HYDROLIGHT TECHNICAL NOTE 2

HOW DOES ANGULAR RESOLUTION AFFECT COMPUTED RADIANCES?

Hydrolight discretizes the polar (θ) and azimuthal (ϕ) directions by dividing the set of all directions (4π sr of solid angle) into two polar caps plus quadrangular regions bounded by lines of constant θ and constant ϕ, which are collectively called quads. Hydrolight then computes the directionally averaged radiance in each quad. The mathematical details of quad partitioning are given in *Light and Water* §4.7 and §8.2. The standard quad partitioning used in Hydrolight consists of two polar caps with a 5 deg half angle in θ and 2(1+9*24) = 434 quads with a nominal (θ, ϕ) resolution of 10 deg by 15 deg. The quad resolution of this standard resolution grid (SRG) is shown by the black lines in Fig. 1.

Hydrolight users occasionally ask if they will get better accuracy by using a higher angular resolution, e.g., 5 deg in θ by 5 deg in ϕ. The quick answer is that *higher angular resolution will give no more than one or two per cent better accuracy, but the Hydrolight run times can increase by an order of magnitude or more.* This note explains that statement.

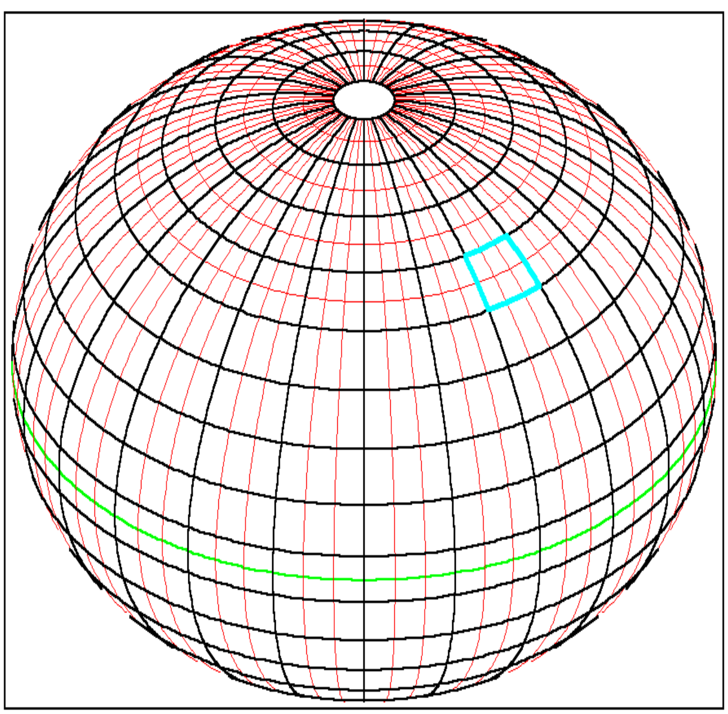

Fig. 1. The unit sphere of directions as partitioned into two polar caps and numerous (θ, ϕ) quads. The black lines show the Hydrolight standard quad resolution. The red lines plus the black lines are the high-resolution grid. The green line is the "equator" separating upward and downward directions; this is a also quad boundary. The blue quad shows one standard quad corresponding to 6 high-resolution quads.

To quantify the effect of angular resolution on computed radiances, I defined a high resolution grid (HRG) as follows. The HRG had a polar cap with a 5 deg half angle in θ for ease of comparison with the polar cap results for the SRG. Polar angles between 5 deg and 45 deg had a 5 deg in θ by 5 deg in ϕ angular resolution. This gave higher angular resolution for the viewing directions (nadir out to ~45 deg) relevant to most ocean color remote sensing. Polar angles between 45 deg and 85 deg had a 10 deg in θ by 5 deg in ϕ angular resolution. The number of quads used to partition the set of all directions is then 2(1+13*72) = 1874. This (θ, ϕ) grid is shown by the red lines in Fig. 1; the black lines of the SRG are also quad boundaries in the HRG.

I then performed a series of several hundred pairs of Hydrolight runs for both Case 1 (chlorophyll concentrations of 0.1, 1.0, and 10 mg Chl m^{-3}) and Case 2 waters; uniform skies and clear skies with solar zenith angles of 0, 30 and 60 deg; wind speeds of 0, 6, and 12 m s^{-1}; and bottom depths of 1, 5, and 10 m (using a non-Lambertian bottom BRDF characteristic of ooid sand), and infinitely deep. Comparisons were made at 7 wavelengths between 400 and 700 nm. Each pair of runs was identical except that one run used the SRG and the other used the HRG.

Figure 2 shows the polar cap radiances computed for the SRG and HRG. The corresponding SRG and HRG radiances were usually within 1% of each other; they differed by more than 2% in only two pairs of simulations. This agreement indicates that the polar cap radiances computed by Hydrolight are almost independent of the grid resolution in other directions. The small differences that did occur were due to a combination of three factors. First, the SRG and HRG runs had slightly different surface transfer functions because of the different Monte Carlo simulations of the wind-blown random sea surface. Second, in the clear-sky cases with the sun at 30 or 60 deg, the sun was "smeared out" over quads of different sizes, so that the incident solar radiance directions were not quite the same. Third, there may have been slightly different levels of accuracy in the discretization of the scattering phase functions in the SRG and HRG.

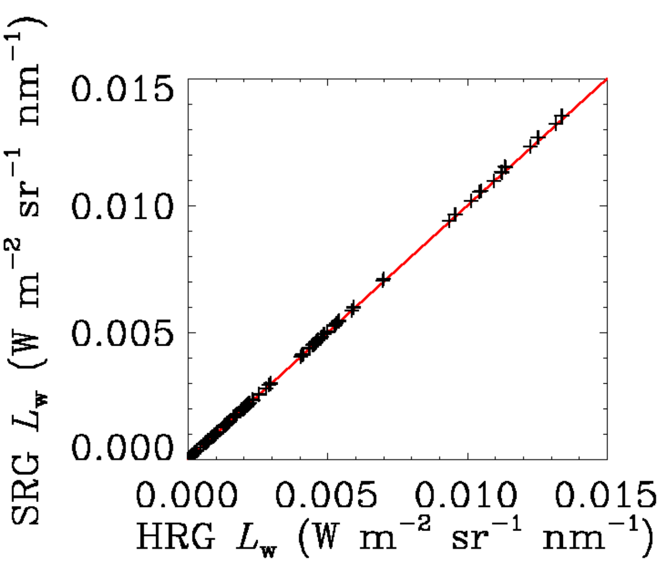

Fig. 2. Comparison of polar cap water-leaving radiances L_w as computed by the SRG and HRG. The red line represents exact agreement between the SRG and the HRG.

Depending on the θ value, each SRG quad covered either 3 or 6 HRG quads, as illustrated by the quad outlined in blue in Fig. 1. The radiance in a given SRG quad should equal the average radiance of the corresponding HRG quads. This equality was hand checked for selected quads and simulations, and the HRG averages generally agreed with the LRG values to within 2%. Again, this indicates that the radiances computed by the HRG were little different than those computed by the LRG.

Figures 3 and 4 show other comparisons. Figure 3 shows polar contour plots of the SRG water-leaving radiance $L_w(\theta,\phi)$ in black and the corresponding HRG radiances for a bottom depth of 1 m. The red and black contours almost exactly coincide, which shows that the water-leaving radiances were the essentially the same for all directions. In this particular simulation, the polar cap radiances differed by 1.3%. Similar agreement holds for the other bottom depths.

The left panel of Fig. 4 shows the SRG (black symbols) and HRG (red symbols) water-leaving radiances $L_w(\theta_v, \phi_v = 90)$ for the same 1 m bottom depth as used in Fig 3. The plotted radiances correspond to the center of the polar plot of Fig. 3 out to the top edge of that plot at $\phi_v = 90$. The right panel of Fig. 4 is for an infinitely deep bottom, with all else being the same as for Fig. 3. As previously seen, the SRG and HRG radiances were the same to within a couple of percent.

Hydrolight's computation time is proportional to the number of quads squared. Thus the HRG runs took longer than the SRG runs by a factor of $(1874/434)^2 = 18.6$. However, for all of the situations studied (various water types, bottom depths, sun angles, wind speeds, and wavelengths), the SRG and HRG Hydrolight-predicted radiances usually agreed to within roughly one percent and almost never differed by more than two percent. This is a greater accuracy that can be obtained from routine radiance measurements. Thus the extra computational expense of running the HRG is unjustified in most calculations relevant to optical oceanography. If the SRG is used but higher angular resolution is needed (e.g., for comparison to radiance measurements at a particular viewing direction), it is likely that a spline fit to the SRG results would give adequate interpolated values at a higher angular resolution.

Irradiances, which are computed from the quad-averaged radiances, have the same level of accuracy. If the SRG and HRG computed radiances differ systematically by 1%, so will the irradiances. In some cases, the irradiances may differ by less, if positive and negative radiance differences tend to cancel.

Although it is unnecessary to run Hydrolight at higher angular resolution, I caution against running it at less resolution than the SRG. The reason is that the sun then becomes so extended over a larger quad that it is no longer close to being nearly a point source with a collimated incident beam (which is how most people regard it). The computed radiances then begin to differ by more than a few percent for simulations that are nominally the same (e.g., "sun at 30 deg"). Such considerations were of course taken into account when I chose the Hydrolight standard quad partition to be what it is.

Curt Mobley September 2002

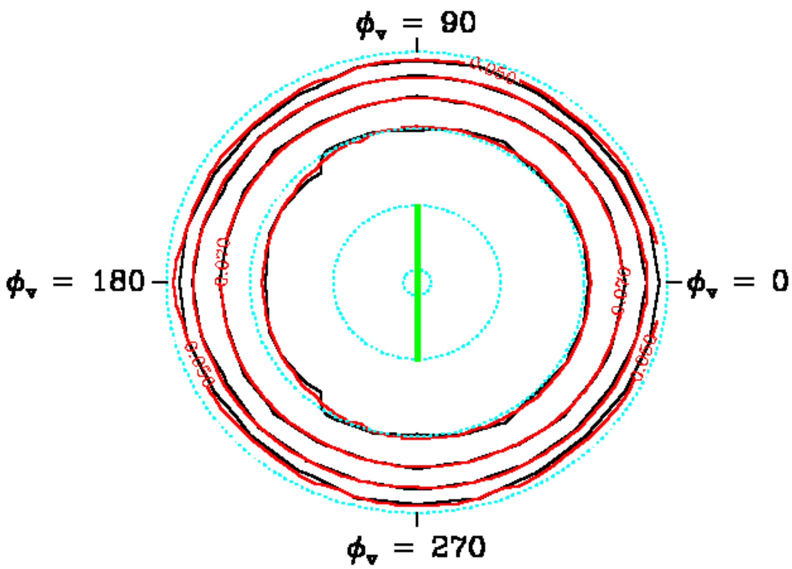

Fig. 3. Polar contour plot of SRG and HRG water-leaving radiances for an ooid sand bottom at a depth of 1 m. The center of the plot is the nadir direction; the dotted blue lines are at polar viewing angles of $\theta_v = 5$ (the nadir-viewing polar cap), 30, 60, and 90 degrees. The sun was at $\phi_v = 0$. The green line shows the nominal scanning region of the PHILLS ocean color sensor (nadir to 30 deg. off nadir, at right angles to the sun).

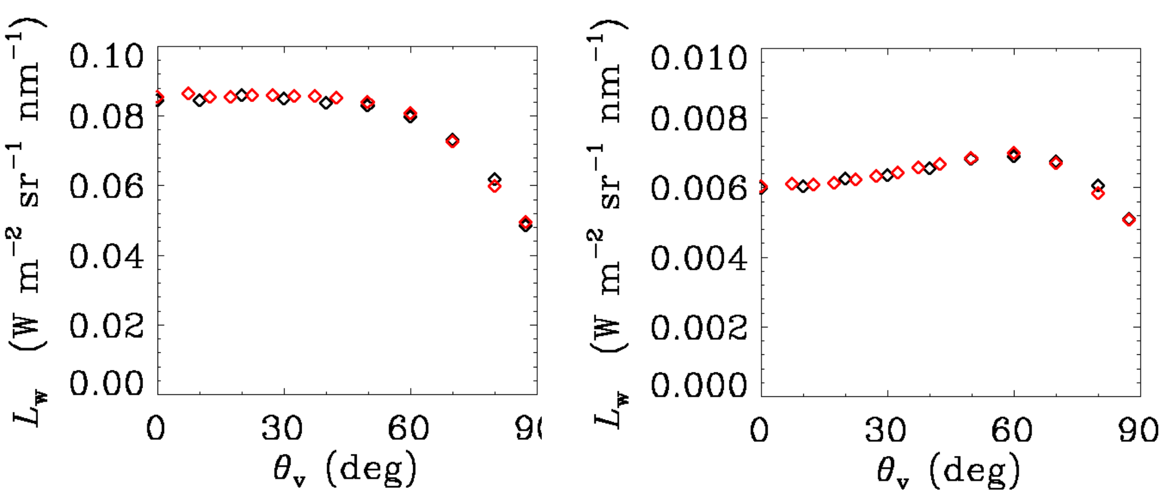

Fig. 4. Water-leaving radiances as a function of nadir viewing angle θ_v in the ϕ_v plane perpendicular to the sun ($\phi_v = 90$). Left panel: 1 m bottom depth. Right panel: infinite bottom depth. Black symbols are for the SRG and red symbols are for the HRG.