The introduction to atmospheric correction on the previous page illustrated the nature of the problem. It is now time to define the problem quantitatively.

The total radiance L_t measured by a satellite-borne sensor at the top of the atmosphere (TOA) comes from contributions by atmospheric scattering, L_{atm}; Sun and sky radiance reflected back upward by the sea-surface and reaching the TOA, L_{surf}^{TOA}; and water-leaving radiance that reaches the TOA, L_w^{TOA}:

$$L_t = L_{atm} + L_{surf}^{TOA} + L_w^{TOA} . \tag{1}$$

For brevity, the viewing direction (θ_v, ϕ_v) and wavelength λ are not shown. Expanding this equation into further levels of detail requires the definition of many different radiances, and precise notation is needed to minimize confusion. The atmospheric contribution L_{atm} is always considered to be at the TOA. However, the surface-reflected radiance and water-leaving radiance can be formulated either at the sea surface or at the TOA. For these radiances, a superscript TOA will be used to specify the TOA value. Thus L_w will denote the water-leaving radiance just above the sea surface, and L_w^{TOA} will denote how much of L_w reaches the TOA. Table center1 summarizes the various radiances introduced in this chapter and used throughout this report.

The atmospheric contribution in Eq. (1), usually called atmospheric path radiance, comes from scattering by atmospheric gases and aerosols, including multiple scattering between gases and aerosols. The path radiance that comes solely from scattering by atmospheric gas molecules is usually called the Rayleigh radiance, L_R, because scattering by molecules is well described by the Rayleigh mathematical model of scattering by particles that are much smaller than the wavelength of light. In the absence of any aerosols, the atmospheric path radiance would equal the Rayleigh radiance. Let L_a denote the aerosol contribution, which is the path radiance that would occur if the atmosphere consisted only of aerosol particles. Let L_{aR} denote the contribution resulting from multiple scattering between aerosols and gases. The total surface reflectance can be separated into a contribution due to direct Sun glint from the water surface, L_g^{TOA}; by background sky radiance reflected by the water surface, L_{sky}^{TOA}; and by Sun and sky radiance reflected by whitecaps and foam, L_{wc}^{TOA}. Thus Eq. (1) can be further partitioned into

$$L_t = L_R + [L_a + L_{aR}] + L_g^{TOA} + L_{sky}^{TOA} + L_{wc}^{TOA} + L_w^{TOA} . \tag{2}$$

In practice, the aerosol and aerosol-gas contributions are usually grouped together and treated as one contribution, sometimes denoted $L_A = L_a + L_{aR}$ and often called just the aerosol contribution. The sky reflectance term is accounted for as part of the Rayleigh correction, which incorporates reflectance by the sea surface. For some sensors that were specifically optimized for ocean color (e.g., CZCS and SeaWiFS), the strongest part of the Sun glint (the Sun's glitter pattern) is avoided by pointing the sensor in a direction away from the Sun so that almost no direct glint is present in the image. However, there is still a correction for residual amounts of Sun glint. Figure figure1 illustrates these contributions to the TOA radiance.

Most papers (e.g., Wang and Bailey (2001), Wang (2002)) rewrite Eq. (equation2) as

$$L_t = L_R + [L_a + L_{Ra}] + T L_g + t L_{wc} + t L_w , \tag{3}$$

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Table 1: Radiance notation. The notation here corresponds to that seen in Fig. figure1. Spectral radiance L has SI units of $\mathrm{W\,m^{-2}\,nm^{-1}\,sr^{-1}}$; in practice $\mathrm{mW\,cm^{-2}\,\mu m^{-1}\,sr^{-1}}$ is often used.

Symbol & Definition
L_t & #1
L_atm & #1
$L_\mathrm{surf}^\mathrm{TOA}$ & #1
L_R & #1
L_r & #1
L_a & #1
L_aR & #1
L_A & #1
L_w & #1
$L_\mathrm{w}^\mathrm{TOA}$ & #1
L_g & #1
$L_\mathrm{g}^\mathrm{TOA}$ & #1
L_sky & #1
$L_\mathrm{sky}^\mathrm{TOA}$ & #1
L_wc & #1
$L_\mathrm{wc}^\mathrm{TOA}$ & #1
L_u & #1

or something very similar. Now, however, L_g, L_wc, and L_w are all measured at sea level. T is the direct transmittance between the sea surface and the TOA along the viewing direction, and t is diffuse transmittance in the viewing direction. These transmittances are discussed on the Atmospheric Transmittances page.

Yet a third formulation can be found in the literature (e.g., Franz et al. (2007), Eq. 1):

$$L_\mathrm{t} = \left(L_\mathrm{r} + [L_\mathrm{a} + L_\mathrm{ra}] + t_\mathrm{dv}L_\mathrm{wc} + t_\mathrm{dv}L_\mathrm{w} \right) t_\mathrm{gv}t_\mathrm{gs}f_\mathrm{p} \,. \tag{4}$$

Here t_dv is the diffuse transmittance along the viewing path of the sensor. t_gv is the transmittance by atmospheric gases in the viewing direction, and t_gs is the transmittance by atmospheric gases in the Sun's direction; these transmittances are usually called gaseous transmittances. f_p is a known instrument polarization-correction factor. Comparison of Eqs. (equation3) and (equation4) shows, for example, that

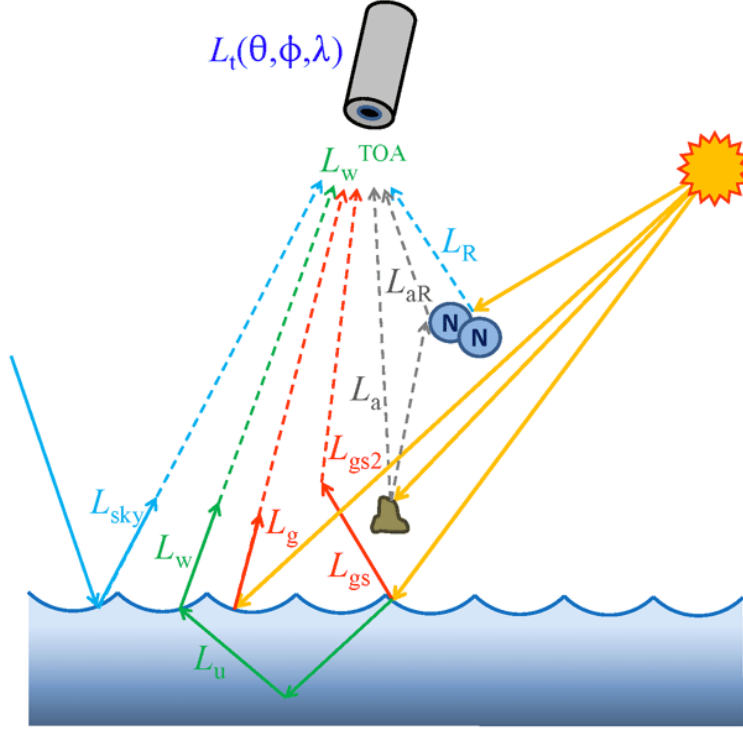$$L_\mathrm{R} = L_\mathrm{r}t_\mathrm{gv}t_\mathrm{gs}f_\mathrm{p} \,.$$

Figure 1: Qualitative illustrations of the various processes contributing to the total TOA radiance. The notation corresponds to Table center1, and the colors correspond to the spectra of Fig. 5 of the previous page. The blue N-N represents a nitrogen (N_2) molecule, or any other atmospheric gas molecule; the brown blob represents an aerosol particle. The red glint terms are discussed on the next page.

Thus the total TOA Rayleigh contribution L_R has been factored into a product of terms involving a Rayleigh term times gaseous transmittances and a polarization-correction factor. The difference between Eqs. (equation3) and (equation4) is primarily a matter of simplification for presentation purposes. The f_p term came into the nomenclature because MODIS has large polarization sensitivity and this requires correction. Earlier papers by Gordon and Wang often ignored the gaseous transmission terms because they were only considering ozone, which could be "taken off the top," so to speak, with the remaining problem being effectively formulated below the ozone layer. The L_r term is computed using a standard atmosphere and only non-absorbing gases N_2 and O_2. This allows "standard" Rayleigh radiances L_r to be computed as a function of Sun and viewing geometry. The gaseous transmittances are computed by use of absorption coefficients, computed path lengths, and gas concentrations for the various gases. The f_p term is computed for each image pixel as a function of atmosphere and surface polarization states (modeled Rayleigh and glint Stokes vectors) and the sensor-specific polarization sensitivity with viewing direction.

All of Eqs. (equation2), (equation3), and (equation4) can be found in the literature. They all give the same TOA total radiance L_t. Which form is used in a particular in-

stance is determined by convenience. Forms (equation2), (equation3) are often convenient for discussions of theory, whereas form (equation4) is convenient for operational atmospheric correction algorithms.

The goal of atmospheric correction is to convert a measured top-of-the-atmosphere radiance L_t into the corresponding sea-level water-leaving radiance L_w. Since only L_t is measured, this requires estimation of the various atmospheric and surface-reflectance terms seen in Eqs. (equation3) or (equation4) so that they can be subtracted from L_t in order to arrive at L_w. How this is done is discussed in Level 2 of this Chapter.