# NOWPAP – PICES
# Joint Training course
# on Remote Sensing Data Analysis

Qingdao, Oct. 21-25, 2013

## Correction of the influence of the atmosphere in Ocean Colour RS

Roland Doerffer

Helmholtz Zentrum Geesthacht / Brockmann Consult

Institute of Coastal Research

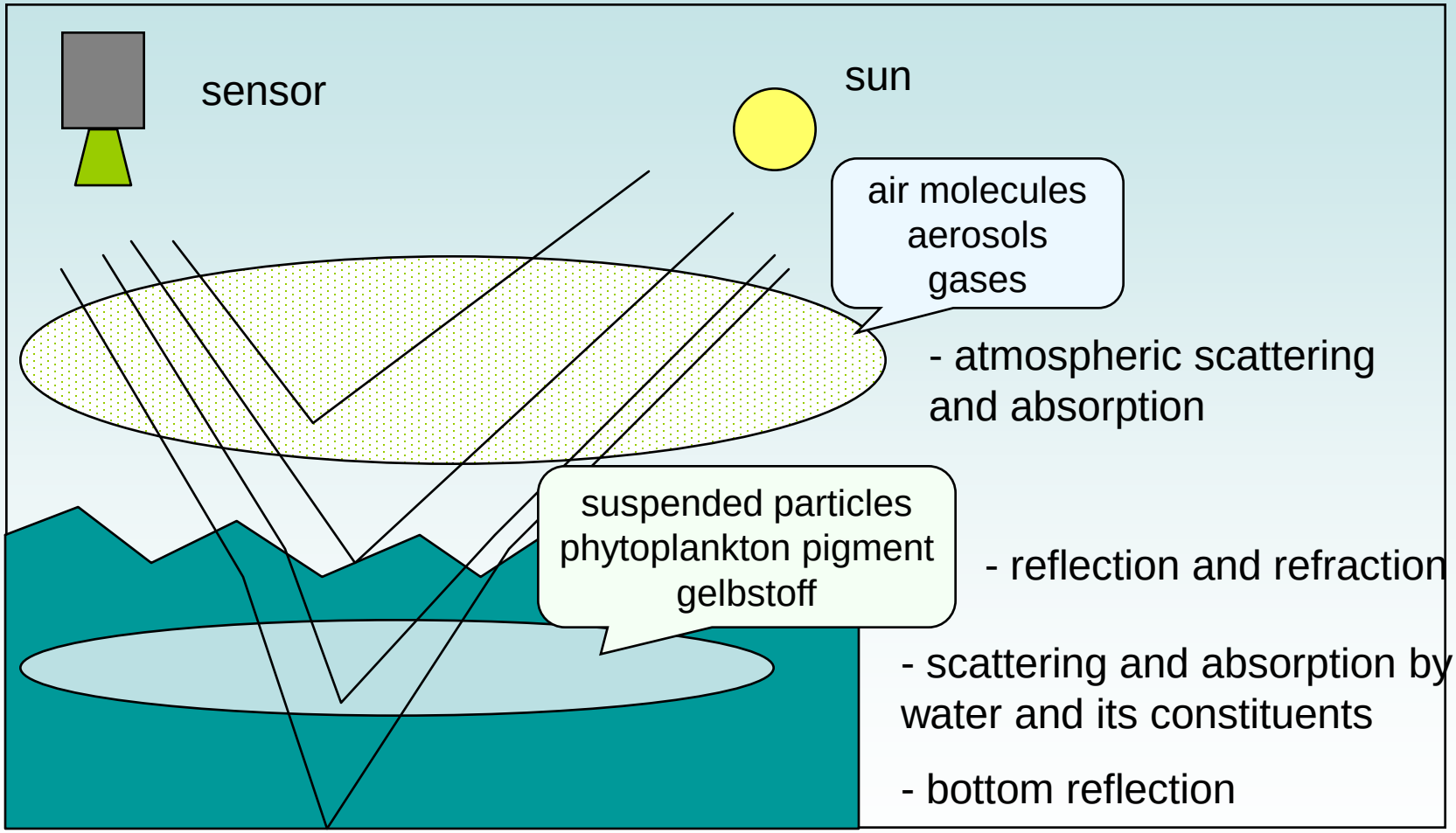
roland.doerffer@hzg.de

Space Shuttle 335 k
20060720 , NASA

# „Atmospheric Correction“

- Goal: to determine the water leaving radiance or water leaving radiance reflectance from top of atmosphere (TOA) radiances or reflectances
- The following quantities have to be determined:
  - Path radiance of the atmosphere
  - Transmittance of solar flux through the atmosphere
  - Transmittance of the radiance at the bottom of atmosphere (BOA) to the satellite
  - Solar light which is reflected at the water surface
    - Direct: sun glint
    - After scattering in the atmosphere: reflected sky light
- Normalisation of the reflectance, i.e. recomputation of the bi-directional reflectance for a sun in zenith and nadir viewing direction
- Further problem is the adjacency effect: sun light, which is reflected by a bright target in the neighbourhood of the water surface and which is then scattred by the atmosphere into the sensor
- Correction of thin and sub-pixel clouds and cloud shadows not included here

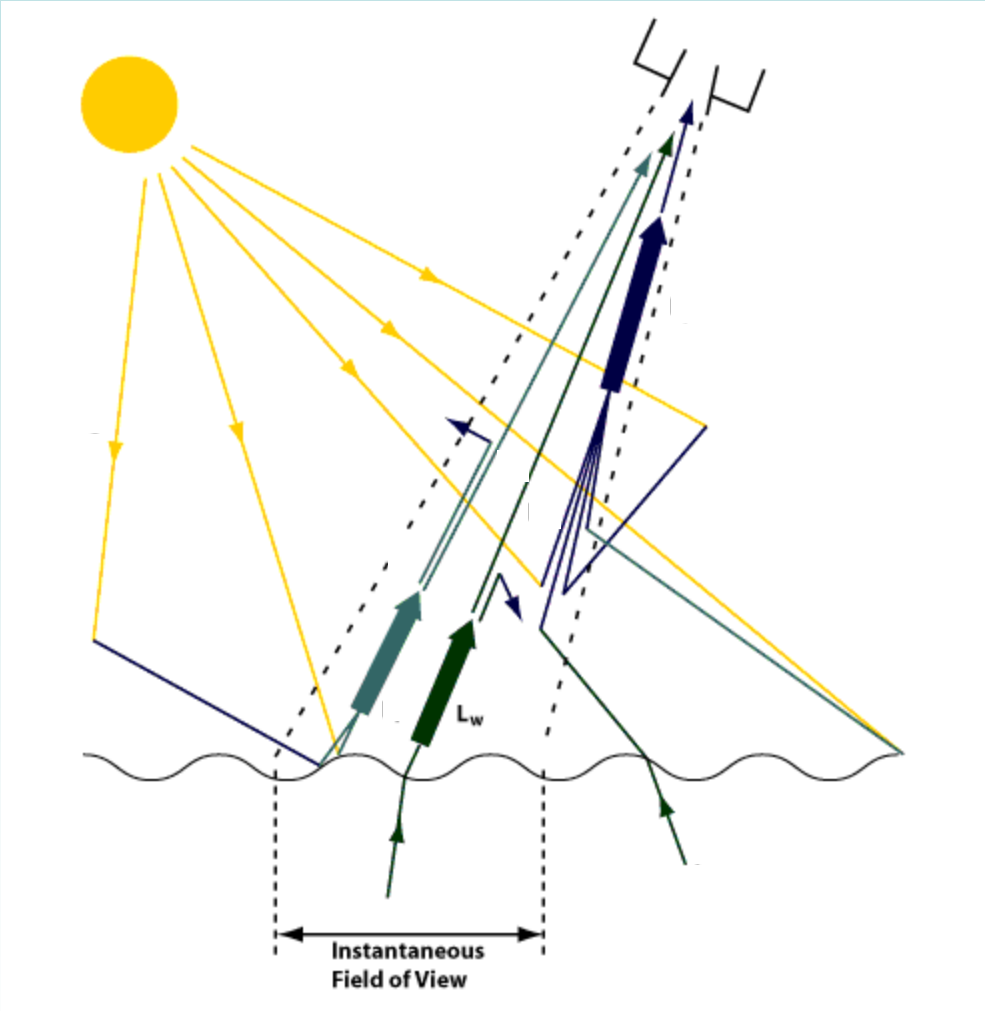
# Basic principles of Water Color RS



# Terms and Expressions

- Optical thickness of atmosphere: $\tau$ = -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

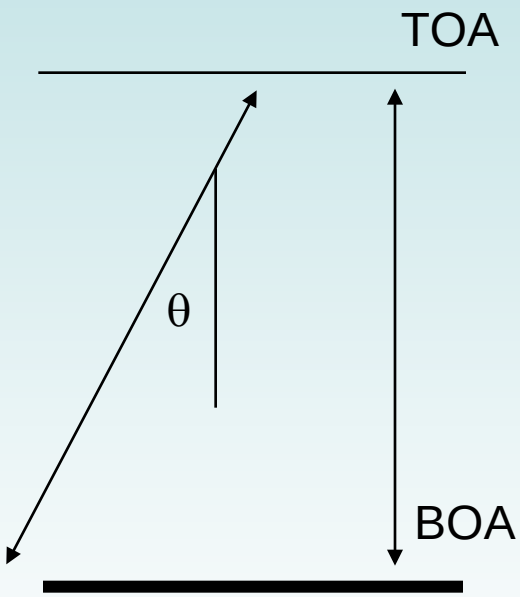
# Light paths to the sensor




the satellite observes both the **ocean** and the **atmosphere**

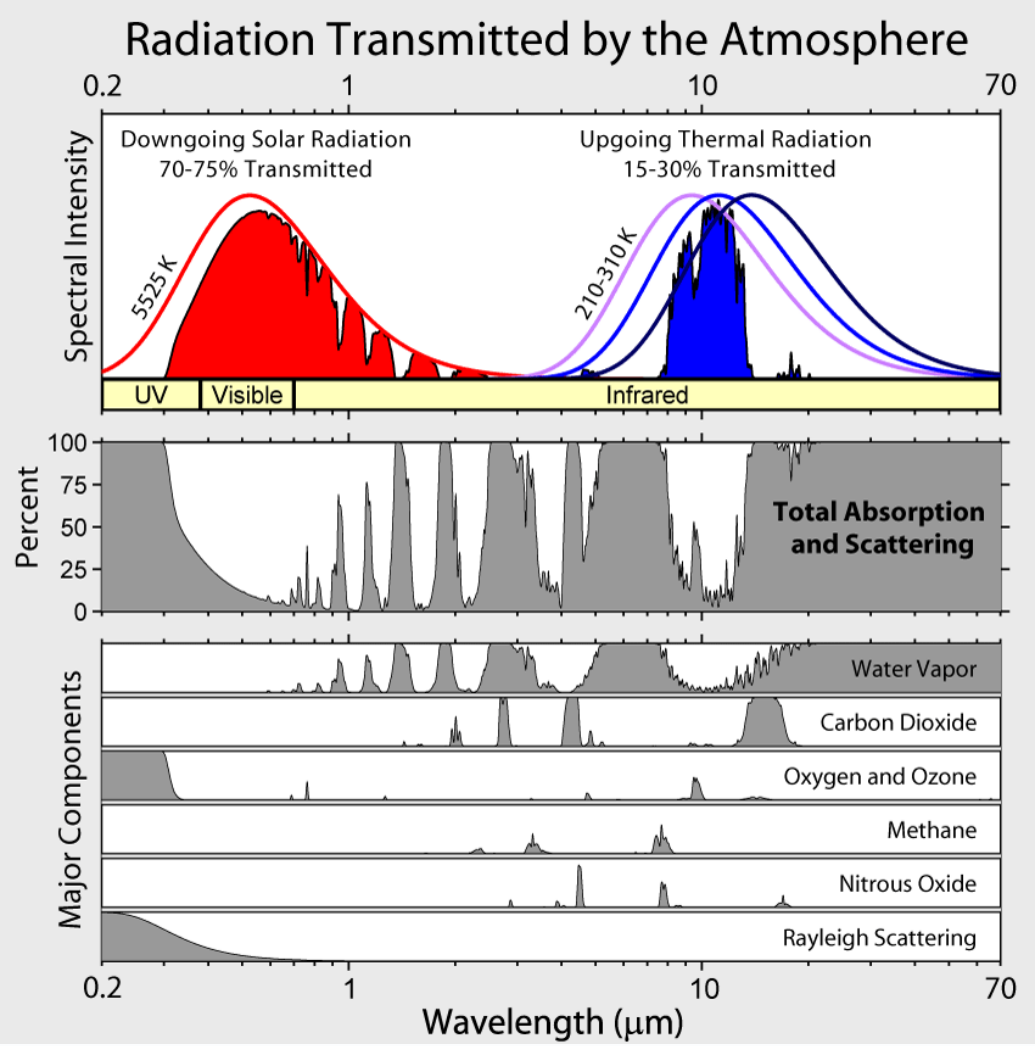
# Optical Thickness, Transmittance, Angstrom

- Beam Transmittance $T = I_z / I_0$
- Extinction tau $\tau = -\log(T)$, $T = \exp(-\tau)$
- $T = \exp(-\tau/\cos(\theta))$
- Aerosol Optical Thickness AOT = $\tau_{ae}$




- Angstrom coefficient:
  - Alpha $\alpha = \log(\tau_{\lambda 1} / \tau_{\lambda 2}) / \log(\lambda_1 / \lambda_2)$

# Solar Spectrum 1



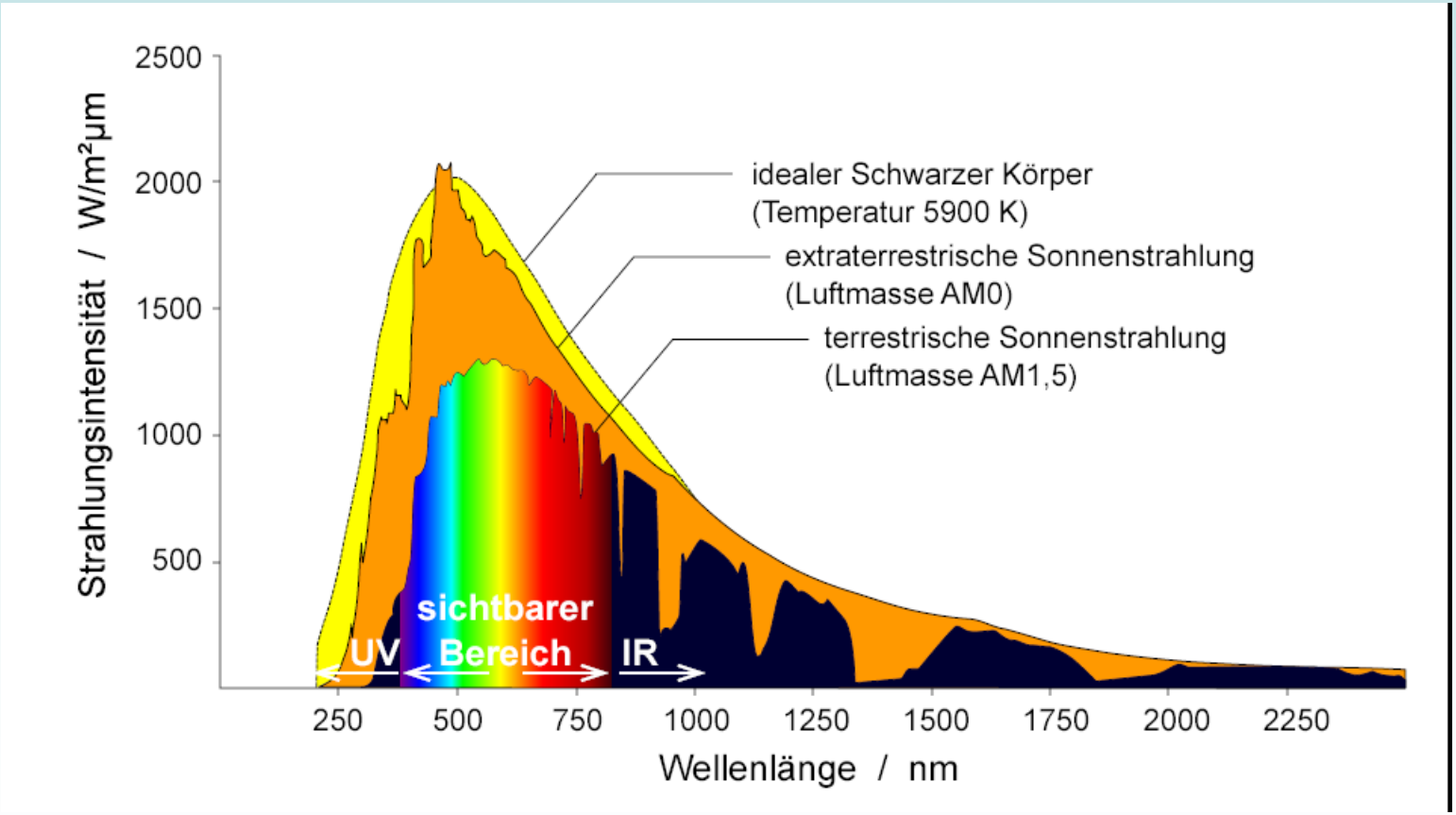

**Composition of earth atmosphere**:

- 78.09% nitrogen
- 20.95% oxygen,
- 0.247% water vapor (variable)
- 0.93% argon
- 0.038% carbon dioxide
- traces of hydrogen, helium, methane, ozone etc.

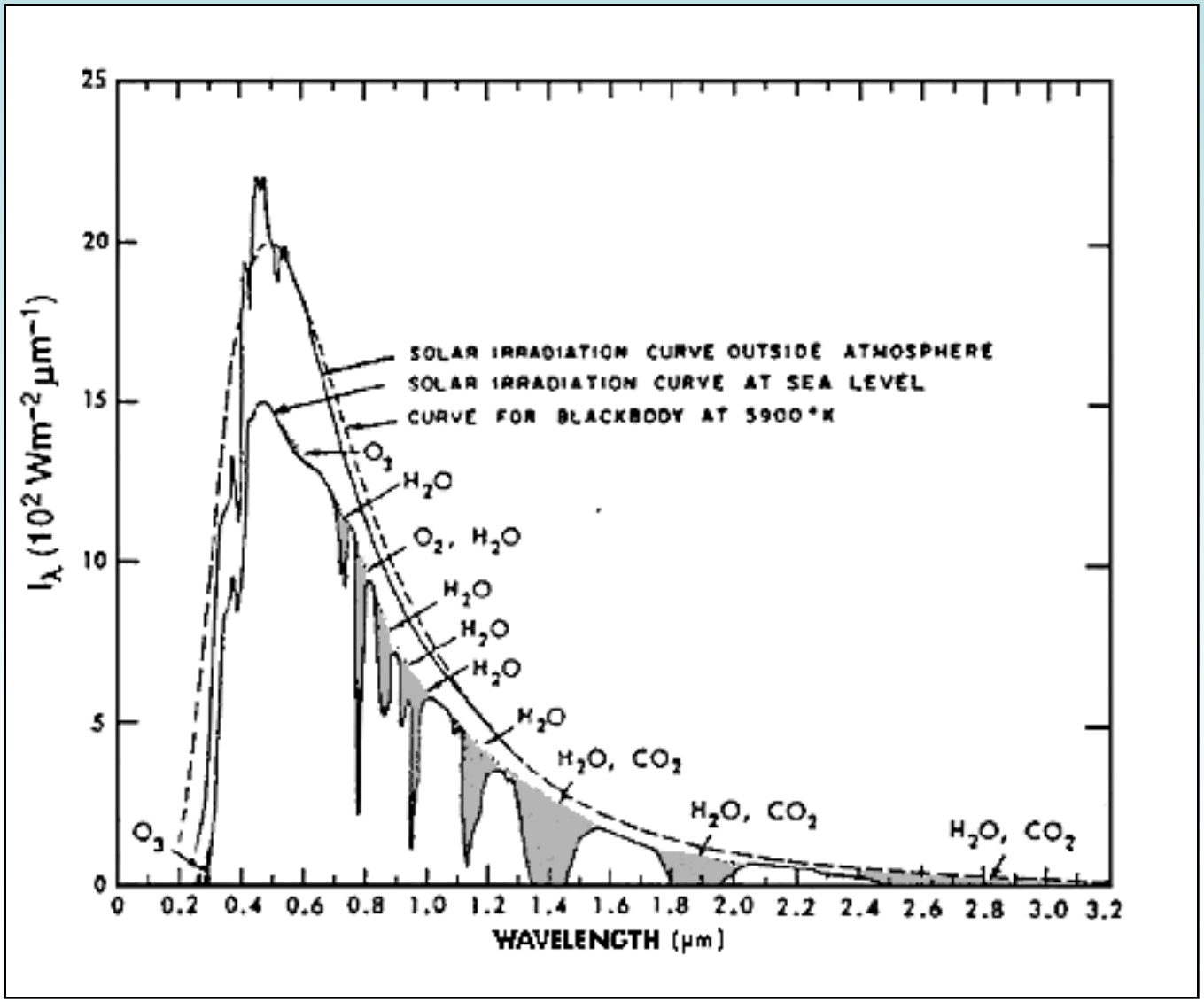
- Gases cause scattering and absorption
- Areas with no absorption are called windows

- Aerosols:
  - Salt cristals
  - Dust from deserts
  - Soot
  - Vulcanic ash

# Solar Spectrum 2

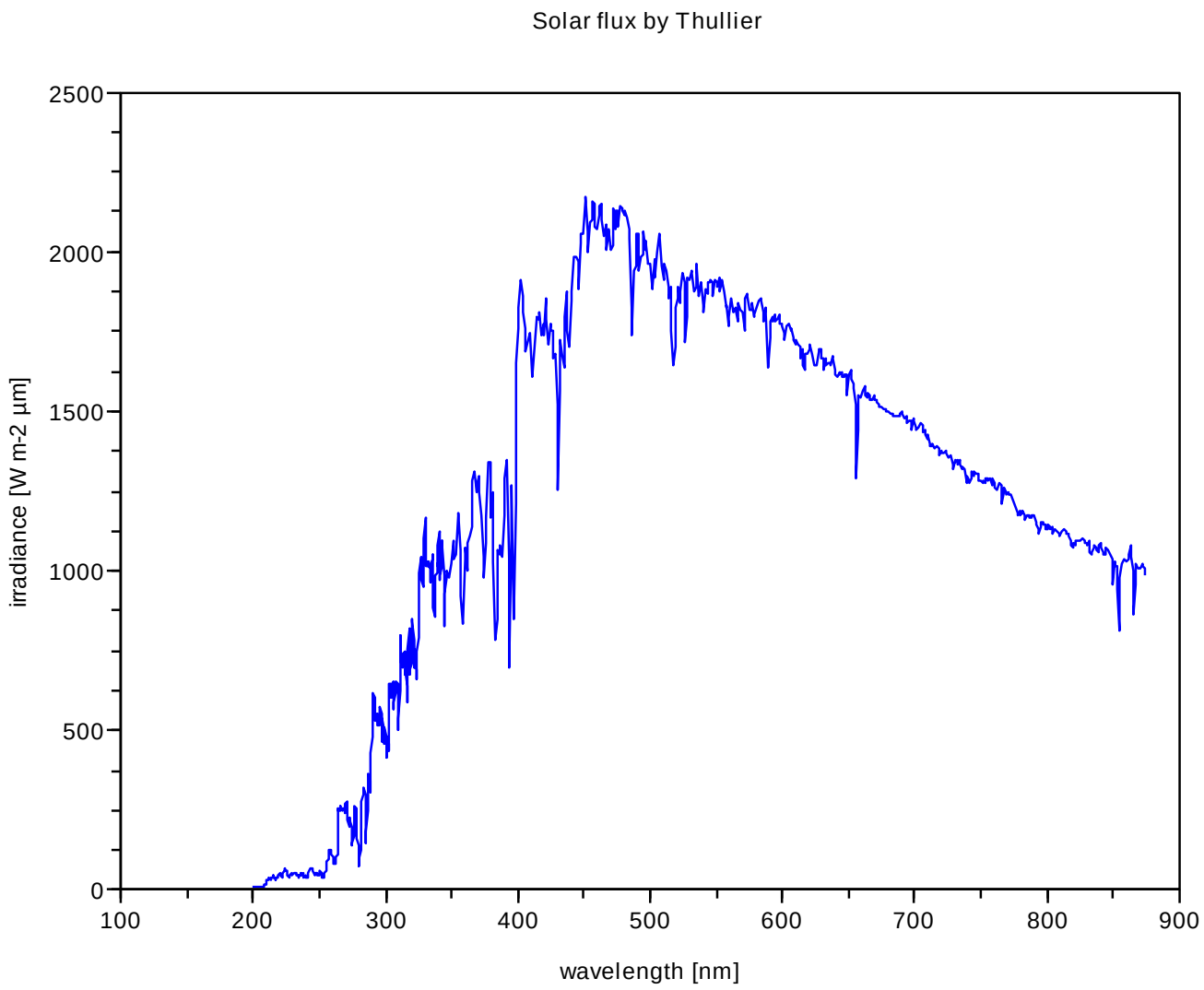


# Atmospheric Transmission

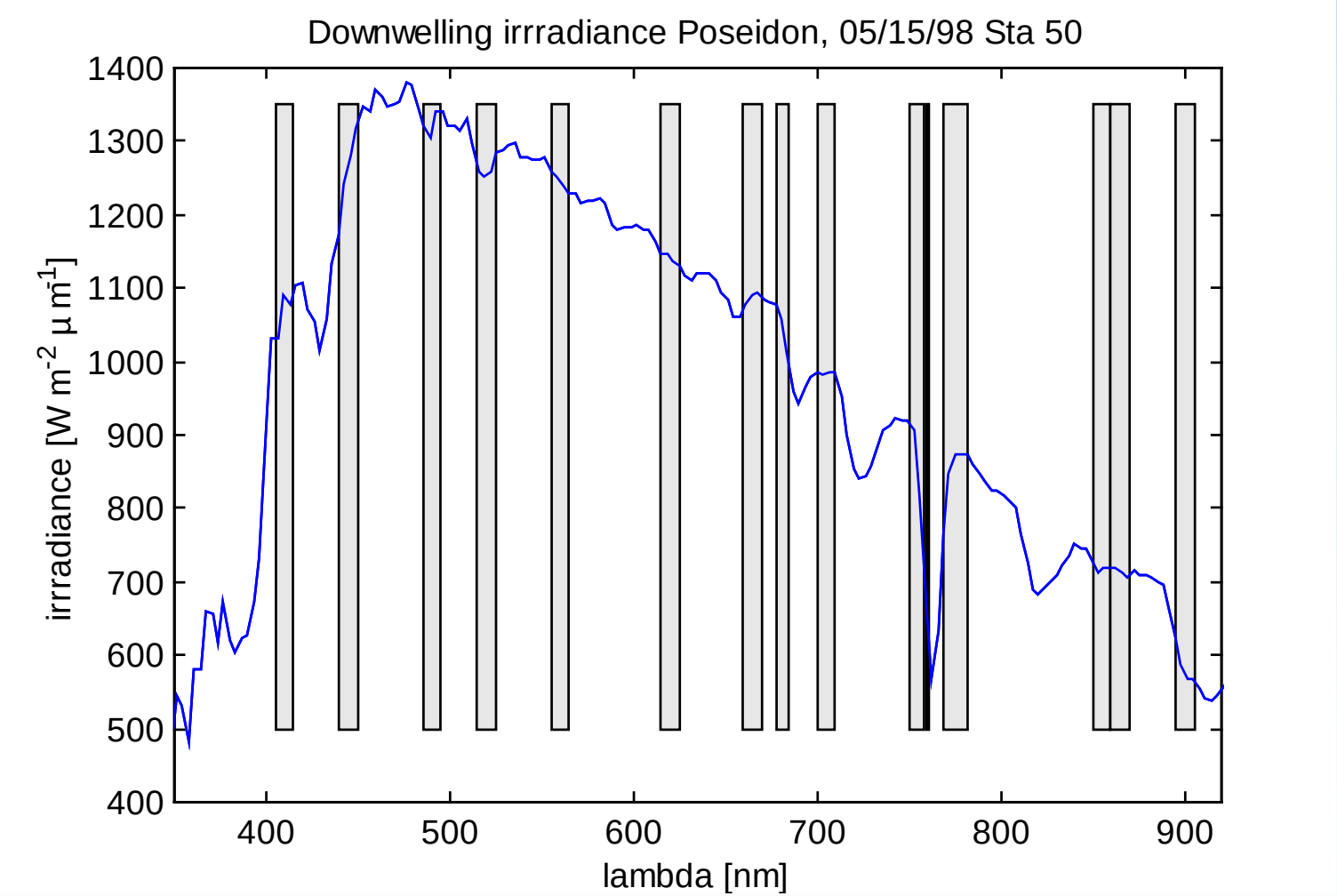



Solar radiation at the top of the atmosphere and the actual radiation at sea level which has been reduced due to absorption by atmospheric gases. The dashed curve is a blackbody at 5900K for comparison with the solar curve outside the earth's atmosphere

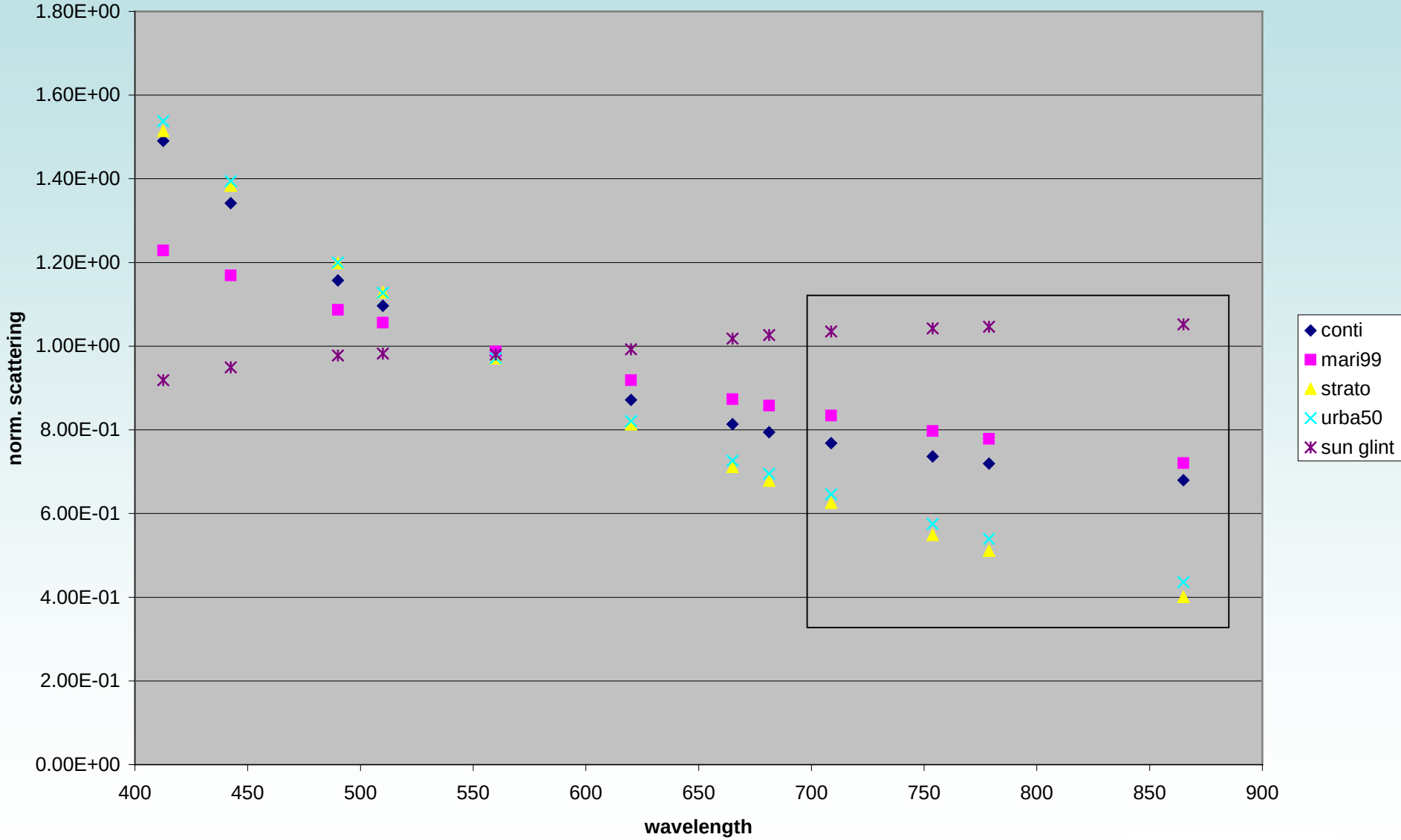
# Solar Flux at TOA (Thullier)

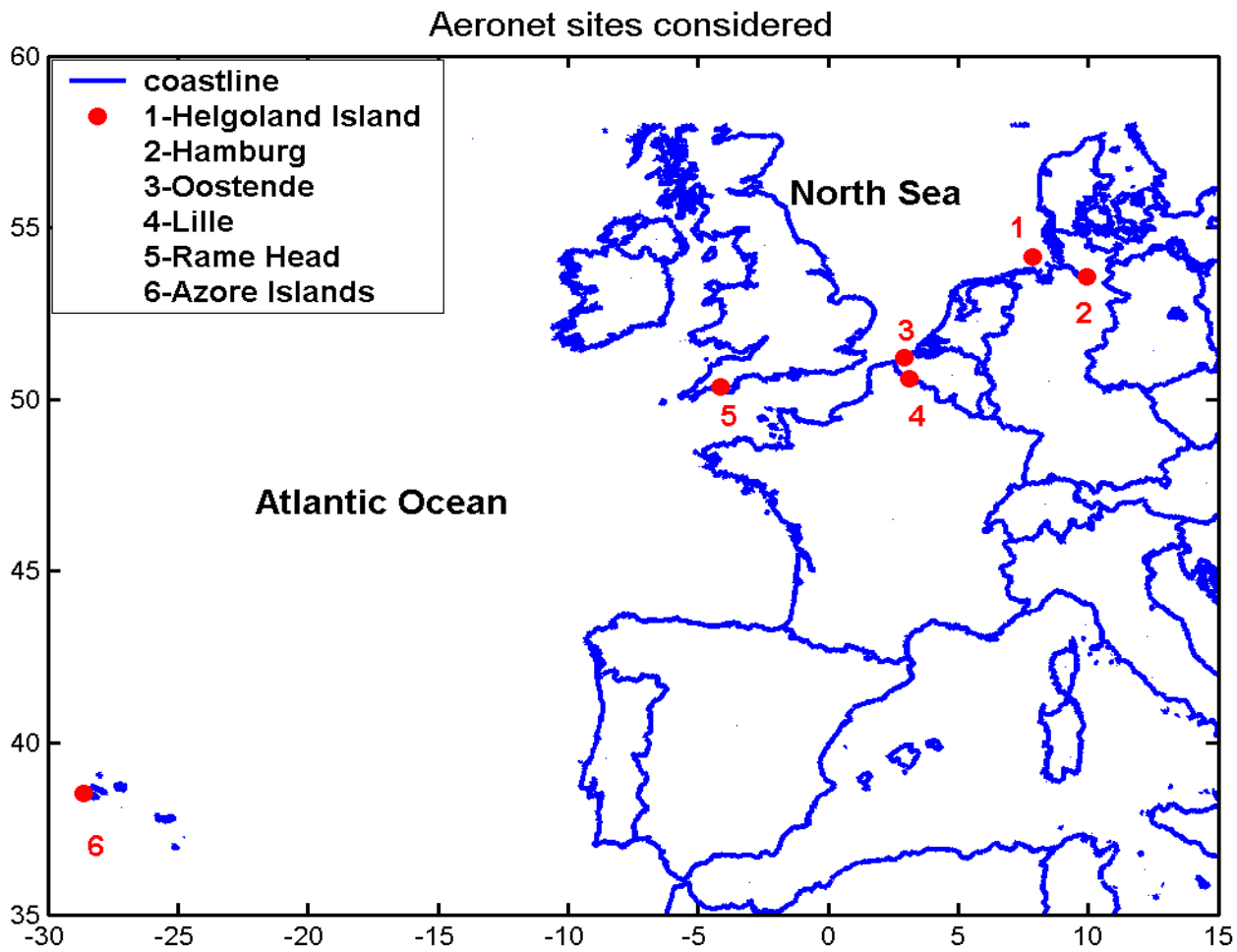


# Downwelling irradiance

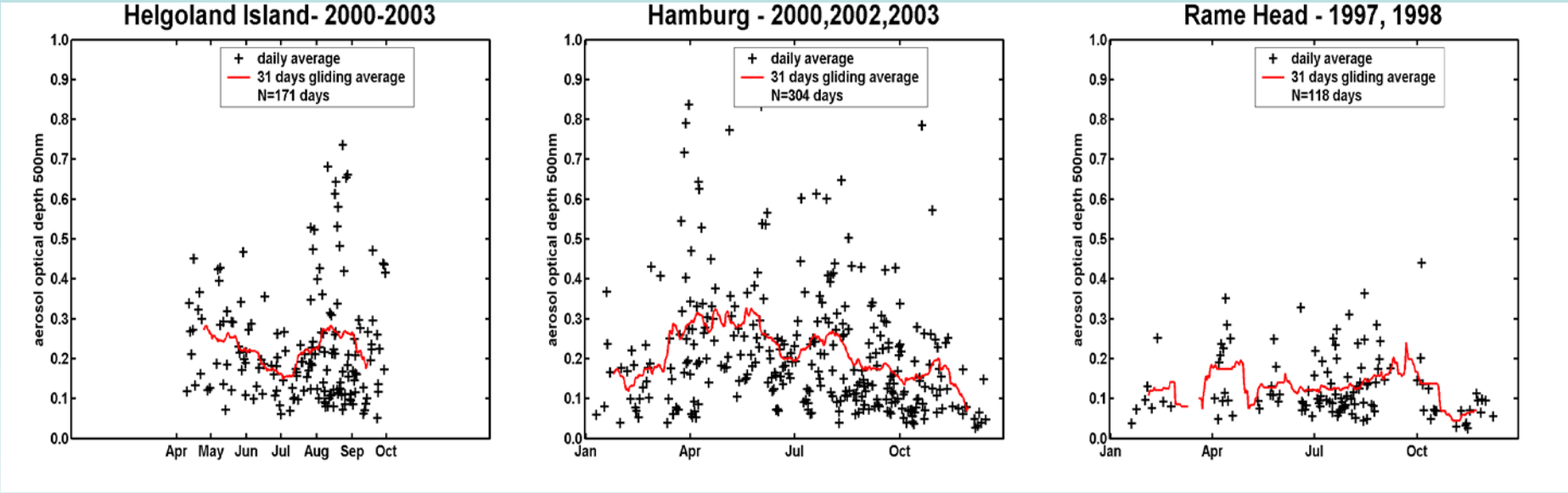


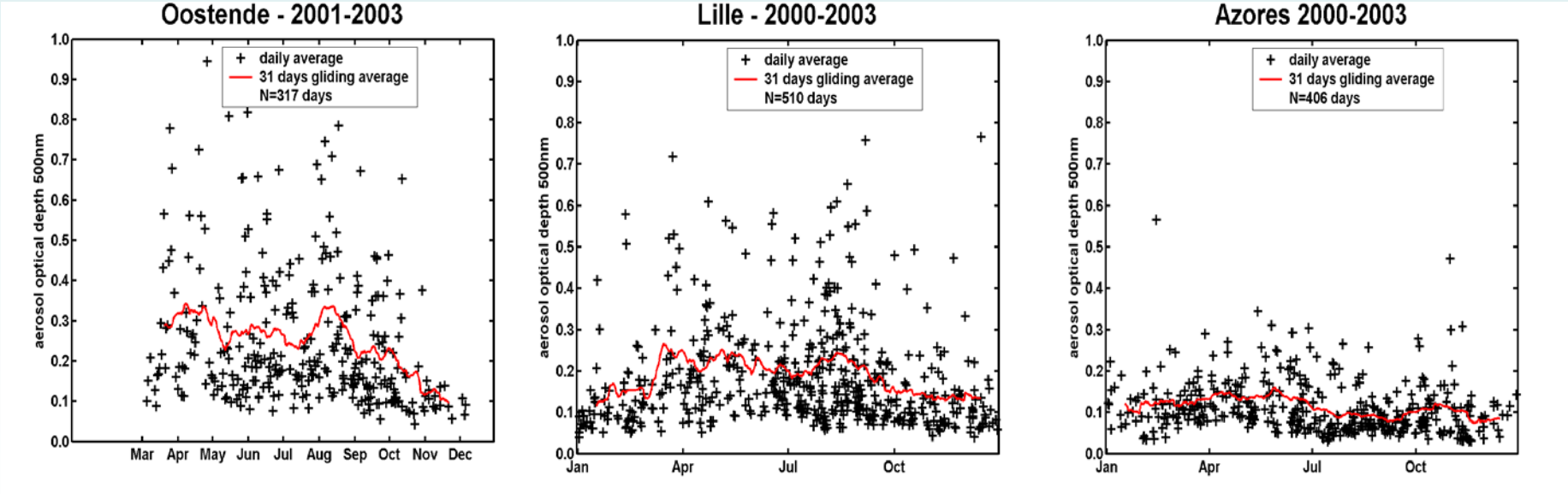
# Aerosol Optical Properties



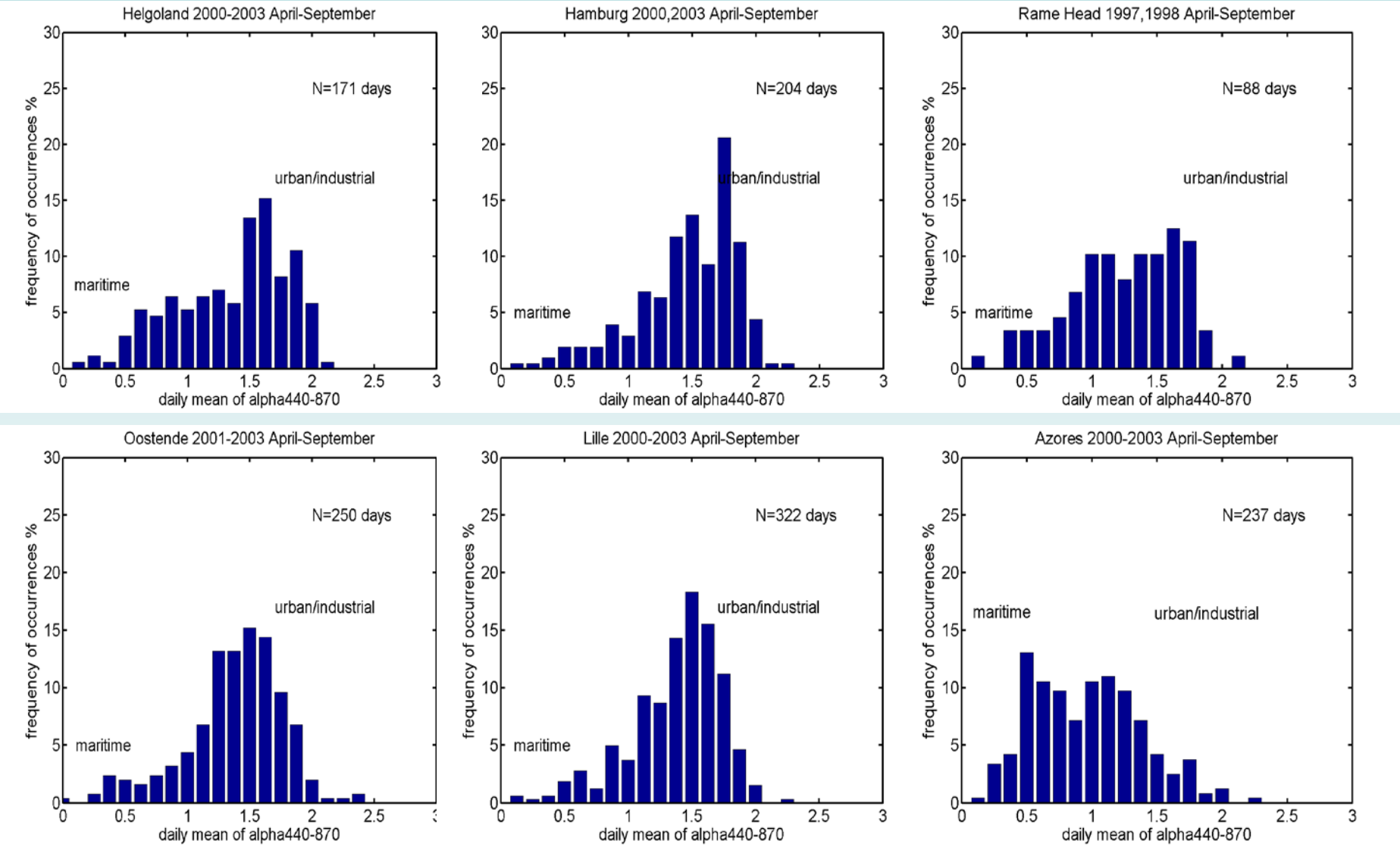

Aeronet sites considered
coastline
1-Helgoland Island
2-Hamburg
3-Oostende
4-Lille
5-Rame Head
6-Azore Islands
North Sea
Atlantic Ocean
1
2
3
4
5
6
60
55
50
45
40
35
-30
-25
-20
-15
-10
-5
0
5
10
15

# Annual variation of the Aerosol optical depth 500nm

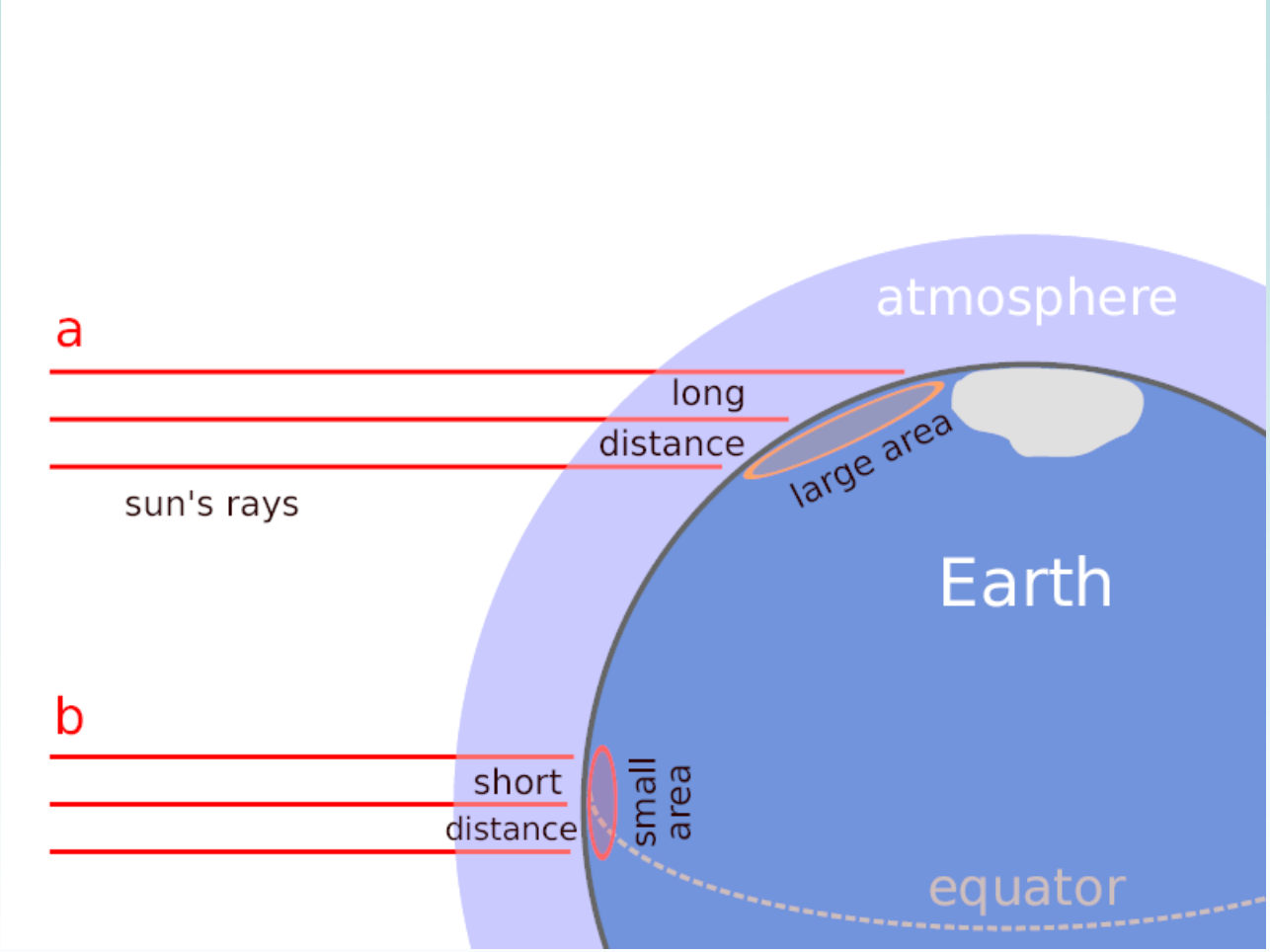


# Frequency of occurrences for Angstrom parameter $\alpha 440\_870$



# Cosine effect



# transmission air-water

*Transmission across the air–water interface* 45

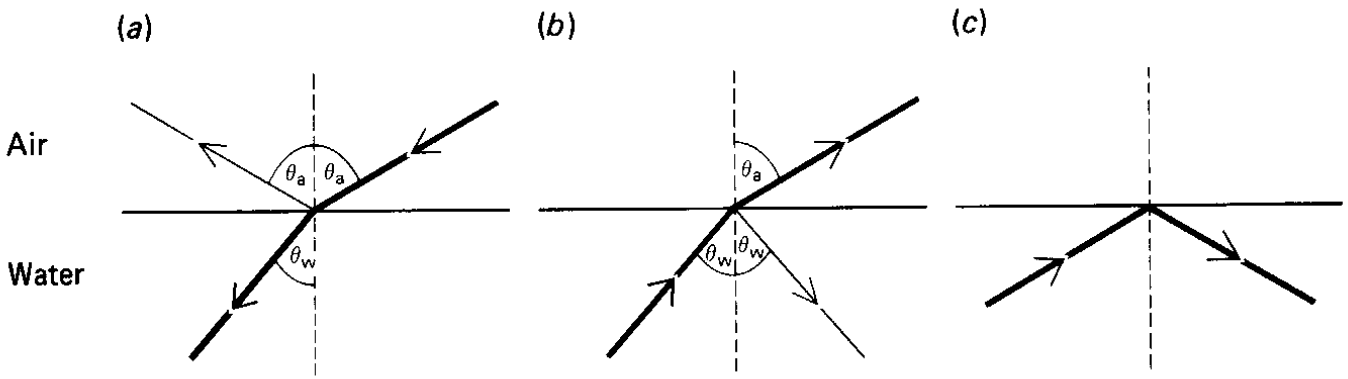



Fig. 2.11. Refraction and reflection of light at air–water boundary. (*a*) A light beam incident from above is refracted downwards within the water: a small part of the beam is reflected upwards at the surface. (*b*) A light beam incident from below at a nadir angle of 40° is refracted away from the 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

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

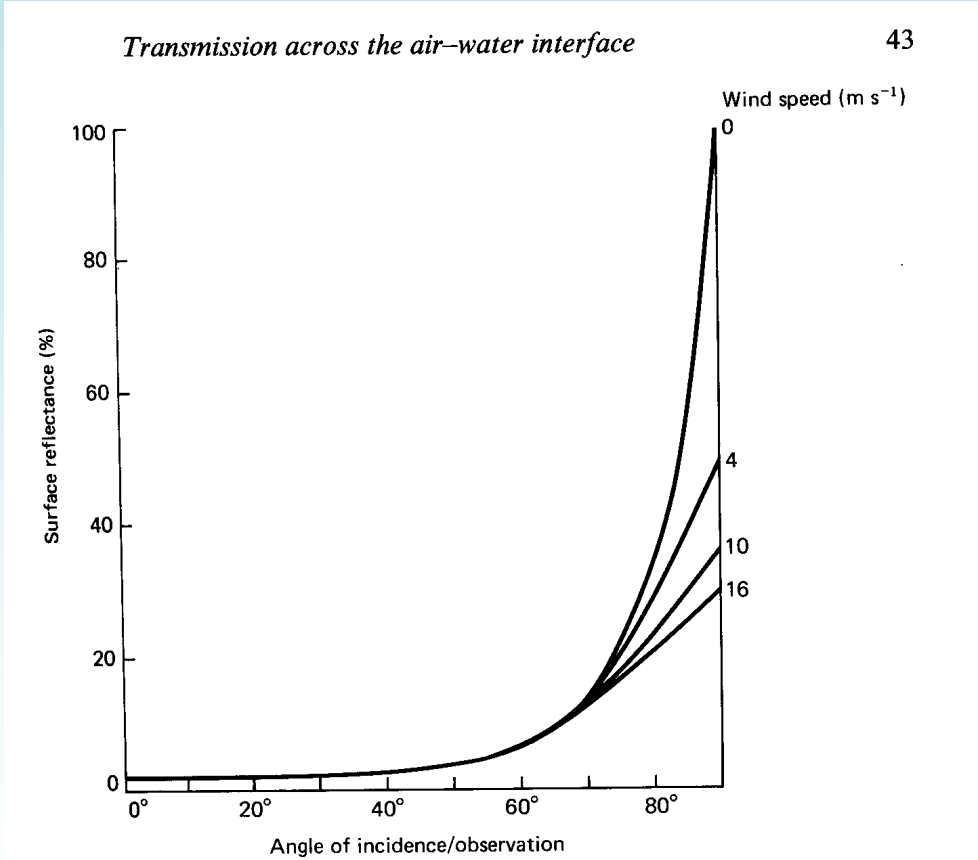


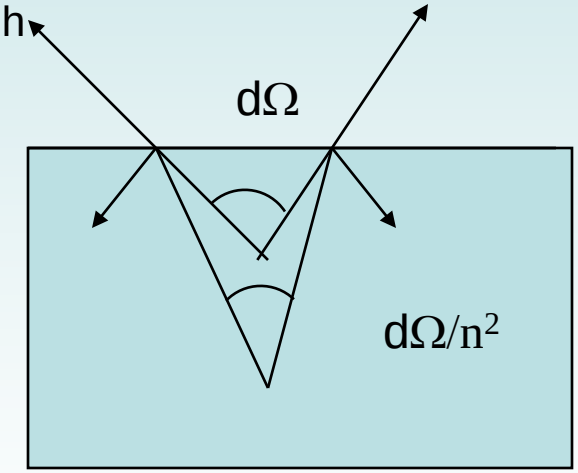

Fig. 2.10. Reflectance of water surface as a function of zenith angle of light (incident from above), at different wind speeds (data of Gordon, 1969; Austin, 1974*a*).

# Remote Sensing Reflectance

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



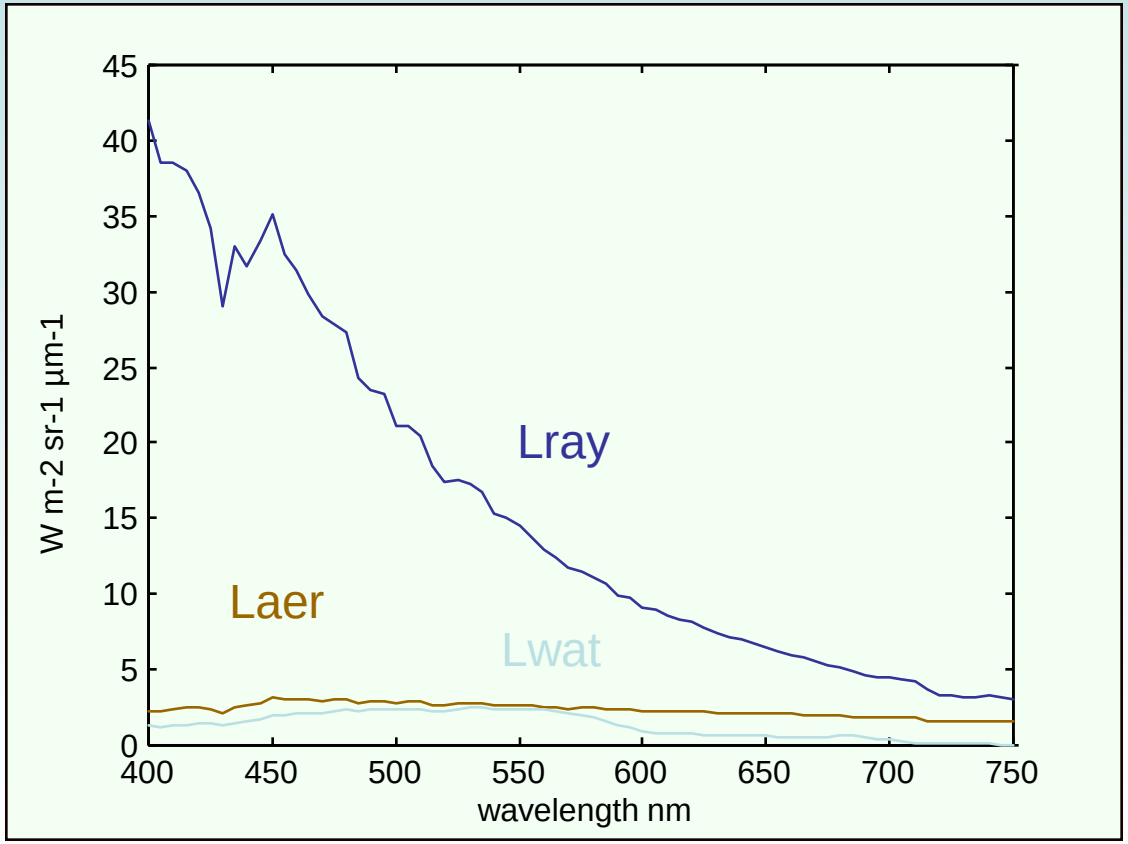

$L_u(0^+) = (t_- / n^2) L_u(0^-)$;  $E_d(0^-) = t_+ Ed(0^+)/(1- \gamma R)$

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

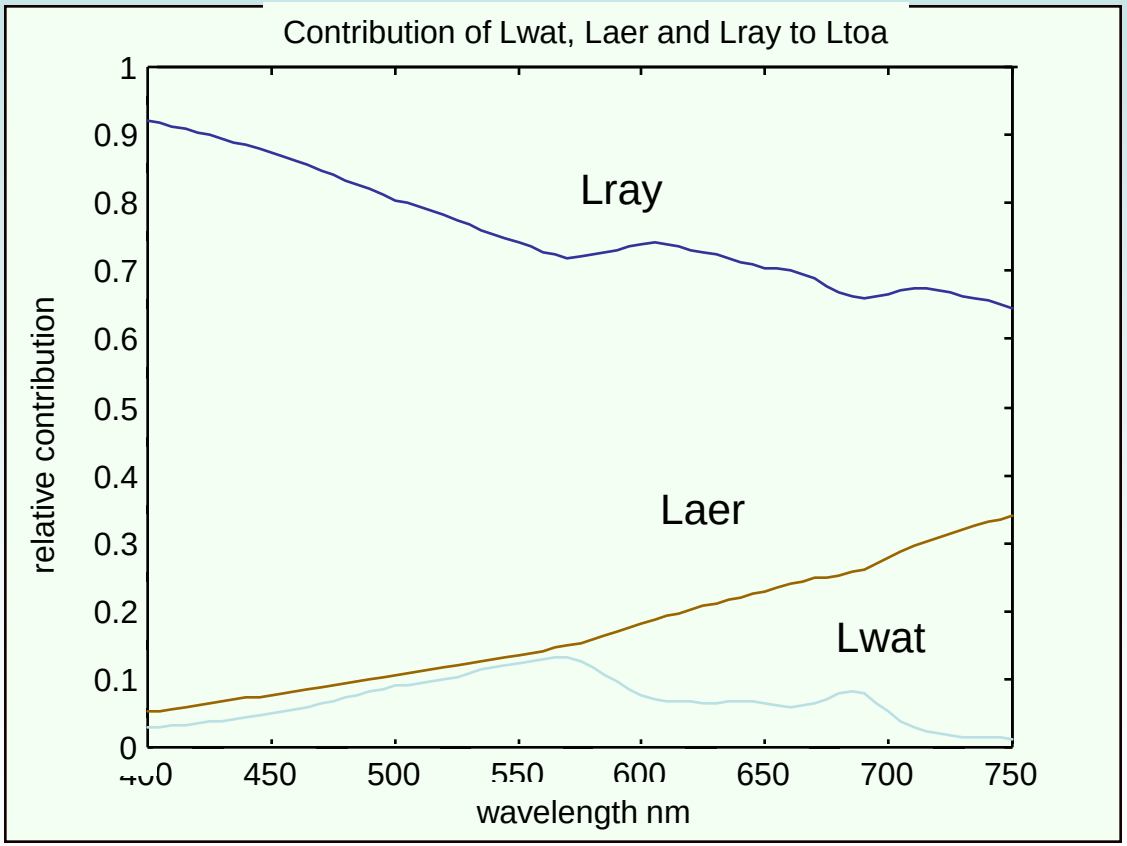
$\zeta = t_- t_+ / n^2$ ;  $\Gamma = \gamma Q$.

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

# Radiances at Top of Atmosphere (TOA)



# The composition of the Radiance Spectrum at Top of Atmosphere



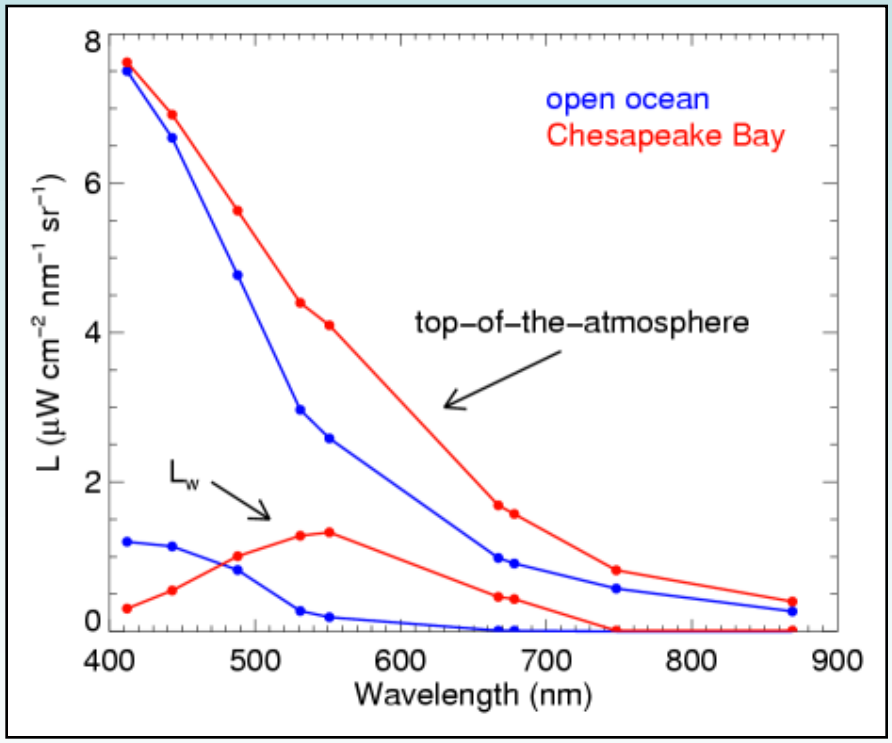

Relative contribution to TOA radiance

water leaving radiance: Lw

aerosol path radiance: Laer

Rayleigh path radiance: Lray

# Ocean color




the atmosphere is 80-90% of the total top-of-atmosphere signal in blue-green wavelengths (400-600 nm)

~1% error in instrument calibration or atmospheric model leads to

~10% error in *Lw*(λ)

# Effects of the atmosphere

gaseous absorption (ozone, water vapor, oxygen)

Rayleigh scattering by air molecules

Mie scattering and absorption by aerosols (haze, dust, pollution)

polarization (MODIS response varies with polarization of signal)

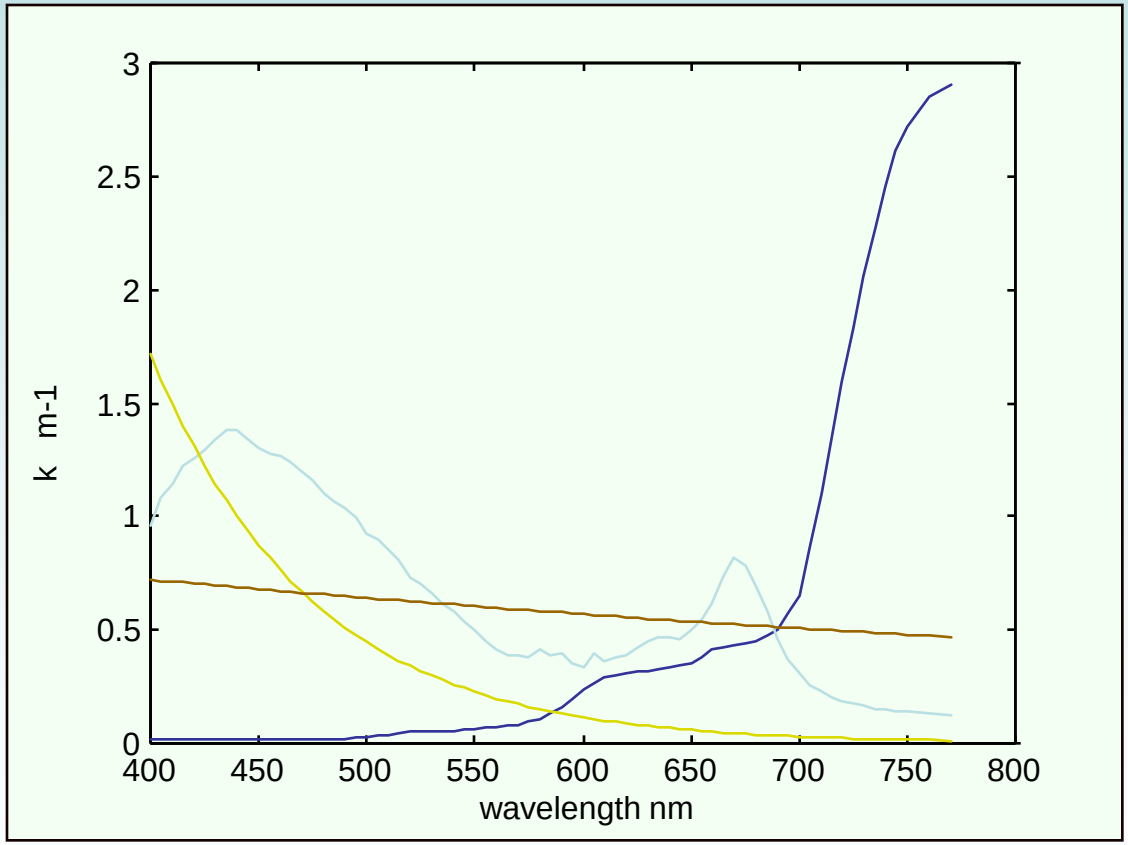
## Rayleigh (80-85% of total signal)

- small molecules compared to nm wavelength, scattering efficiency decreases with wavelength as $\lambda^{-4}$
- reason for blue skies and red sunsets
- can be accurately approximated for a given atmospheric pressure and geometry (using a radiative transfer code)

## Aerosols (0-10% of total signal)

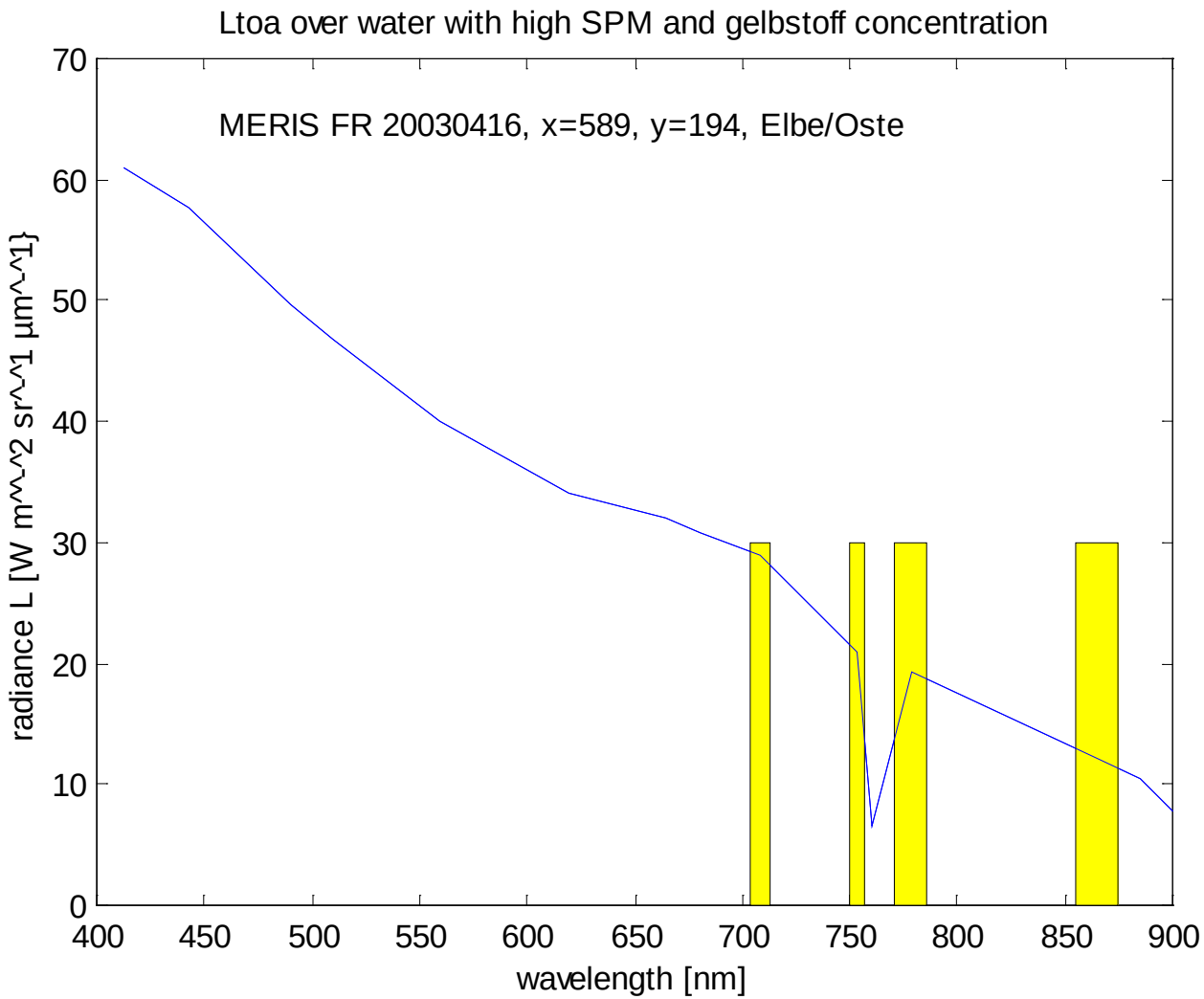
- particles comparable in size to the wavelength of light, scattering is a complex function of particle size
- whitens or yellows the sky
- significantly varies and cannot be easily approximated

# Spectral Attenuation of Water Constituents




Diffuse attenuation k
for pure water, chlorophyll (30µg/l), sus. matter (50 mg/l), gelbstoff

# Bands for atmospheric correction



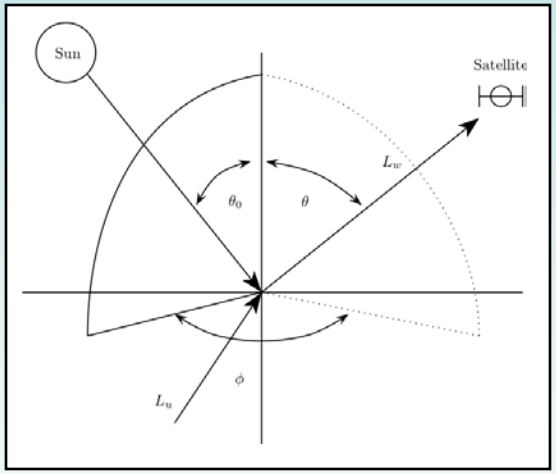
# Atmospheric correction

TOA gas pol glint whitecap air aerosol

$t_d(\lambda)\ L_w(\lambda) = L_t(\lambda) / t_g(\lambda) / f_p(\lambda) - TL_g(\lambda) - tL_f(\lambda) - L_r(\lambda) - L_a(\lambda)$

brdf Sun

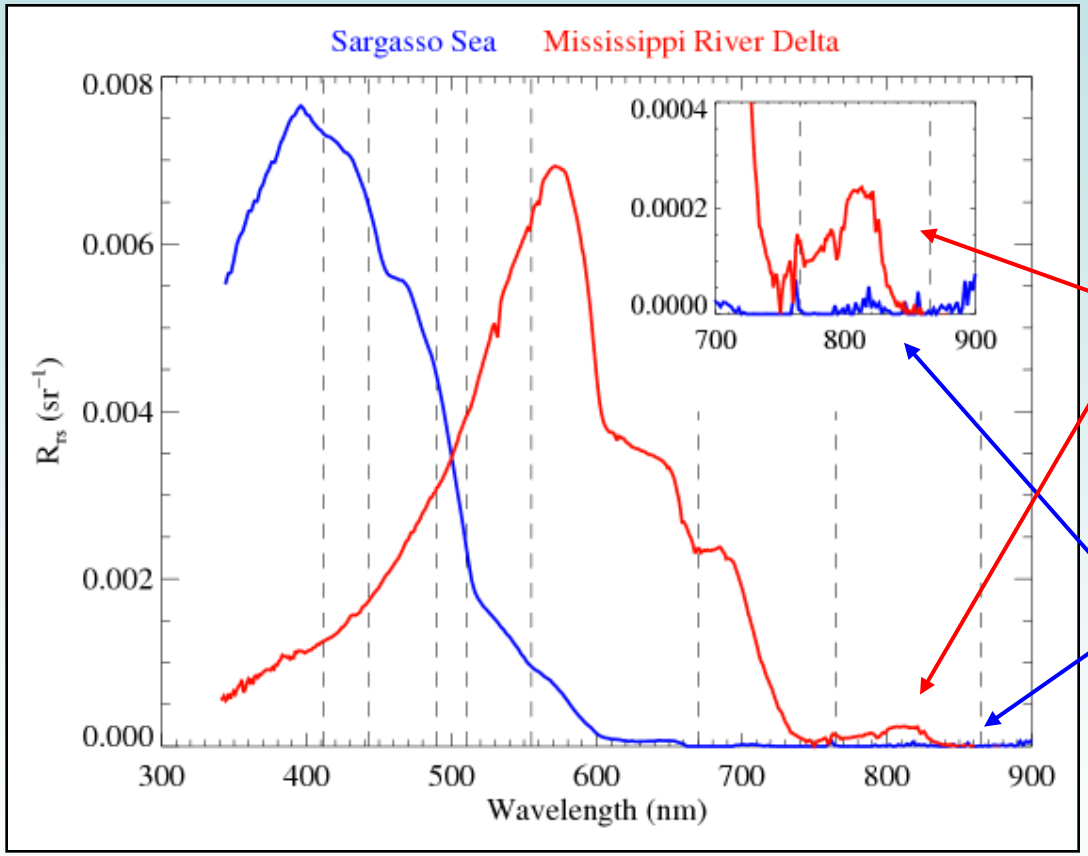
$nL_w(\lambda) = L_w(\lambda)\ f_b(\lambda) / t_{d0}(\lambda)\ \mu_0\ f_0$




But, <u>we need aerosol</u> to get $L_w(\lambda)$

$L_w(\lambda=NIR) \approx 0$ and can be estimated (model extrapolation from VIS) in waters where *Chl* is the primary driver of $L_w(\lambda)$

# Magnitudes of *Lw*(NIR)




Lw(NIR) ≠ 0 (turbid or highly productive water)

Lw(NIR) = 0 (clear water)

# Aerosol determiniation in visible wavelengths

Given retrieved aerosol reflectance at two $\lambda$, and a set of aerosol models fn($\theta$,$\theta_0$,$\phi$).

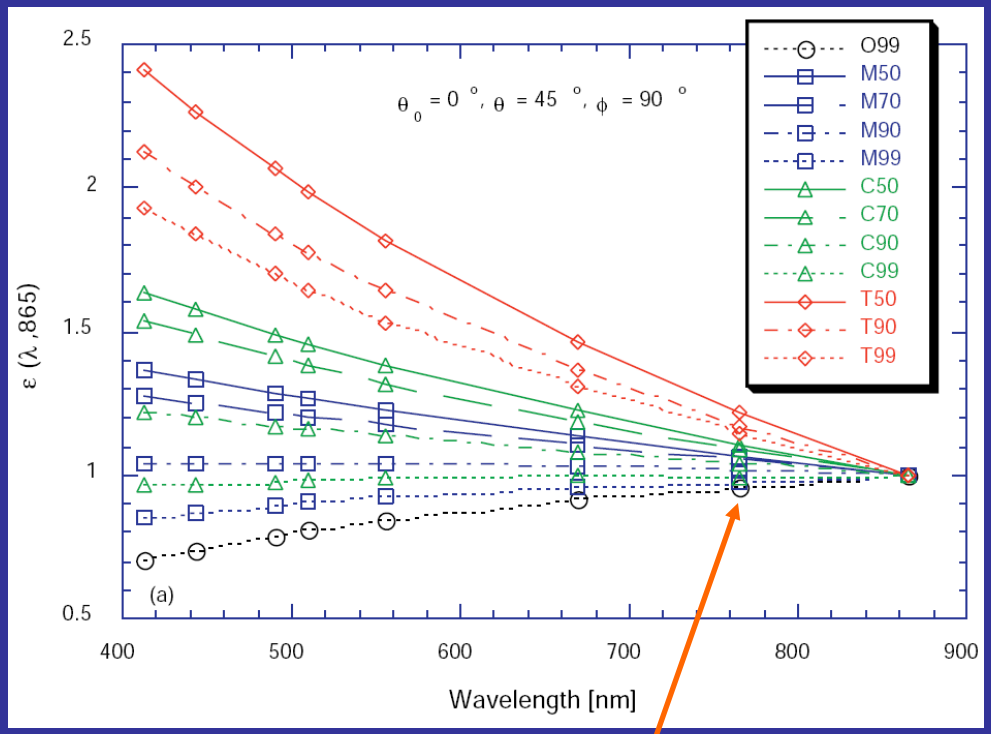
$$\rho = \frac{\pi L}{F_0 \cdot \mu_0}$$

$\rho_a(748)$ & $\rho_a(869)$

$$\rho_a(\mathrm{NIR}) \overset{\text{model}}{\Rightarrow} \rho_{as}(\mathrm{NIR})$$

$$\varepsilon\,(748,869) = \frac{\rho_{as}(748)}{\rho_{as}(869)}$$

$$\varepsilon\,(\lambda,869) = \frac{\rho_{as}(\lambda)}{\rho_{as}(869)}$$




$\varepsilon\,(748,869)$

## Iterative correction for non-zero *Lw*(NIR)

(1) assume Lw(NIR) = 0
(2) compute La(NIR)
(3) compute La(VIS) from La(NIR)
(4) compute Lw(VIS)
(5) estimate Lw(NIR) from Lw(VIS) + model
(6) repeat until Lw(NIR) stops changing

iterating up to 10 times

# Level-2 ocean color processing

(1) determine atmospheric and surface contributions to total radiance at TOA and subtract, iterating as needed.

(2) normalize to the condition of Sun directly overhead at 1 AU and a non-attenuating atmosphere (nLw or Rrs = $nLw/F_0$).

(3) apply empirical or semi-analytical algorithms to relate the spectral distribution of nLw or Rrs to geophysical quantities.

(4) assess quality (set flags) at each step

# POLYMER
# developed by F. Steinmetz

## Atmospheric correction scheme

1. Correction for gaseous absorption and Rayleigh scattering
2. Spectral matching using a model for atmosphere and glint + ocean reflectance:

$$\rho'_{\mathrm{TOA}}(\lambda) = \underbrace{T(\lambda)c_0 + c_1\lambda^{-1} + c_2\lambda^{-4}}_{\substack{\text{Atmosphere} \\ \text{+Sun glint model}}} + \underbrace{t(\lambda)\rho^{+}_{w,\mathrm{mod}}(\lambda, \mathrm{chl}, b_{bs})}_{\substack{\text{Ocean water} \\ \text{reflectance model}}}$$

   - Simultaneous optimization of 5 parameters
   - Using the whole sensor spectrum (from 412 to 865 nm)
3. Iterative optimization using Nelder-Mead simplex method

HYGEOS

Workshop on atmospheric correction over turbid waters, Wimereux, 13-14 June 2012

Courtey of F. Steinmetz, Hygeos

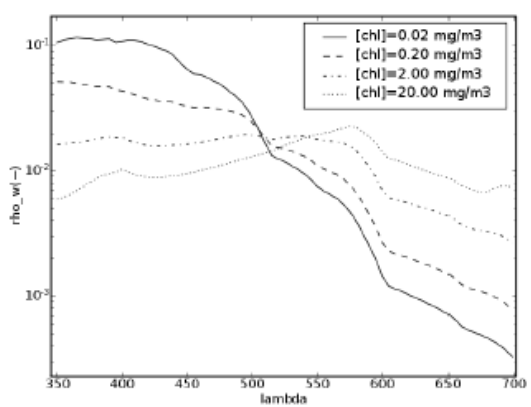
# Polymer model

## Models

- We model the atmosphere + sun glint signal by a polynomial:

$$\underbrace{c_0}_{\substack{\text{sun glint,}\\ \text{clouds,}\\ \text{foam,}\\ \text{aerosols}\\ \text{(coarse mode)}}} + \underbrace{c_1\lambda^{-1}}_{\substack{\text{aerosols}\\ \text{(fine mode)}}} + \underbrace{c_2\lambda^{-4}}_{\text{couplings}}$$

- Water reflectance $\rho_w(\lambda)$: based on Morel and Maritorena (2001). Parameters used:
  - Chlorophyll concentration [chl]
  - Suspended matter backscattering coefficient $Bb_s$




- 5 parameters are finally retrieved

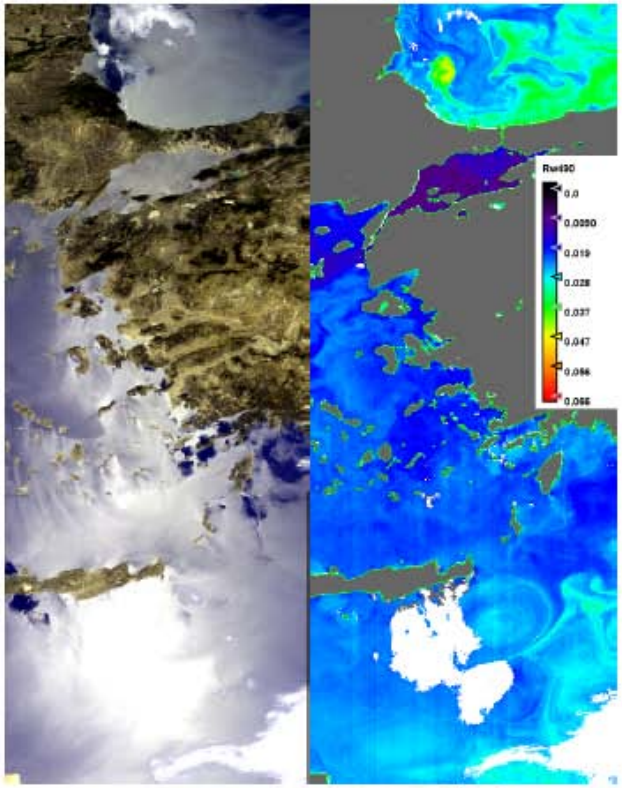
Courtey of F. Steinmetz, Hygeos

# Polymer results

## Example of sun glint correction

Comparison of 2 scenes taken one day apart

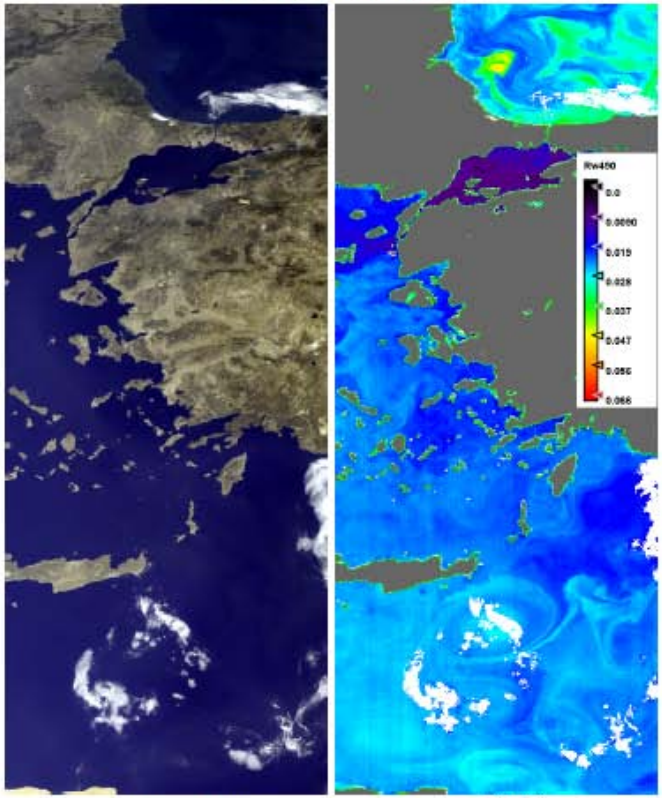
*With sun glint*



RGB composite $\rho_w^+(490)$

May 14, 2007

*Without sun glint*



RGB composite $\rho_w^+(490)$

May 15, 2007

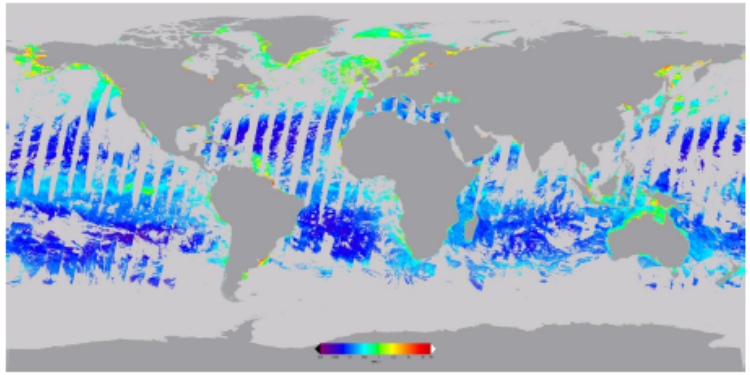
HYGEOS

Workshop on atmospheric correction over turbid waters, Wimereux, 13-14 June 2012

Courtey of F. Steinmetz, Hygeos

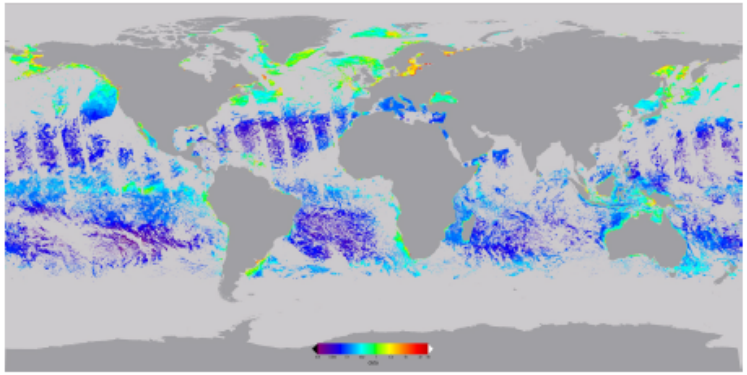
# Polymer: increase of global coverage

## Global coverage increase (Level 3)



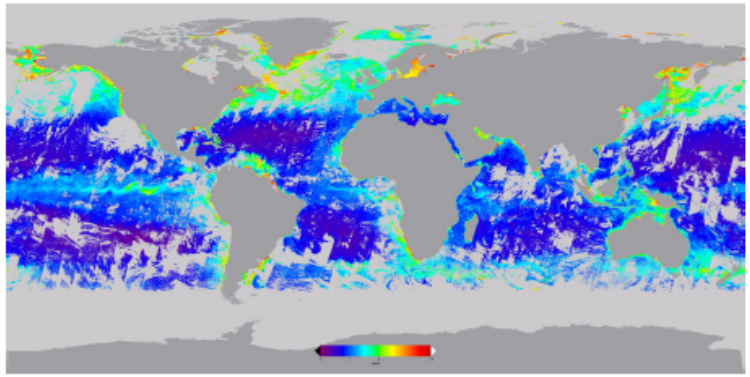
MERIS [chl] MEGS 7.4

(masks HIGH_GLINT, ABSOA_DUST, PCD_1_13)



MODIS [chl]

(3 daily level 3 from OC Web)



POLYMER [chl]

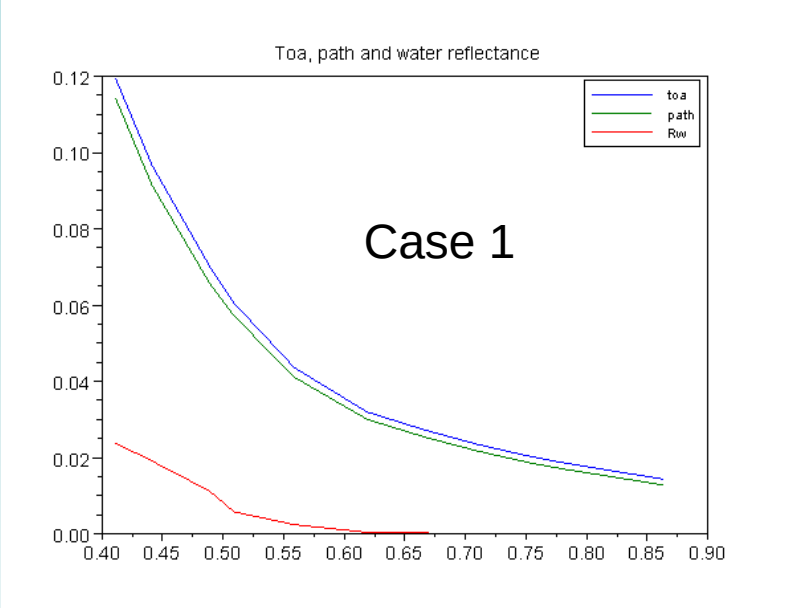
(with POLYMER cloud mask)

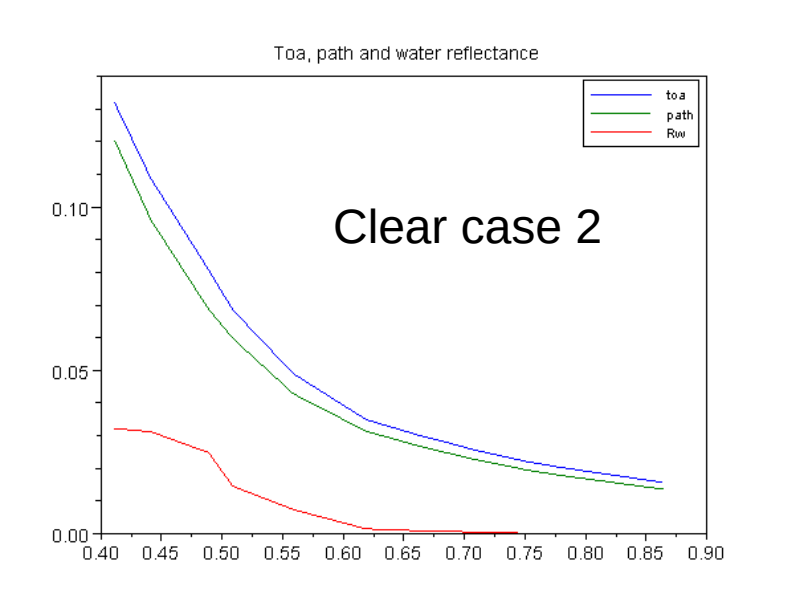
3 days composite
June 3-5, 2003

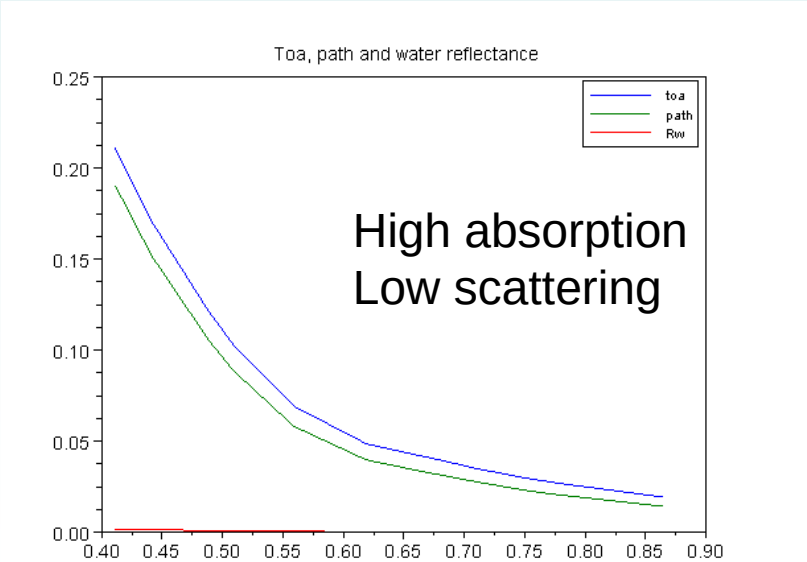
Coverage increase with respect to standard product: about a factor 2

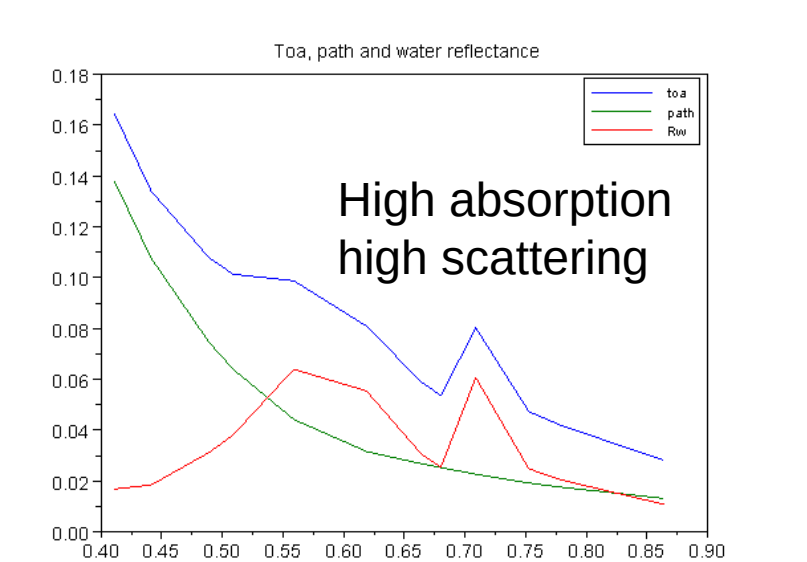
Courtey of F. Steinmetz, Hygeos

# Case 2 water reflectance spectra (simulations)



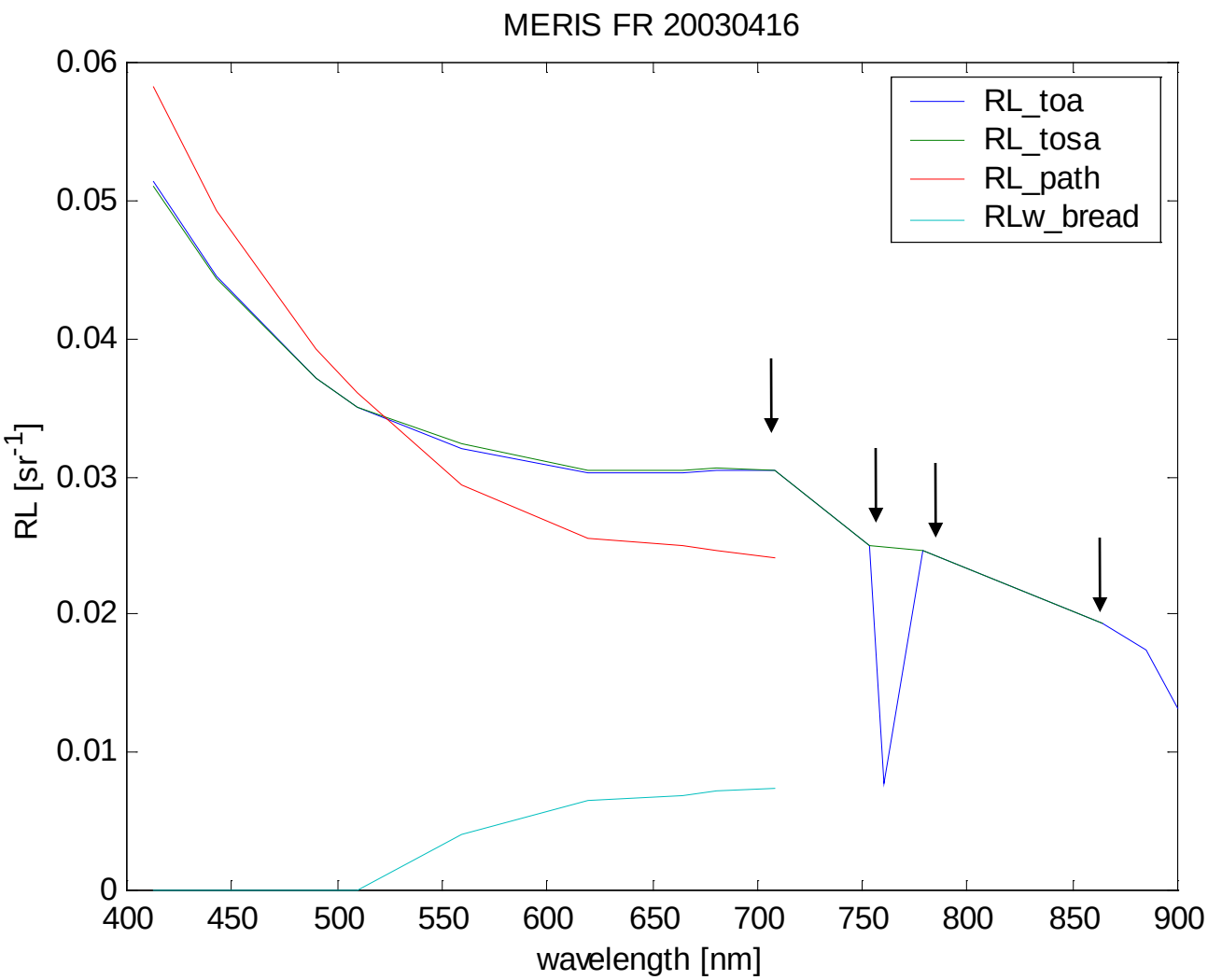



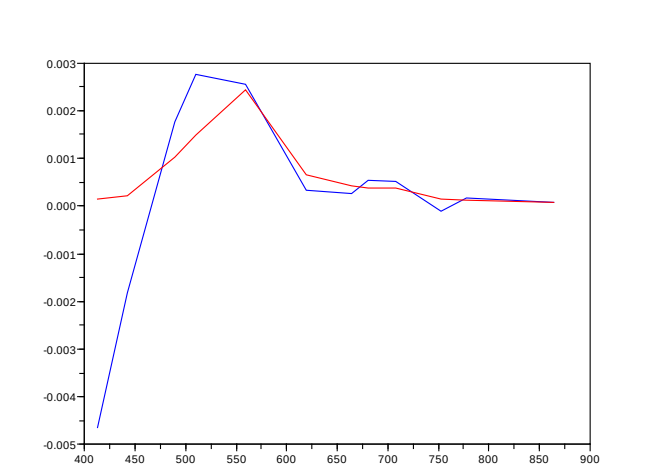

R. Doerffer

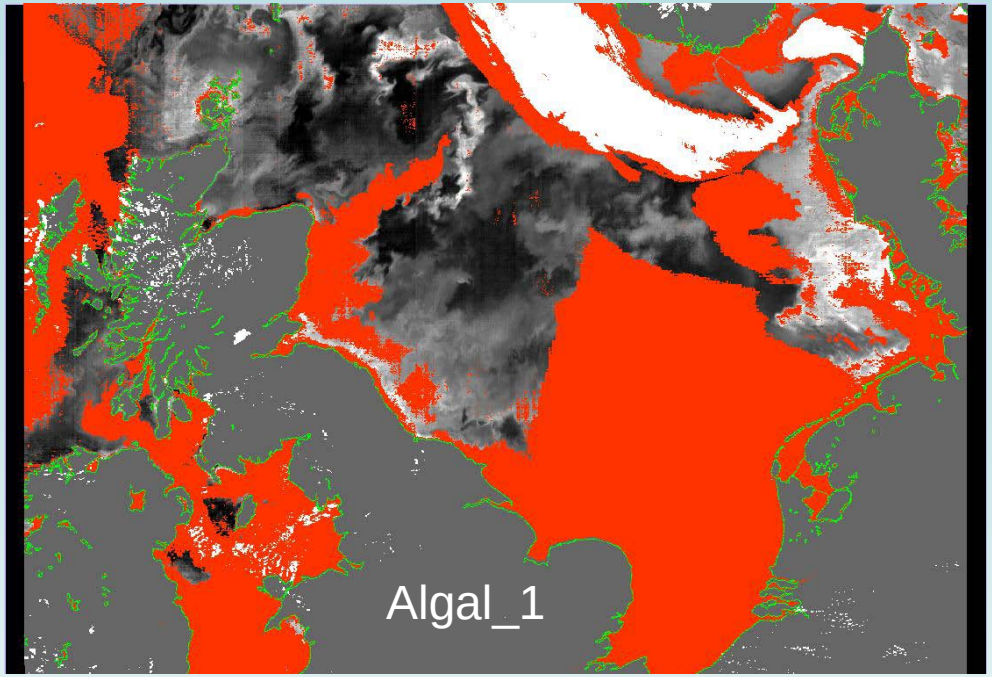
# Strange Spectra producing negative reflectances

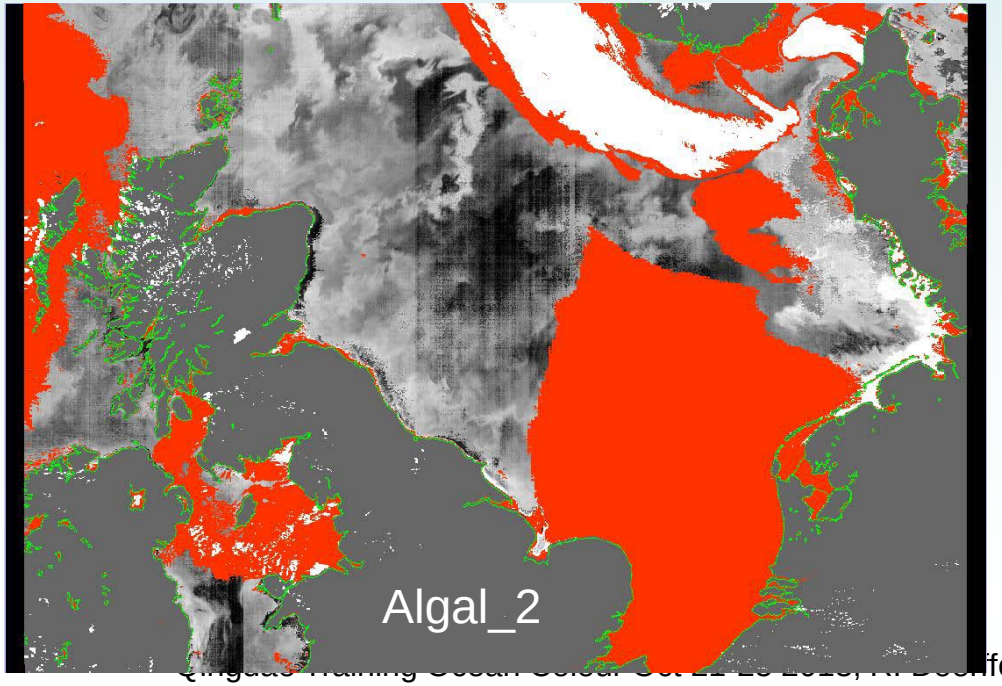


# Main Problems

- Atmospheric correction often not sufficient for all 9 bands
- Partly bands 1-2 negativ, or bands 7,8,9 noisy (in case 1 water)

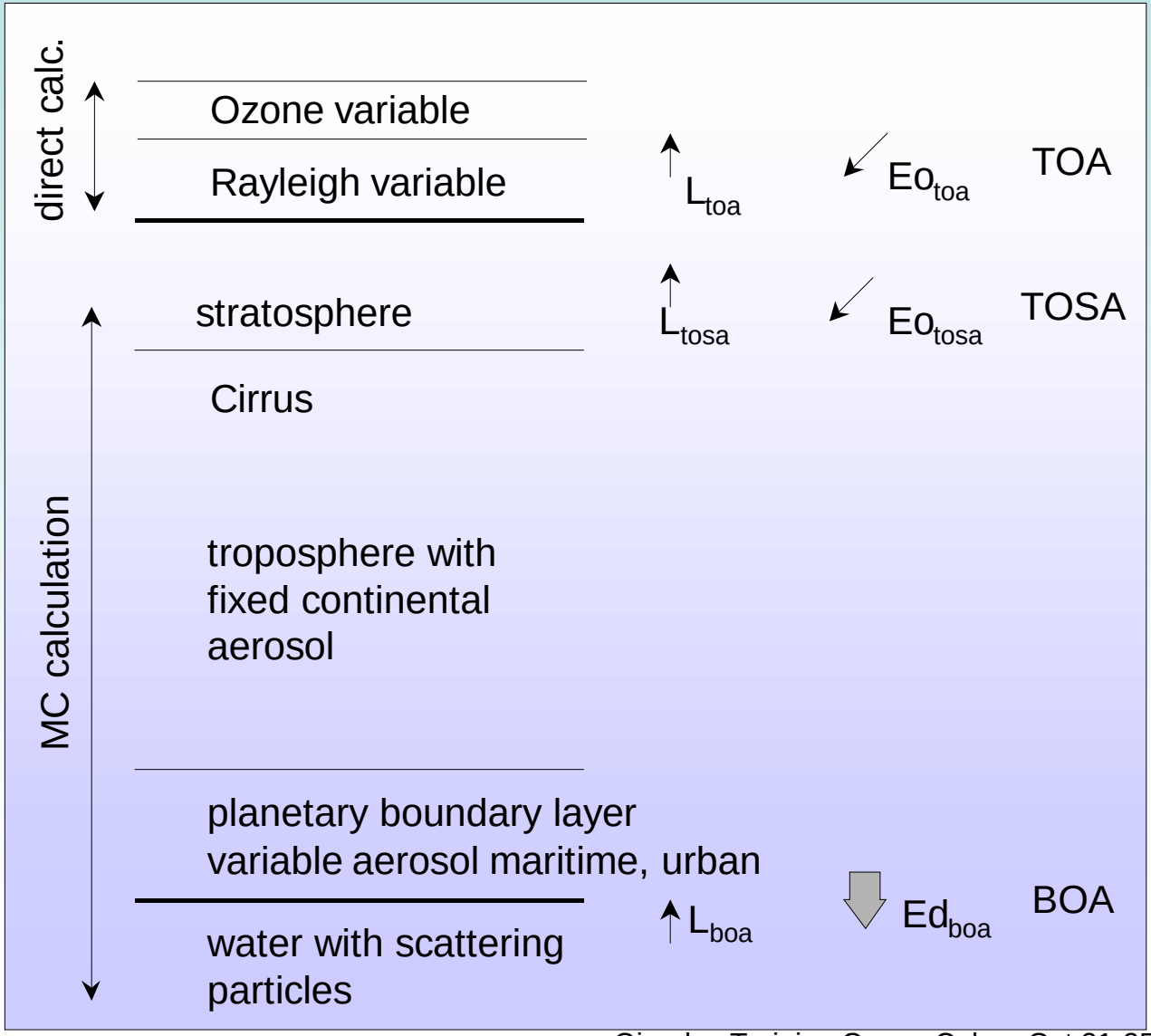


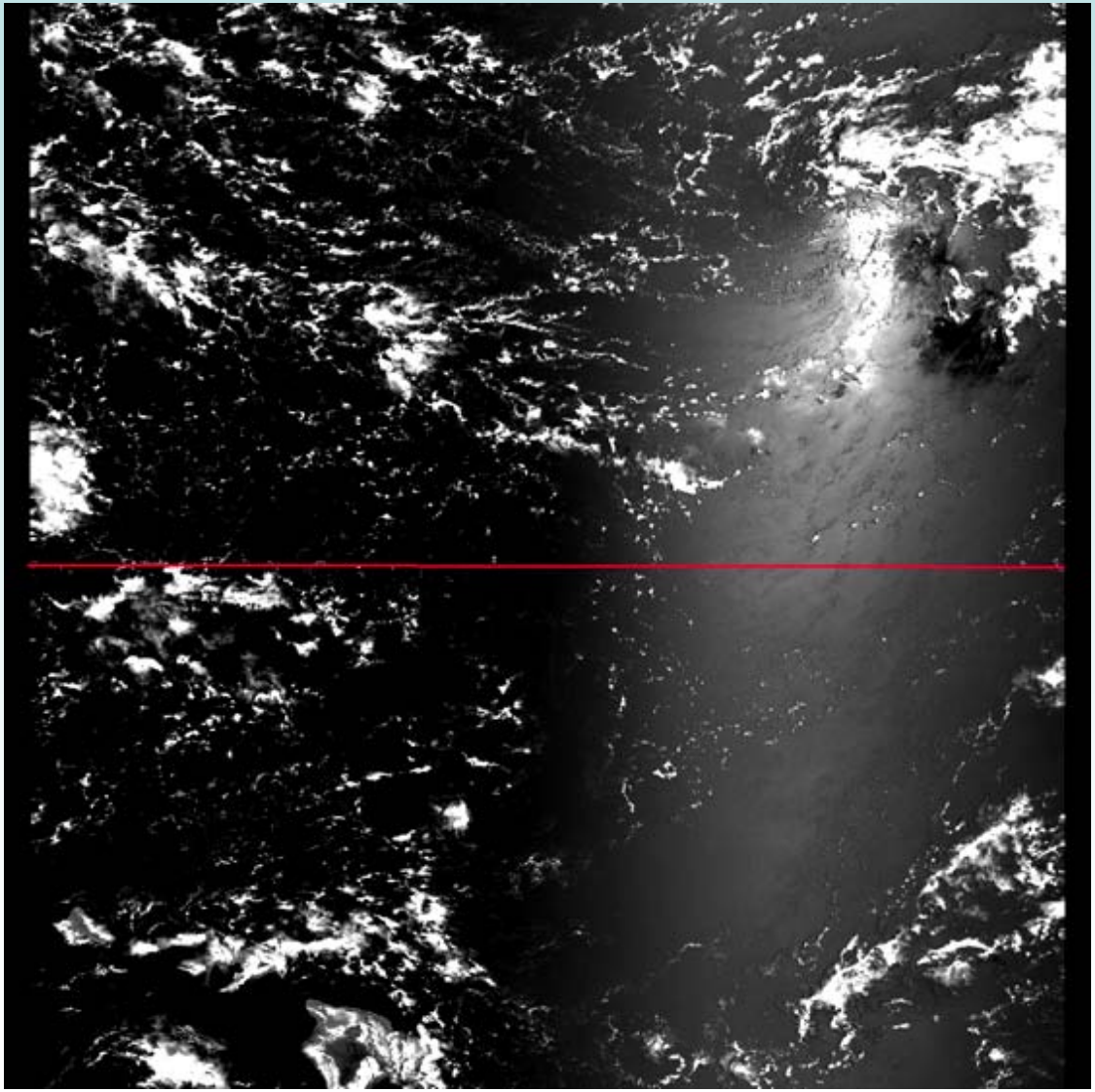



# Design of a Model Atmosphere

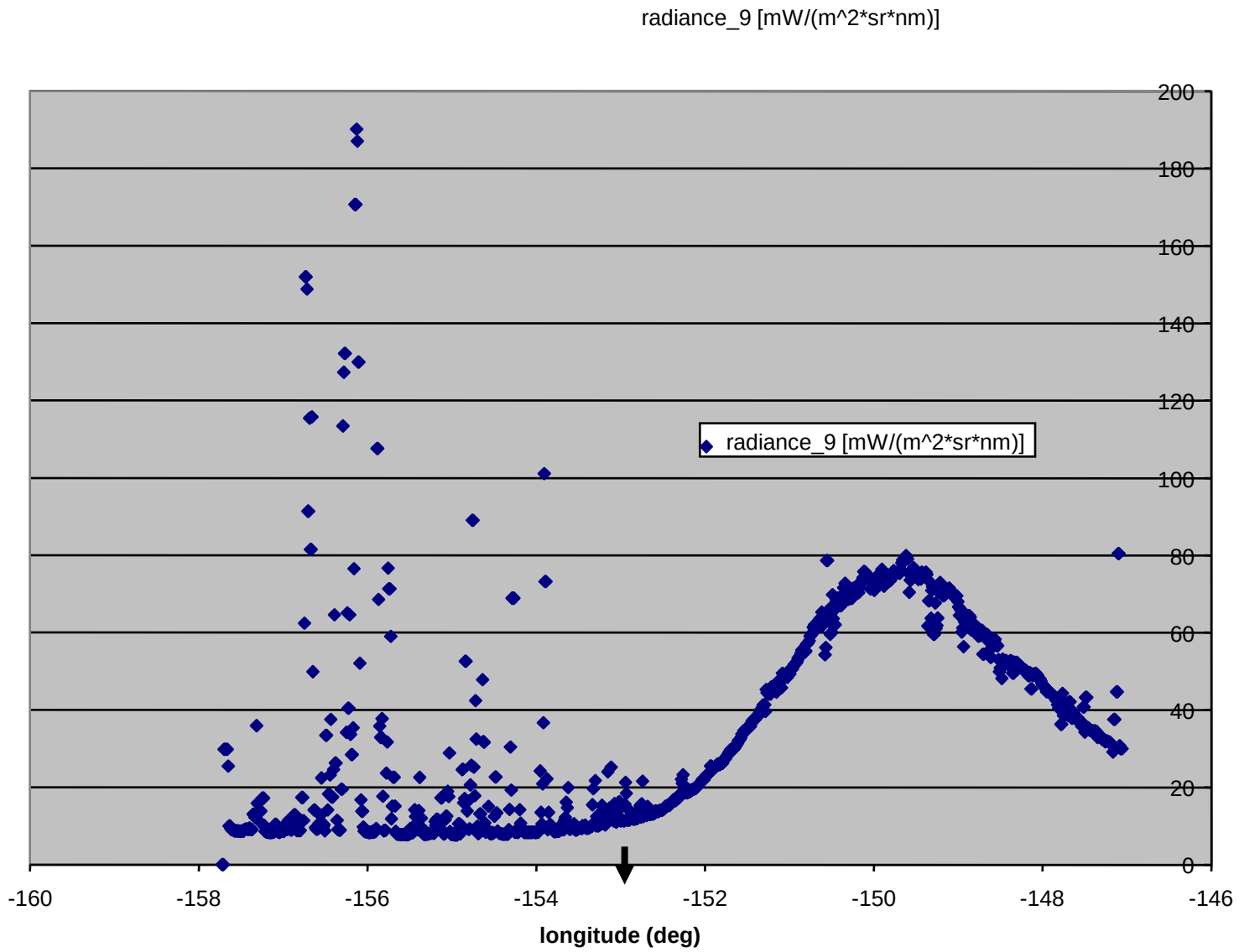
## Model Atmosphere



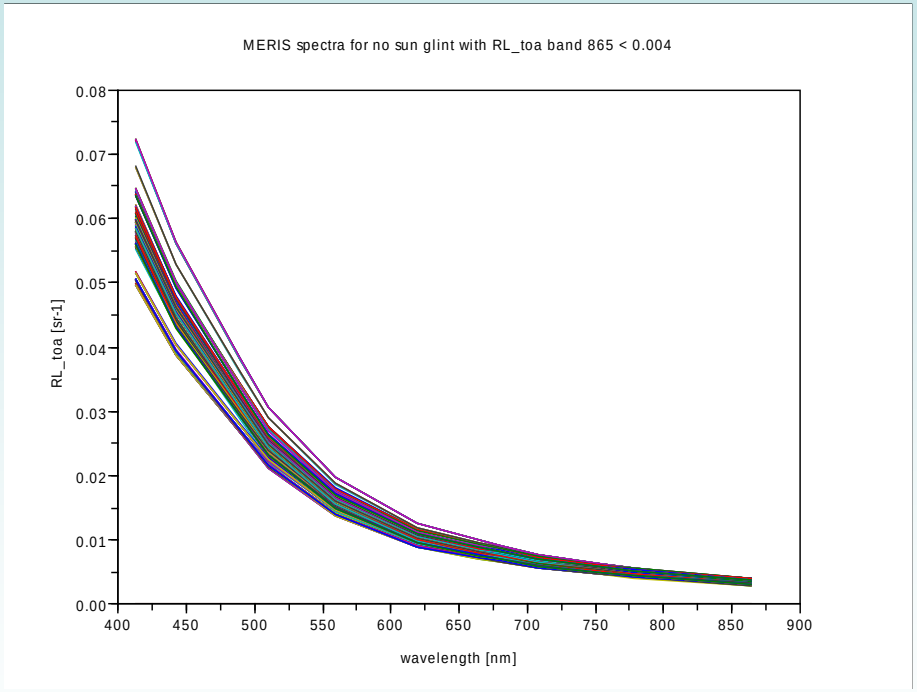
# Sun glint problem: Hawai 20030705

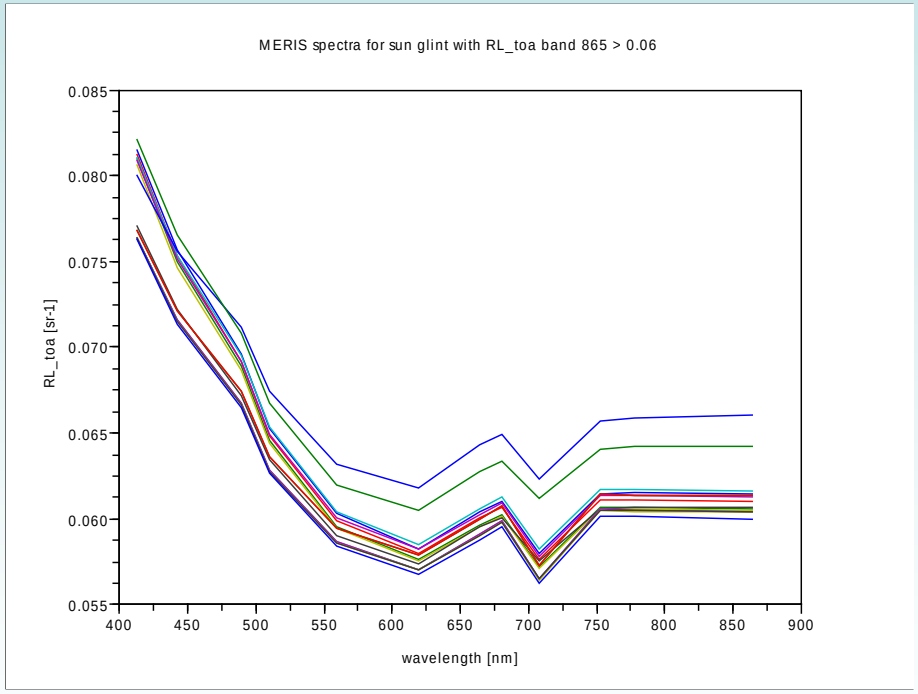


# Cross section Hawai scene

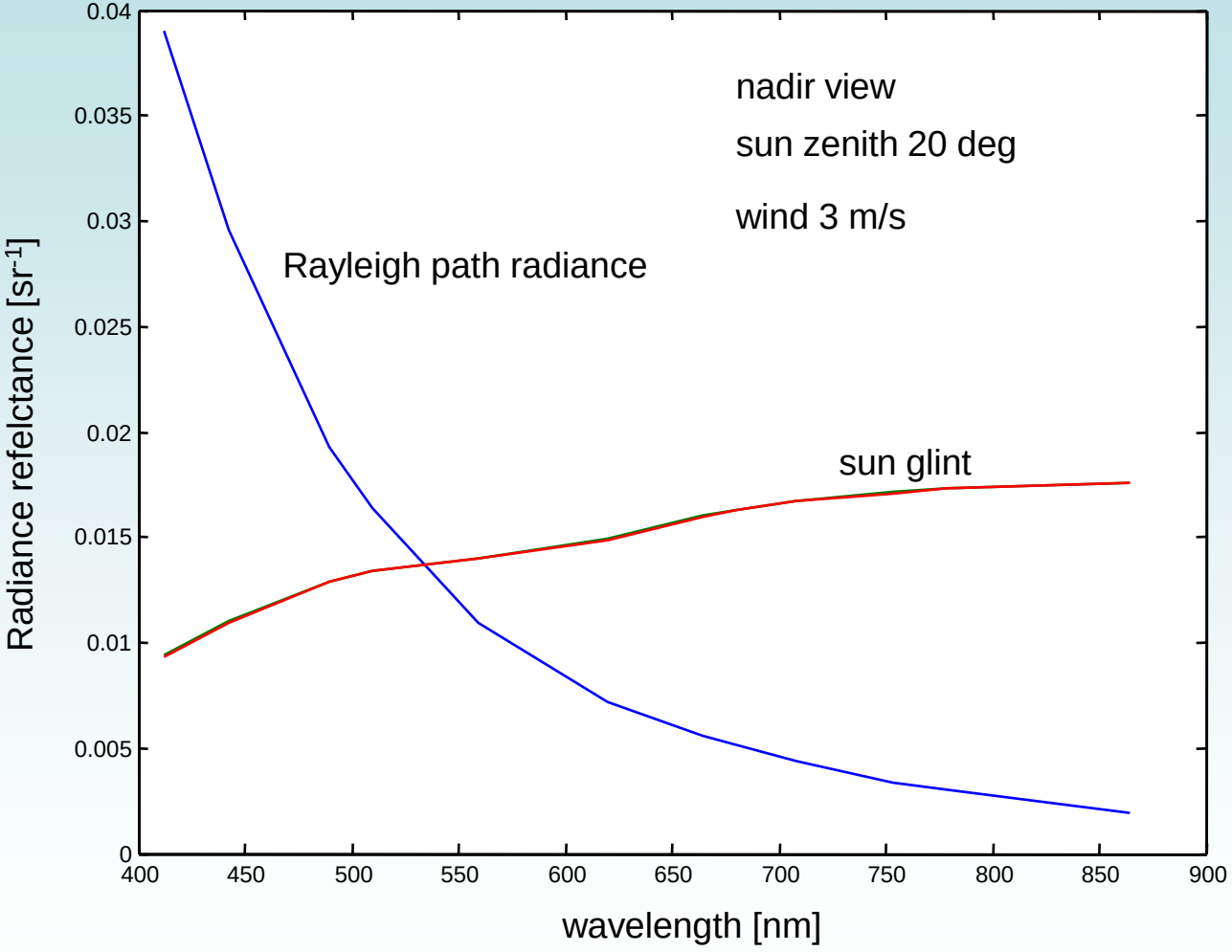


# No glint and high glint TOA reflectance spectra

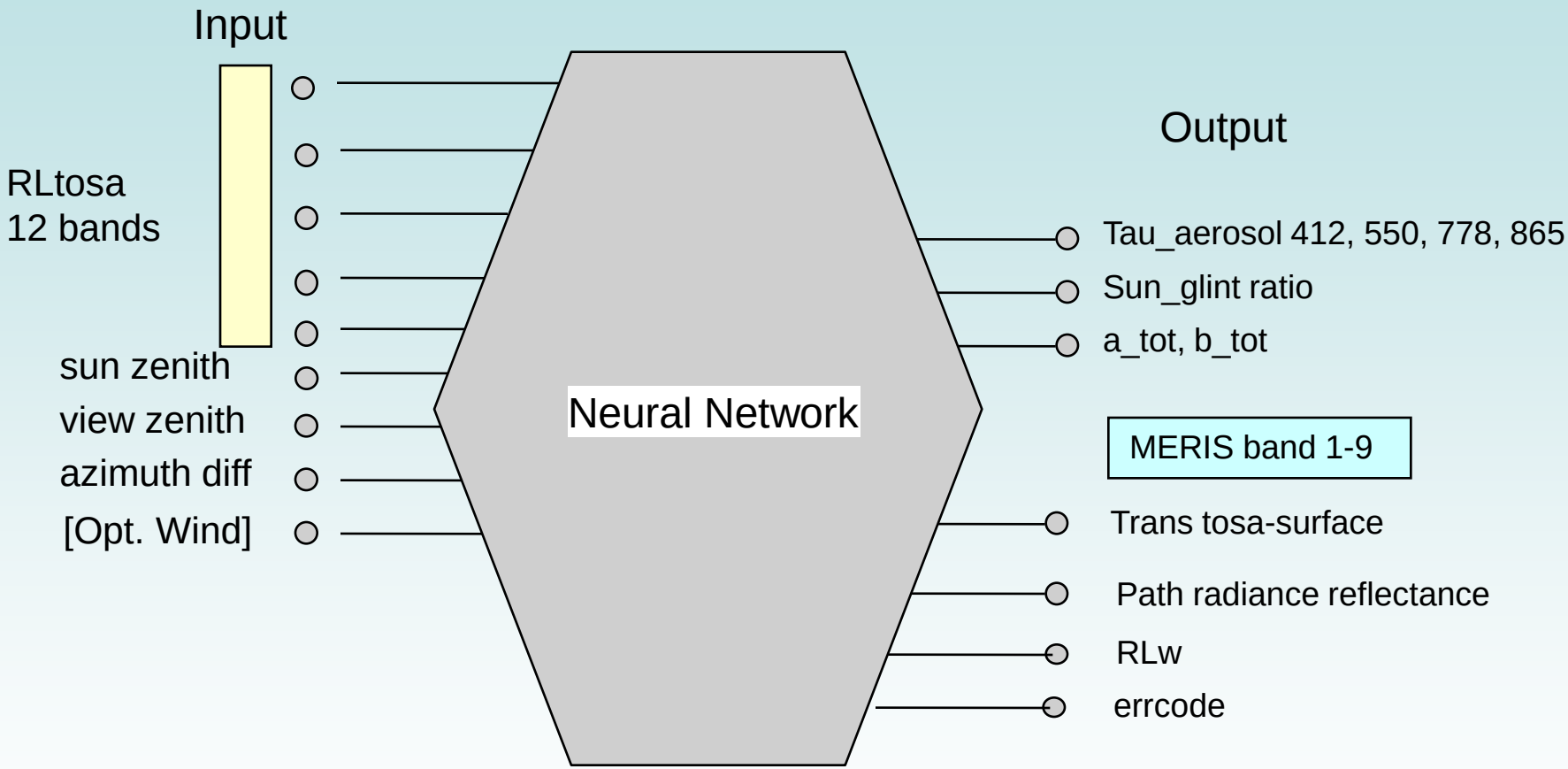


# Simulated Rayleigh path radiance reflectance and sun glint radiance reflectance

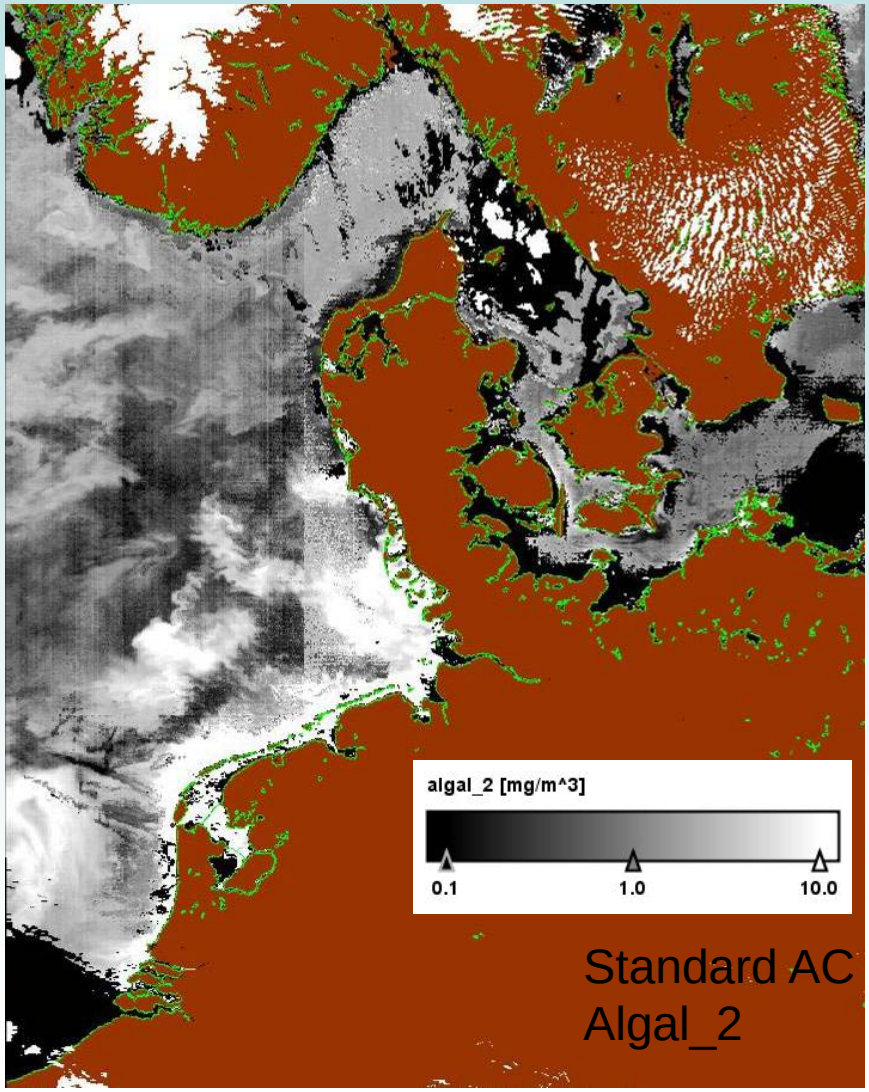


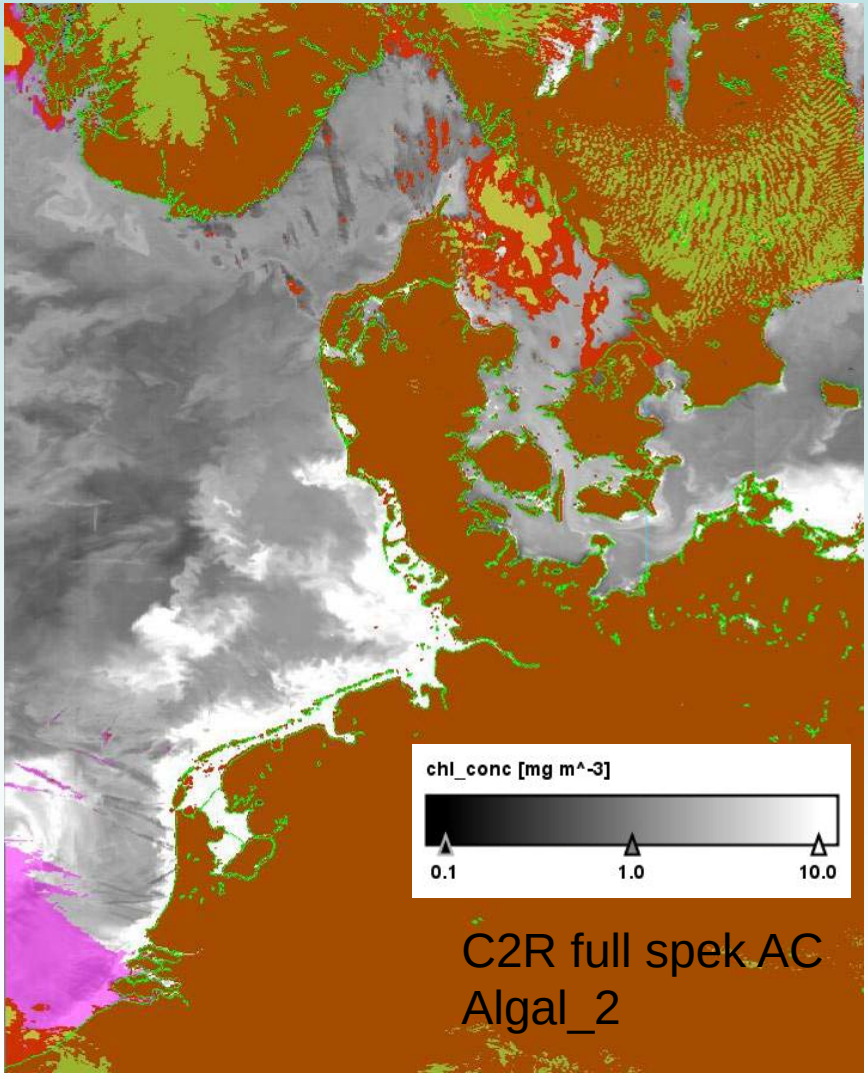
# NN for atmospheric correction - 3rd version in C2R and Glint processor



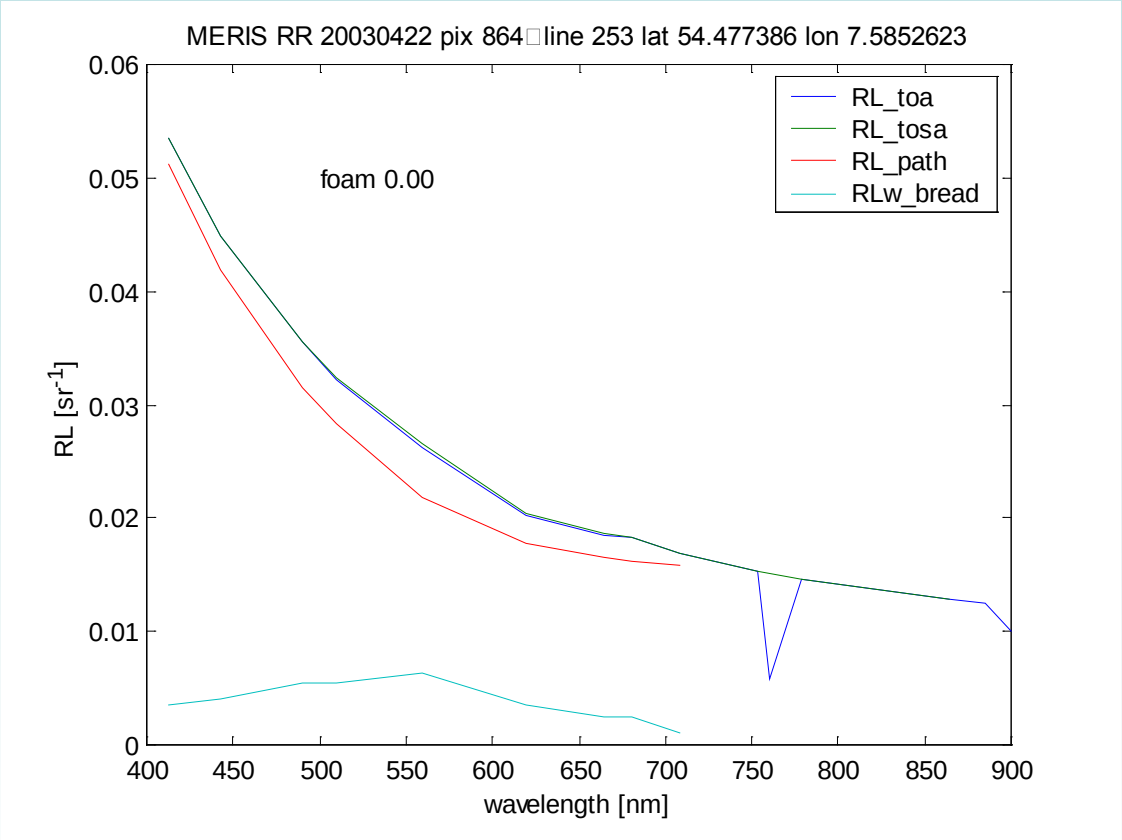

$$RLw(\theta,\phi) = Lw(\theta,\phi) / Ed$$

# MERIS 20070429

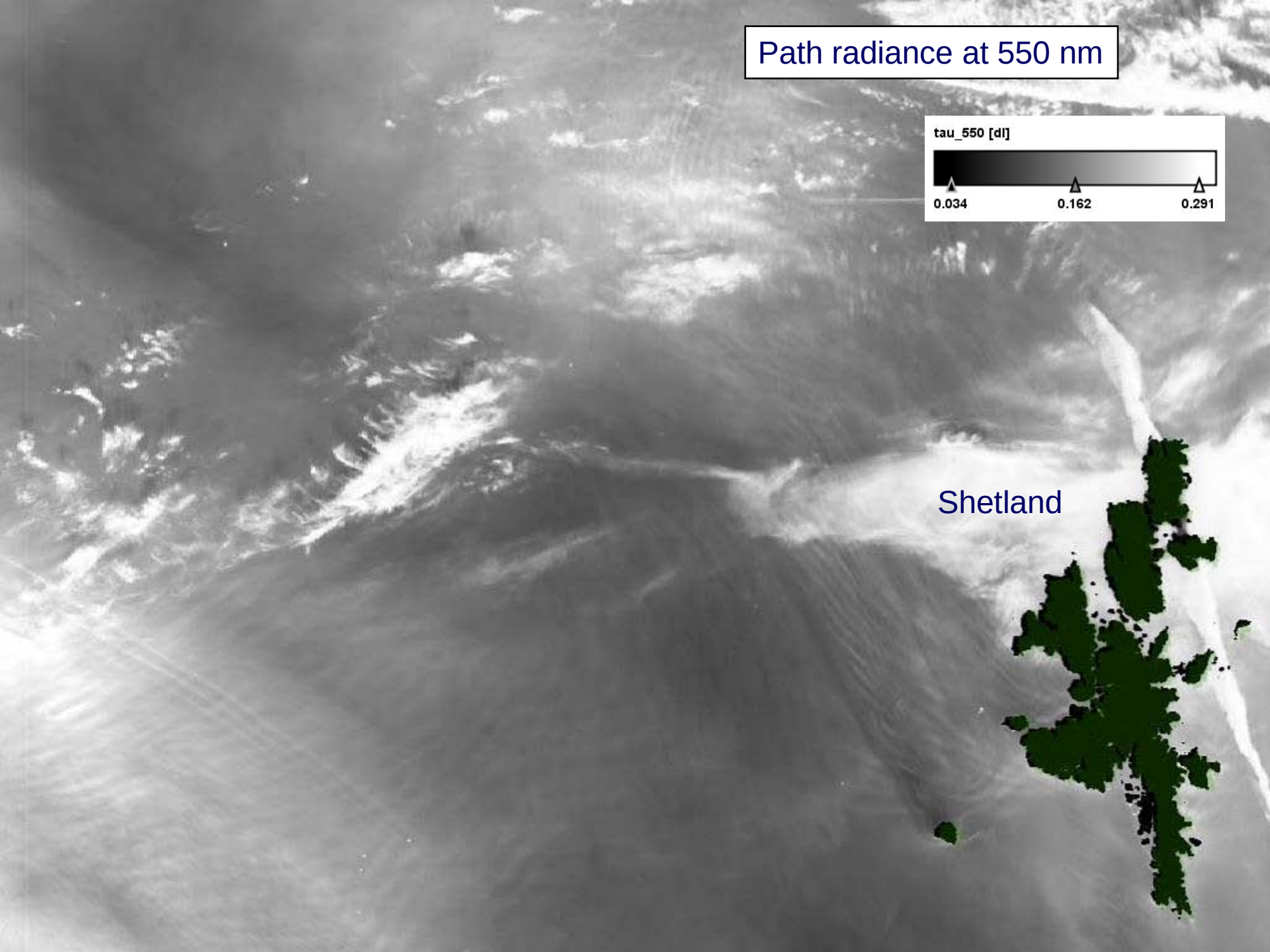


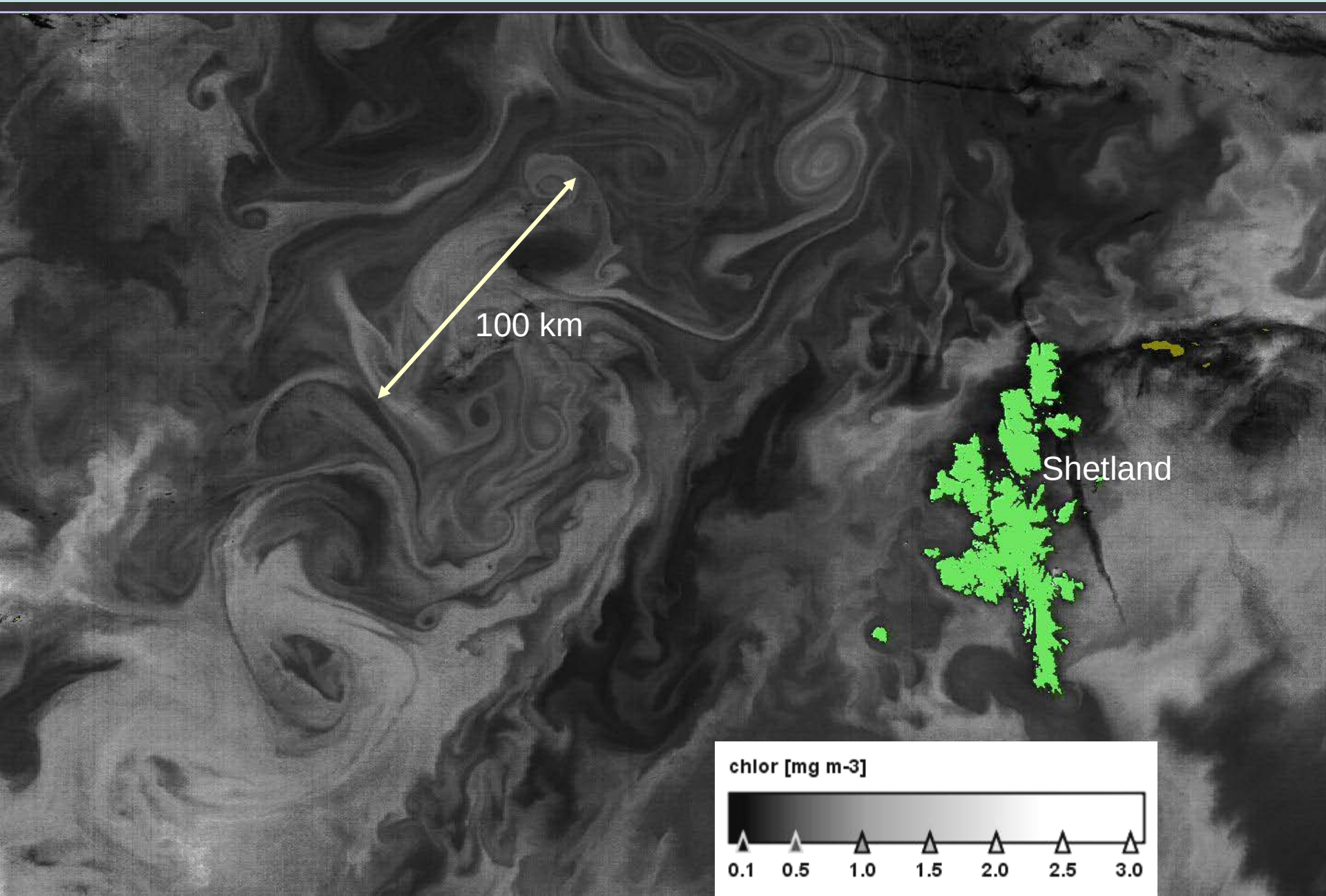
# Radiance reflectance: TOA, path, RLw



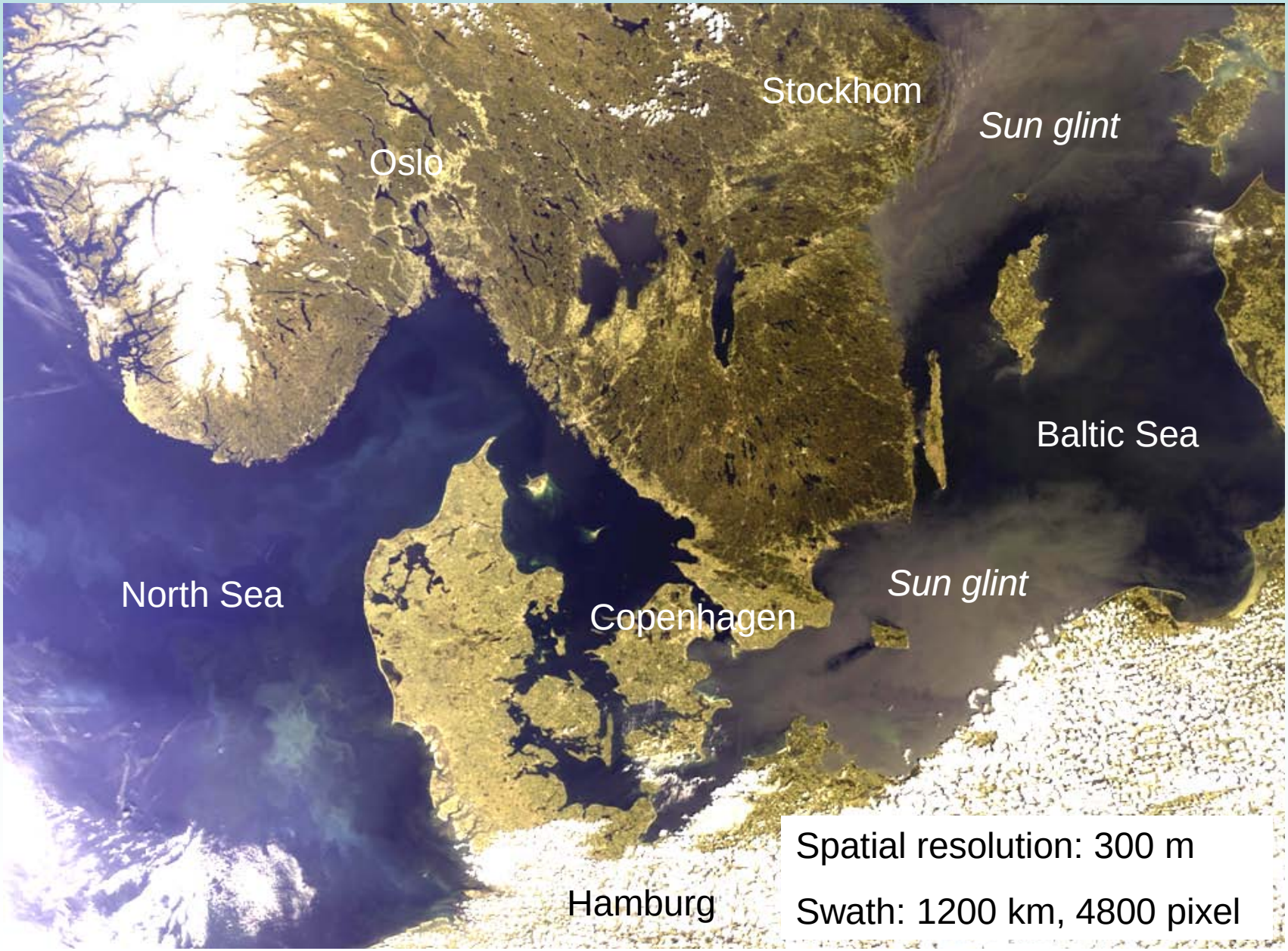

TOA
Radiance reflectance
RLw RGB
Shetland


Path radiance at 550 nm
tau_550 [dl]
0.034
0.162
0.291
Shetland

# C2R Chlorophyll (MERIS FR)



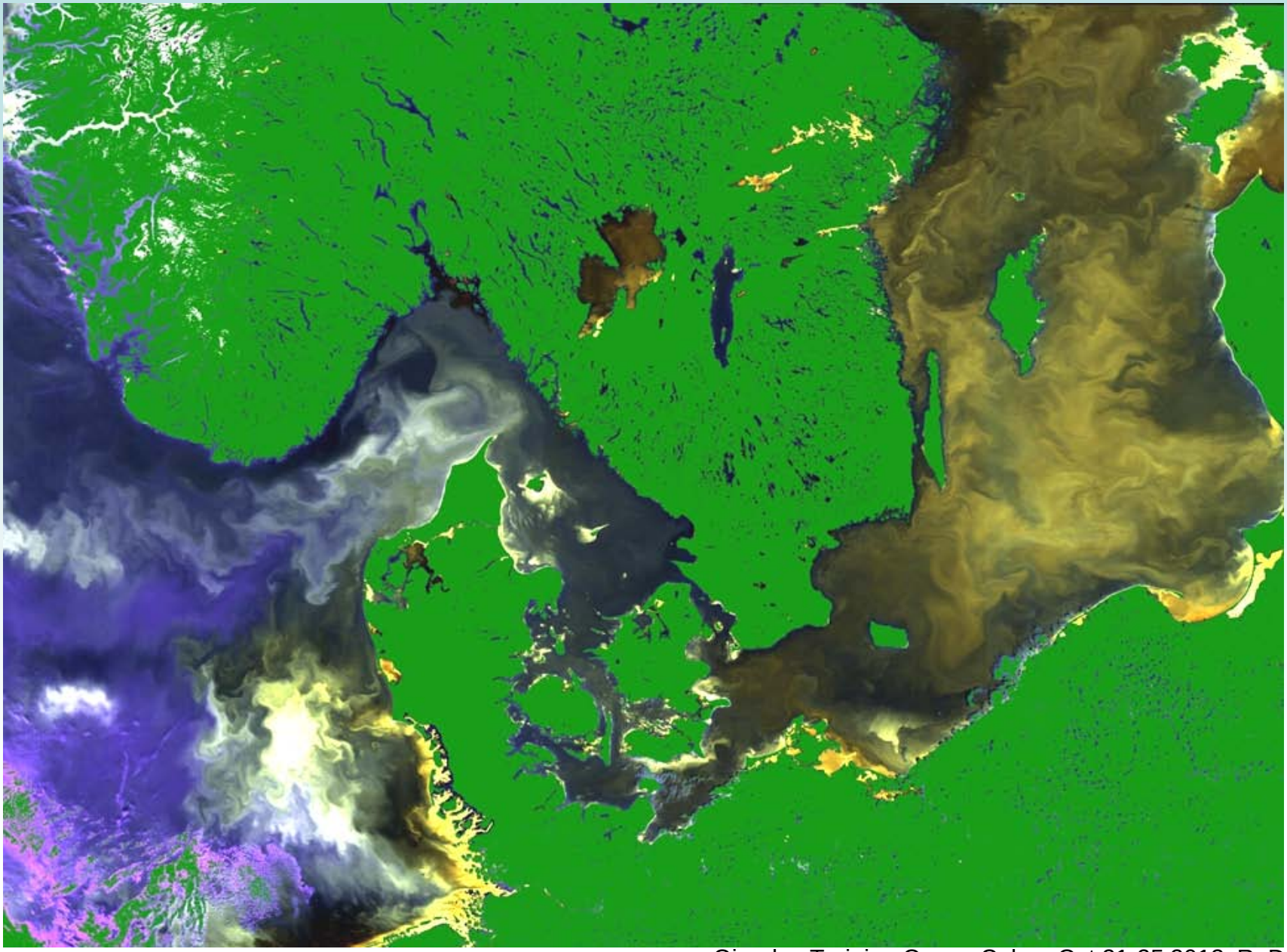
# MERIS full resolution: Baltic and North Sea, 20080606



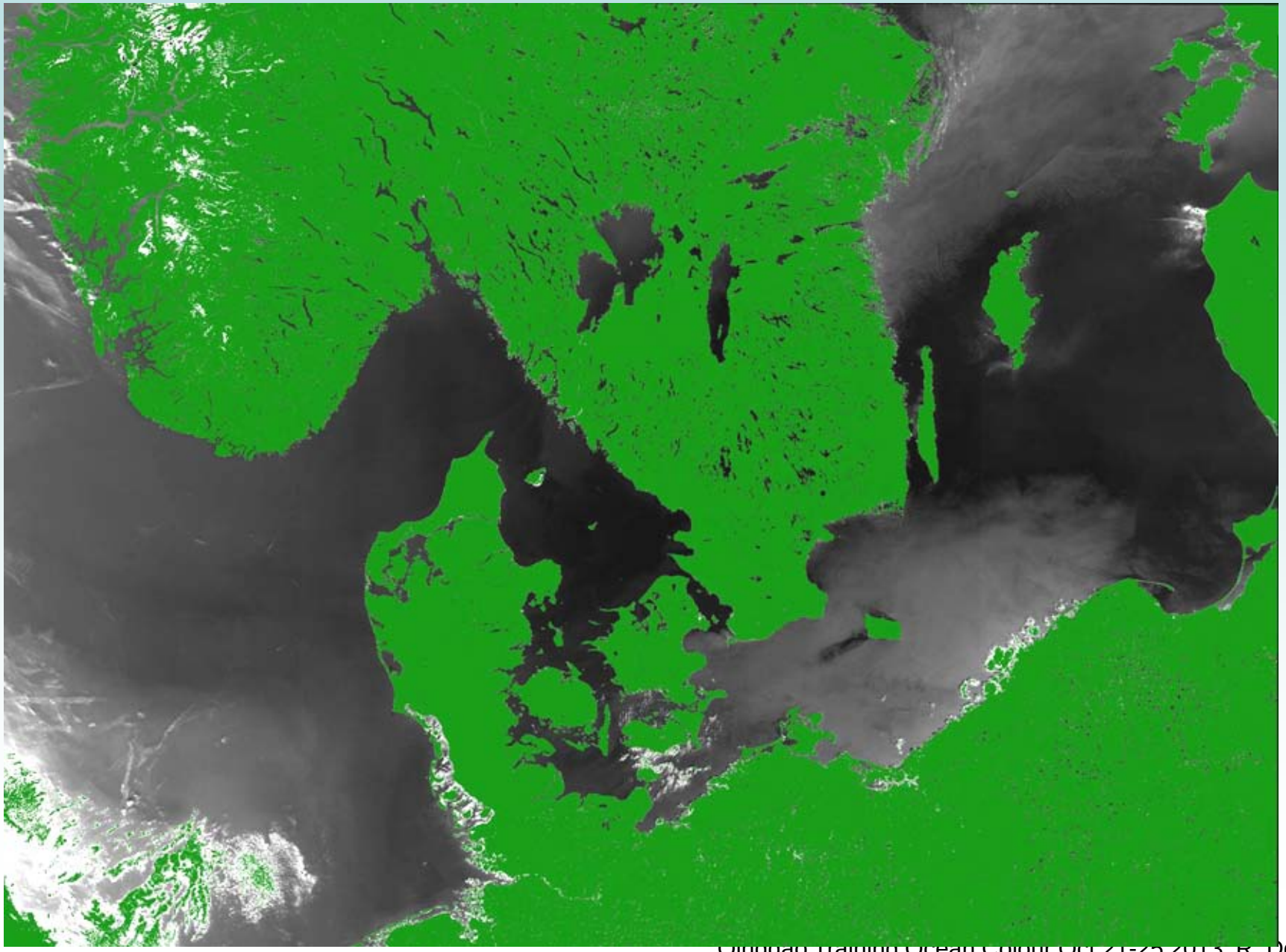

Spatial resolution: 300 m

Swath: 1200 km, 4800 pixel

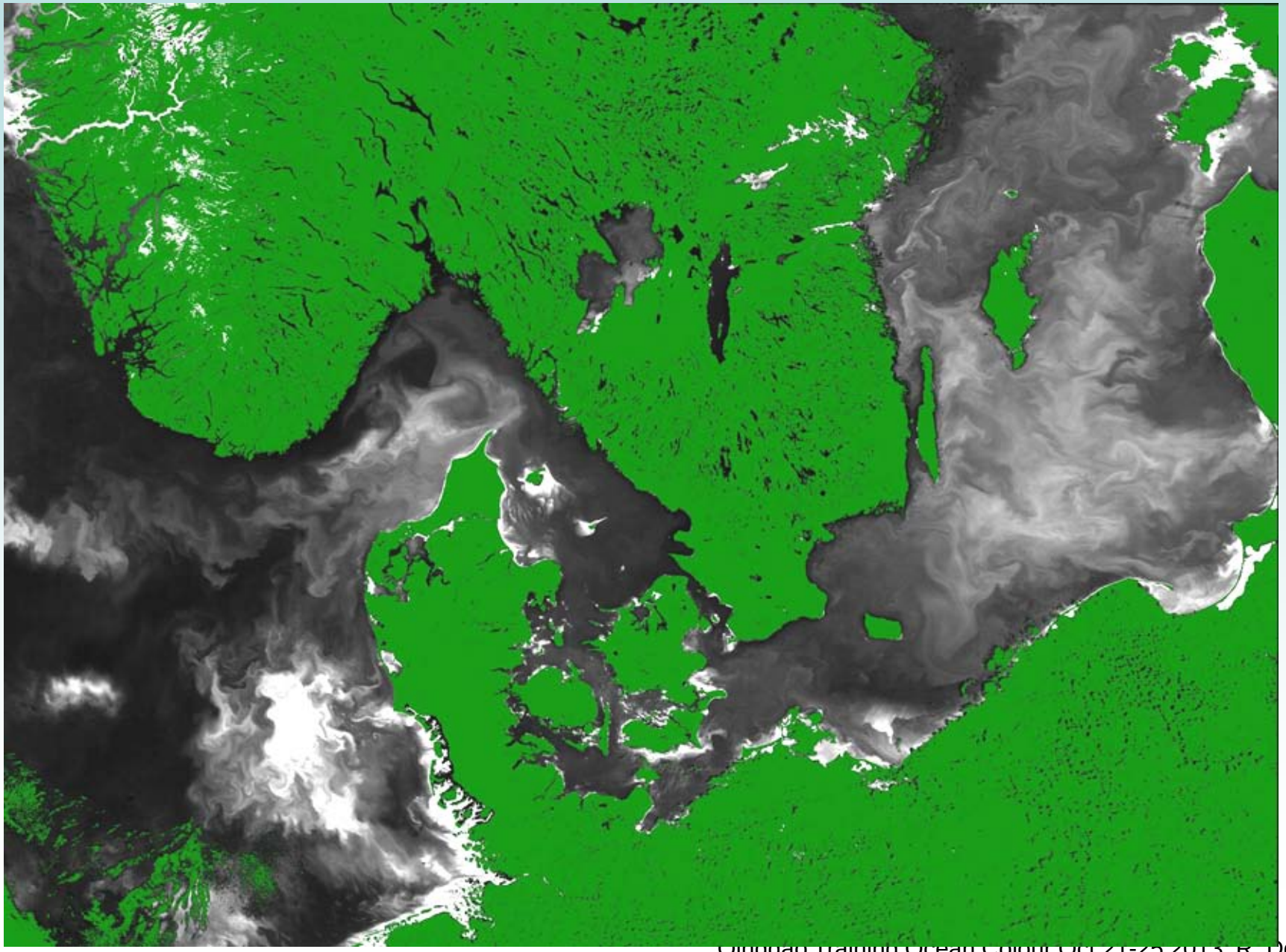
# Water leaving radiance reflectance



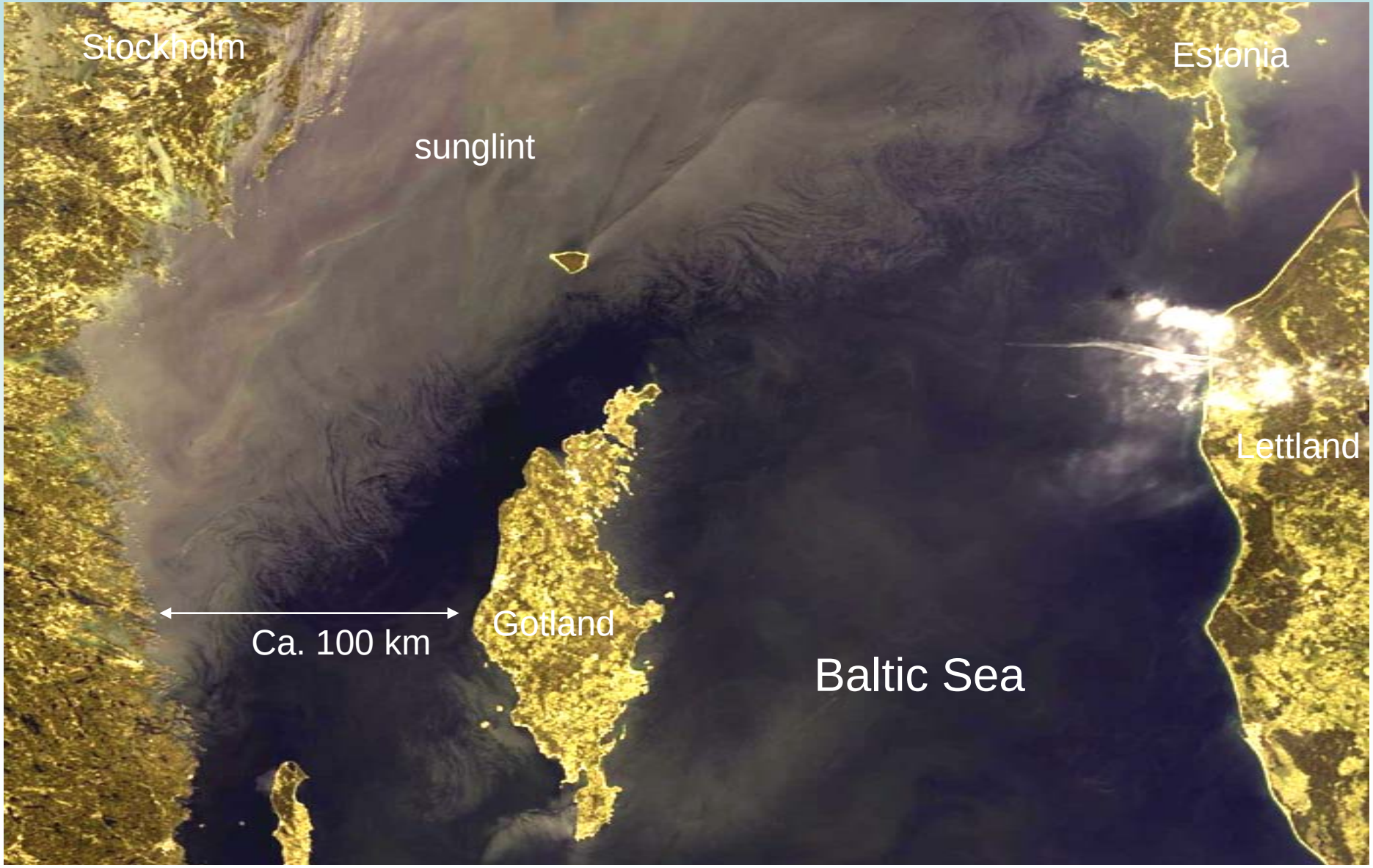
# Path radiance reflectance incl. Sun glint band 5 (560 nm)



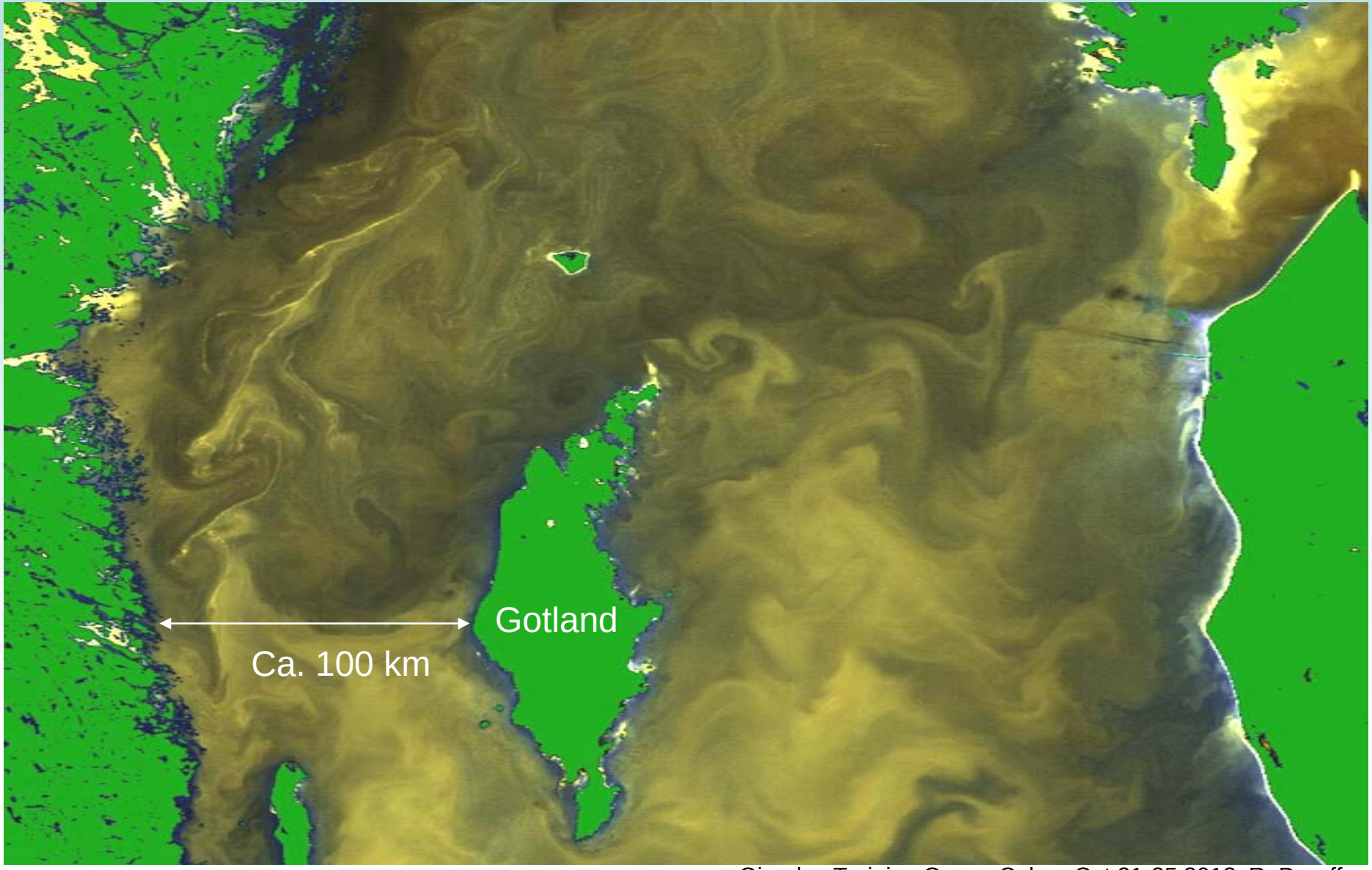
# Water leaving radiance reflectance band 5 (560 nm)



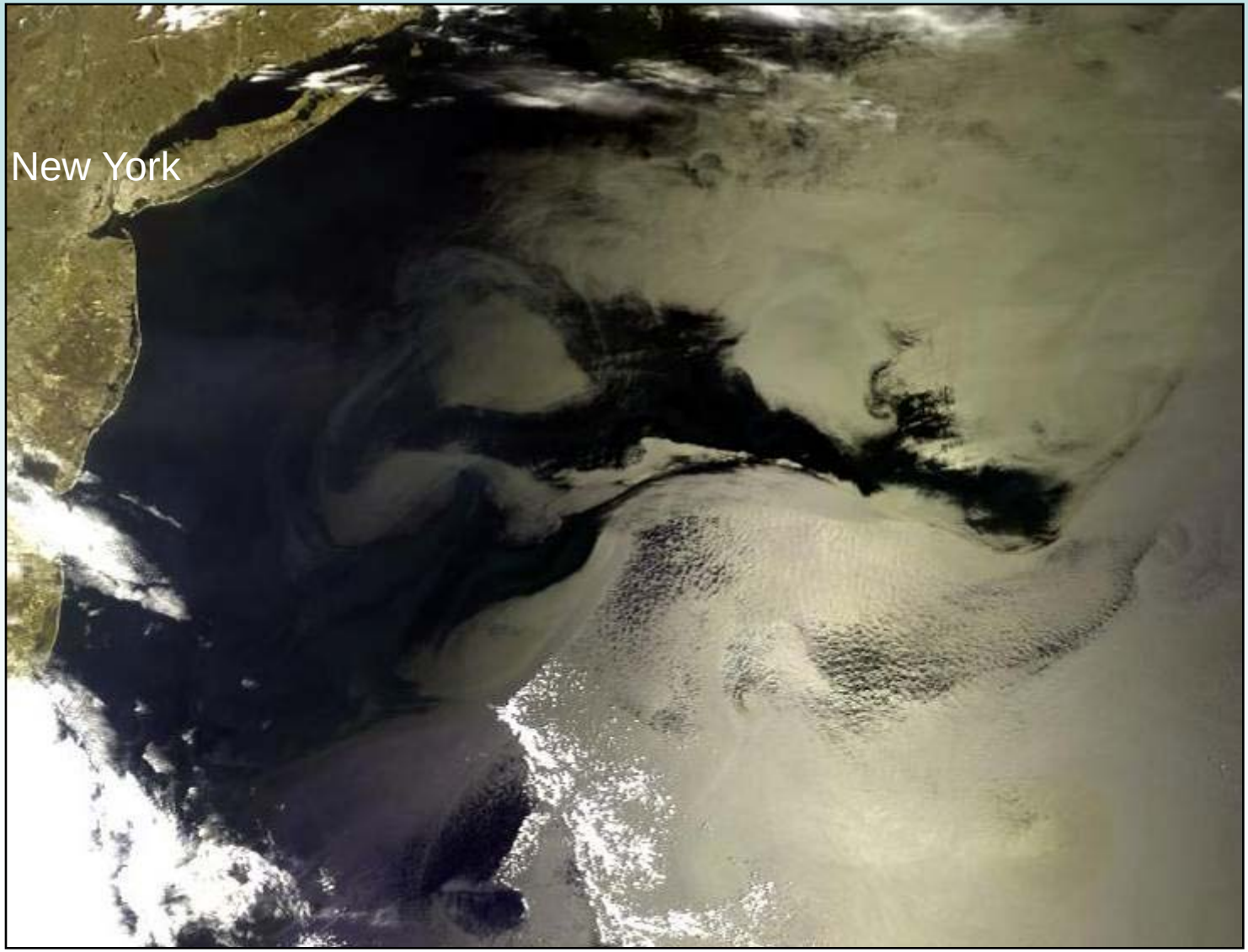
# MERIS FR, Area of Gotland, TOA RLw RGB



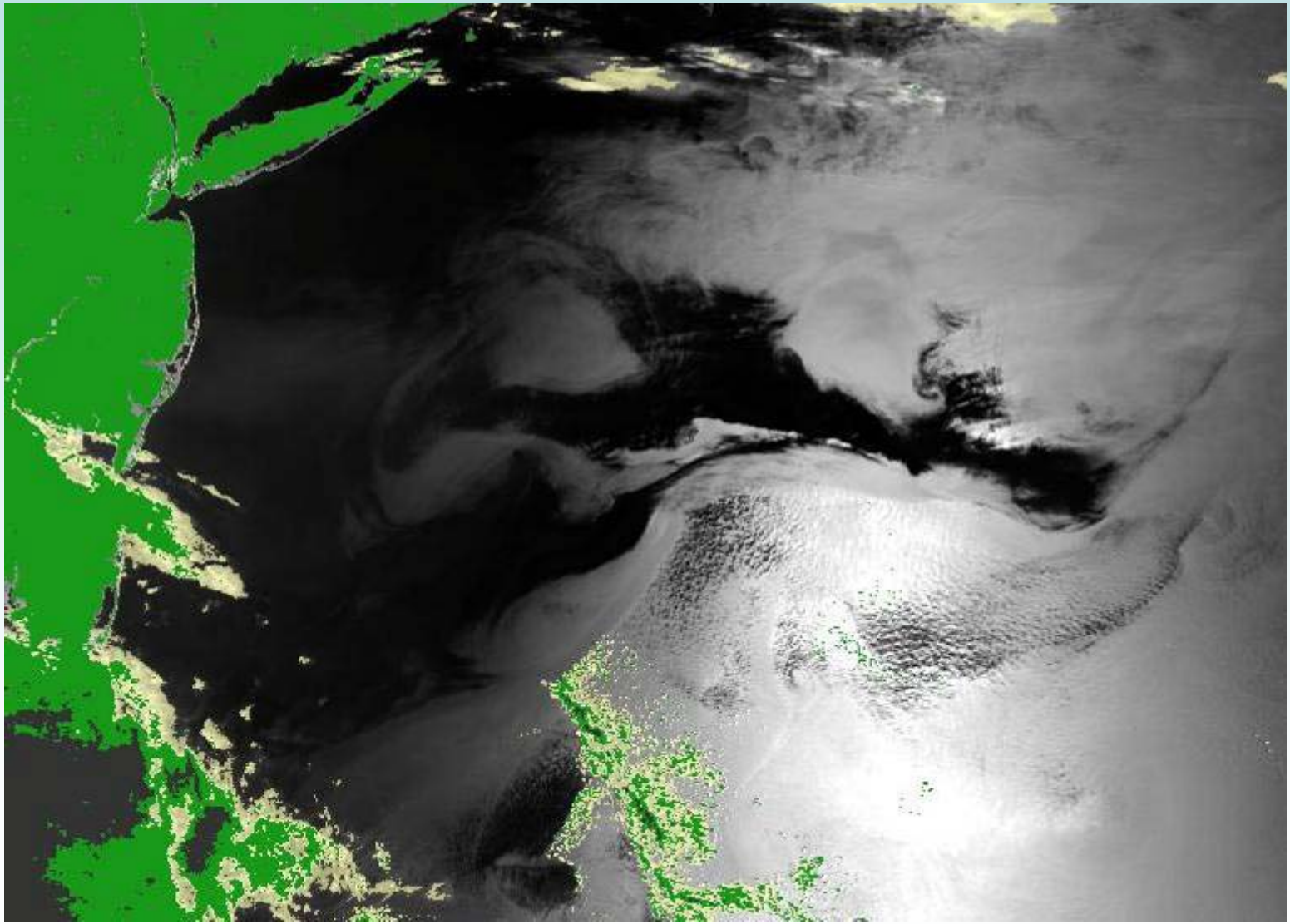
# Water leaving radiance reflectance RGB



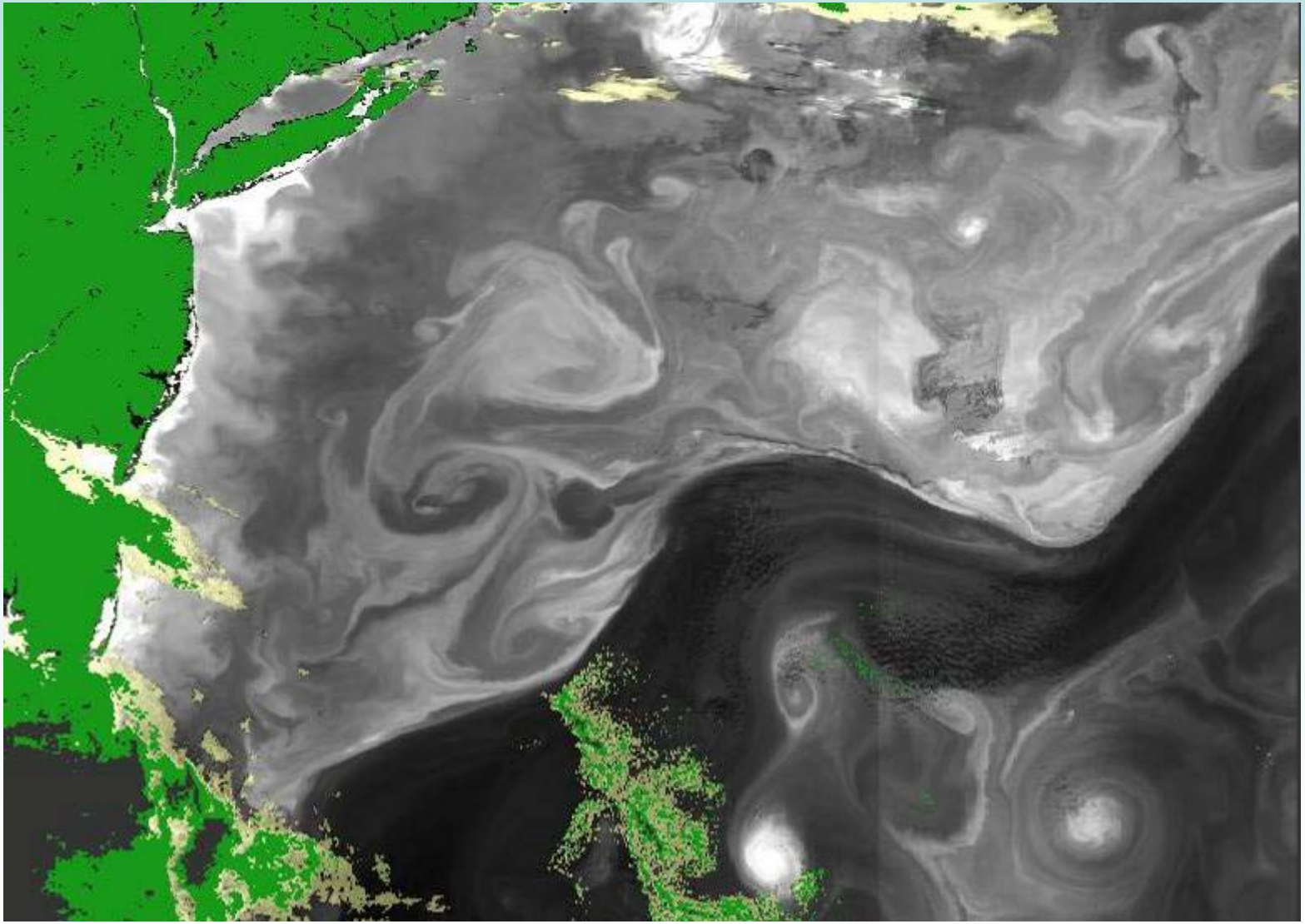
# MERIS 20070505: TOA reflectances RGB



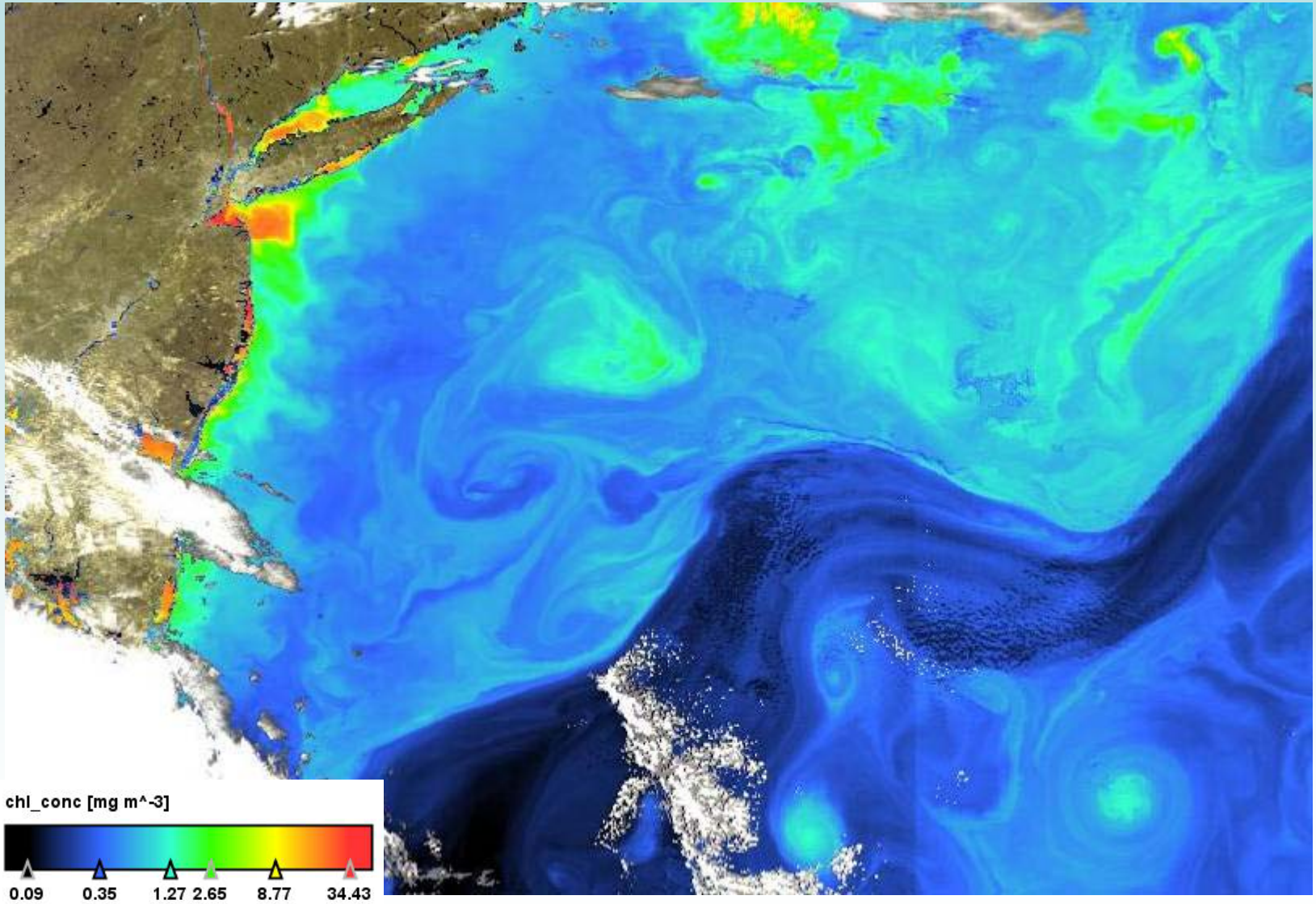
# reflectance RLpath MERIS band 5 (560 nm)



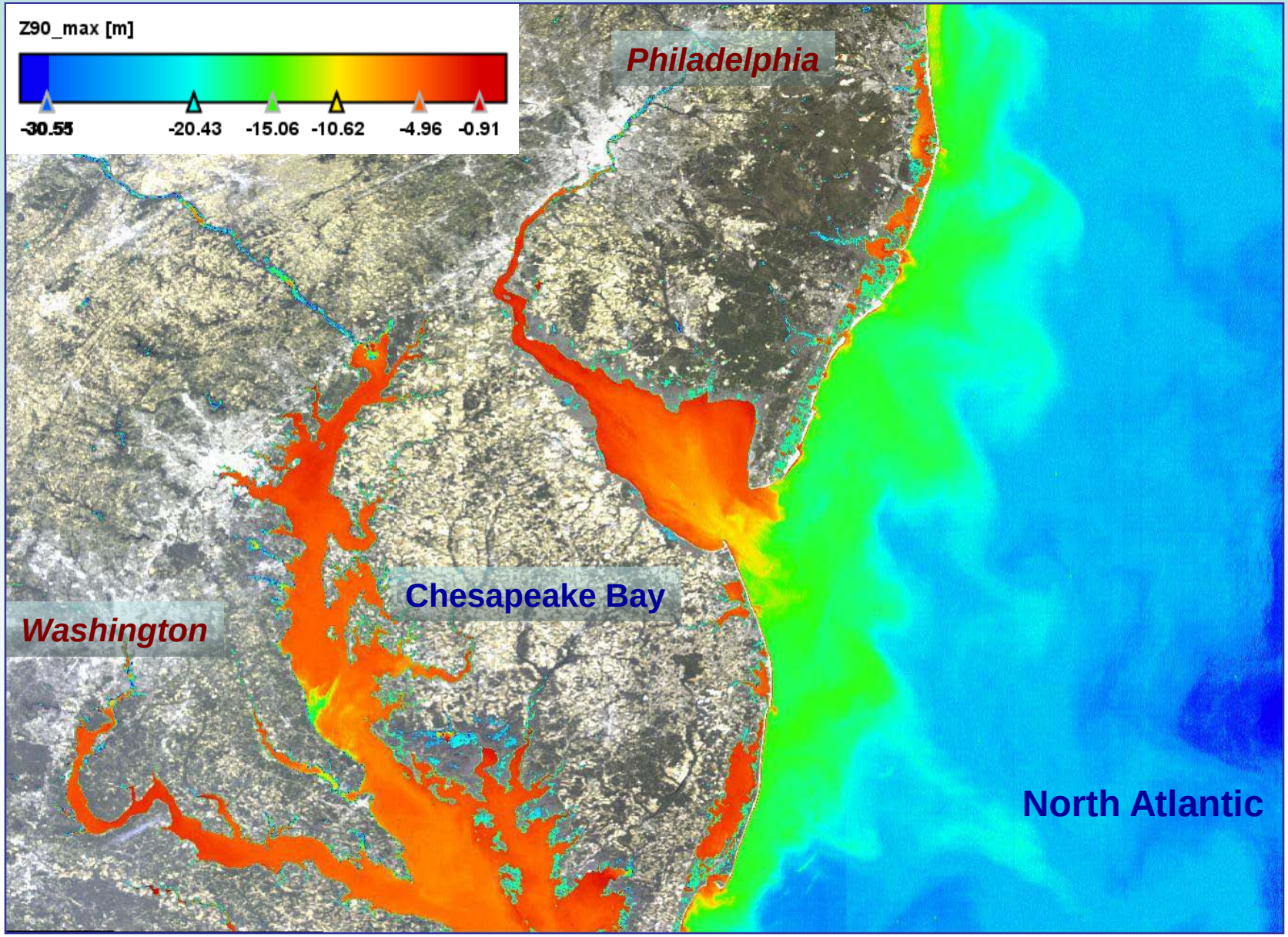
# reflectance RLW MERIS band 5 (560 nm)



# Chlorophyll



# MERIS FR USA East Coast 12.6.2008, Signal depth z90



# Summary and Conclusions

- Atmospheric correction is essential for most ocean colour applications
- Small errors in AC may cause large errors in the retrieval of water optical properties
- For case 1 water: standard technique using information from NIR spectral bands is successful
- For turbid water technique must include contribution by scattering of water constituents in NIR spectral range
- For highly absorbing water  AC must include all spectral bands: forward model and optimization or inverse modeling using neural network
- Correction of sun glint requires also all spectral bands, 2 methods:
  - Neural network
  - Forward model like polymer
- The adjacency effect can be corrected also for standard methods (less necessary for NN and polymer)
- Open issues:
  - Cloud contamination (thin clouds, sub-pixel clouds)
  - Correction of cloud shadows