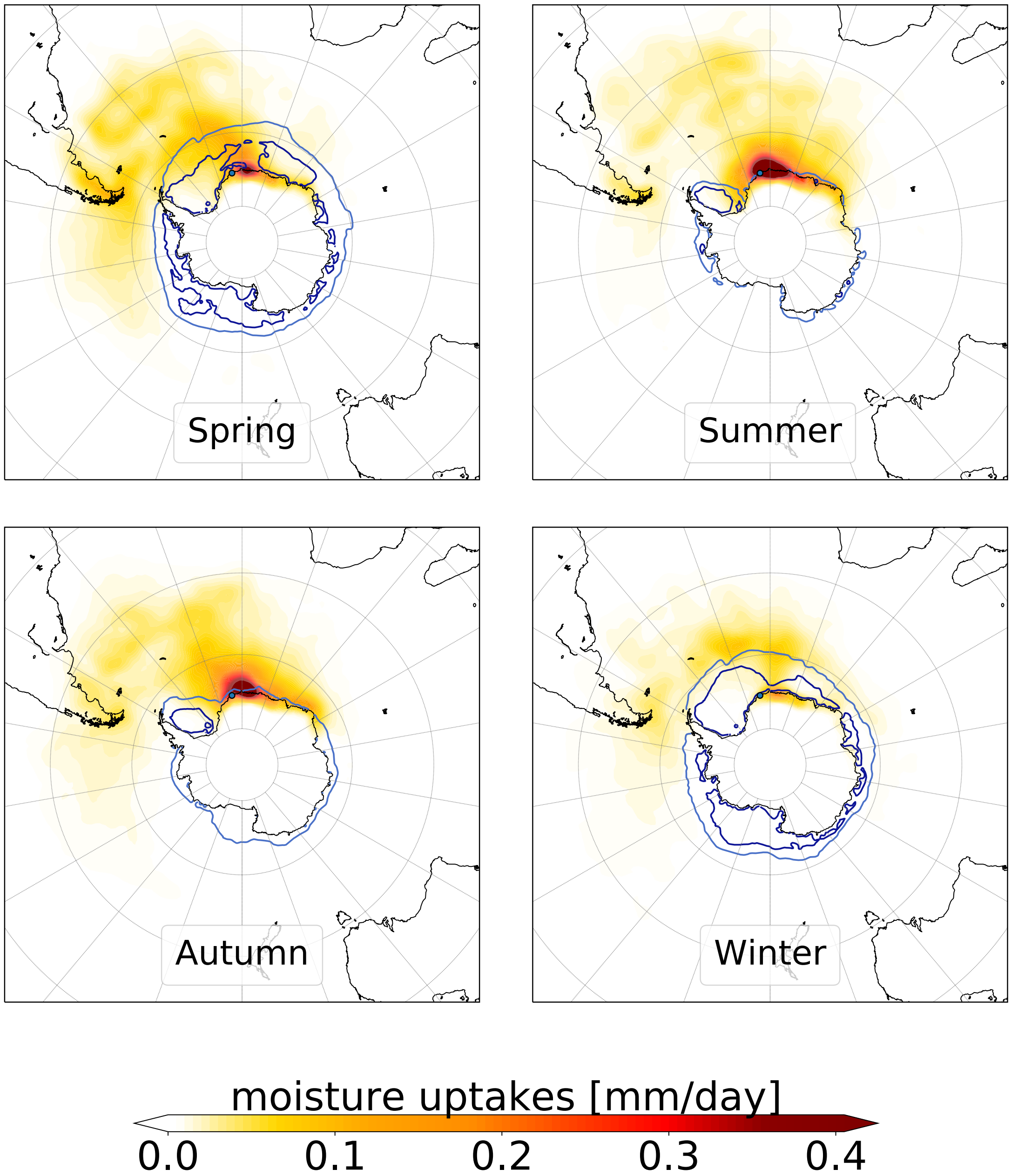

*Figure 1(Figure 5 in the revised manuscript). Simulated mean moisture uptake occurring within the boundary layer [*mm day^{-1}*] in the pathway to Neumayer Station during last 10 days modelled by FLEXPART using ECMWF, ERA5 dataset (Hersbach et al., 2020), for spring (SON), summer (DJF), autumn (MMA), and winter (JJA), considering the year of 2017 and 2018. The mean sea ice edge based on ERA5 reanalysis (Hersbach et al., 2020) for ice coverage more than 45% and 90% is shown with light blue and dark blue lines.*

For example, they show in Fig. 12 that there is a difference in vapor origin between low-d and high-d events. However, the authors do not provide us any insight into WHY these patterns may lead to the observed d values.

The discussion of the high and low *d* values is improved with regard to the origin of the water vapour:

Revised manuscript, Subsection 4.2, line 414:

Changes of *d* in vapour generally are supposed to reflect different climate conditions at the moisture source region (Merlivat and Jouzel, 1979; Pfahl and Sodemann, 2014) and recognized as a tracer that point out the origin of the water vapour (Gat, 1996). Other, less dominant factors that effect *d* are the amount of condensation from source to sink, which is ruled out here since there is no systematic anti-correlation between *d* and δD.
In order to better understand the effect of different pathways and water moisture origins that control *d* changes in vapour at the station, days with extreme values of *d* are examined. As no long-term measurements for *d* in water vapour at Neumayer Station exist, we cannot define extreme *d* values considering multi-year daily average (as done for the analysis of extreme temperature events). Thus, we define extreme *d* values as daily averaged *d* values which are one standard deviation higher or lower than the 14-days average value centered around the corresponding day (7 days before and 7 days after). Analysing the simulated moisture uptake for days with low and high *d* values reveals the influence of the origin of the water vapour on extreme *d* values (revised manuscript, Fig. 11). The moisture corresponding to low daily *d* values is either uptaken in coastal areas east of the station (this occurs mostly in summer) or north-west of it in the South Atlantic Ocean. For such low *d* values of a marine moisture origin, sea surface temperature and near-surface relative humidity are the prime controls (Merlivat and Jouzel, 1979). The occurrence of high *d* in water vapour originating from a sea surface area close to a sea ice margin has been explained by different studies such as Kurita (2011) and Steen-Larsen et al. (2013). Based on the back trajectory simulations, the high *d* values in our measurements can be explained in a similar way. Strong evaporation from sea surface waters into cold humidity-depleted polar air close to the ice-margin (here, areas close to Neumayer Station) will result in strong kinetic effects providing higher *d* values in the water vapour.

For the d, it would be very valuable to understand the long-term trend. Is it related to changes in the vapor origins? And can these long-term changes be understood in terms of the large-scale atmospheric circulation, for example through changes in southern annular mode? Or perhaps it is linked to local effects such as the sea ice extent in the Atlantic sector of the Southern Ocean? These types of analysis would provide some valuable insights into the dynamics, which are currently lacking.

In the revised manuscript, we discuss *d* in more detail (as mentioned above). However, we would like to point out that, in our opinion, the reported two years of vapour data are not yet sufficient to analyse any long-term trend in the Deuterium excess data, although there seems to be a trend towards lower values during the observational period. Nevertheless, since the Picarro instrument is continuously running since 2017, we plan to work on *d* trends in this data set's future studies.

Line 7: d-excess; more commonly just d (lower case italicised).

Corrected as suggested. In the "Abstract" of the paper's revised version, the Deuterium excess signal is defined as *d* and since then used in the whole text.

Revised manuscript, Abstract, line 6:

In contrast to the measured $\delta^{18}O$ and δD variations, no seasonal cycle in the Deuterium excess signal (*d*) in vapour is detected.

Line 23: Buizert et al. (2015) should be WAIS Divide Project Members (2015)

Corrected as suggested:

Revised manuscript, Section 1, line 22:

Recent Antarctic ice core records also allow studying the phasing of climate changes and the linkage between northern and southern polar regions in an unprecedented way (WAIS Divide Project Members, 2015).

Line 32: "clouds": much of the precip in central Antarctica is clear-sky precip (diamond dust).

We changed our argument in the text:

Revised manuscript, Section 1, line 32:

The fundamental physical processes, which link the isotopic fractionation processes during precipitation formation in clouds, the condensation temperature, and the surface temperature at the precipitation location, are well understood (Jouzel and Merli- vat, 1984). However, in the interior of Antarctica, up to 60% of annual precipitation can be diamond dust or so-called clear-sky precipitation, and hoar frost, which are not related to clouds (Walden et al., 2003; Stenni et al., 2016).

*Line 35: temporal relationship *may* differ from spatial relationship.*

Corrected as suggested:

Revised manuscript, Section 1, line 36:

While early studies have assumed an equality between the observed modern spatial temperature–isotope relation and the temporal relation required to reconstruct past temperatures (Petit et al., 1999), it has become clear that the spatial relationship may differ from the temporal relationship (e.g. Sime et al., 2009).

Line 37: Better citation for inversion strength is (Van Lipzig et al., 2002)
Line 39: Another key control is sea ice (Noone & Simmonds, 2004)

Corrected as suggested:

Revised manuscript, Section 1, line 38:

proper isotope paleothermometer calibration is hampered by different processes, like changes in the temperature inversion_strength (Van Lipzig et al., 2002), changes in the seasonality or intermittency of snowfall events (e.g. Masson-Delmotte et al., 2006), changes in the glacial ice sheet height (Werner et al., 2018) and sea ice extent (Noone and Simmonds, 2004), or changes in the origin and transports pathways of moisture to Antarctica (e.g. Masson-Delmotte et al., 2011; Sime et al., 2013).

We thank the referee for this suggestion and discuss sea ice's effect in more detail in the revised manuscript:

Revised manuscript, Subsection 3.3, line 308, (as mentioned above)

Revised manuscript, Subsection 4.2, line 414, (as mentioned above)

Line 72: "sections" instead of "chapters"

Corrected as suggested (in the whole revised manuscript).

Line 92: from the east?

Yes, here we mean wind blowing from the east. We have rephrased the statement, accordingly:

Revised manuscript, Subsection 2.1, line 97:

The prevailing wind direction is from east, caused by the passage of cyclones north of the Antarctic coast in the circumpolar trough.

Line 107: Perhaps define this as the climatology
Line 109: above (below) the climatology

Corrected as suggested:

Revised manuscript, Subsection 2.2, line 115:

The climatology of temperature, specific humidity, and relative humidity is defined as the multi-year daily average value and the standard deviation over the 38-year period from 1981 to 2018 (König-Langlo, 2017). To identify specific days with extreme high or low temperature we compare the daily temperature at the station with its climatology. A day is considered as a warm (cold) event, when its temperature is at least one standard deviation above (below) the climatology (Klöwer et al., 2013).

L*ine 113: "merged to"? What about "reported as"*

Corrected as suggested:

Revised manuscript, Subsection 2.3, line 123:

For our analyses, the data are reported as hourly mean values, if not stated otherwise.

Line 145: what is the philosophy behind the 25h? Is the idea that taking a fixed time of day could introduce biases?

Yes, choosing a 25-hour cycle avoids repetition of the daily calibration at the same time every day but moves the calibration time 1 hour forward per day:

Revised manuscript, Subsection 2.3, line 157:

The 25-hour cycles are chosen to avoid missing the same time of day for all daily observations due to the calibration routine.

Revised manuscript, Appendix A, line 609:

Such 25-hour cycle avoids repetition of the daily calibration at the same time every day but moves the calibration time 1 hour forward per day. By such a calibration interval, we avoid missing the same time period during all days in all measurements.

Line 150: Are the tanks measured at the very end of the campaign against independent standards to ensure there was no drift?

Yes, they are:

Revised manuscript, Subsection 2.3, line 162:

To correct for a potential change in the standards, samples from all liquid standards are taken and measured yearly. For this study, the last sampling was at the end of the campaign in February 2019.

Line 162: Why 2017 only? If you had let your code run during the period of the review process, you would probably have these already. Having the full 2017-2019 period would allow you to analyse the d-excess trend. I would strongly encourage you to run these also. It should be little work, given that the code is working.

We fully agree with the referee and have now expanded the FLEXPART analysis to the full 2017-2019 period.

Revised manuscript, Subsection 3.3, line 308, see comment above.

Line 170: can you add the climatology for comparison (T and q)?

The climatology of temperature, specific humidity, and relative humidity is defined and added to the text and figure

Revised manuscript, Subsection 2.2, line 115, see comment above.

Revised manuscript, Subsection 3.1, Figure 2:

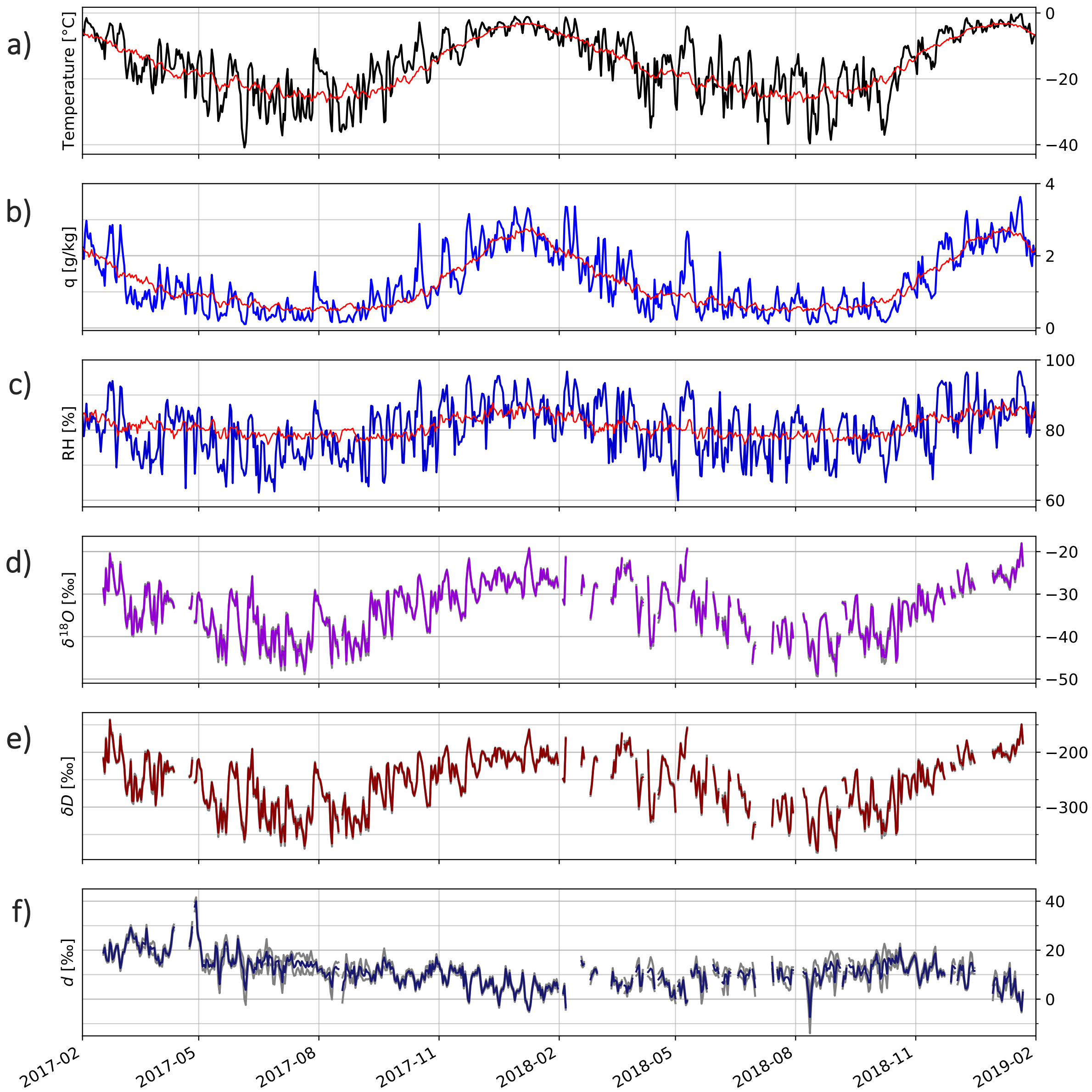

Figure 2 (Figure 2 in the revised manuscript). Daily averaged observations at Neumayer Station from February 2017 to January 2019. Downward: a) 2-m temperature [°C]; b) specific humidity [g kg^{-1}]; c) relative humidity [%]; d) δ^{18}O [‰]; e) δD [‰]; f) d [‰]. To have a better comparison, the climatology (multi-year daily average temperature, specific humidity, and relative humidity over the 38-year period from 1981 to 2018) is shown with a red line in meteorological observations. The determined uncertainties of the Picarro instrumental data (see text) are plotted as gray lines.

Line 183: Can you also say something about the relative (rather than absolute) humidity? That is a much more intuitive parameter. Perhaps add it to the figure?

The relative humidity and its climatology are added to Figure 2 (revised manuscript, Subsection 3.1, Figure 2, see comment above).
We bring the relative humidity to our analysis in different aspects such as:

Revised manuscript, Subsection 3.1, line 228:

Daily relative humidity fluctuates between 59.95% and 96.71% with a mean value of 80.42%.

Revised manuscript, Subsection 3.1, line 235:

The annual average of the specific humidity (relative humidity) for 2017 and 2018 is 1.18 $g\ kg^{-1}$ (79.75 %) and 1.23 $g\ kg^{-1}$ (80.60 %).
Temperature, specific humidity, relative humidity, $\delta^{18}O$, and δD show a clear seasonal cycle in the daily mean data series (Fig. 2) with high values at the end of austral summer (January–February) and low values at the end of austral winter (August– September). No such seasonal cycle is observed for the *d* values.

Revised manuscript, Subsubsection 3.2.1, line 292:

The correlation coefficient for relative humidity and δ18O in different seasons are similar (spring: r = 0.73, summer: r = 0.57, autumn: r = 0.69, and winter: r = 0.65).

Revised manuscript, Subsubsection 3.2.2, line 303:

There are anti-correlations between the specific humidity (relative humidity) values and d for spring, r = −0.50 (r = −0.43), summer, r = −0.71 (r = −0.59), and autumn, r = −0.24 (r = −0.19), which are slightly stronger than the ones between temperature and d. For winter, there is a weak positive correlation between the specific humidity (relative humidity) and d, r = 0.13, (r = 0.04).

Revised manuscript, Subsection 3.5, line 355:

The average of all values of each variable for the diurnal cycle study period (December-January of 2017/18 and 2018/19) are: $\delta^{18}O$: -26.34 ‰; δD: -205.27 ‰; *d*: 5.46 ‰; 2-meter temperature: $-4.25\ ^{\circ}C$; 10-meter temperature: $-3.87\ ^{\circ}C$; specific humidity: 2.49 $g\ kg^{-1}$; relative humidity: 86.30 %; wind speed: 7.53 $m\ s^{-1}$; wind direction: 291 *degree* (we consider only winds with a wind speed of more than 3 $m\ s^{-1}$); shortwave downward radiation: 228.98 $W\ m^{-2}$. Strong diurnal cycles in 2-meter temperature (Fig. 8d, red line), 10-meter temperature (Fig. 8d, green line), specific humidity (Fig. 8e), and relative humidity (Fig. 8f) are detected.

Revised manuscript, Subsection 3.5, line 364:

The amplitudes of the specific humidity and relative humidity are 0.54 $g\ kg^{-1}$ and 4.19 %, respectively.

Revised manuscript, Subsection 3.5, line 368:

Diurnal *d* is rather anti-correlated with relative humidity ($r = -0.59$), while it does not show a considerable correlation with temperature and specific humidity.

Revised manuscript, Subsection 3.5, line 371:

The 2 and 10-meter temperature cycles and consequently $\delta^{18}O$ and δD follow the shortwave radiation (Fig. 8i) with a short delay (around 3 hours) and show the minimum and maximum values at 03:00 UTC (local time) and 15:00 UTC. The relative humidity behaves the other way round and shows the minimum value at 15:00 UTC and and maximum values between 21:00 UTC and 03:00 UTC. *d* has the minimum at 00:00 UTC and the maximum at 09:00 UTC.

Line 192: But the long-term d-excess trend is robust, correct?

As mentioned above, in our opinion the reported two years of vapour data are not yet sufficient to analyse any long-term trend in the Deuterium excess data, although there seems to be a trend towards lower values during the observational period. Nevertheless, since the Picarro instrument is continuously running since 2017, we plan to work on *d* trends in this data set's future studies.

Line 196: Not fully reliable given the large difference in slope of 1.5. Is this a calibration issue? Can you elaborate a little – it seems this does not impact your isotope data, but it would be nice to know where this difference in slope originates.

We have analysed the different q values now in more detail and expanded the corresponding text in the revised manuscript as follows:

Revised manuscript, Subsection 3.1, line 193:

We compare the specific humidity measured by the Picarro instrument with the specific humidity values measured routinely as part of the meteorological observations at Neumayer Station (Schmithüsen et al., 2019). The relationship between these two series of humidity measurements is $q_{(Picarro)} = 1.5q_{(meteorology)}+0.08$ (N = 12198, hourly values between 17 February 2017 and 22 January 2019, r = 0.97, standard error of the estimate = 0.0022 $g.kg^{-1}$; revised manuscript, Fig. 3). The rather high slope between both humidity measurements and also a number of unusual high and low Picarro humidity values motivated us to analyse the difference between both humidity data sets in more detail.
The inlet of the Picarro instrument is situated approx. 17.5 m above the surface level of the station. As the station is placed on a small artificial hill, this surface level is approx. 7.6 m

higher than the surface level of the meteorological mast placed 50 meters besides the station building. Thus, the total height difference between the Picarro inlet and the height of the meteorological humidity measurements is approx. 22 m. In principle, higher humidity values at the Picarro inlet could be explained by a humidity inversion layer above the surface, which could remove near-surface moisture at the meteorological mast position by hoar frost formation. However, temperature differences between a 2-meter temperature sensor at the meteorological mast and temperatures measured on the roof of the station do not exceed 2 °C during our measurement period. No strong temperature inversions are found for the days with extreme Picarro humidity measurements.

To test if contamination by exhaust gases could be another reason for the data mismatch, the wind direction was analysed for those hourly Picarro humidity values which are much higher than the corresponding humidity values measured by the meteorological station. Most of the outliers coincide with a wind direction from the south (and a few from east), which excludes the possibility that a contamination by exhaust gases is the reason for the unusually high Picarro humidity values.

Picarro humidity measurements have been compared with independent humidity observations for a few studies, so far. Aemisegger et al. (2012) calibrated and controlled the humidity of their Picarro instrument by a dew point generator and showed a linear relationship between Picarro measurements and the humidity measured by the calibration system with a slope of 1.27 and an uncertainty of 100-400 ppm (0.06-0.24 $g.kg^{-1}$). Tremoy et al. (2011) reported that the slope between humidity measured by a meteorological sensor and humidity measured by a Picarro instrument can change from 0.81 to 1.47 depending on site conditions. Bonne et al. (2014) also showed a non-linear response of their Picarro instrument compared with the humidity measured by a meteorological sensor. Based on their data, the ratio between Picarro humidity and sensor humidity values changed from 1 to 1.87, depending on the amount of humidity. Compared to the results of these studies, we rate the calculated ratio of our Picarro humidity measurements versus the humidity data from the meteorological mast ($q_{(Picarro)}/q_{(meteorology)} = 1.5$) as unobstructive.

As in previous studies (e.g., Bonne et al., 2014) we will use the Picarro humidity data for the calculation of the humidity response functions required for the calibration of the isotope measurements. All analyses regarding the relationships between water vapour isotopes and local climate variables, on the other hand, are based on the humidity and corresponding temperature data measured at the meteorological mast.

Line 208: Given the strong Antarctic temperature inversion in winter, this 22 m difference may actually matter a lot for temperature and therefore humidity - in the interior of Antarctica, the difference could be up to 10K (Hudson & Brandt, 2005), but the inversion is probably less strong near the coast.

A strong temperature inversion could be one of the reasons for differences between both humidity data sets. Diurnal cycles of the difference between 10-meter temperature and 2-meter temperature in different months of the year during our study (Schmithüsen et al., 2019) show that the difference is rarely more than 1.5°C (Figure 4, not shown in the manuscript).

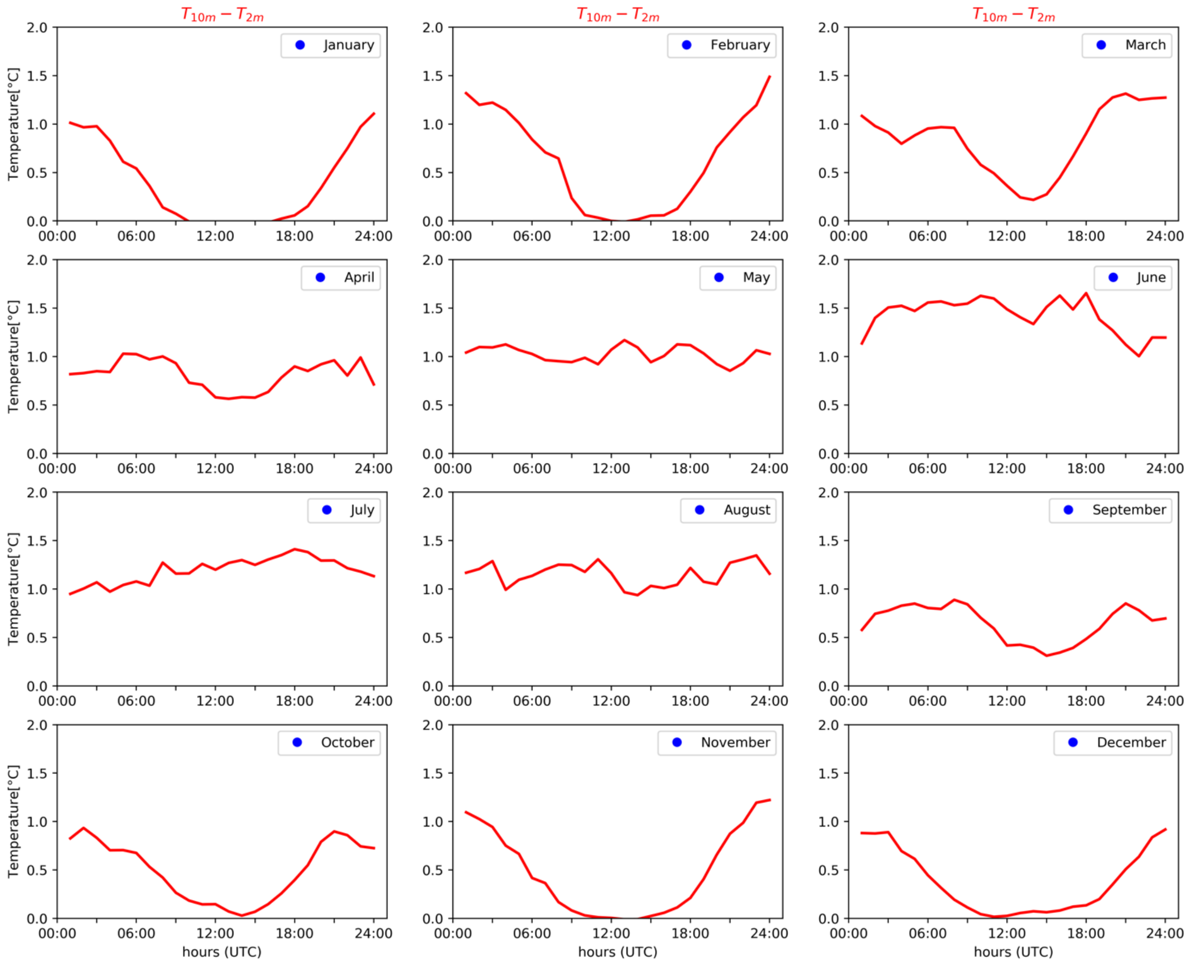

Figure 3. Diurnal cycles of differences between 10-meter temperature and 2-meter temperature for each month of the year for the period of the study from February 2017 to January 2019 (Schmithüsen et al., 2019). Units are °C and the time zone is UTC.

Line 220: How are the seasons defined? Do you use DJF, MAM, JJA, SON?

Yes, the seasons are defined as spring (SON), summer (DJF), autumn (MAM), and winter (JJA). We added this definition to the revised manuscript:

<u>Revised manuscript, Subsubsection 3.2.1, line 253:</u>

The slopes for spring (SON), summer (DJF), autumn (MAM), and winter (JJA) are 0.58 ± 0.03 ‰$^{\circ}C^{-1}$ (r = 0.86), 0.68 ± 0.06 ‰$^{\circ}C^{-1}$ (r = 0.71), 0.63 ± 0.04 ‰$^{\circ}C^{-1}$ (r = 0.83), and 0.48 ±0.03 ‰$^{\circ}C^{-1}$ (r = 0.75), respectively.

Line 223: Enhanced temp variability in winter is seen all over Antarctica (e.g. at SouthPole), and has been explained elsewhere via the stability of the inversion (Hudson &Brandt, 2005). Please refer to some other papers on the meteorology of Antarctica, I think this is more fundamental and not specific to Neumayer. I don't think the reason you state is the correct one necessarily. Please clarify and provide relevant citations.

We fully agree with these arguments and changed the text accordingly:

Revised manuscript, Subsubsection 3.2.1, line 265:

Daily temperature and $\delta^{18}O$ values in summer are less fluctuating than in the other three seasons (revised manuscript, Fig. 4). This might be explained by a weaker temperature inversion, lower sea ice variability, and sublimation and snowmelt activation in summer. Hudson and Brandt (2005) showed that the temperature inversion intensity variations in winter are one reason for the large day-to-day variability of 2-meter temperature in Antarctica. In winter, clouds can be much warmer than the surface, but the temperature inversion keeps the surface cold. Increasing wind speed, considering warm clouds above the surface, can activate a horizontal advection for air with different temperatures, affect the vertical mixing of the inversion layer, and destroy the inversion. Due to these characteristics of the Antarctic climate, stronger inversion can lead to higher temperature variability in winter. However, Connolley (1996) showed that the inversion strength in Antarctic stations depends on the stations' temperature and location. Decreasing temperature leads to a more robust inversion, but this effect is weaker in the coastal stations than the interior stations.
As sea ice can strongly limit the heat flux between a relatively warm ocean and the atmosphere, sea ice coverage variations close to Antarctica's coastal stations can primarily affect the near-surface temperature at the stations (Turner et al., 2020). Decreasing sea ice variability close to the Neumayer Station in summer compared to other seasons, which is true for most other coastal stations in Antarctica, may lower temperature variability.
Another reason for the small temperature amplitude in summer can be a stronger heat loss, which prevents temperatures above zero. At Neumayer Station, the most significant heat loss sources in summer are sublimation and snow melting (Jakobs et al., 2019). The sublimation is primarily temperature-driven and at Neumayer station is significant only in summer. It is one of the main consumers of absorbed solar radiation, removing about 19 % of the annual snowfall at Neumayer Station (van den Broeke et al., 2010). The second source of heat loss at the station is snow melting. In the summertime, when the air temperature can rise above 0°C, the surface snow will reach its melting point and start to melt. For the melting process, the incoming radiative energy is partly used for latent heat uptake, keeping the near-surface temperature close to the melting point. These phenomena can explain the detected cut-off at 0°C of the 2 m temperature (revised manuscript, Fig. 4). It might also partly explain the lower correlation coefficient between the 2 m temperature and $\delta^{18}O$ in summer, as upper air temperatures most likely control the latter.

Section 3.2.2.: I think you need to give us the relative humidity plots to evaluate how meaningful this correlation is. Since q and T are strongly correlated, these observations are unsurprising.

The relative humidity plot is provided (revised manuscript, Subsection 3.1, Figure 2, as mentioned above). Based on another referee's suggestion, we also removed the $\delta^{18}O$-q figure and merge the subsection with the $\delta^{18}O$-T section and explain the link between specific humidity and atmospheric temperature through Clausius–Clapeyron relation in the presence of high relative humidity.

Revised manuscript, Subsubsection 3.2.1, line 286:

At Neumayer Station, the specific humidity is highly correlated with temperature (Jakobs et al., 2019), as expected from the general Clausius-Clapeyron relation between both quantities. As a consequence, the $\delta^{18}O$ values of water vapour at Neumayer Station are strongly correlated not only to temperature, but also to specific humidity (r = 0.85).

Section 3.2.3.: is there a diurnal cycle in isotopes?

Based on another referee's suggestion, we have now additionally analysed the diurnal cycles, considering two months of two sequent summers (December-January of 2017/18 and 2018/19), in order to compare our data with previously reported studies of the diurnal cycle in Antarctica. We added the subsection "Diurnal cycle" to the paper (revised manuscript, Subsection 3.5). In the Discussion section, we discuss our new results:

Revised manuscript, Subsection 3.5, line 350:

3.5 Diurnal cycle

To evaluate the diurnal cycles at Neumayer Station, we consider two months of two sequent summers (December-January of 2017/18 and 2018/19) in order to compare our results with previous studies performed in Antarctica.We derive the daily mean values (the mean of 24 hourly mean values for each day) and subtract it from the time series. The remaining anomalies of all parameters represent an average diurnal cycle (Fig. 8).

The average of all values of each variable for the diurnal cycle study period (December-January of 2017/18 and 2018/19) are: $\delta^{18}O$: -26.34 ‰; δD: -205.27 ‰; *d*: 5.46 ‰; 2-meter temperature: -4.25 °C; 10-meter temperature: -3.87 °C; specific humidity: 2.49 g kg^{-1}; relative humidity: 86.30 %; wind speed: 7.53 m s^{-1}; wind direction: 291 degree (we consider only winds with a wind speed of more than 3 m s^{-1}); shortwave downward radiation: 228.98 Wm^{-2}.

Strong diurnal cycles in 2-meter temperature (Fig. 8d, red line), 10-meter temperature (Fig. 8d, green line), specific humidity (Fig. 8e), and relative humidity (Fig. 8f) are detected. For wind speed, the diurnal cycle is weak (Fig. 8g) and for wind direction no diurnal cycle is detectable (Fig. 8h). In summer, there is no strong temperature inversion close to the surface, at least not for the first 10 meters above surface. The temperature differences between 2-meter and 10-

meter height reaches up to 1 °C during the coldest time of a day, while during half of the day their difference is less than 0.4 °C. The amplitudes of 10-meter temperature (3.63 °C) are less than 2-meter temperature (4.14 °C). The amplitudes of the specific humidity and relative humidity are 0.54 g kg^{-1} and 4.19 %, respectively.

A clear diurnal cycle can be detected for $\delta^{18}O$ (Fig. 8a), δD (Fig. 8b), and *d* (Fig. 8c). The diurnal amplitudes are 2.45 ‰, 21.07 ‰, and 4.87 ‰, respectively. A very high correlation coefficient between $\delta^{18}O$ and 2-meter temperature (r = 0.98) and 10-meter temperature (r = 0.99) suggests the temperature changes as the main driver of water vapour $\delta^{18}O$ diurnal variations. *d* is rather anti-correlated with relative humidity (r = -0.59), while it does not show a considerable correlation with temperature and specific humidity.

The 2 and 10-meter temperature cycles and consequently $\delta^{18}O$ and δD follow the shortwave radiation (Fig. 8i) with a short delay (around 3 hours) and show the minimum and maximum values at 03:00 UTC (local time) and 15:00 UTC. The relative humidity behaves the other way round and shows the minimum value at 15:00 UTC and and maximum values between 21:00 UTC and 03:00 UTC. *d* has the minimum at 00:00 UTC and the maximum at 09:00 UTC.

<u>Revised manuscript, Subsection 3.5, Figure 8:</u>

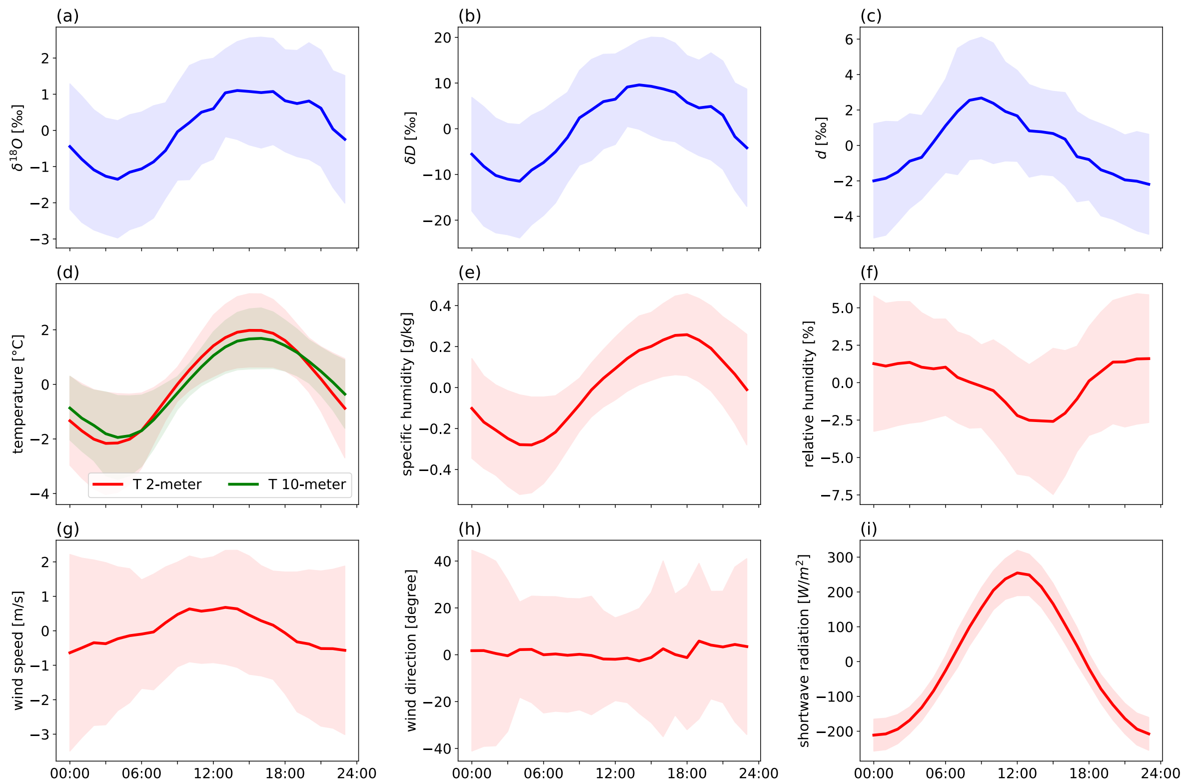

Figure 4. (Figure 8 in the revised manuscript). Anomaly diurnal cycles of (a) $\delta^{18}O$ [‰], (b) δD [‰], (c) d [‰], (d) 2-meter temperature and 10-meter temperature °C], (e) specific humidity [g k^{-1}], (f) relative humidity.[%], (g) wind speed [ms^{-1}], (h) wind direction [degree], (i) shortwave downward radiation [W m^{-2}], and their ±1 standard deviations for two months of two sequent summers (December-January of 2017/18 and 2018/19). Blue colour shows the Picarro instrument measurements and red colour (and green) shows meteorological observations at Neumayer Station. The local time zone at Neumayer Station is equal to UTC time.

Added to Discussion section:

<u>Revised manuscript, Subsubsection 4.3.1, line 463:</u>

To analyse changes during the diurnal cycle, Bréant et al. (2019) categorized their measurements based on the weather conditions as days with a clear sky and days with a cloudy sky. Since we do not find large differences in diurnal cycles related to these two conditions at Neumayer Station, we do not cluster our measurements. At both stations, strong diurnal cycles in $\delta^{18}O$, δD, *d*, temperature and specific humidity are observed. The diurnal cycle of the mostly katabatic winds is stronger at Dumont d'Urville station than Neumayer Station. At Dumont d'Urville station, a relatively low correlation between the diurnal cycle of temperature and $\delta^{18}O$ shows that the temperature cannot be the main driver of $\delta^{18}O$ variations, while at Neumayer Station it is the main driver of diurnal variations of $\delta^{18}O$. At Dumont d'Urville station, diurnal cycle links start with the temperature variations in the continental areas above the station due to the incoming shortwave radiation diurnal cycle. A decrease of incoming shortwave radiation leads to radiative cooling at the continental slopes surface (above the station), resulting in an increase of the katabatic wind, which is characterized by lower $\delta^{18}O$ and higher *d* values and thus causes the diurnal cycles at Dumont d'Urville station. At Neumayer Station, the shortwave radiation affects mainly the local temperature results in $\delta^{18}O$ value variations, while the dominant wind, in the absence of the strong katabatic wind, is from east.

Added to Discussion section:

<u>Revised manuscript, Subsubsection 4.3.2, line 500:</u>

Ritter et al. (2016) chose 18 days of their available measurements to evaluate the diurnal cycles at Kohnen Station. They observed a strong diurnal cycle in temperature, specific humidity, wind speed (mostly katabatic), $\delta^{18}O$, δD and *d*, while at Neumayer Station, a weak daily cycle of wind changes (mostly from east) is detected. For the diurnal variations at Kohnen Station, there exist high correlations between specific humidity and δD ($r = 0.99$) and also between temperature and δD ($r = 0.99$) which highlight the role of 495 temperature in δD and $\delta^{18}O$ diurnal cycles. In contrast to Neumayer Station, the *d* values are strongly anti-correlated with $\delta^{18}O$ and δD at Kohnen Station. Ritter et al. (2016) suggested that this strong anti-correlation is caused by a distillation effect at very low temperatures (mean temperature at Kohnen station during their campaign is -23.40 °C).

The information of the available summer data sets from these three locations (Neumayer Station, Dumont d'Urville, Kohnen Station) are summarized in Table 1.

Table 1. (Table 1 in the revised manuscript). Comparison of summer water vapour isotope studies in different Antarctic stations (Ritter et al., 2016; Bréant et al., 2019). The time period of each study is shown in the table. For Neumayer Station, two months of two summers (December 2017/January 2018 and December 21018/January 2019) are considered.

Diutnal cycle parameter	**Neumayer**	**Dumont d'Urville**	**Kohnen**
diurnal cycle period	all days	only clear sky periods	20/12/2013 - 27/12/2013
temperature [°C]	average value: -4.24 diurnal cycle amplitude: 4.14	average value: -0.5 diurnal cycle amplitude: 4.5	average value: -23.4 diurnal cycle amplitude: 8.7
specific humidity [$g\ kg^{-1}$]	average value: 2.49 diurnal cycle amplitude: 0.54	average value: 1.99 diurnal cycle amplitude: 0.80	average value: 0.74 diurnal cycle amplitude: 0.62
wind [$m\ s^{-1}$]	average value: 7.5 diurnal cycle amplitude: 1.5	average value: 8 diurnal cycle amplitude: 7	average value: 4.5 diurnal cycle amplitude: 3.5
$\delta^{18}O$ **[‰]**	average value: -26.34 diurnal cycle amplitude: 2.45	average value: -30.37 diurnal cycle amplitude: 5.40	average value: -54.74 diurnal cycle amplitude: 4.87
d **[‰]**	average value: 5 diurnal cycle amplitude: 5	average value: 3 diurnal cycle amplitude: 10	average value: 30 diurnal cycle amplitude: 11

Line 263: Is that really the reason? The cyclonic storm tracks are moving from west to east, so opposite to what you state. I am no meteorologist, but I always thought the near-coastal easterlies were driven by Coriolis deflection of the katabatic winds off the continent. Please clarify and provide relevant citations.

We have tried to clarify this text part in the revised manuscript and include many relevant citations (as mentioned above). Large wind direction and wind speed variations at Neumayer Station reflect complex dynamical processes result from travelling cyclones around the station and katabatic winds (Kottmeier and Fay, 1998). There are two main wind directions. The prevailing wind direction is from the east, caused by the passage of cyclones north of the Antarctic coast in the circumpolar trough (here Figure 5-a, as an example of a day with wind from east). These low-pressure systems move toward west around Antarctica while their centres are over the ocean. On Antarctica, there is a high-pressure system. Thus, there is a gradient force from high pressure to low pressure. The balance between the gradient force and the Coriolis force leads to an anti-clockwise circulation around the anticyclone above the continent, but to a clockwise circulation around the cyclone centers (König-Langlo et al., 1998; König-Langlo, 2017).

The second, less frequent, typical wind direction is south to south-west, caused by a mixture of weak katabatic and synoptic influence, when Neumayer Station is situated between a cyclone to the east and an anticyclone to the west (König-Langlo et al., 1998; König-Langlo and Loose, 2007; Rimbu et al., 2014). In fact, the cyclone that had been north of the station has moved eastward, so the former low-pressure area is replaced by a high-pressure ridge. In such a situation, wind speeds decrease and the wind direction changes from easterly to southerly and south-westerly (Figure 5-b, as an example of a day with the main wind from south and south-west).

Figure 5 shows the mean sea level pressure on Antarctica and around the station for two different days: a) 2017-08-01, with the main wind from the east; b) 2017-08-09, with the main wind from the south (katabatic wind). We place this figure within the revised manuscript:

<u>Revised manuscript, Subsection 3.4, Figure 7</u>

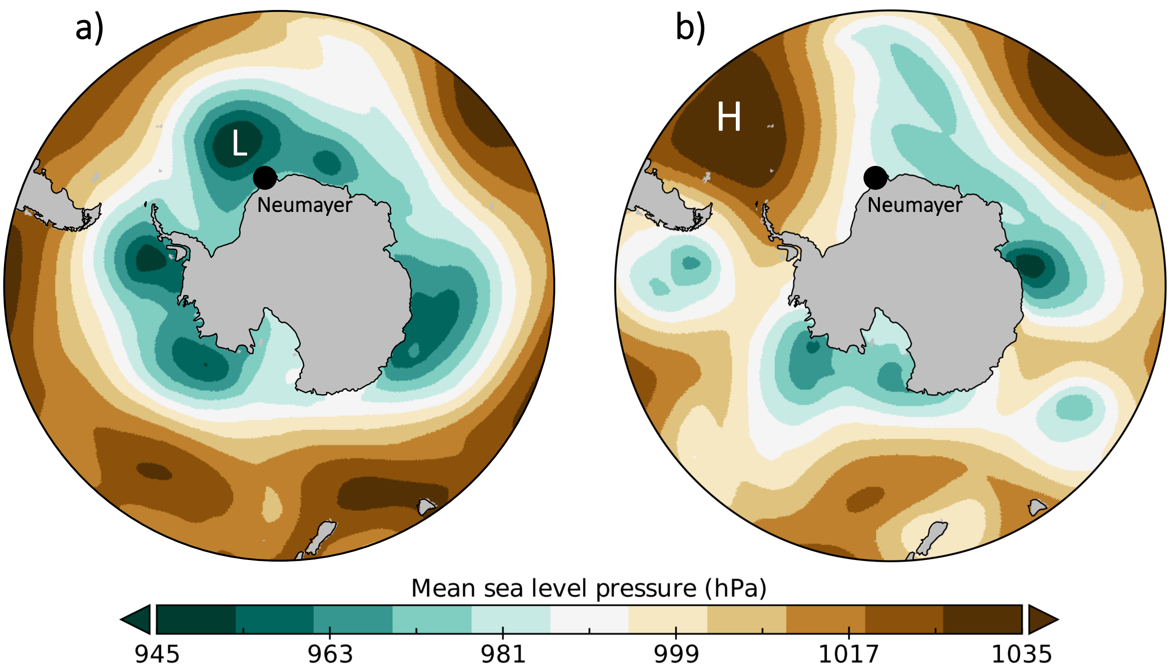

Figure 5. (Figure 7 in the revised manuscript). Mean sea level pressure for two different days: a) 2017-08-01, with a main wind from the east; b) 2017-08-09, with the main wind from the south (katabatic wind). The low-pressure system close to the station is marked by "L" and the high-pressure one is marked by "H". Pressures are given in hPa. Data are from ERA5 data set, ECMWF (Hersbach et al., 2020).

Figure 8: what years of the reanalysis are used?

The figure was based on data for the year 2017. The figure is removed as one of the other referees asked, only the summer and winter views of this figure are shown in the first figure of the paper (revised manuscript, Subsection 2.1, Figure 1). For this new figure, the average of the years 2017 and 2018 is considered.

<u>Revised manuscript, Subsection 2.1, Figure 1:</u>

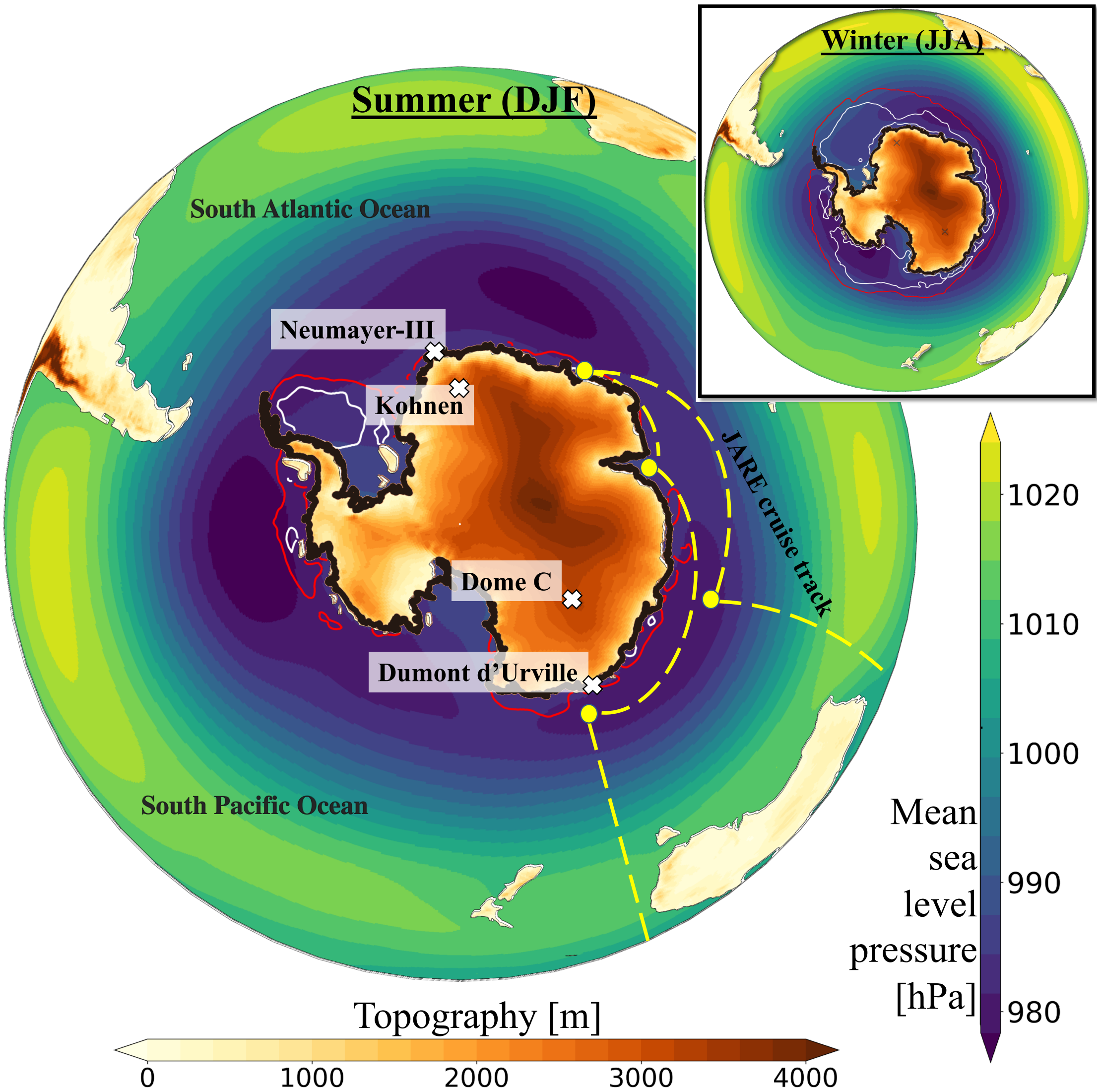

Figure 6 (Figure 1 in revised manuscript). Map of Antarctica with topography [meter], mean sea level pressure [hPa], Antarctic grounding line (black line), and sea ice fraction [red line: fraction > 0.45, white line: fraction > 0.90] in austral summer (big map) and austral winter (small map), considering years of 2017 and 2018. The topography, mean sea level pressure and sea ice fraction are based on meteorological data from the European Centre for Medium-range Weather Forecasts (ECMWF) ERA5 reanalysis (Hersbach et al., 2020) and the Antarctic grounding line is based on Depoorter et al. (2013). The location of our study (Neumayer III) and other studies which provided continuous water vapour isotopic measurements in Antarctica (Ritter et al., 2016; Casado et al., 2016; Bréant et al., 2019) are shown in white colour and JARE cruise track related to Kurita et al. (2016) is shown in yellow colour.

Figure 8: what is the purpose of this figure? I don't see how it contributes to the paper or the narrative

The figure shows the large-scale pressure conditions at Neumayer station. It clarifies the main reason of the wind pattern at the station. As mentioned above, this figure is removed and then merged with the first figure of the paper which shows a general view of the study site (revised manuscript, Subsection 2.1, Figure 1).

Line 283: "the main air path is a cyclonic circulation" What does this mean?

See the comment above.

Figure 9: The vapor pressure over ice via the Clausius Clapeyron has an Arrhenius type relationship, with vapor pressure scaling as exp(-H/RT). So not quite the relationship that you show. Can you plot correctly vs. 1/T (with T in Kelvin), and estimate the Enthalpy H?

We submit a plot of ln(q) vs. 1/T below (Figure 7).
Following a comment of referee #1, we have decided to omit Figure 5 and Figure 9 in the revised manuscript, but rather only discuss the dominance of the Clausius-Clapeyron relationship on the humidity signal at Neumayer Station in the text (as mentioned above).
We are sorry, but we do not fully understand the relevance of estimating the enthalpy H for our analyses. Therefore, we refrain from following this suggestion at this time, but offer to include it in a revised manuscript, if requested.

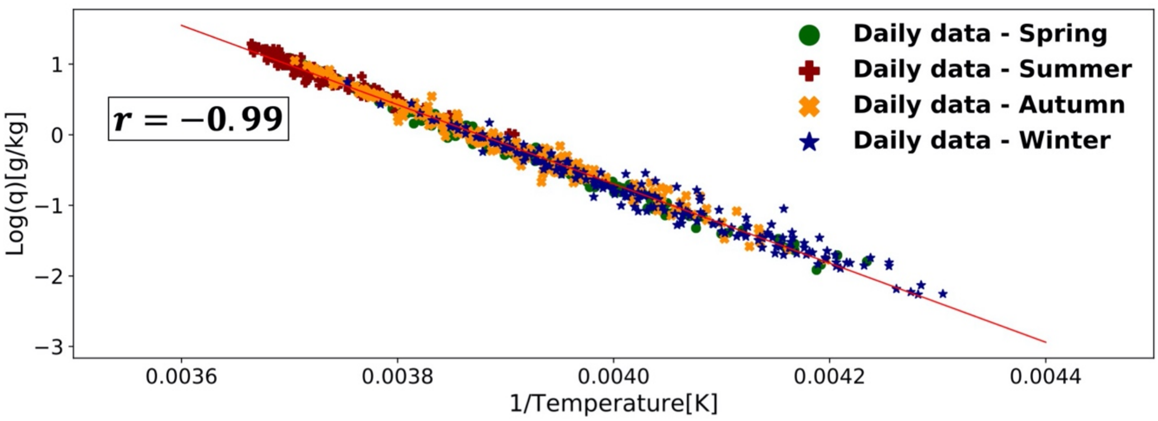

Figure 7. 1/temperature [1/K] vs. natural logarithmic specific humidity [g/kg] from February 2017 to January 2019 at Neumayer Station. Values are daily averaged. The corresponding correlation coeficent is calculated (r=0.99). Different colours indicate different seasons.

Line 288: What form of the CC equation do you use? Please give the equation.

Saturation vapour pressure is the pressure that water vapour is in thermodynamic equilibrium with its condensed state. This pressure determines the amount of water that air can keep, which means at higher pressures, water would condense. Clausius-Clapeyron equation in meteorology shows that this pressure and then the equilibrium between water and water vapour depend on the system's temperature. This equation near-standard temperature and pressure is:

$$\frac{de_s}{dT} = \frac{L_v(T)e_s}{R_v T^2}$$

Where e_s is saturation vapour pressure, T is temperature, L_v is the specific latent heat of water evaporation, and R_v is the vapour's gas constant. To understand the relationship between saturation vapour pressure and temperature for water vapour we use the approximation provided by the August–Roche–Magnus formula.

$$e_s(T) = 6.1094\exp\left(\frac{17.625T}{T + 243.04}\right)$$

Where e_s is in hPa and T is in Celsius. This equation shows the water vapour pressure and then specific humidity depends on the temperature exponentially. We checked this phenomenon at Neumayer Station. Temperature and logarithmic humidity are highly correlated (r = 0.99) at Neumayer Station.

L300-302: I don't understand this point. Can we see this in the data?

Yes there is a high correlation coeffect between the 2-meter temperature and $\delta^{18}O$ value (r = 0.89) and during the observation period, on 86 % of all days that involve warm events at Neumayer Station, the wind came from east. If we look at the relationship between wind direction and $\delta^{18}O$ values, we see that whenever we have wind from east, the $\delta^{18}O$ values are more enriched. But since the wind from the east usually coincides with higher temperature, we cannot distinguish if the isotope signal is controlled by the humidity source (as indicated by the wind direction), the temperature, or both of them. Thus, we decided to only select days with no temperature events (as defined in Subsection 2.2) and analyse the correlation between $\delta^{18}O$ signal and wind direction for this subset of the data. Our findings indicate that the $\delta^{18}O$ value can change with the wind direction, even if no temperature change occurs simultaneously (revised manuscript, Subsubsection 4.1.2).

L305-320: It is not clear what the analysis of the relationship between wind direction and pressure anomaly is based on. Reanalysis data? Case studies? No citations are provided.

König-Langlo et al. (1998) and (König-Langlo (2017) explained the relationship between pressure conditions and wind situation well. Now, these papers are cited in the new version of the manuscript, and the situation is explained in more details (as mentioned above, revised manuscript, Subsection 3.4).

L330: Again, this is unfortunate. How long does it take to run the code? Surely not more than a few days?

As already stated above, we have expanded the FLEXPART simulation to the full two-years period in the revised manuscript (revised manuscript, Subsection 3.3).

L345: This is a valuable observation. Does it make sense that water vapor originating close to the continent has higher d-excess? Please elaborate.

As we mentioned above, the discussion of the high and low *d* values is improved concerning the origin of the water vapour (revised manuscript, Subsection 4.2):
The moisture corresponding to low daily *d* values is either uptaken in coastal areas east of the station (this occurs mostly in summer) or north-west of it in the South Atlantic Ocean. For such low *d* values of a marine moisture origin, sea surface temperature and near-surface relative humidity are the prime controls (Merlivat and Jouzel, 1979). The occurrence of high *d* in water vapour originating from a sea surface area close to a sea ice margin has been explained by different studies such as Kurita (2011) and Steen-Larsen et al. (2013). Based on the back trajectory simulations, the high *d* values in our measurements can be explained in a similar way. Strong evaporation from sea surface waters into cold humidity-depleted polar air close to the ice-margin (here, areas close to Neumayer Station) will result in strong kinetic effects providing higher *d* values in the water vapour.

L352: Is Neumayer data assimilated in ERA-interim?

Yes. This information is added to the revised manuscript:

Revised manuscript, Subsection 3.4, line 338:

However, for cold events (as defined in Section 2.2), the ERA5 dataset has a bias with respect to the katabatic winds (Fig. 6c), although the Neumayer Station meteorological data is assimilated in ERA5.

L370: So does Neumayer have greater relative humidity then?

In the paper (Bréant et al., 2019), there is no number for relative humidity. But from given average temperature and average humidity values, we can estimate the average relative humidity as around 55 % which is lower than the average relative humidity at Neumayer Station for the months December-January of 2017/18 and 2018/19 (86 %).

Section 4.5: The agreement in slope between d18O-T from vapor and precip is remarkable. Do you think this relationship is valid only because you are so close to the coast/vapor source?

Steen-Larsen et al. (2014) observations indicate that surface snow might be at equilibrium with near-surface water vapor (or vice versa). However, their study location was at NEEM, NW

Greenland, far from the coast/vapour source, thus their findings are not directly comparable to our study. Therefore, we plan to further examine the isotopic exchange between water vapour and surface snow at Neumayer Station in future research studies.

We thank referee #2 for his/her detailed comments and suggestions on our manuscript. We hope that we have dealt with all comments in an adequate manner and that the revised manuscript now qualifies for publication in The Cryosphere.

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