

CZCS Atmospheric Correction: Methodology and Approach

Overview

Like all spaceborne radiometers, the Coastal Zone Color Scanner (CZCS) measures the spectral distribution of radiance exiting the top of the atmosphere. However, for ocean color applications, we need the radiance upwelling from *below* the ocean surface.

The atmospheric correction process:

- **Removes** radiance contributions from atmospheric scattering (aerosols and air molecules).
- **Removes** surface contributions (specular reflection and white-caps).
- **Adjusts** for the atmosphere's attenuation of the retrieved water-leaving radiance.

Whenever possible, the Ocean Biology Processing Group (OBPG) uses the exact same process for CZCS as it does for SeaWiFS and MODIS data (e.g., MODIS/Aqua Reprocessing 1.1 & SeaWiFS Reprocessing 5.1). The relative spectral response of each CZCS band generates the Rayleigh and aerosol tables, solar irradiances, and ozone absorption coefficients.

The key difference: The only difference in processing CZCS compared to modern sensors is how we determine aerosol contributions.

The Challenge: Contributions from Aerosols

For modern sensors like MODIS and SeaWiFS, the OBPG uses the Gordon & Wang (1994) method. This method relies on two Near-Infrared (NIR) bands where water-leaving radiance is minimal and predictable. By using an iterative scheme (Stumpf et al., 2003), the OBPG predicts water-leaving radiance from these two NIR bands, retrieves the aerosol radiance, and selects the most appropriate aerosol model.

The CZCS Limitation:

- CZCS does **not** have a pair of NIR spectral channels.
- Its longest available wavelength for ocean observations is **670 nm**.
- Unlike NIR bands, 670 nm has a small but significant water-leaving radiance contribution in clear (oligotrophic/mesotrophic) waters, and even larger, less predictable contributions in turbid waters.

The Solution:

To determine the water-leaving radiance—and thereby the aerosol contribution—at 670 nm, the OBPG developed an iteration scheme similar to Stumpf et al. (2003). We combine this with a fixed assumption about the aerosol type to determine contributions in shorter visible wavelengths.

Step-by-Step Methodology

1. Determining Water-Leaving Radiance at 670 nm

To estimate water-leaving reflectance at 670 nm (R_{rs_670}) from reflectance at 550 nm (R_{rs_550}), the algorithm follows these modeling steps:

1. **Carder et al. (1999)**: Uses a linear relationship between particulate backscattering and R_{rs_550} .
2. **Gould et al. (1999)**: Uses a spectral scattering function to estimate backscattering at 670 nm based on backscattering at 550 nm.
3. **Gordon et al. (1988)**: Uses a radiance model formulation to estimate reflectance at 670 nm from backscattering and absorption.
 - *Absorption Terms*: Account for water (computed *a priori*), particulate matter (estimated from chlorophyll via Bricaud et al., 1998), and gelbstoff/detritus (estimated via Stumpf et al., 2003).

(Note: See Appendix for the C-code snippet of this procedure).

2. Assumption on Aerosol Type (The M99 Model)

Determining actual aerosol type requires at least two wavelengths. Rather than making error-prone assumptions to estimate water-leaving radiance at 550 nm, the OBPG chose to fix the aerosol type to a **maritime aerosol at 99% relative humidity (M99)**.

- M99 is one of the most commonly retrieved aerosol types in global SeaWiFS and MODIS processing.
- *Important*: This is not the same as the "fixed epsilon" approach used in past CZCS reprocessing, as this model dynamically accounts for viewing and solar path geometry dependencies of a maritime aerosol. (*See figure 1*)

epsilon geometry dependence

epsilon is not constant across scan, even for a constant aerosol type

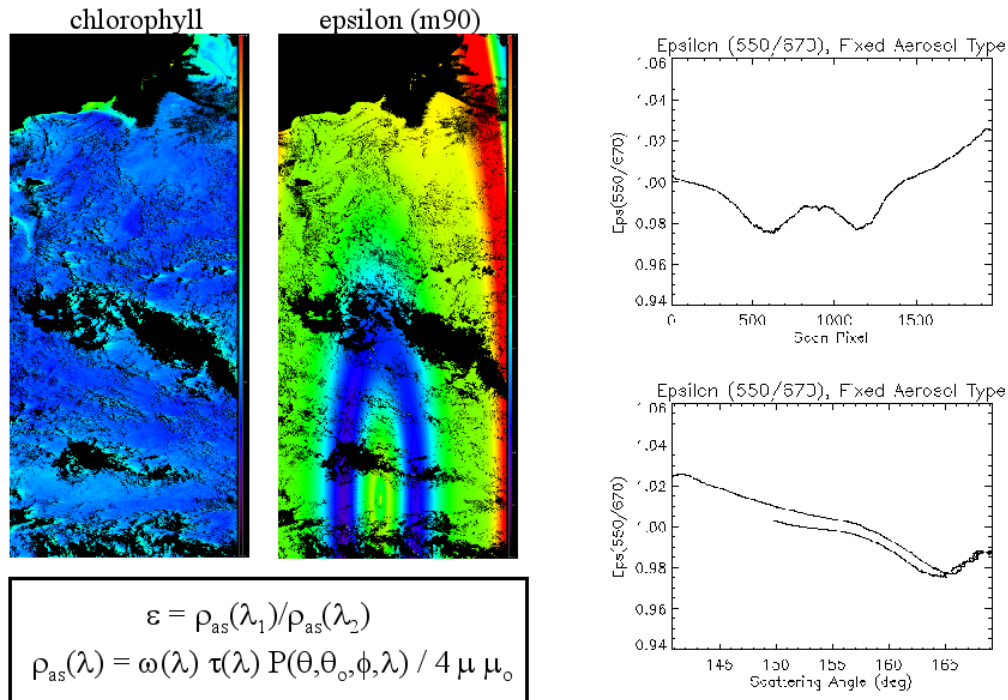


Figure 1: Fixed Aerosol vs Epsilon approach for viewing and solar path geometry dependences of a maritime aerosol

3. The Aerosol Iteration Scheme

With the aerosol type fixed (M99) and a method to estimate Rrs_670 established, the process uses the following iteration loop:

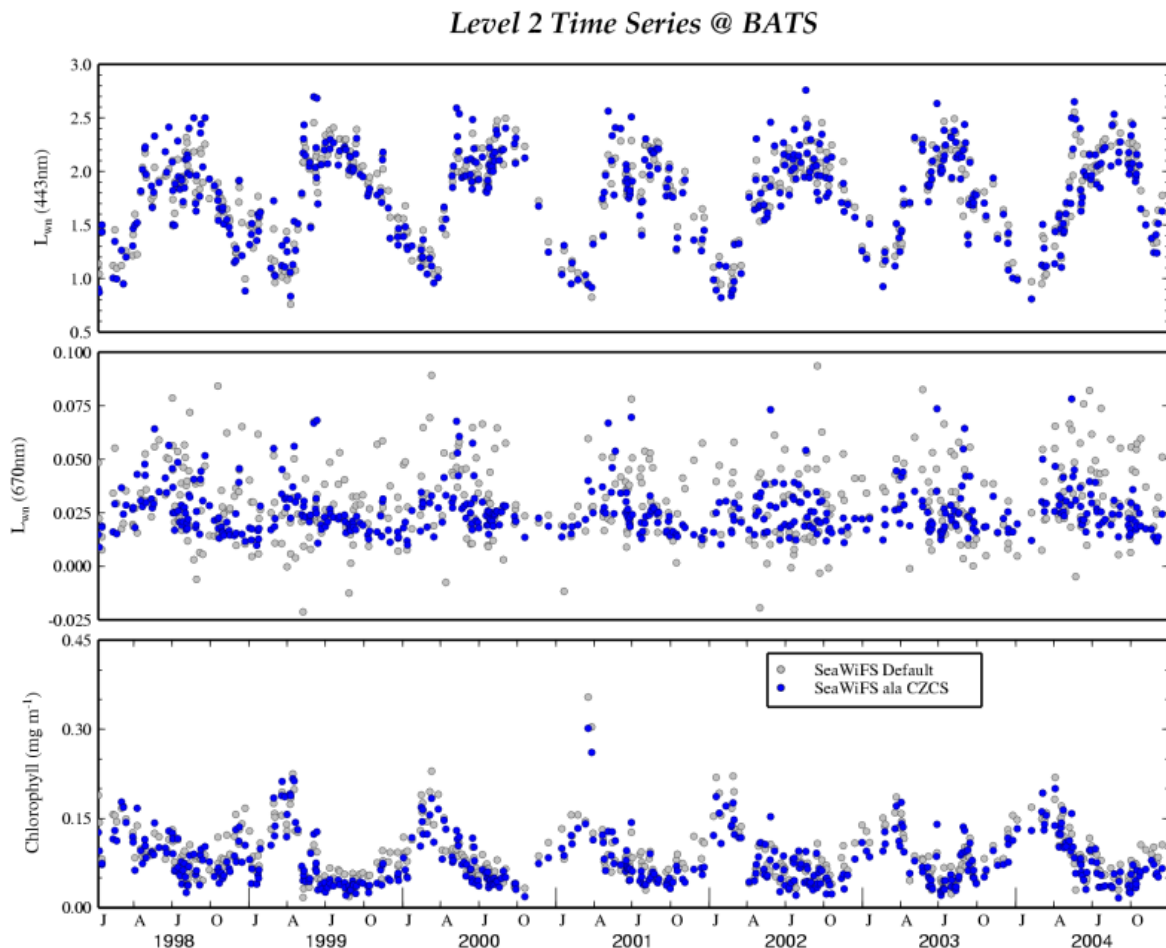
1. **Initialize:** Assume a starting value for Rrs_550 and Chlorophyll (Chl).
2. **Estimate & Subtract:** Estimate Rrs_670 and subtract it from the observed reflectance to retrieve the aerosol reflectance (radiance) at 670 nm.
3. **Extrapolate:** Use the M99 model to extrapolate the 670 nm aerosol radiance to 443, 520, and 550 nm.
4. **Recompute:** Recompute Rrs_550 and Chl, then estimate a new Rrs_670.
5. **Repeat:** Loop through these steps until Rrs_670 stops changing.

Discussion and Future Enhancements

While assuming a fixed aerosol type is not perfect, it is necessary given CZCS's hardware limitations. This scheme mimics modern SeaWiFS/MODIS processing as closely as possible, including full multi-scattering computations.

Verification:

This approach was verified using SeaWiFS data processed two ways: standard NIR vs. the CZCS algorithm (treating SeaWiFS as if it lacked NIR bands). In mesotrophic regions, both methods yielded very similar results for normalized water-leaving radiance (nLw_443), chlorophyll, and nLw_670. (See figure 2)



Potential Future Enhancements:

- **Climatology Integration:** Using a global climatology of aerosol types (e.g., SeaWiFS Angstrom fields) to account for typical seasonal and coastal changes. *Caveat: Assumes variability hasn't changed in 20 years.*
- **Clear-Pixel Interpolation:** Using the clearest ocean observations in each orbit to estimate spectral changes in aerosols, then spatially interpolating the aerosol type to less-clear pixels (similar to Gregg et al., 2002). *Caveat: Requires clear pixels in every scene and assumes geometry independence.*

References

1. **Carder, K. L., et al. (1999).** "Semianalytic Moderate-Resolution Imaging Spectrometer algorithms for chlorophyll a and absorption with bio-optical domains based on nitrate-depletion temperatures", *JGR*, Vol 104, No. C3, pp 5403-5422.
2. **Gould, Jr., R. W., et al. (1999).** "Spectral dependence of the scattering coefficient in case 1 and case 2 waters", *Appl. Opt.*, Vol 38, No. 12, pp 2377-2383.
3. **Gordon, H. R., et al. (1988).** "A semianalytic radiance model of ocean color", *JGR*, Vol 93, pp 10,909-10,924.
4. **Bricaud, A., et al. (1998).** "Variations of light absorption by suspended particles with the chlorophyll a concentration in oceanic (case 1) waters...", *JGR*, Vol 103, pp 31,033-31,044.
5. **Gregg, W.W., et al. (2002).** "NOAA-NASA Coastal Zone Color Scanner Reanalysis Effort," *Appl. Opt.* 41, 1615-1628.
6. **Stumpf, R. P., et al. (2003).** "A Partially coupled ocean-atmosphere model for retrieval of water-leaving radiance from SeaWiFS in coastal waters", *SeaWiFS Postlaunch Technical Report Series*, Vol 22.

Appendix

get_rhown_nir

Routine to estimate nLw_670 from Rrs_550

The following snippet of code is from the MS112 source, `get_rhown_nir.c`:

```
static const float g1 = 0.0949;
static const float g2 = 0.0794;
/* ----- */
/* Description: */
/* This computes the normalized water-leaving reflectances */
/* at the CZCS 670 channel. */
/* */
/* Outputs: */
/* rhown(670) */
/* */
/* Algorithm: S. Bailey, OBPG, July 2005 */
/* Generalization: B. A. Franz, OBPG, 25 Jan 2006 . */
/* ----- */
void rhown_red_5_6(float chl, float aw[], float bbw[], float Rrs[],
float wave[], long ib_red, float rhown[])
{
static firstCall = 1;
static long ib5;
static long ib6;
float a6, aw6, ap6, adg6, bbw5, bb5;
float a, bb;
float salbedo;
float Rrs_red;
float Rrs5, Rrs6;
if (firstCall) {
if ((ib6 = bindex_get(670)) < 0) {
printf("%s line %d: can't find red band\n", __FILE__, __LINE__);
exit(1);
}
if ((ib5 = bindex_get(550)) < 0)
if ((ib5 = bindex_get(555)) < 0)
if ((ib5 = bindex_get(565)) < 0) {
printf("%s line %d: can't find green band\n", __FILE__, __LINE__);
exit(1);
}
}
firstCall = 0;
}
Rrs5 = Rrs[ib5];
Rrs6 = Rrs[ib6];
aw6 = aw [ib6];
bbw5 = bbw[ib5];
if (Rrs6 <= 0.0)
Rrs6 = 0.001;
if (Rrs5 <= 0.0)
Rrs5 = 0.001;
/* Compute particulate absorption at 670 (algal and non-algal) */
chl = MIN(MAX(chl,0.0),64.0);
if (chl > 0.0)
ap6 = 0.019890*pow(chl,0.817742);
else
```

```

ap6 = 0.0;
/* Compute absorption by gelbstoff and detritus at 670 */
adg6 = 0.0;
if ( Rrs5 > 0.0 && Rrs6 > 0.0 )
adg6 = 0.15 - 0.19*(Rrs5 - Rrs6)/Rrs5;
/* Compute total absorption at 670 (incl. band-pass adjustment of 0.8) */
a6 = aw6 + 0.8 * ap6 + adg6;
/* Compute backscatter at 550 from Carder/Lee */
bb5 = (-0.00182 + 2.058*Rrs5 + bbw5);
/* Translate bb to NIR wavelength using Gould */
bb = (-0.00113*wave[ib_red] + 1.62517) / (-0.00113*550.0 + 1.62517) * bb5;
/* Remote-sensing reflectance */
a = a6;
salbedo = bb / (a + bb) ;
Rrs_red = g1*salbedo + g2*salbedo*salbedo;
/* Normalized water-leaving reflectance */
rhown[ib_red] = 0.544*PI*Rrs_red;
}

```