Modeling IR Radiative Loss from Eppley PSP Pyranometers

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ABSTRACT

A method has been developed to estimate IR radiative losses using solar radiation and meteorological data without the need for pyrgeometer data. The modeled IR radiative losses are not as accurate as that obtained using pyrgeometer information, but 95% of the modeled IR radiative losses are with a few W/m^2 of the actual IR radiative losses. Currently this method is limited to having a least some period when pyrgeometers measurements are available. More testing and evaluations are needed at a number of locations to test the general applicability of the model developed.

Keywords: Pyranometer, pyrgeometer, irradiance, IR, modeling, global, diffuse, PSP

1. INTRODUCTION

Since the 1970s, solar radiation data has been collected using Eppley Precision Spectral Pyranometers (PSP). This instrument is classified as a type one instrument, but it does have some systematic errors. Some of these errors relate to ambient temperature and deviation from a perfect cosine response. The factory calibration sheet comes with a plot of responsivity verses temperature and the deviation from true cosine response can be observed in field calibrations using absolute cavity radiometers. Around 2000, the effect of IR radiative loss on pyranometer values was uncovered when diffuse measurements were compared to theoretical values by those involved in the Atmospheric Radiation Measurement (ARM) program[1,2].

The deviation from an exact cosine response is also well documented and efforts are underway at the National Renewable Energy Laboratory to correct for the cosine response and the IR loss. In fact corrected cosine and thermal global data are available on the National Renewable Energy Laboratory (NREL) data page[3] along with the original global data.

Corrections to the PSP for the IR radiative loss are calculated using meteorological and pyrgeometer data[1,2]. However, there are many stations that do not have the pyrgeometer data to correct for the IR loss. In a previous paper[4] a prototype model was developed using one just month of data to estimate the IR radiative loss with just global, beam, and meteorological data.

This paper looks at seven months of data to more thoroughly test the model. In addition, the processing code for this study includes both the full (using both the pyrgeometer (PIR) detector flux and the case and dome temperatures) and detector-only correction methodology[2]. As with the ARM correction processing code, the full correction is applied if available, else the detector-only correction is used. The original paper[4] only used the detector-only correction methodology. In general, use of the full correction methodology increased the calculated IR loss values a few Watts/m^2. The term calculated IR radiative loss refers to the use of this methodology to determine the IR radiative loss.

The paper is organized as follows. First the data are briefly discussed. This is followed by a description of the IR loss mechanism. Then the capabilities of modeling the IR loss are examined from summer to winter in Eugene, Oregon. The findings are discussed along with suggestions for further evaluations.

2. THE DATA

The data used in this study come from the solar radiation monitoring site in Eugene, Oregon operated by the University of Oregon Solar Radiation Monitoring Laboratory (UO SMRL). Some of the parameters measured at this site are global, beam, and diffuse irradiance along with irradiance on tilted surfaces. In addition, ambient temperature, wind speed, relative humidity, and pressure are measured on a one-minute basis. The diffuse data are obtained from a Schenk Star pyranometer that is mounted on a ventilator and shaded by a shade ball on an automatic tracker and from an AC-ventilated shaded Eppley Precision Spectral Pyranometer (PSP) mounted on the same tracker. Most of these data values were sampled every two seconds and one-minute averages were gathered[5].

In May 2007, Chuck Long of Pacific Northwest National Laboratories set up a pyrgeometer at the Eugene site with temperature sensors for the dome and body of the instrument. The pyrgeometer was also mounted on the automatic tracker and a shade ball shaded the dome from direct sunlight. In addition, an Eppley PSP was set up at the site along with relative humidity and ambient temperature sensors. These data were measured every second and one-minute data averages and standard deviations were recorded. A Delta-T Devices model SPN-1 pyranometer was used to obtain global, diffuse, and beam irradiance values to check for sky cover.

The absolute accuracy of the Eppley PSP measurements is roughly ±4%, the Schenk Star measurements have an absolute uncertainty of ±5%, the Eppley NIP has an uncertainty of ±3%, and the pyrgeometer measurements have an uncertainty of ±4%.

The data from May 2007 through January 23, 2008 are used in this study to evaluate seasonal affects on the IR radiative loss.

3. IR RADIATIVE LOSS

The PSP thermopile produces a voltage proportional to the energy flow from the sensing disk to the body of the instrument, the cold junction. At night the energy flow reverses as the sensing disk sees the cold sky (through interacting with the pyranometer’s domes) and a negative voltage results. During the day, there also is some heat flow (IR radiation) from the sensor disk to the sky. This reduces the energy flow thorough the thermopile and hence reduces the voltage produced. This radiation to the sky is called the IR radiative loss, and this produces a systematic error in the pyranometer readings.

4. MODELING IR RADIATIVE LOSSES

At night, the negative PSP readings result from noise and IR radiative losses. In addition, at night sunlight does not affect the measurements making it easier to examine the nature of IR radiative losses. Figure 1 is a plot of nighttime IR radiative loss in Eugene, Oregon during January 2008. The large spike occurs during the a few hours before sunrise on January 4th. It is not clear what caused this spike, and there is no clear change in the meteorological parameters that would make this evident. However, another PSP pyranometer located at the site also has a similar IR loss spike at that time period. Such spikes also occur during other months.

To capture the range of temperature and relative humidity, the nighttime one minute data files from June and December 2007 were combined. Correlations were significant for ambient temperature, relative humidity, wind speed, and hours since sunset. In Fig. 1, there is a slight decrease from sunset to sunrise. However, in June, there is a more pronounced change. The correlation relationship is given in Table 1. The standard error for the correlation is 0.67 W/m^2.

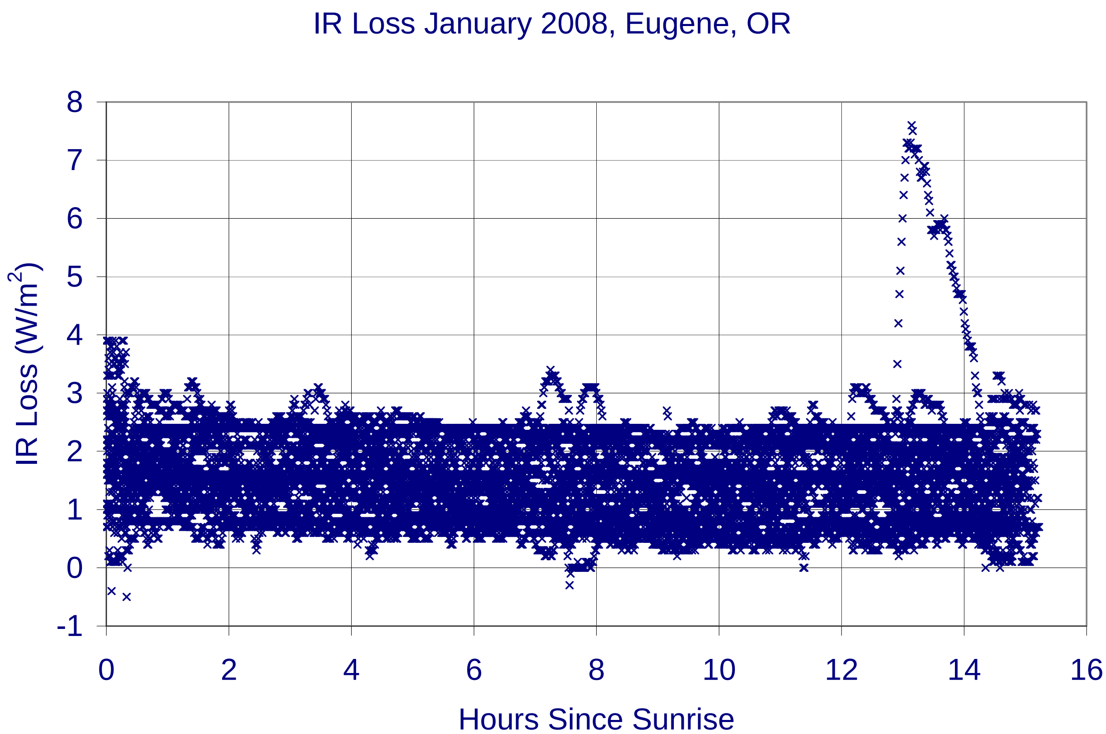

Fig. 1: IR radiative loss values for PSP in Eugene, OR. The spike in IR loss also shows up on other PSPs being monitored at the site.

Looking at the typical values for each parameter given in Table 1, it can be seen that the IR loss is mostly affected by ambient temperature followed by relative humidity. While wind speed and hours from sunset do correlate with the IR loss, their contribution is much smaller and not significant when one considers that the nighttime radiative loss averages around 1.9 W/m^2.

There are two ways to look at the fits to the nighttime IR radiative losses. The first is to plot the difference between the calculated IR loss and the model of this IR loss. This is shown in Fig. 2. The modeled IR values underestimate the high IR loss values and over estimate the low IR loss values.

Table 1: Correlation parameters to the nighttime IR radiative loss fit

Parameter	Coefficient	% Standard deviation	Average	Typical Value
Intercept	-6.732594391	-4.36%	na	-6.73
Air Temperature (K)	0.037519618	2.52%	281 K	10.54
Relative Humidity	-0.023199815	-1.73%	85%	-1.97
Wind Speed (m/s)	0.056107950	5.72%	1.18 m/s	.07
Hours from Sunset	-0.008908429	-9.60%	6.5	-.06

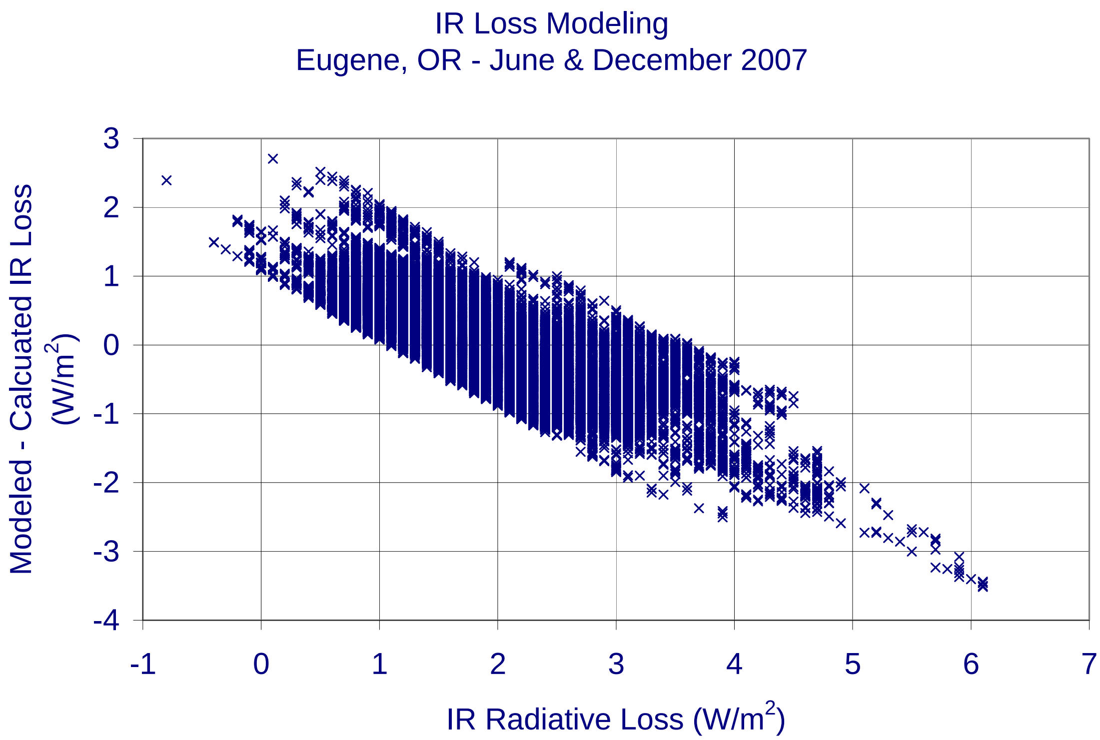

Fig. 2: Plot of the difference between the modeled and calculated IR radiative flux for Eugene, OR. during June and December 2007. Note that the modeled IR values underestimate the high IR values and over estimate the low IR values.

The difference between the modeled and calculated IR loss values also appears in a histogram of the IR radiative loss values in Fig. 3. While the model does account for some of the IR radiative losses, the model does not have the parameters that produce the distribution of IR losses as seen in the data. This indicates that similar shortcomings probably will be in the model for daytime IR losses.

Of course, the best way to account for IR nighttime losses is to zero them out during the night and use the average IR losses just before sunrise and just after sunset to account for the IR losses during the first and last hour of the day as discussed in the previous paper[4].

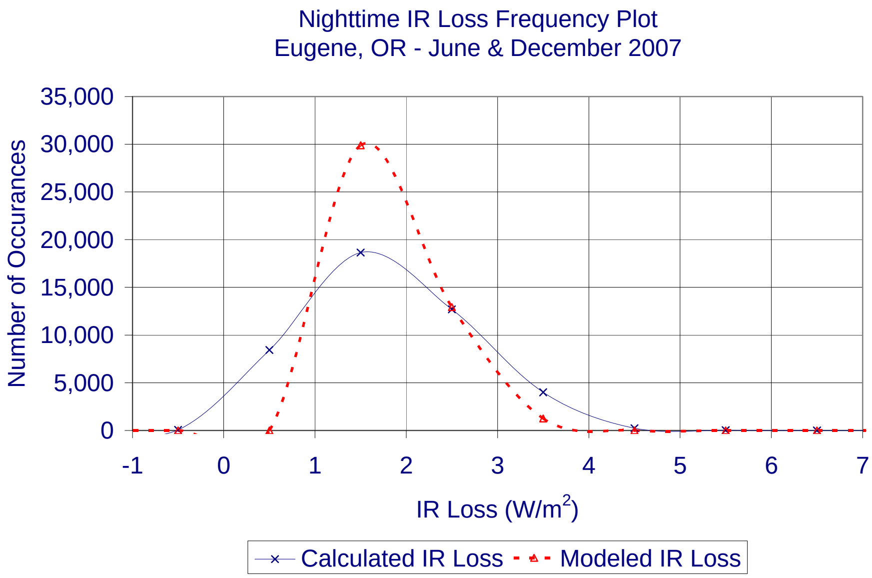

Fig. 3: Histogram of the nighttime IR radiative loss for June and December 2007. Values are binned in 1 W/m^2 intervals.

5. CALCULATING DAYTIME IR RADIATIVE LOSS

Modeling the daytime IR losses should be similar to modeling the nighttime IR losses with the additional input of solar radiation. The additional inputs of direct normal radiation and global radiation were both shown to be correlated with the calculated IR radiative loss. The cosine of the zenith angle (Z) also had a statistically significant correlation.

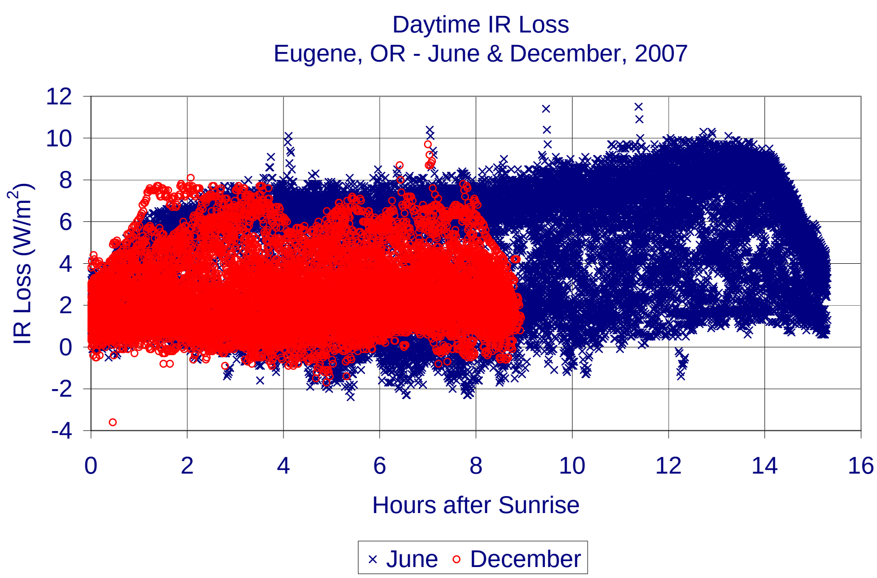

Fig. 4: Daytime IR radiative loss plotted against hours from sunrise. June data points are the blue x's and the December data points are the red circles.

As mentioned in a previous paper[4], the IR radiative loss increases during the day (Fig. 4). Several interesting features appear in the figures. First the June data appear in two groupings, probably related to clear and cloudy days. December data, which is much cloudier, has only a few points that might be classified as clear. The IR radiative loss is expected to be different on clear and cloudy days. In addition, the calculated IR radiative loss can actually be a small radiative gain under certain circumstances during the middle of the day.

Table 2 gives the correlation parameters and their coefficients along with the standard deviations for the model for estimating the IR radiative loss. Note that both the global and beam values were normalized by dividing by their relative extraterrestrial values, giving k_t and k_b respectively. The standard error for the correlation is approximately 1.1 W/m^2.

Table 2: Correlation parameters to the daytime IR radiative loss fit

Parameter	Coefficient	% Standard Deviation	Average	Typical Value
$Cos^2(Z)$	-2.015919306	-1.33%	.287	-0.58
Air Temperature (K)	0.016245749	1.57%	287	4.66
Wind Speed (m/s)	0.171404011	3.13%	1.76	0.30
Relative Humidity (%)	-0.066733752	-2.93%	68	-4.54
RH^2	0.000341808	4.40%	5081	1.74
k_b	15.39136566	0.86%	.202	3.11
k_b^2	-3.712642205	-4.62%	.114	-0.42
k_t	4.505620812	2.43%	.398	1.79
k_t^2	-13.06702546	-1.04%	.221	-2.89
hours after sunrise	0.071509261	2.56%	6.42	0.46

The typical value is obtained by multiplying the average value of each parameter by the correlation coefficient for the parameter. The parameters with the largest contribution to the modeled IR radiative loss are again ambient temperature and relative humidity. In addition both the normalized direct normal beam irradiance and global irradiance influence the modeled IR radiative loss. Wind speed, cosine of the zenith angle (squared) and hours after sunrise also influence the final value, but play less of a role. The contribution of air pressure to the correlation was not statistically significant, although this might play a factor in sites located at higher altitudes.

The difference between the modeled and calculated IR radiative values is shown in Figs. 5 and 6. Figure 5 plots the difference between the modeled and calculated IR radiative loss against the calculated IR radiative loss.

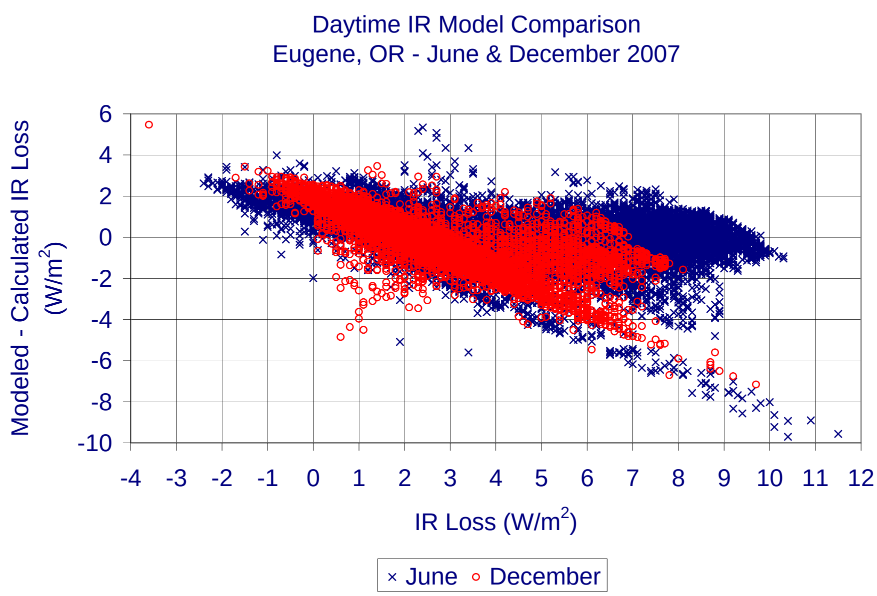

Fig. 5: Plot of modeled minus calculated IR radiative loss plotted against calculated IR radiative loss. The June values are represented by blue x's and the December values are the red circles.

The plot indicates that most of the modeled values are within ±2 W/m^2 of the calculated IR radiative loss values. However there are a significant number of points that are between 2 and 4 W/m^2 less than the calculated values. In addition, as in the nighttime IR loss modeling, the modeled values do not match the low values calculated for the IR loss.

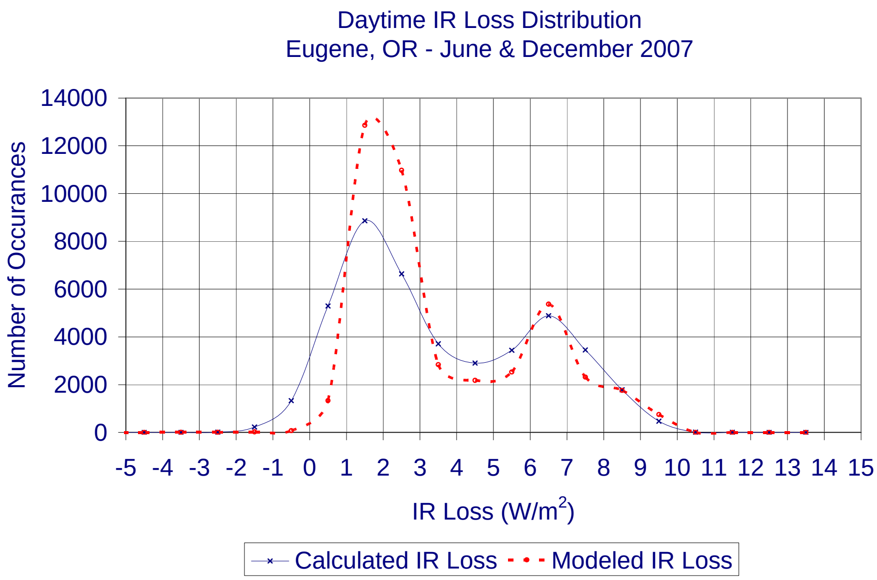

Fig. 6: Histogram of the daytime IR radiative loss for June and December 2007.

The daytime distribution plot of IR radiative loss, Fig. 6, is different than the distribution plots for nighttime plots, Fig. 3, because the daytime plots are much broader and show a double peak. The double peak is mostly from the June values where the clear and cloudy days are quite distinct in character. Still, the modeled distribution does not produce data at the low end of the IR radiative losses (or gains).

The hours from sunrise correlates with IR radiative loss because the IR radiative loss increases during the day, especially during the sunny summer days. The cosine of the zenith angle correlates with the IR radiative loss because about an hour to an hour and a half after sunrise and before sunset, the value and spread of the IR radiative loss changes. In Fig. 7, this is seen as the spread of the IR loss decreases by about a factor of 2 as the cosine of the zenith angle decreases from 0.2 (~78.5°) to zero. Even the December data shows this trend.

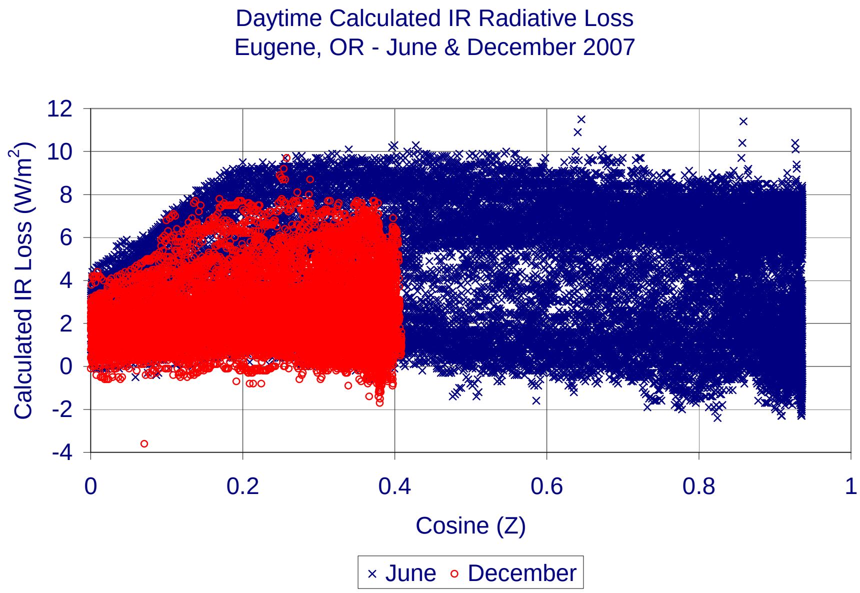

Fig. 7: Plot of IR radiative loss plotted against cosine of the zenith angle. June data points are shown by the blue x's and December data points by the red o's.

6. APPLICATION TO OTHER PYRANOMETERS AND LOCATIONS

This study has been limited to one location, Eugene, Oregon and to one pyranometer. It is known that different pyranometers have different IR radiative loss coefficients. Will the IR loss models scale, or are IR losses different for different pyranometers? One Eppley PSP pyranometer was also measuring global irradiance during the same time period, and one can check the nighttime IR losses to see how the IR radiative losses compare (Fig. 8). This shows that there is a linear relationship between IR radiative losses between these two PSP pyranometers. Note that the PSP used in this study was mounted on a battery powered ventilator while the auxiliary PSP use in Fig. 8 was mounted on an AC powered ventilator. There is a difference in IR radiative loss depending on the type of ventilator used.

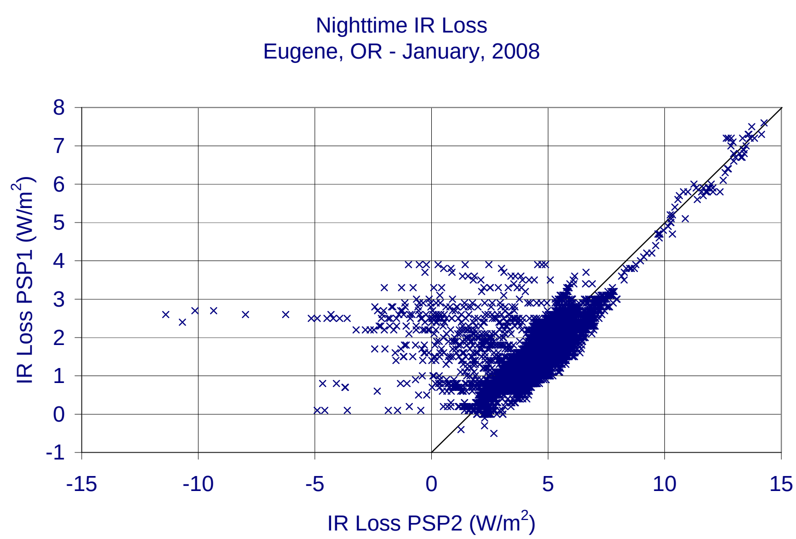

Fig. 8: Plot of IR radiative loss from two different PSP pyranometers at night in January, 2008. Some of the scatter of the points to the left of the main body of points is associated with snowy periods.

Other locations experience different conditions, especially differences in the sky temperature. From the previous paper [3], the IR radiative losses can be significantly larger, 10 or even 20 W/m^2 higher, than those obtained in Eugene. These locations need to be included in the study for a comprehensive model.

7. DISCUSSION AND CONCLUSIONS

Typically, IR radiative losses are calculated using pyrgeometer and auxiliary meteorological data that measure the sky temperature and help determine the dome temperature seen by the pyranometer. Pyrgeometer data are not always available and other means of estimating the IR radiative losses are needed. As discussed in a previous paper [4], it is possible to use the nighttime IR radiative losses to estimate the daytime losses, but this significantly underestimates the IR radiative losses during the day. The model presented in this study will, on average account for the IR radiative losses.

Ideally, one would like to be able to take the IR radiative losses measured at night and correct the PSP data for the IR radiative losses during the day. Several steps have been taken to enable this to happen. A model has been developed that correlates solar radiation and meteorological data to calculated IR losses for one pyranometer at one location. A linear relationship between the nighttime IR radiative losses between two pyranometers has been established, and it is assumed that the model could be applied to the other pyranometer to obtain the daytime IR corrections. This assumption needs to be tested. The next step is to test the model at alternate locations and determine which portions of the model can be universally applied. This is the crucial step in this modeling process and will tell how useful this modeling is.

A methodology has been developed to go back and correct the IR radiative losses for the pyranometer measurements in Eugene during periods with PIR measurements.

In a perfect world, it would not be necessary to correct and enhance the data being measured. However, there are systematic errors in measured data and sometimes it is necessary to make adjustments to measure data to get the accuracy in the results that are needed.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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