Decadal Change in the Rate of Ocean Acidification in the Western Pacific Equatorial Zone

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Tropical and subtropical zones of the western Pacific Ocean accommodate many coral reef habitats and marine biodiversity hotspots where humans critically depend upon them, and the long-term impact of global CO$_2$ increase on coral reef environments could be particularly large.
JMA’s ocean CO$_2$ monitoring at 137ºE repeat line in the western North Pacific

Posters: 54: Enyo et al.
106: Kosugi et al.

Midorikawa et al., *Tellus* 2010; *GRL.*, 2012.
Contents

- Spatial and inter-annual variability in the distributions of carbonate parameters in the western equatorial Pacific.
- Long-term trend of ocean acidification in the western equatorial Pacific warm pool for the past 27 years.
High SST, low salinity, low $pCO_2$, and low TCO$_2$ in the western equatorial Pacific warm pool

- $pCO_2$
- SST
- NTCO$_2$
- SSS

Jan. 2002

High SST, low salinity, low $pCO_2$, and low TCO$_2$ in the western equatorial Pacific warm pool
Inter-annual variability of surface CO$_2$ distributions associated with El Niño Southern Oscillation

$pCO_2$

SST

NTCO$_2$

SSS

Jan. 2001
Jan. 2002
Jan. 2003

Longitude

$SST/°C$

$NTCO_2/\mu$mol$kg^{-1}$

$SSS$

Longitude
Large variability in pH and Ω and little variability in NTA
Long-term trend of ocean acidification in the western equatorial Pacific warm pool for the past 27 years.

**Method**

1. **CO₂ fugacity** in surface water
   - in the warm pool:
     - $T /{°C} \geq 29.0$
     - $S \leq 34.8$
     - $\sigma_t \geq 21.8$

2. **Total alkalinity**
   - $2300 \, \mu\text{mol kg}^{-1}$ at $S=35$

3. **SST, SSS**
   - Dissociation constants of carbonic acid: Lueker et al., 2000.

**Data**

1. **SOCAT V1.5** [1984 - 2008]
2. Historical $p\text{CO}_2$ data
3. JMA’s $p\text{CO}_2$ monitoring data [2009 - 2011]
4. **GLODAP + PACIFICA** [1992 - 2007]
5. Underway $p\text{CO}_2$ / TCO₂ measurements by MRI and JAMSTEC [1994 - 2003]

**TCO₂, pH@SST, Ωarag, Ωcal**
TCO$_2$ and TA measurements in the western equatorial Pacific

GLODAP + PACIFICA
- warm pool
- divergence zone

$pCO_2$-TCO$_2$ underway measurements
- warm pool
- divergence zone.

NTA shows little variability both in space and time over the western equatorial Pacific.
Trends of $fCO_2$ and NTCO$_2$

in the western equatorial Pacific warm pool

Data distribution

Christmas Is. (Kiribati) by NOAA/ESRL

Rate of change

$fCO_2$$_{sw}$ : $+1.31 \pm 0.14$ μatm yr$^{-1}$

$fCO_2$$_{air}$ : $+1.64 \pm 0.01$ μatm yr$^{-1}$

NTCO$_2$ : $+0.77 \pm 0.08$ μmol kg$^{-1}$ yr$^{-1}$
Trends of $f\text{CO}_2$ and NT$\text{CO}_2$

in the western equatorial Pacific warm pool

Data distribution

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NT$\text{CO}_2 : +0.77 \pm 0.08 \mu\text{mol kg}^{-1} \text{ yr}^{-1}$
Trends of pH, $\Omega_{\text{calc}}$ and $\Omega_{\text{arag}}$ in the western equatorial Pacific warm pool

**Rate of change**

- pH$_@$SST: $-0.0013 \pm 0.0001$ yr$^{-1}$
- $\Omega_{\text{calc}}$: $-0.012 \pm 0.001$ yr$^{-1}$
- $\Omega_{\text{arag}}$: $-0.008 \pm 0.001$ yr$^{-1}$
Trends of pH, $\Omega_{\text{calc}}$ and $\Omega_{\text{arag}}$

in the western equatorial Pacific warm pool

Rate of change

$pH_{@\text{SST}}: -0.0013 \pm 0.0001 \text{ yr}^{-1}$

$\Omega_{\text{calc}}: -0.012 \pm 0.001 \text{ yr}^{-1}$

$\Omega_{\text{arag}}: -0.008 \pm 0.001 \text{ yr}^{-1}$
Changes in the mean rate for each decade

atmospheric CO₂ rise & buffer factor

\( f_{CO_2sw} \)

Linear rate

\( d\text{CO}_2/dt \) (µatm yr\(^{-1}\))

\( d\text{NTCO}_2/dt \) (µmol kg\(^{-1}\) yr\(^{-1}\))

\( d\text{pH}_{@SST} \) (yr\(^{-1}\))

\( d\Omega_{arag}/dt \) (yr\(^{-1}\))
Conclusions

- The progress of ocean acidification as a result of the increase of CO$_2$ content was evidenced in the western equatorial Pacific warm pool.

- In the long-term (1985 – 2011), rates of change in $f$CO$_2$, NTCO$_2$, pH and $\Omega$s are slightly slower than those estimated from the rate of the atmospheric CO$_2$ increase and buffer factor.

- However, these rates varied significantly with the period of observation.
Future works

- We need to continue ocean CO$_2$ monitorings both in open oceans and in coastal regions for long-term.
- What control the ocean acidification in such a calm warm pool region;
  - sea-air CO$_2$ exchange in the equatorial Pacific?
  - and/or
  - anthropogenic CO$_2$ transport via the shallow meridional overturning circulation from the South and the North Pacific?
- Any feedbacks from the ocean climate variability?