

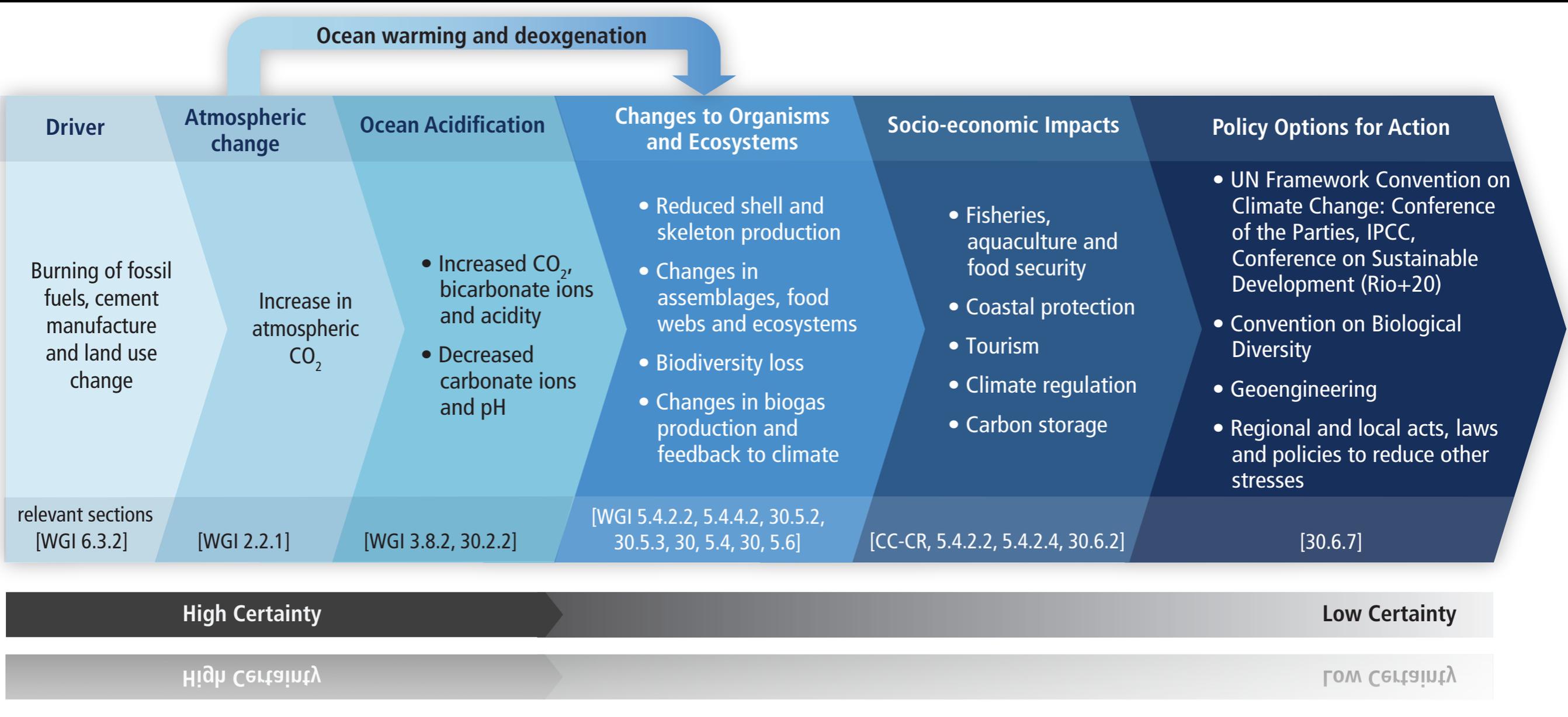
Acidification des océans, causes, conséquences et solutions

Jean-Pierre Gattuso

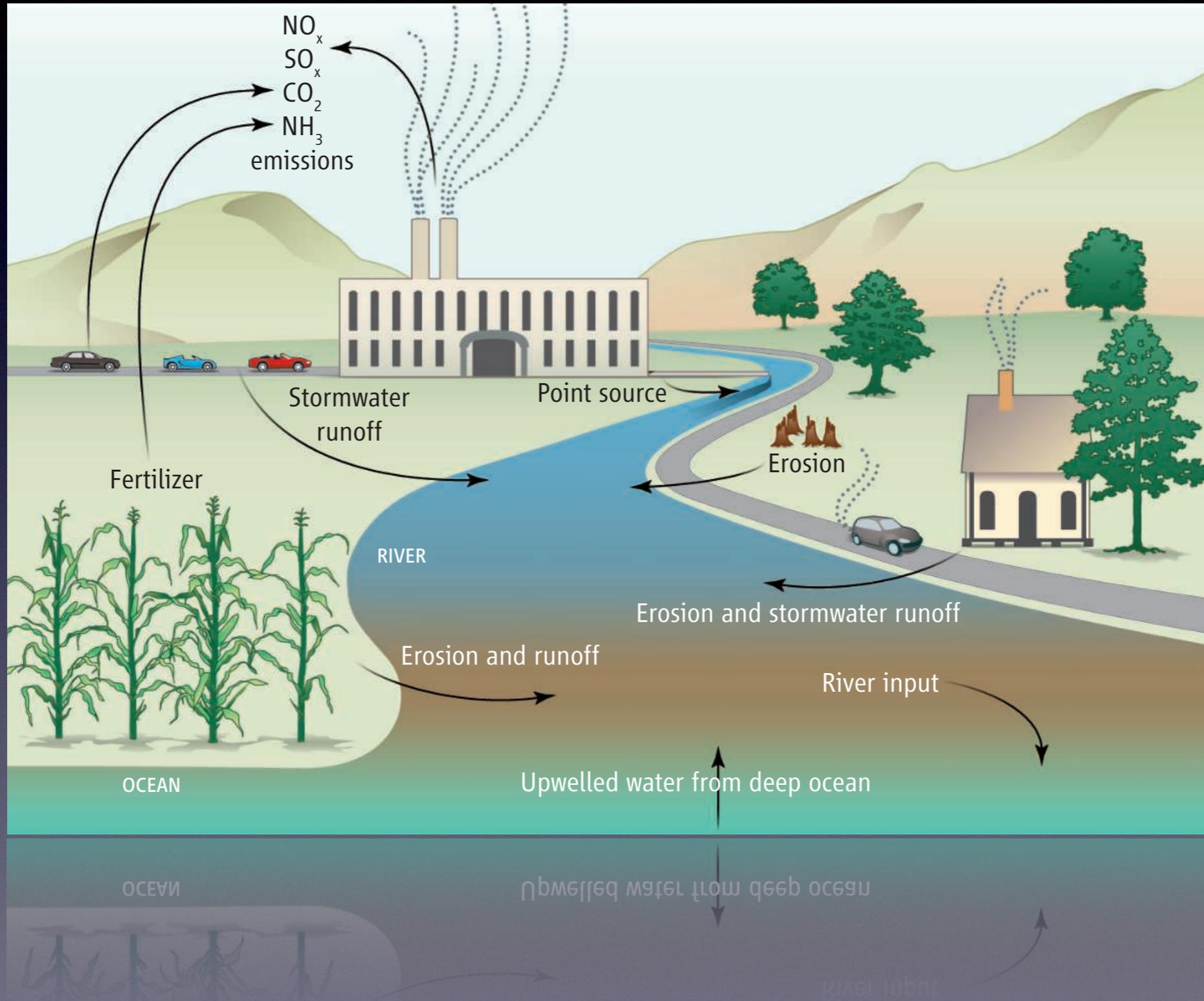
Laboratoire d'Océanographie de Villefranche
CNRS-Université Pierre et Marie Curie-Paris 6



Introduction et sommaire



Causes de l'acidification des océans



Kelly et al. (2011)

Budget global du carbone (2003-2012)

0.8 Pg C yr⁻¹



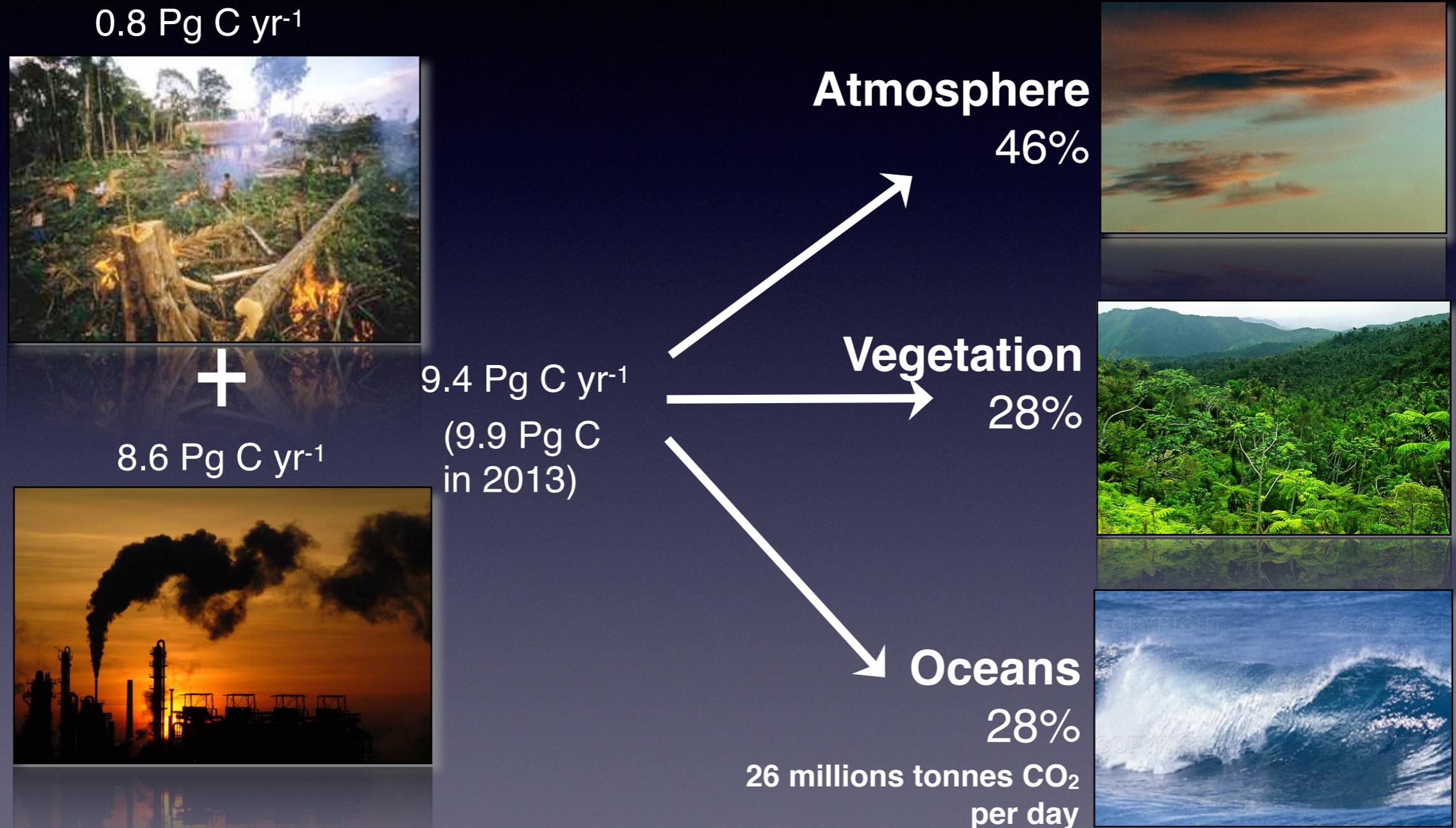
+

8.6 Pg C yr⁻¹

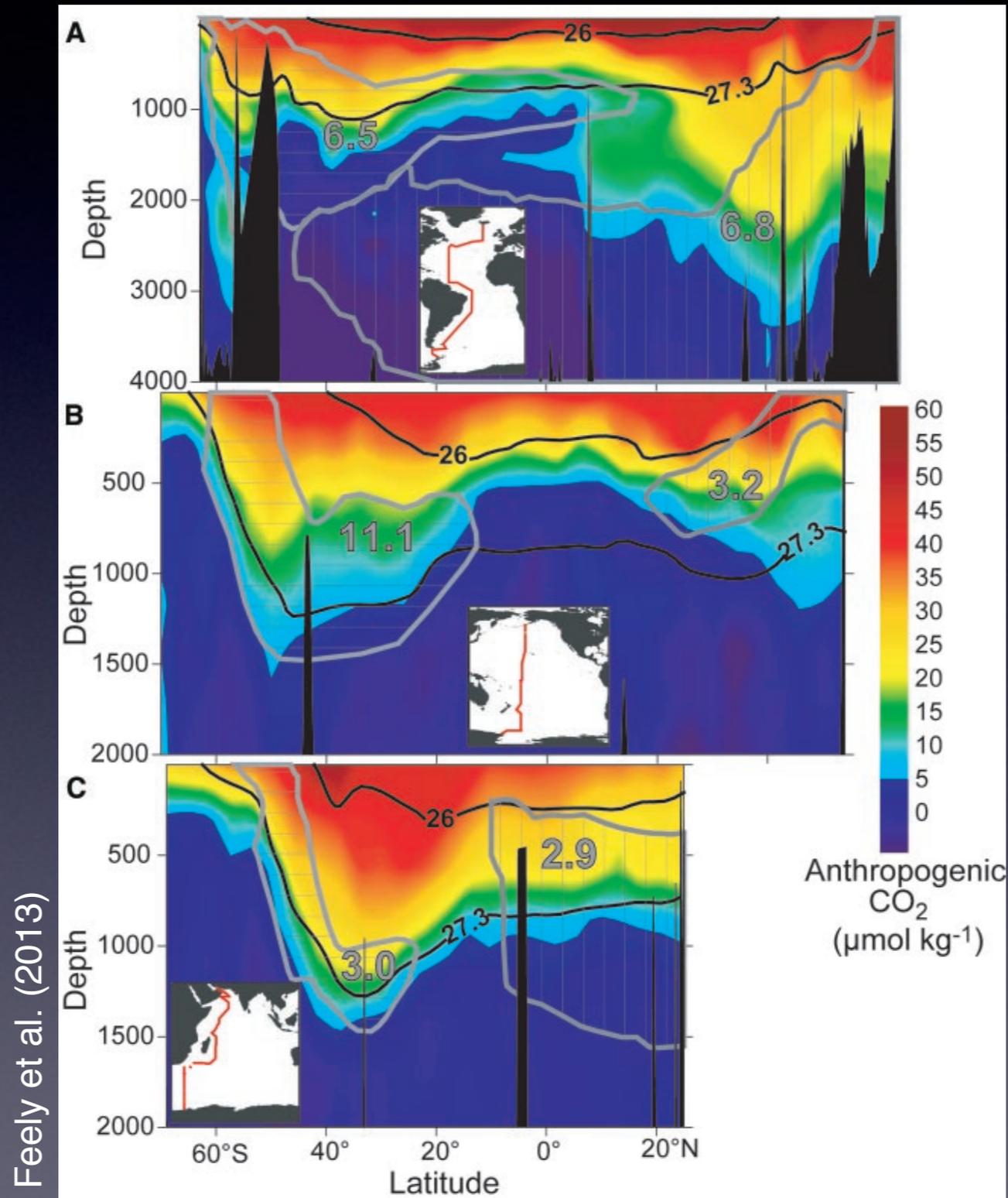
9.4 Pg C yr⁻¹
(9.9 Pg C
in 2013)



Budget global du carbone (2003-2012)

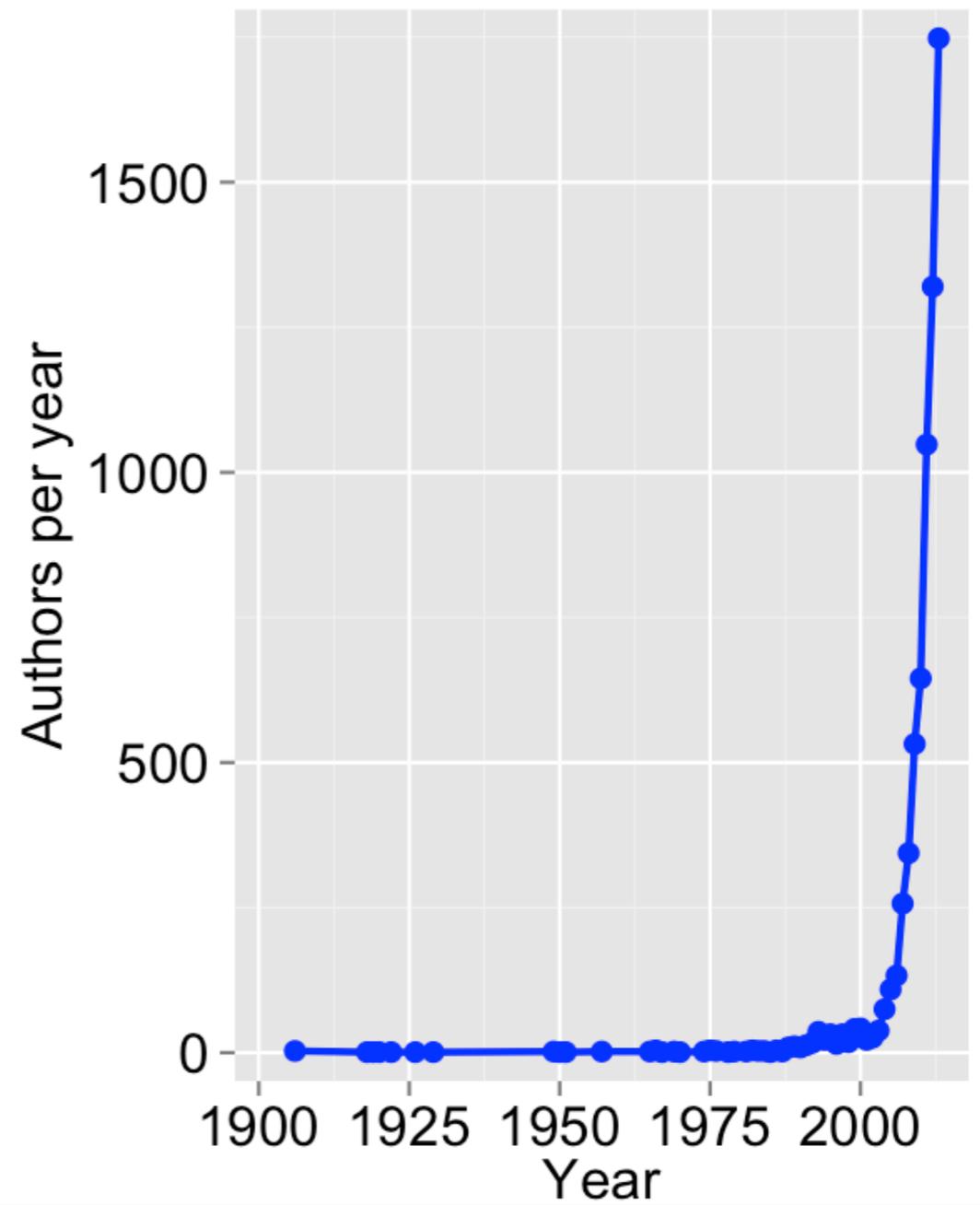
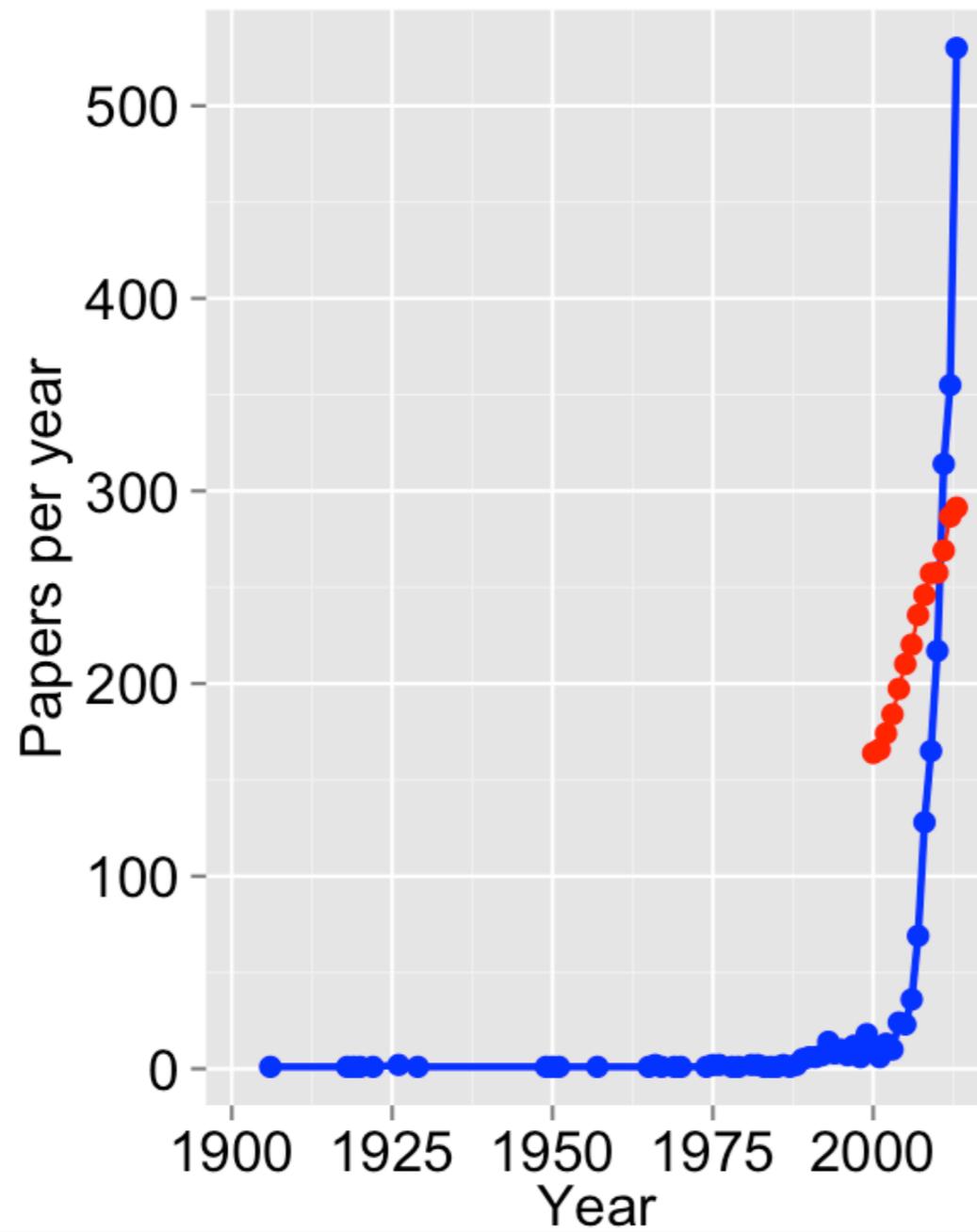


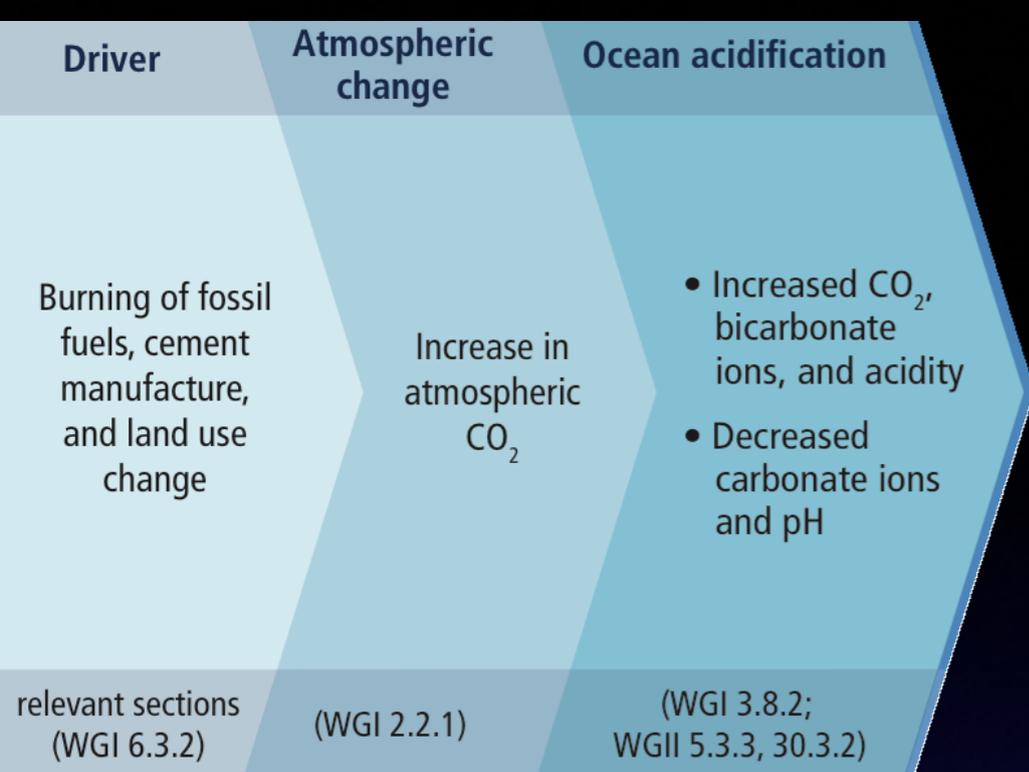
Pénétration du CO₂ en profondeur



Recherches en pleine expansion

After Gattuso and Hansson (2011) and Gattuso et al. (2011)





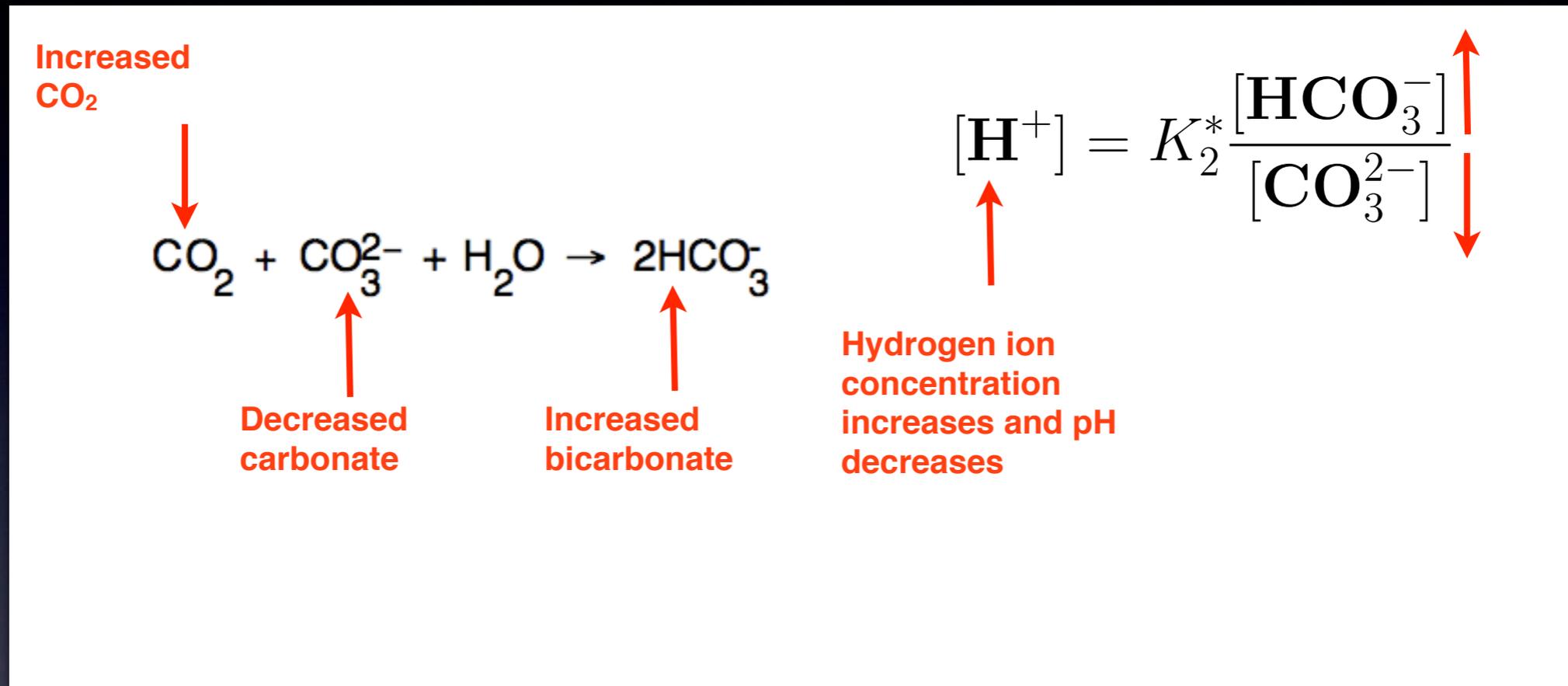
Chemistry: very high confidence

More acidity ↑

↓ Less acidity

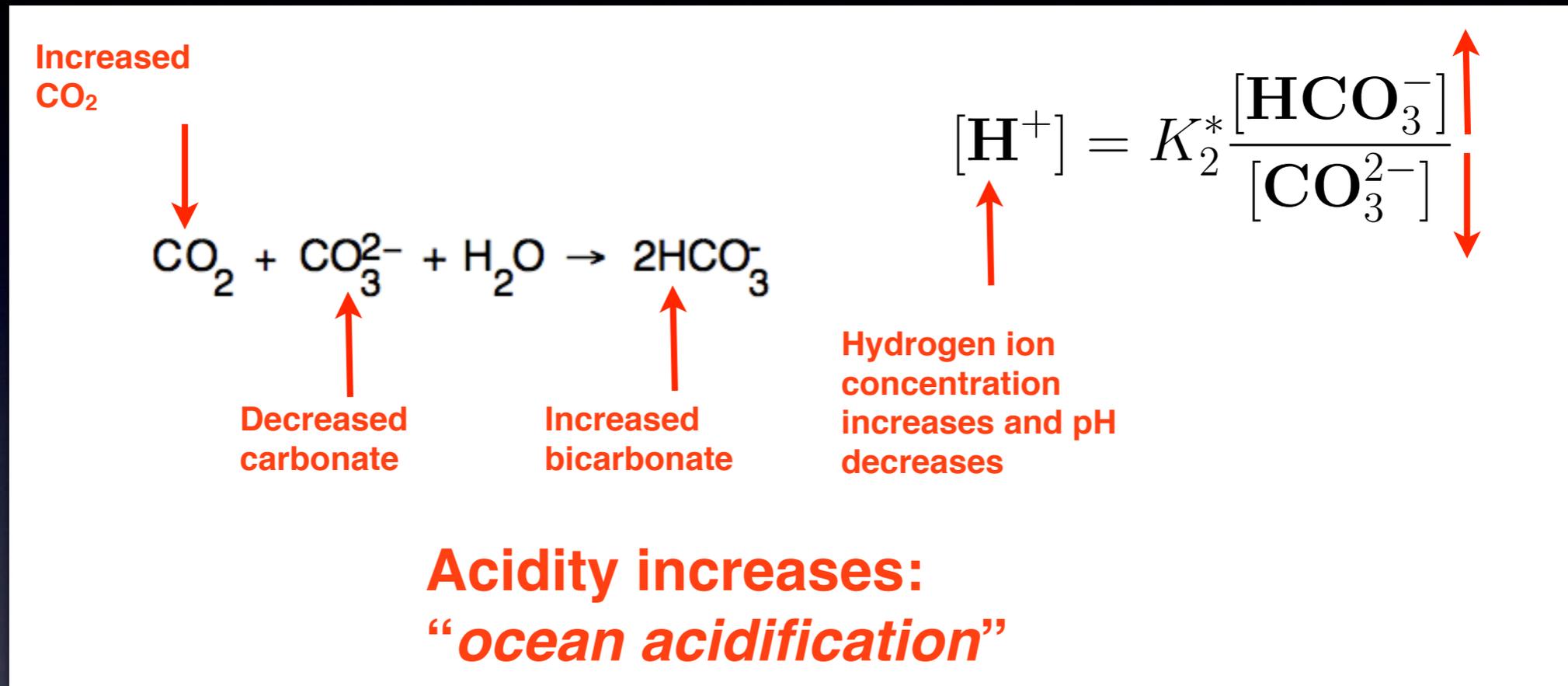
Concentrations of Hydrogen ions compared to distilled water (pH)		Examples of solutions and their respective pH
10,000,000	0	Battery Acid
1,000,000	1	Hydrochloric Acid
100,000	2	Lemon Juice, Vinegar
10,000	3	Orange Juice, Soda
1,000	4	Tomato Juice
100	5	Black Coffee, Acid Rain
10	6	Urine, Saliva
1	7	"Pure" Water
1/10	8	Sea Water
1/100	9	Baking Soda, Toothpaste
1/1,000	10	Milk of Magnesium
1/10,000	11	Household Ammonia
1/100,000	12	Soapy Water
1/1,000,000	13	Bleach, Oven Cleaner
1/10,000,000	14	Liquid Drain Cleaner

Qu'est ce que l'acidification des océans ?

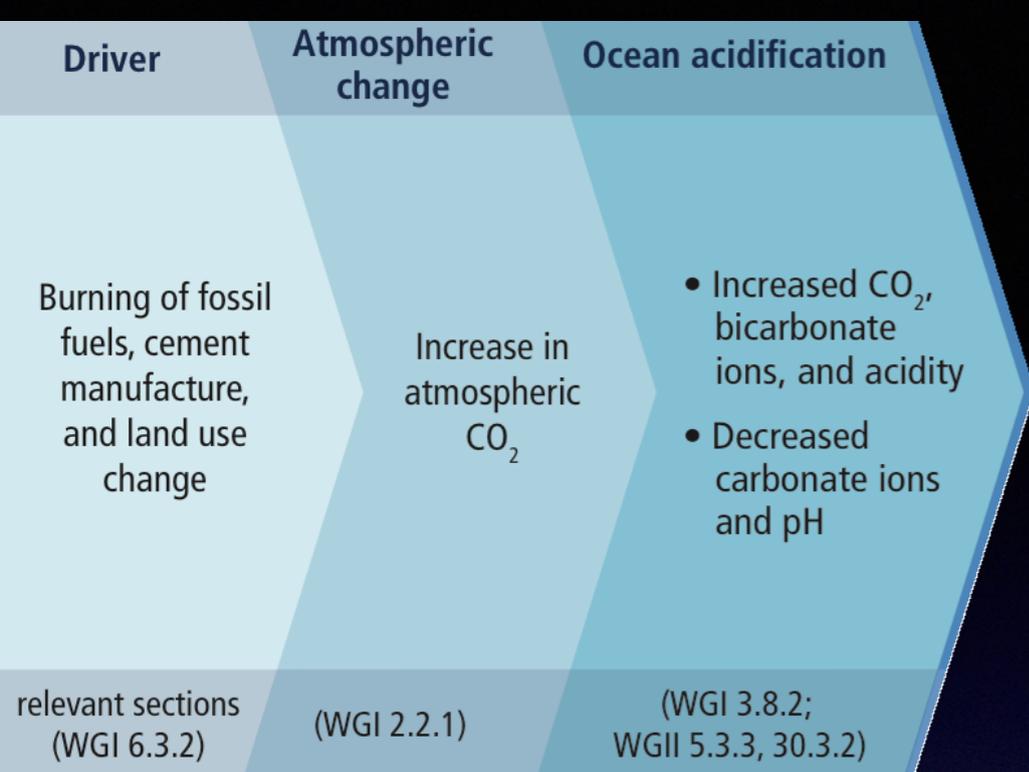


- CO_2 est un gaz acide (produit un acide lorsqu'il se combine avec eau)
- Chacun de nous ajoute 4 kg de CO_2 par jour dans les océans (augmentant son acidité)

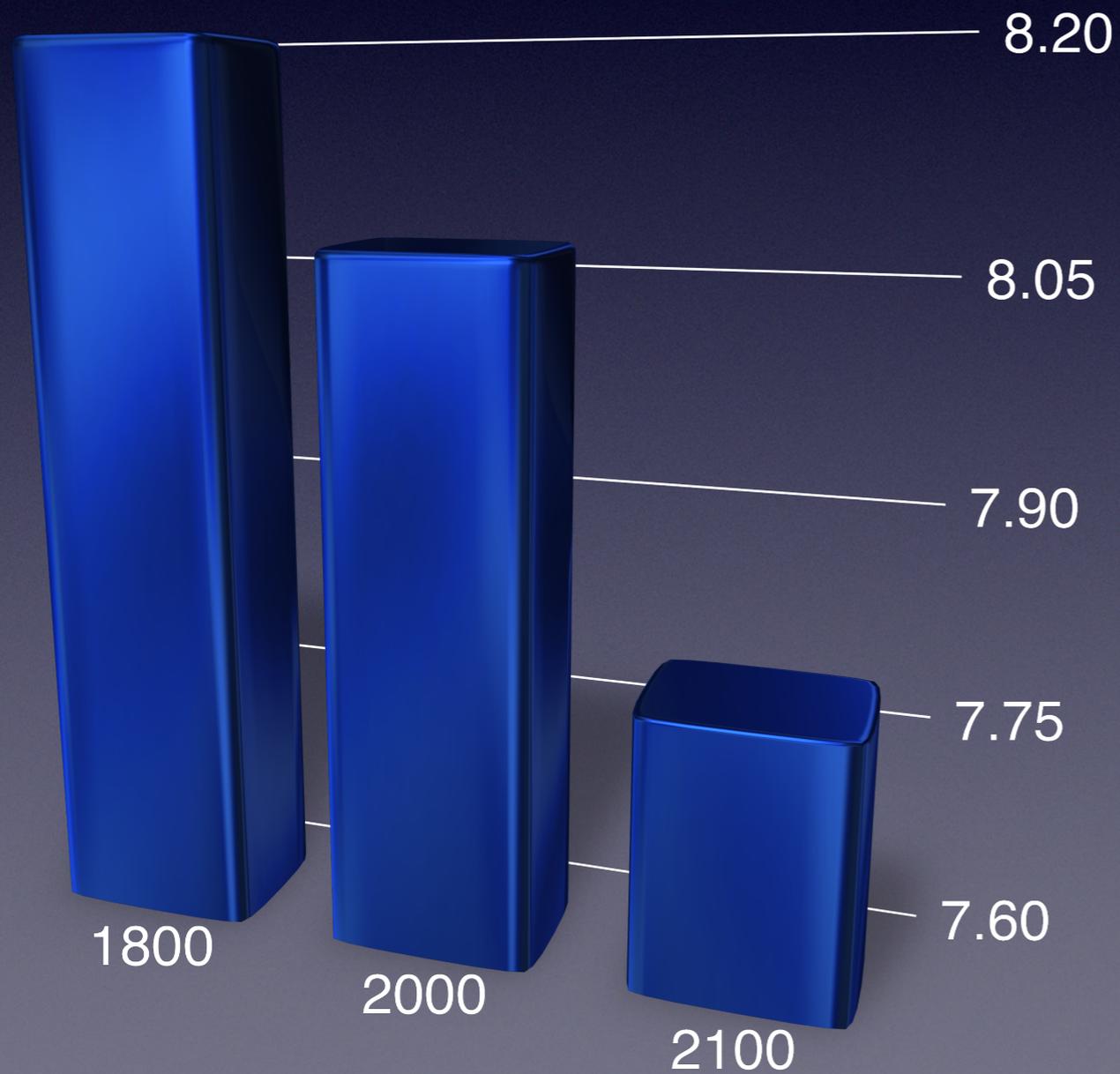
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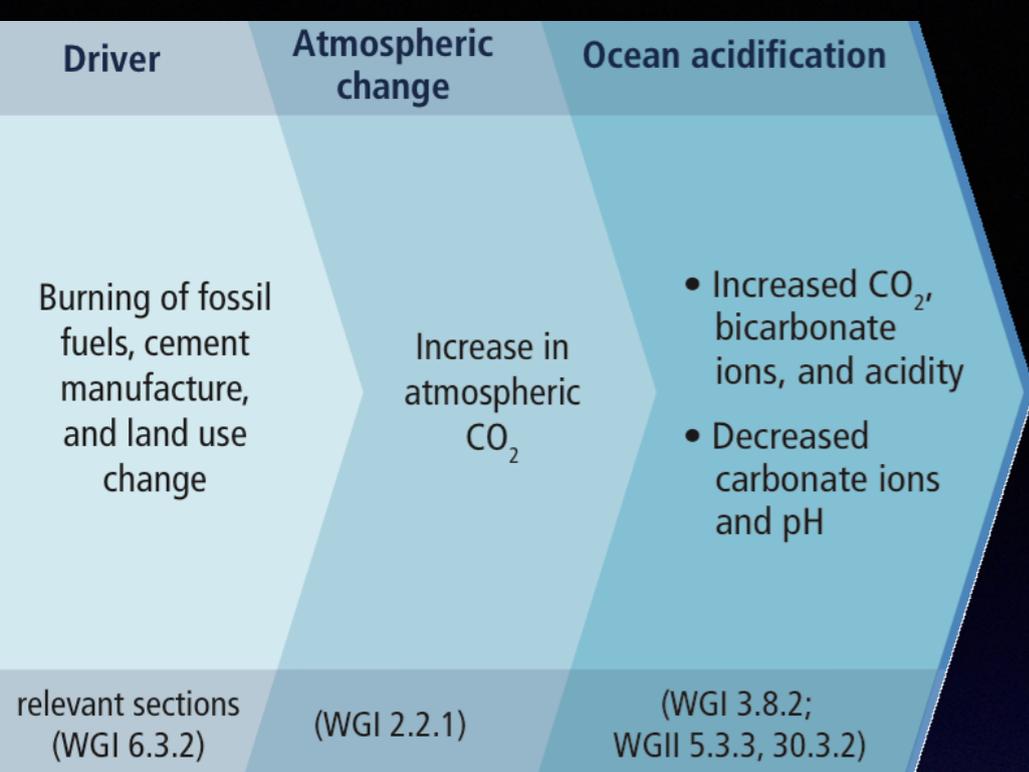


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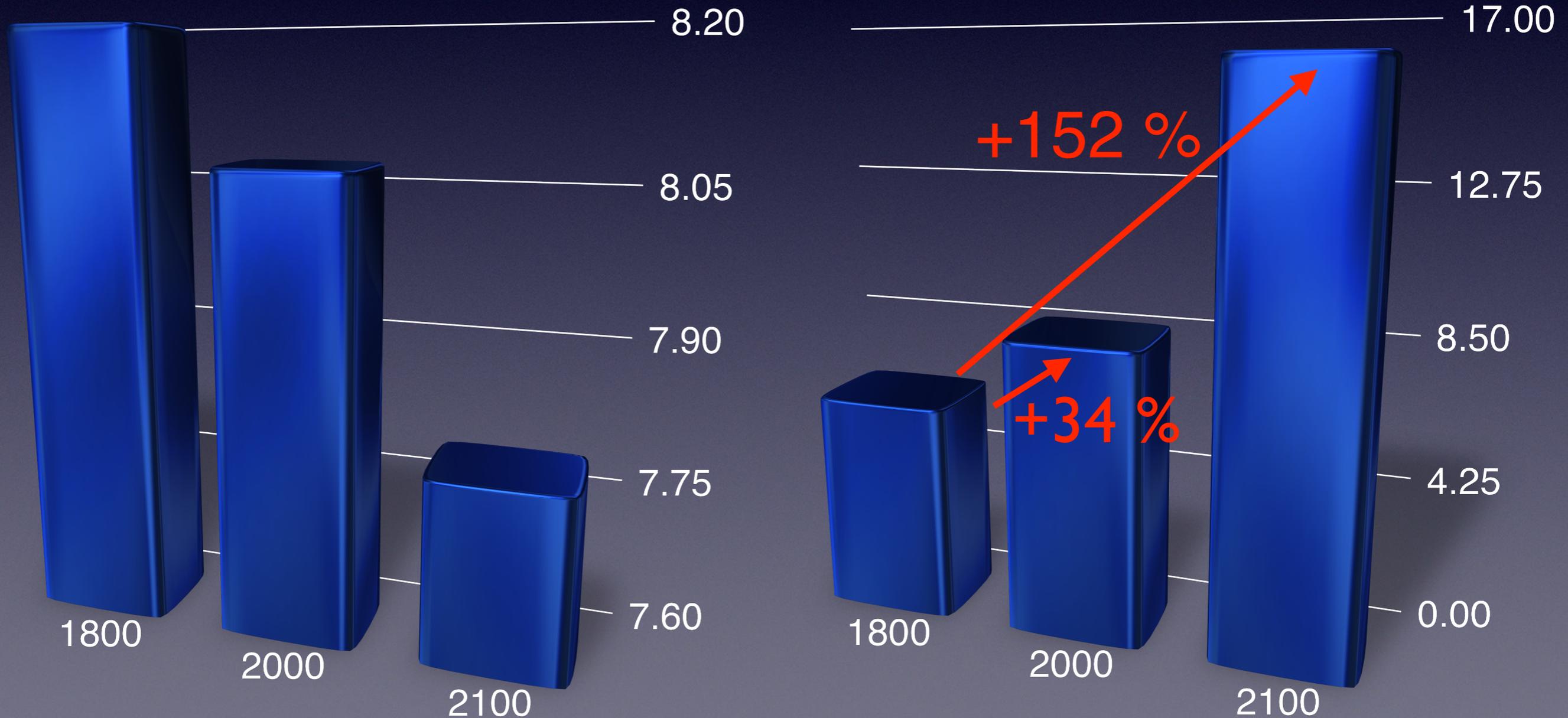
pH and acidity





pH and acidity

Acidity : $\times 10^{-9}$ mol H⁺/kg



« On transforme l'océan en Coca-Cola ! »

LE RAPPORT DU GIEC affine les impacts de l'augmentation des concentrations de CO₂ dans l'atmosphère. Etat de la question avec le climatologue belge Jean-Pascal van Ypersele.

Professeur en climatologie à l'Université catholique de Louvain, Jean-Pascal van Ypersele est également vice-président du groupe II du Giec, consacré aux « impacts » et à l'« adaptation ».

Quelles sont les grandes différences entre ce rapport et celui de 2001 ? Il n'y a pas énormément de différences. (...) Sur le réchauffement, on avait l'essentiel depuis 20 ans, pour ne pas dire 30. Le cœur du problème était déjà là, pour ceux qui voulaient bien en prendre connaissance. L'évidence est aujourd'hui plus précise, plus largement disponible et dispose d'une couverture géographique plus vaste. Le rapport comporte des originalités, notamment sur l'objectif ultime de stabiliser les émissions de gaz à effet de serre de manière à éviter toute perturbation anthropique dangereuse du système climatique. Devrait-il avoir une priorité entre les politiques de réduction d'émission et l'adaptation ?

« L'immense majorité des glaciers recule à cause des changements climatiques. Mais dans les régions où ils sont les réservoirs d'eau pour des villes entières (...) il n'y aura plus d'eau... sauf quand il pleut »

Les deux sont nécessaires. Anciennement, on n'abordait pas ces questions ensemble. Ici, nous faisons l'intégration des deux, sur les liens et les limites entre adaptation et la prévention. Un exemple : on peut très bien se protéger dans les pays développés contre une montée des mers de cinquante centimètres, mais cinq mètres, c'est autre chose. Économiquement d'abord, puis d'un point de vue de la population. Qui voudrait habiter derrière un mur haut de cinq mètres qui contient une mer ou un océan ? Les Hollandais ont travaillé sur cette question. Dans un tel cas, on ne peut qu'envisager l'abandon du territoire.

Le Giec constate que l'augmentation des concentrations de CO₂ aura un impact positif sur les rendements de l'agriculture dans le nord de l'Europe... Oui, mais jusqu'à un certain taux de concentration, ensuite la qualité risque ensuite de chuter. Mais bien sûr, pour l'agriculture, il faut aussi tenir compte des événements extrêmes. Il y a, à ce propos, beaucoup de discussions. L'accès à l'eau ne devrait pas être menacé en Belgique. Ce qui n'est pas le cas de nombreux pays... L'immense majorité des glaciers recule à cause des changements climatiques. Mais dans les régions où ils sont les réservoirs d'eau pour des villes entières se trouvant en contrebas, dans le voisinage, il n'y aura plus d'eau... sauf quand il pleut. Cela change tout. C'est dramatique. C'est le cas en Europe, dans les An-



LE GIEC PRÉVOIT la disparition de la plupart des petits glaciers, en Europe, d'ici à 2050. Situé dans la baie du Roi (Kongsfjorden), en Norvège, le glacier Blomstrandbreen a reculé d'environ deux kilomètres depuis 80 ans. PHOTOS AP

des, au Népal. Que pensez-vous du scénario de l'arrêt du Gulf Stream et d'un refroidissement de l'Europe subit ? C'est un des sujets qui m'insèrent. (...) Le groupe II du Giec a dit très clairement ce qu'il en était. Ce risque est très faible pour l'Europe au XXI^e siècle. À l'opposé, le climat pourrait-il s'emballer si l'homme ne limite pas les émissions de gaz à effet de serre ?

Ce phénomène est également très peu probable. Il est intéressant d'en avoir connaissance. De grandes quantités de méthane gelées pourraient se relâcher en raison de l'effet de réchauffement. C'est important de le savoir en raison de la puissance vingt-cinq fois plus élevée par kilo de ce gaz relâché dans l'atmosphère par rapport au CO₂. Mais la Terre n'est pas sur Vénus, plus proche du Soleil que notre planète, et la position de

notre atmosphère est différente. Il y a déjà tellement de méthane de se trouver loin en dessous de ce seuil là, s'il existe, que la question de l'emballement du climat ne me semble pas être majeure. L'acidification des océans, pointée du doigt pour la première fois, vous inquiète-t-elle davantage ? Une série de facteurs d'amplification s'ajoutent pas forcément brutalement mais rendent le problème d'autant plus

difficile à résoudre que l'on attend pour s'y attaquer. Or, comme le note bien le rapport, l'océan se sature petit à petit en CO₂. C'est un problème majeur dont on va parler beaucoup dans les années qui viennent. Il faut savoir que l'on transforme la composition chimique de l'océan. On le transforme d'une certaine manière en Coca-Cola ! Et je ne pense pas que la vie marine puisse s'y développer aussi facilement que dans de l'eau normale. Est-ce encore utile de produire trois rapports différents mais complémentaires tous les cinq ans. Le Giec ne nécessaire-t-il pas d'être réformé ? Peut-être. Une réflexion informelle a commencé à ce sujet. Rien ne dit que le prochain rapport du Giec, s'il y en a un, dans 5, 6, 7 ans, aura la même structure. Une approche plus intégrée que maintenant est nécessaire. Il y aura une certaine clarification de certains aspects grâce à l'interaction entre les scientifiques et les décideurs. On parle de consensus scientifique sur les changements climatiques. Mais des scientifiques continuent à contester la thèse du réchauffement d'origine humaine. Les rapports du Giec en tiennent-ils compte ? Le Giec fait de l'évaluation de la science et des connaissances scientifiques d'une manière très sérieuse. Prenons un peu

« Le processus du Giec est exhaustif, rigoureux et très lourd. Ses rapports ne sont donc pas manipulés comme on pourrait vouloir le laisser croire. Ils sont au contraire relativement conservateurs... »

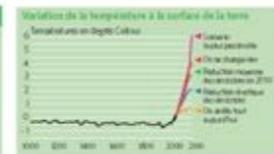
de recul pour constater que ce processus totalement transparent est unique au monde. Dans le cas de ce rapport-ci, la table des matières a été adoptée en 2002. On a lancé un appel ouvert pendant trois mois pour solliciter des auteurs proposés par les gouvernements et désignés par le bureau du Giec en fonction de la qualité des experts en cause. (...) C'est très large. Le projet est ainsi nourri de milliers de commentaires dûment consignés. On sait d'où provient chaque commentaire et le sort qu'il lui est réservé. (...) Le processus du Giec est exhaustif, rigoureux et très lourd. Ses rapports ne sont donc pas manipulés comme on pourrait vouloir le laisser croire. Au contraire, ils sont relativement conservateurs... »

propos recueillis par CHRISTIAN DUERLE ET CHRISTOPHE SOUDRE

CONTROVERSE

C'est l'histoire d'une courbe de hockey (figure de droite) controversée. Établissant un lien entre la concentration des émis-

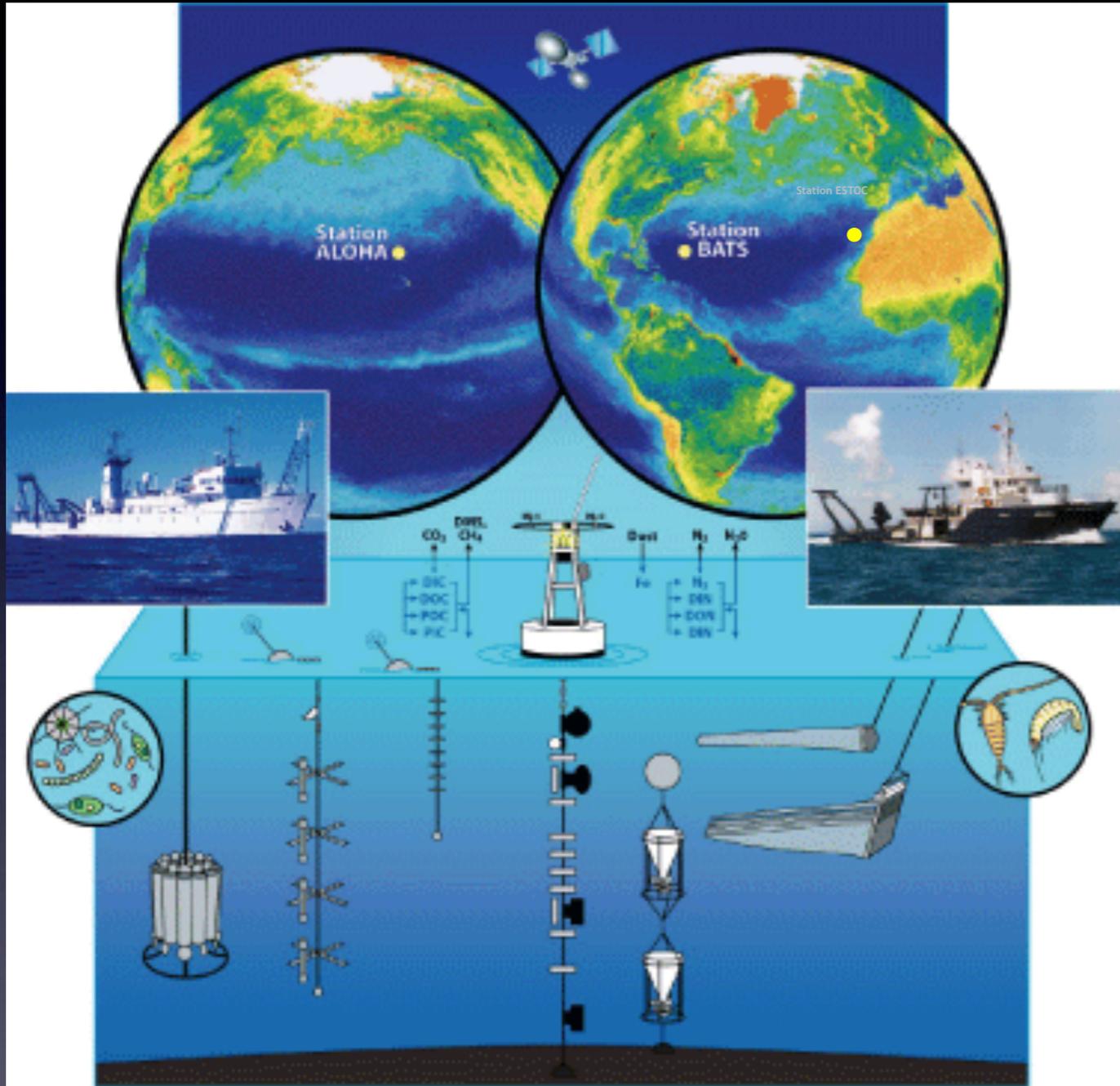
sions de carbone dans l'atmosphère et l'augmentation des températures, ce graphique utilisé en 2001 par le Giec a été épinglé du rapport 2007. Et pour cause, ces calculs (Mann, 1999) auraient omis la période chaude médievale pour cause de sélection inappropriée des données (Mei et al., 2005). Un argument utilisé par les sceptiques pour contester l'origine humaine du réchauffement.



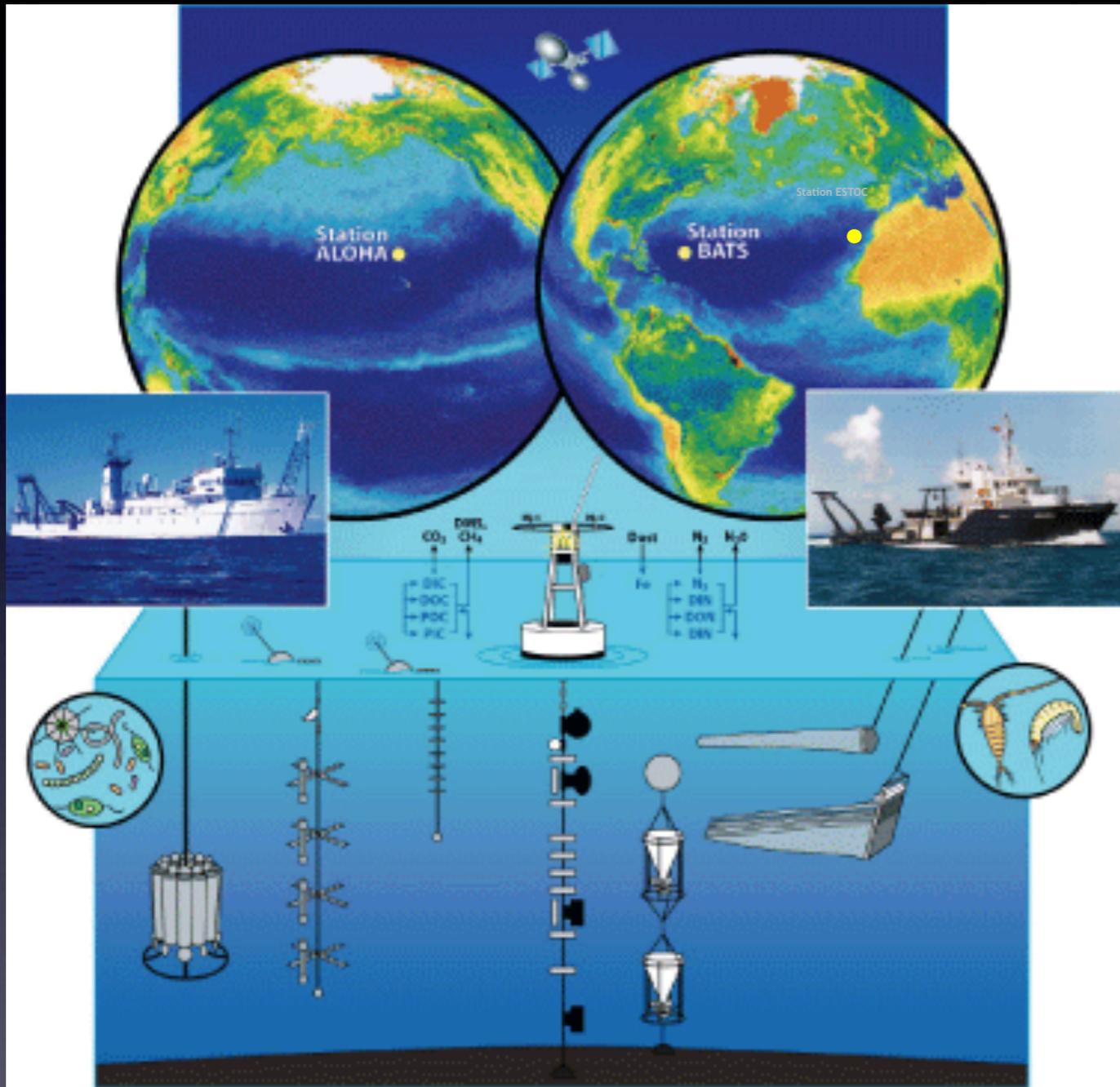
Chaud

La température moyenne du globe a gagné 0,7° depuis cent ans (2° en Belgique). Selon les scénarios, elle devrait encore augmenter de 1,5 à 4° d'ici à 2100. Les températures enregistrées entre décembre et février 2007 ont été les plus élevées jamais enregistrées à cette période de l'année, avec une température moyenne supérieure de 0,72°C à la moyenne du XX^e siècle, selon l'administration américaine.

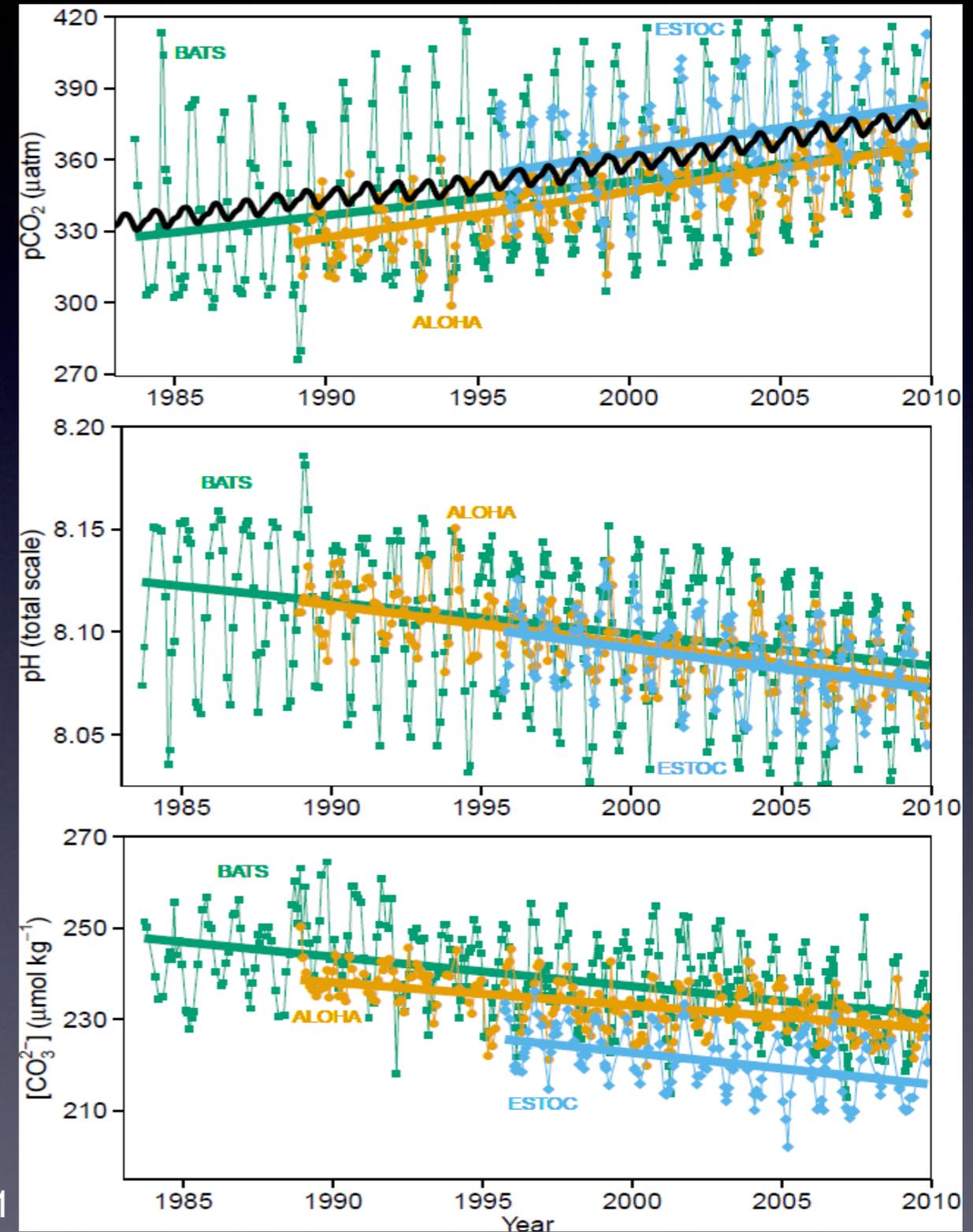
L'acidification des océans peut être mesurée



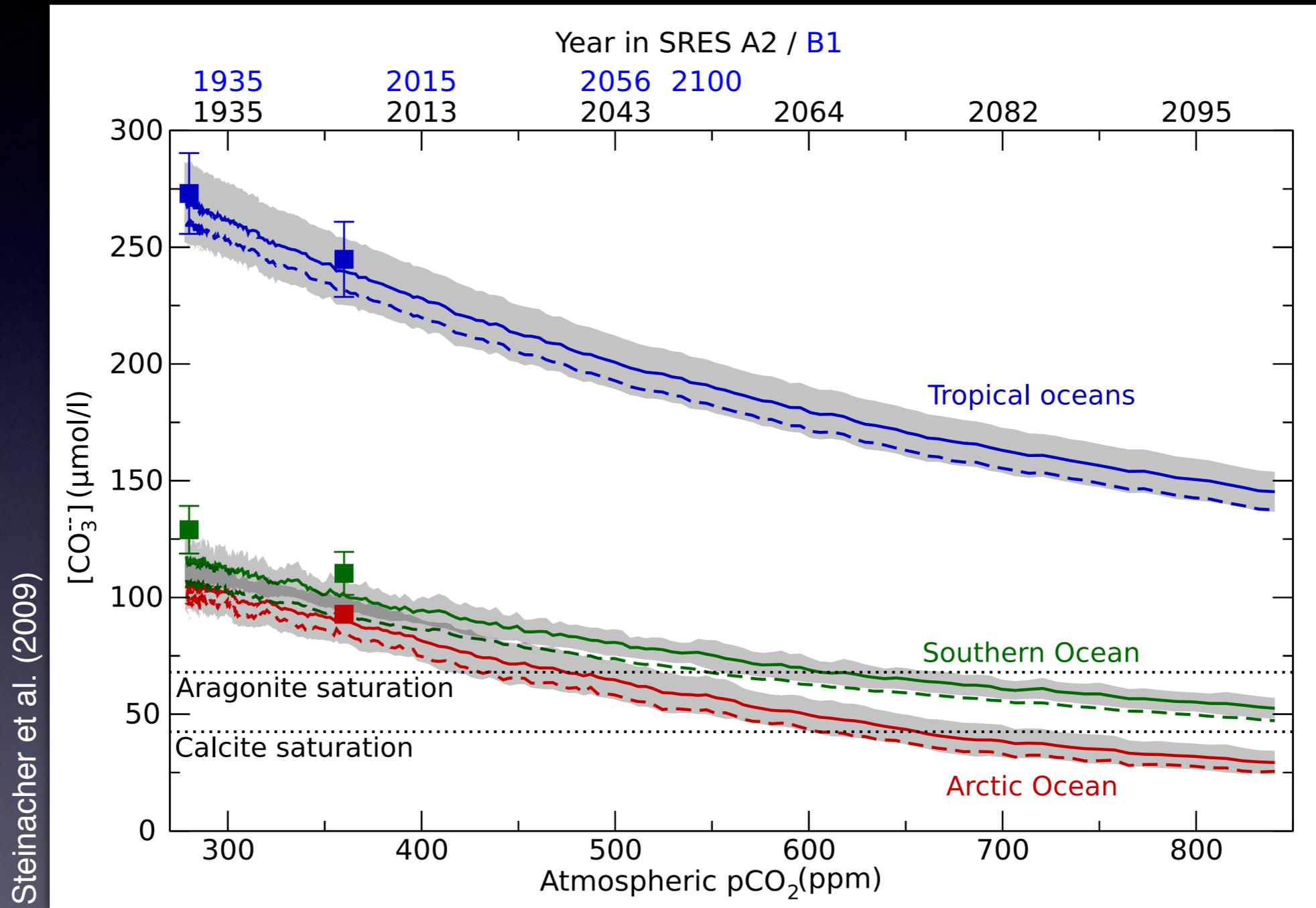
L'acidification des océans peut être mesurée



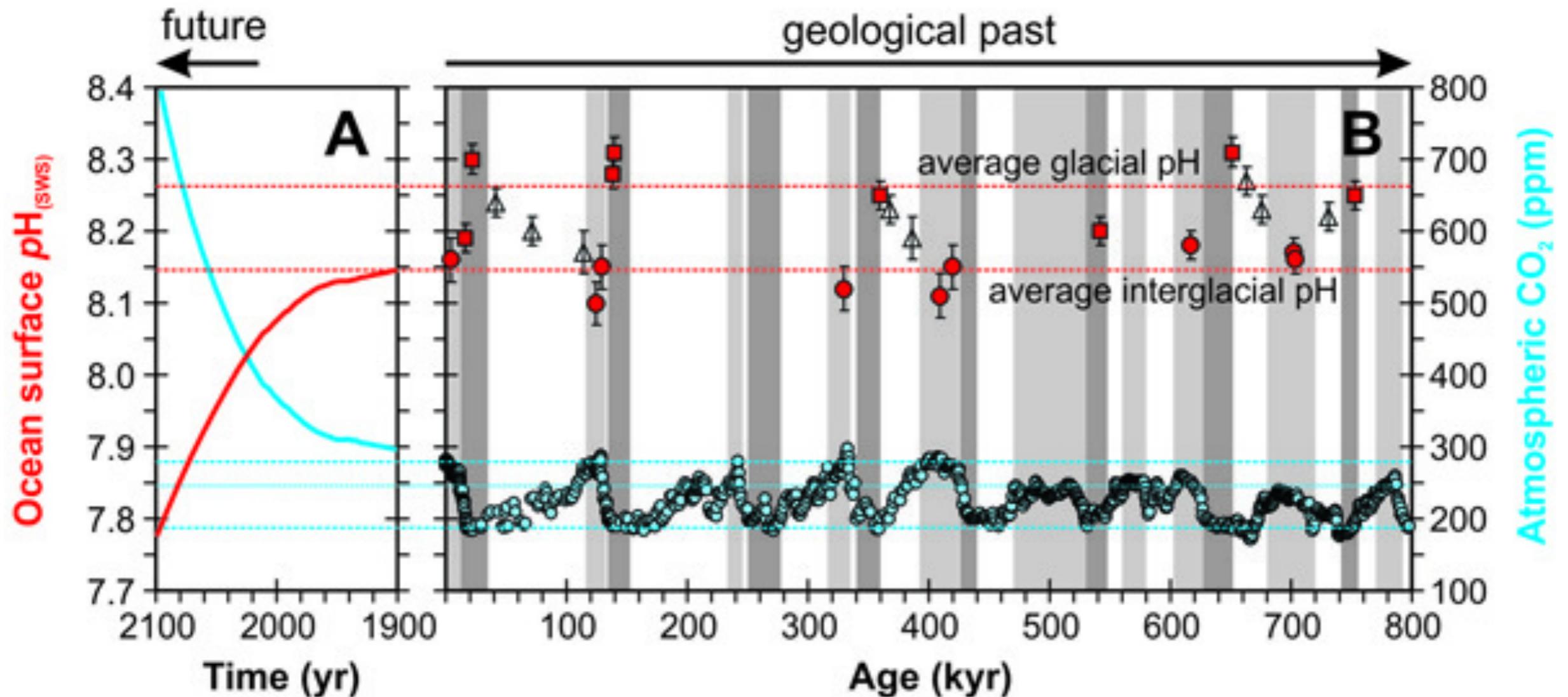
Range 1995-2009:
-0.0015 to -0.0022 units yr⁻¹



Importantes différences régionales



Et dans le passé ?

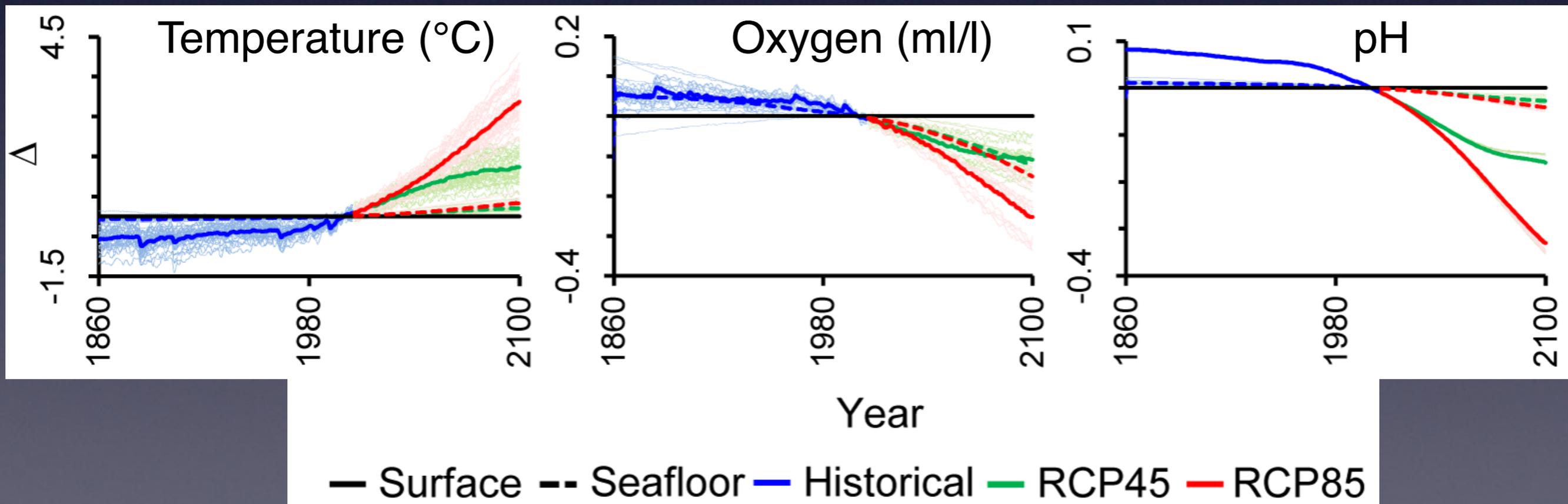


Barker & Ridgwell (2012)

- Largest event since 55 My
- Perhaps fastest event since 300 My

Multiple climate-related ocean stressors

pH
Temperature
Oxygen concentration
Sea level rise



Summary for Policy Makers

OCEAN ACIDIFICATION

Summary for Policymakers
Third Symposium on the Ocean in a High-CO₂ World

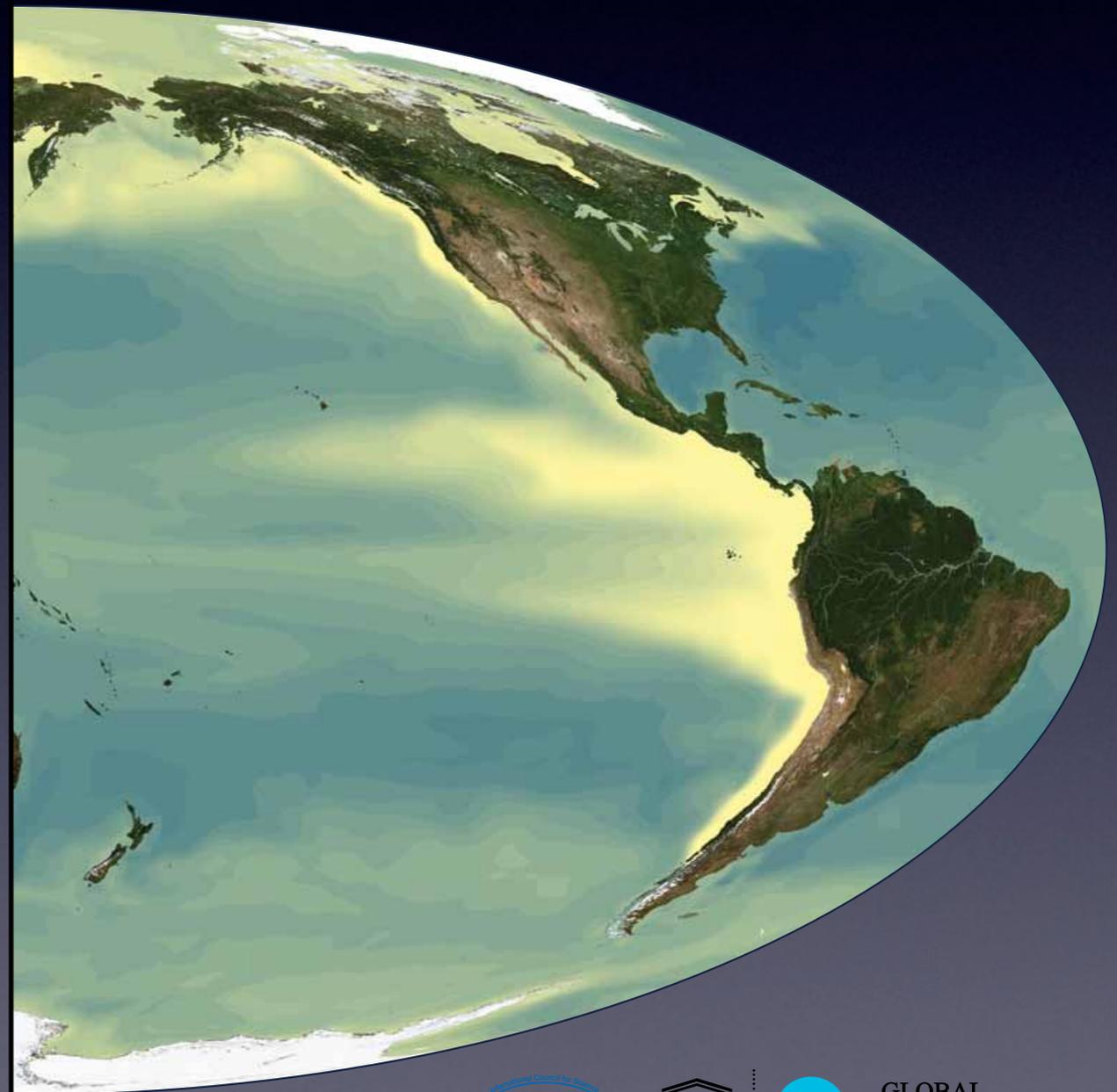
Confidence level

V Very high

H High

M Medium

L Low



Chemistry



The capacity of the ocean to act as a carbon sink decreases as it acidifies and warms

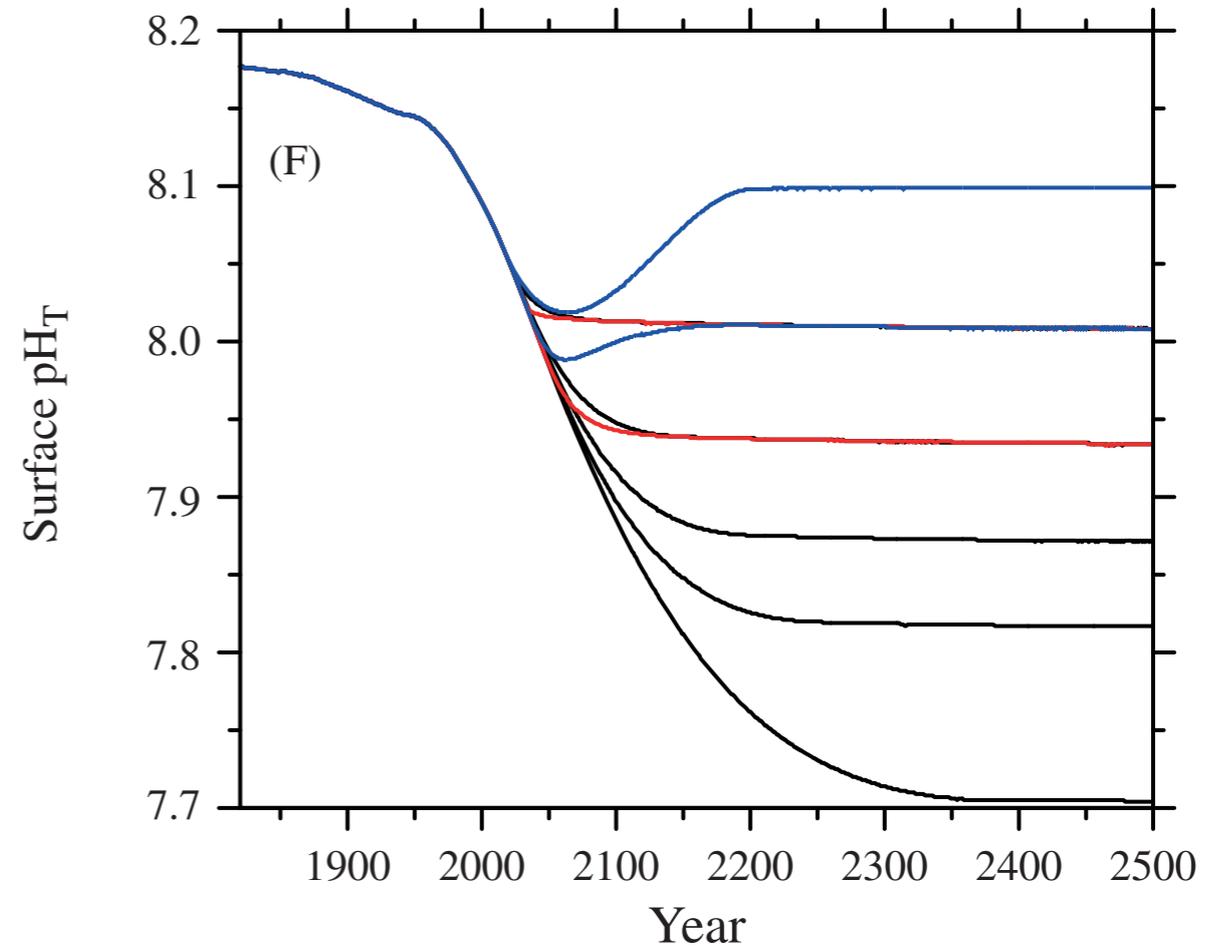
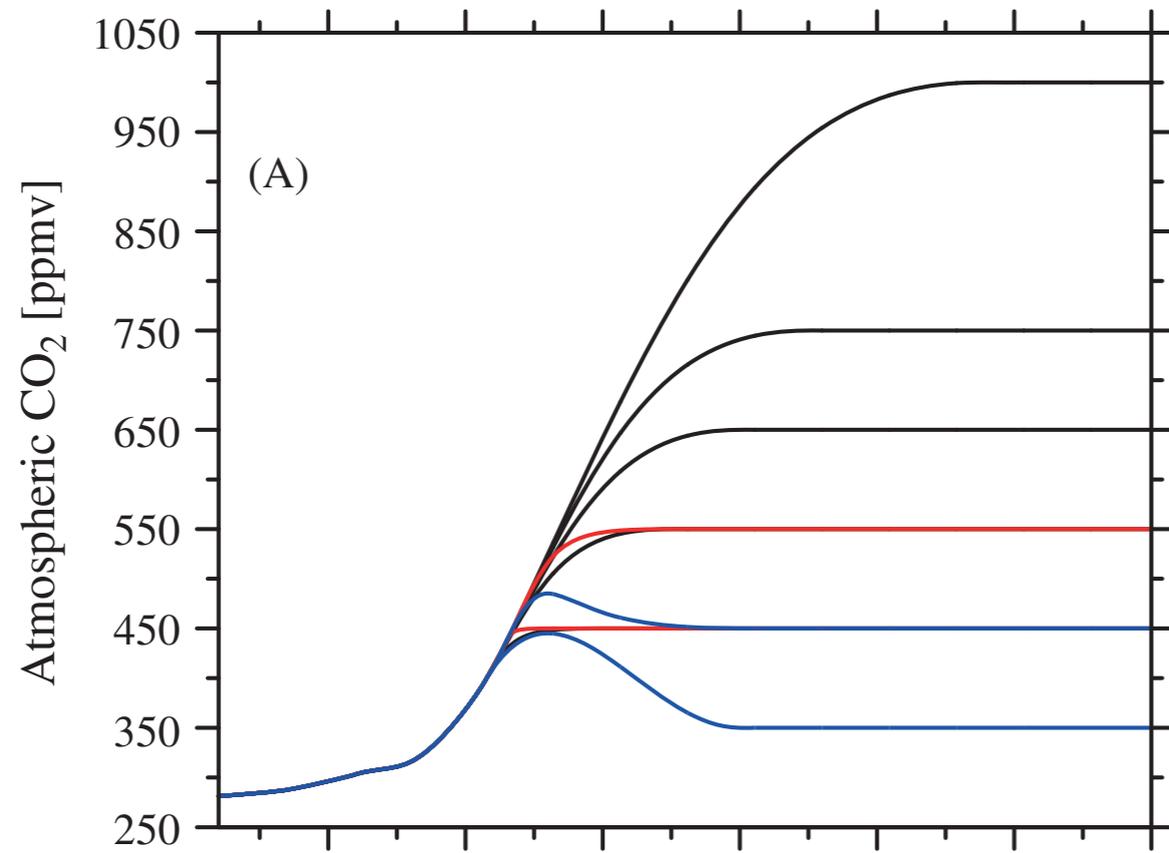


Ocean acidification is caused by CO₂ emissions from human activity to the atmosphere that end up in the ocean



The legacy of historical fossil fuel emissions on ocean acidification will be felt for centuries

Persistance de la perturbation



Joos et al. (2011)

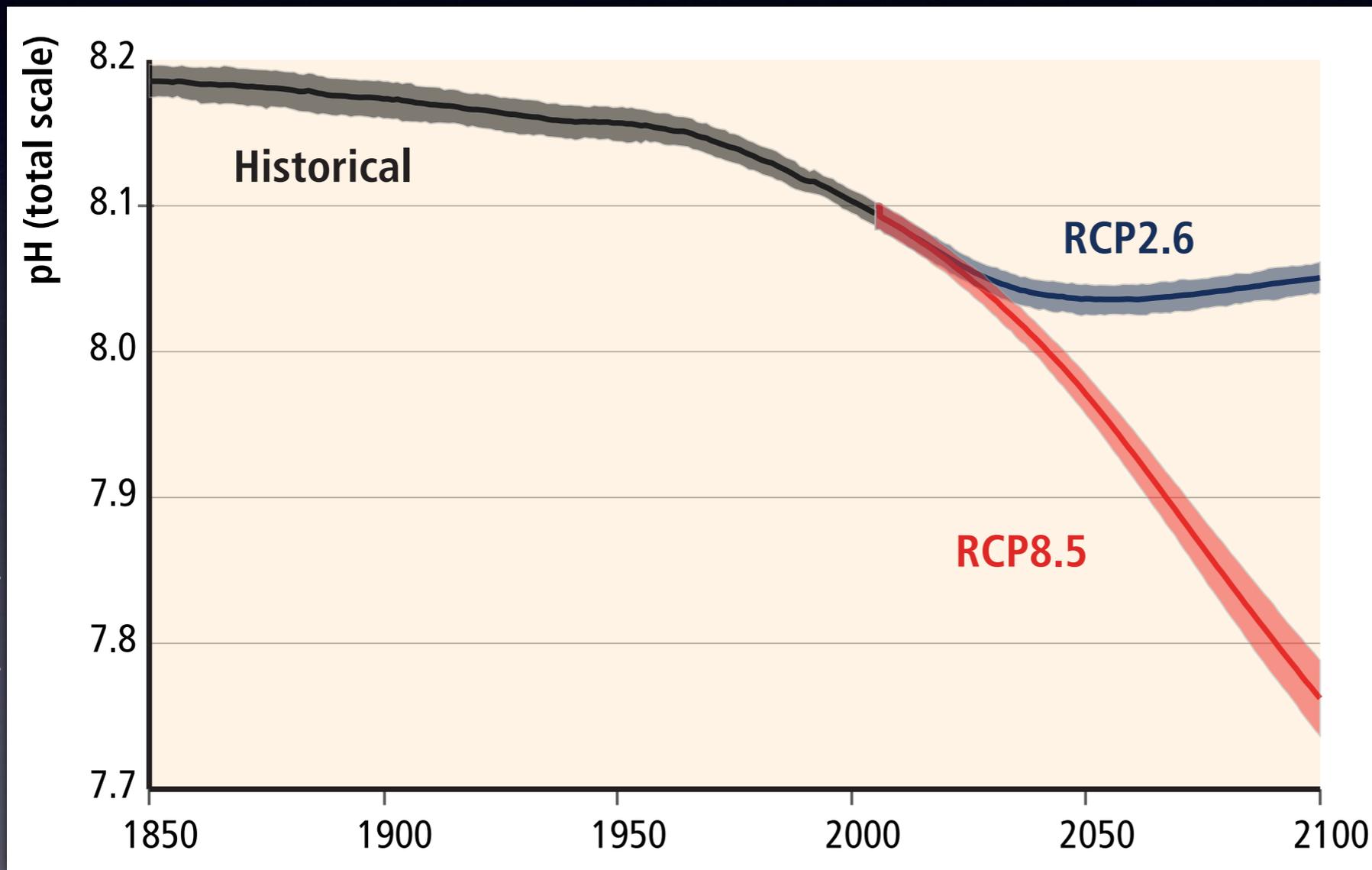


Anthropogenic ocean acidification is currently in progress and is measurable



Reducing CO₂ emissions will slow the progress of ocean acidification

Ciais et al. (2013). IPCC AR5 WG I



Likely surface ocean warming by 2100:

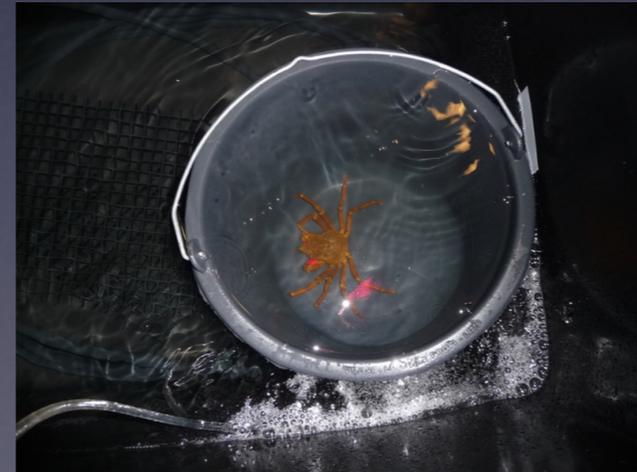
0.6 °C

2 °C

Etudes de laboratoire



PML | Plymouth Marine Laboratory



Etudes sur le terrain

Etudes sur le terrain



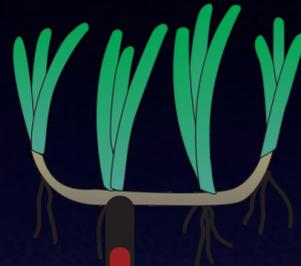
Etudes sur le terrain



Biological response



Cold-water coral communities are at risk and may become unsustainable



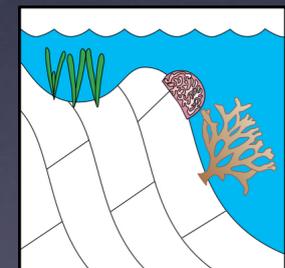
Some plants may benefit



Combination of elevated acidity and temperature negatively affect many organisms



Molluscs among the most sensitive groups



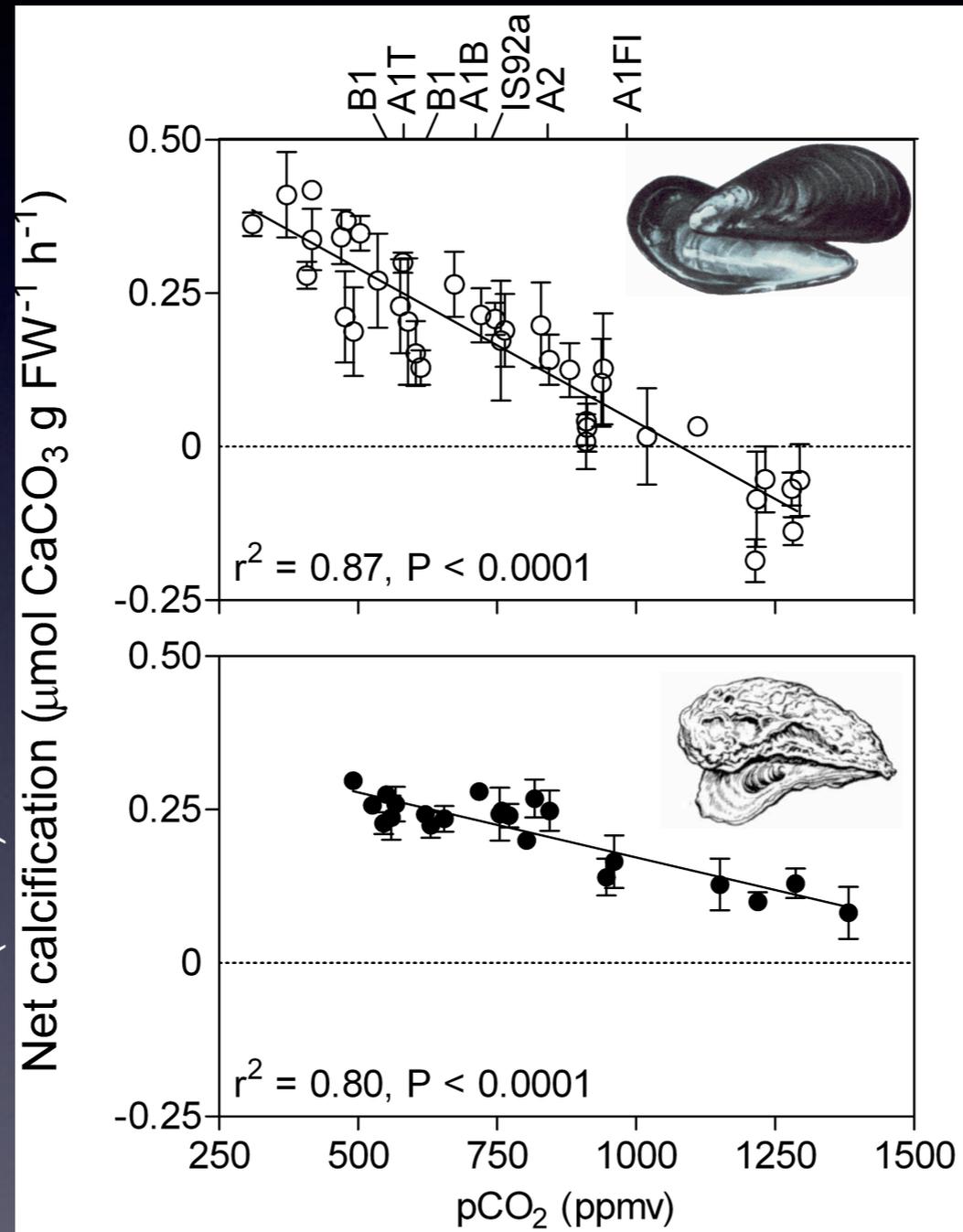
Coral reef erosion will outpace reef building



Impacts on biodiversity, not well constrained

Exemple des mollusques

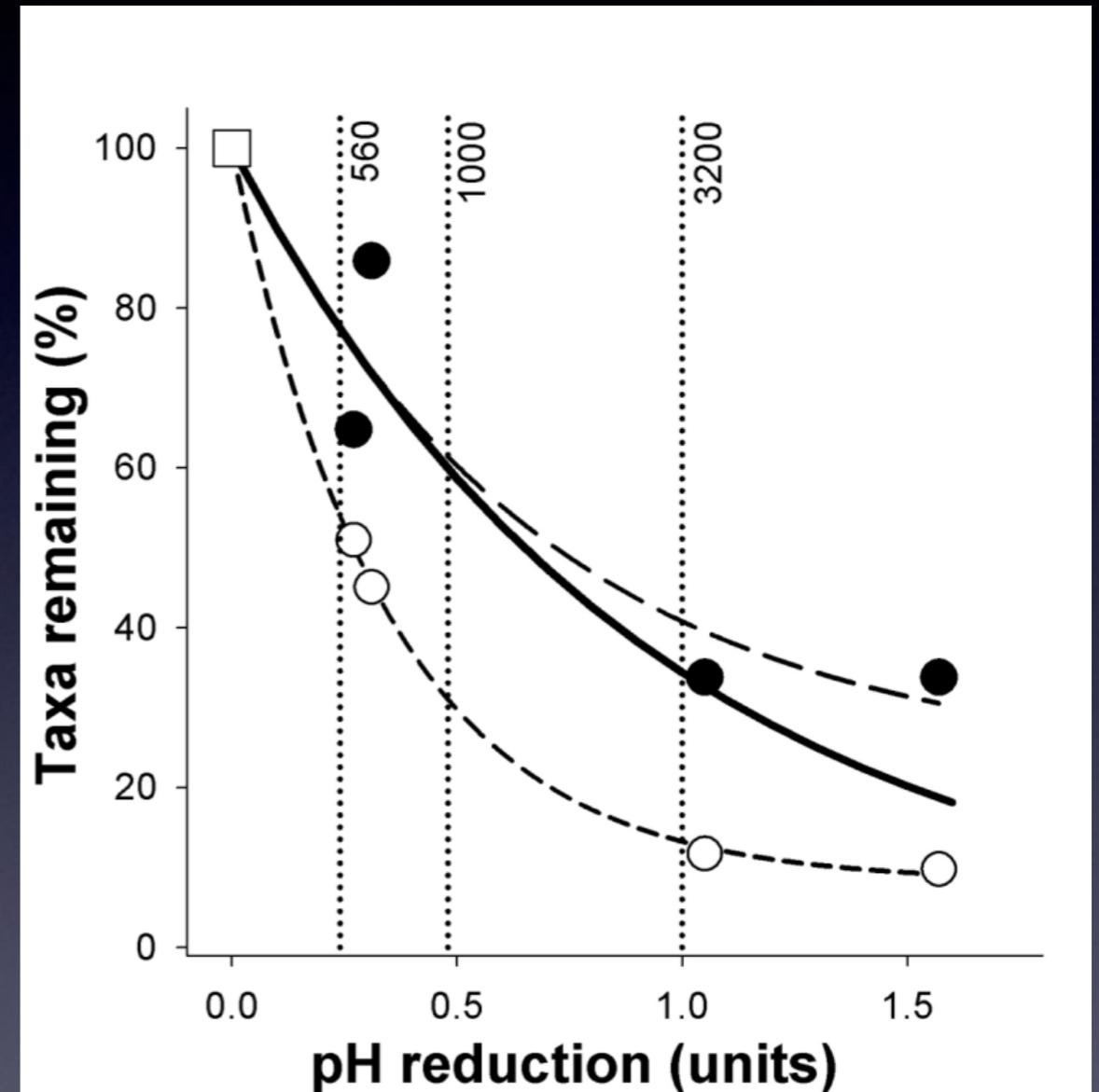
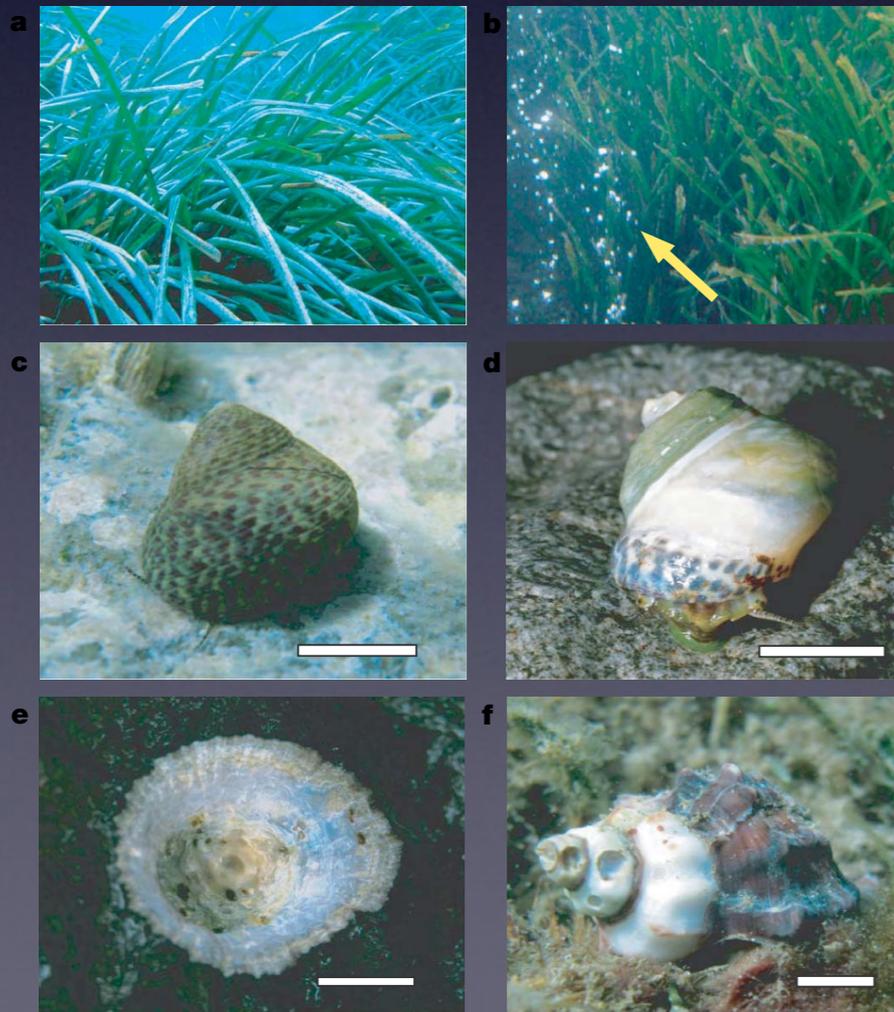
Gazeau et al. (2007)



Field studies: CO₂ vents



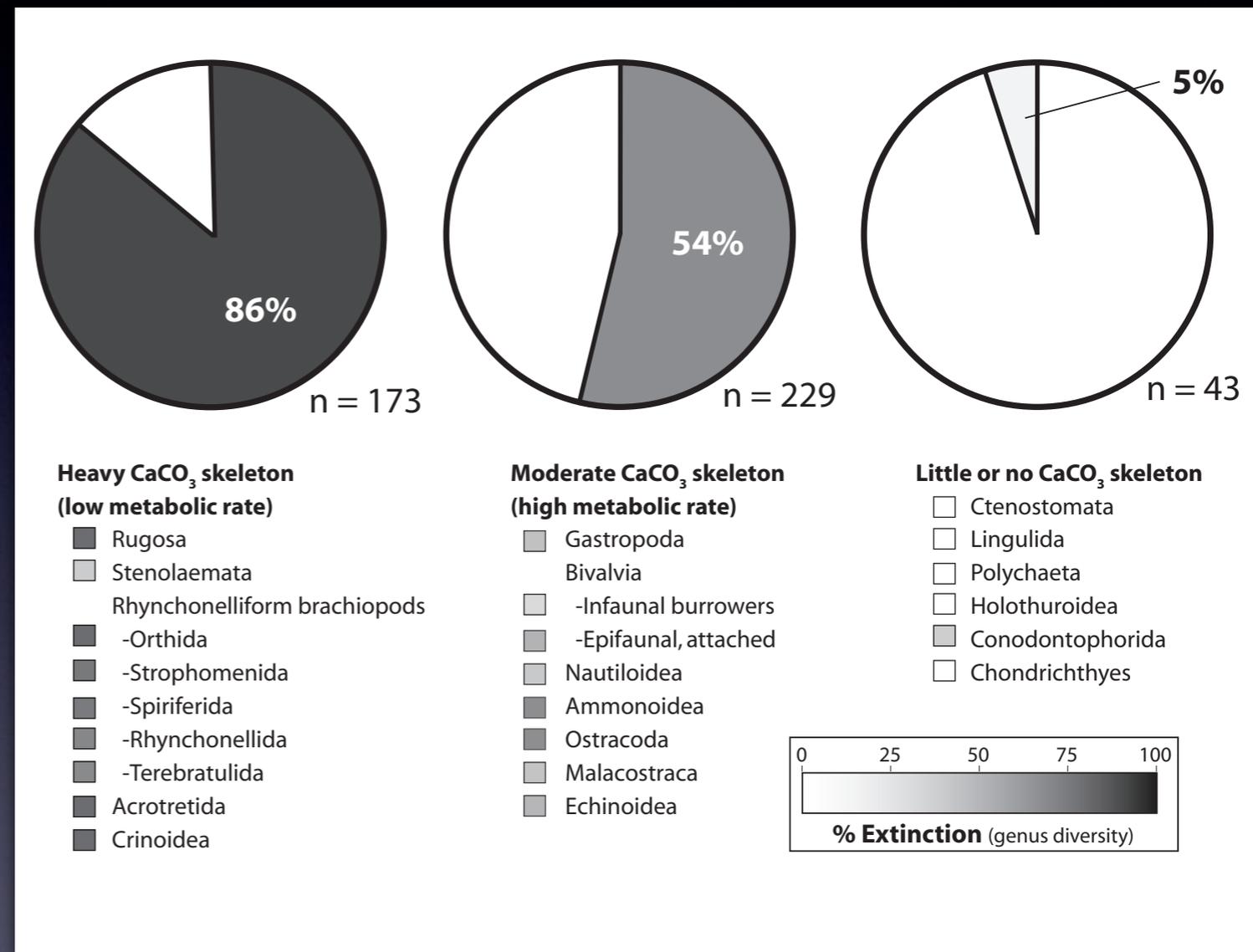
Ischia (Hall-Spencer et al., 2008; Martin et al., 2009)



- Non calcifiers (71 taxa)
- Calcifiers (51 taxa)

Extinctions d'espèces calcaires

- The long view
 - Hypercalcifiers have come and go
 - Response stronger when ocean acidification is combined with anoxia
- Rate is key: biological crisis when pCO₂ rose fast, not when pCO₂ was high
- Selective extinction during the end-Permian crisis
- Timescale of recovery measured in geological times



Biological response



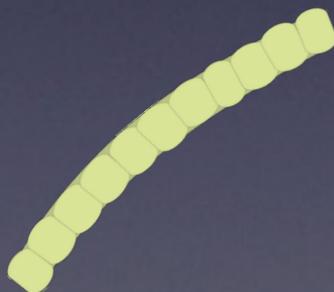
Ocean acidification will adversely affect many calcifying organisms



Pteropod (marine snail) shells are already dissolving



Ocean acidification may have some direct effects on fish physiology, behaviour and fitness



Nitrogen fixation in some cyanobacteria may be simulated

Societies and economies

-  Declines in shellfisheries will lead to economic losses, but their extent is uncertain
-  Negative socio-economic impacts of coral reef degradation are expected but the size of the costs is uncertain
-  Impacts of ocean acidification on ecosystems may affect top predators and fisheries
-  Ocean acidification will alter biogeochemical cycles at a global scale

Brief assessment of consequences

- **Chemical effects:** very high confidence



- **Biological and ecological effects:** high to low confidence



- **Biogeochemistry, society and the economy:** medium to low confidence



- **Knowledge gaps:**

- Multiple stressors

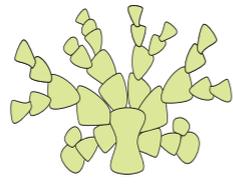
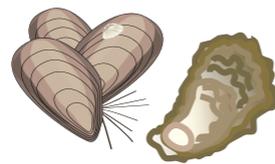
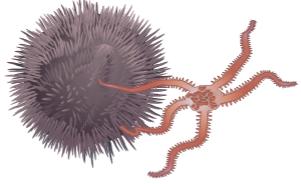
- Evolutionary adaptation

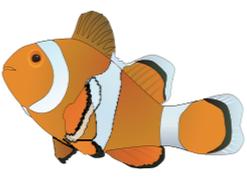
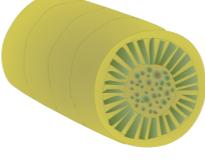
- Response of communities

- Food web, up to predators

Meta-analysis



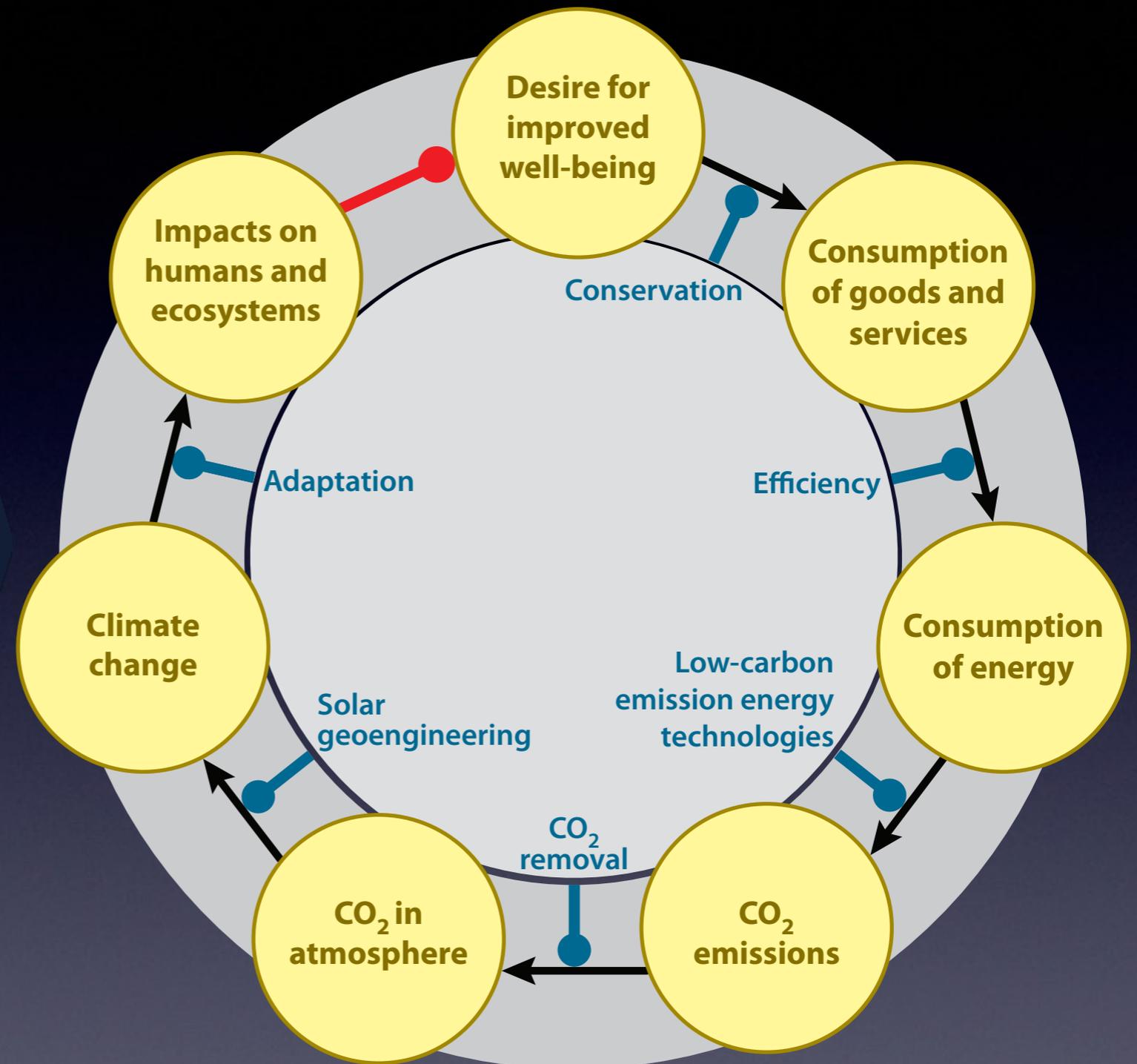
Taxa	Response	Mean Effect
 Calcifying algae	Survival	Not tested
	Calcification	Not tested
	Growth	Not tested
	Photosynthesis	-28%
	Abundance	-80%
 Corals	Survival	Not tested
	Calcification	-32%
	Growth	-23%
	Photosynthesis	Not tested
	Abundance	-47%
 Coccolithophores	Survival	Not tested
	Calcification	-9%
	Growth	Not tested
	Photosynthesis	Not tested
	Abundance	Not tested
 Molluscs	Survival	-34%
	Calcification	-40%
	Growth	-17%
	<i>Development</i>	-25%
	Abundance	Not tested
 Echinoderms	Survival	Not tested
	Calcification	Not tested
	Growth	-10%
	<i>Development</i>	-11%
	Abundance	Not tested

 Crustaceans	Survival	Not tested
	Calcification	Not tested
	Growth	Not tested
	<i>Development</i>	Not tested
	Abundance	Not tested
 Fish	Survival	Not tested
	Calcification	Not tested
	Growth	Not tested
	<i>Development</i>	Not tested
	Abundance	Not tested
 Fleshy algae	Survival	Not tested
	Calcification	Not tested
	Growth	+22%
	Photosynthesis	Not tested
	Abundance	Not tested
 Seagrasses	Survival	Not tested
	Calcification	Not tested
	Growth	Not tested
	Photosynthesis	Not tested
	Abundance	Not tested
 Diatoms	Survival	Not tested
	Calcification	Not tested
	Growth	+12%
	Photosynthesis	Not tested
	Abundance	Not tested

Policy options for action

- UN Framework Convention on Climate Change: Conference of the Parties, IPCC, Conference on Sustainable Development (Rio+20)
- Convention on biological diversity
- Geoengineering
- Regional and local acts, laws and policies to reduce other stresses

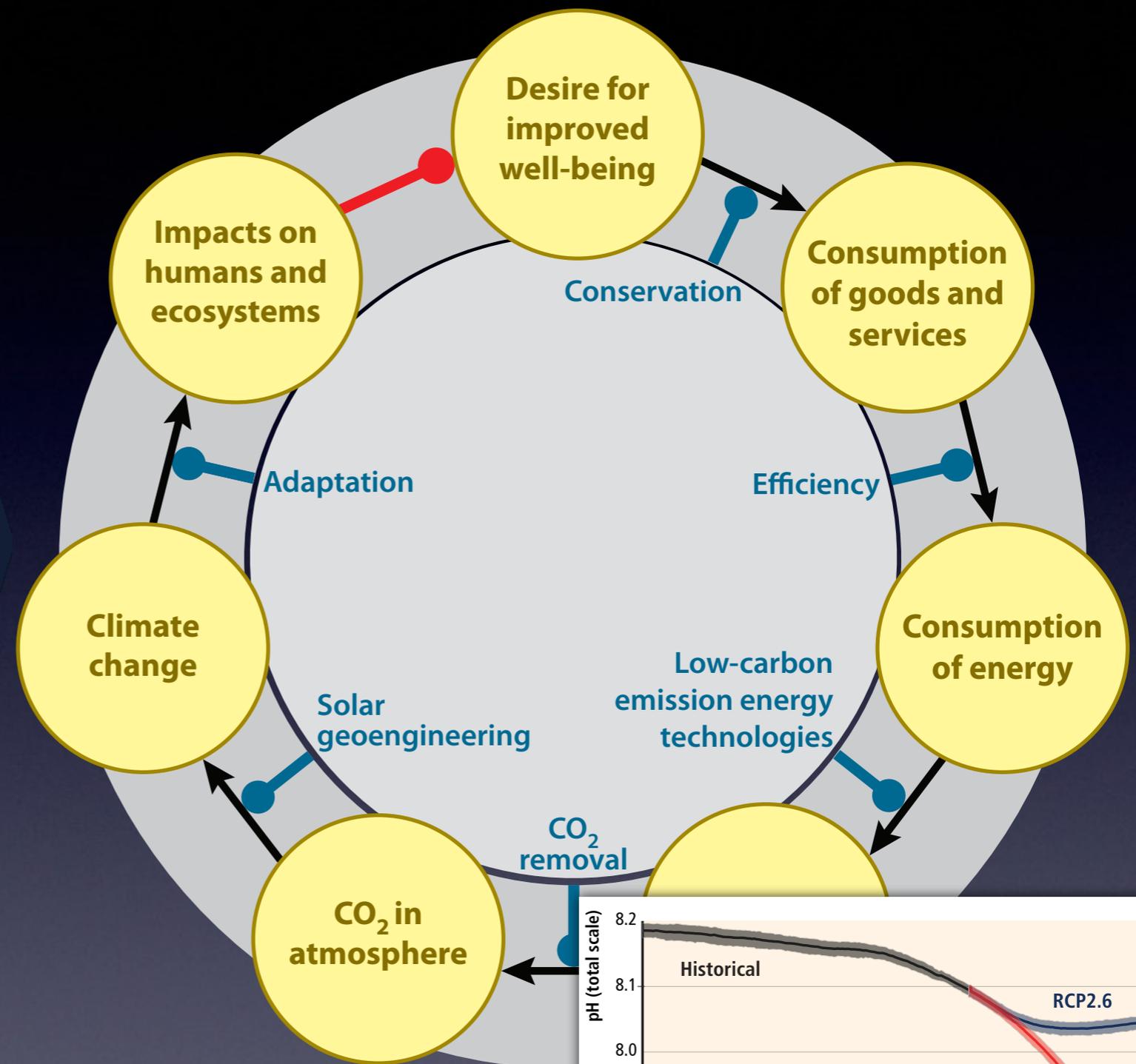
(WGII 30.6.4, 30.7.1)



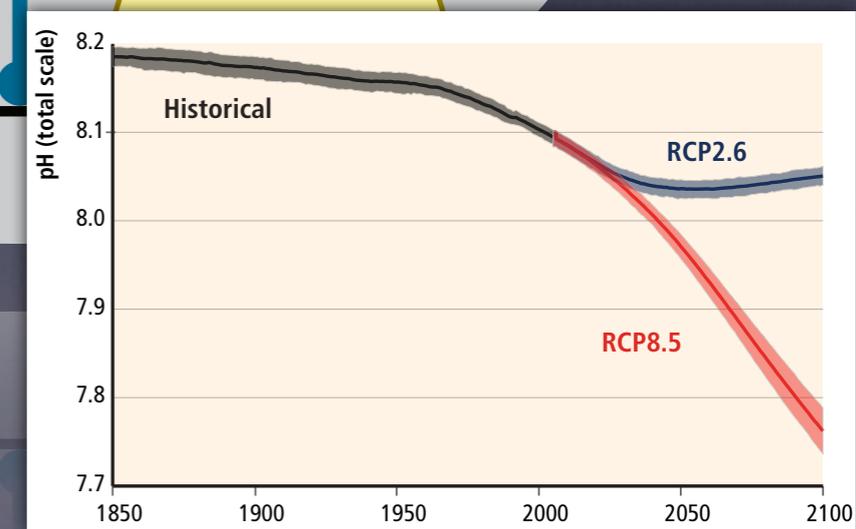
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Caldeira et al. (2013)

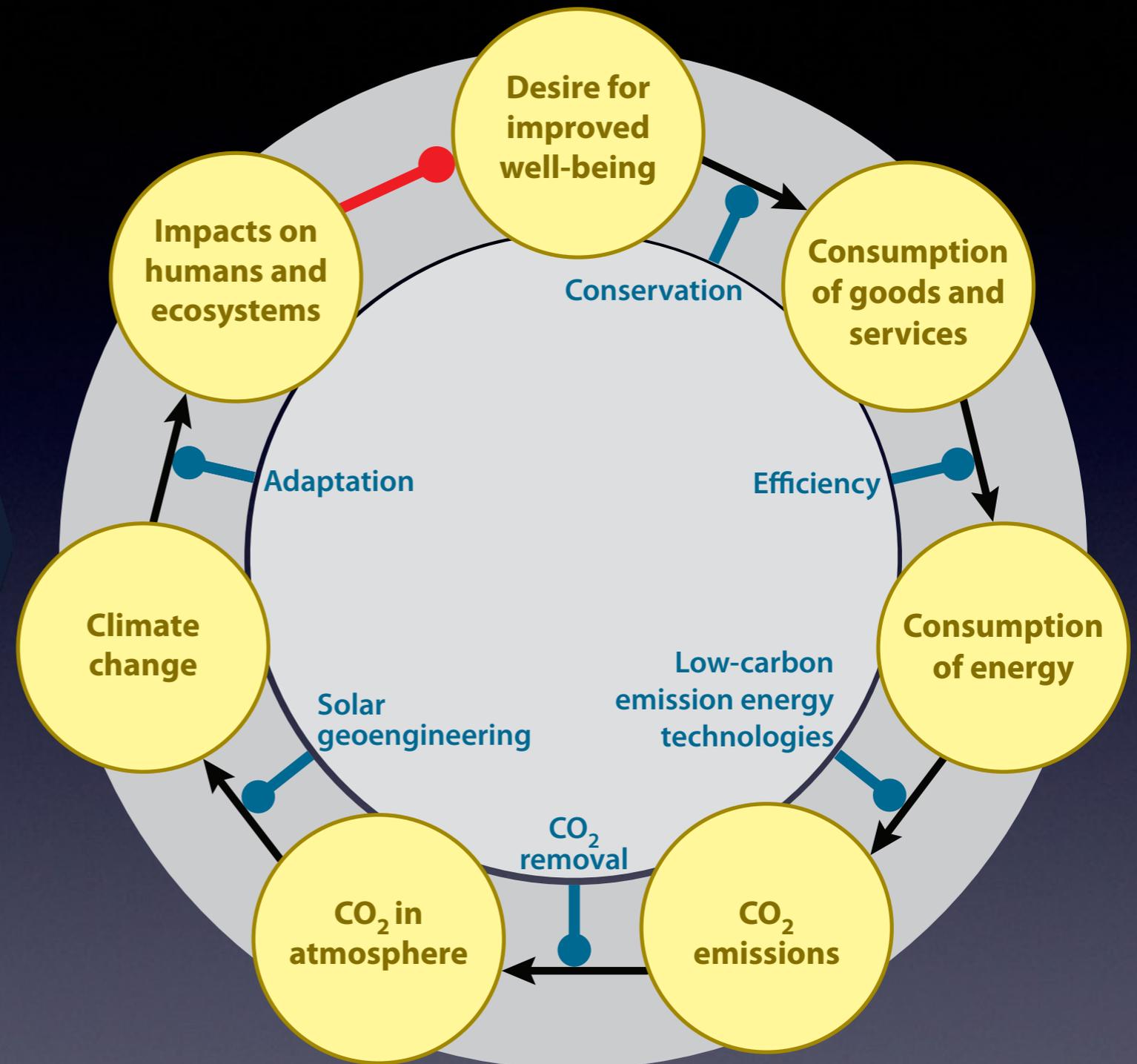


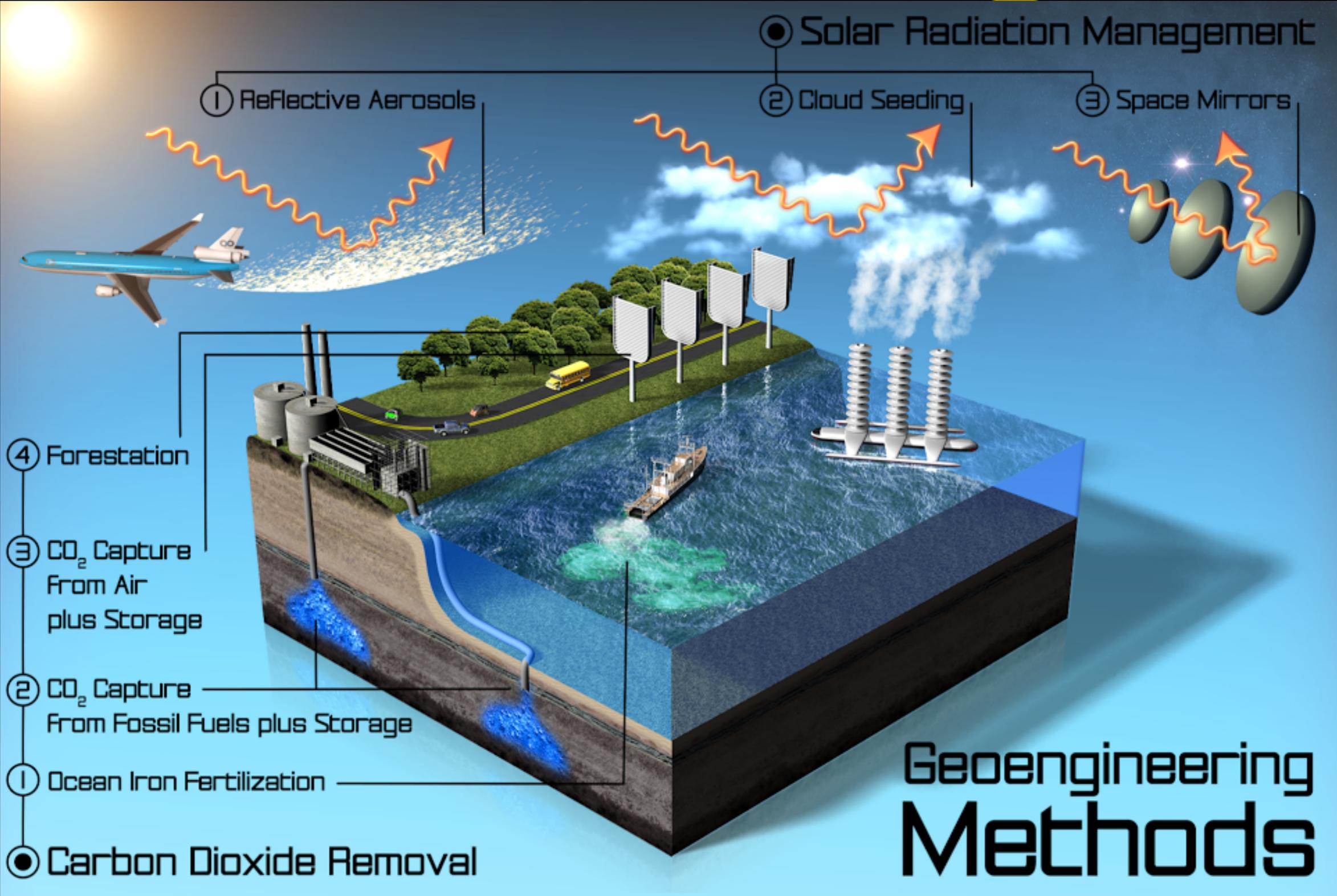
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(WGII 30.6.4, 30.7.1)





mption
 energy

Caldeira et al. (2013)

Geoengineering Methods

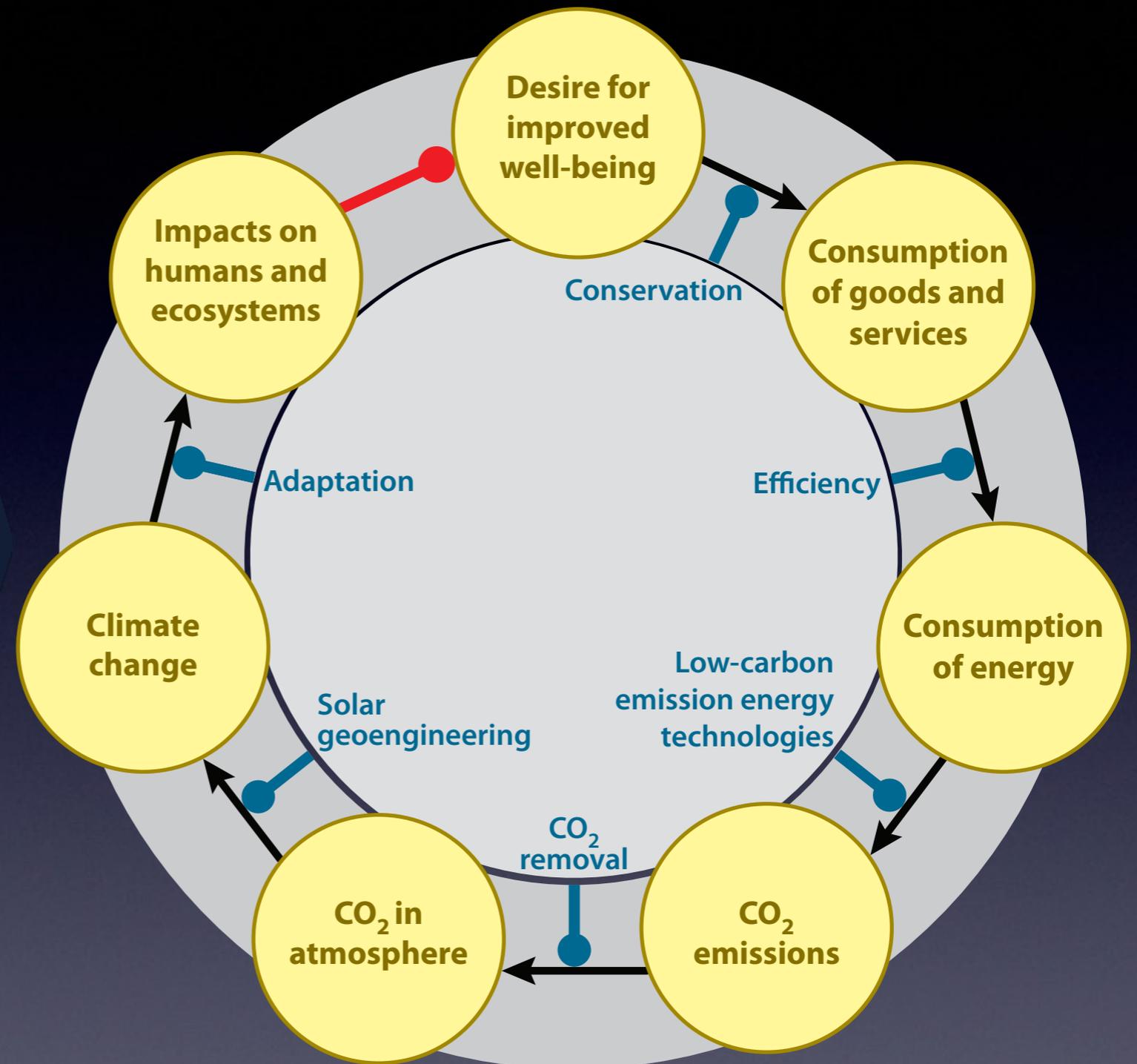
Sources: IPCC / Royal Society | More info: www.get2.cc/5e

climatecentral.org

Policy options for action

- UN Framework Convention on Climate Change: Conference of the Parties, IPCC, Conference on Sustainable Development (Rio+20)
- Convention on biological diversity
- Geoengineering
- Regional and local acts, laws and policies to reduce other stresses

(WGII 30.6.4, 30.7.1)



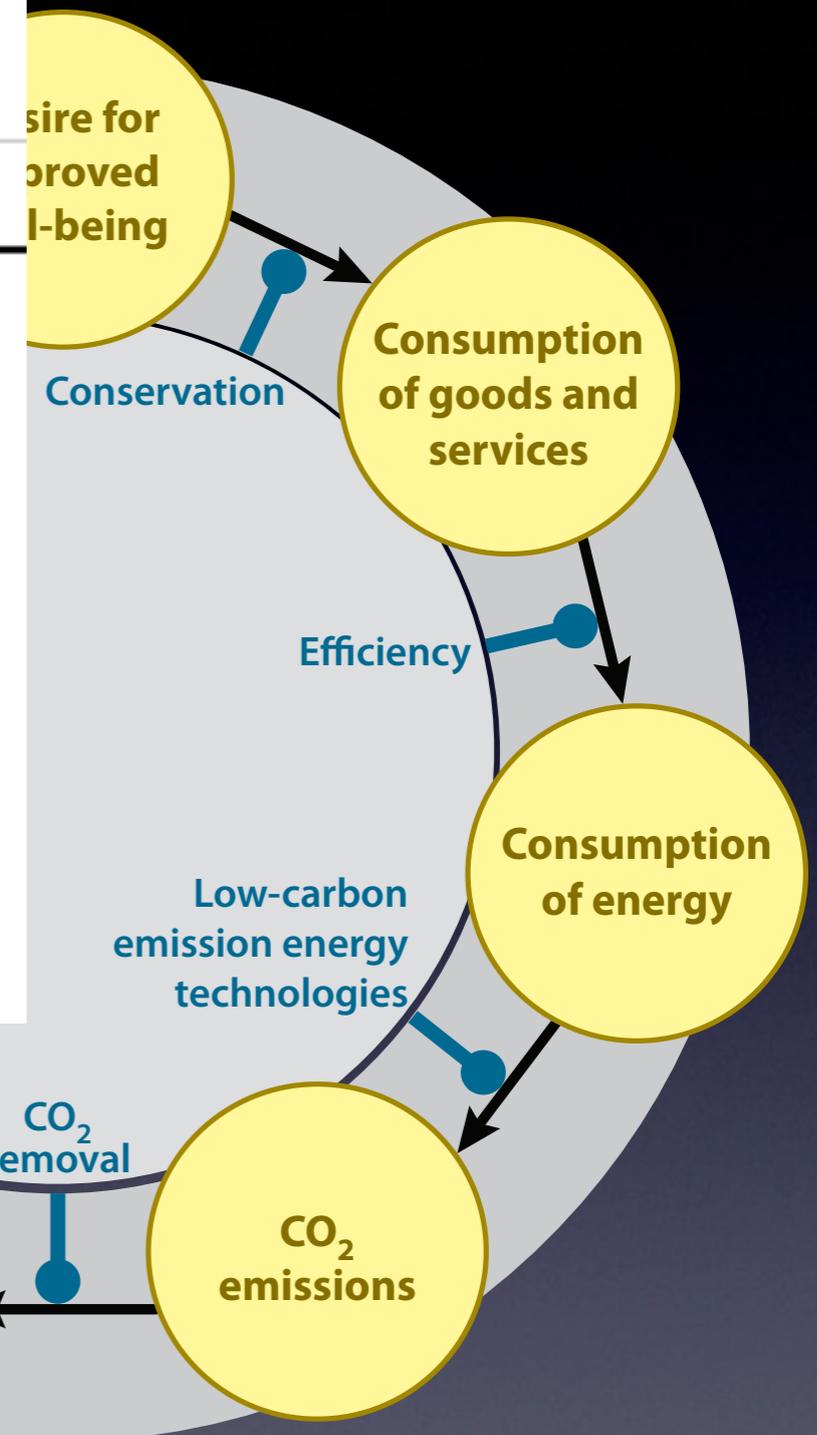
Originally published June 21, 2012 at 9:24 PM | Page modified June 22, 2012 at 1:34 PM

Willapa Bay oyster grower sounds alarm, starts hatchery in Hawaii

A Willapa Bay shellfish company is shifting some of its business to Hawaii because of ocean acidification that scientists believe is killing tiny oyster larvae in shellfish farms along Washington's coast.

and policies to reduce other stresses

(WGII 30.6.4, 30.7.1)

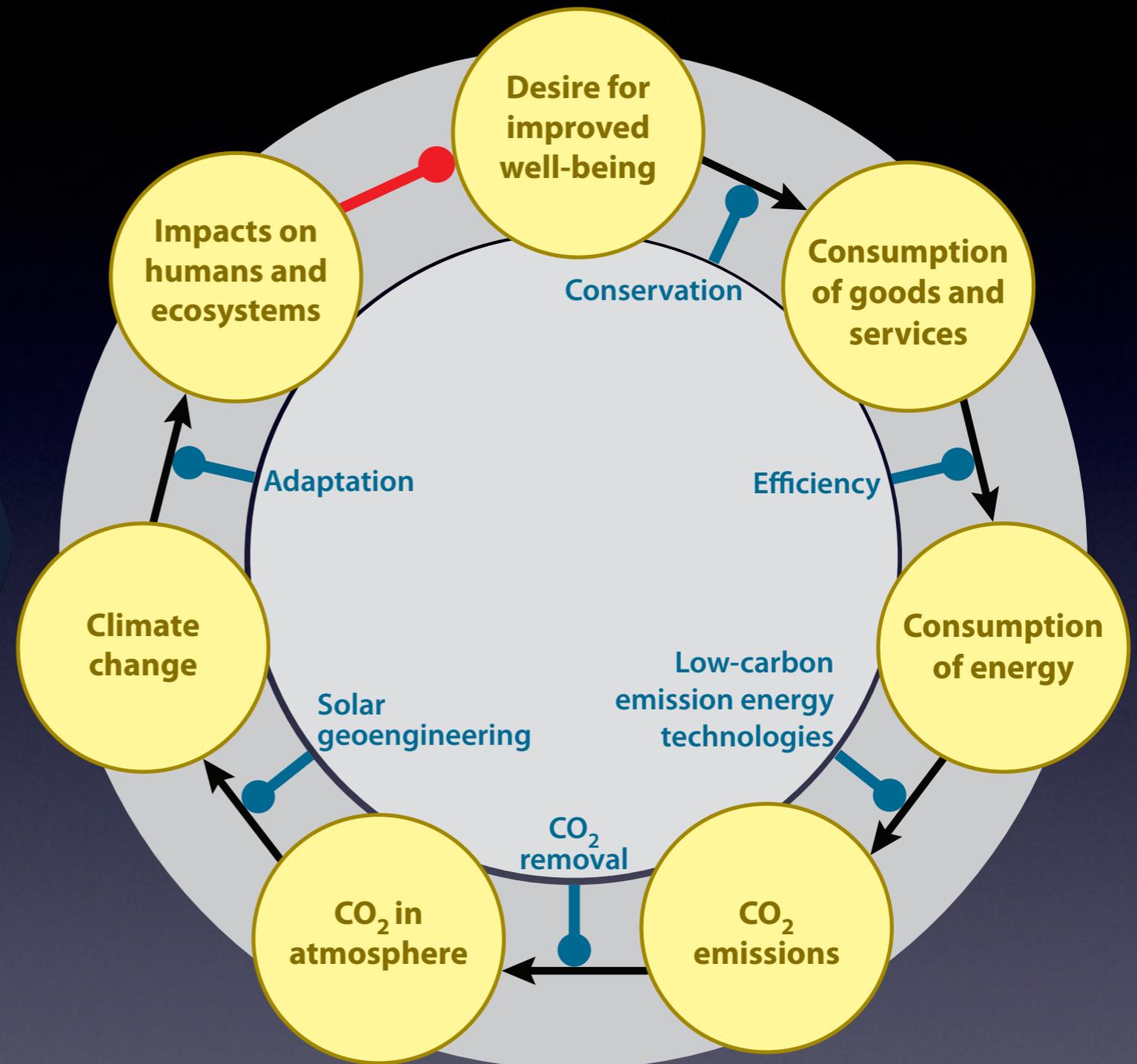


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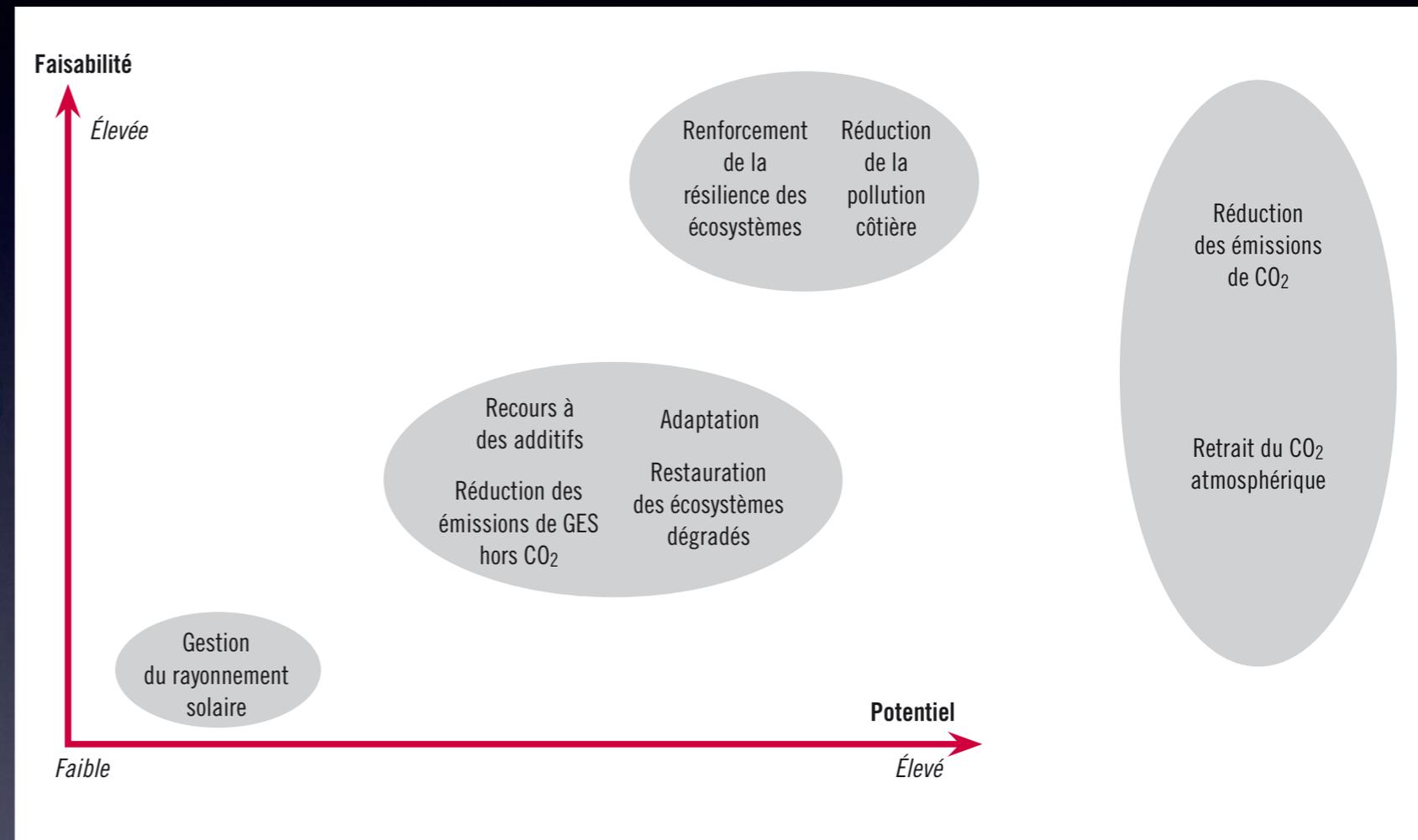


Que faire ?

Policy options for action

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(WGII 30.6.4, 30.7.1)



Billé et al. (2013)

Gattuso et al. (2014; IPCC AR5 WGII)

Dissemination

Messages for Rio+20

Making it clear

A special introductory guide for policy advisers and decision makers

Frequently asked questions about ocean acidification

THE FACTS QUESTIONS ANSWERED

Ocean Acidification: ACTING ON EVIDENCE

Introduction

Ocean acidification is a new field of research in which most studies have been published in the past 10 years. Hence, there are some questions, but many questions remain. Ocean acidification is a multi-disciplinary research area that encompasses topics such as chemistry, paleontology, biology, ecology, biogeochemistry, modeling, and social sciences. Furthermore, some aspects of ocean acidification research, for example the economic assessment, are unique and cross-cutting. For these reasons, the media and the general public find some scientific issues or results confusing.

The U.S. Ocean Carbon and Biogeochemistry (OCB, www.us-ocb.org) program, supported by the European Project on Ocean Acidification (EPOCA), the UK Ocean Acidification Research Programme (www.ukoap.ac.uk), and the UK Ocean Acidification Research Programme (www.ukoap.ac.uk), has compiled a list of frequently asked questions (FAQs). These questions were widely distributed to the research community with the request to draft concise replies summarizing current knowledge, yet avoiding jargon. The replies were then subject to an open peer-review and revision process to ensure availability without any loss of scientific accuracy. The response of the community was enthusiastic. In total, 27 scientists from 19 institutions and 5 countries contributed to the whole process.

We do hope that this FAQ list will prove useful and would like to point out that it is an ongoing process. Anyone is invited to send clarifications or send comments to Sarah Cooley (scooley@veol.com). The list will be revised periodically using this input and maintained at www.us-ocb.org, www.ukoap.ac.uk, and www.oceanacidification.org.uk.

Jean Pierre and Richard Feely (OCB), Jean-Pierre Gattuso (EPOCA), and Carol Turley (UK Ocean Acidification Research Programme)

The name "ocean acidification"

The ocean is not acidic, and model projections say the ocean won't ever become acidic. So why call it ocean acidification?

Ocean acidification refers to the process of lowering the ocean's pH (that is, increasing the concentration of hydrogen ions) by dissolving additional carbon dioxide in seawater from the atmosphere. The word "acidification" refers to lowering pH from any starting point to any end point on the pH scale. This term is used to name other scientific areas (including medicine and food science) to refer to the addition of an acid to a solution, regardless of the solution's pH value. For example, even though seawater's pH is greater than 7 (and therefore considered "basic" in terms of the pH scale), increasing atmospheric CO₂ levels are still causing the ocean's acidity and lowering its pH. In comparison, this language is similar to the word we use when we talk about temperature. If the air temperature moves from +10°C to +5°C (+10°F to +5°F), it is still cold, but we call it "warming." — J. Orr, C.L. Sabine, R. Feely

20 FACTS about Ocean Acidification

This document presents the highlights of the *Frequently Asked Questions* about Ocean Acidification (2010, 2012, www.us-ocb.org), a detailed summary of the state of ocean acidification research and understanding. The FAQs and this fact sheet are intended to aid scientists, science communicators, and science policy advisors asked to comment on details about ocean acidification. In all, 63 scientists from 47 institutions and 12 countries participated in writing the FAQ, which was produced by the Ocean Carbon and Biogeochemistry Project (www.us-ocb.org), the United Kingdom Ocean Acidification Programme (www.ukoap.ac.uk), and the European Project on Ocean Acidification (EPOCA). More information and contacts can be found at any of these websites or at the Ocean Acidification International Coordination Centre's website (www.iaasi.org/ocean-acidification). The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report findings on ocean acidification can be viewed at www.ipcc.ch.

- Ocean acidification (OA) is a progressive increase in the acidity of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO₂) from the atmosphere. It can also be caused or enhanced by other chemical additions or subtractions from the ocean. Acidification can be more severe in areas where human activities and impacts, such as acid rain and nutrient runoff, further increase acidity.
- OA has been well documented with global observations conducted over several decades by hundreds of researchers. It has been definitively attributed to human-generated CO₂ in the atmosphere that has been released primarily by fossil fuel combustion and land use changes.
- Acidity may be thought of as simply the hydrogen ion concentration (H⁺) in a liquid, and pH is the logarithmic scale on which this concentration is measured. It is important to note that acidity increases as the pH decreases.
- Average global surface ocean pH has already fallen from 8.2 pre-industrial value of 8.2 to 8.1, corresponding to an increase in acidity of about 30%. Values of 7.8-7.9 are expected by 2100, representing a doubling of acidity.
- The pH of the open-ocean surface layer is unlikely to ever become acidic (i.e. drop below pH 7.0), because seawater is buffered by dissolved salts. The term "acidification" refers to a pH shift towards the acidic end of the pH scale, similar to the way we describe an increase in temperature from 20°C to 40°C. 40°C is still cold, but we say it's "warming."
- OA is also changing seawater carbonate chemistry. The concentrations of dissolved CO₂, hydrogen ions, and bicarbonate ions are increasing, and the concentration of carbonate ions is decreasing.
- Changes in pH and carbonate chemistry force marine organisms to spend more energy regulating chemistry in their cells. For some organisms, this may leave less energy for other biological processes like growing, reproducing or responding to other stresses.

SECOND INTERNATIONAL SYMPOSIUM ON THE OCEAN IN A HIGH-CO₂ WORLD
MONACO - OCTOBER 6-9, 2008

Monaco Declaration

It was while taking part in the working sessions of the scientific community, which met in Monaco last October for the second international symposium The Ocean in a High CO₂ World, that I expressed my earnest wishes for the Monaco Declaration to be drafted. The seas and oceans absorb one-fourth of the carbon dioxide emitted to the atmosphere from human activities, which in turn is driving their acidification at a rate that is unprecedented. This chemical modification will alter marine ecosystems, upon which over half of the world's population depends for its primary source of food. This declaration, based on amfubante scientific findings and signed by 155 scientists from 26 nations, sets forth recommendations, calling the policymakers to address this immense problem. I strongly support this declaration, which is in full accord with my efforts and those of my Foundation to alleviate climate change. I hope that it will be heard by all the political leaders meeting in Copenhagen in December 2009.

H.S.H. Prince Albert II

ward winning films

one by school children and another by professional film makers

Documents for policy makers – some written by EPOCA's Reference User Group of stakeholders

World leading website and blog on ocean acidification

Dialogue with policy makers and media at climate change negotiations in Copenhagen, Cancun, Capetown and Warsaw

TIPPING POINT

A film by Laurence Jourdan
Camera: Marina Tadjik, Editing: Françoise Boutique
Underwater filming: Yves Glado

Increasing levels of CO₂ in the atmosphere are not only causing global warming. Oceans are absorbing huge quantities of CO₂ which in turn is changing their chemical composition and overall chemistry.

By following leading international researchers, *Tipping Point* will take us around the world and under water to discover how ocean acidification is changing marine ecosystems and what scientific solutions can be found to solve the problem.

Through beautifully shot underwater images and a careful scientific approach, the film tackles the main issues of this relatively new phenomenon by providing solutions before it's too late!

From the producers/directors of Public Enemy Number 1: Carbon and Gulf Stream successfully distributed worldwide.

The film will be available for public projections and events after the 15/12/2010. For more information please contact:

Georama TV Productions
2 rue de la Mare
F-33140 Gabutus
France
tel: +33 (0) 556256
mobile: +33 (0) 6 45594
email: georama@orange.fr

GEORAMATV

TEARMA
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RTP
Ushuaia TV
INFRTE
EUROPEAN COMMISSION
European Research Area
TOTAL FOUNDATION

the other CO₂ problem

A powerful animation from the younger generation on the threat and environmental implications of ocean acidification

ocean acidification

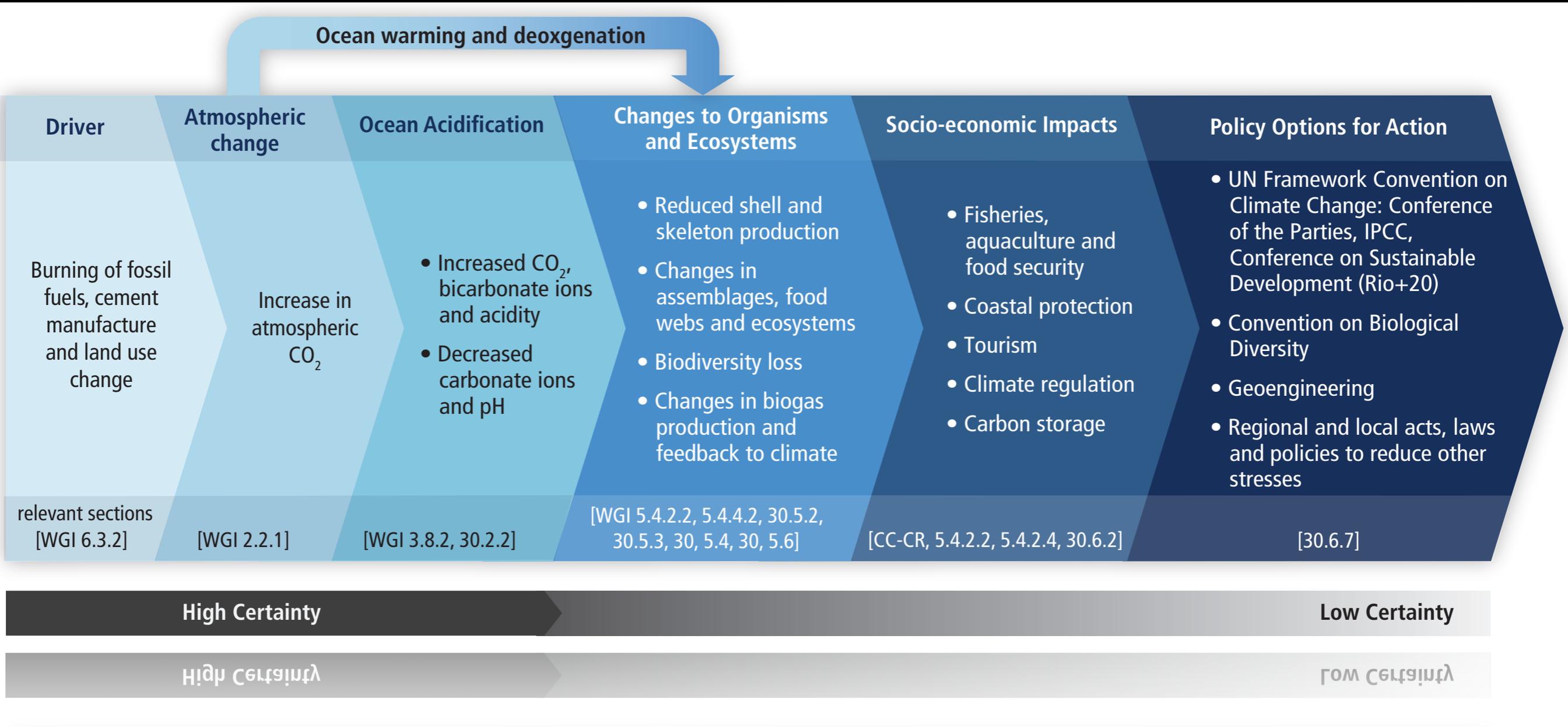
Jean-Pierre Gattuso and Lina Hansson

STARRING

Supporting partners: PML, EPOCA, GEORAMATV, etc.



Conclusion



Conférence climat, Paris (COP21)

- Constitution d'un groupe d'expert : *The Oceans 2015 Initiative*
- Fondation Albert II et Ocean Acidification International Coordination Center
- Information des négociateurs à la lumière des engagements exprimés en mars 2015

Merci !

- Organisateurs de l'Université d'été
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 - Commission Européenne
 - Fondation BNP Paribas
 - Fondation Prince Albert II de Monaco
 - Agence internationale de l'énergie atomique

