CERES S'COOL Project Update:

The Evolution and Value of a Long-Running Education Project

With a Foundation in NASA Earth Science Missions

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ABSTRACT

In January 1997, the Students' Cloud Observations On-Line (S'COOL; http://scool.larc.nasa.gov) Project began with NASA scientists visiting rural Gloucester, Virginia to observe clouds with middle school students. In the 19 years since, this educational outreach component of NASA's Clouds and the Earth's Radiant Energy System (CERES) mission has collected ~141,000 observations from every continent and ocean basin around the world. Thousands of students and teachers have directly engaged in S'COOL. Beginning in 2008 we invited citizen scientists to participate as well.

Over time S'COOL has added more components that engage participants directly with science data analysis, continuing direct ties to CERES research. Whenever possible, the S'COOL team extracts corresponding subsets of CERES data, which are sent to the participant to analyze. Observations can now be matched to images and cloud retrievals from MODIS and measurements from CALIPSO. To date, more than half of S'COOL observation reports correspond to one (or more) CERES overpasses. Comparisons with CERES geostationary satellite cloud retrievals were recently added, making cloud observations at almost any time of day over non-polar regions useful for validation.

A thorough analysis of co-located S'COOL and satellite data was conducted during summer 2015. Results show that the S'COOL community provides high quality observations offering useful insights on the strengths and shortcomings of passive cloud remote sensing from space. This reconfirmed the utility of S'COOL observations to the scientific community and provides observers with deeper insight into the challenges associated with validation of space-based cloud property retrievals.

CAPSULE

Since 1997, the S'COOL Project has engaged students and citizen scientists with NASA Earth science missions through authentic science experiences, observing clouds and comparing data from ground and satellite sources.

1. TWO DECADES OF CONTINOUS GROWTH

Active participation in science among non-professional scientists has flourished over the past twenty years, from the coining of the term “citizen science” in 1995 to hundreds of citizen science initiatives available today (Bonney et al. 2009). NASA’s CERES S’COOL project (Chambers et al. 2003) has contributed to this trend. As shown in Fig. 1, initial steady growth was followed in the early 2000s by more variability as the funding model supporting the S’COOL team changed and less time was available to focus on interactions with the S’COOL community. Participation in recent years has benefitted from internal drivers due to evolving NASA priorities, while external factors also affect participation levels. For example, 2012 was a standout year for satellite matching due primarily to four experienced and prolific participants who each achieved >75% matching with satellite overpasses. Despite these variations, observations have held fairly steady for over a decade, averaging ~8,500 observations/year. This staying power rests on connecting NASA’s research focus on Earth’s energy budget with the benefits of widely distributed ground data through a simple, accessible cloud observation project.

As of January 2016, S’COOL participants have submitted over 140,700 ground observations from 97 countries around the world (Fig. 2). Ground observations correspond to satellite data in ~63% of cases for fixed S’COOL observation sites (primarily schools) and 49% for individual citizen scientists. The S’COOL community thus provides a valuable ground truth dataset, piecing together elements of a global view of clouds and atmosphere from the ground up; this perspective is not attainable by NASA scientists alone.

2. CONTINUOUS IMPROVEMENT OF CAPABILITIES

In Chambers et al., (2003), we identified lessons learned in 5 categories:

- Think globally, act incrementally;
- Keep it simple;
- The internet advantage;
- Teachers are professionals too; and
- Two-way street.

Since then, the S'COOL team has continued to use 2-way communication with educators (and now citizen scientists) to incrementally improve the project by leveraging internet advances, with the goal of keeping S'COOL as simple but effective as possible.

On the satellite data side, we have progressed from the beginning of the project when 1) obtaining corresponding satellite data for a ground observation took literally years to 2) routine CERES processing with matches in ~6 months, to 3) leveraging FLASHFlux processing (Kratz et al. 2014) which produced satellite results within a week, and to 4) today, automating an interface to geostationary (hereafter "GEO") satellite data which produces results within 24 hours. This near-real-time feedback is key to engagement, especially as technology expectations in general have increased. Adding GEO data also greatly increases the observing opportunities for which we can provide matching satellite data, which is very helpful for school-based observers constrained by a daily academic schedule.

On the web interface side, we have leveraged geo-location tools such as Google Maps to facilitate participation by a wider community. Starting in 2008, the addition of an interactive map enabled participants to easily request satellite overpass times for any spot on Earth. This enhancement enables us to invite participation outside of teacher-led formal education settings. As one consequence, S'COOL was featured in a SkyScience campaign in October 2014, part of NASA's celebration of Earth Science Week (www.earthsciweek.org). The event was widely shared on social media and resulted in a substantial uptick in interest and participation (see Figure. 1).

Technical advances have also enabled other new features. In 2000 we leveraged the MODIS Rapid Response site (http://rapidfire.sci.gsfc.nasa.gov/realtime) and later the NASA Worldview tool (https://worldview.earthdata.nasa.gov/) to give participants increasingly personalized satellite imagery corresponding to their report from the ground. Figure 3 shows an example of the current report layout sent to participants, with key features highlighted. In 2014, we added another dimension to ground observation reports by accepting participant photos. Observations that include ground and satellite images (over 1000 so far; see http://scool.larc.nasa.gov/cgi-bin/ObsPhoto.cgi) create a rich collection to explore patterns as well as help participants compare and analyze matches and understand the different strengths and weaknesses of satellite imagery and ground-based human observation.

3. DETERMINING THE EDUCATIONAL VALUE OF S'COOL

An external evaluation by the Bach Center (2006) identified S'COOL's potential and achievements as an effective classroom instructional activity, embodying science, technology, engineering and math (STEM) practices while emphasizing and developing 21st century skills. In 2015 the S'COOL team conducted a project evaluation focused on the experience of participants, primarily K-12 classroom educators (Martin and McCrea 2015). This more recent evaluation addresses many of the changes in approach and capability discussed above. Evaluation findings suggest that S'COOL's success is driven by its dual commitments to education and science. Educators find that S'COOL's process and resources meet their classroom needs (related to standards, curriculum, and performance assessment) and help to interest their students in the processes of science. Students are highly driven and motivated to participate because they are able to contribute to NASA and fill an unmet need through their ground observations. Educators identified a variety of skills and competencies related to the scientific process that S'COOL participation can help develop, from careful observation and detailed recording, to critical thinking, to cloud identification and classification. Additionally, because the S'COOL team is accessible and highly responsive, educators are able to get help to support S'COOL's classroom impact. S'COOL's new GEO option also meets a frequently-cited need of educators, who often had trouble reconciling their daily class schedules with the limited and varying CERES overpass times.

S'COOL's advances and continuous improvement strategies are aimed at motivating and retaining participants. Achieving this goal has the dual benefit of addressing key science education needs and obtaining a large ground-based observation dataset, which can be used to gain insights into satellite data products.

4. SCIENCE APPLICATIONS OF S'COOL OBSERVATIONS

The idea for S'COOL arose because imager-based cloud retrievals (cloud/no cloud; and cloud properties such as phase, optical depth, and height) are some of the foundational data sources used to determine scene characteristics within each CERES footprint and analyze the radiation balance throughout a day, a precursor to understanding Earth's Radiation/Energy Budget (ERB) at climatological time scales (Minnis et al. 2012). Thus it is very important to understand the accuracy of cloud retrievals as biases can influence the CERES-derived ERB.

The accuracy of CERES MODIS (Minnis et al., 2012) and GEO imager cloud retrievals has typically been determined based on comparison with highly accurate products derived from ground- or space-based lidar (e.g. the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP); Minnis et al. 2008) and radar (Smith et al. 2008). Space-based observations are essential for validation as they provide global observations throughout the year. This broad coverage enables identification of retrieval inadequacies that would be difficult to identify with observations from a fixed site. Unfortunately, instruments such as CALIOP observe much of the globe only twice per day in tropical and mid-latitude regions at approximately 1:30 AM/PM local time. CALIOP observations are collected only near the centerline (i.e. nadir) of the MODIS swath. These near-nadir and near-solar-noon CALIOP observations do not permit evaluation of cloud retrieval algorithm accuracy at all hours of the day. This is a key unknown within the cloud retrieval community as variable solar illumination and viewing angle can have a significant impact on algorithm performance (Minnis 1989; Varnai and Marshak 2007).

On the other hand, the combination of the human eye and mind is perhaps the best "remote sensor" for identifying the presence of clouds and characterizing basic properties such as cloud type (stratiform, cumuliform, or cirroform), cloud cover (partly vs. mostly cloudy or overcast), and cloud opacity (transparent, translucent, or opaque). Galaxy Zoo, a citizen science initiative in which participants visually classify galaxy morphologies from Sloan Digital Sky Survey imagery, successfully demonstrated the ability of non-specialists to accurately identify such visual information and provide research-quality data (Lintott et al. 2008; Willett et al. 2013). Humans can also provide observations at any time during daylight hours - and sometimes at night - helping to fill a critical data gap for validation of satellite cloud retrievals.

The cloud properties reported by S’COOL observers were selected to be aligned with the cloud properties derived by the CERES cloud detection algorithms, including cloud coverage, height, layering, and visual opacity. Thus, the cloud observations can be analyzed and compared from two different vantage points. During summer 2015, we conducted an in-depth assessment of S’COOL data. This was the first comprehensive analysis since Chambers et al. (2004). In that time the database of S’COOL observations matched to satellite data had grown 8-fold.

a. Using S’COOL Observations to Validate CERES Cloud Detection Algorithms

Our first analysis compared S'COOL and CERES MODIS cloud detections. Based on the S'COOL observation, the sky was either classified as clear (<5% cloud cover) or cloudy (>=5% cover). Table 1 shows a comparison of S'COOL and CERES MODIS cloud detection using 72,501 S'COOL-MODIS matches from March 2000-May 2015. We found 87.2% agreement between ground observations and satellite detection. These results match MODIS-CALIOP cloud detection comparisons, which also show an agreement of 87% (P. Minnis, personal communication 2016). These results provide confidence in S'COOL observers' ability to discern and accurately report the presence of clouds.

The 12.8% of cases with disagreement between S'COOL observations and CERES MODIS retrievals may shed light on areas of weakness in the CERES MODIS cloud detection algorithm. Examination of the ground-reported cloud types for these cases reveals that the cloud types most frequently missed by the CERES MODIS cloud mask are cirrus and cumulus clouds (Fig. 4). These cloud types are known to be challenging for satellite retrievals: cirrus clouds can be too thin or optically transparent for satellites to detect, while cumulus clouds can be too small to be resolved by the 1-2 km wide MODIS pixels.

b. Assessing the Value of Opacity Reporting

Ground observations of cloud opacity provide another opportunity to evaluate the relative accuracy of CERES MODIS cloud optical depth retrievals. Figure 5 shows histograms representing the frequency of satellite-based optical depth ranges for each of the S'COOL opacity classifications, namely opaque, translucent, and transparent. Increasing optical depths were retrieved on average, as the reported clouds were increasingly opaque from the S'COOL observer's perspective. Picking one of these categories is the most difficult decision for the S'COOL observer and is highly subjective, but the comparison shown here indicates that the observer reports do have some level of skill.

c. Using Active Remote Sensing Instruments to Validate S'COOL Observations

One uncertainty in using S’COOL observations as a validation data source is of course the accuracy of the S’COOL observations themselves. We address this by utilizing the CALIOP lidar and CloudSat radar (Stephens et al. 2002) active remote sensing instruments that provide high vertical resolution two-dimensional (time or Earth latitude/longitude vs. altitude) profiles of cloud boundaries. Co-located S'COOL and CALIOP/CloudSat observations are rare (~0.3% of matched pairs) due to the narrow instrument swaths, but when available provide the opportunity to evaluate cloud identification and layering reported from the ground. We developed display software in MATLAB that overlays the CALIOP/CloudSat 2B-GEOPROF-LIDAR (hereafter CCGL) product (Mace and Zhang 2014) with the S'COOL observation information, providing the S’COOL team and potentially S’COOL observers themselves detailed insight into the strengths and weaknesses of their observations.

Figure 6 provides examples of these co-located data for two cases that exemplify some of the characteristics of the S'COOL observations. For the case in Figure 6a, the two datasets both agree on the presence of a single high cloud layer, confirming the accuracy of the S’COOL observation. On the other hand, Figure 6b is a case where the S’COOL observer only observed a single low level cloud layer, while the CCGL product shows that two higher cloud layers were present. The ground observer reported that the low-level cloud layer was opaque and overcast, indicating that it was too thick for them to see through, therefore preventing them from observing any overlying cloud layers. This situation is not unusual, and the more commonly available passive satellite instruments may not see the low layer in such a case. Thus ground observations from

S'COOL provide a useful complementary view, providing a more complete understanding of the cloud column.

The above analyses of cloud mask, opacity, and layering validate participant data. This shows that data collection from non-professionals can fill a gap in validation of satellite cloud retrievals. S'COOL has provided a robust scientific quality dataset otherwise not available for CERES science.

5. FUTURE OPPORTUNITIES & CHALLENGES

In the next 12 months, S'COOL will be integrated into The GLOBE Program (http://www.globe.gov). GLOBE has also engaged schools in cloud observations since the mid-1990s, but without the tie to satellite data. This larger platform will enable NASA to engage a broader community in this authentic science experience. The GLOBE community will benefit from the ability to compare to satellite data. We have also worked with GLOBE to design and develop a GLOBE Observer app for mobile devices (http://www.globe.gov/globe-data/data-entry/globe-observer), which makes it even simpler for people to observe and report on clouds anytime and anywhere.

NASA's CERES S'COOL Project has grown up through two decades of advancements in technology, evolution of understandings in science literacy, and the blossoming of citizen involvement in the scientific enterprise. In the process S'COOL observers have successfully produced a scientifically valid data set that addresses challenges in satellite cloud retrievals. Today the project serves as an exemplar of an authentic STEM experience that is open to all.

ACKNOWLEDGMENTS

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The data in this paper are the result of the efforts of the S’COOL educator, student, and citizen scientist volunteers, without whom none of this work would be possible. Their efforts are individually recognized at https://scool.larc.nasa.gov/google/All_SCOOLs.kml

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TABLES

Table 1: Test of Cloud Mask: Comparison of S'COOL participant cloud reports with CERES MODIS cloud retrievals from March 2000 to May 2015

	S'COOL Clear	**S'COOL Cloudy**
CERES MODIS Clear	***8099***	2407
CERES MODIS Cloudy	6901	***55094***
Percentage of Correct Cloud/No Cloud Detections: 87.2%		

LIST OF FIGURE CAPTIONS

Figure 1: History of S'COOL participation: **a)** Number of new participants that registered for the S'COOL Project each year. Many participants, once registered, continue participating for years. **b)** Number of ground observations submitted by S'COOL participants (solid orange line) and of simultaneous, co-located CERES satellite cloud retrieval data (dashed orange line). Observations and simultaneous, co-located CERES satellite data from individual citizen scientists "S'COOL Rovers" beginning in 2008 are also shown (solid and dashed blue lines).

Figure 2: S'COOL Project participation spans the globe. Colored icons represent numbers of observations, increasing from blue to red. Diamonds (Circles) represent locations where ≥ 60% (< 60%) of observations correspond to satellite data. An interactive version of this map may be found at http://mynasadata.larc.nasa.gov/scool_observers/.

Figure 3. A sample of the ground and satellite comparison visualization that S'COOL participants receive when their observation report corresponds to a satellite overpass. This example aligns to both GEO and CERES MODIS overpasses. Readers may explore many more reports at: https://scool.larc.nasa.gov/en_query_alldata.html
(a) Reported ground observation
(b) Corresponding satellite retrieved cloud properties
(c) Submitted ground photo (when available)
(d) Corresponding satellite imagery – in this case a GEO image centered on the observer's location, and links to the corresponding MODIS image (in both Rapid

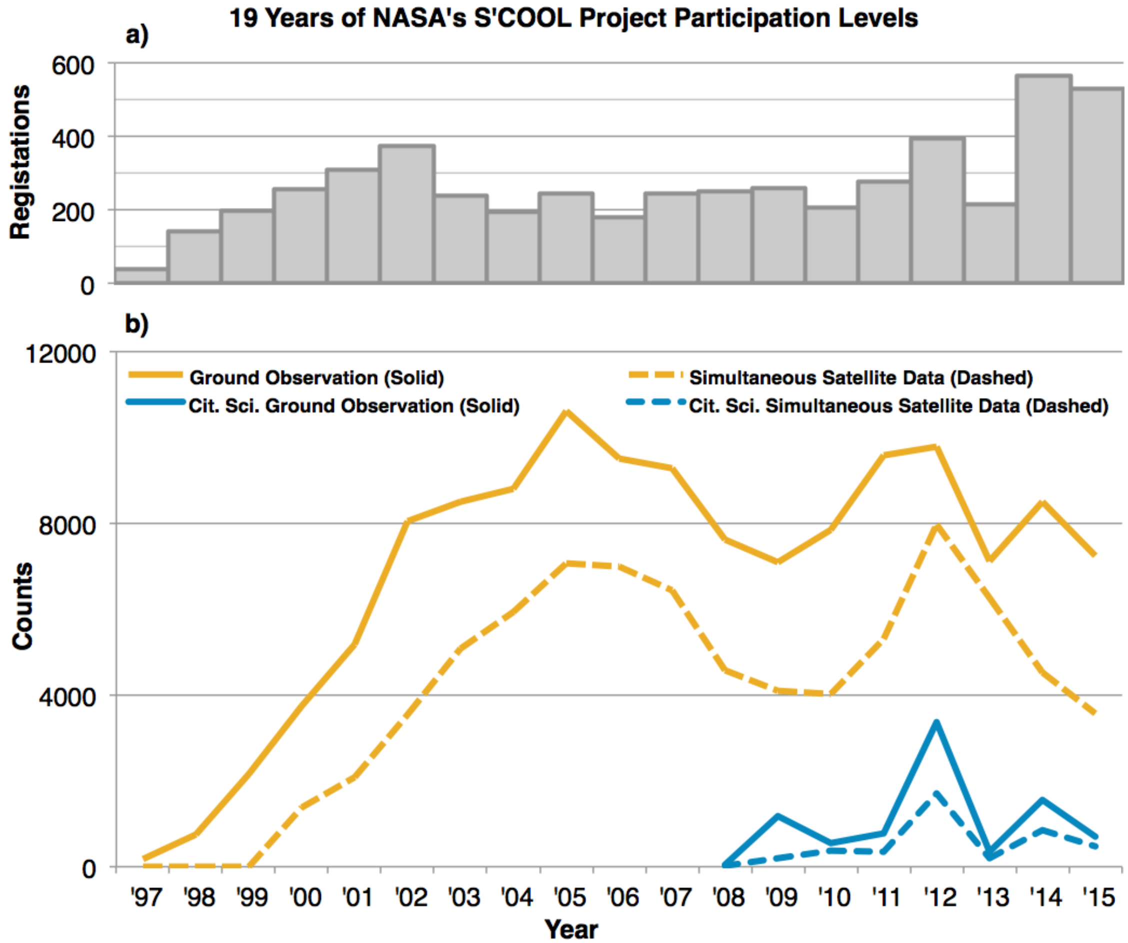
Response and Worldview websites). Also shown is a link to a similar visualization for CERES MODIS rather than GEO.

Figure 4: Frequency of occurrence for each cloud type reported by S'COOL observers when the CERES instrument failed to detect any clouds present. Cirrus and cumulus clouds are the most frequently missed cloud types.

Figure 5: The CERES MODIS optical depth retrieval distribution as a function of the three S'COOL observer cloud opacity categories, (a) opaque, (b) translucent, (c) transparent. On average, observers are correctly classifying opacity: the mean optical depth ($\bar{\tau}$) decreases and the peak in percent occurrence shifts toward a lower optical depth value from panels a to c. The peaks at > 50 optical depth for the transparent and translucent categories are generally an artifact of the matching process and this does not reflect a deficiency in observer skill.

Figure 6: CCGL cloud mask (blue = sky; white = cloud) overlaid with a co-located S'COOL observation. The hatched overlay indicates the cloud height category reported by the S'COOL observer. (a) A case where the S'COOL observer accurately reported a single high cloud layer. (b) A case where the S'COOL observers were unable to see the CCGL-detected cloud layers above the low level cloud they reported due to the high opacity and overcast coverage of the low level cloud. Similarly, a passive satellite instrument would see only the top layer.

FIGURES WITH CAPTIONS



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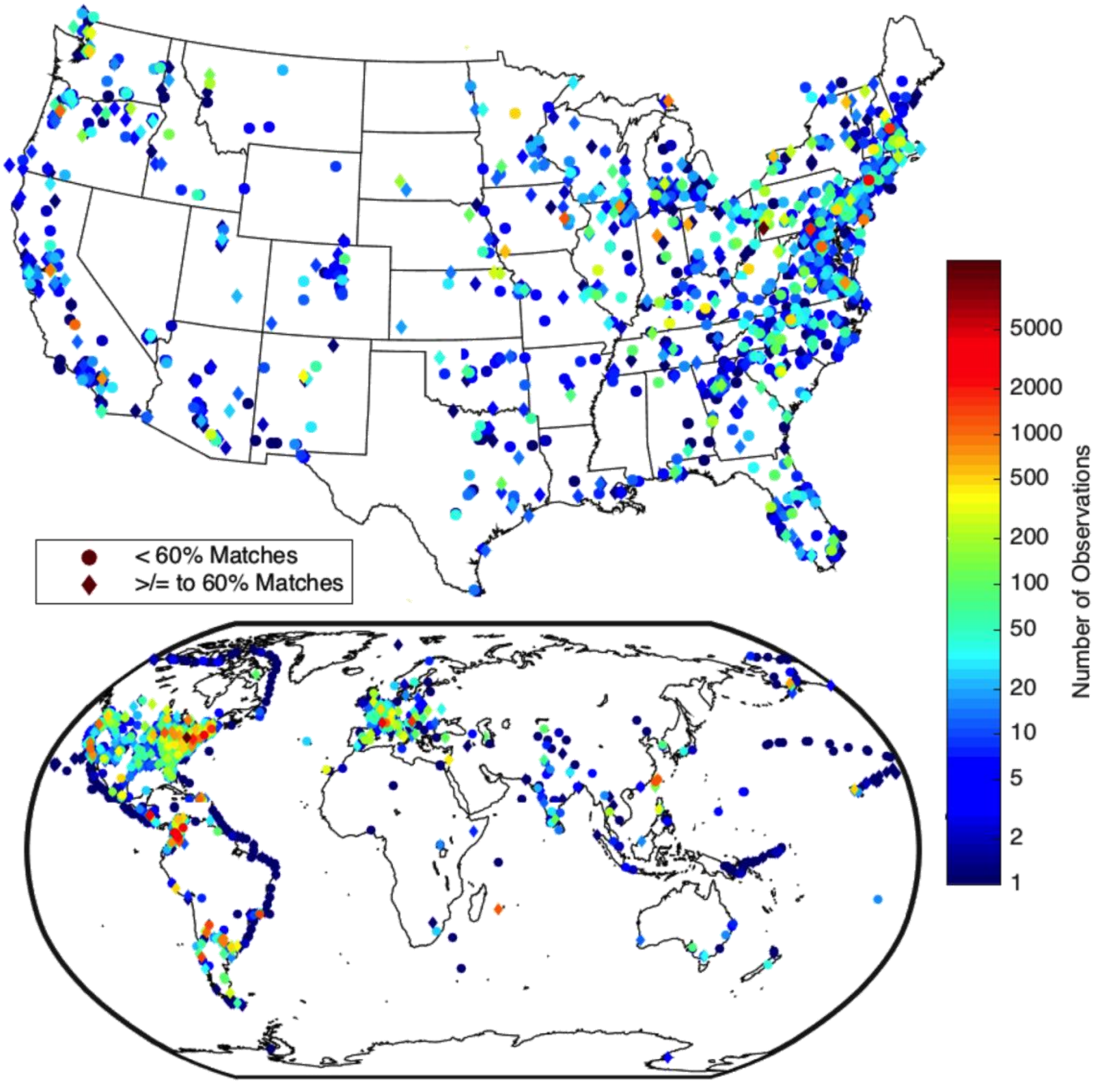

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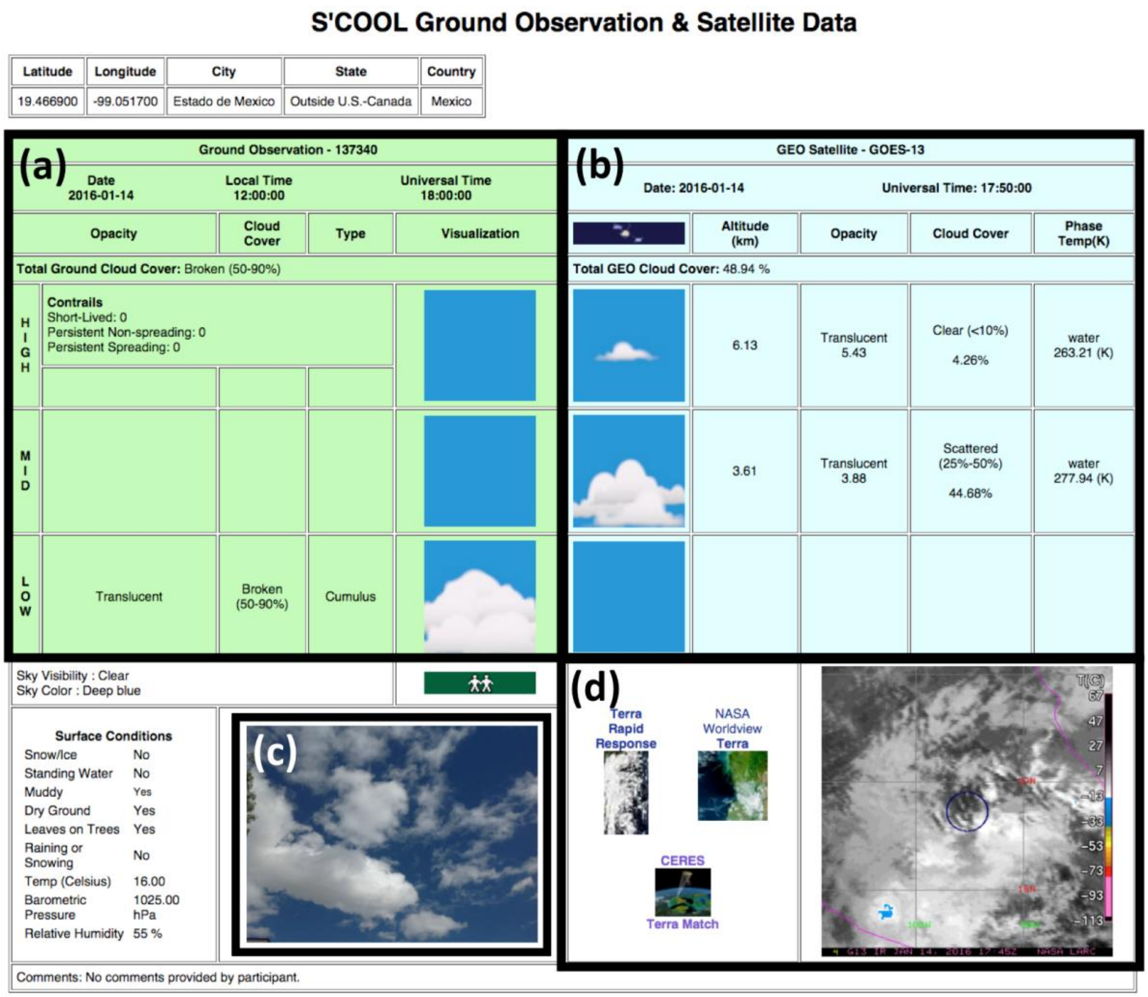

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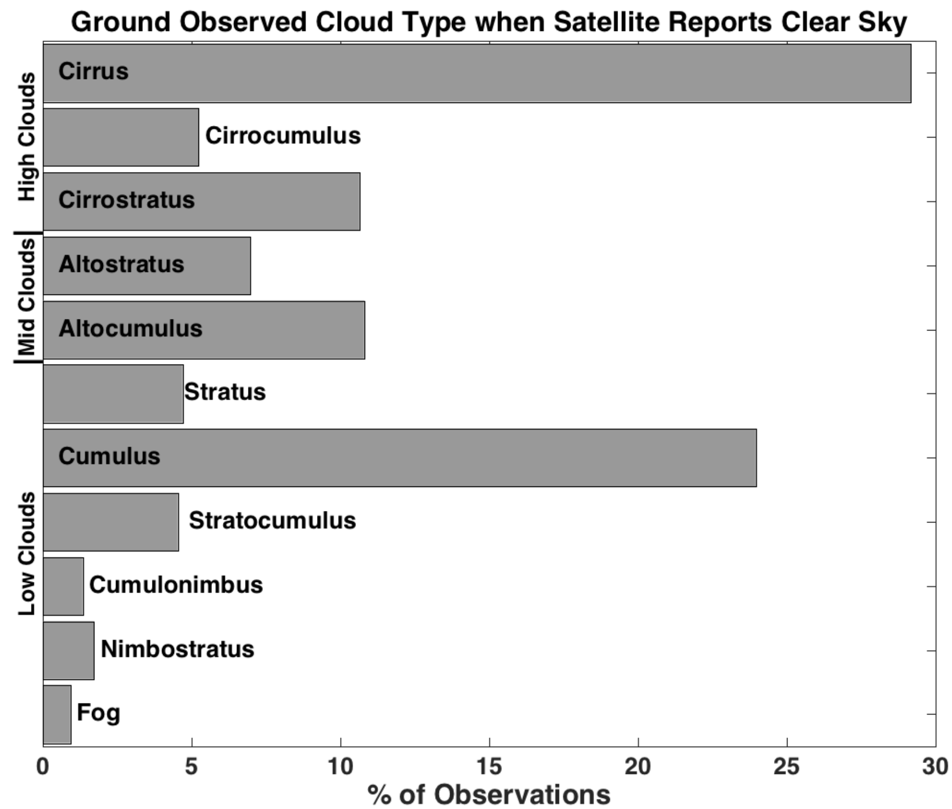

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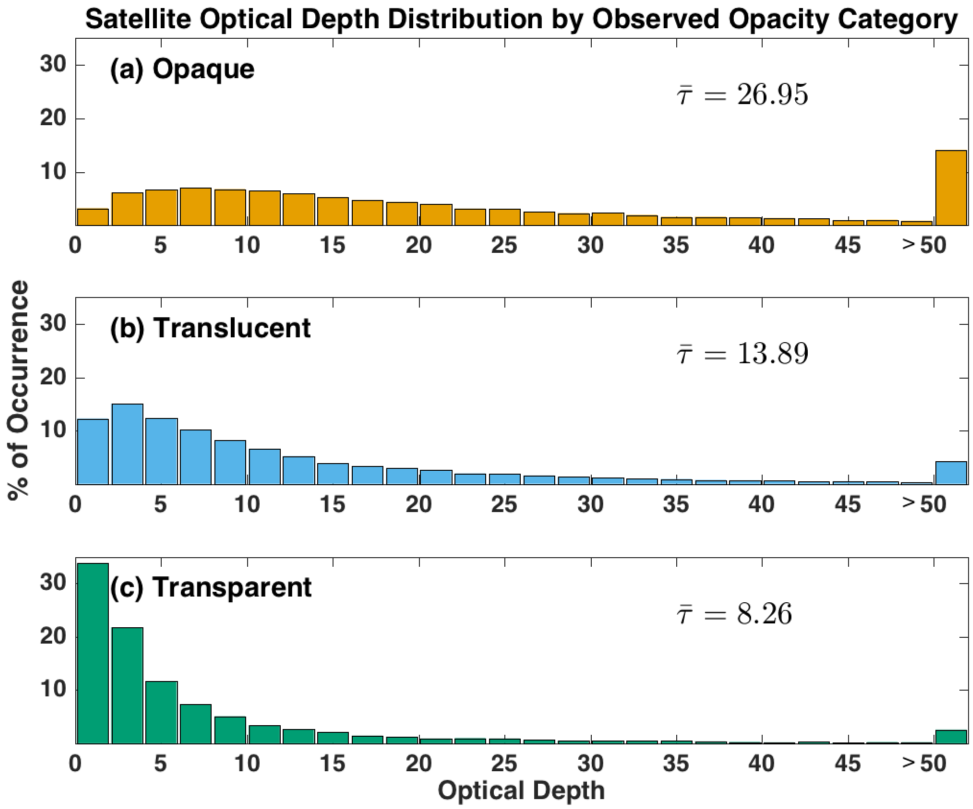

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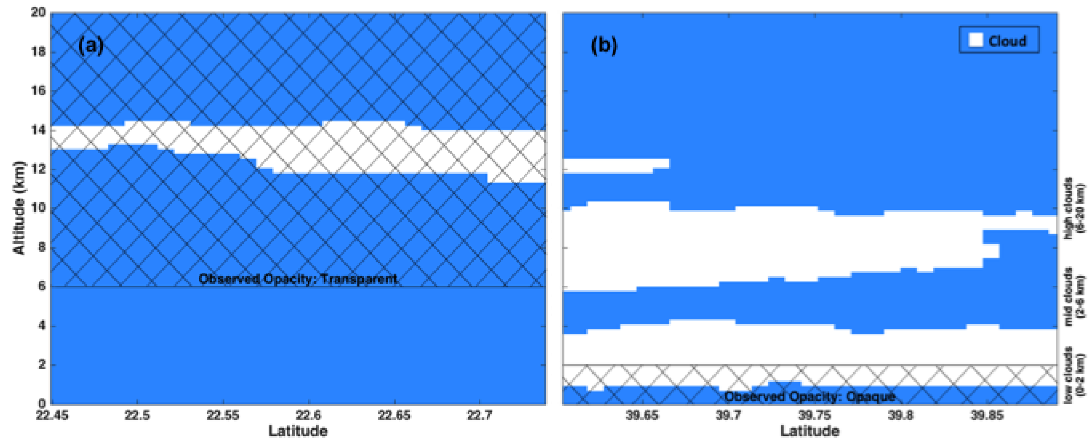

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