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Surface Cloud Grid Version 2 (SFCCLDGRID2) Value- Added Product: Description of Updates to Algorithm Operational Details in Version 2

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Acknowledgments

This data product is based on an earlier version of the surface cloud grid product led by Charles (Chuck) N. Long. Chuck passed away before the completion of this project but was involved in much of the development of this updated version. The authors and the ARM user facility are indebted to Chuck's dedicated work to ensure high-quality broadband radiation measurements and innovative uses of those measurements throughout his career. He will be deeply missed.

Acronyms and Abbreviations

ADI	ARM Data Integrator
ARM	Atmospheric Radiation Measurement
BRS	broadband radiometer station
CF	Central Facility
IR	infrared
IRT	infrared thermometer
LASSO	Large-Eddy Simulation ARM Symbiotic Simulation and Observation
LES	large-eddy simulation
LW	longwave
MET	surface meteorology measurements
netCDF	Network Common Data Form
QA	quality assurance
QC	quality control
QCRAD	Data Quality Assessment for ARM Radiation Data VAP
RADFLUXANAL	Radiative Flux Analysis VAP
SFCCLDGRID	Surface Cloud Grid VAP
SGP	Southern Great Plains
SIRS	solar and infrared radiation station
SW	shortwave
SWFLUXANAL	Shortwave Flux Analysis VAP
UTC	Coordinated Universal Time
VAP	value-added product
VISST	Visible Infrared Solar-Infrared Split Window Technique

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1.0 Introduction

Clouds affect the amount of radiative energy reaching the surface of the earth by decreasing the downwelling shortwave (SW) irradiance and increasing the downwelling longwave (LW) irradiance compared to cloudless conditions. Cloud and radiation measurements from the Central Facility alone are not always comparable to model grid boxes because of local variability in surface and cloud properties. The ARM SGP network has been deployed to address these variability issues with surface-based observations from a network of sites surrounding the Central Facility (CF). The Surface Cloud Grid VAP gives gridded values of cloud and radiation properties over the SGP domain so that comparisons can more accurately be made between model/satellite grid boxes and ground-based observations, as well as an estimate of the regional variability.

This document describes upgrades made to the algorithm used for version 2 of the Surface Cloud Grid Value-Added Product (VAP). The first version of the Surface Cloud Grid VAP (SfcCldGrid1Long; Christy and Long 2005) was developed to use the outputs of the Shortwave (SW) Flux Analysis VAP (SWFLUXANAL; see Long 200, Long and Ackerman 2000, Long et al. 1999) from the Atmospheric Radiation Measurement (ARM) user facility Southern Great Plains (SGP) CF and extended facilities. The original network of 21 sites was unevenly spaced over northern Oklahoma into southern Kansas, covering an area from 95.5° to 99.5° west longitude and 34.5° to 38.5° north latitude, or a 300 km domain. This VAP was paused in November of 2009 when the SGP network of extended facilities was reconfigured to cover a smaller domain. An updated version of the VAP, SfcCldGrid2, designed to run on the reconfigured, smaller domain was developed. This updated version uses the Radiative Flux Analysis (RADFLUXANAL) VAP, an improvement to the SWFLUXANAL VAP that includes longwave irradiance variables and additional data quality checks, as input data is now processed through the Data Quality Assessment for ARM Radiation Data (QCRAD) VAP.

Because an estimate of the distribution of cloud and cloud effects over this entire domain is desirable, both versions of the Surface Cloud Grid VAP apply a multi-pass, weighted sum, analytic approximation technique (Caracena 1987), which uses Gaussian weighting and an imposed scale length, to interpolate to a 0.25° by 0.25° latitude/longitude grid over the SGP domain. The output is provided when solar elevation angles are 10° or greater.

2.0 Input Data

The input data for this VAP are standard ARM netCDF files created from the RADFLUXANAL VAP (Riihimaki et al. 2019). RADFLUXANAL estimates clear-sky broadband radiation values and derived parameters (Long and Ackerman 2000, Long et al. 2006, Barnard and Long 2004, Long and Turner 2008) using broadband radiation measurements from solar and infrared radiation station (SIRS) and surface meteorology measurements (MET) run through the QCRAD VAP (Long and Shi 2006, 2008) for data quality checks and improved best-estimate downwelling shortwave (SW) values.

Data are taken from all active SGP extended facility sites that have data available. The network of extended facilities changed at several points in the measurement history. Around 2011, the extended facilities were moved to fill a 1-degree grid box rather than a 2-degree grid box, reflecting the higher resolution of global climate models. Additional sites were also added around 2015 in support of ARM decadal vision activities to create a mega site at SGP that would drive routine large-eddy simulation (LES) modeling, such as LES ARM Symbiotic Simulation and Observation (LASSO). Table 1 gives a list of when all SGP extended facilities with SIRS radiation data measurements were started and ended. Figure 1 shows the locations of the sites that were active in March of 2020 when this technical report was written.

Table 1. List of SGP extended facilities and their start and end dates. End dates listed as present indicate that they were active in March of 2020. E13* is located at the SGP CF and is considered the primary SGP measurement station. C1 has been used for testing new instrumentation or procedures at different points during the history of measurements at SGP.

Facility Code	Start Date	End Date
C1	3/21/97	Present
E1	1/15/95	10/14/09
E2	3/7/96	10/20/09
E5	6/14/96	11/2/09
E6	3/5/96	10/18/11
E7	5/18/95	11/14/11
E8	9/22/95	11/10/09
E9	1/12/94	Present
E10	7/21/95	10/19/11
E11	6/30/95	Present
E12	1/19/96	Present
E13*	1/7/94	Present
E15	1/12/94	Present
E16	6/2/95	11/15/11
E18	6/20/96	11/17/09
E19	7/8/98	5/23/11
E20	11/3/94	11/17/11
E21	9/11/99	5/1/19
E22	3/16/95	12/1/09
E24	11/7/95	11/14/09
E25	11/12/97	4/3/02
E27	3/15/03	12/4/09
E31	10/13/11	Present
E32	2/4/12	Present
E33	8/17/11	Present
E34	9/2/11	Present

Facility Code	Start Date	End Date
E35	10/5/11	Present
E36	9/28/11	Present
E37	9/28/11	Present
E38	8/23/11	Present
E39	8/23/15	Present
E40	10/7/15	Present
E41	4/13/16	Present

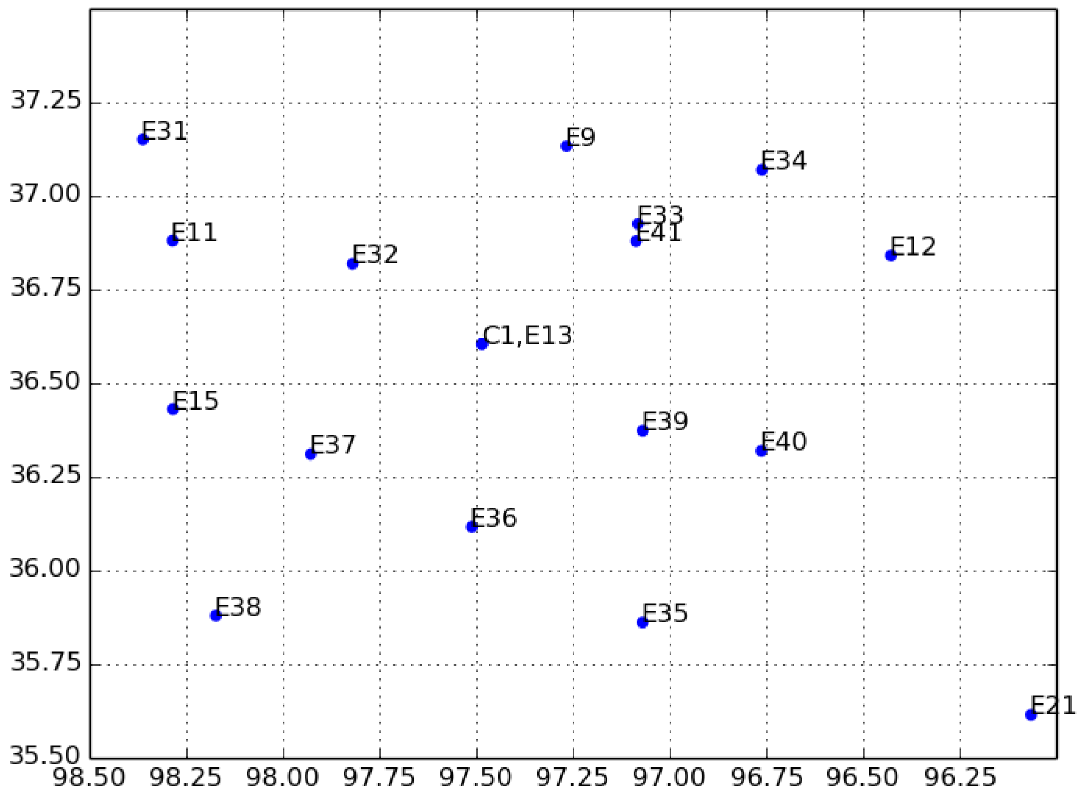

Figure 1. Locations of currently active SGP facilities (as of March 2020). Facilities are plotted by latitude and longitude on the 0.25-degree grid box that measurements are interpolated to in the VAP.

The SFCCLDGRID algorithm uses a technique to calculate the value used for the gridded data product at the CF from the three possible stations at that location (i.e., facilities C1, E13, and the broadband radiometer station [BRS] data) are available. If all three stations report, we take the average of the closest two values. If only two stations report, we use the average. Otherwise, use the only station that reports a value. The input data is averaged to 15-minute time resolution before gridding.

3.0 Output Data

The Surface Cloud Grid VAP produces both a station data product and gridded output for the parameters listed in Table 1.

Table 2. Gridded variables output by Surface Cloud Grid VAP.

Variable Name	Description and Notes
downwelling_shortwave	Measured variable that comes from a best-estimate value in QCRAD that uses the sum of diffuse and direct normal when available and IR loss-corrected total irradiance when not available.
Clearsky_downwelling_shortwave	Estimated variable
Downwelling_longwave	Measured variable
Clearsky_downwelling_longwave	Estimated variable
Upwelling_shortwave	Measured variable
Clearsky_downwelling_shortwave	Estimated variable
Upwelling_longwave	Measured variable
Clearsky_upwelling_longwave	This variable is only recorded during periods that are deemed to be clear; no estimate is given during cloudy periods in this version of RADFLUXANAL.
Diffuse_downwelling_shortwave	Measured variable
Clearsky_diffuse_downwelling_shortwave	Estimated variable
Direct_downwelling_shortwave	Measured variable
Clearsky_direct_downwelling_shortwave	Estimated variable
Cloudfraction_longwave	This variable should be used with significant caution as the LW cloud fraction estimate is considered preliminary.
Cloudfraction_shortwave	This is one of the key estimated variables by RADFLUXANAL and its value is considered of primary interest to this VAP. While interpolating cloud fraction spatially will not necessarily be correct for short periods, this variable is likely of most value in statistical averages and comparisons with other gridded output like satellite data and model output.
Cloud_transmissivity_shortwave	This variable is of high interest and may be more comparable between sites than the measured and estimated clear-sky SW variables individually.

Variable Name	Description and Notes
Visible_cloud_optical_depth	This variable will only be available for overcast conditions so will have many missing periods.
Cloud_radiating_temperature	This is a basic estimated variable from the LW measurements that is likely roughly equivalent to an infrared thermometer (IRT) measurement.

These output variables were chosen because the intent is to use the Surface Cloud Grid VAP output for model comparisons, as well as climatological and statistical research. As is shown in Long and Ackerman (2000), using the ratio of measured over clear-sky fit SW irradiance effectively removes instrument characteristics such as cosine response errors and calibration drifts, thus cloud_transmissivity_shortwave is a variable that may be used with high confidence. This same ratio can be produced with a model, (i.e., the ratio of cloudy model calculations over cloudless model calculations) thus eliminating model-measurement discrepancies in the comparison. The cloudfraction_shortwave variable is also of significant interest given the ability of the data to provide statistical estimates of the spatial variability of cloud occurrence. Comparisons with the Surface Cloud Grid VAP output allow one to effectively separate the problem into the following three components:

- Do the model and measurements agree (the clear-sky case is the "easiest")?
- Do the model and measured cloud amounts agree (i.e., are the model cloud predictions right)?
- If the model can generate the proper amount of clouds in the correct places, then does the model produce the right cloud properties and treat the clouds correctly (i.e., do the cloudy/clear ratios agree)?

4.0 Algorithm

The SFCCLDGRID2 VAP first creates station files that combine radiative flux analysis from all SGP extended facility stations into a single file with a 15-minute-average temporal resolution using the ARM Data Integrator (ADI) framework (Shippert and Gaustad 2017). These files are named sgpsfccldgrid2longstationC1.c1.yyyymmdd.hhmmss.nc and can be a convenient format for comparing data from multiple sites.

These station data are then gridded into a 2-dimensional 0.25-degree latitude-and-longitude grid over the SGP domain using an objective Gaussian interpolation scheme (Caracena 1987). A length scale of 100 km is used for the interpolation. The gridding routine has been implemented in the ADI framework, using a Gaussian length scale of 100 km and applying 16 passes. At least 13 different locations must be present for a successful run of the VAP. Keep in mind that three instruments are collocated at the CF, but only one value will be used.

5.0 Data QC Tests and QC Flags

The data used in the Surface Cloud Grid VAP underwent various quality control (QC) assessments in the QCRAD VAP (see Long and Shi 2006, 2008). Additionally, the SFCCLDGRID VAP applies additional quality assurance (QA) including maximum and minimum limits. For example, cloud fraction values must be between 0 and 1.1. Additionally, we set SW variables (cloud fraction SW, transmissivity, direct, diffuse, shortwave down, and shortwave up) to missing if the sun angle is low (cosz > 80), in both the station product and the gridded product.

Additional tests assure that the impact of missing data on the edges of the domain are labeled as possibly bad or suspect interpolation. Data along edges of the grid for which facilities do not exist or the facilities exist but the data is bad or missing are marked as suspect. This 'edge qc' is applied to each of the four quadrants of the grid independently. For each quadrant, each of the outer two edges of the quadrant are assessed for suspect data by working from the outermost edge inward until the first facility with good data along the edge is encountered. All cells along the edge up to the facility are noted as suspect. This procedure is repeated for a second edge of the quadrant. Using this approach, the lower row of cells in the bottom-left quadrant and the right column of cells in the upper-right quadrant are always suspect as noted by the shaded sections in Figure 3. In Figure 2 the lower-right grid analysis first identifies E40 as the first facility with good data working from the lower-outer edge of the quadrant, coloring the bottom three rows as suspect. It then works from the outer-right edge inward, again identifying E40 as the first facility with good data, and again shading the outer three columns of the lower-right grid.

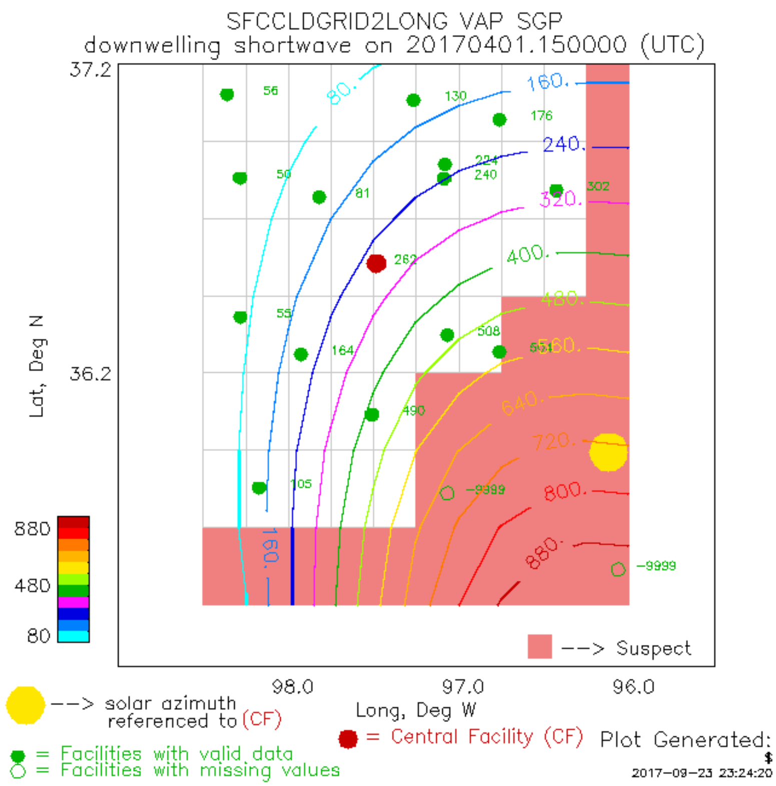

Figure 2. Example of southeast quadrant labeled as suspect due to missing data at the edge of the domain.

6.0 Results

The plots below are sample quick-look images for each of the scientific quantities generated during the SFCCLDGRID2LONG VAP for April 3, 2017, at 1630 Coordinated Universal Time (UTC). In the following figures, a "red" filled circle represents the CF. An open "green" circle indicates that the particular facility did not report any data for that particular time sample. A filled "green" circle indicates the facility was present for the time sample and reported data. In Figures 1 and 2, the shaded "cyan" areas represent where the cloud fraction was 0.0, while the shaded "gray" areas represent overcast conditions. The filled "yellow" circles indicate the solar azimuth referenced to the CF. The "red" filled rectangles indicate regions of the grid that are suspect due to insufficient measurement sites to constrain the interpolation fit. These edge areas are based on extrapolation from sites to the interior and should not be used or else should be used with significant caution.

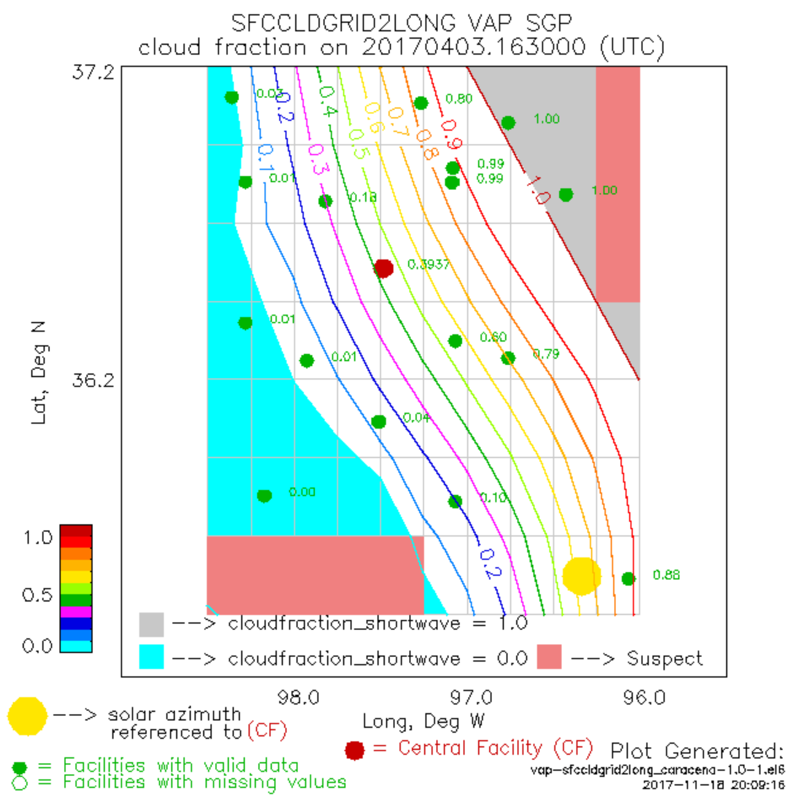

Figure 3. Shortwave derived fractional sky cover.

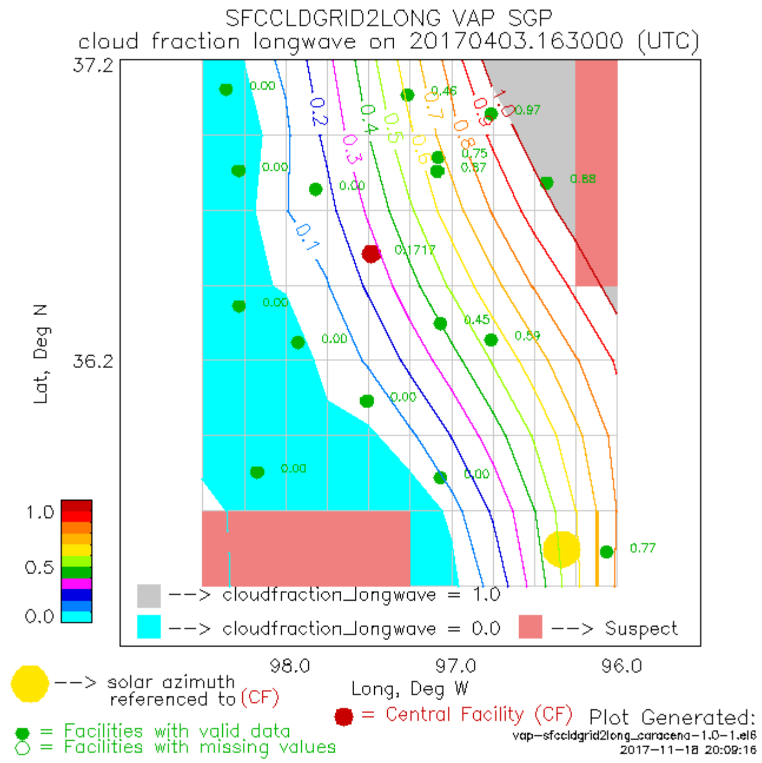

Figure 4. Longwave derived fractional sky cover.

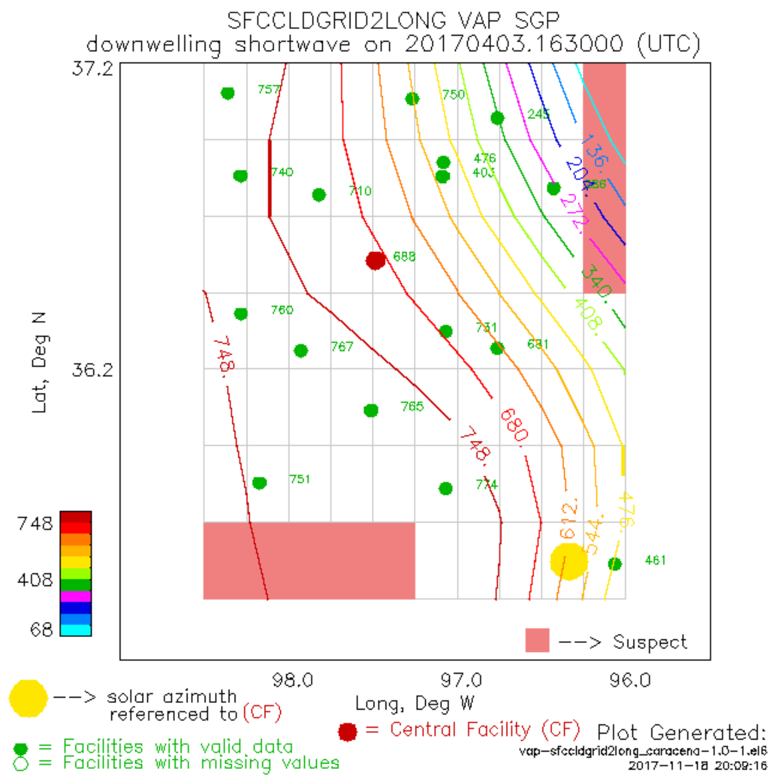

Figure 5. Downwelling shortwave irradiance.

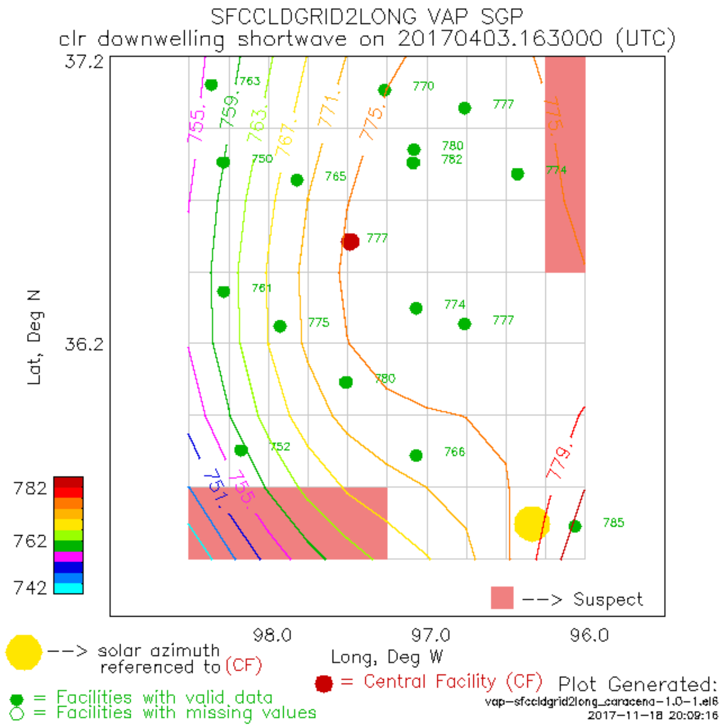

Figure 6. Clear-sky downwelling shortwave irradiance.

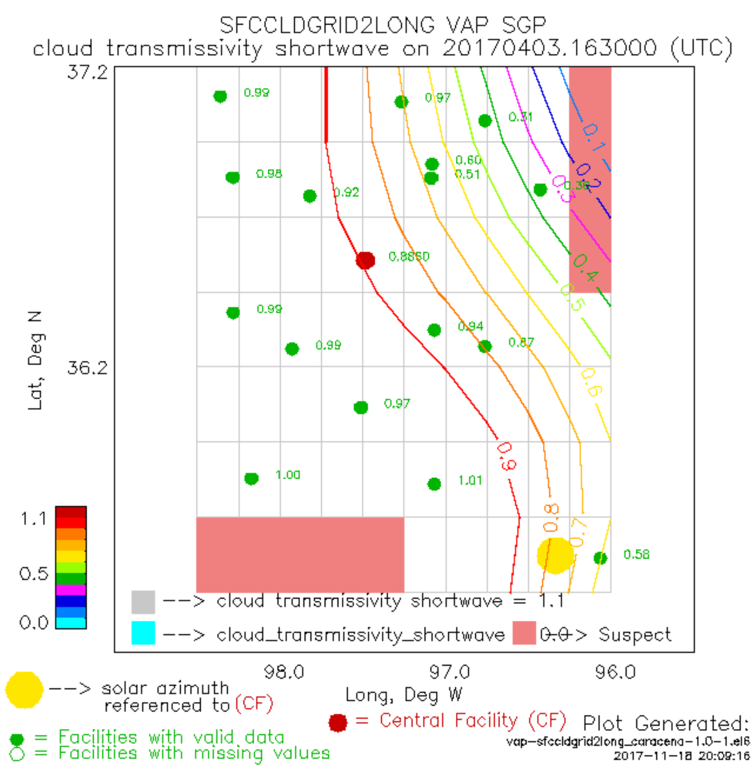

Figure 7. Gridded shortwave effective transmissivity—the ratio of measured over clear-sky total SW down.

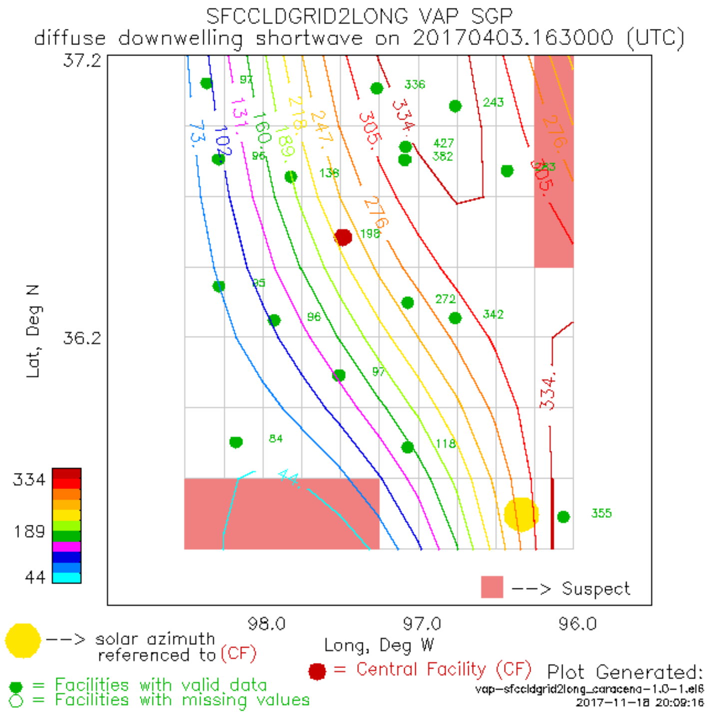

Figure 8. Downwelling diffuse SW irradiance.

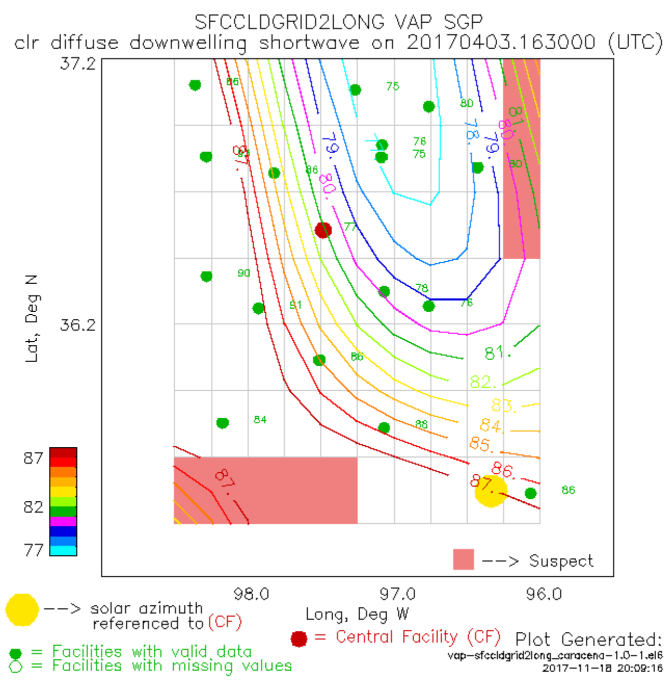

Figure 9. Clear-sky diffuse shortwave irradiance.

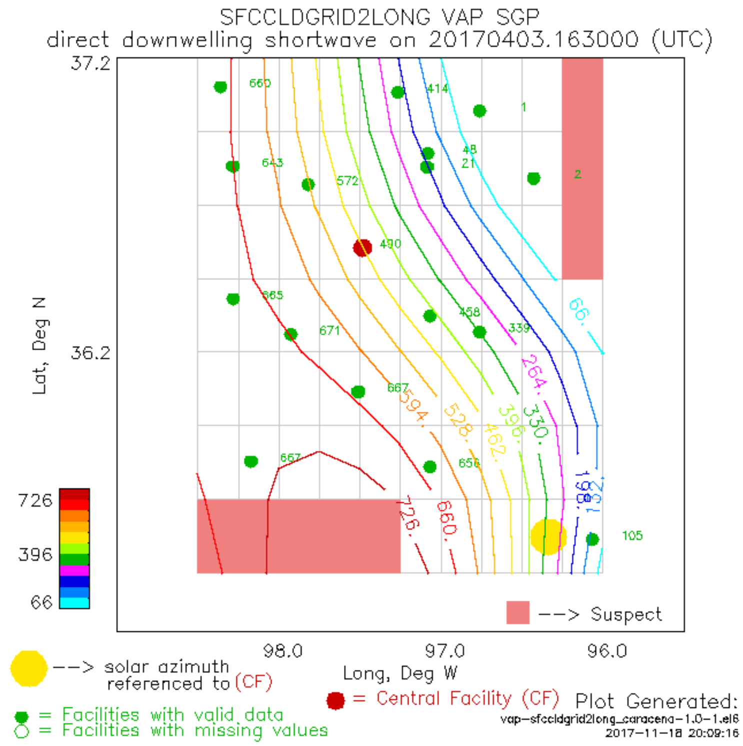

Figure 10. Downwelling direct SW irradiance.

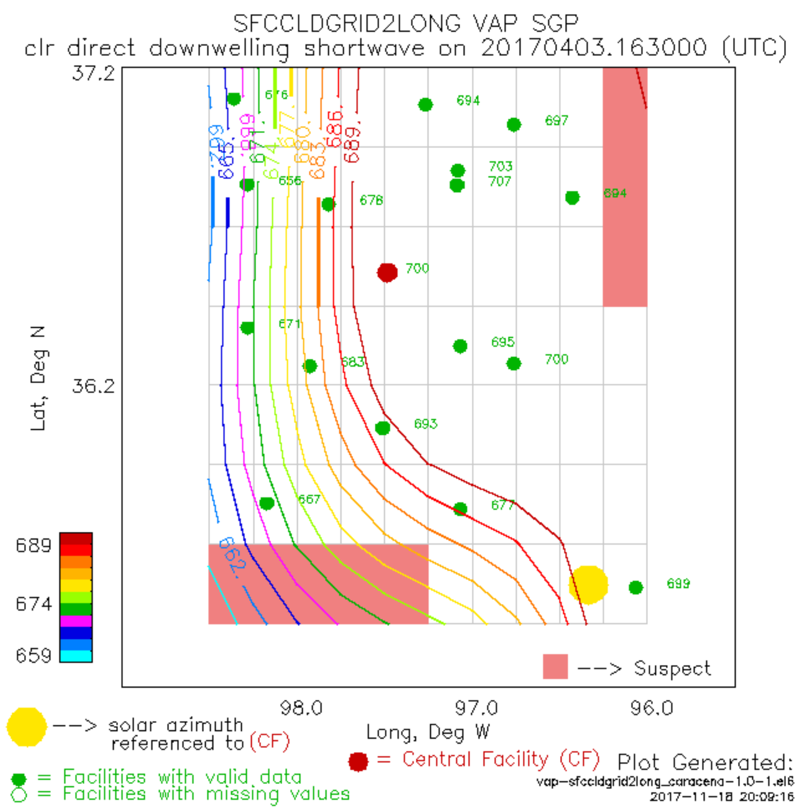

Figure 11. Clear-sky downwelling direct SW.

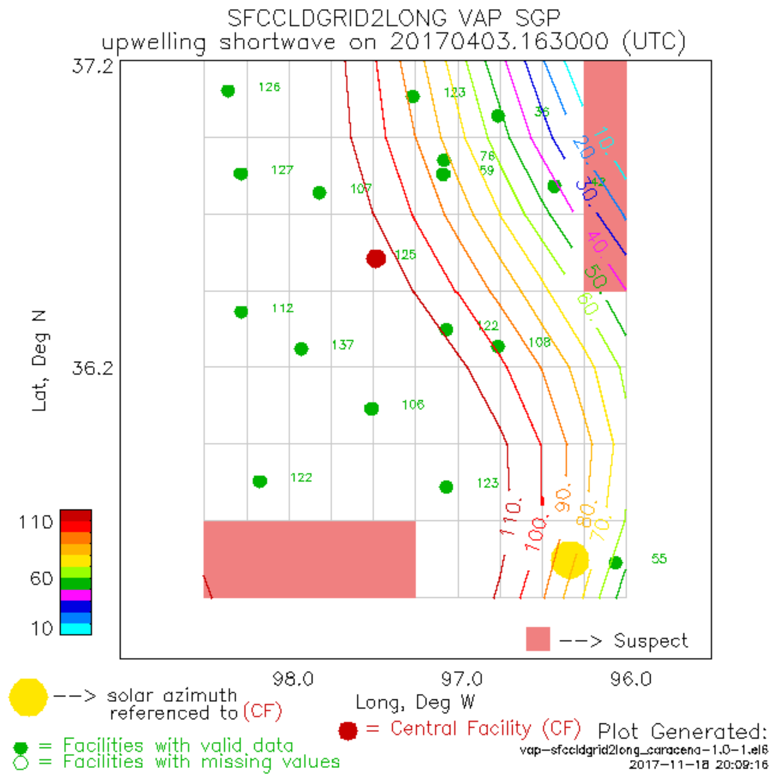

Figure 12. Upwelling SW irradiance.

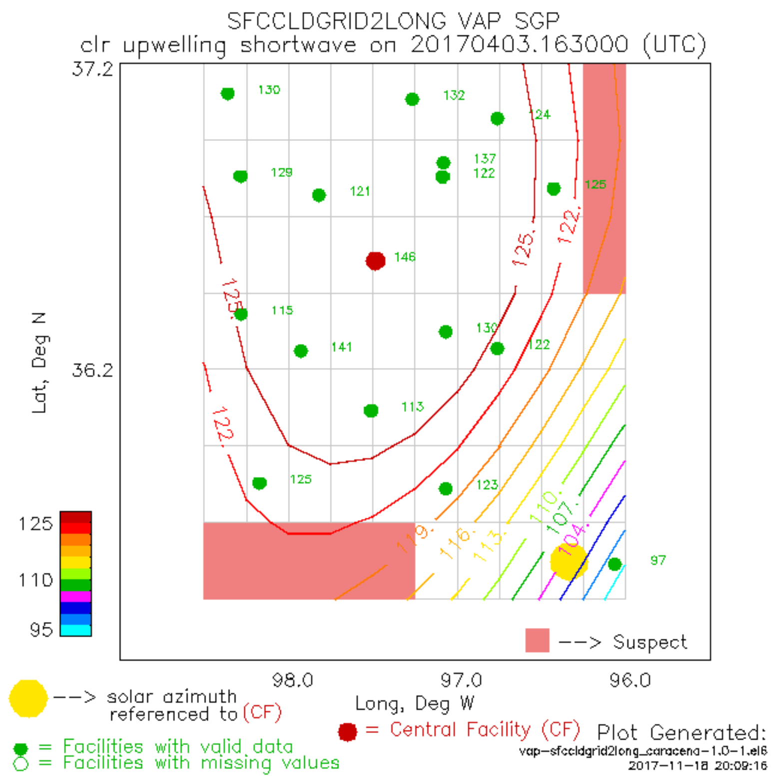

Figure 13. Clear-sky upwelling SW irradiance.

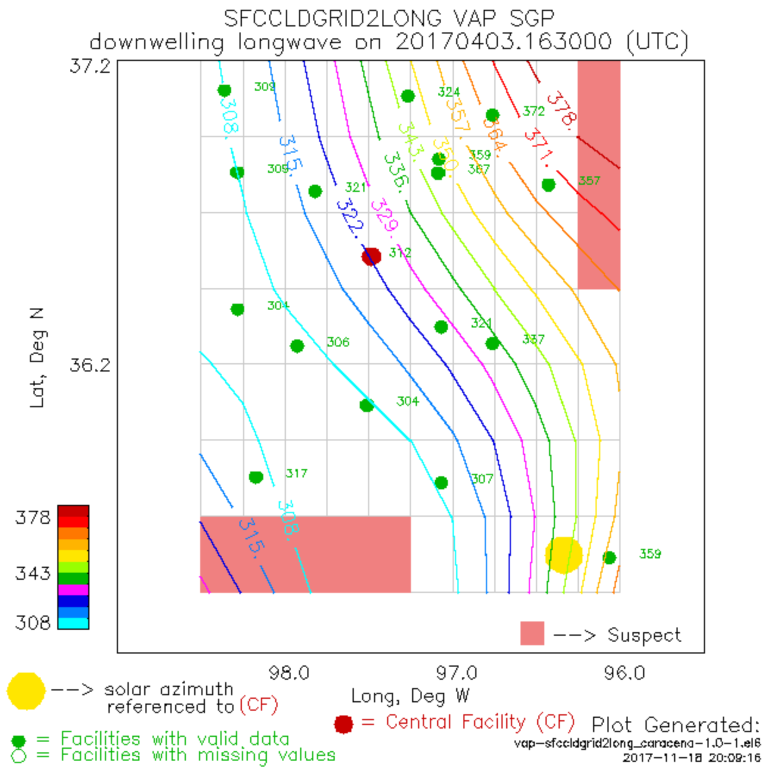

Figure 14. Downwelling LW irradiance.

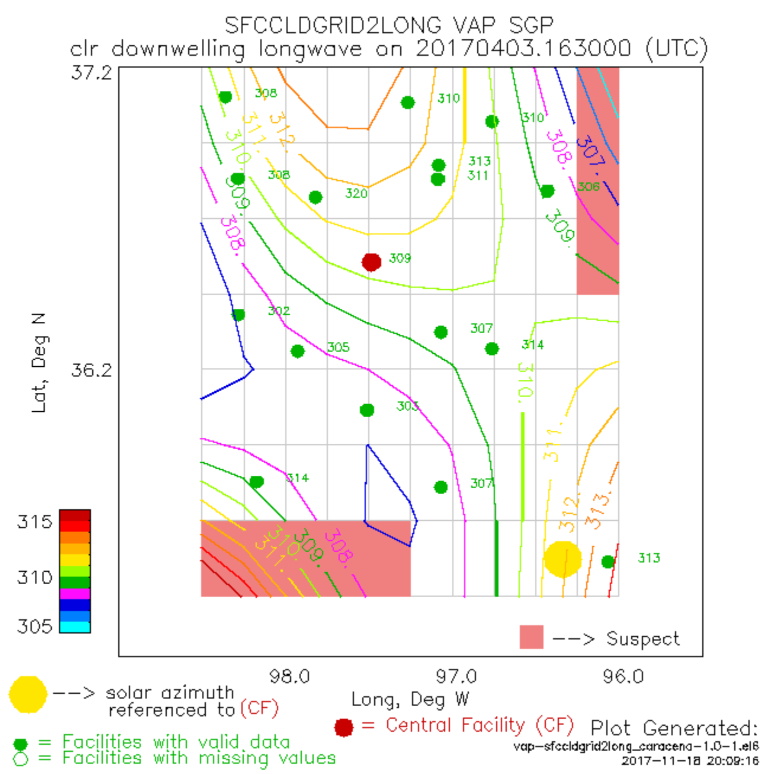

Figure 15. Clear-sky downwelling LW irradiance.

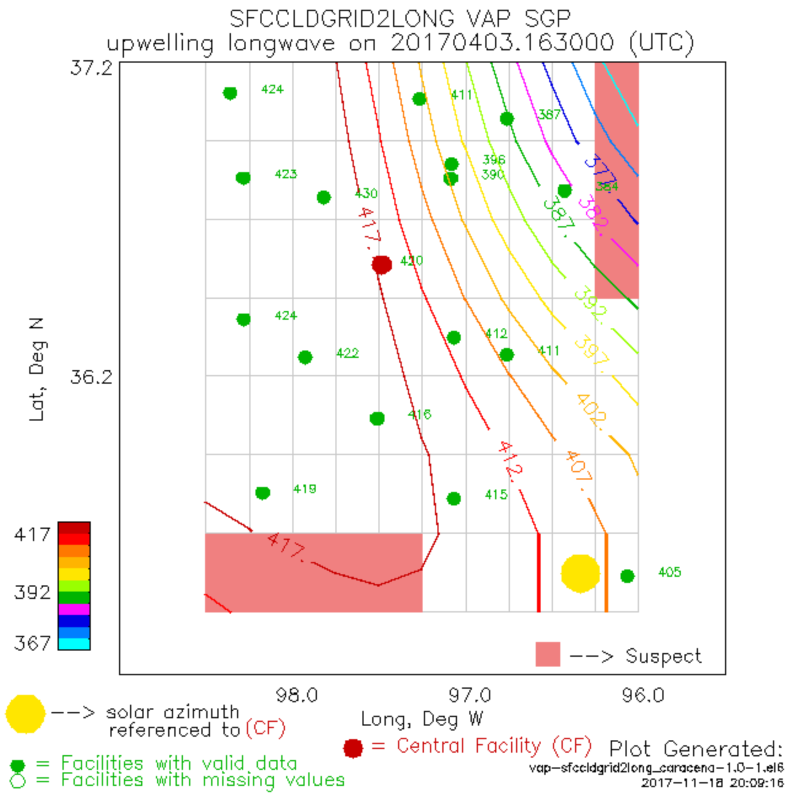

Figure 16. Upwelling LW irradiance.

7.0 Analysis: Evaluation

An analysis was performed on the previous version of the Surface Cloud Grid VAP to calculate the uncertainty errors across the SGP site due to the interpolation by looking for the difference in interpolated values with and without removing one site at a time. This study is described in detail in Long and Christy (2005) and in Christy et al. (2002). In general, they found that the uncertainty was somewhat site dependent (e.g., a site on the edge of the domain had a larger influence than those in the middle of the domain where more data influenced the interpolation) and decreased significantly with averaging time. For example, uncertainties in SW variables at 15-minute resolution were on the order of 10−20% depending on the site but reduced to around 5% in daily averages.

Additional evaluation compared the gridded cloud fraction data to satellite cloud fraction from the VISST (Visible Infrared Solar-Infrared Split Window Technique) satellite product (Minnis et al. 2008, 2011), which combines geostationary and polar-orbiting satellite cloud retrievals over the ARM sites. The VISST data set is available at 30-minute temporal resolution and 0.5-degree latitude-and-longitude resolution. Figure 17 is an example of a comparison from an instantaneous satellite retrieval of cloud fraction to a 15-minute average surface gridded SW fractional sky cover data. The two figures show similar patterns, with overcast skies on the eastern edge of the domain and clear sky in the west/center of the domain.

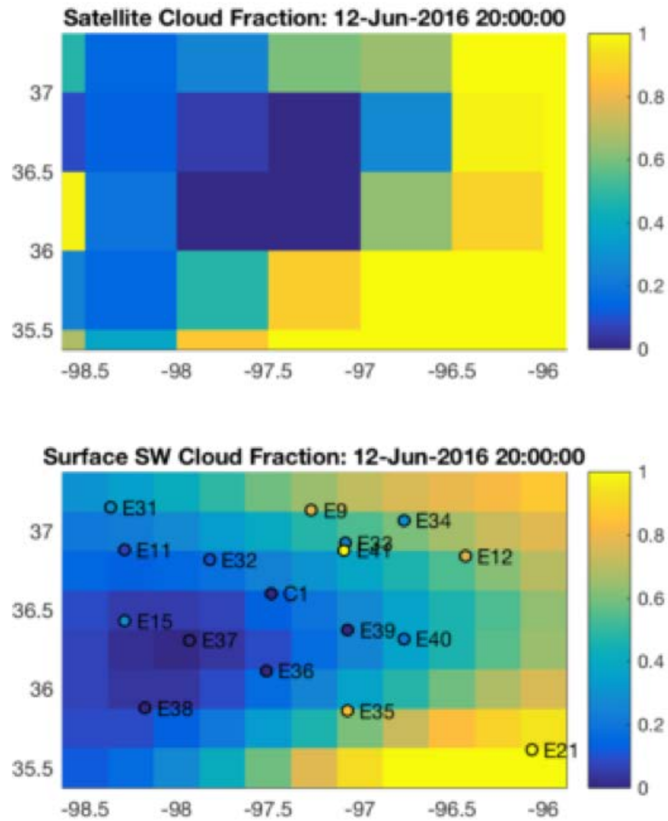

Figure 17. Evaluation of the gridded cloud fraction against satellite cloud fraction data from the VISST product in the ARM Data Center (https://arm.gov/capabilities/vaps/visst). Satellite data are a compilation of measurements from geostationary and polar-orbiting satellites.

Table 3 shows the differences in mean and standard deviation in daily averages between point measurements at the SGP CF and over the surface cloud grid over a 3-month period in 2016. For this long period, we see that there are only small biases, but standard deviations increase with the size of the box being compared to, indicating that for individual days there may be large differences between the point measurement and that over a large box. This is an estimate of how individual point measurements would compare to the geometry of a model gridbox or large satellite footprint.

Table 3. Table of statistics comparing daily average differences between station measurements at the SGP CF and domain average values for the period June-August 2016 for five different size boxes. Mean biases are small over long time periods, but standard deviations increase with larger boxes, indicating potentially large differences between a point measurement and a larger domain on an individual day. The column headings indicate the number of pixels in the box average where each pixel represents a 0.25-degree latitude-and-longitude box.

	1x1		3x3		5x5		7x7		Full	
	mean	st.dev.	mean	st.dev.	mean	st. dev.	mean	st.dev.	mean	st.dev.
Cloud Fraction	0.00	0.06	0.00	0.06	0.00	0.07	0.00	0.08	-0.01	0.11
Shortwave(W/m^2)	1.93	29.56	1.77	30.99	1.48	34.16	1.04	39.26	1.87	49.33
Clearsky SW	-1.34	6.78	-1.30	6.88	-1.27	7.14	-1.29	7.61	-1.94	8.20
Longwave	-0.14	2.07	0.06	2.21	0.42	2.50	0.85	2.96	1.82	4.41
Clearsky LW	0.55	3.10	0.72	3.23	1.02	3.52	1.39	3.97	2.51	5.07

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