Diffuse Attenuation and Secchi Depth Products from MODIS and VIIRS: Product of Ocean Transparency

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Acknowledgements:

NASA Suomi National Polar-orbiting Partnership
NASA Ocean Biology and Biogeochemistry
\[ E_d(\lambda, z) = E_d(\lambda, 0-) e^{-K_d(\lambda) z} \]

**Diffuse attenuation coefficient**

**Morel:**
\[ K_d(\lambda) = K_w(\lambda) + \alpha(\lambda) [Chl]^\beta(\lambda) \]

**Austin & Petzold (1986):**
\[ K_d(\lambda) = K_w(\lambda) + M(\lambda) [K_d(490) - K_w(490)] \]
Austin & Petzold (1981):

\[ K_d(490) = A \left( \frac{L_w(490)}{L_w(555)} \right)^B \]

\[ K_d(490) = \text{Fun} \left( \frac{R_{rs}(490)}{R_{rs}(555)} \right) \]

\[ \log_{10}(K_{bio}(490)) = a_0 + \sum_{i=1}^{4} a_i \log_{10} \left( \frac{R_{rs}(\lambda_{blue})}{R_{rs}(\lambda_{green})} \right) \]

\[ K_{d, 490} = K_{bio}(490) + 0.0166 \]

\[ R_{rs}(\lambda_{blue}) = R_{rs}(486) \]
VIIRS $K_d(490)$

Diffuse attenuation coefficient at 490 nm (m$^{-1}$)

0.01  0.02  0.05  0.1  0.2  0.5  1   2   5
\[ \log_{10}(K_{bio}(490)) = a_0 + \sum_{i=1}^{4} a_i \log_{10} \left( \frac{R_{rs}(\lambda_{blue})}{R_{rs}(\lambda_{green})} \right) \]

\[ Kd_{490} = K_{bio}(490) + 0.0166 \]

\[ \log_{10}(chlor_{a}) = a_0 + \sum_{i=1}^{4} a_i \log_{10} \left( \frac{R_{rs}(\lambda_{blue})}{R_{rs}(\lambda_{green})} \right)^i \]

\[ R_{rs}(\lambda_{blue}) = R_{rs}(443) > R_{rs}(486) \]
The standard K_d(490) and Chl products are 100% co-vary in coastal waters; but ...

\[ K_d (490) = \text{Fun} \left( \frac{R_{rs}(490)}{R_{rs}(555)} \right) \]

AOP: sun angle dependent

Nearly independent of sun angle

The two sides do \textbf{not} match in optical attributes.
It is imperative to generate a more consistent, and un-equivocal, ocean color K product in the 21st century

\[ K_d = \text{fun}(a, b_b, \theta_w) \]

(What et al 2005)
Normalized diffuse attenuation coefficient \((nK_d)\):

\[ nK_d = \frac{K_d}{D_0} \]

\[ D_0 = \frac{f}{\cos(\theta_{sw})} + D_0(sky)(1 - f) \]

\( f? \)
(a) $\lambda = 410 \text{ nm} \; \tau_a (550) = 0.1$

(b) $\lambda = 490 \text{ nm} \; \tau_a (550) = 0.1$

(c) $\lambda = 550 \text{ nm} \; \tau_a (550) = 0.1$

(d) $\lambda = 700 \text{ nm} \; \tau_a (550) = 0.1$

(Lin et al 2016)
(Lin et al. 2016)
\[ f = m_0 \left( m_1 - e^{-m_2 \frac{\lambda}{\lambda_0}} \right) - \left( m_3 \frac{\lambda}{\lambda_0} + m_4 \right) e^{m_5 \frac{\theta_s}{\theta_{s0}}} \]

\[ R^2 = 0.99 \]

MAPE = 0.7%
\[ nK_d = \text{fun}(a, b_b) \]
$K_d \& D_0 \rightarrow nK_d$

(Lin et al 2016)
K vs Chl:

(Lin et al 2016)
Remote Sensing $nK_d$: $R_{rs} \rightarrow a&b_b \rightarrow nK_d$

(Lin et al 2016)
Global sample products from VIIRS:

(Lin et al 2016)
Application of $nK_d(490)$

Water clarity/transparency ...

Angelo Secchi
(1818-1878)
New theoretical relationship for $Z_{SD}$:

$$Z_{SD} \approx \frac{1}{2.5 K_{d}^{tr}} \ln \left( \frac{|r_T - r_{w}^{tr}|}{0.013} \right)$$

$K_{d}^{tr}$: attenuation coefficient in the transparent window

(Lee et al 2015)
Verification of the new Secchi disk theory

\[ R_{rs} \rightarrow a \& b \rightarrow K_d \]

QAA (2002) Lee et al 2005

\[ y = 1.04x + 0.2 \]

(Lee et al 2015)
Global $Z_{SD}$

A much more straightforward product for water clarity!
Conclusions:

1. Traditional ratio-derived $K_d(490)$ product overlooked its AOP characteristics; →
   a) the empirical $K_d(490)$ product has exactly the same spatial pattern as the Chl product in coastal region, which is not supported by ocean optics theory and observations
   b) could be an “🍎 vs 🍊” comparison between satellite $K_d(490)$ and insitu $K_d(490)$

2. n$K_d$ corrects the AOP feature; →
   It is much more accurate when it is derived following a mechanistic scheme;

3. Optical properties have a spectral dependence, thus n$K_d$ at a single wavelength has limited applications. For representation of water clarity, it is better to use Secchi depth.

It is mid 2016 now, we should have long passed the empiricism-based practices for inversion of optical properties.
Thank you!