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Comparison of direct to diffuse ratio from RSS and MFRSR

by

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The direct to diffuse ratio (DDR) primarily is used to retrieve aerosol's single scattering albedo (Herman et al 1997 and Petters et al 2003). The DDR is defined as follows:

$$DDR= (direct\_normal)/(diffuse\_horizontal)$$

The shadownading spectroradiometers, RSS and MFRSR, provide both direct and diffuse components. In RSS output files (*.C1-files at /arm-iop/0special-data/asrc-rss/rss105/) direct normal and diffuse horizontal are corrected for angular response. For any zenith angle *z* and azimuth angle *a* the direct cosine correction cdr(*z,a*) is calculated via interpolation from two south-north and west-east sections that are measured of 2-D cosine function (Michalsky et al 1995). Then the direct is corrected:

$$Direct=Direct/cdr(z,a)$$

For the diffuse component the cosine correction cdf is calculated as follows:

$$cdf=\iint\sin(z)\cos(z)L(z,a)cdr(z,a)da\,dz/\iint\sin(z)\cos(z)L(z,a)da\,dz$$

where L(*z,a*) is sky radiance. The cdf coefficient depends on the model of sky radiance.

We used a simple model with the radiance

$$L(z,a)=1+\cos^2(\theta)$$

where θ is Rayleigh scattering angle calculated for sza=45° (Kiedron et al 2003). Other angles, sza=0° and 90° and other models, such as isotropic and Moon-Spencer skies produce less than ±0.005 differences in cdf. This approach does not take into account wavelength dependence of sky radiance. Subsequently the used diffuse cosine corrections are different for different wavelengths only because a sensor's direct cosine correction cdr is wavelength dependent.

The corrected diffuse is obtained as follows:

$$Diffuse=Diffuse/cdf$$

In Figures 1 and 2 DDR from RSS are depicted (red traces). Note that for larger sun elevation angles (Fig. 2) DDR is more noisy, in particular in NIR. The origin of this is a higher noise in diffuse (blue dotted traces) when sza is smaller. This is because in RSS the direct and diffuse measurements "time share" the same exposure in the detector with a finite dynamic range and the preference is given to the direct measurement. This results in better signal-to-noise (green dotted traces) in direct and lower signal-to-noise in diffuse (blue dotted traces).

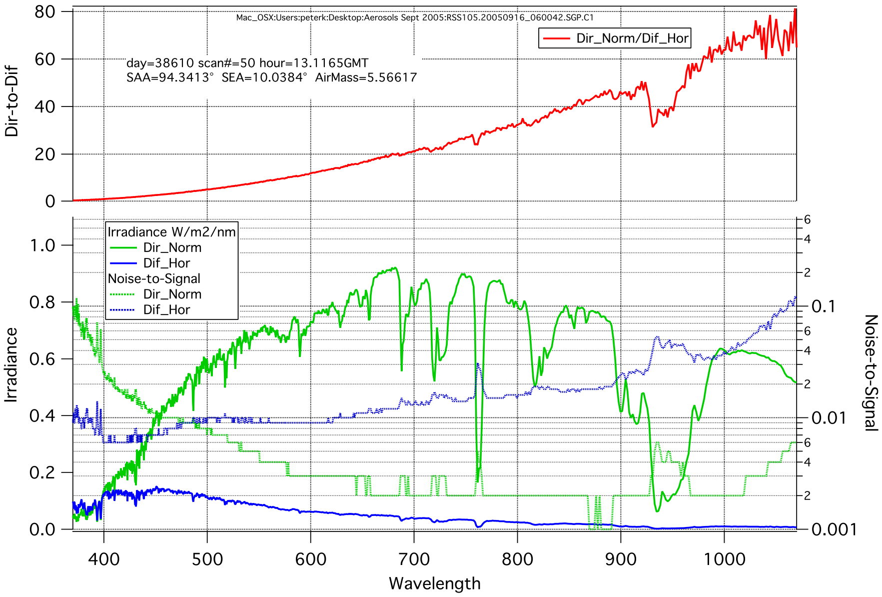


Figure 1. RSS irradiances, noise and DDR from scan at sea=10°.

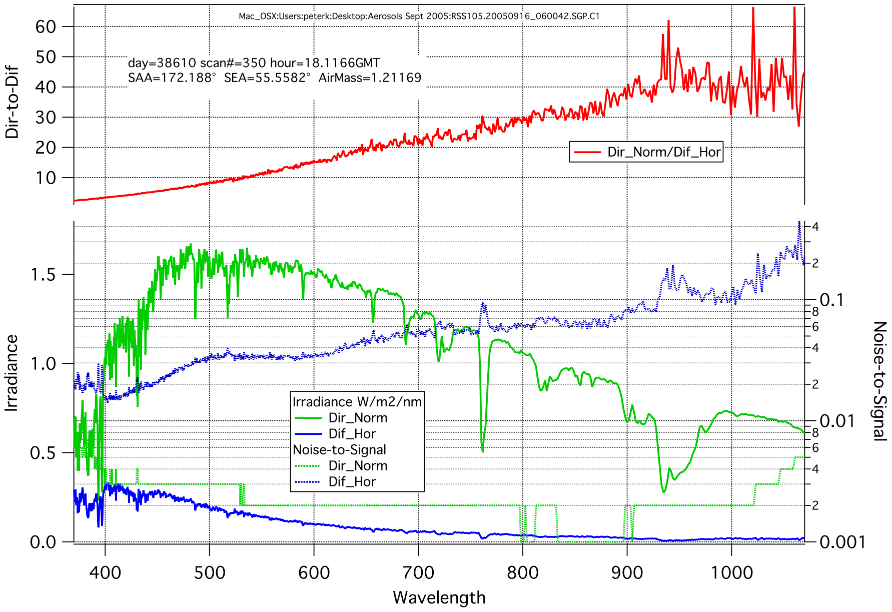


Figure 2. RSS irradiances, noise and DDR from scan at sea=55°.

The diffuse from MFRSR's is not cosine corrected. The data collected and stored in ARM have diffuse component uncorrected!

We compare three collocated (SGP Central Facility) shadowbanding instruments: C1 and E13 MFRSR's and RSS105. From RSS irradiances signals at MFRSR's channels were calculated using C1's filter functions. The DDR's are compared in Figure 3 and in Figure 4 as ratios.

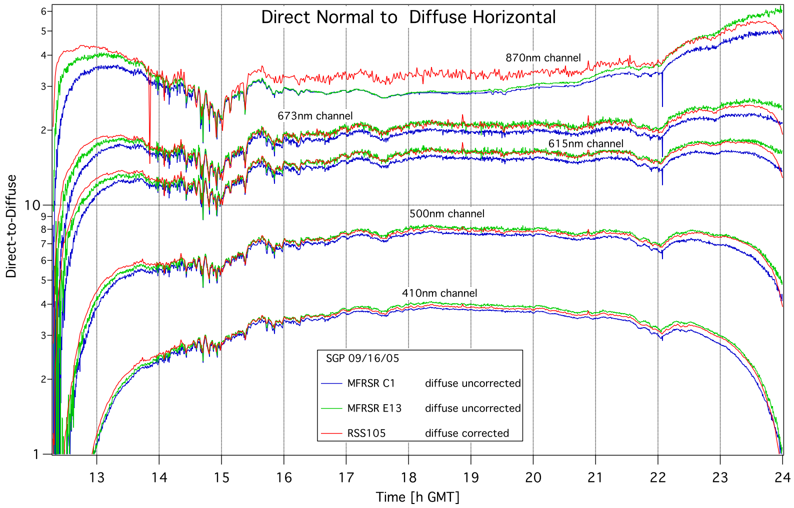


Figure 3. DDR for two MFRSR's and RSS.

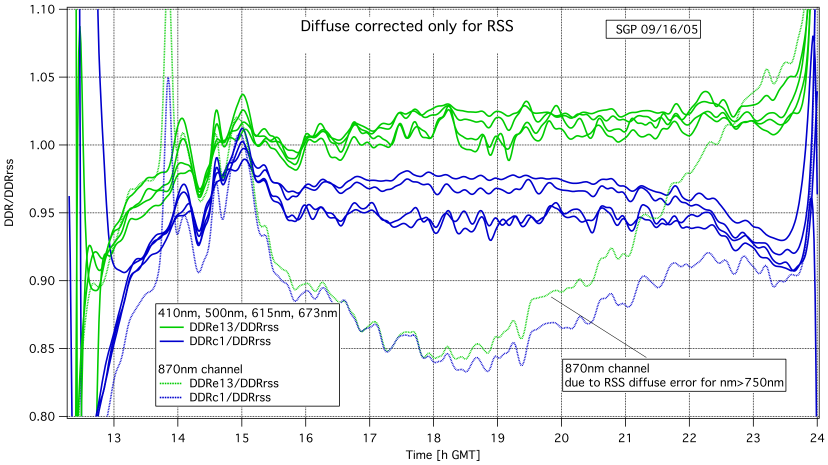
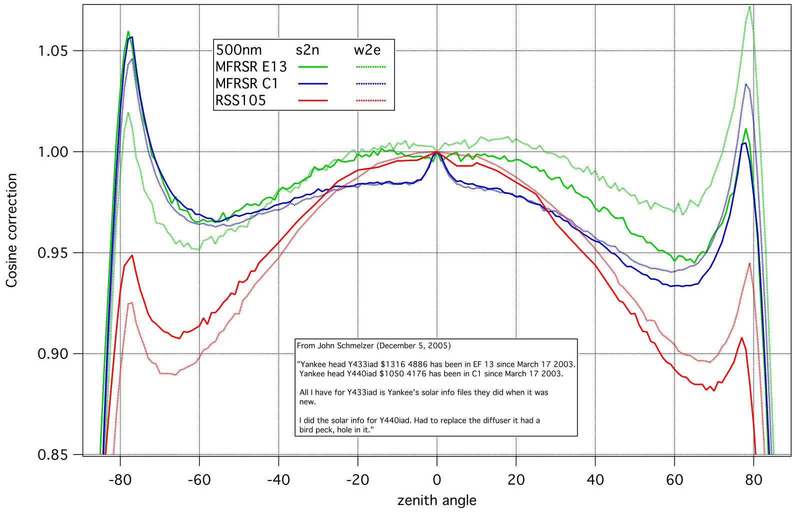


Figure 4. DDR from MFRSR's divided by DDR from RSS. Uncorrected diffuse in two MFRSR's

Using cosine functions in MFRSR's SolarInfo files (see example of 500nm channel in Figure 5) we calculated cdf diffuse cosine corrections for all channels. The results are depicted in Figure 6.



From John Schmelzer (December 5, 2005)

"Yankee head Y433iad $1316 4886 has been in EF 13 since March 17 2003.
Yankee head Y440iad $1050 4176 has been in C1 since March 17 2003.

All I have for Y433iad is Yankee's solar info files they did when it was new.

I did the solar info for Y440iad. Had to replace the diffuser it had a bird peck, hole in it."

Figure 5. Cosine functions for 500nm channel.

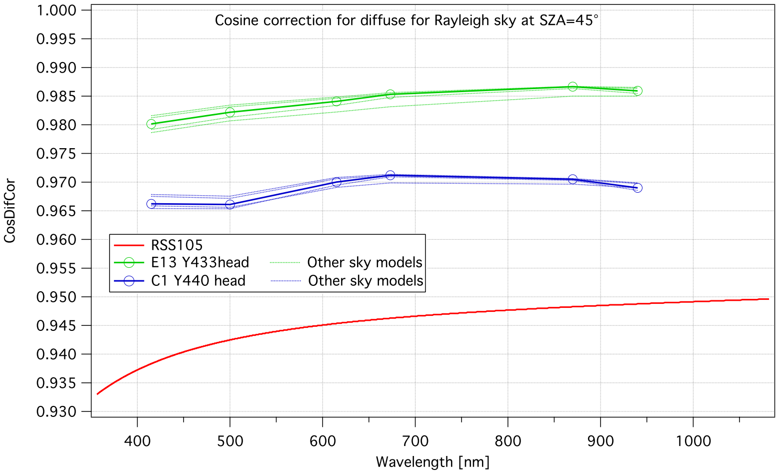


Figure 6. Diffuse cosine correction cdf for two MFRSR's and RSS.

After applying the cdf corrections for E13 and C1 we calculated DDR from MFRSR's. Their ratios to DDR from RSS are depicted in Figure 7.

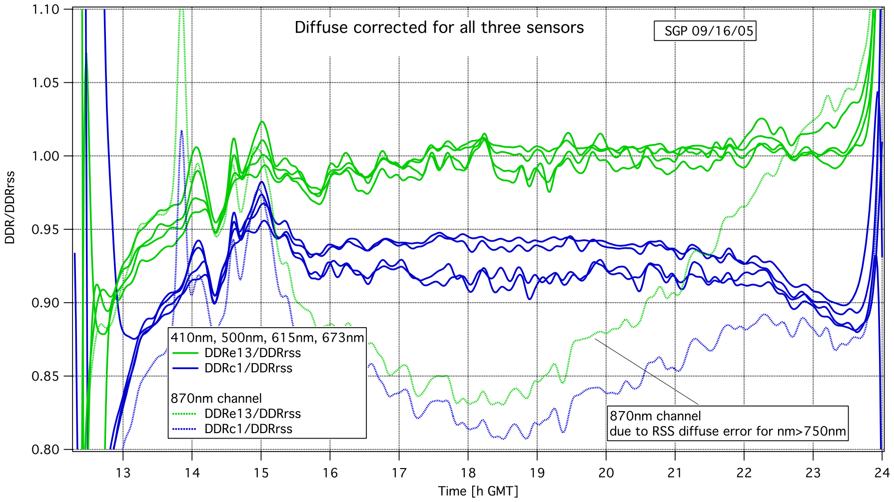


Figure 7. DDR from MFRSR's divided by DDR from RSS. Corrected diffuse in all three sensors.

Observations 1: There is large 5-8% discrepancy in DDR between the two collocated MFRSR's. (see Figure 7). The application of cdf correction makes the discrepancy worse.

Comments: The obvious suspects are the cosine functions. How correct are they for September 2003 data?

The measurement of diffuse in MFRSR may suffer from dark offset errors. Unlike the direct component that is the difference of two measurements where dark signal cancels, the diffuse is the result of summation and subtraction of three signals. There the dark signal does not cancel. The dark is not measured in the real time in MFRSR's.

It should be kept in mind that cosine errors may partially cancel in the direct irradiance that is calibrated via Langley regression (see Appendix). So C1 and E13 may end up yielding similar optical depths.

Observations 2: After correction E13 and RSS agree to within ±1.5% for all channels except 870nm channel (see Figure 7).

Comments: While one doesn't argue with a good result it should be kept in mind that the agreement might be for a wrong reason and the DDR's from C1 could be closer to the truth.

Observations 3: DDR from RSS for wavelengths larger than 750nm is not reliable.

Comments: Large noise and apparent offset error at low diffuse irradiances underestimates diffuse. (see Figure 3 and Figures 1 and 2).

Observations 4: At best ±0.5% accuracy in DDR can be achieved.

Comments: Even for perfectly measured cosine functions ±0.5% will appear from indeterminacy of sky models in cdf calculations. Only and exact model of sky radiance could reduce this error. Errors from cosine function measurement and subsequent deterioration of diffuser will results in larger errors.

Recommendation

1. The diffuse of MFRSR should be corrected or correction coefficients should be made easily available. A database of MFRSR cosine functions should be accessible to data users.
2. To avoid potential dark bias errors MFRSRS should perform measurements at night since equipping them with shatter would be too expensive and not feasible.
3. Cosine functions of MFRSR's should be measured with better accuracy and higher frequency. An alternative is a periodic intercomparison of all MFRSR in one location against perfectly characterized MFRSR standards.
4. DDR from shadowbanding instruments should be used with caution. Sensitivity of retrievals of single scattering albedo to DDR uncertainty should be tested. See Petters et al. (2003) for a good treatment of this issue with UV-MFRSR.

Appendix: Effect of cosine errors on direct irradiance

The shadowbanding instruments when collecting data for Langley in 2-6 air mass range receive the photons with angle of incidence SZA=60°-80°. This is a very precarious region for cosine response where substantial number of photons penetrate cavity through side walls of the external surface diffuser resulting in the bat wing shape (see Figure 5).

If diffuser due to, say, seasonal temperature changes, expands/shrinks and thus protrudes sometimes more or sometimes less above/below the artificial horizon, the cosine function in 60°-80° SZA range will be affected more while throughput for lamp calibration (normal incidence) might be not affected at all

The question is whether applying Vo's from Langley process is warranted in this case? Will they correct/cancel some of these effects?

To answer this let's do the following analysis:

Say signal at air mass m(sza) is V(m) and actual (true) cosine correction at m is cc(m).

The actual direct horizontal transmittance is $T=[V(m)/cc(m)]/Vo$, where Vo is true v-zero.

The tabulated cosine function in the "solar info file" is $ccf(m)$. We do Langley with direct normal counts derived from these direct horizontal counts $V(m)/ccf(m)$. This results in Vof.

Set $k=cc(m)/ccf(m)$ then $V(m)/ccf(m)=k*[V(m)/cc(m)]$ which leads to $Vof=k*Vo$, where Vof is v-zero from Langley regression.

Then we calculate transmittance (in the state of oblivion of cosine function changes):

$$Tf=[V(m)/ccf(m)]/Vof=k*[V(m)/cc(m)]/[k*Vo]=[V(m)/cc(m)]/Vo=T$$

The effect cancels in 2-6 airmass (Langley) range. But it would not necessarily cancel for low air masses resulting in tau and irradiance errors for air masses less than 2.

Note that complete cancellation won't occur when k is not constant in $m=2$-6 range. Non constant k is more likely as for $m=1$ k must be 1 (if the protrusion theory is correct) so it would be expected that $|k-1|$ increases with sza.

References

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