# Improvement in the Assessment of SIRS Broadband Longwave Radiation Data Quality

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## Introduction

Validation of the performance of the Solar Infrared Station (SIRS) pyrgeometers is being conducted for the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP). Cloud and Radiation Testbed (CART) site extended facilities (EFs). Improvements to this effort include comparison of the downwelling longwave irradiance to estimates from several published algorithms based on surface meteorological conditions (including temperature, vapor pressure, and the clearness index). The algorithms provide estimates for clear skies, overcast skies, and all-sky conditions (during daylight only). The clear-sky and overcast-sky estimates provide a range for which the actual data would be expected to fall, while the all-sky algorithm produces an estimate of the flux in any sky condition during the daylight hours. The implementation of these algorithms has improved the detection of erroneous data on a real-time basis.

## Broadband Downwelling Longwave Radiation Algorithms

### Clear-Sky Downwelling Longwave Estimates

1. Monteith (1973): This algorithm, as well as the following, can be used to establish a lower bounds for the downwelling hemispheric flux.

$$\text{downwelling\_ir\_flux} = \text{esky} * \text{sigma} * T^4$$

where esky = .61 + 0.6*sqrt(vap)

Vapor pressure (vap) was obtained from the Surface Meteorological Observing Station (SMOS) or energy balance Bowen ratio (EBBR), or a nearest neighbor if neither an EBBR or SMOS is available. Esky is the sky emissivity.

2. Prata (1996): Prata extensively tested this formula over a large range of environmental temperatures (-40 °C to +40 °C), and with use of radiosonde measurements and LOWTRAN-7. The root mean square error of the formula was estimated at ± 12 W/m$^2$.

$$\text{downwelling\_ir\_flux} = [1.0 - (1.0 + xi) \exp \{-(1.2 + 3.0 * xi) ^{**}.5\}] * \text{sigma} * T^4$$

where xi = 46.5 (vap/T)

## Cloudy-Sky Downwelling Longwave Estimates

1. Monteith (1973): This algorithm can be used to establish an upper bounds for the expectation of the value of the downwelling thermal radiation. This formula was used without modification.

$$\text{downwelling\_ir\_flux} = \text{esky} * (1. + (0.178 - 0.00957 * (T - 290))) * \text{sigma} * T^4$$

## All-Sky Downwelling Longwave Estimates

1. Aubinet (1994): The intent for this algorithm is to establish an expectation for the thermal radiation for all-sky conditions that does not represent a bounds, but an anticipated value. Regression equations to predict the thermal radiation were developed from the surface temperature, the surface vapor pressure, and an estimate of cloudiness. The following algorithm was based on data from near Brussels, Belgium:

$$\text{downwelling\_ir\_flux} = \text{sigma} * \text{Tsky}^4$$

where $\text{Tsky} = 94 + 12.6 * \ln(\text{vap}) - 13 * \text{K0} + .341 * T$

K0 is a sky clearness index which we is calculated by dividing the measured downwelling by a clear-sky estimate. The clear-sky estimate was based on no water vapor, while K0 was smoothed in time for representativeness.

Modifications to Aubinet (1994):

The algorithm did not produce satisfactory results over the SGP CART site with the original regression coefficients. A new set of regression coefficients was regenerated using data from December 1998 from the E13 EF. Multivariate linear regression was used to calculate the new coefficients. Figure 1 is a comparison of the actual fluxes and predicted fluxes from the regression equation. The resulting equation for Tsky based on the December 1998 data:

$$\text{Tsky} = -.1 + 1.74 * \ln(\text{vap}) - 24.3 * \text{K0} + .966 * T$$

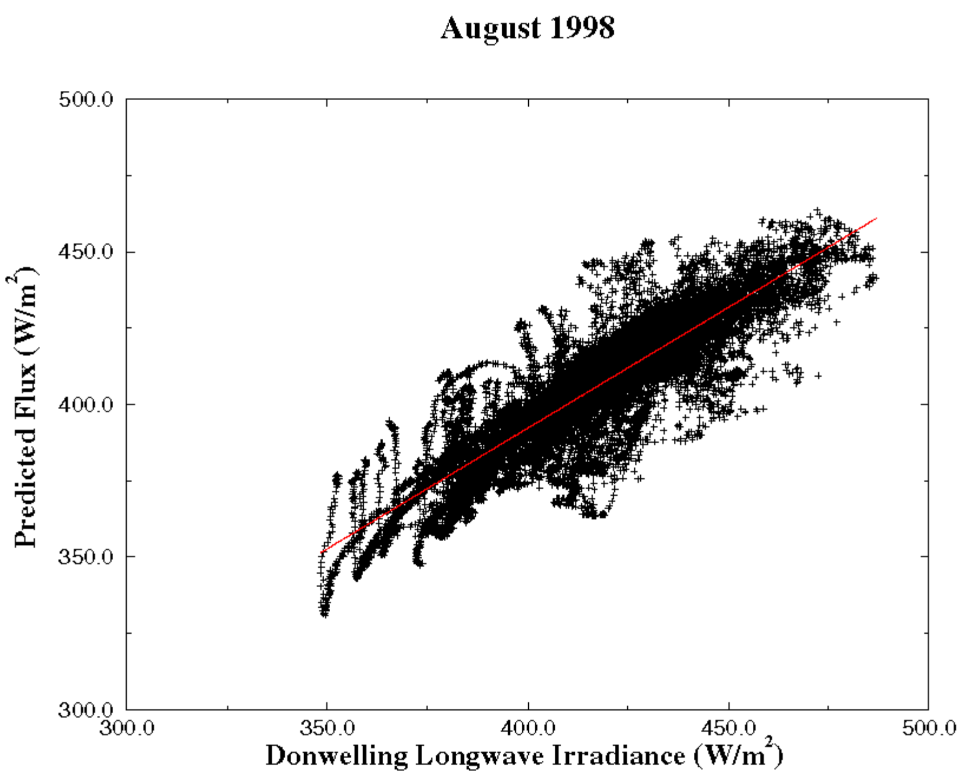


**Figure 1**. Comparison of predicted and actual downwelling longwave fluxes based on data from August 1998.

The best fit line in Figure 1 does not have a slope of unity. The authors thought it would be desirable to account for the slope error, thus the slope and intercept of the regression equation was used to adjust the prediction (which is the equation currently being used for operational quality control graphics):

$$\text{downwelling\_ir\_flux} = ((\text{sigma} * \text{Tsky}^4) - 24.5) / .911$$

A similar equation was generated using data from August 1998 and produced the following results:

$$\text{Tsky} = -1.3 + 7.37 * \ln(\text{vap}) - 7.6 * \text{K0} + .796 * \text{T}$$

and

$$\text{downwelling\_ir\_flux} = ((\text{sigma} * \text{Tsky}^4) - 76.3) / .790$$

# Discussion

## Clear and Cloudy Algorithms

### Pyrgeometer Bias

The use of the clear and cloudy sky algorithms as data bounds has had operational impact for the SGP CART site. The algorithms have identified data that are obviously out of bounds. But the algorithms have been able to detect more subtle variations in radiometer performance that may ultimately be related to calibration issues of pyrgeometers. Figure 2 is a ten-day comparison between the various algorithms and actual downwelling thermal radiation for E9. It is noted that the E9 values have a low bias with respect to the clear estimates of about 25 $Wm^{-2}$ (lesser under cloud sky conditions), while E13 (not shown) does not have a significant bias. It is likely that the E9 radiometer has a slight calibration bias, based on comparison to E13 and other facilities.

The use of surface data may be the ultimate limiting factor to improving the algorithms. For example, when low-level inversions occur over the site, the surface data representativeness comes into question. Vertical variations in temperature and/or vapor pressure outside of climatological means will likely affect this approach.

### Pyrgeometer Noise

The algorithms also provide a basis for evaluation of instrument noise. Figure 3 shows the high amount of instrument noise observed at E25 with respect to the various algorithm estimates. While this situation may be quite obvious, noise of quite a lower magnitude would be detectable from such a comparison.

## All-Sky Algorithm

### Comparison to Data

The all-sky algorithm provides the most direct comparison to the actual downwelling longwave radiation. Figure 4 depicts a day on which the all-sky algorithm compared well to the data at E11. Evaluation of the all-sky algorithm has been anecdotal so far, but more quantitative comparisons can be completed. Limitations with the algorithm include:

- limitations in regression approach to predicting thermal radiation (surface data representativeness, etc.)

- characterization of cloudiness factor using hemispherical data lag between when solar radiometers “see” cloud and pyrgeometers “see” cloud

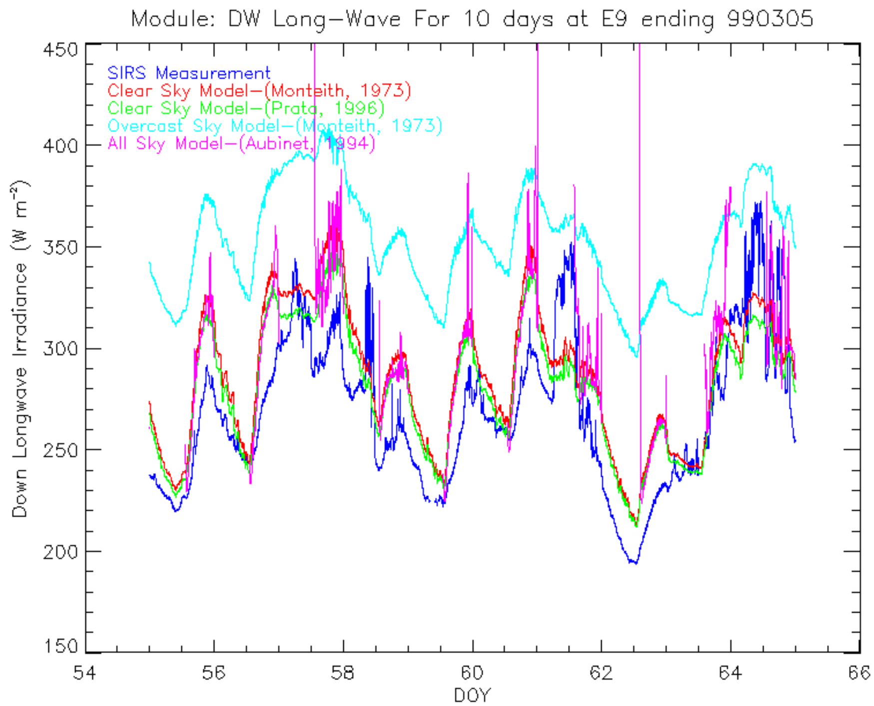


**Figure 2**. Ten-day comparison of predicted and actual downwelling longwave fluxes for E9.

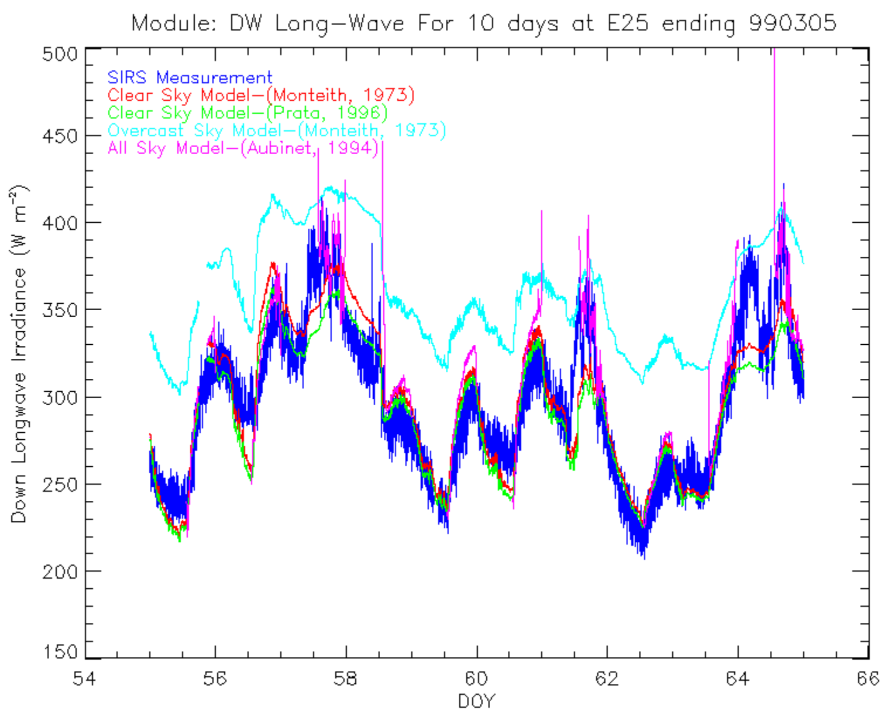


**Figure 3**. Comparison showing noise in the pyrgeometer observations at E25.

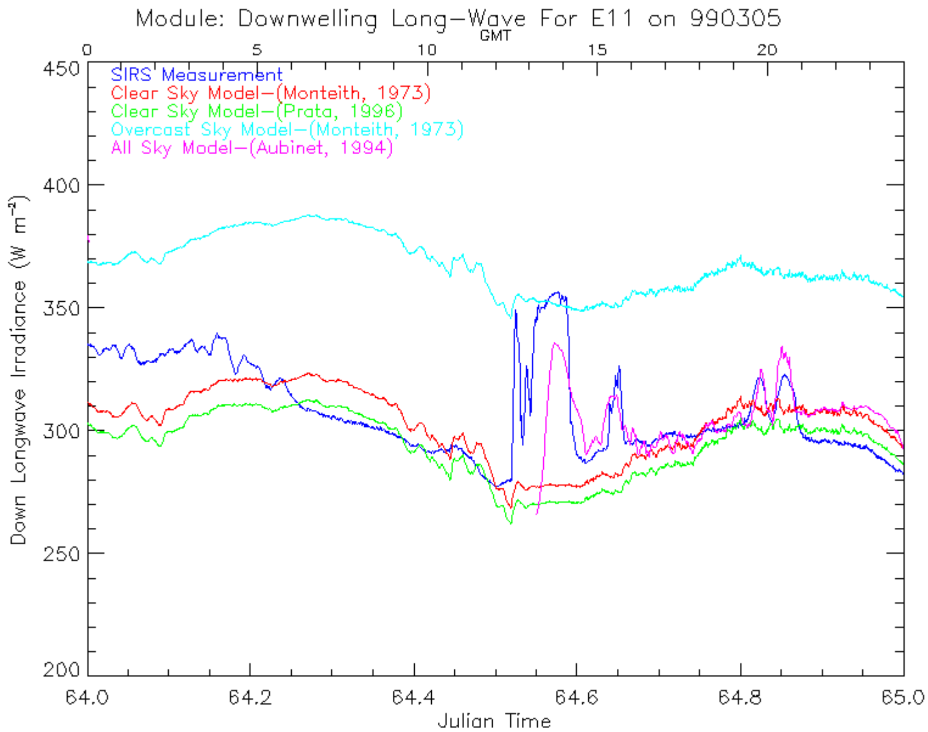


**Figure 4**. Comparison of predicted and actual downwelling longwave fluxes on March 7,1999, at E11. The all-sky algorithm compared very well to the observations on this day.

- use only during daylight conditions
- application for site operations.

The limitation of the current approach is obvious from the comparison of the coefficients calculated from the December and August periods (and to the original coefficients noted by Aubinet). It should be noted that the Aubinet algorithm was intended for daily averages, and not for application to high resolutions data. The cloudiness parameter, K0, has a stronger influence within the December period vs. the August period. This is an intuitive result since the higher amount of precipitable water during August limits the impact of cloud on the downwelling hemispheric flux. The converse is true in December where lower water vapor amounts allow for clouds to be easily “seen” in the thermal radiation data. A new approach is being developed to make an algorithm that will not have such strong seasonal dependency.

The operational significance of the all-sky algorithm has not yet been demonstrated. It is unclear if pyrgeometer malfunctions will be detectable that could not have be detected from the other algorithms. It is possible that the all-sky algorithm could detect events in which the pyrgeometer domes are obscured with condensation or frost during clear skies, but this would likely require very careful examination of the data. It is also possible that long-term averages of the comparison between the algorithm and the pyrgeometer data will reveal peculiarities.

## References

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Prata, A. J., 1996: A new long-wave formula for estimating downward clear-sky radiation at the surface. *Quart. J. Royal Meteorol. Soc*., **122**, 1127-1151.