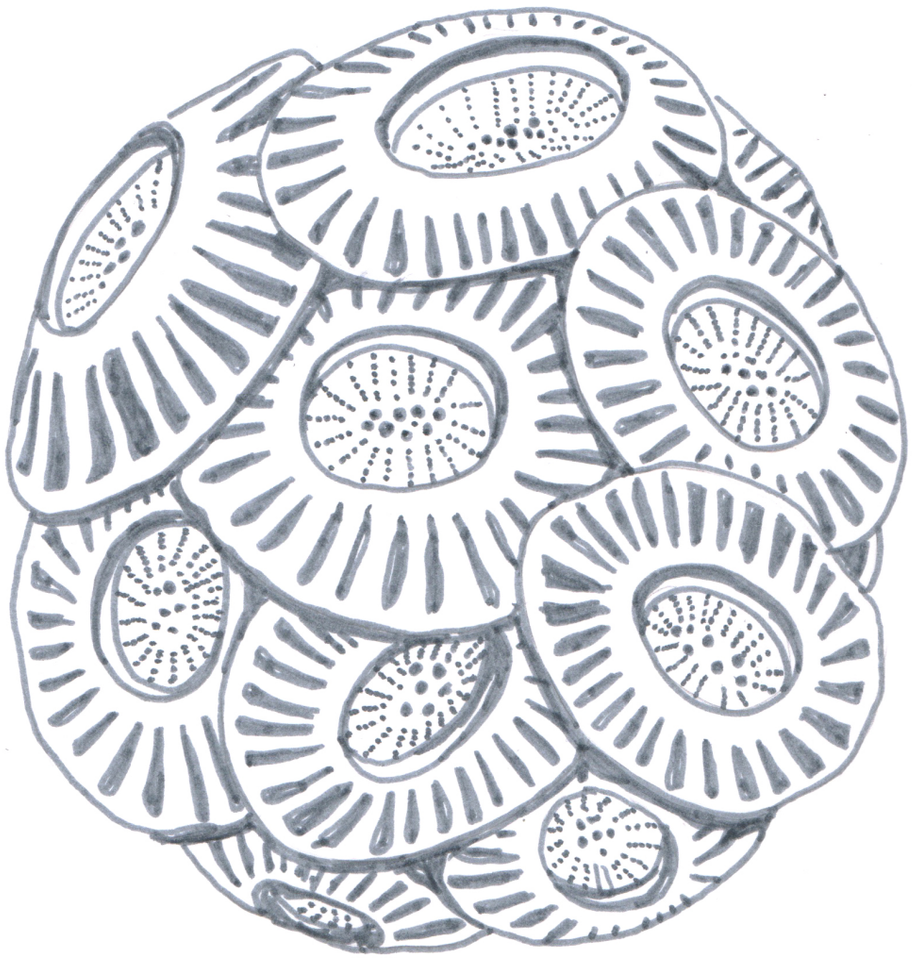
Adding coccolithophores to CESM

Kristen Krumhardt

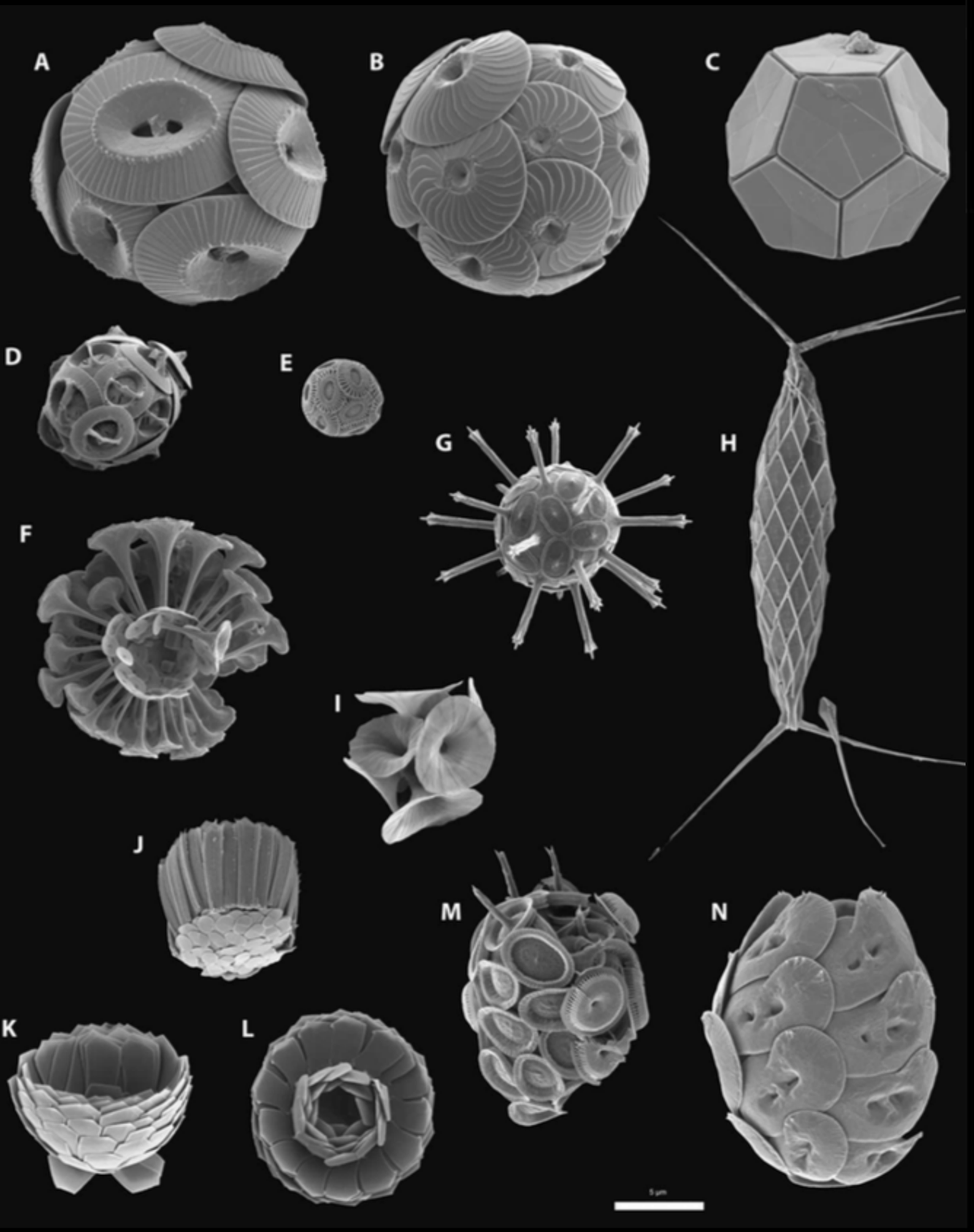
Ocean Working Group Meeting, January 12th, 2018



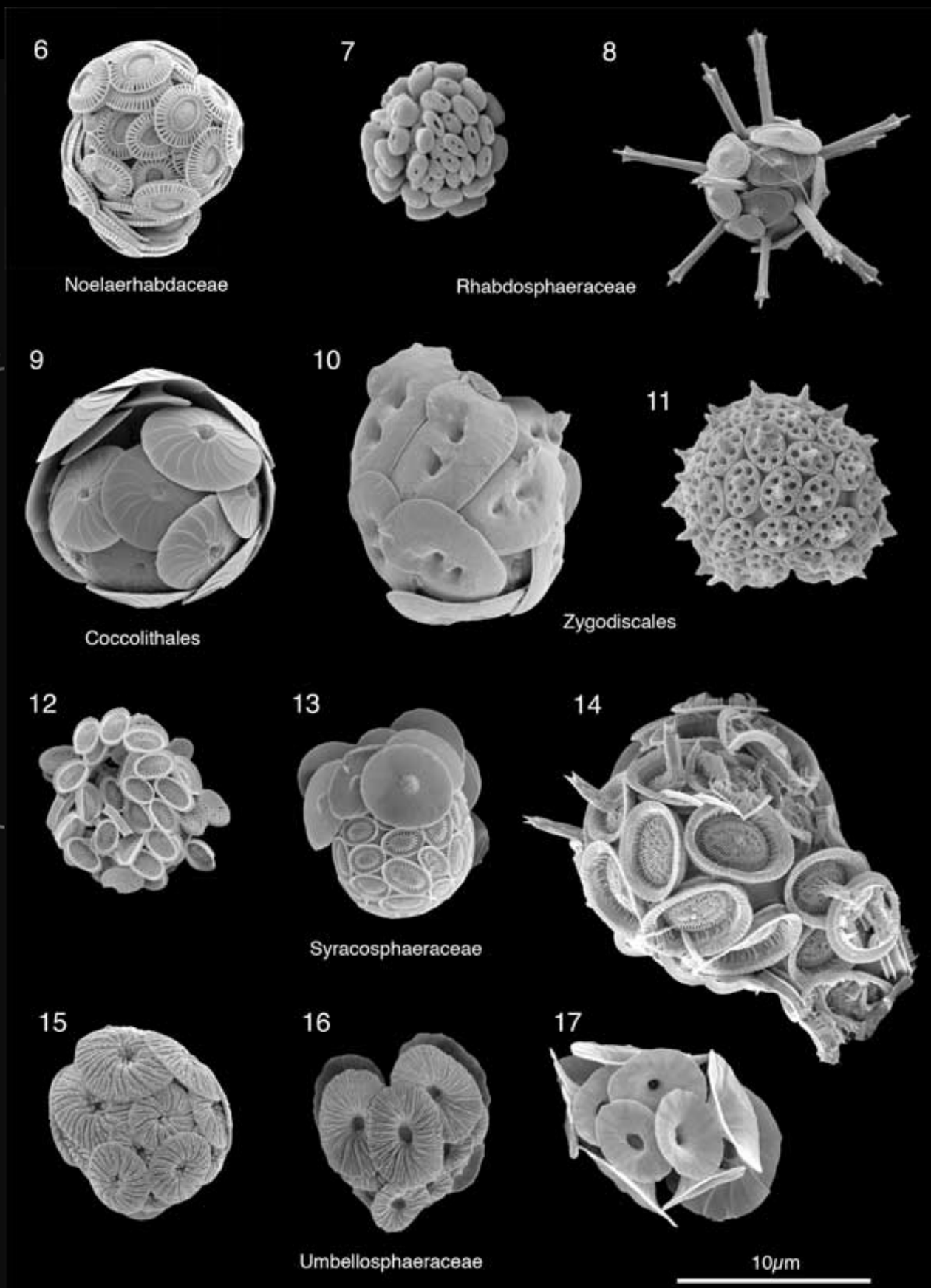
Acknowledgments: Nikki Lovenduski, Matt Long, Mike Levy & Keith Lindsay

Overview

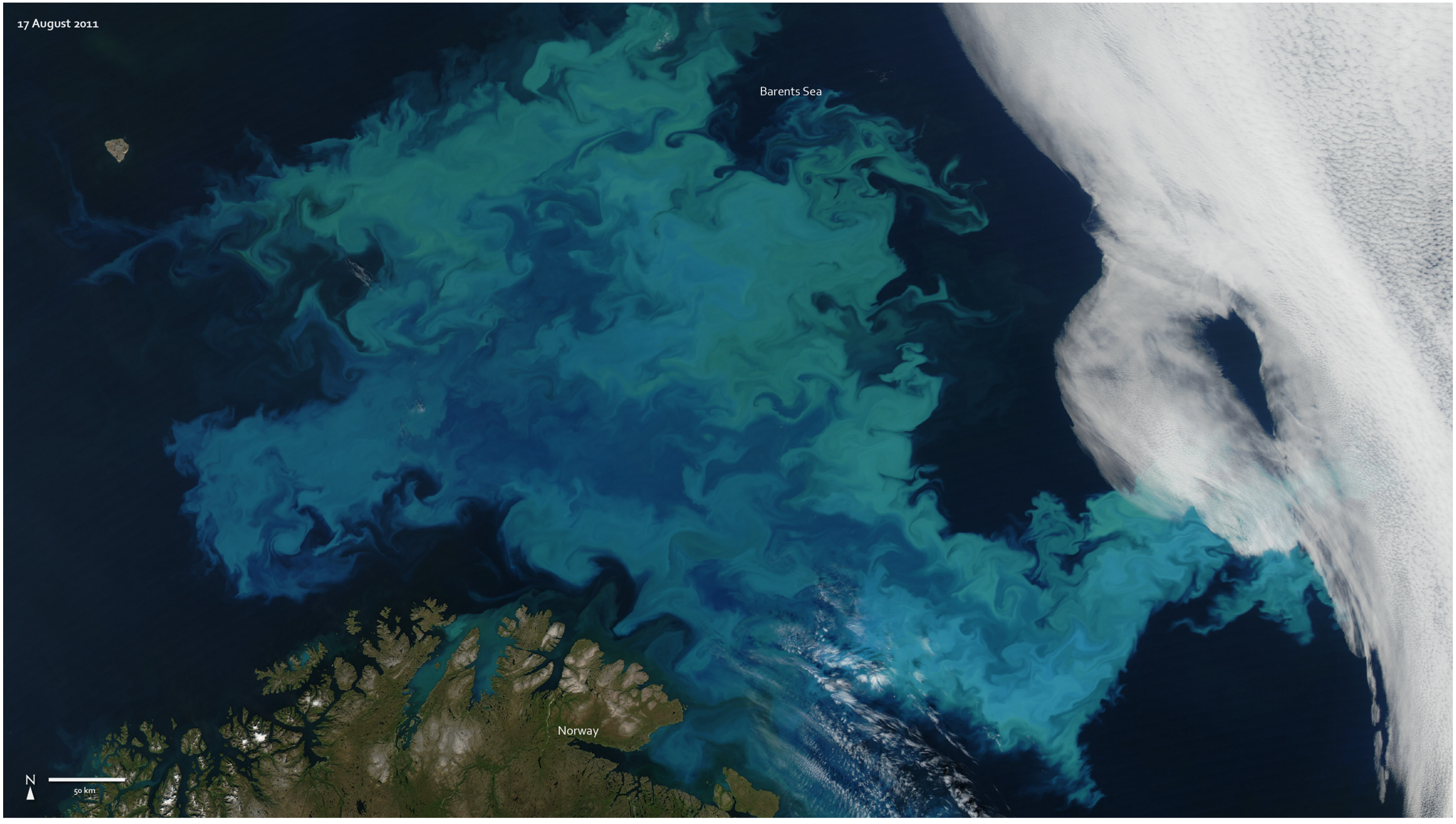
- Background on coccolithophores
- Influence on the global carbon cycle, project goals
- Coccolithophore phytoplankton functional type
- New results: CESM simulations with coccolithophores (PI CO_2 vs. present CO_2)



Monteiro et al., 2016



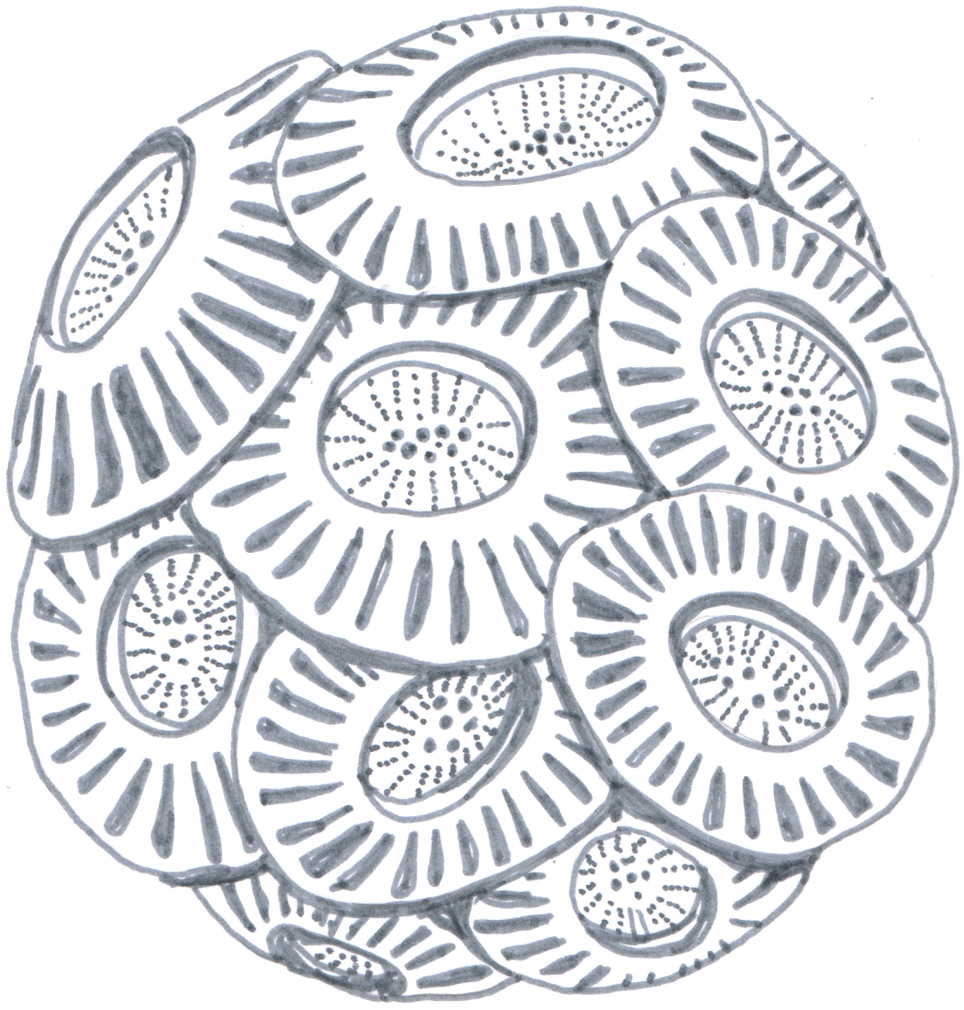
Young et al., 2014

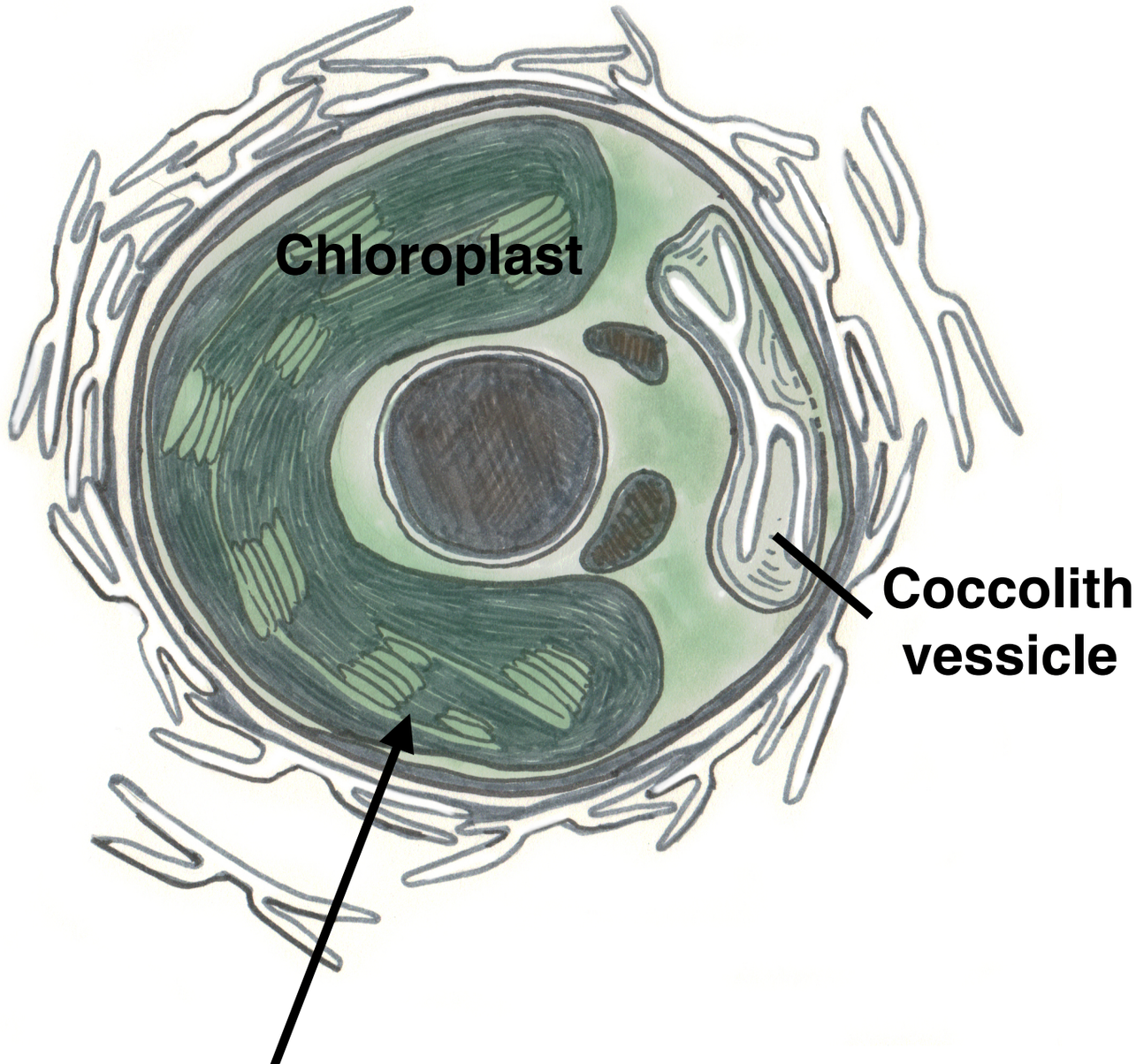


>1000 cells/ml

https://visibleearth.nasa.gov/

Coccolithophores do both photosynthesis and calcification





Particulate Inorganic Carbon (PIC) shell

/

Particulate Organic Carbon (POC) inside

$= \frac{\text{PIC}}{\text{POC}}$

Coccolithophores do both photosynthesis and calcification

CO_2

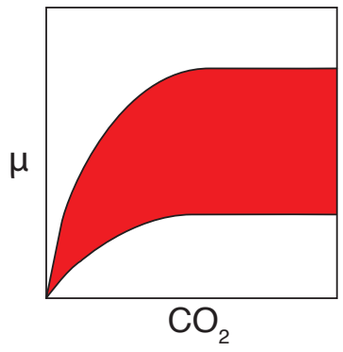
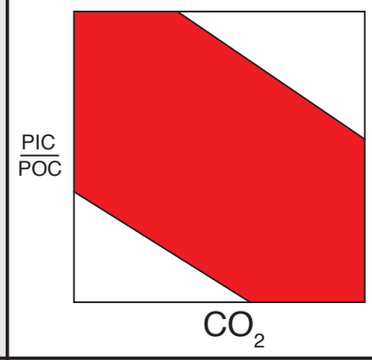
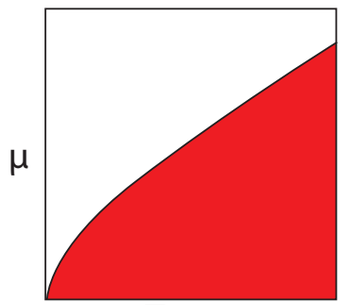
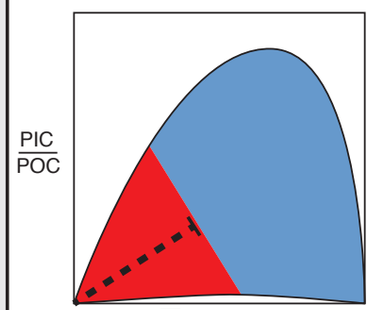
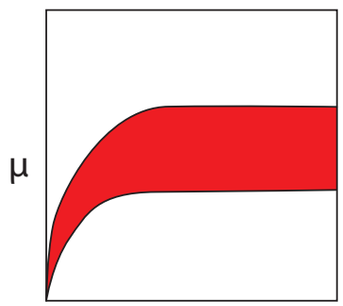
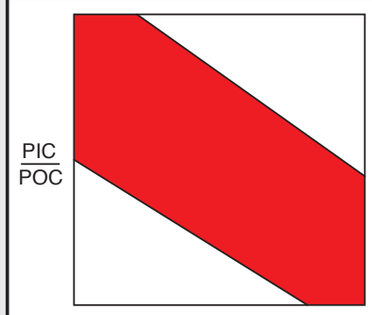
Calcification

CO_2

Photosynthesis

Ballasting carbon export to the deep sea

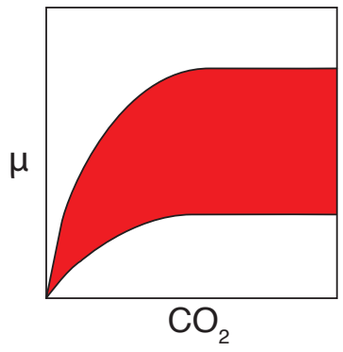
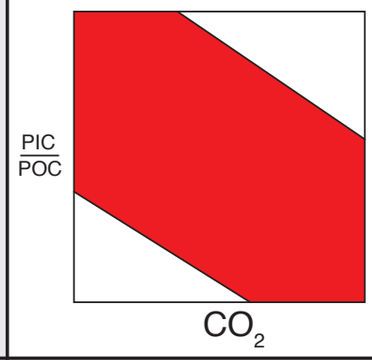
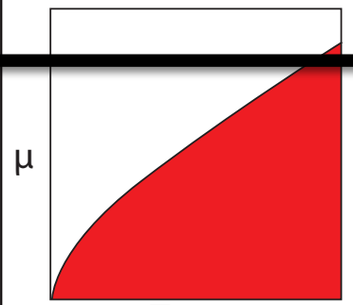
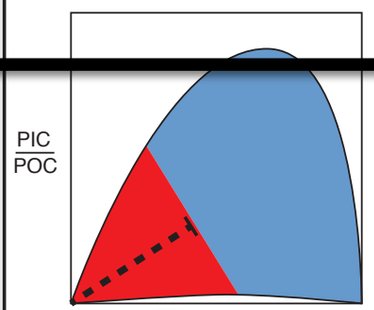
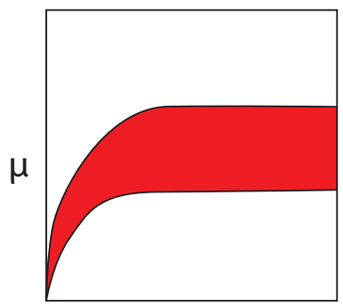
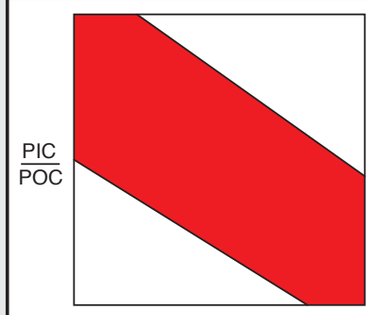
Environmental modulation of growth and calcification

	Growth rate, μ (C_{org} production; d-1)		PIC/POC ratio	
pCO_2		• Carbon limited growth rate at low CO_2 • Large range of senstivities at high CO_2		• PIC/POC generally decreases as CO_2 increases • Large range of responses
Temperature		• Power function determines temperature dependent maximum growth rate		• PIC/POC decreases at low temperatures but relationship at higher temperatures is not as clear
Nutrients		• Efficient nutrient uptake at low concentrations • Comparably high affinity for nutrients		• PIC/POC higher under nutrient limitation and lower under nutrient replete conditions

Red = included in CESM with coccolithophores

Krumhardt et al., 2017, Progress in Oceanography

Environmental modulation of growth and calcification

	Growth rate, μ (C_{org} production; d-1)		PIC/POC ratio	
pCO_2		• Carbon limited growth rate at low CO_2 • Large range of senstivities at high CO_2		• PIC/POC generally decreases as CO_2 increases • Large range of responses
Temperature		• Power function determines temperature dependent maximum growth rate		• PIC/POC decreases at low temperatures but relationship at higher temperatures is not as clear
Nutrients		• Efficient nutrient uptake at low concentrations • Comparably high affinity for nutrients		• PIC/POC higher under nutrient limitation and lower under nutrient replete conditions

Red = included in CESM with coccolithophores

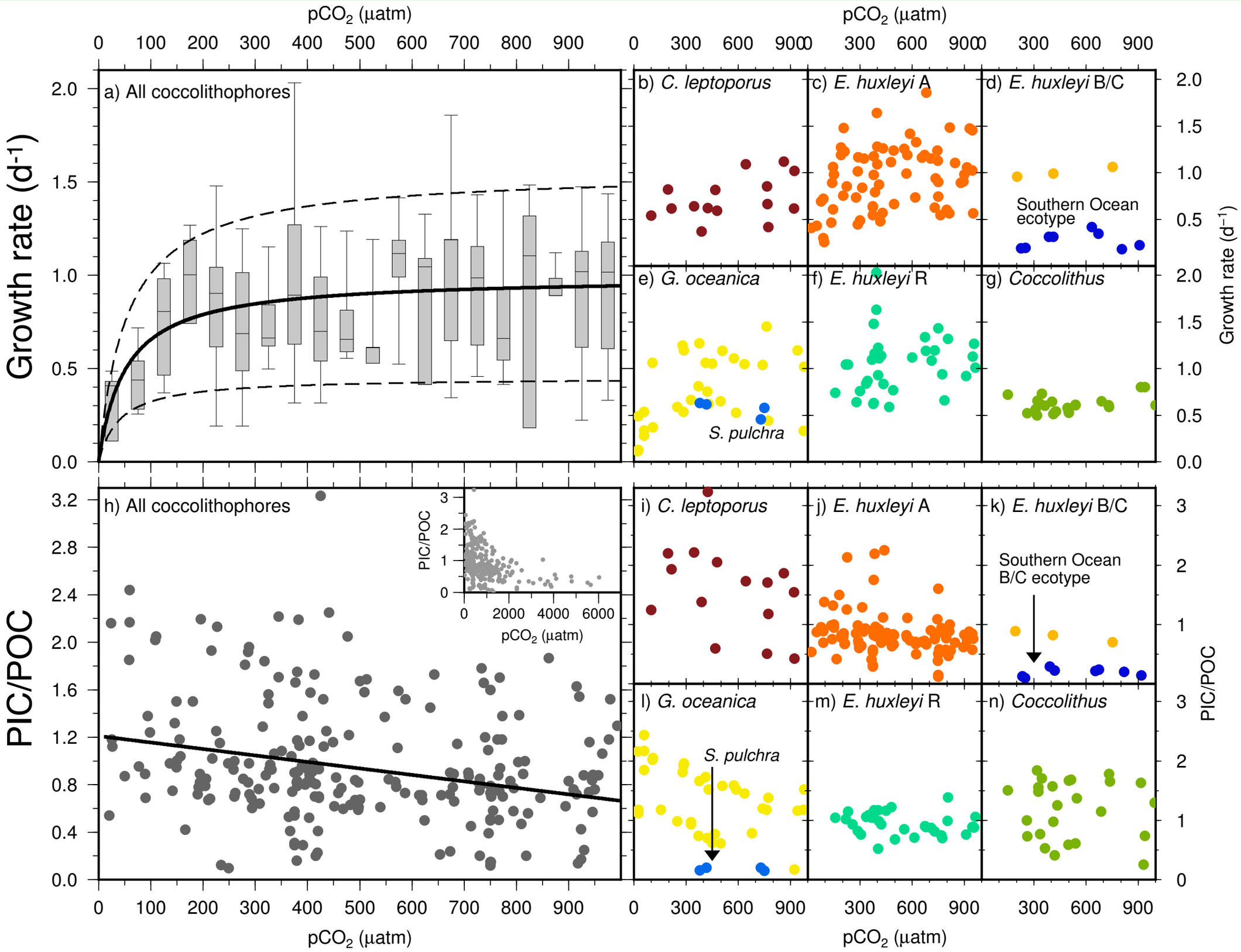
Krumhardt et al., 2017, Progress in Oceanography

CO_2

Growth rate

PIC/POC

(Calcification)



Krumhardt et al., 2017, Progress in Oceanography

Why parameterize explicit coccolithophores?

- Importance of calcification on ocean CO_2 uptake, carbon export to deep sea…
- Environmental modulation of growth and calcification (e.g., ocean acidification threatens pelagic calcifiers).
- How will coccolithophore growth and calcification change with anthropogenic climate change?

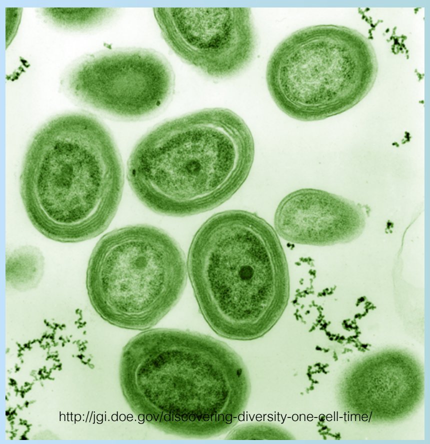
Marine primary production in CESM: 3 PFTs

1) Small phytoplankton

2) Diatoms

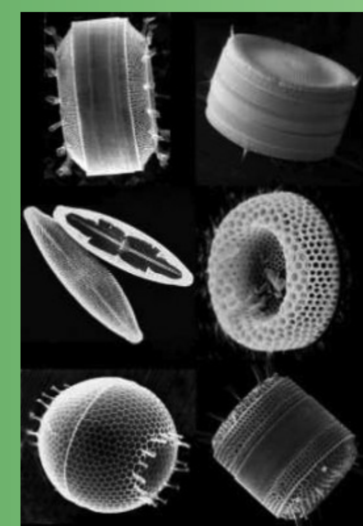
3) Diazotrophs

Prochlorococcus

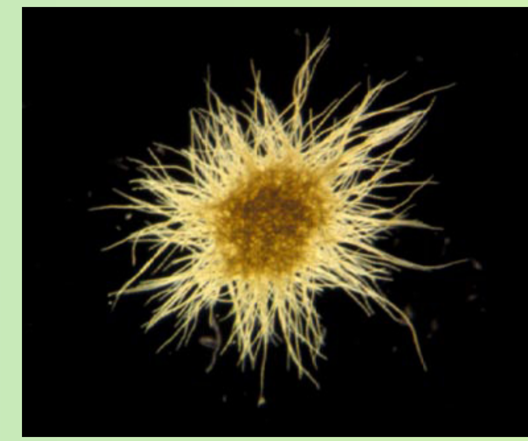


Coccolithophores

+ many others



https://www.nextnature.net/2012/12/nanotech-diatoms/



http://www.whoi.edu/oceanus/feature/having-their-phosphorus-and-eating-it-too

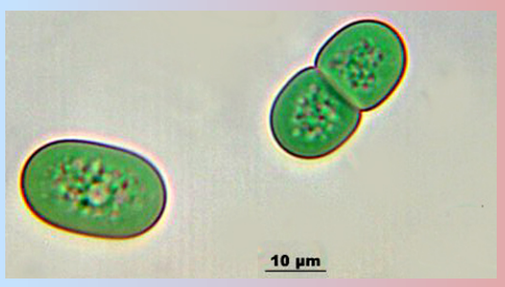
Coccolithophore calcification is modeled as an implicit fraction of small phytoplankton PFT

Putting coccolithophores into CESM

- Using MARBL (Marine biogeochemistry laboratory)
- Adding coccolithophores as a 4th PFT (explicit calcifier)

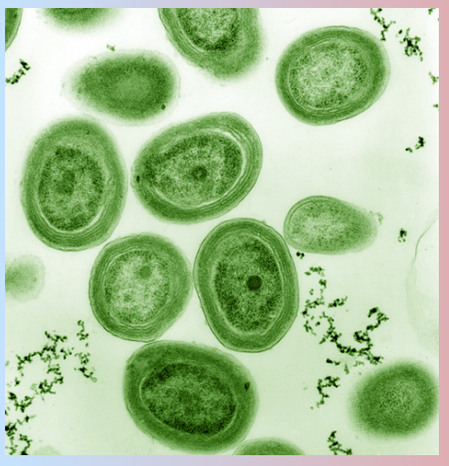
1) Small phytoplankton 2) Coccolithophores 3) Diatoms 4) Diazotrophs

Synechococcus

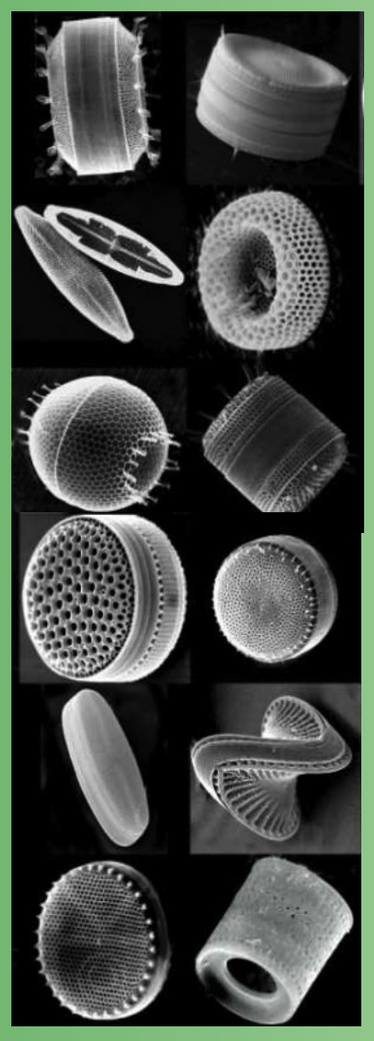


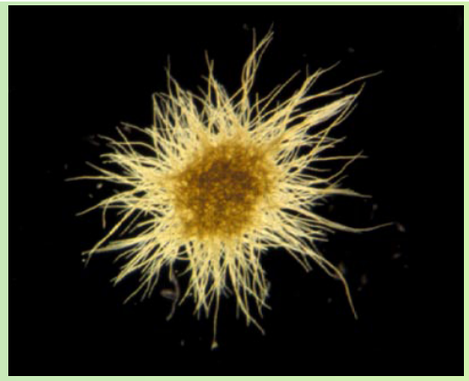
http://cfb.unh.edu/phycokey/Choices/Cyanobacteria/cyano_unicells/SYNECHOCOCCUS/Synechococcus_Image_page.htm

Prochlorococcus



http://jgi.doe.gov/discovering-diversity-one-cell-time/





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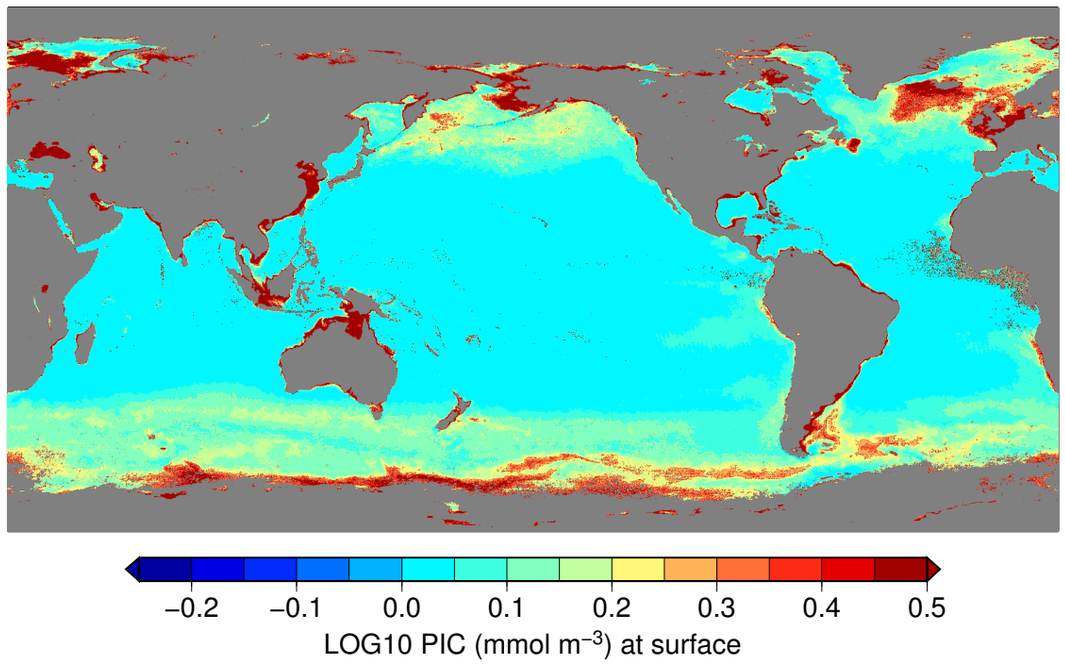
http://cfb.unh.edu/phycokey/Choices/Cyanobacteria/cyano_filaments/cyano_unbranched_fil/untapered_filaments/no_heterocysts/no_vis_sheath/TRICHODESMIUM/Trichodesmium_Image_page.htm

Coccolithophores in CESM: depth integrated $CaCO_3$ production

Surface $CaCO_3$ from satellite

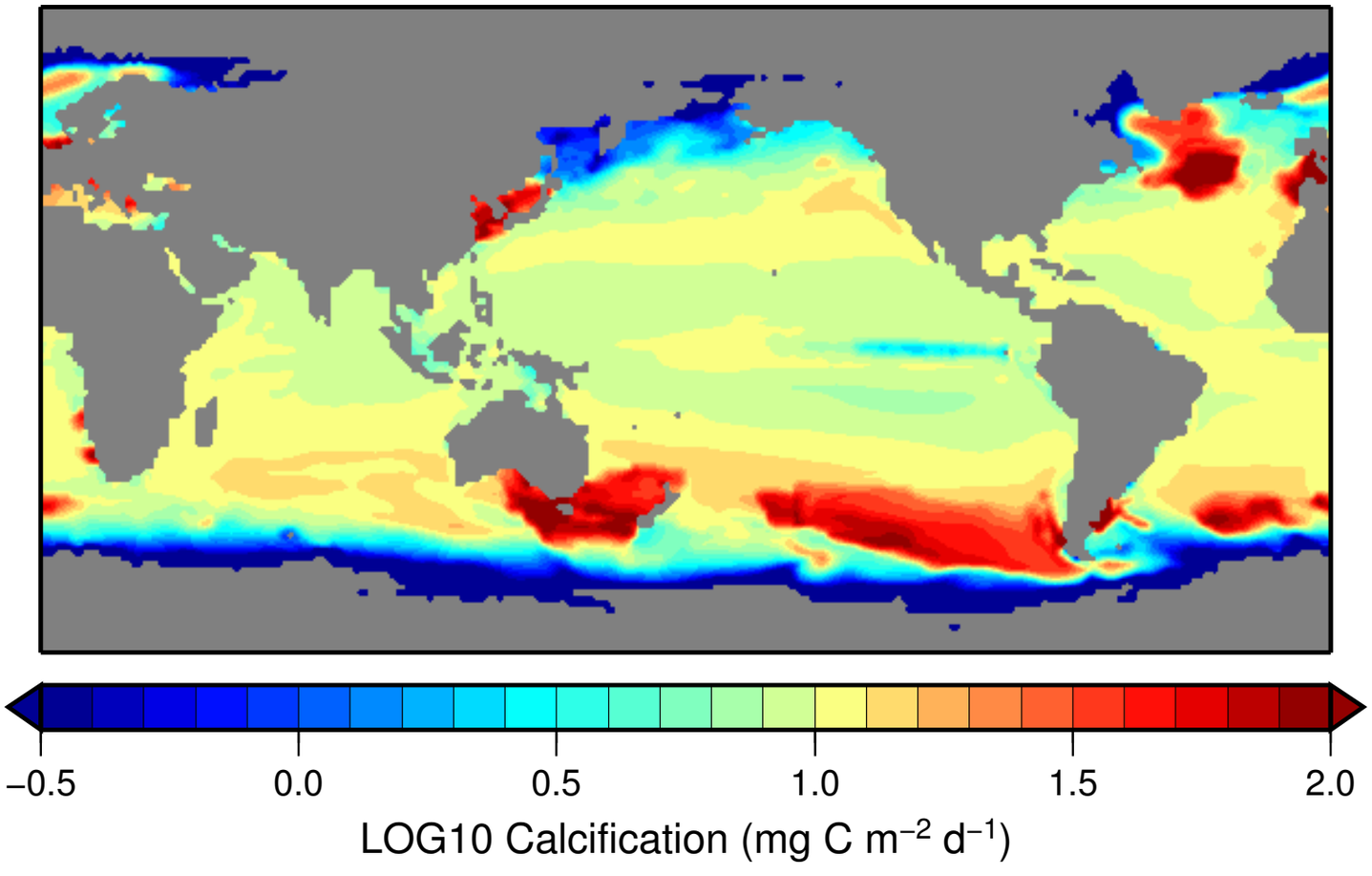
MODIS annual average (mean 2002-2015)



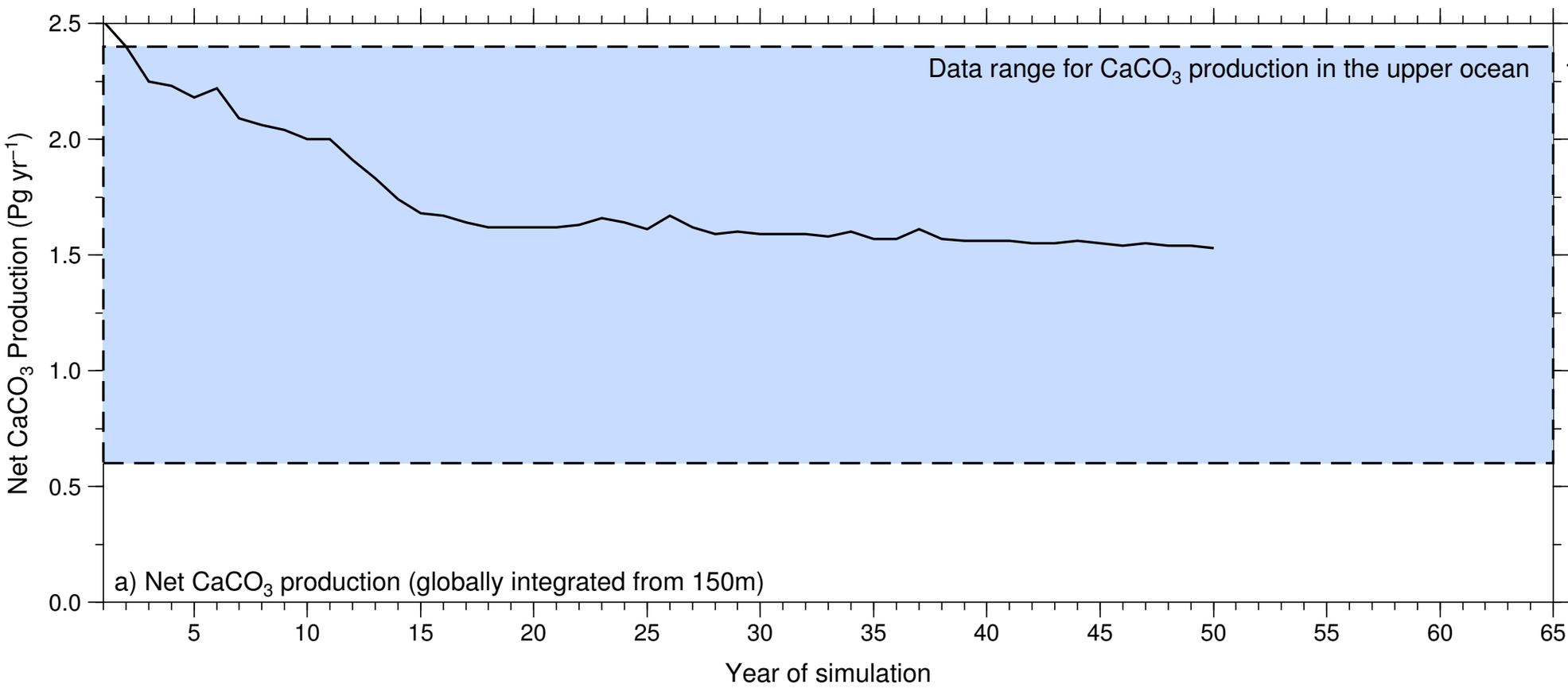
CESM with coccolithophores

Globally integrated $CaCO_3$ Production = 1.53 Pg C yr^{-1}

(other estimates range from 0.8 to 2.4 Pg C yr^{-1})



$CaCO_3$ production observations for validation



Reference	Global calcification (Pg C yr^{-1})	Method
[7]	2.4	Field calcification
[8]	>2.1	Combination
[9]	1.6–2.4	Satellite algorithm
[10;5]	0.29–0.7	Sediment traps, 800–1000m
[11;12]	0.6–1.1	Alkalinity model
[13]	0.8–1.4	Models + alkalinity observations

Methods - CESM simulations with coccolithophores

Experiments:

↑CO_2

↑Temp

↑CO_2 / ↑Temp

Simulation details:

- Ocean/Sea ice only
- “normal year” climate
- 1 degree resolution

Methods - CESM simulations with coccolithophores

Experiments:

↑CO_2

↑Temp

↑CO_2 / ↑Temp

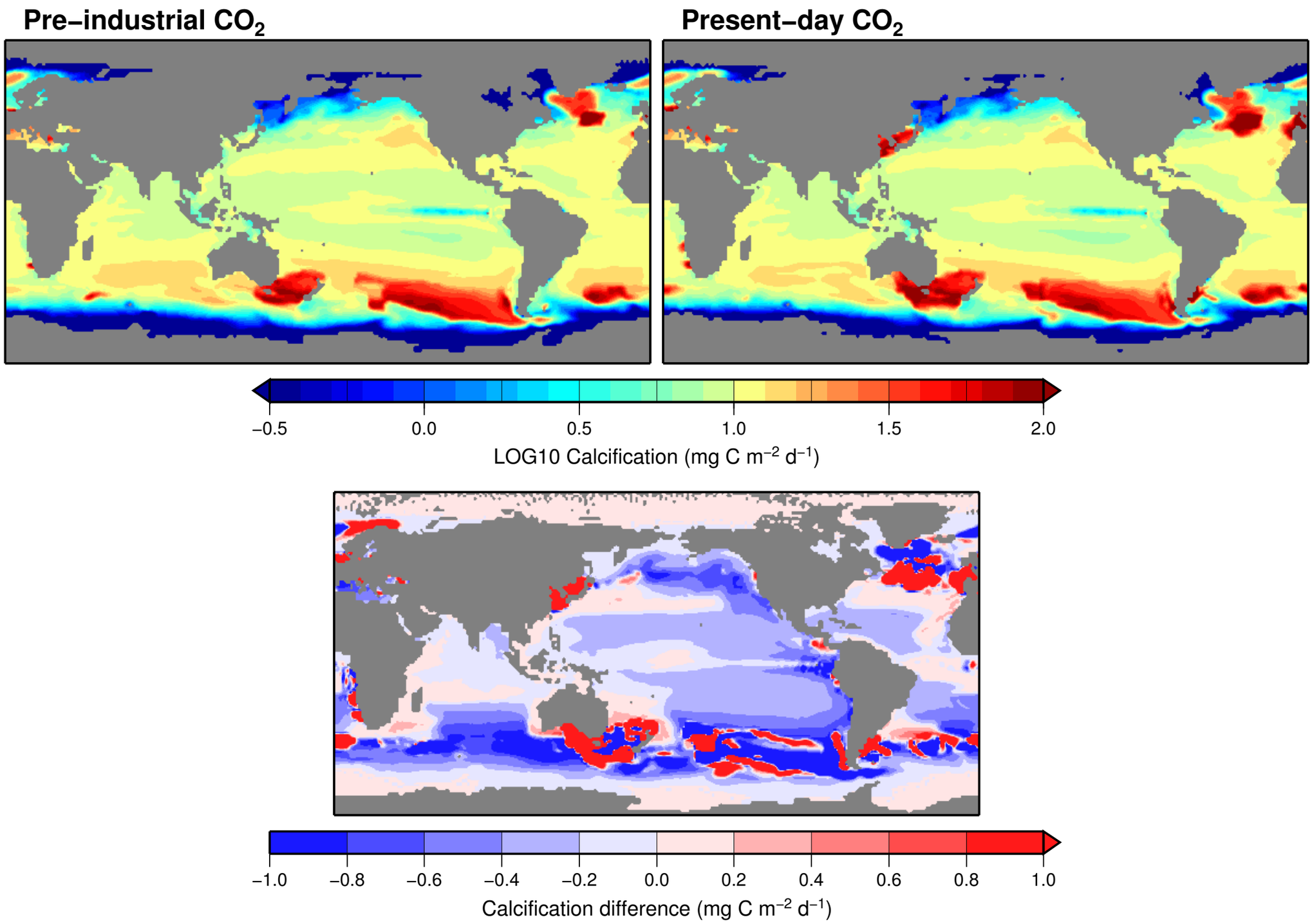
Simulation details:

- Ocean/Sea ice only
- “normal year” climate
- 1 degree resolution

Results from 50-year simulations:

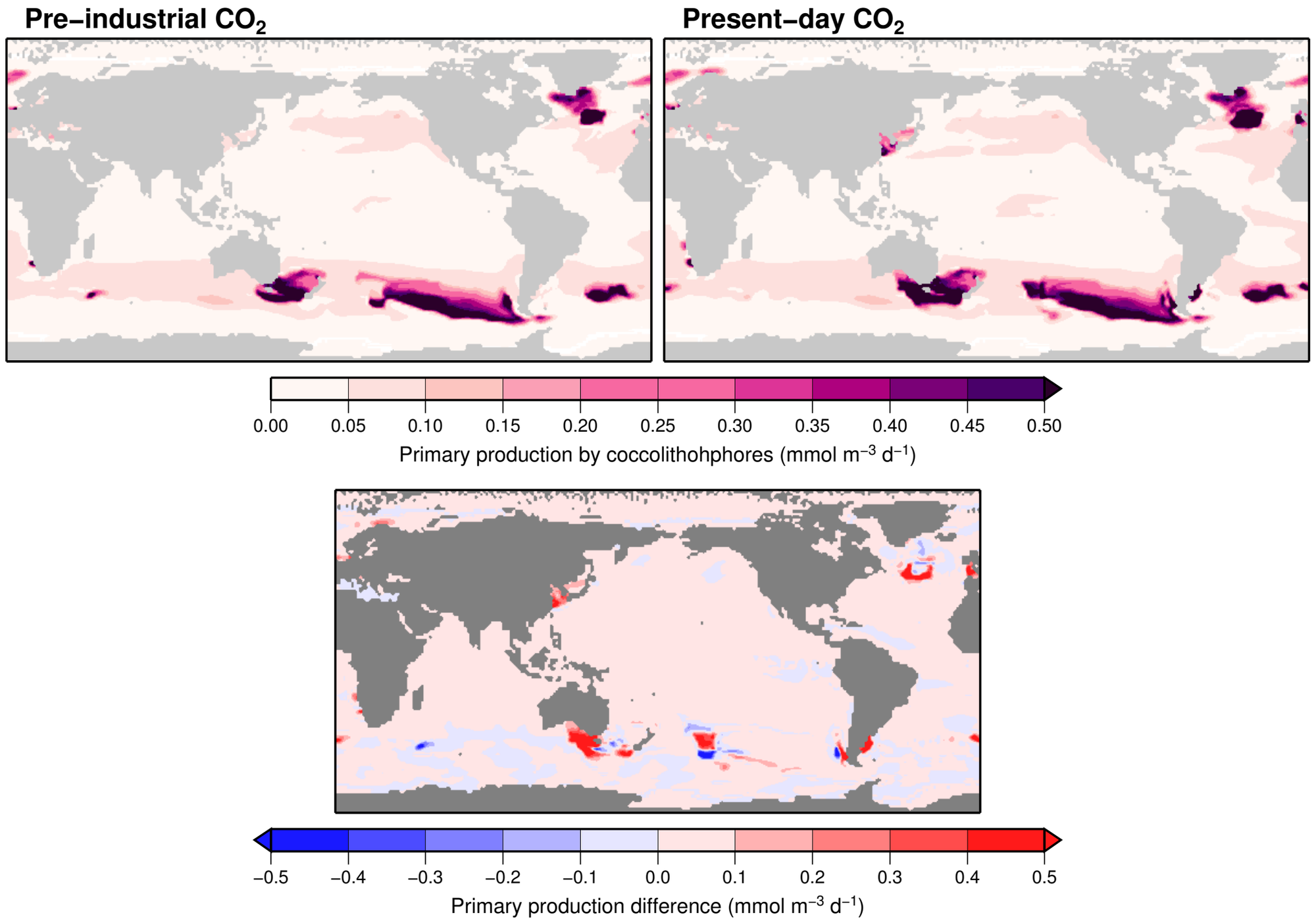
- Pre-industrial CO_2 = 284.7 ppm
- Present day CO_2 = 400.0 ppm

What is the effect of increasing CO_2?: Calcification

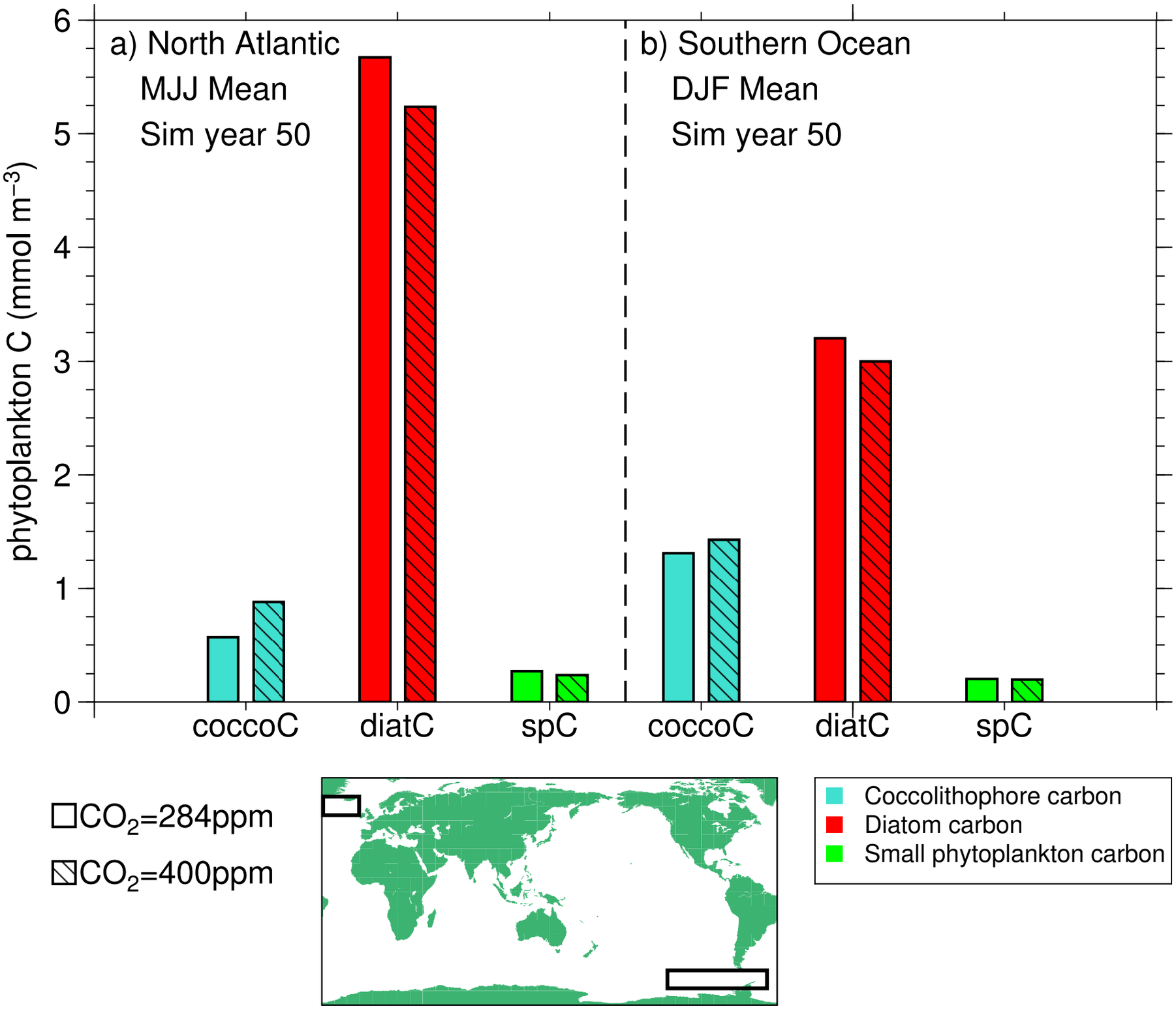


Globally, a 8% increase in calcification.

What is the effect of increasing CO_2?: Coccolithophore primary production



Regional effects of increasing CO_2: North Atlantic and Southern Ocean



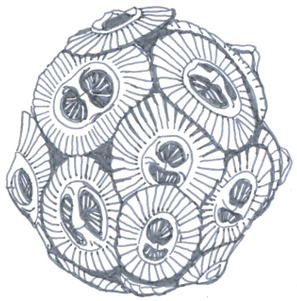
Conclusions and next steps

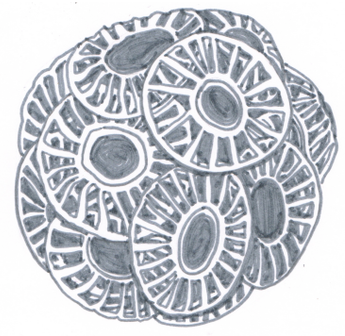
- Coccolithophore growth rates increase from PI CO_2 levels to present-day.

- Overall 8% increase in coccolithophore calcification (balance of positive and negative regional changes).

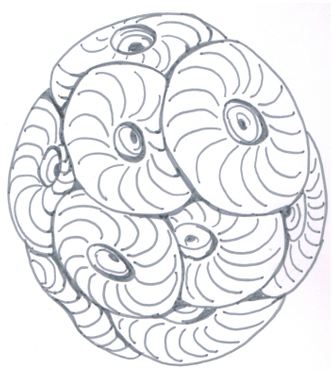
Next steps…

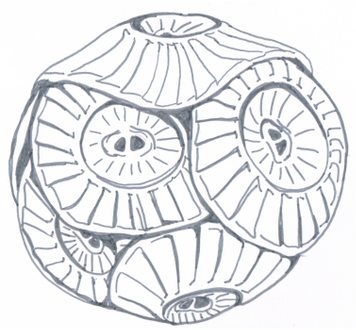
- Continue testing with higher CO_2 levels
- Simulations with increased temperature
- Simulations with *both* increased CO_2 and temperature





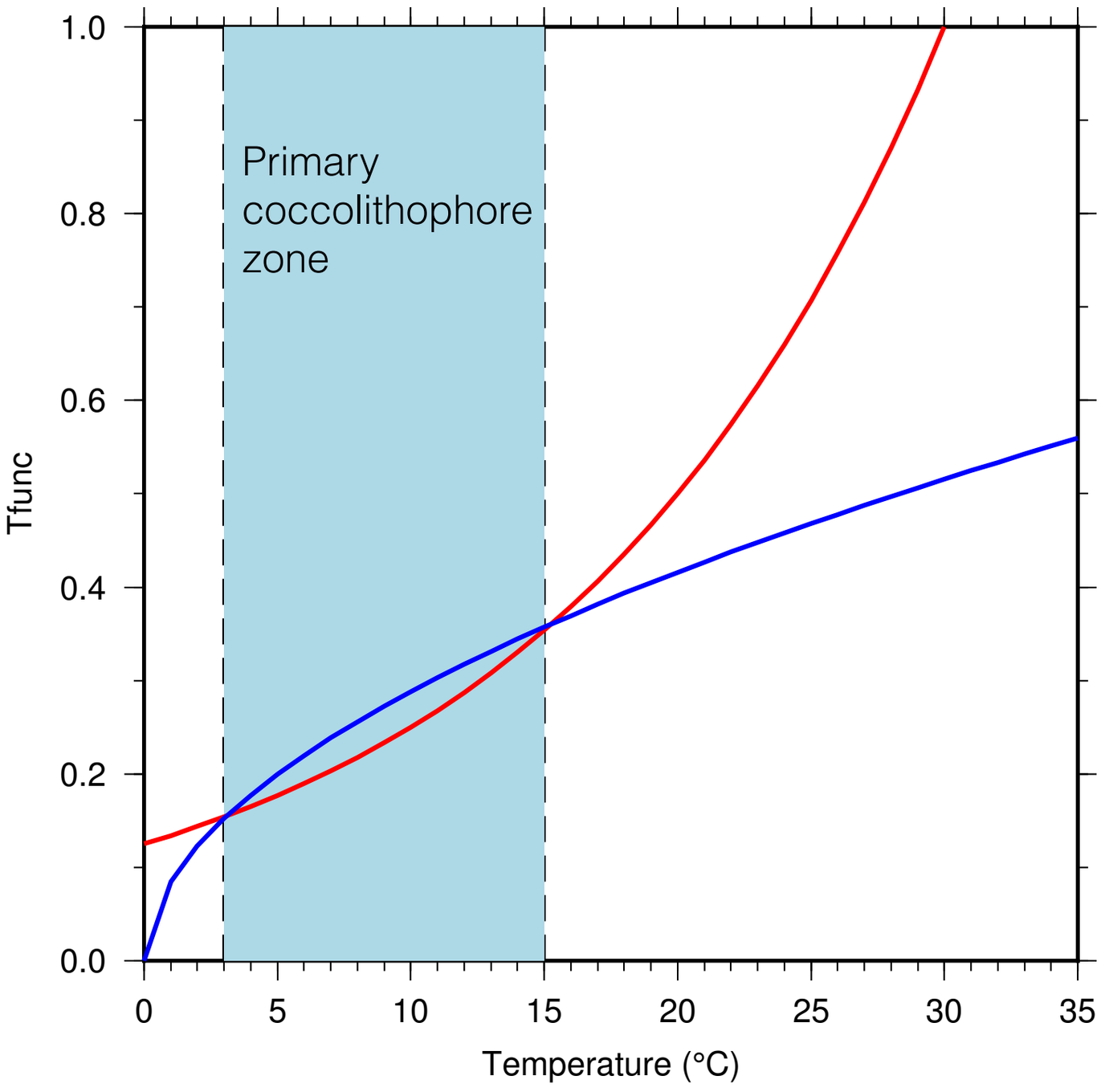
Thanks for your attention!



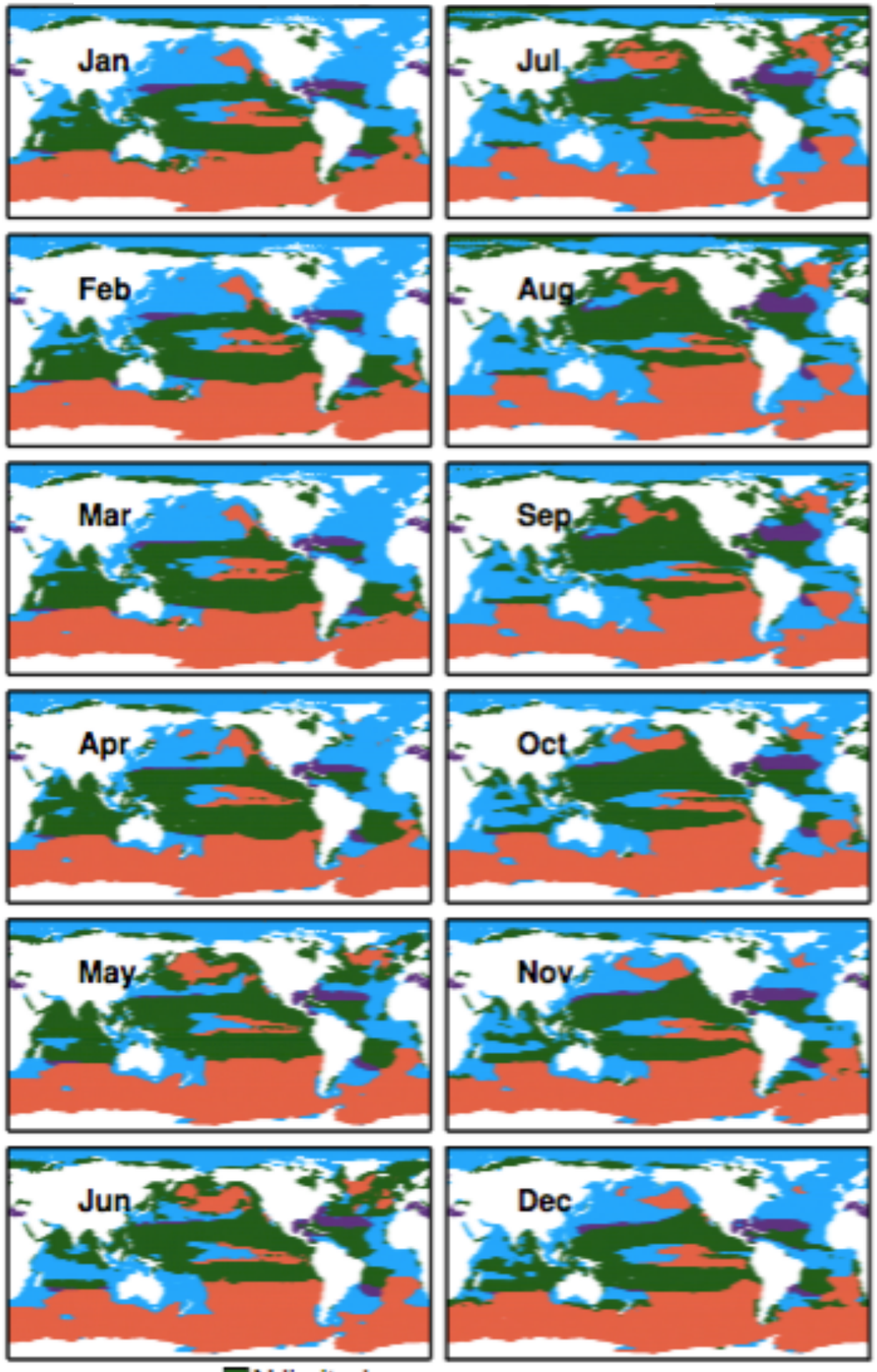


Temperature influence on coccolithophore growth rate

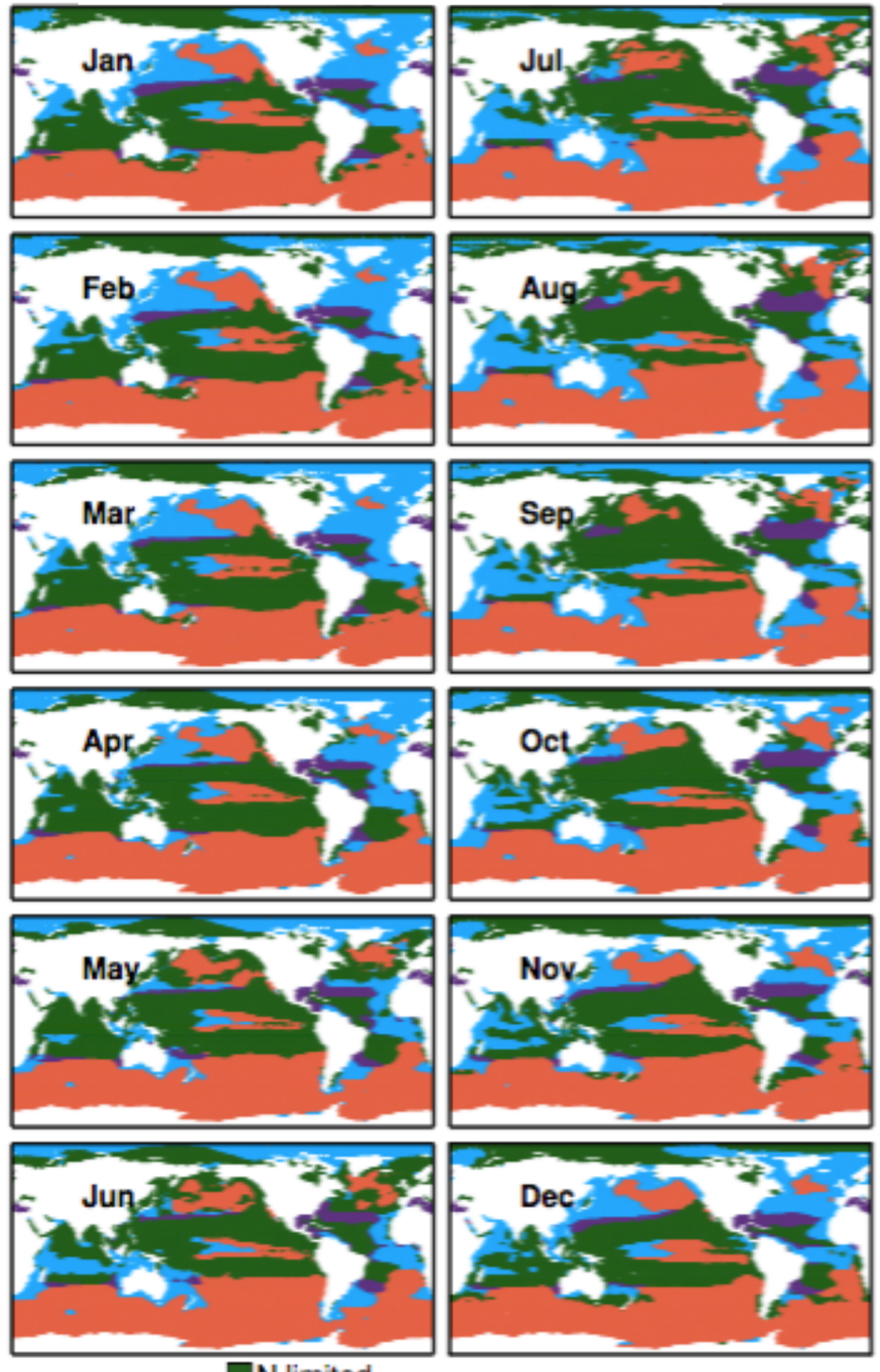
growth rate = max growth rate * Tfunc



Preindustrial CO_2



Present-day CO_2



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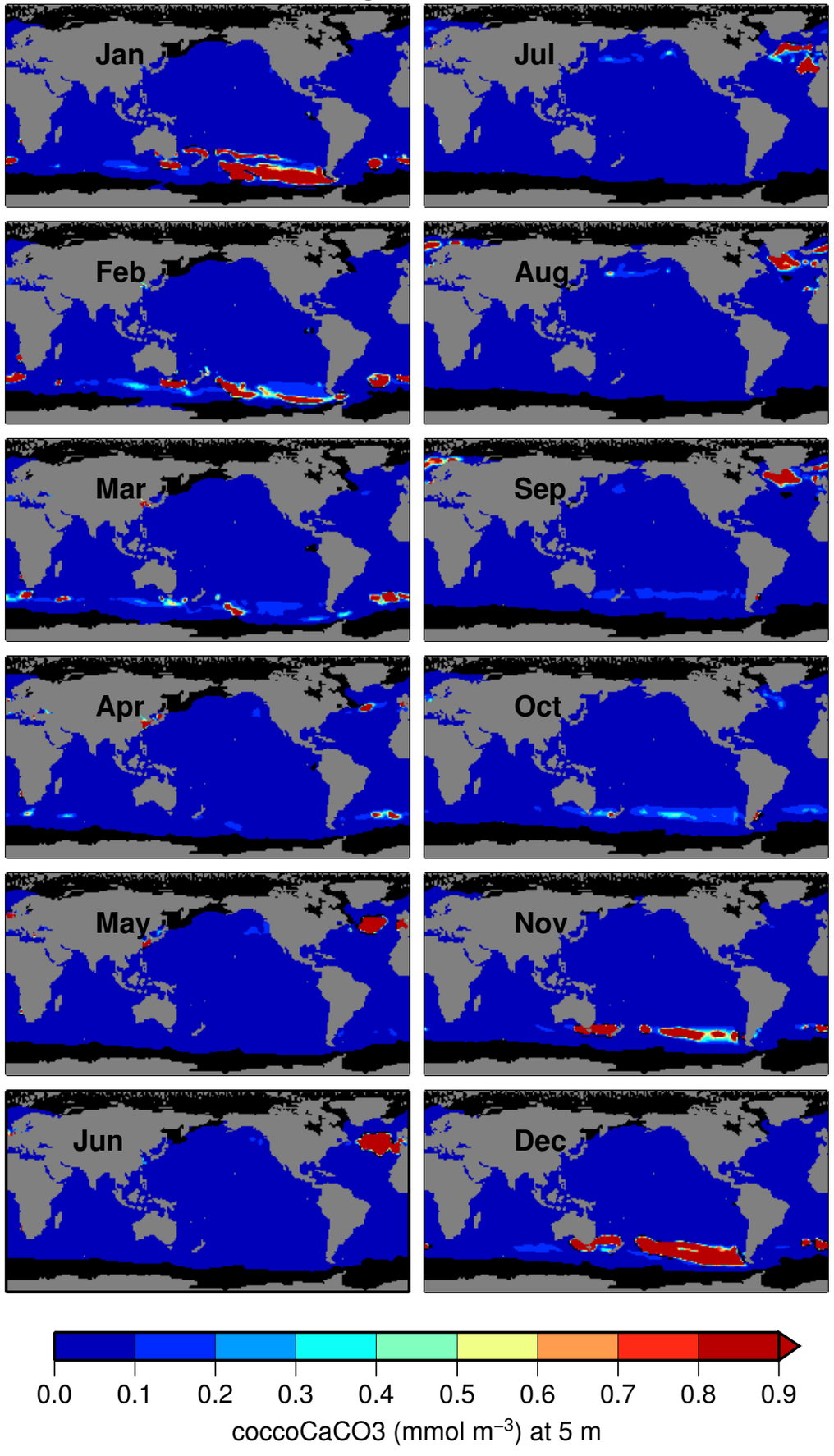

Current small phytoplankton parameterization in CESM

Change small phytoplankton carbon over time

Photosynthesis by small phytoplankton

Grazing

Mortality

Aggregation

$$\frac{d(Sc)}{dt} = P_s - G_s - M_s - A_s$$

Photosynthesis by small phytoplankton

Growth rate

Small phytoplankton carbon

$$P_s = \mu_s \cdot S_c$$

Small phytoplankton growth rate

Max growth rate = 5 d^{-1}

$$\mu_s = \mu_{max} \cdot L_t \cdot L_{Vs} \cdot L_{Is}$$

Temperature limitation

Nutrient (N, P, Fe) limitation

Light limitation