Impacts of Ocean Acidification on the calcium carbonate cycle

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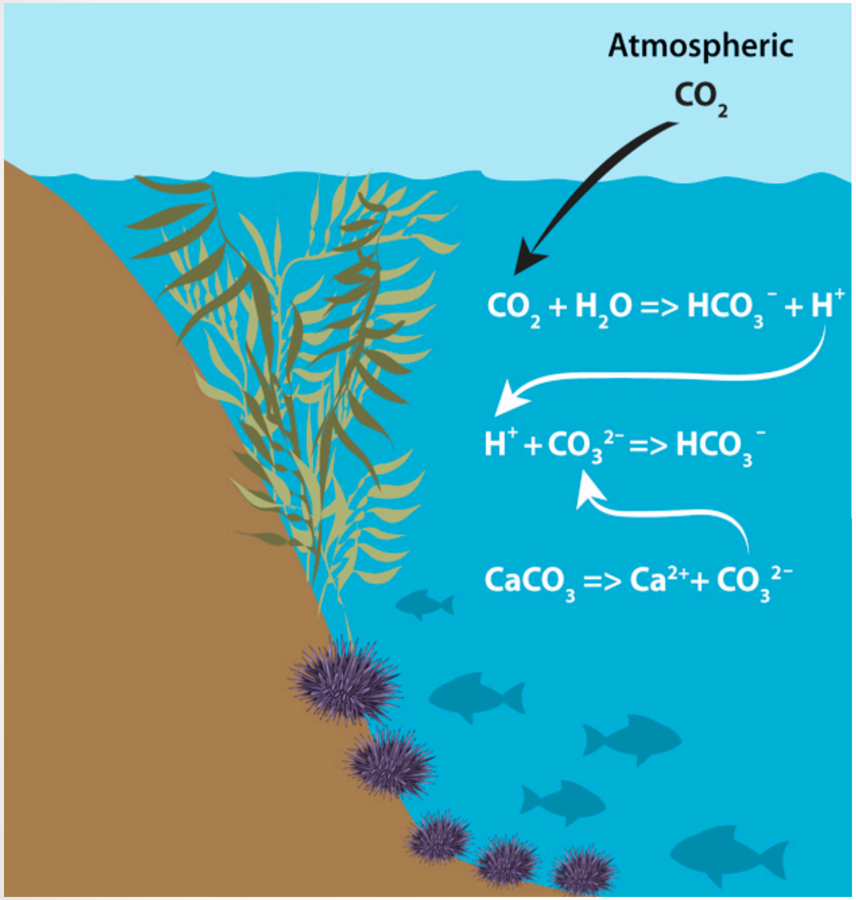
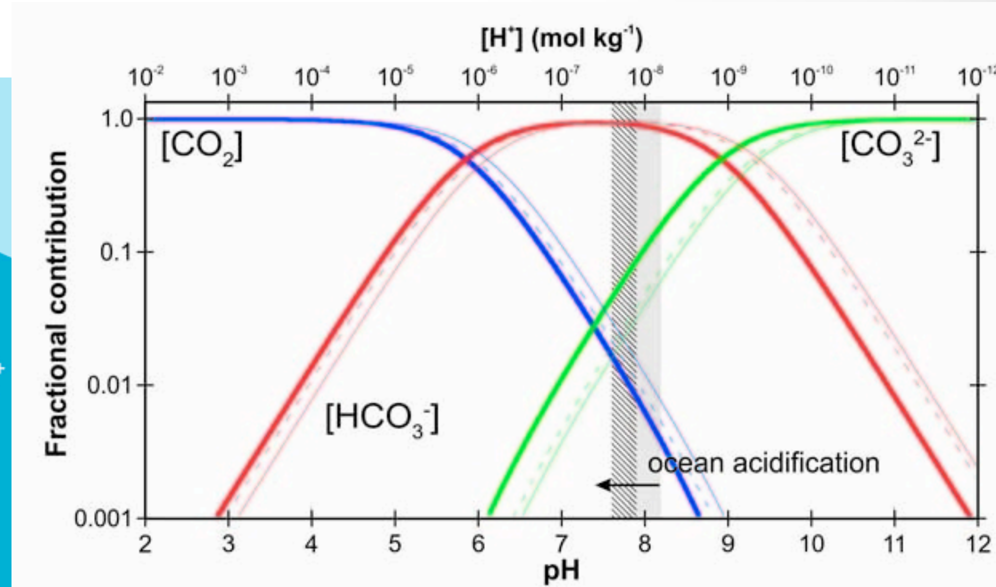
Motivation





•Average pH of the world' s oceans is about 8.2, and is buffered by calcium carbonate;

•About 0.1 pH unit decline since late 1980s due to increasing CO_2

$CaCO_3$ saturation state

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3(s)$$

$$\Omega = \frac{[Ca^{2+}][CO_3^{2-}]}{K}$$

$\Omega > 1 =$ *precipitation*

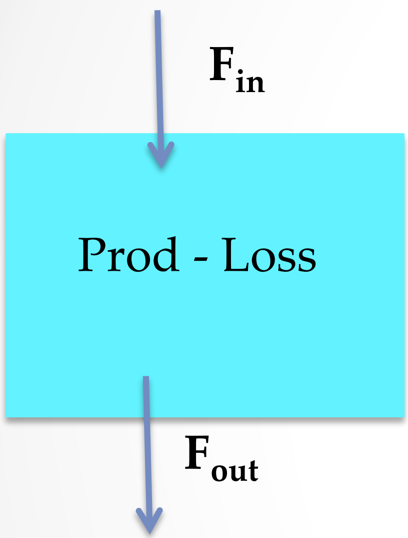
$\Omega = 1 =$ *equilibrium*

$\Omega < 1 =$ *dissolution*

In seawater: Changes in $[Ca^{2+}]$ are small → changes in W largely controlled by changes of $[CO_3^{2-}]$

- $[CO_2]$ ↑ → $[CO_3^{2-}]$ ↓ → $CaCO_3$ dissolution ↑
- $[CO_2]$ ↓ → $[CO_3^{2-}]$ ↑ → $CaCO_3$ precipitation ↑

Modeling Flux and Dissolution of $CaCO_3$



$$\frac{\mathrm{d}F}{\mathrm{d}z} = P - \frac{1}{l}F$$

$$F^{\mathrm{out}} = F(\Delta z) = F^{\mathrm{in}} e^{-\Delta z/l} + lP\left(1 - e^{-\Delta z/l}\right)$$

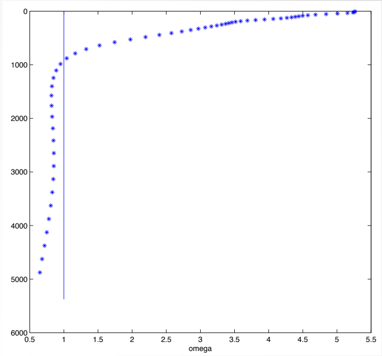
Δz	cm	cell thickness
F^{in}	nmol cm^{-2} s^{-1}	particle flux at top of cell
F^{out}	nmol cm^{-2} s^{-1}	particle flux at bottom of cell
$F(z)$	nmol cm^{-2} s^{-1}	continuous particle flux across cell
P	nmol cm^{-3} s^{-1}	production of particulate matter
R	nmol cm^{-3} s^{-1}	remineralization of particulate matter
l	cm	remineralization length scale

$CaCO_3$ and POC fluxes in previous studies

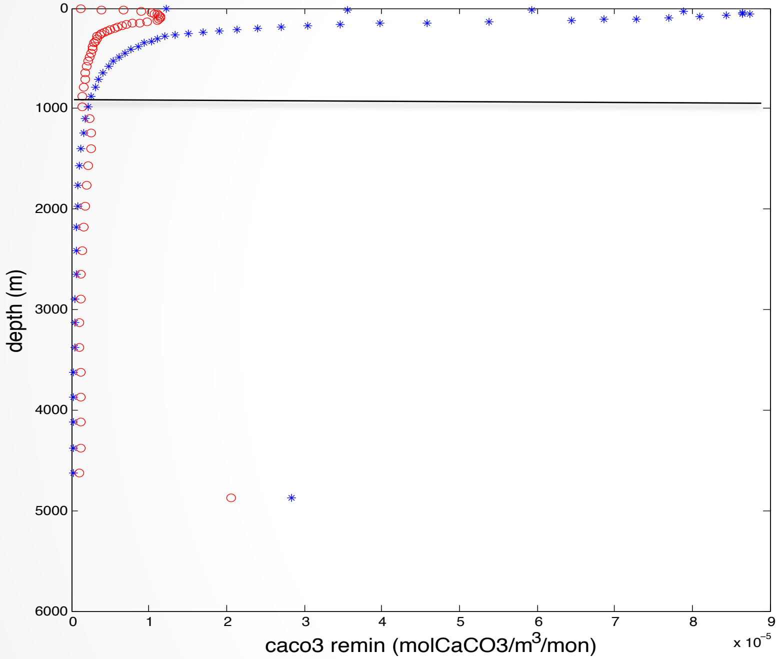
	Berelson et al, 2007	Feely et al, 2004	Honjo et al, 2008	Gangsto et al, 2008	Dunne et al, 2012	Dunne et al., 2007
annual caco3_prod (PgCaCO3/yr)	0.5-1.6	0.8-1.4		0.57		
total remin (PgCaCO3/yr)				0.38		
remin (0-2000m) (PgCaCO3/yr)				0.18		
total burial (PgCaCO3/yr)		0.1-0.14				
caco3_flux out 100m (PgCaCO3/yr)				0.41	0.371	0.52
caco3_flux, 2000m (PgCaCO3/yr)	0.6	0.4	0.41	0.39		0.29
annual caco3_prod (PgCaCO3/yr)	0.4-1.8		5.73			9.6

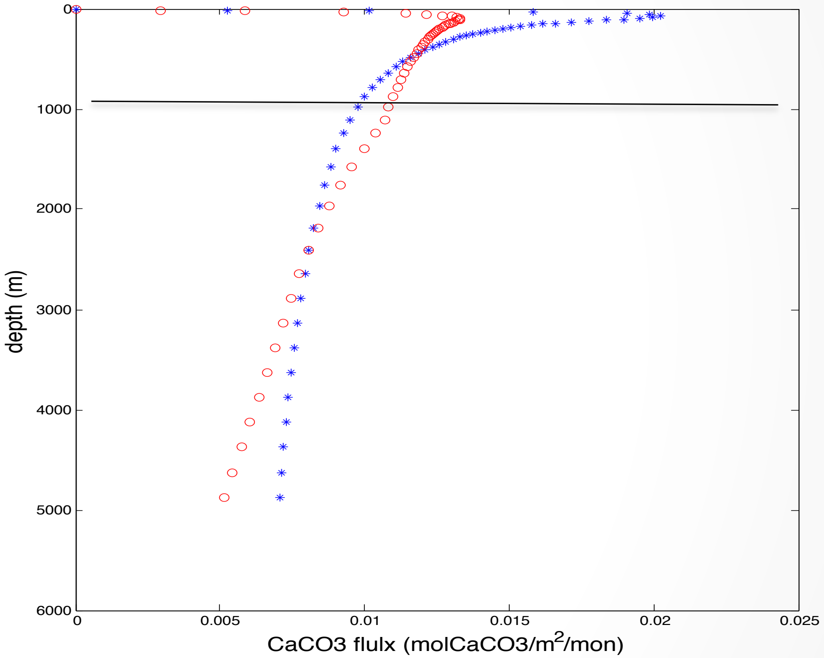
- Lack of observational data;
- Large uncertainties remain.

Vertical Profiles



Examples of changes in CaCO3 flux and remineralization

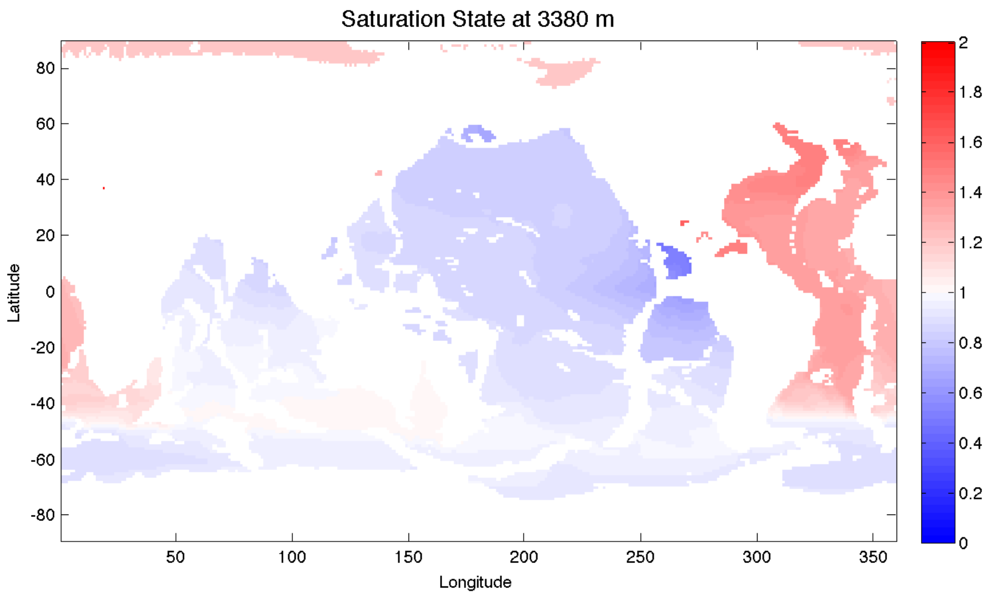


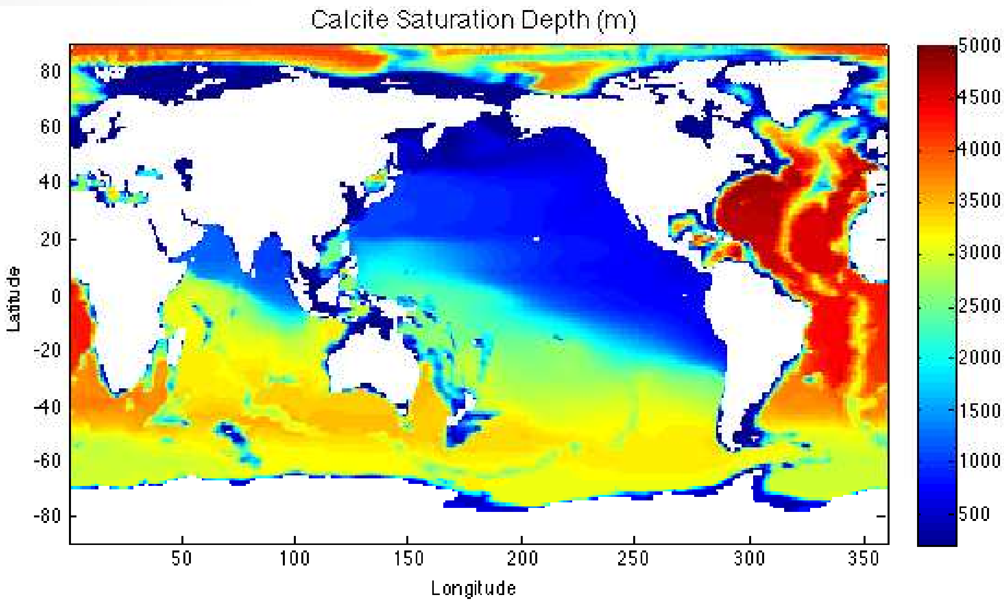


Blue: control case; Red: with Ω feedback

CaCO3 dissolution rate increases when undersaturated

Sediment burial of CaCO3





Standard CESM: all $CaCO_3$ gets buried in sediments shallower than 3300 m and dissolves in deeper sediments

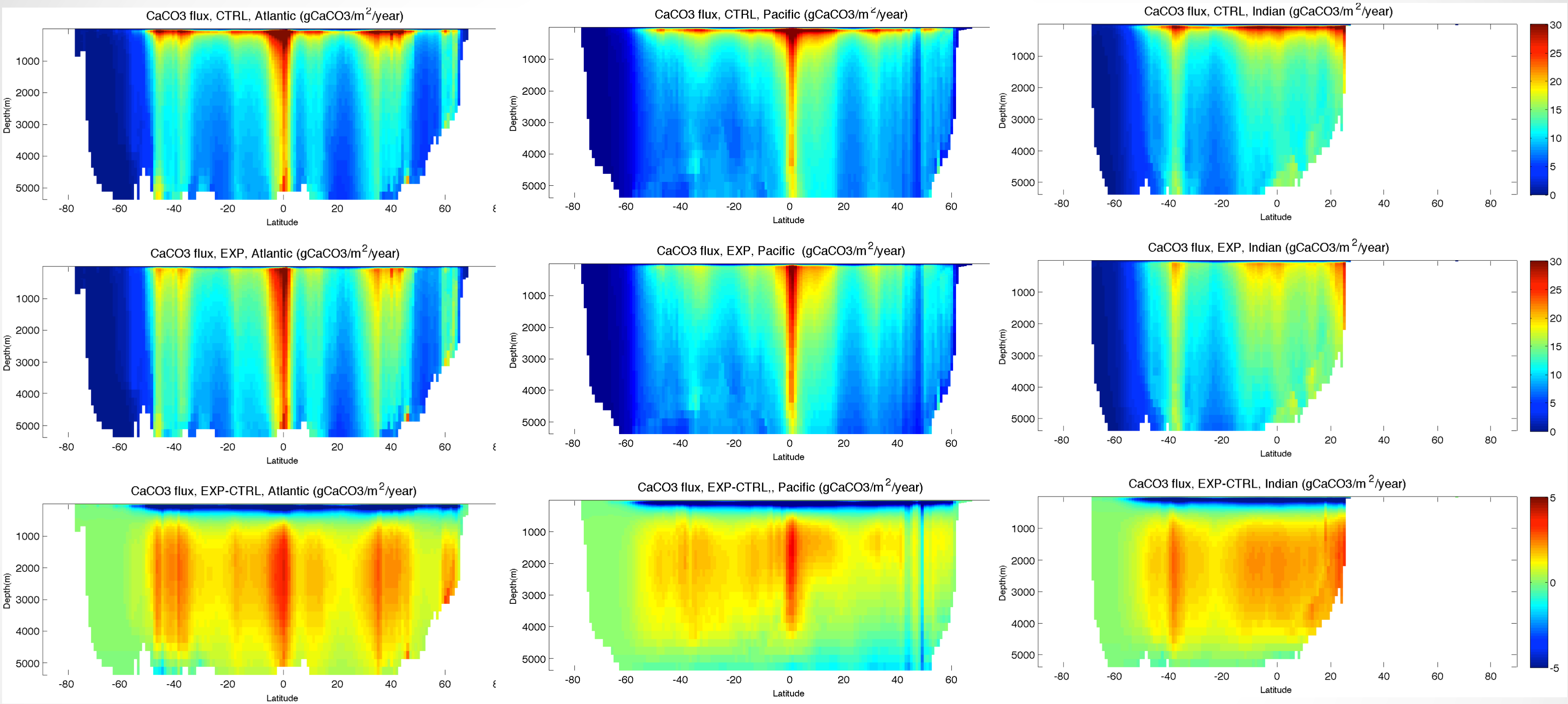
Modification: $CaCO_3$ dissolves if undersaturated. $CaCO_3$ gets buried in sediments shallower than saturation depth.

Simulation results

	Berelson et al, 2007	Feely et al, 2004	Honjo et al, 2008	Gangsto et al, 2008	Dunne et al, 2012	Dunne et al., 2007	control	OA-run
annual caco3_prod (PgCaCO3/yr)	0.5-1.6	0.8-1.4		0.57			1.29	0.71
total remin (PgCaCO3/yr)				0.38			1.133	0.55
remin (0-2000m) (PgCaCO3/yr)				0.18			0.84	0.22
total burial (PgCaCO3/yr)		0.1-0.14					0.15	0.15
caco3_flux out 100m (PgCaCO3/yr)				0.41	0.371	0.52	0.92	0.64
caco3_flux, 2000m (PgCaCO3/yr)	0.6	0.4	0.41	0.39		0.29	0.35	0.4
POC export at 100m (PgC/yr)	0.4-1.8		5.73			9.6	7.29	7.27

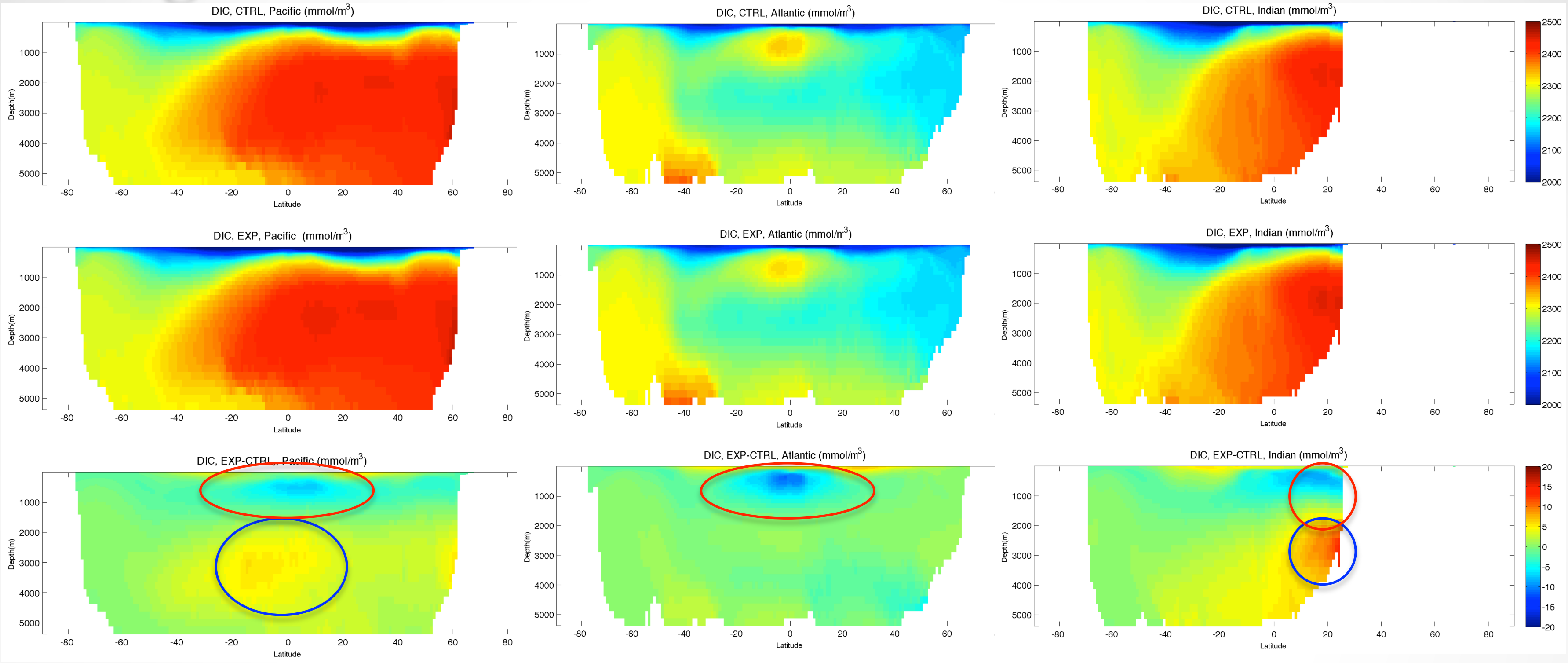
- CaCO3 production is reduced to maintain alkalinity balance;
- ~ 21% of CaCO3 produced is buried, and ~45% dissolved in bottom cells.

$CaCO_3$ flux



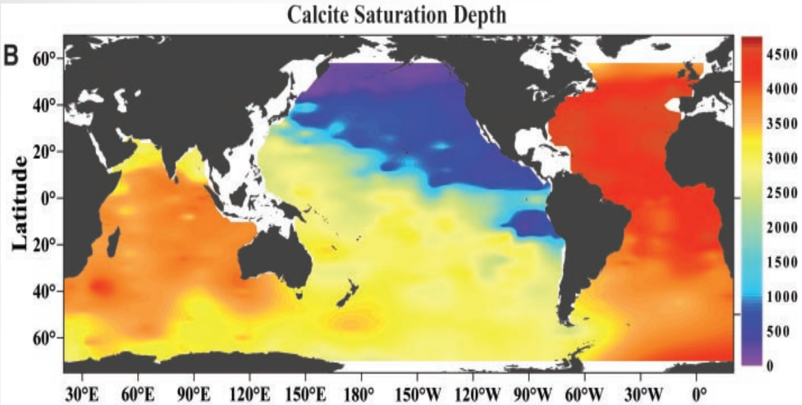
- More CaCO3 fluxes below ~1000m;
- CaCO3 dissolution increases in undersaturated conditions

Changes in DIC distribution



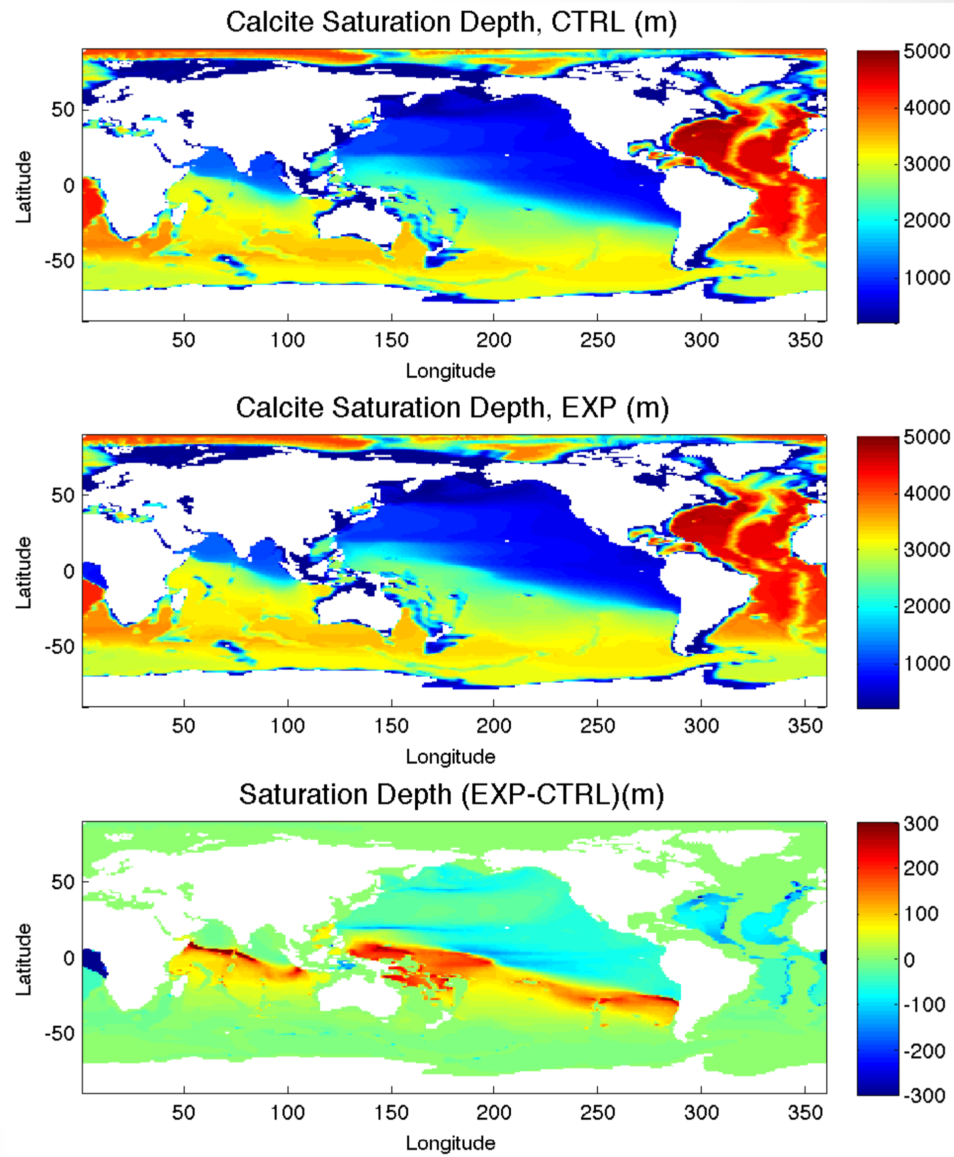
- DIC concentrations slightly decrease in surface seawater and increase in deeper waters;
- Changes in DIC concentrations and alkalinity are small.

Saturation Depth

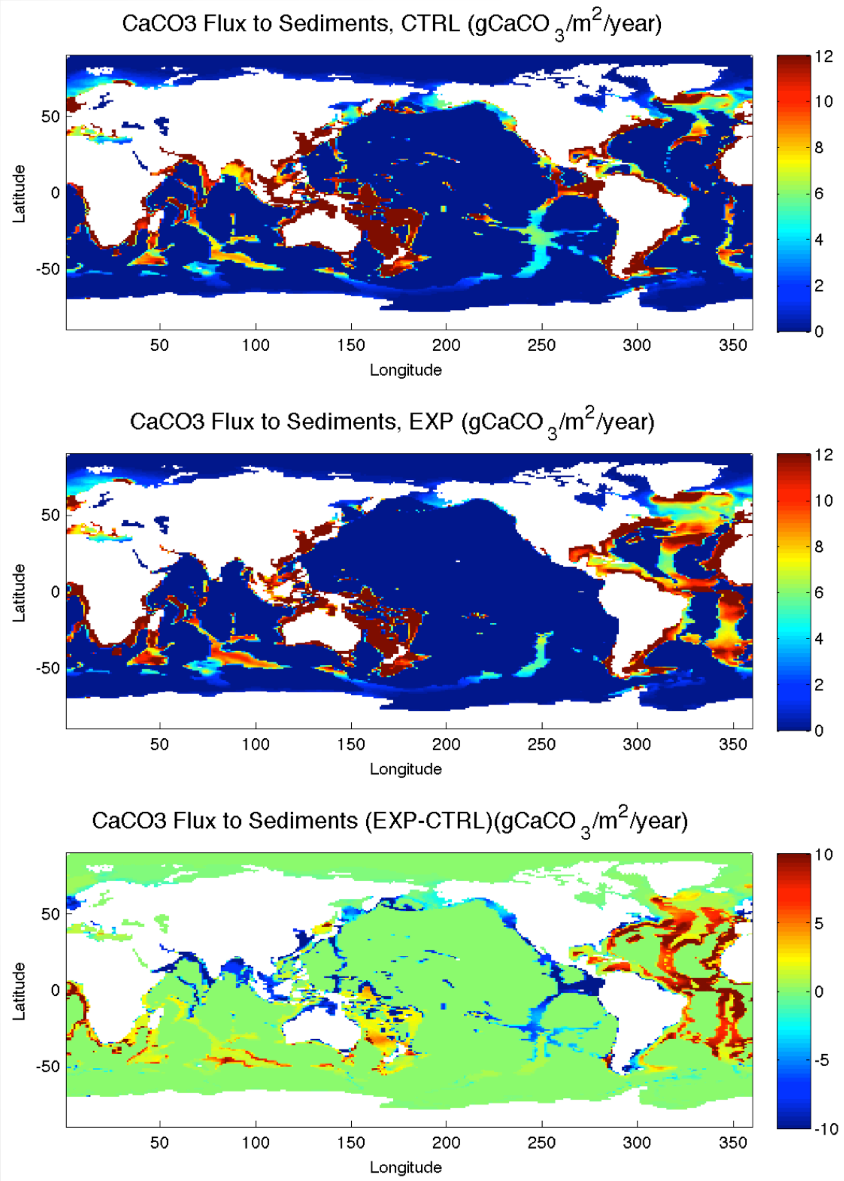


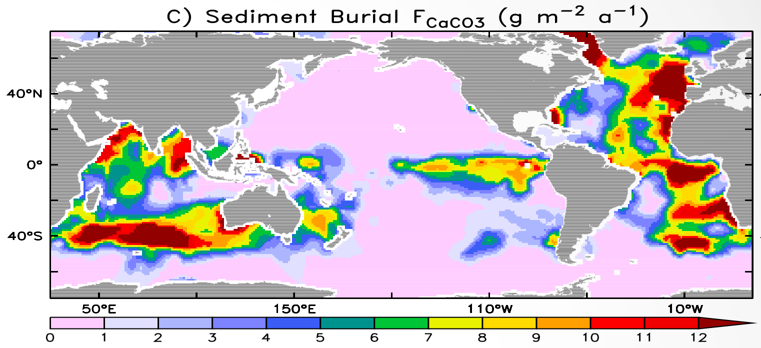
(Feely et al., 2004)

Changes of CaCO3 dissolution profiles lead to changes of [CO_3^{2-}]. This changes Ω and saturation depths.



$CaCO_3$ Burial

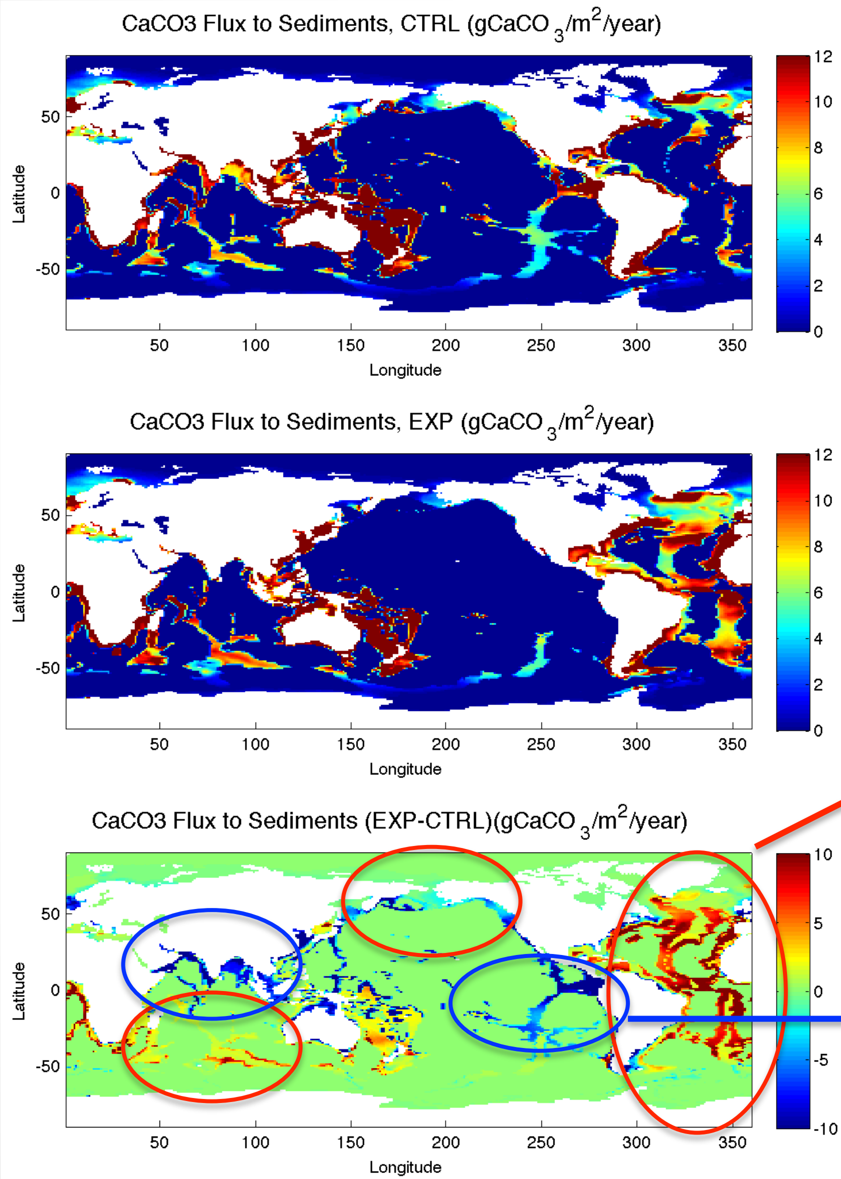


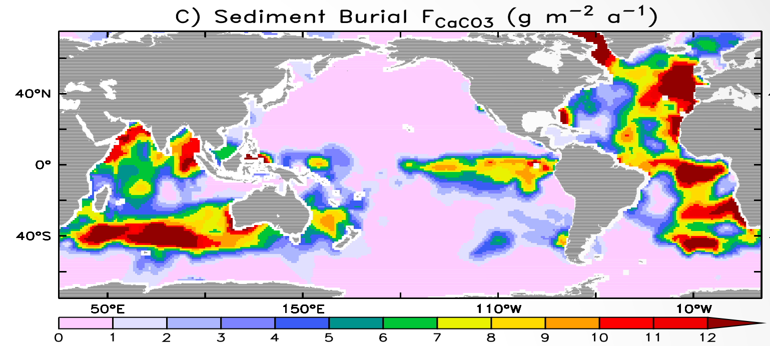


(Dunne et al., 2012)

- $CaCO_3$ burial flux increases in Atlantic Ocean and decreases in Pacific Ocean, controlled by the saturation state in the bottom cell above sediments.

$CaCO_3$ Burial





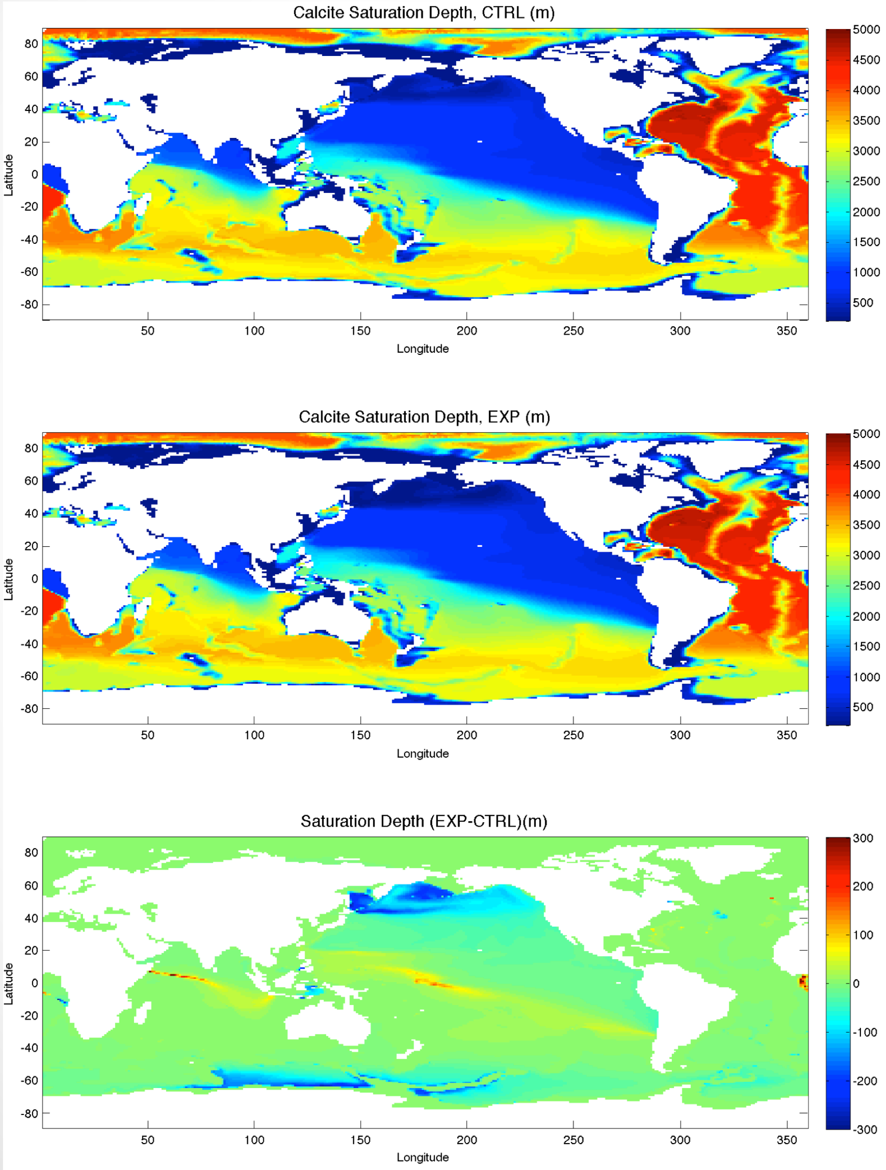
(Dunne et al., 2012)

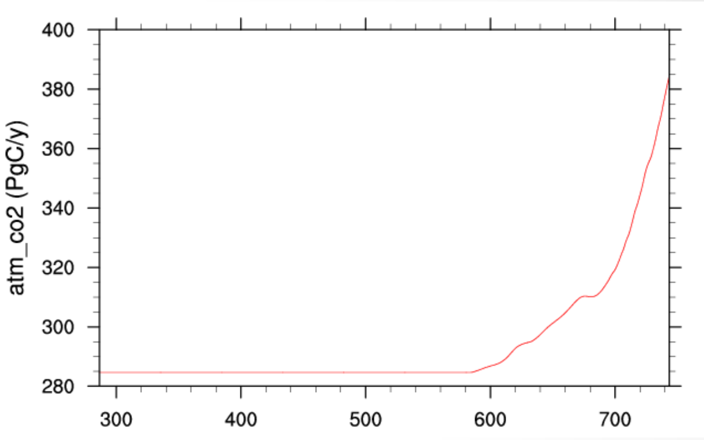
better

worse

Saturation Depth

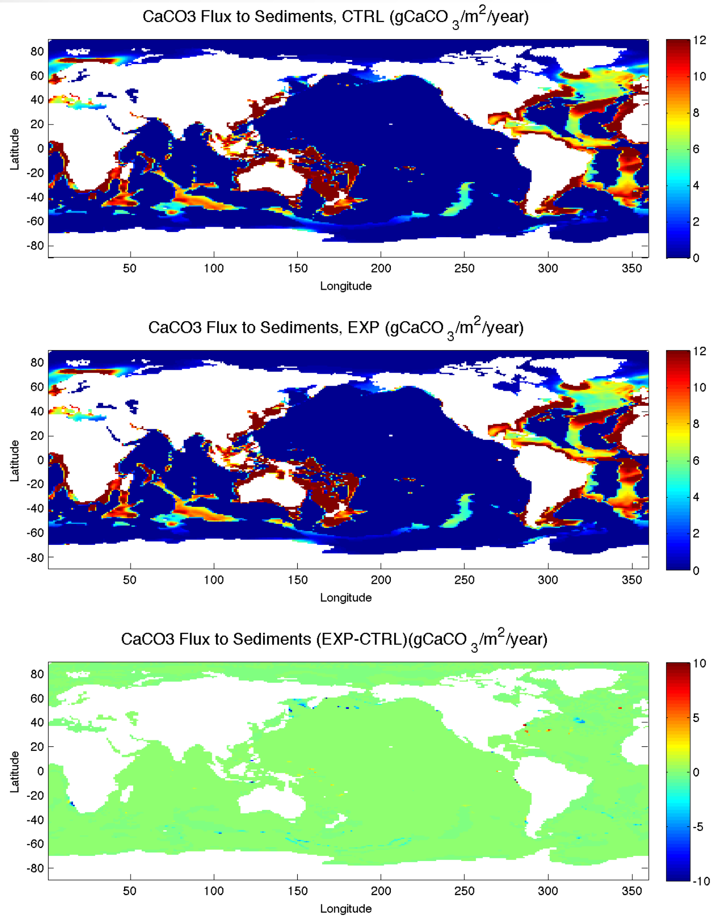
Changes of saturation depths due to increasing CO_2

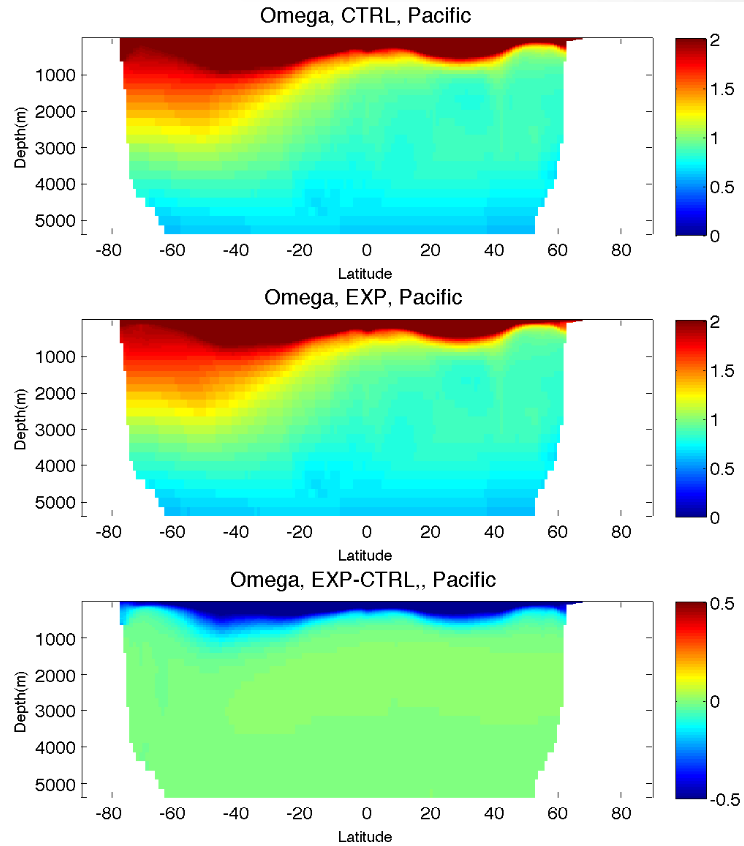




Increasing CO_2 since 1850 leads to shoaling lysocline in N. Pacific and Southern Ocean

$CaCO_3$ burial





- Since 1850, Changes in Ω and [DIC] mainly happen in upper ocean, where Ω>1
- There is no significant changes in the amount of $CaCO_3$ burial

Summary

- With Modifications:
  - Simulation CaCO3 fluxes (2000m and bottom) basically agree with previous studies;
  - Distribution of CaCO3 burial changes: increased burial in Atlantic Ocean
  - Small changes in DIC and alkalinity distributions

- 1850-2009:

  - Increasing CO_2 mainly affected the upper ocean, where $\Omega > 1$. There is no significant changes in $CaCO_3$ dissolution

- Next Step:
  - Incorporating explicit calcifiers,
  - Incorporating effects of Ω on calcification
  - Studying impacts of ocean acidification on the carbon cycle on longer timescales.

Dissolution Length Scale

Dissolution of $CaCO_3$ in standard CESM/BEC:

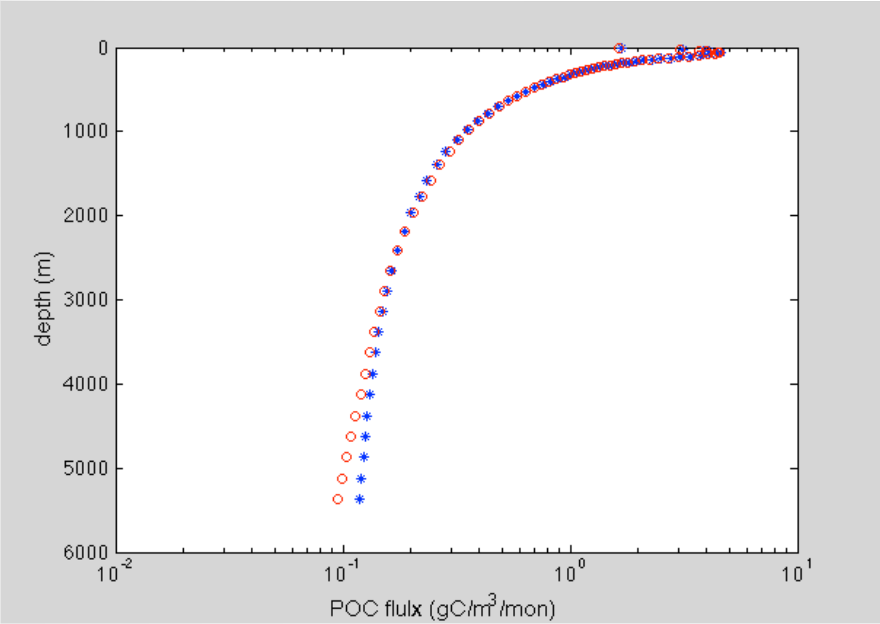
DECAY_CaCO3 = exp(-dz(k) / (scalelength*P_CaCO3%diss))

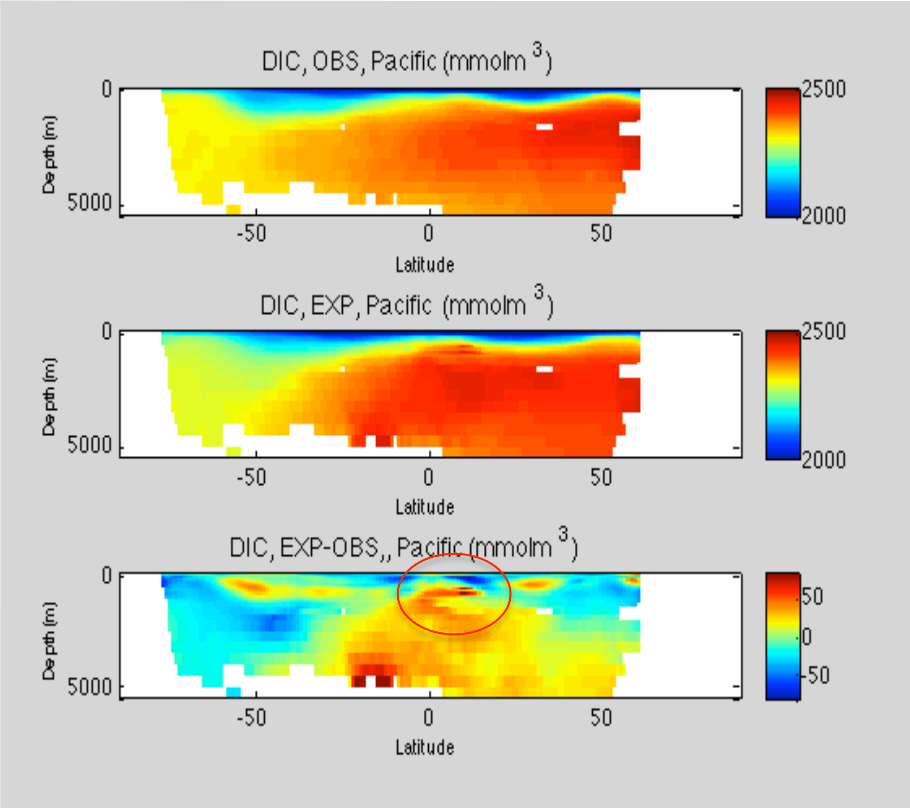
DECAY_CaCO3 is remineralization length scale of CaCO3; dz is the thickness; P_CaCO3%diss is dissolution length; scalelength is a parameter varying with depth

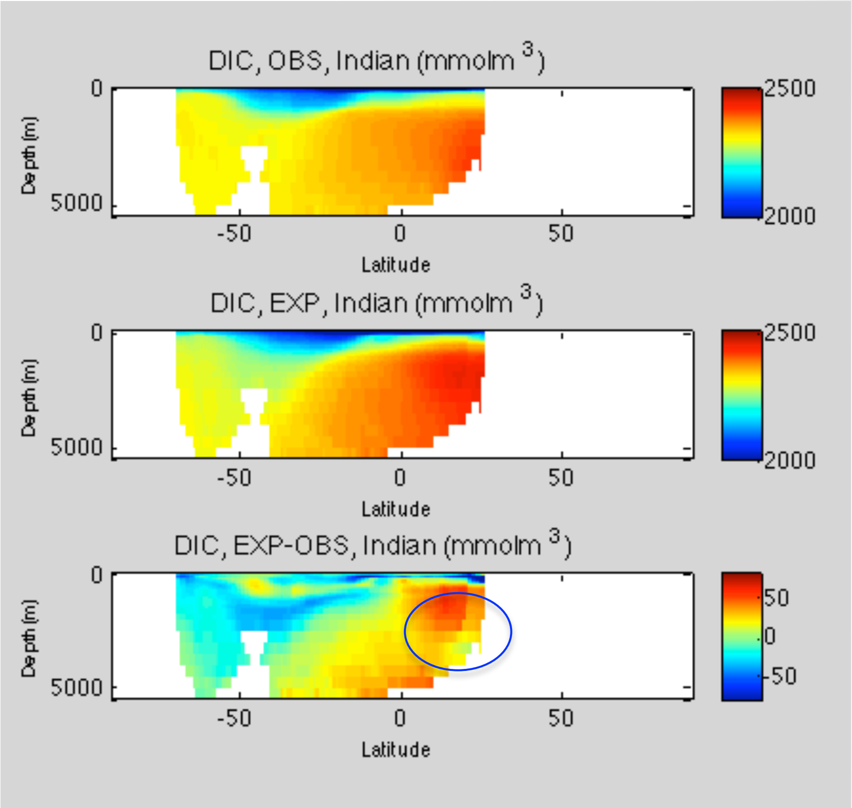
Dissolution of $CaCO_3$ in modified CESM/BEC:

DECAY_CaCO3 = exp(-dz(k) * max(c0, 1-OMEGA_CALC) / (scalelength*P_CaCO3%diss))

Pre-industrial part: POC flux




DIC, OBS, Pacific (mmolm 3)
Depth (m)
Latitude
DIC, EXP, Pacific (mmolm 3)
DIC, EXP-OBS,, Pacific (mmolm 3)


DIC, OBS, Indian (mmolm 3)
Depth (m)
Latitude
DIC, EXP, Indian (mmolm 3)
DIC, EXP-OBS, Indian (mmolm 3)