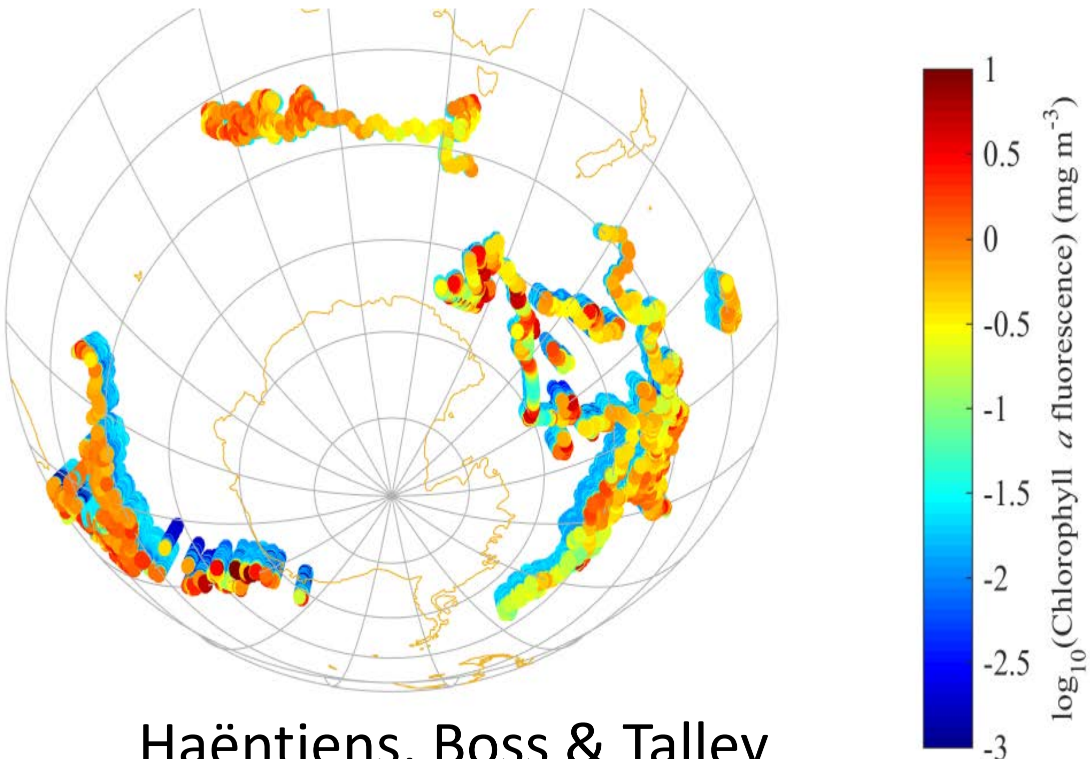
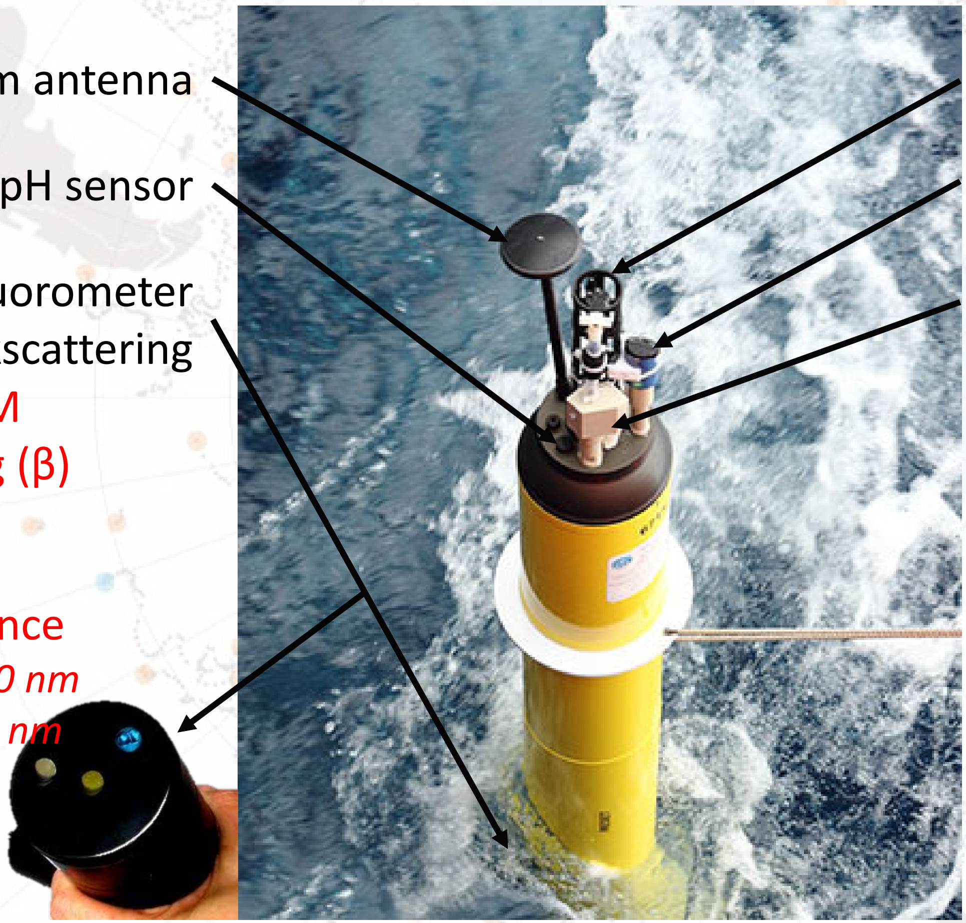
Revisiting Ocean Color Algorithms for Chlorophyll *a* and Particulate Organic Carbon in the Southern Ocean using Biogeochemical Floats



Haëntjens, Boss & Talley

SOCCOM Profiling Floats

Active floats
80 / 200



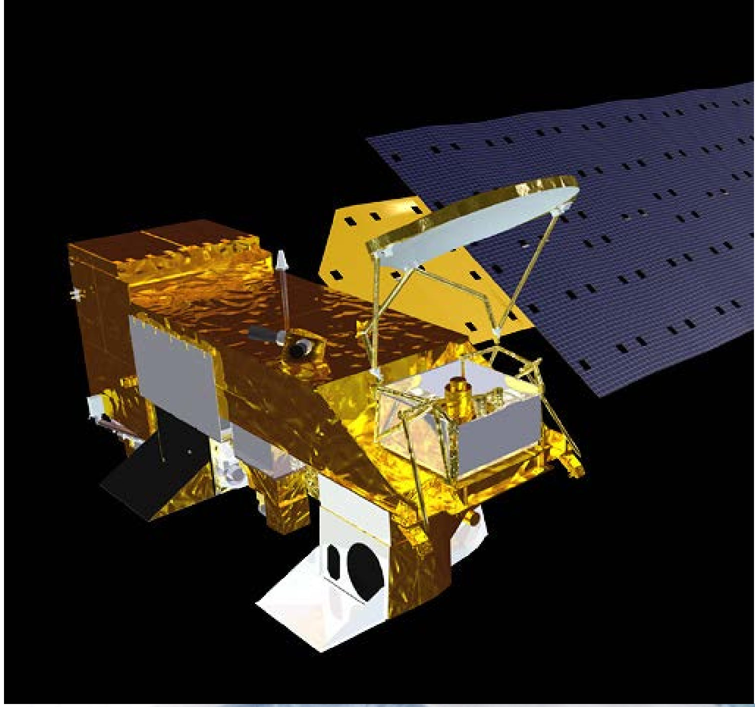
APEX biogeochemical float

Float configuration:

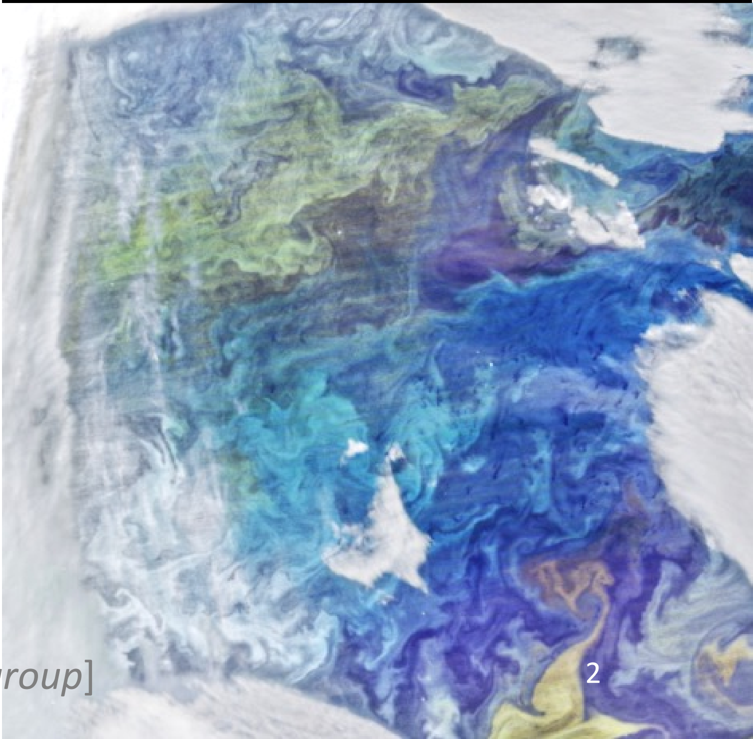
- *Park at 1000 m*
- *Profile from 2000 m to surface*
- *Profile every 5 or 10 days*

[*WET Labs' Report*, 2016; *Johnson et al.*, 2017, submitted]

Ocean Color



- VIIRS
  Visible Infrared Imaging Radiometer Suite
- MODIS *Aqua*
  Moderate Resolution Imaging Spectroradiometer
- Both satellites are:
  - polar orbiting
  - multispectral (visible and infrared detectors)
  - measure top of the atmosphere radiance
    - apply atmospheric correction
  - derive chla and POC from band ratios

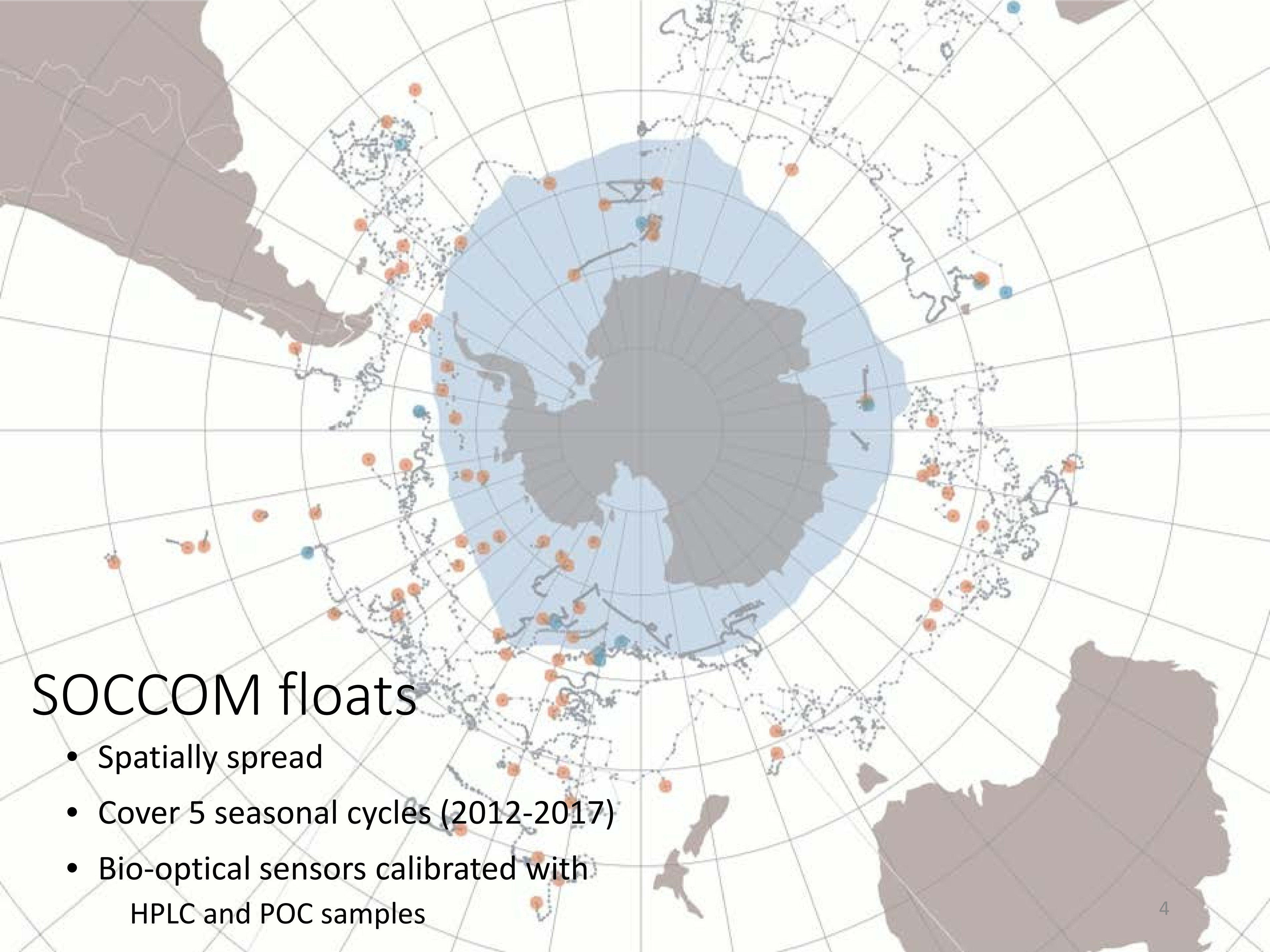


[*Mobley et al.,* 2016; NASA *Ocean Biology and Biogeochemistry group*]

Previous studies

Globally derived chla algorithm OCX validation in the Southern Ocean.

Bias	Dataset Type	Satellite(s)	Reference(s)
2.4	Fluorometrically extracted chla	CZCS	Mitchell and Holm-Hansen [1991] Sullivan et al. [1993]
~2	Fluorometrically extracted chla	SeaWiFS	Dierssen and Smith [2000]
~2	HPLC	ADEOS SeaWiFS MODIS	Mitchell and Kahru [2009] Kahru and Mitchell [2010]
~2	HPLC	MODIS	Guinet et al. [2013]
3-4	HPLC	MODIS VIIRS	Johnson et al. [2013]
1	HPLC	SeaWiFS	Marrari et al. [2006]



SOCCOM floats

- Spatially spread
- Cover 5 seasonal cycles (2012-2017)
- Bio-optical sensors calibrated with
  HPLC and POC samples

Calibrate chlorophyll *a* fluorometers

Fluorescence is a proxy for chlorophyll *a*

chla:fluorescence yield ratio is affected by: the light history, the species composition, and the physiology of the phytoplankton.

Sensor inter-calibration

- calibrate all sensors against a "golden" sensor

Dark correction

- correct for interference with fluorescent dissolved organic matter
- find(min([chla])) at depth and subtract it from all profiles
- similar correction as in *Xing et al.* [2016]

Non Photochemical Quenching

- if sun_elevation > 5°
- mean($chla_{Xing2012}$, $chla_{Sackmann2008}$)

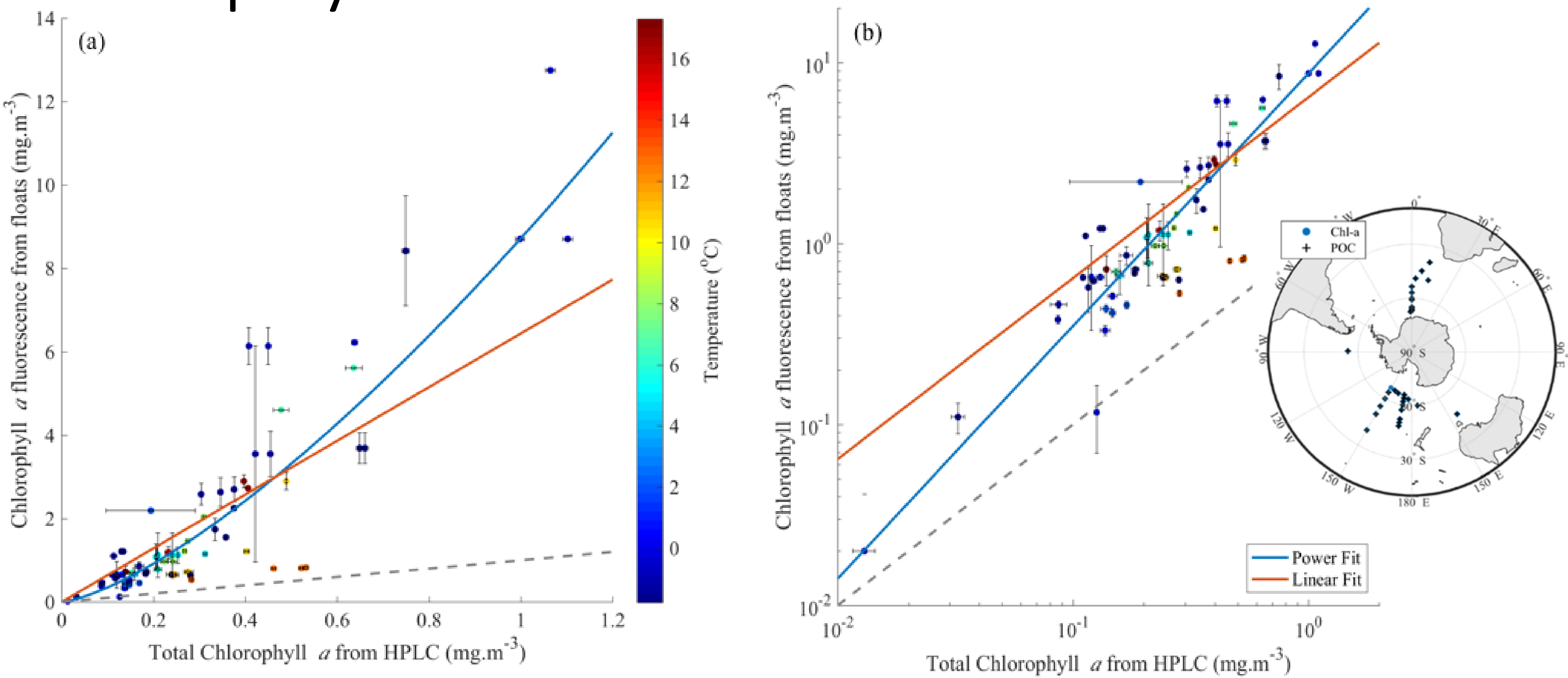
FYI: No significant difference day-only or night-only data.

Slope correction

- compare first profile with [chla] from HPLC taken within 24 hours of deployment (Roesler et al., 2017)

[*Cullen et al.*, 1982]

Relationship between total chlorophyll *a* from HPLC and chlorophyll *a* fluorescence from floats



Relationship	n	r^2	$RMSD$	$RMSRD$
$chla_{HPLC} = 0.15(\pm 0.017) \times chla_{float}$	73	0.77	0.20	0.48
$chla_{HPLC} = 0.213(\pm 0.016) \times chla_{float}^{0.714(\pm 0.242)}$	73	0.80	0.12	0.37

From backscattering to POC

Dark correction

- if available, use pre-deployment dark

From the VSF to particulate backscattering (b_{bp})

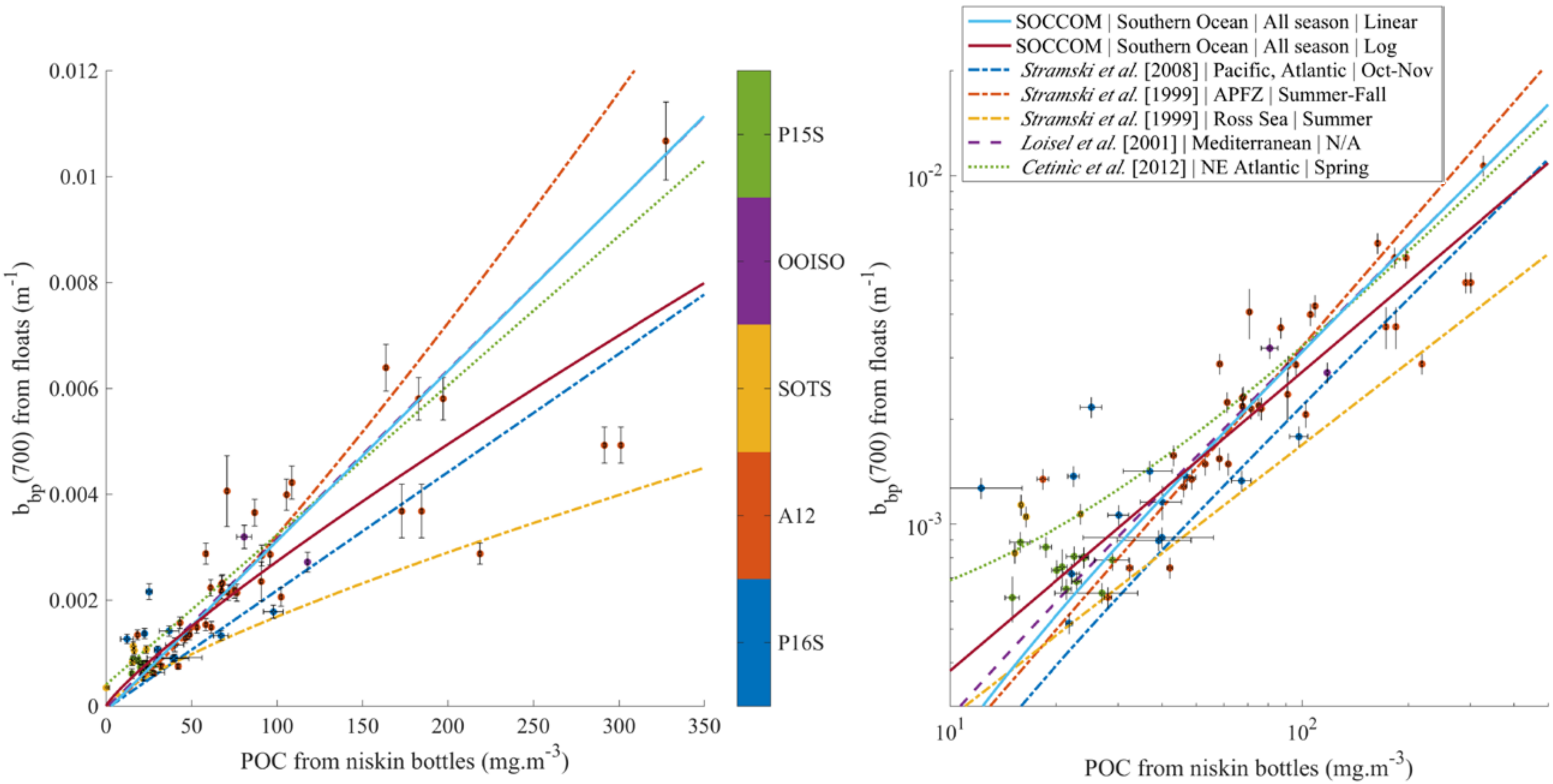
- The VSF of seawater (β_{sw}) is estimated with *Zhang et al.*, [2009]
- The particulate conversion factor (χ_p) is estimated with *Sullivan et al.*, [2013]

From b_{bp} to POC

- Build a relationship specific to our dataset

$$b_{bp} = 2 \times \pi \times \chi_{p(\theta)} \times \left(\beta(\theta) - \beta_{sw}(\theta)\right)$$

Relationship between POC and particulate backscattering at 700 nm



Relationship	n	r^2	$RMSD$	$RMSRD$
$POC = 3.12 \times 10^4(\pm 2.47 \times 10^3) \times b_{bp}(700) + 3.04(\pm 6.78)$	67	0.76	35	0.47
$POC = 9.776 \times 10^4(\pm 1.90 \times 10^4) \times b_{bp}(700)^{1.166(\pm 0.173)}$	67	0.88	40	0.59

Deriving chla and POC from R_{rs}

Download images from NASA Ocean Color Level 2, reprocessing R2014.0

Product	Sensor	Algorithm	Equations
chla	MODIS	OCI[a]	Merged OC3M band ratio algorithm with color index (CI) of *Hu et al.* [2012]
chla	MODIS	J13[b]	$R_{sw} = log_{10}\left(\frac{max(R_{rs}(443), R_{rs}(488))}{R_{rs}(547)}\right)$ $chla_{J13} = 10^{0.6994 - 2.0384R_{sw} - 0.4656R_{sw}^2 + 0.4337R_{sw}^3}$
chla	MODIS	SPGANTv4[c]	$L_{wn}(\lambda) = \frac{F_0(\lambda) \times R_{rs}(\lambda)}{\pi}$ $R = log_{10}\left(\frac{max(L_{wn}(443), L_{wn}(488))}{L_{wn}(547)}\right)$ $chla_{SPGANTv4} = 10^{0.5514 - 2.2434R + 0.0746R^2 - 0.0095R^3 - 0.7790R^4}$ blended with OC3M [*Kahru and Mitchell*, 2010]
chla	VIIRS	OCI[a]	Merged OC3V band ratio algorithm with color index (CI) of *Hu et al.* [2012]
chla	VIIRS	J13[b]	$R_{sw} = log_{10}\left(\frac{max(R_{rs}(410), R_{rs}(443), R_{rs}(486))}{R_{rs}(551)}\right)$ $chla_{J13} = 10^{0.6736 - 2.0714R_{sw} - 0.4939R_{sw}^2 + 0.4756R_{sw}^3}$
POC	MODIS	S08[d]	$POC = 203 \times \left(\frac{R_{rs}(443)}{R_{rs}(547)}\right)^{-1.034}$
POC	VIIRS	S08[d]	$POC = 203 \times \left(\frac{R_{rs}(443)}{R_{rs}(551)}\right)^{-1.034}$

[a] *Hu et al.* [2012]
[b] *Johnson et al.* [2013]
[c] *Kahru and Mitchell* [2010]; *Mitchell and Kahru* [2009]
[d] *Stramski et al.* [2008]

Matching up

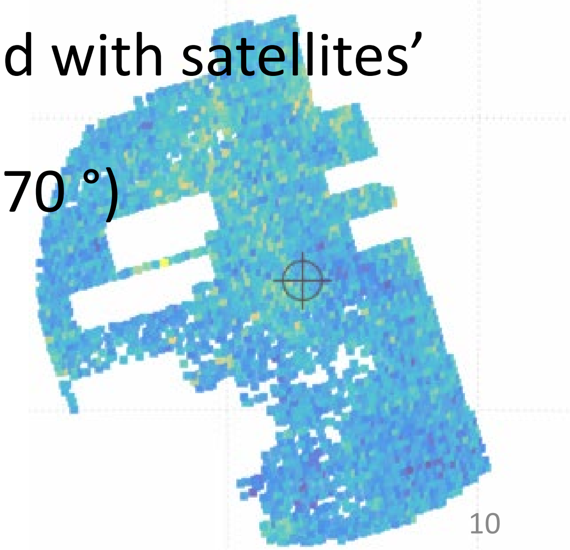
Maximize the quality of the samples:

- narrow time window (+/- 3 hours)
- mean 5x5 pixel box centered on float profile
- good atmospheric correction (mask level 2 flags)
- Weighted vertical integration.

➢ Very few matchups with MODIS

Explained by:

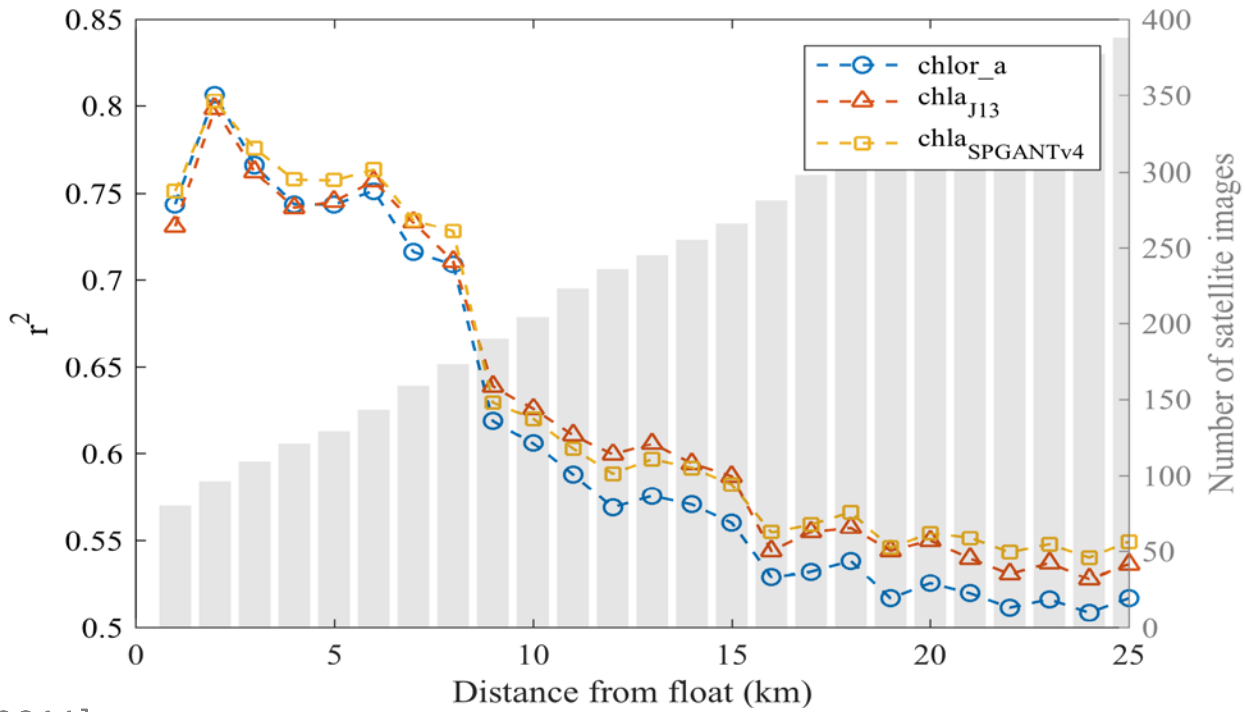
- floats’ surface time is not synchronized with satellites’ overpasses
- polar night, high solar zenith angle (> 70 °)
- high cloud coverage all year long



[*Bailey and Werdell,* 2006]

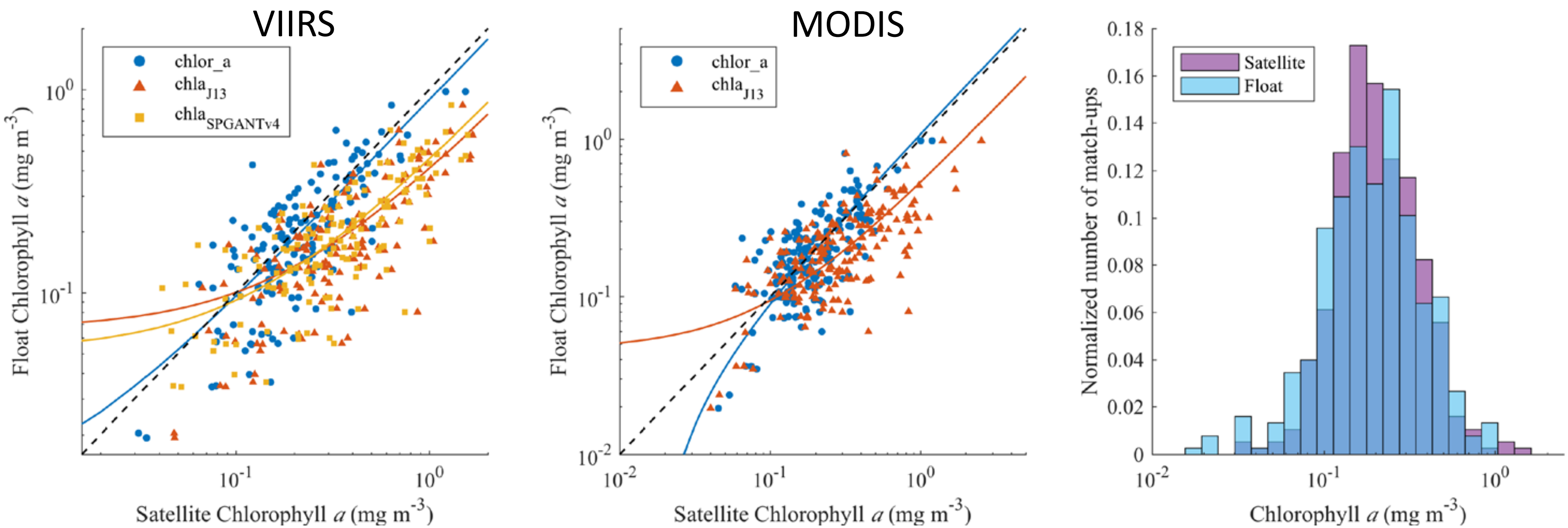
Maximize Number of Matchups

- Widening spatial (8 km) and temporal (24 hr) window
  - increase the number of matchups
  - at the possible cost of quality



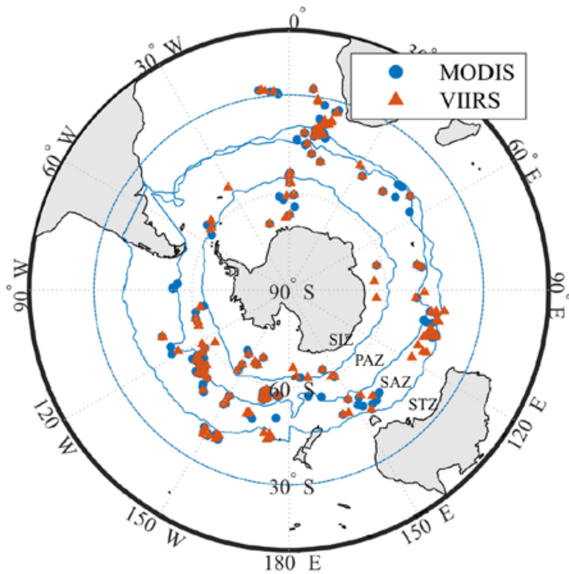
[*IOCCG Report*, 2011]

Comparison with Remote Sensing

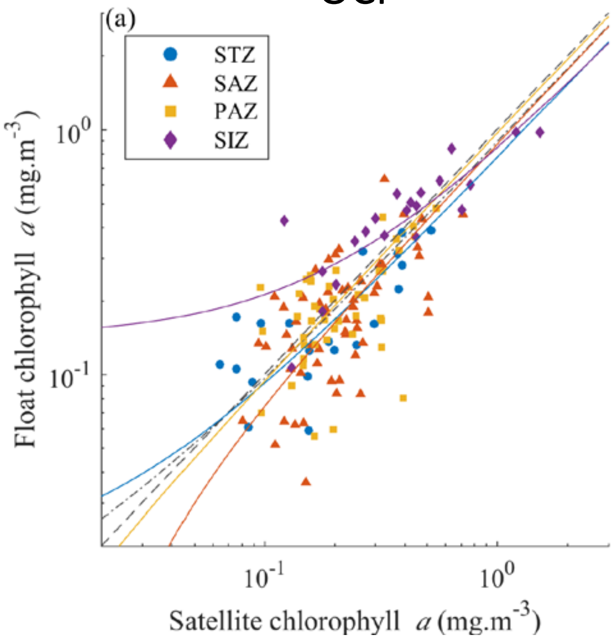


Sensor	Algorithm	Slope Linear	Offset Linear	n	r^2 Linear	$RMSD$ Linear	$RMSURD$ Linear
MODIS	OCI	0.88(±0.04)	0.01(±0.01)	173	0.67	0.11	0.45
MODIS	J13	0.35(±0.02)	0.07(±0.01)	173	0.66	0.43	0.74
MODIS	SPGANTv4	0.41(±0.02)	0.05(±0.01)	173	0.70	0.35	0.68
VIIRS	OCI	1.09(±0.05)	−0.02(±0.01)	203	0.61	0.10	0.44
VIIRS	J13	0.49(±0.03)	0.05(±0.01)	203	0.49	0.28	0.62
both	OCI	0.97(±0.03)	−0.00(±0.01)	376	0.63	0.10	0.45

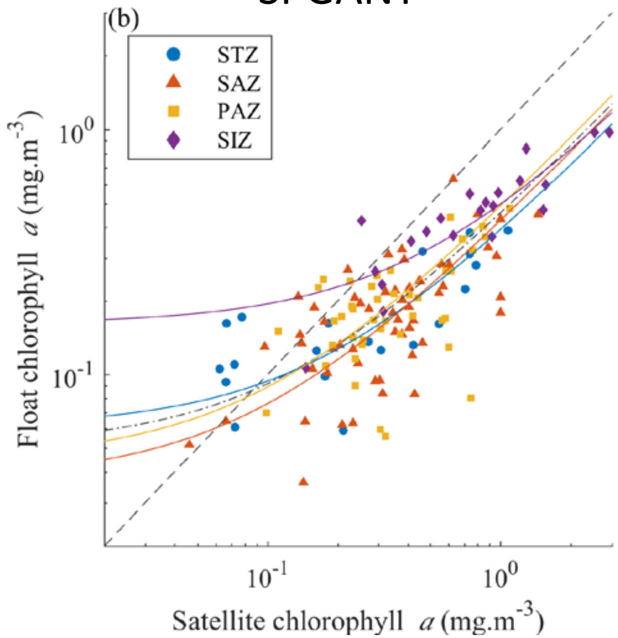
Regional variability:



OCI



SPGANT



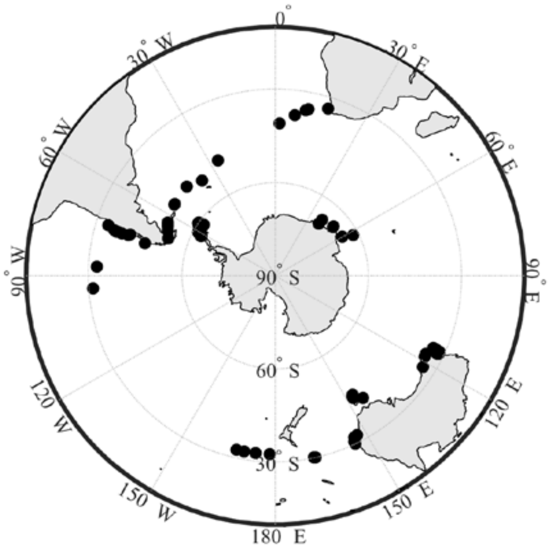
SIZ: Sea Ice Zone
PAZ: Polar Antarctic Zone
SAZ: Subantarctic Zone
STZ: Subtropical Zone

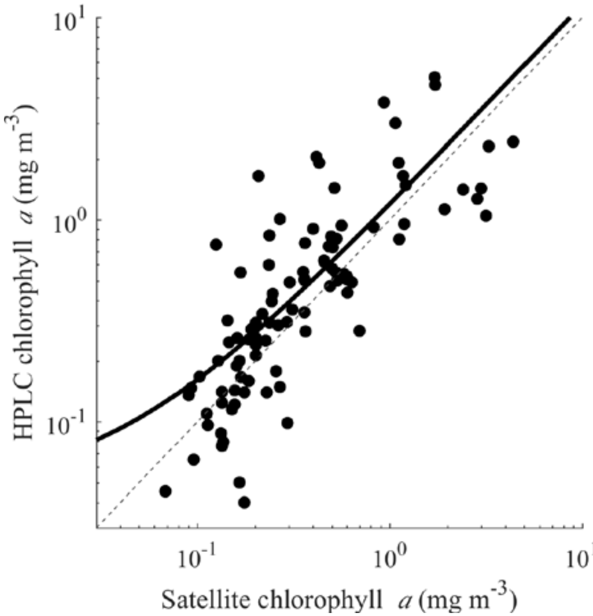
Maximal spatial variability off slope with regions ~20%.

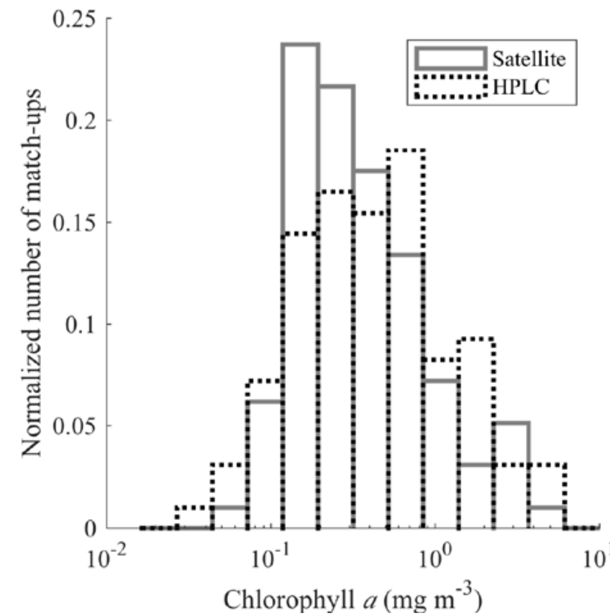
Temporal variability: Not significant.

Independent dataset

all the data available on February 1, 2017, south of 30 °S, on SeaBASS
6242 HPLC samples from 1682 profiles between Oct 1995 and April 2011



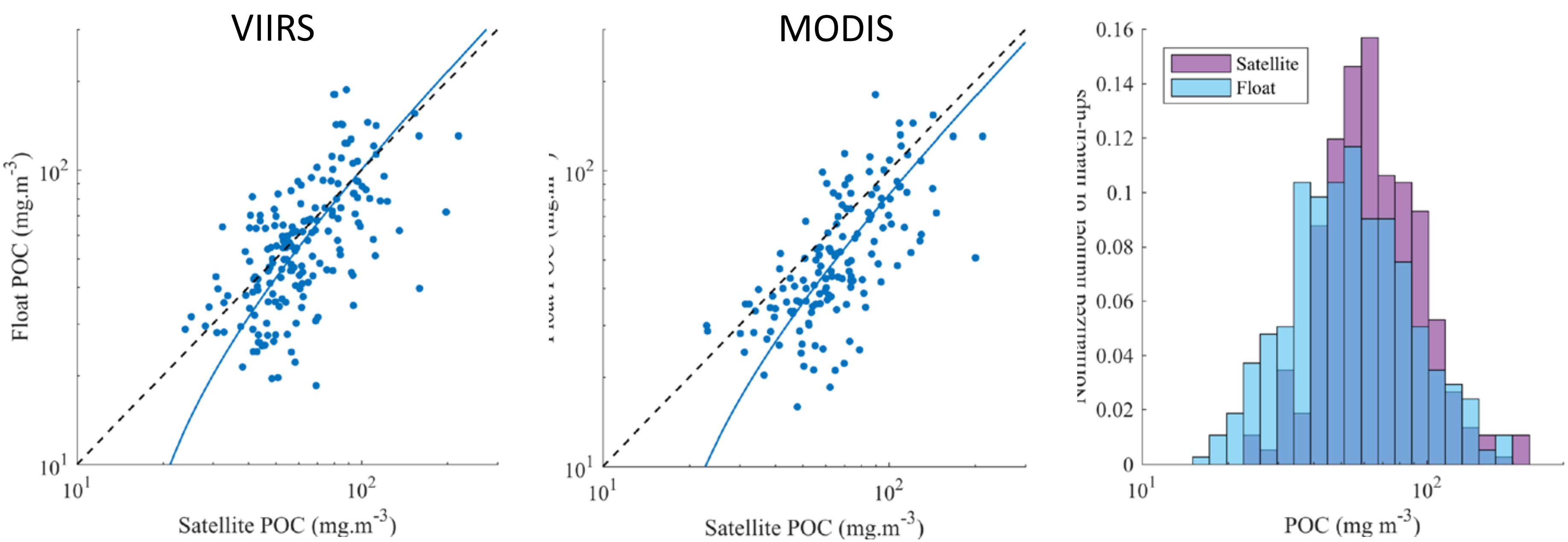




Out of the 659 matchups only 97 respected the criteria defined earlier
MODIS OCI matchups

$chla_{HPLC} = 1.15(\pm 0.11) \times chla_{sat} + 0.05(\pm 0.11)$
RMSD = 0.78 mg m^{-3}
RMSURD = 0.59
N = 97

Comparison with Remote Sensing



Sensor	Algorithm	Slope Linear	Offset Linear	n	r^2 Linear	$RMSD$ Linear	$RMSURD$ Linear
MODIS	POC	0.94(±0.06)	−11.47(±5.08)	173	0.37	31.46	0.44
VIIRS	POC	1.15(±0.07)	−14.30(±5.41)	203	0.34	28.60	0.38
both	POC	1.05(±0.05)	−12.85(±3.79)	376	0.33	29.95	0.41

Conclusion

- OCI performs well in the Southern Ocean
  - bias in our dataset of 9 % for VIIRS and 12 % for MODIS
- POC agrees well with float products
  - relatively low prediction capability

In addition, autonomous floats can be used as a third dimension (depth) to complement remote sensing in the Southern Ocean (4D)

Thank you !

Questions ?

Previous studies

- Under-estimation of global chla algorithm:
  - Species composition
  - Physiology
  - Particulate Composition
- Spatially limited:
  - > 95 % in narrow corridor south of Tasmania [*Johnson et al.*, 2013]
  - Primarily in the Scotia Sea [*Mitchell and Kahru*, 2009]
- Seasonally limited:
  - Primarily austral summer

[*Dierssen et al.,* 2010]

Regional Trends with SeaBASS Dataset