**Normalized water-leaving radiance (IOCCG-6 Meeting, 24-26 January 2001)**

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The "Normalized water-leaving radiances ($nL_w(\lambda)$) are the products generally distributed by the various Space Agencies. They belong to the Level 2 products category.

Actually the radiances (and related "reflectances"), in spite of the normalization, are still depending on the pixel-sun geometry, and therefor are not straight forwardly comparable. This is due to the non-isotropic character of the upward radiance field.

A meaningful use of these $nL_w(\lambda)$, [such as the reproduction of Level 3, the intercomparison between sensors, the merging of data, and even the composition with sea-truth radiometric measurements] is not possible as long as the artifacts resulting from the bi-directional effects have not been removed.

Such a removal is easy in terms of computational effort (the correction is extracted from LUT). It is recommended that the various Agencies make available normalized water-leaving radiances, converted in the same way (same LUT), and in parallel with the classical product. The physics behind the corrections is well understood. The parameterization, however, may evolve according to progress in marine optics. This is the main reason for keeping the classical $nL_w$ product, in such a way that any user can easily correct it according to his own scheme.

# Basic equations

*(simplified)*

✓ $$R = \frac{E_u(0^-)}{E_d(0^-)} = f\,\frac{b_b}{a} \qquad \left(= f'\left(\mathrm{IOP's}\right)\right)$$

✓ $$E_d(0^-) = E_d(0^+)\,\frac{1-\bar{\rho}}{1-\bar{r}R}$$

✓ $$Q = \frac{E_u(0^-)}{L_u(0^-)}$$

✓ $$L_w = L_u(0^-)\,\frac{1-\rho_F}{n^2}$$

$$L_w = E_d(0^+)\;\Re\;\frac{f}{Q}\,\frac{b_b}{a}$$

where

$$\Re = \left[\frac{(1-\bar{\rho})}{(1-\bar{r}R)}\,\frac{(1-\rho_F)}{n^2}\right] \qquad \text{(reflection + refraction)}$$

and

$$E_d(0^+) = \mu_0\;\varepsilon_c\;F_0\;t$$

t : atmospheric transmittance

$F_0$ : extra-terrestrial solar flux (mean Earth-Sun distance : $d_0$)

$\mu_0$ = $\cos(\theta_0)$, $\theta_0$ = solar zenith angle

$\varepsilon_c$ = eccentricity correction = $\left(d_0/d\right)^2$

# Expanded basic equations

- *Re-introducing wavelength, geometry, and Chl (Case 1 waters)*
- *Wind speed and aerosol optical thickness dependencies ignored*

✓ $$R(\theta_0,\lambda,\mathrm{Chl}) = \frac{E_u(0^-)(\theta_0,\lambda,\mathrm{Chl})}{E_d(0^-)(\theta_0,\lambda,\mathrm{Chl})^*} = f(\theta_0,\lambda,\mathrm{Chl}) \cdot \frac{b_b(\lambda,\mathrm{Chl})}{a(\lambda,\mathrm{Chl})}$$

✓ $$E_d(0^-)(\theta_0,\lambda,\mathrm{Chl})^* = E_d(0^+)(\theta_0,\lambda)\frac{1-\bar{\rho}}{1-\bar{r}R(\theta_0,\lambda,\mathrm{Chl})^*}$$

✓ $$Q(\theta_0,\theta',\Delta\phi,\lambda,\mathrm{Chl}) = \frac{E_u(\theta_0,\lambda,\mathrm{Chl})}{L_u(\theta_0,\theta',\Delta\phi,\lambda,\mathrm{Chl})}$$

✓ $$L_w(\theta_0,\theta_v,\Delta\phi,\lambda,\mathrm{Chl}) = L_u(\theta_0,\theta',\Delta\phi,\lambda,\mathrm{Chl})\frac{1-\rho_F(\theta')}{n^2}$$

$$L_w(\theta_0,\theta_v,\Delta\phi,\lambda,\mathrm{Chl}) = E_d(0^+)(\theta_0,\lambda)\ \Re(\theta')\frac{f(\theta_0\lambda,\mathrm{Chl})}{Q(\theta_0,\theta',\Delta\phi,\lambda,\mathrm{Chl})} \cdot \frac{b_b(\lambda,\mathrm{Chl})}{a(\lambda,\mathrm{Chl})}$$

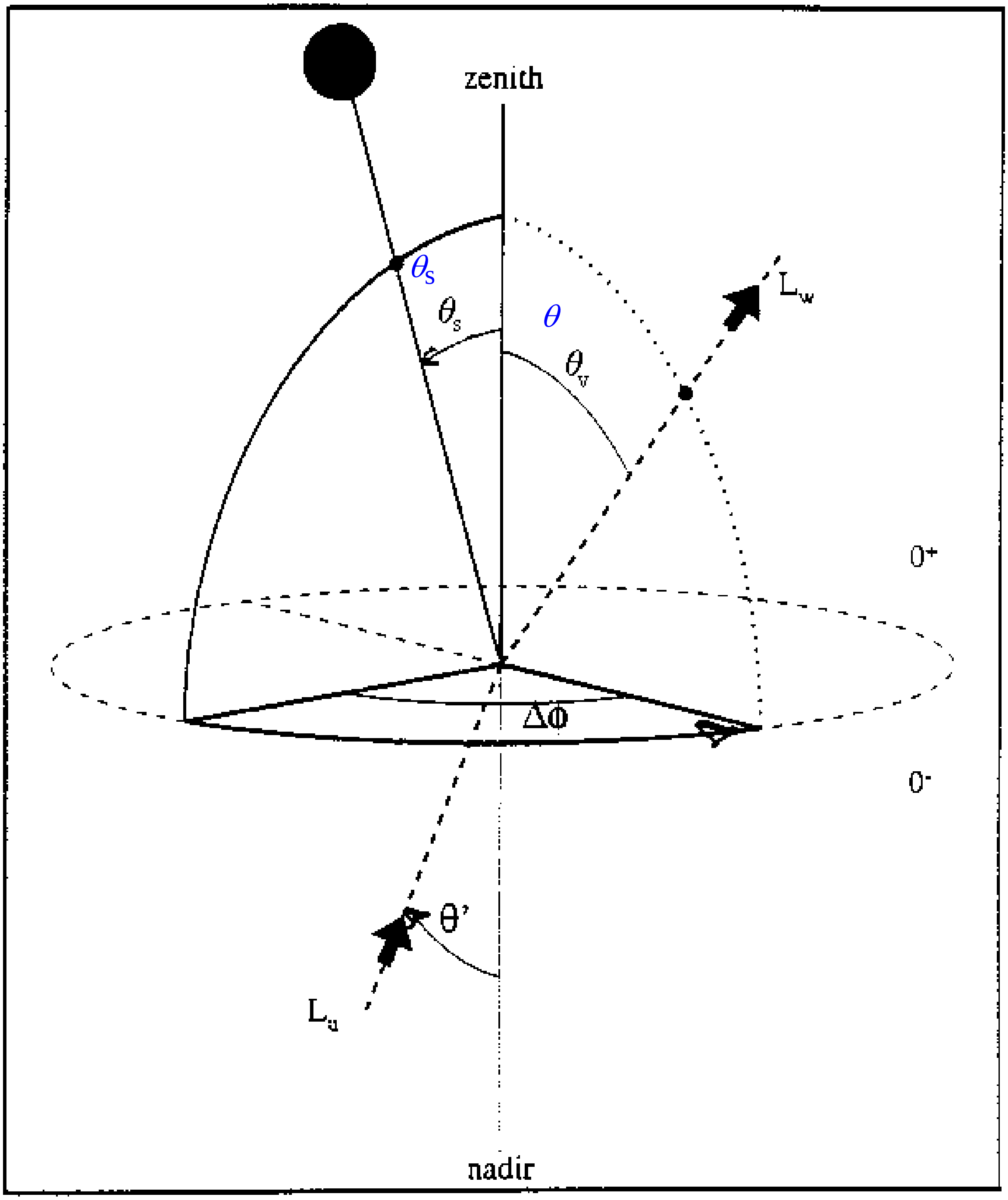
where $\sin(\theta_V) = n \cdot \sin(\theta')$

and $$\Re(\theta') = \left[\frac{(1-\bar{\rho})}{(1-\bar{r}R(\theta_0,\lambda,\mathrm{Chl})^*)}\frac{(1-\rho_F(\theta'))}{n^2}\right]$$ (reflection + refraction)

Note that :

$$E_d(0^+)(\theta_0,\lambda) = \mu_0\ \varepsilon_c\ F_0(\lambda)\ t(\theta_0,\lambda)$$

**** weak dependency on Chl***




$L_u$ = in-water upwelling radiance

$L_w$ = « water-leaving » radiance

$$L_w = L_u \frac{1-\rho_F(\theta')}{n^2}$$

# Useful expressions

*($\lambda$ and Chl omitted)*

**Slant water-leaving radiance :**

$$L_w(\theta_0, \theta_v, \Delta\phi) = [\mu_0 \ \varepsilon_c \ F_0 \ t(\theta_0)] \ \Re(\theta') \ \frac{f(\theta_0)}{Q(\theta_0, \theta', \Delta\phi)} \cdot \frac{b_b}{a}$$

**Eq. (1)**

**Vertically water-leaving radiance originating from nadir (*subscript* "n"):**

($i.e.$, with $\theta_v = \theta' = \Delta\phi = 0$)

$$L_w(\theta_0, 0) = [\mu_0 \ \varepsilon_c \ F_0 \ t(\theta_0)] \ \Re_0 \ \frac{f(\theta_0)}{Q_n(\theta_0)} \cdot \frac{b_b}{a}$$

**Eq. (2)**

when, hypothetically, the sun zenith angle is naught $\theta_0 = 0$

$$L_w(0,0) = [\mu_0(=1) \ \varepsilon_c \ F_0 \ t(0)] \ \Re_0 \ \frac{f_0}{Q_n(0)^*} \cdot \frac{b_b}{a}$$

**Eq. (3)**

* : also denoted $Q_0$

# Gordon and Clark (1981) operational definition of satellite normalized water-leaving radiances

Original definition : $$[L_w]_N^{GC} = L_w^{meas} \frac{F_0}{E_d(0^+)} = \frac{L_w^{meas}}{\varepsilon_c \; \mu_0 \; t(\theta_0)}$$

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➢ When using **Eq. (1)**

$$[L_w]_N^{s} = F_0 \; \Re(\theta') \; \frac{f(\theta_0)}{Q(\theta_0, \theta', \Delta\phi)} \cdot \frac{b_b}{a}$$

*"s" for satellite*

➢ When using **Eq. (3)**

$$[L_w]_N^{ex} = F_0 \; \Re_0 \; \frac{f_0}{Q_0} \cdot \frac{b_b}{a}$$

*"ex" for exact (i.e., when $\theta' = 0$, $\theta_0 = 0$)*

➢ Transforming $[L_w]_N^{s}$ into $[L_w]_N^{ex}$

$$[L_w]_N^{ex} = [L_w]_N^{s} \frac{\Re_0}{\Re(\theta')} \frac{f_0}{Q_0} \left( \frac{f(\theta_0)}{Q(\theta_0, \theta', \Delta\phi)} \right)^{-1}$$ **Eq. (4)**

# From *in situ* determinations to "field" normalized water-leaving radiances

reminder :

**Gordon and Clark (1981) operational definition**

$$[L_w]_N^{GC} = L_w^{meas} \frac{F_0}{E_d(0^+)} = \frac{L_w^{meas}}{\varepsilon_c \ \mu_0 \ t(\theta_0)}$$

**From in-water measurements (when measuring $L_u$ at nadir ➔ $L_w^{inw}$)**

**(superscript "inw" for in-water, and "f" for field)**

$$[L_w^{inw}]_N^f = \frac{L_w(\theta_0, \theta_v = 0)}{\mu_0 \ \varepsilon_c \ t(\theta_0)}$$

**From above-water measurements (when measuring $L_w$ at $\theta_v \neq 0$)**

**(superscript "abw" for above-water)**

$$[L_w^{abw}]_N^f = \frac{L_w(\theta_0, \theta_v, \Delta\phi)}{\mu_0 \ \varepsilon_c \ t(\theta_0)}$$

- **Transforming $[L_w^{abw}]_N^f$ into $[L_w^{inw}]_N^f$**

$$[L_w^{inw}]_N^f = [L_w^{abw}]_N^f \ \frac{\Re_0}{\Re(\theta')} \ \frac{Q(\theta_0, \theta', \Delta\phi)}{Q_n(\theta_0)}$$ **Eq. (5)**

- **Transforming $[L_w^{inw}]_N^f$ into $[L_w]_N^{ex}$**

$$[L_w]_N^{ex} = [L_w^{inw}]_N^f \ \frac{f_0}{Q_n(0)} \left( \frac{f(\theta_0)}{Q_n(\theta_0)} \right)^{-1}$$ **Eq. (6)**

# Summary/Conclusion

**<u>From satellites</u>:** « nLw » = $[L_w]^s_N$

Still dependent on geometry,

- can be corrected for directional effects (Eq. 4), to provide $[L_w]^{ex}_N$ in a reversible way

**<u>From field measurements:</u>**

Above-water measurements $[L^{abw}_w]^f_N$

In-water measurements $[L^{inw}_w]^f_N$

Conversion via Eq. 5

Nadir measurement

Conversion via Eq. 6, provides $[L_w]^{ex}_N$