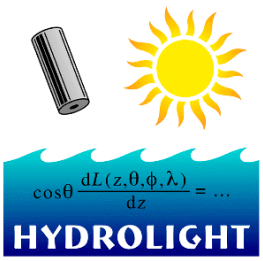
HYDROLIGHT TECHNICAL NOTE 8

COMPUTATION OF THE FOREL-ULE COLOR INDEX IN HYDROLIGHT



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Quantitative specification of the visual color of the ocean is often made using the CIE (*x*,*y*) chromaticity coordinates, which are discussed in *Light and Water*, Chapter 2. HydroLight Technical Note 5, HTN5_Color.pdf, discusses how to convert CIE (*x*,*y*) coordinates to RGB color values for display on a computer screen.

Another measure of ocean color is the Forel-Ule index, which was developed in the late 1800s as a way to quantify the color of the ocean by visually comparing the ocean with a set of 21 tubes containing precisely defined chemical mixtures that give a range colors from "indigo blue" to "cola brown." The FU index has fallen out of use in these days of hyperspectral sensors, but Wernand and van der Woerd (2010a) argue that the extensive historical data set of FU measurements warrants a revival of the use of FU color measurements for studies of long-term changes in the oceans (somewhat reminiscent of that other still useful dinosaur, the Secchi disk).

Wernand and van der Woerd (2010b) measured spectra from standard FU chemical mixtures and computed the CIE (*x*,*y*) values corresponding to each of the 21 FU numbers. Figure 1 shows the range of FU colors (within the limits of how well pdf files and computer screens can reproduce colors). Figure 2 shows a CIE chromaticity plot with the 21 FU values shown as solid squares. These data make it possible for HydroLight to compute the FU number corresponding to the CIE coordinates (*x*,*y*) of any spectrum.

HydroLight first computes the CIE (*x*,*y*) values corresponding, say, to the remote-sensing reflectance spectrum R_{rs} from 400 to 700 nm. The diamond in Fig. 2 shows an example of such a point. To obtain the corresponding FU number, the intersection is found between (1) the line from the CIE white point at (1/3,1/3) through the (*x*,*y*) point for the given spectrum (Fig. 2 shows such a line), and (2) the piecewise linear lines connecting the FU points from 1 to 21. The FU value nearest to the intersection of these two lines is then taken to be the FU number of the computed spectrum. The example in Fig. 2 results in an FU value of 6 for the R_{rs} spectrum obtained for Case 1 water and a chlorophyll value of 5 mg m^{-3}.

HydroLight performs this calculation for the nadir-viewing R_{rs} and for the above-surface, nadir-viewing, total upwelling radiance L_u. The FU number for R_{rs} approximates the color of the water itself, but the number for L_u may better approximate what is seen by an observer because L_u includes both water-leaving and surface-reflected radiance. The two FU numbers are usually equal, but can differ if the surface-reflected sky and sun radiance is a significant part of the total. This can occur if there is specular sun glint in

Fig. 1. Approximate colors of the Forel-Ule indices FU = 1 to FU = 21 (copied from Wernand and van der Woerd, 2010a).

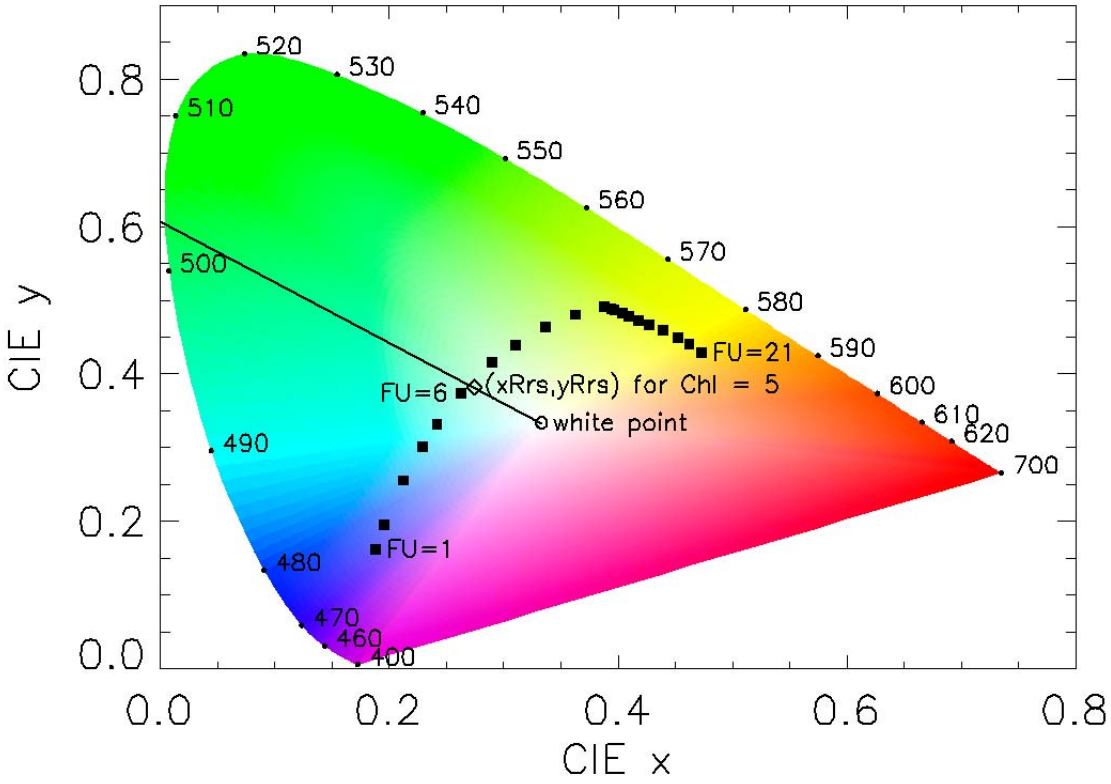

Fig 2. CIE chromaticity plot with the 21 Forel-Ule colors shown by the black squares. The open circle is the white point at $(x,y) = (1/3,1/3)$. The open diamond is the CIE color of the remote-sensing reflectance R_{rs} as calculated by HydroLight using the "new Case 1" IOP model with a chlorophyll concentration of 5 mg m^{-3}. The closest FU value is 6.

the signal, or if the water is highly absorbing (e.g., because of high CDOM concentrations), so that the water-leaving radiance is very small. Table 1 shows a few examples values.

simulation	*Chl* = 0.05	*Chl* = 0.5	*Chl* = 5	*Chl* = 50	*Chl* = 50 + $a_{CDOM}(440)$ = 1 m^{-1}	*Chl* = 50 + $a_{CDOM}(440)$ = 2 m^{-1}	*Chl* = 50 + $a_{CDOM}(440)$ = 10 m^{-1}
FU for R_{rs}	1	3	6	11	17	19	21
FU for L_u	1	3	6	10	15	18	21

Table 1. Forel-Ule numbers for various simulations. Columns 2-5 are for Case 1 water with the given chlorophyll values. Columns 6-8 are for Chl = 50 mg m^{-3}, as in column 5, but with additional CDOM so that the CDOM absorption at 440 nm is 1, 2, or 10 m^{-1}. The sun zenith angle was 50 deg, the wind speed was 5 m s^{-1}, and the sky was clear.

FU values for R_{rs} and L_u are a standard part of the HydroLight (and EcoLight) printout at the end of runs covering at least 400 to 700 nm (beginning with version 5.1.1). The code is in routine HE5/code/common/Color.f, which replaces routine CIExyY.f.

References

Wernand, M.R. and H. J. van der Woerd, 2010a. Ocean color changes in the North Pacific since 1930. *J. Euro. Optical Soc. Rapid Pub*. 5, 10015S.

Wernand, M.R. and H. J. van der Woerd, 2010b. Spectral analysis of the Forel-Ule ocean colour comparator scale. *J. Euro. Optical Soc. Rapid Pub*. 5, 10014S.