Coastcolour Algorithm

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Coastcolour Project
User Consultation Meeting
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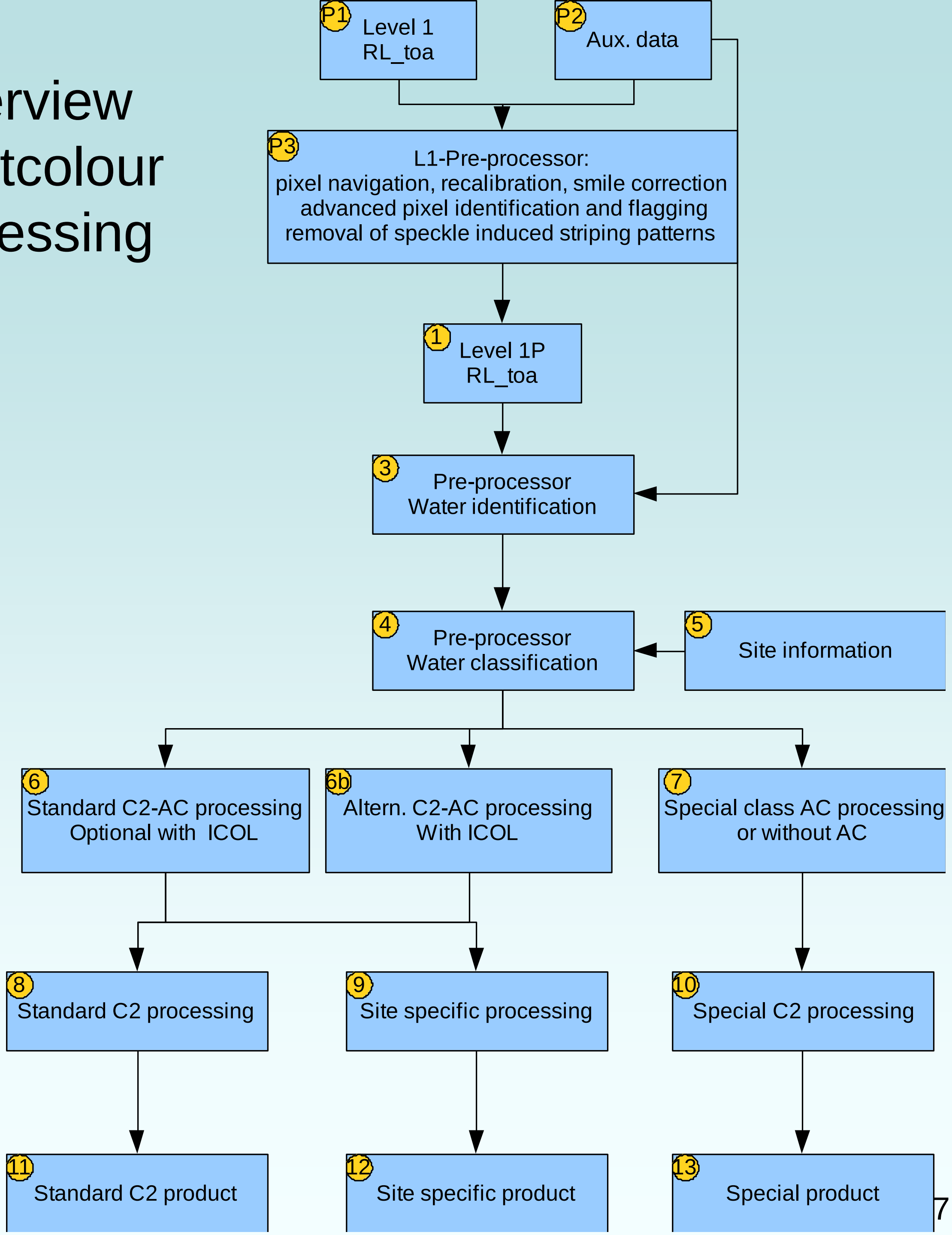
Overview

- L1P processing
- The challenge of Case 2 water algorithms
- Atmospheric correction
- L2 Algorithms: Bio-optical products
  - Neural Network
  - Inverse modelling by optimization
  - Quasi analytical algorithms (QAA)
  - Uncertainties
- Special Algorithms
  - FLH / MCI
  - Functional Types
  - Primary Production
  - Fuzzy Logic algorithm and its use for classification

Overview Coastcolour Processing



L1P processing

Present FR L1 data as archived by ESA do not have 3rd reprocessing quality

L1-> L1P processing includes:

- Improved radiometric calibration
  - Inversion of degradation model (ACRI)
- Improved smile correction (spectral sensor chip pixel adjustment)
  - Method by J.P. Huot
- Equalisation
  - de-striping due to speckle noise, method by M. Bouvet
- Geometric correction (accuracy < 1 pixel)
  - AMORGOS processor (ACRI)
- Cloud screening -> cloud flag
  - Method by FUB / BC, as implemented in BEAM, includes masking of cloud shadows
- Land / water classification -> land flag
  - Method by BC

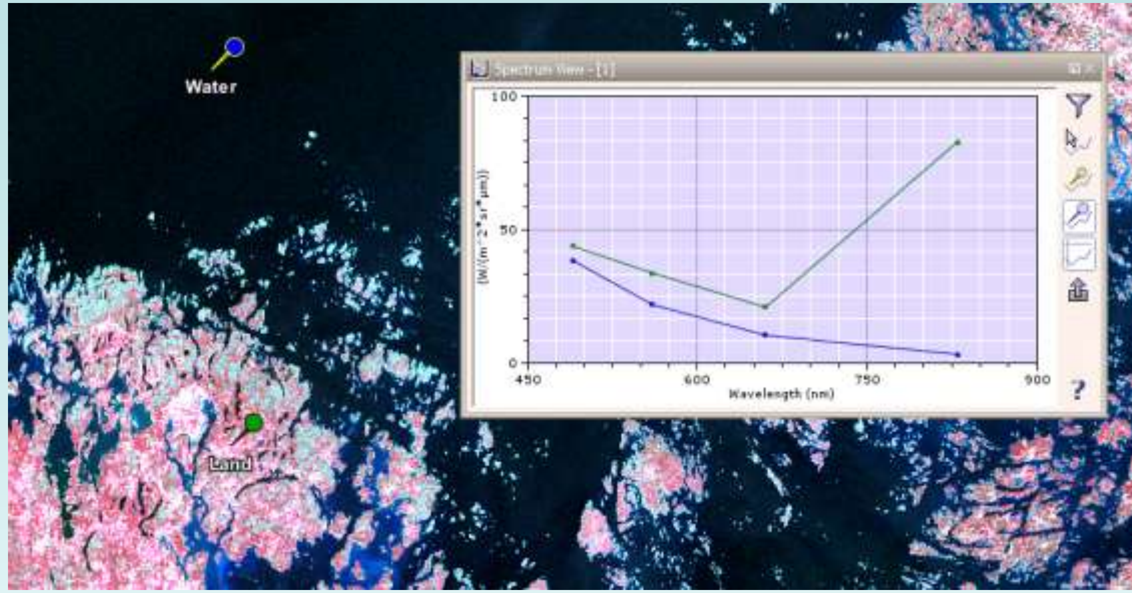
Mixed-Pixel Problem

- Users are interested in a small stripe close to the coast
  - 1nm for Water Framework Directive
  - 3 - 5km expressed by many users in questionnaires
- Users request better screening of pixels
  - sub-pixel mixture of water and non water
  - land
  - floating material
  - clouds

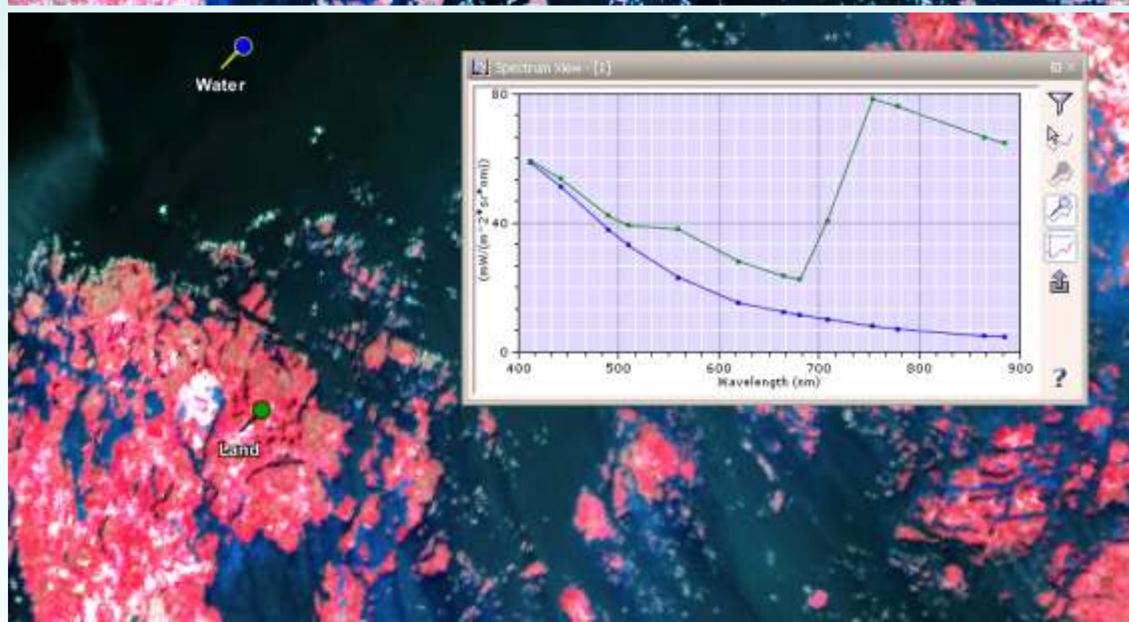
Linear Spectral Unmixing

- Endmember for water and land

Landsat



MERIS



AMORGOS Geometric Correction

- Improvement of the geolocation information of MERIS FR products
  - developed for the ESA DUE project GlobCover by ACRI

- Algorithmic steps
  - calculation of the line of sight from pointing vector
  - ENVISAT orbit and restituted orbit state vector
  - ortho-rectification

- Main differences to the standard geolocation
  - satellite ephemeris and attitude are re-computed from best possible quality sources in order to ensure best achievable accuracy
  - information (longitude l , geodetic latitude f and elevation h) are provided for each image pixel,
  - pixel location is derived accounting for the actual Earth surface elevation along the viewing direction,

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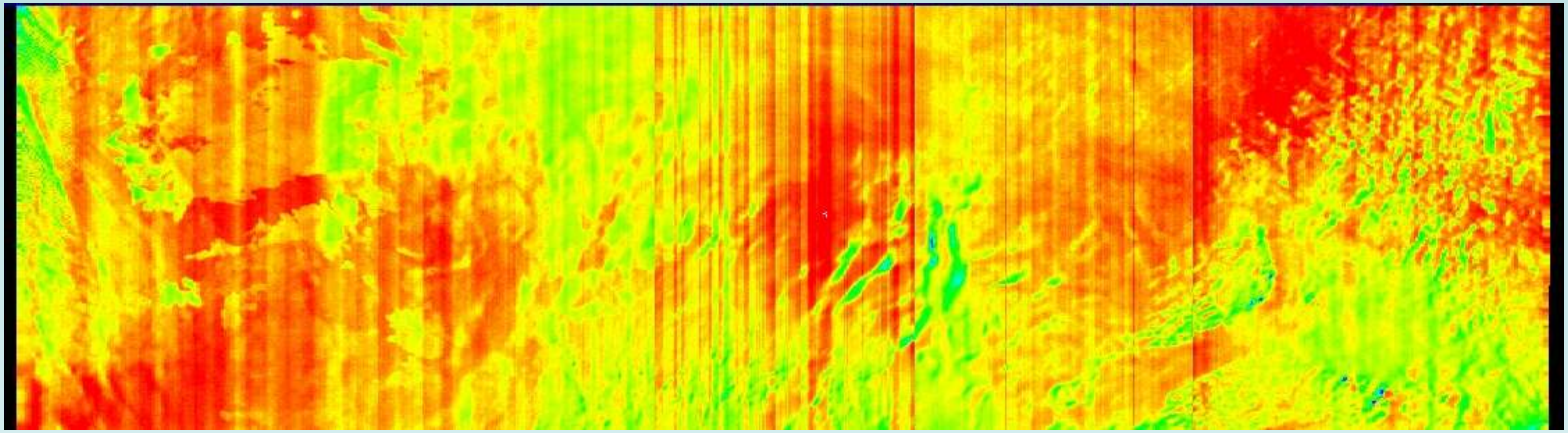
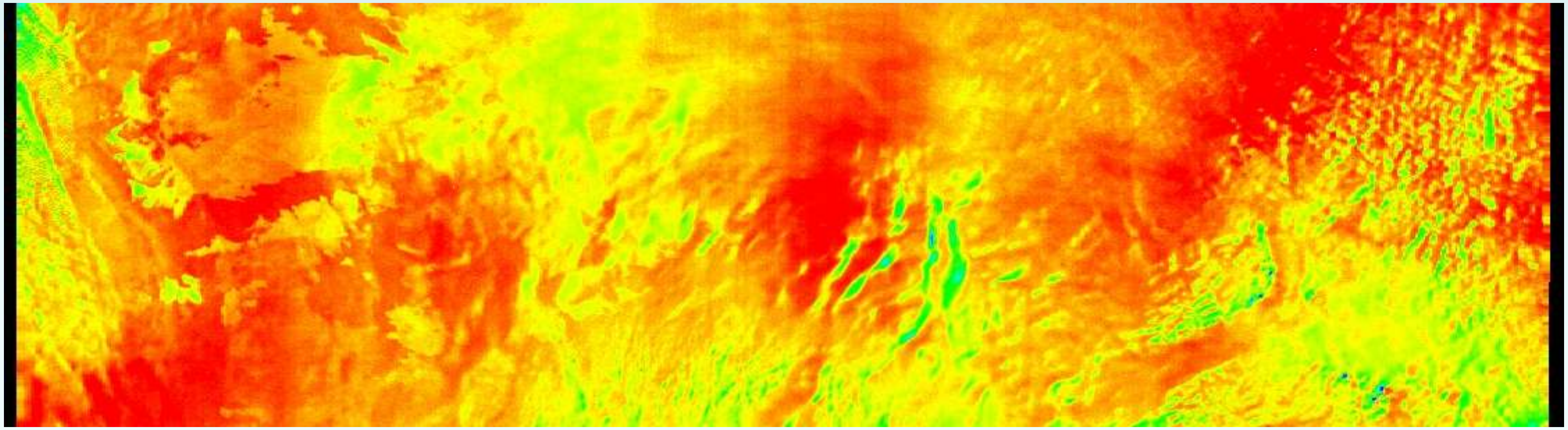
Equalization of MERIS L1b products



With speckle noise (striping)

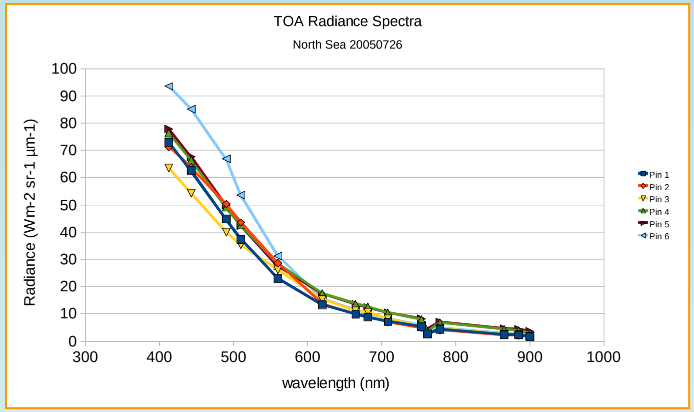


After equalisation

M.Bouvet, ESA

Level 2 Algorithms

What determines the radiance spectrum at TOA?



air molecules

different aerosols

thin clouds

contrails

Sky reflectance

Sun glint

foam

floating material

Suspended particles

dissolved organic matter

Vertical distribution

chlorophyll

Bottom reflection

different phytoplankton species

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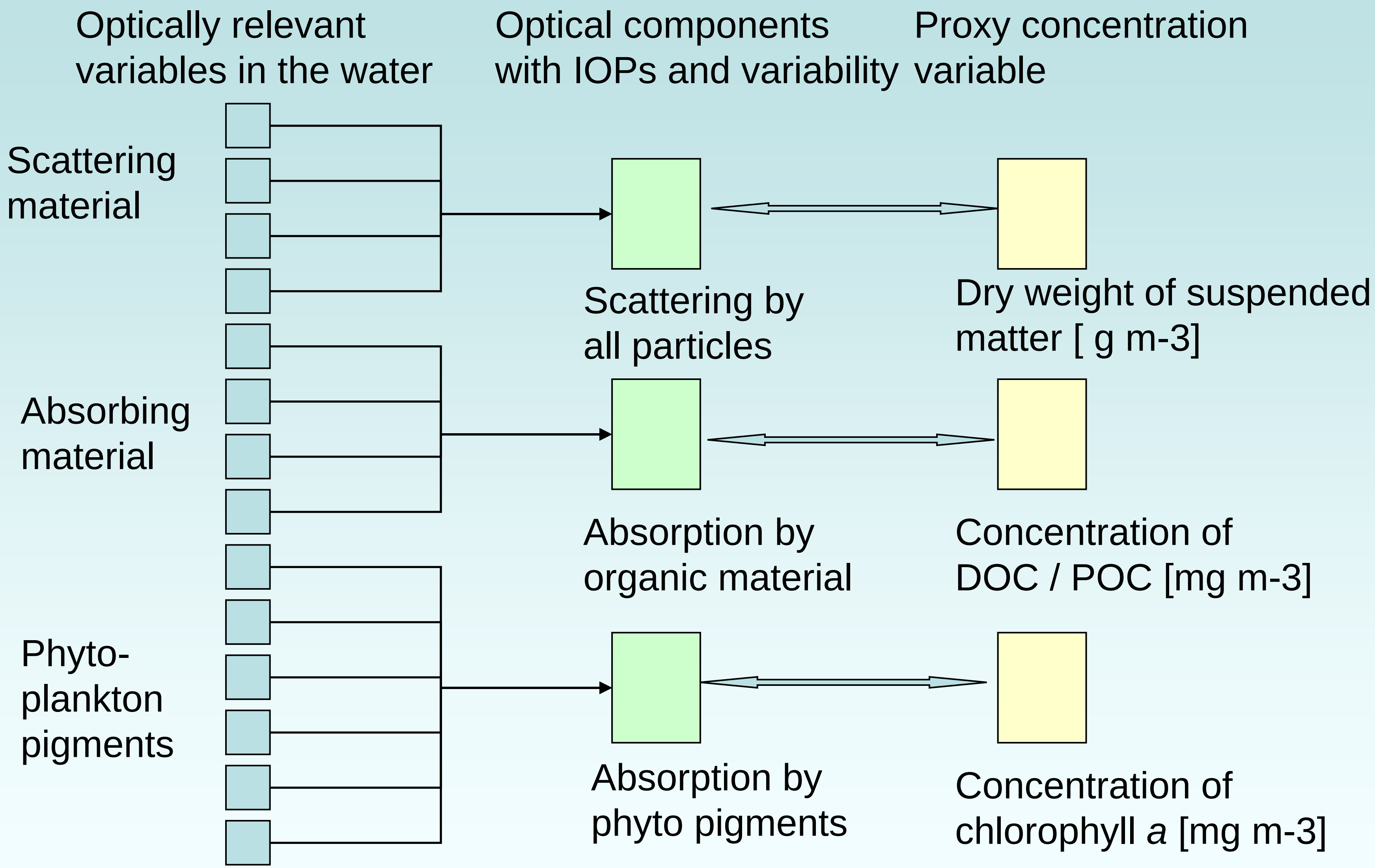
Uncertainties due to the bio-optical model



WARNING

- We have to expect cases with large uncertainties or failures of algorithms

- We need co-algorithms, which
  - detect failures
  - quantify uncertainties and
  - indicate this pixel by pixel

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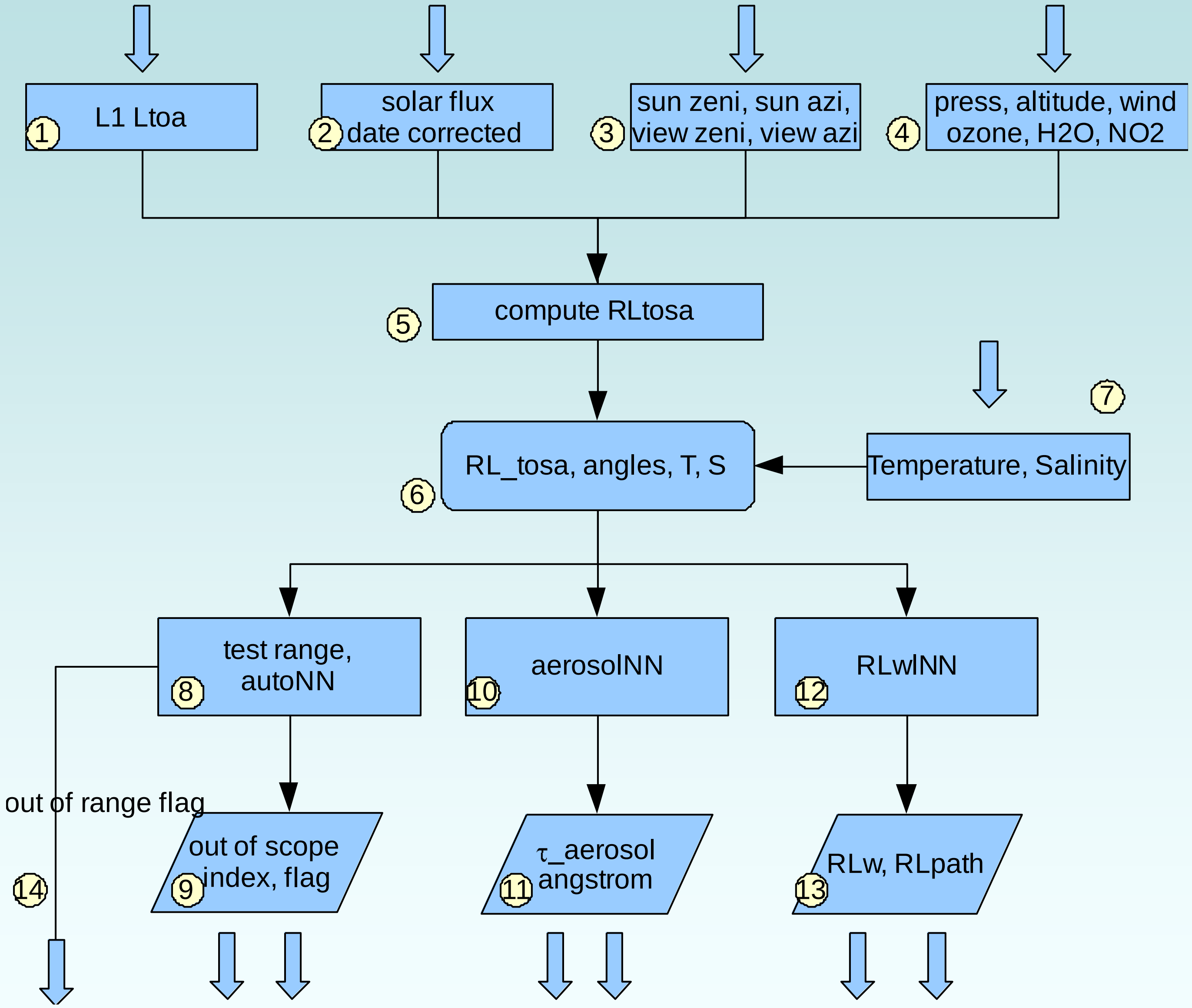
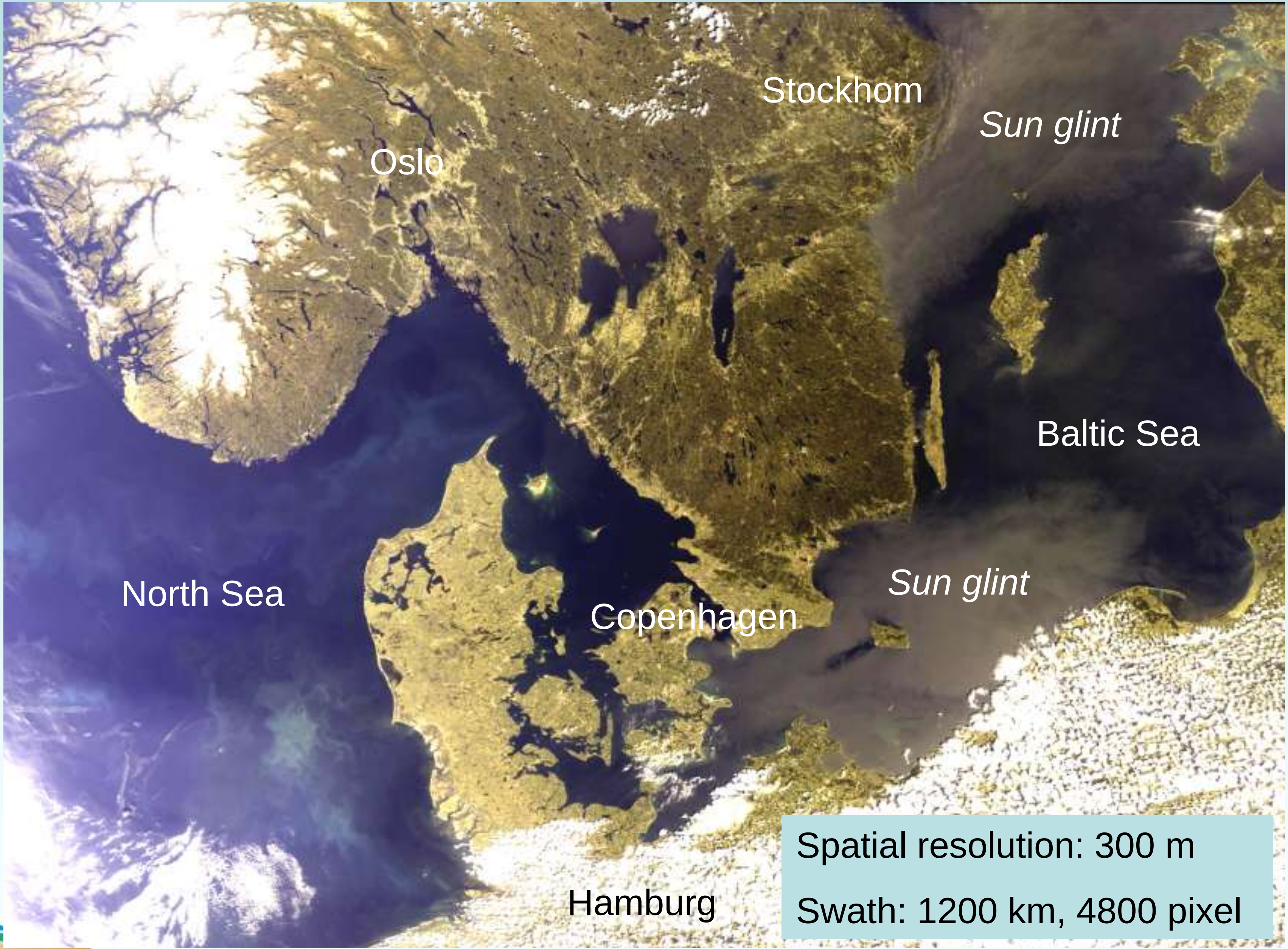
Atmospheric Correction

- Method
  - Neural Network association of water leaving radiance reflectance spectra (RLw) with top of atmosphere reflectance spectra (RLtoa)
  - Uses 12 bands of MERIS
  - Based on radiative transfer simulations
  - Takes different aerosols, thin cirrus clouds and sun glint into account
  - Reflectance by water based on a component model
  - Optional: normalisation of RLw
  - Output products:
    - RLtoa (top of atmosphere reflectances)
    - RLpath (path radiance reflectance)
    - T transmittance
    - RLw (water leaving radiance reflectances)
    - nRLw (normalized water leaving radiance reflectances)

Atmospheric Correction using NN



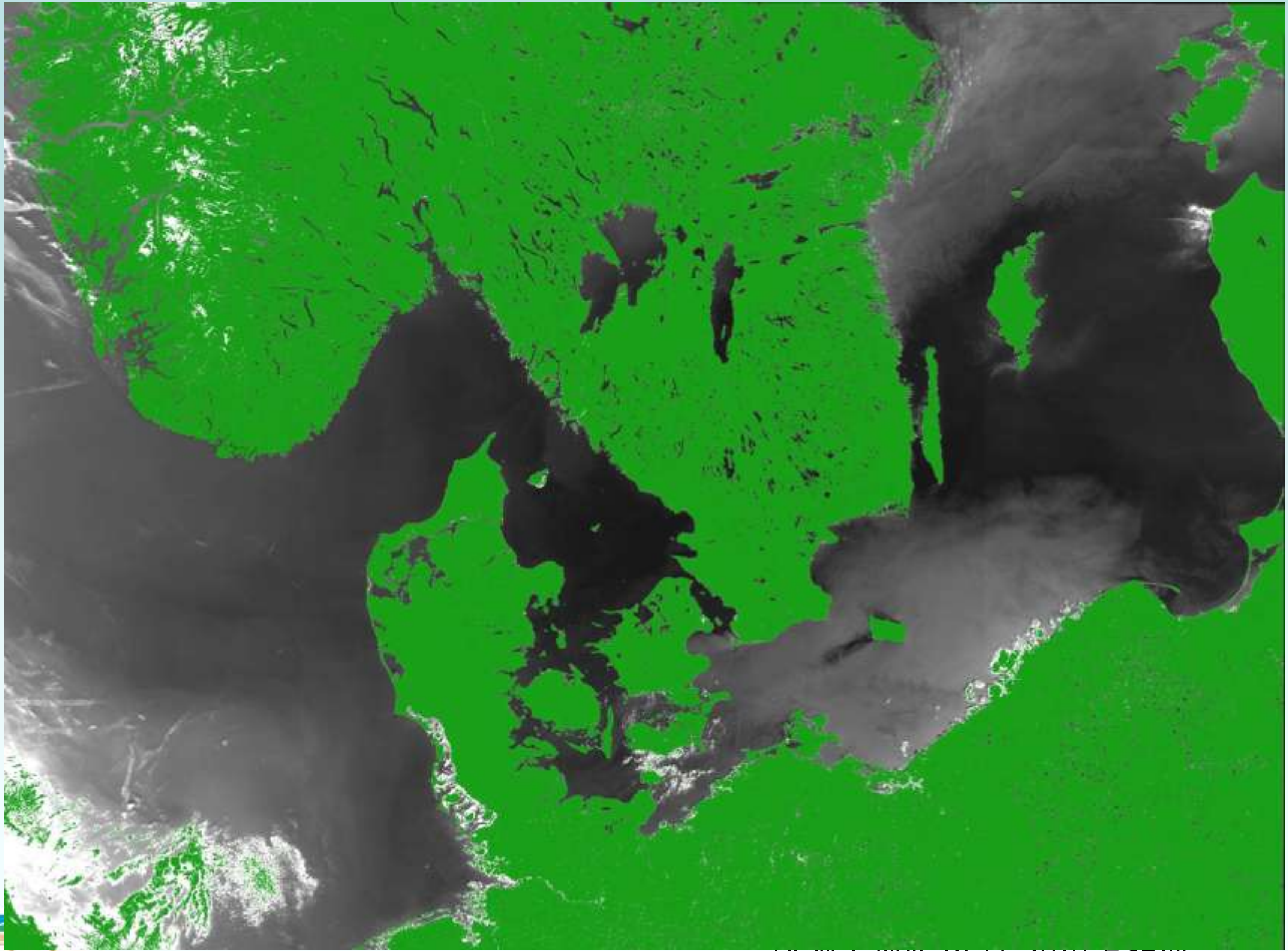
MERIS full resolution: Baltic and North Sea, 20080606



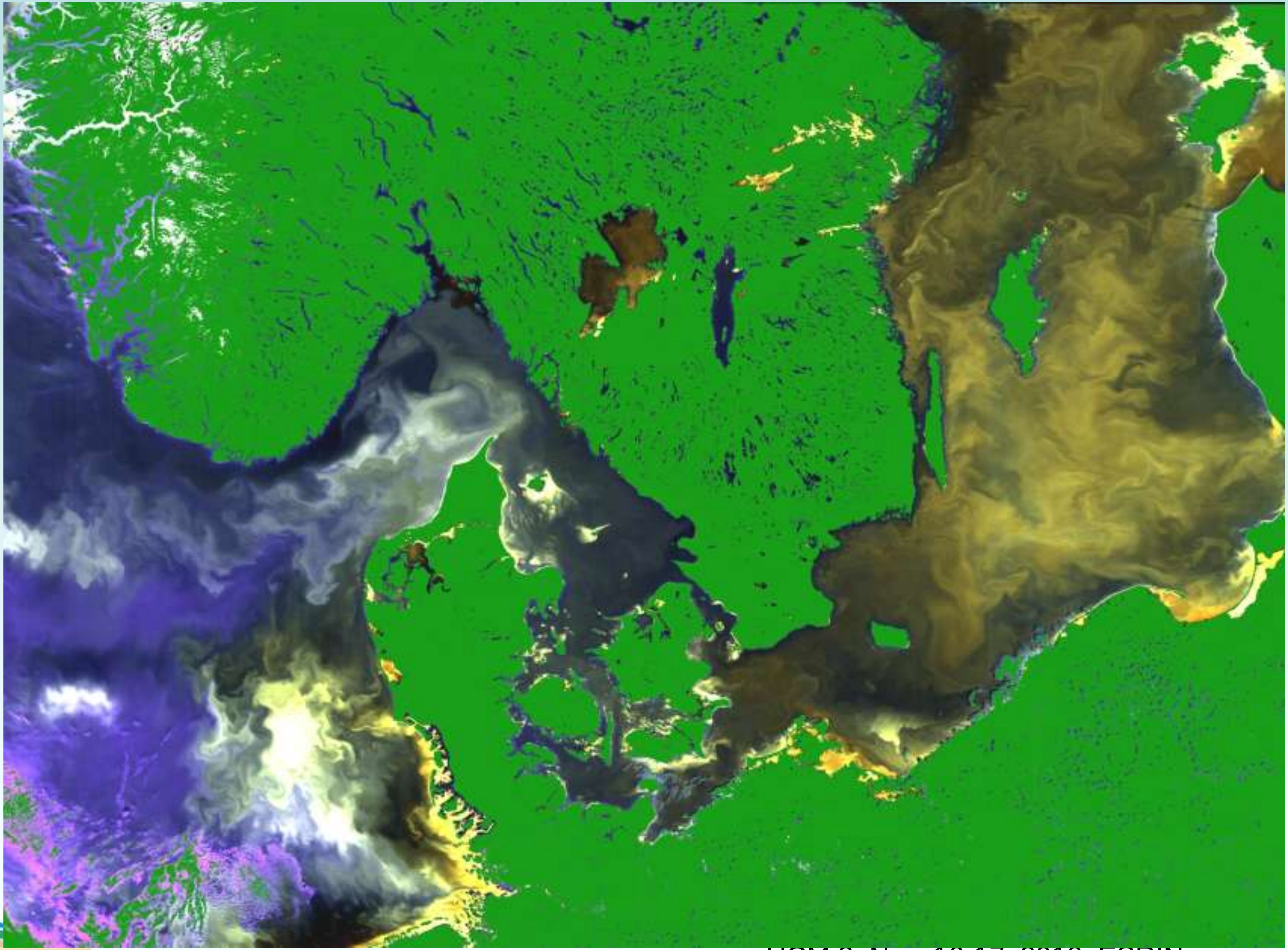
Spatial resolution: 300 m

Swath: 1200 km, 4800 pixel

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



Water leaving radiance reflectance



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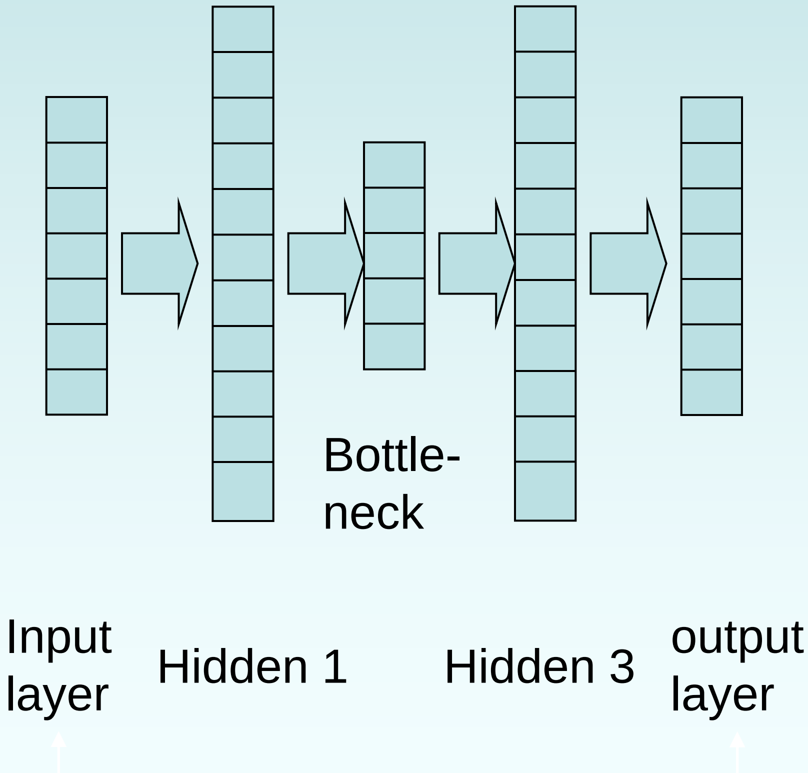
RLtoa Out of Scope

- Purpose
  - Detects top of atmosphere spectra, which are out of scope of the data set used for training of the AC neural network
- Method
  - Method is an auto-associative neural network, which is trained with the same data set and has a bottleneck hidden layer to constrain the relationship between input and output spectra
  - Deviations between the input and output spectra are used as an uncertainty measure and, when above a threshold, to trigger an out of scope flag
- Status
  - Has been developed already for MERIS and tested using a breadboard processor
- ToDo
  - Further tests
  - Re-training according to the final data set for training the AC NN
  - Implementation into BEAM

How to find out of scope spectra?

- Important to detect toa radiance specta which are not in the simulated training data set
- These are out of scope of the AC algorithm
- Auto-associative neural network with a bottle neck layer

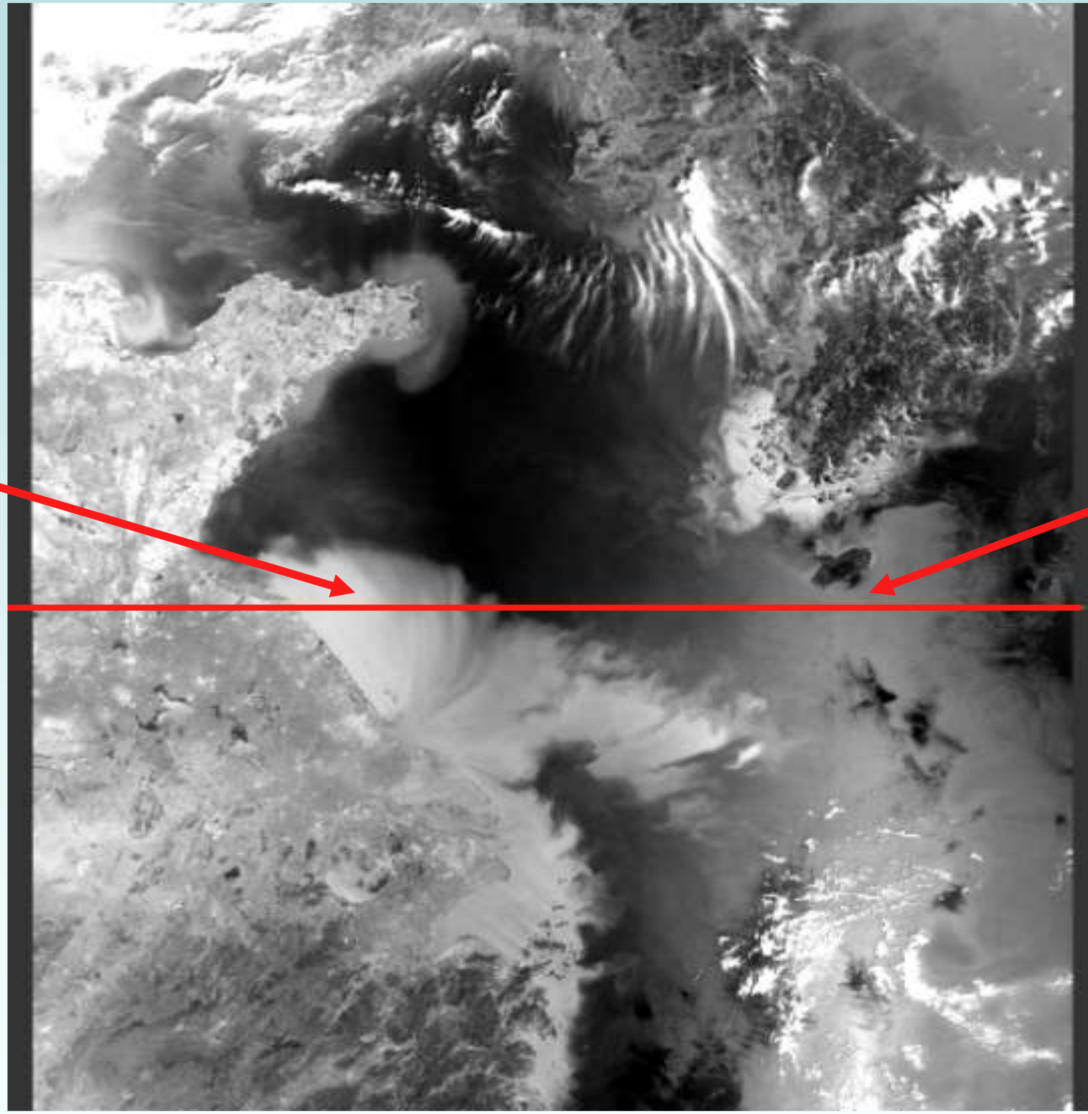


Functions also
as nonlinear PCA
i.e. bottle neck number of
neurons
Provide estimate of
Independent components

For the GAC training data
Set of ~ 1Mio. Cases
Bottleneck minimum was 4-5

Yellow Sea Transect MERIS RLtoa band 5 20030416

Very turbid water



Sun glint

transect

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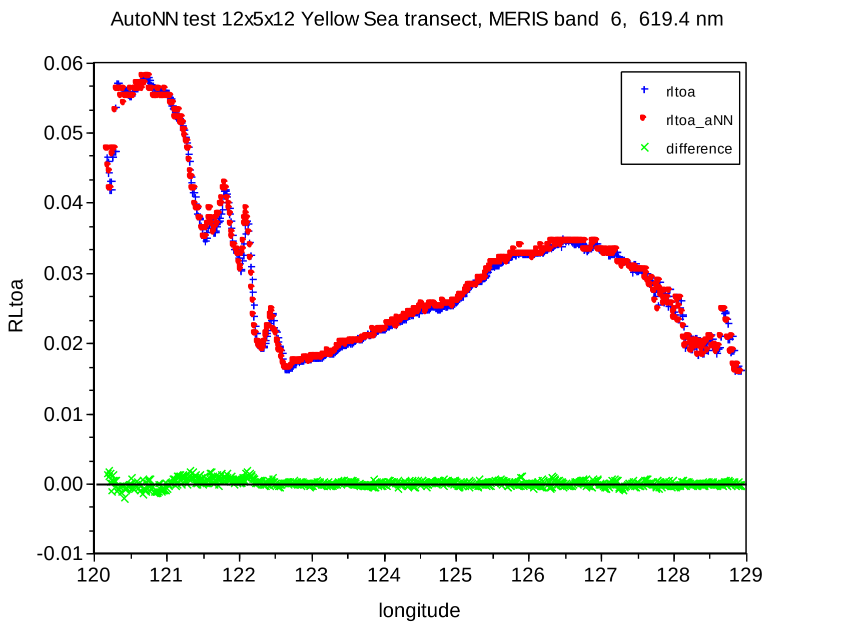
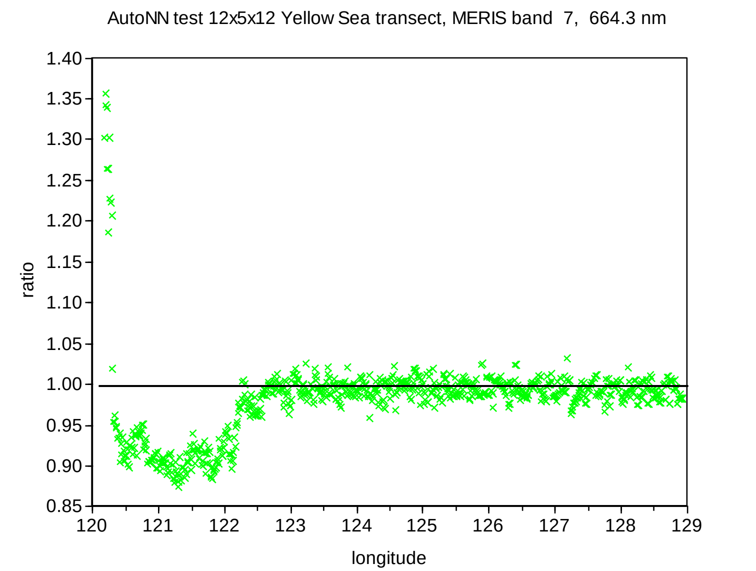
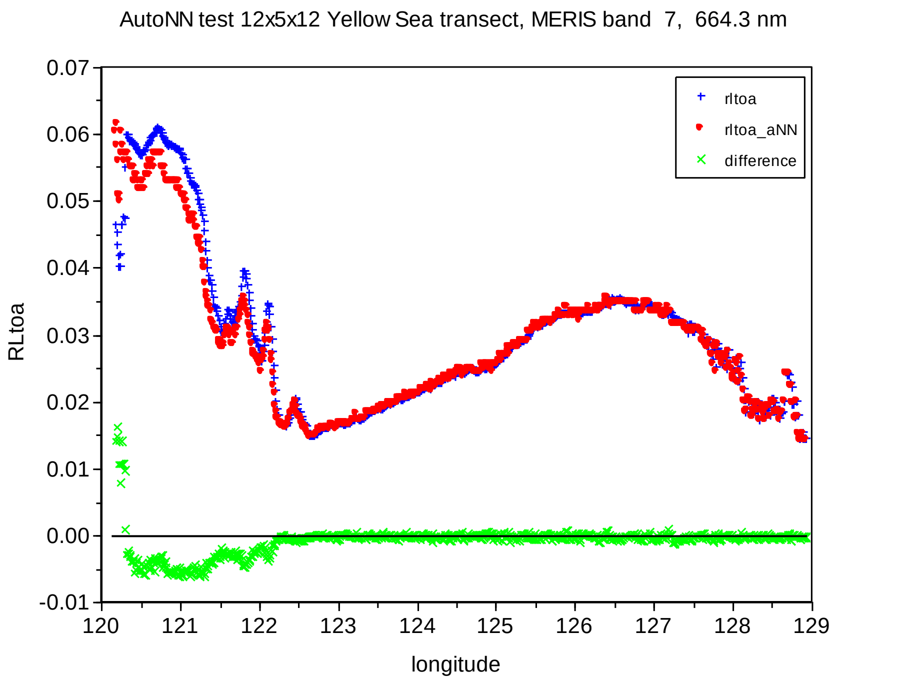
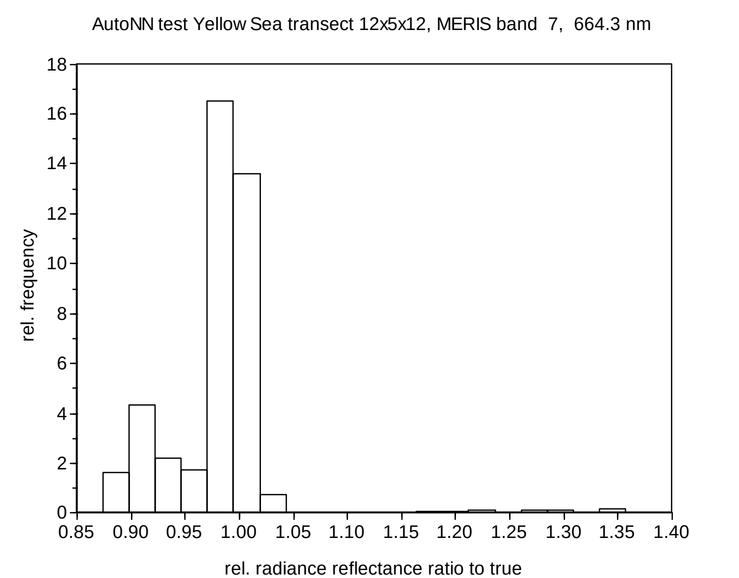


Transect band 6, 7







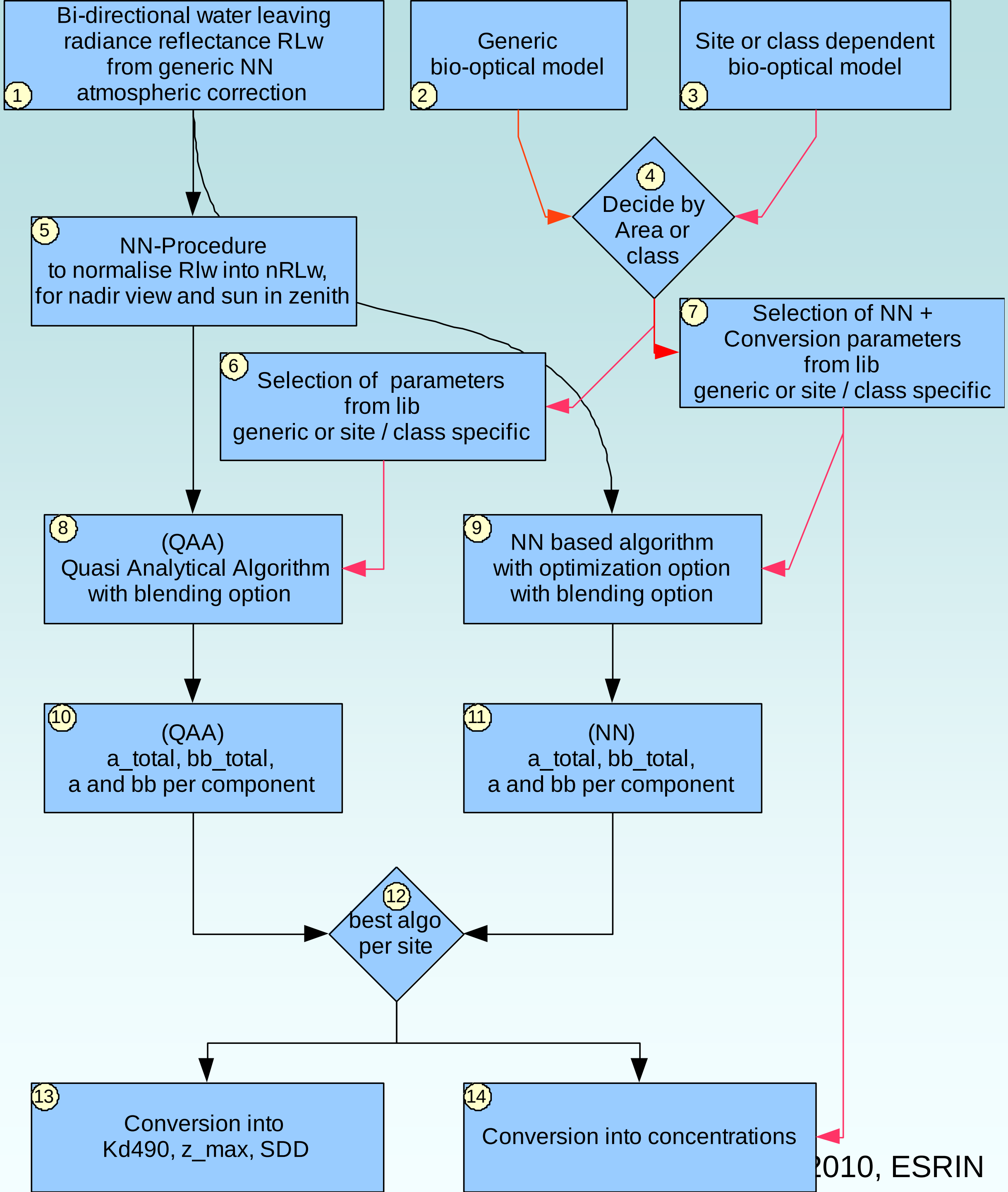
Correction of Land Adjacency Effects

- Purpose
  - Determine and correct the effect of reflectance by land / vegetation surfaces on TOA reflectances of adjacent water areas
- Methods (ICOL + 2 alternatives)
  - ICOL (Improve Contrast between Ocean and Land), it determines the effect of land vegetation on reflectance as a function of the distance of up to 30 km from the coast
  - MUMM algorithm: determines the effect of land vegetation on the similarity spectrum in the near IR and uses this to modify AC
  - NN: include spectra with reflection by land vegetation into training data
- Status
  - ICOL available, but slow for mass production
  - MUMM algorithm: available and tested in Belcolour project, fast
  - NN to be tested, fast
- ToDo
  - Test, compare and assess all three algorithm
  - Implementation into BEAM

Overview Bio-optical Algorithms

- IOPs
- AOPs
- Concentrations
- Uncertainties
- Bottom correction
- Phytoplankton types
- Primary Production

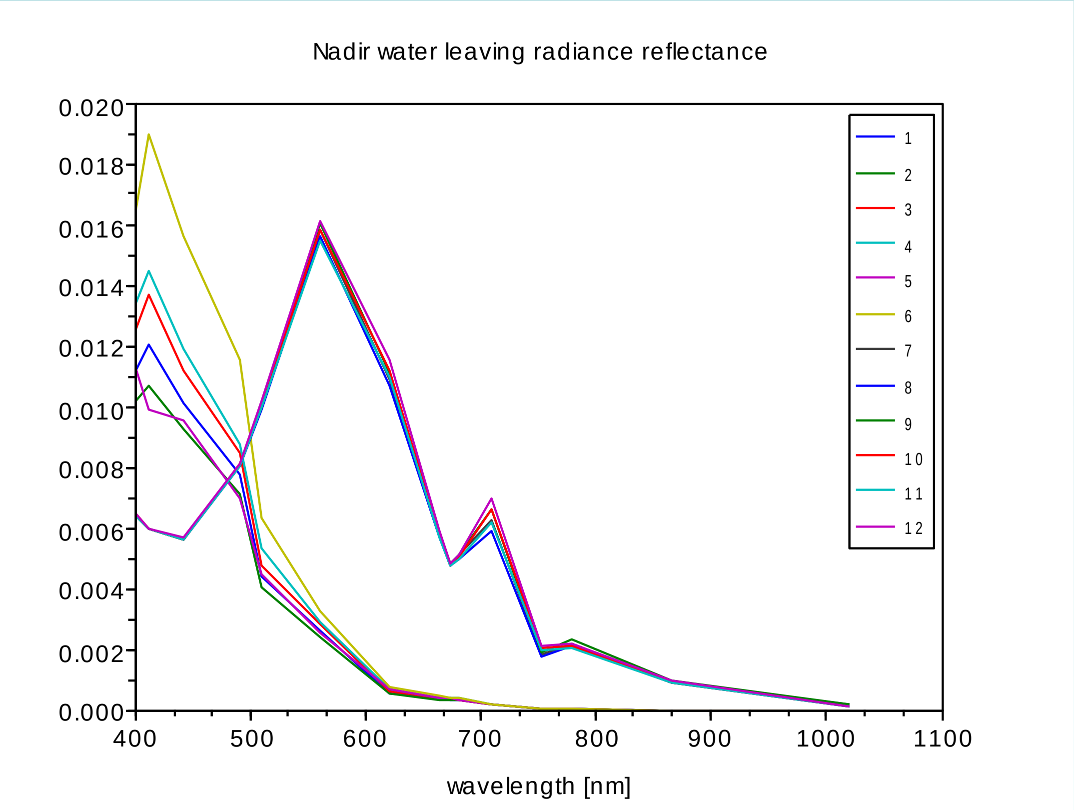
Scheme water processing



IOPs: a_total, a_pig, a_om, b_tsm

- Purpose
  - Determine the total absorption and scattering coefficient of all water constituents and the absorption coefficients of phytoplankton pigments and suspended and dissolved organic matter
- Methods
  - NN with bi-directional RLw and 3 angles as input and a_pig, a_om, b_tsm as output, a_total=a_pig+a_om, optional S, T as additional input, optional forwardNN and optimization procedure
  - QAA semi-analytical algorithm
- Status
  - Both algorithms developed and tested for various conditions
- ToDo
  - Salinity and T effects on scattering and absorption coefficient of pure water has to be implemented in the RTF and used to produce training data set
  - NN with S and T as input has to be trained
  - Version with S and T to be implementation into BEAM

Effect of Salinity and Temperatur

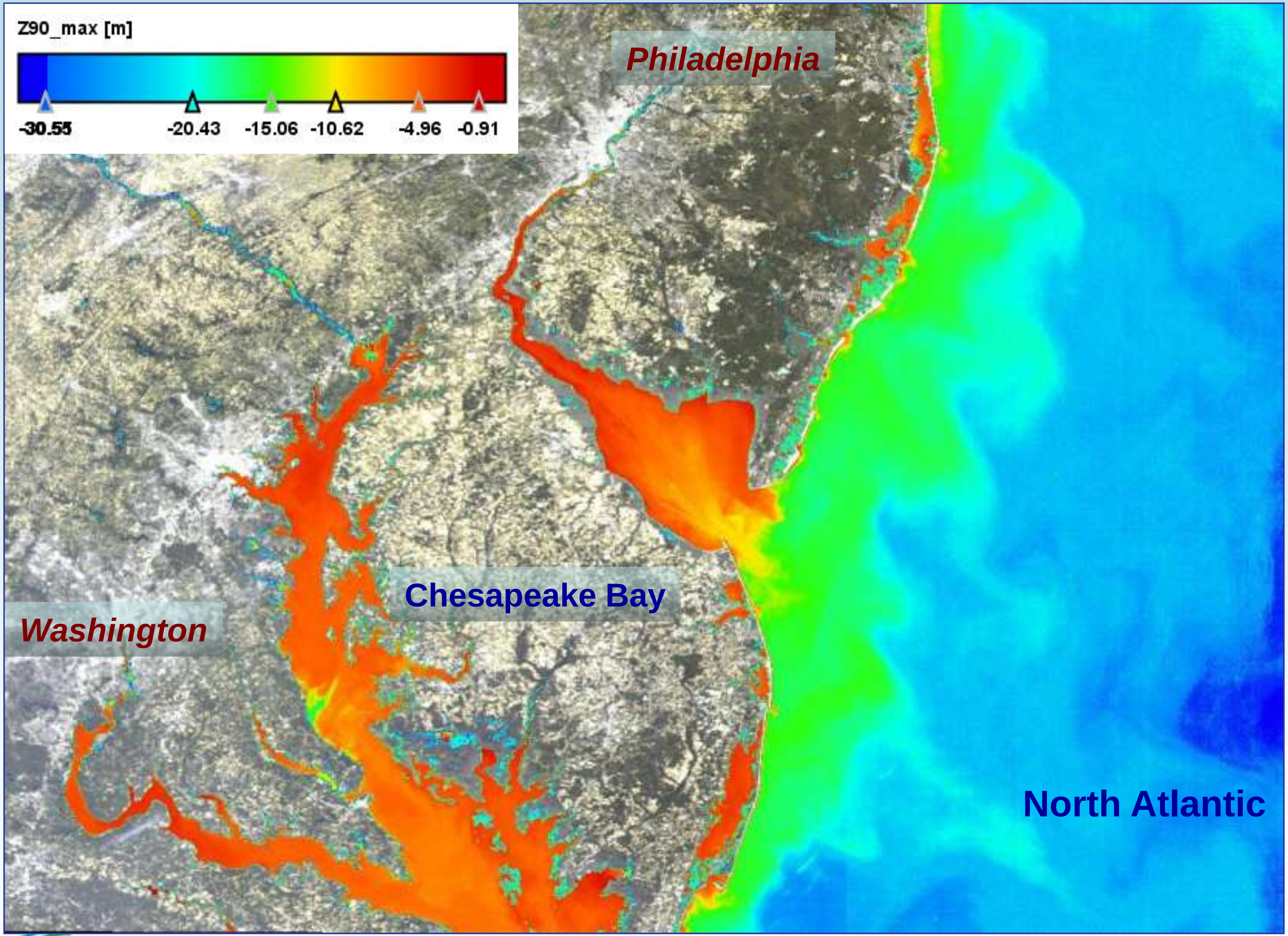


Cases	a	b	S	T
1-3	0.01	0.065	0	30
4-6	0.01	0.065	35	0
7-9	1.0	6.5	0	30
10-12	1.0	6.5	35	0

AOPs: kd_490, kd_lam, kd_min, z90_max, SDD, 1%PAR

- Purpose
  - Determine the transparency of water as the spectral downwelling irradiance attenuation coefficient (kd), the signal depth (z90), Secchi Disk Depth (SDD) and the 1% level of PAR
- Methods
  - NN with bi-directional RLw+angles as input and kd(λ) and 1%PAR as output, then calculate k_min, z90_max from kd(λ)
- Status
  - Kd and z90 are computed using Twoflow model, implemented in BEAM
- ToDo
  - Replace by Hydrolight simulations and train a NN from Hydrolight simulations
  - Implementation into BEAM

MERIS FR USA East Coast 12.6.2008, Signal depth z90



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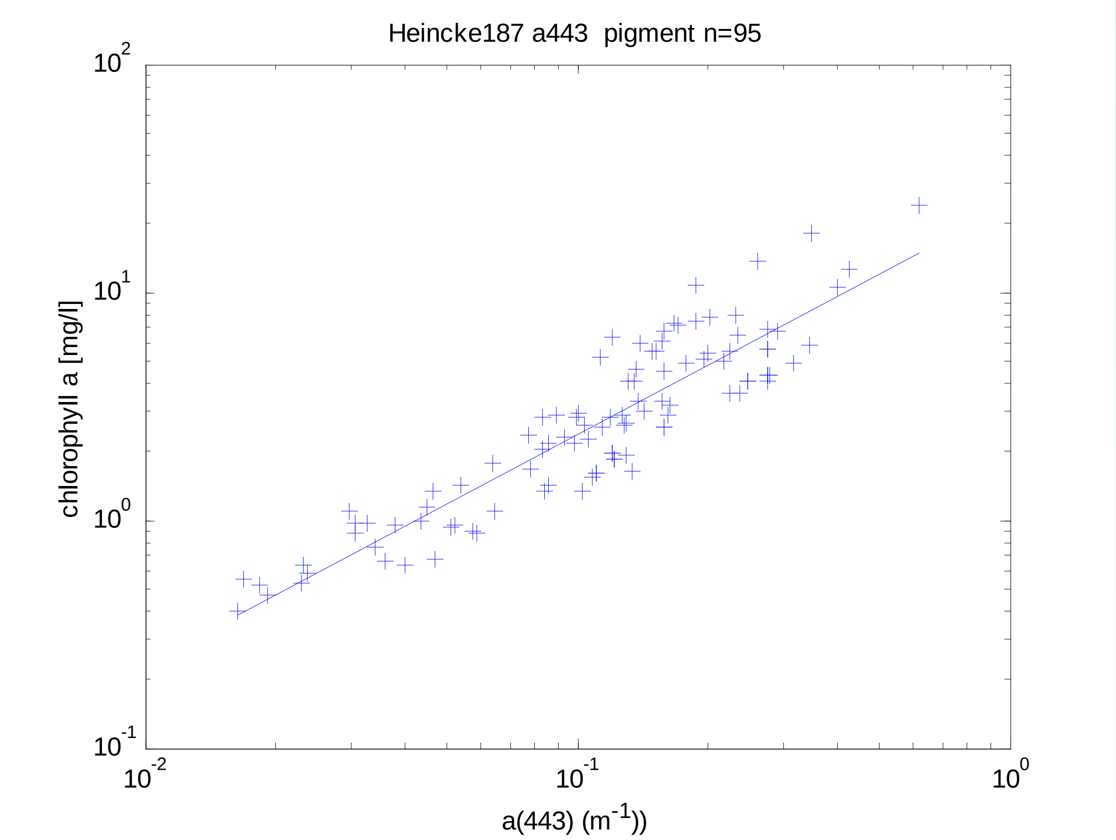
Concentrations: Chl., TSM

- Purpose
  - Convert IOPs into concentrations
- Methods
  - Empirical relationships between IOPs and concentrations and their uncertainties
- Status
  - Implemented in BEAM with conversion factors / formulas, which can be adjusted / defined by the user
- ToDo
  - For local and regional maps replace standard values with values from user supplied data

Pigment absorption – Chl. a, H187



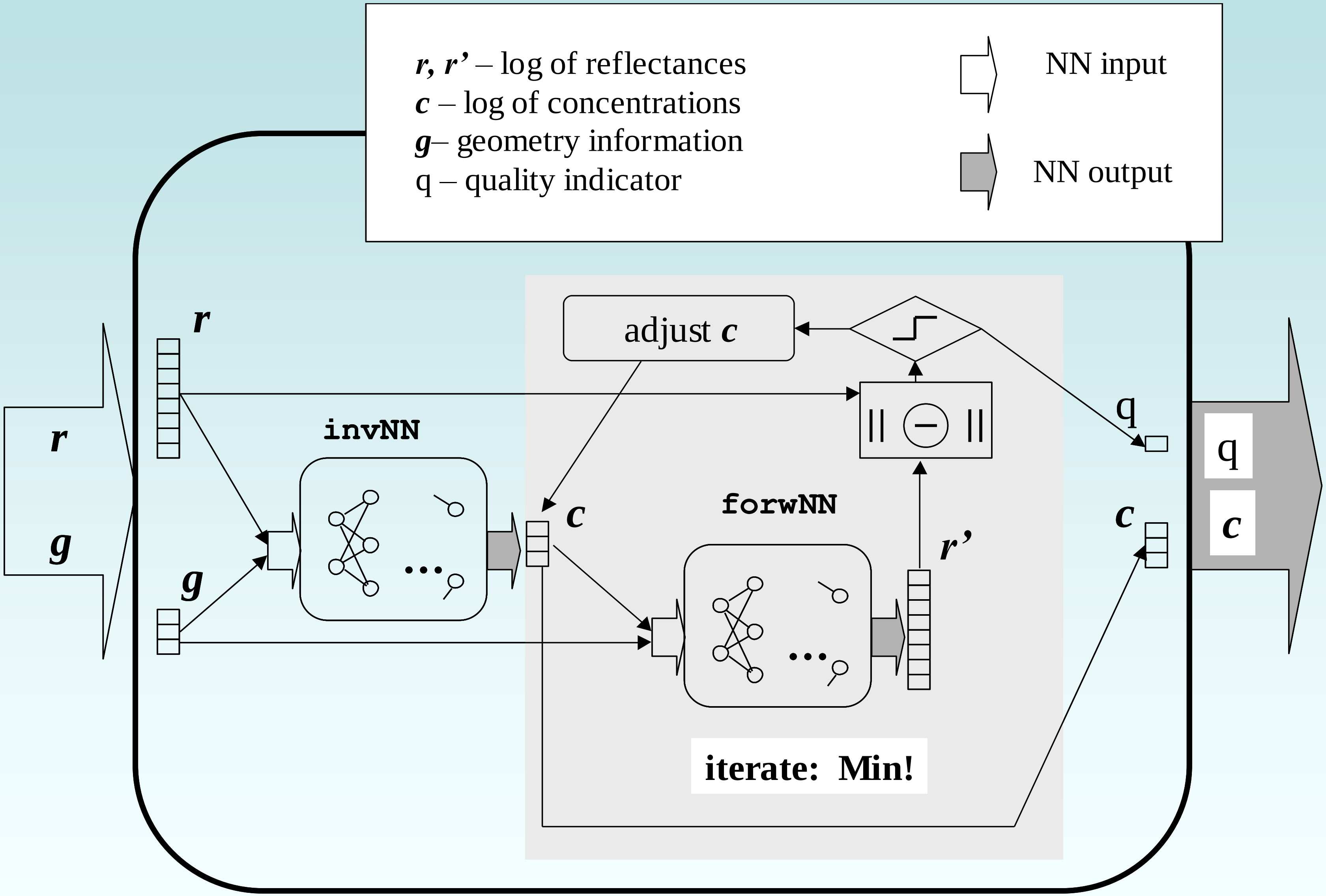
Conversions:

Chl. a [mg m-3] = 21   * a_pig_442 ^1.04

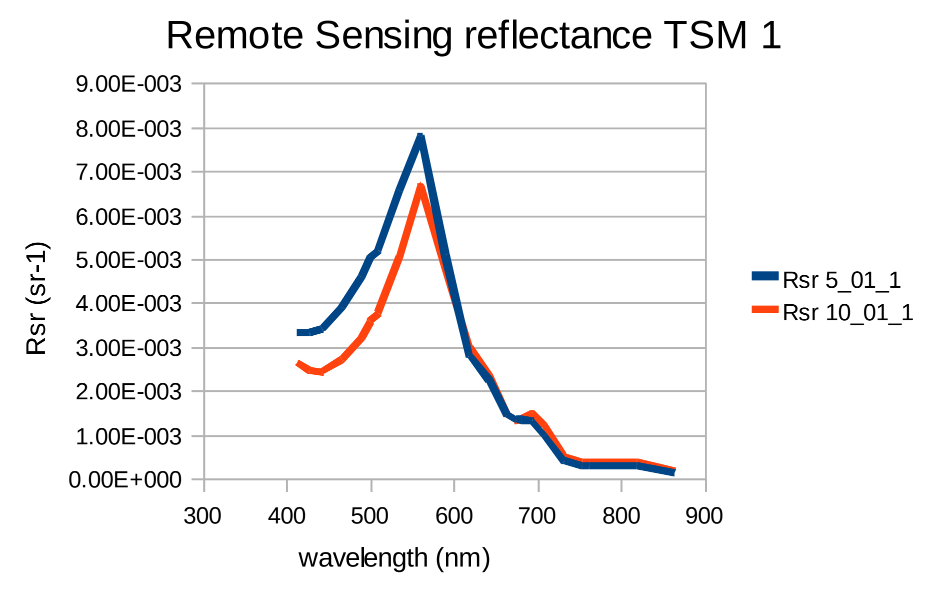
Out of Scope and Uncertainties

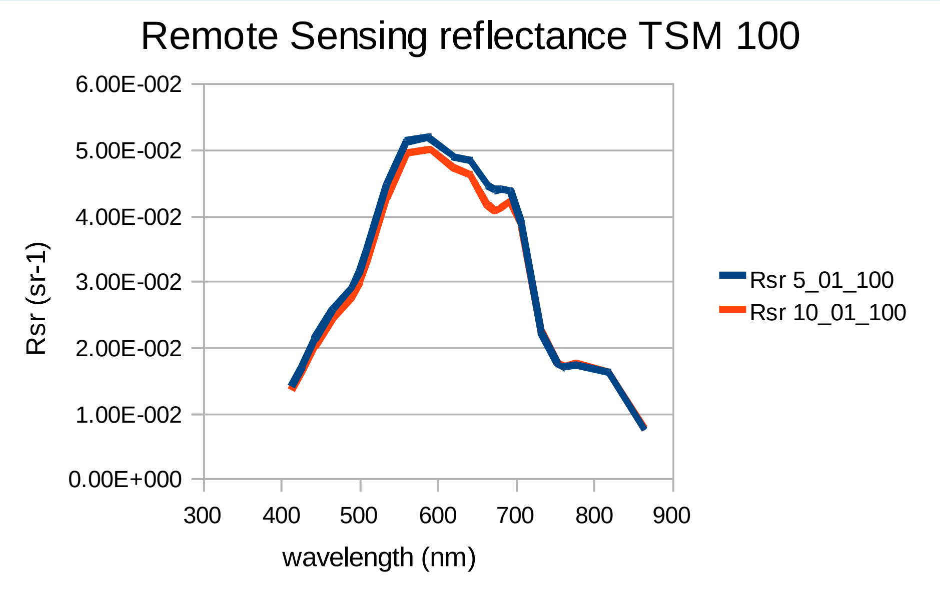
- Purpose
  - Determine uncertainties for RLw, IOPs, AOPs, concentrations
- Methods
  - aaNN for detecting out of scope spectra
  - Backward-forward NN for detecting out of scope spectra
  - Uncertainty range from NN-test analysis and optimization inversion
  - QAA direct error propagation computation
  - Additional uncertainties for concentrations from regression
- Status
  - All methods available, used and tested
- ToDo
  - Update for final NNs
  - Test with breadboard processors
  - Implementation of final procedures in BEAM

NN Engine with optimization



Sensitivity at different concentration ranges and spectral bands





Chl. 5/10 mg m-3
TSM 1 g m-3
aYS(443) 0.1 m-1

Chl. 5/10 mg m-3
TSM 100 g m-3
aYS(443) 0.1 m-1

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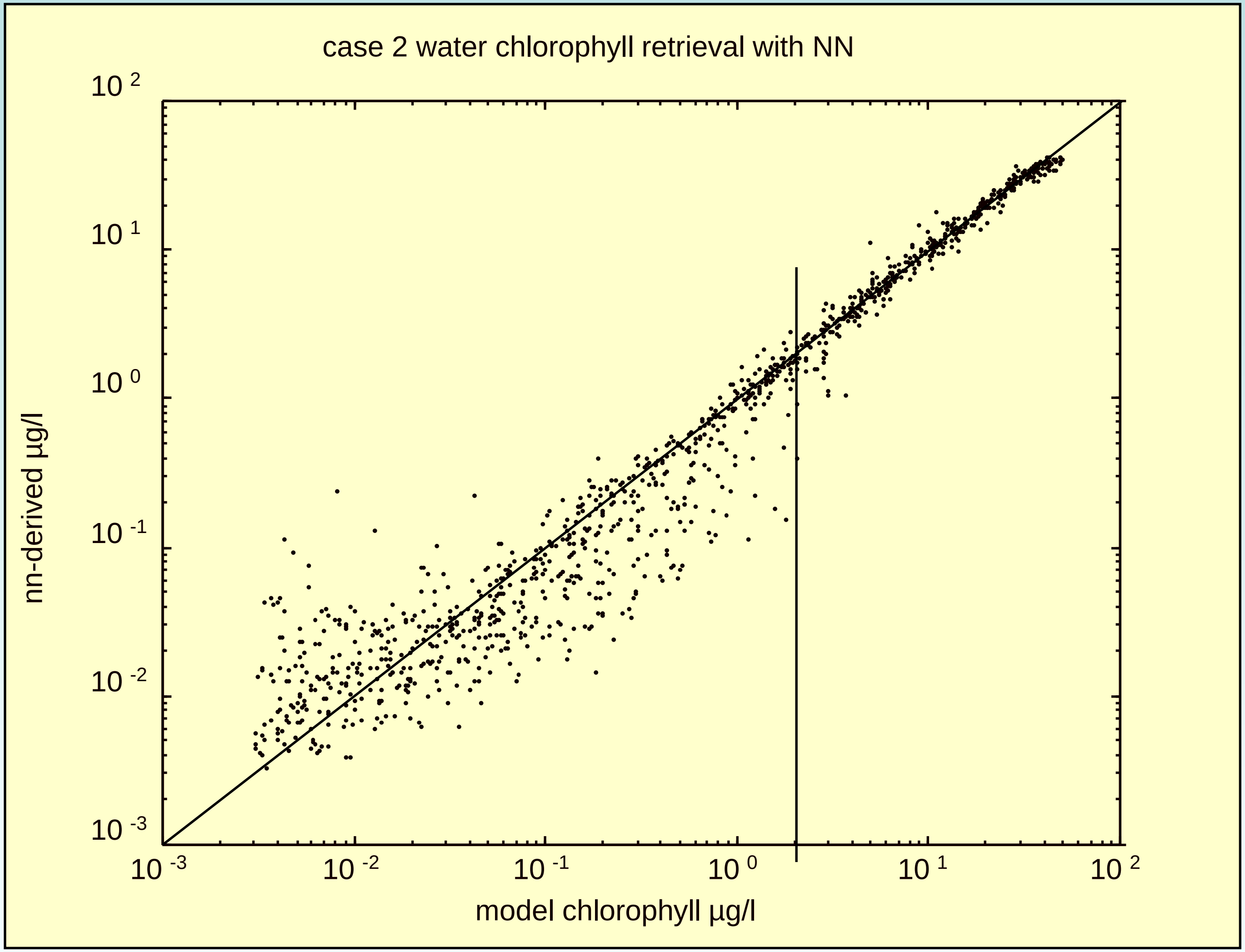
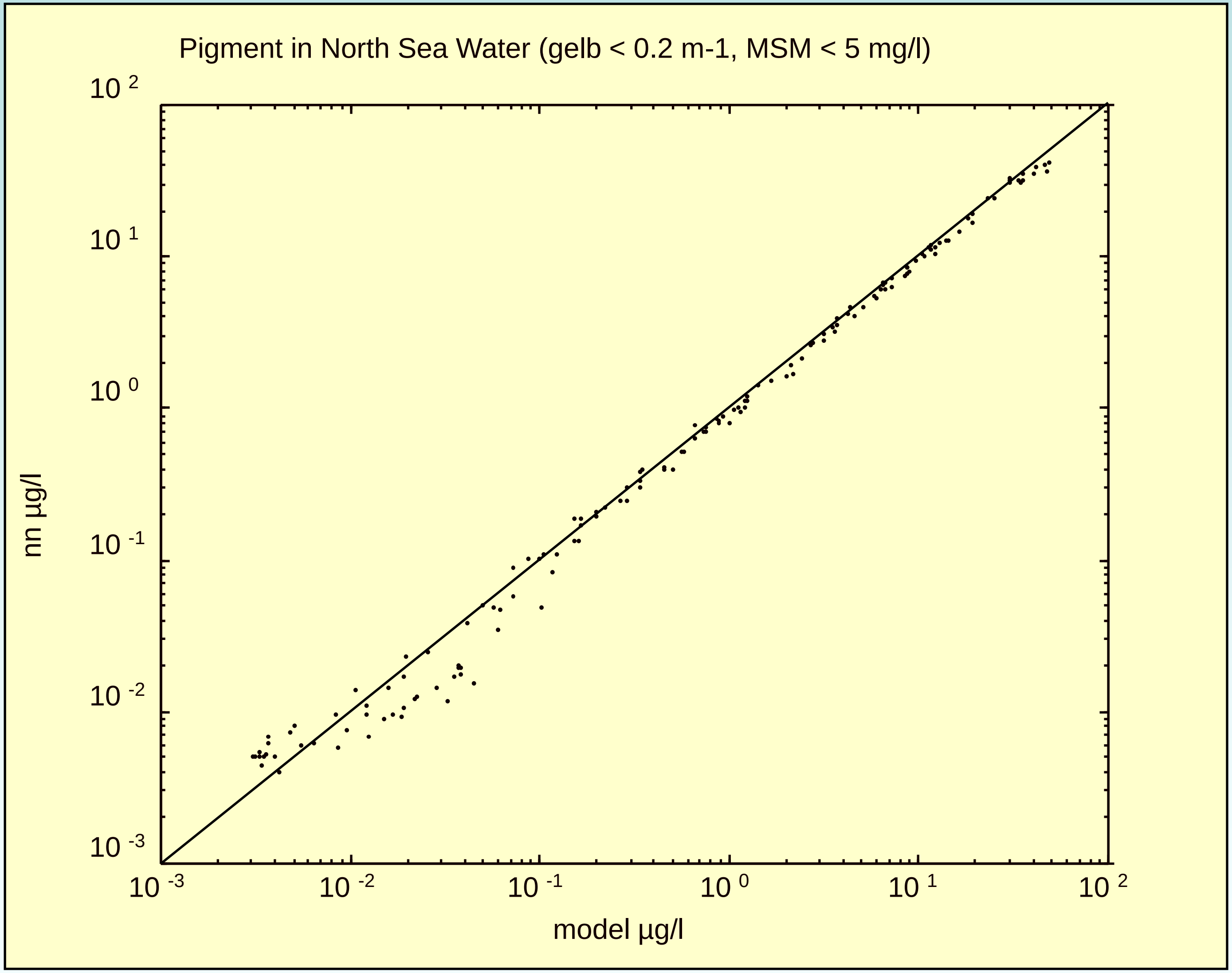
NN sensitivity test, all cases



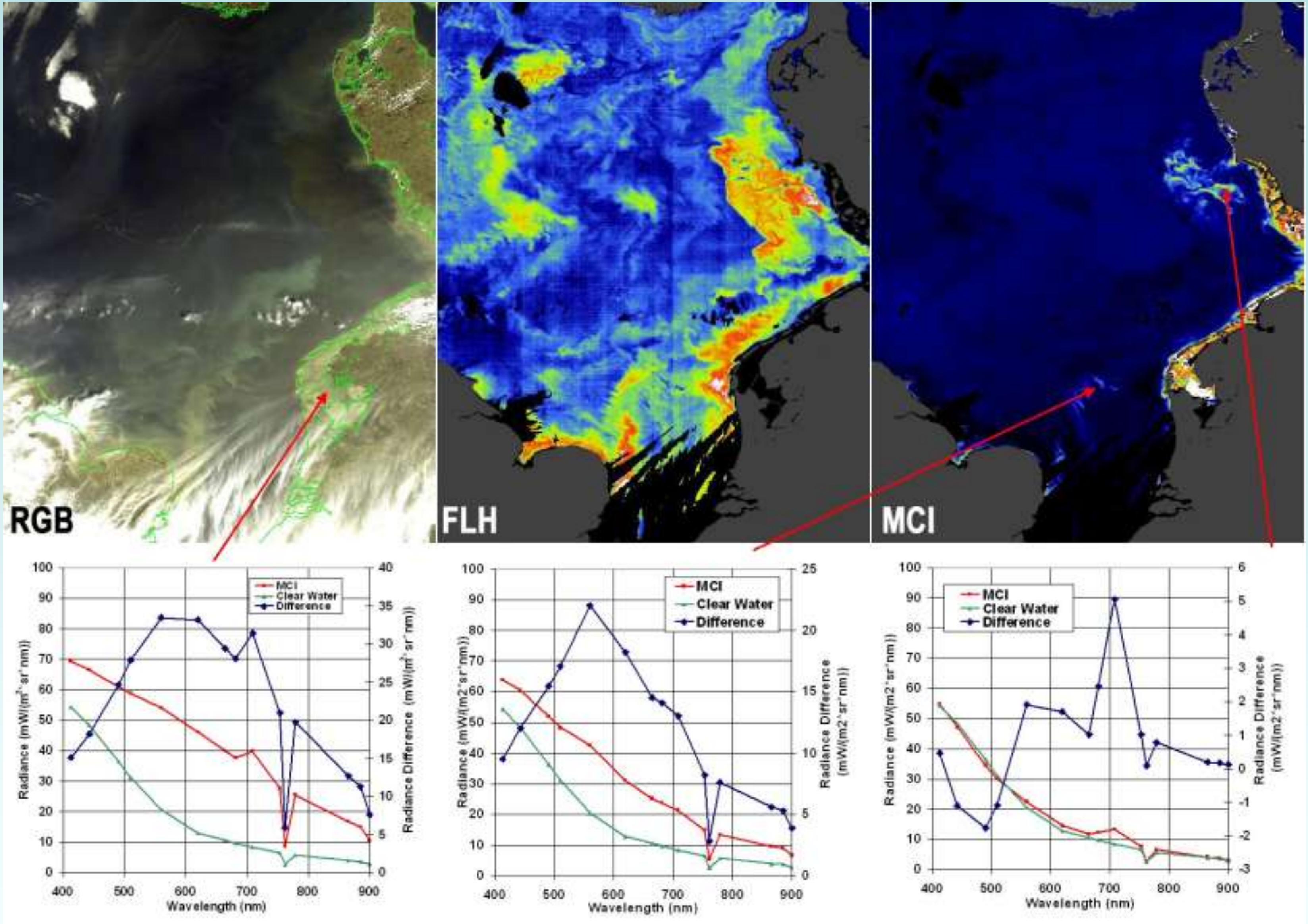
NN sensitivity, typical North Sea water



Special Algorithms

- FLH / MCI
- Bottom reflectance
- Phytoplankton Types
- Primary production
- Fuzzy logic classification

MCI / FLH



Bloom of Verrucophora farcimen (Dictyochophyceae / Heterokonta)
former: Chatonella verrucolosa (Raphidophyceae)

J. Gower

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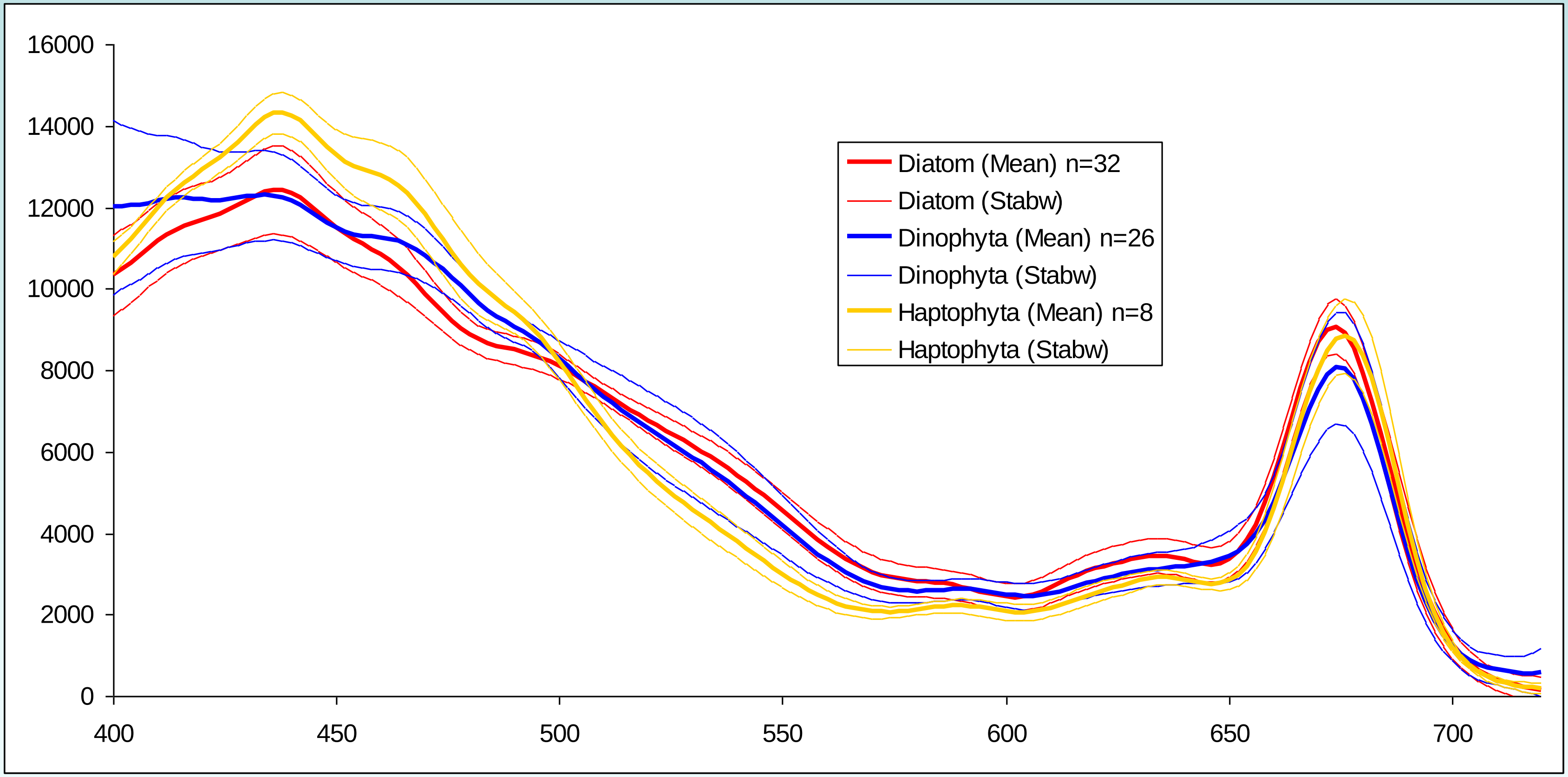
Bottom reflection

- Purpose
  - Exclude or correct bottom reflection influence on RLw
- Methods
  - Exclude areas where bottom reflection problem cannot be solved
  - Exclude or minimize problems by using only bands in the red spectral range where pure water absorption limits the penetration depth
  - Simulate RLw with bottom reflection and water depth, NN with input of water depth and bottom reflection and Z.Lee Algorithm
- Status
  - Method available
- ToDo
  - further tests and implementation
  - Analyse baytheymetry, bottom reflection and water optical properties of the the site, which is affected by bottom reflection and assess the correction and its importance

Phytoplankton Types

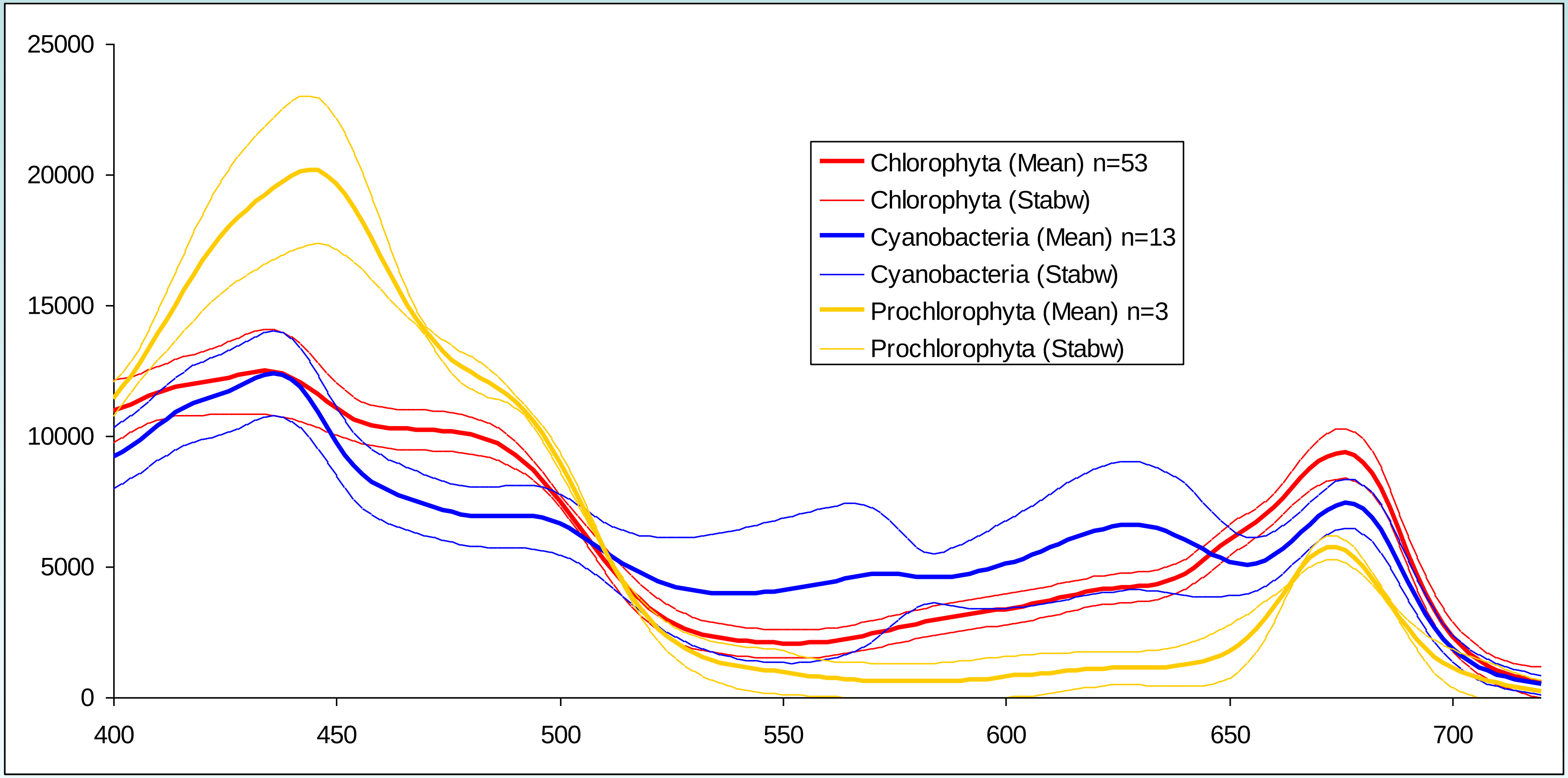
- Purpose
  - Determine phytoplankton types (functional or taxa) from RLws
- Methods
  - Include absorption spectra of different types with their variability as components in the algorithms
  - For NN include these types in the simulation of the training data set and design the NN with more output components related to the types
  - Try derivative spectra for identification
  - Detect exceptional blooms in TOA reflectance spectra, apply alternative atmospheric correction for extreme blooms (e.g. floating Cyanobacteria)
  - Use MCI algorithm to detect these blooms
  - Define an alternative concentration index, e.g. area covered
- Status
  - All alternative methods have to be developed and tested
- ToDo
  - Develop and test alternative procedures

Normalized in vivo Absorption spectra 1



By courtesy of Steffen Gehnke

Normalized in vivo absorption spectra 2

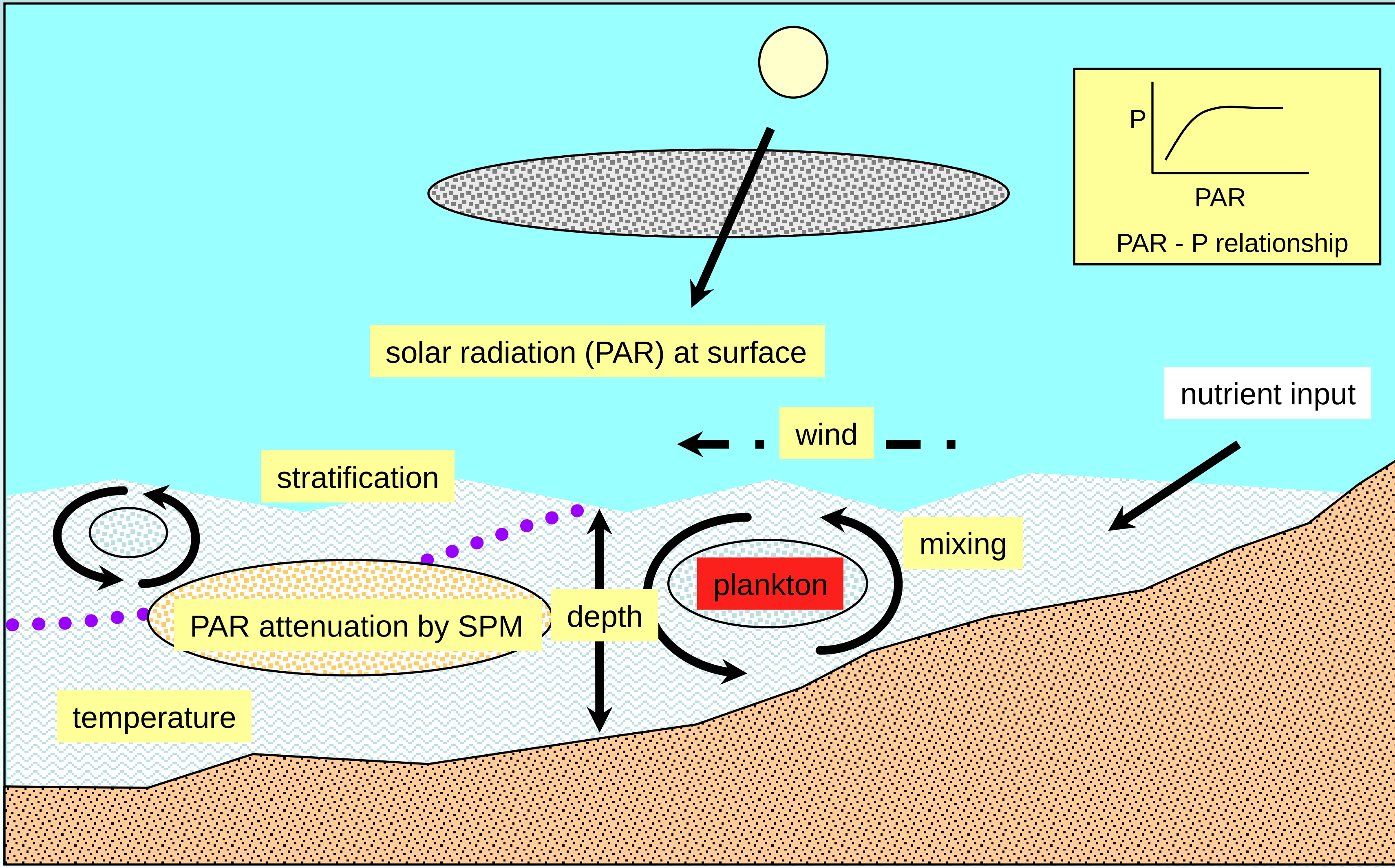


By courtesy of Steffen Gehnke

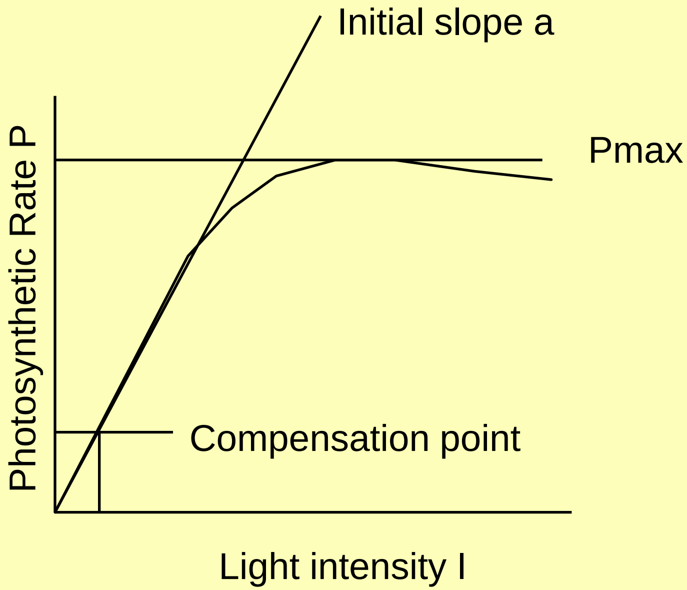
Primary Production

- Purpose
  - Determine daily water column primary production by phytoplankton or potential primary production, unit is per m2 and per 24 h
- Methods
  - Computation by a PP model, which needs chlorophyll, spectral attenuation, PAR over the day, depth of mixed layer and PI parameters
  - Use empirical relationship from biomass, day of year, T
- Status
  - PP model for MERIS for coastal water is available and has been tested
- ToDo
  - Make model operational, replace by NN
  - Compile PI parameters for different sites

Primary Production in Coastal Waters



Scheme for computing PP



PI-relationship

$$P(z) = \frac{B(z) \cdot \alpha \cdot I(z, \lambda)}{\sqrt{1 + (\alpha \cdot I(\lambda, z) / P_{max})^2}}$$

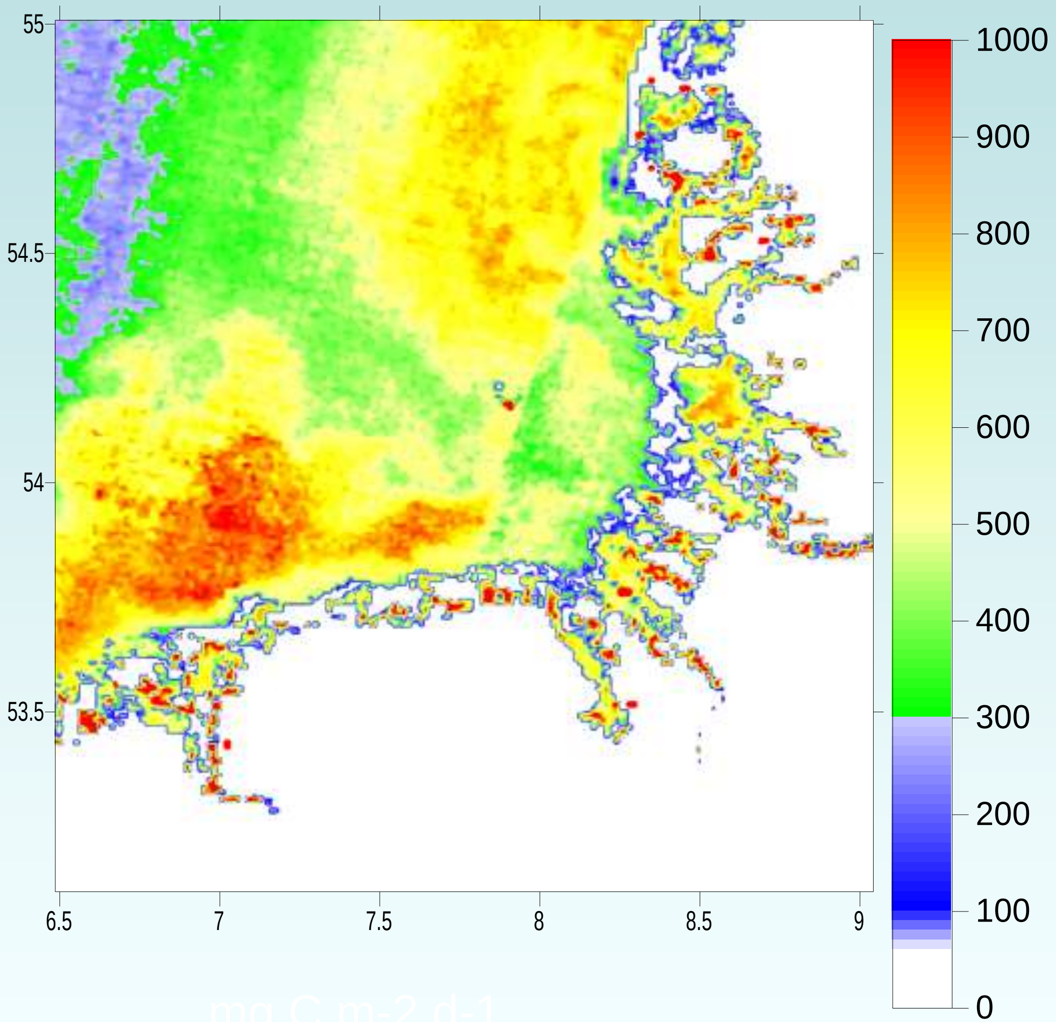
Photosynthesis Equation

Different versions of PP model

All spectral

- PAR available radiation
- PUR (usable radiation
- PSII absorption by photosystem II

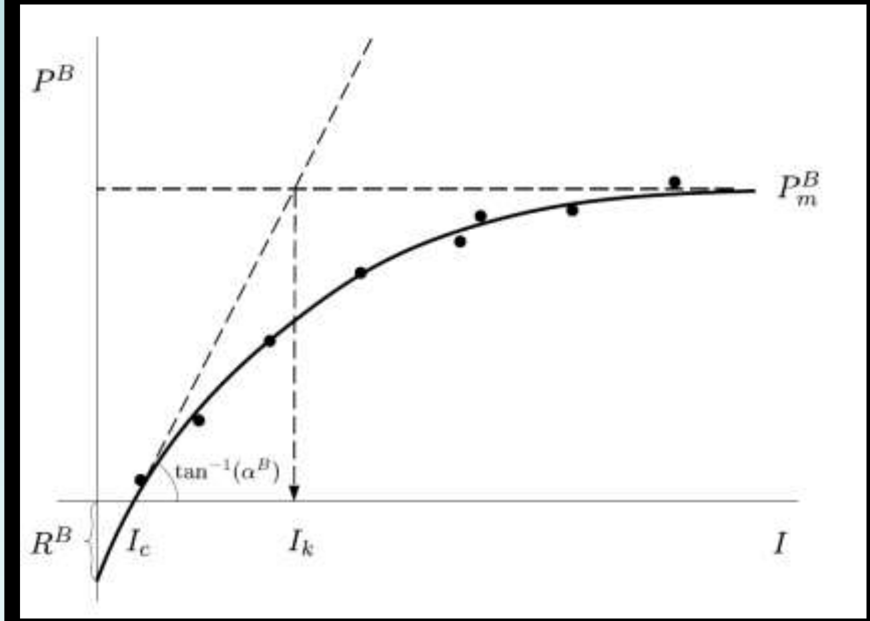
PP Map based on MERIS data

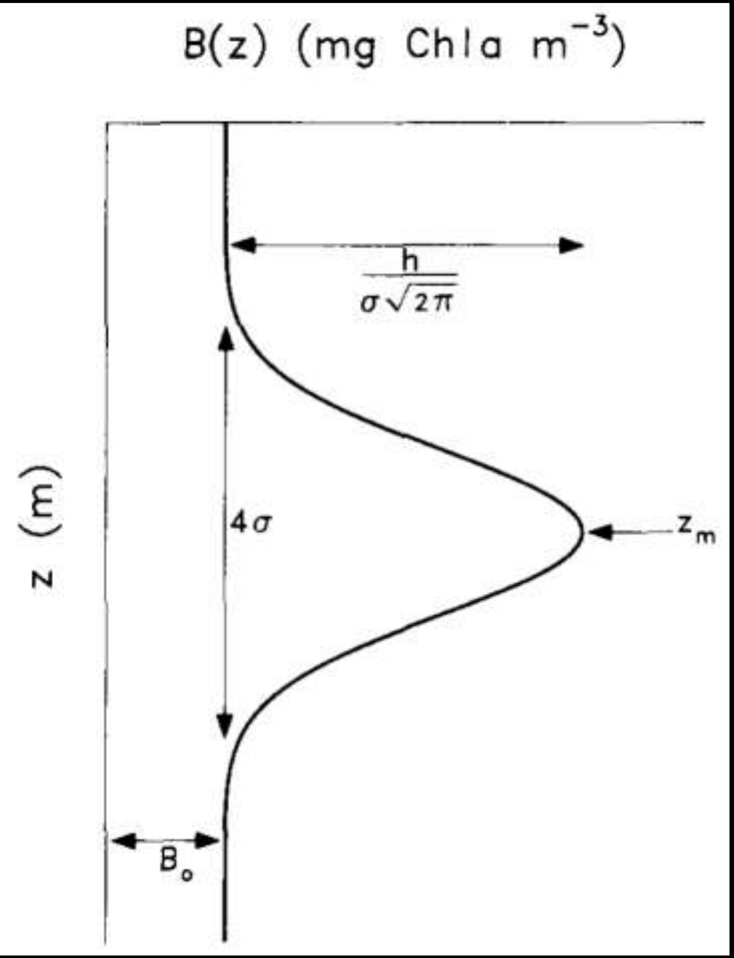


mg C m-2 d-1

Primary Production German Bight

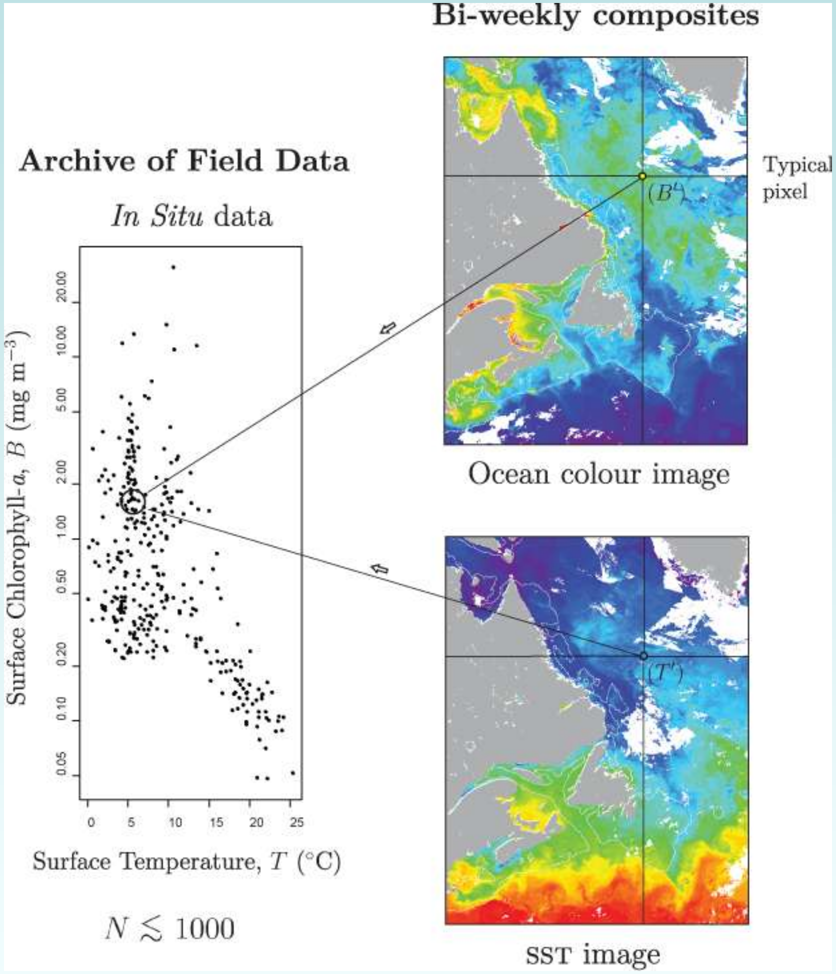
Parameter Assignment for Calculation of Phytoplankton Production

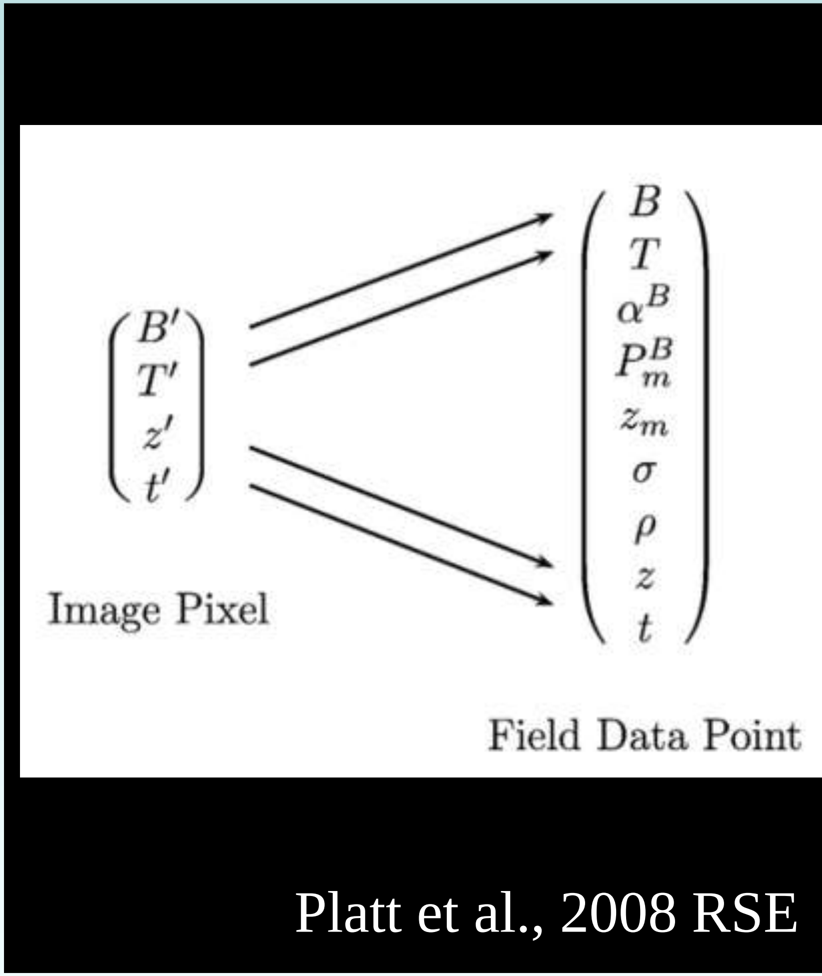




At each pixel, we need to assign two sets of parameters: (i) photosynthesis response, and (ii) vertical structure of chlorophyll.

Nearest-Neighbour Method for Parameter Assignment

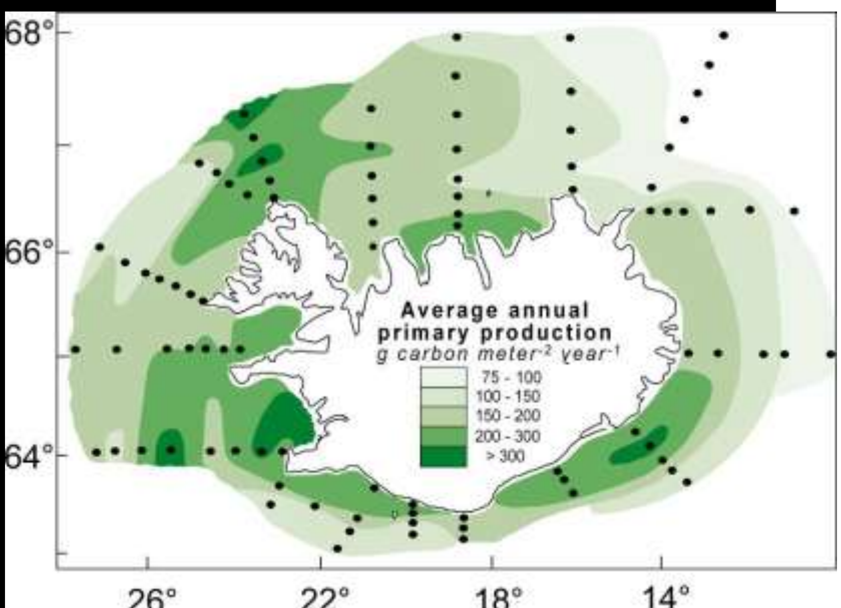


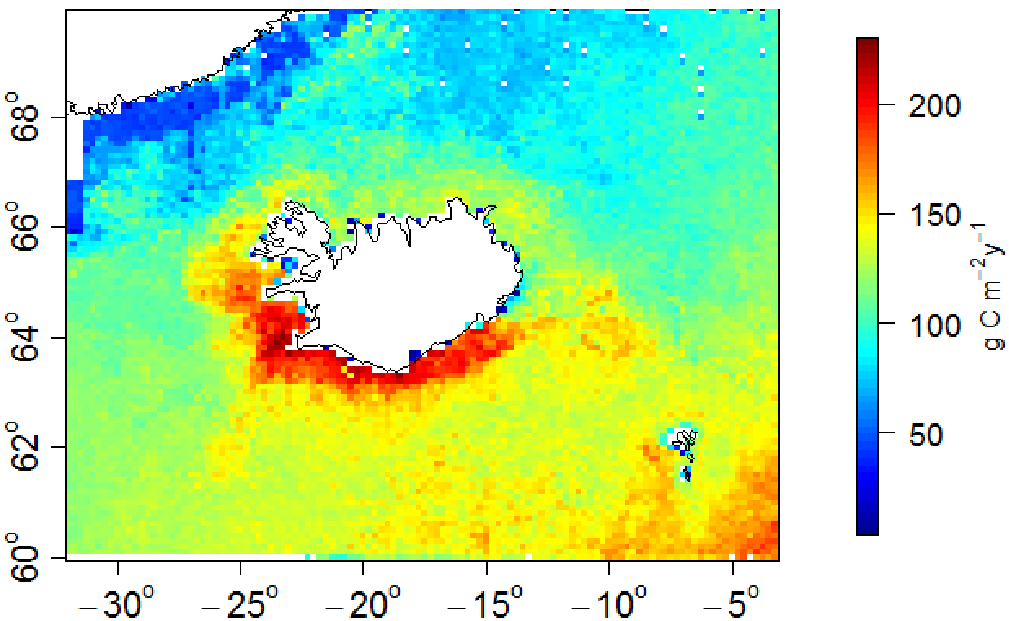


Assigns parameters based on local chlorophyll and temperature, using an archive of parameters organised according to chlorophyll and temperature.

Primary Production around Island through Water Column for Period March - October

Based on data of Thorunn Thordardottir (1925 - 2007)



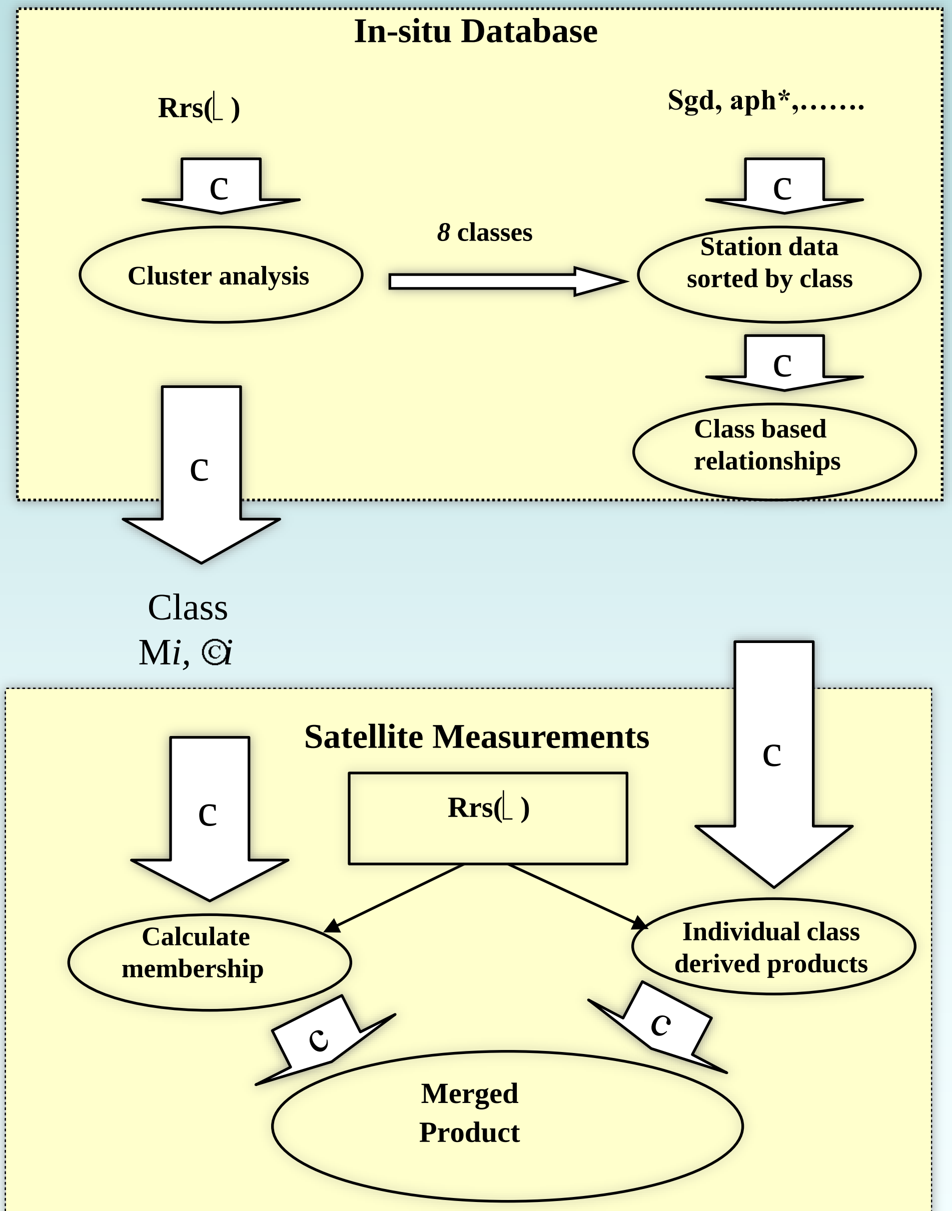


Platt / Sathyendranath

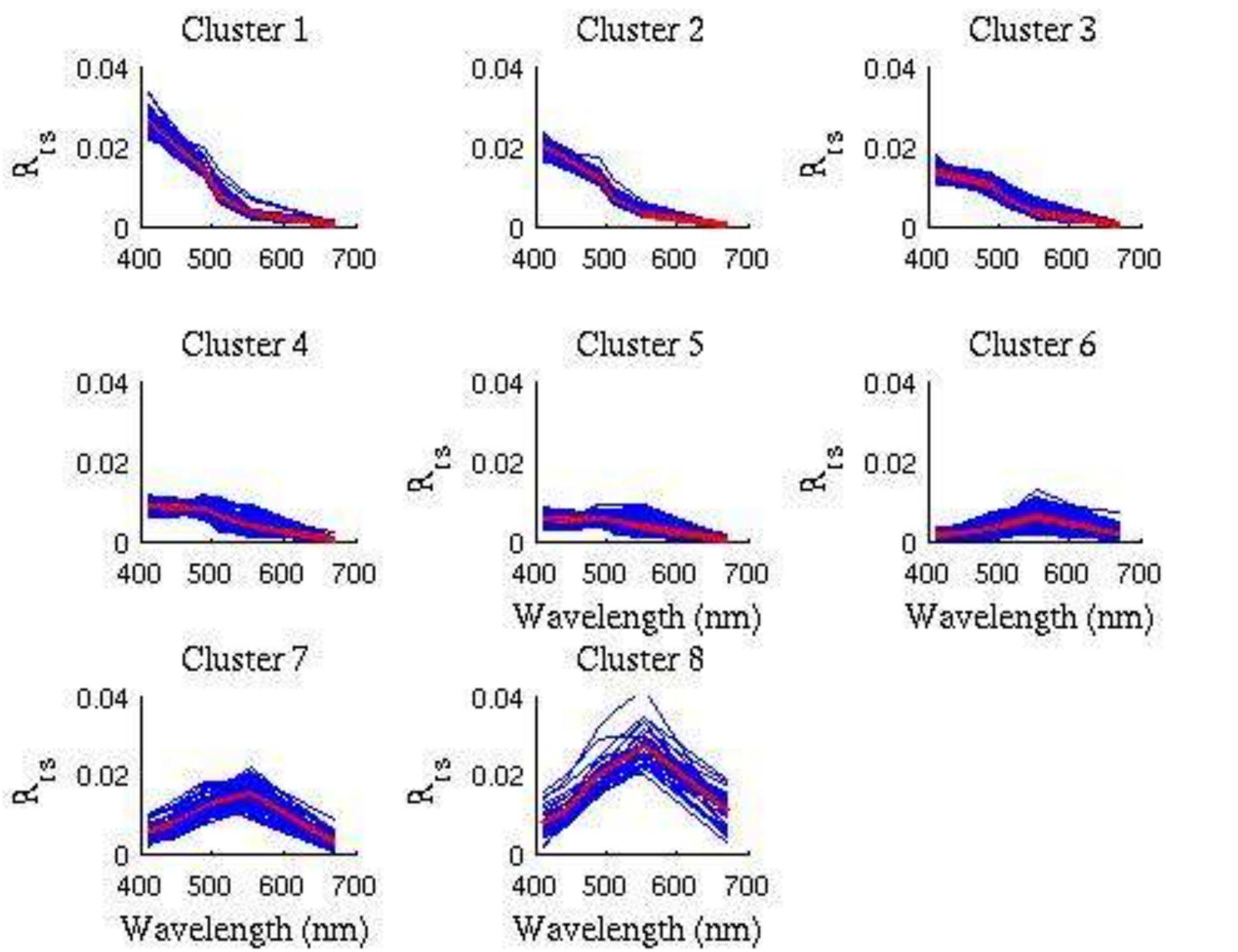
Fuzzy Logic Classification (M. Dowell)

- Different optical water types
- Classification based onoptical properties / reflectance spectra
- No fixed classes but likelihood of membership to a class
- Algorithms for different types of water

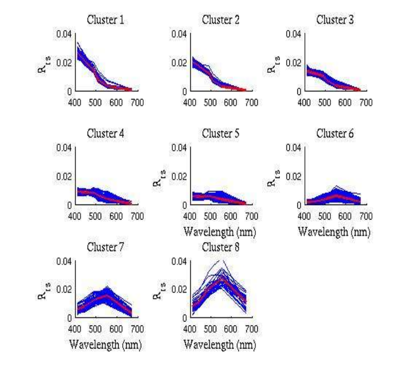
Conceptual Framework for Case based algorithms

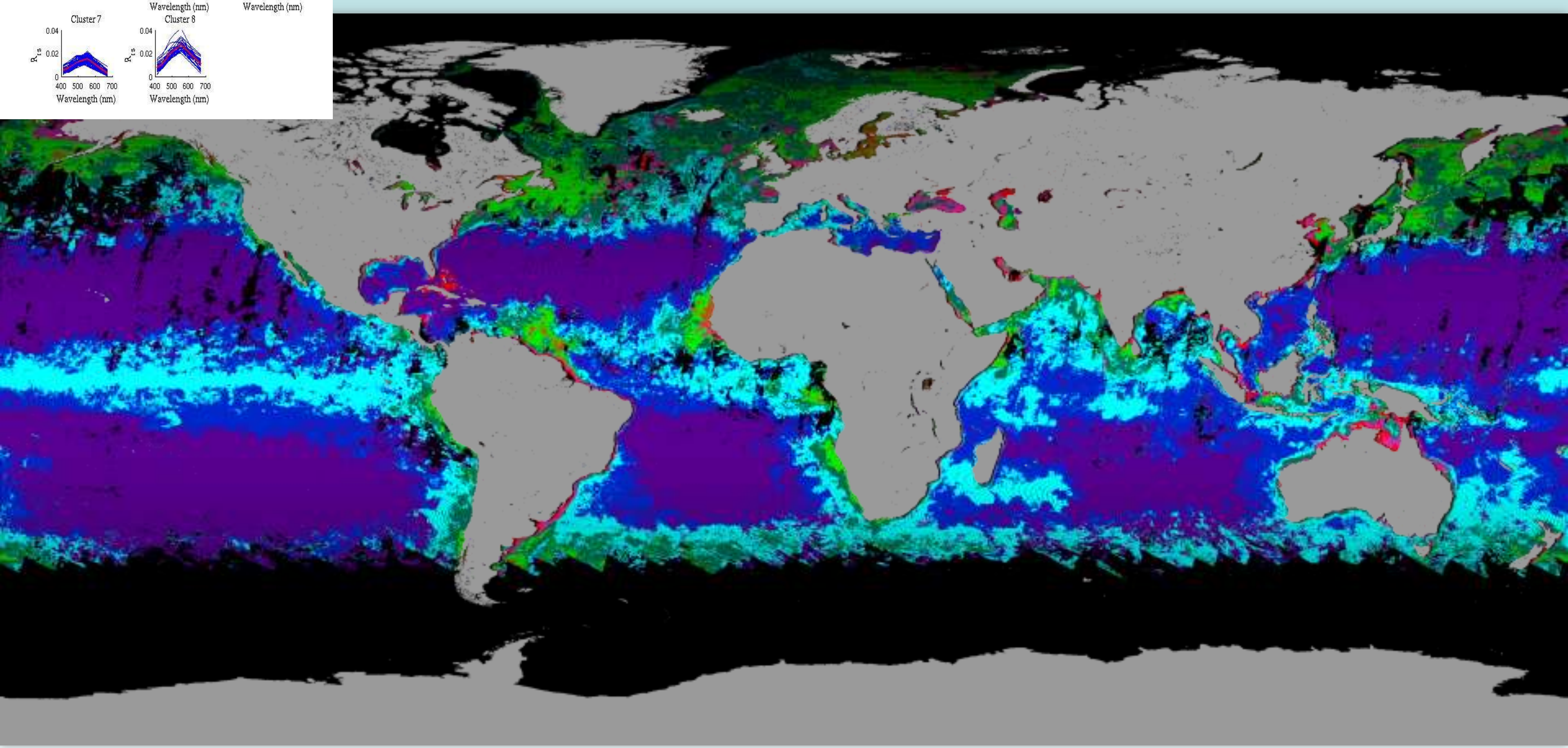


8 objectively identified classes in radiance space



May 2004 MERIS Global Composite





Class 1 Class 2 Class 3 Class 4 Class 5 Class 6 Class 7 Class 8

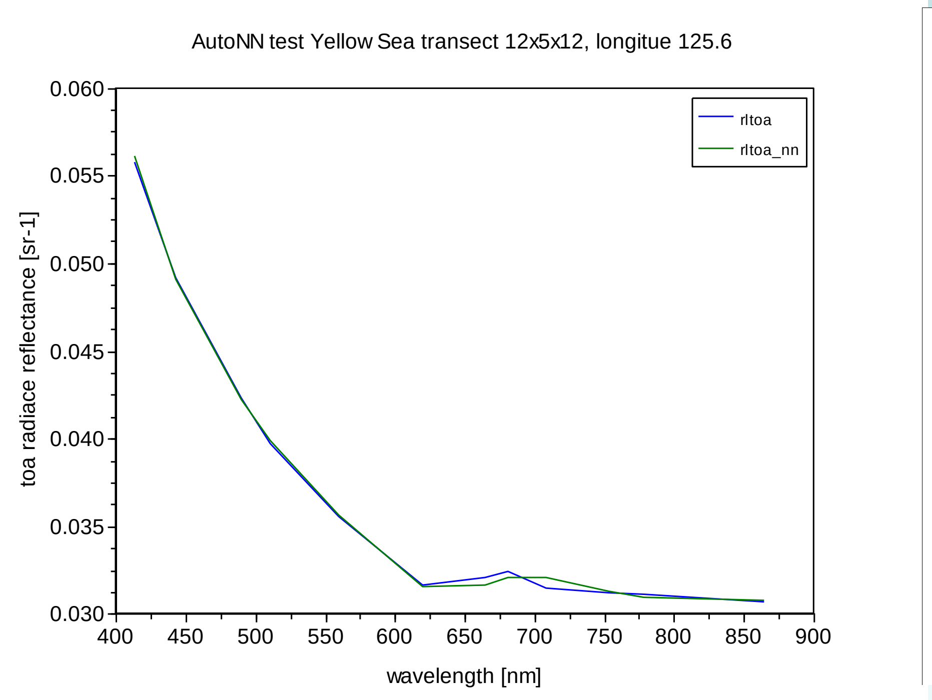
Algorithms Interfaces / User Interaction

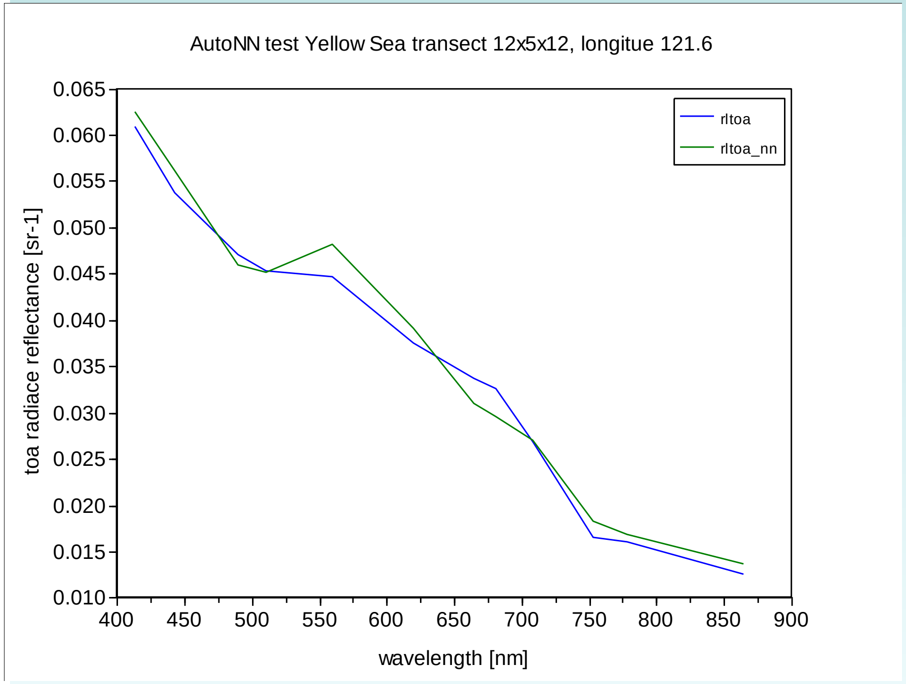
L	Product	Use
1	L1 data: radiances at top of atmosphere as provided by ESA	User processing chain
1	L1P data: further corrections by CC processor	User AC, FLH, MCI
2	L2 RLw: water leaving radiace reflectances (after atmospheric corr.), == remote sensing reflectance RLw = Lw/Ed (sr-1)	Apply user water algorithm, takes angular effects into account
2	Lw: fully normalized water leaving radiance reflectance (sun in zenith, viewing to nadir)	Apply user water algorithm
2	Total absorption and scattering coefficient	Apply user component algorithm, primary production computation
2	Absorption and scattering coefficients for different components (phytoplankton, suspended matter etc.)	Apply user conversion algorithm to compute concentrations, primary production computation
2	Concentrations: dry weight of total suspended matter (TMS) (g m-3) or chlorophyll a (mg m-3)	Use as endproduct or as proxy for other water quality indicators
2	Irradiance Attenuation coefficient, z90	Visibility, primary production, turbidity,Secchi disk depth

Site dependent Algorithms: User input

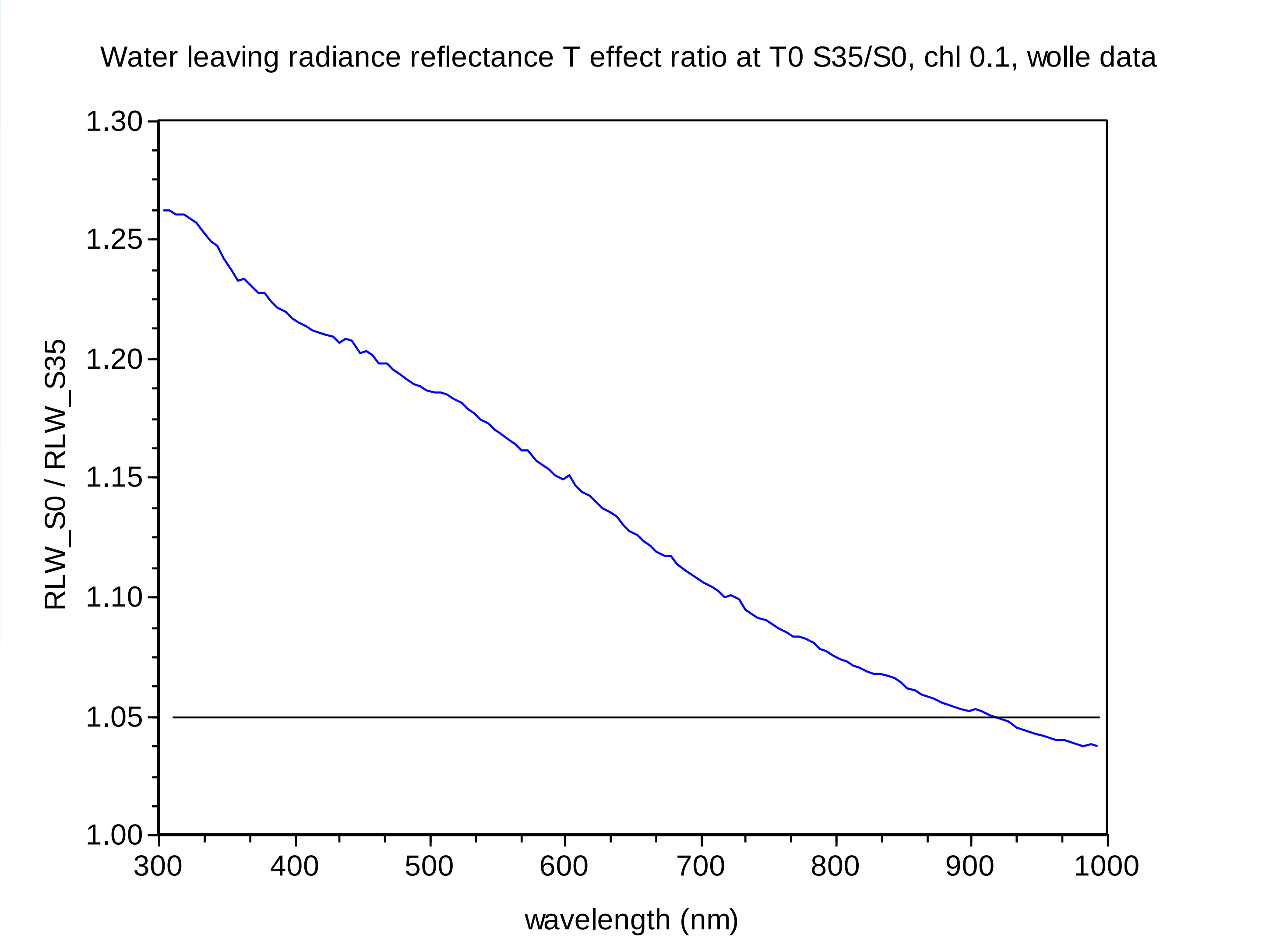
- Information about typical concentration / IOP ranges
- Information about irradiance attenuation coefficient (kd) or Secchi disc depth
- Water depth, bottom reflectance spectra or type of bottom
- Conversion IOPs -> concentrations
- IOPs
  - Absorption spectra of phytoplankton (in vivo, filter pad)
  - Scattering / backscattering coefficients (spectral)
  - Absorption spectra of CDOM (yellow substance), spectral slope coefficient

Out of Scope spectra

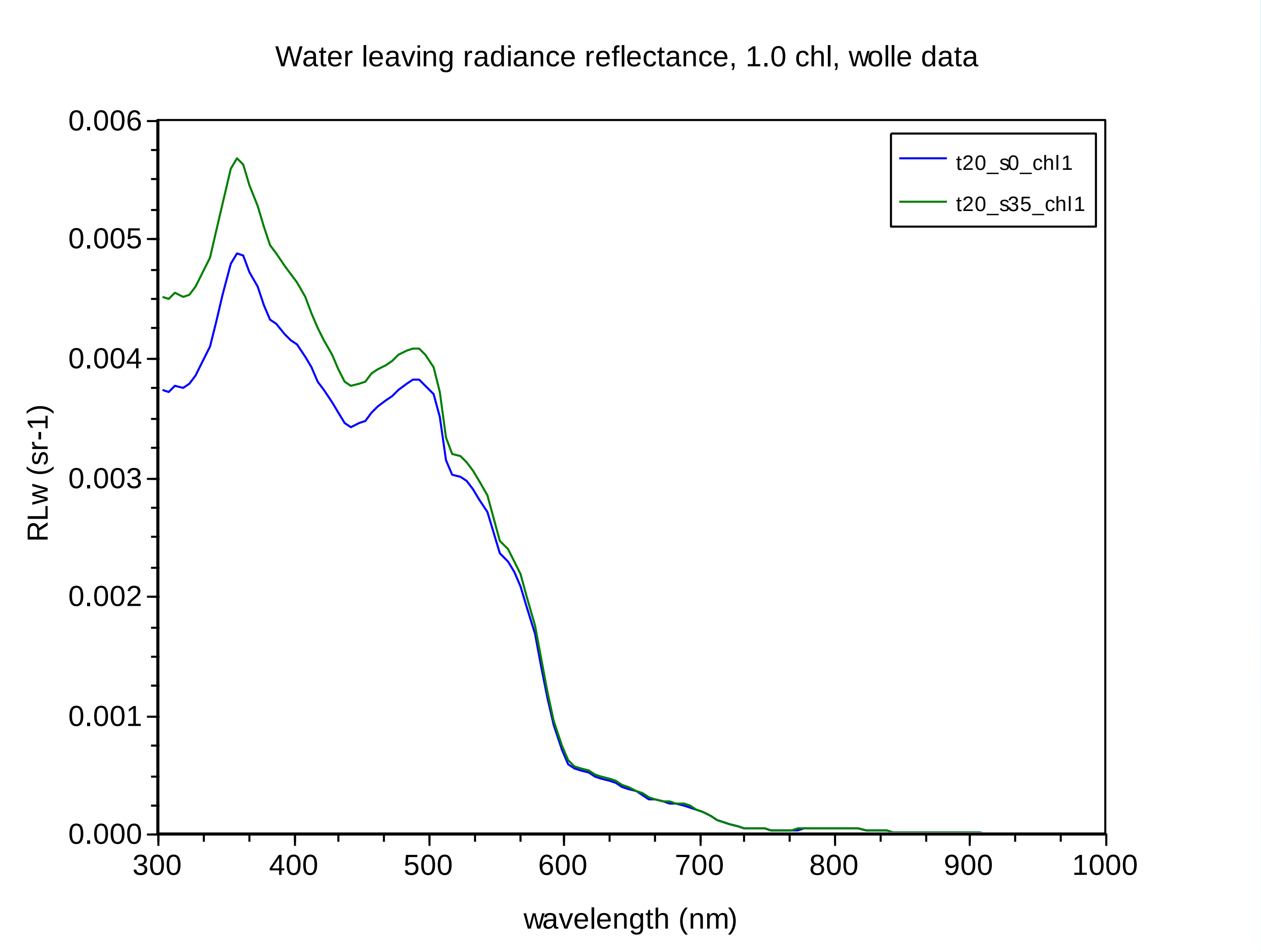




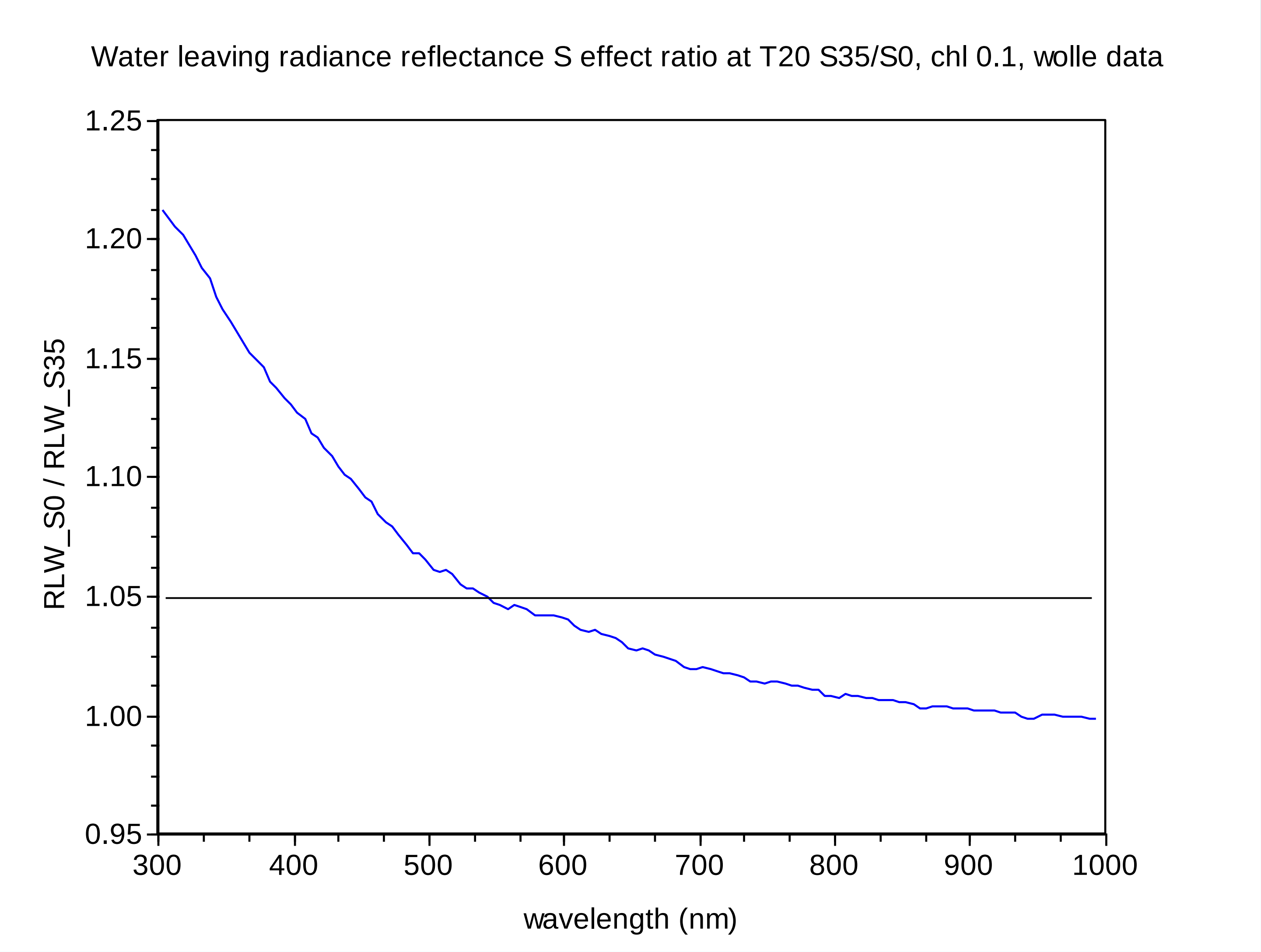
Effect of salinity at T=0



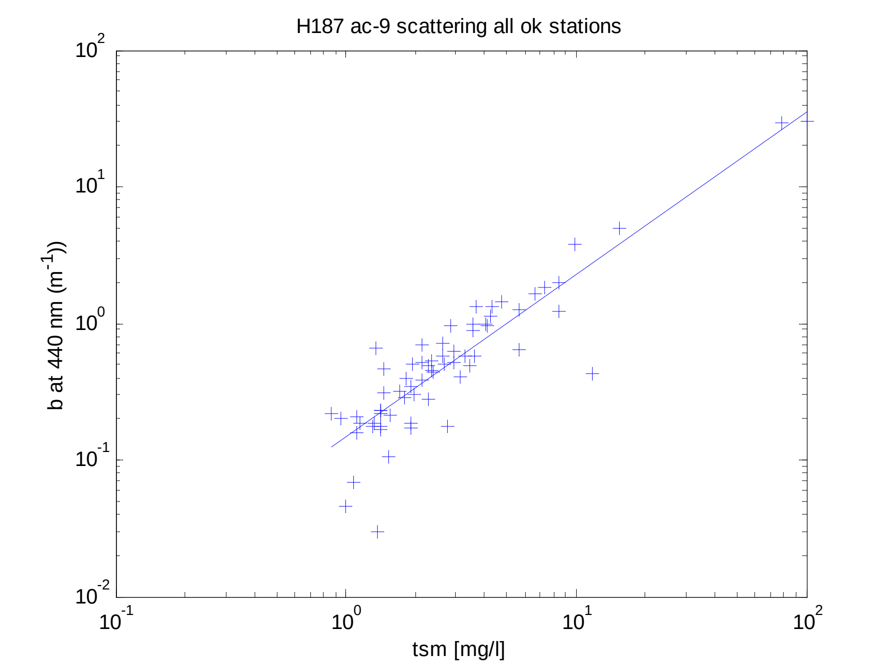
RLw for Chl 1.0 at T20 and S0 / S35



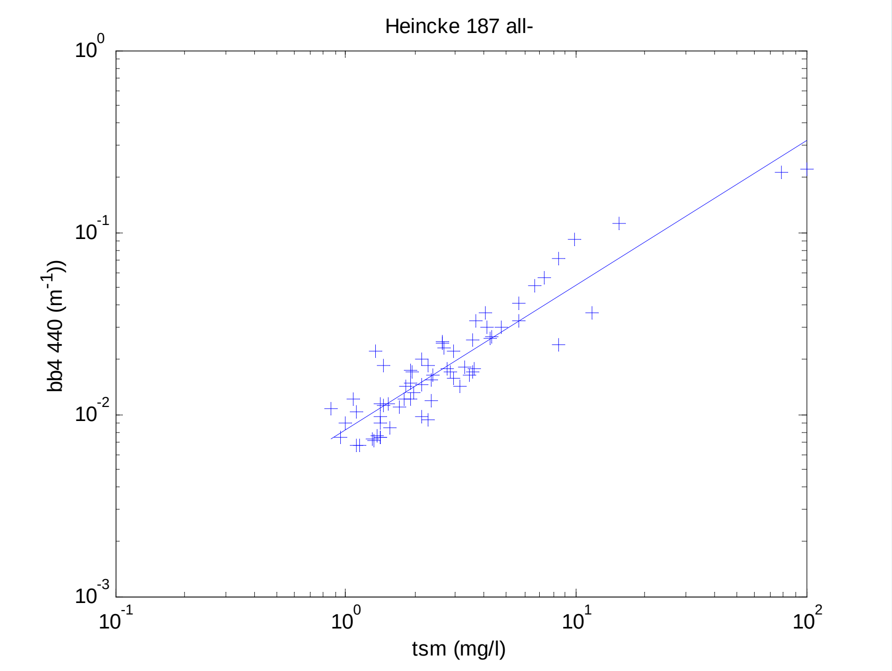
Ratio S35/S0 at Chl. 1.0, T20



TSM scattering, H187



AC-9



BB-4

Conversions:

TSM [g m-3] = 1.72 * b_tsm_442

L1P Format

- L1P TOA Dataset

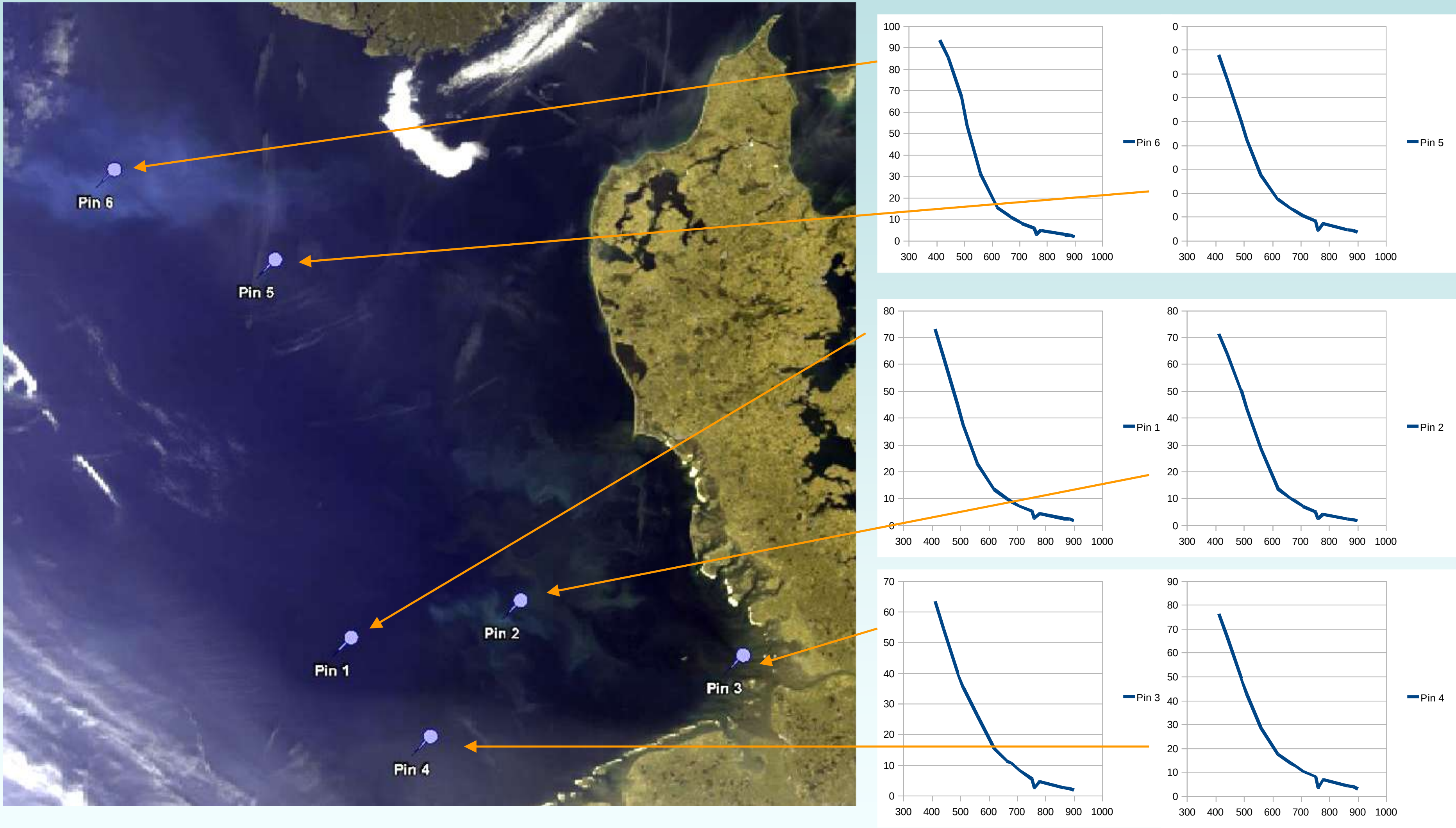
Variable name	Description	Unit	T	Size (W×H)
radiance_<i>	TOA radiances in the 15 MERIS bands		us	15 x 2
detector_index	Index of the MERIS pixel		us	2
l1b_flags	MERIS L1b flags (copy from M1b product)		us	1
l1p_flags	Flags set from pixel identification: cloud, non water risk flag		us	1
				34

- L1P Geo Dataset

Variable name	Description	Unit	T	Size (W×H)
corr_longitude	Ortho-corrected longitude.	deg	sl	4
corr_latitude	Ortho-corrected latitude.	deg	sl	4
altitude	DEM altitude (from GETASSE30)	m	ss	2
				10

Deliverd as net CDF files

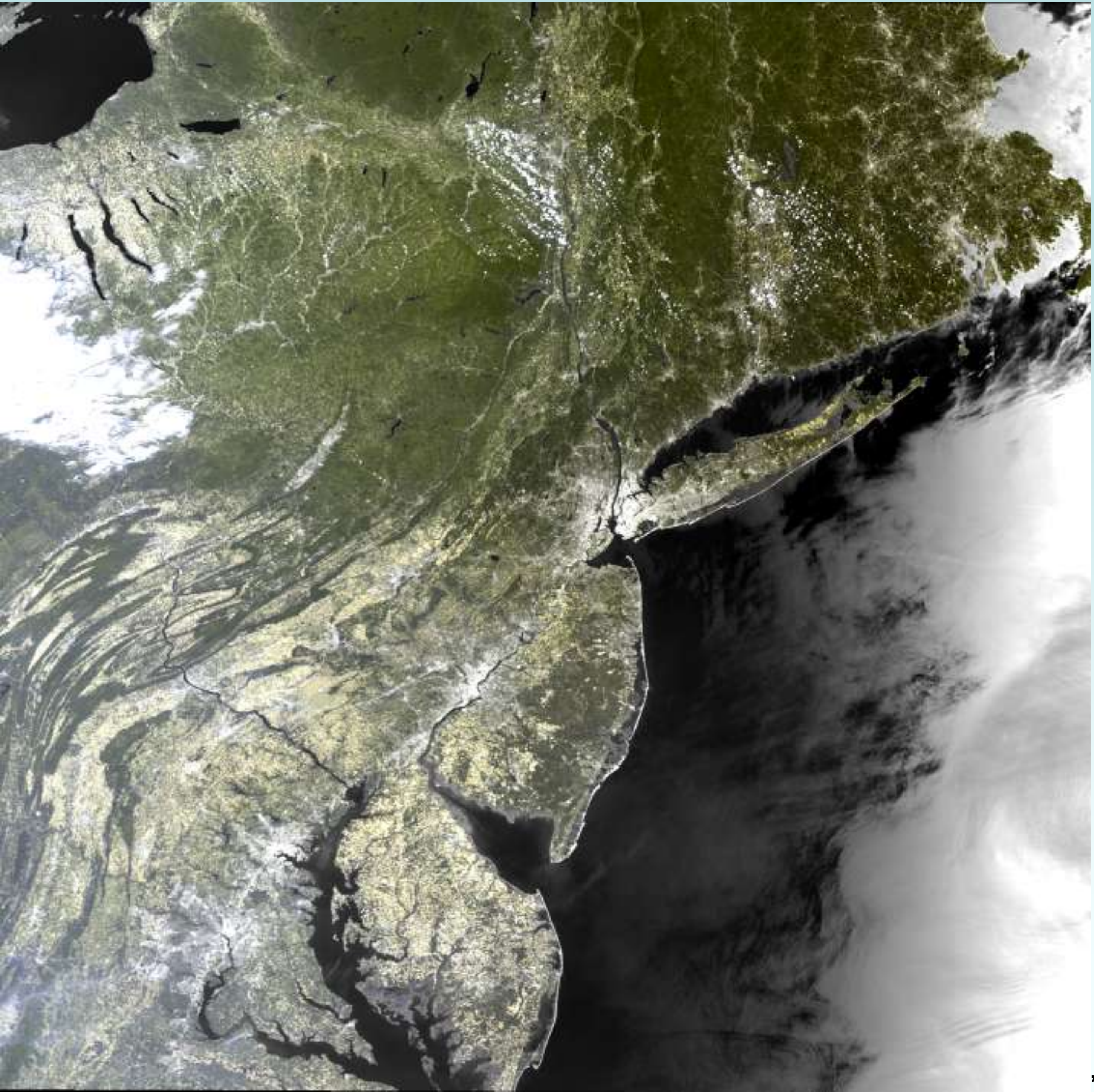
Spectral Variability top of atmosphere



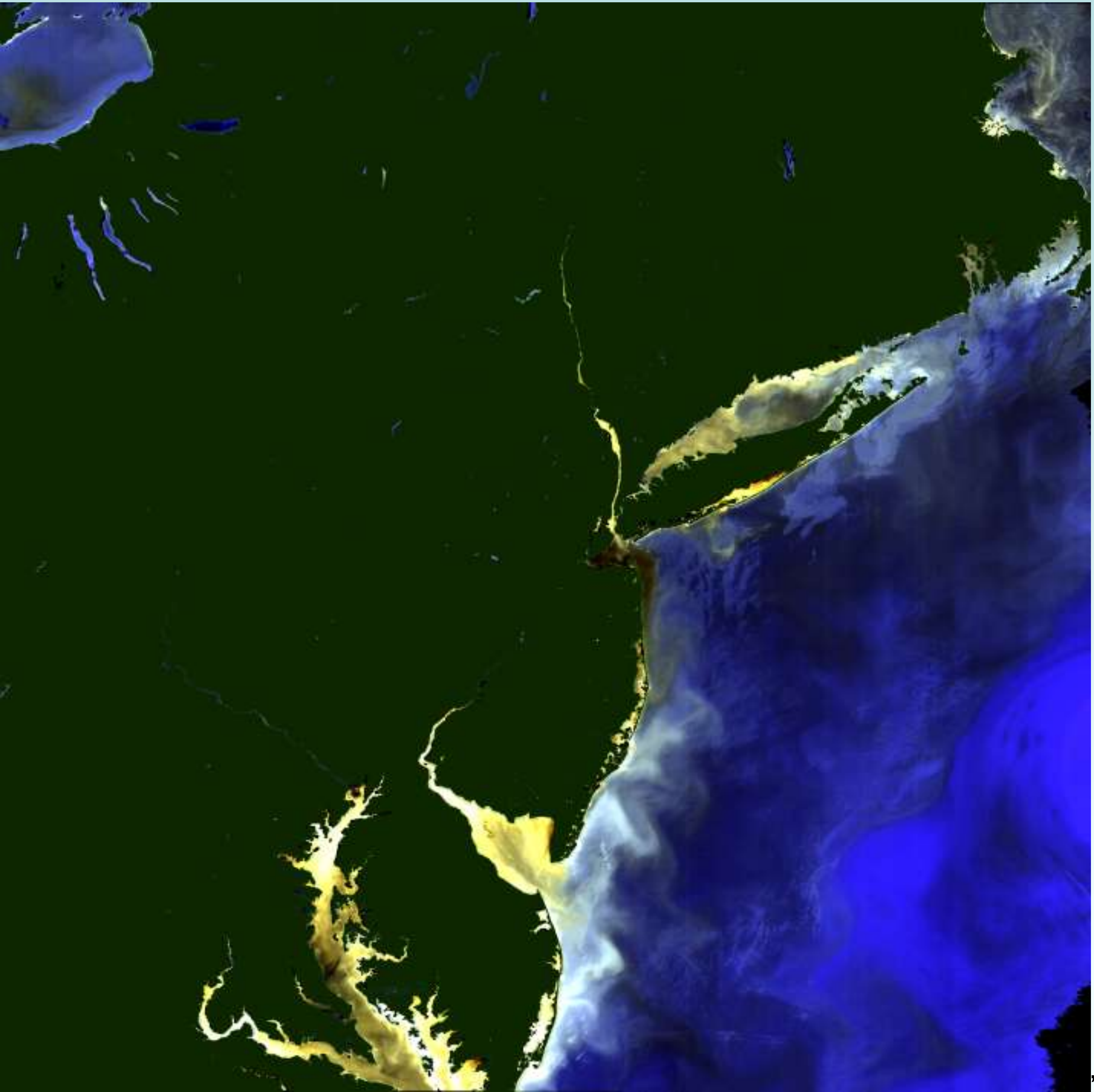
UCM 2, Nov. 16-17, 2010, ESRIN

MERIS FR
20080617

glint ratio > 10 !!

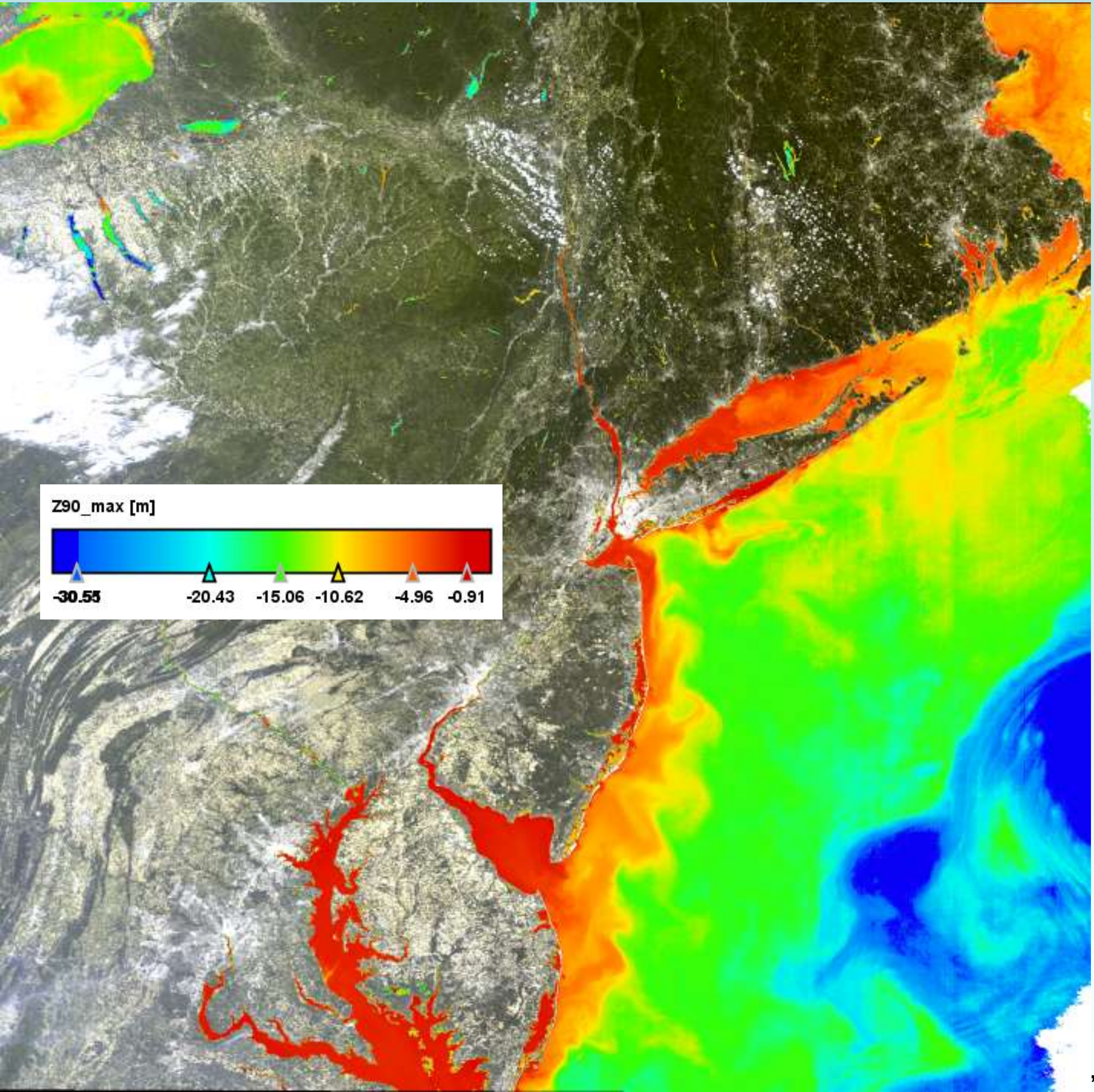


MERIS FR
20080617
RL_path
band 5



MERIS FR
20080617
RL_w RGB

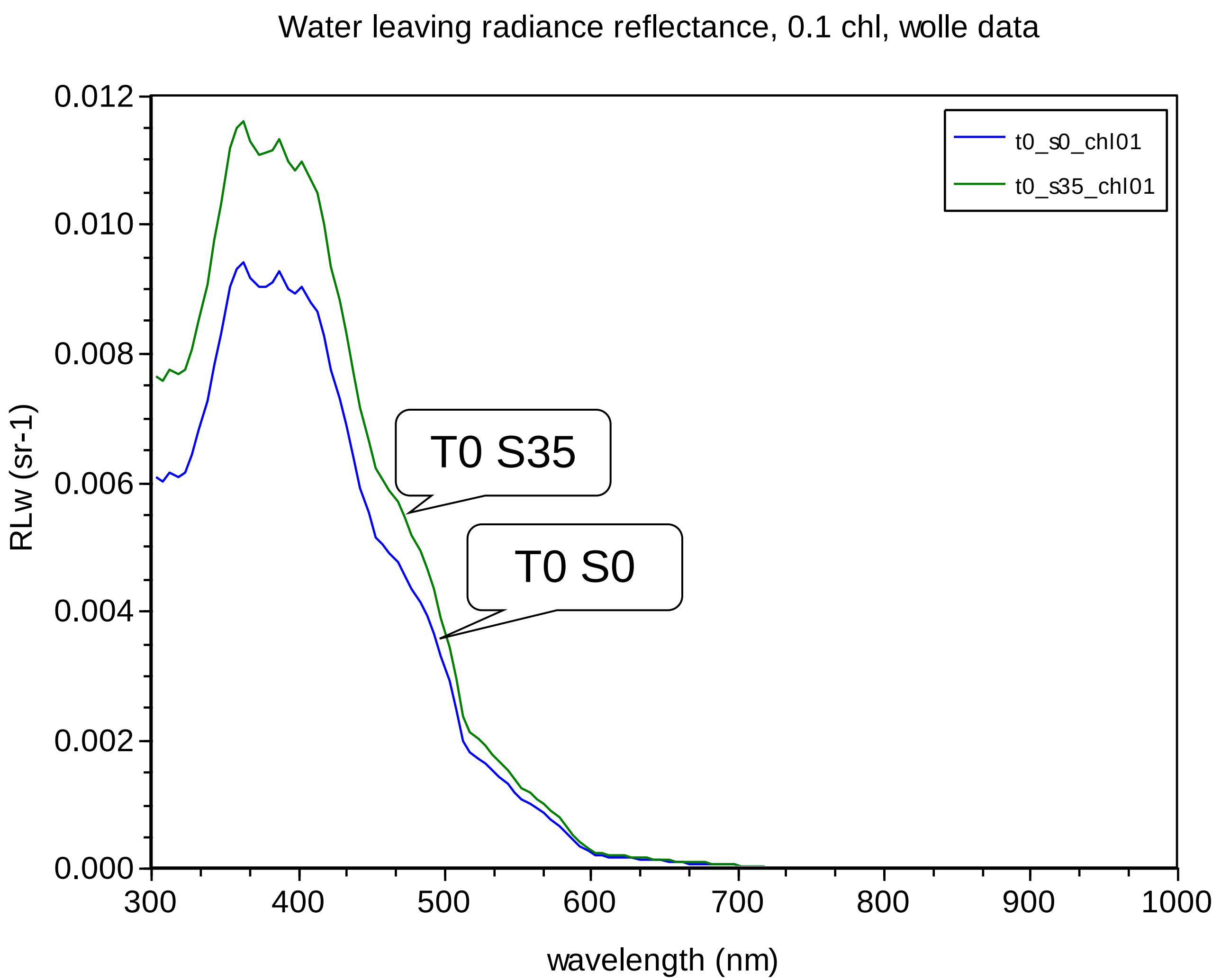
, 2010, ESRIN



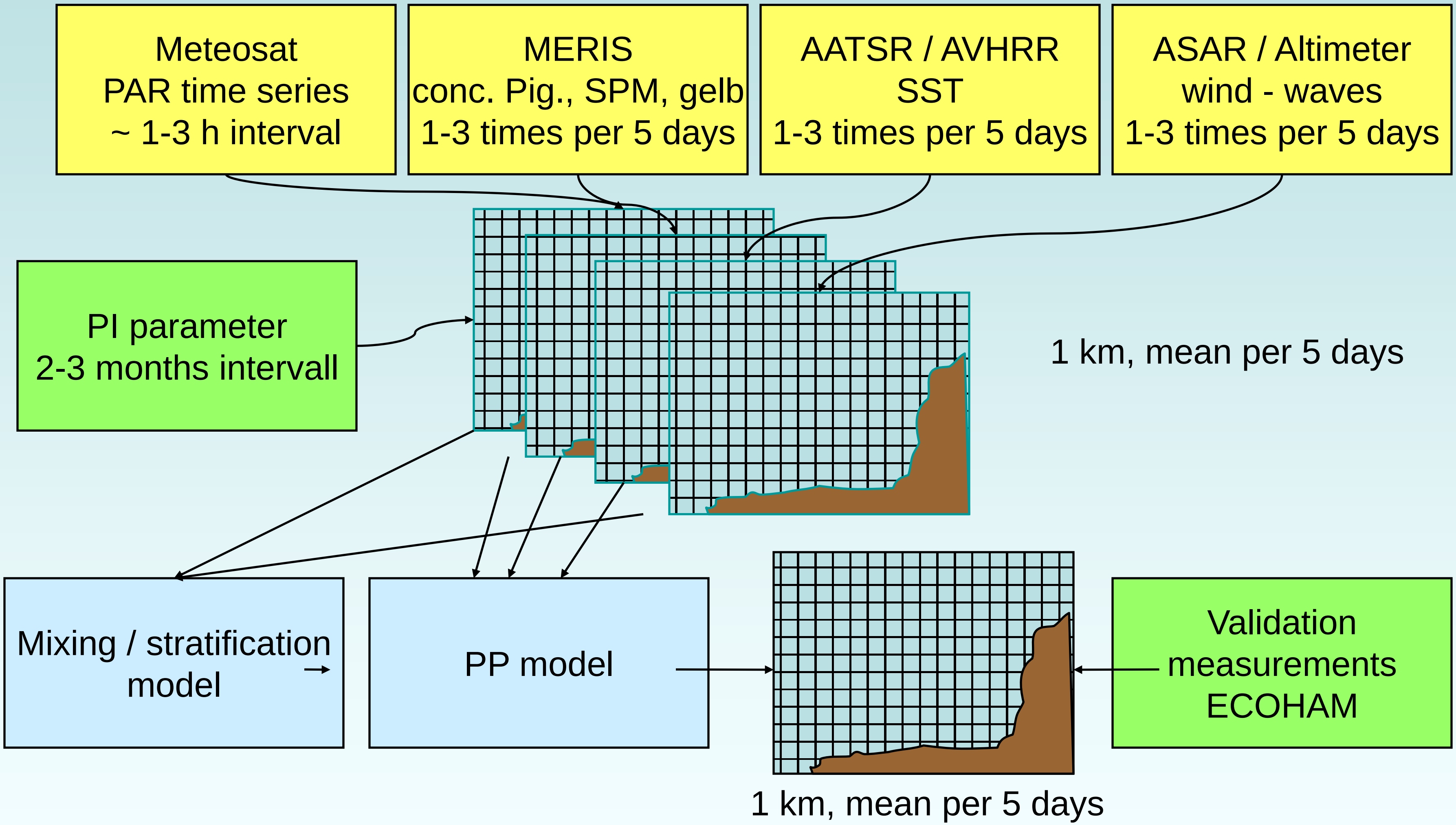
MERIS FR
20080617
z90_max

, 2010, ESRIN

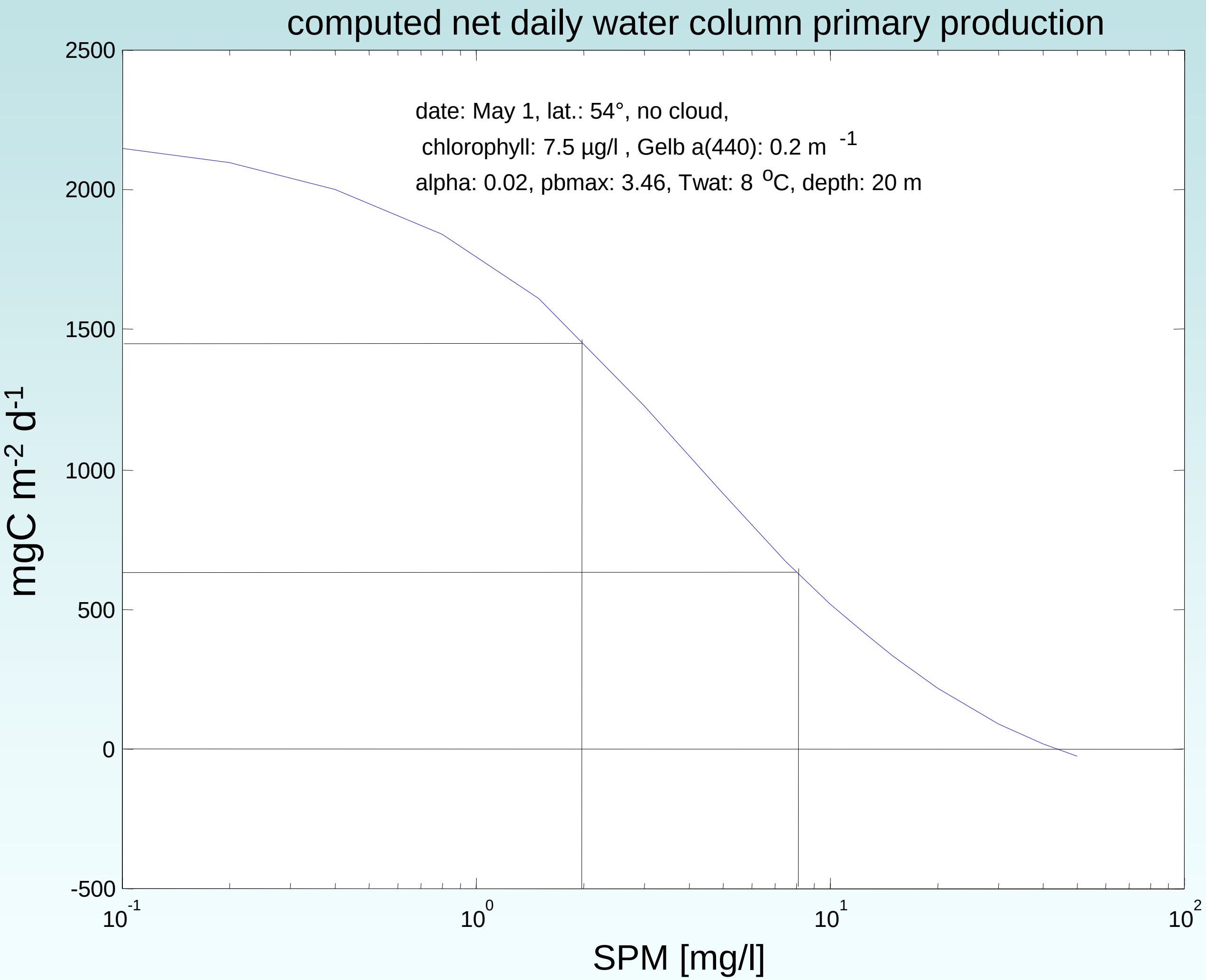
Effect of salinity at T=0



Data assimilation scheme



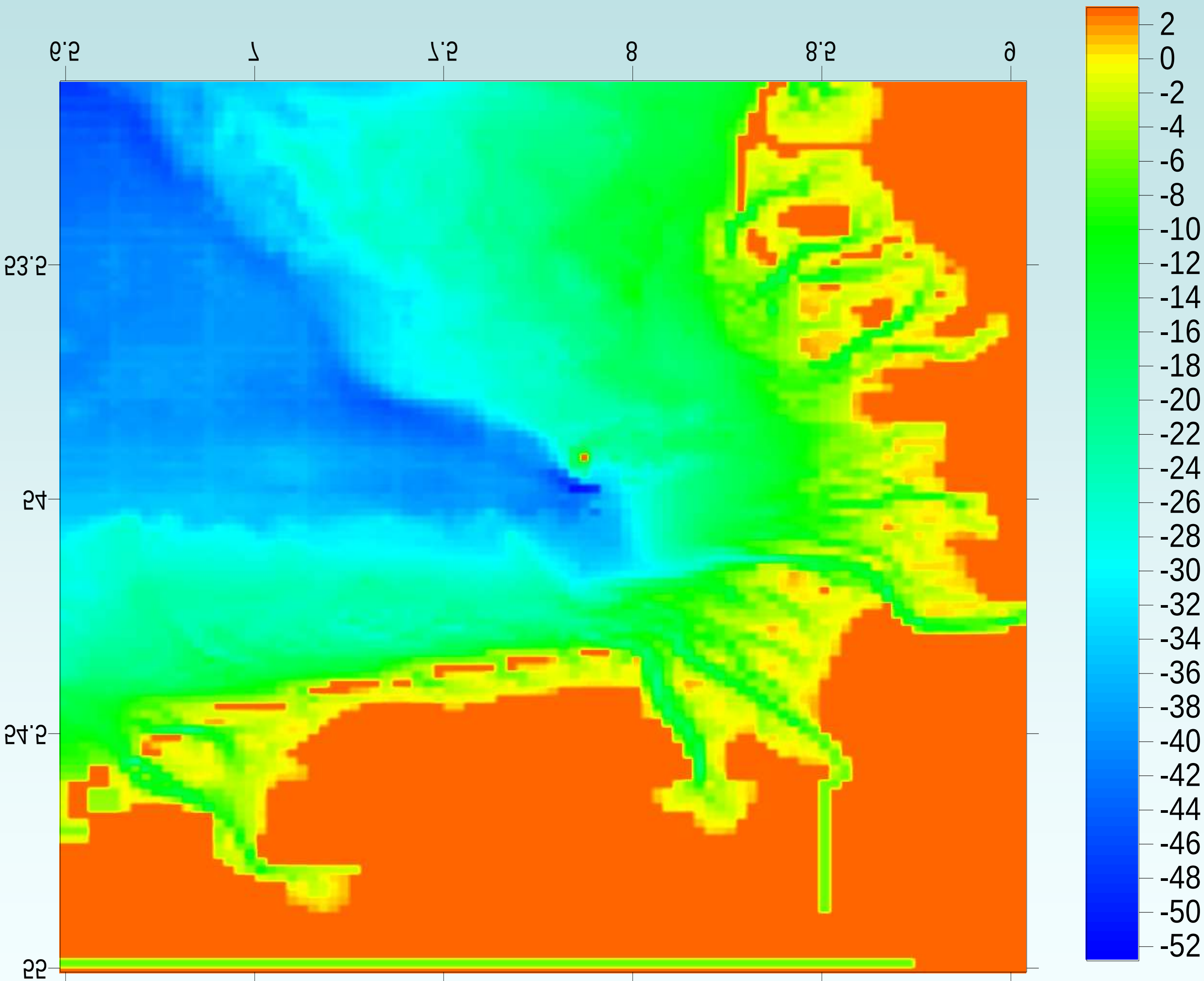
Influence of suspended matter



Chlorophyll 7.5 µg/l
SPM 3 mg/l
gelb a(440) 0.2 m-1
alpha 0.02
pbmax 3.46

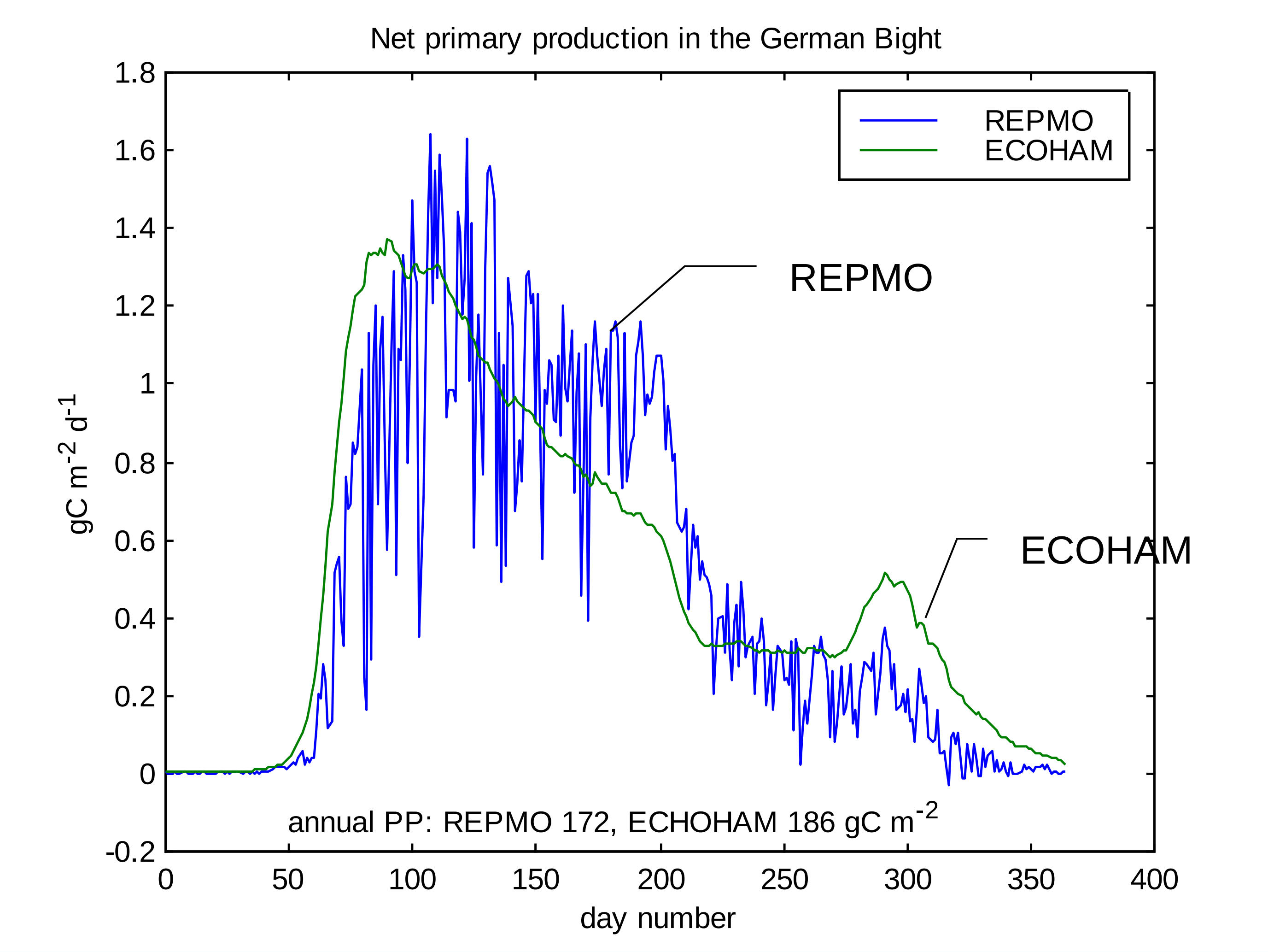
daily production
no clouds
May 1
latitude 54 deg N

Depth



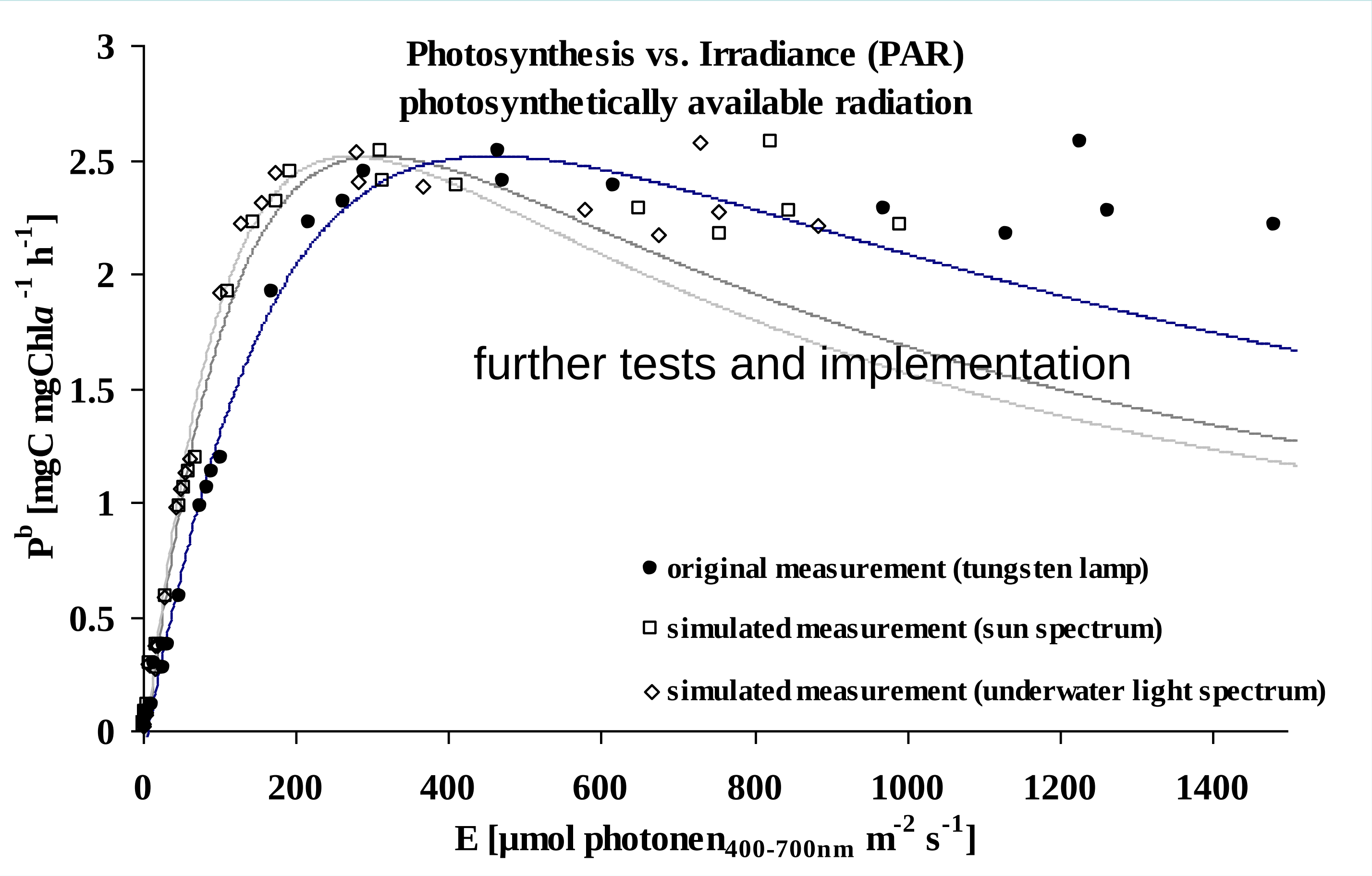
6.5
7
7.5
8
8.5
9
53.5
54
54.5
55
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
-40
-42
-44
-46
-48
-50
-52

Net primary production German Bight 1994: Remote Sensing PP model (REPMO) - ECOHAM

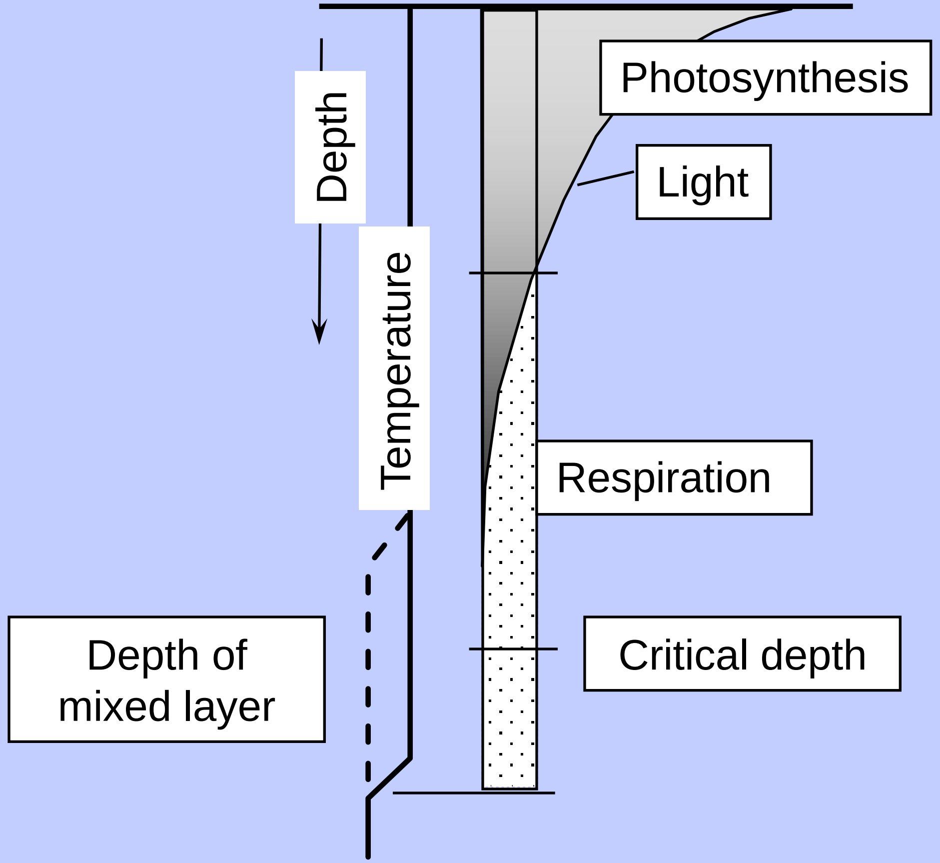


Ca. 2.5 Mio t C y^{-1}

Photosynthesis vs. Irradiance relationship



Scheme of critical depth



Relationship between compensation and critical depth and depth of mixed layer *(Sverdrup scheme)*