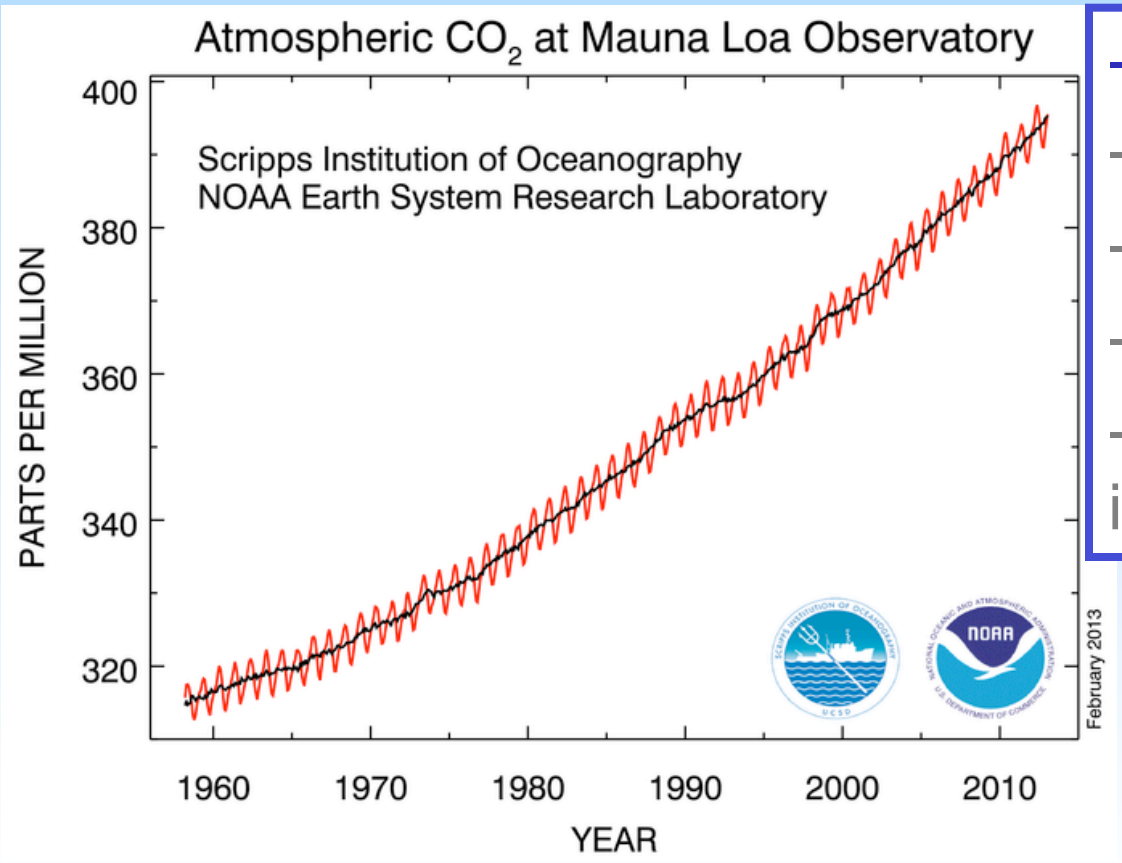
Observing Systems for Constraining Ocean Carbon Uptake and Acidification

Scott Doney
Woods Hole Oceanographic Institution



-Carbon cycle background

-Ocean carbon storage

-Air-sea CO_2 flux

-Ocean acidification

-Autonomous platforms & in-situ sensors

Fate of Anthropogenic CO_2 Emissions (2000-2009)

1.1±0.7 Pg C y^{-1}

+

7.7±0.5 Pg C y^{-1}

4.1±0.1 Pg C y^{-1}

Atmosphere 47%

2.4 Pg C y^{-1}

Land 27%

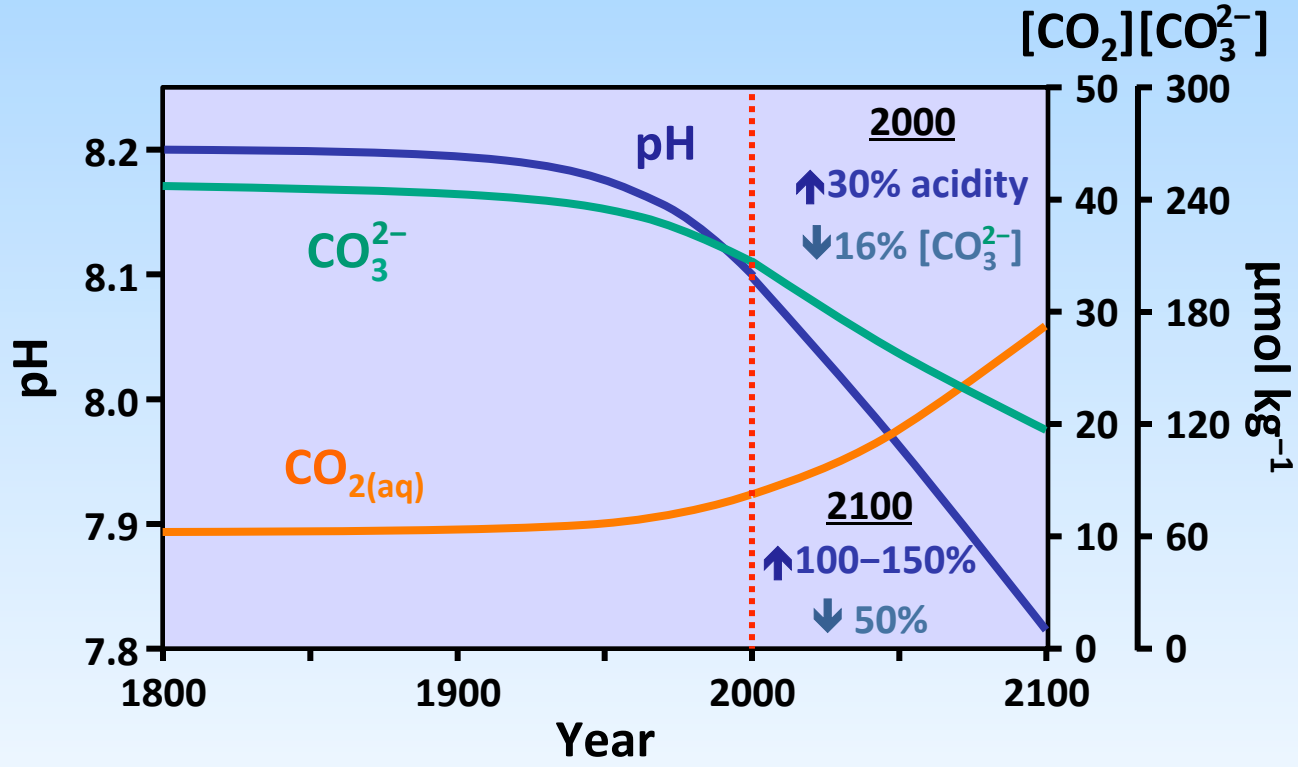
2.3±0.4 Pg C y^{-1}

Oceans 26%

LeQuere et al. Nature Geosciences 2009; Global Carbon Project 2011

Ocean Acidification

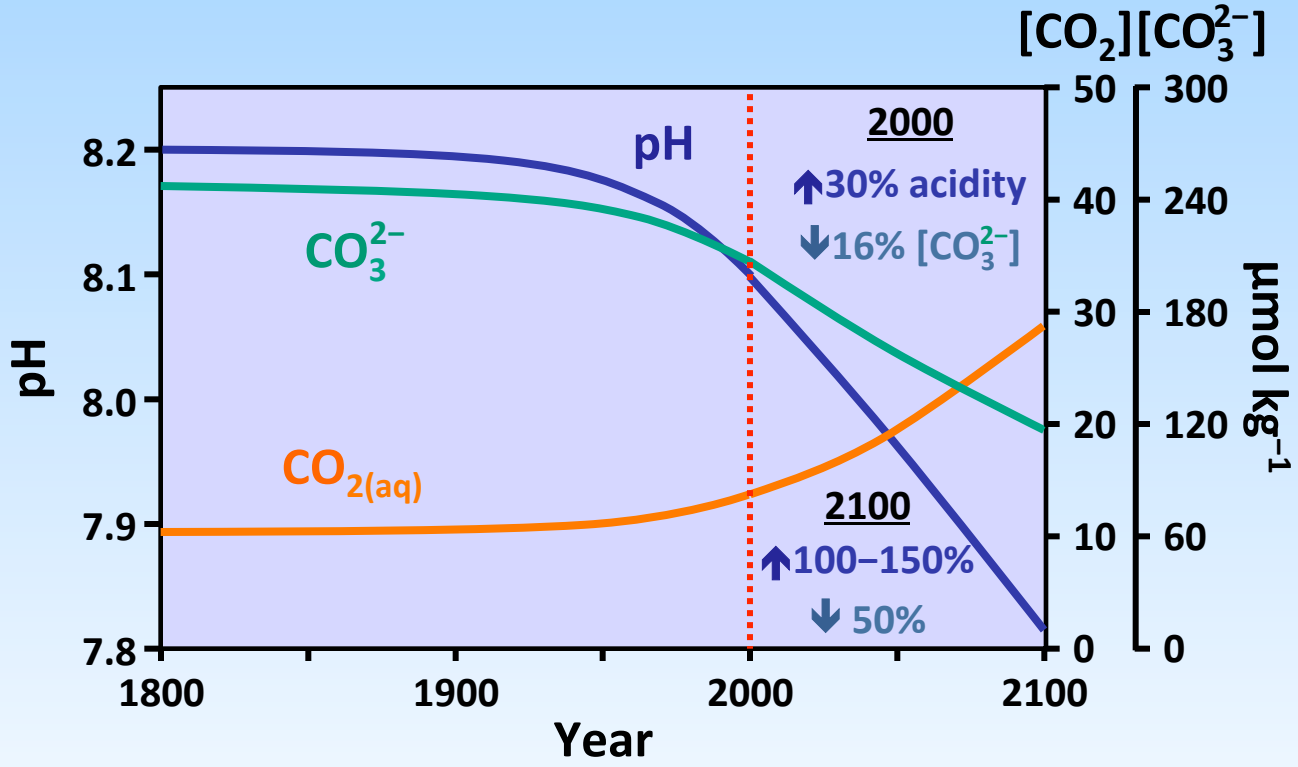
$$CO_2 + H_2O \longrightarrow H^+ + HCO_3^- \qquad H^+ + CO_3^{2-} \longrightarrow HCO_3^-$$



Wolf-Gladrow et al. (1999)

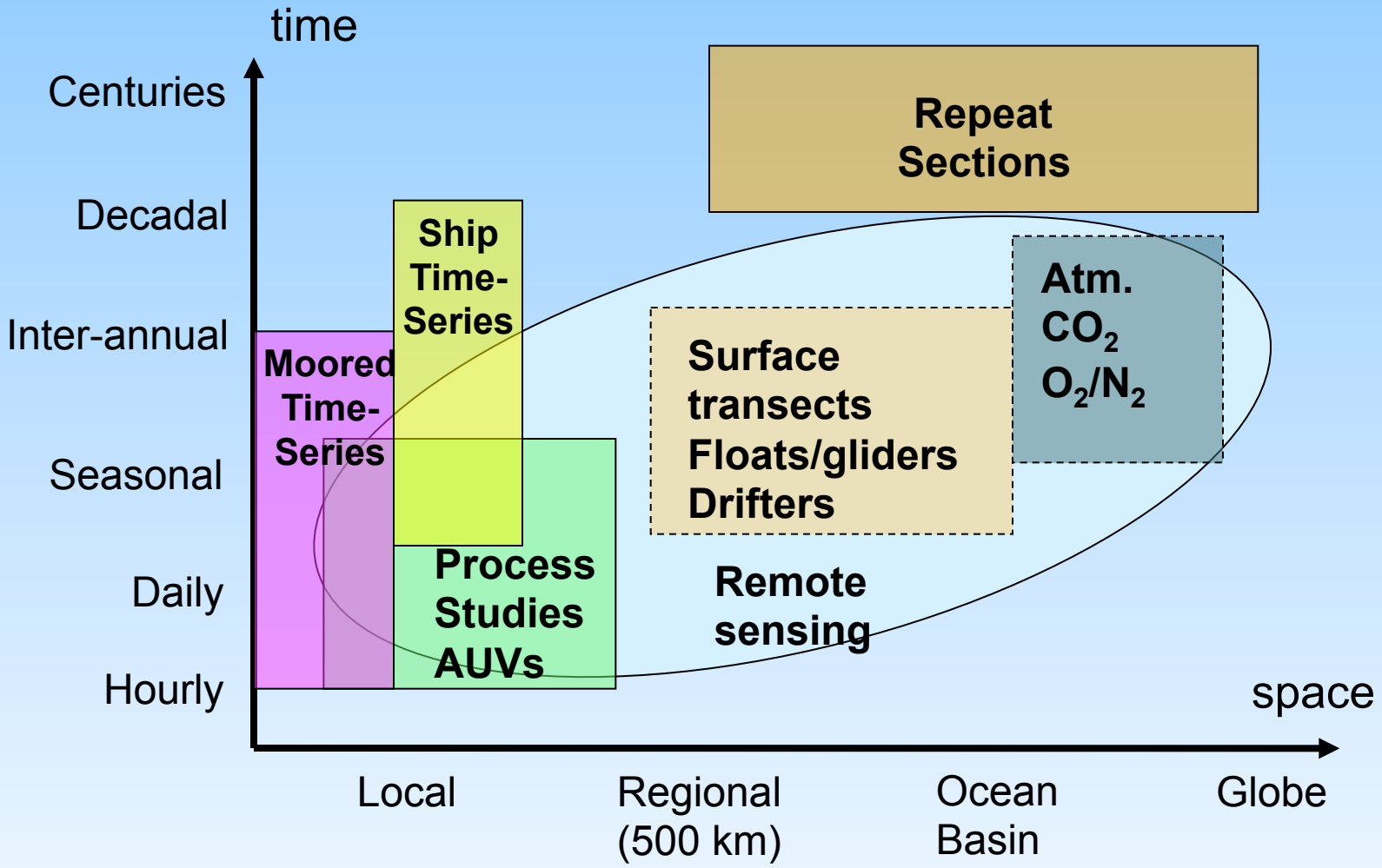
Ocean Acidification

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



Wolf-Gladrow et al. (1999)

Requires Integrated Observational System



-Combine multiple approaches with models & process studies
-Measure 2 of 4 inorganic carbon parameters (dissolved inorganic carbon, alkalinity, pH & pCO_2)

Talk Outline

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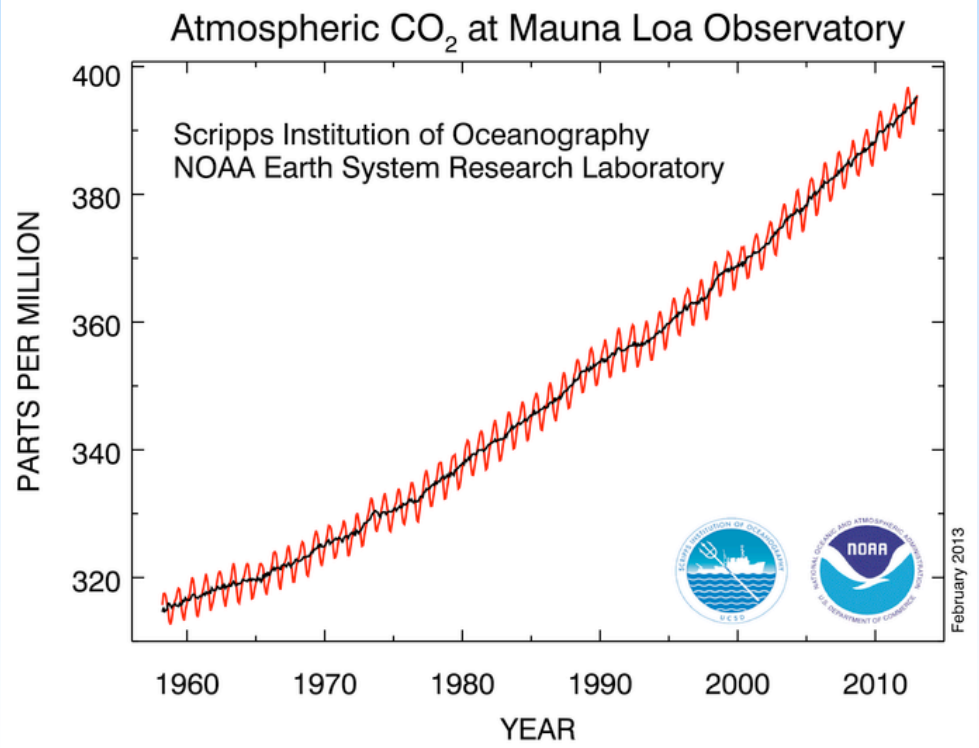

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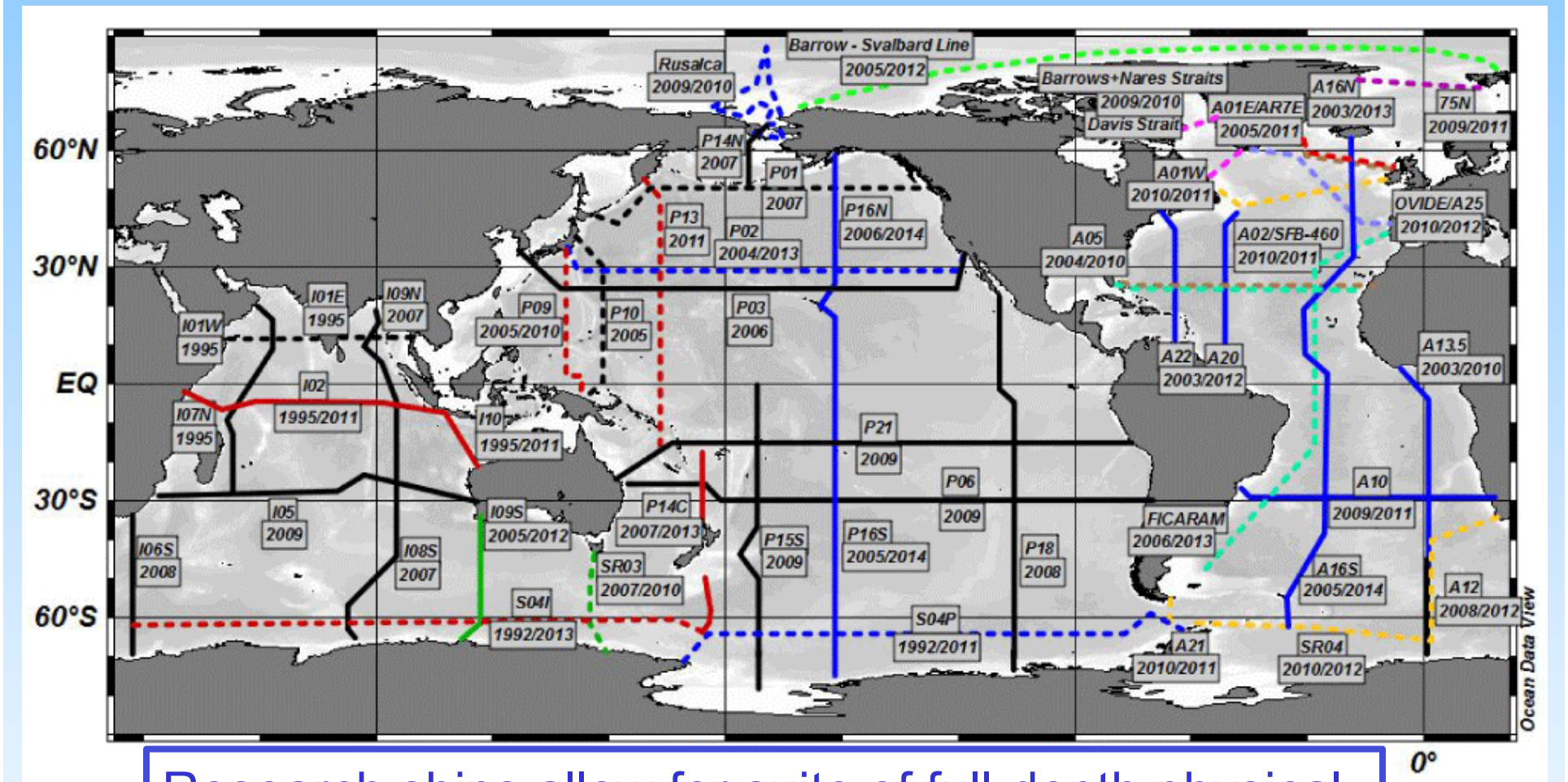
Repeat Hydrography/CO_2 Program



Research ships allow for suite of full-depth physical, biogeochemical & tracer measurements

U.S. Repeat Hydrography (ushydro.ucsd.edu), Go-ship (Go-ship.org)
International Ocean Carbon Coordination Project (www.ioccp.org)

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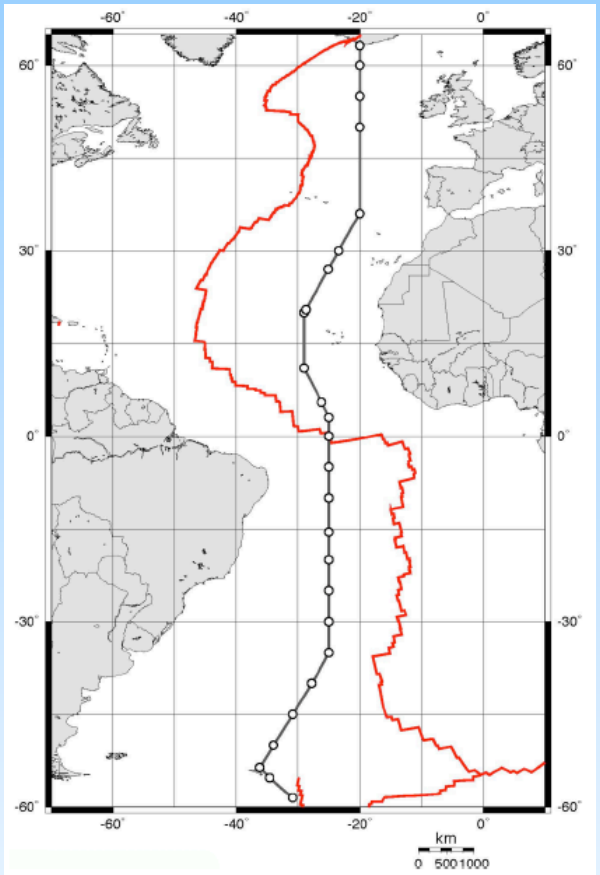
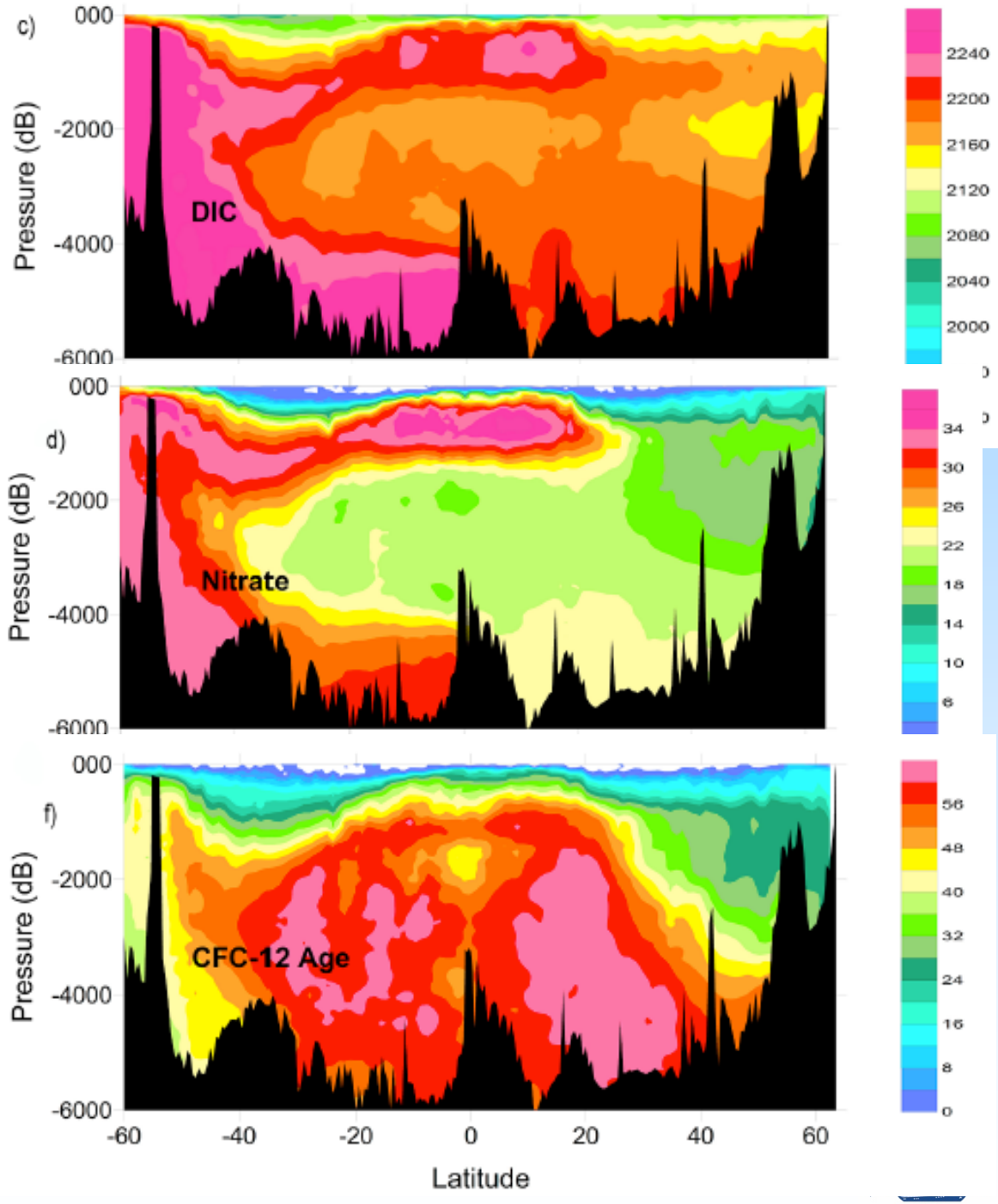
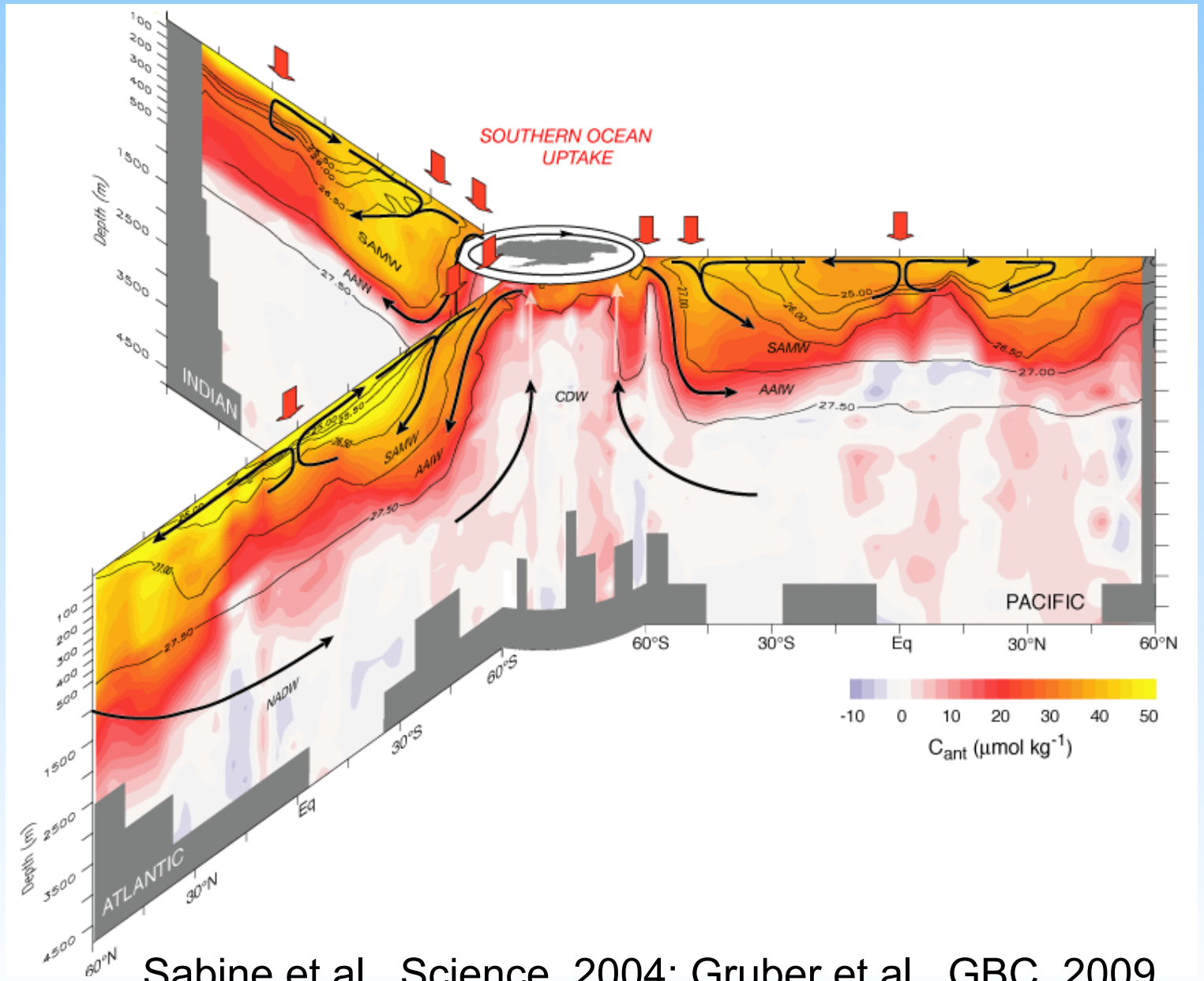
Biogeochemical Fields



Wanninkhof et al.
J. Geophys. Res. Oceans 2010



Anthropogenic CO_2 Distribution & Uptake



Sabine et al., Science, 2004; Gruber et al., GBC, 2009

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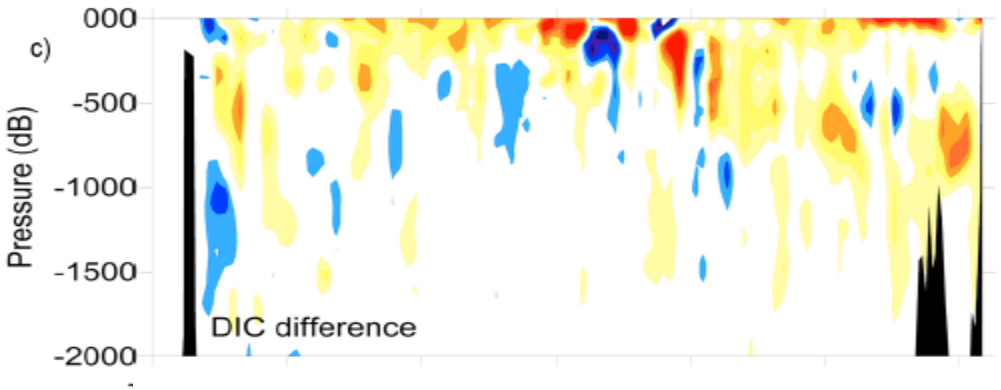
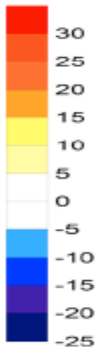
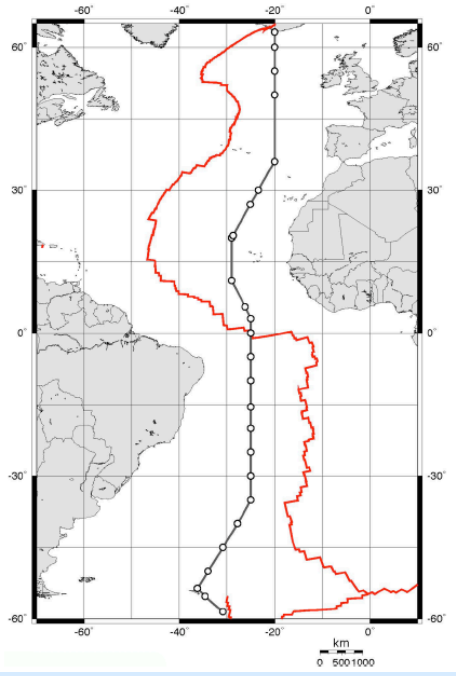
Decadal Changes in Carbon Inventory

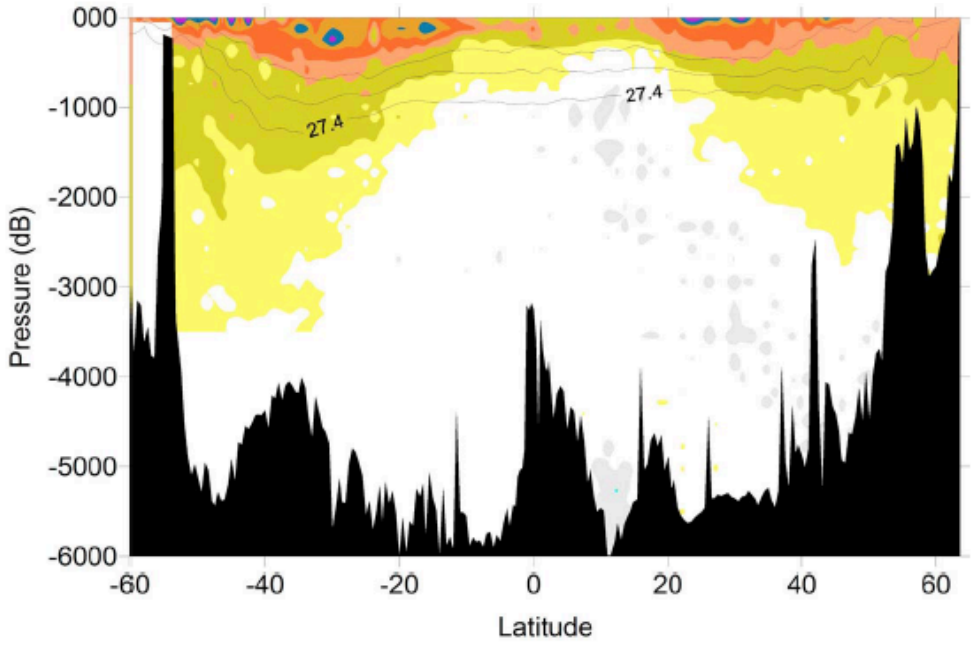
Direct ΔDIC difference





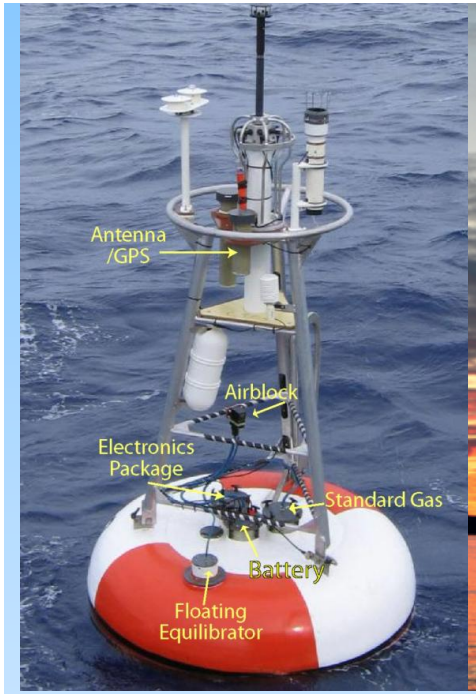


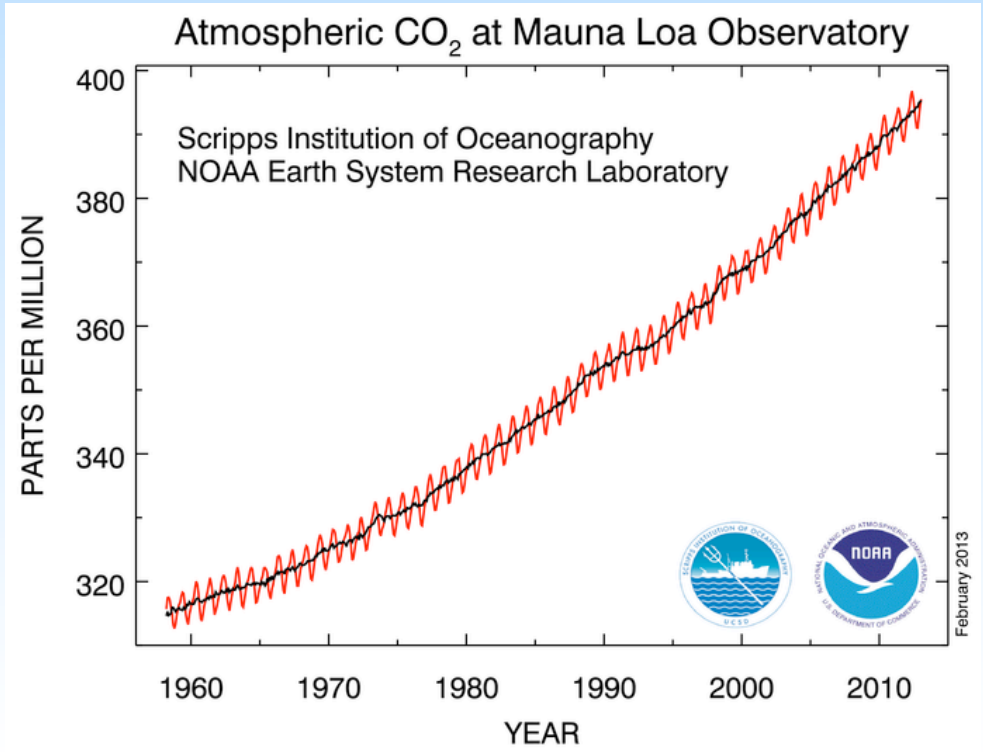
Estimated ΔCanthro difference



Wanninkhof et al. JGR-Oceans 2010

Decadal survey under-samples natural temporal variability; techniques needed to isolate anthropogenic signal





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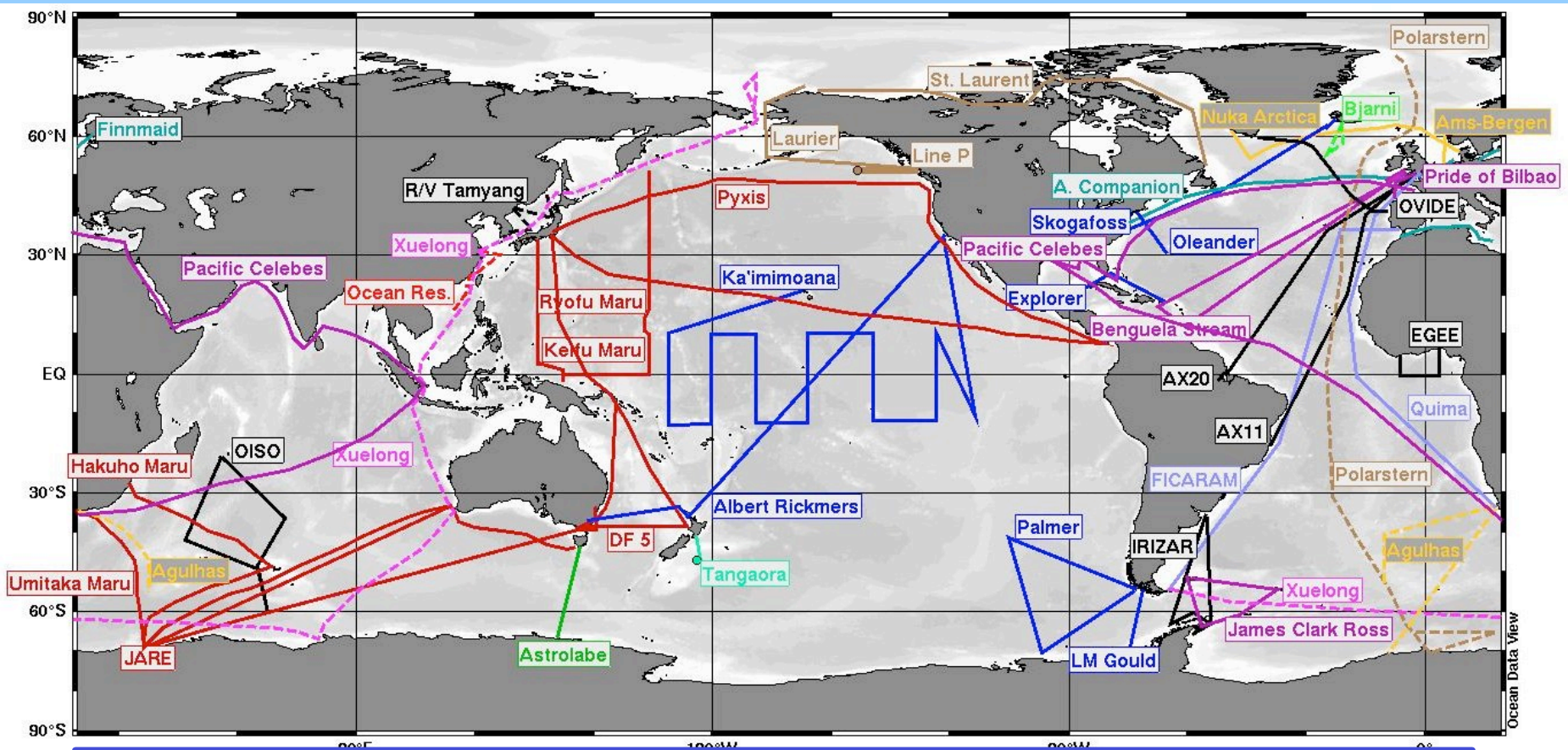
Surface Underway pCO_2 Surveys



-Ships of Opportunity (SOOP): research, commercial & Antarctic resupply vessels

International Ocean Carbon Coordination Project (www.ioccp.org)

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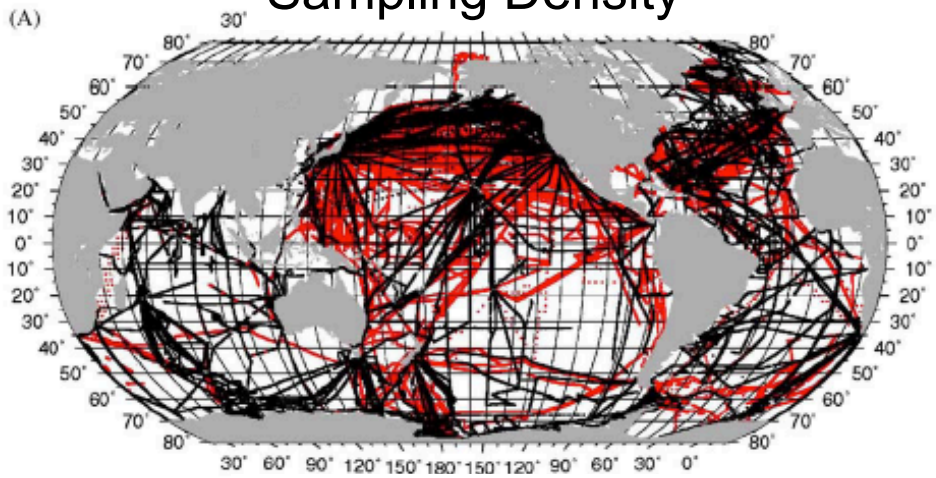
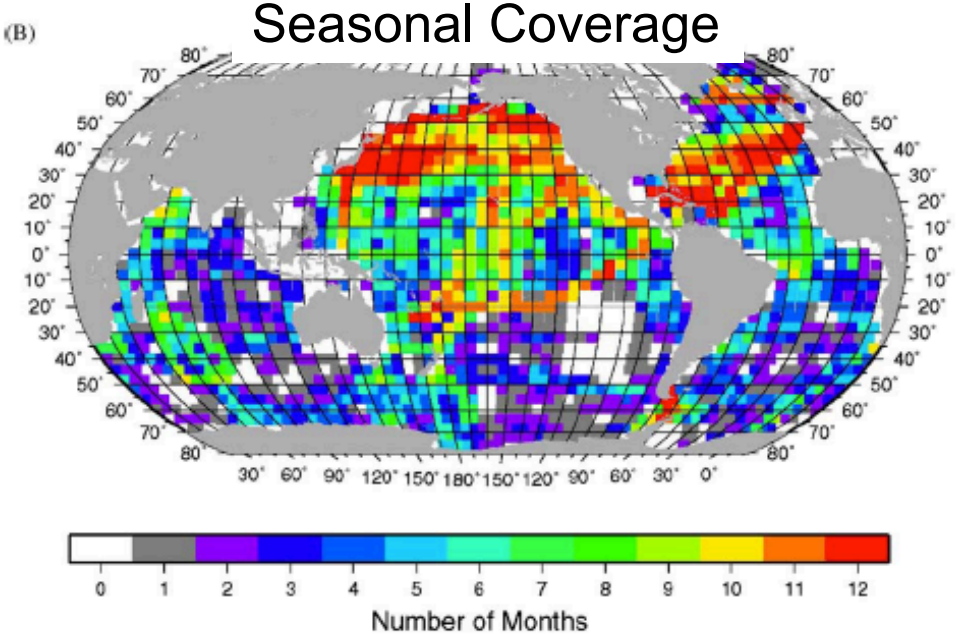
Underway Data & Sea-air CO_2 Flux

Sampling Density

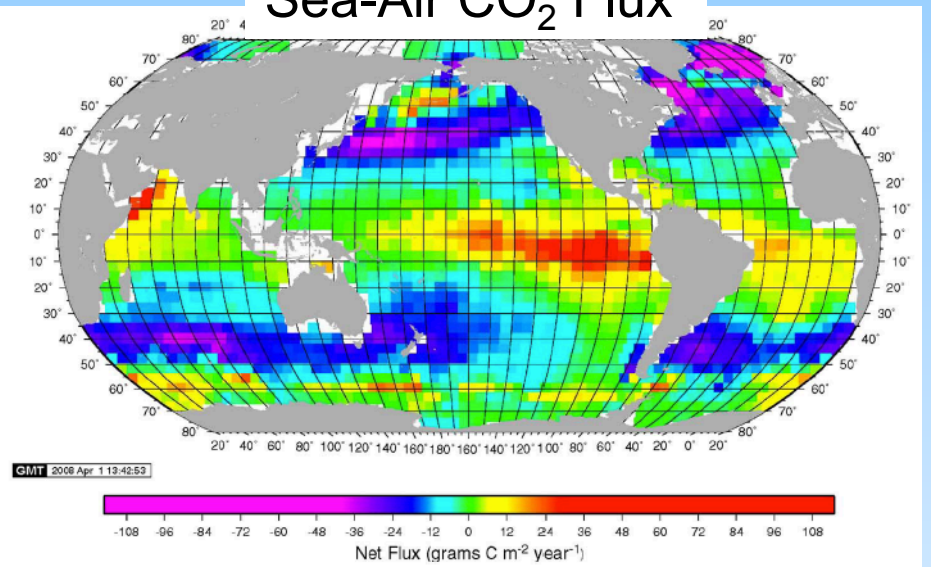


Seasonal Coverage



Takahashi et al. Deep-Sea Res. II 2009

Sea-Air CO_2 Flux



Sea-Air CO_2 Flux =
Kinetic term * thermodynamic term

Flux = k α ($pCO_2^{sea} - pCO_2^{air}$)

k = function(wind speed, …)

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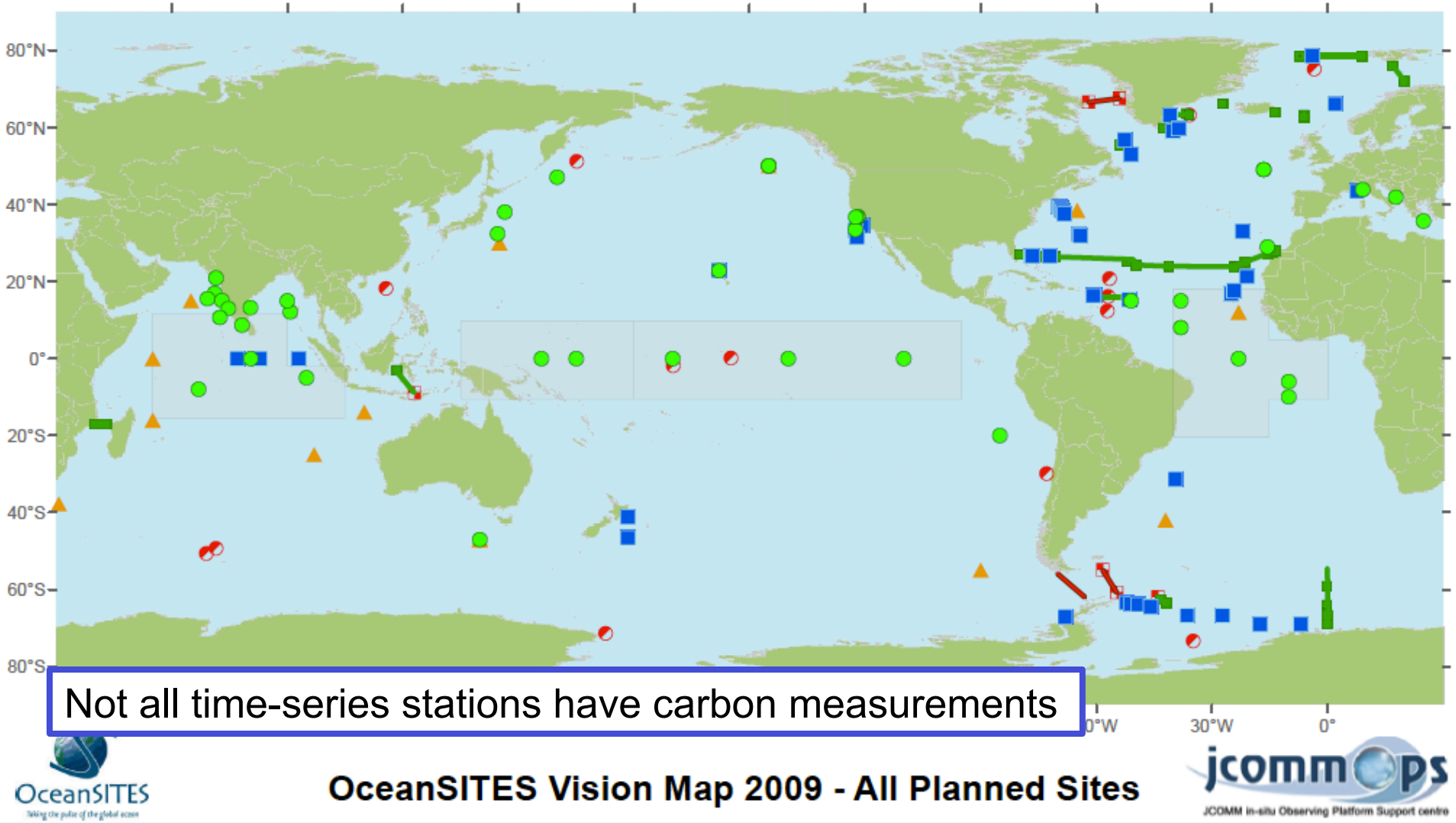
Ocean Time-Series Stations



Not all time-series stations have carbon measurements

OceanSITES

OceanSITES Vision Map 2009 - All Planned Sites

jcommops
JCOMM in-situ Observing Platform Support centre

OceanSITES (www.oceansites.org); http://wo.jcommops.org
International Ocean Carbon Coordination Project (www.ioccp.org)

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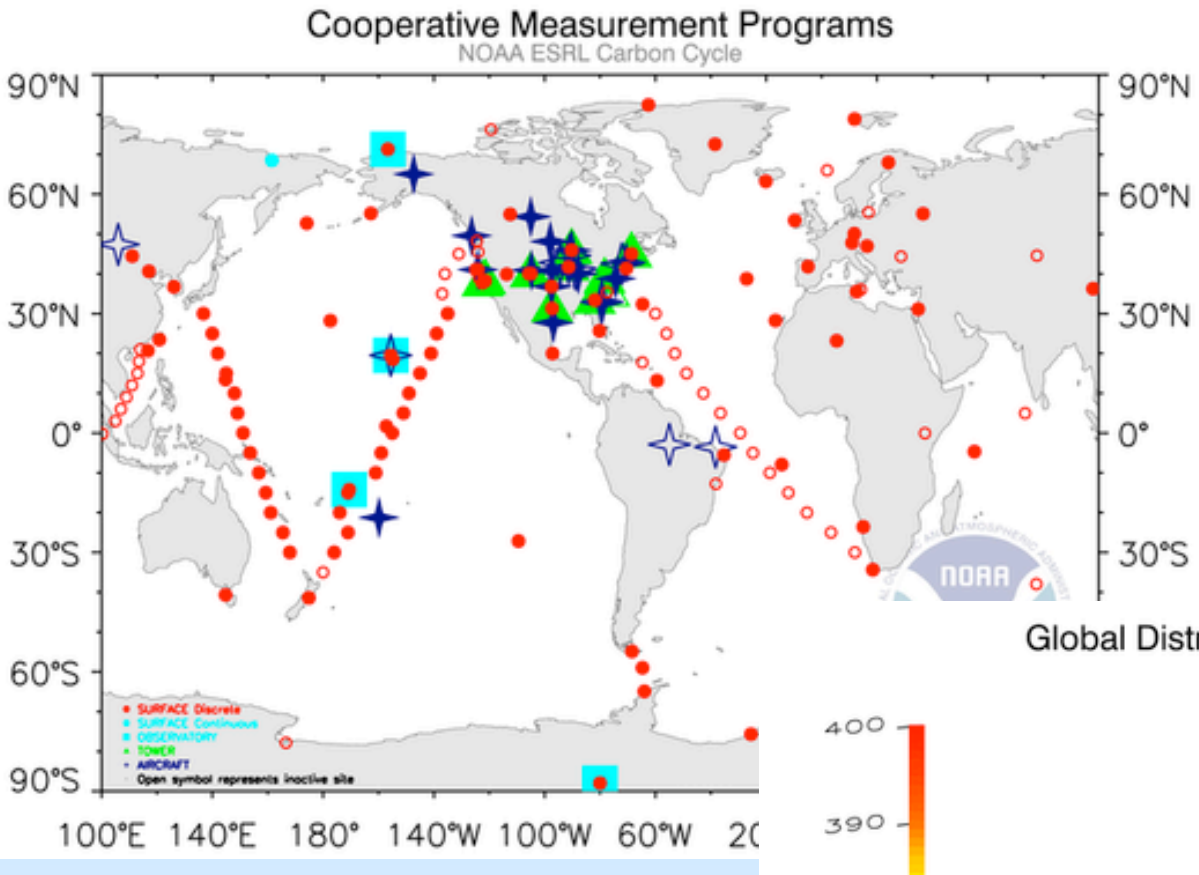
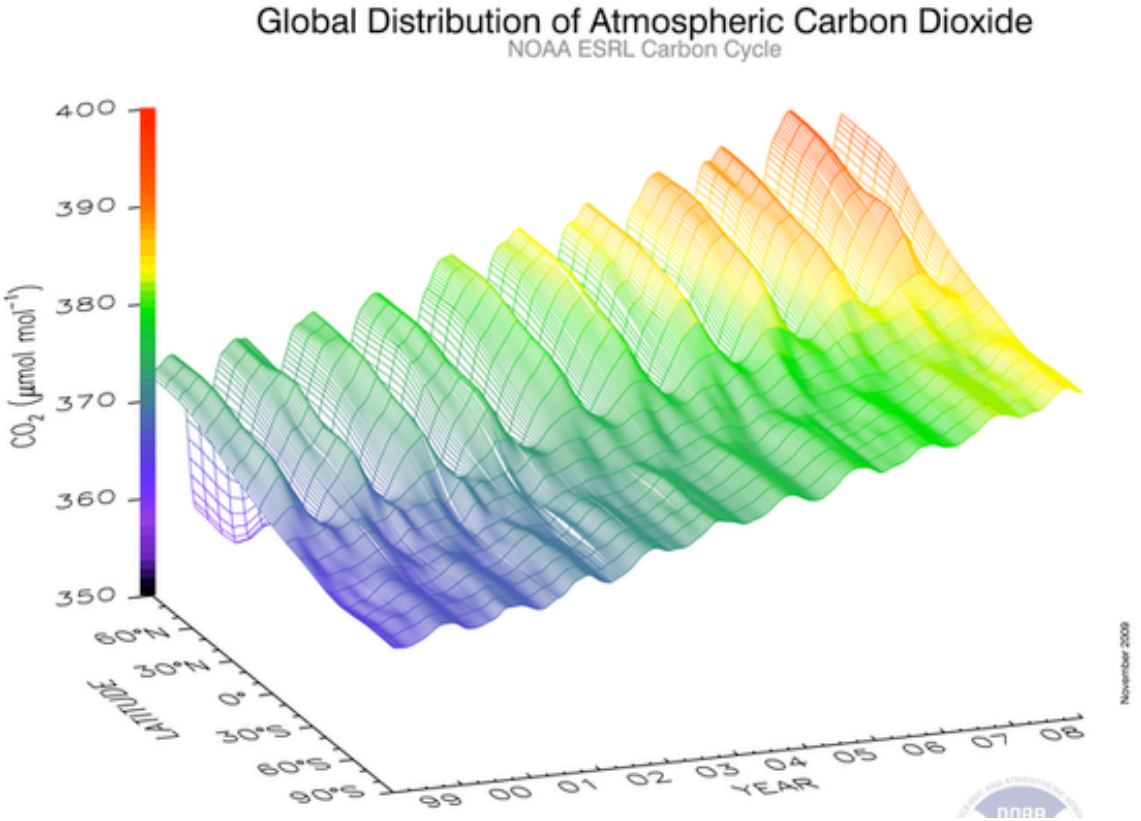
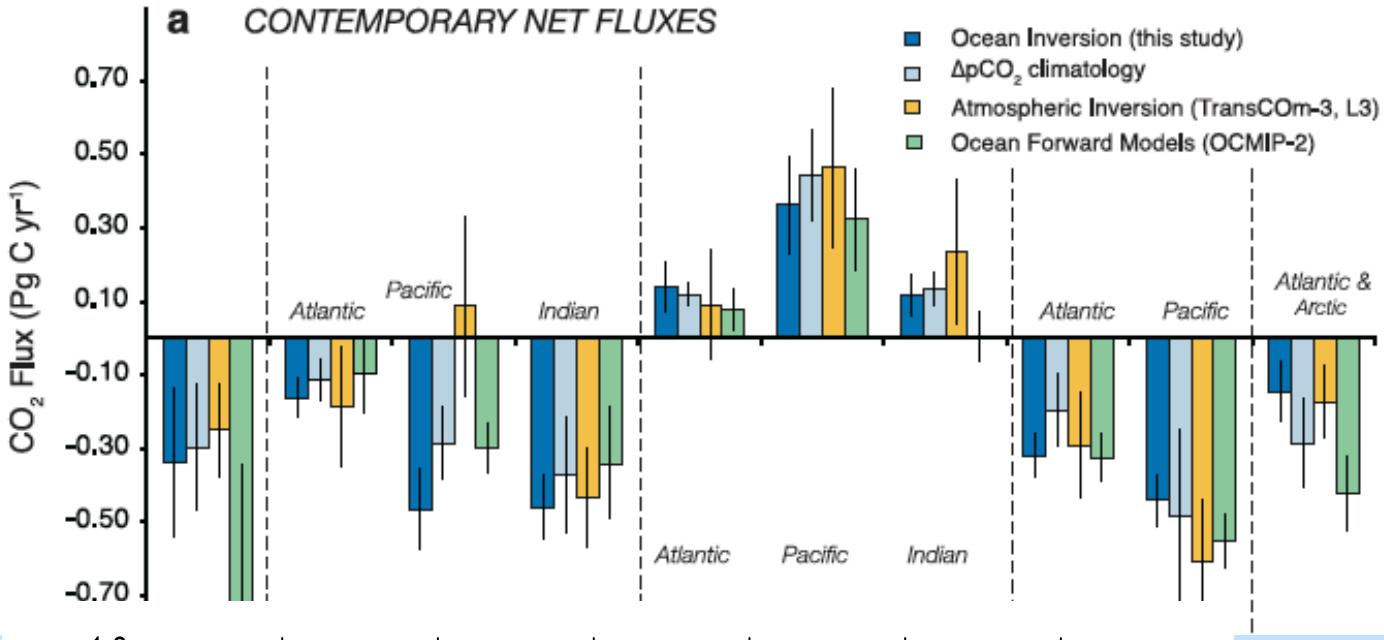
Atmospheric CO_2 Monitoring Network

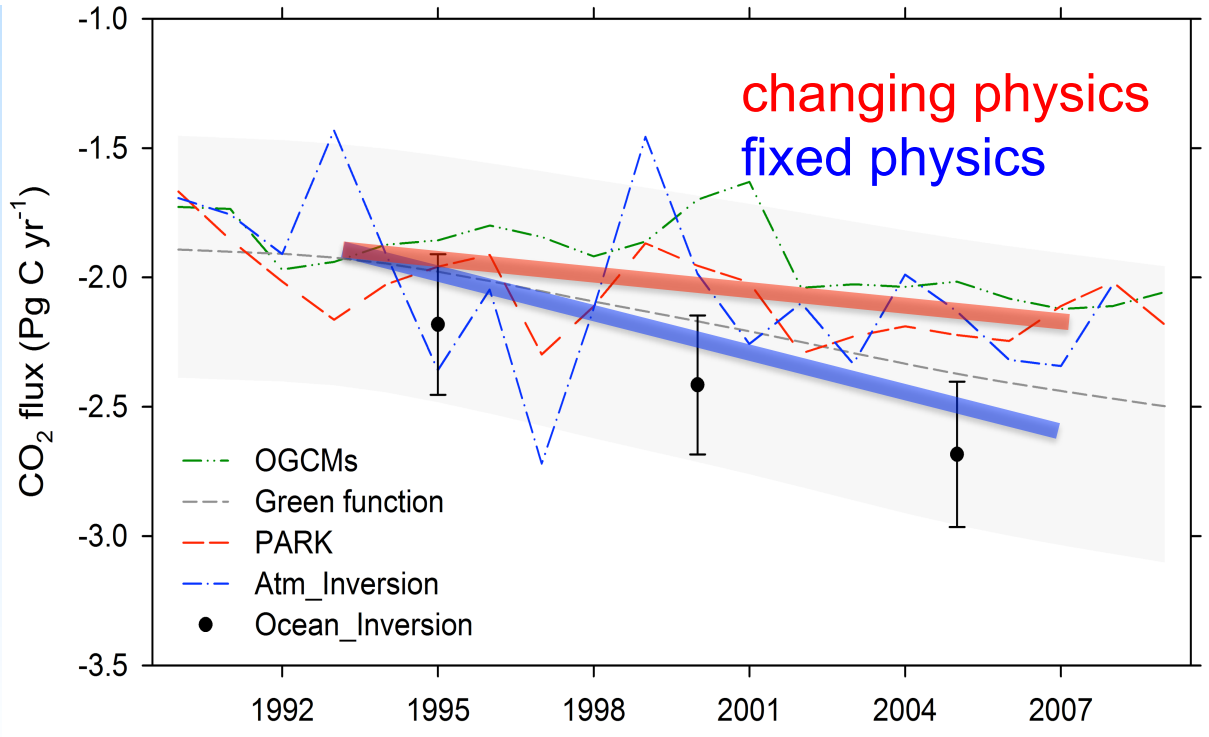




Use atmospheric CO_2 spatial & temporal patterns to assess model process on seasonal & interannual scales

Comparing Ocean CO_2 Uptake Estimates





Gruber et al. Global Biogeochemical Cycles 2009

Wanninkhof et al. Biogeosciences submitted

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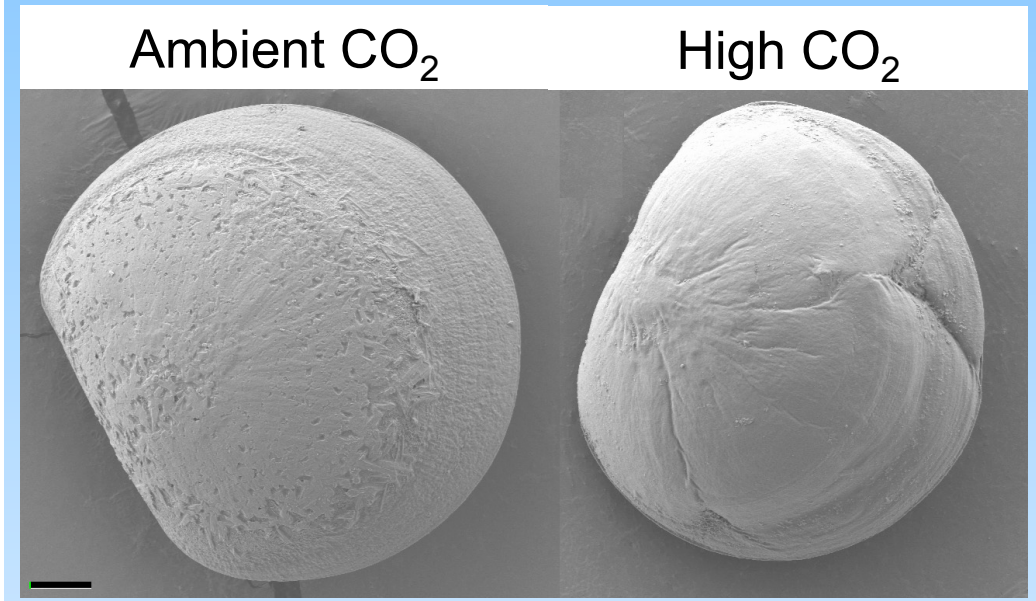
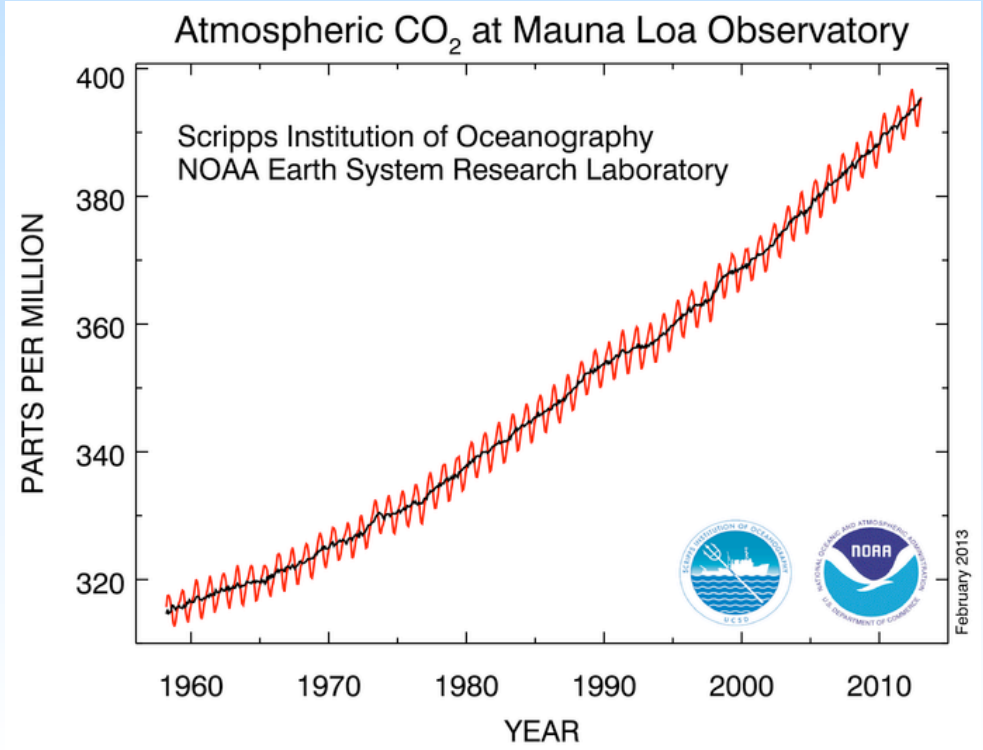
Talk Outline





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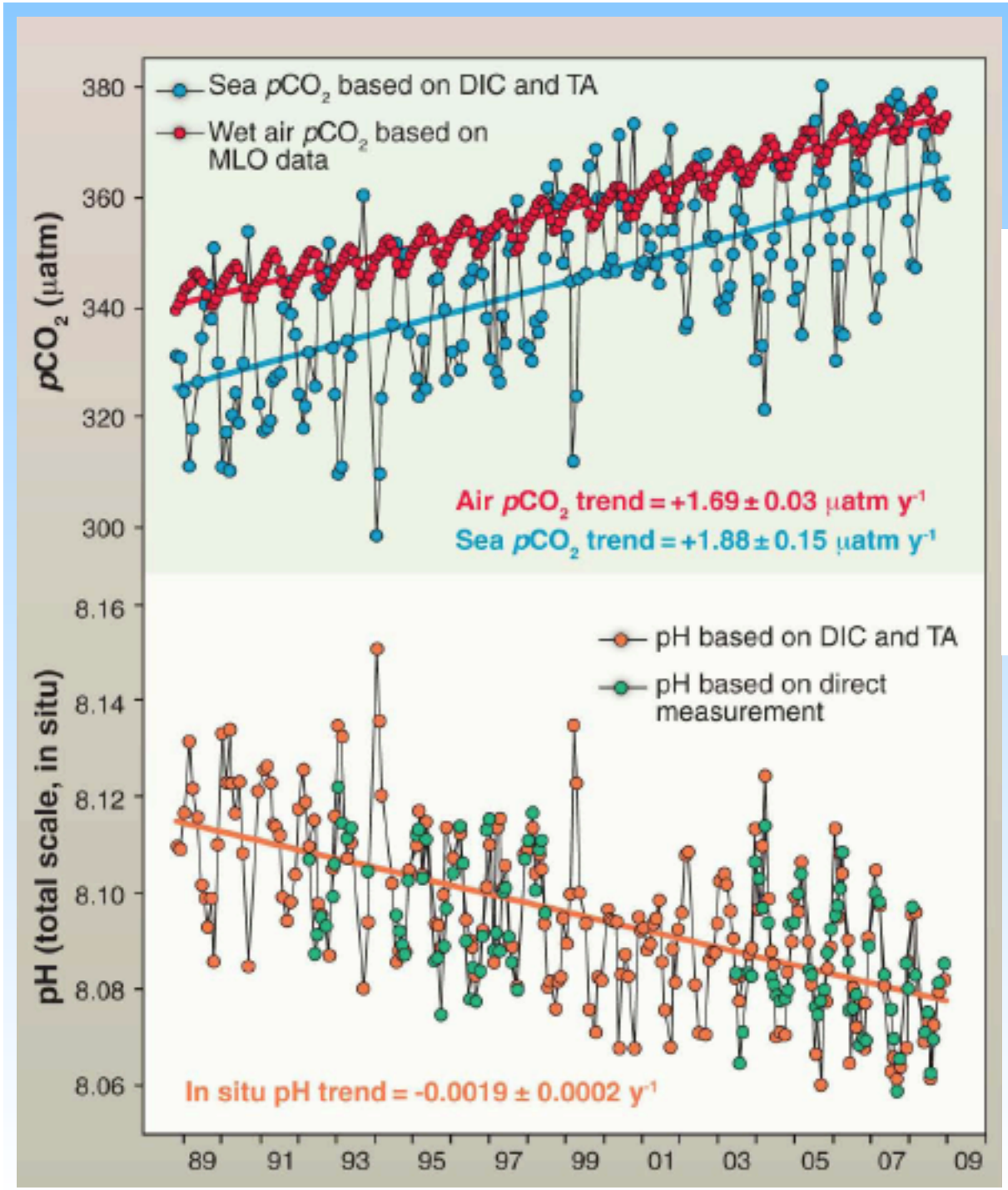
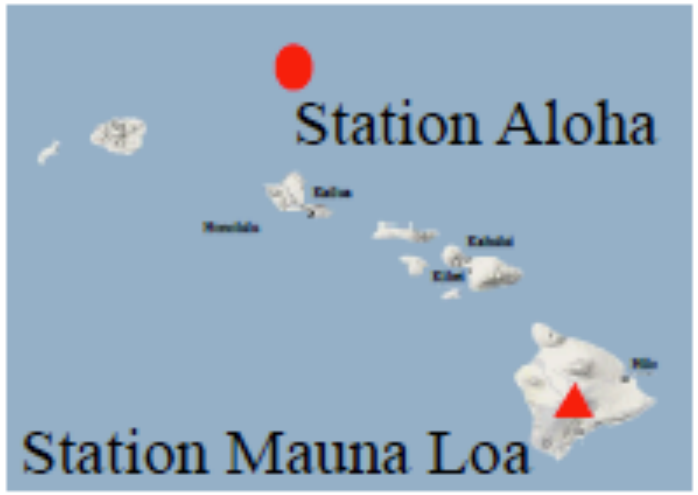
Open-Ocean Time-Series





-Observed rising CO_2 & declining pH

Doney et al. Ann. Rev. Mar. Sci. 2009
Dore et al. PNAS 2009

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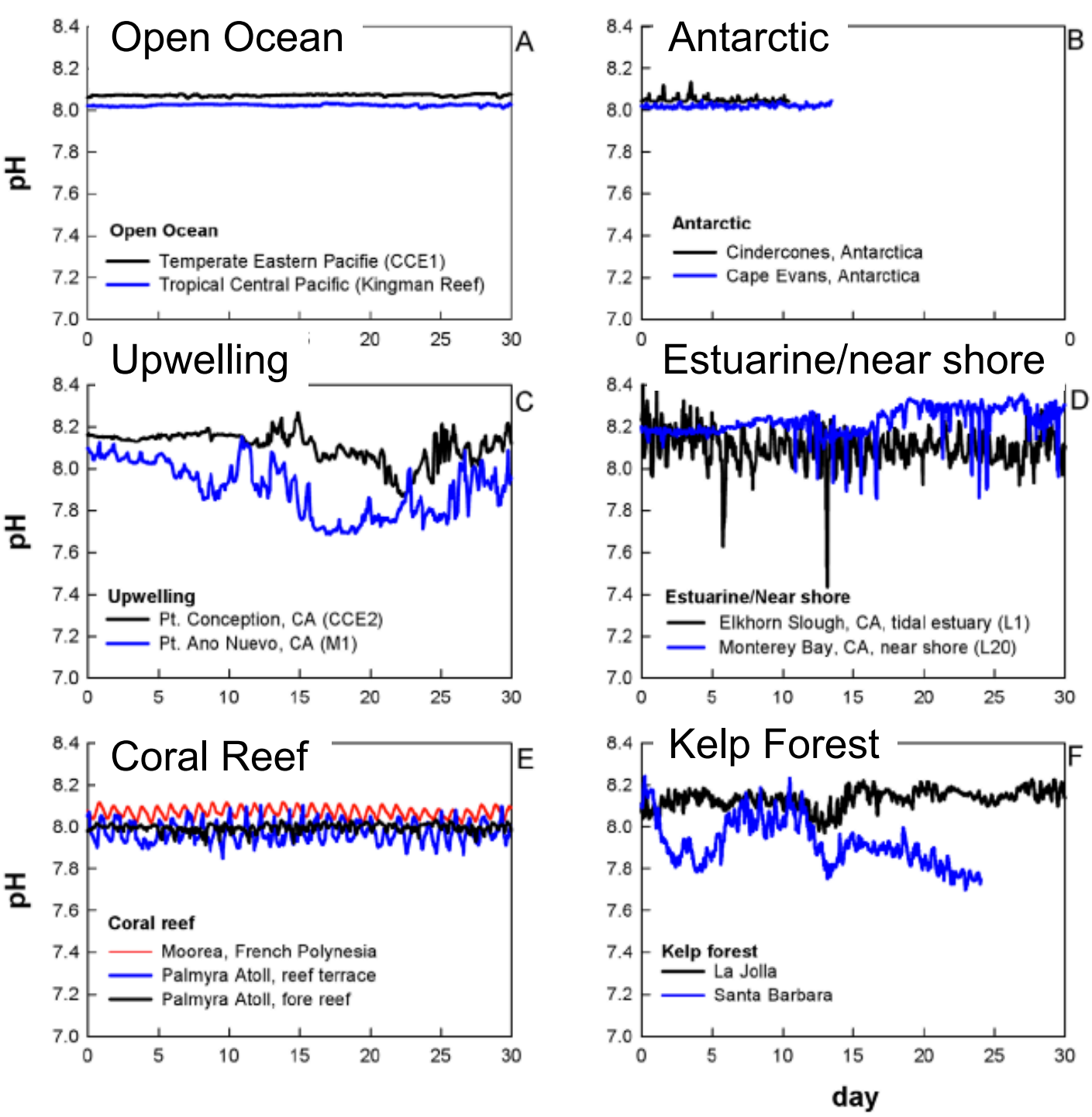

High Frequency Natural Variability

Hofmann et al.
PLoS 2011

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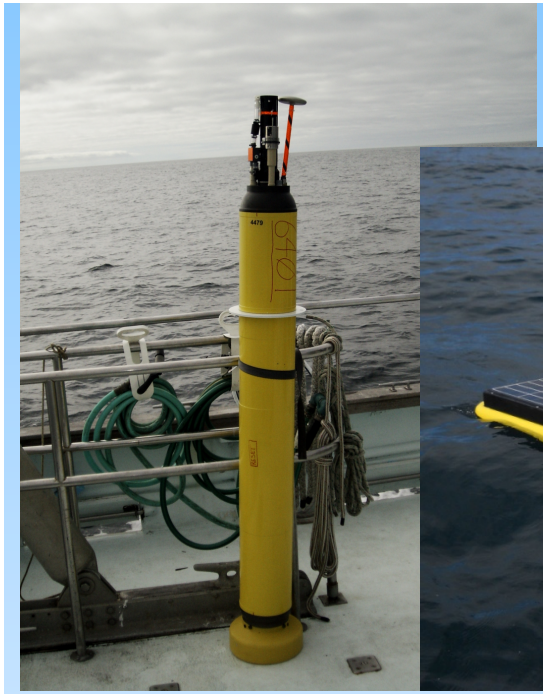

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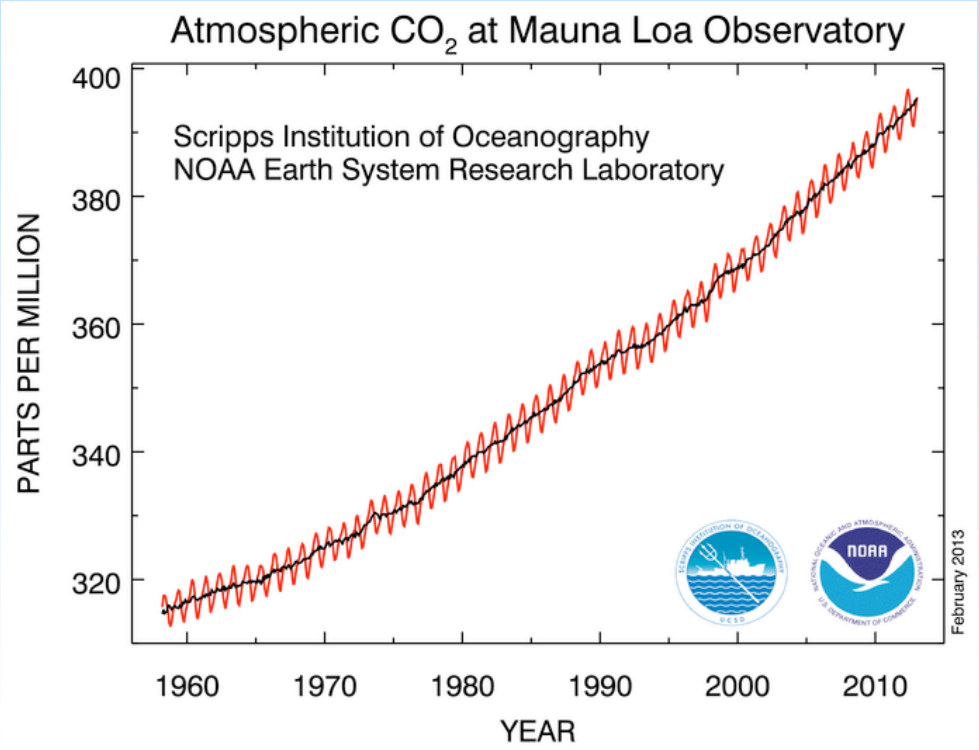
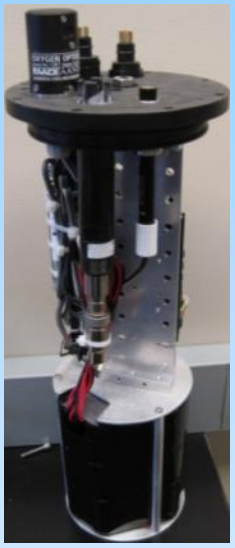


In-situ CO_2 System Sensors



Underway => mooring => profiling

pH: spectrophotometry, *solid-state ion-sensitive transistor*

fCO_2: IR analyzer (surface), gas permeable membranes & pH sensor

under development

DIC: spectrophotometry & CO_2 permeable membrane

alkalinity: titration & spectrophotometry

carbonate ions:

Issues: temporal resolution, stability & calibration

Johnson et al. Oceanography 2009

Byrne et al. OceanObs'09 whitepaper 2010

Martz et al. Limnol. Oceanogr. Methods 2010

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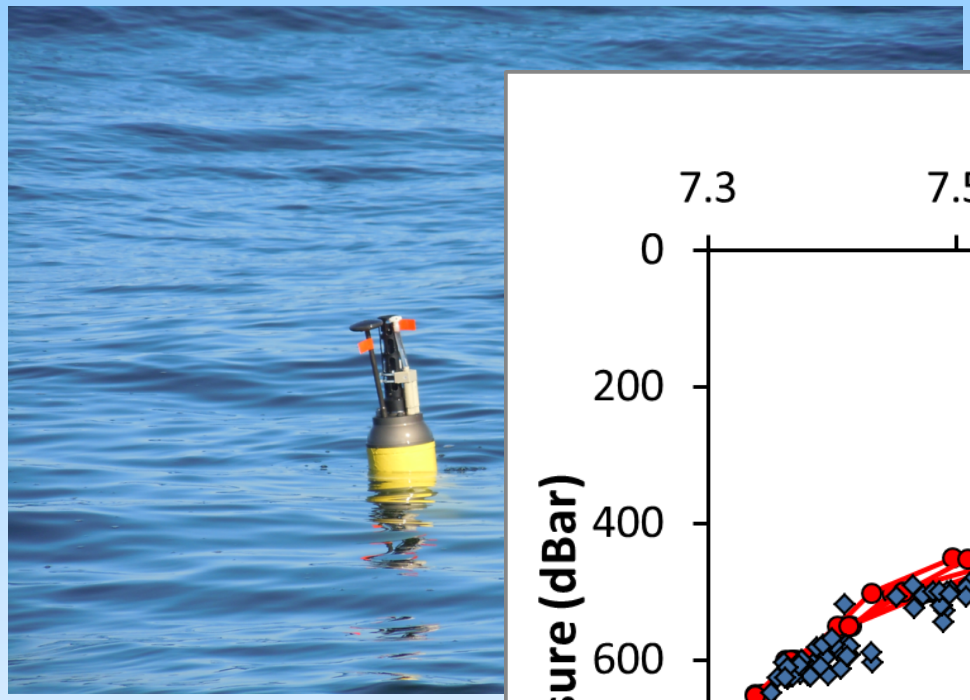
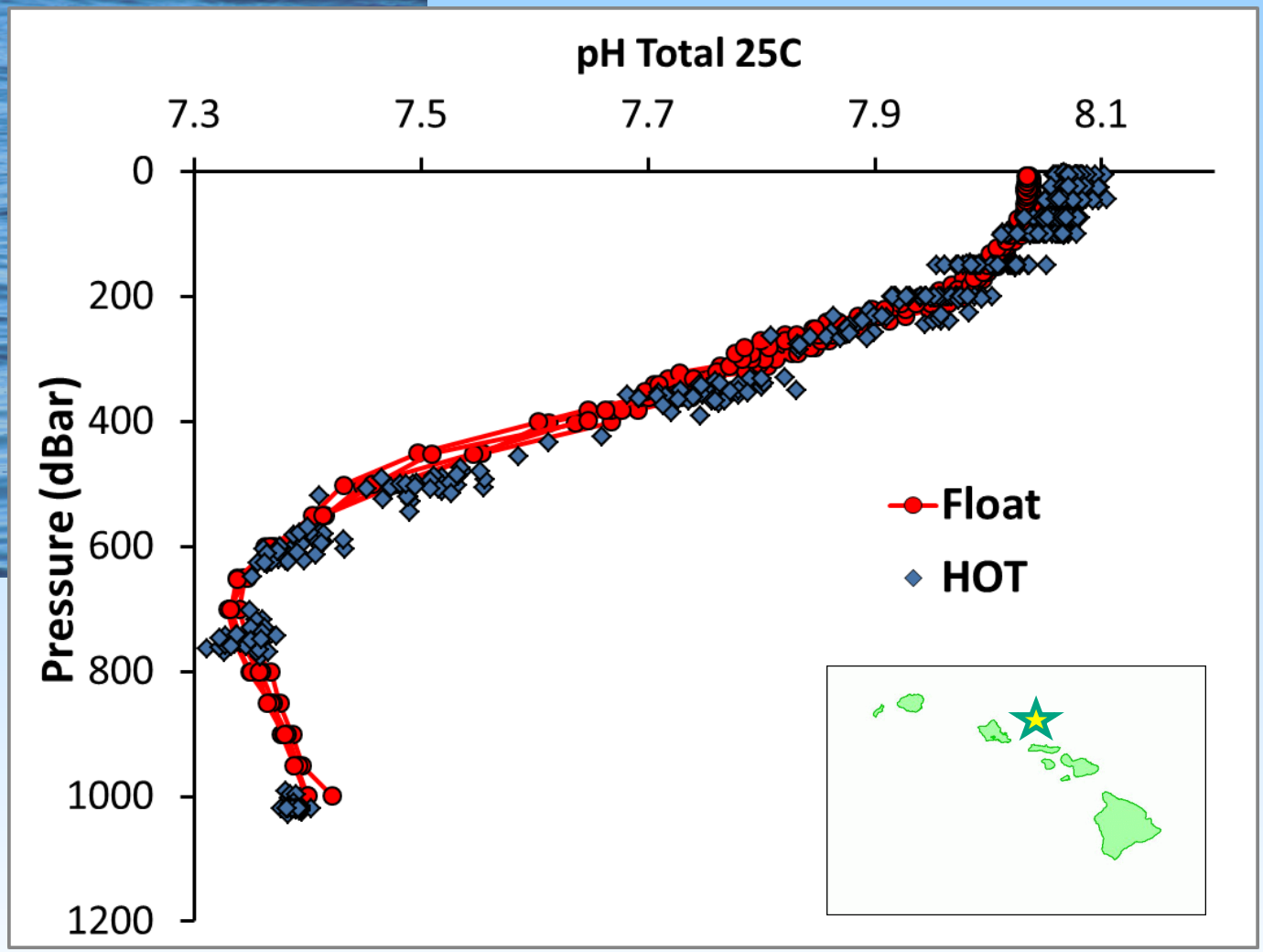
Durafet pH Sensor





K. Johnson (MBARI)
T. Martz (SIO)

Float 7272 data available at
http://www.mbari.org/chemsensor/floatviz.htm

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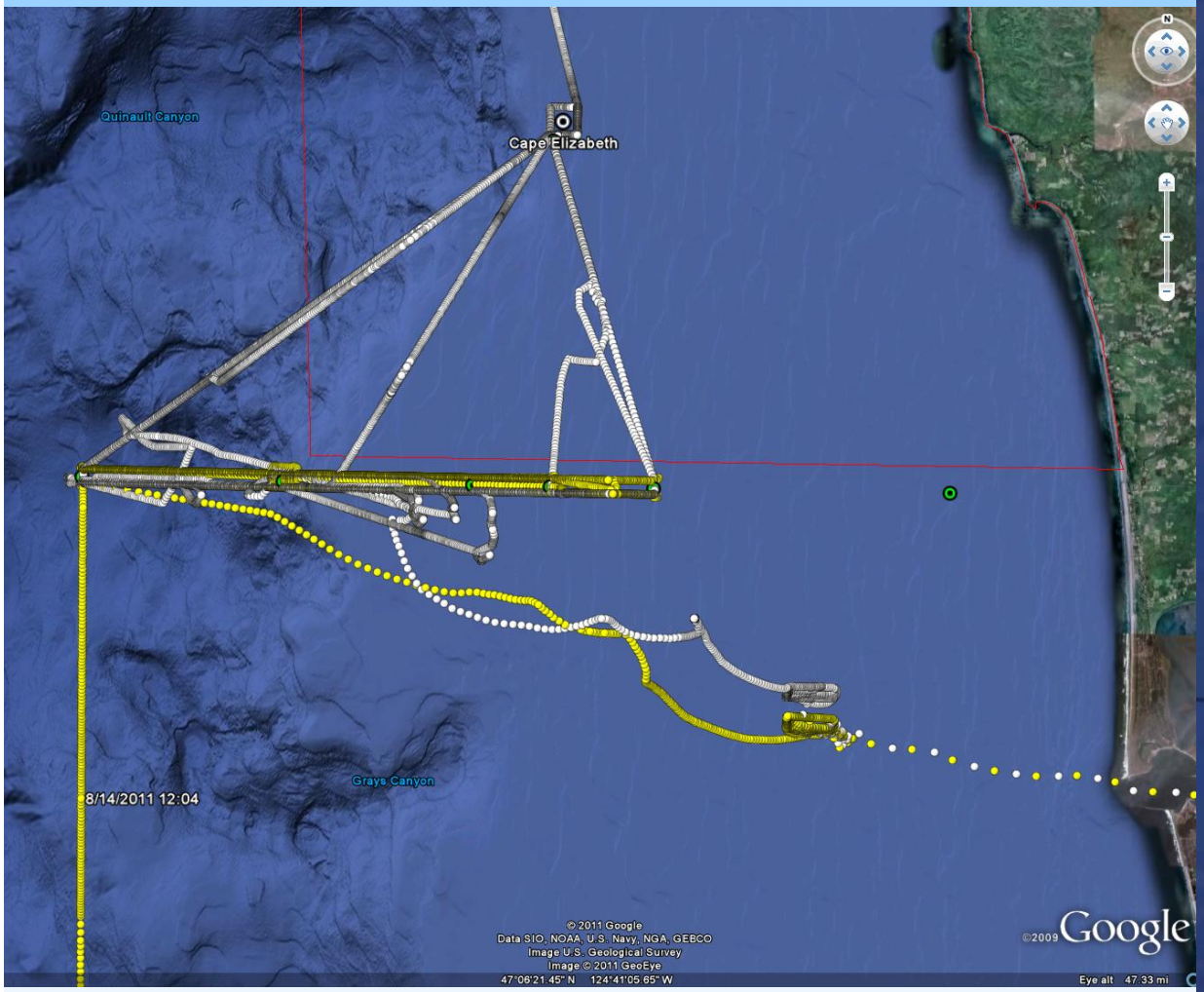
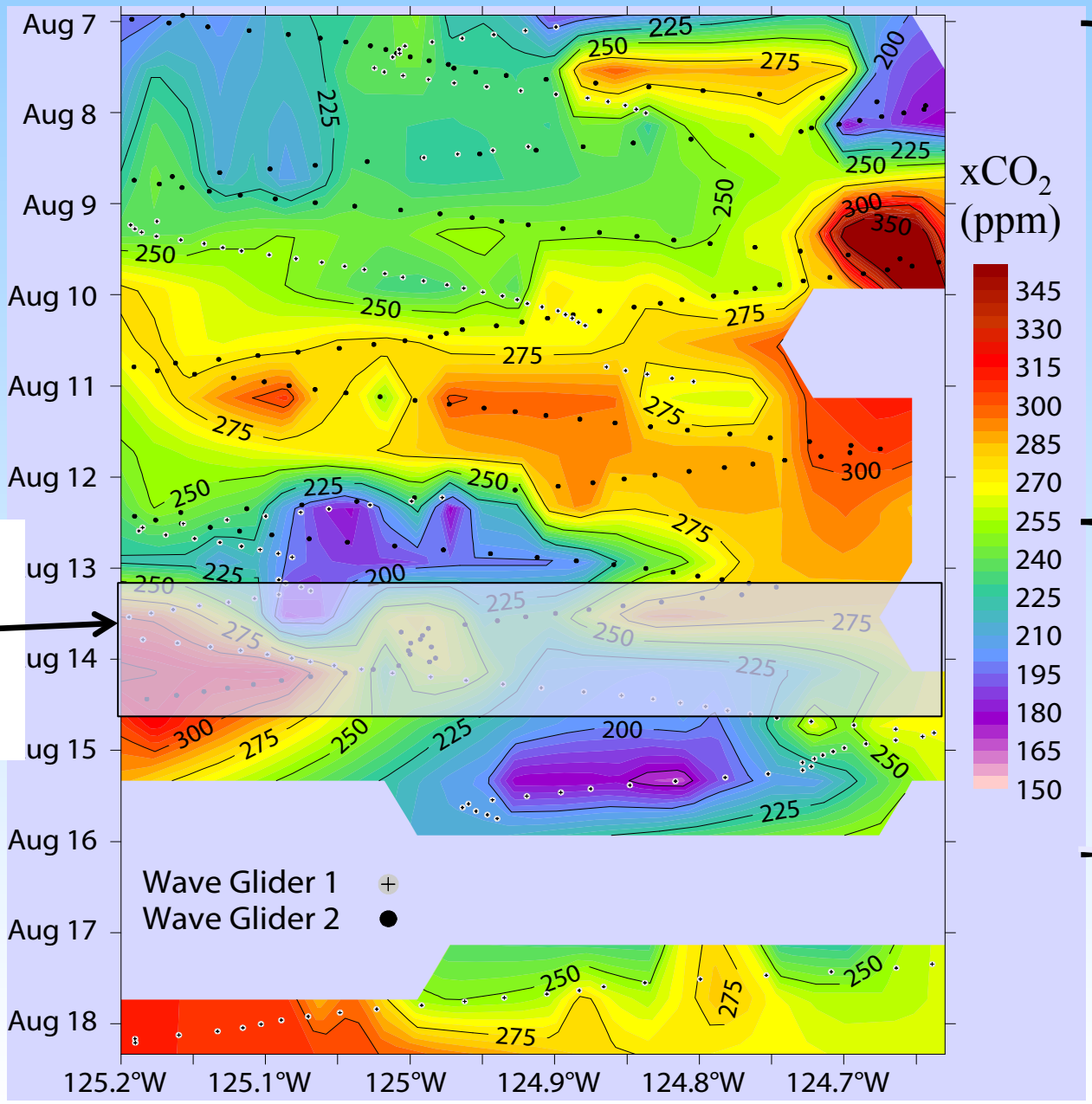
Carbon Wave Glider

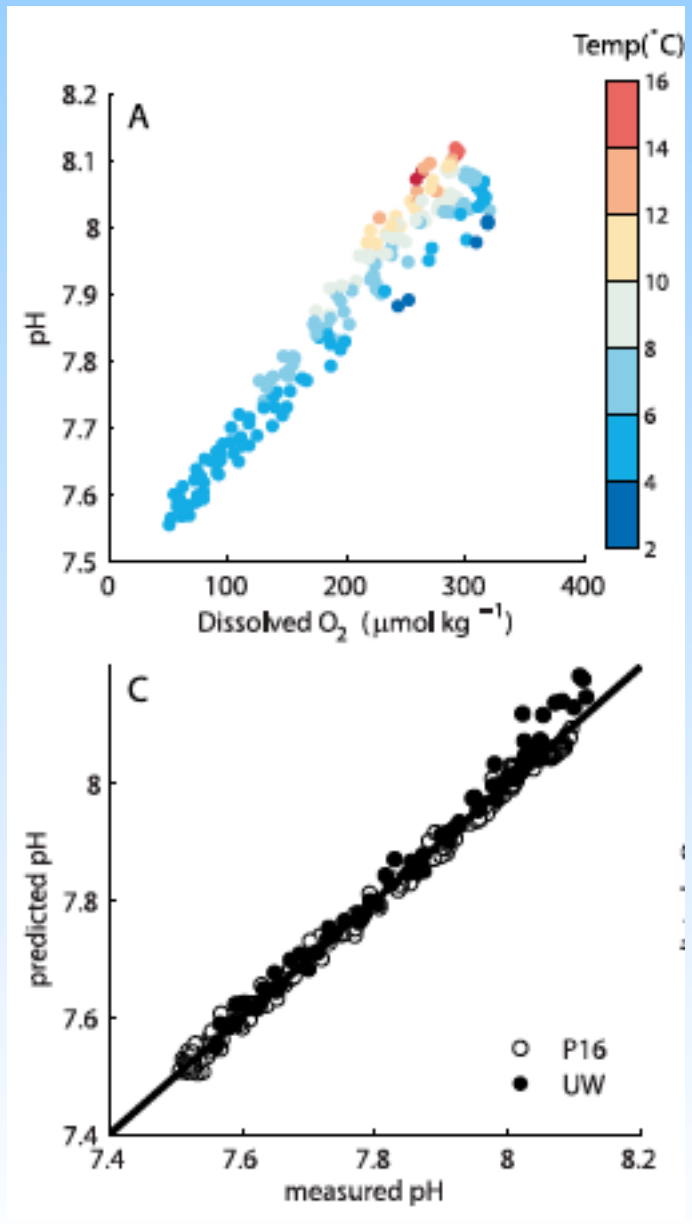


Chris Sabine (NOAA) working with Liquid Robotics and Todd Martz to integrate MapCO_2 and Durafet pH into Wave Glider

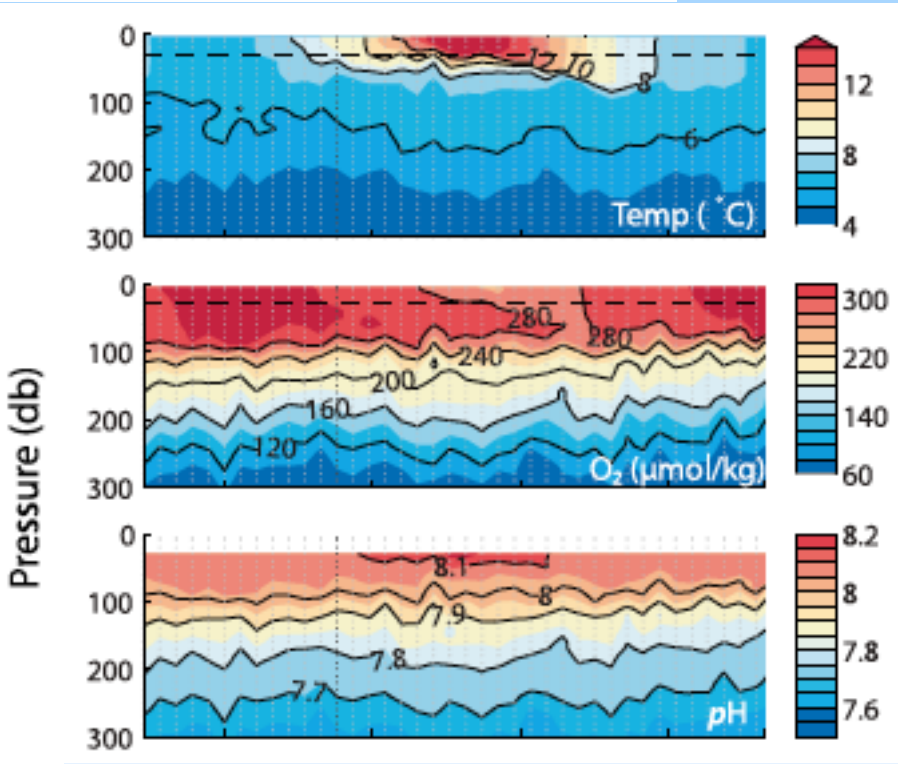
Carbon Wave Glider



Argo-Oxygen & Empirical CO_2 Algorithms



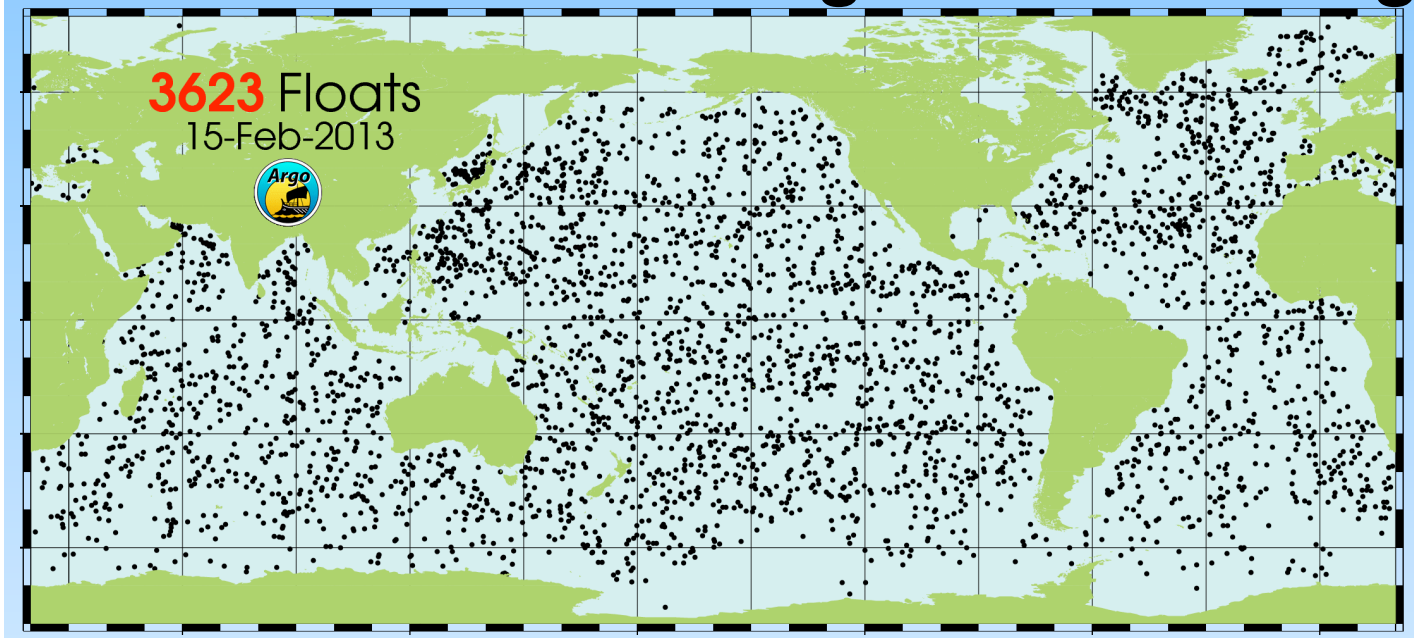
$$pH_{est} = \alpha_0 + \alpha_1 (T - T_r) + \alpha_2 (O_2 - O_{2,r})$$

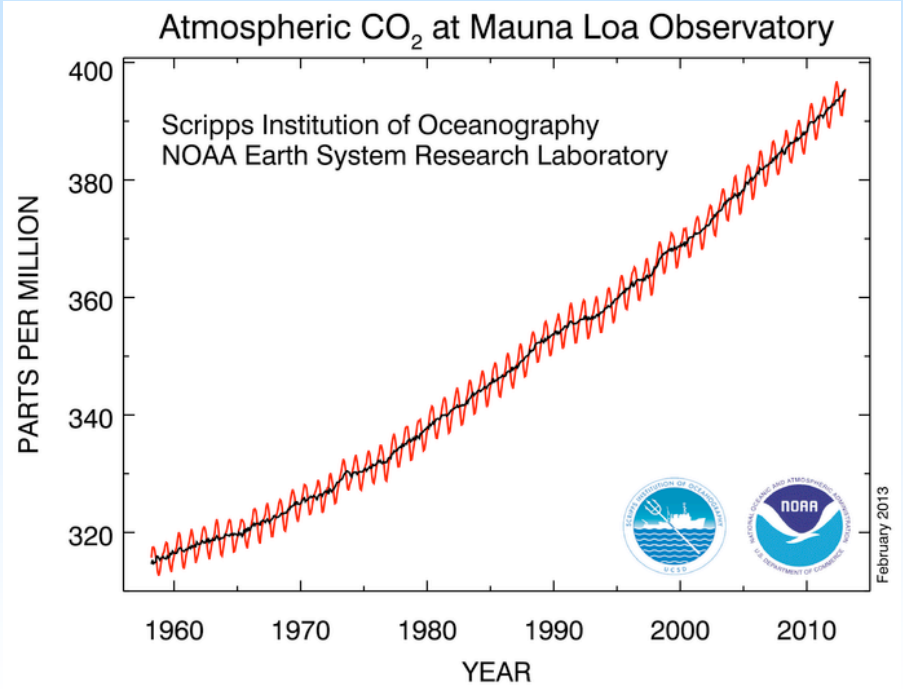


Empirical linear regressions resolve variability but not secular trends

Juranek et al. GRL 2009; 2011

Ocean Biogeochemical Argo





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