Response to Reviewer 1

We sincerely appreciate the reviewer's suggestions and careful reading of the manuscript. Our responses to his/her comments are listed below (in blue):

1) The authors state that the RSP r_e retrievals are at 2.26 μm (line 105, page 4). I could not find information about retrievals at 2.26 μm using the polarimetric technique in the various references. The authors should give more details about the retrieval technique, and perhaps explain why this channel was chosen to retrieve r_e.

We appreciate the reviewer's help in finding this error in the RSP description. The reviewer is correct in that RSP r_e is not derived using the 2.26- μm polarized channel. Instead, the retrieval is derived from the 0.865-μm polarized channel (see Alexandrov et al, 2012, section 3). We have rewritten the RSP description to read:

"Flight level (~ 7 km ASL) solar polarized and unpolarized reflectance measurements taken at 0.865 μm from the airborne NASA GISS RSP while above cloud were used to derive r_e and τ"

More details about the technique are provided in our response below.

2) How do the authors justify that the RSP r_e retrievals at 2.26 μm are mostly sensitive to the cloud top (optical depth ≈ 1) (lines 176-177, page 6)? Based on the work by Platnick (2000), they state that 3.79-3.9 μm satellite r_e is representative of about 2 optical depths down from the cloud top (line 161, page 5). Stating that the RSP retrievals at 2.26 μm are weighted higher in the cloud than the satellite retrievals at 3.79-3.9 μm seems inconsistent with Platnick (2000). Please explain.

The RSP retrieving technique substantially differs from the standard satellite visible bi-spectral reflectance technique. That is, the photon penetration principle described in Platnick (2000) for MODIS-like retrievals is not applicable to the polarization technique. Briefly, The RSP views the same target at different angles around the rainbow scattering (~137-165˚), allowing for multiple polarized reflectance measurements for the same target (see Section 2.1). Thus, the algorithm for retrieving RSP r_e exploits the shape of the polarized reflectance as a function of scattering angle. It has been shown that the shape of the polarized reflectance can be modeled as a function of scattering angle, cloud droplet effective radius, and effective variance of the droplet size distribution (via Mie calculations). As the polarized rainbow is typically a single scattering phenomenon, this is generally limited to the uppermost cloud layer. Numerical results in Alexandrov et al. (2012, in the reference section) confirm that RSP r_e is sensitive to a cloud layer with an optical depth of around 1.0 from the cloud top. Regarding the use of RSP polarized reflectance based from other channels, differences in the retrieved r_e are within 0.6 μm (Alexandrov et al., 2012), with differences primary influenced by the strength of the polarization signature, which tends to be weaker for longer wavelengths. In the revised manuscript, we corrected the description of the RSP algorithm.

3) I believe that a discussion regarding the expected differences between retrievals at 2.26 μm (RSP) and 3.70-3.90 μm (satellites) is missing.

As discussed in our previous response, the physical principle that enables the derivation of r_e using RSP is different from the bi-spectral method applied to satellite imager observations. We have added the following sentence to emphasize the different technique.

" Lastly, we note that the algorithm for deriving satellite r_e differs from the RSP algorithm, in that satellite-based r_e relies on the dependence of shortwave-infrared unpolarized reflectance on r_e (and an assumed value for effective variance, with reflectance monotonically decreasing with r_e), whereas RSP is based on the dependence of the polarized reflectance on the scattering angle, r_e, and effective variance near the rainbow."

4) The authors state that post-deployment evaluation of the CDP probe showed that there was an overcounting of droplets for all bins (lines 94-96, page 3) and that as a result, CDP could provide only r_e, but not water content, extinction coefficient, and cloud droplet number concentration. Therefore, I don't understand how the authors could determine the $\tau=2$ altitude level from the top to determine CDP cloud-top r_e (lines 166-167, page 5). Please explain.

The reviewer raises a good point. Uncertainties in the sampling area are expected to be much less than 50 %. This uncertainty would propagate to cloud droplet number concentration as well as extinction and water content, yielding similar relative biases. We tested $\tau=1$-3 (a range that is larger than the expected uncertainty in the measurements) and the results were nearly identical for cloud droplet effective radius (± 0.1 μm). In other words, the optical depth threshold is insensitive to the overcounting issue with the CDP probe. We have added the following sentence to explain this point:

"The r_e calculation is minimally sensitive to the τ threshold and CDP overcounting as variations of 1.0 and 3.0 (a range larger than CDP overcounting uncertainty) yield changes in r_e close to 0.1 μm"

5) The authors mention the presence of supercooled liquid water clouds during the cold months when they present the airborne observations (line 85, page 3), and in the conclusion, they state that both supercooled and warm boundary layer clouds are a climatological feature (lines 331-332, page 10). However, I do not see any discussion on this topic in the presentation of the results. Why is this important? Are the comparisons different for supercooled and water clouds? Please develop.

Given the increasing interest in supercooled clouds and their importance in climate sensitivity simulated by models (e.g. Zelinka et al. 2020, GRL, https://doi.org/10.1029/2019GL085782), we briefly mentioned the supercooled cloud presence during periods of the NAAMES deployment. From a remote sensing perspective, supercooled liquid and warm clouds are treated in the same by the algorithm in terms of their optical properties.

Specific comments

Abstract, line 18: I suggest specifying in the abstract which GOES-13 and MODIS (Aqua and Terra) products are used for the study.

Done, thanks

"Satellite retrievals of cloud droplet effective radius (r_e) and optical depth (τ) from the Thirteenth Geostationary Operational Environmental Satellite (GOES-13), and the MOderate resolution Imaging Spectroradiometer (MODIS) onboard Aqua and Terra, based on the Cloud and the Earth's Radiant Energy System project algorithm,.."

Introduction or where relevant: please define "effective radius".

We added the following description in the introduction:

"cloud effective radius (r_e, the ratio of the third to the second moment of the droplet size distribution)"

Lines 70 and 84, page 3: I found that Fig. 1 was not very informative because too small. I would suggest 1 panel per campaign with the associated mean Aqua "cloud cover". It looks like the caption should actually say "low cloud fraction".

We modified the figure following the recommendations of the reviewer. Given the main focus of the paper, assessment of satellite retrievals for overcast scenes, a detailed description of cloud variability during the three NAAMES campaigns is beyond the scope of our study.

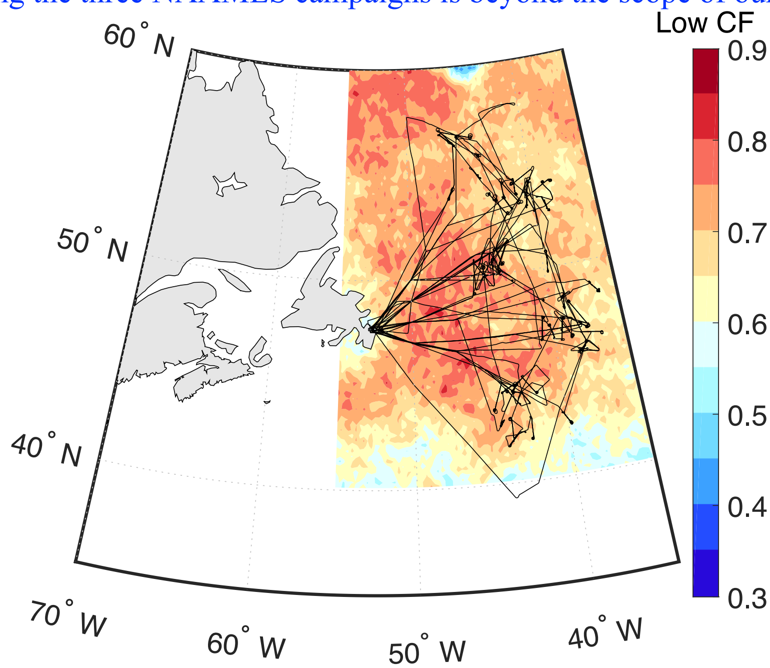

Figure 1: Mean Aqua-MODIS low-cloud cover and aircraft tracks (black lines) during the three NAAMES campaigns in November 2015, May 2016, and September 2017.

Line 85, page 3: please explain how RSP data could confirm the presence of supercooled cloud tops during the cold months. During which campaign(s)?

Supercooled clouds typically occurred during the November campaign (2015). As the rainbow is a signature of liquid droplets, as long as the cloud temperature is below 0˚C and the RSP observes the rainbow, the cloud can be identified as being formed by supercooled clouds at the cloud top. We added the following sentence to explain this:

"…and corroborated by NAAMES RSP data as the presence of a rainbow (observed in cloud tops with liquid droplets) was prevalent during the three deployments."

Line 150, page 5: Please describe the CERES SSF product and provide a reference.

In the revised version, we added the following sentence:

"The MODIS cloud products evaluated here are identical to the ones used to generate the CERES Single Scanner Footprint (SSF) product. SSF includes top-of-the-atmosphere radiative fluxes from the CERES instrument and MODIS cloud retrievals (CERES algorithm) averaged within the CERES footprint (~20 km, Loeb et al., 2018). Here, we use pixel resolution CERES-

MODIS retrievals (1 km x 1 km at nadir and 4.8x2 km at the scan edge) subsampled every other pixel, due to computational constraints, to achieve an effective 2 km x 2 km resolution at nadir."

Line 193, page 6: The authors give an overview of the cloud vertical structure during the campaign. Is it for only one of the 3 campaigns? If yes, which one? Please clarify. Should results for warm clouds and supercooled clouds be shown separately?

Again,

The reviewer is correct, the profiles were constructed using data from the three campaigns (this is clarified in the revised version). Since the occurrence of supercooled and warm liquid clouds is not relevant from a remote sensing perspective, we decide to not include such analysis.

Line 195, page6; Fig. 3: the authors state earlier in the text (lines 86-87) that cloud sampling was limited to boundary layer liquid clouds with a mean cloud top height of 1376 m±602 m (± standard deviation). What about cloud base?

770± 363 m. The value is now reported in the revised manuscript.

Lines 287 to 290, page 9: this discussion is difficult to follow without an illustration or at least a reference.

Rather than repeating schematics that are available in the literature, we now cite Figure 1 in Marshak et al. (2006, in the reference section).

Lines 321-322, page 10: please explain how the effective variances shown in Fig. 12 (not Fig.11) were retrieved. Is it from RSP or CDP?

Figure 12 was derived from the CDP probe using the following formula:

$$v_{eff} = \frac{\int_0^{r_{max}} (r - r_e) r^2 n(r) dr}{r_e^2 \int_0^{r_{max}} r^2 n(r) dr}$$

The definition of effective variance is now included in the manuscript.

Technical comments:

Line 140, page 5: "east-west" => could be rephrased.

We slightly rephrased the sentence to read:

"Imager is approximately 3.2 km x 9.3 km for the east-west (zonal, 3.2 km) and meridional (9.3 km) components, respectively."

Line 321-322, page 10: Fig.11 should be Fig. 12

Corrected, thanks.

References: the format does not seem compliant with AMT specifications.

We appreciate the reviewer's comments. The revised manuscript lists the references with the appropriate format.