Radiance to Reflectance for GOES-8 Channel 1

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The following is a discussion on converting GOES-8 Imager visible radiance measurements to reflectance values. An overview of GOES-8 Imager is provided then the reflectance equation is derived.

GOES-8 Imager - Channel One

The Imager aboard GOES-8 reports radiance measurements in count values ranging from 0 to 1023 counts. The linear response of the sensor provides the following calibration equation to convert counts (n) to radiance (L):

$$L = mn + b \tag{A.1}$$

where m is the inverse of sensor responsivity and b is the offset. The pre-launch values of these calibration coefficients, measured at ITT in Fort Wayne, Indiana, are m = 0.551 $Wm^{-2}\,ster^{-1}\mu m^{-1}count^{-1}$ and b = -15.3 $Wm^{-2}ster^{-1}\mu m^{-1}$ (available at the WWW site http://climate-f.gsfc.nasa.gov/~chesters/text/imager.calibration.html).

These values are only valid prior to launch and soon thereafter. Otherwise, the sensor is subject to response drift, which has been noticed in visible data from GOES-8. Weinreb (1995) calculated a decrease in responsivity of about 15%. But, there exist methods to determine these calibration coefficients in-flight, although they require a priori knowledge of the surface reflectance and atmospheric optical properties. Surfaces such as the ocean and deserts are useful for this process because their spatially homogeneous reflectances are well-studied. Whereas atmospheric optical properties, such as vertical structure of optical depth, single scatter albedo and asymmetry parameter of aerosols, are usually assumed variables. Aerosols over the ocean have a relatively constant distribution and optical parameters, whereas aerosols over land are variable in both respects. These atmospheric variables are used in a radiative transfer model to calculate a radiance the satellite sensor should detect. This method was used by Fraser et al. (1984) to calculate GOES-7 VISSR coefficients from a region in the Atlantic Ocean.

Reflectance

The following discussion of reflectance does not include spectral dependence. Surface reflectance, solar emittance and the Imager sensor response have different spectral dependencies. Therefore, radiances mentioned hereafter are band-averaged quantities, averaged over the spectral response of the GOES-8 Imager. The process of this band averaging is discussed in the next section.

Figure A.1 shows the geometry of a radiance from a source direction (the Sun) with zenith angle θ_o and azimuth angle ϕ_o reflected by a surface (dA) into the direction θ and ϕ (Stephens, 1994). The equation of reflected radiance (L_r) defined by Kidder and Vonder Haar (1995) is:

$$L_r(\theta_r, \phi_r) = \int_0^{2\pi}\int_0^{\pi/2} L_i(\theta_i, \phi_i)\gamma_r(\theta_i, \phi_i; \theta_r, \phi_r)\cos\theta_i \sin\theta_i d\theta_i d\phi_i \qquad \text{(A.2)}$$

where L_i is the incident radiance from the direction (θ_i, ϕ_i), which is partially reflected (γ_r) into the direction (θ_r, ϕ_r). γ_r is the bi-directional reflection function (BDRF) which requires:

$$\int_0^{2\pi}\int_0^{\pi/2} \gamma_r(\theta_r, \phi_r; \theta_o, \phi_o)\cos\theta_r \sin\theta_r d\theta_r d\phi_r \equiv A \qquad \text{(A.3)}$$

such that γ_r is the fraction of L_i reflected to the direction θ_r, ϕ_r and A is the total fraction of reflected light in all directions, the albedo. Then, considering the sun as the only source, L_i becomes a delta function:

$$L_i(\theta_i, \phi_i) = \begin{cases} L_o & \theta_i = \theta_o, \phi_i = \phi_o \\ 0 & \theta_i \neq \theta_o, \phi_i \neq \phi_o \end{cases} \tag{A.4}$$

where L_o is the solar emitted radiance. Also, if the reflecting surface is assumed to be a Lambertian reflector, then incident radiance is reflected uniformly in all directions. Defining:

$$\gamma_r(\theta_r, \phi_r; \theta_o, \phi_o) = \frac{\rho}{\pi} \tag{A.5}$$

so

$$\int_0^{2\pi} \int_0^{\pi/2} \gamma_r(\theta_r, \phi_r; \theta_i, \phi_i) \cos\theta_r \sin\theta_r d\theta_r d\phi_r \equiv \rho . \tag{A.6}$$

Using equations A.4 and A.5, equation A.2 becomes:

$$L_r(\theta_r, \phi_r) = L_o \cos\theta_o \Omega_o \frac{\rho}{\pi} \tag{A.7}$$

where Ω_o is the solid angle of the sun subtended by the earth. Thus,

$$L_r(\theta_r, \phi_r) = \frac{\rho}{\pi} F_o \cos\theta_o \tag{A.8}$$

where $F_o = L_o \Omega_o$.

Calculation of GOES-8 Imager Channel 1 Reflectance

So from equation A.8, visible reflectance is calculated from the GOES-8 Imager by:

$$\rho = \frac{\pi L_r(\theta_r, \phi_r)}{F_o \cos\theta_o}. \tag{A.9}$$

L_r is calculated from Imager data and the calibration coefficients discussed above. The latitude and longitude of the image pixel and time of satellite scan determine $\cos\theta_o$. F_o is the incident radiance at the same wavelengths that measure L_r. So F_o is the theoretical value if the satellite were to look directly at the sun. It is determined by:

$$F_o = \frac{\int_0^\infty S_\lambda w_\lambda d\lambda}{\int_0^\infty w_\lambda d\lambda} \tag{A.10}$$

where w_λ is the spectral response, or weighting function, of channel 1 of the Imager and S_λ is the spectral irradiance of the Sun. Figure A.2 shows the solar emittance and figure A.3 shows the relative weighting function of channel 1 of the Imager on GOES-8. From figure A.3, it can be seen that there exist limits on the weighting function outside of which the sum approaches zero:

$$\int_0^{\lambda_{min}} w_\lambda d\lambda + \int_{\lambda_{max}}^\infty w_\lambda d\lambda \approx 0 \tag{A.11}$$

where λ_{min} and λ_{max} are determined from w_λ. In the weighting function provided (Weinreb, personal communication), $[\lambda_{min}, \lambda_{max}] = [0.45, 1.01\mu m]$. So equation A.11 becomes:

$$F_o = \frac{\int_{\lambda_{min}}^{\lambda_{max}} S_\lambda w_\lambda d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} w_\lambda d\lambda} \tag{A.12}$$

Applying the data in figures A.2 and A.3 to equation A.12 results in:

$$F_o = 1627.945 \text{ Wm}^{-2} \tag{A.13}$$

Therefore, visible reflectance is calculated by:

$$\rho = \frac{L_r(\theta_r, \phi_r)\pi}{1627.945\cos\theta_o} = \frac{L_r(\theta_r, \phi_r)}{518.191\cos\theta_o} = \frac{L_r(\theta_r, \phi_r)}{\cos\theta_o} 1.92979 \times 10^{-3}. \qquad \text{(A.14)}$$

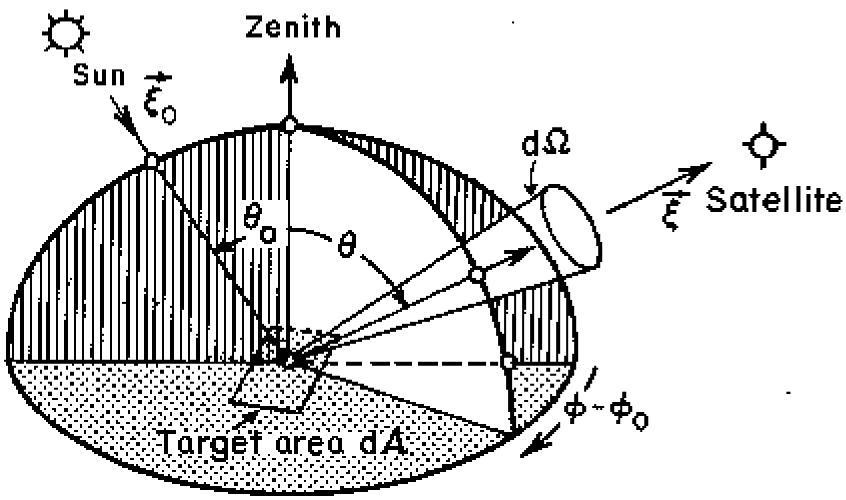

Figure A.1 - Schematic of reflected radiance, L(θ,ϕ), by target area, dA, for the source being the sun, F_o(Stephens, 1994).

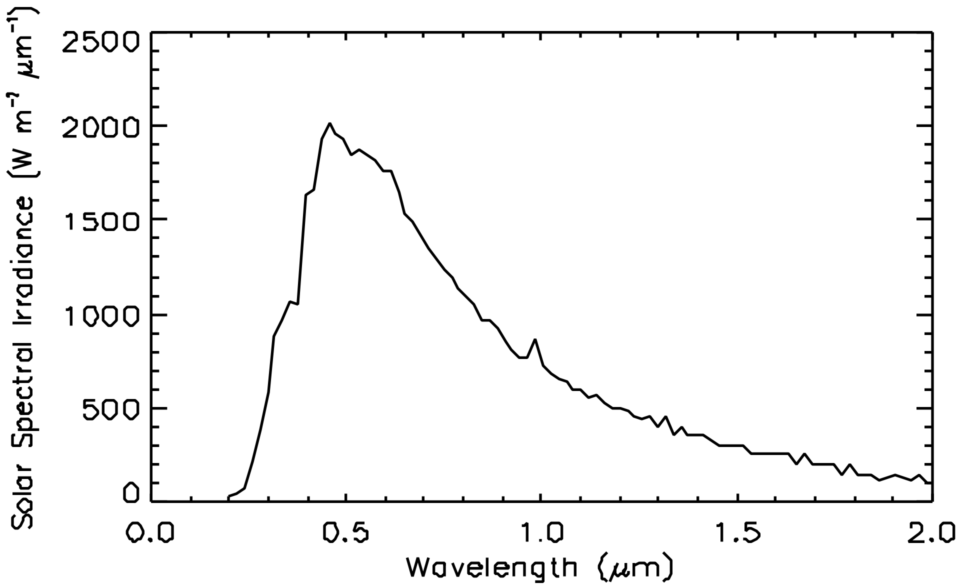

Figure A.2 - The solar spectral irradiance as a function of wavelength.

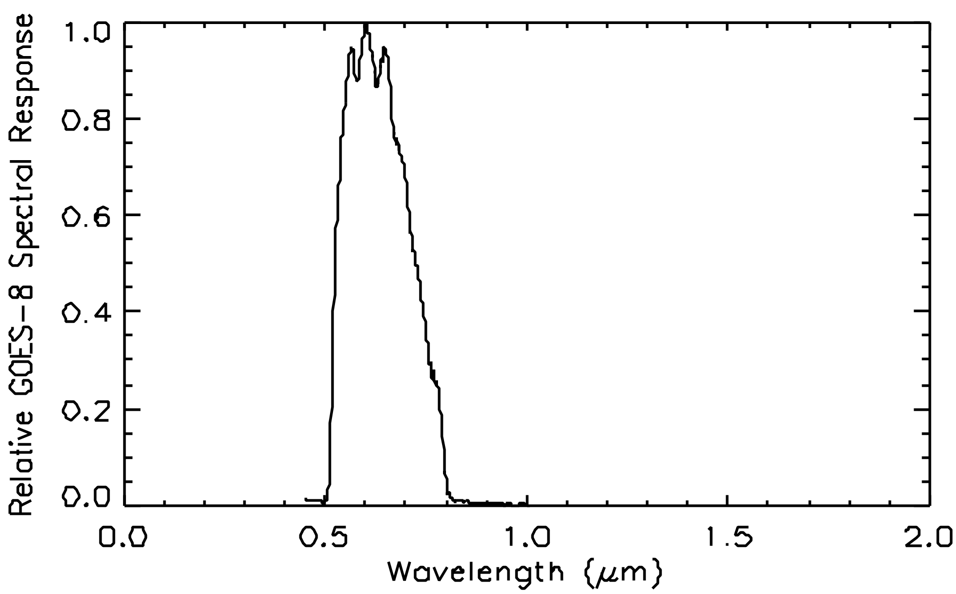

Figure A.3 - The relative weighting function (or spectral response) as a function of wavelength.