

The paper addresses a significant logistical and scientific challenge in Antarctic climate research: the manual sampling of precipitation for stable water isotope analysis.

Traditional manual sampling presents logistic challenges and exposes samples to post-depositional effects (mainly sublimation and metamorphism) prior to collection, which can alter the snow pristine isotopic values. To overcome this, the authors present an autonomous method for the continuous and combined measurement of both water vapor and precipitation δD using a single laser spectrometer.

The aim is to provide high-temporal-resolution data to better understand the Antarctic atmospheric water cycle, evaluate general circulation models, and improve the interpretation of past climate signals in ice cores.

We thank the reviewer very much for this constructive assessment and for the pertinent questions that helped improve the manuscript. The answers are inserted in red and citations from the manuscript are indicated in blue.

Specific comments

Line 21 (Abstract) I would not use the term “condensed water” here

1) Thank you for this remark, we changed the expression by: “capable of analysing very small water contents”

Line 30 (Abstract) Is it LMDZ6iso or LMDZ6-iso (with the hyphen) as in other parts of the manuscript? I think it is LMDZ6iso

2) Thank you, we changed all occurrences by LMDZ6iso

Line 52-53 change “Adding the water isotopes in the models permits to test and improve the representation of the atmospheric water cycle in the models” with “Adding water isotopes to the models allows for the testing and improvement of the representation of the atmospheric water cycle”

3) Thank you for the suggestion, we modified the text accordingly.

Line 78 Change “weird” with “anomalous”

4) This is corrected

Line 111-116 How do you differentiate between snowflakes and water vapor signal when using the “snowflake inlet”?

5) Thank you for this important question. The differentiation between measurements obtained from the “snowflake inlet” and the “water vapor inlet” is ensured through a dedicated log file that records the valve position continuously to identify precisely the timing of each inlet switch.

However, we would really like to clarify that it is not possible to distinguish between signals originating from snowflakes and those from water vapor when using the “snowflake inlet” alone. The measured signal in this configuration inherently includes both contributions whenever snowflakes

enter the inlet. We clarified this in the text: “The second inlet (“snowflake inlet”) is oriented upward with a small aperture (1/8”) to allow snowflakes collection in addition to water vapor.”

To isolate the snowflake contribution, we rely on an alternating measurement strategy between the water vapor inlet and the snowflake inlet. The “water vapor inlet” measurements are used to estimate the background vapor signal, which is then subtracted from the “snowflake inlet” measurements as described in section 2.5.

Figure 1 I see that the snow sampling tray is attached to a wood platform, which is higher than the tray itself, plus the sampler is very close to a blue shelter; don’t you think this could heavily interfere with the snow precipitation sampling?

The wind vane, which I suppose turns in line with wind direction, is also placed close to a building which shields the wind (and snow) from that direction

6) Thank you for this important remark. We acknowledge that the snow sampling setup is not ideal and may be influenced by shielding effects from the surrounding buildings. The positioning of both the sampling tray and the wind sock was primarily chosen according to the dominant wind direction, see new Table 1 in section 2.1, to indeed limit the influence of the nearby buildings. For logistical considerations, in particular the need to ensure safe and practical access for winterover personnel during harsh winter conditions, it was important to place the tray and the wind sock close to the buildings and access path. Moreover, the sampling tray is primarily designed to collect vertically falling snow, for which the influence of the nearby shelter is expected to be limited.

Yet, we recognize that shielding and some influence of local airflow disturbances cannot be fully excluded and represents a limitation of the current setup. We add this sentence in section 2.2: “The collection device location was constrained by logistical requirements (easy winter access) but oriented toward the dominant wind direction, minimizing potential shielding by nearby buildings.”

Line 181 The time of the plots seems to go between 15:30 and 16:30, more than between 15:00 and 18:30 UTC

7) Thank you, the text was modified accordingly

Line 186 Change “In the example shown on Figure 2” with “In the example shown IN Figure 2”

8) Thank you, this is corrected (lines 368 and 190)

Line 208 What is the “The δD of precipitation”? Does it refer to the snowflake sampling or to the manual precipitation sampling? It is not clear. You should also define δD_p and δD_{cp}

9) Thank you for the remark, we added a definition of δD_p and δD_{cp} in lines 212-213: “The δD of precipitation (for both online sampled precipitation δD_p and manually collected precipitation δD_{cp}) is consistently enriched relative to the vapor and exhibits significant intra-event variability, with rapid changes reaching ~100 % within approximately 3 hours, as observed in Figure 4b”

The definition is also recalled in Figure 4 caption.

Line 228 Change “(Affolter et al., 2014) showed that differences” with “Affolter et al. (2014) showed that differences”

10) The text has been changed accordingly in lines 170-171 and 228

Line 294-295 While it is true that precipitation on the East Antarctic plateau has limited amounts, the frequency is not so low and you have to consider that it is also hard to discriminate between real snowfall events, blowing snow, hoar frost and diamond dust. All the aforementioned events produces snowflakes which, in your automated system, might be misinterpreted as snowfall, if not supported by other types of observations

Line 304-307 I think you have also to consider the input of possible blowing snow inside the inlet without precipitation occurring. A larger diameter inlet could facilitate the snowfall sampling, but it will eventually collect also more wind-drifted snow

Line 309-311 Compared to the system used in this study, the proposed setup would likely be more susceptible to blowing snow contamination

11) Thank you for these very important remarks. We agree that with the current instrumental setup it is not possible to unambiguously discriminate between different types of solid precipitation and near-surface ice particles (snowfall, blowing or drifting snow, etc.).

However, we believe that this new type of combined observation provides valuable information, as each type of ice/snow particle is associated with distinct formation and transformation pathways that may leave specific signatures in the isotopic composition. These new measurements may help to better constrain and eventually disentangle the different contributions, even if they cannot be directly separated “physically” with the current setup. To better interpret these signals, additional observations are required. These include surface meteorological measurements (such as wind speed and direction), snow particle counters, snow imaging systems (to characterize particle shape and type), and remote sensing instruments (radars, lidars). This multi-instrumental approach is being developed within the framework of the AWACA (Atmospheric Water Cycle over Antarctica) project.

We have added one sentence to explicitly state this at the end of section “2.2 Water isotopes instrumental set-up”:

It should be noted that the present set-up does not allow discrimination between different types of ice particles (e.g., snowfall, drifting or blowing snow). Additional observations are required to disentangle these contributions on physical basis, like wind speed and direction, snow particle counters, snow imaging systems (to characterize particle shape and type), and remote sensing instruments (radars, lidars).

Line 335-336 Change “does not reproduce well” with “does not accurately reproduce” and change “simulations often showing a too smoothed evolution” with “simulations often showing an overly smoothed evolution”

12) The text has been changed accordingly.

Chapter 4.2.2 Your claim is that the metric $\Delta(\delta D)$ can be interpreted as an indicator of the temperature or altitude difference between the surface and the level of snow formation, provided that the vertical isotopic gradient remains approximately constant.

Are you sure that the vertical gradient remains constant? Isn't it possible that precipitation occurs during temperature inversion and thus the vapor equilibrating with snowflakes is enriched in δD compared to the surface vapor you measured? Do you have vertical temperature profiles from the periods you studied?

Have you also considered that snowflakes might experience sublimation during their descent?

13) Thank you for this remark. We agree that the interpretation of $\Delta(\delta D)$ as a proxy for the temperature or altitude difference between the surface and the snow formation level relies on several, strong simplifying assumptions. We note that a similar metric has been used in previous papers for such retrievals [Lowenthal et al. 2011, 2016].

There is indeed no reason to expect the vertical isotopic gradient to remain constant under all atmospheric conditions, especially in the presence of temperature inversion during precipitation, which could complicate the interpretation of $\Delta(\delta D)$. We also agree that sublimation during snowflake descent is another process that may affect the isotopic composition. This effect is not considered in our interpretation and is mentioned as a limitation at the end of section 4.2.2 (last paragraph). Our intention is not to provide a quantitative retrieval of formation height or temperature, but rather to propose a first interpretation of $\Delta(\delta D)$ variability for the selected event, which we think may reflect changes in cloud processes, under idealized conditions. We do not have systematic, high frequency vertical temperature profiles for the studied events. In future work, a complete analysis combining complementary observations and more in-depth model analysis would be necessary to further investigate the $\Delta(\delta D)$ metric (e.g., its sensitivity to variations in vertical temperature gradients). Section 4.2.2 is currently being revised to better clarify the assumptions, limitations, the interpretation of the results and the perspectives.

Line 337-338 Although LMDZ6iso seems to capture pretty well the isotopic composition of precipitation, it looks like it fails to reproduce its variability within the event, especially for the final part of precipitation events; how do you explain that?

14) Thank you for this remark. At this stage, we think that some differences can be explained when the precipitation amount is low and the measured isotopic composition is dominated by blowing/drifted snow contribution, which are not implemented in the model. For case 2, during the last part of the event (starting on April 17th), we typically observed no precipitation samples in the sampling tray (vertical precipitation), and no signal is observed with the micro rain radar on the lower gate, whereas snow was still collected by the wind sock sampler. In addition, the ceilometer (CL31) measured this day an intense backscattering signal in the first meters (0-80 m) with no precipitation above. This could indicate a larger contribution from blowing snow/drifted snow which is not accounted in the model, and explain the mismatch observed in δD between the model and the observations on April 17th. Some elements of this discussion have been added in section 4.2.1: "This discrepancy is particularly marked when surface snow was still collected despite no recorded vertical precipitation, suggesting a dominant contribution from blowing and/or drifted snow not represented in LMDZ6iso, which may explain the δD_p mismatch. The overall better agreement with δD_p in the model could indicate that surface vapor isotopic signals are dominated by boundary-layer processes that are challenging to represent at the model resolution, while precipitation isotopes during the three events are mainly controlled by large-scale moisture transport and conditions during condensation at higher altitudes."

Figure 8 The caption should be clearer: $\Delta(\delta D)$ should be better explained and the difference between

$\Delta(\delta D_p)$ or $\Delta(\delta D_{cp})$ should be described

Line 375 Change “at 01:00 UTC” with “between 00:00 and 05:00 UTC”

Line 376-377 You have to specify that this rise occurs on April 17th

15) Thank you for these helpful suggestions. We modified Figure 8 caption, we also replaced “at 01:00 UTC” with “between 00:00 and 05:00 UTC” and specified that the increase occurs on 17 April. $\Delta(\delta D)$, $\Delta(\delta D_p)$ or $\Delta(\delta D_{cp})$ have been detailed in the caption as well. In addition, parts of this paragraph have been rephrased to improve clarity and readability.

Line 378-379 You wrote “a first part occurring in April 15th before the cloud descent to ground level with low values of $\Delta(\delta D)$ ”: first, change “in April 15th with ON April 15th”, then you say that the $\Delta(\delta D)$ values are low in this timeframe while, as confirmed in figure 8, and in line 381-382 you state that “In the first part of the event, from April 15th to before 03:00 UTC on April 16th, $\Delta(\delta D)$ shows much lower values, around $\sim -65\%$ with a large variability. During this period, the MRR mostly (change “mostly with “mainly”) shows high reflectivity values (10-20 dBZ) extending from the surface up to 3 km, with cloud tops exceeding the radar’s observational range, indicating that snow particles likely originate from high altitudes.”

However, when looking at figure 8, the cloud base height during this timeframe seems quite low (at least after 05:00 UTC on April 15th); how do you explain it? Do you think this precipitation formed in a cumulonimbus (although, to my knowledge, these clouds were never observed at Dumont D’Urville Station, with the exception of pyrocumulonimbus clouds), at a significantly higher height than the cloud base?

16) Thank you for this very interesting remark. Our observations do not allow us to conclude that the precipitation originated from a cumulonimbus cloud, and addressing this question would go beyond our dataset and the scope of this study.

The main point of this paragraph is that in the first part of the event (before the vertical dashed line), based on the MRR observations, ice particles are detected throughout a layer extending from near the surface up to 3 km (maximal range), with high reflectivity values and positive fall velocities. This suggests that the snowflakes collected at the surface may have undergone growth over a large vertical extent, rather than forming exclusively near the cloud base. In other words, the cloud base height does not necessarily represent the primary region of particle formation or mass acquisition. The vertical development of the cloud could partly explain the relatively low values of $\Delta(\delta D)$, although this is a first-order interpretation based on strong simplifying assumptions. The corresponding paragraph of section 4.2.2 is being rephrased to better explain this point, together with the changes detailed in answer 13).

Line 384-388 Please specify whether these two maxima in $\Delta(\delta D)$ are either $\Delta(\delta D_p)$ or $\Delta(\delta D_{cp})$: looks like $\Delta(\delta D_{cp})$ to me. You should always specify when referring to either $\Delta(\delta D_p)$ or $\Delta(\delta D_{cp})$, or to both of them

17) Thank you for this remark. Indeed, the local maxima are observed on $\Delta(\delta D_{cp})$, the text was modified accordingly. We also added a sentence in line 413-414:

On April 17th, only $\Delta(\delta D_{cp})$ is observed, with no snowflakes entering the inlet. This contribution comes mainly from the wind sock (see Figure 4).

At some point in the paper you should talk about the snow accumulation from the three snowfall cases you studied and possibly compare the measured accumulation with the model output

18) This is indeed an important point, which we think would benefit from a dedicated and more detailed analysis in a separate study. In the present manuscript, our primary objective is to introduce the sampling methodology and to highlight open questions and perspectives, rather than to provide a full model/data comparison.

There is a pluviometer at DDU, specifically designed to reduce the impact of blowing snow, but it is not entirely immune to contamination (Wiener et al., 2025). As a result, the recorded accumulation cannot be directly interpreted as true snowfall, so there is a need to correct or filter the data, which is beyond the scope of this study. We however examined the pluviometer data for case studies 1 and 2 (the instrument was not operational during event 3) and performed a preliminary comparison with model outputs. This comparison is informative but it remains difficult to interpret quantitatively at this stage and that's why we can't include these preliminary data in our manuscript.

One notable feature in case study 2 during the last part of the event (starting on April 17th) is that no precipitation is recorded by the pluviometer, which confirms at least qualitatively the absence of precipitation with the MRR and the absence of snow samples in the sampling tray (see answer 14 for more details).

Line 428-430 It is unclear whether this system can differentiate between drifting and falling snow. If it can, please detail the mechanism used to distinguish the two

19) Thank you for this remark. Indeed, the current sampling system does not allow us to directly distinguish between drifting snow and falling snow because both are collected indistinguishably at the inlet, a sentence has been added to state this at the end of section 2.2. We note that these two types of snow may be associated with different physical processes that could be reflected in their isotopic composition (see answer 11). In particular, drifting snow particles are likely to have interacted with near-surface vapor and may approach isotopic equilibrium with the local atmospheric conditions. In contrast, freshly falling snowflakes are expected to retain an isotopic signature more representative of their cloud origin, as they experience limited time for equilibration during descent. We modified the corresponding sentence as follows:

“This opens up new possibilities for evaluating the implementation of cloud processes and their impact on the isotopic composition of precipitation, for improving the representation of snowflake-atmosphere interactions (particularly during sublimation), and for helping to constrain the contributions of falling, drifting and blowing snow, which arise from different transport and transformation pathways.”