NASA Progress Report: NASA Award Number, NNX11AL95G, entitled, EVALUATION OF VIIRS CLOUD EDRS AND EXTENDING MODIS CLOUD DATA RECORDS INTO THE NPP TIMEFRAME

This is the year 2012-2013 progress report for grant NNX11AL95G. The proposal is a joint UW Madison and NASA Goddard project. This report presents the accomplishments at UW Madison. This is the second year of funding. The primary focus of our work this past year was evaluating the IDPS cloud products and implementing alternative cloud algorithm for VIIRS to aid in the IDPS evaluation. We have accomplished both tasks with the final evaluation report delivered to NASA headquarters earlier this year. Highlights and initial results of this work are presented as part of this report.

An evaluation of CTP performance from the first year of operation is presented. This section has two main components. The first conducts a detailed analysis of the IDPS VIIRS CTP through comparison with the CTP products provided by EOS A-train sensors. One source comes from the MODIS CTP products (MYD06) and the other from the very accurate active sensor measurements in the EOS A-train (CALIPSO and CloudSat). The active sensor provides high accuracy but for only a specific (and very narrow, about 80 m cross-track for CALIOP) portion of the imager swath. Imager–to–imager comparisons cover a large range of viewing angles. These comparisons are complementary and are sufficient to assess the current VIIRS cloud products with respect to the other operational sensors.

While the match-up periods between CALIPSO and VIIRS occur for a brief period (about 12 hours every 3 days), global coverage is provided over a period of months as shown in **Figure 3.1**. Figure 3.1 shows the intersections between VIIRS and CALIPSO for the focus time period of the VIIRS evaluation (May – September 2012) using a time difference threshold of ±20 min. The consistent pattern of coincidence results from the very similar orbital characteristics of NPP and the A-Train. As previously mentioned, the match methodology is documented in *Nagle and Holz* [2009].

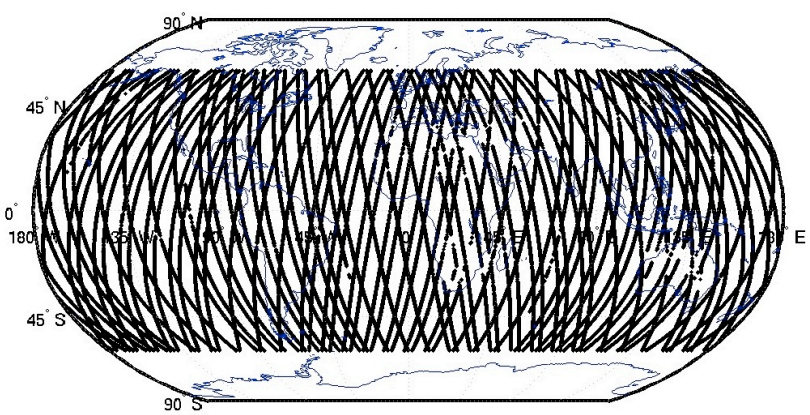

Fig. 3.1. The location of coincident VIIRS and CALIPSO observations with coincidence defined as 20 minutes between viewing the same location. Notice the very regular pattern of intersections.

A pictorial example of the physical collocation between VIIRS and CALIOP is presented in **Figure 3.2**. The VIIRS cloud products are retrieved at the pixel level (IP)

and then averaged to the EDR product scale as specified in the contract. We note that the process adopted in the IDPS software to build the VIIRS EDRs from the IPs is unclear and unsupported in the documentation. That is, it is unclear what decisions are made and what filtering criteria are adopted in developing the EDR products. For this reason, we cannot replicate the EDRs from the IPs to better understand the IDPS cloud products. Because of our lack of understanding of the EDR aggregation process, we instead focus on the pixel–level retrievals provided in the IP products. This reduces complications in interpreting the impact of the EDR aggregation. As shown in **Fig 1**, the spatial characteristics of the CALIOP surface footprint are approximated as a 80–meter wide line projected onto the Earths surface with the length of the line a function of the averaging used to generate the CALIOP cloud products. The CALIOP-VIIRS collocation process for the period between May 1–August 11 2012 resulted in a total of over 1.8 million cloudy-sky collocated match-ups.

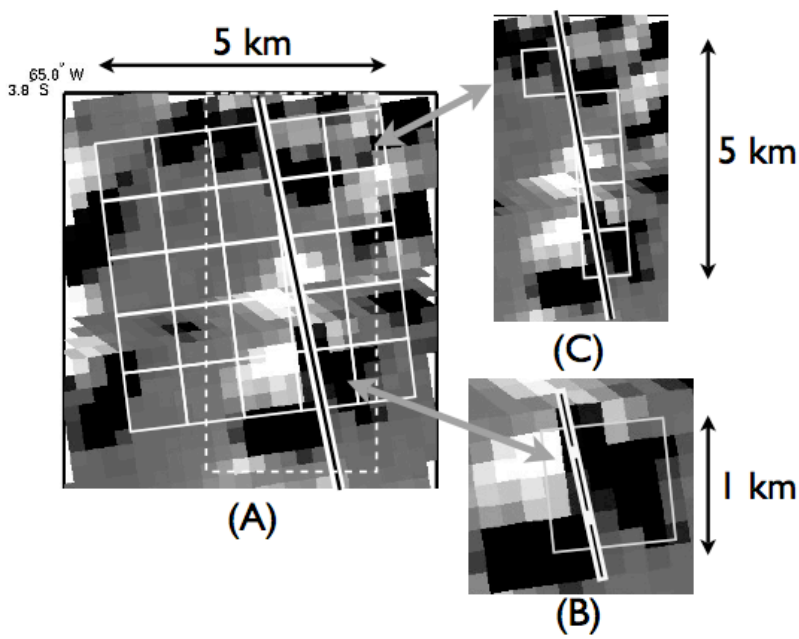

Fig. 3.2. Collocation geometry between CALIOP and VIIRS. Panels (a) and (c) present the EDR scale resolution with panel (c) presenting an approximate 750 meter resolution IP collocation. The image background image depicts sub–pixel cloud features.

The CALIOP V3 cloud layer products (CLay-Prov_V3-02) and the cloud profile product (CPro-Prov-V3-02) are used in the comparisons. For CTH, the CALIOP 5 km resolution product is used rather than the higher-resolution product. Although this does oversample the VIIRS IP resolution, it provides improved signal to noise (SNR) and lower uncertainties for the CALIOP cloud retrievals. For the CALIOP CTH evaluation, we use the Cloud Layer Top Altitude and the cloud feature classification product that provides cloud phase information. The cloud top height resolution for CALIOP is 60 m [*Winker et al.*, 2007]. Use is made of the VIIRS Quality Assurance (QA) information provided as part of the IP CTH retrieval. The QA provides information about retrieval convergence and identifies the retrieval method. The VIIRS CTH algorithm has four discrete retrieval methods that are selected as a function of day/night and cloud phase.

As part of the evaluation we separate the analysis as a function of the retrieval method noted in the QA.

3.3 Evaluation Results

Comparisons with CALIOP

Figure 3.3 presents the histogram of difference between the VIIRS IP and CALIOP CTH retrievals separated by retrieval methodology for approximately 5 months of global observations. The CTH differences are presented in terms of (VIIRS-CALIOP) so that a positive difference means that VIIRS has a higher CTH than CALIOP. Similar comparisons between MODIS and CALIOP (MODIS-CALIOP) indicate that optically thin high clouds (e.g., cirrus) tend to have a bias of 1-2 km because cirrus tend to be geometrically thick but optically thin, and a passive radiance retrieval tends to place a cloud at a depth into the cloud where the integrated optical thickness COT~1. In this situation, CALIOP observes the uppermost boundary of the cloud layer while the passive imager is more indicative of an optical depth into the cloud, leading to a negative bias.

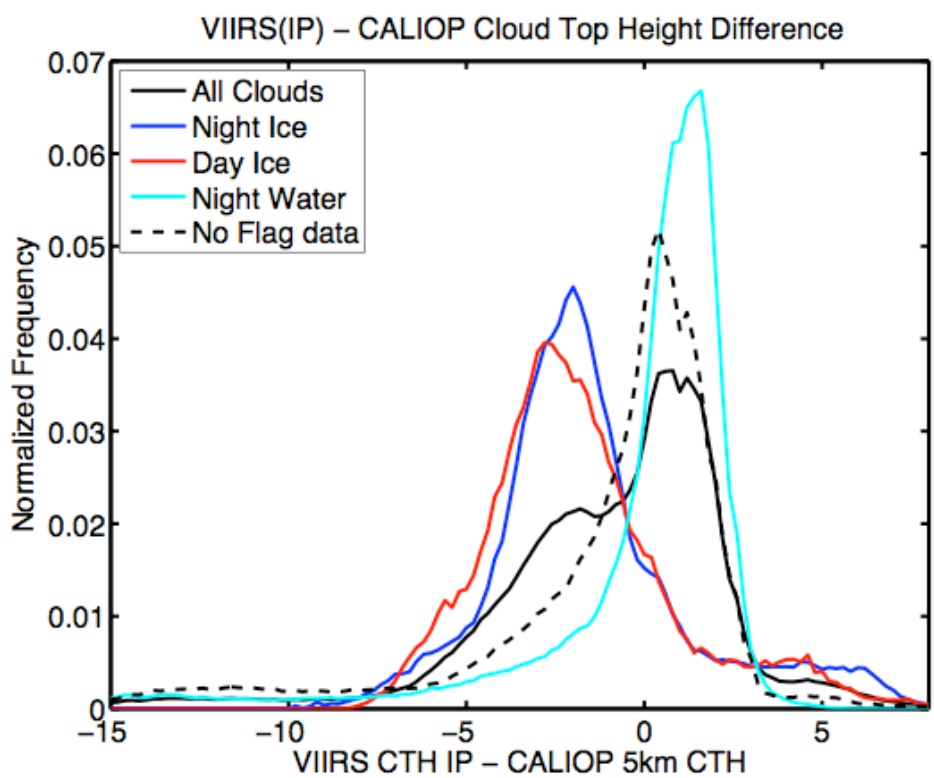

Fig. 3.3. The global distribution of CTH differences between CALIOP and VIIRS IP retrievals is presented. The results are separated by VIIRS retrieval method. Negative differences translate to VIIRS underestimating the CTH.

The CALIOP 5 km CTH product has both a very low uncertainty and high sensitivity (60 m). Other then a small random component of uncertainty resulting from the spatial and temporal sampling differences between CALIOP and VIIRS, the biases presented in **Figure** translate directly to biases in the VIIRS CTH. The combined distribution of all

CTH retrievals (solid black) is bimodal with a very defined positive peak at +(2-3 km) and a second peak with a –(3-4 km) difference. The positive peak denotes cases when the VIIRS CTH overestimates the cloud top height relative to CALIOP. The separation of the biases as function of the VIIRS retrieval in **Figure 3.3** reveals a clear relationship between the cloud retrieval methodology and CTH biases compared to CALIOP. **Table 3.2** presents the global mean and standard deviation of the differences between VIIRS IP and CALIOP for the four retrieval paths.

For both (day/night) the water (low cloud) retrievals systematically overestimate CTH with the nighttime mode of the distribution at approximately +2 km. The day water cloud retrieval also has a positive bias although slightly smaller. Based on these results, we further investigated the retrieval algorithm and identified a clear deficiency in the CTH-P retrieval that may explain this bias. We found that the CTH-P algorithm does not correctly account for the frequent temperature inversions in the lower atmospheric resulting in the algorithm incorrectly relating cloud top temperature to CTH. In addition to the positive bias there is also a negative bias in the water cloud retrievals in **Figure 3.3** with the negative tail extending to -10 km.

The ice cloud retrievals for day and night are presented in the figure as the red and blue solid distributions. Surprisingly the day and night performance is similar despite using different spectral channels and retrieval methodologies. Both ice cloud retrievals demonstrate a negative bias (lower VIIRS CTH) relative to CALIOP with the peak in the distribution between 3-4 km lower than CALIOP. There is also a significant overestimation of the CTH with a positive tail for a significant fraction of the VIIRS-CALIOP match-ups with biases as large as +8 km relative to CALIOP. One cause for these cases could be that when the CTH-P retrieval does not converge and as a result selects the tropopause as the cloud top height. Another cause could be the presence of low-level water clouds beneath the upper-level cirrus; in such cases, the inferred CTH lies between the upper and lower cloud layers. Some amount of low bias in the distribution is not unexpected due to the different inherent sensitivity differences between CALIOP and a passive imager such as VIIRS. That being said, the underestimation of VIIRS is larger than we would have expected and deserves further investigation.

The regional dependence of the CTH-P retrievals is provided in **Fig. 3.4** on a 5˚x5˚ equal-angle grid. CTH differences are aggregated in each grid cell, from which are calculated the mean and standard deviations of the CTH differences between CALIOP and VIIRS. The results are separated by optically thin (COT < 1, left column) and optically thick (COT > 1, right column). The figure demonstrates that there is a strong regional dependence on the VIIRS CTH-P performance with the results strongly correlated by the dominant cloud regimes for each region. The areas of bright red over ocean in the figure (VIIRS over estimating the CTH) occur in regions dominated by stratocumulus or mid–level clouds. However, there is also a CTH overestimation over the Tibetan Plateau and also over other high-elevation terrain. Behavior of the VIIRS CTH algorithm needs further investigation over high-elevation terrain, and also over regions with sparse vegetation such as South Africa and central Australia. Conversely, the underestimation of the CTH for ice clouds occurs primarily in the Tropics and also over the high-elevation terrain in Antarctica. The non-opaque ice cloud analysis will have only so much accuracy with only the VIIRS IR-window channels being used for the CTH. An improvement in the CTH could arise through two avenues: (a) for daytime, use of the 1.38-μm channel could improve the ice cloud retrievals, and (b) use of the CrIS

hyperspectral IR absorption channels to infer mid-to-high level CTP/CTH for both day/night conditions.

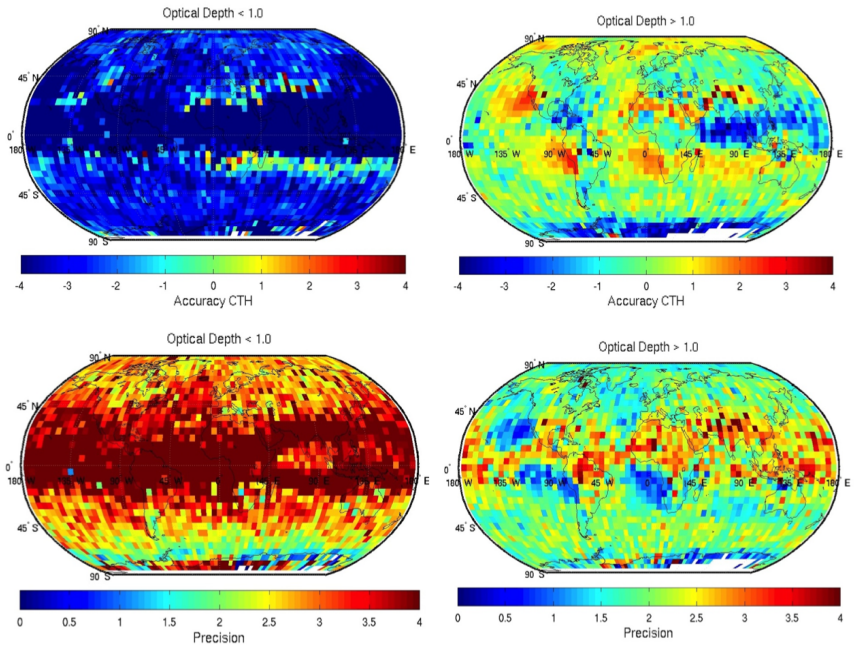

Fig. 3.4. The global distribution of CTH differences between CALIOP and VIIRS IP retrievals is presented. The results are separated by VIIRS retrieval method. Negative differences translate to VIIRS underestimating the CTH.

As a metric for these results, we summarize the CTH evaluation results in terms of the JPSS performance specifications presented in **Table 3.1**. From the gridded results presented in **Fig. 3.4**, we calculate the percent of the 5˚ grid boxes that meet the specifications. To account for the collocation uncertainty between CALIOP and VIIRS that is estimated to be less than 1 km, the precision requirements were reduced by 1 km (i.e., 3 km for COT < 1 and 2 km for COT > 1).

CTH CALIOP Comparison Summary:

The VIIRS CTH retrieval demonstrates significant biases when compared to CALIOP.

The CTH performance is strongly dependent on the algorithm selection, which in turn depends on cloud thermodynamic phase (e.g., day water or day ice).

For ice clouds, the retrieval can both significantly underestimate and overestimate the CTH when compared to CALIOP. For cases of overestimation, we suspect the algorithm does not converge on a valid solution and instead selects the tropopause as the CTH. The large underestimation likely is combination of algorithm performance issues and sensitivity differences between the active and passive observations (CALIOP vs VIIRS).

For low to mid-level clouds the algorithm systematic overestimates CTH.

The previous analysis evaluated the pixel-level IP cloud-top height. However, the IP product is not intended for use by the general community. Rather, the CTP EDR is the official product made available to the community through CLASS. Aside from out

previous comment that the EDR aggregation is not documented, we did assess the VIIRS pressure EDR using products from May 1, 2012. While the IP QF value for cloud products are detailed but often confusing and lacking key information, the EDR QF's are standardised across all EDRs and easy to interpret. Each EDR provides a 4-level integer quality flag that represents the "Overall Quality" of the EDR. The difference in global gridded CTP with and without QF filtering is dramatic [TBD: refer to combined Fig. 3.5, 3.7 from original Heidinger Word document]. Not surprisingly, our finding is that the user of the EDR product must use Quality Flags (QF) to properly use the product. Without the QF flags, users are very likely to misuse the product, potentially resulting in flawed analyses. Unfortunately, our experience with providing global cloud products is that users generally do not use quality flags, and if they do, they are not always used properly. As a result of our own lessons-learned, the Collection 6 COP Level-2 data sets are no longer using QA bits to isolate the key pixel populations.