Reviewer Report for egusphere-2024-540

Paper Summary

This study in investigates cloud property sensitivities of two IR BTD cloud phase tests based on simulations of SEVIRI radiances at three IR window channels. The authors rigorously delineate the role of cloud phase, Reff, tau, and ice habit which are related to the spectral differences in bulk single scattering properties when those cloud parameters are changed. The study focuses on a single ocean scene with a fixed Ts and atmospheric profile. The authors also investigate the connected roles of CTT and the non-linear radiance-to-brightness-temperature conversion on the BTDs. Both nonlinearity effect and decrease in CTT introduced positive BTDs. The BTDs showed most sensitivity to CTT, followed by tau, the BTD non-linearity effects and spectral dependent single scattering properties of ice and liquid that change with particle size and ice habit assumptions. Sensitivity studies are also performed using the bounding properties (e.g., tau, CTT) of realistic mid-latitude cloud properties. The author's also compare their BTDs with SEVIRI observations to further justify the realism of the BT spectra. Overall, the study illustrates that BTD-based phase retrievals are complex, and the factors influencing the BTD are not only due to differences in cloud microphysical properties and optical depth.

Review Summary

This paper is well written and well thought out. In terms of justifications for this study (as written in the intro), the modeling methods, and the overall conclusions, I do not have many comments. The results of the study also seem very reasonable and the author's explain them in a lot of detail. In fact, I would even suggest trying to reduce some detail and possible redundancies in the results section. The results section was a bit hard to get through, mainly in differentiating sections 5 and 6. The comments below should clarify some of my confusions regarding the results section. Overall, this is a solid paper and I recommend it for publication after the relatively minor comments below are addressed by the authors.

Major Comments:

1. I believe the title of the paper could be modified slightly to better align with the methodology of the paper and be more specific and accurate. I suggest replacing "*information content*" with "*sensitivity analysis*" in the title. "*Information Content*" may give the reader the impression that a mathematical information content analysis will be performed with a metric such as the commonly used Shannon Entropy (Shannon & Weaver [1949]). Also, since the study is only focused on a particular ocean case with a standard US atmosphere, it would be beneficial to write something like "*Over Mid-Latitude Oceans*" into the title. Additionally, "*with respect to cloud phase"* seems slightly misleading, since a number of cloud properties are examined, not only phase. The sensitivity study seems more comprehensive than just the role of cloud phase in the BTDs. I suggest changing the words "*cloud phase"* to something like "*cloud phase and other properties".* I think it would improve the title's accuracy and scope.

2. Sections 5 and 6 appear to perform very similar analyses and they could be consolidated into a single section in order to avoid confusion for the reader. For example, figure 8 shows BTDs for a range of ice cloud CTTs, which are nearly identical to the realistic

range of CTTs for ice clouds used in Section 6. It seems that Section 6 is providing (1) an emphasis on the BTDs expected for the realistic boundaries of observed cloud properties and (2) comparisons of the BTDs together over the range of realistic cloud scenes (e.g. Figure 10). If that is the case, please make that clear as you transition from Figure 6-8 to Figure 9 and beyond.

3. The title of section 6.3 in the main paper is somewhat confusing, because a "*generalization*" of the findings would presumably include more discussion than just for cloud geometric thickness and viewing geometry effects on BTDs, in my view. A simple way to address this issue, is to change the title of the section to reflect the specific content of this subsection (i.e., cloud thickness and viewing geometry). Furthermore, I am not sure how much value the cloud geometric thickness discussion adds to the paper overall, as this should be including more vertical variations in temperature and humidity within the cloud layer, which does not appear to be in the scope of the paper. I recommend removing the discussion on geometric thickness in section 6.3, and moving the satellite viewing geometry discussion to the appendix.

4. On line 548, the author's write "*Overall, we expect the BTDs to be useful in retrieving mixed-phase cloud*". It is well known that identifying mixed phase clouds with passive remote sensing is extremely challenging, if not impossible in some cases. The author's state on line 544: "*We expect the BTD values of mixed phase clouds to lie between ice and liquid values, as they represent a transition between the two."* The mixed phase cloud BTDs being in between the ice and liquid BTD solution spaces introduces ambiguity when trying to differentiate between liquid, ice and mixed phase clouds using the BTD approach. Furthermore, mixed phase clouds can exist at the temperatures in which both ice and supercooled liquid clouds can exist, which further complicates the use of BTDs for mixed phase cloud classification (based on the relationship between CTT and BTDs). I suggest that the author's further justify in the conclusion their claim that the SEVIRI BTDs can be used for identification of mixed phase clouds or modifying the statements in the conclusion that speculate on mixed phase cloud classification success.

5. Throughout the paper, the sensitivity of BTDs to CTTs is emphasized, and rightly so. However, the sensitivity to CTT is more accurately described as a sensitivity to the thermal contrast between the cloud top and surface if I am not mistaken. In polar regions, for example, the thermal contrast tends to be very low and CTTs can be low as well, and this BTD approach becomes less useful. I suggest that the authors make sure to emphasize the cloud-surface-temperature contrast impact (in addition to CTT) clearly in the abstract and conclusions of the paper.

6. I recommend adding a clear statement in the conclusion that emphasizes that the study focuses on a single ocean scene with a fixed atmosphere, and the results shown could change depending on the scene (e.g., Tropical vs. Subarctic). This can be followed by a brief discussion how variations in surface types (surface emissivity), surface temperature, and atmospheric temperature and humidity (discussed already in the results section) may impact the conclusions of the paper. The results of the paper already provide information

for this additional discussion, and the inclusion of this would make the paper more complete, in my view. A few sentences would be sufficient.

Minor Comments:

1. Figure 3: Can the authors place a horizontal black line to the left of the "tau=0.5" in the upper left legend of panel a? That would make a clear connection between the tau value and the black curve. It would also be beneficial for the reader if the authors added the CTT for the lower radiance curve B(CTT) to the figure, as this can provide context for the lower panels. Also adding the BT values to the figure (for the SEVIRI channels) with the corresponding colors would help readers to better understand the arguments being made.

2. Table 1: Can you include the total column water vapor amount for the US standard atmosphere? It would be useful for context when "switching on/off" molecular absorption.

3. Line 247: "*This means that for a given τ in the figures the water content is held constant for the scenario with and without scattering*". I'm not sure why the water content statement is there, because changing the water content would change the physical cloud. Optical thickness is the quantity being held constant here for each scattering scenario.

4. Figure 5: It would be beneficial to include something like "*w/scattering*" for the lower panels, just for the reader's benefit. Or the panels can be arranged to have no scattering on one column and w/scattering for the other column.

5. Line 435: "*about −2K in the figure*". What figure are the authors referring to?

6. Figure 10: It could be beneficial to include example BTD threshold lines or joint BTD solution spaces for liquid and ice phase here (perhaps from one of the BTD algorithm references that were cited in the intro). This gives the reader an intuition for how the BTDs are typically used for phase classification, and how confounding factors like CTT may lead to shifts into or out of ice and liquid BTD solution spaces. It also provides clarity on why mixed phase cases are so difficult with this method.

7. Did you use SEVIRI spectral response functions in your radiative transfer simulations? If so, please specify. If not, please mention that in the radiative transfer methods section.

8. Section 5.1: Can the authors make a comment on why you did not use different habits in the scattering sensitivity analyses? The overall conclusions may not change, but a sentence mentioning how the results would change if the ice habit was changed would be helpful.

9. Line 87*: "These findings help to better understand and improve the working principles of phase retrieval algorithms".* To be more accurate, could the authors write as "*brightness temperature difference phase retrieval algorithms*"?

10. Figure 6: Above the panels, could the authors use CTT instead of CTH? Using CTT provides the readers for more relevant context, as the results can be compared to other figures with the same CTT as used in this Figure. I recommend doing this for other figures that may show CTH instead of CTT.

11. Line 438 "*Overall, the phase information contained in BTD(8.7-10.8) comes mainly from its sensitivity to CTT for clouds with* $\tau \lessapprox 10$ *and from its sensitivity to CTH".* Since the CTH and CTT are directly correlated in the authors experimental setup mentioning CTH here seems redundant.

12. I suggest writing units into relevant figure legends where they are missing, or specify in the captions (e.g., Reff legend values in Figure 6).

13. Line 546: When the author's write "*Therefore, if the CTT/ CTH and Reff values are similar between liquid/mixed or mixed/ice…".* I am not sure what the author's mean by liquid/mixed and ice/mixed here. It doesn't seem to be defined anywhere in the paper. Please clarify.