MERIS US Workshop

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MERIS Level 2 processing

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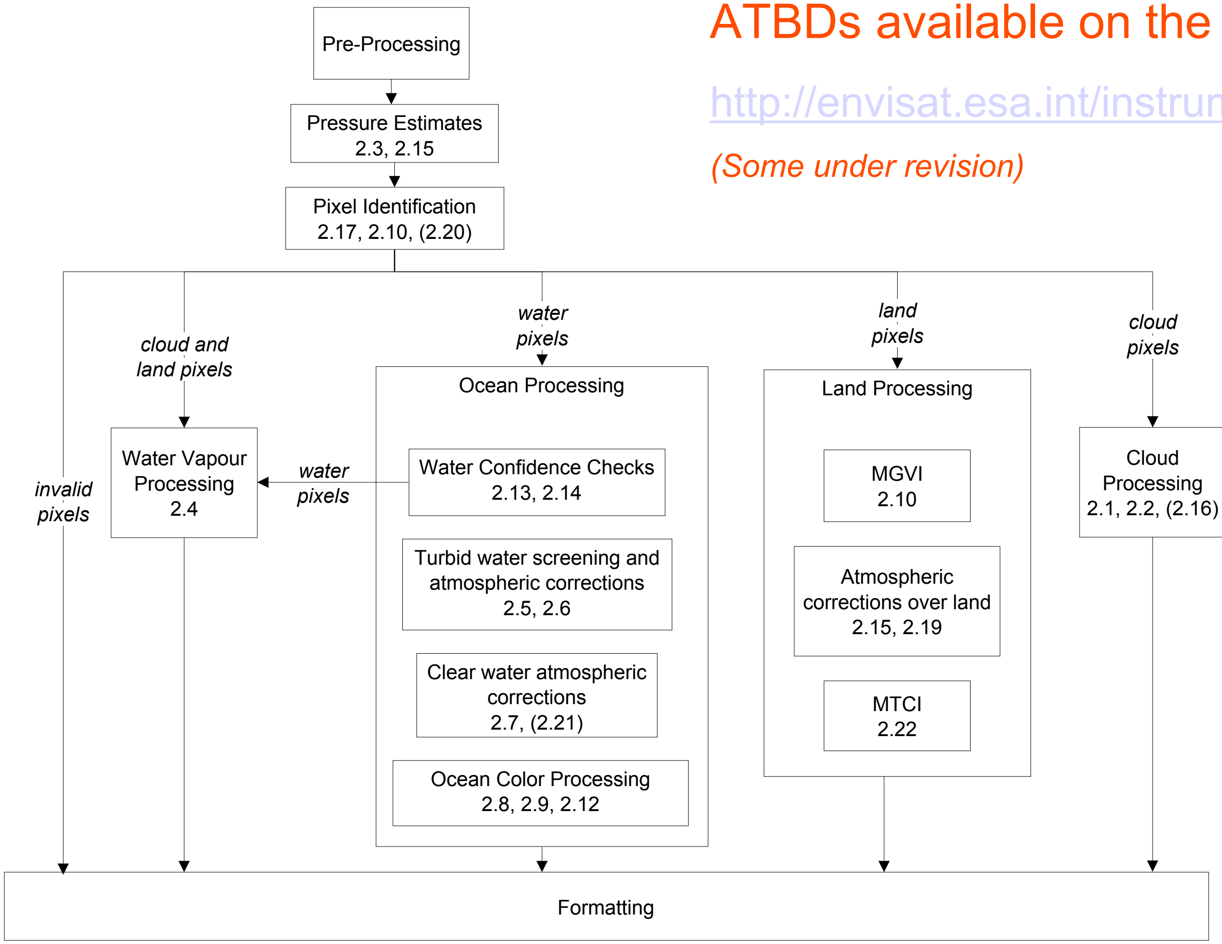
Presentation Outlook

- PART 1: MERIS L2 PROCESSING GENERAL OVERVIEW
  - Common Processing
  - Cloud Branch
  - Land Branch
  - Water Branch
- PART 2: WATER BRANCH ALGORITHMS,
  A MORE DETAILED DESCRIPTION
  - Atmosphere correction
  - Ocean Color
- PART 3: TOWARD VICARIOUS ADJUSTMENT
  OF MERIS TOA REFLECTANCE (at Level 2)

MERIS LEVEL 2 PROCESSING
PART 1

MERIS L2 PROCESSING
GENERAL OVERVIEW

Functionnal breakdown



ATBDs available on the web at:

http://envisat.esa.int/instruments/meris/atbd/

(Some under revision)

MERIS ESL:

Institutes:
- FUB
- GKSS
- JRC
- LISE/ULCO
- LOV
- PML

Companies:
- ACRI
- BC

Pre-processing

- For ***all*** pixels:
  - Interpolate all annotations at pixel
  - Derive *surface* pressure from ECMWF *mean sea level* and pixel altitude
- For ***valid*** pixels only:
  - convert L1b radiance **L** into TOA reflectance **ρ**

Pressure processing

From

- measurement within the O2-A absorption line at 761 nm (band 11) and reference at 753 nm (band 10)
- accurate knowledge of the band 11 central wavelength
  - ➡ Cloud Top Pressure (neural net)
  - ➡ Surface Pressure (polynomials)

- Derived at every valid pixel (input to classification)
- Valid product only over relevant surface types (cloud and land pixels, respectively)

Pixel identification

- Goal: sort valid pixels into Cloud, Water and Land
- Means:
  - Cloud screening:
    - spectrum values & slopes (on Rayleigh corrected reflectance)
    - pressure tests
  - Land/water discrimination:
    - *A priori* land/water classification
    - radiometric (clear sky) land/water reclassification where *a priori* is questionable (on gas corrected reflectance)

Smile Correction

- "Smile": in-FOV variation of channels central wavelength
- Can affect Level 2 products if not accounted for
- Need for a simple and robust smile correction
  - First order correction $\rho_{ng}^{*} = \rho_{ng} + \frac{\partial \rho}{\partial \lambda}.\Delta\lambda$
  - Restricted to Land and Water pixels
  - Restricted to surface dependent subset of bands
  - Based on surface dependent spectral slope estimates

Cloud branch

- Compute the ***cloud albedo***, ***cloud optical thickness***, ***cloud type*** products (in addition to already available ***cloud top pressure***)
- Albedo and optical thickness are derived from polynomials of $L_{TOA}(753)$ using geometry and surface albedo dependant coefficients. Polynomial coefficients are derived from radiative transfer simulations.
- *Cloud type* product is an *index* computed from CTP and CA (defined by ISCCP climatology project)

Total Column Water Vapour

- Determine column water vapour content above all surfaces from absorption at 900 nm
- Polynomials of $T=L_{TOA}(900)/L_{TOA}(885)$ (from RT simulations)
- Surface dependent algorithms
  - Above land and water with high glint:
    - Correct for surface reflectance and its spectral dependency, estimated from L_T at 753, 885, 900
    - Account for surface pressure (vertical profile)
  - Above water, no/low glint :
    - Correct T for aerosol estimated from L_T at 779, 865
  - Above cloud :
    - Account for cloud optical thickness (a MERIS cloud product)
    - Account for underlying surface albedo

Land branch

MERIS
Global Vegetation Index

Atmosphere Corrections
over Land

↓

MERIS
Terrestrial Chlorophyll Index

Land branch

MERIS Global Vegetation Index

Atmosphere Corrections over Land

MERIS Terrestrial Chlorophyll Index

- Atmosphere & geometry insensitive vegetation index
- Remove unwanted pixels → flags
- Based on ***normalised*** ρ_{TOA}(B,R,IR) (→ anisotropic)
- Computes rectified ρ_R for R & IR (→ top of canopy at ref geometry)
- Computes MGVI(ρ_R(R), ρ_R(IR)) (→ ≡FAPAR)

Land branch

MERIS Global Vegetation Index

Atmosphere Corrections over Land

MERIS Terrestrial Chlorophyll Index

- compute top of aerosol ρ_{top} (all pixels)
- Retrieve aerosol over vegetation
  - select DDV pixels using ARVI
  - biome climatology & models → ρ_S at 3 bands
  - find best aerosol model α and τ_{443} so that $\{\rho_S\}_{(3\ bands)}$ propagated to TOA match measures

Land branch

MERIS Global Vegetation Index

Atmosphere Corrections over Land

MERIS Terrestrial Chlorophyll Index

- Remove unwanted pixels → flags
- Based on ρ_{TOP}(R, IR1,IR2)
- MTCI $= \dfrac{\rho_{TOP}(753) - \rho_{TOP}(709)}{\rho_{TOP}(709) - \rho_{TOP}(681)}$

Water branch

Water confidence checks

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Turbid water screening and atmosphere correction

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Clear water atmosphere correction

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Ocean color processing

Water branch

Water confidence checks

↓

Turbid water screening and atmosphere correction

↓

Clear water atmosphere correction

↓

Ocean color processing

- High and medium glint flags
- Glint correction
- Whitecaps flag
- High inland water flag
- Ice, haze, high aerosol flag

Water branch

Water confidence checks

↓

Turbid water screening and atmosphere correction

↓

Clear water atmosphere correction

↓

Ocean color processing

→

- Identify bright waters (sediment dominated case 2, CASE2_S flag)
- Estimate sediment load
- Estimate IR marine signal ρ_w

Water branch

Water confidence checks

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Turbid water screening and atmosphere correction

↓

Clear water atmosphere correction →

- Identify aerosol: τ_{865}, α_{NIR} (from IR where ρ_w known)
- Estimate atmosphere path reflectance including molecular/aerosol coupling
- Provide ρ_w (all b but 761 & 900)
- Flags: quality and science

↓

Ocean color processing

Water branch

Water confidence checks

Turbid water screening and atmosphere correction

Clear water atmosphere correction

Ocean color processing

From ρ_w, provide:

- Algal 1 (case 1)
- Algal 2, TSM, YS (case 2)

- Instantaneous Photosynthetically Available Radiation (PAR)

MERIS LEVEL 2 PROCESSING PART 2

A MORE DETAILED DESCRIPTION OF WATER BRANCH ALGORITHMS

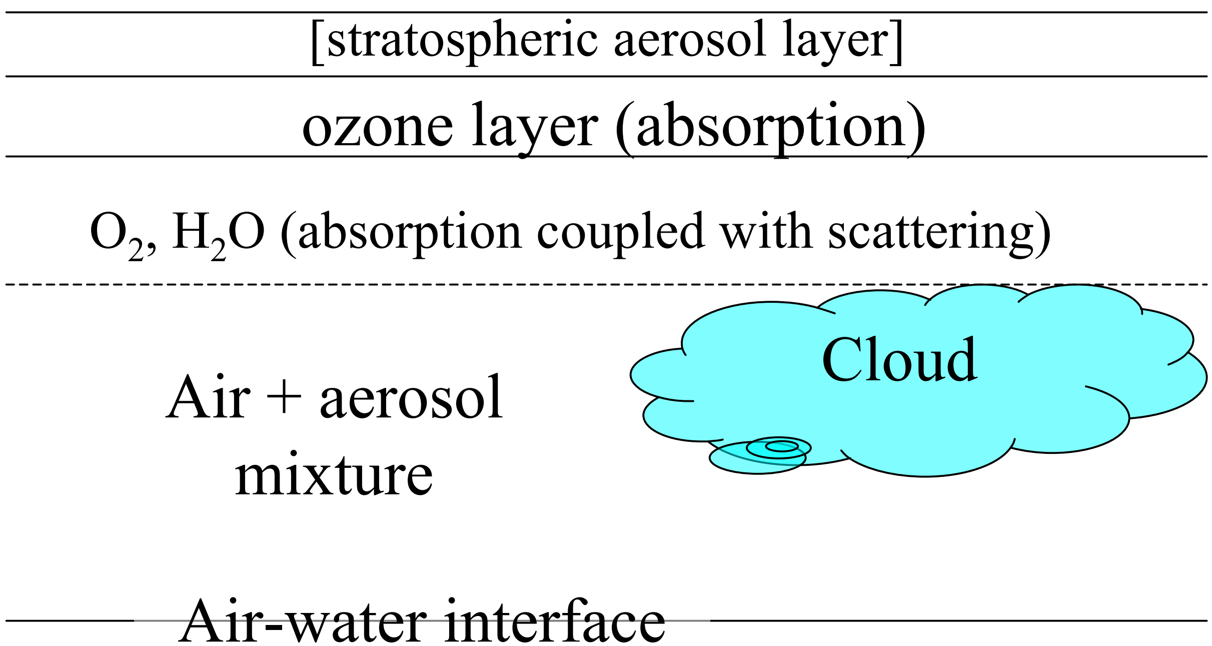
Water Processing: more details

- Input: top of atmosphere reflectance
- Mains steps:
  - Atmosphere correction
    - Gas correction (O_3, H_2O, O_2)
    - Pixels screening & glint
    - Coupled molecules/aerosols correction
    - → directional water leaving reflectance

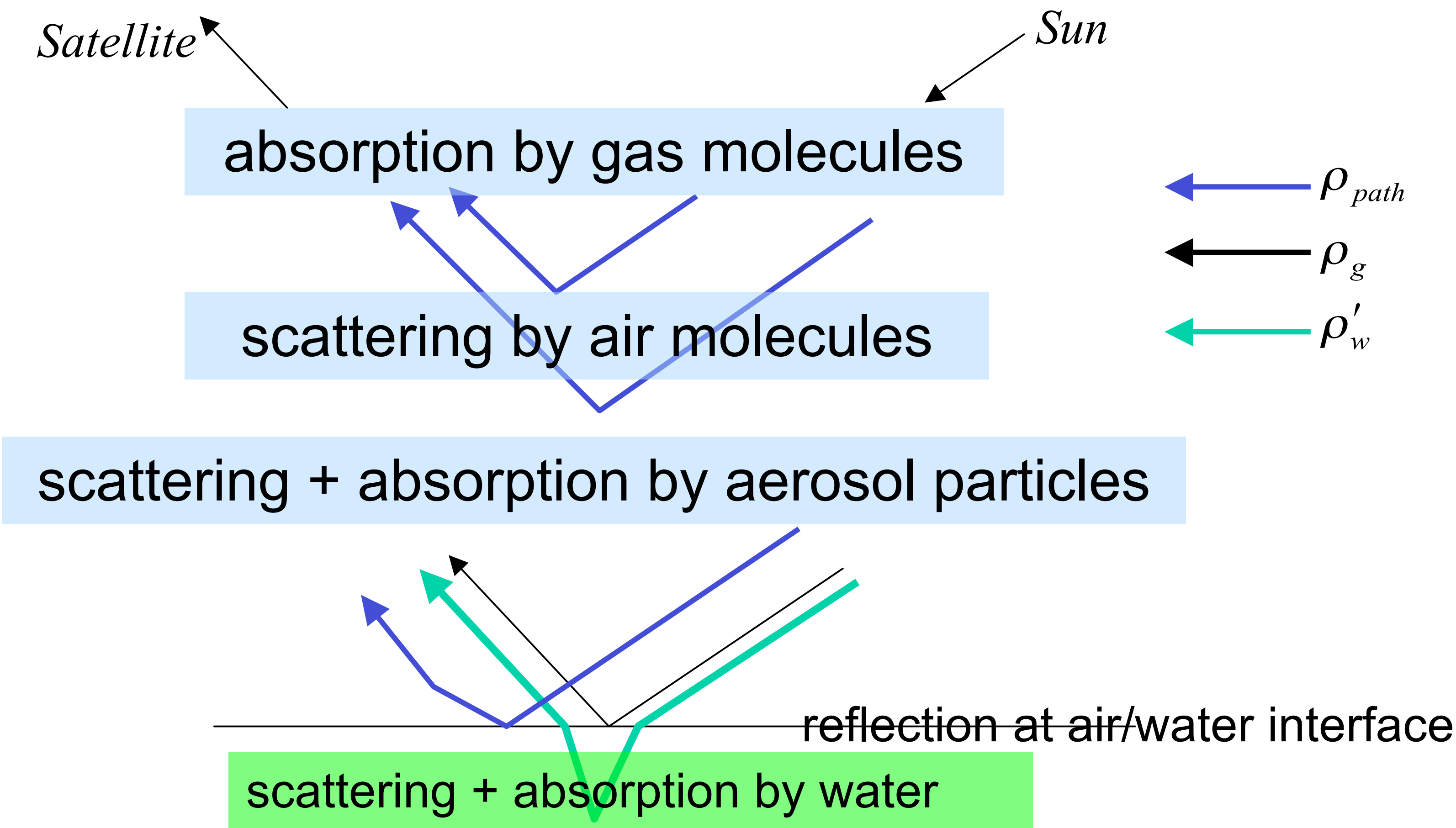
$$\rho_w = \pi \frac{L_w}{E_d^{(0+)}}$$

  - Ocean color processing
    - Chl 1 from band ratio (case 1)
    - Chl 2, TSM, YS from Neural network (case 2)

Water processing: atmosphere model



Water processing: simplified signal model



$$\rho = t_g.\left(t_{dir}.\rho_G + \rho_{path} + t_{up}.T_d.\rho_w\right)$$

Water Processing: gas correction

Gas corrections

- O_3: transmittance t_{O3} from ECMWF ozone and optical thickness for each band
- H_2O: transmittance at any band $t_{H2O}(b)$ estimated from measured $t_{H2O}(900)$
- O_2: transmittance at any band $t_{O2}(b)$ estimated from measured $t_{O2}(761)$

Water Processing: glint & bright pixels

Pixels screening & glint flagging/correction:

- Glint reflectance estimates: Cox & Munk anisotropic model (revised with Ebushi & al parameters, and fed by ECMWF wind vectors)
- 2 glint thresholds and flags:
  - high glint: to high for reliable correction ($\rho_G \geq \alpha.\rho(865)$)
  - medium glint: correction is required and possible ($\varepsilon \leq \rho_G < \alpha.\rho(865)$) → $\rho_{GC}(\lambda) = \rho_{ng}(\lambda) - t.\ \rho_G$
- "Bright pixels" screening: undetected clouds, haze, high aerosols and ice flagged (from a reflectance test at 412)
- Whitecaps: raise flag upon wind speed, no correction

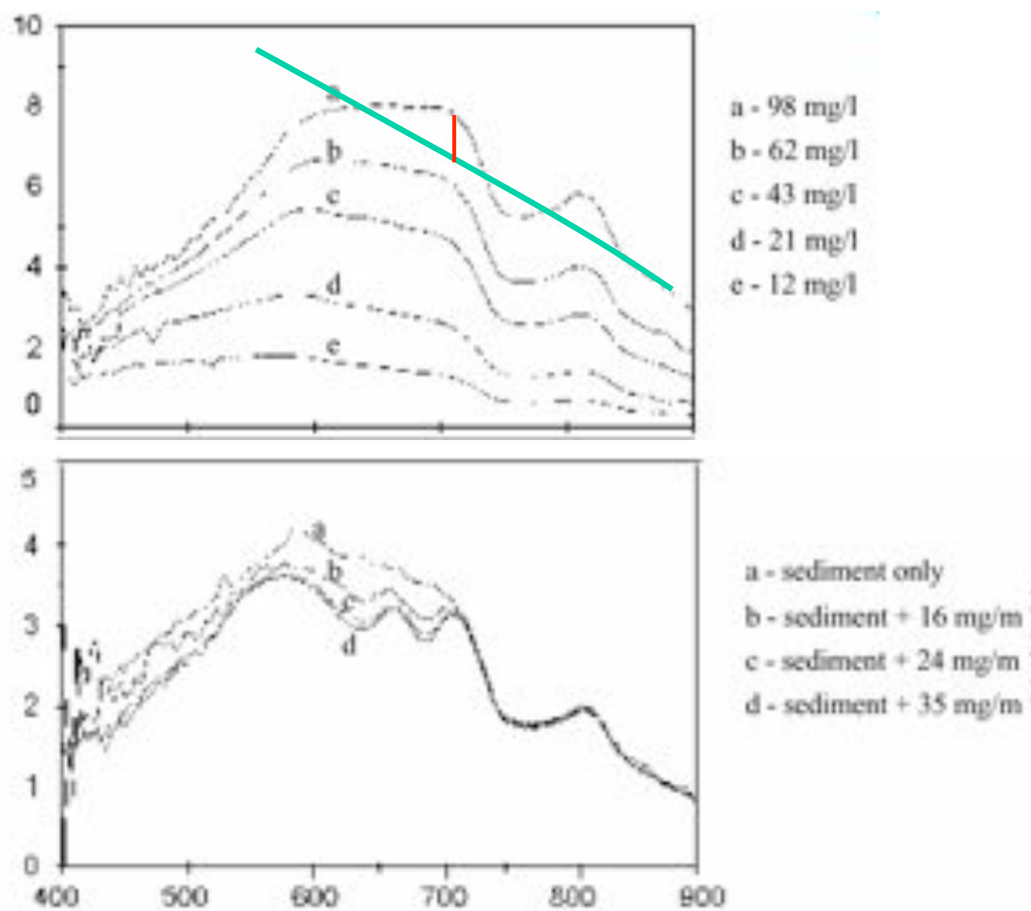
Water Processing: path reflectance

- Based on a classical "black ocean in the NIR" approach
- Using standard aerosol models closed to SeaWiFS ones
- With some specificities:
  - Rayleigh/aerosol coupling accounted for through the use of ρ_{path}/ρ_R (ATBD 2.7)
  - Extension to (moderately) sediment loaded waters through estimation of $t.\rho_w$ in the NIR (ATBD 2.6)
  - Additional aerosols with steep spectral dependency
  - Detection of absorbing aerosols using "deficit of reflectance at 560 nm" (ATBD 2.7) and corresponding additional models (Moulin et al)

Water Processing: turbid waters

Purpose:

- To identify waters with significant backscatter in the NIR
- To provide corresponding reflectance estimates allowing atmosphere corrections



Water Processing: turbid waters

- Simplified atmospheric model : single scattering approximation

  $\rho_{rc} = \rho_{GC} - \rho_R$ so that $\rho_{rc} - t\rho_w = \rho_a$

  t = diffuse transmission up & down, Rayleigh only

$$\rho_{GC} = \rho_R + \rho_a + t.\rho_w$$

$$\frac{\rho_a(b1)}{\rho_a(b2)} = \left(\frac{\lambda(b1)}{\lambda(b2)}\right)^n$$

- Find n and TSM that explain ρ_{RC} at 709, 779 & 865

$$\begin{cases} \rho_{rc}(865) - t\rho_w(865) = [\rho_{rc}(779) - t\rho_w(779)].\left(\frac{\lambda(779)}{\lambda(865)}\right)^n \\ \rho_{rc}(865) - t\rho_w(865) = [\rho_{rc}(709) - t\rho_w(709)].\left(\frac{\lambda(709)}{\lambda(865)}\right)^n \end{cases}$$

- Realized using a simplified ρ_w model

$$\rho_w = \pi \cdot \Re \cdot f/Q \cdot \frac{b_{bw} + b_{bp}^* \cdot TSM}{a_w}$$

- Ends up with $t.\rho_w$ estimates at 779, 865 + CASE2_S flag

(ATBD 2.6 under revision)

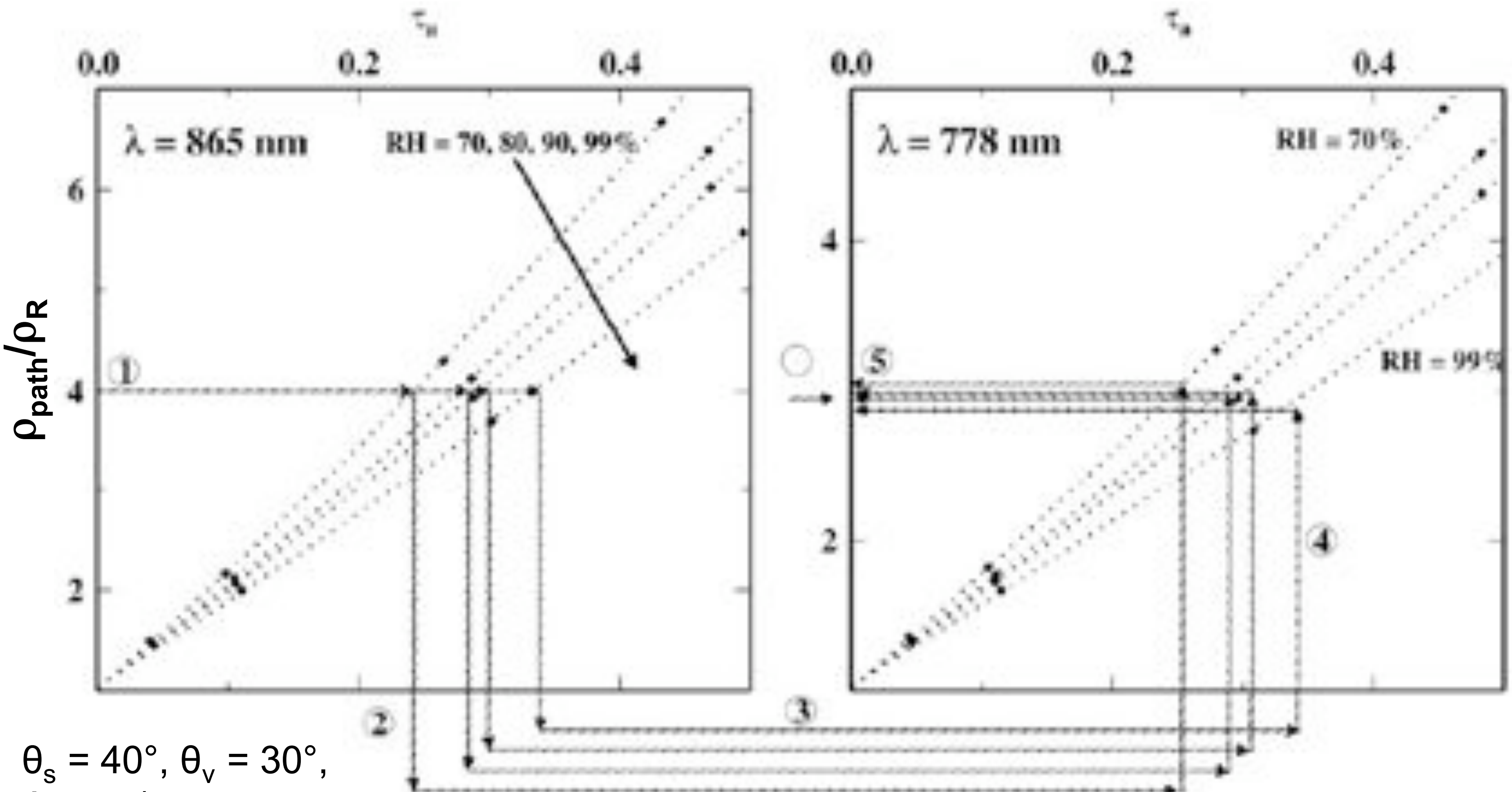
Water Processing: aerosol identification

Principle:

- Inputs: $\rho_{path}=\rho_{GC} - t.\rho_w$ at 779 and 865 (=ρ_{GC} in case 1)
- Tabulated relationships:
  - $\rho_{path}/\rho_R=f(\tau,\lambda,\Omega,model)$, (1)
  - $\tau=f^{-1}(\rho_{path}/\rho_R,\lambda,\Omega,model)$ (2)
  - $\tau(\lambda,model) = \tau(\lambda_{ref},model)$ (3)
- For all aerosol models:
  - Measured ρ_{path}/ρ_R at 865 gives τ_{865} using (2)
  - τ_{865} gives τ_{779} using (3)
  - τ_{779} gives ρ_{path}/ρ_R at 779 using (1)
- Select pair of models most closely bracketing measured ρ_{path}/ρ_R at 779 and mixing ratio that fits.

Water Processing: aerosol identification

Illustration with a set of 4 maritime models



θ_s = 40°, θ_v = 30°,
$\Delta\varphi = \pi/2$.

Water Processing: aerosol identification

Global procedure:

- identification done over the whole set of non-absorbing aerosols (MAR, COA, RUR with various RH + 3 "blue")
- best pair is selected, derive: $\rho_{path}^{calc} = \left(\frac{\rho_{path}}{\rho_R}\right)^{calc} \cdot \rho_R$ at 510 nm
- If not CASE2_S then:
  - Get $\rho_w(510)$ using $\rho_w = \cdot \frac{\rho_{GC} - \rho_{path}^{calc}}{t_{up} \cdot t_{dwn}}$
  - If $\rho_w < (mean+\sigma)_{climatology}$ repeat procedure with the absorbing aerosol families → new candidate pairs
  - Select the one that minimizes $|\rho_w - (mean+\sigma)_{climatology}|$
- Proceed to correction at all bands

Water Processing: aerosol products

- Aerosol optical thickness at 865nm
- Aerosol Angstrom exponent (779-865)
- Atmosphere correction flags:
  - validity flag for aerosol products
  - OADB (out of aerosol database: limited representativity)
  - ABSO_D: absorbing aerosols were selected
  - CASE2_S: significant scattering by water in the NIR
  - Medium glint
  - High glint
  - Ice/haze/high aerosol

Water Processing: Ocean Color

Ocean color products:

- Algal 1 index (~Chl_a concentration, $mg.m^{-3}$): case 1
- Algal 2 index (~Chl_a concentration, $mg.m^{-3}$): case 2
- Total Suspended matter ($g.m^{-3}$): case 2
- Yellow Substance (absorption at 442, m^{-1}): case 2
- Flags:
  - Validity flags for each product
  - CASE2_Anomalous: excess of reflectance at 560 as compared to derived Algal1 → anomalous scattering

Water Processing: Algal 1

- In Case 1 water,
  - R(λ) is a function of algal pigments
  - R(442)/R(560) (or R(490)/R(560)) is directly related with Chl

$$R = \frac{E_u}{E_d}$$

E_u : upwelling irradiance (integral of radiance) just below the surface

E_d : downwelling irradiance

$$\rho_w = \pi . \Re . \frac{R}{Q}$$

contribution of the air-water interface ($\Re$)

bi-directional distribution of the upwelling radiance (Q) (*depends on Chl*)

From MERIS case 1 model: $\rho_w = \pi \cdot \Re(\theta_S, \theta_V, \tau, w) \cdot \frac{f(\lambda, \theta_S, \tau, w, Chl)}{Q(\lambda, \Omega, \tau, w, Chl)} \cdot \left[{b_b}/{a} \right] (\lambda, Chl)$

Water Processing: Algal 1

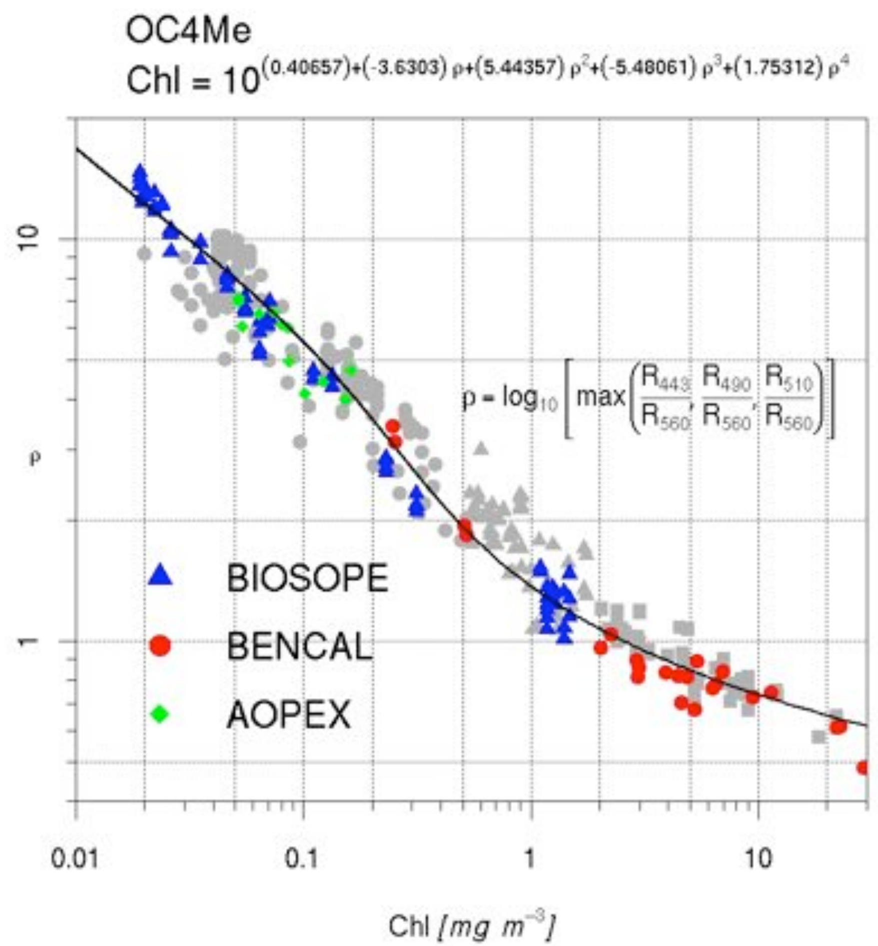
- Reflectance correction for bi-directionality requires knowledge of Chl → iterative method:
  - Select highest $\frac{\rho'_w(b_i)}{\rho'_w(b_{ref})}$ ratio among $b_i \in \{443, 490, 520\}$, $b_{ref}=560$
  - Normalization of ρ_w ratio using tabulated f/Q (Chl dependent)

$$band\_ratio = \frac{\rho'_w(b_i)}{\rho'_w(b_{ref})} \cdot \frac{Q_i}{Q_{ref}} \quad \left(= \frac{f/Q\,(b_{ref})}{f/Q\,(b_i)} \cdot \frac{\rho'_w(b_i)}{\rho'_w(b_{ref})} \cdot \frac{f_0(b_i)}{f_0(b_{ref})} \right)$$

  - *log* Chl1 = polynomial (band_ratio)

Iterative process

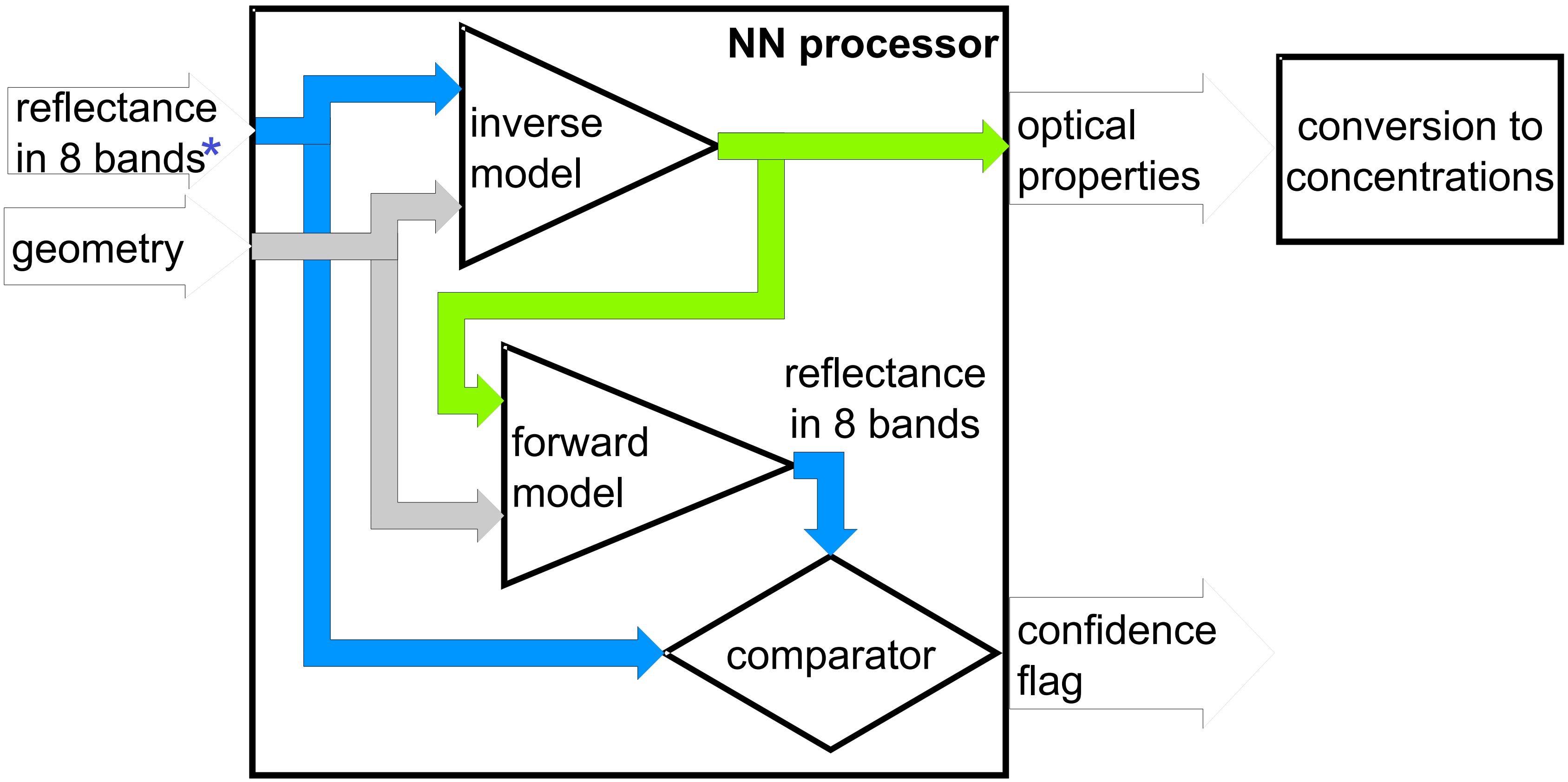
Water Processing: Algal 1



Water Processing: Case 2 Neural Network

- Case 2 waters:
  - Described by *optical components*:
    - Phytoplankton pigment absorption a_{pig}
    - Absorption of all other substances a_{yp}
      (dissolved Gelbstoff y and non-algal particles p)
    - Scattering of all particles b_p
  - Global inversion is done using a Neural Network (NN), provides $a_{pig}(442)$, $a_{yp}(442)$, $b_p(442)$ from reflectance in 8 bands
  - NN is trained offline over a large data set produced by Radiative Transfer model
  - Internal consistency verification with a forward model NN
  - Components converted to concentrations using reversible relationships

Water Processing: Case 2 Neural Network



*: 412 to 709, excluding 681

Water Processing: Case 2 Neural Network

- Neural Net principle and training conditions are described in a recent publication:
  - Doerffer, R. and Schiller H. (2007) 'The MERIS Case 2 water algorithm', Internal Journal of Remote Sensing, 28:3, 517-535
- As well as:
  - MERIS ATBD 2.12 *(under revision)*
  - MERIS Reference Model Document *(under revision)*

MERIS LEVEL 2 PROCESSING
PART 3

TOWARD VICARIOUS ADJUSTMENT OF MERIS TOA REFLECTANCE

Vicarious Adjustment: Principle

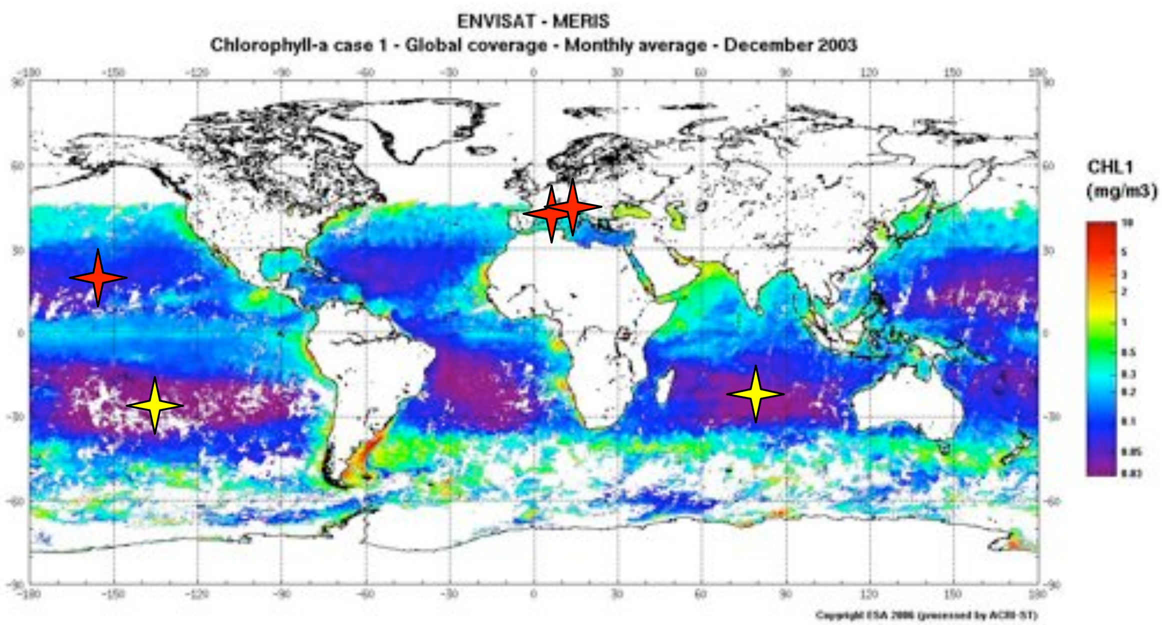
- Based on the work currently led at NASA for SeaWiFS and MODIS vicarious calibration, see Franz et al. 2007, Bailey et al. 2007.
- Consist in computing averaged multiplicative gain factors to correct the "TOA signal", thanks to a DB of reference in-situ ρ^t_w
  - "TOA signal" = Level 2 reflectance pre-corrected for smile, gaseous absorption, glint, i.e. at input of the Water AC algorithm
  - $\rho_{gc}^{new}(\lambda) = \rho_{gc}(\lambda)*G(\lambda)$ for λ in the VIS and NIR
- Two-step approach separating the NIR and VIS channels, avoiding iterative procedure within the AC algorithm
  1. First adjust one of the two NIR bands used in aerosol retrieval (the other one assumed perfect) → G(779) for MERIS AC
  2. AC being now assumed "perfect", adjust all other bands → $G(\lambda)$
- The methodology fully imbricates the sensor response and the processing:
  - The gains need to be updated each time a change occur in the processing (LUT, algorithm, L1b calibration, etc…)
  - A strong effort of traceability in the gain computation, with respect to all other processing parameters, should be maintained.

Vicarious Adjustment: Principle

- Computation starts from the decomposition: $\rho_{gc}(\lambda) = \rho_{path}(\lambda) + t_d(\lambda) . \rho_w(\lambda)$
- Knowing the true (or targeted) signal through in-situ measurements, individual gains are computed matchup per matchup by
  - $g_i(\lambda) = [\rho^t_{path}(\lambda) + t^t_d(\lambda) . \rho^t_w(\lambda)] / [\rho_{path}(\lambda) + t_d(\lambda) . \rho_w(\lambda)]$
- Average gains are finally derived: $G(\lambda) = mean(g_i(\lambda))$
- To calibrate the NIR, one requires:
  - the most NIR band (865) is perfectly calibrated *(→ assumption)*,
  - $\rho_w(\lambda_{NIR})$ is truly negligible, (→ *oligotrophic sites)*
  - aerosol spectral dependency is known (→ specific sites).
- Thus one has
  - $\rho^t_{gc}(865) = \rho_{gc}(865) = \rho_{path}(865)$
  - $\rho^t_{gc}(779) = g_i(779).\rho_{gc}(779) = \rho^t_{path}(779)$
- Using provides $\rho^t_{path}(779)$ **hence $g_i(779)$**
- Once NIR is calibrated, $\rho^t_{path}(\lambda)=\rho_{path}(\lambda)$ and $t^t_d(\lambda)=t_d(\lambda)$ at all bands, **hence $g_i(\lambda)$**

Vicarious Adjustment: implementation

- NIR calibration sites: **South Pacific Gyre and South Indian Ocean**, selected model MAR 90% (including continental background in the free troposphere and H_2SO_4 in the stratosphere of fixed τ_{550} = 0.025 and 0.005 resp.)
- In-situ data: AAOT, BOUSSOLE and MOBY (foreseen : NOMAD)



Data selection:

- no flags within 25x25 px

Results in:

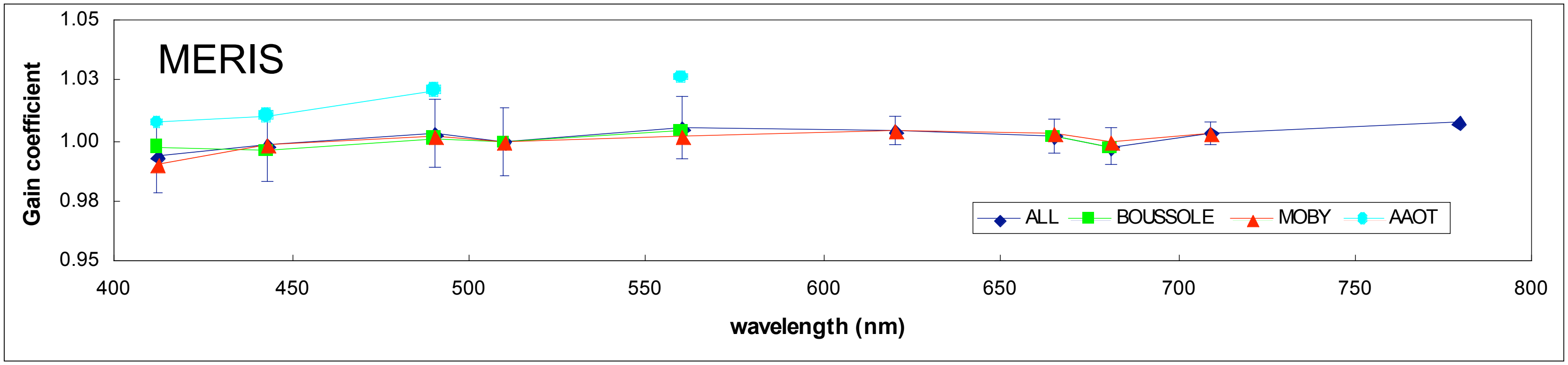
NIR (2003 & 2007 only):

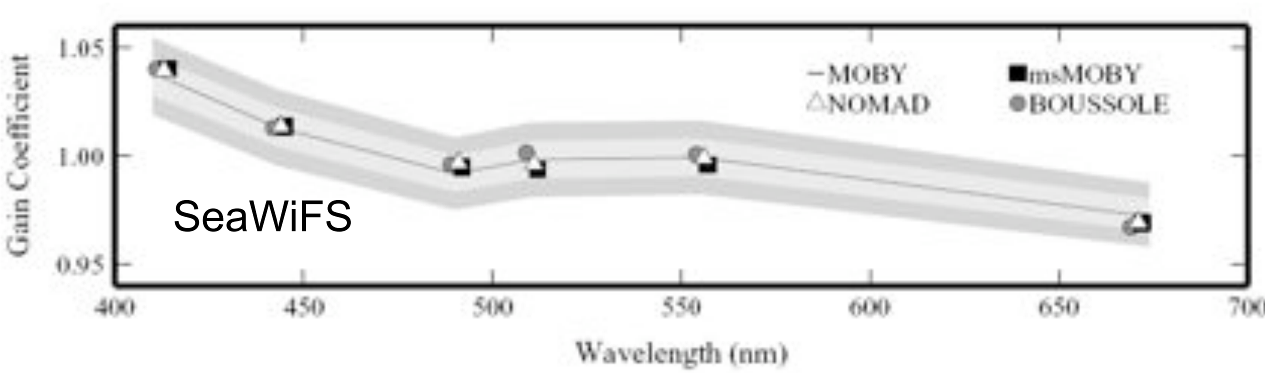
- 14 at SPG
- 34 at SIO

VIS:

- 28 at MOBY
- 29 at BOUSOLE
- 3 at AAOT

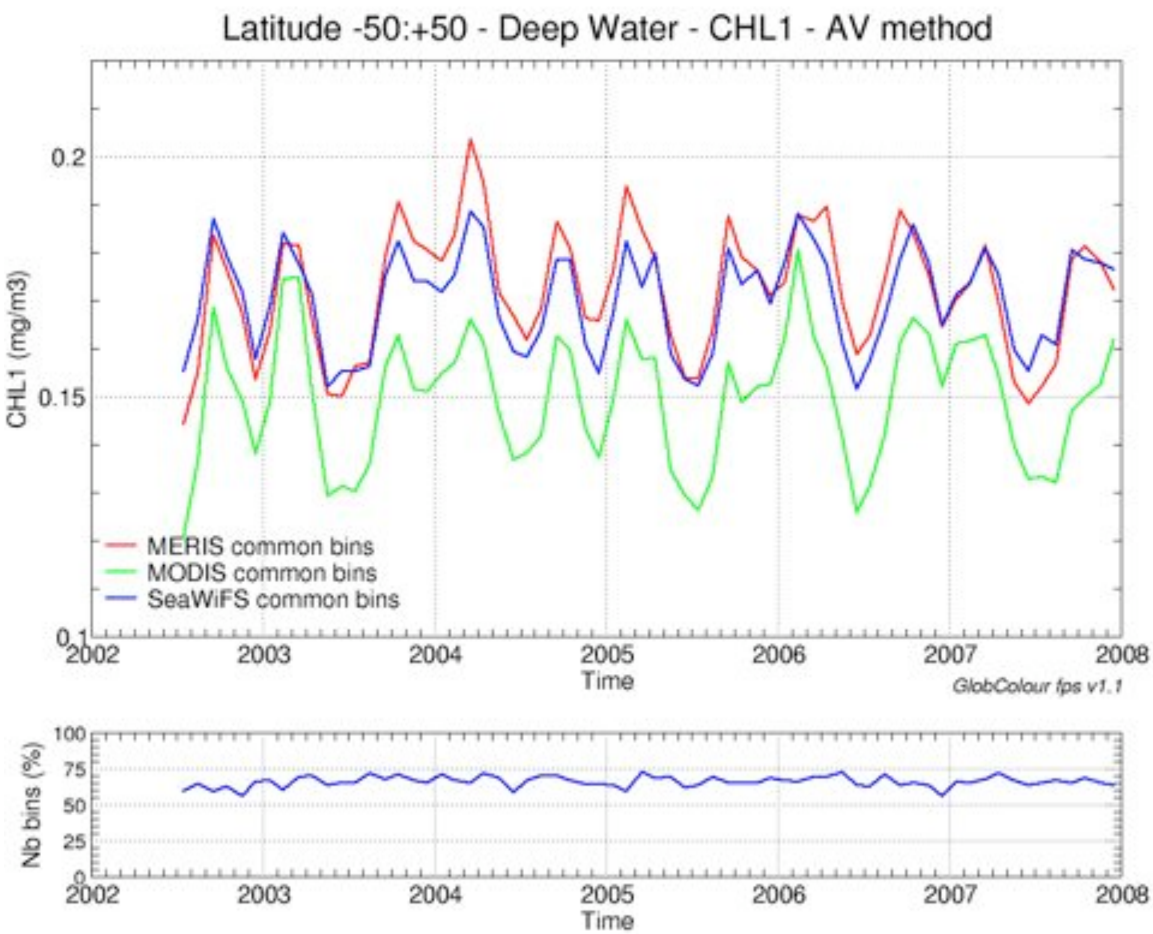
Vicarious Adjustment: Preliminary Results





SeaWiFS figure from **Bailey S.W., S.B. Hooker, D. Antoine, B.A. Franz, P.J. Werdell, « Sources and assumptions for the vicarious calibration of ocean color satellite observations », Applied Optics, 47(12), 2035-2045.**

INTER-SENSOR COMPARISONS: CHLa



MERIS:
no vicarious
adjustment

Source GlobColour,

Courtesy:

SeaWiFS: NASA (v5.2)

MODIS: NASA (v1.1)

MERIS: ESA (v2.0Q)