Final REPORT FOR NASA GRANT NNX15AG12GT (**"Development of VIIRS L2 Cloud and L3 Gridded Atmosphere Team Products for NASA Research and EOS Data Record Continuity**

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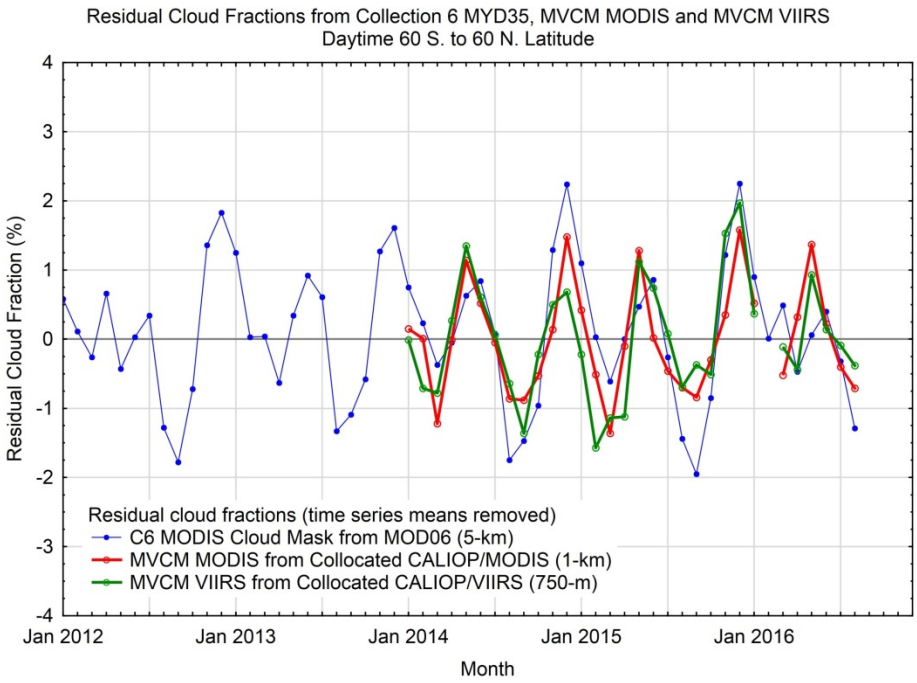
1. SUMMARY OF WORK DONE

This is the final report for the project. The focus of this grant is to support the continued development of the VIIRS L2 and L3 atmosphere algorithms. This the summary of the components of the effort as well as the attached manuscript submit as part of this research from this research:

MODIS-VIIRS Cloud Mask (MVCM)

The MVCM is being developed to aid in the production of climate-quality products across the entire time period covered by the MODIS and VIIRS instruments. To this end, the algorithm uses only measurements from spectral bands that are found on both instruments. The MVCM closely follows the methodology of the MODIS cloud mask (MOD35); however, upgrades have been made that include an increase in spectral tests, added angular dependence to some test thresholds, and fine tuning of thresholds. During the year 2016, the following tasks were completed:

1) Adjusted 0.86 μm and 0.86/0.65 μm thresholds for sun-glint regions
2) Adjusted ocean 0.86 μm thresholds to improve consistency between Aqua and SNPP
3) Adjusted VIIRS 1.38 μm cloud test thresholds for polar and near-polar waters
4) Added 1.6 μm cloud test for daytime oceans; sza-dependent thresholds; adds more sensitivity to broken/thin low clouds
5) Fixed error in thresholds files for daytime snow/ice
6) Made snow/ice detection more consistent between MODIS and VIIRS
7) Adjusted VIIRS surface emissivity correction in the 11-12 μm BTD transmissive cirrus test over snow/ice



The plot below shows a time series of cloud fraction residuals (time series means subtracted from monthly mean values) for MOD35 (blue), MVCM MODIS (red), and MVCM VIIRS (green).

Agreement between the three is good, especially for the MVCM algorithm as applied to MODIS and VIIRS. The three capture seasonal variations in cloud cover reasonably consistently but mean cloud fractions differ by several percent. MOD35 detects about 5% more clouds than MVCM MODIS and about 6% more than MVCM VIIRS, presumably due to the use of more spectral bands, hence more information, in the MOD35 algorithm.

The MODIS-VIIRS Cloud Mask (MVCM) is a multi-spectral cloud detection algorithm designed to operate on both MODIS and VIIRS imagery data to produce consistent cloud amounts and to facilitate generation of consistent cloud products between the two instruments. The methodology follows that of the MODIS cloud mask (MOD35) closely, utilizing a "fuzzy logic" algorithm where individual spectral cloud tests are combined to form a "confidence of clear sky" for each pixel containing valid data. Level-1b radiance data and ancillary inputs (e.g., surface temperatures, total precipitable water, snow/ice background maps, etc.) are also similar to those used for MOD35. The MVCM uses consistent spectral measurements between VIIRS and MODIS as much as is feasible; one exception is substituting the 2.1 μm for the 1.6 μm band in MODIS data because of malfunctioning detectors on the Aqua MODIS instrument. The consistency requirement between MODIS and VIIRS dictates that radiance data from absorbing channels on MODIS that are not found on VIIRS cannot be used as inputs, such as those in the 15 μm CO_2 band or in the 7.3 and 6.7 μm water vapor bands. For ease of use by the satellite community, output files contain the same 48-bit per pixel output as seen in MOD35 data but also include the final clear-sky confidence values (0.0-1.0 where 0.0 is confident cloud and 1.0 is confident clear). Output also includes latitude, longitude, solar zenith and azimuth, and sensor zenith and azimuth for each pixel.

Work Progress

Work began by removing the Collection 6 MOD35 code from the quasi-operational environment of MODAPS (MODIS Adaptive Processing System) that produces MODIS products on a 5-minute granule-by-granule basis. The code was then adapted to read radiance and geolocation data from Intermediate Format Files (IFF) produced by the Atmosphere Science Investigator-led Processing Systems (SIPs) located at the University of Wisconsin-Madison. HDF-4 output files were constructed that include the original (MOD35) 48-bits per pixel, but also clear sky confidence values and geolocation, solar, and viewing angles for each pixel.

Though the MVCM is patterned closely after MOD35, due to the removal of some absorbing bands, extensive re-tuning of the MODIS side of the algorithm is required, along with initial efforts for VIIRS processing. Several rounds of tuning have already been completed. Also due to the use of fewer bands, work-arounds for several sub-programs were necessary, including sun-glint, polar night, and night ocean processing. Work on sun-glint and night ocean is largely completed but polar night continues to be a work in progress.

Several enhancements have been made to Collection 6 MOD35 cloud tests. Solar and viewing angle corrections to the 0.86 μm daytime ocean cloud test thresholds were added, as well as viewing angle corrections to 0.65 μm land day thresholds. Due to significant differences in

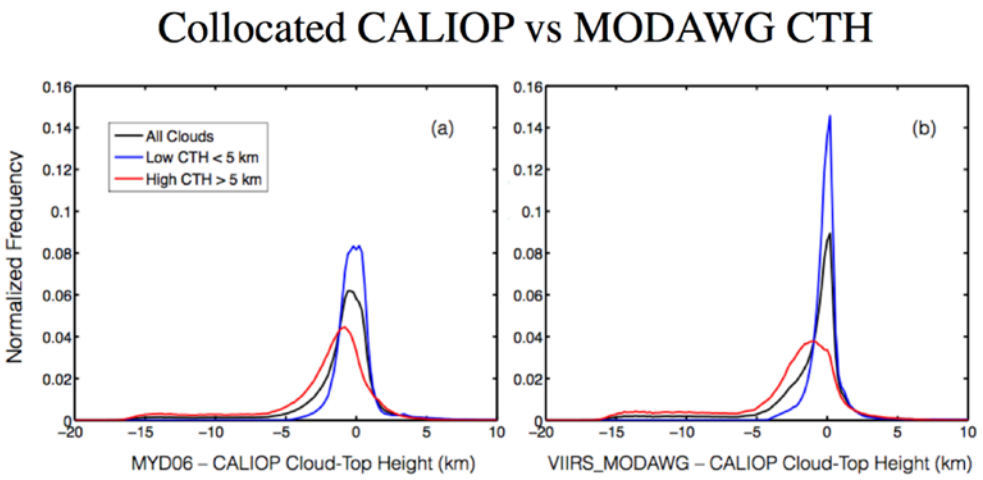
spectral response between the MODIS and VIIRS 1.38 μm bands, cloud test thresholds were re-derived for VIIRS data using collocated CALIOP cloud data for a clear sky vs. cloudy sky reference. In addition, the MODIS thresholds were re-tuned to detect more thin cirrus and both MODIS and VIIRS thresholds were made functions of solar zenith angle. Snow detection improvements for taiga and montane environments were made but more tuning of the various thresholds is required.

IR Cloud Products

We have continued to support the development and validation of the VIIRS IR cloud products that include Cloud Top Height, Cloud Top Temperature, Cloud Top Pressure, and IR phase. These products are generated using the CLAVRx algorithms that has been modified to work with the VIIRS IR bands which do not include CO_2 absorption channels. The focus on the past year of research has been to continue the integration of the cloud products with the cloud optical property retrievals developed by the Platnick team. A significant milestone has been accomplished which involved changing the output format of the MVCM, IR cloud products, and the optical property retrievals to netcdf 4 with the goal of releasing a beta version of VIIRS cloud products in 2017. We have continued the validation using collocated CALIOP cloud products and inter-comparisons with MODIS retrievals. A VIIRS/CrIS and manuscript focused on the integration for the sounder/imager has been submitted.

We have implemented a window channel cloud top height and IR phase retrieval that can be applied to both VIIRS and MODIS data. The retrieval is based on years of development as part of the PATMOS-X retrieval package that was designed to work with the NOAA imagers that do not have absorption channels. The cloud top height retrieval was tested on a year of MODIS and VIIRS observations. A comparison of the results validated using CALIOP is presented in figure 2. We are now focusing on effort on continued validation of the window CTH retrieval with comparison between MODIS C6 and CALIOP. We expect to start experimenting with adding collocated CrIS CO2 absorption channels in the upcoming year.

Figure 1 The differences between the MODIS (A) and VIIRS (B) compared to CALIPSO is presented. Negative differences result when MODIS/VII



RS CTH is

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