A long term study of the effect of elevated CO_2 on marine calcification using the Biosphere 2 coral reef mesocosm as a model system

Chris Langdon

Lamont-Doherty Earth Obs. of Columbia Uni.

Palisades, NY 10964

langdon@ldeo.columbia.edu

Outline

- Background
  - CO_2 emissions (270 Gt C since 1751) have changed the chemistry of the atmosphere and are beginning to change the chemistry of the surface ocean.
  - These changes could have a direct effect on the physiology of marine organisms.
    - ↑CO_2 may increase rates of photosynthesis in regions where nutrients are not limiting
    - ↓CO_3^{2-} may decrease rates of calcification

Outline

- If these changes were big enough the balance between photosynthesis and calcification could be upset.
  - Coral reefs could be the first ecosystems to feel the effects
    - less able to keep up with sealevel rise
    - less able to compete for space with faster growing algae
    - more susceptible to boring organisms and storm damage
  - Negative effects could extend to seagrass and mangrove ecosystems that are commonly associated with coral reefs
    - loss of important fisheries
    - loss of income associated with tourism mostly falling on poor third world countries

Outline

- If the effects extend to other and perhaps all calcifying organisms
  - a CO_2 dependent reduction in the rate of global calcification would constitute a negative feedback on the rate of increase of atmospheric CO_2 of ~0.3 Gt C y^{-1}
  - this wouldn't make a dent in the ~3 Gt C y^{-1} that is currently accumulating in the atmosphere but it could have been important in the past in stabilizing atmospheric CO_2
  - during glacial-interglacial cycles the strength of marine calcification could have varied by 20% or 0.1-0.2 Gt C y^{-1}

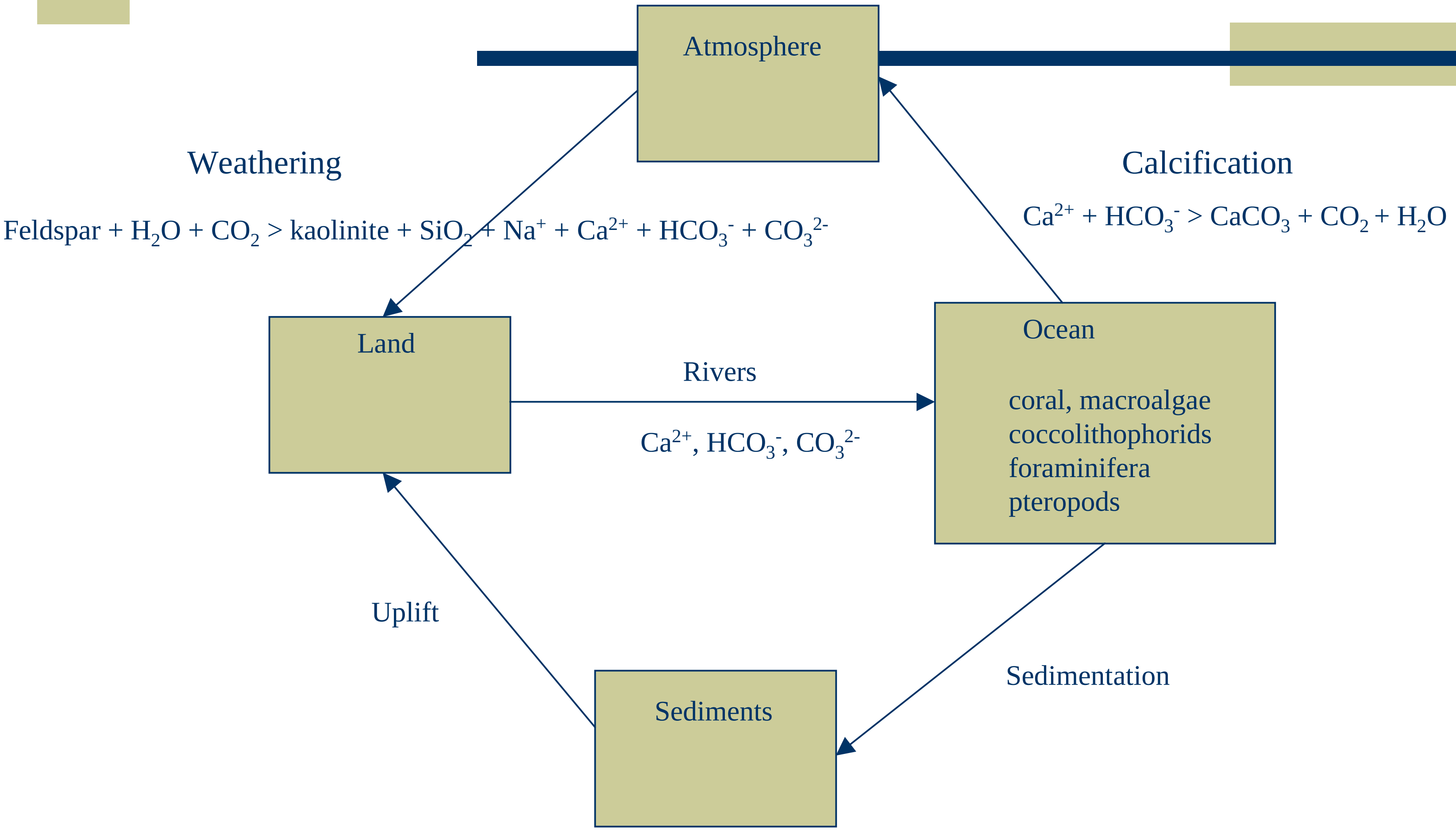
Outline

- How do we get some answers?
  - Historical approach
    - Detailed records of coral growth over glacial-interglacial cycles not available
    - Expected response over the last 200 years is only 10%, probably too small to separate from other environmental factors
    - We can start monitoring coral growth and Ω now but by the time we have definitive results it may be too late.

Outline

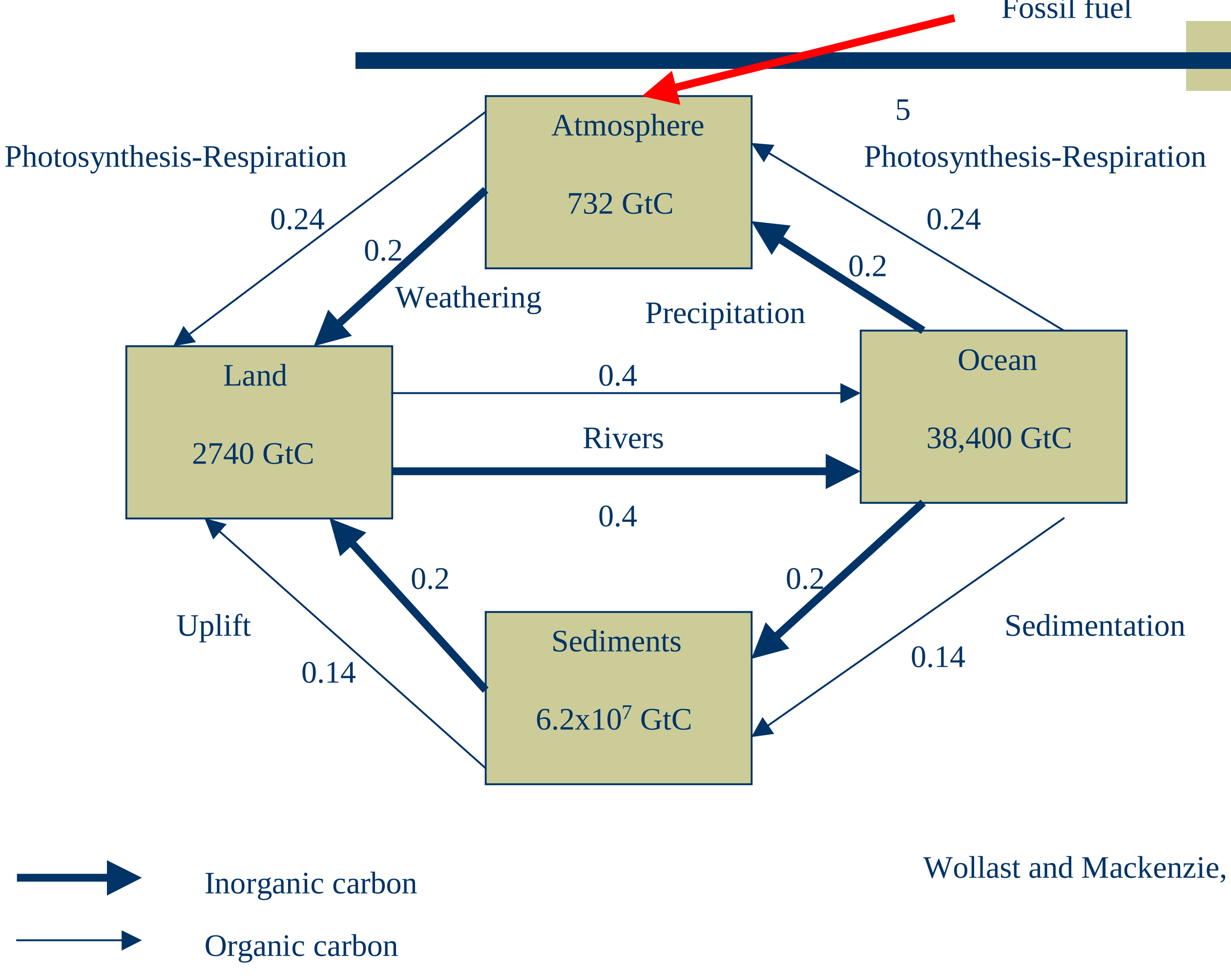
- Experimental approach
  - Manipulate carbonate chemistry to simulate future conditions and observe the effect on calcification and photosynthesis on different time scales
  - Need to choose a model system
    - Shallow tropical environments contribute 40% of global carbonate production. Coral reefs are the archetype community for these environments and may be especially sensitive to rising CO_2 as mentioned earlier.
    - B2 offers a coral reef community where long term, controlled experiments are possible

Marine carbonate cycle



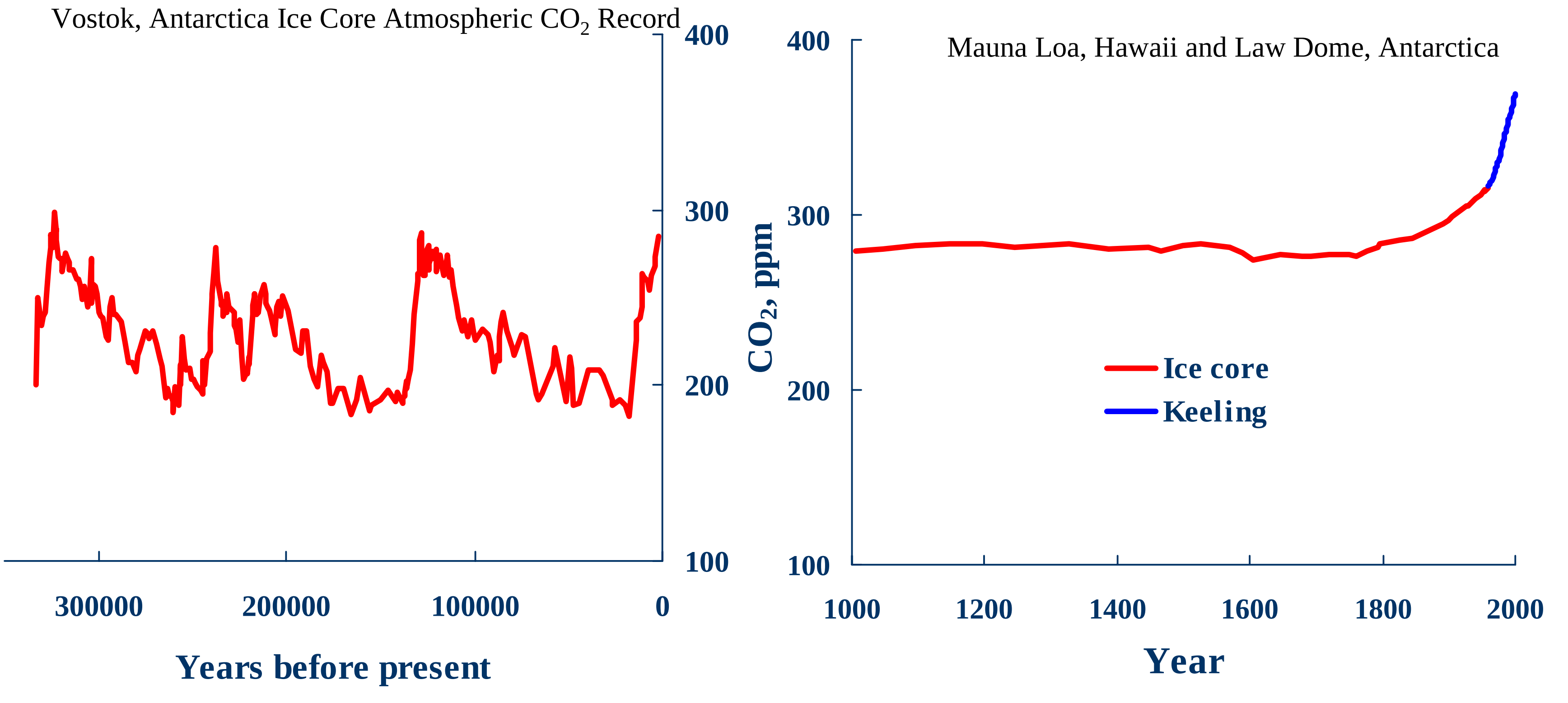
Global carbon cycle

fluxes in GtC y^{-1}



Wollast and Mackenzie, 1989

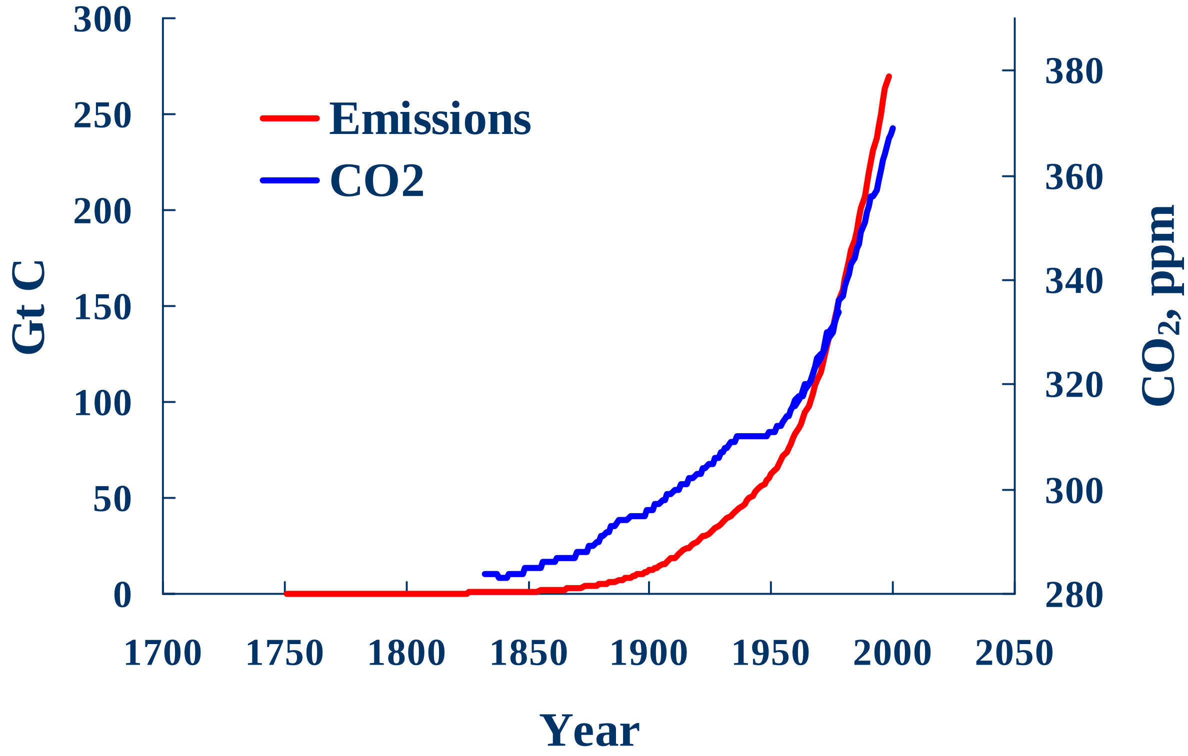
Trends in atmospheric CO_2



Barnola et al. (1999)

Etheridge et al. (1998) and Keeling Whorf (2001)

Global Emission of CO_2



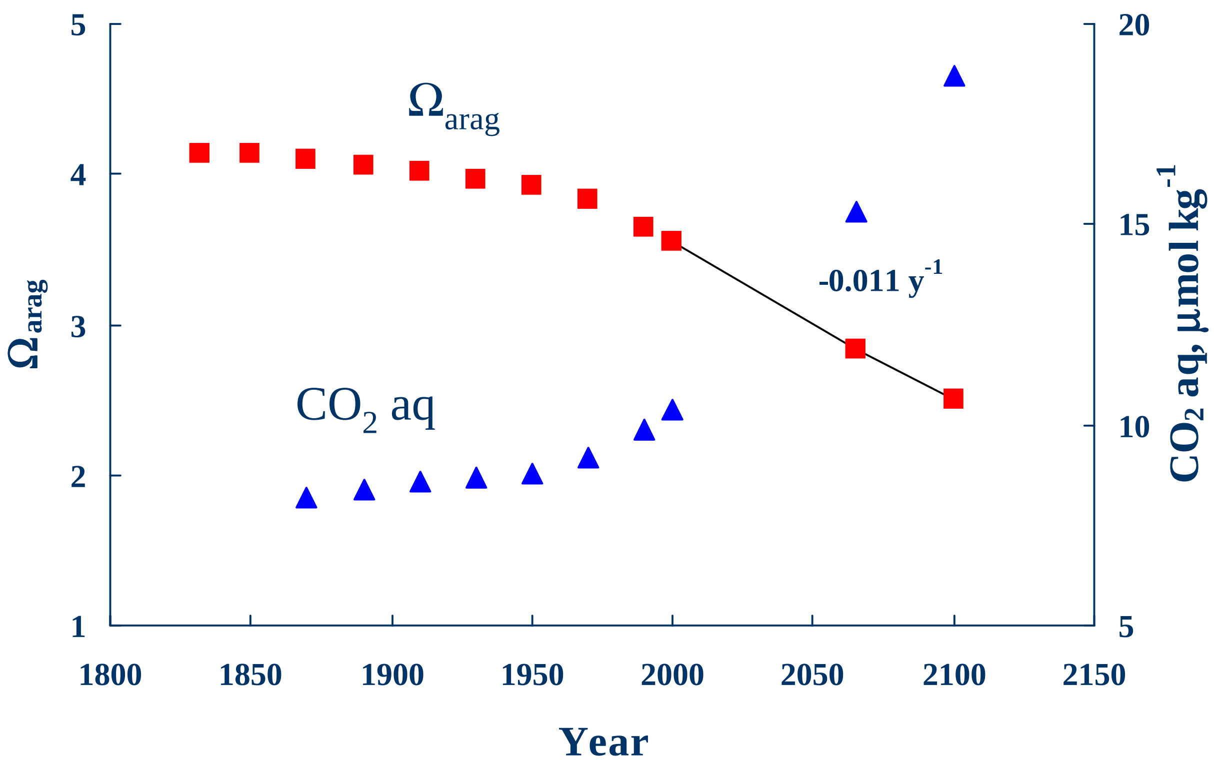
Marland, Boden and Andres (2001)

Link between atmospheric CO_2 and the rate of calcification

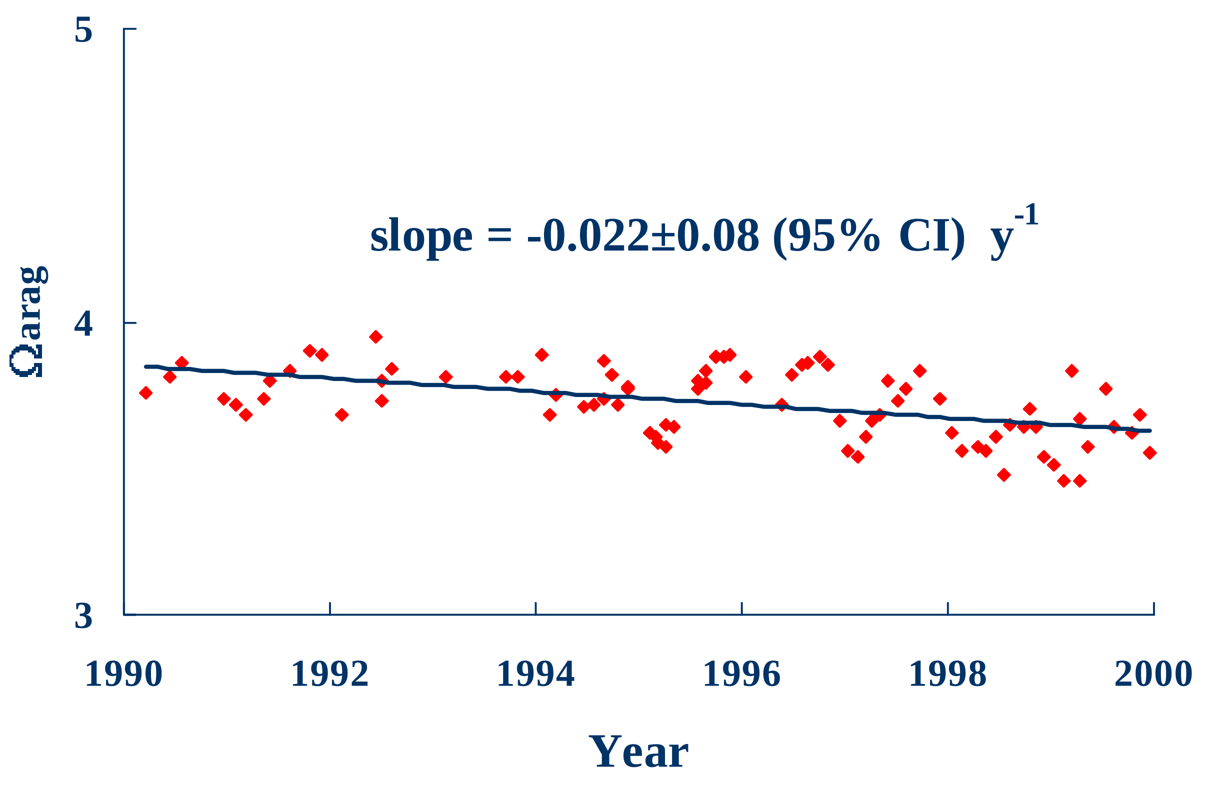
- $CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2HCO_3^-$
- $\Omega_{arag} = [Ca^{2+}][CO_3^{2-}]/K_{sp}$
- $R = k(\Omega-1)^n$

Calculated changes seawater carbonate chemistry

(assuming IS92a business a usual scenario, S=35, TA=2300)



Observations at the Hawaii Ocean Times Series Station



Biosphere 2 coral reef biome

Corals in B2 ocean

Montipora

Siderastrea

Porites

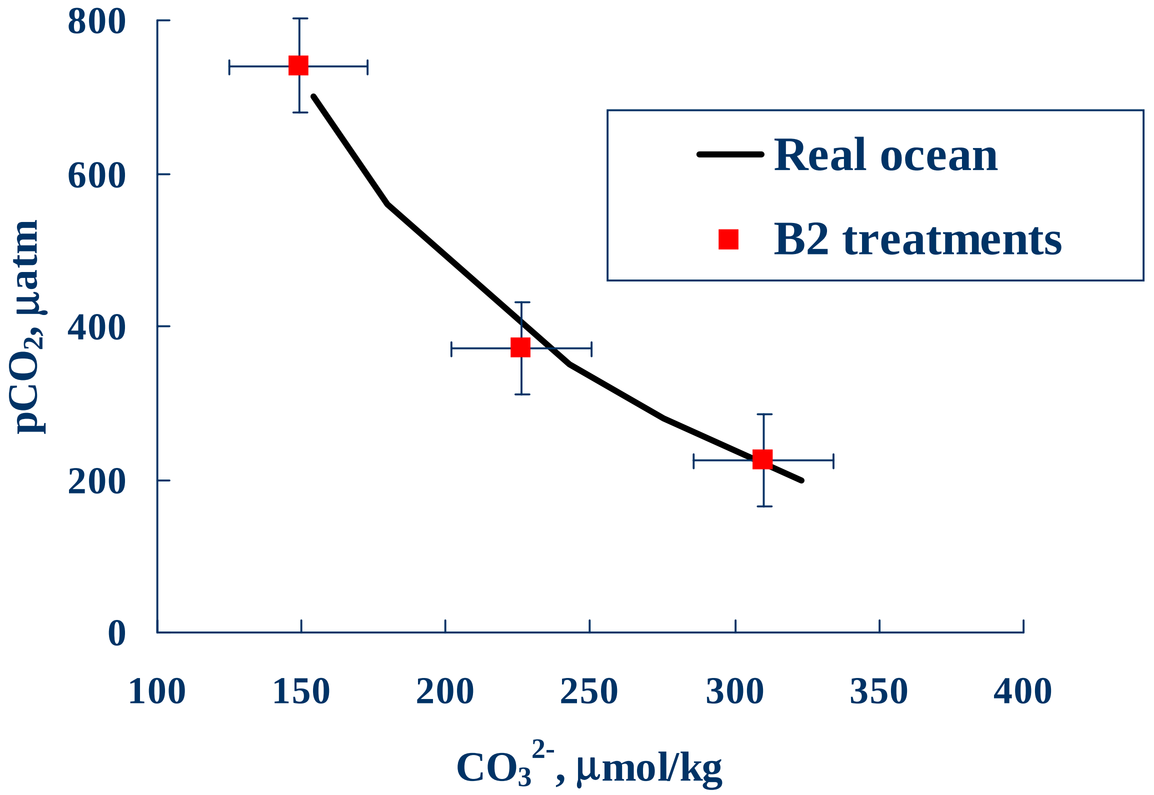
Experimental design

- Simulate real world changes by varying pCO_2 between 200, 350 and 700 µatm at regular 4 monthly intervals and observe the effect on community net primary production and calcification.
- Manipulate pCO_2 by adjusting TA with additions of HCl and NaOH while holding TCO_2 constant by additions of $NaHCO_3$ and Na_2CO_3.

Chemical treatments

	n weeks	pCO_2 µatm	HCO_3^- µmol kg^{-1}	CO_3^{2-} µmol kg^{-1}	pH sws
LGM	29	225±29	1546 ±70	310±28	8.23±0.04
PD	47	371±55	1696±76	226±25	8.05±0.06
FUT	43	741±99	1954±45	149±18	7.81±0.06

Comparison of experimental manipulations and real world changes

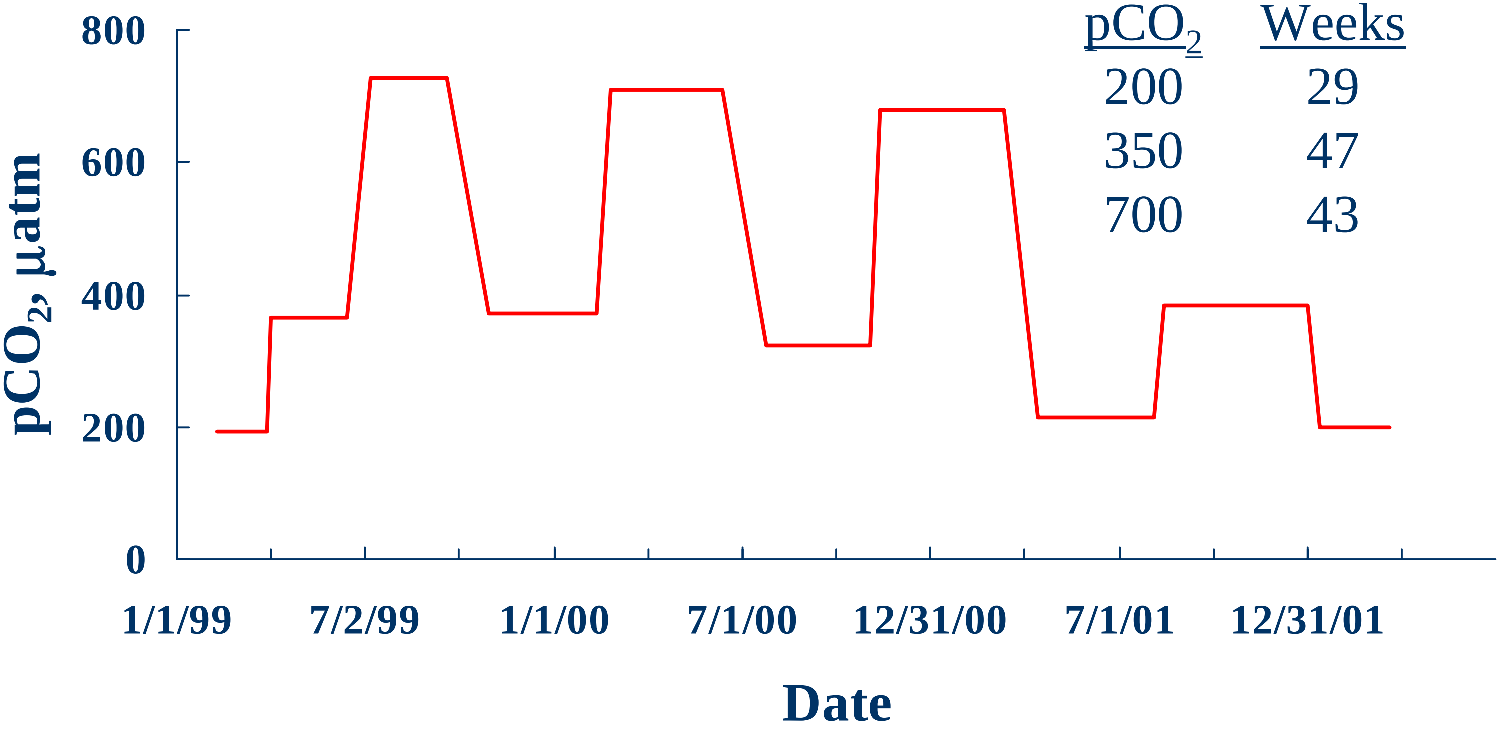


Calculation of Calcification and Net production

- G (mmol $CaCO_3$ m^{-3} d^{-1}) = -0.5(3.5)ΔTA/Δt

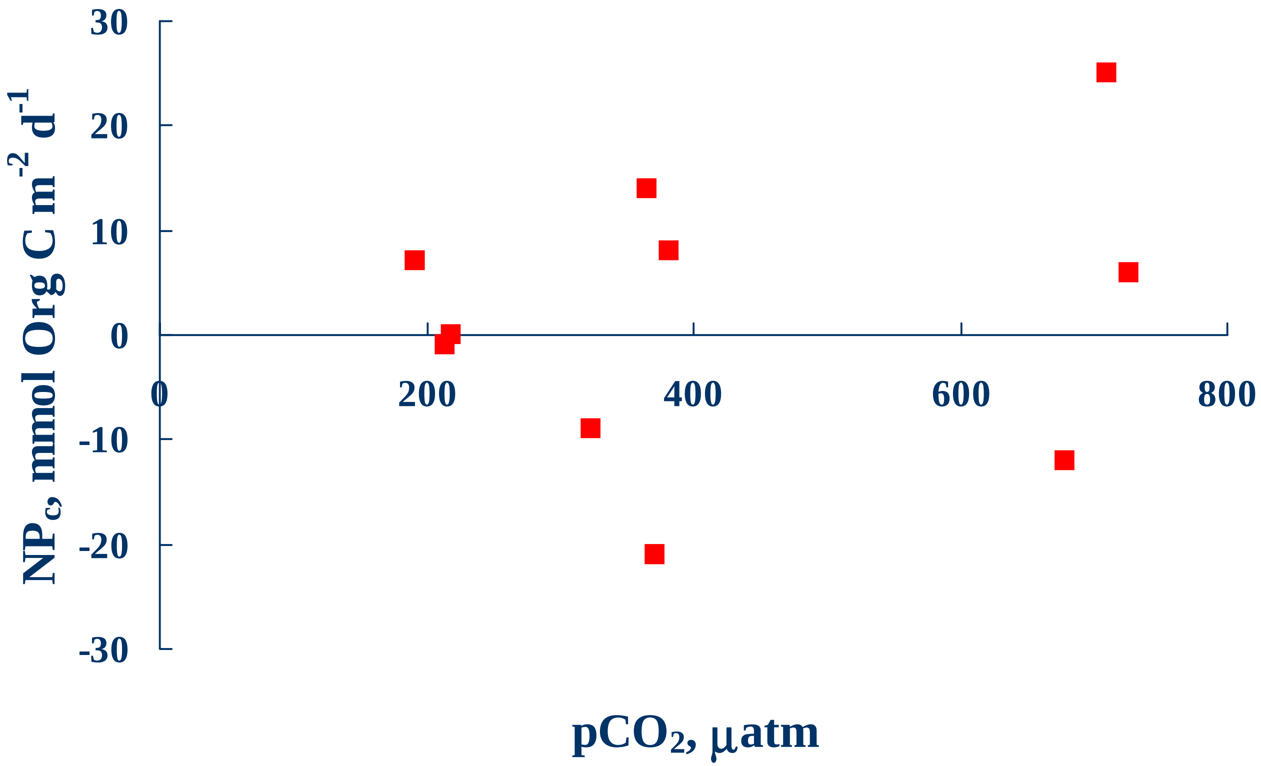
- NP_c (mmol Org C m^{-3} d^{-1}) = 3.5($\Delta TCO_2/\Delta t$ - 0.5ΔTA/Δt) + (1.8 m d^{-1})(0.027 mmol m^{-3} μatm^{-1})($pCO_{2,w}$-$pCO_{2,a}$)

Time line of CO_2 treatments

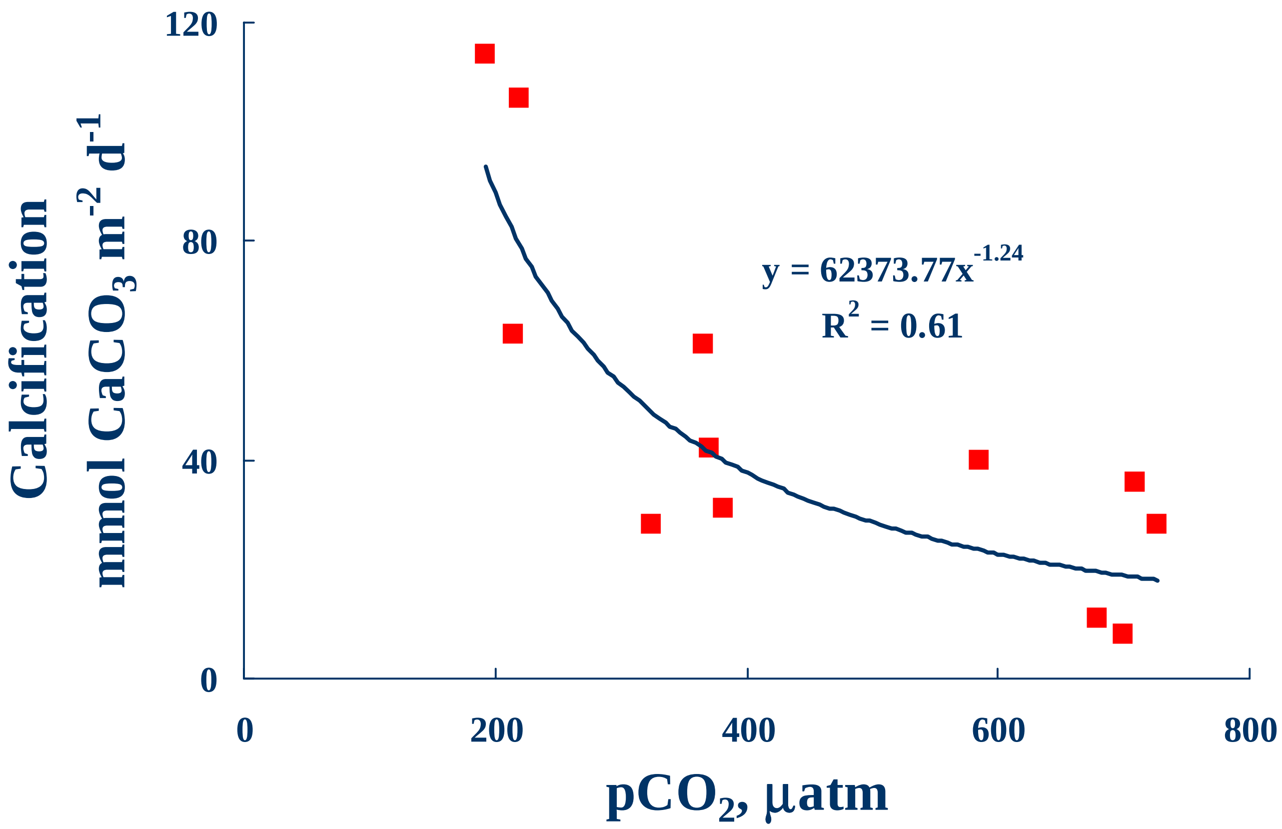


pCO$_2$	Weeks
200	29
350	47
700	43

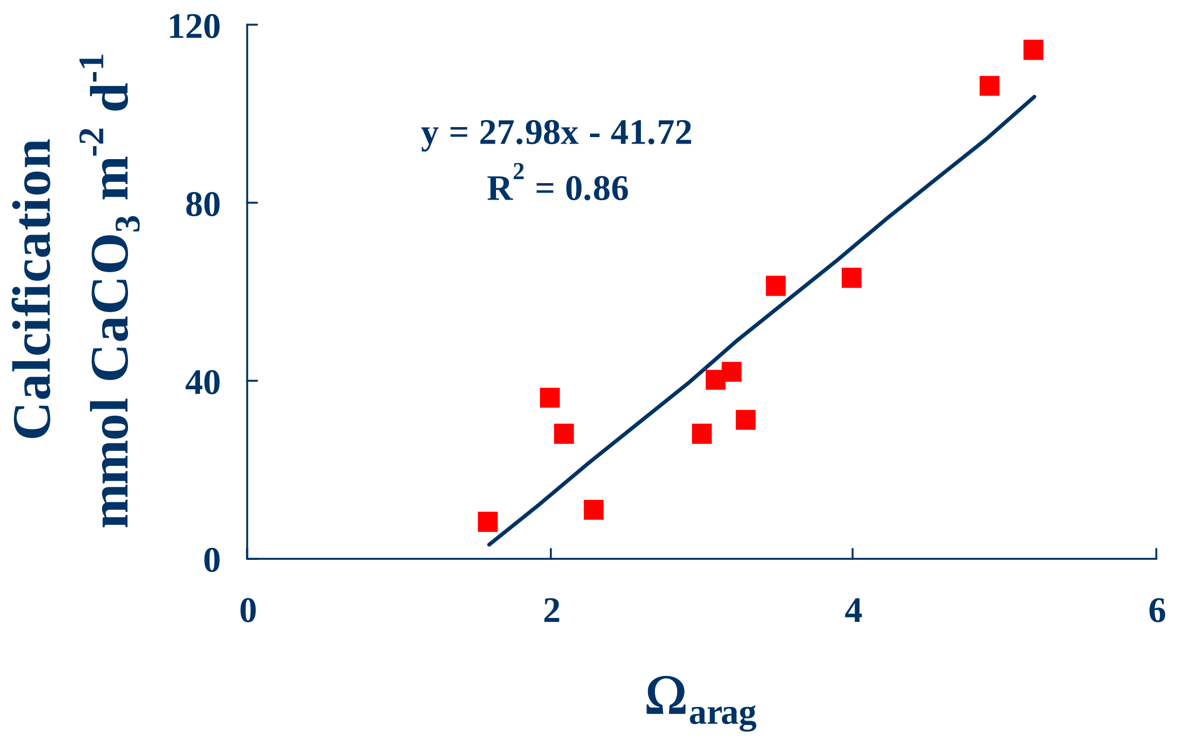
Effect of CO_2 on net community production



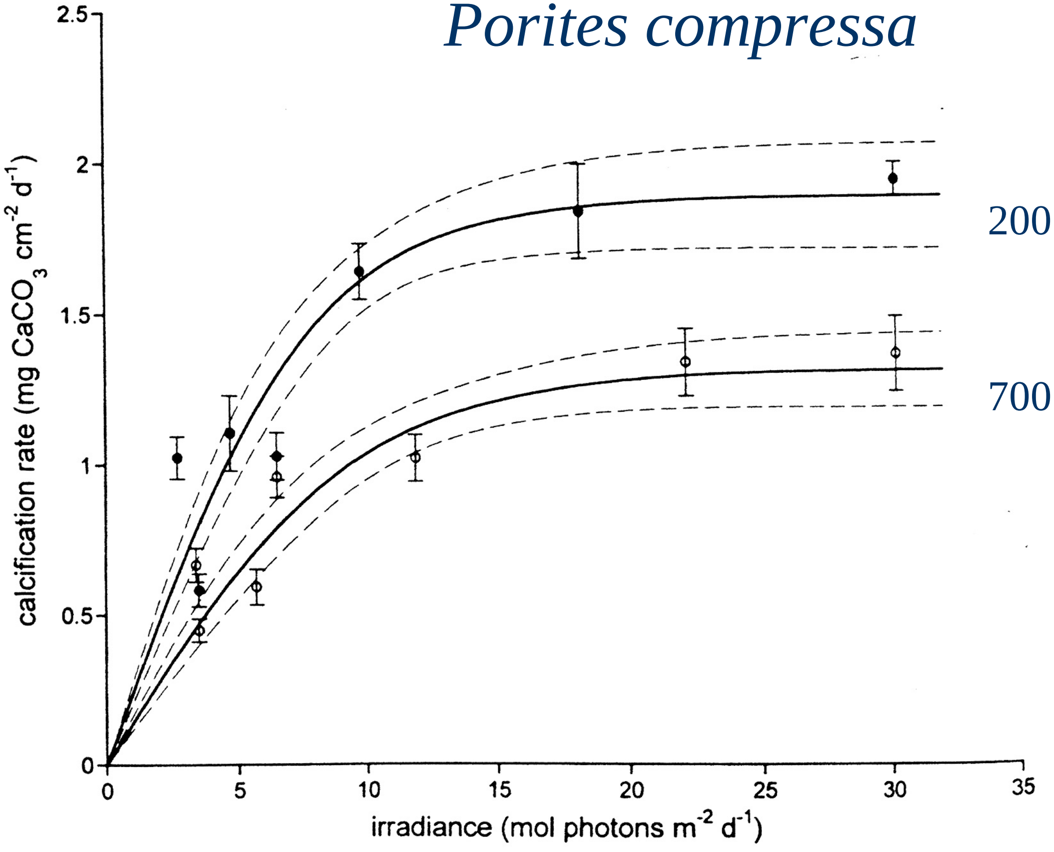
Effect of CO_2 on community calcification



Saturation state controls calcification

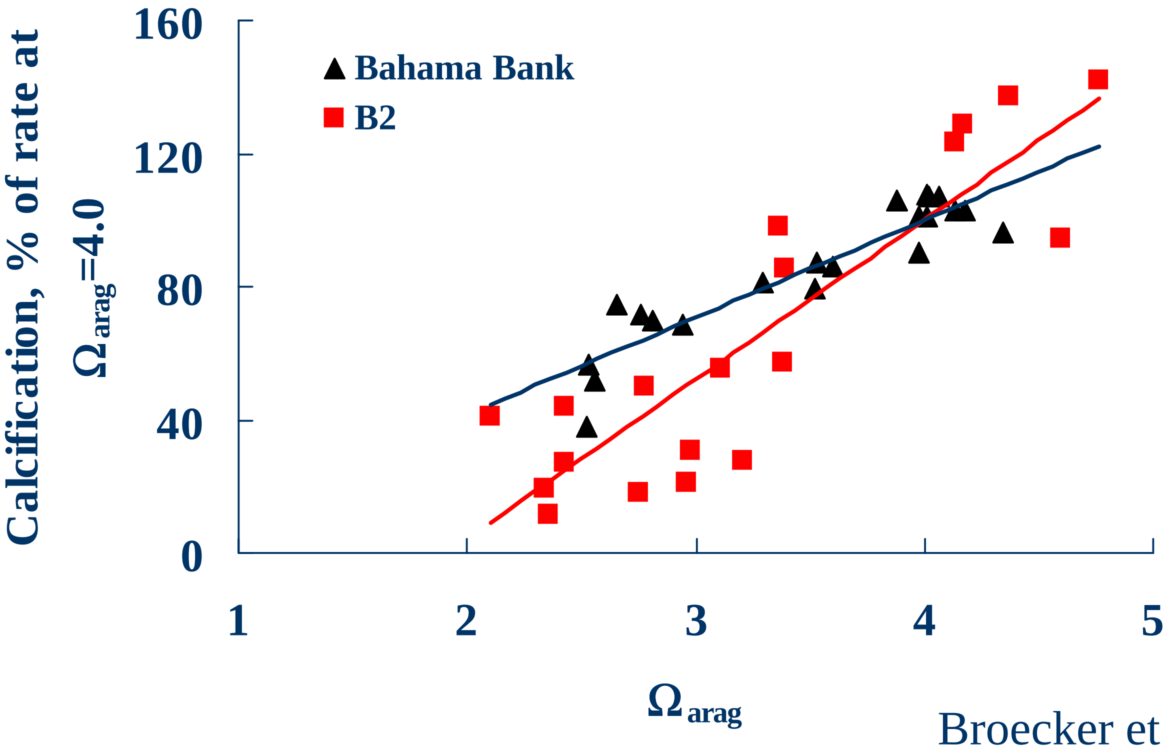


Phase 3- Species specific responses



Marubini et al., 2001

Comparison of B2 with Great Bahama Bank



Broecker et al., 2001

Effect of a doubling in CO_2 (350-700) on calcification, (% decrease)

Calcareous macroalgae

Amphiroa foliacea	-36	Borowitzka, 1981
Porolithon gardineri	-16	Agegian, 1985
Corallina pilulifera	-44	Gao et al., 1993

Corals

Stylophora pistillata	-3	Gattuso et al., 1998
Porites porites	-16	Marubini & Thake, 1999
Porites compressa	-27	Marubini et al., 2001
Acropora sp.	-37	Schneider & Erez, 2000
Porites/Montipora	-50	Langdon & Atkinson, in prep.

Coccolithophorids

Emiliania huxleyi	-10	Riebesell et al., 2000
Gephyrocapsa oceanica	-29	“ “
Natural pop. (N. Pac.)	-38	“ “
Emiliania huxleyi	-*17*	Zondervan et al., 2001
Gephyrocapsa oceanica	*–29*	“ “

Community

Biosphere 2	-40	Langdon et al., 2000
Monaco mesocosm	-21	Leclercq et al., 2000
Bahama Bank	-30	Broecker & Takahashi, 1966

Conclusions

- Photosynthesis and calcification are not tightly coupled with respect to their response to rising CO_2.
  - ↑CO_2 NP_c unchanged ↓Calcif.
- There is a nonlinear relationship between calcification and pCO_2
  - for 200 to 280 µatm pCO_2↑ Calcif.↓ 34%
  - for 350 to 700 µatm pCO_2↑ Calcif.↓ 58%

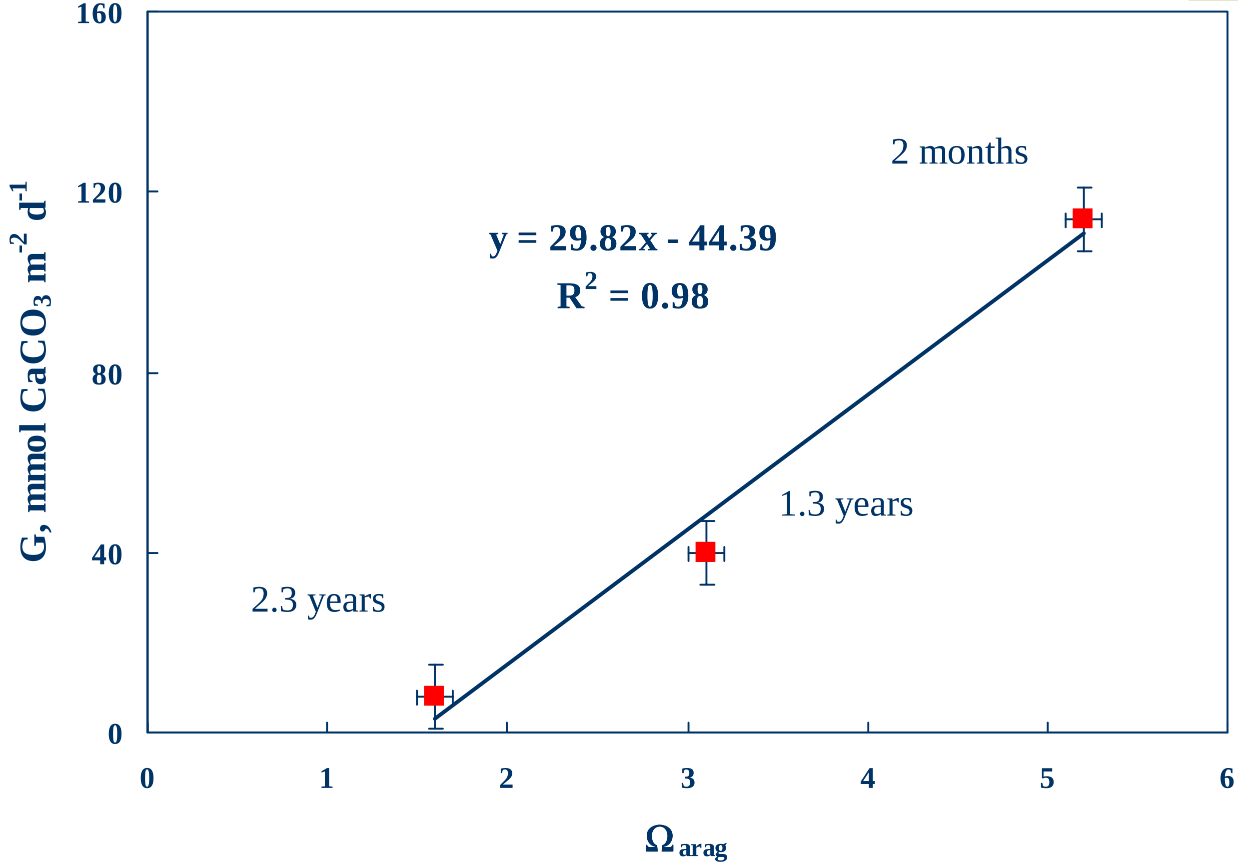
Conclusions

- Data are consistent with the hypothesis that saturation state (Ω) controls the calcification of the B2 coral reef system, several species of coral, calcareous red algae, cocco-lithophorids and a natural community dominated by green algae.
- Consequences of reduced calcification to corals and coral reefs
  - reduced ability to compete for space and light
  - reduced ability to keep up with sealevel rise
  - increased susceptibility to erosion and damage by fish, boring organisms and storms.

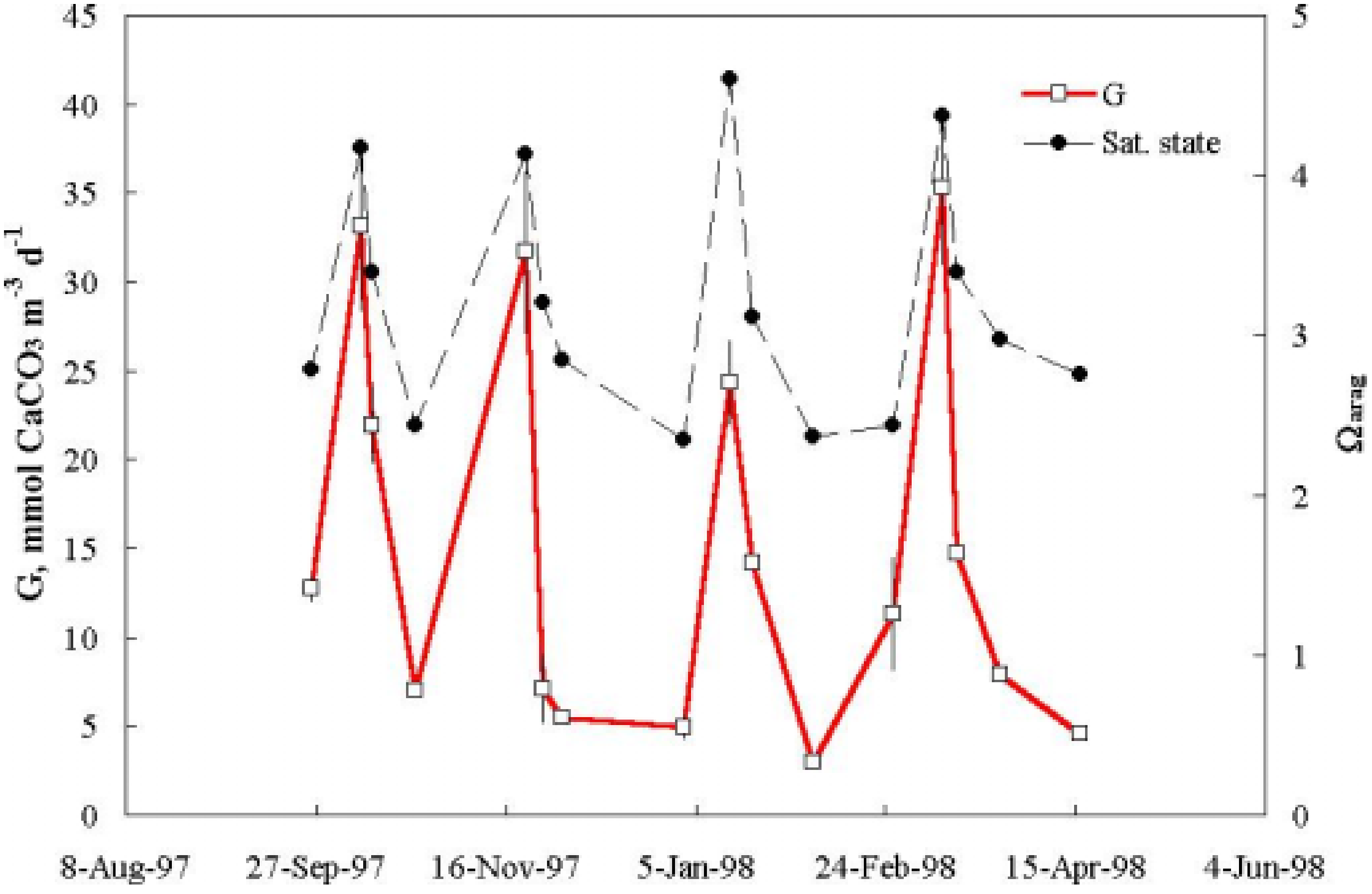
Conclusions

- From a geochemical point of view the reduction in the ratio of calcification to net photosynthesis as CO_2 rises provides a negative feedback on atmospheric CO_2 levels.
- Such a feedback mechanism was first suggested based on laboratory culture experiments here we show that the mechanism can also be demonstrated for a very different community of organisms and at a much larger spatial and longer temporal scale.

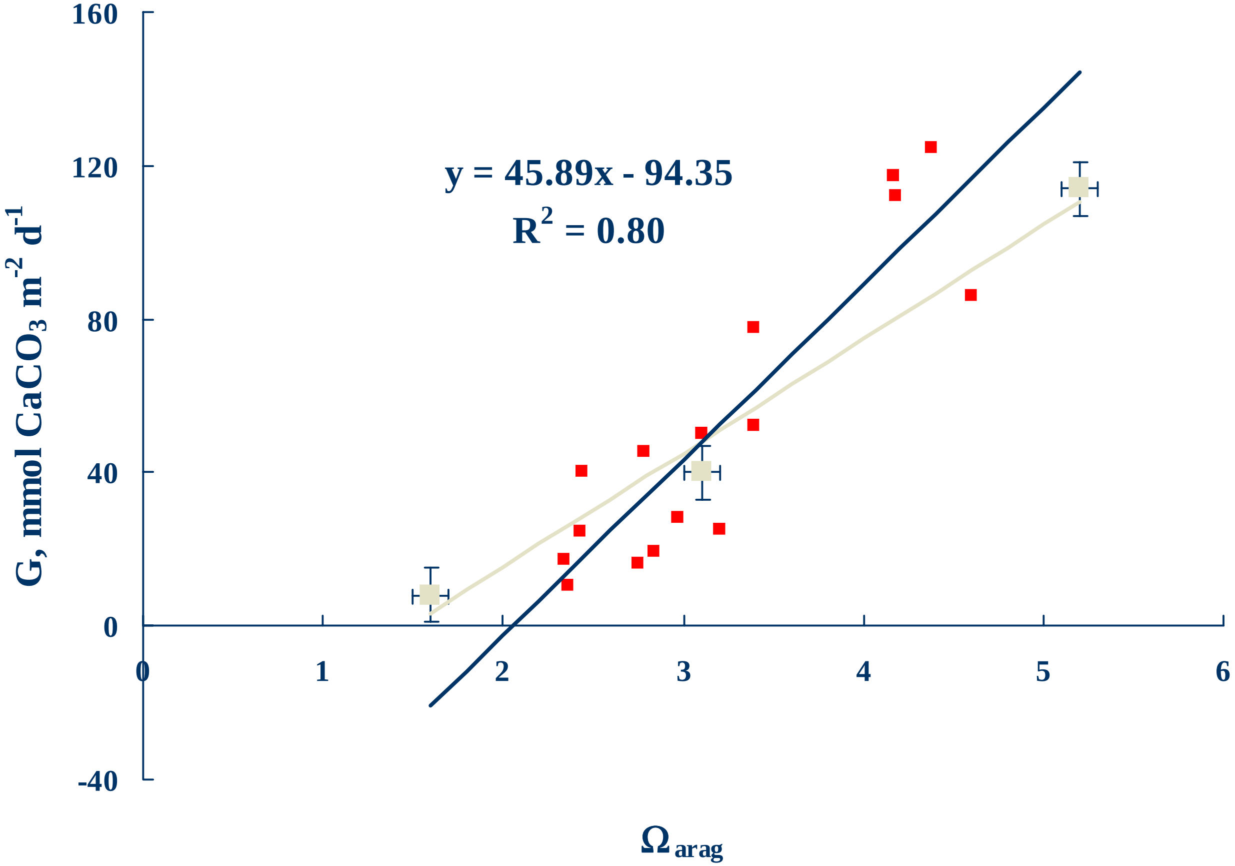
Phase 1 – long-term response



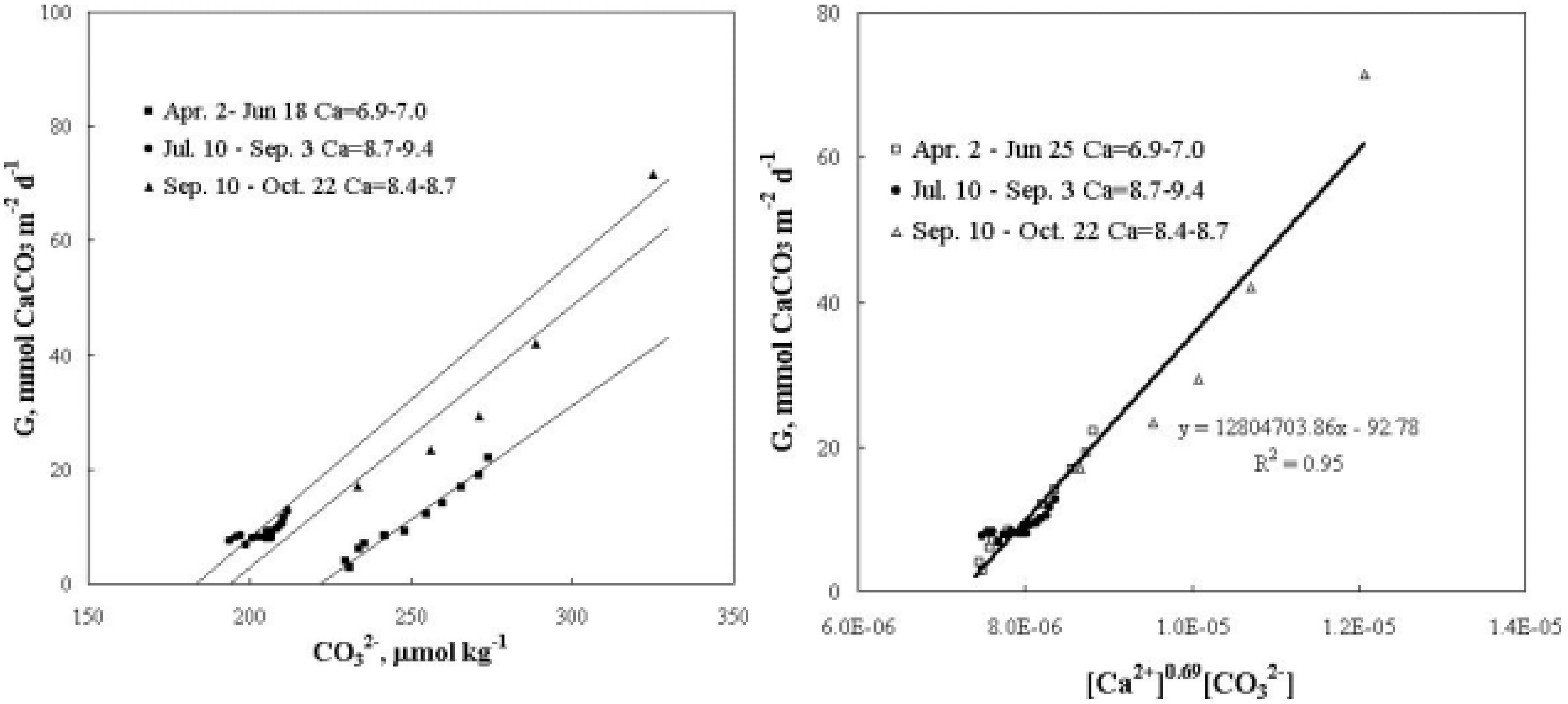
Phase 2 – rapid flip floping of Ω_{arag}



Phase 2 – short term response

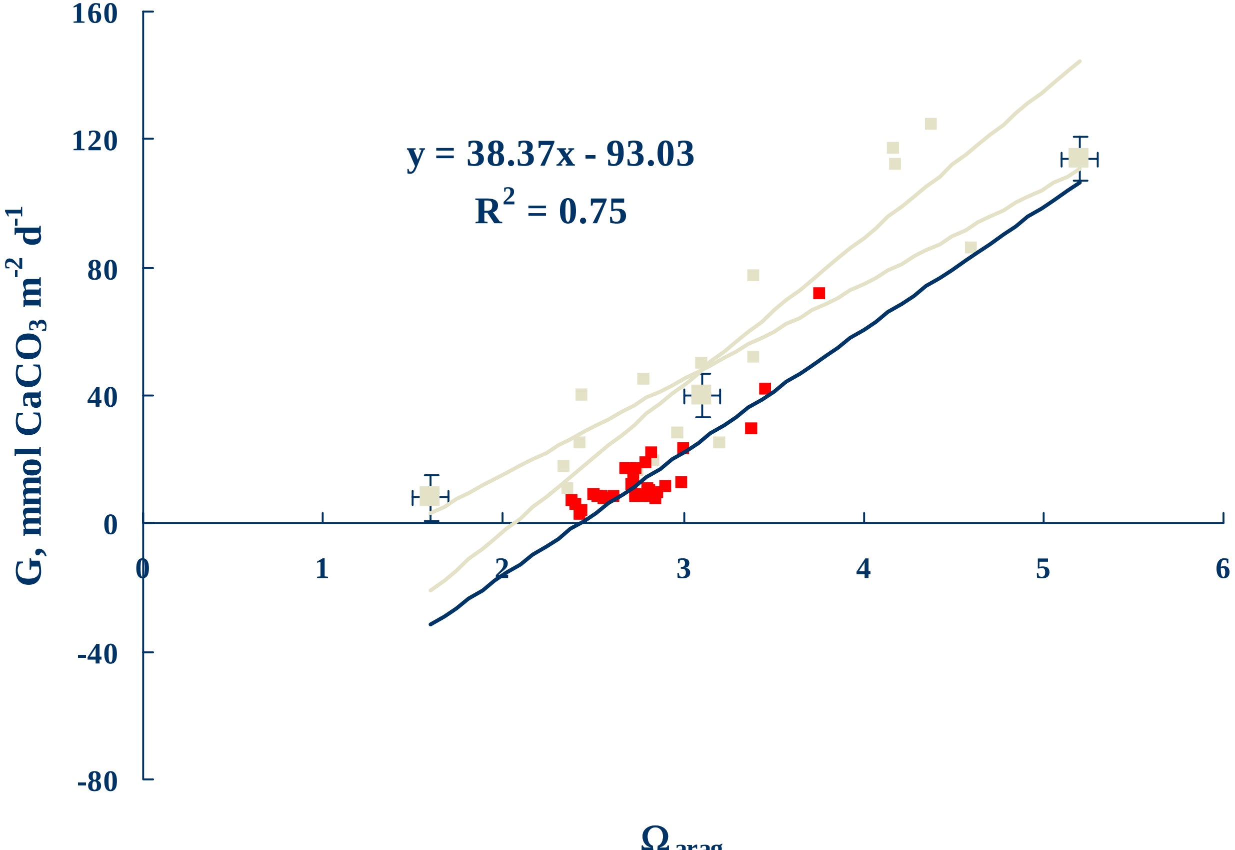


Phase 2 – test of saturation state hypothesis



Langdon et al., 2000

Saturation state dependence – all time scales



Conclusions

- Studies preformed in different ways all show that calcification of corals and coralline algae will decline due to rising CO_2.
- Production of framework and fill carbonate on coral reefs will decline to 50-97% (avg. 70%) of 1880 rates by the year 2065.

Implications

- Corals may produce weaker more easily damaged skeletons.
- Linear growth of corals may decrease making them less able to keep up with rising sealevels.
- Due to latitudinal gradient in Ω high latitude coral reefs should be the first to be affected.

Future work

- Need to determine effect of reduced calcification on skeletal density and linear growth rate of corals.
- Need to start monitoring calcification or carbonate accumulation on a few natural reefs. Many things might cause a reduction in calcification but if a latitudinal pattern emerges with high latitudes sites showing the greatest reduction the CO_2 hypothesis would be supported.