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

Version 1.3

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Abbreviations

Acronym	Descriptions and Weblinks
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 overhead cloud reports from human observers submitted through the GLOBE (Global Learning and Observations to Benefit the Environment) Program. The ground-based cloud observations submitted through various protocols and methods, including the GLOBE Observer mobile app, are then collocated with satellite observations of clouds 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 User Guide.

Background

Ground-satellite collocation, or satellite matching of cloud observations, started in 2017 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. 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 an example of a satellite match table) 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. 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 for the clouds protocol can be found on the NASA GLOBE Clouds webpage.

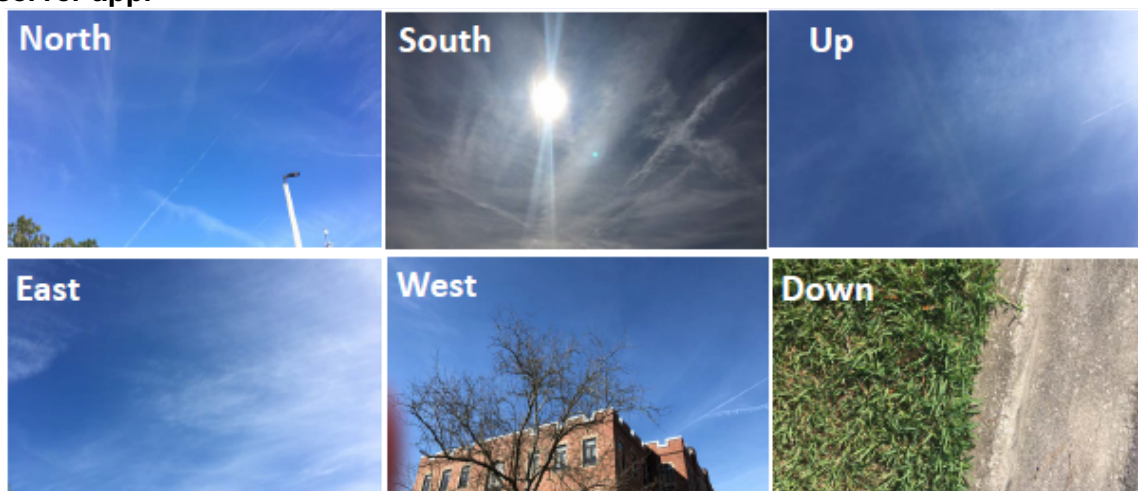## Description of Ground Observations

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, sky visibility, presence of low-, mid-, and high-level clouds and contrails, and opacity (see Table 1 and Image 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. Table 1 shows the required and optional fields for both GLOBE-trained participants and GLOBE Observer users. Data submitted via email cannot include images. The GLOBE Program's Data Entry website has more information.

Table 1. Required and optional fields in GLOBE Clouds

Observations	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%, Overcast90-100%	N
Pictures	App assists in directional photos North, South, East, West, Up, and Down	N
Surface Condition	Yes/No: Snow/Ice, Standing Water, Muddy, Dry Ground, Leaves on Trees, Raining/Snowing	Y

Image 1. Sample of pictures volunteers can take using The GLOBE Program's GLOBE Observer app.

Collocation of Ground Observations with Satellite Data

The NASA GLOBE Clouds team collocates submitted observations with those from 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 2**).

Cloud properties such as height and coverage are generally not measured directly but must be inferred from visual or instrumental observations. Instruments carried by geostationary and the polar orbiting Aqua/Terra satellites carry passive radiometric instruments that receive visible and infrared radiation reflected/emitted by the Earth and its atmosphere. These measurements can be interpreted with automated, empirical, and theoretically-based algorithms to infer a wide range of cloud characteristics. Some algorithms also use data from other sources, such as additional satellite instruments. The retrieval algorithms are complex and rely on simplifying assumptions and ancillary information that can at times lead to errors in the retrieved cloud properties.

CALIPSO is a somewhat different type of satellite because it carries a combination of active and passive sensors. The active sensor is an onboard lidar that actively emits a light beam towards the earth that is reflected back to the instrument allowing a somewhat more direct measurement of the Earth and atmosphere. The data received by CALIPSO also requires interpretation with retrieval algorithms to infer the presence, altitudes, and extinction rates of hydrometeors, and to distinguish clouds from aerosol particles, and other small objects in the atmosphere.

No single cloud observation method or system, whether it be human visual or from an active or passive satellite or ground-based sensor, is able to provide a complete and accurate depiction of cloud properties across the Earth under the many conditions that naturally occur. Instead, this is best achieved by combining all of this information in optimal ways that exploit their various strengths and avoid or minimize their various limitations.

Image 2. Example Satellite Match Table

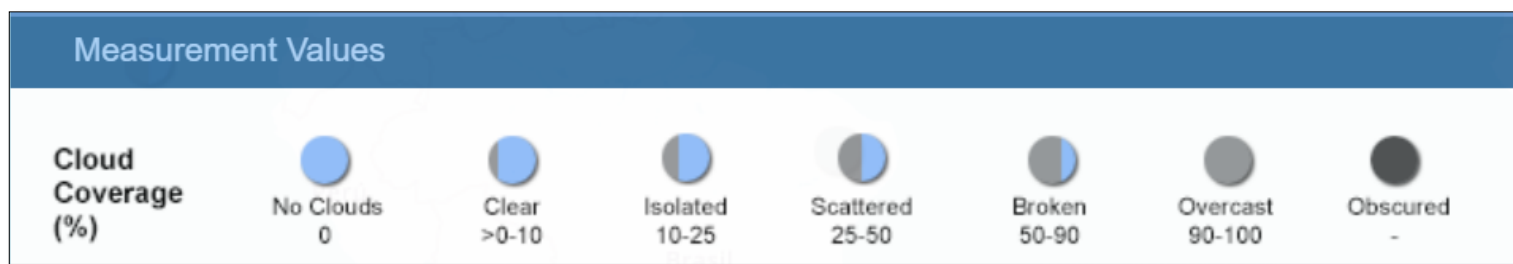| NASA Cloud Observation and Satellite Match				
Satellite	**GEO**	**Aqua**	**Terra**	**Your Observation**
Universal Date/Time 2020-08-09	19:33	19:55	19:49	19:47
Latitude Range Longitude Range	45.5 to 46.14 -118.81 to -118.17	45.47 to 46.27 -118.94 to -118.14	45.38 to 46.18 -118.82 to -118.02	**Latitude 45.816700 Longitude -118.490900**
Total Cloud Cover	Scattered 26.47%	Few 0.02%	Few 0.79%	**No Clouds Observed**
HIGH Cloud Cover / Cloud Altitude / Cloud Phase / Cloud Opacity	No Clouds	No Clouds	Few (0.79%) 8.05 (km) Ice 246.39 (K) Transparent	No Clouds Observed
MID Cloud Cover / Cloud Altitude / Cloud Phase / Cloud Opacity	No Clouds	No Clouds	No Clouds	No Clouds Observed
LOW Cloud Cover / Cloud Altitude / Cloud Phase / Cloud Opacity	Scattered 26.47% 1.14 (km) Water 308.34 (K) Transparent	Few (0.02%) 1.32 (km) Water 297.26 (K) Transparent	No Clouds	No Clouds Observed
Corresponding NASA Satellite Images. Click to view image --->	*GOES-17* Visible Infrared GEO Tutorial	*MODIS* Rapid Response Worldview	*MODIS* Rapid Response Worldview	Sky Visibility : Clear Sky Color : Blue

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

[text box]

Submit Comment

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

- The white column on the left lists all the variables reported. Note that you report cloud cover and cloud opacity for each height. Satellites report cloud altitude, cloud phase, cloud opacity, and cloud cover.
- The green column on the right displays your observations. Your observations also include information reported on surface conditions and all sky photographs submitted with your report.
- The circles next to cloud cover reports are a visual representation of the values reported (see **image 3**).

Image 3. Cloud cover measurement values represented in circles with various shades of blue and gray.

- The small pictures found at the bottom of each satellite column are the satellite images taken by the corresponding satellite at about your same location and time. The images are centered in the latitude and longitude of the cloud observation.

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.

**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.

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, 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 area within the satellites field of view.

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 and South America. Meteosat 11, Meteosat 8, and Himawari-8 provide cloud data over other parts of the world that re derived 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 online satellite overpass calculator.

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 (). 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 4**). A summary of these results is *not* displayed on the satellite match table as is done with the other possible satellites/instruments.

Image 4. Example Ground Observation with Satellite Collocation with CALIPSO
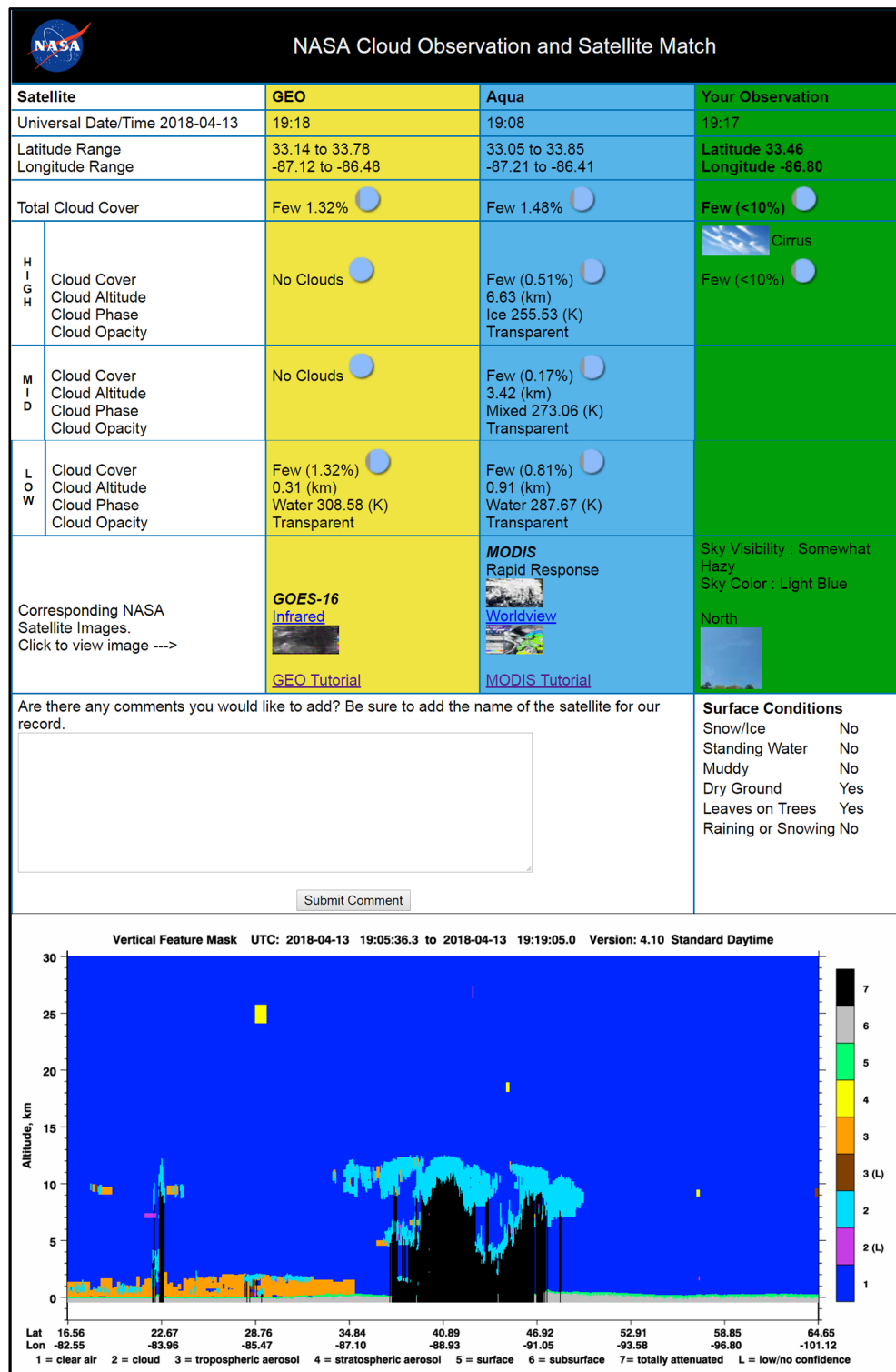
Reconciling GLOBE and Satellite Classifications

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). 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 ranges 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. Cloud phase (liquid, ice, or both mixed) is determined based on the measured cloud temperature in Kelvin. Table 5 shows how cloud phase is classified (see parameter SSF-107 for CERES example). Data are collected for the altitude range and reported on the satellite match table.

Table 5. Cloud phase Classifications

Cloud phase classification	Values
Liquid	1
Mixed	1 < value < 2
Ice	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 in the Clouds Data section of the GLOBE Observer website. 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 for dust data and eclipse data are available, as is a list of data variables, units, and definitions.

Useful Links

1. Satellite Overpass Schedule Tool: scool.larc.nasa.gov/GLOBE/globe_overpass-en.html
2. Satellite Match Table Example: go.nasa.gov/3l5Dupt
3. NASA's EOSDIS Worldview: worldview.earthdata.nasa.gov
4. CALIPSO - Data User's Guide - Browse Image Tutorial: go.nasa.gov/3Mb0L5g
5. CALIPSO Quality Statements: go.nasa.gov/3LaVr0e
6. NOAA Geostationary Satellite Server (with full disk images): www.goes.noaa.gov
7. Example Ground Observation with Satellite Collocation with CALIPSO:
   a. Satellite Match Table (ground, GEO and Aqua data): go.nasa.gov/3FI2JHG
   b. Corresponding CALIPSO Vertical Feature Mask: go.nasa.gov/3McHdxt
8. Satellite and GLOBE data sets available for download: observer.globe.gov/get-data/clouds-data
9. List of Data Variables, Units, and Definitions: go.nasa.gov/3LgDXzW

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