Oceanic CO_2 Observations in the North Pacific

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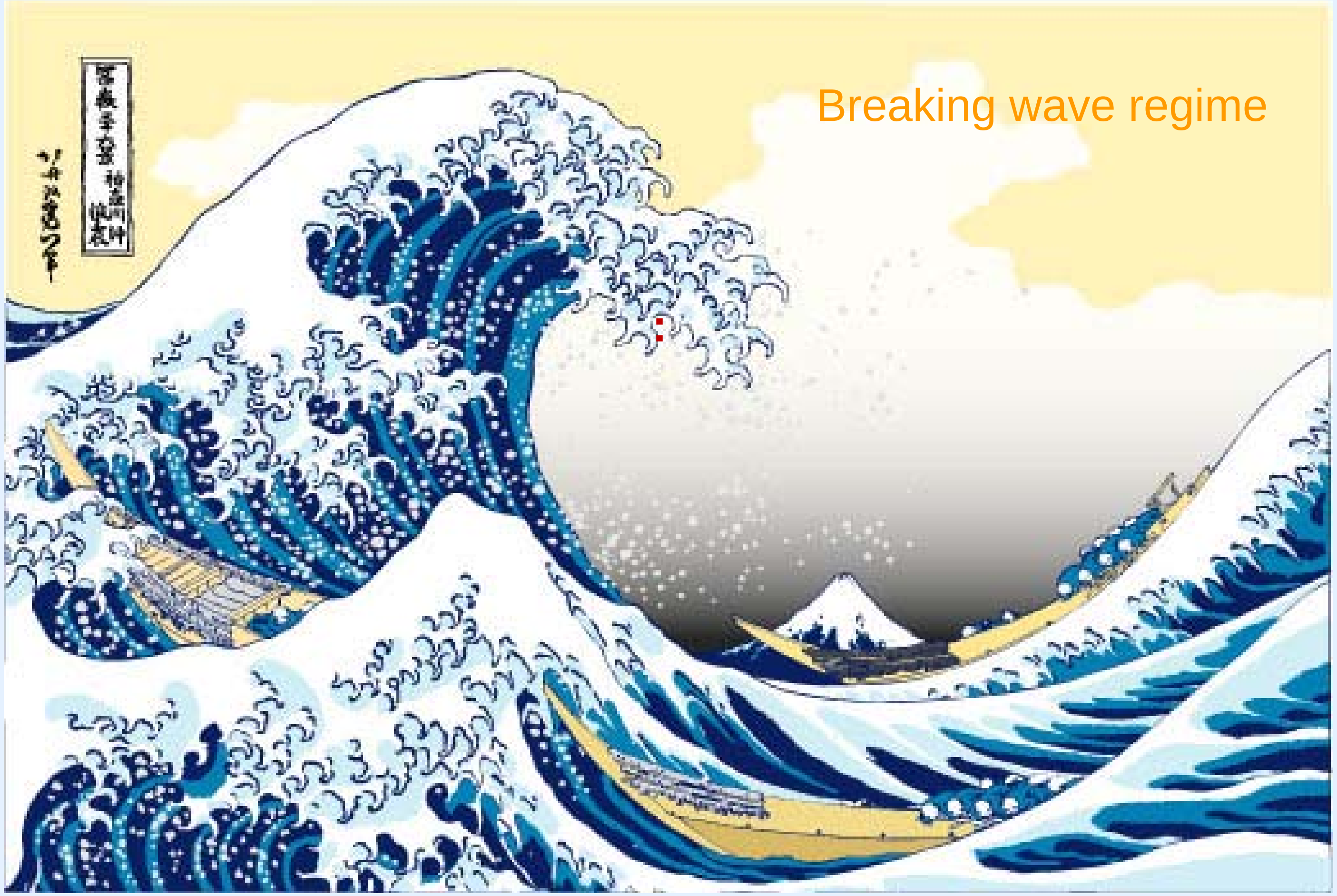

葛飾北斎(1760-1849)

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A brief review of international efforts on the observations of …

1. Partial pressure of CO_2 in surface seawater (pCO_2^{sw})

- Data synthesis
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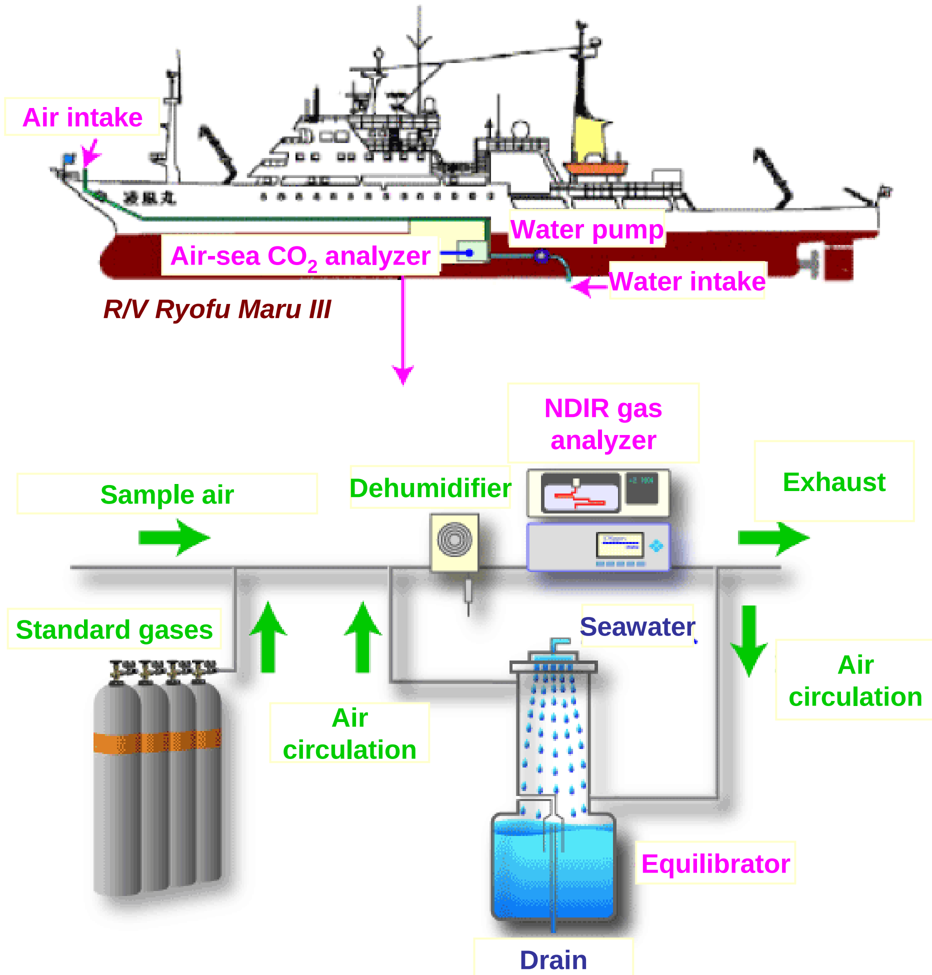
  - Long-term trend
- On-going repeat observations

2. Dissolved inorganic carbon (DIC or TCO_2) in the water columns

- Data synthesis
  - Anthropogenic CO_2
  - Decadal trend
- On-going repeat observations
  - Implementation plan for the PICES CO_2 data synthesis

What is the partial pressure of CO_2 "in seawater" ?



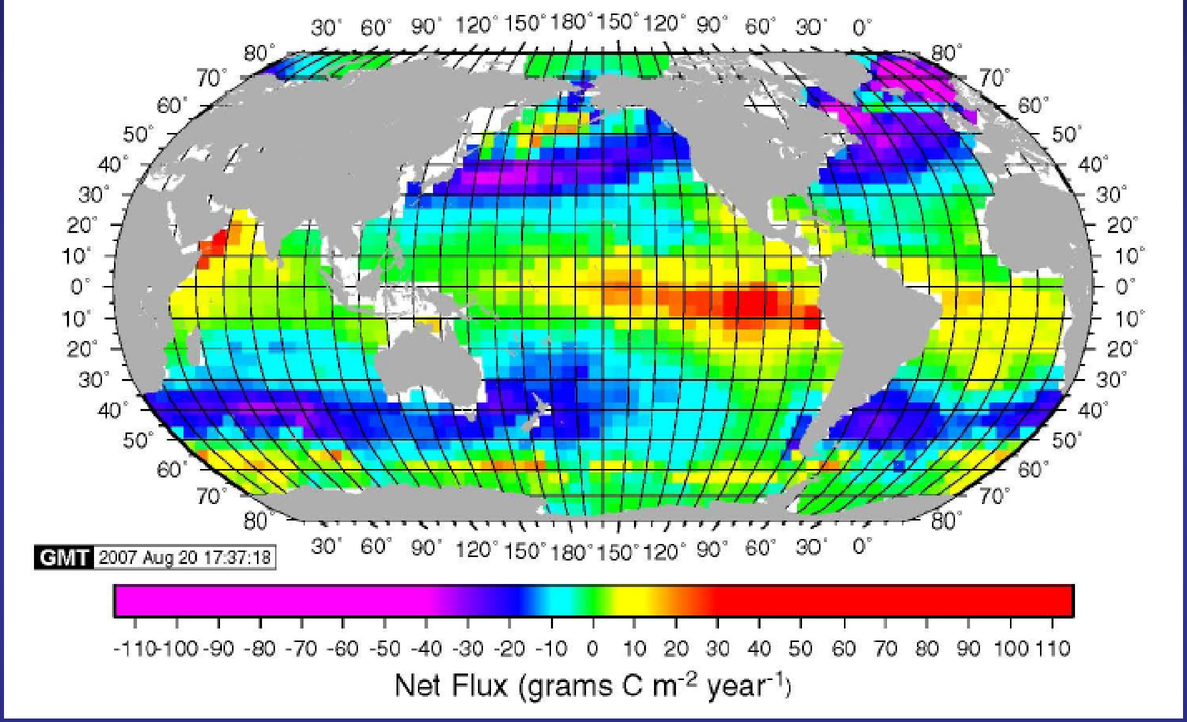
http://www.data.kishou.go.jp/kaiyou/db/co2/knowledge/observation.html

It is the partial pressure of CO_2 in an aliquot of air that is in equilibrium with a great excess of seawater.

It quantitatively indicates the status of super-saturation or under-saturation of CO_2 in seawater with respected to the atmospheric CO_2, and is the key parameter in discussing the air-sea CO_2 flux.

Climatological air-sea CO_2 flux

From 3 million pCO_2 data from 1970 to 2006



Air-sea CO_2 Flux

$= k\, K_0\, (pCO_2sw - pCO_2air)$

K : CO_2 transfer piston velocity

K_0 : CO_2 solubility in seawater

Mean annual air-sea CO_2

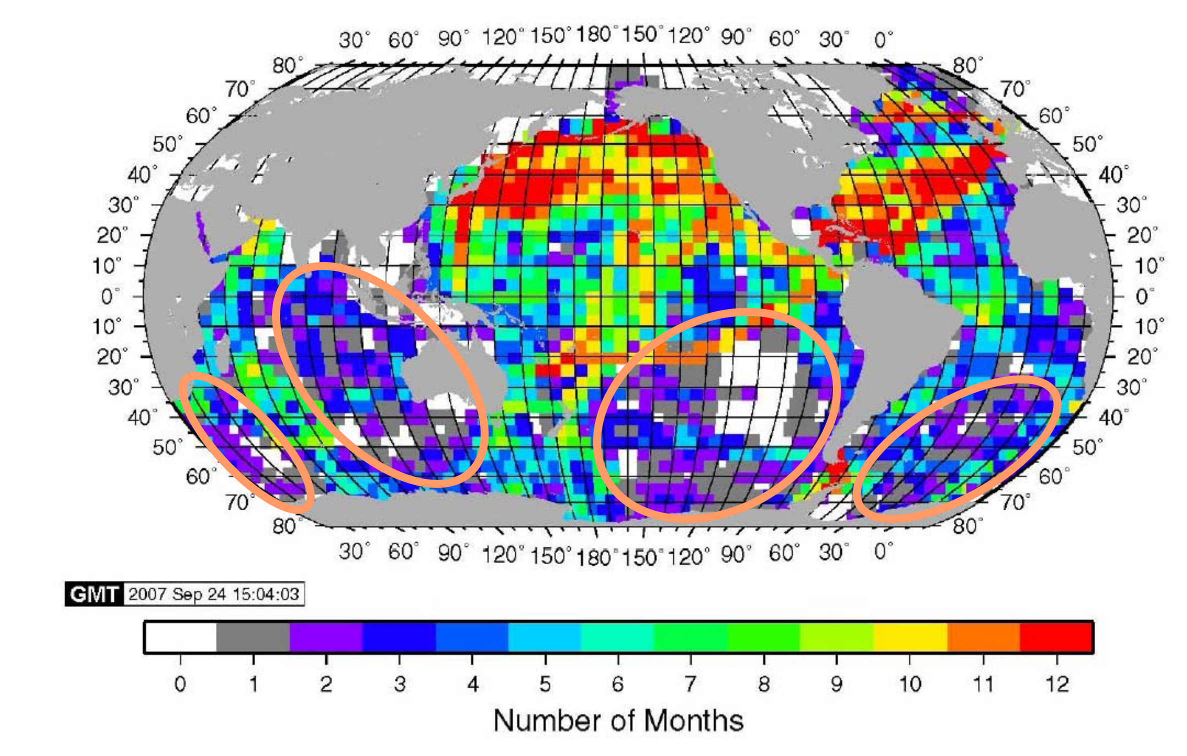
$= -1.4 \pm 0.7$ PgC yr^{-1}

Takahashi et al. submitted

Usefulness :
- ✓ Understanding ocean carbon cycle processes
- ✓ Validating prognostic ocean carbon cycle models
- ✓ Constraining atmospheric CO_2 inversions

Problems :
- ✓ Uncertainty in the piston velocity
- ✓ Undersampling in space and time

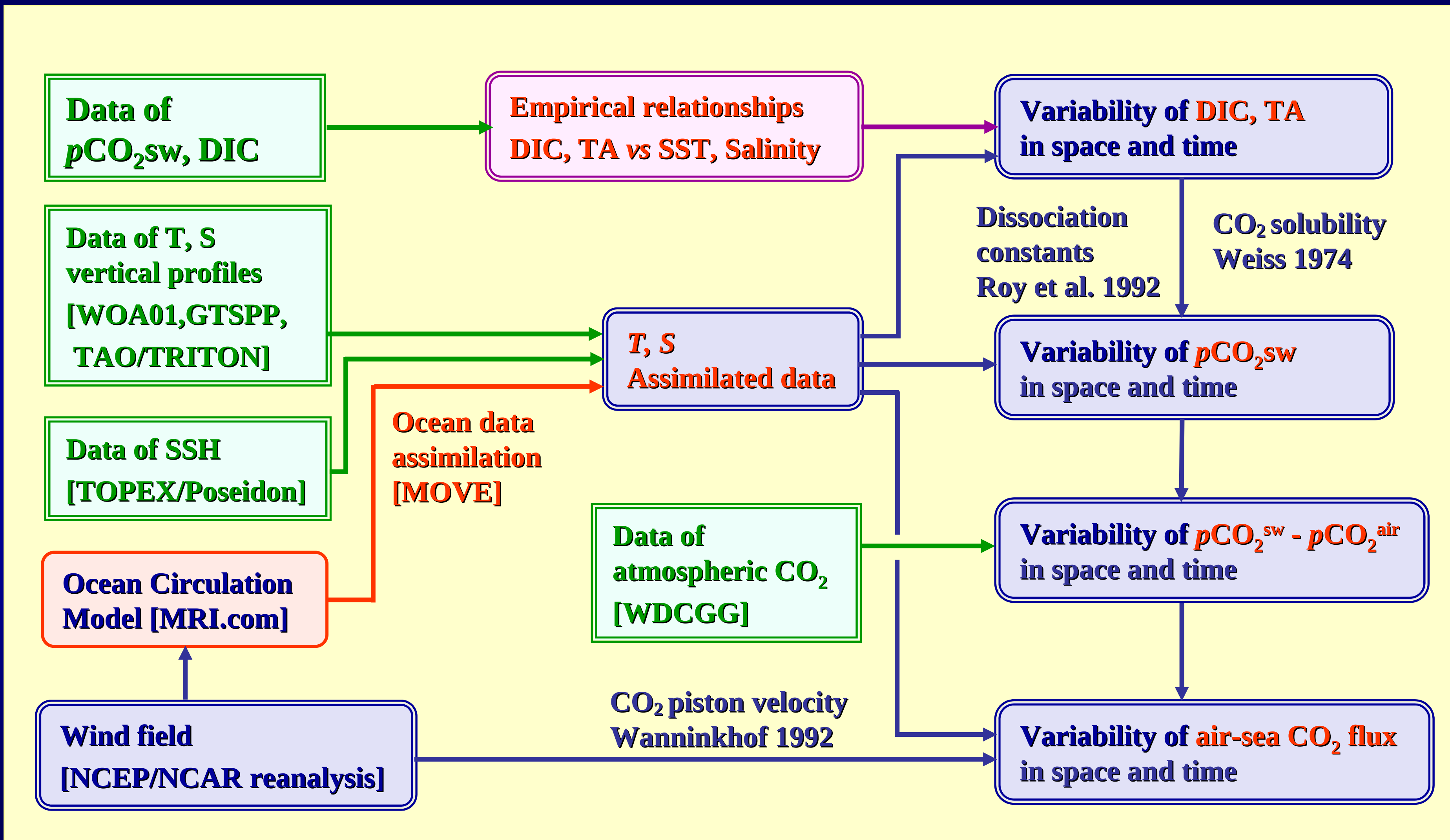
Number of months observation of $p\mathrm{CO_2}$sw



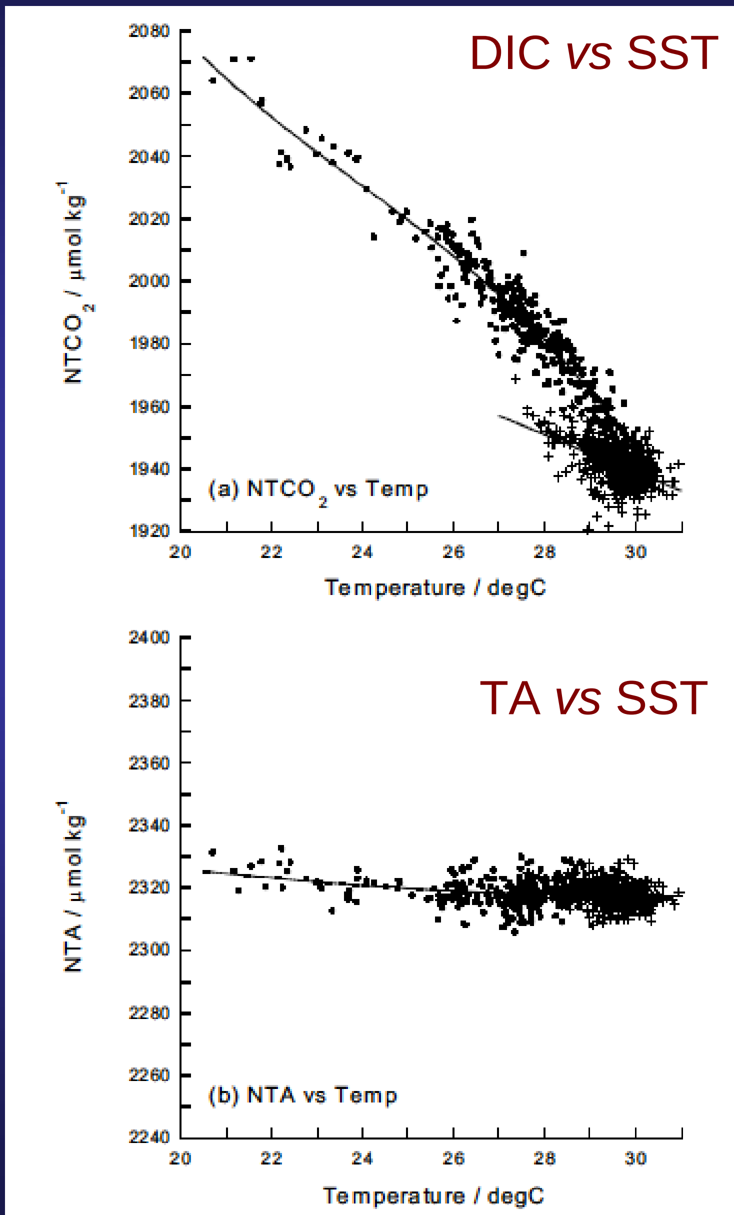
Oceans in the southern hemisphere have been badly undersampled.

To fill these gaps, an autonomous $p\mathrm{CO_2}$ sensor on a small float is now under development at MIO/JAMSTEC

An empirical method to estimate the variability in space and time



Empirical relationship between DIC and TA *vs* SST and Salinity



Equatorial Divergence zone ($s > 34.6$)

$ntco_2$

$= 0.448 + 0.014y - 0.790t + 0.164s - 0.136t^2 + 0.305ts - 0.457s^2 + 0.016t^3 - 0.190t^2s + 0.319ts^2 - 0.007s^3$

Warm / fresh pool ($s \leqq 34.6$)

$ntco_2$

$= -0.178 + 0.012y - 0.776t + 0.021s + 0.107t^2 - 0.003ts - 0.008s^2$

Uncertainty : ±6.8 μmol kg^{-1} (divergence zone)
±6.3 μmol kg^{-1} (warm/fresh pool)

$nta = 6.396 - 0.053\,t + 0.015t^2$

Uncertainty : ±3.6 μmol kg^{-1}

where

$ntco_2 = (NTCO_2/\mu mol\ kg^{-1} - 2000)/50$

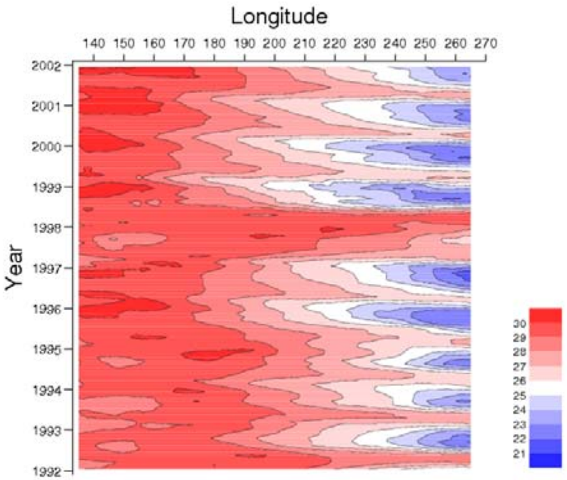
$nta = (NTA - 2000)/50$

y = year - 1995

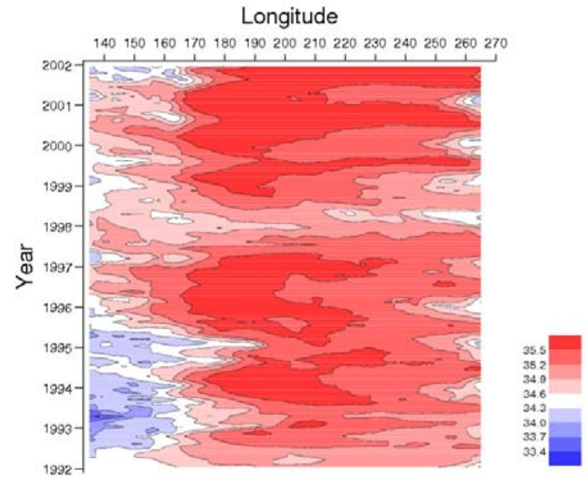
$t = (SST/^{o}C - 25)/3$

$s = (SSS - 35)/0.5$

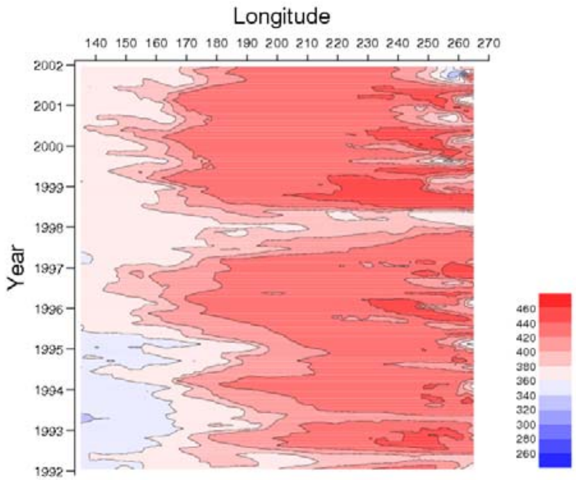
Time (1992-2001) - longitude (135° E - 85° W) distributions in the equatorial Pacific (mean of 0° - 5° S)



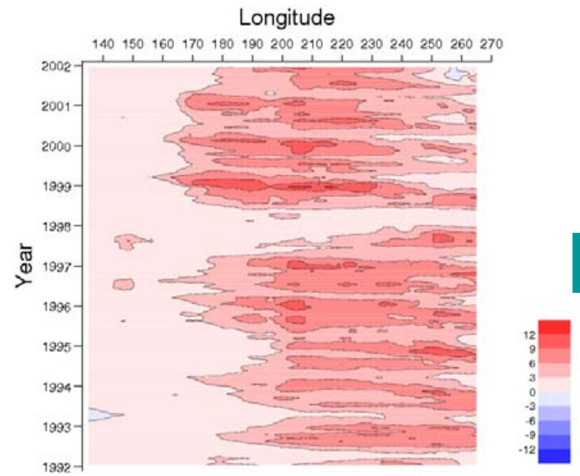
SST (satellite)



Salinity (data assimilation)



pCO_2sw



Air-sea CO_2 flux

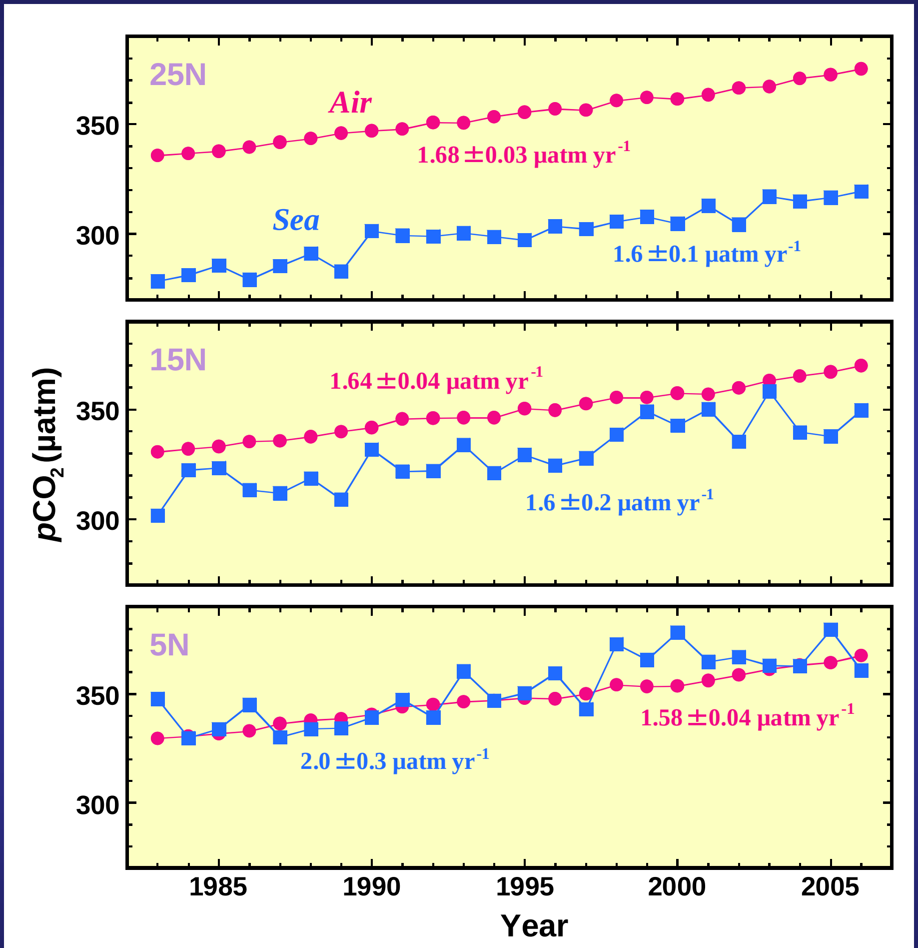
+0.2 PgC yr^{-1}
(El Nino)

to

+0.6 PgC yr^{-1}
(La Nina)

Long-term trend of pCO_2sw in the subtropical zone

137° E line

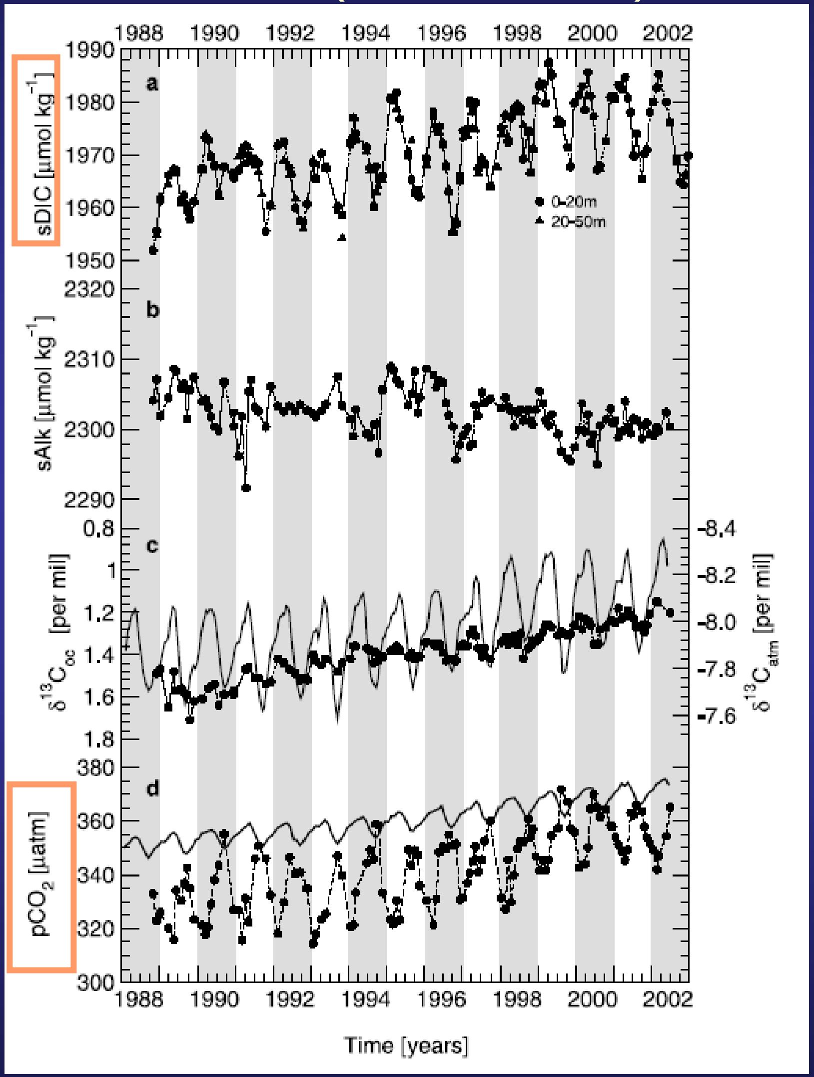


Observation have been made every late January since early 1980s.

Inoue et al., *Tellus,* 1995..

Midorikawa et al., *Geophys. Res. Lett.,* 2005.

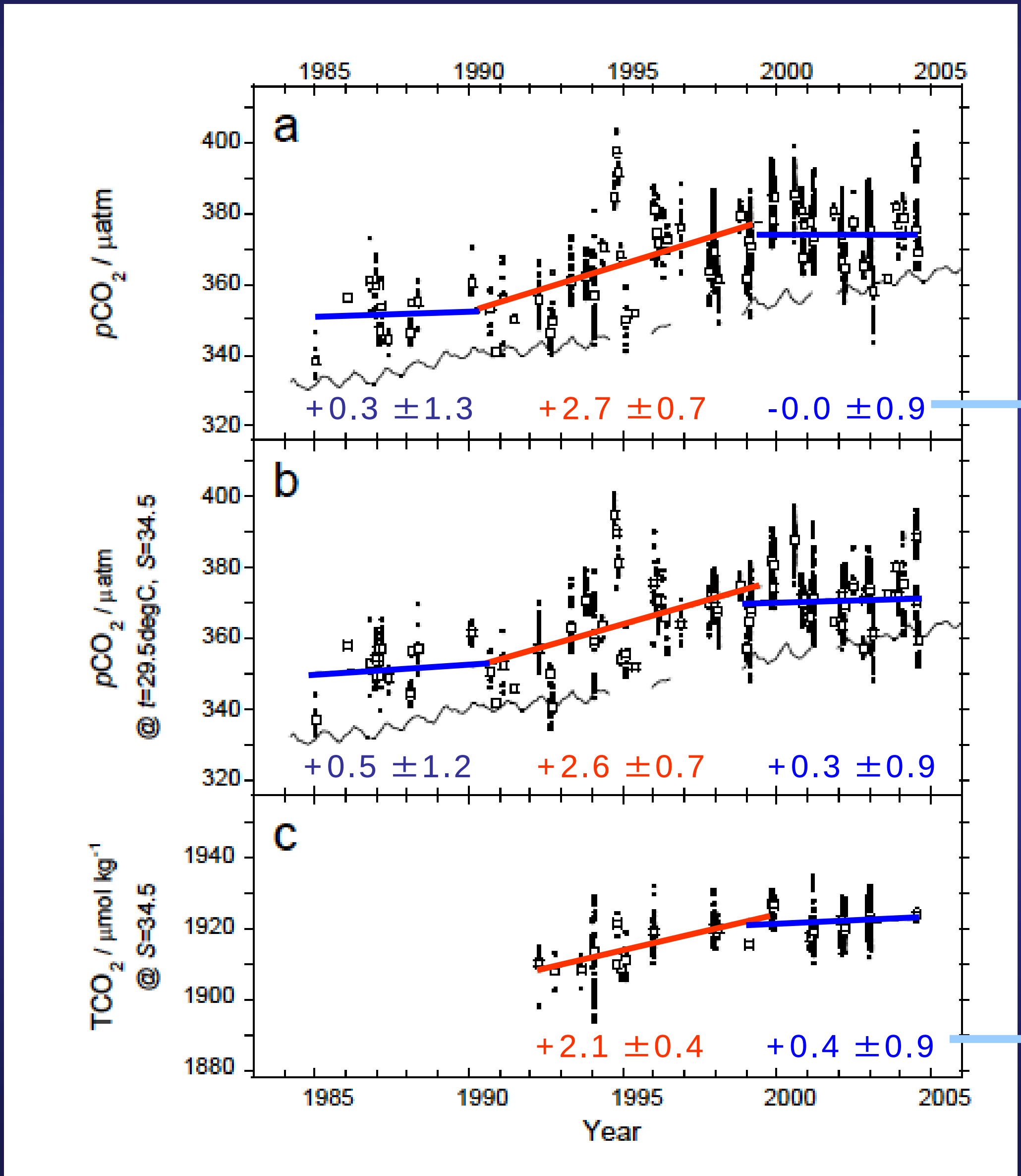
ALOHA (near Hawaii)



Dore et al., *Nature,* 2003.

Keeling et al., *Global Biogeochem. Cycles,* 2004.

Long-term trend of pCO_2sw in the western equatorial Pacific warm pool



Salinity ≤ 34.8,
SST ≥ 29.0 ºC
$\sigma_t \geq 21.4$

Increasing rate / µatm yr^{-1}

pCO$_2$sw is increasing, but it is likely that the increase rate is changing in decadal time-scale.

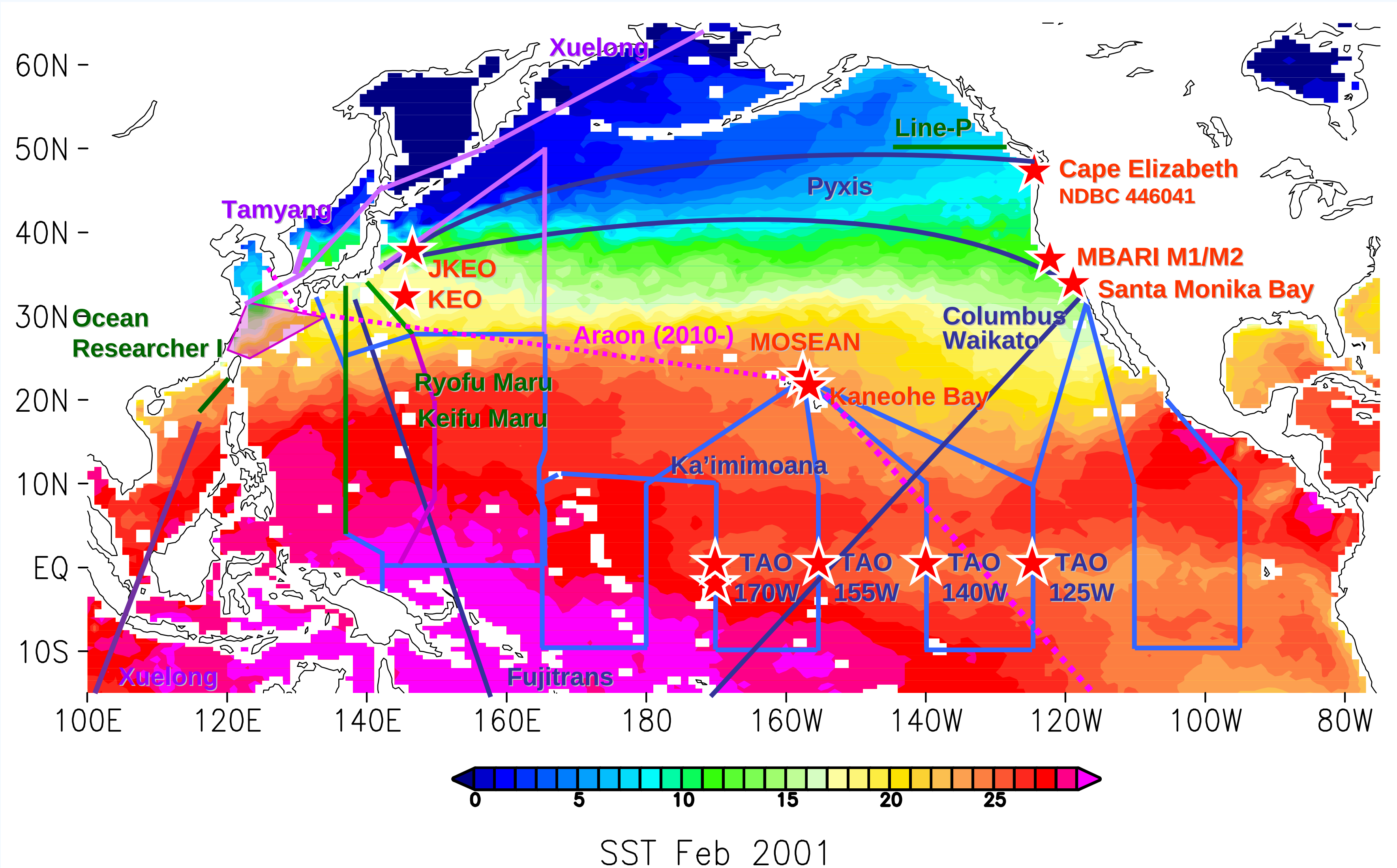
Increasing rate / µmol kg^{-1} yr^{-1}

Ishii et al. submitted

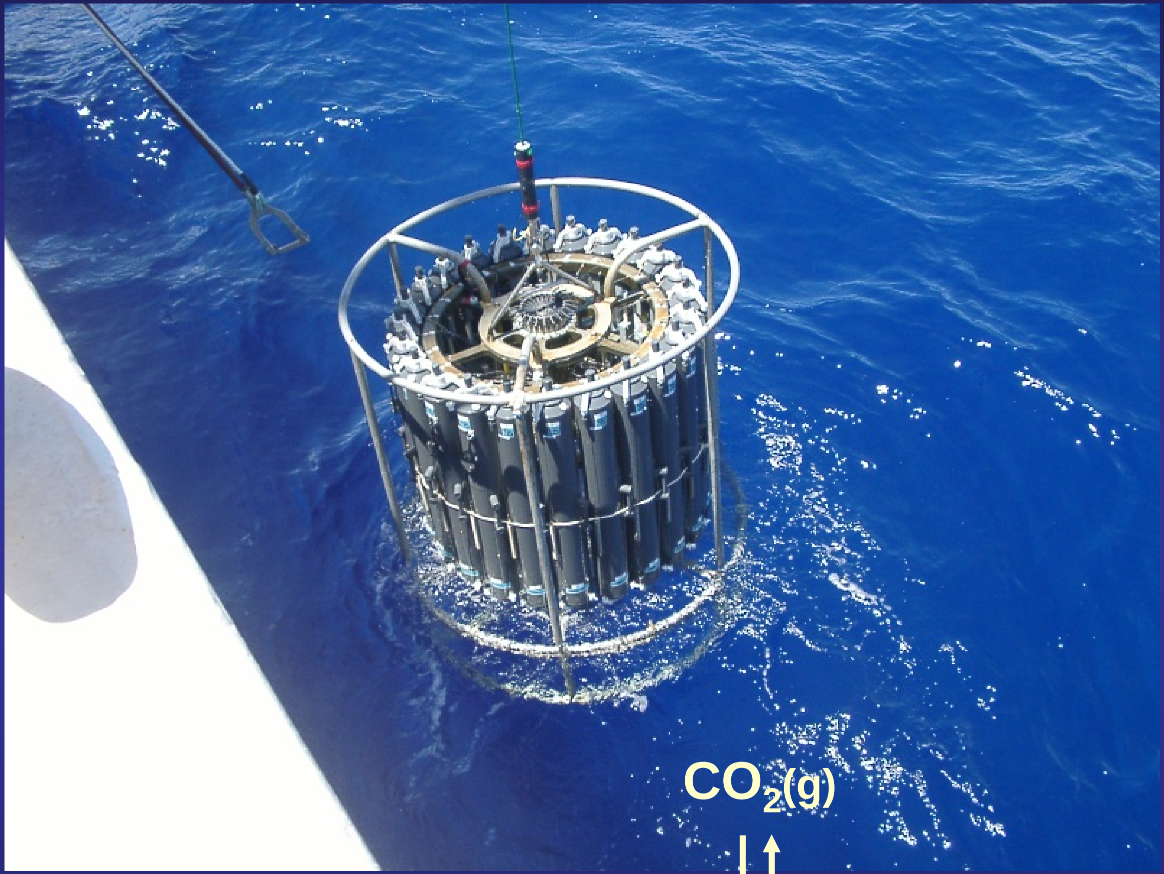
Moorings and underway observations for near-surface water CO_2

★ Continuous

Monthly, Bimonthly — Seasonal — Biannual — Annual



Dissolved Inorganic Carbon (DIC) at depths



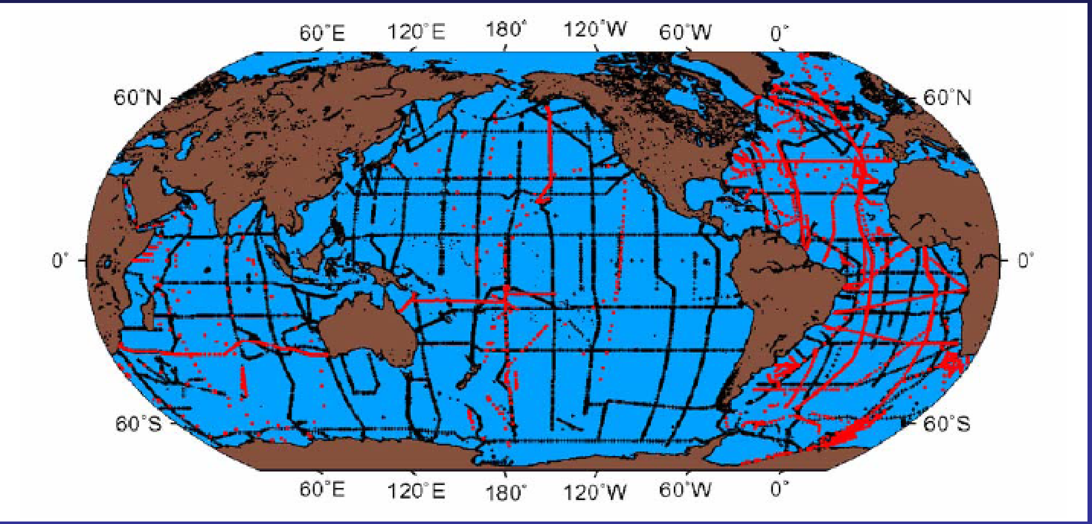
$CO_2(g)$

⇅

DIC: $CO_2(aq)^* \underset{}{\overset{-H^+(aq)}{\rightleftharpoons}} HCO_3^-(aq) \underset{}{\overset{-H^+(aq)}{\rightleftharpoons}} CO_3^{2-}(aq)$

$= pCO_2sw \cdot K_0$

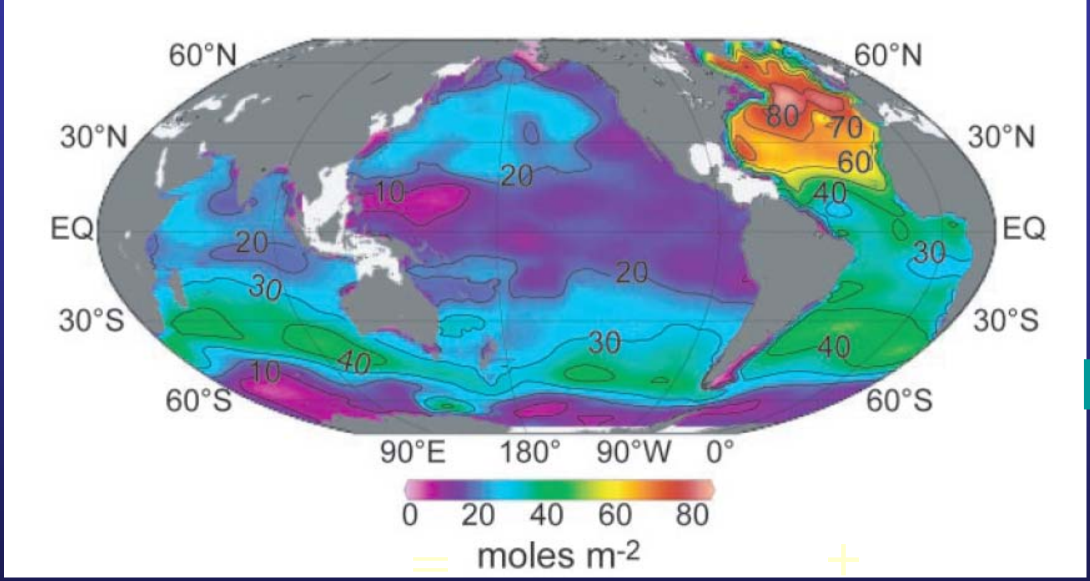
Global CO_2 Survey in the 1990s : a benchmark



~72,000 sample locations collected in the 1990s with precisions of

± 2 µmol kg^{-1} for DIC (± 2/2000)

± 4 µmol kg^{-1} for TA (± 4/2200)



Sabine et al. 2004

Emissions from fossil fuel and cement production

244 ± 20 PgC (1800 - 1994)

Storage in the atmosphere

165 ± 4 PgC

Uptake and storage in the ocean

118 ± 19 PgC

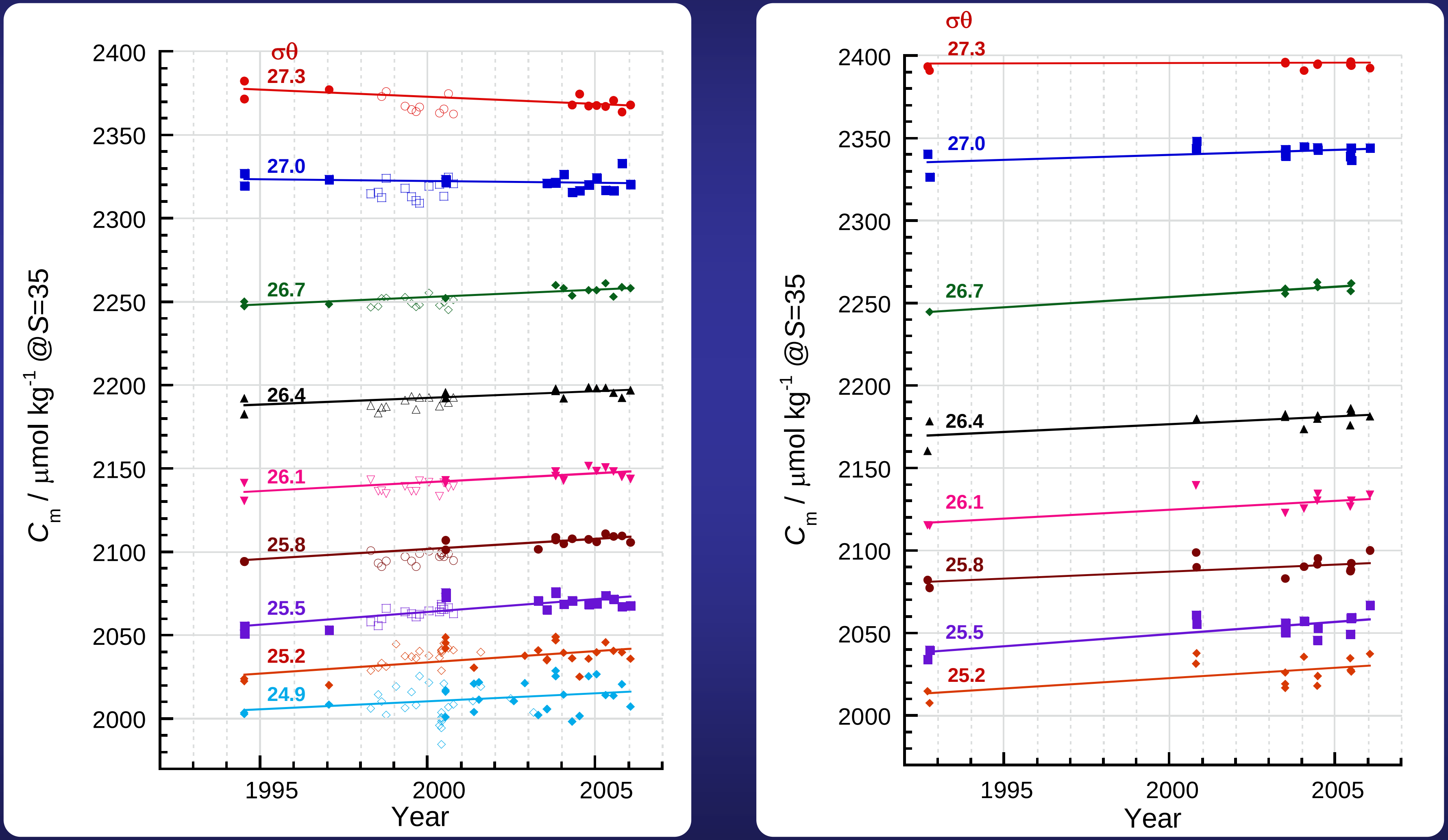
Net terrestrial balance

-39 ± 28 PgC

Trend of DIC on Isopycnal Surfaces

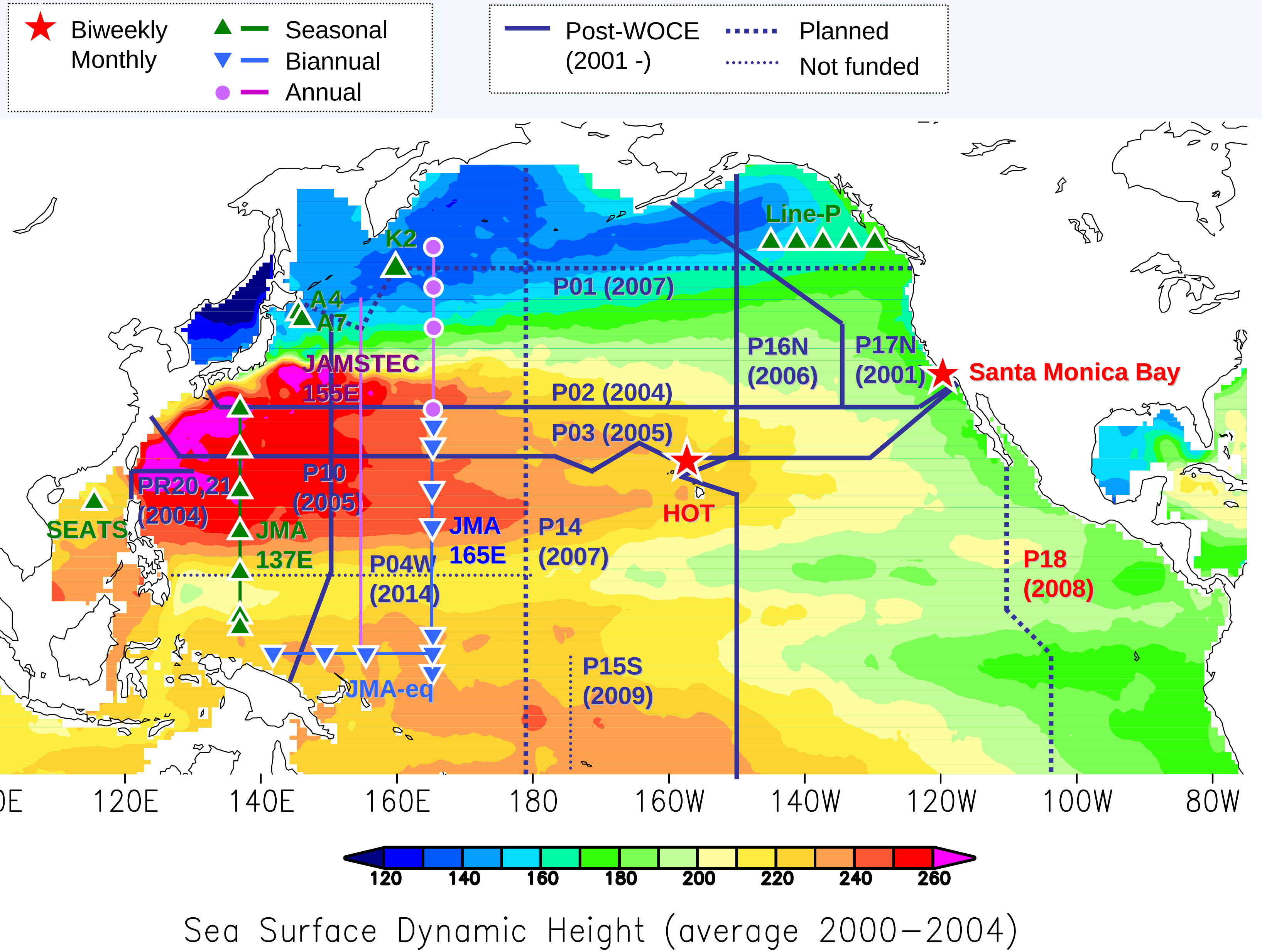
137°E, 27.5°- 31.5°N & **135.25°E**, 29.5°N

165°E, 28°- 30°N,



At both sites, significant increasing trends of DIC have been observed at $24.9 \leqq \sigma_\theta \leqq 26.8$

Time-series stations and repeat lines for water column CO_2



Water column CO_2 data synthesis in the Pacific Ocean is now underway

- **Planned** as an activity of

  "The North Pacific Marine Science Organization, Carbon and Climate Section (PICES CC-S)"

  Co-chair : T. Saino (Nagoya U.) and J. Christian (Victoria U.)
  Working group: R. Feely (PMEL), M. Ishii (MRI), A. Kozyr (CDIAC), A. Murata (JAMSTEC), C. Sabine (PMEL), T. Suzuki (MIRC), N. Tsurushima (AIST)

- **Overall goals:**
  - Create a quality controlled data base of water column CO_2 related data for the Pacific.
  - Estimate anthropogenic CO_2 and natural variability in the Pacific from regional to basin scales.

- **Data submission deadline :** January 2009.

- **Implementation plan**

  http://www.pices.int/members/sections/CC.aspx

Thank you