

SOCLIM Annual meeting, September 18-19, 2017

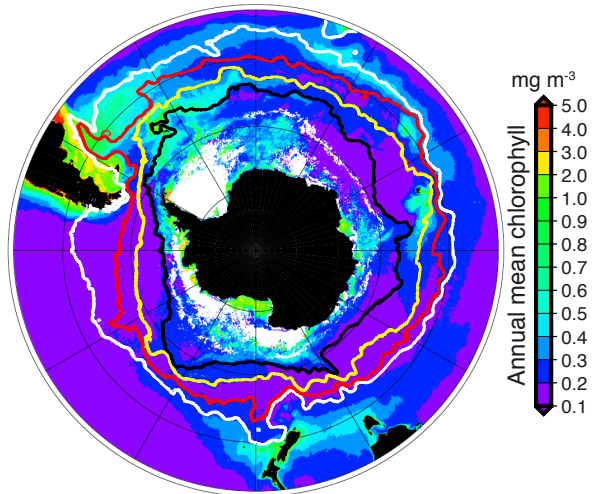
Mechanisms behind bloom initiation and magnitude in the
Southern Ocean:
From global to regional scale

Mathieu Ardyna
Laboratoire d'Océanographie de Villefranche (LOV)

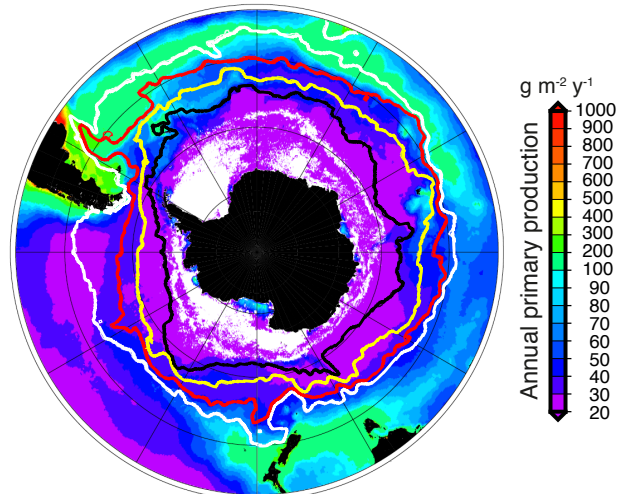
MAIN COLLABORATORS: L. Lacour, M. Rembauville, S. Sergi, L. Oziel, F.
D'Ovidio, J.B. Sallée, F. D'Ortenzio, S. Blain, K. Arrigo, H. Claustre

PHYTOPLANKTON DYNAMICS AND BIOGEOGRAPHY IN THE SOUTHERN OCEAN

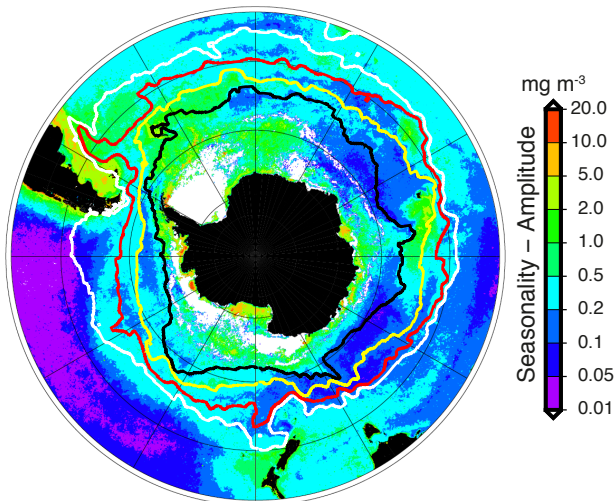
Mean annual chlorophyll (mg m^{-3})



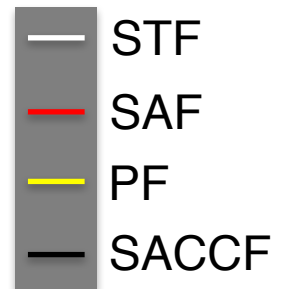
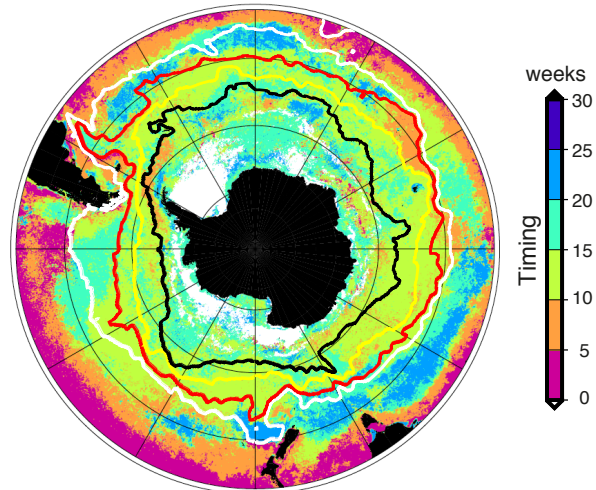
Annual primary production ($\text{g C m}^{-2} \text{y}^{-1}$)



Seasonality - Amplitude (mg m^{-3})

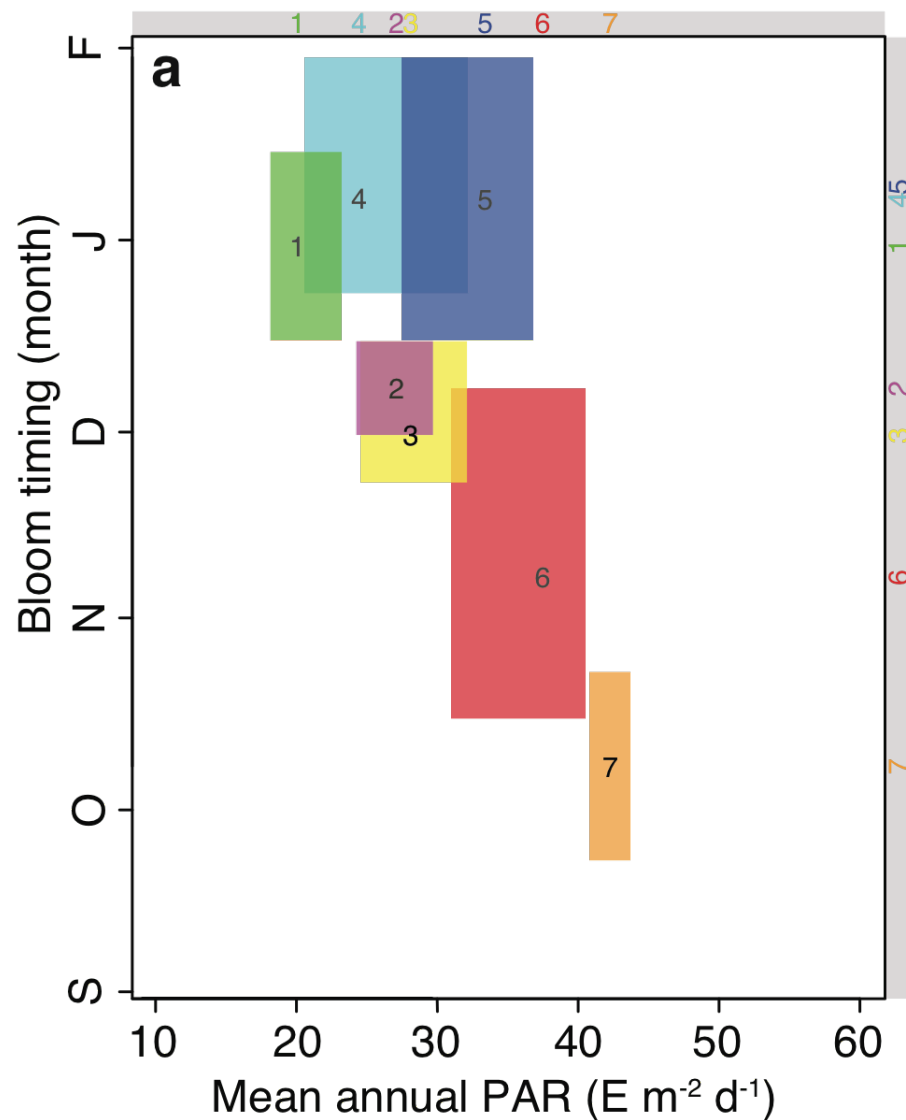
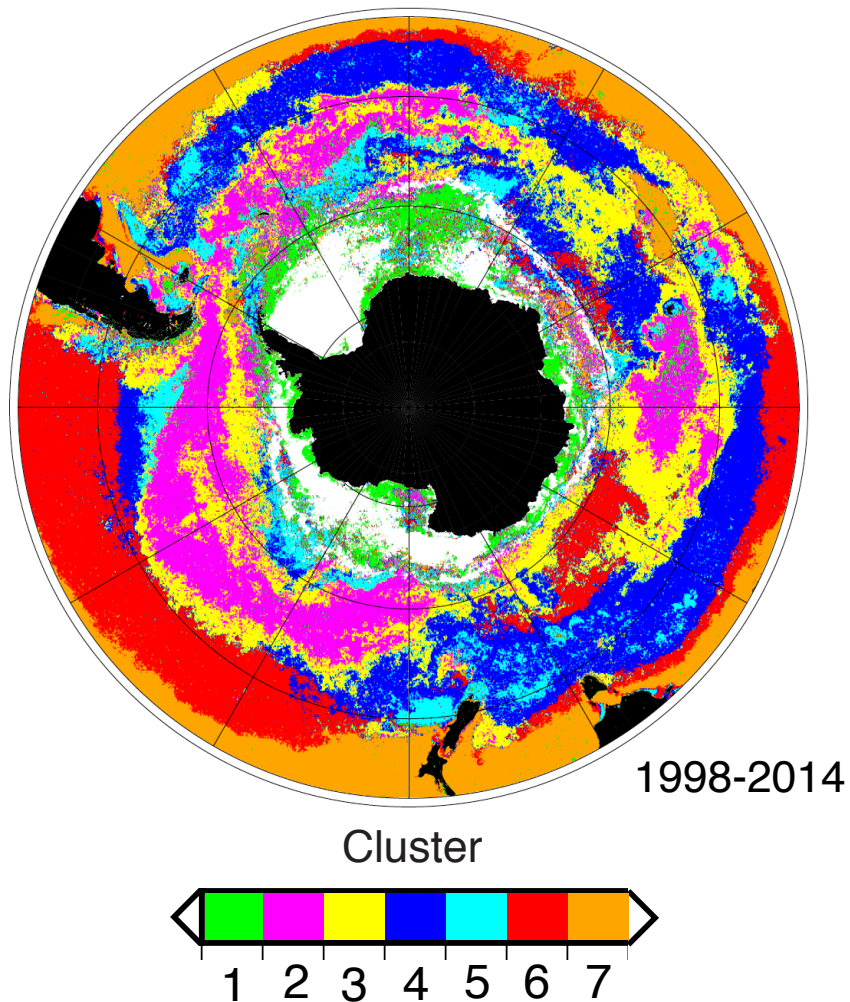


Maximum timing bloom (wks)



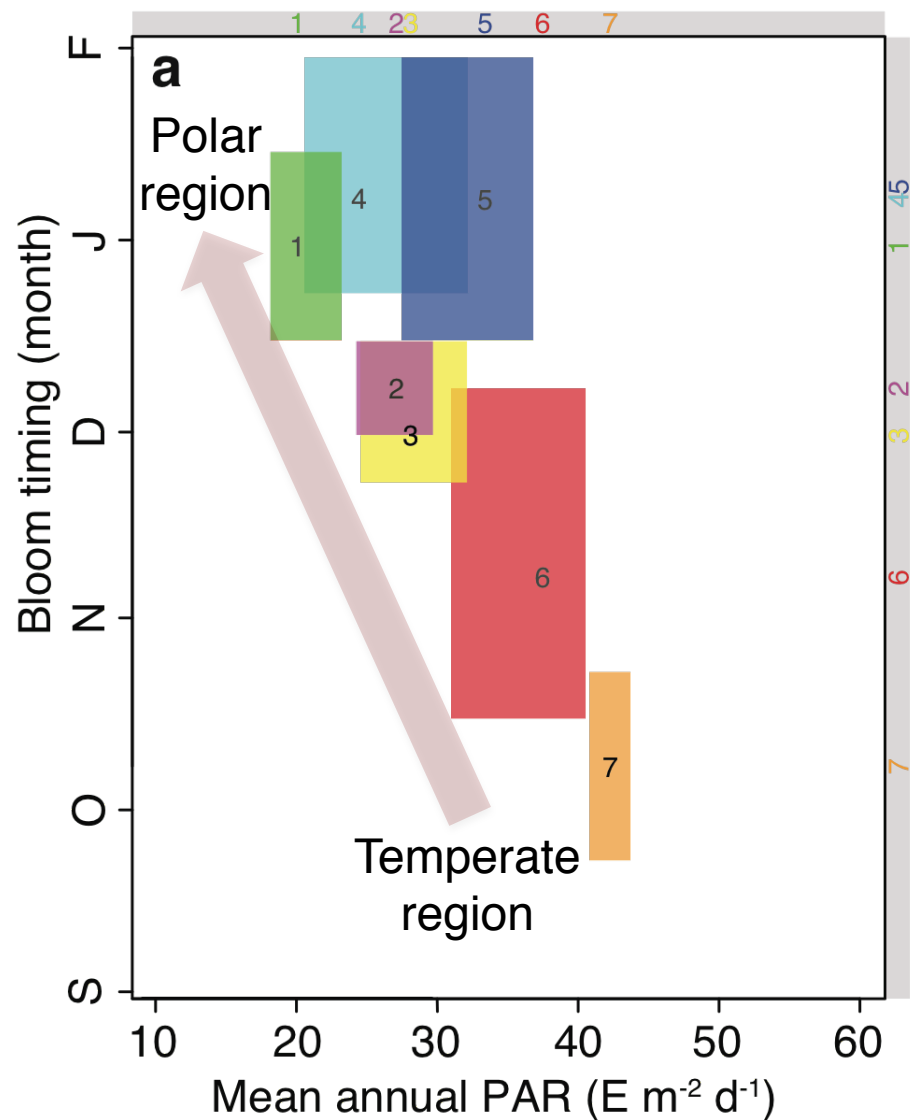
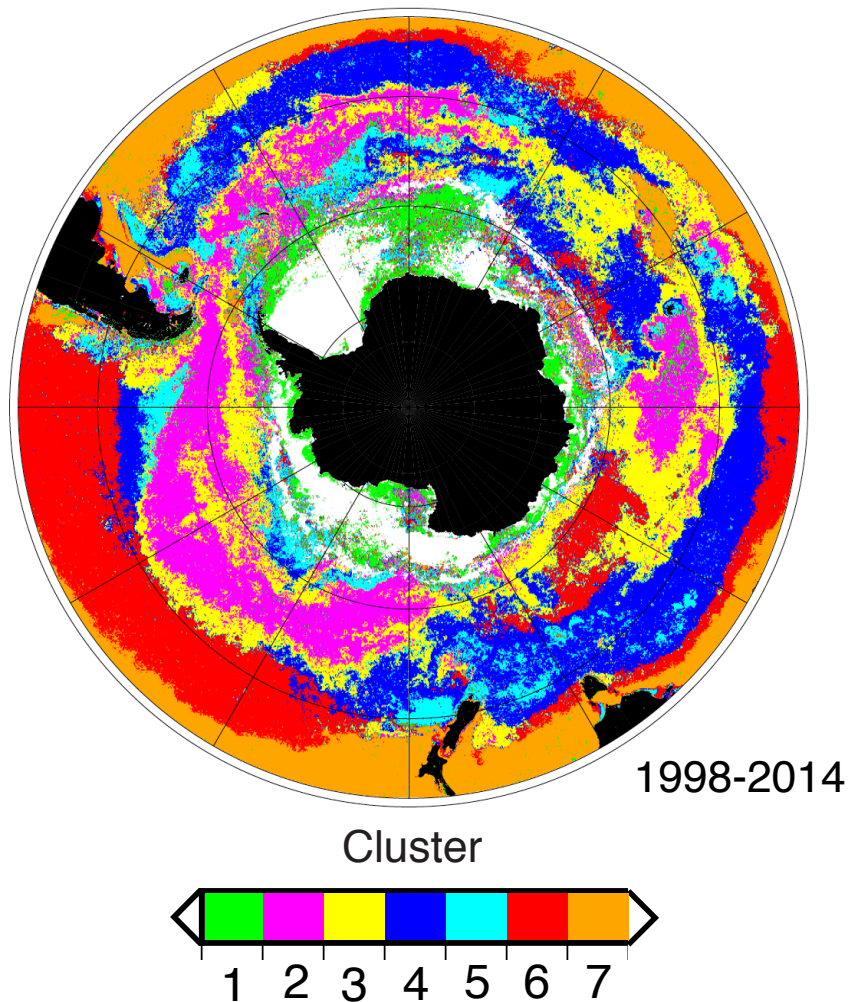
DRIVERS OF THE PHYTOPLANKTON PHENOLOGY IN THE SOUTHERN OCEAN

Static biogeographic-derived analysis (K-means analysis)



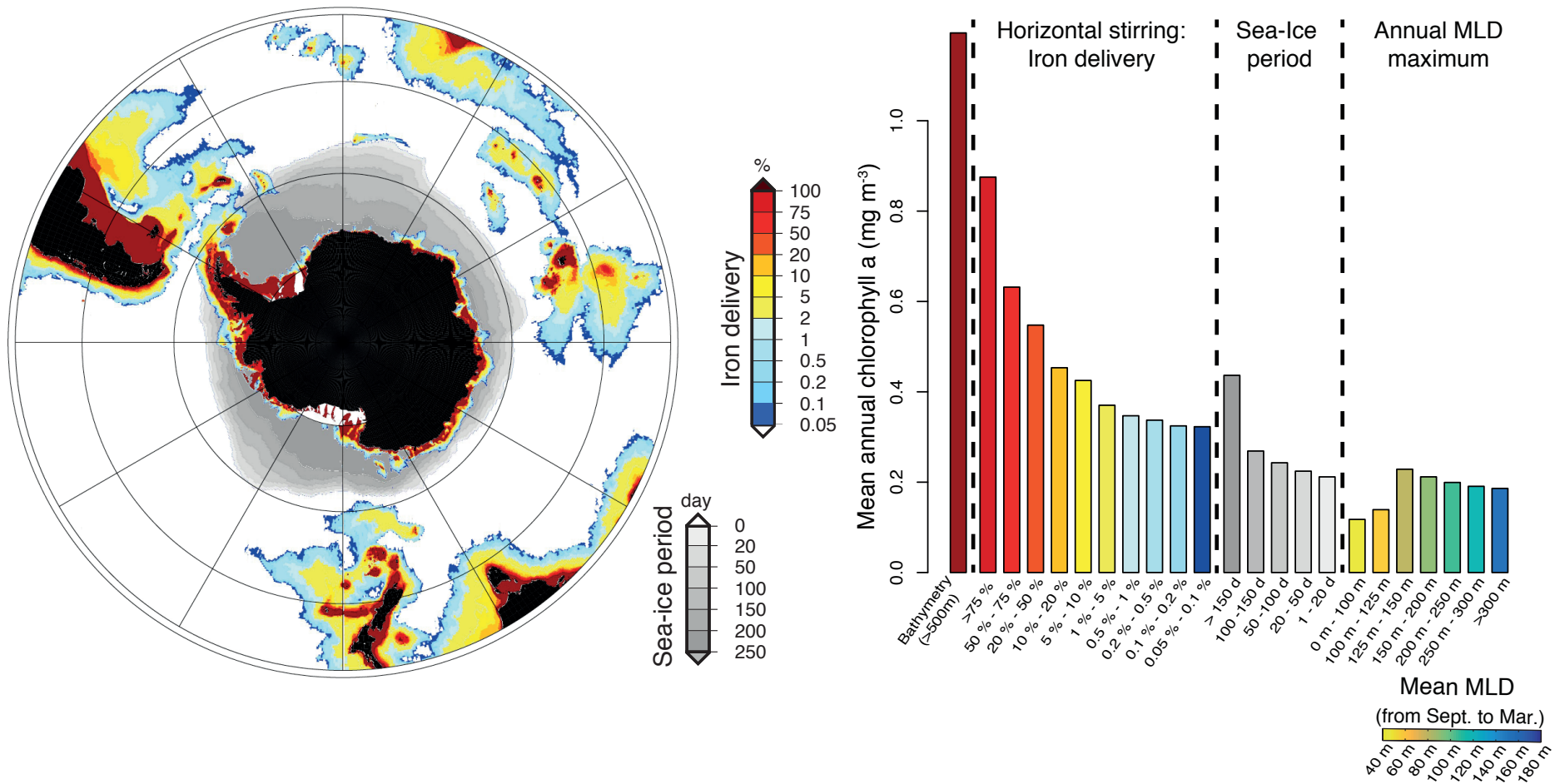
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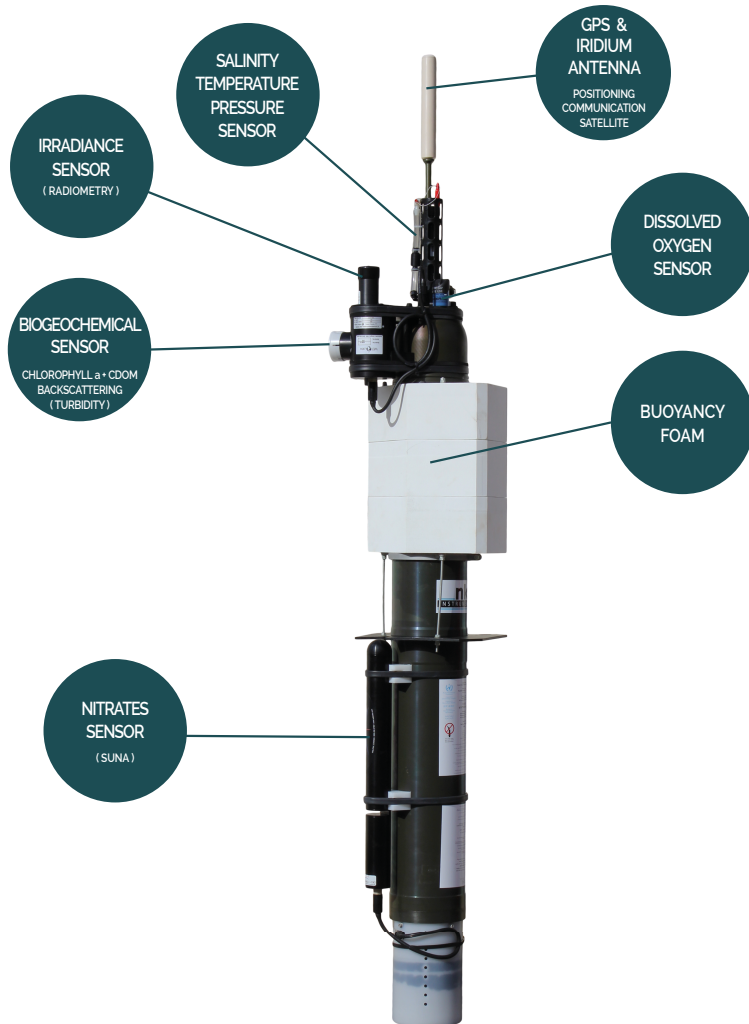
DRIVERS OF THE PHYTOPLANKTON BIOMASS IN THE SOUTHERN OCEAN

Iron availability: Combining satellite, Argo network and lagrangian modeling



SATELLITE LIMITATION & COMPLEMENTARITY OF THE BGC-ARGO NETWORK

PROFILING FLOAT PROVOR CTS 4 / PROVIO II



Novelty of using BGC-ARGO floats in the Southern Ocean:

- The whole annual cycle covered with 1-5 days of time resolution.
- Contribution/Impact of the verticality on annual NPP estimates/nutrient inventories
- Complementary information with biogeochemical sensors (bio-optics, irradiance, nitrate, oxygen).
- Validation of satellite-derived products (i.e. chlorophyll, bbp).

OUTLINE

*Mechanisms behind bloom initiation and magnitude in the
Southern Ocean:
From global to regional scale*

- Defining annual phytoplankton cycles across the different domains of the Southern Ocean

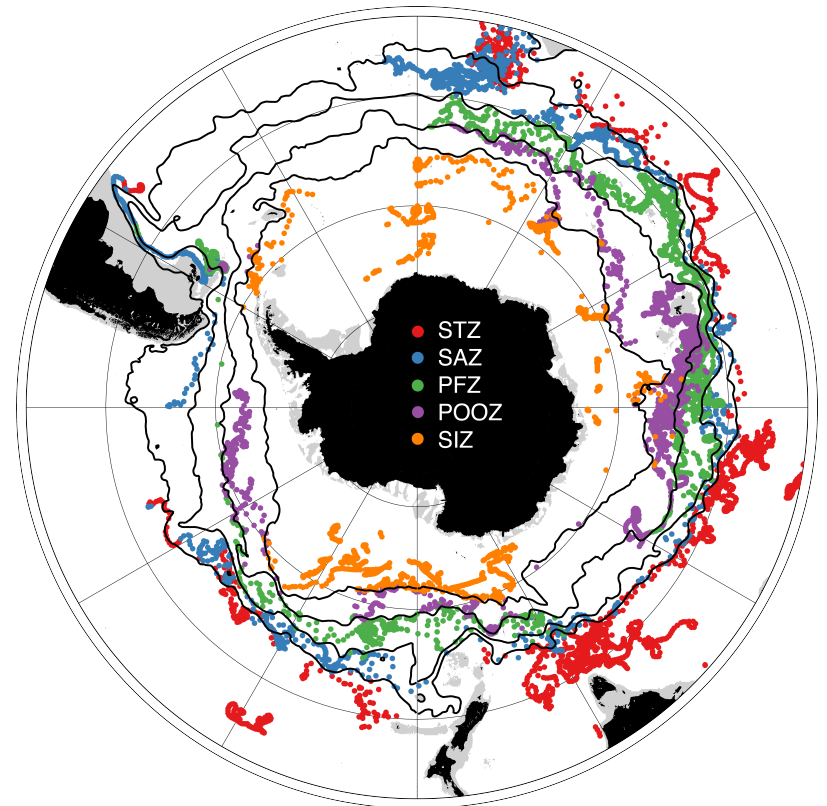
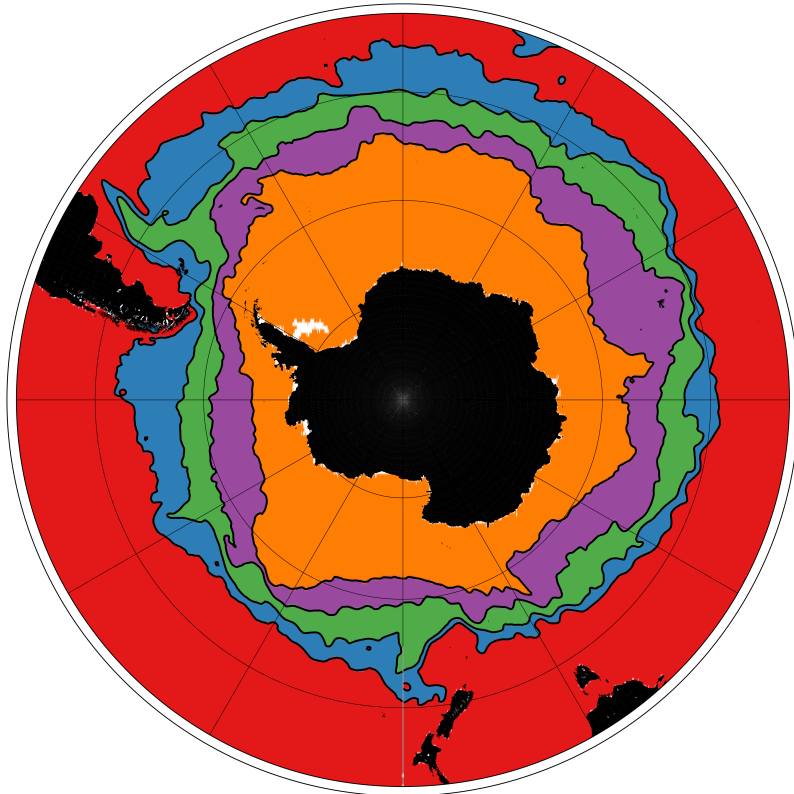
OUTLINE

*Mechanisms behind bloom initiation and magnitude in the
Southern Ocean:
From global to regional scale*

- Defining annual phytoplankton cycles across the different domains of the Southern Ocean
- Assessing the environmental forcing on:
 - Bloom initiation and magnitude
 - Phytoplankton assemblage/physiology

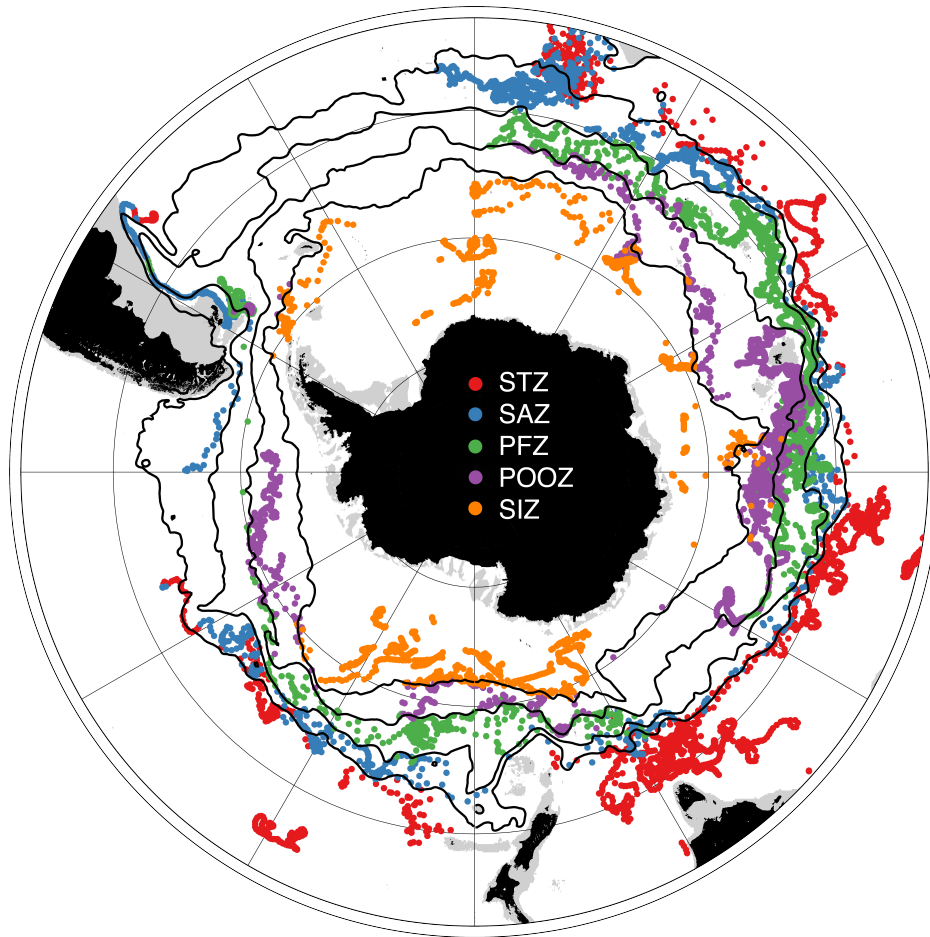
BGC-ARGO NETWORK IN THE SOUTHERN OCEAN

Biogeographic-derived analysis (Maps of Absolute Dynamic Topography)



Total ~14500 BGC-ARGO profiles
Period: 2010-09-13 until now

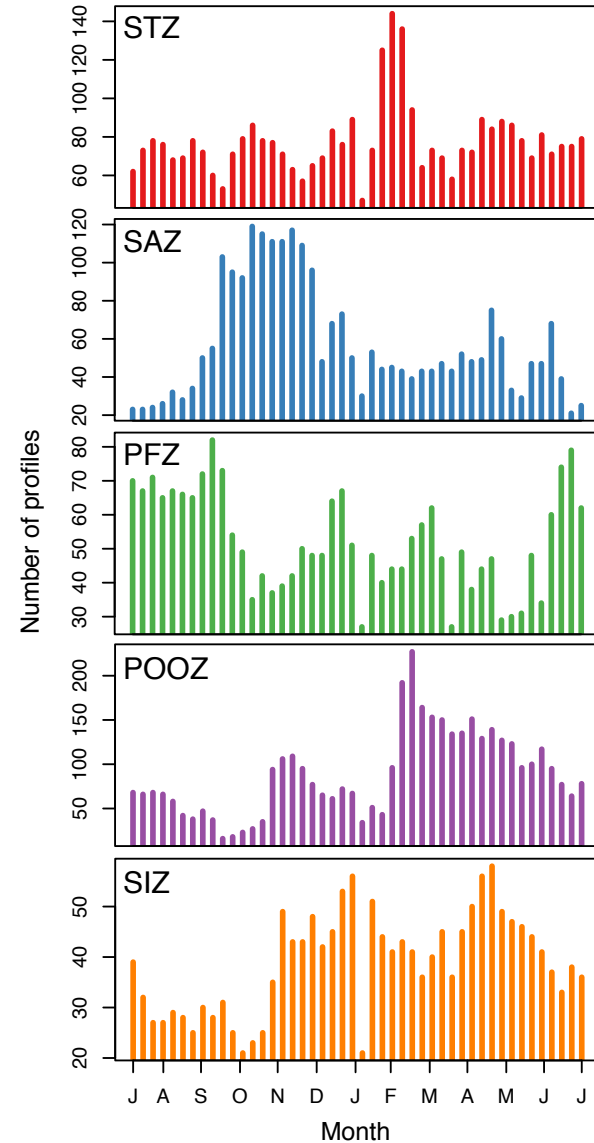
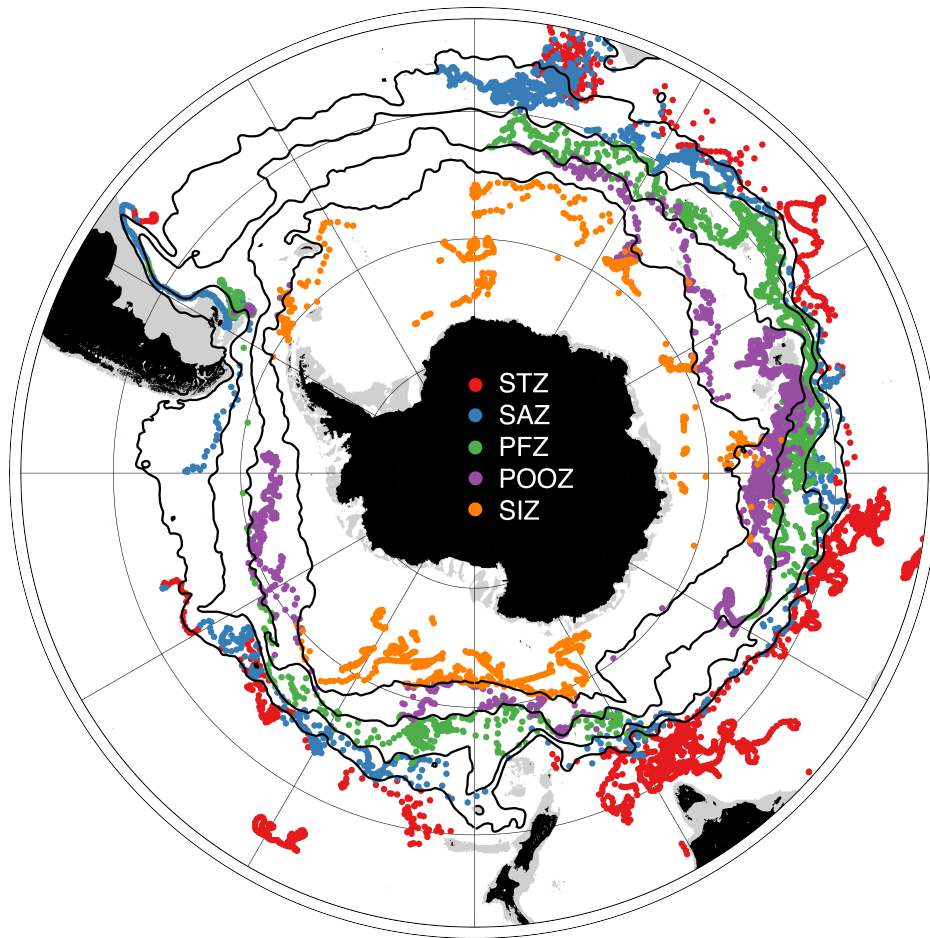
ANNUAL PHYTOPLANKTON CYCLES USING BGC-ARGO FLOATS



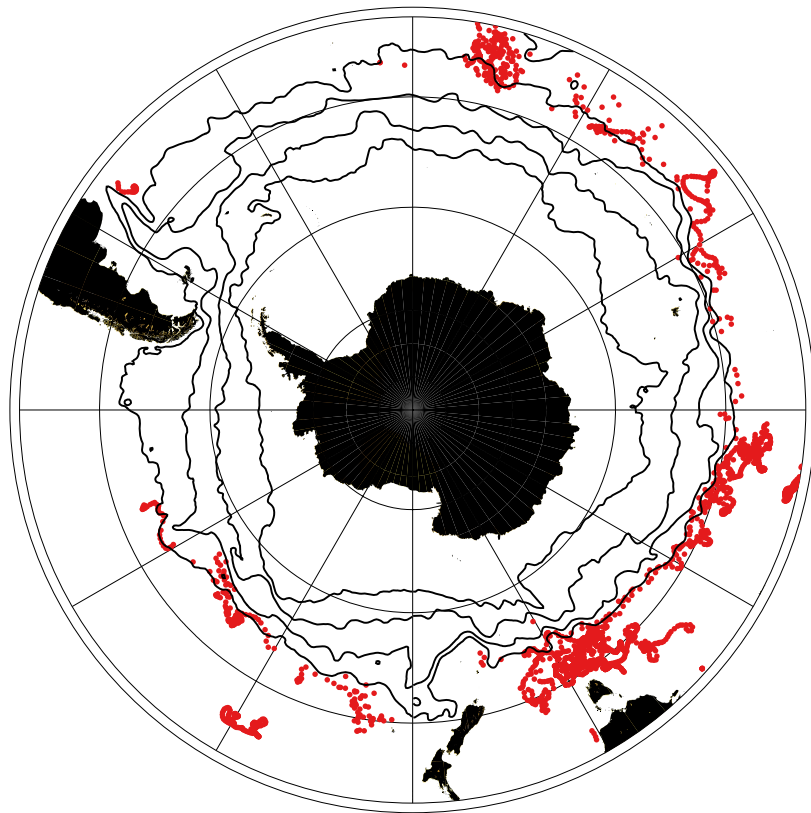
Institution	Num. float	Num. profiles	Contribution of the total profiles (%)
AOML-NOAA	80	3931	27
BODC	2	423	3
CORIOLIS	27	4564	32
CSIRO	16	5062	35
INCOIS	7	435	3
TOTAL	132	14415	

Total ≈14500 BGC-ARGO profiles
Period: 2010-09-13 until now

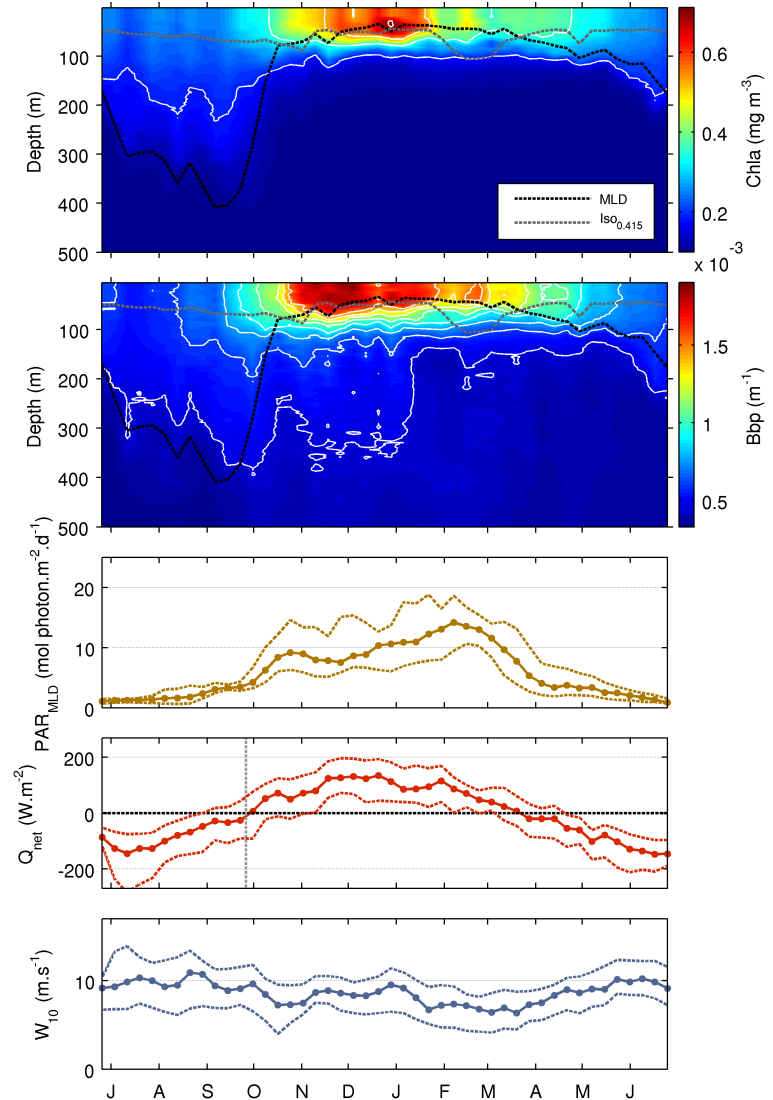
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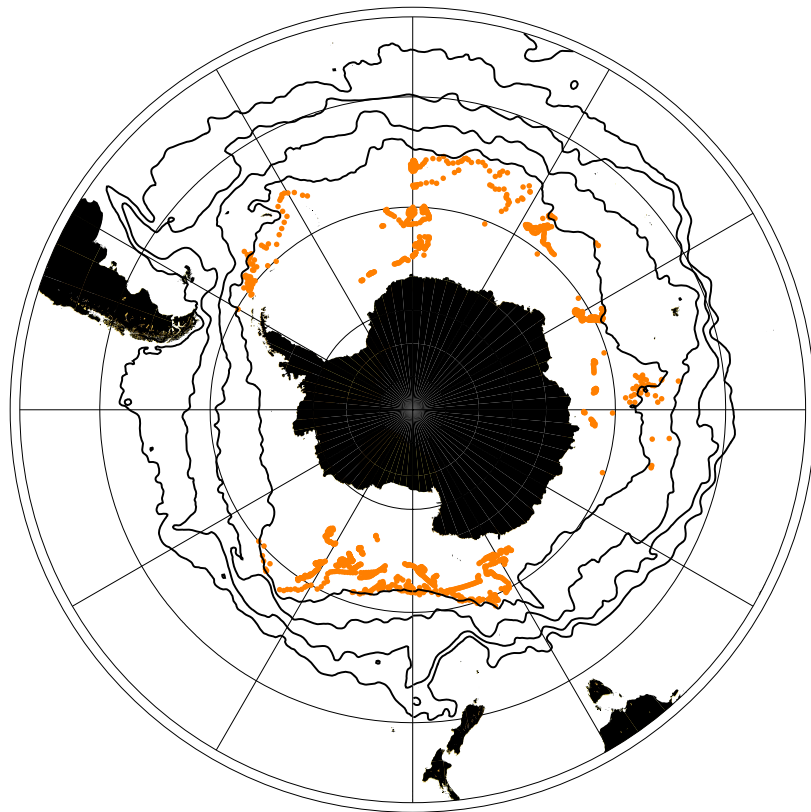
ANNUAL PHYTOPLANKTON CYCLES IN THE SUBTROPICAL ZONE



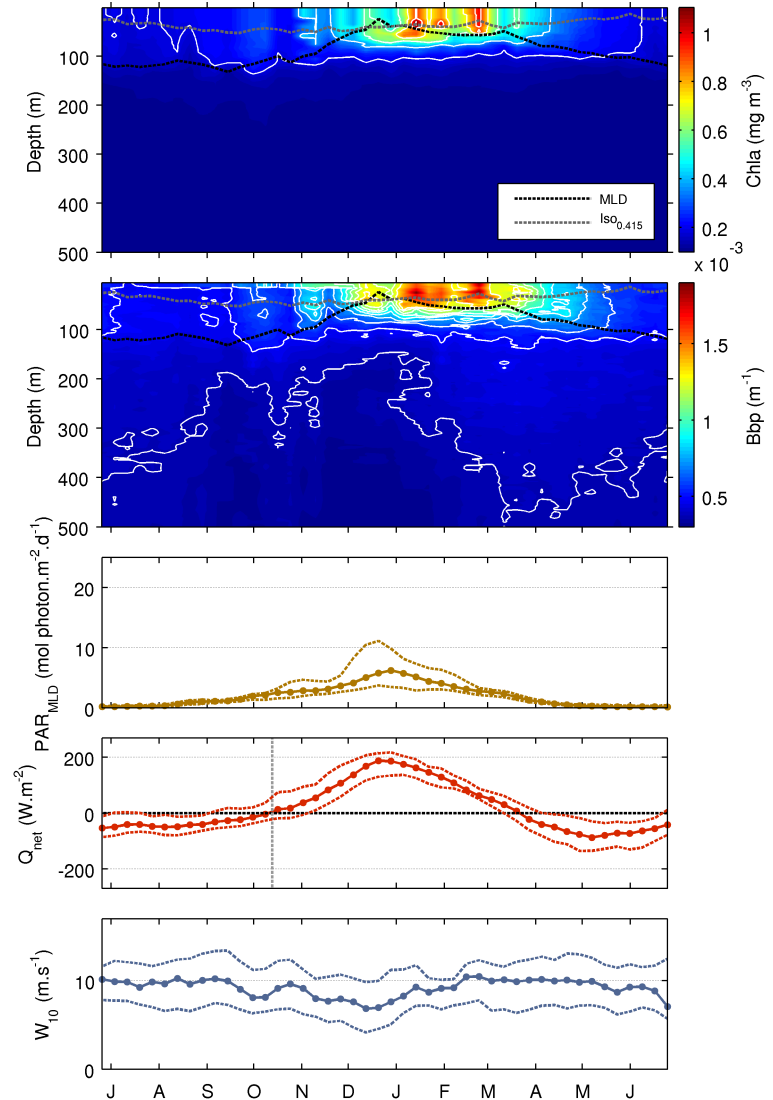
Subtropical/Temperate Zone



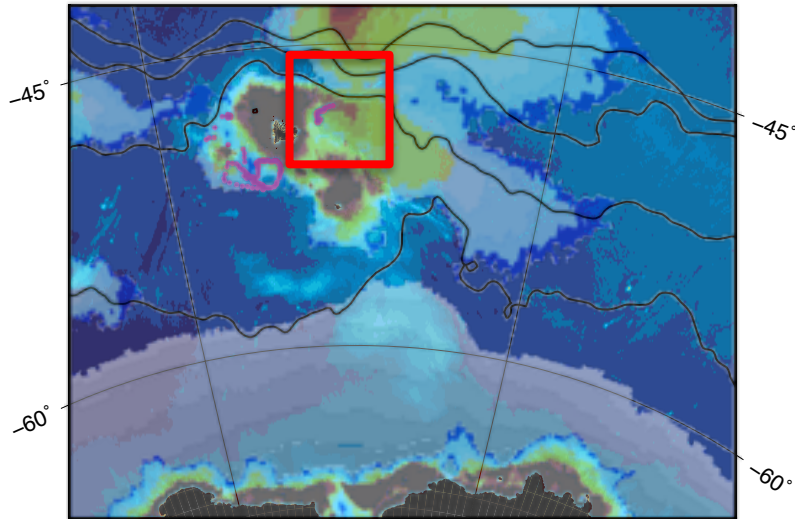
ANNUAL PHYTOPLANKTON CYCLES IN THE SEASONAL ICE ZONE (SIZ)



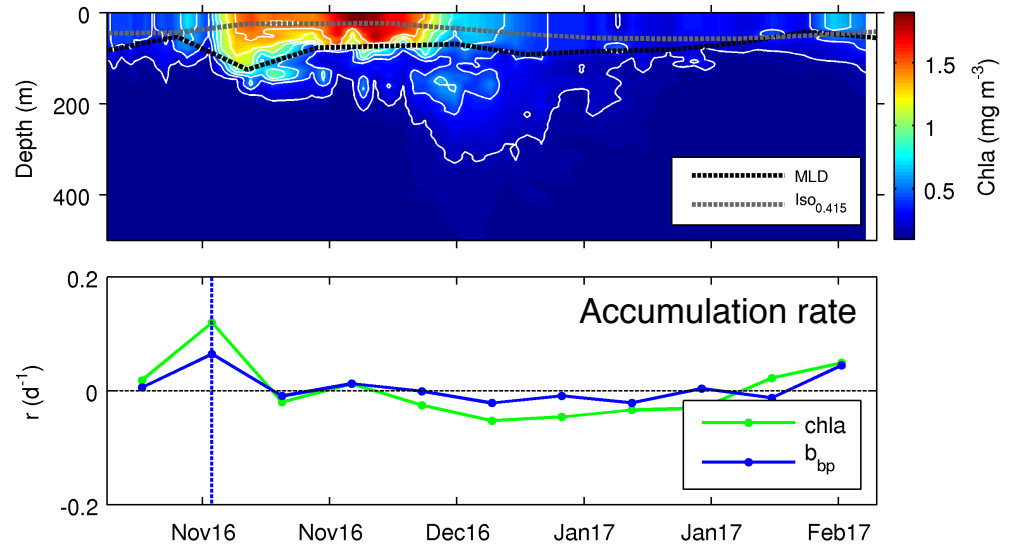
Seasonal Ice Zone



DETERMINING THE ACCUMULATION RATE AND BLOOM INITIATION

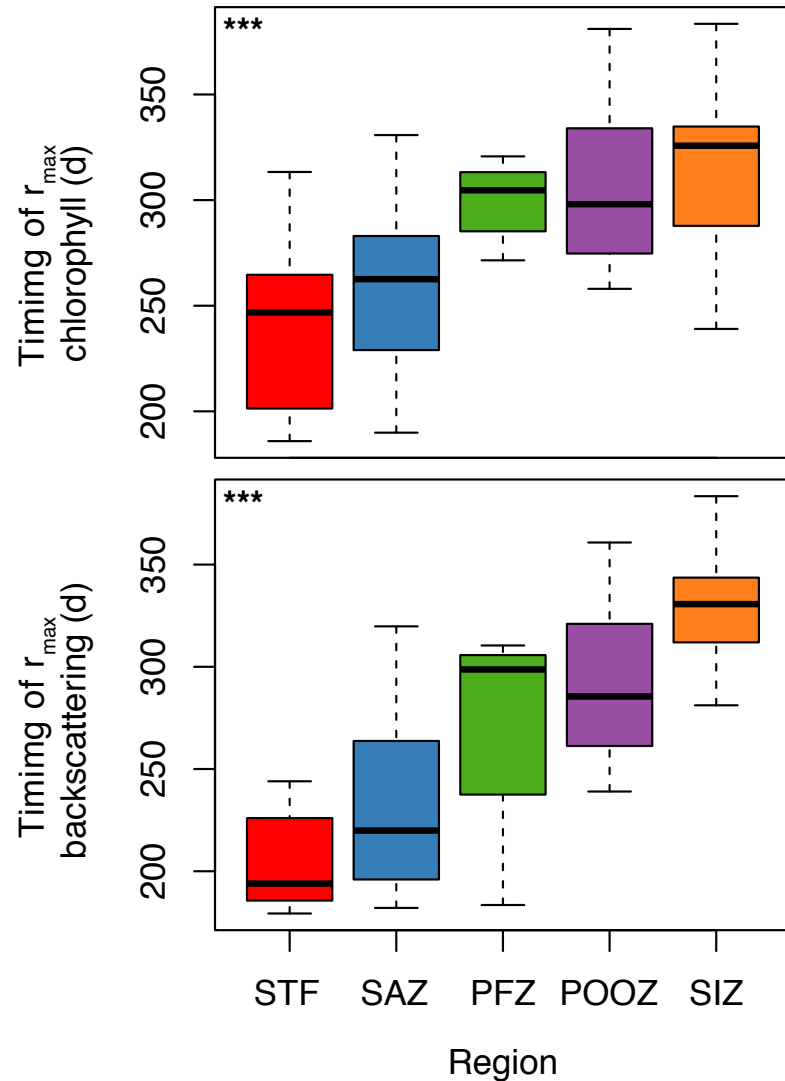
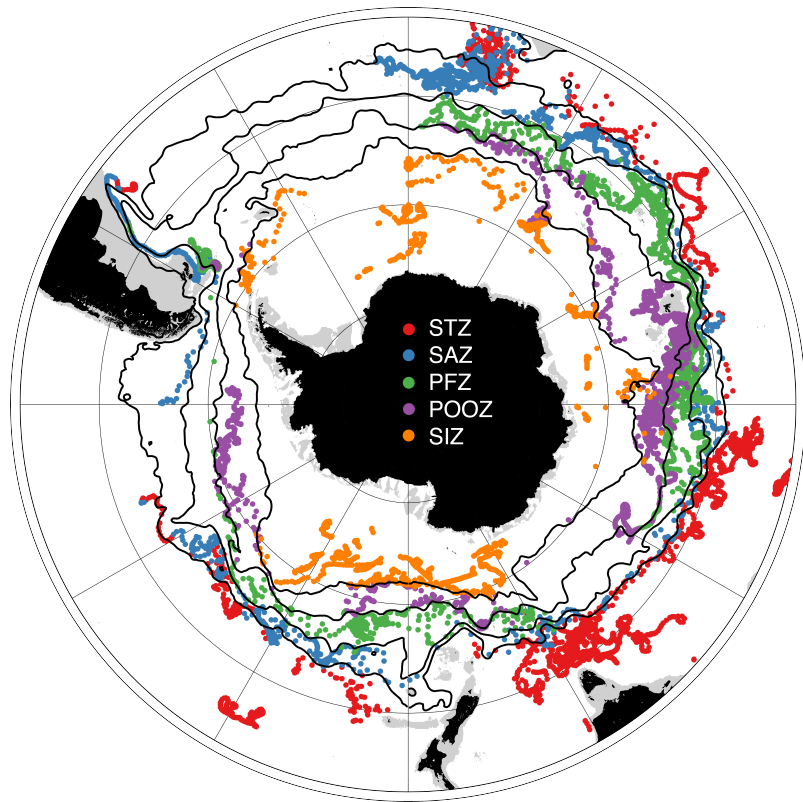


LOV BGC-Argo float
(Nov. 2016 - ongoing)

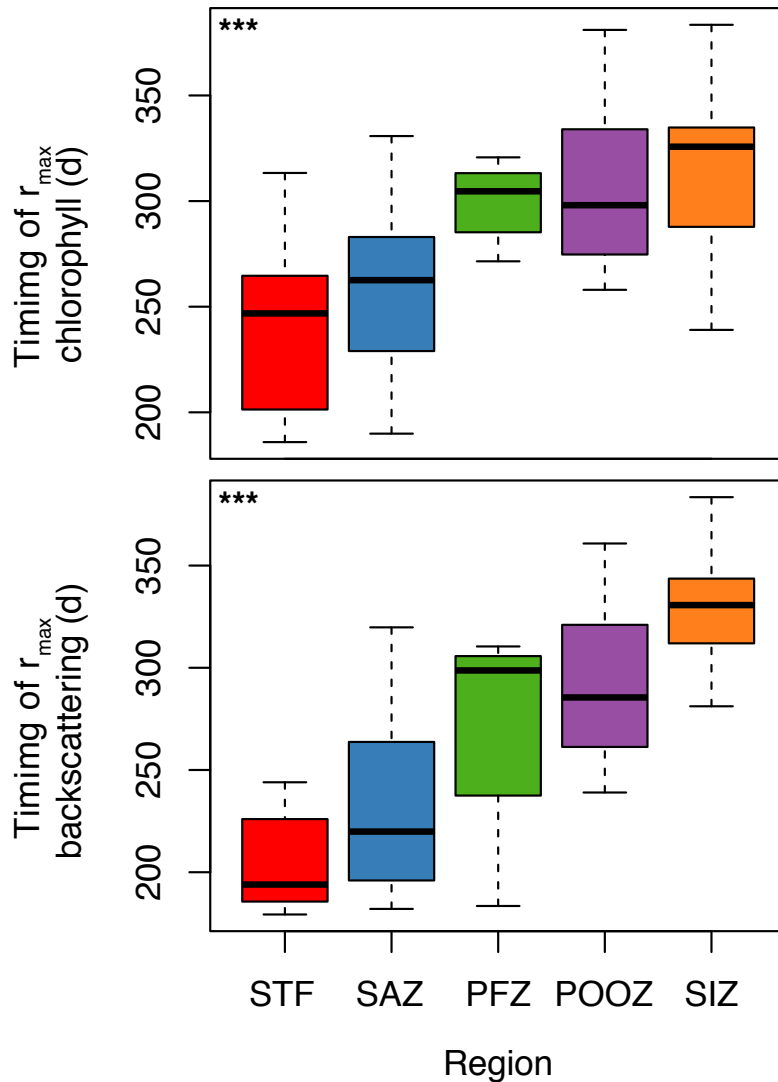


$$r_{i=b,chl}(t + \Delta t/2) \equiv \begin{cases} \frac{1}{\bar{P}_i} \frac{d\bar{P}_i}{dt} \approx \frac{2}{\Delta t} \frac{(\bar{P}_i(t + \Delta t) - \bar{P}_i(t))}{(\bar{P}_i(t + \Delta t) + \bar{P}_i(t))} & \text{if } \frac{dMLD}{dt} < 0 \ \& \ MLD > z(0.415) \\ \frac{1}{\int P_i} \frac{d \int P_i}{dt} \approx \frac{2}{\Delta t} \frac{(\int P_i(t + \Delta t) - \int P_i(t))}{(\int P_i(t + \Delta t) + \int P_i(t))} & \text{all other cases} \end{cases}$$

BLOOM INITIATION IN THE SOUTHERN OCEAN



BLOOM INITIATION IN THE SOUTHERN OCEAN



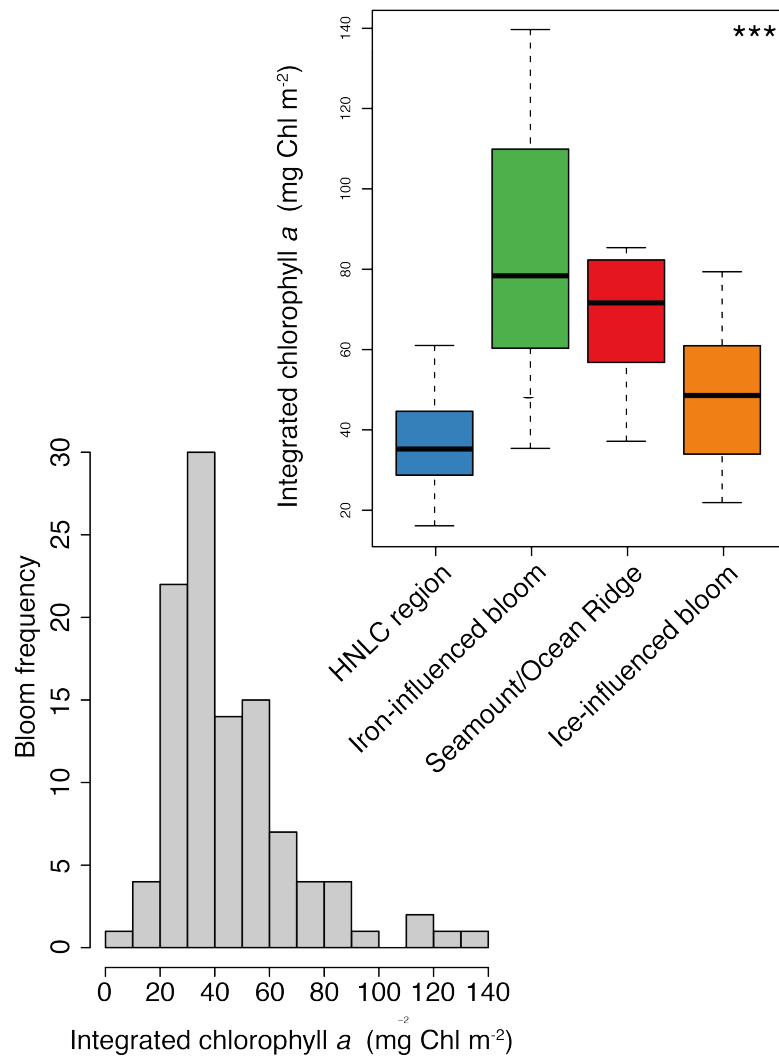
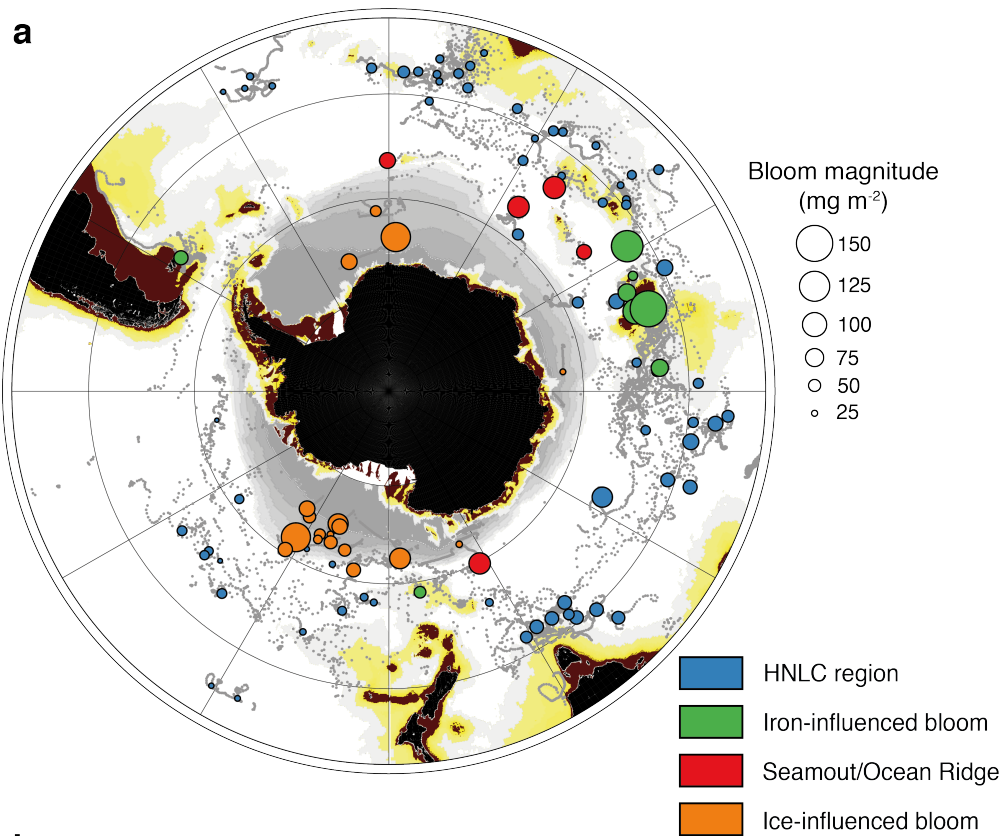
Seems to support the latitudinal satellite-derived trend in bloom initiation.

With the BGC-Argo floats, we will go further by examining:

- Heat flux
- Wind stress
- Light-mixing regimes
- Sea-ice proximity

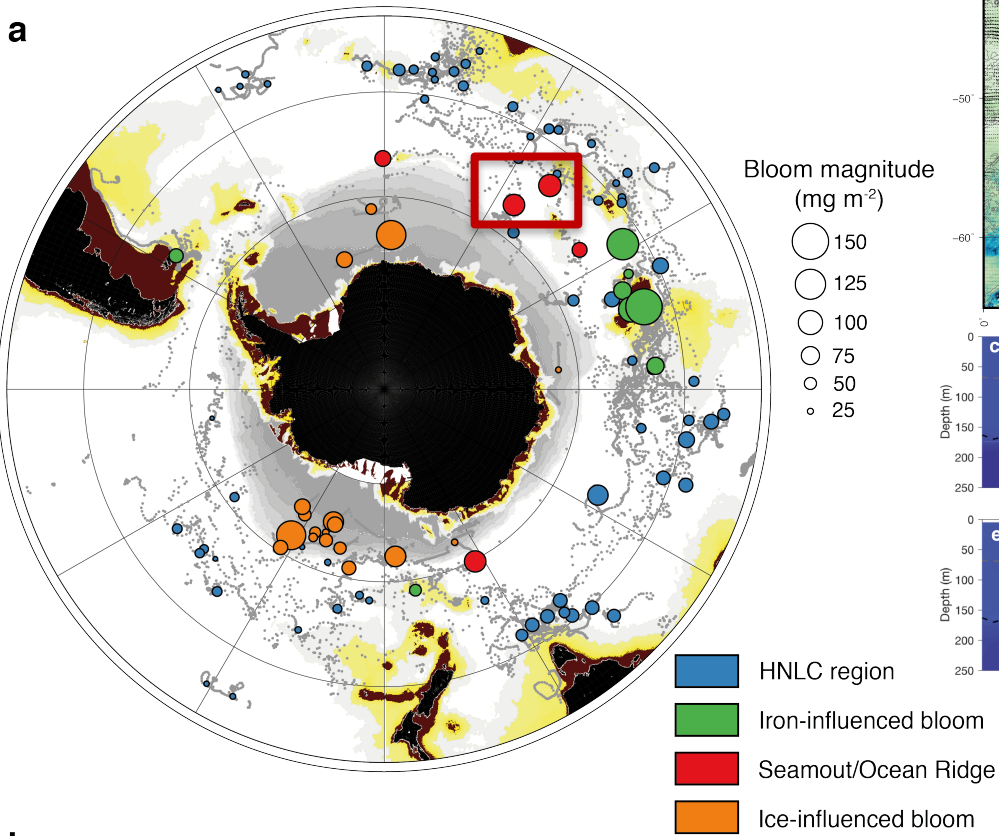
which may modulate the timing of the bloom initiation

BLOOM MAGNITUDE INITIATION IN THE SOUTHERN OCEAN



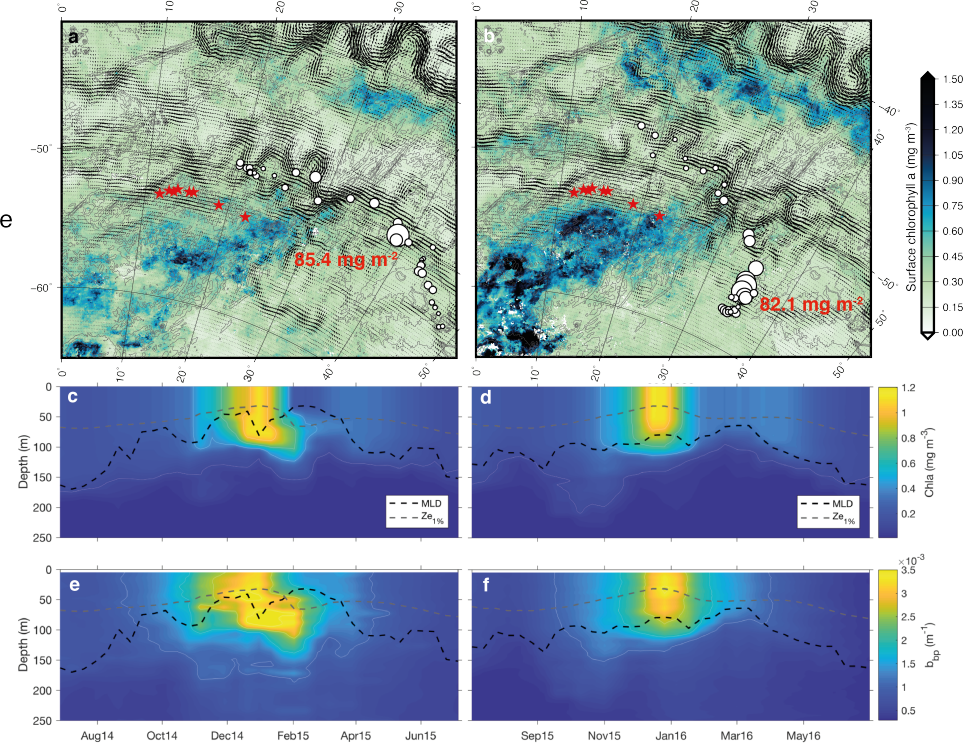
Still preliminary !!

RECURRENT MASSIVE BLOOMS IN A HNLC REGION



Year 2014
WMO 2902130

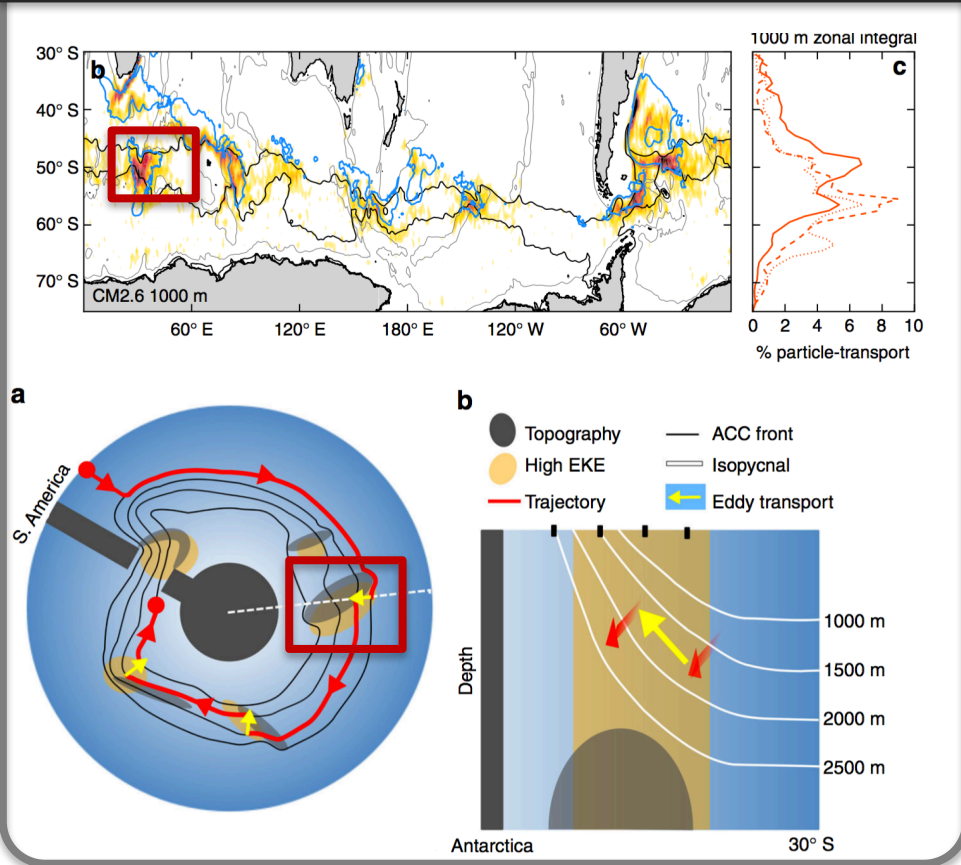
Year 2015
WMO 6901585



Still preliminary !!

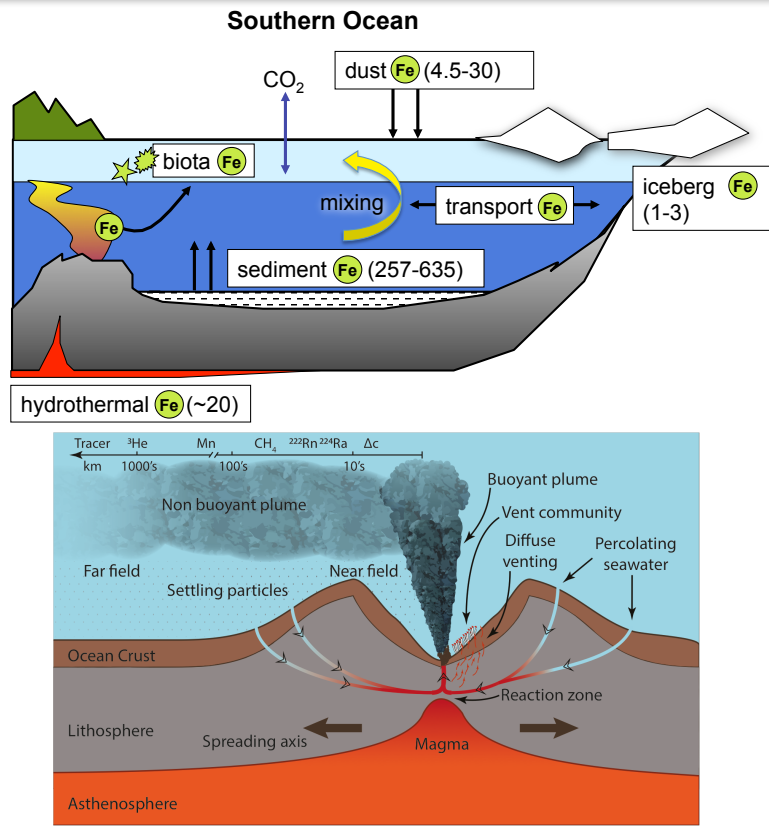
POTENTIAL UPWELLED HYDROTHERMALLY IRON-ENRICHED DEEP WATERS ????

Location of upwelled deep waters



Tamsitt et al., NC 2017

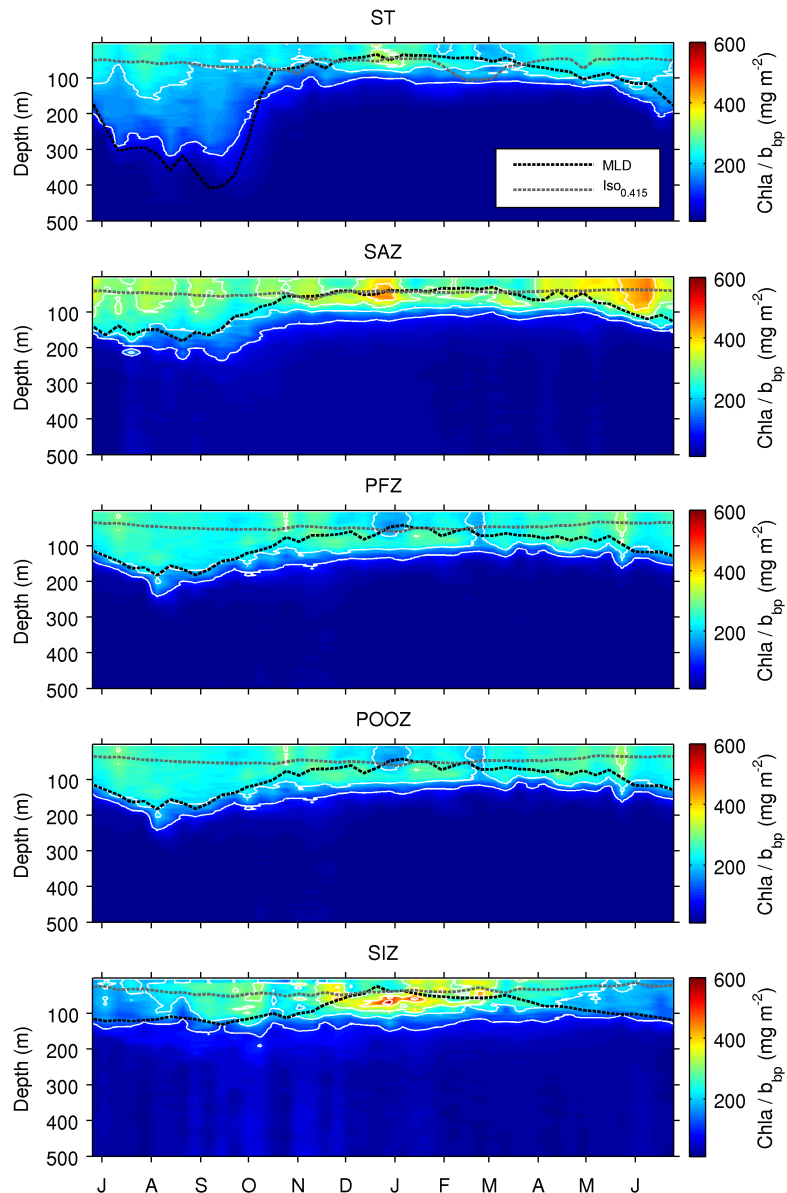
Role of hydrothermal vents



Holmes et al., 2017

Still preliminary !!

BIO-OPTICAL PROPERTIES OF PHYTOPLANKTON ASSEMBLAGES: CHL/BBP RATIO



When carefully used, Chl/bbp ratio could be used as index of changes in phytoplankton community.

Need to be careful with:

- Photo acclimation: (- with more light)
- Nutrient limitation (+)
- High abundances of heterotroph/coccolithophore (-)
- Lithogenic/inorganic particles (-)

BIO-OPTICAL PROPERTIES OF PHYTOPLANKTON ASSEMBLAGES: CHL/BBP RATIO

GLM model:

$$chl:bbp \sim intercept + Chl + PIC + T + PAR_{MLD} + MLD + Q_{net} + W_{10}$$

Zone	n	R ²	Int	Chl	PIC	T	PAR _{MLD}	MLD	Q _{net}	W ₁₀
STZ	1458	0.66	-0.06	0.65	-0.17	0.11	-0.62	-0.16	ns	-0.05
SAZ	3793	0.57	-0.07	0.68	-0.26	-0.10	-0.33	-0.25	ns	ns
PFZ	1980	0.64	-0.14	0.69	-0.29	-0.12	-0.26	ns	ns	ns
POOZ	3305	0.67	0.05	0.65	-0.21	-0.08	-0.39	0.13	ns	-0.04
SIZ	1155	0.79	ns	0.80	ns	ns	-0.11	ns	ns	ns

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No strong effects of the heat flux and the wind (and also of the water temperature)

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Zone	Chl	PIC	PAR _{MLD}	Hypothesis
STZ	++	+	+++	Strong photo acclimation
SAZ & PFZ	++	++	+	Succession between diatoms/prymnesiophytes in the « Great Calcite Belt » (Balch et al. 2016)
POOZ	++	+	+	Mix between photoacclimation and phytoplankton succession
SIZ	+++			Succession between diatoms/no diatoms, weak photo acclimation

PERSPECTIVES

- Thanks to these BGC-Argo floats, we will have a comprehensive understanding of the bloom initiation and magnitude across the different domains of the Southern Ocean.

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- A large variability in the bloom magnitude is observed and appears to be related to distinct iron-replenishment mechanisms (advective transport, sea-ice and seamounts proximity). The potential presence and role of hydrothermally iron-enriched deep waters need to be confirmed.

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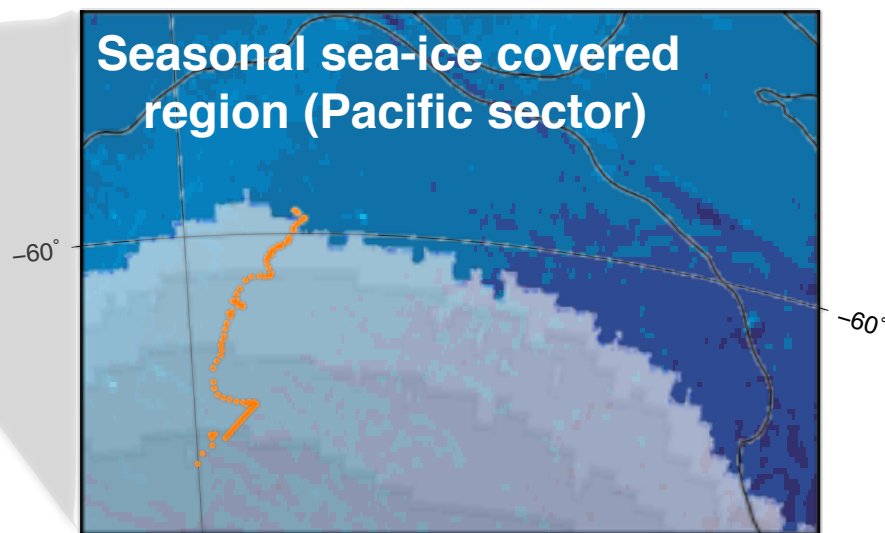
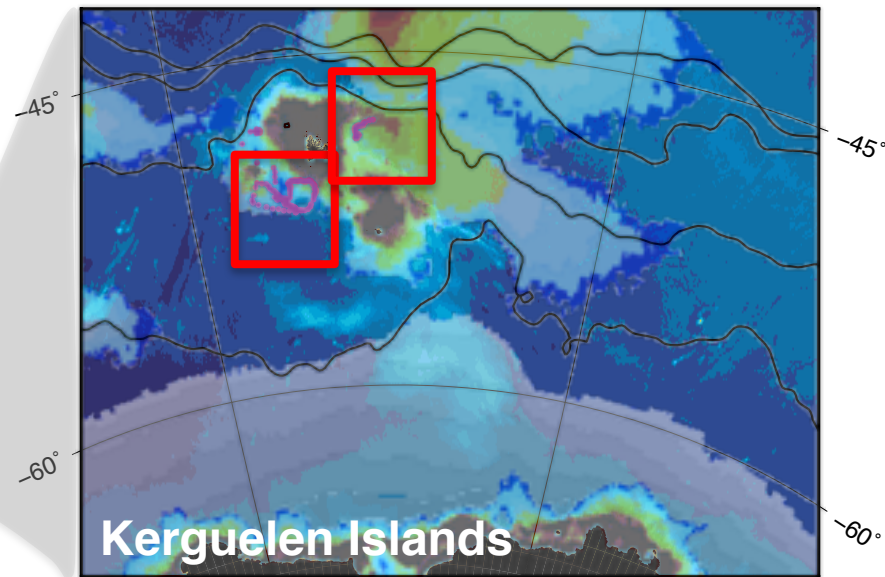
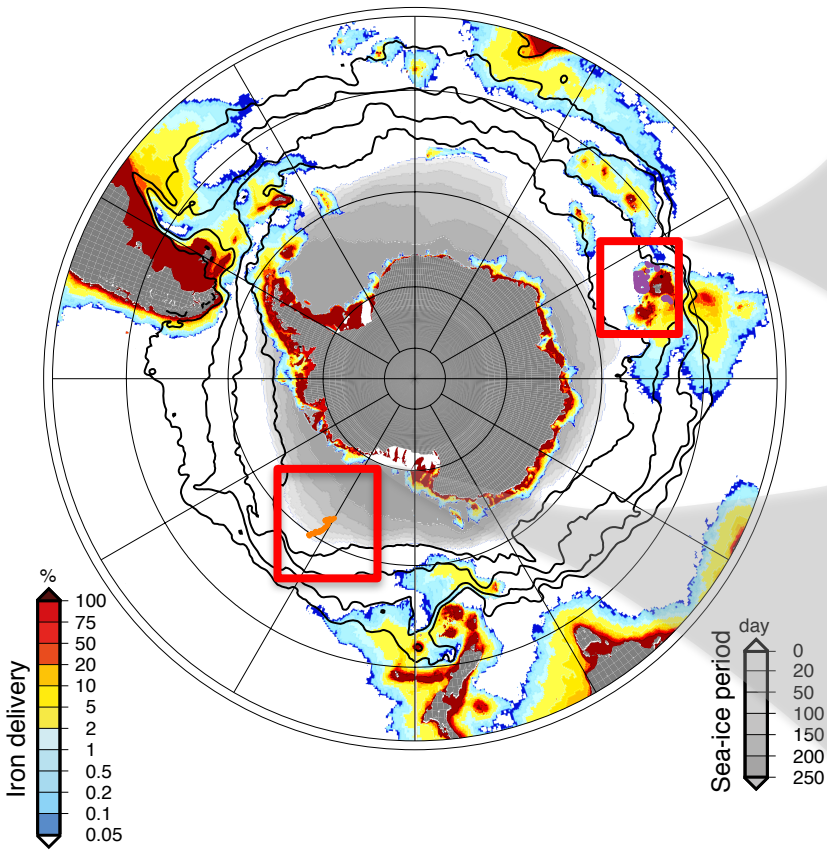
- Additional information may be retrieved on the phytoplankton assemblage/physiology based on bio-optical sensors.

An aerial photograph of a glacier system. A river flows through a valley, surrounded by brownish, rocky terrain. The glacier is dark blue and black, with numerous white icebergs and chunks of ice floating in the water. The background shows a vast, white, snow-covered or ice-covered landscape.

Questions ???

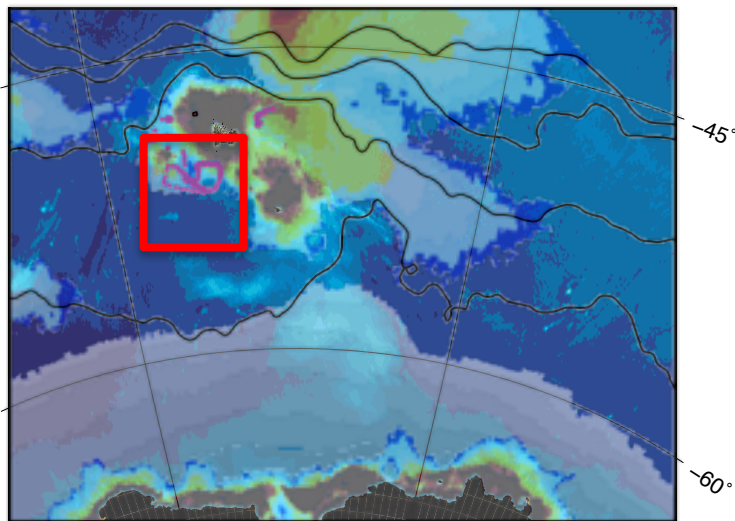
THREE CASE STUDIES FOR EXAMINING BLOOM INITIATION

Southern Ocean: Iron- and sea ice-influenced regions

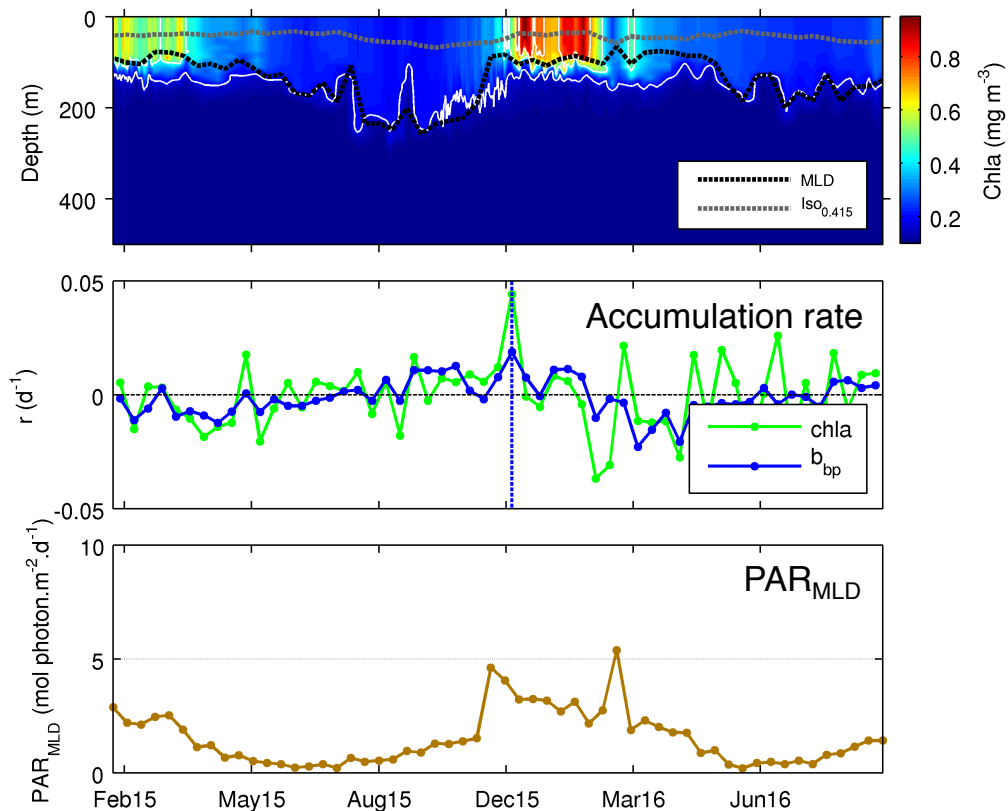


BLOOM INITIATION AND MAGNITUDE IN HNLC REGION

HNLC region:
West of Kerguelen

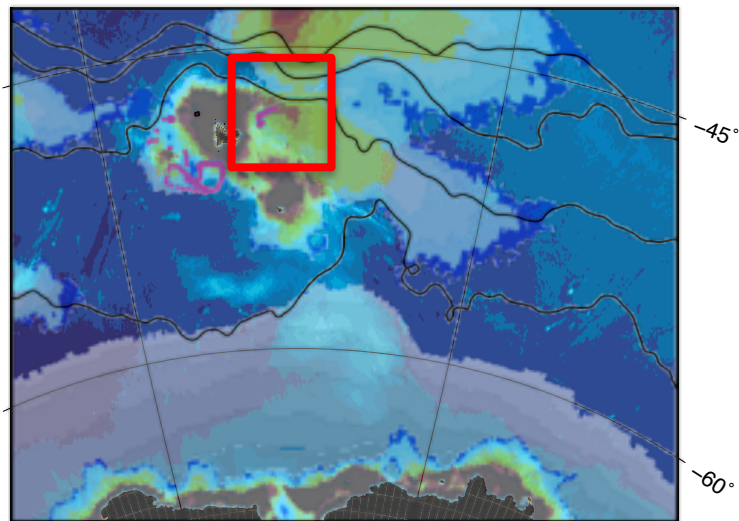


LOV BGC-Argo float
2 complete annual cycle
(Feb. 2015 - ongoing)

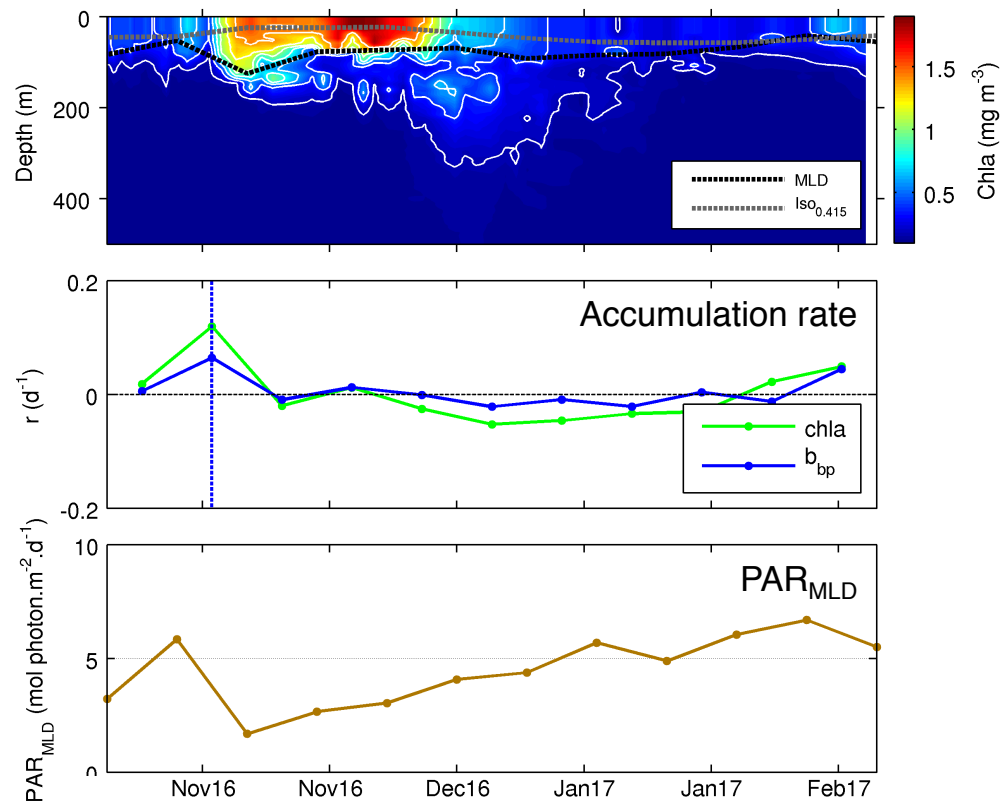


BLOOM INITIATION IN A NATURAL IRON FERTILIZED REGION

**Natural iron fertilized region:
East of Kerguelen**

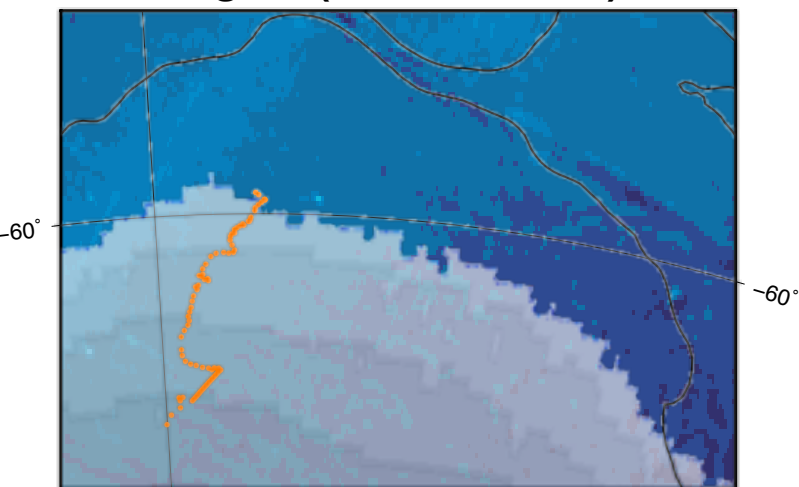


LOV BGC-Argo float
1 incomplete annual cycle
(Nov. 2016 - ongoing)

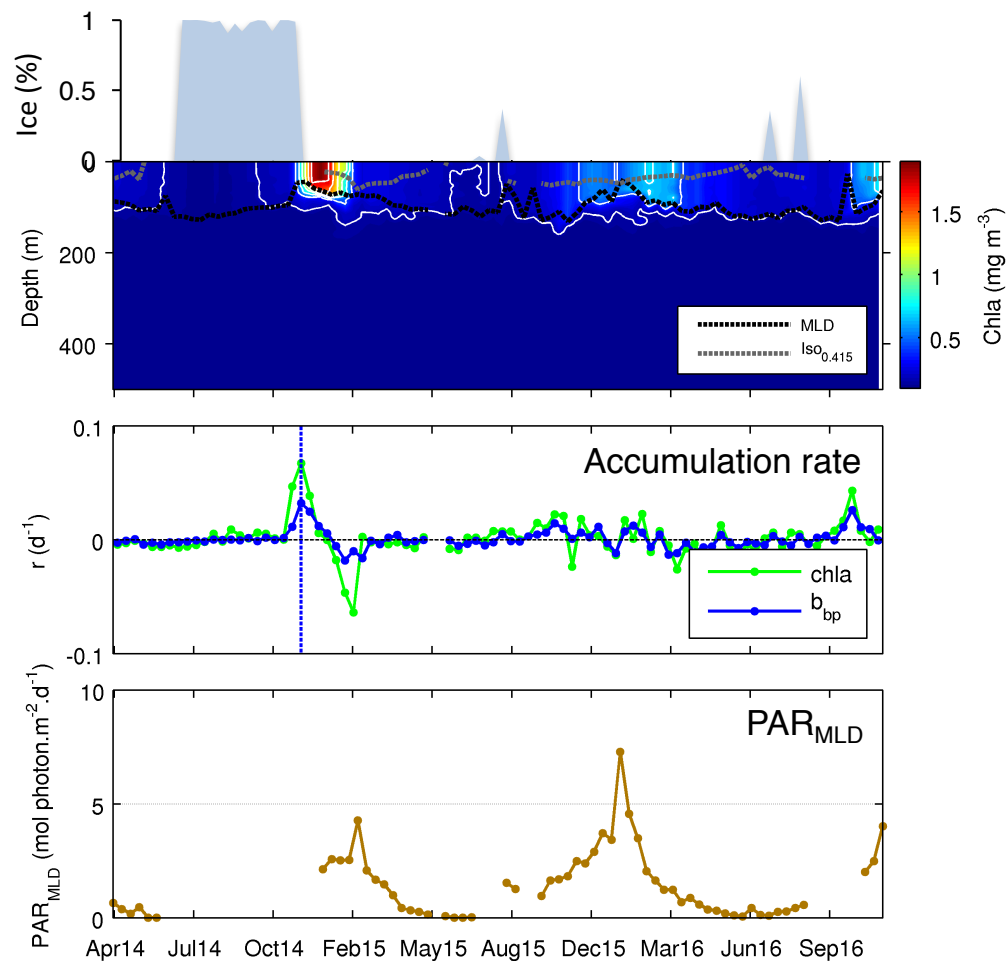


BLOOM INITIATION IN A SEASONAL SEA-ICE COVERED REGION

Seasonal sea-ice covered region (Pacific sector)

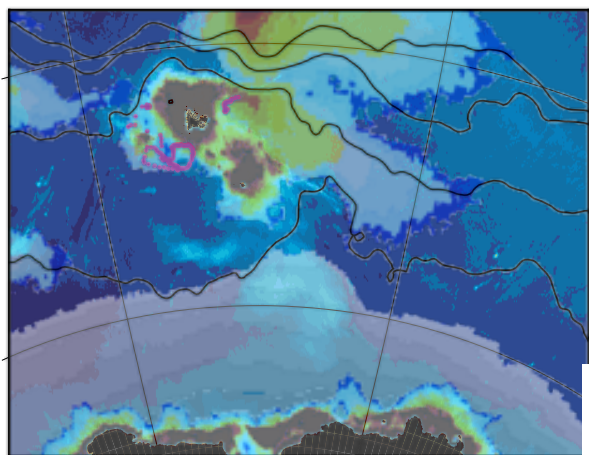


SOCCOM BGC-Argo float
2 complete annual cycles
(Apr. 2014 – Nov. 2016)

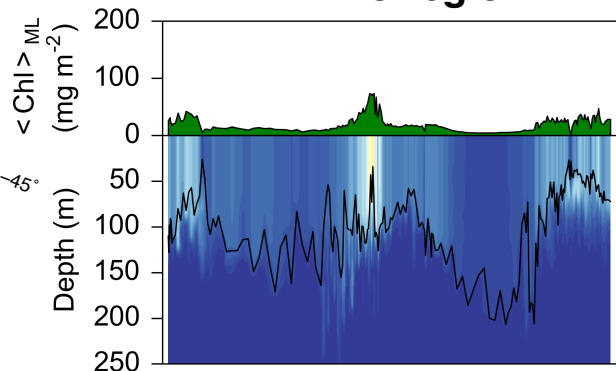


BLOOM EXPORT IN HNLC *VERSUS* NATURAL IRON FERTILIZED REGIONS

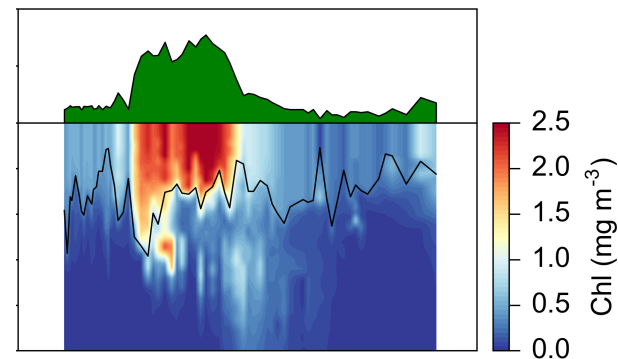
**Kerguelen Islands:
SOCLIM expedition**



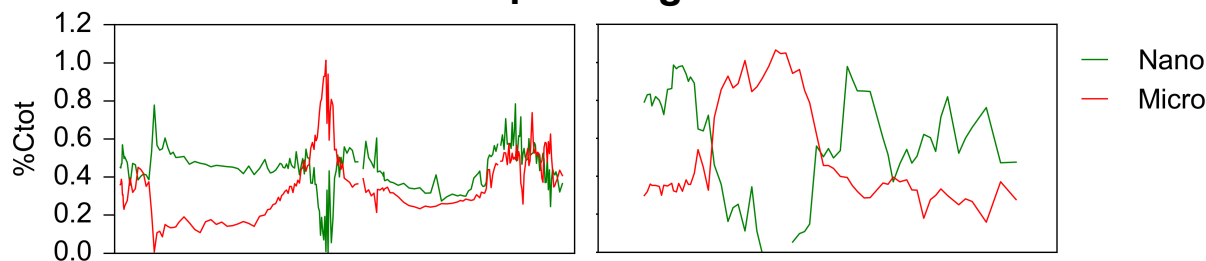
HNLC region



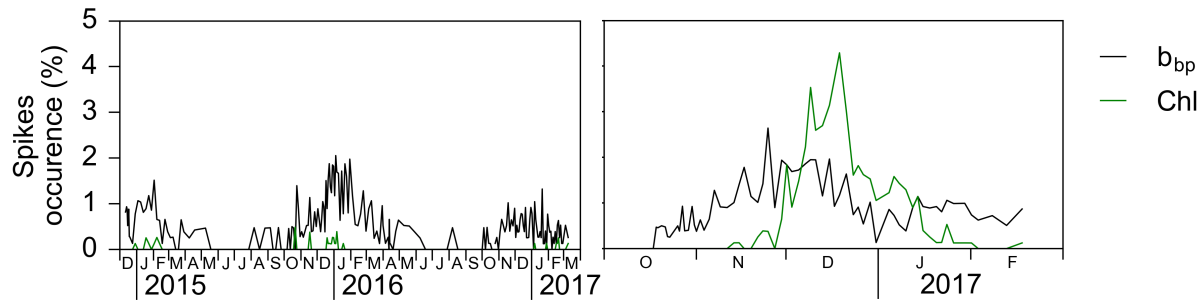
**Natural iron
fertilized region**



Bio-optical signals

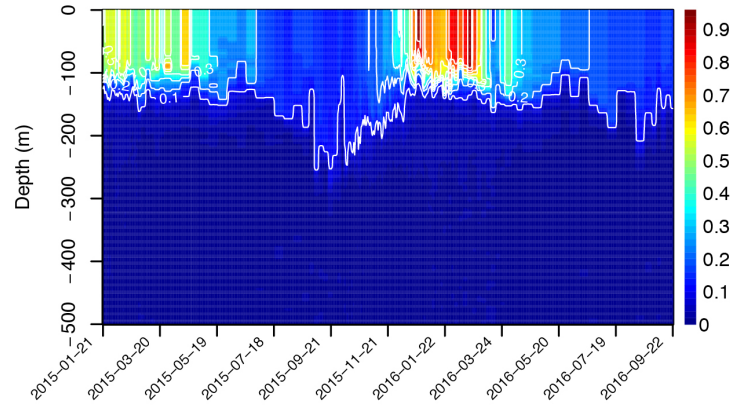


Spike analyses below the MLD

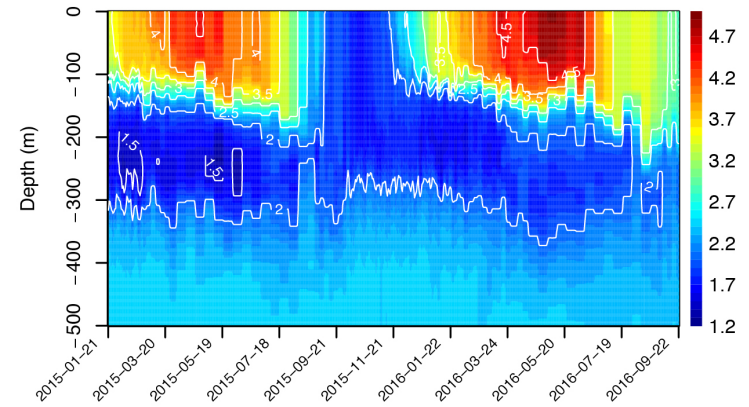


6. BLOOM INITIATION AND MAGNITUDE IN HNLC REGION

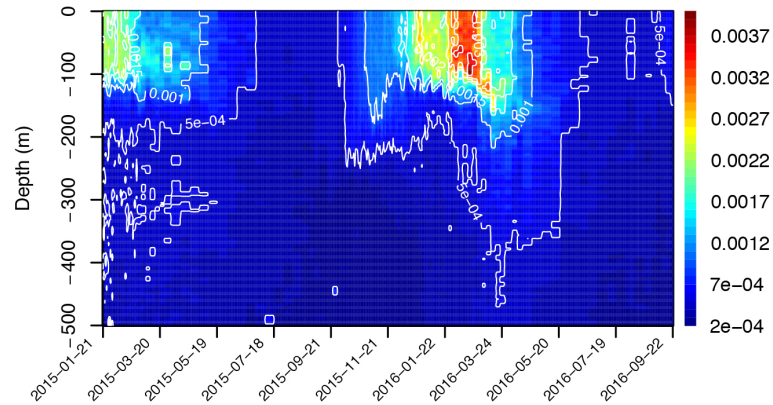
Float = 6901574 – N. profiles = 178
Chlorophyll



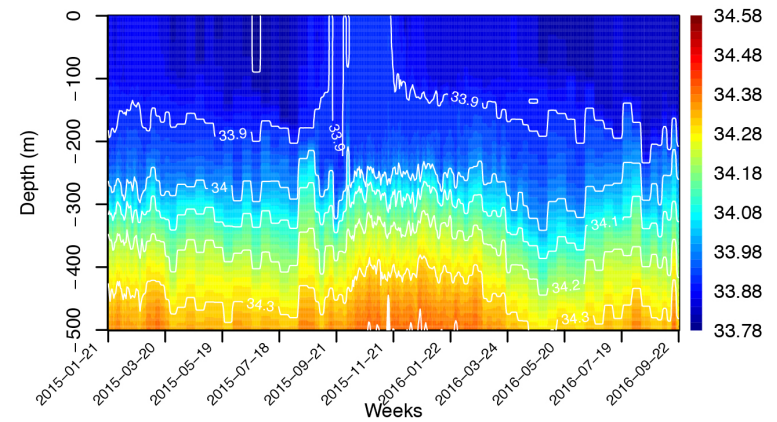
Temperature



Backscattering

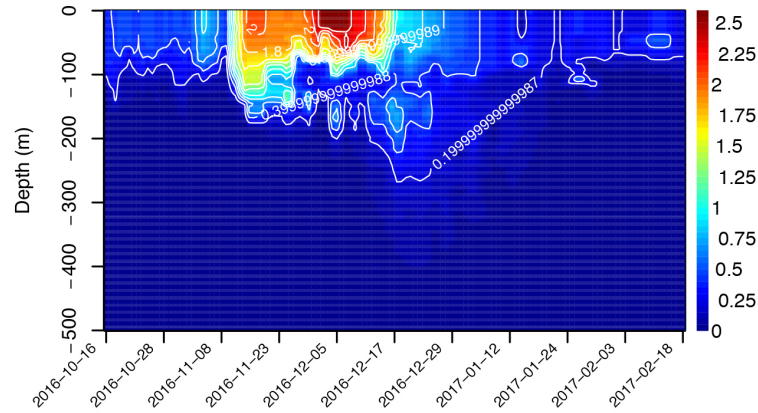


Salinity

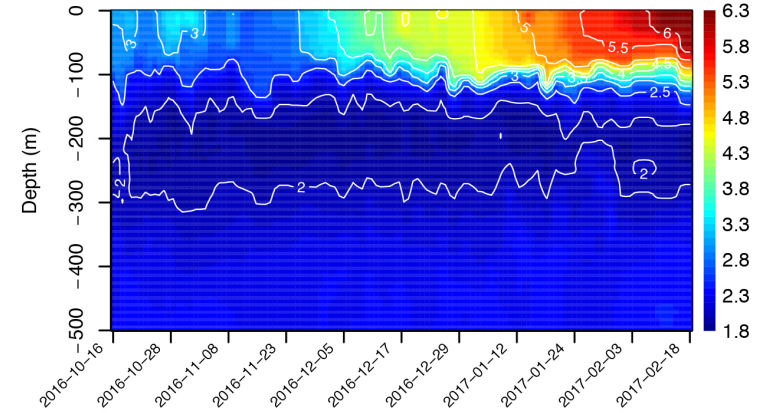


6. BLOOM INITIATION IN A NATURAL IRON FERTILIZED REGION

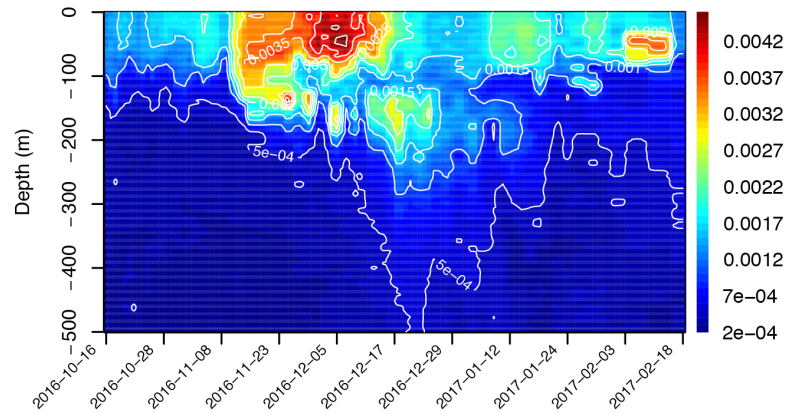
Float = 6902738 – N. profiles = 65
Chlorophyll



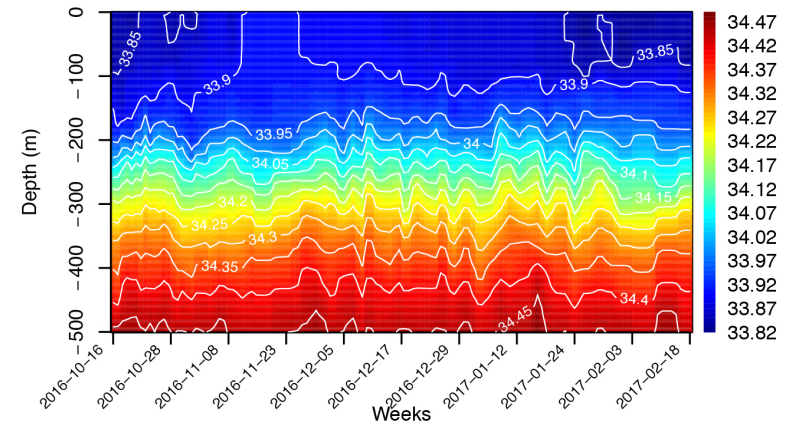
Temperature



Backscattering

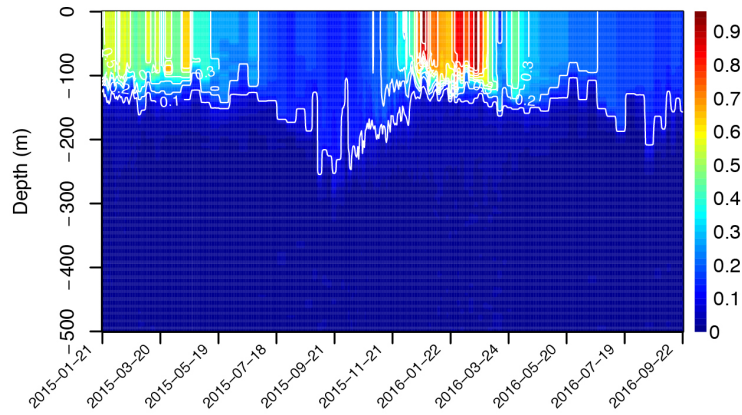


Salinity

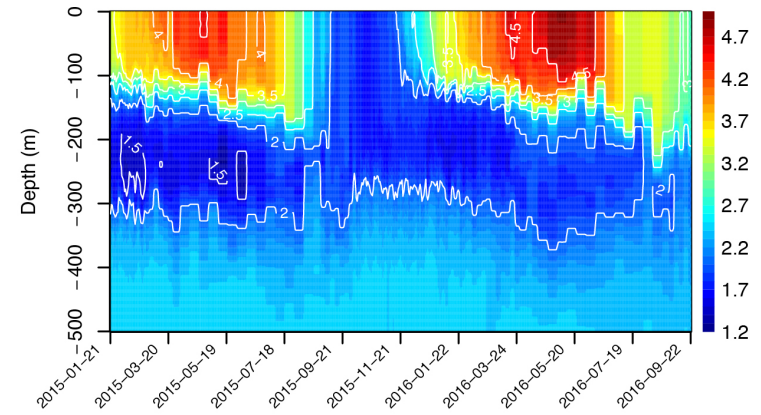


6. BLOOM INITIATION IN A SEASONAL SEA-ICE COVERED REGION

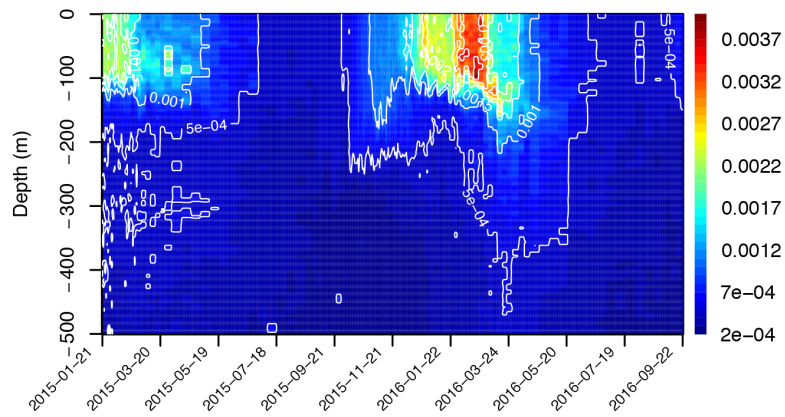
Float = 6901574 – N. profiles = 178
Chlorophyll



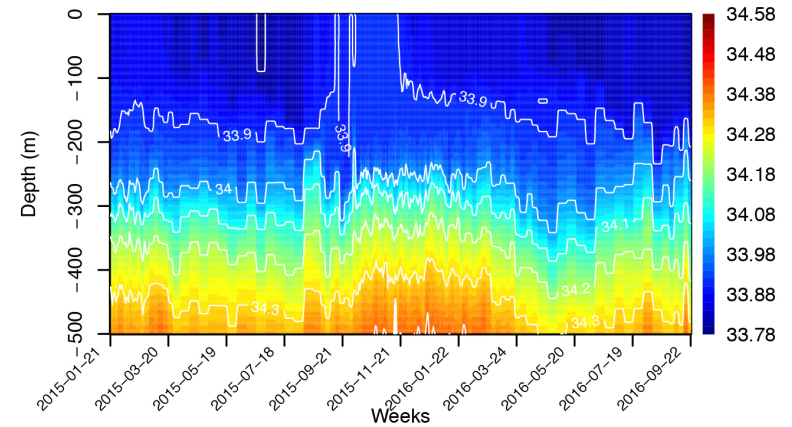
Temperature



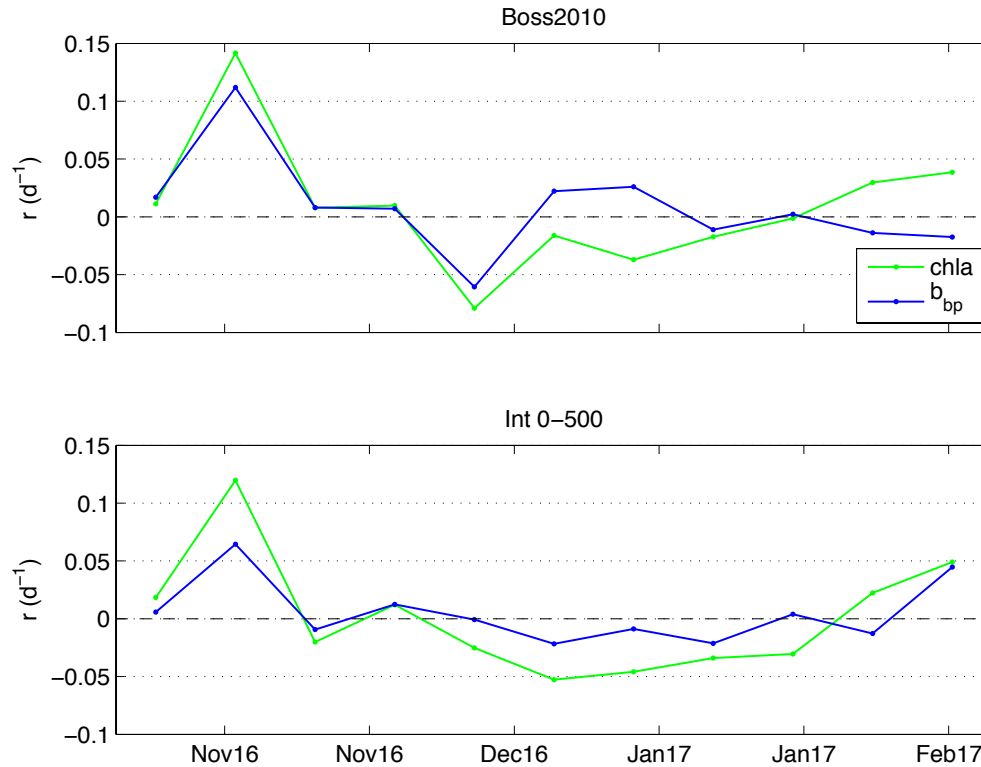
Backscattering



Salinity

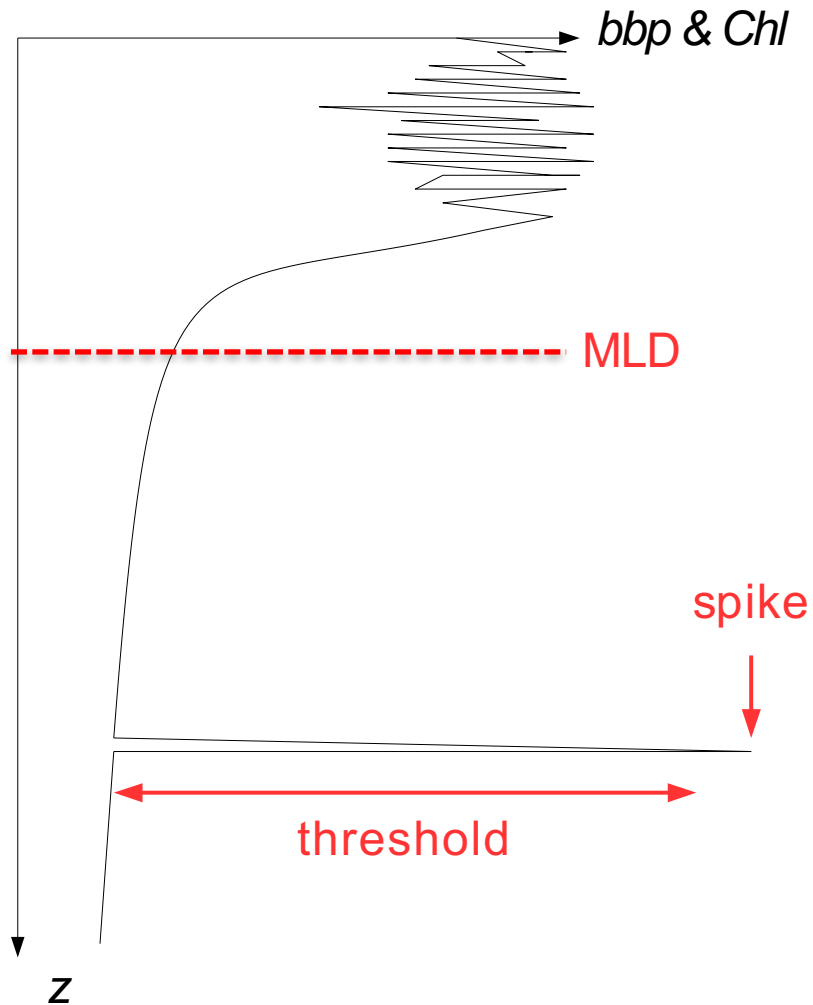


GROWTH DETERMINATION: TESTING TWO METHODS



$$r_{i=b,chl}(t + \Delta t/2) \equiv \begin{cases} \frac{1}{\bar{P}_i} \frac{d\bar{P}_i}{dt} \approx \frac{2}{\Delta t} \frac{(\bar{P}_i(t + \Delta t) - \bar{P}_i(t))}{(\bar{P}_i(t + \Delta t) + \bar{P}_i(t))} & \text{if } \frac{dMLD}{dt} < 0 \ \& \ MLD > z(0.415) \\ \frac{1}{\int P_i} \frac{d \int P_i}{dt} \approx \frac{2}{\Delta t} \frac{(\int P_i(t + \Delta t) - \int P_i(t))}{(\int P_i(t + \Delta t) + \int P_i(t))} & \text{all other cases} \end{cases} \quad (4)$$

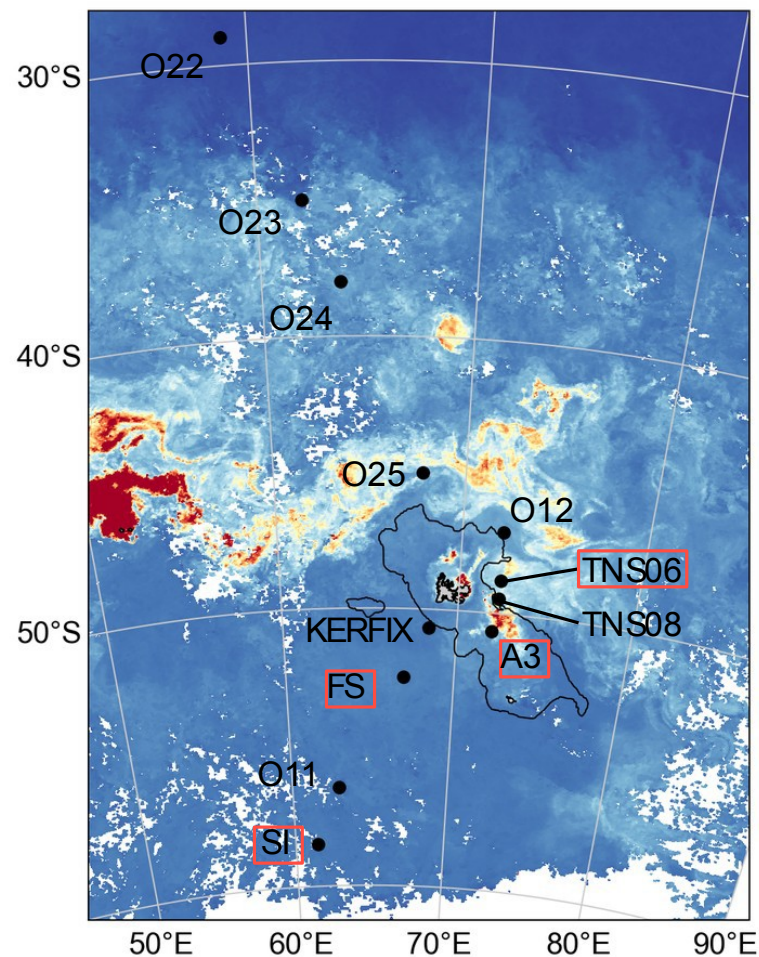
2. SPIKE DETECTION: INDICATOR OF AGGREGATES



Spike when
signal > baseline - threshold

(Briggs et al. 2011)

6. SOCLIM EXPEDITION: PREDICTING PLANKTON ASSEMBLAGES FROM BGC-ARGO



The SOCLIM cruise (October 2016)

- 14 stations (28 °S – 58.5 °S)
- CTD/O₂/chl/bbp/cp
- 8 BGC-Argo floats (2 proval)

Partitioning carbon

Plankton group	Contains	Method	Volume (μm ³)	Carbon content (pgC)
Bact	Heterotrophic bacteria	Cytometry	0.25 ^a	0.015 ^a
	Prochlorococcus		0.68 ^b	0.029 ^b
Pico	Synechococcus	Cytometry	0.86 ^b	0.080 ^b
	Picoeukaryotes		2.76 ^b	0.73 ^b
Nano	Nanoplankton	Cytometry	284 ^c	15 ^c
Micro	Diatom (55 groups)		Shape-specific ^d	C = 0.117 V ^{0.881 e}
	Dinoflagellate (14 groups)	Optical	Shape-specific ^d	C = 0.670 V ^{0.819 e}
	Ciliate (4 groups)	microscopy	Shape-specific ^d	C = 0.216 V ^{0.939 e}
	Silicoflagellate (1 group)		3288	C = 0.261 V ^{0.860 e}

^a Bratbak (1985)

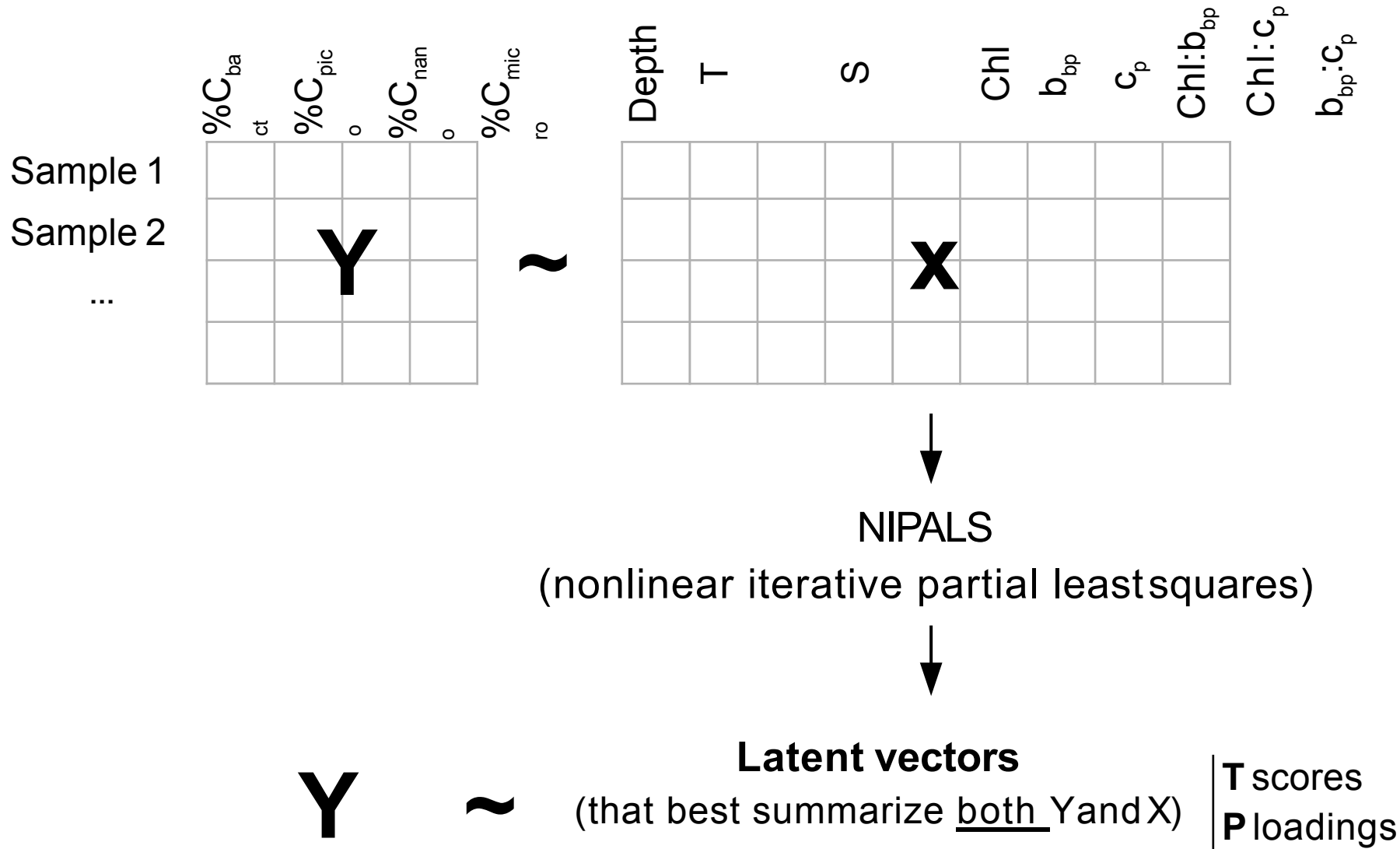
^b Grob et al. (2007)

^c Verity et al. (1992)

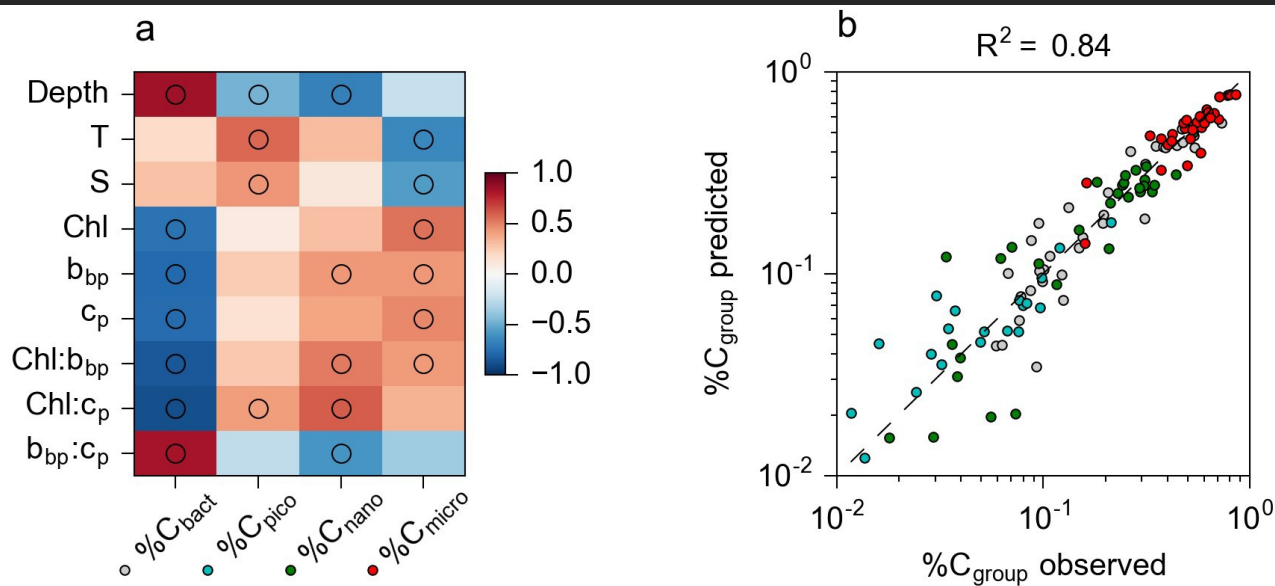
^d Hillebrand et al. (1999)

^e Menden-Deuer and Lessard (2000)

6. SOCLIM EXPEDITION: PREDICTING PLANKTON ASSEMBLAGES FROM BGC-ARGO



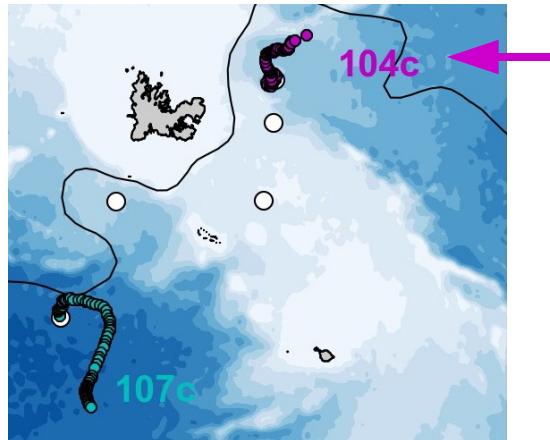
6. SOCLIM EXPEDITION: PREDICTING PLANKTON ASSEMBLAGES FROM BGC-ARGO



NIPALS (nonlinear iterative partial leastsquares)

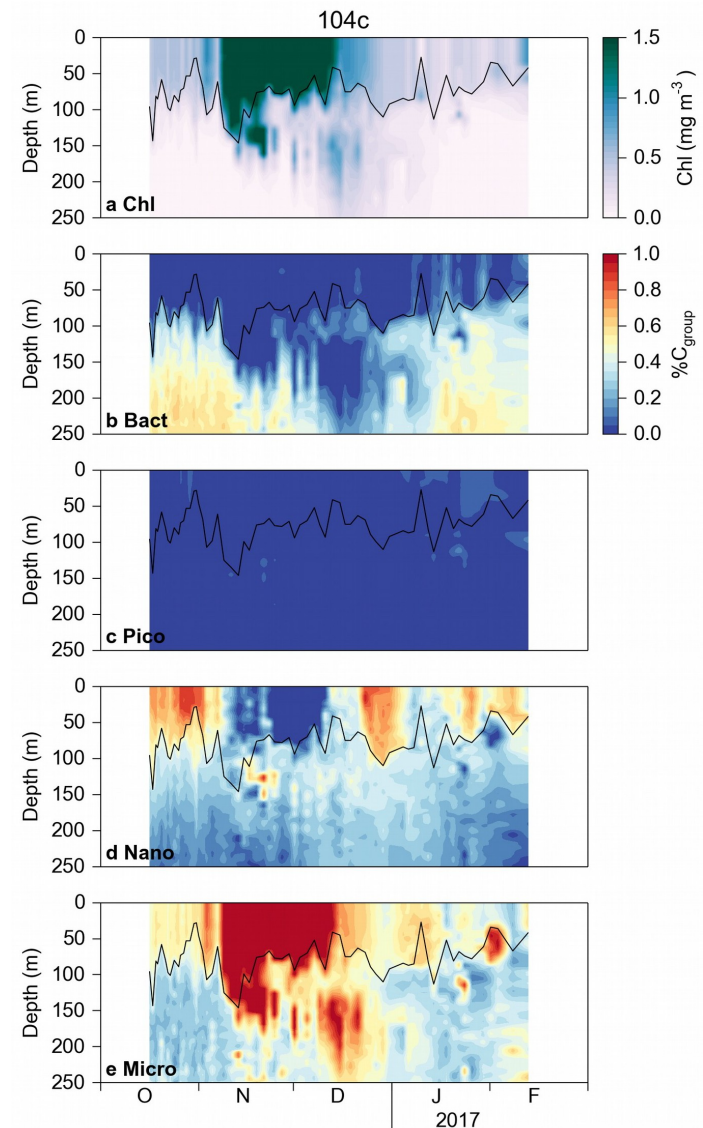
Plankton group	R^2	RMSE (%)
Bacteria	0.71 ± 0.11	14 ± 4
Pico	0.61 ± 0.15	26 ± 2
Nano	0.65 ± 0.13	19 ± 6
Micro	0.59 ± 0.14	17 ± 5
Pooled	0.84 ± 0.06	6 ± 1

6. SOCLIM EXPEDITION: PREDICTING PLANKTON ASSEMBLAGES FROM BGC-ARGO



Float 104c

- Downstream KP plateau
- Productive AAZ
- High Chl $> 1.5 \text{ mg m}^{-3}$
- Major micro bloom



OUTLINE: CNES PROPOSAL

Capturing phytoplankton dynamics in the Southern Ocean: *From satellite to BGC floats*

1. Defining a dynamical biogeography of the Southern Ocean based on regional-derived environmental and biological patterns using satellite-derived observations

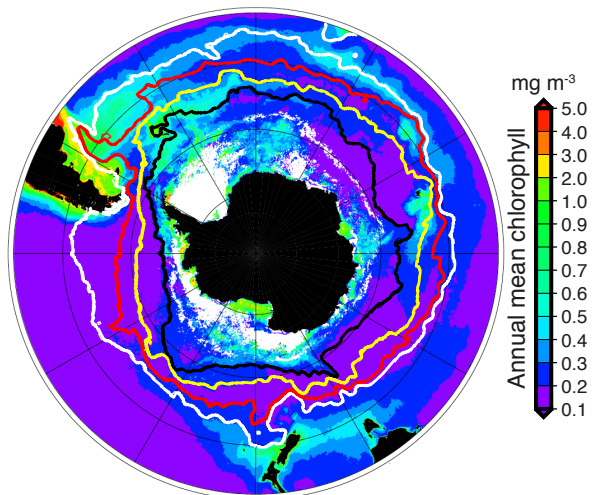
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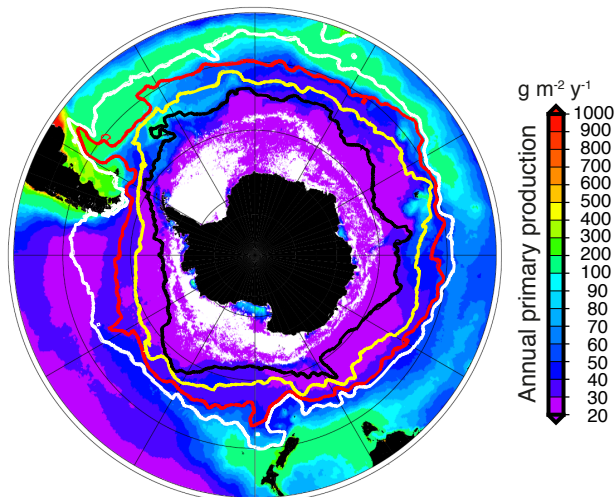
1. Defining a dynamical biogeography of the Southern Ocean based on regional-derived environmental and biological patterns using satellite-derived observations
2. Characterizing regional specificities in the vertical distribution/phenology/productivity of phytoplankton communities using BGC-Argo data

PHYTOPLANKTON DYNAMICS IN THE SOUTHERN OCEAN

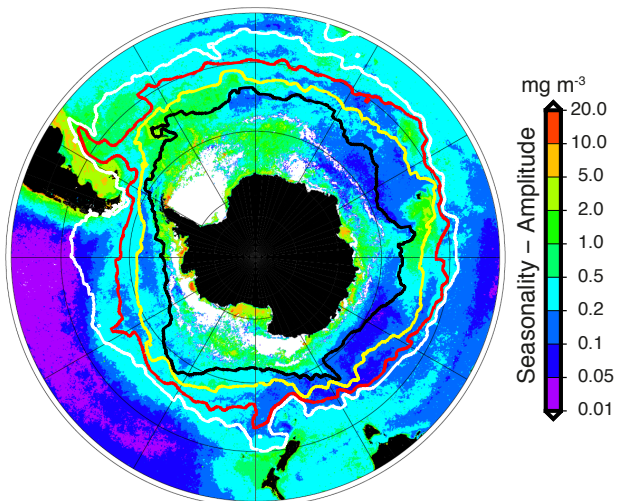
Mean annual chlorophyll (mg m^{-3})



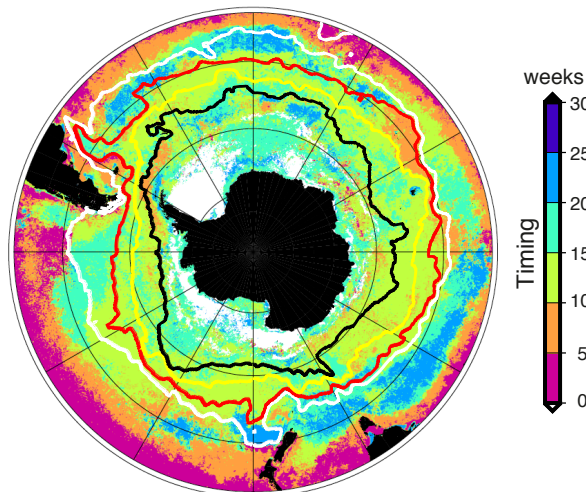
Annual primary production ($\text{g C m}^{-2} \text{y}^{-1}$)







Seasonality - Amplitude (mg m^{-3})



Maximum timing bloom (wks)

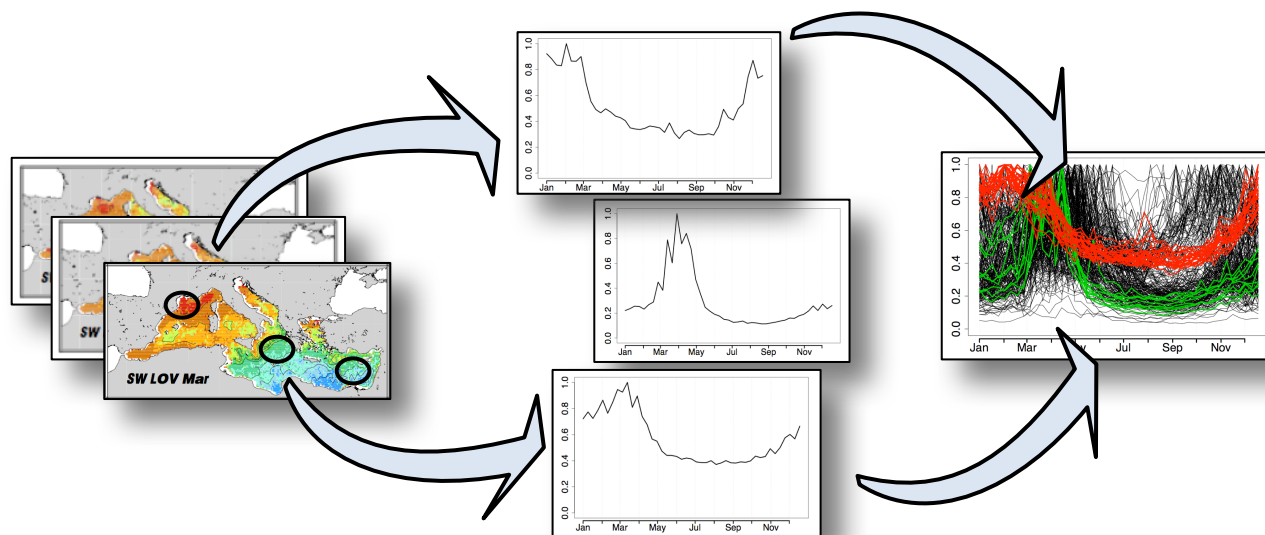


-  STF
-  SAF
-  PF
-  SACCF

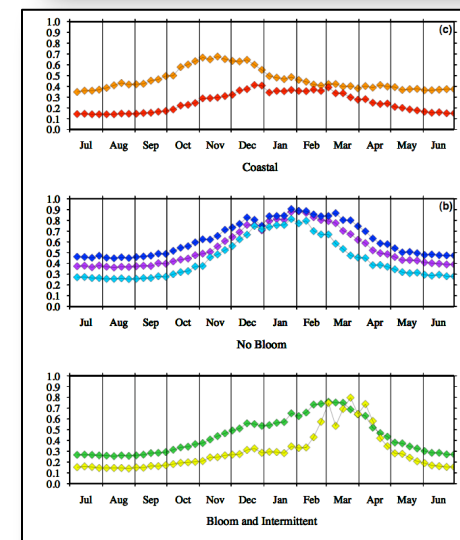
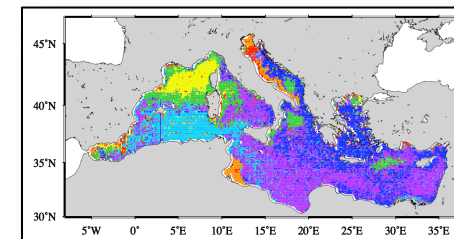
PHYTOPLANKTON PHENOLOGY IN THE SOUTHERN OCEAN

Biogeographic-derived analysis: Cluster K-means analysis

Grouping spatially satellite-derived chlorophyll time series to determine biogeographic patterns

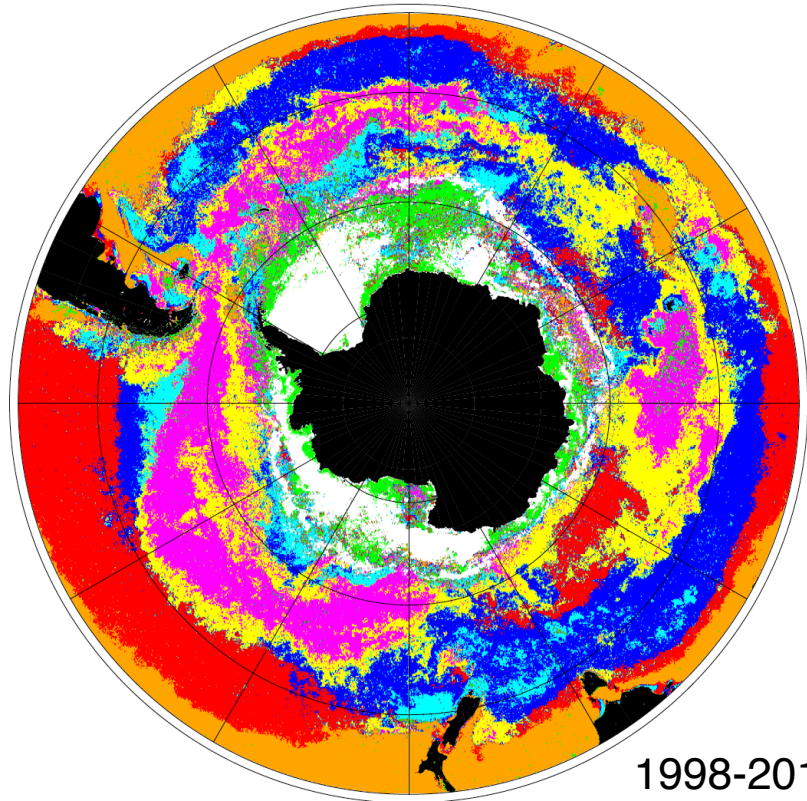


Applied in the Mediterranean Sea, the North Atlantic and at the global scale.

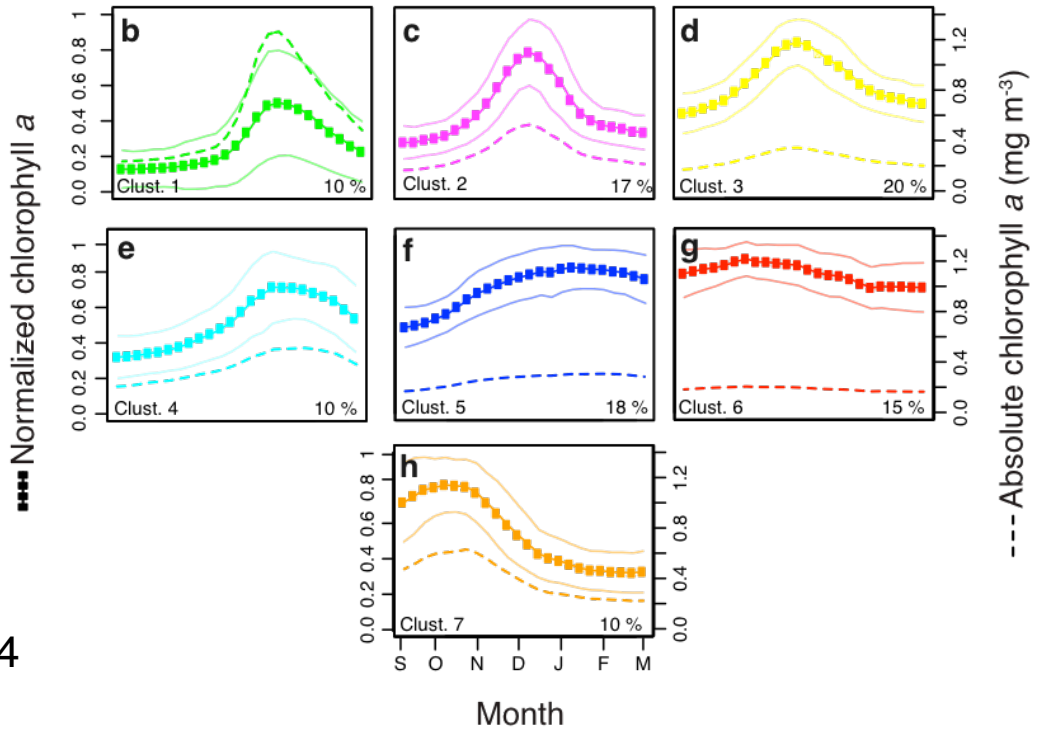


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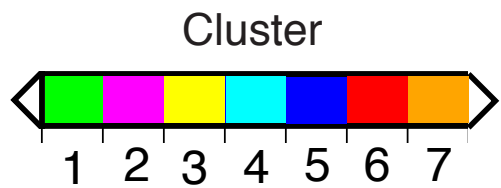
Cluster K-means analysis: 7 distinct bio-regions based on similar large-scale patterns in annual chl *a* cycle



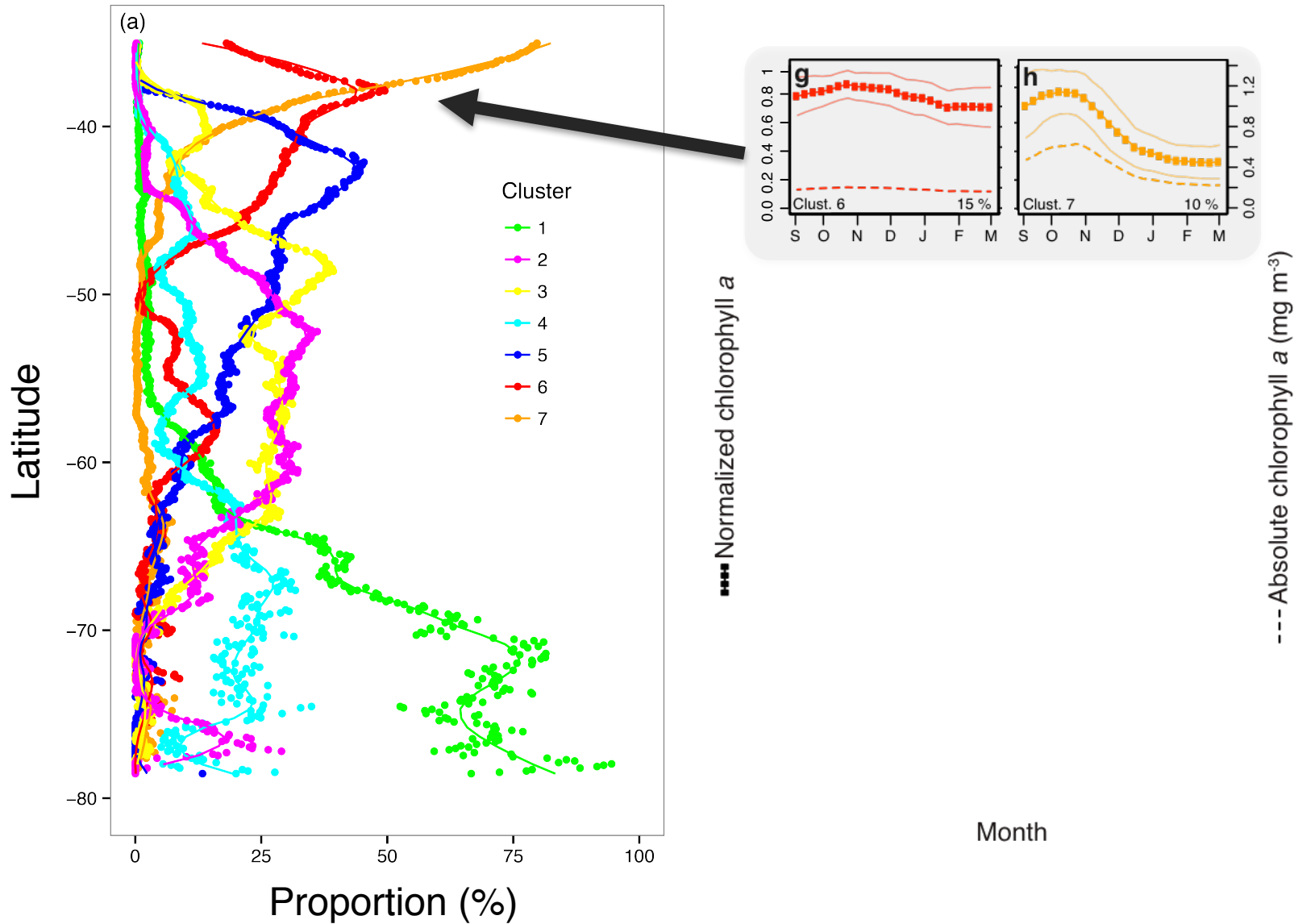
1998-2014



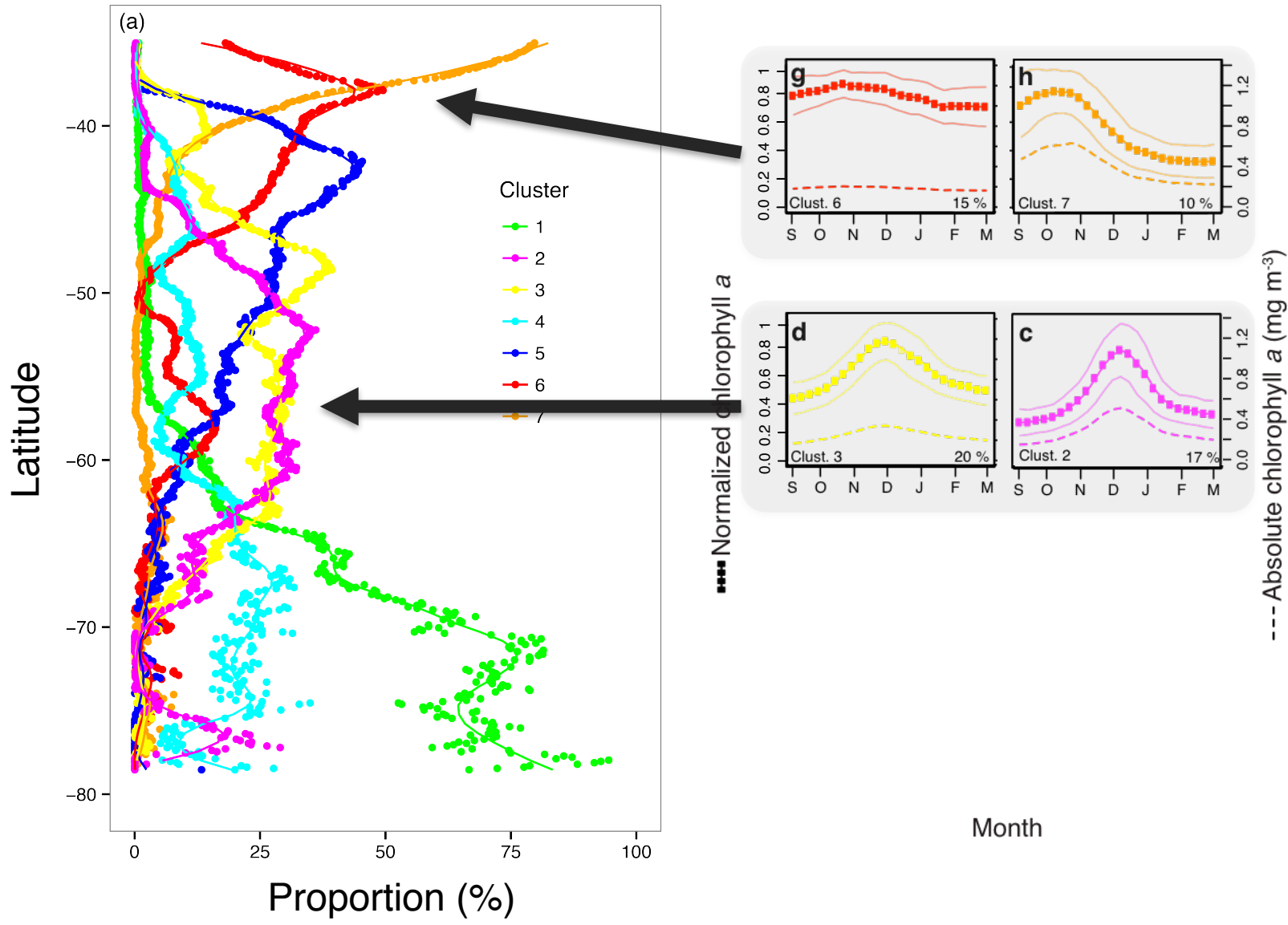
Satellite-derived product:
GLOBCOLOUR 8-day



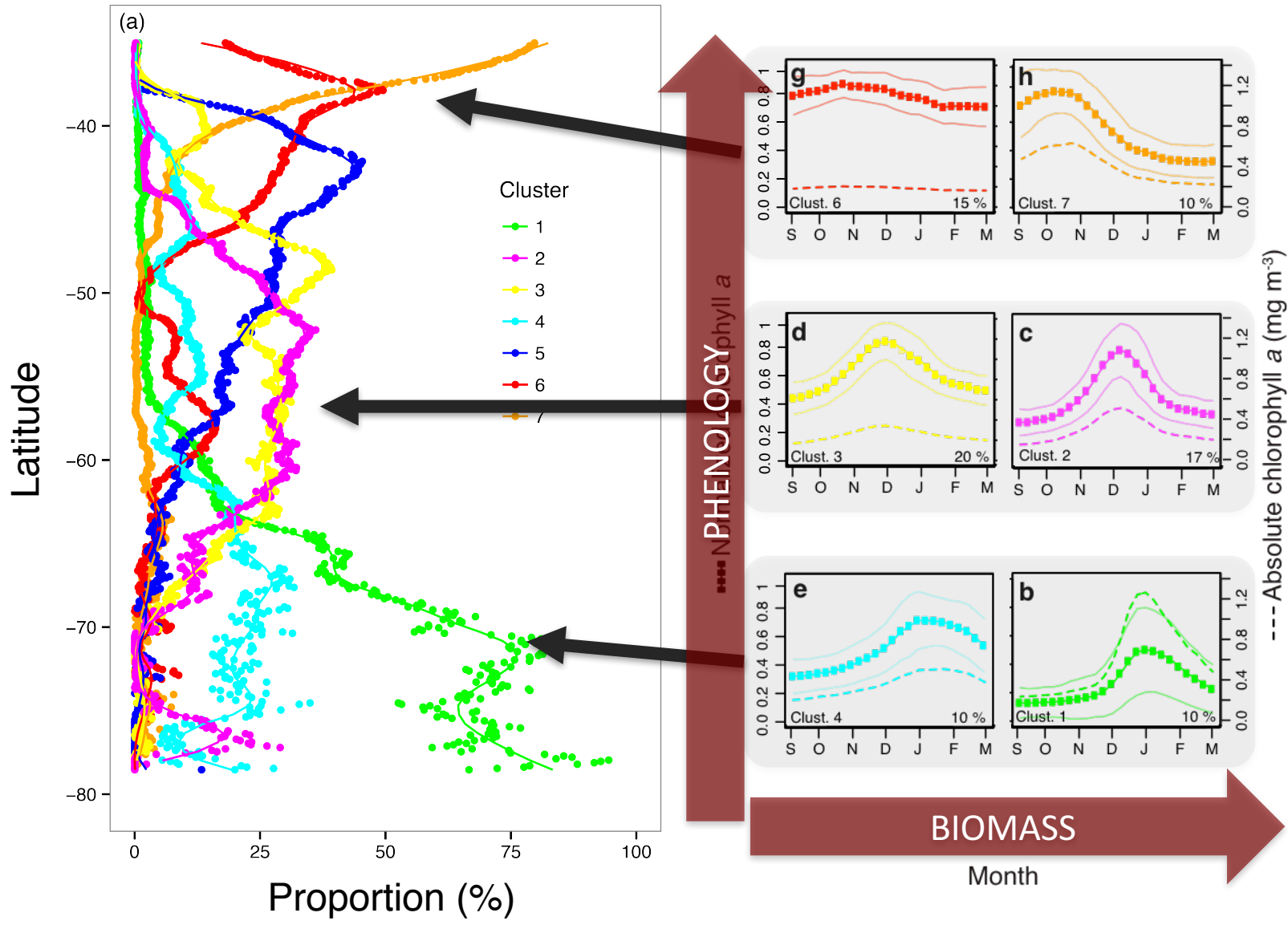
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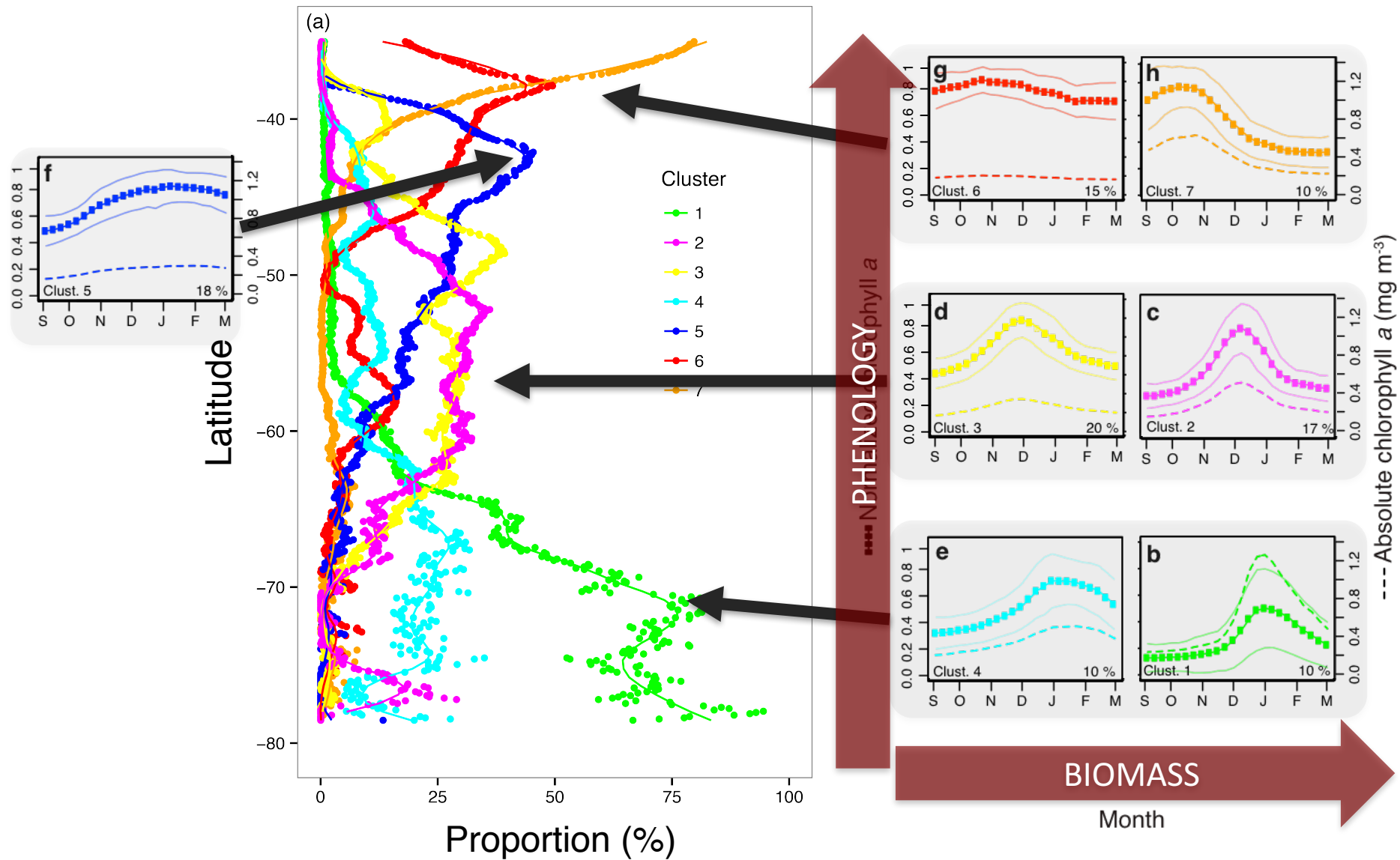
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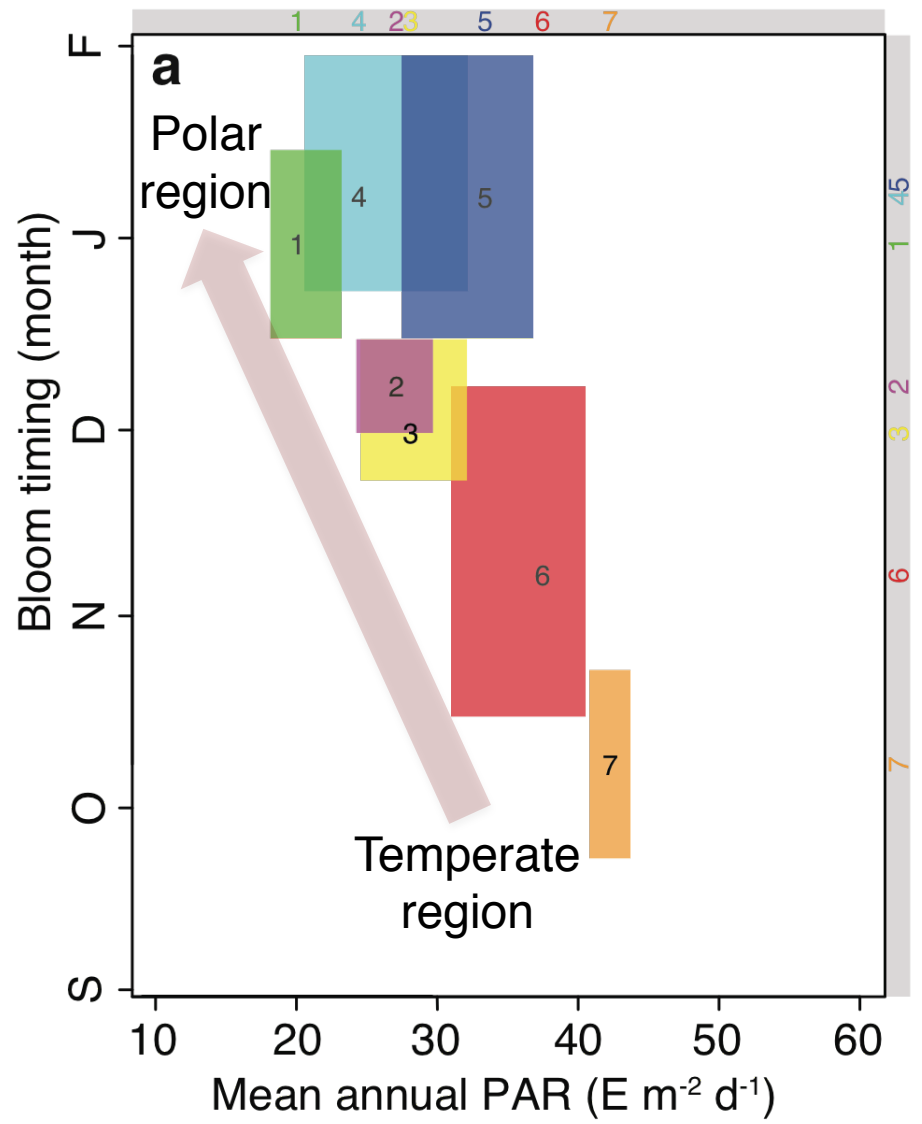
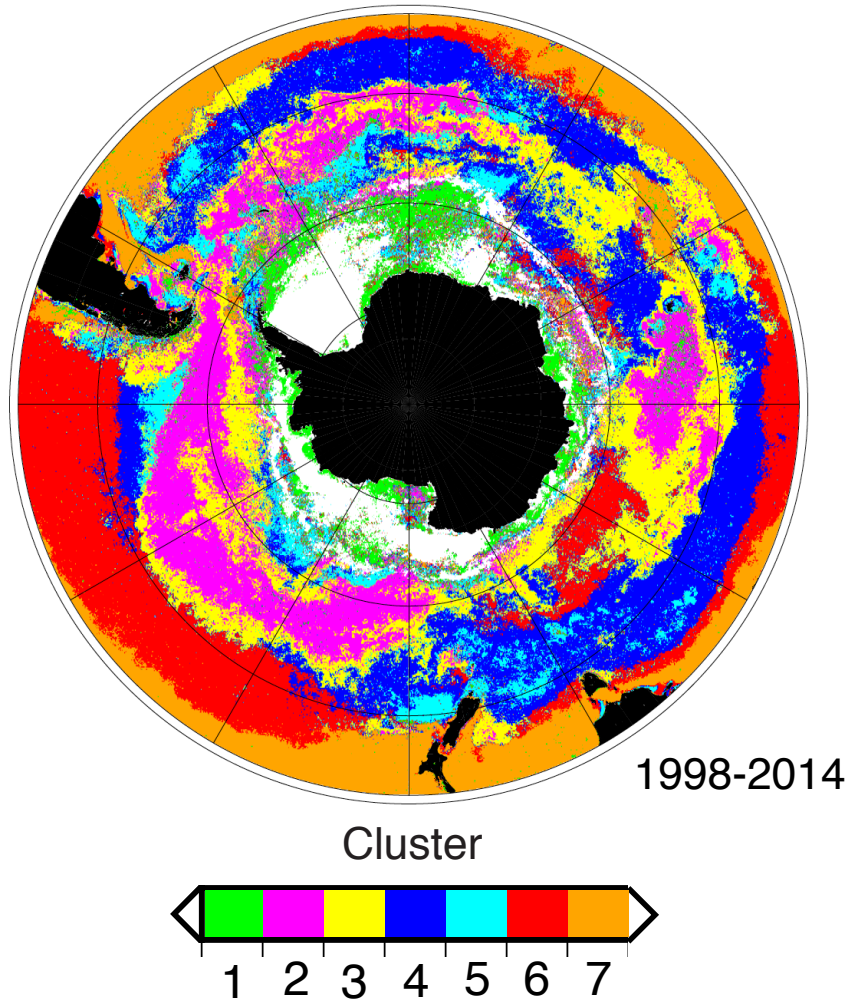


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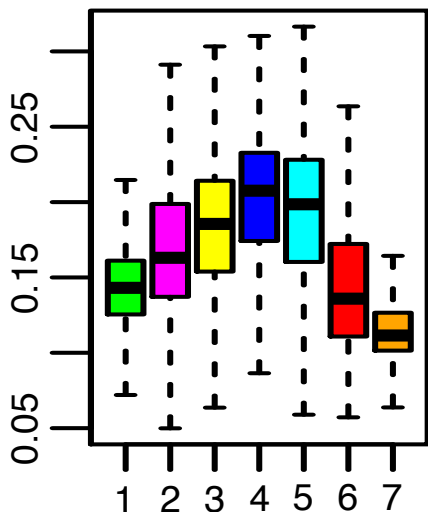
Biogeographic-derived analysis
(D'Ortenzio & Ribera d'Alcalà 2009)



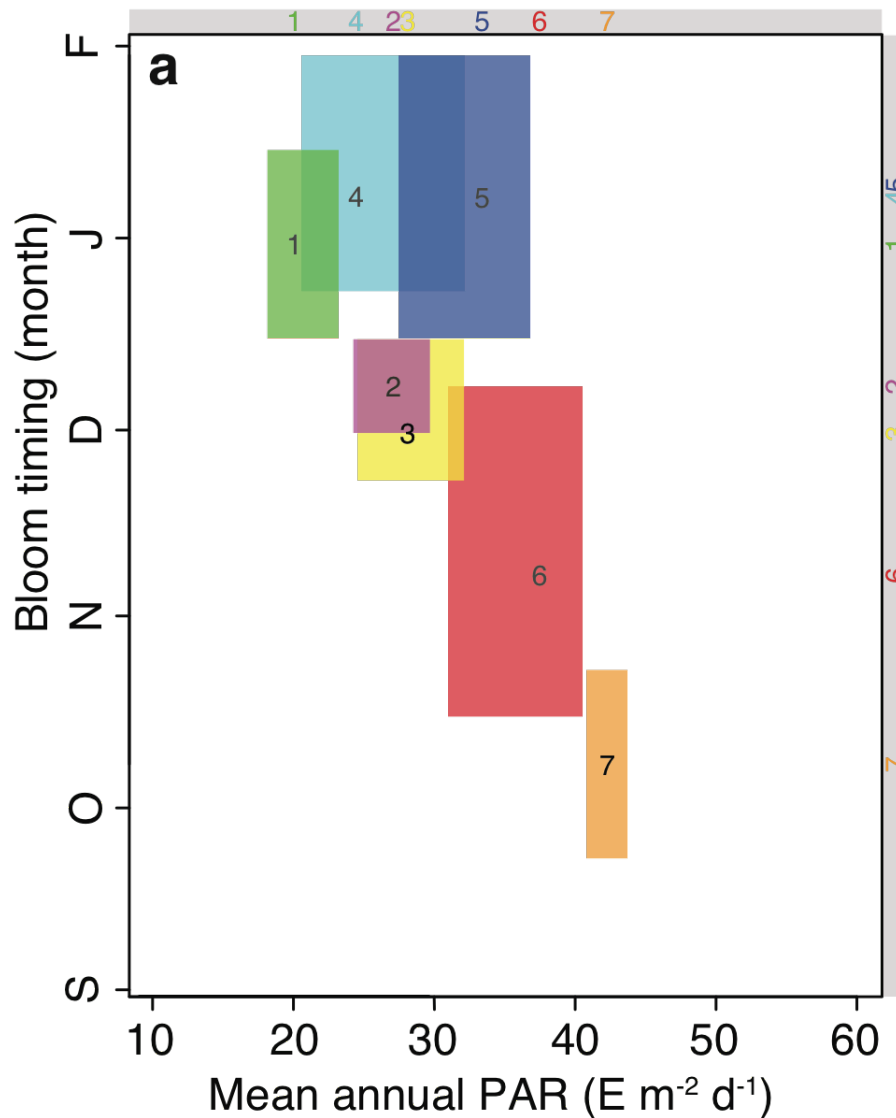
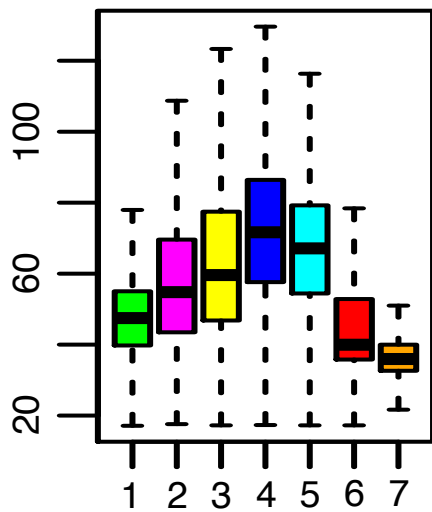
PHYTOPLANKTON PHENOLOGY IN THE SOUTHERN OCEAN

Bio-region 5 in the ACC current
(high wind stress and deep mixed layer)

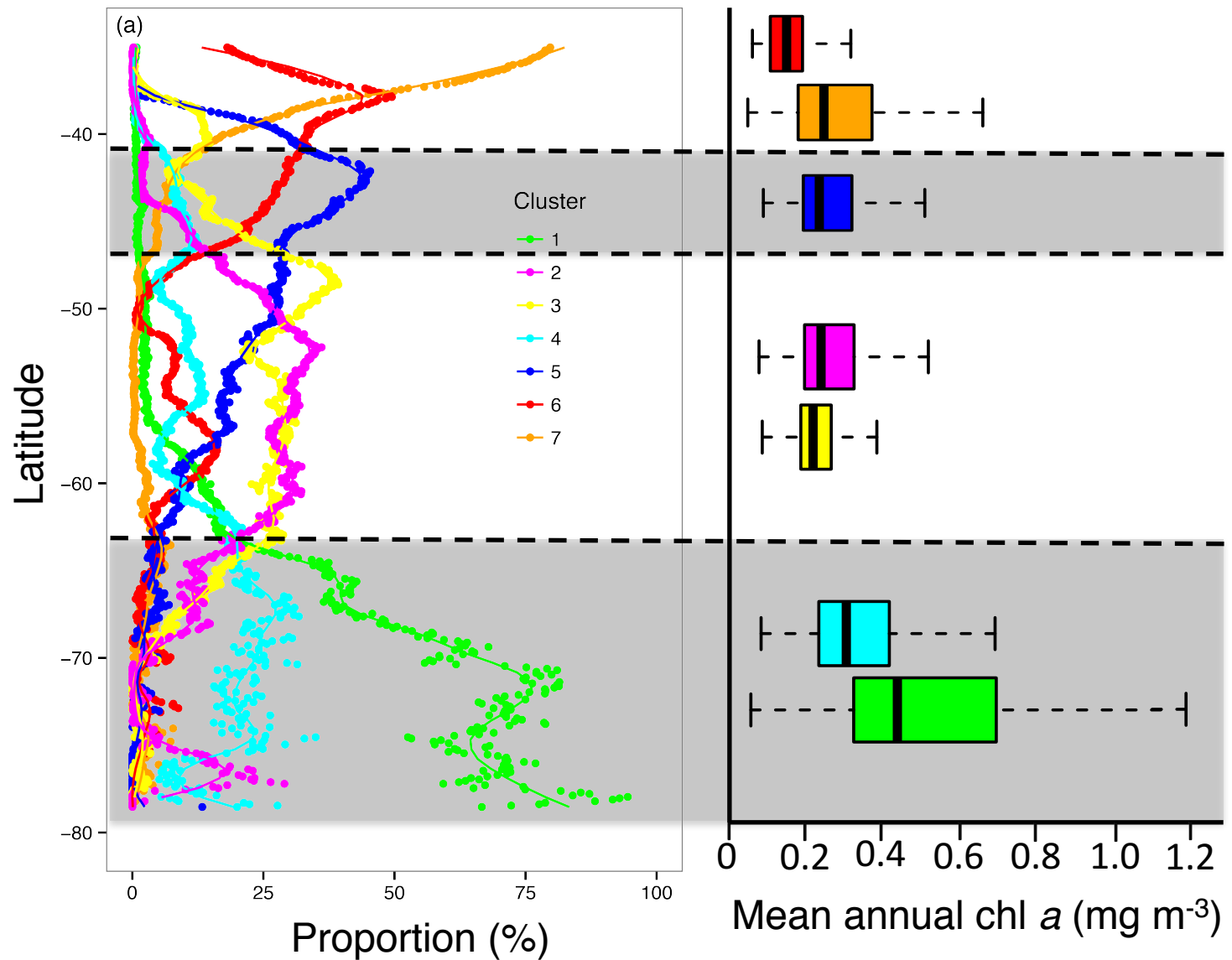
Wind stress (PA)



Mixed layer depth (m)



PHYTOPLANKTON BIOMASS IN THE SOUTHERN OCEAN



IMPACT OF IRON SUPPLY MECHANISMS ON PHYTOPLANKTON BIOMASS

We disentangle the impact of **four important iron supply mechanisms** on phytoplankton biomass at the scale of the Southern Ocean:

These surface-layer iron-sources are **shallow plateaus** (<500 m) which:
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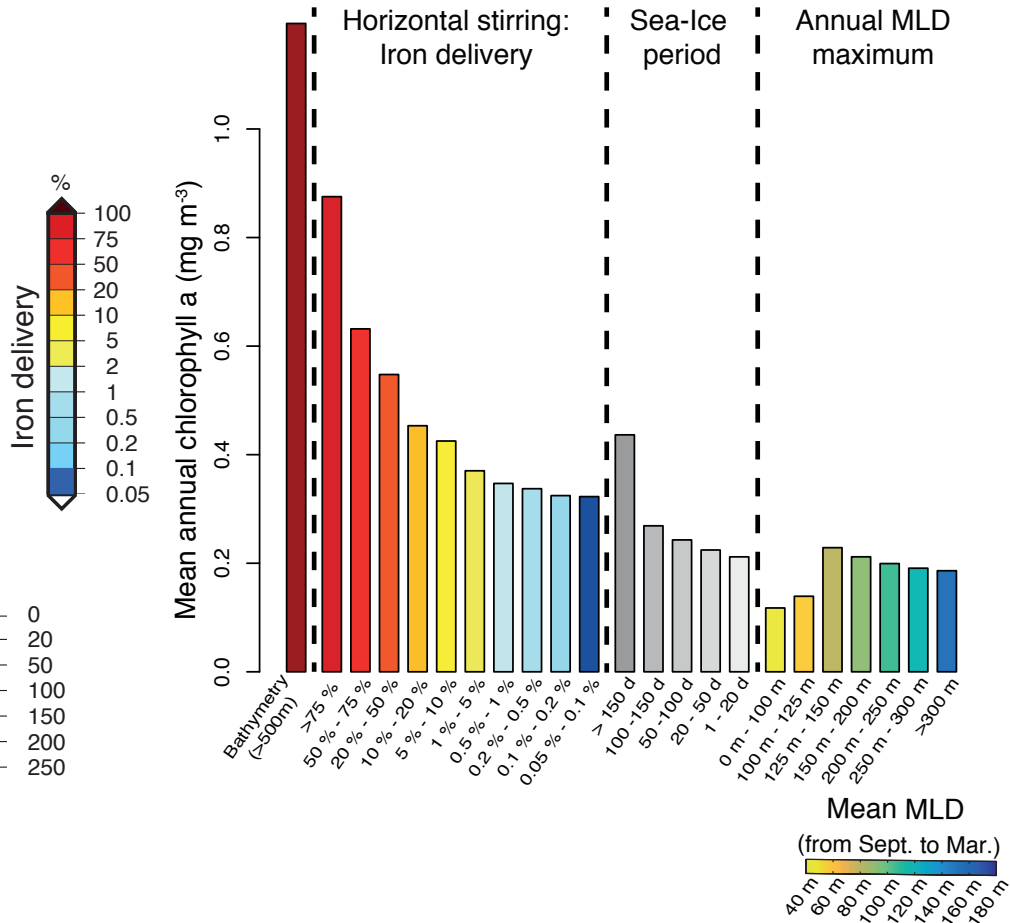
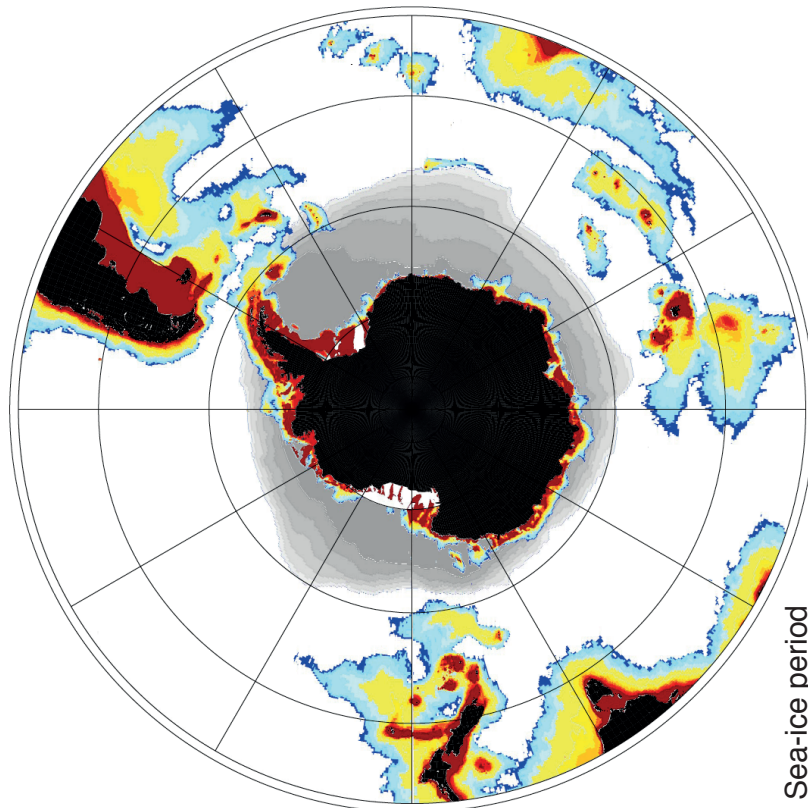
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- (4) **vertical mixing through deep convection**, which can entrain iron from deep water (climatology).

IMPACT OF IRON SUPPLY MECHANISMS ON PHYTOPLANKTON BIOMASS

Combining satellite, Argo floats and lagrangian modeling

(D'Ovidio et al. 2015, Pellichero et al. 2016)



FINDINGS OF THIS STUDY

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- Clear decoupled environmental control of phytoplankton biomass and phenology in the Southern Ocean.
- A latitudinal gradient in the bloom occurrence was underpinned following the light regime, with some exception in specific light-mixing regime conditions (i.e., well-mixed waters).
- Crucial role of iron replenishment via different mechanisms is highlighted (nearby the coast and the sea-ice cover, transport via geostrophic advection, local vertical replenishment) on phytoplankton biomass.

ANNUAL PHYTOPLANKTON CYCLES IN POLAR FRONT ZONE (PFZ)

