Determination of Fluxes from ULV/DLV observations
M. G. Tomasko

Determination of Diffuse Upward and Downward Flux

The method of estimating the diffuse upward and downward fluxes from the ULV and DLV observations is derived here both for the case of analysis of Titan observations and for observations on Earth using the film filter over the ULV and DLV diffusers.

The case for Titan is considered first. The instrument output is given by

$$DN - DNdark = \mathrm{Resp}_{peak} \int \left[\int I \ (\lambda, \vartheta, \varphi) \mathrm{Rel}_{spec}(\lambda) d\lambda \right] \mathrm{Rel}_2(\vartheta, \varphi) d\Omega \qquad (1.)$$

where DN is the data number observed, DNdark is the data number due to the electrical bias when the instrument is in the dark, Resp_{peak} is the peak absolute responsivity (at the maximum of the spectral and spatial relative response functions) of the instrument, Rel_2 is the relative spatial response function when the observations were collected, and I is the diffuse intensity from zenith angle Theta, ϑ and azimuth angle, Phi φ. The relative spectral response function and the relative spatial response functions are dimensionless, and normalized to unity at their peaks. The units of the peak responsivity are data numbers/(watt/sq. m).

The shape of the relative spectral response function, Resp_{spec} (λ)), is given in Fig. 1.

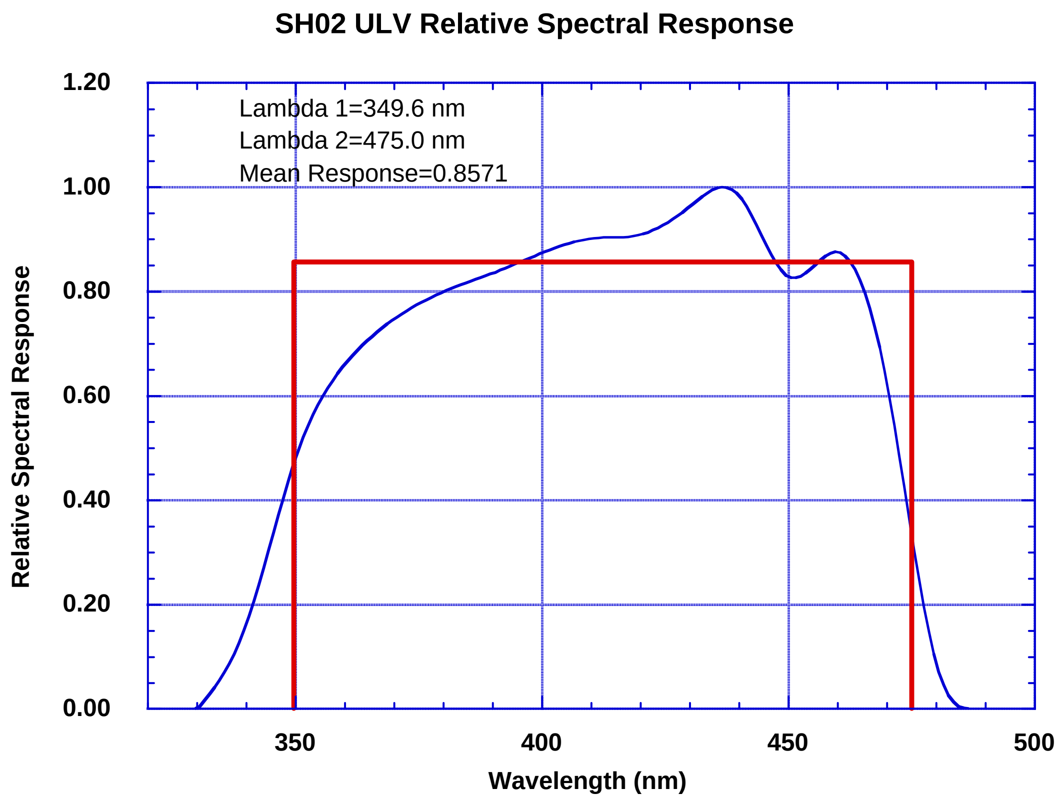

Figure 1. The relative spectral response of SH02 ULV channel. Also shown are the boundaries of an equivalent rectangular filter that gives the same response for a variation of intensity with wavelength that can be described by a polynomial up to second order in wavelength.

The straight lines in Fig. 1 show the equivalent rectangular filter that gives the same integrated response as the actual filter for any spectrum I(λ) that can be described by a polynomial of degree 2 or less. While the solar spectrum is much more complex than a quadratic polynomial in this spectral region, most of the variations are due to Fraunhoffer solar lines that vary much more rapidly with wavelength than the relatively smooth relative response function of the violet photometer. Tests have shown that the error in approximating the exact integral of solar energy between 350 and 475 nm by the equivalent filter is less than about 1% for the solar spectrum or modifications of it that gradually absorb rapidly increasing energy at shorter wavelengths across the filter. Hence, we can say to good accuracy that

$$\int I(\lambda,\vartheta,\varphi)\mathrm{Rel}_{spec}(\lambda)d\lambda = 0.8571\int_{350\,nm}^{475nm} I(\lambda,\vartheta,\varphi)\,d\lambda = 0.8571\, I_{350}^{475}(\vartheta,\varphi) \qquad (2.)$$

Thus, we have

$$DN - DNdark = 0.8571\ \mathrm{Resp}_{peak}\int I_{350}^{475}(\vartheta,\varphi)\ \mathrm{Rel}_2(\vartheta,\varphi)d\Omega \qquad (3.)$$

Now we replace the integrated intensity in direction Theta, Phi, (ϑ,φ) with <I>, the integrated intensity averaged over all directions (weighted with the relative spatial response function). Then the average wavelength integrated intensity, <I> is given by

$$< I > = \frac{DN - DNdark}{0.8571\ \mathrm{Resp}_{peak}\int \mathrm{Rel}_2(\vartheta,\varphi)d\Omega} \qquad (4.)$$

Recall that when the responsivity of the instrument was measured, the integral of the spatial response function was not known, and was set to unity. Thus the measured responsivity, $\mathrm{Resp}_{\mathrm{meas}}$ was determined by

$$\mathrm{Resp}_{meas} = \frac{DN - DNdark}{\int I(\lambda)\mathrm{Rel}_{spec}(\lambda)d\lambda} \qquad (5.)$$

where I(λ) is the intensity at wavelength λ which is essentially constant over directions in the integrating sphere. From (5) and (1) we see that

$$\mathrm{Resp}_{\mathrm{peak}} = \mathrm{Resp}_{meas} \Big/ \int \mathrm{Rel}_1(\vartheta,\varphi)\,d\Omega \qquad (6.)$$

where Rel_1 is the relative spatial response function during the absolute calibration tests, that is, without any external filters on the DISR sensor head.

Substituting (6) into (4) gives

$$< I > = \frac{(DN - DNdark)\int \mathrm{Rel}_1(\vartheta,\varphi)d\Omega}{0.8571\ \mathrm{Resp}_{meas}\int \mathrm{Rel}_2(\vartheta,\varphi)d\Omega} \qquad (7.)$$

Note the appearance of the integrals over the relative spatial response without filters on the sensor head Rel_1 and with the filters on the sensor head Rel_2.

For the measurements in the atmosphere of the Earth, the film filter was included over both the ULV and DLV diffusers. The transmission of the film filter can be divided into two parts. The silver grains act to provide a transmission Tg less than one. This part of the transmission is assumed to be independent of direction of the incident radiation. The second part of the film filter is due to the opacity of the film substrate itself. This is described by an exponential along the slant path of radiation through the film. The total transmission due to both effects is T where

$$T(\vartheta) = Tg\exp(-\tau/\cos(\vartheta)) \qquad (8.)$$

For observations in the atmosphere of the Earth, equation (1) becomes

$$DN - DNdark = 0.8571\,\mathrm{Resp}_{true}Tg\int I_{350}^{475}(\vartheta,\varphi)\mathrm{Rel}_1(\vartheta,\varphi)\exp(-\tau/\cos(\vartheta))d\Omega \qquad (9.)$$

with this relation, it is possible to define

$$\mathrm{Rel}_2 = \mathrm{Rel}_1\exp(-\tau/\cos(\vartheta)) \qquad (10.)$$

Note that for the violet filter, Tg is about 0.017, and τ is about 0.07. With these values,

$$\int \mathrm{Rel}_1(\vartheta,\varphi)d\Omega = 0.674 \qquad (11.)$$

and

$$\int \mathrm{Rel}_2(\vartheta,\varphi)d\Omega = 0.597 \qquad (12.)$$

Thus,

$$< I > = \frac{(DN - DNdark)\ \ 0.674}{(0.8571)\ (0.017)\ \ \mathrm{Resp}_{meas}\ \ 0.597} \qquad (13.)$$

The intensity <I> above is properly averaged over the field of view of the instrument, and integrated over wavelengths from 350 to 475 nm.

The above value of <I> refers to the field of view of the instrument centered at one location (azimuth) of the ULV or DLV. For the DLV, two measurements are made,

approximately 180° apart in azimuth. These values at 178° and 358° can simply be averaged to give the average intensity, Iave in azimuth. Thus we have

$$\mathrm{I}ave = 0.5(<\mathrm{I}_{178}> + <\mathrm{I}_{358}>) \tag{14.}$$

Finally, the upward flux, Fup between 350 and 475 nm is given by

$$\mathrm{Fup} = \pi\ \mathrm{Iave} \tag{15.}$$

For the downward diffuse flux, measurements are made at azimuths relative to the sun of 5.5°, 140°, and 180°. It is possible to estimate Iave by averaging the measurements at 5.5° and 180°, or alternatively, to use the average value of a cosine (azimuth) function fit to the three measurements. Here

$$DN(\varphi) = \mathrm{A} + \mathrm{B}\cos(\varphi) \tag{16.}$$

The cosine function needs to be determined to get the direct beam flux, so this is available for use in the diffuse downward flux. In that case, the diffuse downward flux, F down dif, is given by

$$\mathrm{F\ down\ dif} = \frac{\pi\,(\mathrm{A} - DNdark)\ \ 0.674}{(0.8571)\,(0.017)\ \ \mathrm{Resp}_{meas}\ \ 0.597} \tag{17.}$$

Determination of Direct Flux

When the sun is located at a zenith angle ϑ_s and the instrument is pointed at an azimuth φ_s relative to the sun, the instrument produces a response

$$\begin{aligned} DN - DNdark &= (DN_{diffuse}(\varphi_s) - DNdark) \\ &+ \mathrm{Resp}_{peak}\ T(\vartheta_s) \iint Isun(\lambda, \vartheta_s, \varphi_s)\mathrm{Rel}_{spec}(\lambda)d\lambda \mathrm{Rel}_1(\vartheta_s, \varphi_s)d\Omega \end{aligned} \tag{18.}$$

Here $\mathrm{DN}_{\mathrm{diffuse}}$ is the signal due to diffuse sky light on the field of view of the instrument when centered at azimuth φ_s relative to the sun. The intensity of the sun can be thought of as the flux from the direct solar beam divided by $\Delta\Omega_S$, the solid angle of the sun. The limits of integration of the direct solar beam, $d\Omega$, are also the solid angle of the sun. Thus, we have

$$\begin{aligned} DN - DNdark &= (DN_{diffuse}(\varphi_s) - DNdark) \\ &+ \mathrm{Resp}_{peak}\ T(\vartheta_s) \int \frac{F_{sun}(\lambda, \vartheta_s, \varphi_s)}{\Delta\Omega_s} \mathrm{Rel}_{spec}(\lambda)d\lambda \mathrm{Rel}_1(\vartheta_s, \varphi_s)\Delta\Omega_s \end{aligned} \tag{19.}$$

This becomes

$$DN - DNdark = (DN_{diffuse}(\varphi_S) - DNdark)$$
$$+\mathrm{Resp}_{peak}\ \mathrm{Rel}_1(\vartheta_S,\varphi_S)\ 0.8571\ T(\vartheta_S)\ F_{350}^{475} \qquad (20.)$$

Now we write the diffuse counts at the azimuth of the direct flux measurement as the cosine function determined from the measurements where the direct beam was shaded, from (16). This gives

$$DN - DNdark = (A + B\cos(\varphi) - DNdark)$$
$$+\mathrm{Resp}_{peak}\ \mathrm{Rel}_1(\vartheta_S,\varphi_S)\ 0.8571\ T(\vartheta_S)\ F_{350}^{475} \qquad (21.)$$

Substituting for the peak response and solving for the integrated flux of the direct beam gives

$$F_{350}^{475} = \frac{\left[DN(\varphi_S) - DNdark - (A + B\cos(\varphi_S) - DNdark)\right] \int \mathrm{Rel}_1(\vartheta,\varphi) d\Omega}{0.8571\ T(\vartheta_\mathrm{S})\ \mathrm{Resp}_{meas} \mathrm{Rel}_1(\vartheta_S,\varphi_S)} \qquad (22.)$$

with T(ϕ) given by (8) above. Substituting the values of the terms determined above gives

$$F_{350}^{475} = \frac{\left[DN(\varphi_S) - DNdark - (A + B\cos(\varphi_S) - DNdark)\right] 0.674}{(0.8571)\,(0.017) \exp(-0.07 / \cos(\vartheta_S))\ \mathrm{Resp}_{meas} \mathrm{Rel}_1(\vartheta_S,\varphi_S)} \qquad (23.)$$

The downward flux carried by the direct solar beam is Fdown dir and is given by

$$\mathrm{F\ down\ dif} = \cos(\vartheta_\mathrm{s})\ F_{350}^{475} \qquad (24.)$$

The total downward flux is the sum of the direct downward flux and the diffuse downward flux. The total downward flux minus the upward flux is the net flux. The change in the net flux between two altitudes is the flux absorbed by the intervening layer and is available for heating the layer.