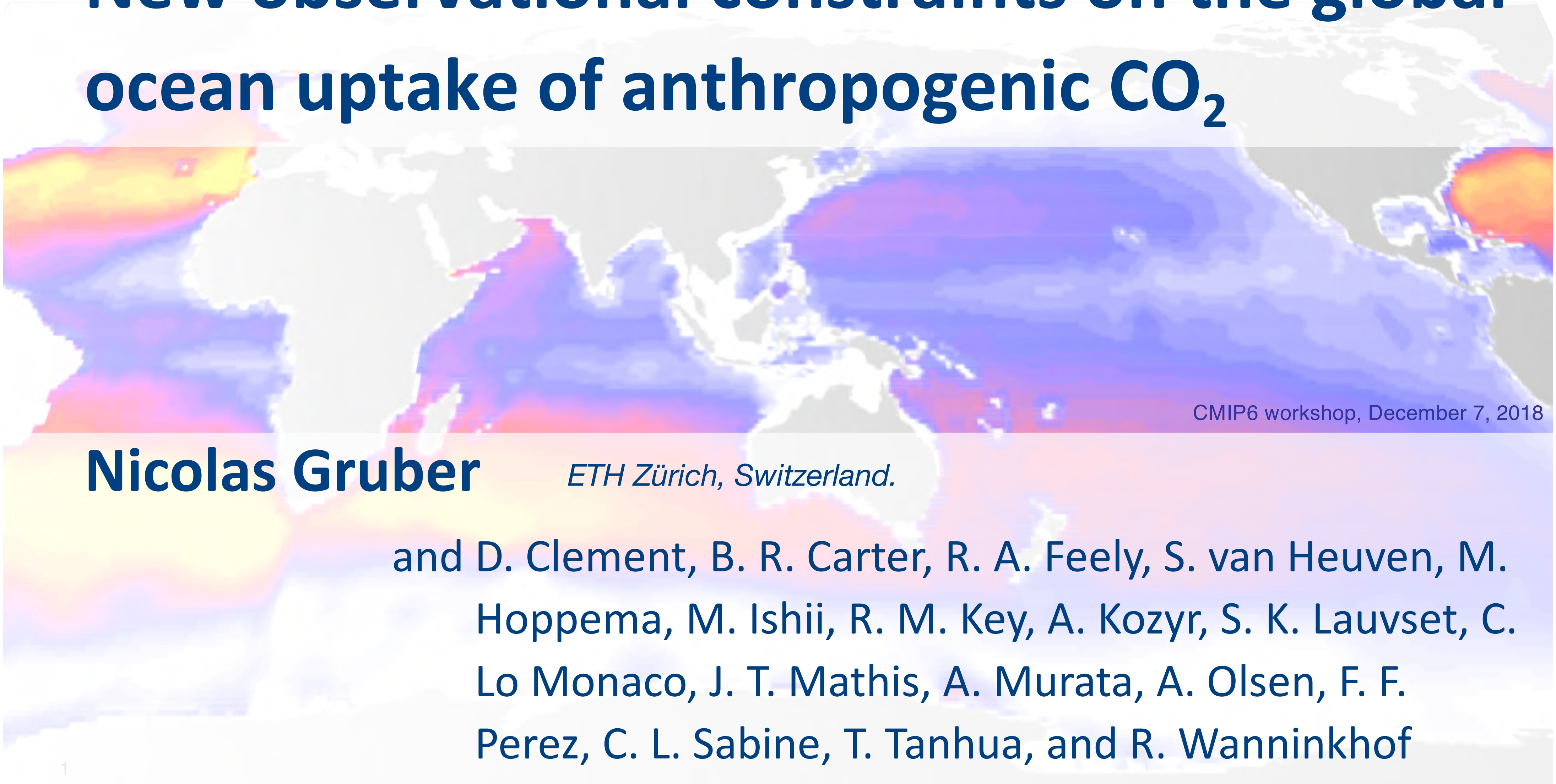
New observational constraints on the global ocean uptake of anthropogenic CO_2

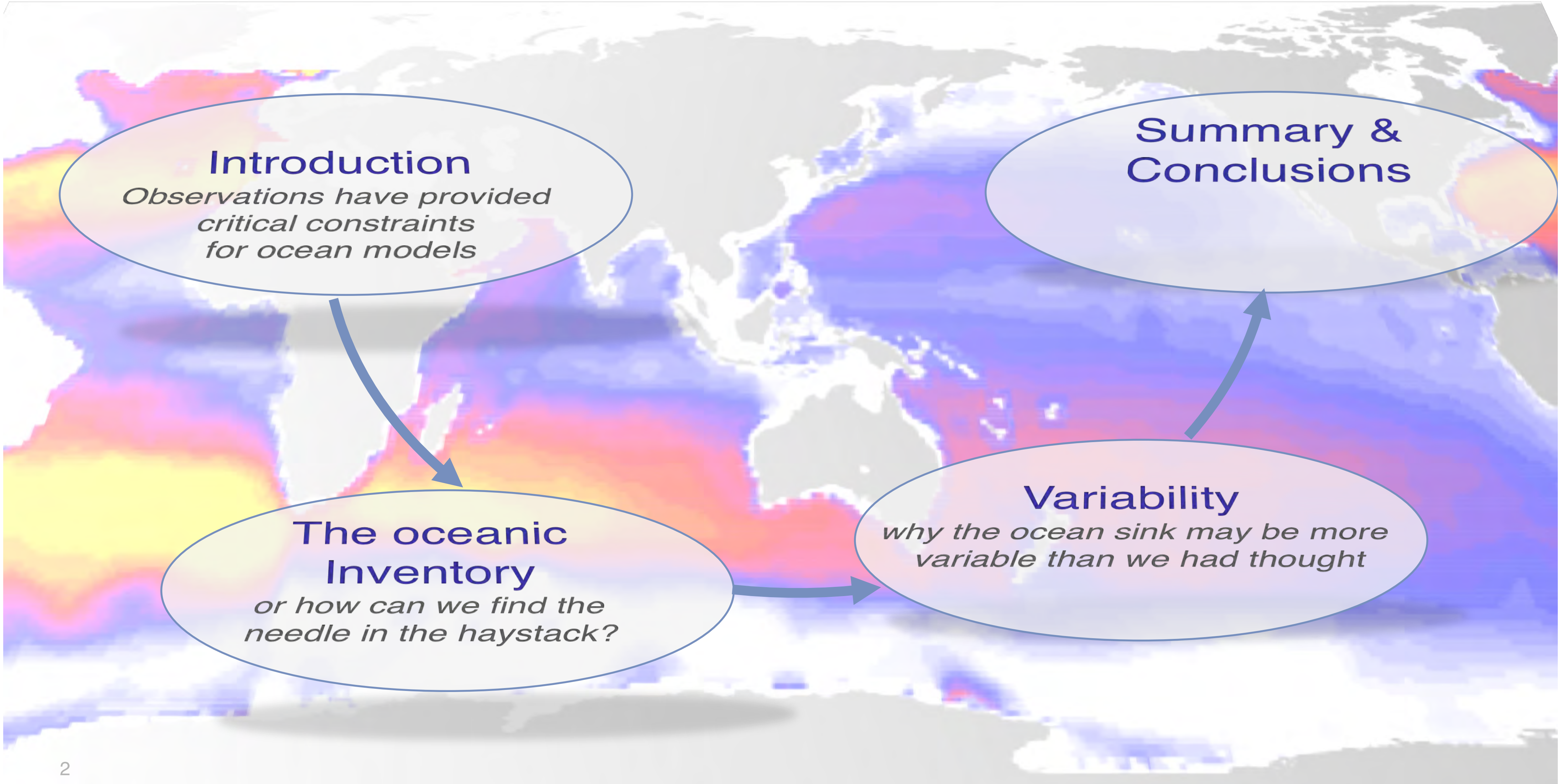


CMIP6 workshop, December 7, 2018

Nicolas Gruber *ETH Zürich, Switzerland.*

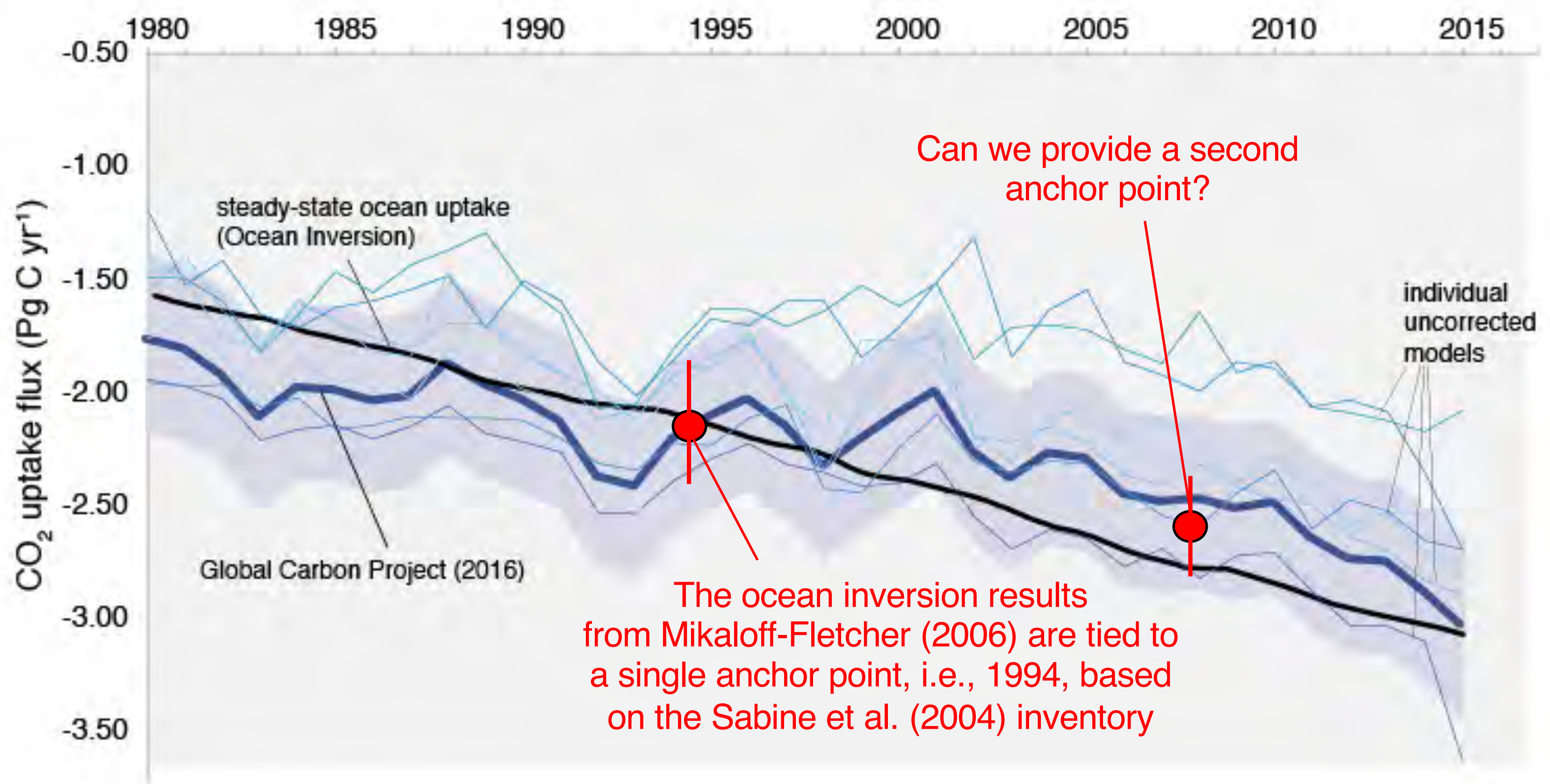
and D. Clement, B. R. Carter, R. A. Feely, S. van Heuven, M. Hoppema, M. Ishii, R. M. Key, A. Kozyr, S. K. Lauvset, C. Lo Monaco, J. T. Mathis, A. Murata, A. Olsen, F. F. Perez, C. L. Sabine, T. Tanhua, and R. Wanninkhof

Outline



Introduction
Observations have provided critical constraints for ocean models
The oceanic Inventory
or how can we find the needle in the haystack?
Variability
why the ocean sink may be more variable than we had thought
Summary & Conclusions

Ocean carbon cycle models tend to underestimate ocean uptake



At least those that contribute to GCP's annual budget

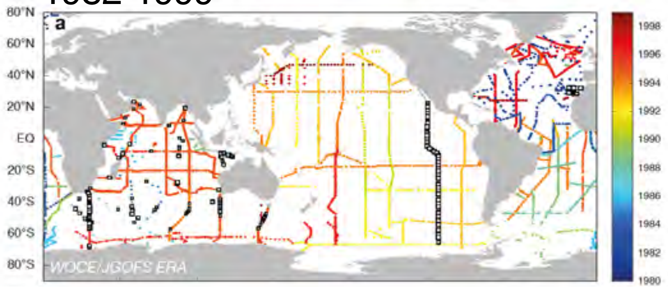
Current generation ocean carbon cycle models simulate an ocean uptake that is ^ is lower than the ocean inversion suggest

Redrawn from Le Quéré et al. (2017)

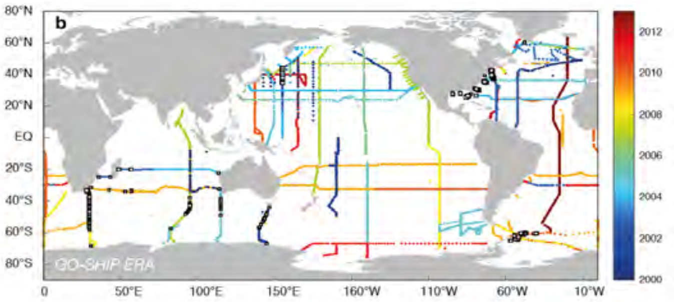
Dealing with sparse data…
requires sophisticated analysis and mapping methods

INTERIOR OCEAN DATA

1982-1999



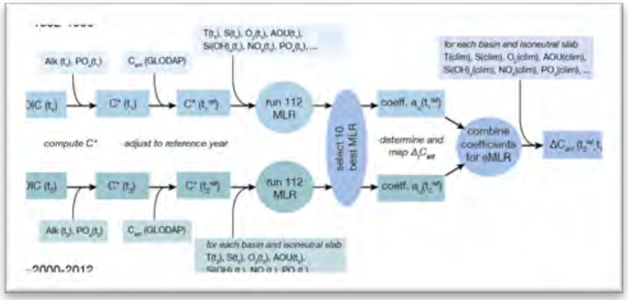
2000-2012



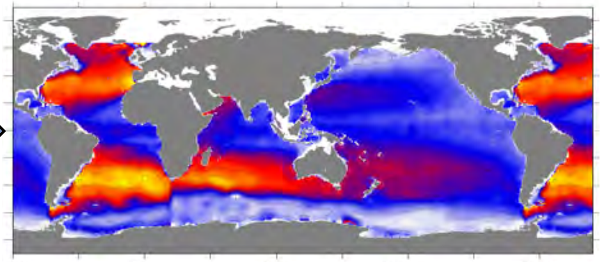
glodap v2

eMLR(C*) method

Clement and Gruber (1998)

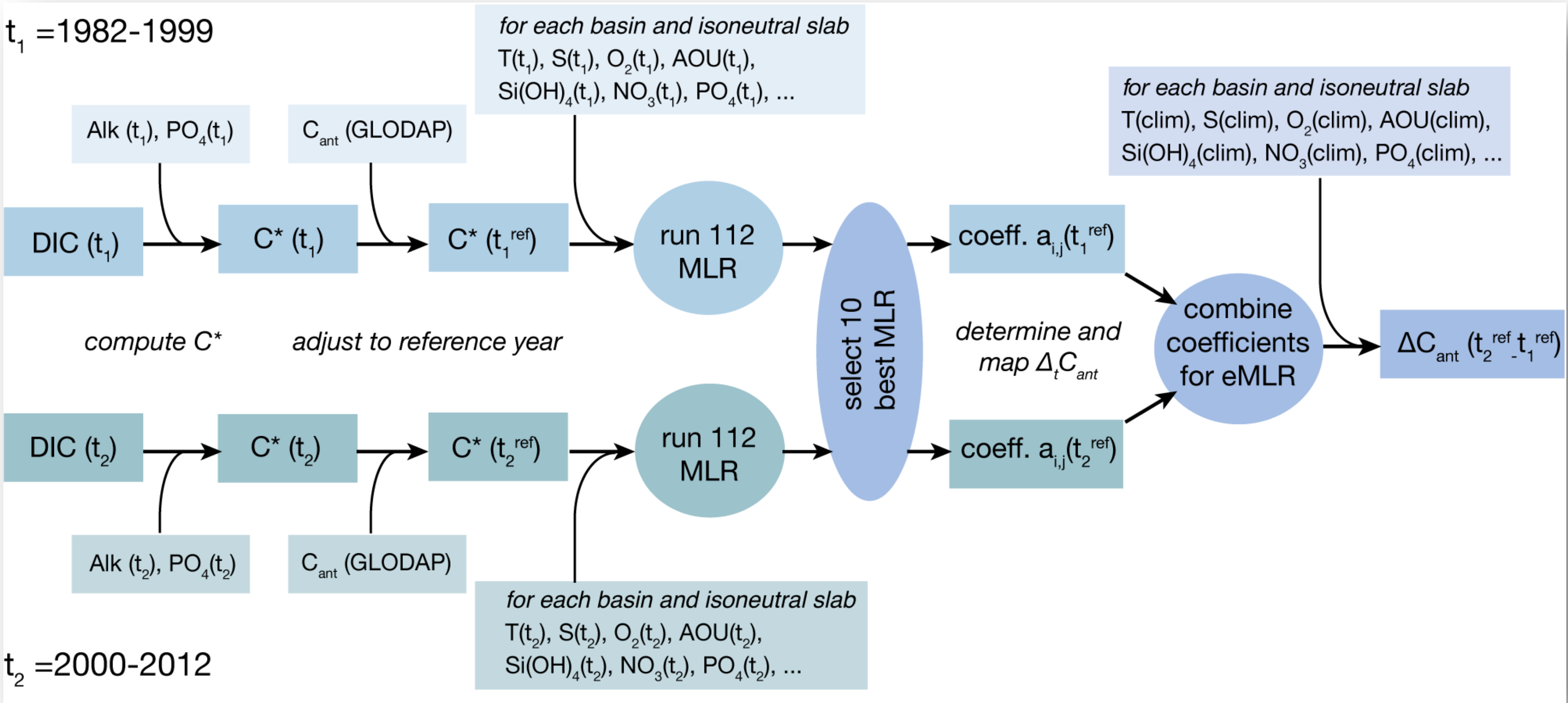


CHANGE IN C_{ant}

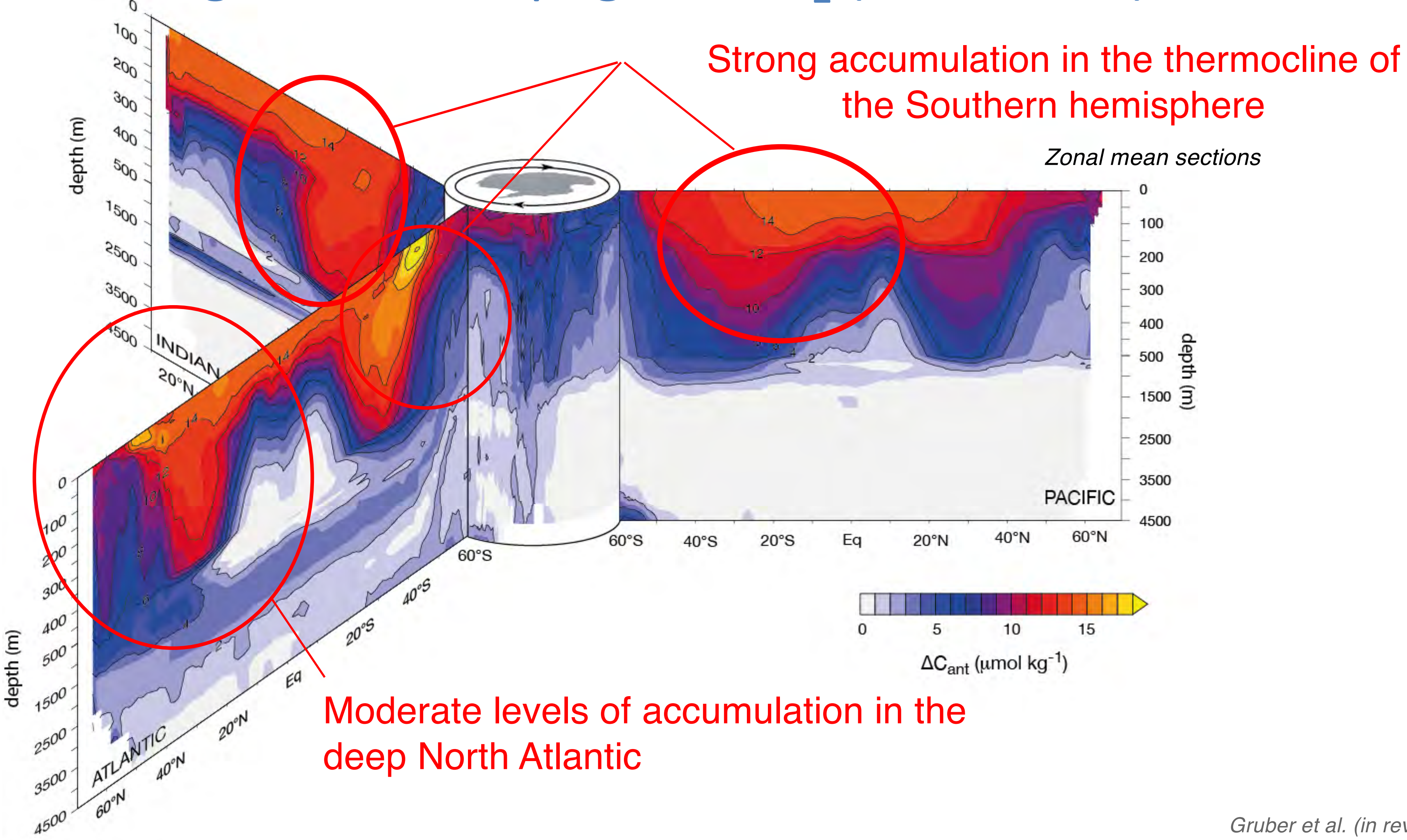


1x1°, 2007 minus 1994

Dealing with sparse data…
requires sophisticated analysis and mapping methods



Interior changes of anthropogenic CO_2 (1994-2007)

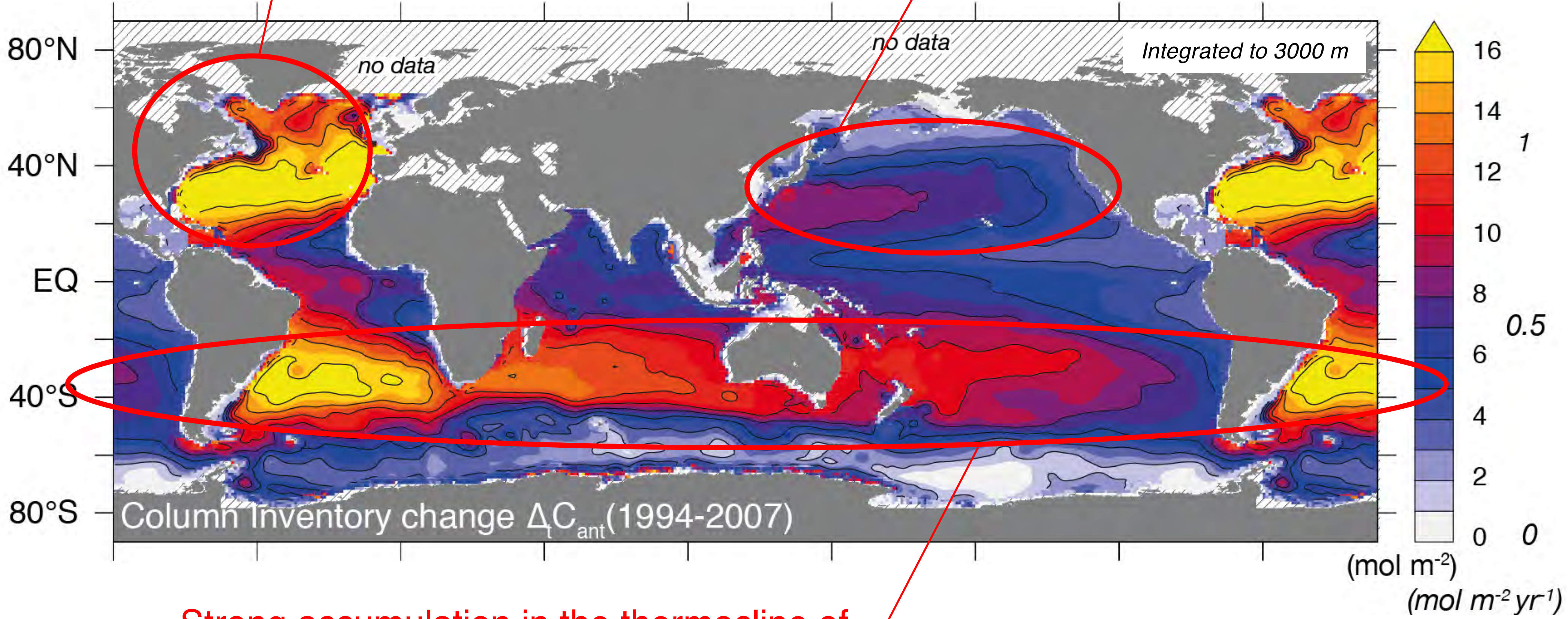


Gruber et al. (in review)

Storage rate of anthropogenic CO_2 (1994-2007)

Moderate to strong accumulation in the North Atlantic

Low accumulation in the North Pacific

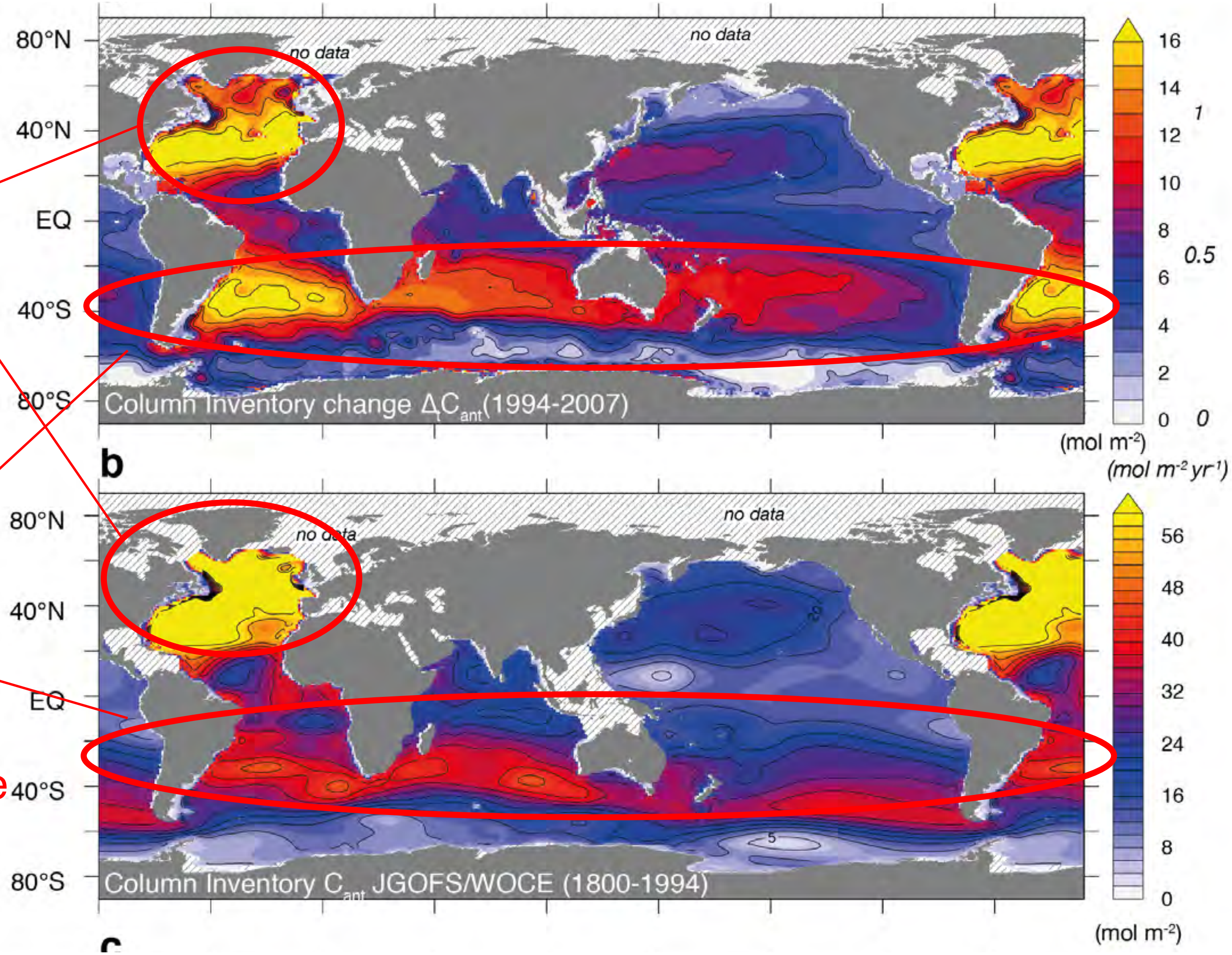


Strong accumulation in the thermocline of the Southern hemisphere

Gruber et al. (in review)

Decadal ant. CO_2 storage (1994-2007) vs total inventory

Weaker North Atlantic uptake



Stronger uptake and asymmetry between basins in the southern hemisphere

Decadal storage

1994-2007

33 ± 4 Pg C

(2.5 ± 0.3 Pg C yr^{-1})

Total inventory

1850-1994

118 ± 17 Pg C

(includes unmapped basins)

Gruber et al. (in review)

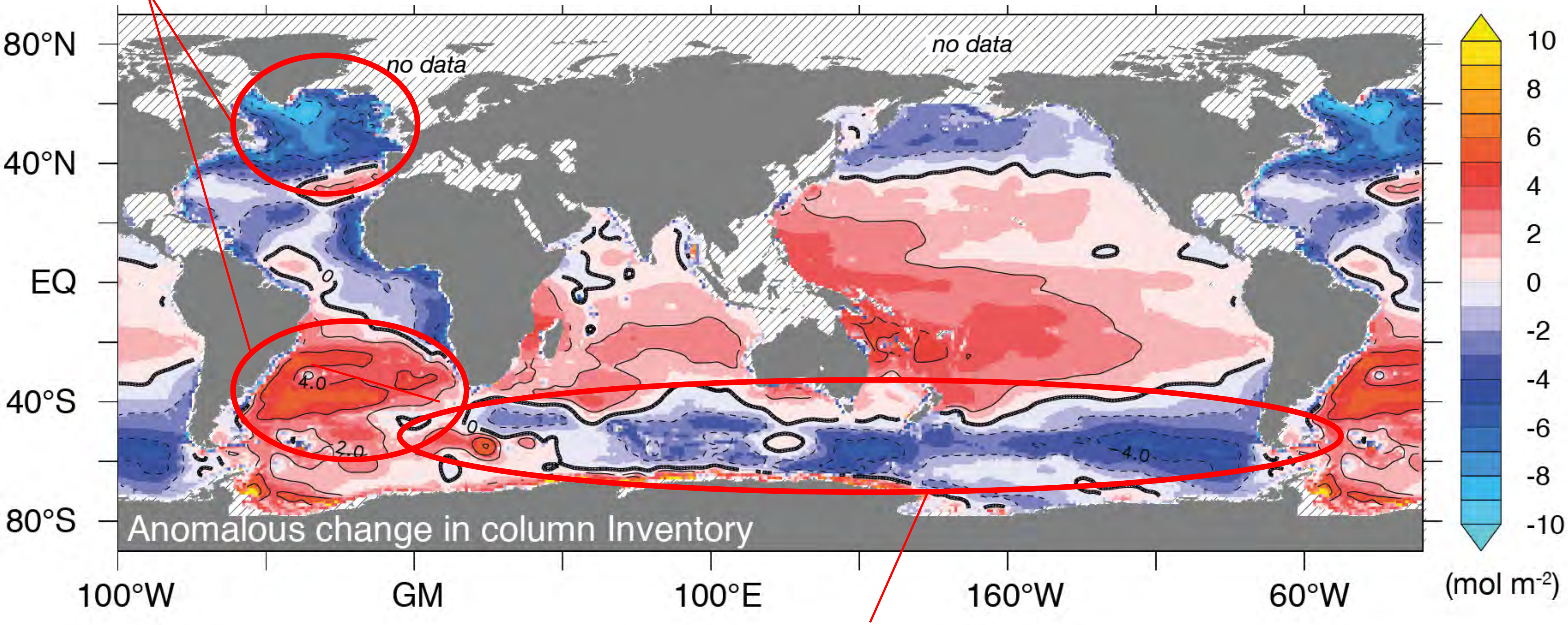
Anomalous CO_2 storage (the role of climate variability)

Strong asymmetry in the Atlantic

Transient steady-state

from Sabine et al. (2004)

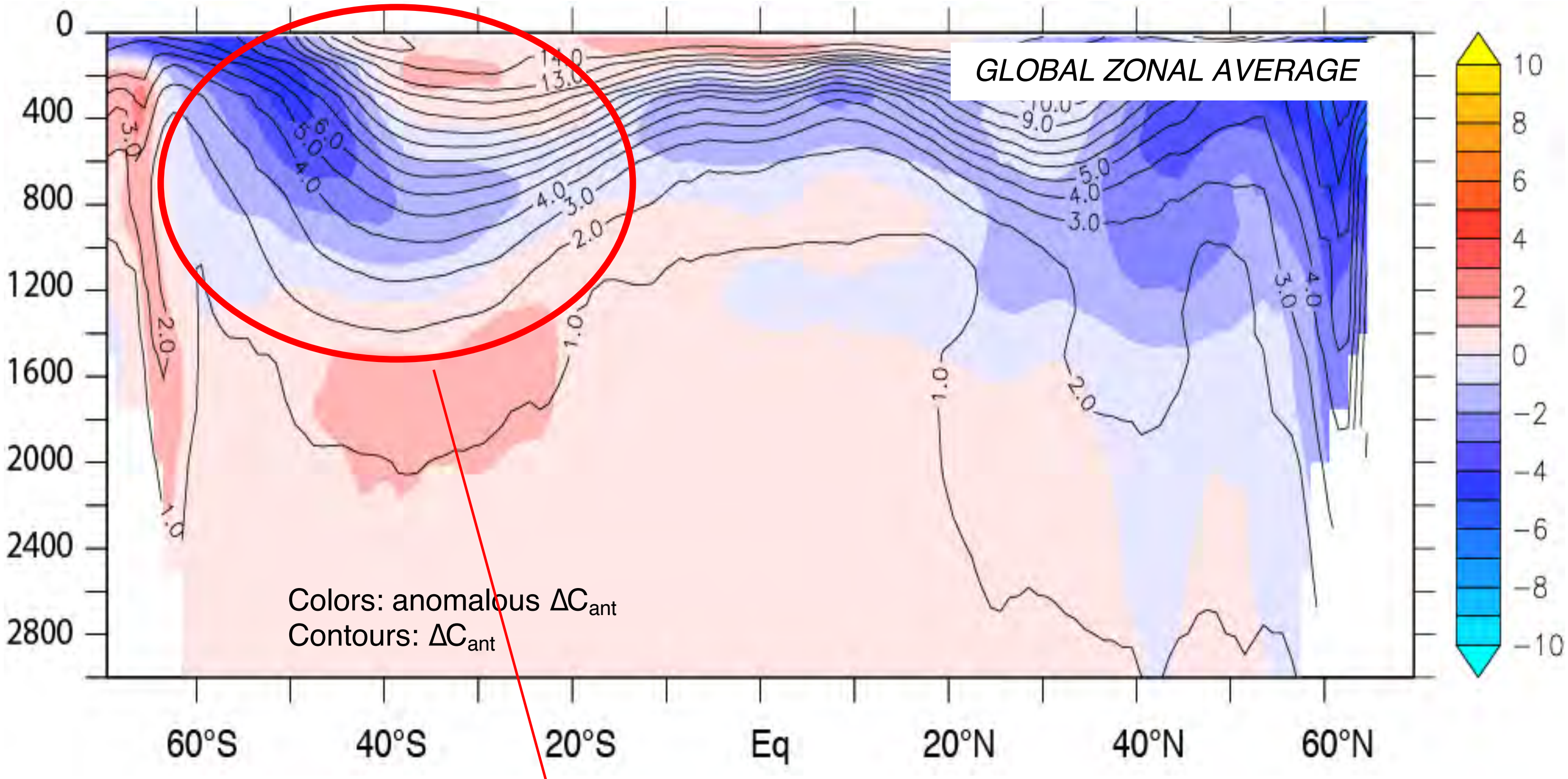
$$\text{Anomalous } \Delta C_{ant} = \Delta C_{ant} - \Delta C_{ant}^{expected} = \Delta C_{ant} - 0.28{*}C_{ant}(1994)$$



Low accumulation in the Southern Ocean (Indian and Pacific sectors)

Gruber et al. (in review)

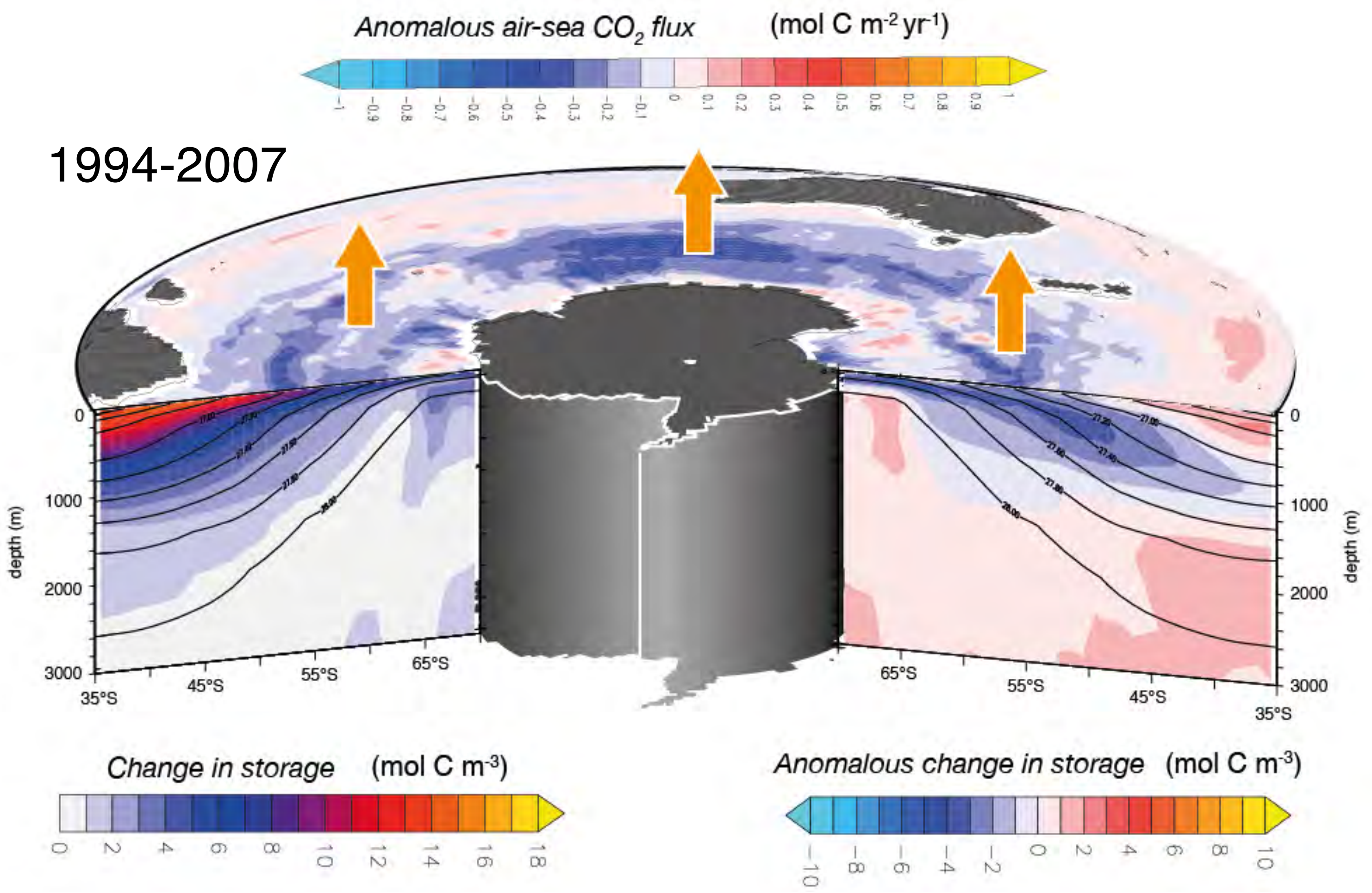
Zonal mean section of anomalous CO_2 storage (1994-2007)



Signal of reduced uptake of ant. CO_2 in the Southern Ocean can be traced into the thermocline

Gruber et al. (in review)

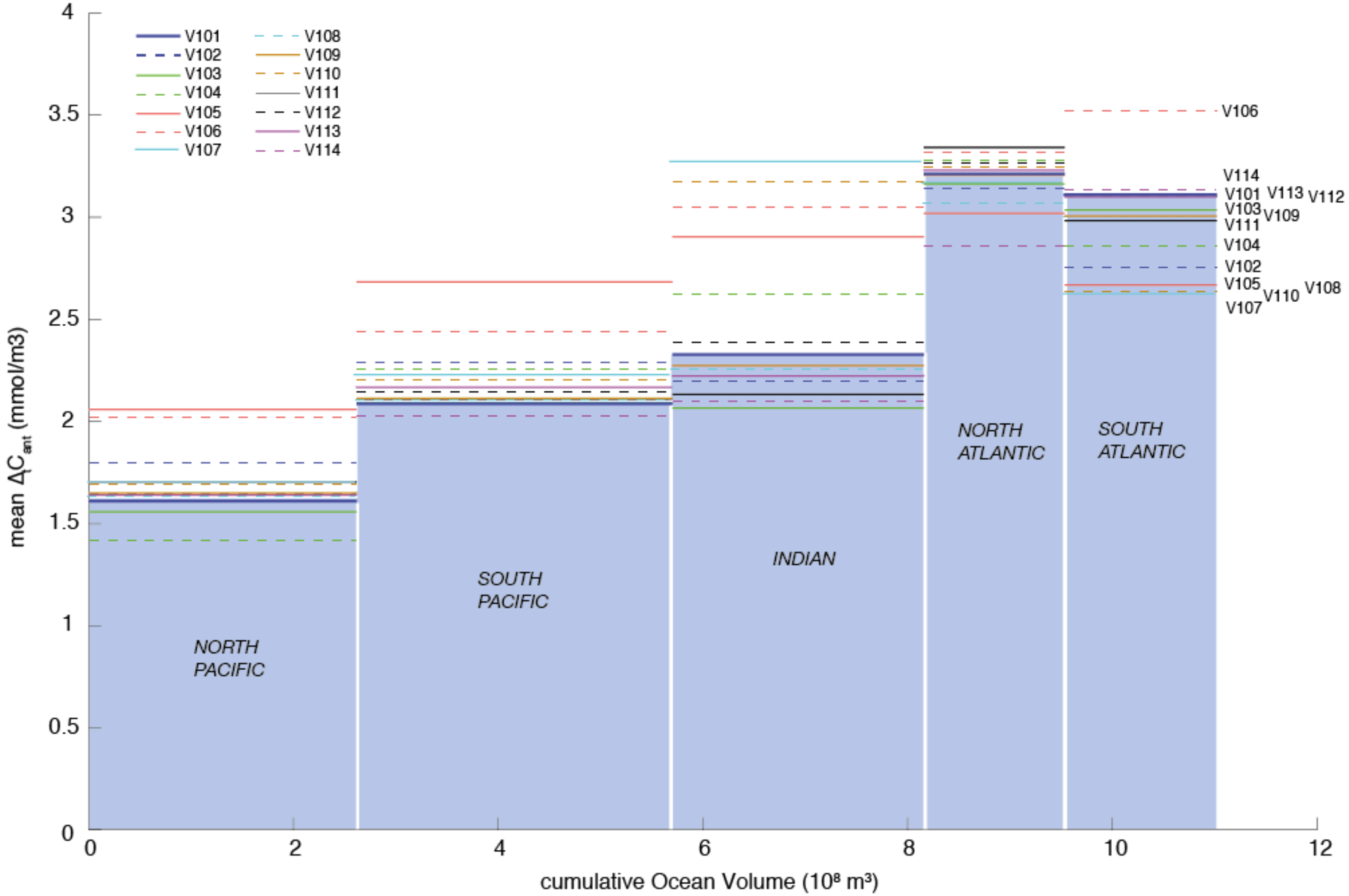
Connecting the changes in the ocean interior to the sfc. fluxes



We can start to connect the ocean interior changes (in Cant) to the changes in the surface air-sea fluxes of (natural and ant.) CO_2…

Gruber et al. (2019)

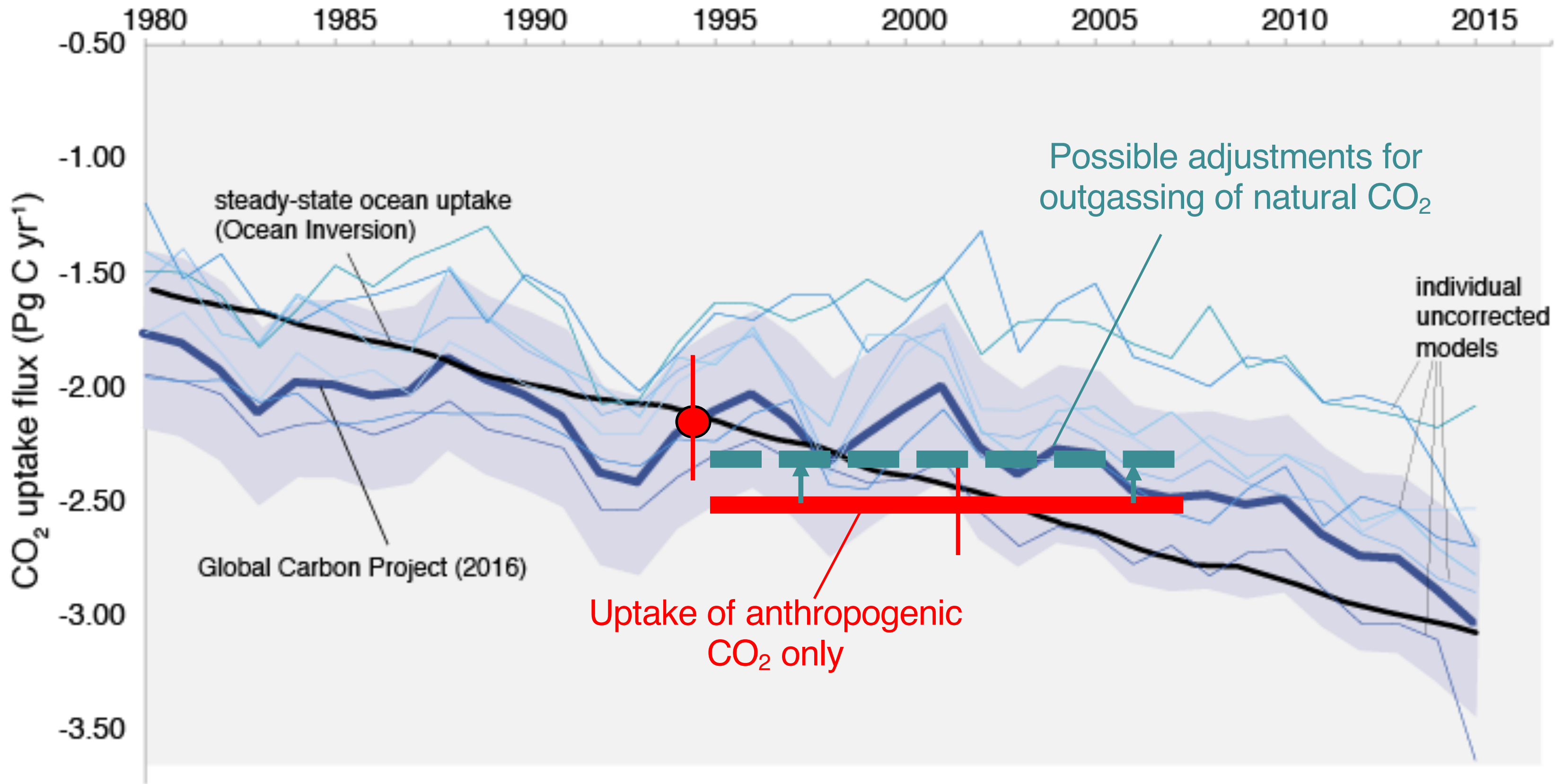
A word on uncertainties



Systematic errors were estimated by creating an ensemble of 14 estimates, using different assumptions along the decision tree of the method.

Gruber et al. (in review)

This ocean interior data based provides a new anchor point



The new anchor point suggest an uptake consistent with the forward projection from the ocean inversion estimate, i.e., confirming that most ocean models tend to underestimate the ocean uptake.

Redrawn from Le Quéré et al. (2017)

Implication for global carbon budgets

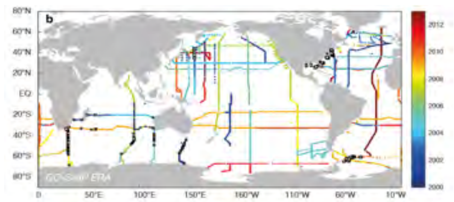
CO_2 sources and sinks	1800 to 1994 (Pg C) (a)	1994 to 2007 (Pg C) (b)
Constrained sources and sinks		
(1) Emissions of C_{ant} from fossil fuel and cement production	244±20	94±5 (c)
(2) Increase of CO_2 in the atmosphere	-165±4	-50±1 (d)
(3a) Uptake of C_{ant} by the ocean	**-118±19**	**-33± 4(e)**
(3b) Loss of natural CO_2 by the ocean	7 ± 10(f)	5±3 (g)
(3) Net ocean CO_2 uptake	-111±21	-28±5
Inferred terrestrial balance		
(4) Net terrestrial balance [-(1) -(2) -(3)]	32 ± 30	-16±7
Terrestrial balance		
(5) Emissions of C_{ant} from land use change	100 to 180	16±6(h)
(6) Terrestrial biosphere sink [-(1)-(2)-(3)] -(5)	-68 to -148	-32±9

1994-2007
Ocean uptake fraction for Anthropogenic CO_2: 30±4 %

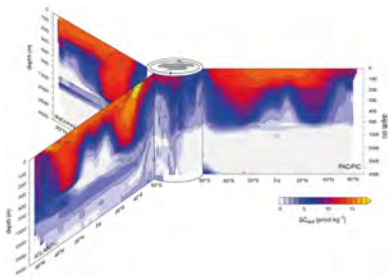
1994-2007
Outgassing estimated from Landschützer et al. (2016)

1994-2007
Ocean uptake fraction for contemporary CO_2 : 25±5 %

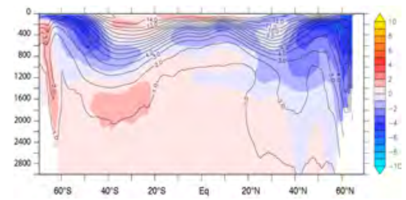
Summary and Conclusions



- Thanks to large *international observational efforts*, we are now able to address decadal time-scale variability of the ocean carbon sink.



- These observations confirm that the ocean has *taken up 30% of the anthropogenic CO_2* emitted into the atmosphere.



- The observations also reveal a substantial amount of *variability* in this uptake, including a possible loss of natural CO_2

These data can provide numerous new constraints for ocean models…

All data will be made available through NCEI:
Globally gridded 1° x1° resolution, with uncertainties

An upcoming opportunity: RECCAP2

1st meeting: 18-21. March 2019: Japan

POTENTIAL TOPICS

1) Global ocean CO_2 flux variability over the last three decades: Models, observations, and processes
2) Global ocean storage change. Models, observations, and processes
3) The ocean carbon sink: the integrated view
4) Variability in the Southern Ocean carbon sink
5) Carbon sources and sinks of the global coastal region
6) ….