Values of D for Estimation of Remote Sensing Reflectance from Above-Surface Measurements

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In 1999 I published a paper in *Applied Optics*, 38(36), p 7442-7455 on the problems inherent in estimating the remote-sensing reflectance R_{rs} from measurements of the sky and ocean radiance made from just above the sea surface. These notes assume familiarity with that paper.

The key to converting the radiance measurements to R_{rs} is having a good value for D, the proportionality factor that relates the radiance measured when the detector views the sky to the reflected sky radiance measured when the detector views the sea surface. That is, D = (surface-reflected radiance)/(sky radiance) for the particular viewing geometry and environmental conditions. See Fig. 1 and Eq. (4) of the paper for the details.

In the paper I gave examples of the dependence of D on wind speed, viewing direction, and solar zenith angle. The conclusion was that an optimum (but never perfect) viewing geometry is to view the sea surface at a nadir angle of around 40 degrees and an azimuthal angle of around 135 degrees relative to the sun (i.e., looking away from the sun, halfway between having the sun at your back and at your side). This geometry minimizes the chance of getting sun glitter in the measured ocean radiance.

I have had several people ask me for a more extensive table of D values than can be obtained from the figures in the paper. I'm happy to oblige and have generated the file `rhoTable_AO1999.txt`, which you can download from the HydroLight Users Group on Yahoo (http://groups.yahoo.com/group/HydroLightUsers/). That file gives D values as a function of wind speed (0 to 14 m/s), sun zenith angle (0 to 80 deg), and viewing direction (10 deg in nadir angle and 15 deg in azimuthal angle) for clear sky conditions at 550 nm. However, the use of this table requires that the viewing geometry and sky conditions be such that D can be assumed to be independent of wavelength, as discussed next.

A couple of HydroLight users have pointed out that the D values in the HydroLight standard printout vary (sometimes very little, but sometimes a lot) with wavelength. (The D values are in the last column of the output labeled "`Radiances Just Above the Water Surface`.") They then rightly ask, "How can D vary with wavelength, since it describes how the sea surface reflects radiance, and the real index of refraction (as used in HydroLight) is 1.34, independent of wavelength?" The answer lies in the observation that D is *not* an inherent optical property of the sea surface.

The sky radiance distribution changes as a function of wavelength. In particular, the ratio of background sky to direct solar irradiance changes in the RADTRAN model that is used within HydroLight, even if the angular pattern stays the same.. This means that there are different amounts of sun glitter being seen by the sensor at different wavelengths, all else (viewing geometry, wind speed, etc.) being the same. That in turn means that D will have some wavelength dependence because the sky radiance changes even though the surface reflectance properties are the same at each wavelength.

You can verify this with a couple of HydroLight runs:

1) For U (wind speed) = 6 m/s, say, do a run at one wavelength (say 550 nm) and use the "idealized sky model" option with a uniform background sky and a sun zenith angle of 30 deg. Let the ratio of background sky irradiance to total be 0.1. You get a table of D values in the printout.

2) Repeat the run with everything the same, except let the ratio of background to total sky irradiance be 0.3. You get a different table of D values. The differences in D will be the greatest for viewing angles that catch a lot of sun glitter, and the D values will be almost identical for angles that don't get much sun glitter.

Figure 1 shows D as a function of wavelength for two viewing geometries. The wind speed was 6 m/s, the sun was at 30 deg in a clear sky, and the water was Case 1 with a chlorophyll concentration of 1 mg/m^3. For this high sun angle and a nadir viewing direction (looking straight down), there is a significant amount of sun glitter within the instrument field of view. The amount of sun glitter depends on wavelength because the sky conditions depend on wavelength; D thus varies by a factor of two between 350 and 800 nm. For the optimum viewing geometry, there is almost no sun glitter seen by the instrument, and D is essentially independent of wavelength.

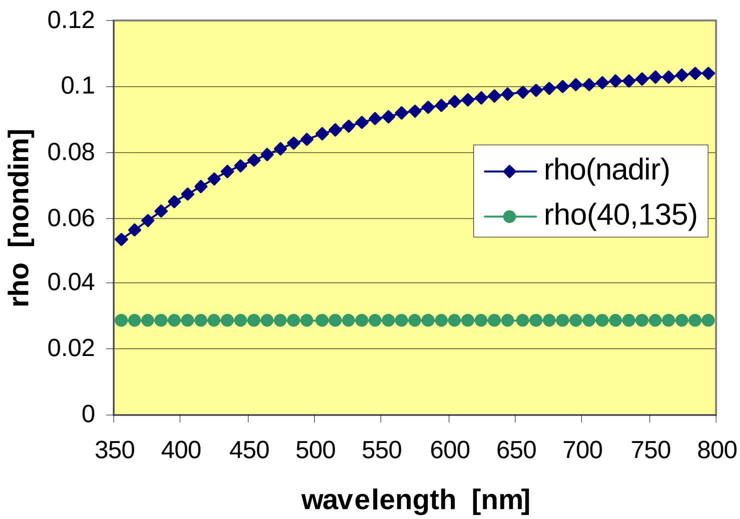

Fig. 1. Example D values as a function of wavelength. The sun is at a zenith angle of 30 deg in a clear sky; the wind speed is 6 m/s. The blue points are for nadir viewing; the green points are for the optimum viewing geometry of (2_v = 40 deg, N_v = 135 deg).

As I commented in the last paragraph of section 5 of the paper, D "... is strongly dependent on sky conditions, viewing geometry, sea state, and sometimes wavelength." As seen above, if you hold the ocean and instrument conditions fixed but change the sky conditions, you change D. If you are viewing sun glitter, not only is the value of D large, but it is also wavelength dependent. The table of D values was generated for 550 nm. Its use at other wavelengths assumes that the sky conditions and viewing geometry are such that D is nearly independent of wavelength.

My main purpose in writing the *Applied Optics* paper (which came from a lecture on this stuff in a summer course) was to point out that D is not an inherent optical property of the sea surface (as is the Fresnel reflectance), and that it's really hard (actually impossible) to know what D value to us in a particular situation. All you can do is make an educated guess and hope for the best. Fortunately, educated guesses work pretty well if you're careful to avoid sun glitter and cloud reflectances.