Breakout session *"Hyperspectral science and applications for shelf and open ocean processes"*

Hyperspectral ocean color imagery and applications to studies of phytoplankton ecology

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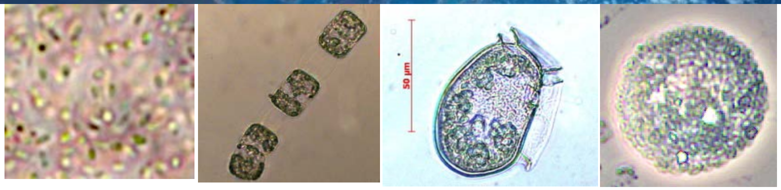

PhytoDOAS group work with SCIAMACHY/ENVISAT: Bracher et al. BG 2009, Sadeghi et al. OS 2012, Sadeghi et al. BG 2012, Dinter et al. OS 2015, Wolanin et al. RSE in press

Contributions: T. Dinter, A. Sadeghi, A. Wolanin, V. Rozanov, M. Vountas, J. P. Burrows, I. Peeken, R. Röttgers, M. Soppa

Ryan et al. (2014) work with HICO in Monterey Bay

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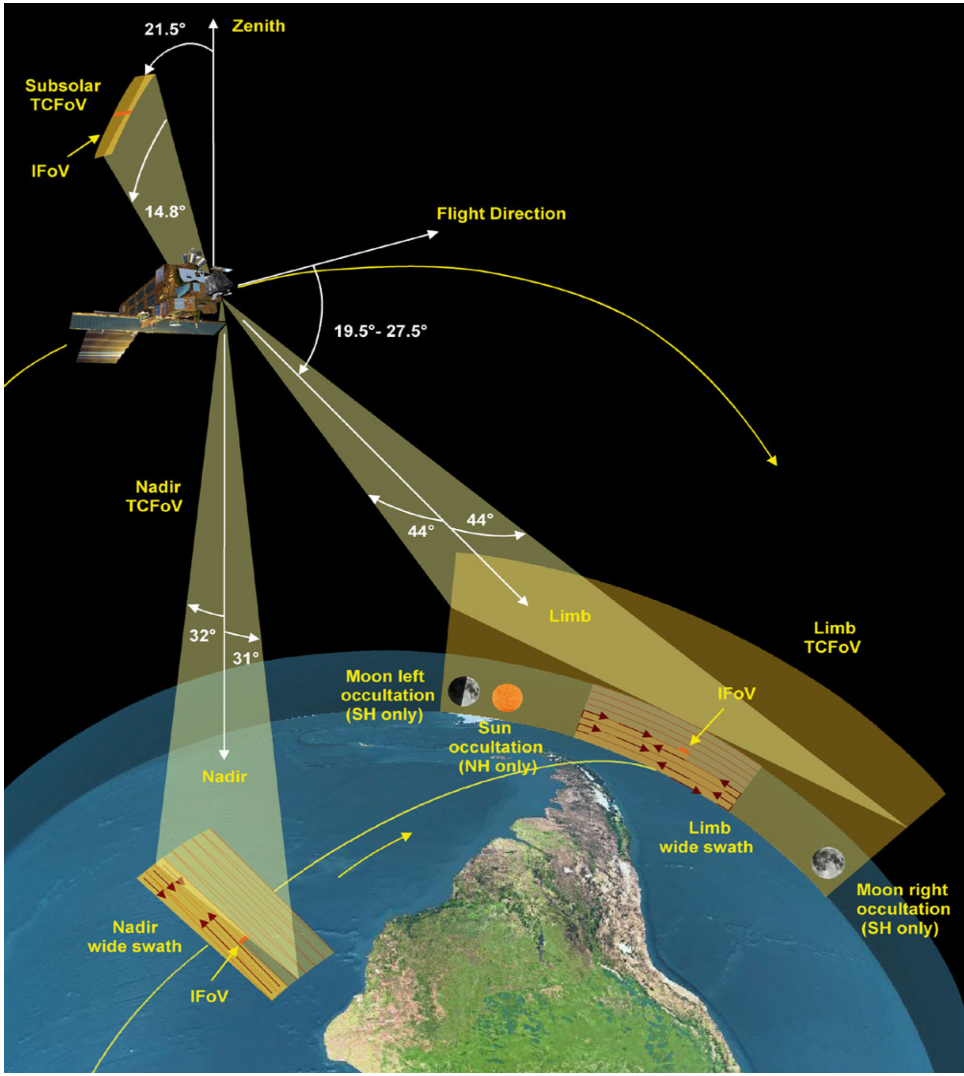
Global Hyperspectral Satellite data used by Phytooptics Group

SCIAMACHY* onboard ENVISAT

- relatively high spectral resolution (0.2 nm to 0.5 nm)
- 240 – 2380 nm (8 spectral channels)
- Pixel size: 30 km × 60 km at best
- Nadir/limb alternating measurements (6 days global coverage)
- March 2002 – April 2012



Outlook global coverage 1 day:

- GOME-2 (MetOp-A / –B in operation since 2007 / 2012, MetOp-C planned for 2018-40kmx40km)
- OMI/AURA (2004-) & TROPOMI/Senti-nel-5P (2016; 7x7km) - only until 520 nm

*Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY

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The PhytoDOAS Method

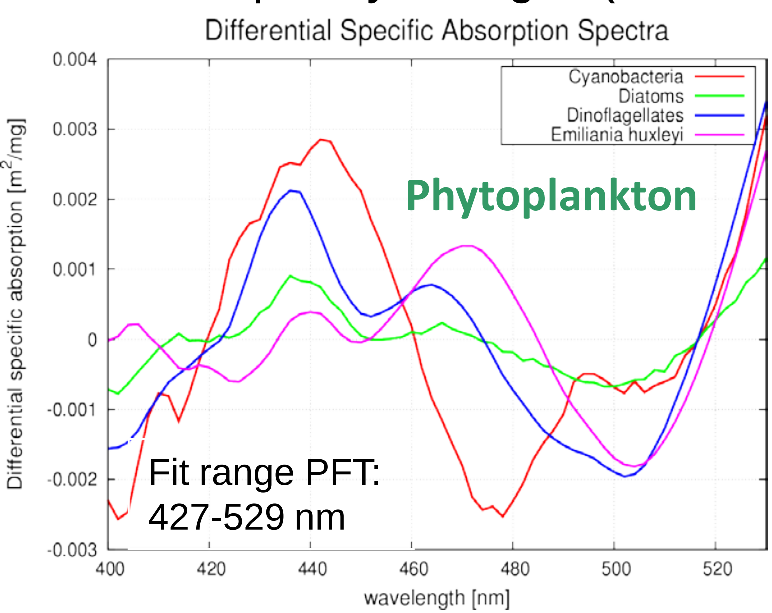
• Differential Optical Absorption Spectroscopy applied to Phytoplankton and to oceanic inelastic processes: based on Beer-Lambert-Law, aims to fulfill following minimization

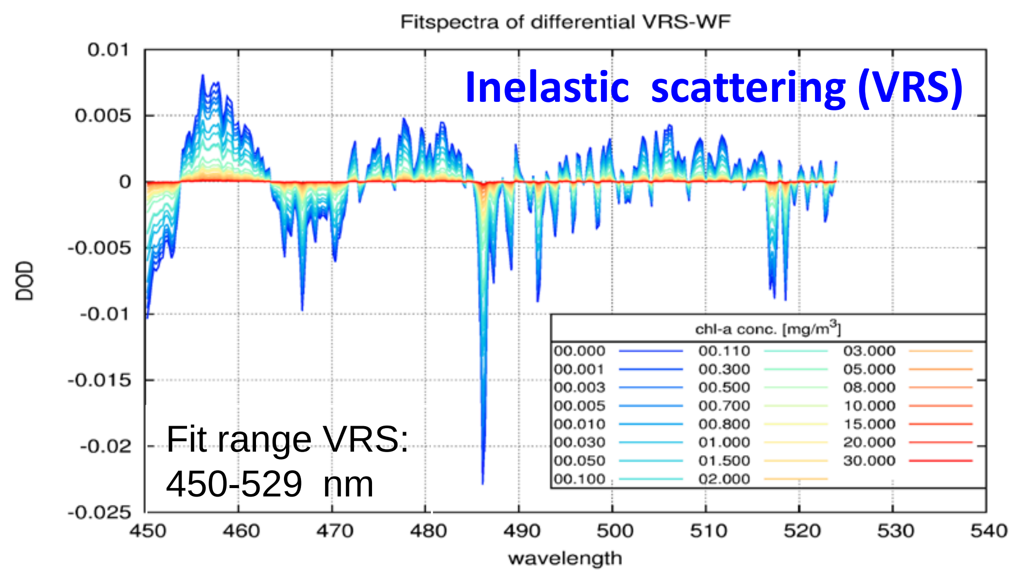
$$I(\lambda) = I_0(\lambda)\cdot e^{-\tau(\lambda)} \Rightarrow \tau(\lambda) = \ln\left(\frac{I_0(\lambda)}{I(\lambda)}\right)$$

$$\left\| \tau(\lambda) - \sum_{k=1}^{K} S_k\sigma_k(\lambda) - \sum_{j=1}^{J} S_j a_j(\lambda) - S_{VRS}\nu(\lambda) - S_l r_l(\lambda) - \sum_{i=0}^{I} x_i\lambda^i \right\| \Rightarrow min.$$

Atmosphere Phytoplankton Inelastic scattering (VRS), water Polynom

- Satellite earthshine and solar spectra from satellite
- Measured absorption spectra of all relevant absorbers
- Low frequency changes (Mie/Raleigh sc., …) approximated with low order polynomial

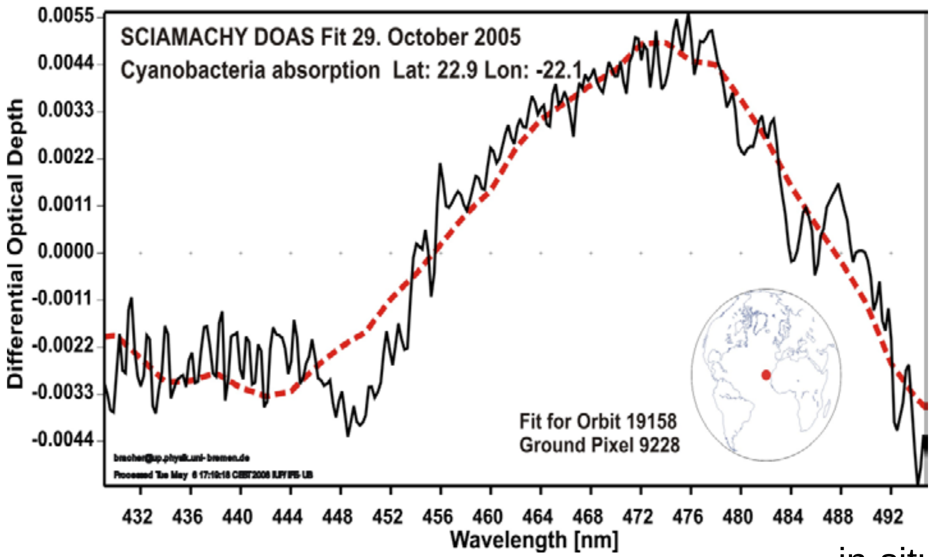




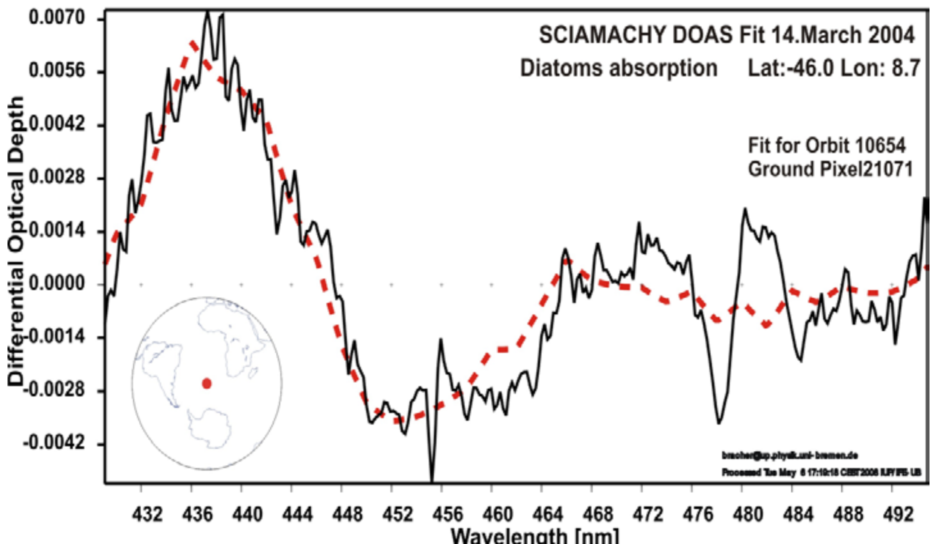
PhytoDOAS from SCIAMACHY Data: Examples of PFT fit results

Absorption of phytoplankton groups by PhytoDOAS - comparisons to collocated in-situ data

only cyanobacteria



dominated (>8o%) by diatoms



--- in-situ reference spectrum

— SCIAMACHY

Bracher et al. 2009

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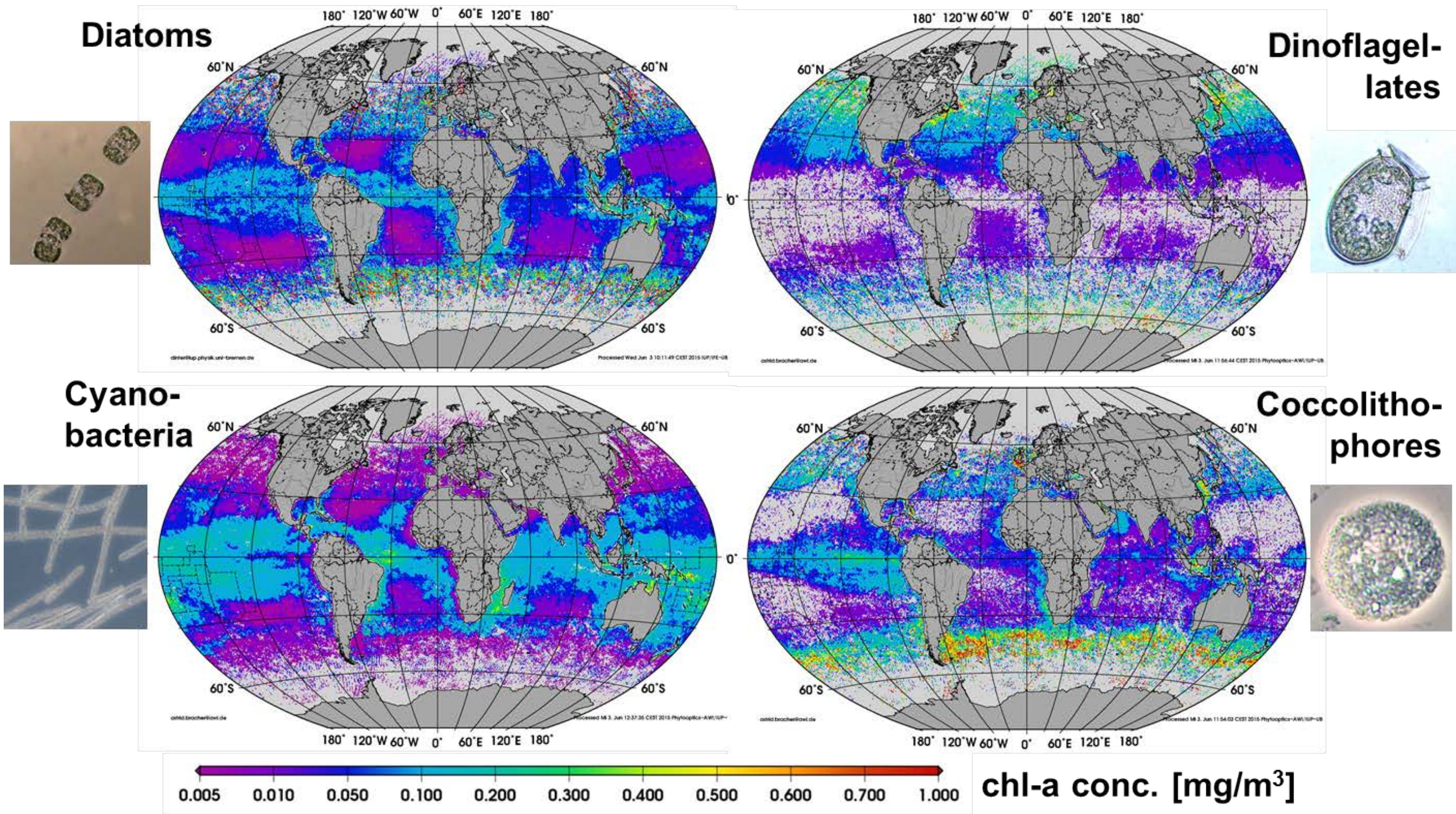
PhytoDOAS Phytoplankton Groups from hyper-spectral satellite data: Mean Chl-a March 2007



Bracher et al. BG 2009; Sadeghi et al. OS 2012

Longterm data set: SCIAMACHY (2002-2012)

Drawback: Spatial resolution ~60 km x 30 km (0.5°lat/lon - monthly resolution)

Application of PhytoDOAS times series data: Sadeghi et al. BG 2012, Ye et al. 2012

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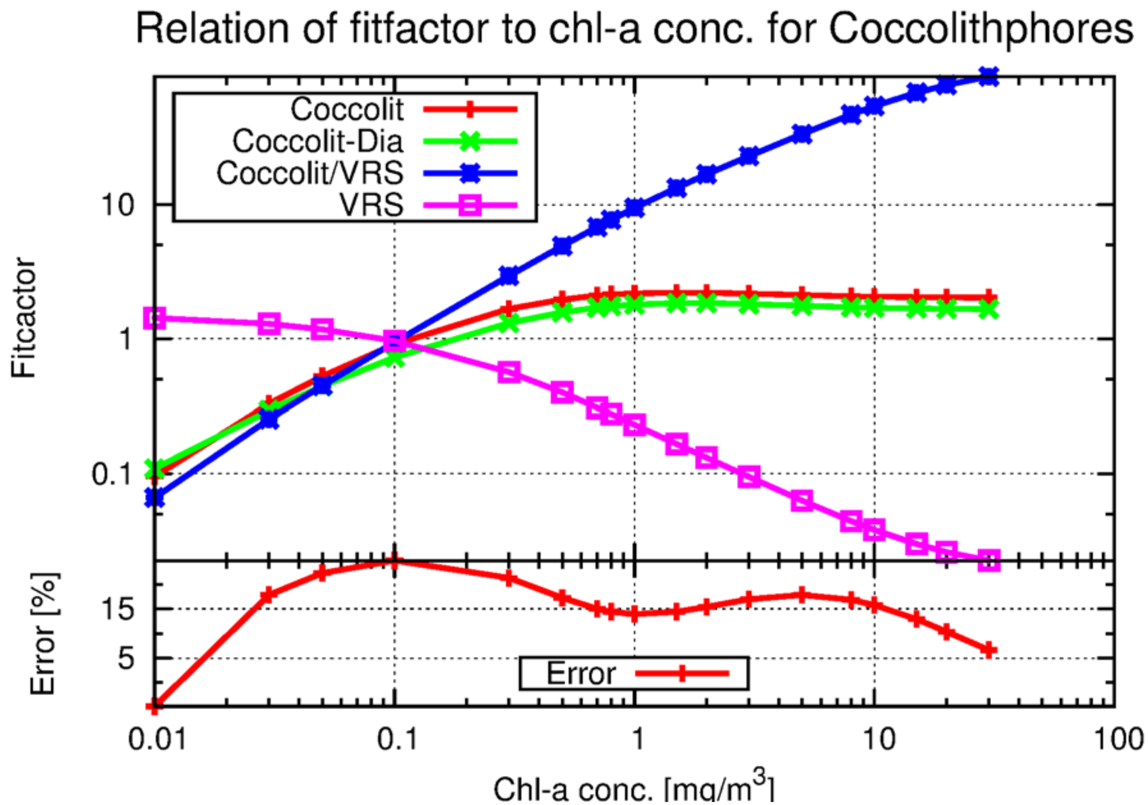
Sensitivity study for PhytoDOAS



Coupled ocean-atmosphere radiative transfer model SCIATRAN (Rozanov et al. 2014): simulates top of atmosphere spectra with definite chl-a conc. of cocco-lithophores

Spectra then used in PhytoDOAS retrieval

Inelastic scattering (VRS) fitfactor definite relation to coccolithophore chl

Coccolithophores' fitfactor only definite until 1 mg/m^3

Coccolithphores divided by VRS (proxy for observed light path) give definite relation up to 30 mg/m^3

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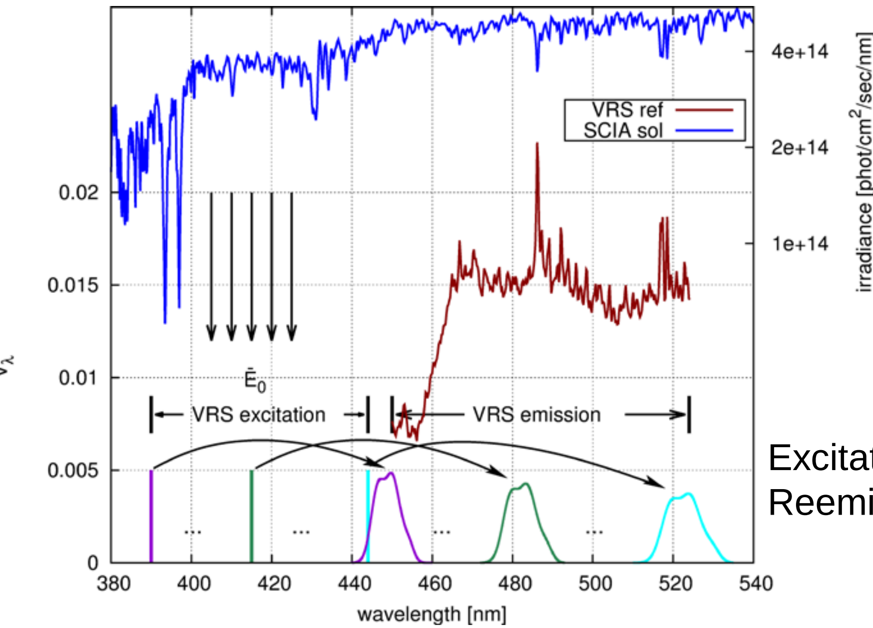
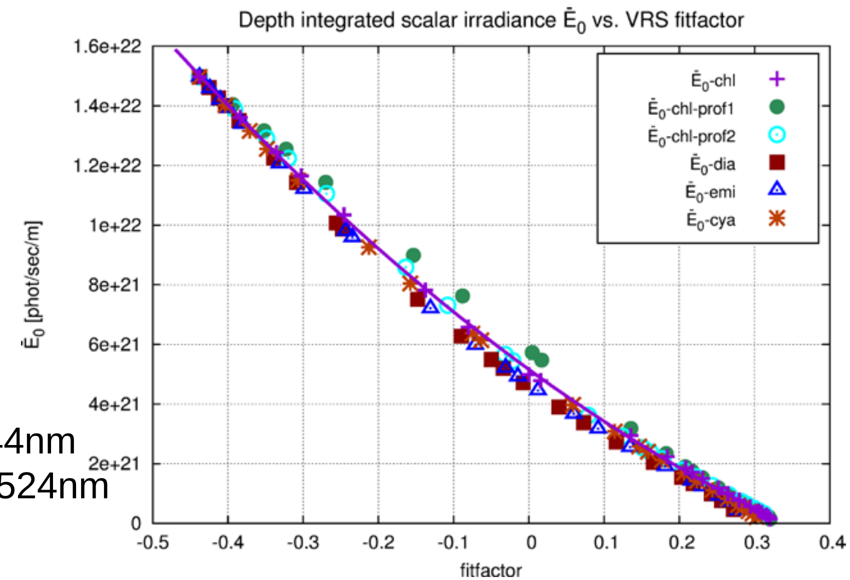
Light availability in ocean water utilizing Vibrational Raman Scattering (VRS) identified in hyperspectral data

Radiative transfer simulations to model filling in of Fraunhofer lines by inelastic scattering of light in water



Excitation 390-444nm
Reemission 450-524nm

Dependence of E_0 on VRS-fit factor with varying input of specific phytoplankton absorption and profile stratification



Then modelled filling-in spectra fitted in SCIAMACHY data via DOAS to obtain inelastic scattering in ocean waters (VRS)

Derived VRS fit-factor used to calculate

→ light availability in water (i.e. scalar irradiance = E_0)

→ PFT Chla (= PFT-fit factor / VRS-fit factor * X)

Dinter et al. Ocean Science 11: 373-389 (2015)
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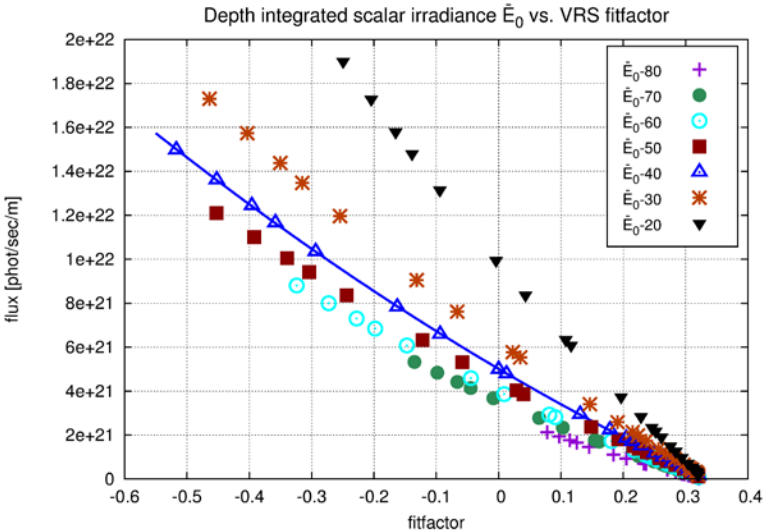
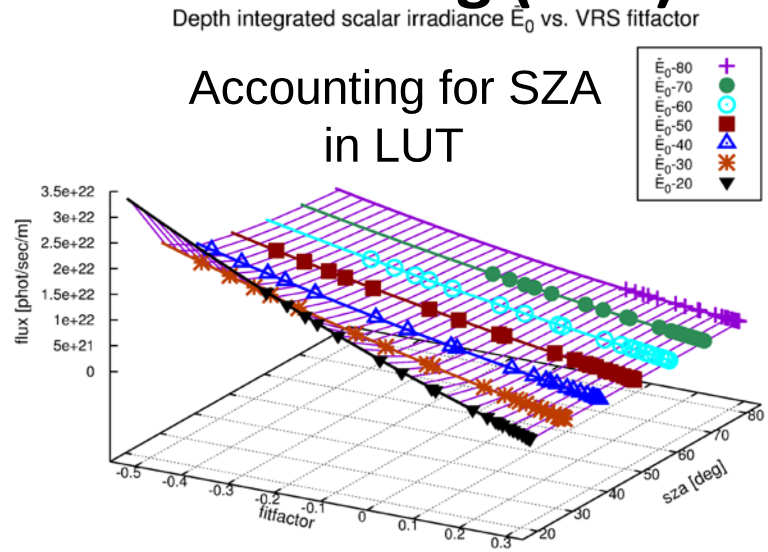
Determination of the light availability in ocean water utilizing Vibrational Raman Scattering (VRS)

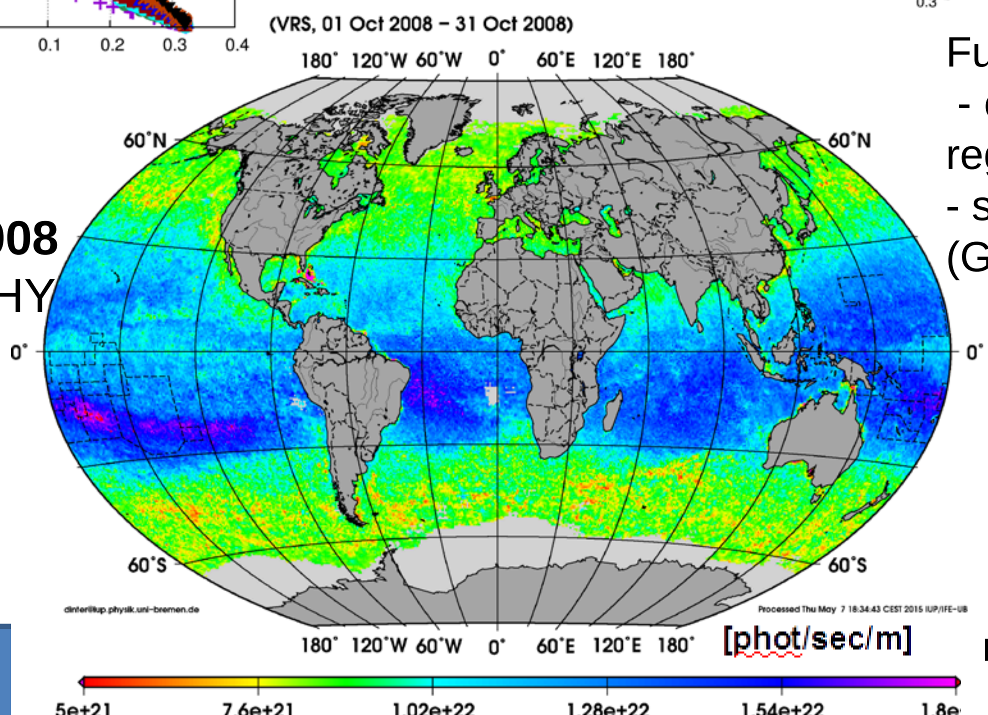
Dependence of E_0 to SZA



Accounting for SZA in LUT



Light availability in ocean water for Oct 2008 derived from SCIAMACHY utilizing VRS-fit factor

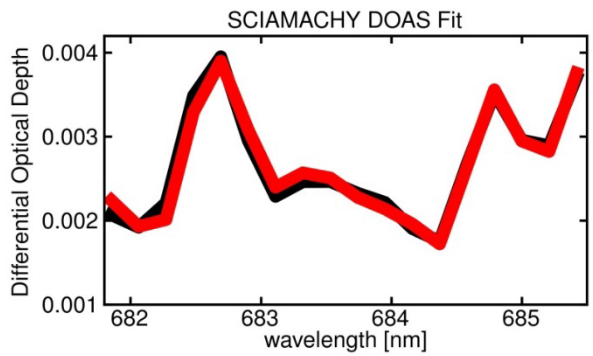


Excitation at 390-444.5nm
Reemission at 450-524nm

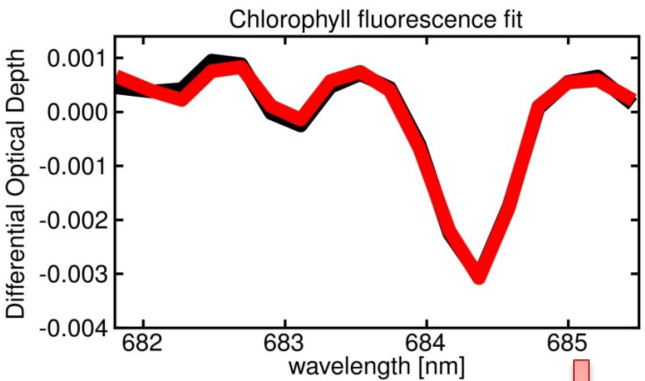
Future: adapt to
- other wavelength regions
- similar sensors (GOME-2, TROPOMI)

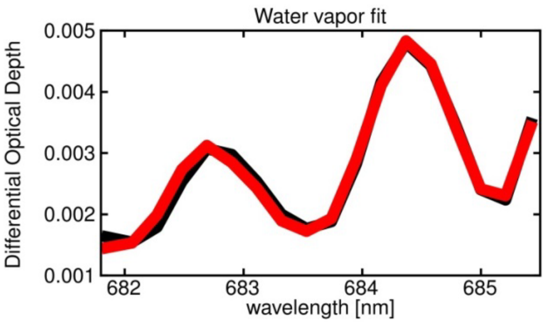
Dinter et al. Ocean Science 11: 373-389 (2015)

Chl fluorescence from SCIAMACHY: sample fit



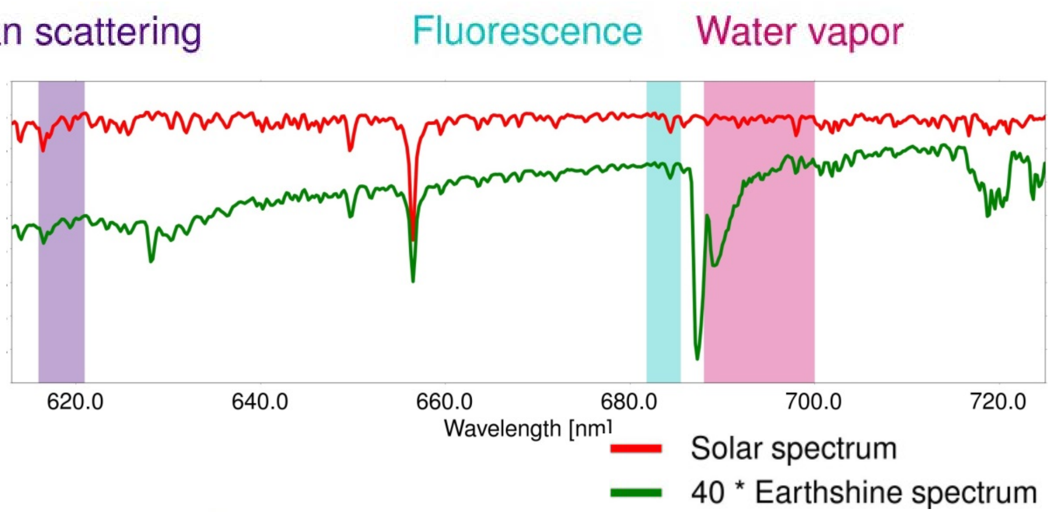
Chl fluorescence
DOAS Fit window
681.8 nm – 685.5 nm





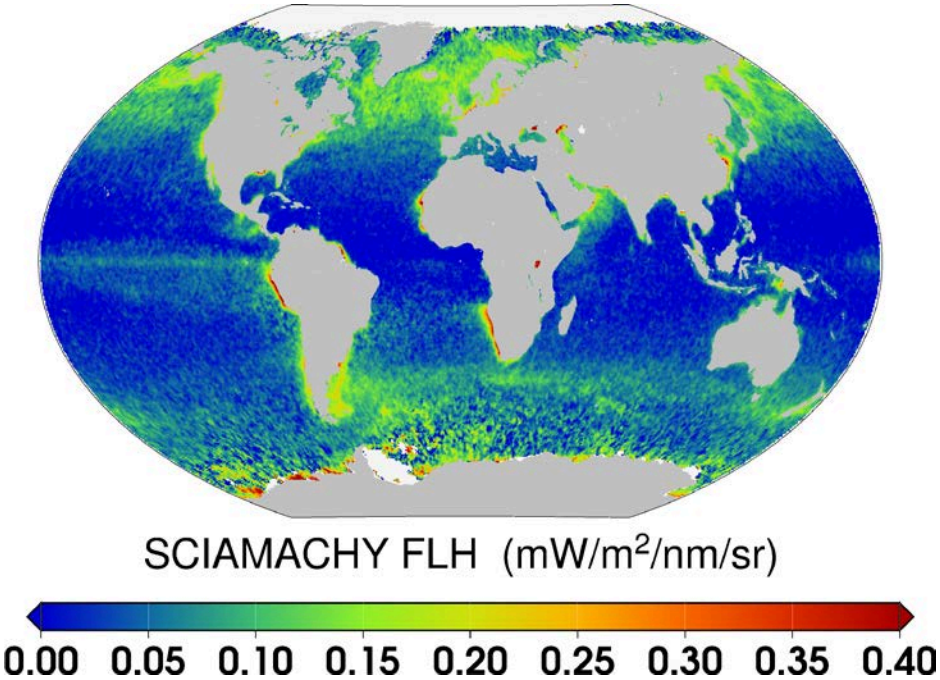
Account for:

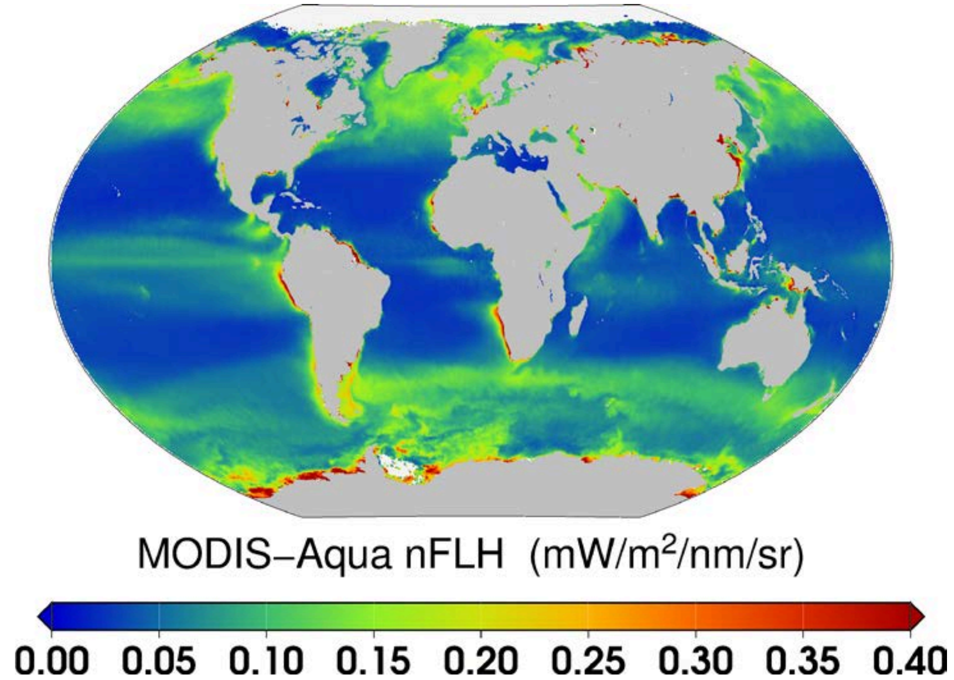
- water vapor,
- inelastic scattering (rotational and vibrational Raman scattering),
- background radiance (atmospheric transmittance & surface reflectance).



Fluorescence Line Height (2003-2011):

hyper- (SCIAMACHY) vs. multispectral (MODIS)





PhytoDOAS retrieves filling-in of Fraunhofer Lines from backscattered (hyperspectral, 681-686 nm)

Wolanin et al. Remote Sensing of Environment: in press

Multispectral (665, 677, 746 nm) algorithm by Behrenfeld et al. (2009)

http://oceancolor.gsfc.nasa.gov/cgi/l3

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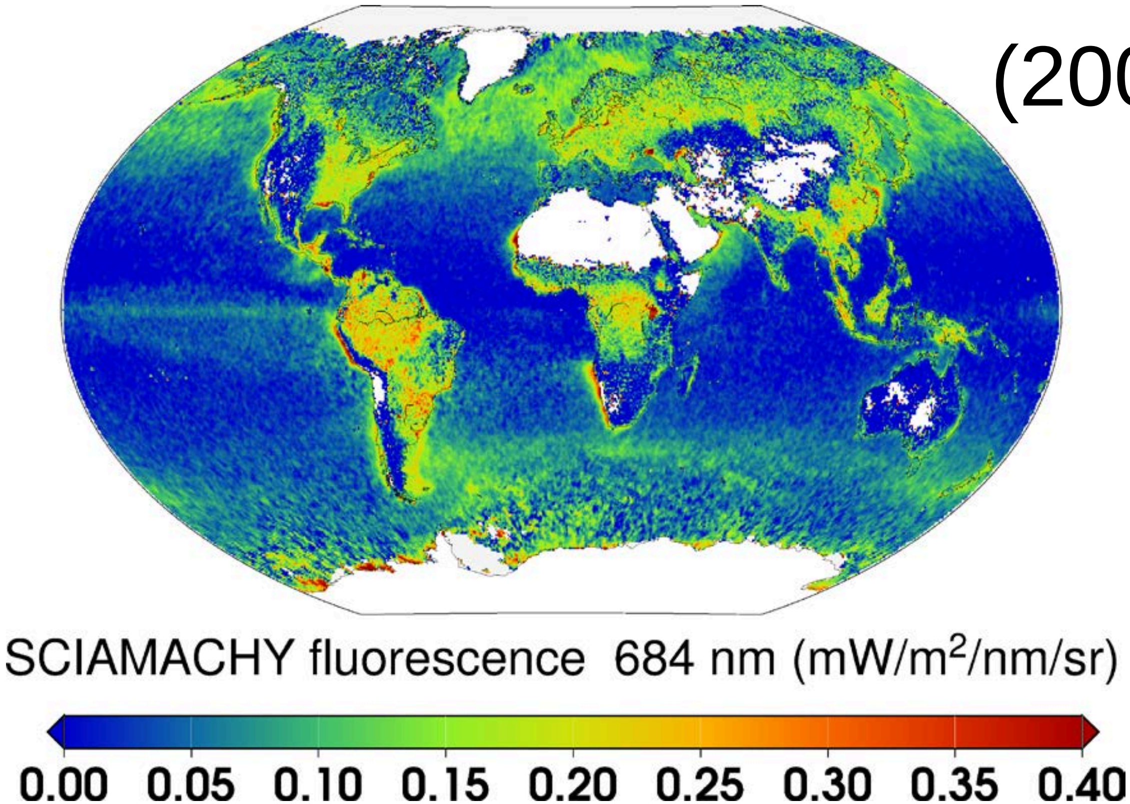
PhytoDOAS to retrieve red fluorescence peak applied globally to SCIAMACHY data
(extension to terrestrial vegetation)

(2003-2011)



Wolanin et al. Remote Sensing of Environment: in press

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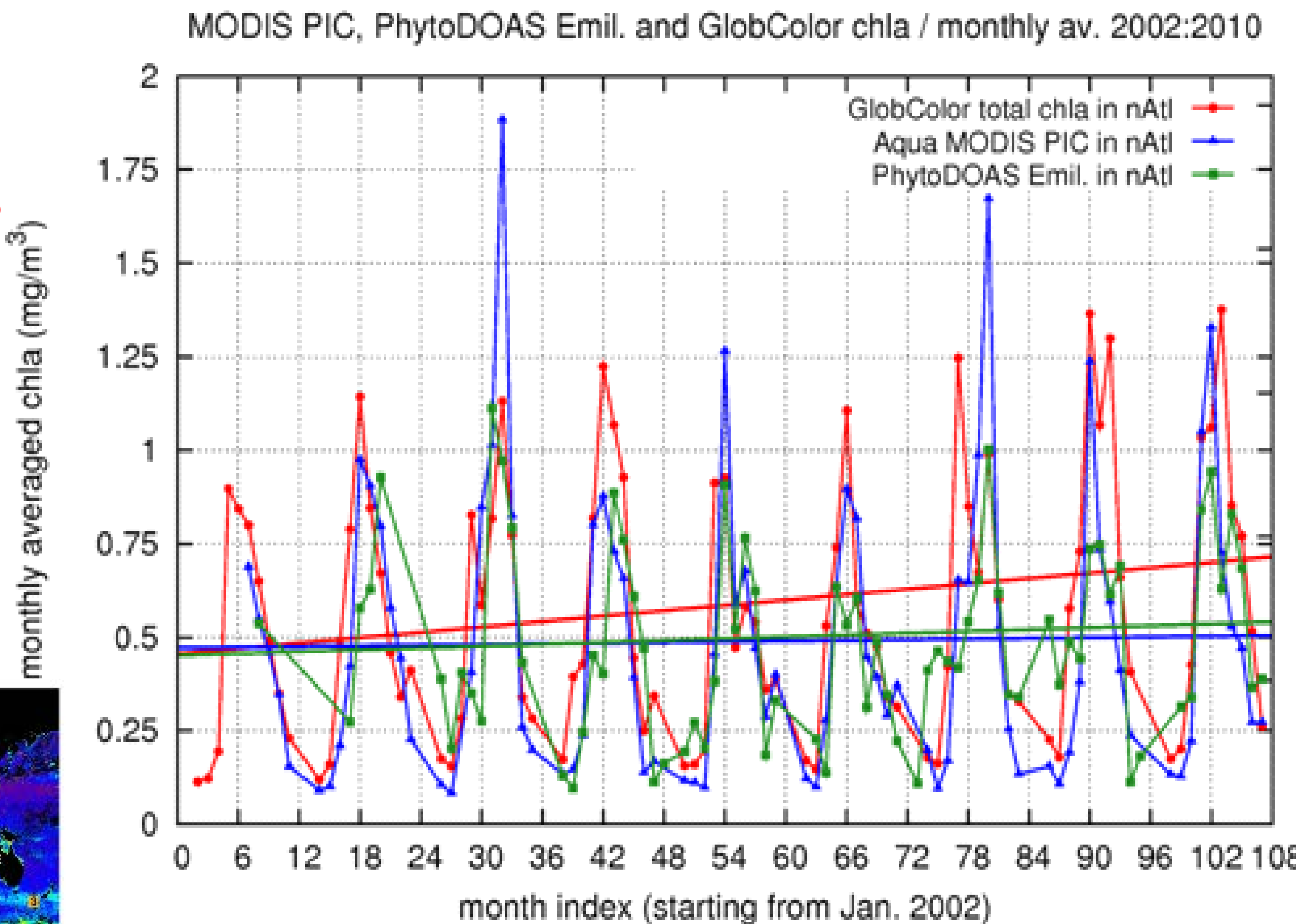
Time Series of Coccolithophores in the North Atlantic (53°N-63°N/14°W-24°W; 2002-2010); Sadeghi et al. BG 2012

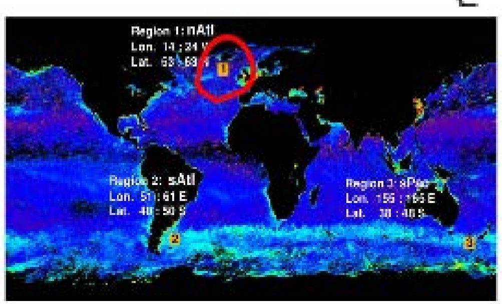
Objectives:
- test and improve PhytoDOAS
- develop independent method to study coccolithophores

GlobColour (MERIS-SeaWiFS-MODIS merged) tot chl-a

PIC from MODIS

PhytoDOAS coccolithophore chl-a





Sadeghi et al. Biogeosc. 2012

Monthly means 2003-2010 at 53°N-63°N / 14°W-24°W

Wind (AMSR-E)

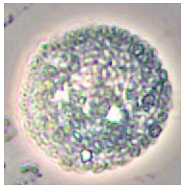
SST (AVHRR)

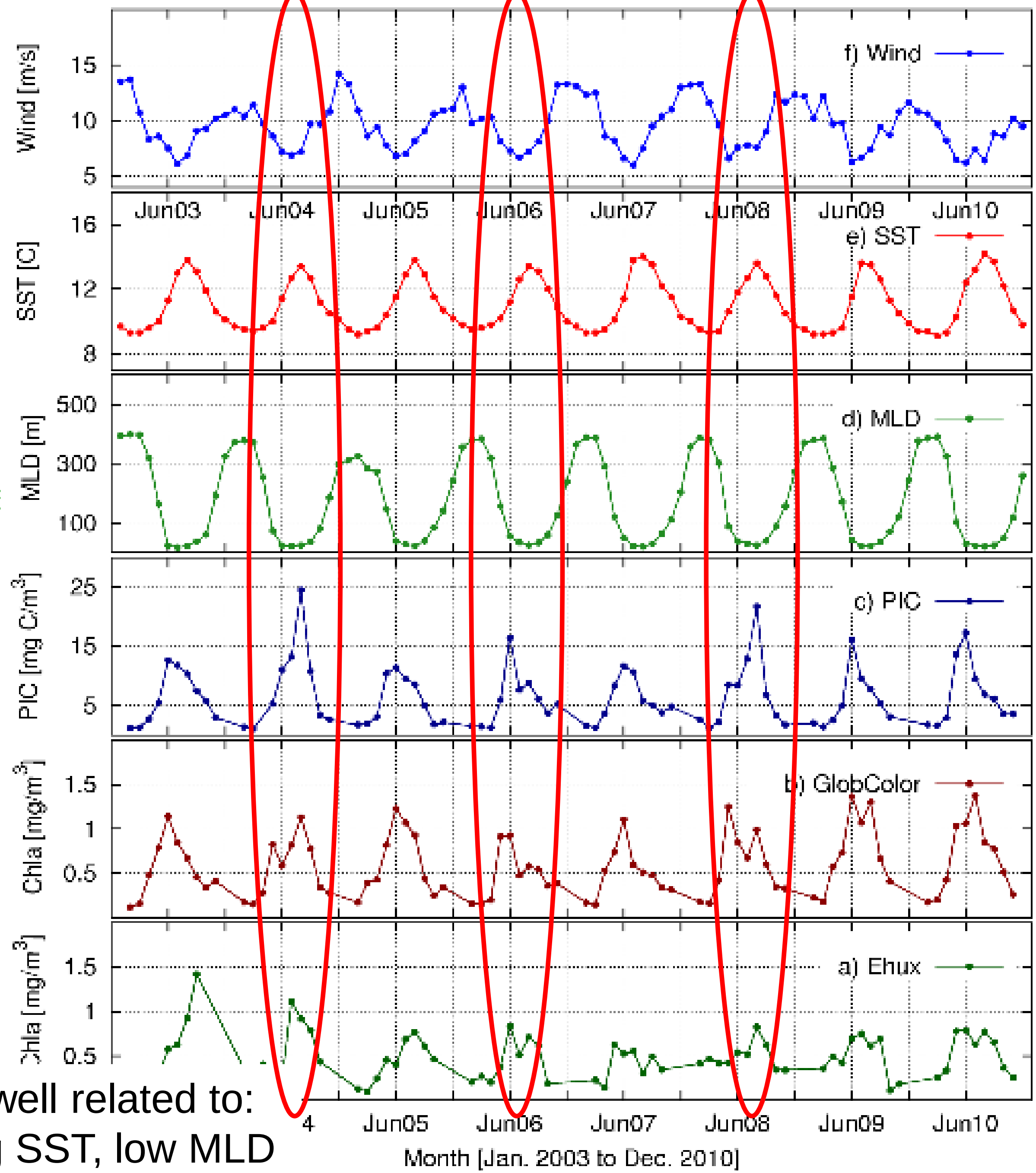
MLD (from FNMOC model output and SODA data assimilation
www.orca.science.oregonstate.edu/1080.by.216 thly.hdf.mld.fnmoc.php)

PIC (MODIS)

GlobColour tot chl-a

PhytoDOAS Coccolithophore chl-a





PhytoDOAS coccolithophores well related to:
PIC, total chla, low wind, rising SST, low MLD

Key issues & benefits associated with hyperspectral data of SCIAMACHY using DOAS in marine science

+ Identification of **high spectrally resolved** optical imprints of water constituents using the **full spectral** information:
  - Quantiative identification of PFTs
  - Identification of inelastic scattering processes (requires <0.5 nm resolution) which enable determination of underwater light availability
  - Retrieval of marine and terrestrial Chl fluorescence (simultanuously)

+ Easy and efficient approach to account for atmospheric effects

+ Additional information and verification of empirical algorithms (band ratio) applied to multispectral ocean color imagery

- less spatial resolution and spatial coverage than multispectral ocean color sensors which limits also validation with in-situ data

Outlook:

Application to GOME-2 missions (2007-, 2012-, 2017– 40kmx40 km), OMI (2004-; 13kmx18km), TROPOMI on Sentinel-5-P, S-4, S-5 (2015-, 2019-, 2020-; 7kmx7km); daily coverage

Evaluation and improvement of parametrizations of biogeochemical (BGC) parameters in coupled bgc-ocean-modelling

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HICO for phytoplankton ecology research: Monterey Bay, California

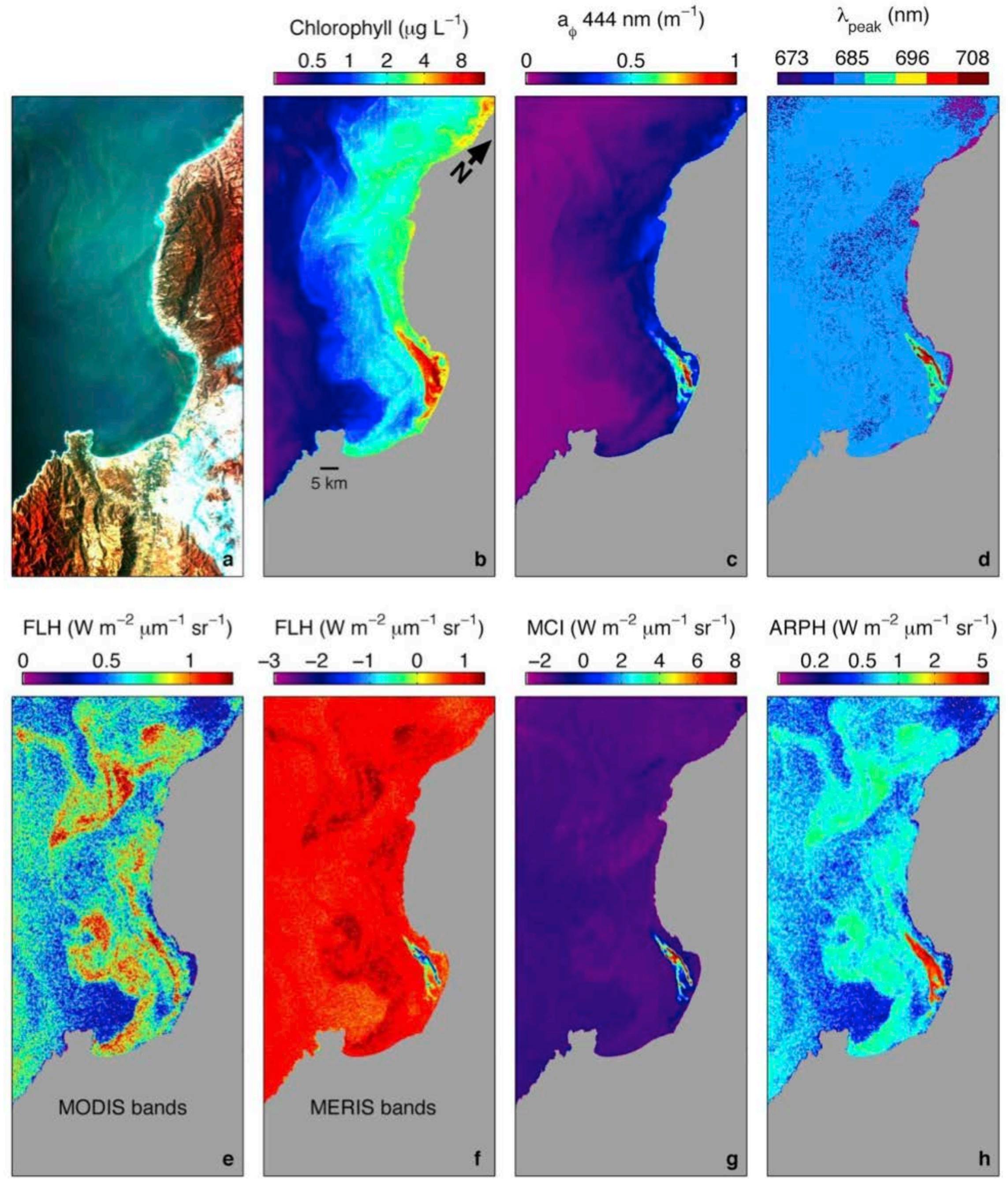
Goal

Integrate HICO with other remote sensing and in situ data to study coastal phytoplankton ecology

Methods

HICO data atmospherically corrected; band-ratio and linear baseline (spectral shape) algorithms applied

Products →



Ryan, Davis, Tufillaro, Kudela and Gao (2014) Remote Sensing

Key issues and benefits associated with hyperspectral data of HICO in marine science

+ Spectral resolution:

1) Enables **applying any multispectral algorithm** for the benefits that the multispectral algorithm offers, as motivated by the optical properties of the water being studied and the research questions being asked.

2) Detection of **dense, near-surface (dinoflagellate) blooms** by **resolving the near infrared reflectance peak** caused by them: high spectral resolution in red to NIR enables identifying **NIR peak intensity** somewhere near its center λ (ARPH- adaptive reflectance peak height) -this spectral resolution enables a more consistent intensity quantification of peak

+ Spatial resolution:

Detection of distinct patches of bloom types which can be small

- Underdevelopment: not enough ($) efforts into better atmospheric correction(!) by the community.
- Calibration also was an issue
- Low temporal resolution and spatial coverage: Balance of spatial and spectral resolution can be tuned to observing requirements.

Ryan, Davis, Tufillaro, Kudela and Gao (2014) Remote Sensing