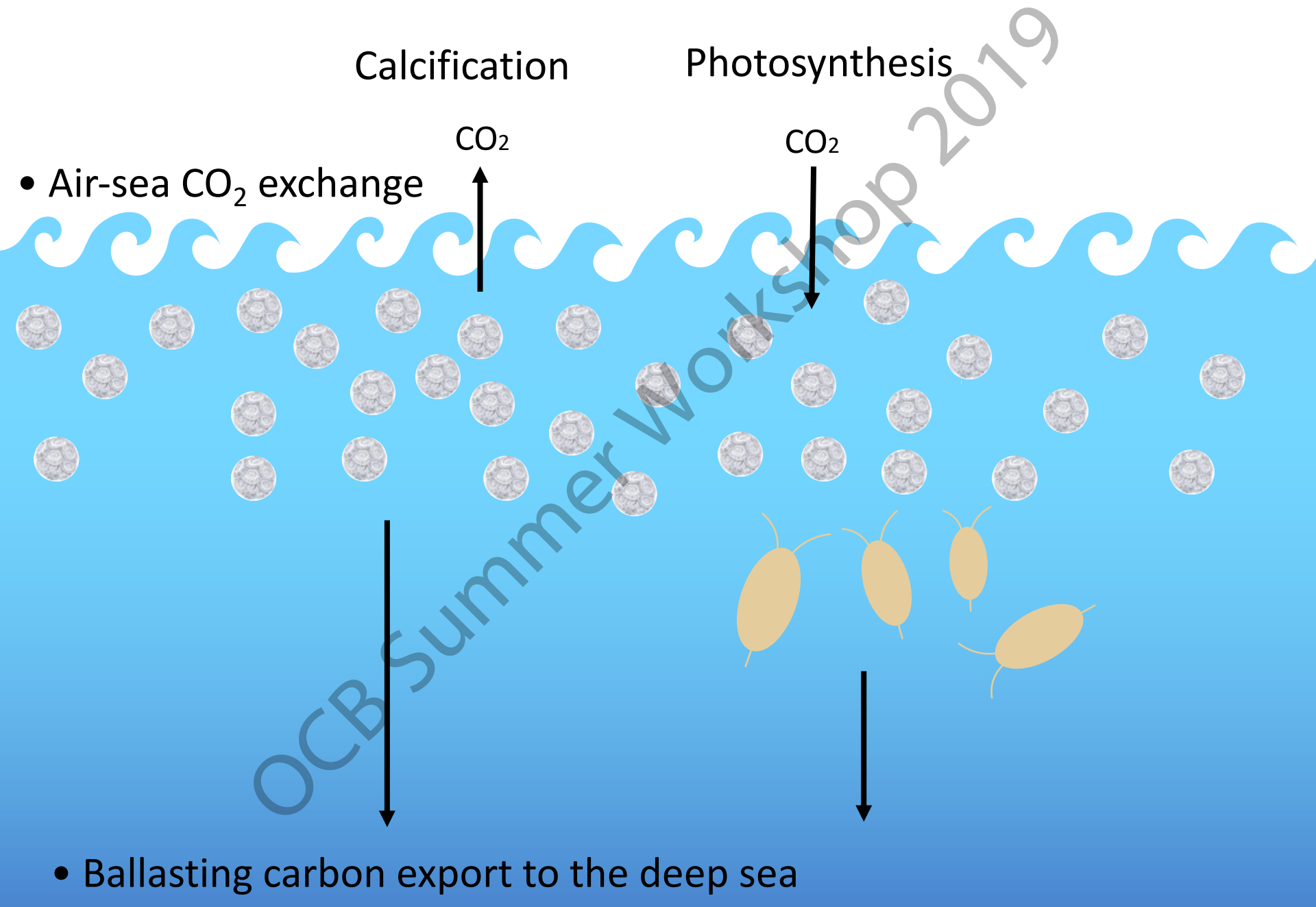
# The multifaceted response of coccolithophores to increasing $CO_2$

## Recent observations and Modeling

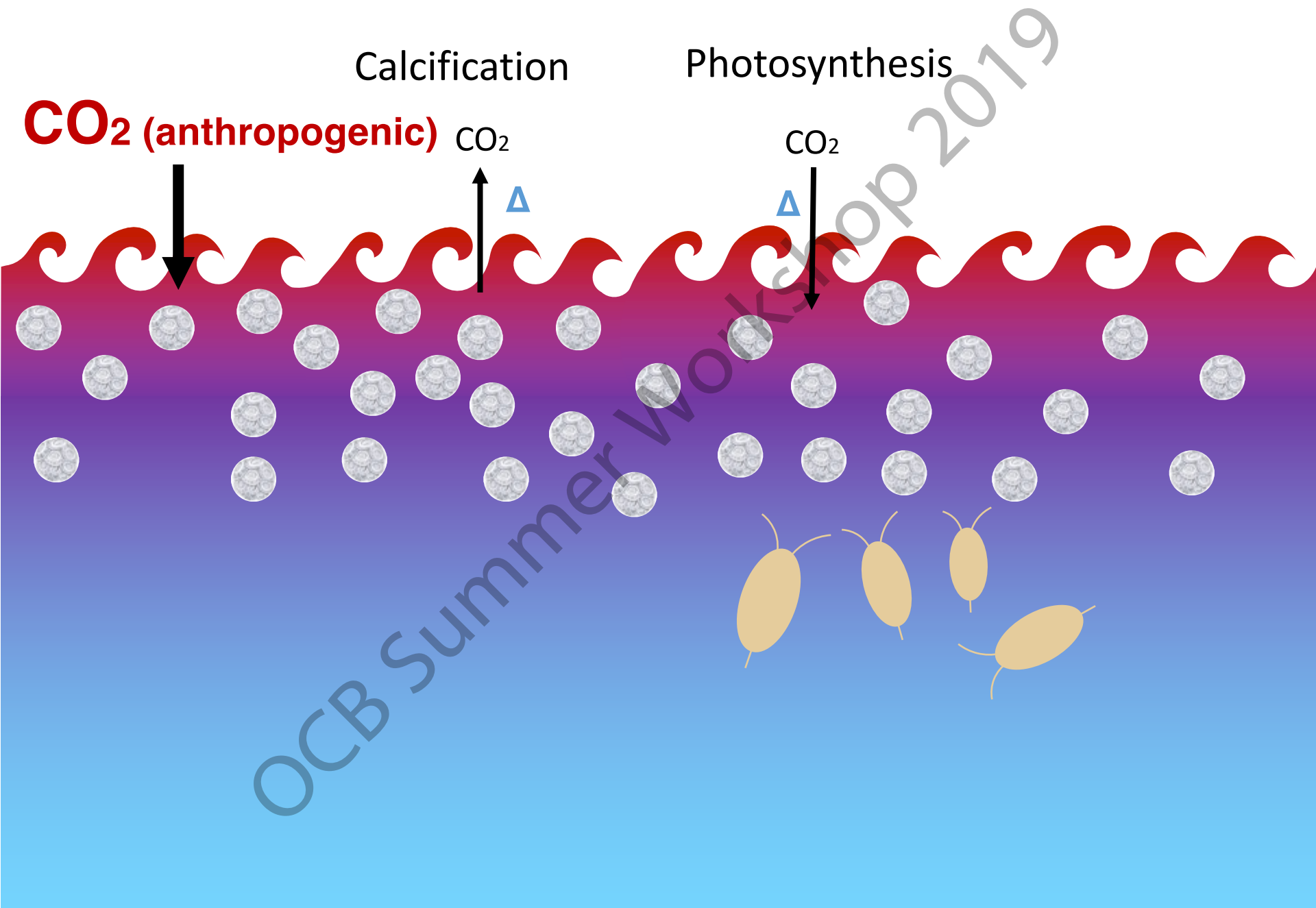
Kristen Krumhardt

OCB 2019, Calcification session

# Coccolithophores have a unique influence on the carbon cycle



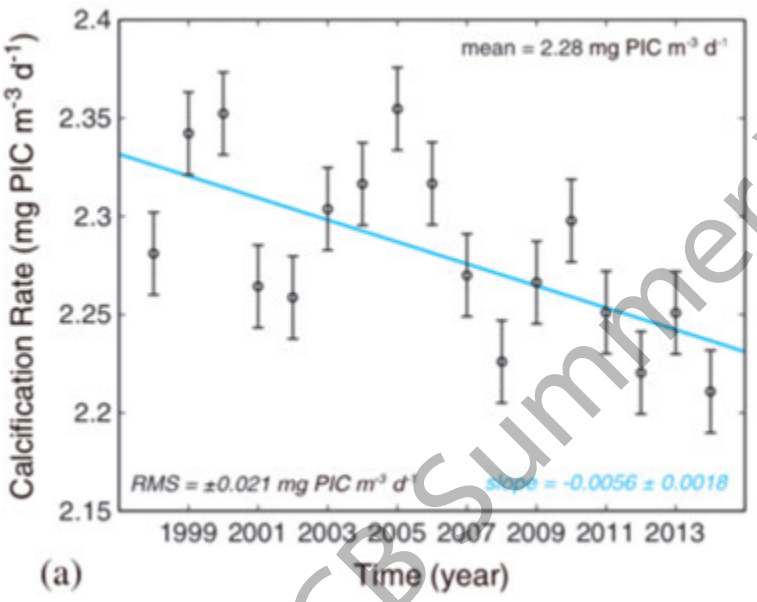
# Coccolithophores have a unique influence on the carbon cycle

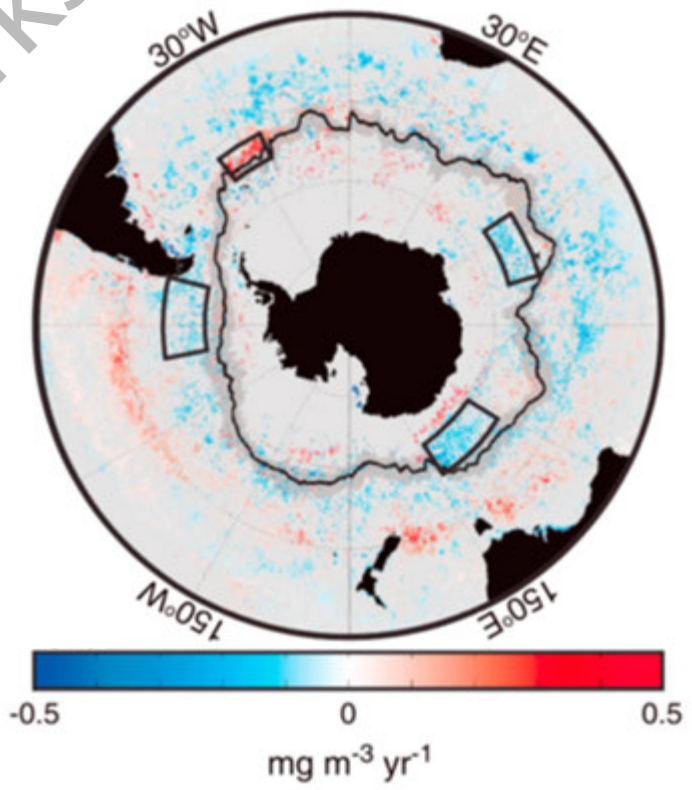


# Recent observations of coccolithophore change 1

## Decreased calcification in the Southern Ocean over the satellite record

**Natalie M. Freeman[1] and Nicole S. Lovenduski[1]**



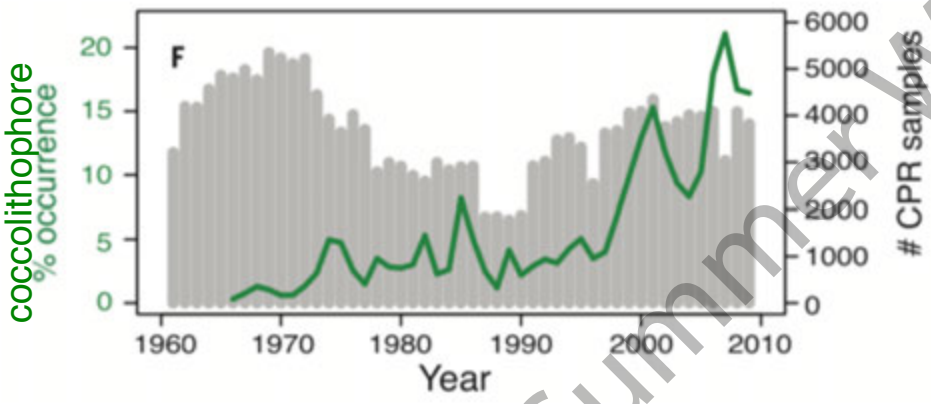



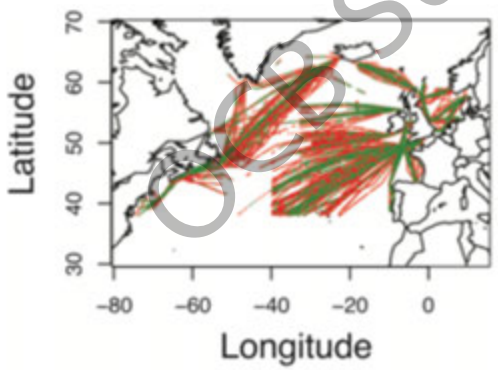

Freeman & Lovenduski, 2015, GRL

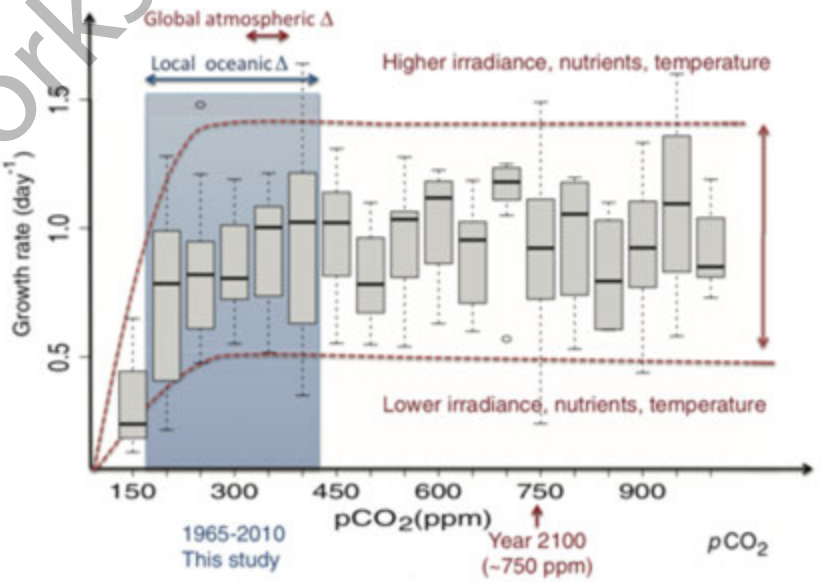
# Recent observations of coccolithophore change 2

## Multidecadal increase in North Atlantic coccolithophores and the potential role of rising $CO_2$

Sara Rivero-Calle,[1,2*] Anand Gnanadesikan,[1*] Carlos E. Del Castillo,[1,3] William M. Balch,[4] Seth D. Guikema[5]



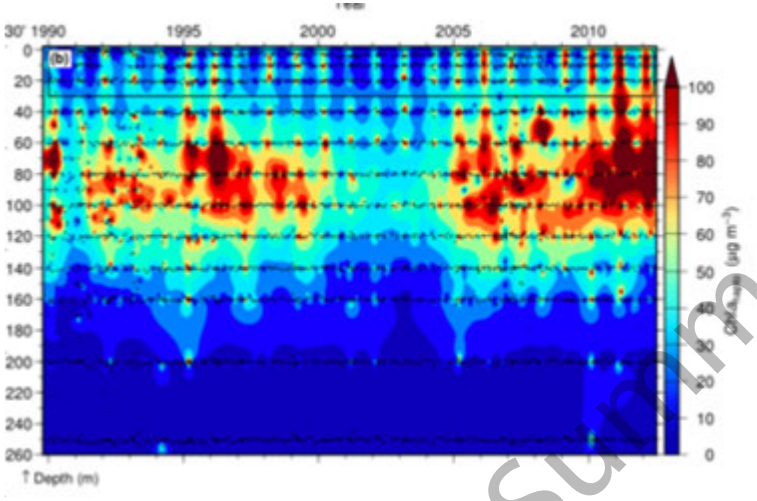


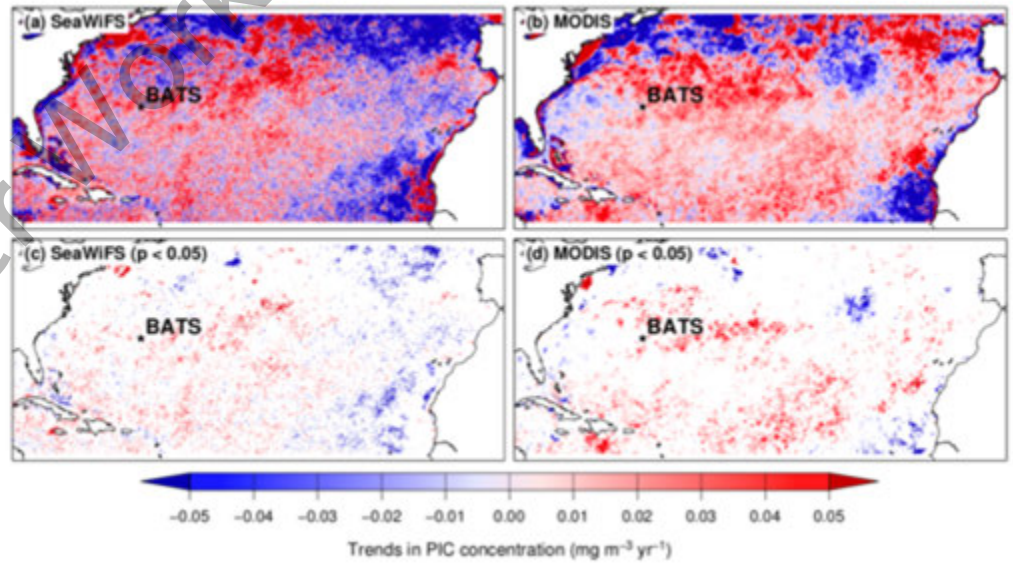

Rivero-Calle et al., 2015, Science

# Recent observations of coccolithophore change 3

## Apparent increase in coccolithophore abundance in the subtropical North Atlantic from 1990 to 2014

Kristen M. Krumhardt[1], Nicole S. Lovenduski[2], Natalie M. Freeman[2], and Nicholas R. Bates[3]


Coccolithophore pigments at BATS show significant positive correlation with DIC, in contrast to total chlorophyll.

Krumhardt et al., 2016, Biogeosciences

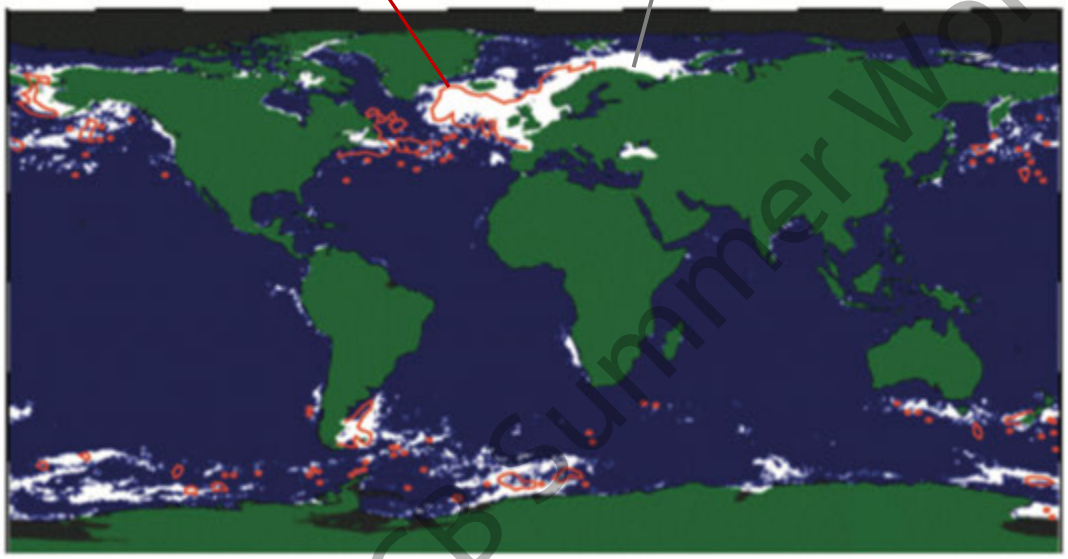
# Recent observations of coccolithophore change 4

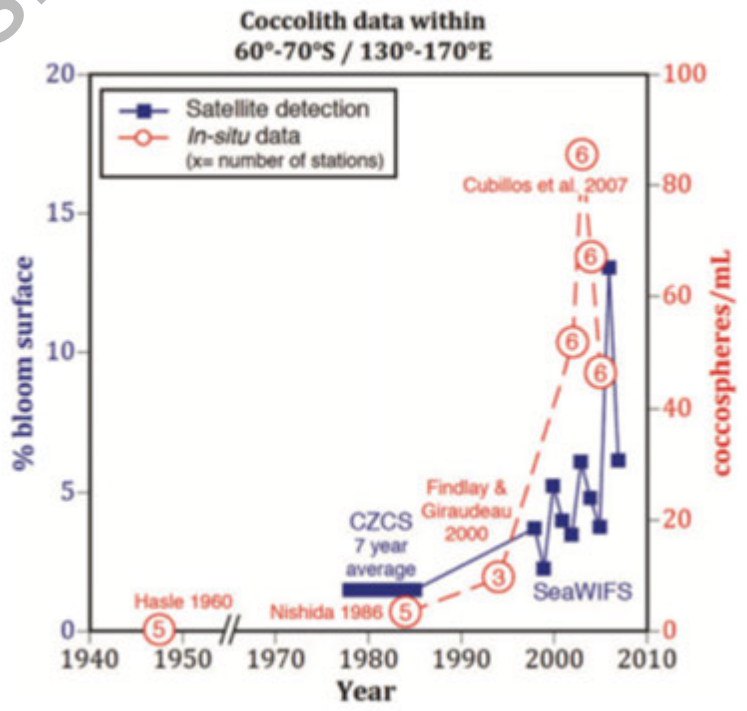
## Poleward expansion of the coccolithophore *Emiliania huxleyi*

AMOS WINTER[1]*, JORIJNTJE HENDERIKS[2], LUC BEAUFORT[3], ROSALIND E. M. RICKABY[4] AND CHRISTOPHER W. BROWN[5]

Maximum bloom extent (1978-1986)

SeaWIFS extent (1997-2007)



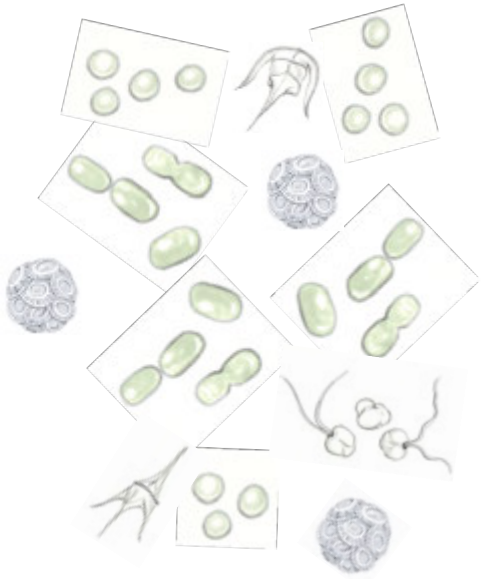




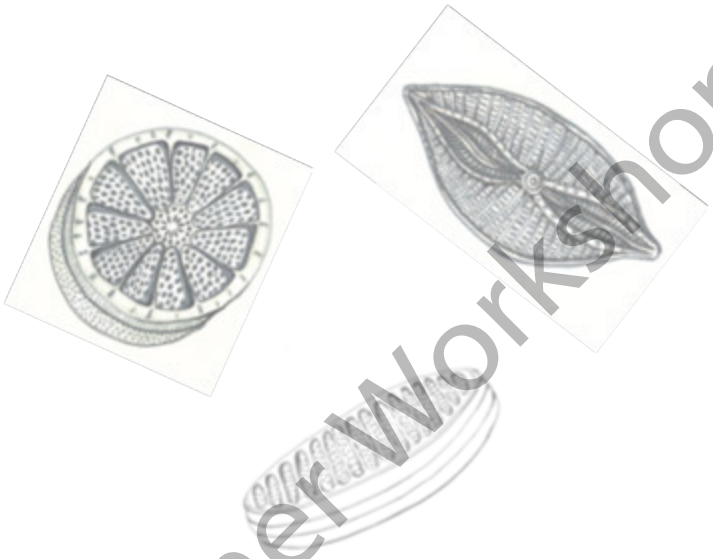

Winter et al., 2013, Journal of Plankton Research

# CESM ocean ecosystem model

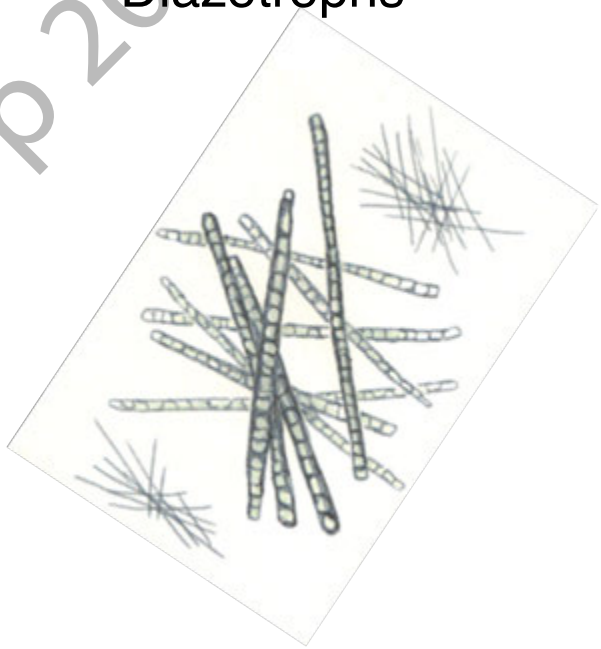
Small phytoplankton



Diatoms

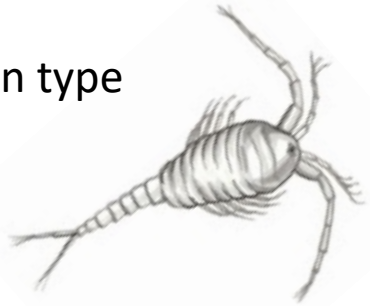


Diazotrophs



+

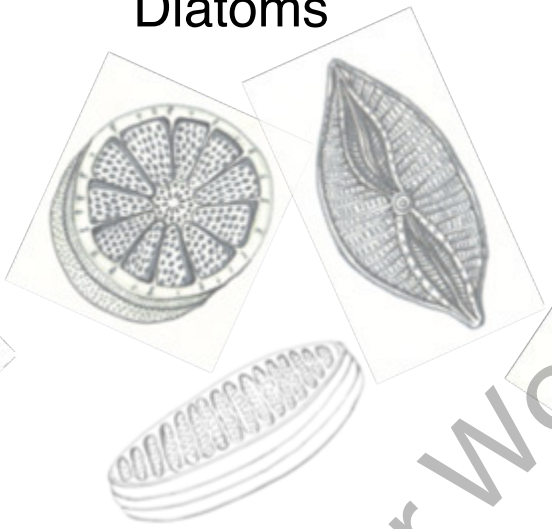
zooplankton type



# CESM ocean ecosystem model

Small phytoplankton

Diatoms

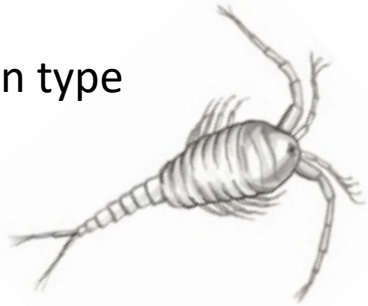


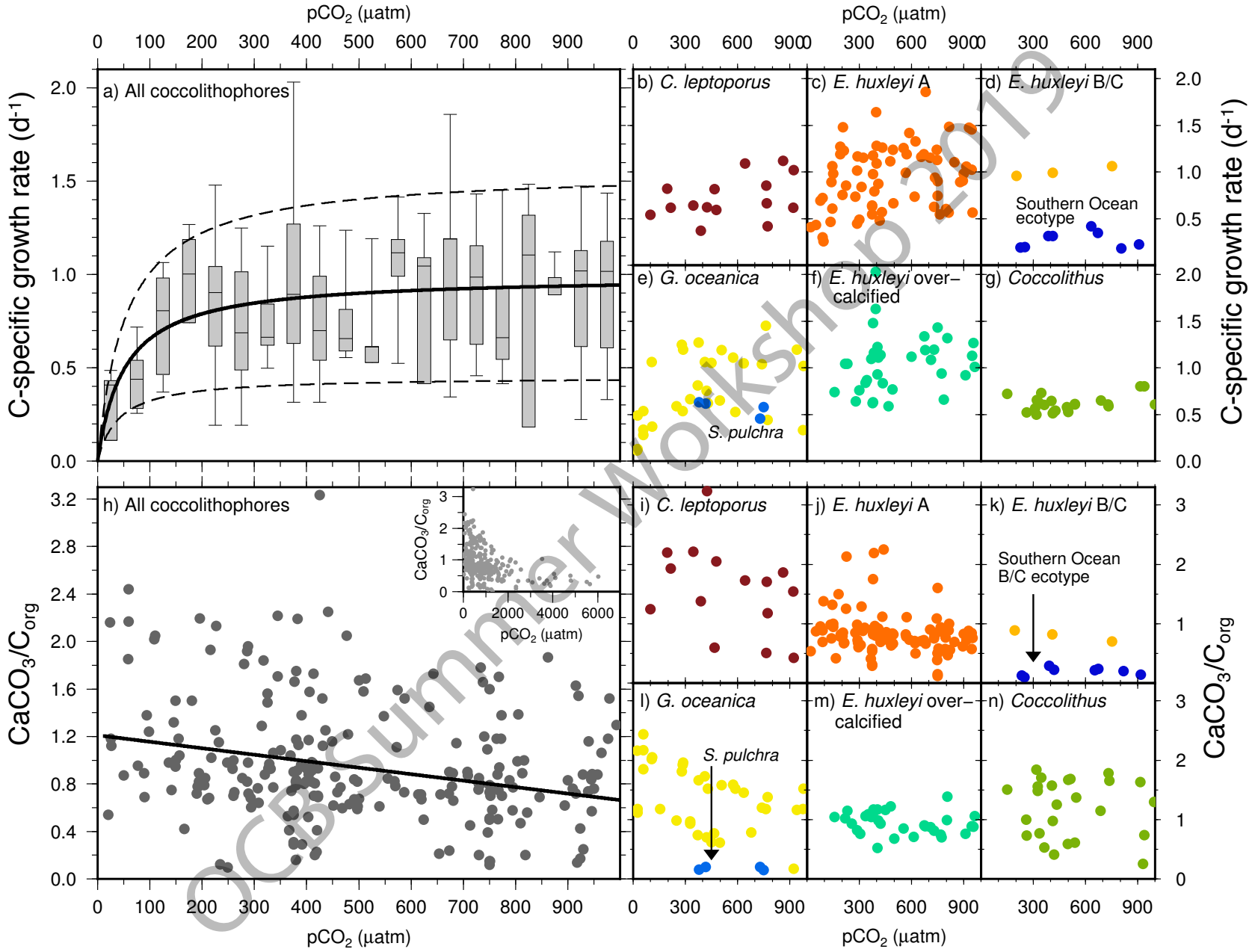
Diazotrophs

Coccolithophores

+

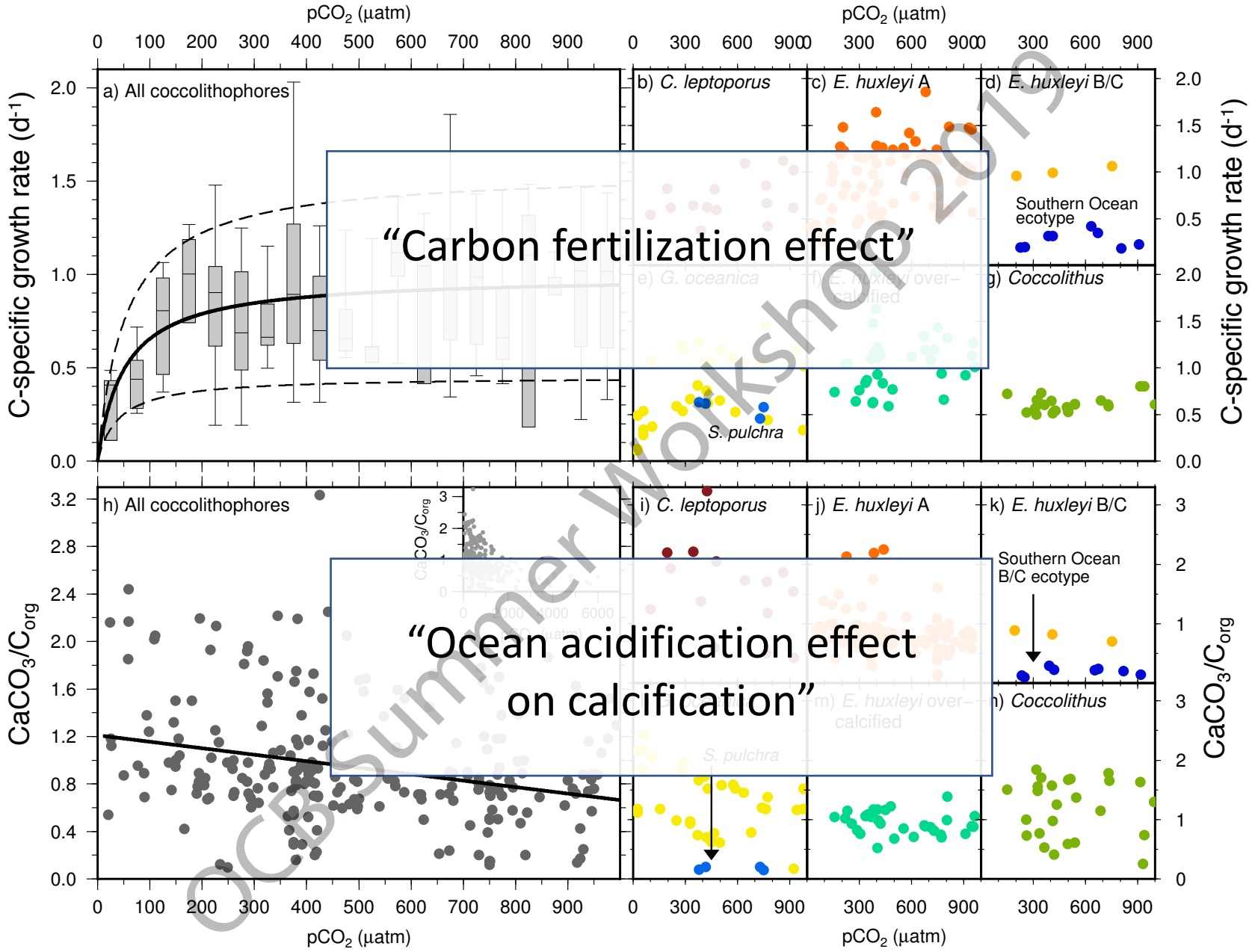
zooplankton type





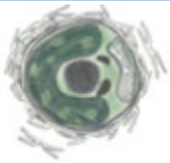


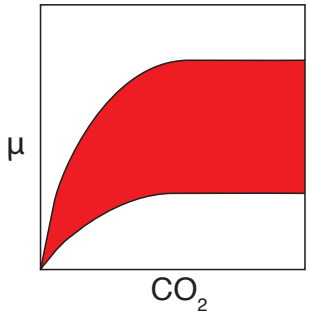
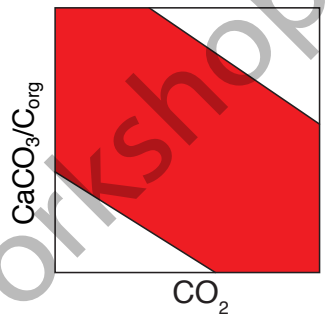
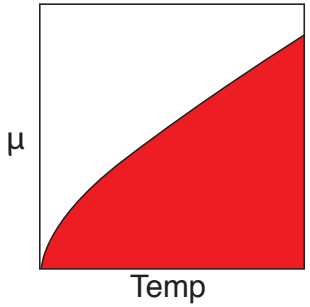
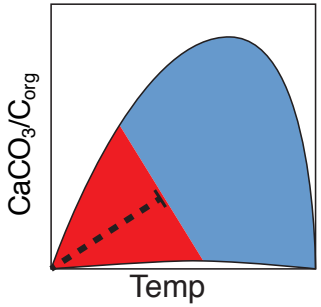
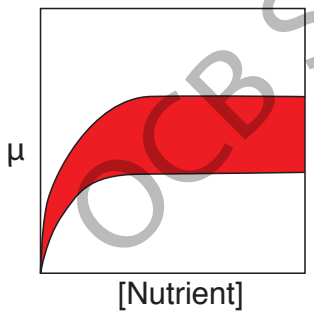
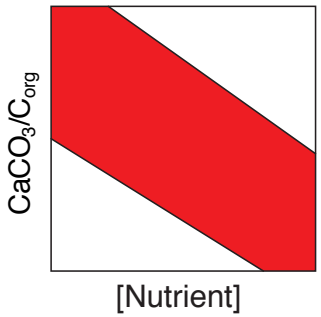

Krumhardt et al., 2017, Progress in Oceanography




Krumhardt et al., 2017, Progress in Oceanography

# Creating a phytoplankton functional type representative of coccolithophores



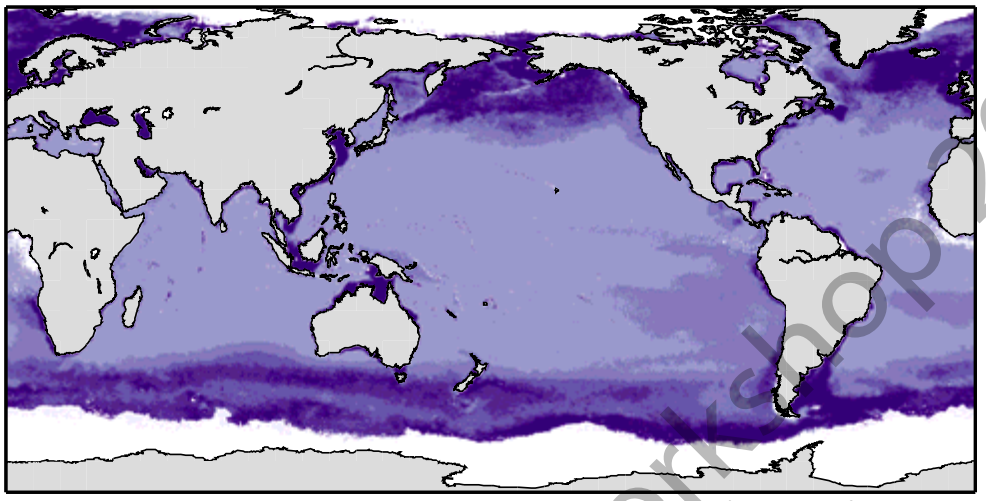
| | Growth rate, μ ($C_{org}$ production; d-1) | | $CaCO_3/C_{org}$ | |
|---|---|---|---|---|
| $pCO_2$ |   | • Carbon limited growth rate at low $CO_2$<br>• Large range of senstivities at high $CO_2$ |   | • $CaCO_3/C_{org}$ generally decreases as $CO_2$ increases<br>• Large range of responses |
| Temperature |   | • Power function determines temperature dependent maximum growth rate |   | • $CaCO_3/C_{org}$ decreases at low temperatures but the relationship at higher temperatures is not as clear |
| Nutrients |   | • Efficient nutrient uptake at low concentrations<br>• Comparably high affinity for nutrients |   | • $CaCO_3/C_{org}$ increases under nutrient limitation and decreases under nutrient replete conditions |



Krumhardt et al., 2017, Progress in Oceanography

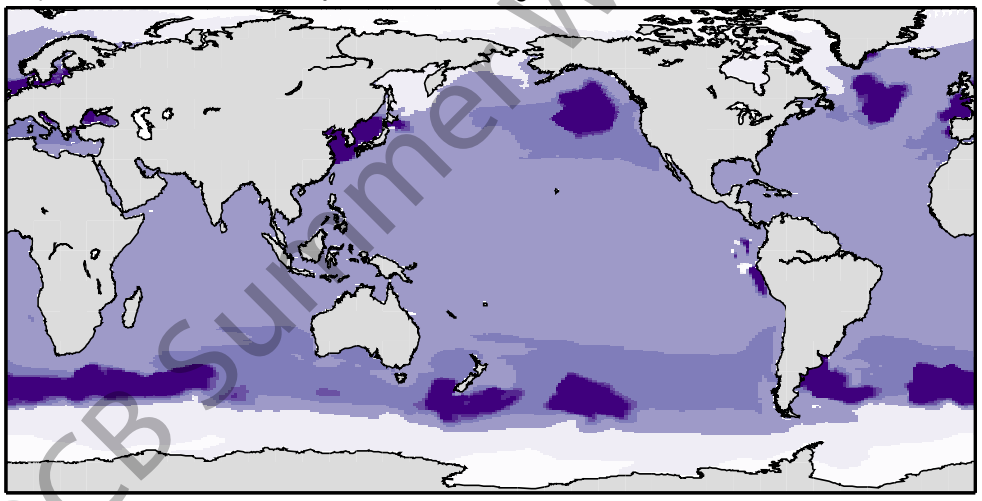
# Model validation

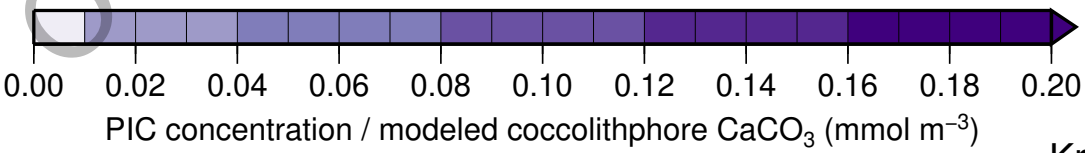
a) MODIS Particulate Inorganic Carbon (PIC) *



* Masked for SST>2C

b) CESM coccolithophore $CaCO_3$

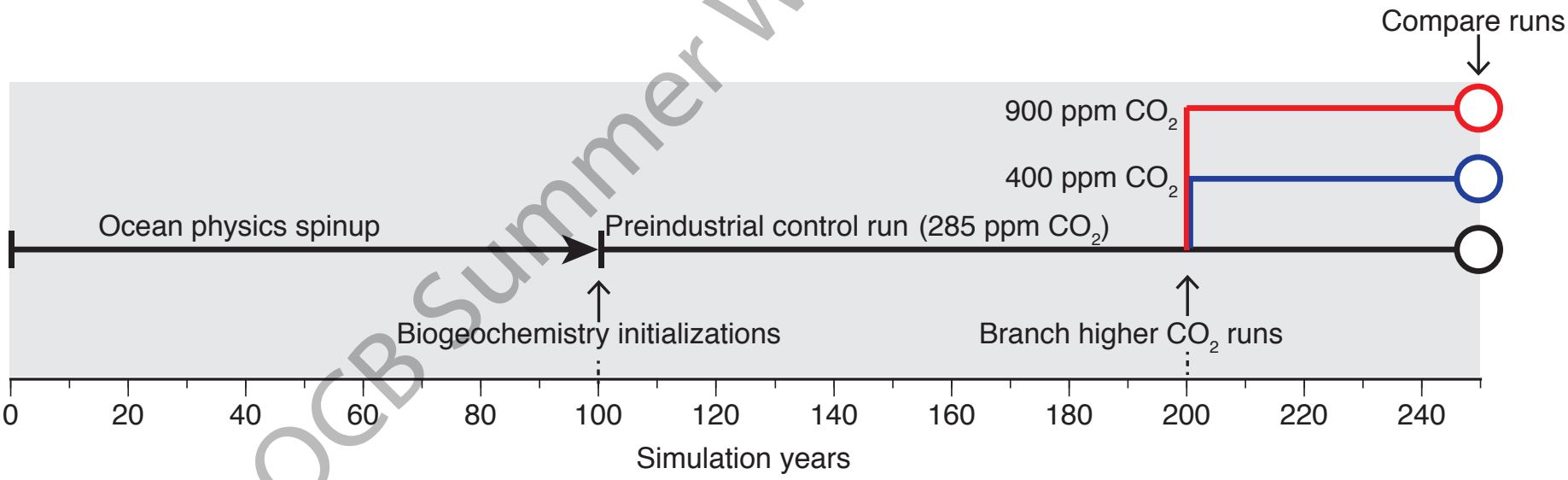





Krumhardt et al., 2019, JAMES

# Methods: Isolating the effects of increasing $CO_2$

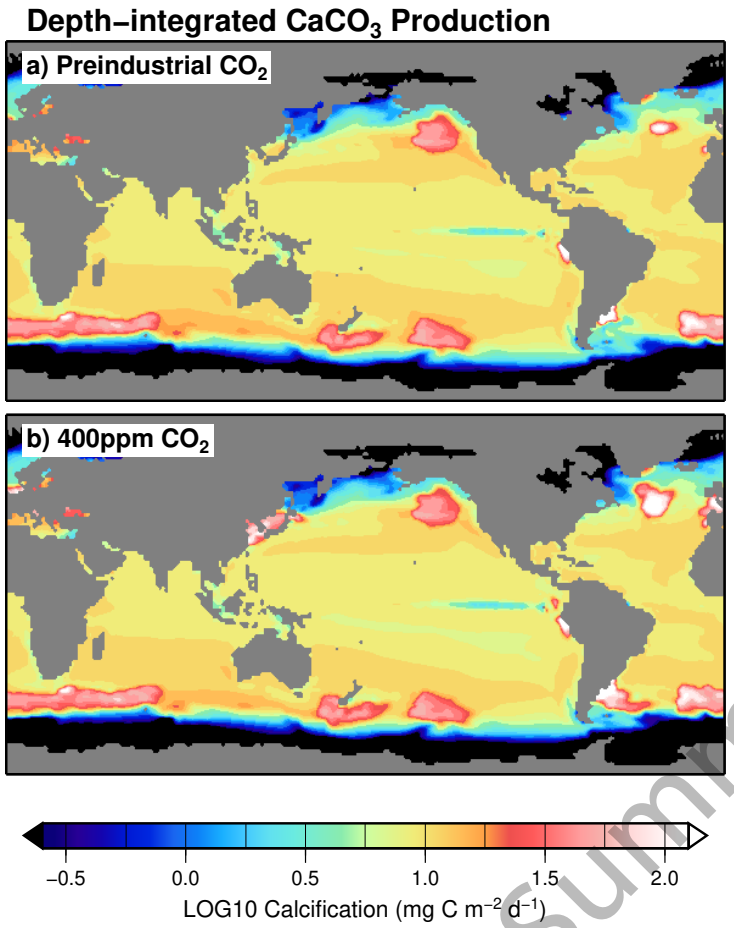
- Ocean/Sea ice only
- "normal year" climate
- 1 degree resolution
- Pre-industrial control run
- Branch higher $CO_2$ runs
- No effect of warming yet…

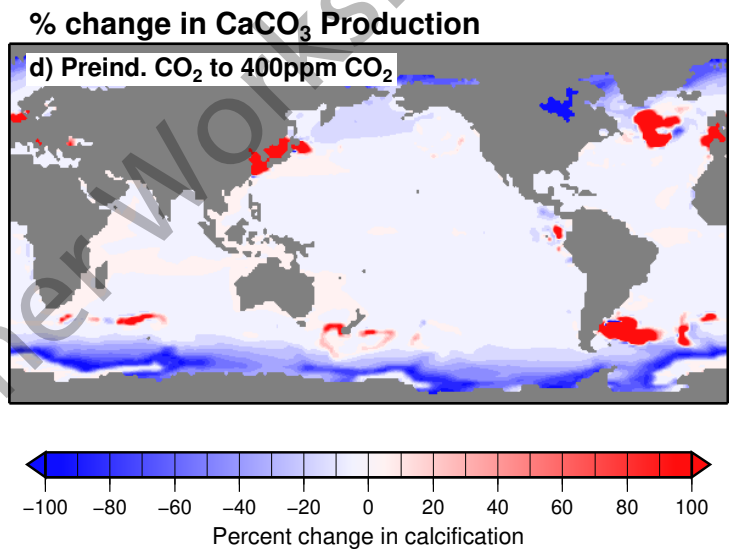





Krumhardt et al., 2019, JAMES

# Increasing $CO_2$ results in + and - changes in calcification



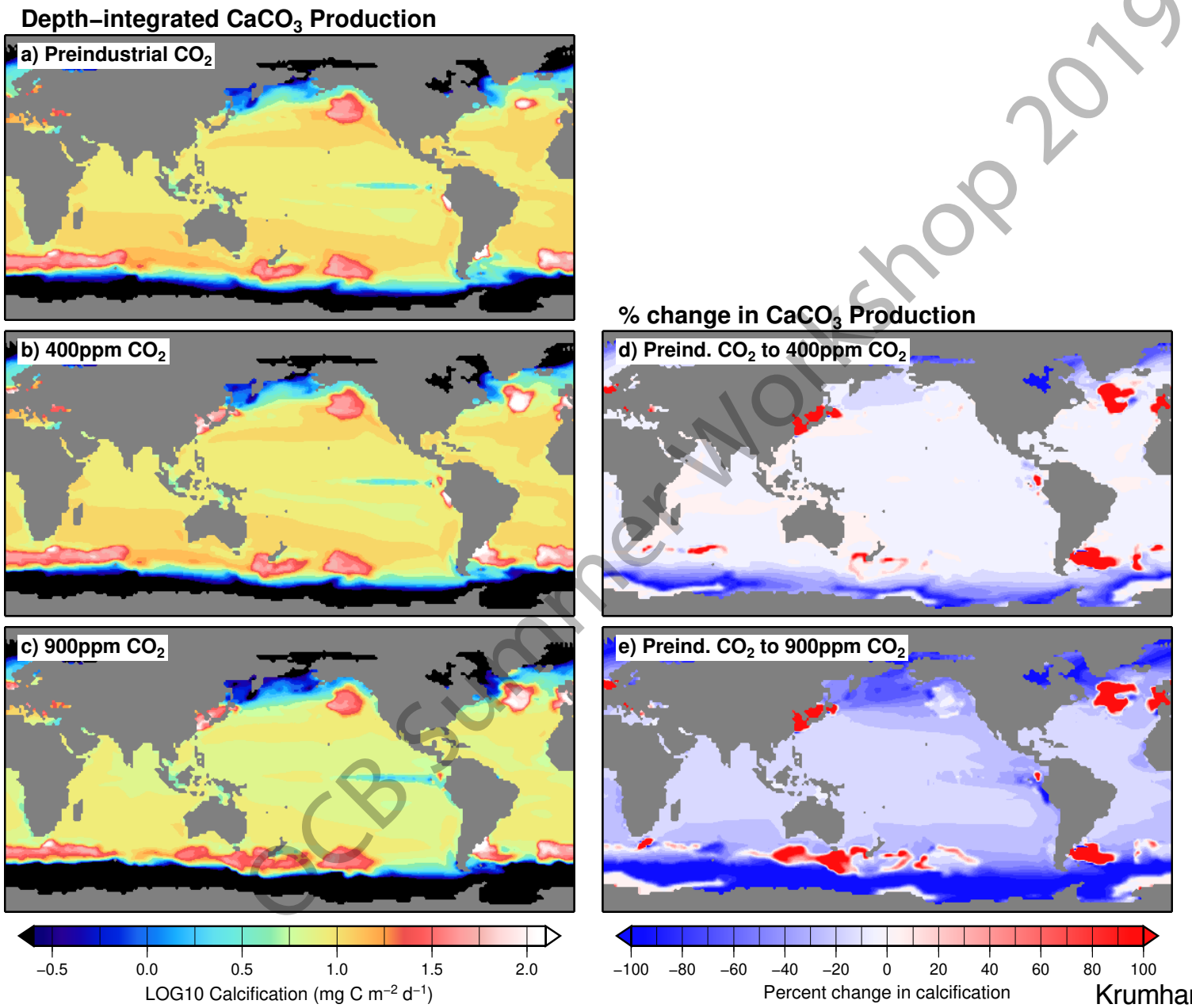

% change from PI

+6% globally



Krumhardt et al., 2019, JAMES

# Increasing $CO_2$ results in + and - changes in calcification





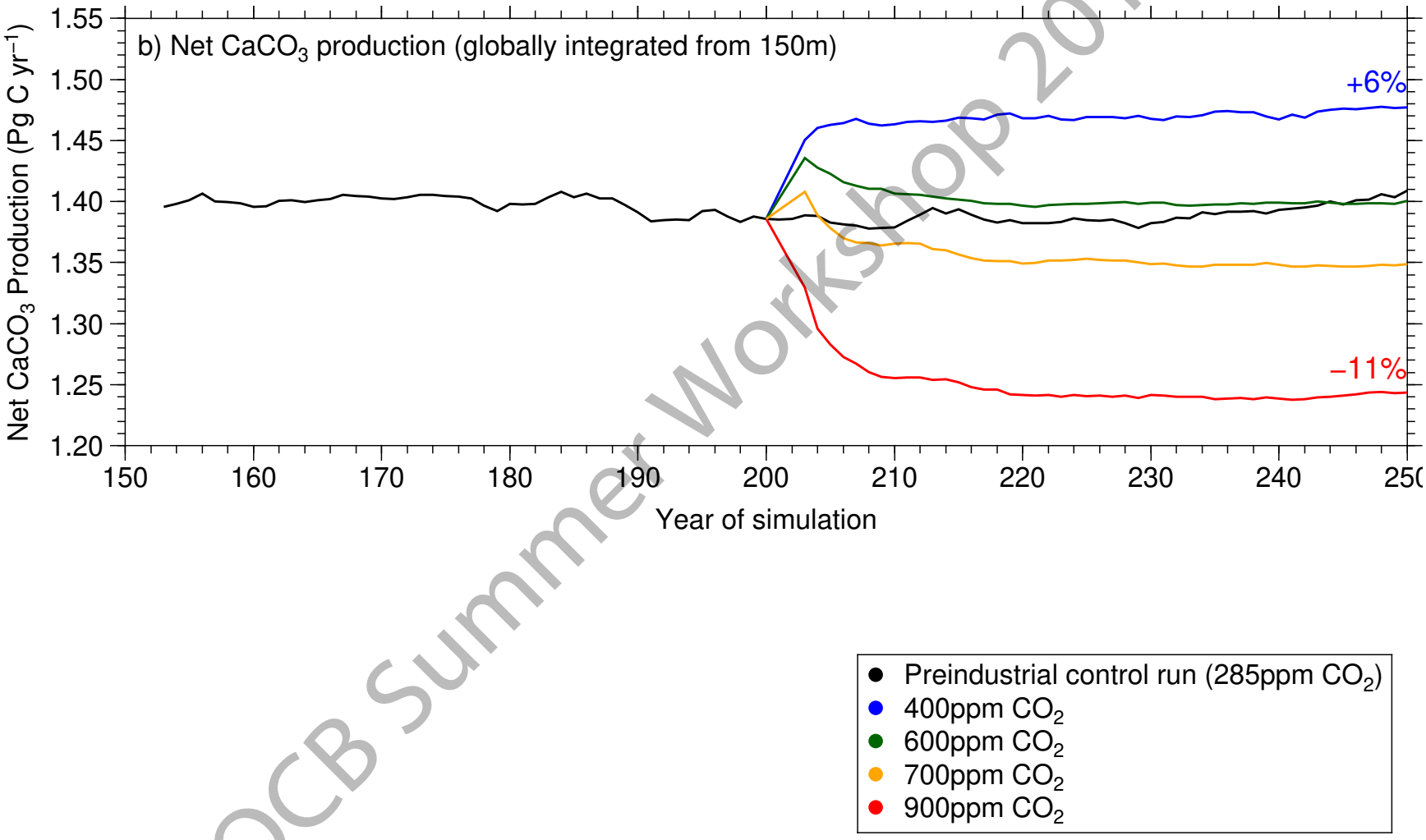

% change from PI

+6% globally

-11% globally

Krumhardt et al., 2019, JAMES

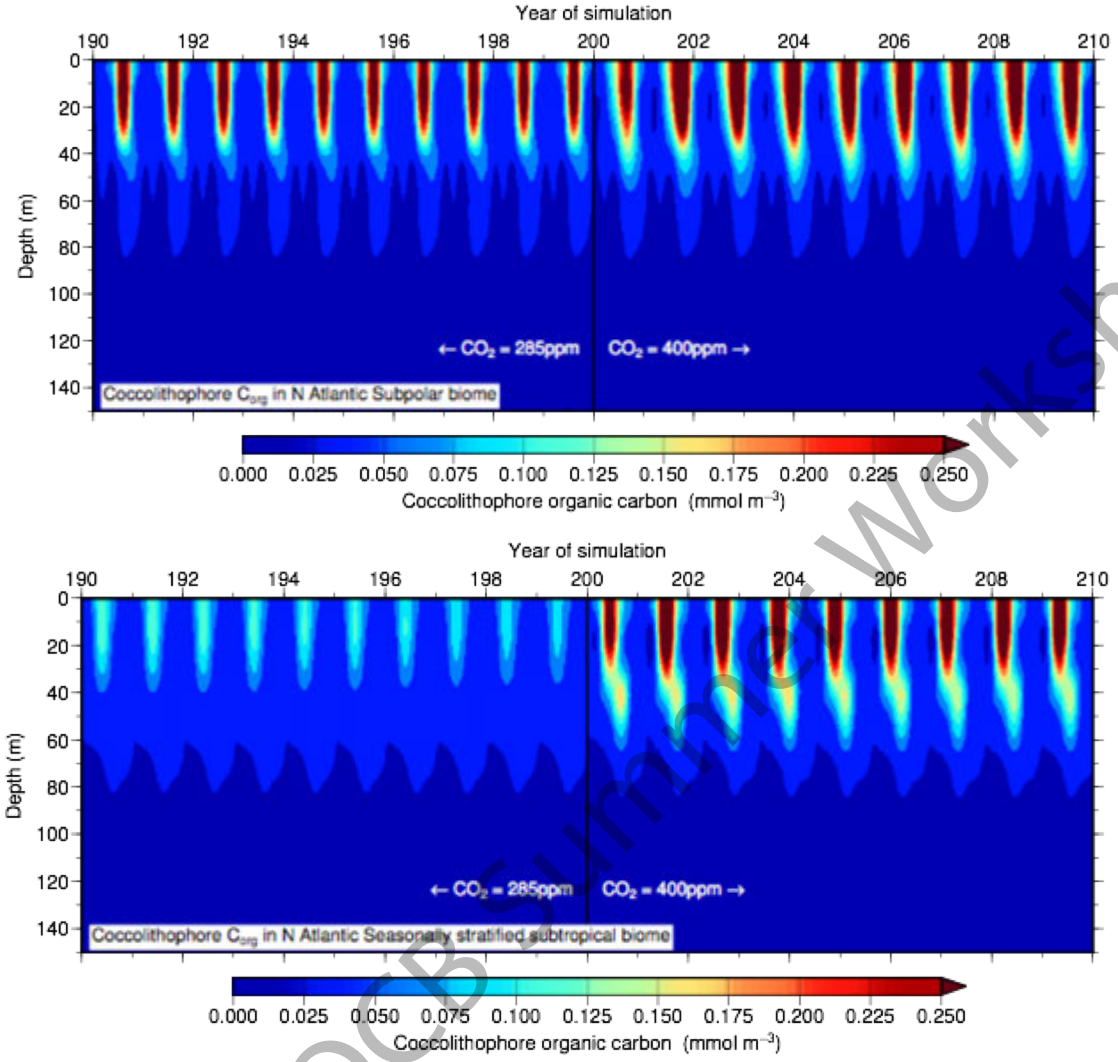
# Increases and decreases in calcification balance at ~600ppm






Krumhardt et al., 2019, JAMES

# Coccolithophores increase in the North Atlantic from 285 to 400 ppm $CO_2$




**Subpolar biome**

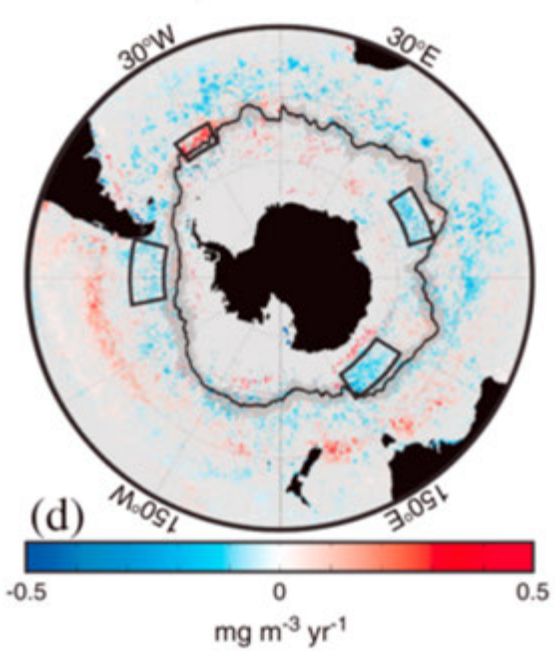
**Subtropical seasonally stratified biome**



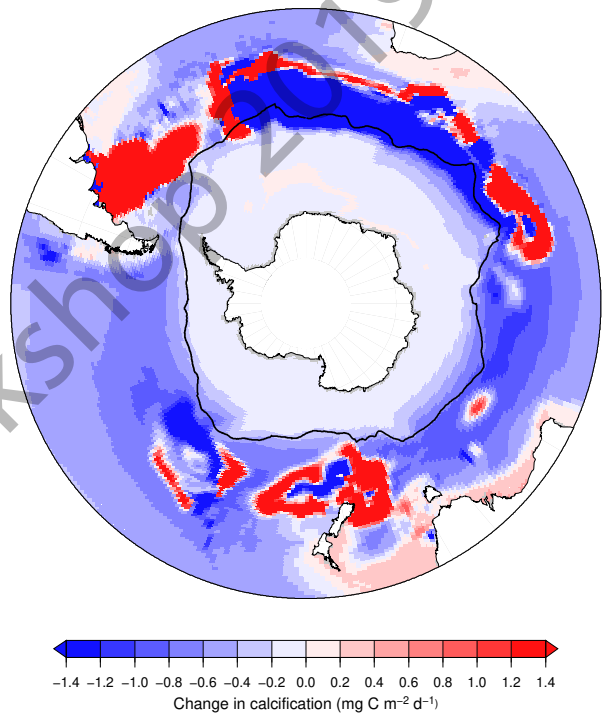
- Similar to observations reported in Rivero-Calle et al. (2015) & Krumhardt et al. (2016)

Krumhardt et al., 2019, JAMES

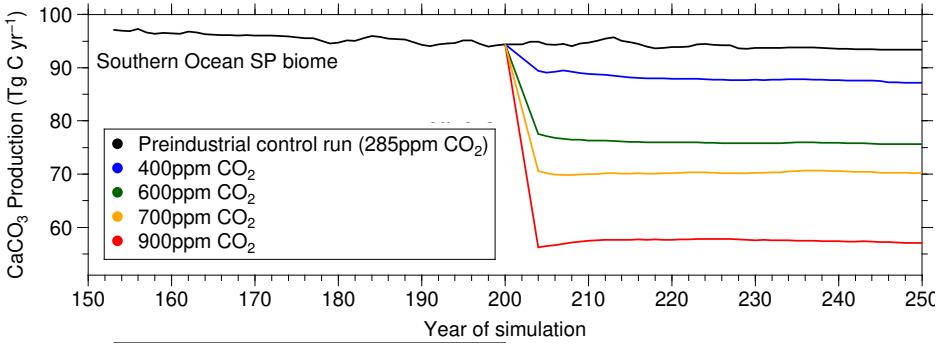
# Coccolithophore calcification changes in the Southern Ocean with increasing $CO_2$




**Change in calcification from PI to 400ppm**



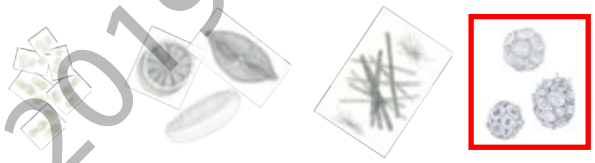

- Increasing calcification in a few areas of Southern Ocean, but decreasing overall



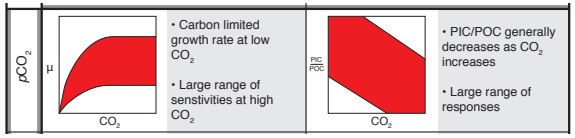

Freeman & Lovenduski, 2015; Krumhardt et al., 2019, JAMES

# Summary of $CO_2$ experiments

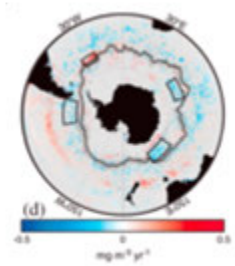
- Explicit coccolithophore parameterization in CESM.



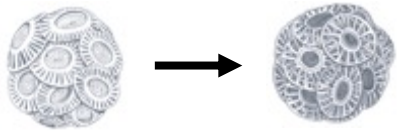
- Increasing $CO_2$ has 2 main physiological effects on coccolithophores: carbon fertilization, decreased calcification from OA.




- Changes supported by observations.



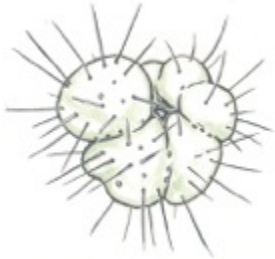
- Increasing $CO_2$ results in more coccolithophores in certain regions, but lower $CaCO_3/C_{org}$ ratios.



- Biogeochemical implications of findings (export and air-sea $CO_2$ uptake)

# Limitations of model study and future directions

- Just testing the effects of $CO_2$ increase -- warming may complicate these changes.
- Normal year forcing -- simulations with interannual variability would be more realistic.
- No negative feedback of low calcification (e.g., increased grazing).
- Zooplankton calcifier currently absent from model.



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Thank you for your attention!



## Cited studies:

Freeman, Natalie M., and Nicole S. Lovenduski. "Decreased calcification in the Southern Ocean over the satellite record." *Geophysical Research Letters* 42, no. 6 (2015): 1834-1840.

Krumhardt, Kristen M., Nicole S. Lovenduski, Natalie M. Freeman, and Nicholas R. Bates. "Apparent increase in coccolithophore abundance in the subtropical North Atlantic from 1990 to 2014." *Biogeosciences* 13, no. 4 (2016).

Krumhardt, Kristen M., Nicole S. Lovenduski, M. Debora Iglesias-Rodriguez, and Joan A. Kleypas. "Coccolithophore growth and calcification in a changing ocean." *Progress in Oceanography* 159 (2017): 276-295.

Krumhardt, K. M., N. S. Lovenduski, M. C. Long, M. Levy, K. Lindsay, J. K. Moore, and C. Nissen. "Coccolithophore growth and calcification in an acidified ocean: Insights from Community Earth System Model simulations." *Journal of Advances in Modeling Earth Systems*.

Rivero-Calle, Sara, Anand Gnanadesikan, Carlos E. Del Castillo, William M. Balch, and Seth D. Guikema. "Multidecadal increase in North Atlantic coccolithophores and the potential role of rising CO2." *Science* 350, no. 6267 (2015): 1533-1537.

Winter, Amos, Jorijntje Henderiks, Luc Beaufort, Rosalind EM Rickaby, and Christopher W. Brown. "Poleward expansion of the coccolithophore Emiliania huxleyi." *Journal of Plankton Research* 36, no. 2 (2013): 316-325.