Authors response - AMT

Application of the shipborne remote sensing supersite OCEANET for profiling of Arctic aerosols and clouds during Polarstern cruise PS106 – Griesche et al.

Response to Anonymous Referee #2 (22 January 2020)

We would like to thank the Anonymous Referee #2 for dedicating time in order to improve the manuscript and giving help by providing us with valuable comments and suggestions. We have revised the initial submission, and hope that the manuscript is now acceptable for publication.

Our point-by-point response to the review comments is written here in bold font.

Overall summary of major changes:

We would like to inform the referee about the following major changes:

- **Revision of the abstract due to suggestion of Referee #2**
- **Reprocessing of the Cloudnet data with an Arctic MWR-retrieval considering the comments of both Referees #1 and #2**
- **Included a better evaluation of the capability of the motion stabilization according to comments by both Referees #1 and #2**
- **Improved the discussion of the eddy dissipation rate and fog/low-level stratus retrievals as well as Cloudnet in general considering the comments by both Referee #1 and #2**

Detailed responses:

The authors describe the deployment of the Oceanet remote-sensing container during a cruise to the Arctic. Right now it is not clear if the authors want to present technical development or research findings. The authors briefly describe a new motion stabilisation platform and a new data processing method for fog detection. However, they fail to provide a validation that those are working. The remainder of the paper is dedicated to case studies. The paper is of interest to the community but needs major revisions. First of all, the authors need to make up their mind if this should be a paper for AMT or ACP. There are further major items that need to be addressed before it can be considered for publication:

- [Abstract] The Abstract appears to be more of an introduction than a concise summary of the paper. Key points of the article are missing. Please rewrite the Abstract.

We rewrote the paragraph in such a way that it provides a more concise summary.

- [MWR retrieval] One of the major issues with this work is related to the analysis of the microwave radiometer measurements. I do not agree with the assumption that atmo- spheric conditions in the Arctic are comparable with those during winter in the Nether- lands. In the Netherlands the minimum temperature rarely reaches 0◦C; also radiative balance is not comparable. The analysis needs to be repeated with a customised Arctic retrieval. Radiosonde data can be obtained from several research cruises in the Arctic since 1990 and are also available from research stations around the Arctic.

Meanwhile, we reprocessed the MWR data with an retrieval that was created by University of Cologne for the location of Ny Alesund (78.9°N, 11.8°E). We mention this in the revised manuscript. The data will also be uploaded as a new version to Pangaea. Same holds for the depending Cloudnet-processed data set on Pangaea. Fig. 1 shows the correlation of the two data sets. Overall, the correlation is quite linear, especially for the IWV/PRW. Only in the low-LWP range <100 g/m², considerable relative biases can be found.

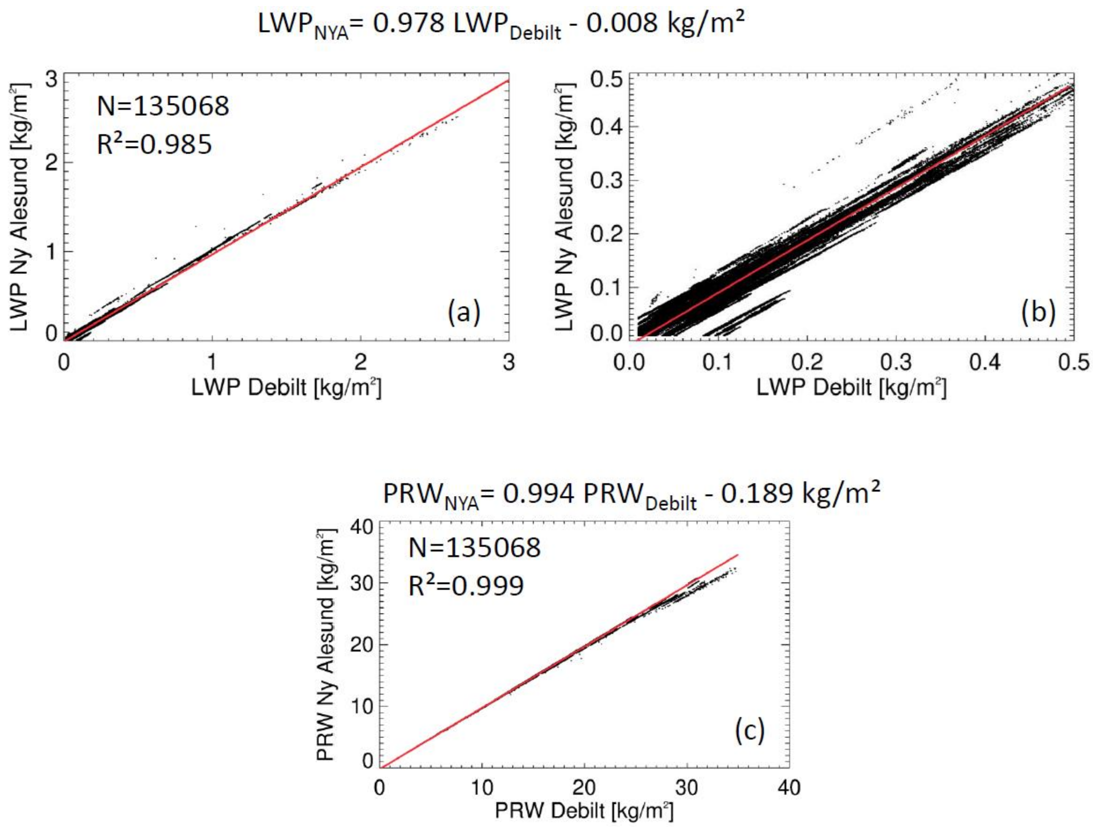

Fig. 1: Comparison of LWP (a, b) and IWV/PRW (b) derived from (unflagged) MWR observations with retrievals from De Bilt and Ny Alesund.

- [Motion stabilisation] The authors should provide proof that the roll and pitch was actively levelled out for the motion-stabilised radar measurement. Please provide a time series of roll angles for the ship and radar during roughest sea and the probability distribution of radar roll angle for at least a 1 h period with greatest ship roll. Further information on the measurement conditions is needed to assess the performance of the motion stabilisation platform. What was the maximum roll angle? What was the ship’s mean horizontal velocity when underway? What was the wave-induced velocity perturbation in open water?

The discussion of the motion stabilization and its influence on the measurements has been improved. We have compared the pitch and roll movement of the Polarstern to the respective measurements of a small single board computer (Beaglebone Blue) mounted on the cloud radar during different periods of the campaign. From the comparison, we conclude that the stabilization was challenging when RV Polarstern cruised through open waters. Under these conditions, the vertical pointing accuracy could be reduced to within 1° off-zenith. While breaking through the ice and during the ice-floe period, the platform stabilized the vertical pointing with an accuracy of 0.5°.

The heave correction was further analyzed and quantified by investigating the Doppler velocity spectrum of the corrected and uncorrected Doppler velocity. The applied heave correction reduced the signal induced by the vertical movement of the cloud radar in the power spectral density of the Doppler velocity by a factor of 15.

- [Eddy dissipation rate] The validation of eddy dissipation rate is not convincing. At what height was the tethered balloon located? Below a cloud or within a cloud? What are the reasons for the over- and underestimation? Also, it would be good to have more than two comparisons cases between the Radar and the measurements with the tethered balloon or to provide justification why this is not done. Please also provide the ÉZ˙ values from tethered balloon and radar for both cases.

We have extended the discussion on the EDR retrieval and included additional information, like the height of the tethered balloon, in the manuscript. The standard variation of the derived EDR values has been calculated to better evaluate the retrieved values. We also added another comparison of EDR between the cloud radar and the tethered balloon. Adding more comparisons is not possible as the measurement strategy of the balloon was not only focused on clouds and therefore no more co-located observations are available.

- [Cloudnet and cloud definition] There are several issues related to the Cloudnet retrieval. Right now it is often unclear what has been done. For instance, the description of the classification mask (Page 13, line 261) does not agree with the shown Cloudnet target classification in Figure 9a. Please provide more details on Cloudnet in general and on the classification mask and the target classification for readers that are not fa- miliar with the method. Further, it is not clear if the presented definition of liquid and mixed-phase clouds (page 12, second paragraph) is an official Cloudnet product such as the target classification or if it is a new data product developed by the authors. In that context, why not use the target classification as in comparable studies based on multi-sensor retrievals? In those, Arctic mixed phase clouds are defined when both liquid/supercooled water and ice particles are present and when ice particles are identified directly below liquid and mixed-phase regions (e.g. Shupe 2011, Mioche et al. 2015). For comparison of cloud statistics from different campaigns it is important to use the same definition as already used in the literature.

We agree with the reviewer that the Cloudnet retrieval has certain caveats. This study presents a calibrated data set of measurements, which is suitable for synergistic retrievals such as Cloudnet. To provide comparable statistics to other retrievals the data set should be processed with the respective retrieval. We adapted our introduction of Cloudnet to the simpler classification mask, which is based on the categorization bits. This classification mask is used in the manuscript in Figures 11(a) and 16(a).

The differentiation between supercooled liquid clouds and mixed-phase clouds at a temperature right below 0°C remains difficult. In the mentioned Figure, a cloud radar pixel was detected right below the cloud. In this situation, it is not possible with present remote sensing methods to differentiate between ice and supercooled liquid. This is only done by dew point temperature. In this case, the cloud top temperature was very close to 0°C and supercooled liquid has been found in Arctic stratiform clouds down to -4°C (Zhang et al., 2017).

- [Fog detection] The information related to the fog detection is not adequate to evaluate if the proposed method works. Please make use of the visibility sensor aboard Polarstern to assess your findings as well as to test if your assumed SNR value of 40 can be used to reliably detect fog. Just as a reminder, fog is defined when the visibility is below 1 km. The visibility sensor can also be used to distinguish between fog and low clouds. In that regard, please compare the detected low cloud layers with the observation of the ceilometer aboard Polarstern. The first height bin is much lower than the first height bin of the Polly system. Also would it not be better to use the ceilometer for detection of fog and low cloud layers? First of all the first cloud layer is lower and the Ceilometer on Polarstern is a CL51 which reports the vertical visibility in case that the lowest height bins are obscured due to precipitation and/or fog?

We decided to change our naming and to call our new product low-level stratus cloud instead of fog. This is closer to reality as the Polly system is only able to observe clouds starting from a height of >50m. To assess whether the SNR of 40 is a reasonable, we made a comparison between the low-level stratus cloud occurrence using three different SNR thresholds in addition to the occurrence of fog by means of the horizontal visibility sensor from Polarstern. Figure 2 shows this comparison. In blue (green) the low stratus occurrence due to a SNR of 20 (60) is indicated. Orange shows the original findings with the SNR of 40. The dashed red lines shows the frequency of occurrence of horizontal visibility below 1 km. The SNR value of 40 was manually found to provide the best visual correlation with the visibility measurements as well as to signatures of signal attenuation in the time-height cross-sections of the Cloudnet attenuated backscatter coefficient and HATPRO LWP measurements (see, e.g., Fig. 4 of this reply letter or Figs. 10 and 14 in the manuscript).

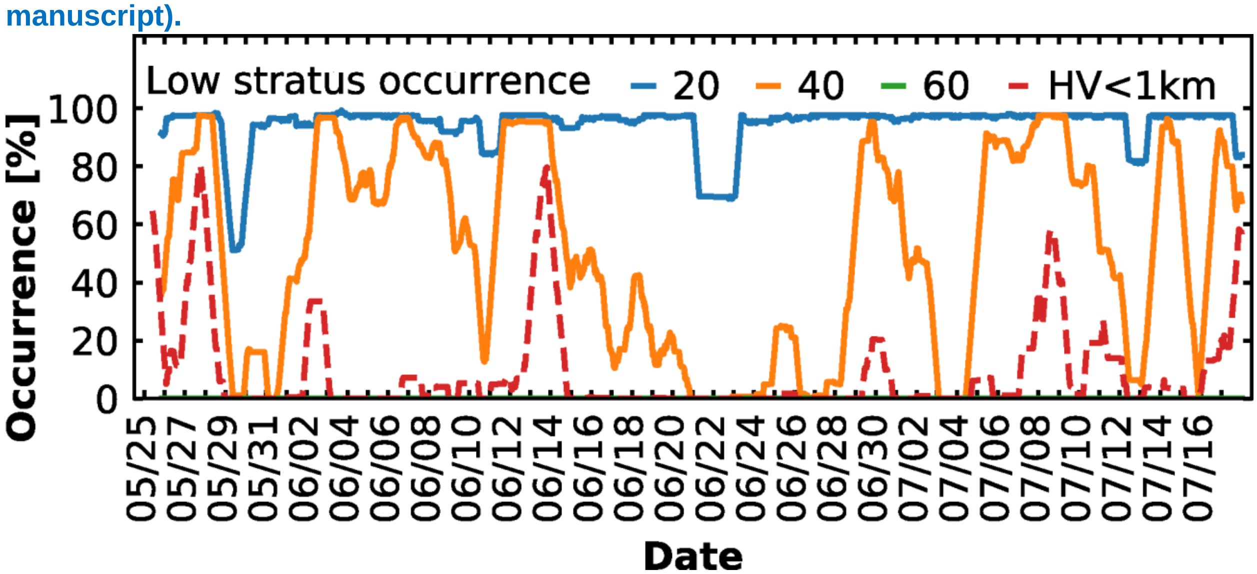

Fig. 2: Comparison of low stratus occurrence due to a SNR of 20 (blue), 40 (orange) and 60 (green) and visibility below 1 km (HV, dashed red).

Minor issues

- Line 88, Please also cite Ehrlich et al. (2019) for ACLOUD

Done

- Line 122: It is not clear if only winter time radiosondes from De Bilt are used in the retrieval. Please clarify. But even better would be to revise the retrieval using actual Arctic measurements.

We used a retrieval the location of Ny Alesund. See answer to major comment above.

- Line 126: An Arctic retrieval based on ERA-Interim data should be compared to a retrieval based on Radiosonde data. Systematic errors in ERA-Interim data (e.g. Wesslén et al., 2014, for temperature bias) can have an influence on the MWR retrieval. Consider using ERA5 instead.

We used a retrieval the location of Ny Alesund. See answer to major comment above.

- line 153: Please provide the typical error range of the RS92 measurements

Done

- line 270: Do you mean T or Td (dew point temperature here).

We deleted this paragraph (but Td was meant).

- line 344: Can you please verify if the mixing depth provided by GDAS1 is comparable to the observed mixing depth. It is known that models have problems to provide realistic mixing depth in the Arctic.

We have removed the mixing depth analysis provided by trace from the study. Nevertheless, we provide ensemble trajectories in Figure 8 in the revised manuscript. There it is well demonstrated that approximately 50% of the ensemble trajectories passed the European continent where they were involved in boundary layer processes, as indicated by the PBLH values of the underlying GDAS1 data.

- line 354: Do you mean Figure 4.1.1? And the profiles are shown to a height of 2.5 km not 2.0 km.

Indeed, we wanted to refer to (old) Figure 4.1.1. We changed the text also to 2.5km.

- line 356: Since ice particles are below the liquid stratocumulus the cloud should be reclassified as mixed-phase cloud (see major comments).

We agree that this is an ambiguous cloud situation. Still we rather stick with liquid or liquid-dominated cloud. See also answer to major comment on the Cloudnet retrieval.

- line 375: As observed by Shupe et al. (2013). Please add citation.

Done

- The figures do not appear in the order they are discussed in the text. Please revise.

Done

- Figure 6b is not necessary and should be omitted.

Figure 6b has been removed.

- Figure 15: Fog and low cloud should have different colours. Again use the visibility sensor to distinguish between fog and low clouds. Add visibility to the plot. Also add the observed backscatter from the CL51 as comparison as an extra plot next to it.

As also pointed out by Reviewer #1, the terminology 'fog' is indeed inappropriate to describe what we intend to detect. We thus renamed the 'fog' flag to 'low level stratus clouds'. This better describes that we aim with our approach on detecting clouds, which are (1) located above the visibility sensor of Polarstern and (2) located below the good-performance-range of the ceilometer CL51 (deployed on Polarstern). The Figure below (Fig. 4) demonstrates this approach and the advantages. Figure 4(a-d) present cloud parameters as derived from the CL51 ceilometer observations aboard Polarstern during the time period from 07 Jun 2017, 21 UTC to 08 Jun 2017, 09 UTC. Figure 4(e) shows the combined Cloudnet (>165 m) and PollyXT-based (<165 m height) cloud masks and periods of fog (horizontal blue lines) as derived from the on-board visibility sensor of Polarstern (which is Figure 17 in the manuscript). Figure 4(f) shows the liquid water path as measured by the microwave radiometer HATPRO of OCEANET. The figure demonstrates nicely the situation that frequently occurred: Almost for the whole time period CL51 shows a cloud deck, confirming that there were actually clouds present. However, the reported cloud base is continuously above 150 m height during most of the time. Even when the visibility sensor indicated fog (22:00-23:30 UTC on 7 June), the ceilometer cloud base was >200 m. The ceilometer also reports clouds at heights, where the combined lidar + cloud radar cloud mask from Cloudnet does not show any clouds at all. This is especially visible in the time period from 05-08 UTC on 8 June. This means, that the actual cloud base must have been located lower than the lowest height of Cloudnet. And this is when the lidar data of PollyXT is of help: The threshold of SNR>40 provides a good and reasonable estimate of the actual cloud boundaries at heights <165 m .

We decided to not do a detailed discussion of the issues of the CL51 within the manuscript. However, from our observations it is clear, that the reported cloud bases from the CL51 are continuously too high, at least in situations with very low clouds present. We hope that Figure 4 demonstrates well to the reviewers that the new cloud mask from PollyXT is valuable. The cloud mask will also be published in Pangaea to provide other users a good estimate of the low-cloud occurrence - a very important parameter for the radiative and water balances.

- Figure 17: How is fog height determined? That needs to be discussed in 3.3.3. Add visibility to the plot.

The low level stratus height was determined by the lowest and the highest PollyXT pixel of the low level stratus mask, which exceeded the SNR-threshold. We added a flag to indicate periods of horizontal visibility < 1 km in Figure 17.

- line 500, e.g. Sotiropoulou et al. (2014) and (2016) considered low clouds from ceilometer/Halo and radar measurements.

We have considered their findings in our discussion.

- Line 762: Somag, the provided link does not work. Please provide an open link or add the information to the text.

Done

- Figures 7, 10 (upper panel), and 13: Please use same scale for T and RH in all plots.

Done

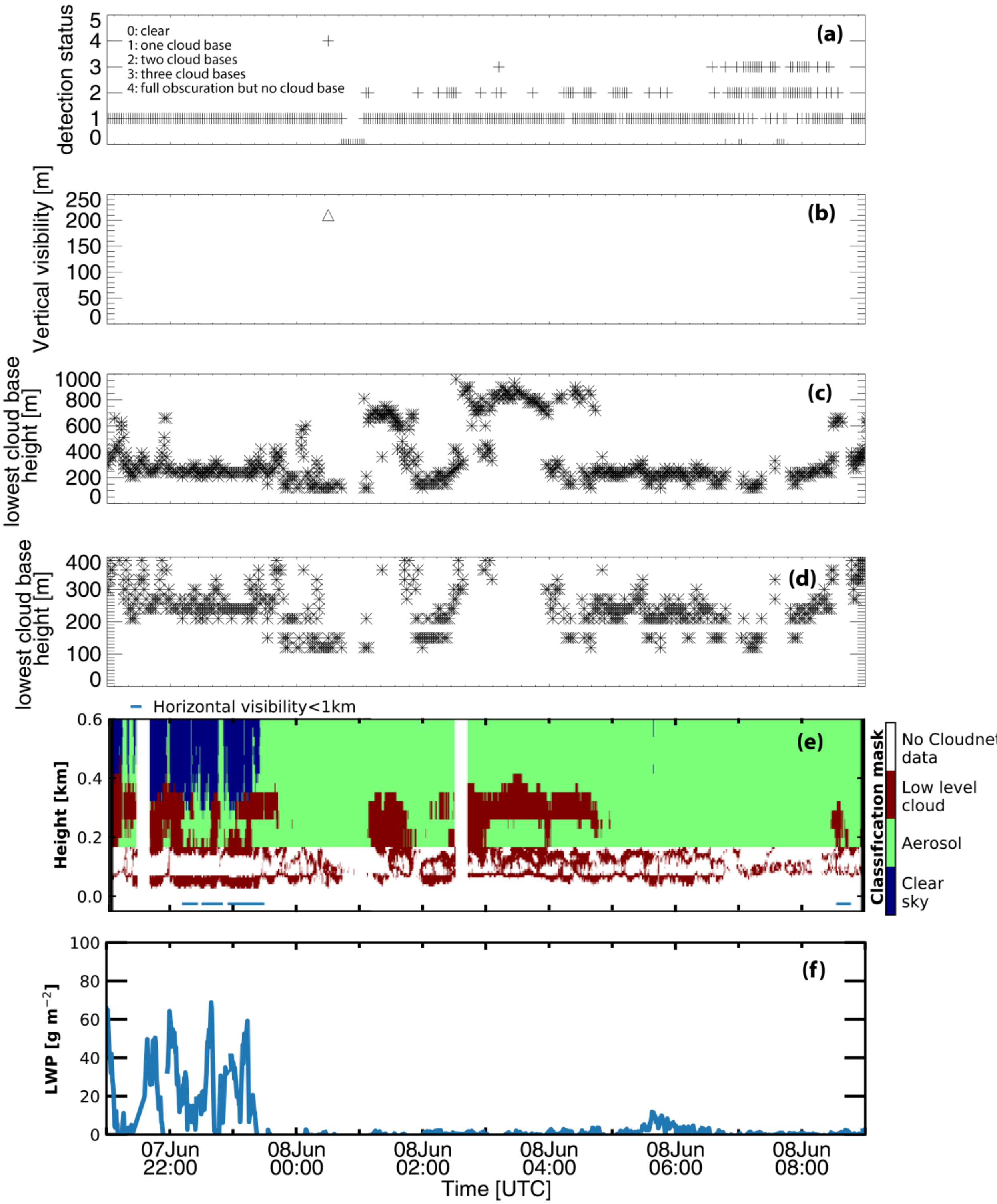

Fig. 4: Comparison of ceilometer-derived cloud bases, PollyXT 'low stratus' detection mask and visibility sensor for the Polarstern observations from 07 Jun 2017, 21 UTC to 08 Jun 2017, 09 UTC. (a) Detection Status of the CL51 Ceilometer; (b) vertical visibility from CL51 (if detection status equals 4); (c) and (d) height of lowest cloud base from CL51; (d) Cloudnet cloud and aerosol mask (above 165 m), PollyXT low-stratus mask (below 165 m) and fog-periods (horiz.

blue lines) as derived from the visibility sensor; (f) liquid water path as derived from the microwave radiometer HATPRO.

References:

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