Reply to comments by Anonymous Referee #2

The authors appreciate for your constructive comments and suggestions. We will revise the manuscript by taking your comments into account.

Below are the *reviewer #2 comments* in blue and our response in black.

General Comments

The authors of the manuscript titled 'Development of a Peltier-based chilled-mirror hygrometer for tropospheric and lower stratospheric water vapor measurements' describe SKYDEW, a new chilled-mirror hygrometer for weather balloons that measures water vapor from the ground up to about 25 km altitude using thermo-electric cooling. The maximum altitude is constrained by the instrument's ability to dissipate heat and by outgassing from the balloon flight train. The latter is a common issue for balloon hygrometers.

The instrument and its principle of operation are documented comprehensively in the text and in the figures, together with a well-funded uncertainty analysis. The data processing is inspired from a 'golden point' approach introduced recently by a Swiss research group. The processing departs from the traditional averaging techniques and appears to be well suited for SKYDEW's aggressive PID controller, achieving frost point retrievals with a vertical resolution that I estimate from the figures about 50 m. It is unclear from the text how much of the processing is automatic and how much is based on user input. User input is not uncommon for this type of instruments.

Regarding automatic processing, most of the processes are currently automated and do not require subjective analysis. However, the validation of the detection of the phase transition from water to ice is still insufficient. As explained below, we can distinguish the phase on the mirror by analyzing the behavior of the scattered light. Nevertheless, it still requires more comprehensive and diverse validation with the radiosonde relative humidity (RH) values under various conditions.

SKYDEW is able to measure several kilometers into stratosphere, which is an improvement compared to Snow White, a thermo-electrically cooled balloon hygrometer of previous generation. The approach of using different operating set points for three different regions of the atmosphere is new, as far as I know, and is reasonable.

Regarding the measurement limitations, it has been observed that SKYDEW can measure altitudes over 25 km in many areas, excluding the polar regions at daytime. Under specific conditions, such as those in Lindenberg during nighttime, it has been demonstrated that measurements can be made up to nearly 30 km.

SKYDEW's detector is located on top and outside of the instrument housing, similarly to the night version of Snow White. This design may allow for a better ventilation and heat dissipation and overall a faster response. On the other hand, the open design potentially increases the fragility of the sensor and may increase the risk of self-contamination when flown through saturated layers of the atmosphere, as the comparison with MLS retrievals shown in the text suggests. In addition, placing the sensor at the top of the instrument prioritizes ascent data over descent data.

We decided not to incorporate an inlet tube, such as those used in CFH and NOAA FPH, in order to avoid the possibility of the tube itself becoming a source of contamination. We believe that the contamination indicated in the comparison with MLS retrievals is likely due to the balloon and string, rather than self-contamination.
SKYDEW was originally designed for ascent sounding; hence the sensing part is located at the top of the instrument package. For descent sounding, ideally, SKYDEW should be attached in an upside-down orientation, similar to the FLASH instrument. We are currently developing a special hanging system to switch the instrument-package direction for ascent and descent sounding.

It is unfortunate that only one dual sounding is used for the reproducibility evaluation presented in this paper. The unexplained difference in the stratosphere of about - 0.5 K (or ~ 10%) w.r.t. to the CFH reference is also unfortunate, albeit based only on a very limited number of soundings and only one with CFH and SKYDEW on the same balloon. It appears that a full evaluation of the measurement accuracy of SKYDEW will be only possible further down the road, when more data is available. Nevertheless, the results presented in this initial paper are encouraging and the calculated uncertainties seem reasonable.

We have conducted over 10 comparisons with the CFH so far (Sugidachi 2019). The profiles from the 5 soundings, excluding sounding data with some doubtful data in either of the two instruments, show that the SKYDEW readings are slightly smaller (less than approximately 0.5K) compared to the CFH readings in the lower stratosphere. However, these data have not yet been analyzed using the golden point method.
We will re-analyze these data using a new algorithm, which we will modify based on the reviewer's comments, and present the results in the revised manuscript.

References:

Sugidachi, T. : Meisei SKYDEW instrument: analysis of results from Lindenberg campaign, in 11th GRUAN Implementation and Coordination Meeting, Singapore, 23 May 2019 https://www.gruan.org/gruan/editor/documents/meetings/icm-11/pres/pres_0803_Sugidachi_SKYDEW.pdf (last access: 2 June 2024)

The text is scientifically sound and within the scope of AMT, well structured, with some typing, grammar and referencing errors. While the presentation quality of some of the figures may be improved (especially in terms of dpi) they are readable and understandable.

The revision should correct technical errors and expand Section 3 with a few more clarifications.

We will make sure to correct the typing, grammar, and referencing errors as noted in your specific comments in the revised manuscript. We appreciate your thorough review and attention to detail.

In view of MLS decline and of the phase-down of hydrofluorocarbons, this presentation about an instrument capable of measuring lower stratospheric water vapor with thermo-electric cooling is relevant to the scientific community.

Specific comments

1: you may consider adding 'SKYDEW' into the title of the paper

We will add 'SKYDEW' into the title as below.
"Development of a Peltier-based chilled-mirror hygrometer **SKYDEW** for tropospheric and lower stratospheric water vapor measurements"

51: consider rewriting 'perform poorly in the dry stratosphere'. Operational radiosondes have been used in moist stratospheric conditions (e.g. Vömel et al. 2022).

We will revise as suggested.

67: 'these remote sensing techniques'. Which other ones? You have only mentioned Raman lidar in this paragraph.

We will revise as suggested. In the revised manuscript, 'these remote sensing techniques' is changed to ‘this remote sensing technique’. Because the remote sensing sensors are generally calibrated using with the in-situ instrument such as radiosonde, we had used plural form “techniques” here.

133 / Figure 1: Interesting design, with the sensor placed on top and outside the instrument, without inlet/outlet tubes. This departs from CFH/FPH. Could this explain the contaminated profiles shown in Figure 15, or is this due to contamination from the balloon and its flight train? On the other hand, the SKYDEW design may allow better ventilation and heat dissipation, and overall a faster response? Is this assumption correct?

As mentioned in response to the general comment, we believe that the source of contamination indicated in Figure 15 is mainly from the balloon and string, not self-contamination. Most parts of the sensor, including the radiator and copper plate, except for the sensor cover, are thermally connected to the hot side of the Peltier device. This means that these parts are always warmer than the ambient air during ascent sounding, making it difficult for water to attach to the sensor parts.
However, the rig and string used to secure the SKYDEW and radiosonde may become contaminated in cloud conditions. Even with the configuration that places the SKYDEW sensor part at the top, the balloon and string can still be a source of contamination.
The design that places the sensor outside allows for better ventilation to release the heat from the hot side of the Peltier device. However, during the daytime, solar radiation heats the radiator, which can affect the lower cooling limit.

What is the 'cover' in Figure 1 (c) and what is it made of? Is it used to guide the airflow over the detector? And/or to act as a protection against hydrometeors when flying in clouds?

The sensor cover is made of an aluminum plate, and it serves two main purposes. First, it prevents direct solar radiation from entering the optical detector, as strong direct solar radiation can cause errors, even if the light source is modulated. Second, it is used to guide the airflow, as you mentioned.
We will add an explanation about the material and purpose of the sensor cover to the revised manuscript.

The hot side radiator looks interesting. What is the purpose of the two ‘screws’ on the upper part of the radiator? For heat dissipation?

The two screws on the upper part are for the wire to fix the radiator. For the previous version of SKYDEW, the ethanol was used for additional cooling of the radiator. This wire was used for the guidance to ethanol tube. For the current version, this wire is used only for fix the radiator.

136: Figure 2 suggests a maximum achievable cooling of about -50 C, not -90 C.

We will revise as suggested.

139: What is the wavelength of the light source and what is the modulation frequency? What is the technology (e.g. LED + Photodiode)?

The optical sensor module in our system uses a red LED and a photodiode, with a peak wavelength of 660 nm. However, the modulation frequency is not publicly disclosed.

140: What is the overall size (cm x cm x cm) of the SKYDEW instrument?

The dimensions of the SKYDEW are 128 mm(W) x 93 (D) x 300 (H). We will add this information in the revised manuscript.

146: The intensity of the scattered light is used in the processing and in the uncertainty analysis (Sections 3 & 4). Why do you consider it 'housekeeping data'?

Because SKYDEW is an instrument designed to measure the dew/frost point, other parameters were considered auxiliary data. However, the intensity of the scattered light is particularly important for analyzing the dew/frost point profile, especially when compared with other housekeeping data. Accordingly, we will modify line 146 in the manuscript as follows:

"Except for the mirror temperature and the intensity of the scattered light, these parameters are used as housekeeping data to monitor whether the system is working properly. The mirror temperature is directly linked to dew/frost point and the intensity of the scattered light is essential parameter to estimate dew/frost point correctly as described in Section 3 and 4."

175: Incorrect, liquid water has a vapor pressure higher than ice, not lower.

We will revise this sentence as suggested.
"Below 0 °C, liquid water has a vapor pressure higher than that of ice"

204: Poor reference for specific humidity and precipitable water. In fact, this sentence may be removed entirely, as it provides no added value to the manuscript.

We will delete this sentence as suggested.

226: In Figure 2, do the dashed lines correspond to parametrizations using Equations 7 and 8? If so, please mention this and provide parameter values.

No, the dashed lines are not theoretical values derived from Equations (7) and (8); they are simply fitting lines created using a quadratic function. As you have correctly pointed out, the meaning of these dashed lines is not clear. Therefore, we will add the theoretical lines derived from Equation (7) for greater clarity in the revised manuscript. Furthermore, the values at the lower stratosphere (-70°C, 100hPa, and 5m/s ascent) will be represented as a grey line in right panel. Estimating the heat transfer coefficient under no wind conditions is complex, so we have not indicated the theoretical line in the middle panel.

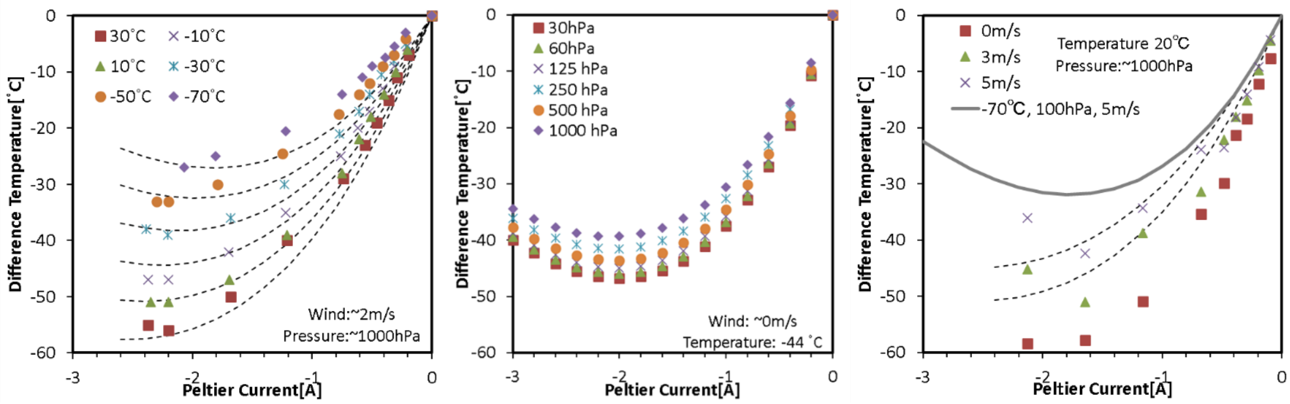

Figure R2-1. The revised figure about the cooling performance. The dashed lines indicate the theoretical values calculated by Eq. (7), using the parameter $\alpha = 0.0099, \beta = 0.0432,\ R_e = 0.48,$ $and\ S = 0.00025$. See the detailed information shown within each panel for different symbols, colors, and lines.

288: Do you mean here that during a phase transition, you can distinguish if the mirror temperature corresponds to the dew point or to the frost point solely from the behavior of the scattered light?

Yes, we can distinguish the phase on the mirror by observing the behavior of the scattered light. The automatic processing system uses the oscillation period of the scattered light, i.e., the interval between golden points. When the water on the mirror changes into large ice particles, the controller's oscillation period becomes longer, meaning that the intervals between Golden Points (GP) also become longer. The heating control creates fine ice particles, making the periods shorter again.

After launch, the point where the GP interval rapidly become longer is identified as the phase transition timing. To be more specific, when the interval of the Golden point, as indicated by the gray line in Figure 9(d), becomes larger than a set threshold compared to the initial value, it is considered that a phase change has occurred. Tentatively, the threshold is set at 15 m. In many cases, the transition point corresponds to that estimated from the comparison with the radiosonde relative humidity (RH) value. For instance, in Figure 9(d), the interval of GP shows a sharp increase at approximately 3.5km, which indicates the phase transition.

293: Is an intentional heating at -12.5°C also performed in NOAA FPH? Hall et al. 2016 do not mention it.

This statement is indeed incorrect, thank you for pointing that out. Hall et al. (2016) do not mention it. They detect the phase transition by comparing with RH sensor and behavior of the mirror temperature. We will modify this sentence as follows.
"For the CFH ~~and NOAA FPH~~, the forced freezing algorithm is applied at a mirror temperature of –12.5 °C to eliminate the phase ambiguity."

321: From what I understand, Equation (11) fits to the 'golden points' in Section 3, i.e. the condensate on the mirror neither grows nor shrinks at the frost point. What is actually the relationship between the (mean) size of the ice crystals and the scattered light intensity in SKYDEW? Consider writing a few sentences why the 'golden points' of Poltera et al. 2021 apply to SKYDEW's scattered light signal.

At the golden point, the left term of Equation (11) should be equal to zero, which results in T_{fp}=T_m. Therefore, the golden point can be applied to all chilled-mirror hygrometers in principle. We will add the following sentence at line 356: "Here, the golden point represents the equilibrium points when the condensate on the mirror neither grows nor shrinks, which corresponds to the evaporation rate in Equation (11) being zero."
Regarding the relationship between ice crystals and scattered light intensity, we can estimate the scattered light intensity from the ice particle, assuming backscattering by Mie scattering as described at line 301. By estimating the size and number of ice particles at each condition shown in Figure 5, we can say that many ice particles form on the mirror when the size is small to compensate for the weak signals from individual small ice particles.
As a rough estimation, at a temperature of -20 °C, the radius of the condensate is about 5-10 um and the number is 75 counts/mm^2. At a temperature of -40 °C, the radius of the condensate is about 3-5 um and the number is 400 counts/mm^2. At a temperature of -60 °C, the radius of the condensate is about 1.5-3 um and the number is 2880 counts/mm^2. These mirror conditions with different ice particles result in roughly the same order of total scattered light intensity. However, the speed varies according to Equation (11).

331: ice 'crystals', not 'droplets'.

We will revise as suggested.

364: Is the removal of intentional heating data performed automatically by software?

Yes, the removal of intentional heating data is performed automatically by the software. During the heating controls, the Peltier current is less than 0A, which indicates the heating of the mirror. Simultaneously, the scattered light signal drops below the target level (base level + 0.3 V for the first step and base level + 0.25 V for the second step) and approaches to the base level. If this behavior is detected, the mirror temperature data are removed for a duration of 40 seconds. Also, in case of reaching the cooling limit, where the Peltier current is at its maximum (>2.3 A), and the scattered light drops below the base level +0.15 V, the mirror temperature data is also removed.

383: This paragraph needs further clarification. Do you extract the 'golden points' on the smoothed mirror temperature, or from the original mirror temperature? From Figure 7 (upper left), it seems that the points are extracted from the original profile, but this is not how I understand the text. Moreover, how do you perform the final smoothing of the extracted 'golden points'? They seem to come at irregular time intervals. Do you linearly interpolate between the 'golden points' on a 5 Hz time axis and then smooth with a Gaussian filter of sigma=1.5 seconds?

A Gaussian filter was applied to the original data even though they are with irregular time intervals. We will modify the algorithm, including this smoothing process, in the revised manuscript according to the reviewer's comment. The main modifications are as follows: (1) Up sampling is not applied; the golden point is detected from 1Hz sampling data. (2) The raw selected golden points are resampled at regular 1 Hz points with interpolation.

We have also realized that the caption is incorrect - this example profile is not the same as the one in Figure 6. The profile in Figure 7 was the sounding result on 5 November 2019. We will correct this and include a more detailed explanation in this section in the revised manuscript.

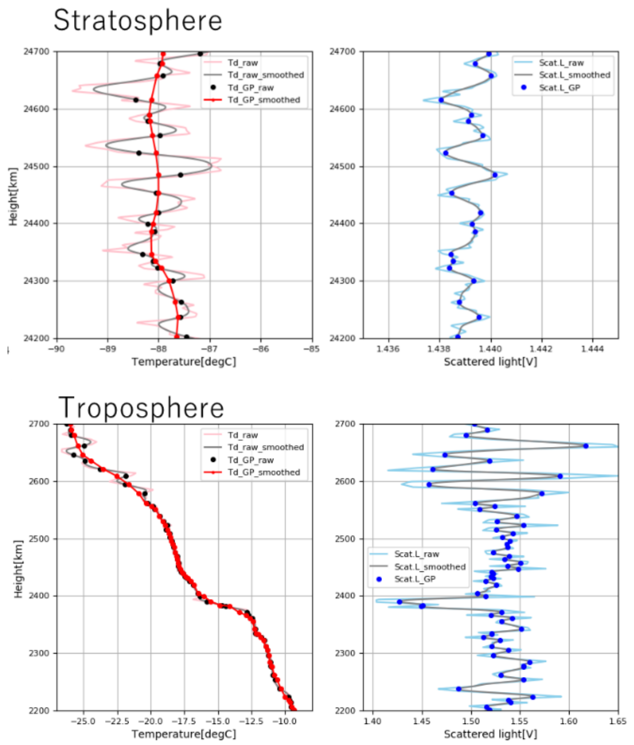

Figure R2-2 As for the Figure 7 in the original manuscript, but with the addition of black dots indicating the detected raw golden points.

430: In Table 1, you write '~ 1.0 K at max' for this uncertainty component, why not write this here? Moreover, what about the typical uncertainty value when oscillations are 'normal'?

We will modify the value in Table 1. We will add the typical two values for the normal case and for the large oscillation case separately. But, these values will be changed in the future according to the modification of the algorithm.

Table 1: Uncertainty sources and estimates for SKYDEW.

Uncertainty parameter	Value (k=1)	(Un)/correlated
Mirror_temp measurement, u_mirror	$0.052=(u\_mrr1^2+u\_mrr2^2+u\_mrr3^2)^{0.5}$	correlated
PT temperature calibration, u_mrr1	$0.07/\sqrt{3}$	correlated
Resistance measurement u_mrr2	$0.005\sqrt{3}$	correlated
Thermal gradient of mirror, u_mrr3	$0.015/\sqrt{3}$	correlated
Golden point detection error, u_GP_error	**> 1.0K in case of the large oscillation**	uncorrelated
	0.2K at normal	
Filtering deviation, u_filter	**>0.5K in case of the large oscillation**	uncorrelated
	<0.1K at normal	

Contamination by cloud	Depend on the situation strongly.	correlated
Aerosol effect and curvature effect	negligible	correlated
Total uncertainty, u_DP	$=(u\_mirror^2+u\_GP\_error^2+u\_filter^2)^{0.5}$	

452: Intentionally heating the mirror first at -12.5 C, such as CFH, seems reasonable for an ascending balloon, as it almost certainly ensures that the mirror condensate is liquid water before the heating stage and ice after it. SKYDEW heats its mirror first at -36 C, i.e. at a temperature where the condensate has very likely already phase-transitioned to ice, which complicates the mirror condensate phase determination. Why not perform the first heating stage at a lower temperature in SKYDEW?

The reason we chose to initiate the intentional heating at -36°C with SKYDEW, despite it being a temperature where the condensate has likely already phase-transitioned to ice, is due to our past experimental results. When we attempted to initiate the intentional heating at -12.5°C, as done for CFH, we often experienced failures where ice particles did not form, and super cooled water droplets remained on the mirror for an extended period.
Therefore, we selected a temperature where we could be certain that ice particles would form. As mentioned earlier, the phase transition can be detected automatically. Our intention was to avoid having large ice particles, formed from water during the phase transition, remaining on the mirror for extended periods. Such large ice particles are not suitable for the PID controller in SKYDEW.

From this paragraph, it is unclear how you determine the phase of the condensate in practice. From the amplitude and frequency of the scattered light fluctuations? Or from the comparison with the partnering radiosonde RH sensor? Or both? Can this be performed automatically by software?

Yes, we can distinguish the phase on the mirror by monitoring the behavior of the scattered light. The automatic processing system uses the oscillation period of the scattered light, i.e., the interval between golden points. When the water on the mirror changes into large ice particles, the periods driven by the PID controller become longer, meaning the intervals between Golden Points (GP) also become longer. The heating control creates fine ice particles, causing the periods to shorten again.
The point where the GP interval rapidly lengthens is considered as the phase transition timing. Currently, the threshold is set at 15m. In many cases, the transition point corresponds to that estimated from the comparison with the radiosonde relative humidity (RH) value. For instance, in Figure 9(d), the interval of GP shows a sharp increase at approximately 3.5km, which

indicates the phase transition.

455: Incorrect, cubic ice on the mirror would cause a lower mirror temperature.

We will revise as suggested.

504: How large is the air temperature uncertainty uT? Please provide a typical value or an upper bound

The air temperature uncertainty for this particular sounding is approximately 0.2 K. The uncertainty tends to increase at higher altitudes during the daytime due to the influence of solar radiation. However, at nighttime, the uncertainty remains fairly constant from the surface to the stratosphere (as per Kizu et al. 2019). Most SKYDEW soundings, including the sounding mentioned in your question, were performed at nighttime. We will add the typical value in the revised manuscript.

511 / Figure 9 (h): the uncertainty due to pressure is surprisingly small compared to e.g., Hall et al. 2016 for FPH? Why is that? How large is the air pressure uncertainty uP? Please provide a typical value or an upper bound

For this particular sounding with the RS-11G radiosonde, the pressure uncertainty is estimated to be less than 0.15 hPa in the stratosphere. The pressure of the RS-11G is derived from the GPS height. On the other hand, the iMet-1-RSB and RS-80, which are used for the NOAA FPH, are equipped with a pressure sensor. The uncertainties of these devices seem to be larger than that of the RS-11G, especially in the stratosphere. In the revised manuscript, we will add the typical value for the pressure uncertainty in the stratosphere.

567: You mention at the beginning that several SKYDEW-CFH comparisons have been performed, yet only two soundings are discussed, only one on the same balloon. Is the -0.5 K difference in the stratosphere systematic in all soundings so far, or does it appear only on these two soundings?

As mentioned above, we will add the comparison with CFH in the revised manuscript.

588: the MLS data has been averaged over how many +- hours or days?

In the original study, all data from the same day as the balloon release were used. However, in the revised manuscript, we will modify the comparison results with the MLS data using a more appropriate averaging method. This will be reanalyzed by referring to Hurst et al. (2023), which uses temporal and spatial coincidence criteria of +/-18 hours, +/-2° latitude, and +/-8° longitude. Additionally, we will use the same average kernel vertically as the MLS data.

596: The measurements took place during the summer monsoon, which probably increases the risk of contamination for this type of instruments. Nevertheless, do you know where the outgassing that you mention here comes from? Is it the SKYDEW sensor probe itself that suffered from icing in the saturated troposphere? Or is it from the balloon and its flight train? > 50 m train lines are generally recommended for measuring stratospheric water vapor, have you used such longer lines?

We cannot definitively determine the source of the contamination from outgassing in this case. Given that the balloon and string are positioned above the sensor part of SKYDEW, outgassing from these parts could easily be a source of contamination. The radiator is close to the mirror part, but it is made of metal and is warmer than the air temperature. Therefore, it is not easy for water vapor to be attached onto this surface. However, water droplets and ice particles in clouds may attach to the sensor part. It is recommended to avoid cloudy conditions for stratospheric water vapor measurements, in addition to rainy conditions.
We usually use a 50m unwinder for most soundings, including those at the YMC-BSM campaign. However, in certain limited cases, such as when the landing point is estimated to be near a city area in Japan, we use a 30m unwinder and a 600g balloon for safety reasons.
We will revise line 439 accordingly.

You mention that the soundings on 1 & 3 June passed through saturated layers, but what happened on 27 May? What is the reason for the disagreement with MLS above 20 km on that day? The 27 May sounding has for example not been excluded from the comparison with RS11G on Figure 14.

There is a high possibility that the payload passed through a thin cloud layer during the sounding on 27 May as well as 1 & 3 June. The oscillation in the scattered light signal at approximately 13 km corresponds to the near-saturated layer shown in the frost point profile. When SKYDEW passes through a cloud layer, such oscillation often occurs, especially in the upper troposphere, due to the aggressive PID tuning. The sounding on June 1 was similar to that on June 3, with a thick cloud layer present in the upper troposphere.
Contamination from clouds in the upper troposphere does not significantly impact the measurements in the troposphere. More specifically, while such contamination may cause a

slight bias above the cloud layer, we have included the results from these soundings in Figure 14. This is because the effect on the comparison at the troposphere level is considered minimal.

We will modify lines 594-596 as follows: "For the soundings on 27 May, 1 June, and 3 June, the SKYDEWs passed through saturated air or cloud layers in the upper troposphere. There is a possibility that the ascent measurements of these two profiles were affected by contamination from outgassing."

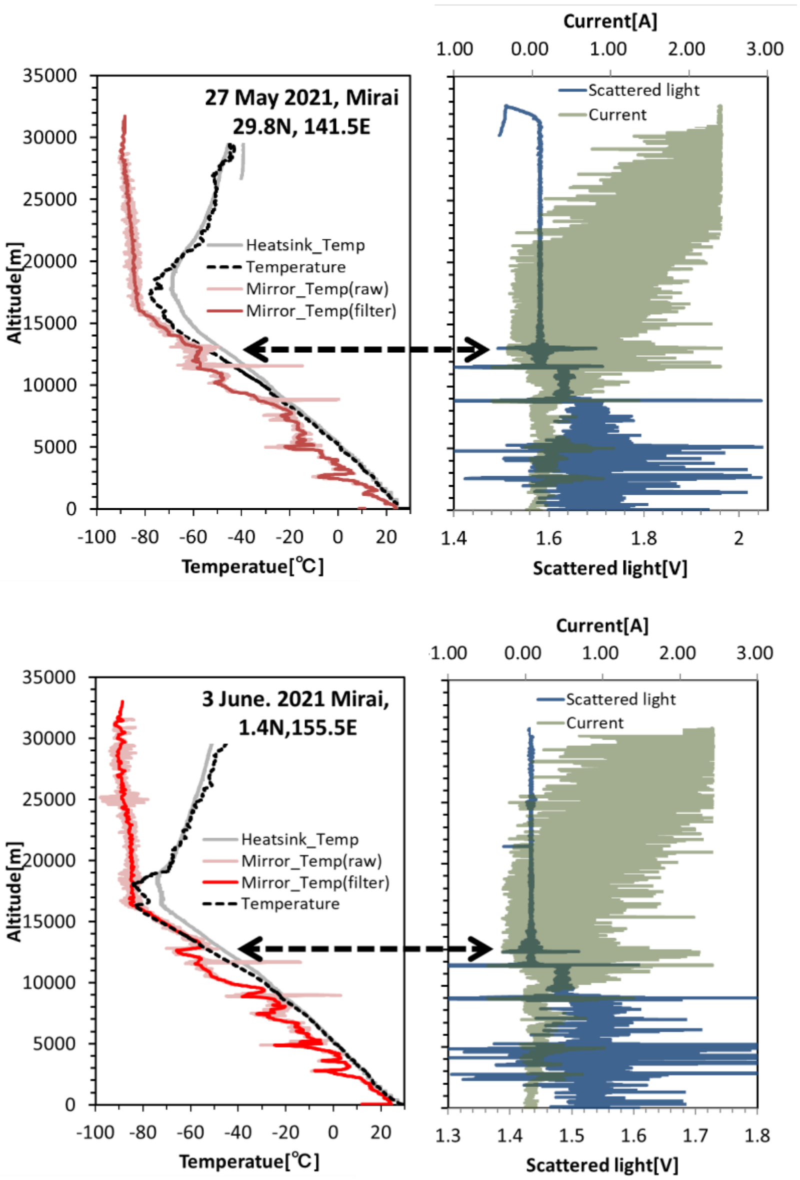

Figure R2-2 the example of the contaminated soundings

629: Why is controlled descent a challenge for SKYDEW? Is this because SKYDEW might lose its condensate before balloon turnover? Or is it because of the position and orientation of the sensor?

There are indeed two main challenges as you mentioned. Firstly, it takes a long time to form condensate on the mirror at stratospheric altitudes due to the limited cooling capacity of the Peltier cooler. Therefore, the balloon's turnover needs to occur just before the loss of the condensate, and this altitude can vary depending on atmospheric conditions. An algorithm that allows SKYDEW to detect the cooling limit and control the balloon's ascent/descent is necessary. Alternatively, the balloon should be turned over at a sufficiently low altitude before the condensate is lost.

In addition to ensuring that the condensate is not lost, the sensor's orientation should be upside down for descent soundings. This issue is common for operational radiosondes such as the RS-11G and RS41, as most of them are designed for ascent soundings. A system to switch the orientation of the payload is needed for accurate measurements during descent.

We will revise the last sentence to: "because the current version of SKYDEW is designed for ascent measurements only."

Technical corrections

Here a list of typing and referencing errors that I was able to spot, sorted by line number or figure number.

We will correct these typing and referencing errors in the revised manuscript as per your comments. Thank you for pointing them out.

21: selects the equilibrium point

25: in regions

46; The Brewer-Dobson circulation

63: integration time

66: Whiteman et al. 2006 is missing from the reference list

89: Hurst et al. 2023

90: I have found the NOAA instrument description in Vömel et al. 1995 (10.1029/95JD01000), not Vömel et al. 1995 (doi:10.1029/95GL02940).

93: water vapor concentrations. Generally, stick to either American or British.

96: cooperation agreement

98: the Fluorescent Advanced Stratospheric Hygrometer

98: the Vaisala RS92 radiosonde

110: analog

123: Put the 3 in CFH3 in subscript

129: Section 5

129: Section 6

136: a temperature difference

150: Vaisala RS41, Intermet 54

162: You have two Vömel et al. 2016 references, please distinguish between the two in the text

172: You have three Vömel et al. 2017 references, please distinguish between the three in the text

174: Fujiwara et al., 2003

181: Vömel et al. 2007 mention -53 C, not -55 C.

182: You have three Vömel et al. 2017 references, please distinguish between the three in the text

193: WMO (2021)

216: between the mirror surface and ambient air, and S

220: thermal conductivity of air,

225: For higher air temperature

230: high cooling power is needed

235: (PT100) which has

251: the control output corresponds to the current

259: A proportional controller alone cannot eliminate

266: which depends

276: at an air temperature of ~0 °C and at ~-13 °C dew point.

285: This implies that the output of the PID controller

308: As in the cloud formation process, the number of IN on the mirror may reflect the temperature dependence of the ice-nucleation process on the mirror.

334: at an as low as possible

343: when the mirror temperature reaches about –36 °C.

406: remove underscore before 'to reduce this distribution'

462: (Thornberry et al., 2011).

467: Thornberry et al (2011)

472: Pruppacher and Klett, 1997

484: Kizu et al. (2018) is missing from the reference list

492: in long time series

540: A dual sounding with two SKYDEWS

543: worked properly.

548: Smaller oscillations are required for better measurements, although the oscillations due to the aggressive setting of the PID controller are needed to detect the golden points.

559: The deviation is large in the troposphere

611: dynamic changes of atmospheric water vapor.

615: The Peltier cooling creates a temperature difference of more than 40 K

726: Missing new line between '2022' and 'Sakata, R.'

744: Vömel

794: which corresponds to the right axis.

796: Photographs show the condensate on the mirror.

799: Condensates on the mirror at air temperatures of

819: the detected golden points

831: Profile of dew/frost point

837: Frost point profile on 26 November 2021

863: The center panel shows

875: Gray shading indicates the uncertainty of SKYDEW (k = 2).

877: Mirror temperature measurement, u_mirror

878: Resistance measurement u_mrr2: missing 'divide' sign between 0.005 and ¥sqrt{3}

Figures 6 (b) and 9 (b): The sign of the Peltier current is inconsistent w.r.t Figure 2.

Figure 14 (a): The 'black dashed line' appears to be missing in Figure 14 (a). Please add the line in the figure, or remove this sentence from the figure caption.