# Climate Data Record (CDR) Program

## Quality Assurance Results and Summary

## Outgoing Longwave Radiation (OLR) – Monthly and Daily

CDR Program Document Number: TBD by CDR Program Document Manager
Originator Document Number: TBD by PI organization or use N/A
Revision 1.0 / Aug 1, 2017
DSR Number: DSR-XXX by CDR Program Document Manager

# REVISION HISTORY

| Rev. | Author | DSR No. | Description | Date |
|---|---|---|---|---|
| 1.0 | Hai-Tien Lee<br>Univ. of Maryland | DSR-XXX | QA Summary update submission to CDR Program | 8/31/2017 |
| 2.0 | Hai-Tien Lee<br>Univ. of Maryland | DSR-XXX | QA Summary update submission to CDR Program | 8/31/2018 |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

# TABLE of CONTENTS

# LIST of FIGURES

## LIST of TABLES

# 1. Introduction

## 1.1 Purpose

The purpose of this document is to provide the updated assessment of the Monthly and Daily OLR CDR products and summarize the Quality Assurance results, supplementing the existing C-ATBD document.

## 1.2 Referencing this Document

This document should be referenced as follows:

Quality Assurance Summary for Monthly and Daily OLR CDR products

## 1.3 Products Relevant to this Document

OLR CDR products involved in this QA summary report are listed in Table 1.

**Table 1** Release of the OLR CDR products as of Aug 31, 2018.

| Product Version | Software Version | Data Span | Remarks |
|---|---|---|---|
| OLR-Monthly CDR | v02r02-1 | 1979.01 – 2018.06 | Obsolete as of July 2018, replaced by v02r07. Last update is for June 2018. |
| OLR-Monthly CDR | v02r07 | 1979.01 – 2018.07 | Upgraded version. Operational as of July 2018. |
| OLR-Daily CDR | v01r02 | 19790101-20161231 | Final product. 2017 product is pending on Gridsat data availability. |
| OLR-Daily CDR | v01r02-preliminary | 19790101-20180830 | Interim product |

# 2. Quality Control/Assurance Procedures

## 2.1 QC/QA components

The complete QC/QA includes the following components that are shown in Fig. 1. Their attributes are explained below. This document focuses on the updated **QA-C2** evaluations for the Monthly and Daily OLR CDR from which the ultimate accuracy, precision and stability of the product are assessed.

QC for Measurement (Instruments)

- Telemetry (health and performances)
- Radiometric (radiance calibration)
- Internal consistency (inter-satellites; operational rad calibration)
- External verification (emulation with IASI, CrIS)

QA for OLR Retrieval (Algorithms)

- Instantaneous at HIRS Field of View (FOV) level
- Internal consistency (inter-satellites coincident OLR retrievals)
- Averages: 2.5° Monthly; 1° Daily; Zonal; Orbital ascending/descending;
- External verification sources

The QC blocks include the following components:

Telemetry

- QC-A1: Noise level (NEdN)
- QC-A2: Calibration flag
- QC-A3: Instrument Quality flag (overall)
- QC-A4… Other telemetry parameters

Radiance

- QC-B1: Gain/offset stability
- QC-B2: Inter-satellites (daily collocation)
- QC-B3: External reference (Operational HIRS, IASI emulation)

The QA blocks include the following components:

Collocated and Coincident retrievals

- QA-A1: on the instantaneous FOV basis

Orbital

- QA-B1: check consistency between ascending/descending orbits and day/night differences

Daily & Monthly products

- QA-C1: compare to other operational satellite products and numerical model outputs, e.g., NESDIS AVHRR/HIRS, NWP simulations, etc.
- QA-C2: compare to broadband measurement products, e.g., ERBE, CERES, ScaRab, etc.

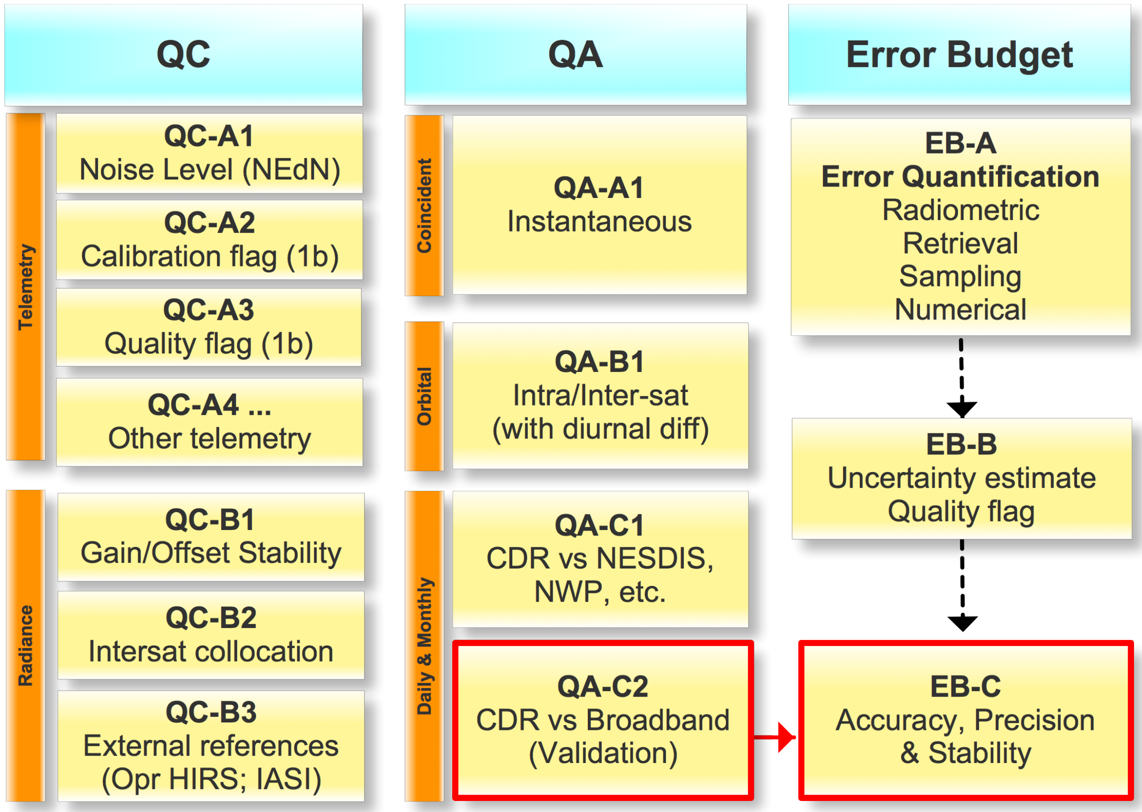


Fig. 1 OLR CDR Quality Assurance components.

## 2.2 Real-time QC/QA Monitoring

The real-time monitoring provides the operational QC/QA for the product generation. The OLR CDR products, their inputs, and the critical processes were visualized for routine online monitoring.

- Monthly and Daily OLR CDR v01r02-Preliminary product: http://olr.umd.edu/index.html and http://olr.umd.edu/index_alt.html
- GSIP OLR monitoring http://olr.umd.edu/CDR/Daily/GSIP/
- HIRS observations and Leo+Geo blending process monitoring http://olr.umd.edu/CDR/Daily/HIRS/
- Error check for the "1-day lag" v01r02a-interim product: http://olr.umd.edu/CDR/Daily/v01r02a-interim/graph_check_error/

# 3. Reference Data Products

## 3.1 Availability of the reference data products

Table 1 lists the reference data sets currently available for the QA evaluations.

**Table 1** Reference OLR products for OLR Monthly and Daily CDR Quality Assurance Evaluation as of Aug 6, 2018.

| Product Name | Version | Data Coverage | Instrument | Satellite |
|---|---|---|---|---|
| **ERBE S4** | | 1985-1989 | ERBE scanner | ERBS, NOAA-9, NOAA-10 |
| **ERBS S4** | WFOV Ed3_rev1 | 1985-1999 | ERBE non-scanner | ERBS |
| **EBAF-TOA** | Ed4.0 (rev)<br>Ed2.8 | 2000.03-2018.03<br>2000.03-2017.02 | CERES | Terra, Aqua combined |
| **SYN1deg-Day SYN1deg-3Hr** | Ed4A | 2000.03-2018.03 | CERES | Terra, Aqua combined, with geo |
| **SYN1deg-Day SYN1deg-3Hr** | Ed1A | 2012.02-2017.10 | CERES | Terra, NPP combined, with geo |
| **SSF1deg** | Ed4A | 2000.03-2018.03 (Terra)<br>2002.07-2018.03 (Aqua) | CERES | Terra, Aqua |
| **SSF1deg** | Ed1A | 2012.02-2018.03 (NPP) | CERES | NPP |
| **SSF** | Level-2 | 2000.03-2018.03 | CERES | Terra, Aqua, NPP |

## 3.2 Changes in the EBAF Ed4.0 product

The CERES EBAF 4.0 data set was re-released on March 7, 2017 (for some bug fix) and has been extended to Jan 2017 (as of Aug 1, 2017). The detailed information about the changes and improvements over the previous Ed2.8 version can be found in the Data Quality Summary document (CERES_EBAF_Ed4.0_DQS.pdf). Table 2 compares the global mean of the TOA fluxes from EBAF Ed4.0 and the EBAF Ed2.8 for Mar 2000 to Jan 2017.

The Ed 4.0 version supersedes the Ed. 2.8 with the following relevant key changes:

- TOA fluxes are constrained using same approach as EBAF Ed2.8 but using 10 years of Argo (Roemmich et al., 2009) instead of 5 years.
- The approach of using geostationary data used in Ed4.0 differs from that in Ed2.8, which derived separate scene dependent diurnal corrections for each of the five geostationary satellite domains for each calendar month.
- EBAF Ed4.0 incorporates all of the algorithm improvements that have recently been implemented in creating the Edition4.0 suite of CERES data products. This includes improved instrument calibration, cloud properties, ADMs and time-interpolation

and space averaging with hourly geostationary imager measurements. The meteorological assimilation data used is based upon GEOS 5.4.1 throughout the record and MODIS radiances and aerosol input files are from Collection 5 (C5) through March 2017. C5 production is expected to stop after March 2017 and be superseded by Collection 6.

- EBAF Ed4.0 time-averaging is performed using GMT whereas EBAF Ed2.8 used local time.
- Substantial algorithm improvements were made in EBAF Ed4.0 clear-sky flux determination.
- EBAF Ed4.0 narrow-to-broadband regressions 4 spectral channels for SW

**Table 2** Global mean of the TOA fluxes from EBAF Ed4.0 and the EBAF Ed2.8 for Mar 2000 to Jan 2017. Unit: ($Wm^{-2}$).

| | Ed 2.8 | Ed 4.0 | Ed2.8 minus Ed4.0 |
|---|---|---|---|
| **All-sky LW** | 239.69 | 240.27 | -0.53 |
| **All-sky SW** | 99.60 | 99.14 | 0.39 |
| **All-sky Net** | 0.90 | 0.88 | -0.02 |

There are trended differences between Ed2.8 and Ed4.0. The main impact comes from the MODIS cloud optical depth retrievals, while there is a negative trend in the global cloud optical depth in Ed3A, the trend has been corrected to a small negative value in Ed4. This directly affects the TOA SW, and in turns, changes the LW and Net. Fig. 1 shows the time series of the difference in SW and LW between Ed2.8 and Ed4. Fig 2 shows the time series of the TOA global mean fluxes, comparing the differences between Ed2.8 and Ed4, with the estimates of the changes in their linear trends.

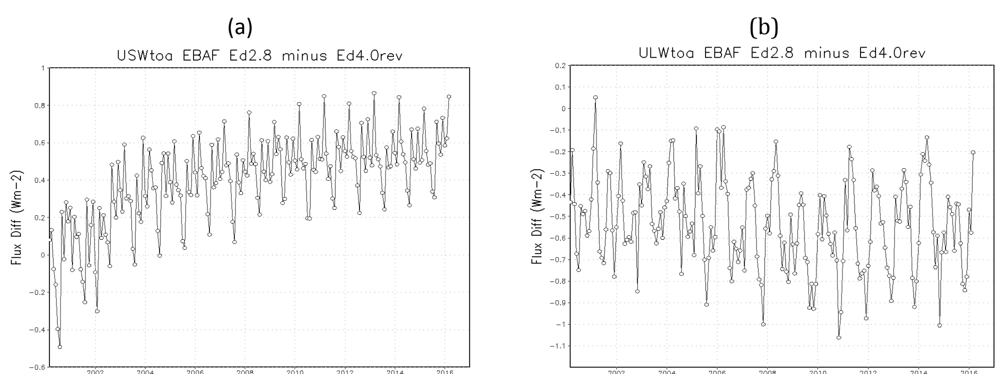


Fig. 2 Changes in EBAF-TOA fluxes in Ed4.0 relative to Ed2.8, a) SW fluxes; b) LW fluxes.

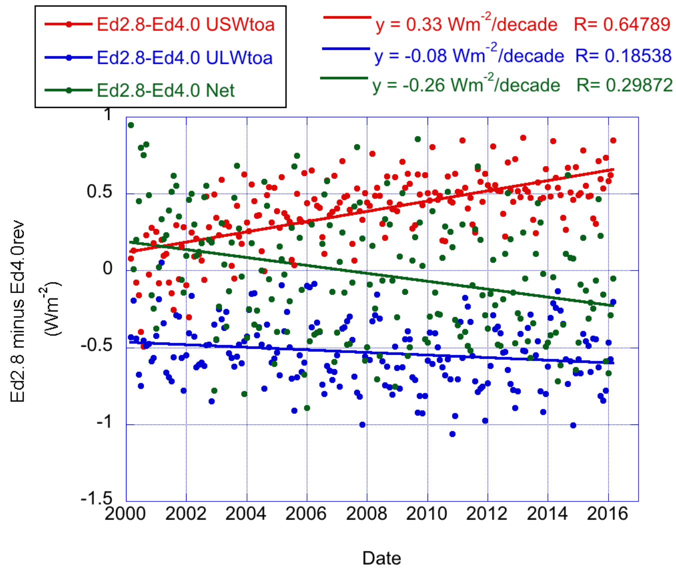


Fig. 3 Comparison of TOA fluxes between Ed2.8 and Ed4. The Ed2.8 minus Ed4 differences show trended changes for SW of about 0.33 $Wm^{-2}$ per decade; for LW of about -0.08 $Wm^{-2}$ per decade; and for Net of about -0.26 $Wm^{-2}$ per decade.

# 4. GridSat CDR and GSIP Product Issues

## 4.1 Geo data for Interim Daily OLR Production

The GOES-16(R) became operational since January 2018, however, the Advance Baseline Imager (ABI) OLR that supposedly to be generated within the GSIP production is not available, due to delayed implementation pending on funding availability. In order to maintain the continuous GOES-East coverage of geostationary observations, the ABI radiance data is obtained through the STAR-CICS data transfer agreement, and the the ABI OLR is retrieved locally. The ABI OLR has been incorporated in the Interim Daily OLR CDR production since Jan 1, 2018. Full disk ABI OLR is available at each 15 minutes (compared to 3-hourly from GOES-13). The increased temporal and spatial resolution improved the accuracy of daily OLR integral over this region.

Fig. 4 shows the hourly composite OLR from GOES-13 Imager and the GOES-16 ABI observations, for 20:30UT Dec 18, 2016.

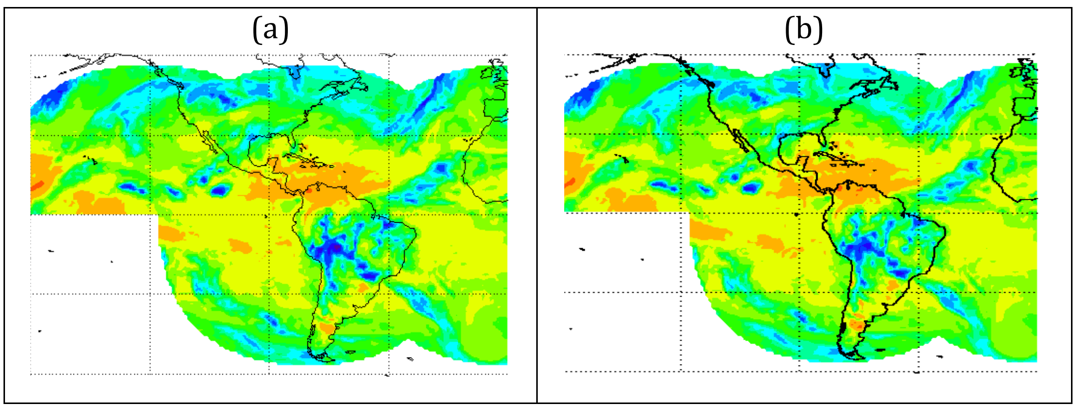


Fig. 4 Comparison of hourly composite OLR over GOES-East full disk domain (centered on 75W) derived from (a) GOES-13 Imager versus (b) GOES-16 ABI instruments for 20:30UT Dec 18, 2016

The Indian Ocean coverage provided by Meteosat-7 at 41.5°E was no longer available since March 2017 when replaced by Meteosat-8, leaving the interim daily OLR to be determined from HIRS observations only in this region. Several issues, including the software needed for handling McIDAS data format and lack of updated cloud mask from University of Wisconsin, have blocked the Meteosat-8 data from being used in the GSIP production.

The western Pacific geo coverage (140°E) provided by MTSAT-1/2 on Himawari-6/7 have been replaced by Himawari-8/9 Advanced Himawari Imager (AHI) observations. AHI is a 16-band multispectral imager similar to the ABI on GOES-16, but with a faster 10-minutes full-disk scanning rate. The AHI OLR retrieval has been implemented for the GSIP developmental system, but not yet migrated to the operational production system. The AHI OLR data is thus pushed in from the STAR developmental system to CICS as a temporary measure. The AHI data is very important for observing the strong convective activities over the western Pacific region. However, the current AHI data flow through the STAR development system is very unstable that hinders the daily OLR integral accuracy for this region.

OLR coefficients for the upcoming Meteosat-11 and Himawari-9 have also been derived and provided to STAR to be implemented in the GSIP production.

## 4.2 QC problem in GridSat water vapor channel

The GridSat CDR product provides the brightness temperature for the Windows and the Water vapor channels from the geostationary satellites. Some bad data caused by, e.g., noisy transmissions, were not completely filtered out. And QC on the water vapor channel is not as strict as on the Windows channel. These bad data propagate into the final Daily OLR CDR. While relying on and expecting the improvement of QC in the GridSat CDR production, we have devised a temporary fix that could prevent some bad data of certain patterns from entering OLR CDR production.

The revised GridSat OLR software is termed "v3_fix001", with the following changes:

- Changed missing value -31999 to a lower limit -6000.
- Replace WVP1 by WVP2 for high latitudes over Meteosat-7 domain (Indian Ocean) bounded by longitudes [28.565, 98.775]
- irwvp(2980:3983,1:300)=irwvp2(2980:3983,1:300)
- irwvp(2980:3983,1701:2000)=irwvp2(2980:3983,1701:2000)

The QC by checking missing value "-31999" cannot filter the bad data in the water vapor channel of Meteosat-7. The v3_fix001 version uses an ad hoc fix that replaces water vapor channel observations with the observations from the neighboring satellites (i.e., the 2nd nearest observations) at higher latitudes. Fig. 5 shows the OLR derived from Gridsat v02r01 for 2016.01.27.21 using the original v3 software to illustrate this problem. The improvement in Daily OLR CDR production with v3_fix001 Gridsat OLR software can be clearly seen in Fig. 6.

Note that the v3_fix001 Gridsat OLR software has only applied to the 2016 Final Daily OLR CDR production. The reprocessing of the entire Daily OLR CDR time series with this revised software is under consideration.

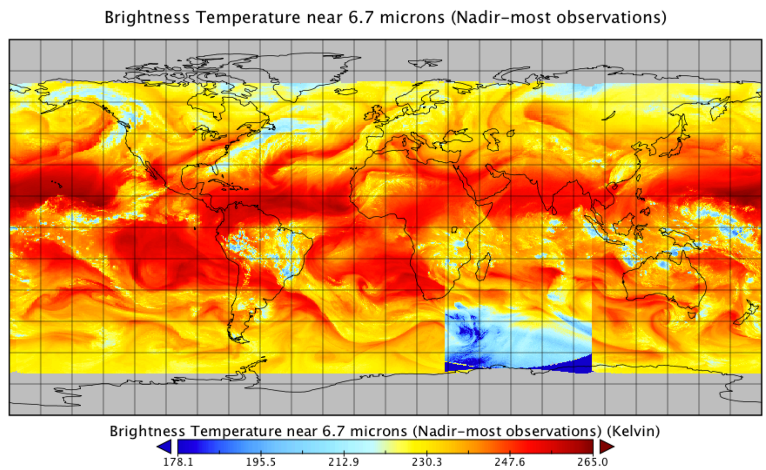


Fig. 5 OLR derived from Gridsat v02r01 for 2016.01.27.21 using v3 software. The QC by checking missing value "-31999" cannot filter the bad data in the water vapor channel of Meteosat-7 and those bad data entered OLR CDR production, causing the entire region bluish where OLR is erroneously too low in southern Indian Ocean.

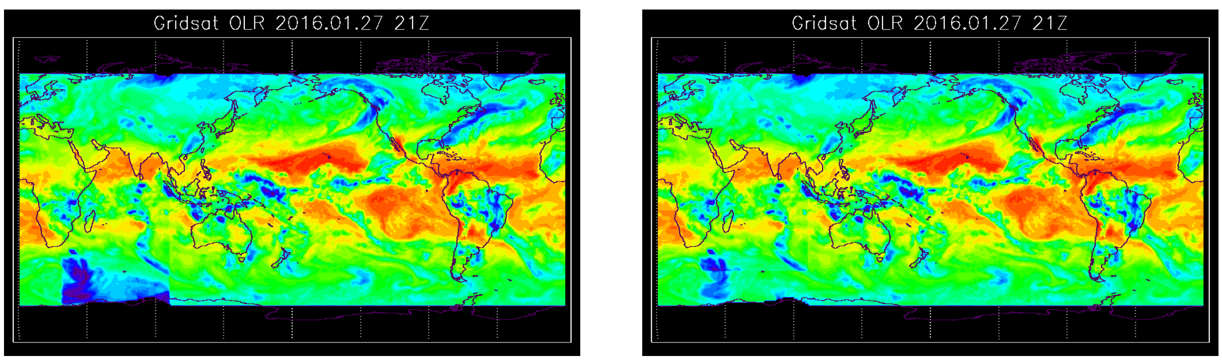


Fig. 6 Comparison of OLR derived from Gridsat v02r01 for 2016.01.27.21 using (a) v3, versus (b) v3_fix001 software. The OLR is now without problems as the bad Gridsat water vapor data were substituted from the other geostationary satellites sources.

## 4.3 New Geo QC Tools

An experimental QC tools for Geo-based OLR data has been developed to tackle the bad transmission line and noises in the data. The "zonal anomaly detection" scheme compares the zonal means and variances among the hourly files in one day (8 or 24 files) to detect abnormal values, assuming certain level of continuity in time. This type of abnormality is usually linked to bad transmission lines. This method first calculates the baseline means and standard deviations for those within 2-sigmas. Then, uses 3,4,5-sigmas thresholds successively with three iterations to recalculate both the zonal means and standard deviations and to pick out the anomalous hours/bands. Fig. 7 shows the before and after of the QC application for MTSAT2 data on Nov 15, 2014.

This tool is still in developmental phase yet to be implemented for the GSIP and Gridsat data processing.

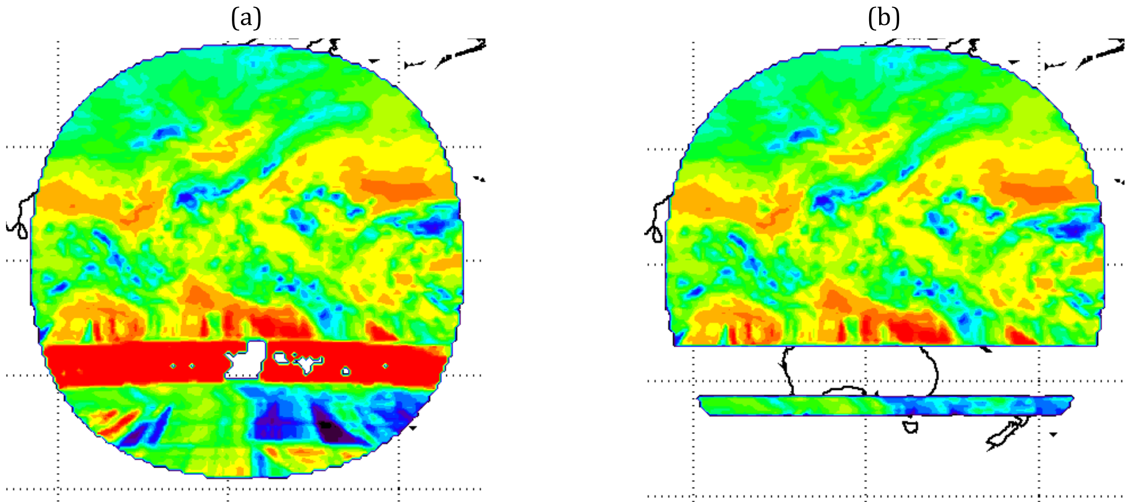


Fig. 7 Comparison of OLR retrievals from MTSAT2 for 00:30 Nov 15, 2014 (day 319) for (a) before and (b) after the QC application of zonal anomaly detection scheme. The obvious bad data in southern hemisphere were removed, while a thin band of "good" data were kept intact.

## 4.4 Comparison of Interim and Final Daily OLR CDR

The Final Daily OLR CDR uses the GridSat CDR product to provide the geostationary satellite observations, while the Interim Daily OLR CDR uses the NESDIS operational GSIP product as the alternative input . The comparisons of the two products provide indication about possible elevation of errors in the production of daily OLR CDR caused by the use of geostationary data.

Fig. 8 shows the global mean and standard deviations for the 1-deg grid daily OLR between the Interim and the Final Daily OLR CDR product. The spikes in either the mean or the standard deviation provide indications of anomalous geo input data or blending process that require attentions, e.g., for day 290.

Fig. 9 shows the case study for Oct 17, 2016 (day 290) where relatively larger differences between the Interim and Final Daily OLR products were found between the GSIP based and the GridSat based OLR estimation in the later half of the day. Preliminary examinations cannot determine which data source is in error, however.

Fig. 10 shows the annual mean differences between the Interim and Final Daily OLR CDR products for year 2016. One can notice the blue circular patterns at the rims of each geostationary full disk coverage. These differences require more detailed analysis. The negative biases over Australia are resulted from the lack of geostationary observations in GSIP data over the MTSAT region, lead to consistent negative biases in the HIRS-only diurnal integration. This error would be removed when Himawari-8/9 AHI observations enter the production.

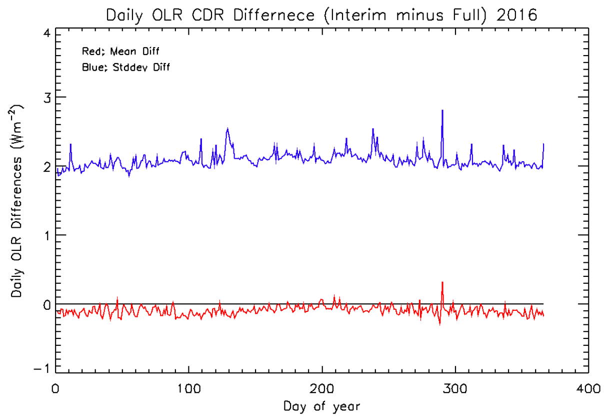


Fig. 8 Comparison of OLR derived from Gridsat v02r01 for 2016.01.27.21 using (a) v3, versus (b) v3_fix001 software. The OLR is now without problems as the bad Gridsat water vapor data were substituted from Fig. Daily mean and standard deviation of the OLR differences between the Interim and Final Daily OLR CDR products, for year 2016.

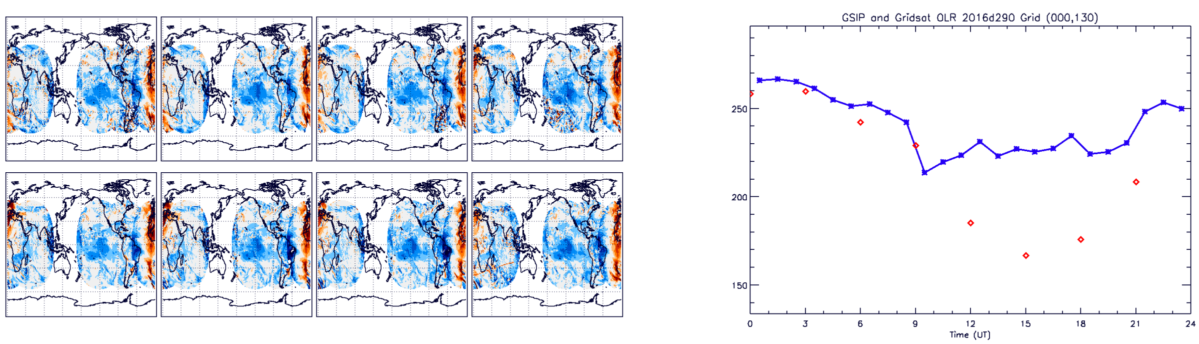


Fig. 9 GridSat and GSIP based OLR estimations for Oct 17, 2016 (day 290) seemed to be strongly disagreed some hours (see right panel) of this day for a vertical zone near the 0° longitude (orange area on left panel).

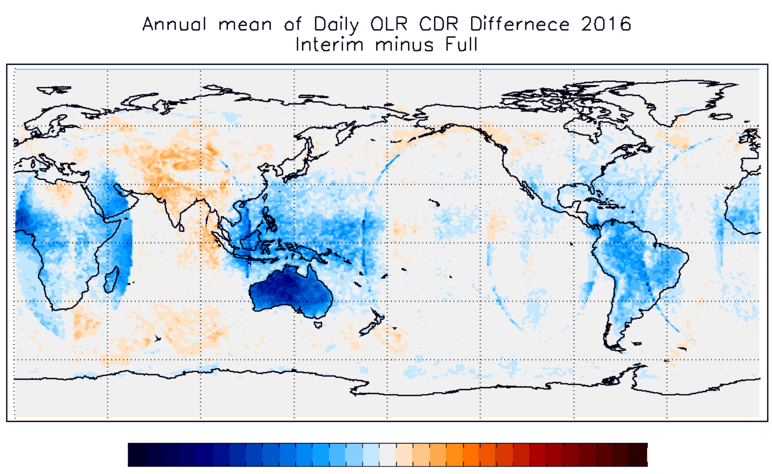


Fig. 10 Annual mean differences between the Interim and Final Daily OLR CDR products, for year 2015.

# 5. Quality Assurance of Geo-Leo Blending Process

The geostationary-based OLR is calibrated against the HIRS-based OLR with the "7-day boxcar" scheme. Fig. 11 shows examples of the examination for the Geo to Leo calibration by comparing the calibrated geo-OLR to the reference HIRS OLR with the collocated/coincident data points. This examination assures the correctness of the implementation of the calibration procedure.

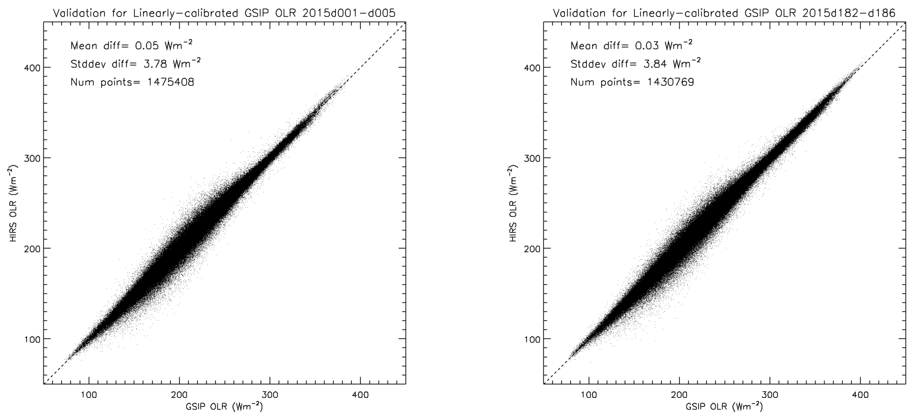


Fig. 11 Comparison of the calibrated geo-OLR versus the reference HIRS OLR with the collocated (within 1°x1° box) and coincident (within ±30 minutes) data points, for Jan. 1-5 [left] and July 1-5, 2015 [right]. The mean differences are essentially zero, as expected, with standard deviations of about 3.8 $Wm^{-2}$.

# 6. Monthly OLR CDR v02r07 Upgrade

As of July 2018, the operational Monthly OLR CDR v02r02-1 have been replaced by the v02r07 version, an upgrade that uses revised OLR regression models for more consistent OLR retrievals among various HIRS instruments – results in significant improvement in time series stability. Fig. 12 summarizes the impact of the changes by comparing their anomalies time series. The consistencies between the Monthly and Daily OLR CDR are greatly improved with the upgrade of the Monthly OLR CDR. Fig. 13 shows the statistics for the global mean differences between the monthly-integrated Daily OLR CDR v01r02 and the Monthly OLR CDR v02r02-1 and v02r07, respectively.

Fig. 14 shows the mean and standard deviations of the OLR differences between v02r02-1 and v02r07 for reference purposes.

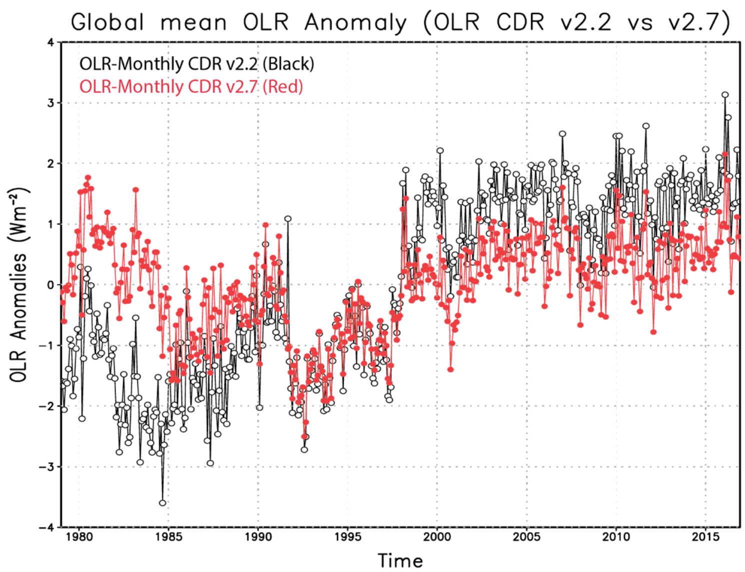


Fig. 12 Comparison of the OLR anomalies derived from the Monthly OLR CDR versions v02r02 (black) versus the new version v02r07 (red). The spurious upward trend found in the v02r02 is removed in v02r07 as the improved accuracy in intersatellite calibrations, due to the greatly improved consistency in the OLR retrievals among different HIRS instruments.

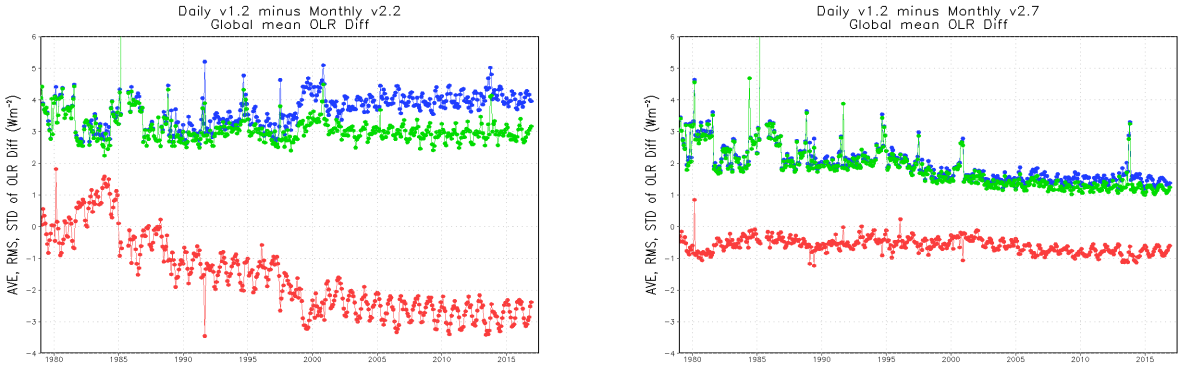


Fig. 13 Statistics of the differences of the Monthly OLR between the monthly-integrated Daily OLR CDR v01r02 and the Monthly OLR CDR v020r2-1 [left] and v02r07 [right] products. (red: mean differences; green: standard deviations; blue: rms) The right panel shows good agreement and consistencies between the Daily v1.2 and Monthly v2.7 OLR CDR products, whereas the v02r02-1 Monthly OLR is having spurious trend and less accuracy in OLR retrievals. Note that the spikes are mostly related to the missing data. The decrease in standard deviations/rms differences between Daily v1.2 and Monthly v2.7 [right panel] post year 2000 is attributed to the better sampling in the HIRS observations, such that it reduces the temporal integral errors in diurnal variations in the Monthly OLR CDR production.

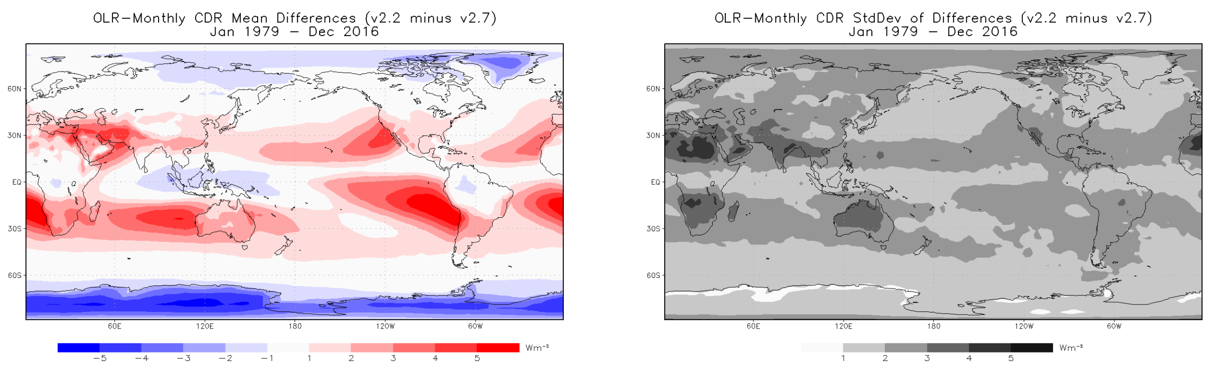


Fig. 14 Mean [left] and standard deviation [right] of the differences of the Monthly OLR between the Monthly OLR CDR v020r2-1 and v02r07

# 7. Quality Summary Updates

## 7.1 Monthly OLR CDR v02r02-1 and v02r07

Comparisons of Monthly OLR CDR products to the reference data set EBAF Ed4.0 clearly show the significant improvement in the v02r07 upgrade. (See Figs. 15-19). For the comparison purposes, the EBAF product has been converted from the original 1°x1° to 2.5°x2.5° grid resolution. The comparisons have been extended to Feb 2018.

The improvements in the v02r07 Monthly OLR CDR can be clearly seen in the subtropical lands and eastern part of the oceans, Greenland, and Antarctica, with overall significant reduction in rms and standard deviation of OLR differences for the v02r07 Monthly OLR CDR minus CERES EBAF v4.0 compared to those of the v02r02-1. Although there is still consistent disagreement in the annual cycles, the v02r07 did improve the agreement in annual cycle with respect to EBAF. The v02r07 significantly improves the agreement the spatial variation with respect to the EBAF v4.0 monthly OLR maps compared to that of the v02r02-1. The standard deviations of the OLR differences between the Monthly OLR CDR v02r07 and EBAF Ed4.0 indicates significant improvement with an overall lower values and the removal of annual cycle dependency.

The global mean OLR differences over the period March 2000 to Feb 2018 between the Monthly OLR CDR v02r07 and EBAF Ed4.0 is about **-1.6 $Wm^{-2}$**, with the overall standard deviations is about **1.8 $Wm^{-2}$** and rms differences of about **2.5 $Wm^{-2}$**. Note that the overall rms differences between Monthly OLR CDR v02r02-1 and EBAF Ed4.0 is about 3.1 $Wm^{-2}$.

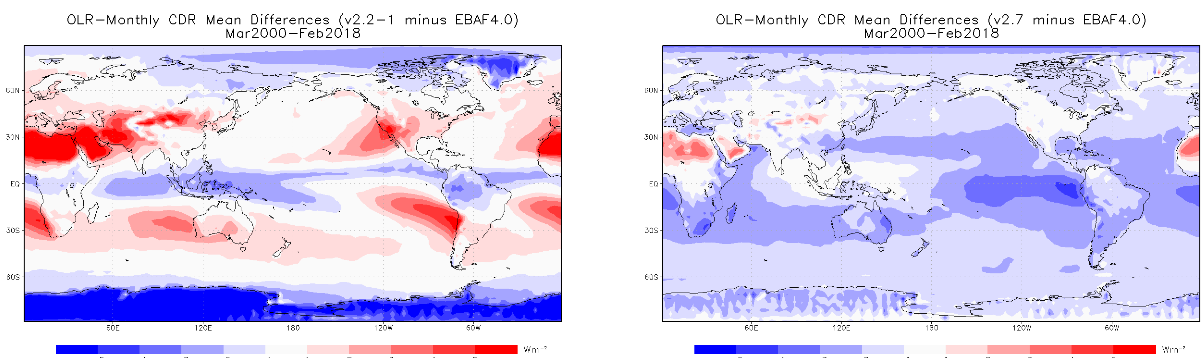


Fig. 15 The mean differences for Monthly OLR CDR v02r02-1 [left] and v02r07 [right] with respect to the reference data set EBAF Ed4.0 for the period March 2000 to Feb 2018. The improvements in the v02r07 Monthly OLR CDR can be clearly seen in the subtropical lands and eastern part of the oceans, Greenland, and Antarctica.

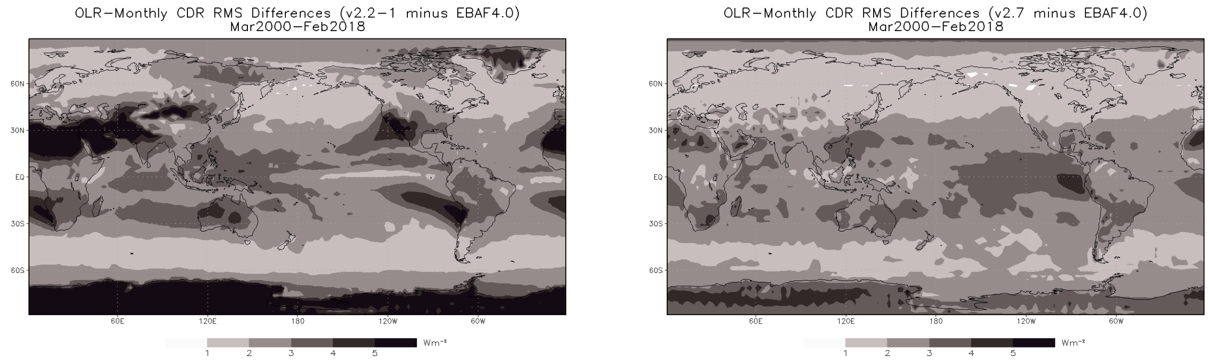


Fig. 16 Similar to Fig. 15 but are for the rms differences, showing significant reduction in rms OLR differences for the v2.7 (right) compared to that of the v2.2-1 (left).

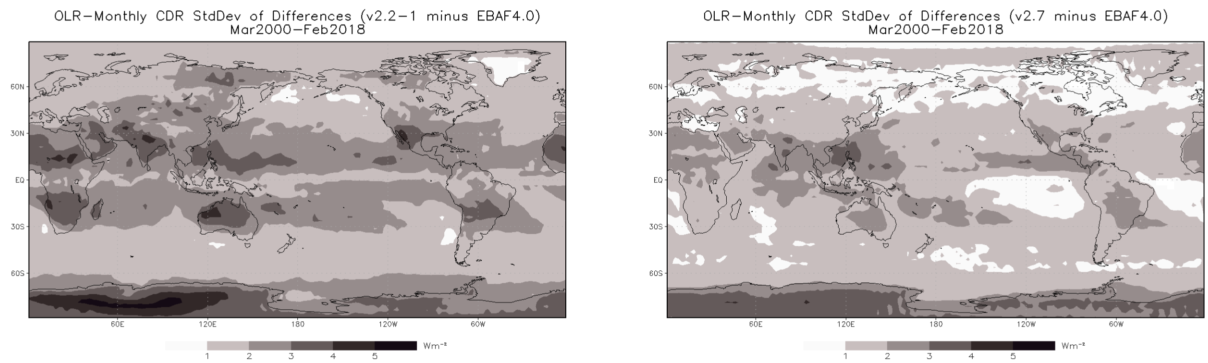


Fig. 17 Similar to Fig. 15 but are for the standard deviation of the differences, showing significant reduction in standard deviation of OLR differences for the v2.7 (right) compared to that of the v2.2-1 (left).

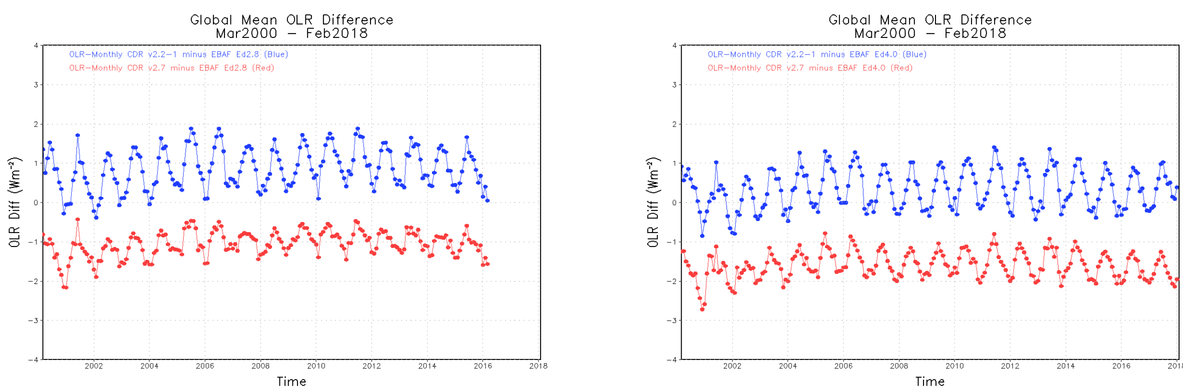


Fig. 18 Time series of the global mean monthly OLR differences between the OLR CDR products (blue: Monthly OLR CDR v02r02-1; red: v02r07) and the EBAF Ed2.8 [left] and the EBAF Ed4.0 [right]. Although there is still consistent disagreement in the annual cycles, the v02r07 did improve the agreement in annual cycle with respect to EBAF. Note that the EBAF Ed4.0 OLR is about 0.5 $Wm^{-2}$ higher than the Ed2.8 (cf. Table 2).

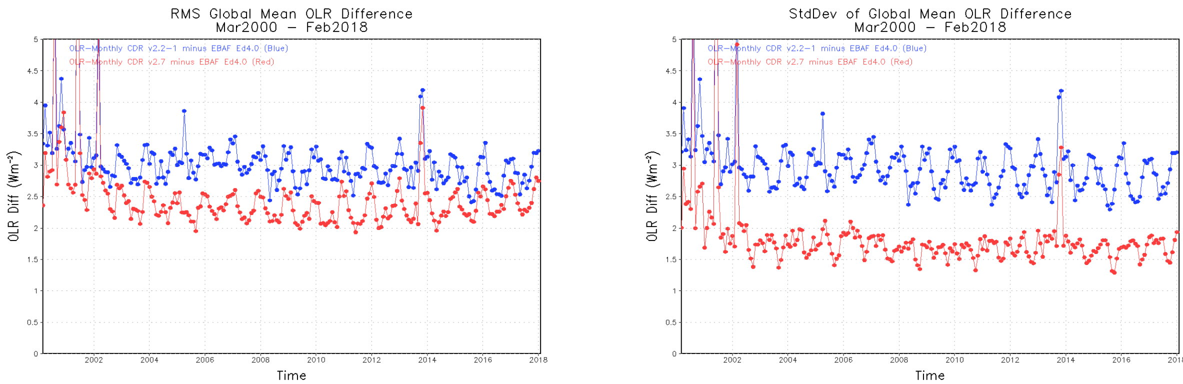


Fig. 19 Time series of the [left] rms and [right] standard deviation of the global mean monthly OLR differences between the OLR CDR products and the EBAF 4.0. [blue: Monthly OLR CDR v02r02-1; red: v02r07] The v02r07 significantly improves the agreement the spatial variation with respect to the EBAF v4.0 monthly OLR maps compared to that of the v02r02-1. The standard deviations of the OLR differences between the Monthly OLR CDR v02r07 and EBAF Ed4.0 [right panel, red curve] indicates significant improvement with an overall lower values and removal of annual cycle dependency. The spikes in the standard deviation plot are related to the incomplete sampling (missing days) in the CERES observations for monthly mean derivation. The relatively larger rms and standard deviation between 2000.03 and 2002.06 are due to the increase uncertainty in CERES SYN product when CERES observations are only available from Terra. The introduction of the Aqua reduced the daily integral uncertainties in CERES SYN and EBAF products.

## 7.2 Daily OLR CDR v01r02

The release of the Final Daily OLR CDR v01r02 for year 2017 is delayed, due to problems in updating the GridSat CDR product.

The precision and accuracy of the Daily OLR CDR product are determined by the comparisons to monthly-integrated Daily OLR CDR with the reference EBAF Ed4.0 OLR products on the 1°x1° resolution.

The global mean OLR differences over the period March 2000 to Feb 2018 between the Daily OLR CDR v01r02 and EBAF Ed4.0 is about **-2.3 Wm$^{-2}$**, with the overall standard deviations is about **1.5 Wm$^{-2}$** and rms differences of about **2.8 Wm$^{-2}$**. (See Fig. 20) Note that the CERES OLR product has an uncertainty of about 1.5%. Fig. 21 shows the spatial distribution of the mean and standard deviations of the OLR differences.

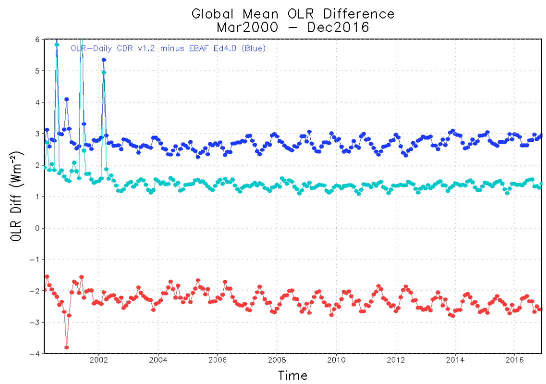


Fig. 20 Time series of the global mean monthly OLR differences [red], the standard deviations of the differences [cyan], and the rms differences [blue] between the monthly-integrated v01r02 Daily OLR CDR and the EBAF 4.0. The overall average for the mean, std, and rms differences are about -2.3, 1.5, and 2.8 $Wm^{-2}$, respectively.

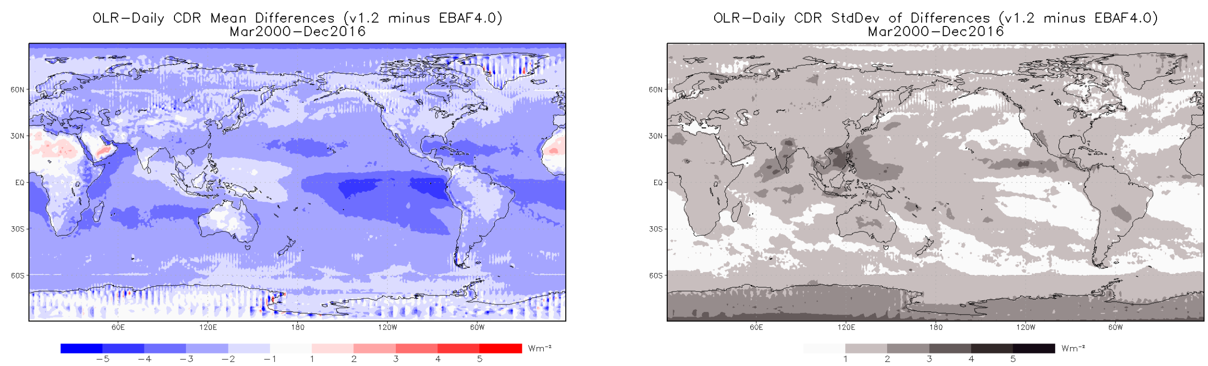


Fig. 21 Spatial distribution of the mean [left] and the standard deviation of differences [right] of Daily OLR CDR v01r02 relative to EBAF Ed4.0 for the period March 2000 to Feb 2018.

The comparisons of the monthly OLR anomalies between the Daily OLR CDR and the CERES EBAF OLR product over the global and tropical domains are shown in Figs. 22 and 23, with respect to the climatology base March 2002 – Feb 2016.

The OLR anomaly variability of the two products tracks each other in excellent synchronization and superb agreement in magnitude. The slope of the OLR anomalies differences for the **global** is **-0.18±0.05 $Wm^{-2}$/decade** and the slope for the tropical domain is **-0.05±0.05 $Wm^{-2}$/decade**, at 2-sigma level. This satisfies the stability requirement for climate quality data: ±0.3 $Wm^{-2}$/decade.

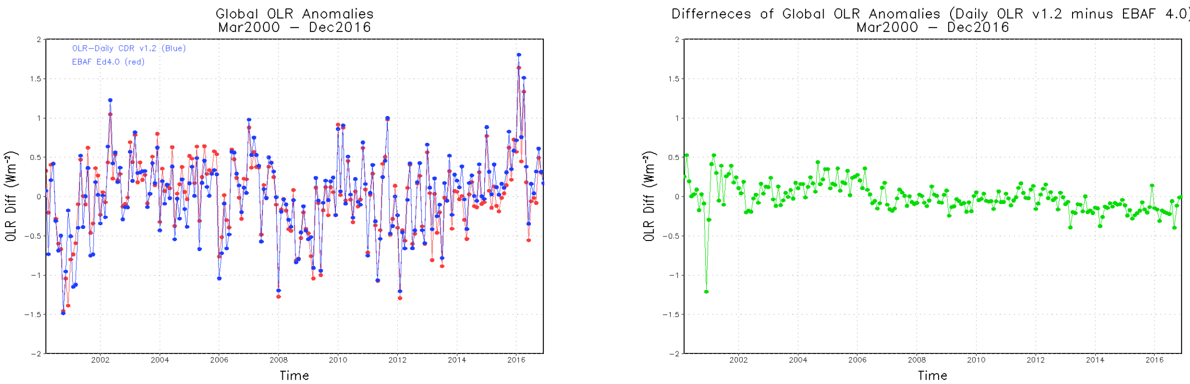


Fig. 22 Spatial distribution of the mean [left] and the standard deviation of differences [right] of Daily OLR CDR v01r02 relative to EBAF Ed4.0 for the period March 2000 to Feb 2018.

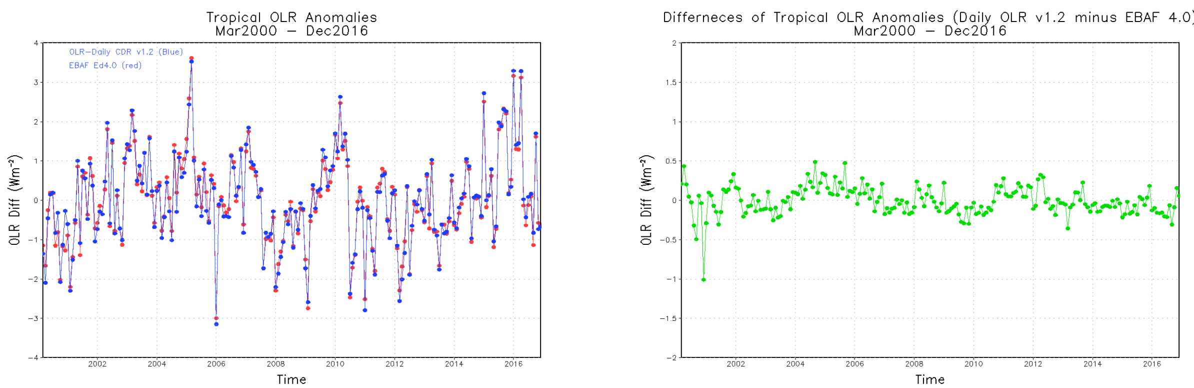


Fig. 23 Similarly but is for the tropical domain [20S,20N].

# 8. References

References for CERES Data Sets

Loeb, Norman G., et al. (2009): Toward Optimal Closure of the Earth's Top-of-Atmosphere Radiation Budget. *J. Climate.,* **22**(3), 748-766. http://dx.doi.org/10.1175/2008JCLI2637.1 (for EBAF-TOA products)

Doelling, David R., et al. (2013): Geostationary Enhanced Temporal Interpolation for CERES Flux Products. *J. Atmos. Ocean. Tech.*, **30**(6), 1072-1090. http://dx.doi.org/10.1175/JTECH-D-12-00136.1 (for SYN1deg products)

Doelling, David R., et al. (2016): Advances in Geostationary-Derived Longwave Fluxes for the CERES Synoptic (SYN1deg) Product. *J. Atmos. Ocean. Tech.*, **33**(3), 503-521. http://dx.doi.org/10.1175/JTECH-D-15-0147.1 (for SYN1deg products)

Loeb, Norman G., et al. (2016): CERES Top-of-Atmosphere Earth Radiation Budget Climate Data Record: Accounting for in-Orbit Changes in Instrument Calibration. *Remote Sensing*, **8**(3), 182. http://dx.doi.org/10.3390/rs8030182 (Instrument Calibration for SSF products)

Su, W.; Corbett, J.; Eitzen, Z.; Liang, L. (2015): Next-generation angular distribution models for top-of-atmosphere radiative flux calculation from CERES instruments: validation. *Atmos. Meas. Tech.,* **8**(8), 3297-3313. http://dx.doi.org/10.5194/amt-8-3297-2015 (Angular Direction Model for SSF products)

Su, W.; Corbett, J.; Eitzen, Z.; Liang, L. (2015): Next-generation angular distribution models for top-of-atmosphere radiative flux calculation from CERES instruments: methodology. *Atmos. Meas. Tech.,* **8**(2), 611-632. http://dx.doi.org/10.5194/amt-8-611-2015 (Angular Direction Model for SSF products)

Young, D. F.; Minnis, P.; Doelling, D. R.; Gibson, G. G.; Wong, T. (1998): Temporal Interpolation Methods for the Clouds and the Earth's Radiant Energy System (CERES) Experiment. *J. Appl. Meteorol.,* **37**(6), 572-590. http://dx.doi.org/10.1175/1520-0450(1998)037<0572:TIMFTC>2.0.CO;2 (SSF1deg products)