Atmospheric Correction

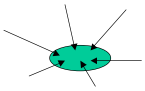
Ichio ASANUMA
The Tokyo University of Information Sciences

1. Irradiance, radiance, and reflectance
2. Water leaving radiance through the atmosphere
3. Normalized water leaving reflectance or radiance
4. Extraterrestrial Solar spectrum
5. Extrapolation of aerosol reflectance in visible bands from two NIR bands
6. Fail of algorithm with strongly-absorbing aerosols
7. NIR iterative correction for nLw(λNIR) ≠ 0
8. Estimate of NIR atmospheric effect from SWIR
9. Practice
10. References

1. Irradiance, radiance, and reflectance

1. **Irradiance :** flux per unit surface area (W.m-2.nm-1)

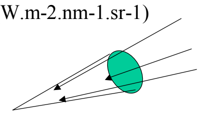
E



cosine collector

2. **Radiance :** flux per unit area and per unit solid angle (W.m-2.nm-1.sr-1)

L



3. Reflectance

R=Eu/Ed (no dimension)

4. Remote Sensing Reflectance

1. Rrs=Lu/Ed (sr^{-1})

2. Water leaving reflectance through the atmosphere

- $\rho = \pi L / \mu_0 F_0$

ρ is the reflectance,
L is the radiance in a given solar and viewing geometry,
F_0 is the extraterrestrial solar irradiance,
μ_0 is the cosine of the solar zenith angle.

- $\rho_t(\lambda) = \rho_r(\lambda) + \rho_a(\lambda) + \rho_{ra} + t(\lambda)\,\rho_{wc}(\lambda) + t(\lambda)\,\rho_w(\lambda)$

ρ_t is the total reflectance measured at the top of the ocean-atmosphere system,
ρ_r is reflectance resulting from multiple scattering by air molecules in the absence of aerosols, which is theoretically computed from atmospheric pressure,
ρ_a is the reflectance resulting from multiple scattering by aerosols in the absence of the air,
ρ_{ra} is the multiple interaction term between molecules and aerosol (e.g. photons first scattered by air molecules and then scattered by aerosols or photons scattered by aerosols then air molecules)
ρ_{wc} is the reflectance at the sea surface that arises from sunlight and skylight reflecting from whitecaps on the surface,
ρ_w is the water-leaving reflectance,
t is the atmospheric diffuse transmittance.

3. Normalized water leaving reflectance or radiance

- $n\rho_w(\lambda) = \rho_w(\lambda) / \{ t(\lambda) \cos(\theta) \}$
- $nL_w(\lambda) = L_w(\lambda) F_0(\lambda) / \{ \cos(\theta) E_d(\lambda) \}$

$= L_w(\lambda) / \{ t(\theta) \cos(\theta) \}$

$= R_{rs}(\lambda) F_o(\lambda)$

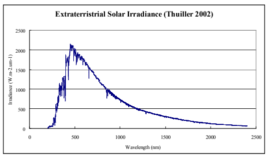
Fo is the mean extraterrestrial solar irradiance,
Ed is the downwelling irradiance at the surface,
t(θ) is the atmospheric diffuse transmittance,
θ is the solar zenith angle.

The normalized water-leaving reflectances provide a more meaningful comparison among different sensors and systems. The normalized water leaving radiance value is a function of the solar irradiance, which may vary with a sensor band's spectral response.

4. Extra-territristial Solar Spectrum

Neckel, H. and D. Labs (1984) The Solar radiation betwee 3300 and 12500 A, Sol. Phys. 90, 205-258.
Smith, E. V. P. and D.M.Gottlib (1974) Solar flux and its variation, Space Sci. Rev. 16, 771-802.
Thuillier, G., G.M.Herse, P.C.Simon, D.Labs, H.Mandel, D.Gillotay, and T.Foujols (1998) The visible solar spectral irradiance from 350 to 850 nm as measured by the SOLSPEC spectrometer during the ATLAS-1 mission, Sol. Phys. 177, 41-61.
Thuillier, G. (2001) Solar Spectral Reference Spectrum, ISCS 2001 Symposium on International Solar Cycle Studies 2001 – Solar Variability, Climate, and Space Weather; Longmont, Colorado, USA, June 13-16.
Thuillier, G., M. Herse, P. C. Simon, D. Labs, H. Mandel, D. Gillotay, and T. Foujols, The solar spectral irradiance from 200 to 2400 nm as measured by the SOLSPEC spectrometer from the ATLAS 1-2-3 and EURECA missions, Solar Physics (to be submitted). (2002)

SeaWiFS	**Neckel & Labs (1984)**	**400-1250 nm**
MODIS	**Thuillier et al. (1998)**	**350- 800 nm**
	Neckel & Labs (1984)	**800-1100 nm**
	Smith & Gottlib (1974)	**1100-2500 nm**
MERIS	**Thuillier et al. (2002)**	**200-2400 nm**
GLI	**Thuillier et al. (2002)**	**200-2400 nm**



5. Extrapolation of aerosol reflectance in visible bands from two NIR bands

5-1. $\rho_a(\lambda)+\rho_{ra}(\lambda)$ is given for two λs at NIR1 & NIR2.

$$\underline{\rho_t(\lambda)} = \underline{\rho_r(\lambda)} + \rho_a(\lambda) + \rho_{ra}(\lambda) + \underline{t(\lambda)\,\rho_w(\lambda)}$$

Sensor measured radiance
Computed Rayleigh scattering
=0, because $\rho_w(\lambda)$ is negligible at NIR.

5-2. $\rho_a(\lambda)+\rho_{ra}(\lambda)$ is approximated by the single scattering aerosol reflectance $\rho_{as}(\lambda)$.

$$\rho_{as}(\lambda) = \rho_a(\lambda) + \rho_{ra}(\lambda)$$

5-3. Aerosol type determination from two bands at NIR1(765nm) & NIR2(865nm).

$$\varepsilon_{as}[\lambda_{NIR1},\lambda_{NIR2}] = \rho_{as}(\lambda_{NIR1}) / \rho_{as}(\lambda_{NIR2})$$

5-3-1. Traditional Angstrom coefficient method, Gordon (1978)

$$n = \ln \{ \varepsilon_{as}[\lambda_{NIR1},\lambda_{NIR2}] \} \ln\{\lambda_{NIR1} / \lambda_{NIR2}\}$$

$$\rho_w(\lambda) = \{ \rho_t(\lambda) - \rho_r(\lambda) - \rho_{as}(\lambda_{NIR2}) (\lambda/\lambda_{NIR2})^n \} / t$$

5-3-2. Gordon & Wang (1994) method

$$c = \ln \{ \varepsilon_{as}[\lambda_{NIR1},\lambda_{NIR2}] \} / (\lambda_{NIR1} / \lambda_{NIR2})$$

$$\rho_w(\lambda) = \{ \rho_t(\lambda) - \rho_r(\lambda) - \rho_{as}(\lambda_{NIR2}) \exp(c\,\lambda/\lambda_{NIR2}) \} / t$$

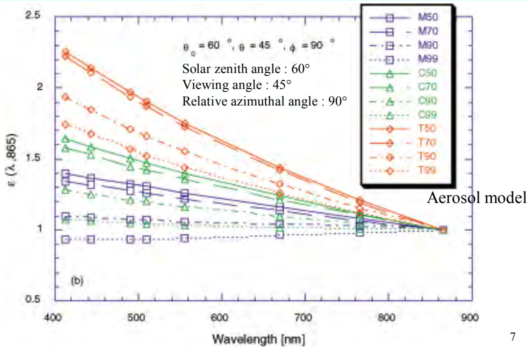
For both operation, the transmission term t can be approximated as:

$$t = \exp[-(\tau_r 0.5 + \tau_{oz}) / \cos\theta_v]$$

,where τ_r is the Rayleigh optical thickness, τ_{oz} is the ozone optical thickness and $\cos\theta_v$ is the approximation to the path length.

5-4. Atmospheric correction parameter for 12 SeaWiFS aerosol models

$\varepsilon_{as}(\lambda,865)=\rho_{as}(\lambda)/\rho_{as}(865)$

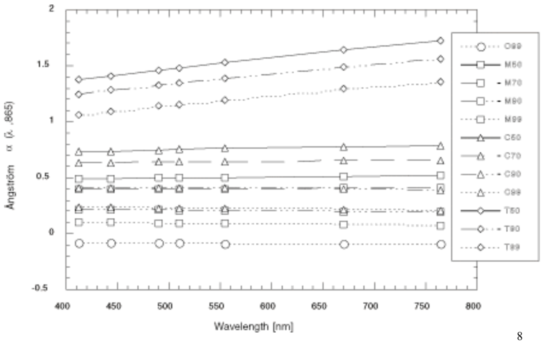


Solar zenith angle : 60°
Viewing angle : 45°
Relative azimuthal angle : 90°

Aerosol model

5-5. Angstrom coefficient for 12 SeaWiFS aerosol models

α(λ,865) value is nearly independent of the wavelength for the Oceanic, Maritime, and Coastal aerosol models.



6. Fail of algorithm with strongly-absorbing aerosols

6-1. Strongly-absorbing aerosols :

- wind-blown mineral dust (Saharan dust, Yellow sand)
- anthropogenic aerosol.

6-2. Spectral matching algorithm (SMA) described by Gordon, Du, and Zhang (1997)

6-3. Spectral optimization algorithm (SOA) developed by Chomko and Gordon (1998).

6-4. Spectral Matching Algorithm (SMA)

Gordon, Du, and Zhang (1997)

- In the SMA, a discrete set of realistic aerosol models is adopted, and no interpolation between models is attempted.
- 12 distinct models (4 size distributions × 3 vertical distributions).
- The water reflectance model was that proposed by Gordon et al. (1988) in which $nLw(\lambda, Pw)$ is specified by the phytoplankton pigment concentration C and a scattering parameter b^0.
- The best combinations of aerosol model, aerosol optical depth, pigment concentration, and scattering parameters are determined to minimize the cost function $S(P_A, P_w)$.

$$S^2(P_A,P_w) = \Sigma \{1-[\rho_t^c(\lambda) - \rho_r^c(\lambda)]/[\rho_t^m(\lambda) - \rho_r^m(\lambda)]\}^2$$

The computed "c" is

$$\rho_t^c(\lambda) - \rho_r^c(\lambda) = \rho_a(\lambda,P_A) + t_0(\lambda,P_A) t_v(\lambda,P_A) n \rho_w(\lambda,P_w)$$

  - P_A : to specify aerosol model as a function of P_A
  - P_W : to specify water model as a function of P_W.

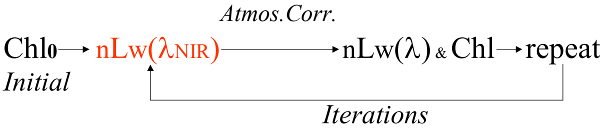
6-5. Spectral Optimization Algorithm

(SOA by Chomko and Gordon (1998))

- limitations with the SMA:
  (1) realistic aerosol models are required, i.e., the quality of the retrievals is directly related to the quality of the aerosol models;
  (2) such aerosol models are almost of necessity discrete, preventing interpolation between models.
- SOA utilizes following parameters to specify $La(\lambda, Pa)$
  - ν : a relative abundance of particles for Junge power-law size distribution,
  - $\tau_{a(865)}$: an aerosol optical thickness at 865 nm,
    - ν and $\tau_{a(865)}$ are determined from the NIR with nLw=0,
  - a real and imaginary parts of the refractive index (m_r and m_i),
  - a phytoplankton pigment concentration C,
  - a scattering parameter b_0,
    - m_r, m_i, C, and b_0 are estimated from visible bands by minimizing S(Pa,Pw),
    - This method is not appropriate to Saharan dust, but should be applicable to carbonaceous aerosols.

7. NIR iterative correction for $nLw(\lambda_{NIR}) \neq 0$

D.Siegel et.al., Applied Optics (2000)



Atmos.Corr.

Chl_0 → $nLw(\lambda_{NIR})$ → $nLw(\lambda)$ & Chl → repeat

Initial

Iterations

The iterative procedure entails an initial guess for Chl, an estimate for $nLw(\lambda_{NIR})$ and its removal from the radiation budget, and application of the existing SeaWiFS atmospheric correction algorithm to retrieve a new Chl. This process is repeated until a converged Chl value is obtained.
The initial Chl value is set to 0.2 mg m^{-3} and iterations are stopped once the final Chl retrieval is within 20% of the last iterate. Typically, 1 (open ocean) to 3 (coastal waters) iterations are required. If the first iterated Chl value is less than 0.3 mg m^{-3}, the iterations are terminated.

8. Estimate of atmospheric effect at NIR from SWIR

Wang and Shi, 2005

- MODIS provided more possibility to estimate the atmospheric effect at the near-infrared (NIR) bands from the short wave infrared (SWIR) bands
- NIR : 748 and 869 nm
- SWIR : 1240 and 1640 nm

- The ocean is black at SWIR due to absorption even in the coastal region.

- NIR（Open water) ➔SWIR➔NIR（Coastal water)

9. Practice

1. Compute the Rayleigh radiance from the SeaWiFS L1A data and display.
2. Compute the aerosol radiance from the SeaWiFS L1A data and display.
3. Remove the Rayleigh radiance from the SeaWiFS L1A data and generate a false color image.
4. Conduct an atmospheric correction to compute the normalized water leaving radiance for all SeaWiFS channels with the different thresholds for the cloud albedo. “Cloud albedo=1.1” to “1.5” or “2.0”.

All practice could be conducted by the SeaDAS. Select “Process” from the main menu and kick off “msl12”. You are able to chose parameters to be computed from the menu.

10. References

Antoine, D. and A. Morel (1999) A multiple scattering algorithm for atmosphere correction of remotely sensed ocean colour (MERIS instrument): principle and implementation for atmospheres carrying various aerosols including absorbing ones. Int. J. Remote Sensing, 20, 1875-1916.

Chomko, R. M. and H. R. Gordon (1998) Atmospheric correction of ocean color imagery: Use of the Junge power-low aerosol size distribution with variable refractive index to handle aerosol absorption. Applied Optics 37, 5560-5572.

Gordon, H. R. (1978) Removal of Atmosphere Effects from Satellite Imagery of the Oceans. Applied Optics, 17, 1631-1636.

Gordon, H. R. and M. Wang (1994) Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: a preliminary algorithm. Applied Optics, 33, 443-452.

Gordon, H. R., T. Du, and T. Zhang (1997) Remote sensing ocean color and aerosol properties: resolving the issue of aerosol absorption. Applied Optics, 36, 8670-8684.

Gordon, H.R., R. M. Chomko, and C. Moulin (2000) Advanced atmospheric correction algorithms. Ocean Optics, Monaco.

Moore, G. F., J. Aiken and S. J. Lavender (1999) The atmospheric correction of water colour and the quantitative retrieval of suspended particulate matter in Case II waters: application to MERIS. Int. J. Remote Sensing, 20, 1713-1733.

Siegel, D. A., M. Wang, S. Maritorena, and W. Robinson (2000) Atmospheric correction of satellite ocean color imagery: the black pixel assumption. Applied Optics, 39. 3582-3591.

Wang, M. and B. A. Franz (2000) Comparing the Ocean Color Measurements Between MOS and SeaWiFS: A Vicarious Intercalibration Approach for MOS. IEEE Trans. Geos. And Remote Sensing, 38, 184-197.

Wang, M. and W. Shi, Estimation of ocean contribution at the MODIS near-infrared wavelengths along the east coast of the U.S.: Two case studies, Geophys. Res. Lett., 32, L13606, doi:10.1029/2005/GL022917.