Contacts:

Dr. Laura Riihimaki
NOAA GML/CIRES
325 Broadway Street
Boulder, CO 80305

laura.riihimaki@noaa.gov
720-263-2016

John Augustine
NOAA GML
325 Broadway Street
Boulder, CO 80305

john.a.augustine@noaa.gov
720-258-6480

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NOTICE: The Radiative Flux Analysis methodology is the result of many years of research by Dr. Charles N. Long. These data products are made available to you by NOAA ESRL GMD with the understanding that at the minimum you will clearly acknowledge the source, and where appropriate, include Dr. Long as a co-author, as part of any presentation of results (including manuscripts for publication, talks, and posters).

Use the following references in any publications that use RadFlux data or concepts:

Long, C. N. and T. P. Ackerman, (2000): Identification of Clear Skies from Broadband Pyranometer Measurements and Calculation of Downwelling Shortwave Cloud Effects, JGR, 105, No. D12, 15609-15626.

Long, C. N. and D. D. Turner (2008): A Method for Continuous Estimation of Clear Sky Downwelling Longwave Radiative Flux Developed Using ARM Surface Measurements, J. Geophys. Res., 113, doi:10.1029/2008JD009936.

Other references that potentially could be cited are listed near the end of this document.

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DATA DISTRIBUTION:

SURFRAD RadFlux data are available at the GML website:

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

To get to a specific file, advance to the appropriate station directory, and then to the specific year directory, e.g., for Bondville 2024 data:

https://gml.noaa.gov/aftp/data/radiation/surfrad/RadFlux/bon/2024/

FILE STRUCTURE:

Daily SURFRAD RadFlux files have the extension ".lw1" They are organized with a header record containing the list of variables described below. The header is followed by the 1-min. data for the station and day chosen.

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"YYYYMMDD.lw1" "YYYYMMDD.rfa" and "YYYYMMDD.flx" files:

Zdate	date in YYYYMMDD format, based on GMT
Ztim	time in hhmm format, based on GMT
Ldate	date in YYYYMMDD format, based on LST
Ltim	time in hhmm format, based on LST
CosZ	Cosine of the solar zenith angle
AU	earth-sun distance in AUs
SWdn	best estimate downwelling SW from sum or global pyranometer (W/m^2)
CSWdn	estimated clear-sky downwelling SW (W/m^2)
LWdn	downwelling LW from pyrgeometer (W/m^2)
CLWdn	estimated clear-sky downwelling LW (W/m^2)
SWup	upwelling SW from pyranometer (W/m^2)
CSWup	estimated clear-sky upwelling SW (W/m^2)
LWup	upwelling LW from pyrgeometer (W/m^2)
CLWup	estimated clear-sky upwelling LW (W/m^2)
DifSW	measured downwelling diffuse SW (W/m^2)
CDifSW	estimated clear-sky downwelling diffuse SW (W/m^2)
DirSW	measured downwelling direct SW (W/m^2)
CDirSW	estimated clear-sky downwelling direct SW (W/m^2)
ClrF	Clear sky flag, 1 if SW detected clear sky, 2 if LW detected, 9 if CLW>LW, 3 if only std and Ta-Te diff OK and ONLY LWup accepted as clear
LWup	[NOT LWdn!!!], else 0 if cloudy
TauF	Tau flag, 1 if liq g used, 2 if ice g used, 0 if not calculated
TlmF	T limit flag, 1 if SW Scv used, 2 if LW Scv used, 3 if avg Ec used, 4 if lim=0.965*Ta used, 5 if just config limit temp used, 0 if not calculated
LWScv	estimated effective LW fractional sky cover
SWScv	estimated fractional sky cover from SW
CldTau	estimated effective visible cloud optical depth (only for SWScv>0.95)
CldTrn	estimated effective SW cloud transmissivity (SWdn/CSWdn ratio)
TeLim	Ice cloud temp limit (K)
LWTe	Sky brightness temp from LWdn (K)
CldTmp	estimated effective cloud radiating temperature

CldHgt   estimated effective cloud radiating height
Tair   air temperature (K)
VPrs   vapor pressure (mb)
RH   Relative Humidity (%)
RHfac   RH adjustment to Ec
Ec   effective clear-sky LW emissivity
Wspd   Wind speed (same as input)
LWlw   (if included) Contribution to clear-sky LWup from LWdn term (W/m^2)
SWlw   (if included) Contribution to clear-sky LWup from SWnet term (W/m^2)
RHlw   (if included) Contribution to clear-sky LWup from RH term (W/m^2)
Wslw   (if included) Contribution to clear-sky LWup from Wspd term (W/m^2)

There may be other columns of data if the provider used the option to include up to 20 extra variables. Hopefully the column header abbreviations in this case are self-explanatory as to what the variables are...if not, contact me for more info.

NOTE: that no data quality testing has been applied
to any of these extra variables by this processing. Hopefully data quality has been applied in producing the input files.

GENERAL RadFlux DESCRIPTION:

The Radiative Flux Analysis is a technique for using surface broadband radiation measurements for detecting periods of clear (i.e. cloudless) skies, and using the detected clear-sky data to fit functions which are then used to produce continuous clear-sky estimates. The clear-sky estimates and measurements are then used in various ways to infer cloud macrophysical properties. Detailed descriptions of the methodology are given in the papers referenced, and a listing of the derived parameters, are given below.

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Notes on the output files of the Radiative Flux Analysis code:

All data used as input are first tested with the QCRad methodology (Long and Shi, 2006, 2008).

Various portions of the Radiative Flux Analysis methodology are described in Long and Ackerman (2000), Long and Gaustad (2004), Long (2004, 2005), Long et al., (2006), Long and Turner (2008), Barnard and Long (2004), and

Barnard et al. (2008). The clear-sky LW and LW effective sky cover techniques are based on the pioneering work of Marty and Philopona (2000) and Durr and Philipona, (2004), which in turn use a formulation from Brutsaert (1975).

Some of this effort is a work-in-progress, and not all of the methodologies have undergone peer review. I am releasing these results to those interested with the understanding that some of these variables (as described below) are at this point preliminary results only.

Calculated variables that are considered "solid":

Estimates of clear-sky downwelling GlobalSW, DifSW, DirSW, upwelling SW; SW fractional sky cover; Cloud optical depth for sky cover > 0.95; effective cloud transmissivity; clear-sky downwelling LW, clear-sky upwelling SW, effective clear-sky emissivity.

Calculated variables that are considered "good":

LW sky cover

Some calculated variables that are "work in progress":

Estimated clear-sky upwelling LW (if .flx. or .rfa files), cloudy sky radiating temperature (equivalent to NFOV IRT measurements), Cloud height estimates (CLOUD HEIGHT ESTIMATES VERY CRUDE, USE AT YOUR OWN RISK!!! SEE DETAILED DESCRIPTION BELOW.)

Notes:

The cloud optical depth estimates are based on a technique by Barnard et al. (2008). This technique, a derived relationship based on the results of Min and Harrison (1996) and Min et al. 2004 is officially only valid for overcast skies (sky cover > 0.90). Thus, the current output includes cloud optical depth only for sky cover > 0.90 for now. Also, comparisons conducted as part of the ARM CLOWD project suggest that the Min and Harrison (1996) technique itself tends to overestimate the cloud optical depth for thinner clouds (Tau < 5) (Dave Turner, personal communication). Recent work using TWP-ICE data has prompted a change to using the total (global) SW in our formulation instead of the diffuse as in Min and Harrison, which appears to do well to compensate for this thin cloud overestimation (Barnard et al., 2008). Finally, an attempt is made to detect when the cloudiness present is likely to be ice clouds, for which an asymmetry parameter for ice (0.8 from Fu, 1996) should be used rather than the standard 0.87 used for liquid water clouds. The sky brightness temperature calculated from the downwelling LW using the Stephan-Boltzman relationship (Te) is compared to a limit temperature. The limit temperature is calculated using the effective clear-sky broadband LW emissivity (Ec) estimated by the Radiative Flux Analysis code (Long, 2004; Long and Turner, 2008) and the assumption that (1-Ec) is the extent to which clouds can influence the downwelling LW measurement. Then assuming a brightness temperature for the cloudy sky that contains a cloud at -40 C (where to first order only ice can exist), a limit is calculated as:

$$LWice = LWclr + Scv*(1-Ec)*sigma*Tice^4$$

$$Tlim = (LWice/sigma)^{0.25} - 2.0$$

Where LWice is the limit in terms of LW irradiance, LWclr is the estimated clear-sky LW, Scv is the fractional sky cover, sigma is the Stephan-Boltzman constant, Tice is the cloudy-sky brightness temperature for a cloud at -40 C, and Tlim is the limit in terms of sky brightness temperature. Then for times with Te is less than Tlim, an asymmetry parameter of 0.8 is used in the calculation of cloud optical depth, else 0.87 is used. From analysis of ARM Darwin TWP-ICE data, Tice is set to 248 K to represent the ice cloudy sky brightness temperature.

The estimated clear-sky downwelling LW is derived from a technique based on Brutsaert (1975). Unlike the Brutsaert formulation, we use the known clear-sky periods and the corresponding measured clear-sky downwelling LW to calculate lapse rate coefficients. These calculated lapse rate coefficients are then interpolated for cloudy periods, similar to the SW technique. Comparisons show that about 80% of the estimated clear-sky LW falls within 4 W/m^2 of the corresponding clear-sky measured LW, and within 8 W/m^2 radiative transfer calculations (which themselves agree with clear-sky measurements at the 4 W/m^2 level) used as a comparison under cloudy skies (Long and Turner, 2008). There is a known "problem", however, in that the only information available for LW estimation is surface measurements. For those times of abrupt major changes in temperature or humidity profiles significantly differing from the data the lapse rate coefficients were determined from, such as cold front passages, the clear-sky LW estimates will exhibit greater error. This same problem occurs for model calculations due to the interpolation through time in between sonde profiles (Long and Turner, 2008). Fortunately, these conditions occur infrequently.

The LW effective sky cover is from a technique developed by Durr and Philipona (2004), but with some differences. Durr and Philipona use a climatologically derived and applied formulation for clear-sky effective broadband LW emissivity, whereas those here are derived from surrounding clear-sky data. In addition, Durr and Philipona use a calculation of downwelling LW standard deviation for the hour preceding the time of interest in their sky cover prediction, where here I use a running 21-minute standard deviation centered on the time of interest. The variable is deemed as the "effective LW sky cover" in that the downwelling LW at the surface is insensitive to high and thin clouds, thus the sky cover is essentially most representative of the amount of low and mid-level cloudiness (Long, 2004; Long and Turner, 2008). The original Durr and Philipona retrieval is in Oktas, so their inherent uncertainty is at least 1/8 of sky cover. I use a 7-minute running mean to smooth the results. ARM is working on fielding an Infrared Sky Imager that eventually should provide the data needed to refine the (or even develop a new) approach, similar to how I used TSI data to develop the SW sky cover technique.

CSWup - There are identified problems associated with guesstimating upwelling SW measurements using only detected clear-sky measurements, and then interpolating fit coefficients as we do for the downwelling SW (Long, 2005). For instance, when it snows, it's cloudy, thus the "fit" is way off until the next "clear enough" day for fitting after the snow event. This introduces a large error during the period, and for times of snow melt. Data show that the bi-directional reflectance function also changes over time depending on the surface characteristics. Thus, the current procedure for estimating clear-sky upwelling SW is to look through the data and take a daily average for all data from 1100 through 1300 local standard time. This captures, at least on a daily basis, the major changes in surface albedo such as those from snow accumulation or snow melt. A second pass through the data then uses the "daily noon average" as a constant, and determines a function for any data that include at least 25% of the total SW produced by the direct component (i.e. significant direct sunlight producing the bi-directional nature of the albedo dependence) using the cosine of the solar zenith angle as the independent variable. Again, these fit coefficients are interpolated for days when insufficient direct SW data are available for fitting. The function is then multiplied times the estimated clear-sky SWdn to produce a continuous estimate of clear-sky SWup. My examination of these results so far suggest this technique does pretty much eliminate the "gotcha" of it always being cloudy when it snows, and does a better job than just multiplying the measured albedo (SWup/SWdn which often behaves erratically through time depending on whether the direct sun is blocked by cloud or not) times the clear-sky SWdn. A paper on the technique is in progress.

CLWup - In the "lw1" output files, when there are values other than "-9999.0" present they represent the actual measured upwelling LW when that time was determined to be effectively clear-sky for the broadband LW. For the "rfa and "flx" output files, the clear-sky upwelling LW uses the same detected SW and "LW effective" clear-sky data to empirically derive fit coefficients that are again interpolated for cloudy periods (Long, 2005). In this case, since the upwelling LW is tied to the total surface energy exchange including latent and sensible heat, the independent variables used are the downwelling LW, the net SW, 2-meter relative humidity, and wind speed. These last are used as surrogates to help account for the unknown relative changes in surface sensible and latent heat partitioning with respect to the radiative terms. Comparisons show that over 90% of the estimations agree with detected clear-sky LWup measurements to within 5 W/m^2. Though estimation of the accuracy of the interpolated values has yet to be investigated, visual inspection indicates that the results appear intuitively reasonable. The major assumption here is that the surface radiating temperature responds relatively quickly to changes in the radiative input to the surface, which is the case for land surfaces, but not so for water or snow surfaces. For water, such as oceans or swampy ground, the thermal mass of the water precludes rapid temperature response. For snow covered ground, a significant portion of the energy can be tied up in water phase change which then does not go into changing the surface skin temperature. Thus this technique does not work for water, snow, and ice surfaces.

Cloud field temperature and height estimates - these are "work in progress". I use the measured and clear-sky estimated LWdn, the LW sky cover amount, and Independent Pixel Approximation arguments to estimate the LW effective radiating ("cloud") temperature. The uncertainty in this estimation is largely driven by the uncertainty associated with the LW effective sky cover. The value generated assumes a single layer of cloudiness covering the "LW sky cover" portion of the sky, and with uniform radiating properties. Thus, this value is best described as an "effective cloud field radiating temperature" with all the assumptions that the word "effective" usually implies. Comparisons have shown that for LW sky cover of 50% or more, the retrieved radiating temperatures show remarkable agreement with corresponding IRT measurements. However, the agreement rapidly degrades for LW sky < 50%, thus we limit these retrievals for times when the LW sky cover is > 50%.

In addition, given a good cloud radiating temperature estimate, one must then figure out how to reasonably translate that temperature to a cloud height. I use here the difference between the estimated cloud field radiating temperature and the ambient air temperature, and a simple 10-degree-C-per-km lapse rate to estimate the effective cloud field radiating height. THIS IS VERY CRUDE!!! Note that the imaginary "radiating surface" relates approximately to about one optical depth into the cloud, and so is NOT located at the same height as the cloud physical boundary as would be determined by a lidar or cloud radar. Again, this is a work in progress, and to some degree these values are included in the output files as "place holders" for a time when better cloud height estimations might be possible through further development. USE THESE AT YOUR OWN RISK FOR NOW.

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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.

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