Oceans and Ecosystems Research

Changing levels of Oceanic Carbon Dioxide

Rik Wanninkhof

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AOML Program Review, 4-6 March 2014

Programmatic drivers of Ocean Carbon Cycle efforts
US Carbon Cycle Science Program

- **An interagency effort**

  Carbon Cycle Science Plan: www.carboncyclescience.gov within the USGCRP Strategic Plan and the annual research priorities of the USGCRP

- Federal Ocean Acidification Research and Monitoring Act (FOARAM) Act of 2009
- **A global community effort** (IOC, WCRP, Future Earth/ICSU)

  International efforts in support of assessments of the Global Carbon Project http://www.globalcarbonproject.org/

Overarching questions

- What is the sea-air CO_2 flux across the interface (SOCAT & Takahashi)?
- What are the decadal changes in inventories of anthropogenic carbon(GO-SHIP)?
- What are the patterns of coastal ocean CO_2 levels *and how are they affecting marine biota?* (Ocean acidification)

The Problem

- Atmospheric CO_2 levels are changing due to release of the green house gas CO_2 which is considered a pollutant (EPA, 2009).
- Pollutant levels and impact of pollutants require monitoring.
- Of the 10 Pg C emitted by burning of fossil fuels, ≈50 % remain in the atmospheric, the remainder is taken up by land plants and oceans.
- We study the uptake by the oceans both from a "bookkeeping" perspective, and to assess impact of rising CO_2 levels on biogeochemistry.

In 2009 EPA qualified the increasing CO2 levels as a pollutant along with the other greenhouse gases Ch4, N2O, HCFCs, PCFCs, and SF6

How much is 10 Pg C?

In 2012 9.7 Pg C was released to the atmosphere by burning of fossil fuel. Of the total emissions from human activities during the period 2003-2012, about 45% accumulated in the atmosphere, 27% in the ocean and 27% on land (GCP, 2013).

Mitigation by capture is challenging:

If compressed into liquid CO_2 and stored as suggested as a mitigation action this equates to filling the volume of the Empire State building every day

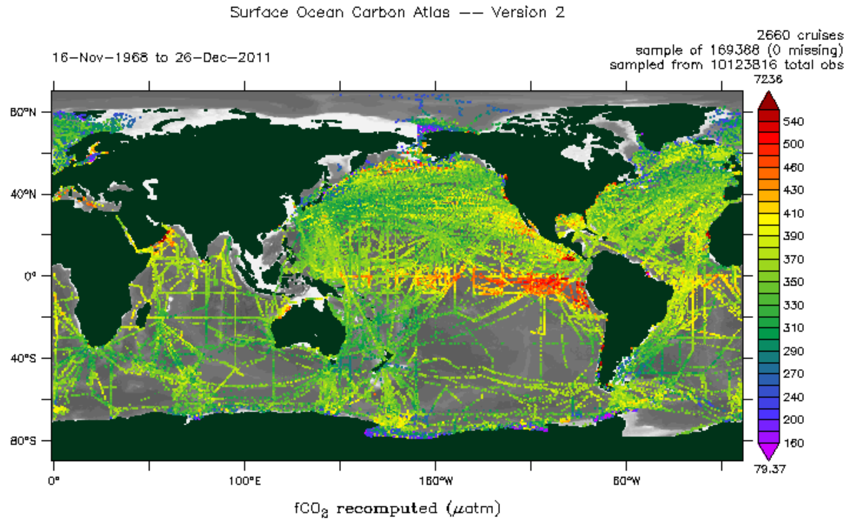
What is the sea-air CO_2 flux across the interface?

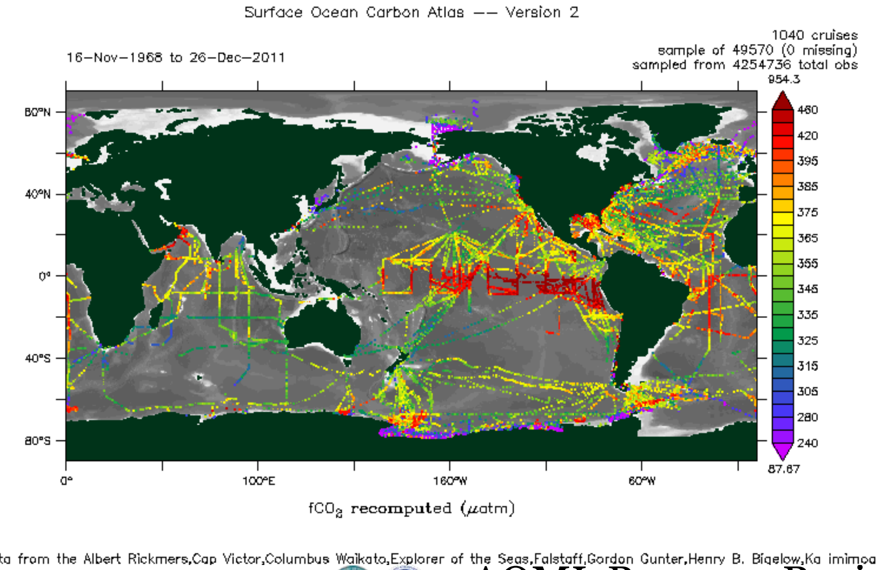
Efforts: SOCAT & Takahashi climatology

Performance measure: Constrain the sea-air CO_2 fluxes to 0.2 Pg C/yr

The NOAA funded ship of opportunity program lead by AOML (2 NOAA labs, 3 CIs ,ad 3 academic institutions) with 15 ships contribute 50 % (≈ 5 M datapoints) of the global surface water CO2 data (IOCCP-SOCAT)

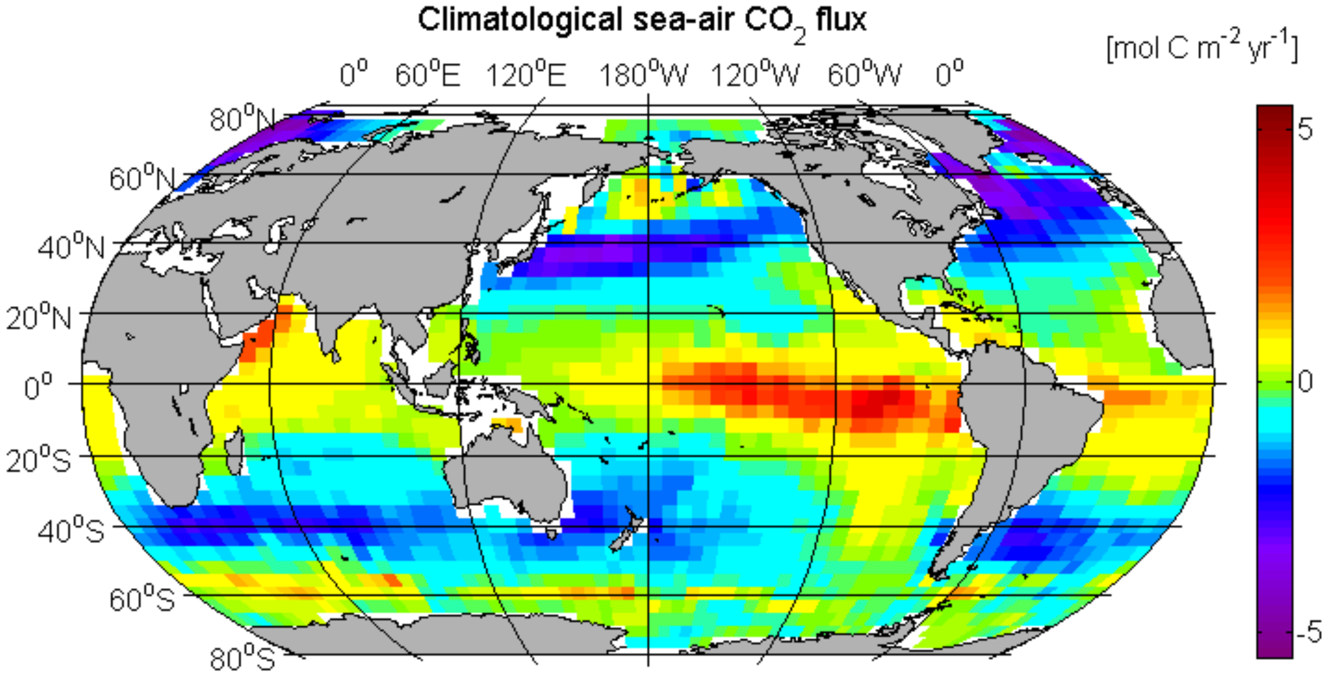
A Multi-national Effort: USA, Japan, Australia, Norway, England, France, Netherlands, Germany, Spain, China





Product: Magnitude of Flux- State of the system

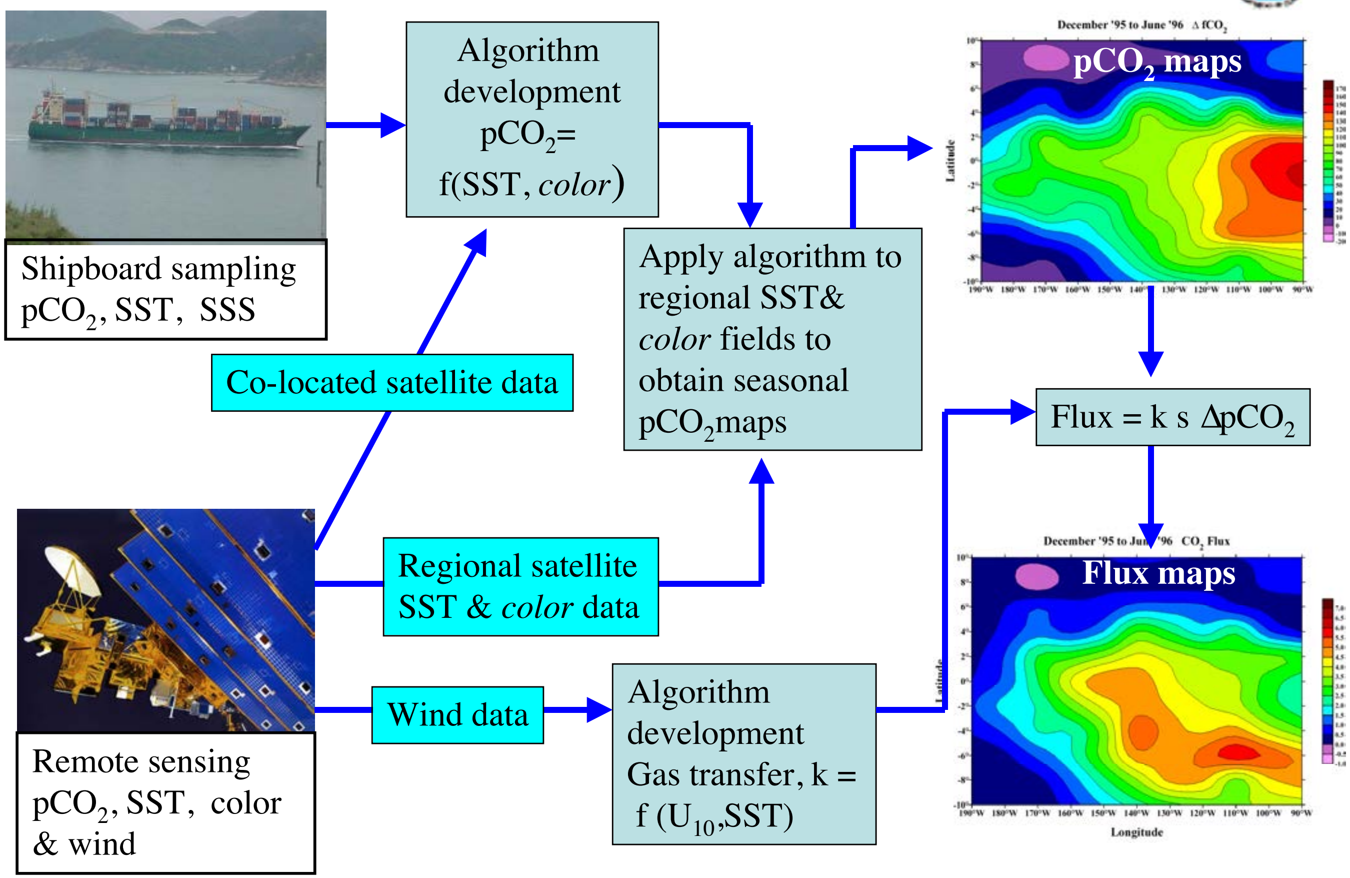
- Takahashi climatology- a baseline for sea-air fluxes and the premier constraint for models (net open ocean sea-air flux is 1.3 Pg C yr^{-1})



Non El-Nino year centered on 2005

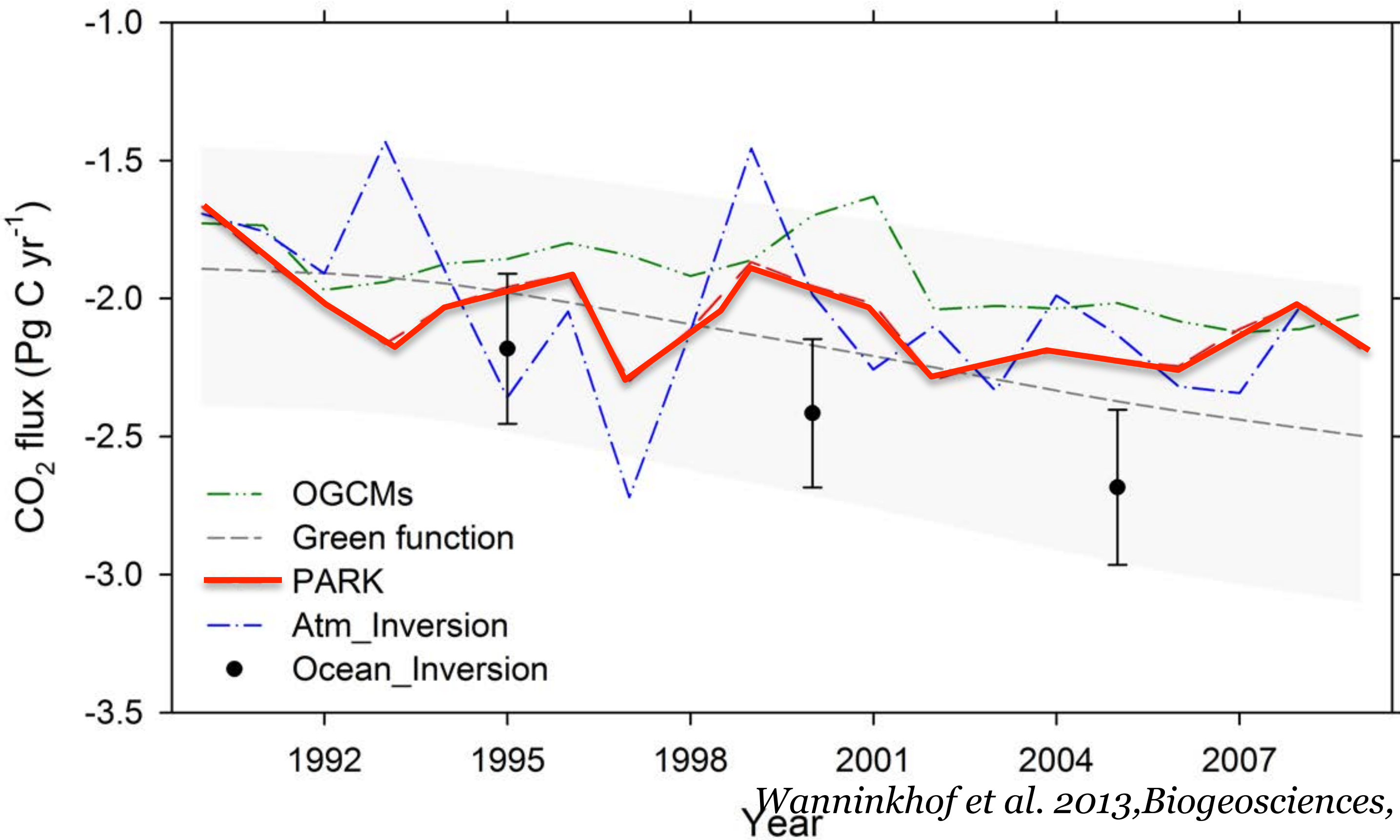
Flux maps: near real-time maps to determine magnitude variability and trends

Producing Seasonal CO_2 Flux Maps



Global Ocean Carbon Uptake: Magnitude, Variability and Trends

Rik Wanninkhof[1], Geun-Ha Park[2], Taro Takahashi[3], Colm Sweeney[4,14], Richard Feely[5], Yukihiro Nojiri[6], Nicolas Gruber[7], Scott C. Doney[8], Galen A. McKinley[9], Andrew Lenton[10], Corinne Le Quéré[11], Christoph Heinze[12] , Jörg Schwinger[12], Heather Graven[7,13], Samar Khatiwala[3]



Wanninkhof et al. 2013,Biogeosciences, RECCAP

Trends in ocean uptake :

Estimates based on surface values are appreciably shorter than models based on interior changes: artifact or feedback?

Median sea–air anthropogenic CO_2 fluxes for the different approaches centered on year 2000.

Approach	Anthr. CO_2 flux	Uncertainty	IAV[e]	SAV[f]	Trend
	$Pg\,C\,yr^{-1}$	$Pg\,C\,yr^{-1}$	$Pg\,C\,yr^{-1}$		$(Pg\,C\,yr^{-1})$ $decade^{-1}$
Empirical	−2.0	±0.6[a]	0.20	0.61	−0.15
OBGCM	−1.9	±0.3[b]	0.16	0.38	−0.14
Atm. Inversion	−2.1	±0.3[c]	0.40	0.41	−0.13
Ocean Inversion	−2.4	±0.3[d]			−0.5[j]
Interior (Green function)[g]	−2.2	±0.5	–	–	−0.35
O_2/N_2[h]	−2.2	±0.6			
O_2/N_2[i]	−2.5	±0.7			

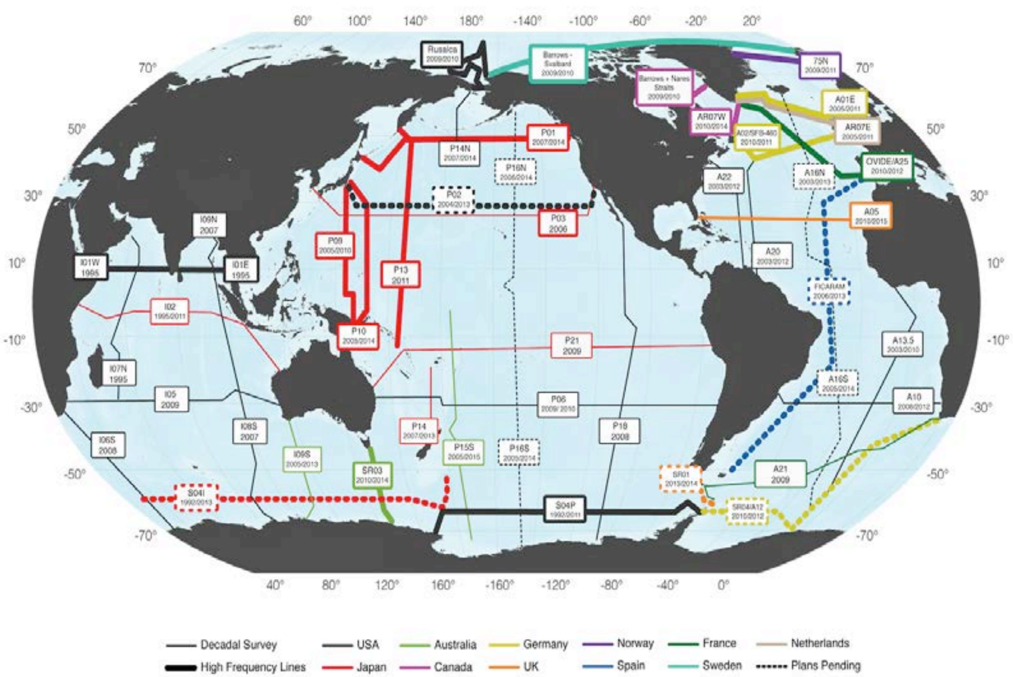
Wanninkhof et al. 2013

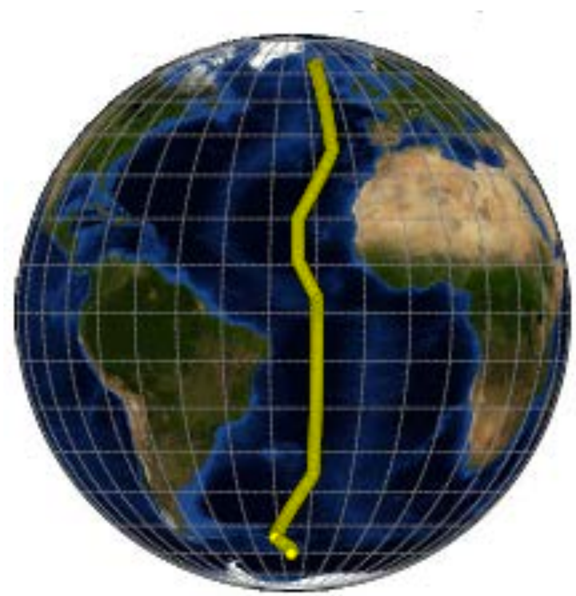
What is the decadal change in ocean carbon inventories ?

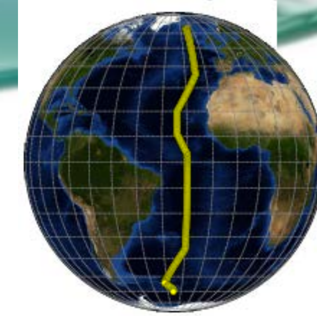
Global Ocean- Shipbased Hydrographic Investigations Program/CLImate VARiability program

GO-SHIP/CLIVAR focuses on man-induced and natural change in the ocean on climate relevant timescales

Performance measure: Quantify change in anthropogenic CO_2 inventory over decadal time scale to within 10 %



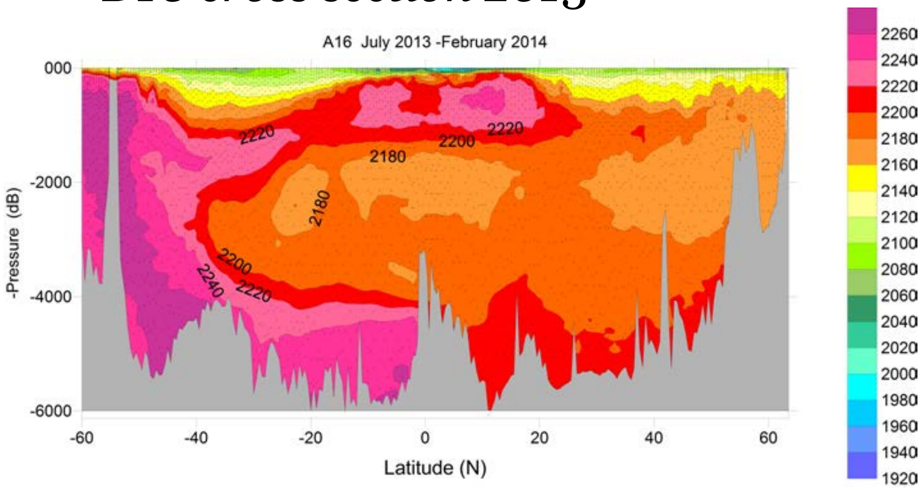




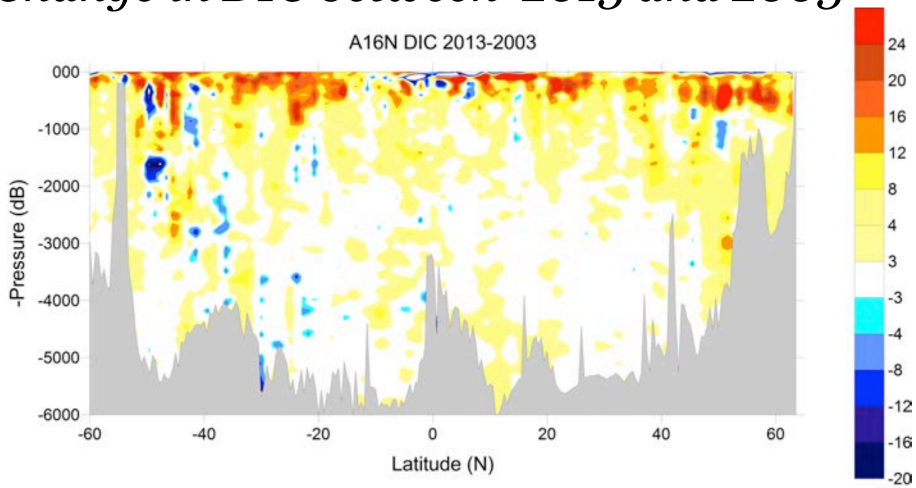
GO-SHIP CLIVAR/CO2 A16 section

Lead by scientists at AOML
Participants from 2 NOAA labs., 3 CI's, 10 academic institutions

DIC cross section 2013

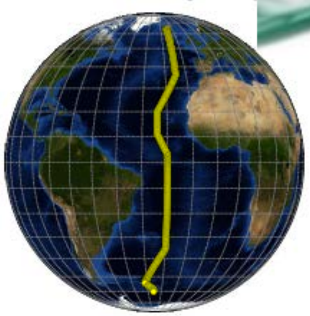


Change in DIC between 2013 and 2003



Primary purpose: Serving climate quality data within 6-months to the science community

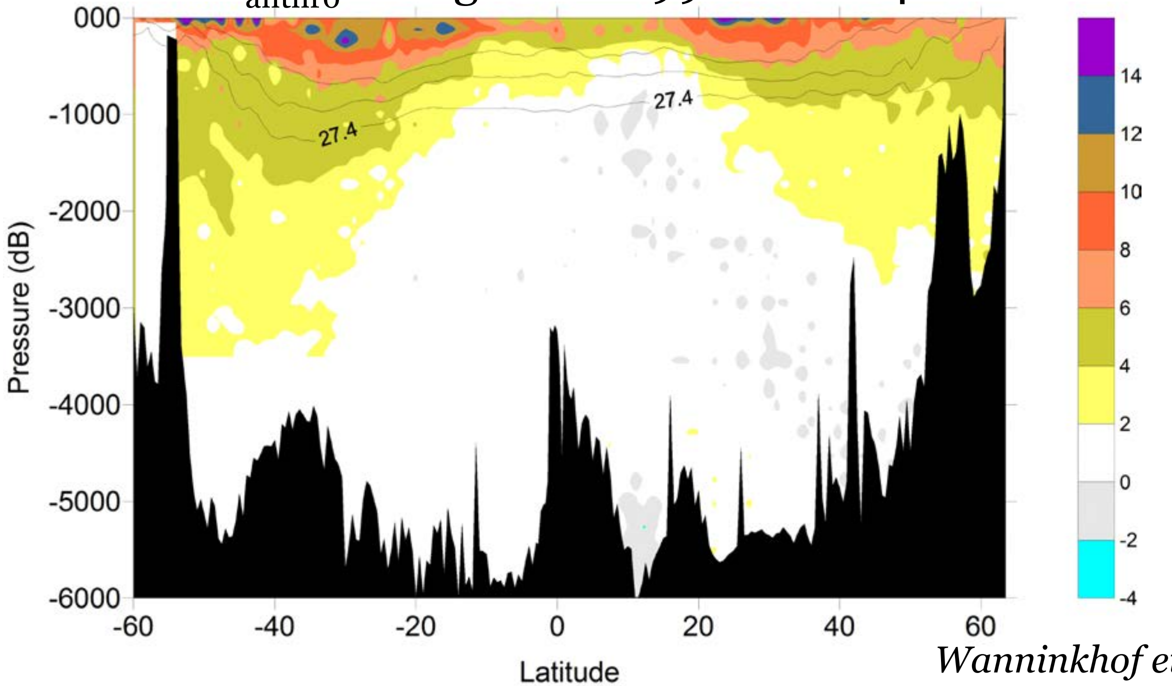
About 5000 DIC datapoints from 3 cruise sections
Shipboard data management and QC tools provides ability for shipboard checks
Preliminary data of sufficient quality for qualitative state and change estimates



Determining change in anthropogenic CO2 (C_{anthro})requires accounting for natural variability

Utilize: Co-variance of “natural” DIC with nutrients and oxygen
Use of inert transient tracers (CFC, SF_6)

C_{anthro} change from 1990 to 2004

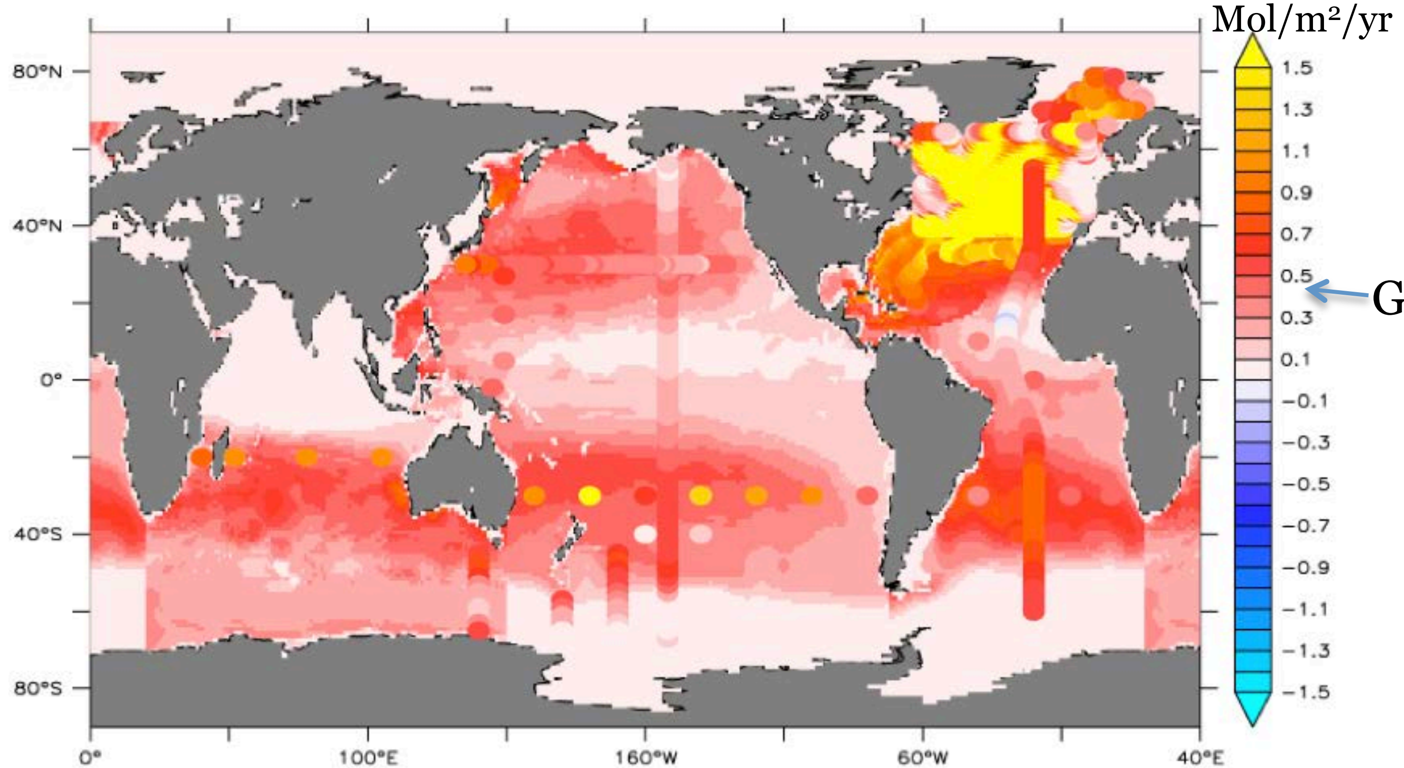


Wanninkhof et al. 2010

Highlight: Greater uptake in S. Atlantic than N. Atlantic

Wanninkhof, R., Doney, S., Bullister, J. L., Levine, N. M., Warner, M. J., and Gruber, N.: Detecting anthropogenic CO2 changes in the interior Atlantic Ocean between 1989 and 2005, J Geophys. Res., 115, , C11028, doi:10.1029/2010JC006251, 2010.

Comparison of global estimate of C_{anthro} of decadal change with individual lines (mid 2000's - mid1990's)



Gruber et al., 2014

The background estimate are preliminary results based on a modified eMLR method (Clement and Gruber, 2014), while the individual dots represents published estimates based on the original eMLR method, such as Wanninkhof et al., 2010 (Atlantic A16) and Sabine et al. 2008 (Pacific P16

What are the patterns of coastal ocean CO2 levels *and how are they affecting marine biota?* **(Ocean acidification)**

Performance measure: determine aragonite saturation state to 0.2

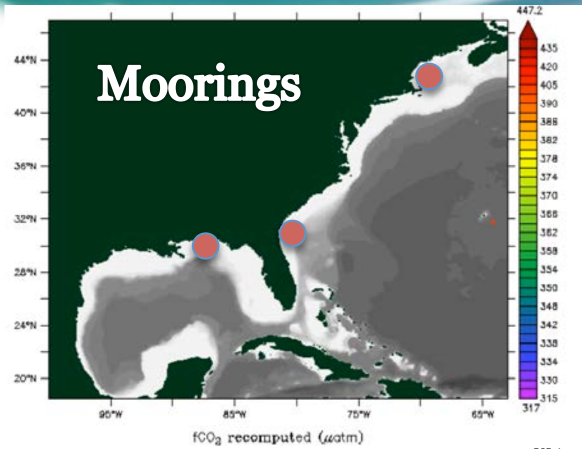
Focus on building a coastal observing system with emphasis on water column carbon dynamics

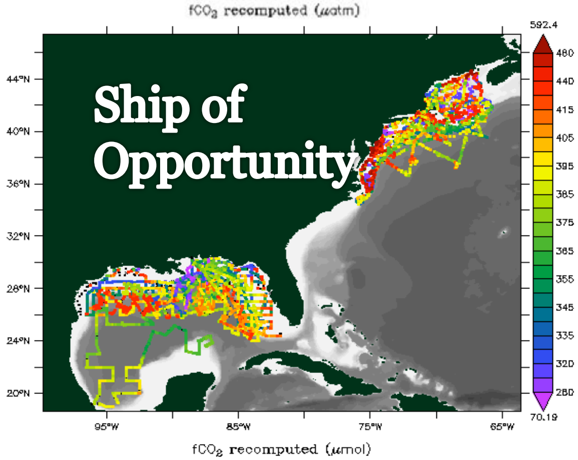
Applying what we've learned in to open ocean to the coastal ocean.

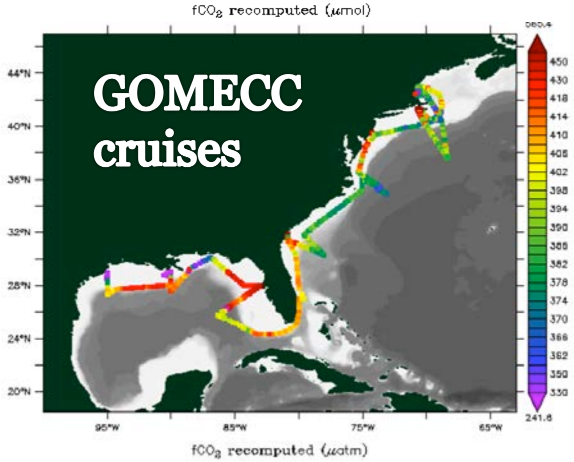
- Instrumental techniques
- Data management
- Data Quality Control
- Data interpolation

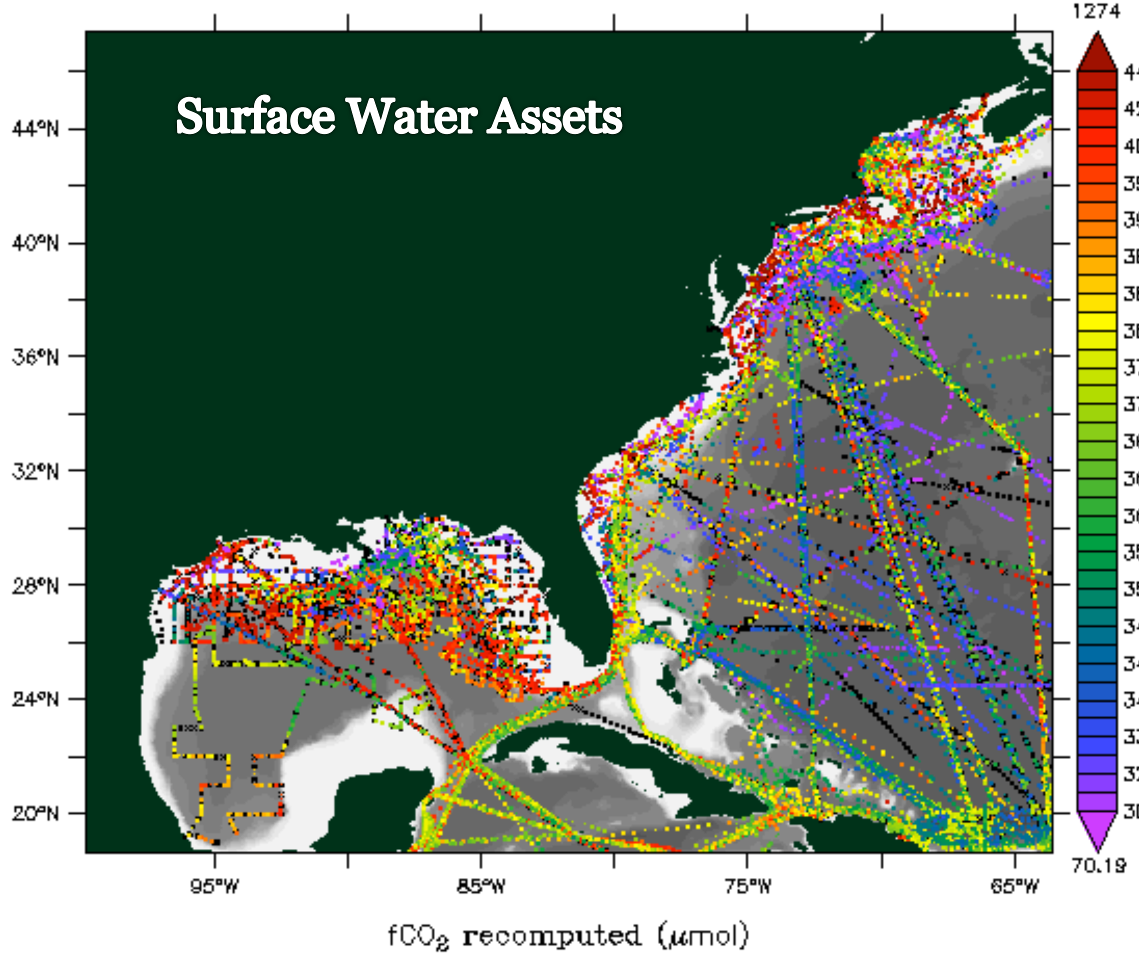
If we extrapolate open ocean data to the coast we obtain a coastal sink for carbon of -0.18 pG C year (independent assessments of coastal fluxes -0.1 to -1 Pg C with most recent estimates ≈0.2 Pg C)

Observing Assets



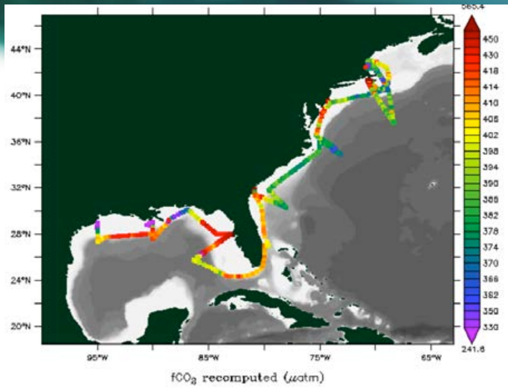






GOMECC Cruises

Water Column Determination of Saturation States Ω_{Ar}



Cross sections of Ω_{Ar} on GOMECC-1

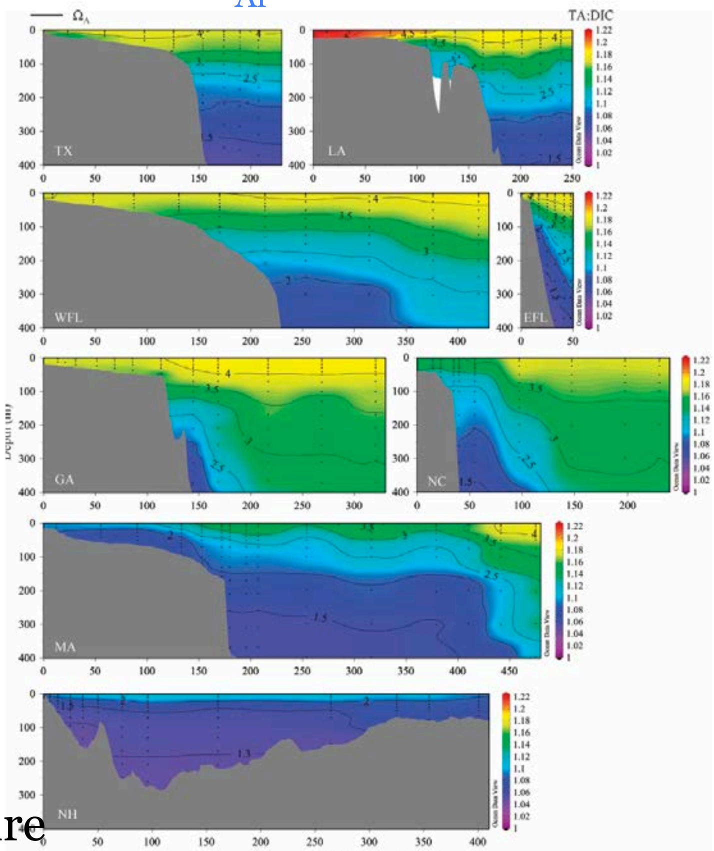
Texas

Florida

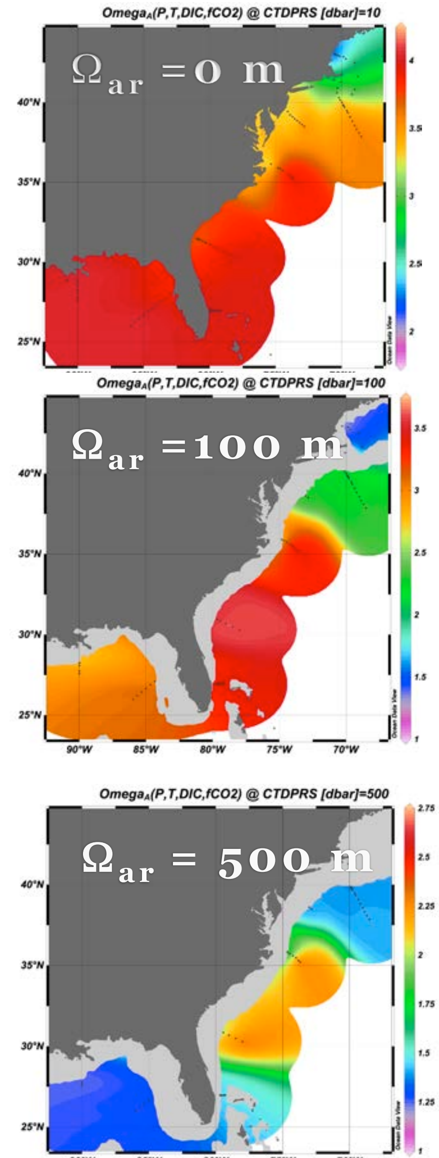
Georgia

Mass

New Hampshire



Wang et al. 2013



Surfaces of Ω_{Ar} from GOMECC 2

Aragonite Saturation State (Ω_{ar}) Maps

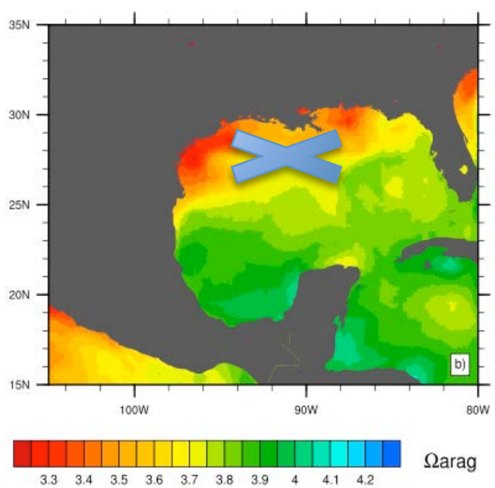
Aragonite Saturation State: $\Omega_{Ar} = [Ca^{2+}] [CO_3^{2-}]/K_{sp}$

Modelling/Algorithm development

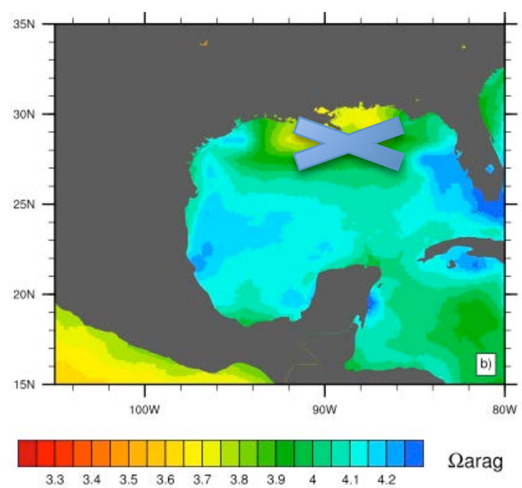
$\Omega_{ar} = f\,(Alk, pCO_2)$

$Alk = f\,(SSS, SST)$

Dry season



Wet Season



Validation

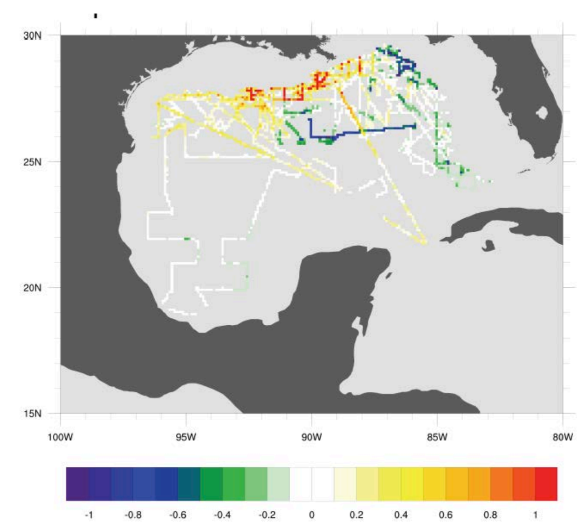


Photo: David Wisegarver, PMEL

Long-term goal: Climate Adaptation and Mitigation
Objective: Improved scientific understanding of the changing climate system and its impacts

The need to advance understanding of the climate system and climate impacts, improve climate predictions and projections, and better inform adaptation and mitigation strategies is urgent. Key scientific uncertainties limit scientists' ability to understand and predict changes in the climate system. This is particularly true for monthly-to-decadal timescales and at the regional and local levels for which scales are highly relevant to planning and decision making.
http://www.ppi.noaa.gov/goals/

You've got to measure and measure well before you can understand

Charge

As outlined in the “purpose of the review” section of the “charge to reviewers,” Laboratory scientific reviews are conducted to help the Laboratory:

1. in its strategic planning of its future science,
2. to ensure that Laboratory research is linked to the NOAA Strategic Plan,
3. is relevant to OAR mission and priorities,
4. is of high quality as judged by preeminence criteria,
5. and is carried out with a high level of performance.