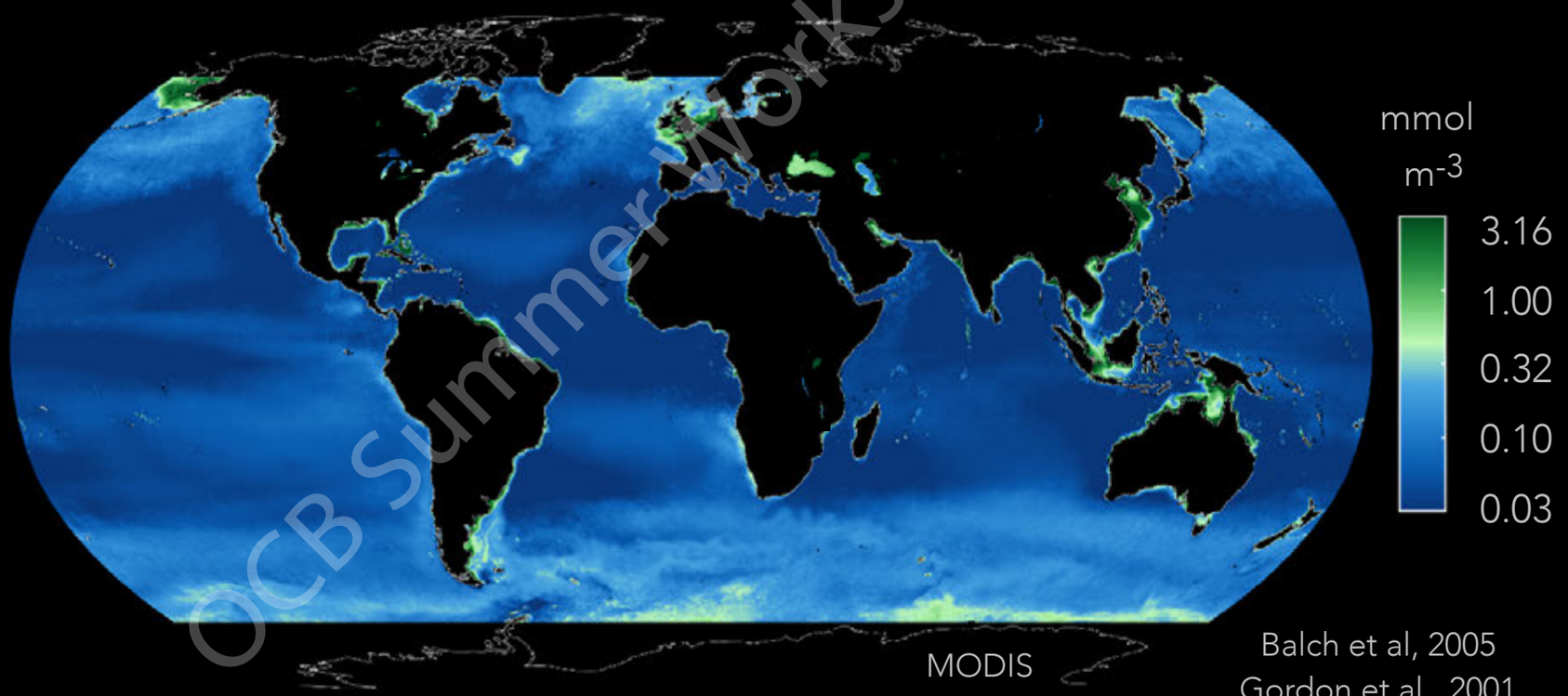
Ocean Carbon & Biogeochemistry

Studying marine ecosystems and biogeochemical cycles in the face of environmental change

2019 OCB Summer Workshop

Calcification and the Carbon Cycle



June 26, 2019

Andrea Fassbender, Jessica Cross, & Sensational Session Speakers

Global Carbonate Cycle

1. Pelagic calcite precipitation
2. Calcite dissolution & sedimentation
3. Neritic calcite precipitation
4. Ocean CO_2 loss caused by calcification
5. Carbonate rock weathering
6. Subduction and decarbonation
7. Silicate rock weathering
8. Volcanic emissions

Calcium carbonate
$CaCO_3$

Precipitation
$Ca^{2+} + 2HCO_3^- \leftrightarrow CaCO_3 + CO_{2(aq)} + H_2O$

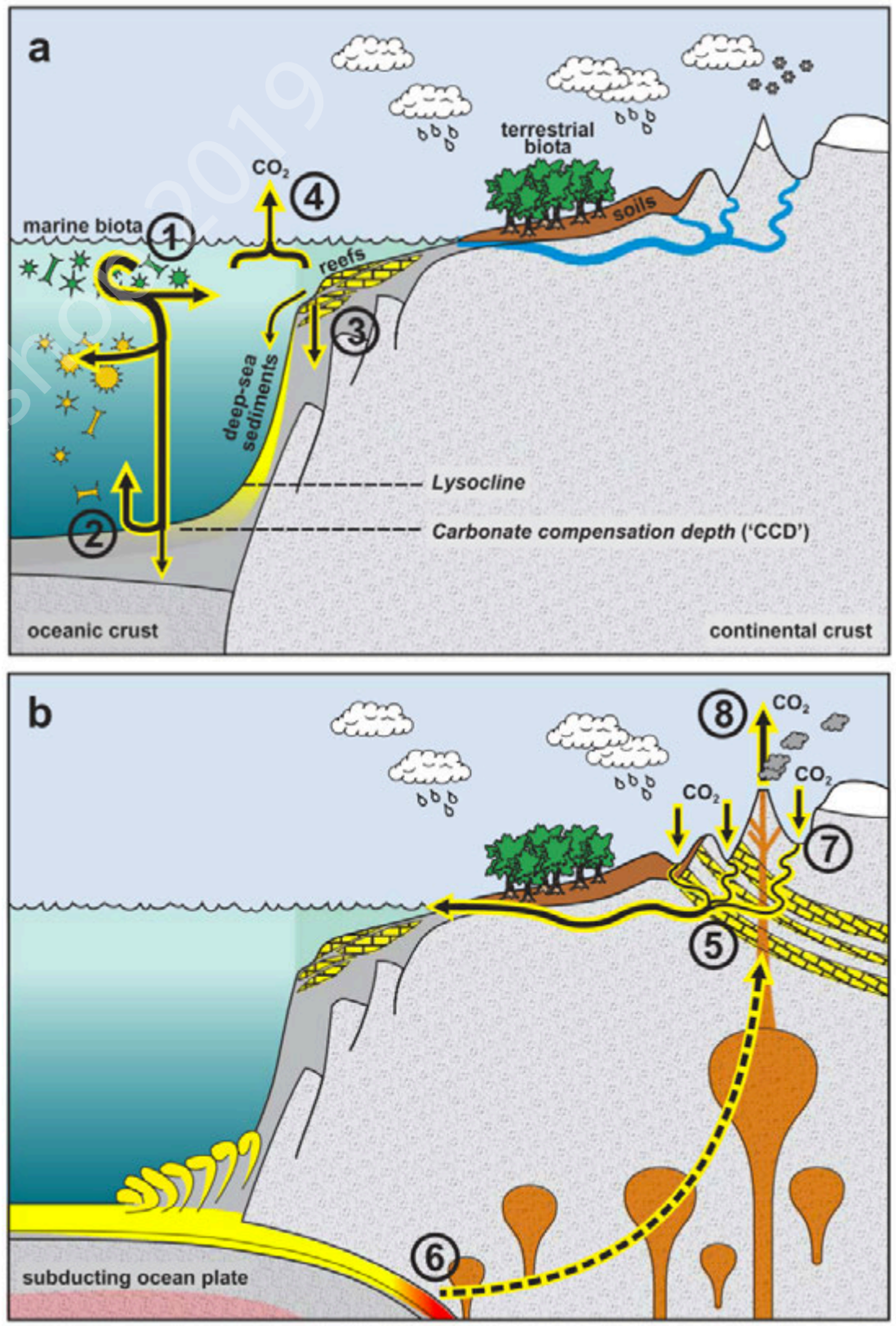
Dissolution
$CaCO_3 \rightarrow Ca^{2+} + CO_3^{2-}$

ELSEVIER Earth and Planetary Science Letters 234 (2005) 299–315
www.elsevier.com/locate/epsl

Frontiers

The role of the global carbonate cycle in the regulation and evolution of the Earth system

Andy Ridgwell[a,*], Richard E. Zeebe[b]



Ridgwell & Zeebe, Earth & Planetary Sci. Lett., 2005

Global Carbonate Cycle

1. Pelagic calcite precipitation
2. Calcite dissolution & sedimentation
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Open questions in the field:

- What drives calcification?
- How does $CaCO_3$ influence carbon export?
- What processes do paleo records reflect?

ELSEVIER Earth and Planetary Science Letters 234 (2005) 299–315
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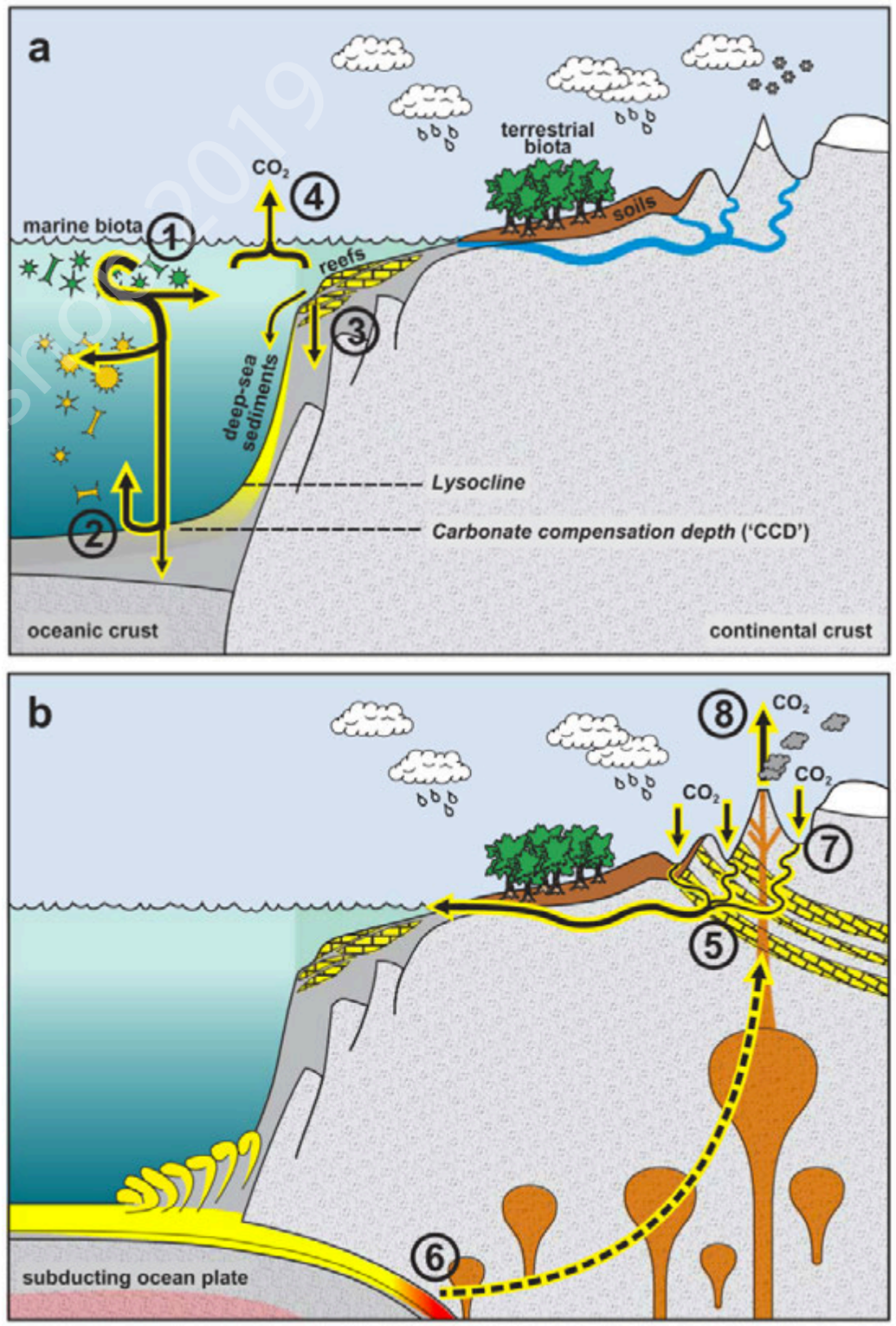
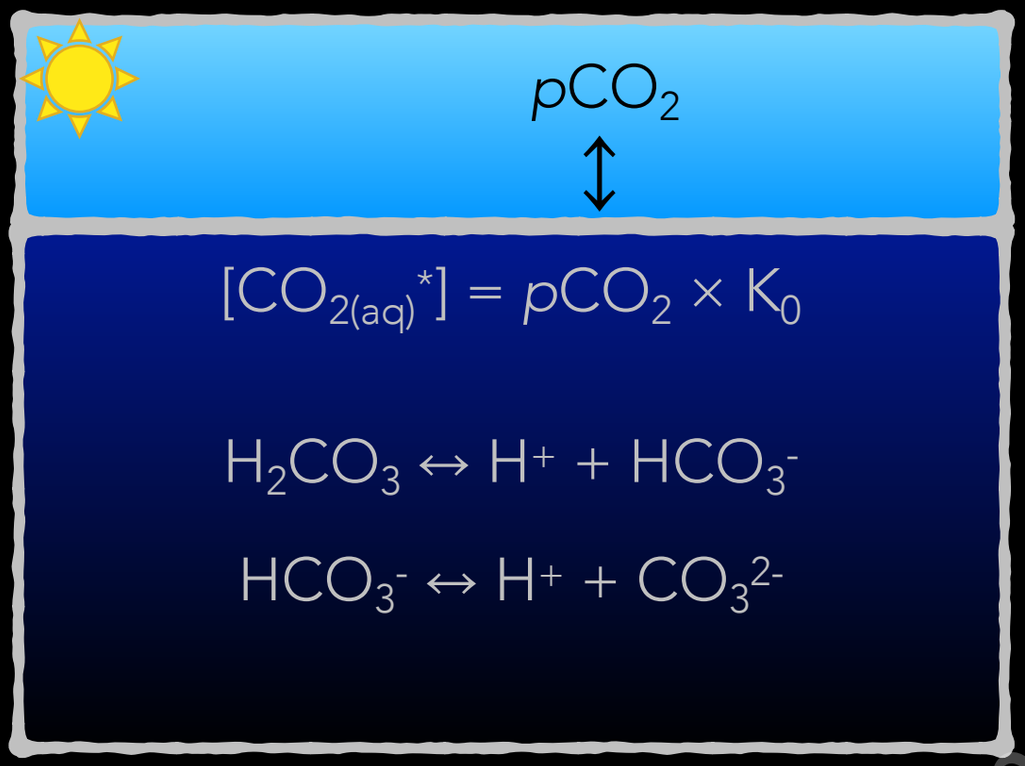
The role of the global carbonate cycle in the regulation and evolution of the Earth system

Andy Ridgwell[a,*], Richard E. Zeebe[b]

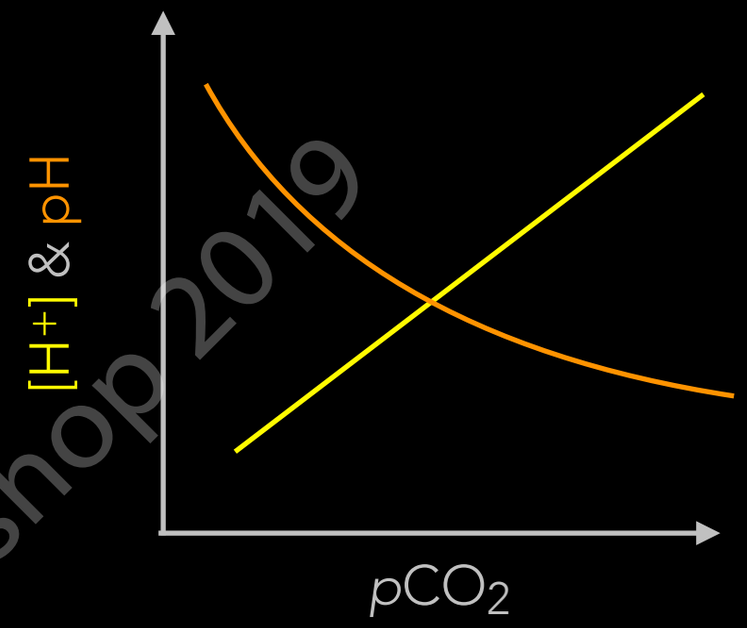


Ridgwell & Zeebe, Earth & Planetary Sci. Lett., 2005

CliffsNotes Carbonate Chemistry

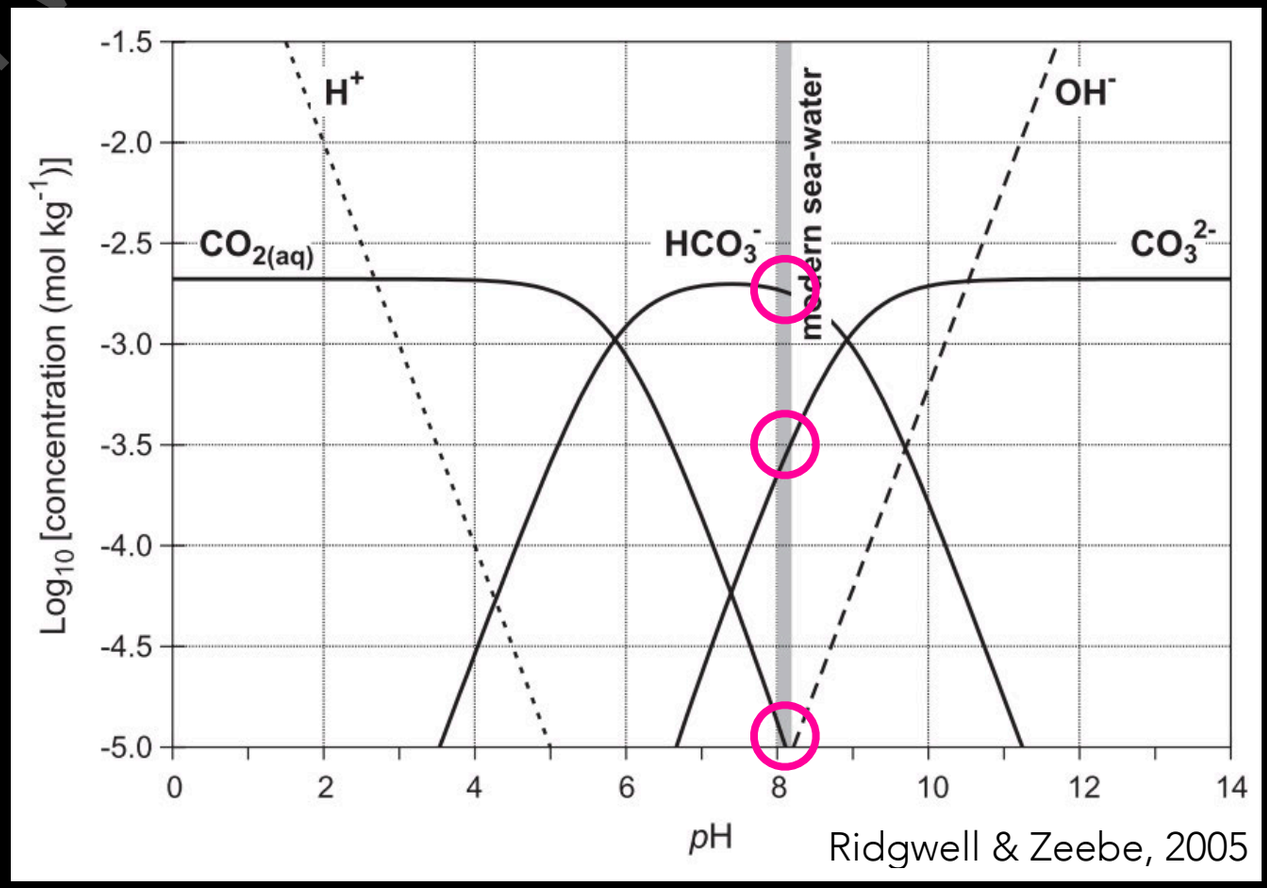


$$pH = -\log_{10}[H^+]$$



$DIC = [CO_{2(aq)}^*] + [HCO_3^-] + [CO_3^{2-}]$

Bicarbonate Ion:	HCO_3^-	90%
Carbonate Ion:	CO_3^{2-}	~10%
Carbon Dioxide:	$CO_{2(aq)}^*$	<1%



Ridgwell & Zeebe, 2005

Carbonate Mineral Saturation States

$$\Omega = \frac{[CO_3^{2-}] \times [Ca^{2+}]}{{}^*K_{sp}}$$

Supersaturated: Ω>1

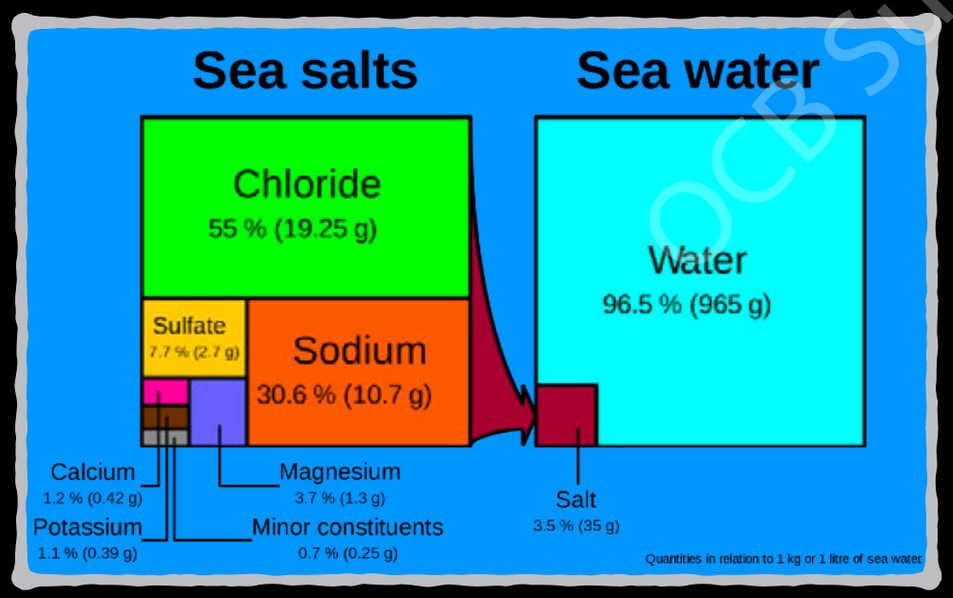
Undersaturated: Ω<1

$[Ca^{2+}]$: 10.28 mmol kg^{-1}

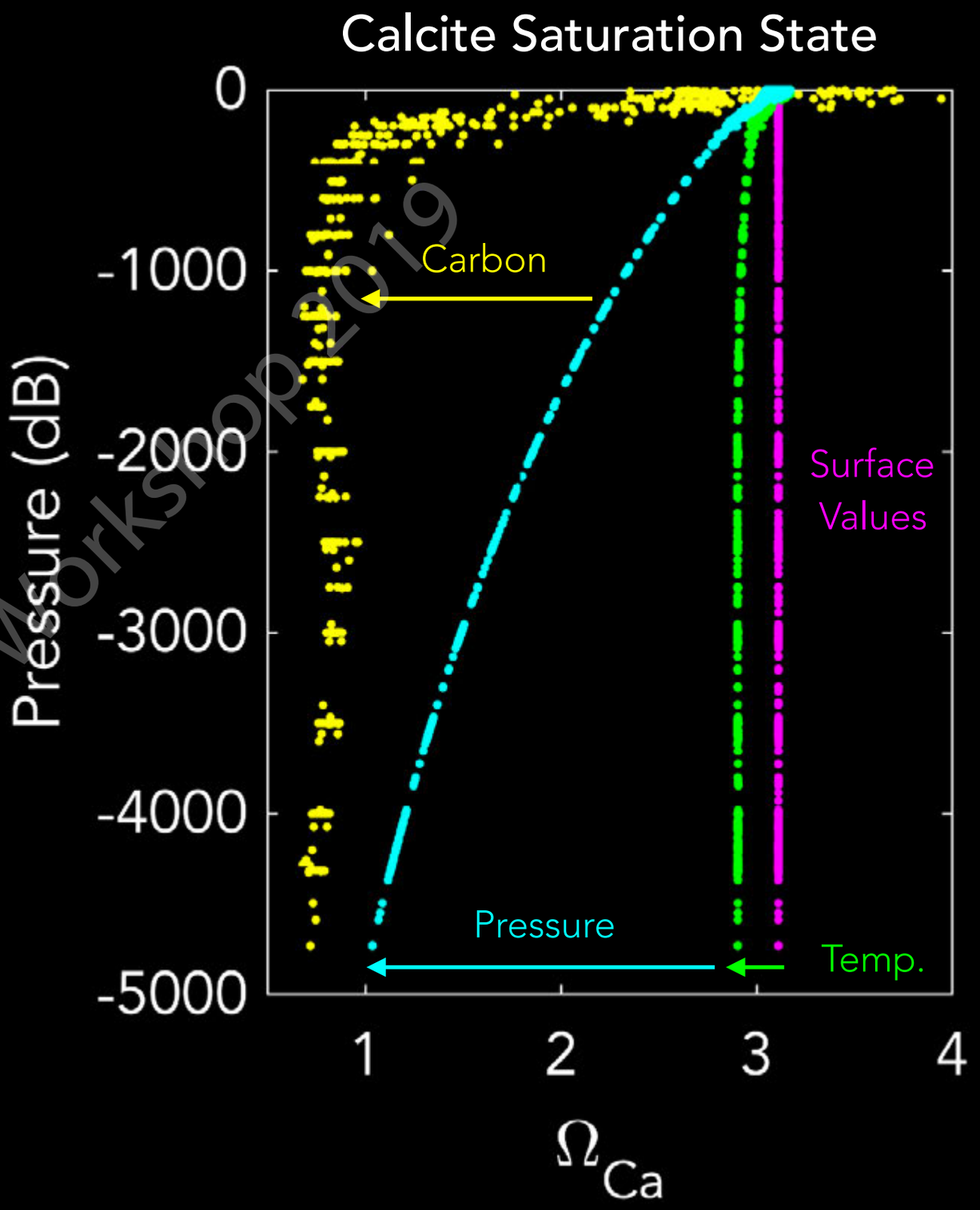
$[HCO_3^-]$: 1.80 mmol kg^{-1}

$[CO_3^{2-}]$: 0.25 mmol kg^{-1}

-Emerson & Hedges, 2008

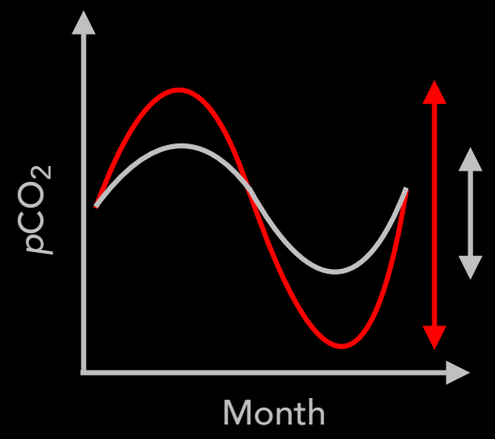


Wikipedia



GLODAPv2_2019 data near Ocean Station Papa
figure after Kawahata et al., 2019

Seasonal Cycle Changes in Ocean Carbonate Chemistry

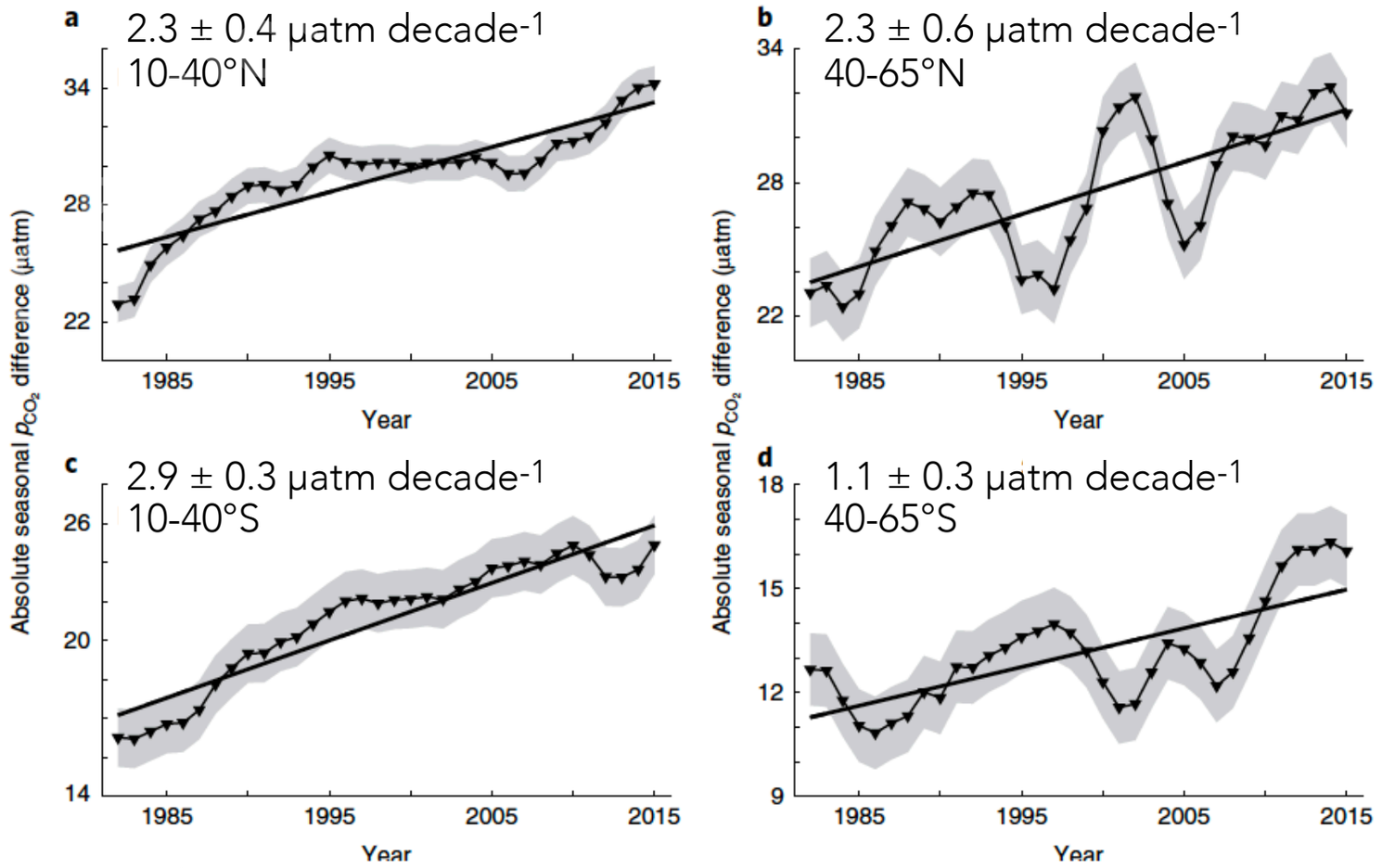


Rodgers et al., GBC, 2008
Egelston et al., GBC, 2010
Cai et al., Nat. Geo., 2011
Jokiel, Bull. Mar. Sci., 2011…
Shaw et al., Global Change Bio., 2013
Shultz & Riebesell, Mar. Biol, 2013
Jury et al., Water, 2013
Hauck & Völker, GRL, 2015
McNeil &. Sasse, Nature, 2016
Hagens & Middelburg, GCA, 2016

LETTERS
https://doi.org/10.1038/s41558-017-0057-x
nature climate change

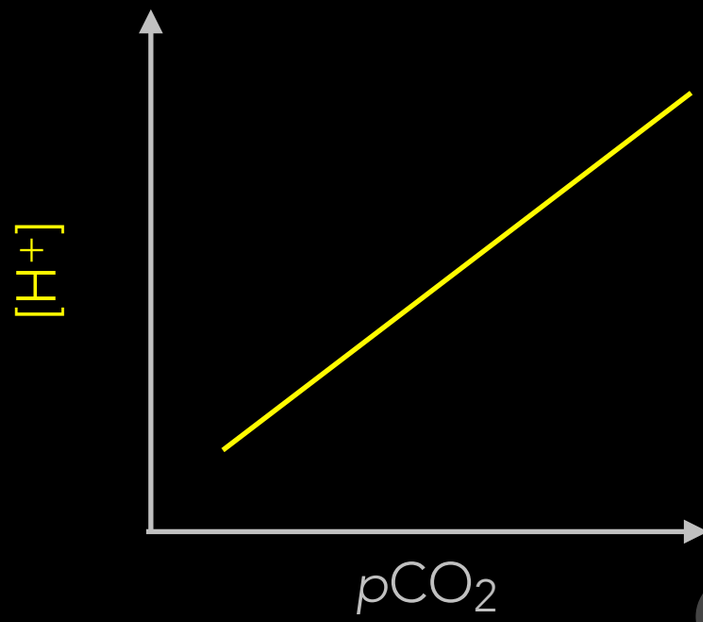
Strengthening seasonal marine CO_2 variations due to increasing atmospheric CO_2

Peter Landschützer[1*], Nicolas Gruber[2], Dorothee C. E. Bakker[3], Irene Stemmler[1] and Katharina D. Six[1]



Landschützer et al., Nat. Clim. Change, 2018

Implications for Ocean Acidification



Asymmetries discussed in:

- Pacella et al., PNAS 2018
- Fassbender et al., GBC, 2018

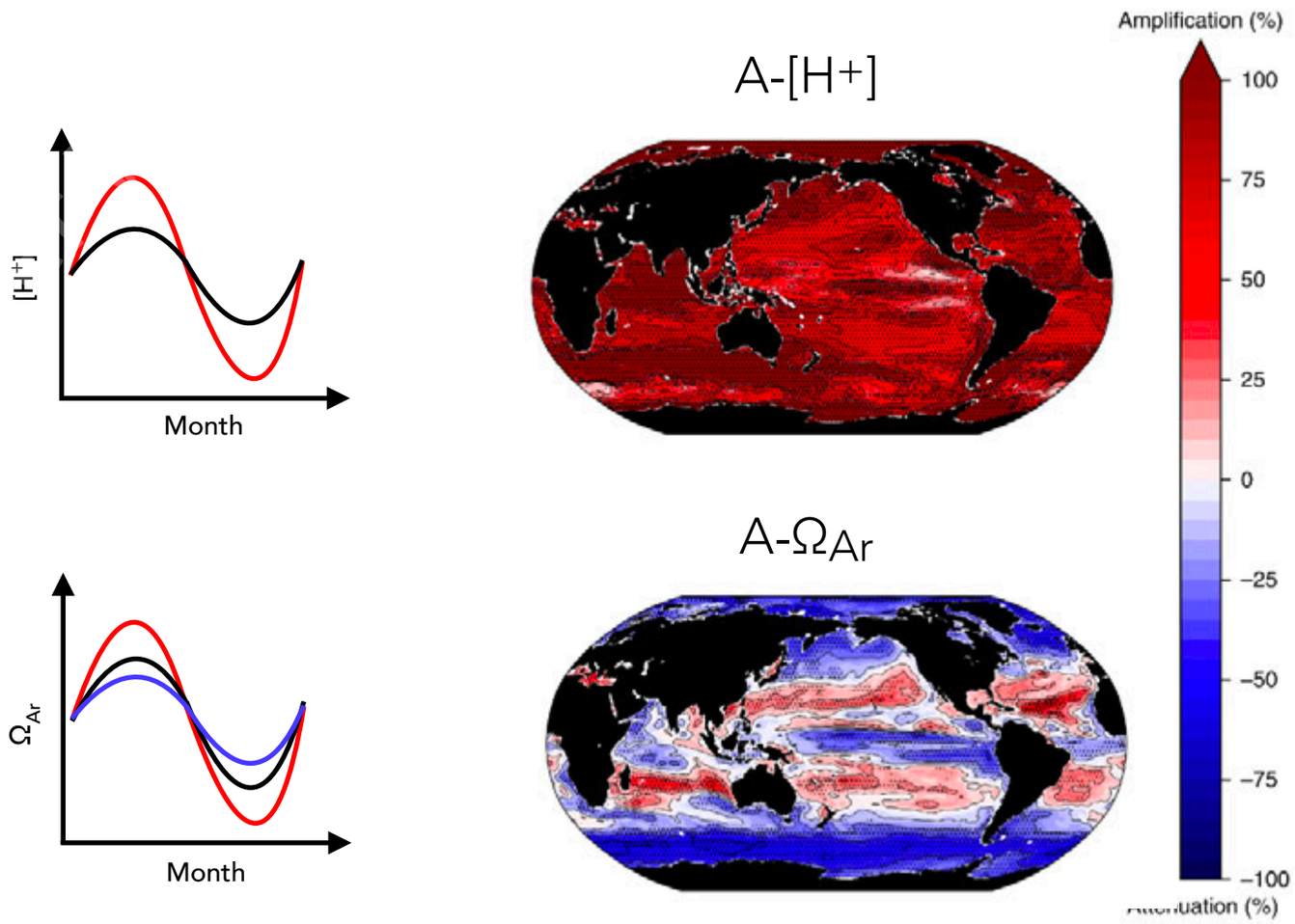
nature climate change

LETTERS

https://doi.org/10.1038/s41558-017-0054-0

Diverging seasonal extremes for ocean acidification during the twenty-first century

Lester Kwiatkowski* and James C. Orr



Kwiatkowski and Orr, Nat. Clim. Change, 2018

How Important is Seawater Chemistry in Calcification?

$Ca^{2+} + \mathbf{HCO_3^-} \leftrightarrow \mathbf{H^+} + CaCO_3$

$Ca^{2+} + \mathbf{CO_3^{2-}} \leftrightarrow CaCO_3$

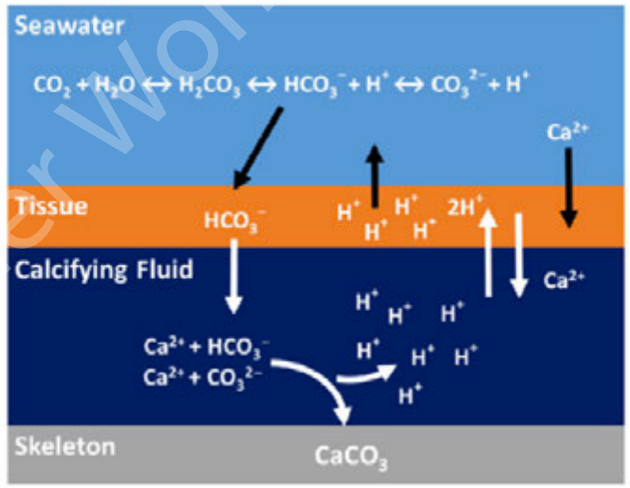
ICES Journal of Marine Science

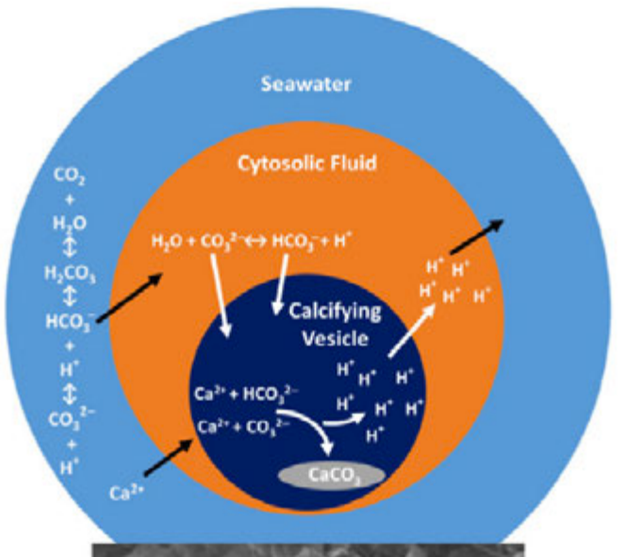
ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

Food for Thought

The Omega myth: what really drives lower calcification rates in an acidifying ocean

Tyler Cyronak[1]*, Kai G. Schulz[2], and Paul L. Jokiel[3]

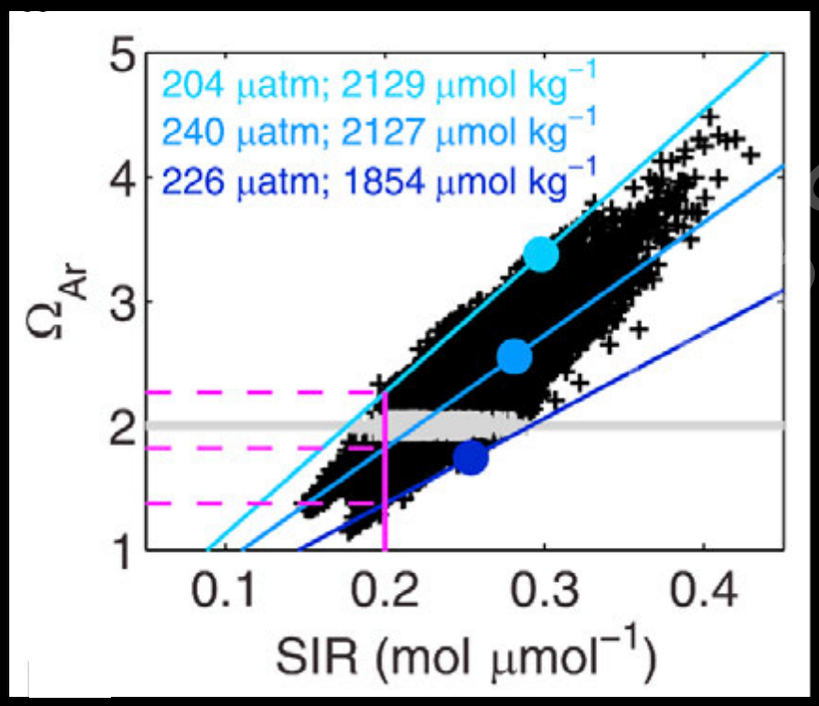




Cyronak et al., ICES J of Mar. Sci., 2015

Colluding Metrics?

Substrate-to-Inhibitor Ratio (SIR) = $\frac{[HCO_3^-]}{[H^+]}$

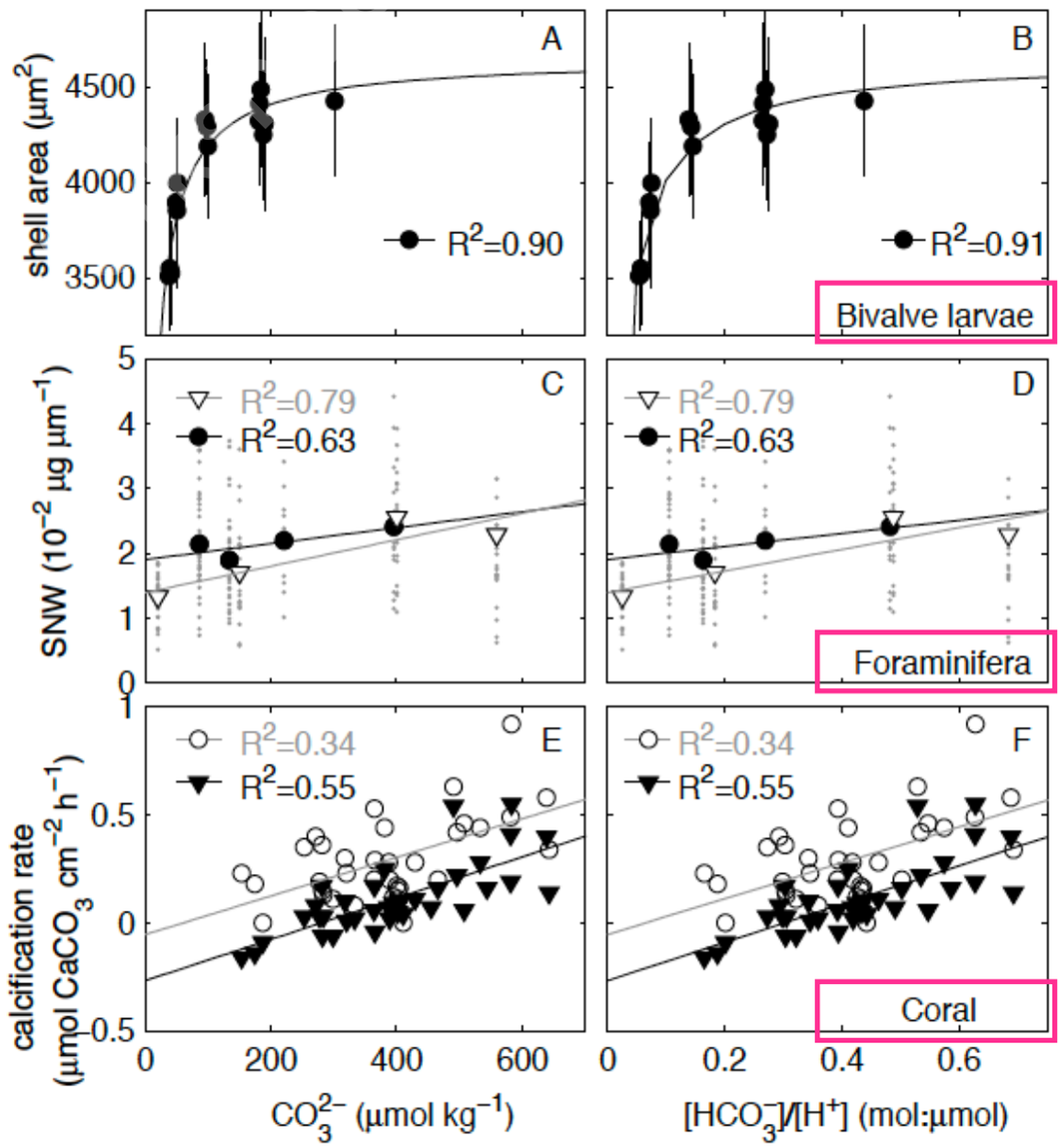


Fassbender et al., GRL, 2016

Reconsidering the role of carbonate ion concentration in calcification by marine organisms

Biogeosciences Open Access

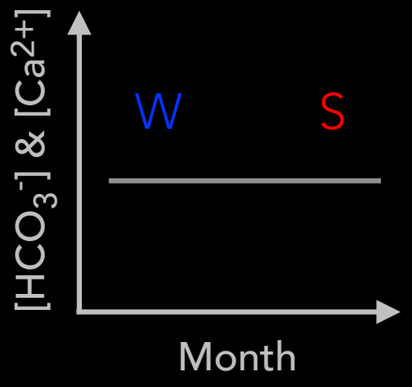
L. T. Bach
GEOMAR Helmholtz Centre for Ocean Research Kiel, 24105 Kiel, Germany

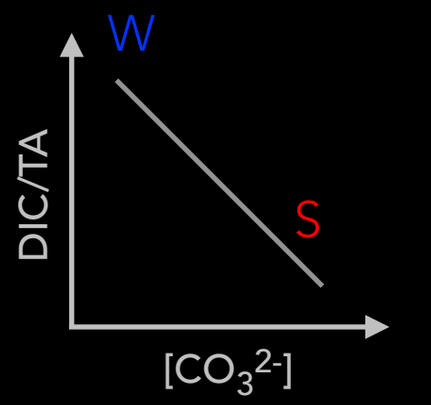


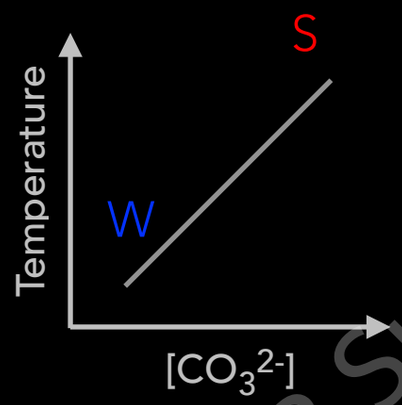
Bach, Biogeosciences, 2015

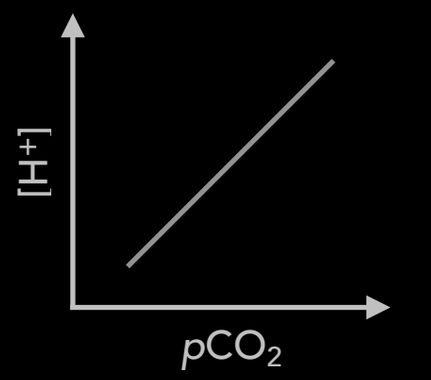
Lab Metrics vs. Real World Mechanisms

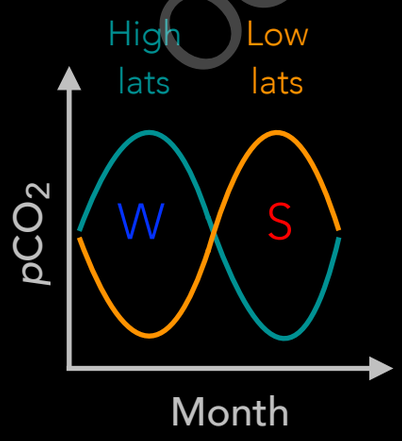
$$SIR = \frac{[HCO_3^-]}{[H^+]} \qquad \Omega = \frac{[CO_3^{2-}] \times [Ca^{2+}]}{{}^*K_{sp}}$$











AGU PUBLICATIONS

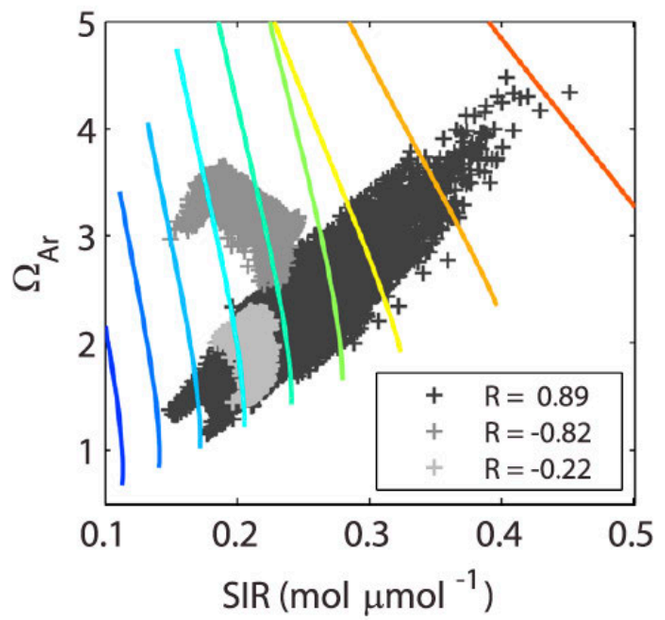
Geophysical Research Letters

RESEARCH LETTER
10.1002/2016GL068860

Key Points:
- Alternative indicators of biological

Consideration of coastal carbonate chemistry in understanding biological calcification

Andrea J. Fassbender[1], Christopher L. Sabine[1], and Kirsten M. Feifel[2]



Obs:
CE: 13,397
KEO: 14,768
OSP: 12,703

400 µatm:
- 1600 µmol kg-1
- 1800 µmol kg-1
- 2000 µmol kg-1
- 2200 µmol kg-1
- 2400 µmol kg-1
- 2600 µmol kg-1

2100 µmol kg-1:
- 200 µatm
- 150 µatm
- 100 µatm

Fassbender et al., GRL, 2016

Longer-term Perspective

- Undersaturation and low [CO_3^{2-}] are constrained to the high latitudes.
- Declines in SIR-driven calcification would be expected globally.

Reconsidering the role of carbonate ion concentration in calcification by marine organisms

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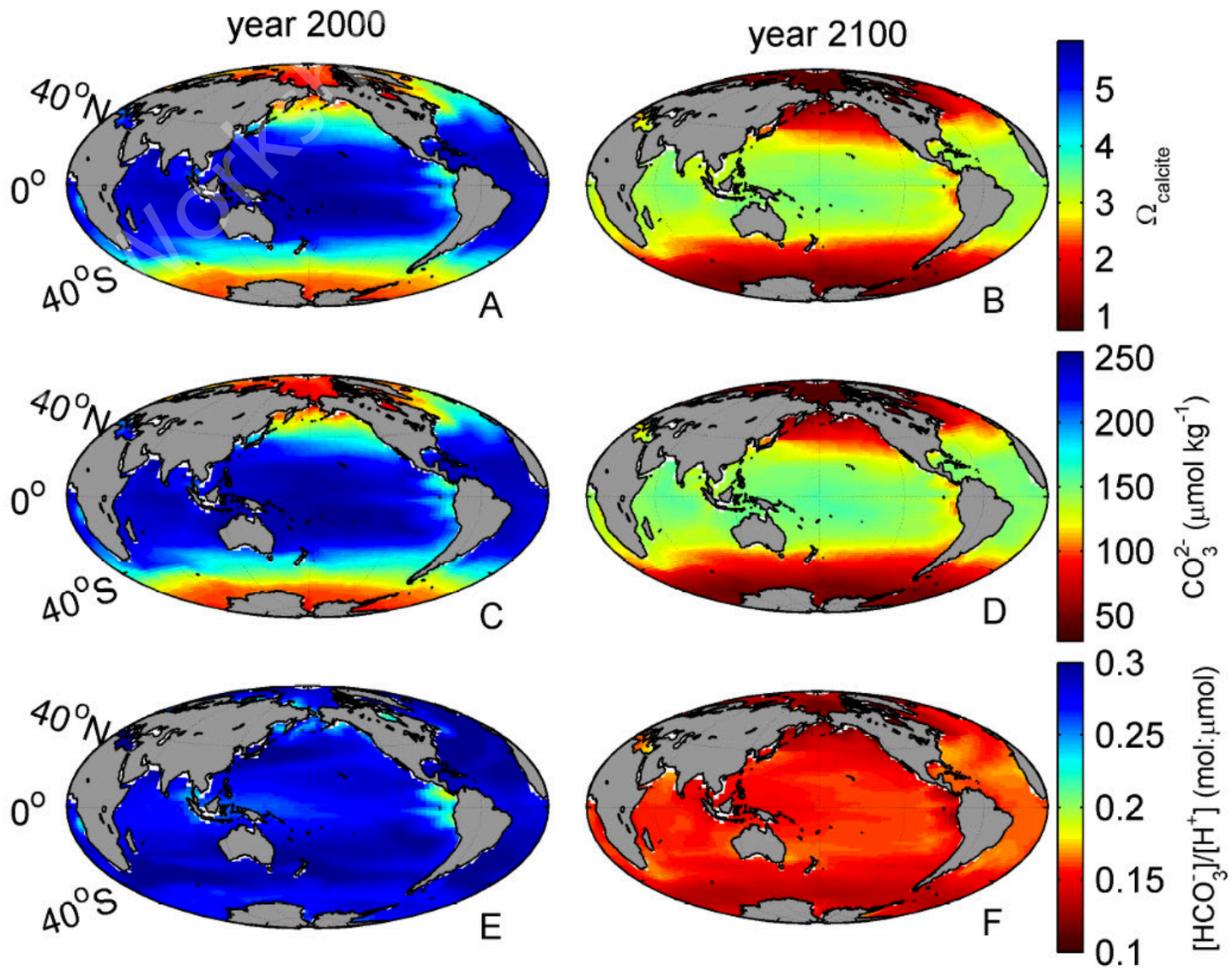


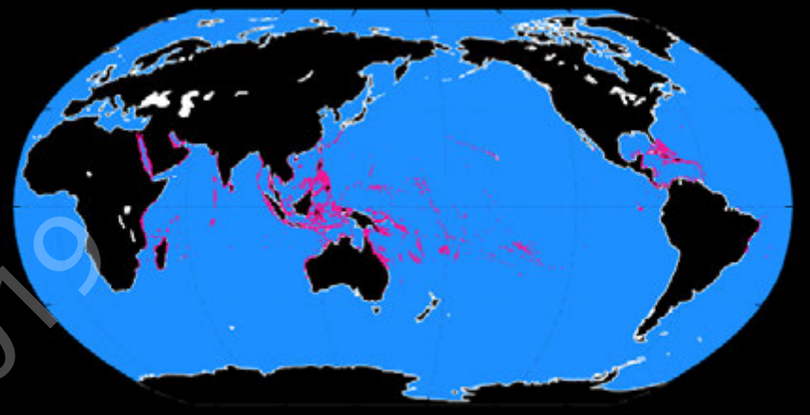
Bach, Biogeosciences, 2015

Corals

Weifu Guo (WHOI)

Are we there yet? Predicting coral calcification response to ocean acidification: From microscale mechanisms to macroscale responses

Warm Water Coral Reefs



ReefBase Global Database

Chasing Coral

Shellfish

George Waldbusser (OSU)

Understanding the complex controls on biocalcification:
A closer look at SIR and saturation state

Arctic Hunter crew members handle crab pot in Bering Sea

Photos: Steve Ringman / The Seattle Times

Nisbet family's Goose Point Oyster Co. in Willapa Bay

Coccolithophores

Balch 2018, after
Geisen et al., 2002

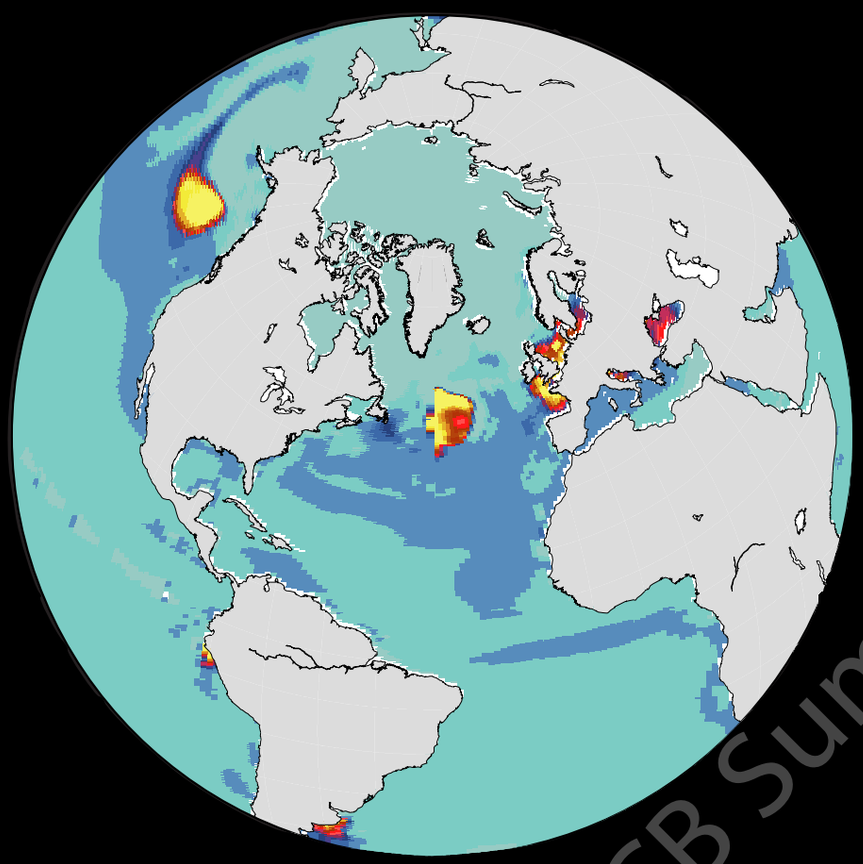
Lennart Bach (IMAS Hobart)

Carbonate chemistry control on coccolithophore calcification: New findings and future directions

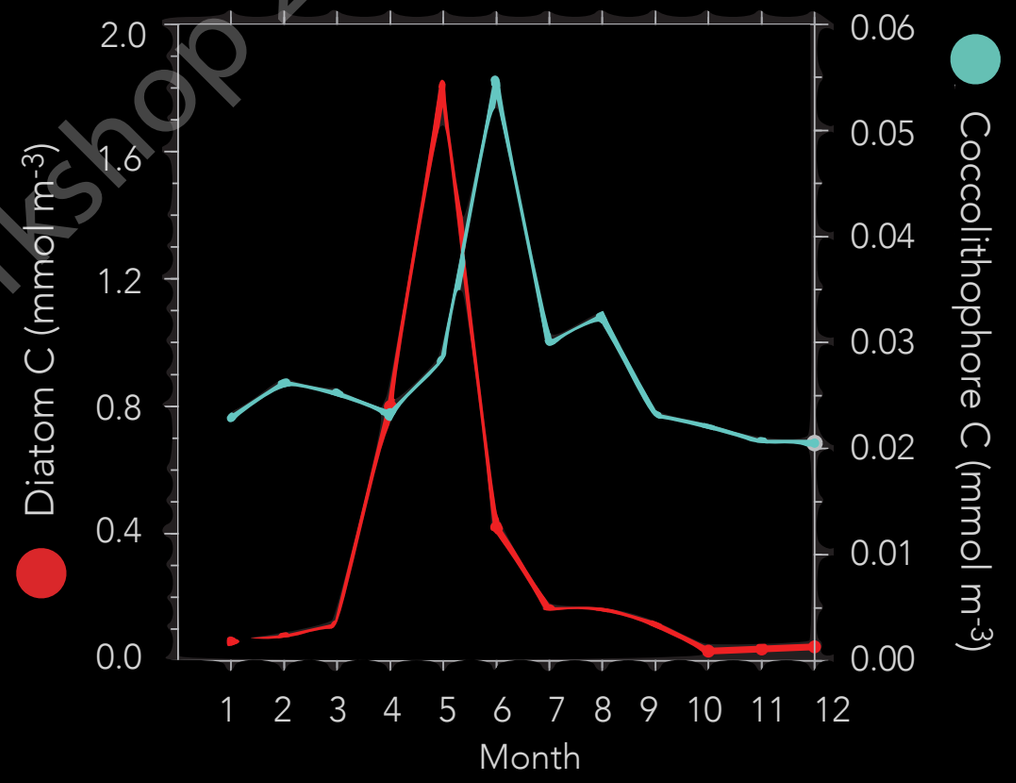
NASA

Modeling Coccolithophores

Coccolithophore photosynthesis, June



North Atlantic subtropical seasonally stratified biome



Krumhardt et al., 2019

Kristin Krumhardt (NCAR)

The multifaceted response of coccolithophores to increasing CO_2: Recent observations and modeling

Carbon Cycle Feedbacks

Bernard Boudreau

The role of calcification in carbonate compensation

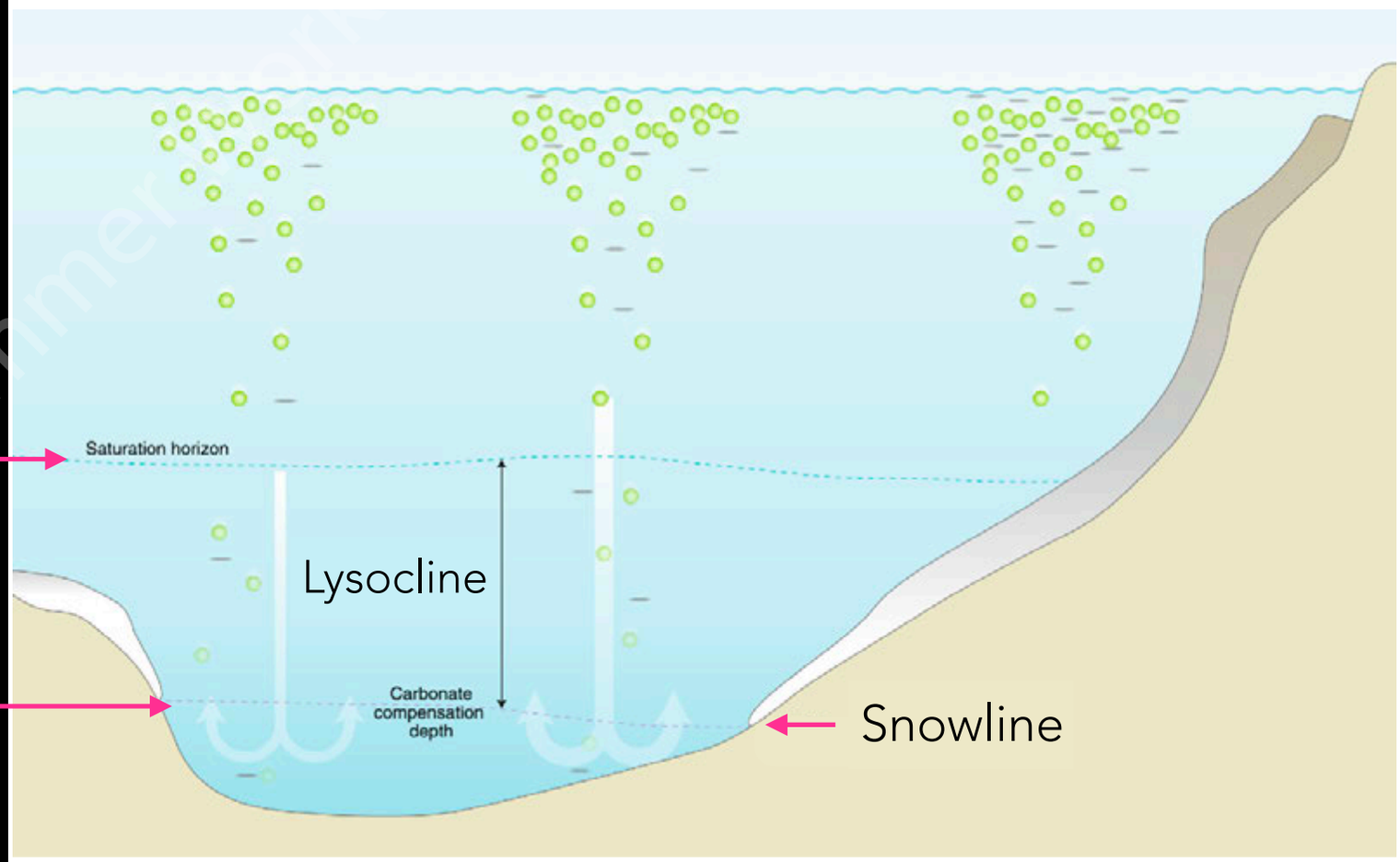
PERSPECTIVE
https://doi.org/10.1038/s41561-018-0259-5
nature geoscience

The role of calcification in carbonate compensation

Bernard P. Boudreau[1*], Jack J. Middelburg[2] and Yiming Luo[3*]

Saturation horizon

Carbonate compensation depth (CCD)



Boudreau et al., Nat. Geosci., 2018

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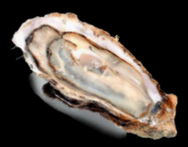

- Determining the metric(s) that best describes how calcifiers will respond to changing seawater carbonate chemistry is a critical need.
- Consideration of ecosystem function and interactions will be required to improve our understanding of coccolithophore calcification at a global scale.
- Calcifiers have the capacity to alter ocean alkalinity rapidly (e.g., decades) and impose long-term changes in the marine carbonate cycle.