Ocean Color Algorithms for the Southern Ocean – Constraining the Carbon cycle

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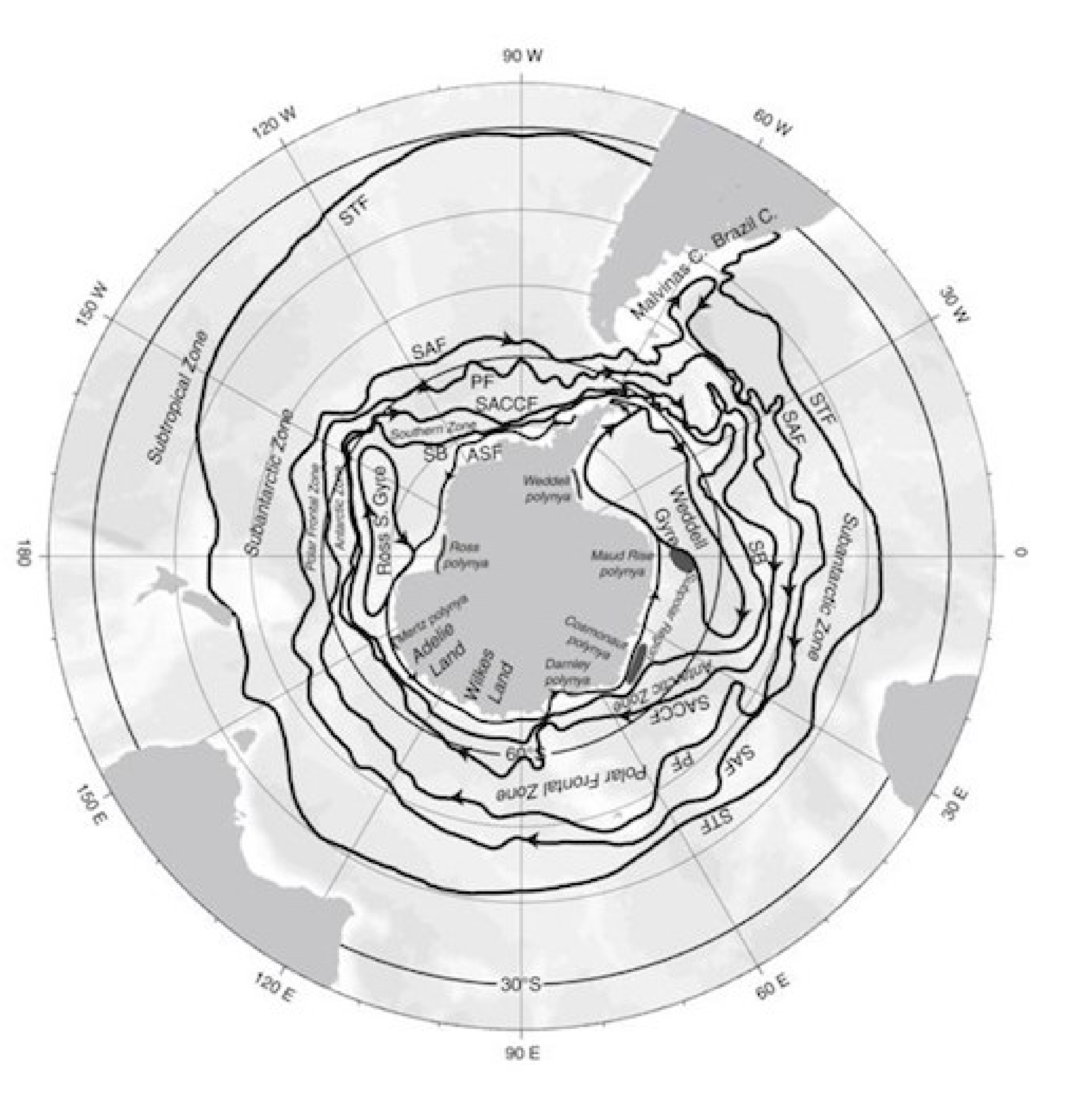


Antarctic Fronts:

South ACC

Polar Front

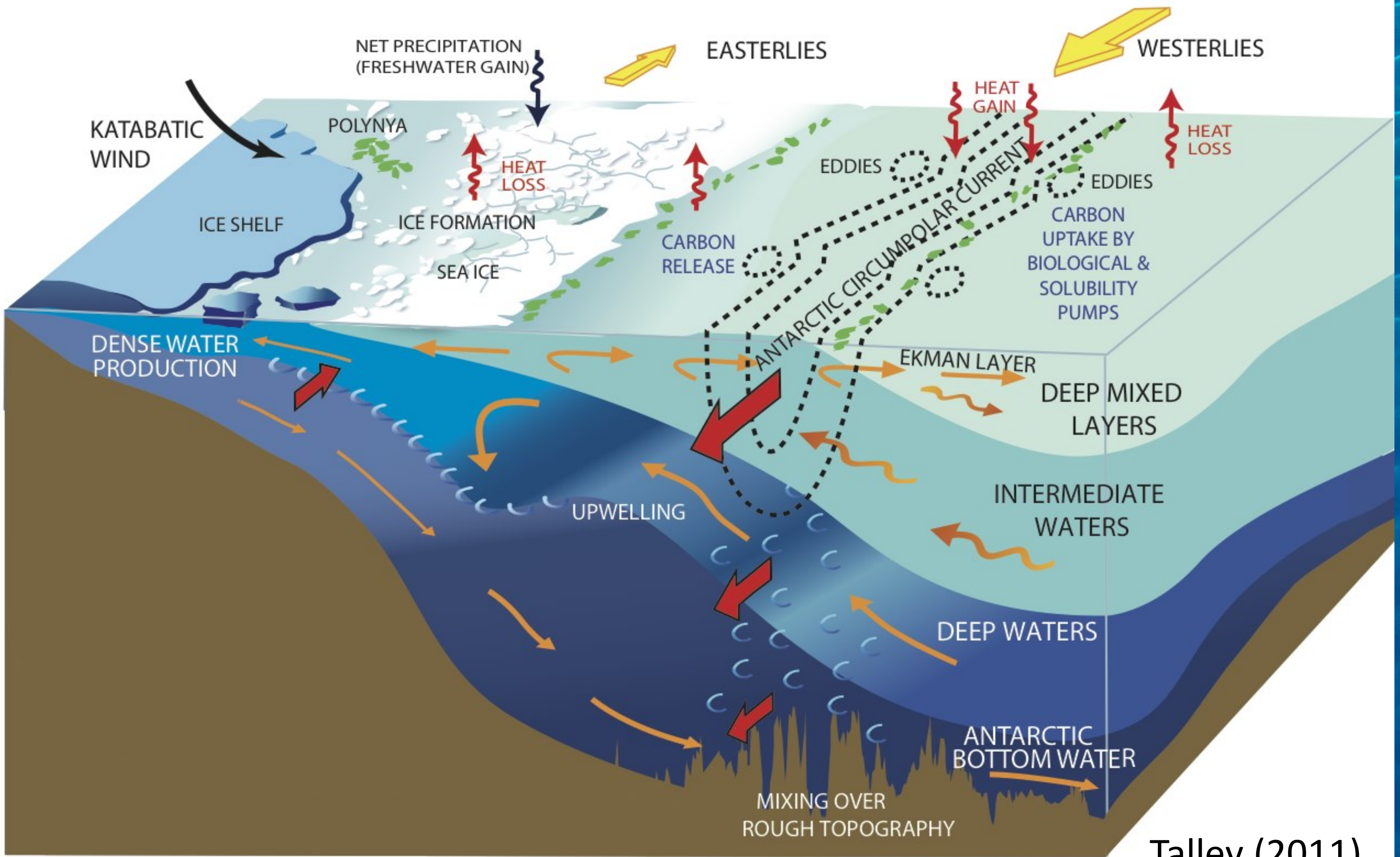
SubAntarctic

SubTropical

Gyres (3)

e.g. Orsi et al. (1995)

Complexity of Southern Ocean waters



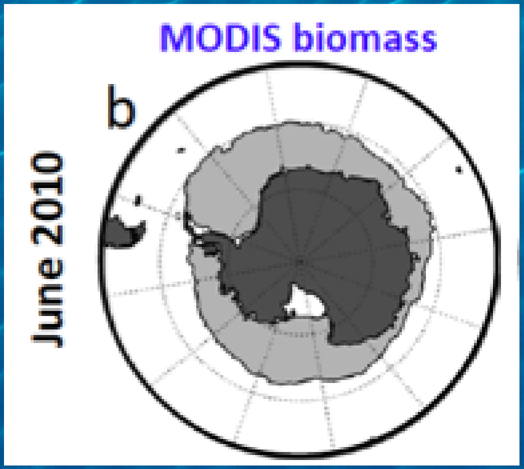
Talley (2011)

SO Carbon Cycle from space

- Remote sensing:
  - accurate reflectance spectrum at high solar angles
- Variables of interest:
  - Better interpretation of b_{bp} signal
  - Phytoplankton biomass (chlorophyll a, carbon)
  - Phytoplankton Primary Production (NPP), growth
  - Net Community Production (NPP - Respiration)
  - Carbon Flux out of the Euphotic Zone/Mixed Layer

Phytoplankton Biomass

- First large-scale limitation is winter time (April to September) to for which no ocean color data can be retrieved due to solar zenith angle being too large



1. Winter measurements:

Lidar (e.g. MESACAL)
Atmospheric correction (e.g. POLYMER)

2. Year-round field measurements:

Profiling floats (BGC Argo)
Optical sensors existing mooring (OI)

Discrepancies

Q1: Can we explain discrepancies between different investigations of Southern Ocean bio-optical algorithms based on time, sector, proximity to sea ice and continental shelves, temperature, latitude, and methodology?

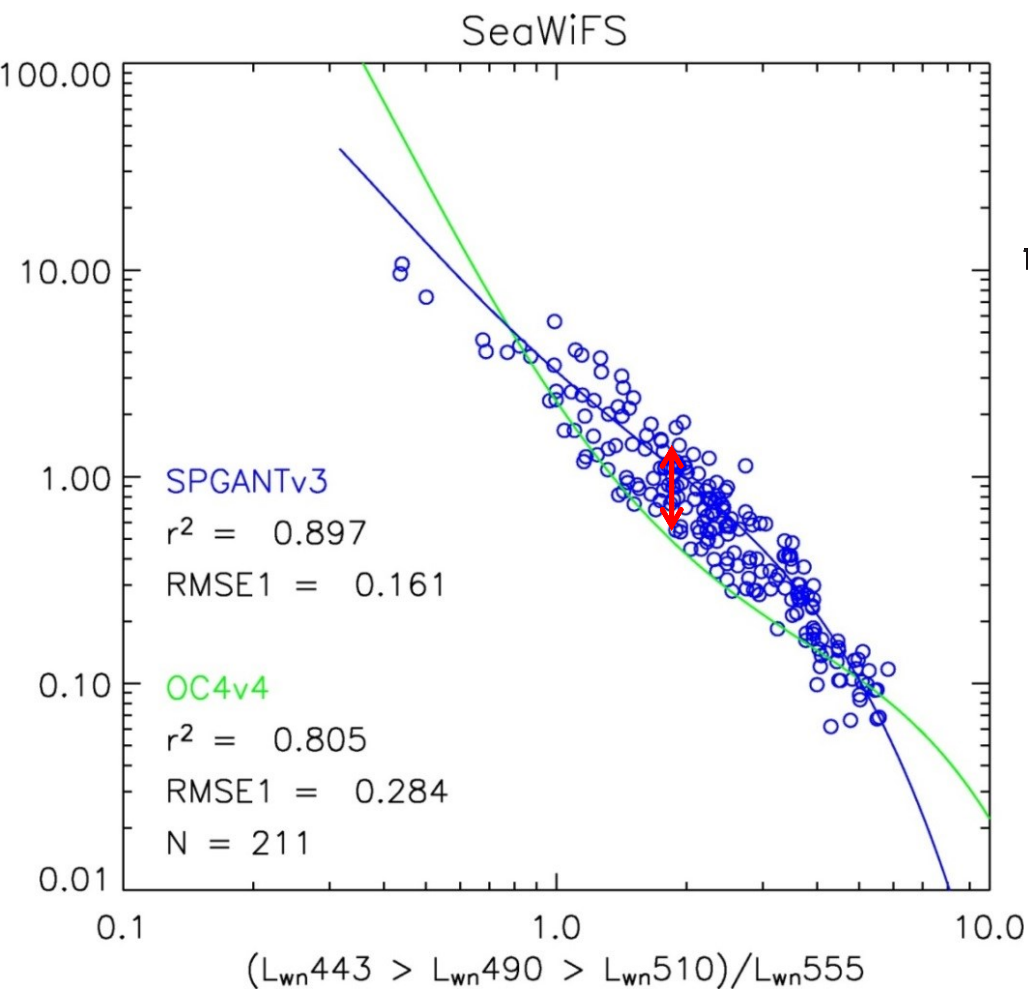
Discrepancies among SO algorithms (NASA's global and regional algorithms)

Southern Ocean Chl-a algorithm: Chl-SPGANT

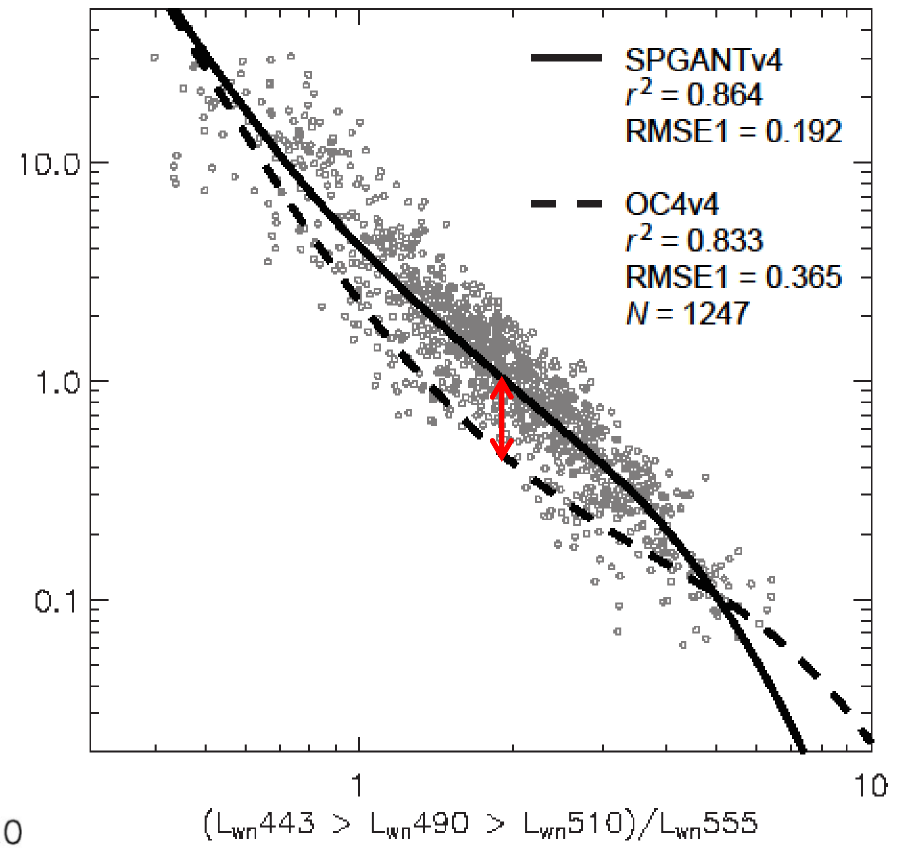
Version 3, 2006, Mitchell & Kahru (2009) using *in situ* *Lwn* and *Chla* (both fluorometric and HPLC) from cruises NBP9711, REV9801, REV9802, AMLR2000, AMLR2001, AMLR2004, LMG0402, AMLR2006; N = 211

Version 4, Kahru & Mitchell (2010), included all stations in SeaBASS south of 55S: total of 1247 stations

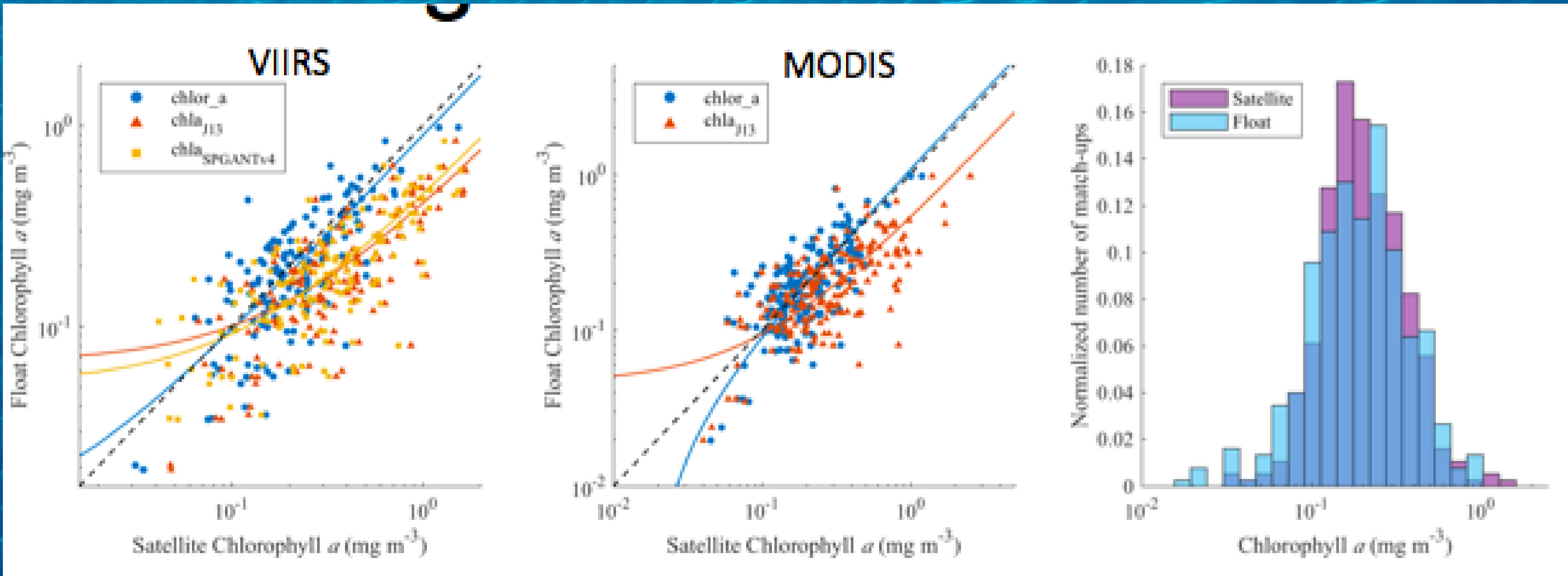
Conclusion: NASA OC4v4 *chlor_a* underestimates 2-3 x at 0.2 < Chla < 3 mg m^{-3}



Polynomial fits between log10 of Maximum Band Ratio (MBR) and Chla for SeaWiFS, MODISA, GLI, OCTS, MERIS



SOCCOM Results (biogeochemical floats)



Atmospheric Correction

- Q2: Can atmospheric corrections be improved to expand the time-space domain of ocean color data at higher solar zenith angles?
- Possibility of better correction with spherical geometry (or polynomial)
- White caps included as aerosols (winds >10 m/s) is not optimal for spectral correction
- Better cloud flag identification

SO Algorithm Development

- Q3: Do we have the data sets needed to calibrate/validate reflectance spectrum/fluorescence signals?
- Summer data, subjective sampling, low data density compared to other oceanic domains
- Opticals sensors in GO_Ships
- Optical variables with vertical resolution
- Imaging flow cytometry (automated phytoplankton composition and size)
- SIMBIOS-type optical van to take advantage of ships of opportunity
- Above-water radiometry
- Phytoplankton carbon (Cphyto)
- Calcite estimation
- Creation of a Southern Ocean database (SeaBASS-like)

AGU PUBLICATIONS

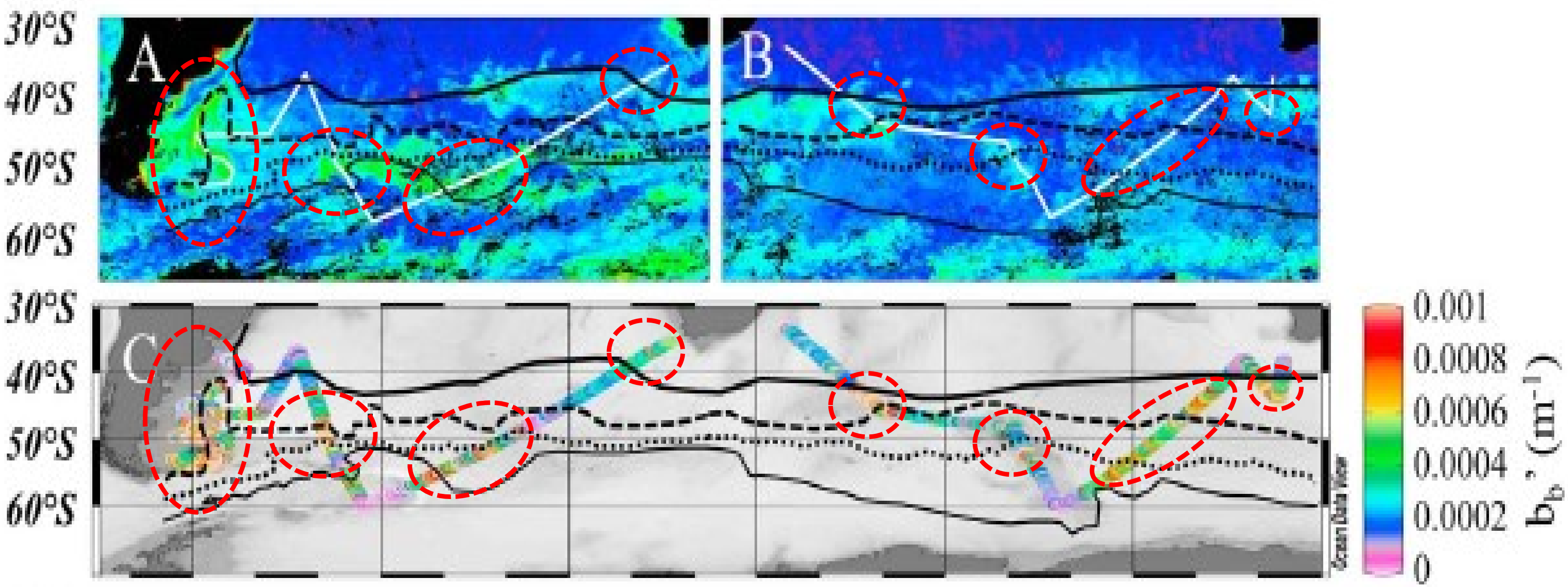
Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1002/2016GB005414

2016

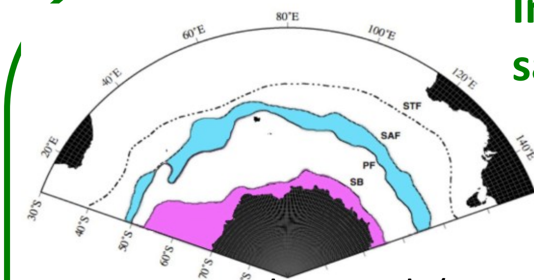
Factors regulating the Great Calcite Belt in the Southern Ocean and its biogeochemical significance

William M. Balch[1], Nicholas R. Bates[2,3], Phoebe J. Lam[4,5], Benjamin S. Twining[1], Sarah Z. Rosengard[4,6], Bruce C. Bowler[1], Dave T. Drapeau[1], Rebecca Garley[2], Laura C. Lubelczyk[1], Catherine Mitchell[1], and Sara Rauschenberg[1]

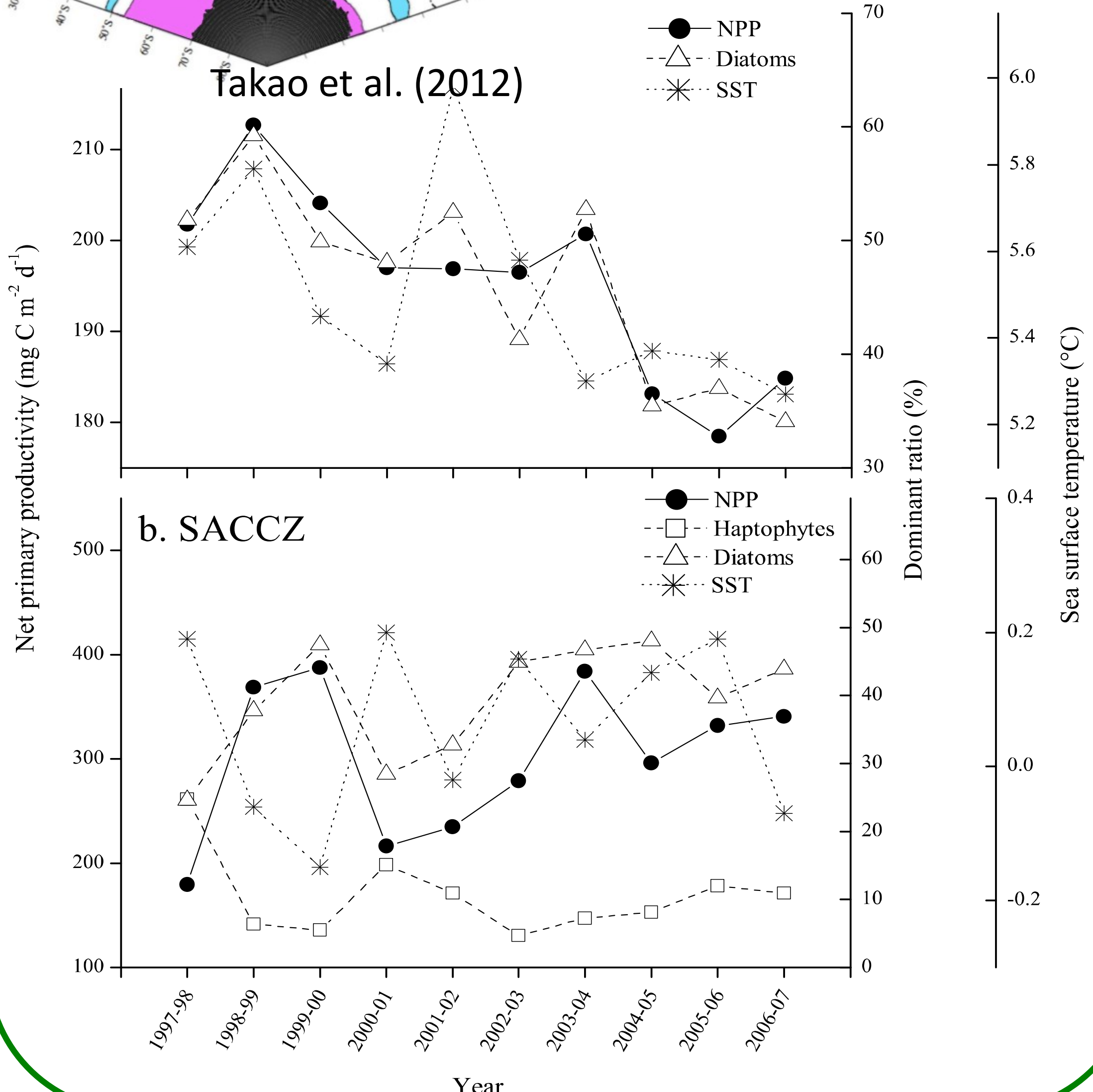


Interrelationship among satellite NPP, PFTs and SST

Takao et al. (2012)



Takao et al. (2012)



Scientific roadmap for long time series PFT data from OC

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

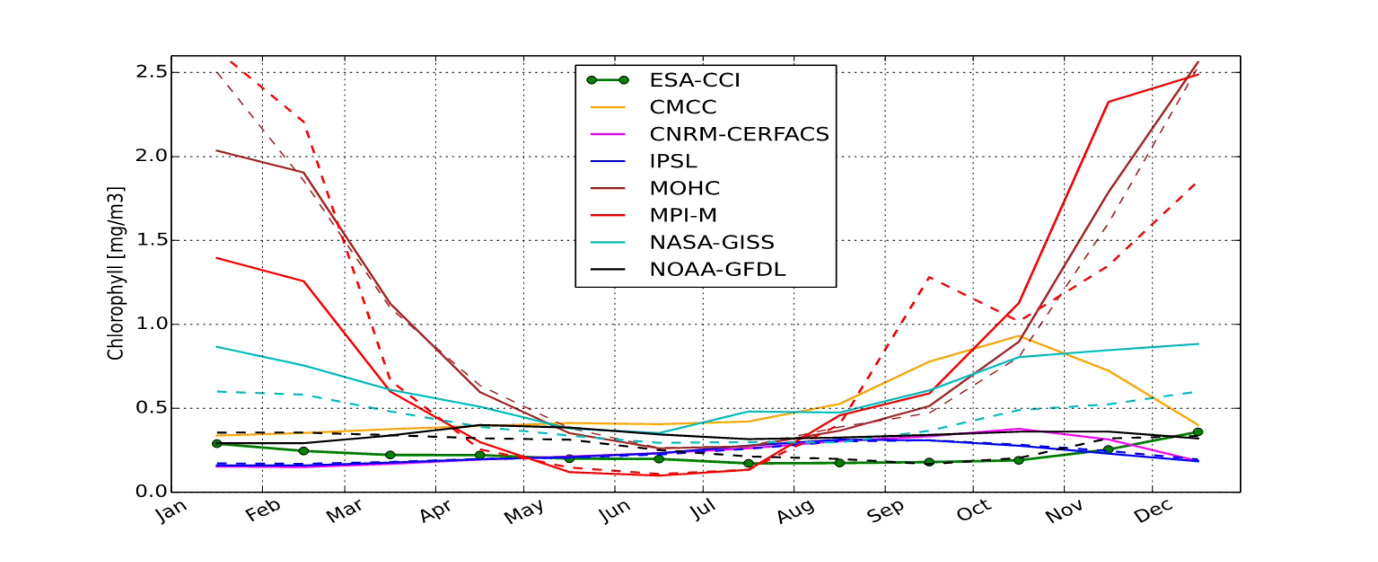
Gap	Status	Medium-term action	Long-term action
Satellite Sensors	Multispectral sensors with limited PFT information Limited exploitation of hyperspectral: - SCIAMACHY PFT data but low coverage/resolution - AC failed to derive hyper-spectral Lw, RRS data (HICO)	Develop AC for hyper-spectral sensors Adapt 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

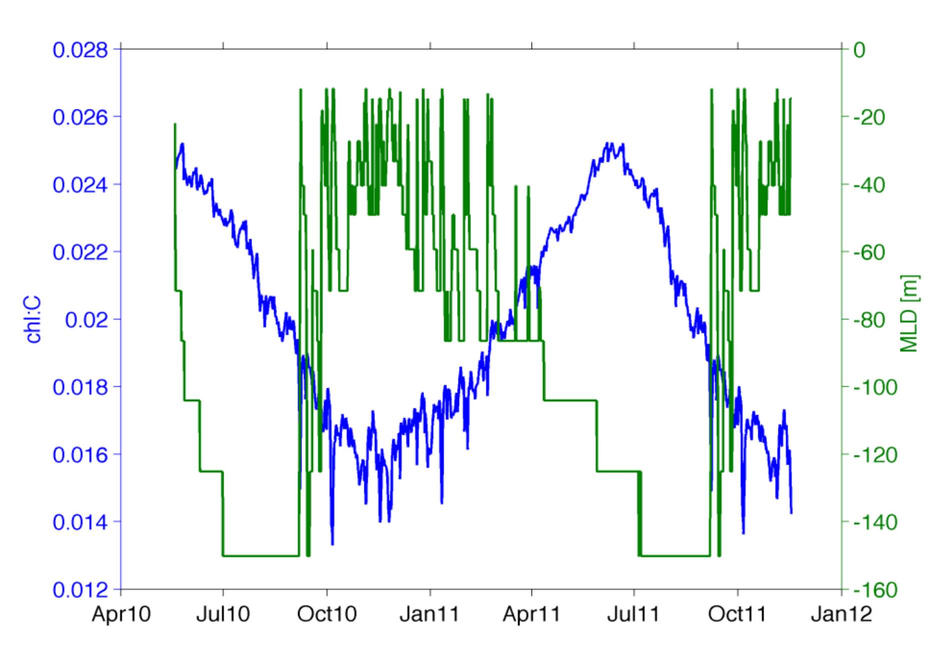
4-D ocean

- Q4: How can we merge bio-optical-ARGO and satellite data for a better 4-D representation of plankton biomass and productivity for the SO?
- Full support for the BGC floats
- SO Modeling is essential for low-sampled region

Implications for models

The seasonal mismatch may result from the models assumption that all seasonal variability is simply due to acclimation by McKiver et al. (2015)



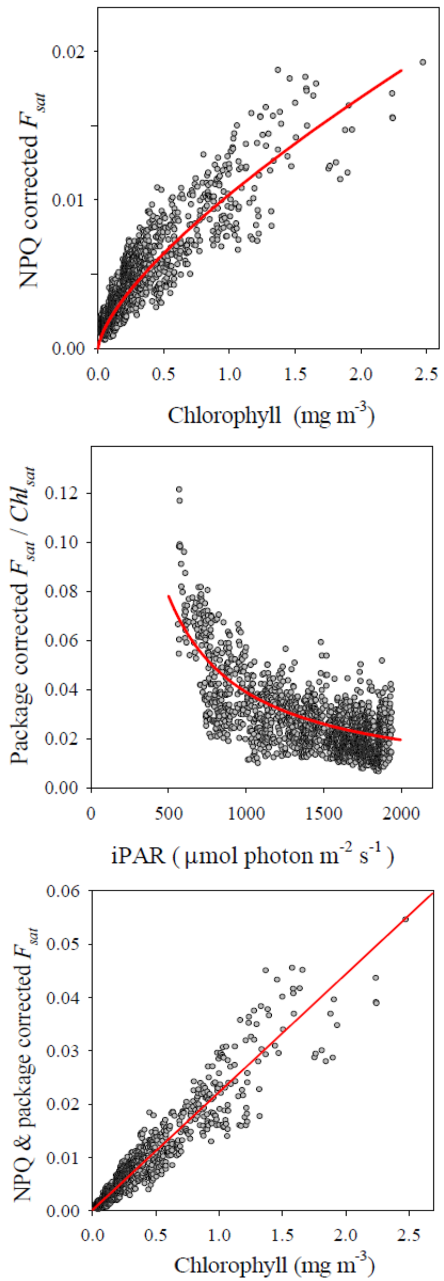


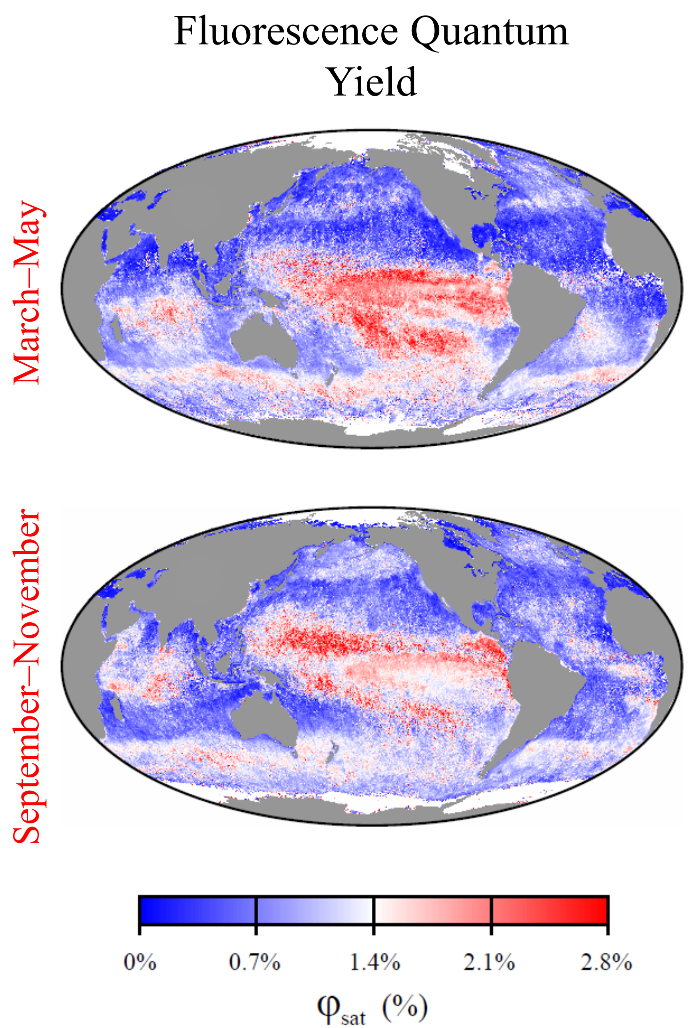
Models need to accommodate for variable chl-a:C_{phyto} ratio that reflect phytoplankton adaptation to low light conditions in spring (low optimal chl-a:C_{phyto} ratio) and higher optimal chl-a:C_{phyto} ratios with species-specific increasing growth rates in summer.

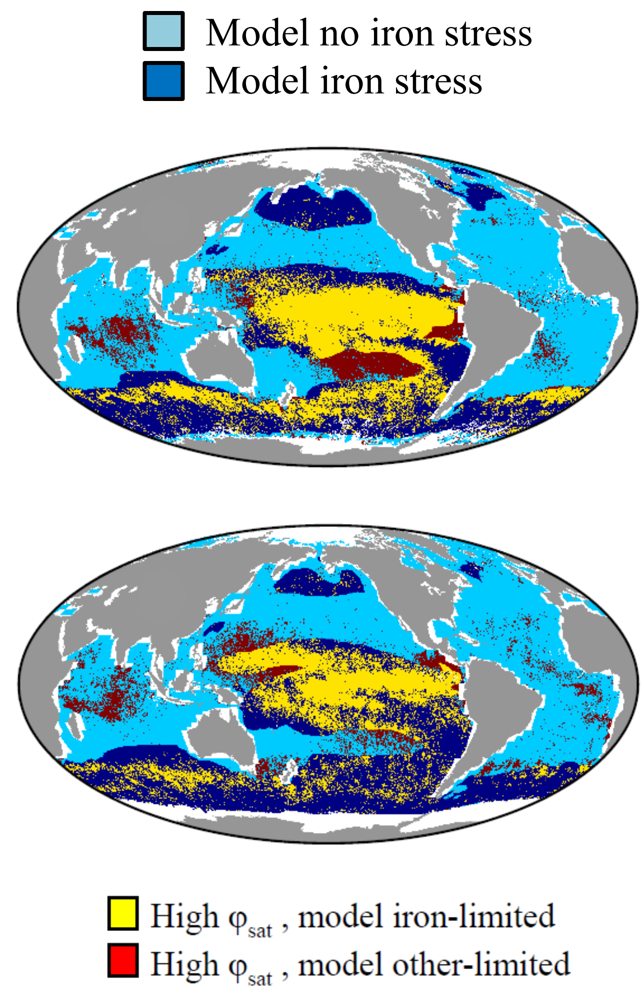
Emerging Technologies

- Q5: What are emerging technologies that can improve the quality and number of observations *in situ* and airborne in the Southern Ocean needed to improve algorithms and models?
- LIDAR (space and on board ships)
- Automated optical sensors and species identification
- Hyper-spectral backscattering sensor

The Missing Iron Stress Signal







Behrenfeld et al. 2009. Biogeoscience 6, 779-794
Westberry et al. 2013. Deep-Sea Research I, 73, 1-16

Field Campaigns

- Q6: What are the plans in the international community for recent and future field campaigns to advance our understanding of Southern Ocean carbon cycle using satellite ocean color and other observations?
- ACE (2016-2017 Antarctic Circumpolar Experiment, International)
- Future ICESSOC (International Coordinated Experiment of the Southern Ocean Carbon Cycle, USA)
- Future SOOS (Southern Ocean Observing System, International)
- SOCLIM (2016 Kerguelen, France)
- CSIR cruises on board Agulhas (South Africa)
- SOCCOM (80 floats with bio-optics, NSF/NASA)

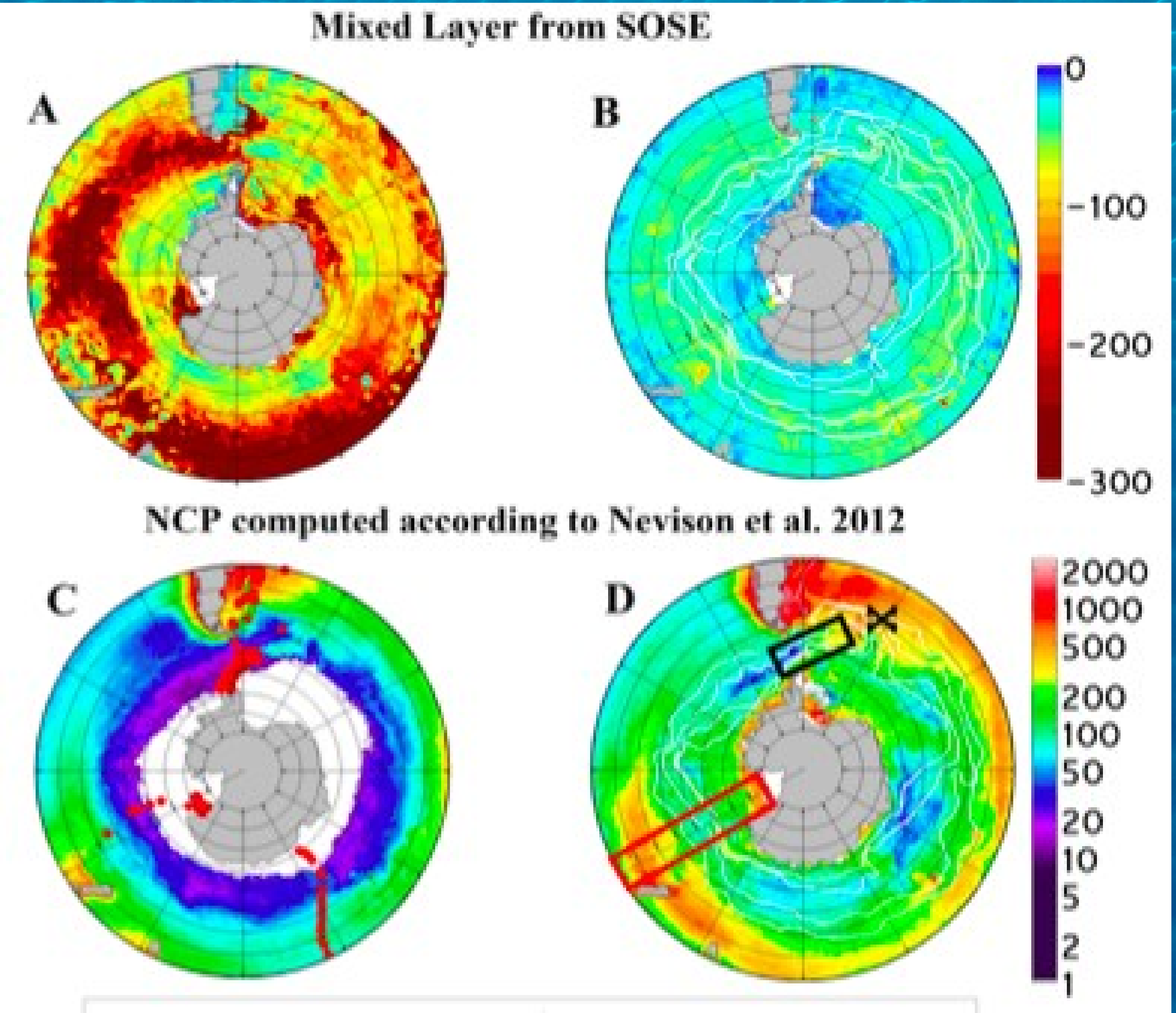
Project #1

"A bio-optical approach to understanding long term changes in phytoplankton abundance and composition in the Southern Ocean and their impact on the biological productivity"

A 3-month expedition,
3 main groups involved:

(Curtin Uni., Perth, Australia)
PI: **D. Antoine**
(CSIR, Cape Town, South Africa)
PI: **S. Thomalla**
(NASA, GSFC, USA)
PI: **S. Hooker**

Q7: How can we improve the understanding of relationship between surface satellite observations and organic carbon export?



Modeling Improvements (Laws 2004)
Expected results from EXPORTS (SO version)

Summary

- C cycle in the Southern Ocean: why can’t we constrain it?
- Phytoplankton physiology: why can’t we detect iron limitation in SO?
- Usefulness of 2015 IOCCG report on high latitudes
- Creation of a SO ocean color community