EURO-ARGO, July 4-5, 2017

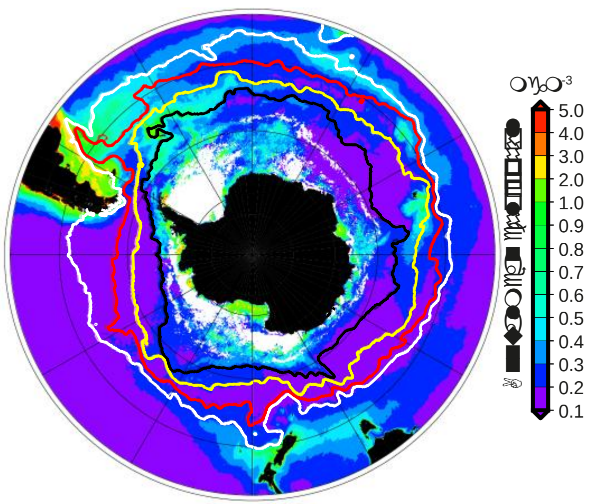
Latitudinal contrasted annual phytoplankton cycles in phenology and biomass in the Southern Ocean: *Mechanisms behind bloom initiation and magnitude*

Mathieu Ardyna
Laboratoire d'Océanographie de Villefranche (LOV)

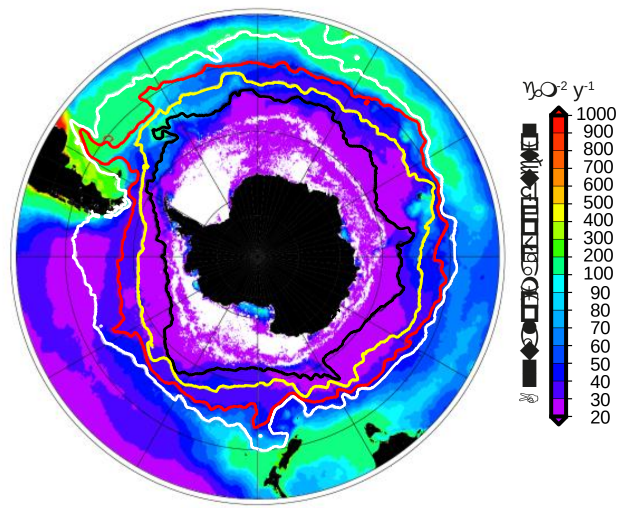
MAIN COLLABORATORS: L. Lacour, M. Rembauville, F. D'Ovidio, J.B. Sallée, L. Oziel, E. Boss, K. S. Johnson, H. Claustre

Phytoplankton dynamics and biogeography in the Southern Ocean

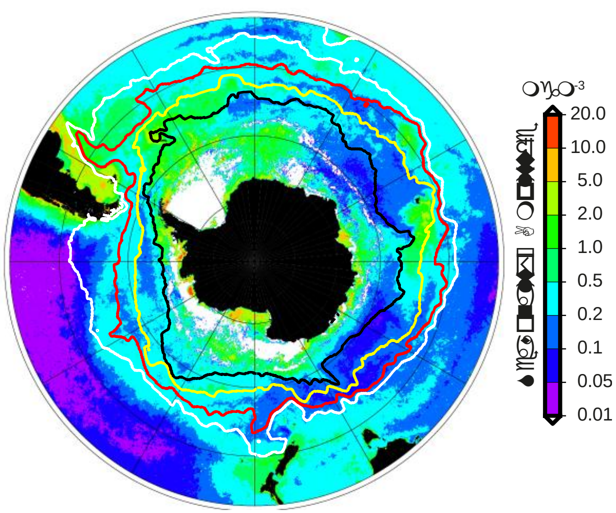
Mean annual chlorophyll (mg m^{-3})



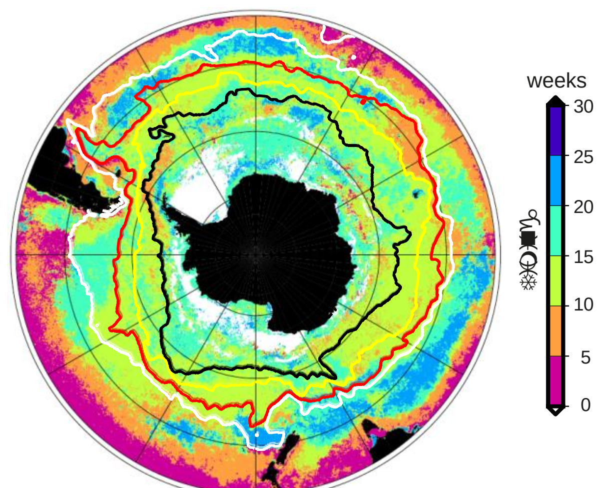
Annual primary production (g C m^{-2} y^{-1})

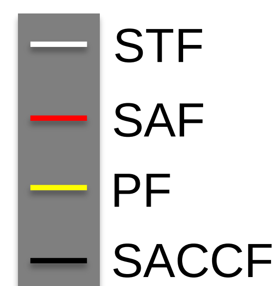


Seasonality - Amplitude (mg m^{-3})



Maximum timing bloom (wks)

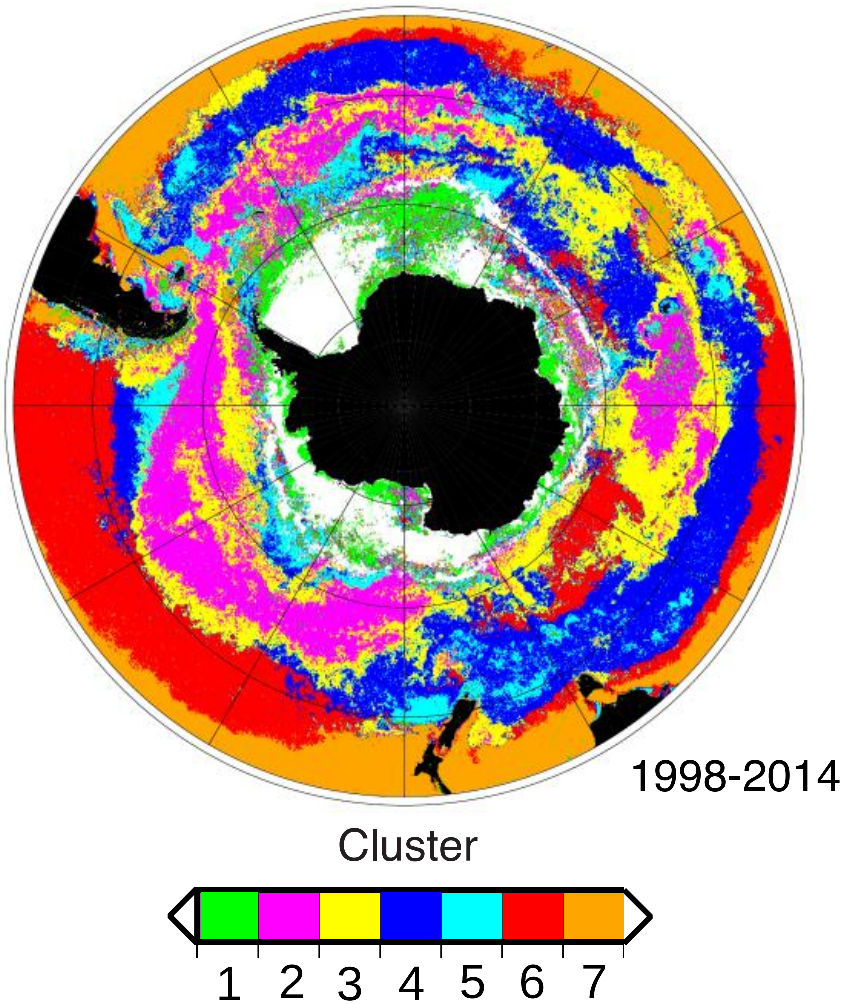


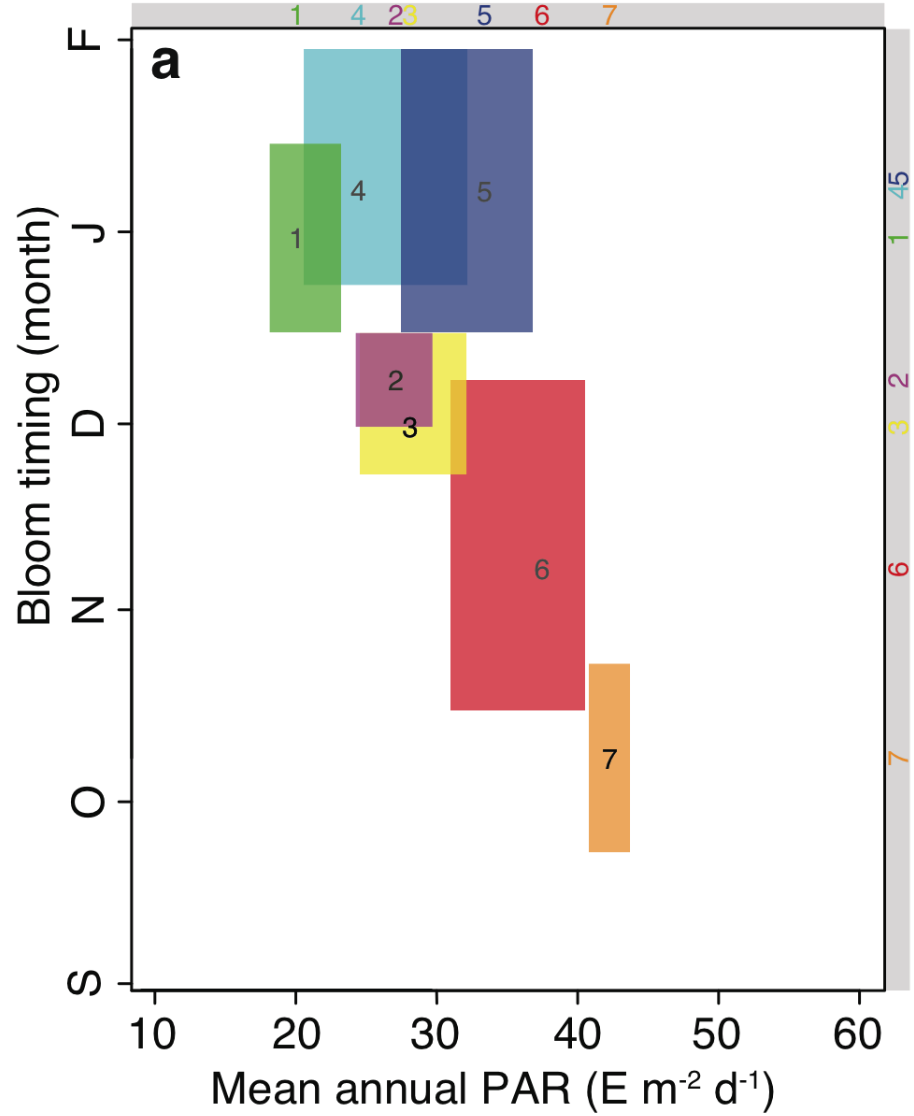


Ardyna et al., GRL 2017

DRIVERS OF THE PHYTOPLANKTON PHENOLOGY IN THE SOUTHERN OCEAN

Static biogeographic-derived analysis (K-means analyis)





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Drivers of the phytoplankton phenology in the Southern Ocean

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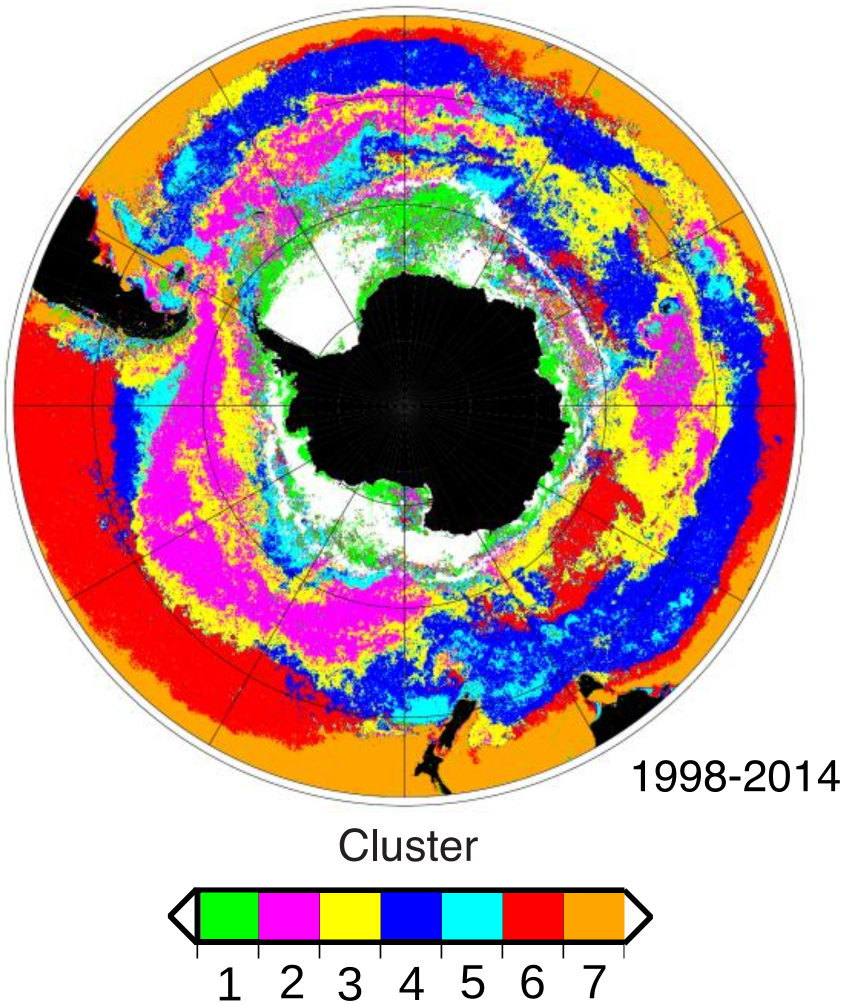
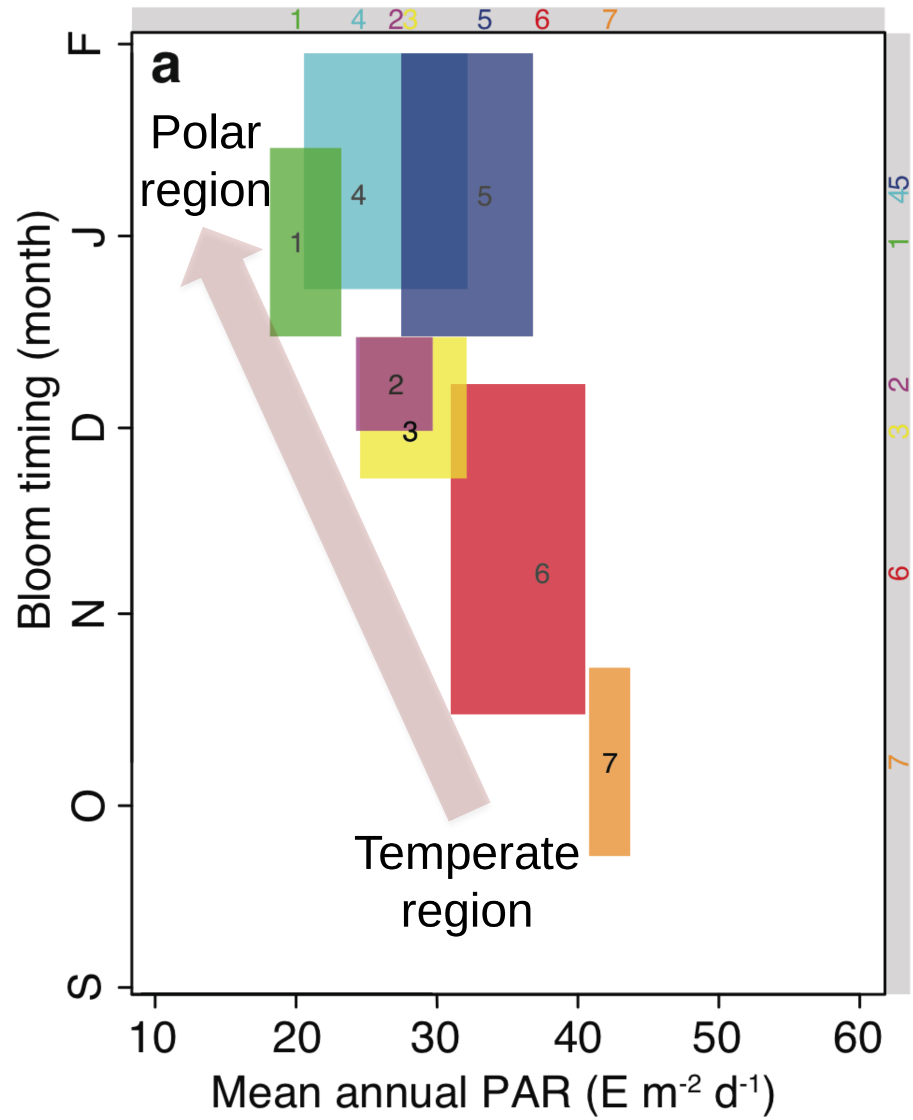
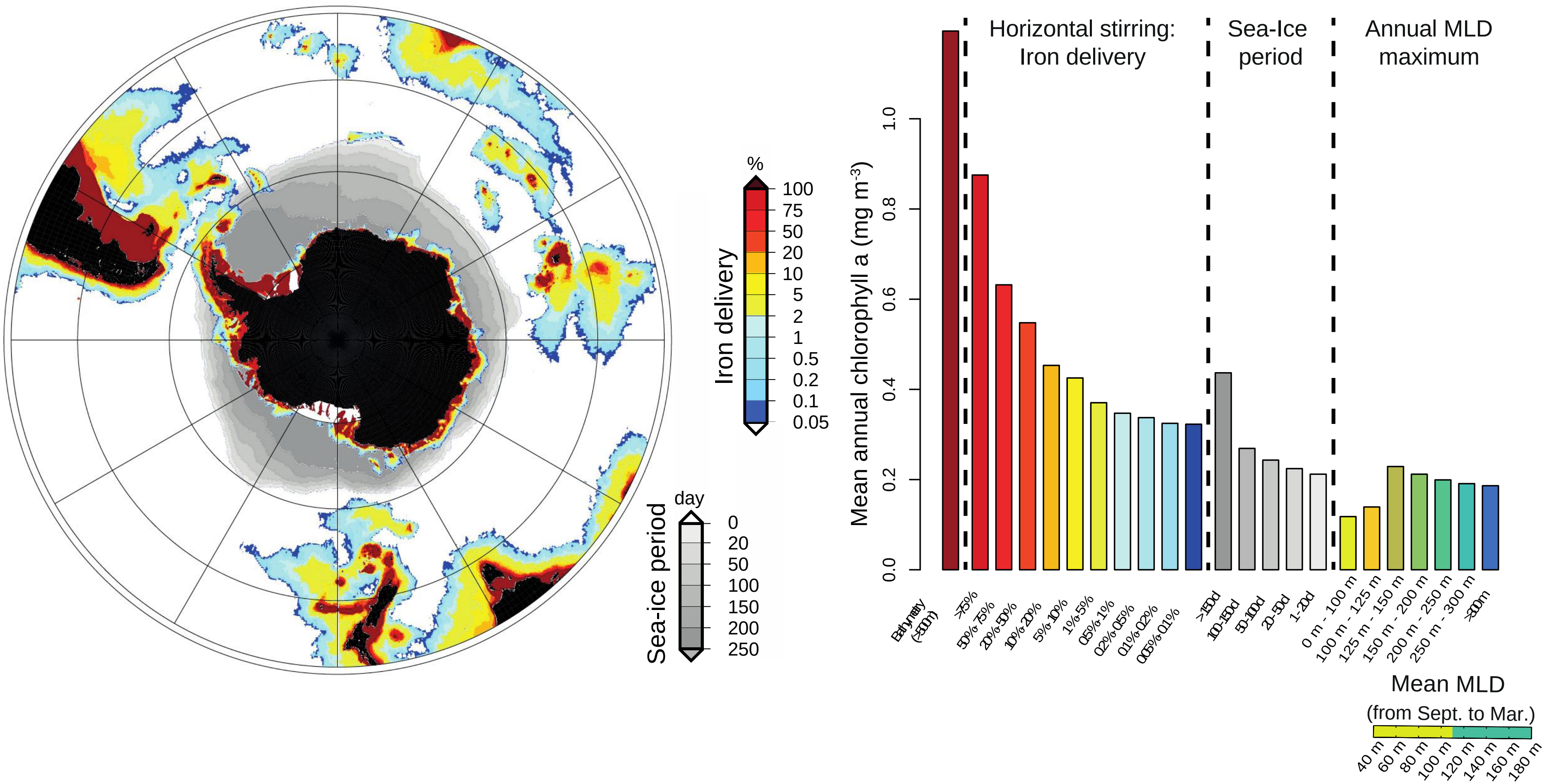




Ardyna et al., GRL 2017

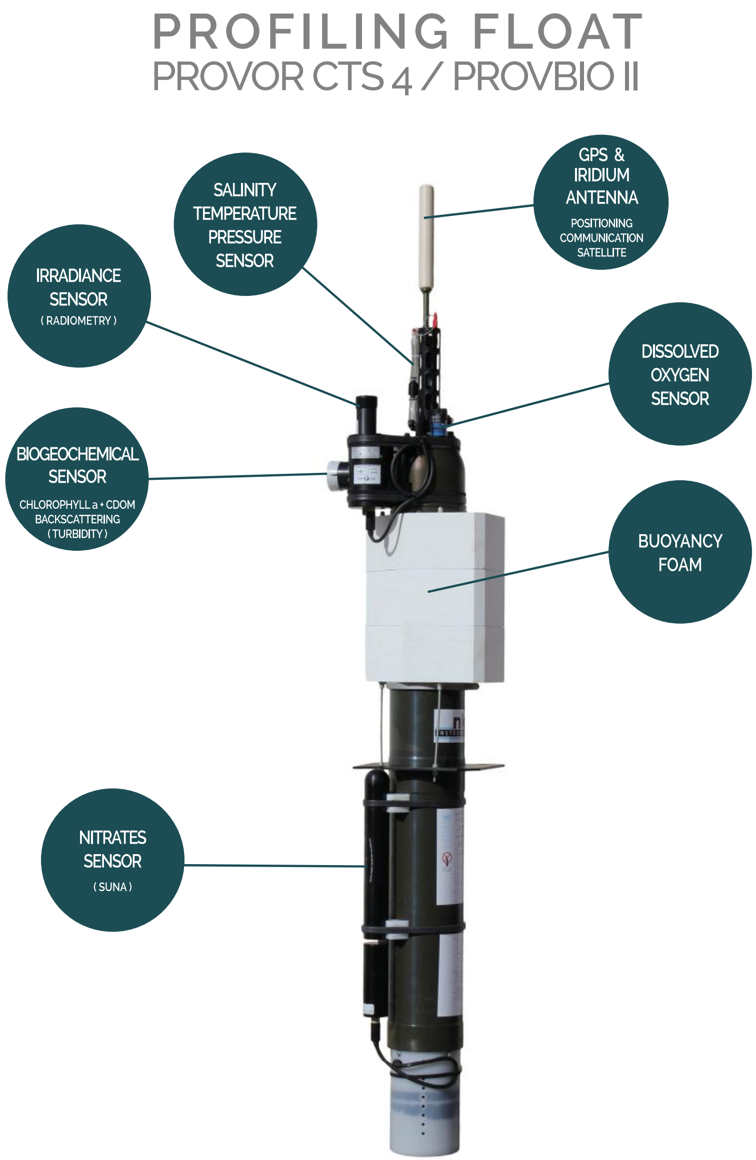
DRIVERS OF THE PHYTOPLANKTON BIOMASS IN THE SOUTHERN OCEAN

<u>Iron availability:</u> Combining satellite, Argo network and lagrangian modeling



Ardyna et al., GRL 2017

Satellite limitation & complementarity of the BGC-Argo network



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

Latitudinal contrasted annual phytoplankton cycles in phenology and biomass in the Southern Ocean:
Mechanisms behind bloom initiation and magnitude

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

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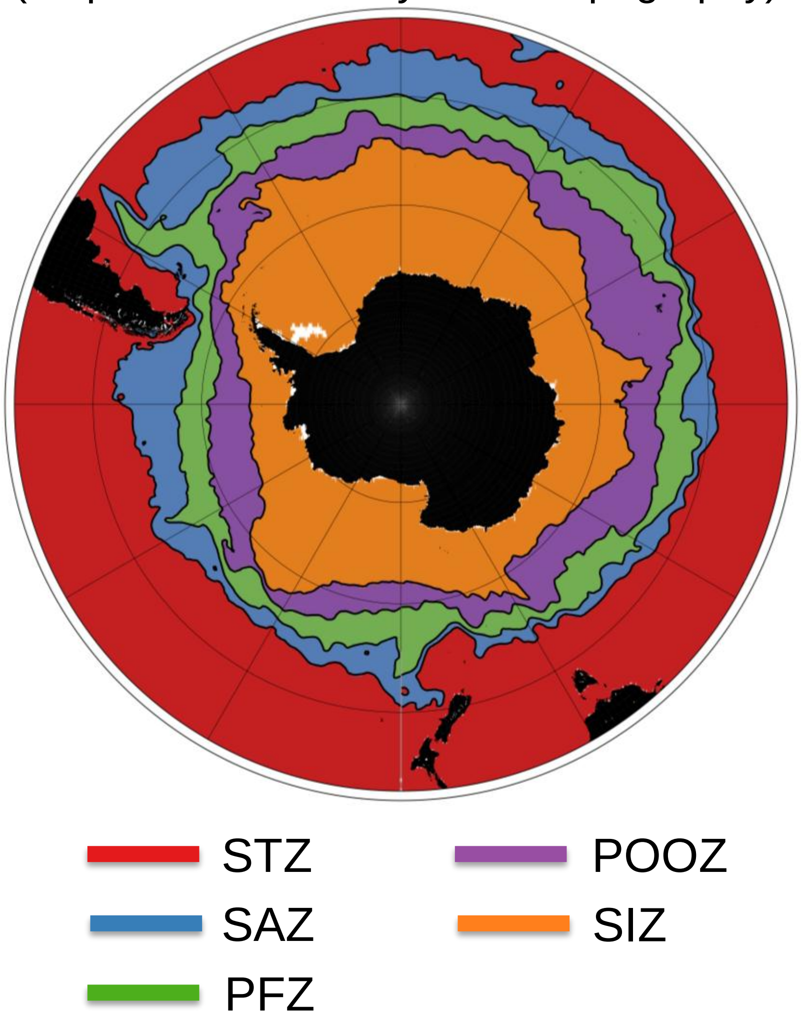
- Defining annual phytoplankton cycles across the different domains of the Southern Ocean

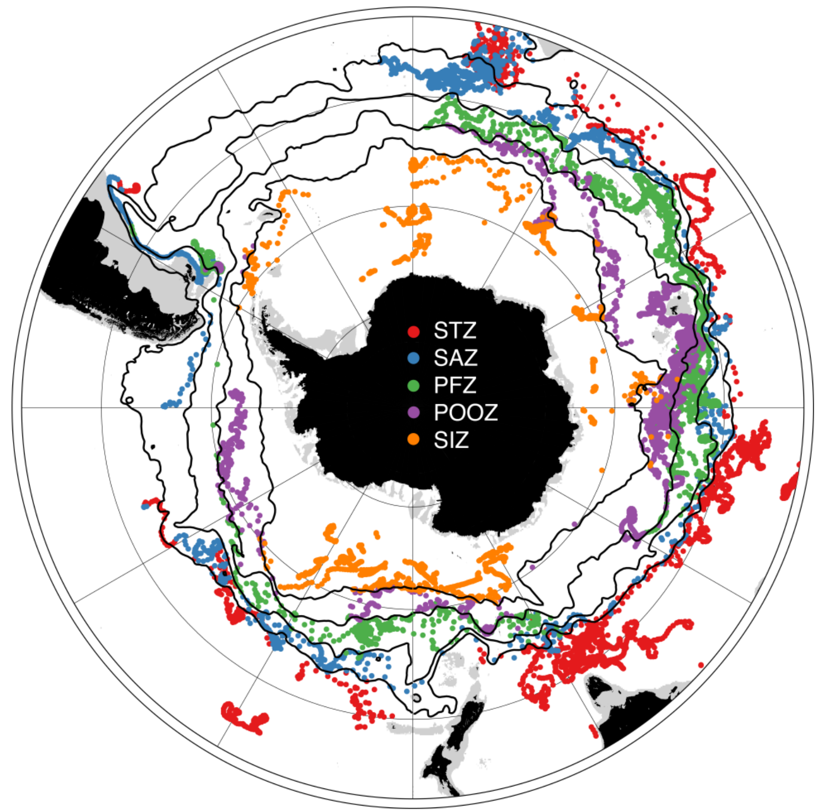
- Assessing the environmental forcing on:
    - Bloom initiation and magnitude
    - Phytoplankton assemblage/physiology

BGC-ARGO Network in the Southern Ocean

Biogeographic-derived analysis

(Maps of Absolute Dynamic Topography)

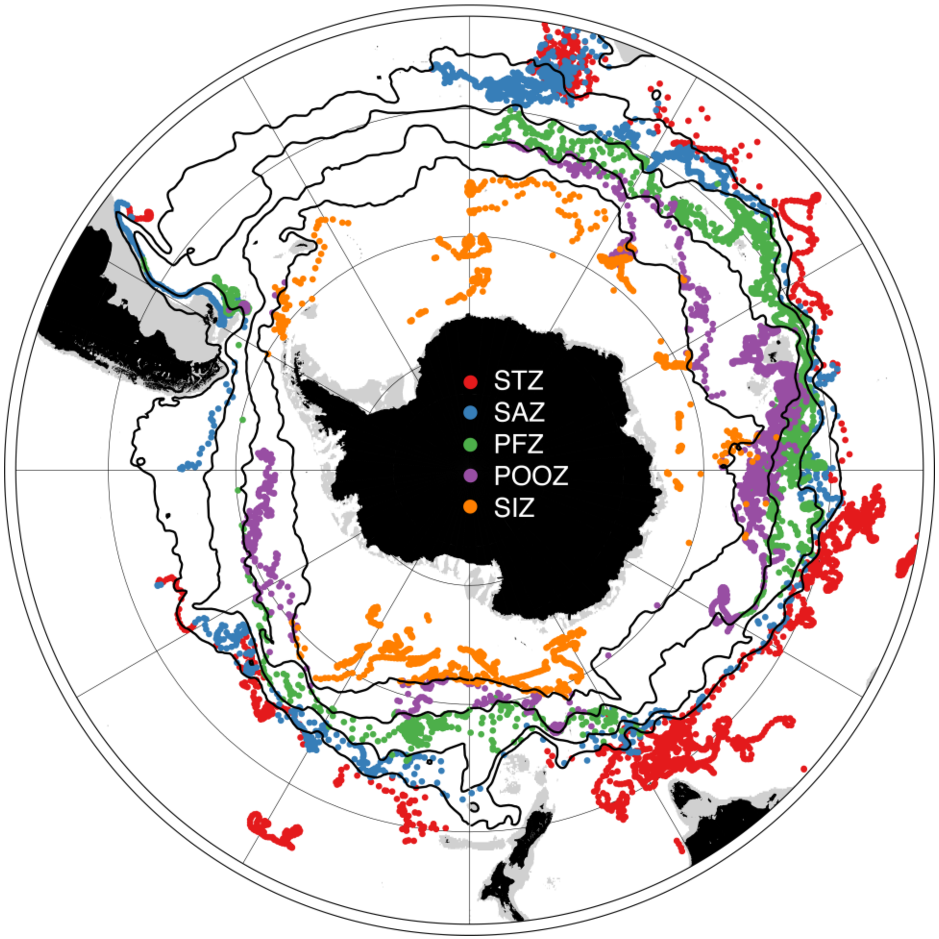




Total ≈**13000 BGC-ARGO profiles**

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	52	3485	26
CORIOLIS	27	4408	33
CSIRO	16	4489	37
INCOIS	7	403	43
TOTAL	102	12785	

Total ≈**13000 BGC-ARGO profiles**

Period: 2010-09-13 until now

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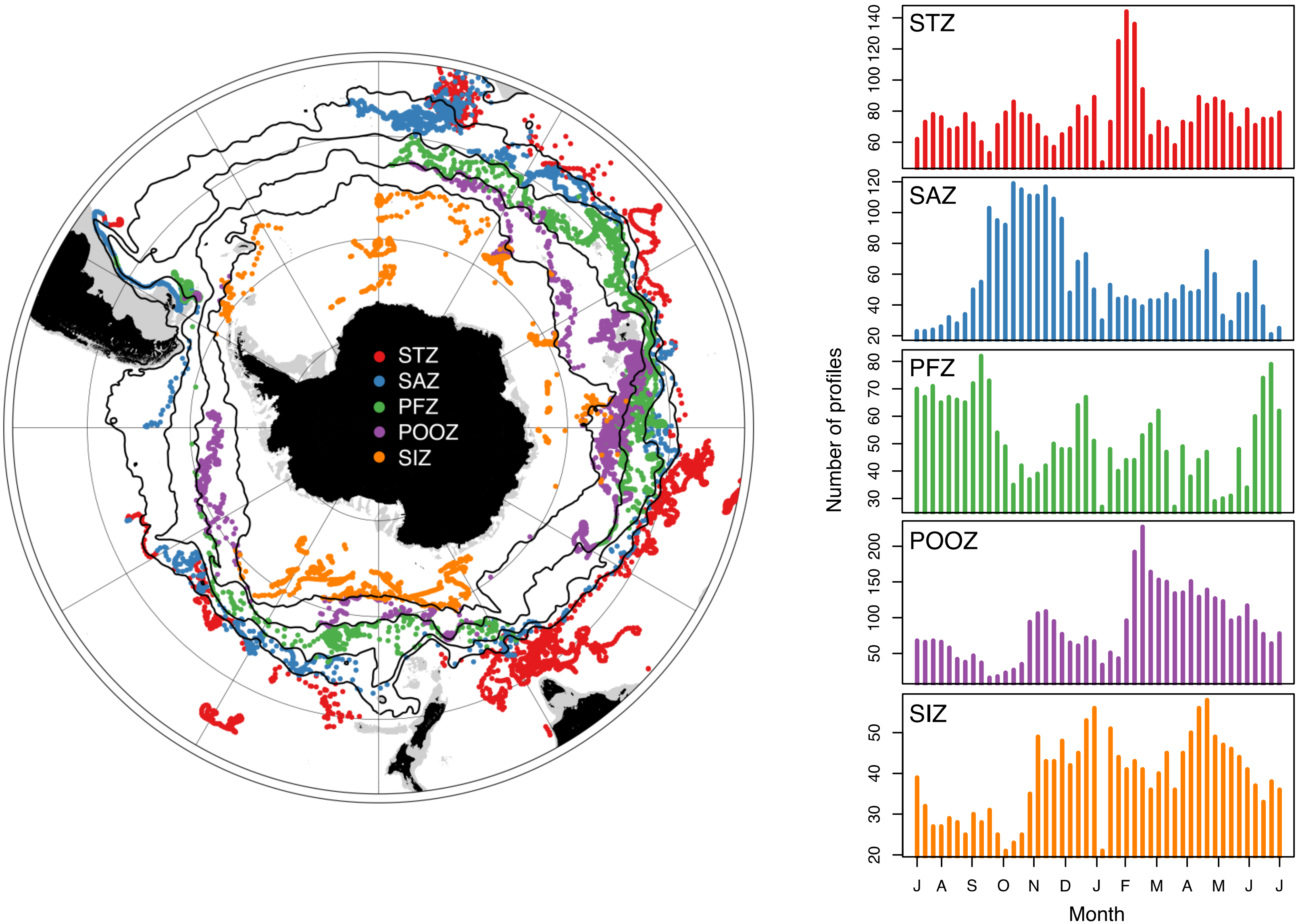
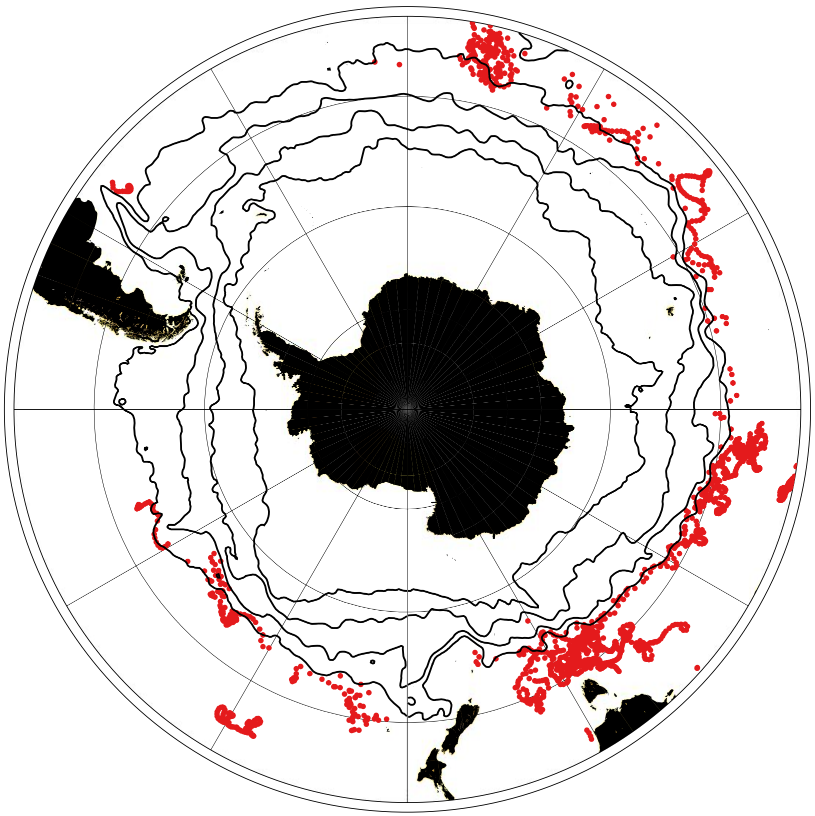
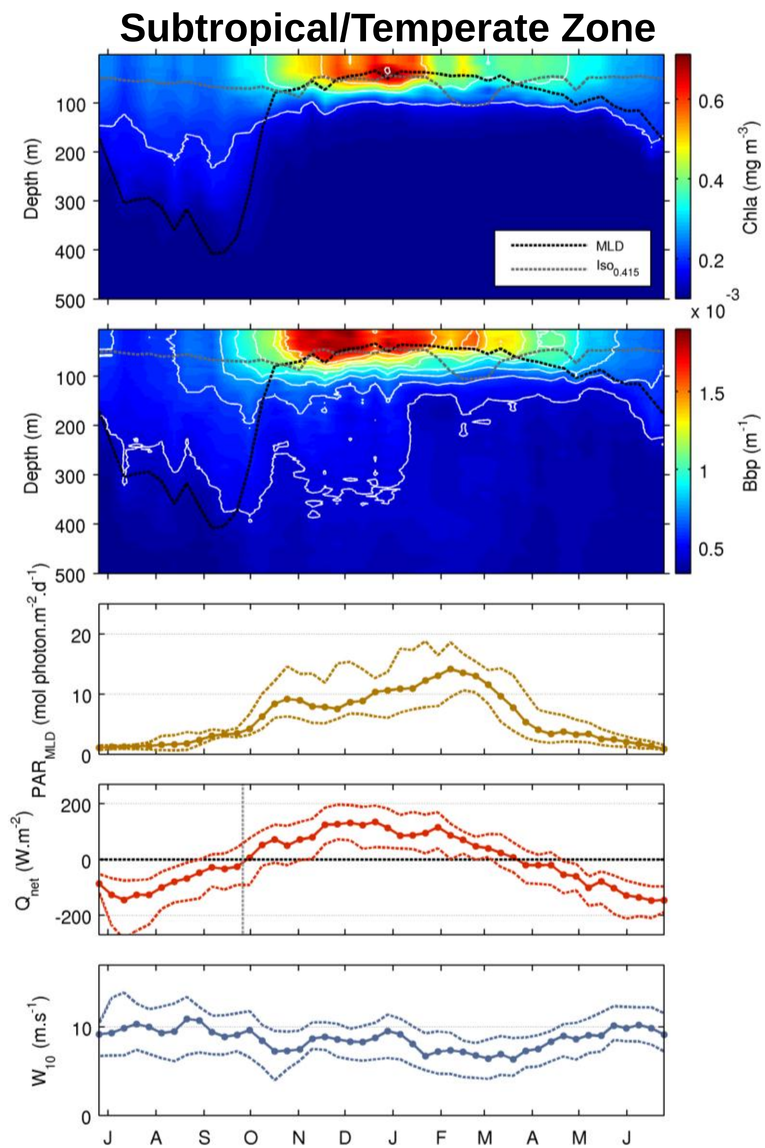


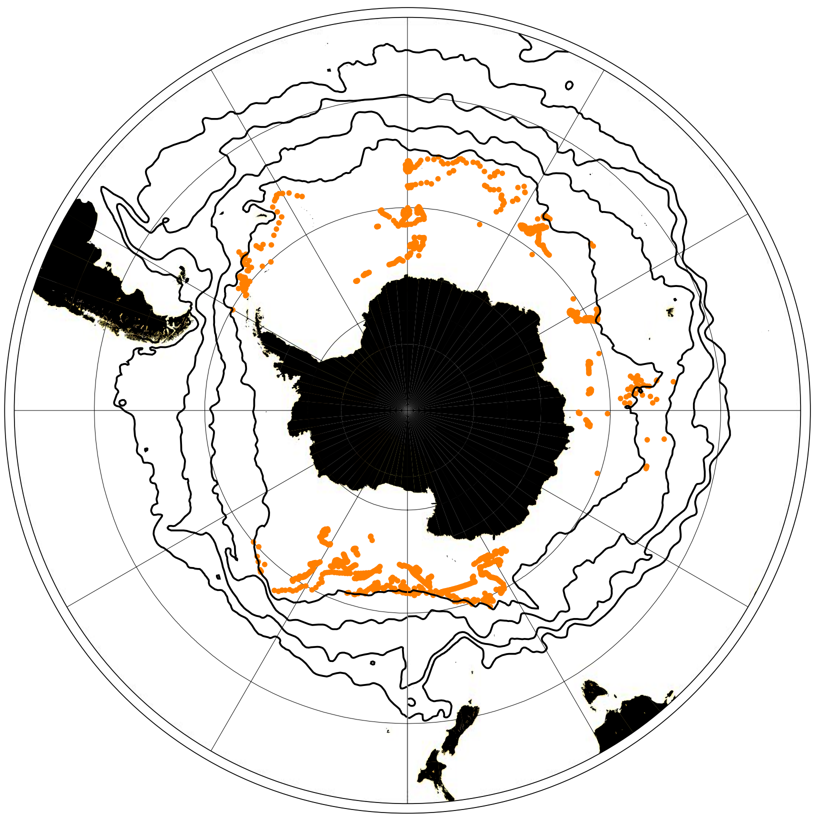
ANNUAL PHYTOPLANKTON CYCLES IN THE SUBTROPICAL ZONE



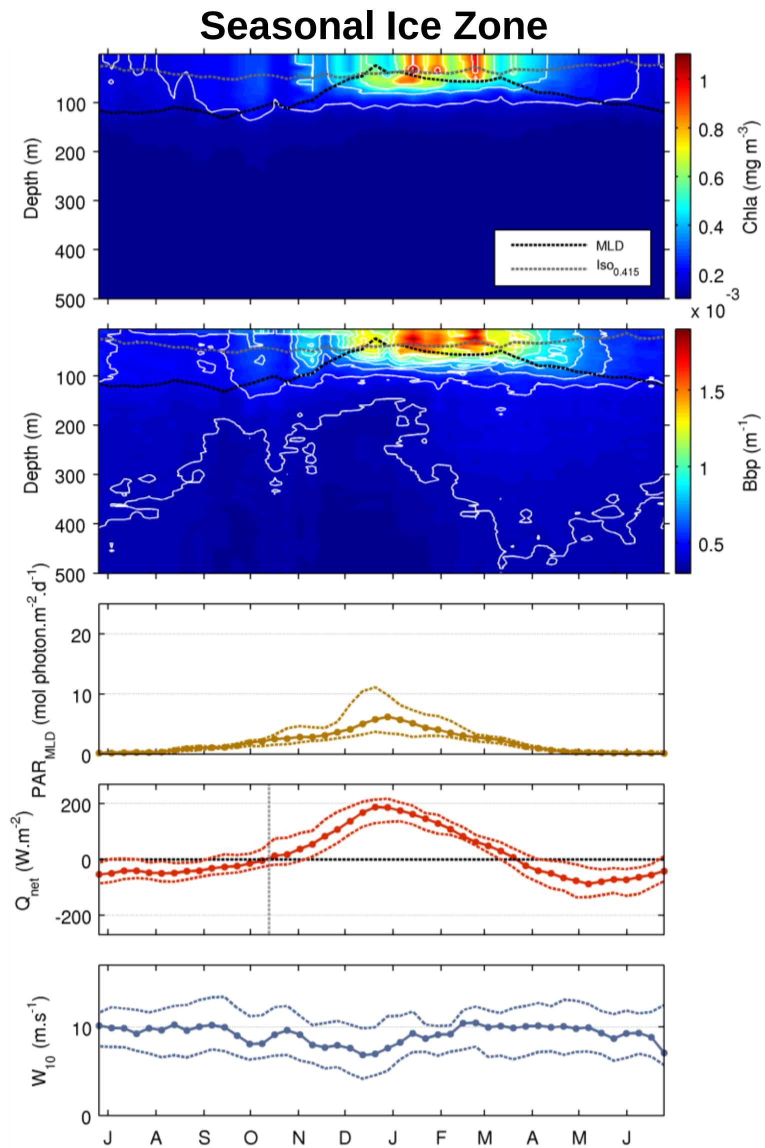
STZ
SAZ
PFZ
POOZ
SIZ



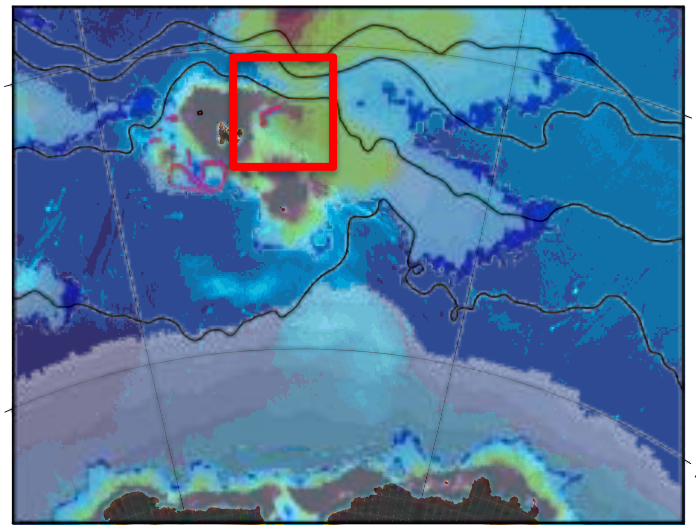
ANNUAL PHYTOPLANKTON CYCLES IN THE SEASONAL ICE ZONE (SIZ)



STZ
SAZ
PFZ
POOZ
SIZ

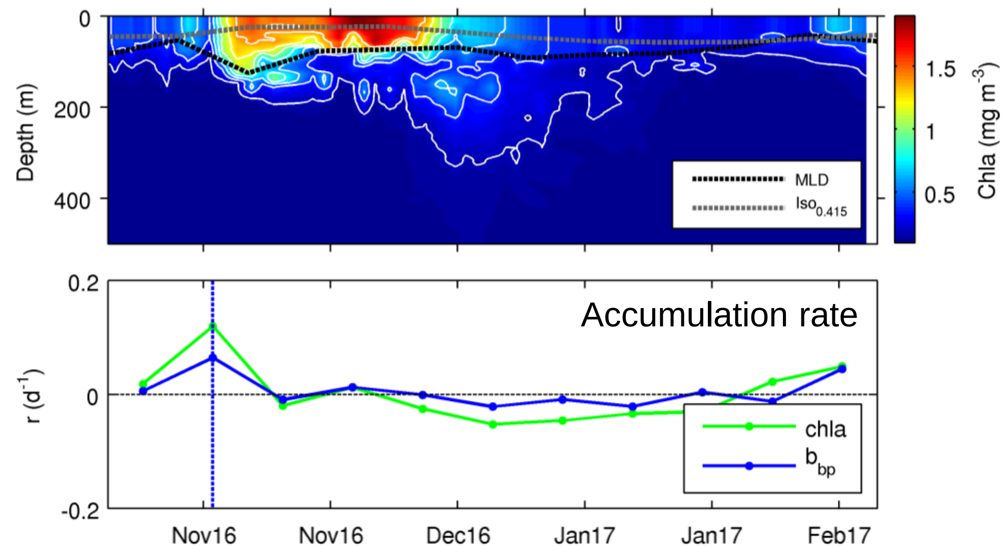


DETERMINING THE ACCUMULATION RATE AND BLOOM INITIATION



LOV BGC-Argo float

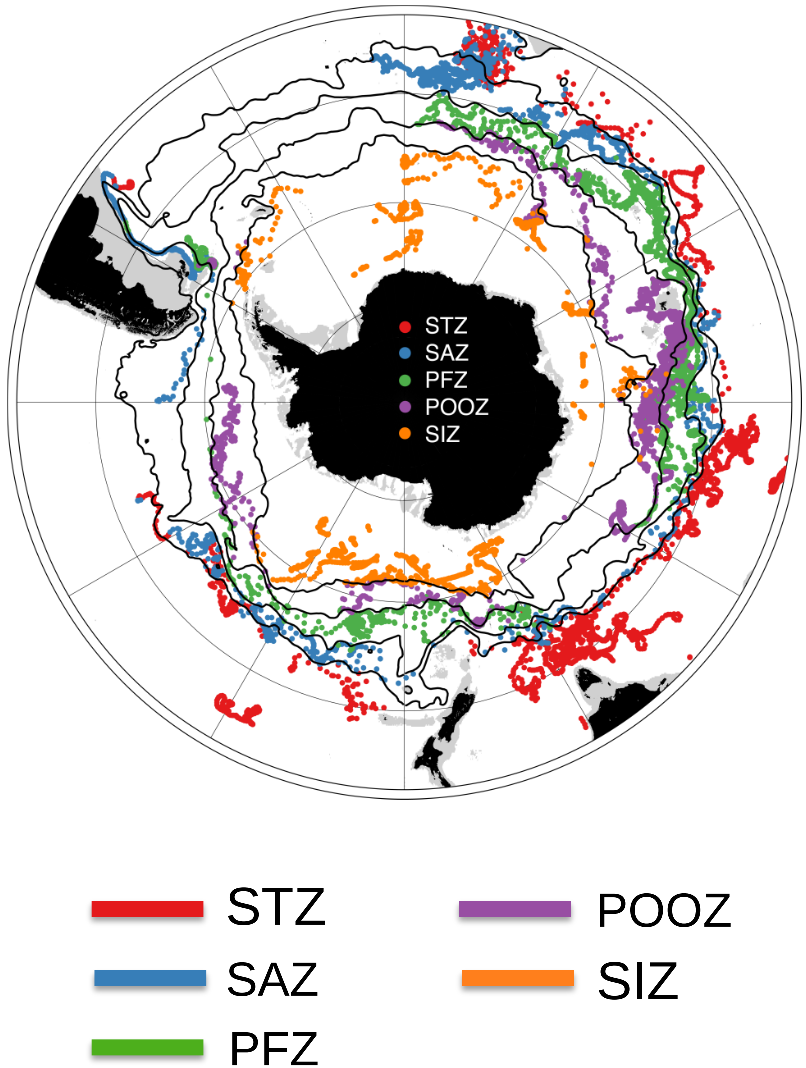
(Nov. 2016 - ongoing)

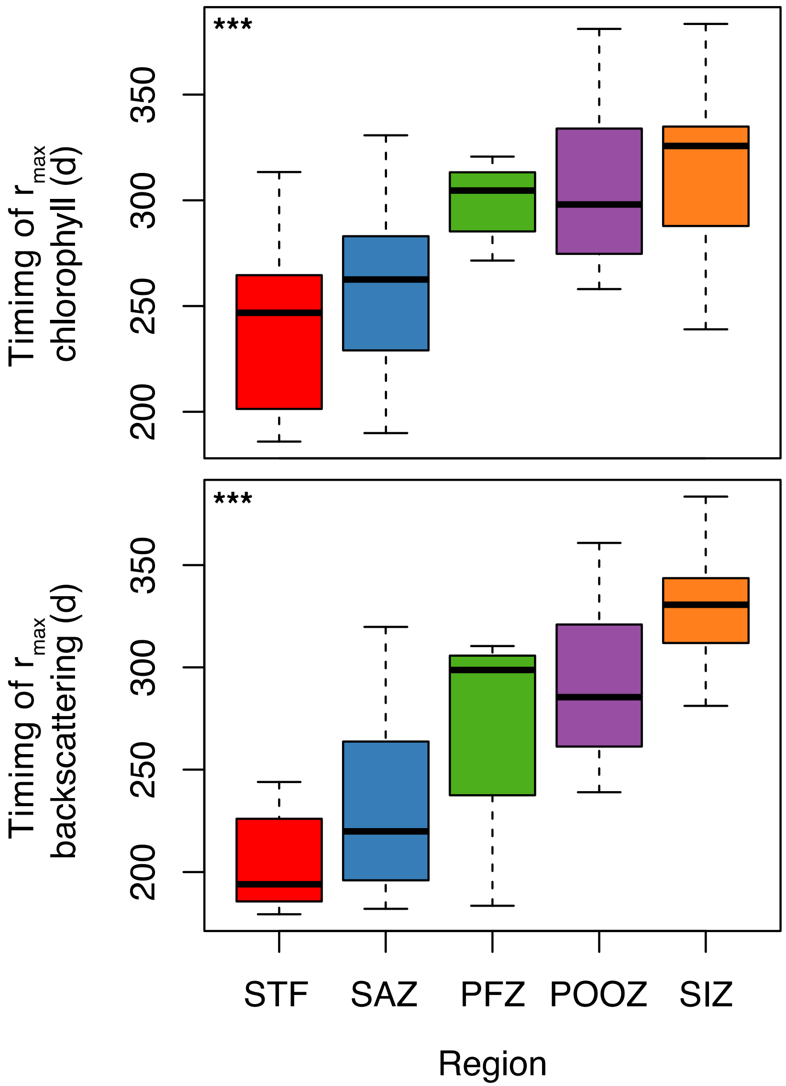


$$r_{i=b,chl}(t+\Delta t/2) \equiv \begin{cases} \dfrac{1}{\overline{P}_i}\dfrac{d\overline{P}_i}{dt} \approx \dfrac{2}{\Delta t}\dfrac{\left(\overline{P}_i(t+\Delta t)-\overline{P}_i(t)\right)}{\left(\overline{P}_i(t+\Delta t)+\overline{P}_i(t)\right)} & \text{if } \dfrac{d\mathrm{MLD}}{dt} < 0 \;\&\;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

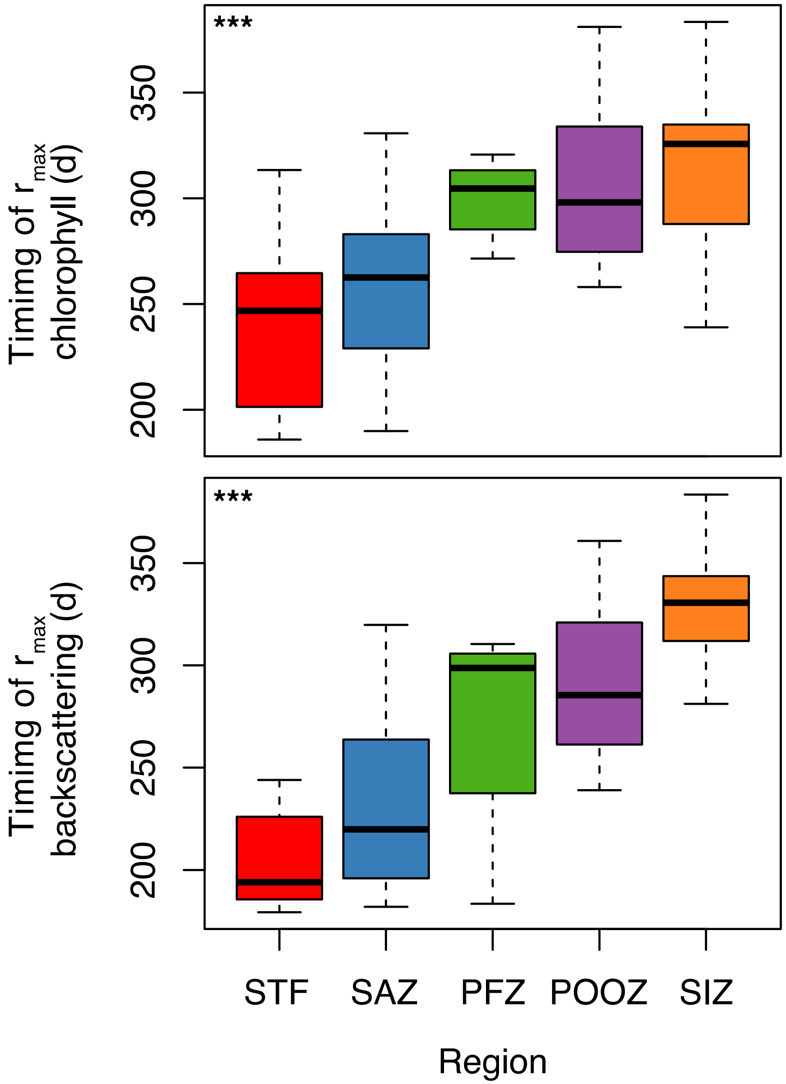
Boss et al. 2010, Behrenfeld et al. 2015

Bloom initiation in the Southern Ocean





Bloom initiation in the Southern Ocean



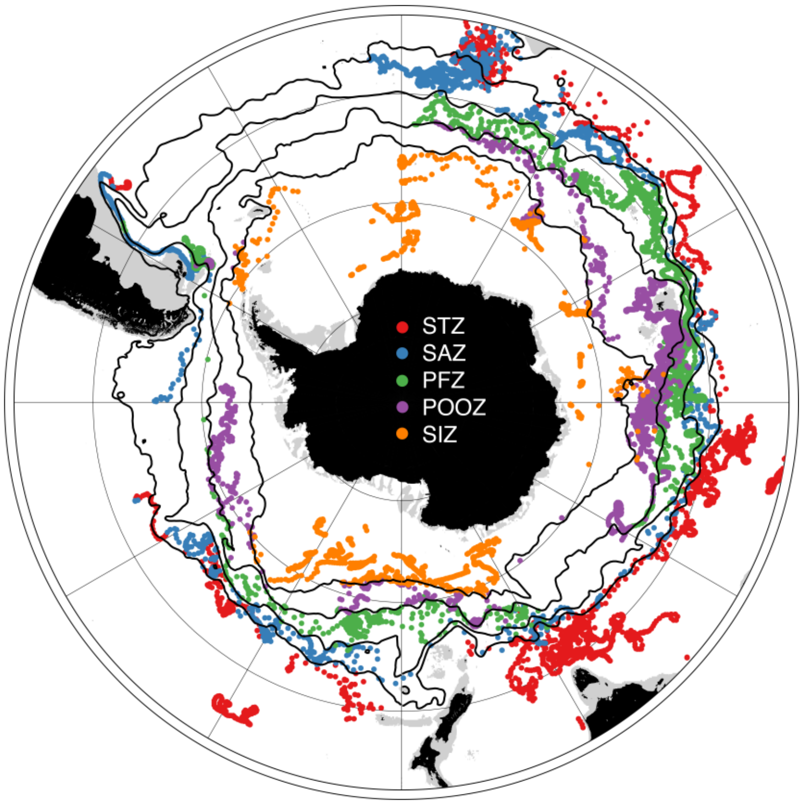
Seems to support the latitudinal satellite-derived trend in bloom initiation.

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

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

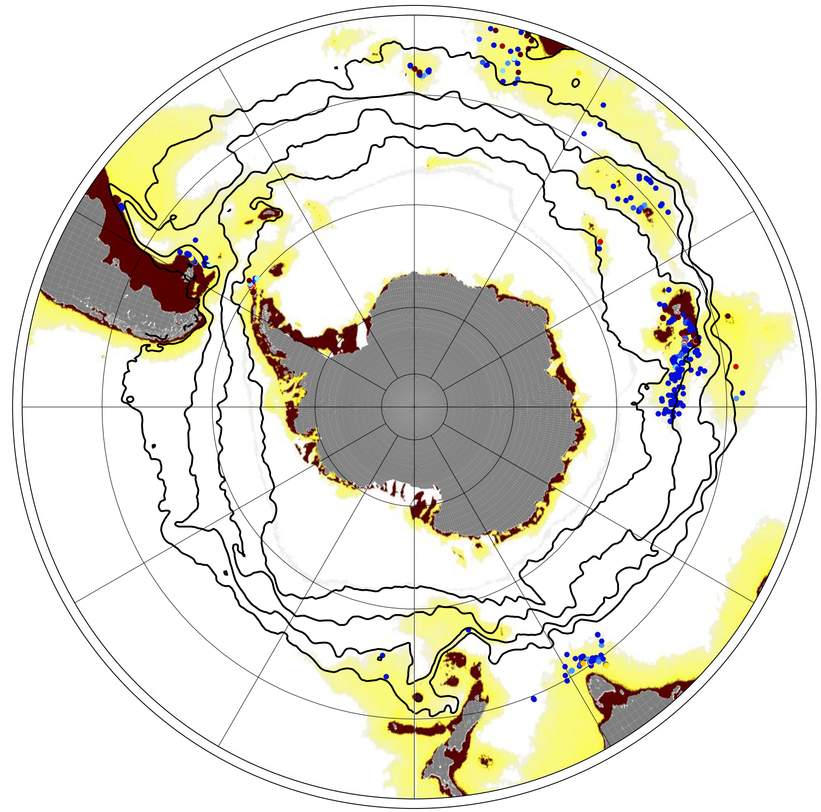
which may modulate the timing of the bloom initiation

Determining the BGC-Argo floats in natural iron fertilized regions



STZ
SAZ
PFZ
POOZ
SIZ

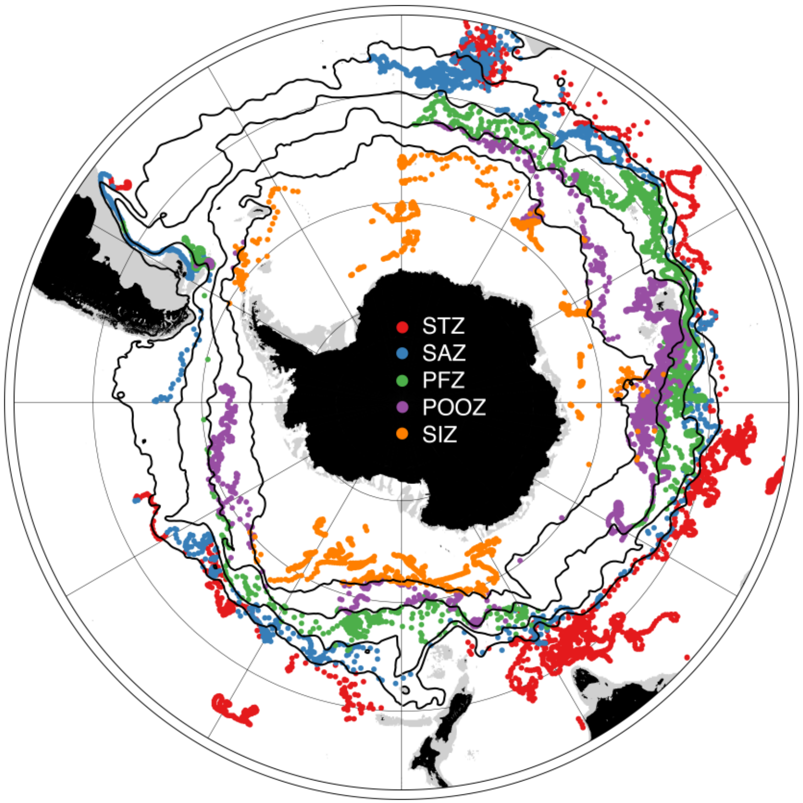
Synergies between BGC-Argo floats and iron-enriched water particles trajectories



Natural iron fertilized waters

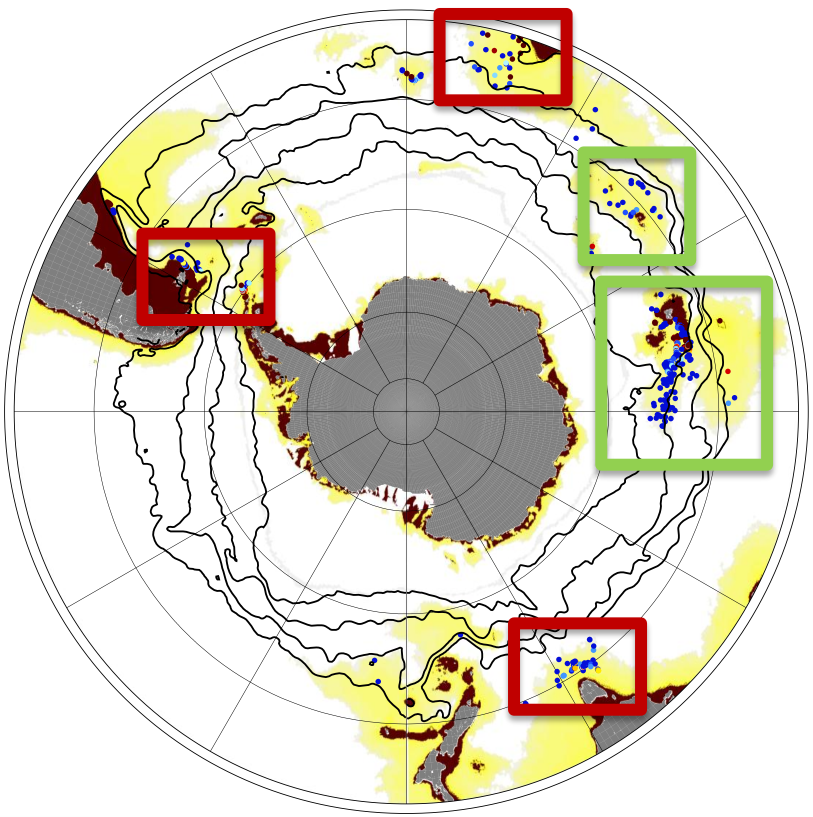
Still in development !!

DETERMINING THE BGC-ARGO FLOATS IN NATURAL IRON FERTILIZED REGIONS



STZ
SAZ
PFZ
POOZ
SIZ

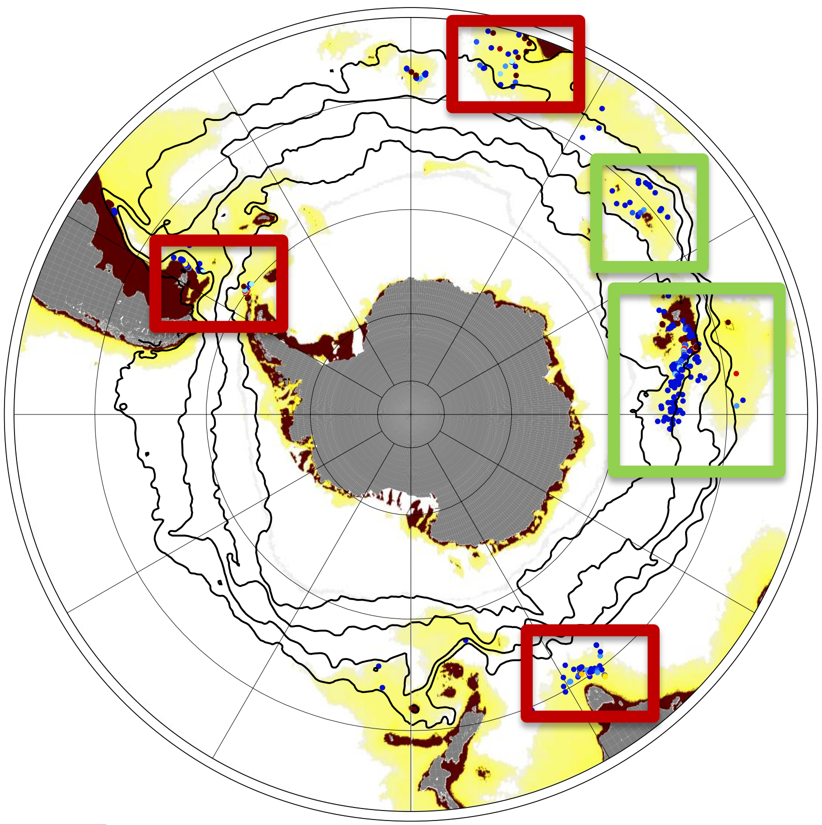
Coupling BGC-Argo floats with iron-enriched water particles trajectories



Continental shelf
Island

Still in development !!

Bloom magnitude in natural iron fertilized regions



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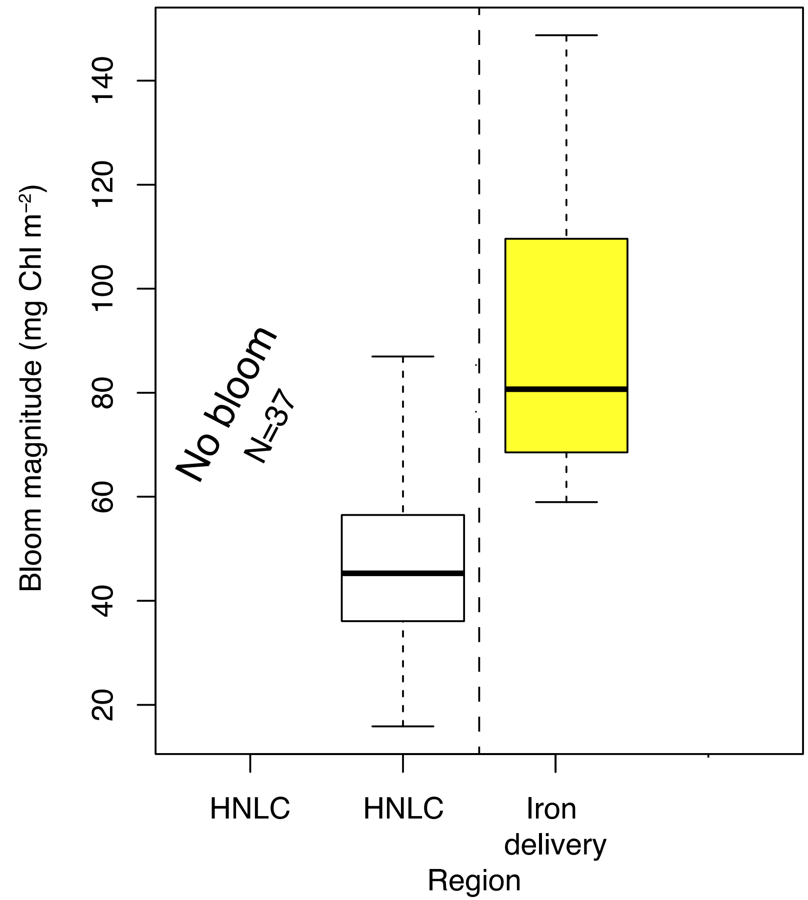
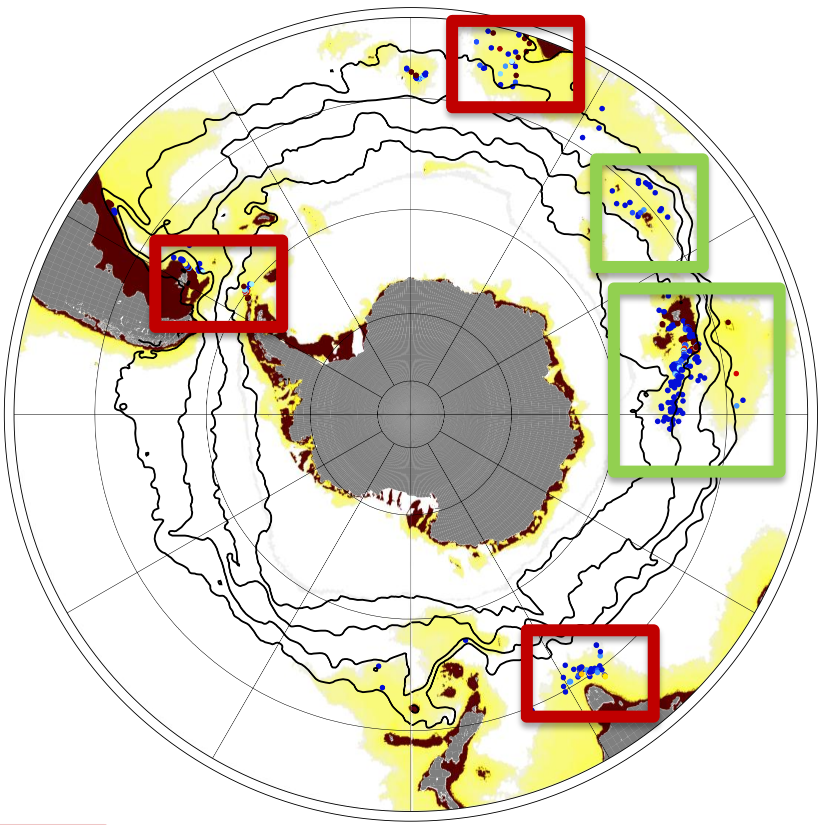


Still in development !!

Bloom magnitude in natural iron fertilized regions



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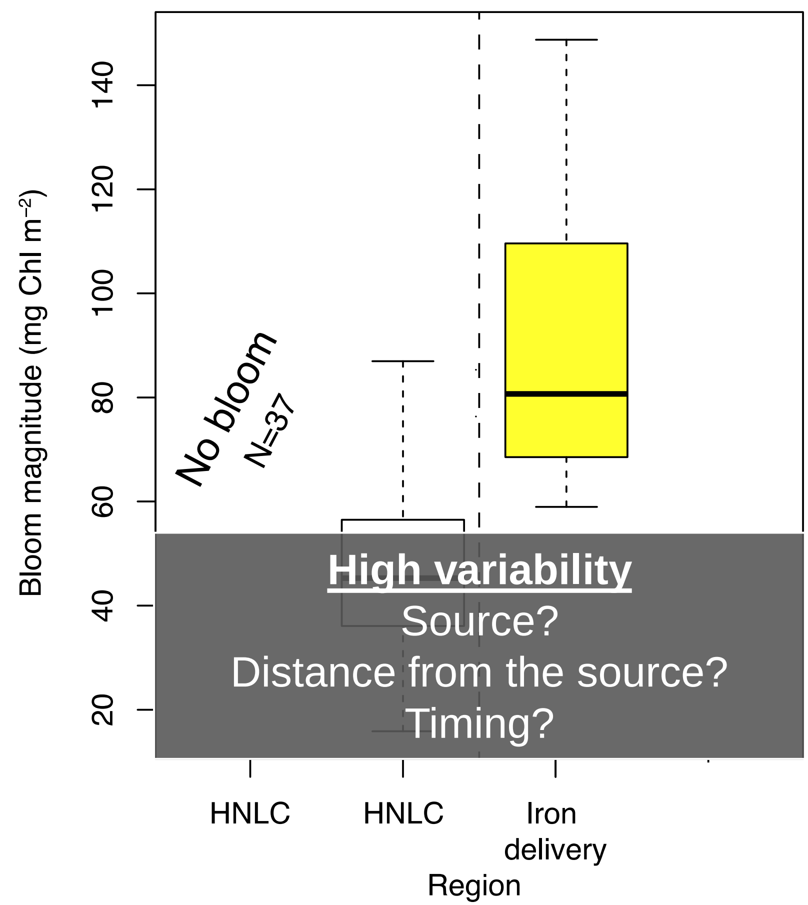
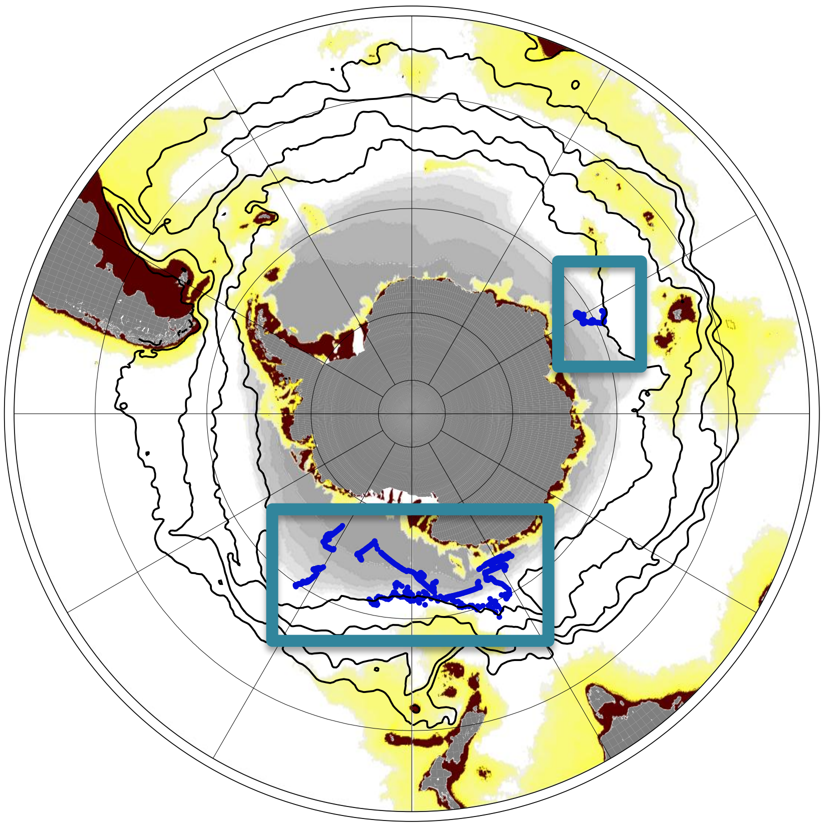


Still in development !!

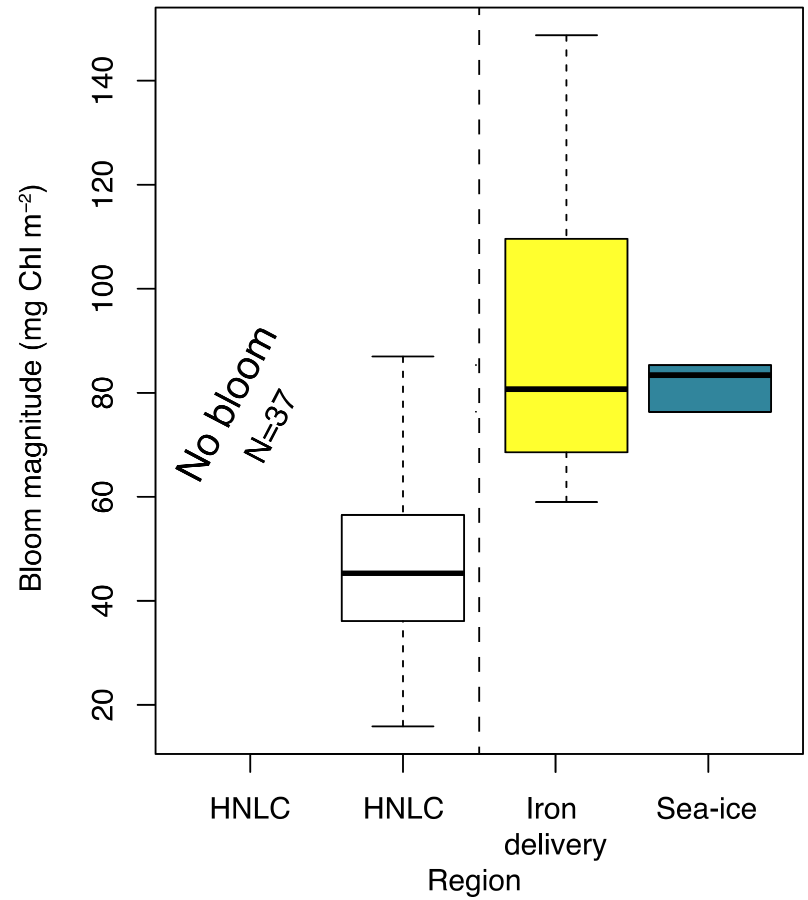
BLOOM MAGNITUDE IN SEASONAL SEA-ICE COVERED REGIONS

Coupling BGC-Argo floats with satellite-derived sea-ice dynamics



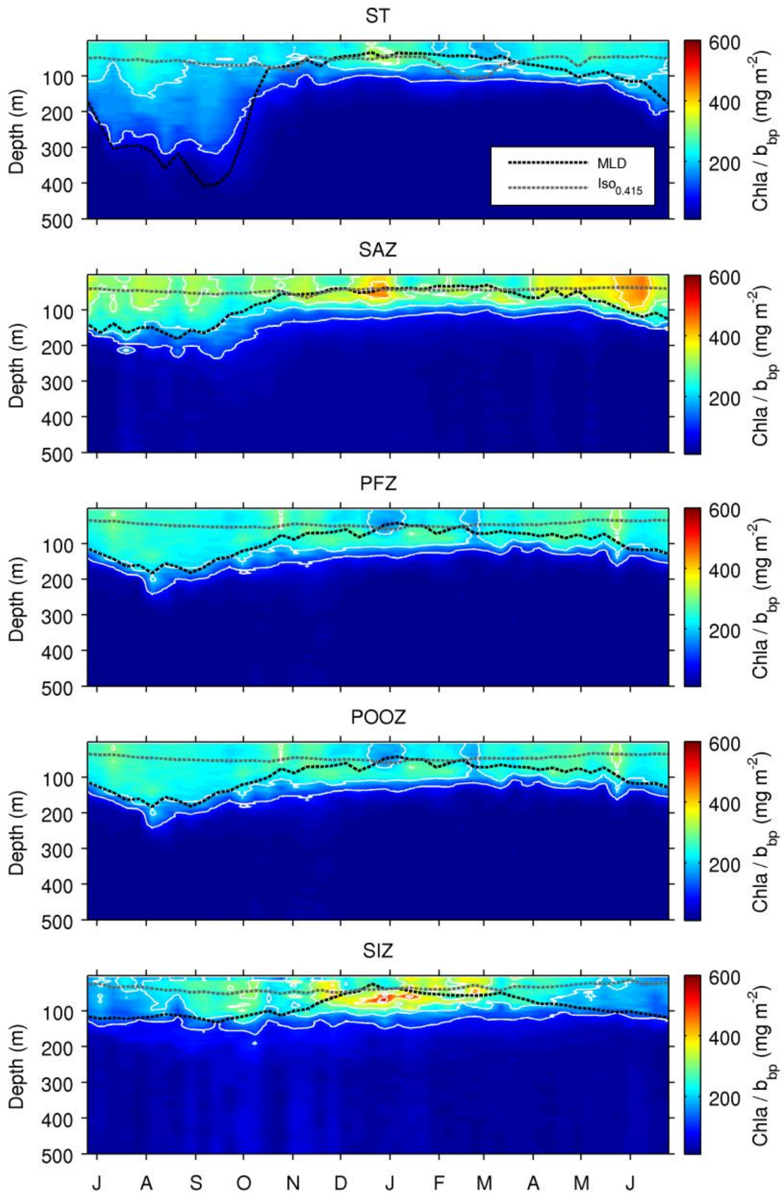
Continental shelf

Sea-ice



Still in development !!

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 (-)

Cetinic et al. 2015

Bio-optical properties of phytoplankton assemblages: Chl/bbp ratio

GLM model:

chl:bbp ~ intercept + Chl + PIC + T + PAR_{MLD} + MLD + Qnet + W10

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

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

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

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

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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

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- Seasonal sea-ice covered regions have different mechanisms behind the bloom initiation; i.e., triggered by increasing light by the receding sea-ice cover.

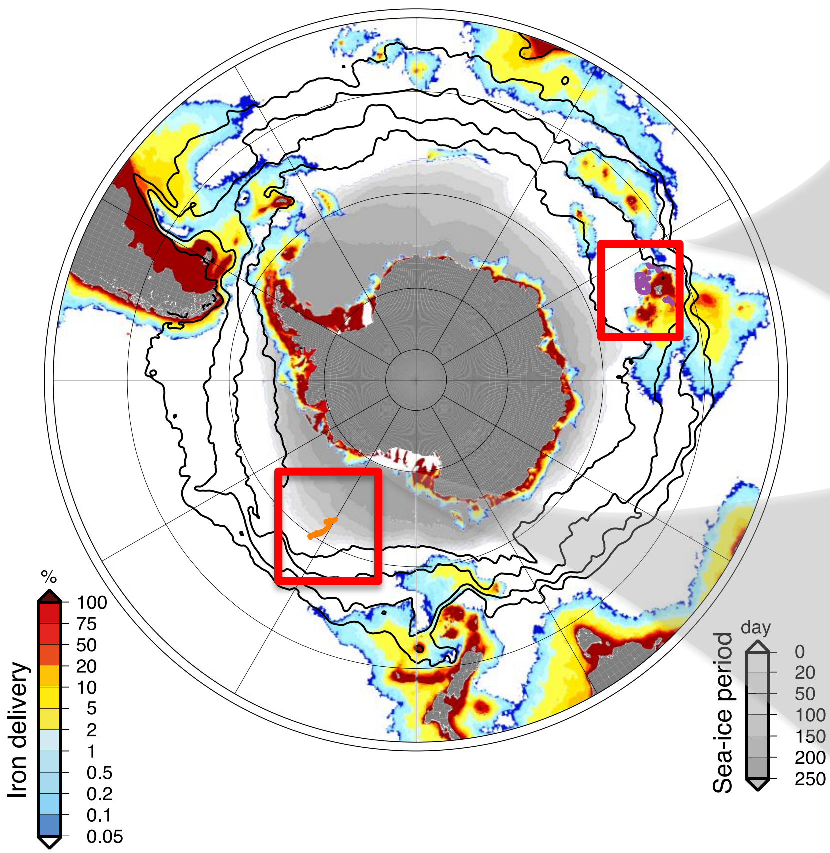
- Additional information may be retrieved on the phytoplankton assemblage/physiology based on bio-optical sensors (see the next talk of Mathieu Rembauville).

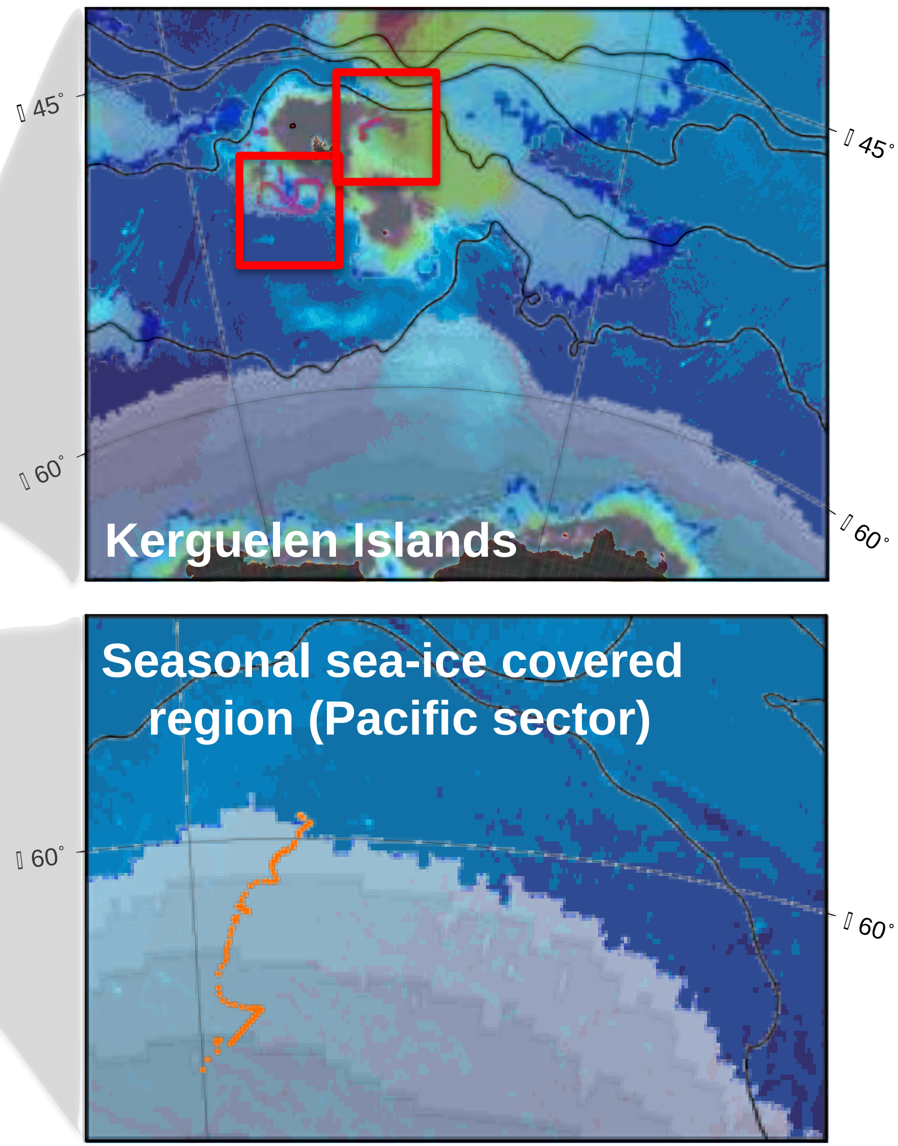
Questions ???

THREE CASE STUDIES FOR EXAMINING BLOOM INITIATION

Southern Ocean:

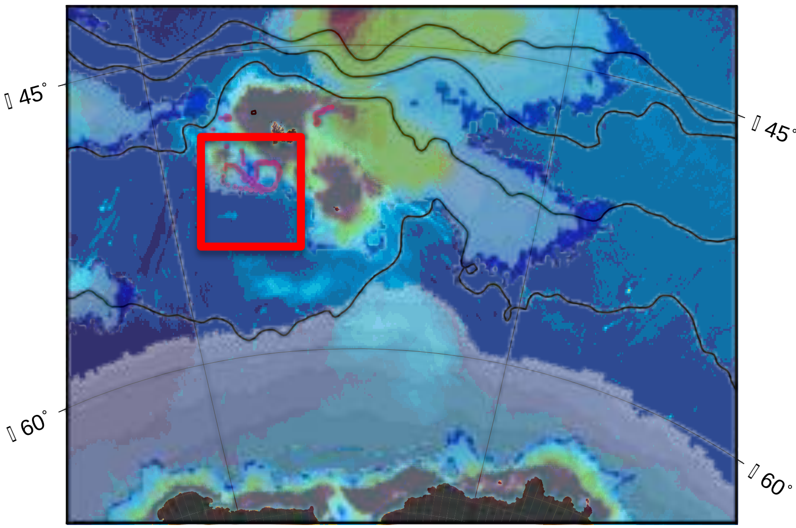
Iron- and sea ice-influenced regions



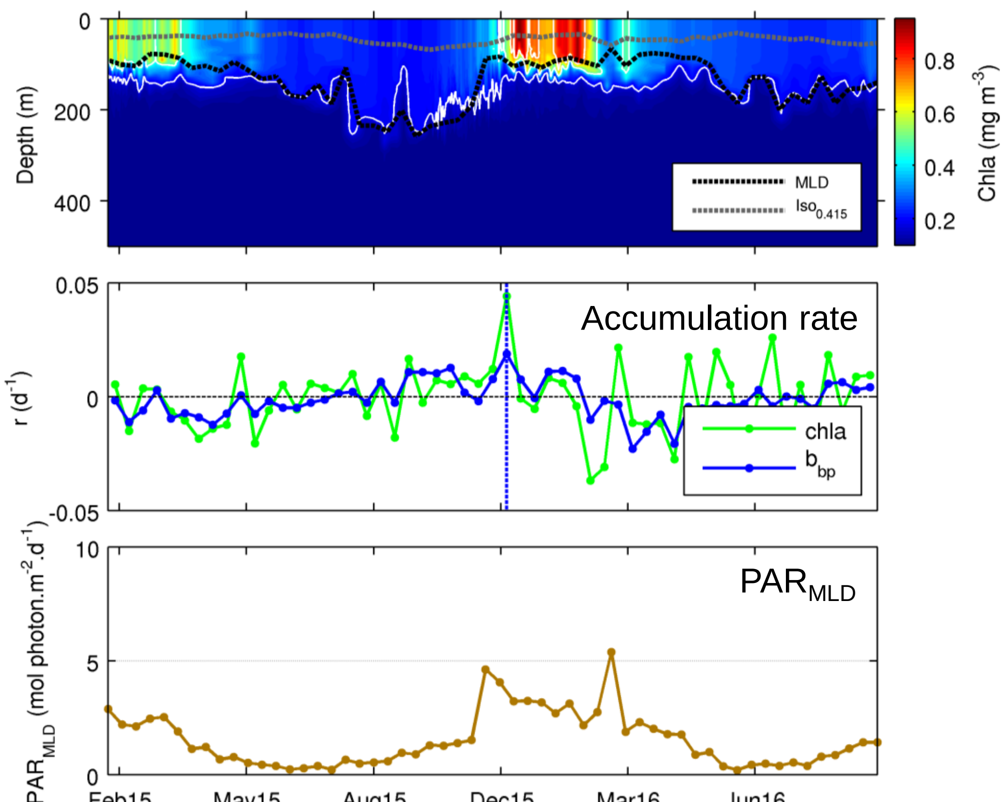


BLOOM INITIATION AND MAGNITUDE IN HNLC REGION

HNLC region:
West of Kerguelen

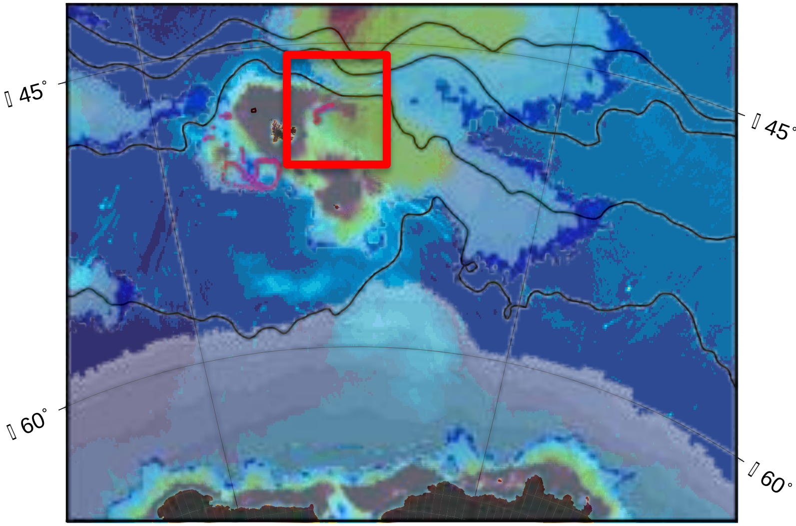


<u>LOV BGC-Argo float</u>
2 complete annual cycle
(Feb. 2015 - ongoing)

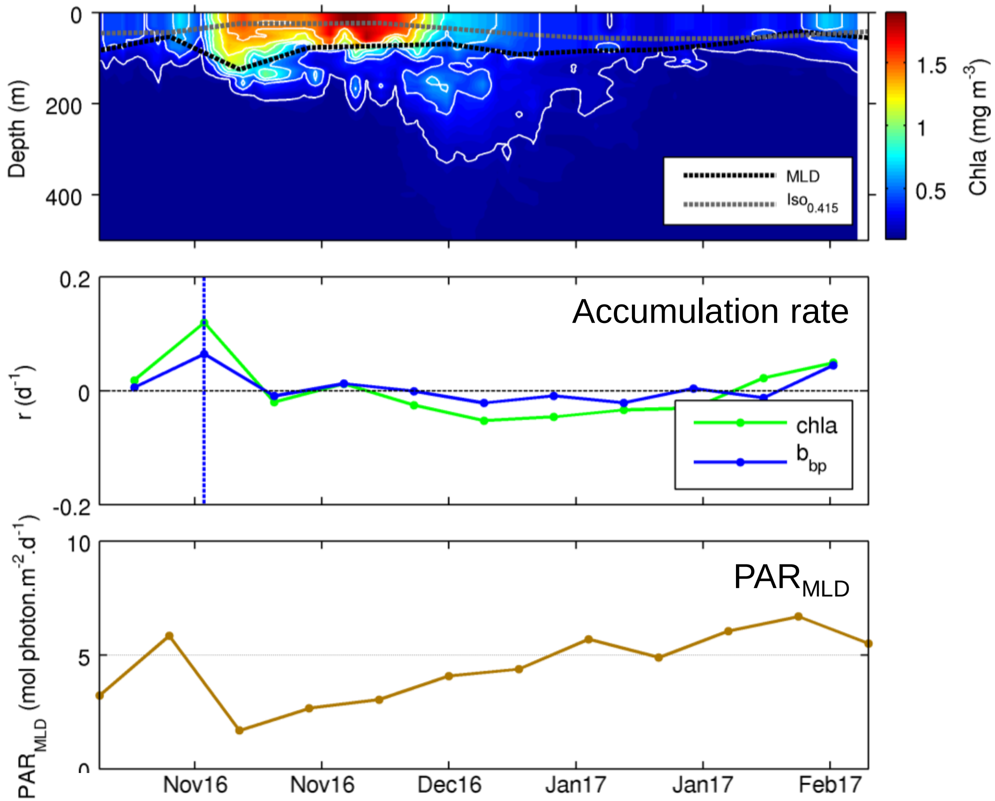


BLOOM INITIATION IN A NATURAL IRON FERTILIZED REGION

Natural iron fertilized region:
East of Kerguelen

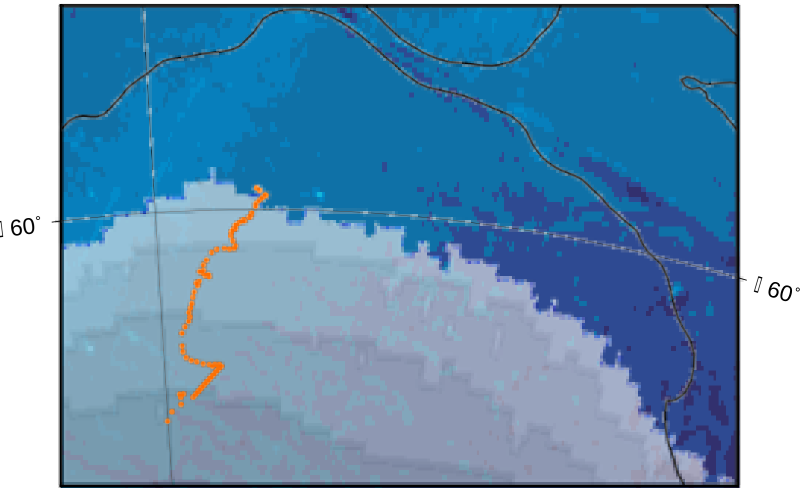


<u>LOV BGC-Argo float</u>
1 incomplete annual cycle
(Nov. 2016 - ongoing)



BLOOM INITIATION IN A SEASONAL SEA-ICE COVERED REGION

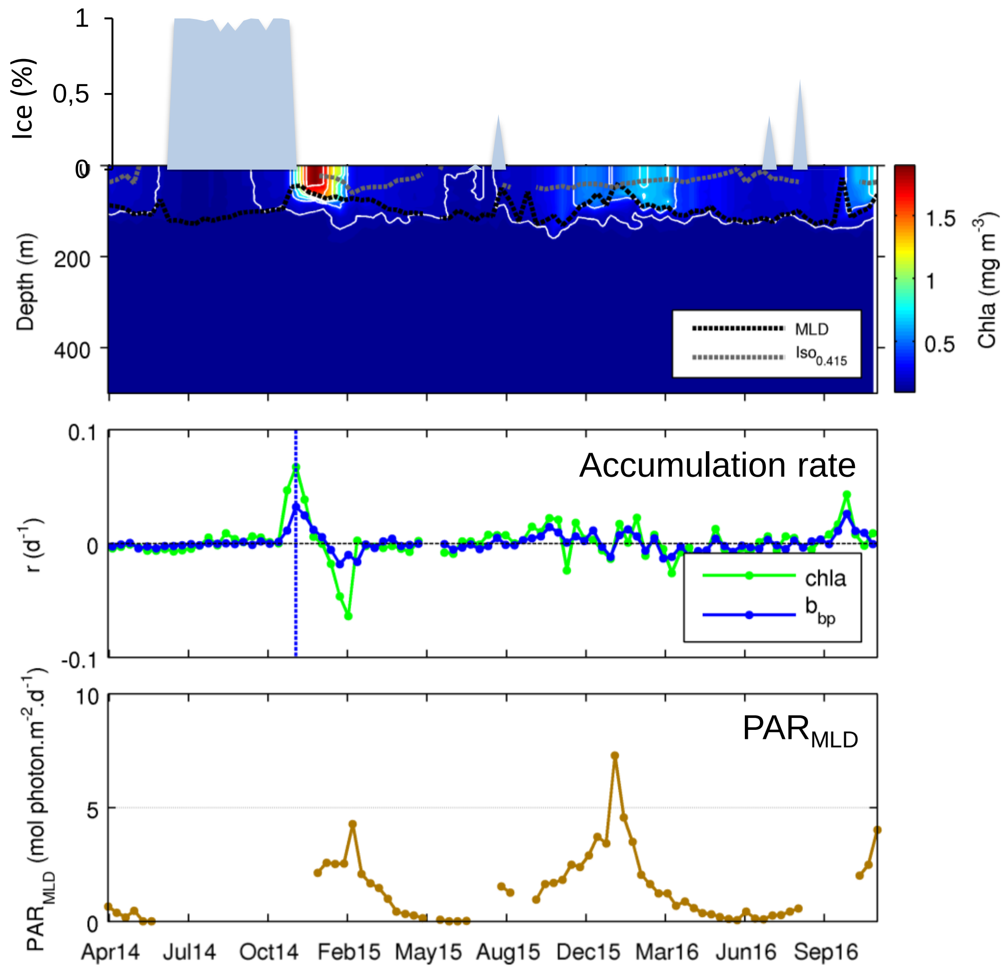
Seasonal sea-ice covered region (Pacific sector)



SOCCOM BGC-Argo float

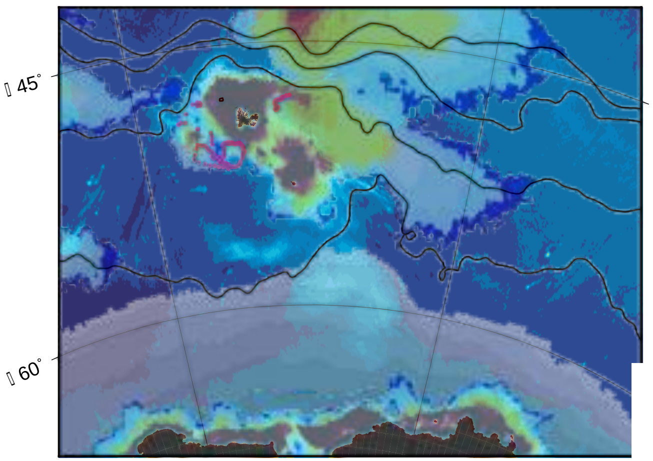
2 complete annual cycles

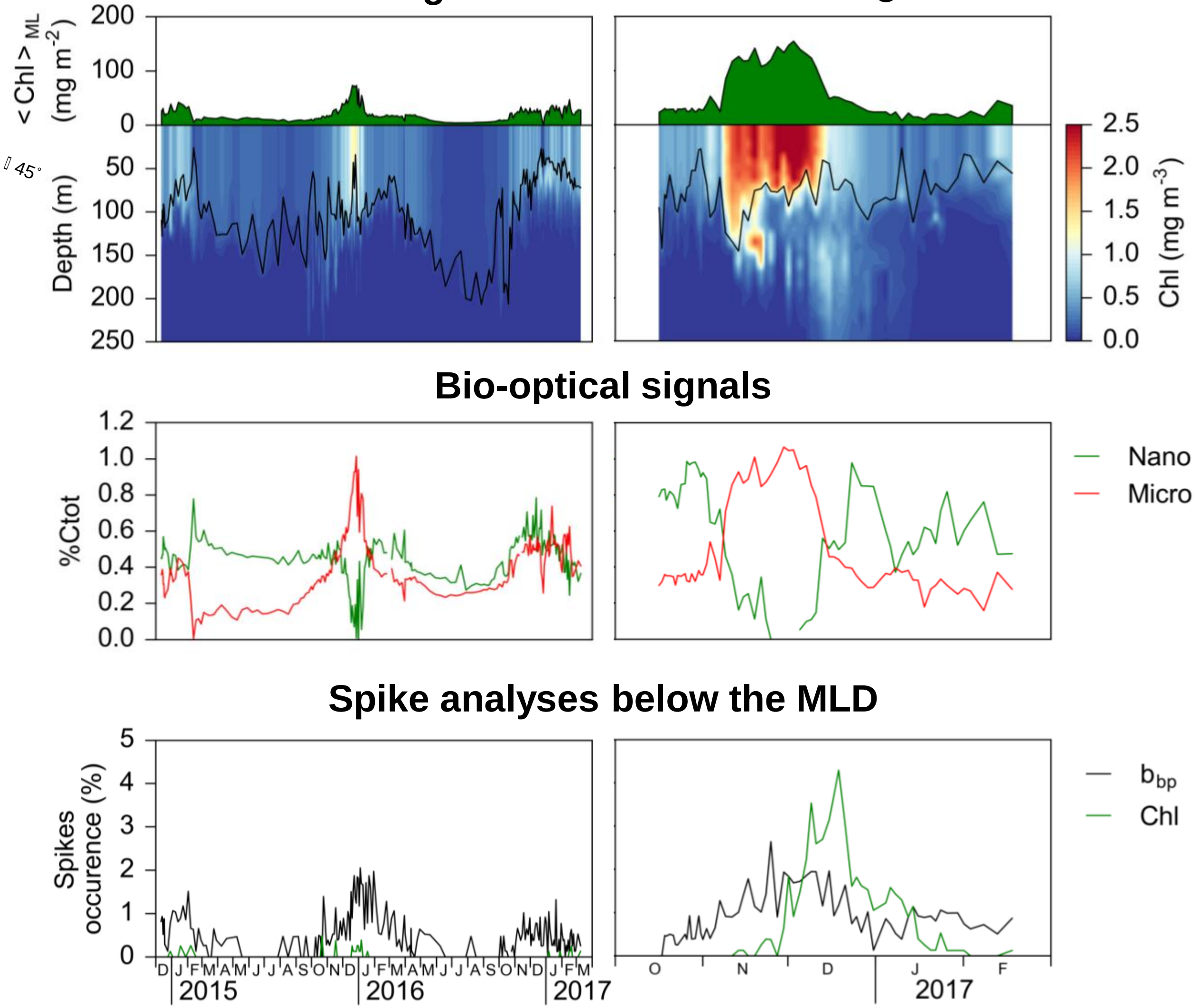
(Apr. 2014 – Nov. 2016)



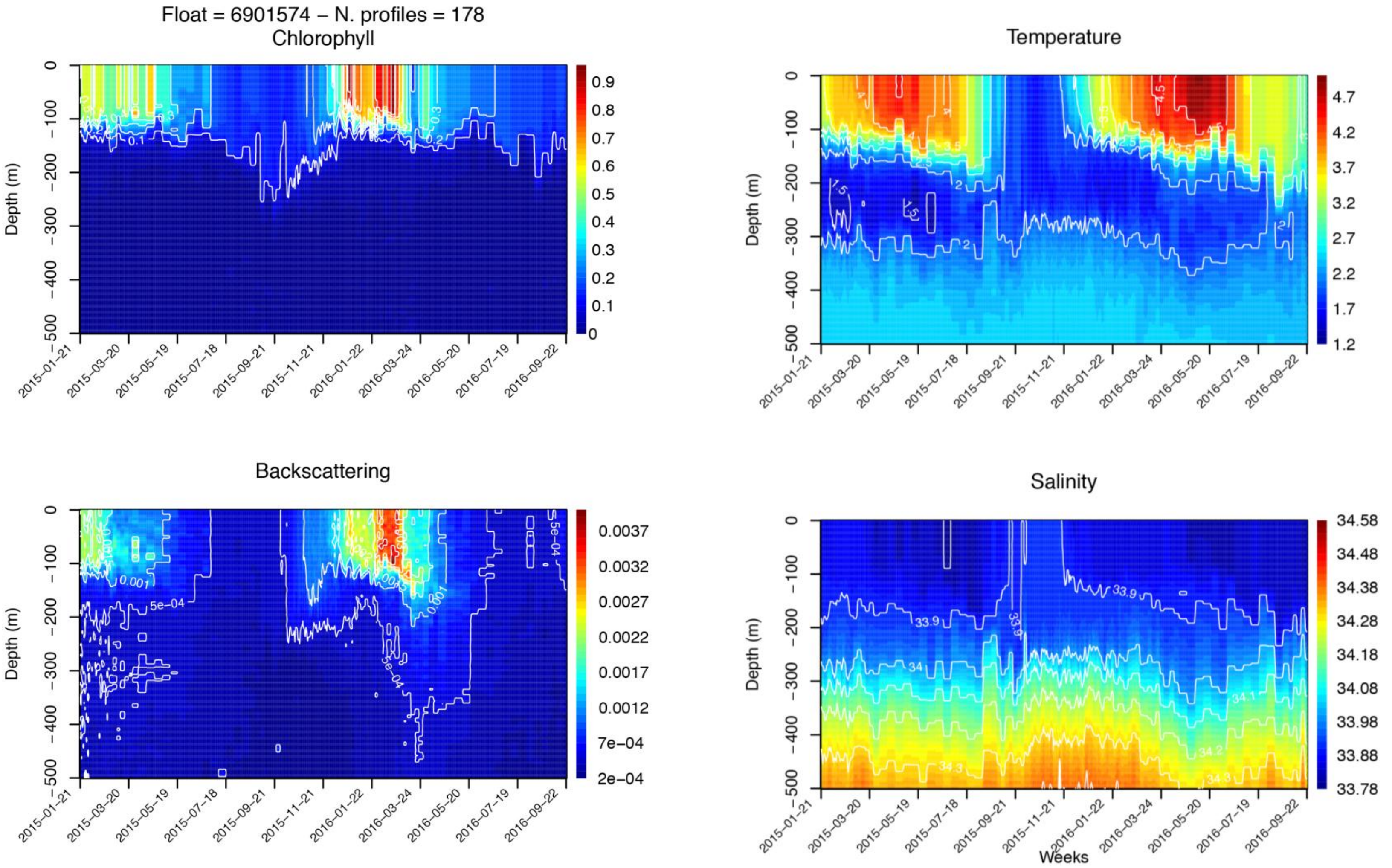
BLOOM EXPORT IN HNLC *VERSUS* NATURAL IRON FERTILIZED REGIONS

Kerguelen Islands: SOCLIM expedition

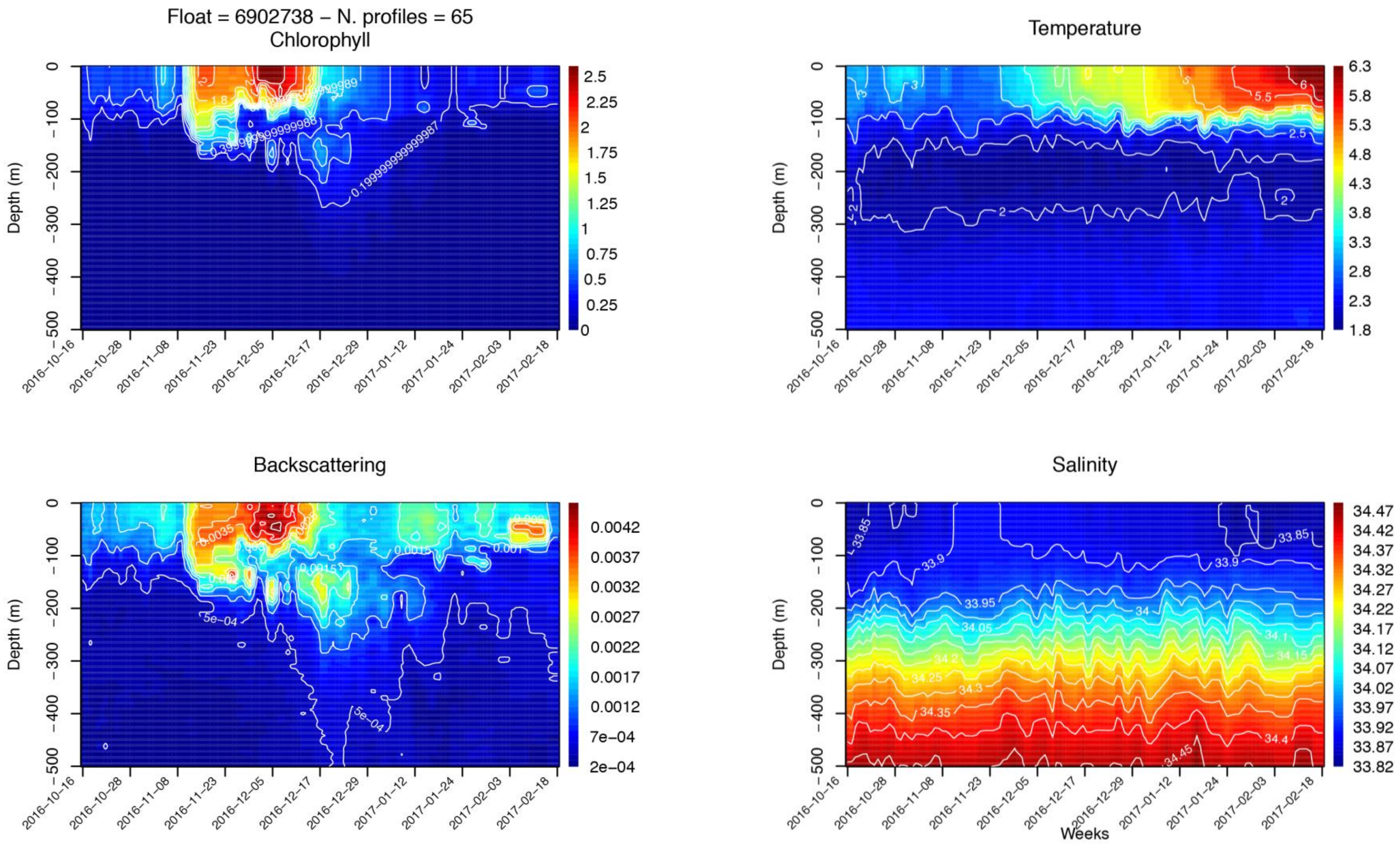




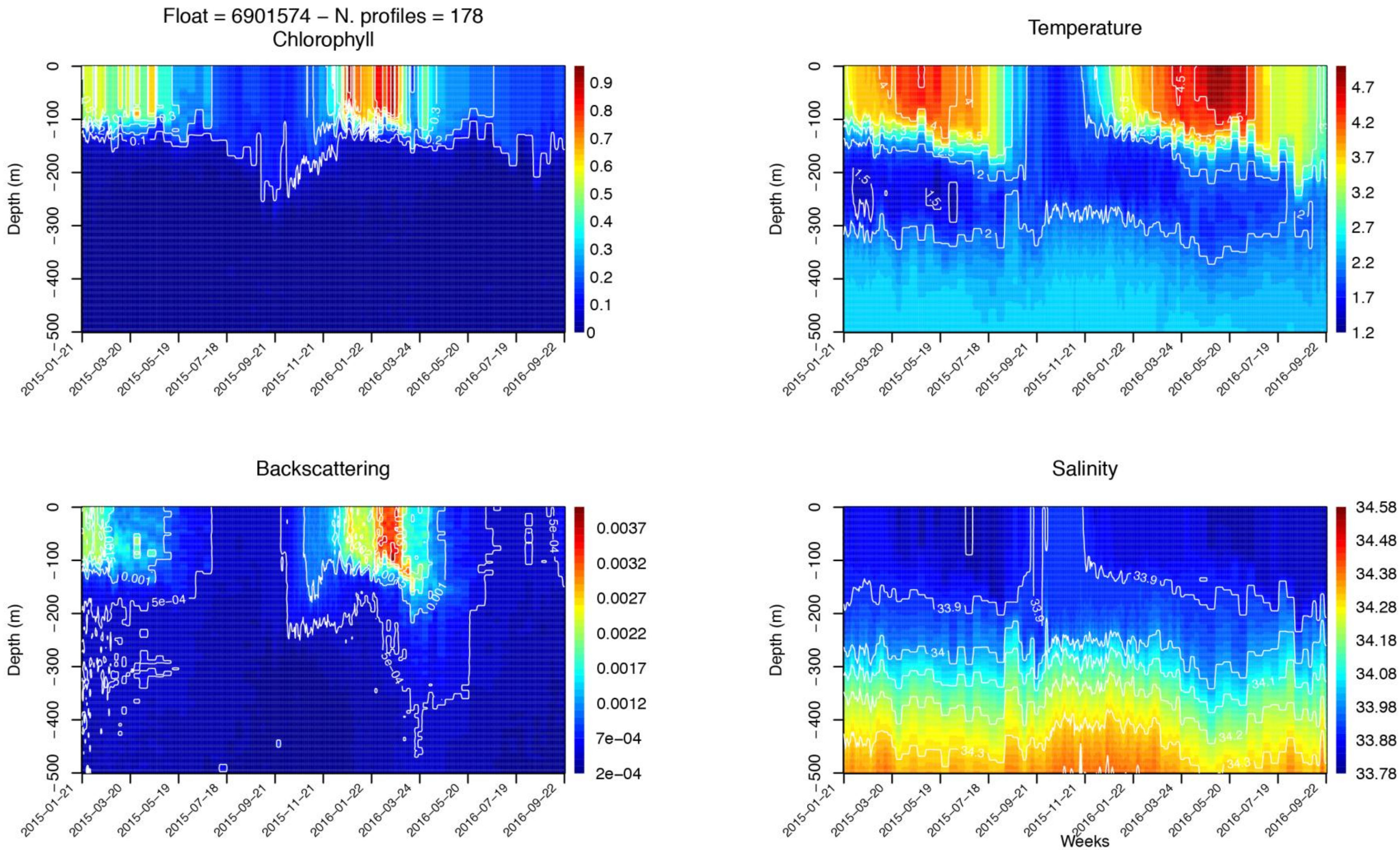
6. BLOOM INITIATION AND MAGNITUDE IN HNLC REGION



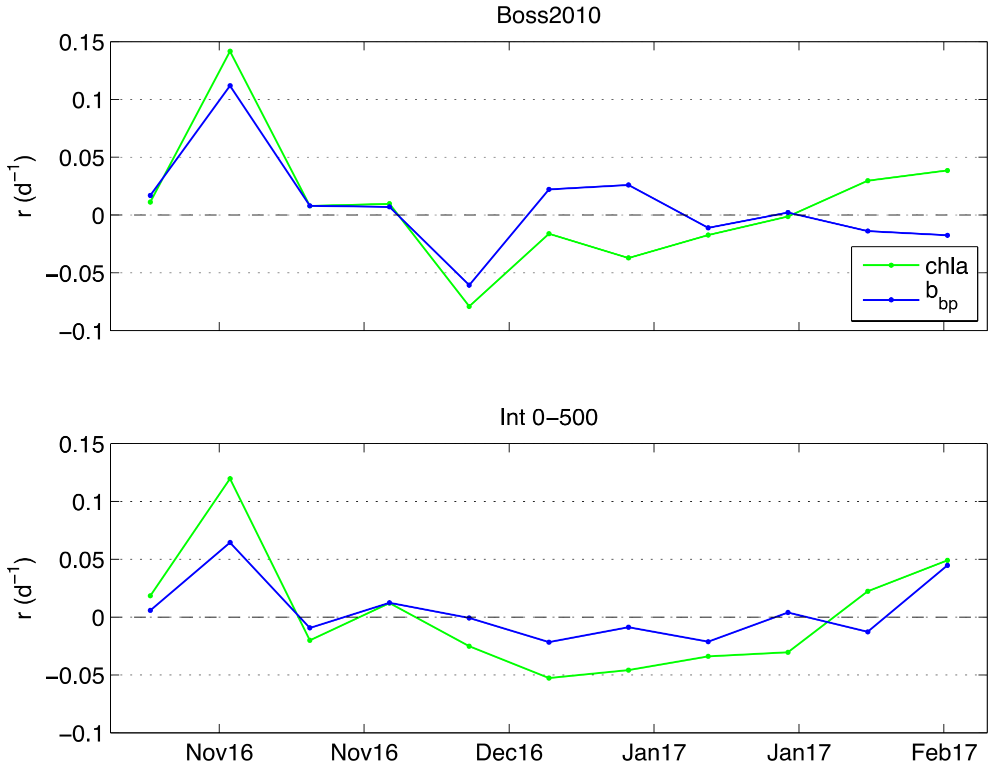
6. BLOOM INITIATION IN A NATURAL IRON FERTILIZED REGION



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



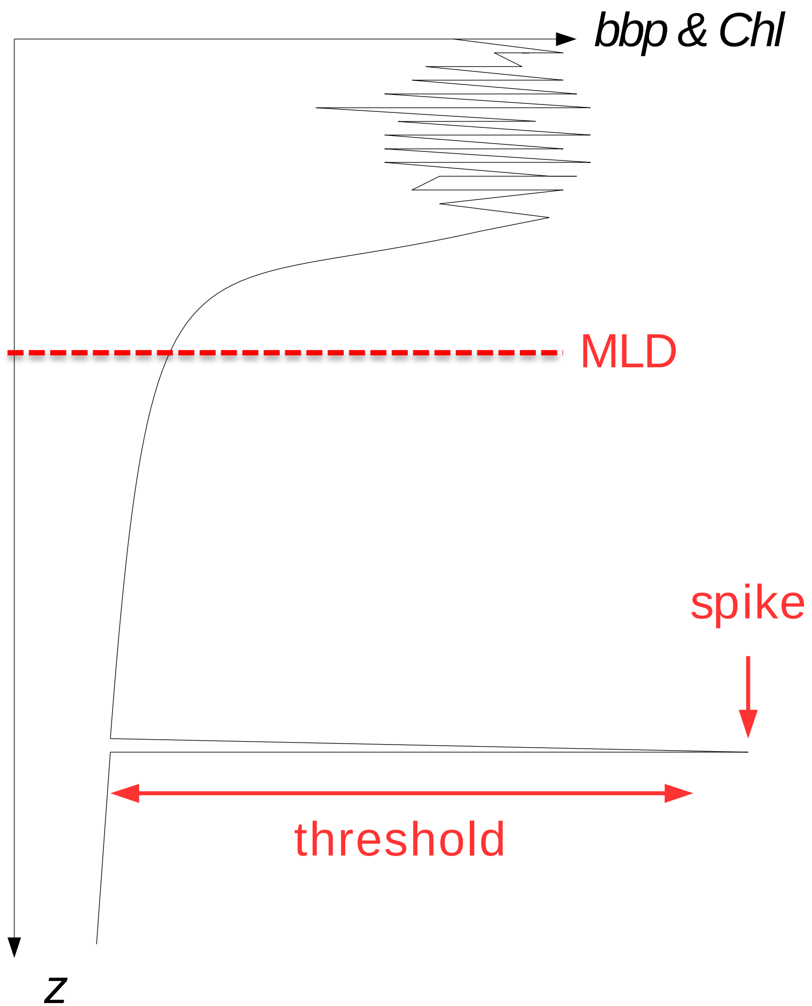
Growth determination: testing two methods



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

Boss et al. 2010, Behrenfeld et al. 2015

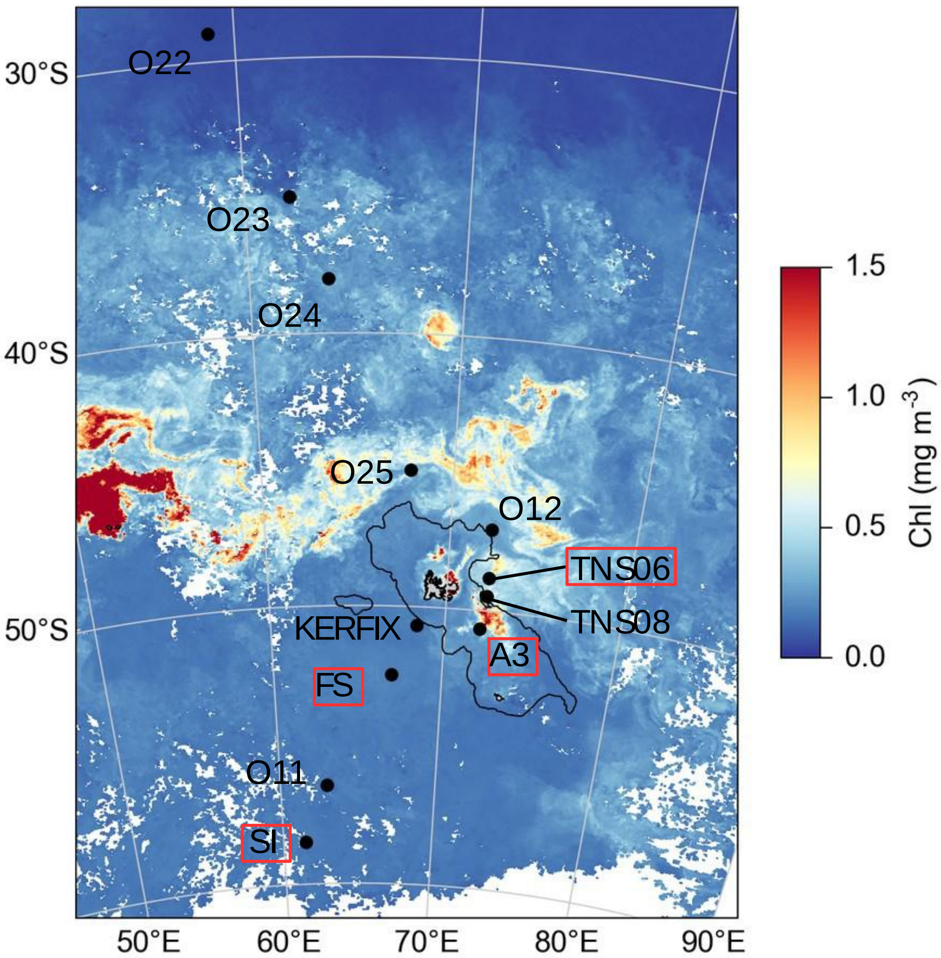
2. Spike detection: Indicator of aggregates



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 (µm³)	Carbon content (pgC)
Bact	Heterotrophic bacteria	Cytometry	0.25[a]	0.015[a]
Pico	Prochlorococcus	Cytometry	0.68[b]	0.029[b]
	Synechococcus		0.86[b]	0.080[b]
	Picoeukaryotes		2.76[b]	0.73[b]
Nano	Nanoplankton	Cytometry	284[c]	15[c]
Micro	Diatom (55 groups)	Optical microscopy	Shape-specific[d]	$C = 0.117\ V^{0.881}$ [e]
	Dinoflagellate (14 groups)		Shape-specific[d]	$C = 0.670\ V^{0.819}$ [e]
	Ciliate (4 groups)		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)

Courtesy of M. Rembauville

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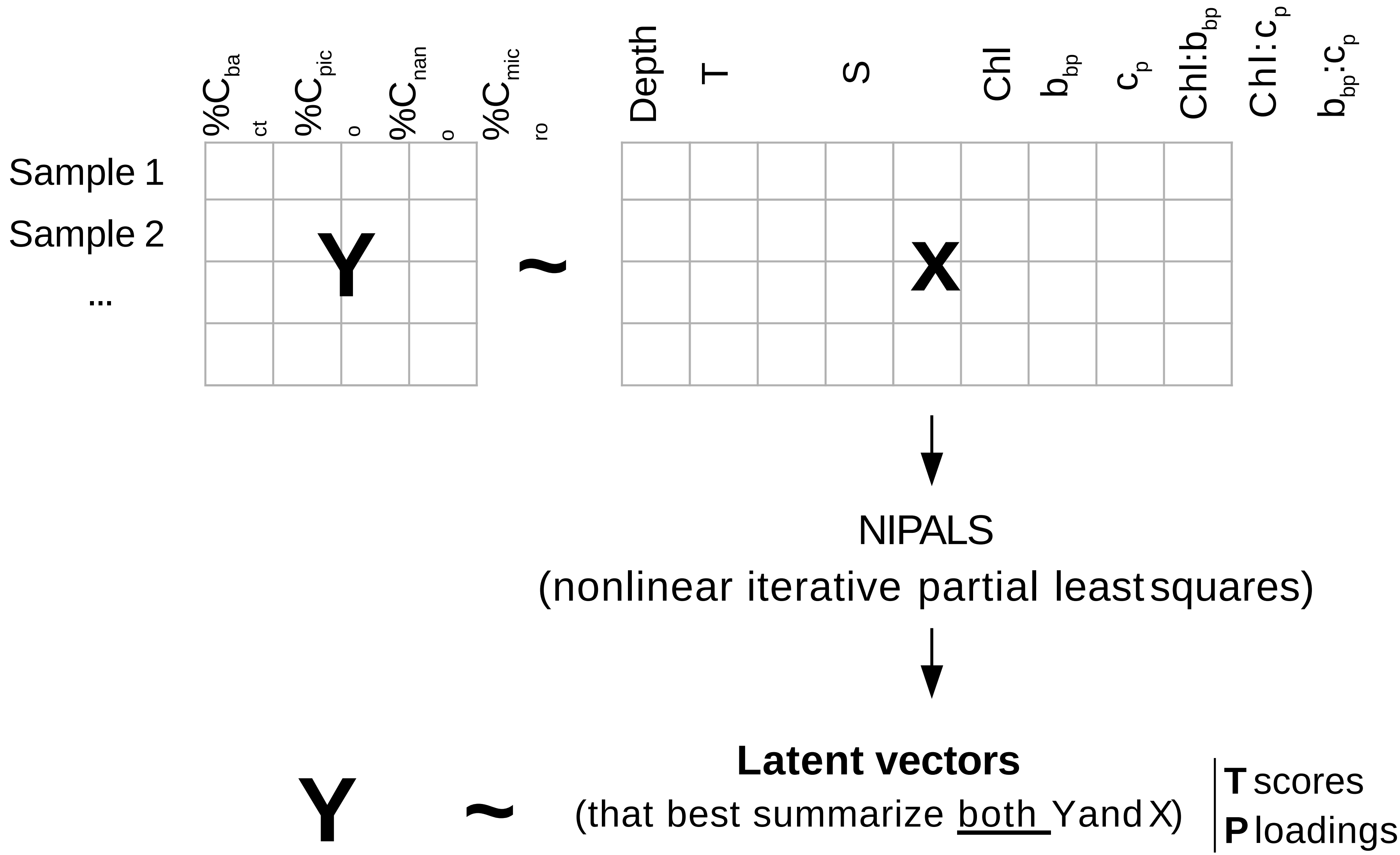

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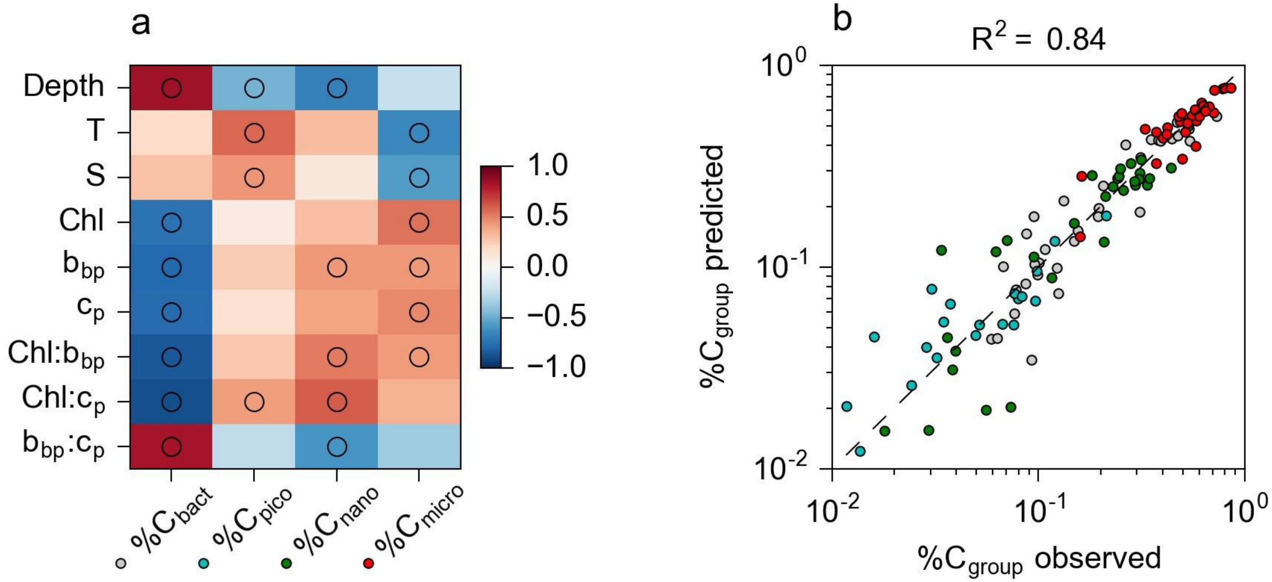
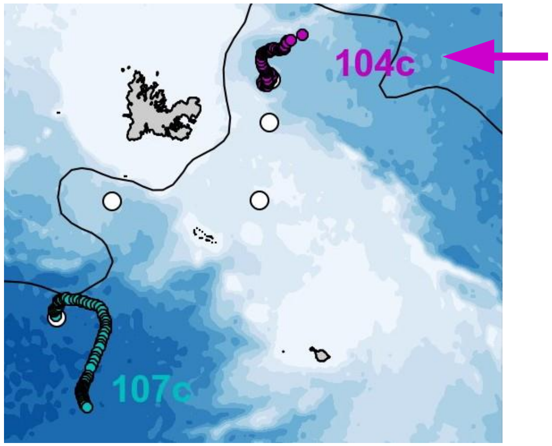


NIPALS (nonlinear iterative partial leastsquares)

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

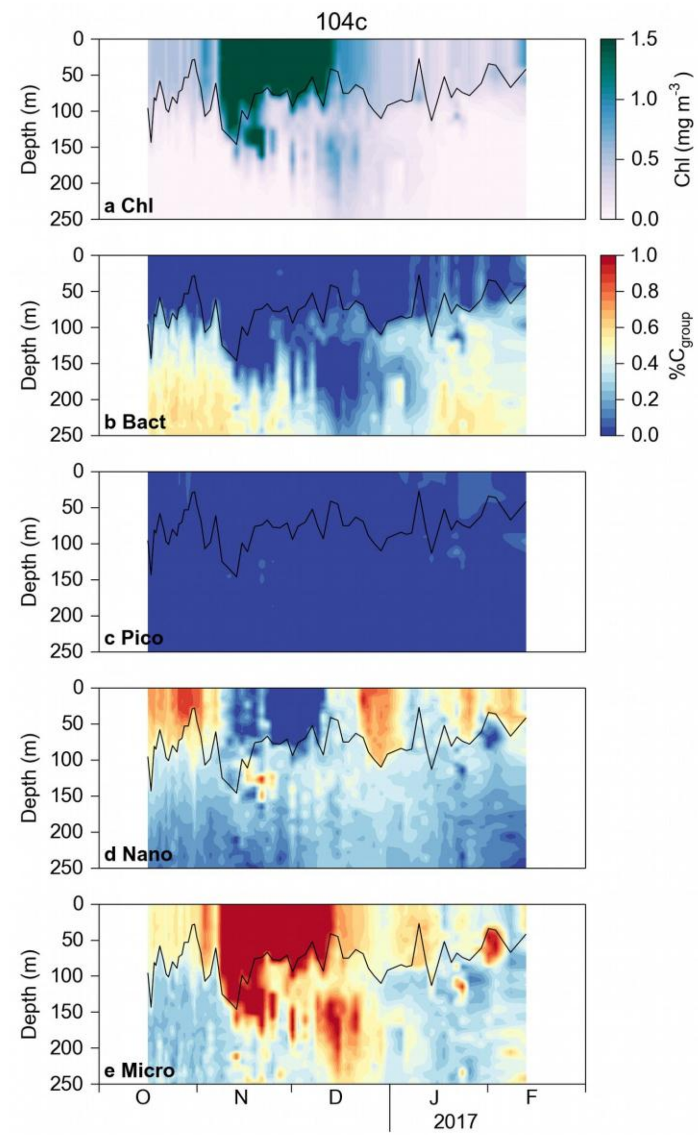
Courtesy of M. Rembauville

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



Float 104c

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



Courtesy of M. Rembauville

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

Outline: CNES proposal

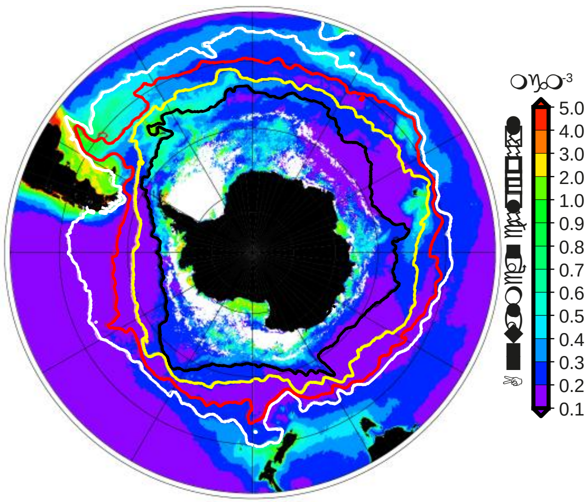
Capturing phytoplankton dynamics in the Southern Ocean: *From satellite to BGC floats*

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

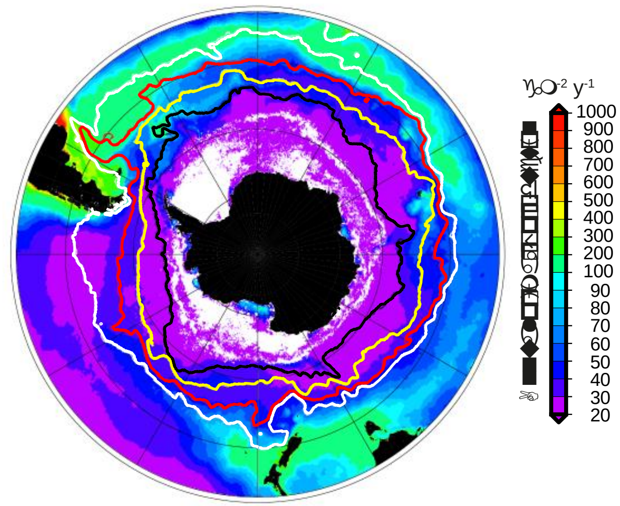
2. Characterizing regional specificities in the vertical distribution/phenology/productivity of phytoplankton communities using BGC-Argo data

Phytoplankton dynamics in the Southern Ocean

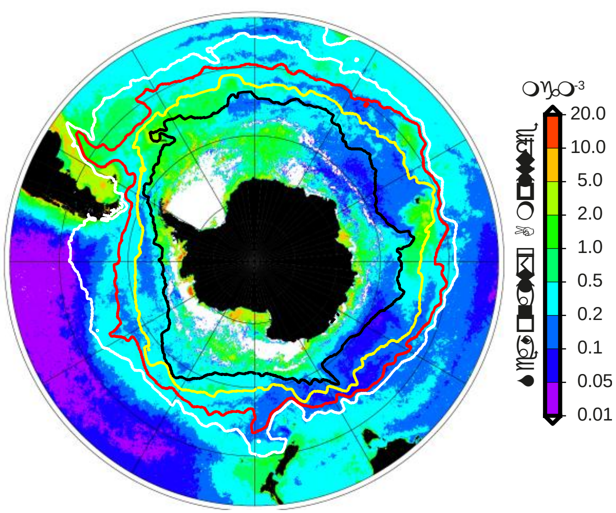
Mean annual chlorophyll (mg m^{-3})



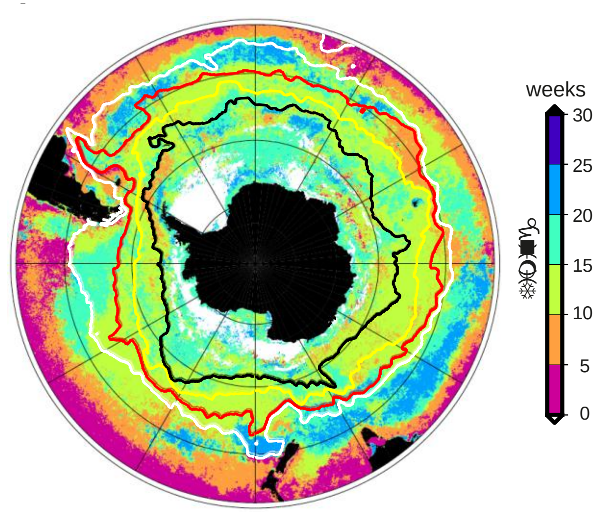
Annual primary production (g C m^{-2} y^{-1})

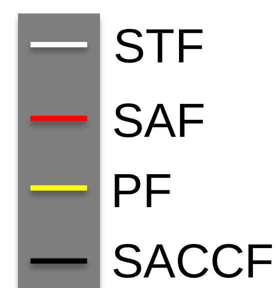


Seasonality - Amplitude (mg m^{-3})



Maximum timing bloom (wks)

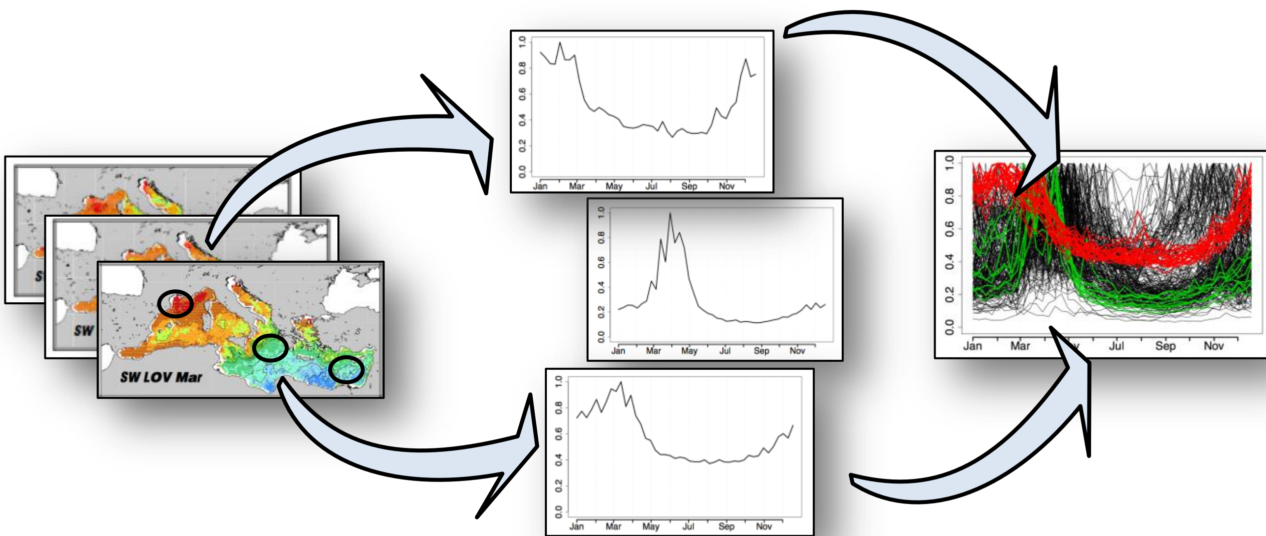


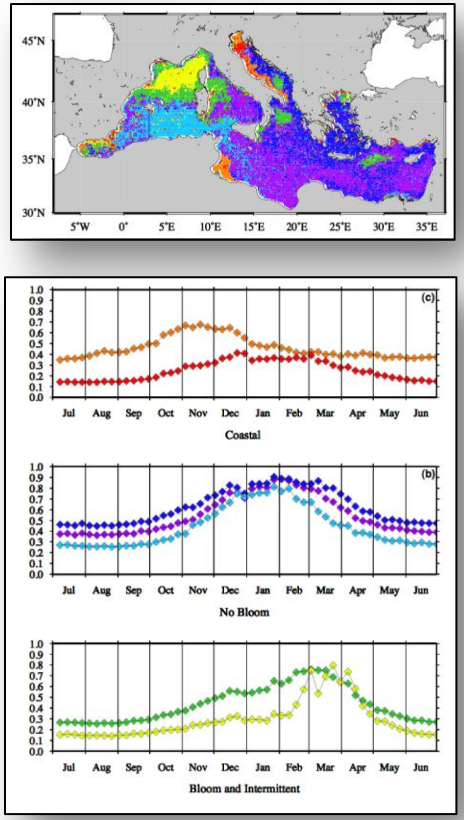


Phytoplankton phenology in the Southern Ocean

<u>Biogeographic-derived analysis:</u> Cluster K-means analysis

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



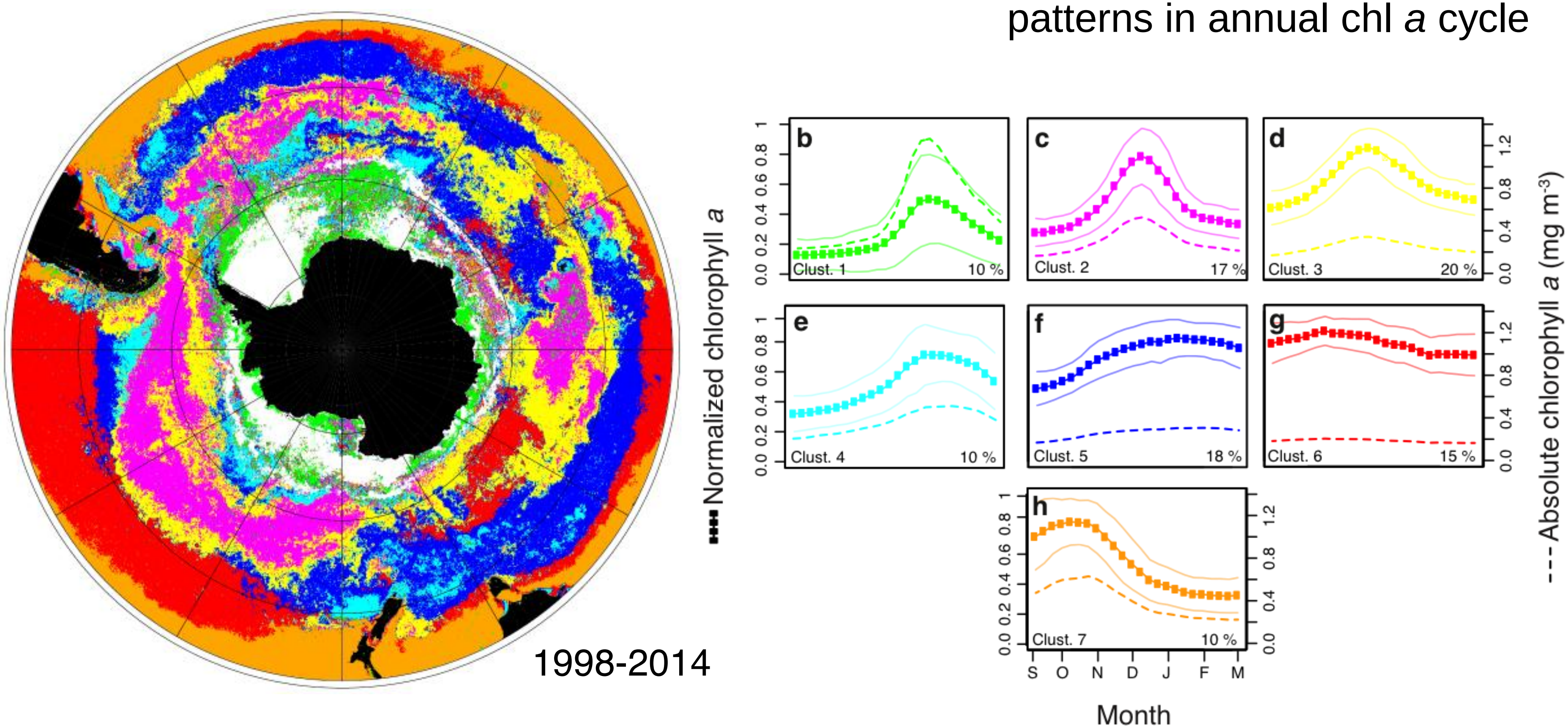


Applied in the Mediterranean Sea, the North Altantic and at the global scale.

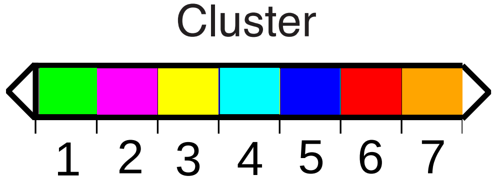
Courtesy of F. D'Ortenzio

Phytoplankton phenology in the Southern Ocean

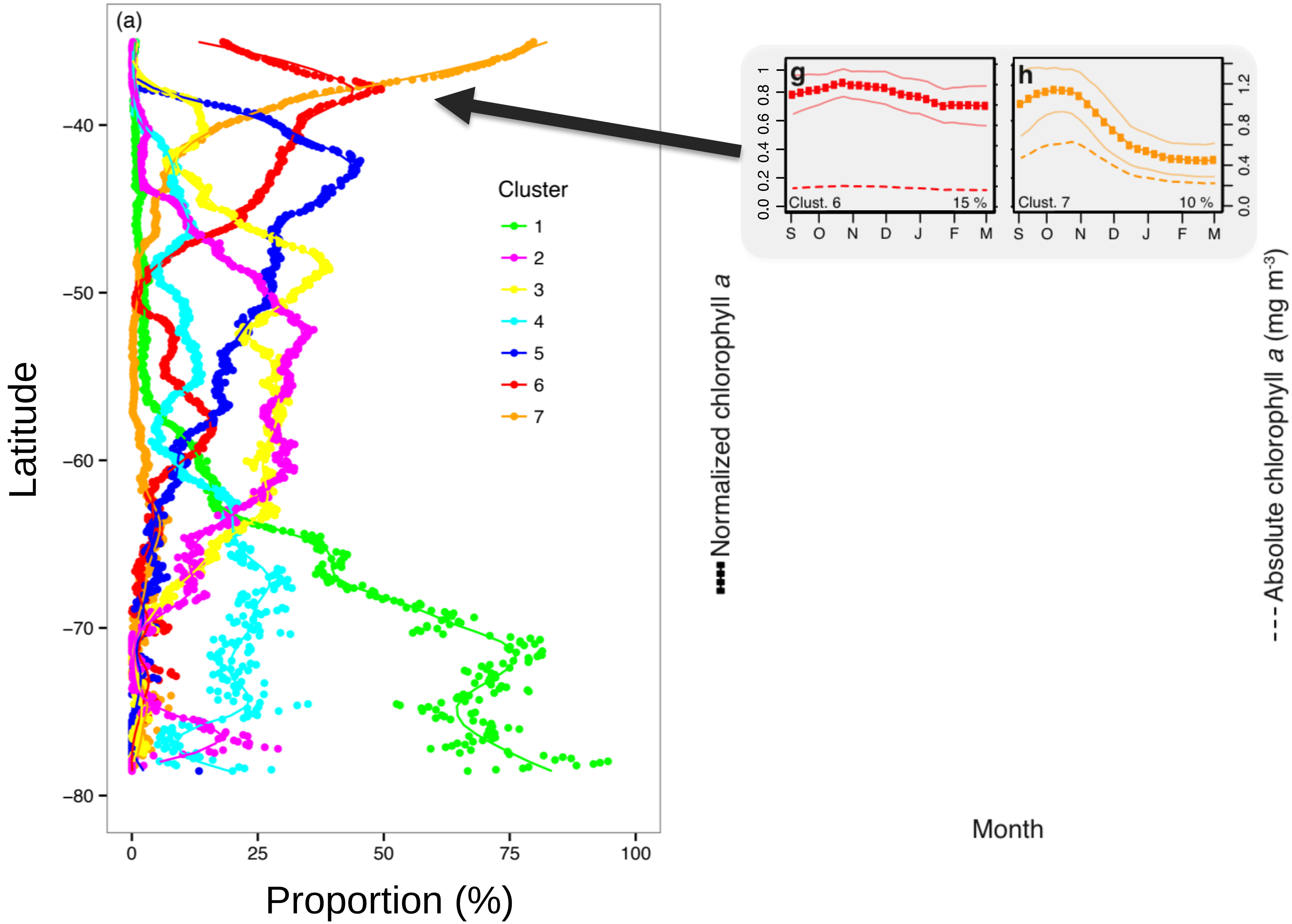
Cluster K-means analysis: 7 distinct bio-regions based on similar large-scale patterns in annual chl *a* cycle



Satellite-derived product:
GLOBCOLOUR 8-day



Phytoplankton phenology in the Southern Ocean



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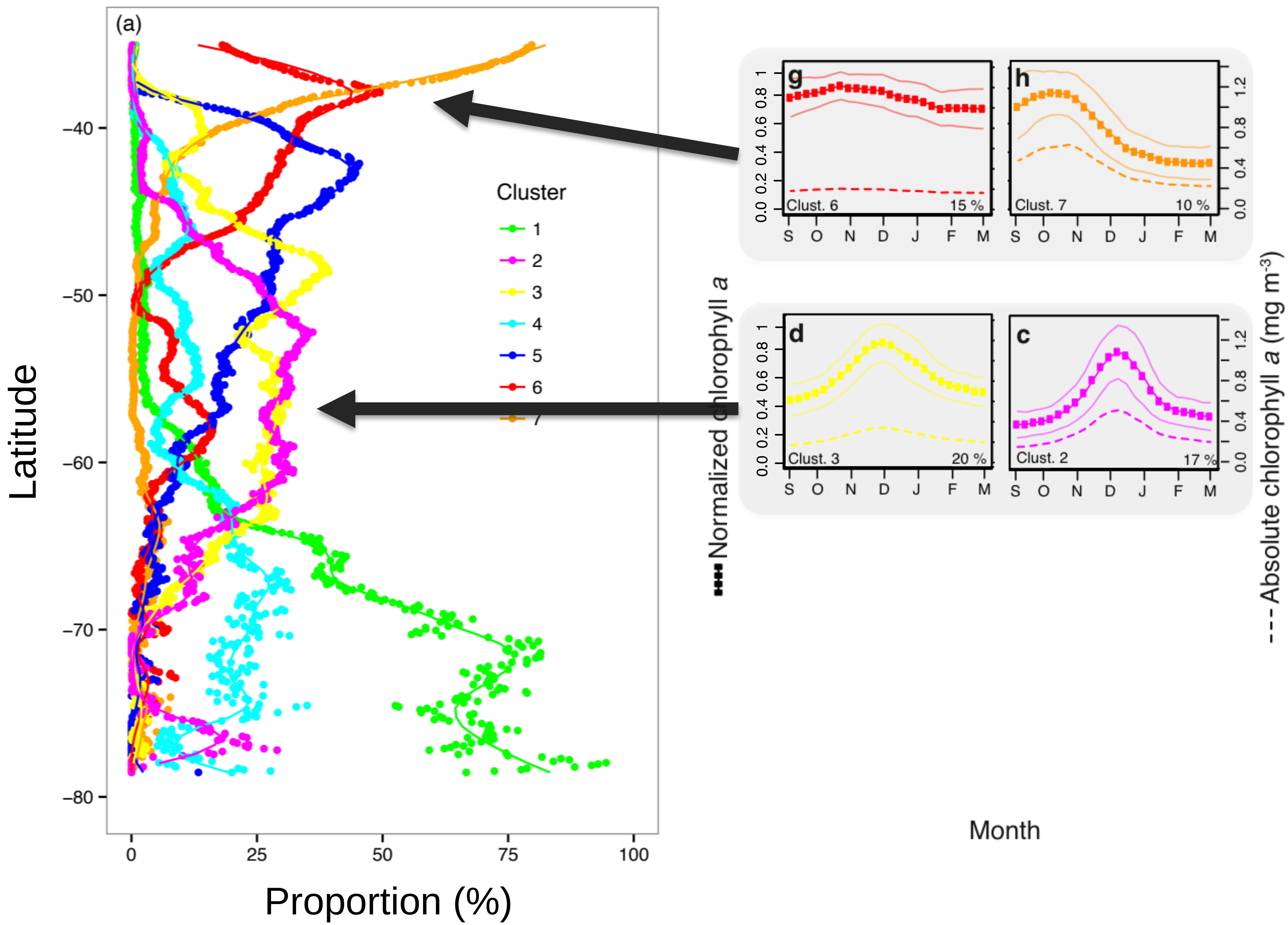

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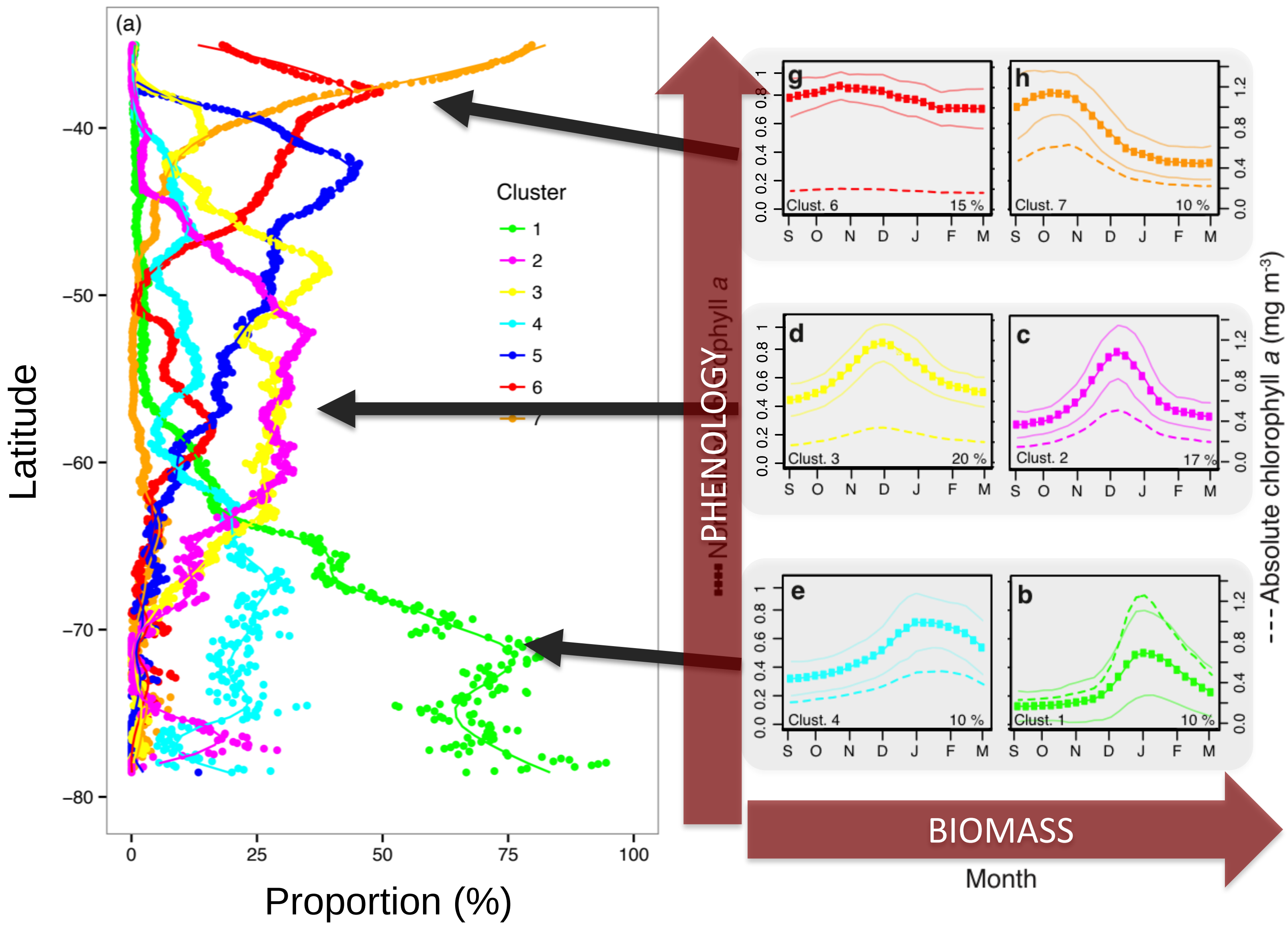

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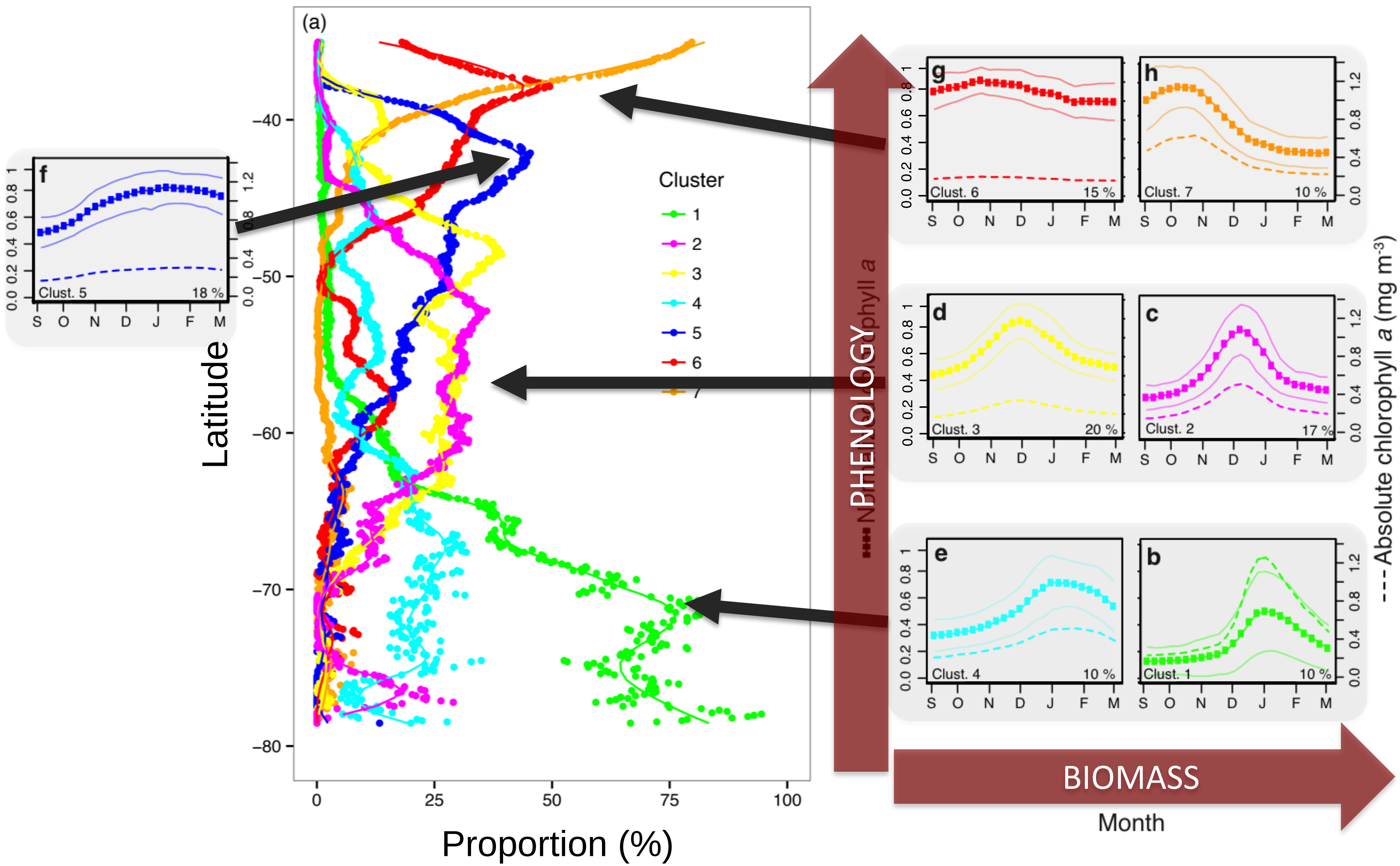
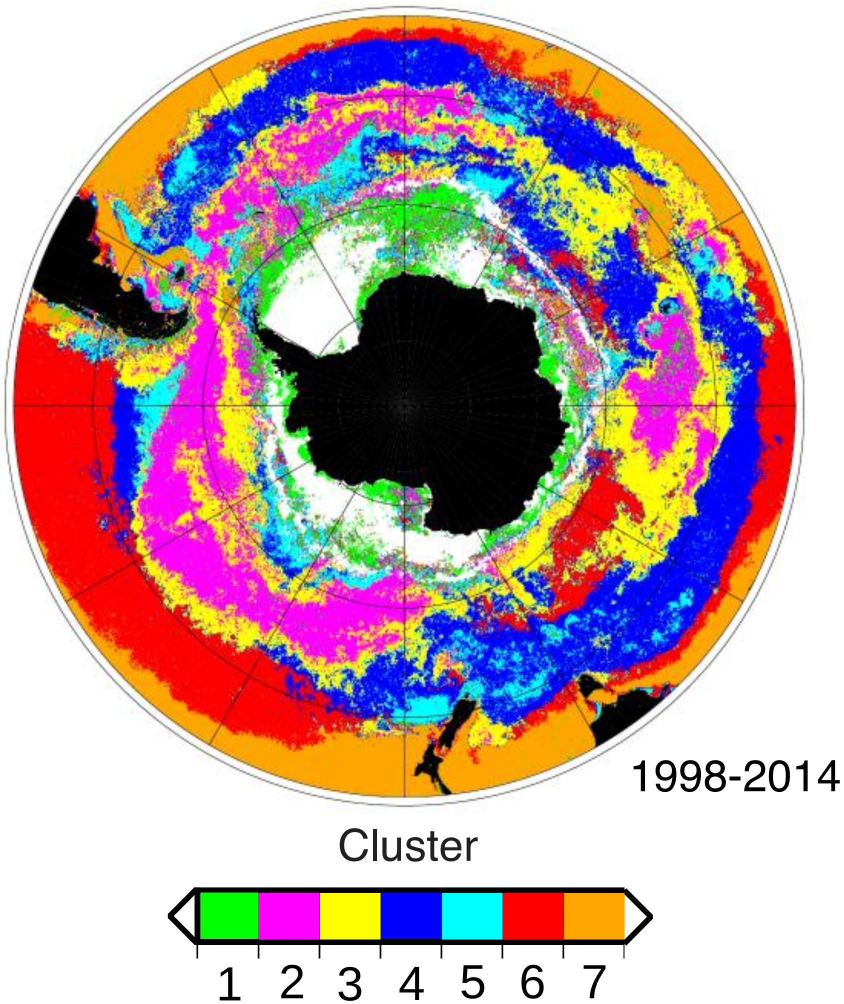
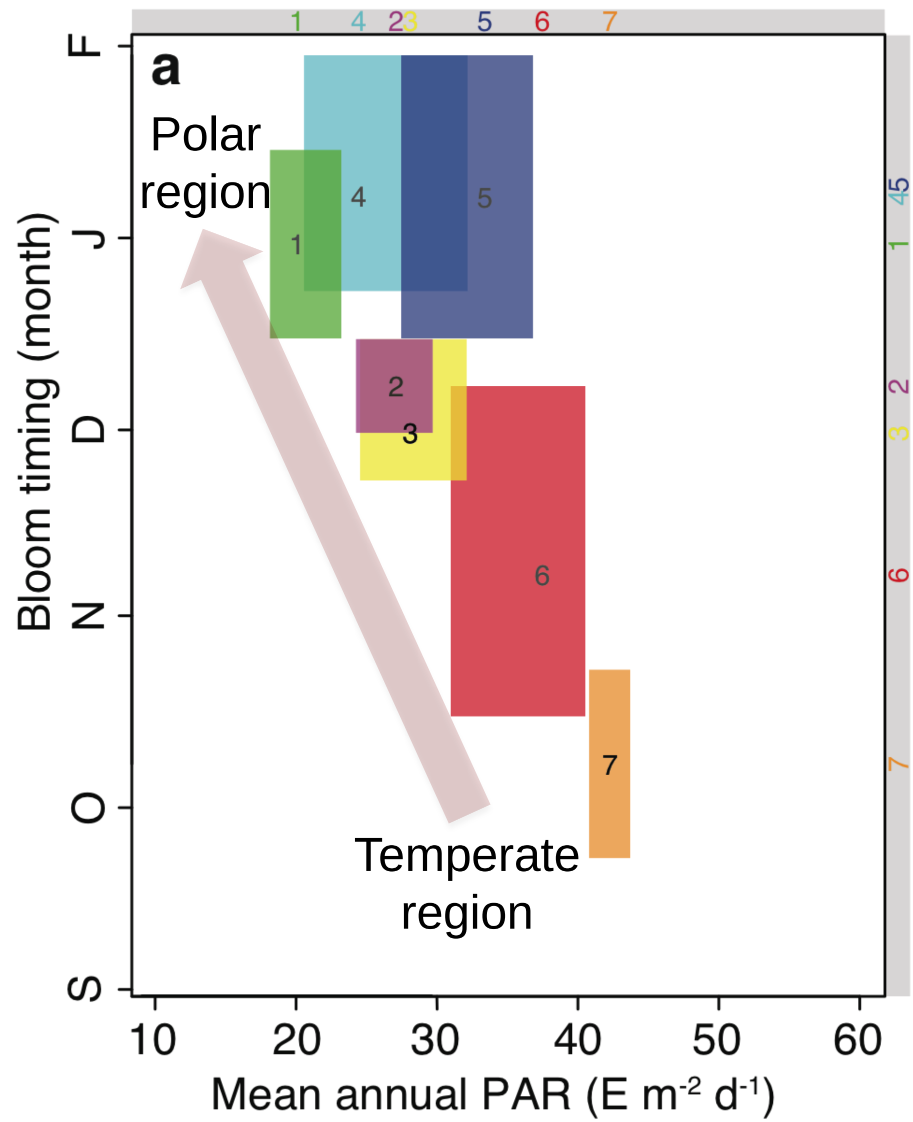


Phytoplankton phenology in the Southern Ocean

Biogeographic-derived analysis

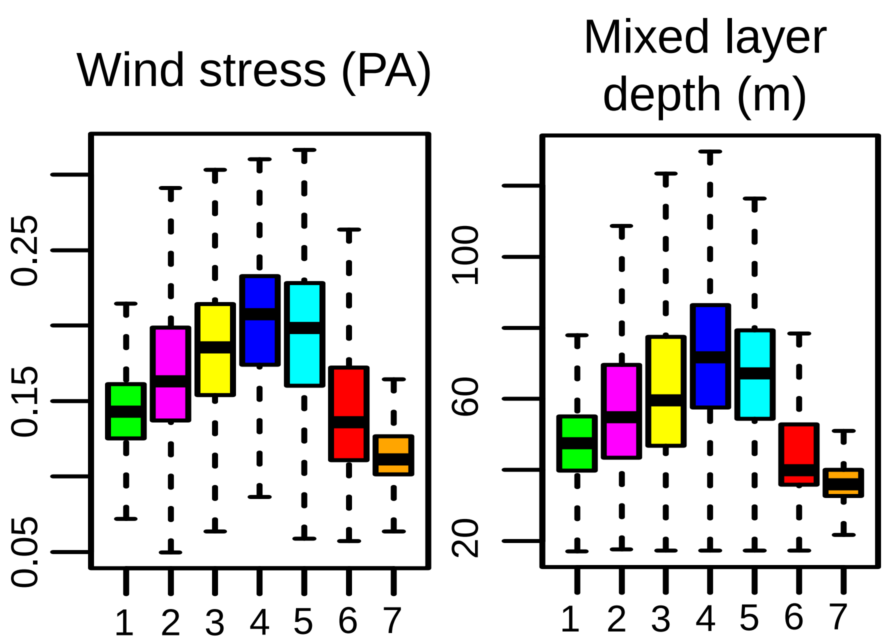
(D'Ortenzio & Ribera d'Alcalà 2009)

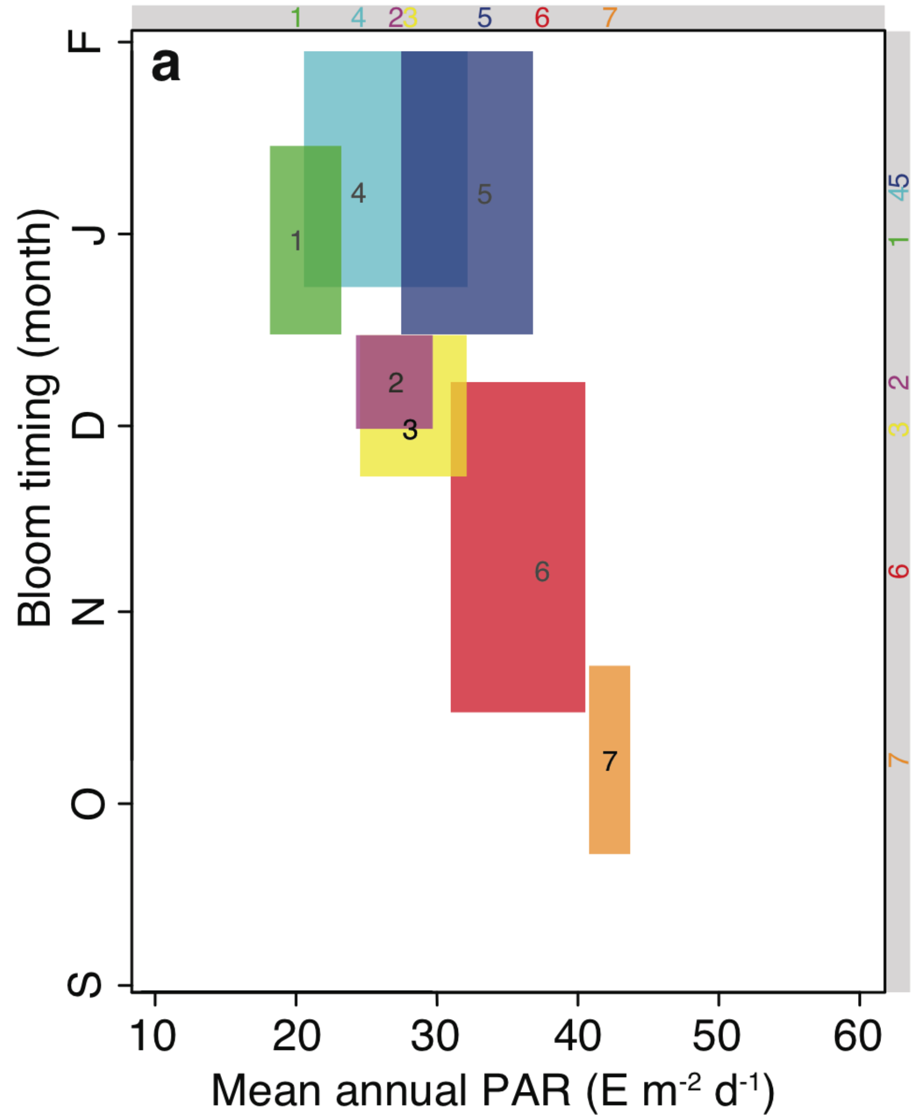




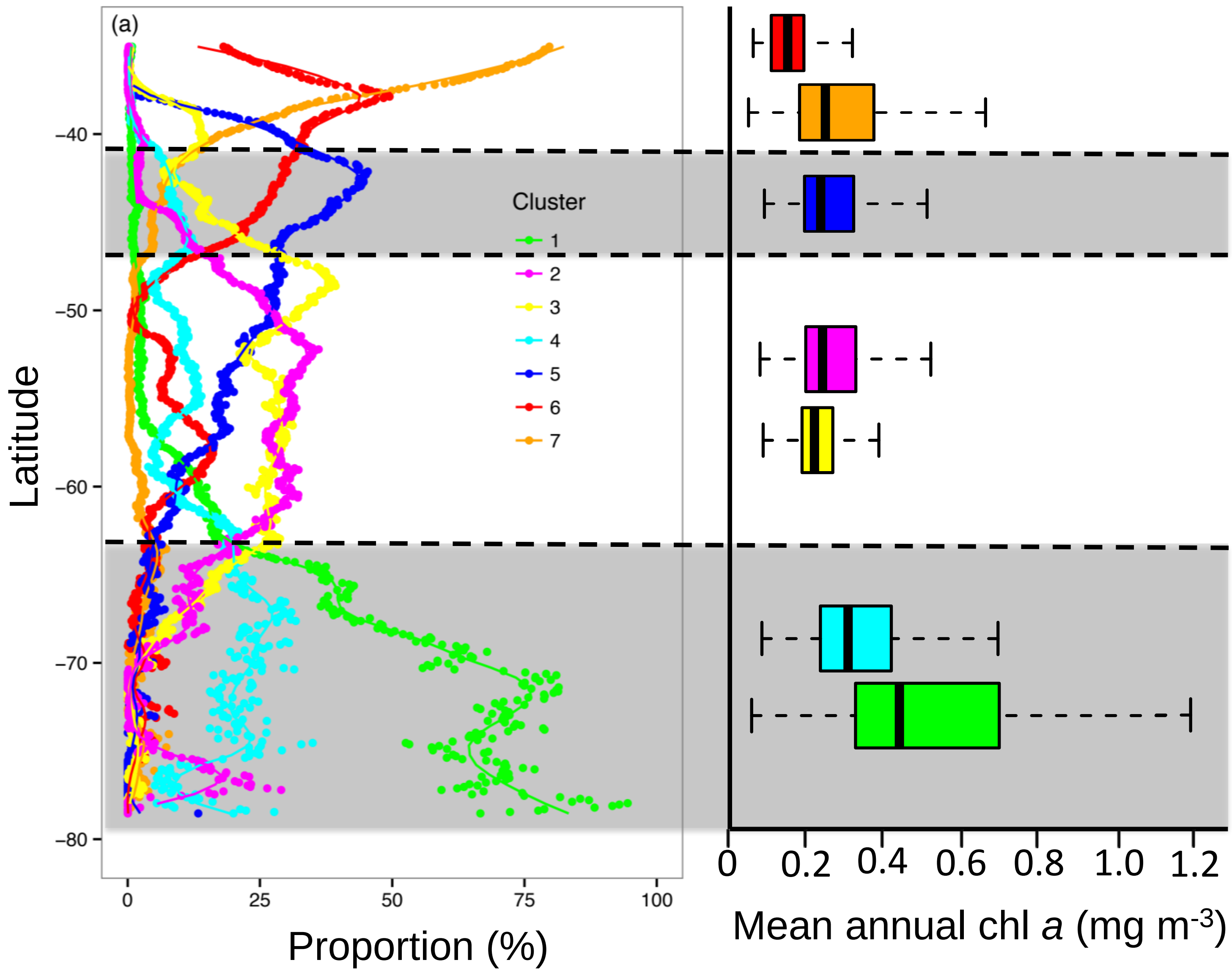
Phytoplankton phenology in the Southern Ocean

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





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:
(1) locally recharge the surface-layer in iron (climatology)

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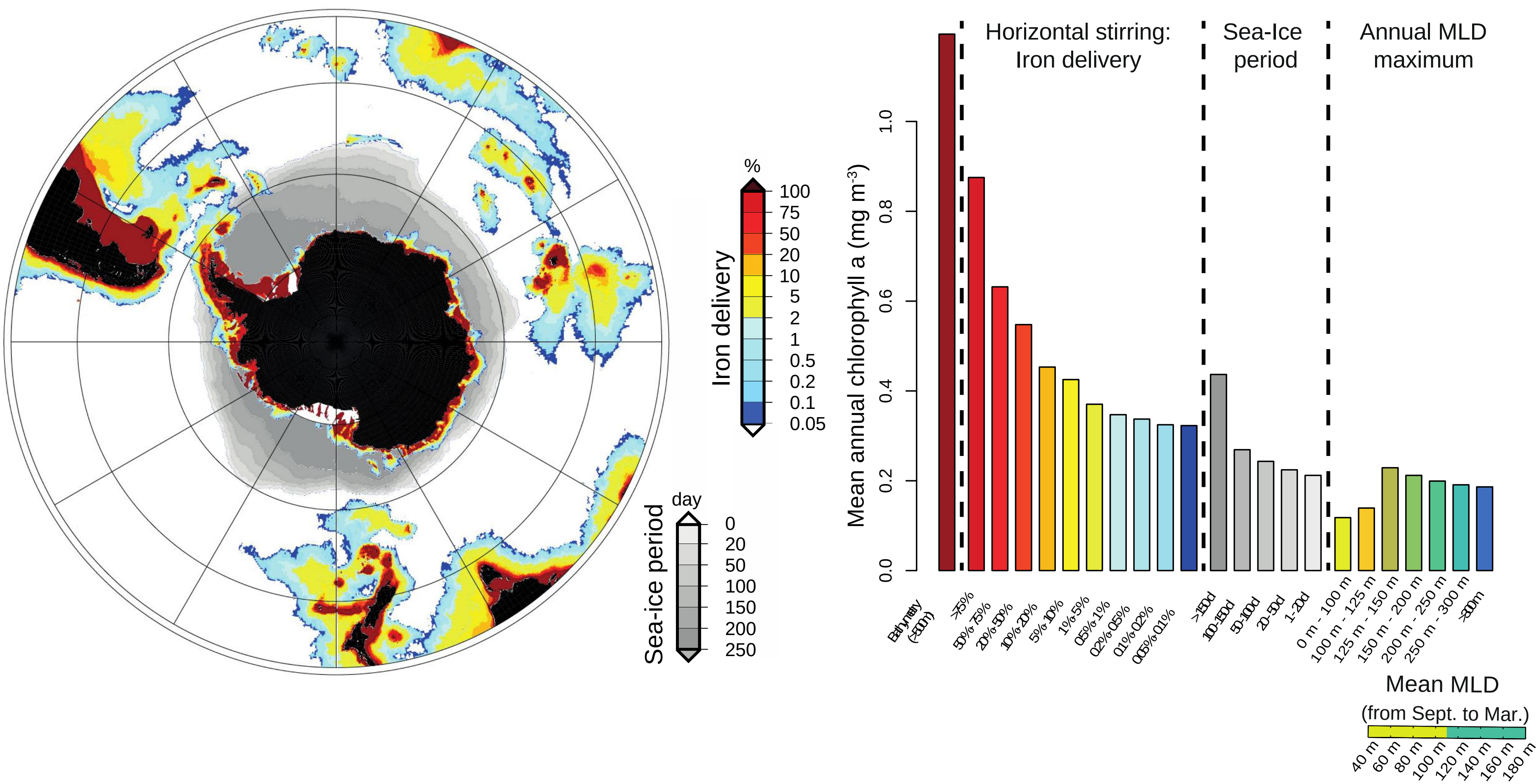
(4) **vertical mixing through deep convection**, which can entrain iron from deep water (climatology).

IMPACT OF IRON SUPPLY MECHANISMS ON PHYTOPLANKTON BIOMASS

<u>Combining satellite, Argo floats and lagrangian modeling</u>

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



Findings of this study

- Clear decoupled environmental control of phytoplankton biomass and phenology in the Southern Ocean.

Ardyna, M., H. Claustre, J.B. Sallée, F. d'Ovidio, B. Gentili, G.L. van Dijken, F. D'Ortenzio, and K. Arrigo, Delineating environmental control of phytoplankton biomass and phenology in the Southern Ocean. *In review in GRL.*

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- Clear decoupled environmental control of phytoplankton biomass and phenology in the Southern Ocean.

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- 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.

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Annual phytoplankton cycles in Polar front Zone (PFZ)