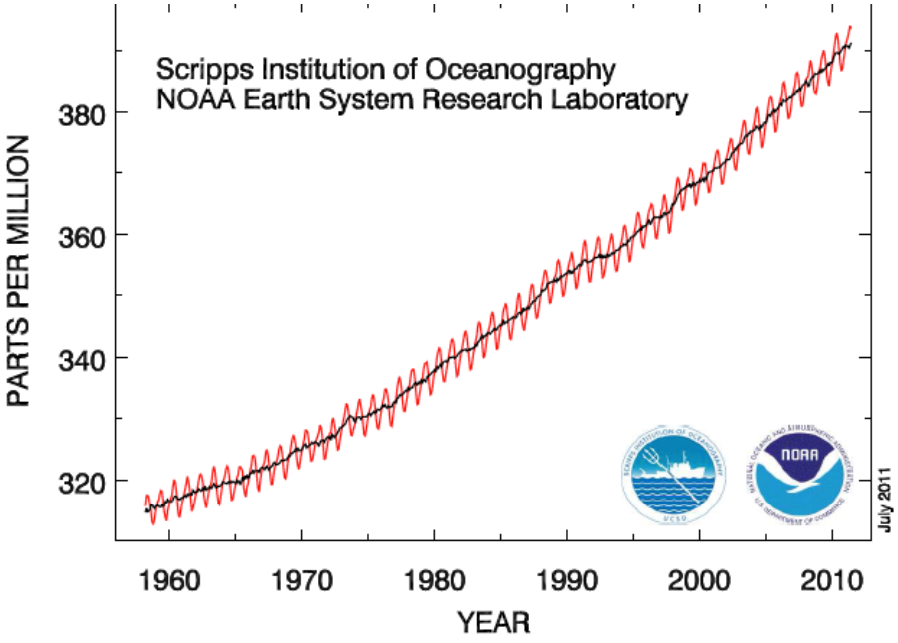
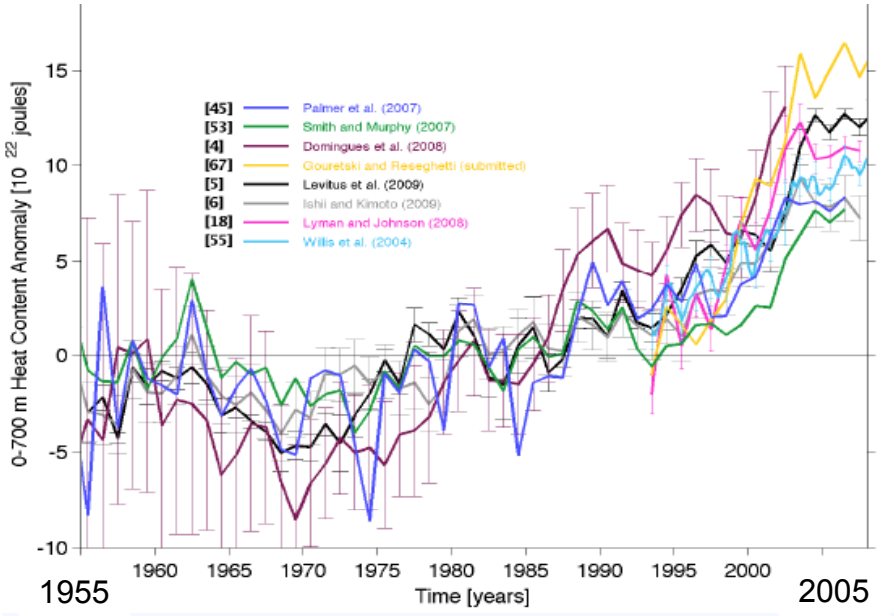
OCB and U.S. CLIVAR: Scientific Questions & Global Observing Capabilities

Scott Doney (WHOI)

Atmospheric CO_2 at Mauna Loa Obs.



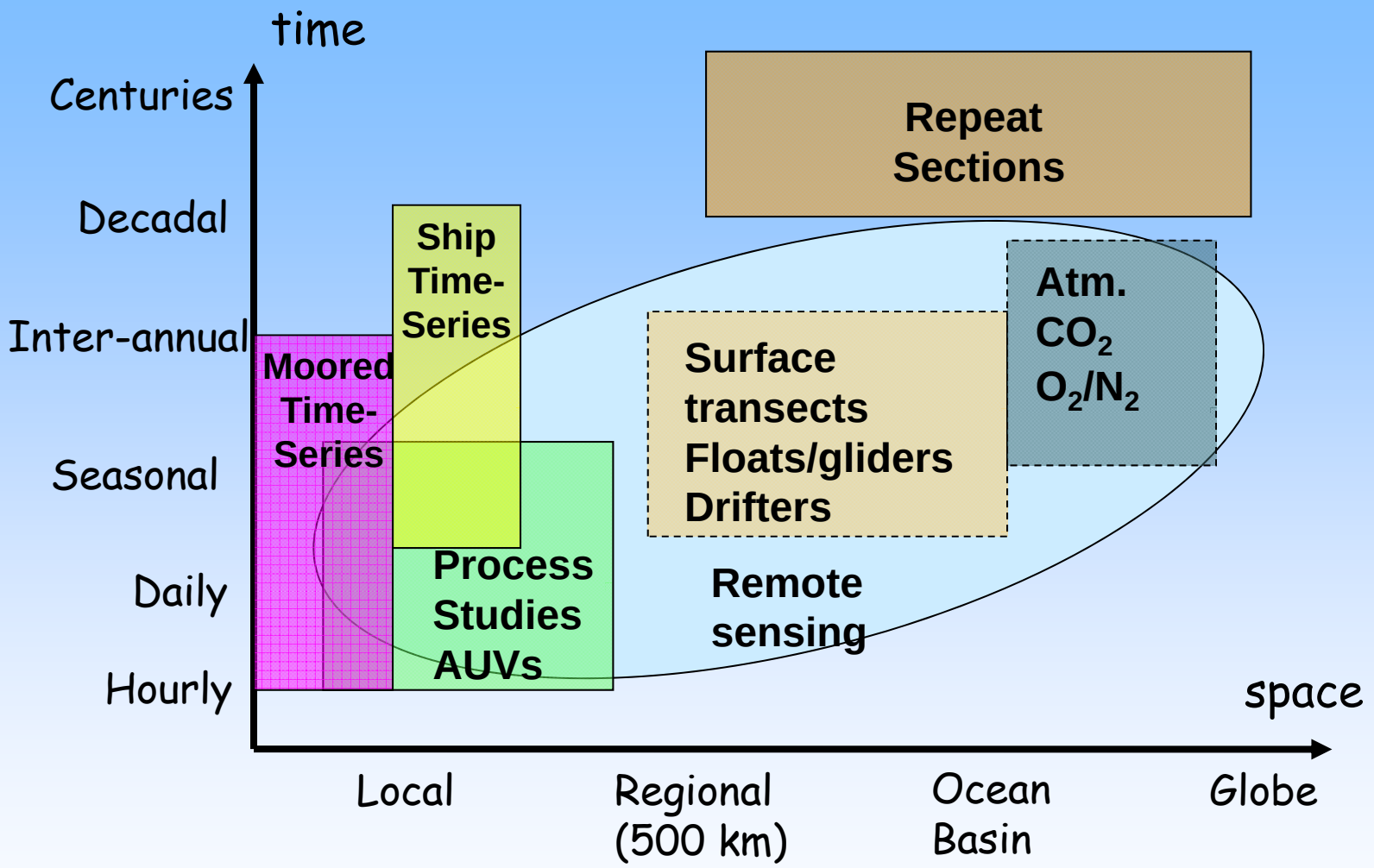
Ocean Heat Content Anomaly



How can we take better advantage of scientific synergies & leverage common observational approaches?

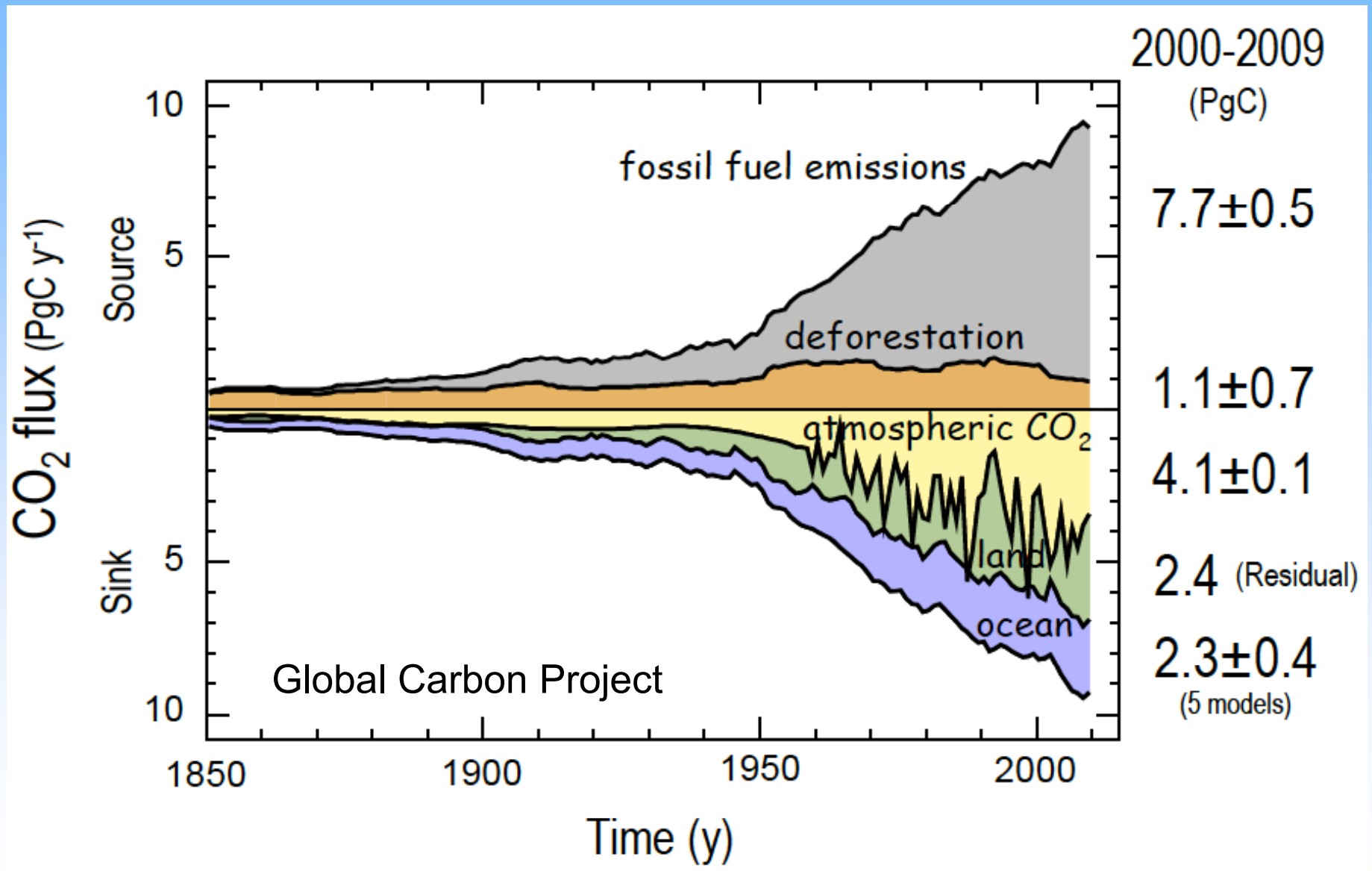
WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Time/Space Scales of Observational Platforms



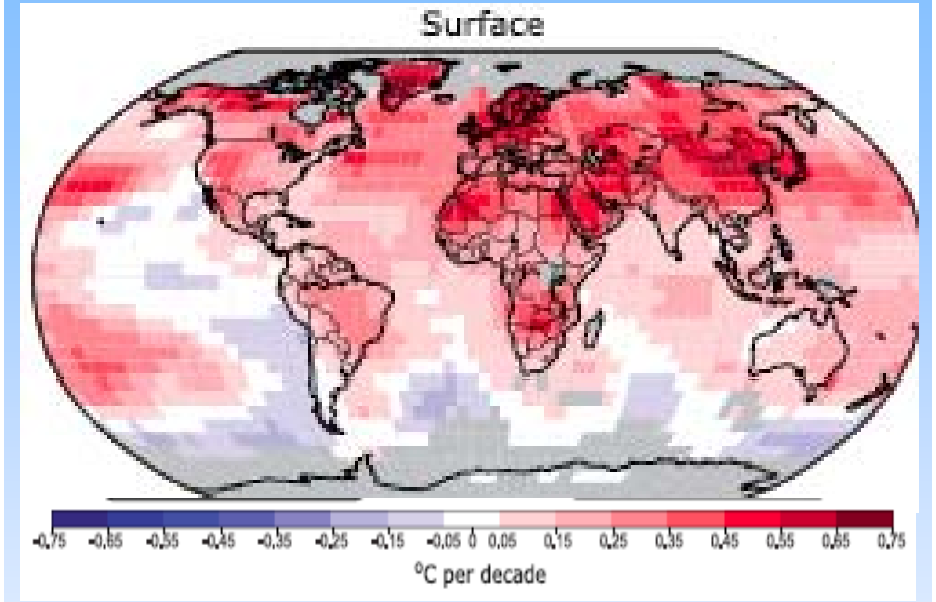
-Individual platforms have strengths & weaknesses
-Integrate multiple approaches with models & process studies
-Growing promise of autonomous platforms

Human Perturbation to Global Carbon Cycle

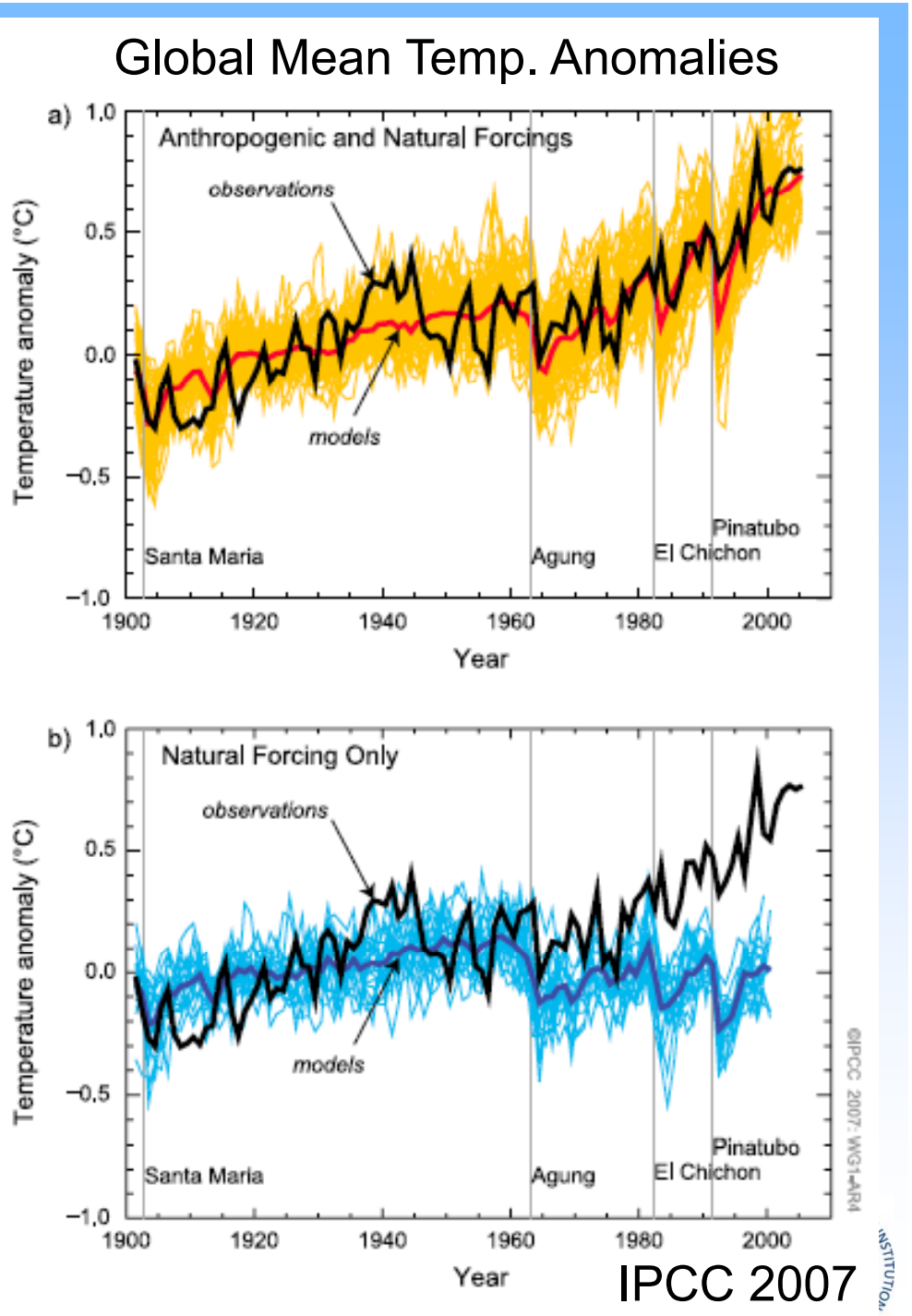


Canadell et al. PNAS 2007; LeQuere et al. Nature Geosciences 2009

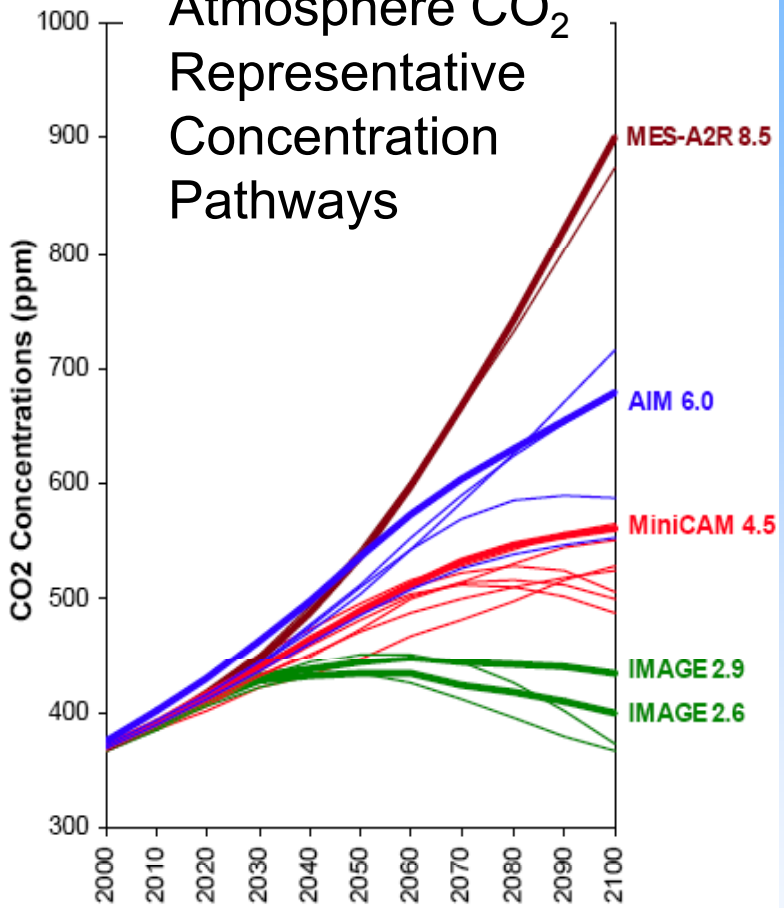
Surface Temperature Trends

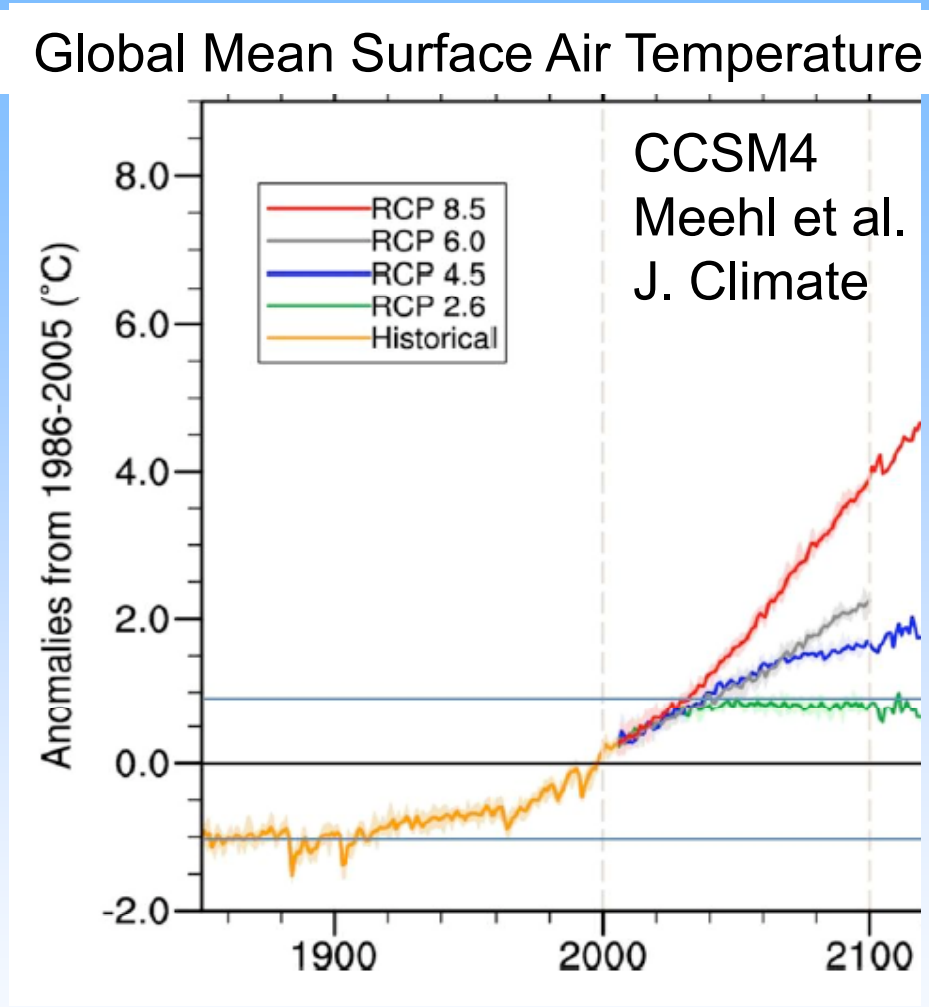


Detection & attribution of anthropogenic climate change signals from background of natural internal variability & other external forcings



Future Climate Projections

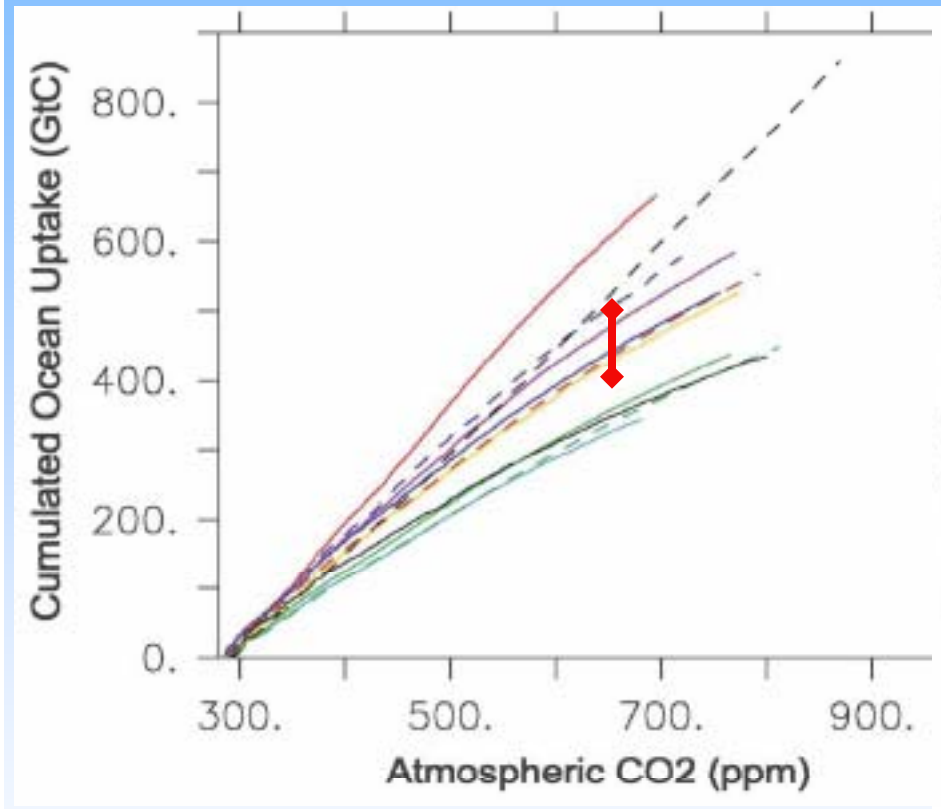




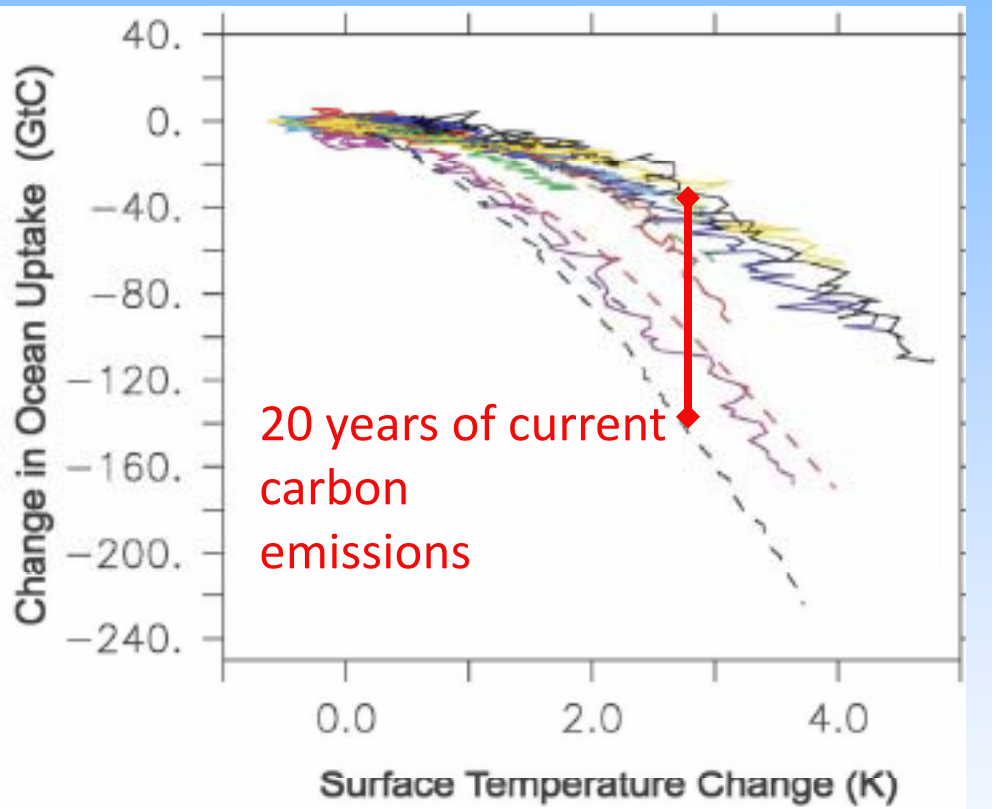
-CO_2 emissions (social, political, economic, geological)
-atmospheric CO_2 (carbon sinks, climate-carbon feedbacks)
-climate sensitivities (clouds, water vapor)

Uncertainties about Future Ocean Uptake

Strength of Ocean CO_2 Sink



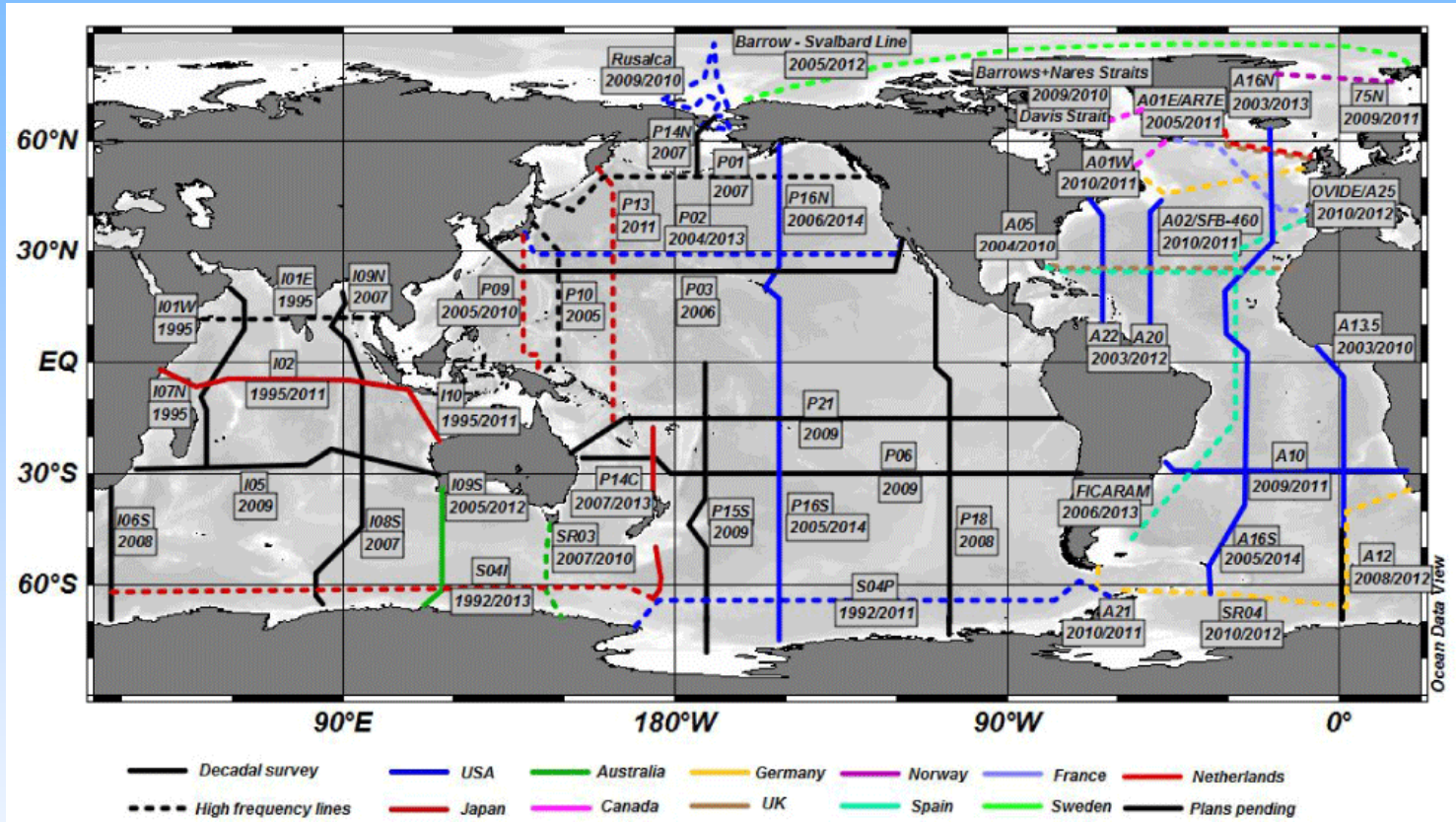
Sensitivity to Climate Warming



-Ocean slows climate change by removing atmosphere CO_2
-Under climate change ocean less effective in removing CO_2
-Observational constraints on uptake & sensitivity to climate

Friedlingstein et al., J. Climate, (2006)

Repeat Hydrography/CO_2 Program



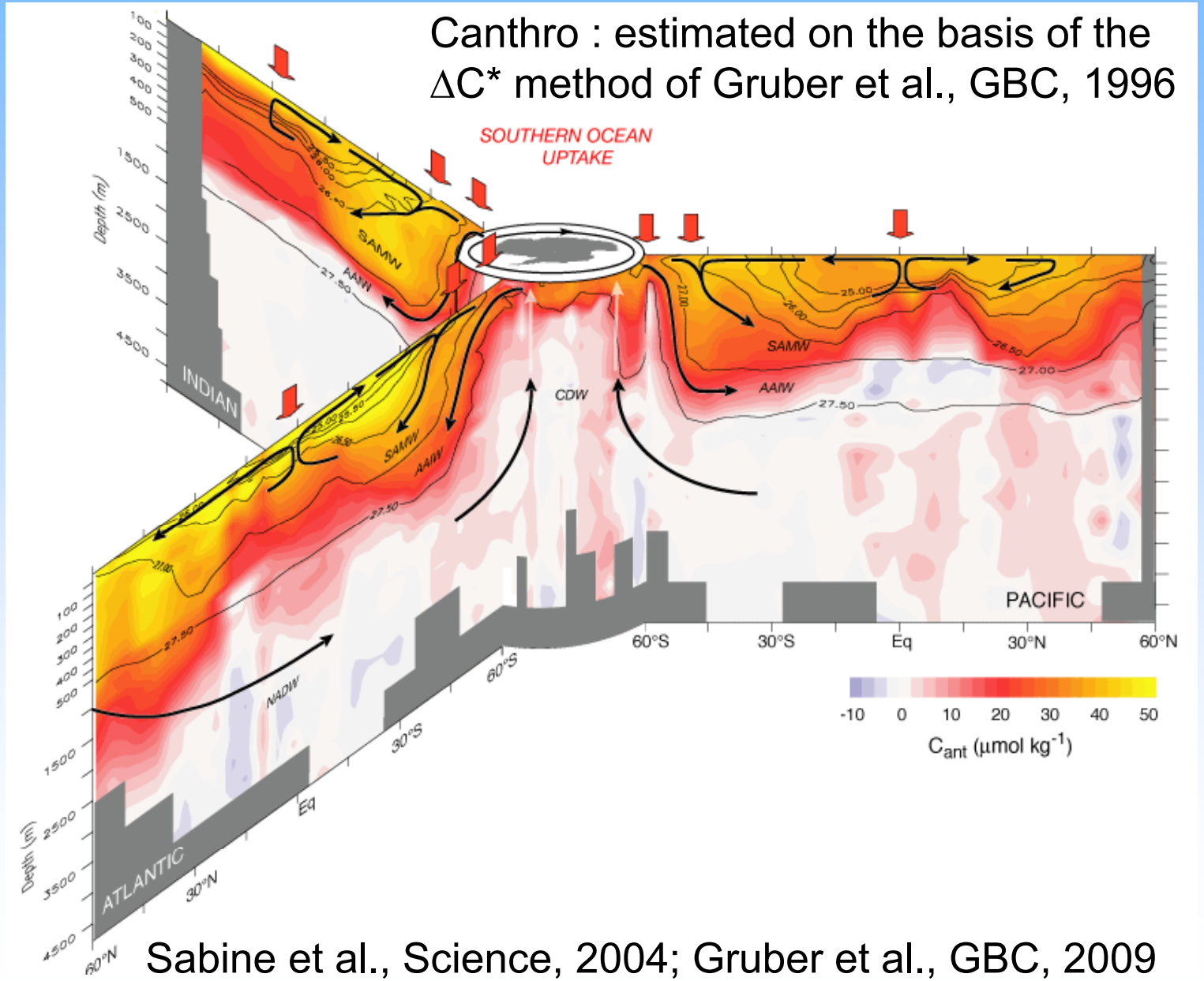
Ships allow for suite of full-depth physical, biogeochemical & tracer measurements

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

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Anthropogenic CO_2 Distribution & Uptake

Canthro : estimated on the basis of the ΔC* method of Gruber et al., GBC, 1996

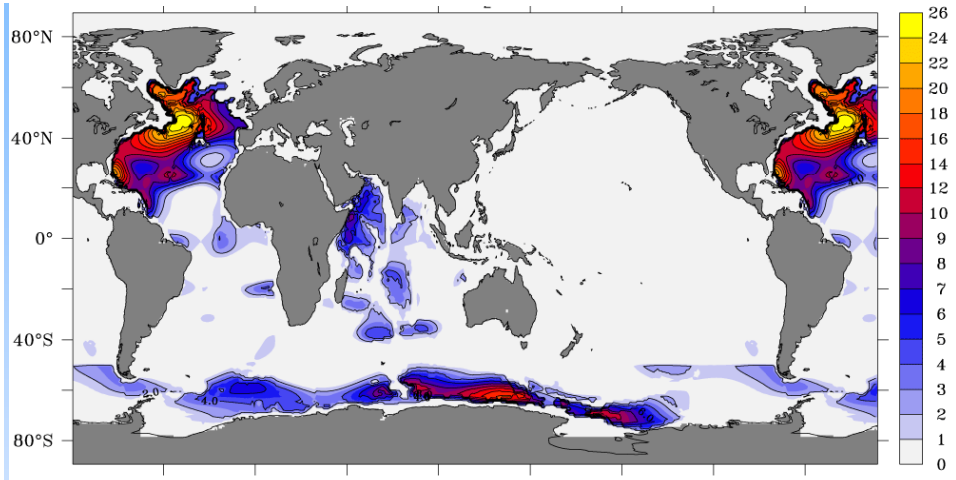


Sabine et al., Science, 2004; Gruber et al., GBC, 2009

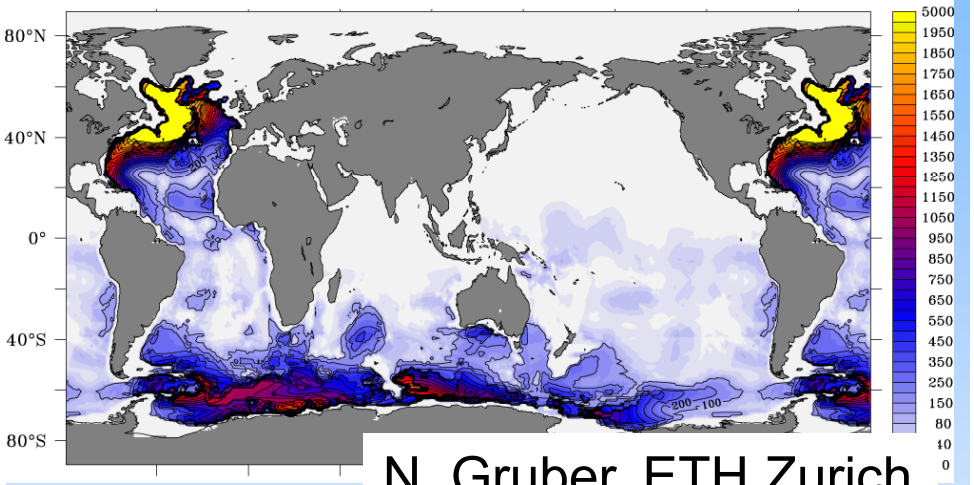
WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Deep-Water Trends

Inventory C_{anthro} below 2000 m

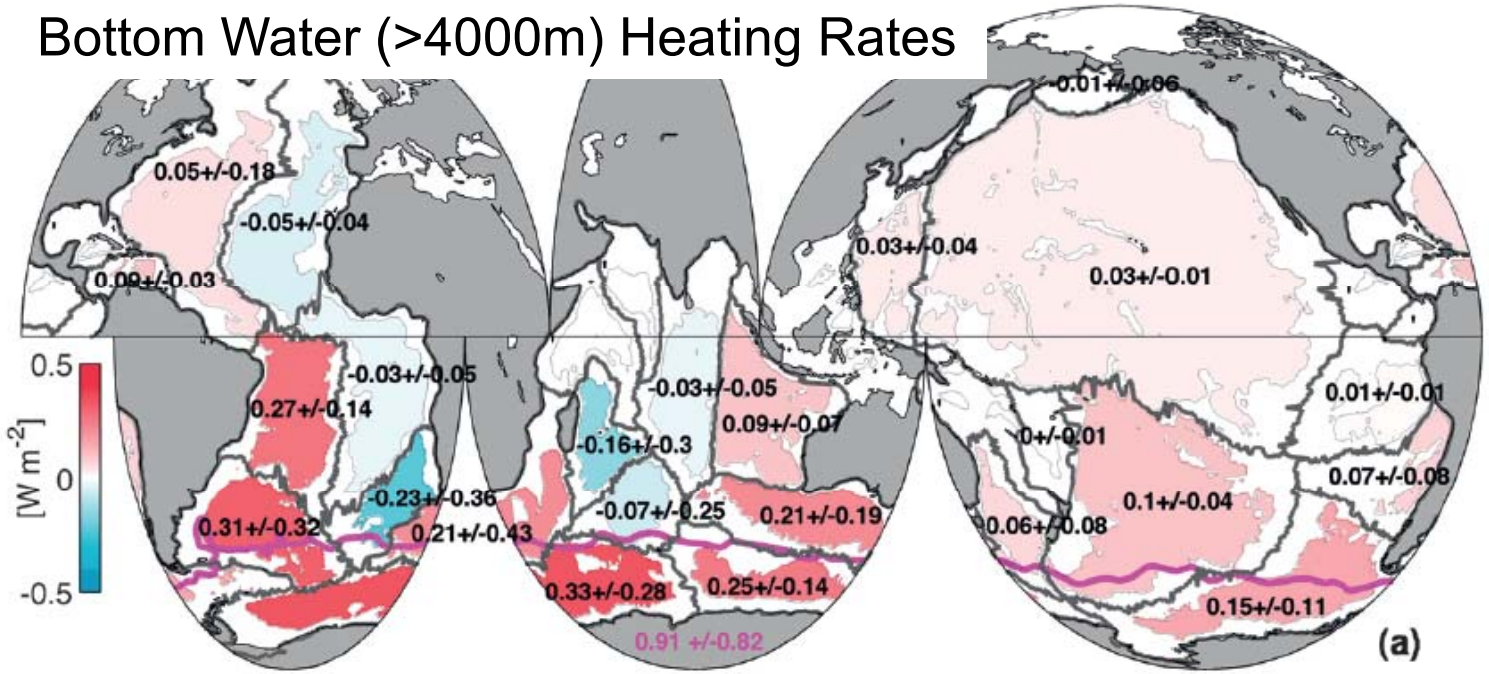


Inventory CFC-11 below 2000 m



N. Gruber, ETH Zurich

Bottom Water (>4000m) Heating Rates

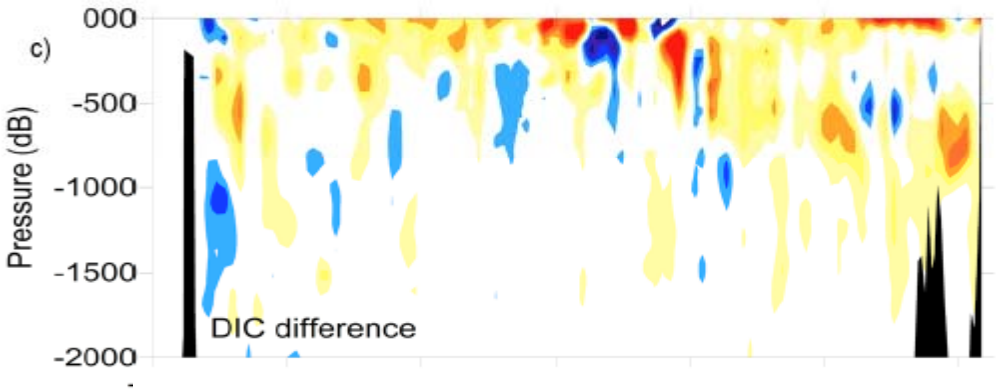


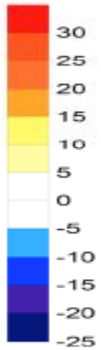
Purkey & Johnson J. Climate 2010

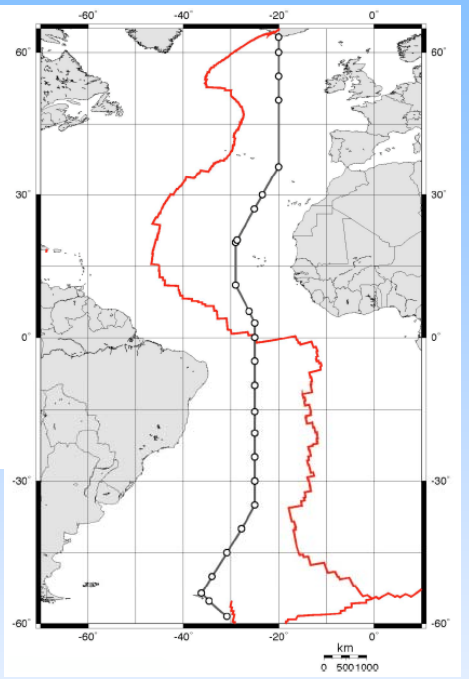
WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Decadal Changes in Carbon Inventory

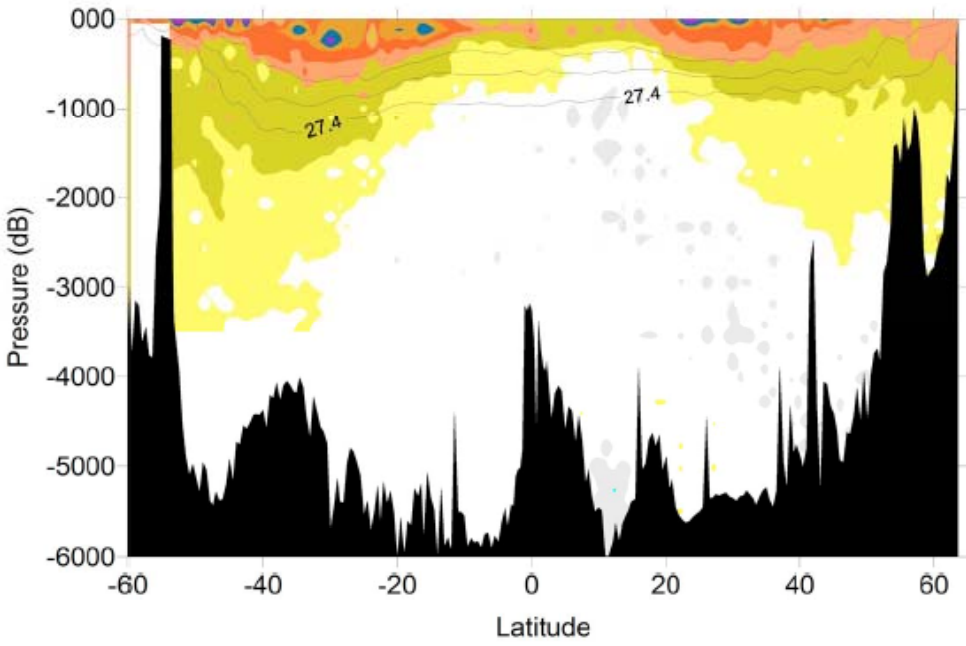
Direct ΔDIC difference

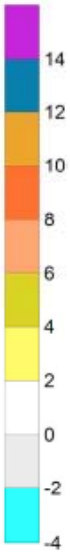






Estimated ΔCanthro difference





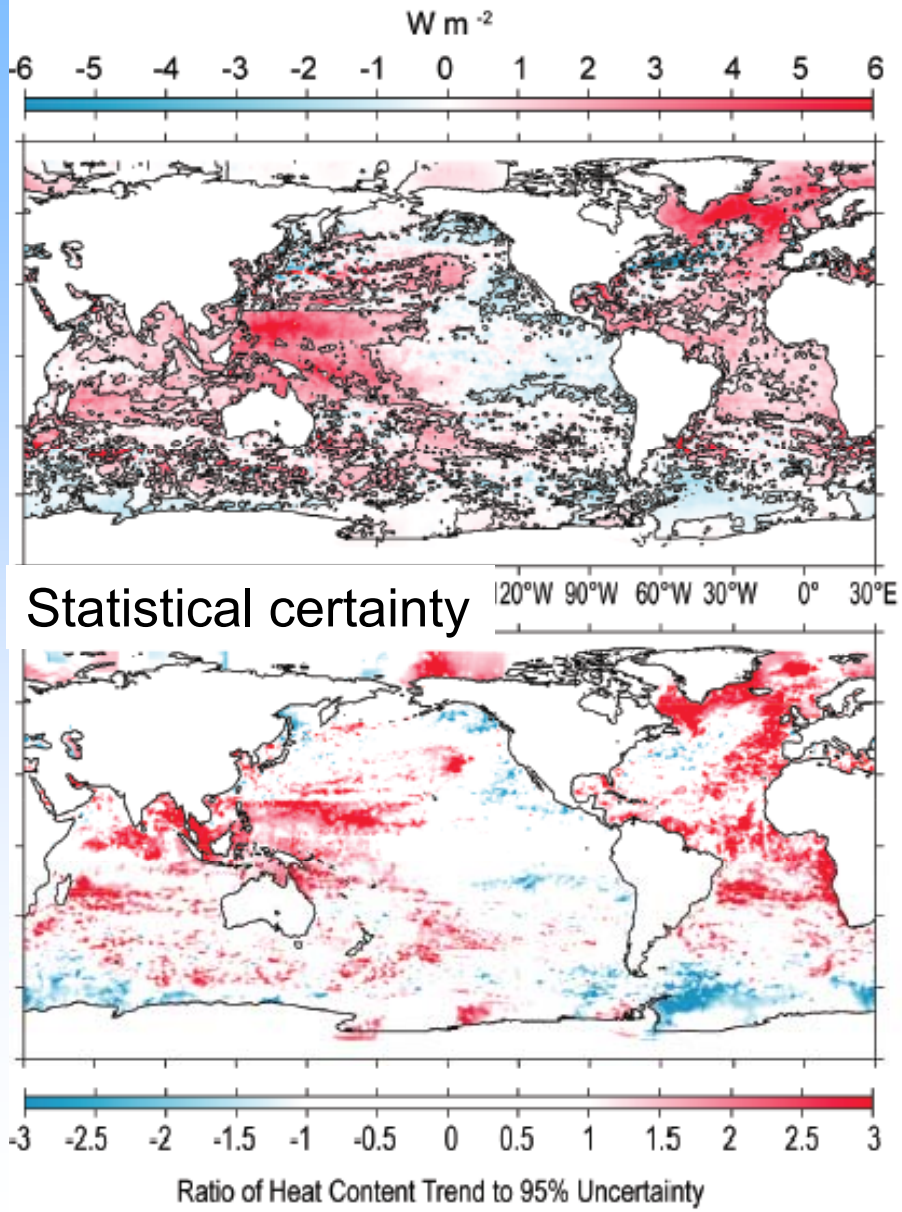
Repeat hydrography under-samples natural temporal variability; techniques needed to isolate anthropogenic signal

Wanninkhof et al. JGR-Oceans 2010

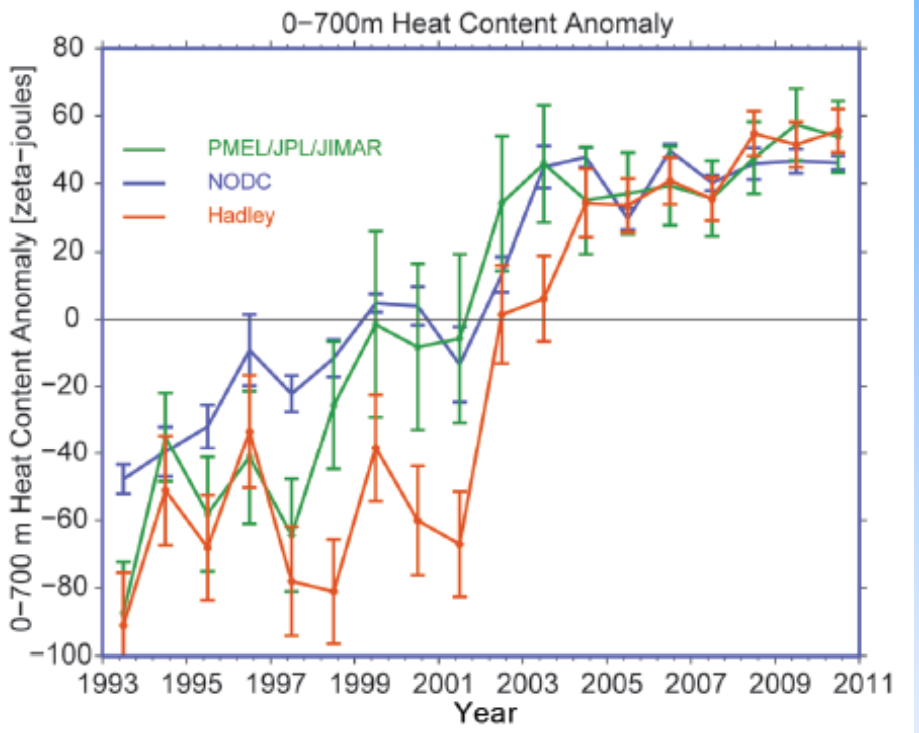
WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Upper Ocean Heat Content

Linear trends 1993-2010



Statistical certainty

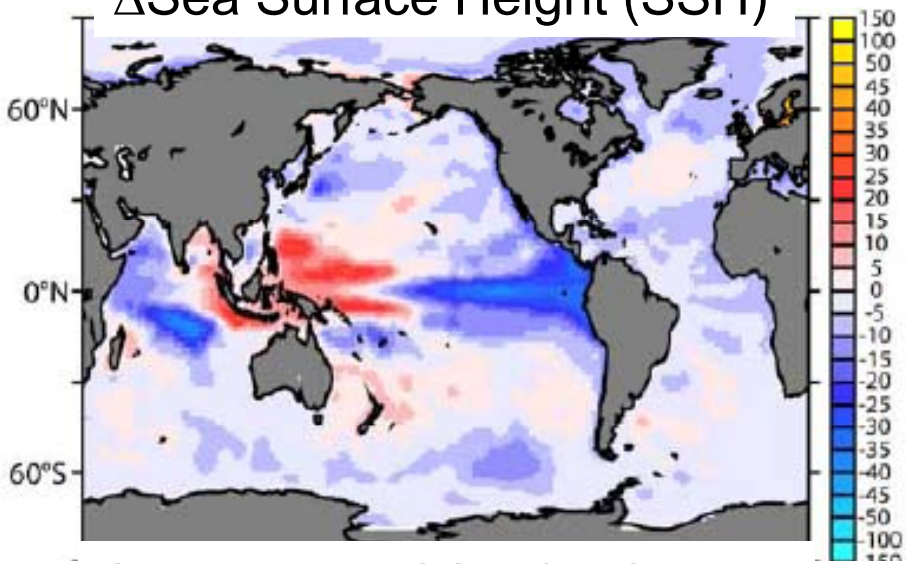


Merging of data from satellite altimetry, Argo floats, XBTs, and CTDs

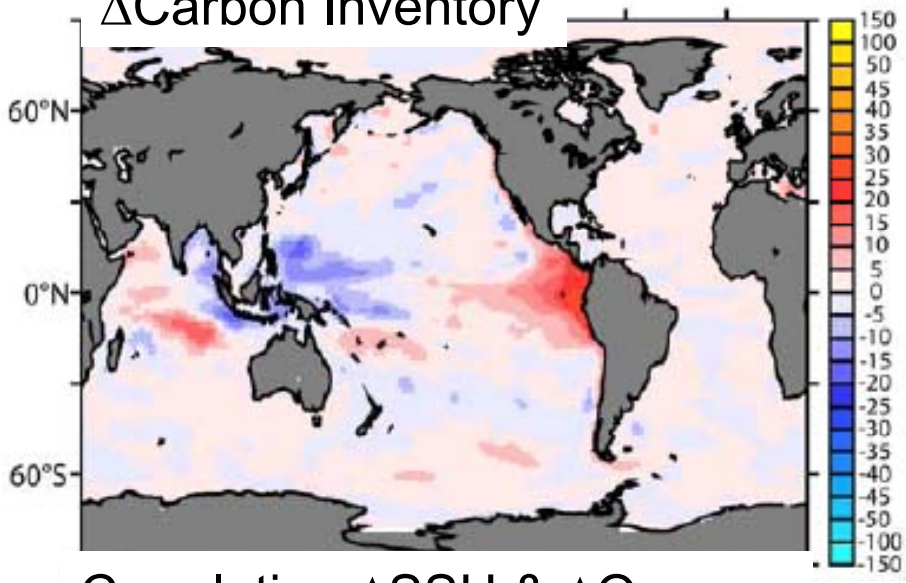
Willis et al. JGR Oceans, 2004
Johnson et al. in *State of the Climate 2009*, BAMS 2010

Subannual to Interannual Variability

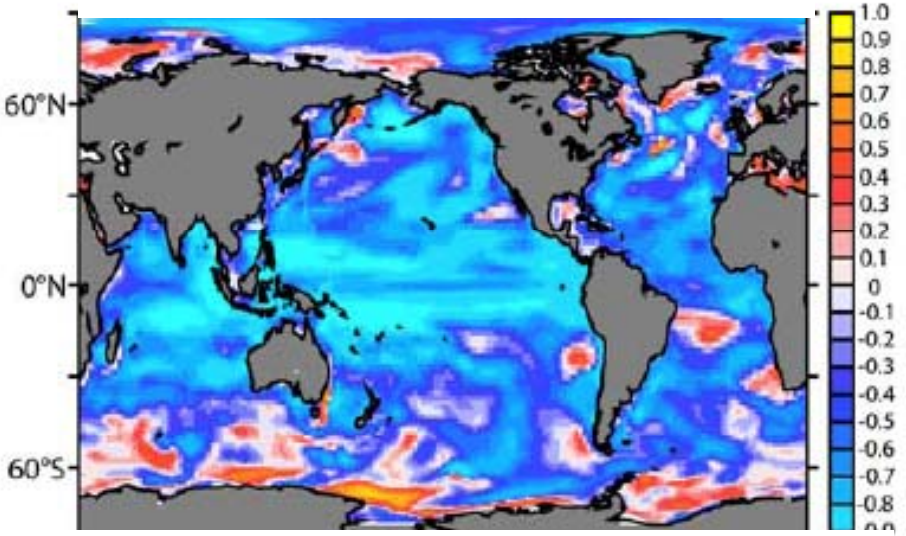
ΔSea Surface Height (SSH)



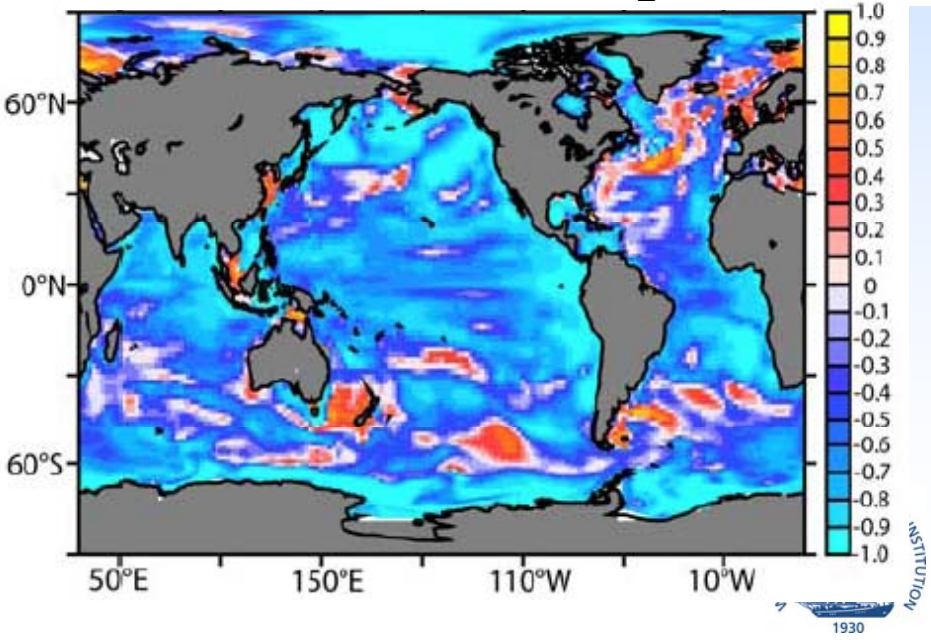
ΔCarbon Inventory



Correlation ΔSSH & ΔCarbon

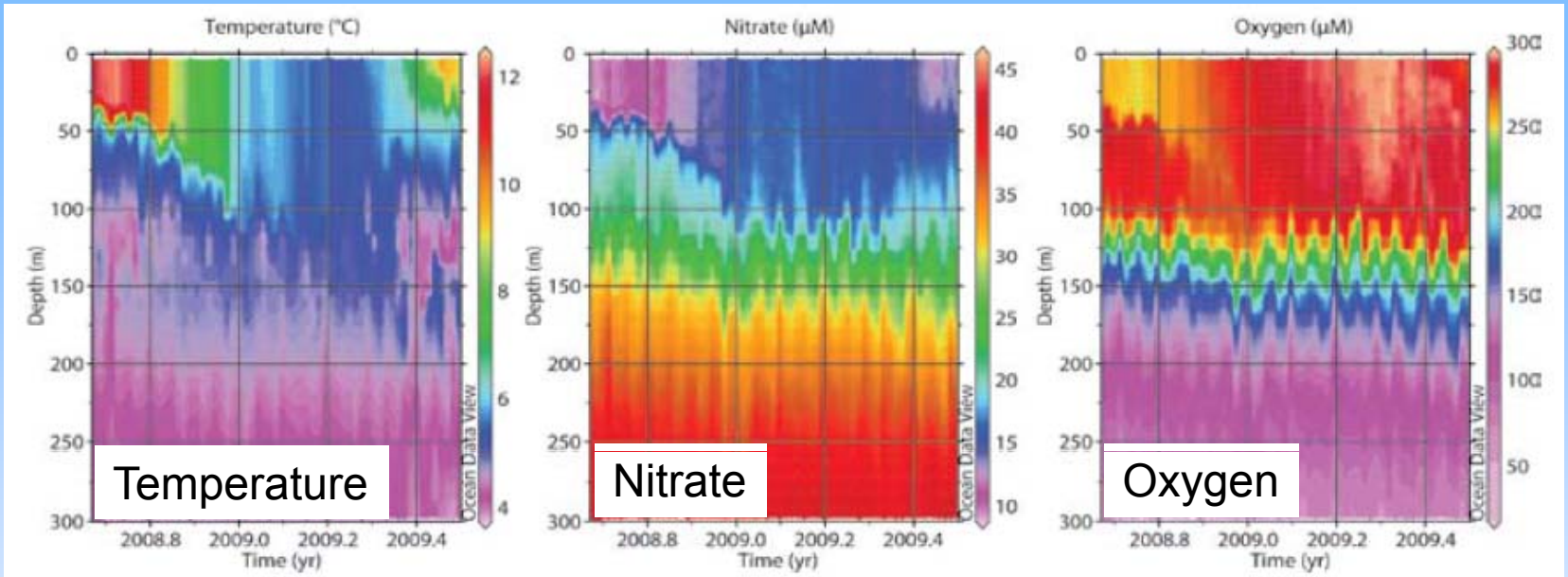


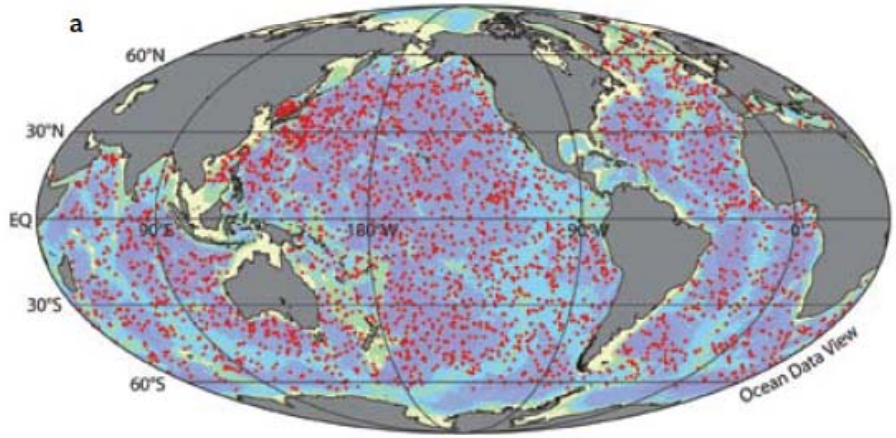
Correlation ΔSSH & ΔO_2

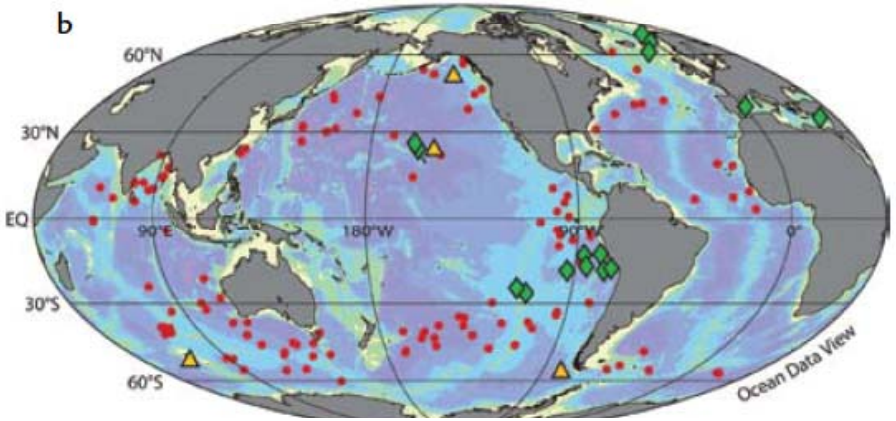


Rodgers et al. JGR-Oceans 2009

Biogeochemistry on Profiling Floats





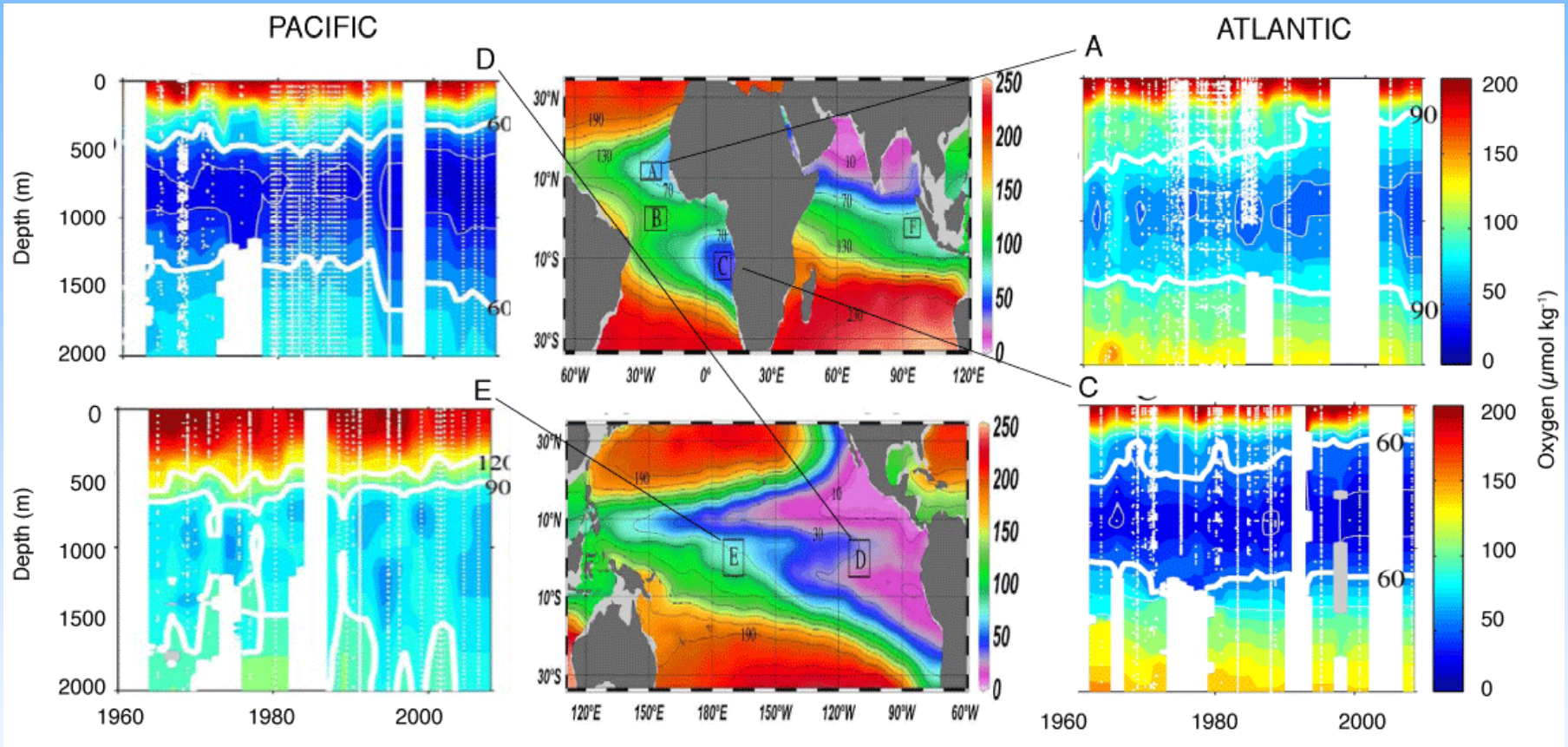


Oxygen Nitrate

Bio-optics

Johnson et al. Oceanography 2010

Ocean Deoxygenation & O_2 Minima

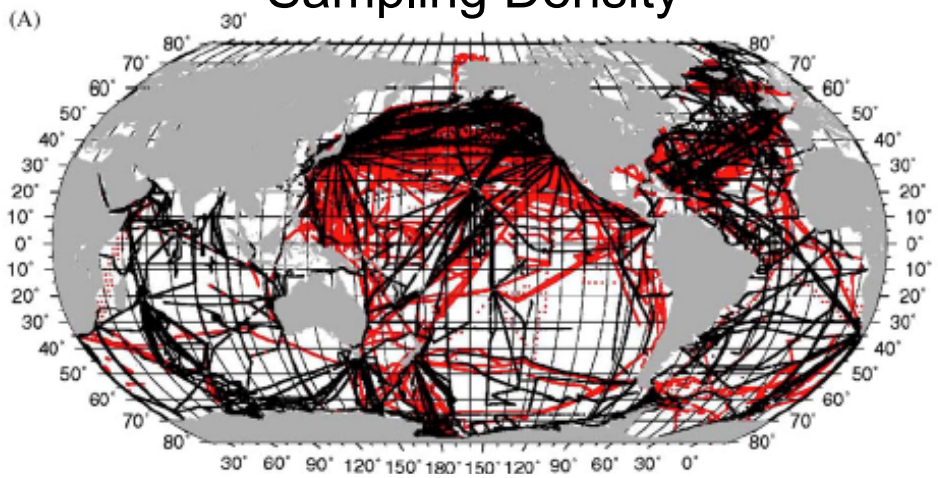


Stramma et al., Science, 2008

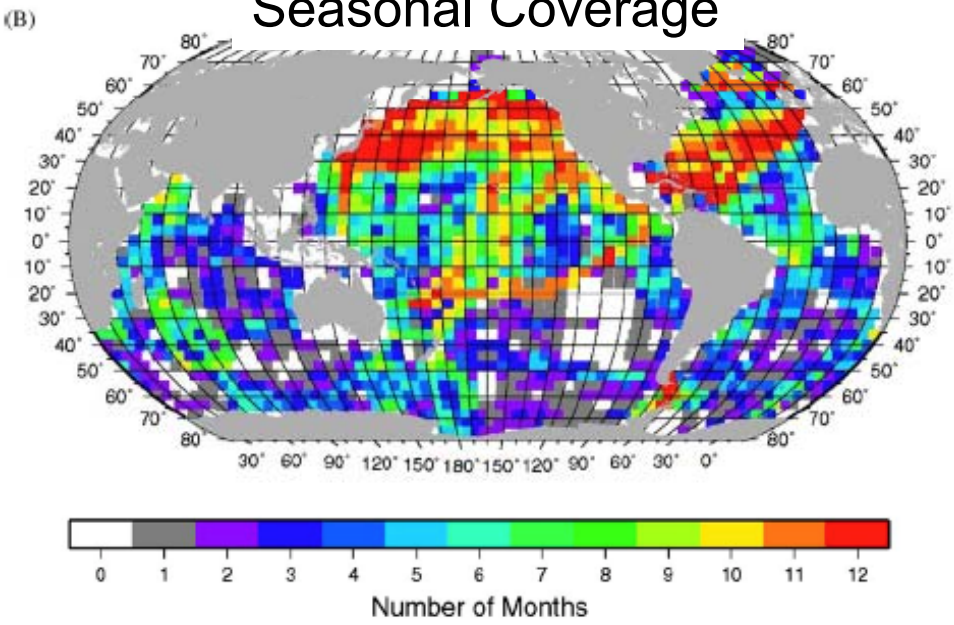
-Oxygen loss from warming & altered circulation
-Expansion of the regions with hypoxia

Underway Data & Sea-air CO_2 Flux

Sampling Density

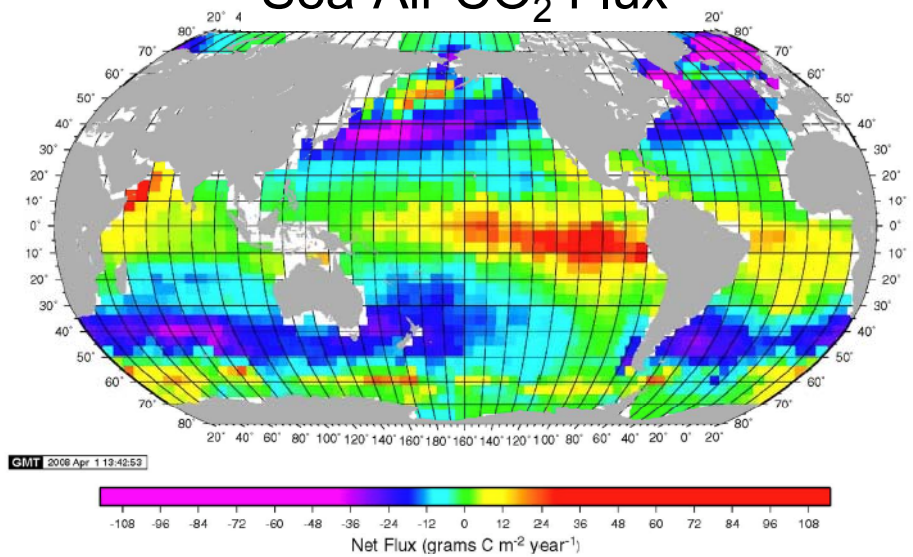


Seasonal Coverage



Takahashi et al. Deep-Sea Res. II 2009

Sea-Air CO_2 Flux

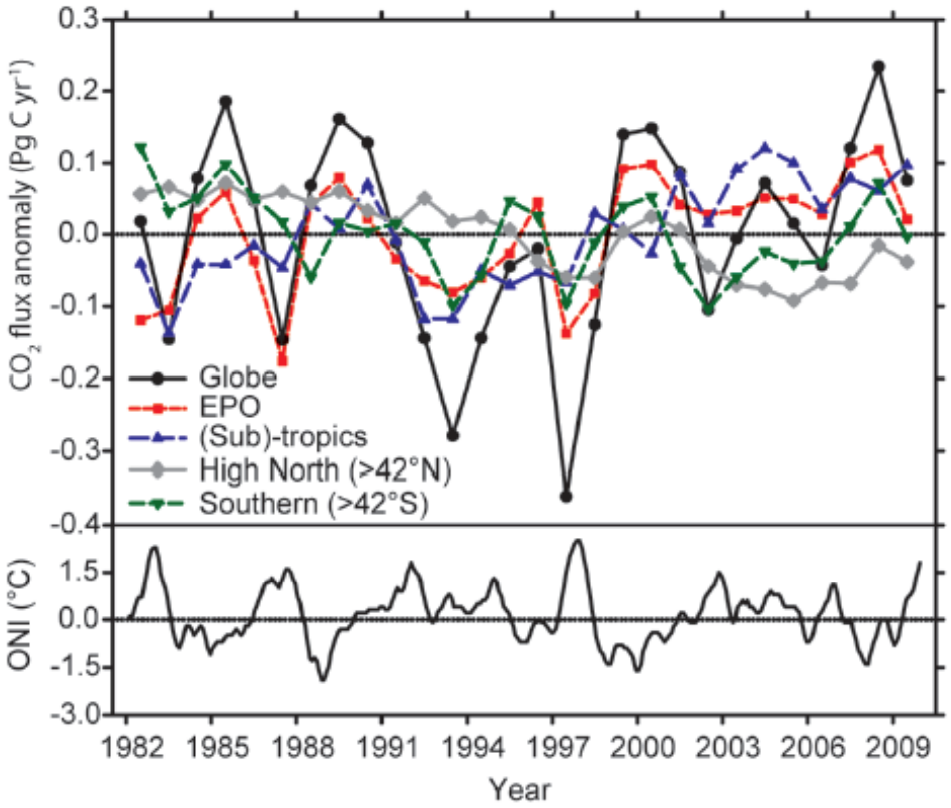


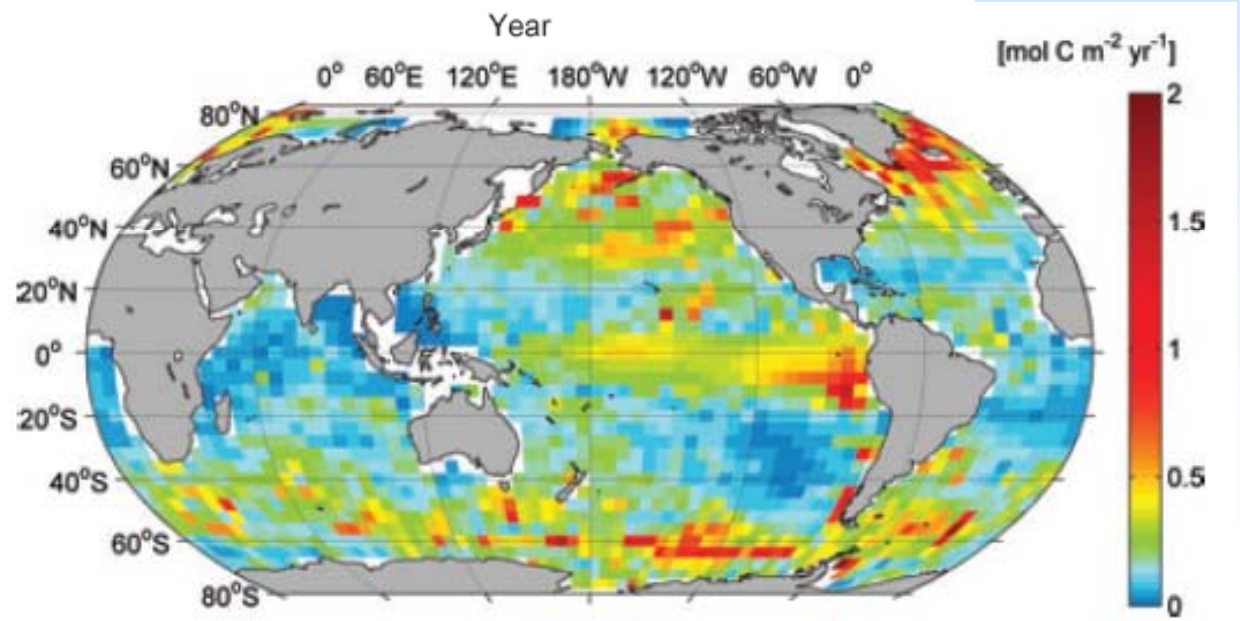
Estimate seasonal climatology of CO_2 Flux from

- Measured sea-air ΔpCO_2 data
- Wind-speed from reanalysis or scatterometer
- Empirical gas transfer velocity relationship
- Correct sea-air ΔpCO_2 to common reference year

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Sea-air CO_2 Flux Interannual Variability



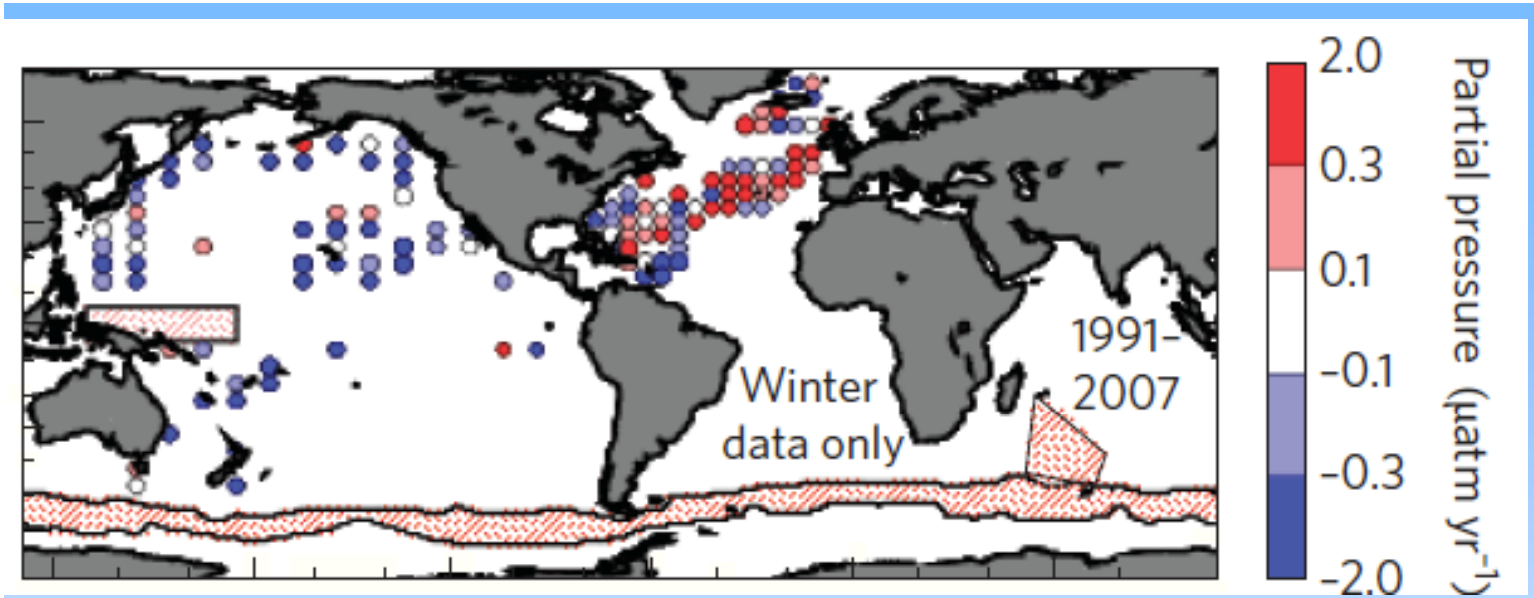


Time-varying pCO_2 diagnostic from regional pCO_2-SST regressions (possible errors in Southern Ocean)

Park et al.
Tellus 2010

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

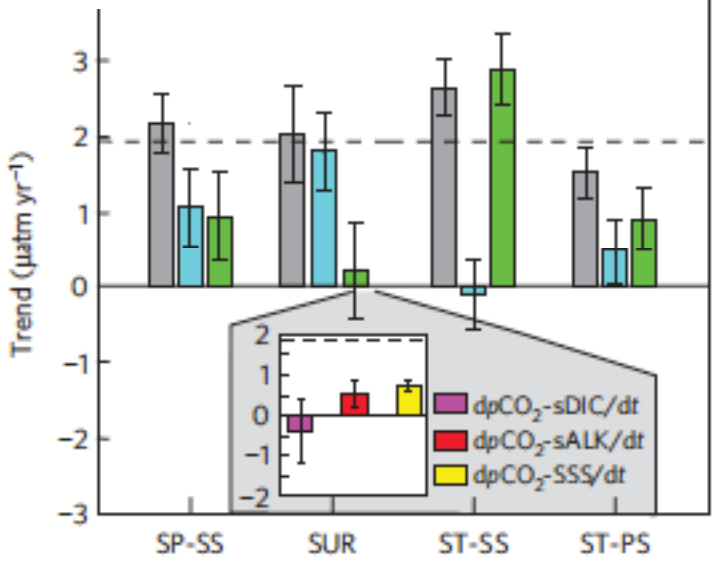
Sea-Air pCO_2 Trends



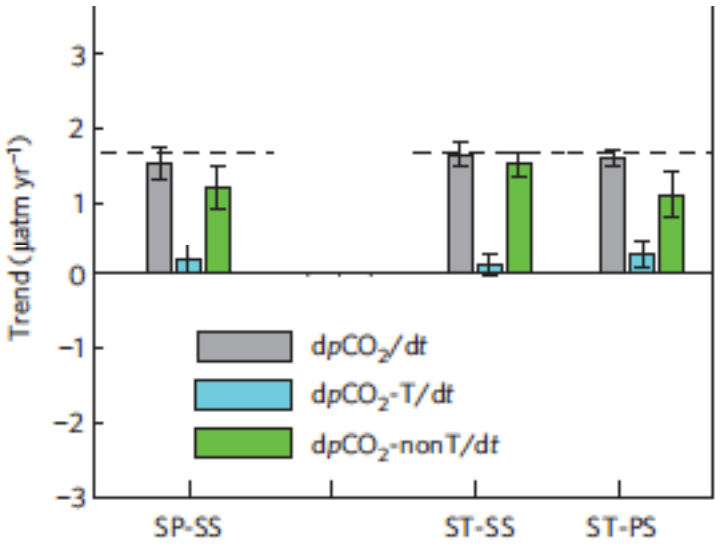
Red
reduced
ocean
uptake

Le Quere et al. Nature Geosciences (2009)

Decadal Trend (1993-2005)



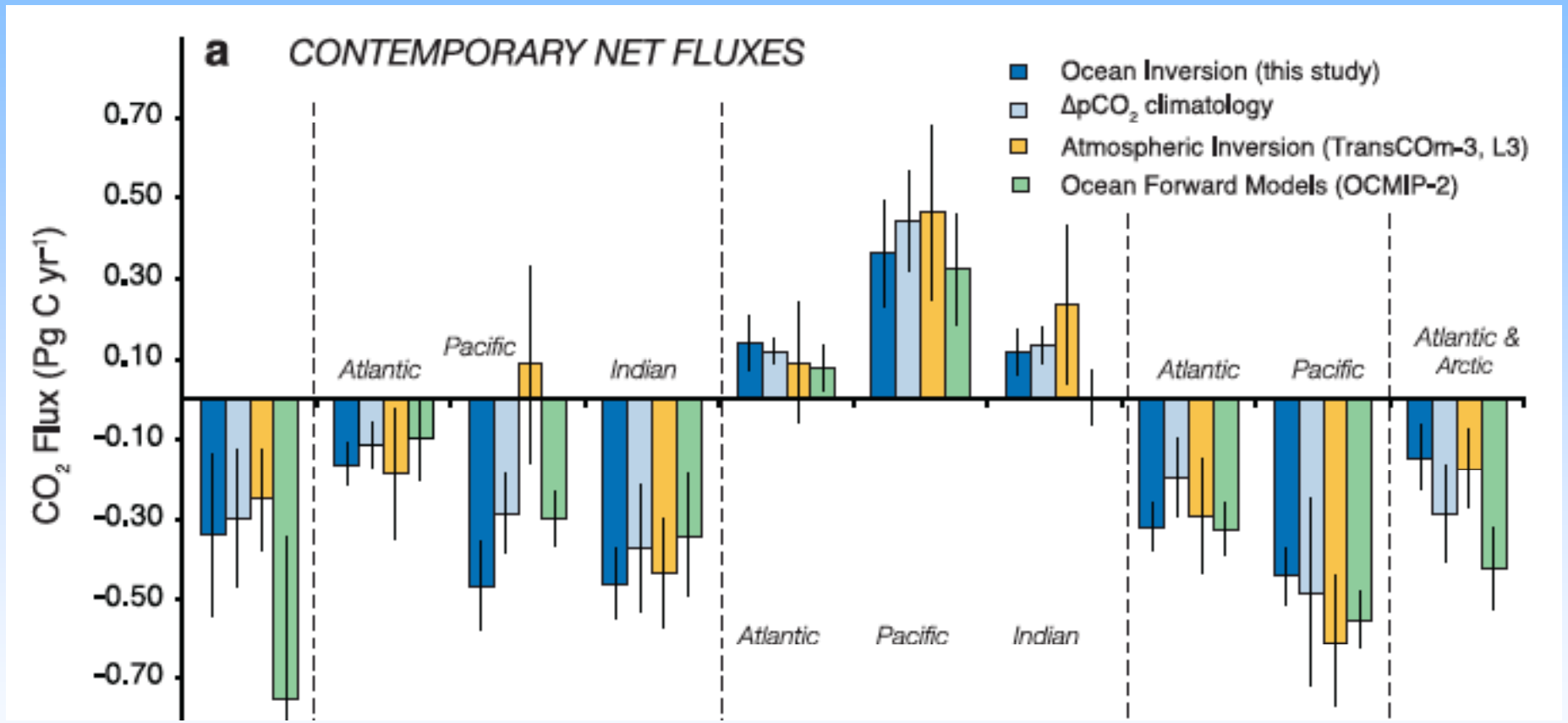
Multi-decadal Trend (1981-2009)



McKinley et al. Nature Geosciences (2011)

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

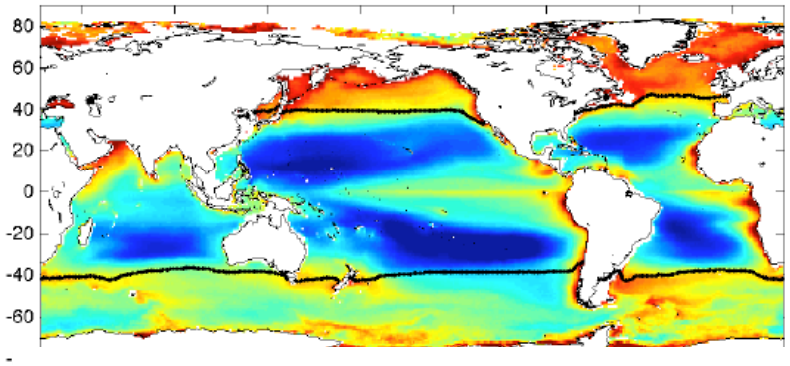
Observations, Inverse Models & Forward Models



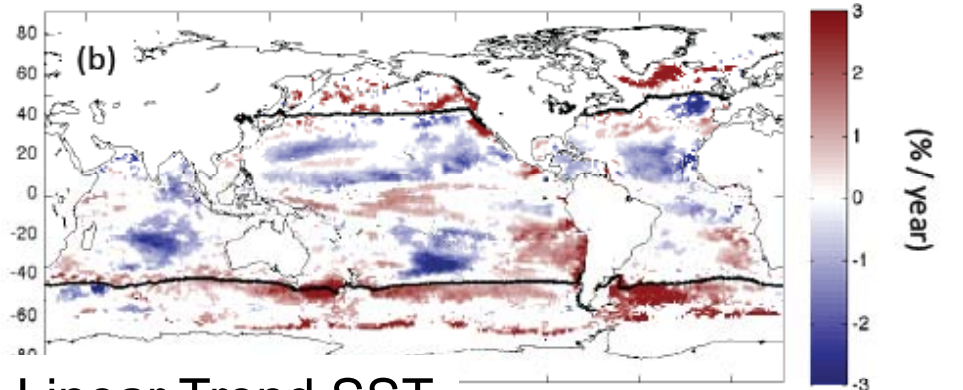
Gruber et al., GBC, 2009

Satellite Ocean Color & SST

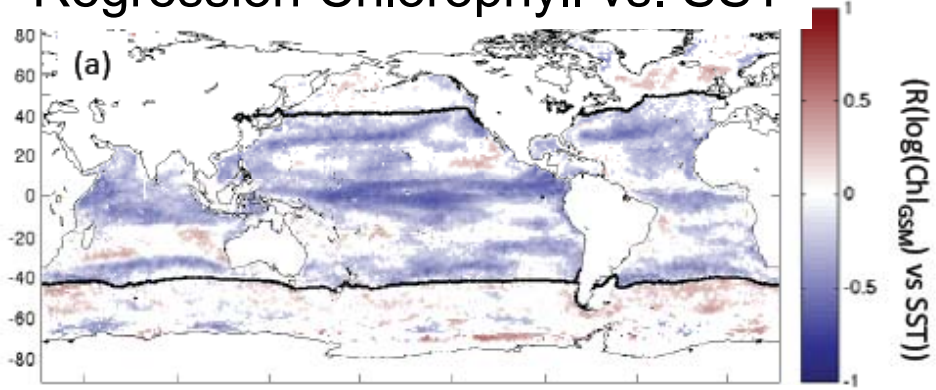
Time-mean SeaWiFS Chlorophyll



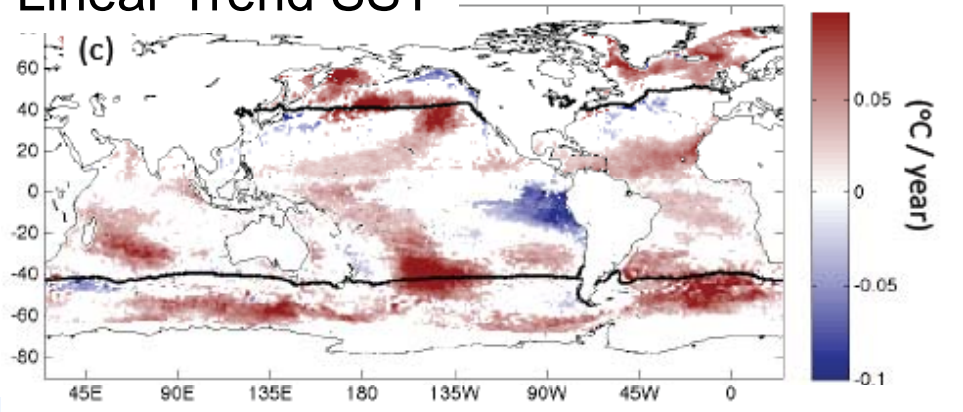
Linear Trend SeaWiFS Chlorophyll



Regression Chlorophyll vs. SST



Linear Trend SST



Tropics/subtropics:

-chlorophyll anti-correlated with SST

-physiological responses to light

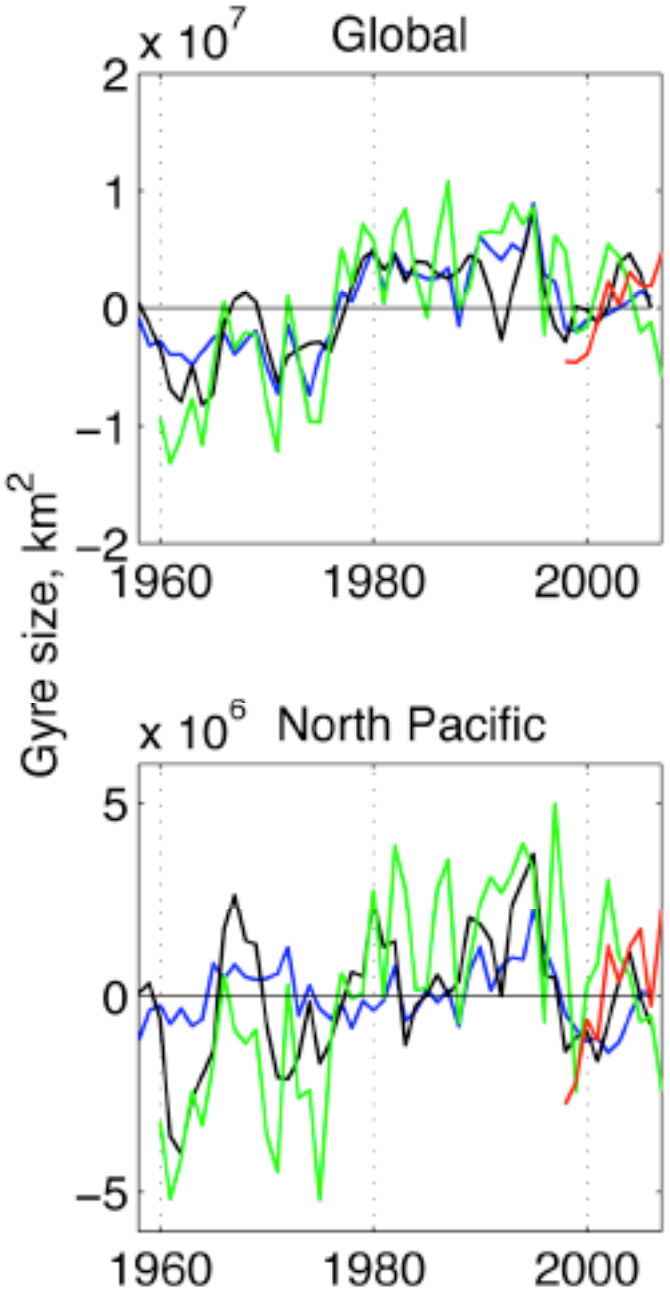
Subpolar/polar:

-variations dominated by biomass

Siegel, Behrenfeld, McClain et al. in prep.

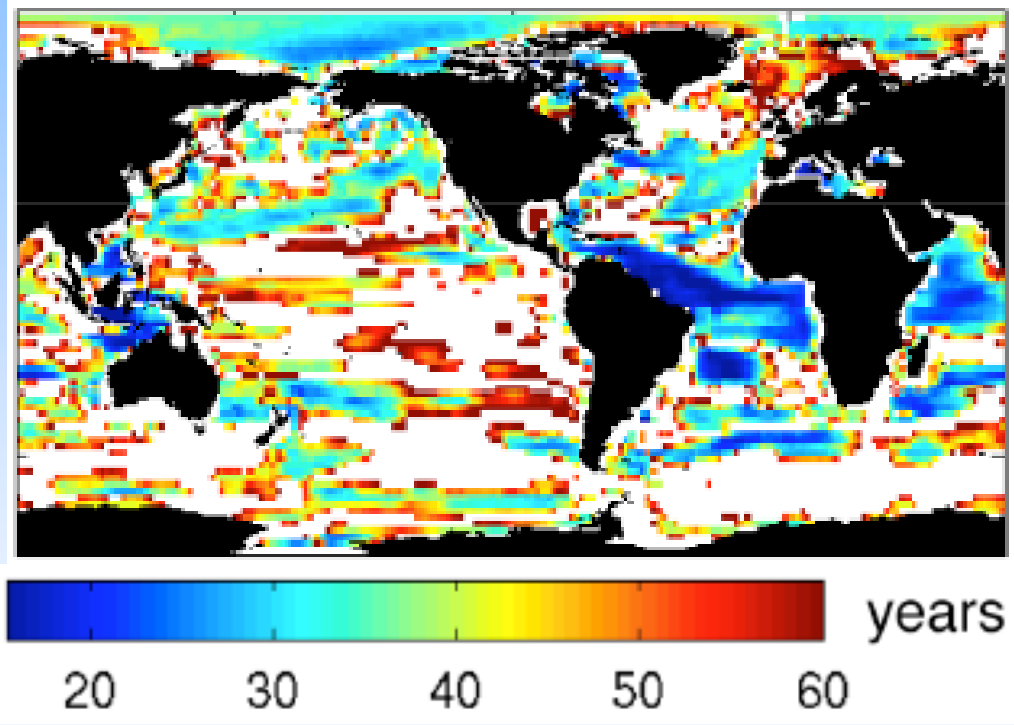
WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Area of Low Chlorophyll



Detecting Trends & Natural Variability

Record Length to Detect Climate Trend



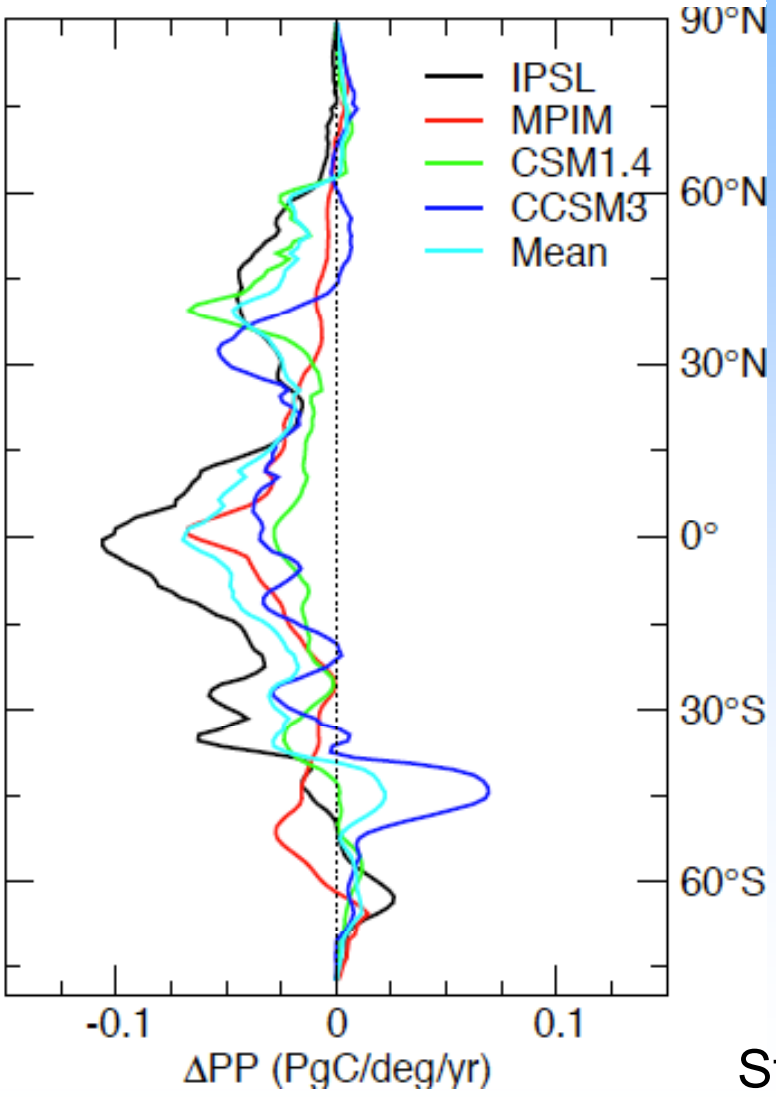
-Present observational record (red) is too short to definitively detect climate signals

Henson et al., Biogeosciences, 2010
Yoder et al., Acta Oceanol. Sinica, 2010

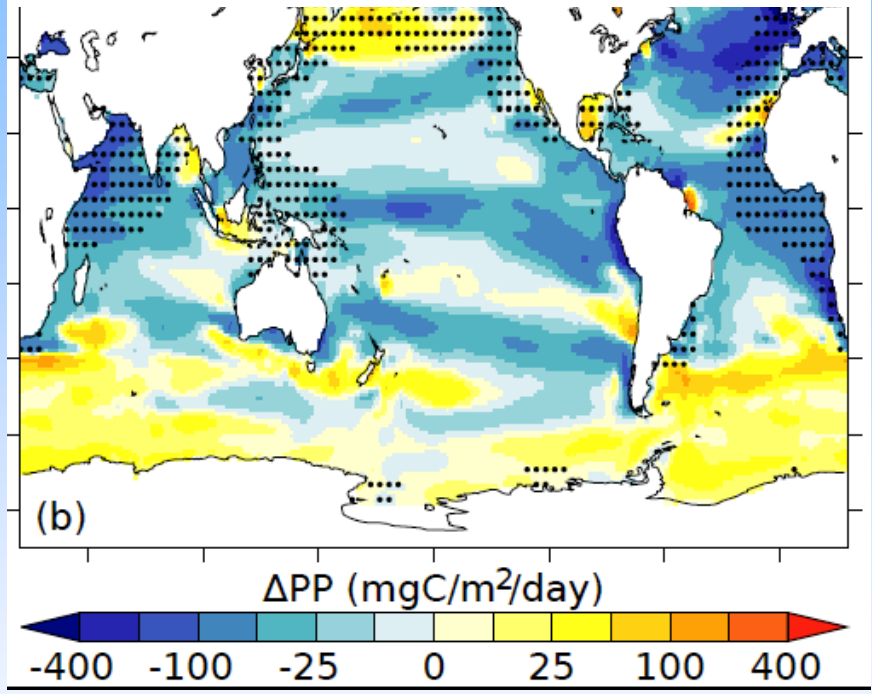
WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Projected Climate Impacts on Productivity

21st Century Change in zonal integrated primary production



Multi-model Ensemble (stippled regions large contemporary errors)

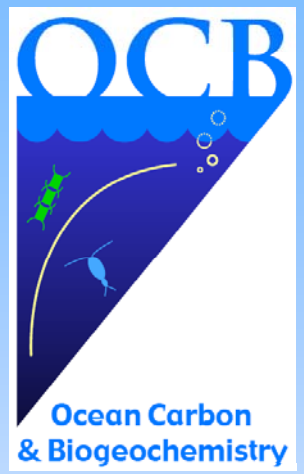


-Less production in tropics
stratification; reduced nutrients
-More production at high latitudes
mixed layers; sea-ice; warming

Steinacher et al. Biogeosciences 2010

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Some Final Thoughts



-Circulation, heat & biogeochemistry coupled on seasonal to decadal scales

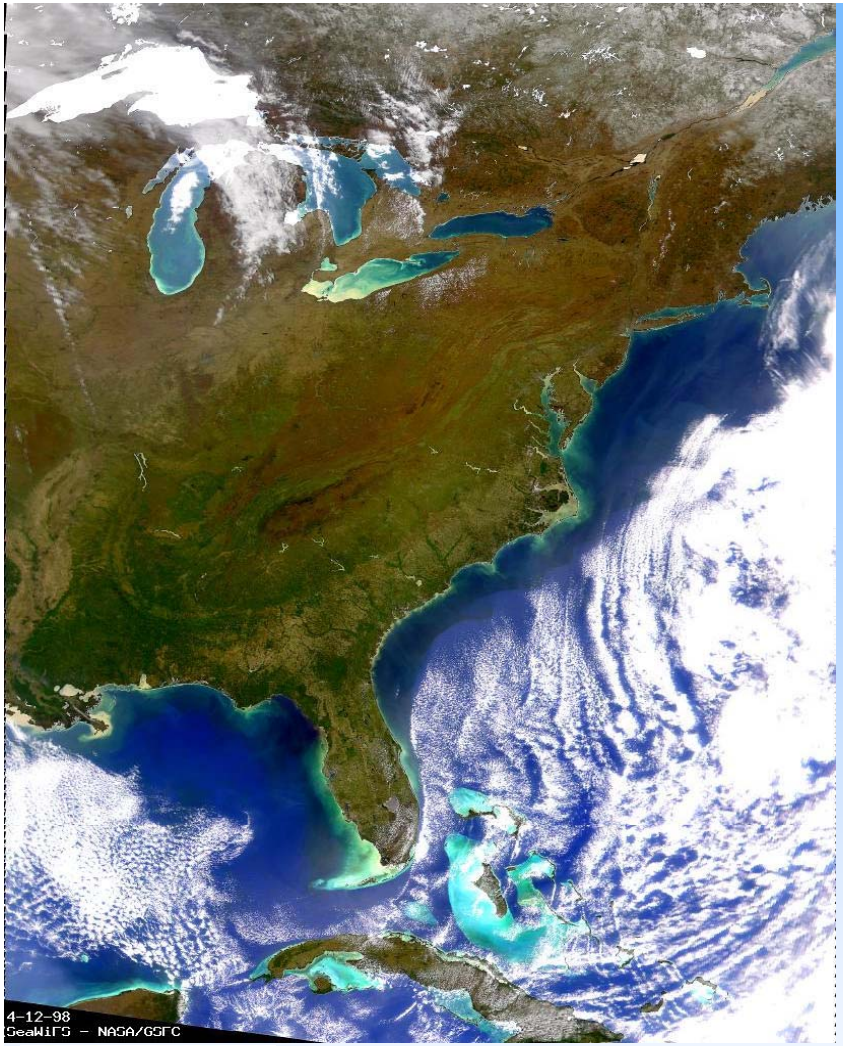
- detection & attribution of secular trends
- mechanisms & feedbacks
- other biological & chemical data (e.g. bio-optics)

-Opportunities

- autonomous sensors & platforms
- distributed networks (quality vs. quantity)
- deep-water trends (ships?)
- data assimilation & reanalysis

-Challenges of sustained observations

- climate quality data
- funding models
- social dynamics



Scott Doney
Woods Hole Oceanographic Institution
sdoney@whoi.edu

Special Thanks To:
Mike Patterson
Nicholas Gruber
Rik Wanninkhof

OCB Ocean Carbon & Biogeochemistry

U.S. CLIVAR Climate Variability & Predictability

Climate Variability & Predictability CLIVAR World Climate Research Programme

NASA

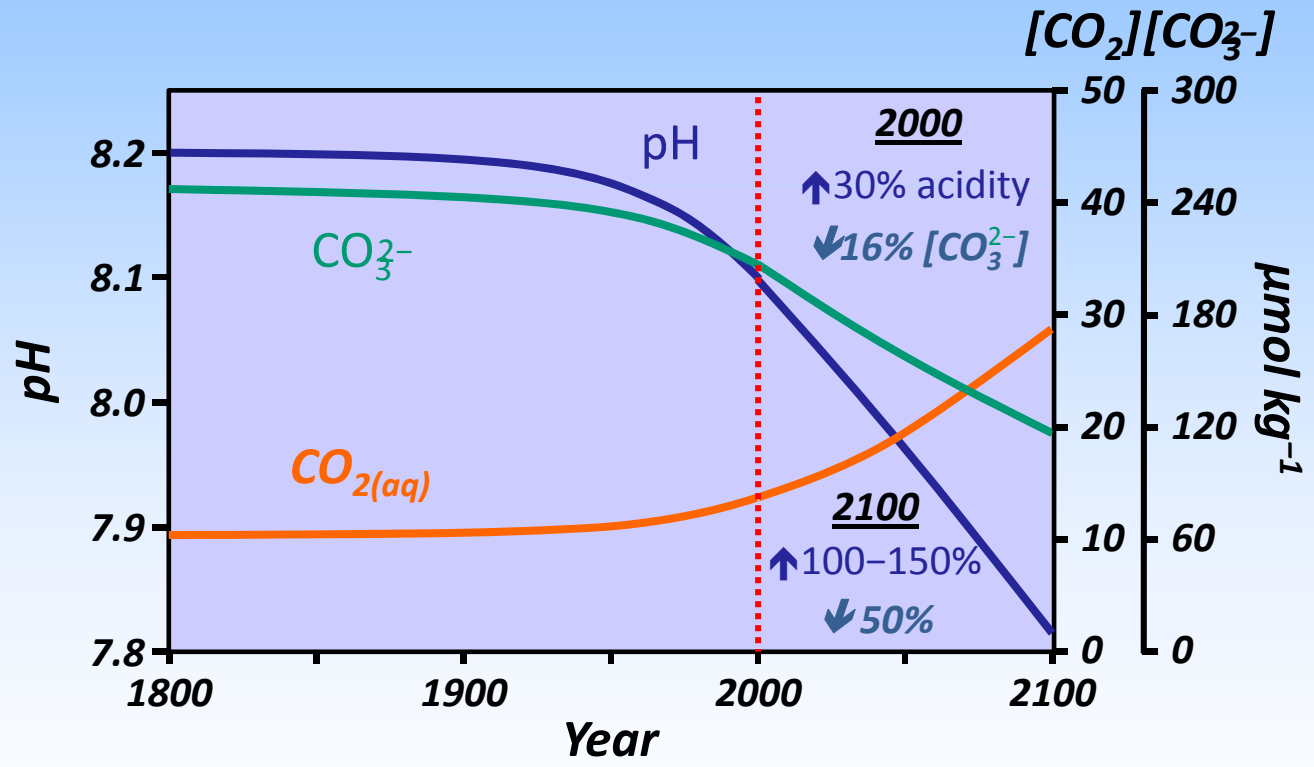
NSF

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

Woods Hole Oceanographic Institution 1930

Ocean Acidification

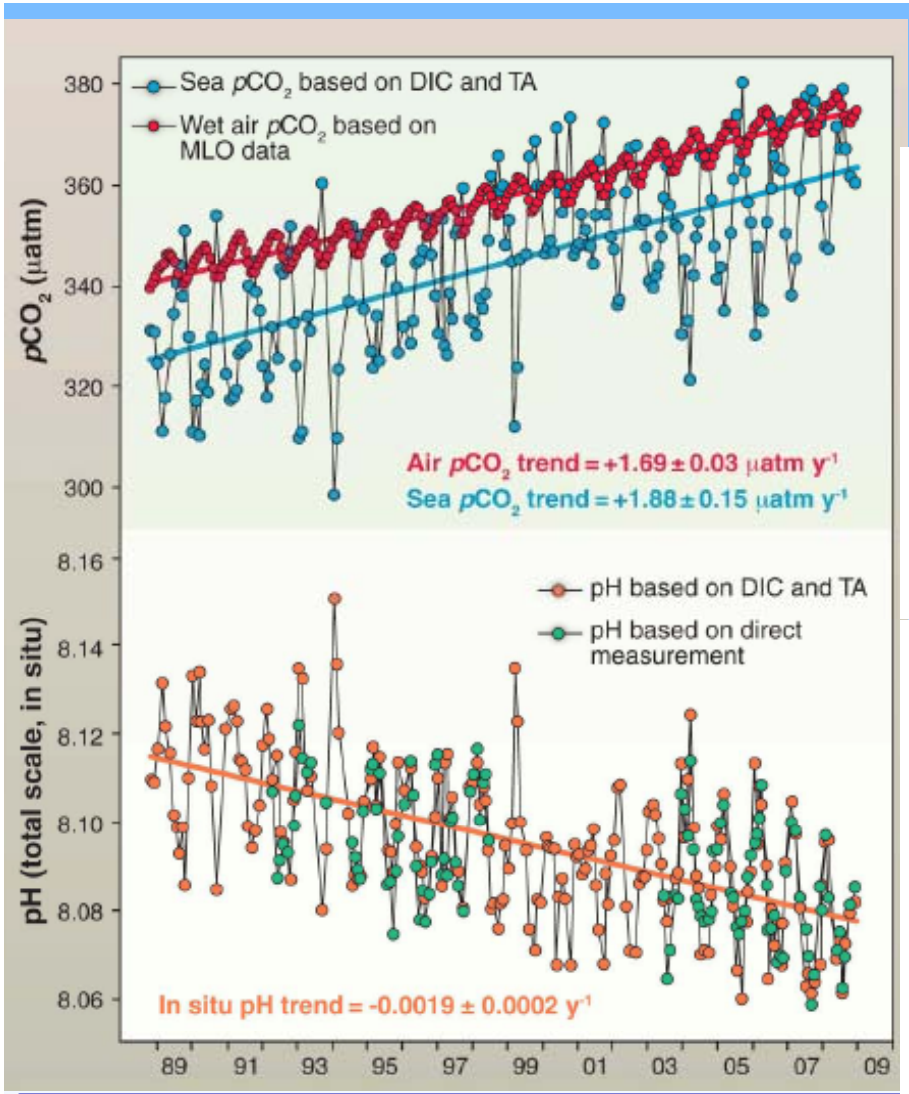
$$CO_2 + H_2O \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^- \Leftrightarrow 2H^+ + CO_3^{2-} + H_2O \Leftrightarrow 2H^+ + CO_3^{2-} \longrightarrow HCO_3^-$$



Wolf-Gladrow et al. (1999)

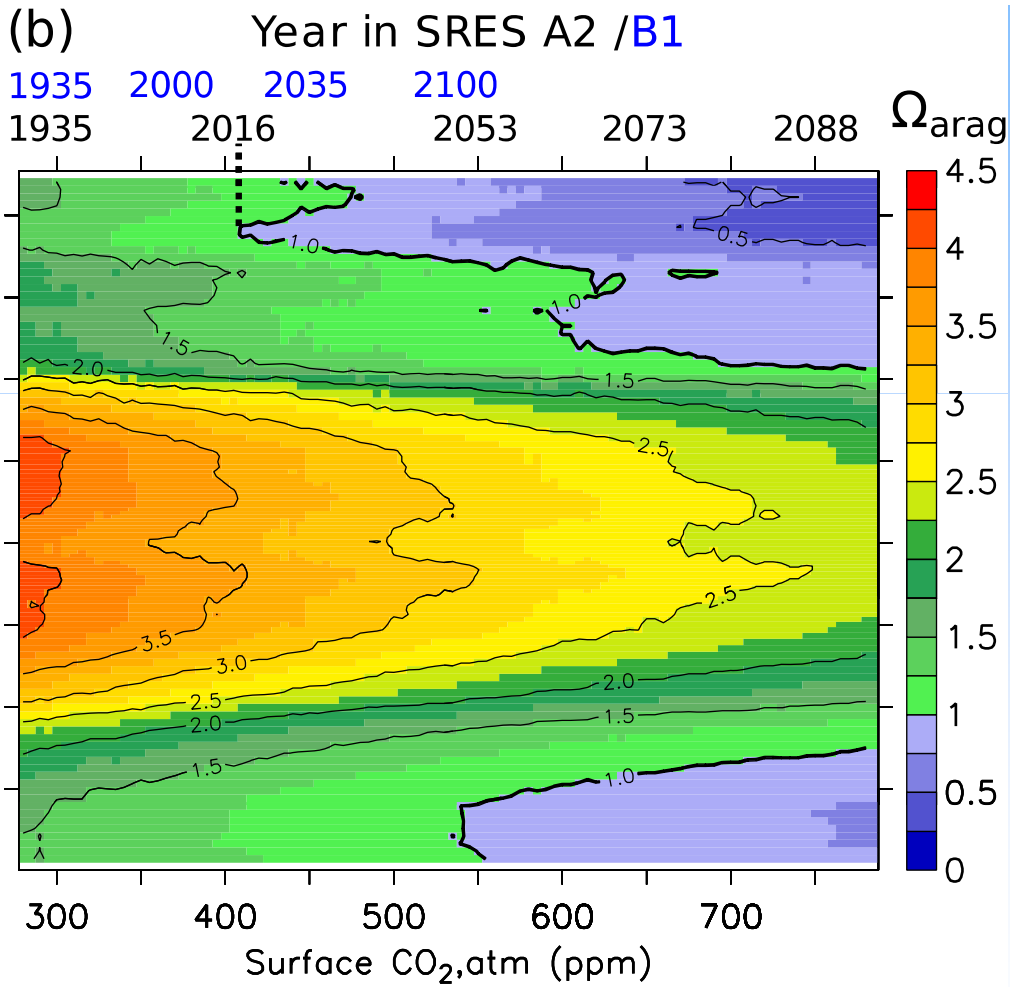
WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Ocean Acidification



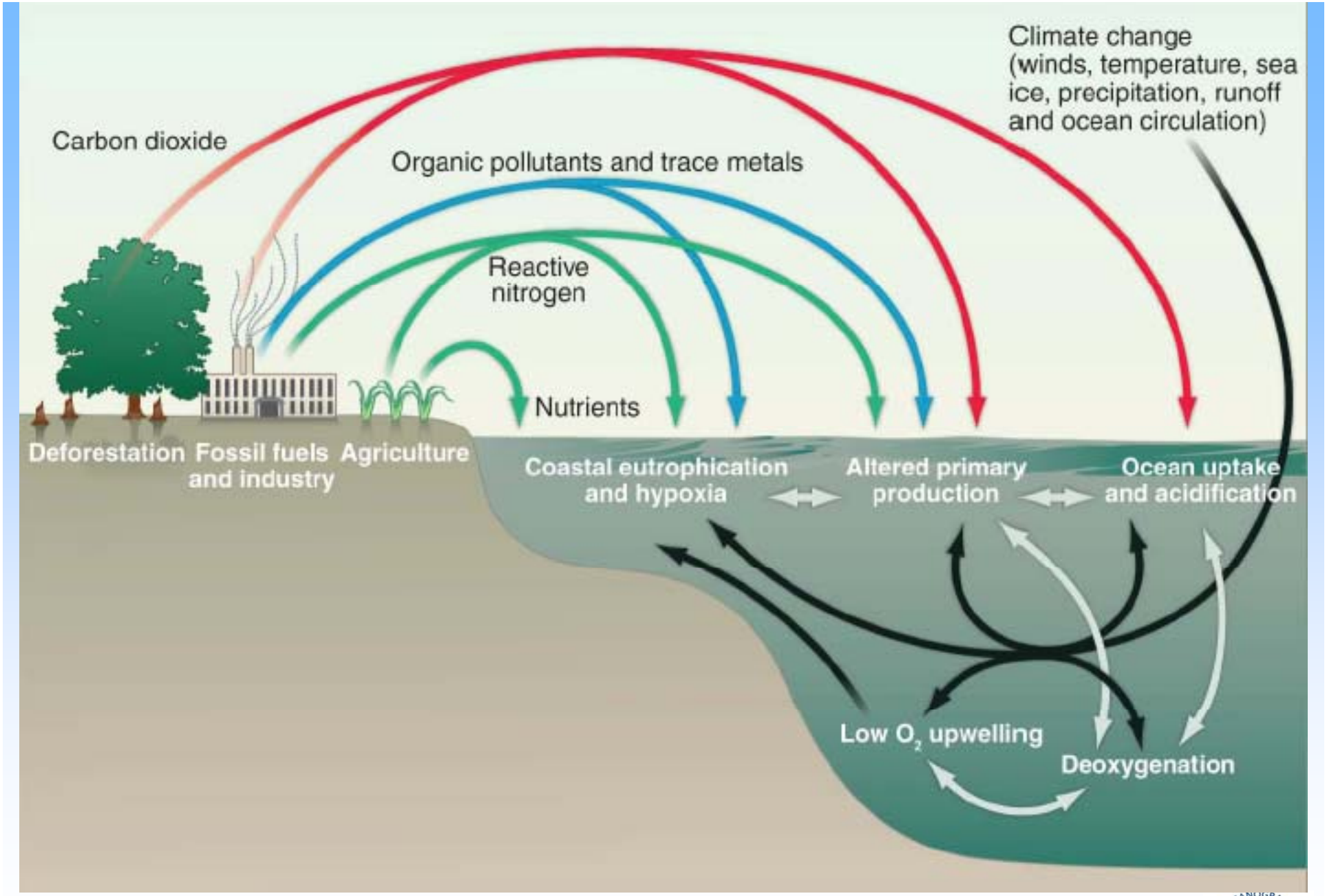
-Rising CO_2; declining pH & $CaCO_3$ saturation state
-Polar waters undersaturated for aragonite by mid-century

$CaCO_3$ Saturation State (aragonite)



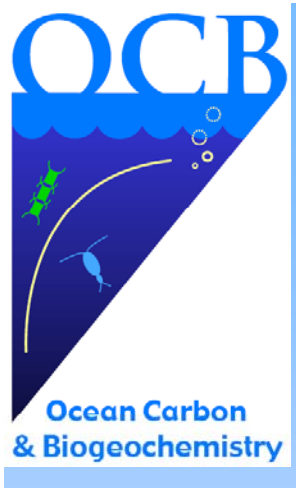
Doney et al. Ann. Rev. Mar. Sci. 2009; Dore et al. PNAS 2009; Steinacher et al. Biogeosciences 2009

1930



Doney, Science (2010); Science Special Section on Oceans

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930



Overarching OCB Scientific Themes

- Oceanic uptake and release of atmospheric CO_2 and other greenhouse gases
- Climate sensitivities of biogeochemical cycles and interactions with ecosystem structure

Current Research Priorities Most Relevant to CLIVAR

- Ocean carbon uptake and storage
- Ocean acidification
- Expanding low oxygen zones
- Climate sensitivities of and change in ecosystem structure & associated impacts on biogeochemical cycles

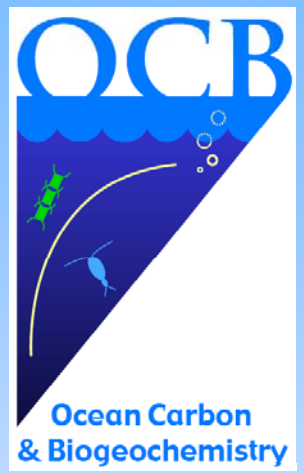
Int. CLIVAR Imperatives (2010-2014)

-Anthropogenic climate change
-Decadal variability, predictability & prediction
-Intraseasonal/seasonal predictability & prediction
-Earth system models (atm. & ocean components)
-Data synthesis & analysis
-Ocean observing system

Relevant U.S. CLIVAR Scientific Topics

- Atlantic meridional overturning circulation
- Deep ocean hydrography
- Ocean data Analysis/reanalysis
- Decadal variability/predictions
- Climate Process Teams (CPTs)
- Southern Ocean
- Carbon & marine ecosystems

Overlapping OCB-CLIVAR Science



- Impact of changes in circulation & heat content on carbon sources/sinks
- Coupled physical/biogeochemical processes governing future ocean heat, carbon sources/sinks & ecosystem structure
- Responses of ocean carbon sources/sinks to anthropogenic forcing

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Satellite Ocean Color

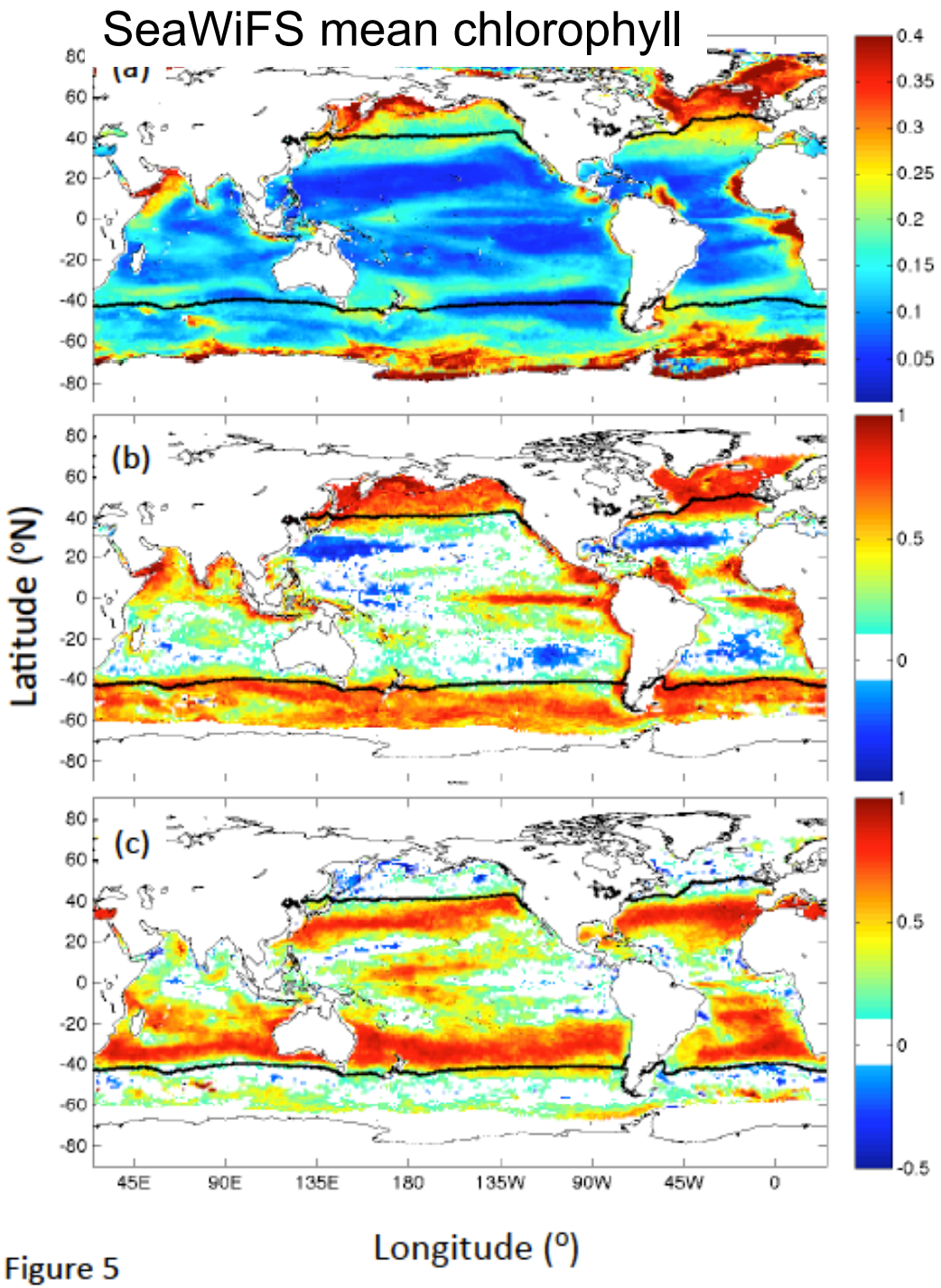
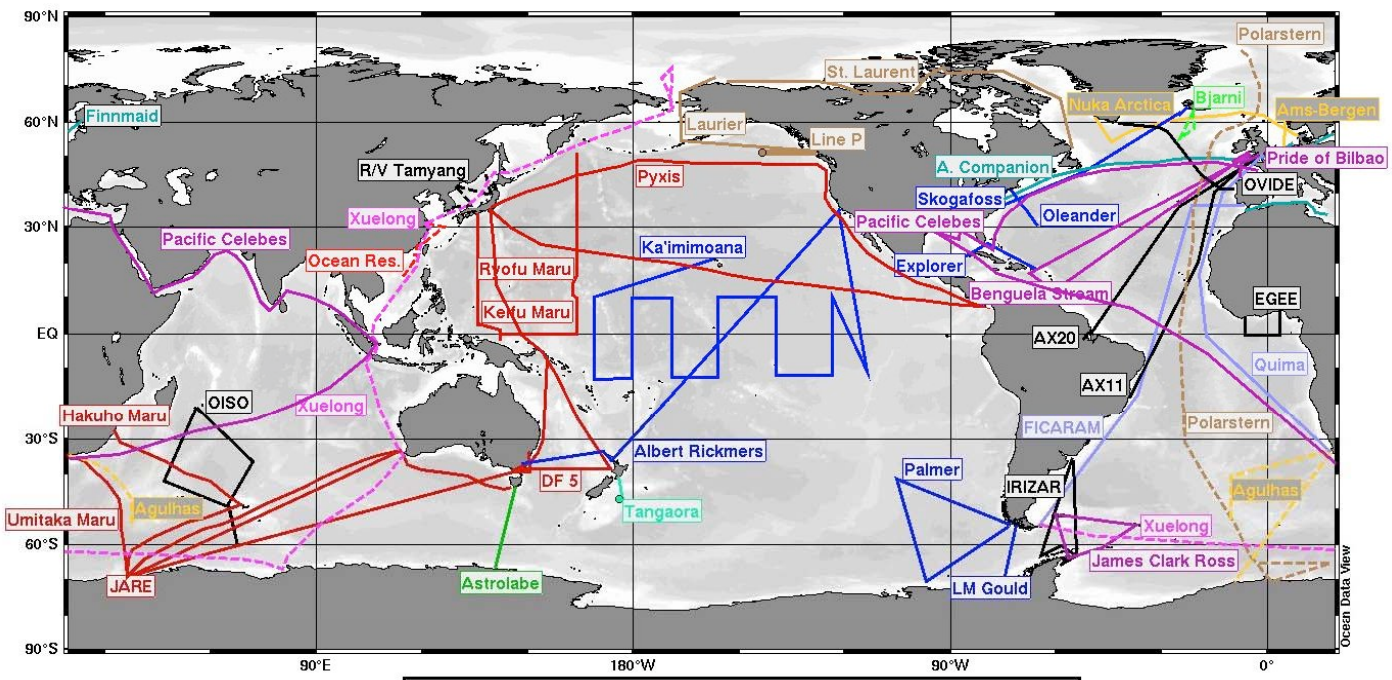
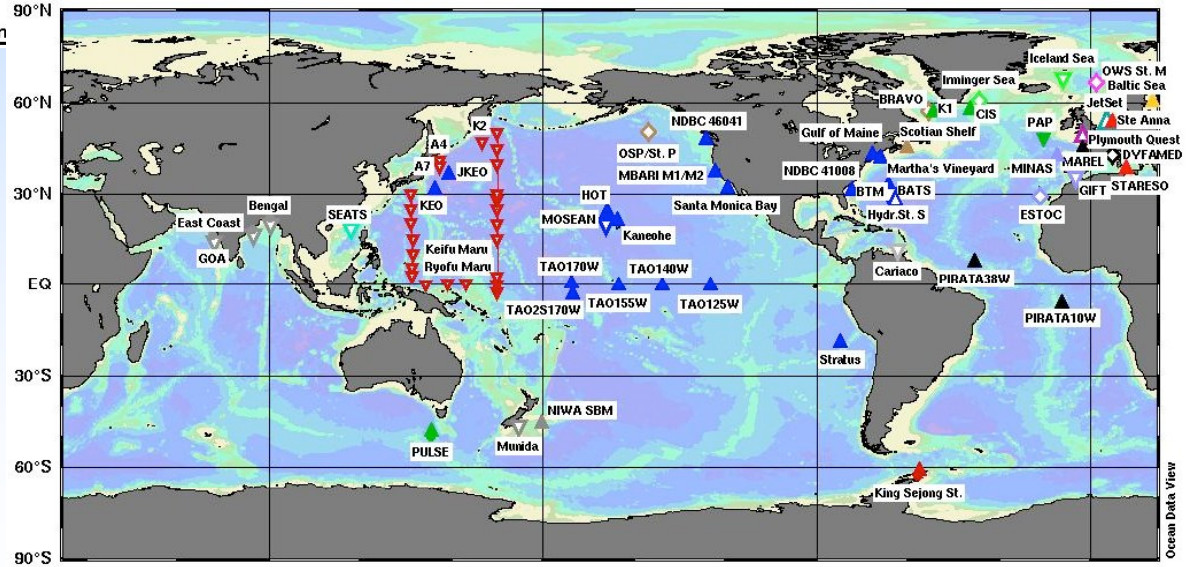
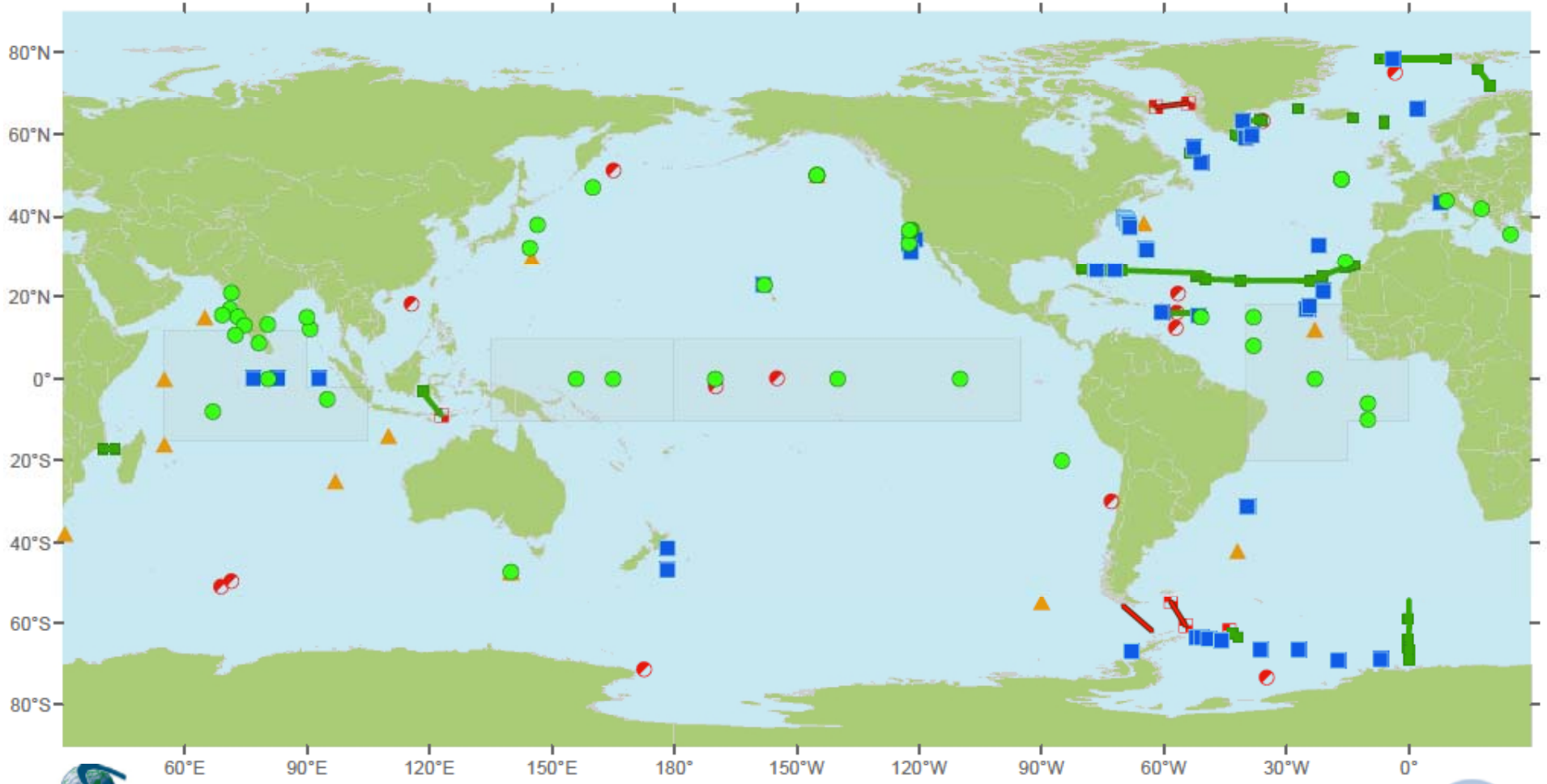


Figure 5

Siegel, Behrenfeld, McClain et al. in prep.


90°N
60°N
30°N
EQ
30°S
60°S
90°S
90°E
180°W
90°W
0°
Finnmaid
R/V Tamyang
Xuelong
Pacific Celebes
Ocean Res.
Ryofu Maru
Keifu Maru
Pyxis
Laurier
St. Laurent
Line P
Polarstern
Nuka Arctica
Bjarni
Ams-Bergen
Pride of Bilbao
A. Companion
OVIDE
Skogafoss
Oleander
Pacific Celebes
Ka'imimoana
Explorer
Benguela Stream
EGEE
AX20
AX11
Quima
FICARAM
Polarstern
Agulhas
Xuelong
James Clark Ross
LM Gould
Palmer
IRIZAR
Albert Rickmers
DF 5
Tangaora
Astrolabe
JARE
Umitaka Maru
Hakuho Maru
OISO
Xuelong
Agulhas
Ocean Data View
US
France
Canada
New Zealand
Japan
Germany
Spain
China
UK
Iceland


90°N
60°N
30°N
EQ
30°S
60°S
90°S
90°E
180°W
90°W
0°
Iceland Sea
Irminger Sea
OWS St. M
Baltic Sea
JetSet
Ste Anna
Plymouth Quest
DYFAMED
MAREL
STARESO
GIFT
BRAVO
K1
CIS
PAP
NDBC 46041
Gulf of Maine
Scotian Shelf
OSP/St. P
MBARI M1/M2
NDBC 41008
Martha's Vineyard
MINAS
BTM
BATS
Hydr.St. S
ESTOC
Santa Monica Bay
HOT
Kaneohe
MOSEAN
K2
A4
A7
JKEO
KEO
SEATS
Bengal
East Coast
GOA
Keifu Maru
Ryofu Maru
TAO170W
TAO140W
TAO155W
TAO125W
TAO2S170W
Cariaco
PIRATA38W
PIRATA10W
Stratus
NIWA SBM
Munida
PULSE
King Sejong St.
Ocean Data View
Triangles - Surface Measurements
Inv. Triangles - Water Column Measurements
Filled - Buoy, Tower
Empty - Ship, Platform
US
Canada
Spain
Iceland
Venezuela
Japan
France
Norway
UK
Sweden
Germany
Belgium
Taiwan
India
Australia
New Zealand
Netherlands
Korea
Proposed



OceanSITES Vision Map 2009 - All Planned Sites

OceanSITES Moorings and Observatories (91)

- OPERATING Real time data (44)
- OPERATING Delayed Mode data (47)

Planned or Discontinued (32)

- PLANNED Real time data (15)
- PLANNED Delayed Mode data (0)
- DISCONTINUED (17)

Transport sites (19)

- OPERATING (16)
- DISCONTINED (3)
- Transport Stations
- Discontinued

Note: This status was based on information provided in 2009.