Perspective

The Two Faces of “Case-1” Water

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Morel’s “Optical modeling of the upper ocean in relation to its biogenous matter content (Case 1 waters)” (J. Geophys. Res. - Oceans, Vol. 93, pp. 107,49-10,768, 1988) laid the groundwork to model the optical properties of natural waters based on the concentration of chlorophyll ([Chl], in mg/m³). As stated in the abstract, it aims “tentatively to interpret the optical behavior of oceanic case-I waters,” where “Chlorophyll-like pigment concentration is used as the index to quantify the algal materials,” because [Chl] is routinely measured in marine/oceanic surveys. Specifically, Morel developed “statistical relationships between this index and the depth of euphotic layer, the spectral values of the attenuation coefficient for downwelling irradiance, or the scattering coefficient,” and further, “a pigment-dependent optical model is developed.” Thus, such a system allows many aspects of oceanographic applications when [Chl] (”this index”) is provided. In part, this system established [Chl] at the core of traditional ocean color remote sensing. To implement this system, however, it is necessary to have a complete understanding of the definition and evolution of this Case-1/Case-2 system, especially the qualitative definition of Case-1/Case-2 versus the practical separation of Case-1/Case-2 as well as the quantitative modeling of the optical properties of Case-1 waters.

1. Definition of Case-1 and Case-2 Waters

The terms “Case 1” and “Case 2” were first proposed by Morel and Prieur in 1977 [1]. From measurements of 81 sites of various waters, Morel and Prieur found that these reflectance spectra reflect “two extreme cases,” where “Case 1 is that of a concentration of phytoplankton high compared to that of other particles,” while “in contrast, the inorganic particles are dominant in case 2, and pigment absorption is of comparatively minor importance.” Further, Morel and Prieur stated that “in both cases dissolved yellow substance is present in variable amounts ....” As such, “An ideal case 1 would be a pure culture of phytoplankton and an ideal case 2 a suspension of nonliving material with a zero concentration of pigments.” [1] Such a biparty separation of natural waters is well illustrated in Figure 1 [2]. This idealized definition thus clearly indicated that Case-1 or Case-2 waters are not based on location, nor based on the value of [Chl], rather based on the relative importance of phytoplankton in contributing to the optical properties. Therefore, oceanic waters are not always Case-1, while coastal/inland waters are not necessarily Case-2 [3-5]; in a year, the water body of the same location could be either Case-1 or Case-2 [3, 4].

2. Difficulties in Practical Separation of Case-1 or Case-2

Based on the above definitions, Morel and Prieur [1] stated that “Obviously, these ideal situations are not encountered in nature ....” This difficulty is also stressed in IOCCG Report #3 [2] that “the classification, by its very nature, cannot be implemented in a very strict quantitative fashion.” To separate Case-1 vs. Case-2 waters, Morel and Prieur [1] suggested to use the “ratio of pigment concentration: scattering coefficient.” For the cases shown in Morel and Prieur [1], the ratio [Chl]/b(550) is >>1 mg/m² for Case-1 waters (see Fig. 6 of Morel and Prieur [1]), and this ratio is generally < 1.2 mg/m² for Case-2 waters (see Fig. 7 of Morel and Prieur [1]), with b(550) (in m⁻¹) the scattering coefficient at 550 nm. On the other hand, as pointed out in Morel and Prieur [1], “It must be kept in mind that intermediate situations with intermediate values of this ratio are in fact more common.” More importantly, Morel and Prieur [1] did not suggest a criterion or
“boundary” for users to practically separate Case-1 waters from Case-2. Because of the ambiguity and the no existence of exact boundaries between Case-1 and Case-2, Mobley et al. [4] suggested to drop the “Case-1” and “Case-2” terms.

Furthermore, even if there is a criterion based on [Chl]/b(550) ratio, it is required to have both [Chl] and b(550) data first before a water body could be classified into Case-1 or Case-2. Since ocean color remote sensing does not have a direct measurement of either property, such a requirement could not be met from ocean color remote sensing.

### 3. The Workaround

Clearly, the Case-1 and Case-2 “extremes” highlighted in Morel and Prieur [1] mainly provide some reasons behind the contrast of the observed reflectance spectra or “a framework for interpreting bio-optical observations” [5], not really intended to separate global natural waters into Case-1 or Case-2 (i.e., those non-Case-1, see Figure 1). What really spread the use of Case-1 (and Case-2) is this paper of Morel’s [6] “Optical modeling of the upper ocean in relation to its biogenous matter content (Case I waters).” As stated earlier, this is because that in this paper, Morel provided explicit, although empirical, relationships so a user can use [Chl] to calculate the apparent and inherent optical properties of the global oceans. For instance, for the estimation of the euphotic zone depth ($Z_{eu}$, in m) and the spectrum of the diffuse attenuation coefficient ($K_d$, in m$^{-1}$), Morel came up with

$$Z_{eu} = 38.0[\text{Chl}]^{-0.428},$$  

(1)

$$K_d(\lambda) = K_w(\lambda) + \chi(\lambda)[\text{Chl}]e(\lambda).$$  

(2)

Here $K_w$ is the contribution from pure (sea)water, and $\lambda$ represents wavelength. A table is provided for the values of $K_w(\lambda)$, $\chi(\lambda)$, and $e(\lambda)$ [6]. Thus, with these relationships, physical and biological oceanographers can quickly and easily obtain the thickness of the euphotic zone and the distribution of solar radiation in the upper water column, which can be incorporated in the estimation of primary production and/or estimation of heat budget, etc.

However, in developing the empirical relationships for “Case-1” waters (including those later updated in Morel and Maritorena [7]), a purely data driven process, only “The turbid case II waters, always encountered near the coast, were excluded …” via “visual observation combined with the knowledge of the geographical position of the station.” What these statements imply is that the data used to draw the regressions are not really the Case-1 “extreme cases” defined in Morel and Prieur [1] or in IOCCG Report #3 [2]; the data rather included waters of not-so-turbid Case-2 waters and waters having various contributions of yellow substance. In addition, these regressions ignored a key feature that the apparent optical properties depend on the distribution of light field, e.g., sun angle. It is thus not surprising to see deviations, sometimes quite large [5], around the regression lines of optical properties for a given [Chl] (see Figure 1(b) for an example). Especially when the temporal variation of [Chl] reflects a change of photoacclimation of phytoplankton [8], it will be more difficult to estimate the optical properties of phytoplankton using [Chl]. Therefore, these relationships in essence reflect observed average dependences of oceanic waters and driven by the data accumulated, not really the relationships of “Case-1” waters defined in Morel and Prieur [1]. For such practical modeling of “Case-1” waters, as highlighted in Antoine et al. [5], it would be a misinterpretation “that case I waters are those where optical properties are determined only by phytoplankton (or chlorophyll a).” As such, apparently, there is a relaxation or an evolution, on the definition and use of the term “Case-1,” which was stricter in Morel and Prieur [1] but relaxed in Morel [6] and Morel and Maritorena [7], with the latter representing mainly average relationships obtained from oceanic waters.
4. A Few Extra Points

4.1. On the Modeling of \( K(PAR) \). In this classical paper, Morel [6] also pointed out an error in earlier practice of marine optics, but it is generally overlooked by the community. Historically and even today, the diffuse attenuation coefficient of photosynthetical available radiation (PAR), \( K(PAR) \), is quite often described as

\[
K(PAR) = K_w(PAR) + k_c[\text{Chl}] + K_x, \tag{3}
\]

with \( K_w \) the partial contribution from pure (sea)water and assumed a constant, \( k_c \) (in \( m^2/mg \)) the chlorophyll-specific attenuation coefficient also assumed a constant, and \( K_x \) the contributions from other substances not covarying with phytoplankton. Morel [6] pointed out that such an expression is not valid for the evaluation of \( K(PAR) \). This is because (1) PAR is not monochromatic, rather in a broad spectral range (~400-700 nm), and (2) water’s attenuation is highly spectrally selective, where most red photons (~600-700 nm) are absorbed by water molecules in the upper few meters, which left the less attenuating blue-green photons penetrate deeper in most natural waters. Thus, \( K_w \) and/or \( k_c \) cannot be constant vertically even for homogeneous waters. This phenomenon can be illustrated mathematically through

\[
K_w(PAR) = -\frac{1}{z} \ln \left( \int_{400}^{700} E_\mu(\lambda) \exp \left( -K_w(\lambda)z \right) d\lambda \right), \tag{4}
\]

Here \( E_\mu \) is the scalar irradiance at sea surface, with \( z \) (in m) for water depth from surface. Because spectral \( K_w \) changes drastically in the 400–700 nm range, it is easy to see \( K_w(PAR) \) changes for different layer or thickness \( z \) of a water column. The same argument also applies to \( k_c \). Following the same approach, \( K(PAR) \) also varies significantly in the upper water column [9] even for homogeneous waters, which is thus an “ambiguous” property if the depth information is not provided [10]. In a more general sense, since AOPs are dependent on the light field, they are not additive as expressed by Equation (3) [11].

4.2. Optical Properties in the UV Domain. Through the years of evolution regarding the concept of “Case-1,” a more common understanding is that “Case 1 waters are those waters in which phytoplankton … are the principal agents responsible for variations in optical properties of the water” [2], with an underlying assumption that “… the contribution from other substances, if present, is relatively small in Case 1 waters …” [2]. It appears that such a condition is more appropriate in the visible (400-700 nm) domain but runs into difficulties in the UV, where in general, the absorption coefficient of yellow substance is significantly stronger than that from phytoplankton. Especially, as pointed in Bricaud et al. [12] and echoed in Morel et al. [13], yellow substances “do not seem correlated to the local pigment content.” As a result, for the global ocean, it is thus not surprise to see widely scattered relationships between \( K_d(360) \) and \( K_d(490) \) (Figure 2).

In addition, mycosporine-like amino acids (MAAs) have strong absorption in the UV domain [14]. Since MAAs have no relationships to [Chl], these components further complicate the practice of using [Chl] to model optical properties in the UV.

4.3. A Correction. In the development of reflectance models, Morel and Gentili [16] expressed the total absorption coefficient \( a \) (in \( m^{-1} \)) as

\[
a(\lambda) = \left( a_w(\lambda) + 0.06A(\lambda)[\text{Chl}]^{0.65} \right) \left( 1 + 0.2Y(\lambda) \right), \tag{5}
\]

with \( a_w(\lambda) \) the absorption coefficient of pure (sea)water and \( Y(\lambda) \) the contribution of yellow substance to \( a \). This expression is a typo, which overstated the contribution of \( a_w(\lambda) \),
but in the literature, there are no small number of users following this expression for the total absorption coefficient. As pointed out in Morel and Maritorena [7], the intended expressions are

$$a(\lambda) = a_\infty(\lambda) + 0.06A(\lambda)[\text{Chl}]^{0.65} + a_y(\lambda), \quad (6)$$

$$a_y(\lambda) = a_y(440) \exp (-0.014(\lambda - 440)), \quad (7)$$

$$a_y(440) = 0.2\left[a_\infty(440) + 0.06A(440)[\text{Chl}]^{0.65}\right], \quad (8)$$

where $a_y(\lambda)$ is the absorption coefficient of yellow substance.

5. Concluding Remarks

There are two “Case-1” waters: ideal (or theoretical) and practical. Ideal Case-1 reflects phytoplankton culture, which is hardly met in natural environments, except during some phases of phytoplankton blooms, while practical Case-1 reflects modeling of optical properties using [Chl], i.e., a one-variable model for optical properties. Because of its simplicity (with various degrees of uncertainties, some are accepted) and the widely available [Chl], this practical Case-1 has been utilized in a wide range of oceanography studies in the past decades and today. This practice to some degree transferred oceanic waters to “Case-1 waters,” although the two actually do not match exactly [5]. While this system by Morel [6] (and its later revisions) significantly advanced the field of ocean optics and ocean color remote sensing, as suggested by Mobley et al. [4], for less ambiguity or controversy, it appears now better to use “oceanic waters,” rather than “Case-1 waters,” to describe the optical variability of this large water body. Furthermore, as practiced by many researchers including Morel et al. [13], it is time and important to go beyond the overall average relationships between optical properties and [Chl] and to focus on the scatters (the “second-order” variations) around the regression lines, which would greatly expand our knowledge and understandings of the relationships between optical properties and environmental parameters or indexes.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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