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Coral Reef Studies

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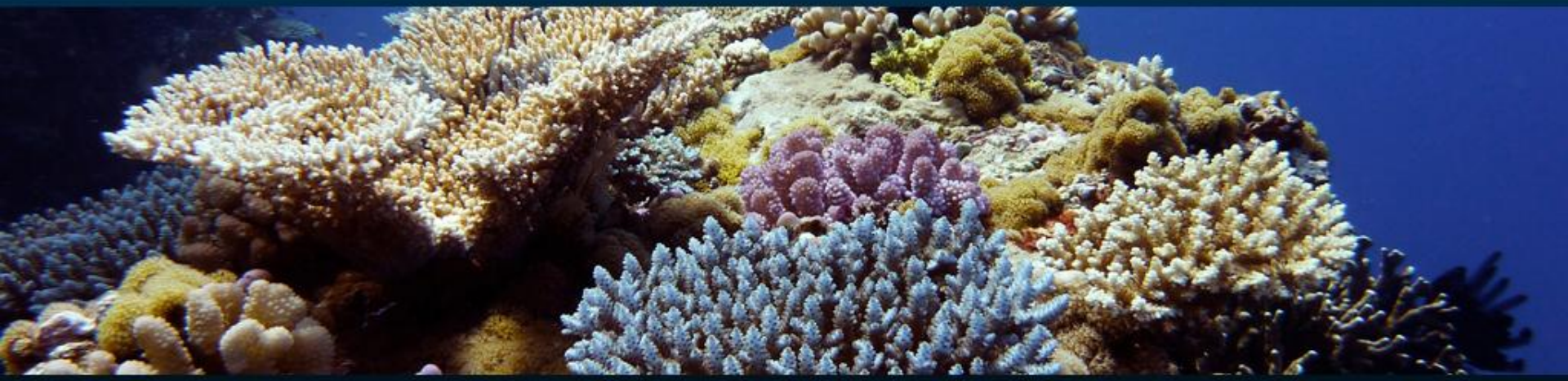
OCEANS & GLOBAL CLIMATE CHANGE: *challenges*

Professor Malcolm McCulloch *FAA FRS*

ARC Laureate Fellow, The University of Western Australia



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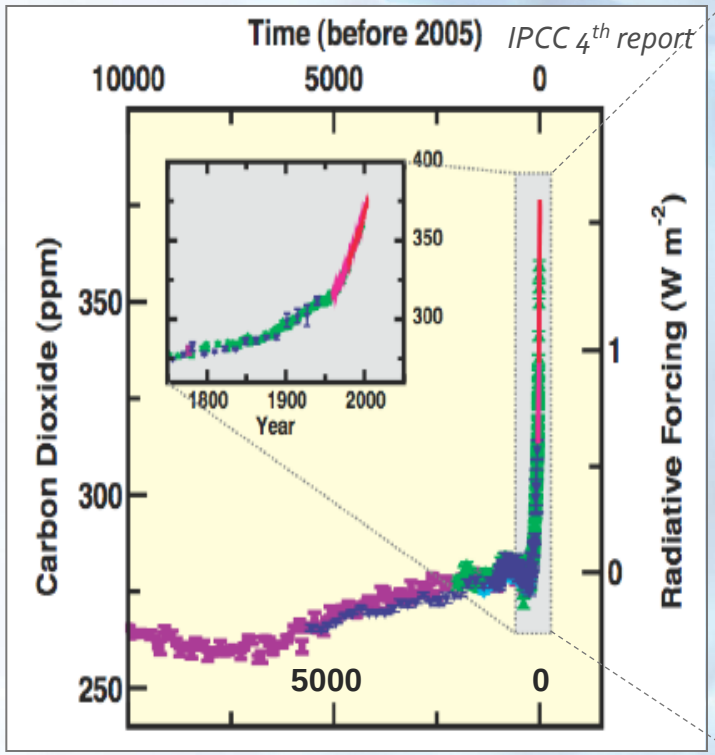
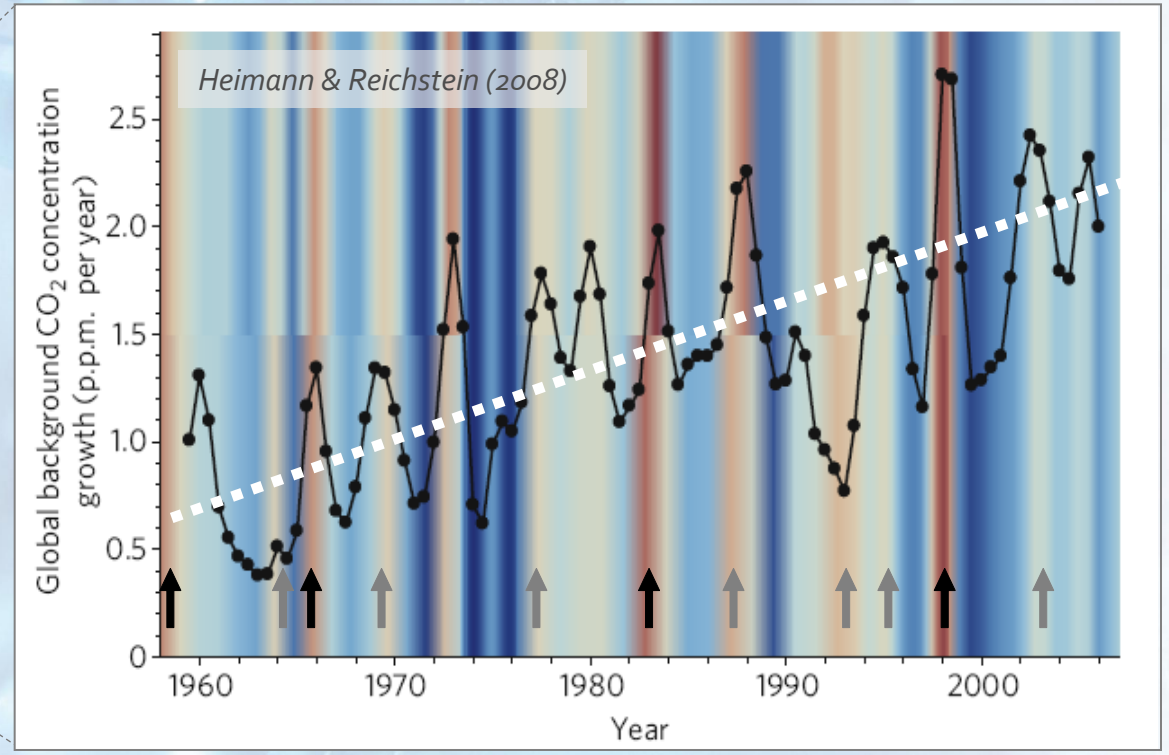
CLIMATE CHANGE: *rapidly increasing co_2*

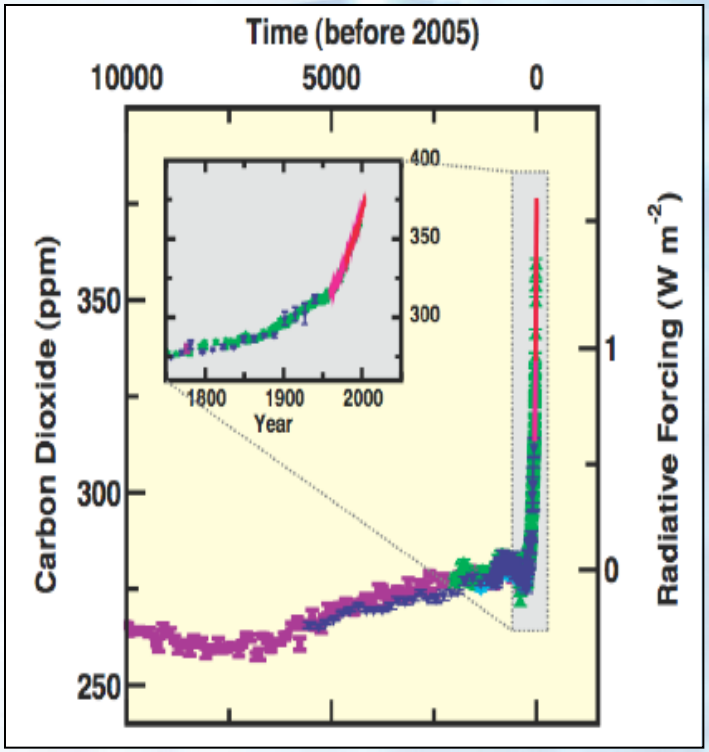


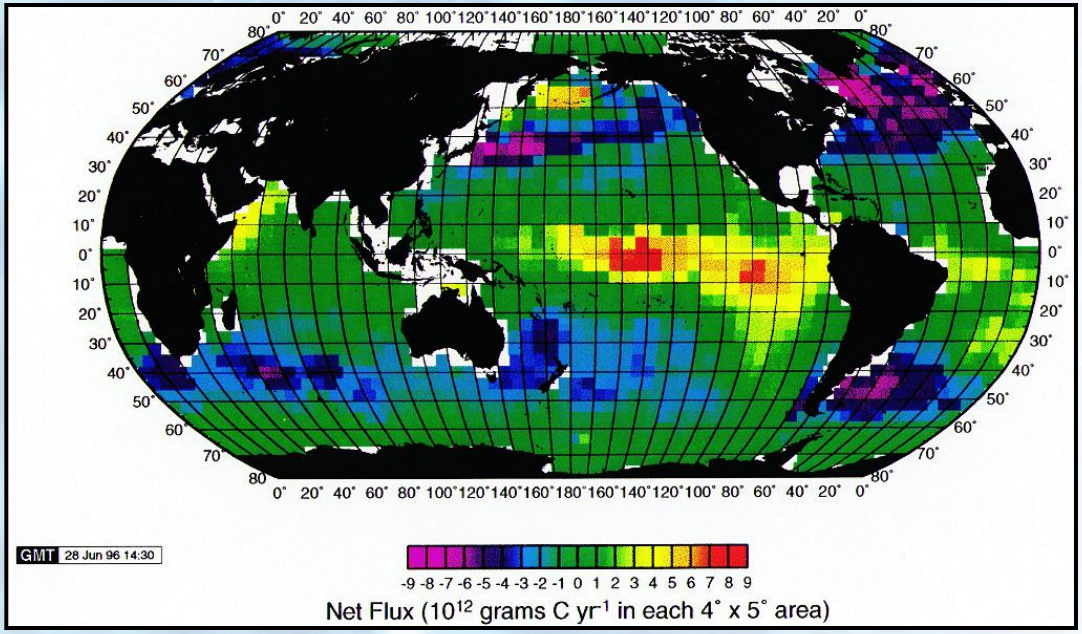


Rapid increase in CO_2 due to burning of fossil fuels

- rate of increase in CO2 unprecedented
- fossil fuel burning the major driver

THE OCEANS & CLIMATE CHANGE





Key Role of the Oceans:

- most important (30% to 40%) sink for heat & CO_2

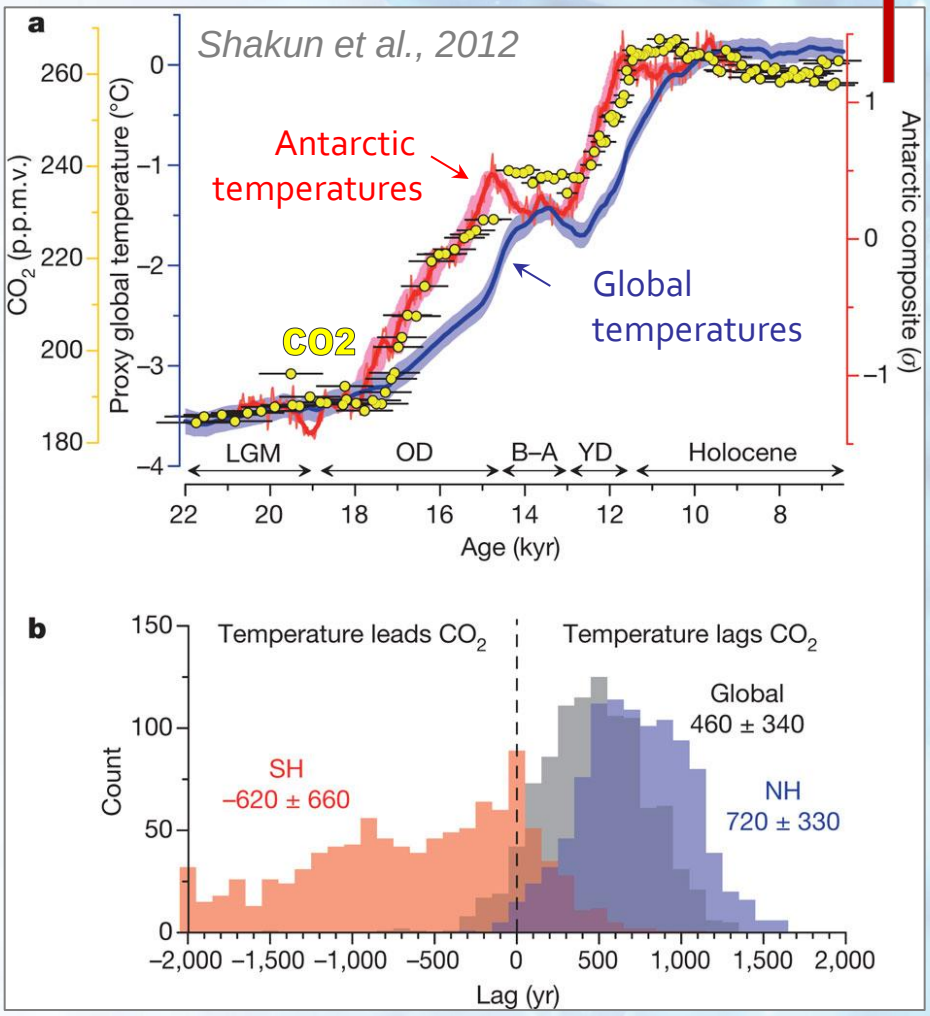
but at the cost of:

- increased sea level
- higher temperatures
- ocean acidification

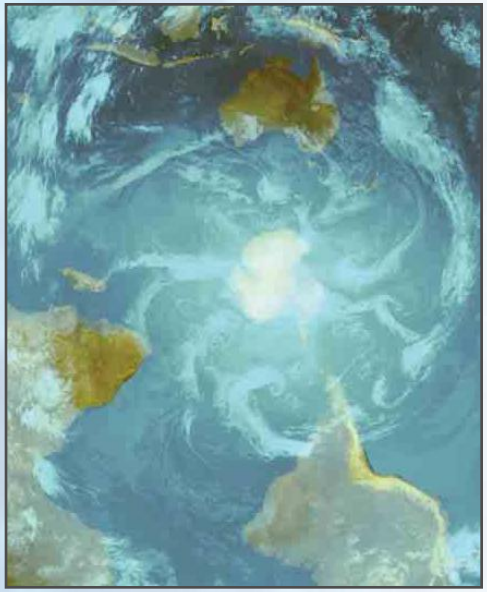
GLOBAL WARMING: *from the Last Ice-Age*

Present-day CO_2

Close link between rising CO2 & global warming



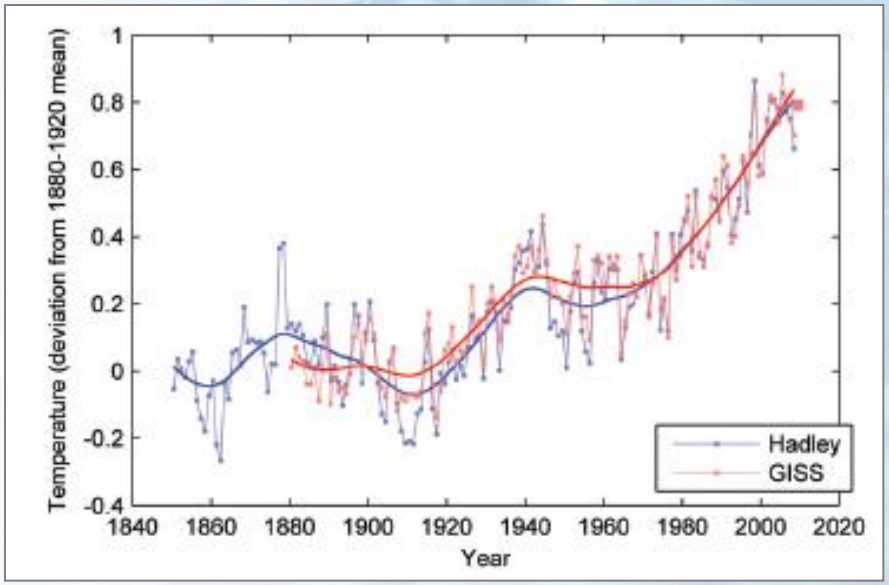
Antarctic view



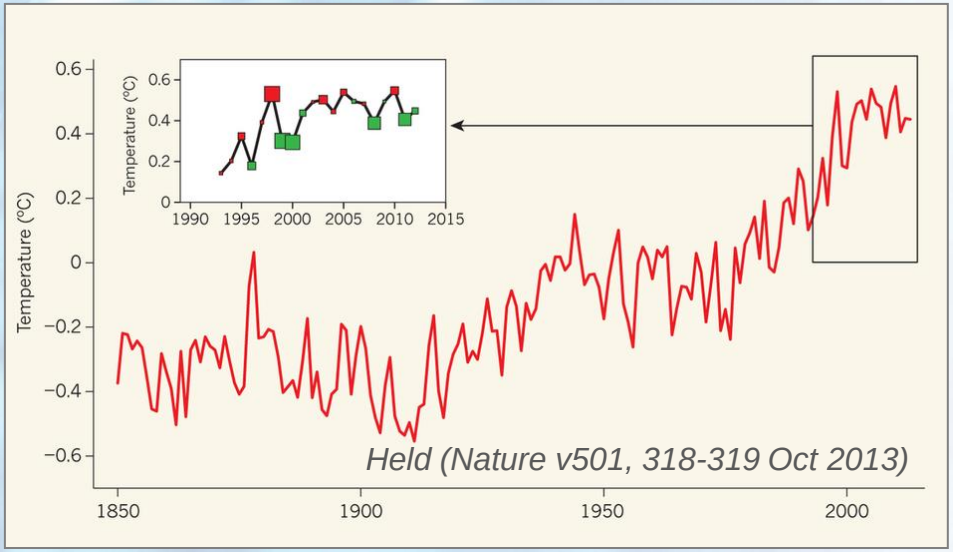
Last Deglaciation

- *S. Hemisphere orbital forcing initiates warming of Antarctic & **rise in CO2***
- *this drives changes in deep-ocean 'Atlantic' circulation, **hiatus** & further **rise in CO2***
- ***rising CO2** & N. Hemisphere orbital forcing causes global warming (Interglacial period)*

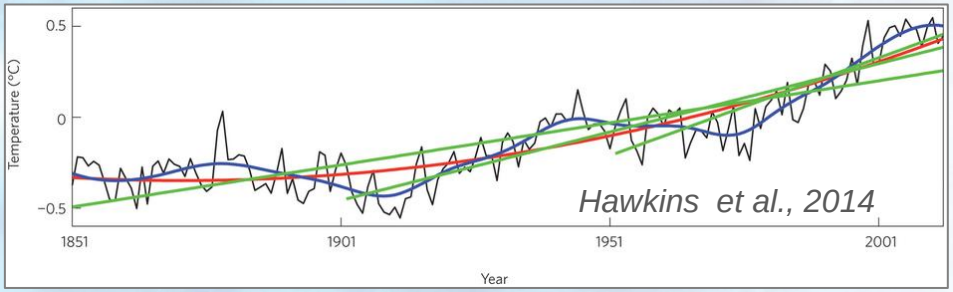
GLOBAL WARMING: *recent records*



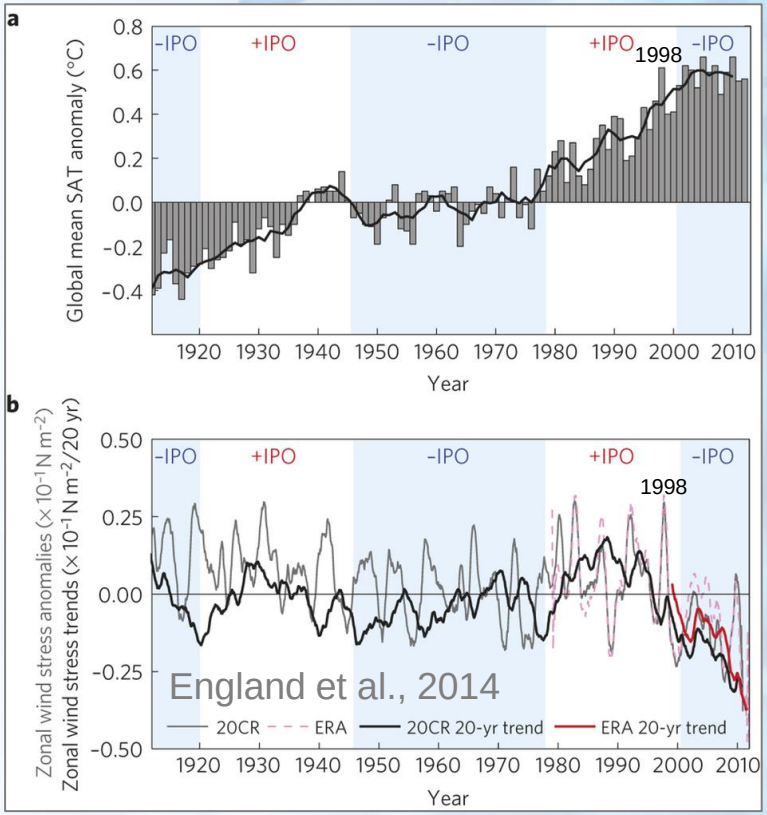
Hiatus in global temperatures during the last decade: *geologic record shows that this is not uncommon as the Earth warms*



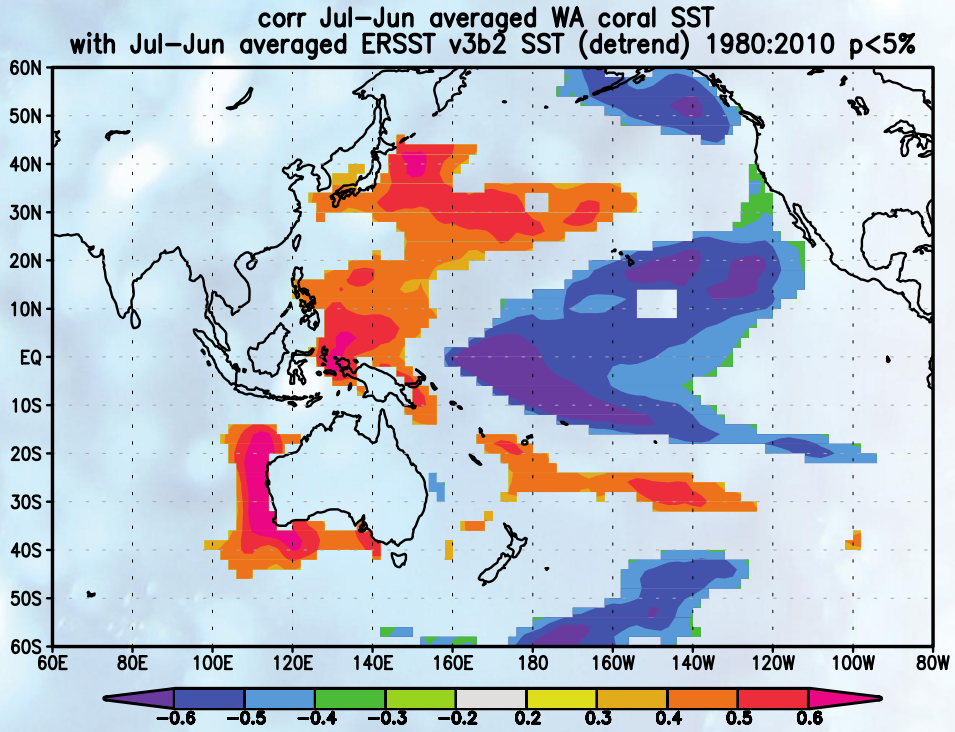
- The 2000 – 2010 decade is still the warmest yet recorded
- *Hiatus* is part of 'natural' variability but now superimposed upon anthropogenic warming
- Changing patterns of deep ocean circulation: ENSO, PDO implicated
  Kosaka et al. (2013), England et al.(2014), Huber & Knutti (2014)



GLOBAL WARMING: *recent records*



Strong control of La Nina phase on Western Australian marine heat-waves

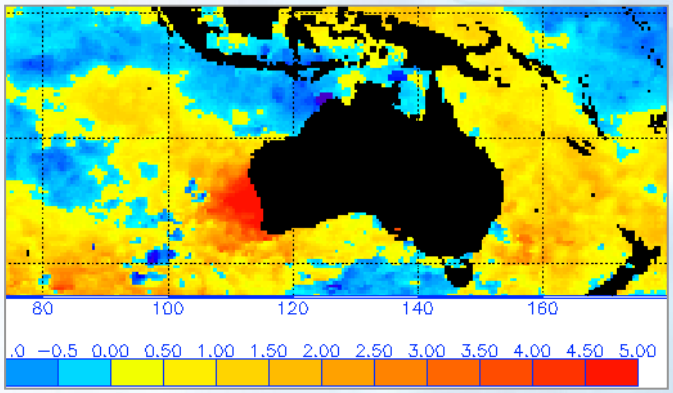


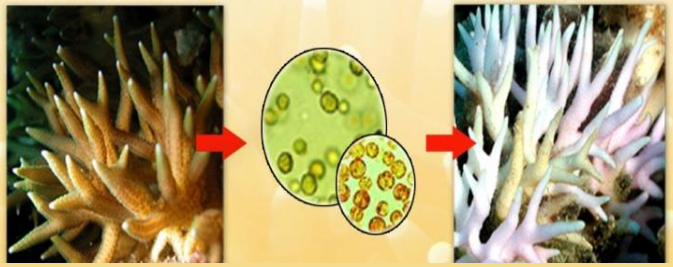
Jens Zinke et al., (Nature Communications 2014

- Strong control of IPO (PDO) & ENSO (El Nino v's La Nina) phases on global temperatures
- Hiatus likely a temporary respite due to dominance of La Nina phase (& cool PDO ?)

GLOBAL WARMING: *coral bleaching*

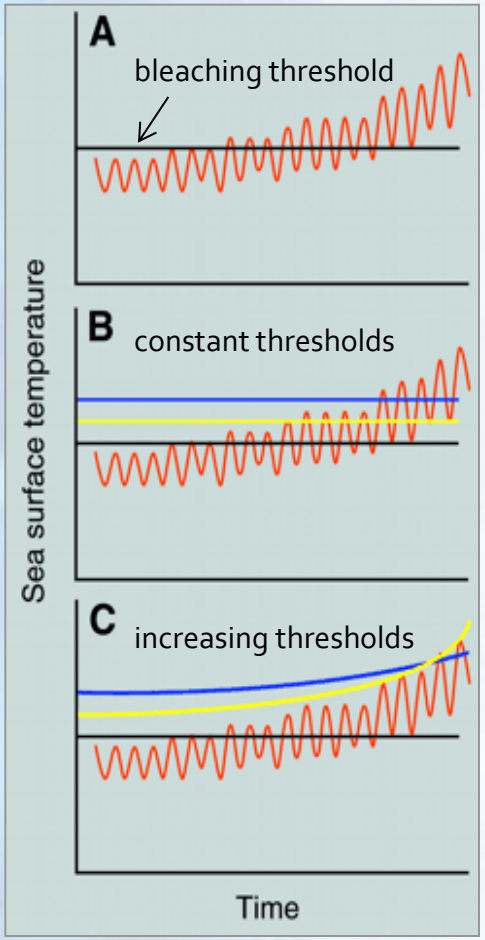
Example : 2011 La-Niña & coral bleaching along WA coast





Coral bleaching: loss of photosynthetic symbionts (zooxanthellae)

Hughes et al. (2003)



Feb-Mar 2011:

QUESTION:

- can corals adapt/acclimatise (ie increase resilience) to the combined effects of *rapid warming* & ocean acidification (OA) ?

  - eg response to return of even more intense '1998 El Nino' like conditions ?

OCEAN ACIDIFICATION

Carbonic acid produced as CO_2 dissolves in seawater:

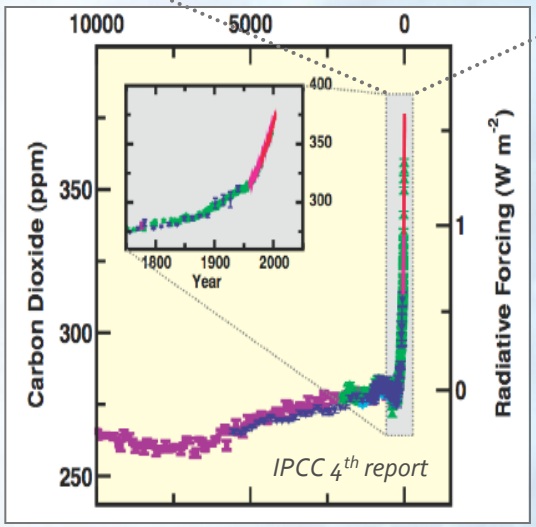
Atmosphere

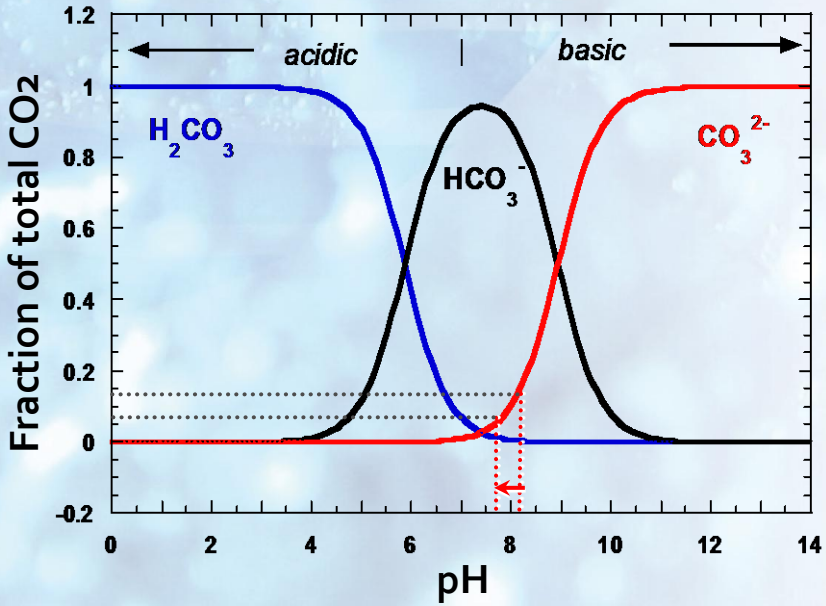
Seawater

CO_2 (aq) + H_2O ⟷ HCO_3^- + H^+

H^+ + CO_3^{2-} ⟷ HCO_3^-

CO_3^{2-} + Ca^{2+} ⟷ $CaCO_3$ (calcification)



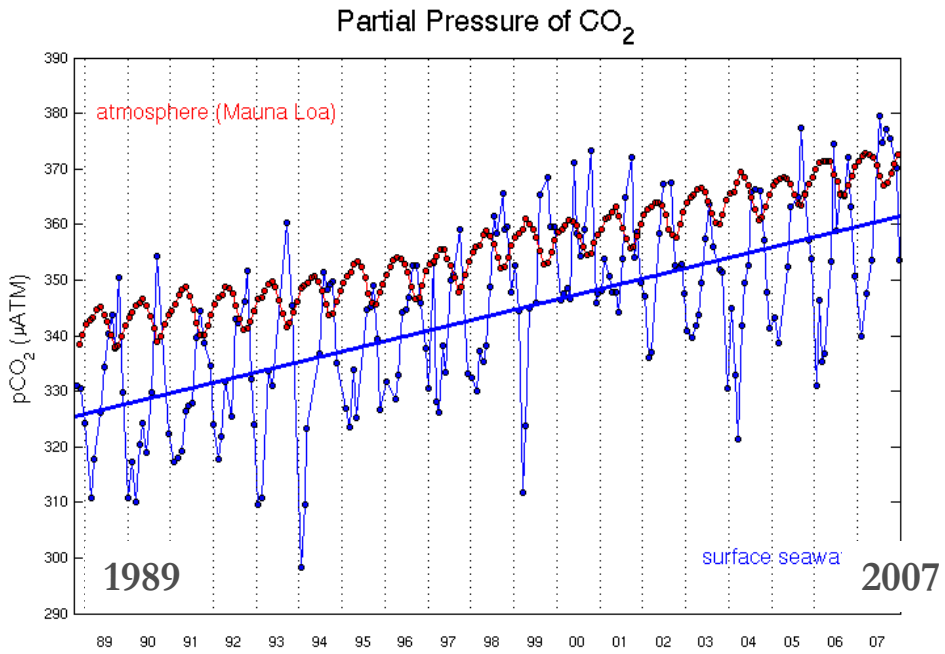


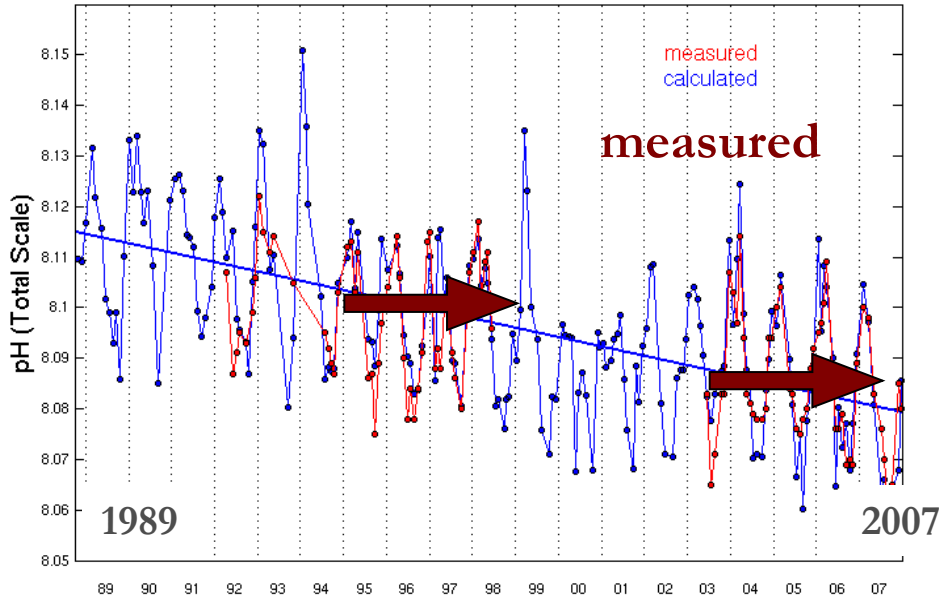
"Ocean Acidification"

	x1 CO_2	x2 CO_2
	280 ppm	560 ppm
HCO_3^-	1770	1870
CO_3^{2-}	225	140
*p*H	8.18	7.92

- decreasing seawater pH & carbonate saturation state ($\Omega \sim [Ca][CO_3^{2-}]/\kappa$) due to rising atmospheric CO2

Offshore Hawaii





OCEAN ACIDIFICATION:
in-situ measured records

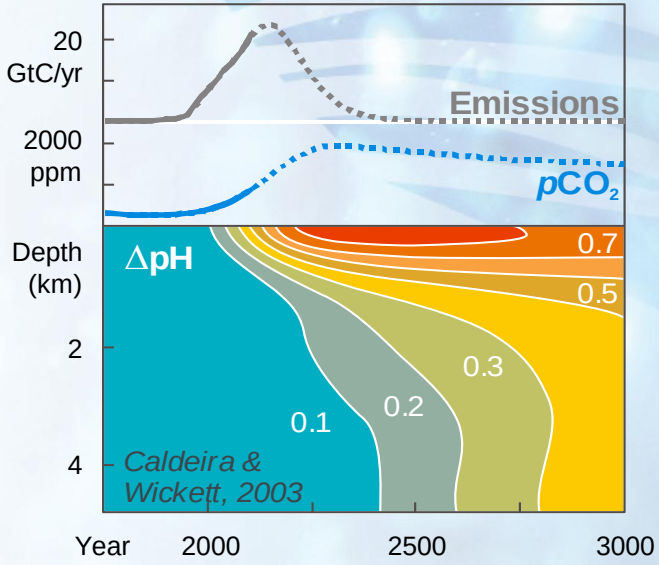
Instrumental Records:

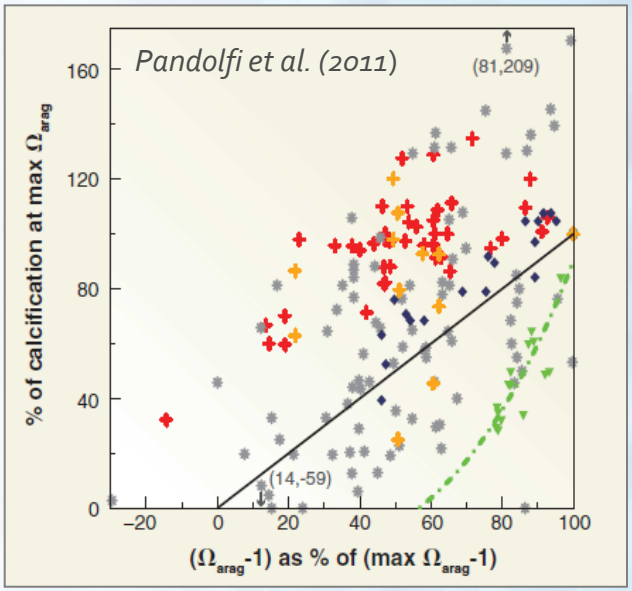
- Hawaiian Ocean Time Series (*HOTS*)
- Offshore Bermuda (*BATS*)

Records are limited duration (~*20 years*) & regionally restricted

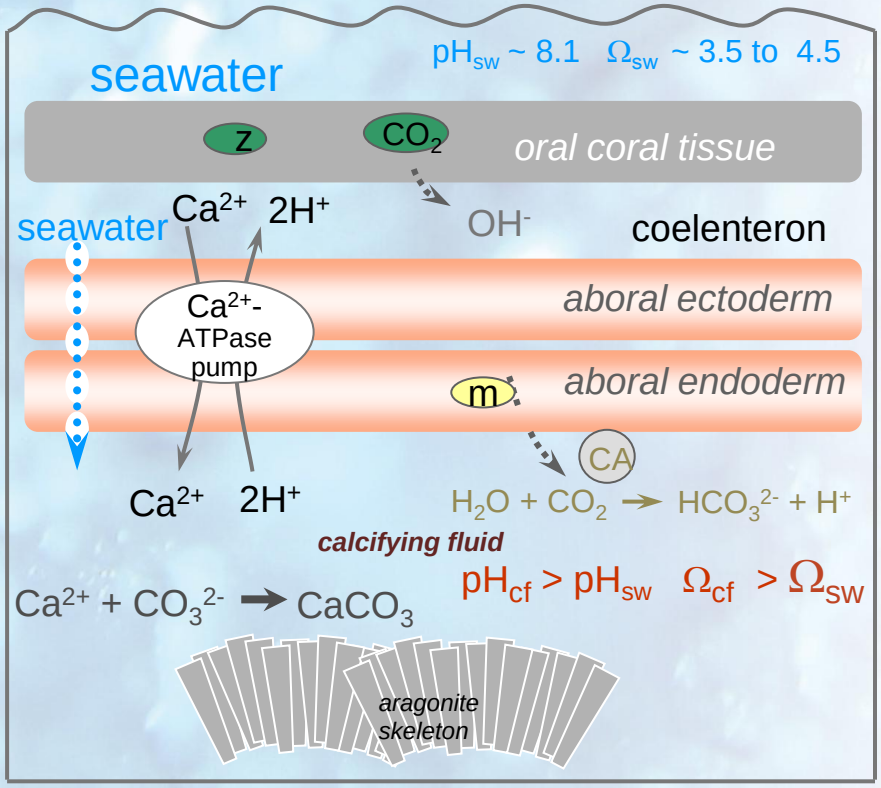
Urgent need for long-term records

OCEAN ACIDIFICATION: *coral response*



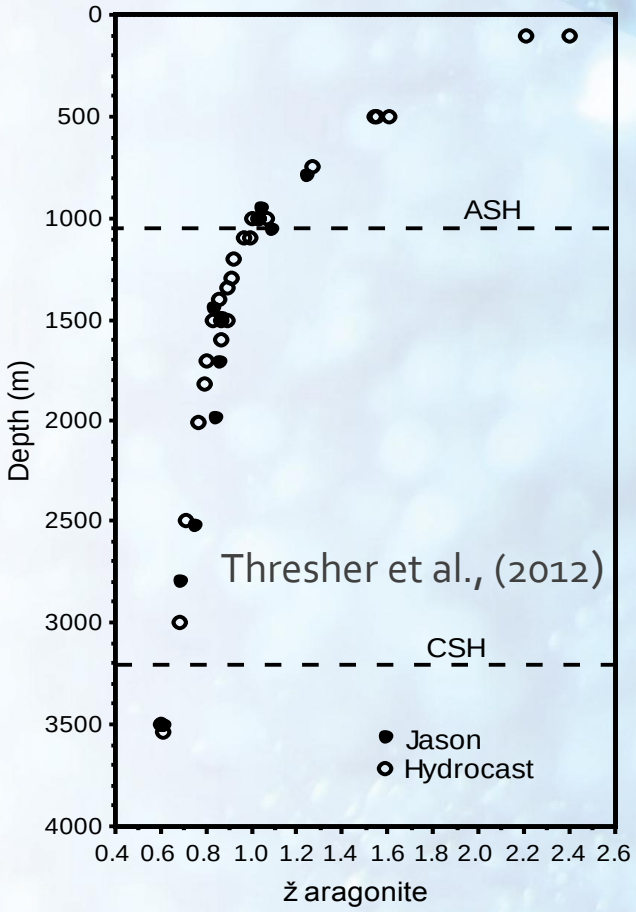


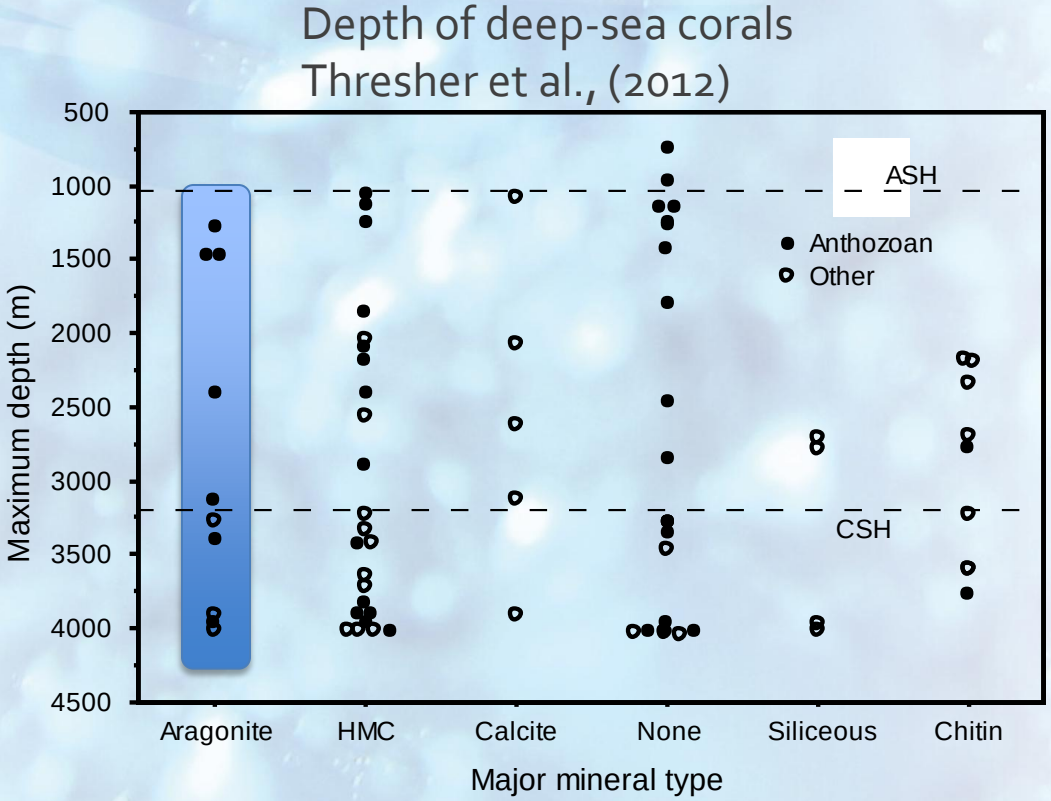
- Why is the response of coral calcification to saturation state so variable (*high & low sensitivity*)?
  - *better understanding of coral calcification processes needed*
  - *how does biogenic pH regulation work?*



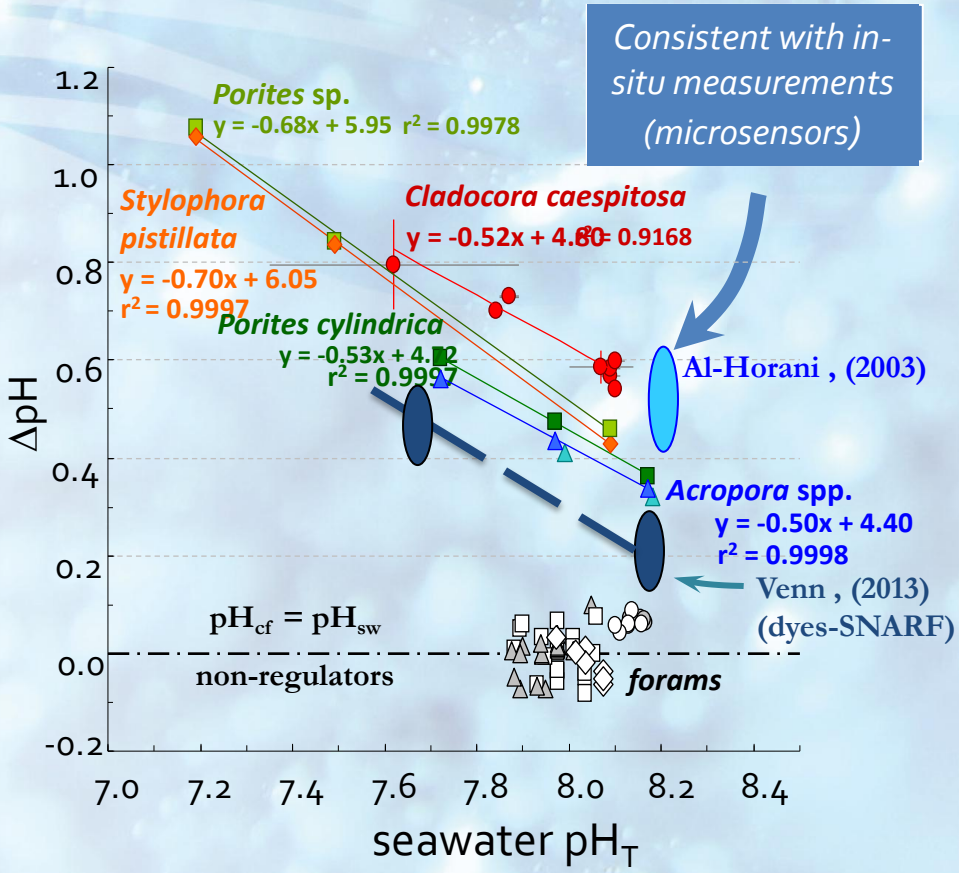
OCEAN ACIDIFICATION: *deep-sea corals*

- **pH up-regulation enables deep-sea (aragonite) corals to exist below the (aragonite) saturation horizon (ASH where Ω < 1)**





OCEAN ACIDIFICATION: *pH up-regulation*

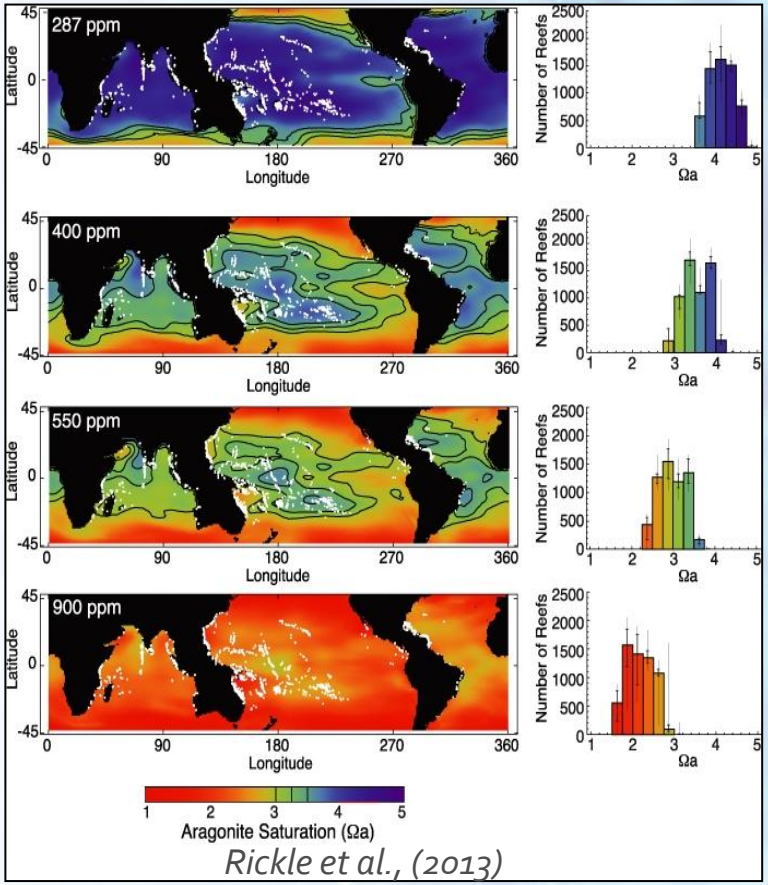


- biological regulation of internal pH in corals

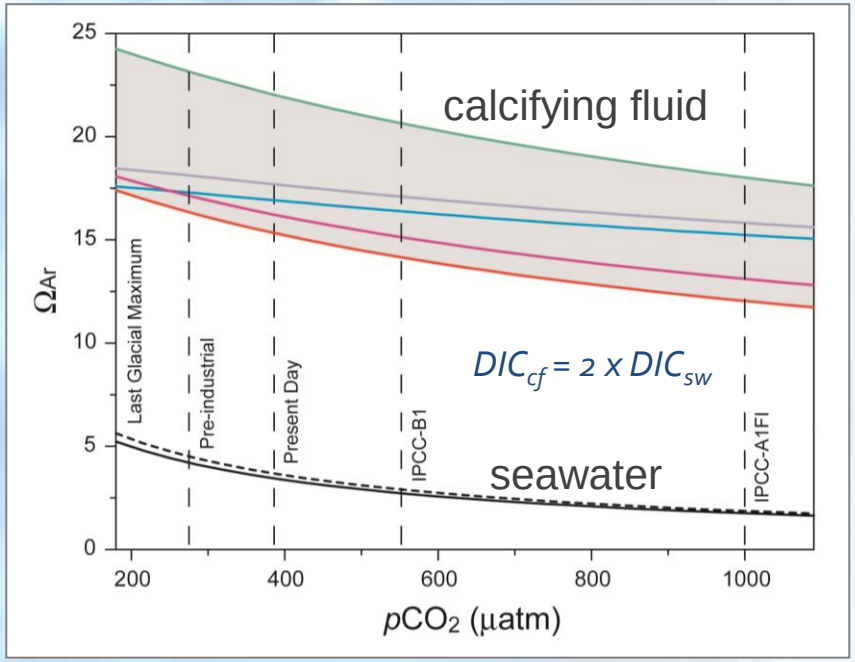
$$\Delta pH = pH_{calcifying\ fluid} - pH_{seawater}$$

OCEAN ACIDIFICATION: *saturation state*

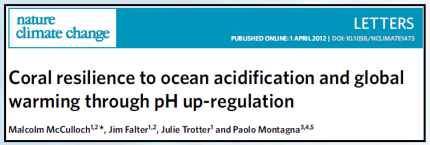
- decreasing saturation state (Ω) of surface waters due to rising CO_2
- partially countered during biogenic calcification by physiological up-regulation of calcifying fluid pH and hence (Ω_{cf})



Rickle et al., (2013)

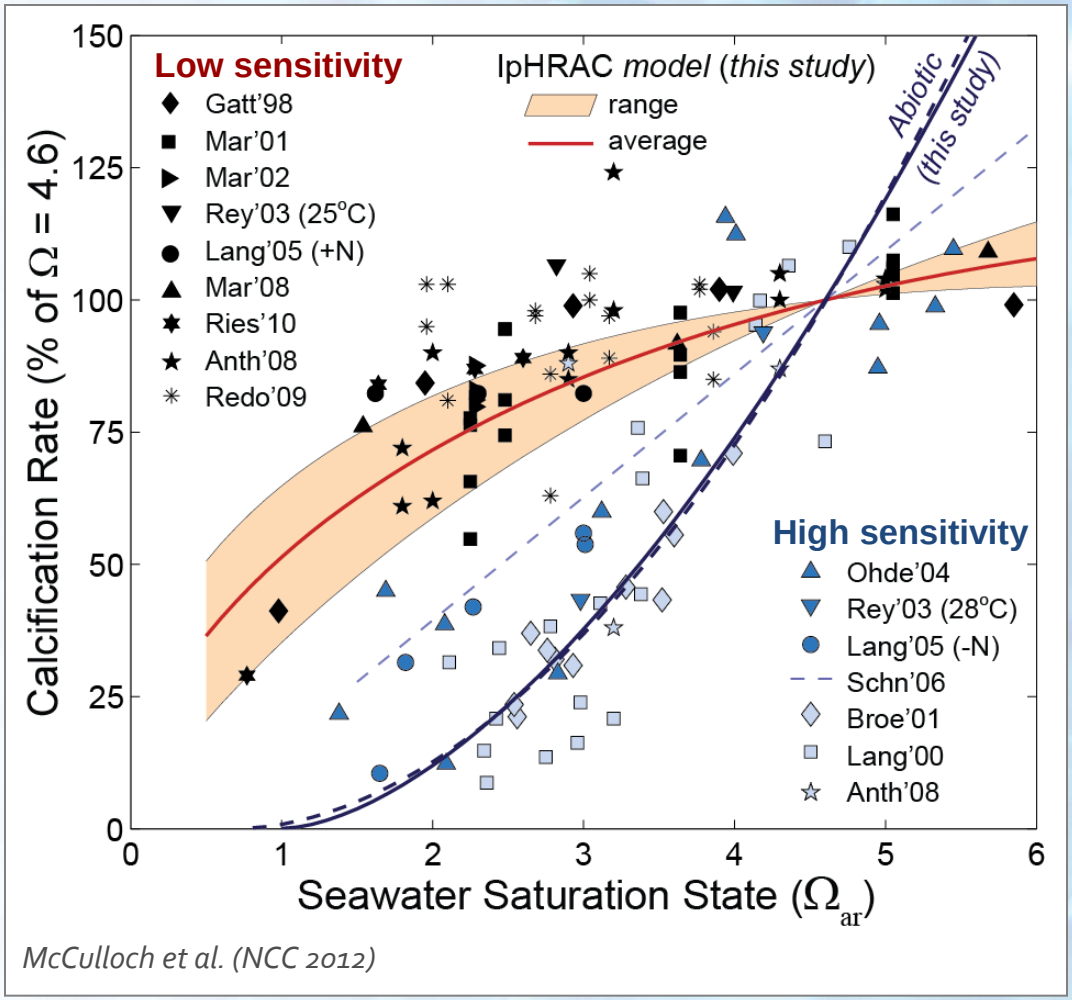


$$\Omega = [Ca^{2+}][CO_3^{2-}]/K_{sp}$$



UNDERSTANDING CORAL CALCIFICATION RATES

❖ Removing the confusion: *pH up-regulation & calcification*



McCulloch et al. (NCC 2012)

Internal **pH** **R**egulation **A**biotic **C**alcification: **IpHRAC** model

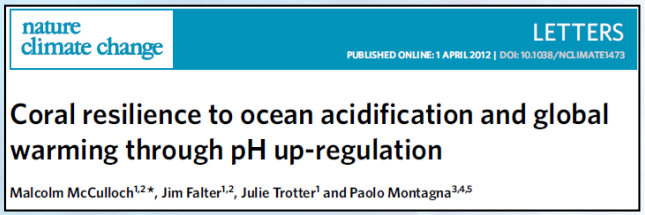
(*McCulloch et al. NCC, 2012*)

Abiotic Calcification rate:

$$G = k_T(\Omega_{cf} - 1)^{N_T}$$

Ω_{cf} is calcification fluid

K_T & N_T are temp (T) dependent


nature climate change

LETTERS

PUBLISHED ONLINE: 1 APRIL 2012 | DOI: 10.1038/NCLIMATE1473

Coral resilience to ocean acidification and global warming through pH up-regulation

Malcolm McCulloch[1,2]*, Jim Falter[1,2], Julie Trotter[1] and Paolo Montagna[3,4,5]

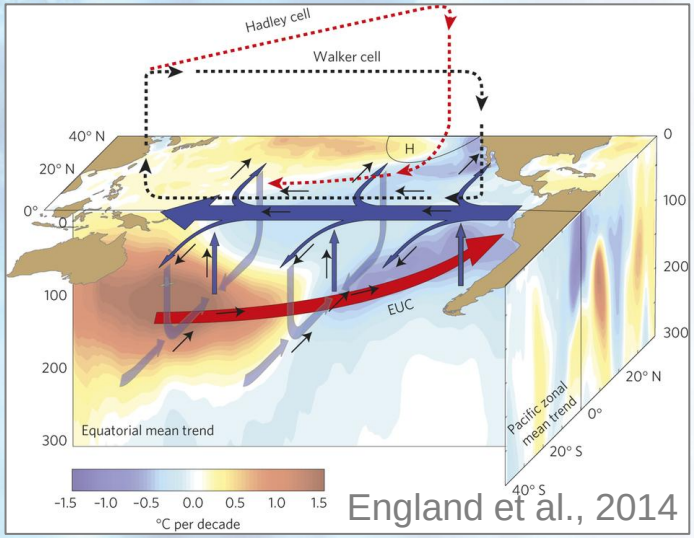
CHALLENGES: *The Oceans & Climate Change*

1. **Urgent need to understand causes of the hiatus in global warming & better predict future warming**
   - interactions between eg La Nina & cool IPO phases and
   - the role of **deep ocean** interactions on centennial, millennial timescales

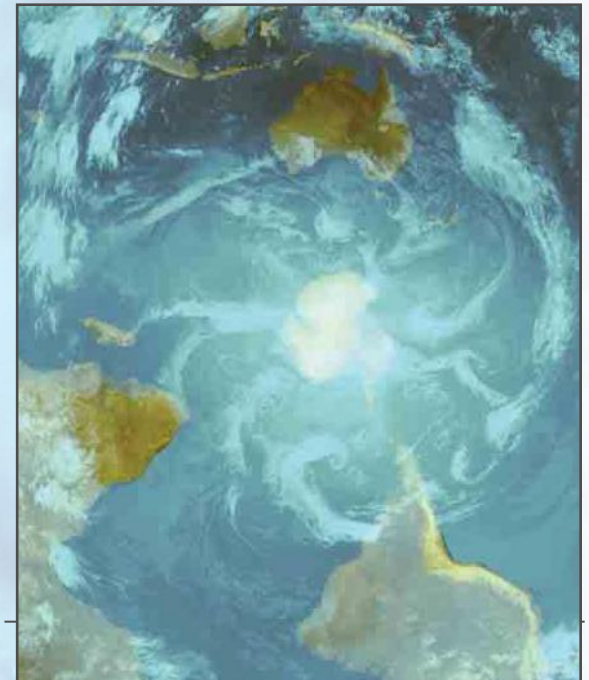
2. **Critical role of Antarctic wrt:**
   - instability of grounded ice-sheets & rapid (catastrophic) rise in sea levels
   - **deep-water** formation & global impacts

3. **Role of Pacific & Indian southern ocean deep-ocean circulation in modulating /controlling global climate change (not just N. Atlantic) ?**

4. **Response of marine biota (especially corals) to global warming and ocean acidification**
   - inherent resilience versus finite ability to adapt/acclimatise to rapid change



England et al., 2014



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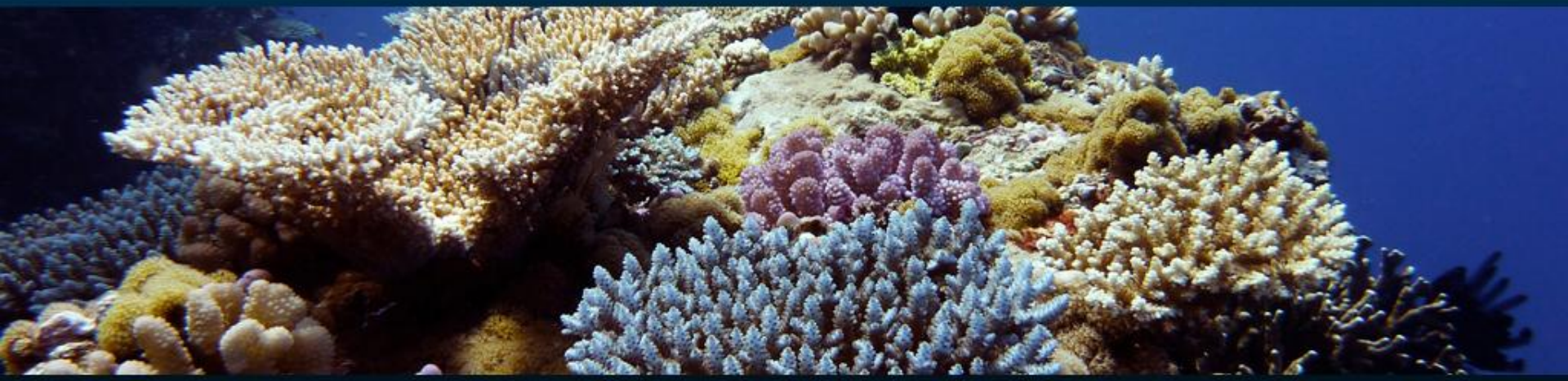

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