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1 **Coastal water vapor isotopic composition driven by katabatic wind variability in summer at Dumont**  
2 **d'Urville, coastal East Antarctica**

3

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7

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13 **Abstract**

14 Dumont d'Urville station, located on the East coast of Antarctica in Adélie Land, is in one of the windiest  
15 coastal region on Earth, due to katabatic winds downslope from the East Antarctic ice sheet. In  
16 summer, the season of interest in this study, coastal weather is characterized by well-marked diel  
17 cycles in temperature and wind patterns. Our study aims at exploring the added value of water vapor  
18 stable isotopes in coastal Adélie Land to provide new information on the local atmospheric water cycle  
19 and climate. An important application is the interpretation of water isotopic profiles in snow and ice  
20 cores recently drilled in Adélie Land. We present the first continuous measurements of  $\delta^{18}\text{O}$  and d-  
21 excess in water vapor over Adélie Land. During our measurements period (26/12/2016 to 03/02/2017),  
22 we observed clear diel cycles in terms of temperature, humidity and isotopic composition. The cycles  
23 in isotopic composition are particularly large given the muted variations in temperature when  
24 compared to other Antarctic sites where similar monitoring have been performed. Based on data  
25 analyses and simulations obtained with the regional MAR model on the coastal Adélie Land, we suggest  
26 that the driver for  $\delta^{18}\text{O}$  and d-excess diel variability in summer at Dumont d'Urville is the variations of  
27 the strength of the wind coming from the continent: the periods with strong wind are associated with  
28 the arrival of relatively dry air with water vapor associated with low  $\delta^{18}\text{O}$  and high d-excess from the  
29 Antarctic plateau. Finally, in addition to the interpretation of snow and ice core isotopic profiles in the  
30 coastal regions, our study has implications for the evaluation of atmospheric models equipped with  
31 water isotopes.

## 32 **1. Introduction**

33 Adélie Land, located on the coast of Antarctica, in the Indian Ocean sector (Figure 1) is one of the  
34 windiest coastal regions on Earth, due to katabatic winds blowing downslope from the East Antarctic  
35 Plateau (Pettré et al., 1993; Wendler et al., 1997; König-Langlo et al., 1998). This region is also  
36 associated with a coastal winter polynya playing a key role on sea ice formation, deep water formation,  
37 and associated food webs (Kusahara et al., 2017). Large variations of regional sea ice extent have been  
38 monitored since 1979 (Massom et al., 2013), with maximum expansion of pack ice up to 300 km from  
39 the coast (Massom & Stammerjohn, 2010; Tamura et al., 2016). Sea ice may persist during summer  
40 months (Smith et al., 2011). Located at (66°39'S, 140°00 E) in Adélie Land, the Dumont d'Urville station  
41 (hereafter DDU) has provided continuous weather monitoring since 1957 (Périard & Pettré, 1993). In  
42 summer, the season of interest in this study, coastal weather is in general characterized by well-  
43 marked diel cycles in temperature and wind patterns, associated with the contrasted influence of  
44 katabatic winds during night time and frequent upslope sea breezes during day time (Gallée & Pettré,  
45 1998). Recent monitoring studies in coastal Adélie Land have evidenced the importance of blowing  
46 snow as well as snow sublimation processes induced by local atmospheric dynamic for the regional  
47 surface mass balance of the Antarctic ice sheet (Barral et al., 2014; Amory et al., 2015; Grazioli et al.,  
48 2017). As an example, the recent study of Grazioli et al. (2017) suggests that low-level sublimation  
49 linked to katabatic winds can lead to a 35% reduction of snowfall on the East Antarctic coast and to a  
50 17% reduction when considering whole Antarctica. One objective of our study is thus the need to  
51 better document and understand the processes affecting atmospheric moisture transport and snow-  
52 air exchanges in coastal polar areas with climatic conditions comparable to Adélie Land.

53 Here, we explore the added value of water isotopes to document the local and regional atmospheric  
54 water cycle through presentation of new stable isotopic measurements on water vapor performed in  
55 the summer season during 40 days at DDU near the surface. Water stable isotopes are integrated  
56 tracers of the atmospheric water cycle, as equilibrium and kinetic fractionation leave an imprint of  
57 each process occurring along the moisture path: evaporation, atmospheric moisture transport, and  
58 condensation (Jouzel, 2013). In Antarctic ice cores, water stable isotopes are amongst the core classical  
59 measurements. In high accumulation regions, they are combined with ice core chemistry  
60 measurements to identify seasonal cycles and develop ice core layer counted chronologies (e.g.  
61 Roberts et al., 2015; Thomas et al., 2017). In central Antarctic regions, the variability of water stable  
62 isotopes ( $\delta^{18}\text{O}$  or  $\delta\text{D}$ ) in precipitation is dominated by a fingerprint of local temperature variability at  
63 daily, seasonal and inter-annual scales (Stenni et al., 2016). In contrast to sites located on the East  
64 Antarctic plateau where the temperature-driven distillation effect is more important than oceanic  
65 source effects on precipitation water isotopic variations (e.g. Touzeau et al., 2016), the climatic

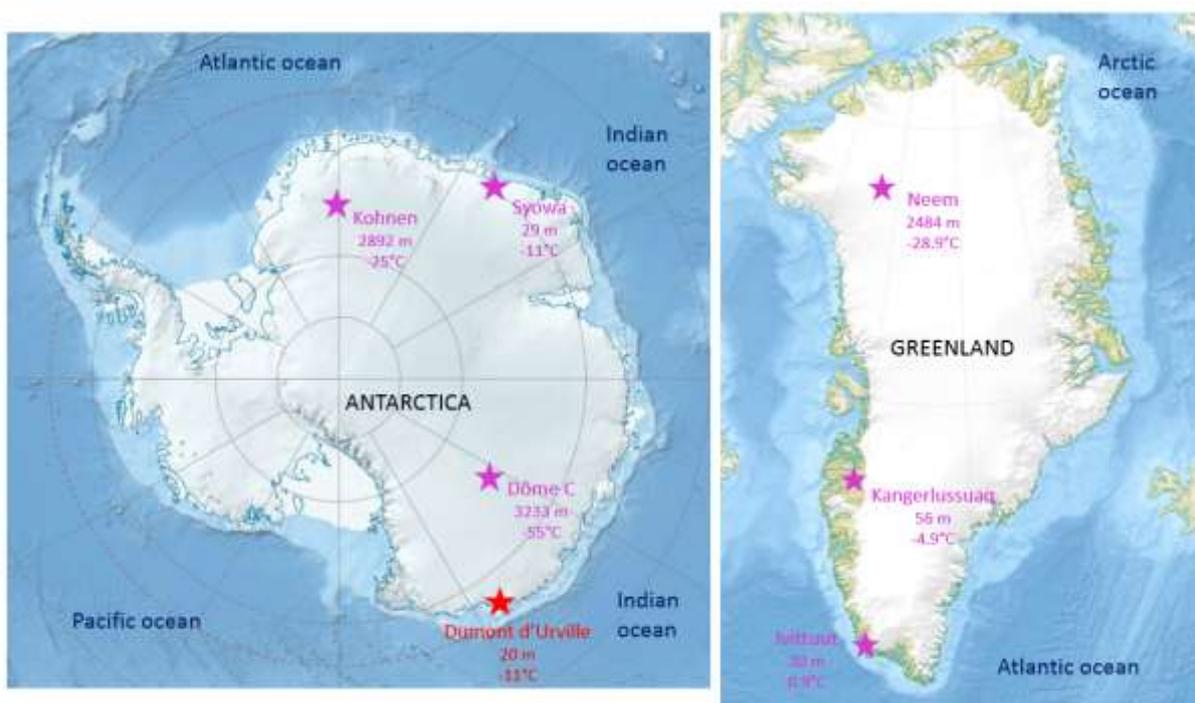
66 interpretation of water isotopic composition in coastal regions is more ambiguous (e.g. Altnau et al.,  
67 2014; Goursaud et al., 2016). Indeed, the influence of the origin of precipitation on water isotopes  
68 composition is probably more important in coastal regions than in the Antarctic plateau (Jouzel et al.,  
69 2013). In addition, in coastal areas characterized by intense winds, deposition effects linked to  
70 sublimation of falling snow and post-deposition effects linked with remobilization of surface snow (e.g.  
71 blowing snow) are expected to alter the snow isotopic composition, hence complicating the climatic  
72 interpretation of the water stable isotope variability (e.g. Landais et al., 2017). Finally, isotopic  
73 composition can be affected by microphysical processes in clouds and precipitation (Moore et al.,  
74 2016) and summer precipitation at DDU can be significantly rimed (Grazioli et al., 2017) which has an  
75 effect on the isotopic composition of precipitation. Recently, one 22.4 m ice core spanning the period  
76 1946-2006 was retrieved 10.24 km far from DDU. Decadal variations in  $\delta^{18}\text{O}$  are parallel to decadal  
77 variations in DDU surface air temperature (Goursaud et al., 2017), but sub-decadal variations remain  
78 unexplained and could arise from variations in moisture origin as well as deposition or post-deposition  
79 “noise”, calling for water isotope measurements in the vapor to decipher the processes at play at the  
80 scale of weather events. Our study thus aims at providing bases for the interpretation of snow and ice  
81 core in Adélie Land in terms of past climate and water cycle dynamic. This is particularly relevant in the  
82 context of the project ASUMA (Improving the Accuracy of the SURface Mass balance of Antarctica, 2014  
83 – 2019) which recently enabled collection of numerous 20 – 40 m snow cores in the coastal Adélie  
84 Land.

85 Recent studies have used continuous monitoring of water stable isotopes in surface water vapour and  
86 surface snow in Antarctica to explore the influences of both atmospheric dynamic and post-deposition  
87 effects on surface snow isotopic composition (Casado et al., 2016; Ritter et al., 2016). These studies  
88 have evidenced patterns of diel variations, and demonstrated that the surface snow isotopic  
89 composition can change in-between precipitation events in parallel with changes in vapour isotopic  
90 composition, itself driven by changes in atmospheric advection patterns, as initially observed above  
91 the Greenland ice sheet (Steen-Larsen et al., 2014). Diel variations in surface vapour isotopic  
92 composition were also reported in summer in polar regions with no snow cover, for instance in  
93 Kangerlussuaq, West Greenland (Kopeck et al., 2014). In this site, the diel variations were attributed to  
94 local boundary layer characteristics involving sea breeze processes. Day to day surface vapour isotopic  
95 variations monitored from a ship were also related to shifts in very local atmospheric circulation  
96 patterns near Syowa, on the East Antarctic coast (e.g. Kurita et al., 2016a; Kurita et al., 2016b).

97 Summarizing, our study is motivated by the need to better understand the drivers of water vapour  
98 isotope variations in Adélie Land for (i) ice core interpretation, (ii) exploring the added value of water  
99 stable isotopes to provide new information on the local atmospheric moisture budget and thus (iii)  
100 improving our knowledge of the present and recent coastal climate and water cycle variations. This is

101 relevant for the regional surface mass balance of the ice sheet as well as for the evaluation of  
102 atmospheric models equipped with water isotopes. We have thus implemented a laser spectroscopy  
103 instrument to measure continuously the isotopic composition of water vapor at DDU during summer  
104 2016-2017, taking advantage of the excellent facilities of the station.

105 This paper is organized as follows. We first report (Section 2) the experimental set up, as well as the  
106 calibration of the isotopic measurements to provide continuous  $\delta^{18}\text{O}$  and d-excess measurements in  
107 the water vapor at DDU during 40 days. The analysis of the calibrated dataset (Section 3) depicts  
108 different periods of measurements based on weather conditions, especially wind regimes, sky  
109 conditions and one snowfall event. The unequivocal isotopic diel cycles in DDU surface water isotopes  
110 are characterized in terms of amplitude and timing (Section 4) and compared with local meteorological  
111 data as well as diel cycles observed in continuous water vapor  $\delta^{18}\text{O}$  time series in other polar regions.  
112 We then summarize our key findings and suggest ways forward (Section 5).

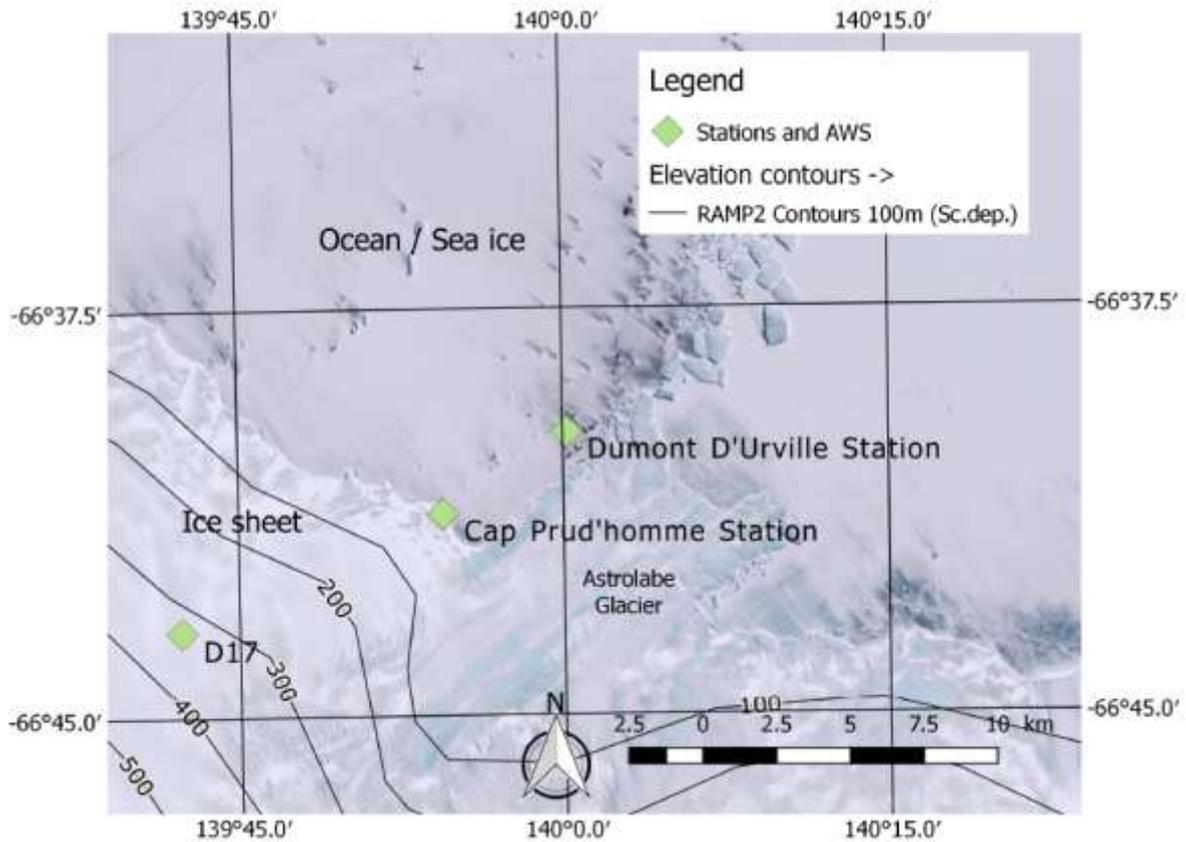


113  
114 *Figure 1: Maps of Antarctica (left) and Greenland (right) showing the location of our study site (red)*  
115 *and the location of other sites where continuous water stable isotope records have provided insights*  
116 *on diel variations (pink). For each site, height and near-surface mean annual temperature are given.*

117  
118 **2. Analytical method**

119 We installed a PICARRO Li-2130 laser spectroscopy in the “Laboratoire 3” shelter, located on  
120 the inland side of DDU station (Figure 2). A 6 m length heated copper tube has been deployed to  
121 continuously sample water vapor at 2 m above the ground. The extremity of the tube was covered by  
122 a Gelman Zefluor 0.5  $\mu\text{m}$  filter to prevent the inflow of precipitation or blowing snow. Continuous

123 measurements of water vapor isotopic composition took place during 40 days from December 26<sup>th</sup>  
124 2016 to February 3<sup>rd</sup> 2017. Except for one electrical shutdown on January 4<sup>th</sup> 2017, the only  
125 interruptions of our monitoring occurred during bi-daily calibrations.

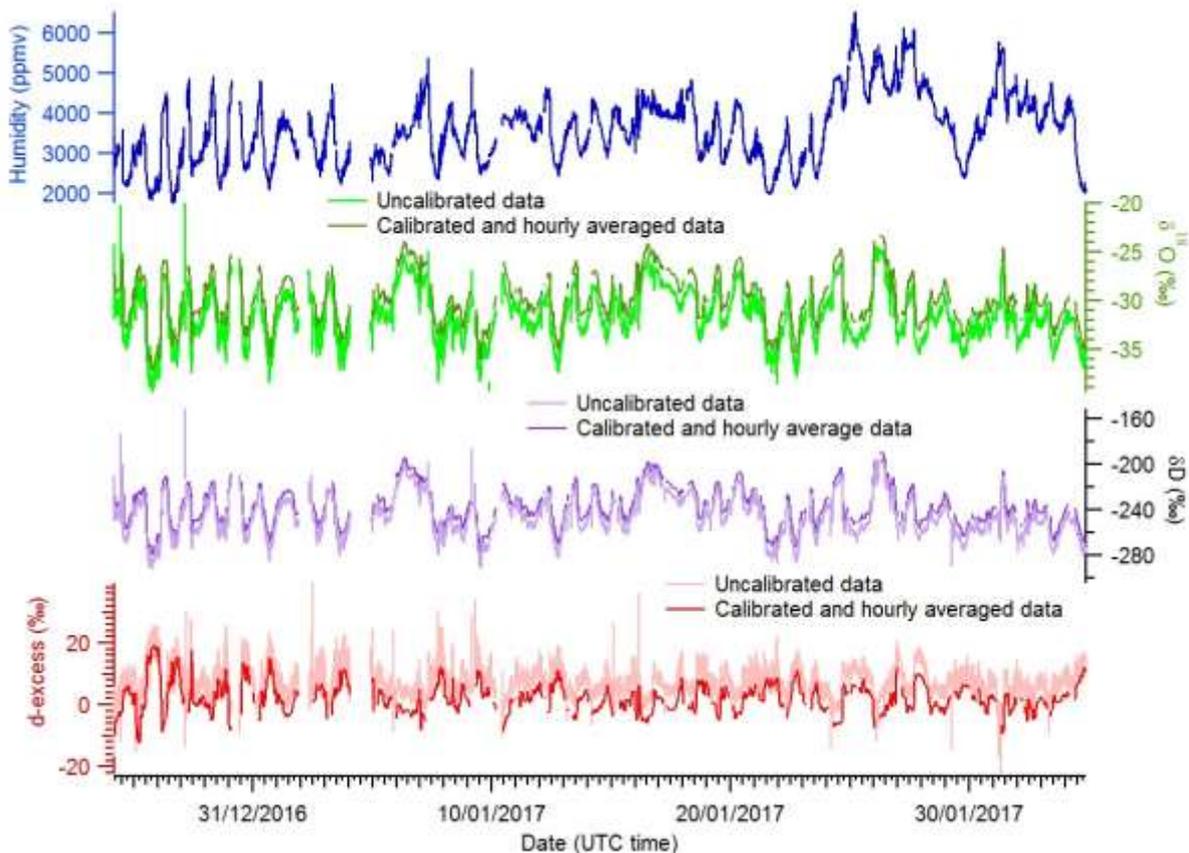


126

127 *Figure 2: Map of DDU station showing the location of the two AWS installed at Cap Prud'homme and*  
128 *D17. Background image is a 15-m resolution Landsat Image Mosaic of Antarctica from the area taken*  
129 *between 1999-2002 (Bindschadler et al., 2008). Elevation lines are extracted from the digital elevation*  
130 *model from Radarsat Antarctic Mapping Project Digital Elevation Model Version 2 (RAMP2, Liu et al.,*  
131 *2001). The map was designed with Quantarctica3*  
132 *([https://www.qgis.org/fr/site/about/case\\_studies/antarctica.html](https://www.qgis.org/fr/site/about/case_studies/antarctica.html)).*

133 During our monitoring period, the volume water vapour mixing ratio (referred to as humidity in the  
134 following) varied between 2000 and 6000 ppmv (or 1.244 to 3.732 g.kg<sup>-1</sup>). The raw  $\delta^{18}\text{O}$  values varied  
135 typically between -23 and -35‰ (Figure 3). The procedure for calibration of the raw data is detailed in  
136 supplementary online material (SOM). Despite problems with the calibration module during the first  
137 weeks after installation (default in the electrical powering of the instrument), we applied as much as  
138 possible the corrections proposed in previous studies as follows (see also SOM). We corrected the raw  
139 laser spectroscopy  $\delta^{18}\text{O}$  measurements for (1) the influence of humidity on  $\delta^{18}\text{O}$  and  $\delta\text{D}$  values, (2)  
140 shifts between measured  $\delta^{18}\text{O}$  ( $\delta\text{D}$ ) and true  $\delta^{18}\text{O}$  ( $\delta\text{D}$ ) values and (3) the temporal drift of the  
141 instrument for  $\delta^{18}\text{O}$  and  $\delta\text{D}$  (Tremoy et al., 2012; Steen-Larsen et al., 2013). The uncertainties on the  
142 isotopic measurements mainly result from scattering of the calibration points as well as missing

143 calibration points during several weeks. The upper limits of uncertainties on the absolute values of  
 144  $\delta^{18}\text{O}$  and d-excess ( $\delta\text{D}-8*\delta^{18}\text{O}$ ) vary respectively between 1‰ and 3.5‰ and between 5‰ and 25‰.  
 145 This uncertainty, mainly linked to unknown drift because of calibration issues during this field season,  
 146 should be applied on the absolute values of  $\delta^{18}\text{O}$  and d-excess but not on their short-term variations  
 147 at the timescale of a few days. In the following sections of this manuscript, we thus do not discuss  
 148 much the absolute values of  $\delta^{18}\text{O}$  and d-excess but rather focus on the short-term (diel) variability.  
 149



150  
 151 *Figure 3: Humidity (blue),  $\delta^{18}\text{O}$  (green),  $\delta\text{D}$  (violet) and d-excess ( $\delta\text{D}-8*\delta^{18}\text{O}$ , red) measured by the*  
 152 *laser spectroscopy instrument at DDU. Raw data (initial resolution of one second but averaged over*  
 153 *one minute here) are shown in light green, light violet and light red for  $\delta^{18}\text{O}$ ,  $\delta\text{D}$  and*  
 154 *d-excess respectively. Calibrated  $\delta^{18}\text{O}$ ,  $\delta\text{D}$  and d-excess data (hourly resolution) are shown in dark*  
 155 *green, dark violet and red, respectively.*

156  
 157 The DDU weather station provides continuous measurements at hourly resolution. Temperature and  
 158 humidity are measured from a Vaisala HMP 110 probe in a standard meteorological shelter, 1.5 m  
 159 above the ground surface. Wind speed and direction are measured on a 10 m tower located a few  
 160 meters from the meteorological shelter. Surface wind directions can be used to separate between  
 161 winds with continental origin and winds with oceanic origins. Jourdain (2001) and Angot et al. (2016)

162 identified oceanic winds at DDU in the range from 270 to 110°, the other winds having a continental  
163 origin.

164 January 2017 is a relatively warm month with a mean monthly air temperature of -0.4°C, compared to  
165 a mean January temperature of -0.9 °C ( $\pm 0.9^\circ\text{C}$ ) over the whole 1957 -2017 record, though not extreme  
166 (a mean air temperature of 1°C was recorded in January 1972 and 2010). In January 2017, the sea ice  
167 extent around DDU is among the three largest summer sea ice extents observed around DDU (with  
168 January 2012 and January 2013) over the last 44 years, as estimated from the Hadley Center Sea Ice  
169 and Sea Surface Temperature data set HadISST.2 (Titchner & Rayner, 2014), comparable to the sea ice  
170 extent observed in January 2012 and 2013. Even though a direct causal link has not been proven with  
171 sea ice extent, we note that the January 2017 Southern Annular Mode index is unusually low, showing  
172 the lowest value since 1993, and the 5<sup>th</sup> lowest value since 1984 (Marshall, 2003).

173 In addition, for this study we used the meteorological data recorded by the automated weather  
174 station (AWS) set up at Cap Prud'homme (66.688°S, 139.907°E, 5 km from Dumont d'Urville on the  
175 continent, 27 m above sea level, Figure 2). The sensor characteristics are listed in Favier et al.  
176 (2011). Quantities were recorded as half-hourly means of measurements performed at 10 s time  
177 intervals. In addition to the temperature, humidity and wind characteristics, this dataset also displays  
178 radiative data (e.g. incoming shortwave and longwave fluxes, outgoing longwave flux).

179 The data obtained at DDU and at Cap Prud'homme are well correlated at the hourly scale over  
180 the whole period of measurements with the same amplitude of the signal (Figure 4). The temperature  
181 and wind speed data from Cap Prud'homme are very useful data for our study because (1) they were  
182 obtained on the continent, in an area more directly influenced by the katabatic winds, and (2) the data  
183 are less affected by buildings on the station as in DDU. Finally, note that the Cap Prud'homme data are  
184 obtained at a highest resolution so that they are often preferred compared to the DDU data.

185

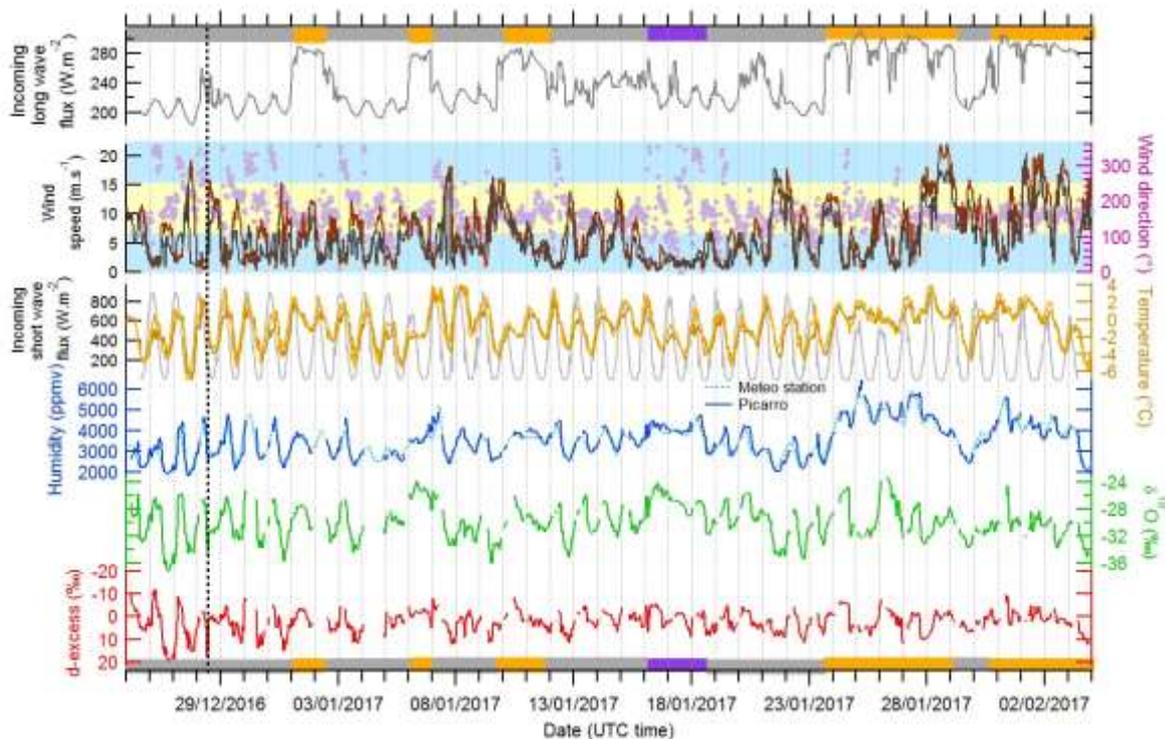
### 186 **3. Results**

187

188 Figure 4 displays our 40-day record of DDU water vapor isotopic composition in parallel with  
189 temperature, humidity, wind speed, wind direction and incoming short- and longwave fluxes, the latter  
190 indicating the cloud coverage. The time series for water vapor isotopic composition are overall well  
191 correlated with humidity and temperature (see Table 1). While we do not comment on the long term  
192 trends of the water isotopic compositions because of calibration issues reported above, we note that  
193 humidity measured with the same instrument and validated by other sensors reaches high levels  
194 (above 5000 ppmv) during the period between January 25<sup>th</sup> and 28<sup>th</sup>, corresponding to the longest

195 snowfall event of the monitoring period. This period is also associated with high incoming longwave  
 196 flux showing radiation as expected under wet and cloudy conditions. Wind speed does not exhibit  
 197 much long term variability (i.e. at the timescale of a few days/weeks) except for a period with almost  
 198 no wind between the 16<sup>th</sup> and the 18<sup>th</sup> of January and periods of strong winds at the end of January /  
 199 beginning of February when cloudy conditions prevail.

200 At shorter timescales, we observe strong diel cycles in  $\delta D$ ,  $\delta^{18}O$ , temperature, humidity, and wind  
 201 characteristics. The diel variations in wind direction are however beyond detectability in the case of  
 202 very low wind speeds (i.e. below  $3 \text{ m}\cdot\text{s}^{-1}$  such as between the 16<sup>th</sup> and the 18<sup>th</sup> of January with also no  
 203 variation in the other climatic variables in this case confirming that the absence of signal in the wind  
 204 direction is a physical signal). The most reliable wind direction is the one measured when wind speed  
 205 is larger than  $5 \text{ m}\cdot\text{s}^{-1}$ : in this case, wind has a continental origin and displays katabatic characteristics  
 206 (SOM). The northward wind direction with relatively weak wind is less reliable. Diel cycles of  $\delta^{18}O$ ,  
 207 temperature, humidity, wind speed and d-excess are visible almost over the whole period. We  
 208 nevertheless observe a strong variability on the amplitude of the different cycles. As examples,  
 209 maximal (minimal) amplitudes of diel cycles in  $\delta^{18}O$ , temperature and humidity are respectively  $11.5\text{‰}$   
 210 ( $0.9\text{‰}$ ),  $8^{\circ}\text{C}$  ( $1^{\circ}\text{C}$ ),  $2640 \text{ ppmv}$  ( $280 \text{ ppmv}$ ).



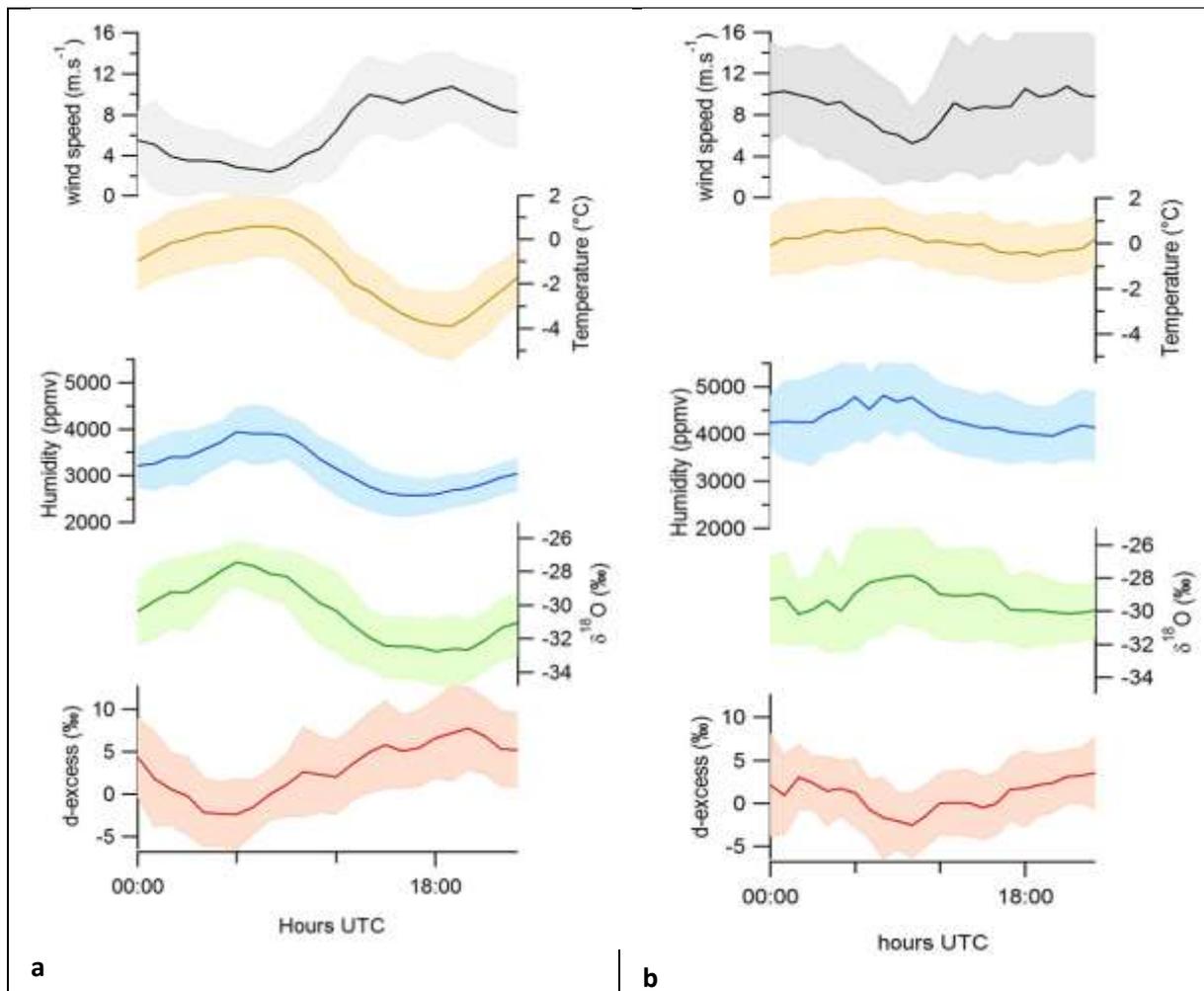
211  
 212 *Figure 4: Evolution of incoming long wave flux (used here to differentiate cloudy from clear sky*  
 213 *conditions), wind strength (bordeaux), wind direction (purple dots) and temperature (orange) from the*  
 214 *Cap Prud'homme automatic weather station. Evolution of temperature (light orange), wind speed*  
 215 *(black) and humidity from DDU meteorological station together with the evolution of humidity,  $\delta^{18}O$*

216 *and d-excess (inverted axis) from DDU Picarro instrument. In the second upper panel, the horizontal*  
217 *blue and yellow bands stand for the range of direction winds originating from the ocean or from the*  
218 *continent respectively. The grey, orange and violet rectangles indicate the periods with different*  
219 *weather conditions (clear sky, cloudy, no wind). The snowy period (25<sup>th</sup> to 28<sup>th</sup> of January 2017) is*  
220 *included in the cloudy periods. The dashed vertical line corresponds to a specific event discussed in*  
221 *section 4.*

222

223 We have clustered our measurements based on the weather conditions in periods with clear sky (grey  
224 on Figure 4), cloudy conditions (orange on Figure 4) and no wind conditions (violet on Figure 4,  
225 corresponding to days without katabatic wind occurrence even during the night). During the period  
226 without wind, only a small diel cycle is observed in the temperature record but no clear diel cycles are  
227 observed in the humidity and  $\delta^{18}\text{O}$  records. During the clear sky periods, clear diel cycles are observed  
228 in temperature (mean amplitude of 4.5°C), humidity (mean amplitude of 1300 ppmv),  $\delta^{18}\text{O}$  (mean  
229 amplitude of 5.4 ‰), d-excess (mean amplitude of 10 ‰) and wind speed (mean amplitude of 7 m.s<sup>-1</sup>)  
230 (Figure 5a). In most cases, there are significant correlations (Table 1) between temperature, humidity  
231 and  $\delta^{18}\text{O}$  while both d-excess and wind speed are significantly anti-correlated with these 3 parameters.  
232 However, the correlation between  $\delta^{18}\text{O}$  and near surface temperature diel cycles is surprisingly low  
233 ( $R^2=0.24$ ), given the relationship between temperature, atmospheric distillation and isotopic depletion  
234 leading to a strong correlation ( $R^2=0.9$ ) on the Antarctic plateau between near surface temperature  
235 and  $\delta^{18}\text{O}$  of precipitation or surface snow along transects (Touzeau, et al., 2016; Stenni et al., 2016;  
236 Masson-Delmotte et al., 2008). When extracting the typical average diel cycles for the 5 parameters  
237 mentioned above (Figure 5a), we do not observe significant temporal shift between the maxima /  
238 minima in each record: temperature maximum is synchronous with minimum in wind speed, maximum  
239 in  $\delta^{18}\text{O}$ , maximum in humidity and minimum in d-excess. During the cloudy periods, diel cycles are less  
240 marked and the (anti-)correlations between the different parameters are much less clear (Figure 5b).  
241 In this case, we note a correlation between temperature and humidity as well as an anti-correlation  
242 between  $\delta^{18}\text{O}$  and d-excess.

243



244

245 *Figure 5: Average diel cycles of wind speed, temperature, humidity,  $\delta^{18}O$  and d-excess during periods*  
 246 *with clear sky conditions (a) and cloudy conditions (b) (see Figure 4 for identification of these time*  
 247 *periods). The hourly data for the two different periods were averaged to produce the respective mean*  
 248 *diel cycles. The envelopes in light colors were obtained from the standard deviation of the data obtained*  
 249 *over the different days within each period. The time zone at DDU is UTC+ 10.*

250

251

Periods Variables	Clear Sky	Cloudy
d-excess vs temperature	0.18 (-6 ‰.K <sup>-1</sup> )	0.01
humidity vs temperature	0.49 (221 ppmv.K <sup>-1</sup> )	0.32
$\delta^{18}\text{O}$ vs temperature	0.24 (0.39 ‰.K <sup>-1</sup> )	0.11
d-excess vs $\delta^{18}\text{O}$	0.73 (-0.42)	0.56
$\delta^{18}\text{O}$ vs humidity	0.73 (0.003 ‰.ppmv <sup>-1</sup> )	< 0.01
d-excess vs humidity	0.51 (-0.42 ‰.ppmv <sup>-1</sup> )	< 0.01
Wind speed vs temperature	0.27 (1.1 m.s <sup>-1</sup> .K <sup>-1</sup> )	0.05
Humidity vs wind speed	0.36 (-244 ppmv.s.m <sup>-1</sup> )	0.09
$\delta^{18}\text{O}$ vs wind speed	0.36 (-0.34 ‰.s.m <sup>-1</sup> )	0.11
d-excess vs wind speed	0.11 (-0.42 ‰.s.m <sup>-1</sup> )	< 0.01

252

253 *Table 1: Correlation coefficients ( $R^2$ ) between different climatic and/or isotopic parameters during the*  
254 *clear sky and cloudy periods at DDU based on hourly data (N=505 for clear sky periods; N=289 for cloudy*  
255 *periods). The slope between the two parameters is also reported within brackets for clear sky conditions*  
256 *when correlation and anti-correlation coefficients are at the highest. Note that although wind speed*  
257 *and d-excess appear correlated on figure 5b on an average diel cycle, this is not the case when taking*  
258 *all the individual data from the cloudy period.*

259

## 260 4. Discussion

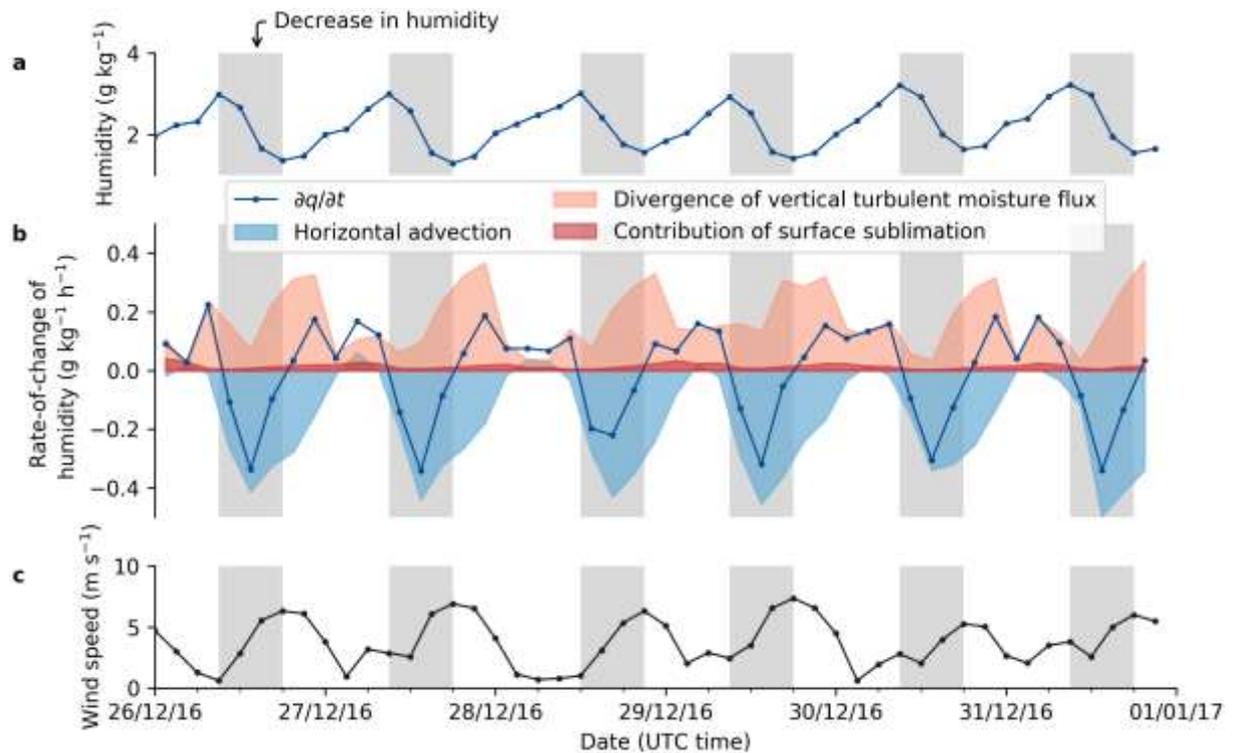
### 261 4-1- Drivers of the diel variations of the isotopic composition

262 The relatively low correlation between temperature and  $\delta^{18}\text{O}$  even during the clear sky conditions rules  
263 out local air temperature as the main driver of vapor  $\delta^{18}\text{O}$  diel variations. The correlation is much  
264 stronger between  $\delta^{18}\text{O}$  and humidity variations for clear sky conditions ( $R^2=0.73$ , N=505). Two  
265 explanations can be proposed for driving these common variations at this stage: snow sublimation  
266 from the surface and advection and mixing in the atmosphere. In order to decipher these effects, we  
267 performed a comparison with outputs from the Modèle Atmosphérique Régional MAR (v3.6.4) forced  
268 by ERA-Interim over the Antarctic ice sheet at a 35 km horizontal resolution for the period of  
269 measurements (Agosta et al., 2019 extended to the years 2016 and 2017 for this study). A comparison

270 of the temperature, wind speed and humidity measurements with the corresponding series obtained  
 271 by the model in the grid cell containing DDU (SOM) shows that this model is adapted to study the  
 272 atmospheric dynamic at the diel scale in this site, and particularly the variations of humidity (SOM).  
 273 The model enables us to disentangle the relative contribution of the local source of humidity from  
 274 surface sublimation (surface turbulent moisture flux) to the variations of humidity related to horizontal  
 275 air advection and the vertical turbulent moisture flux (mixing) according to the continuity equation  
 276 applied to the water vapor in the atmospheric boundary layer (Garratt, 1994, equation 4):

277 
$$\frac{\partial q}{\partial t} = -\mathbf{u} \cdot \nabla q - \nabla \cdot \mathbf{E}$$
 equation (1)

278 where  $\frac{\partial q}{\partial t}$  is the rate of change of specific humidity  $q$  ( $\text{kg kg}^{-1} \text{s}^{-1}$ ) over time  $t$  (s),  $-\mathbf{u} \cdot \nabla q$  is the  
 279 advection of water vapor by the wind  $\mathbf{u}$  ( $\text{m s}^{-1}$ ), and  $-\nabla \cdot \mathbf{E}$  is the divergence of the turbulent  
 280 moisture flux  $\mathbf{E}$  ( $\text{kg kg}^{-1} \text{m s}^{-1}$ ). We neglect source and sink of humidity by condensation and sublimation  
 281 in the atmosphere, as we focus on clear sky days when the atmosphere is undersaturated and blowing  
 282 snow absent (see below). The advection term is dominated by the horizontal component, whereas the  
 283 divergence of the turbulent moisture flux is dominated by the vertical component. Fig. 6 shows that  
 284 the decrease in humidity is driven by the horizontal advection of dry continental air during the night,  
 285 when the katabatic wind forms and strengthens, while the vertical turbulent mixing with the upper  
 286 atmosphere drives the increase in humidity. The contribution of surface sublimation to the increase  
 287 in humidity is one order of magnitude lower than the contribution of upper air mixing.



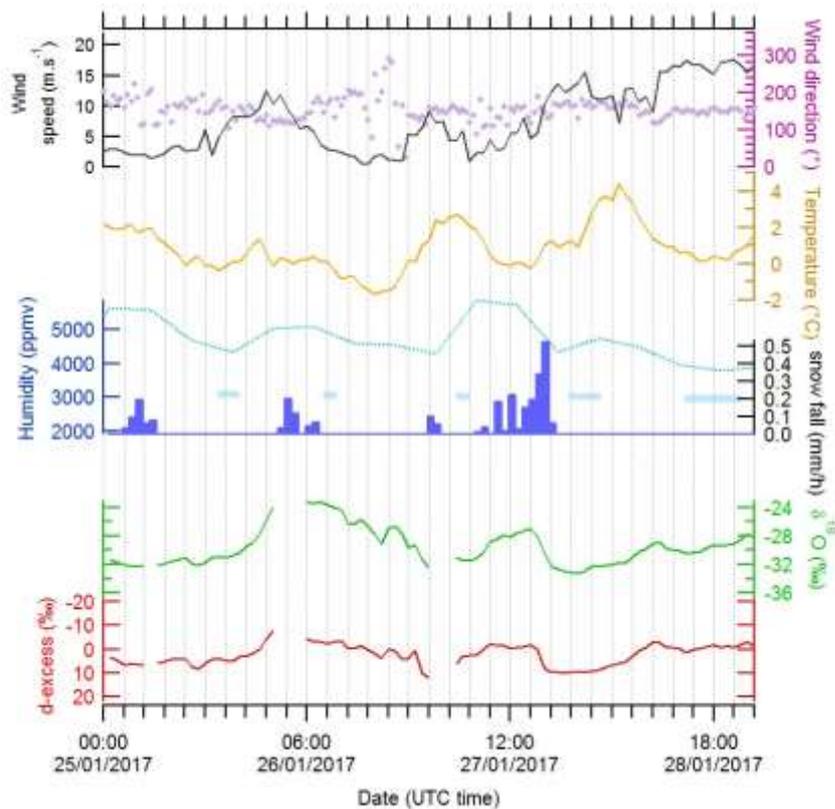
288

289 **Figure 6:** (a) Humidity, (b) rate-of-change of humidity (blue line), and (c) wind speed in MAR surface  
290 atmospheric layer (0-2 m) during clear sky days, in average for 3 h time steps. In (b), the contributions  
291 to the rate of change of humidity are displayed in plain color : the horizontal advection in light blue and  
292 the divergence of vertical turbulent moisture flux in light red (first and second terms of the right hand  
293 side of equation 1). The contribution of surface sublimation to the rate-of-change of humidity, which is  
294 a component of the divergence of vertical turbulent moisture flux, is shaded in red. Grey bands show  
295 periods when humidity decreases (negative rate of change of humidity in panel b).

296

297 The proposed mechanism linking wind speed, humidity and water isotopic composition at the diel scale  
298 at DDU is the following. The continental temperature above DDU region exhibits a diel cycle linked to  
299 the decrease of incoming shortwave between 6:00 UTC and 18:00 UTC (Figure 5a). During this period,  
300 the radiative cooling at the surface of continental slopes induces the establishment of a strong  
301 katabatic flow that advects dry and cold air from the continent to the coastal region. The water vapor  
302 advected by these strong continental winds is characterized by low  $\delta^{18}\text{O}$  and high d-excess since  
303 surface snow  $\delta^{18}\text{O}$  has been shown to decrease and d-excess to increase from the coast to inland  
304 Antarctica (e.g. Masson-Delmotte et al., 2008; Touzeau et al., 2016). We thus propose that katabatic  
305 dynamics around DDU has a key role in driving diel cycles. This is particularly true during clear sky  
306 summer conditions when the radiative cooling is the strongest.

307 During cloudy period, diel temperature variations are muted (Figure 5b). The wind speed cycles are  
308 also less systematic over this period with days associated with relatively strong wind (e.g. beginning of  
309 February). During the arrival of a low pressure system at DDU (as observed between the 25th and the  
310 28th of January), higher wind speed is correlated with higher humidity (and with  $\delta^{18}\text{O}$  to a lesser extent)  
311 and with the occurrence of precipitation events (Figure 7). This can be interpreted as a significant  
312 proportion of marine air entering in the system. Sublimation during precipitation events may also  
313 contribute to explain the increase in  $\delta^{18}\text{O}$  since the few maxima in  $\delta^{18}\text{O}$  occur in most cases during  
314 precipitation events or the presence of virga. The time series is however too short to enable a firm  
315 conclusion based on a robust statistical approach. During this period, the anti-correlation between  
316  $\delta^{18}\text{O}$  and d-excess is preserved, as also observed during cloudy and clear sky conditions. Only with very  
317 weak surface winds (lower than  $3 \text{ m}\cdot\text{s}^{-1}$ ) does the anti-correlation between  $\delta^{18}\text{O}$  and d-excess at the  
318 diel scale disappear.



319  
 320 **Figure 7:** Focus on the DDU weather and water isotopic data over the snow period. The wind direction,  
 321 wind speed, temperature and humidity data are from the DDU weather station. The hourly snowfall  
 322 rate and the presence of virga (horizontal light blue bars on the middle panel) are from Durán-Alarcón  
 323 et al. (2018).

324  
 325 Evolution of isotopic composition in this region may also arise from other processes, such as the  
 326 influence of sublimation of blowing snow not taken into account in the MAR version of the model used  
 327 here. Indeed, Barral et al. (2014) showed that sublimation of blowing snow affects vertical humidity  
 328 profiles in Adélie land. Barral et al. (2014) evidenced a correlation between relative humidity of the  
 329 low level of the atmosphere and katabatic wind speed at the windy plateau station D17. This is  
 330 interpreted as an increase in sublimation of blowing snow during strong wind conditions. At DDU, the  
 331 situation is however different. First, using our temperature and humidity records to calculate relative  
 332 humidity, we show that the atmosphere is always undersaturated at DDU, except during snowfall  
 333 events. Second, under clear sky conditions, diel cycles of relative humidity are anti-correlated with  
 334 wind speed at DDU (similarly to the anti-correlation between specific humidity and wind speed  
 335 observed in Figure 5a) in contrast with the positive correlation observed by Barral et al. (2014) at D17.  
 336 Third, if sublimation of local blowing snow was a large source of surface vapor, then one would expect  
 337 to observe a parallel increase of surface vapor  $\delta^{18}\text{O}$  as snow is enriched in heavier isotopes compared  
 338 to water vapor. In contrast, we observe an anti-correlation between  $\delta^{18}\text{O}$  and wind speed (Figure 5a).

339 Finally, a comparison with the D3 (~ 1 km from Cap Prud'homme) and D17 (cf Figure 2) data for blowing  
340 snow (not available at DDU) shows that the flux of blowing snow is strong only at the end of the  
341 measurement period, beginning of February when the  $\delta^{18}\text{O}$  values are not higher than for the rest of  
342 the period. Based on these lines of evidence, we conclude that diel variations in atmospheric dynamics  
343 and associated variations in transport of air masses from the plateau to the coast are better candidates  
344 to explain the  $\delta^{18}\text{O}$  and d-excess diel cycles than diel variations in the sublimation of blowing snow at  
345 DDU. This may contrast with the situation on a coastal plateau station such as D17.

346

#### 347 **4-2- Comparison between DDU diel cycles and diel cycles at other polar locations**

348 We now compare the occurrence, amplitude and characteristics of diel cycles in DDU isotopic records  
349 with other available records from polar regions. We explore whether there are systematic links  
350 between the characteristics of diel cycles in surface water vapor  $\delta^{18}\text{O}$  and those in meteorological  
351 variables, as well as the relationships between diel isotopic cycles and geographic characteristics such  
352 as the distance to the open sea. Table 2 summarizes the characteristics of diel cycles observed in all  
353 available water vapor isotopic datasets to the authors' knowledge from Greenland and Antarctica.  
354 These records encompass summer seasons, most of them with documented snowfall events. At each  
355 site, diel cycles of temperature and humidity are identified most of the time. We thus calculated a  
356 characteristic diel cycle at each site through an average over a period of 5-7 consecutive days with  
357 unequivocal diel cycles of average amplitude. The smallest amplitudes of temperature diel cycles are  
358 observed in coastal regions of Antarctica (DDU and Syowa) as expected from the oceanic influence.  
359 Indeed, in coastal regions, the proximity of water is often associated with more cloudiness. In addition,  
360 the proximity of the ocean increases the proportion of latent heat flux and decreases the proportion  
361 of sensible heat flux with immediate consequences for the air temperature. The smallest amplitudes  
362 of the water vapor  $\delta^{18}\text{O}$  and d-excess diel cycles are also observed at some coastal stations (Syowa,  
363 Ivittut). Inland Antarctica,  $\delta^{18}\text{O}$  diel cycles display amplitudes larger than 4.5‰; diel temperature  
364 variations are also large (larger than 8°C). There is however no systematic correspondence between  
365 the amplitude of the temperature diel cycle and the amplitude of the  $\delta^{18}\text{O}$  diel cycle. This is particularly  
366 remarkable at DDU, where we observe a relatively small amplitude of temperature diel cycles  
367 (comparable to the other coastal stations in Antarctica), but an unusually large amplitude of the  $\delta^{18}\text{O}$   
368 diel variations (5.40 ‰ against 2.23 and 1.36 ‰ at the coastal locations of Syowa and Ivittut). The  
369 relatively strong  $\delta^{18}\text{O}$  diel variations observed at the coastal DDU station is in fact rather comparable  
370 to the one observed in the coastal station of Kangerlussuaq in summer 2011 (amplitude of  $\delta^{18}\text{O}$  diel  
371 cycle of 3.51 ‰ to be compared to 1.36 ‰ at the Greenland coastal station of Ivittut). This pattern  
372 was attributed to the alternation between sea breeze and katabatic winds (Kopeck et al., 2014).

		Dôme C <sup>a</sup>	Kohnen Station <sup>b</sup>	NEEM <sup>c</sup>	Ivittuut <sup>d</sup>	Syowa <sup>e</sup>	Kangerlussuaq <sup>f</sup>	DDU <sup>g</sup>
Temperature (°C)	Average value	-30.8	-23.4	-10.3	9.5	-1.9	10.0	<b>-0.5</b>
	Diel cycle amplitude	11.1	8.7	9.7	7.6	3.2	10.3	<b>4.5</b>
Humidity (ppmv)	Average value	600	1200	3100	11100	3900	7400	<b>3200</b>
	Diel cycle amplitude	500	1000	2100	1900	600	2200	<b>1300</b>
$\delta^{18}\text{O}$ (‰)	Average value	-68.94	-54.74	-43.83	-18.88	-28.12	-30.50	<b>-30.37</b>
	Diel cycle amplitude	6.48	4.87	3.01	1.36	2.23	3.51	<b>5.40</b>
d-excess (‰)	Average value	58	30	37	9	15	14	<b>3</b>
	Diel cycle amplitude	22	11	4	7	8	11	<b>10</b>
Period used for cycles characterization (days)		04/01/15 to 11/01/15	20/12/13 to 27/12/13	01/07/10 to 08/07/10	13/07/12 to 20/07/12	28/01/14 to 04/02/14	08/08/11 to 15/08/11	<b>Clear sky periods of this study</b>
Period of measurements (days)		25/12/14 to 17/01/15	17/12/13 to 01/01/14	24/05/10 to 29/07/10	01/07/12 to 31/07/12	20/01/14 to 09/02/14	21/07/11 to 15/08/11	<b>25/12/16 to 03/02/17</b>
Height of measurements (m)		2	0.2 – 3	0.1 – 1.5	5	1	1	<b>2</b>
Strong snowy period (days)		Not documented	19/12/12, 03/01/13, 07/01/13 and 17/01/13	28/06/10	Not documented	17/01/15 to 19/01/15	Not documented	<b>25/01/17 to 28/01/17</b>

374 Table 2: Comparison of the diurnal evolutions of the climatic (temperature, humidity) and isotopic ( $\delta^{18}\text{O}$ , d-excess) parameters for different polar sites where  
375 isotopic composition of water vapor is available. <sup>[a]</sup>Casado et al., 2016; <sup>[b]</sup>Ritter et al., 2016; <sup>[c]</sup>Steen-Larsen et al., 2011; Steen-Larsen et al., 2013; <sup>[d]</sup>Bonne et  
376 al., 2014; <sup>[e]</sup>Kurita et al., 2016a, Kurita et al., 2016b; <sup>[f]</sup>Kopec et al., 2014; <sup>[g]</sup> This study

377

378 At all sites exhibiting a diel cycle, the warmest hours are also associated with the highest humidity level  
379 and the highest  $\delta^{18}\text{O}$  values. The link with wind speed is less systematic: higher wind speeds are  
380 observed during the warmest hours at Dome C, but during the coldest hours at DDU. A significant  
381 correlation is identified between  $\delta^{18}\text{O}$  and temperature diel variations at most polar sites (DDU,  
382 Kohnen, Dome C, Ivittuut, Kangerlussuaq, NEEM), and for intra-seasonal variations in the absence of  
383 strong snow events at NEEM and Ivittuut, Greenland. At the diurnal scale, the  $\delta^{18}\text{O}$  vs temperature  
384 slope is lower for continental sites ( $\sim 0.6 \text{ ‰}\cdot\text{°C}^{-1}$  on average) than for coastal sites where isotopic  
385 diurnal cycles are clearly visible (i.e. Kangerlussuaq and DDU,  $1.2 \text{ ‰}\cdot\text{°C}^{-1}$  on average). This confirms  
386 the similarities of the diel cycles identified in the short records available at Kangerlussuaq (25 days)  
387 and DDU (40 days), and motivates a detailed analysis of the water vapor isotopic variations on the two  
388 sites. We note that both records are hampered by calibration issues. No calibration of the isotopic data  
389 is presented for the Kangerlussuaq record, and we have reported the problems encountered with the  
390 standard delivery module at DDU and the resulting uncertainties.

391 The meteorological characteristics encountered during boreal summer 2011 in Kangerlussuaq and  
392 austral summer 2016-2017 in DDU reveals some similarities. Both exhibit a rather large amplitude of  
393 summer diel cycle for water vapor  $\delta^{18}\text{O}$  in link with wind speed cycles. These two locations are affected  
394 by katabatic winds, stronger at DDU than at Kangerlussuaq (between 2 and 7  $\text{m}\cdot\text{s}^{-1}$  at Kangerlussuaq in  
395 Kopec et al. (2014), and between 0 and 20  $\text{m}\cdot\text{s}^{-1}$  at DDU in this study). Despite these similarities, local  
396 summer humidity levels are much lower at DDU than at Kangerlussuaq. This difference is first due to  
397 lower mean temperature at DDU. In addition, Kangerlussuaq is located in an alluvial flatland, near the  
398 confluence of two major regional rivers originating from the Russell Glacier, and its peak precipitation  
399 usually occurs in July-August. In summer 2016-2017, the presence of sea ice up to a distance of 70 km  
400 from DDU probably also contributed to our low humidity levels.

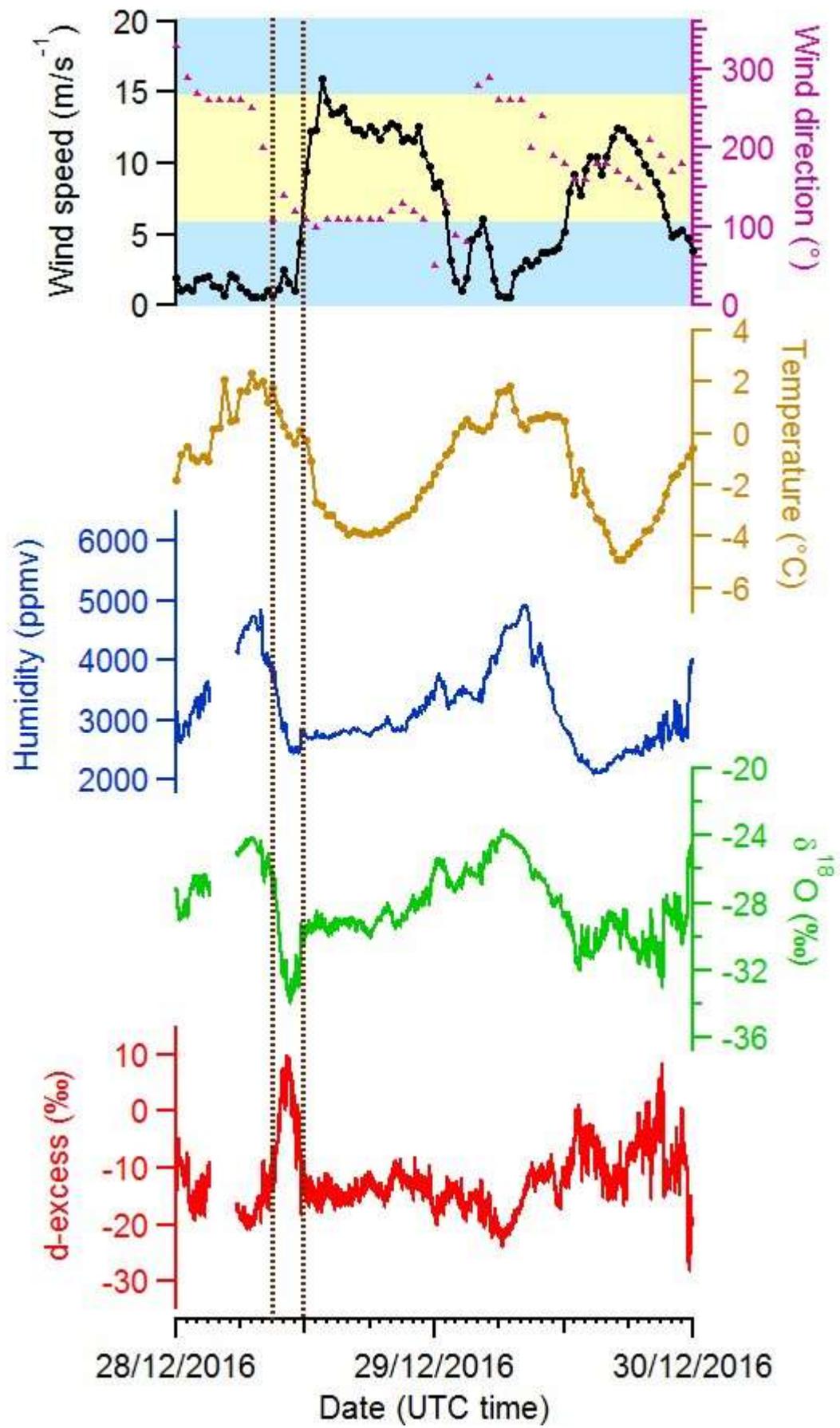
401 At Kangerlussuaq, the  $\delta^{18}\text{O}$  and d-excess diel variations are explained by shifts in moisture origin, linked  
402 to local wind directions (Kopec et al., 2014). At night, continental winds bring relatively dry air with  
403 low  $\delta^{18}\text{O}$  (high d-excess) of water vapor from the continent to the coastal station in the atmospheric  
404 boundary layer. During the day, due to increasing coastal land surface temperature, a sea breeze  
405 phenomenon occurs, bringing air masses with higher humidity levels of oceanic origin associated with  
406 high  $\delta^{18}\text{O}$  (low d-excess). At DDU, we could not identify such a sea breeze phenomenon during summer  
407 2016-2017 based on the wind data from DDU and the neighboring weather stations (Cap Prud'homme,  
408 D3, D17). The diel cycles may thus rather be triggered by variations in the intensity of continental  
409 winds, themselves related to diel temperature variations over the continent. The occurrence of a  
410 summer sea breeze phenomenon was clearly observed at DDU in earlier years (Pettré et al., 1993;

411 Jourdain, 2001; Angot et al., 2016). It may have been prevented by the particularly large sea ice extent  
412 during January 2017.

413

#### 414 **4-3- Sharp intra-daily isotopic variations and added value of water isotopes measurements**

415 Finally, the fact that the impact of katabatic winds is also obvious in diel cycles of humidity and  
416 temperature questions the added value of measuring the isotopic composition of water vapor in  
417 addition to measurements of humidity only for the study of water cycle organization. Still, our record  
418 permits to identify at least one case in which continuous measurements of  $\delta^{18}\text{O}$  and d-excess in the  
419 water vapor reveal an event not captured in the temperature and humidity series. We focus on a  
420 particular rapid event which occurred on December 28<sup>th</sup>, with a 3h sharp negative peak of  $\delta^{18}\text{O}$  of 8.5  
421 ‰ (with  $\delta^{18}\text{O}$  values reaching -34 ‰), close to the amplitude of the average diel cycle (Figure 8). The  
422 associated d-excess increase is very strong and reaches 26 ‰, i.e. more than twice larger than the  
423 amplitude of the diel cycle during clear sky conditions. While the beginning of this remarkable isotopic  
424 excursion (decrease in  $\delta^{18}\text{O}$  and increase in d-excess) corresponds to a decrease in humidity, hence  
425 probably an increase of arrival of dry air from the continent, the d-excess abrupt decrease and  $\delta^{18}\text{O}$   
426 abrupt increase 3 h later are in phase with abrupt change in the wind strength. This particular event  
427 shows the potential of water isotopes measurements to bring an added value on our knowledge of the  
428 atmospheric dynamics. It also shows that the atmospheric dynamics and associated wind  
429 characteristics should be considered for further interpretation of the water isotopic records in ice cores  
430 from coastal Adélie Land.



432 *Figure 8: Focus on a peak of  $\delta^{18}\text{O}$  and d-excess (vertical dashed brown lines) on the 28<sup>th</sup> of December*  
433 *2016. Wind strength and temperature data are from Cap Prud'homme to have a better temporal*  
434 *resolution (30 minutes)*  
435

## 436 **5. Conclusion and perspectives**

437 We presented the first water vapor isotopic record at the coastal station DDU in Adélie Land, a region  
438 strongly influenced by katabatic winds. During a 40-day measurement period, we evidenced clear and  
439 strong diel cycles especially during clear sky conditions. They can be explained by the occurrence of  
440 strong katabatic winds when continental temperature is low. During the coldest hours of the day,  
441 continental gravity winds increase downslope leading to enhanced arrival of low  $\delta^{18}\text{O}$  and high d-  
442 excess in the water vapor at DDU. The comparison with available water vapor records in other polar  
443 sites supports close links between katabatic wind regimes and isotopic diel variations. Indeed, while  
444 diel cycles are not clearly seen in the water vapor isotopic composition of polar coastal sites of Ivittuut  
445 and Syowa, strong isotopic diel cycles are observed in the water vapor of the windiest coastal sites  
446 affected by diel variations of katabatic wind speed (Kangerlussuaq and DDU).

447 Since our water vapor isotopic record is longer at DDU than the one recorded at Kangerlussuaq, we  
448 are also able to highlight the added value of water isotopes with respect to humidity record for the  
449 study of water cycle in Adélie Land. In particular, short ( $\sim 3$  hours) peaks in  $\delta^{18}\text{O}$  and d-excess as  
450 captured in our record correspond to abrupt changes in wind strength. This confirms that  $\delta^{18}\text{O}$  of water  
451 vapor in coastal regions affected by katabatic winds is much more sensitive to air mass origins than  
452 e.g. to temperature or humidity. This finding has the potential to influence the interpretation of coastal  
453 ice core records in these regions (Goursaud et al., 2017).

454 The insights from our field campaign may not be fully representative of average conditions at DDU.  
455 One of the limits of our study is that sea ice did not break down at DDU during the 2016-2017 summer  
456 season, a rare but not unusual situation which very probably affected DDU weather conditions,  
457 including surface water vapor and its isotopic composition. Convection can also occur over an ocean  
458 free of ice leading to non-local mixing with the atmosphere above the boundary layer potentially  
459 affecting the isotopic composition. Obtaining longer records, including winter periods, is important to  
460 encompass a larger range of weather and climate conditions to further inform the interpretation of  
461 the isotopic records in Adélie Land.

462

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