The effect of modelling mechanistically phytoplankton photophysiology on the seasonal cycle of primary production in polar regions

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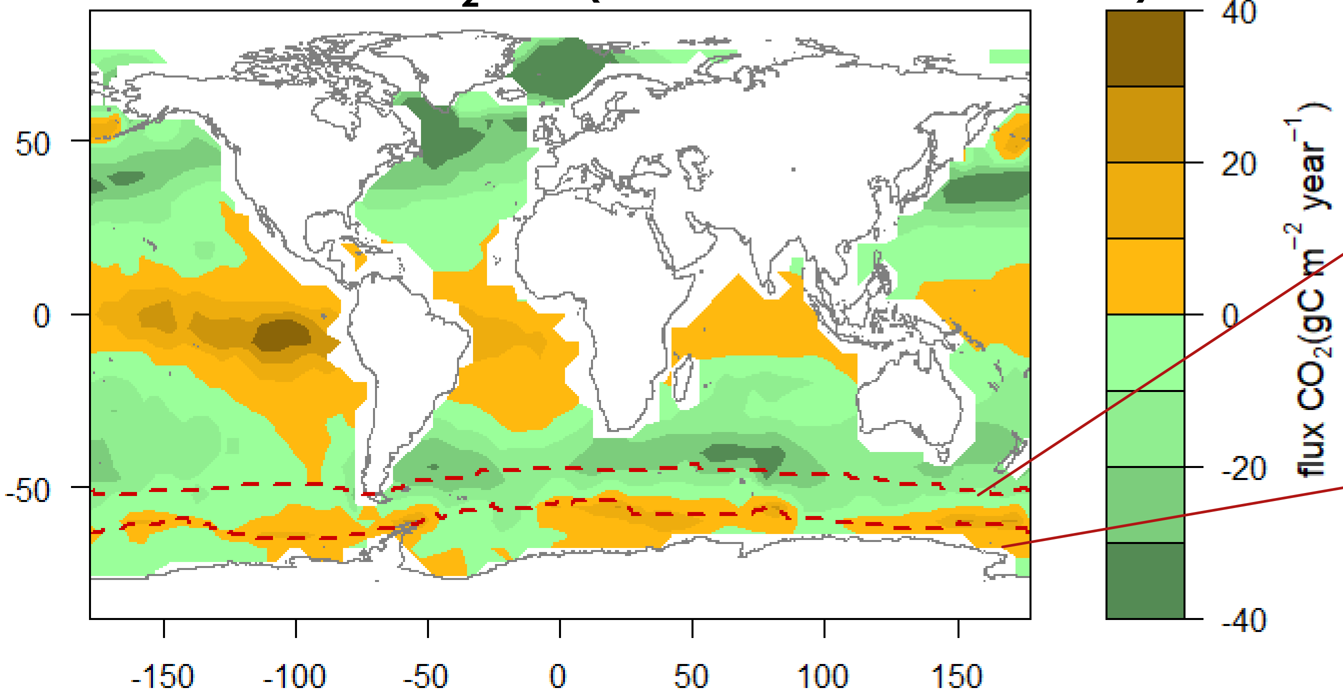
Seasonal Cycle of air-ocean CO_2 flux in Polar and Sub-polar Biomes

Polar regions, in particular the Southern Ocean, play a key role in sea-air CO_2 exchange.

Total annual CO_2 flux (Takahashi et al. 2009 DRPart II)



- - - - Defined by mean biomes proposed by Fay et al. 2014 ESSD

Sub-Antarctic Zone

~46-60°S

SST < 8°C

↓ Carbon uptake

Antarctic Zone

>60°S

ICE coverage > 50%

↑ Outgassing

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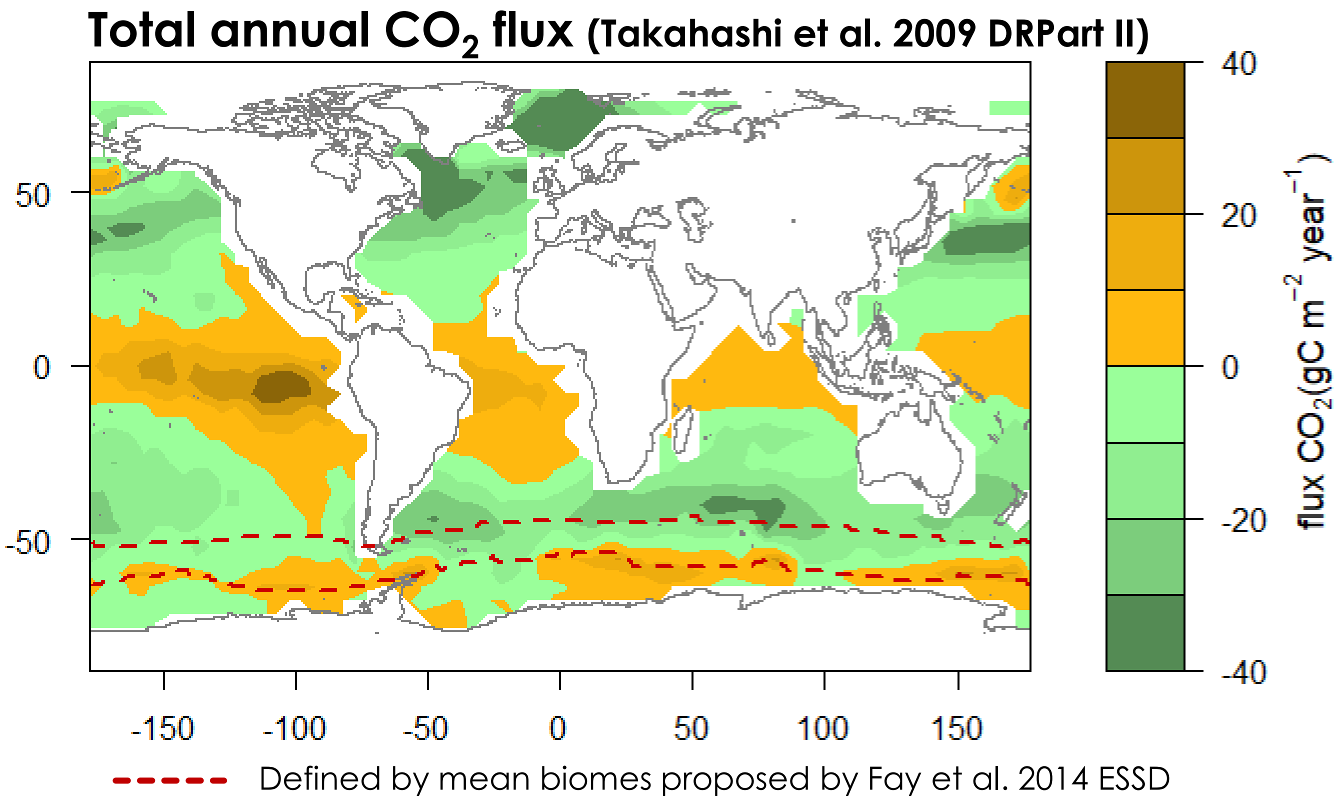
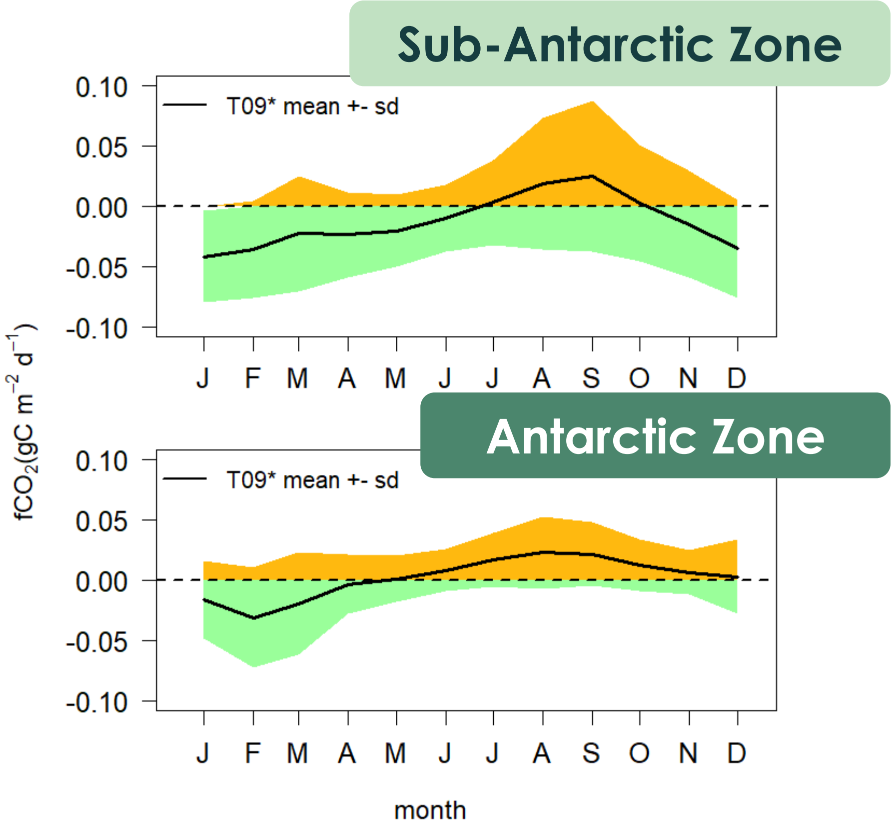
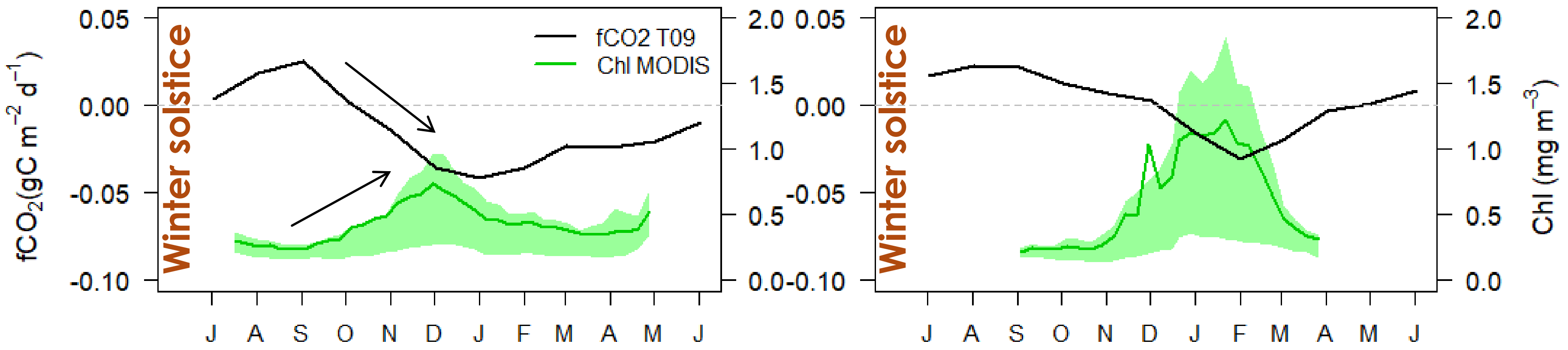




The seasonal cycle of air-ocean CO_2 flux shows phases of net flux of carbon into the atmosphere (outgassing) and net ocean carbon uptake.

Seasonal Cycle of Primary Production in the Southern Ocean

The relative importance of both phases and hence the total annual flux depends on the interaction of physical, chemical and **biological mechanisms**.



Accurate description of the phasing and amplitude of the **cycle of primary production** is crucial for evaluating the strength of the CO_2 sink in the Southern Ocean.

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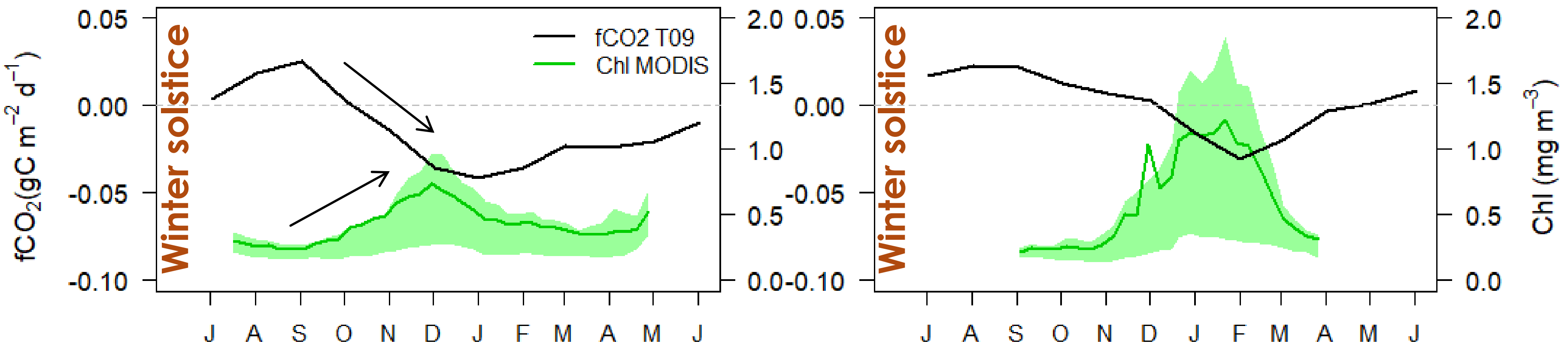

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Common bias in the modelling of the seasonal cycle of PP in the SO:

Mongwe et al, 2016 OM, 2018 BGS

- too early onset
- too fast accumulation
- not sustained blooms through the summer

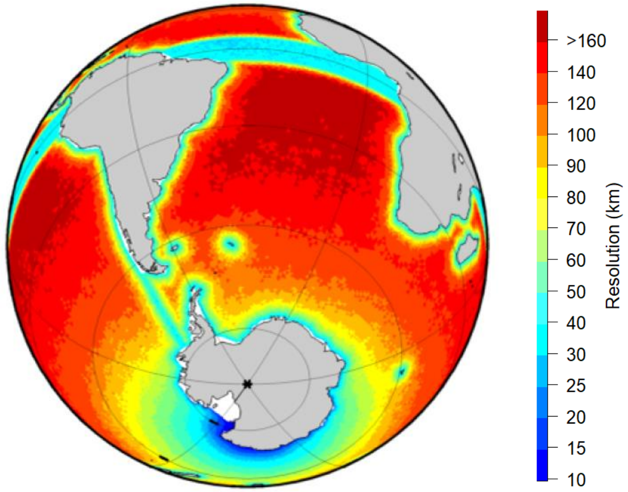
Does photo-physiology of phytoplankton impact the seasonal cycle of primary production?

Sea ice-ocean and ecosystem model

FESOM (**F**inite-**E**lement/volume **S**ea ice-**O**cean **M**odel)

Multi-resolution sea ice-ocean model that solves the equations of motion on unstructured meshes.

- Atmospheric forcing: **JRA55** and **CORE2**.
- Spin up: 2000-2010
- 2011 8-daily output

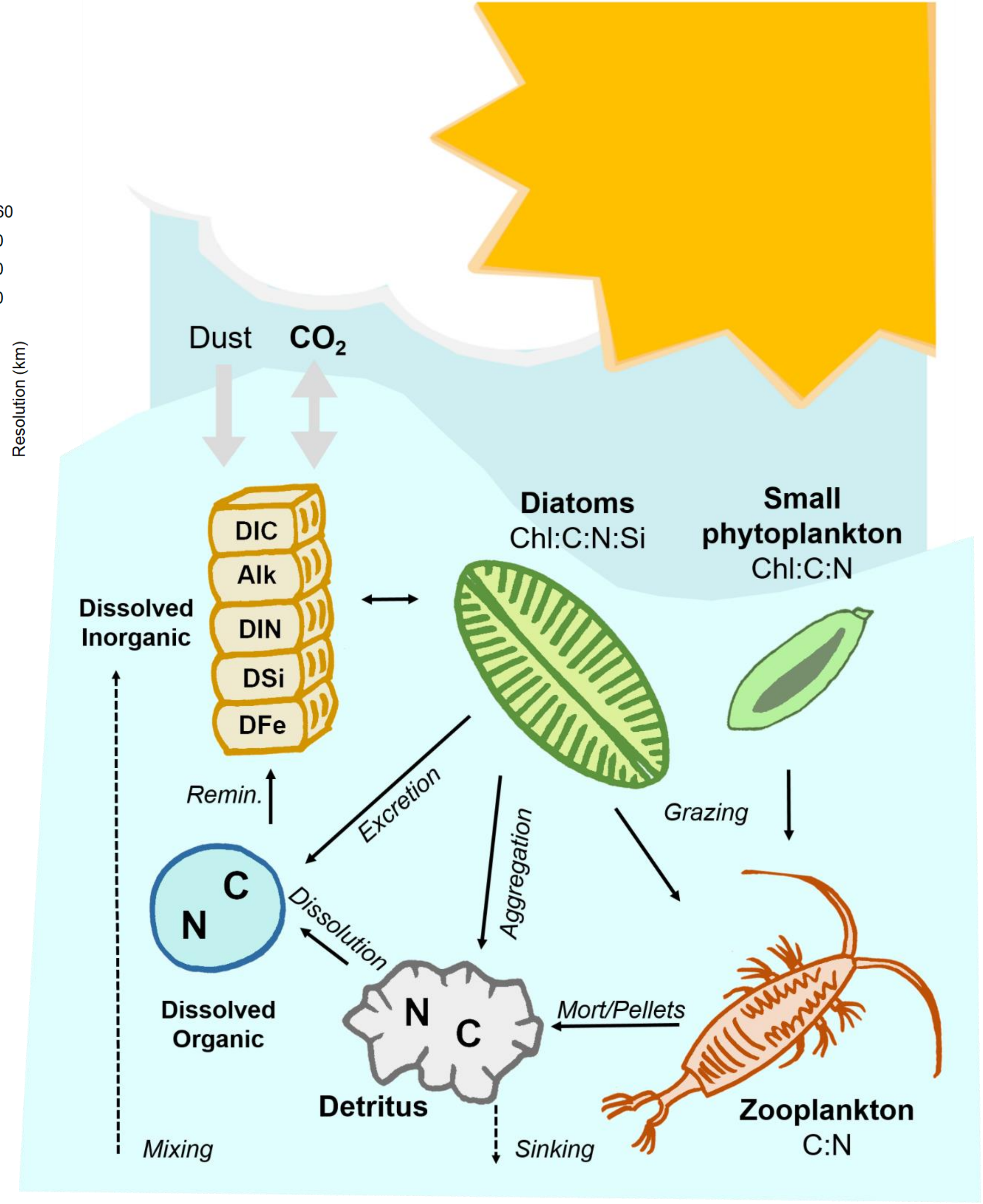


Schourup-Kristensen et al, 2014 GMD

REcoM2 (**R**egulated **Eco**system **M**odel version2)

Quota-based biogeochemical model that carries:

- 21 tracers
- DIC and alkalinity for the carbonate system
- nutrients DIN, silica and iron
- two phytoplankton classes: **small phytoplankton** and **diatoms**
- one zooplankton group



Re-parameterizing the phytoplankton growth model

Primary production depends on the cellular quota of photosynthetic pigments (**Chl:C**).

Content of Chl increases by biosynthesis that is regulated by a **photoacclimation** term.

Loss of Chl is generally consider as a **constant** or a temperature-dependent rate.

$$\frac{dChla}{dt} = Chla \times \left(Assimilation^{C}_{Chl} \times \frac{P}{\alpha\theta E} - \mathbf{constant} \right)$$

Nutrient limited

Light regulated

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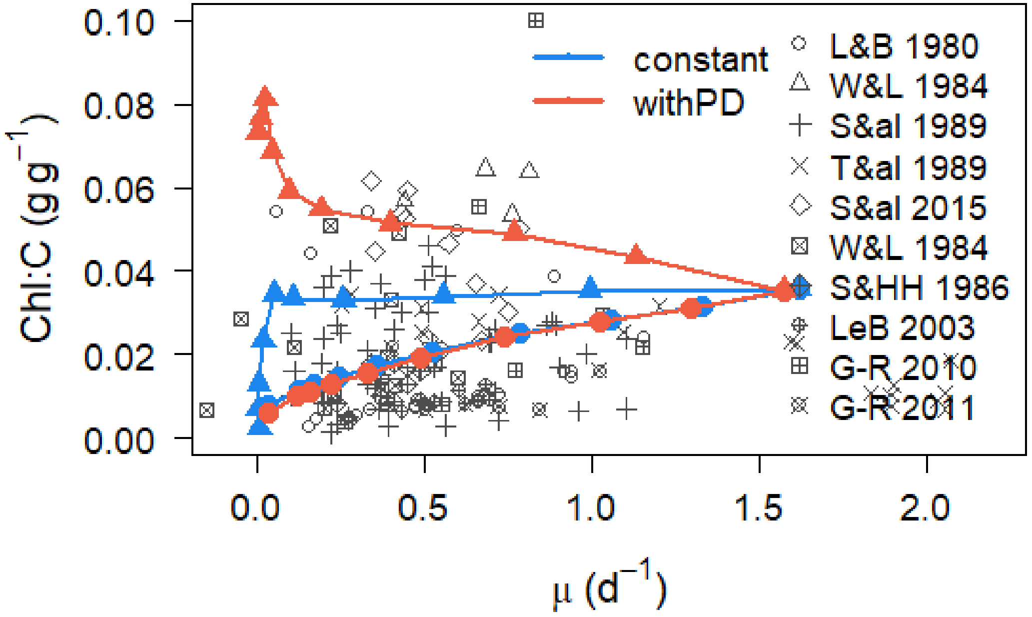
The loss of Chl was substituted by a term proportional to photosynthetic activity and hence, accounts for the light-dependent loss of photosynthetic pigments (**photodamage**).

$$\frac{dChla}{dt} = Chla \times \left(Assimilation_{Chl}^{C} \times \frac{P}{\alpha\theta E} - \mathbf{k}\left(\mathbf{1} - \mathbf{e}^{\frac{-\alpha\theta E}{P_{max}}}\right) \right)$$

$f(E, Chl:C)$

Re-parameterizing the phytoplankton growth model

Photodamage term (**PD**) subtracted from Chla production provided **Chl:C** ratios that responded to **nutrient** and **light** limitation in better agreement with observations.



Figures replotted from Álvarez et al, 2018 GBC

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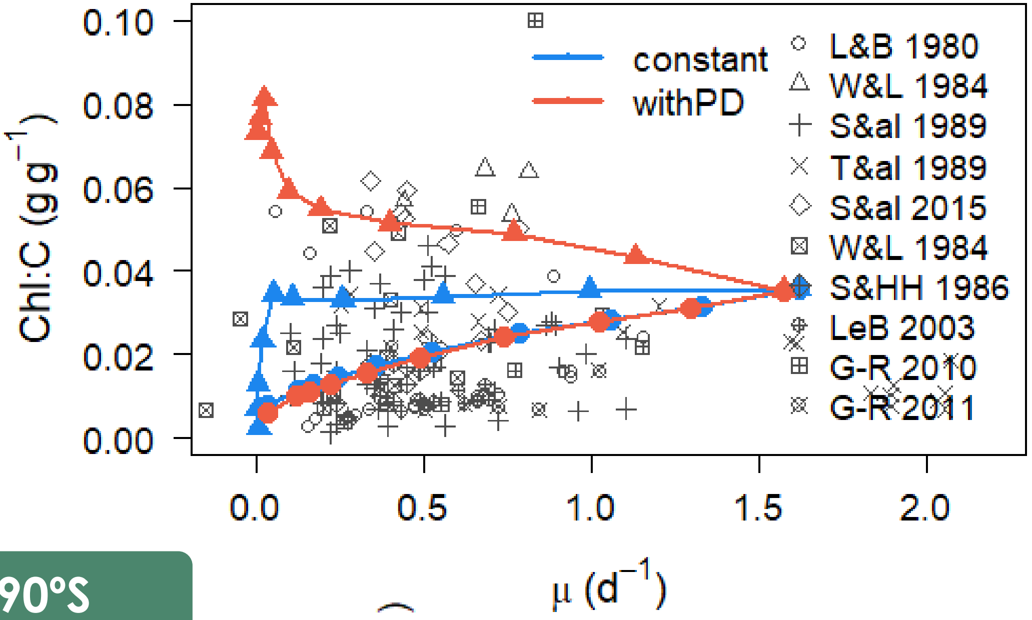
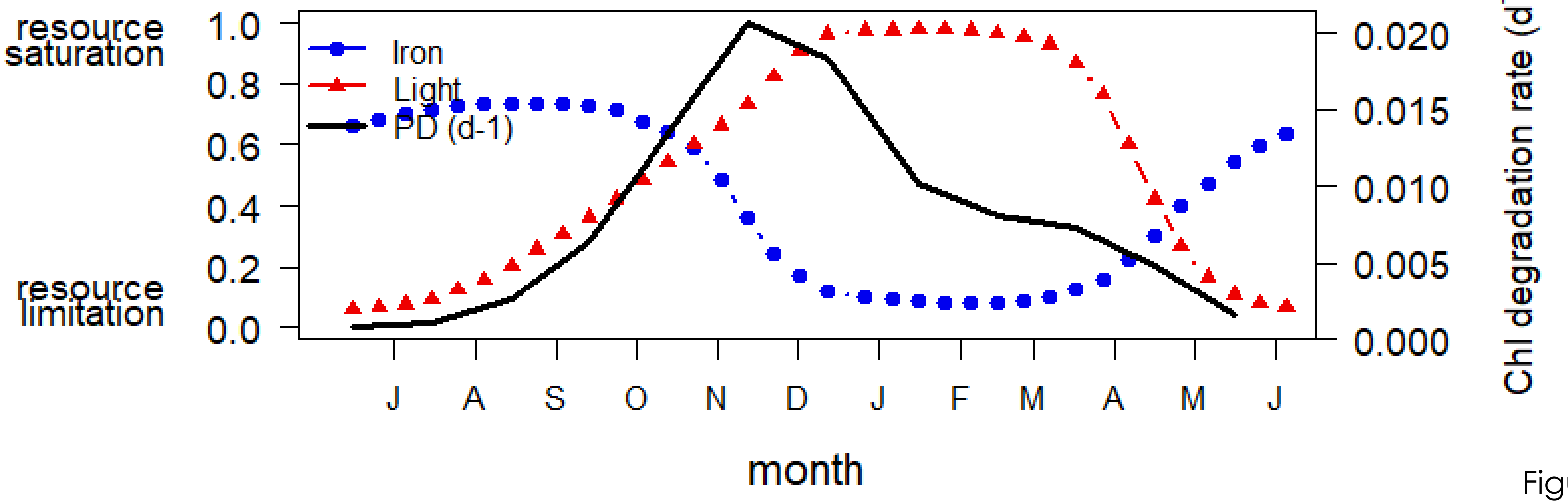
Also, the photodamage rate (d^{-1}) varied seasonally.



Southern Ocean 60-90°S



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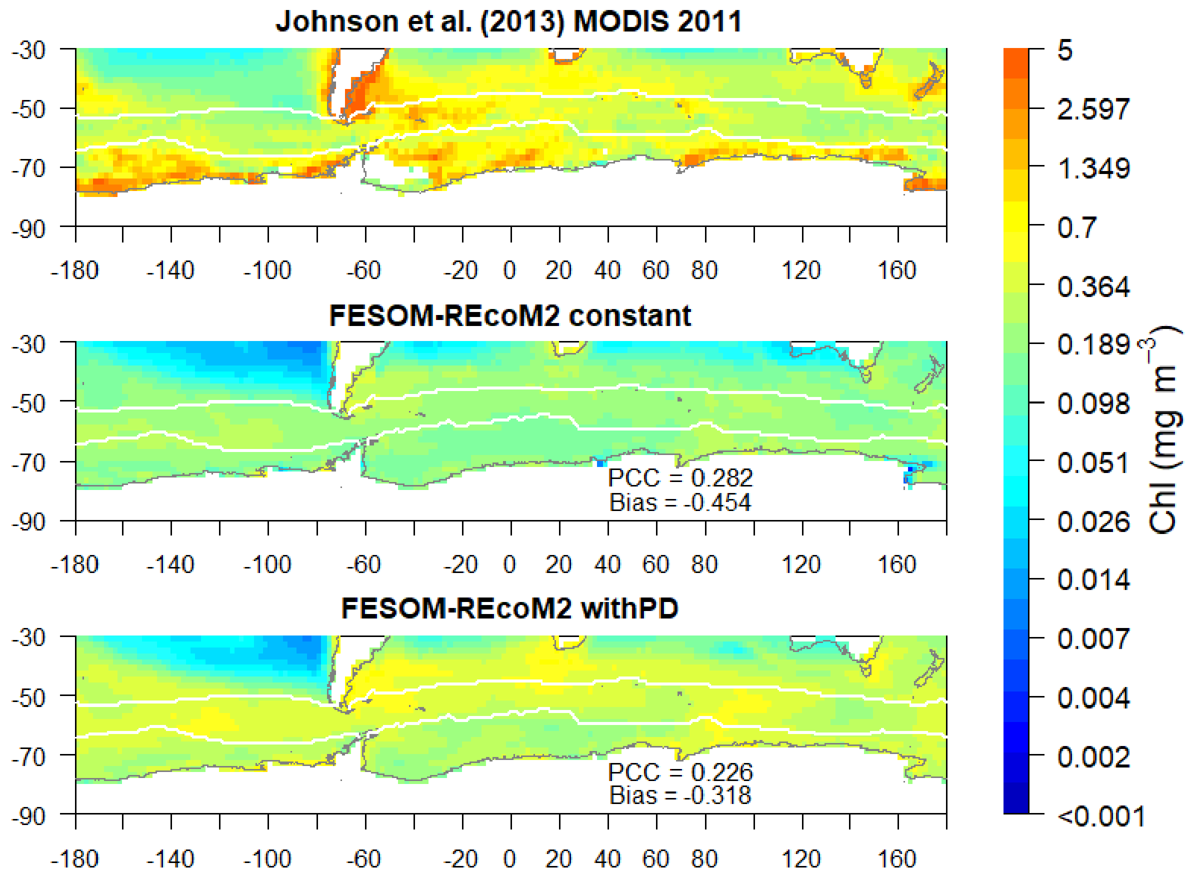
Annual mean and seasonal cycle of Chla

With photodamage (withPD) the annual mean concentration of **surface chlorophyll** increased in both biomes, SAZ and AZ. It was still too low in AZ compared to observations.



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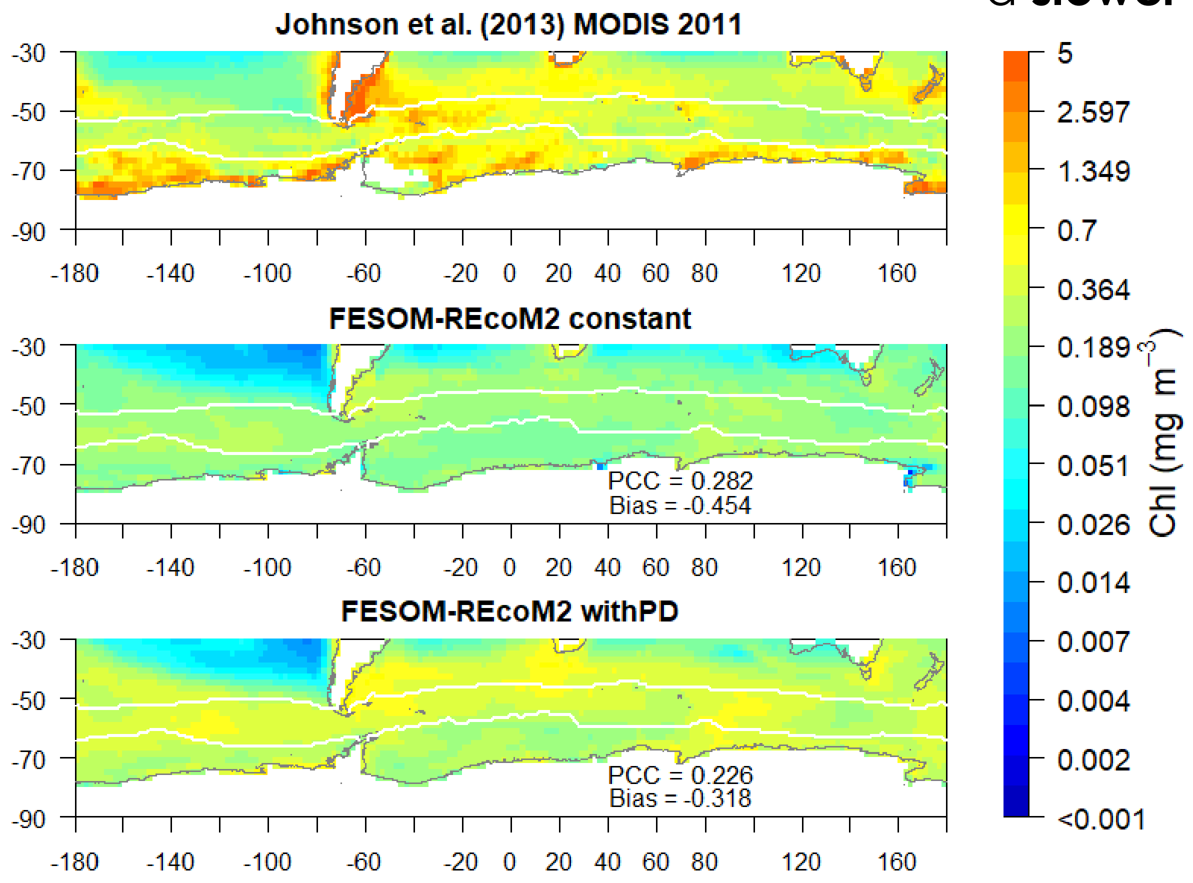
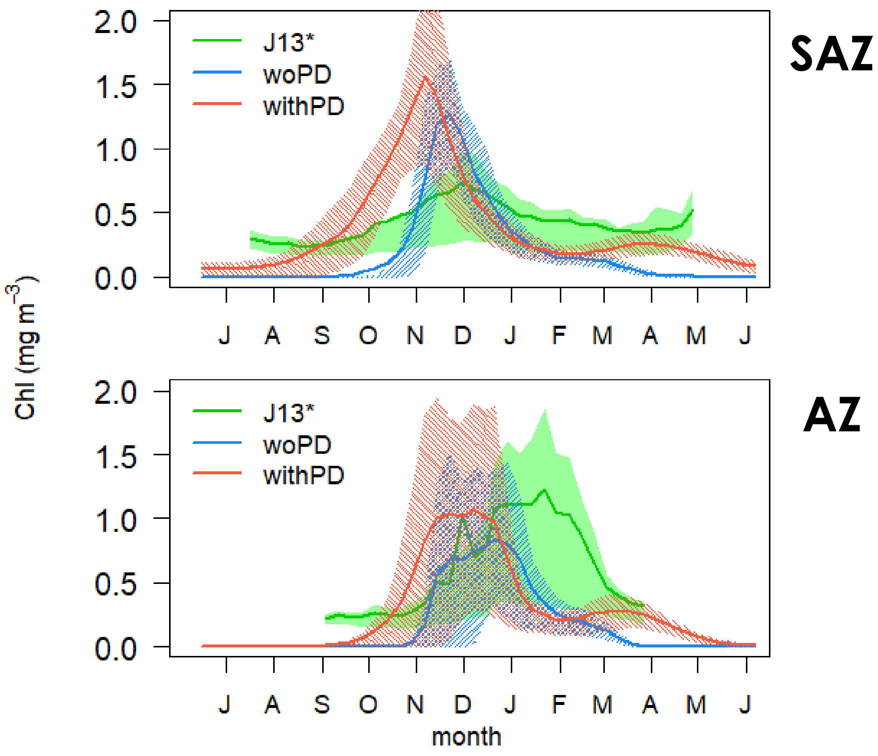
The productive season occurred early compared to observations but withPD the model simulated a **slower** growing phase and a **longer** growing period.





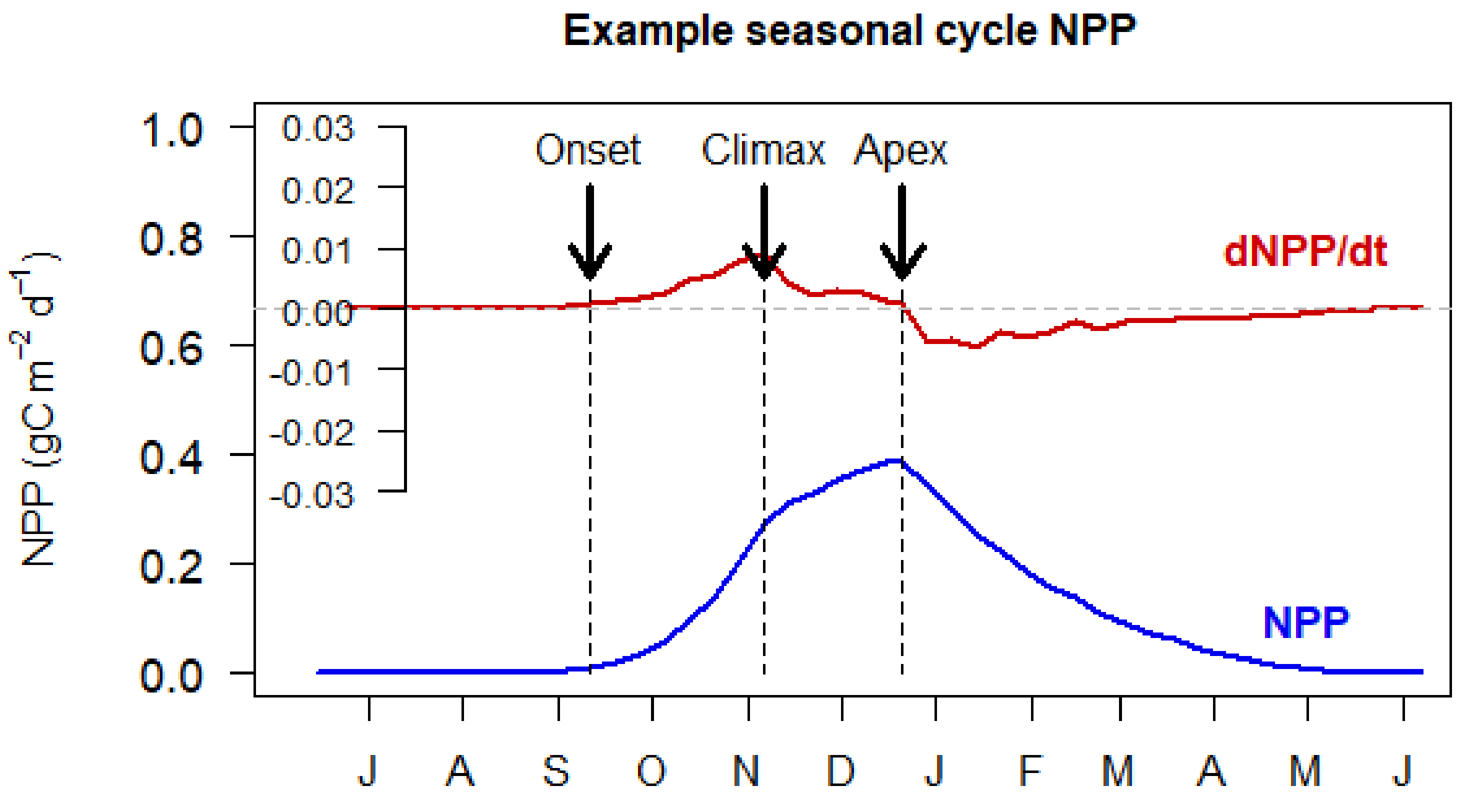
* Source: Johnson et al. (2013) MODIS 2011 + SO-specific algorithms

Development of the bloom: phenology indexes

The timing of the bloom was decomposed into three events following (Llort et al, 2015).

1. **ONSET**: NPP=min, dNPP/dt>0
2. **CLIMAX**: dNPP/dt=max
3. **APEX**: NPP=max, dNPP/dt=0

Chl (mg m^{-3})
NPP (gC m^{-2} d^{-1})
dNPP/dt



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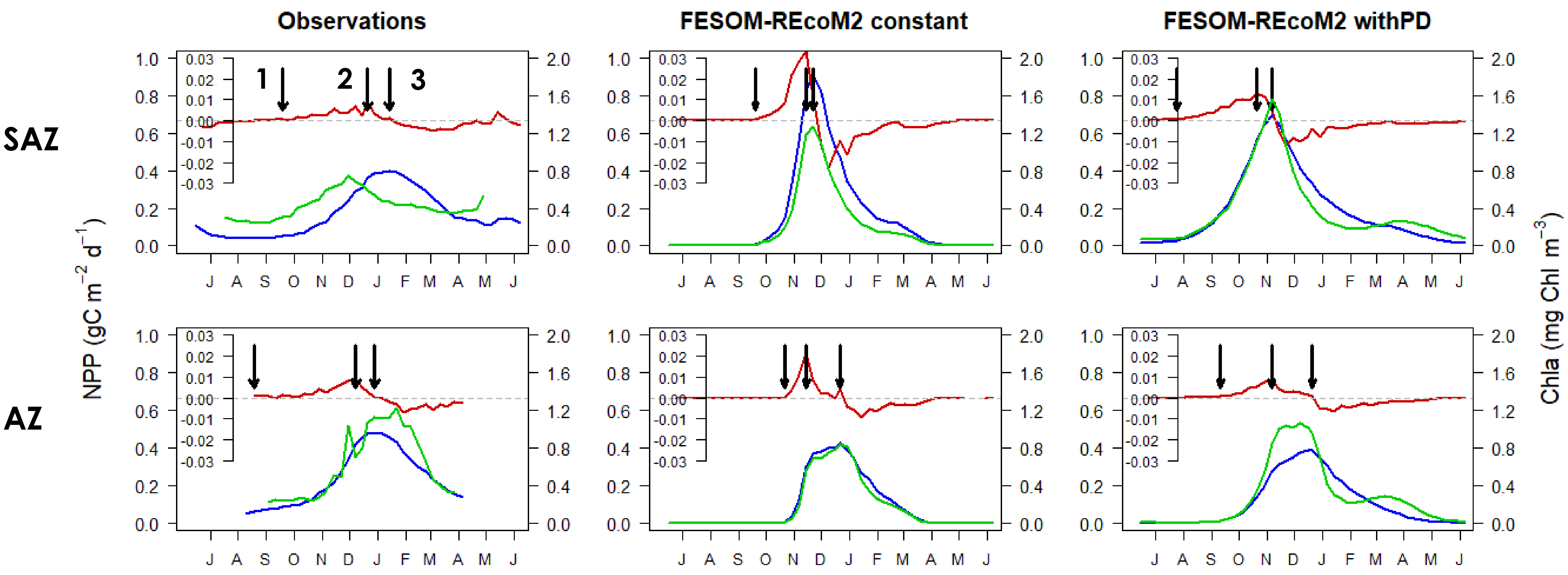

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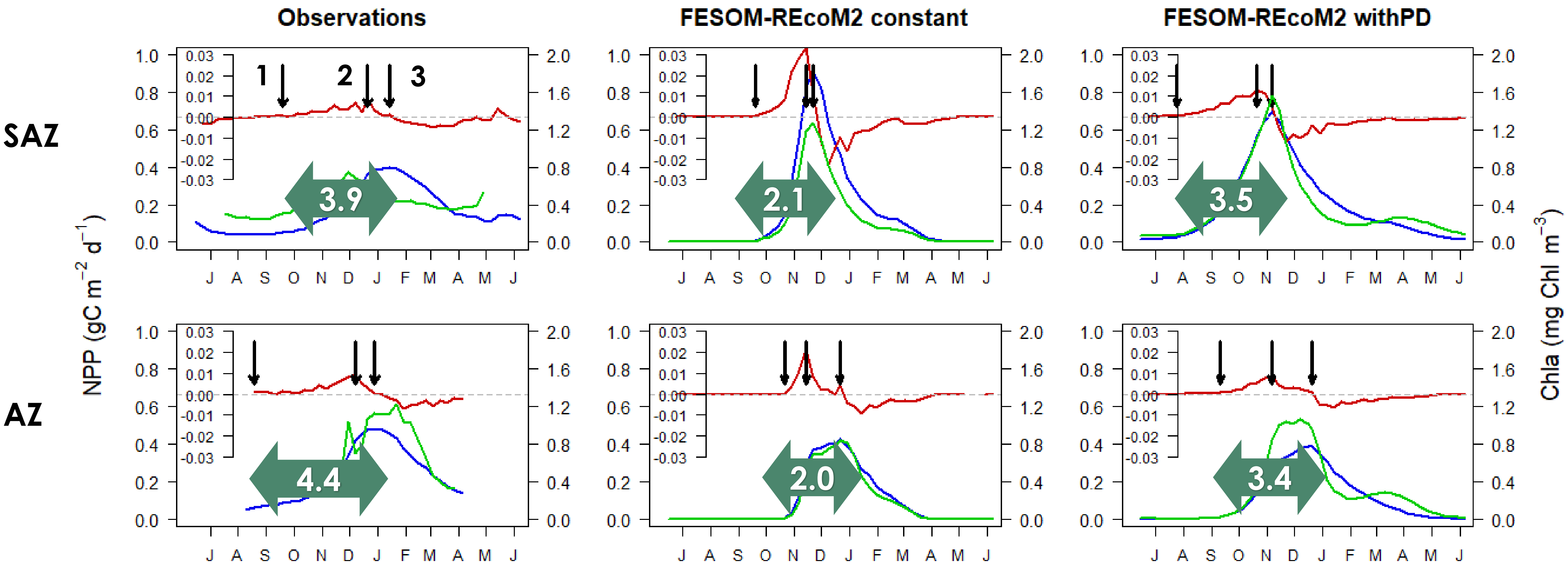


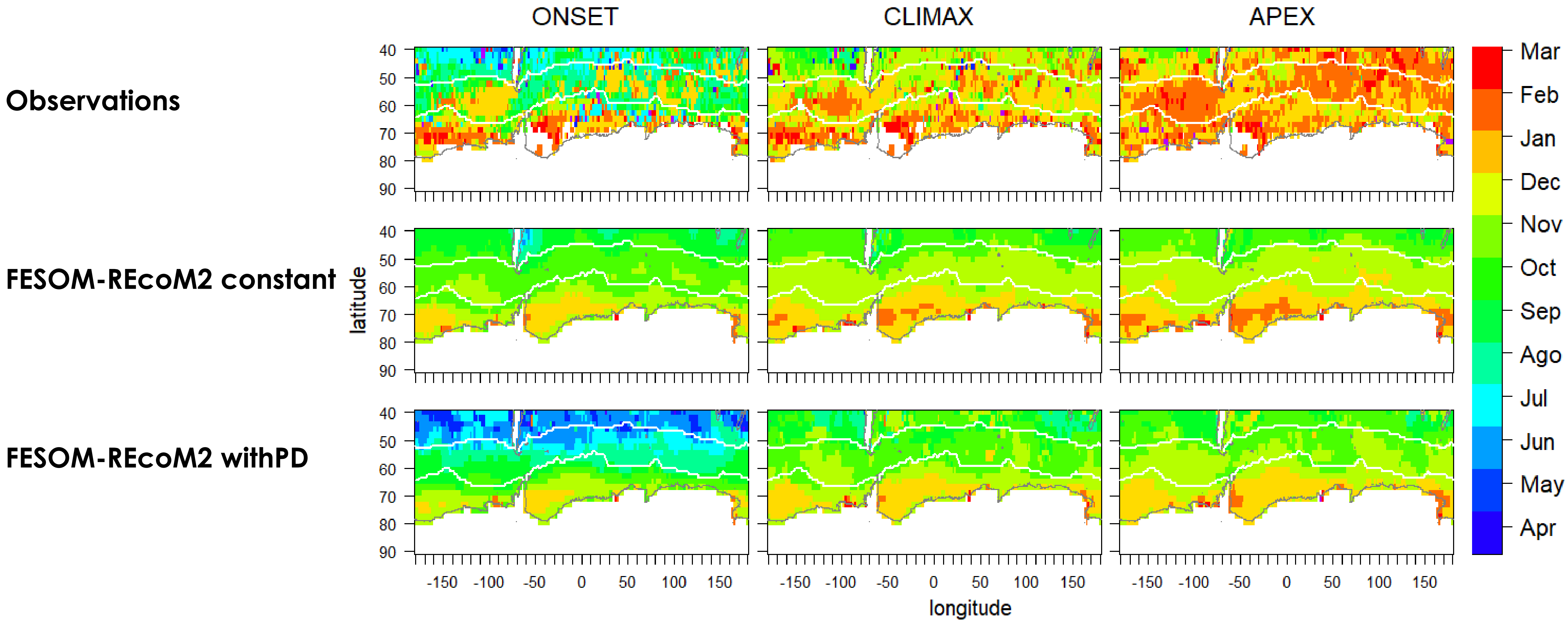
Chl (mg m^{-3})
NPP (gC m^{-2} d^{-1})
dNPP/dt

Development of the bloom: spatial variability

The spatial variability in the **ONSET** was better captured by the model withPD.

Length of growing period was longer in the model run withPD.

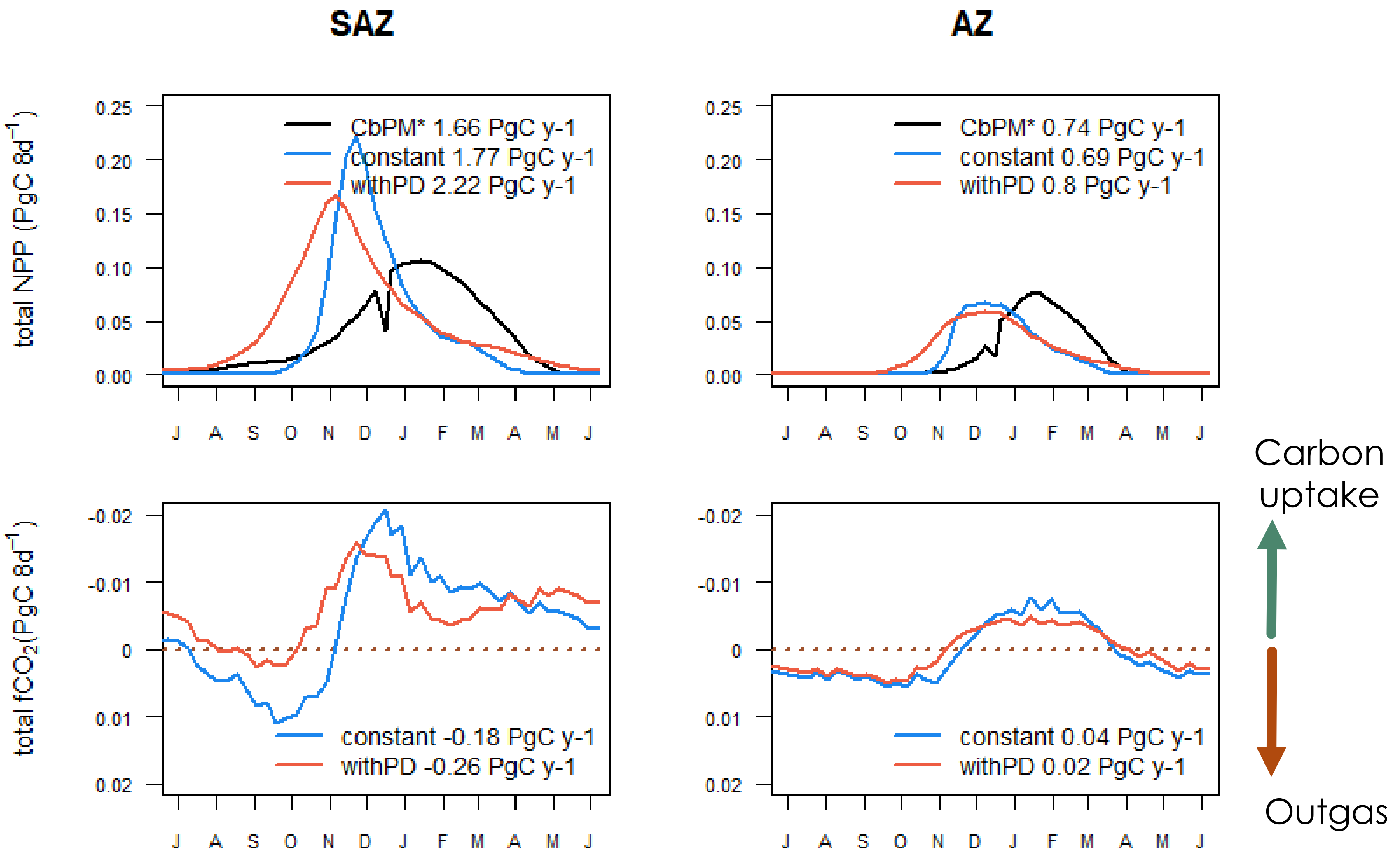
Both model runs simulated **too early bloom** developments.



Seasonal cycles of NPP and sea-air CO_2 flux

Total annual NPP increased in FESOM-REcoM2 withPD both in SAZ and AZ.

The slower rate of accumulation of phytoplankton in FESOM-REcoM2 withPD translated in a **slower rate of carbon sink** into the ocean.



* Source: Carbon-based Production model (Westberry et al. 2008) climatology 2008-2010

Summary

- Mechanistic description of photo-physiological mechanisms, such as photodamage, helps improving the simulation of **Chl:C** as a function of light and nutrient limitations.
- The simulated spring-summer bloom **accumulates biomass slower** and **lasts longer** than previous model versions both in the SubAntactic and Antarctic Zones.
- Could this help to constrain the air-sea flux of CO_2 in these regions? Promising results, although further work is needed (in biogeochemical timecales).
- Lack of improvement on the timing of the onset of the bloom.

Work in progress

- Explore the influence of the timing of re-stratification after winter mixing (Rodgers et al. 2014 BGS).
- Include the effect of a second group of **zooplankton** and explore the consequences in bloom development of increased grazing pressure.

Thanks!

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