The evolution of optical water mass classification probably dates to the first deployment of the Secchi disc from the papal yacht "L’Immaculata Concezione" on April 20, 1865. Invented at the request of the Commander of the papal navy by Father Pietro Angelo Secchi, the Secchi disc continues in widespread use (Figure 1). Secchi depth atlases provide a broad view of the variability of optical properties in natural waters (Arnone, 1985). Although these measurements represent the largest assemblage of in situ optical data, they are extremely limited in spatial and temporal coverage.

By the late 1800s and early 1900s, transparency measurement was enhanced by the use of color-based comparators invented by the Swiss limnologist Françoise-Alphonse Forel. His instruments were the first to show that “water color” could be used to define water masses. However, the approach simply classifies water samples with reference to a series of standards (Figure 2); it is a nonquantitative approach that does not take into account the way different constituents of the water contribute to ocean color.

Upon the development of reliable underwater radiometry toward the end of World War II and the publication of large-scale empirical data sets by Roswell Austin, Raymond Smith, Karen Baker, John Tyler, and Nils Gunnar Jerlov, optical water mass classification formally became a quantitative science. In the 1950s, Jerlov developed the first quantitative classification method to represent the world’s oceans; his approach was based on spectral diffuse attenuation coefficients and used data collected with spectral irradiance instrumentation (Jerlov, 1951). His most elaborate classification entailed three open-ocean classes and nine coastal water types (Figure 3). Application of this classification scheme is also limited by data availability, but improves upon the Secchi classification by quantifying the optical properties with in situ instrumentation.

The current explosion of interest in optical water-mass classification owes its birth to developments in both biology and physics. Quantitative description of the absorption spectra of water, for example, showed that optical properties are due to the presence of phytoplankton and other particulate matter. The first systematic studies of oceanic and coastal water types were published in the mid-1970s by Jerlov (1976). Jerlov’s classification scheme is based on the spectral diffuse attenuation coefficients observed at the surface, and takes into account the presence of particulate matter. It is also flexible enough to be applied to other parts of the world, such as the Arctic and Antarctic regions.

Figure 1. Oceanographic Secchi discs, first introduced in 1865, are used to measure the clarity of water in both the open-ocean and the coastal zone. A Secchi disc is lowered into the water until it just disappears from view; this depth is recorded and the disc lowered a bit further. The average of the initially recorded depth and the depth at which the disc first reappears upon ascent is referred to as the “Secchi depth.” The deeper the Secchi depth, the clearer the water. Secchi depths measured in the clearest waters are typically on the order of 40 m (e.g., 41 m in the Eastern Mediterranean; Megard and Berman, 1989). Photo courtesy of David Phinney, Bigelow Laboratory for Ocean Science.

Figure 2. One of the oldest empirical methods for categorizing water color, the Forel-Ule color scale, is still available commercially. Water color, observed against a white background, is compared to the color of 22 standards ranging from deep blue to brown; the original Forel scale was introduced in 1889 by Swiss limnologist Françoise-Alphonse Forel, and was expanded upon three years later by the German limnologist Willi Ule (Hutchinson, 1975). Photo courtesy of Janet Vail, Grand Valley State University.

Figure 3. In 1951, Jerlov synthesized observational data from surface waters and proposed three different optical water mass types based on three normal transmittance curves (above left). By 1964, two intermediate types were added (IA and IB) because a number of oceanic transmittances fell between the canonical types I and II. Shipboard measurements provided the global map of the oceanic water types represented above. In 1976, Jerlov used observations from the coast of North America and Scandinavia to expand the system to include nine coastal transmittance types (above left). Figures reprinted from Jerlov (1976) with permission.
algal pigments, the development of methods to extract these pigments from environmental samples, and the development of radiative transfer theory laid the foundation for the derivation of algorithms to retrieve important optical properties from ocean-color measurements made from space (Figure 4).

Initially, Morel and Prieur (1977) classified water masses as simply Case 1 or Case 2, based on spectral reflectance and attenuation. Case 1 waters are those in which variation in color are dominated by phytoplankton and their associated degradation products. As noted by Mobley et al. (this issue), the Case 1/Case 2 dichotomy continues to provide a central focus for debate and discussion.

Remote-sensing algorithms are being developed for many optical properties of seawater, including spectral absorption and spectral back-scattering. These can be applied universally to coastal and offshore waters and are being evaluated in a number of regional field studies. Multivariate combinations of these satellite-derived optical parameters provide a basis for generating unique optical fingerprints for different water masses. As illustrated in Figure 5, three of the main components of ocean color (absorption by phytoplankton, detritus, and colored dissolved organic matter [CDOM]) can be used to classify coastal waters. Because the parameters used in this approach are very sensitive to biological and chemical processes, multivariate optical water mass classification has the potential to extend our understanding of fundamental ecological processes in the ocean in the same way that classification systems based on temperature and salinity have led to fundamental advances in our understanding of physical oceanography.

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