CERES Cloud Working Group Report

CERES Science Team Mtg., Virtual#4, 12-14 Oct 2021

W. L. Smith, Jr.
NASA Langley Research Center, Hampton, VA

S. Sun-Mack (modis/viirs lead), Q. Trepte (mask), G. Hong (models), P. Minnis (supreme advisor), D. Painemal (val),

Y. Chen (clr props, test runs), C. Yost (val), R. Smith (web, NPP), R. Brown (QC),

R. Palikonda (GEO lead), S. Bedka (retrievals, val), D. Spangenberg (everything), M. Nordeen (GEO),

B. Scarino (cal, Tskin, GEO), F-L. Chang (CO2, cork), Cecilia Wang (machine learning)

E. Heckert (web), B. Shan (GEO), Churngwei Chu (web), Zhujun Li (val)

SSAI, Hampton, VA

L. Nguyen (IT lead, GEO), NASA Langley Research Center

P. Heck (retrieval code), CIMSS, UW-Madison

P. Yang (ice models), Texas A&M University

Thanks to Dave Doelling and his TISA/calibration teams!
Cloud Working Group Objectives

Produce pixel-level cloud properties from LEO & GEO imager radiances

• Include cloud mask, thermodynamic phase, optical depth, effective radius, temperature, height, etc.

• Must be inferred at high resolution within coarser CERES footprints even under the most difficult conditions (e.g. at night, over snow/ice, in the presence of thin cirrus and heavy aerosols)

• Used by other WG’s to convert measured radiances to radiative fluxes, to compute surface fluxes, and to improve the time interpolation of radiative fluxes.

• Must be as spatially and temporally consistent as possible across platforms in order to minimize discontinuities in the CERES CDR
Topics

• Data processing status
• Ed4 GEO timeseries/discontinuities
  • Opportunity to update parts of record
• Ed5 progress
  • Clear sky radiance improvements
  • Optical depth over snow/ice
• Use of ancillary snow/ice data products
• Publication/documentation update
<table>
<thead>
<tr>
<th>Clouds Processing Status (MODIS &amp; VIIRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>*<em>CERES-MODIS Edition 4 (<em>CDR)</em></em></td>
</tr>
<tr>
<td>Aqua: Jul 2002 – July 2021 (~19 y)</td>
</tr>
<tr>
<td>Terra: Feb 2000 – July 2021 (~21.5 y)</td>
</tr>
<tr>
<td>- Uses frozen Ed4 cloud codes delivered in 2013</td>
</tr>
<tr>
<td>- MODIS Collection 5 radiances thru Feb 2016,</td>
</tr>
<tr>
<td>- MODIS Collection 6.1 March 2016 – present and scaled to C5 for consistency over entire record</td>
</tr>
<tr>
<td>- Terra-MODIS normalized to Aqua-MODIS (Sun-Mack, et al. 2018)</td>
</tr>
<tr>
<td><strong>CERES-VIIRS Edition 1A</strong></td>
</tr>
<tr>
<td>SNPP: Jan 2012 – July 2021 (~9.5 y)</td>
</tr>
<tr>
<td>NOAA-20: Jan 2018 – July 2021 (~3.5 y)</td>
</tr>
<tr>
<td>- Uses VIIRS Ed1A cloud code</td>
</tr>
<tr>
<td>- SNPP uses forward processing calibrations (C1 radiances), not scaled to MODIS; has discontinuity ~2016 due to a calibration update by SIPS</td>
</tr>
<tr>
<td>- N20 uses C2 radiances and scaled to MODIS C5</td>
</tr>
<tr>
<td><strong>CERES-VIIRS Edition 2A</strong></td>
</tr>
<tr>
<td>SNPP: Jan 2012 – Sept 2016 (~4.5 y)</td>
</tr>
<tr>
<td>- Uses VIIRS Ed1A cloud code</td>
</tr>
<tr>
<td>- Uses C2 radiances and scaled to MODIS C5</td>
</tr>
<tr>
<td>*<em>CERES-VIIRS Edition 1B (<em>CDR)</em></em></td>
</tr>
<tr>
<td>NOAA-20: Jan 2018 – Dec 2018 (~1 y)</td>
</tr>
<tr>
<td>May 2020 – Aug 2020 (~3 m)</td>
</tr>
<tr>
<td>- Being reprocessed</td>
</tr>
<tr>
<td>- Uses new version of VIIRS cloud code (temporary continuity version until Ed5 is released)</td>
</tr>
<tr>
<td>- Fills Aqua-MODIS gap in Aug 2020</td>
</tr>
</tbody>
</table>
Cloud Fraction Comparison
2018 Monthly Mean Timeseries

Daytime Polar

• All versions agree well overall
• Ed1B in slightly better agreement with MODIS
• Satellites track each other better in daytime

Nighttime Polar

• Ed1B polar cloud fraction increased ~5%
• In better agreement with MODIS Ed4
• Poor Ed1B agreement when no fusion data
Nighttime Cloud Fraction Comparison
2018 Monthly Mean Timeseries

Nighttime Polar Ocean

Nighttime Polar Land

Last meeting:
Ed1b polar night cloud problem early in record
(no fusion data)

Invoked and tuned a ‘no fusion data’ branch in the cloud mask
Much better agreement
An update to EBAF is necessary (Loeb/Kato 2:20 pm today)

1) **One reason: to account for artifacts and discontinuities in GEO cloud retrievals, which impact EBAF surface fluxes.**

- EBAF-Surface fluxes will be processed with MODIS/VIIRS imager cloud retrievals (no GEO).

- After EBAF reprocessing is complete, SYN1deg will also be reprocessed for the entire record and this will include GEO data.

  1) Cloud team has identified some parts of the GEO record that can be reprocessed relatively quickly with modest algorithm updates to reduce some of the discontinuities.

  2) These can be employed in the intermediate version SYN1deg if completed by next spring

  3) Development of a more comprehensive GEO processing strategy for Ed5 continues
### Ed4 GEO Record

21 different GEO satellites processed thru March 2021

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Available Channels (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOES-8</td>
<td>0.6, 3.9, 6.7, 11, 12</td>
</tr>
<tr>
<td>GOES-9</td>
<td>0.6, 3.9, 6.7, 11, 12</td>
</tr>
<tr>
<td>GOES-10</td>
<td>0.6, 3.9, 6.7, 11, 12</td>
</tr>
<tr>
<td>GOES-11</td>
<td>0.6, 3.9, 6.7, 11, 12</td>
</tr>
<tr>
<td>MTSAT-1R</td>
<td>0.6, 3.7, 6.7, 11, 12</td>
</tr>
<tr>
<td>MTSAT-2R</td>
<td>0.6, 3.7, 6.7, 11, 12</td>
</tr>
<tr>
<td>GOES-12</td>
<td>0.6, 3.7, 6.7, 11, 13.3</td>
</tr>
<tr>
<td>GOES-13</td>
<td>0.6, 3.7, 6.7, 11, 13.3</td>
</tr>
<tr>
<td>GOES-14</td>
<td>0.6, 3.7, 6.7, 11, 13.3</td>
</tr>
<tr>
<td>GOES-15</td>
<td>0.6, 3.7, 6.7, 11, 13.3</td>
</tr>
<tr>
<td>MET-8</td>
<td>0.6, 3.9, 6.7, 11, 12, 1.6, 8.7, 13.3</td>
</tr>
<tr>
<td>MET-9</td>
<td>0.6, 3.9, 6.7, 11, 12, 1.6, 8.7, 13.3</td>
</tr>
<tr>
<td>MET-10</td>
<td>0.6, 3.9, 6.7, 11, 12, 1.6, 8.7, 13.3</td>
</tr>
<tr>
<td>MET-11</td>
<td>0.6, 3.9, 6.7, 11, 12, 1.6, 8.7, 13.3</td>
</tr>
</tbody>
</table>

- CERES GEO approach in Ed4 utilizes as much available spectral information as possible to help improve accuracy and consistency with MODIS
- Results in some inconsistencies across GEO platforms (due to different algo’s)
- Have been mitigated to some degree in CERES ERB data products but becoming more difficult
- Goal for Ed5 is to improve consistency across all GEO’s
Ed4 GEO Timeseries

Daytime Cloud Fraction Anomalies

[Graph showing time series of daytime cloud fraction anomalies for different regions, including Western Pacific and GOES-West.]
Ed4 GEO Timeseries

Nighttime Cloud Fraction Anomalies

- GOES-West
- GOES-East

Cloud Fraction

2-6%

10-25%

GMS-5
Met-7
GOES-9
Met-5

Greenwich
Indian Ocean
Western Pacific

Time (m/m/yyyy)
Ed4 GEO Timeseries

Daytime Cloud Optical Depth

[Graph showing Time (mm/yyyy) on the x-axis and Cloud Optical Depth on the y-axis, with two sub-plots representing GOES-West and GOES-East, and three sub-plots representing Greenwich, Indian Ocean, and Western Pacific.]
Ed4 GEO Timeseries

Nighttime Cloud Optical Depth

Cloud Optical Depth


Time (mm/yyyy)

Indian Ocean
Western Pacific

Greenwich
GOES-West
GOES-East

Met-10
Ed4 GEO Timeseries

Daytime Cloud Phase

Cloud Phase

Ice

liquid

Time (mm/yyyy)


GMS-5
Met-7
Met-5

Greenwich
Indian Ocean
Western Pacific
GOES-West
GOES-East
Main conclusion from time series

- The 2-channel satellites (GMS-4, Met-5 & Met-7) and Met-10 are most problematic

Possible solutions that can be addressed within ~ 6-months

- Re-run Met-10 record with Met-11 code (SEVIRI imager on both satellites) Completed!
  - *Met-10 code had lots of bugs that were fixed for Met-11*
- Tune the algorithms for the 2-channel satellites to produce cloud properties more consistent with the modern satellites (to the extent possible) Just Started
- Deliver these new versions for Syn1deg processing Next spring
Reprocessed MET-10 Evaluation
(uses Met-11 code)

Nighttime cloud optical depth markedly more consistent
New Met-10 (March 2013)
Optical Depth Consistency Check in Timeseries

Optical Depth (NIGHT)

Optical Depth (DAY)

Linear Average

* 5.9 (new Met10)

15.6

* 14.5
Reprocessed MET-10 Evaluation
(uses Met-11 code)

WATER CLOUD EFFECTIVE RADIUS (DAY)

DAYTIME $R_e$ markedly more consistent
Reprocessed MET-10 Evaluation
(uses Met-11 code)

ICE CLOUD EFFECTIVE RADIUS (DAY)

DAYTIME $R_e$ markedly more consistent
New Met-10 (March 2013)

Nighttime Consistency Check

Total Cloud Fraction

Cloud Fraction

* 63

Time (mm/yyyy)

Water Cloud Fraction

Cloud Fraction

* 36 (new Met10)

Time (mm/yyyy)

Ice Cloud Fraction

Cloud Fraction

* 26 (new Met10)

Time (mm/yyyy)
Updating Cloud Properties For GEOs With Two Channels

• **Goal:** Get closer to Multi-Channel Results (see time series)
  
  o Adjust 2-channel code for 2-channel instruments (ongoing)
    - Qualitative comparisons to multi-chan results since comparing different years
  
  o Apply 2-channel code to multi-channel instruments (coming soon)
    - Quantitative comparisons for same month/year/satellite

• **Started with Nighttime IR-Only Cloud Algorithm, Met-7 → Met-8**
  
  o Algorithm changes are simpler and easy to evaluate, start with cloud %
  
  o Fewer derived properties so fewer unintended consequences

• **Just starting Daytime 2-Channel Cloud Algorithm, Met-7 → Met-8**
  
  o Apply night changes first, then the more complex algorithm & more properties

• **Complete Met-7 updates, apply to Met-5 & GMS-5, tune if necessary**
MET-7 TEST (NIGHT)
Total Cloud Fraction

Revision 1
Clear/Cloud Threshold Adjustments
Land: 6K changed to 5K
Ocean: 3K changed to 1K

Ed4 (IR Only)
Met-7 (April 2014)

Ed4 Baseline (Multi-Channel)
Met-8 (April 2019)

Revision 1 (IR Only)
Met-7 (April 2014)

Ocean 53.57
Land 50.67

Ocean 70.34
Land 55.86

Ocean 70.62
Land 59.76
MET-7 TEST (NIGHT)
Total Cloud Fraction

Ed4 Met-7 (IR Only) minus Baseline Met-8 (Multi-Chan)
[April 2014 minus April 2019]

Mean diff
Ocean: -16.8%
Land: -5.2%

Revision 1
Clear/Cloud Threshold Adjustments
Land: 6K changed to 5K
Ocean: 3K changed to 1K
Revision 1 Met-7 (IR Only) minus Baseline Met-8 (Multi-Chan) [April 2014 minus April 2019]

Mean diff
Ocean: + 0.3 %
Land: + 3.9 %

Revision 1
Clear/Cloud Threshold Adjustments

Land: 6K changed to 5K
Ocean: 3K changed to 1K
MET-7 TEST (NIGHT)
Cloud Fraction By Phase

Revision 1
Clear/Cloud Threshold Adjustments

Land: 6K changed to 5K
Ocean: 3K changed to 1K

Ed4 Met-7
(IR Only)
April 2014

Revision 1 Met-7
(Multi-Chan)
April 2014

Clear/Cloud adjustments increase mostly water cloud amounts

Little change in ice cloud amounts
MET-7 TEST (NIGHT)
Water Cloud Fraction

Revision 1
Clear/Cloud Threshold Adjustments

Land: 6K changed to 5K
Ocean: 3K changed to 1K

Ed4 (IR Only)
Met-7 [April 2014]

Ed4 Baseline (Multi-Chan)
Met-8 [April 2019]

Revision 1 (IR Only)
Met-7 [April 2014]

Ocean | Land
---|---
37.81 | 32.36
41.18 | 25.30
54.86 | 41.36
MET-7 TEST (NIGHT)

Ice Cloud Fraction

Revision 1
Clear/Cloud Threshold Adjustments

Land: 6K changed to 5K
Ocean: 3K changed to 1K

Ed4 (IR Only)
Met-7 [April 2014]

Ed4 Baseline (Multi-Chan)
Met-8 [April 2019]

Revision 1 (IR Only)
Met-7 [April 2014]

Ocean
Land

15.75
18.31

28.90
29.99

15.76
18.40
MET-7 TEST (NIGHT)
Water Cloud Fraction

Revision 1 (IR Only)
Met-7 [April 2014]
Ocean 54.86
Land 41.36

Revision 2
Cloud Phase Threshold Adjustments
253K changed to 258K (need less water cloud)

Ed4 Baseline (Multi-Chan)
Met-8 [April 2019]
Ocean 41.18
Land 25.30

Revisions 1 & 2 (IR Only)
Met-7 [April 2014]
Ocean 51.05
Land 36.02

5K change Not enough
MET-7 TEST (NIGHT)
Ice Cloud Fraction

Revision 1 (IR Only)
Met-7 [April 2014]

Revision 2
Cloud Phase Threshold Adjustments

253K changed to 258K
(need more ice cloud)

Ed4 Baseline (Multi-Chan)
Met-8 [April 2019]

Revisions 1 & 2 (IR Only)
Met-7 [April 2014]

Ocean Land
15.76 18.40
28.90 29.99
19.57 23.73

5K change
Not enough
The cloud mask and derived cloud properties rely on knowledge of the background or ‘clear sky’ radiances. Key inputs are:

- Skin temperature (T_{skin}) to compute the clear sky emission temperature at TOA for the IR channels (surface emissivity, atmospheric correction also required)
  - T_{skin} comes from reanalysis system (GEOS5.41 in Ed4)
- Spectral surface bidirectional reflectance for the solar channels
Large differences (obs much warmer) over land especially in daytime
Calculations use GEOS 5.41 Tskin but significant differences also found for other modeling systems
Can impact cloud retrievals (especially thin cirrus)
Cloud mask is tuned to some degree to account for these differences, but adjustments are needed anytime the reanalysis system is updated or changed
GOES-7 11 µm Clear Sky Temperature
- relationship to surface air temperature

Spring 1994 ARM IOP in the SGP

Minnis et al. 1994, NASA RP
Deep Neural Network for Predicting Skin Temperature as Observed from Satellites

- work by Ben Scarino

**Input (X)**
- 2-meter Air Temperature (MERRA-2)
- Latitude
- Longitude
- Local Time
- SZA
- IGBP (homogenous)

**Truth (Y)**
- December 2020 Global GEO Satellite Skin Temperature
- 100% Clear Sky Regions Only

**Output (Ŷ)**
- Predicted Satellite Skin Temperature
Daytime Skin Temperature Difference (Dec 2020)
GEO minus MERRA-2

Nighttime Skin Temperature Difference (Dec 2020)
GEO minus MERRA-2
Tskin Validation

**BIAS**
- Merra-2 minus observed

**SDD**
- Merra-2 minus observed
- Nnet minus observed
Skin Temperature Difference (Dec 2020)
Nnet minus GOES (independent test dataset)

Skin Temperature Difference (Dec 2020)
Nnet minus MERRA-2 (independent test dataset)
GEO Clear Sky Reflectance Update

• In CERES MODIS and VIIRS forward processing, a clear sky reflectance updating scheme is employed to update the snow/ice/land reflectances based on clear pixels discerned by the cloud mask. These provide input for the cloud algorithms the following day.

• In CERES GEO processing, there is no updating scheme. Instead static monthly mean clearsky overhead albedo maps (for the 0.65 µm band) created from an AVHRR climatology are employed to estimate the GEO land surface bi-directional reflectance by applying directional models developed from MODIS and bidirectional models developed from ERBE for desert and from aircraft data (Kriebel) for all other land types.

• Compared to GEO observations, the AVHRR based approach leads to large errors over some surface types at various times of day

• For Edition 5, we plan to develop a more robust clear sky reflectance method based on global hourly GEO data (reduce impact of uncertainties in DRM and BRDF models)
GOES-16 Clear-Sky Reflectance Comparison

- monthly hourly composites created using two years of data, stored as OA and tested in the cloud retrieval system (S. Bedka)
Cloud Phase using AVHRR OA Map

Cloud $\tau$ using AVHRR OA Map

AVHRR minus GOES Observed Clear-Sky Reflectance Difference

March 12, 2019

- Difference between AVHRR predicted and the Observed clear-sky reflectance in this region is between 0.06 and 0.13. Differences are largest over deciduous broadleaf forest IGBP type.

- Note large areas of no retrievals (gray) and low confidence clouds in the cloud phase image.
• Using the observed OA map results in significant improvement in cloud phase for cirrus (fewer weak clouds, fewer misclassifications) and a much lower occurrence of no retrievals.
• There is a slight increase in cirrus cloud optical depth.
• More work is needed to implement the GEO compositing approach in our retrieval system and assess the impact on the cloud mask and cloud properties.
Multi-spectral Hybrid Approach for Estimating Cloud Optical Thickness over Snow/ICE for Ed5
Water Clouds, Day Time, Aqua

ED4 Optical Depth


global ave=8.824998 polar ave=18.29042 non-polar ave=4.407797 [0.049999,150.0000]
20190315 hr 4
Aqua

1.6 tau

1.24 tau
20190315 hr 19
Aqua
ED4 Optical Depth

Water Clouds, Day Time

ED5 (Hybrid) Optical Depth
Water Cloud:

Mean (Std)

Ed4: 23.4 (40.5)
Ed5: 14.9 (30.7)

Ice Cloud:

Mean (Std)

Ed4: 10.9 (25.7)
Ed5: 7.4 (23.1)
Use of Sea-Ice information in CERES Cloud Algorithms

- Cloud working group uses NSIDC/AFWA sea-ice concentration for cloud mask and cloud optical properties.
- Current product being used does not provide data over lakes or along coastlines (~50 km near coastline is unknown).
Coastal Snow & Ice Unknown (~ 50 km) regions from NSIDC
Coastal issue
Hudson Bay
Coastal issue
Hudson Bay
Sea-ice concentration on lakes always 0 from NSIDC
Lake Winnipeg
2021 CWG Publications


Minnis, P., et al., 2021: VIIRS Ed1A Clouds Data Quality Summary, just completed


QUESTIONS ?