Status report on the EOS validation investigation: Surface Radiation Budget and Cloud Measurements for NASA's EOS CERES Program

John Augustine and Chuck Long
September 12, 2001

Objectives

The objective of this investigation is to use SURFRAD network data and special research-supporting ancillary measurements and analyses to provide validation information for the three CERES-equipped EOS satellites, TRMM, Terra, and Aqua. We are now at the end of the fourth year of funding. The goals of this year were:

1) Convert the PC version of the clear-sky identification program to SRRB Unix systems,
2) Improve TSI data access,
3) Improve the surge protection for the TSIs at SURFRAD stations,
4) Further investigate and improve the interpolated soundings' accuracy,
5) Investigate methods of analysis for SURFRAD MFRSR data, and
6) Submit manuscripts for publication.

Although of the above tasks were addressed, some that are not on this list that will benefit the EOS program were also undertaken.

Accomplishments

Clear-sky identification software successfully transferred to SRRB

The clear-sky envelope fitting (clear-id) and data quality control software for surface solar measurements (Long and Ackerman, 2000) was delivered to SRRB in Boulder. The algorithm operates on one day of solar component data, using empirical means to objectively determine totally clear-sky periods. If enough such points are identified, a daily envelope is fit to the global solar, diffuse and direct solar, UVB, and PAR data, thus providing a good estimate of the clear-sky irradiance in those bands for the entire daylight period. The difference between the clear-sky fit and the measurements gives a quantitative estimate of cloud forcing. Because the measurements are used to determine the clear-sky envelope, i.e., no modeling is involved, these quantitative forcings are free of instrument and measurement error. Other products of these calculations are unique data quality control parameters and estimated hemispheric cloud fraction.

The clear-id software as delivered to SRRB was designed to run on a PC and to be controlled by DOS scripts. After several months of conversion to Unix and debugging, the code was successfully transferred to the SRRB workstations and verified. The new SRRB version includes, tolerance of UTC-based data files, a preprocessor that automatically sets up the configuration file, and a post processor that automatically displays the measured data and clear-sky fits for examination by the operator (e. g., Fig. 1).

The Unix version of the clear-id software was applied from January 1997 to the present to the four original stations, Bondville, Fort Peck, Goodwin Creek, and Table Mountain (Boulder). The January 1997 start time was chosen because the algorithm requires solar component data, preferably independently measured direct and diffuse. It was not until the 1996 SURFRAD instrument exchanges that diffuse solar was added to SURFRAD's complement of measurements. The clear-id analysis was applied to the two newest stations, Penn State and Desert Rock, for their whole tenure (mid 1998 – present). Clear-id product files were transferred SRRB's anonymous ftp site directory at

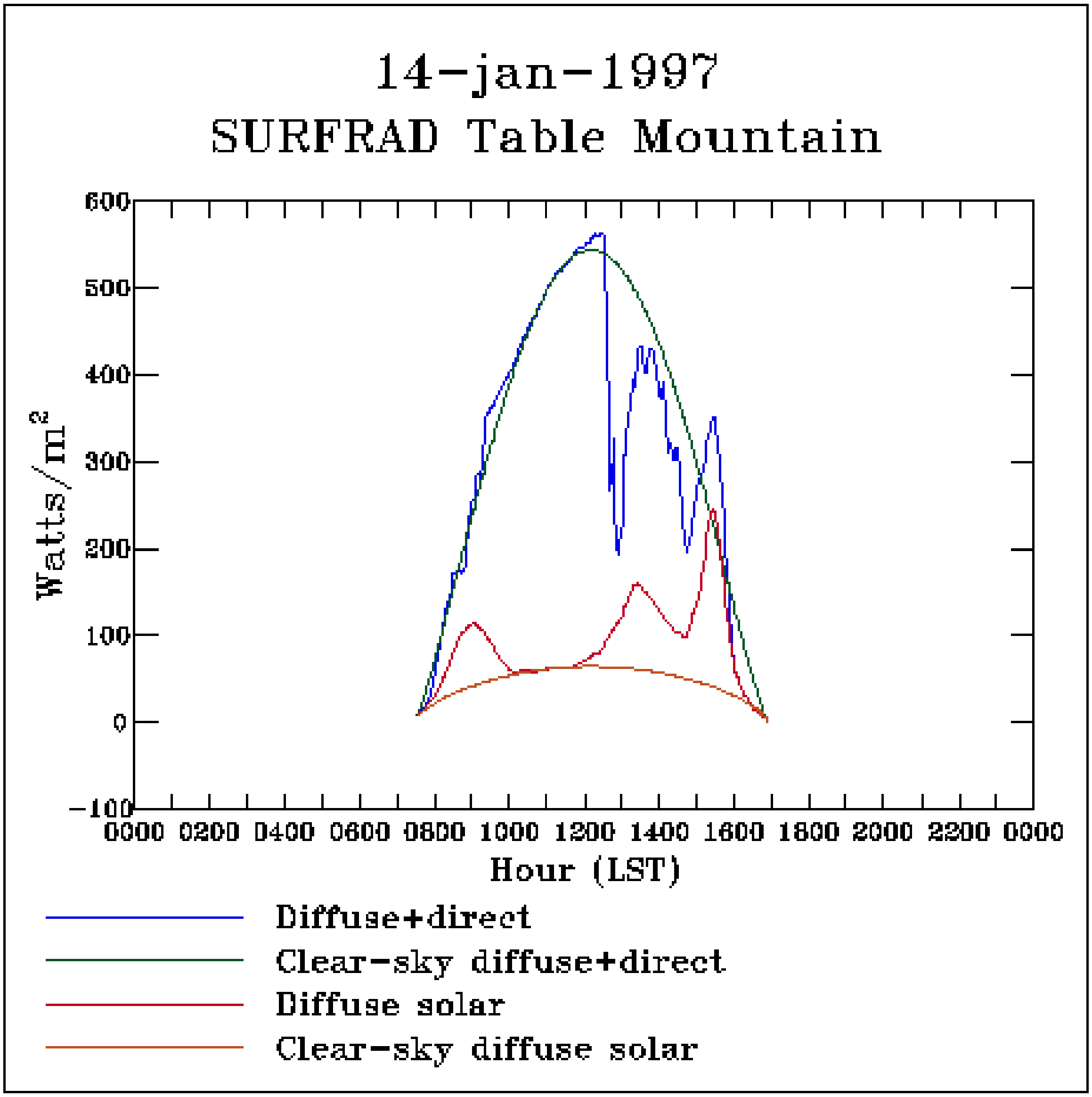


Figure 1. Sample product of the SRRB Unix-base clear-sky identification software for January 14, 1997 for Table Mountain. The green and the orange lines are the clear-sky fits for the component sum and diffuse solar, respectively. The blue and red are the actual measured component sum and diffuse solar data.

ftp://ftp.srrb.noaa.gov/pub/clearid. These are text files that have .swf and .c15 extensions. The .swf files are at the three min. resolution of the SURFRAD data. The .c15 files contain 15-minute averages of the values in the .swf files, and also contain empirically estimated hemispheric fractional cloud cover information (Long et al., 1999). Filenames are of the form yyyymmdd.c15 and yyyymmdd.swf. Readme files (c15_readme.txt and swf_readme.txt) that explain the format of these files are included at the station level of the directory structure. In July 2001, David Rutan at NASA Langley was contacted concerning the availability of these data for inclusion into EOS validation web site (http://www-cave.larc.nasa.gov/cave) for distribution to EOS investigators.

Total Sky Imager topics

Installations completed

In October 2000, a two by three meter climate-controlled trailer, on which the Total Sky Imager (TSI) was to be mounted, was hauled to Fort Peck, MT and installed (Fig. 2). This housing was designed and built at SRRB. Its purpose is to serve as a platform for the SURFRAD TSI and to house the TSI computer as well as the station's uninterruptable power supply. The trailer is located about 15 m southeast of the SURFRAD station, far enough from the solar tracker to preclude interference with the radiation measurements.

Figure 2. The Total Sky Imager and support enclosure was installed at the Fort Peck SURFRAD station in October 2000.

TSI data infrastructure established

Hemispheric sky images recorded at a one-minute frequency are stored on a removable large-capacity jaz disk on the local TSI computers. This disk is exchanged every two months at each location. Hourly images and one-minute cloud fraction files are downloaded daily from each site and checked. An ftp site has been set up at ftp://space.srrb.noaa.gov to distribute these files. The directory tree begins at /pub/TSI/. There are two subdirectories under /TSI, one for one-minute cloud fraction data (/CloudFrac), and the other for hourly hemispheric sky images (/Daily). The directory /pub/TSI/CloudFrac contains subdirectories that correspond to each station called BDN-CF, FPK-CF, DRA-CF, GWN-CF, TBL-CF, and PSU-CF. It also has a readme-CF file that explains the structure of the cloud fraction files. Hemispheric cloud fraction filenames are of the form [sta]yyyymmdd.txt, where [sta] refers to bnd, fpk, gwn, tbl, dra, and psu.

Under /pub/TSI/Daily/ are station subdirectories called BND-Images, DRA-Images, FPK-Images, GWN-Images, PSU-Images, and TMT-Images. These contain the latest two weeks of hourly TSI images and the corresponding processed (decision) images. The hemispheric sky image filenames are of the form [sta]yyyymmddhhmmss.jpg. Processed images illustrate the TSI interpretations using blue for clear sky, white for opaque cloud, and gray for thin cloud. These files have the same naming convention as the hemispheric sky images, but use .png as the extension. One-minute jpg and png images are available on CD upon request.

TSI parameters being optimized for each site

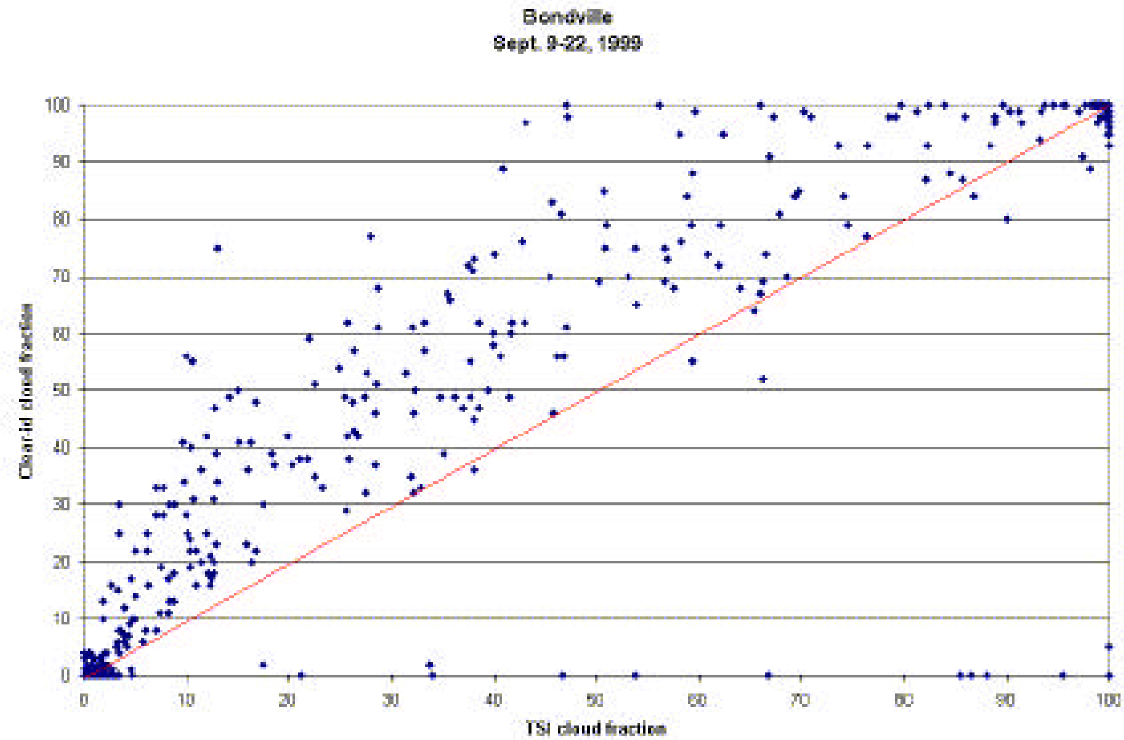
Each TSI must be optimized through a variety of settings to compensate for the climatic conditions in which it operates as well as for slight differences in the characteristics of the individual cameras. There are three primary types of settings for each TSI system. The first is a brightness setting of the camera. As the name indicates, this sets the "lightness" or "darkness" of the sky images. The second setting type designates the size of regions for masking glint from around the solar disk and the horizon at high solar zenith angles. The third primary setting type controls the sensitivity of the criteria used to distinguish between thin and opaque clouds and between thin cloud and clear sky. Setting up a TSI is an iterative process that requires assigning these parameters, watching the raw and processed cloud images, and making adjustments as necessary. This process must be repeated until the operators are satisfied with the cloud definitions and the TSI-based computations of hemispheric fractional cloud cover. Note that the camera brightness setting is the only critical one; all the other settings may be changed and the data reprocessed with the new parameters. These tuning exercises are ongoing for all the TSI systems.

The default camera brightness setting for these systems was 5. Upon viewing the products for several weeks, it was determined that the camera brightness levels should uniformly be set to 6. TSI computed cloud fractions derived with both brightness settings were compared to an empirical estimation of hemispheric fractional cloud cover based on the clear-id processing. Results improved after the brightness level was changed to 6. Note in Fig. 3 that with the camera brightness set to 5, there is a clear-id cloud fraction bias, but for a setting of 6, the scatter is more evenly distributed about the 1:1 line. In past comparisons of TSI and empirically-derived clear-id cloud fractions, the RMS scatter about the 1:1 line was typically about 13% (Long et al., 1999).

As discussed above, one of the primary settings involves sensitivities to thin cloud, opaque cloud, and clear sky that are set as thresholds of the red/blue ratio. At Desert Rock, the common occurrence of cirrus caused high TSI biases, forcing adjustments to these thresholds. The change of the brightness parameter from 5 to 6 significantly improved the comparison to the clear-id hemispheric cloud fractions, but there remained a strong TSI bias. This was remedied after the red/blue thresholds were adjusted. Similar problems were encountered with Fort Peck TSI images and the appropriate adjustments were made. The original threshold settings were only slightly adjusted for the other sites. Before the all of the TSI data are reprocessed in total, the sun glint mask areas will be optimally sized.

Improve the surge protection for the TSIs at SURFRAD stations

There have been ongoing efforts at SRRB to develop an effective and reasonable method for protecting the SURFRAD TSI's from electrical surges. When these systems were first installed, the manufacturer was asked about how best to protect the mirror control board (TT8) from surges, given that our plan was to keep it connected to the PC continuously to be able to remotely set the system clock. The manufacturer actually prefers the TT8 board to *not* stay continually connected to the PC, however, doing so greatly



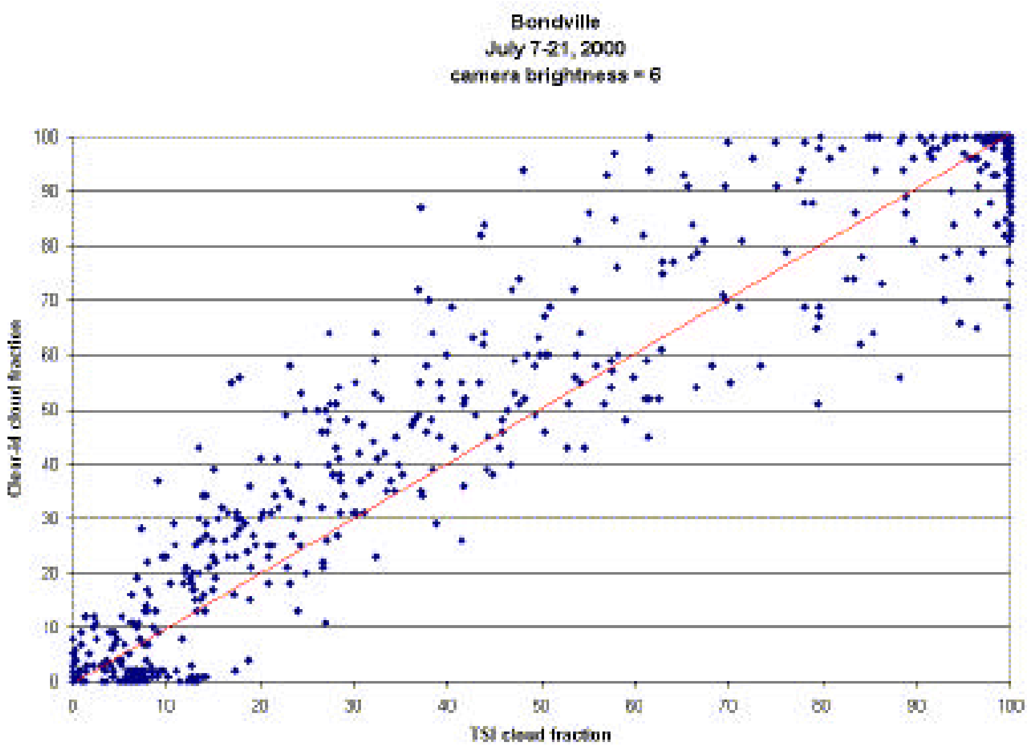


Figure 3. Comparison of clear-id-derived cloud fraction and TSI cloud fraction at Bondville for camera brightness of 5 (upper) and 6 (lower).

facilitates the remote maintenance of each TSI system. Since SRRB insisted on configuring the systems in this way, they recommended the use of an optical isolation device. A serial line optical isolation device was found and installed in all SURFRAD TSIs during the 2000 instrument exchanges. Although this optical isolator can protect the board from relatively strong line surges, we suspect it can be overwhelmed by very strong surges induced by nearby lightning strikes. This likely happened at Desert Rock during an intense lightning storm during July 2001 when the TSI TT8 board was lost. Under the assumption that the device failed to protect the TT8 board in this circumstance, other options are being considered. These all include using a length of fiber optic cable to break the continuity of the copper wires; however, the cost vs. benefit may not be worthwhile when considering the replacement cost of the TT8 board and the relatively expensive fiber optic solutions.

Sounding interpolation improved

All SURFRAD interpolated rawinsonde-type soundings were reprocessed with new and improved code that checks hydrostatic consistency in the lower part of the interpolated profiles. If the lower part of a sounding does not pass the hydrostatic test, then the low-level lapse rate is retrieved and used to extrapolate meaningful temperatures. This addition has especially improved the interpolated soundings near the surface.

New code has been added to interpolate a sounding to the location of the proposed Canaan Valley, WV SURFRAD station (not yet established). All national sounding network data from Jan. 1, 1995 to the present were reprocessed using the improved code and the Canaan Valley addition. These data are available from the "Soundings" link on the SURFRAD web page <http://www.srrb.noaa.gov/surfrad/surfpage.htm>. Each of these files contains interpolated soundings for six SURFRAD station locations (including Canaan Valley) and the actual sounding for Desert Rock. Any interpolated sounding may be downloaded or plotted on a skewT-logP background at the web site. A text file that explains the file format is also available. For convenience, compact disks of the interpolated soundings are available upon request to EOS investigators.

MFRSR calibration and AOD analysis method developed and tested

The Multi Filter Rotating Shadowband Radiometers (MFRSR) used at SURFRAD stations are not calibrated. However, irradiance values are not needed for the determination of optical depth. Langley plots, i. e., the log of the output signal of the MFRSR (I) for a narrow spectral band plotted as a function of solar path length, are used to infer the total optical depth. Extrapolation of the plotted line to the y-intercept gives the value that the instrument would read for a path length of zero (I_0), i. e., the extraterrestrial signal. This serves as the calibration value for the instrument. The slope of the Langley plot is the total optical depth. To retrieve aerosol optical depth (AOD), 500 nm channel data is used. The AOD is revealed when contributions owing to Rayleigh scattering and ozone absorption are removed from the total optical depth.

Because the instrument's sensitivity may drift with time, the I_0 "calibration" may also drift. Therefore I_0 needs to be determined periodically. It is best to establish the calibration over the period of analysis for a particular event, or systematically in time for operational purposes. Another problem with the use of Langley plots in determining AOD is that aerosol concentration may change during the day, and that other atmospheric noise (e.g., sub-visual cirrus) may increase the uncertainty of the slope. To reduce noise, we have adopted a method originally suggested by Dr. Bruce Forgan where only those MFRSR measurements that corresponded to clear-sky points from the Long and Ackerman clear-sky analysis are used to determine I_0.

To test this method we chose two high pollution events that occurred over the Front Range of Colorado on April 13 and 17, 2001 which corresponded to the arrival of a Mongolian dust cloud over Colorado and simultaneous meteorological conditions conducive to the trapping of boundary layer air. MFRSR data from the Table Mountain SURFRAD station were used. To determine the representative I_0 and background AOD, 20 days with notable periods of objectively determined clear-skies were chosen from March through May of 2001. The Langley plots for these periods were remarkably free of noise and thus deemed trustworthy to provide a good calibration. From these a representative I_0 of 7.3567 ±0.0526 was determined for the three-month period.

The representative background total optical depth for the 20 quasi-clear-sky days was computed by weighted average, i. e., weighting each individual day's retrieved total optical depth according to the number of clear-sky points used in that day's Langley plot. This resulted in an average background total optical depth of 0.2228. The contributions owing to Rayleigh scattering (.1155) and ozone absorption (0.01) were subtracted, resulting in an average background AOD for the three-month period of 0.0973. This value is in close agreement with the results of Flowers et al. (1969) for the Boulder area in Springtime.

The representative I_0 for the 500 nm channel was applied to all MFRSR 500 nm measurements on the two high pollution days, thus giving the temporal variation of the AOD through each of the days. For April 17, aerosol optical depths ranged from 0.4 in late morning to 0.3 in the late afternoon (Fig. 4). The time series for April 13 (not shown) shows that the AOD decreased from 0.33 in the late morning to 0.15 in the afternoon.

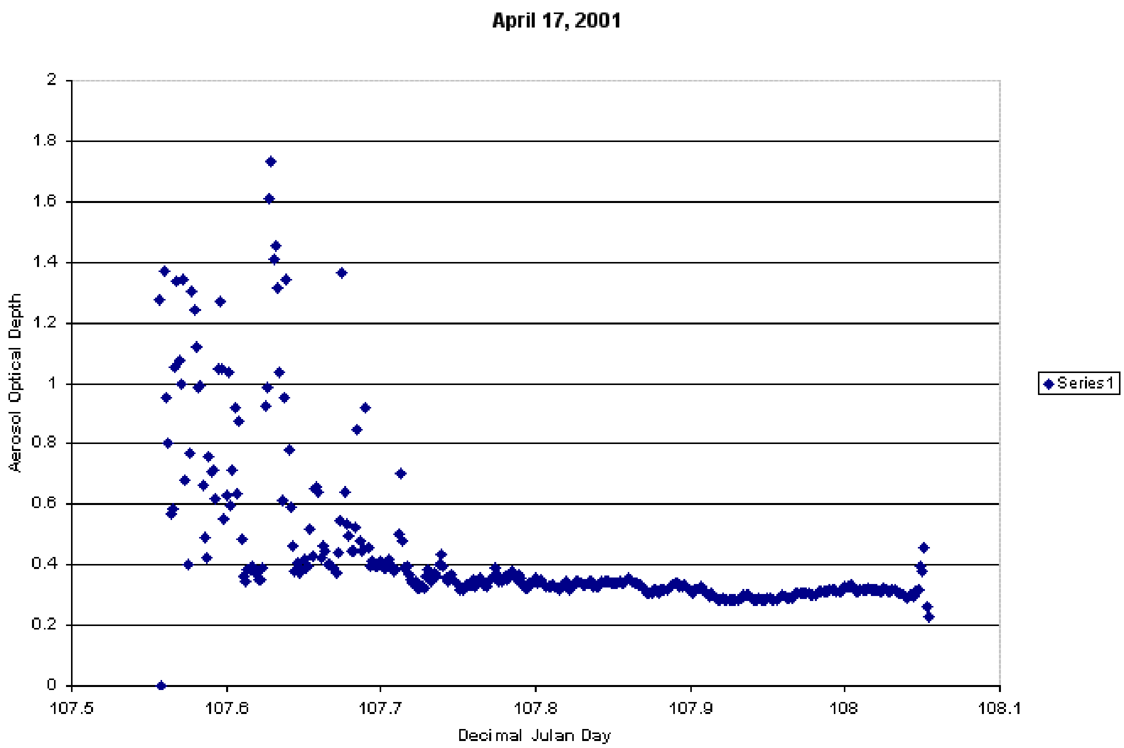


Figure 4. Time series of aerosol optical depth (AOD) for Boulder, CO for April 17, 2001. The time scale on the abscissa is in UTC decimal day of year (day 107 is April 17). The high optical depths in the early part of the day are erroneous owing to cloud contamination. At the time corresponding to 107.7, the clouds disappear and the AOD variation is true.

Given that this procedure is labor intensive and requires some subjectivity, it is unclear how it could be automated. However, with funding provided by the NASA EOS program, we were able to develop a reasonably accurate AOD analysis procedure for SURFRAD MFRSR data that can easily be applied to selected periods of interest.

Improvements at SURFRAD stations that benefit EOS validation

In the 2001 instrument exchanges, all diffuse solar pyranometers (shaded PSPs) were replaced with Eppley model 8-48 pyranometers. This was necessary because it has been known that the PSP (and any other thermopile-based pyranometer) has an inherent error owing to radiational (infrared) cooling of the sensor to the inner dome, which produces erroneous offsets of –10 to –20 Wm^{-2} during clear nights (Dutton et al., 2001). This error is also present in daytime solar measurements but its magnitude is difficult to quantify; however, it is exacerbated in the diffuse measurement because the sensor is shaded. The advantage of the model 8-48 pyranometer is that its signal is a differential between three separate black and white surface pairs. These surfaces radiate equally in the infrared, thus no erroneous offset (night or day) results. The model 8-48 is not used for global solar measurements because of concerns related to the instrument azimuthal response to the direct component at low sun angles, which is not a factor when used for diffuse measurements.

This change has improved the quality of the downwelling solar measurement at SURFRAD stations. It has been accepted that the best measure of global solar radiation is the sum of the direct and diffuse components. The pyrheliometers used to measure direct solar have the highest accuracy (± 2-3%) because they are calibrated directly with an absolute cavity radiometer. Now that the diffuse measurement has been improved by eliminating the offset error, the component sum has thus been improved. The global solar measurement at SURFRAD stations is made only for redundancy. After all of the diffuse radiometers are replaced with model 8-48 pyranometers, a correction scheme suggested by Dutton et al. (2001) will be applied to all historical SURFRAD diffuse solar measurements.

Collaborations with the CERES Science Team

Submitted clear-id processed data for all SURFRAD stations through summer 2001 to Dave Rutan for insertion into the CAVE archive and web site.

Responded to a request from an EOS validation team to recover interpolated SURFRAD station sounding data for the three days of July 1998 for which the network sounding data, and thus the interpolated soundings, were unknowingly missing.

Publications

A paper entitled "The effect of snow cover and cloud type on the surface radiation budget at SURFRAD network stations" by John Augustine, John DeLuisi and Chuck Long was presented at the AMS 11th Symposium on Meteorological Observations and Instrumentation, held in Albuquerque, NM, Jan. 14-19, 2001.

A paper entitled: "Retrieval of cloud properties using surface meteorological and broadband irradiance measurements," by Charles N. Long, John A. Augustine, J. C. Barnard, and Thomas P. Ackerman was presented at the 8th Scientific Assembly of IAMAS (International Association of Meteorology and Atmospheric Sciences), which was held in Innsbruck, Austria on July 10-18, 2001. This work involves the use the information being gathered at sophisticated instrument sites such as ARM SGP, i.e., lidars, cloud radars, microwave radiometers, to develop the means of retrieving at least some knowledge of cloud properties using the more standard instrumentation such as surface meteorology and broadband irradiance measurements, which are more readily available. Long et al. (1999) has already developed the means to use the clear-sky retrievals to infer fractional sky cover from irradiance measurements during daylight hours. Research is underway to extend the range of cloud properties that can be retrieved such as cloud type classification, cloud base height, cloud base temperature, and nighttime cloud amount, within reasonable uncertainty limits.

Planned activities

Optimum settings of the TSI processing algorithm that distinguish clear sky from thin cloud and thin from opaque cloud, and sizes of sun glint mask areas will be determined, and all TSI imagery will be reprocessed.

Continue to run the clear-id code on a quasi-monthly basis for all stations for distribution to EOS investigators.

A method, now in development, that involves the calculation of clear-sky longwave emission based on temperature and humidity may lead to the ability to infer infrared cloud forcing. When adapted successfully to SURFRAD, infrared cloud effects will be included in the fifteen-minute data (.c15) files produced by the clear-id code. All Clear-id code will have to be adapted to include infrared cloud forcing.

A source of three-hour model soundings was found within ARL to use to fill the rather large 12-h temporal void between the synoptic times. This utility provides access to the grided model soundings and will interpolate, via bilinear means, to any location--in this case to the SURFRAD station locations. In the coming year, we plan to develop software to automatically retrieve three-hour-interval model soundings for the SURFRAD station locations, convert them to the SURFRAD sounding format, and disseminate them along with the 0000 and 1200 UTC interpolated soundings.

Apply the correction scheme described in Dutton et al., 2001 to all historical SURFRAD diffuse solar data taken before the model 8-48 pyranometers were deployed at the SURFRAD stations.

References

Dutton, E. G., J. J. Michalsky, T. Stoffel, B. W. Forgan, J. Hickey, D. W. Nelson, T. L. Alberta, and I. Reda, 2001: Measurement of broadband diffuse solar irradiance using current commercial instrumentation with a correction for thermal offset errors, *J. Atmos. And Oceanic Tech*., 18, 297-314.

Flowers, E. C., R. A. McCormick, and K. R. Kurfis, 1969: Atmospheric Turbidity over the United States, 1961-1969, *J. Appl. Meteor.*, **8**, 955-962.

Long, C. N. and T. P. Ackerman, 2000: Identification of Clear Skies from Broadband Pyranometer Measurements and Calculation of Downwelling Shortwave Cloud Effects, *J. Geophys. Res.*, 105, D12, 15,609-15,626.

Long, C. N., T. P. Ackerman, J. J. DeLuisi, and J. Augustine, 1999: Estimation of Fractional Sky Cover from Broadband SW Radiometer Measurements, *Proc. 10th Conf. on Atmos. Rad.*, June 28-July 2, 1999, Madison, Wisconsin.