11.12 Using integrated surface radiation measurements to infer cloud properties.

C. N. Long(1), J. C. Barnard(1), J. Calbo(2), T. P. Ackerman(1)

(1) Pacific Northwest National Laboratory, Richland, WA, USA
(2) University of Girona, Girona, Spain

Introduction

In recent years the advance of cloud measurement instrumentation has lead to the deployment of several sophisticated surface cloud and radiation sites such as those of the DOE Atmospheric Radiation Measurement (ARM) Program. These data are used in the retrieval of cloud properties, especially microphysical. In turn, the retrieved properties are used for developing, improving, and testing models and satellite retrievals. However, one drawback to these sophisticated measurement suites is their cost. Thus, there are but a few sites of this type around the globe.

Conversely, there are many surface radiation measurement sites such as those in the Baseline Surface Radiation Network (BSRN), the NOAA Surface Radiation (SURFRAD) Network, the ARM network, the Australian Bureau of Meteorology network, and the NOAA Climate Modeling Diagnostics Laboratory (CMDL) network, to name just a few. These sites all provide measurements of broadband shortwave (SW) and longwave (LW) irradiance, and standard surface meteorological parameters. Methodologies have been developed to use these surface measurements to infer properties about the clouds that affect them.

SW measurements and inferred properties

Starting with the detection of daylight clear (i.e. cloudless) sky periods using a technique developed by Long and Ackerman (2000, JGR), we can empirically fit functions to the clear-sky data, interpolate for cloudy periods, and then continuously estimate the clear-sky downwelling SW. A comparison of the measured and clear-sky irradiances then determines the downwelling SW cloud effect. These clear- and all-sky data are then used to infer fractional sky cover amounts after a technique developed by Long et al. (1999).

Corresponding author address: Dr. Charles N. Long, P. O. 999, MSIN: K9-38, Richland, WA, USA 99352; chuck.long@pnl.gov

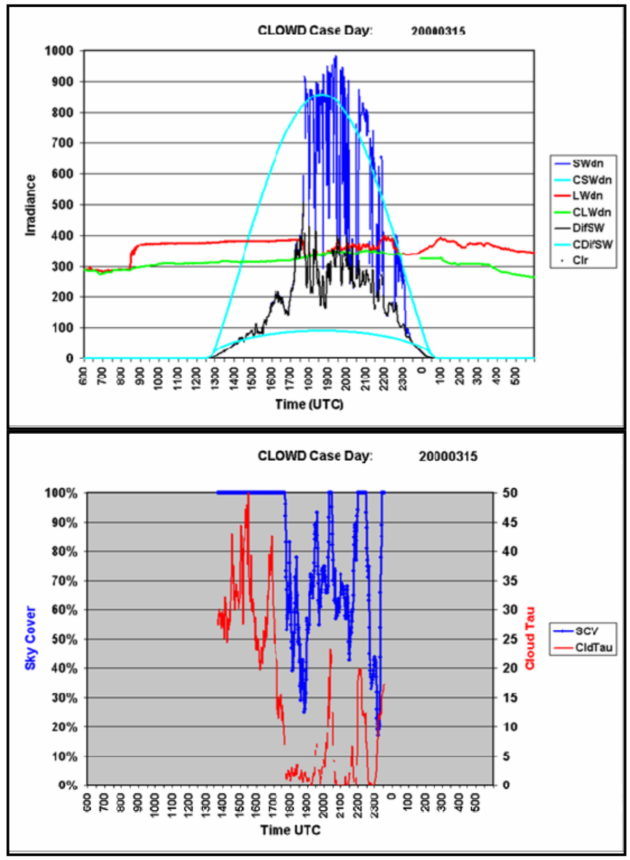

Figure 1: Upper panel shows the measured (blue) and clear-sky (light blue) downwelling total SW on March 15, 2000 at the ARM SGP site. Included are the measured (black) and clear-sky (light blue) diffuse SW, and the measured (red) and clear-sky (green) downwelling LW. Lower panel shows the daylight fractional sky cover (blue) and liquid water cloud optical depth (red) inferred from the data in the left panel.

More recently, a technique has been developed to derive cloud visible optical depths (Barnard and Long, 2004). The Barnard and Long technique is based on a methodology by Min and Harrison (1996) that uses Multi-Frequency Rotating Shadowband Radiometer spectral measurements, but for broadband SW instead. In both cases the retrieved optical depths assume an effective plane-parallel spherical droplet cloud, and are known to overestimate for small optical depths. We are currently working on refining the retrievals to account for water/ice differentiation. We use independent pixel approximation arguments for partly cloudy skies. An example of these retrievals is given in Figure 1 for March 15, 2000 at the ARM Southern Great Plains (SGP) site. This daylight period started out overcast with fairly optically thick cloudiness, with a changeover to a sky containing thinner broken clouds.

LW clear-sky irradiance

Our current work is geared toward similar retrievals using LW measurements, i.e. the detection of LW effective clear-sky periods, continuous estimation of clear-sky downwelling LW, and determination of LW cloud effect. Related work in this area has been described by Marty and Philipona (2000), Duerr and Philipona (2004), and Long, (2004). All of these techniques are based on a formulation for estimating clear-sky downwelling LW proposed by Brutsaert (1975) using surface measurements of air temperature and humidity.

In our approach, we start with the detected clear-sky periods from the SW analysis (Long and Ackerman, 2000). We additionally detect “LW effective clear-sky” periods using an analysis of the variability of the LW time series (after Marty and Philipona, 2000). Since both clear-sky and overcast downwelling LW measurements are typified by low variability through time, we also use the temperature difference between the sky brightness temperature (calculated using the Stephan-Boltzman relation and the measured LW) and the ambient air temperature measured at screen height. If a 21-minute running standard deviation of the measured LW is less than 0.7 Wm^{-2} and air temperature – brightness temperature difference is greater than 12 K, then data are considered “LW clear-sky”. We then use both the SW and LW detected clear-sky measurements to calculate Brutsaert formulation lapse rate coefficients, and interpolate the coefficients for cloudy periods similar to SW analysis technique.

Figure 2 shows a comparison of calculated and measured downwelling LW for detected clear-sky periods over eight years at the ARM SGP site. The original Brutsaert formulation using a standard lapse rate coefficient produces an RMS standard deviation from X=Y of about 16 Wm^{-2}, with a slope significantly different from 1. Our new technique produces an RMS deviation of only about 4 Wm^{-2}, and a slope of 1. Thus, we have improved the estimation of downwelling clear-sky LW by about a factor of 4 over the original Brutsaert methodology. Figure 1 shows our estimated clear-sky downwelling LW for this day as the green line.

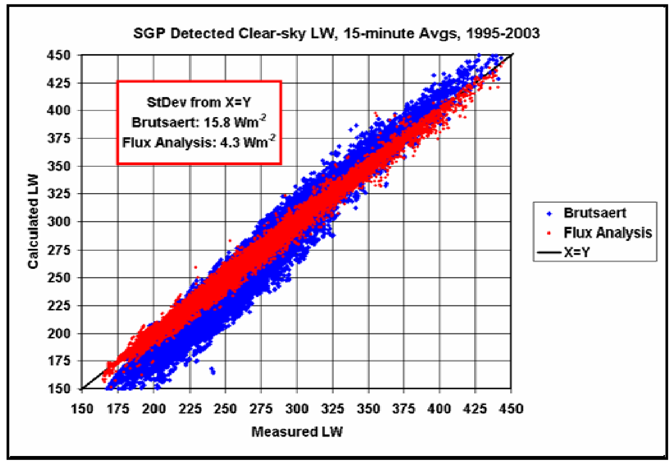

Figure 2: Comparison of measured clear-sky downwelling LW to corresponding calculations using the original Brutsaert (blue) and our Flux Analysis (red) methodologies.

LW effective sky cover

Techniques are being developed to estimate effective LW sky cover (primarily consisting of the low and mid-level cloud amounts) from the broadband LW measurements. Durr and Philipona (2004) related the variability of downwelling LW measurements and a ratio of the "effective LW emissivity" from measured LW over the "effective clear-sky LW emissivity" (from Marty and Philipona, 2000) to observer reports of low and mid-level cloud amounts. They use a climatology-based method for clear LW estimates and “tuned” threshold limits, along with LW variability over the previous hour, to classify LW effective sky cover estimated in oktas. We have implemented the Durr and Philipona technique, but with the difference that our downwelling clear-sky LW is estimated from surrounding data as described, and we use a running 21-minute standard deviation centered on the time of interest instead of from the previous hour. Thus, at this point some “tuning” is needed to refine our methodology.

In an alternate technique, Han and Ellingson (1999) and Takara and Ellingson (2003) developed a means to infer LW effective sky cover using spectral interferometer (AERI) measurements in the 8 – 12 micron infrared window. In this technique, they estimate both the clear-sky and overcast sky flux values, then use independent pixel approximation arguments and the measurements to estimate LW effective sky cover. In similar manner, our LW Flux Analysis provides the needed clear-sky and measured LW. We can use Infrared Thermometer (IRT) measurements to infer cloudy sky radiating brightness temperature, and then use the Flux Analysis effective clear-sky LW emissivity and IRT to estimate the overcast LW influence on the LW measurement.

Figure 3 shows sky cover estimates inferred for March 25, 2003 at the ARM SGP site. As can be seen, both LW techniques show good agreement with the SW inferred sky cover for lower clouds, as noted by the cloud radar cloud base height estimates in yellow. However, the LW techniques have greater difficulty agreeing for higher cloud bases, as shown for periods between 300 – 700 UTC, and after 2100 UTC this day. Given further refinement of these LW techniques, we will then be able to reliably estimate LW effective sky cover both day and night, as opposed to the daylight-only retrievals from the SW technique.

Cloud effective radiating temperature

If we have an IRT, we can infer cloud base effective radiating temperature after accounting for the effects of the intervening atmosphere below cloud base, and screening the data to remove partially filled FOV and optically thin clouds. Alternatively, we can use independent pixel approximation arguments, the broadband LW effective cloud amount, the estimated LW clear-sky emissivity, and the clear-sky and measured LW to estimate the cloud field effective brightness temperature using equation 1. This technique assumes a single plane-parallel cloud layer, and as mentioned above the results are most valid for low and middle clouds.

$$T_{cld} = \{(LW-LW_{clr})/([1-\varepsilon_c]*SCV_{LW}*\sigma)\}^{1/4} \qquad (1)$$

Where: T_{cld} is the cloud field effective brightness temperature, LW is the measured LW, LW_{clr} is the clear-sky LW, ε_c is the clear-sky LW emmisivity, SCV_{LW} is the LW effective sky cover, and σ is the Stephan-Boltzman constant.

Once a cloud temperature is determined, one can find that temperature on a temperature profile of the atmosphere above the site. However, it must be realized that the cloud brightness temperature is really the brightness temperature of an imaginary "effective radiating surface". This "surface" is representative of a physical depth into the cloud that is radiatively comprised of the integrated cloud emission, typically about an optical depth of about 1 or so into the cloud. Thus, any comparison of physical cloud boundary with the height of the "effective radiating surface" temperature on the temperature profile would naturally exhibit a difference dependant on the macro- and microphysical properties of the cloud itself. This height difference can be significantly different, on the order of kilometers, for high and thin clouds.

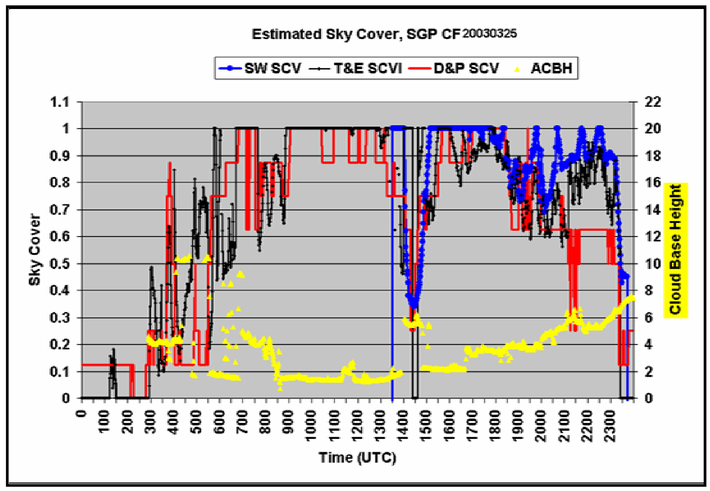

Figure 3: Sky cover estimates as inferred using SW (blue), LW IRT (black), and LW broadband techniques as described. Yellow is the cloud base estimates from cloud radar measurements.

Summary

Using surface radiation and meteorological measurements, we can now infer useful cloud information such as:

- Clear-sky downwelling SW and LW
- Corresponding SW and LW cloud effect
- SW and LW fractional sky cover
- Cloud visible optical depths
- Cloud effective radiating temperature

Our continuing research includes using these inferred properties to develop a methodology for sky classification by cloud type, which should significantly improve proposed techniques such as the one by Calbó et al. (2001). In addition, we are investigating with some success the estimation of clear-sky upwelling SW and LW irradiances. These last will give the means for inferring what has been defined in the literature as the complete surface SW and LW cloud radiative cloud forcing. However, none of the analyses and cloud properties retrievals are possible without the needed surface measurements on which they are based. As such, we highly urge and recommend that all surface measurement sites include measurements of:

- Broadband downwelling and upwelling SW and LW irradiances
- SW component (direct and diffuse)
- Surface meteorology (T, RH, Prs, Wspd, Wdir)
- Vertical NFOV IRT measurements

References:

Barnard, J. C., and C. N. Long, (2004): A Simple Empirical Equation to Calculate Cloud Optical Thickness Using Shortwave Broadband Measurement, JAM, 43, 1057-1066

Brutsaert, W., (1975): On a Derivable Formula for Longwave Radiation from Clear Skies, Water Resour. Res., 11(3), 742– 744.

Durr, B., and R. Philipona (2004), Automatic cloud amount detection by surface longwave downward radiation measurements, J. Geophys. Res., 109, D05201, doi:10.1029/2003JD004182.

Calbó, J., J-A. González, D. Pagès (2001): A Method for Sky condition classification from ground-based solar radiation measurements, JAM, 40, 2193-2199.

Han, D. and R. G. Ellingson, 1999: Cumulus cloud formulations for longwave radiation calculations, J. Atmos. Sci., 56, 837-851.

Long, C. N., (2004): The Next Generation Flux Analysis: Adding Clear-sky LW and LW Cloud Effects, Cloud Optical Depths, and Improved Sky Cover Estimates, 14th ARM Science Team Meeting Proceedings, Albuquerque, New Mexico, March 22-26, 2004

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., 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.

Marty, C., and R. Philipona (2000), The clear-sky index to separate clear sky from cloudy-sky situations in climate research, Geophys. Res. Lett., 27, 2649–2652.

Min, Q., Harrison, L. C., (1996): Cloud Properties Derived from Surface MFRSR Measurements and Comparison with GOES Results at the ARM SGP Site, Geophysical Research Letters, Vol. 23, pp. 1641-1644.

Takara, E. E., and R. G. Ellingson, 2003: Using narrow and wide field of view instruments to evaluate longwave parameterizations for fair weather cumulus cloud fields, Proceedings of the Thirteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting, March 31 to April 4, 2003, Broomfield, Colorado.