Scientific Roadmap for Phytoplankton Diversity from Ocean Color

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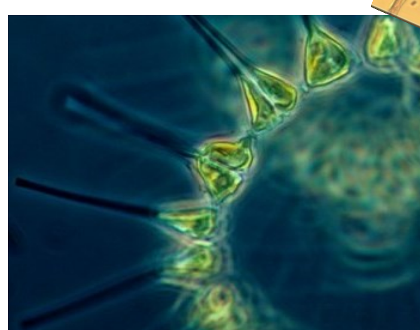
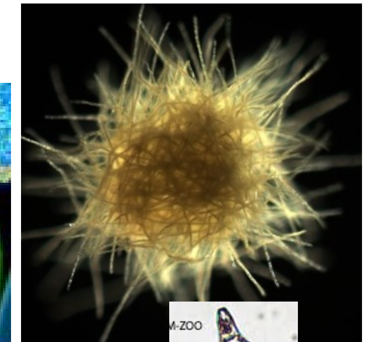
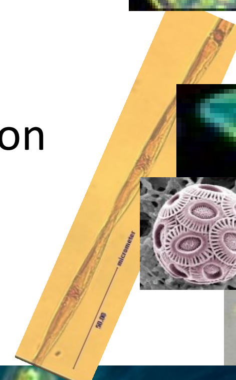
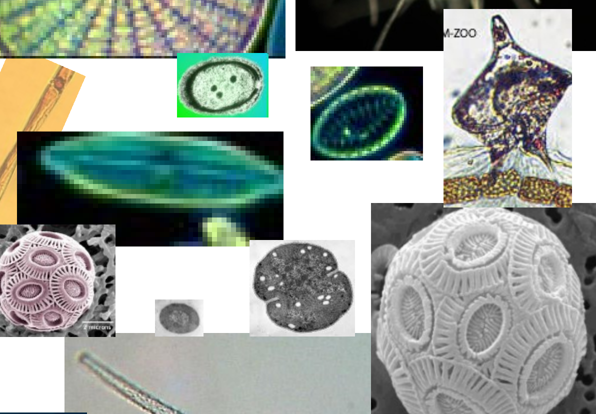
<u>Phytoplankton differ in terms of</u>:

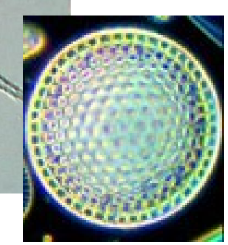
size biogeochemical function nutrient uptake
accessory pigments morphology thermal niche
predation protection/avoidance chain/colony formation
symbiosis
....

Phytoplankton diversity matters:

- As base of foodweb
- For carbon cycling
- For resilience of ecosystem

Courtesy to
S. Dutkiewicz, MIT

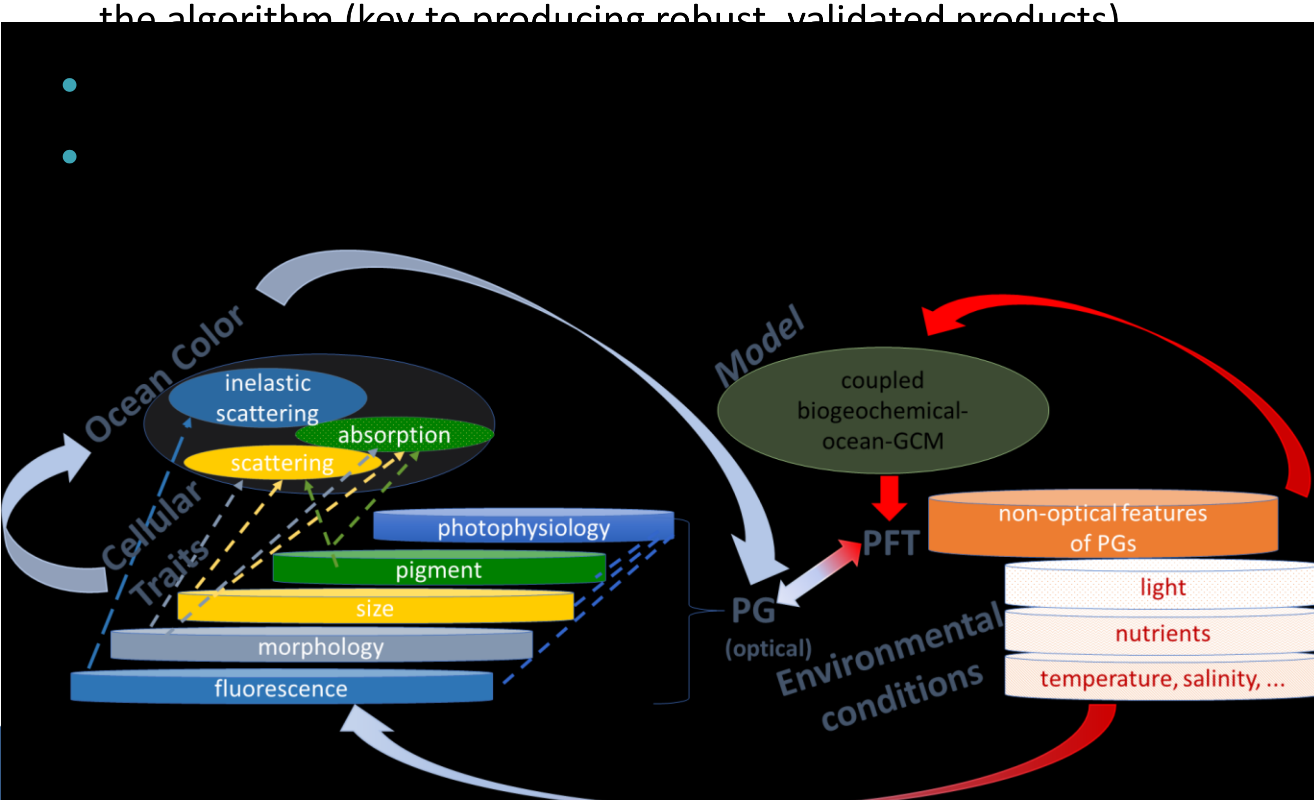
Scientific Roadmap for Phytoplankton Diversity from OC

Bracher & 20 more PFT-experts worldwide (2017) Frontier in Marine Science 4: 55

Developing algorithms on phytoplankton diversity (PFTs) from OC very active research for > decade.

Scientific roadmap identified user needs, summarizes the current state and pinpoints major gaps in long-term objectives to deliver space-derived phytoplankton diversity data (PFT) that meets the user requirements. Specific way forwards are to:

- Improve match between what can be produced/what is actually needed by users
- Improve methodology for quantifying systematically errors associated with PFT products at each step of the algorithm (key to producing robust, validated products)
- m development & validation)
- al optical approach to PFTs
ed compared to multi-spectral



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3952 Vol. 56, No. 14 / May 10 2017 / Applied Optics Research Article

applied optics

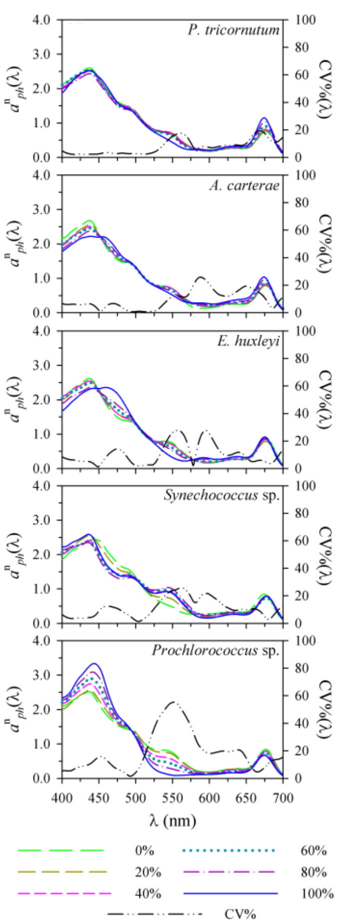
On the discrimination of multiple phytoplankton groups from light absorption spectra of assemblages with mixed taxonomic composition and variable light conditions

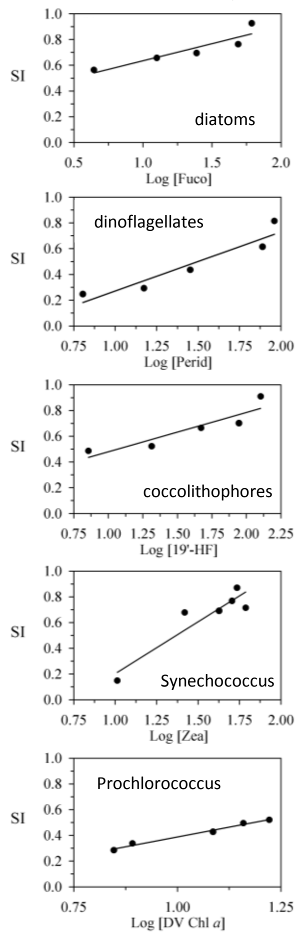
Emanuele Organelli,[1,2,*] Caterina Nuccio,[1] Luigi Lazzara,[1] Julia Uitz,[3] Annick Bricaud,[3] and Luca Massi[1]

Use of the fourth-derivative spectra of phytoplankton light absorption coefficients (400-700 nm, 1 nm resolution) to:

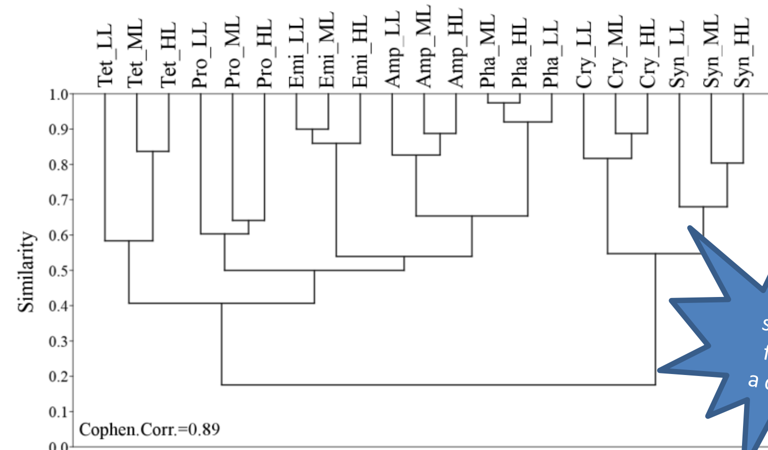
1) investigate uncertainties and limits for phytoplankton group discrimination from assemblages with mixed taxonomic composition;
2) evaluate the extent to which modifications of the absorption spectral features due to variable light conditions affect the optical discrimination of phytoplankton.

5 algal groups can be quantified from the bulk light absorption spectrum (if group contribution > 20% in terms of TChl *a*)

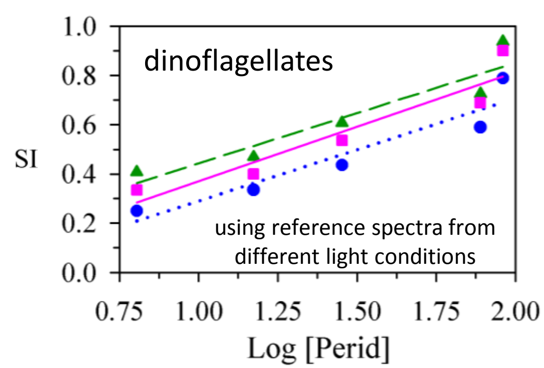


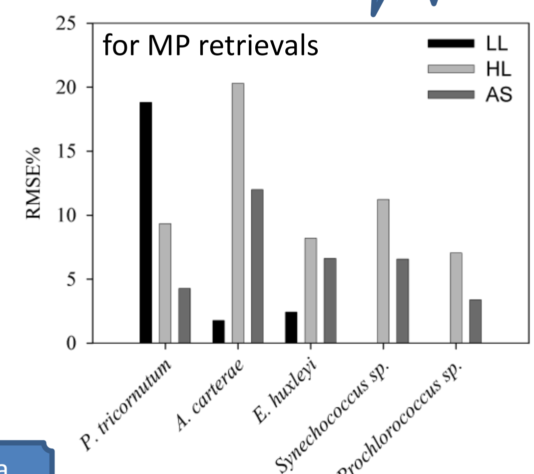


Intra-specific plasticity of light absorption spectra due to changes in light conditions does not significantly affect optical classification and discrimination of phytoplankton (<u>RMSE <21% for retrieval of Marker Pigment concentrations</u>)



Each species forms a cluster





SI indicates similarity with respect to reference spectra

PhytoDOAS Method (Bracher et al. 2009, Sadeghi et al. 2012)

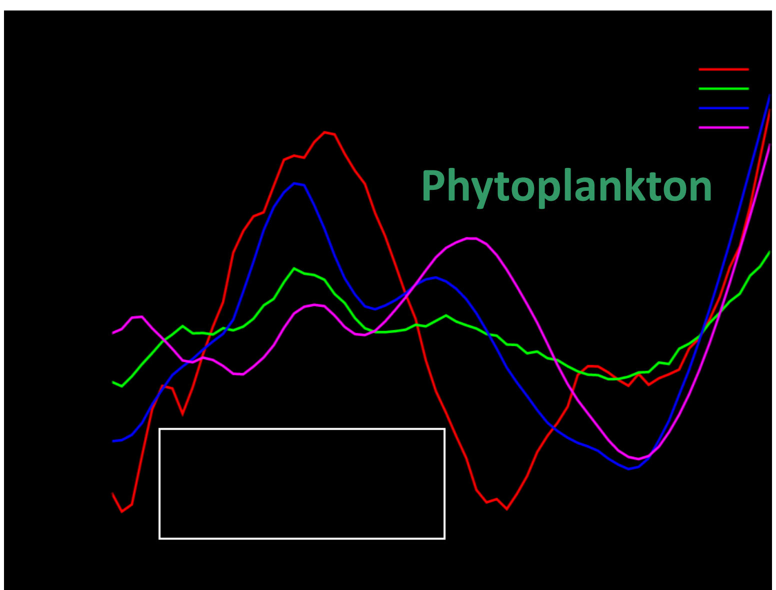
- Differential Optical Absorption Spectroscopy applied to Phytoplankton and to oceanic inelastic processes: based on Beer-Lambert-Law, aims to fulfill following minimization

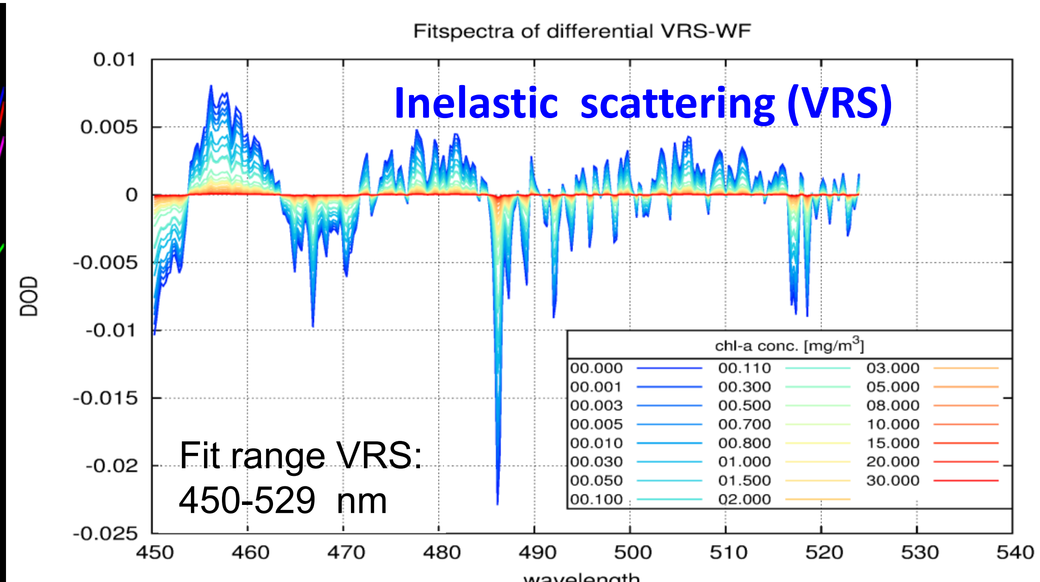
$$I(\lambda) = I_0(\lambda) \cdot e^{-\tau(\lambda)} \Rightarrow \tau(\lambda) = \ln\left(\frac{I_0(\lambda)}{I(\lambda)}\right)$$

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

Atmosphere Phytoplankton Inelastic scattering (VRS), water Polynom

- Satellite earthshine and solar spectra (e.g, SCIAMACHY/ENVISAT)
- Measured absorption spectra of all relevant absorbers
- Low frequency changes (Mie/Rayleigh sc., …) approximated with low order polynomial

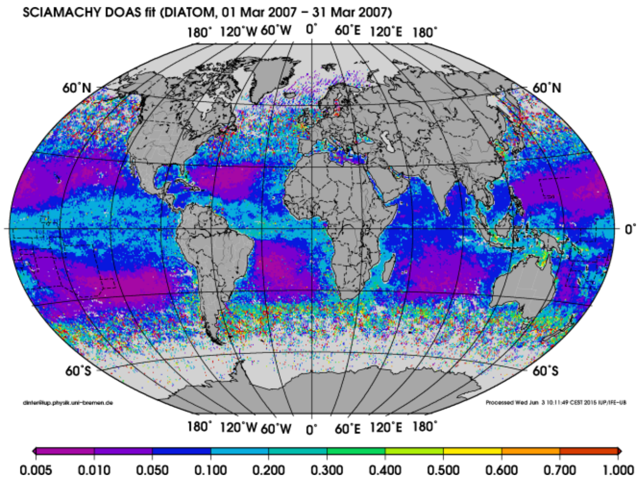


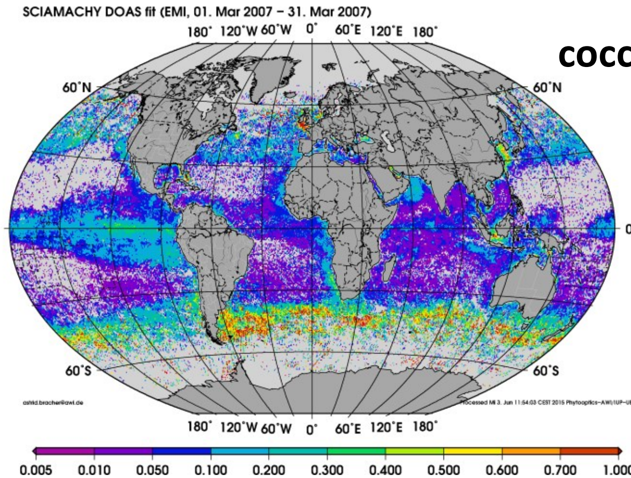


PhytoDOAS applied to hyperspectral (<1 nm) SCIAMACHY/ENVISAT (Bracher et al. Biogeosc. 2009, Sadeghi et al. Ocean Science 2012)

Monthly Chl-a Concentration (mg m^{-3}) – March 2007

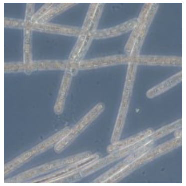
diatoms

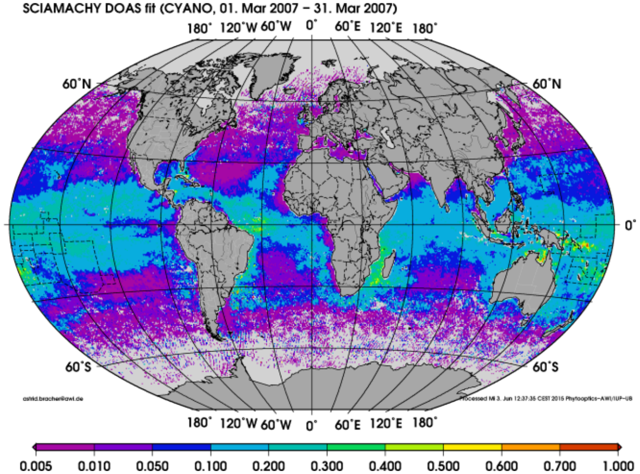




coccolithophores

cyanobacteria





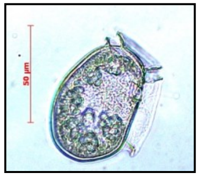
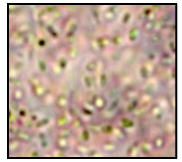
Longterm data set: SCIAMACHY (2002-2012)
https://doi.pangaea.de/10.1594/PANGAEA.870486

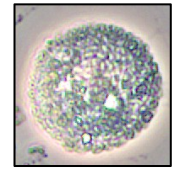
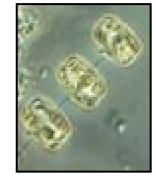
SCIAMACHY Drawback:
- spatial resolution ~60 km x 30 km
- 6 day, open ocean only
- Only top of atmosphere data available: difficult data handling

Application to current sensor OMI (2004 unitl today): **IOCS-Poster Oelker et al.**
Merging with multispectral: SynSenPFT 4 km, daily - **IOCS-Poster Losa et al.**

Spectral Band Requirements for PFT Retrievals

Wolanin, Soppa, Bracher (2016).Remote Sensing 8: 871

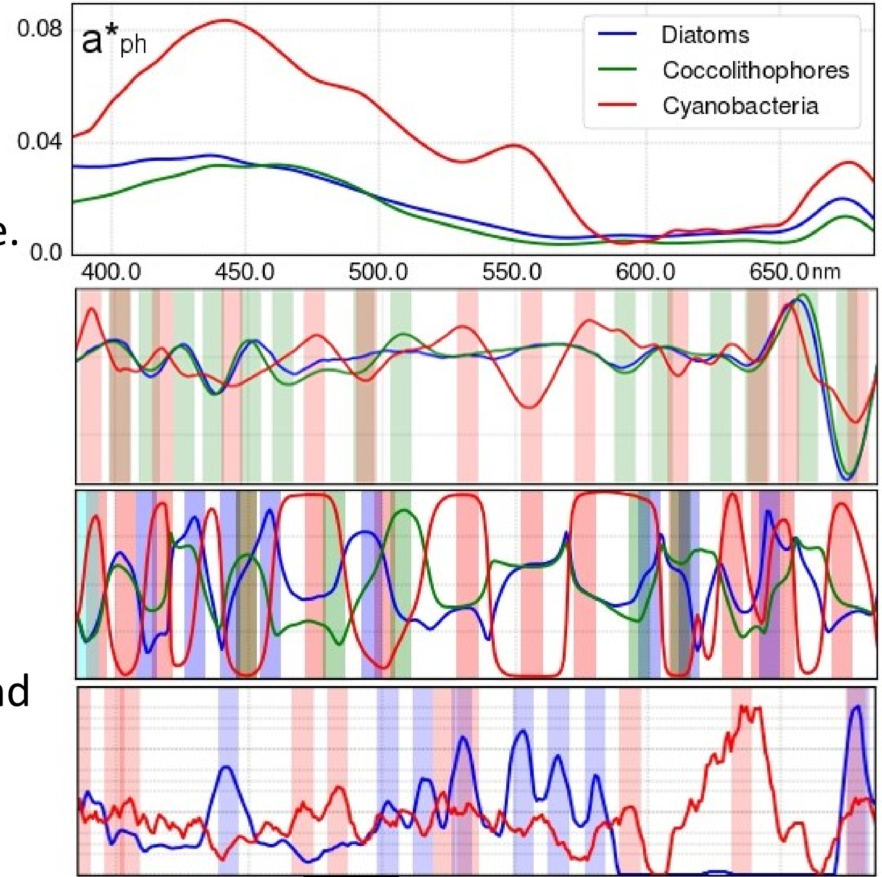




Retrieving diatom, coccolithophore & cyanobacteria chl-a with GIOP applied to simulated RRS & abs. data (>100 000,, 6 PFT mixtures): selected bands, continuous data, OC sensors

Major results

1. Hyperspectral data at 5 nm resolution: best results for discriminating multiple PFTs :
2. Small reduction of bands improves performance.
3. No specific band setting best for all PFTs.
4. MERIS best for diatoms & cyanos, SeaWiFS for coccos.
5. Adding 380, 500, 530 nm bands to OLCI may enable optical retrievals of this 3 PFTs.
6. Choice of band settings depends on
- internal variability of the dataset investigated
- different PFTs drive different spectral changes and hence lead to a different choice of bands.



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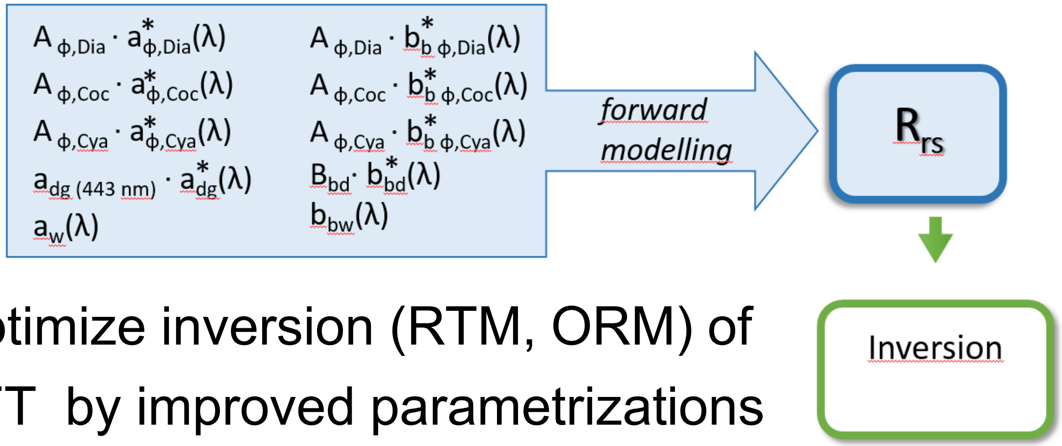
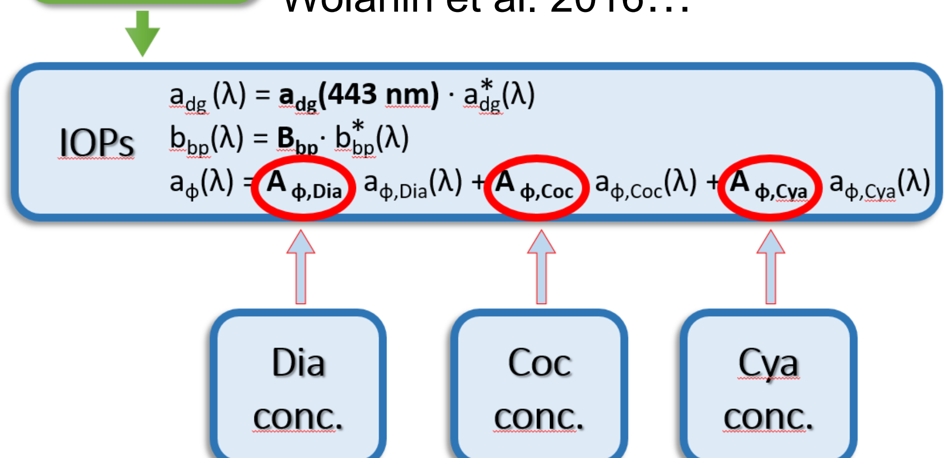
Exploit inversion to get PFT from R_{RS} data: hyperspectral and multispectral with more bands



Inversion methods to build on: Moisan et al. 2013, Chase et al. 2013 **& IOCS poster,** Organelli et al. 2013, Zhan et al. 2013; Evers-King et al. 2014, Werdell et al. 2014, Xi et al. 2015 & **IOCS poster**, Wolanin et al. 2016…



- Optimize inversion (RTM, ORM) of PFT by improved parametrizations of IOPs (mainly scattering!)
- Test PFT inversions for various hyper-spectral sensor settings (HICO, SCIAMACHY, OMI, TROPOMI, EnMAP, PACE)
- Test PFT inversions on OLCI data with 3-4 bands added

(e.g. Operation Change Request for S3-B commissioning phase)

Scientific roadmap for long time series PFT data from OC

Bracher & 20 more PFT-experts worldwide (2017) Frontier in Marine Science 4: 55

Gap	Status	Medium-term action	Long-term action
Satellite Sensors	Multispectral sensors with limited PFT information Limited exploitation of hyperspectral: - SCIAMACHY PFT data but low coverage/resolution - AC failed to derive hyper-spectral Lw, RRS data (HICO)	Develop AC for hyper-spectral sensors Adapt hyperspectral PFT algorithms to current hyperspectral satellite data Develop synergistic hyper& multispectral PFT products	Exploit adding bands to multispectral (OLCI,…) Merge all sensors' PFT da-ta for long term coverage Launch hyperspectral OC sensors (PACE, …)
Uncer-tainties	Deficient theoretical background for inversions? RTM lack PFT-info (esp. bb) No appropriate in-situ HPLC-not really PFT, other PFT data require integration Spectral IOPs (esp. bb) limited	Optimize inversion (RTM) Round-Robins: PFT data format, method & QC Exploit all *in-situ* PFT, auton. techniques, hyper AOP&IOP Use complementary data to constrain algorithms	**Framework for clear traceability of errors** Curate existing data sets Ensure complete PFT, hyperspectral IOP & AOP acquisition