pk.asrc.08.10.2004

Cosine correction in rss105

RSS105 is not a Lambertian spectroradiometer. For this reason both direct and diffuse irradiances have to be corrected.

Direct irradiance correction

The direct horizontal irradiance must be divided by the normalized cosine correction. The cosine correction for rss105 is specified by two files: *rss105w2e.030421_040809* and *rss105s2n.030417_040809* that were obtained from measurements in lab where angular responses were measured for two azimuthal planes (West to East and South to North). Values of corrections for other azimuth and solar zenith angles are obtained via interpolation between these two files.

The cosine correction is wavelength dependent. Each file is defined at eight 130 pixel wide intervals. The center of each interval corresponds to the following wavelengths: 367, 394, 428, 472, 533, 621, 755 and 958nm. The curves are plotted in Figures 1 and 2.

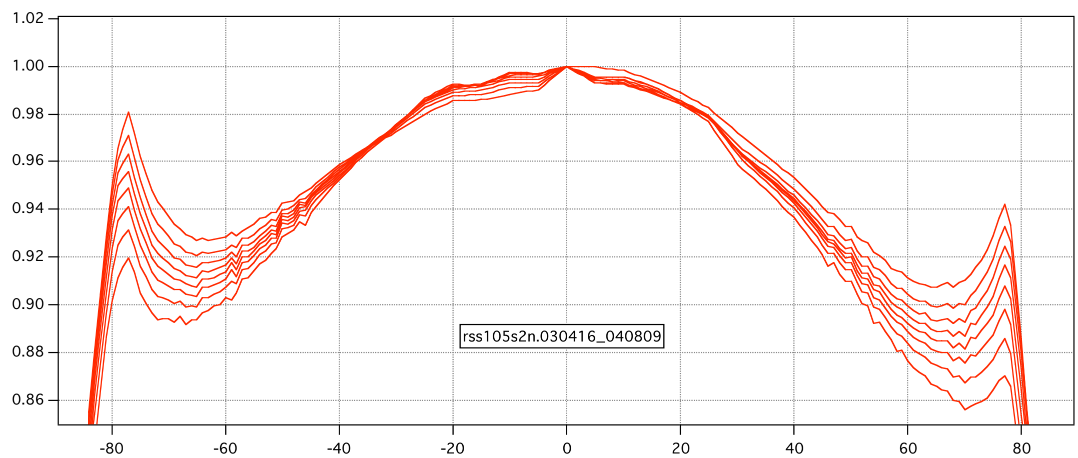

Figure 1. Normalized cosine responses in South-to-North azimuthal plane.

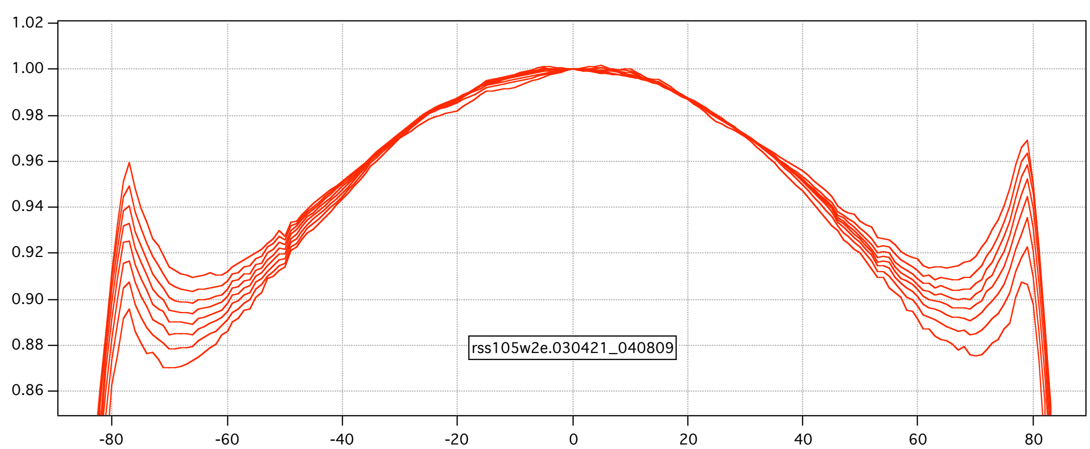

Figure 2. Normalized cosine responses in West-to-East azimuthal plane.

Diffuse irradiance correction

The diffuse irradiance must be divided by the diffuse normalized cosine correction. The diffuse cosine correction was calculated as ratio between integrated Rayleigh sky radiance (SZA=45°) produced by RSS105 and to that produced by a Lambertian sensor. The diffuse cosine correction is depicted in Figure 3.

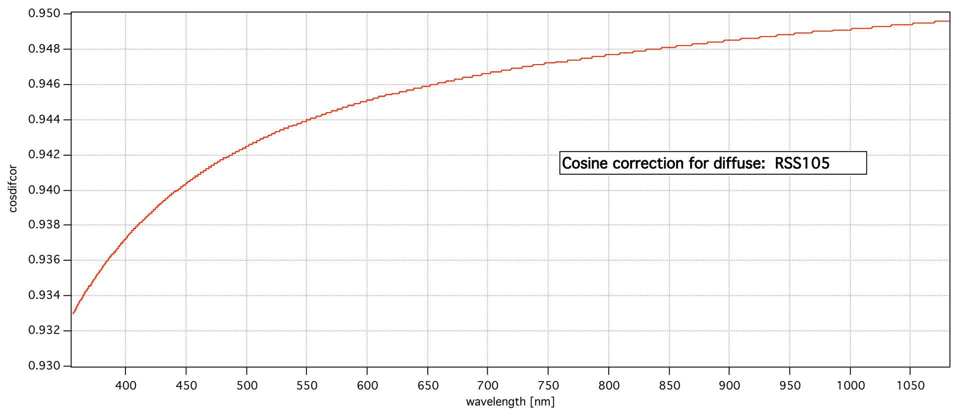

Figure 3. Diffuse cosine correction.

Polarization sensitivity

The diffuser of RSS105 has residual polarization sensitivity. The polarization sensitivity is defined as:

$$P=(A_{TM}-A_{TE})/(A_{TM}+A_{TE})$$

where A_{TM} and A_{TE} are angular responses for TM and TE linear polarizations, respectively.

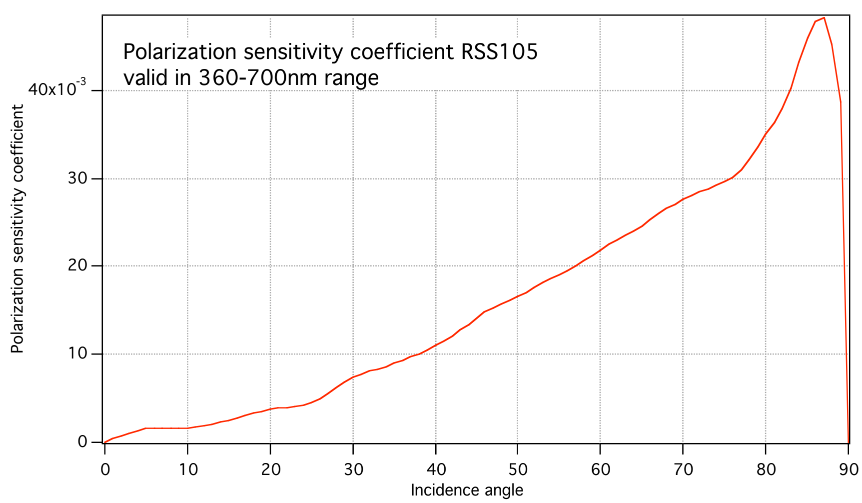

Figure 4. Polarization sensitivity.

The polarization sensitivity was measured with linear polarizer. The measurements were valid in 360nm-700nm range. Slight wavelength dependence was ignored when deriving the curve depicted in Figure 4.

Application of corrections

Direct irradiance is corrected routinely in RSStk program. All output files contain corrected direct irradiance.

Diffuse irradiance is currently not being corrected. New format of data will provide corrected diffuse and total horizontal as a sum of corrected direct and corrected diffuse.

Polarization is provided for error estimates only when dealing with the diffuse irradiance of clear sky. This magnitude of polarization effect if not corrected underestimates diffuse irradiance by about 1.5% for small solar zenith angles and overestimates it by about 1% for large solar zenith angles. For SZA approximately 55° the effect is nil*. There is no intention to use it in programs that generates calibrated and corrected RSS output files.

File Locator

File description	File name	Location
Cosine correction files for direct irradiance	rss105w2e.030421_040809 rss105s2n.030417_040809	ftp://oink.asrc.cestm.albany.edu/pub/RSS105/SGP/Aux/
Diffuse iradiance cosine correction	rss105_cosdifcor_030421	ftp://oink.asrc.cestm.albany.edu/pub/RSS105/SGP/Aux/
Polarization sensitivity coefficient	rss105_PolarizSensCoef_03421	ftp://oink.asrc.cestm.albany.edu/pub/RSS105/SGP/Aux/

* Kiedron, P. and J. Michalsky, *Measurement errors in diffuse irradiance with non-Lambertian radiometers,* International J. Remote Sensing, 24, 237-247, 2003

Appendix: Measurements issues and accuracy

A: Cosine response measurements

The measurements were performed on large cosine bench at ASRC lab in April 2003. The Xe arc source was monitored with reference Si-diode via fused silica 45° beam-splitter. To compensate polarization introduced by the beam-splitter another beam-splitter oriented at 45° but in sagittal plane was added.

The measurements were performed for the following zenith angles:

0, 95, 90, 89, 88,…,45, 40,…0, -5,…,-45, 46,…,90, 95, 0

The measurement for w2e was started from East and for s2n was started from North, so first the positive angles were measured.

At za=±90° alignment was checked during and after measurement.

At each angle from 4 to 20 (depending on signal-to-noise ratio) 400ms exposures were taken. Each exposure before being summed up was divided by the reference diode signal.

In data processing the measurements at ±95° were not used to correct for stray light as the latter was negligible.

Three measurements at za=0° were interpolated in time and used to normalized measurements at other angles. In the ratios occasionally slight residual NIR emission lines were observed indicating that slight wavelength shifts were occurring during measurements. The wavelength was not corrected. Instead the ratio for each angle was fitted with 3rd degree polynomial. This effectively removed wavelength shift effects in NIR. Then the results were interpolated for 179 angles between –89° to 89°.

Measurements at few angles (at most three per file) were corrupted. Then the measurement was replaced with the interpolation from two neighboring angles.

A: Cosine response precision

The cosine correction files consists of 8 bins uniformly spaced every 130 pixels. The cosine correction for each bin is an average of 21 pixels (±10) pixels arround the center of the bin. The typical maximum error of binning is less than ±0.5% (Figure 1A). If however the cosine corrections uses interpolation to generate corrections for other pixels, the error would be even smaller.

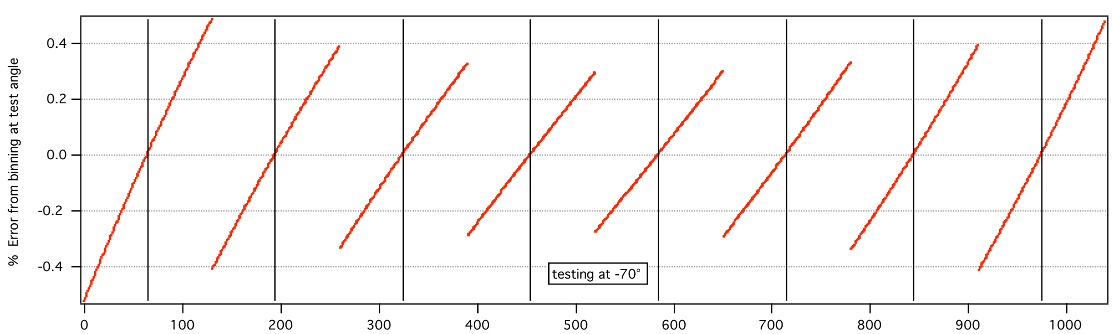

Figure 1A. Binning error measured at za=-70°.

In each orientation measurement was performed twice on two separate days. The differences between these measurements give us some idea about the precision of the measurements and subsequent data processing. In Figures 2A and 3A the differences for eight bins are plotted. In Figure 4A we also compare the cosine correction obtained from two measurements for TM an TE polarizations.

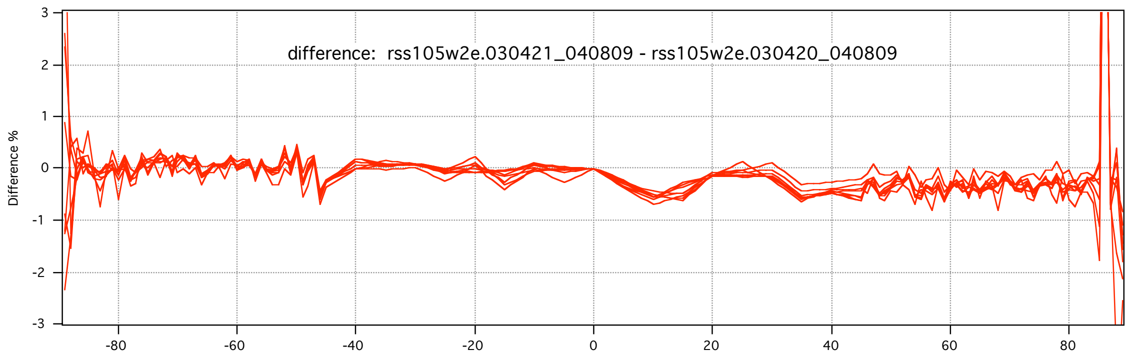

Figure 2A. Difference of two measurements of w2e correction.

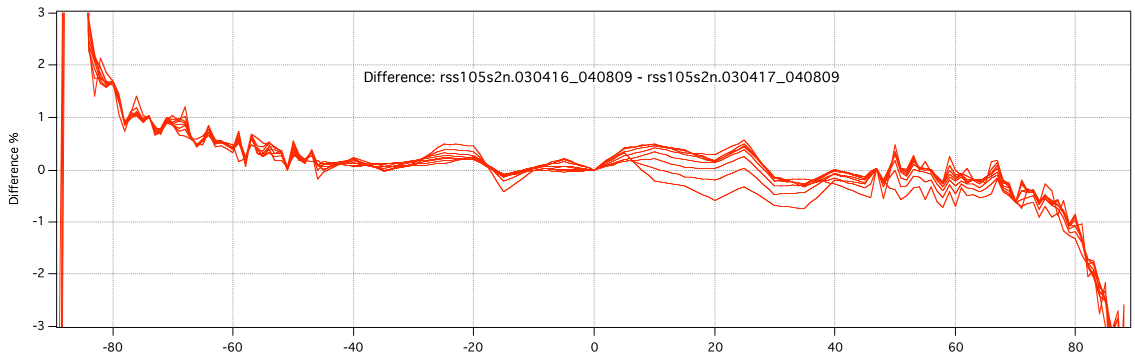

Figure 3A. Difference of two measurements of s2n correction.

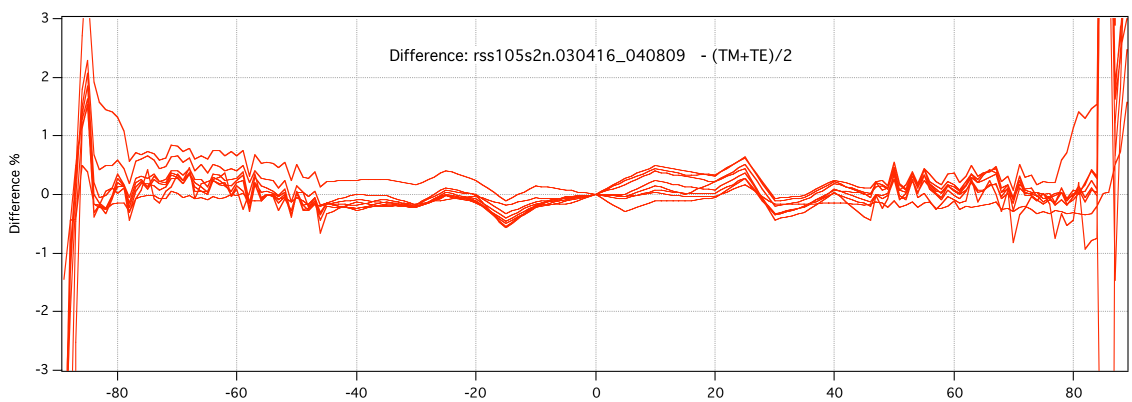

Figure 4A. Difference of two measurements of s2n correction. The second measurement was derived from the average of TM and TE polarizations.

The results indicate that cosine corrections may contain systematic ±0.5% errors within ±80° range that most likely were caused by imperfect correction of lamp intensity fluctuations. Also we observe that the two measurements of s2n cosine corrections differ by ±1% at ±80° . This could have occurred due to angle errors.

The angle errors in application of cosine correction to field data is practically uncorrectable. Slight tilt of sensor (1°-3°) may cause error up to 2% in 60°-80° range of zenith angles.

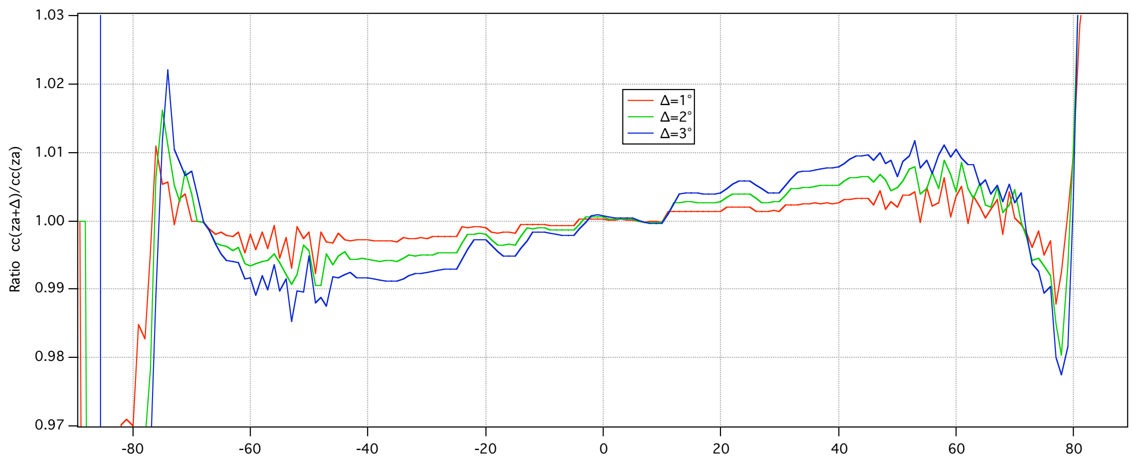

Figure 5A. Effect of tilt on cosine correction.

A: Diffuse cosine correction

The diffuse cosine correction is calculated as

$$diffcor = \frac{\int \sin(z)\cos(z) A(z,a) R(z,a) dzda}{\int \sin(z)\cos(z) R(z,a) dzda}$$

where z and a are zenith and azimuth angles, $R(z,a)$ is sky radiance and $A(z,a)$ is normalized cosine correction.

The result depends on sky radiance. In Figure 6A *diffcor* is calculated for five different sky radiances.

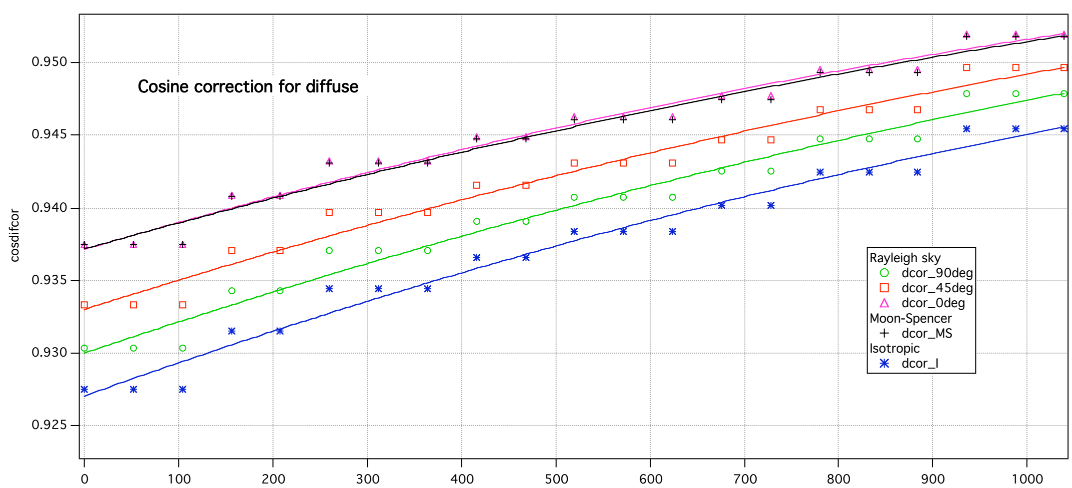

Figure 6A. Diffuse cosine correction for five sky radiances.

The impact of different sky radiances is small. It seems that isotropic sky and Moon-Spencer sky differ the most and the Rayleigh sky at SZA=45° splits the difference*. Thus if we use the latter for all cases , the errors would be ±0.5% at most.

A: Polarization sensitivity

Cosine responses were measured for TE and TM polarization using linear dichroic polarizer that was effective up to 700nm. The results that were "symmetrized" are presented in Figure 7A.

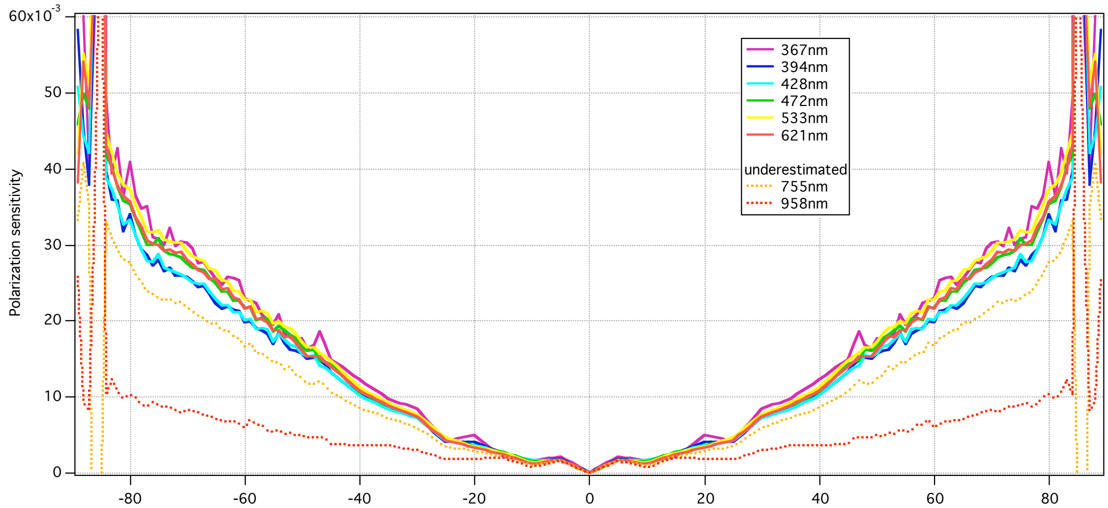

Figure 7A. Polarization sensitivity for 6 wavelengths. The polarizer did not provide 100% polarization for 755nm and 958

We observe slight dependence on wavelength in 367-621nm wavelength range with increased polarization sensitivity for shorter wavelengths.

* More precisely we used the single scattering Rayleigh sky approximation.