CHLOROPHYLL TO CARBON RATIO DERIVED FROM AN ECOSYSTEM MODEL WITH EXPLICIT PHOTODAMAGE

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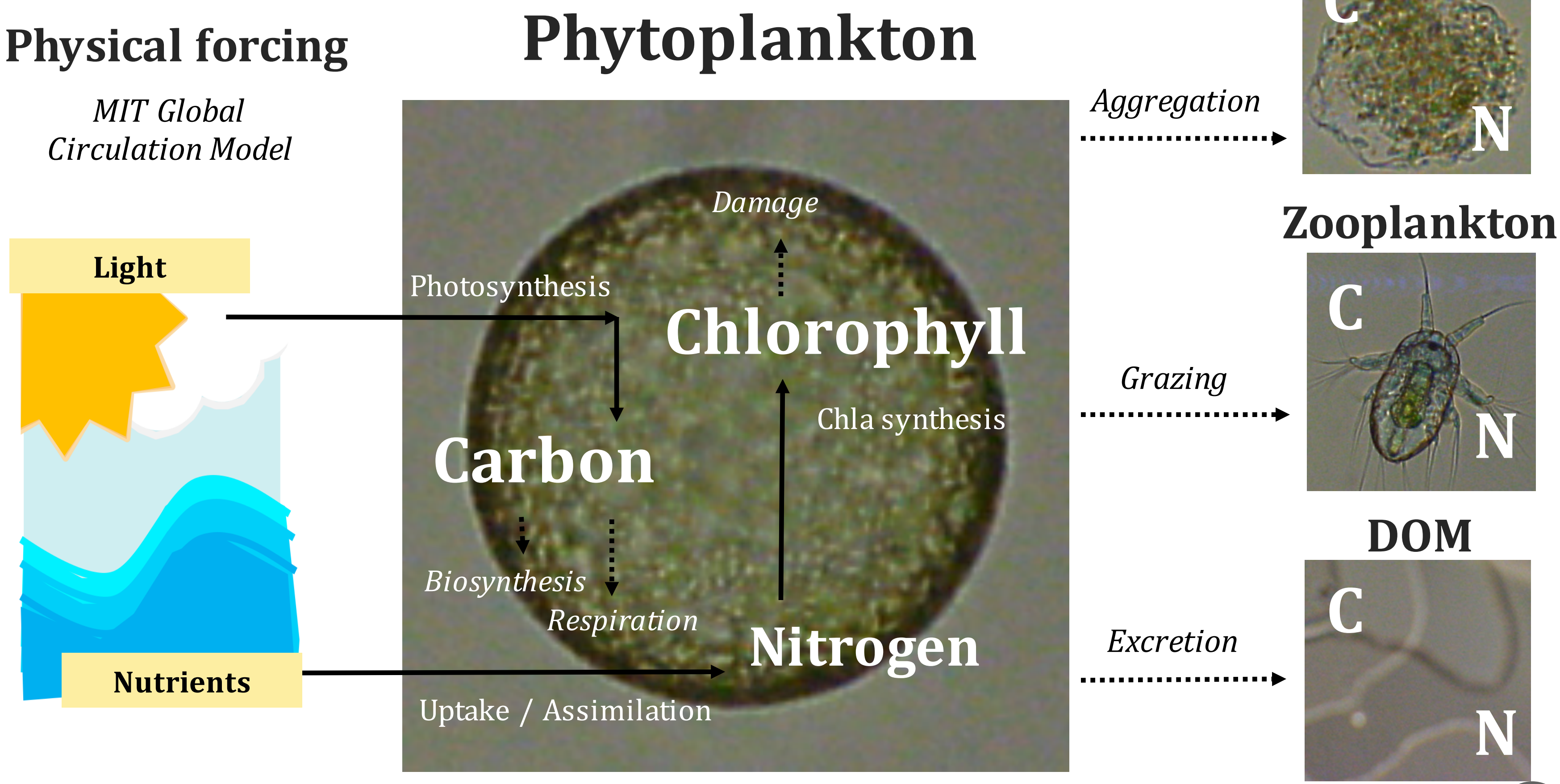
REcoM-2 and the role of photophysiology

REcoM-2 is an **ecosystem model** coupled to the MITgcm.
It defines carbon, nitrogen and chlorophyll as state variables, allowing **variable stoichiometry.**



REcoM-2 and the role of photophysiology

Tuning of parameters by comparison to satellite-based chlorophyll.

Accurate surface fields for phytoplankton chlorophyll.

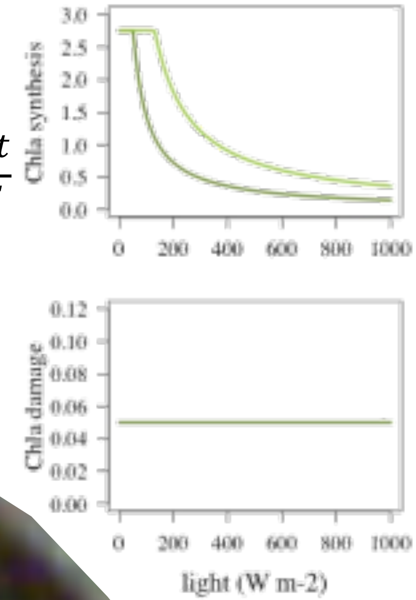
Unrealistic patterns in low light conditions:

- below surface,
- during polar winter,
- under ice sheets.

Chl = synthesis - damage

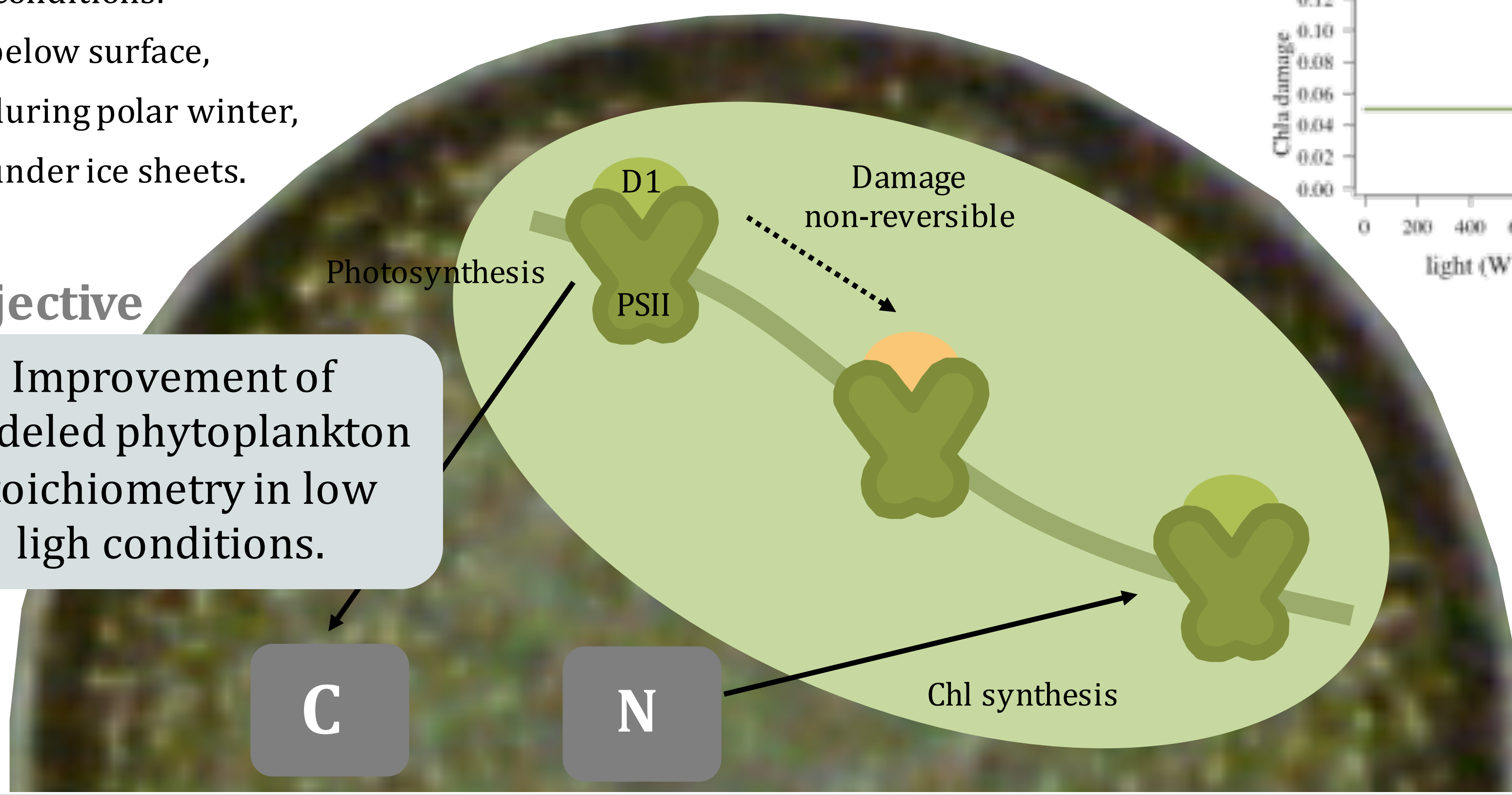
$$Chl\ syntesis = N\ assim \times Chl{:}N_{max} \times \frac{Phot}{\alpha \theta E}$$

$$Chl\ damage = constant$$



Objective

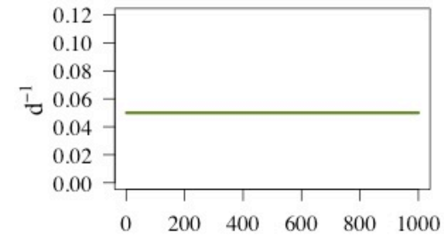
Improvement of modeled phytoplankton stoichiometry in low ligh conditions.



Parameterization of chlorophyll non-reversible damage

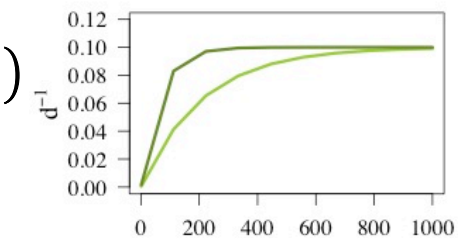
Constant inactivation rate (d^{-1}).

$$Chl\ damage = constant\ (k)$$



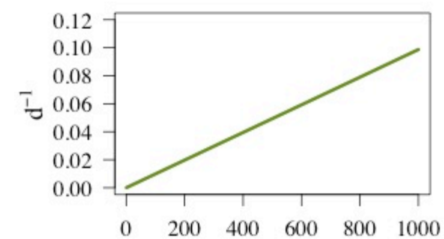
Inactivation proportional to the *degree of light saturation of the photosynthetic apparatus* (Pahlow 2005, Pahlow and Oschlies 2009).

$$Chl\ damage = k \times \left(1 - e^{\frac{-\alpha\theta E}{Pmax}}\right)$$



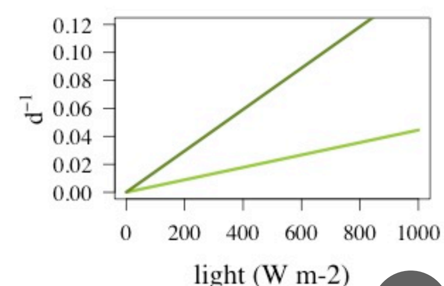
Inactivation proportional light intensity (Kok 1956, Han 2002, Oliver 2003).

$$Chl\ damage = kE$$



Inactivation proportional light intensity and antenna size.

$$Chl\ damage = k\theta E$$



Model accuracy: satellite chlorophyll and literature Chl:C

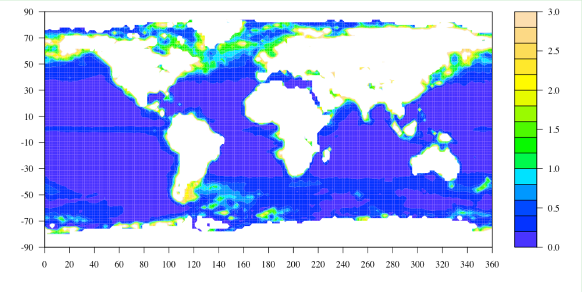
Set *k* values → model run → Output annual climatology | Chlorophyll Chl:C ratio

Chlorophyll: satellite

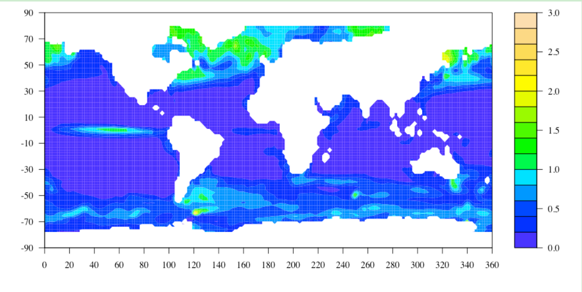
annual means at surface

2000-2015

OC-CCI



REcoM



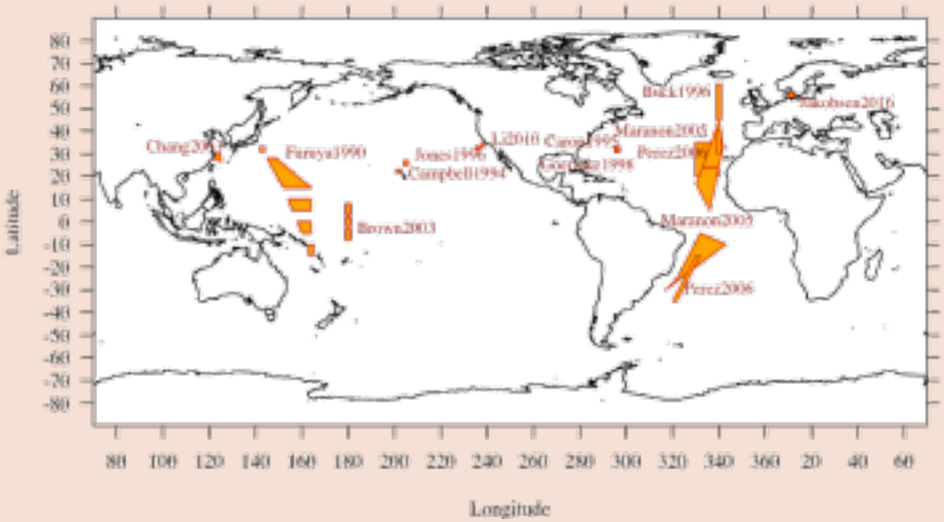
Chl:C ratios: literature

upper 200m; n≃100

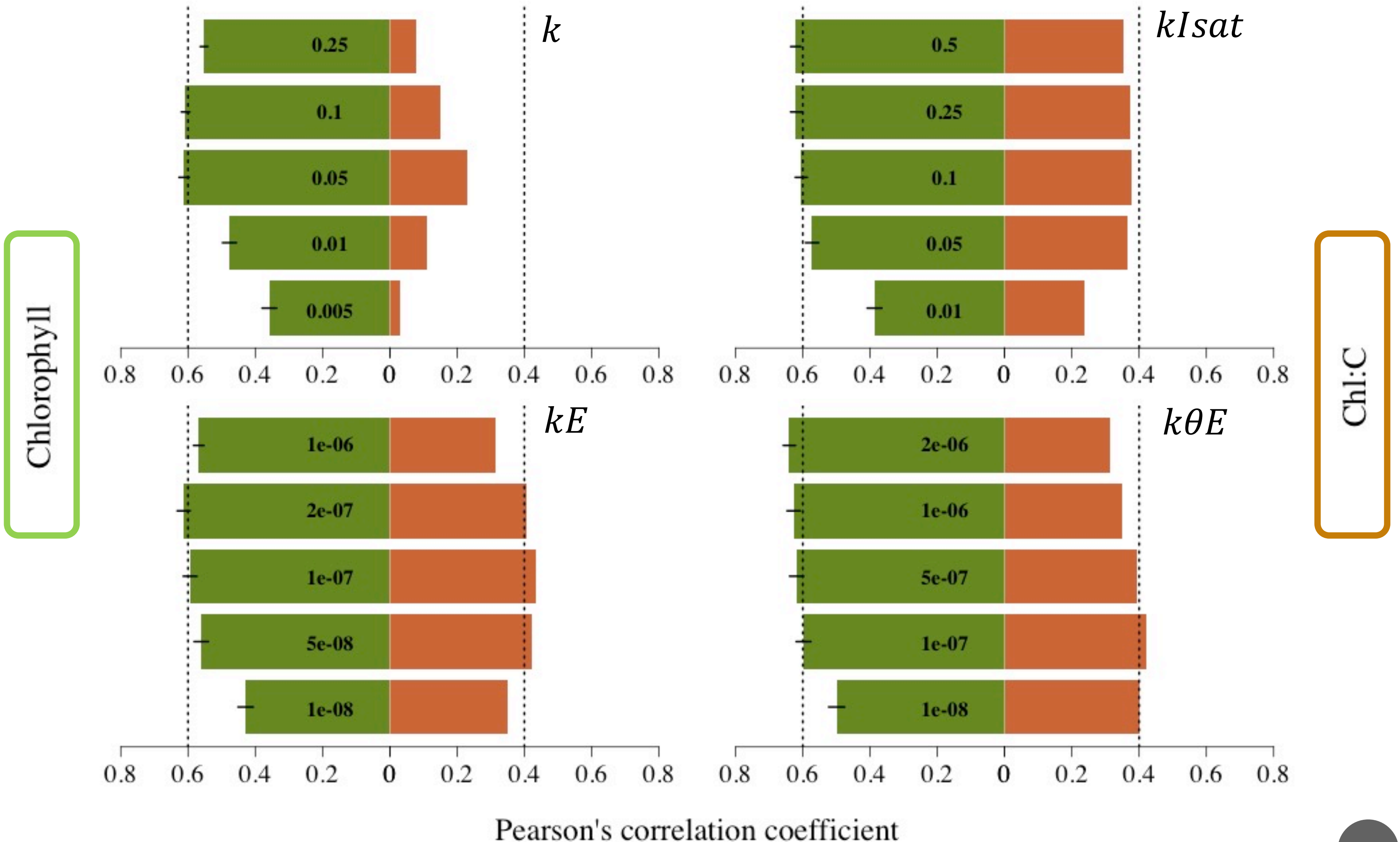
1990-2014

Authors	Year	Pacific Ocean
Li et al.	2010	California coastal curr.
Furuya	1990	North & Equatorial P.
Chang et al.	2003	East China Sea
Brown et al.	2003	Equatorial Pacific
Cambell et al.	1994	Hawaii
Jones et al.	1996	Hawaii

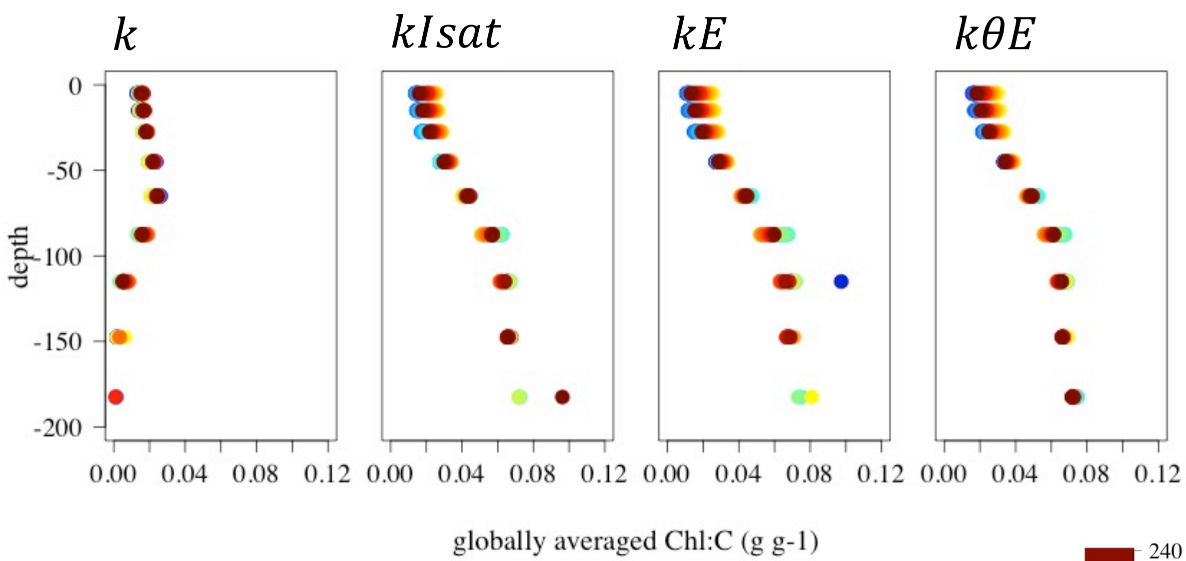
Authors	Year	Atlantic Ocean
Jakobsen & Markager	2016	Baltic Sea
Buck et al.	1996	North Atlantic
Marañon	2005	Atlantic gyres
Perez et al.	2006	A. subtr. gyres
Caron et al.	1995	Sargaso Sea
Goericke & Welschmeyer	1998	Sargaso Sea



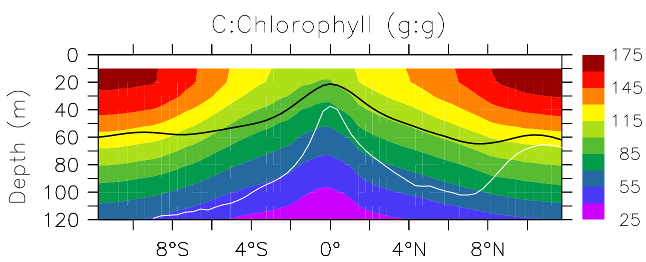
Correlation with satellite chlorophyll and literature Chl:C

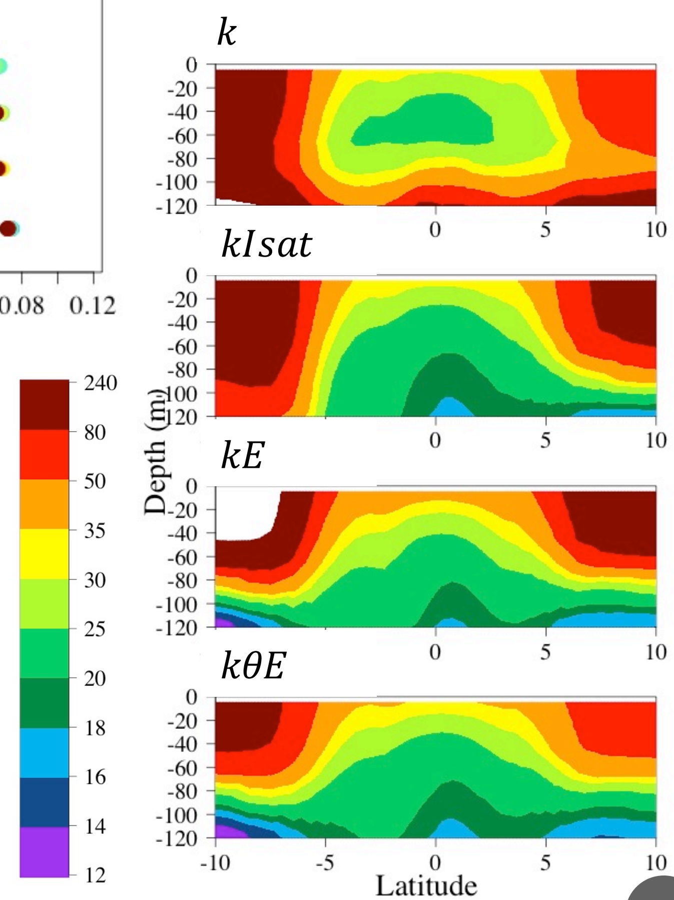


Analysis of patterns: Chl:C gradient in depth



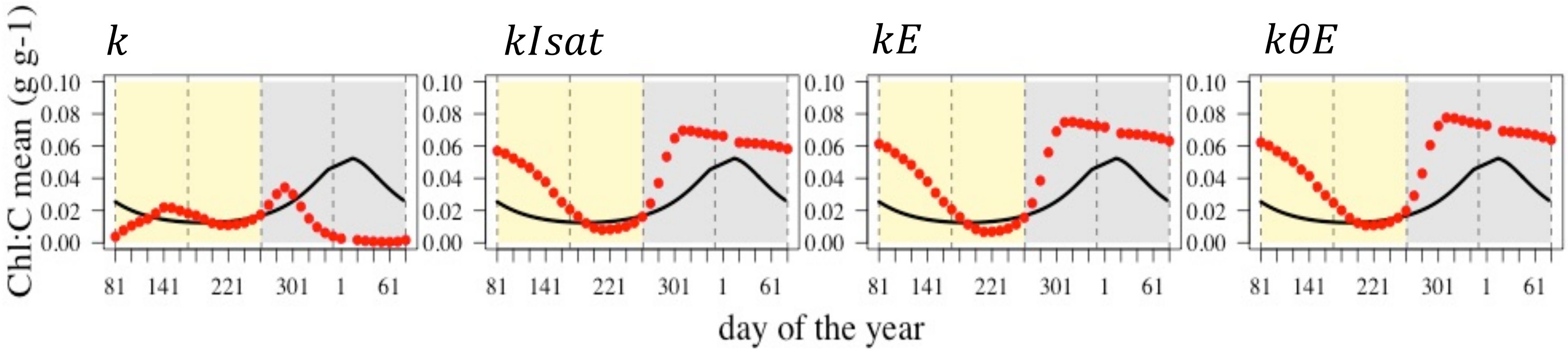
Wang *et al* (2013) JMS. Phytoplankton carbon and chlorophyll distributions in the equatorial Pacific.





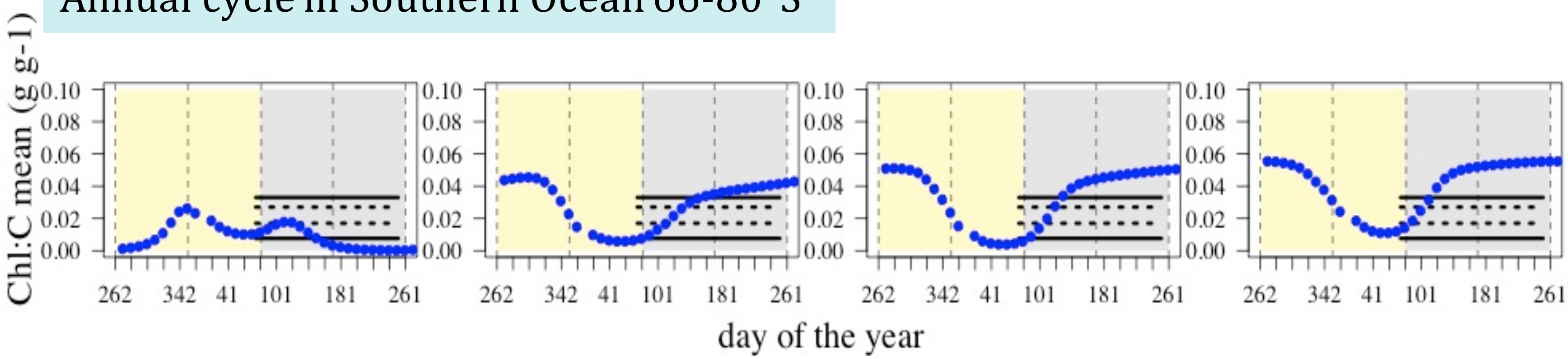
Analysis of patterns: seasonality at high latitudes

Annual cycle at Northern latitudes 66-80°N



Jackobsen & Markager (2016) L&O. Chl:C annual cycle at 56°N (1990-2014)

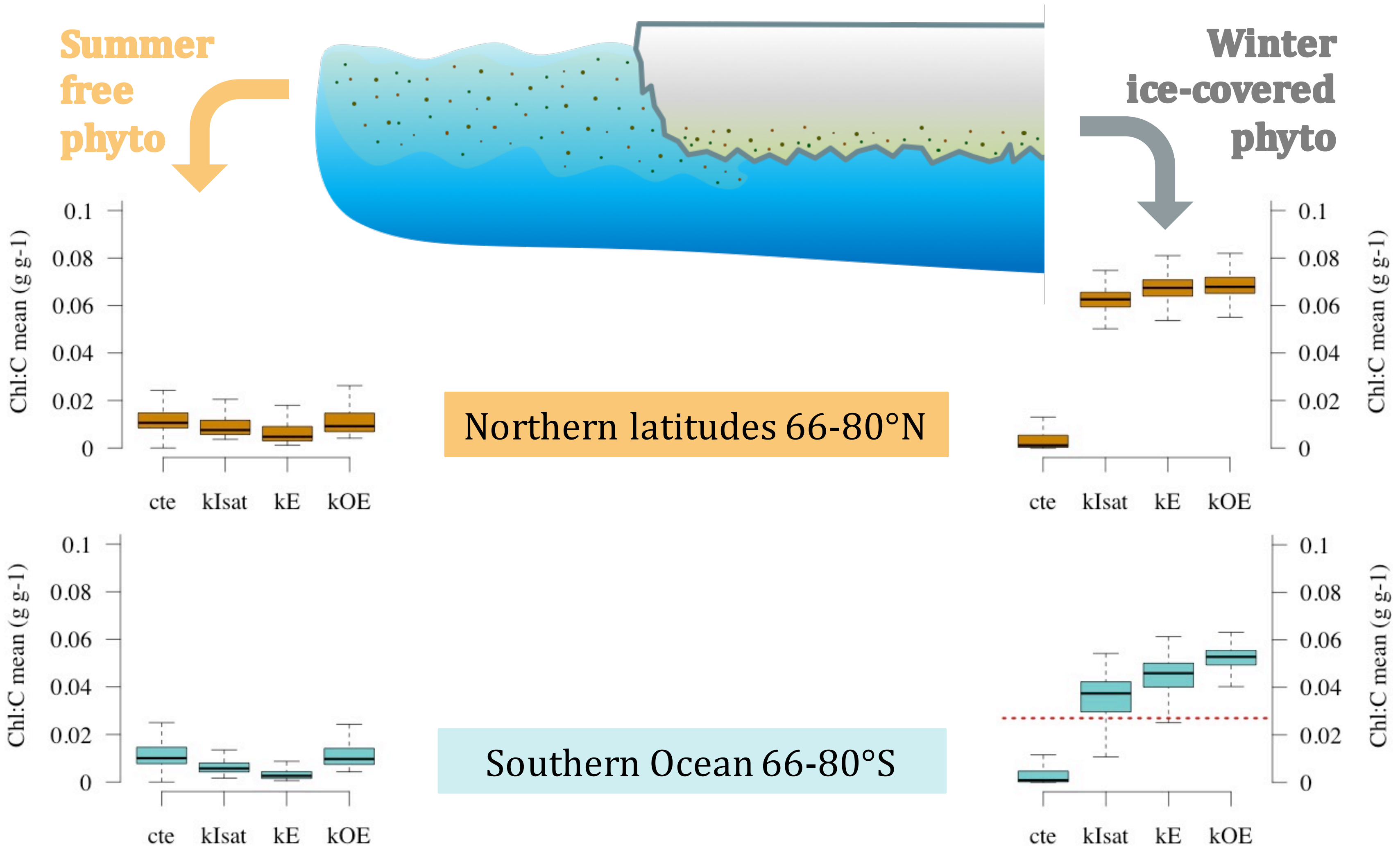
Annual cycle in Southern Ocean 66-80°S



Sakshaug & Holm-Hansen (1986) L&O. Range of Chl:C at 61°S

Daly (1990) L&O. Range of Chl:C at 60°S

Analysis of patterns: Chl:C under the ice sheet



Daly (1990) L&O. Chl:C under the ice at 60°S

Summary and conclusions

Optimization of models with surface chlorophyll can be biased towards the description of high light conditions.

Modelling non-reversible damage to chlorophyll as a function of light intensity provides:

- accurate surface chlorophyll fields.
- realistic phytoplankton stoichiometry in conditions not seen by satellites.

Thanks!

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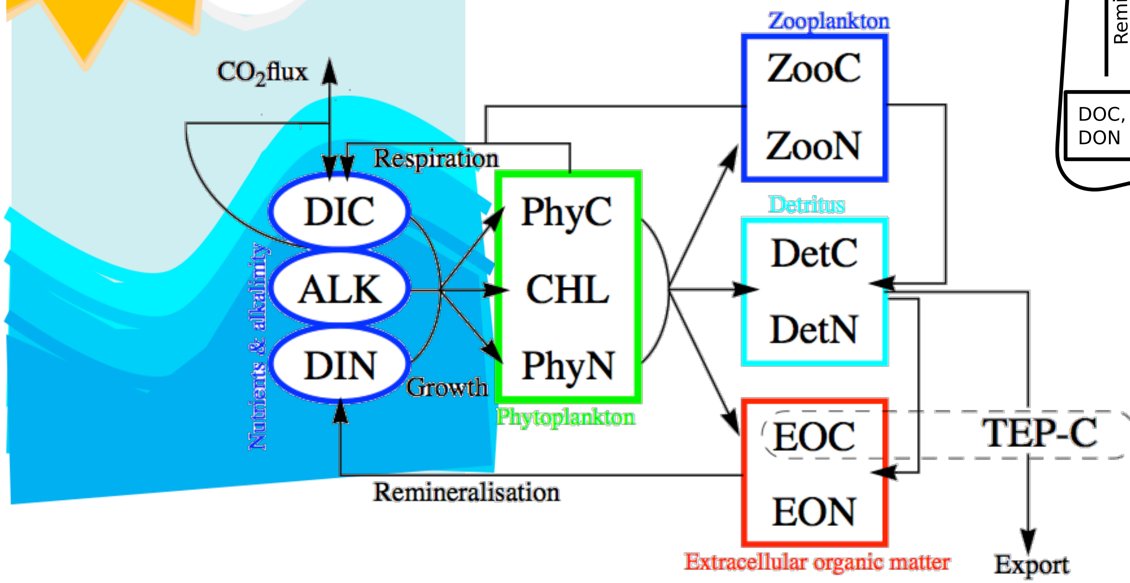
Details physical forcing and ecosystem model

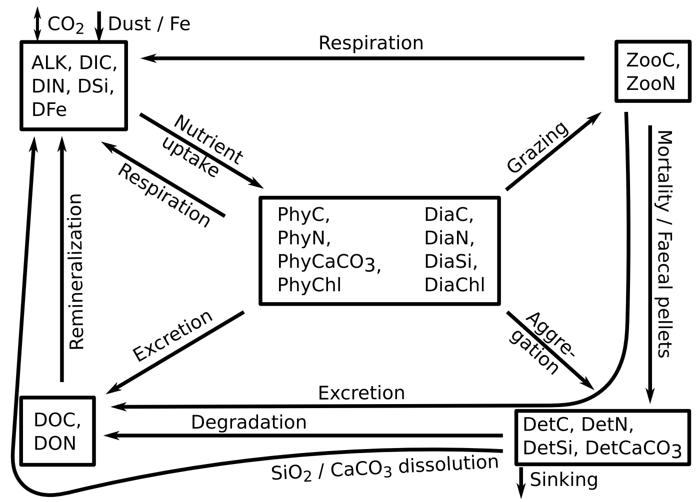
Initial values: Levitus World Ocean Atlas (Garcia et al., 2006)
Global Ocean Data Analysis Project (Key et al., 2004).

Model grid: 2° long / 0.38 to 2° lat / 30 depth layers, 0 to 5450m.

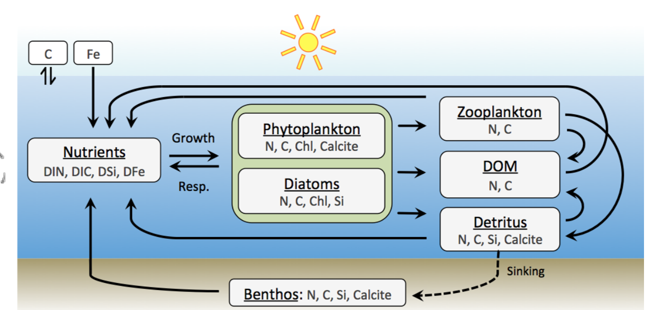
Model spin-up: 4 years.
Output: 1 year in 10daily steps.



by Schartau 2004.

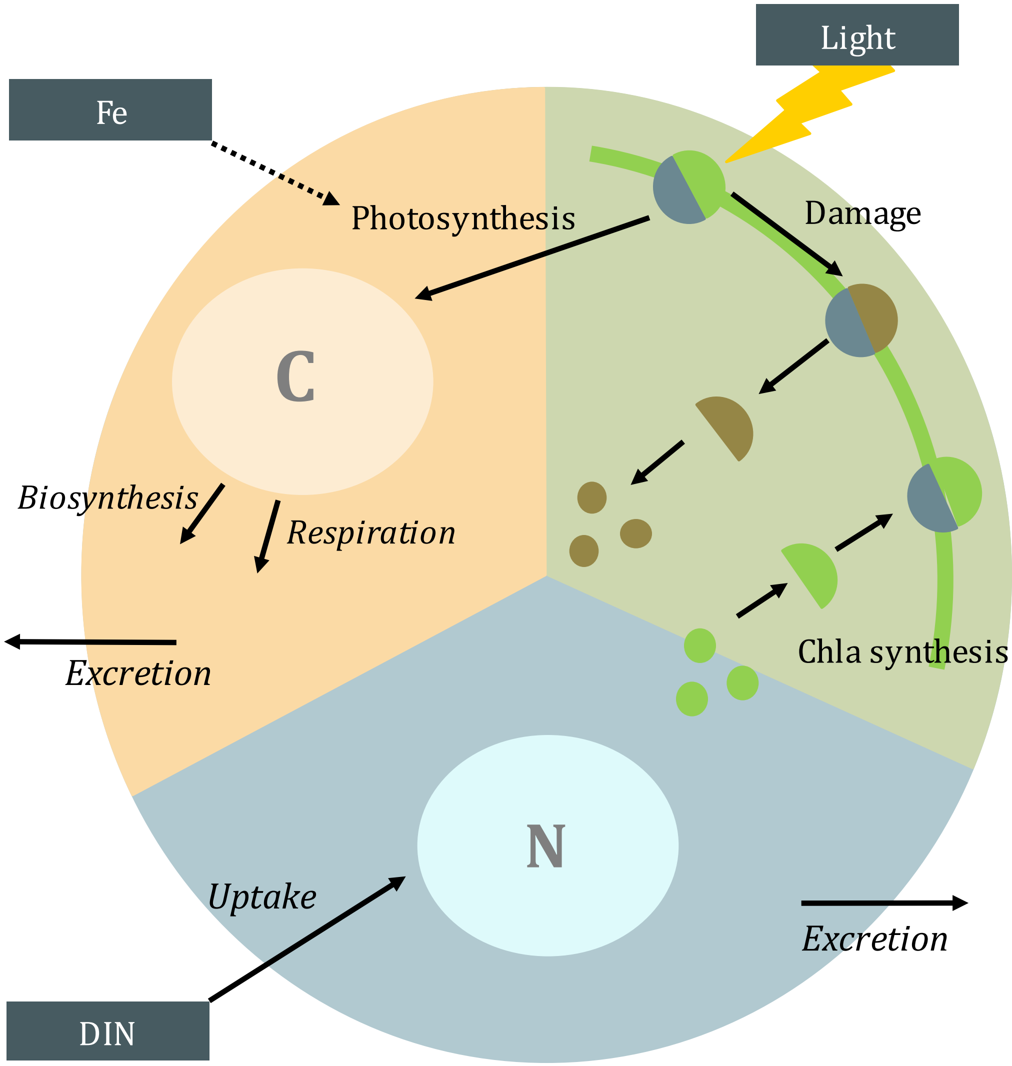


by Hauck 2013.



by Schourup-Kristensen 2014.

Phytoplankton growth model



All phytoplankton

lim = Liebig's law (DIN,Fe)
Pmax = Pcm * lim * Tfunc
Photosynth =Pmax*(1-exp((-α * Chl:C * E)/ Pmax))
N_assim = Vcm * Pmax * Qmax * Ni/(Ni + kdin) * lim(Qmax)
Chl_synth = N_assim * Chl:Nmax*(Phot/(Chl:C* α *E)))
Respiration = Rref * Tfunc + **Biosynth***N_assim

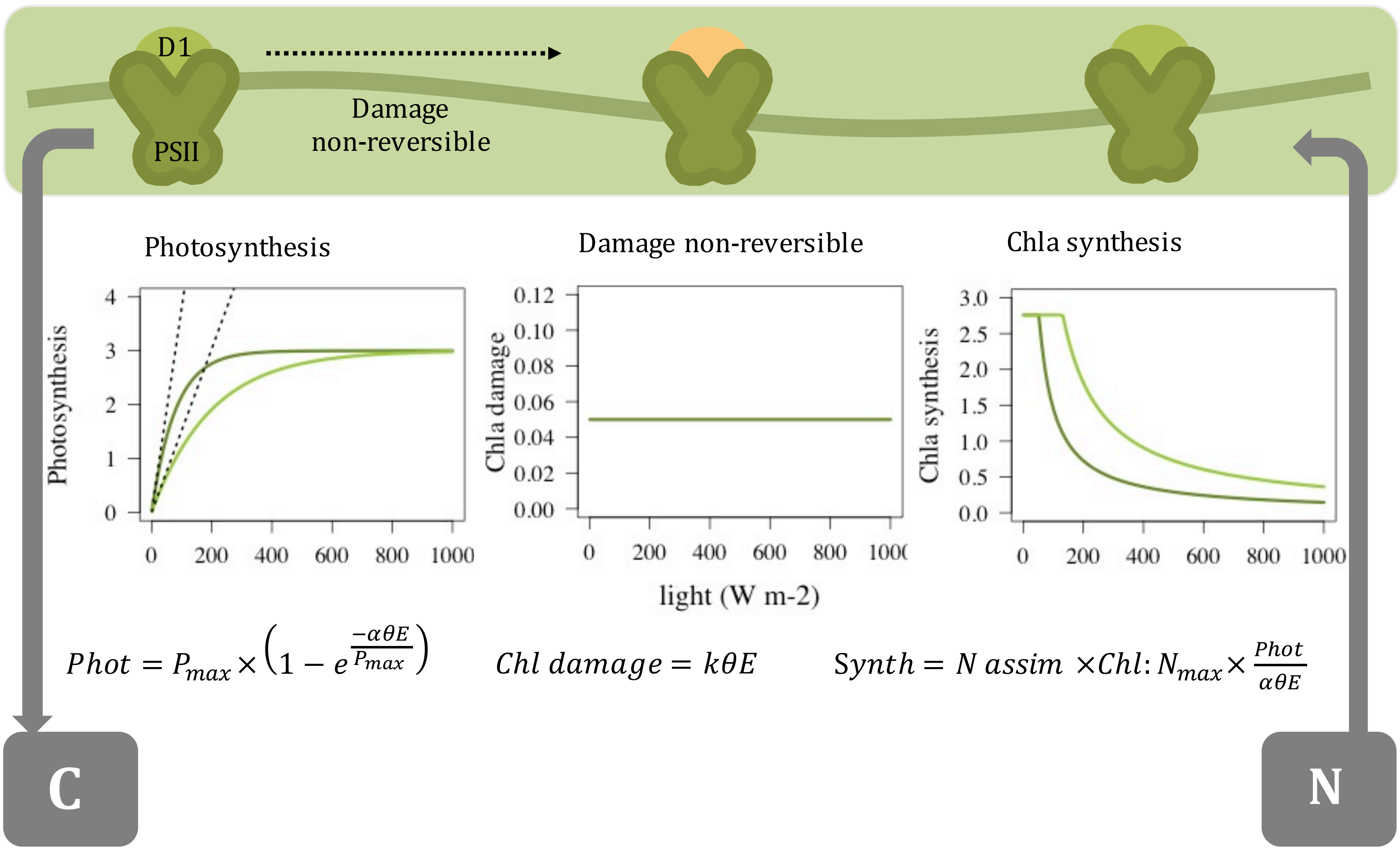
dC = (**Phot** - **Respiration** - **excretionC**) * phyC
dN =(**N_assim*** phyC) – (**excretionN***phyN)
dChl =(**Chl_synth***phyC) – (**damageCHL***phychl)

additional for diatoms

lim = Liebig's law (DIN,Fe, Si)
Si_assim = Vcm*Pcm*SiCuptake*Si/(Si + ksi)* lim(Qmax)*lim(Simax)*Tfunc
Resprate = Rref *Tfunc + Biosynth*N_assim + Sisynth*Si_assim

dSi=(**Si_assim***phyC)- (**excretionSi***phySi)

Phytoplankton growth model: processes dependent on light



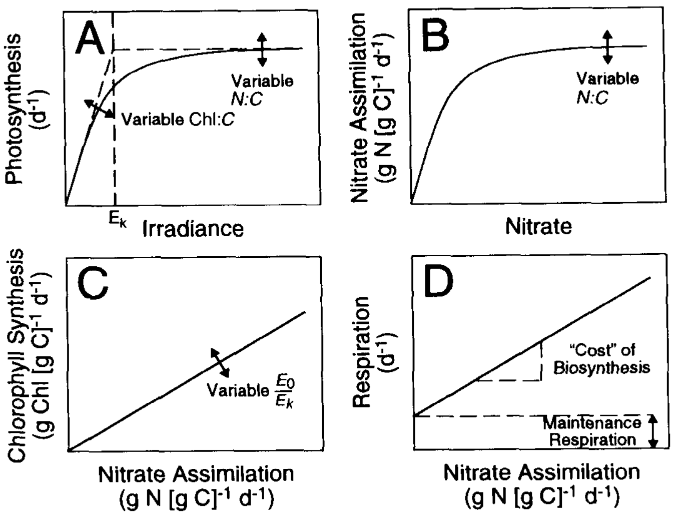
$$Phot = P_{max} \times \left(1 - e^{\frac{-\alpha\theta E}{P_{max}}}\right)$$

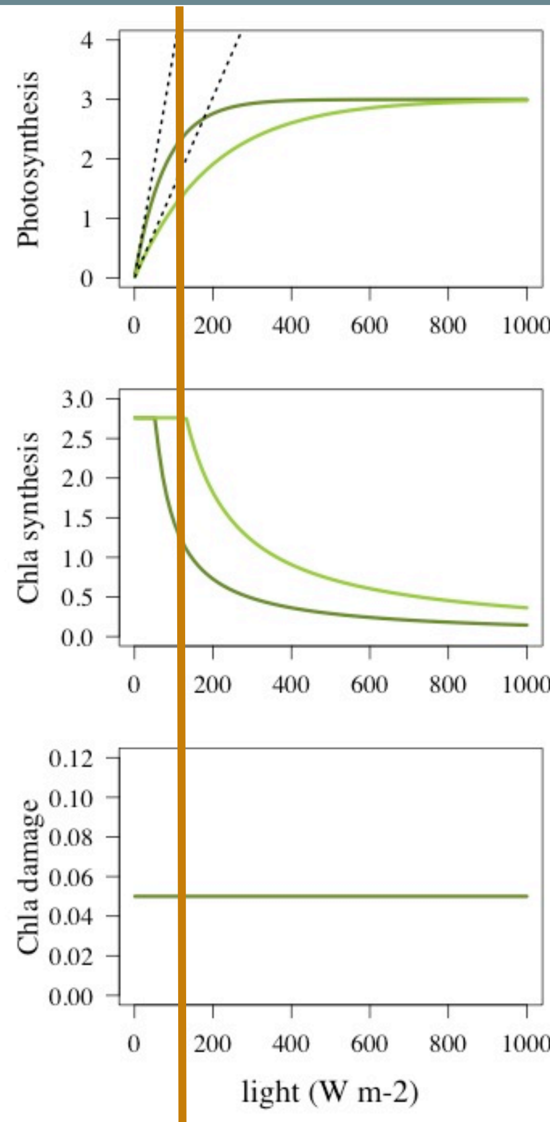
$$Chl\ damage = k\theta E$$

$$Synth = N\ assim\ \times Chl{:}N_{max} \times \frac{Phot}{\alpha\theta E}$$

Phytoplankton growth model: high vs low light

Geider *et al.*(1998) L&O. A dynamic regulatory model.





Photosynthesis

$$= P_{max} \times \left(1 - e^{\frac{-\alpha\theta E}{P_{max}}}\right)$$

Chla syntesis

$$= N\ assim \times Chl{:}N_{max} \times \frac{Phot}{\alpha\theta E}$$

$$Chla\ damage = k$$

Light limitation

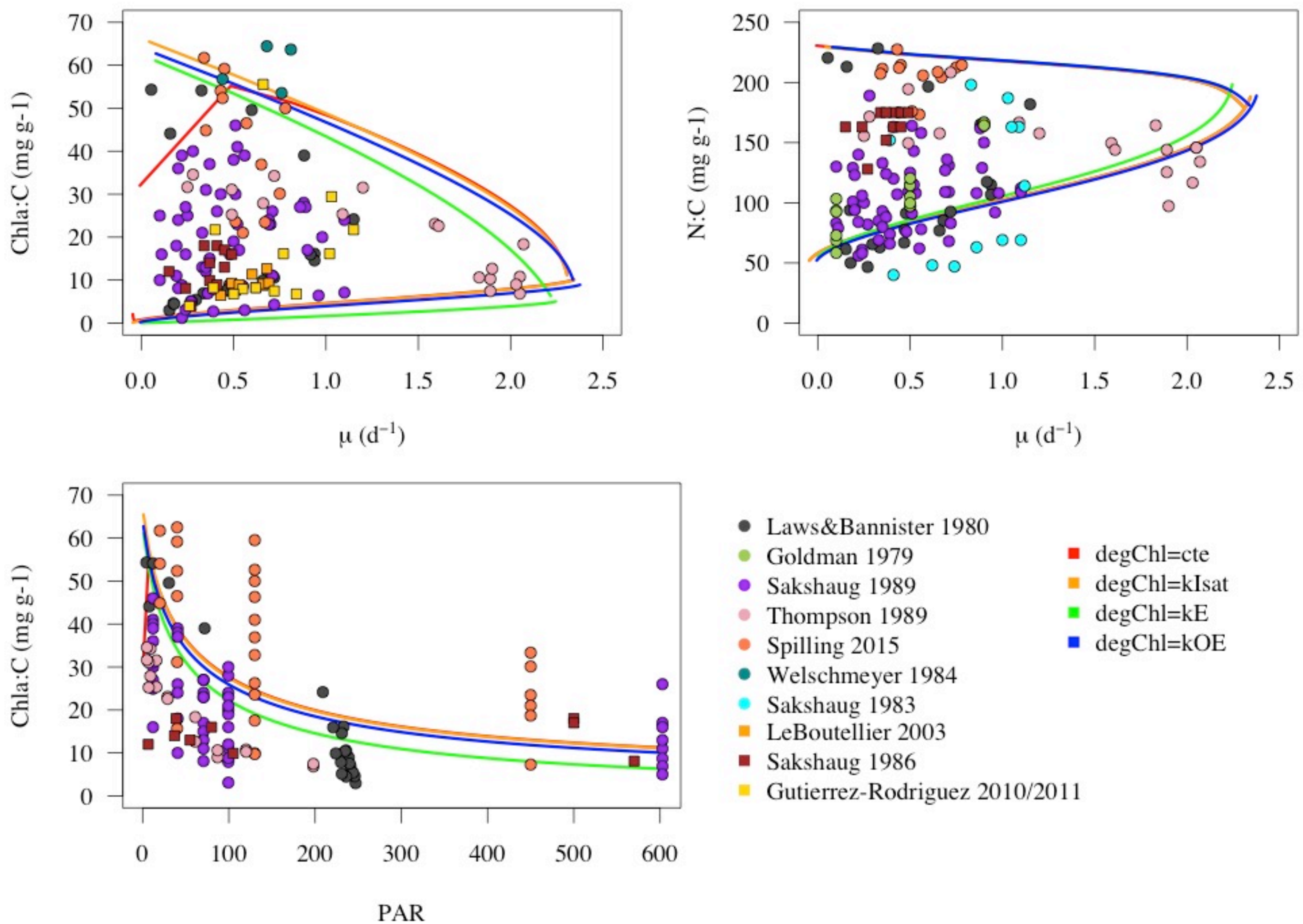
$$\frac{Phot}{\alpha\theta E}=1$$

Light saturation

$$\frac{Phot}{\alpha\theta E}<1$$

Phytoplankton growth model: steady state solutions

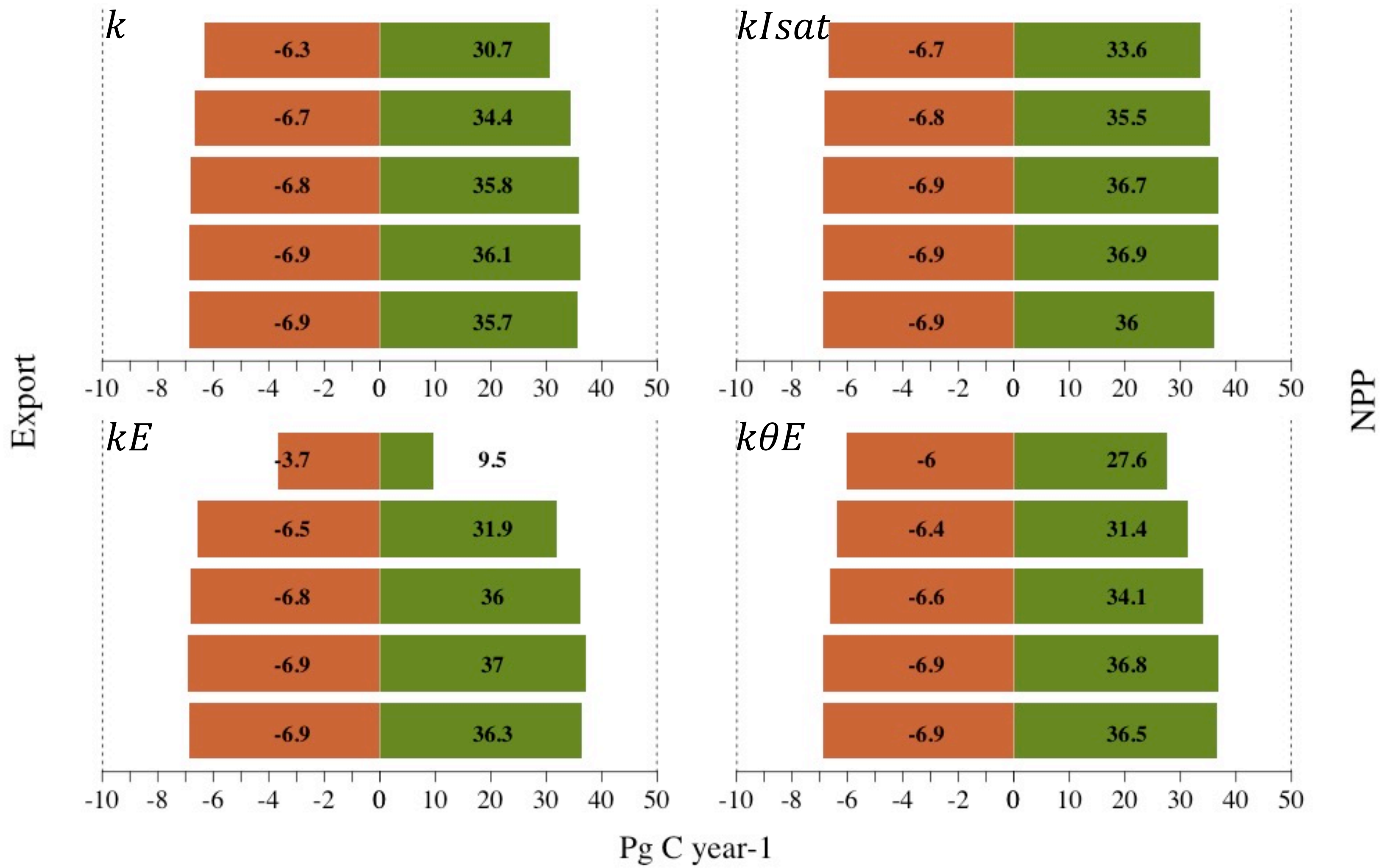
Phytoplankton growth model → Steady state → output | Cell quotas (Chl:C, N:C) Growth rate



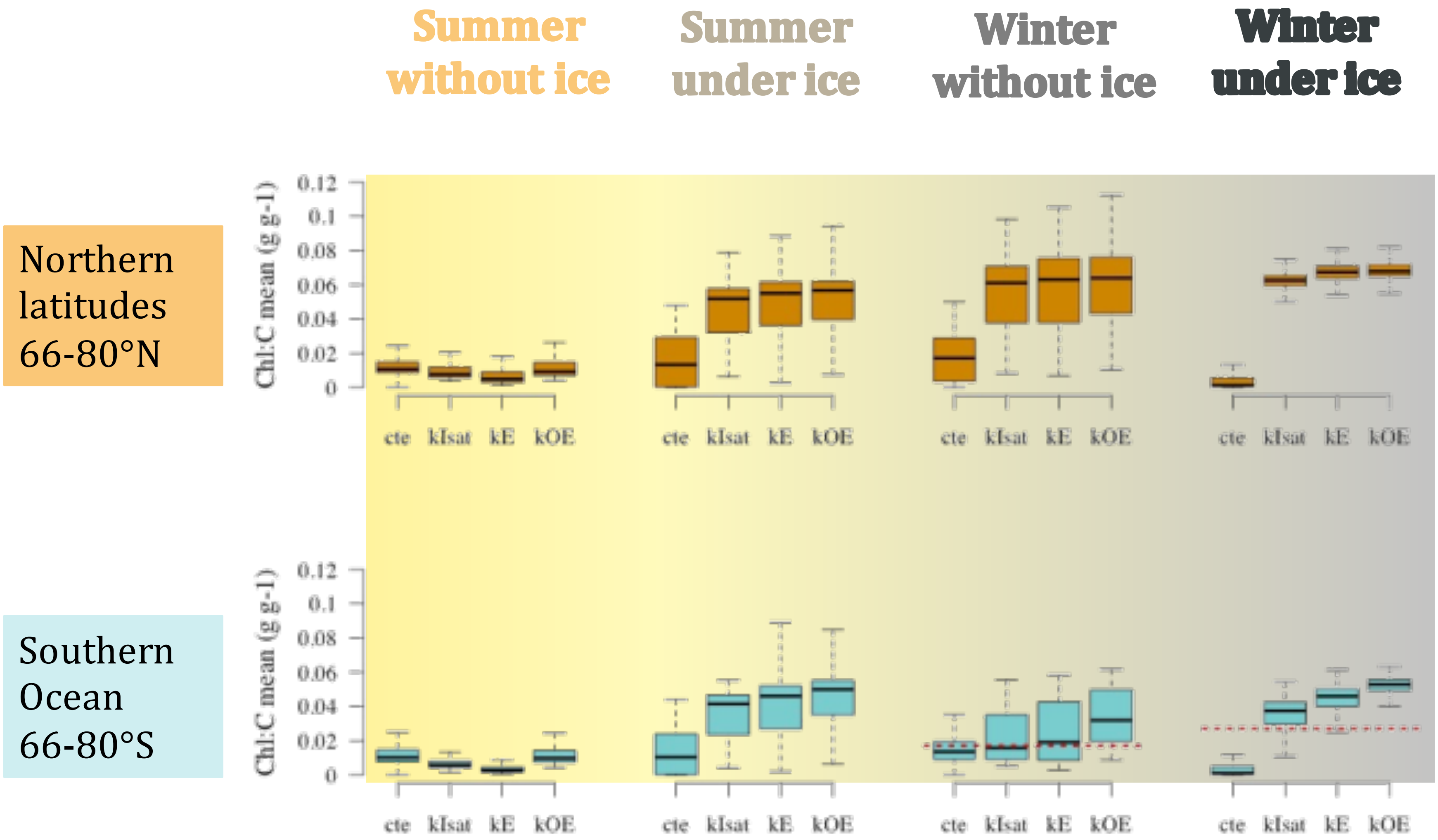
Light-limited

N-limited

Model accuracy: other metrics, annual NPP and export production



Analysis of patterns: Chla:C under the ice sheet



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