DESCRIPTION OF SURFRAD DAILY DATA FILES

Contact:

John Augustine
NOAA GML
325 Broadway Street
Boulder, CO 80305
email: john.a.augustine@noaa.gov
Phone: 720-238-6480

Use the following references in any publications that use SURFRAD data:

Augustine, J. A., J. J. DeLuisi, and C. N. Long, 2000: SURFRAD—A national surface radiation budget network for atmospheric research. *Bull. Amer. Meteor. Soc.* **81**, 2341-2357.

Augustine, J. A., G. B. Hodges, C. R. Cornwall, J. J. Michalsky, and C. I. Medina, 2005: An update on SURFRAD—The GCOS surface radiation budget network for the continental United States, *J. Atmos. And Oceanic Tech.*, **22**, 1460–1472.

See the end of this document for "Fair use" data practices and licensing policies that pertain to SURFRAD data.

DATA DISTRIBUTION:

Daily SURFRAD text data files for each station may be downloaded from GML at the following location:

https://gml.noaa.gov/aftp/data/radiation/surfrad/

To get to a specific file, advance to the appropriate station directory, and then to the specific year directory, e.g., for Bondville 2003 data: https://gml.noaa.gov/aftp/data/radiation/surfrad/bon/2003/

SURFRAD data are actually processed in near-real-time every 15 minutes. These real-time data files build during the day and have the same names and structure as the daily quality-controlled files on the GML FTP site, but they are not checked for quality, so use at your own risk. The real-time data files are available at:

https://gml.noaa.gov/aftp/data/radiation/surfrad/realtime/

One-minute SURFRAD data files are also available in NetCDF format from NOAA's National Centers for Environmental Information (NCEI)archive. NCEI has assigned a DOI to that dataset of https://doi.org/10.25921/rjq4-cq67 .

FILENAME INFORMATION:

SURFRAD data files distributed by GML contain one day of data for one station. The FTP directories from which SURFRAD data are distributed are organized by station and year. The naming convention for SURFRAD data filenames is "stayyjjj.dat", where sta is a three-letter station identifier, yy represents the last two digits of the year (i.e., 95 for 1995, 00 for 2000), and jjj is the day of year. A "day of year" in a filename that is less than 100 would be preceded by one or two zeros, e.g., day 75 would appear as 075, day 2 would appear as 002 in the filename.

"bon" is the station identifier for Bondville, Illinois
"fpk" is the station identifier for Fort Peck, Montana
"gwn" is the station identifier for Goodwin Creek, Mississippi
"tbl" is the station identifier for Table Mountain, Colorado
"dra" is the station identifier for Desert Rock, Nevada
"psu" is the station identifier for Penn State, Pennsylvania
"sxf" is the station identifier for Sioux Falls, South Dakota

The extension ".dat" is used because both radiation and meteorological data are included. The file "bon95099.dat" contains all of the radiation and meteorological data for Bondville for day 99 of 1995 (9-apr-1995).

SURFRAD data processing software is year 2000 compliant. The year within the data files is written unambiguously with 4 digits on each line.

DATA STRUCTURE:

SURFRAD data on the GML FTP site are organized into daily text files. Before 1-jan-2009 the data were reported as 3-min averages. As of 1-Jan-2009 SURFRAD data are reported as 1-min. averages. SURFRAD data on the GML FTP site may be read with the section of FORTRAN code shown below. The format was specified in such a way to ensure that all entries are separated by at least one space so that the files may be read with free format. SURFRAD follows the quality control (QC)philosophy of the WMO's Baseline Surface Radiation Network (BSRN). Bad data are deleted, but questionable data are only flagged. Integer QC flags follow each data point.

A QC flag of zero indicates that the data point is good, having passed all QC checks. A QC flag greater than 0 indicates that the data failed at least one level of QC. For example, a QC value of 1 means that the recorded value is beyond a physically possible range, or it has been affected adversely in some manner to produce a knowingly bad value. A value of 2 indicates that the data value failed the second level QC check, indicating that the data value may be physically possible but should be used with scrutiny, and so on. Missing values are indicated by -9999.9 and should always have a QC flag of 1.

The following section of FORTRAN code may be used to read daily SURFRAD files:

```
      parameter (nlines=1440)
      character*80 station_name
c
      integer year,month,day,jday,elevation,version
      integer min(nlines),hour(nlines)
c
      real  latitude,longitude,dt(nlines),zen(nlines),direct_n(nlines)
      real  dw_solar(nlines),uw_solar(nlines)
      real  diffuse(nlines),dw_ir(nlines),dw_casetemp(nlines)
      real  dw_dometemp(nlines),uw_ir(nlines),uw_casetemp(nlines)
      real  uw_dometemp(nlines),uvb(nlines),par(nlines)
      real  netsolar(nlines),netir(nlines),totalnet(nlines),temp(nlines)
      real  rh(nlines),windspd(nlines),winddir(nlines),pressure(nlines)
c
      integer qc_direct_n(nlines),qc_netsolar(nlines),qc_netir(nlines)
      integer qc_dwsolar(nlines),qc_uwsolar(nlines),qc_diffuse(nlines)
      integer qc_dwir(nlines),qc_dwcasetemp(nlines)
      integer qc_dwdometemp(nlines),qc_uwir(nlines)
      integer qc_uwcasetemp(nlines),qc_uwdometemp(nlines)
      integer qc_uvb(nlines),qc_par(nlines)
      integer qc_totalnet(nlines),qc_temp(nlines)
      integer qc_rh(nlines),qc_windspd(nlines),qc_winddir(nlines)
      integer qc_pressure(nlines)
c
c
      lun_in = 20
      open(unit=lun_in,file=[filename.dat],status='old',readonly)
.
.
.
      read (lun_in,10) station_name
  10  format(1x,a)
      read(lun_in,*) latitude, longitude, elevation
c
      icount = 0
      do i = 1,nlines
c
      read(lun_in,30,end=40) year,jday,month,day,hour(i),min(i),dt(i),
     1 zen(i),dw_solar(i),qc_dwsolar(i),uw_solar(i),qc_uwsolar(i),
     2 direct_n(i),qc_direct_n(i),diffuse(i),qc_diffuse(i),dw_ir(i),
     3 qc_dwir(i),dw_casetemp(i),qc_dwcasetemp(i),dw_dometemp(i),
     4 qc_dwdometemp(i),uw_ir(i),qc_uwir(i),uw_casetemp(i),
     5 qc_uwcasetemp(i),uw_dometemp(i),qc_uwdometemp(i),uvb(i),
     6 qc_uvb(i),par(i),qc_par(i),netsolar(i),qc_netsolar(i),netir(i),
     7 qc_netir(i),totalnet(i),qc_totalnet(i),temp(i),qc_temp(i),rh(i),
     8 qc_rh(i),windspd(i),qc_windspd(i),winddir(i),qc_winddir(i),
     9 pressure(i),qc_pressure(i)
c
      icount = icount + 1
  30  format(1x,i4,1x,i3,4(1x,i2),1x,f6.3,1x,f6.2,20(1x,f7.1,1x,i1))
```

```
c
      enddo
  40  type *,'end of file reached, ',icount,' records read'
.
.
.
```

The file structure includes two header records; the first has the name of the station, and the second gives the station's latitude, longitude, elevation above mean sea level in meters, and the version number of the file. These are followed by at most, 1440 lines of 1-min. data or 480 lines of 3-min. data. Files are organized in Universal Coordinated Time (UTC). The date, time, and solar zenith angle are given on every line. Data are reported as 1- or 3-minute averages of one-second samples. Reported times are the end times of the 1- or 3-min. averaging periods, i.e., the data given for 0000 UTC are averaged over the period from 2359 (or 2357) of the previous UTC day, to 0000 UTC. The solar zenith angle is reported in degrees on each line of data. It is computed for the central time of the averaging period of the sampled data. Missing-data periods within the files are not filled in with missing values, therefore, a file with missing periods will have fewer than 1440 lines for 1-min. data, or 480 lines for 3-min. data.

Radiation values are reported to the tenths place. Although this is beyond the accuracy of the instruments, data are reported in this manner in order to maintain the capability of backing out the raw voltages at the accuracy that they were originally reported.

The variables, their data type, and description are given below:

station_name	character	station name, e. g., Goodwin Creek
latitude	real	latitude in decimal degrees (e. g., 40.80)
longitude	real	longitude in decimal degrees (e. g., 105.12)
elevation	integer	elevation above sea level in meters
year	integer	year, i.e., 1995
jday	integer	Julian day (1 through 365 [or 366])
month	integer	number of the month (1-12)
day	integer	day of the month(1-31)
hour	integer	hour of the day (0-23)
min	integer	minute of the hour (0-59)
dt	real	decimal time (hour.decimalminutes,(23.5 = 2330)
zen	real	solar zenith angle (degrees)
dw_solar	real	downwelling global solar (Watts m^-2)
uw_solar	real	upwelling global solar (Watts m^-2)
direct_n	real	direct-normal solar (Watts m^-2)
diffuse	real	downwelling diffuse solar (Watts m^-2)
dw_ir	real	downwelling thermal infrared (Watts m^-2)
dw_casetemp	real	downwelling IR case temp. (K)
dw_dometemp	real	downwelling IR dome temp. (K)
uw_ir	real	upwelling thermal infrared (Watts m^-2)
uw_casetemp	real	upwelling IR case temp. (K)
uw_dometemp	real	upwelling IR dome temp. (K)
uvb	real	global UVB (milliWatts m^-2)
par	real	photosynthetically active radiation (Watts m^-2)

netsolar	real	net solar (dw_solar - uw_solar) (Watts m^-2)
netir	real	net infrared (dw_ir - uw_ir) (Watts m^-2)
totalnet	real	net radiation (netsolar+netir) (Watts m^-2)
temp	real	10-meter air temperature (¯C)
rh	real	relative humidity (%)
windspd	real	wind speed (ms^-1)
winddir	real	wind direction (degrees, clockwise from north)
pressure	real	station pressure (mb)

Diffuse solar and station pressure were not originally part of the SURFRAD suite of measurements. These were added to all stations in the 1996-97 time frame. Early data files from all stations have places for these parameters, but they are filled with missing values until the time when those instruments were installed.

Diffuse and global solar processing:

It is not unusual that thermopile-based solar instruments register a small negative signal at night. Most of this error is attributed to the thermopile cooling to space. These erroneous offsets are manifested in the global and diffuse solar measurements, but not in the pyrheliometer that measures direct-normal solar irradiance. Erroneous nighttime offsets in the diffuse and global solar measurements of between 0 and -10 Wm^-2 are typical, but can be as great as 30 Wm^-2. Because this behavior is common, only nighttime signals that drop below -30 are flagged. The erroneous offset is also present in daytime data, but is masked by the solar signal. A way to correct this error in the daytime diffuse measurements has been developed. It is described in Dutton et al, 2001 (J. Atmos. and Ocean Tech., 18, 297-314). Their method involves the development of a relationship between the thermopile output of a collocated pyrgeometer and the negative diffuse signals for nighttime periods. That relationship is then applied to all diffuse data (night and day).

As of March 19, 2004, all diffuse solar data prior to the 2001 instrument exchanges at each station have been corrected using the Dutton et al. method.

The Eppley model 8-48 pyranometer, which has been used for the diffuse measurement since the 2001 instrument exchanges, does not have this problem. The model 8-48 pyranometer relies on a differential signal between a black and a white surface on the detector. Since these two surfaces emit the same in the infrared, the differential signal owing to infrared cooling of the sensor's surface is zero. Thus, there is little or no offset owing to radiative cooling of the 8-48.

The global solar sensor has the same infrared cooling problem, but solar heating inside of the dome during the day prevents development of a simple relationship using nighttime data that is applicable during the day. Direct solar heating is not a problem with the diffuse pyranometer because it is, by practice, shaded. Therefore, the global solar measurement is not yet correctable, and should only be used in cases when the direct-normal and diffuse solar measurements are not available.

Net radiation processing:

Net radiation, net solar, net infrared, and total net (net solar + net infrared) are computed and reported in the daily processed files. In computing net solar (downwelling solar - upwelling solar) the best measure of downwelling solar is used. When direct-normal and diffuse solar are available, and deemed to be of good quality, their sum (direct-normal*cosSZA + diffuse) is used for the downwelling solar in the net solar calculation. Otherwise, the global solar measurement is used. Whenever any of the solar measurements are negative (owing to cooling of the thermopile near dusk and dawn), they are set to 0 before computing the net radiation.

Net solar is computed for solar zenith angles between 0 and 96 degrees. The net solar calculation is extended beyond 90, to 96 degrees to account for civil twilight.

All radiation parameters, except UVB, are reported in units of Watts m^-2; UVB is reported in milliWatts m^-2.

UVB processing:

The UVB flux is given as the total measured surface UVB flux convoluted with the erythemal action spectrum, i.e., that part of the UVB spectrum responsible for sunburns on human skin (erythema) and DNA damage. It is reported in this way because the response function of the UVB instrument approximates the erythemal action spectrum; thus the reported value is most representative of what the instrument is actually measuring.

Erythemal UVB irradiance reported in SURFRAD data files is computed for 300 Dobson units of ozone. This is done because the ozone value over the stations is unknown during the near real-time processing. If the ozone for a particular day is less than 300 Dobson units, then the reported UVB irradiance would be less than it should be. If the user would like to correct reported SURFRAD UVB measurements for the actual ozone, correction tables are available. Contact the webmaster for these tables.

The field UVB instruments are calibrated against a triad of "standard" UVB instruments that are maintained by NOAA's Central UV Calibration Facility. The standard instruments are periodically calibrated in the sun by comparing their broadband measurements to the integrated output of UV spectroradiometers. These calibrations are transferred to the field instruments just before they are deployed in the network by operating them side-by-side for a few days. To accomplish this transfer, a scale factor, which is simply a ratio of the test instrument's daily integral to that of the mean of the standards, is computed for each day that the test UVB instrument is run alongside the standards. The mean of the daily scale factors is used to transfer the standards' well-maintained calibrations to the test instruments when they are deployed in the field.

Mean calibration factors for the UVB standards are computed as a function of solar zenith angle, and are applied to the field instrument as such in the daily processing. For example, to compute the UVB irradiance, the output voltage, is multiplied times the Standards' calibration factor for the solar zenith angle that the measurement was made, then that result is divided by the scale factor for that field instrument.

The following table lists the UVB Standards' calibration information computed using the September 23, 1997 UV Spectroradiometer intercomparison data.

erythemal conversion factor (W m^-2 / V)	solar zenith angle	
0.136	0.0	extrapolated
0.136	5.0	
0.136	10.0	
0.135	15.0	
0.134	20.0	
0.133	25.0	
0.132	30.0	
0.131	35.0	
0.130	40.0	
0.129	45.0	
0.128	50.0	
0.128	55.0	
0.129	60.0	
0.132	65.0	
0.138	70.0	
0.147	75.0	
0.164	80.0	
0.191	85.0	
0.220	90.0	extrapolated

Similar calibration tables for the three UVB standards were computed for June 22, 2003, they are:

erythemal conversion factor (W m^-2 / V)	solar zenith angle	
0.150	0.0	extrapolated
0.150	5.0	
0.150	10.0	
0.149	15.0	
0.148	20.0	
0.147	25.0	
0.145	30.0	
0.144	35.0	

0.143	40.0	
0.141	45.0	
0.140	50.0	
0.140	55.0	
0.141	60.0	
0.144	65.0	
0.149	70.0	
0.159	75.0	
0.177	80.0	
0.206	85.0	
0.240	90.0	extrapolated

PAR processing:

To be consistent with other reported radiometric data in the file, values of photosynthetically active radiation (PAR) are reported in units of Wm^-2. The factory calibration for our Quantum sensors that measure PAR does not transform raw output from the instrument to these units; rather, it converts the sensor output to umoles (of photons) m^-2 s^-1. These units are converted to Wm^-2 by dividing umoles m^-2 s^-1 by 4.6, which is the conversion factor derived for the solar spectrum. To convert the reported value back to the original units, simply multiply our reported values times 4.6. The theoretical basis for converting umoles (of photons) m^-2 s^-1 to Wm^-2 for various light sources (including the sun) is described in Proceedings of the NATO Advanced Study Institute on Advanced Agricultural Instrumentation, 1984. W. G. Gensler (ed.), Martinus Nijnoff Publishers, Dordrect, The Netherlands.

QUALITY CONTROL AND QUALITY ASSURANCE

SURFRAD data distributed on the ftp site are provisional. NOAA has attempted to produce the best data set possible, however the data quality is constrained by measurement accuracies of the instruments and the quality of the calibrations. Regardless, NOAA attempts to ensure the best quality possible through quality assurance and quality control. The data are subjected to automatic procedures as the daily files are processed. At present, they are subjected only to this first-level check, and a daily "eye" check before being released, however, as quality control procedures become more refined, they will be applied, and new versions of the data files will be generated.

Quality assurance methods are in place to ensure against premature equipment failure in the field and post deployment data problems. For example, all instruments at each station are exchanged for newly calibrated instruments on an annual basis. Calibrations are performed by world-recognized organizations. Pyranometers and pyrheliometers have been calibrated at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, or the World Meteorological Organization's (WMO) Region 4 Regional Solar Calibration Center at NOAA in Boulder, Colo., which is maintained by GML. Calibration factors for the UVB instrument are transferred from three standards maintained by GML’s National UV Calibration Facility in Boulder. In general, all of the standards the GML and NREL are traceable to NIST, WMO, or their equivalent.

SURFRAD pyrgeometers are calibrated using three standards maintained at NOAA's Field Test and Calibration Facility at Table Mountain near Boulder, CO. SURFRAD pyrometer standards' calibrations are traceable to the WISG world standard device in Davos, Switzerland, where they are calibrated annually. In general, all of the standards at NOAA/Boulder and at DOE/NREL are traceable to world standards or an equivalent. Calibration factors for the UVB instrument are transferred from three standards maintained by GML's National UV Calibration Facility in Boulder. Finally, in order to maintain continuity between the returned instruments and their replacements, all instruments are gauged against three standard instruments before and after field deployment.

INSTRUMENTS:

1. The Yankee UVB Broadband Radiometer

The UVB radiometer measures erythemally weighted UVB irradiance in the range from 280 to 320 nm. Field UVB instruments are calibrated by referencing them to three standard instruments that are rigorously maintained by NOAA's Central UV Calibration Facility. Calibrations for these instruments are applied as a function of solar zenith angle.

2. The LI-COR Quantum (PAR) Sensor

The LI-COR Quantum (Photosynthetically Active Radiation, or PAR) sensor measures radiation in the band from 400 to 700 nm, which is the part of the solar spectrum that activates photosynthesis in plants. The PAR sensor sits on the main platform at SURFRAD stations and collects downwelling global radiation in the PAR band. These instruments are sent to the manufacturer annually for calibration.

3. The Normal Incidence Pryheliometer (NIP) and Kipp & Zonen CHP1

Pyrheliometers measure direct-normal solar radiation in the broadband spectral range from 280 to 3000 nm. Those used at SURFRAD stations are calibrated on a yearly basis using a cavity radiometer traceable to the WWR in Davos.

During the instrument exchanges in 2016, Eppley NIP pyrheliometers were replaced with the Kipp & Zonen CHP1 pyrheliometers at all SURFRAD stations

4. The Spectrolab SR-75 pyranometer

Pyranometers measure global downwelling and upwelling solar irradiance at SURFRAD stations. These instruments are sensitive to the same broadband spectral range as the NIP, 280 to 3000 nm. They are calibrated on a yearly basis.

An inherent problem with solid black thermopile pyrometers, such as the SR-75 and Eppley PSP, is that their sensor cools to space (if it is directed upward) and that causes a negative signal. This is apparent at night where it shows up as an erroneous negative irradiance that can be as great as -30 Wm^-2. Daytime data also contain this error but it is overwhelmed by the large solar signal. This error especially affects the diffuse measurement made by a PSP because the sensor is shaded. Therefore, the PSP is not used for the diffuse measurement.

5. Eppley 8-48 "black and white" pyranometer

This pyranometer has been used for the diffuse solar measurement since 2001. The 8-48 has been found to have desirable properties for this measurement because it does not use a solid black surface for the detector and thus does not have the "nighttime" offset problem. These instruments are sensitive to the same spectral range as the other broadband solar radiometers, 280 to 3000 nm. They are also calibrated on a yearly basis.

6. Precision Infrared Radiometer (PIR)

Two PIRs measure upwelling and downwelling thermal infrared irradiance. They are sensitive to the spectral range from 3000 to 50,000 nm. NOAA maintains three standard PIRs that are calibrated biennially by PMOD in Davos, Switzerland, and are used to calibrate field PIRs.

Fair use policy, license, etc.:

Findable and Accessible:
SURFRAD data are archived in many places including international archives and within NOAA at the NOAA Centers for Environmental Information (NCEI). Our data are freely available to users both from NCEI and on our GML web-site (e.g. GML web-site, GRAD ftp data access). The NCEI archive assigns a DOI to the data-sets including the radiation data from our networks.

Fair Use:
These data are made freely available to the public and the scientific community in the belief that their wide dissemination will lead to greater understanding and new scientific insights. To ensure that GML receives fair credit for their work please include relevant citation text in publications (see below). We encourage users to contact the data providers, who can provide detailed information about the measurements and scientific insight. In cases where the data are central to a publication, co-authorship for data providers may be appropriate.

License: