At the International Conference Center, Hiroshima, Japan on 16th Oct.

Decadal changes of dissolved inorganic carbon in the Pacific

Akihiko Murata, Shinya Kouketsu, Toshimasa Doi,
Kazuhiko Hayashi and Yuichiro Kumamoto

Ocean Climate Change Research Program,
Research Institute for Global Change (RIGC),
Japan Agency for Marine-Earth Science and
Technology (JAMSTEC)

Course of talking

- Background
  - History of ocean inventory study
- Data and method
  - Data used
  - How to estimate total, anthro. and natural CO_2 changes
- Results
  - Decadal changes of total, anthro. and natural CO_2
  - Water column inventories
- Summary and future studies

PICES

JAMSTEC

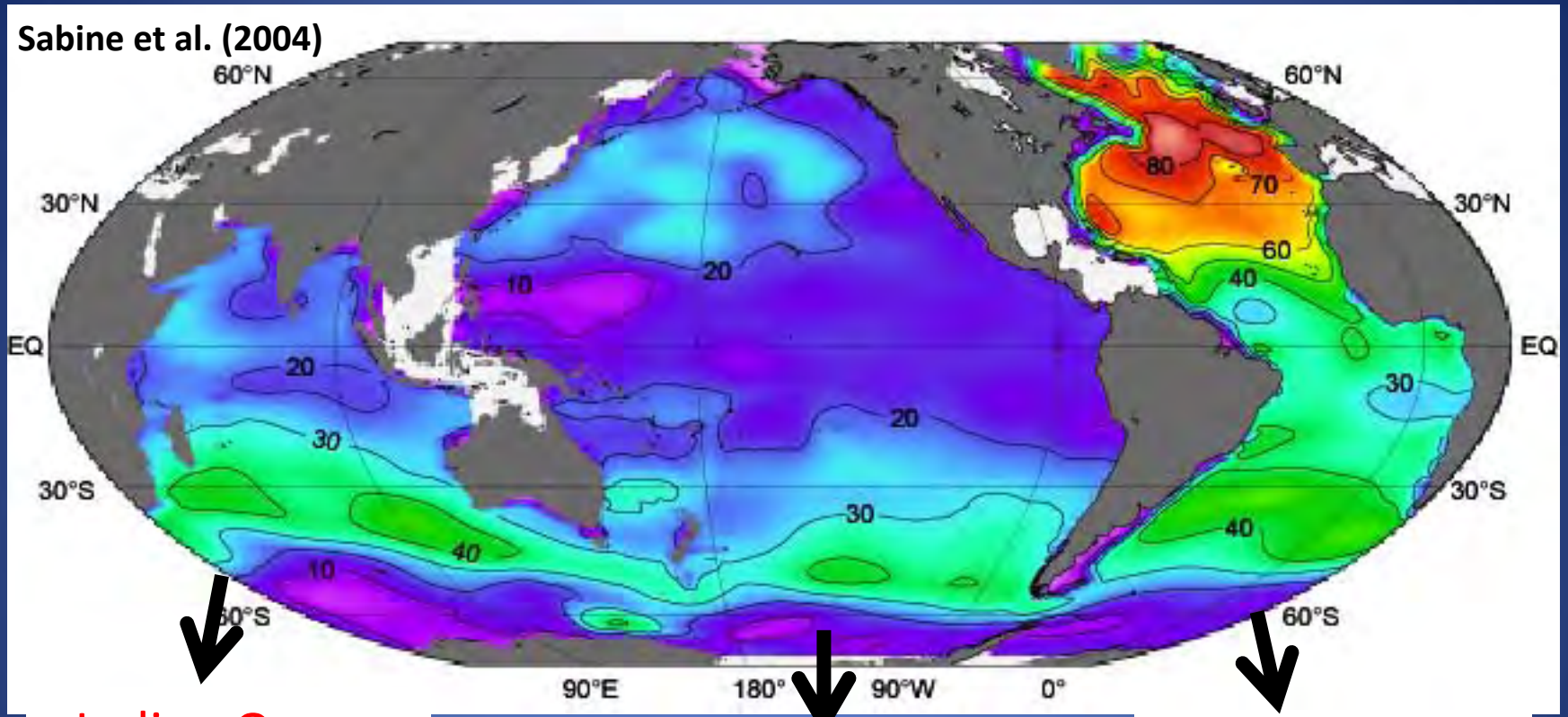
History of ocean inventory study

- During the late 1980s to the 1990s, WOCE, JGOFS, and national programs, etc. provided baseline data.
- About 10 years ago, data-based inventories were obtained.
- From 5 years ago, data synthesis activities such as CARINA, PACIFICA, GLODAP, etc. are continuing.
- Detecting decadal-scale changes

PICES

JAMSTEC

Anthro. CO_2 in the ocean (mol m^{-2})



Indian Ocean
22 Pg C

Pacific Ocean
44 Pg C

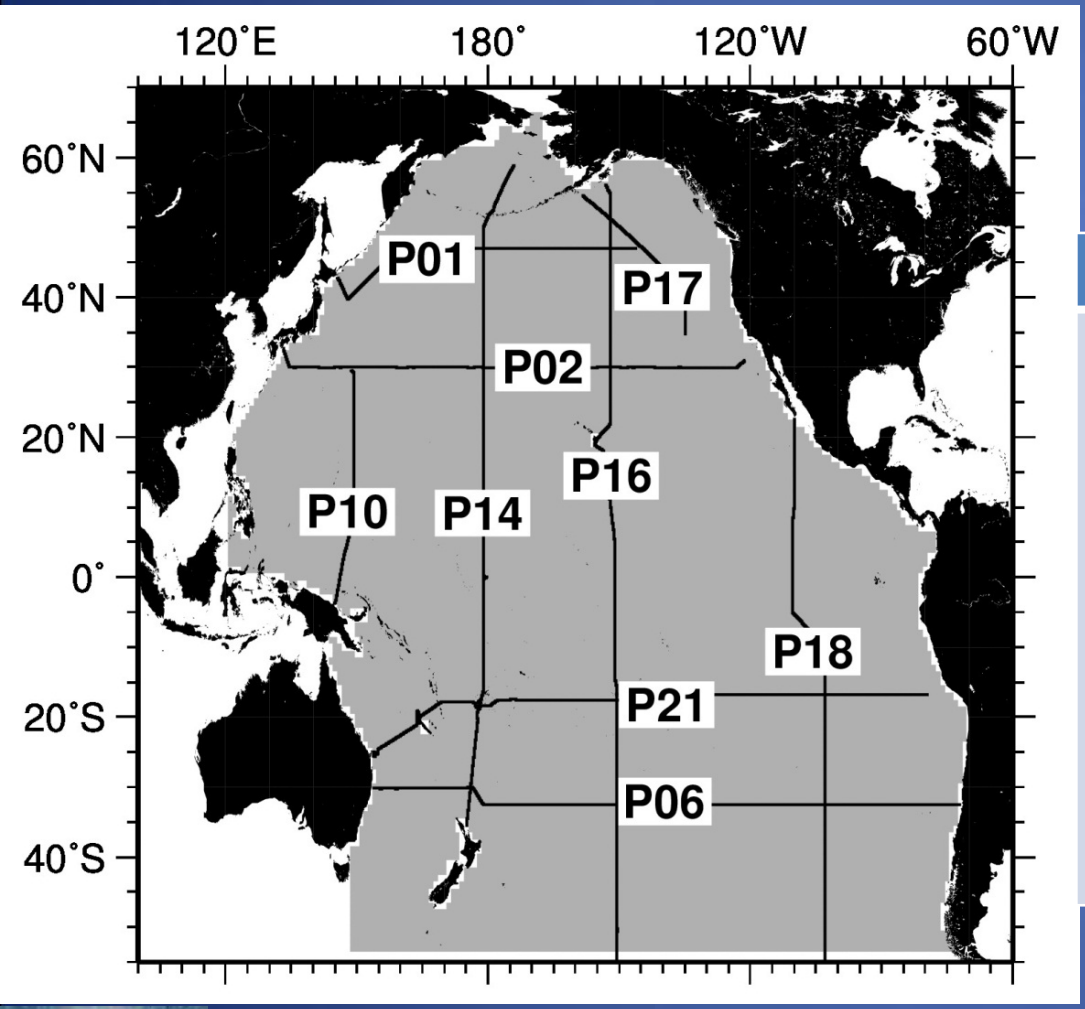
Atlantic Ocean
40 Pg C

Global inventory = 118 ±19 PgC for the Anthropocene
(1800 – 1994)

PICES

JAMSTEC

Data used



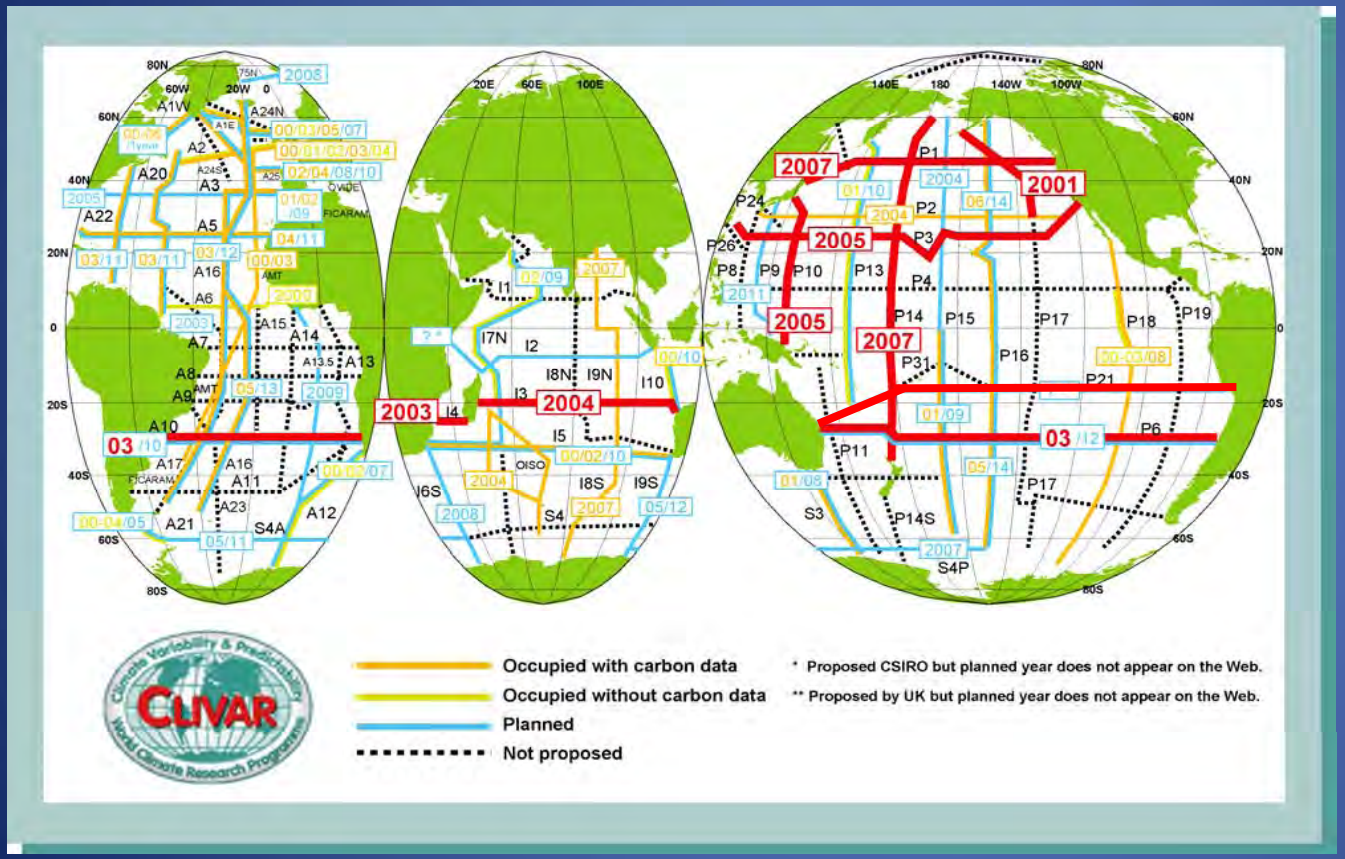
Line	WOCE	Revisit
P01	1999	2007
P02	1994	2004
P06	1993	2003
		2009
P10	1993	2005
P14	1992/1993	2007
P16	1991	2005/2006
P17	1993	2001
P18	1994	2008
P21	1994	2009

PICES

JAMSTEC

Data obtained by JAMSTEC

R/V Mirai



After 2000, over 50% of the WOCE stations in the Pacific Ocean were re-occupied by JAMSTEC.

Available from CDIAC and CCHDO

Calculation method (1)

- Total CO_2 changes (ΔC_T)

$$\Delta C_T = C_T(R) - C_T(W),$$

where $C_T(R)$ and $C_T(W)$ indicate dissolved inorganic carbon measured in Revisit and WOCE cruises, respectively.

- Anthro. CO_2 changes (ΔnC_T^{CAL})

$$\Delta nC_T^{CAL} = nC_T^{CAL}(R) - nC_T^{CAL}(W),$$

where $nC_T^{CAL}(R)$ and $nC_T^{CAL}(W)$ are the preformed C_T (= C_T – 0.69 × AOU) for Revisit and WOCE cruises, respectively. “n” implies that the values are normalized to a salinity of 35.

PICES

JAMSTEC

Calculation method (2)

- Natural CO_2 changes (ΔnC_{AOU})

  $\Delta nC_{AOU} = nC_{AOU}(R) - nC_{AOU}(W)$,

where $C_{AOU}(R)$ and $C_{AOU}(W)$ are equal to 0.69 $\times$ AOU for Revisit and WOCE cruises, respectively. “n” implies that the values are normalized to a salinity of 35.

- Water column inventories of anthro. (ΔnC_T^{CAL}) and natural (ΔnC_{AOU}) CO_2 changes

  20° longitudinal or 10° latitudinal interval.

PICES

JAMSTEC

Shortcomings of method used

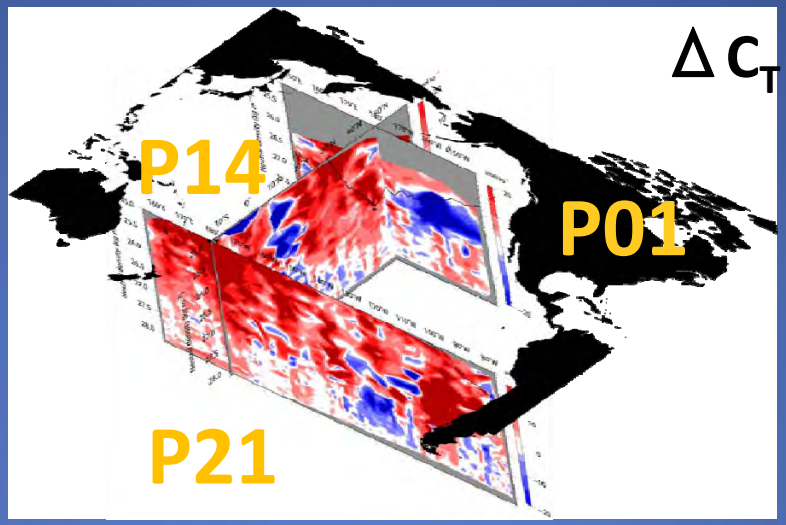
- Assumptions
  - No significant changes in A_T
  - Constant ΔC_{Tdiseq}
  - Constant Redfield ratio
  - •
  - •
  - •

Hold true on a basin scale

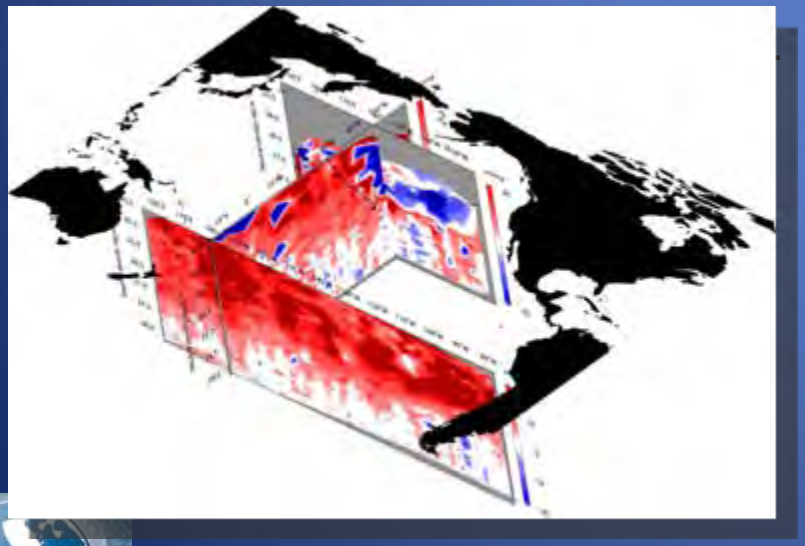
For the details, refer to Kouketsu et al. (201?), GBC.

Distributions of ΔC_T, ΔnC_T^{CAL} and ΔnC_{AOU} along 3 sections

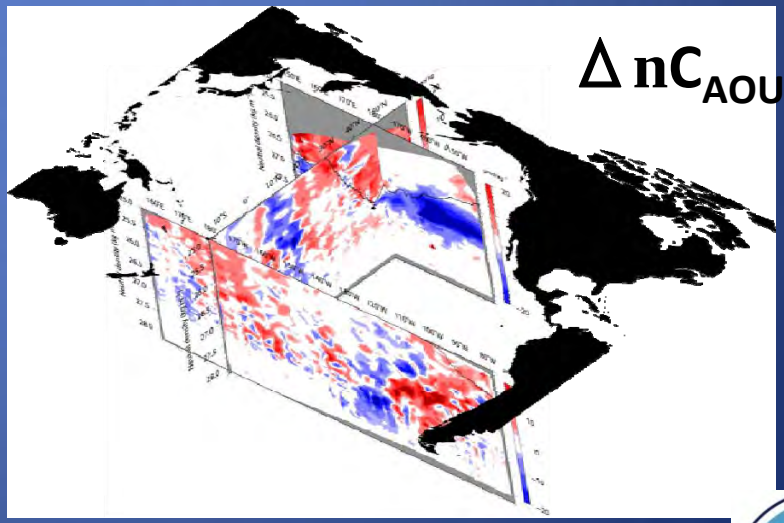
Total CO_2



Anthro. CO_2



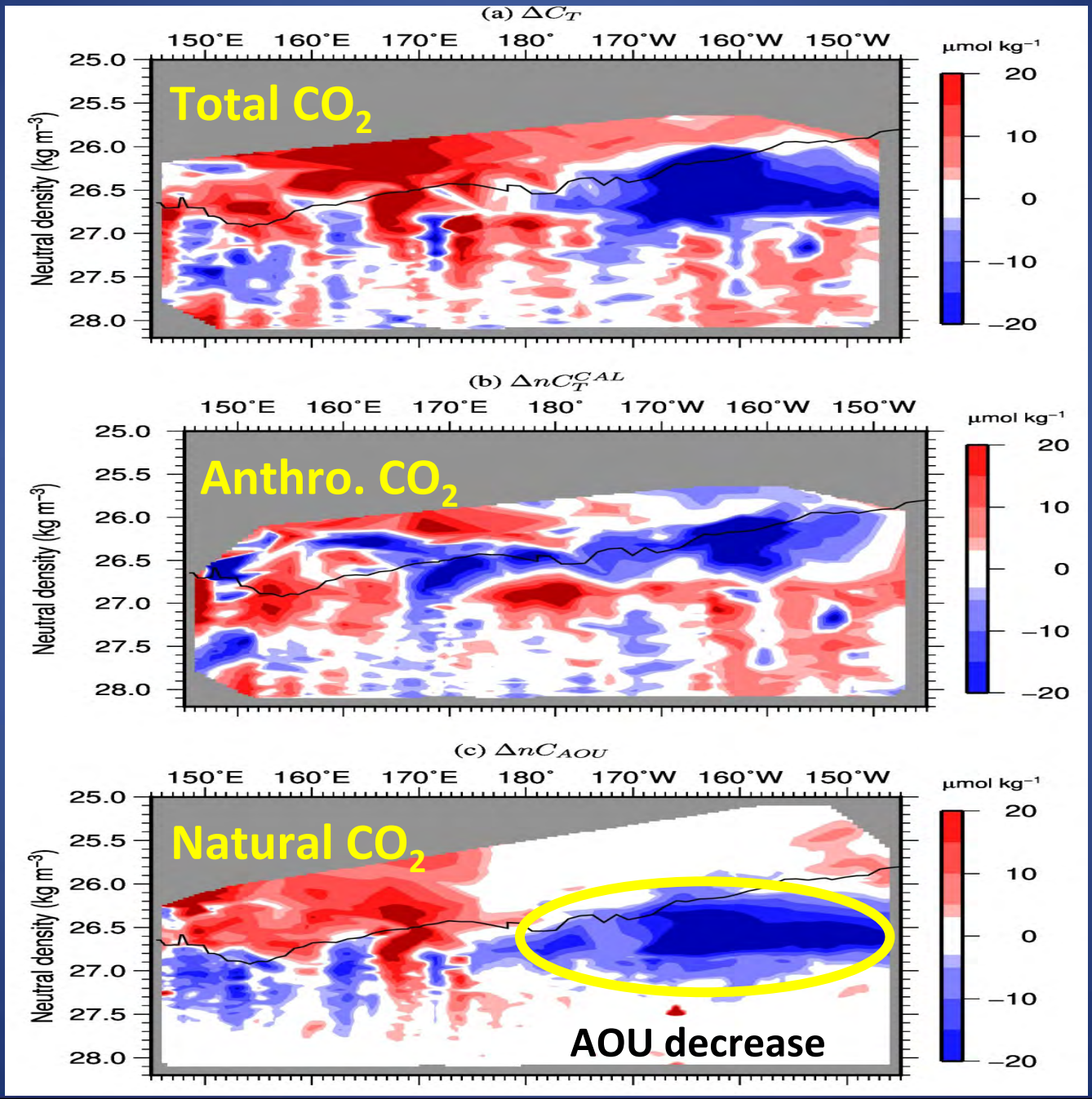
Natural CO_2



PICES

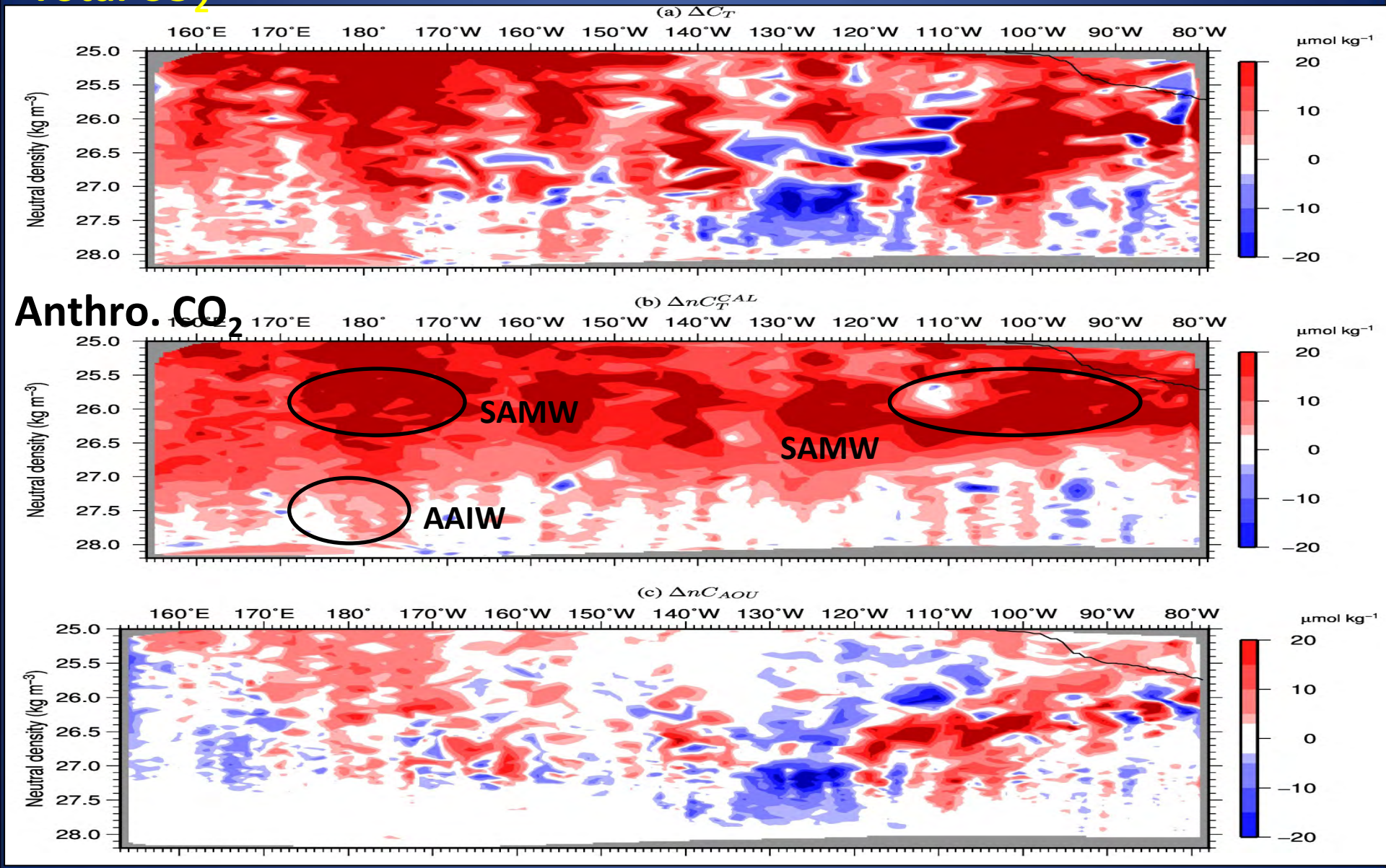
JAMSTEC

P01


(a) ΔC_T
Total CO_2
(b) ΔnC_T^{CAL}
Anthro. CO_2
(c) ΔnC_{AOU}
Natural CO_2
AOU decrease
150°E 160°E 170°E 180° 170°W 160°W 150°W
25.0 25.5 26.0 26.5 27.0 27.5 28.0
Neutral density (kg m^{-3})
μmol kg^{-1}
20 10 0 −10 −20

P21

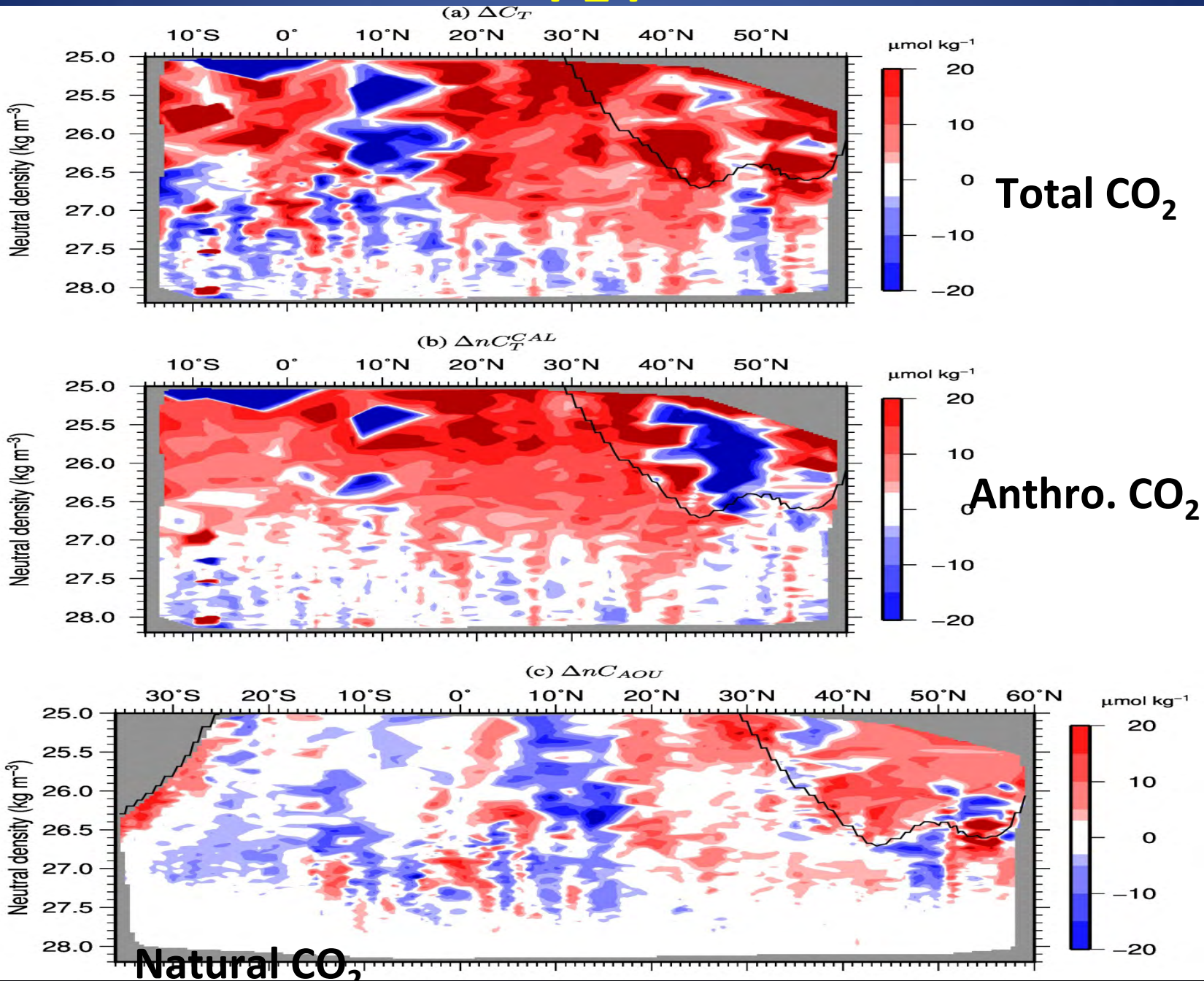
Total CO_2



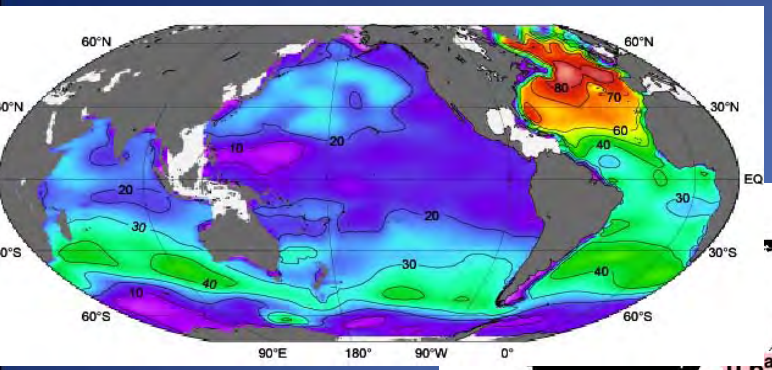
Anthro. CO_2

Natural CO_2

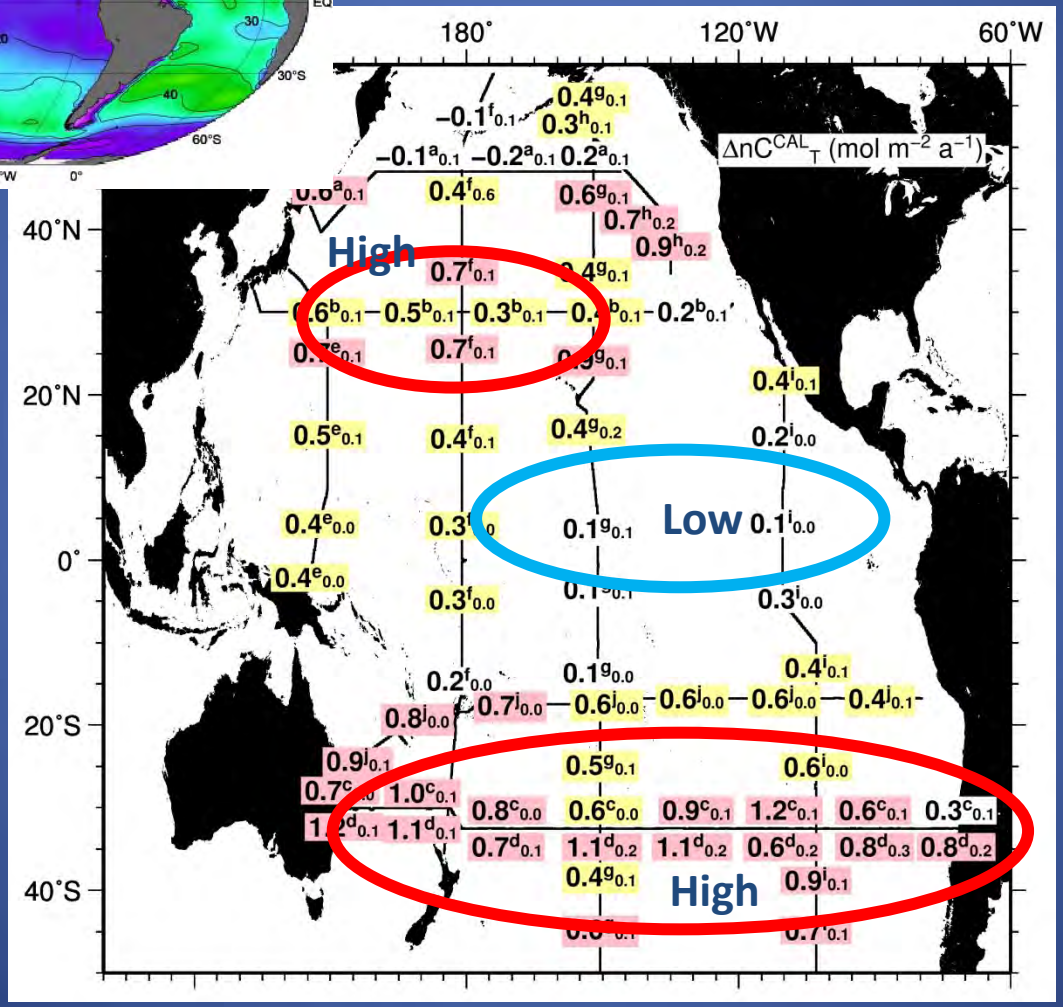
P14


(a) ΔC_T
10°S 0° 10°N 20°N 30°N 40°N 50°N
Neutral density (kg m^{-3})
25.0 25.5 26.0 26.5 27.0 27.5 28.0
µmol kg^{-1}
20 10 0 −10 −20
Total CO_2
(b) ΔnC_T^{CAL}
10°S 0° 10°N 20°N 30°N 40°N 50°N
Neutral density (kg m^{-3})
25.0 25.5 26.0 26.5 27.0 27.5 28.0
µmol kg^{-1}
20 10 0 −10 −20
Anthro. CO_2
(c) ΔnC_{AOU}
30°S 20°S 10°S 0° 10°N 20°N 30°N 40°N 50°N 60°N
Neutral density (kg m^{-3})
25.0 25.5 26.0 26.5 27.0 27.5 28.0
µmol kg^{-1}
20 10 0 −10 −20
Natural CO_2

Specific water column inventories of anthro. CO_2 changes



Anthropocene



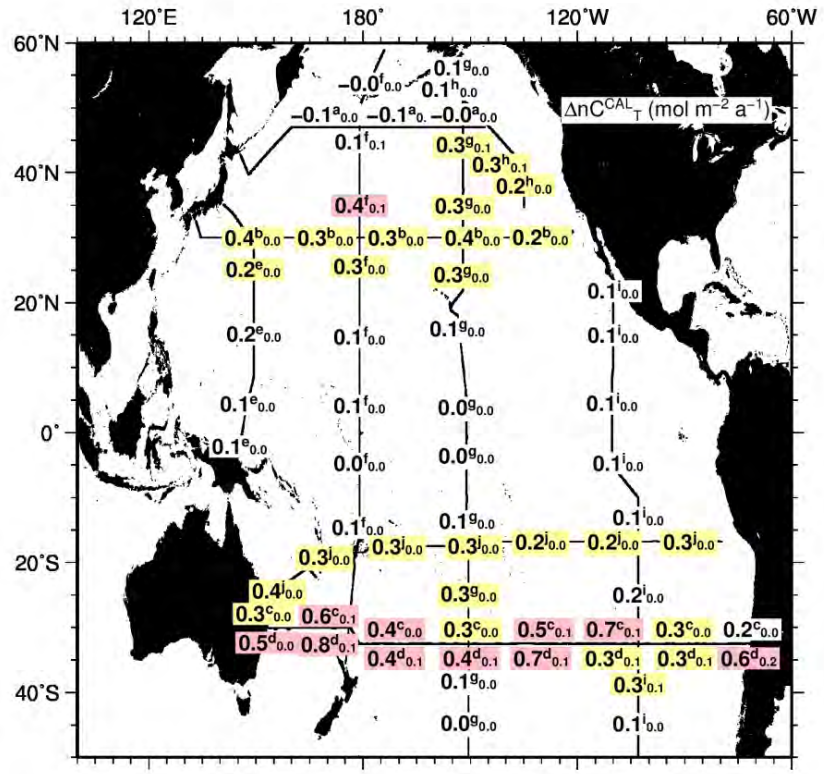
Recent decade

PICES

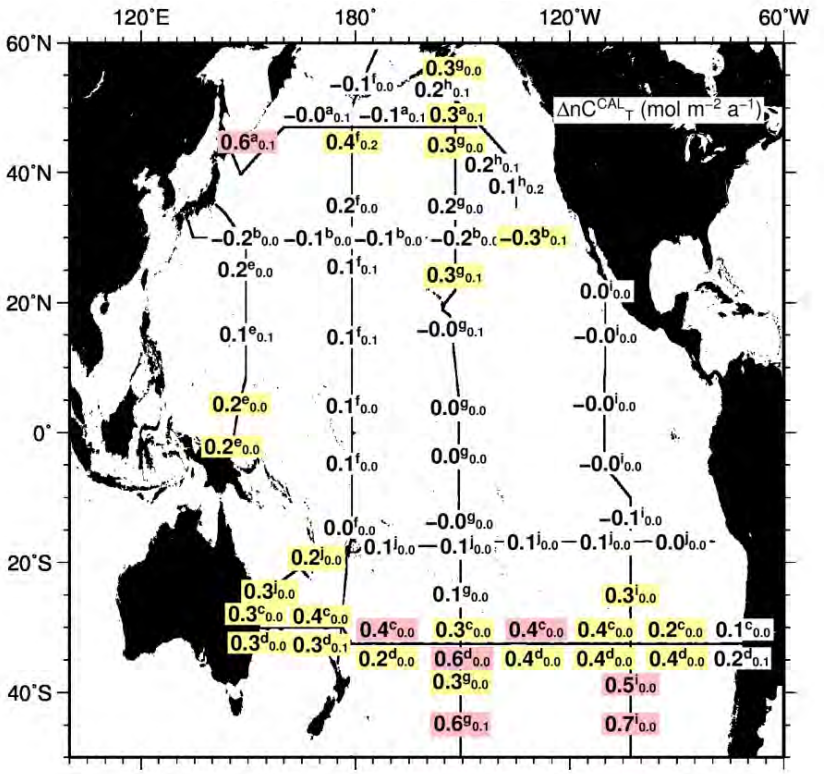
JAMSTEC

Specific water column inventories of anthro. CO_2 changes for mode and intermediate waters

Mode water



Intermediate water

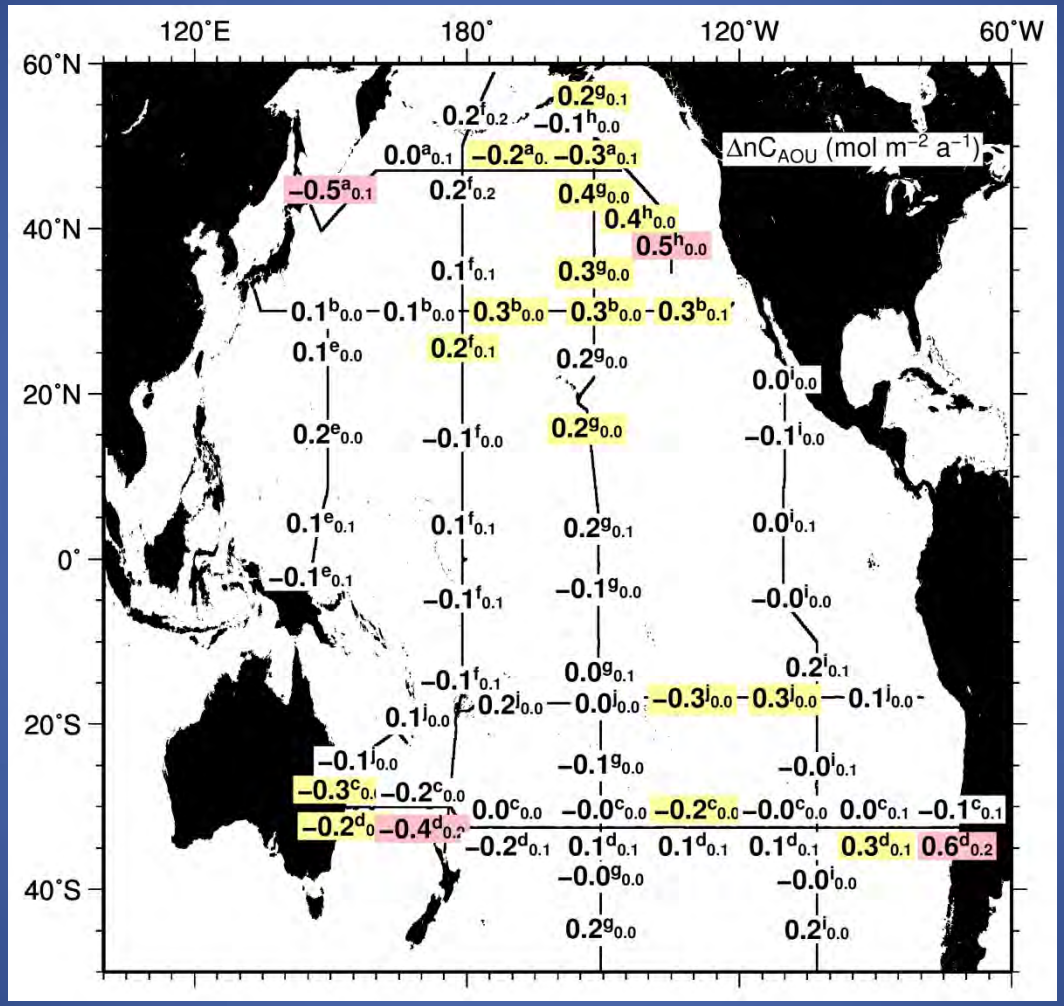


MW: γ_n = 25.6–26.5 and 25.6 –26.8 kg m^{-3} for the North and South Pacific, respectively.
IW: γ_n = 26.6–27.6 and 26.9 –27.6 kg m^{-3} for the North and South Pacific, respectively.

PICES

JAMSTEC

Specific water column inventories of natural CO_2 changes



Decadal storages of anthropogenic and natural CO_2 for latitudinal bands

Area	ΔnC_T^{CAL} PgC decade^{-1}	ΔnC_{AOU} PgC decade^{-1}
40°N – 65°N	0.3±0.2	–0.1±0.1
20°N – 40°N	1.5±0.2	0.5±0.1
20°S – 20°N	2.7±0.4	0.3±0.3
50°S – 20°S	3.9±0.3	–0.1±0.3
50°S – 65°N	**8.4±0.5**	**0.6±0.4**

Values show average ± standard error

About 40% of the estimate for the global ocean (2.2 PgC a^{-1}; Fletcher et al. 2006)

PICES

JAMSTEC

Summary

- ✓ In the Pacific, anthropogenic CO_2 both increased (> 20 μ mol kg^{-1}) and decreased (< –20 μ mol kg^{-1}) on a decadal scale.
- ✓ Decadal-scale storage of anthropogenic CO_2 north of 40°N was close to ± 0 mol m^{-2} a^{-1}.
- ✓ In the subtropical regions of both hemispheres, an increasing trend of > 10 μ mol kg^{-1} for oceanic uptake of anthropogenic CO_2 was found, reflecting accumulation in mode waters.
- ✓ Water column inventories calculated throughout the Pacific Ocean revealed relatively high values (> 0.7 mol m^{-2} a^{-1}) in the subtropical regions of both hemispheres and low values in the tropical Pacific.

PICES

JAMSTEC

Summary (cont.)

- ✓ The distribution pattern of water column inventories of anthropogenic CO_2 changes is similar to previous estimates for the Anthropocene, implying that the re-distribution processes of anthropogenic CO_2 have not changed on a basin scale over the last decade.

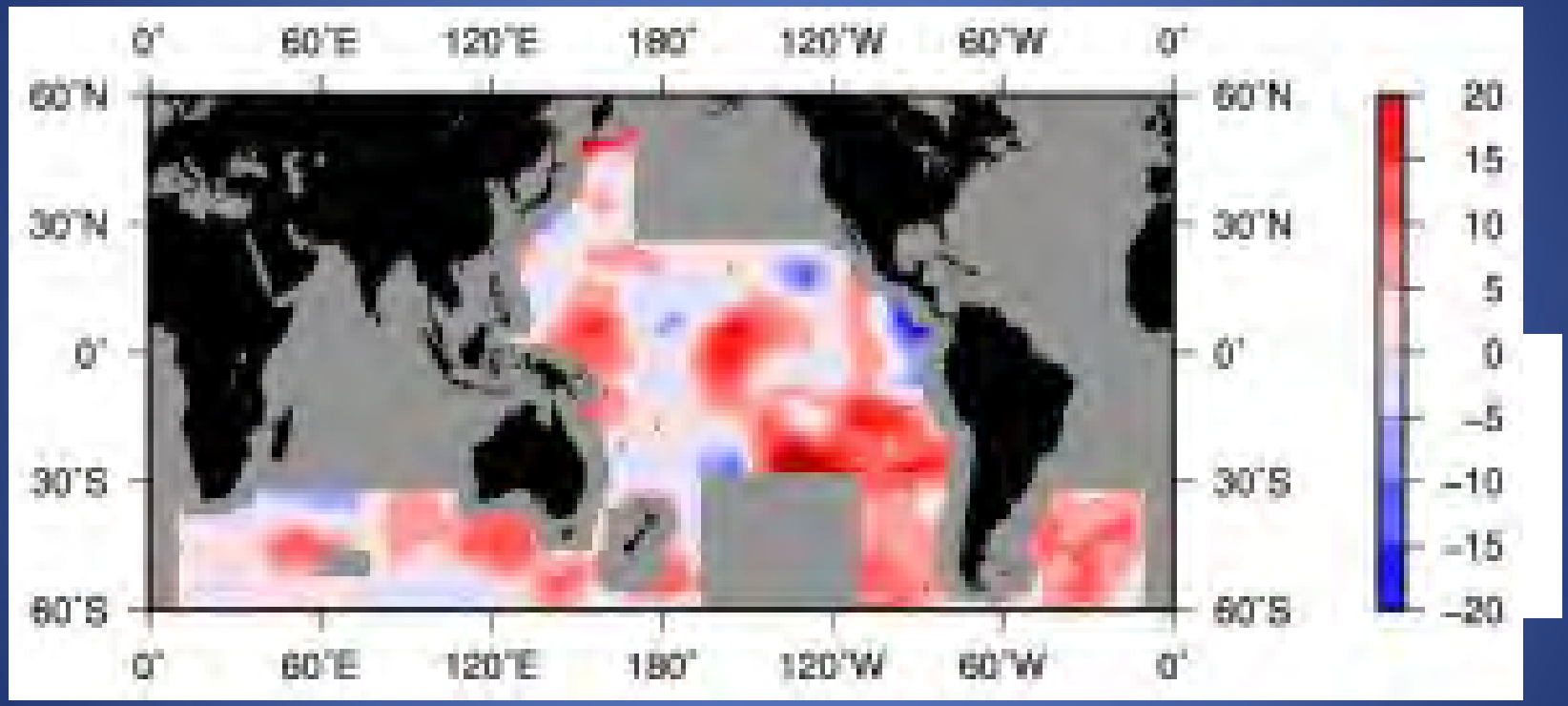
- ✓ The total anthropogenic and natural CO_2 storage in the Pacific Ocean was estimated at 8.4 ± 0.5 and 0.6 ± 0.4 PgC decade^{-1}, respectively.

PICES

JAMSTEC

Future studies

- Global mapping with CARINA, PACIFICA, etc.



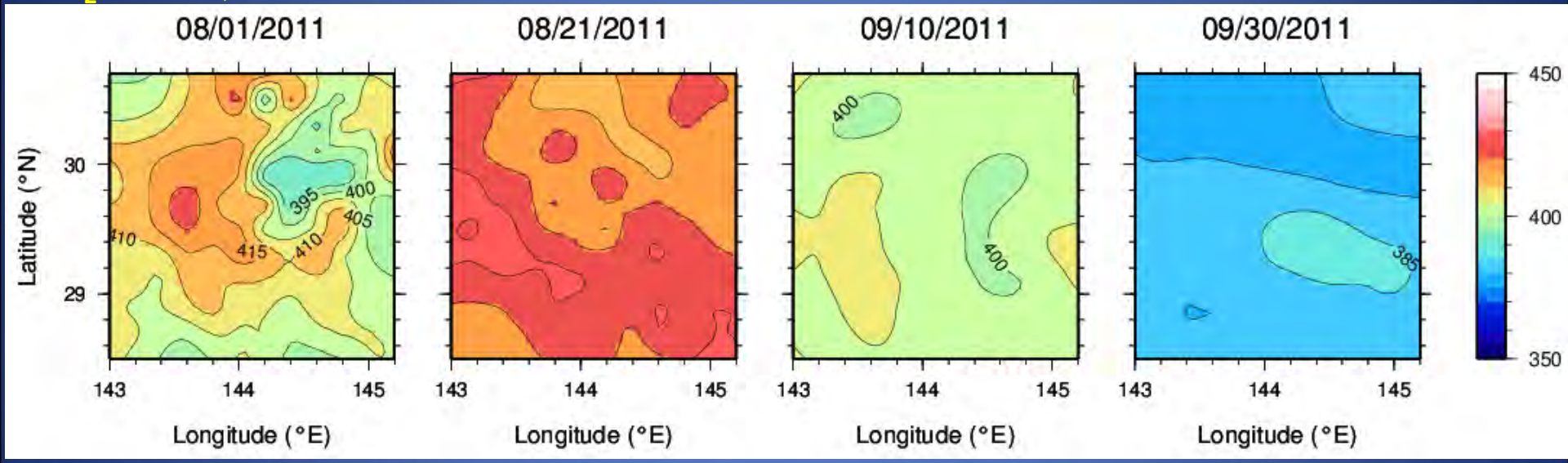
PICES

JAMSTEC

Future studies (cont.)

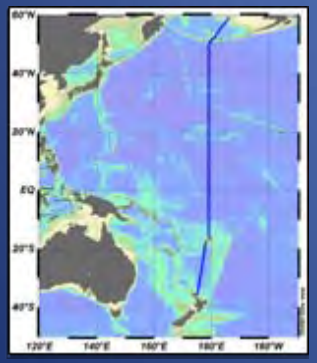
- Influences of meso-scale eddies

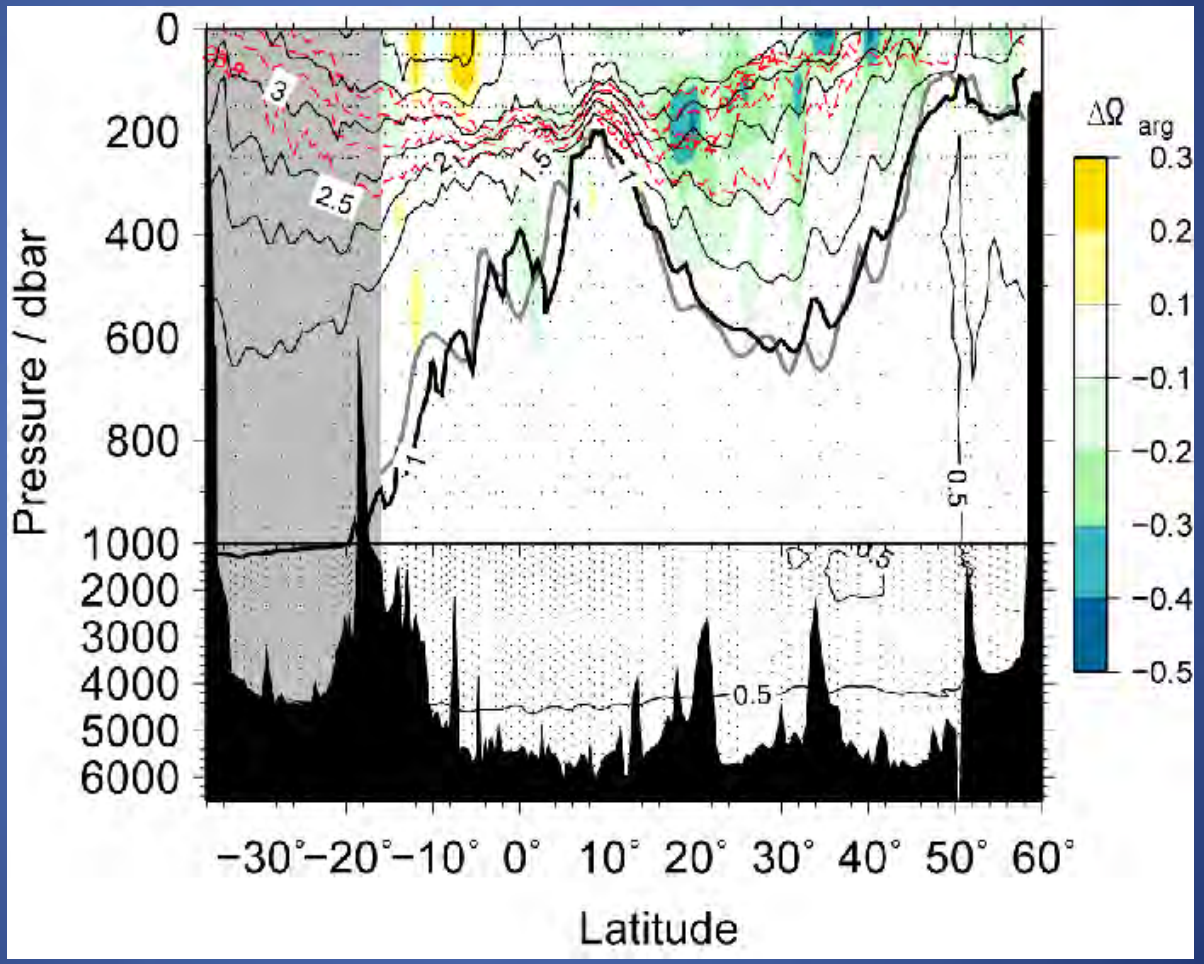
pCO_2 (μ atm) reconstructed from T, S, and DO Argo floats with T, S and DO sensors



Future studies (cont.)

- Ocean acidification





Murata and Saito (2012)

Thank you for your attention!

PICES

JAMSTEC