Assessment of Cloud Parameters in the NPOESS Environmental Data Records and Climate Data Records

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Final Report

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1. Goals as stated in the proposal:

The primary goal of this work was to evaluate the global cloud products produced with the Northrop Grumman (NG) Aerospace Systems Operational Build 1.5 algorithms at the Atmosphere Product Evaluation and Algorithm Testbed (PEATE). The PEATE is responsible for applying the NG operational software to global data, and for performing other tasks related to calibration/validation efforts for the NPP Science Team. In addition to evaluating the NG cloud products on their performance over various regions (e.g., tropics, mountains, oceans, polar regions), these NGAS cloud products are to be compared with those produced operationally by the MODIS science team. This evaluation will be performed for both daytime and nighttime conditions. As part of these activities, we need to work closely with the NOAA VIIRS cloud team to compare the cloud properties obtained from the NG operational code with the properties obtained from heritage algorithms such as those produced from the High Resolution Infrared Radiometer Sounder (HIRS) and CLAVR-x (Clouds from AVHRR-extended). The NOAA investigators are co-located at SSEC, and the PI has worked closely with these and other SSEC scientists for many years. As such, the coordination of activities is not an issue. The ultimate goal is to ensure that the NPOESS cloud products are derived efficiently and are of sufficient quality for the environmental data records (EDRs) to be climate data records (CDRs).

This report summarizes results for the duration of this proposal.

2. Focus of Work

The largest uncertainty existing in the NG cloud retrieval algorithms is in its lack of application to global data. Another large uncertainty lies in the immense complexity of the data system developed to accommodate these (and all other) algorithms. While the cloud retrieval approaches adopted by NG have been applied to a handful of scenes, there has not been any demonstrated experience in applying them globally. Our experience is that no retrieval scheme can be considered mature without being applied to global data. The software ideally should be exercised and evaluated using data from all regions regardless of surface, atmospheric, and satellite viewing conditions. If you want to ensure readiness before launch, this is a recommended course of action.

However, this is not the approach that NG adopted. What we were provided at the end of 2008 for evaluation were two full orbits of products from a mini-IDPS system located at NASA GSFC. The mini-IDPS processing system employs the entire NGAS code build, but has very little in the way of computing resources. The two full orbits (each orbit is about 100 minutes) of data were from January 25, 2003, well before the launch of either CloudSAT or CALIPSO. These products were based on MODIS data that were used to develop VIIRS proxy data. Part of the evaluation process was to figure out what sort of changes occurred in making the VIIRS proxy data from the original MODIS data. The spatial resolution of the VIIRS proxy data is about 800 m, rather than the 1-km aggregated data (e.g., MYD021km) we work with from MODIS. Furthermore, the scan swath was lengthened for VIIRS proxy data by replicating MODIS data from pixels near the edges of the swath and simply making a mirror image of these pixel radiances. Therefore, our evaluation of the NG cloud products was limited to portions of the swath that exclude the swath edge. Based on the comparison of these proxy products to those from MODIS for the same swaths, the PI wrote a report and suggested a change in the future course of action. As noted in the report, the comparison of these two orbits with the actual MODIS Collection 5 products showed significant differences in just about every cloud parameter.

We want to emphasize several issues here:

a. NG could have easily simplified our evaluation process by making VIIRS proxy data and associated products available for a time period when Calipso/CloudSAT data were also available. This did not occur.
b. More than two orbits are needed to evaluate how the NG algorithms are going to work. NG was unable to provide any additional products for evaluation.
c. There has been limited progress by NG personnel towards resolving noted scientific issues with the cloud algorithms, such as the use of a Henyey-Greenstein phase function to build look-up tables (LUTs) for water clouds rather than using Mie theory, overly-complicated LUTs for water and ice clouds that do not follow the approach used in current global operational cloud retrieval systems, ice cloud LUTs that do not incorporate advances made over the past decade in microphysical measurements or light scattering theory, the inability to use global surface 1-km albedo and emittance maps, and more. It is quite reasonable to expect that the eventual cloud products will have significant differences with currently available operational cloud products from either geosynchronous or low-Earth-orbiting sensors.

A very time-consuming effort was expended on the part of the PEATE personnel to subset the operational cloud retrieval software from the operational build, wrap this software in a local computing environment that would provide relevant ancillary data, and then run this software internally at the PEATE on global VIIRS proxy data. After about two years of effort, this was discontinued because of the complexity of the operational data system designed by NG for this project. More details will be provided upon request.

3. Relevant Progress

Given the lack of ability to exercise the official NG cloud retrieval software and the fact that the launch of NPP kept slipping, our effort turned towards more productive avenues. Examples of two avenues that we will follow when VIIRS and CrIS become operational are provided below. A description of the anticipated approach for the other cloud parameters will be provided upon request.

3.a Use of AIRS and MODIS to evaluate MODIS Spectral Response Functions

This example is provided to show our close relationship with sensor cal/val efforts. Tobin et al. (2006a) describe an absolute radiometric comparison of AIRS to the aircraft-based Scanning High-Resolution Interferometer Sounder (HIS), while studies comparing the AIRS L1B radiances and the AIRS clear-sky forward model (SARTA) indicate a relative accuracy of about 0.2 K (Tobin et al. 2006b; Strow et al. 2006). Tobin et al. (2006b) assume a circular shape for the AIRS FOV since the point of the comparisons is to assess the radiometric bias, which can be done with uniform scenes that are insensitive to the details of the FOV shape. Tobin et al. (2006b) describe an approach for evaluating MODIS infrared band spectral response functions (SRFs) by comparing AIRS and MODIS radiance data. In this example, the exploratory study of Tobin et al. (2006b) is expanded from evaluation of one full orbit to analyzing collocated AIRS and MODIS data for the first day of every month in 2003 (except November, for which 2004 data were used due to an issue with the AIRS sensor in November 2003). The MODIS Collection 5 Level-1B (L1B) radiances and 1–km geolocation data were used, while the AIRS L1B radiances were generated using version 5.0.0.0. Most but not all of the 2378 AIRS spectral channels were used (some of the channels were not recommended for use by the AIRS science team and were excluded in Level 2 processing).

The SRF evaluation process begins with convolving the high-spectral resolution AIRS data with a given MODIS band's SRF. Then, the 1-km spatial resolution MODIS data are collocated to an individual lower spatial resolution AIRS FOV (assumed to be circular) and averaged. For comparison purposes, spatially uniform scenes are used. Only those AIRS FOVs where the standard deviation of the collocated MODIS brightness temperatures is less than or equal to 0.2K are selected, i.e., the data are filtered for uniform scenes with low variability. Figure 1 provides (AIRS–MODIS) brightness temperature differences (BTD) for MODIS band 35 (13.9 μm) for the first day of every month in 2003. The BTDs are color coded as a function of latitude, with red points coming from high latitudes in the northern hemisphere, green points coming from the Tropics (low latitudes), and blue points coming from high latitudes in the southern hemisphere. The BTDs in the Tropics remain fixed at about –1.5K, but the higher latitude BTDs change with the season. While the AIRS-MODIS BTDs are shown for uniform scenes, one might expect that if all scenes were included the bias would not change but that the scatter would increase.

Tobin et al. (2006b) suggested that a slight shift in the MODIS spectral response functions could mitigate this effect. For MODIS band 35 they suggested shifting the MODIS SRF by 0.8 cm^{-1}; the reanalyzed data with the suggested SRF shift for MODIS band 35 are shown in Figure 2. Note that applying the correction to the BTDs reduces the latitudinal differences; the lower latitudes decrease from 1.5K to 0.2K. Additionally, the BTD differences are now consistent from month to month. A single small shift in the SRF has largely eradicated the AIRS-MODIS BT latitudinal and seasonal differences. This finding is also the primary reason why Collection 6 cloud products will show so much improvement in determining optically thin high-level cloud heights, so much so that products can now be generated at 1-km resolution.

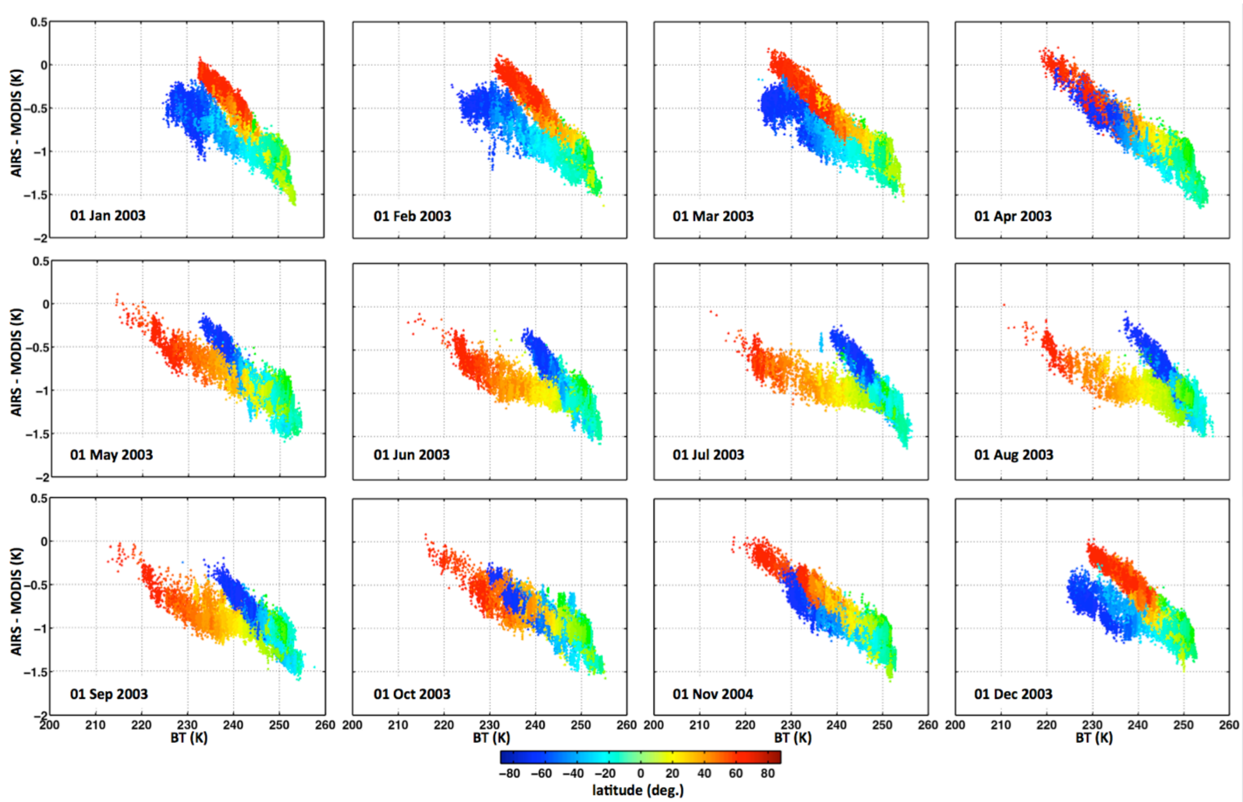

Figure 1: The (AIRS–MODIS) brightness temperature differences (BTD) are shown as a function of 11-µm scene brightness temperature (BT). The (AIRS-MODIS) BTD are calculated with AIRS data convolved using the nominal MODIS SRF (i.e., unshifted). The BTDs are color coded as a function of latitude, with red points coming from the high latitudes in the northern hemisphere and the blue points come from high latitudes in the southern hemisphere.

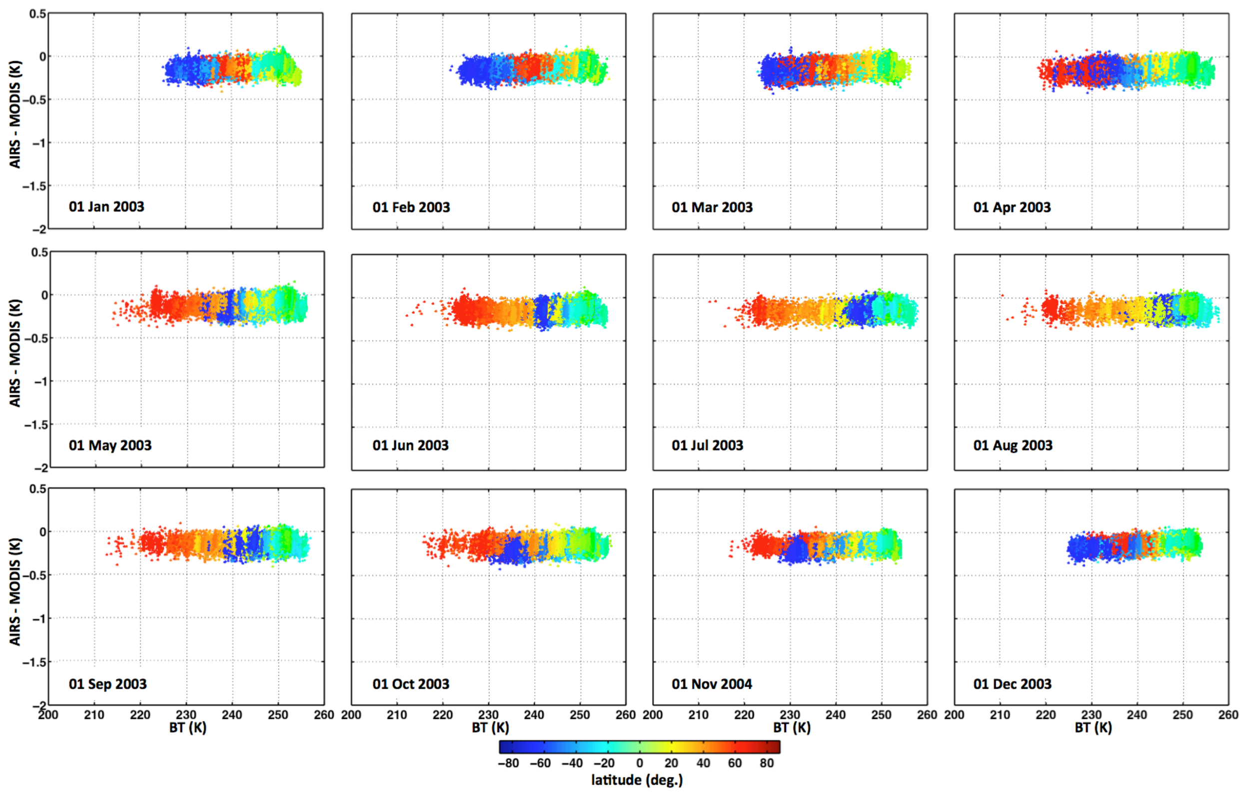

Figure 2: Same as the previous figure, but the AIRS–MODIS data are convolved after shifting the nominal MODIS SRF by 0.8 cm^{-1}.

Note that this approach will be quite useful for assessing the calibration accuracy and consistency over time of the VIIRS IR window channels since CrIS and VIIRS are co-located on the same platform. The effect shown in Figs. 1 and 2 are quite noticeable for this particular MODIS band in the 15-µm CO_2 absorption region, but for window bands, this type of cal/val effort will probably not have such dramatic results. Nonetheless, it is appropriate to monitor these bands as part of the VIIRS cloud retrieval effort. Now that we have an approach for merging MODIS and AIRS data, it can be adopted for VIIRS and CrIS on NPP (and any other platform with similar instruments).

3.b Infrared thermodynamic cloud phase

The approach adopted for inferring cloud phase from VIIRS should be similar to that used by MODIS. Through MODIS Collection 5 (C5), the IR thermodynamic cloud phase product was based solely on analysis of 8.5– and 11–µm brightness temperatures (BTs) in 5x5 pixel arrays where the radiances for the cloudy pixels are averaged to reduce radiometric noise. The C5 phase algorithm returns one of the following classes: *ice, water, mixed-phase*, and *uncertain*. Reported limitations of the MODIS C5 approach are that (1) optically thin cirrus may not be classified as ice phase, and (2) supercooled water or mixed-phase cloud identification is problematic.

Baum et al. (2012) discuss recent improvements to improve the phase discrimination of ice clouds by using cloud emissivity ratios (e.g., Heidinger et al. 2010). Without showing equations, the cloud emissivity is simply a ratio of radiance differences for a single band or wavelength. The cloud emissivity for two or more bands can be related through the use of a term called the β parameter, which is a ratio of cloud emissivities for two bands. The importance of the β parameter is that it merges measured satellite radiances with clear-sky radiances provided by either a forward radiative transfer model or from pixels determined to be clear sky through use of a cloud-clearing approach. By accounting for the clear-sky radiance, the influence of the surface is decreased from that found in the measured brightness temperature differences employed in the Collection 5 (and earlier) thermodynamic phase method, which is similar to the approach adopted by NG.

As a complement to window bands used in the cloud emissivity method, IR absorption bands provide useful information regarding the cloud height (Heidinger et al. 2010). For MODIS, measurements are available in both the broad H_2O and CO_2 absorption regions. The 7.3 µm band is used to further discriminate between optically thin ice clouds and low-level clouds; this band is chosen instead of one of the 15-µm bands because it is less affected by detector striping. Note that VIIRS does not have an absorbing IR channel, so we anticipate that the skill in discriminating ice clouds will not be as high as for MODIS.

The following example developed for MODIS Collection 6 (Baum et al. 2012) demonstrates how the use of these band pairs improves the identification of optically thin ice clouds. Figure 3 illustrates the utility of incorporating the β parameter for cloud phase for a MODIS granule recorded at 1630 UTC on 28 August, 2006, over the northern Atlantic Ocean. In the false color image (Figure 3a), ocean is dark, land is green, cirrus is blue, optically thick ice (southern tip of Greenland) and optically thick ice cloud are magenta, and low clouds are yellow/white. Figure 3b shows results obtained from the Collection 5 MYD06 product for IR phase at 5-km resolution, and Figure 3c shows the same set of IR phase tests applied at 1-km spatial resolution. For the Collection 5 results, the "mixed-phase" pixels are merged into the "uncertain" category. The reason for this is that comparisons of the MODIS IR phase with the CALIOP Version 3 cloud phase indicate that the MODIS IR phase algorithm cannot unambiguously identify the presence of supercooled water or mixed-phase clouds. The planned Collection 6 discrimination of ice phase clouds is improved in the results shown in Figure 3d. The "mixed-phase" category is being eliminated as a separate category so that results will be provided as *ice*, *water*, or *uncertain*.

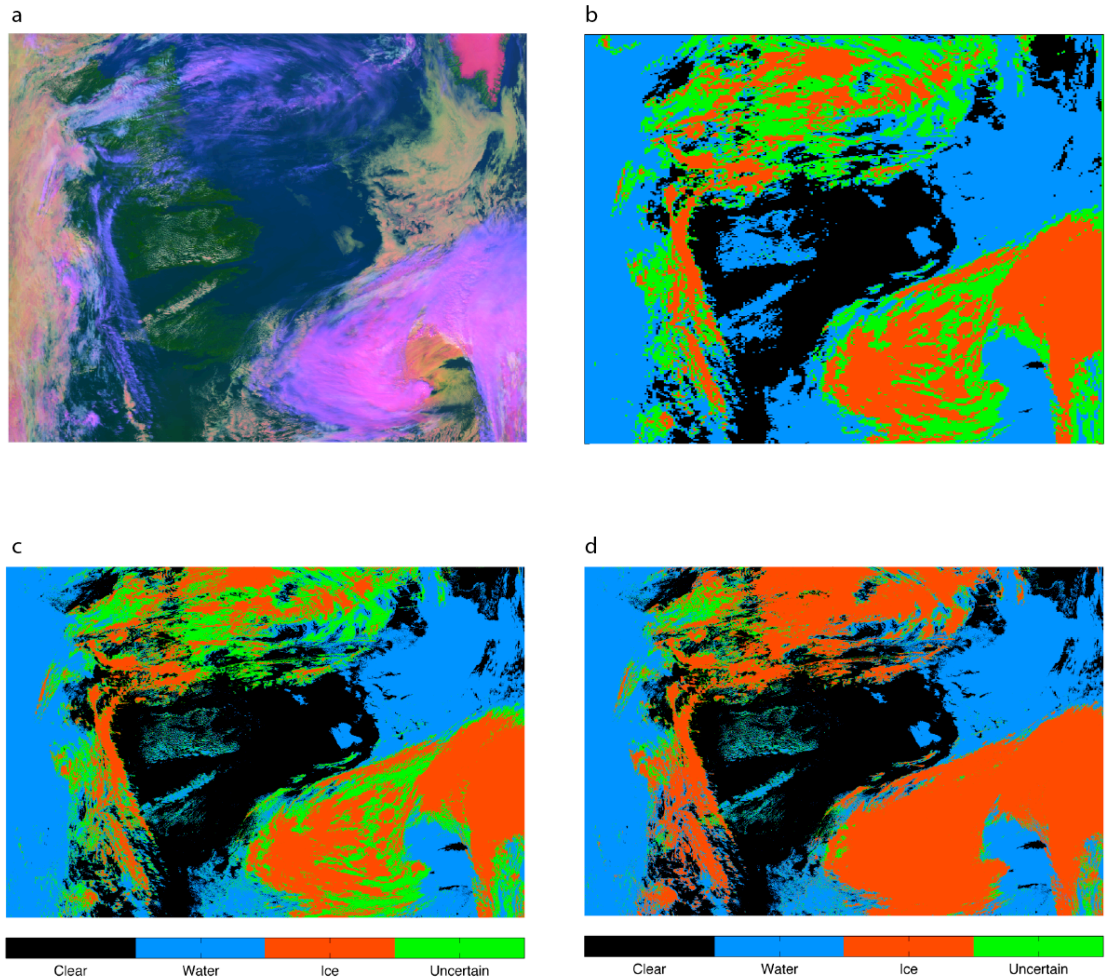

Figure 3: Results of IR cloud phase for a MODIS granule at 1630UTC on 28 August, 2006, over the northern Atlantic Ocean with Nova Scotia and Newfoundland in the center left of the image and Greenland in the upper right hand corner of the image. (a) a false color image (Red: 0.65 µm; Green: 2.15-µm, Blue: 11-µm reversed) where ocean is dark, land is green, cirrus is blue, optically thick ice cloud is magenta, and low clouds are yellow/white, (b) Collection 5 IR phase results at 5-km resolution, (c) Collection 5 IR phase algorithm applied at 1-km spatial resolution, and (d) improved IR cloud phase. For the Collection 5 results, the “mixed-phase” pixels are merged into the “uncertain” category, as will be done with Collection 6.

3.c Comparison of CALIOP and MODIS Collection 6 cloud phase

With the approach discussed in Holz et al. (2008), MODIS–CALIOP collocation files are prepared routinely at the PEATE for cloud products. These collocation files can be analyzed to produce global comparison statistics. As it turns out, the NPP platform, which is in a higher orbit than Aqua, will become aligned with the A-Train sensors every 3 days or so for a brief period of time. When the NPP platform is aligned with the Aqua platform, and also CALIOP, we will be able to perform similar comparisons of VIIRS to MODIS and CALIOP cloud phase as shown below.

Cloud thermodynamic phase retrievals from both MODIS and CALIOP (Hu et al. 2009) are presented as the likelihood of inferring water/ice phase as a function of

CALIOP mean cloud temperature. Both MODIS and CALIOP products are filtered so that results are shown only for collocations where CALIOP data indicate single-layered clouds and an optical thickness $\tau > 0.5$. At each CALIOP mean cloud temperature, the CALIOP or MODIS cloud phase retrievals at that temperature are normalized so that the percentages of each category (water, ice, and uncertain) sum to 100%. Figs. 4a and 4b show the results from CALIOP for ocean and land respectively. The CALIOP ice-water phase confidence flags were not used to filter the results – all data were used. After filtering the CALIOP results for single-layered clouds and leaving out the most optically thin clouds, there are only a few percent of uncertain retrievals in the CALIOP Version 3 products except at warm cloud temperatures above 285K over land. This indicates that CALIOP is able to infer the presence of ice or water clouds fairly unambiguously. Over both land and ocean, it is somewhat surprising to find that CALIOP infers the presence of a high percentage of water clouds at cloud temperatures below 250K.

In comparison with the CALIOP results, the MODIS results shown in Figs. 4c and 4d over ocean and land, respectively, both indicate much higher percentages of pixels for which the cloud phase retrieval is uncertain, especially between 240K and 260K. While the improvements in the MODIS cloud phase algorithm presented in this study pertain mostly to optically thin ice clouds, the ability to infer the presence of supercooled water clouds is problematic using only IR bands. The results for MODIS are provided as a function of CALIOP mean cloud temperature, not optical thickness; the results include retrievals over a range of cloud optical thicknesses. It should be noted that the use of the emissivity ratios over land for the MODIS cloud phase are influenced to some degree by the quality of the surface temperature provided by the meteorological model product.

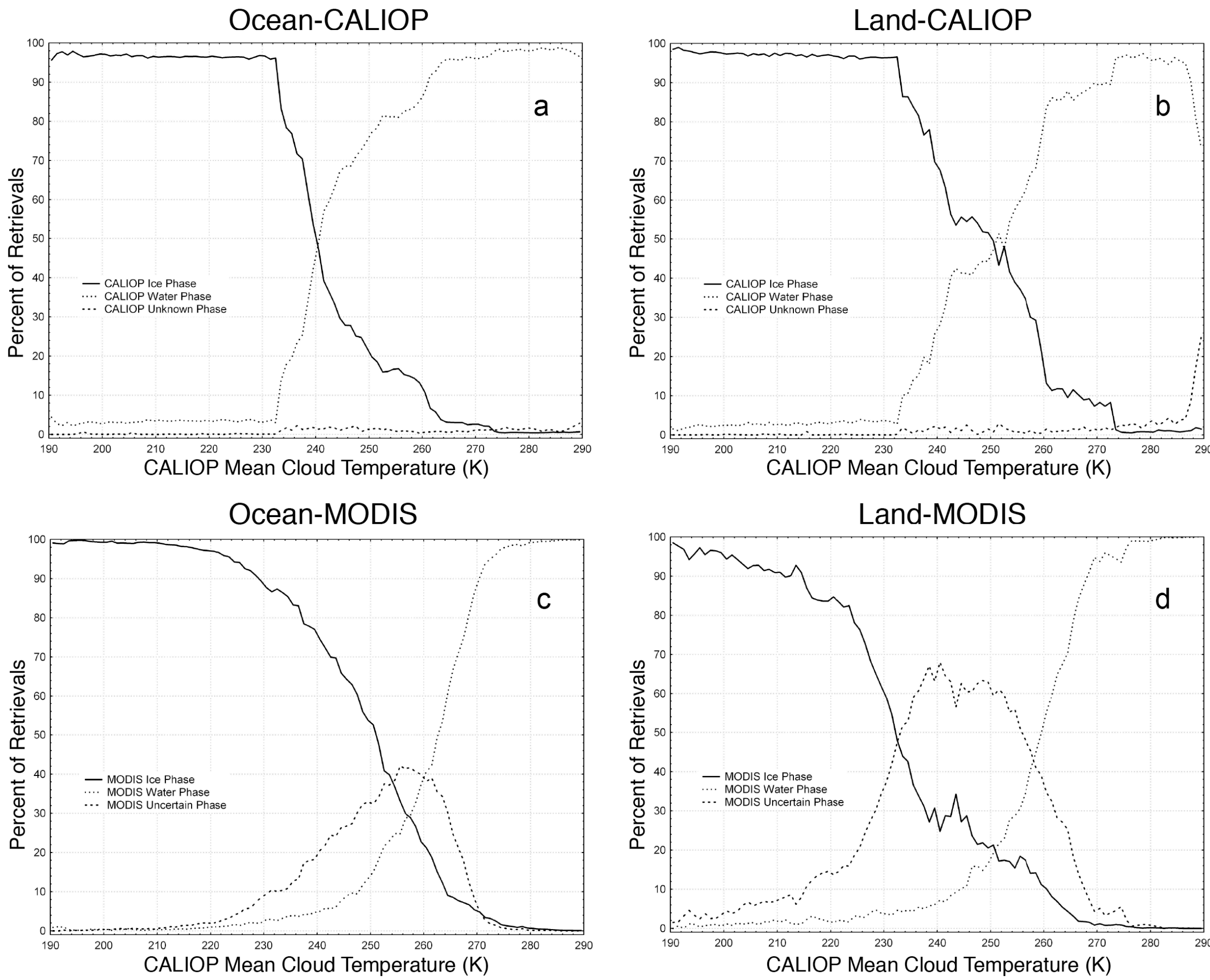

Figure 4: Likelihood of inferring the presence of ice or water cloud as a function of cloud top temperature in the pixel collocations between MODIS and CALIOP for August, 2006. The results are filtered to observations of single-layered clouds that have an optical thickness > 0.5 as determined from the CALIOP Version 3 product. CALIOP cloud phase is presented as a function of CALIOP mean cloud temperature over (a) ocean and (b) land. For comparison, MODIS cloud phase is presented as a function of CALIOP mean cloud temperature over (c) ocean and (d) land. Note that CALIOP has a class called “unknown” in the Version 3 data product while MODIS uses the term “uncertain.”

The NG software does not include these developments for improving the inference of cloud phase from IR bands, and it is unlikely that their software could be updated easily since it would require that their software have the ability to provide radiances from a radiative transfer model. Our approach for MODIS will be used for VIIRS processing at the PEATE.

Summary

Since the launch of NPP slipped beyond the time period of this proposal, our time has instead focused on building the infrastructure necessary to provide global cloud properties from VIIRS data, as well as assess the operational NG products.

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