Gridded Satellite B1 FCDR - Monthly Means

1. Intent of this Document and POC

1a. Intent

This document is intended for users who wish to compare satellite derived observations with climate model output in the context of the CMIP/IPCC historical experiments. Users are not expected to be experts in satellite derived Earth system observational data. This document summarizes essential information needed for comparing this dataset to climate model output. References are provided at the end of this document to additional information.

Dataset File Name (as it appears on the ESGF):

TBD

1b. Technical Point of Contact for this dataset

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2. Data Field Description

CF variable name, units	**TBD**
Spatial resolution	1/4° (~25 km) rectangular grid
Temporal resolution	Averaged monthly, Jan. 1980 - Mar. 2016
Coverage	70° N to 70° S and 180° W to 180° E

3. Data Origin

The "Gridded Satellite (GridSat) B1 Fundamental Climate Data Record (FCDR) Monthly Means" are monthly averaged infrared window brightness temperatures. The GridSat-B1 data derive from their source ISCCP (International Satellite Cloud Climatology Project) B1 data. Thus to understand GridSat-B1, one must have a general understanding of ISCCP B1 data.

3.1 ISCCP B1 data

ISCCP B1[1] data derive from full resolution geostationary meteorological satellite data that has been subsampled to 10 km and 3-hr. The data primarily consist of visible (~0.6 um) and infrared window (~11 um) observations. However, the ISCCP B1 data does include information from other instrument channels, which are available from newer satellites.

The geostationary meteorological satellites available to ISCCP are displayed in Figure 1. In general, there are 5 traditional geostationary positions, but with some variation due to

[1] In ISCCP documents, "A" data referred to full resolution data. Hence, "B1" data was the first subsampling of the A data. So B1 has no meaning beyond that it is subsampled from full resolution.

failures, new launches, etc. These are: GOES West, GOES East, Europe/Africa, Indian Ocean, and Japan/Australia. The United States operates satellites at two positions: GOES (Geostationary Operational Environmental Satellite) West (135 deg West) and GOES East (75 deg West). In times of satellite failure, though, they have used a central location near 105 deg West. The Meteosat (MET) satellite has historically provided observations at the Europe/Africa position of 0 deg East. In 1998, the MET-5 satellite was moved to the Indian Ocean coverage location to provide the international community a geostationary satellite for this gap. The Japanese have historically operated a meteorological satellite at 140 deg East. Two geostationary positions have been provided for limited times. This includes the South America position (60 deg W) where Brazil operated the two retired GOES satellites. The Chinese also provided B1 data for two of their geostationary satellites for a limited time as well. These are available through ISCCP B1, but were not incorporated into GridSat given their limited period of record.

The ISCCP B1 IR window data were inter-calibrated in order to make the record homogeneous through time and space. See §4 for more details.

The values represent satellite observations for an instrument directly above the location. So while the observations have been corrected for directional effects, no other atmospheric corrections were made. That is, they represent top of the atmosphere observations and not a surface skin temperature, etc.

ISCCP B1 data are are subsampled from geostationary satellites. The source geostationary data are approximately three hourly. The satellite observations are from observations that satisfy two conditions: 1) the scans observe the entire full disk of the Earth and 2) they occur near the 3 hourly time slots of 00, 03, 06, ..., 21 UTC. Therefore, the data are considered a global snapshot of the environment at a given time (i.e., there is no temporal averaging). In short, the geostationary data are subsampled in time to roughly 3 hour intervals.

The data are spatially subsampled as well. While most geostationary instruments have historically made observations as high as 1 km visible data and 4 km IR data, the GridSat source data was subsampled to provide an inter-consistent spatial characteristic. The data are subsampled to roughly 8-10 km. For most satellites, this means taking every other IR pixel. Hence, native data at 4km resolution is sampled to 8 (e.g., from GOES and GMS) while data from 5 km imagers are sampled to approximately 10 km. These resolutions represent the optimal resolution at the equator (directly below the satellite). The spatial footprint increases with distance away from the subsatellite point.

The ISCCP B1 data derive from more than 30 satellites and are provided to NOAA in dozens of formats. The data need to be mapped, in order to assign observations to a given location. Furthermore, the observations need to be calibrated (i.e., converted from satellite units to radiance or brightness temperatures). While this is not too complex to describe for one satellite data and format, it is nearly impossible to document for the satellites, formats and satellite projections provided to ISCCP.

3.2 GridSat-B1 infrared window brightness temperature data

The primary benefit of GridSat is that it provides calibrated, mapped and quality controlled data to users. Rather than providing data in the native satellite projection, the data are mapped to an equal angle grid. The data are also provided in brightness temperature (Kelvin) rather than the instrument values from each of the satellite providers.

GridSat B1 data are sub-sampled to an 0.07 degree equal angle grid. This approximates the ISCCP B1 resolution of 8-10 km (at the Equator). The value at each cell represents the ISCCP B1 satellite pixel closest to that location. This produces 5143 pixels in the east west direction. The coverage is 70 deg N to 70 deg S, stopping short of the poles since Geostationary satellites can not see the Earth much past 70 deg, providing 2000 pixels in the North/South direction.

3.3 GridSat-B1 monthly means

The monthly mean GridSat B1 files provide monthly values at a quarter degree resolution. The following process summarizes the steps:

1. Calculate spatial average of each GridSat file, averaging all GridSat cells within a given grid box.
2. Calculate temporal average for each time of day, producing 8 monthly grids representing the mean temperature at 00, 03, 06, …, 21 UTC for a given month.
3. Calculate the monthly average as the mean of the 8 grids from step 2.

This calculates the mean diurnal cycle and then averages over the diurnal cycle. In so doing, a missing image does not bias the result.

4. Validation and Uncertainty Estimate

The infrared window data provided in GridSat has undergone 3 sets of calibration, which are summarized below.

4.1 On board calibration

Each of the instruments providing infrared window observations has an on-board calibration system. The radiometer views two targets that help to convert instrument count values into radiance or temperature values. The instruments are designed to view space and a warm blackbody emitter that is set at a constant temperature. These two calibration targets provide observations of known temperatures that can then be used to convert instrument observations to geophysical units. The relative accuracy of these units has improved over the years, but noise estimates are less than 2K.

4.2 ISCCP inter-calibration

The ISCCP system relies on using observations from several geostationary and polar-orbiting satellites to observe clouds. This requires an inter calibration. Thus, the ISCCP calibration approach was to take the nominal calibration provided by the satellite operator (described in §4.1) and derive a normal calibration that normalizes all instrument temperatures to the afternoon polar orbiter instrument. Lastly, the ISCCP calibration proves an absolute calibration where the normalized calibration values are made consistent through time. So to summarize, the nominal calibration is that provided to ISCCP from the satellite operator, the normal calibration is that which makes the observations spatially uniform and the absolute calibration ensure consistency through time. The result is very important for the GridSat data.

The ISCCP absolute calibration was applied to the ISCCP B1 values to derive temporally and spatially consistent radiance dataset.

4.3 HIRS inter-calibration

The HIRS instrument was used to check for temporal or spatial biases in the calibration of the ISCCP calibration (see Knapp, 2008). That investigation found a previously missed ISCCP calibration error that resulted in a bias for colder temperatures. This correction is applied to GridSat data (Figure 2).

When GridSat was developed, the ISCCP calibration ended in 2009. Thus, a similar approach was developed to normalize ISCCP B1 observations to HIRS data in order to inter calibrate the GridSat data. This approach (Knapp, 2012) was used for infrared window observations from 2010 forward.

5. Considerations for Model-Observation Comparisons

When comparing GridSat monthly values to other observations, the following issues should be considered. The issues are listed in order of likely impact on comparisons.

5.1 View zenith correction

The most significant impact on monthly comparisons is the satellite view zenith effect. Tropospheric water vapor absorption causes the observed temperatures to be less than the surface skin temperature. The amount of absorption (and reemission) increases as the path length through the atmosphere increases. Thus, at larger view zenith angles, the effect significantly decreases the temperature observed by the satellite. This effect is called limb brightening (so called because colder temperatures are generally portrayed as brighter values in most satellite imagery). Joyce et al (2000) developed a technique to reduce this effect on geostationary data, effectively normalizing observation to a nadir-like brightness temperature. This approach was used in GridSat to reduce the impact of atmospheric brightening on brightness temperatures.

However, the adjustment was empirically derived for satellites in orbit at the time. It is likely that the adjustment has bias errors when applied to satellites with very different spectral responses. Thus, there may be a bias error as a function of the satellite view zenith angle.

5.2 Gaps in coverage

Another issue is changes in the geostationary satellite coverage. Significant gaps include:

- The gap caused by the failure of GOES 5. The solution was to move GOES-6 to a location that covers more of the U.S. and leave it there until a replacement satellite was launched and available: GOES-7
- The gap caused by the failure of GOES 6. Similar to the failure of GOES-5, the GOES-6 failure caused shifting of satellites. Additionally, the Europeans shared a satellite, by shifting Meteosat 3 to an Atlantic Ocean Data Coverage (at 50 degrees West) and later an extended ocean data coverage (XADC) at 75 degrees west.
- The Indian Ocean gap. There was no geostationary data available to the international weather community until the Europeans moved Meteosat 5 to the Indian Ocean Data Coverage for a field experiment, in 1998. The international community convinced them

to leave the satellite at that position. However, prior to 1998, the region has very large view zenith angles.

The impact of these changes on the long-term monthly GridSat temperatures causes long-term changes in view zenith angles. Thus, the mean view zenith angle over the U.S. changes and this will produce slight bias changes when comparing observations between times with different view zenith angles.

5.3 Differences in instrument spectral response functions

The instruments on the various geostationary satellites have different spectral response functions (figure 3). Some of this has been minimized by normalizing the data using HIRS infrared window channel (see next issue). However, some of the differences can't be corrected when normalizing. Once such instance is that the instruments have varying levels of water vapor absorption. This is manifested as bias differences as a function of satellite zenith angle. The view zenith angle correction described above was developed for geostationary satellites operating in 2000 (GOES-8,10, MET 5, 7 and GMS 5). Other instruments will have different water vapor absorption amounts. This leads to different view zenith angle dependencies that should be applied, but aren't available at present. Thus, the impact of the varying instrument response is some bias in temperature as a function of view zenith angle.

5.4 Normalization of all instruments to a HIRS channel 8 (IR window) spectral response.

The data are intercalibrated using the HIRS channel 8 in order to assure that the satellite record is consistent through time and between satellites. A correction is applied to each satellite to bring them to a uniform calibrator: channel 8.

6. Instrument Overview

The instruments that make up the GridSat B1 data are part of the historical constellation of geostationary weather satellites, which have been operated by various countries since the 1970s.

The United States NOAA maintains the Geostationary Operational Environmental Satellite (GOES) series. NOAA maintains observations of the Earth at two primary positions: GOES-East at 75 degrees West and GOES-West at 135 degrees West. The first 7 in the series (GOES-1 through 7) are spin-stabilized satellites. These older satellites had a VISSR (Visible Infrared Spin Scan Radiometer) instrument that had an Infrared and visible channel. However, later VISSRs also provide observations at a other wavelengths (notably, the water vapor channel). Data from these satellites are included in GridSat from 1980 through 1995 (when the GOES-7 service ended). The channels generally had a bit depth of 6 to 8 bits. Full disk scans were made at half hour intervals. A newer series (GOES 8-15) was first launched in 1994 with a new instrument - GOES-Imager - for weather observations (the GOES sounder is not used for ISCCP or GridSat). The GOES Imager provided 5 channels (Visible, Near Infrared Window, Water Vapor, IR Window and IR Split Window, though later series changed the IR Split Window to a longer wavelength CO_2 channel). The newer satellite is three-axis stabilized which allows rapid scanning. A complex scan schedule was created to allow more frequent observations of the United States. However, the 3-hourly full disks were maintained. The Imager has better navigation, higher bit depth (10-bits), and linear visible response (previous GOES had quadratic visible response). The first of the GOES-R series was launched in November 2016. GOES-R (now GOES-16) will be included in GridSat when it operationally replaces either GOES-13 or 15.

The Japanese Meteorological Agency (JMA) maintains the Himawari satellite series at 140 degrees East (though some slight deviations from this occur for newer satellites). The first group of these are the GMS (Geostationary Meteorological Satellites). The GMS 1 through 4 satellites used a VISSR instrument that was similar to the early GOES satellites - spin stabilized, half-hourly full disk coverage, etc. The GMS-5 satellite is a spin-stabilized instrument, but the VISSR was upgraded to a 5-channel suite similar to the GOES-Imager wavelengths. The MTSAT (Multifunction Transport Satellite) 1R and 2 are also included in GridSat. These satellites are very similar to the GOES-8 through 15 satellites, using an Imager-like instrument and a 3-axis stabilized satellite platform. The latest Japanese satellite (Himawari-8) is has been included in GridSat since the July of 2015. This new satellite has 16 channels (though only 3 are included in GridSat data) with higher bit depth, more accurate navigation and visible calibration.

The MeteoSat series (Meteorological Satellite) provides observations at the Prime Meridian (and later, the Indian Ocean). The series was started by the European Space Agency and is now administered by EUMETSAT. The initial series (Meteosat 2-7) was a spin-stabilized satellite providing 3 channels of observations: visible, infrared window and water vapor channel. This is the only series in GridSat to regularly provide water vapor channels in the 1980s. The Meteosat 8 and 9 are newer satellites (Meteosat Second Generation), providing improved instrumentation (12 channels, expanded bit depth, etc.) on a spin-stabilized satellite.

Thus, the GridSat data provide information from nearly 30 satellites originating from 3 countries, provided by numerous agencies in dozens of formats. The GridSat data vastly simplifies data access by providing observations in a more modern format, navigating imagery to a fixed grid and unifying the calibration. Thus GridSat represents a long-term, stable and easy to use set of observations.

7. References

Primary Reference

Knapp, K. R., S. Ansari, C. L. Bain, M. A. Bourassa, M. J. Dickinson, C. Funk, C. N. Helms, C. C. Hennon, C. D. Holmes, G. J. Huffman, J. P. Kossin, H.-T. Lee, A. Loew, and G. Magnusdottir, 2011: Globally gridded satellite (GridSat) observations for climate studies. *Bulletin of the American Meteorological Society*, **92**, 893-907. **doi:10.1175/2011BAMS3039.1**

Other relevant references

ISCCP Paper describing the ISCCP calibration method used for 1983-2009:

Brest, C.L., W.B. Rossow, and M.D. Roiter, 1997: Update of radiance calibrations for ISCCP. *Journal of Atmospheric and Oceanic Technology*, **14**, 1091-1109, doi:10.1175/1520-0426(1997)014<1091:UORCFI>2.0.CO;2.

Paper describing the IR calibration method used for 1980-2009:

Knapp, K. R., 2008: Calibration of long-term geostationary infrared observations using HIRS. *Journal of Atmospheric and Oceanic Technology*, **25**, 183-195.

Paper describing the IR calibration method used for 2010-present:

Knapp, K. R., 2012: Inter-satellite bias of the high resolution infrared radiation sounder water vapor channel determined using ISCCP B1 data. *Journal of Applied Remote Sensing*, **6**, 063523.

Paper describing the algorithm used to correct IR window observations for view angle effects:

Joyce, R., J. Janowiak, and G. Huffman, 2001: Latitudinally and Seasonally Dependent Zenith-Angle Corrections for Geostationary Satellite IR Brightness Temperatures. *Journal of Applied Meteorology*, **40**, 689-703.

Paper describing ISCCP B1 data:

Knapp, K. R., 2008: Scientific data stewardship of International Satellite Cloud Climatology Project B1 global geostationary observations. *Journal of Applied Remote Sensing*, **2**, 023548

GridSat website:

http://www.ncdc.noaa.gov/gridsat/

8. Dataset and Document Revision History

Rev 0 - December 2016

This is a new document/dataset based on the NOAA GridSat-B1 v02r01 FCDR.

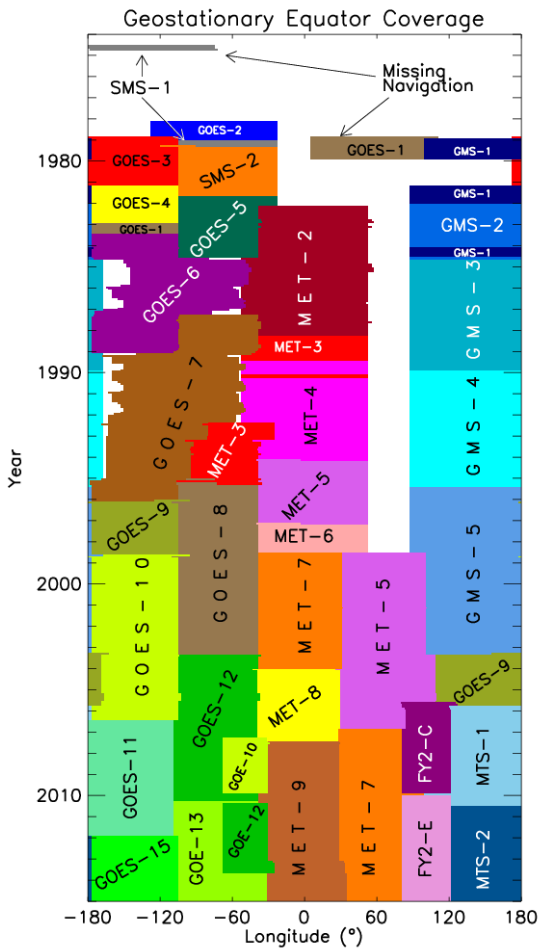

Figure 1 - Geostationary Quilt - the position of geostationary satellites making up the ISCCP B1 record. The positions through time are optimal coverages based on monthly mean positions.

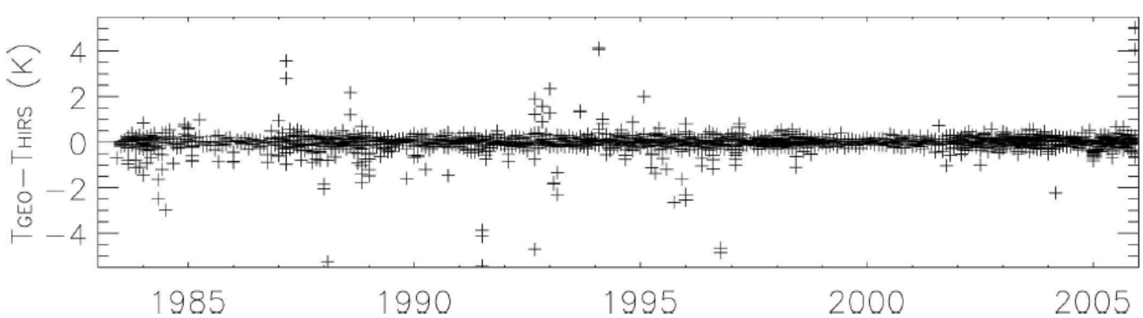

Figure 2 - Time series of monthly mean differences between HIRS and ISCCP B1, from all geostationary satellites available from 1983-2006.

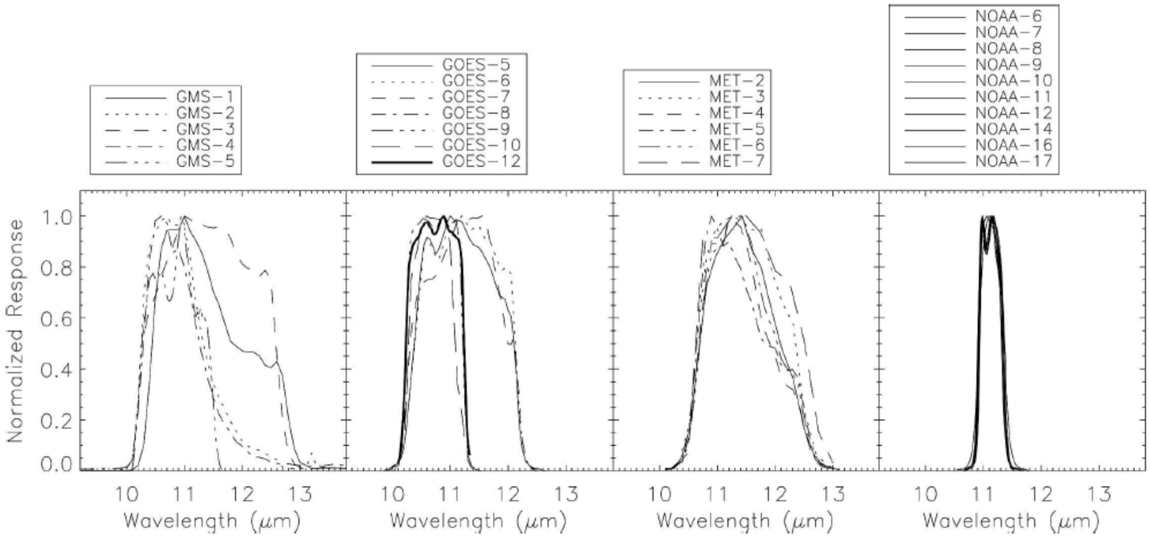

Figure 3 - Spectral response functions of the IR window channels on the various geostationary weather satellites used in GridSat along with the HIRS channels (to which the geostationary satellites are calibrated).