Climate Research

Ocean Carbon – Adrienne Sutton
Richard Feely, Simone Alin,
Chris Sabine, Jeremy Mathis

PMEL Carbon Group

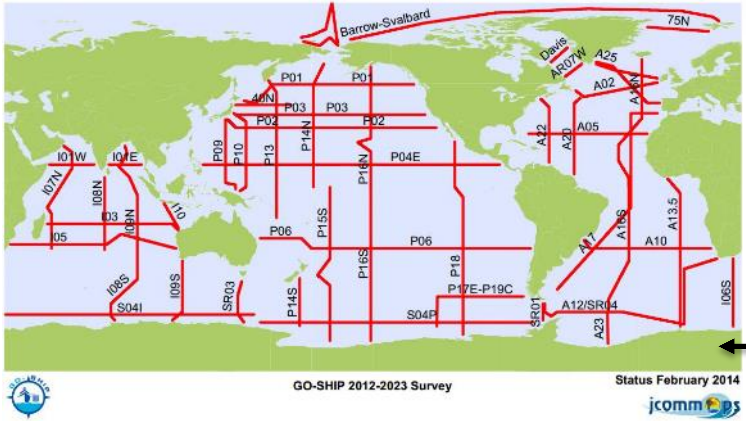
Mission: advance our scientific understanding of the ocean carbon cycle

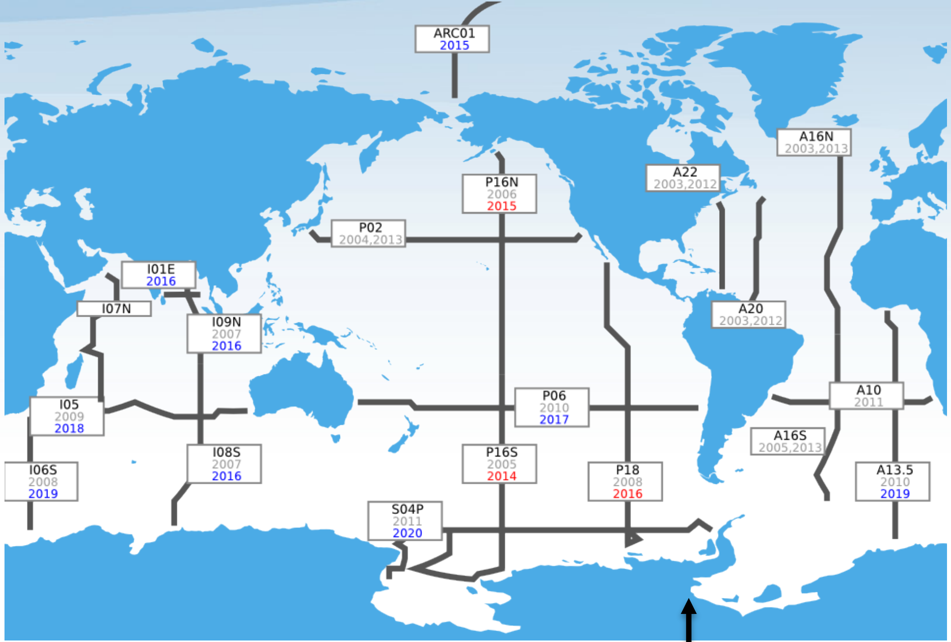
Why?: key to society's ability to anticipate and respond to climate and its impacts

Outline

- Overview of carbon observations
- Relevance of ocean carbon research and obs
- Accomplishments
- Why PMEL?
- Future directions

Observations

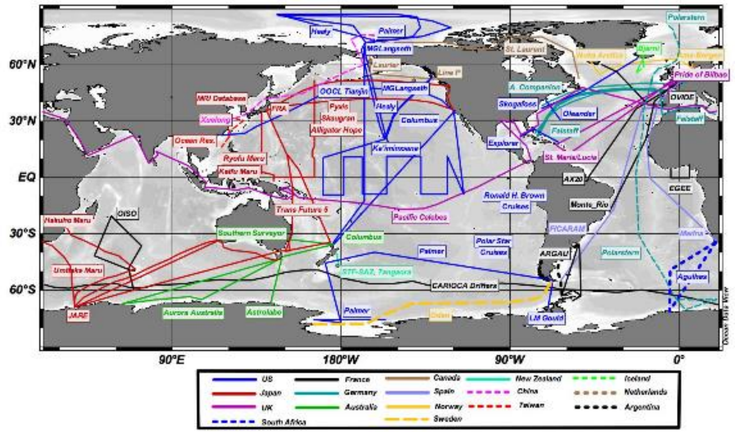


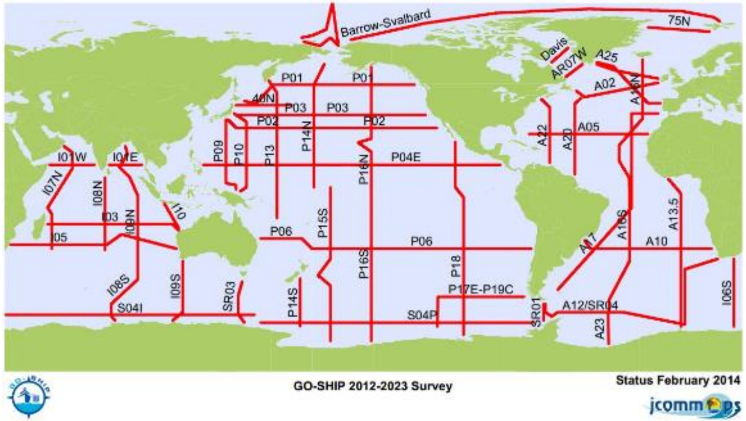


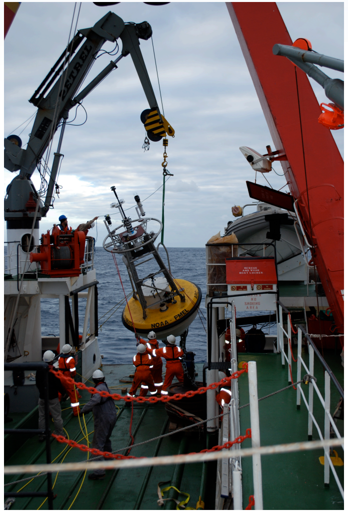
GO-SHIP hydrographic sections

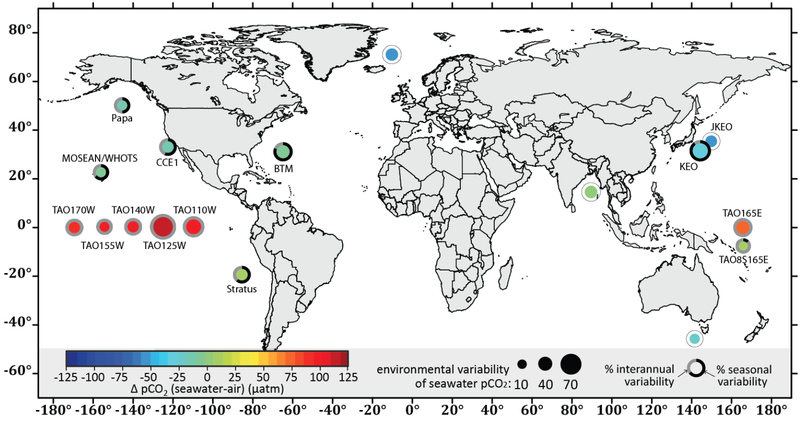
U.S. led GO-SHIP sections

Observations





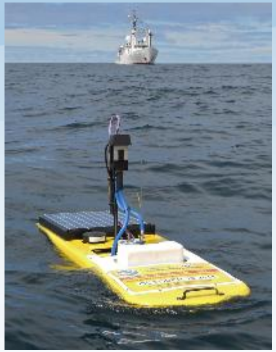




Observations +

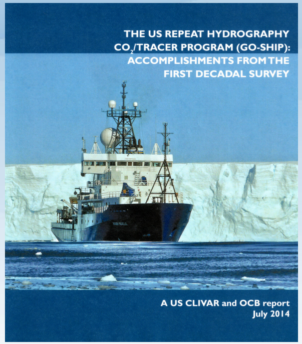
Develop new technologies

(e.g. carbon wave glider)



Establish methodology and standards

(e.g. community standard analytical methods)

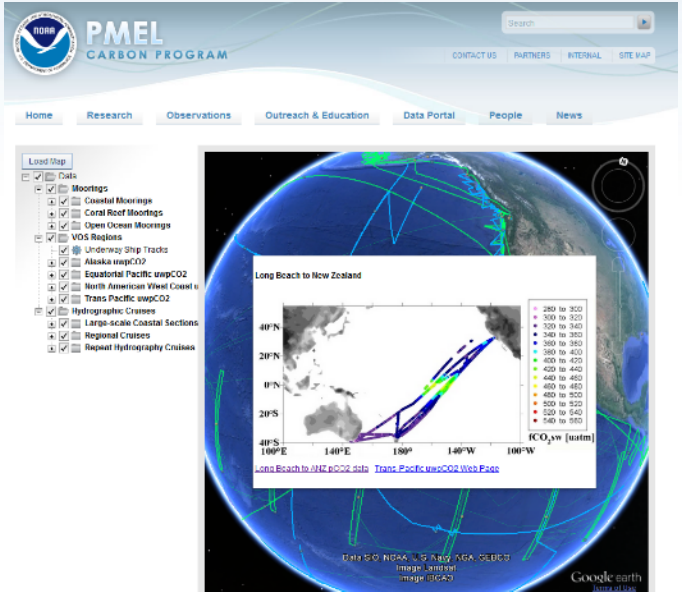


Play leading role in building and maintaining the networks

(e.g. US and international GO-SHIP)

Manage, QC, and archive data

(e.g. www.pmel.noaa.gov/co2/)

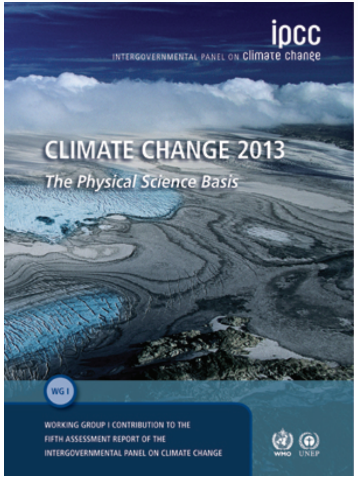


Create data synthesis products

(e.g. SOCAT, RECCAP)

Contribute to climate assessments

(e.g. IPCC)



Relevance

Global community effort

Global Carbon Project goal: Develop a complete picture of the global carbon cycle

U.S. interagency effort

U.S. Carbon Cycle Science Program goal: Provide a scientific strategy for conducting federal carbon research

NOAA/OAR/PMEL effort

NOAA long-term goal: An informed society anticipating and responding to climate and its impacts

Relevance

To support this goal, the PMEL Carbon Group:

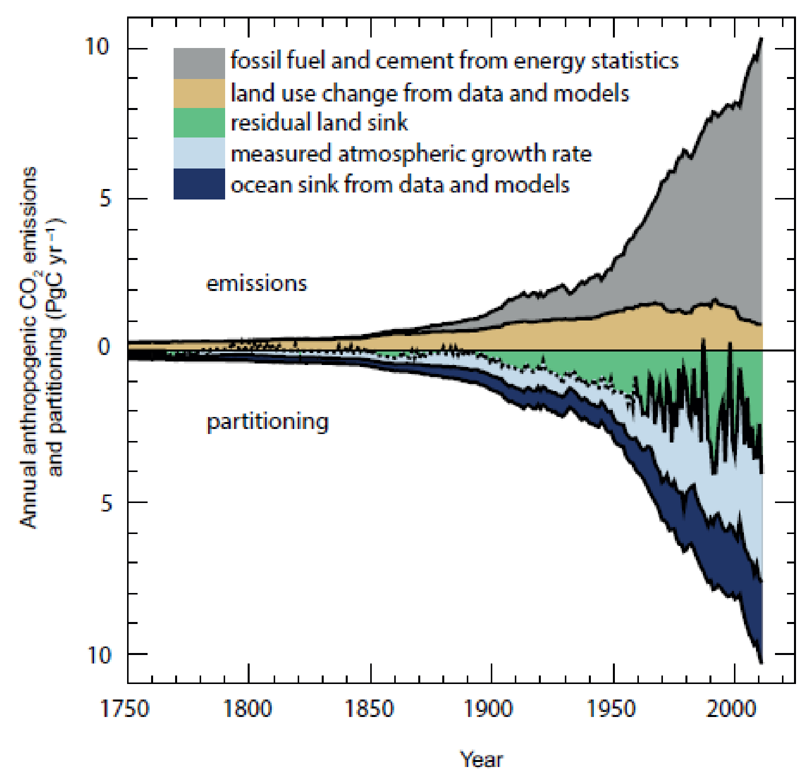
- maintains long-term carbon observations to improve our understanding of the changing climate system
- contributes to data synthesis efforts and assessments
- engages in outreach to the public on ocean carbon issues

NOAA/OAR/PMEL effort

NOAA long-term goal: An informed society anticipating and responding to climate and its impacts

The Ocean CO_2 Challenge

Is the ocean sink keeping pace with atmospheric CO_2 increases?



IPCC AR5

The Ocean CO_2 Challenge

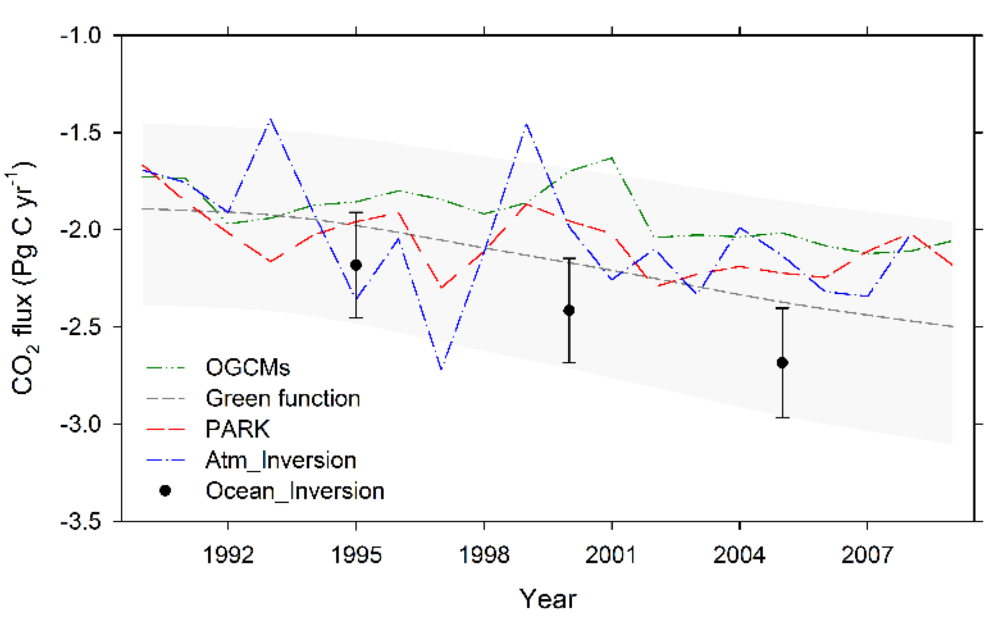
Is the ocean sink keeping pace with atmospheric CO_2 increases?

Current estimates of anthropogenic CO_2 ocean uptake range from 2.0 – 2.5 Pg C yr^{-1}

ocean is keeping pace with atm. CO_2 increases

ocean is NOT keeping pace with atm. CO_2 increases

Sustained observations **and** modeling are necessary to answer this question



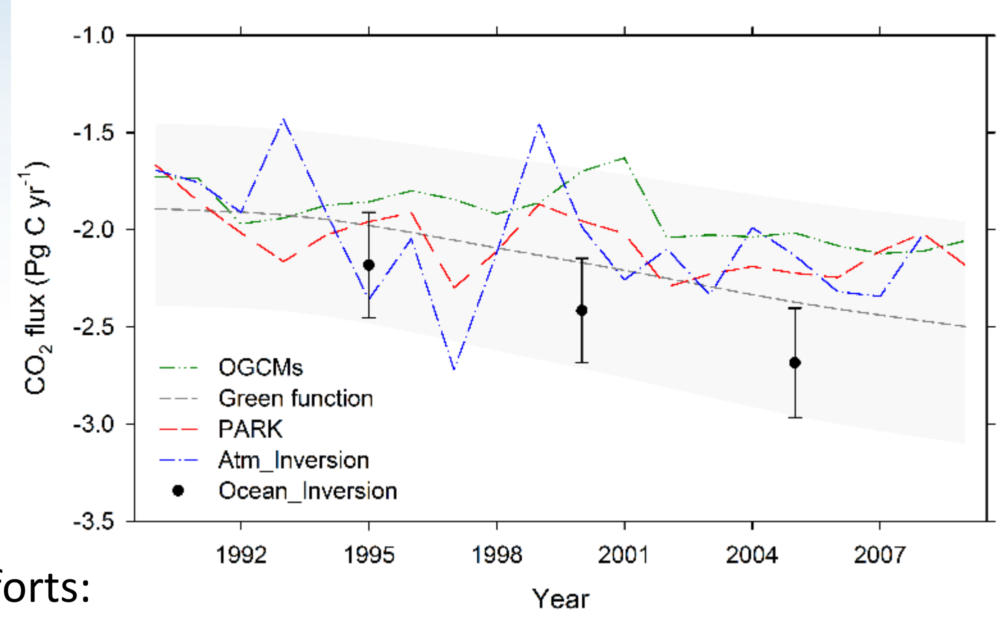
Wanninkhof et al. 2013, Biogeosciences, RECCAP

The Ocean CO_2 Challenge

Is the ocean sink keeping pace with atmospheric CO_2 increases?

Sustained ocean carbon observations constrain:

1) surface ocean CO_2 flux (e.g., SOCAT and Takahashi climatology)
2) decadal changes in inventories of anthropogenic carbon (e.g., synthesis of GO-SHIP observations)



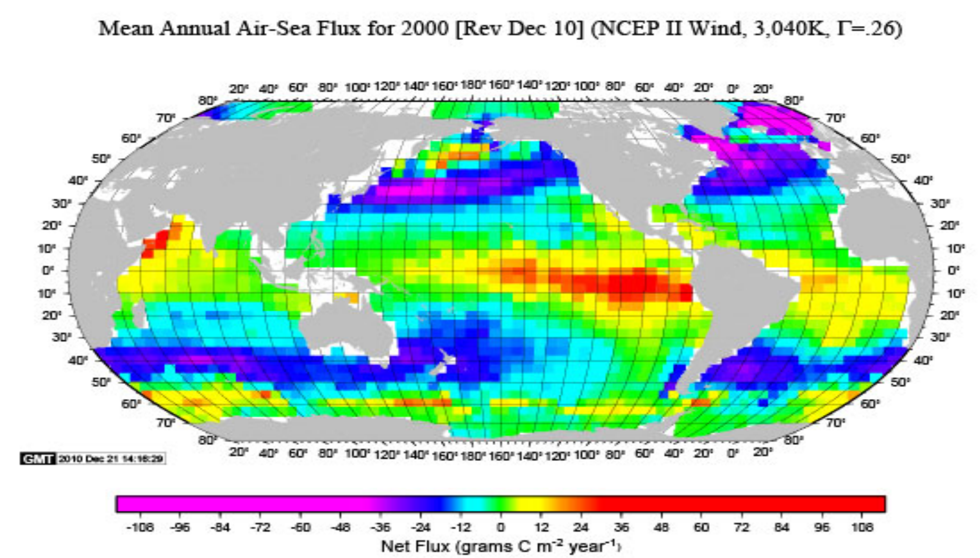
Wanninkhof et al. 2013, Biogeosciences, RECCAP

Next 5 slides show examples of these efforts: examples of **quality** and **performance**

Accomplishments: *surface*

Takahashi CO_2 Climatology: a baseline for air-sea fluxes and the premier constraint for models

Takahashi et al. 2009, Deep Sea Res. II



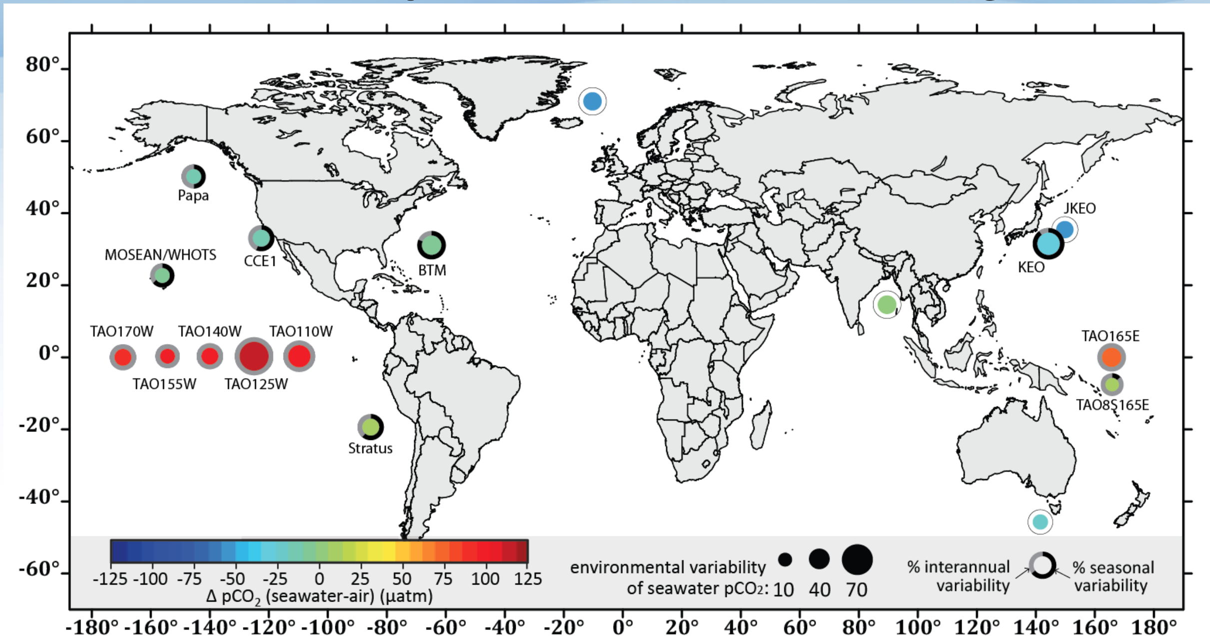
Observations: Ship of opportunity program led by PMEL and AOML contributes 50% of global surface ocean CO_2 data in SOCAT

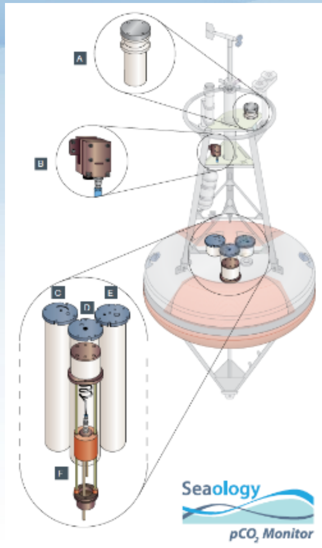
Science: Global air-sea flux estimate based on observations is -2.0 ± 0.6 Pg C yr^{-1}

Accomplishments: *surface*

Mooring CO_2 location, mean, and variability

Modified from Sutton et al. in review, ESSD

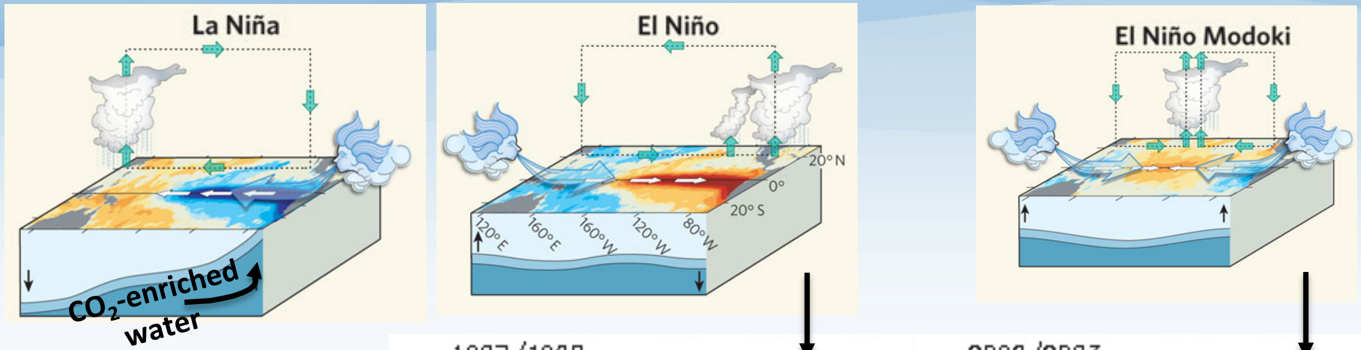




Observations: PMEL mooring data account for 75% of "alternative" platform data in SOCAT

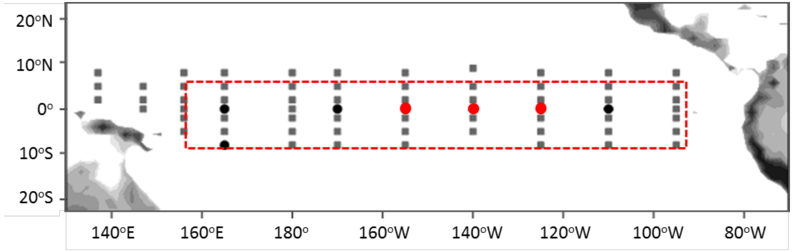
Science: Developed new autonomous, climate-quality method for tracking surface CO_2

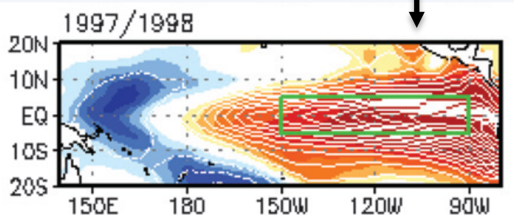
Accomplishments: *surface*

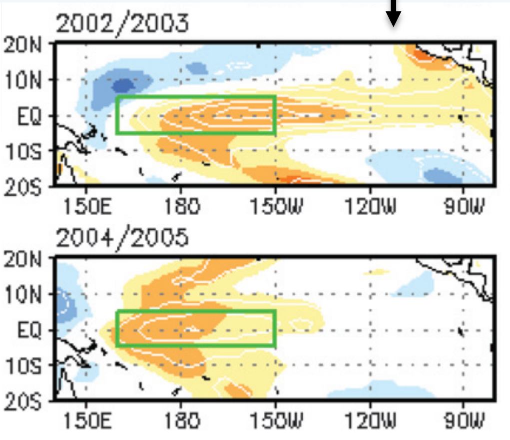


Ashok and Yamagata 2009, Nature

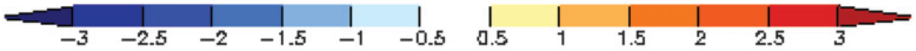
Area of interest on next slide:







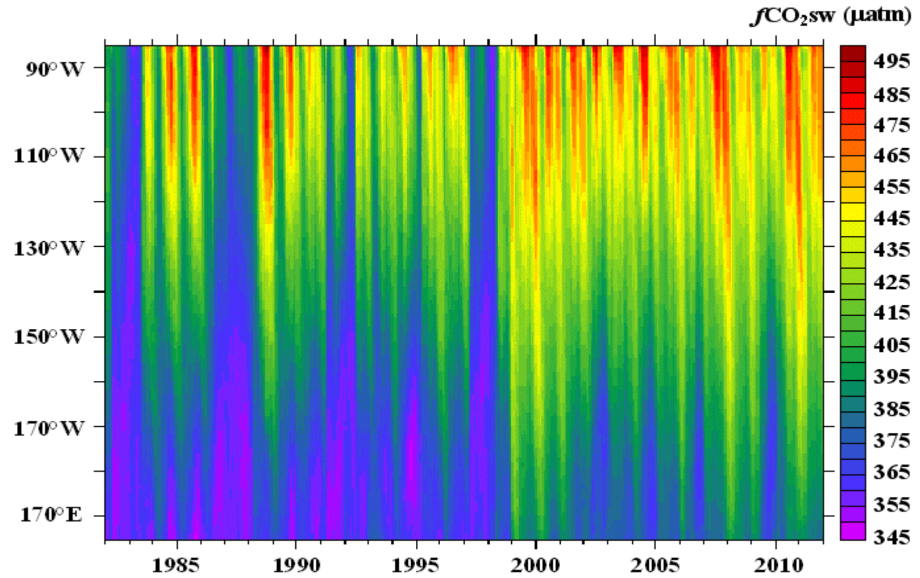
Kug et al. 2009, J Climate



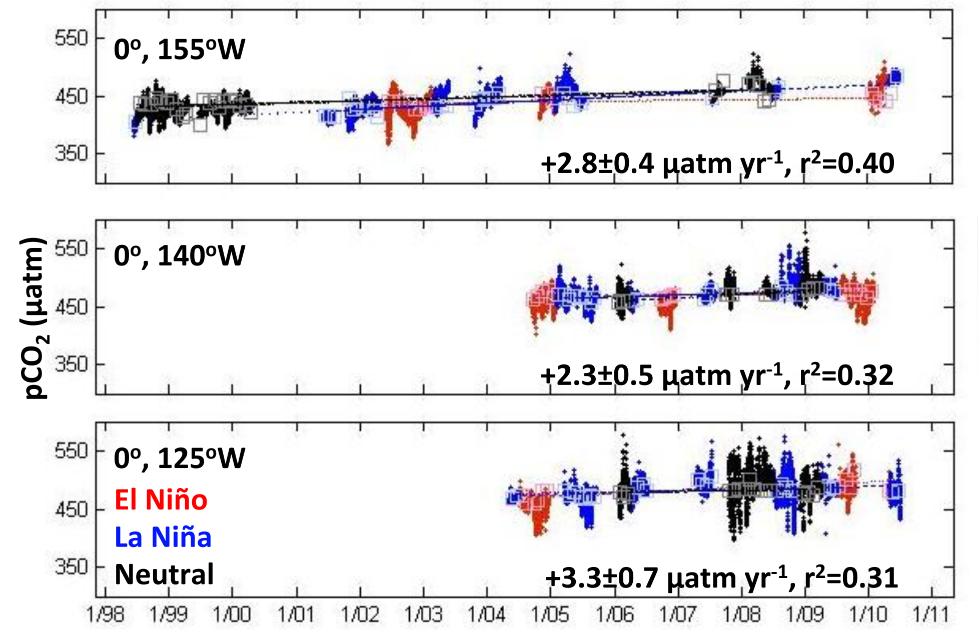
SST anomalies

Accomplishments: *surface*

All surface CO_2 observations: Feely et al. in prep



Mooring observations: Sutton et al. 2014, GBC

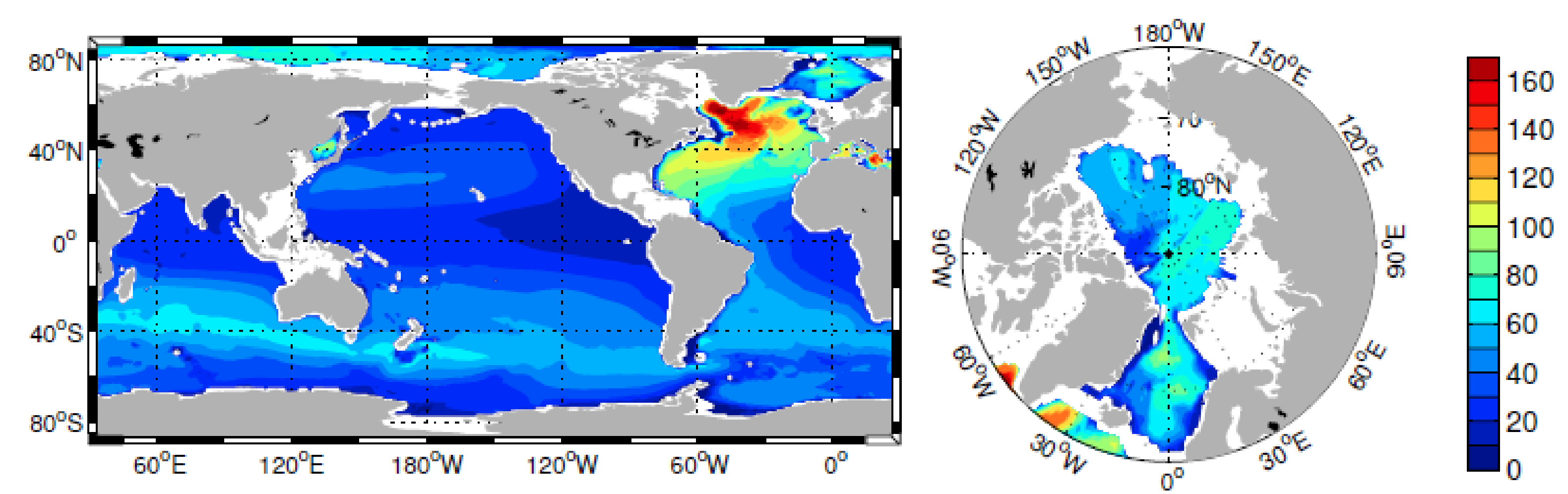


Observations: Sustained a >30 year surface ocean CO_2 time series in the Tropical Pacific

Science: Quantified decadal variability, i.e., a 10-14% increase in CO_2 flux since 1998

Accomplishments: *interior*

2010 column inventories (mol m^{-2}) of anthropogenic CO_2: Khatiwala et al. 2013

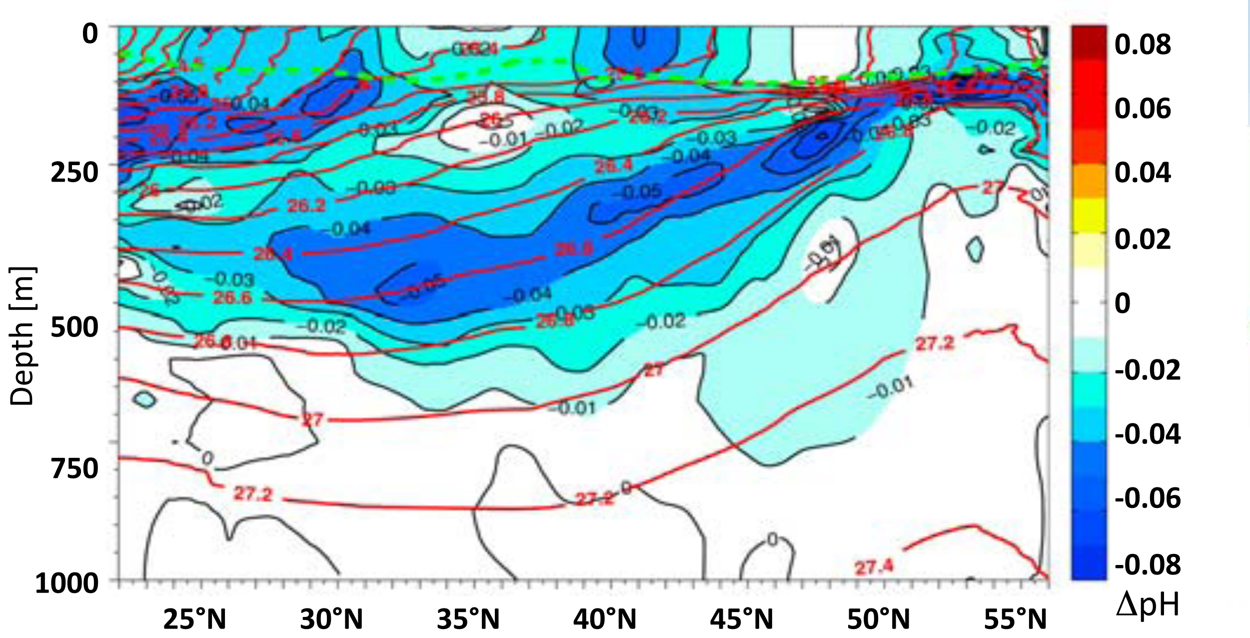


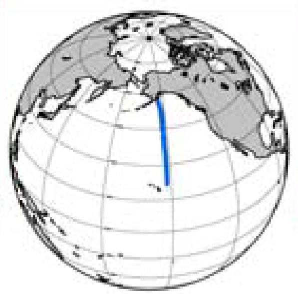
Observations: Carbon observations from repeat hydrographic sections provide one method necessary to quantify the ocean sink of anthropogenic CO_2

Science: Ocean has taken up 37 Pg C or about 30% of CO_2 emissions between 1994 and 2010

Accomplishments: *interior*

Change in pH between 1991 and 2006 from CLIVAR/WOCE P16 cruises: Byrne et al. 2010, GRL

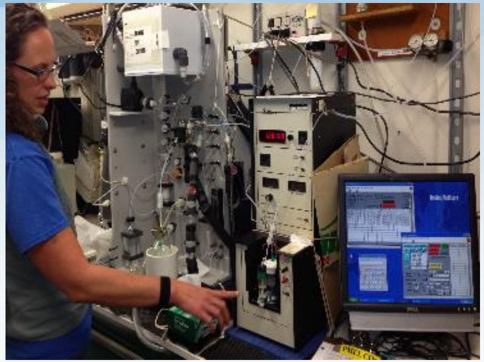




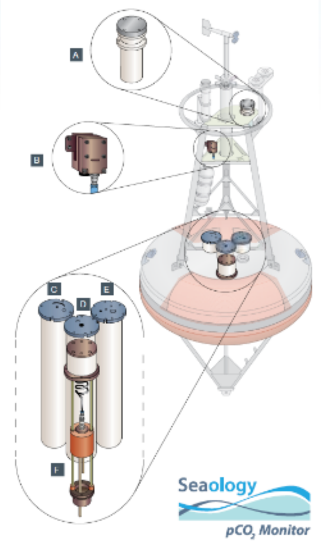
Observations: Carbon observations have laid the groundwork for the field of OA

Science: 1st basin-wide direct observations of declining pH (average of -0.025)

What makes PMEL unique?



Infrastructure and expertise that support innovation of high-quality sustained observations
(e.g. leveraged platforms, EDD)



Established partnerships within PMEL that provide linkages through all stages of research
(e.g. collaborative cruises, data management expertise)

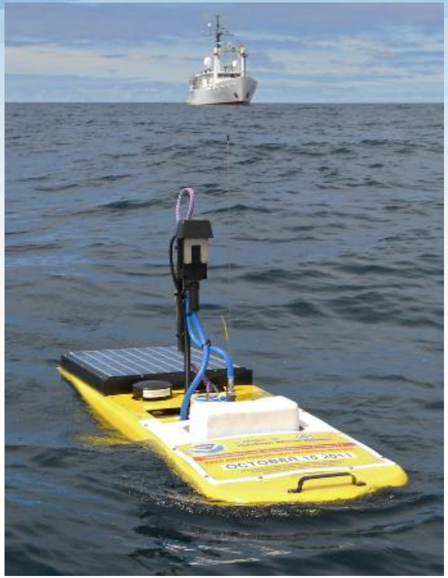
Flexibility to leverage and build off of our observing infrastructure
(e.g. connection with CIs and other partners)

What makes PMEL unique?

PMEL Carbon Group collaborators since 2008:

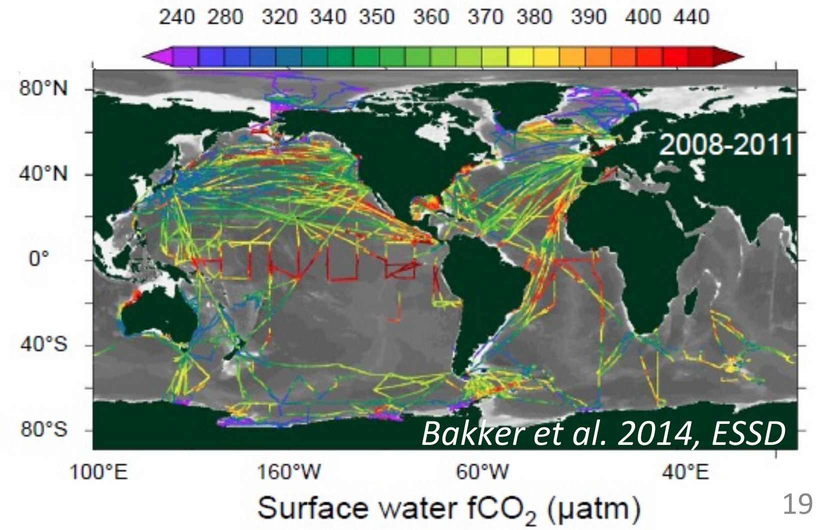
Data from Scopus. Word cloud from wordle.net.

Future Directions



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			

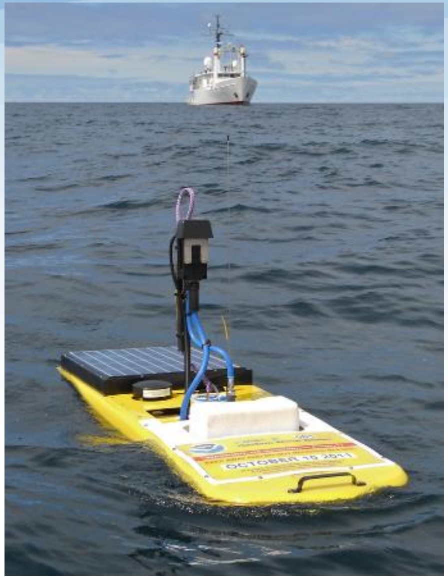
Wanninkhof et al. 2013, Biogeosciences, RECCAP

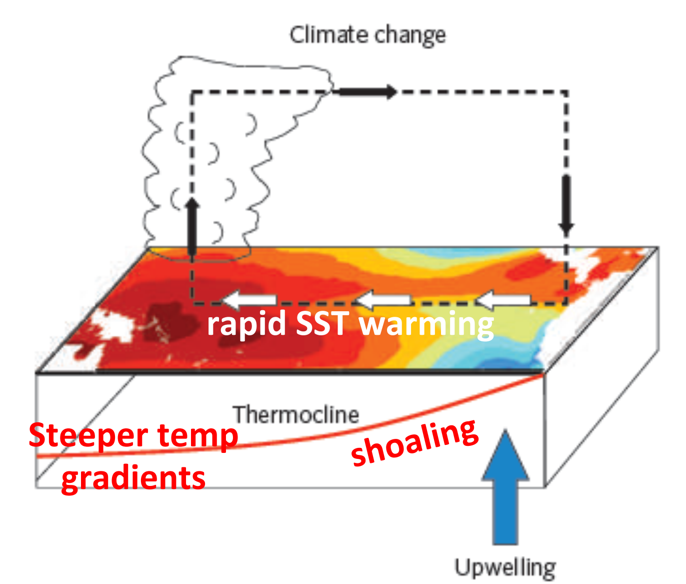


Bakker et al. 2014, ESSD

Ocean Carbon future direction: increased spatial coverage via new autonomous technologies to lower uncertainties in air-sea CO_2 flux estimates

Future Directions





Ocean Carbon future direction: expand carbon observations and research in the Tropical Pacific to better understand long-term change

nature climate change
LETTERS
PUBLISHED ONLINE: 19 JANUARY 2014 | DOI: 10.1038/NCLIMATE2100

Increasing frequency of extreme El Niño events due to greenhouse warming

Wenju Cai[1,2]★, Simon Borlace[1], Matthieu Lengaigne[3], Peter van Rensch[1], Mat Collins[4], Gabriel Vecchi[5], Axel Timmermann[6], Agus Santoso[7], Michael J. McPhaden[8], Lixin Wu[2], Matthew H. England[7], Guojian Wang[1,2], Eric Guilyardi[3,9] and Fei-Fei Jin[10]

Summary

Relevance

Is the ocean sink keeping pace with atmospheric CO_2 increases? How does a changing ocean sink impact society's ability to anticipate and respond to climate change?

Quality

We are a center of excellence for high-quality and cutting-edge carbon observations.

Performance

We've contributed to major advancements in our knowledge of ocean carbon:

- observations suggest the ocean is not keeping pace w/ CO_2 emissions growth rate
- based on the repeat hydrography observations, ocean has taken up 37 Pg C or about 30% of CO_2 emissions between 1994 and 2010
- discovery of decadal variability in CO_2 flux from the Equatorial Pacific, the largest natural oceanic source of CO_2