Acidification of the Global Ocean: Observational Evidence & Projections to 2100 with the Canadian Earth System Model (CanESM)

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Environment Canada Environnement Canada

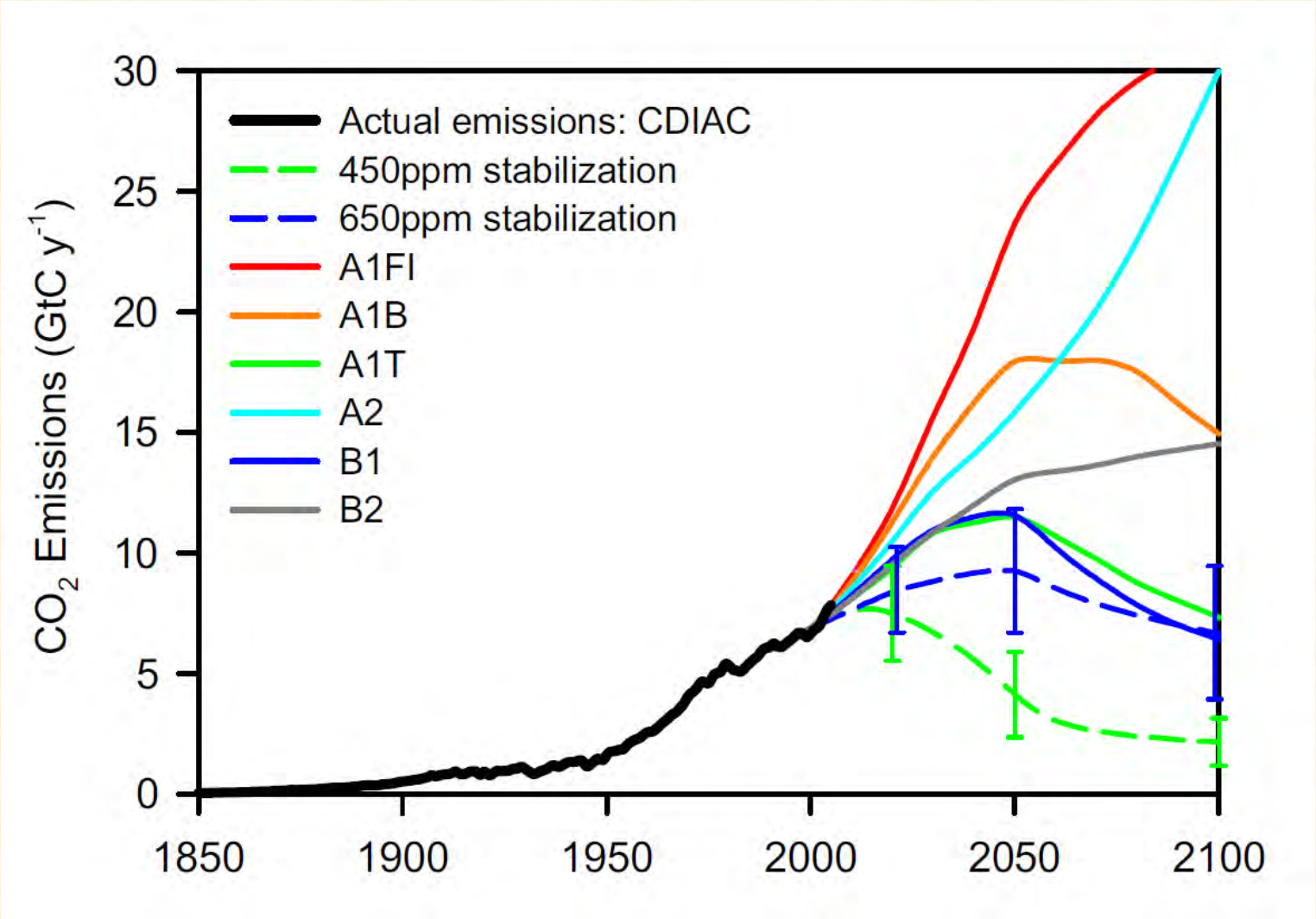
Fisheries and Oceans Canada Pêches et Océans Canada

CCCma

U. Victoria

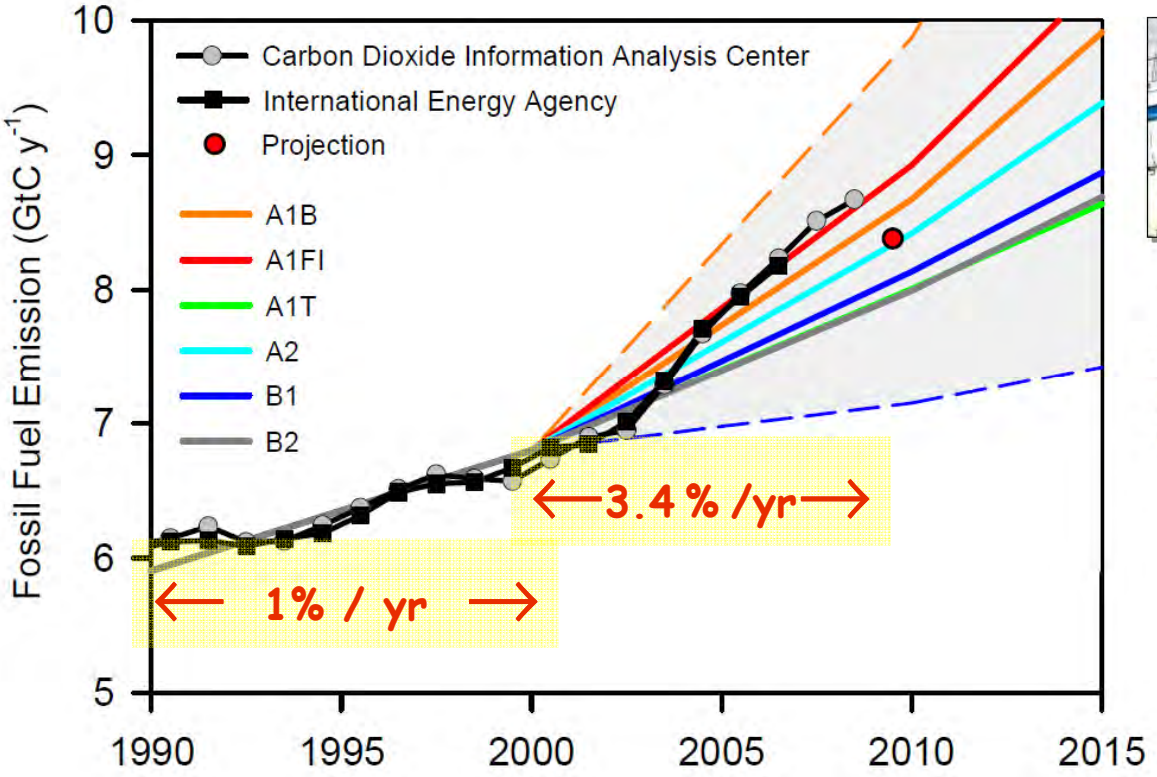
IOS

Future 'SRES' CO_2 Emissions Scenarios



[from Raupach et al.,US. Proc. Natl Acad Sci, Vol. 104, 12 June 2007]

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



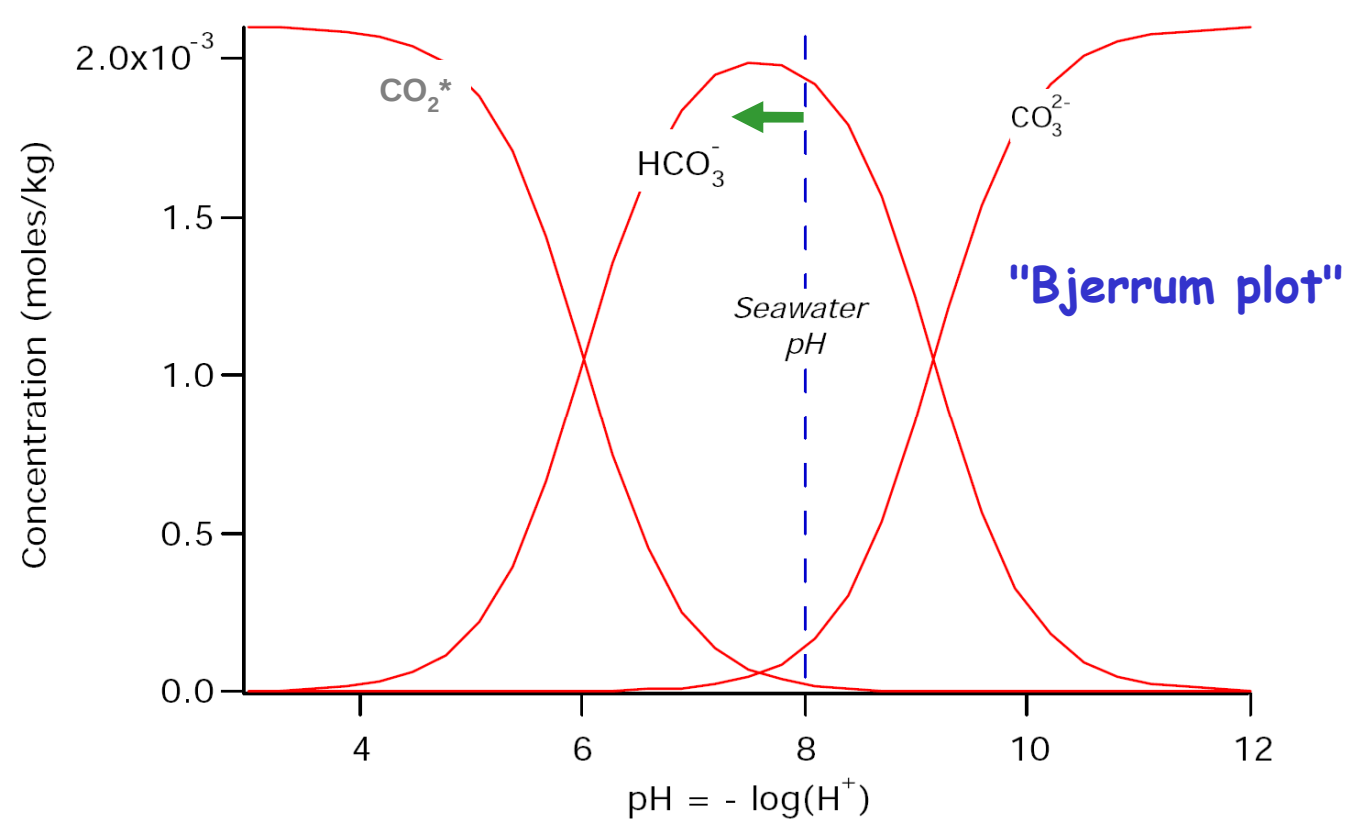
Projection 2009
Emissions: -2.8%
GDP: -1.1%
C intensity: -1.7%

Raupach et al. 2007, PNAS, updated; Le Quéré et al. 2009, Nature-geoscience; International Monetary Fund 2009

Adding CO_2 Increases Ocean Acidity

$$CO_2 + H_2O \underset{}{\overset{K_1}{\leftrightarrow}} HCO_3^- + H^+ \overset{K_2}{\leftrightarrow} CO_3^{2-} + 2H^+$$

$$CO_2 + H_2O + CO_3^{2-} \Rightarrow 2HCO_3^-$$



Open Ocean pH Is Decreasing

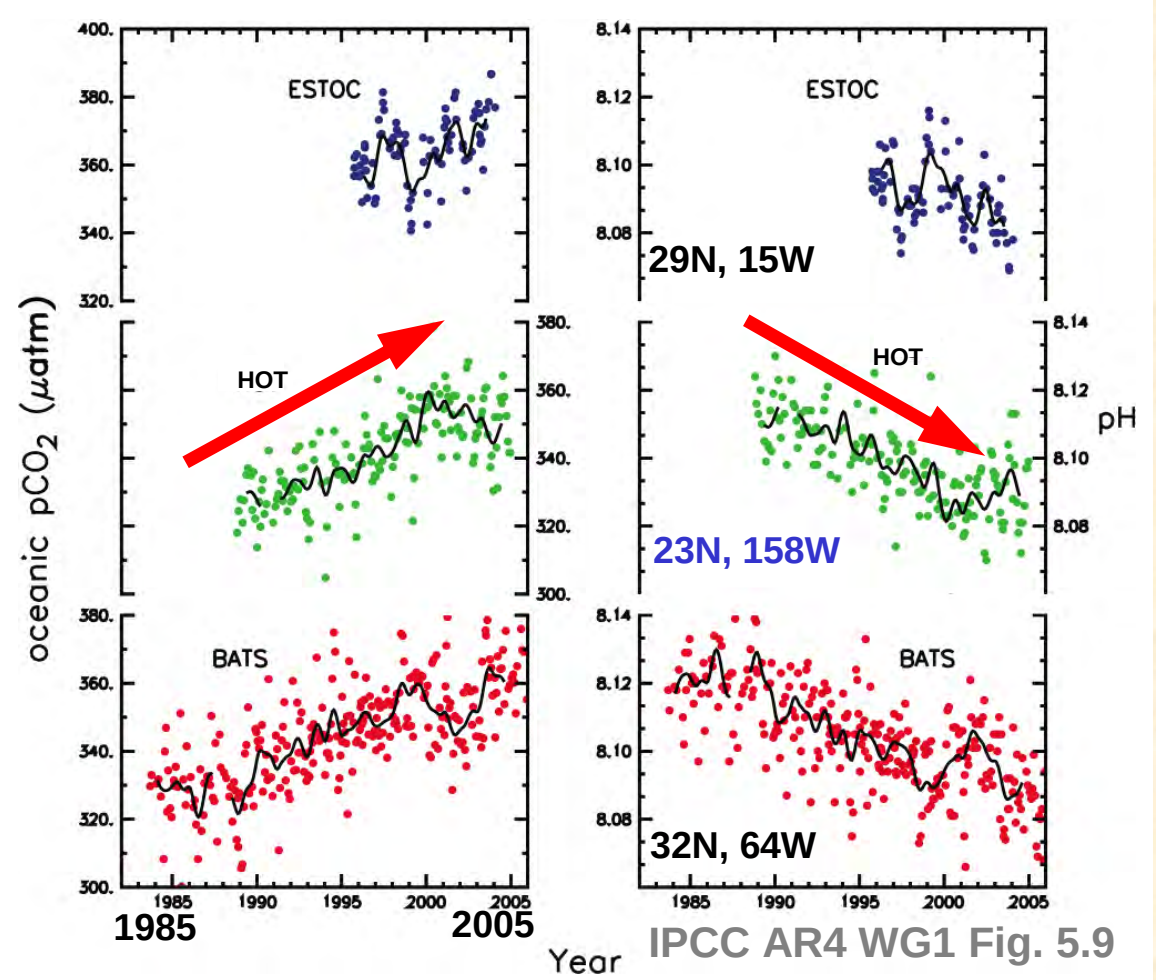
Left

- *Surface pCO_2 increases with time*

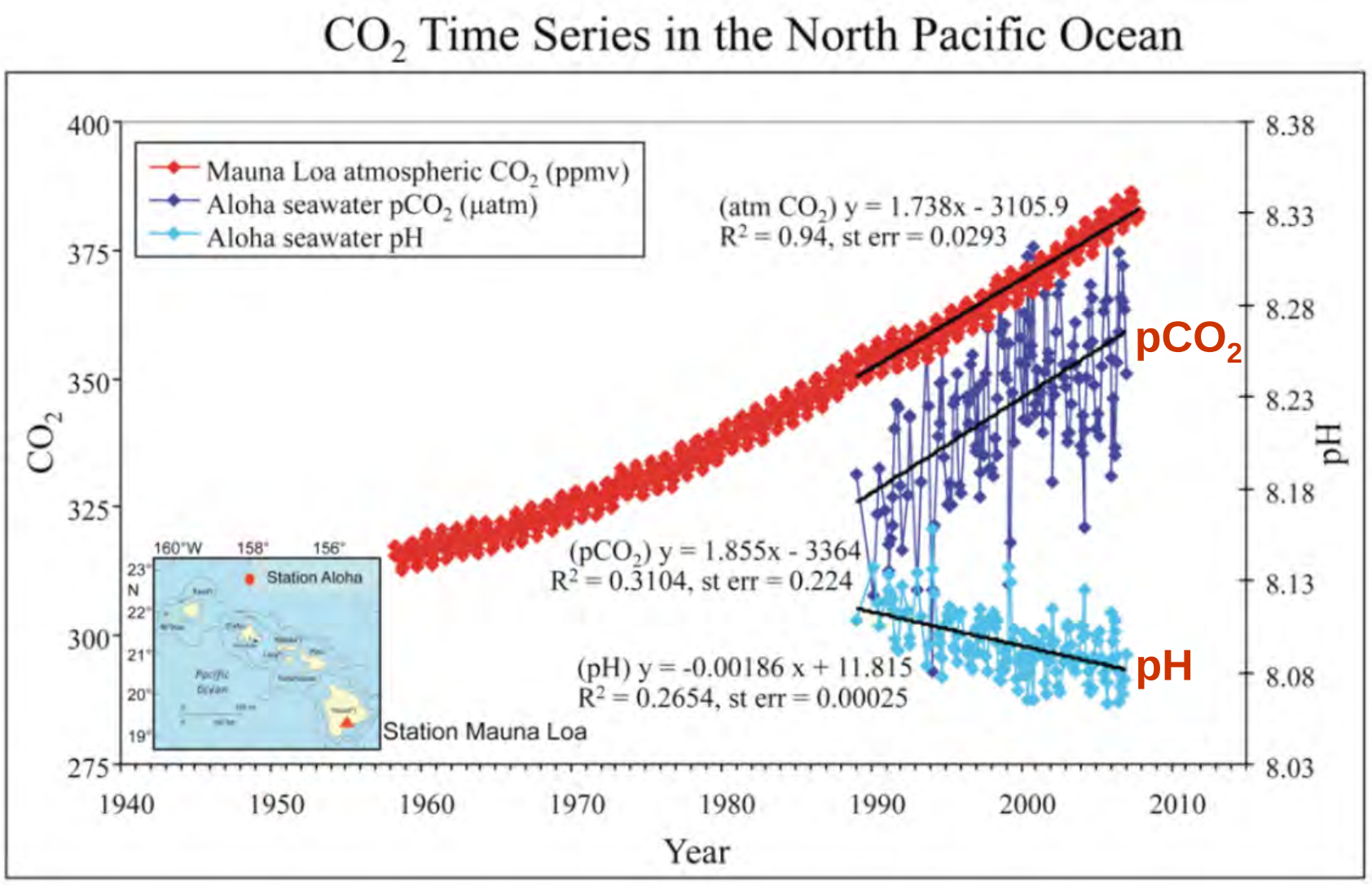
Right

- *Surface pH decreases*

pH = -log [H^+]



Ocean Surface pCO_2 Tracks Atmospheric pCO_2



Iglesias-Rodriguez et al., 2010. Plenary Paper, OceanObs09, ESA Publ. WPP-306

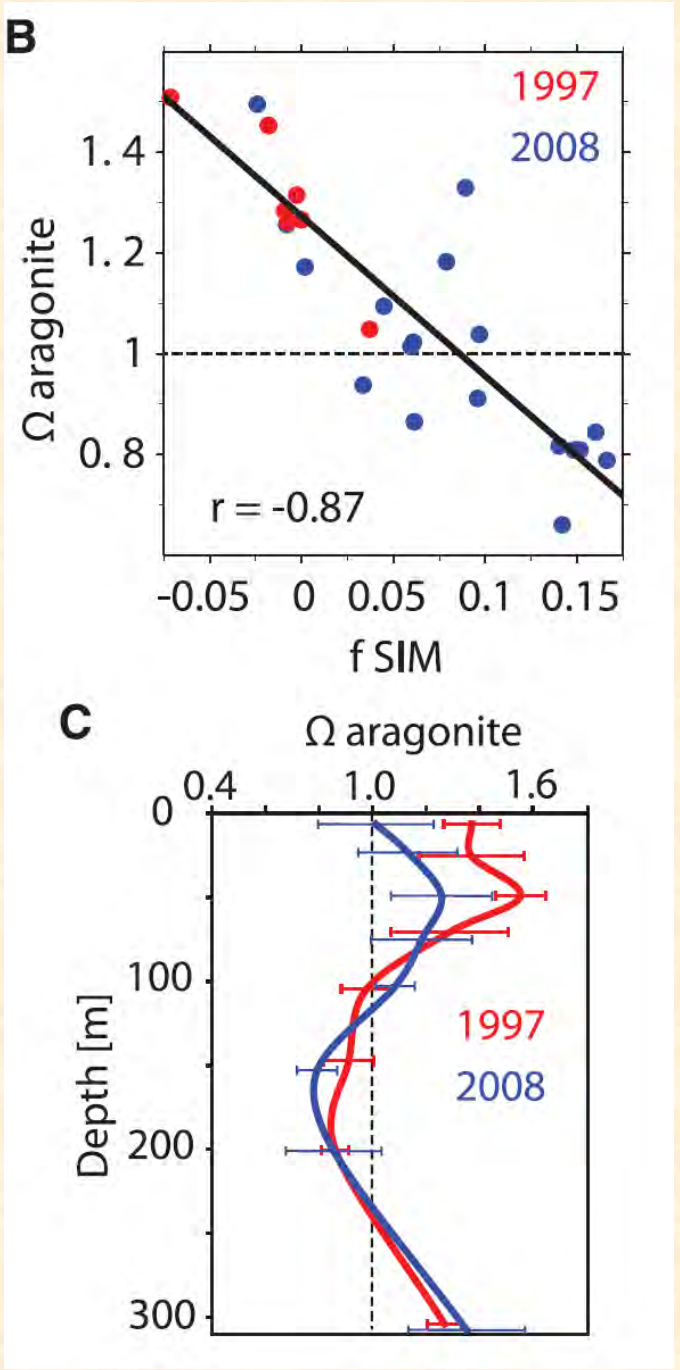
Arctic Ocean Acidification in the Canada Basin

B. Degree of aragonite saturation Ω
versus
Fraction of Sea Ice Meltwater
fSIM (upper 20 m)

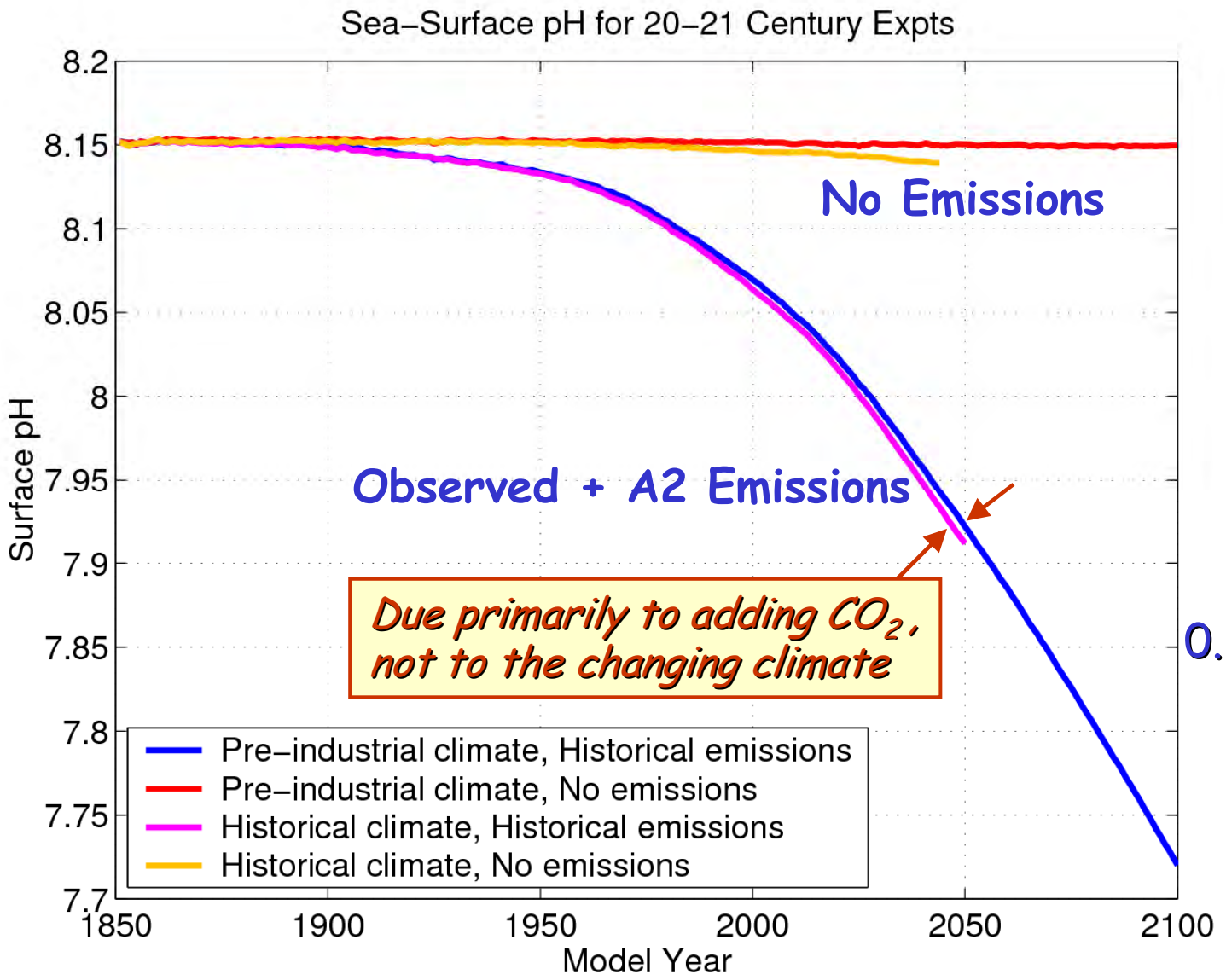
C. Depth profile of aragonite saturation Ω

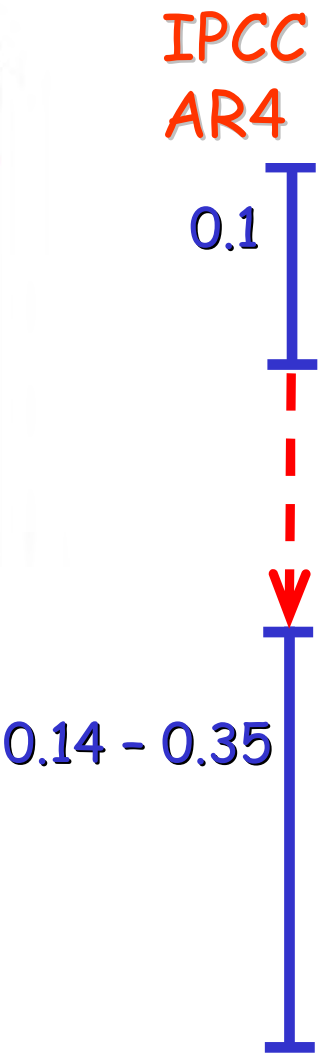
(for stations where bottom >2000m)

Yamamoto-Kawai, McLaughlin, Carmack, Nishino and Shimada, Science, 20 Nov 09

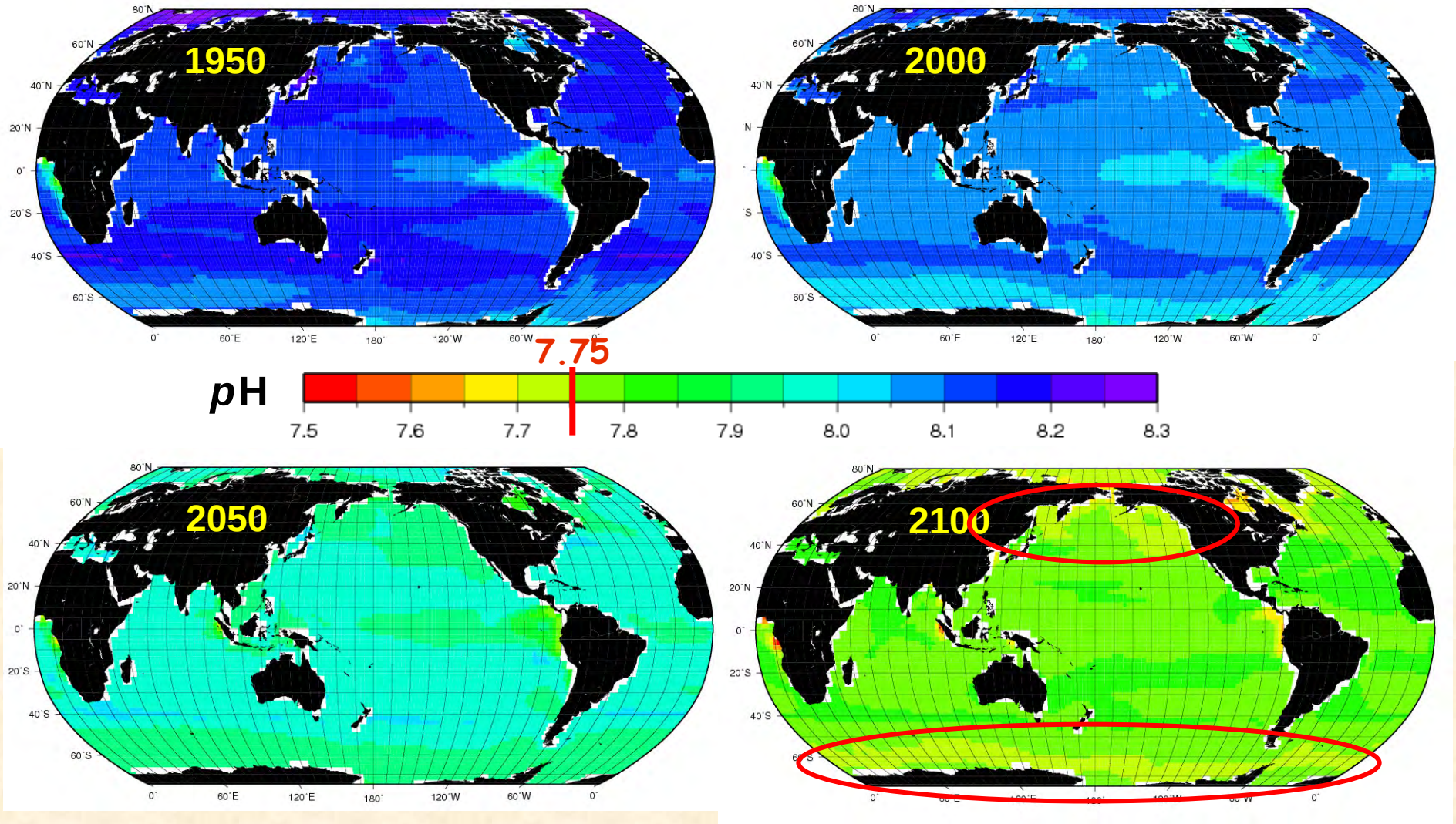


CCCma Ocean Model Surface pH Decrease



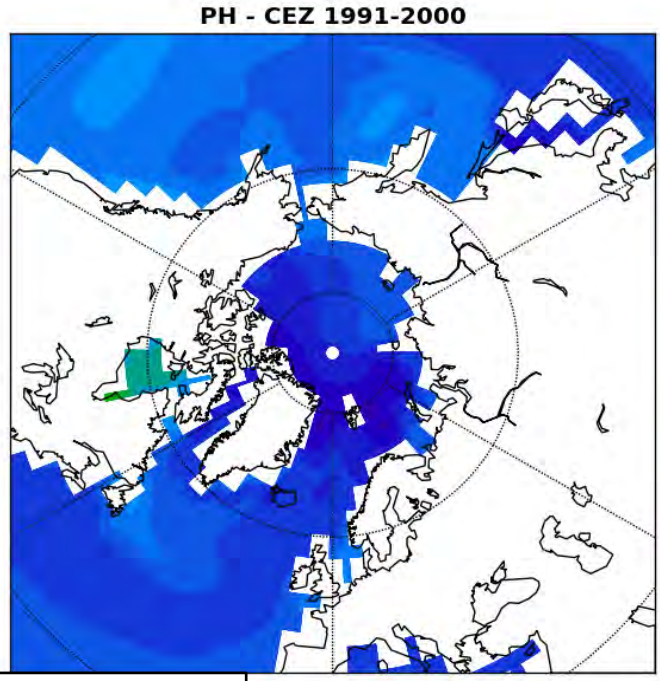


The Acidification of the World Ocean



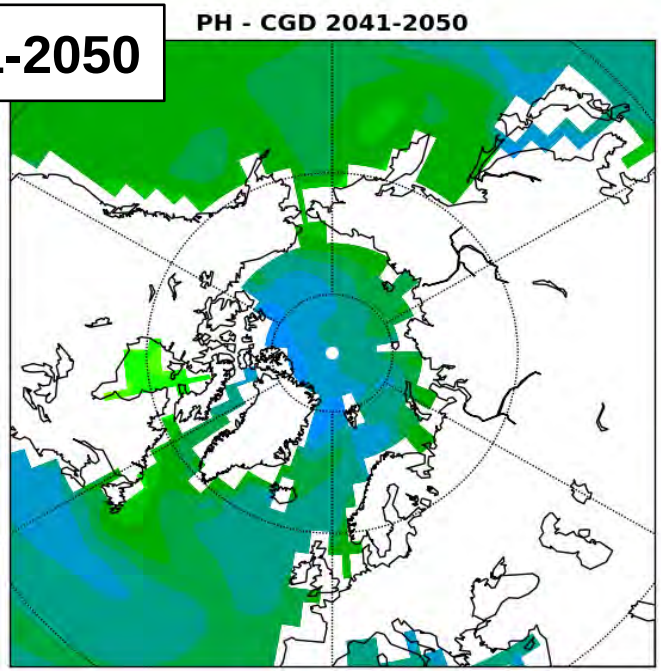
'A2' Scenario from the Canadian Centre for Climate Modelling and Analysis (CCCMA) Earth System Model CanESM1: *Zahariev, Christian & Denman, 2008; Arora et al., 2009, J. Climate; Christian et al., 2010, JGR-Biogeosciences*

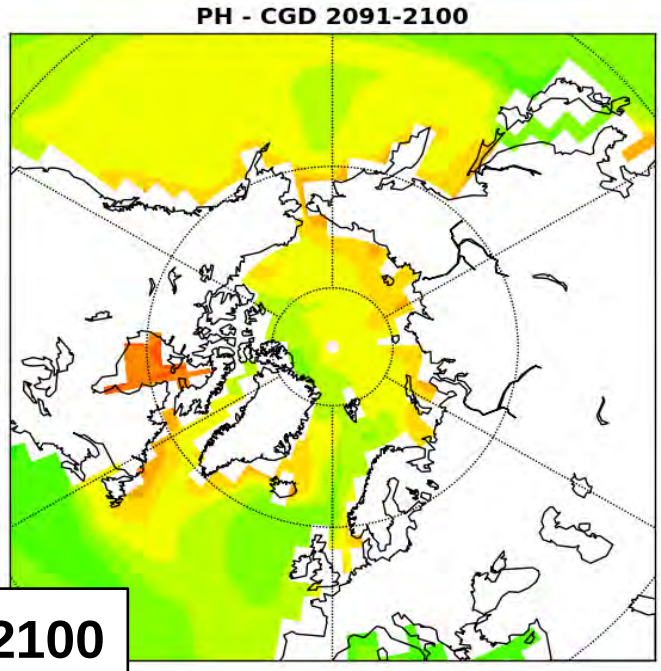
pH in the Arctic Ocean



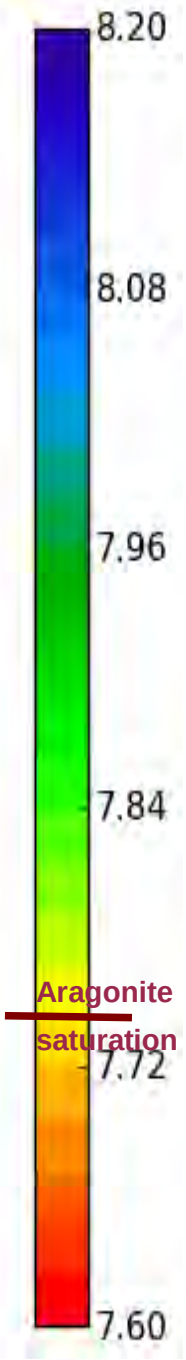
1991-2000

2041-2050





2091-2100



'A2' CanESM1.1 Simulations

[Nadja Steiner, CCCMA/IOS]

IOP Publishing
Environmental Research Letters
Environ. Res. Lett. **4** (2009) 024007 (8pp)
doi:10.1088/1748-9326/4/2/024007

Anticipating ocean acidification's economic consequences for commercial fisheries

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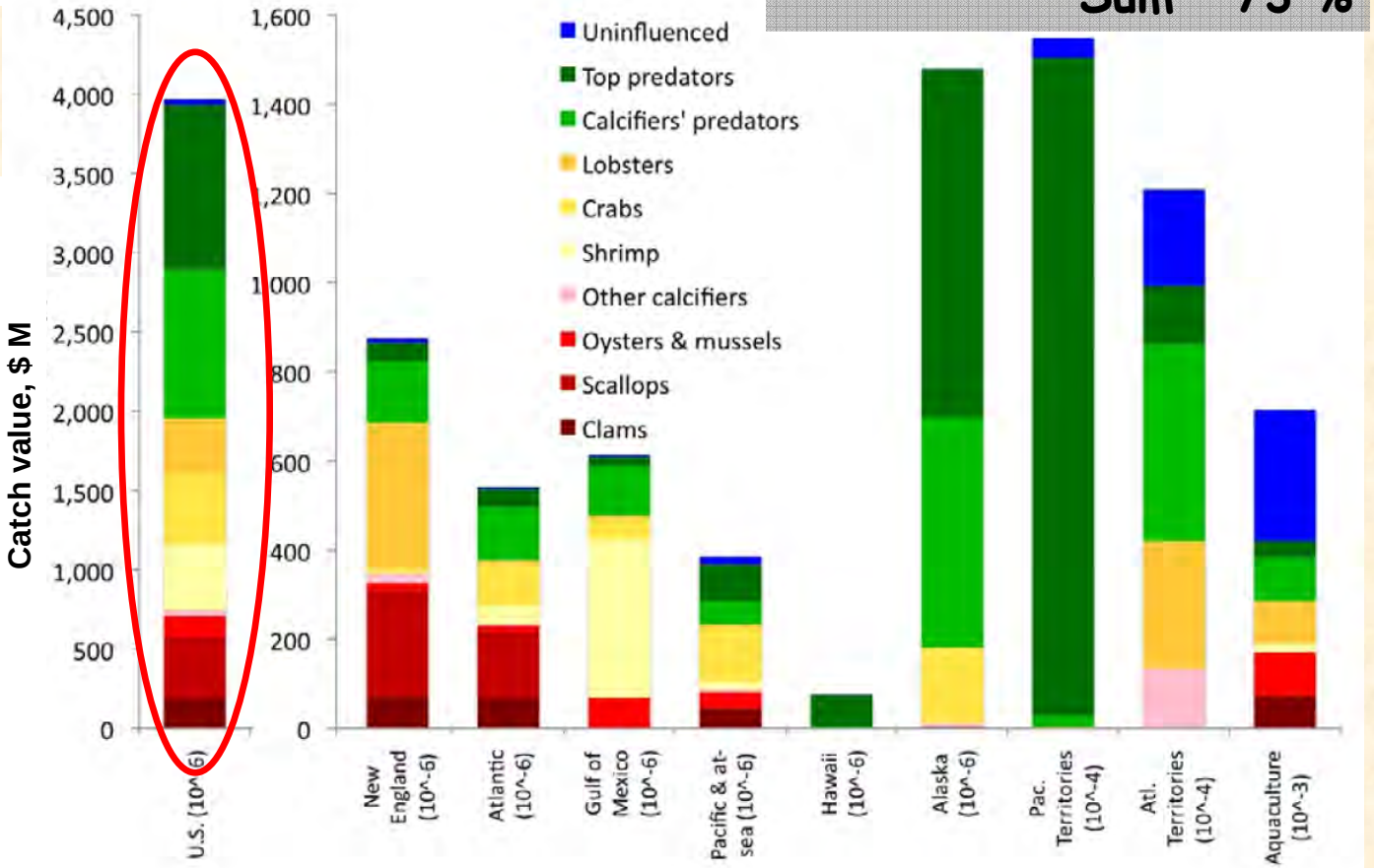
US 2007 Fisheries 'Primary Value'

Mollusks	19%
Crustaceans	30%
Direct Predators on calcifiers	24%
Sum	73 %

Greens - predators

Yellows – primarily calcite $CaCO_3$

Reds – primarily aragonite



Effect of High pCO_2 Besides pH

[P. Brewer & E. Pelzer, Science 324, p327,2009]

Simple oxic respiration: $C_{org} + O_2 \rightarrow CO_2$

The free energy relation is:

$$\Delta G = \Delta G^o - RT \ln\{[fCO_2] / [C_{org}][f\ O_2]$$

Rearranging, simplifying and replacing fugacity f with partial pressure p they define

a **Respiration Index**: $RI = \log_{10}(pO_2 / pCO_2)$

The basic idea is that the lower the ambient O_2, the more energy it takes to transfer O_2 across the cell wall into the organism for respiration, and the higher the ambient CO_2, the more energy required to transfer CO_2 from respiration out of the cell into the surrounding water.

Two classes of geoengineering schemes:

(1) those that affect atmospheric CO_2 concentration (e.g., ocean fertilization) ***[aka 'CDR: Carbon Dioxide Removal']***

(2) those that affect Earth's radiative balance, independently of CO_2 (e.g., stratospheric sulphate aerosol)

[aka 'SRM: Solar Radiation Management']

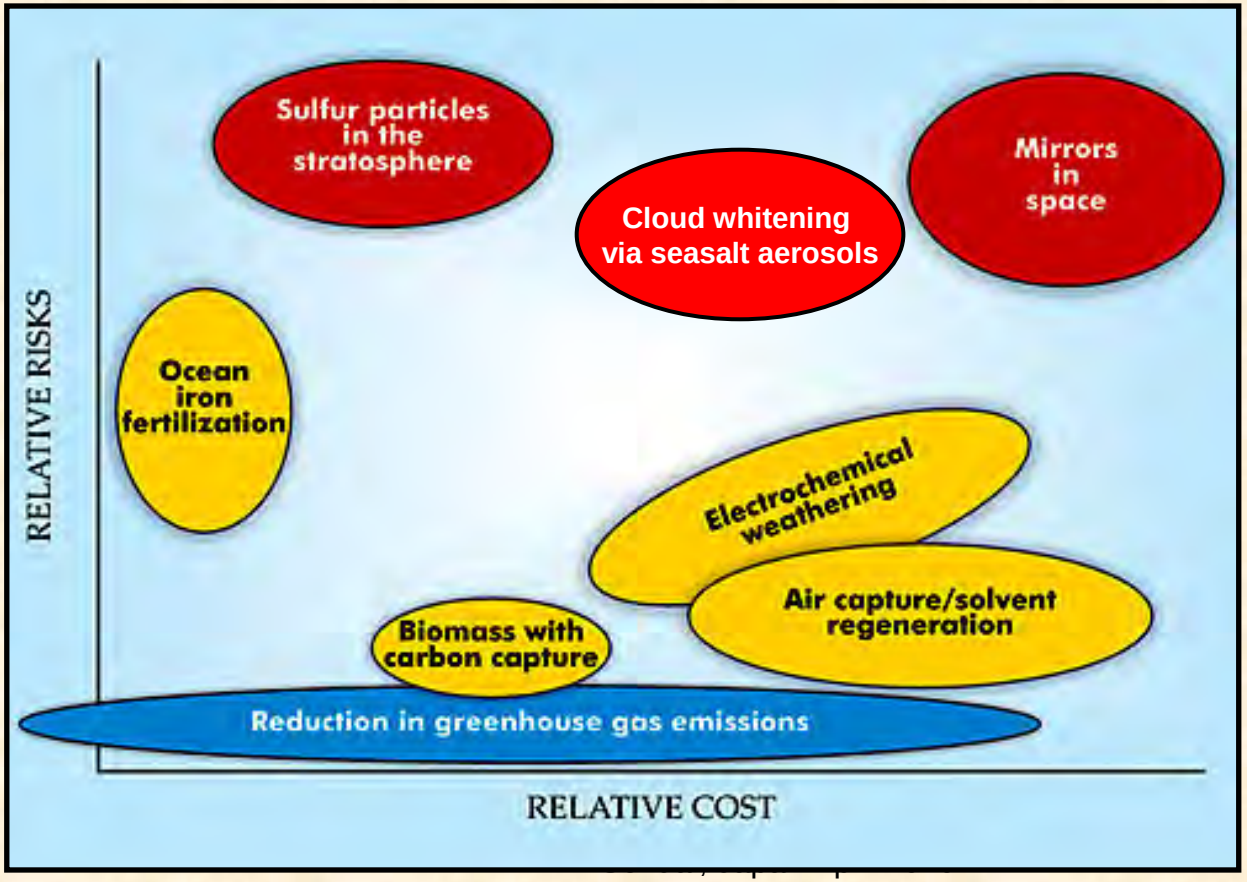
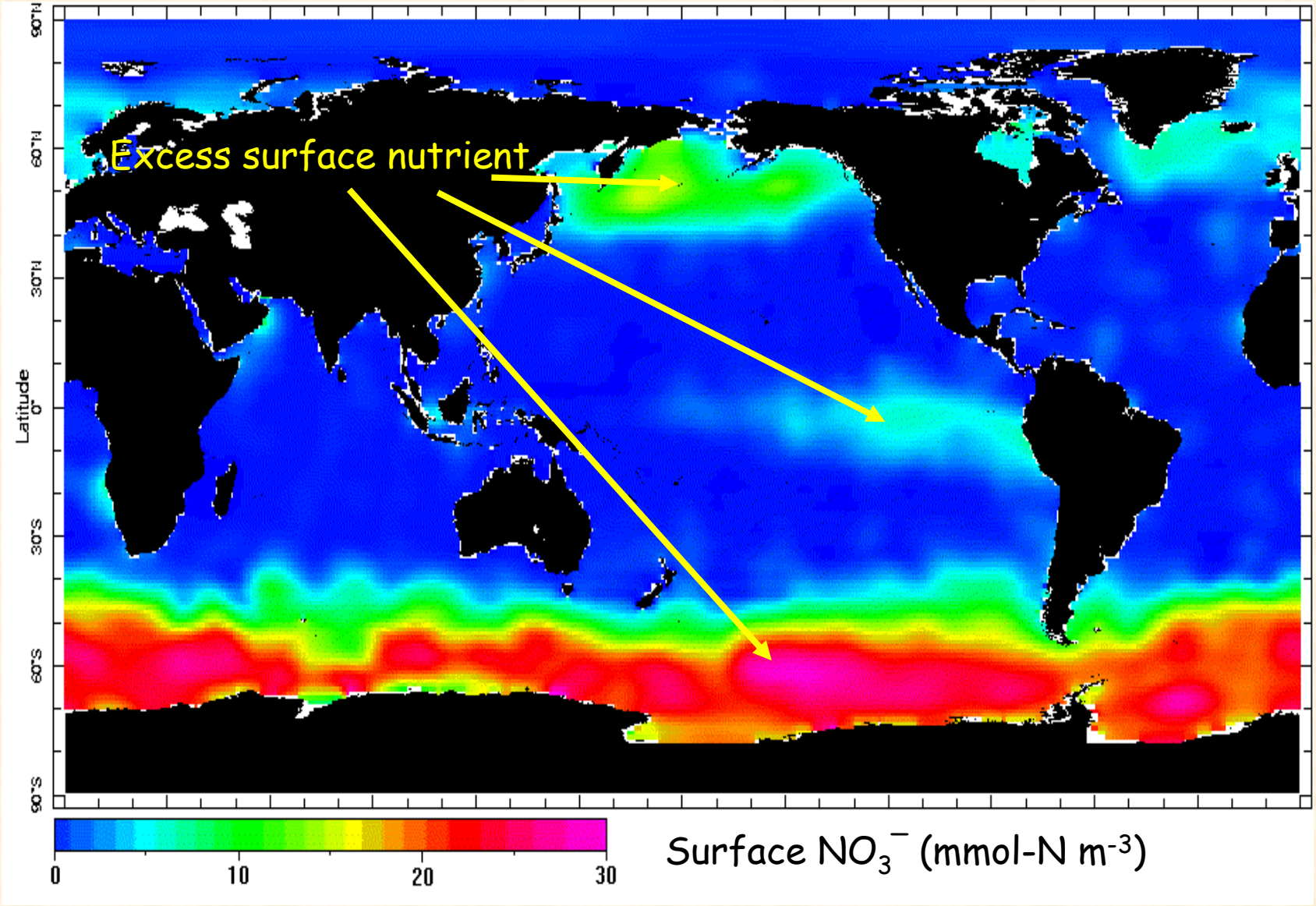


diagram by Kurt House, Harvard University (from Physics Today, August 2008)

Geoengineering by Ocean Iron Fertilization aims to reduce atmospheric CO_2 by shifting 'excess' carbon from surface to subsurface ocean using 'excess' nutrients



Ocean Acidification & Geoengineering

- If we do not limit fossil fuel emissions, we will have accelerating ocean acidification
- Solar Radiation Management can possibly slow climate warming but does nothing to slow ocean acidification
- Iron fertilization may enhance acidification locally and would occur where the oceans are already closest to aragonite $CaCO_3$ undersaturation
- All levels of ecosystem will be affected

Thank-you