High-resolution ocean and atmosphere pCO_2 time-series measurements from open ocean and coastal moorings

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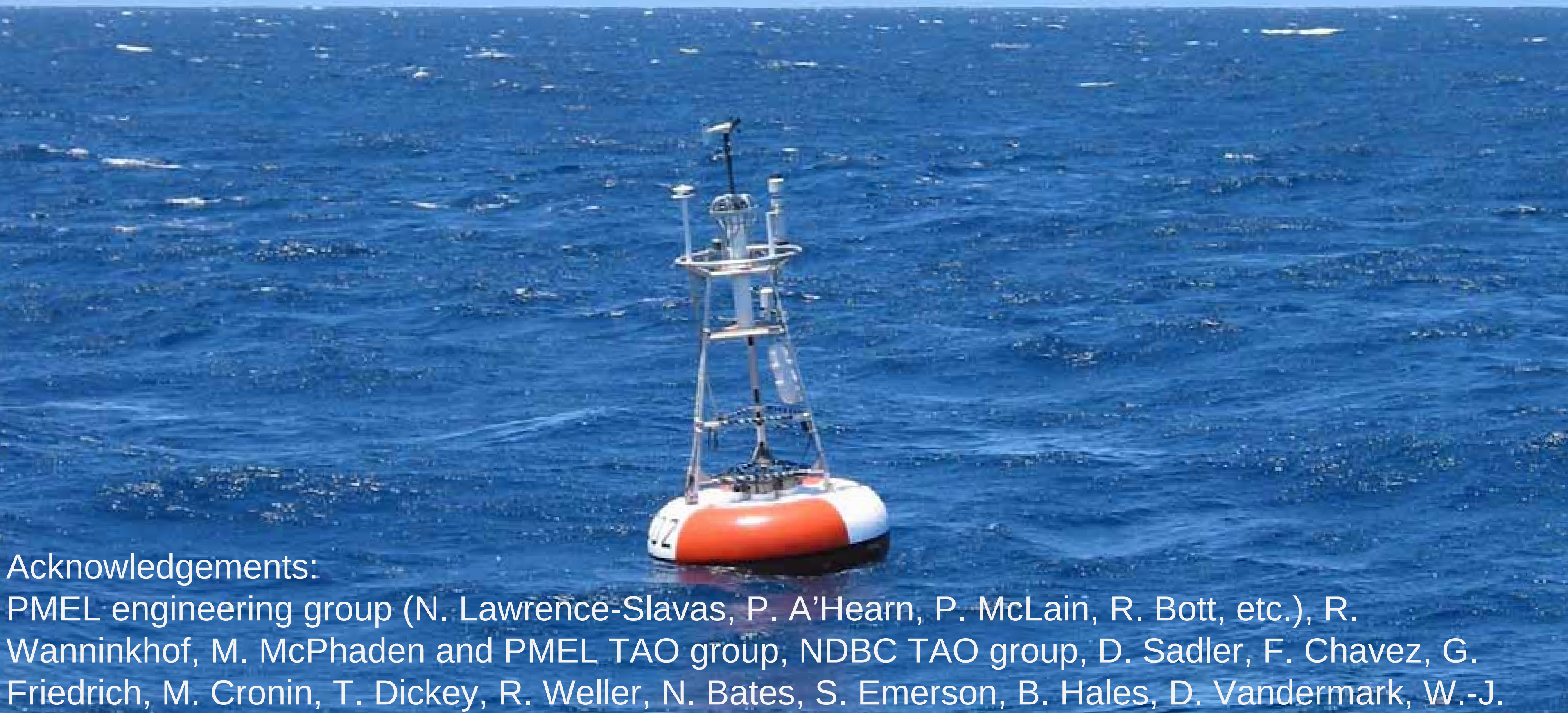
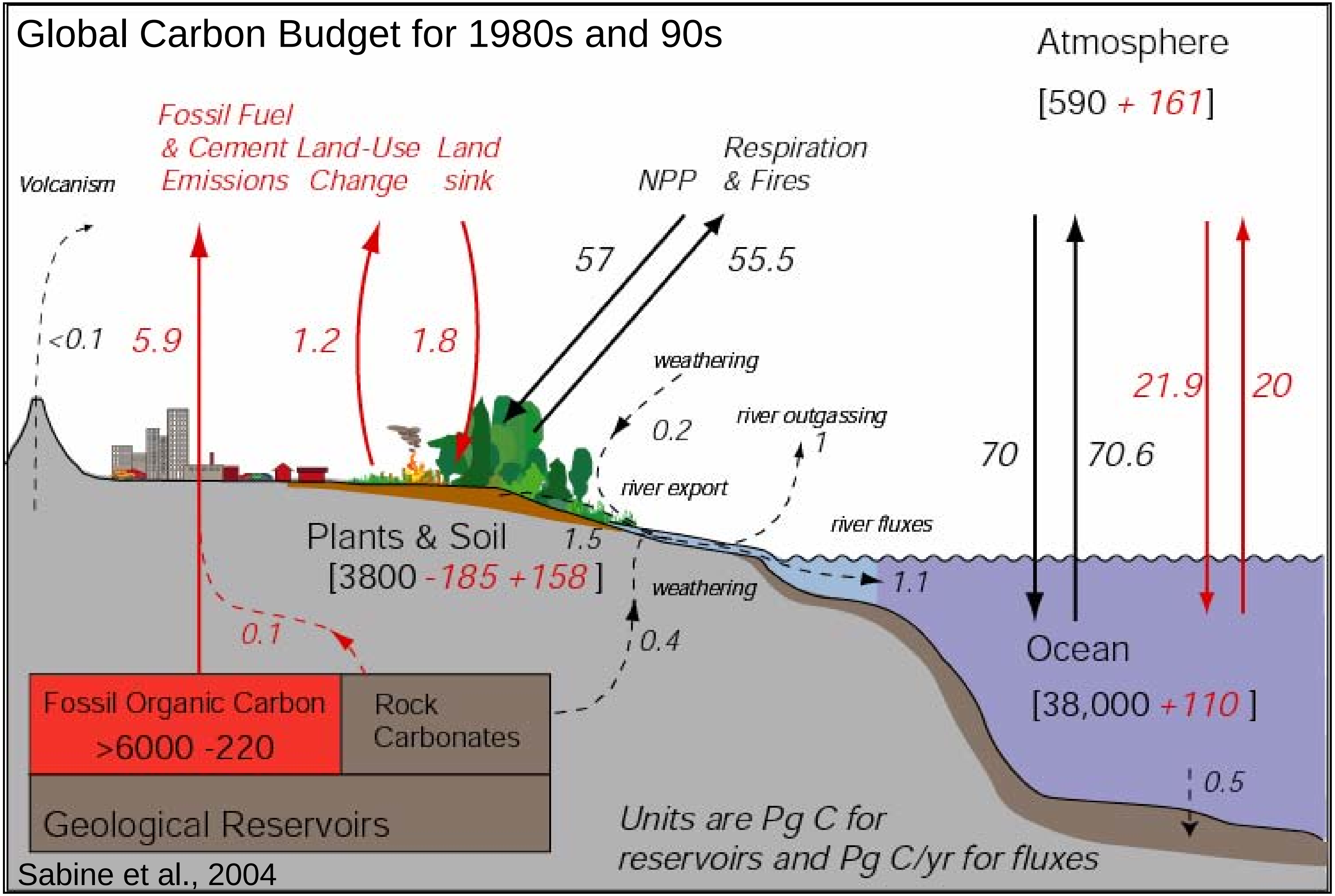
NOAA/PMEL



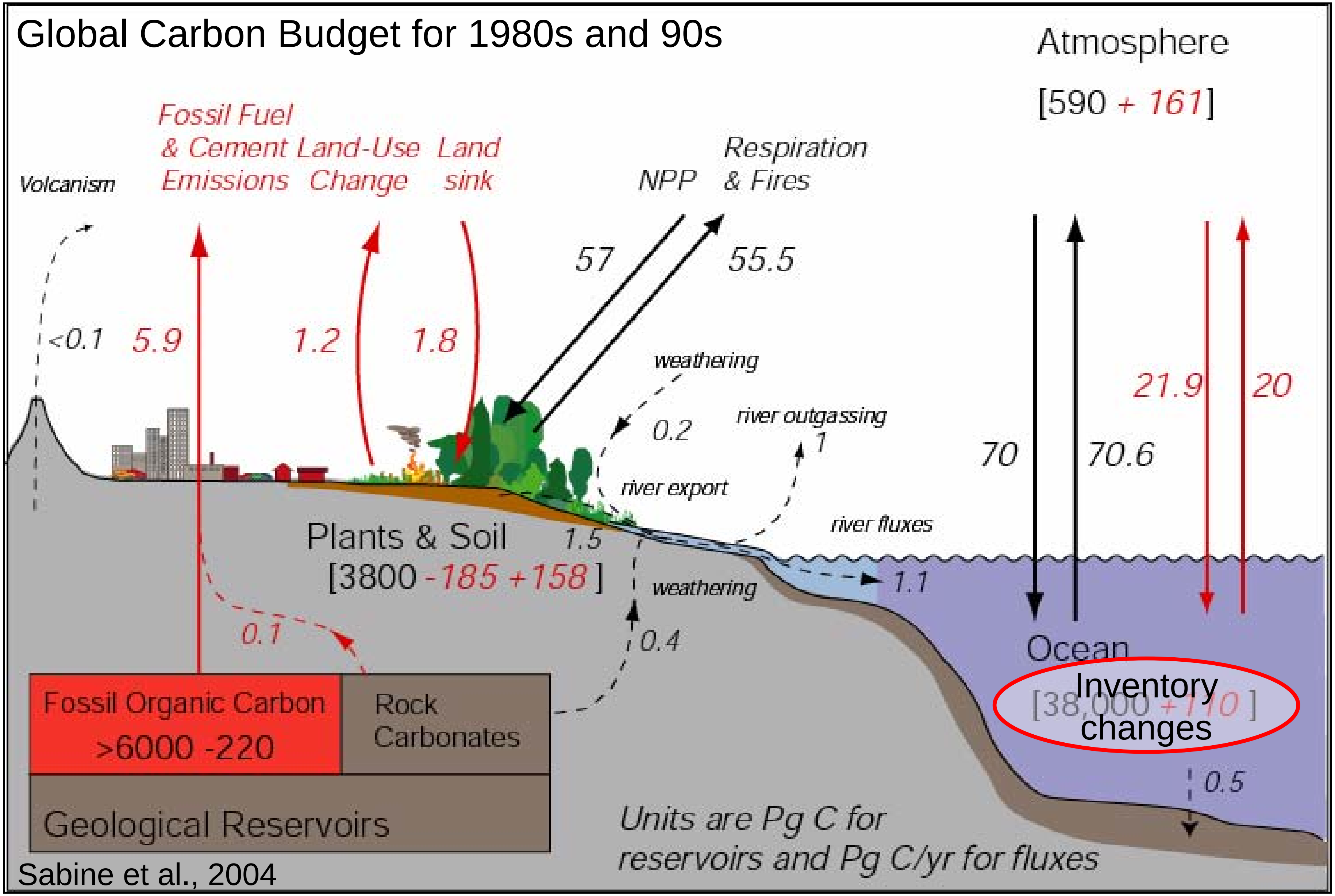
Acknowledgements:
PMEL engineering group (N. Lawrence-Slavas, P. A'Hearn, P. McLain, R. Bott, etc.), R. Wanninkhof, M. McPhaden and PMEL TAO group, NDBC TAO group, D. Sadler, F. Chavez, G. Friedrich, M. Cronin, T. Dickey, R. Weller, N. Bates, S. Emerson, B. Hales, D. Vandermark, W.-J.

Global Carbon Budget for 1980s and 90s



Sabine et al., 2004

Mission: Understand the role of the oceans in the global carbon cycle and its evolution over time.



Global Carbon Budget for 1980s and 90s

Inventory changes

Sabine et al., 2004

One approach is to evaluate changes in global carbon inventory over time.

CLIVAR/CO$_2$ Repeat Hydrography

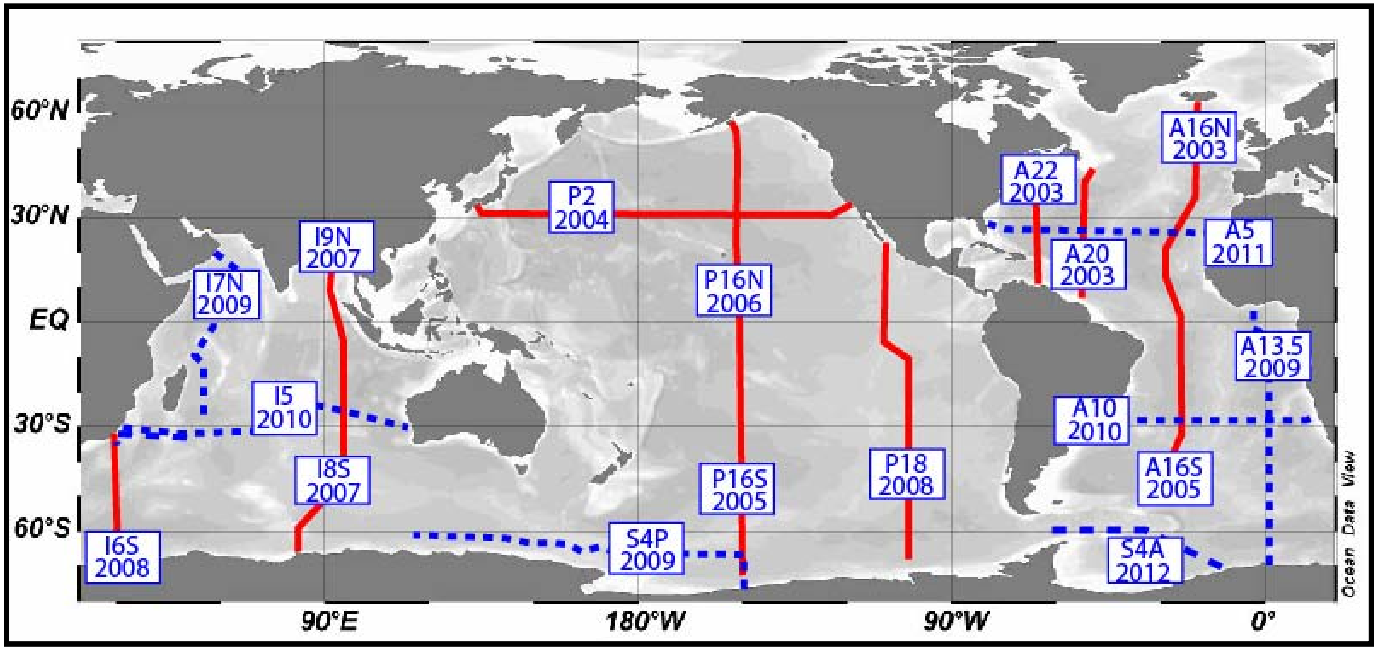
R.A. Feely, C.L. Sabine, R. Wanninkhof, G.C. Johnson, J.L. Bullister, M. Barringer, C.W. Mordy, J.-Z. Zhang, M.F. Lamb, D. Greeley, F.J. Millero, and A.G. Dickson

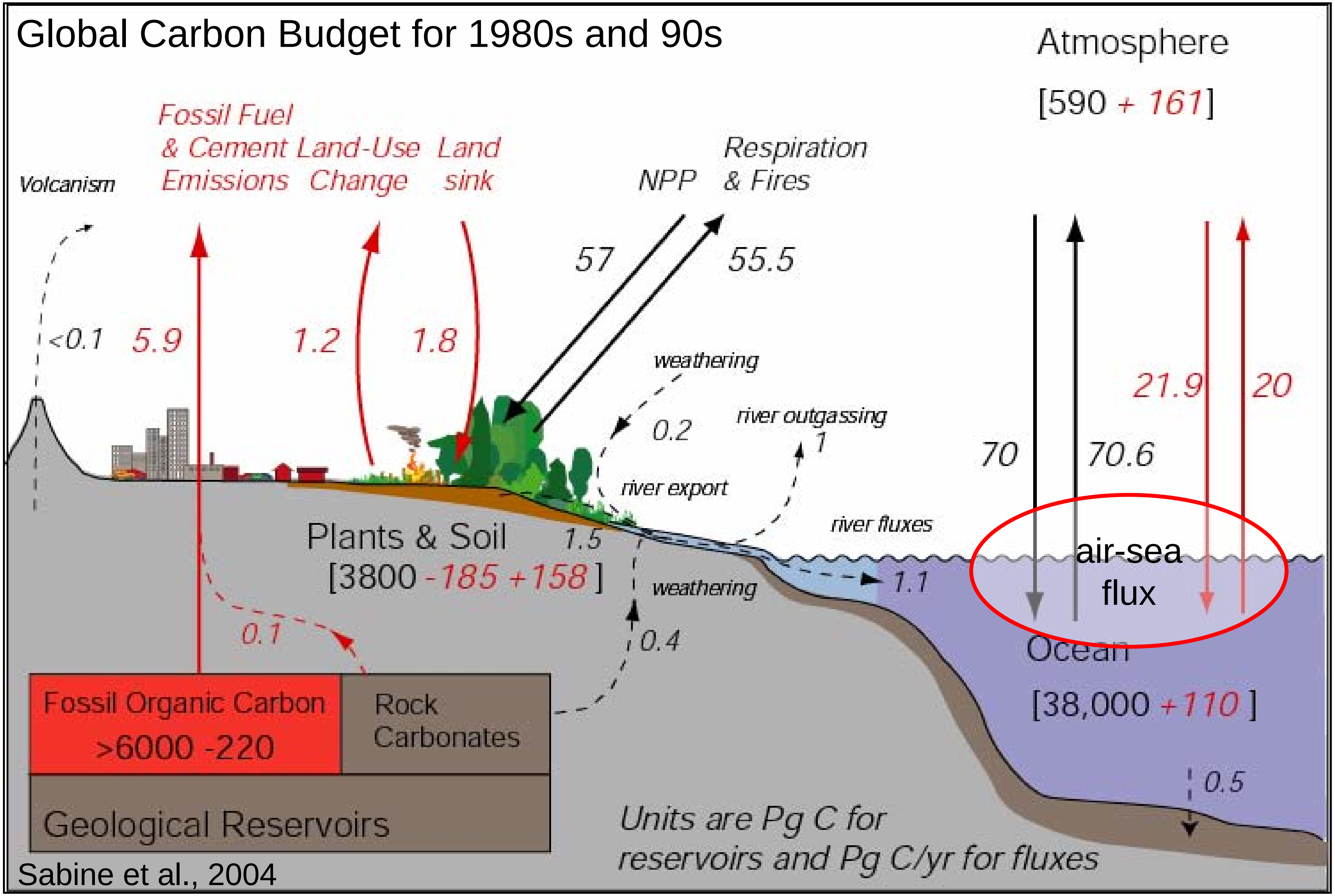
Goal: To quantify decadal changes in the inventory and transport of heat, fresh water, carbon dioxide (CO$_2$), chlorofluorocarbon tracers and related parameters in the oceans.

Approach: The sequence and timing of the CLIVAR/CO$_2$ Repeat Hydrography cruises have been selected so that there is roughly a decade between them and the WOCE/JGOFS global survey.

Achievements: The U.S. CLIVAR/CO$_2$ Repeat Hydrography Program has completed 9 of 18 lines and is on schedule to complete global survey by 2012.

Global map of planned CLIVAR/CO$_2$ Repeat Hydrography Program hydrographic sections





Sabine et al., 2004

A second approach is to evaluate the net air-sea exchange of CO_2.

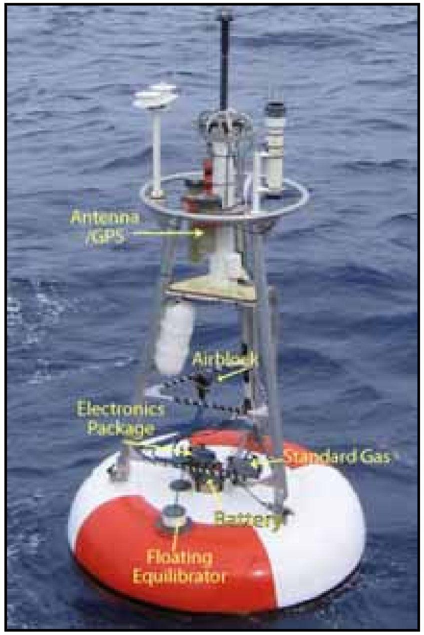
Surface pCO_2 measurement Projects

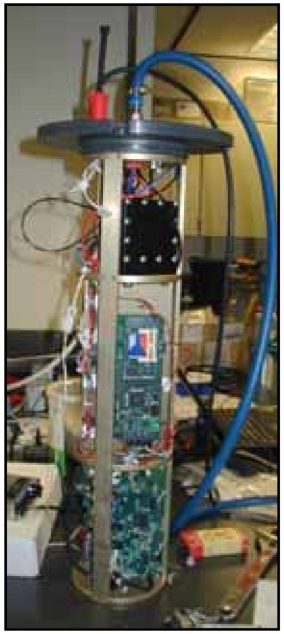
R. Wanninkhof, C.L. Sabine, R. Feely, T. Takahashi, S. Sutherland, N. Bates,
F. Chavez, S. Cooke, F. Millero and S. Maenner

Goal: To quantify the daily to interannual variability in air-sea CO_2 fluxes and understand the mechanisms controlling these fluxes.

Approach: Make autonomous surface pCO_2 measurements using research and volunteer observing ships (VOS) to get spatial coverage at seasonal time scales and using a network of surface moorings to get high frequency temporal resolution.

Achievements: The VOS program has outfitted 7 ships and has a full data exchange policy with 4 other ships. The moored pCO_2 program currently has 10 open ocean systems deployed.





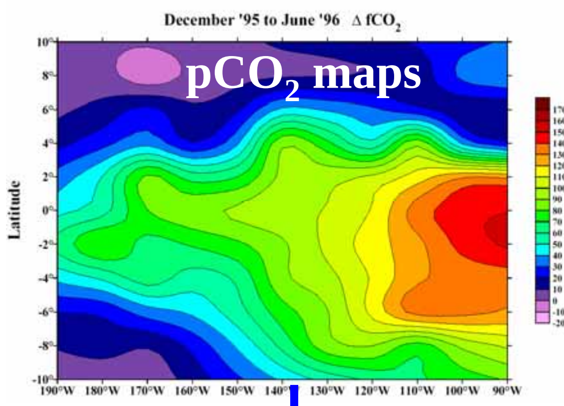
Concept: Use Multiple Platforms to Produce Seasonal CO_2 Flux Maps

In situ sampling
pCO_2, SST, SSS

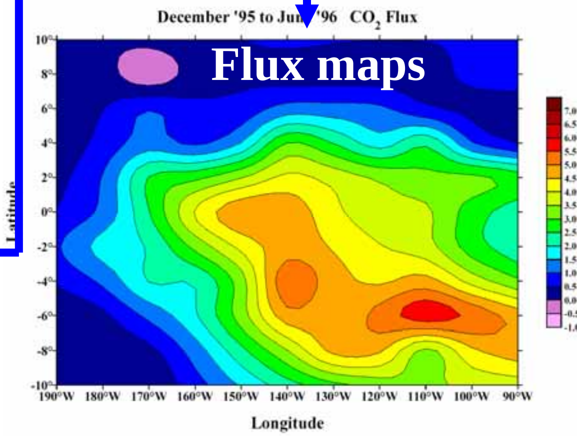
Algorithm development
pCO_2= f(SST, *color*)

Co-located satellite data

Apply algorithm to regional SST& *color* fields to obtain seasonal pCO_2maps



Flux = k s ΔpCO_2



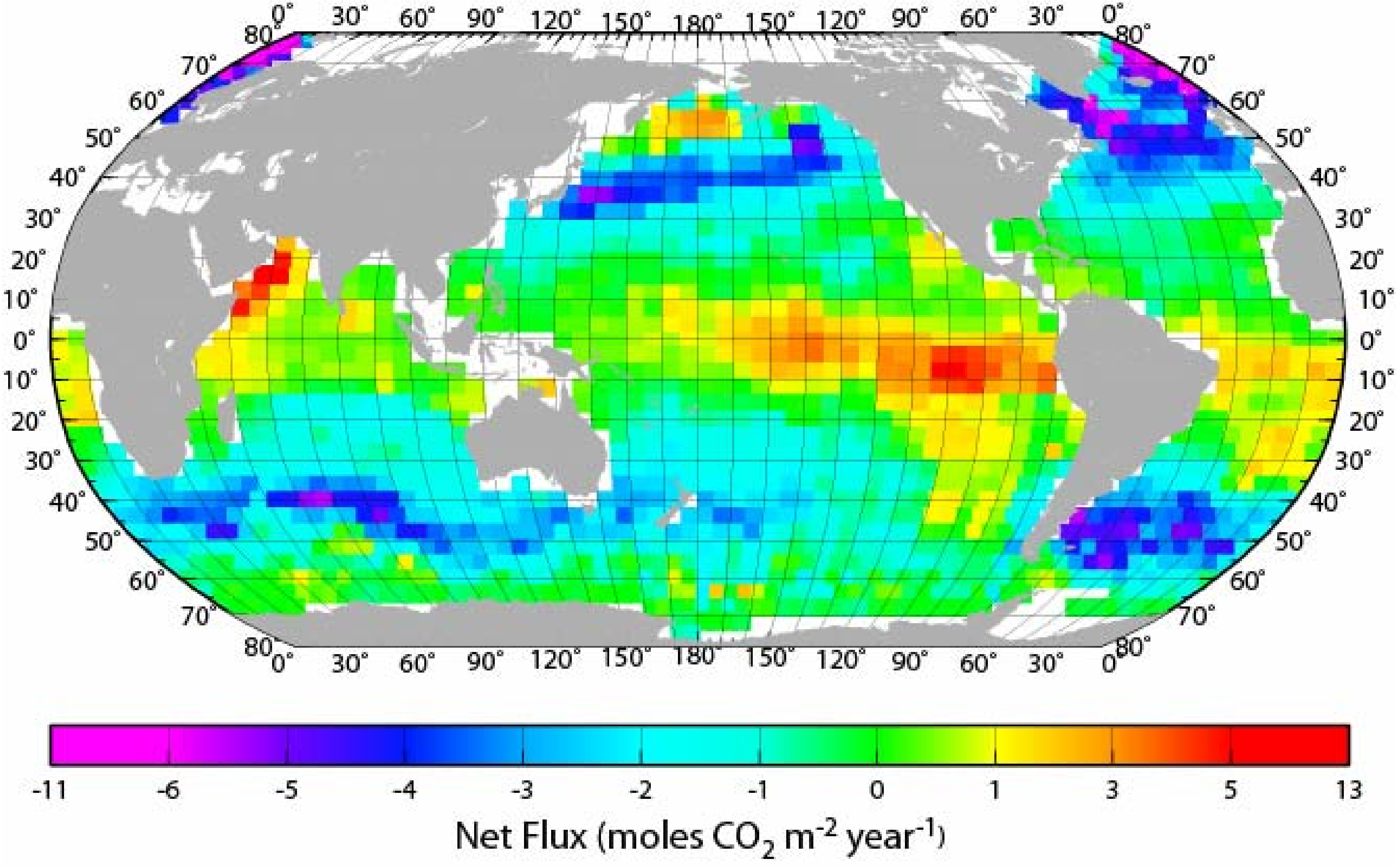
Remote sensing
SST, color & wind
Soon SSS

Regional satellite SST & *color* data

Wind data

Algorithm development
Gas transfer, k = f (U_{10},SST)

Takahashi climatological annual mean air-sea CO_2 flux for reference year 1995

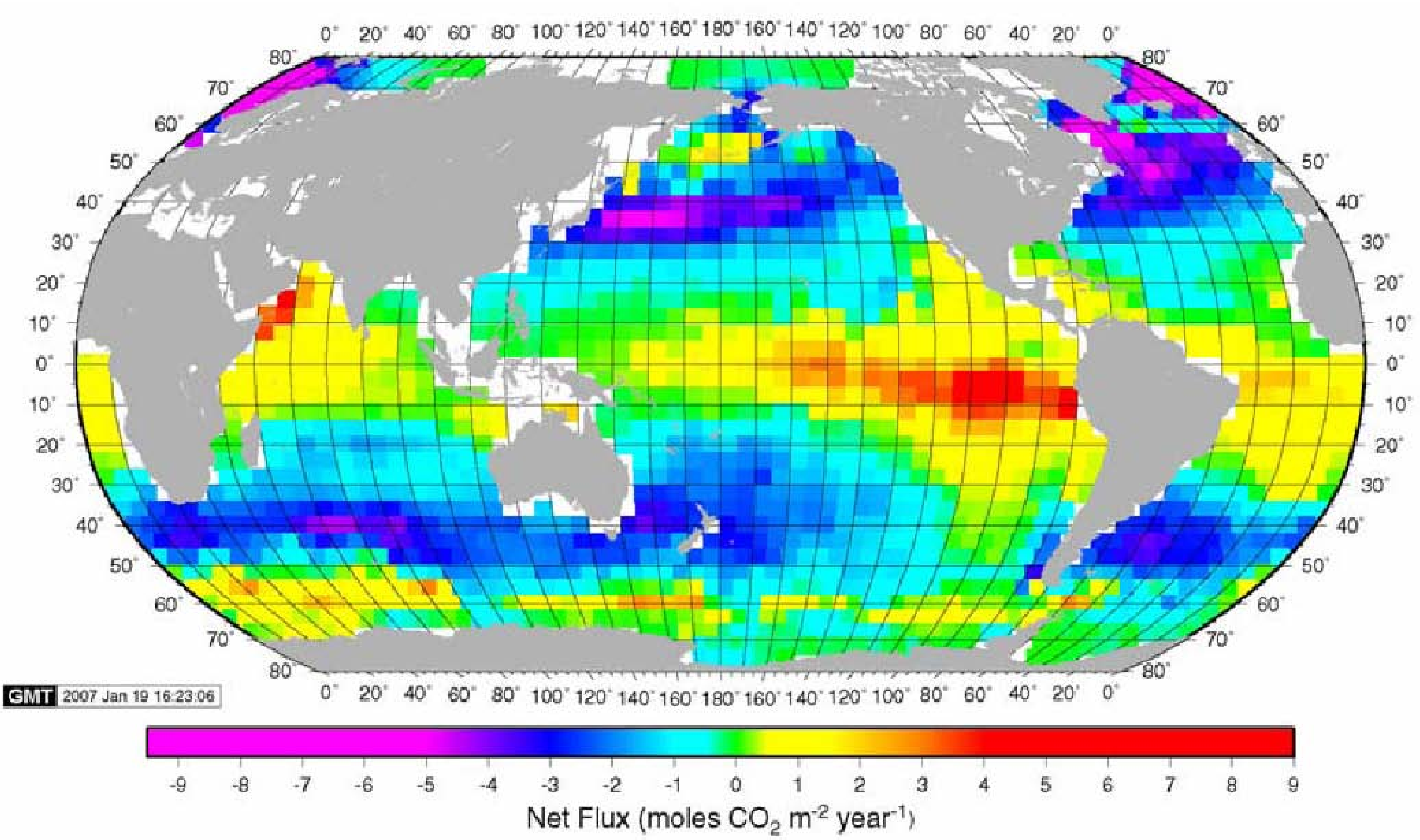


Based on .94 million measurements since 1970 and NCEP 41 year winds.

Global flux is 1.5 Pg C/yr

Takahashi et al., Deep Sea Res. II, 2002

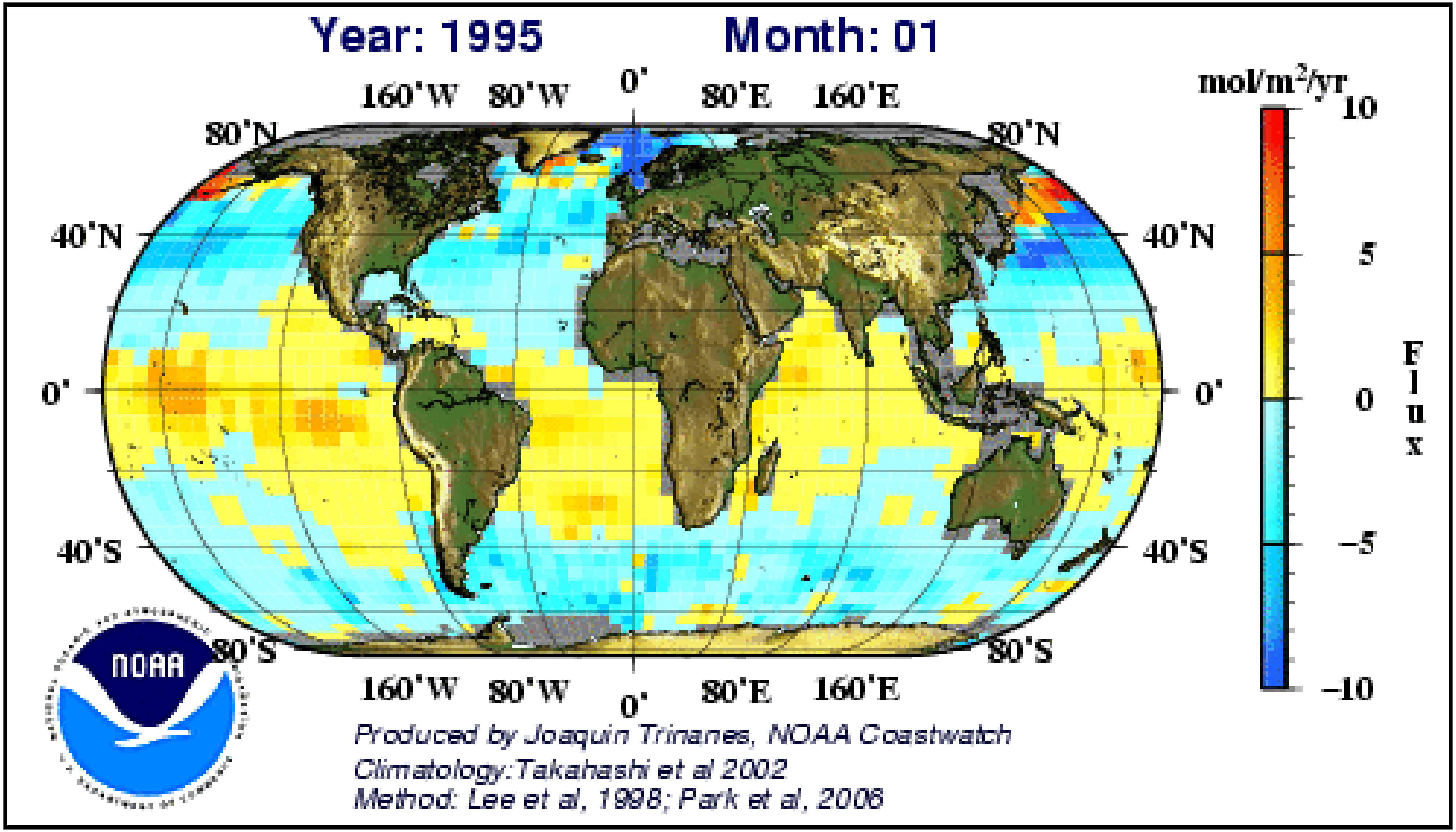
Takahashi climatological annual mean air-sea CO_2 flux for reference year 2000



Based on 2.791 million measurements since 1970 and
NCEP/DOE/AMIP II reanalysis.
Global flux is 1.22 Pg C/yr

Takahashi et al., Deep Sea Res. II, submitted

Global Flux Map suggests an interannual variability of 0.18 Pg C



Produced by Joaquin Trinanes, NOAA Coastwatch

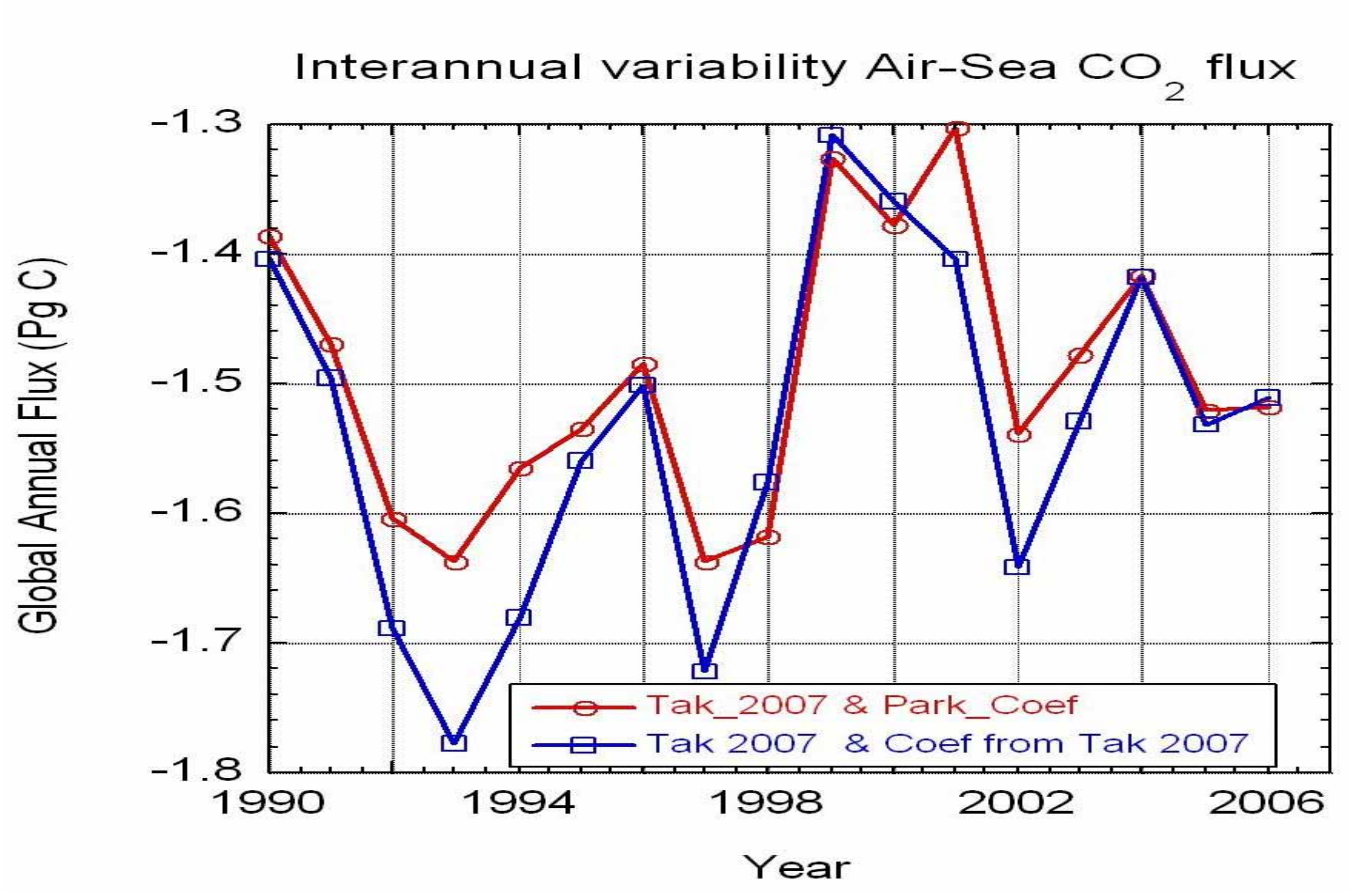
Climatology: Takahashi et al 2002

Method: Lee et al, 1998; Park et al, 2006

Approach:

1. Improving regional relationships by incorporating additional parameters (e.g. mixed layer depth, chlorophyll)
2. Improving regional relationships using ship-based and moored pCO_{2sw} observations

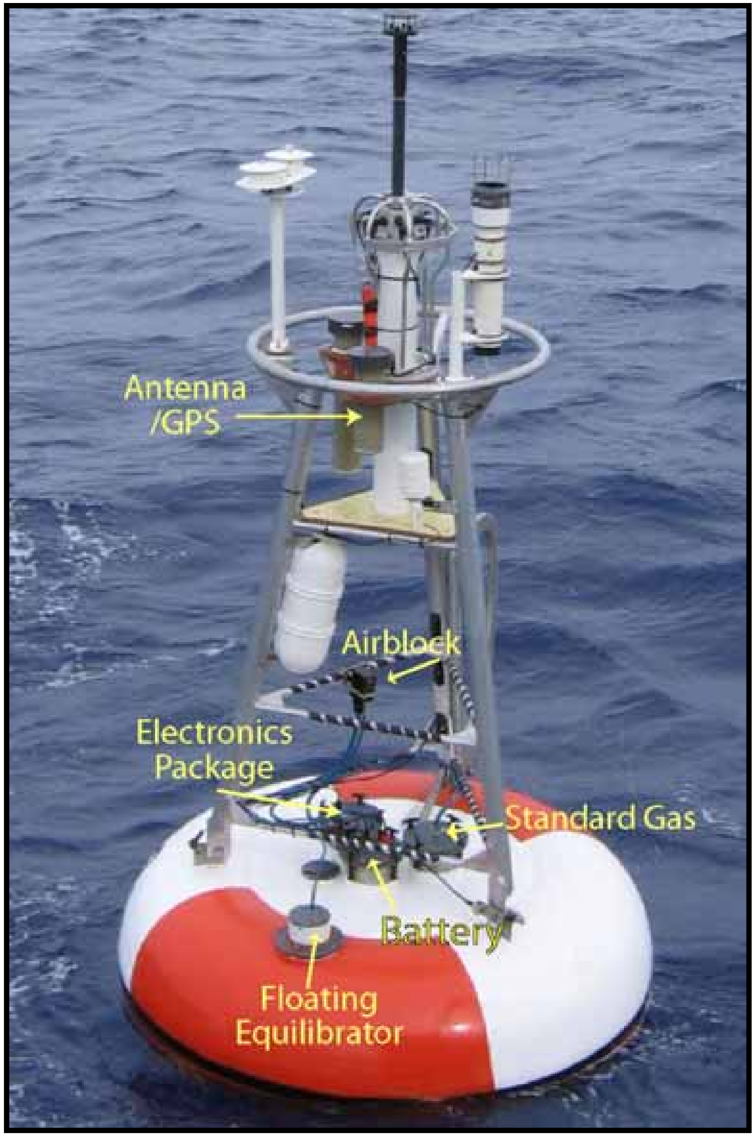
New results suggest a 30% larger interannual variability



To know if this is real, we need to better understand the time and space scales of variability in the ocean

PMEL Moored Autonomous pCO_2 ($MAPCO_2$) system

initial design is from the MBARI drifters of Gernot Friedrich and Francisco Chavez



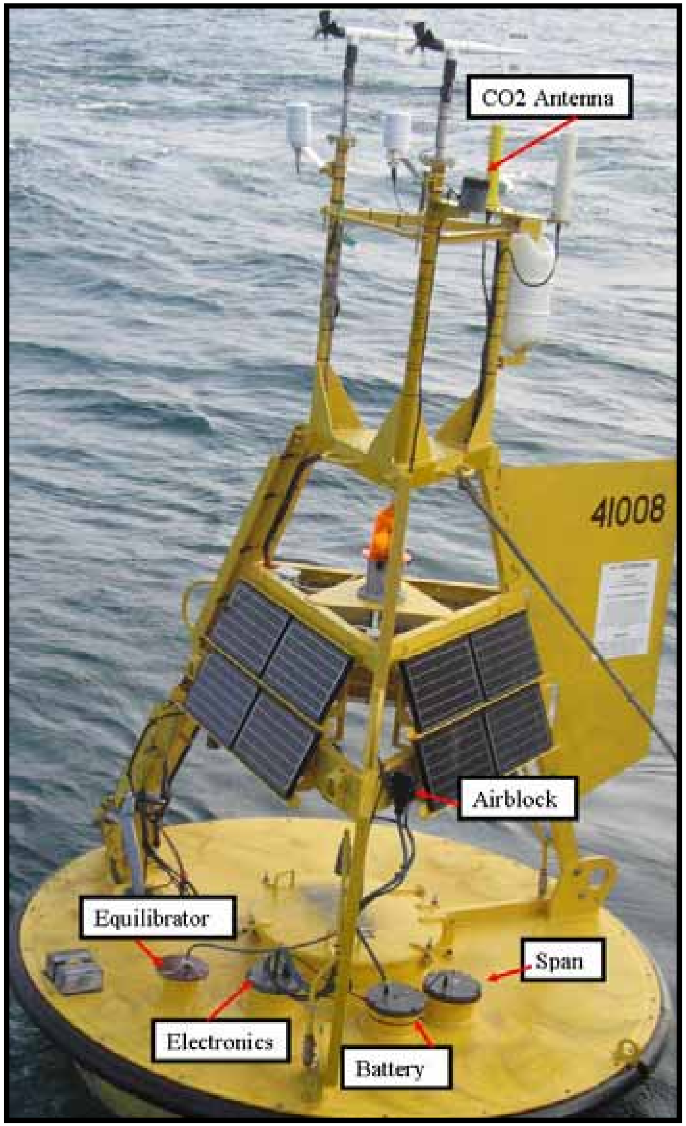
The Basics:

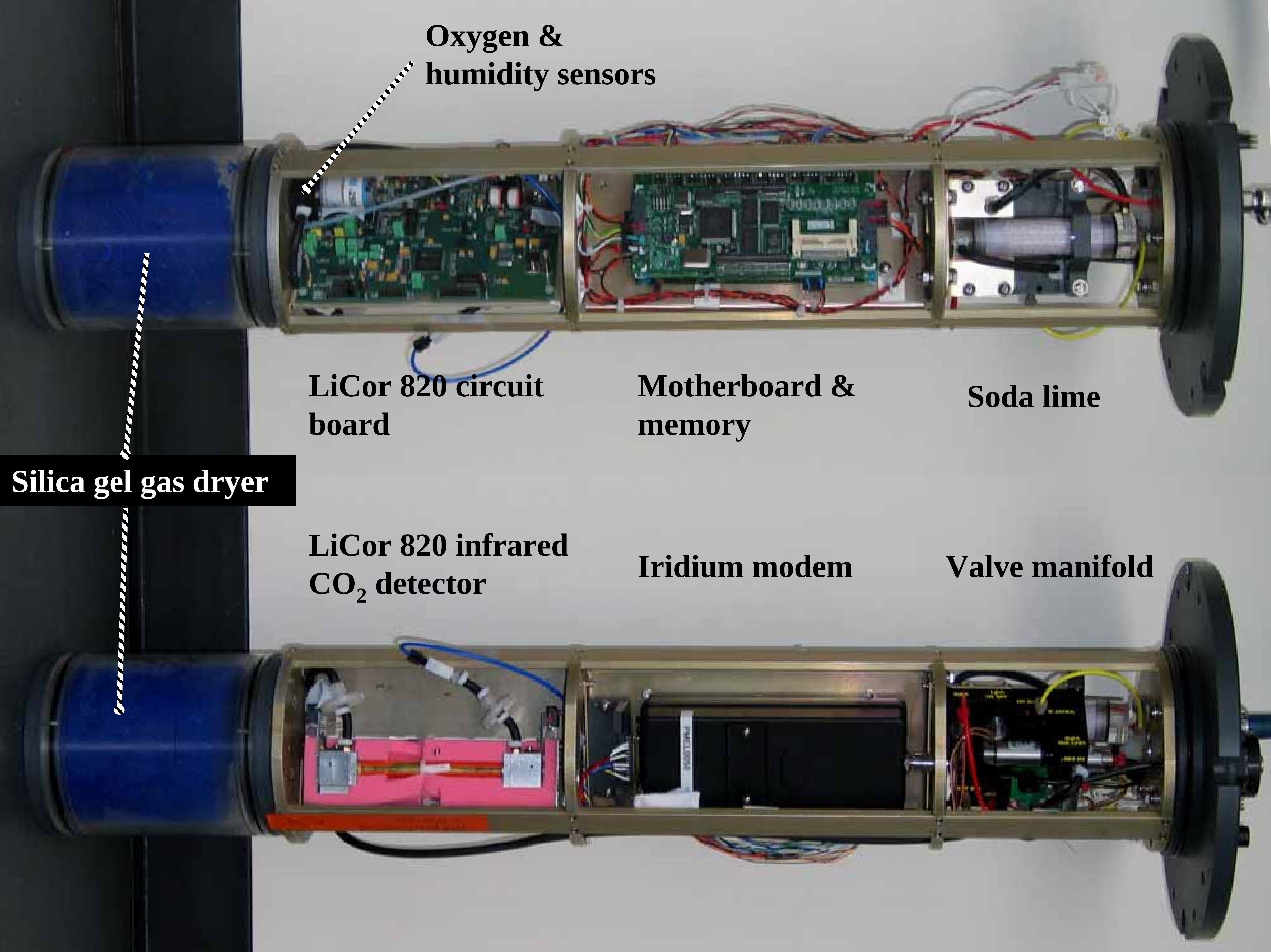
LiCor 820 NDIR detector to measure air and water CO_2

gas calibration traceable to WMO standards

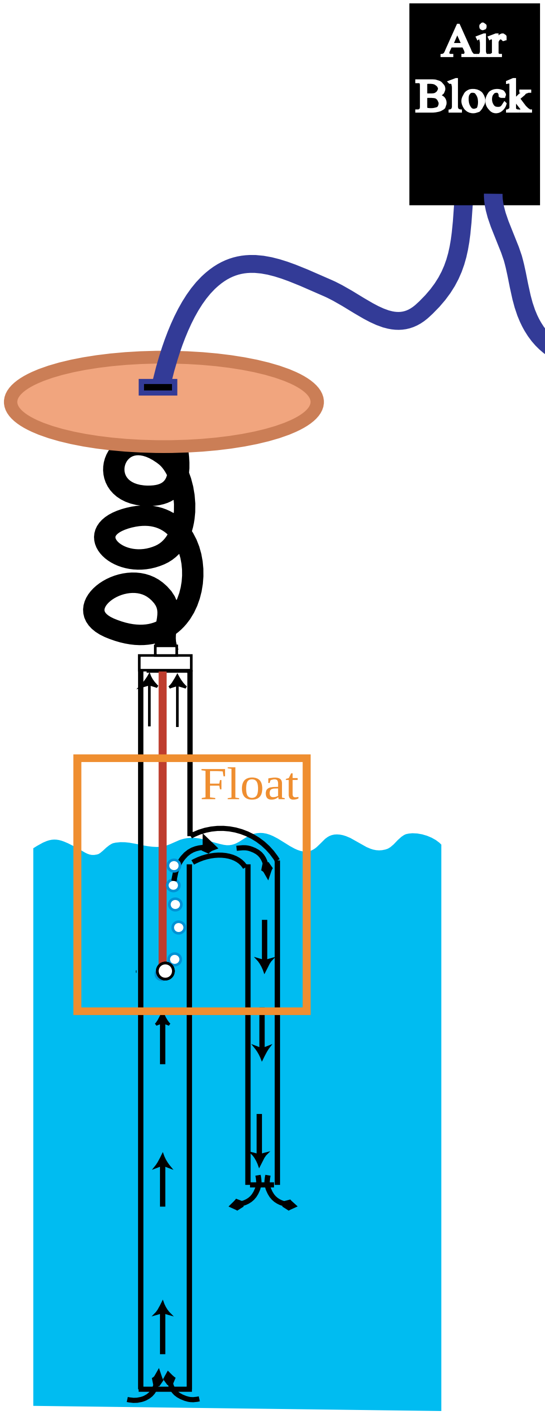
Self contained modular design to fit a range of buoys

daily satellite data transmission




Oxygen & humidity sensors
LiCor 820 circuit board
Motherboard & memory
Soda lime
Silica gel gas dryer
LiCor 820 infrared CO_2 detector
Iridium modem
Valve manifold

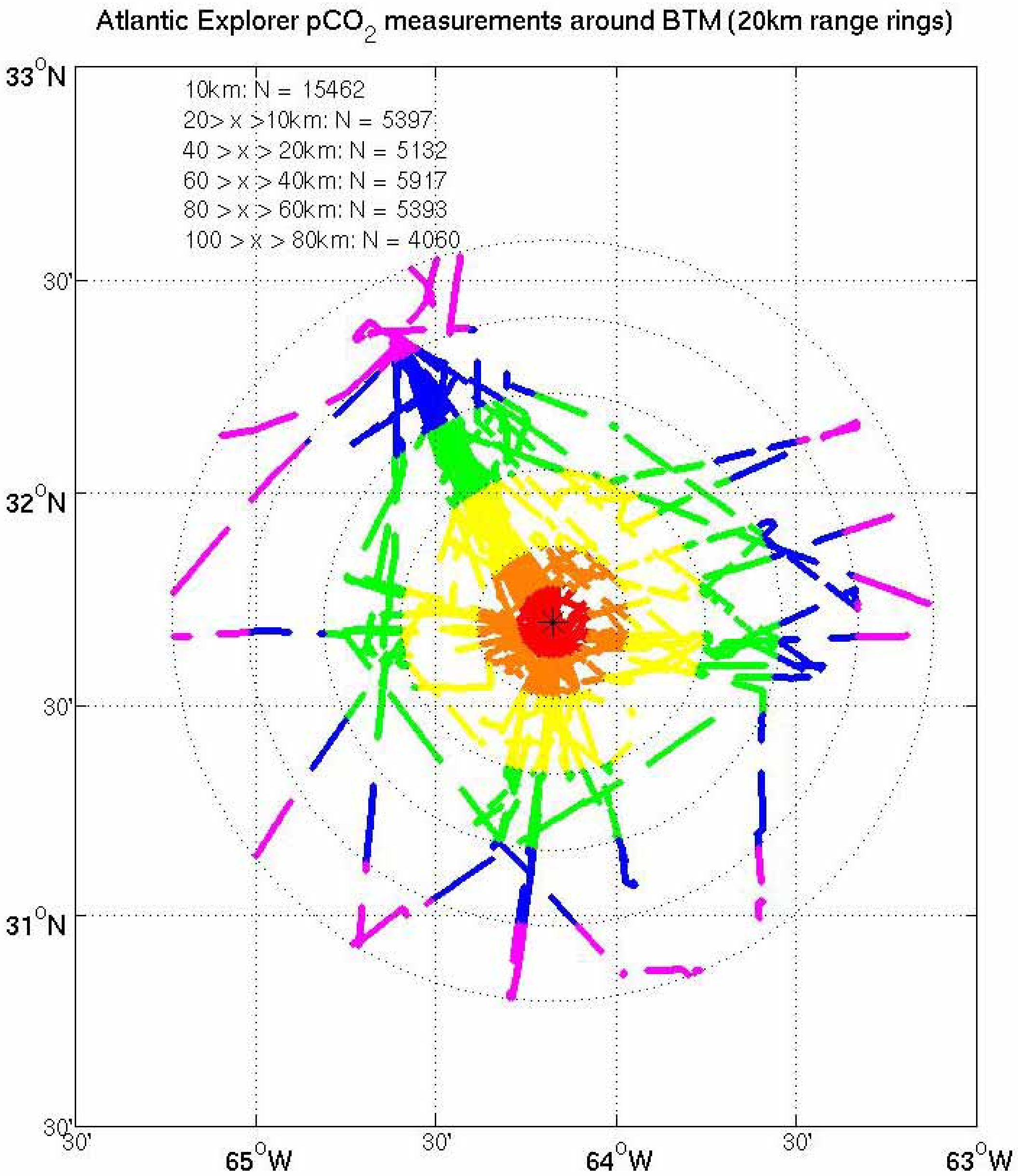
The Equilibrator



Bubble type equilibrator that sits directly in the surface seawater with a recirculated headspace gas. Nominal time of recirculation 10 minutes.

The equilibrator is made from a copper-nickel alloy to prevent biofouling

Relating Underway Data to Moored Data

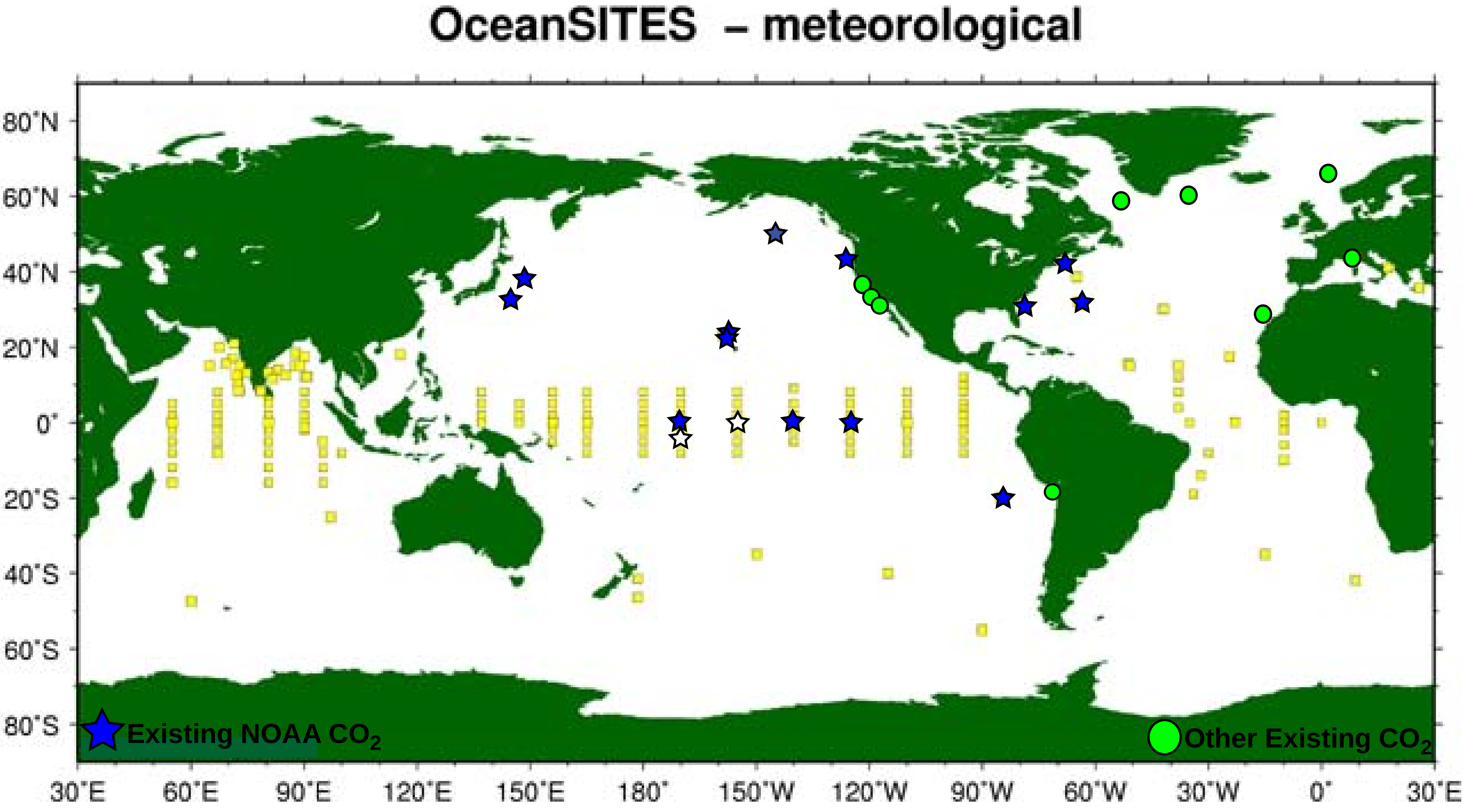


From N. Bates

Average difference between BTM and AE for measurements within 10 km and 3 minutes is less than 0.5 ±4.7 µatm (n=15,462)

By comparing data over a range of distances one can begin to assess the correlation length scales for the region

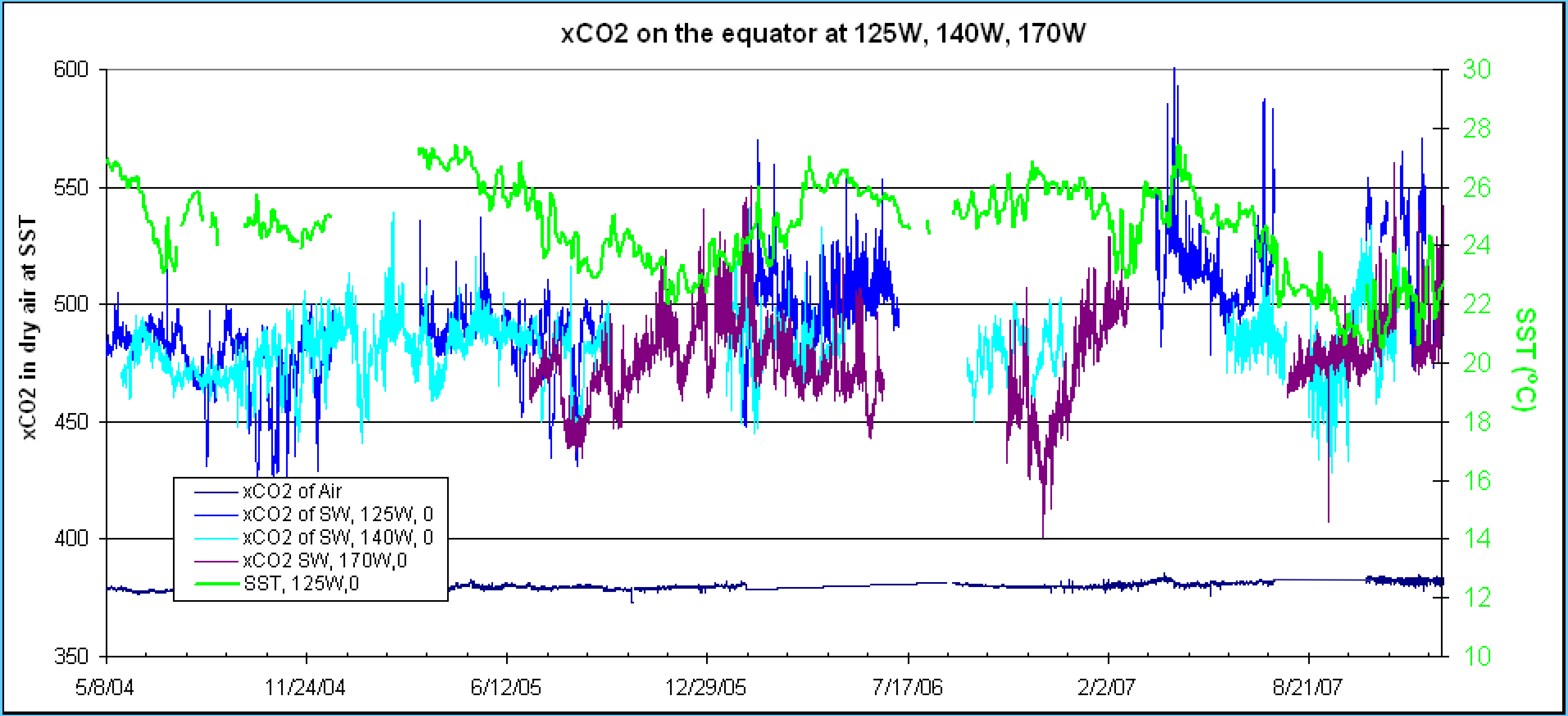
NOAA’s existing pCO_2 moorings are designed to build on the OceanSITES reference flux sites



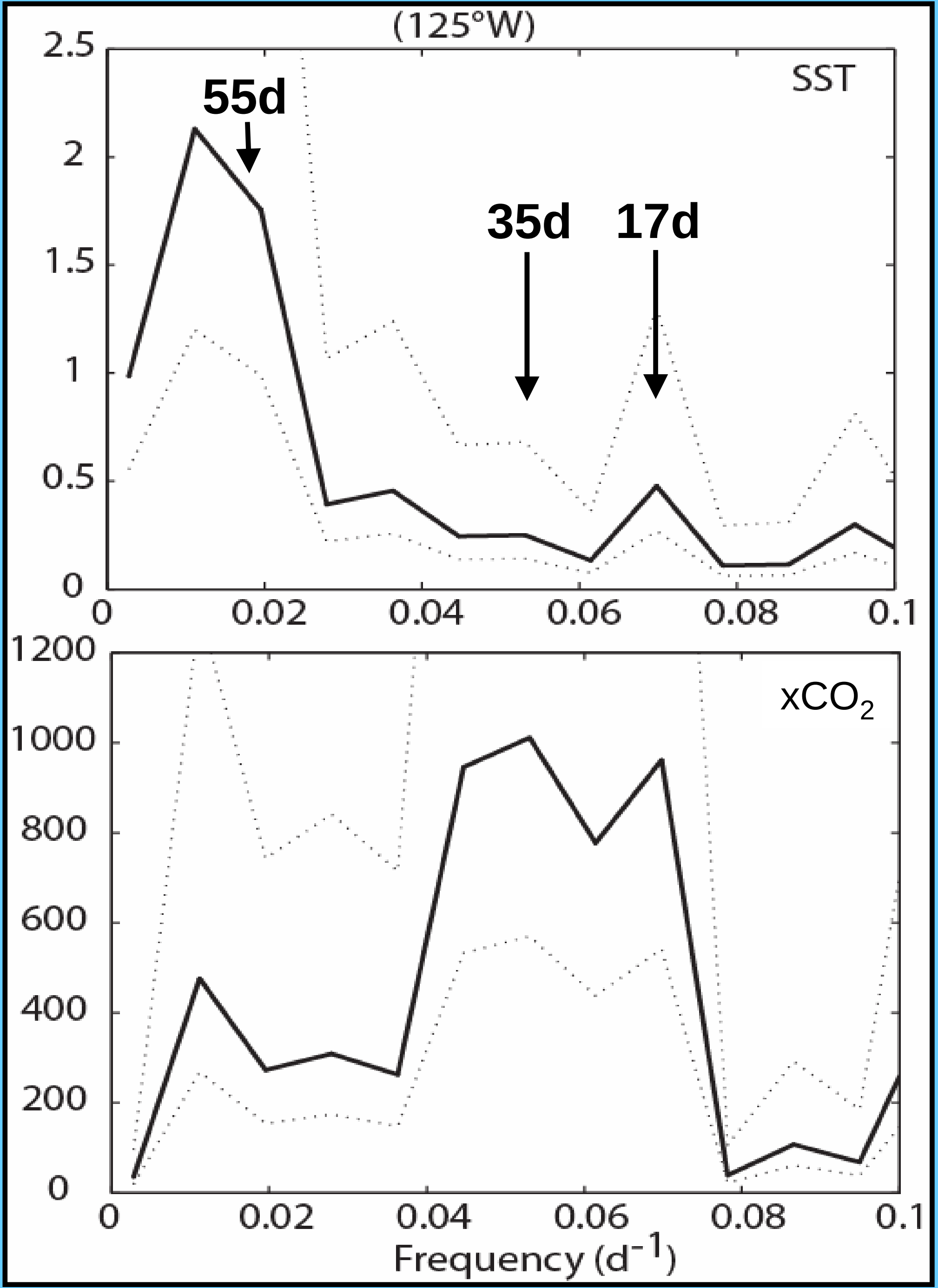
Equatorial Pacific

ENSO variations: ~ 80-100 ppm Seasonal amplitude: ~20-30 ppm

Sub-seasonal variations: ~50-60 ppm Diurnal cycle: ~20-40 ppm



Seasonal cycle in CO_2 is relatively small…only about half of what one would expect from the magnitude of the seasonal temperature signal, but there is significant higher frequency variability.



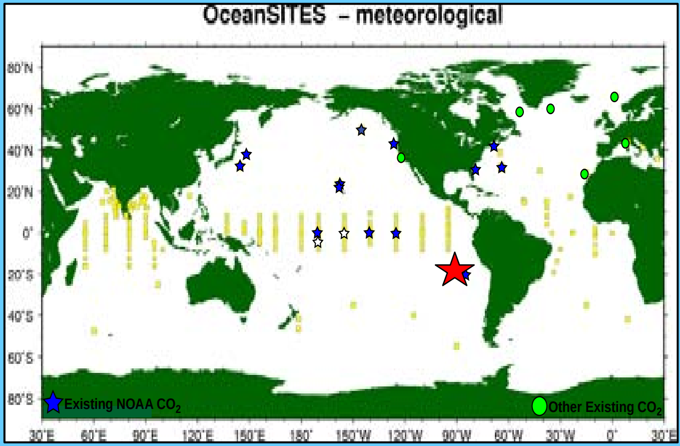
Spectral analysis indicates that variability is dominated by two frequencies:

Tropical Instability Waves
with frequencies of 17-35 days

Kelvin Waves
with frequencies of 53-60 days

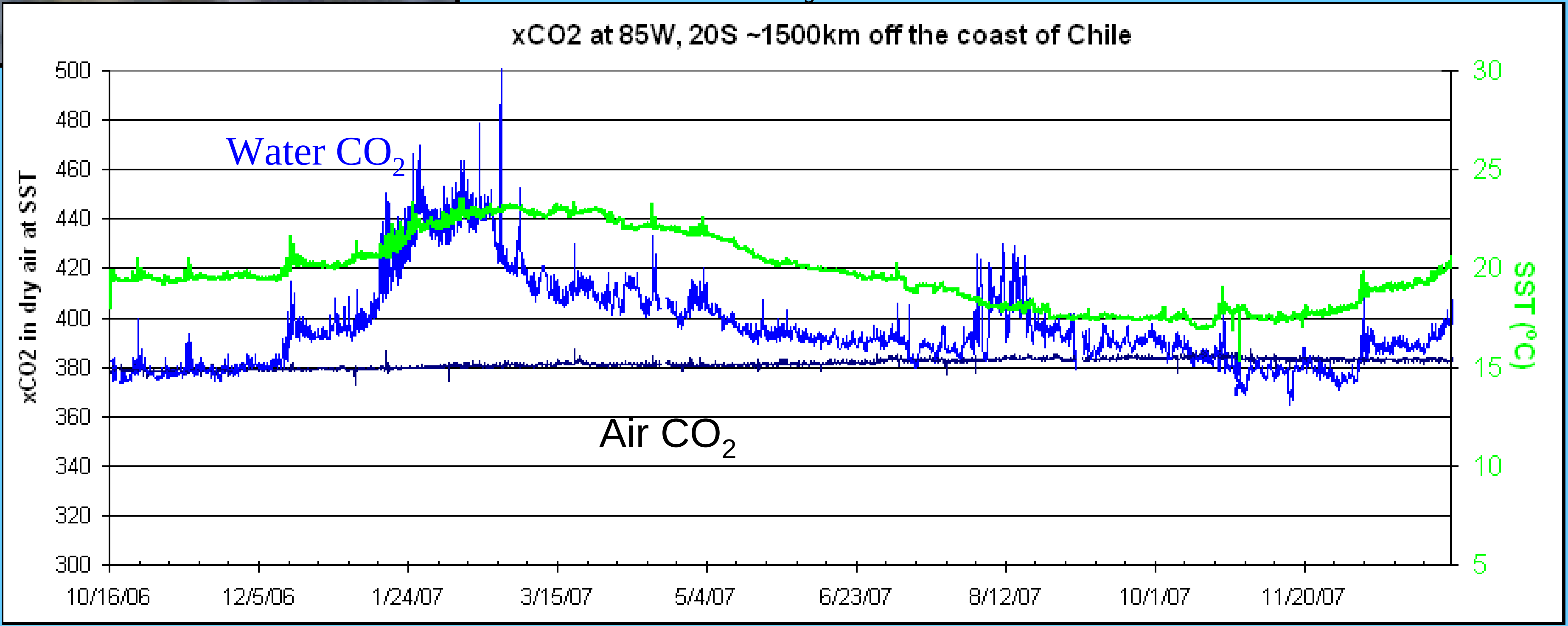
Note that Kelvin waves show the most energy in SST, but the TIWs show more energy in xCO$_2$

STRATUS Mooring

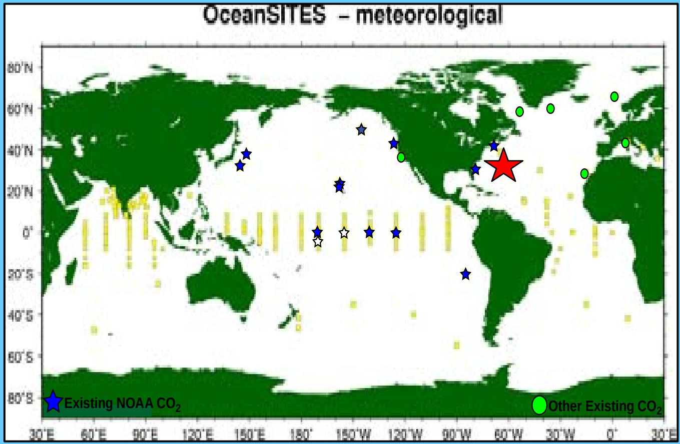


Seasonal amp:
~70 ppm (?)
Sub-seasonal variations: ~30 ppm
Diurnal cycle: 2-8 ppm

Primarily watermass controlled.

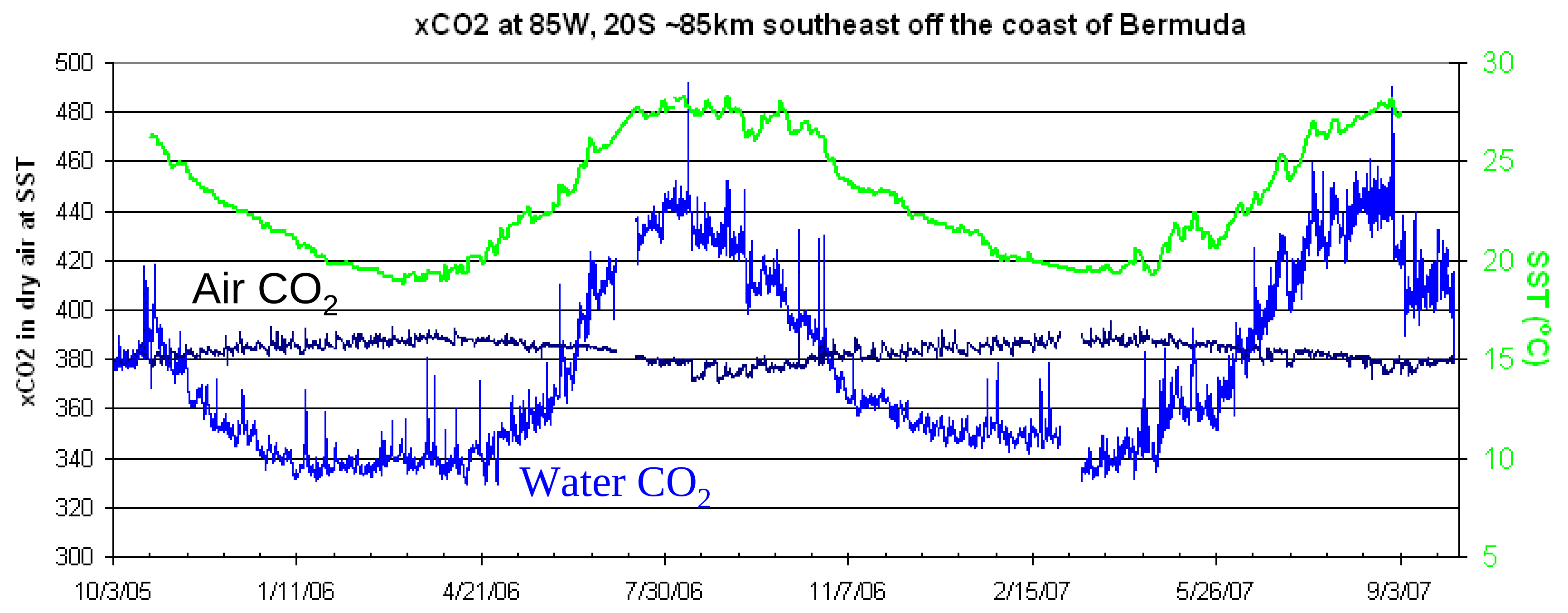


Bermuda Test-bed Mooring

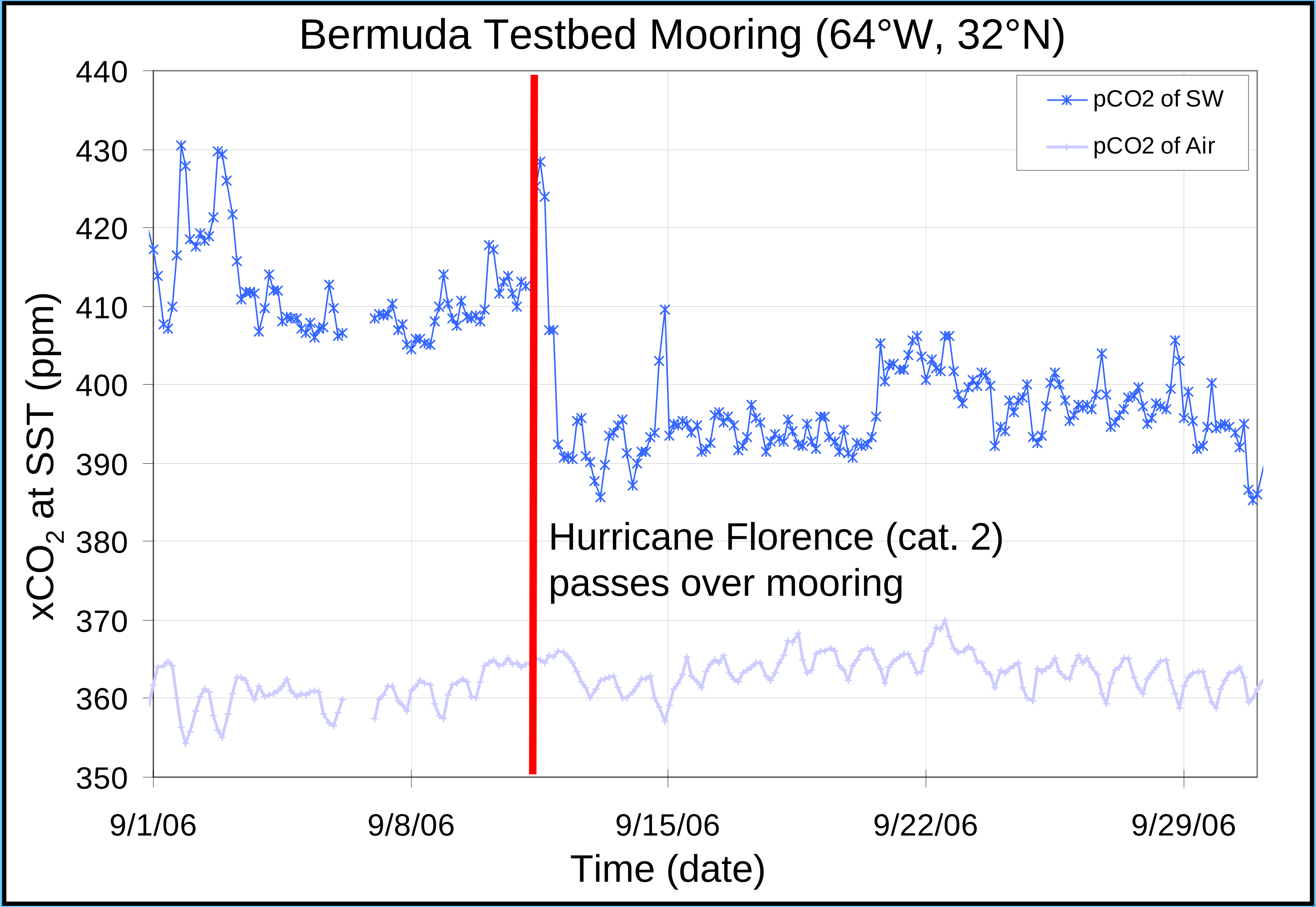


Seasonal amp: ~120 ppm
Sub-seasonal variations: ~20 ppm
Diurnal cycle: 2-9 ppm

Primarily temperature controlled

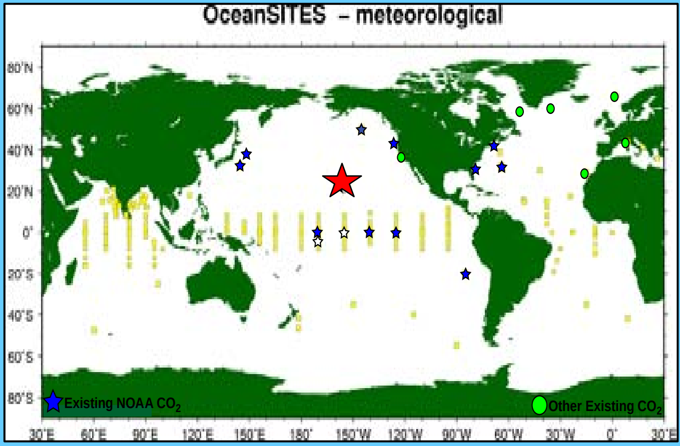

xCO2 at 85W, 20S ~85km southeast off the coast of Bermuda

moorings can capture variability missed between ship visits



Hurricane Florence (cat. 2) passes over mooring

MOSEAN mooring near Hawaii

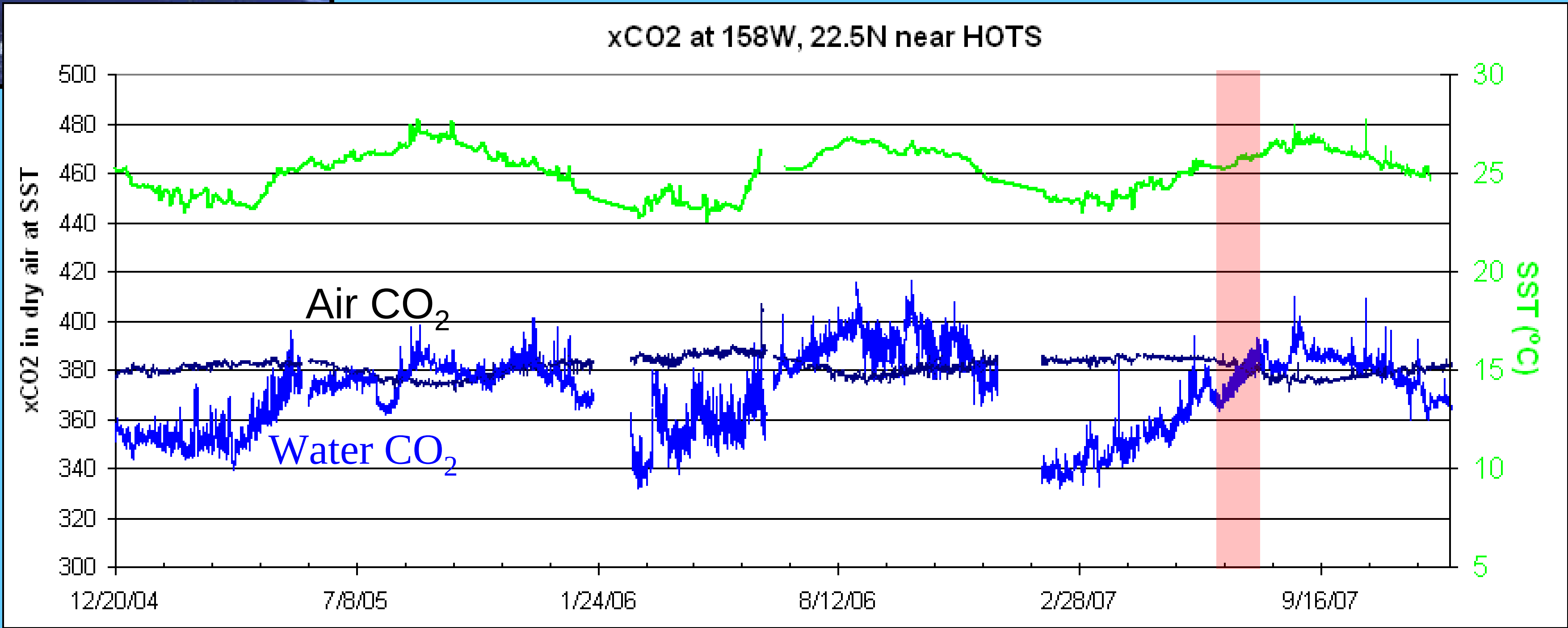


Seasonal amp.: ~60 ppm

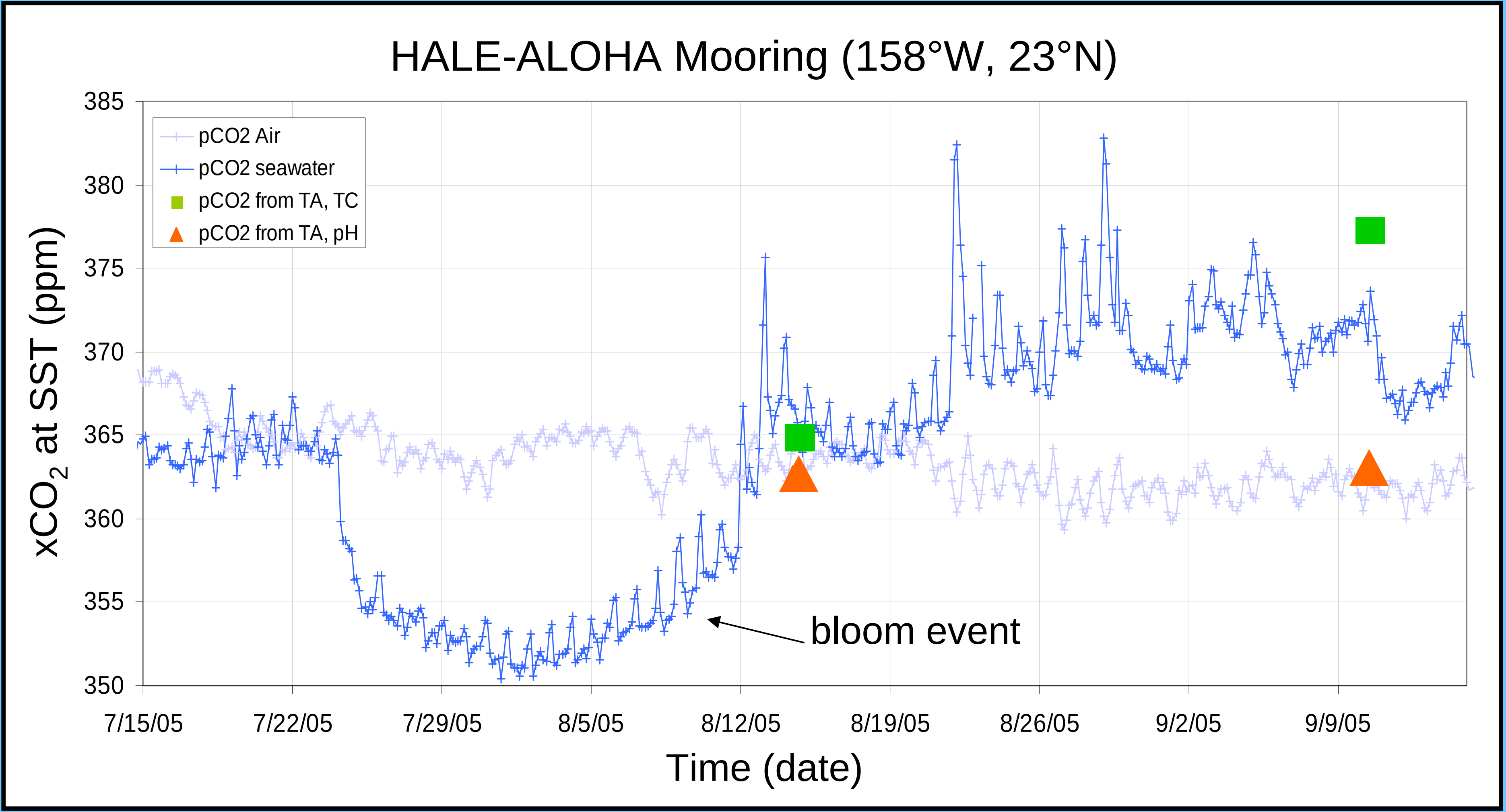
Sub-seasonal variations: ~15 ppm

Diurnal cycle: 3-8 ppm

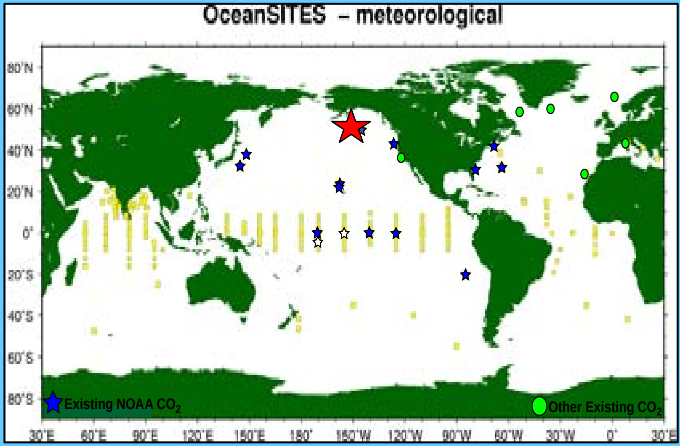
Combined temperature and biological control



moorings can capture variability missed between ship visits



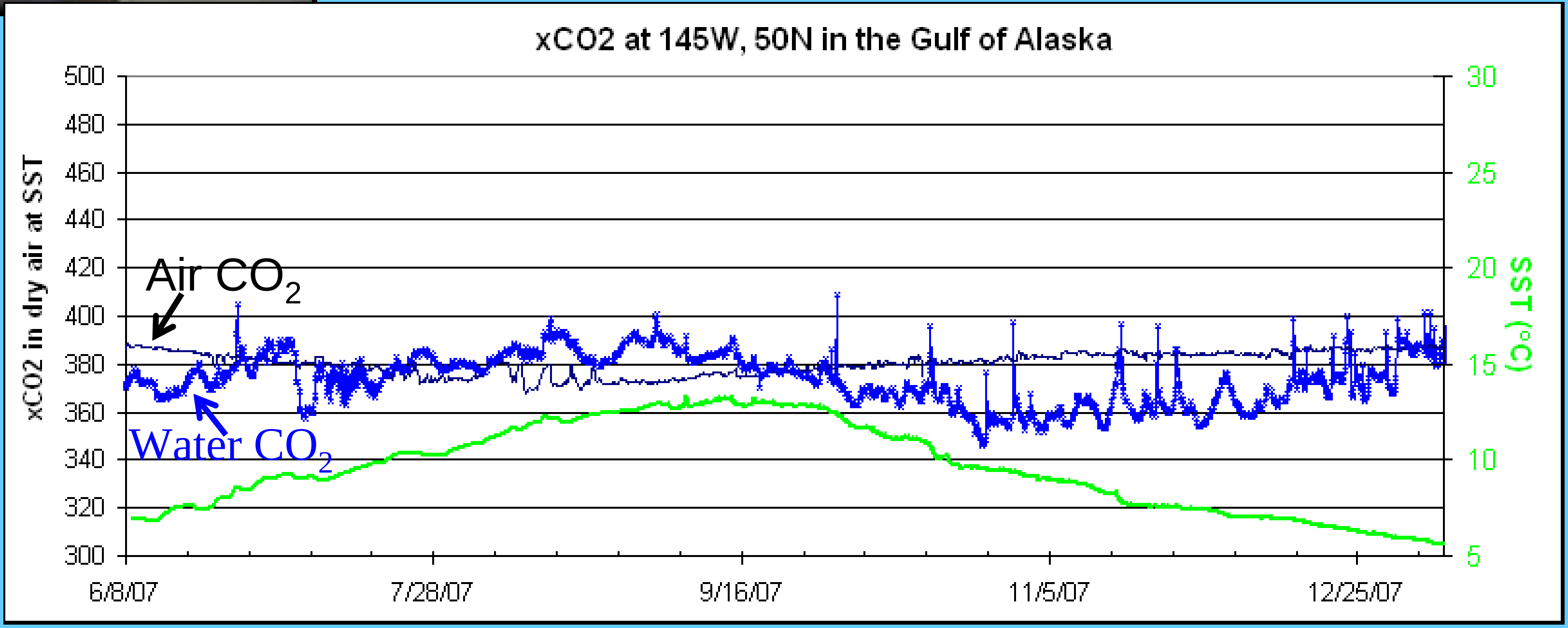
Station - Papa



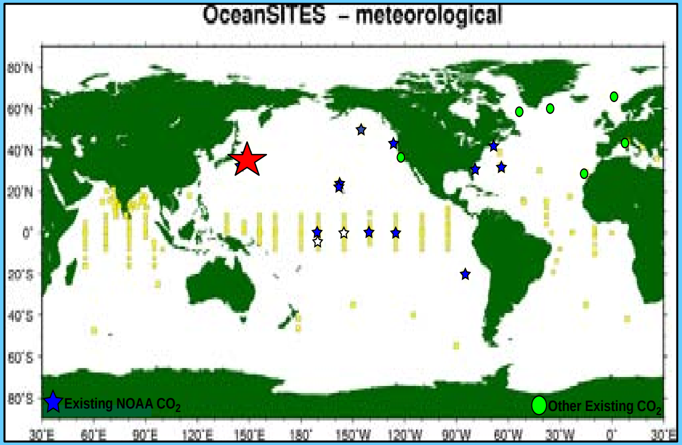
Seasonal amp.: ~40 ppm

Sub-seasonal variations: ~15 ppm

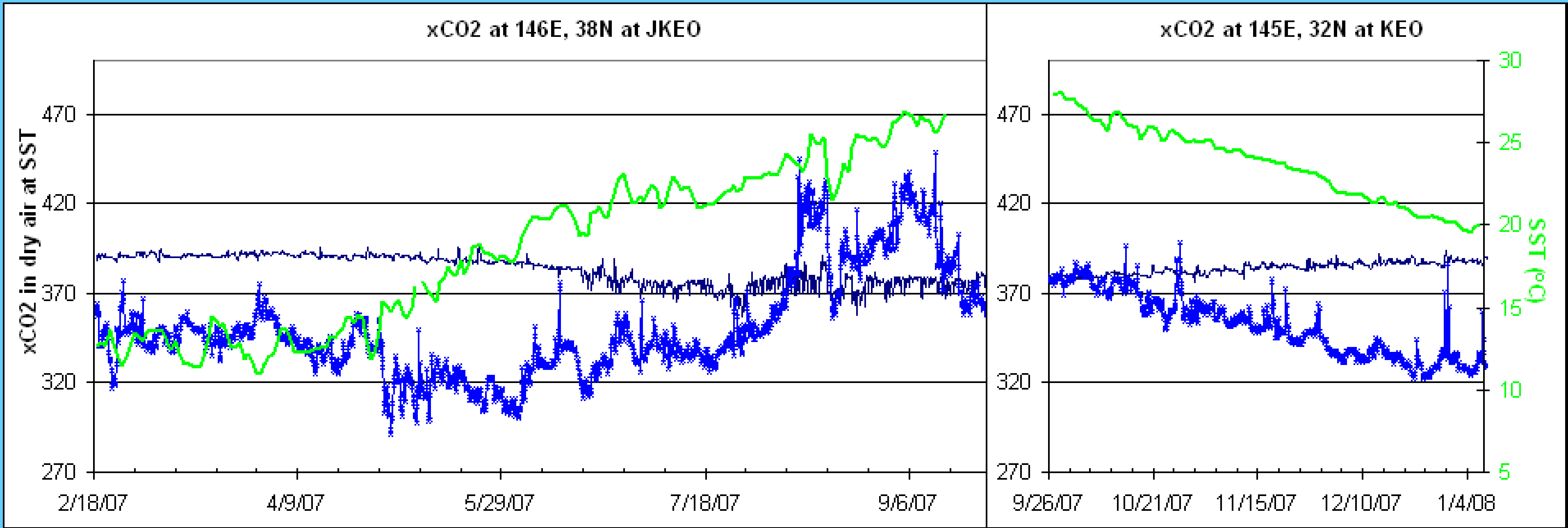
Diurnal cycle: none obvious



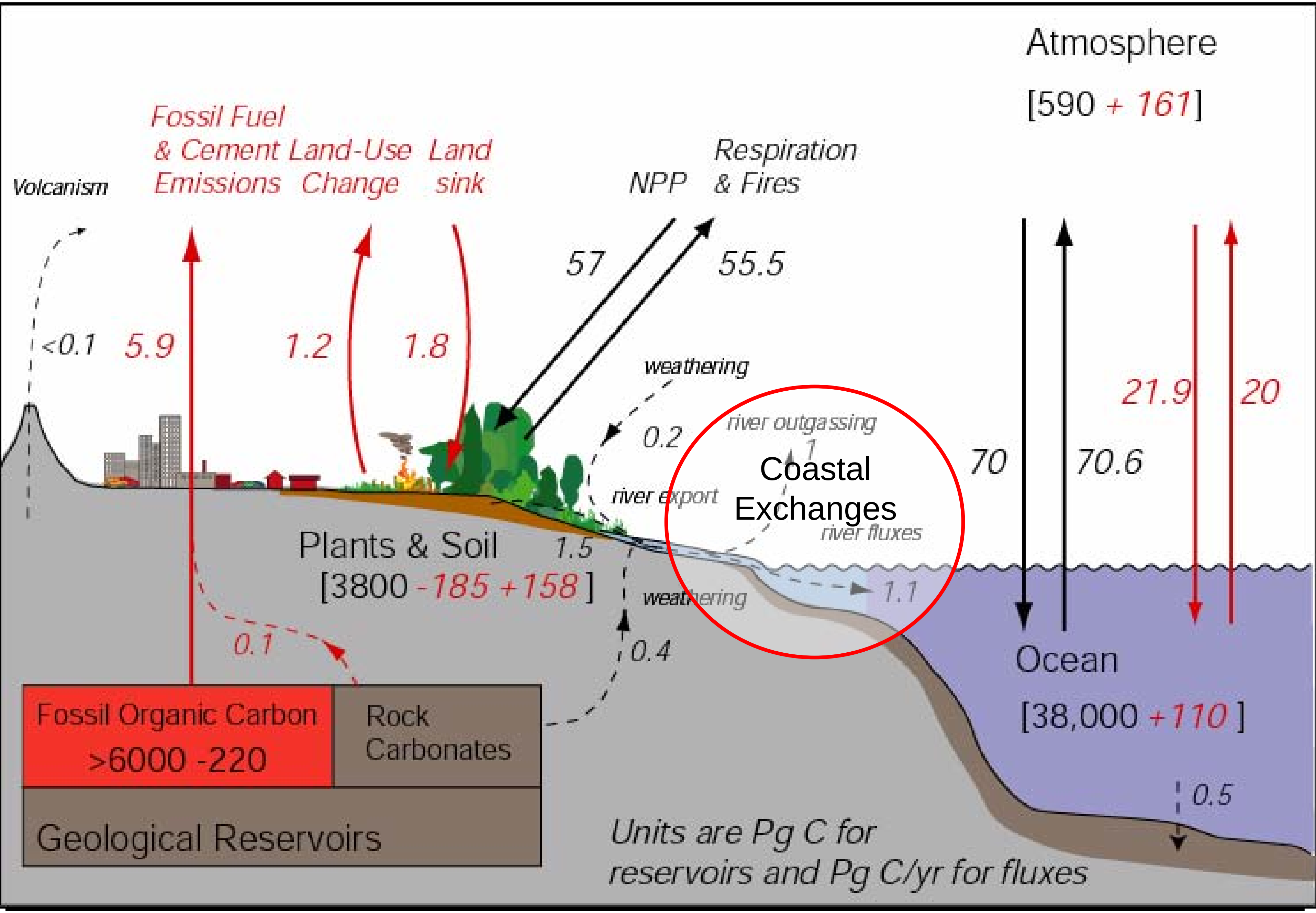
Northwest Pacific Sites - KEO and JKEO



Seasonal amp.: ~120 ppm
Sub-seasonal variations: ~50 ppm
Diurnal cycle: 5-10 ppm



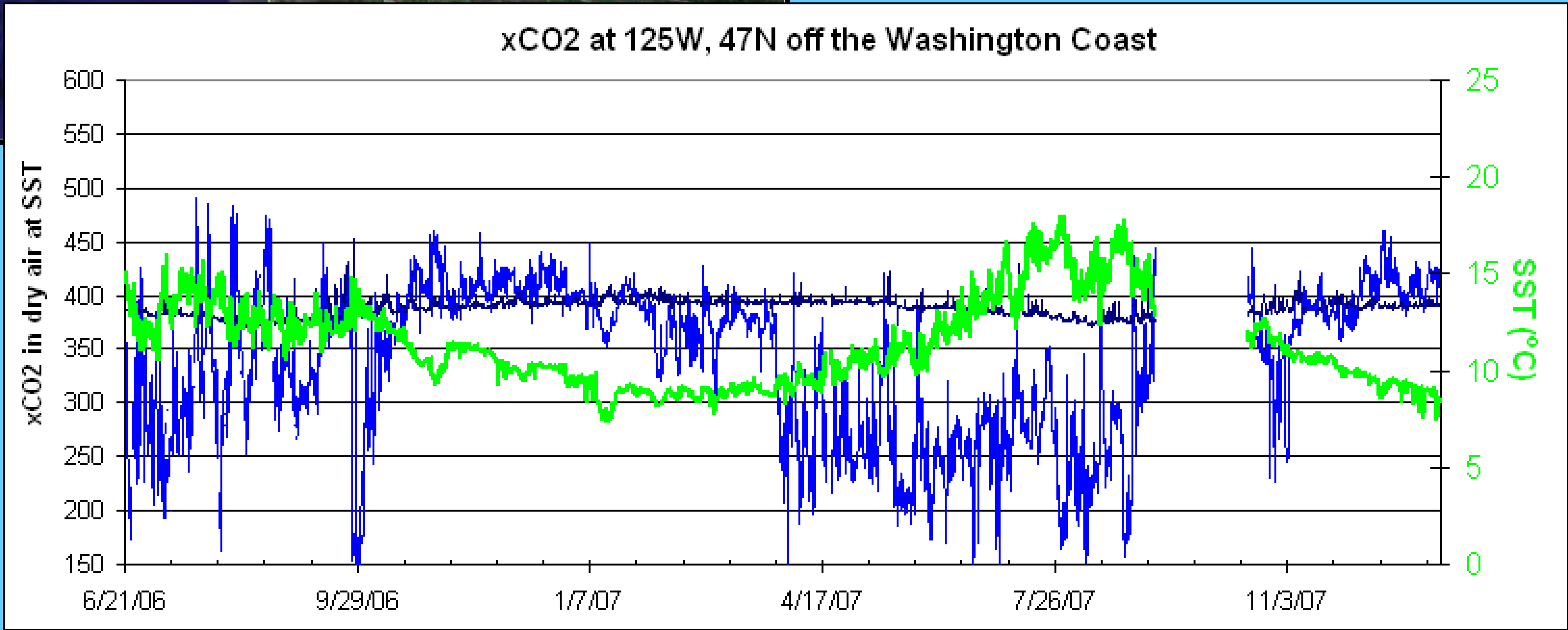
Developing New Directions: Coastal Studies



NDBC 46041
Cape Elizabeth

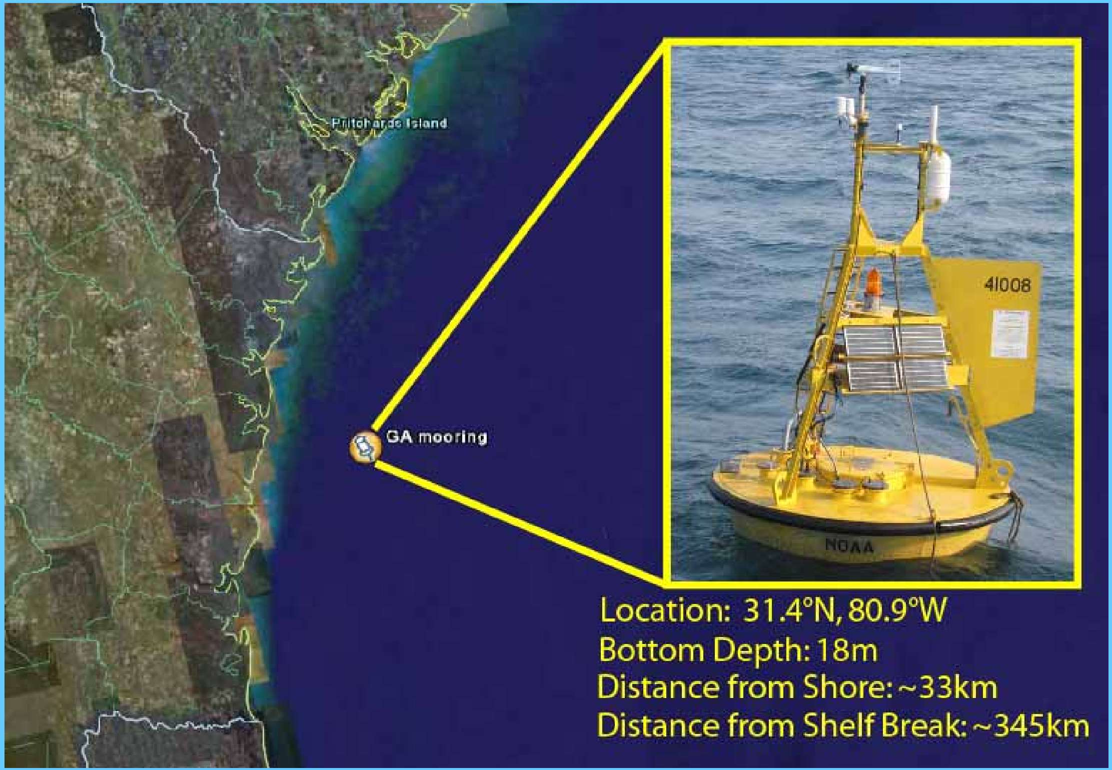
The WA site does not show a strong regular diurnal signal in the summer. Although there is variability on time scales of 1-3 days. Most of this variability is thought to be associated with summer upwelling events, some of which drove the surface water CO_2 higher than atmospheric.

Location: 47.3°N, 124.7°W
Bottom Depth: 132m
Distance from Shore: ~31km
Distance from Shelf Break: ~2km

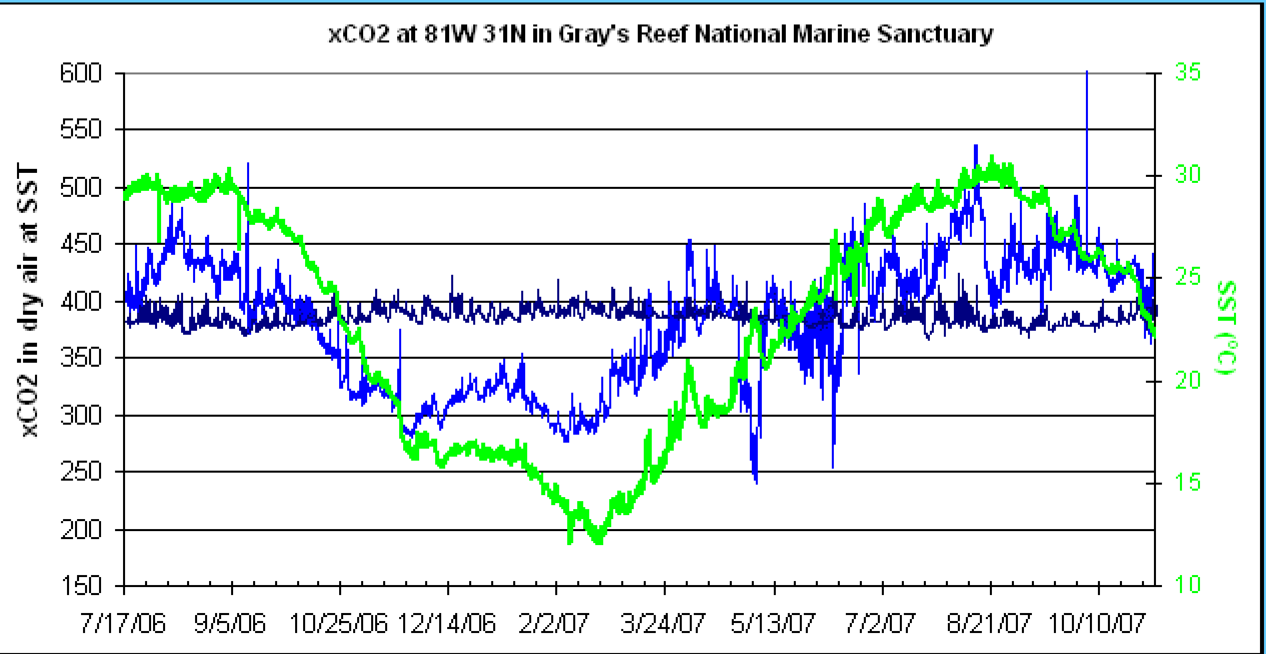

xCO2 at 125W, 47N off the Washington Coast

Georgia

Although the seasonal temperature cycle is the dominate control of the 200 ppm seasonal CO_2 range, there is some CO_2 variability on time scales of days to weeks. While some are associated with variations in temperature, others are not suggesting that biological or advective mechanisms may also play a role at these time scales.



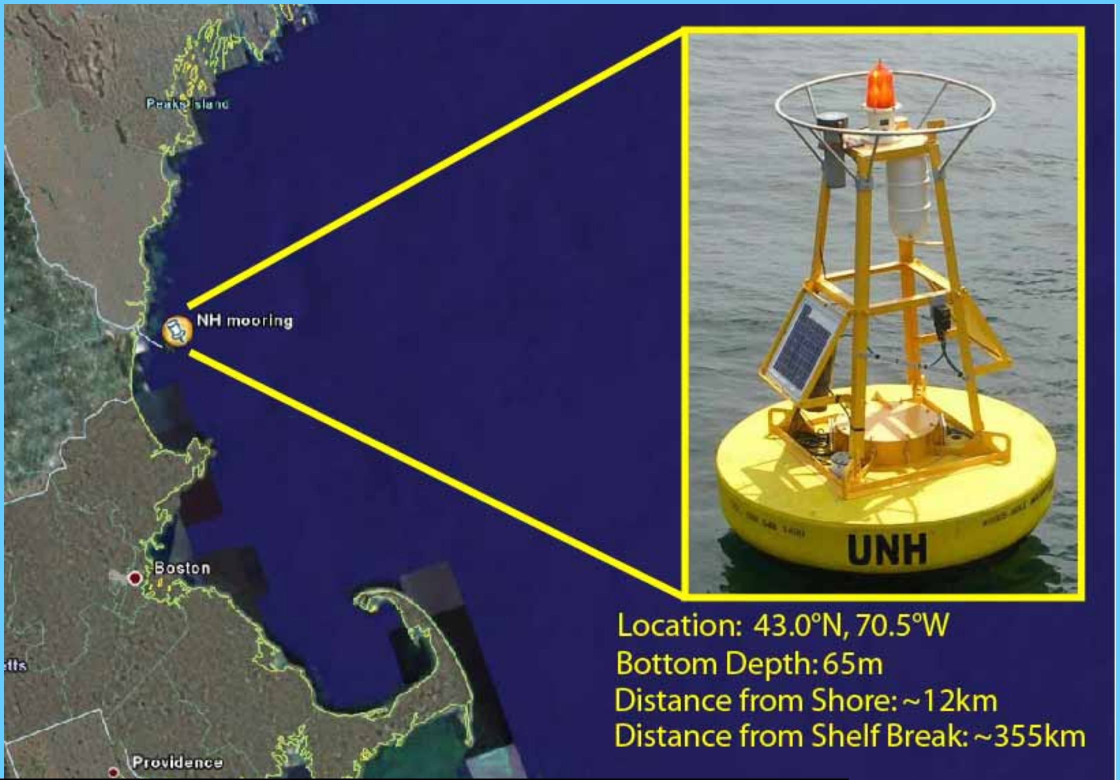
Location: 31.4°N, 80.9°W
Bottom Depth: 18m
Distance from Shore: ~33km
Distance from Shelf Break: ~345km


xCO2 at 81W 31N in Gray's Reef National Marine Sanctuary

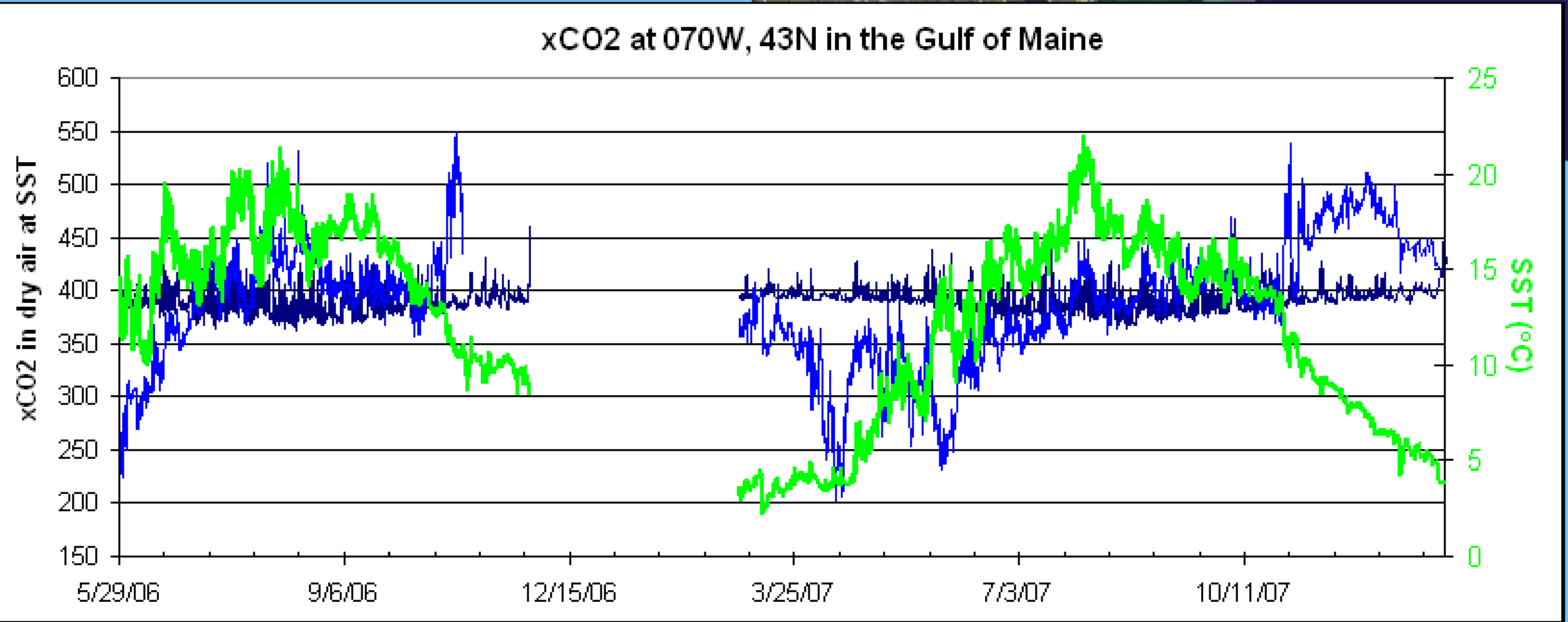
The GA site does show a clear diurnal signal in CO_2 during the summer. The CO_2 variations are generally positively correlated with the temperature variations, but the magnitude of the temperature changes is not large enough to account for all of the observed CO_2 changes.

New Hampshire

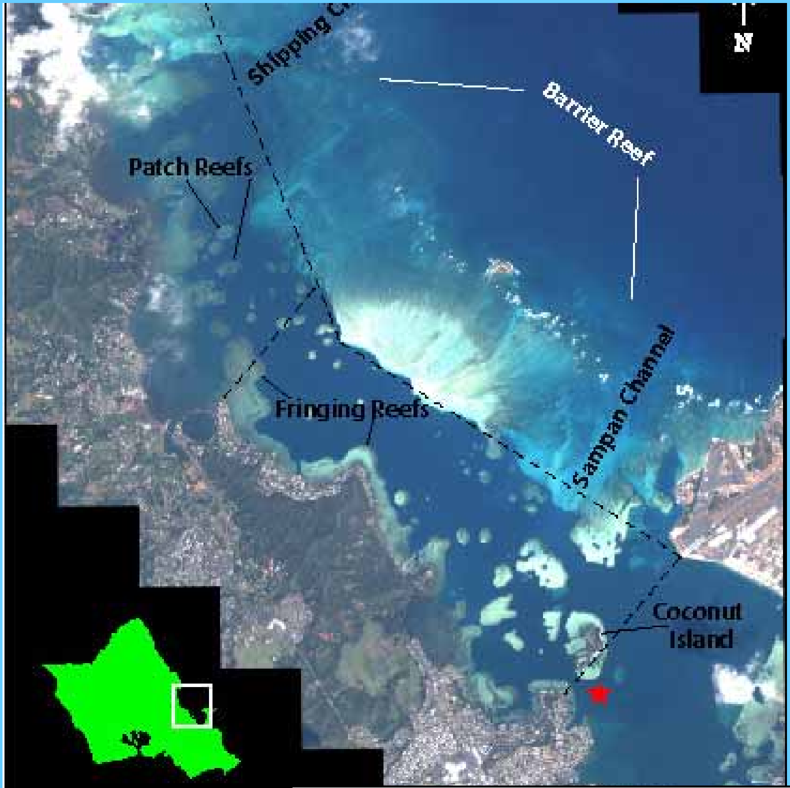
The two dominant sub-seasonal events in the NH mooring are the very low CO_2 values in the spring caused by spring blooms and an indication of very high CO_2 values at the beginning of winter likely caused by mixing after the first major winter storm passed through the area.



Location: 43.0°N, 70.5°W
Bottom Depth: 65m
Distance from Shore: ~12km
Distance from Shelf Break: ~355km

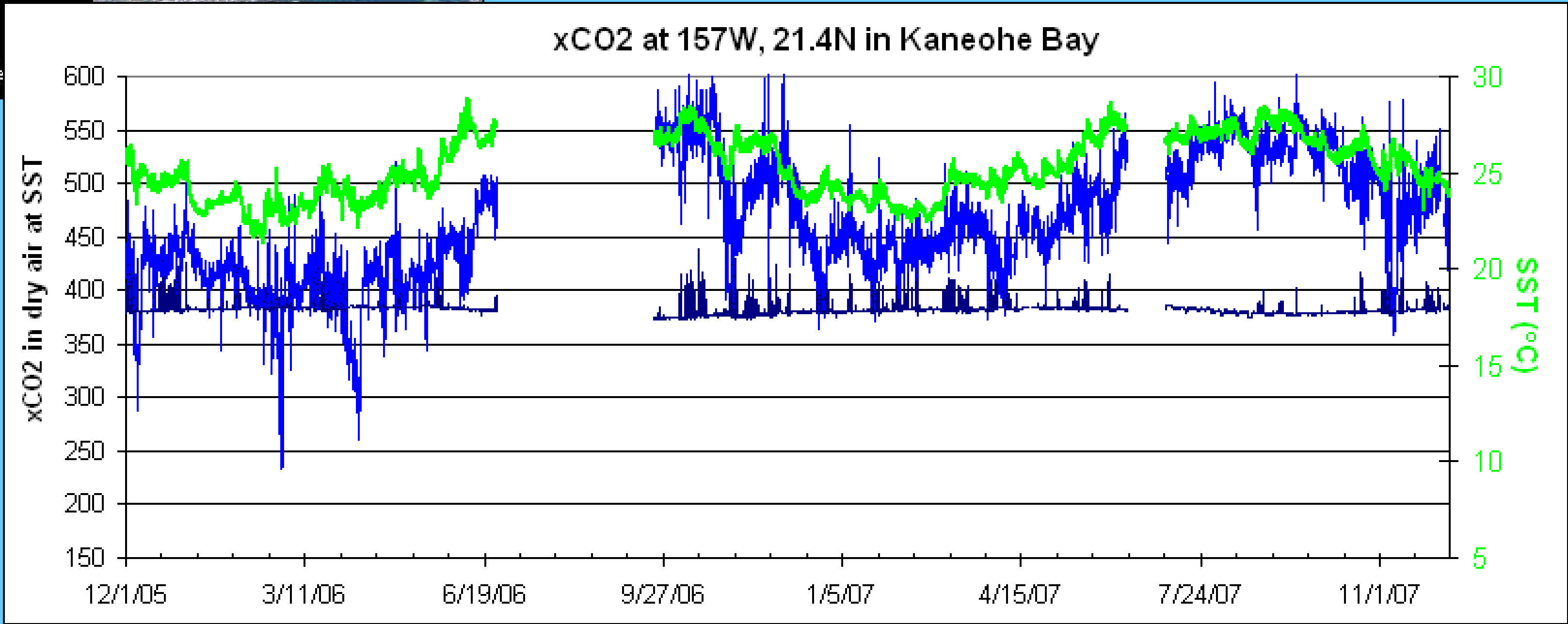

xCO2 at 070W, 43N in the Gulf of Maine

Kaneohe Bay, HI



Ikonos Image ©
Space Imaging LLC
Image prepared by Dr. Eric Hochbe

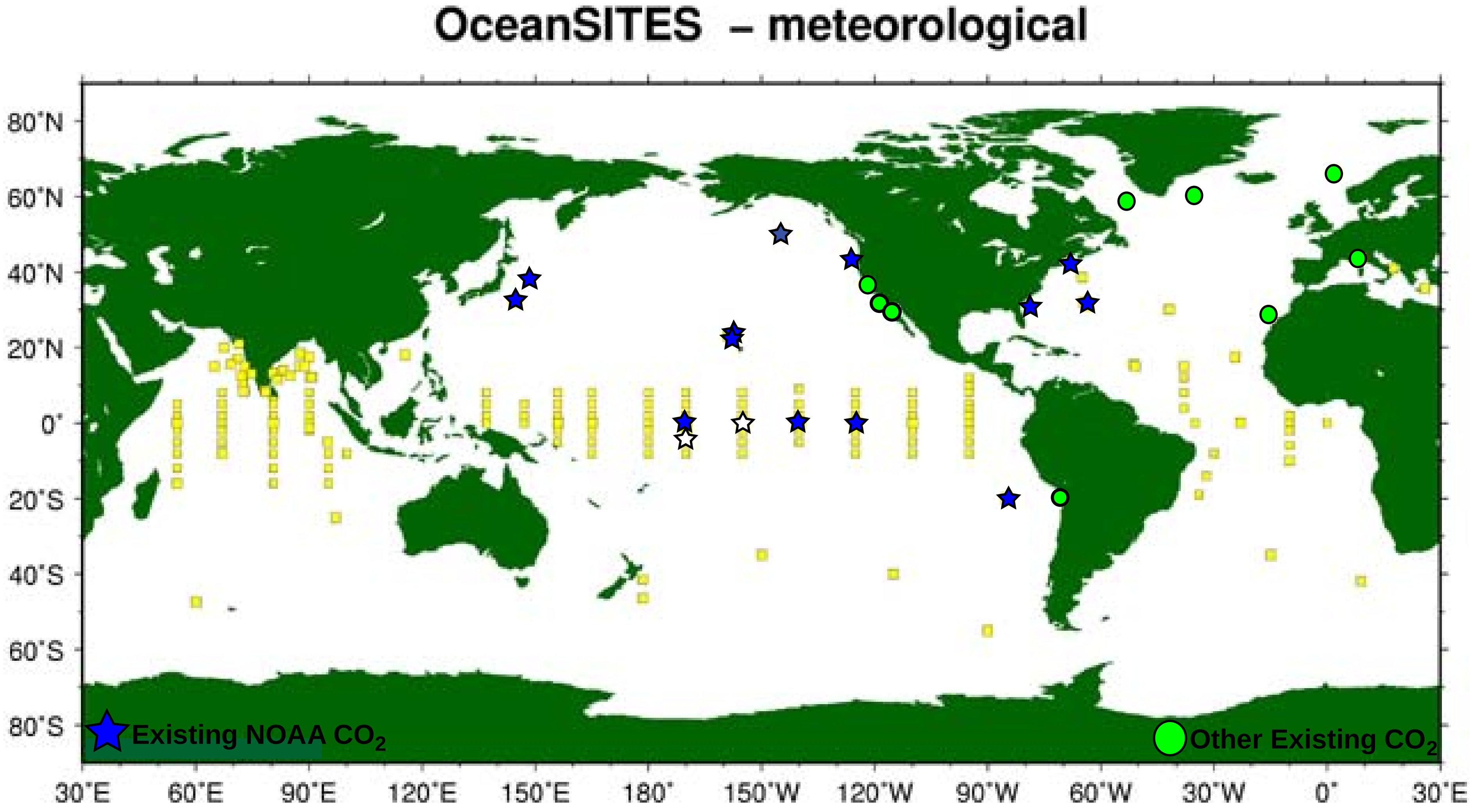
Relatively enclosed bay with significant calcification. This calcification keeps the pCO_2 high. Also see impacts of storm events.


xCO2 at 157W, 21.4N in Kaneohe Bay

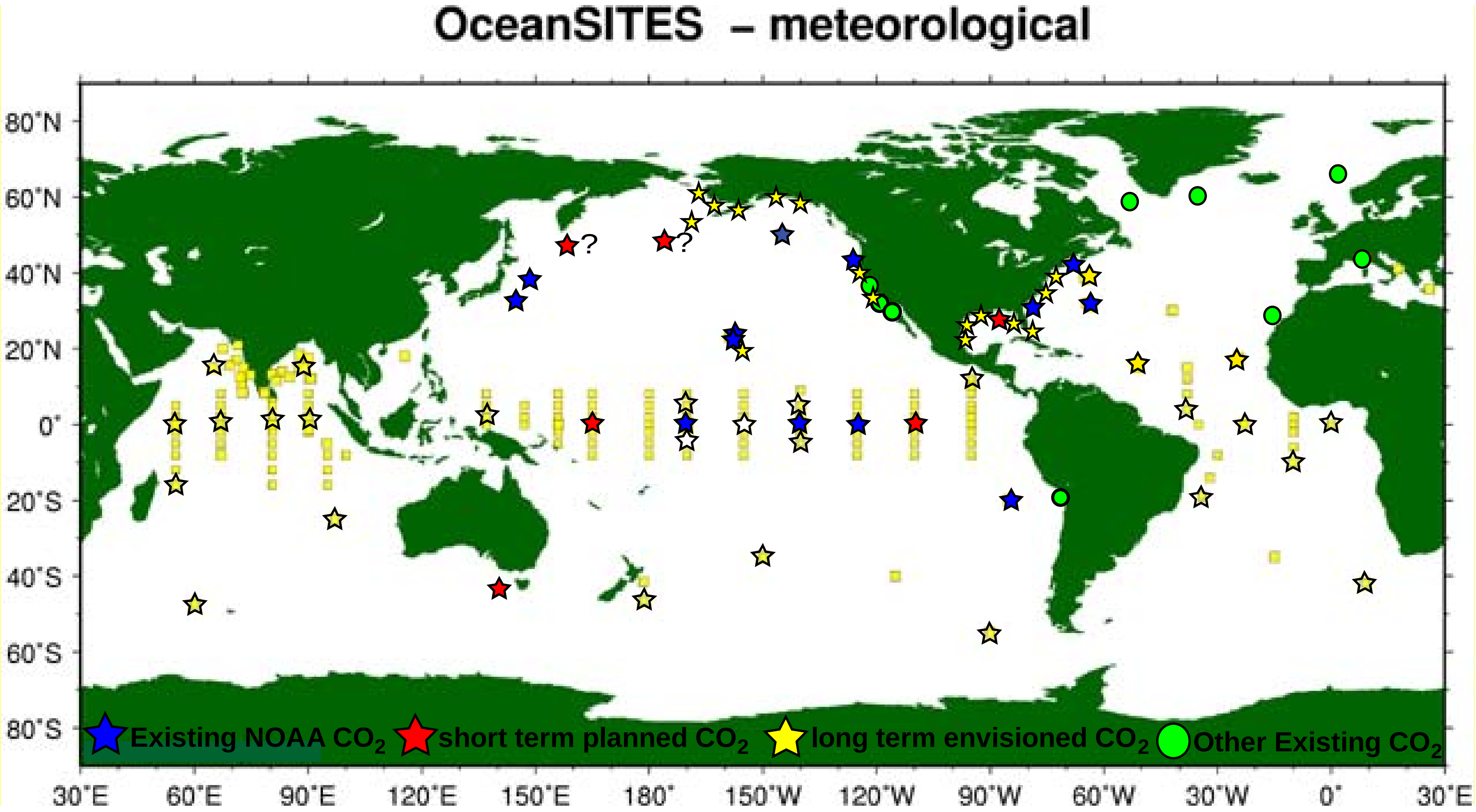
Conclusions

1. We are using multiple approaches to assess the ocean sink for CO_2.
2. The different approaches provide information over different time scales ranging from hours todecades.
3. Moorings are the best mechanism for evaluating high frequency variability from hours to years.
4. All mooring locations examined to date have significant variability over a range of time scales with unique interactions between the different forcings that need further study.
5. We are working to expand our mooring network in an effort to develop a better understanding of the different scales and spatial patterns of variability.
6. I welcome opportunities to collaborate with others to include a $MAPCO_2$ system new platforms.

NOAA’s existing pCO_2 moorings are designed to build on the OceanSITES reference flux sites



Existing and planned pCO$_2$ moorings are designed to build on the OceanSITES reference flux sites and NDBC coastal moorings



Thank You !