Evaluation of VIIRS cloud top property climate data records and their potential improvement with CrIS

SECOND YEAR REPORT
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Dr. Bryan A. Baum (PI)
Space Science and Engineering Center
University of Wisconsin-Madison
Madison, WI 53705
bryan.baum@ssec.wisc.edu

Drs. W. Paul Menzel and Elisabeth Weisz (Co-I's)
Space Science and Engineering Center
University of Wisconsin-Madison
Madison, WI 53705
paulm@ssec.wisc.edu

Dr. Nadia Smith
Space Science and Engineering Center
University of Wisconsin-Madison
Madison, WI 53705
nadia.smith@ssec.wisc.edu

Specific goals of this proposal are to:

- Evaluate the EDR cloud products developed from VIIRS data,
- Implement cloud-top height/pressure retrieval software at the Atmosphere PEATE based solely on IR hyperspectral data (i.e., AIRS, IASI, and eventually CrIS),
- Analyze the hyperspectral IR data independently from that of the imager, at least initially. The approach is to build a daily map by adopting a common grid, intercompare the gridded cloud heights, and decide on a straightforward way to use the hyperspectral IR data to improve problem areas in the imager products,
- Continue to develop an approach in parallel that merges the imager and sounder data more directly using MODIS+AIRS (Aqua) and also AVHRR+IASI (MetOp-A). This additional complexity provides a mechanism to improve the imager pixel-level cloud top heights. This process will be extended to regional and subsequently global data,
- Compare VIIRS cloud products to those from VIIRS+CrIS upon launch of NPP, and
- Conduct studies to evaluate the cloud products from morning/afternoon imager-sounder sensor pairs and their uncertainties. Our intent is to mitigate cloud height differences caused by sensors so that we can isolate morning and afternoon cloud signatures.

This report summarizes results for the period May 2012 – March 2013, the second year of funding for this particular effort. The team is pleased to report significant progress towards accomplishment of the above stated goals. Our second year of effort concentrated on evaluating the VIIRS cloud EDRs through comparison with products from MODIS and CrIS. Most importantly, we completed our evaluation of the VIIRS cloud EDRs, with some results presented below. Our evaluation was included in the report on VIIRS EDR cloud properties (provided to NASA HQ on March 18, 2013) led by Dr. Steven Platnick (NASA GSFC). We also want to note two new papers published recently as part of this effort (Weisz et al. 2012 and Smith et al. 2013). Now that the NPP cloud EDR assessment is completed, we anticipate that more time will be spent on working towards developing an alternate approach to producing more mature cloud products, which will result in more papers being prepared and submitted this year.

Papers and reports resulting from this grant over the past year:

Weisz, E., W. P. Menzel, N. Smith, R. Frey, E. E. Borbas, and B. A. Baum, 2012: An approach for improving cirrus cloud top pressure/height estimation by merging high spatial resolution infrared window data with high spectral resolution sounder data. *J. Appl. Meteor. Clim.*, **51**, 1477-1488.

Smith, N., W. P. Menzel, E. Weisz, A. Heidinger, and B. A. Baum, 2013: A uniform space-time grid for comparison of global satellite cloud products: Characterization and sensitivity studies. *J. Appl. Meteor. Clim.*, **52**, 255-268.

Platnick, S., S. A. Ackerman, B. A. Baum, A. K. Heidinger, R. E. Holz, M. D. King, W. P. Menzel, S. Nasiri, E. Weisz, and P. Yang: Assessment of IDPS VIIRS cloud products and recommendations for EOS-era cloud climate data record continuity. Provided to NASA HQ on March 18, 2013.

Second Year Progress

A brief summary of recent progress is listed below.

1. Dr. Nadia Smith improved our ability to compare regional and global cloud products from multiple sensors (e.g., VIIRS and CrIS); her paper on this research has now been published. This approach plays a prominent role in generating the results presented in this report.
2. Our evaluation of the VIIRS EDR cloud products is summarized in the Platnick et al. (2013) evaluation report submitted to NASA HQ on 18 March, 2013. Some results from our analysis are provided below.

Highlights of Research Results

To summarize the analysis we performed to evaluate the VIIRS EDR (aggregated on a 5-km spatial scale) cloud-top pressures (CTP): *the VIIRS EDRs contain (a) serious artifacts and (b) suffer from implementation issues*. Furthermore the CTP product can only be interpreted correctly through use of the appropriate overall quality flag, something that most users do not take the time to understand adequately. More details on these issues are in the Platnick et al. (2013) report. For the remainder of this annual report, we compare the VIIRS EDRs to both MODIS and CrIS cloud top pressures. We note that the Atmospheres PEATE provided the MODIS Collection 6 cloud products and also the VIIRS EDRs for a month of data.

VIIRS–MYD06 Comparisons: Context with MODIS products

There are no global monthly gridded products provided for VIIRS. To provide a consistent way to filter the cloud products similarly for different sensors, we developed a new approach for our gridded CTP assessment activities. The goal is to develop a method with which any geo-referenced parameter, at any level of processing (L1B/L2), can be projected from its non-uniform instrument domain to a uniform space-time domain. As such, the gridded output is tailored to specific research needs but is created for a user-defined (not product-defined) length of time, from any suite of instruments relevant to the study. Our approach is called the space-time gridding (STG) method and is documented in Smith et al. [2013]. The STG approach results in a daily gridded product at a user-selected spatial resolution (i.e., the space element). A longer–term product is developed in a subsequent step from the daily maps (i.e., the time element).

For the high cloud comparisons of global cloud top pressure shown in **Fig. 1**, the results for the month of September 2012 are aggregated and presented on a 1˚x1˚ grid. The data are filtered as follows: (a) CTP ≤ 440 hPa and (b) the viewing zenith angle $\leq 32^{\circ}$. As such, the results are for high-level clouds only. Our evaluation is based on the MODIS Collection – 6 5 – km CTP results provided by the Atmosphere PEATE and the VIIRS EDRs at 5 km resolution. The (MODIS-VIIRS) CTH difference plot indicates that in general, daytime MODIS cloud top pressures are about 50 - 100 hPa lower (clouds are higher) than those from VIIRS, with even larger differences in the nighttime comparison. Note that VIIRS has different algorithms for nighttime and daytime ice cloud retrievals. At the level of ice clouds in the troposphere, a rule of thumb is that 1 km ~ 50 hPa. Thus there is a bias of 1–3 km in high-level cloud heights between MODIS and VIIRS, with VIIRS CTH generally lower than MODIS. This is not always the case, however. For example, in the daytime comparison over the Himalayas and the Tibetan Plateau, the opposite is true – MODIS CTP values are higher than VIIRS (i.e., clouds are lower). This raises a red flag because cloud retrievals are tricky over high elevation terrain, and the VIIRS EDR algorithms have not been through a rigorous evaluation.

A low-level cloud comparison (CTP > 680 hPa) between MODIS C6 and VIIRS EDRs is shown in **Fig. 2** for the same month of data, September 2012. For Collection 6, MODIS implemented a new approach for determining low-level cloud top pressures/heights. This was a high priority after comparisons with CALIPSO Version 3 products indicated that the MODIS cloud top height values were too high (i.e., CTP was too low). The issue was most prevalent over marine stratocumulus regions where low–level temperature inversions are common. Since the VIIRS EDR CTP products never benefitted from comparisons with CALIPSO, this issue remains in the EDR products. For low–level water clouds, a rule of thumb is that 1 km ~ 100 hPa. The results in Fig. 2 suggest that the VIIRS low-level cloud top heights are biased high by 1-2 km compared to MODIS.

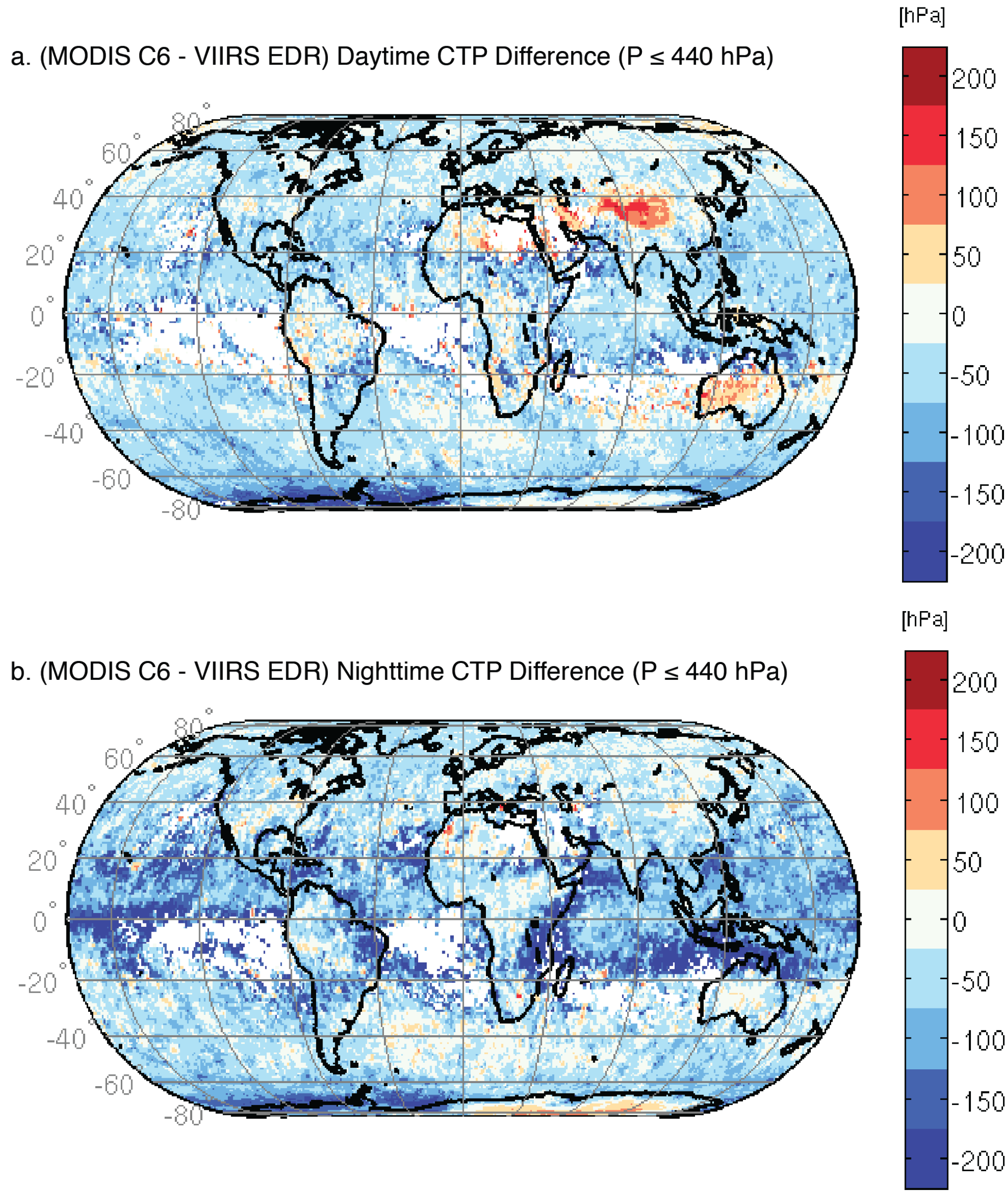

Fig. 1. Results for high-altitude cloud top pressures (CTP ≤ 440 hPa) differences between MYD06 Collection – 6 5 km CTP and VIIRS 5 km EDR CTP for the full month of September 2012. Cloud top pressure (in hPa) is presented on a 1° equal-angle grid for the (MODIS–VIIRS) differences for (a) daytime and (b) nighttime.

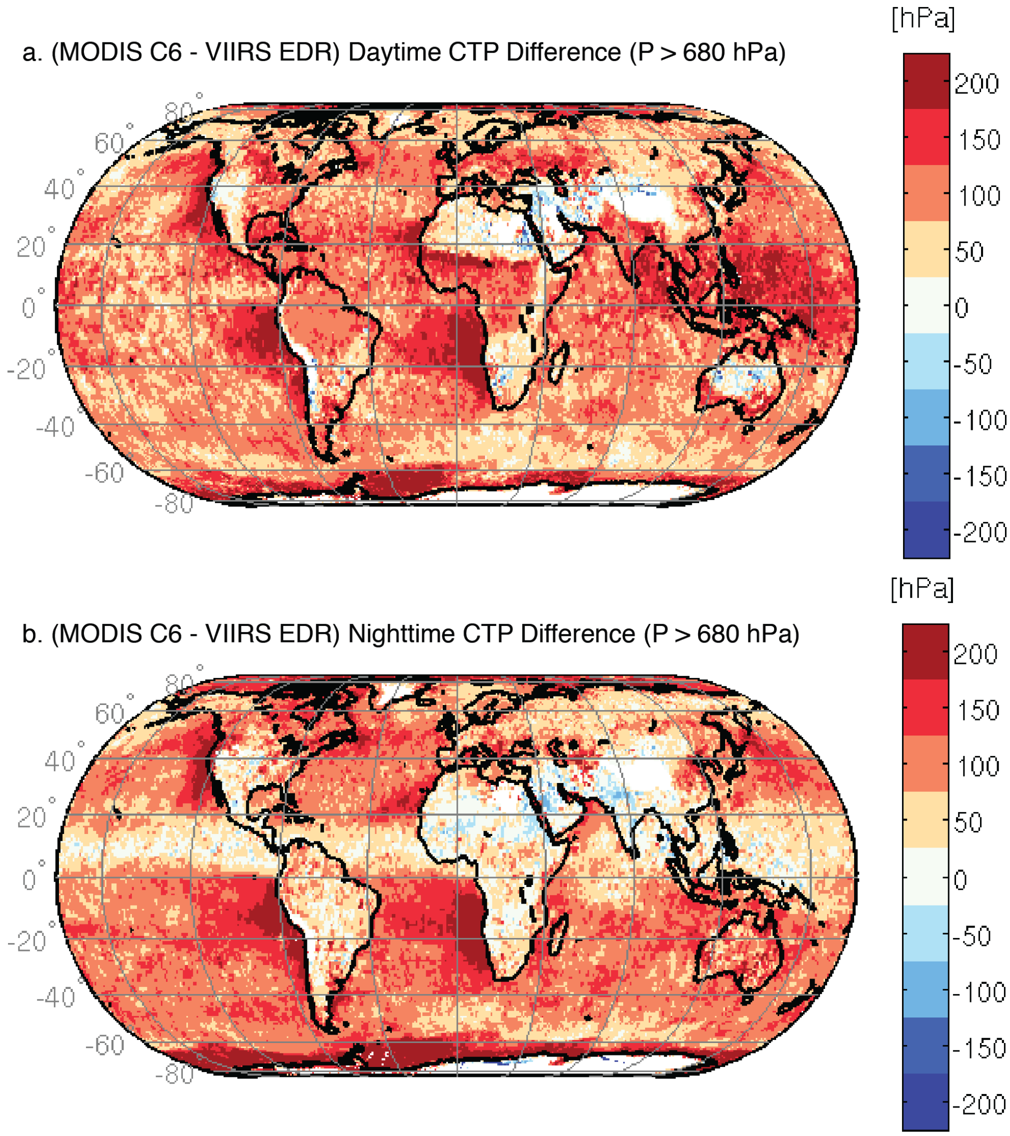

Fig. 2. Same as Fig. 5 but for low-altitude cloud top pressures (CTP > 680 hPa).

<u>What can CrIS provide?</u>

To demonstrate the potential information content provided by CrIS, **Fig. 3** shows high cloud CTP differences between VIIRS EDRs and CrIS for September, 2012. The CrIS results are based on a new dual regression approach (Smith et al. 2012). The space-time gridding approach is used to generate the monthly averaged CTPs for each sensor on a 1˚x1˚ equal angle grid for both daytime and nighttime results. There are several issues to note here. As with MODIS, there is a general bias between the CrIS and VIIRS CTP results for high-level clouds, i.e., ($P \leq 440$ hPa). VIIRS generally has a higher CTP, thus putting the height lower than CrIS (pressure and cloud height are inversely related). The bias is greater for nighttime than for daytime. While not shown, the frequency of high clouds in the VIIRS EDRs is much lower than for either MODIS or CrIS. Another issue is that part of the CTP day-night difference may result from the VIIRS EDR cloud phase assumed in the retrieval process. Regardless of the cause, or causes, of the differences, the CTP differences between CrIS and VIIRS often exceed 100 hPa. With the yardstick of 50 hPa ~ 1 km for high-level clouds, this indicates cloud top height differences of approximately 2-3 km, with the largest differences in the Tropics.

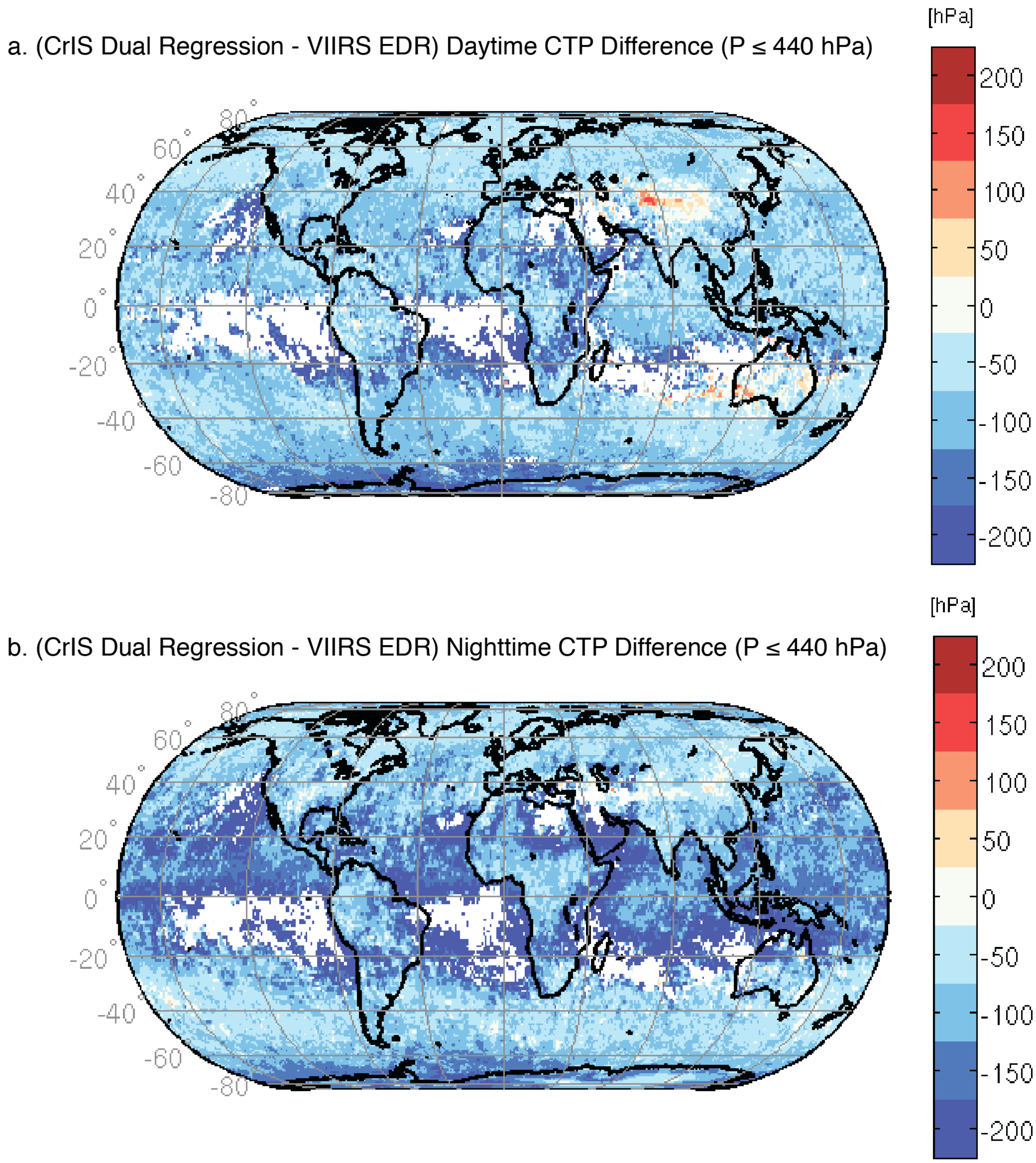

Fig. 3: Differences in high-level cloud top pressure between the CrIS dual-regression method and the VIIRS EDR values for (a) daytime and (b) nighttime. Negative values (in blue) indicate that VIIRS CTPs generally have higher values than those from CrIS, which relate to lower cloud top heights.

Fig. 4 shows the high-level cloud CTP differences between the gridded MODIS C6 5-km product and CrIS for September 2012. The monthly averaged CTPs for each sensor are shown on a 1˚x1˚ equal angle grid for both daytime and nighttime results. Over much of the globe, the differences between CrIS and MODIS are within 50 hPa of each other, with MODIS CTP tending to be a bit lower than CrIS. Over ocean, there are regions that display higher CTP differences, and these areas tend to have both high frequencies of low-level stratocumulus and low frequencies of cirrus. It is not uncommon for optically thin cirrus to overlay the low-level clouds in these regions. While this needs further exploration, CrIS data seem to provide a greater sensitivity to optically thin cirrus regardless of whether a lower-level cloud is present in the field of view.

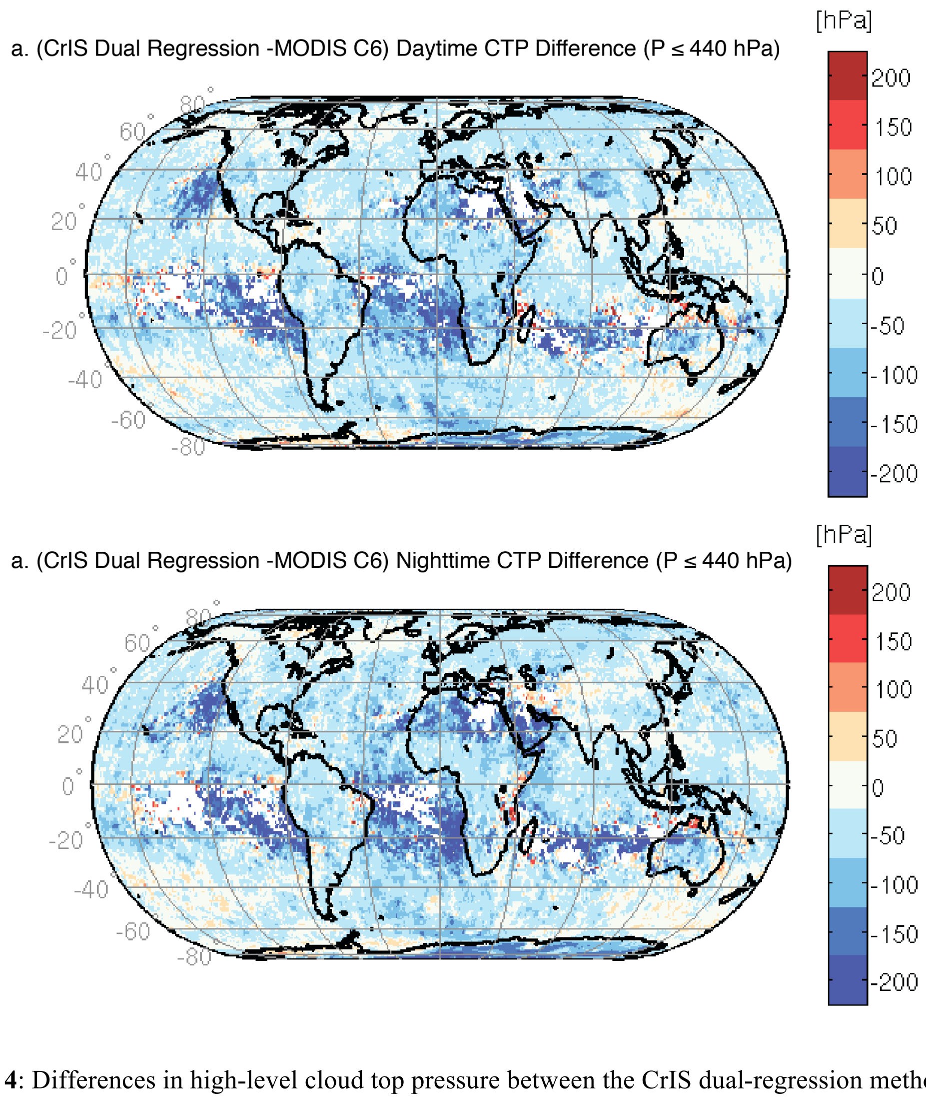

Fig. 4: Differences in high-level cloud top pressure between the CrIS dual-regression method and the MODIS Collection 6 5-km CTP values for (a) daytime and (b) nighttime. Negative values (in blue) indicate that MODIS CTPs generally have higher values than those from CrIS, which relate to lower cloud top heights. Note that for most of the globe, the CTP differences are within 50 hPa. There are regions over ocean that display higher CTP differences; these areas tend to have both high frequencies of low-level stratocumulus and low frequencies of cirrus.

Summary

A thorough evaluation of the VIIRS EDRs based on products from the month of September 2012 indicates that there are serious artifacts in the EDR products. Some of these issues are due to algorithm problems; others are due to implementation. Additionally, the values of the cloud top pressures are significantly different from those that will be expected in the MODIS C6 products. In the time remaining under this grant, we will work towards determining the most efficient way to mitigate these differences by augmenting the VIIRS information content with that from CrIS.

Additional References:

Smith, W. L., E. Weisz, S. V. Kireev, D. K. Zhou, Z. Li and E. E. Borbas, 2012: Dual regression retrieval algorithm for real-time processing of satellite ultraspectral radiances. *J. Appl. Meteor. Clim*., **51**, 1455-1476.