## Response to Anonymous Referee #1 Interactive comment for ‘Application of infrared remote sensing to constrain in-situ estimates of ice crystal particle size during SPartICus’ by S. J. Cooper and T. J. Garrett

**Overview comments: The reviewer states ‘It was found that remote sensing results are in general agreement with in situ observations. Based on these case studies, the authors argue that their remote sensing method is reliable and can therefore be used to retrieve whether and how many small ice particles (with) re<20 um) exist in thin cirrus clouds.’**

It is important here to note that we did not use the in-situ measurements in attempt determine if our infrared bi-spectral method was ‘reliable’. In fact, we did the opposite. We used our infrared bi-spectral retrieval scheme in attempt to determine the validity of the in-situ measurements. This infrared bi-spectral scheme, presented in our previous paper Cooper and Garrett (2010), was based upon a detailed uncertainty analysis and was designed to confidently identify the presence of small ice particles with effective radius less than 20 μm. Our idea simply was to identify those infrared radiometric signatures that could only be associated with small particles less than 20 μm, regardless of any potential inversion uncertainties such as ice crystal shape, ice particle size distribution, atmospheric profile, or errors in cloud temperature. Given such a retrieval scheme, we could then use it as a constraint on in-situ measurements to determine if observed small particles may be the result of shattering events during the invasive measurement process or if they may have formed through natural mechanisms.

**General Comments: ‘My major concern on the present study is whether it tells us anything meaningful given the fact both in situ measurement and remote sensing are subject to big uncertainties and they are quite different in terms of sampling volume. I understand this is a philosophical question and difficult to answer.’**

We agree with the reviewer that inherent uncertainties in both remote sensing and in-situ measurement techniques make validation or comparison of cirrus cloud properties problematic. Such concerns, of course, do not apply to just our effort presented here but to all cloud validation efforts across the atmospheric community. But in fact, a rigorous understanding of the uncertainties inherent to the cirrus cloud retrieval problem motivated our bi-spectral retrieval design and scientific approach. Again, the idea was to identify extreme radiometric signatures (very large brightness temperature difference, BTD) that could only be associated with small particles less than 20 μm regardless of any other uncertainties in our bi-spectral approach. The costs of such approach are that we lose precision in estimated particle size (we only know a particles is small) and we can only apply the technique for very specific cloud conditions as discussed in the paper. The benefit of our approach is that we have confidence in our retrieval result, i.e. the cloud particles are small, which can then be compared to in-situ estimates. In this paper, we also extend the technique to identify large particles greater than 20 μm based upon low BTD and very specific cloud and atmospheric conditions.

We also agree with the reviewer in that there is no way to exactly match remote sensing observations with in-situ sampling volume. We did, however, try to minimize the effects of this sampling issue by selection of our test cases. We only selected test cases where the Learjet was in large homogenous areas of high BTD cirrus clouds at the time of the MODIS overpass. So, regardless of the exact plane location relative to the timing of the overpass, the Learjet was in thin cirrus clouds that were dominated in a radiative sense by small ice crystals. (Alternately, for one case we find the Learjet in a large area of low BTD cirrus indicating the dominant radiative presence of large ice crystals.) It is possible, of course, that the Learjet could be in a small patch of large ice crystals for these thin cirrus clouds dominated radiatively by small crystals. Although again, such an argument could be used to negate any attempt to validate cloud properties from remote sensing efforts or vice versa.

**Comment 1 Sampling bias: The authors pointed out (Pg. 3064 line5), "Due to the cautious nature of the BTD retrieval scheme, the relatively small number of Aqua overpasses, and the necessity of having the plane located reasonably near to an acceptable BTD cloud field, we found only a handful of good test cases for comparingMODIS and airborne measurements during the SPartICus campaign." This indicates that their remote sensing method is only applicable to a small subset of SPartICus field campaign. Some information, maybe in a table, should be given on this potential sampling bias. For example, how many times MODIS overpassed the SPartICus campaign. How many cases can be selected from the overpasses for comparison between in situ and remote sensing results. What are the reasons (e.g., cloud too thick?, no collocation?) that some cases are not suitable for comparison?**

The reviewer is correct in that our infrared bi-spectral technique to identify small particles (< 20 μm) cannot be used for all cloud cases. We must limit its application to those few radiometric signatures and cloud/ atmospheric properties that allow us to confidently determine if the particles are 'small', as discussed frequently in this paper and the proceeding Cooper and Garrett (2010) paper. We therefore do not use this technique to try to estimate average cloud properties for SPartICus. We make no comment on the relative number of large ice crystals or small ice crystals for these clouds. Instead we use our technique to identify specific clouds that must be composed of predominately 'small' or 'large' ice crystals so that we can determine if available in-situ measurements are consistent. To stress the fact that we do not aim to determine average cloud properties, we added the following sentence in the last paragraph of the introduction,

*'However, given the limited number of good test cases for our technique during the campaign, and the fact that our infrared technique was not considered for design of the campaign, we cannot present either a broad characterization of SPartICus cloud properties or a definitive analysis of in situ instrument performance.'*

**Comment 2 How small is "generally small"? Uncertainty analysis is needed for the remote sensing results: The authors used "generally small" or "generally large" throughout the manuscript. But how small is "generally small"? I think the authors**

**can do better than this and present some more quantitative results. Also important is a through uncertainty analysis. As shown in many previous studies, remote sensing of ice cloud microphysics is subject to substantial uncertainties. This is especially true for IR-based retrieval, because IR method is not only subject to uncertainties in cloud properties but also significantly to the uncertainties in artillery data like atmospheric profile. Therefore a detailed analysis of the uncertainties is needed to convince the reliability of the remote sensing method. Uncertainties that should be analyzed include, ice particle shape, cloud top temperature and in-cloud temperature variation.**

A rigorous uncertainty analysis for our retrieval scheme was presented in Cooper and Garrett (2010), as discussed in this manuscript. It examined the effects of assumption of ice crystal habit, form of ice particle size distribution, atmospheric temperature and humidity profiles, cloud optical depth, surface emissivity, mis-classification of single-layer cloud scene, etc. on the veracity of our retrieval scheme. Some of the uncertainty analysis (form of particle size distribution) was referenced from an earlier work (Cooper et al., 2003) that also focused on the infrared retrieval of cirrus clouds. Due to these numerous sources of uncertainties for the retrieval, we do not pretend that we (or anyone for that matter) can give a very precise estimate of particle effective radius, e.g. 14.6 μm. Through selection of an appropriately high threshold for BTD for our retrieval scheme, however, we can identify particles must be 'small' (less than 20 μm). These particles might be 10 μm or they might be 15 μm, but in no way can they be larger than 20 μm regardless of any uncertainties in the inversion process.

**Comment 3 Consistency of the underlying physics between in situ and remote sensing: The effective radius from the in situ measurement is based on some empirical image-to mass relationship in Baker et al. Is this image-to-mass relationship consistent with the assumption of cloud physics used in the remote sensing algorithm? If not, what is the impact of the discrepancy on the comparison between in situ and remote sensing results?**

The definition of effective radius between Spec Inc. reported in-situ measurements and our retrieval scheme is the same as described in Equation 1. We use our retrieval results in hopes of evaluating the veracity of this Spec Inc. reported effective radius. Any observed differences between our retrieval scheme and Spec Inc. effective radii could be attributed to 1) shattering during the measurement process 2) limited instrument collected efficiencies or 3) errors in shattering algorithm to produce cloud properties. However, we find in general good agreement between the two techniques with only a small discrepancy for one test case.

**Comment 4 Bi-modal particle size distributions: It seems from Figure 5, the ice particle size distribution is bi-modal. What is the assumption of ice particle size distribution in the remote sensing algorithm? Single mode or bi-modal? Is it possible to implement bimodal size distribution in the remote sensing algorithm? What will be the retrieval results based on bi-modal size distribution? If not possible, why?**

The effects of both single mode and bi-modal distributions were explicitly considered in the design of the bi-spectral retrieval scheme, please see Cooper and Garrett (2010) and Cooper et al. (2003).

**Comment 5 Other cloud properties: The comparison has been focused on effective radius, but how about other cloud properties such as cloud optical thickness and ice water path? One may argue that cloud optical thickness and ice water path are the "first order" cloud parameters to compare, effective radius is kind of "second order" thing because of its definition. Some comparison on optical thickness and ice water path should be presented and discussed for the sake of evaluating the remote sensing accuracy**.

The purpose of our bi-spectral scheme was to provide a constraint on in-situ estimates of ice particle size from the SPartICus field campaign. Such a goal was motivated by the current scientific debate over the accurate characterization of cirrus cloud ice particle size distributions. While other topics such as the retrieval of IWP or optical depth from the satellite perspective are interesting, our scheme does not retrieve such items nor would it be easy to estimate such integrated cloud properties from in-situ measurements for comparison.