General comments, referee #1:

The paper describes the development of a new cryogenically cooled water vapor radiometer observing the 22 GHz line from ground. Since the 22 GHz line is rather weak, especially for observing the upper mesosphere, where high spectral resolution is required to resolve the pressure broadened line shapes, cooling is beneficial. The goals of the development include to achieve optimal performance in terms of sensitivity (receiver temperature) at moderate power consumption, to get a compact design for several purposes and to introduce a novel calibration technique (frequency switch) for ground-based 22 GHz water vapor radiometers. The described novel instrument concept and the reported results show a clear progress in the development for these kinds of instruments and fits well within the scope of AMT. The overall presentation is well structured and clear. I recommend publication after minor revision

Referee #1: We would like to thank Referee #1 for the constructive and positive assessment of our manuscript and for recommending publication after minor revision. We appreciate the referee's recognition of the motivation for cryogenic cooling at 22 GHz—particularly for achieving improved sensitivity for mesospheric observations where high spectral resolution is required—as well as the relevance of our design goals (low receiver temperature at moderate power consumption, compact implementation, and the introduction of frequency-switch calibration). We have carefully addressed the requested revisions and updated the manuscript accordingly to improve clarity and completeness

Specific comments

Comment 1: Introduction, lines 21-22 ... accompanied by ...: the sentence looks a bit ambiguous. Please shortly describe the mechanism of freeze drying on production of the hydroxyl radical (so that the reader does not have to read the reference).

Reply comment 1: Rephrased the sentence.

Comment 2: Line 26: there are earlier papers showing the effect of SSWs on water transport as measured with 22 GHz radiometers (e.g. Seele & Hartogh GRL, 2000). Please add the reference

Reply comment 2: Added to the revised manuscript.

Comment 3: Line 37. Note that Kiruna is in Sweden. The cited instrument operated both in Norway (Andenes) and Sweden (Kiruna).

Reply comment 3:Changed.

Instrumental design:

Comment 4: Lines 114-115: ... better mechanical properties... Please list the properties

Reply comment 4: Rephrased the sentence and cited new papers that explain the easier machinability and lower losses of UHWMPE over HDPE.

Comment 5: Line 118: Why sqrt(sqrt)? Please provide a short explanation.

Reply comment 5: We added more context.

Comment 6: Lines 118 ff and Figure 4 caption: it does not get clear how much the ARC improves the measurements. Please quantify. What is the maximum acceptable window deformation and

how thick does the window have to be (for the given diameter) that the deformation stays below this tolerance? Is the thickness of one wavelength sufficient?

Reply comment 6: From the thermal and mechanical simulations that we have performed, we calculate a deformation along the beam path of -3.5mm for the window. This is a simplified simulation with the focus to identify the thermal load at the cold head location. Plastic deformation of the UHMWPE window material starts at the yield stress of approximately 19 MPa, as specified in the manufacturer datasheet (ISO 527). Stresses below this value result in elastic deformation only. Although, from the tests we performed with a window of 224mm diameter and 1 lambda thickness, the window experienced plastic deformation, but survived and didn't break. As for the tolerance, it is important to design the window with a safety factor of 2. Based on these simulations and corresponding laboratory measurements, we anticipate for the final design a ARC thickness of 13.7 mm and a diameter of 125 mm.

Comment 7: Line 134: Is there a list of instrument requirements that were defined before the instrument was developed? What defines the requirement for a sidelobe level of -35 dB?

Reply comment 7: It is important to keep the sidelobe levels for the corrugated horn and reflector low, specifically lower than the radiometric noise. Low sidelobe levels are essential for ground-based microwave radiometers in order to suppress coupling to radiation from the ground and surrounding structures, which are at much higher physical temperatures than the observed atmospheric emission. A sidelobe level below −35 dB limits such contributions ensuring that sidelobe contribution remains negligible compared to radiometric noise and calibration uncertainties.

Comment 8 :Line 139: Why is the spillover unit dBi and not dB? What defines the -30 dB?

Reply comment 8: We corrected the unit to dB. The reason for -30 dB spillover for the reflector is a compromise between the mirror size (given by available space) and the far field beamwidth of FWHM of 3 deg. It was also shown according to Dueber et al. that this is a good compromise. While trying to achieve even lower spillover values the size of the reflector will increase significantly. Rotating such a large mirror also poses new challenges for the mirror flipping and the size of the main frame, limiting the possibility of the instrument for deployment at the observatory.

Comment 9 :Line 142: please specify the mechanical mirror parameters a bit more precisely: what is the material thickness and mass of the mirror?

Reply comment 9: The mass has been added in the text, line 147. As for the thickness, it can not be defined as it varies significantly in the shape of the mirror.

Comment 10: Line 149: It is a bit difficult to decipher all details in Figure 7. Please add a zoomed-in version with an x-scale of +- 5 degrees.

Reply comment 10: Added a zoomed in version as requested. Figure 7b.

Comment 11: Line 164 ff: Please mention here that the Hallgren et al system also contains temperature-tunable internal hot and cold loads. This seems to be the main reason why the system is larger than the CRYOWARA system. A short discussion would fit here what are the pros and cons of internal loads compared to the ambient hot load you are using and the "atmospheric" cold load.

Reply comment 11: We added a paragraph to the discussion addressing the raised point.

Comment 12: Line 170: please specify power consumption and service interval length

Reply comment 12: Details are now included.

Comment 13: Figure 9 shall contain dimensions

Reply comment 13: We added the dimensions to the Figure 9 caption.

Comment 14: Line 195: it does not get clear whether you are using MLI, etc. or not. Isn't it beneficial to take advantage of it? How much would the thermal load be reduced?

Reply comment 14: Rephrased the sentence to make it clear that we don't use MLI currently. We have not performed simulations to identify how much it will improve.

Comparison with MIAWARA

Comment 15: Line 203: ...far-field gain of 35.6 dB... ff: here it shall be dBi I guess (or is it related to a dipole antenna?)

Reply comment 15: Changed to dBi. Line 221.

Comment 16: Lines 209 ff: discussion about the performance comparison. I would like to see a bit more quantified discussion here. The advantage of the new system is the better noise temperature and at the same time the dual polarization measurements (reducing the measurement time for the same SNR by a factor of 2). On top of the receiver temperatures the observing conditions have to be taken into account. I propose to add number for typical seasonal conditions at the Zimmerwald location (you have a statistic from MIAWARA) e.g. in winter and summer and provide an integration time required for a retrieval up to 80 km with MIAWARA and CRYOWARA. This would demonstrate the big advantage (especially of the dual-polarization approach) of the new system.

Reply comment 16:

Although the observing conditions cannot be compared directly at this stage, because all results presented in this paper were obtained with the breadboard setup installed in a laboratory at the University of Bern (level −1) and the measurements were performed through a microwave window with a restricted view surrounded by buildings, a first-order estimate shows brightness temperatures of 68 K in winter and 107 K in summer over 2025, reflecting the higher typical opacity in summer. The receiver temperature stays stable between the seasons. MIAWARA typically requires an observation time of **24 h** to reach retrieval altitudes of ~80 km, which it achieves on about **80%** of the days per year. Applying the seasonal scaling above, this corresponds to an expected CRYOWARA integration time of approximately **3.5 h** in winter and **4.5 h** in summer (median values), i.e. on the order of a few hours. This demonstrates the substantial advantage of the cryogenic receiver temperature together with the dual-polarization approach, and suggests that CRYOWARA should be able to reach comparable retrieval altitudes even on days with less favourable observing conditions (e.g. within precipitation gaps).

Comment 17: Table 2: please explain why MIARAWA with its single-polarization approach also needs two HEMT amplifiers. Please check dB/dBis.

Reply comment 17: The two LNAs in MIAWARA have historic reasons. The Gain of the first LNA is sufficiently high to remove the second LNA without compromising the T_sys. MIAWARA-C has only one RF LNA in each receiver chain. Table 4.

Comment 18: About the CRYOWARA spectrometer mentioned in Table 2: I checked the specification on the website of the manufacturer and found a maximum bandwidth of 160 MHz, but you mention 200 MHz here. Please clarify.

Reply comment 18: The I/Q sampling rate is 200MHz, which results in a 200MHz wide spectrum. The spectrometer has internal anti-aliasing filters, and for that reason the manufacturer specifies a bandwidth of 160MHz, but the actual usable bandwidth is slightly wider.

The effect of the internal filters is visible in the increase of the system noise temperature at frequency offsets larger ±80MHz in Fig. 19

Calibration

Comment 19: Line 229: ...channels is then calibrated... If you mean a total power calibration please mention it here.

Reply comment 19: Rephrased the sentence in the text.

Preliminary results

Comment 20: Figure 18b: please mention the integration time as in 18a. What is the little bump at about -50 MHz? Why is it shifted between the two polarizations? Please provide an additional plot 18c integrating the two polarizations. The spectral noise should go down by sqrt(2) in case the two signals are not correlated. Please prove that this is the case.

Reply comment 20: Addressed in the text. An explanation is provided for the bump and the integration time has been added. 18c plot uploaded. The spectral noise is mentioned and it does reduce by sqrt(2). Figure 18 panel c.

Comment 21: Typos etc:

Reply comment 21: Corrected.

Comment 22: Line 79: Table ??

Reply comment 22: Added the missing table. Table 1.

Comment 23: General: check use of dB and dBi and correct it accordingly

Reply comment 23: We revised the manuscript as suggested.

General comments, referee #2:

The Institute of Applied Physics at the University of Bern has during the years designed several state of the art micro-wave radiometer systems for ground-based measurements of vertical profiles of different middle-atmospheric parameters such as ozone, water vapor, temperature and winds.

This paper follows this tradition and present a new generation of a 22 GHz radiometer system for the observation of middle atmospheric water vapor content using a cryogenically cooled low noise amplifier frontend. The cooling gives a low receiver temperature, which enables shorter integration times before a certain signal to noise ratio is achieved, than with an uncooled system. This means that vertical profiles of water vapor with a high temporal resolution can be retrieved from the measured spectra. Apart from the cooling the authors also implement frequency-switching instead of the often used load-switching method. Frequency-switching also shortens the observation time needed to achieve a certain signal to noise ratio, since much less time is spent observing a calibration load.

The paper is clear and concise, but also detailed enough to be very important for the microwave community observing the atmosphere. I am looking forward to when a follow up paper with the first retrievals is published.

My opinion is that the paper is very well suited to be published in AMT and my recommendation is that the paper is accepted for publication. I have no other suggestions of minor revisons than already given by the other reviewer.

Referee #2: We thank Referee #2 for the encouraging and positive assessment of the manuscript. We appreciate the recognition of the benefits of the cryogenically cooled front end and the frequency-switching approach. We have implemented the minor revisions suggested by the other referee and have further improved the manuscript accordingly. We also share the referee's interest in a follow-up publication presenting the final instrument and first retrieval results.