GOESR3 Periodic Reporting

Reporting Period: **July 2019 – December 2019 (1st half of FY19 funding cycle)**

Team Lead: John M. Haynes
Team Members: Yoo-Jeong Noh, Steven D. Miller, Andrew Heidinger

Project Title: Improving the ABI Cloud Layers Product for Multiple Layer Cloud Systems and Aviation Forecast Applications
Project Number: 479

Executive Summary

This project seeks to improve the classification and categorization of multilayer cloud scenes by the GOES ABIs, while simultaneously improving the Cloud Cover Layers (CCL) product that identifies the height category of clouds in any given ABI pixel. The general methodology is threefold: (1) To investigate the usefulness of certain cloud proxies, such as layer relative humidity, by training on actively-sensed cloud layer boundaries; (2) To develop a new multispectral retrieval that uses ABI radiances to determine separation between cloud layers in known multilayer situations (currently implemented using machine learning); and (3) To fuse this information together with our own statistical cloud base algorithm, which has been trained on radar and lidar-observed cloud boundaries.

In this reporting period, we made significant product toward these objectives, and are converging on a final algorithm that will be meet the stated goals of improving the CCL product for multilayer scenes.

Progress toward FY19 Milestones

This section will address overall progress toward FY19 milestones achieved, focusing mostly on the July through December 2019 reporting period (previous progress will be summarized as required). Milestones, bulleted and in italics, are referenced.

To date a variety of improvements have been made from the cloud cover layers (CCL) algorithm as it existed at the start of this project. The first is that the algorithm has been transformed from a simple algorithm with three height-based categories, high (H), middle (M), or low (L), to an algorithm with six categories (adding H+M, M+L, and H+M+L; we refer to this as the CCL V2 algorithm). An incremental minor improvement on top of this is that the algorithm can now be run on five flight-level based levels, a change that was made based on input from our operational partners, and already incorporated into CLAVR-x with collaboration with Andy Heidinger (NOAA cloud team lead) and CIMSS team.

Our progress during the reporting period is focusing on what we refer to as CCL V3. This algorithm represents an improvement to the V2 algorithm that focuses on multilayered clouds, and specifically on our ability to detect low clouds that are at least partially obscured by overlying higher clouds. In particular, our newest work utilizing machine learning to detect such low clouds matured significantly during this reporting period. While still using a variety of multispectral ABI information as originally proposed, we have shifted our focus to the random forest model, training an algorithm that places clouds vertically in a scene utilizing training observations derived from the CloudSat radar and CALIPSO lidar. Combining these observations with estimates of the vertical profile of moisture in the atmosphere has allowed development of an ABI-based algorithm for low-cloud detection (which is also applicable to other sensors, including VIIRS). During this reporting period we have improved the probability of detection of low clouds under cirrus (for example) with the ABI from 22 to 69% in a ~30 day test period that is independent of the training data (Figure 1). This comes at the expense of a higher number of false alarms, but the false alarm rate for low cloud under cirrus is less than 25% and we expect that we can reduce this number by using more training data and improved characterization of the earth's surface.

As outlined in the next section, our current focus is on (1) improving this algorithm using more data and refined inputs, and (2) implementing the algorithm in a way that is feasible operationally.

- *Extensively test and validate algorithm using CloudSat, CALIPSO, EarthCare, and ARM data, as availability allows.*

We have now extensively validated the CCL V2 changes against chiefly space-based radar and lidar observations from CloudSat and CALIPSO (EarthCare has not yet launched). Figure 2, for example, shows joint statistics of cloud height categorization for a ~30 day period using the CCL V2 algorithm applied to GOES-16 ABI data, compared to CloudSat/CALIPSO. Each panel represents a CLAVR-x category, and shows the performance of CCL V2 (green bars) versus the "truth" determined from the rada/lidar (blue bars). For a given cloud configuration (e.g. HML) in a given panel (e.g. Cirrus), ideally the green bars should match the blue bars. In the example just given, CloudSat/CALIPSO observes clouds in all three height categories about 20% of the time that CLAVR-x identifies the cloud type as cirrus; but CCL V2 identifies clouds in all three height categories only 2% of the time. This plot quantifies the expected shortcoming that CCL is biased against detecting the lower cloud layer in multilayer scenes. Note also that H+L is not possible with CCL V2, but our newest work on CCL V3 is addressing this.

We also continue to compile ground-based measurements (ceilometer, lidar, and surface meteorological observations) from the ARM sites (NSA, Alaska and SGP, Oklahoma) for validation and monitoring of the algorithm performance.

- *Complete incorporation and display test of the product in AWIPS II or N-AWIPS.*

Working with Amanda Terborg (AWC/CIRA), Daniel Lindsey (NOAA), and Debra Molenar (NOAA), we have developed an initial N-AWIPS display for the CCL product (Figure 3). The display shows clouds layer combinations in a variety of colors, comparable to the SLIDER interface we produce in near-real time (https://col.st/rCOLI). Having now determined how to setup a data feed of this product to AWC via LDM, we are ready to engage with AWC in the best way to proceed with evaluation of this product in the first half of 2020.

- *Visit Aviation Weather Center to deliver hands on training.*

In August 2019, PI John Haynes visited the AWC in Kansas City, MO, to update staff on our CCL work, garner user feedback, and interact with forecasters on the operations floor. Gathering user feedback on how satellite cloud products are used by AWC forecasters was invaluable. We now have a better understanding of user needs for low-cloud products, and how our CCL work will benefit AWC forecasters, particularly in the arena of general aviation forecasting. The machine-learning approach we have embraced was well received, and as mentioned in the above paragraph, this visit spurred work to develop an N-AWIPS interface that can be used by operational forecasters.

- *Present results at GOES-R meeting and at AMS or AGU.*

This work was presented in an oral presentation at the American Meteorological Society / EUMETSAT Joint Satellite Conference in Boston, Massachusetts, in September 2019.

Haynes, J. M., Y. J. Noh, S. D. Miller, A. K. Heidinger, and J. M. Forsythe, 2019: Cloud boundary detection in multilayer scenes with the GOES ABI. 2019 American Meteorological Society / EUMETSAT Joint Satellite Conference, Boston, MA.

No GOES-R meeting occurred in this reporting period.

Plans for Next Reporting Period

In the next reporting period we will further refine our low cloud detection model in an attempt to improve the probability of detection of low cloud, and reduce false alarms. This will involve using a greater training data set (i.e. a longer period of CloudSat/CALIPSO/ABI matchups), and refining our feature selection process. We are currently exploring how better characterization of the earth's surface (in particular, the detection of ice or snow) can improve cloud detection and eliminate false alarms caused by high-albedo surfaces.

- *Complete implementation of new algorithm into the CLAVR-x processing system (as a development/transition tool for NOAA operational algorithms).*

We are currently determining the best way to implement our machine learning based method into the Enterprise algorithms. The random forest implementation we are utilizing is written in Python, while the Enterprise algorithms are Fortran-based. Fortunately, our current algorithm can be run as a post-process, completely separately from the existing CCL V2 code.

- *Complete VISIT module training module for AWC forecasters.*

User training will be provided to our operational partners at AWC either in person (as originally planned), or remotely (given current travel restrictions in effect at the time of this writing).

- *Publish results in a journal.*

A paper is in preparation describing our algorithm and its operational utility.

Additional Information

1. Interaction with operational partners –

John Haynes visited the Aviation Weather Center in August 2019 to gather user feedback and interact with forecasters, as described in this semi-annual report. The CIRA team regularly participated in the Cloud Team teleconferences and meetings for user-developer interactions including Aviation/Arctic Proving Ground Initiative" established on the JPSS side.

2. Conference/workshop participation –

Haynes, J. M., Y. J. Noh, S. D. Miller, A. K. Heidinger, and J. M. Forsythe, 2019: Cloud boundary detection in multilayer scenes with the GOES ABI. 2019 American Meteorological Society / EUMETSAT Joint Satellite Conference, Boston, MA.

Noh, Y. J., S. D. Miller, J. M. Haynes, J. M. Forsythe, C. J. Seaman, A. Heidinger, A. Walther, and Y. Li,

2019: Improvement of Nighttime Cloud Geometric Thickness Retrieval Integrating Multi-Sensor Observations and Numerical Model Simulations. 2019 AMS-EUMETSAT Joint Satellite Conference. 28 September - 4 October 2019, Boston, MD.

Noh, Y. J., 2019: CIRA's satellite products, COMET Weather Analysis and Forecasting course for Korea Meteorological Administration forecasters. 14 May 2019, Boulder, CO.

Noh, Y. J., J.-H. Kim, S. D. Miller, 2019: Satellite Cloud Vertical Layers for Aviation Weather Applications. 2019 Korean Meteorological Soc. Annual Fall Meeting, Oct. 30 – Nov. 1, 2019, Gyeongju, South Korea.

Noh, Y. J, S. Miller, J. Haynes, J. Forsythe, C. Seaman, A. Heidinger, A. Walther, Y. Li, S. Wanzong, and W. Straka, 2019: Satellite Cloud Base/Layer Product and Aviation Weather Applications. 4th KNU CARE International Conference, Sept. 23-24, 2019, Gyeongju, Korea. (Invited talk).

In addition to the above conference presentation, the work was discussed with a small group of CloudSat developers at a meeting at the University of Wisconsin, in September 2019.

3. Outside project publicity – none

4. Journal articles – none

Key Graphics

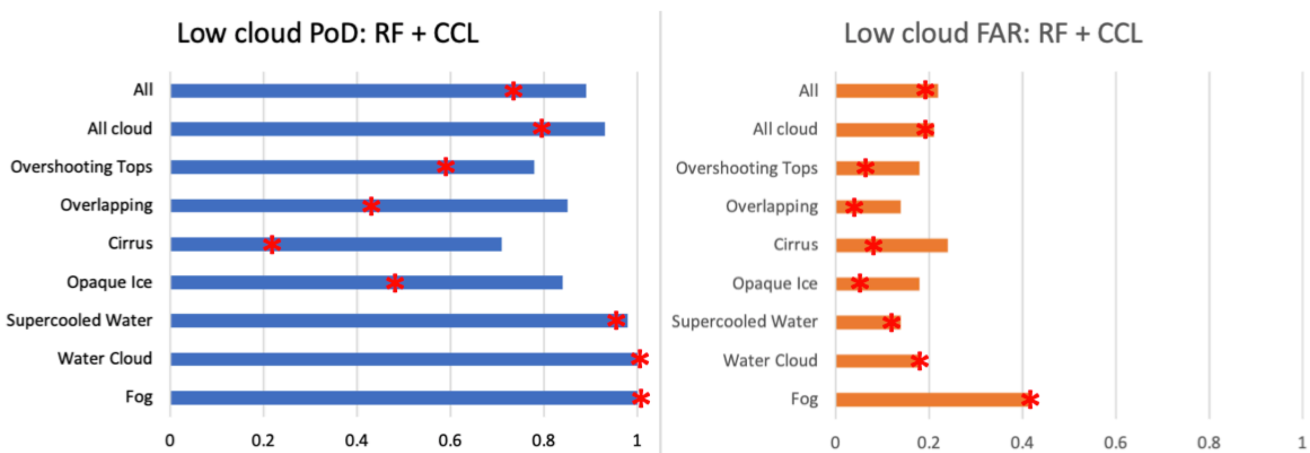

Figure 1. Probability of detection (PoD; left panel) and false alarm ratio (FAR, right panel) of low cloud detection, as a function of CLAVR-x cloud type (labels on vertical axis). The bars represent either the PoD or FAR of an algorithm that classifies low cloud as occurring whenever the CCL algorithm detects low cloud OR the random forest implementation detects low cloud. The red asterisks represent the original CCL algorithm.

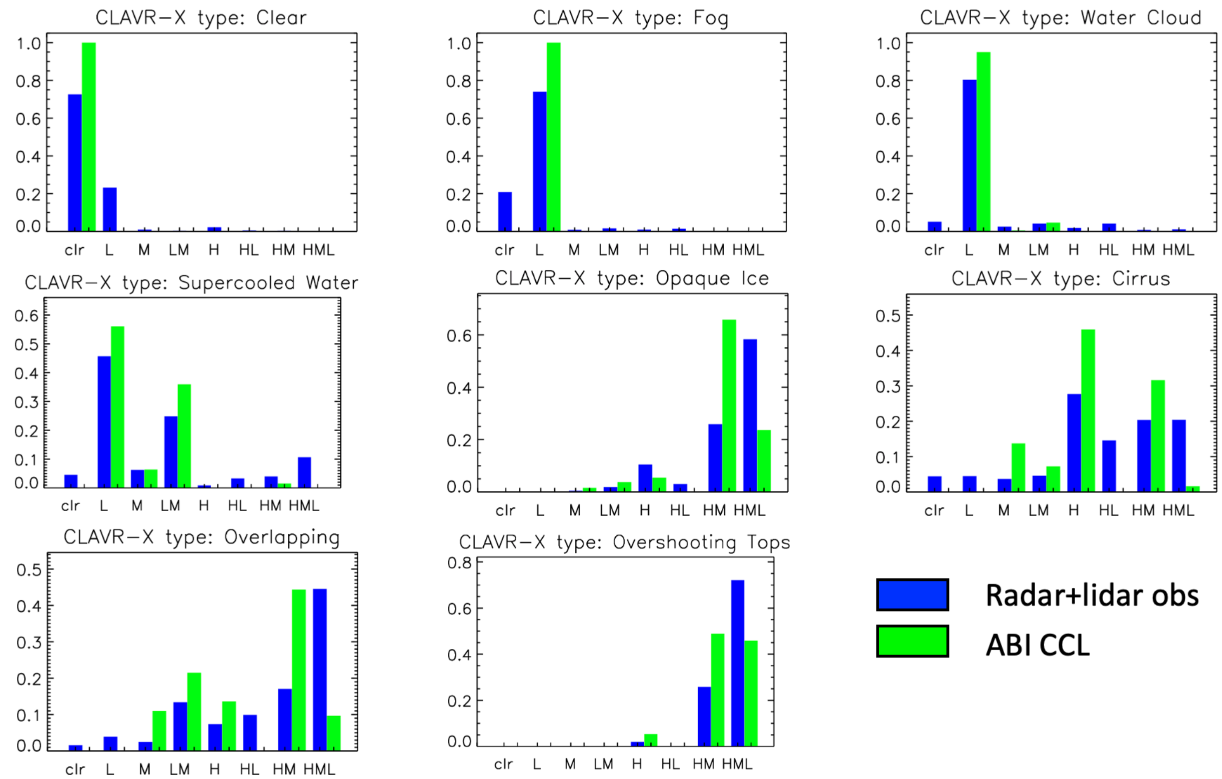

Figure 2. Cloud statistics for eight different CLAVR-x categories showing statistics of joint observations between GOES-16 ABI, CloudSat, and CALIPSO (each panel represents one such category). The vertical axis of each panel is the fraction of observed cases during the test period. The horizontal axis shows the vertical height categories. Blue bars are radar+lidar observations, green bars are ABI using the CCL V2 algorithm.

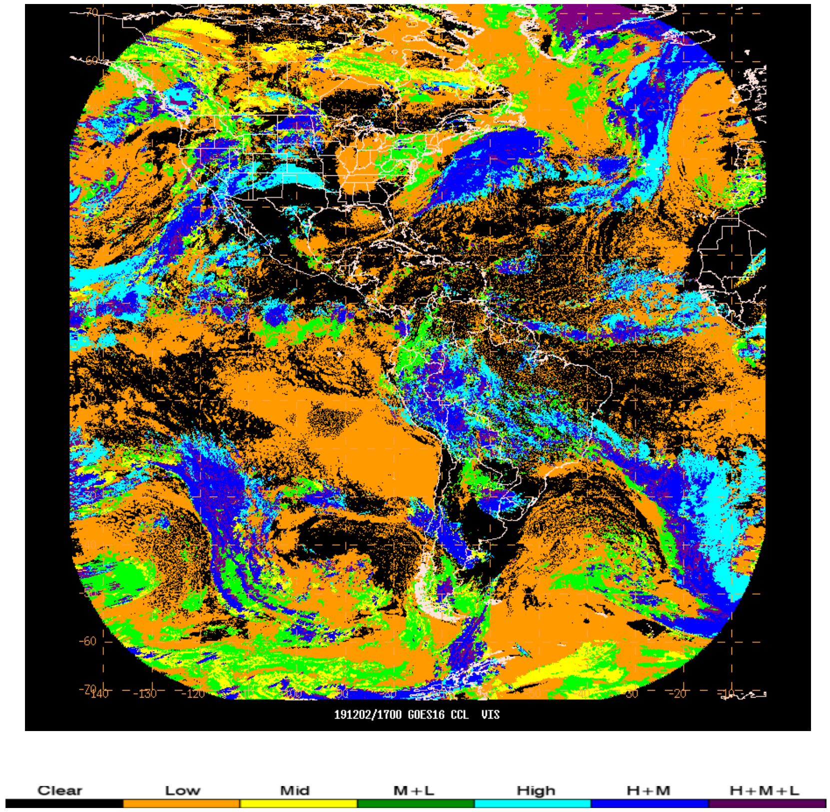

Figure 3. Initial test version of an N-AWIPS product display for CCL. Colors represent different combination of high (H), mid (M), and low (L) cloud layers.