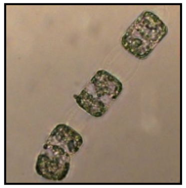
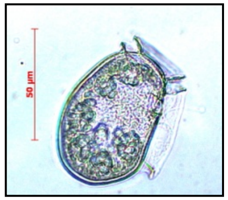
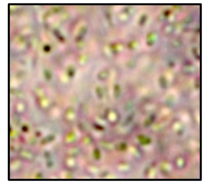
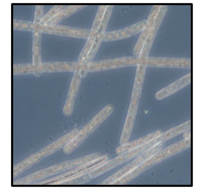
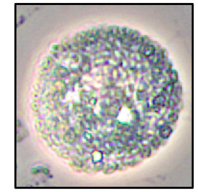
     

Photos: Sonja Wiegmann, Phytooptics, AWI

The Southern Ocean phytoplankton diversity from space and numerical modelling

AWI, Bremerhaven: S. N. Losa, M. A. Soppa, M. Losch, T. Dinter, and A. Bracher
IUP, University of Bremen: J. Oelker, A. Richter, V. Rozanov, and J. P. Burrows
MIT, Cambridge, USA: S. Dutkiewicz

thanks to S. Trimborn (AWI)

SPP-Antarctic “PHYSYN”
Antarctic phytoplankton in response to environmental change studied by a synergistic approach using multi- and hyperspectral satellite data (PhySyn)

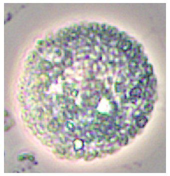
28 March 2018, International Polar Conference, Rostock

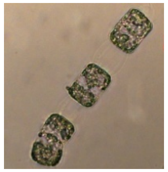
Southern Ocean phytoplankton diversity: observational based evidence

- The coccolithophores *vs.* diatoms in the Great Calcite Belt (GCB)

  (Signorini et al., 2006; Smith et al. 2017)

  calcifier/silicifier





- Southern Ocean diatom size diversity

  (Quéguiner 2013; Deppeler&Davidson, 2017; Tréguer et al. 2018)

  silicifiers to different extend

- Co-existence of haptophytes coccolithophores and *Phaeocystis sp.*

  (Signorini et al., 2006; Alvain et al., 2008; Hopkins et al., 2015; Deppeler&Davidson, 2017)

  Phaeocystis sp.: carbon and sulfur (dimethyl sulfide producer) cycling

Need for well validated long-term data with good spatial and temporal coverage to study and understand the distribution of major phytoplankton groups (phytoplankton functional types = PFT) and their changes over time

Outline

PhySyn satellite phytoplankton diversity retrievals

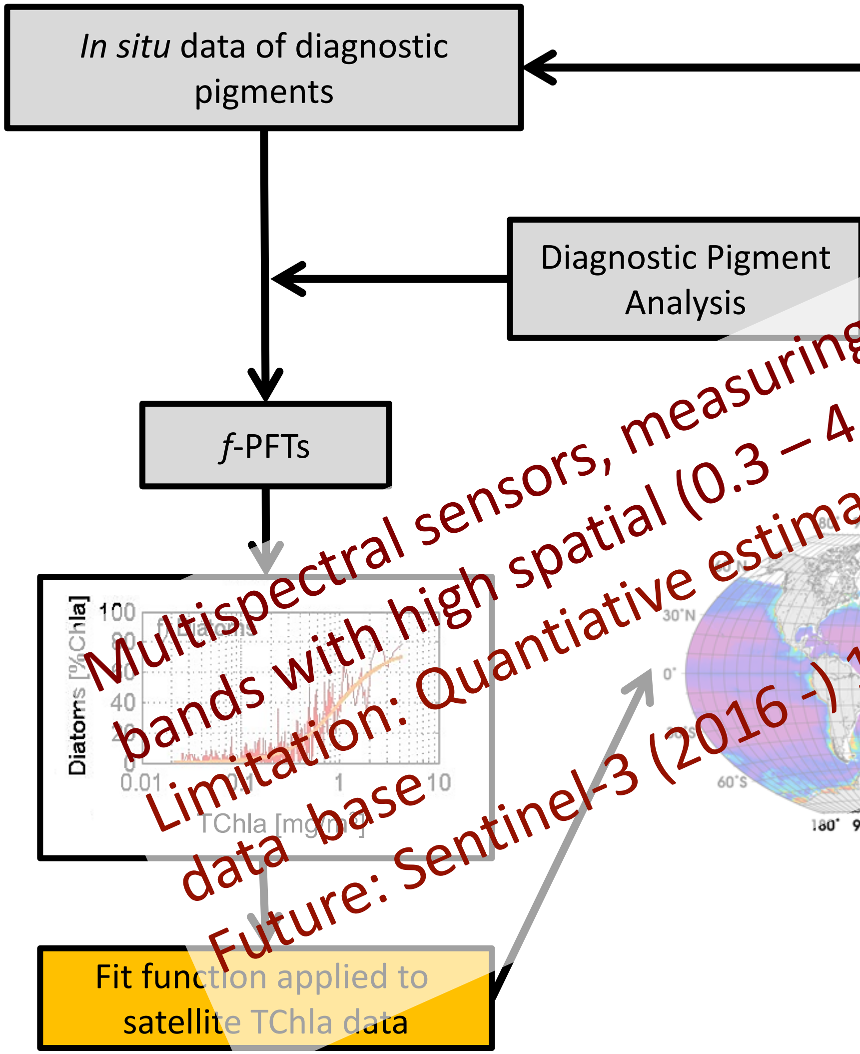
- hyper-spectral based
- multi-spectral based
- synergistic PFT estimates (SynSenPFT)
- the Great Calcite Belt diatom and coccolithophores Chla retrievals

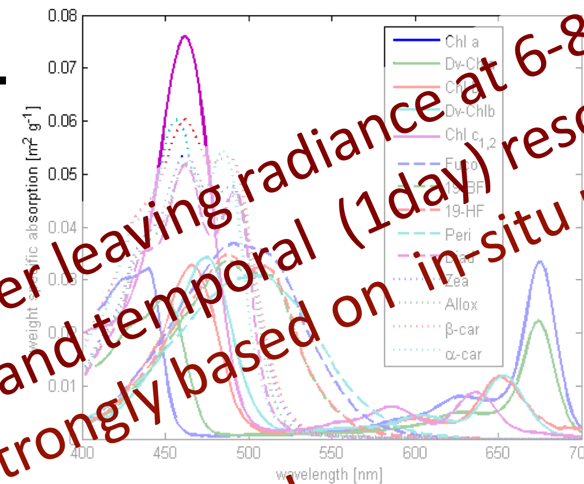
PhySyn numerical simulations

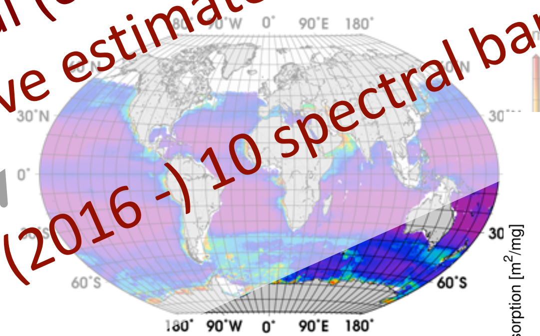
- Darwin-MITgcm coupled physical/biogeochemical model
- accommodation for the Southern Ocean (SO)
- simulated SO phytoplankton diversity

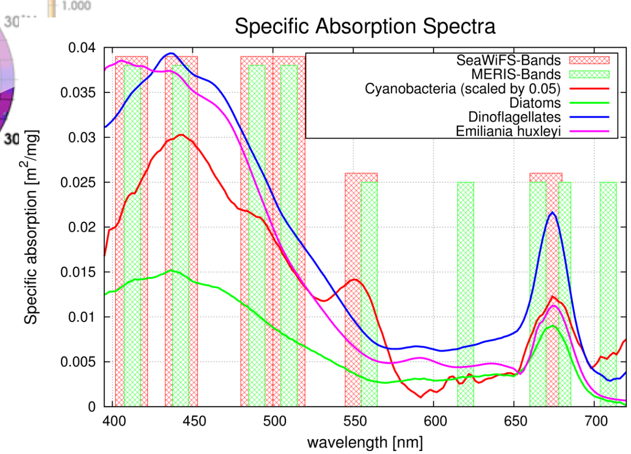
Summary/outlook

Satellite retrievals – OC-PFT (Hirata et al., 2011)









Multispectral sensors, measuring water leaving radiance at 6-8 bands with high spatial (0.3 – 4 km) and temporal (1day) resolution

Limitation: Quantiative estimates strongly based on in-situ pigment data base

Future: Sentinel-3 (2016 -) 10 spectral bands!

Improved OC-PFT for diatoms: *Soppa et al. (2014)*

Used for Phenology study of diatoms in Southern Ocean: *Soppa et al. (2016)*

Satellite retrievals - PhytoDOAS method

Differential Optical Absorption Spectroscopy applied to Phytoplankton and to oceanic inelastic processes: based on Beer-Lambert-Law

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

Bracher et al. 2009, Sadeghi et al. 2012

aims to fulfil following minimization

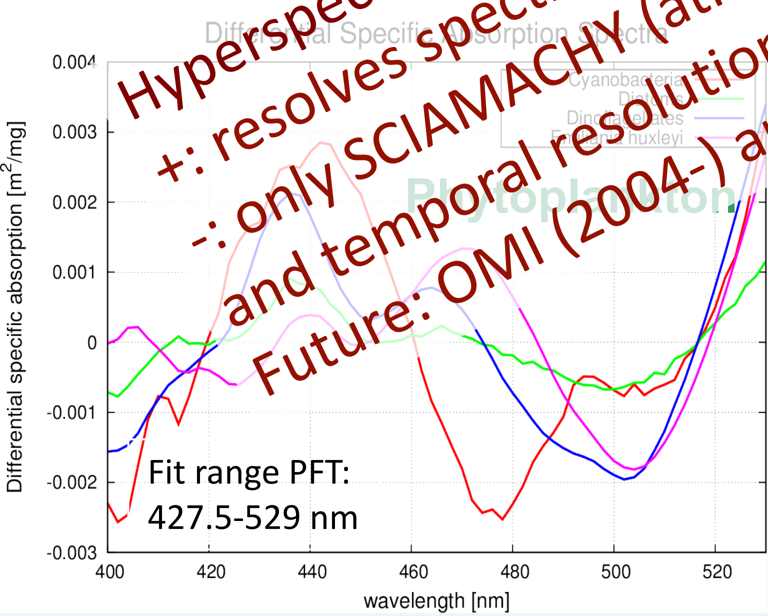
$$S_j = Arg\ min \left\| \tau(\lambda) - \sum_{k=1}^{K} S_k \sigma_k(\lambda) - \sum_{j=1}^{J} S_j a_j(\lambda) - S_{VRS}\gamma(\lambda) - S_{I} r(\lambda) - \sum_{i=0} p_i \lambda^i \right\|$$

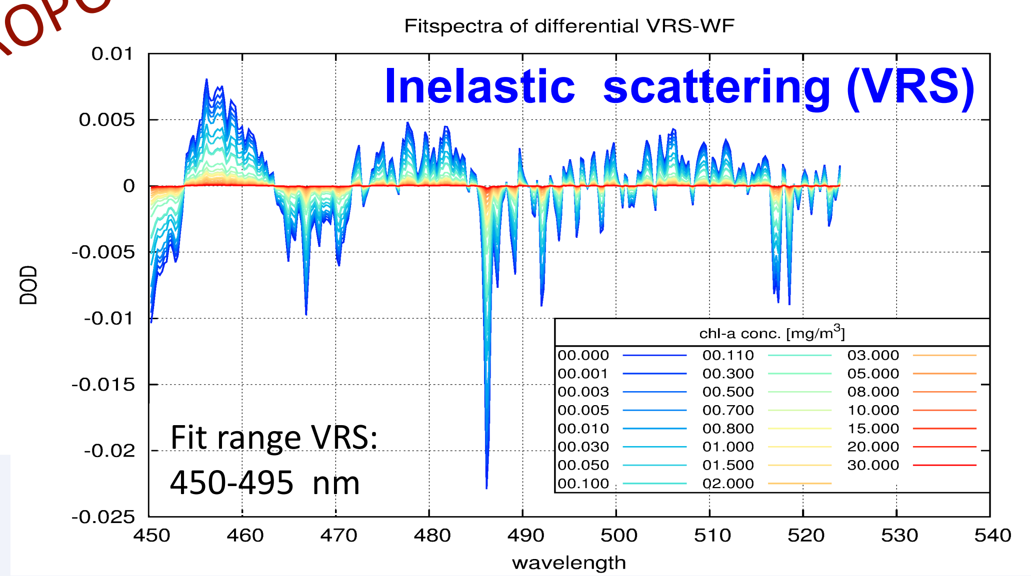
Atmosphere Phytoplankton Inelastic scattering (VRS) water Polynom

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

Dinter et al. 2015

Hyperspectral sensors, measuring back scattered radiance at TOA,
+: resolves spectral fingerprints of various phytoplankton groups
-: only SCIAMACHY (atmospheric sensor) with low spatial (30-60km)
and temporal resolution (2-6 days) and end of mission in 2012
Future: OMI (2004-) and TROPOMI (2018-) with 7-20 km & 1-2 days





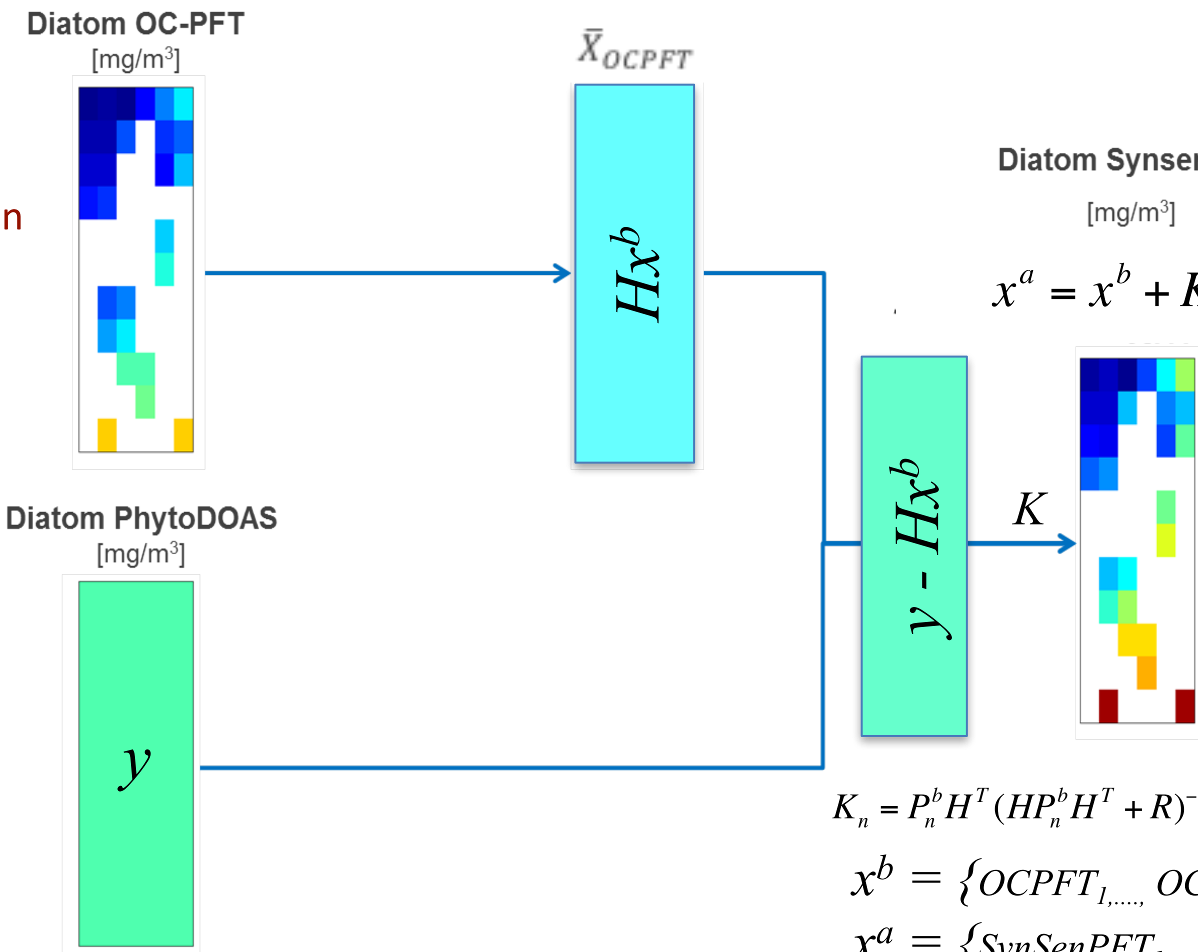
Combination of the two products: SynSenPFT algorithm

https://doi.pangaea.de/10.1594/PANGAEA.870486 (Losa et al. 2017)

funded in parts by PHYSYN

high spatial and temporal resolution (daily 4km x 4km)

less empirical because driven by spectral retrieval



4km x 4km
global
daily
2002-2012

$$K_n = P_n^b H^T (H P_n^b H^T + R)^{-1}$$

$$x^b = \{OCPFT_{1,....,} OCPFT_N\}$$

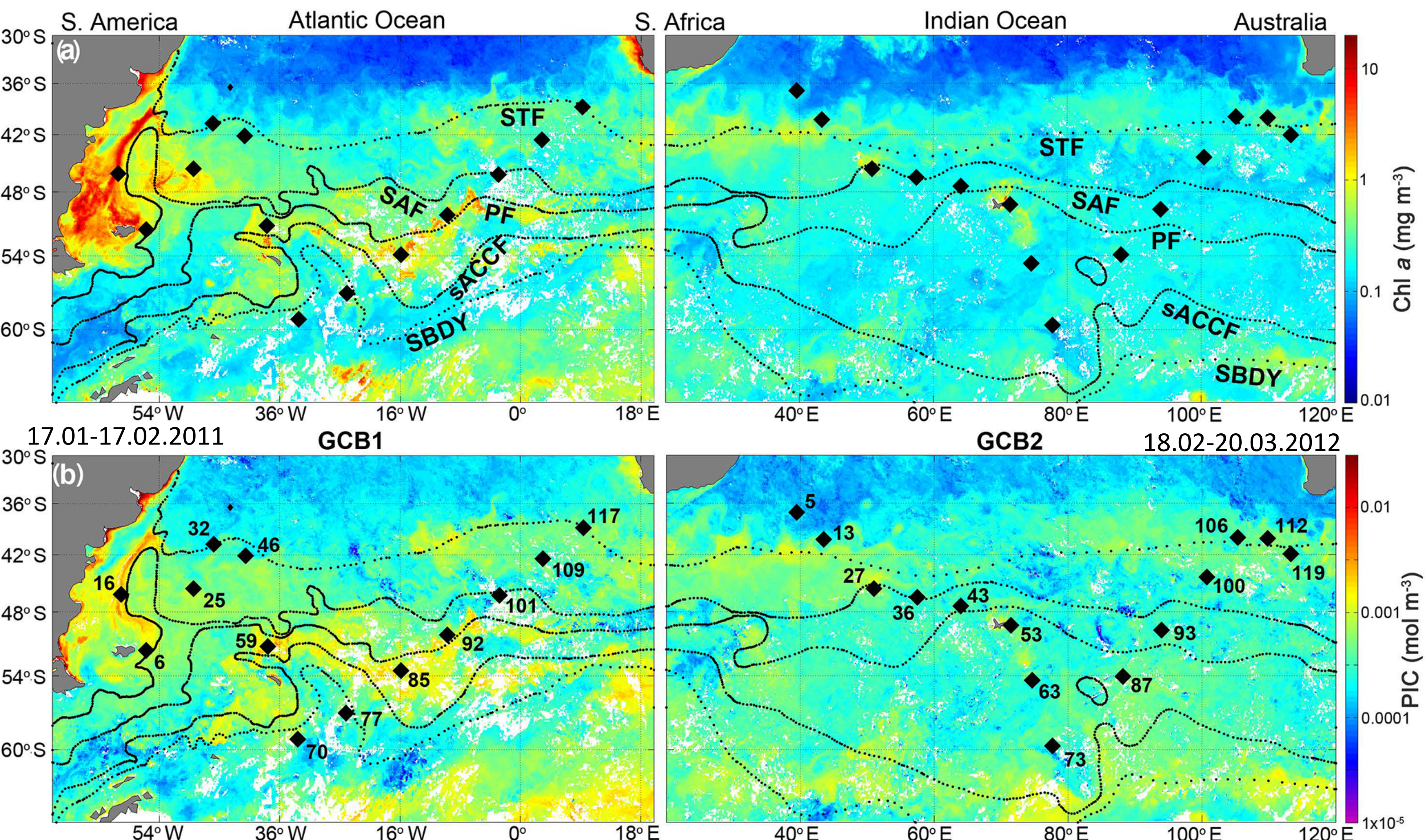
$$x^a = \{SynSenPFT_{1,....,} SynSenPFT_N\}$$

P_n^b - OC-PFT error covariance matrix

R - PhytoDOAS error covariance matrix

H - an observational operator that projects x^b to the y space

The Great Calcite Belt



Smith et al. (2017) The influence of the environmental variability on the biogeography of coccolithophores and diatoms in the Great Calcite Belt, Biogeosciences, 14, 4905–4925.

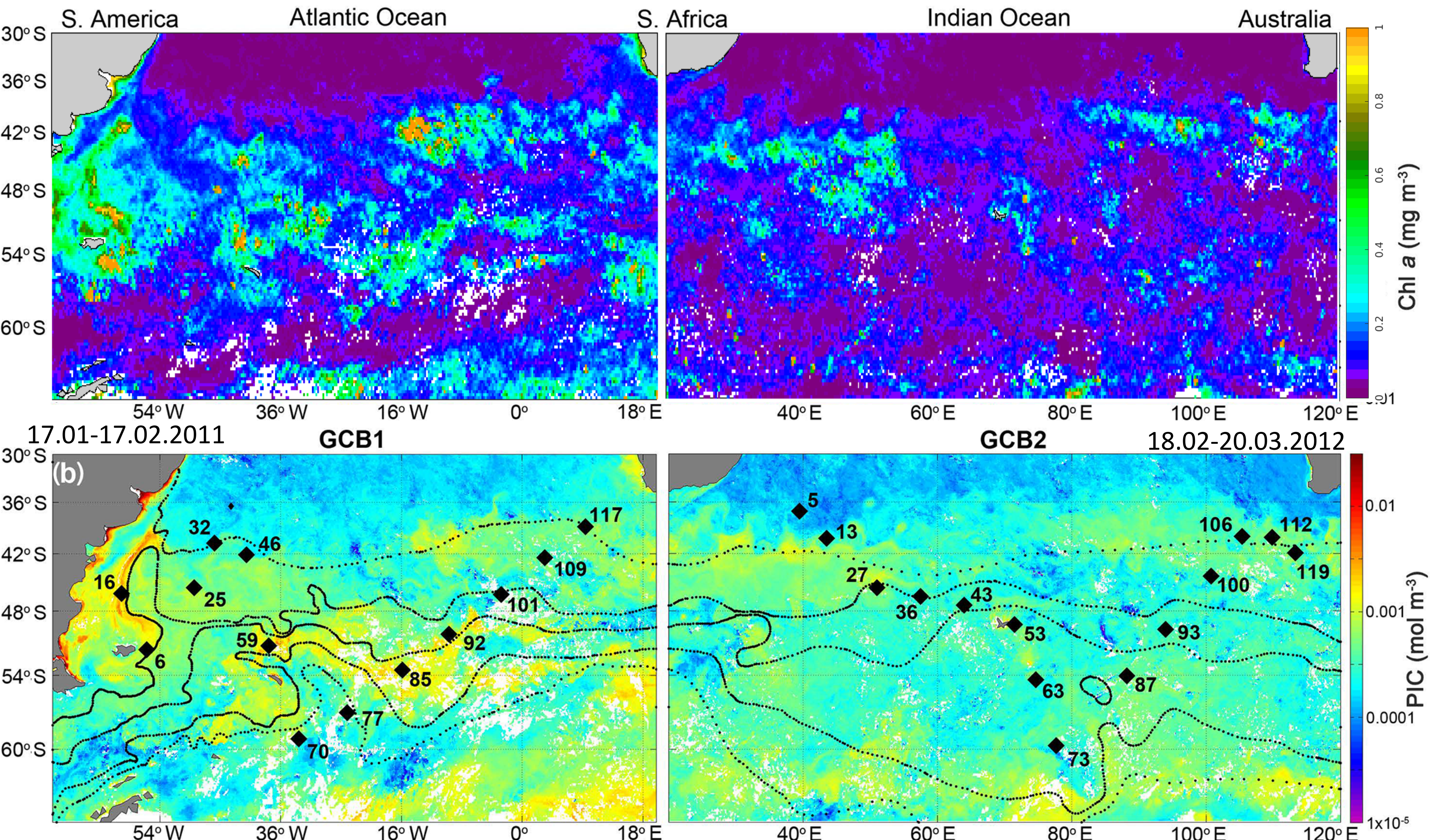
PHYTOOPTICS Helmholtz Young Investigators Group

Universität Bremen

AWI HELMHOLTZ ASSOCIATION

PhySyn: SynSenPFT coccolithophores retrievals

The Great Calcite Belt

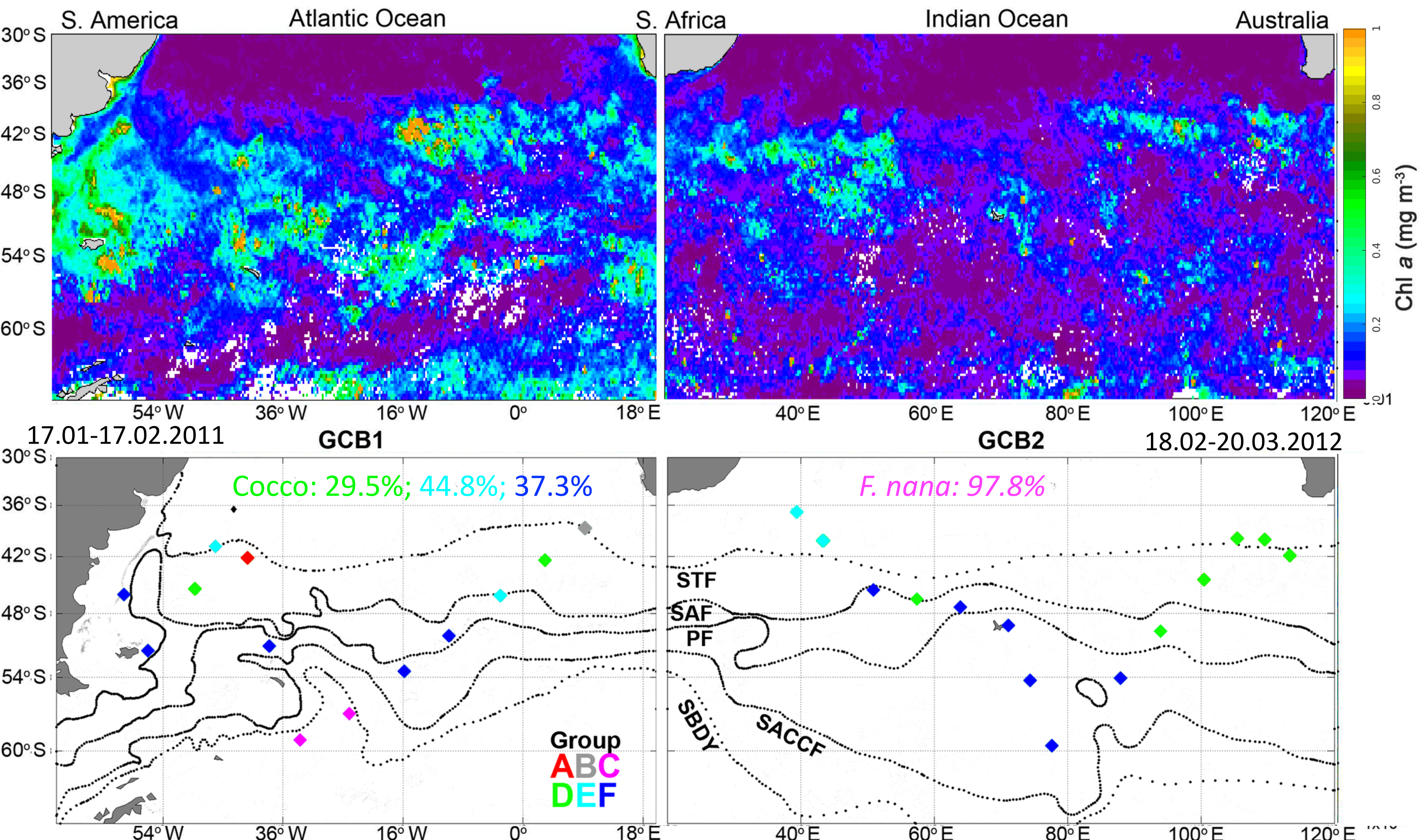


Smith et al. (2017) The influence of the environmental variability on the biogeography of coccolithophores and diatoms in the Great Calcite Belt, Biogeosciences, 14, 4905–4925.

DFG-SCHWERPUNKTPROGRAMM 1158 ANTARKTIS FORSCHUNG mit vergleichenden Untersuchungen in arktischen Eisgebieten

PhySyn: SynSenPFT coccolithophores retrievals

The Great Calcite Belt



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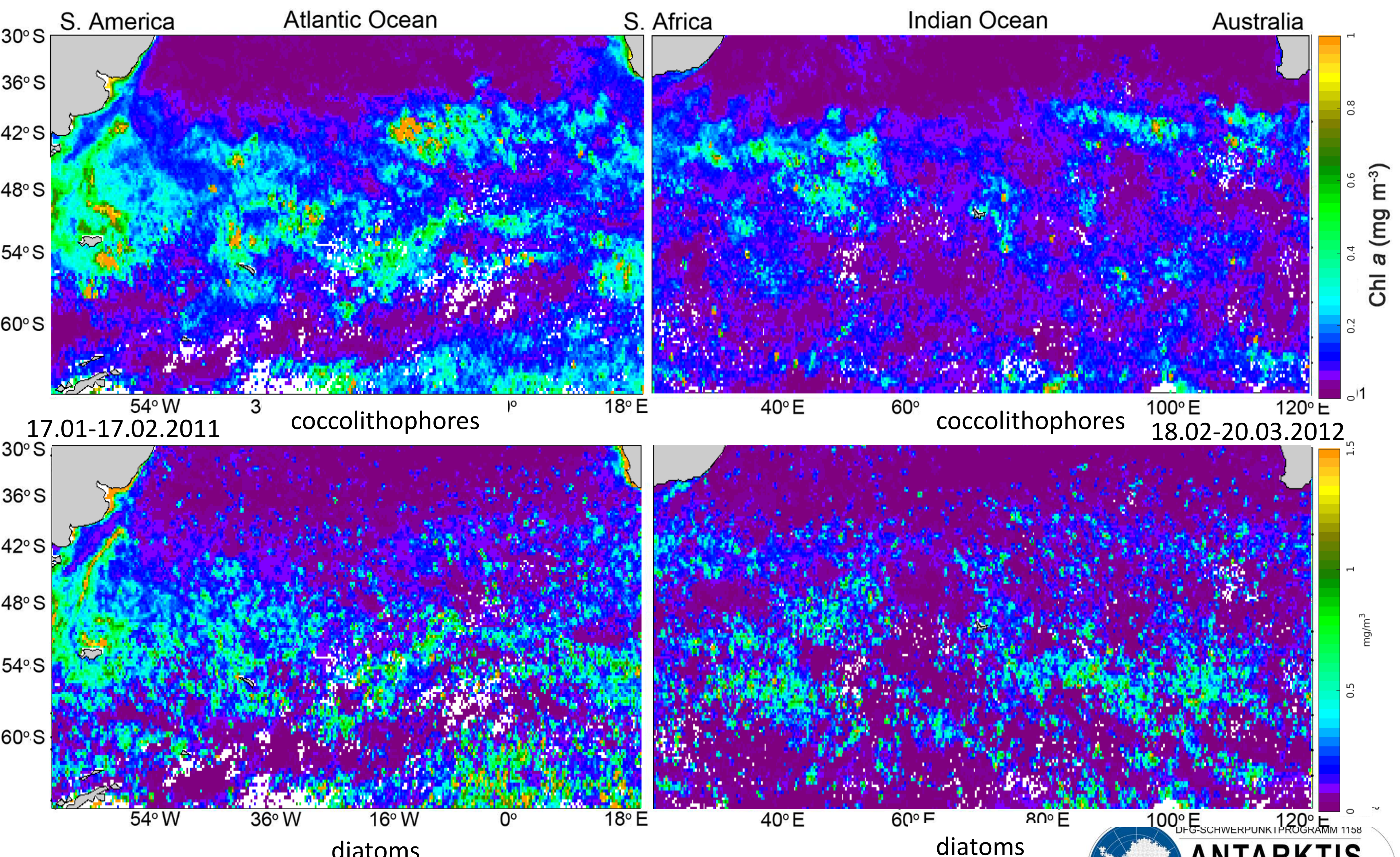
Universität Bremen

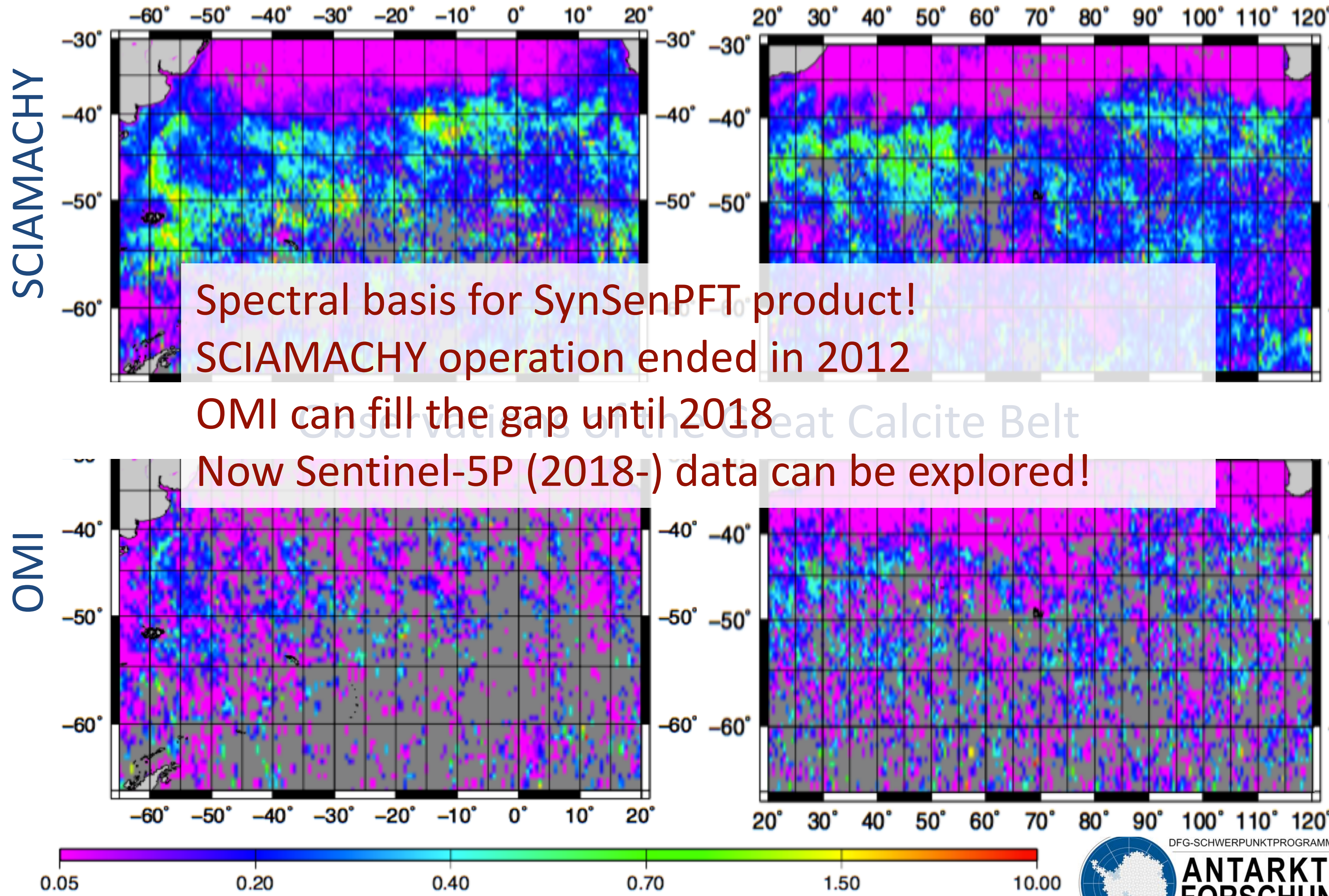
PhySyn: the SynSenPFT retrievals

The Great Calcite Belt



ANTARKTIS FORSCHUNG

SCIAMACHY *vs.* OMI PhytoDOAS coccolithophores retrievals



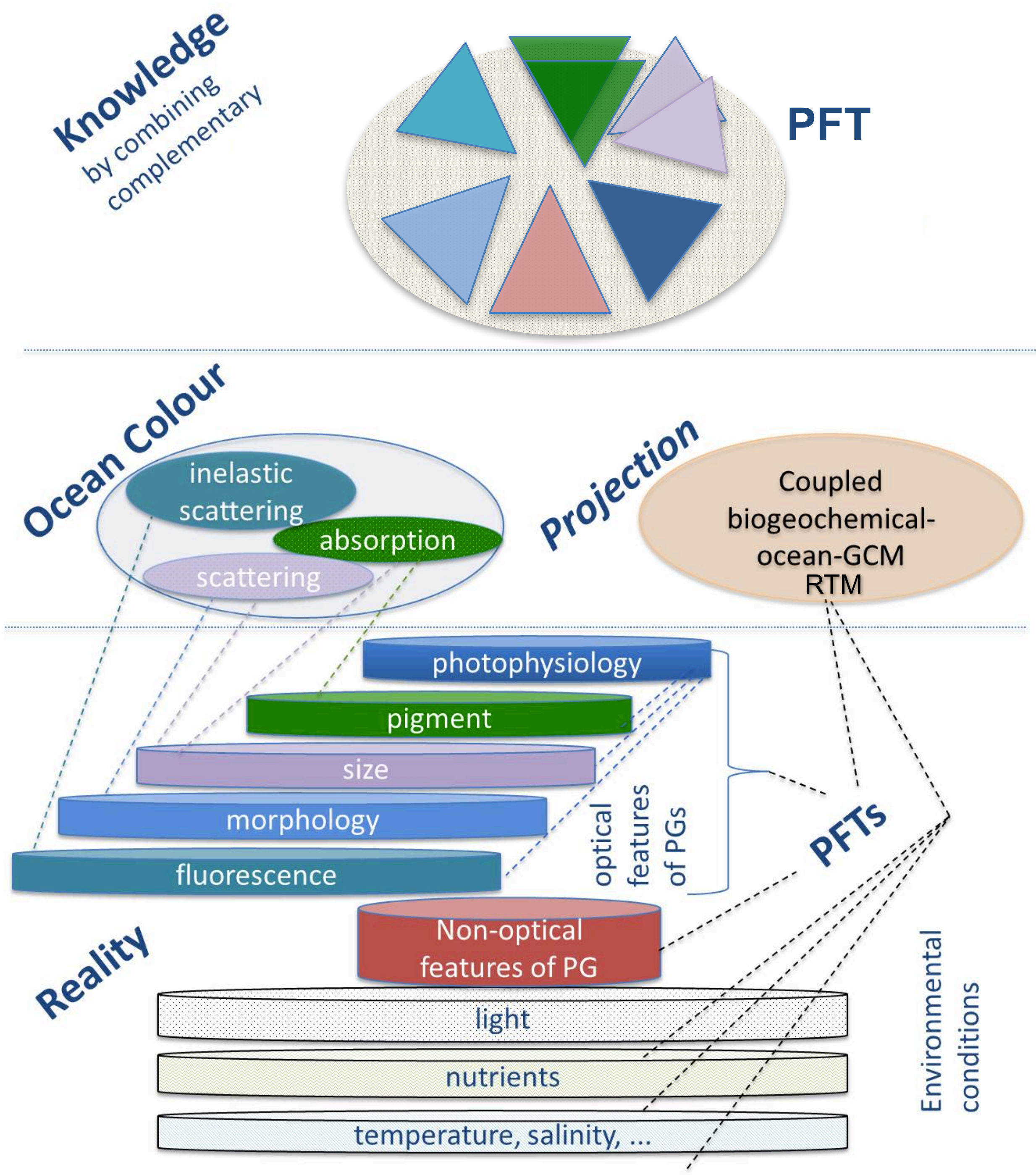
Spectral basis for SynSenPFT product!
SCIAMACHY operation ended in 2012
OMI can fill the gap until 2018
Now Sentinel-5P (2018-) data can be explored!

Mismatch between model PFTs / satellite data

Phytoplankton Diversity – a variety of Phytoplankton Functional Types (PFTs) or other Phytoplankton Grouping (PG)

Bracher et al. (2017) Obtaining Phytoplankton Diversity from Ocean Color: A Scientific Roadmap for Future Development

Representation error in Janjić et al. (2017)



PhySyn: Adapting the biogeochemical model Darwin to the Southern Ocean

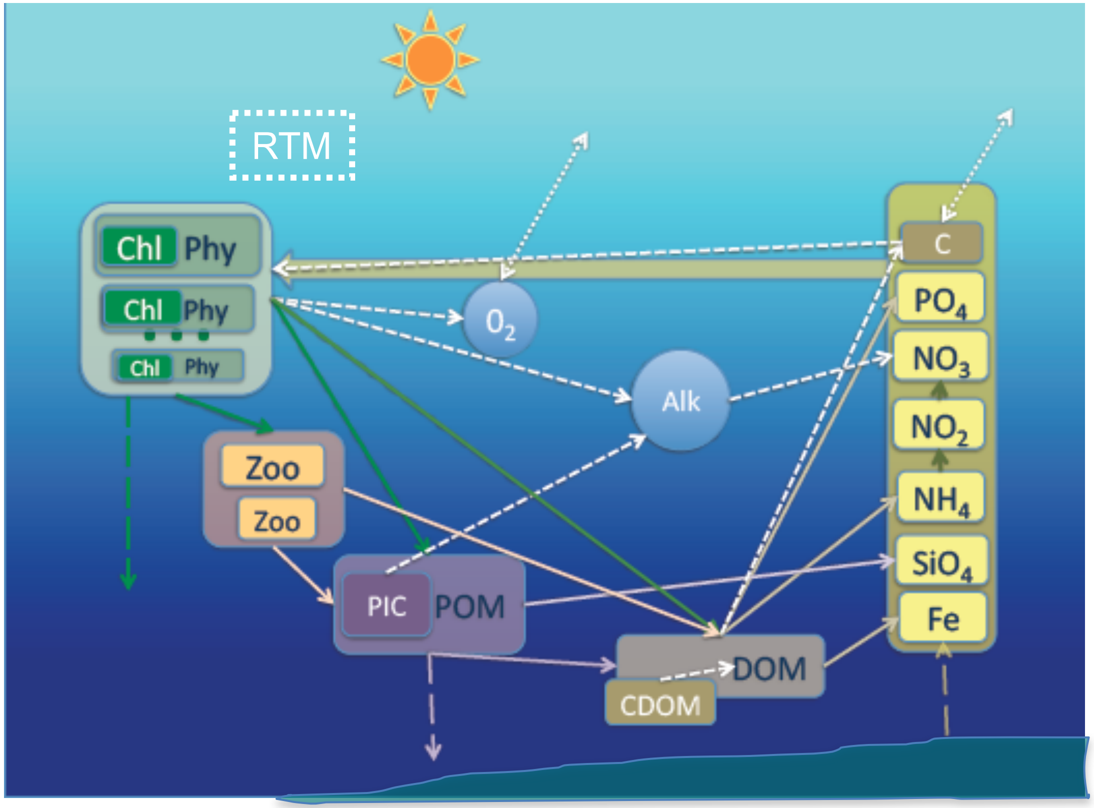
Biodiversity impacts the cycling through different pools

We consider 6 PFTs:

- Diatoms
- other large eukaryotes;
- coccolithophores;
- *Prochlorococcus*;
- other pico phytoplankton;
- N-fixer (incl. *Trichodesmium*);

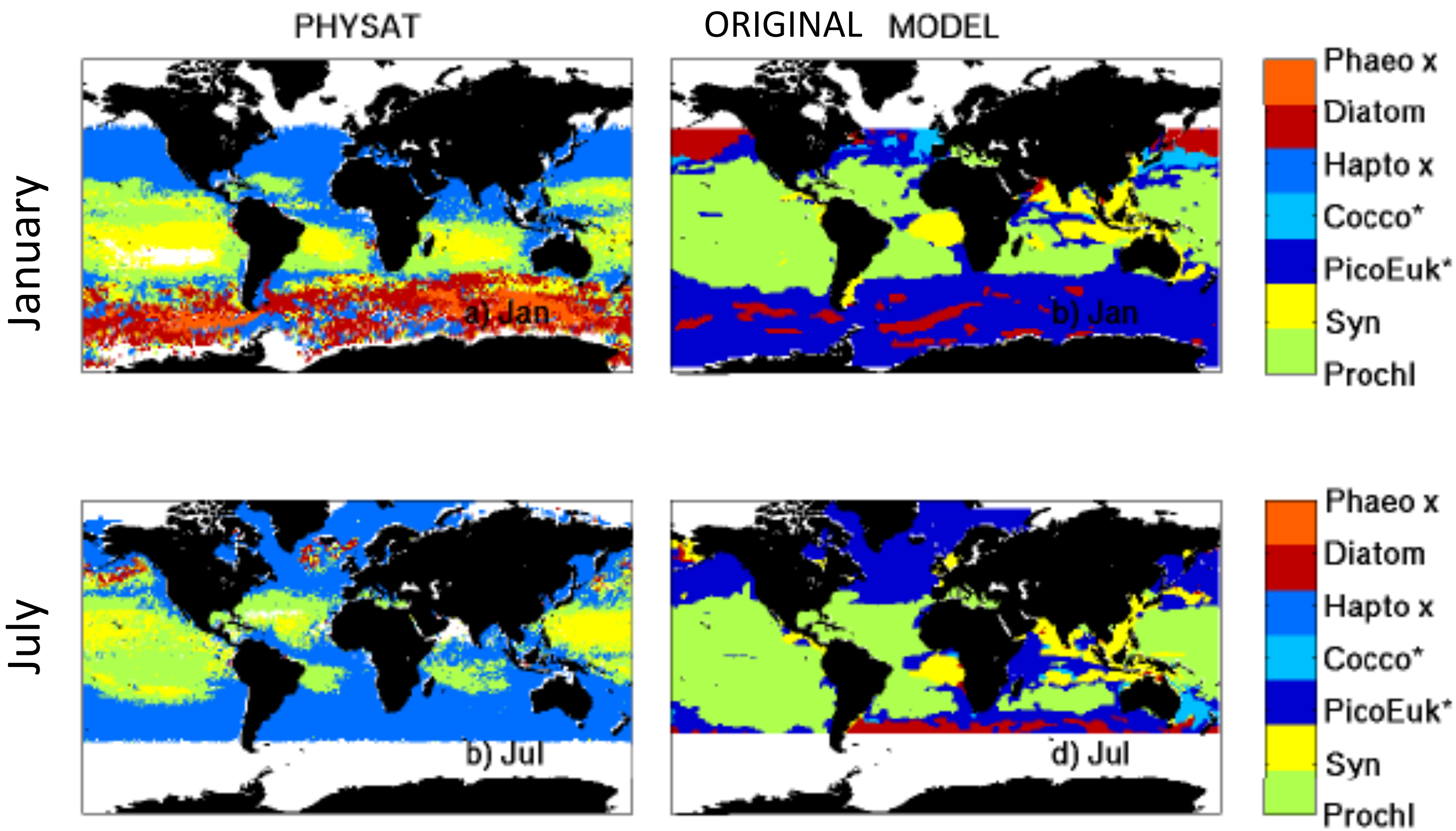
among other 42(41) biogeochemical tracers

Coupled to MITgcm on a cubed-sphere grid (Menemenlis et al., 2008; ~18 km hor. resolution)



The schematic diagram of the Darwin biogeochemical model (produced in accordance with the model description by Dutkiewicz et al., 2015)

Satellite PHYSAT (Alvain et al. 2008) *vs.* former Darwin-MITgcm: mean PFT dominance

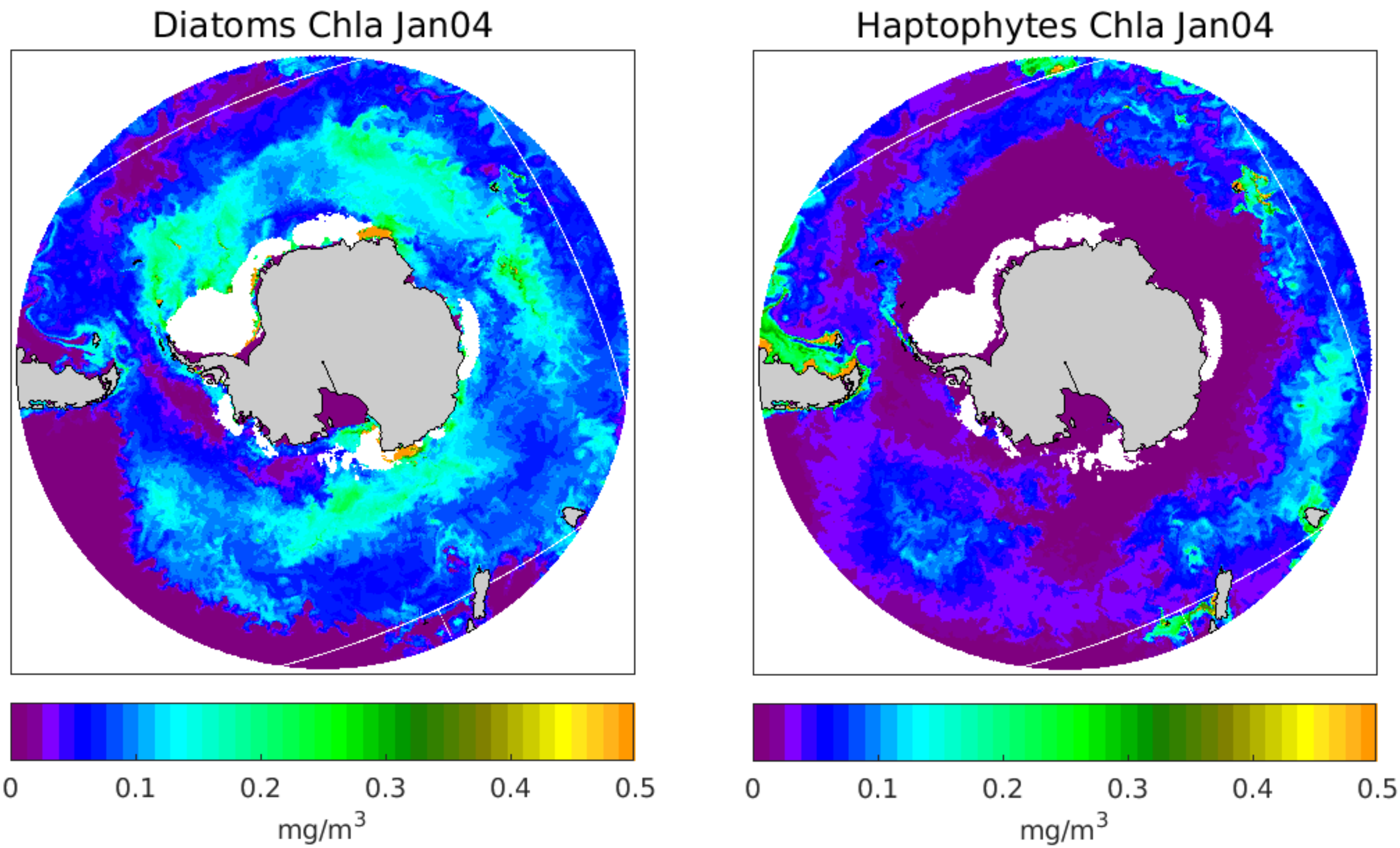


Dutkiewicz et al., 2015

PhySyn: Darwin model adaptation for the Southern Ocean with respect to these observed phenomena

- The coccolithophores *vs.* diatoms in the Great Calcite Belt
  - assumed coccolithophores physiology corrected (Losa et al. 2004) to account for
    - high affinity for nutrients
    - immune to photoinhibition (Tyrrell and Taylor, 1996)
    - ability to escape grazing control (Huskin et al. 2000, Nejstgaard et al. 1997)
- Southern Ocean diatom diversity
  - two distinct size classes introduced for diatoms (as two different model variables)
    - smaller and "slightly silicified and fast growing" at lower latitudes
    - larger and "strongly silicified slowly growing cells" at high latitudes
- Co-existence of coccolithophores and *Phaeocystis sp.*
  - several sensitivity experiments when treating differently the size/physiology (some of the experiments show a signature of *Phaeocystis sp.*)
    - competition within the haptophytes remains a delicate issue

PhySyn Darwin-MITgcm modeling results: The Great Calcite Belt



The coupled model simulations were performed with resources provided by the North-German Supercomputing Alliance (HLRN)

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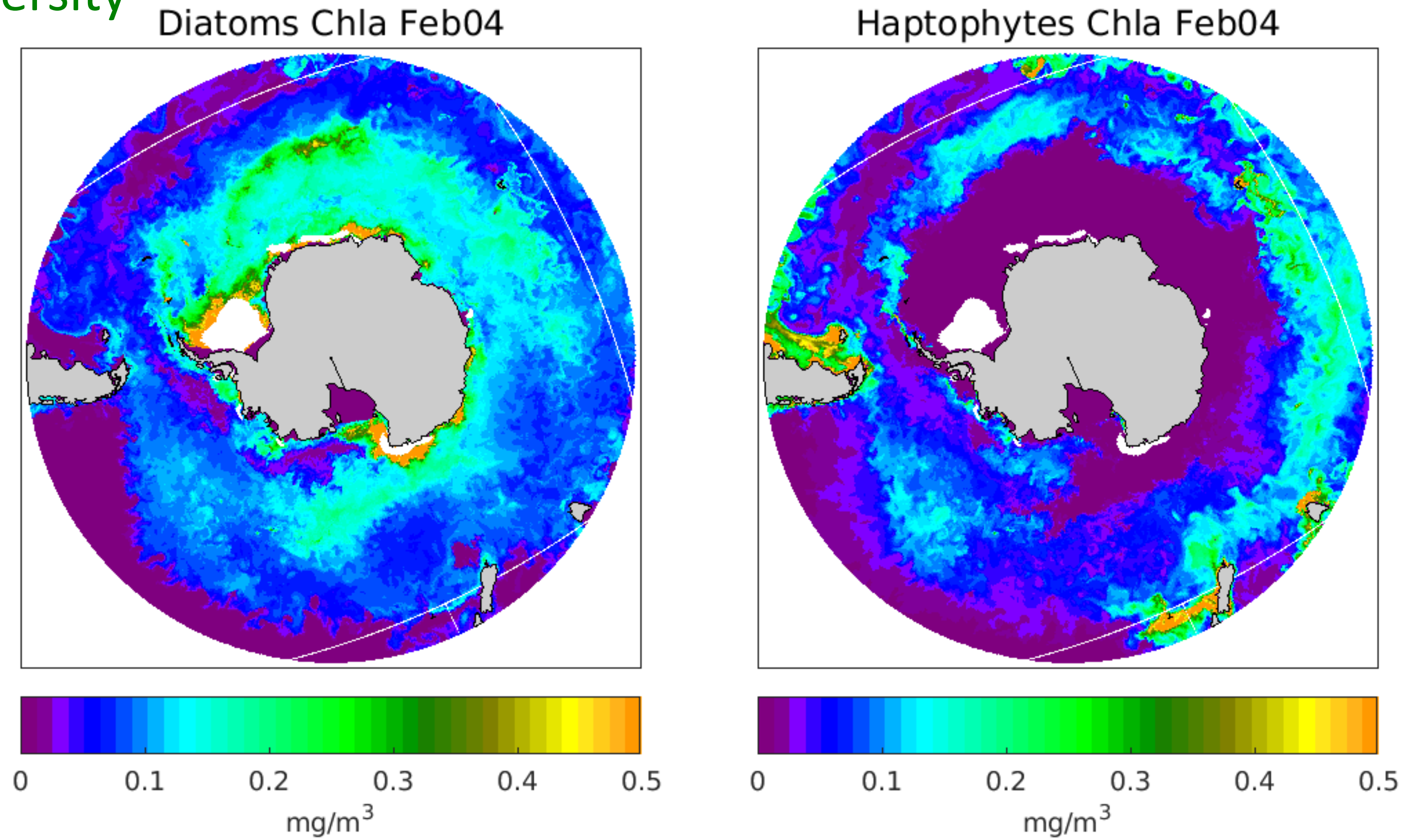
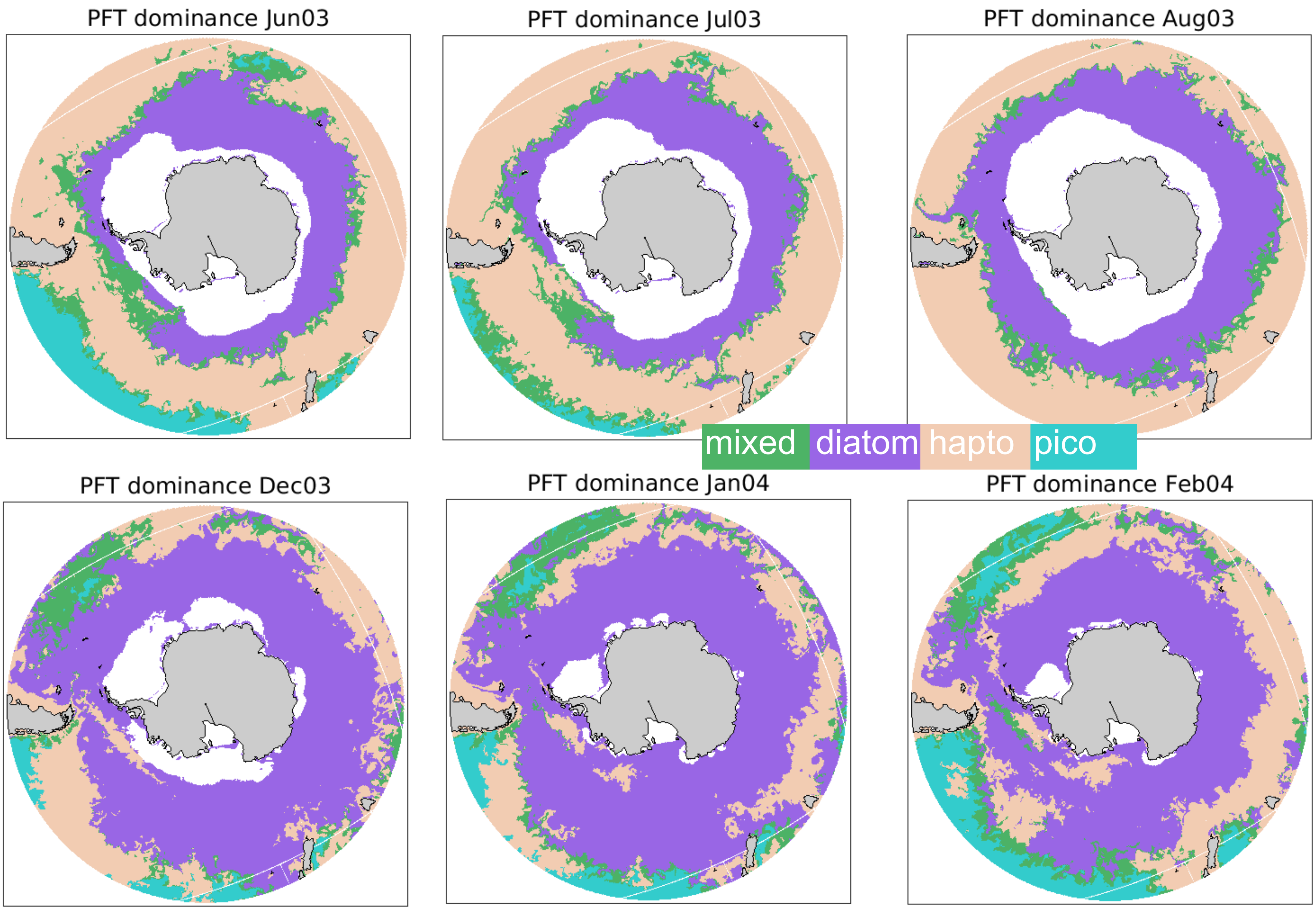
PhySyn Darwin-MITgcm modeling: The GCB due to diatom diversity



Improved spatial distribution and phenology!

PhySyn Darwin-MITgcm modeling: improved PFT dominance

(pico – represents *Prochlorococcus*)



Summary

- The coccolithophores *vs.* diatoms in the Great Calcite Belt
  - distinguishable by the PHYSYN satellite retrievals (PhytoDOAS, SynSenPFT)
  - reproduced/simulated by the PHYSYN Darwin-MITgcm model

  ➢ long time series data to analyse/investigate the phenomena, its physical and biogeochemical drivers

  Despite the OMI sensor degradation, the information assimilated with SynSenPFT would allow to bridge the current and future satellite missions

- Introduction of the Southern Ocean diatom diversity and corrected coccolithophores physiology in the model improved the simulated distribution of the PFTs
  - biochemical/physiological hypothesis on the GCB phenomena

- Further model developments are needed to plausibly simulate *Phaeocystis sp.* dynamics and phenology

Outlook – further to improve/develop/collect

Coupled physical/biogeochemical modeling

- changes in size/life stage of *Phaeocystis ant.* (Popova et al. 2007, Moisan&Mitchell 2018, Bender et al. 2018) – long term
- simulation for a longer time period

Satellite phytoplankton diversity retrievals

- hyper-spectral based – OMI, TROPOMI
- Synergistic PFT estimates (SynSenPFT algorithm extended)
- with multi-spectral based – OLCI – long term

Model and data synergy – data assimilation – long term

Need *in situ* observations

Thank you!

The SynSenPFT Chla estimates and model simulations were obtained with resources provided by the North-German Supercomputing Alliance (HLRN)