Ocean Biogeochemistry (C, O_2, N, P)
Achievements and challenges

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Using input from the following CWP:

Hood; *Ship-based Repeat Hydrography*

Monteiro; *A global sea surface carbon observing system*

Feely; *An Observational Network for Ocean Acidification*

Gruber; *Adding Oxygen to Argo*

Claustre; *Bio-optical profiling floats*

Byrne; *Sensors and Systems for Marine CO2 System Variables*

Adornato; *In Situ Nutrient Sensors*

Borges; *Carbon Dynamics in Coastal Oceans*

The future oceans: biogeochemical challenges

WGBU (2006)

Warming up,
Rising high,
Turning sour,
Getting deoxygenated

These drivers will stress marine biogeochemistry and ecosystems in a way that we only have begun to fathom.

Outline

1. Ocean carbon sink: Revelle's perpetual quest

   or why we still need VOS and a repeat hydrography program

2. Ocean acidification: The flip-side of the coin

   or why there is no free lunch

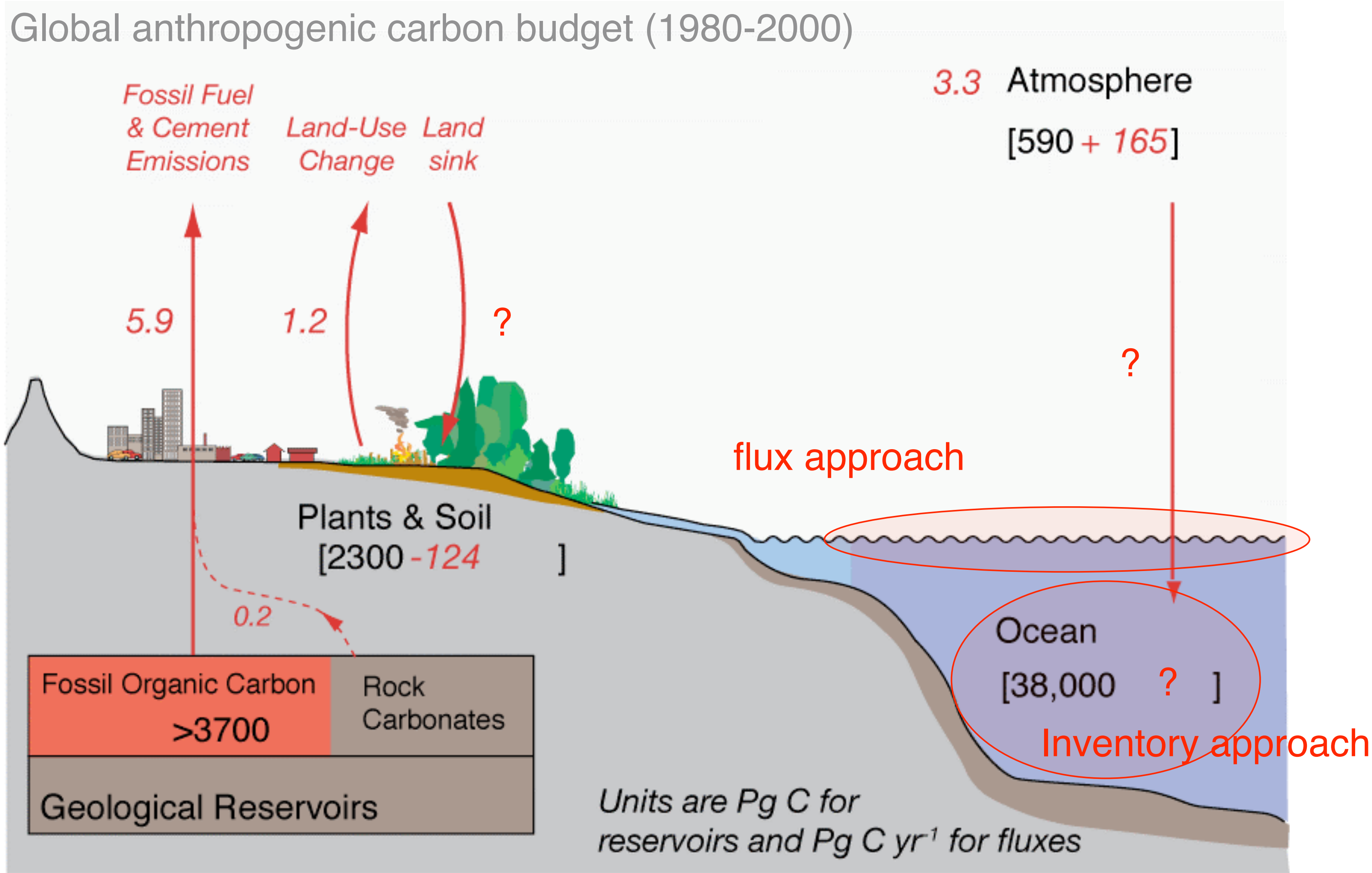
3. Ocean deoxygenation:

   or why we would like to add oxygen sensors on Argo

4. Toward an integrated observing system:

   or how should all of this work together?

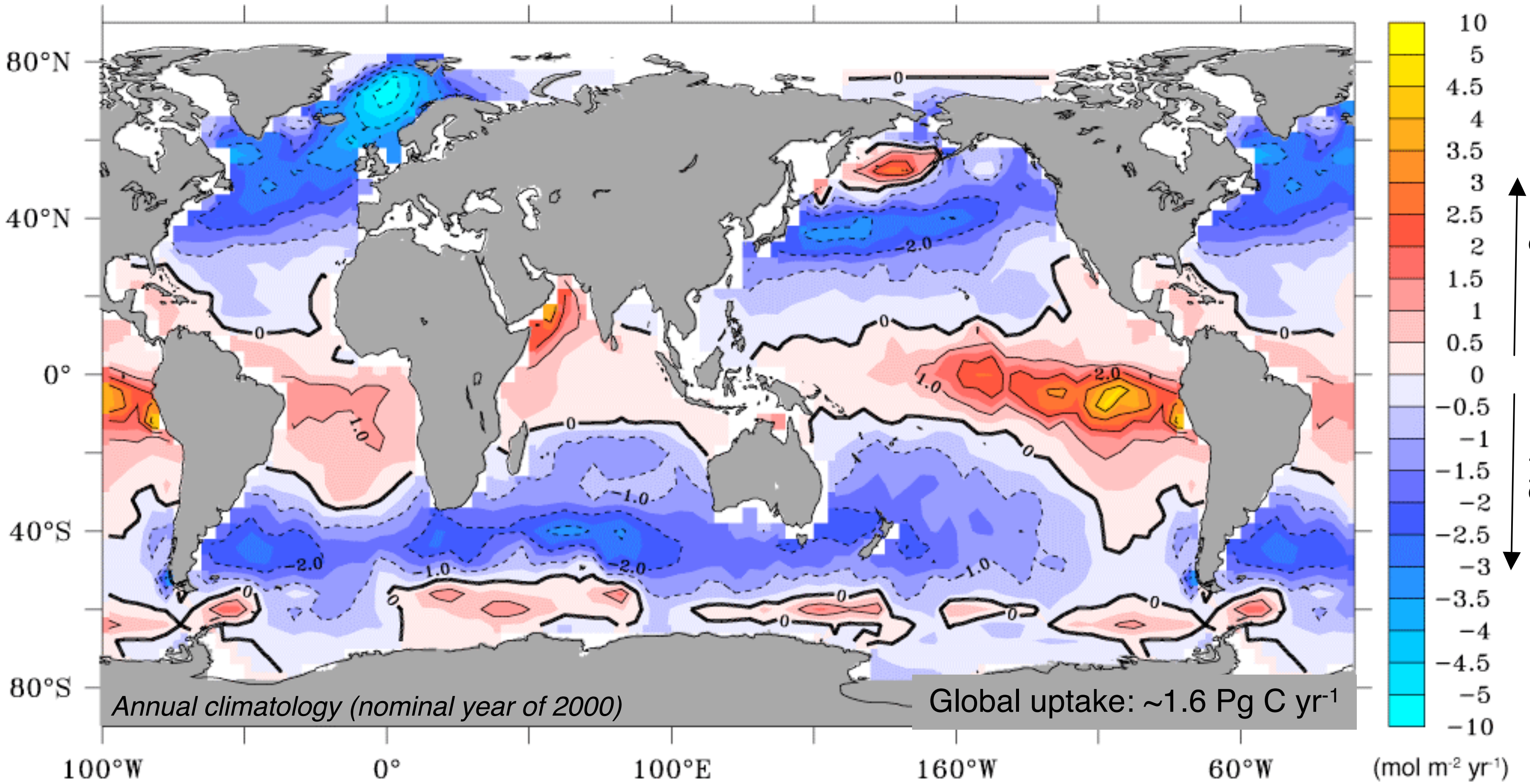
Revelle's perpetual quest for the ocean carbon sink



Sarmiento and Gruber (2006)

Flux approach: Oceanic Sources and Sinks for CO_2

Building on a surface pCO_2 observing system

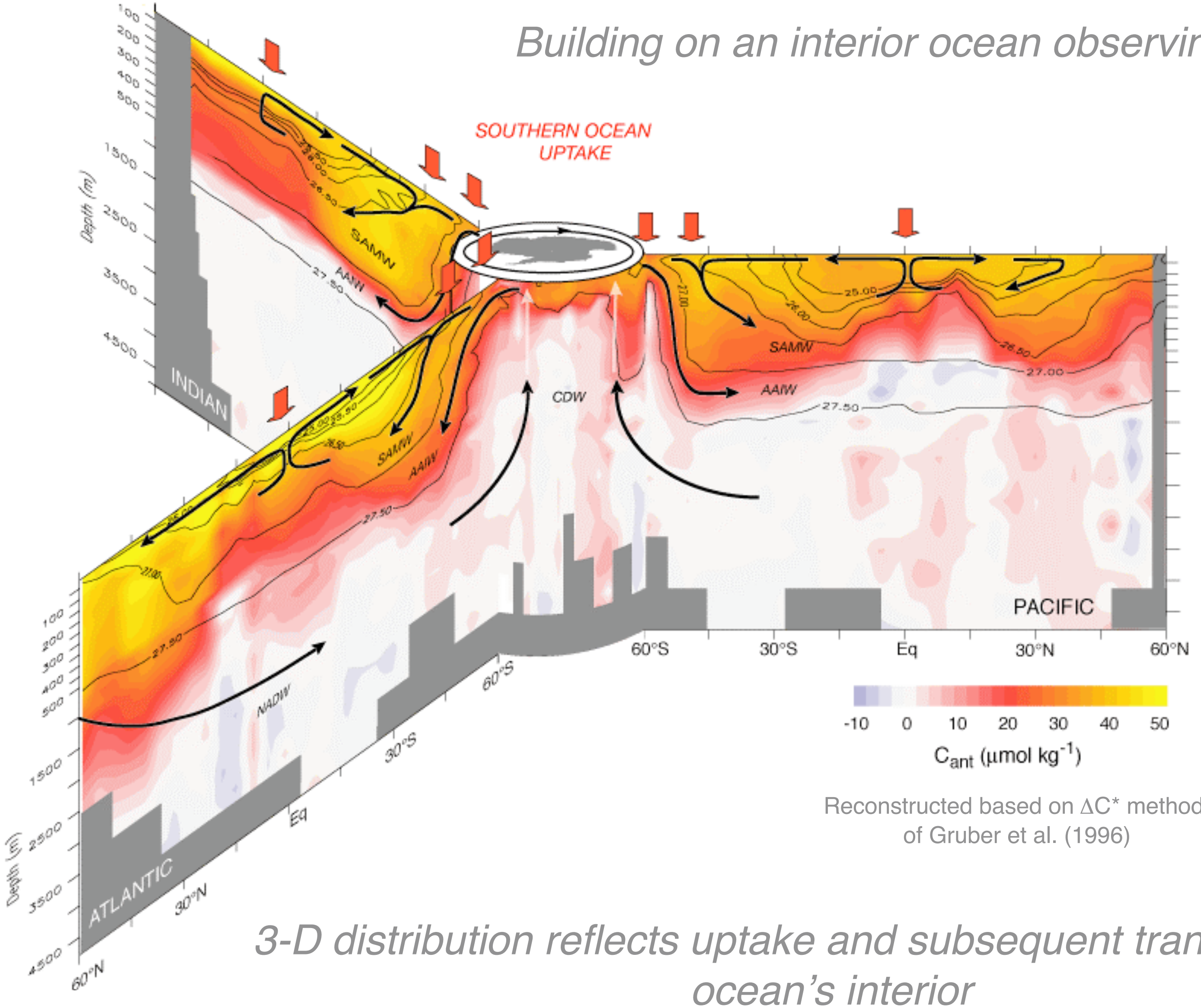


But flux estimates are still associated with substantial uncertainty and they are essentially limited to a time-mean view.

Takahashi et al. (2009)

Inventory approach: Distribution of anthropogenic CO_2

Building on an interior ocean observing system



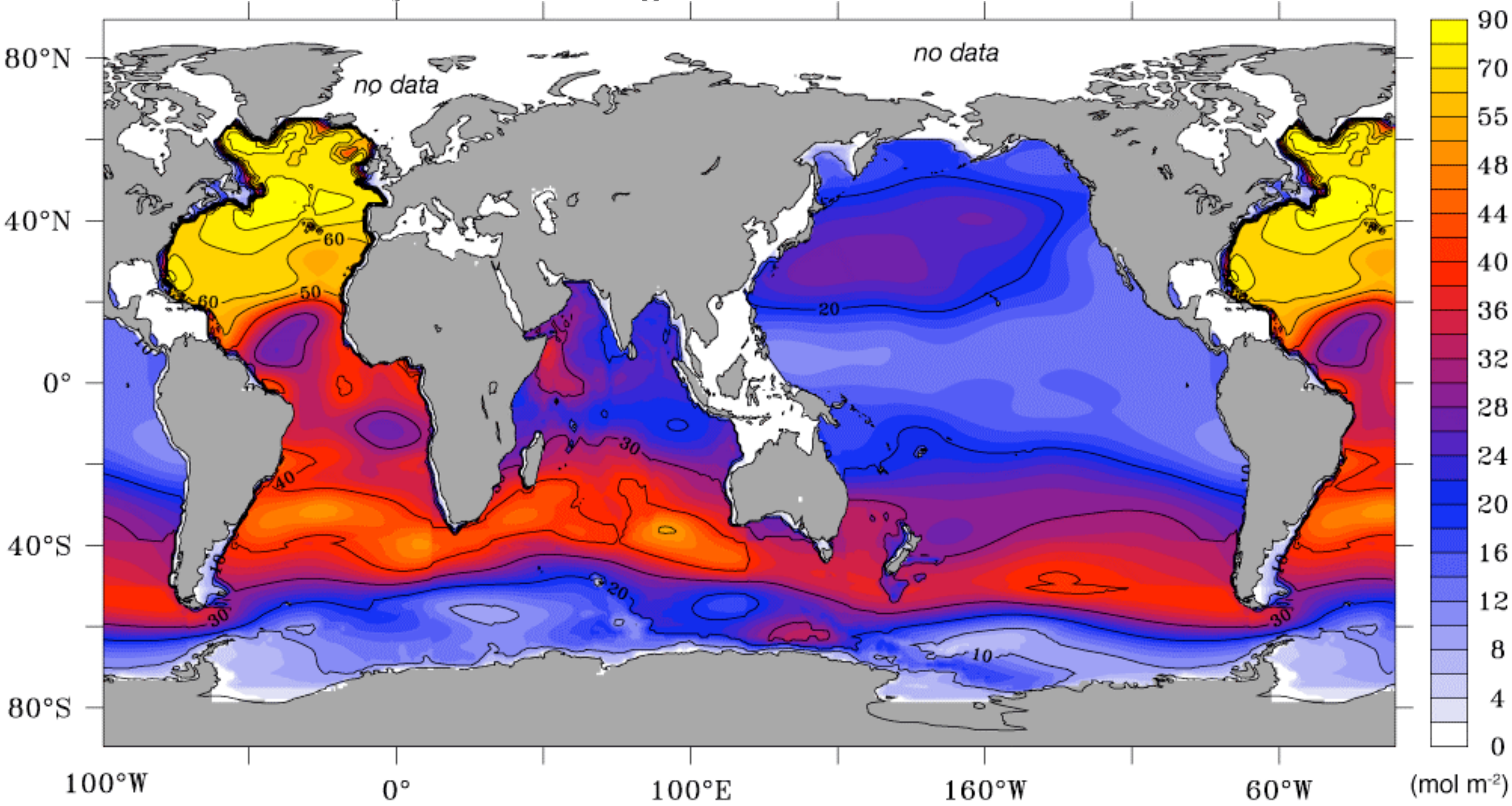
Reconstructed based on ΔC* method of Gruber et al. (1996)

3-D distribution reflects uptake and subsequent transport in the ocean's interior

Gruber et al. (2009)

Oceanic inventory for anthropogenic CO_2 (~1994)

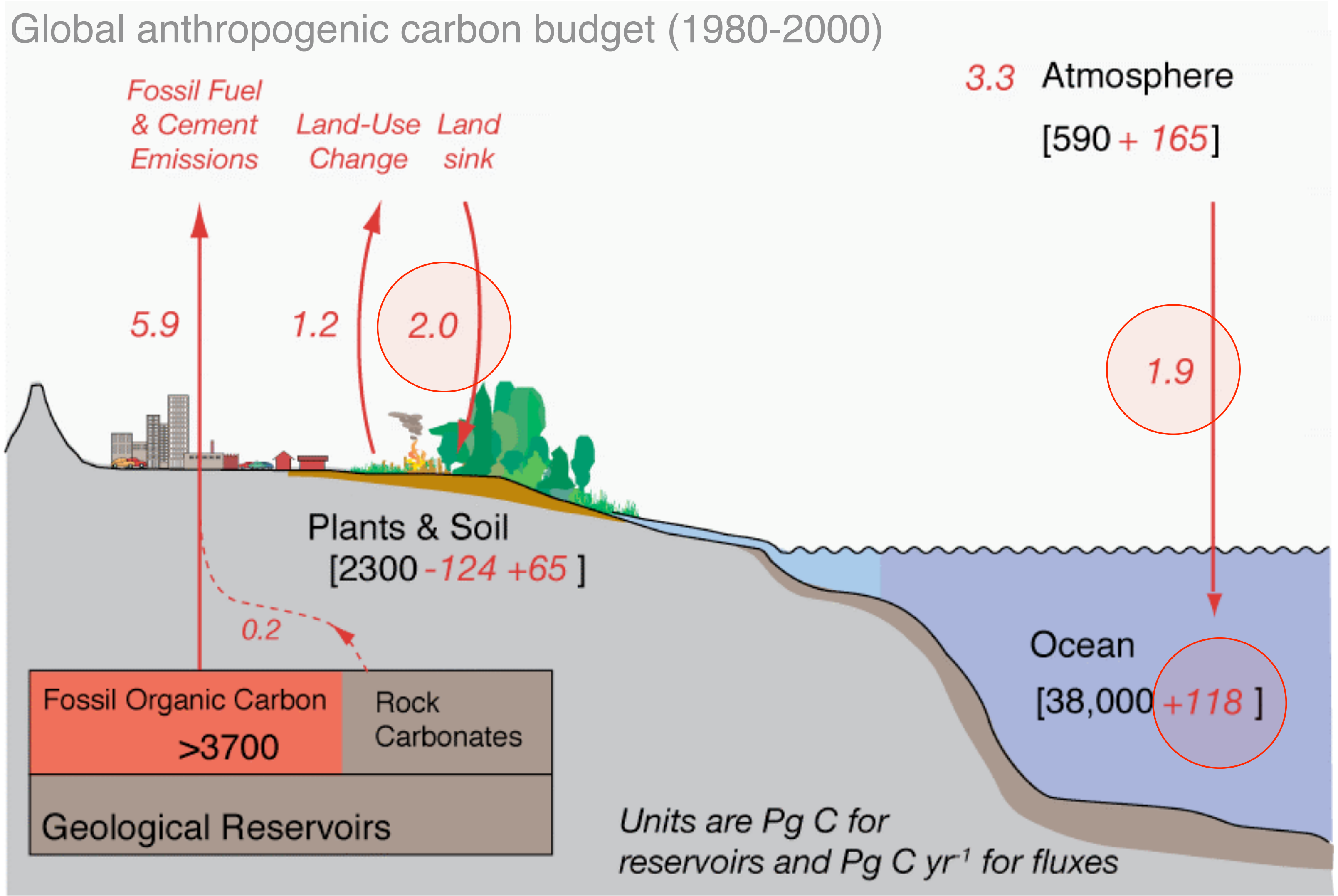
Global Inventory: 118 ± 19 Pg C



But this is based on a single set of surveys conducted in the late 1980s and early 1990s, i.e. we have very limited information about the temporal evolution of the oceanic uptake of anthropogenic CO_2

Data from Sabine et al. (2004)

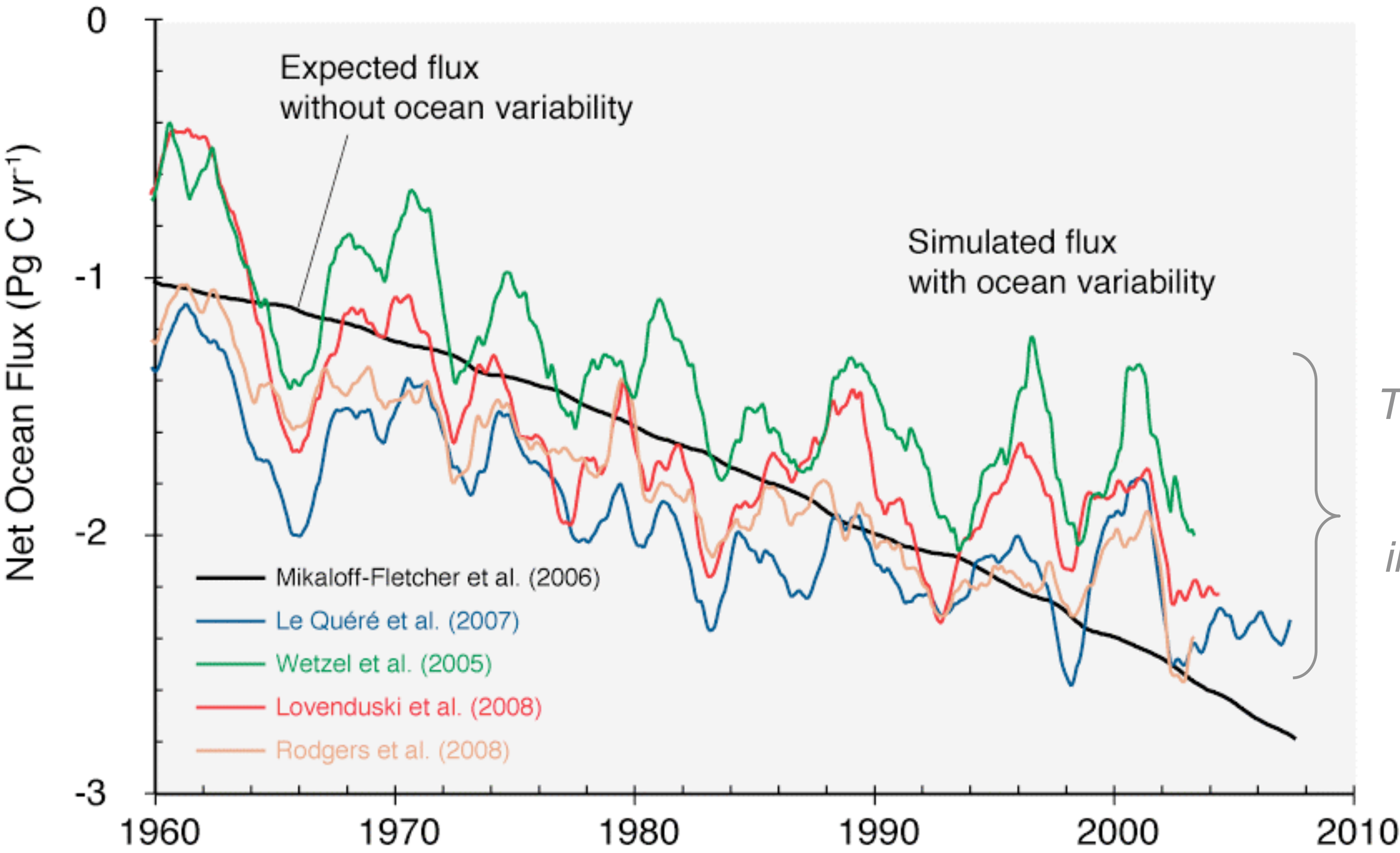
Revelle's perpetual quest for the ocean carbon sink resolved



Sabine et al. (2004); Sarmiento and Gruber (2006)

The changing ocean carbon sink

Models indicate a substantial deviation from the expected trend!

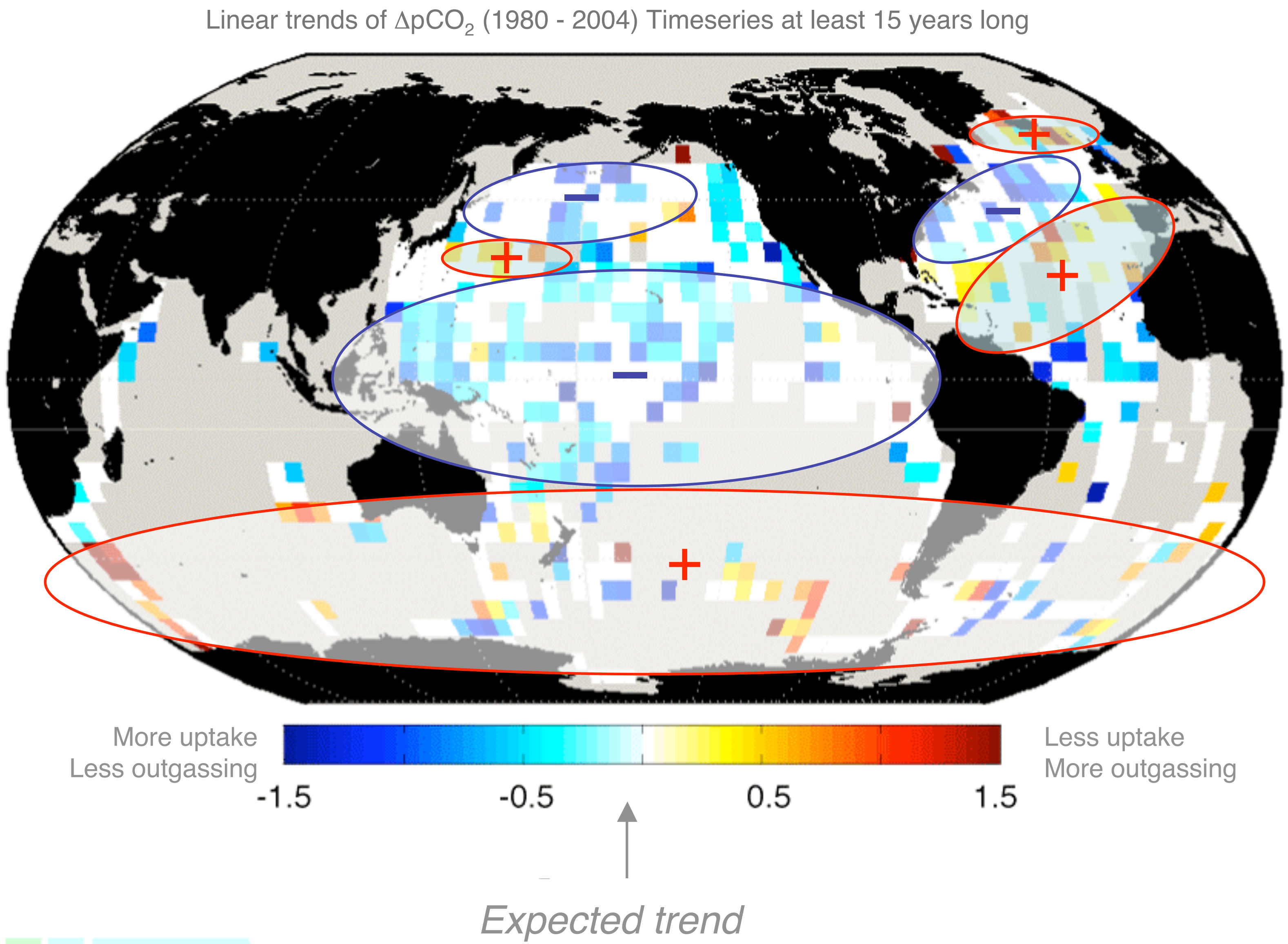


Trend away from expected increase in sink

Our ability to assess the validity of these trends with observations is very limited!

Sarmiento et al., in revision

Surface ocean trends - what can the pCO_2 data tell us?



Oberpriller and Gruber (in prep.)

Ocean carbon sink: Key objectives & challenges

Objective

The ocean is the only other reservoir besides the atmosphere to track the **fate of the anthropogenic CO_2**.

It is imperative to continue measuring the oceanic uptake of CO_2 and its subsequent storage in the interior!

Repeat Hydrography	Surface $p CO_2$ network	Timeseries stations	Carbon-Sensors

Challenge

Changing ocean circulation and biology make this task more demanding, but provide ample opportunity to turn the "noise" into a signal for understanding the impact of climate variability and change on the ocean carbon cycle.

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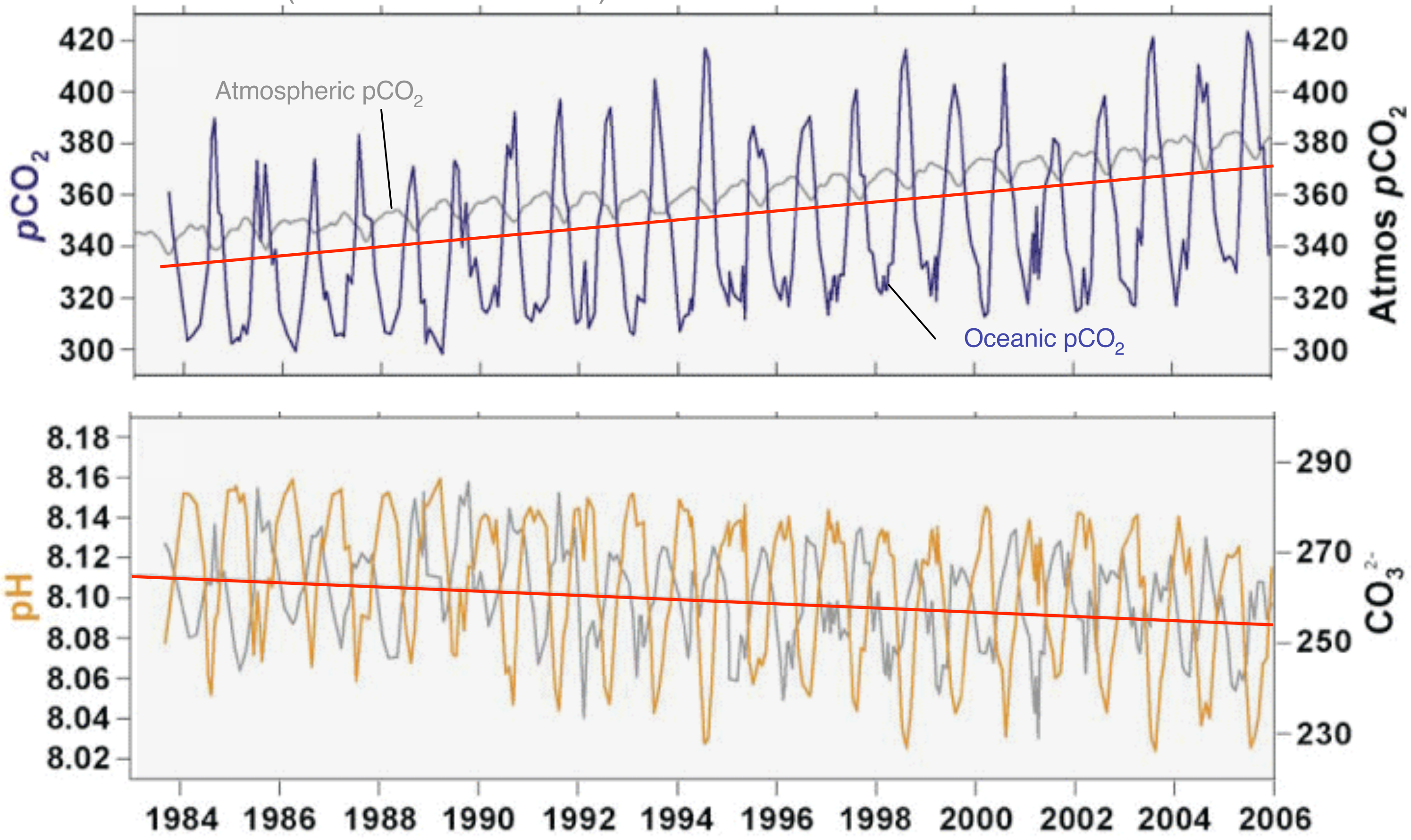
The flipside of the coin: Ocean acidification

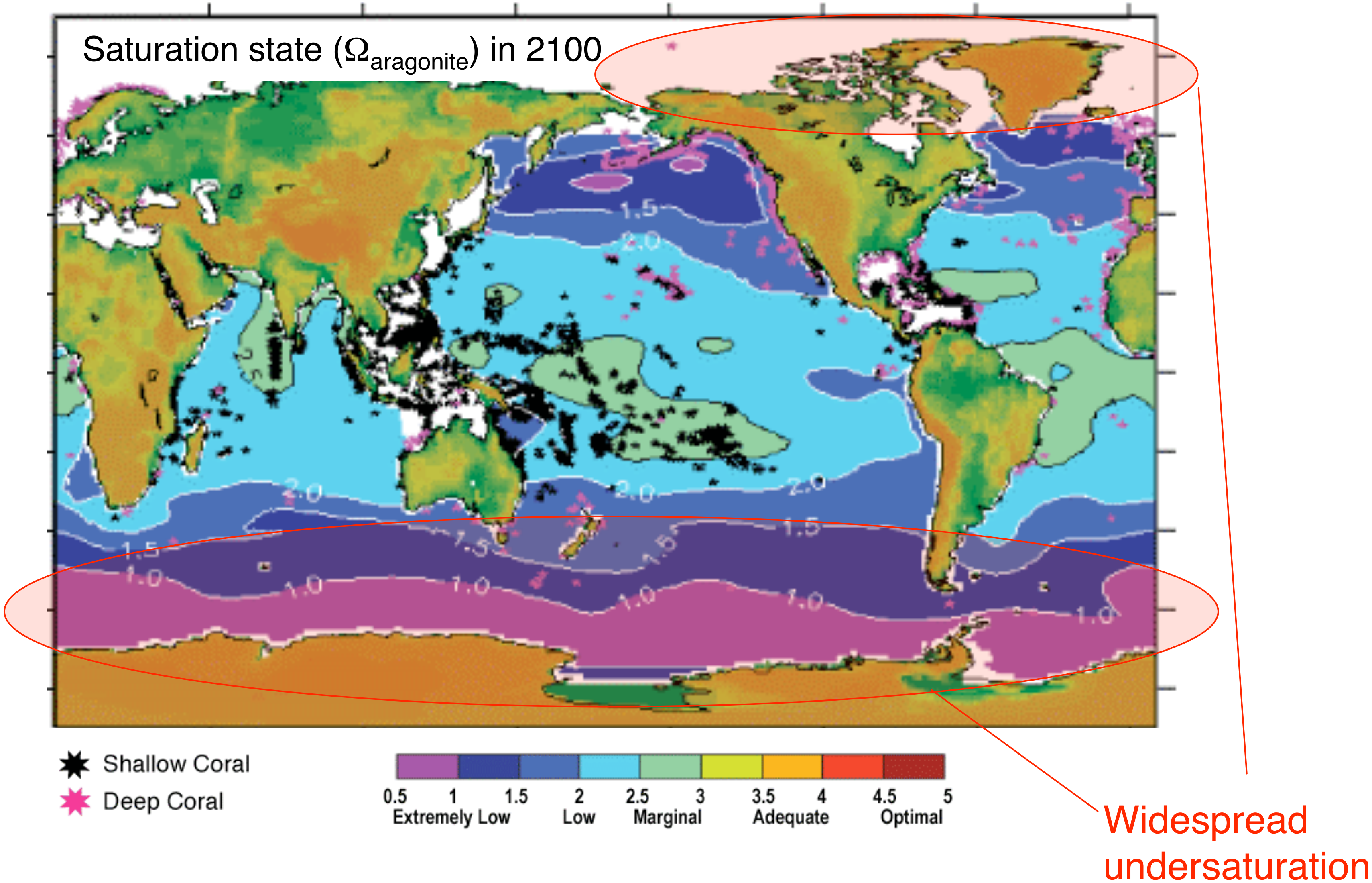
Bermuda (Station "S" & BATS)



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

Bates (1997)

The flipside of the coin: Ocean acidification



Large changes are looming ahead

Kleypas et al. (2006)

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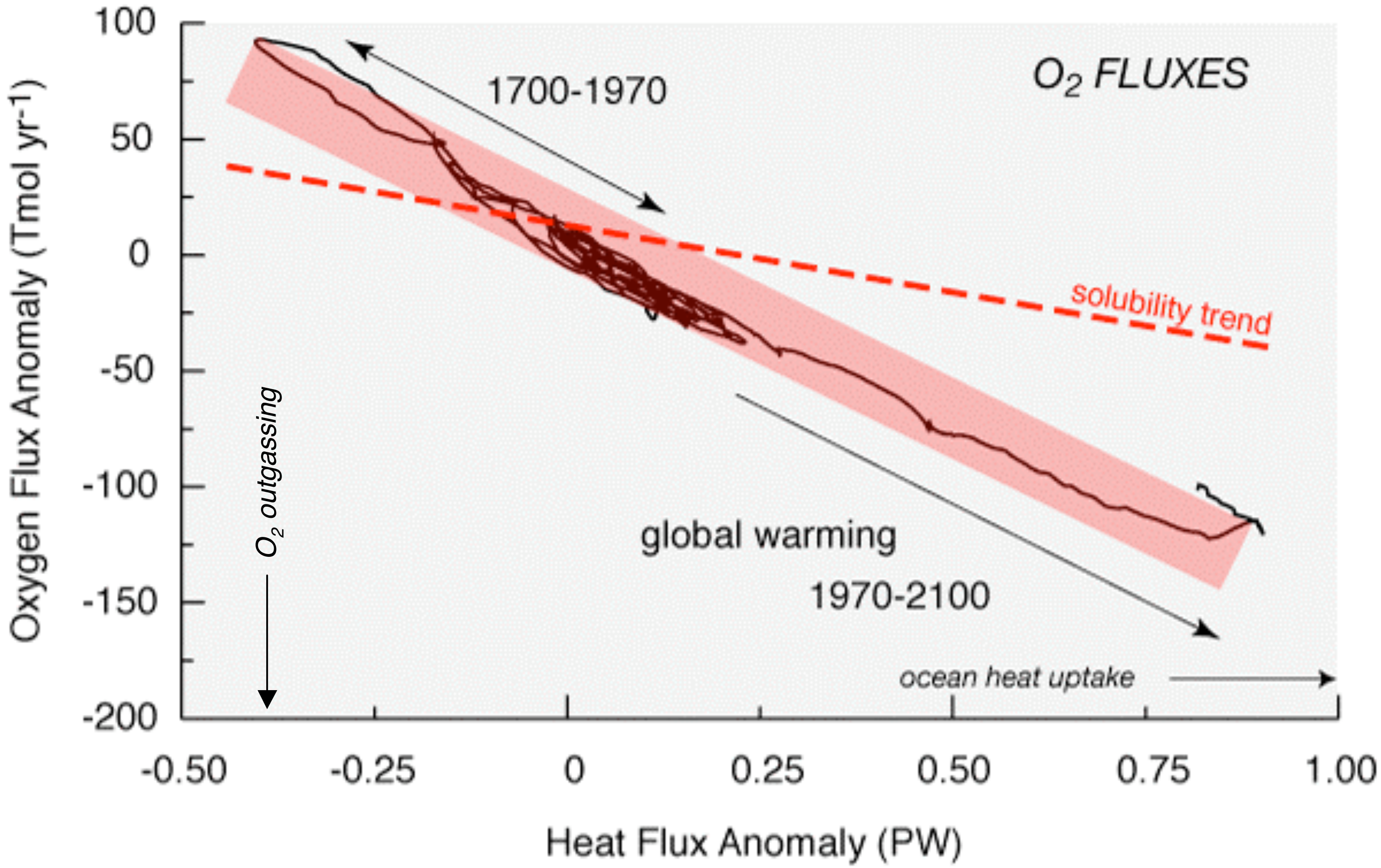
Ocean warming causes the ocean to deoxygenate

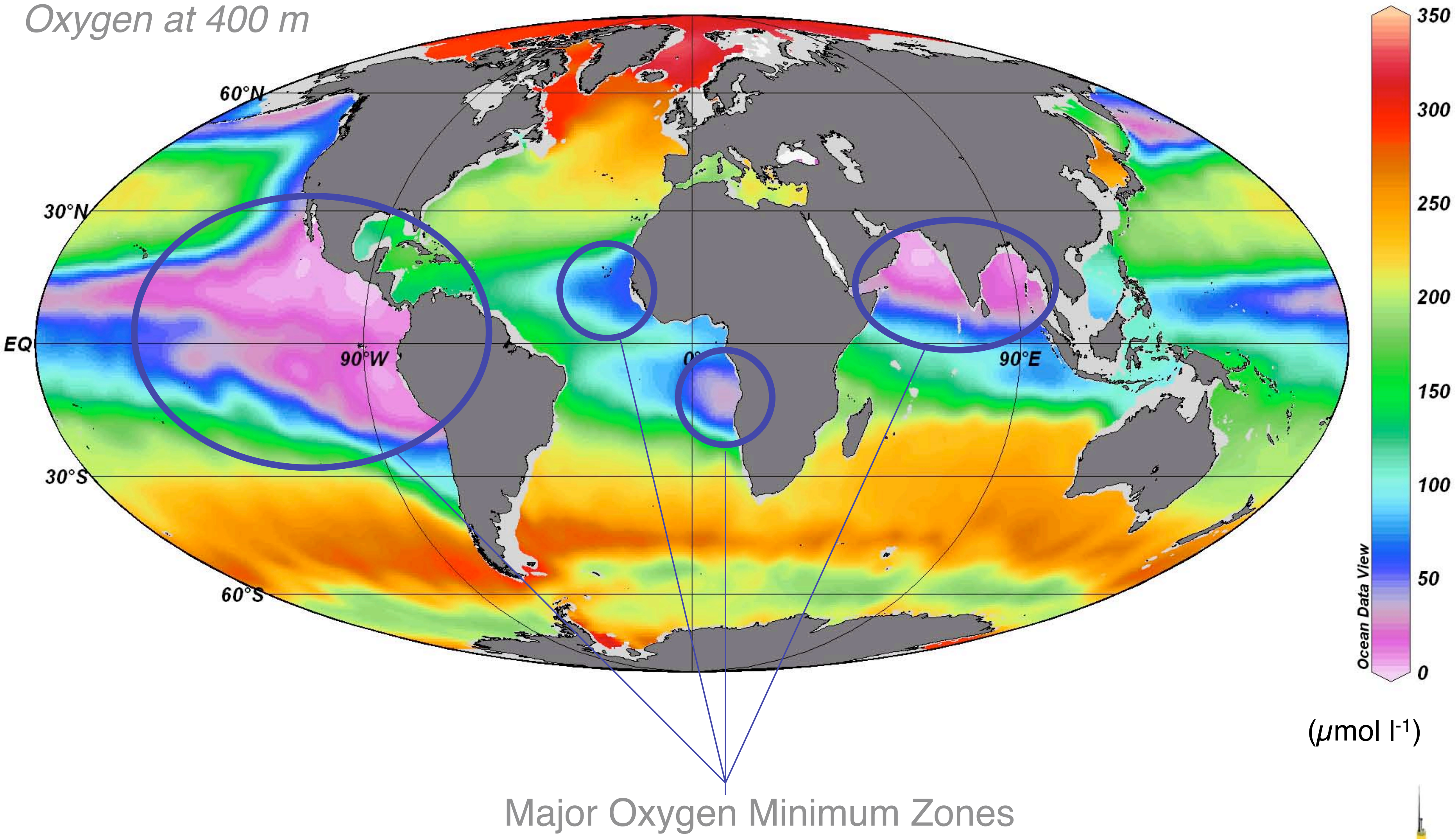


The ocean outgassing trend is larger than expected based on the solubility only

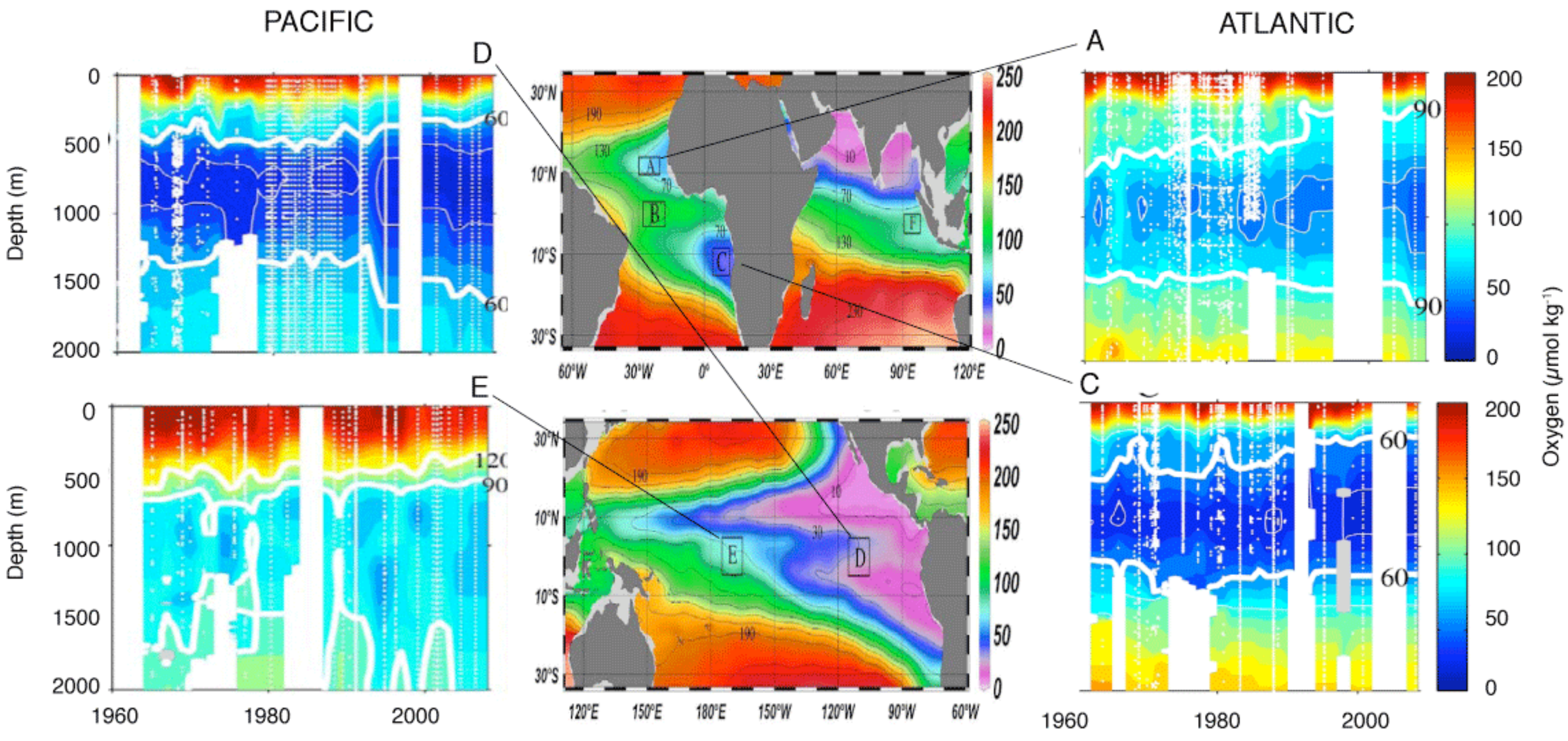
Based on Plattner et al. (2002)

Oxygen minimum zones may be particularly affected

Oxygen at 400 m



Evolution of oxygen content in O_2-minimum regions



Stramma et al. (2008)

Several O_2-minimum zones have lost O_2 in the recent decades, resulting in a expansion of the regions with hypoxia

Ocean deoxygenation: Key goals & challenges

The ocean will be *losing* substantial amounts of *oxygen* in response to ocean warming and stratification.

***Oxygen on Argo** provides a unique opportunity to document this loss and to develop strategies to mitigate its impact on ecosystems*

Oxygen on Argo provides also a window of opportunity to study seasonal dynamics of ocean production and export and many other things!

But, a large-scale pilot project still needs to be undertaken...

Putting it all together...

Warming up, Rising high, Turning sour, Getting deoxygenated

To address these coupled challenges, we need an integrated strategy:

Readiness/
Implementation

Repeat Hydrography

Maintain - enhance for acidification, variability

Surface observations (incl. time-series stations)

Maintain - enhance automatization

Argo-biogeochemistry

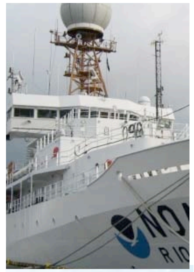
Develop - deploy in steps, starting with O_2

Sensor-development

Accelerate, particularly for carbon parameters

Model-data integration

Develop




The End.