The Ocean in a High-CO_2 World-II

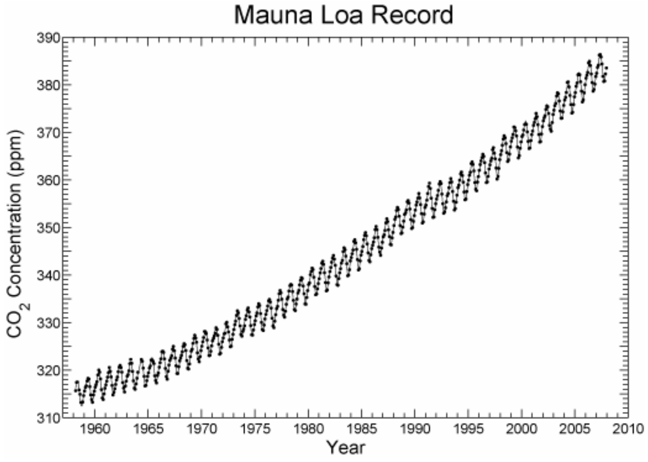
Biogeochemical Consequences of Ocean Acidification, and Feedbacks to the Earth System

Laurent Bopp (IPSL/LSCE, France)

Thanks to J. Orr, M. Gehlen, A. Lenton,
R. Gangsto, B. Schneider, C. Heinze, M. Vogt, A. Oeschlies, …

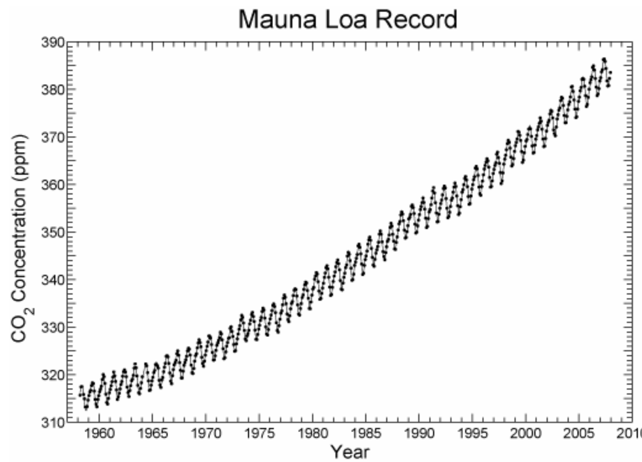
CARBOOCEAN EPOCA cnrs cea Sciences de l'environnement Institut Pierre Simon Laplace

Ocean Acidification and Climate Change



Atmospheric CO_2 Concentration (ppm)

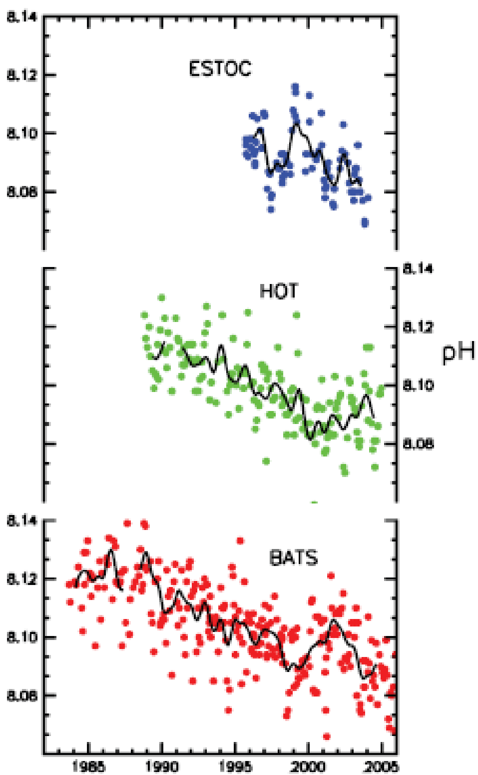
Ocean Acidification and Climate Change



Atmospheric CO_2 Concentration (ppm)

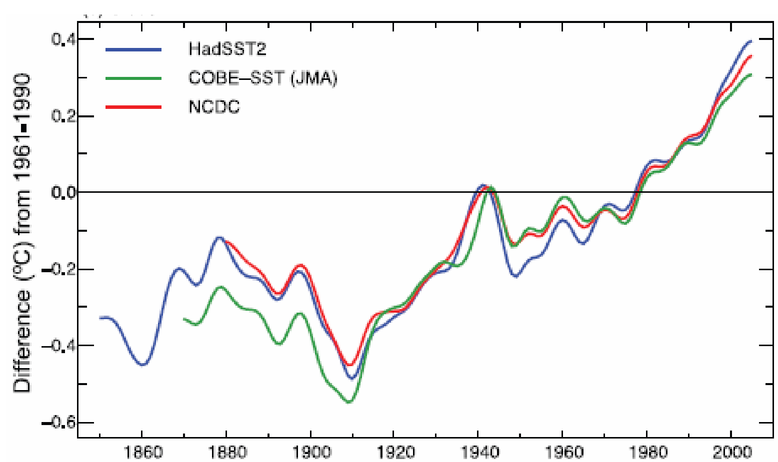
Ocean Acidification

Surface Ocean pH



“ The Other CO_2 Problem “

Climate Change



Surface Ocean Temperature (°C)

Ocean Acidification and Climate Change

Key question:

Can we consider Ocean Acidification & Climate Change separately?

Ocean Acidification and Climate Change

Key question:

Can we consider Ocean Acidification & Climate Change separately?

At organism or ecosystem-level:

(Some) studies combine changes in pH & changes in temperature / nutrients

But at global- or regional-level ?

Ocean Acidification and Climate Change

Key question:

Can we consider Ocean Acidification (OA) & Climate Change separately?

Part 1. Potential Consequences of OA on Climate Change?

- Air-Sea carbon fluxes and atmospheric pCO_2
- Marine emissions of nitrous oxide (N_2O)
- Marine emissions of dimethylsulfide (DMS)

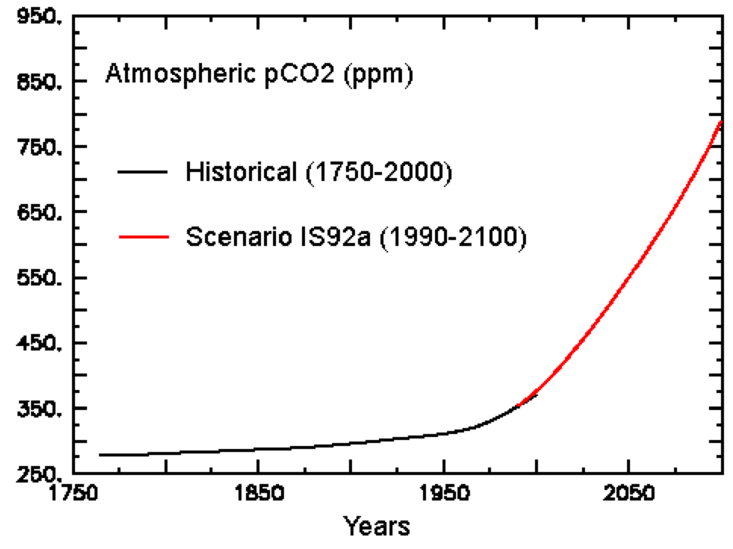
Part 2. Modulation of OA by Climate Change?

- Global picture
- 3 case studies : deep North Atlantic Ocean,
  Arctic Ocean, Southern Ocean

NB: Time-period considered here : Preindustrial to 2100

Impact of OA on Climate Change : CO_2

1 – Saturation of ocean carbon sink because of **carbonate chemistry**



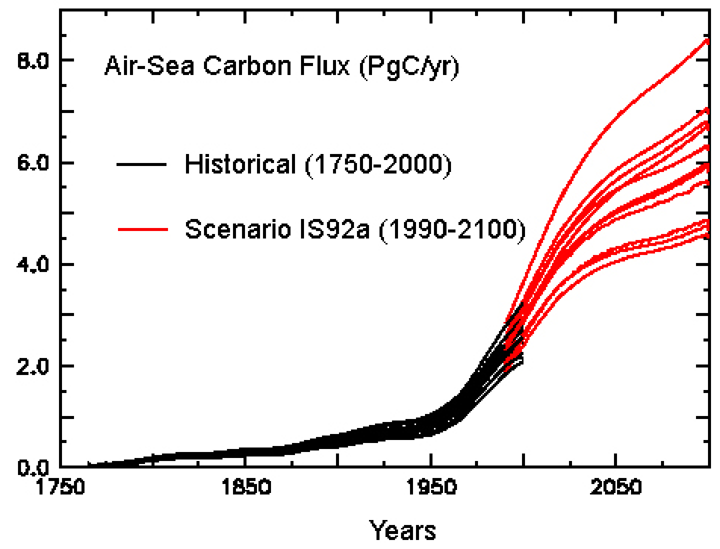
- Revelle factor from 10 in 2000 to 12.5 in 2100

$$R = (\delta pCO_2/\delta DIC) / (pCO_2/DIC)$$

(Revelle and Suess, 1957)

- Shown by ocean carbon models (cst biology)

(OCMIP-2 models, Orr et al. 2002)



⇒ Large positive effect on CO_2 and climate change

Impact of OA on Climate Change : CO_2

2 – Impact on **calcification** and feedback on atm. CO_2

- In global ocean biogeochemical models,
  - (pelagic) calcification represented in a very simplistic way
  - in most models, no impact of [CO_3^{2-}] on calcification

Impact of OA on Climate Change : CO_2

2 – Impact on **calcification** and feedback on atm. CO_2

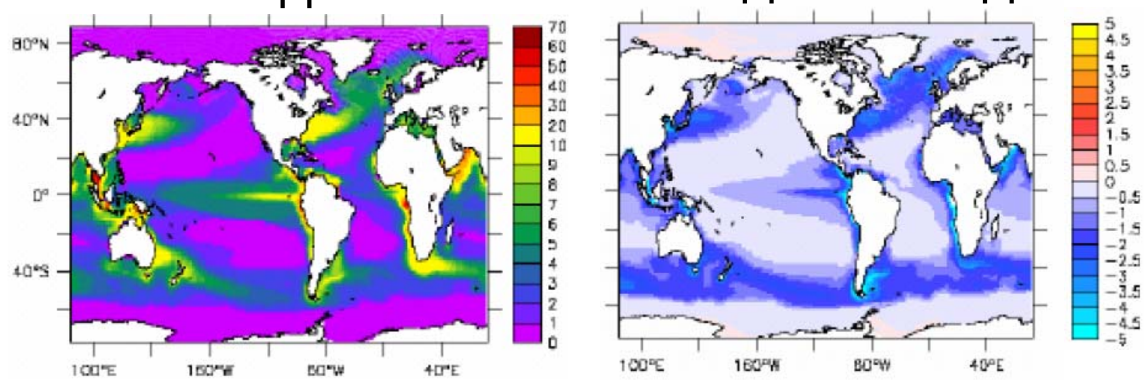
- In global ocean biogeochemical models,
  - (pelagic) calcification represented in a very simplistic way
  - in most models, no impact of $[CO_3^{2-}]$ on calcification

- In a few studies, $P_{CaCO3} = f(CO_3^{2-})$ [for all : P_{CaCO3} ↘ if CO_3^{2-} decrease…]
  Heinze (2004), Gehlen et al. (2007), Gangsto et al. (2008), …

Pelagic Calcification

286 ppm

1144 ppm – 286 ppm



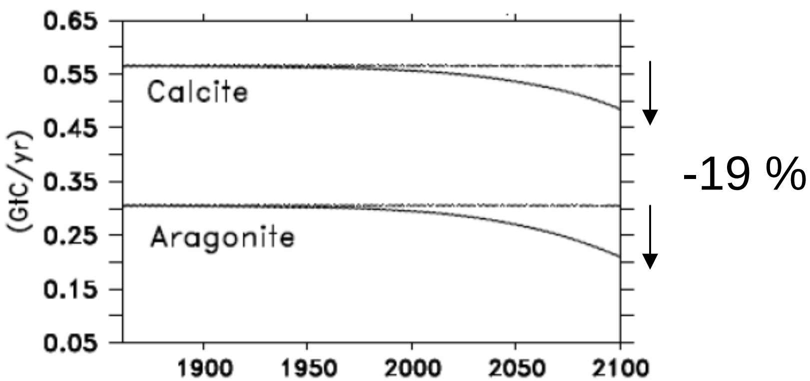
Gehlen et al. 2007

Impact of OA on Climate Change : CO_2

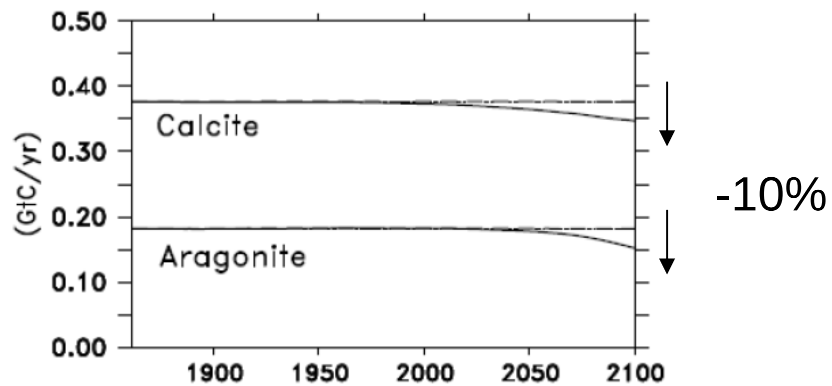
2 – Impact on **calcification** and feedback on atm. CO_2

- Reduced calcification & reduced dissolution of $CaCO_3$

Calcification



Dissolution



(Gangsto et al. 2008)

- Impact on air-sea C fluxes and atmospheric pCO_2

Gehlen et al. 2007 : excess ocean uptake of **6 GtC** (at 1144 ppm)
Heinze 2004 : reduced atm. pCO2 by **10 ppm** (at 1413 ppm)

⇒ (Low) Negative effect on CO_2 and climate change

(if increased calcification with reduced CO_3, low positive effect…)
(conclusion only valid for time scales investigated here)

Impact of OA on Climate Change : CO_2

3 – Impact on **organic matter** export production (already reviewed by Ulf)

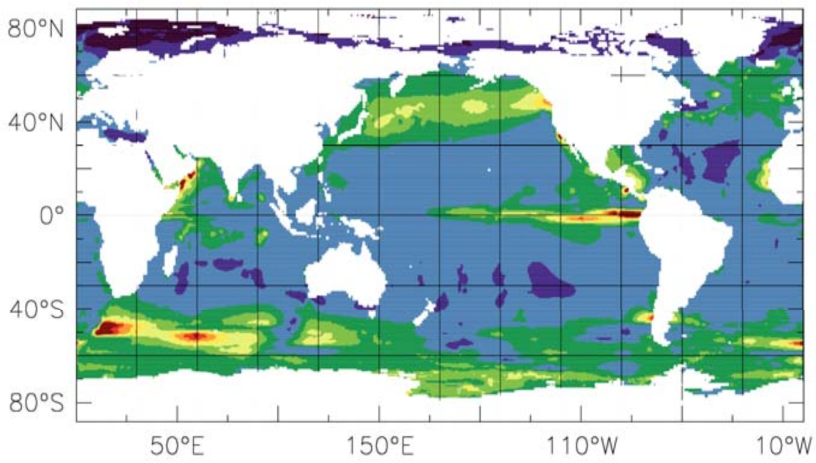
- Ballast effect (Klaas and Archer, 2002, Heinze, 2004)
  => export ↘ => (small) positive effect on CO_2 & CC
- C/N ratio in organic matter (Riebesell et al. 2007, Oeschlies et al. 2008)
  => export ↗ => (small) negative effect
- Metal (Fe) speciation (Eike's talk) => export ↗ => (??) negative effect
- N_2-fixation (Barcelo e Ramos et al. 2007)
  => export ↗ => (??) negative effect
- Other effects…

⇒ ??? effect on CO_2 and climate change

Impact of OA on Climate Change : N_2O

- The ocean is a natural source of N_2O to the atmosphere of 1.8 – 5.8 TgN y^{-1}

(total anthropogenic source : 6.7 TgN y^{-1})



N_2O Flux   mgN/m2/yr

(Nevison et al., 2005)

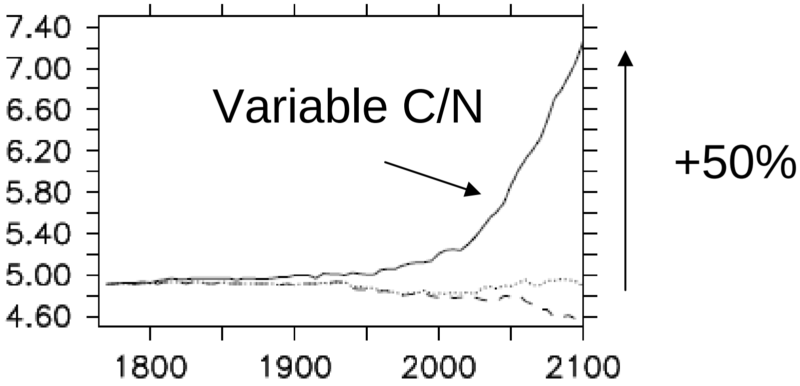
Impact of OA on Climate Change : N_2O

- The ocean is a source of N_2O to the atmosphere of 1.8 – 5.8 TgN y^{-1}

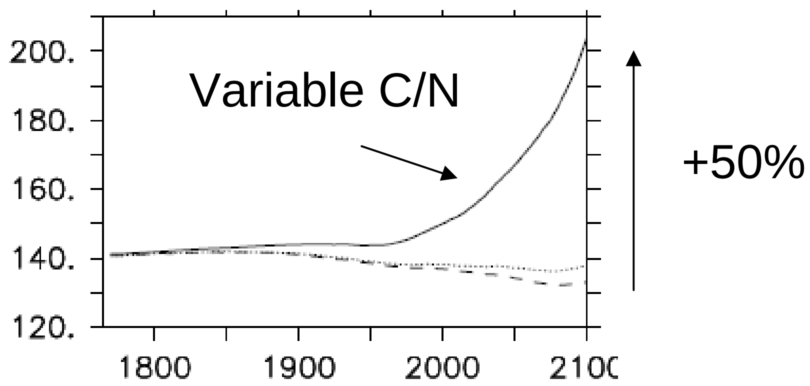
(total anthropogenic source : 6.7 TgN y^{-1})

- OA could increase suboxic water volume & denitrification (Oeschlies et al. in press)

Suboxic Volume



Denitrification



- Emissions of N_2O ?: likely to increase…

⇒ Positive effect on N_2O and climate change

Impact of OA on Climate Change : DMS

- The ocean is a source of dimethylsulfide (DMS) to the atmosphere : ~ 20 TgS y-1

(DMS – Cloud Condensation Nuclei – Radiative Forcing, Charlson et al. 1987)

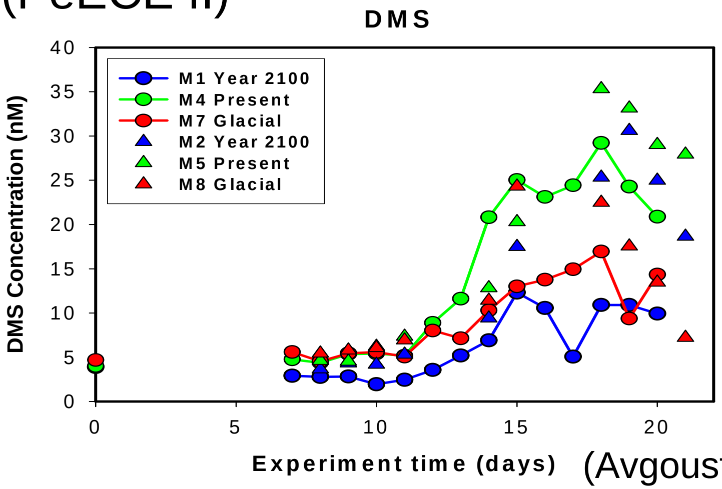
Impact of OA on Climate Change : DMS

- The ocean is a source of dimethylsulfide (DMS) to the atmosphere : ~ 20 TgS y-1

(DMS – Cloud Condensation Nuclei – Radiative Forcing, Charlson et al. 1987)

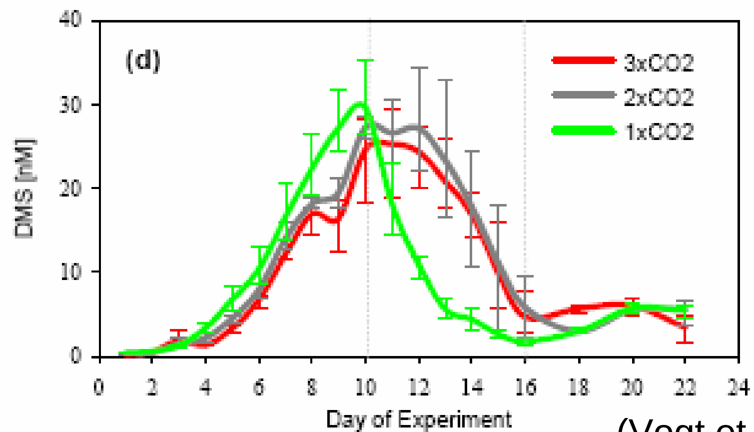
- Only information from mesocosm studies…but very contradictive

(PeECE II)



(Avgoustidi et al unpubl.)

(PeECE III)



(Vogt et al. 2008)

DMS $_{\text{present}}$ > DMS $_{\text{2100 or Glacial}}$

DMS $_{\text{2 or 3xCO2}}$? DMS $_{\text{1xCO2}}$

Mechanisms : phyto. community, bacteria, viruses, …

(see talk by F. Hopkins)

Impact of OA on Climate Change : Summary

Part I

- CO_2 : chemistry : large positive effect on atm. CO_2 and climate change
  calcification : negative effect
  organic matter : positive (C/N, Fe, N-fix) and negative (ballast) effects

- N_2O : positive effect on atm. N_2O and climate change

- DMS : no consistent response..

NB: Time-period considered here : Preindustrial to 2100

Modulation of Ocean Acidification by Climate Change

The Global Picture:

- Climate change => ↘ carbon sinks => ↗ atm. pCO2 => more acidification…

(Friedlingstein et al. 2006) (Plattner's talk earlier this week)

[depends on the partitioning between land and ocean carbon sinks]

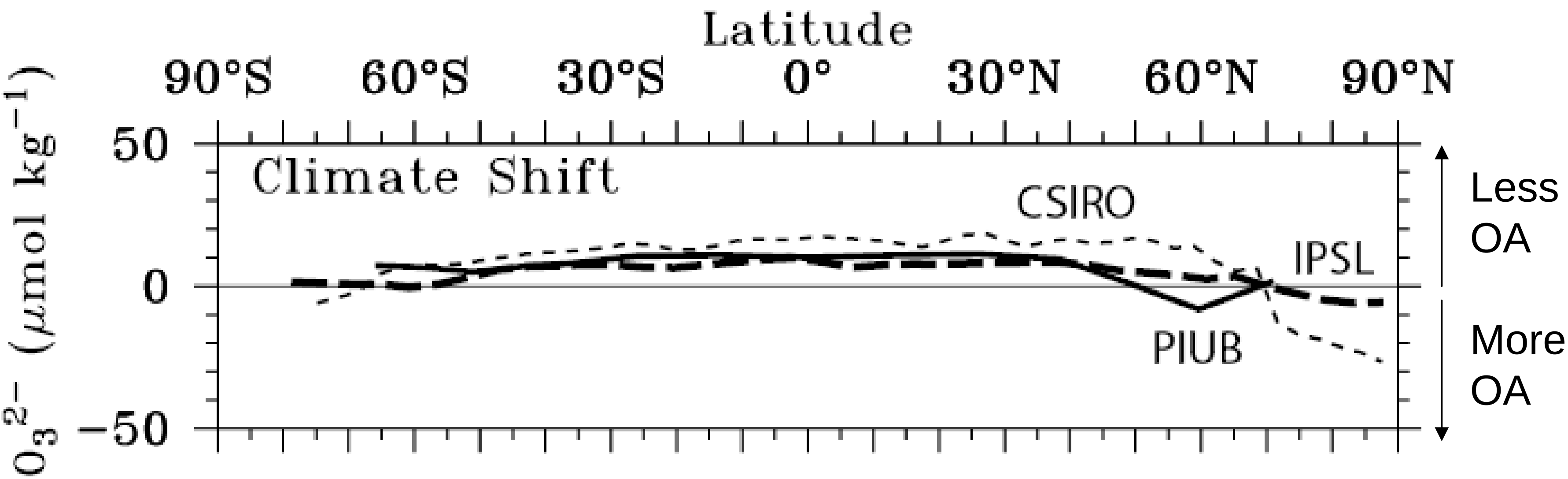
Modulation of Ocean Acidification by Climate Change

The Global Picture:

- Climate change => ↘ carbon sinks => ↗ atm. pCO2 => more acidification…

(K. Plattner's talk earlier this week)

- But … ↘ ocean carbon sink and warmer ocean => less acidification….



Change in CO_3^{2-} bewteen 2100 and PI (Orr et al. 2005)

Modulation of Ocean Acidification by Climate Change

The Global Picture:

- Climate change => ↘ carbon sinks => ↗ atm. pCO2 => more acidification…

(Plattner's talk earlier this week)

- But … ↘ ocean carbon sink and warmer ocean => less acidification….

"Therefore, our analysis suggests that physical climate change alone will not substantially alter high-latitude surface CO_2 during the twenty-first century".

(Orr et al. 2005)

Modulation of Ocean Acidification by Climate Change

3 case studies:

- Deep waters of the North Atlantic Ocean (See Poster by Gehlen et al.)

- Surface waters of the Arctic Ocean (Orr et al. subm + Poster)

- Surface waters of the Southern Ocean (Lenton et al. subm)

Modulation of Ocean Acidification by Climate Change

3 case studies:

-1- Deep waters of the North Atlantic Ocean (See Poster by Gehlen et al.)

Changes in deep-water pH from IPSL coupled carbon-climate model in 2100

: included both ocean acidification and climate change
: pH decreases by more than 0.2 for 50% of NA seabed in 2100 (A2)

Modulation of Ocean Acidification by Climate Change

3 case studies:

-1- Deep waters of the North Atlantic Ocean (See Poster by Gehlen et al.)

=> Climate change reduces OA

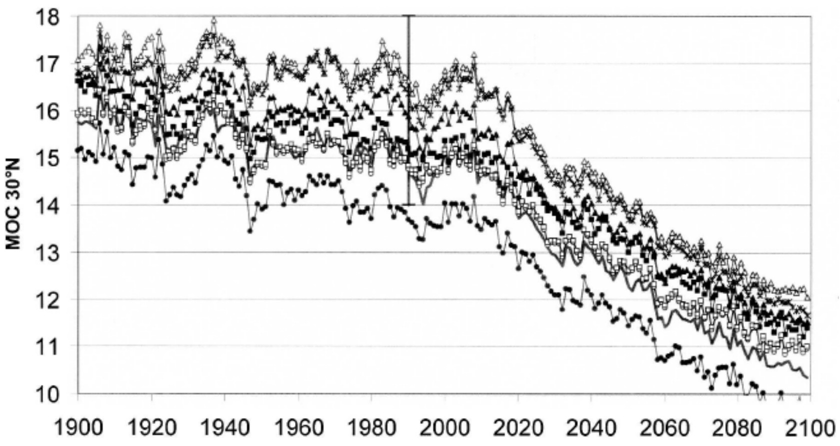
(25 % discount !)

Modulation of Ocean Acidification by Climate Change

3 case studies:

-1- Deep waters of the North Atlantic Ocean (See Poster by Gehlen et al.)

Mechanisms :
Reduced deep water formation…



(Schneider et al. 2007)

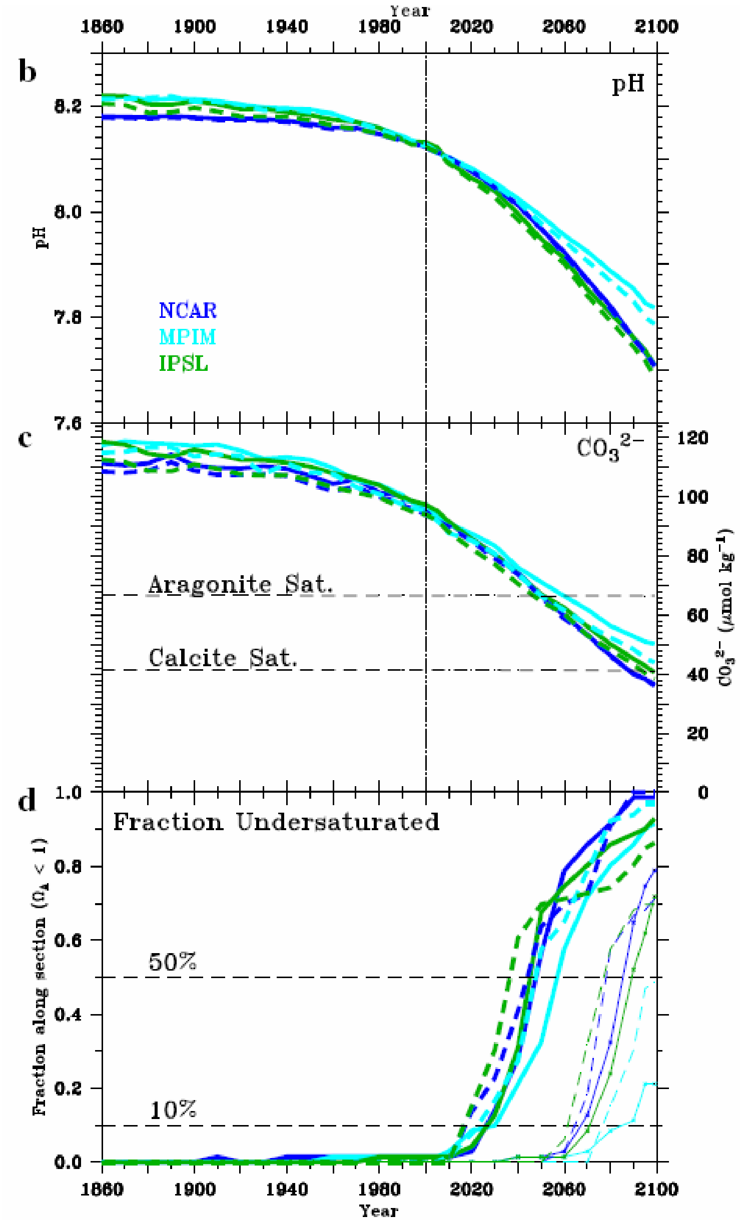
⇒ **Climate change reduces OA**

Modulation of Ocean Acidification by Climate Change

3 case studies:

-2- Surface waters
of the Arctic Ocean (Orr et al. subm)

3 Coupled models: NCAR, MPIM, IPSL

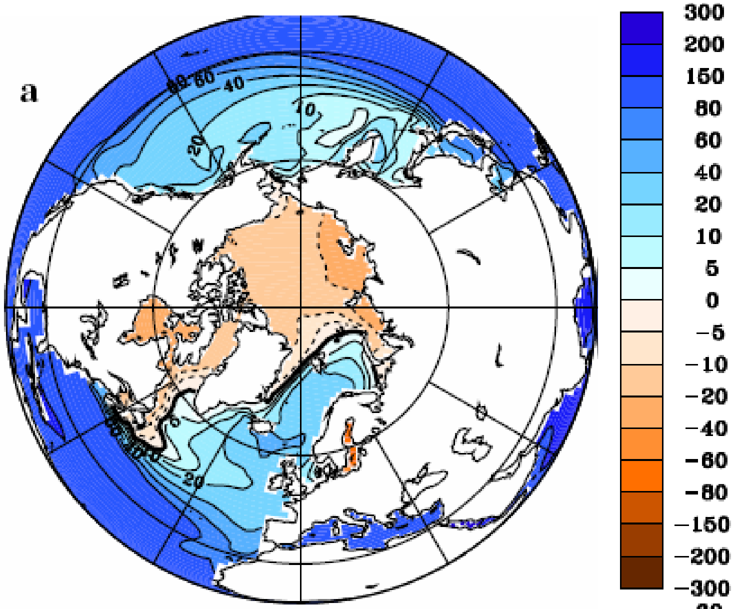


Modulation of Ocean Acidification by Climate Change

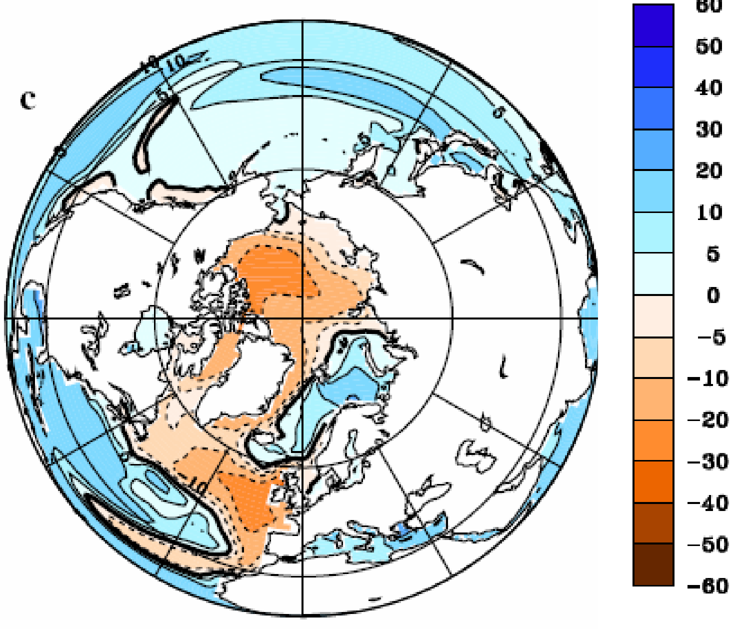
3 case studies:

-2- Surface waters
of the Arctic Ocean (Orr et al. subm, + poster)

ΔCO_3^{2-} at $2xCO_2$
(567 ppm)



Climate Change effect on $[CO_3^{2-}]$



Mechanisms: freshwater input,
sea ice melting
stratification, …

⇒ **Climate change amplifies OA (by > 10%)**

Modulation of Ocean Acidification by Climate Change

3 case studies:

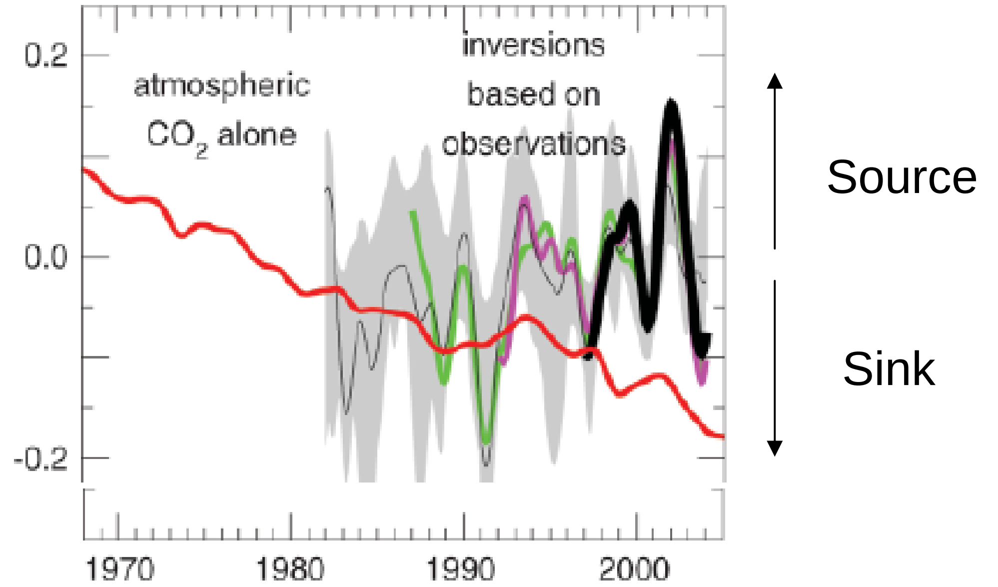
-3- Surface waters of the Southern Ocean (Lenton et al. subm)

-Le Quéré et al. 2007:

Increased winds over 1980-2004

↓

Less carbon uptake in the SO



Net Carbon Flux (South of 40°S, GtC/yr)

Modulation of Ocean Acidification by Climate Change

3 case studies:

-3- Surface waters of the Southern Ocean (Lenton et al. subm) [last 25 yrs]

- IPSL Coupled model: Ensemble runs with/without stratospheric O_3 over last 25 yr

With O_3 decrease:

→ - stronger winds
- less carbon uptake

(consistent with Le Quéré 2007
& Takahashi / Metzl 2008 data)

Question: Less uptake => less acidification ?

Modulation of Ocean Acidification by Climate Change

3 case studies:

-3- Surface waters of the Southern Ocean (Lenton et al. subm) [last 25 yrs]

… More Acidification with O_3 ↘ …. Because more natural DIC is upwelled…

$\Rightarrow$ **Climate change (stronger winds in SO) amplifies OA**

Ocean Acidification and Climate Change

Part I

- CO_2 : chemistry : large positive effect on atm. CO_2 and climate change
  calcification : negative effect
  organic matter : positive (C/N, Fe, N-fix) and negative (ballast) effects

- N_2O : positive effect on atm. N_2O and climate change

- DMS : no consistent response..

Part II

- Climate change effect on OA : globally, **not 1st order**

- But regionally, may have a strong effect on pH and $[CO_3^{2-}]$

  - by increasing / reducing air-sea carbon flux
  - by redistributing DIC, Alkalinity in the ocean

OA and CC need to be considered together