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 #1 (16 January 2020)

We would like to thank the Anonymous Referee #1 for spending time in order to provide us with fruitful comments and suggestions and thus to help us to improve the manuscript. The initial submission has been adapted, and we 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 Referee #1 and #2**
- **Included a better evaluation of the capabilities of the motion stabilization according to comments by both Referee #1 and #2**
- **Improved the discussion of the eddy dissipation rate and fog/low-stratus retrievals as well as Cloudnet in general considering the comments by both Referee #1 and #2**

Detailed responses:

This paper presents the instruments deployed on the icebreaker Polarstern and close by on a temporary ice-camp and results obtained during a summer cruise performed in the frame of the AC3 German project in 2017. Several remote sensing equipment, including a motion-stabilized 35-GHz cloud radar were deployed and combined with meteorological observations in high Arctic. This experiment concurred to a very important goal on a better documentation and understanding of Arctic change, through the presentation of a campaign and results obtained to better document Arctic cloud forcing. After introducing the context, this paper first gives a general description of the instrumentation deployed on board the ice-breaker Polarstern and on the ice camp, technical challenges, new developments, analysis methods and results obtained during the campaign. It finally focuses on case studies.
Two main points are highlighted in the paper which are 1) the first involvement of the cloud radar Mira-35 and the development of a motion stabilization system to ensure stable observations. Corrections and results obtained from vertical wind spectra to derive on the turbulent kinetic energy eddy dissipation rate (EDR) are presented; 2) the focus on low-level clouds and the presence of fog from synergies of lidar and radar within Cloudnet, and the retrieval of radiative cloud properties.

The topic is of importance to the community. The paper is clearly written, and presented in a very comprehensive way. The context of the paper is well introduced although additional general information should be given on existing surface based observations. The two main points presented also need some additional information and discussion. The paper is worth publishing after minor revisions are made. They are addressed here below.

Detailed comments Page 2, line 27 : "decline of the Arctic sea ice" precision to be added on period of the year (summer ?) or ice type (multi-year sea-ice) ?
We added details "This is observed as a change of several parameters such as the drastic decline of the Arctic sea ice during all seasons, but especially in summer, in both extend and thickness".

Page 2, line 45-47 : Arctic observations refer to aircraft and shipborne measurements, but Arctic ground-based stations should be discussed (IASOA network, Uttal et aL, BAMS 2016 DOI:10.1175/BAMS-D-14-00145.1) in which remote sensing instruments are implemented at Barrow (Dong et al., 2010, doi:10.1029/2009JD013489, Eureka (Blanchard et al., JAMC 2014 doi: 10.1175/JAMC-D-14-0021.1) for example. Drifting buoys have also recently been equipped in the high Arctic with lidar in the frame of the IAOOS project (DiBiagio et al., JGR 2018, doi: 10.1002/2017JD027530 ; Mariage et al., Opt. Exp. 2016, doi: 10.1364/OE.25.000A73).
We extended the discussion about ground-based stations and buoy observations, as requested.

Page 2, line 54, replace by a more recent reference Winker et al., BAMS, 2010, doi:10.1175/2010BAMS3009.1.
Done

Page 4, line 88 : Figure 1 legend : mark days also on the track in the upper figure
We added some dates for orientation also into the top subfigure of Fig. 1.

Page 4, line 94 : mention if Polar measurements have already been performed ?
We added information about previous cruises.

Page 5, lines 103 and 104 : 532 instead of 512 ?
Corrected

Page 5, line 110: "allow to determine the shape" this is too strong a statement. As the authors write further in the text, it allows to discriminate shape between spherical and non-spherical particles, but several shapes can give the same depolarization ratio
We rephrased the respective passage in the text and provide references to the available applications of polarization measurements.

Page 6, lines 125-26 : the authors "do think that the atmospheric conditions in summer in the Arctic are comparable to those in winter in the Netherlands ". I don't think so. Surface temperature are close to zero over ice and surface-atmosphere interactions are different
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 dataset on Pangaea. Fig. 1 shows the correlation of the two datasets. 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.

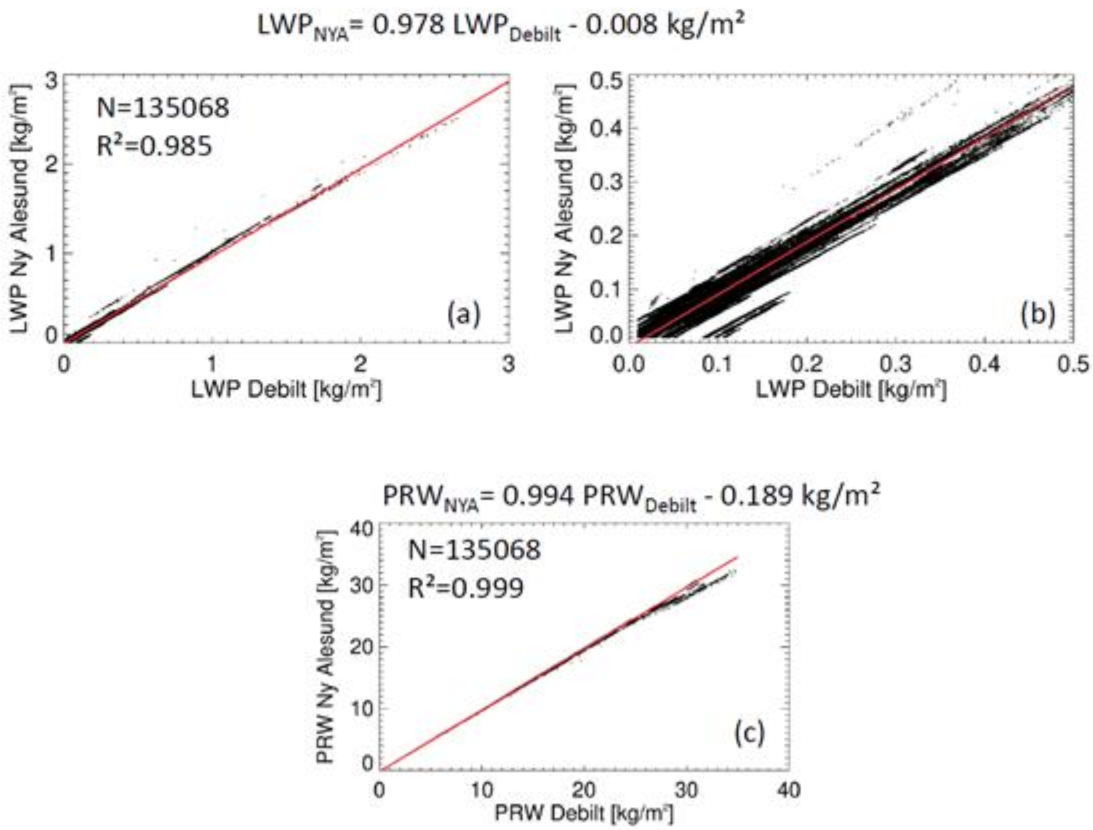

Fig. 1: Comparison of LWP (a, b) and IWV/PRW (b) derived from (unflagged) MWR observations with retrievals from De Bilt and Ny Alesund.

Page 7, Table 1 : Add information on the auxiliary measurements (tethered balloon, sonic anemometer, pyranometers, ...)
Done

Page 8, Figure 3 legend : extend period limits on the vertical with dotted lines
Done

Page 10, Figure 5: put the histograms outside the figure so to better see the full 2D plot
Done

Page 10, line 194 to 246 : Extend discussion on error induced by the correction. What is the expected in terms of residual contribution ? What bias is to be considered in the sigma correction, and error induced as an additional error. This can be discussed from the spectrum shape, errors and confidence in the limits of analysis to be used. Present/discuss more in detail the corrected spectrum in section versus non-corrected one and versus the sonic anemometer one.
We have extended the discussion and used the Fourier analysis to further quantify the effect of the heave correction.

Page 11, line 230 : typo vertical
Corrected

Page 12, Figure 6 shows linearized fit from sonic only, what would be the one from corrected spectrum ? Discuss values retrieved from the range of the fit identified from the residual errors and confidence in the correction.
We added the spectrum for both cloud radar Doppler velocity and sonic. Also we calculated the standard deviation of all good fits to estimate the uncertainty of the approach.

Page 12, Figure 6 legend : refers to values of EDR, but hypotheses for deriving EDR from radar should be more discussed (see above).
First, we have removed the subfigure 6(b) as suggested by Reviewer 2. Concerning the approach of EDR retrieval from radar data, we provide an extensive introduction to the topic in Section 3.2.1.

Page 12, line 251 : Iacono et al., 2208, is not a general reference for RRTMG. This ref is to be replaced by a more appropriate one.
We replaced the reference by Mlawer 1997, Barker 2003 Clough 2005.

Page 13, line 288 : It is OK here, but more generally for Arctic clouds I am not sure of that, as for supercooled precipitating clouds
We removed the respective sentence about liquid water attenuation.

Page 14, line 310 : a strong attenuation
Done

Page 14, line 318 : I would suggest to use scattering ratio Sr as well, which would further allow to discuss fog issue using lidar measurements only assuming a threshold in Sr
Dealing with lidar signals in the very near range (below 300m) is bound to the presence of technical caveats. Mainly, it is the incomplete overlap of the receiver-field-of-view and the laser beam. Derivation of physical values, such as SR or att. BSC, from single-channel elastically backscattered light is thus impossible very close to the ground, even for the near-range channels of PollyXT (complete overlap at 120 m). We thus decided to rely on the utilization of the technical value SNR for the detection of the cloud layers below 50 and 160 m height, which delivers very good results.

Page 15, line 348 : I would suggest to extend presentation here and discuss meteorological context change to introduce cases studies and overall meteorological patterns observed leading to the various cases analyzed. I would suggest to move Figure 11 here and briefly discuss more general transport evolution over the period studied (not necessarily adding a figure).
We added an introduction to the overall synoptic situation based on Knudsen et al (2018) who gave a synoptic overview of the PS106 campaign.

Page 20, Figure 10 : I would suggest to present lidar scattering ratio instead of backscattering coefficient (to better support aerosol/fog/cloud discrimination).
The provided attenuated backscatter coefficient is a standard product of the Polly-XT processing chain (Baars et al., 2017). We thus would like to keep this parameter presented in Fig. 12 (version of Figure 10 from before the revision), as it is the default lidar parameter in Cloudnet and as we show it as standard parameter in other publications.

Page 23, and 24 : Synergies between the remote sensing instruments and auxiliary observations from aboard Polarstern were analyzed by means of Cloudnet classification procedure. This procedure is shown to induce caveats because of limitations in the radar range measurements. More discussions on the way this could be mitigated using lidar measurements should be included.

We extended the discussion of the caveats of Cloudnet and our approach to address them with the lidar measurements.

Page 23, lines 429-432 : PollyXT "Though detected fog almost continuously during the case study, : : :". How is this done ? Explain in the text how this can be translated in an additional information below 165 m in a quantitative way from scattering ratio.

As also pointed out by Reviewer #2, 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. 2) demonstrates this approach and the advantages. Figure 2 (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 2 (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 2(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 2 demonstrates well to the referees 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.

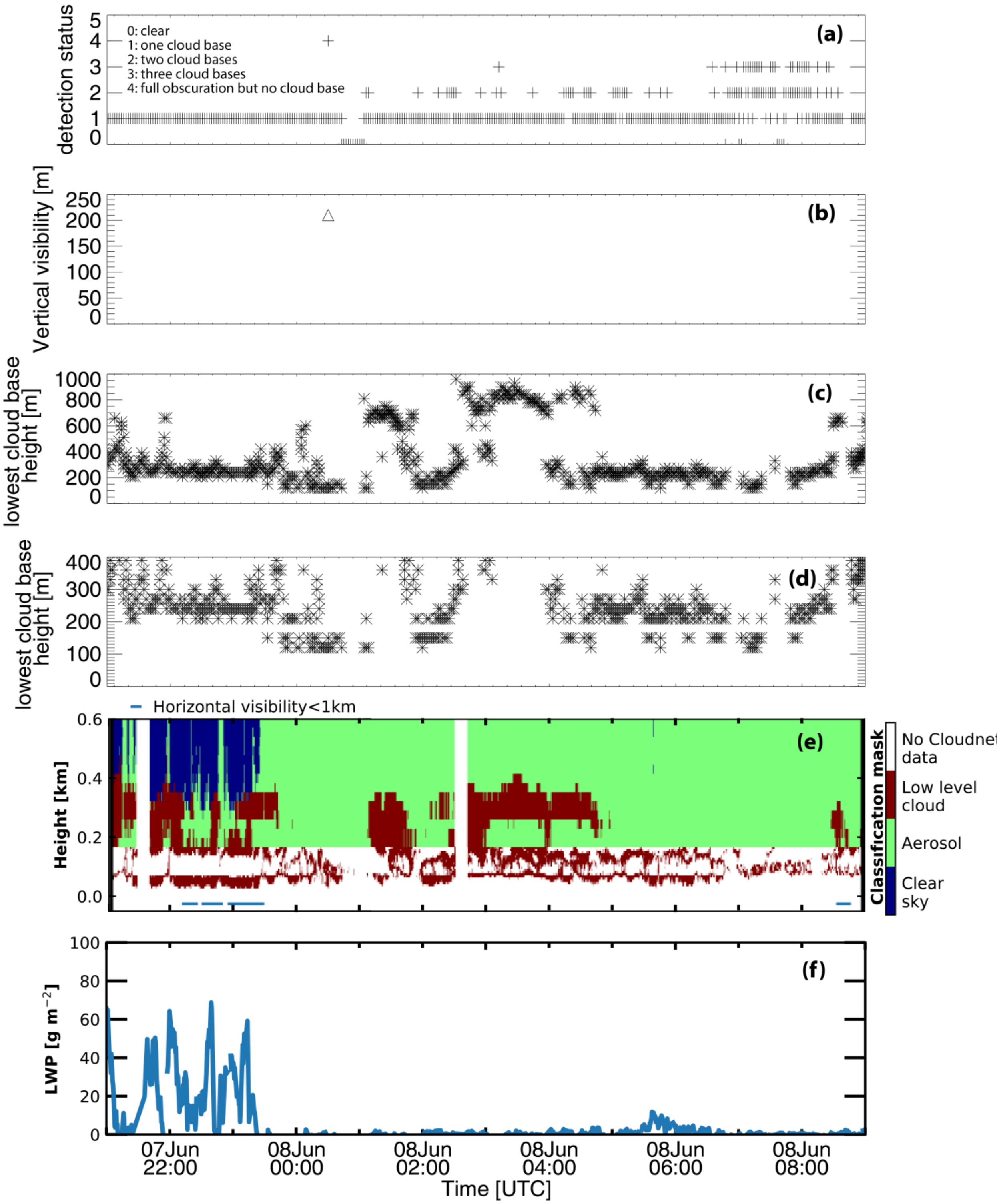

Fig. 2: Comparison of ceilometer-derived cloud bases, PollyXT 'low stratus' detection mask and visibility sensor for the Polarstern observations from 07 Jun 2017, 21 UTC to 08 Jun 2017, 09 UTC. (a) detection Status of the CL51 Ceilometer; (b) vertical visibility from CL51 (if detection status equals 4); (c) and (d) height of lowest cloud base from CL51; (d) Cloudnet cloud and aerosol mask (above 165 m), PollyXT low-level 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.

Page 24, Figure 15 : Blue color below 165 m shows occurrence of clear air <165m. It is thus misleading as no information is available from Cloudnet. Should be another color corresponding to unknown (white?) instead of blue below 165 m in Fig 15. Could be replaced by dots corresponding to fog color on a white background from the discussion on fog detection by lidar only.

Done

Page 24 line 435 : "above the fog layer" meaning well above !

Changed 'above' to 'well above'.

Page 28, lines 509-510 : Yes, frequently observed from surface-based IAOOS observations as reported in Mariage et al., 2016

We included their findings in our discussion.