Introduction into Ocean Colour Remote Sensing
Part II Atmospheric Correction

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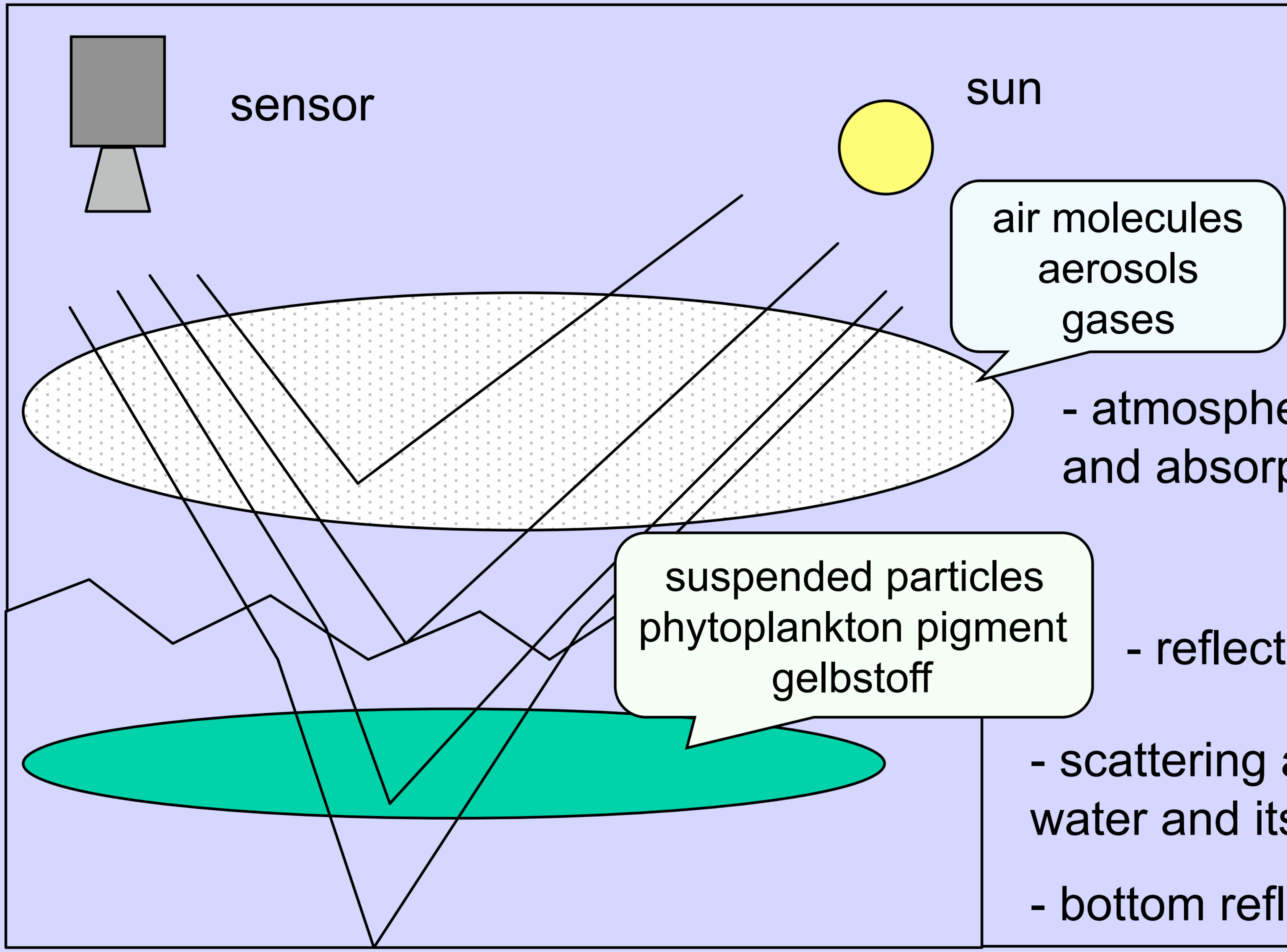
Basic principles of Water Color RS



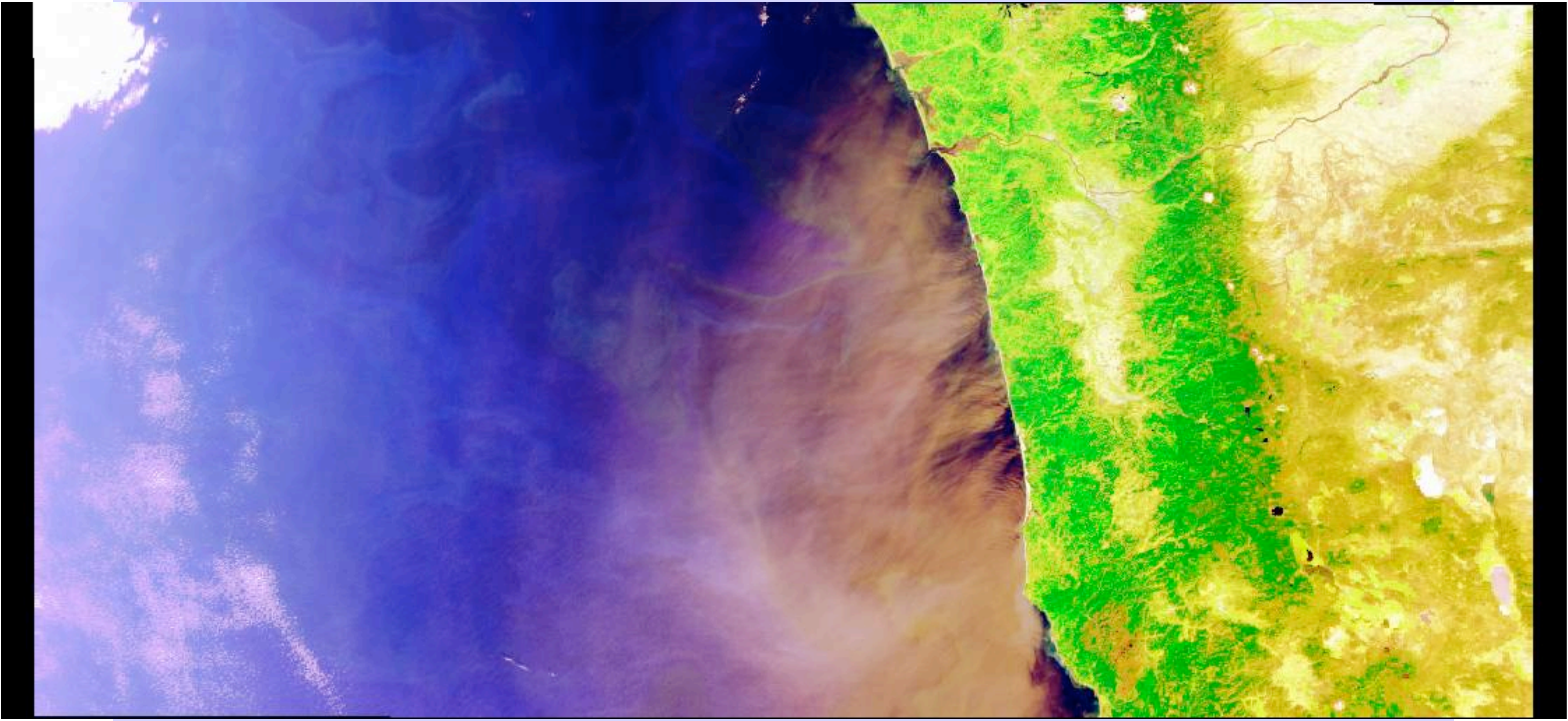
- atmospheric scattering and absorption

- reflection and refraction

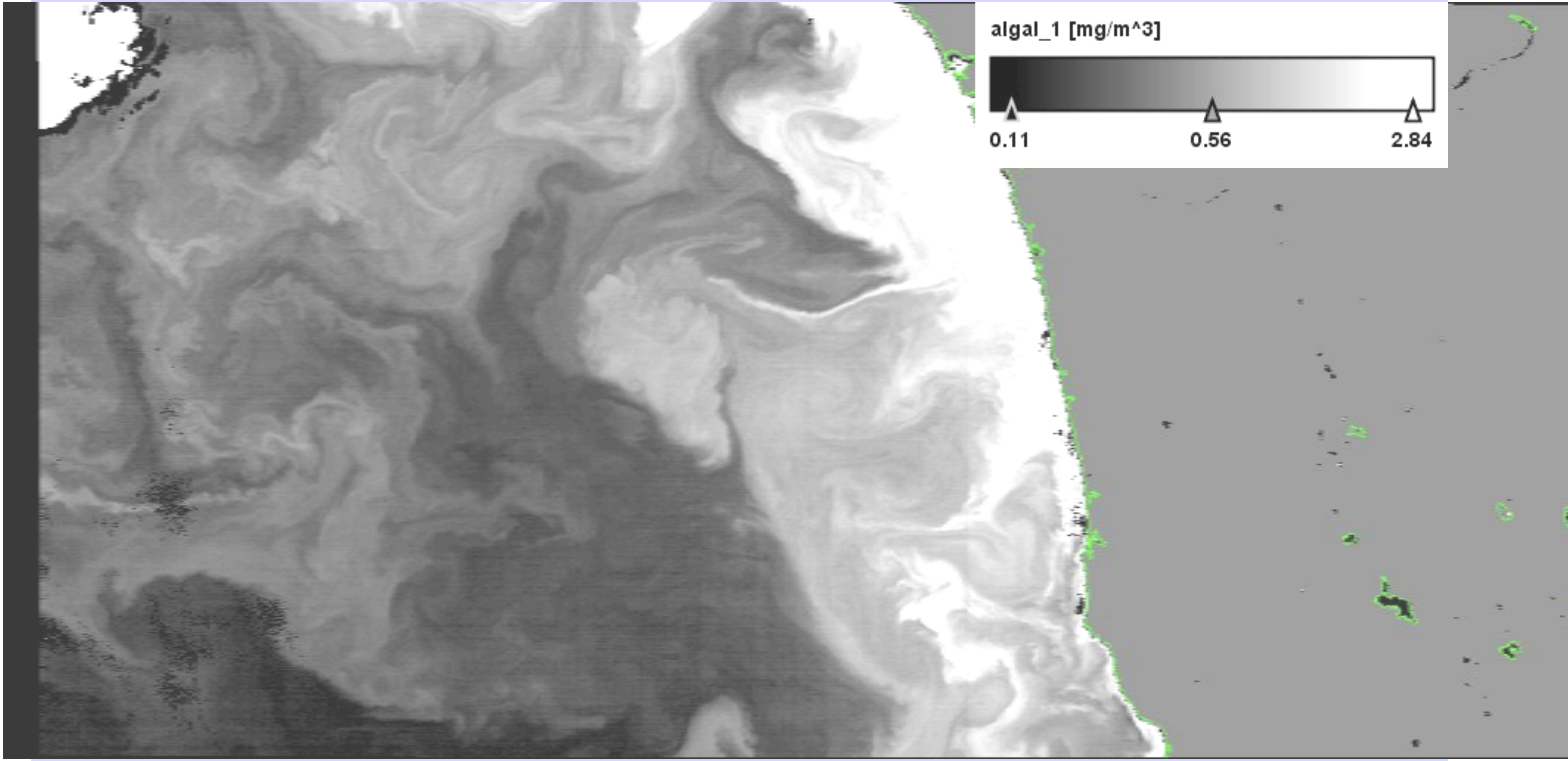
- scattering and absorption by water and its constituents

- bottom reflection

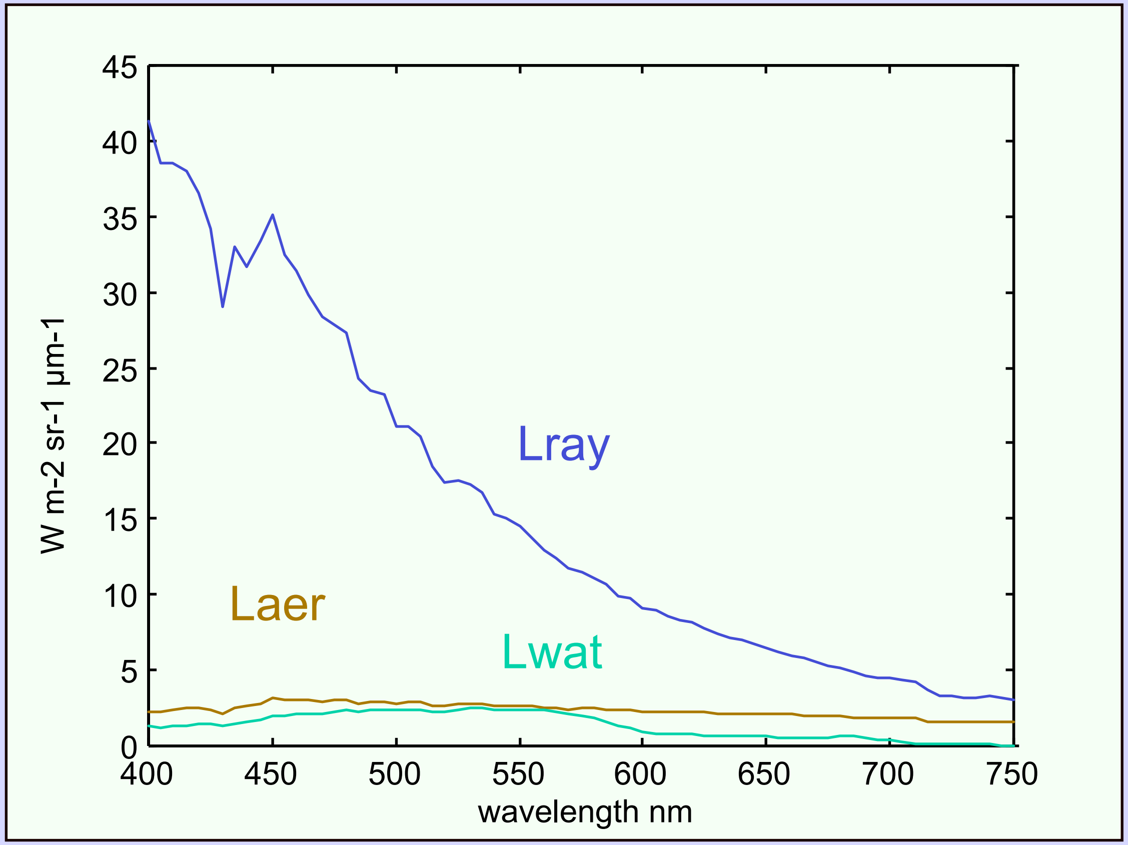
MERIS RR Pacific Coast off Oregon



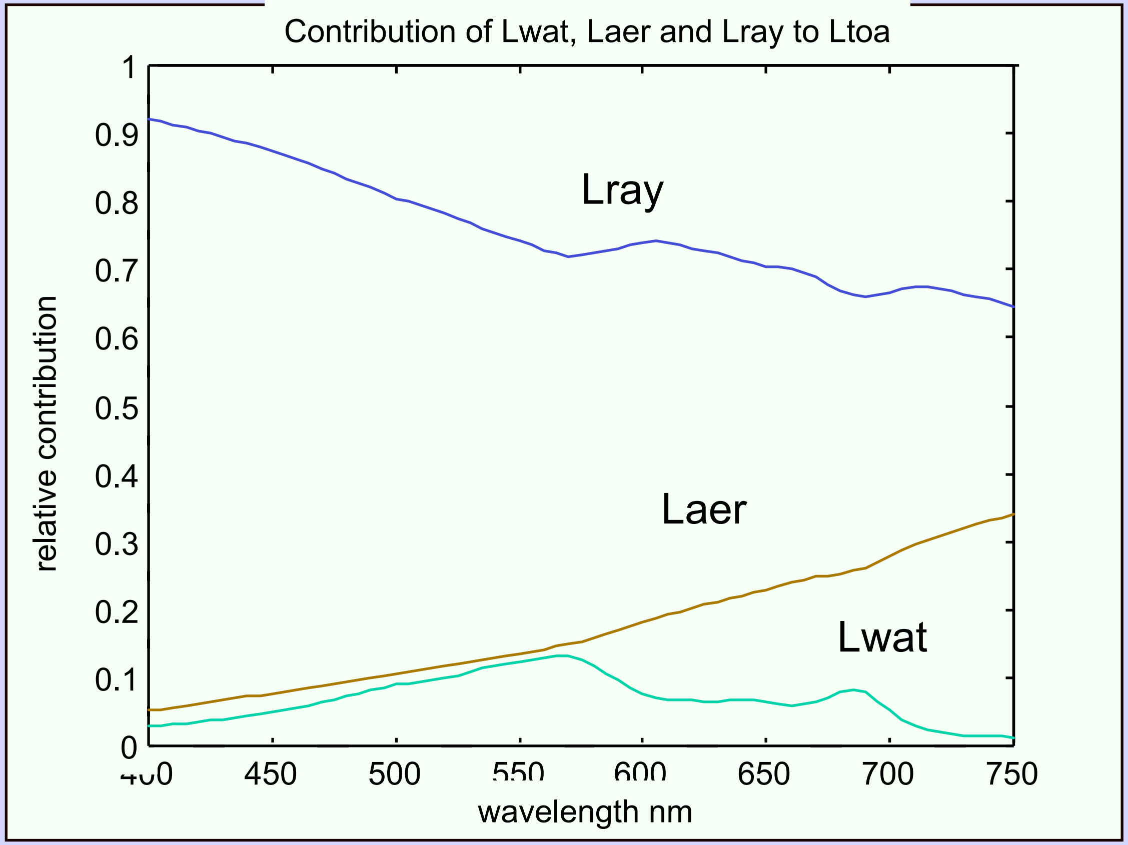
Chlorophyll distribution



Radiances at Top of Atmosphere (TOA)



The composition of the Radiance Spectrum at Top of Atmosphere



Relative contribution to TOA radiance

water leaving radiance: Lw

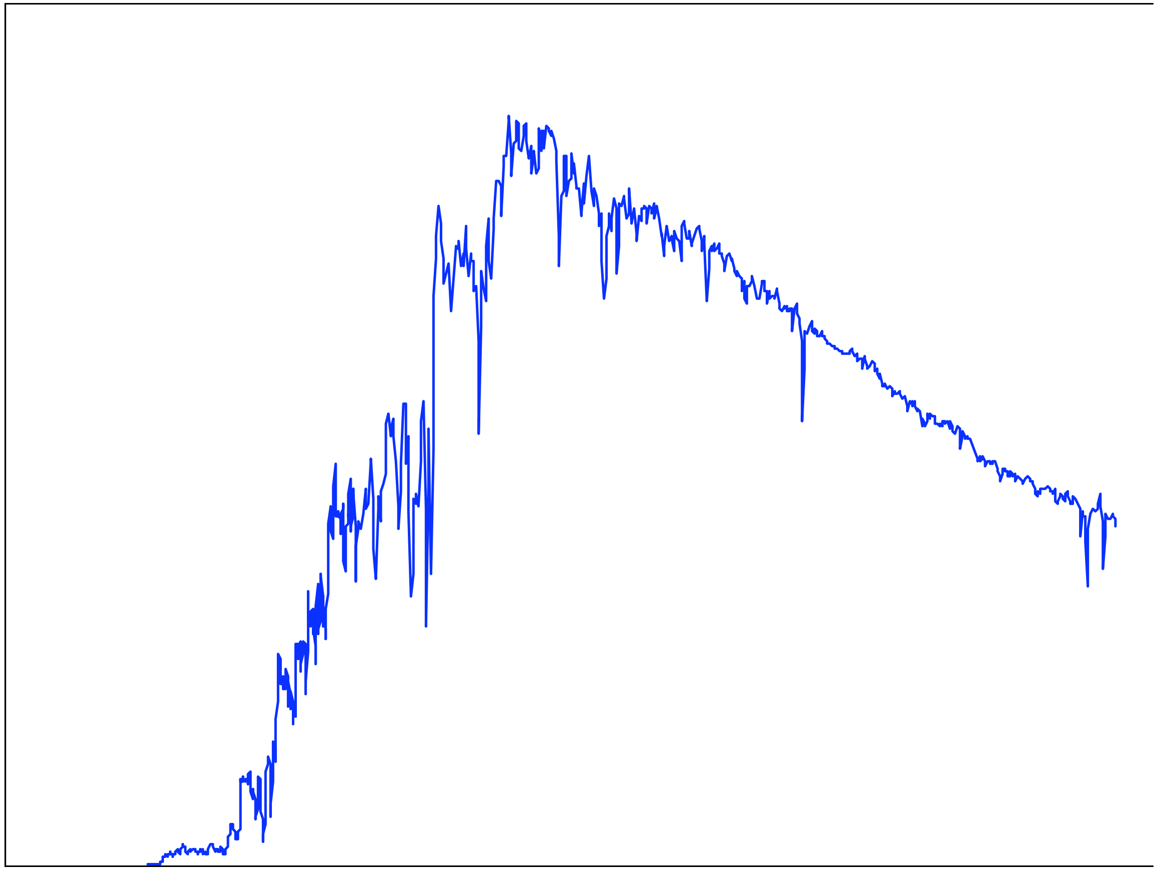
aerosol path radiance: Laer

Rayleigh path radiance: Lray

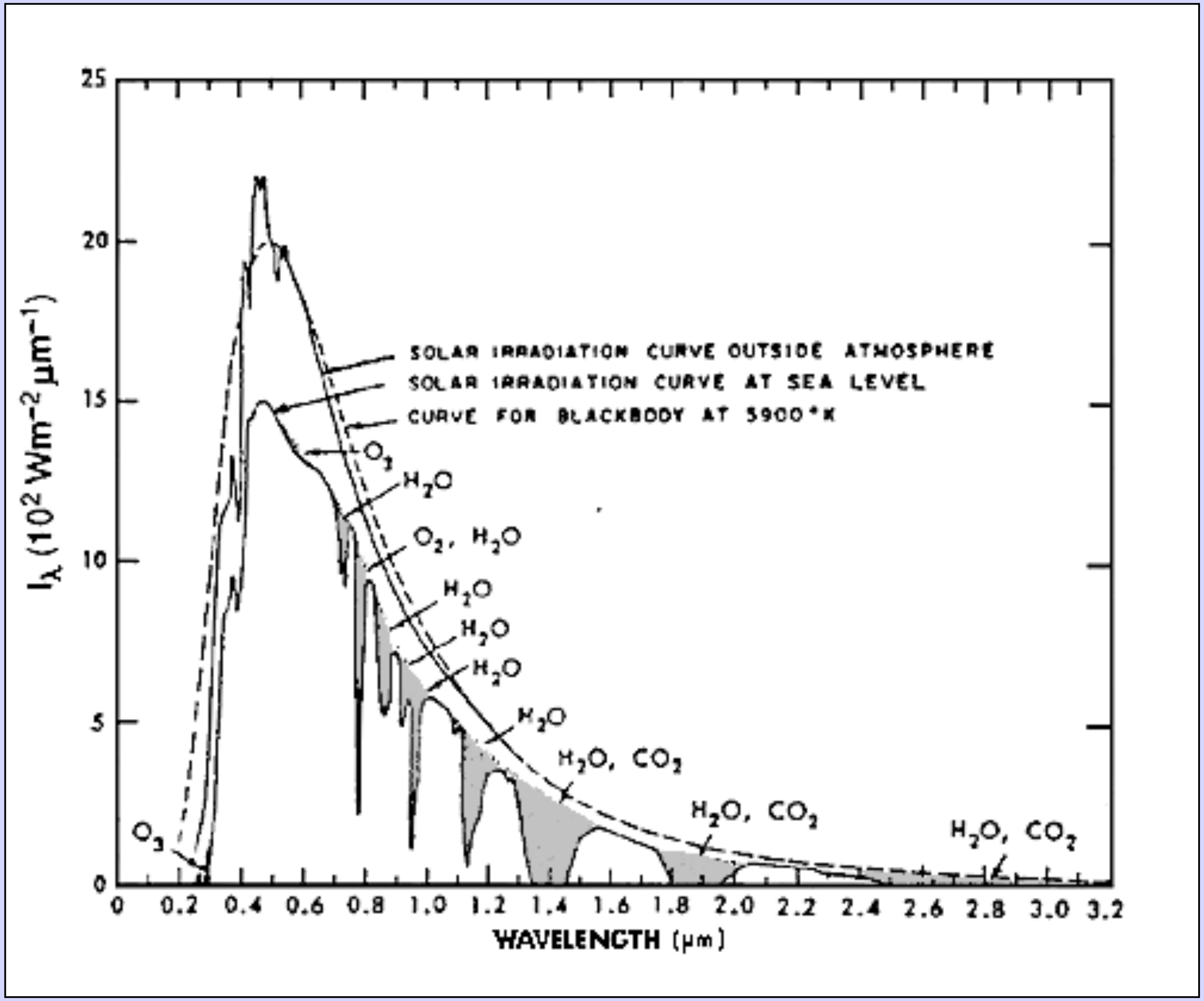
Terms and Expressions

- Optical thickness of atmosphere: τ = -log(T), T= transmittance of beam TOA-BOA
- AOT aerosol optical thickness: thickness of only the aerosol component
- Angstrom coefficient (alpha): spectral shape of AOT $\alpha = -\log(\tau_1 / \tau_2) / \log(\lambda_1 / \lambda_2)$
- Path radiance: the radiance without the contribution from below the water surface
- Specular reflectance: air/sea interface fresnel reflection, depends on index of refraction
- TOA Top of atmosphere, BOA Bottom of Atmosphere
- Water leaving radiance (reflectance): radiance from below the water surface
- Remote sensing reflectance: water leaving radiance / irradiance above surface
- Atmospheric transmittance: transmittance of a beam
- Rayleigh scattering: scattering by air molecules (N2, O2)
- Cloud detection: identification of clouds, problem if optically thin or smaller than a pixel

Solar Flux at TOA (Thullier)

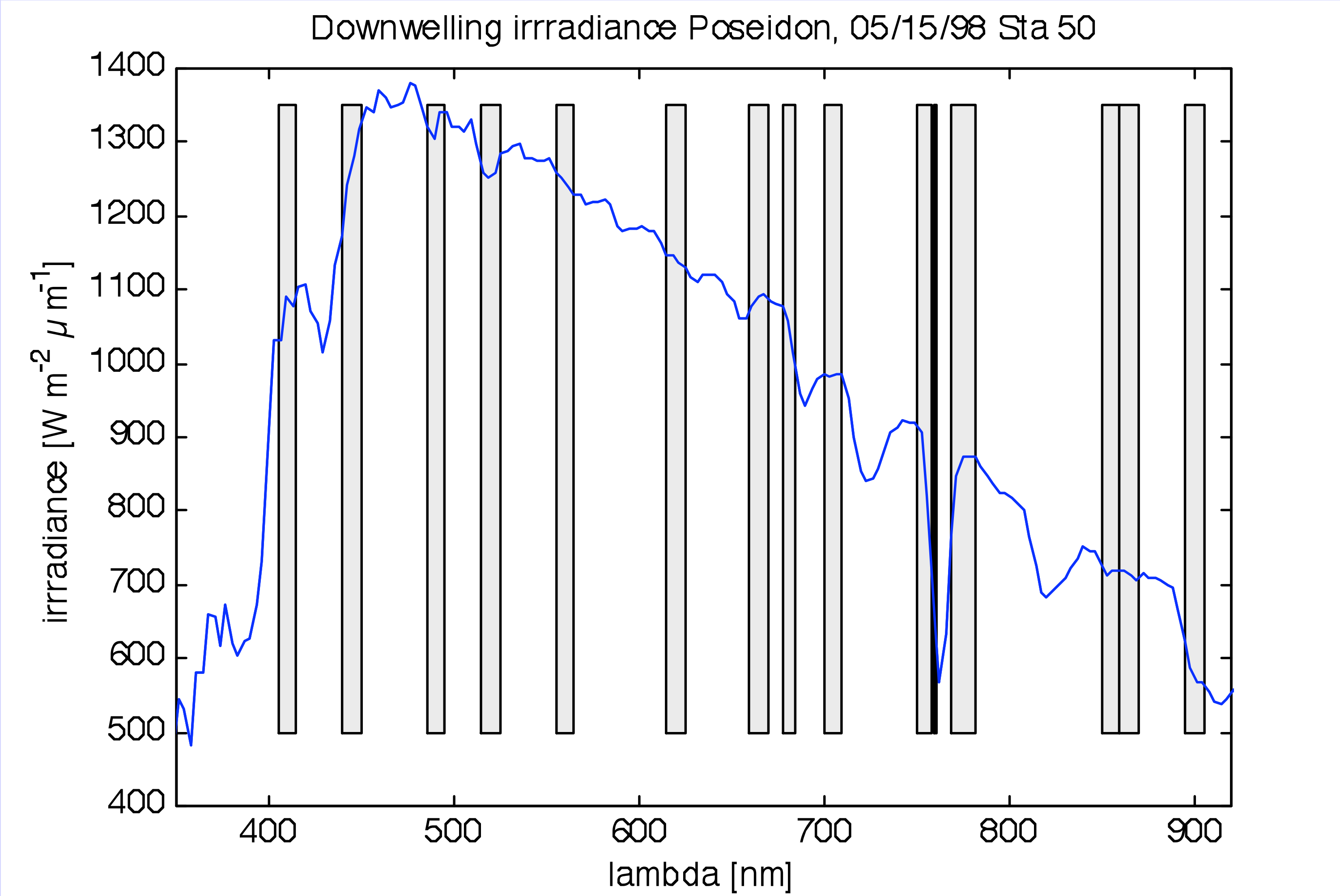


Atmospheric Transmission



Solar radiation at the top of the atmosphere and the actual radiation at sea level which has been reduced due to absorption by atmospheric gases. The dashed curve is a blackbody at 5900K for comparison with the solar curve outside the earth's atmosphere

Downwelling irradiance



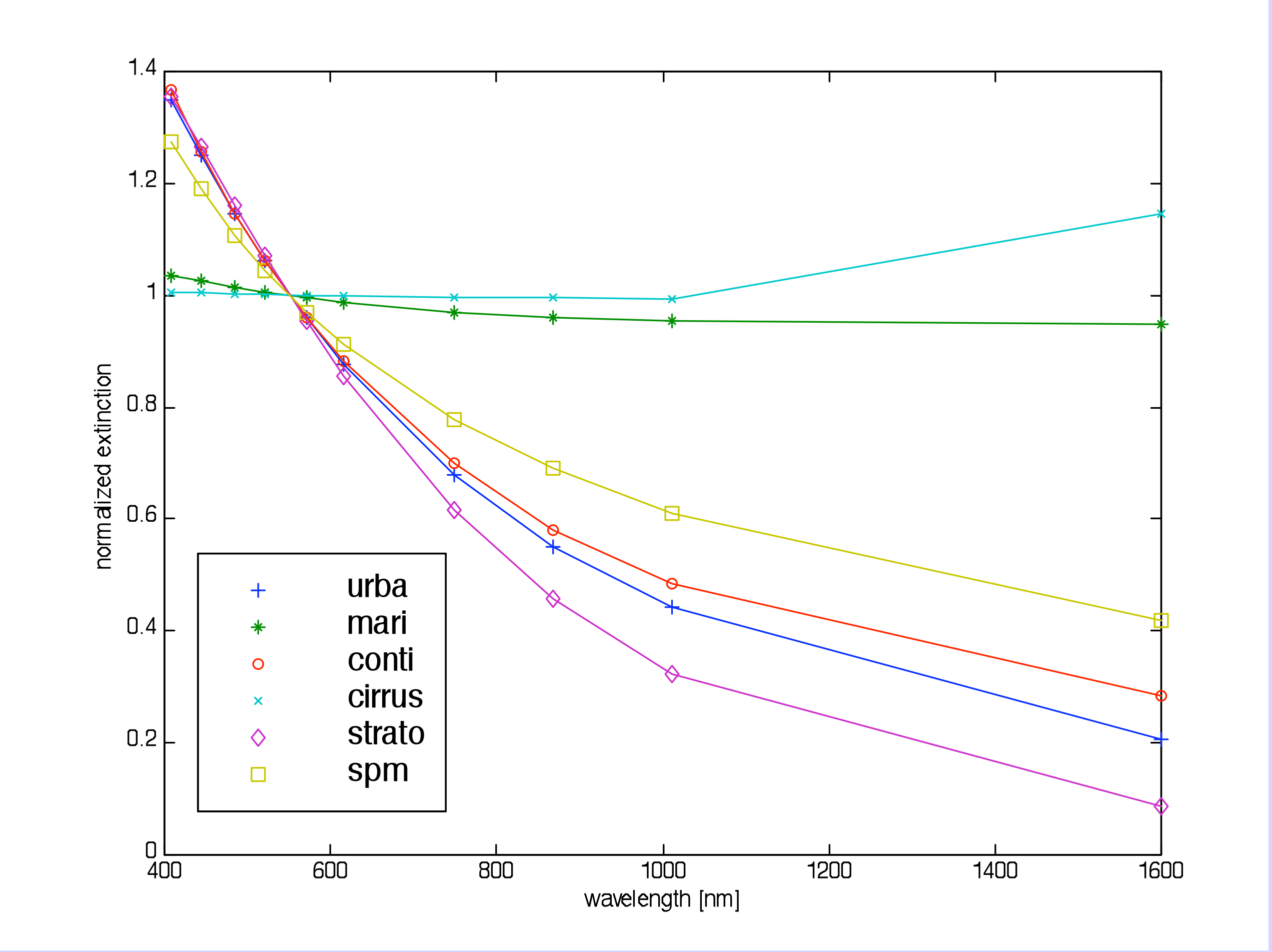
Aerosol models

The "standard" atmospheric vertical structure.

The standard atmosphere vertical structure adopted here is based on the profile recommended by WCRP (1986) for open oceanic areas. It is typical of clear oceanic atmospheres, and is as follows :

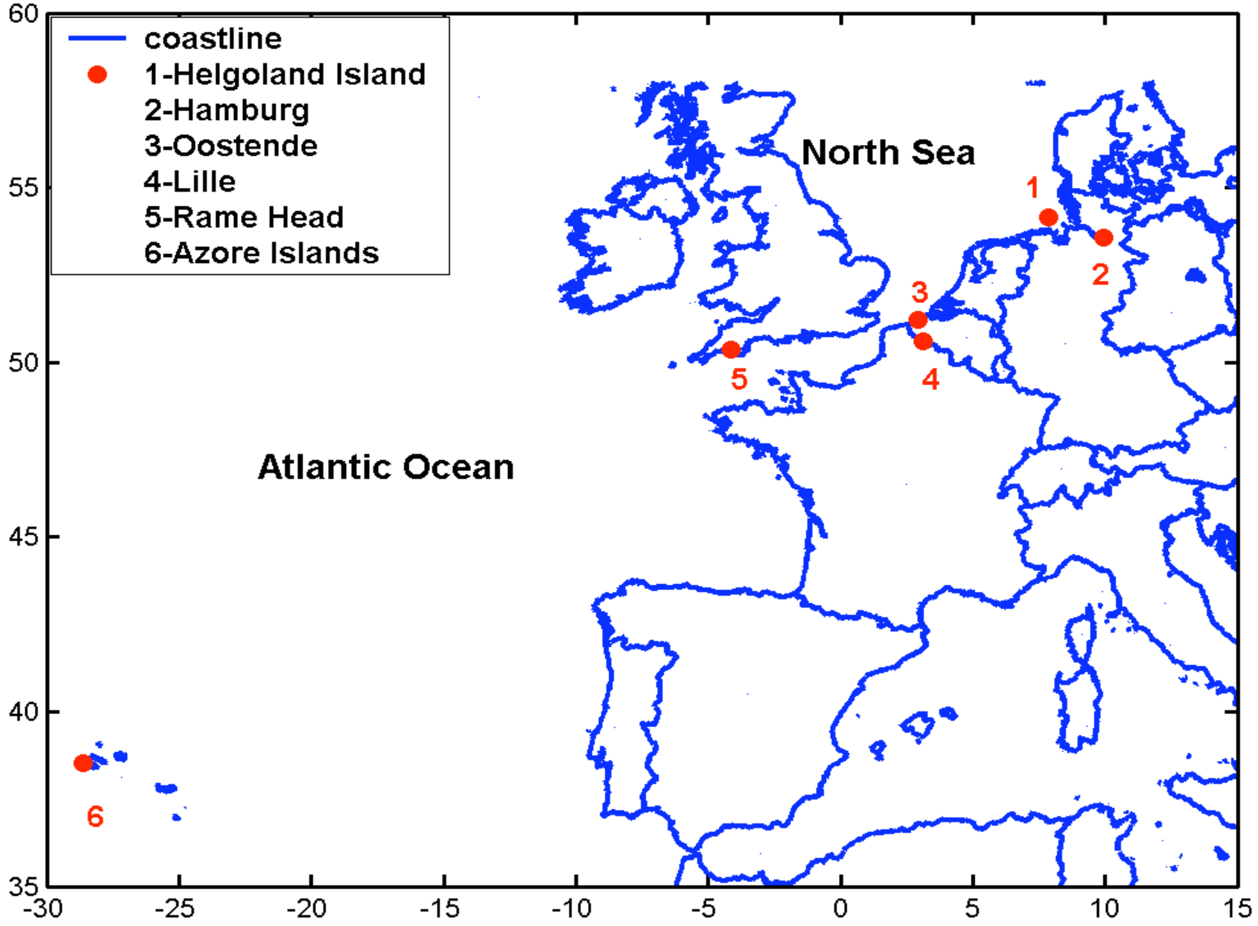
- Boundary layer (0-2 km) :
  Maritime aerosol model (Shettle and Fenn, 1979), for RH = 70, 80, 95, 99%
  Optical thickness is made varying from 0.03 to 0.50 at 550 nm.
  (non-absorbing aerosols, ω about 0.98-0.99)
- Free troposphere (2-12 km) :
  Continental aerosol (WCRP, 1986)
  Optical thickness is constant, and equal to 0.025 at 550 nm.
  (slightly absorbing aerosol : $0.95 < \omega < 0.98$)
- Stratosphere (12-50 km) :
  A 75% solution of sulfuric acid in water (WCRP, 1986)
  Optical thickness is constant, and equal to 0.005 at 550 nm.
  (non-absorbing aerosol, ω about 0.99)

Aerosol Extincion in Model Atmosphere

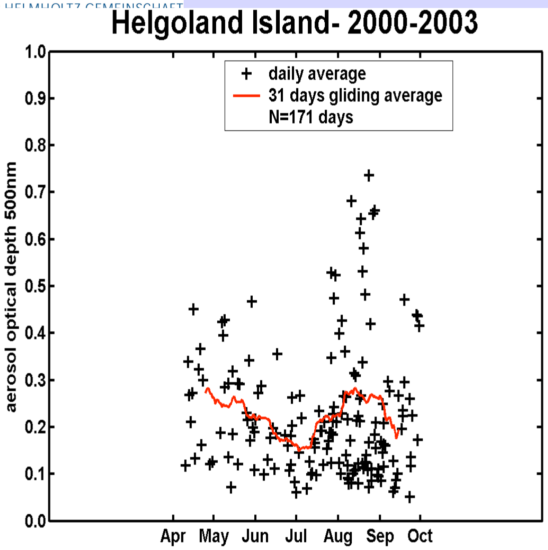


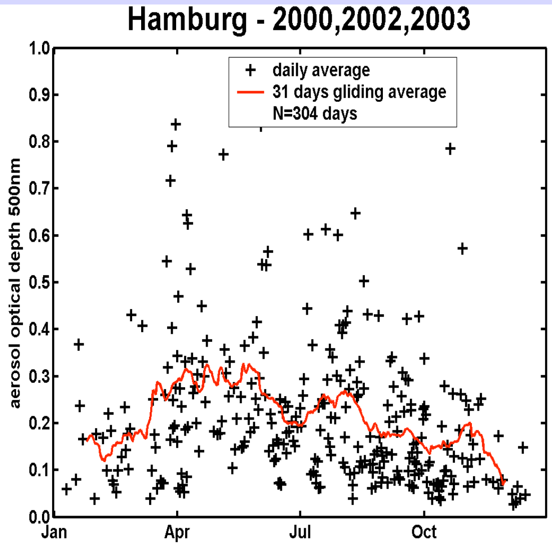
normalized at 550 nm, urban aerosol with 50%, maritime with 99% humidity

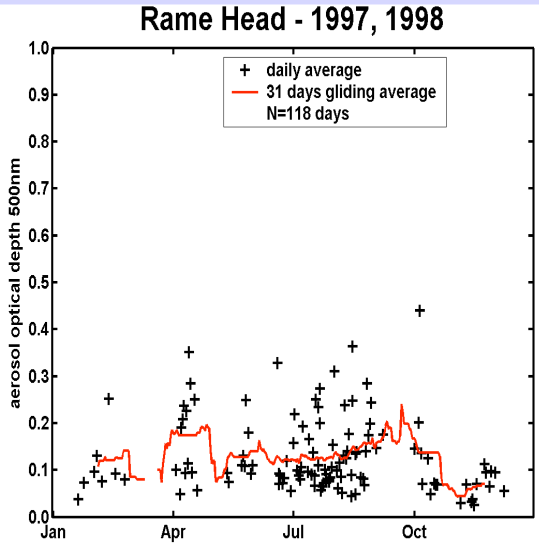
Aeronet sites considered

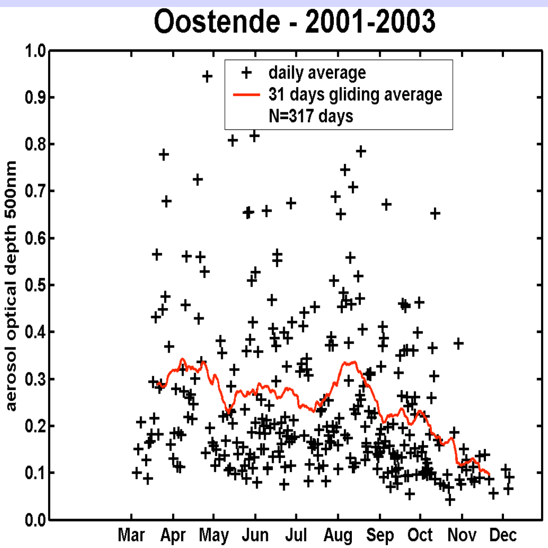


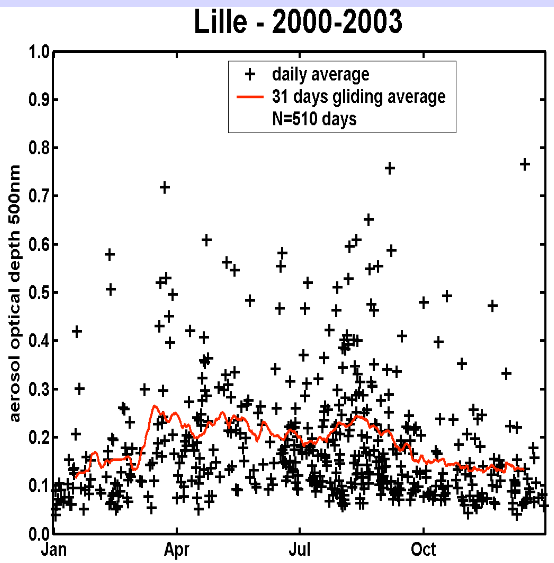
Annual variation of the Aerosol optical depth 500nm

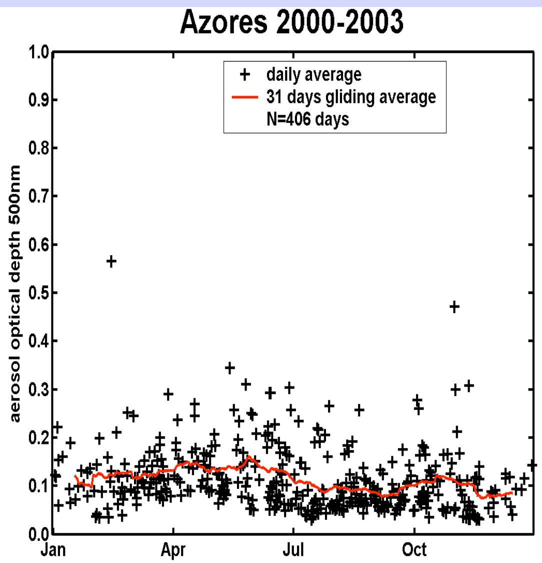




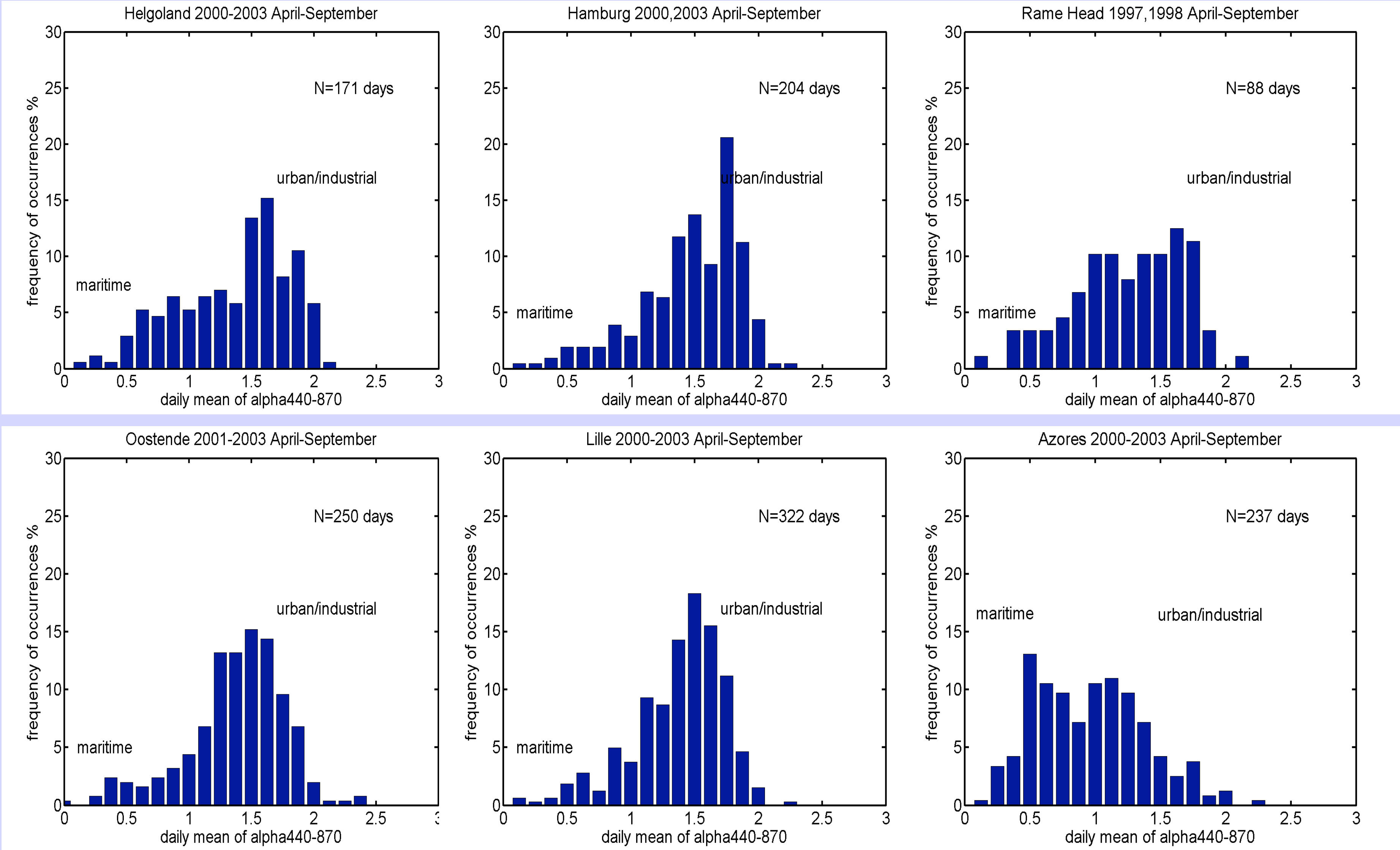








Frequency of occurrences for Angstrom parameter α440–870



Scheme of atmospheric correction

L1b
TOA radiance spectrum

↓

cloud detection

↓

path radiance,
transmittance

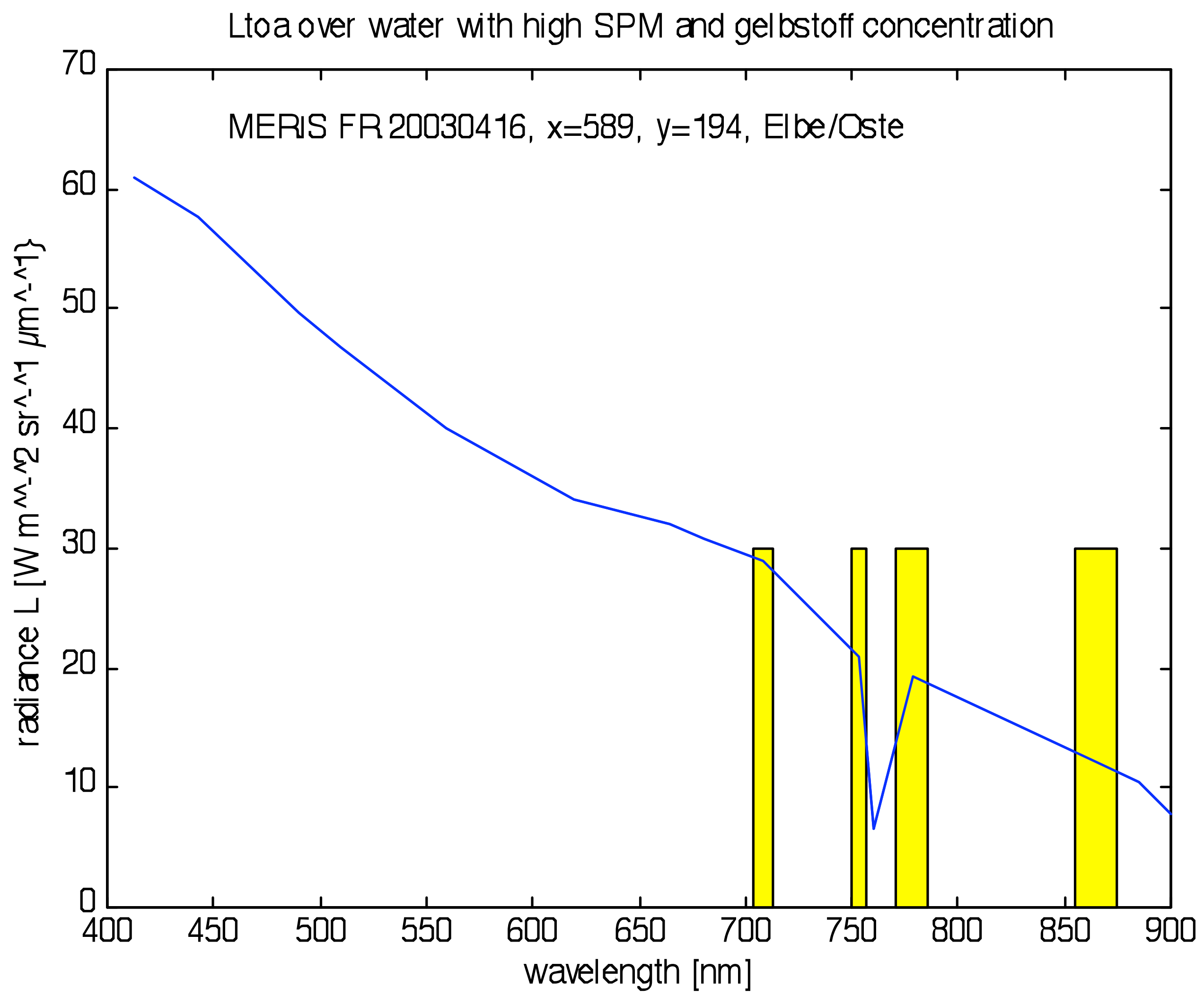
↓

water leaving
radiance (reflectance)

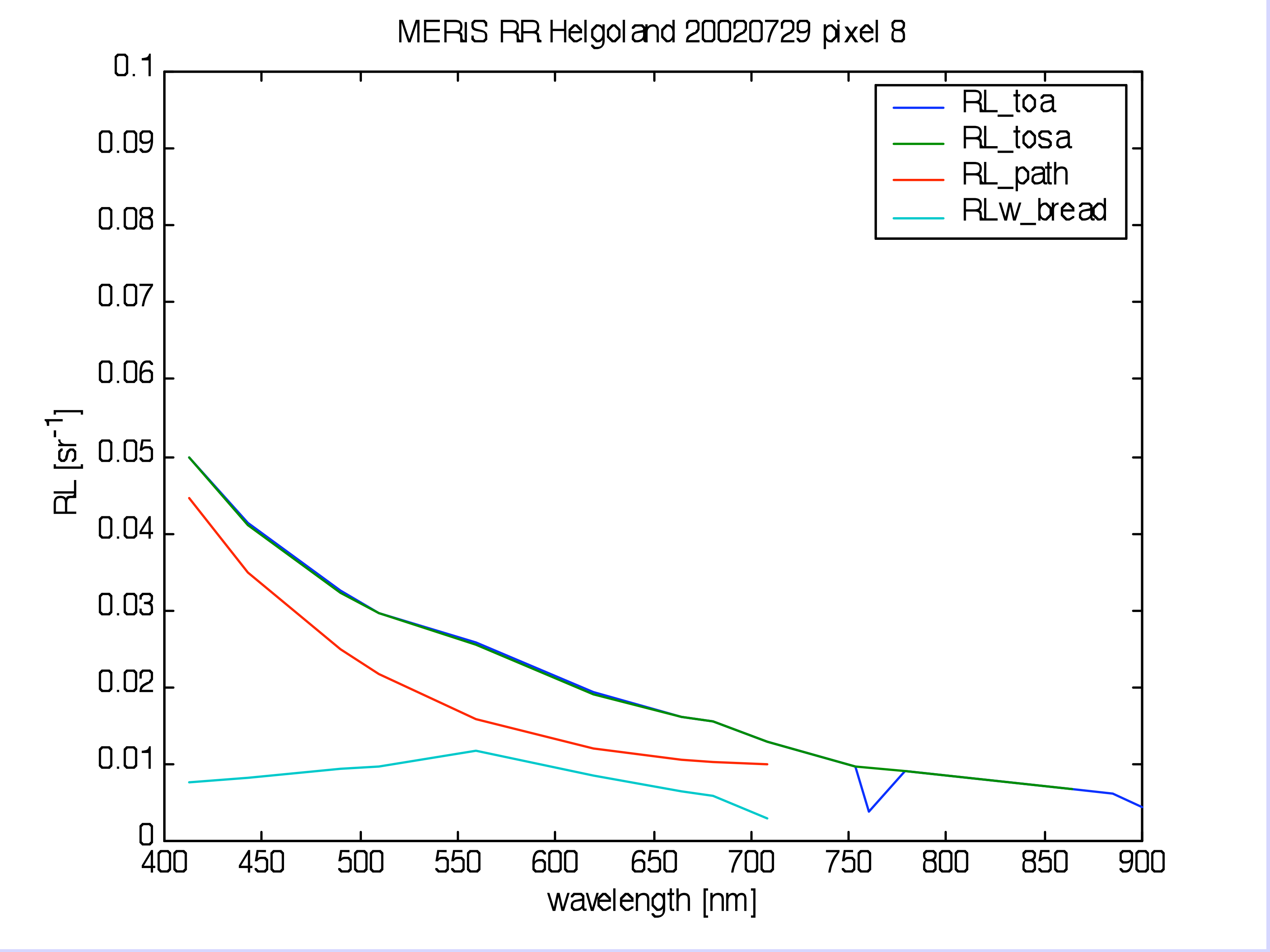
depends on:

- date and time
- latitude, longitude
- sun and observation angles
- clouds and aerosols
- absorbing gases (O2, O3, H2O)
- atmo. pressure
- specular reflectance of sky and direct sun light, waves
- foam and floating material

Bands for atmospheric correction

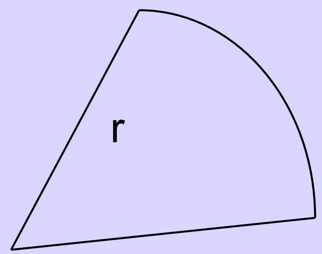


Radiance reflectances



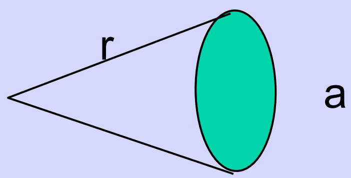
Angles and Radiometry

Radiant arclength / radius [rad]
Circle: 360 deg = 2.pi.r / r = 2.r.pi
1 sr= 360/(2.pi) = 57.3 deg



Steradiant ω:

Sphere surface: $4.pi.r^2$
area / $radius^2$ [sr]
sphere: $4.pi.r^2 / r^2 = 4.pi$ sr



Irradiance: E [$W\ m^{-2}\ \mu m^{-1}$], downwelling, upwelling irradiance E_d, E_u

Radiance: L [$W\ m^{-2}\ sr^{-1}\ \mu m^{-1}$]

Irradiance reflectance Eu / Ed dimensionless

Radiance reflectance Lu / Ed dimension sr-1

transmission air-water

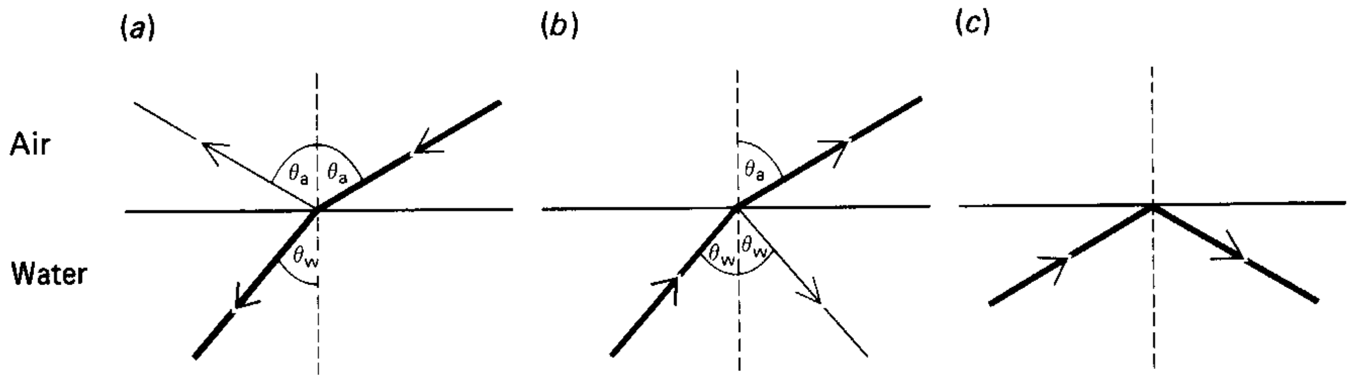


Fig. 2.11. Refraction and reflection of light at air–water boundary. (*a*) A light beam incident from above is refracted downwards within the water: a small part of the beam is reflected upwards at the surface. (*b*) A light beam incident from below at a nadir angle of 40° is refracted away from the vertical as it passes through into the air: a small part of the beam is reflected downwards again at the water–air boundary. (*c*) A light beam incident from below at a nadir angle greater than 49° undergoes complete internal reflection at the water–air boundary.

Snell's Law

$$\frac{\sin\theta_a}{\sin\theta_w} = \frac{n_w}{n_a}$$

$n_w = 1.34$

Specular reflectance

Fresnel's Equation
for unpolarized light

$$r = \frac{1}{2}\left(\frac{\sin^2(\theta_a - \theta_w)}{\sin^2(\theta_a + \theta_w)} + \frac{\tan^2(\theta_a - \theta_w)}{\tan^2(\theta_a + \theta_w)}\right)$$

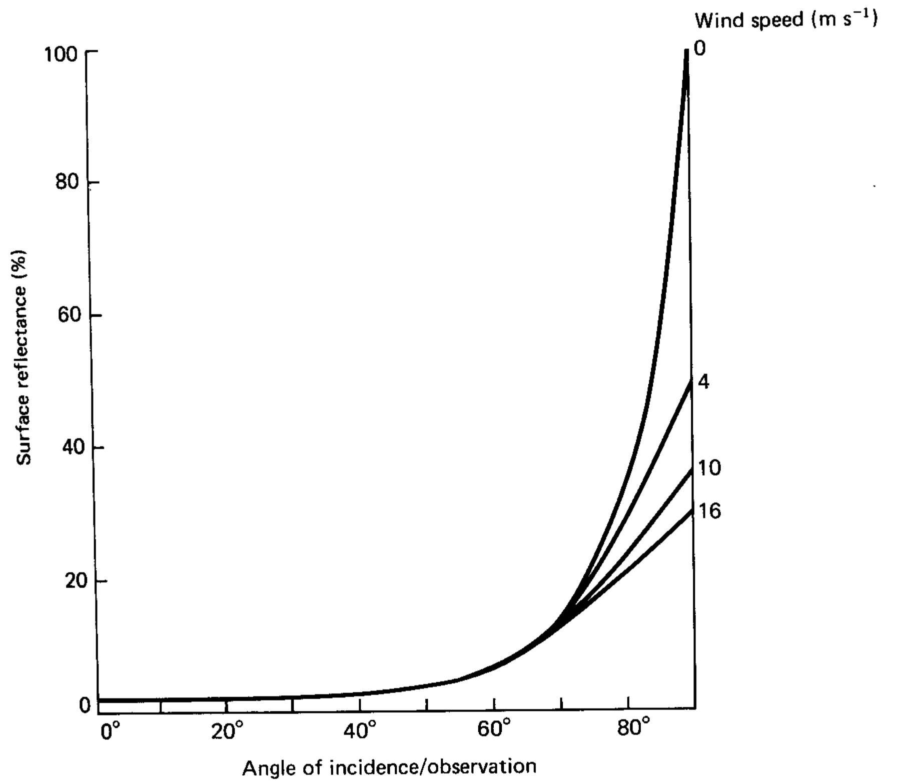


Fig. 2.10. Reflectance of water surface as a function of zenith angle of light (incident from above), at different wind speeds (data of Gordon, 1969; Austin, 1974*a*).

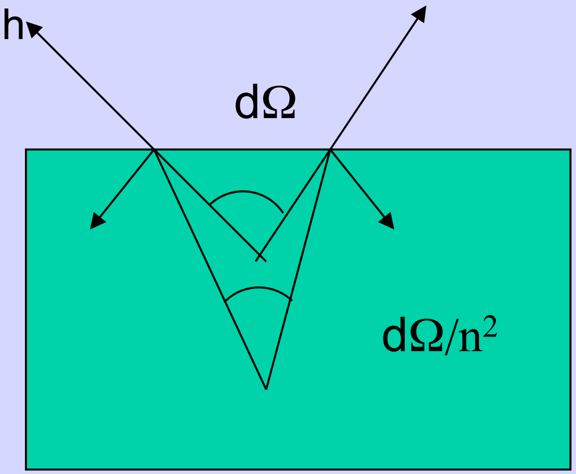
Remote Sensing Reflectance

FORSCHUNGSZENTRUM
in der HELMHOLTZ GEMEINSCHAFT

For comparison with the satellite-sensed signal, it is needed to consider the above-surface remote-sensing reflectance which is the ratio of the upwelling radiance to the downwelling irradiance just above the sea surface

$R_{RS}(\lambda, \theta, \varphi, 0^+) = L_u(\lambda, \theta, \varphi, 0^+) / E_d(\lambda, 0^+)$.

The subsurface upwelling radiance $L_u(0^-)$ passing through the sea surface decreases due to reflection and refraction; the above-surface downwelling irradiance passing through the sea surface decreases due to reflection but it is augmented due to internal reflection of the subsurface upward flux from the sea surface



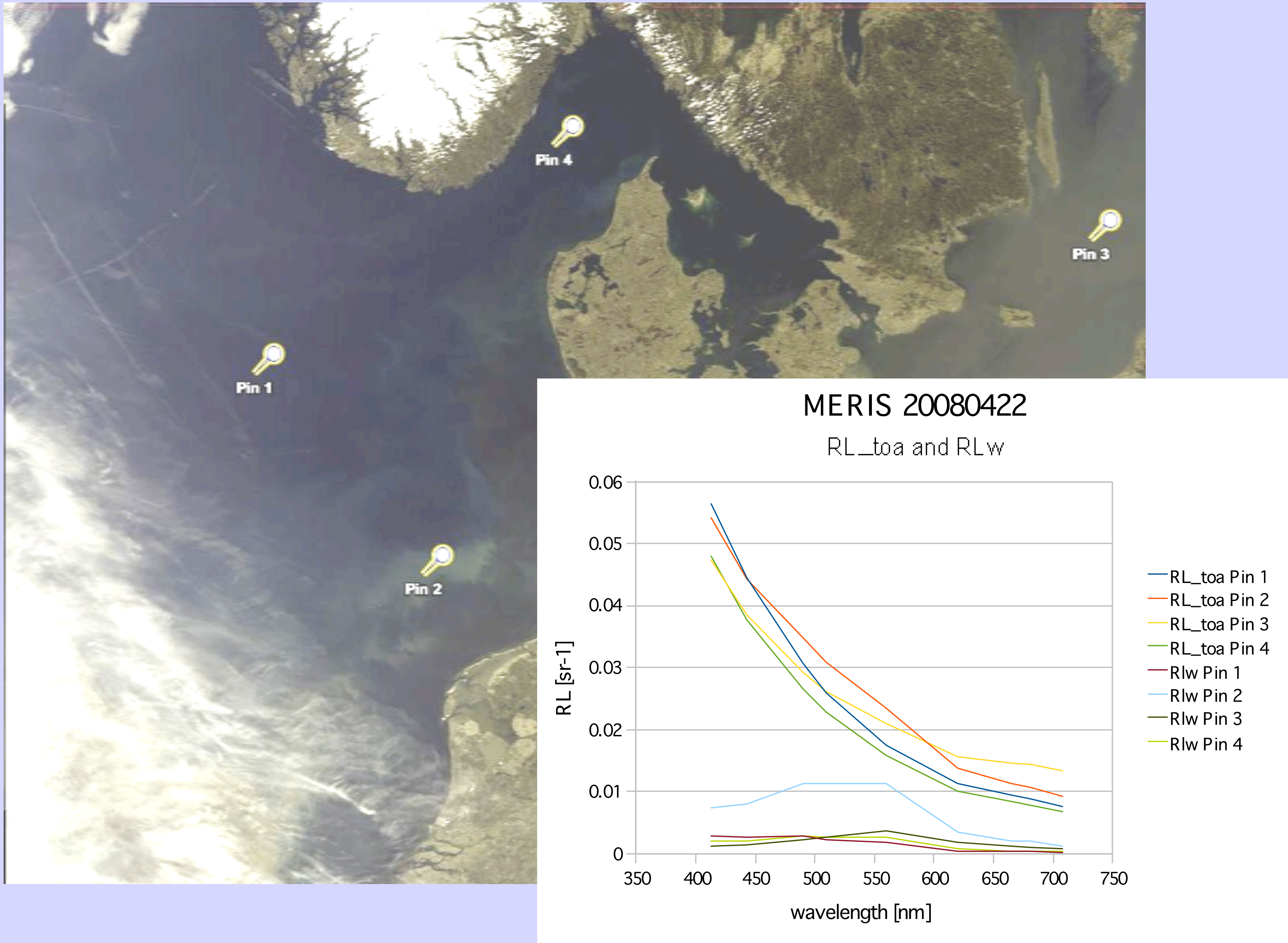
$L_u(0^+) = (t_- / n^2) L_u(0^-)$; $E_d(0^-) = t_+ Ed(0^+)/(1-\gamma R)$·

$R_{RS} = (t_- t_+ / n^2) r_{RS} /(1-\gamma R)$; $R_{RS} = \zeta r_{RS} /(1-\Gamma r_{RS})$;

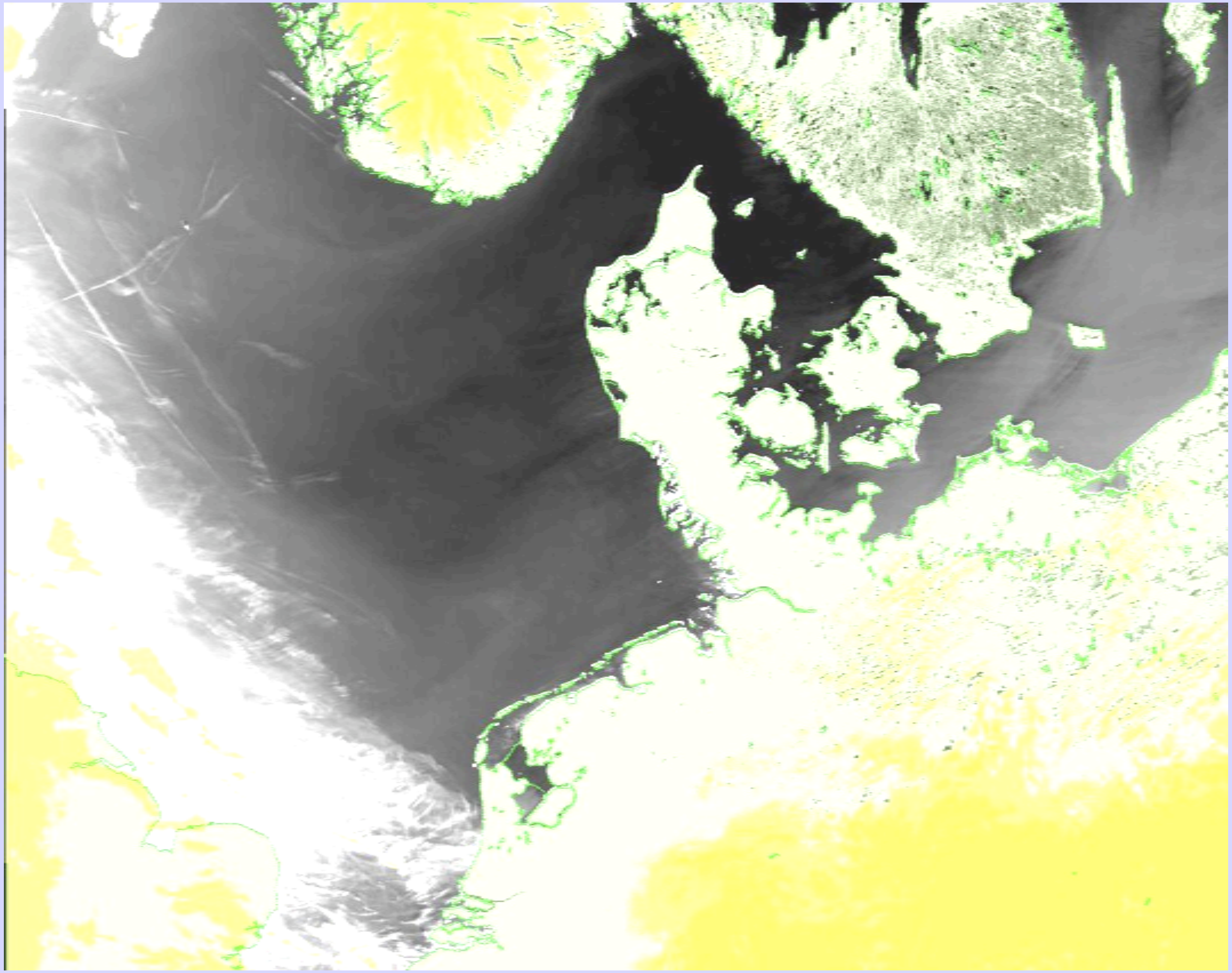
$\zeta = t_- t_+ / n^2 \times$; $\Gamma = \gamma Q$.

For nadir viewing: $\zeta \approx 0.518$, $\Gamma \approx 1.562$, (Lee et al. 1998).

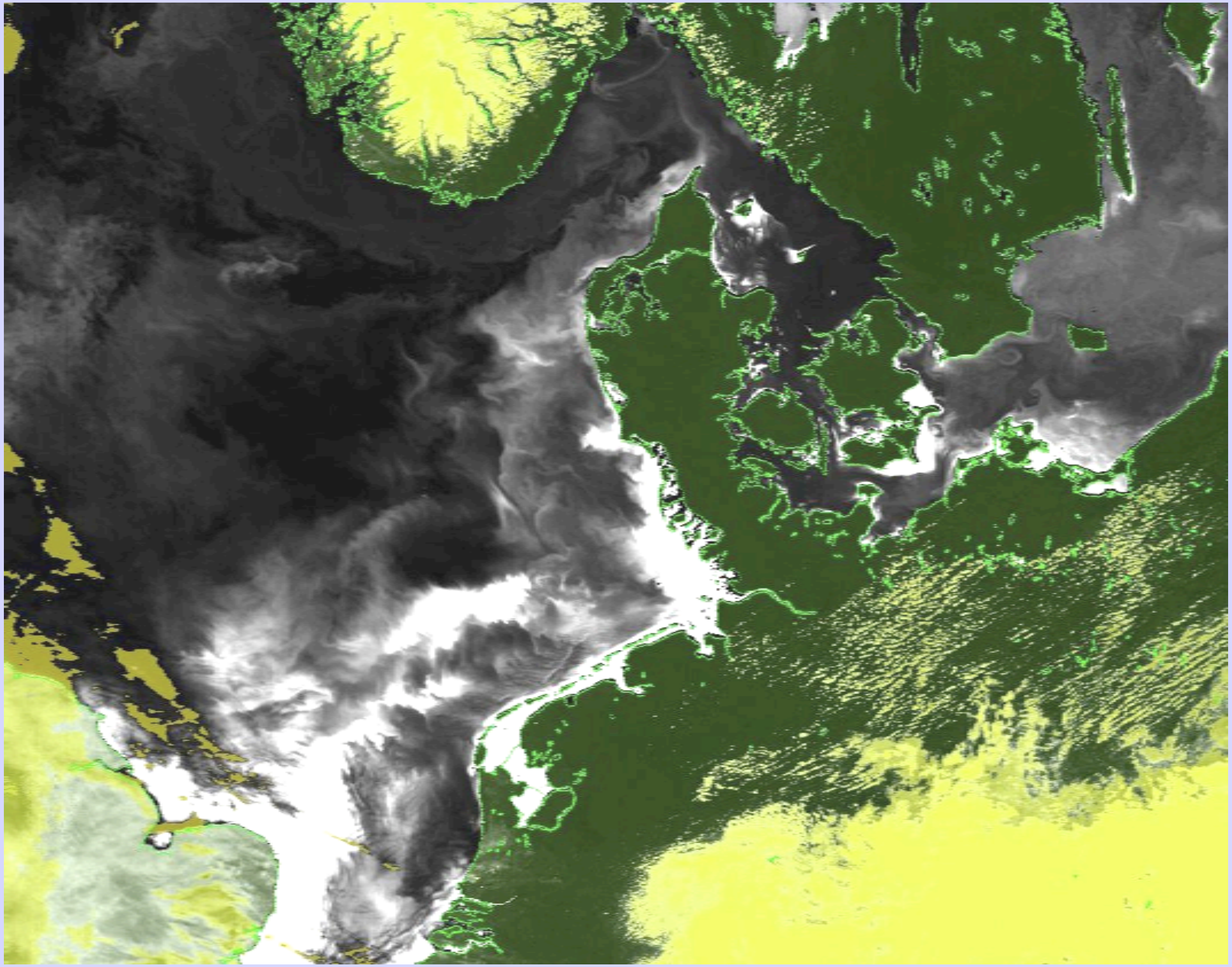
MERIS L1 RR TOA RGB 20080422



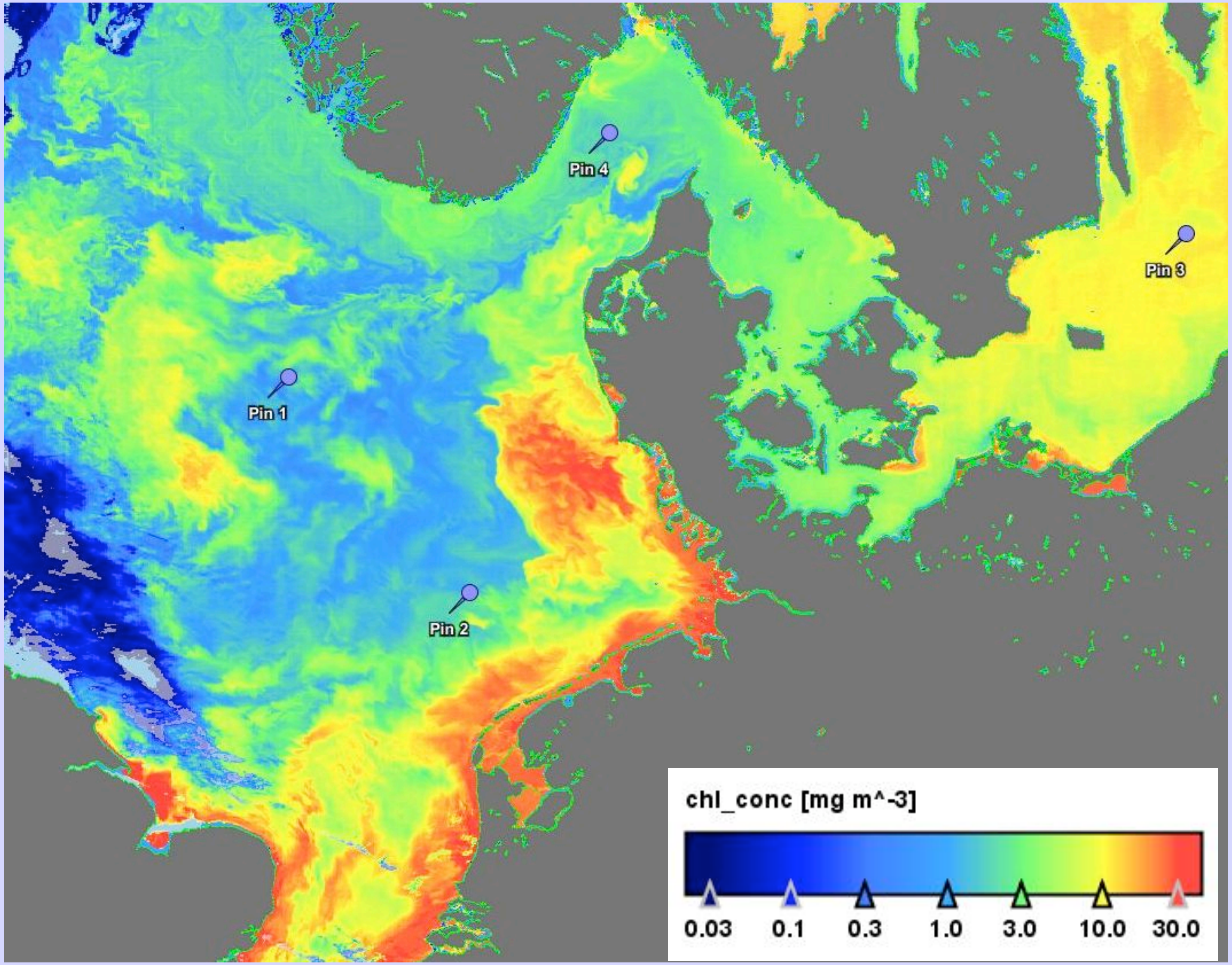
MERIS 20080422 RLpath band 5 (560 nm)



MERIS 20080422 RLw



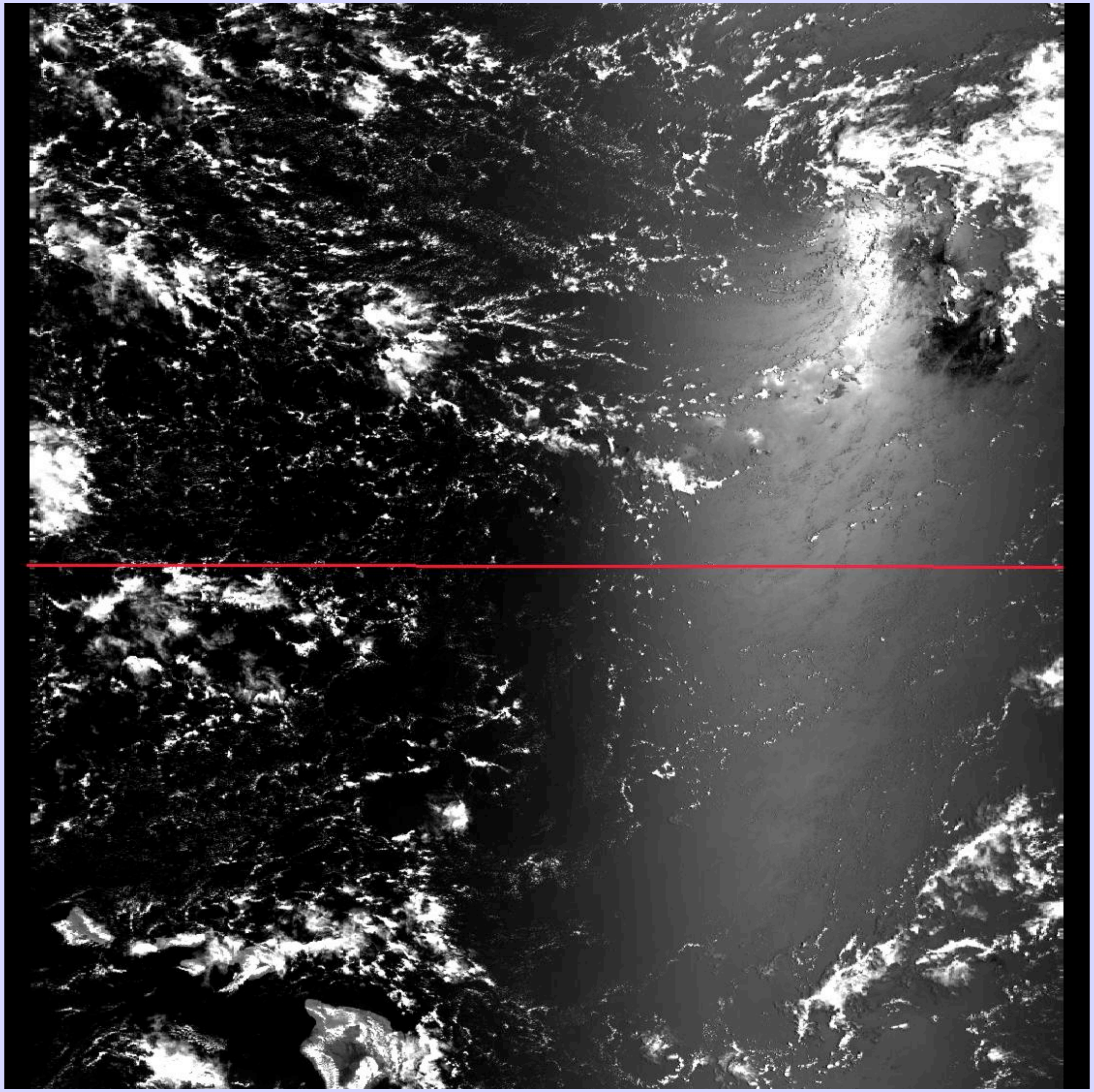
MERIS 20080422 Phytoplankton Chlorophyll



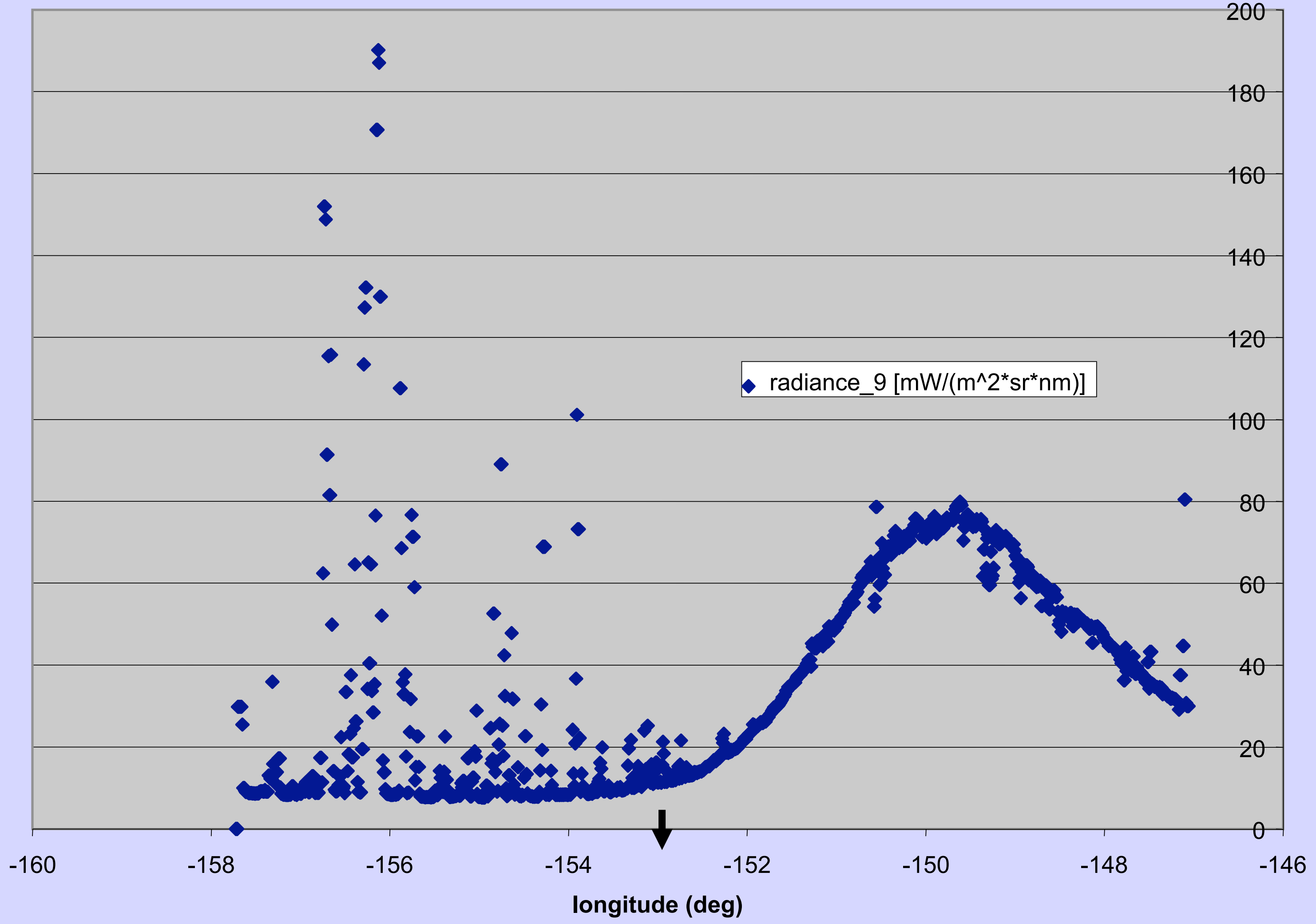
Separation of path and water leaving radiance in turbid waters

Sunglint

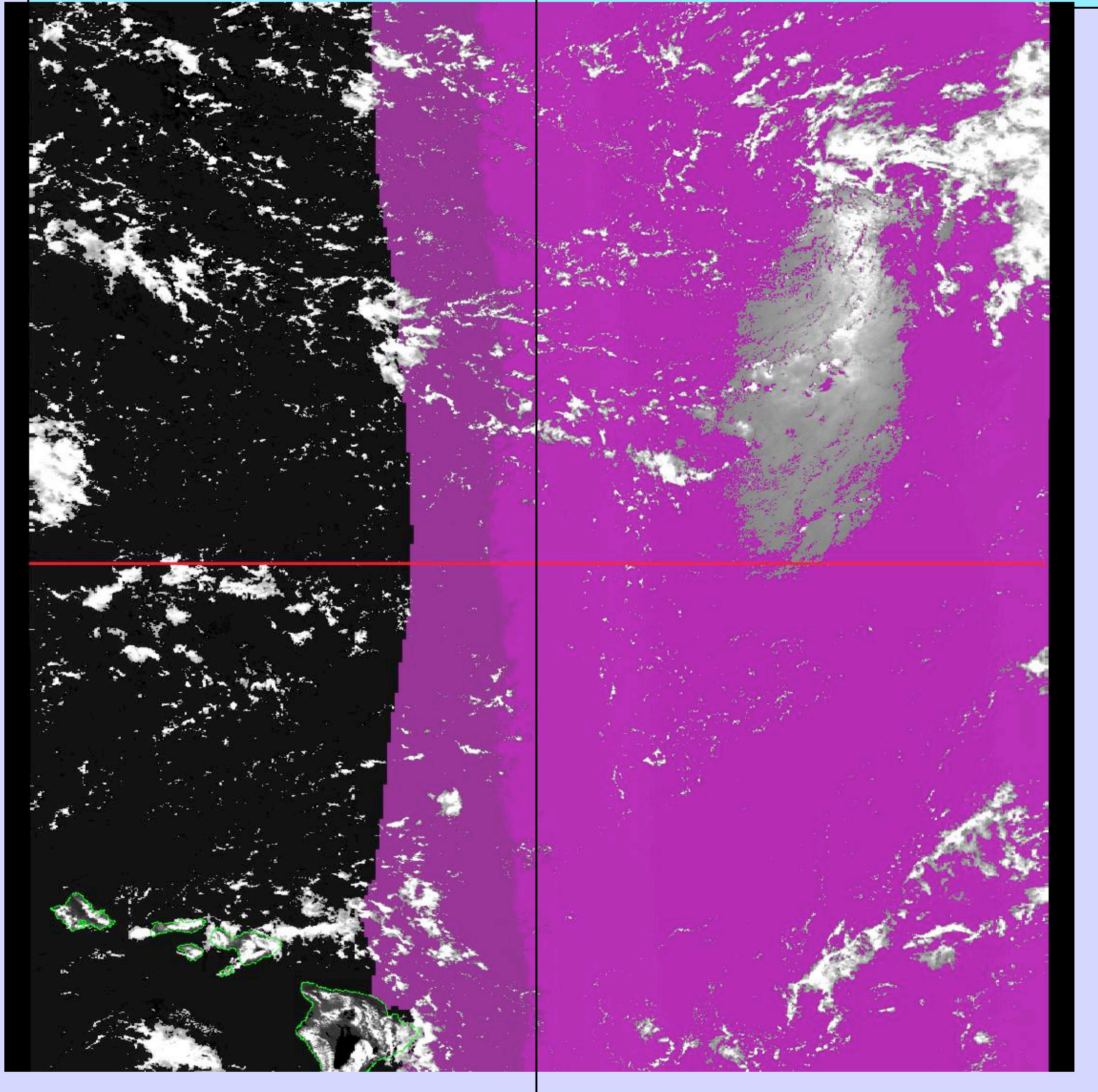
Hawai 20030705



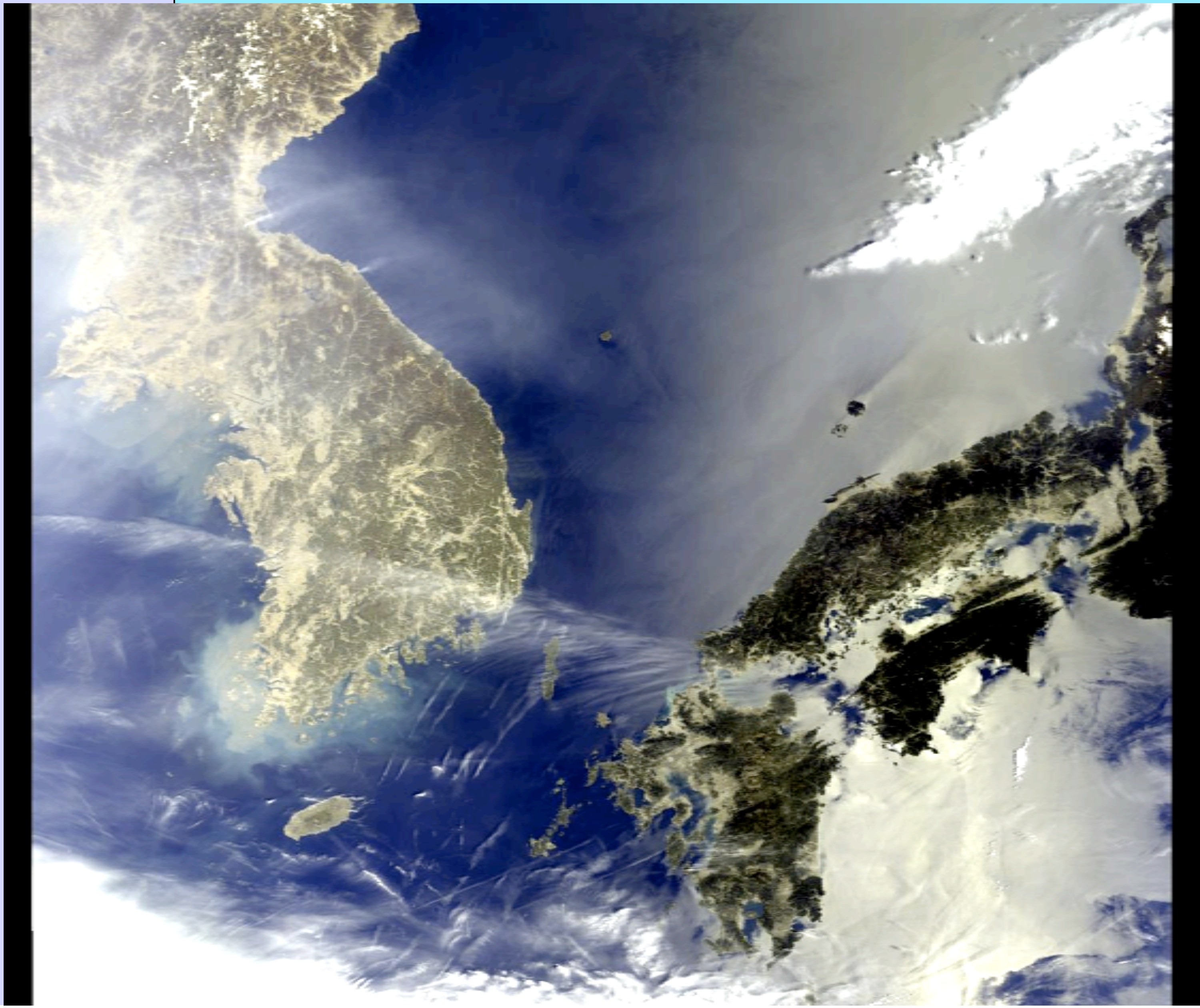
radiance_9 [mW/(m^2*sr*nm)]



Sun glint mask for medium and high glint



MERIS 20070429 LTOA RGB



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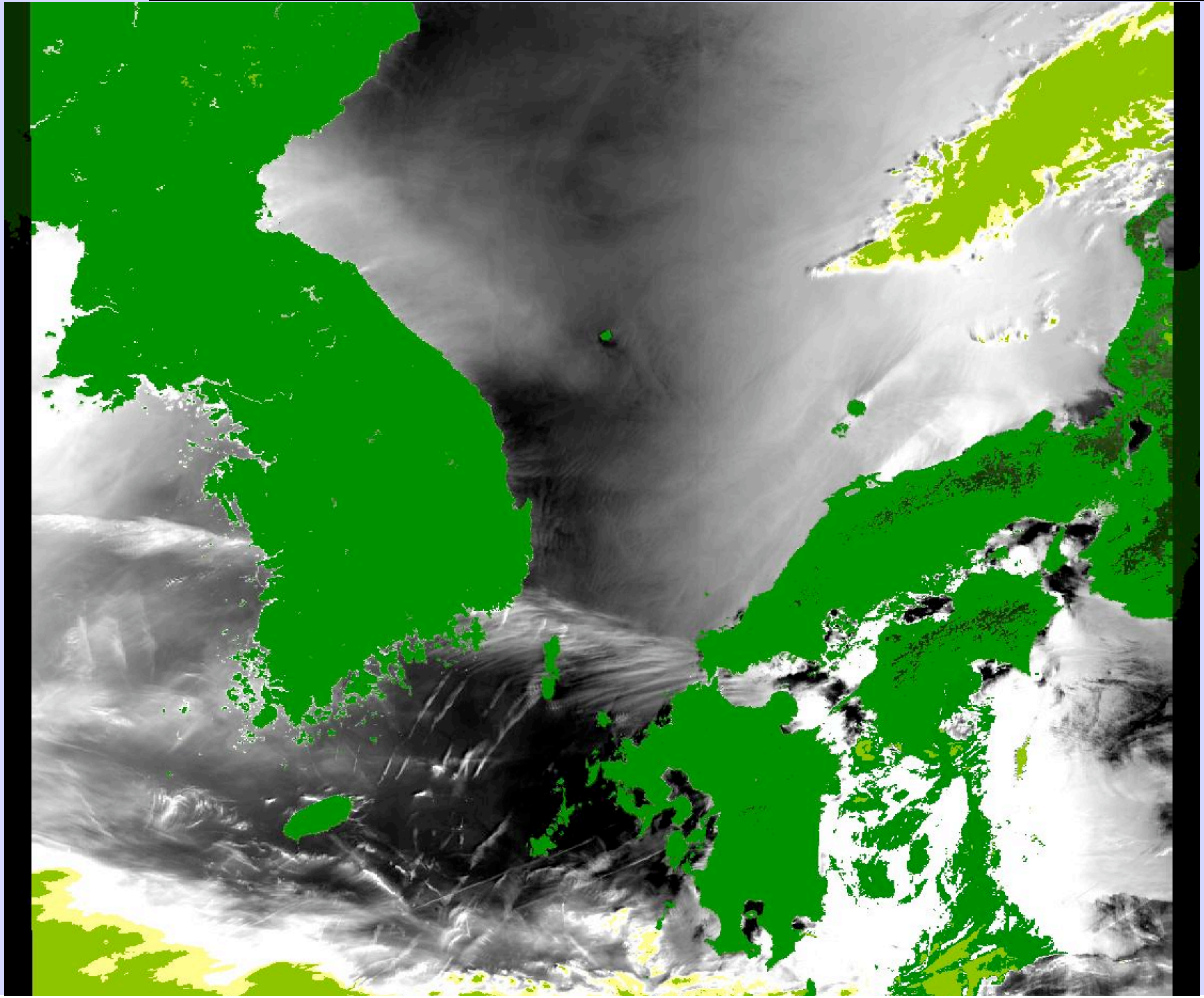
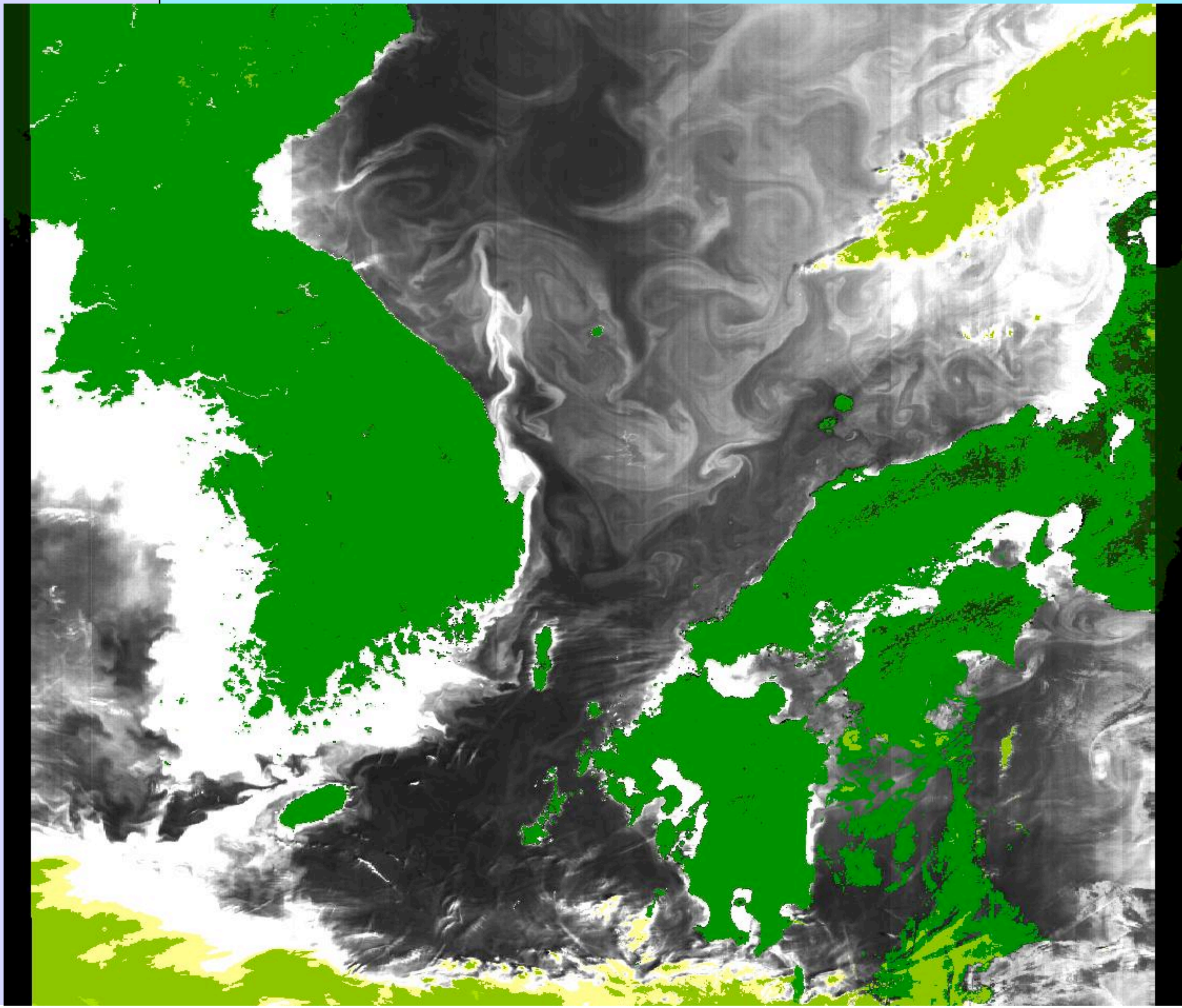
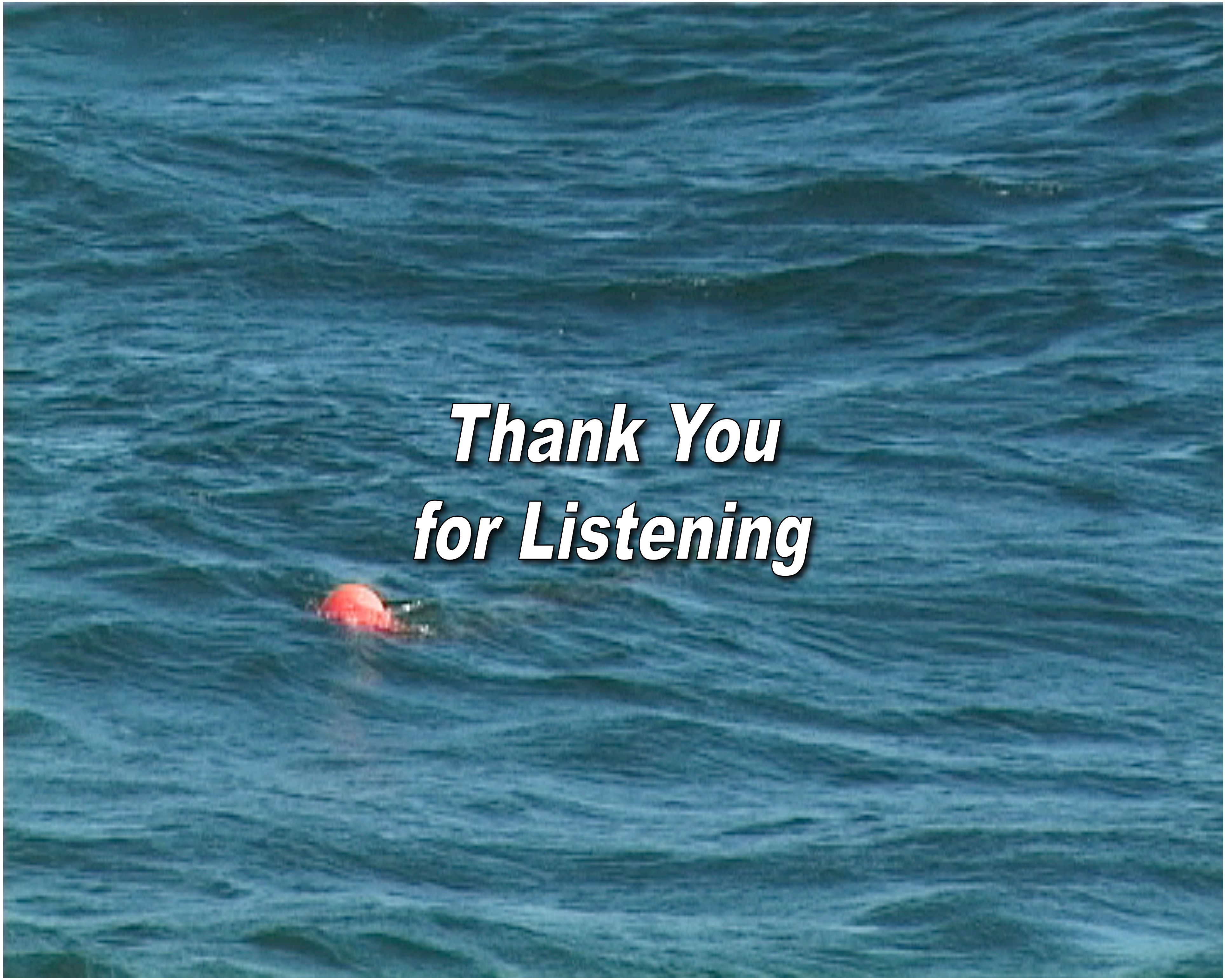
C2R AGC Path radiance reflectance band 5



Water leaving radiance reflectance band 5




Thank You
for Listening