NASA GLOBE Clouds: Documentation on How Satellite Data is Collocated to Ground Cloud Observations

Version 1.2

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Abbreviations

CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation, https://www-calipso.larc.nasa.gov/
CERES	Clouds and the Earth's Radiant Energy System, https://ceres.larc.nasa.gov/
GLOBE	Global Learning and Observations to Benefit the Environment, https://www.globe.gov
GOES	Geostationary Operational Environmental Satellite, https://www.goes.noaa.gov/
FLASHFlux	Fast Longwave and Shortwave Flux, https://ceres.larc.nasa.gov/data/#flashflux-ssf-level-2
S'COOL	Students' Cloud Observations On-Line, https://scool.larc.nasa.gov
SatCORPS	Satellite ClOud and Radiation Property retrieval System, https://satcorps.larc.nasa.gov/

Abstract

The NASA GLOBE Clouds team at NASA Langley Research Center in Hampton, Virginia, USA receives all cloud observations submitted through the GLOBE (Global Learning and Observations to Benefit the Environment) Program. Cloud observations submitted through various protocols and methods, including the GLOBE Observer mobile app, are then collocated with satellite data from various Earth-observing platforms, a process referred to as a satellite match. This document is a guide to how the ground-satellite collocation or satellite match is done by the team. A full description of The GLOBE Program's dataset can be found in the GLOBE Data Users Guide (https://www.globe.gov/globe-data/globe-data-user-guide).

Background

Ground-satellite collocation, or satellite matching of cloud observations, started in 2016 for GLOBE participants when the S'COOL (Students' Cloud Observations On-Line) Project merged with GLOBE and became NASA GLOBE Clouds. The S'COOL Project (Chambers et al., 2003 and 2017) collected cloud observations from students, teachers, and the general public and sent a personalized email to each participant whenever there was a ground-satellite collocation of cloud observations to report.

The NASA GLOBE Clouds team matches GLOBE cloud observations to corresponding satellite data (https://www.globe.gov/web/s-cool). GLOBE participants can "opt in" to receive notifications on their mobile device about polar orbiting satellite flyovers or check online (see satellite overpass schedule tool). If an observer's cloud observation is matched to satellite data, and the user opted-in to receive emails from GLOBE, the user will receive a Satellite Match Table for every collocation (see satellite match table example) in a personalized email from NASA within one week of submitting their observation. The NASA GLOBE Clouds team uses an application programming interface or API specific for the team to pull cloud observations daily from The GLOBE Program's database. The cloud observations can then be matched to multiple geostationary satellites, CERES instruments onboard Aqua and Terra, and CALIPSO. The satellite match table includes images from these satellites centered on the observation location.

Description of GLOBE participants

Individuals contributing cloud observations need to be in a GLOBE country (see map of participating countries, https://www.globe.gov/globe-community/community-map). These individuals fall into two groups: those that have received formal GLOBE protocol training, and those that are trained via the tutorials supplied with the GLOBE Observer app. Users that receive formal training are often classroom educators who want to teach their students the protocols (i.e., methods) to collect and enter data for GLOBE's additional protocols (i.e., beyond what is available in the GLOBE Observer app.) Users that have received formal training can enter data through other mechanisms in addition to the GLOBE Observer mobile app, including data entry desktop forms, GLOBE's Data Entry mobile app, and email data entry. GLOBE Observer mobile app users need only view the tutorials supplied within the app before submitting data. Detailed steps for the clouds protocol can be found on the NASA GLOBE Clouds webpage (https://www.globe.gov/web/s-cool/home/observation-and-reporting).

Description of Ground Observations

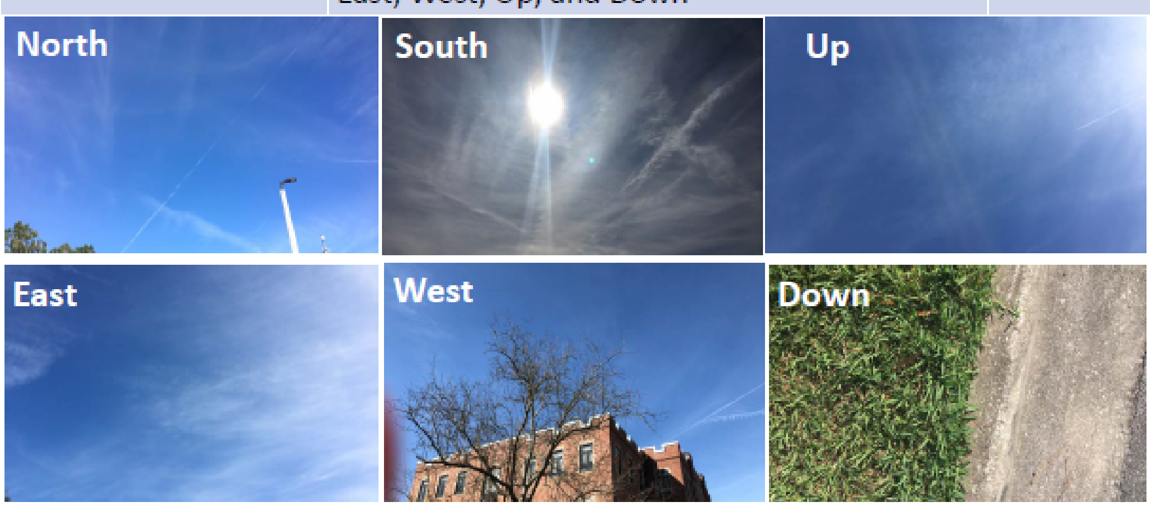
Each GLOBE cloud observation contains information about the percent of sky covered by clouds, the presence of obscurations, and surface conditions (e.g., snow or ice on the ground). An obscuration occurs when more than 25% of the sky is obscured by either sand, smoke, haze, heavy snow, fog, spray, dust, blowing snow, heavy rain, or volcanic ash, preventing the user from seeing the sky or clouds. Optional fields for cloud observations are: sky color (https://www.globe.gov/web/s-cool/home/observation-and-reporting/sky-color); sky visibility (https://www.globe.gov/web/s-cool/home/observation-and-reporting/sky-visibility); presence of low-, mid-, and high-level clouds and contrails; types of clouds and contrails (https://www.globe.gov/web/s-cool/home/observation-and-reporting/cloud-type); and opacity (https://www.globe.gov/web/s-cool/home/observation-and-reporting/cloud-visual-opacity; see **Table 1**).

Users are encouraged to conduct their observations in an outdoor area with a relatively unobstructed view of the sky. Users have the option to take photographs of the sky (north, south, east, west, up) and surface conditions (down). The GLOBE Observer mobile app guides users to align their smartphone camera in the correct direction and tilted to a 14 degree angle, then automatically takes the photographs (https://www.globe.gov/web/s-cool/home/observation-and-reporting/globe-observer-tips-and-tricks). **Table 1** shows the required and optional fields for both GLOBE-trained participants and

GLOBE Observer users. Data submitted via email cannot include images (see https://www.globe.gov/globe-data/data-entry).

Table 1. Required and optional fields in GLOBE Clouds

Observation	Detailed Options	Required
Total Cloud Cover	No Clouds, Few <10%, Isolated 10-25%, Scattered 25-50%, Broken 50-90%, Overcast 90-100%	Y
Obscuration (if > 25% sky covered)	Sand, Spray, Smoke, Dust, Haze, Blowing Snow, Heavy Rain, Fog, Volcanic Ash	Y
Sky Color (if <50% cloud cover)	Deep Blue, Blue, Pale Blue, Light Blue, Milky	N
Sky Visibility (if <50% cloud cover)	Unusually Clear, Clear, Somewhat Hazy, very Hazy, Extremely Hazy	N
Cloud Types by Height	High: Short-lived Contrails, Persistent Contrails, Persistent Spreading Contrails, Cirrus, Cirrostratus, Cirrocumulus Middle: Altostratus, Altocumulus Low: Fog/Stratus, Nimbostratus, Stratocumulus, Cumulus, Cumulonimbus	N
Opacity by Height	Opaque, Transparent, Translucent	N
Cloud Cover by Height	No Clouds, Few <10%, Isolated 10-25%, Scattered 25-50%, Broken 50-90%, Overcast 90-100%	N
Surface Condition	Yes/No: Snow/Ice, Standing water, Muddy, Dry Ground, Leaves on Tress, Raining/Snowing	Y
Photographs	App assists in directional photos North, South, East, West, Up, and Down	N



Collocation of Ground Observations with Satellite Data

The NASA GLOBE Clouds team collocates submitted observations multiple geostationary satellites, CERES instruments onboard Aqua and Terra, and CALIPSO. This process is referred to as a satellite match. A satellite match table is produced that summarizes collocation results. The table is then sent in a personalized email to the ground observer (see **Image 1**).

Cloud properties such as height and coverage are generally not directly measured by satellites, with the partial exception of CALIPSO. The passive-observing satellite instruments carried by geostationary and Aqua/Terra satellites instead directly measure the visible and infrared radiation reflected/emitted by Earth. Cloud properties are estimated by an automated retrieval algorithm, which calculates the most likely cloud properties in a given location based on the measured radiance. Some algorithms also use data from other sources, such as additional satellite instruments. The retrieval algorithms are complex and can introduce errors for a variety of reasons beyond uncertainties in the direct satellite measurements. The satellite-retrieved cloud properties should not be considered absolute truth, but rather the best estimate of cloud properties that can be provided by satellite observations.

CALIPSO is a somewhat different case because the onboard lidar directly measures the presence, altitudes, and extinction rates of hydrometeors, aerosol particles, and other small objects in the atmosphere. However, CALIPSO requires a retrieval algorithm to determine other meteorological properties, such as distinguishing cloud hydrometeors from aerosol particles. The cloud/aerosol height and opacity provided by CALIPSO are likely to be highly accurate, but other properties are subject to uncertainties from the retrieval algorithm.

Modernization of Code for Aqua and Terra Satellite Matches

Overview

When a GLOBE Clouds observation is taken within 15 minutes of a satellite overpass, the observation is matched to satellite data. However, the code used to perform the matching specifically to Aqua and Terra was written over 20 years ago in Fortran. The code has recently been rewritten into Python, a modern programming language with widespread support. Not only does the rewritten code help modernize our infrastructure, but it fixes several bugs found in the original software, including not handling missing data properly and not properly handling observations made around midnight UTC. As of **3 April 2022**, the rewritten satellite code has been put into production.

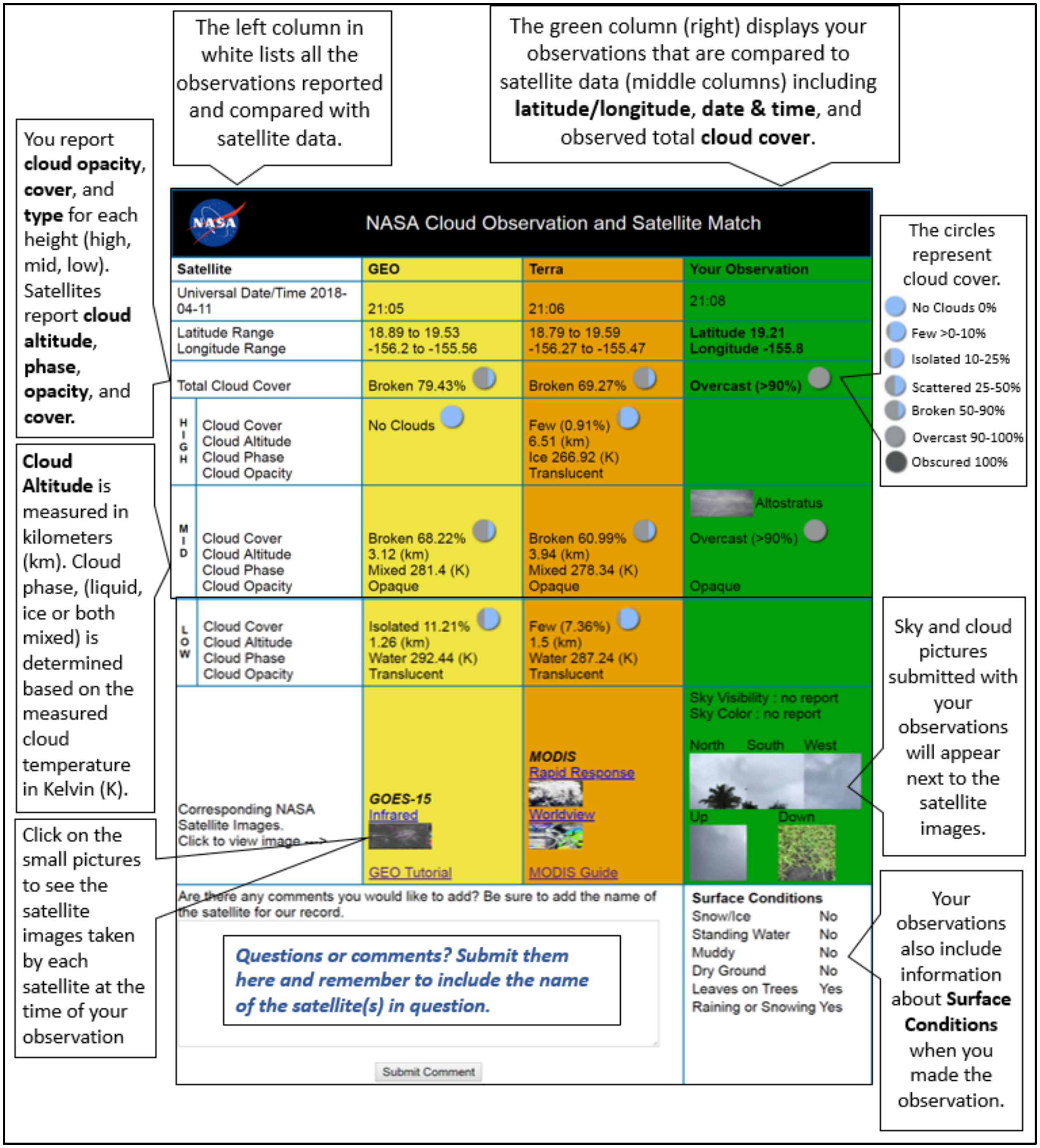
Technical Changes

- The new code uses a slightly extended matching window of +/- 15:59.9 (compared to 15:00 previously). This was done to maintain backwards compatibility, as the old code previously matched certain observations within this time rage. This has a side effect of generating about 7% more matches than before.
- The new code makes proper use of default values in the FLASHFlux* satellite data product. Default values are values that signal the data is missing and should not be used. Data with these values are ignored while they were previously zeroed and then used.
- The new code considers the full matching window even if this matching window extends across multiple days. For example, an observation made on 1/1/2022 at 23:50 could be matched to data from 1/2/2022 before 00:05. The old code did not consider matching windows that extended across multiple days.
- The new code uses hourly FLASHFlux SSF data while the old code uses FLASHFlux SSFS** data, this may create minor variations. The FLASHFlux SSFS data product specially created for S'COOL and used when the team transitioned to The GLOBE Program. This smaller subset was an average of the FLASHFlux SSF data product and made it easier to manage by the team. FLASHFlux SSFS is no longer made available.

**Fast Longwave and Shortwave Flux (FLASHFlux) data product:* It is a low latency (< 7 days from observations) TOA and parameterized surface radiative fluxes at CERES Single Scanner Footprint (SSF) level and global gridded fluxes. Suitable for quick-look assessment, educational and applied science uses. Not intended for appending to other CERES data products for long-term variability studies. https://ceres.larc.nasa.gov/data/#flashflux-ssf-level-2

The daytime binary ***SSF SCOOL (or SSFS)* validation product contains all subsetted footprints over SCOOL validation sites which have a solar zenith angle of less than 90 degrees. The nighttime binary SSF SCOOL validation product contains all subsetted footprints over SCOOL validation sites which have a solar zenith angle greater than or equal to 90 degrees.

Image 1. Example Satellite Match Table



Footprint Definition

The satellite derived products (visible and infrared images) provided in the satellite match table are centered on the latitude/longitude reported with the observations.

1. Geostationary Satellites

The NASA Langley SatCORPS team, part of the CERES cloud processing group, provides geostationary satellite data to the NASA GLOBE Clouds team. Matches to geostationary satellites include both a visible and an infrared image, remapped to 1.0-km resolution. The resolution of the images, before remapping, can range between 1-3 km for visible and 2-4 km for infrared projections, depending on the satellite. The full image displayed in the satellite match table covers 400x400km, with a 40 km diameter area marked by a red circle. **Table 2** displays the geostationary satellites used for collocation including the latitude and longitude bounds of the fields of view they can observe.

Cloud products from geostationary satellites are stored on the NASA GLOBE Clouds system for up to a month after they are collected. Any observations submitted to the GLOBE Program beyond a month from the observation date/time cannot be collocated to geostationary satellites. Cloud retrievals must produce at least 75% valid data (or absence of "no retrieval" flags) within the 40-km footprint surrounding the ground observer to produce a satellite collocation. In general, about 2-5% of the total number of pixels over an entire satellite image might result in a "no retrieval" flag for the cloud product retrieval. This can happen with weak cloud signatures and conflicting (or bad) input data. Although it happens in low percentages for an entire satellite image, these "no retrieval" pixels can cluster more near an observer's location within the 40-km footprint.

GOES satellites provide half hourly data, as well as hourly full disk data (view of the Earth centered on the Equator; see NOAA Geostationary Satellite Server for examples) over North America. Meteosat 11, Meteosat 8, and Himawari-8 data run once per hour for the full disk. Ground observations will be collocated if observations are within 15 minutes to the available data. This means that areas within the GOES fields of view will match if observations are within 15 minutes from every half hour or hourly data, as long as the cloud products retrieve at least 75% valid data. Locations within the Meteosat and Himawari fields of view will result in collocation if observations are within 15 minutes from every hour, as long as the cloud products retrieve at least 75% valid data.

In Summary:

Matches to geostationary satellites occur if observations are within 15 minutes from every half hour to hourly data within the GOES field, and 15 minutes within every hour in locations within the Meteosat and Himawari fields of view (see Table 2). Spatially, the match includes all geostationary data within a 40 km radius circle around the ground observation and includes both an infrared and visible image (Colón Robles et al., 2020).

Table 2. List of geostationary satellites used for collocation

Geostationary Satellite	Area Coverage by GLOBE Regions*	Instrument Onboard the satellite used for collocation	Latitude bounds	Longitude bounds
GOES West https://www.goes.noaa.gov/goesfull.html	North America, Latin America and Caribbean, Pacific Ocean	Imager	60N-60S	105-180W
GOES East https://www.star.nesdis.noaa.gov/GOES/fulldisk.php?sat=G16	North America, Latin America and Caribbean, Atlantic Ocean	Advanced Baseline Imager (ABI)	60N-60S	37.5-105W
Meteosat-11 https://www.goes.noaa.gov/f_meteo.html	Europe and Eurasia, Near East and North Africa, Africa, Asia and Pacific Indian Ocean	Spinning Enhanced Visible and Infrared Imager (SEVIRI)	60N-60S	37.5W-41E
Meteosat-8 https://www.goes.noaa.gov/f_meteo.html	Europe and Eurasia, Near East and North Africa, Africa, Asia and Pacific Indian Ocean	Spinning Enhanced Visible and Infrared Imager (SEVIRI)	60N-60S	41-95E
Himawari-8 https://www.goes.noaa.gov/f_himawari-8.html	Asia and Pacific Pacific Ocean	Advanced Himawari Imager (AHI)	60N-60S	95-180E

**GLOBE Countries and Regions - https://www.globe.gov/globe-community/community-map*

2. Aqua and Terra

The NASA GLOBE Clouds team uses the CERES FLASHFlux SSF data product to match GLOBE cloud observations to Aqua and terra. A 0.4 degree latitude/longitude radius is used around the ground observation as a footprint. Any satellite data within this defined footprint are averaged to provide the comparison. Observations are matched to data derived by instruments onboard a satellite if the following are met:

- the satellite swath is within the radius defined around the observation
- the satellite passes over the footprint within 15 minutes before or after the observation
- data from the satellite are available for the location and time

Collocations include true color images from the MODIS instruments onboard Terra and Aqua, centered on the location of the observation and displayed using NASA's Worldview Visualization platform (see NASA's EOSDIS WorldView).

GLOBE Observer app users can opt to be notified of Aqua and Terra overpasses. Satellite overpass schedules for Aqua and Terra can also be obtained by using the satellite overpass calculator (see https://scool.larc.nasa.gov/GLOBE/globe_overpass-en.html.

3. CALIPSO

CALIPSO measures the vertical profile of the atmosphere using a laser beam with an approximately 70-meter width at the Earth's surface. This results in a very narrow swath of observations, leading to fewer satellite matches to ground observations as compared to the other satellites. Ground observations that are within 10 km and 15 minutes of CALIPSO's path will result in a collocation. Observations that are matched, or collocated, with CALIPSO receive a link to the vertical feature mask for their latitude and longitude. The CALIPSO vertical feature mask describes the vertical and horizontal distribution of cloud and aerosol layers observed by the CALIPSO lidar (https://www.globe.gov/web/s-cool/home/satellite-comparison/how-to-read-a-calipso-satellite-match). Different features are designated by CALIPSO (e.g. cloud or aerosol, or the cloud ice/water phase) are available for each layer detected (see **image 2**). A summary of these results is *not* displayed on the satellite match table as is done with the other possible satellites/instruments.

Image 2. Example Ground Observation with Satellite Collocation with CALIPSO

NASA Cloud Observation and Satellite Match

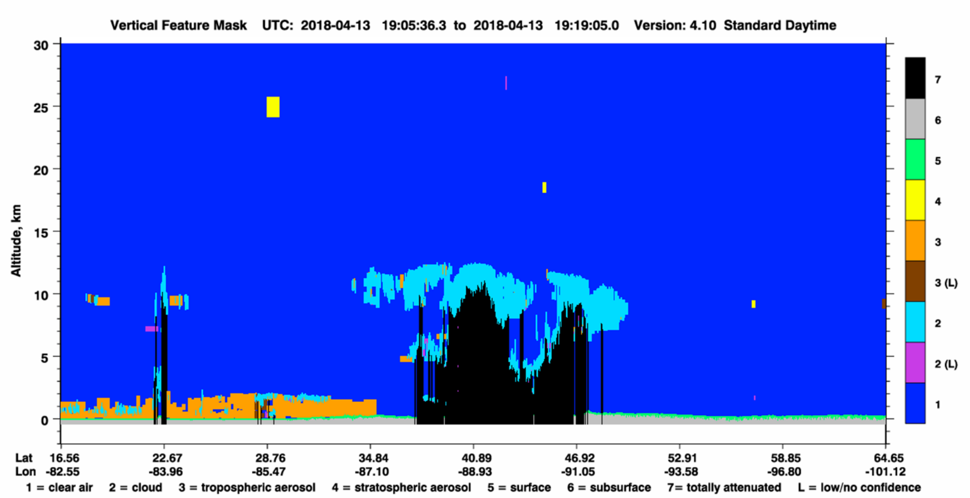
Satellite	GEO	Aqua	Your Observation
Universal Date/Time 2018-04-13	19:18	19:08	19:17
Latitude Range Longitude Range	33.14 to 33.78 -87.12 to -86.48	33.05 to 33.85 -87.21 to -86.41	**Latitude 33.46** **Longitude -86.80**
Total Cloud Cover	Few 1.32%	Few 1.48%	**Few (<10%)**
HIGH: Cloud Cover Cloud Altitude Cloud Phase Cloud Opacity	No Clouds	Few (0.51%) 6.63 (km) Ice 255.53 (K) Transparent	Cirrus Few (<10%)
MID: Cloud Cover Cloud Altitude Cloud Phase Cloud Opacity	No Clouds	Few (0.17%) 3.42 (km) Mixed 273.06 (K) Transparent	
LOW: Cloud Cover Cloud Altitude Cloud Phase Cloud Opacity	Few (1.32%) 0.31 (km) Water 308.58 (K) Transparent	Few (0.81%) 0.91 (km) Water 287.67 (K) Transparent	
Corresponding NASA Satellite Images. Click to view image --->	***GOES-16*** Infrared GEO Tutorial	***MODIS*** Rapid Response Worldview MODIS Tutorial	Sky Visibility : Somewhat Hazy Sky Color : Light Blue North

Are there any comments you would like to add? Be sure to add the name of the satellite for our record.

Submit Comment

Surface Conditions

Snow/Ice	No
Standing Water	No
Muddy	No
Dry Ground	Yes
Leaves on Trees	Yes
Raining or Snowing	No



Reconciling GLOBE and Satellite Classifications

Altitude

Altitude is the height at which the instruments onboard satellite detects a cloud. Algorithms designed by scientists are the way altitude is detected, which detections of altitude are based on observations and weather forecast model data. Cutoff values have been defined by where cloud types are generally encountered as defined by meteorologist (see the World Meteorological Organization's Definitions of Clouds - https://cloudatlas.wmo.int/clouds-definitions.html). The NASA GLOBE Clouds team uses these same altitude ranges to compare satellite detection of clouds with ground observations (**Table 3**). A possible consequence of this set definition is that a single cloud layer, an extensive nimbostratus cloud for example, can be split by the satellite into two levels because the cloud may extend beyond the arbitrary cut-off definitions.

Table 3. Definition of altitude ranges to define the three basic cloud levels

Altitude range of satellite observation (km)	GLOBE cloud type
Above 6	High clouds (contrails, cirrus, cirrocumulus, or cirrostratus)
2-6	Mid level clouds (altostratus or altocumulus)
0-2	Low clouds (fog/stratus, stratocumulus, cumulus, nimbostratus, or cumulonimbus)

Opacity

Satellites measure opacity in terms of optical depth. The following ranges have been defined to best compare ground observations of sky opacity to satellite data (**table 4**)

Table 4. Opacity values selected to match the three options for ground observers

Optical depth range from satellite	Opacity category for ground observer
Above 10	Opaque
3-10	Translucent
Transparent	Transparent

Cloud Cover

The same categories and values are used for both ground and satellite reports (see **Table 1**).

Cloud Phase and Temperature

Cloud phase and temperature are collected from the satellite data and reported to help ground observers best compare the cloud properties with the cloud type observed. **Table 5** shows how cloud phase is classified (see parameter SSF-107 for CERES example - https://ceres.larc.nasa.gov/documents/collect_guide/pdf/SSF_CG_R2V1.pdf). Data are collected for the altitude range and reported on the satellite match table.

Table 5. Cloud Phase Classifications

Liquid	Value = 1
Mixed	Value >1 but < 2
Ice	Value = 2

GLOBE Clouds and Matched Satellite Data Available

The NASA GLOBE Clouds team is making available a curated, analysis-ready GLOBE dataset that includes the GLOBE Clouds data and the satellite matched data. The data is provided as CSV files and posted on the GLOBE Observer website https://observer.globe.gov/get-data/clouds-data. These are subsets of GLOBE data that have been post-processed by a scientist on the GLOBE team and are being made available for broader use by the community.

Georeferenced subsets of the clouds data sets are also available:

Dust data, https://observer.globe.gov/get-data/dust-data
Eclipse data, https://observer.globe.gov/get-data/eclipse-data

List of data variables, units, and definitions is available at https://www.globe.gov/web/s-cool/home/satellite-comparison/data-variable-units-and-definitions.

Useful Links

1. Satellite Overpass Schedule Tool - https://scool.larc.nasa.gov/GLOBE/globe_overpass-en.html
2. Satellite Match Table Example - https://www.globe.gov/web/s-cool/home/satellite-comparison/how-to-read-a-satellite-match
3. NASA's EOSDIS Worldview - https://worldview.earthdata.nasa.gov/
4. CALIPSO - Data User's Guide - Browse Image Tutorial - https://www-calipso.larc.nasa.gov/resources/calipso_users_guide/browse/index.php
5. CALIPSO Quality Statements - https://eosweb.larc.nasa.gov/sites/default/files/project/calipso/quality_summaries/CALIOP_L2VFMProducts_3.01.pdf
6. NOAA Geostationary Satellite Server (with full disk images) - https://www.goes.noaa.gov/
7. Example Ground Observation with Satellite Collocation with CALIPSO:
    a. Satellite Match Table - https://scool.larc.nasa.gov/cgi-bin/NASA-GLOBESatMatch.cgi?observation_id=116-111805-39703922-201804131917
    b. Corresponding CALIPSO Vertical Feature Mask - https://www-calipso.larc.nasa.gov/data/BROWSE/production/V4-10/2018-04-13/2018-04-13_18-38-38_V4.10_3_6.png
8. Satellite and GLOBE data sets available for download - https://observer.globe.gov/get-data/clouds-data
9. List of Data Variables, Units, and Definitions - https://www.globe.gov/web/s-cool/home/satellite-comparison/data-variable-units-and-definitions

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