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An overview of the ocean CO_2 increase in the western North Pacific subtropical and tropical zones

(S10-8179)

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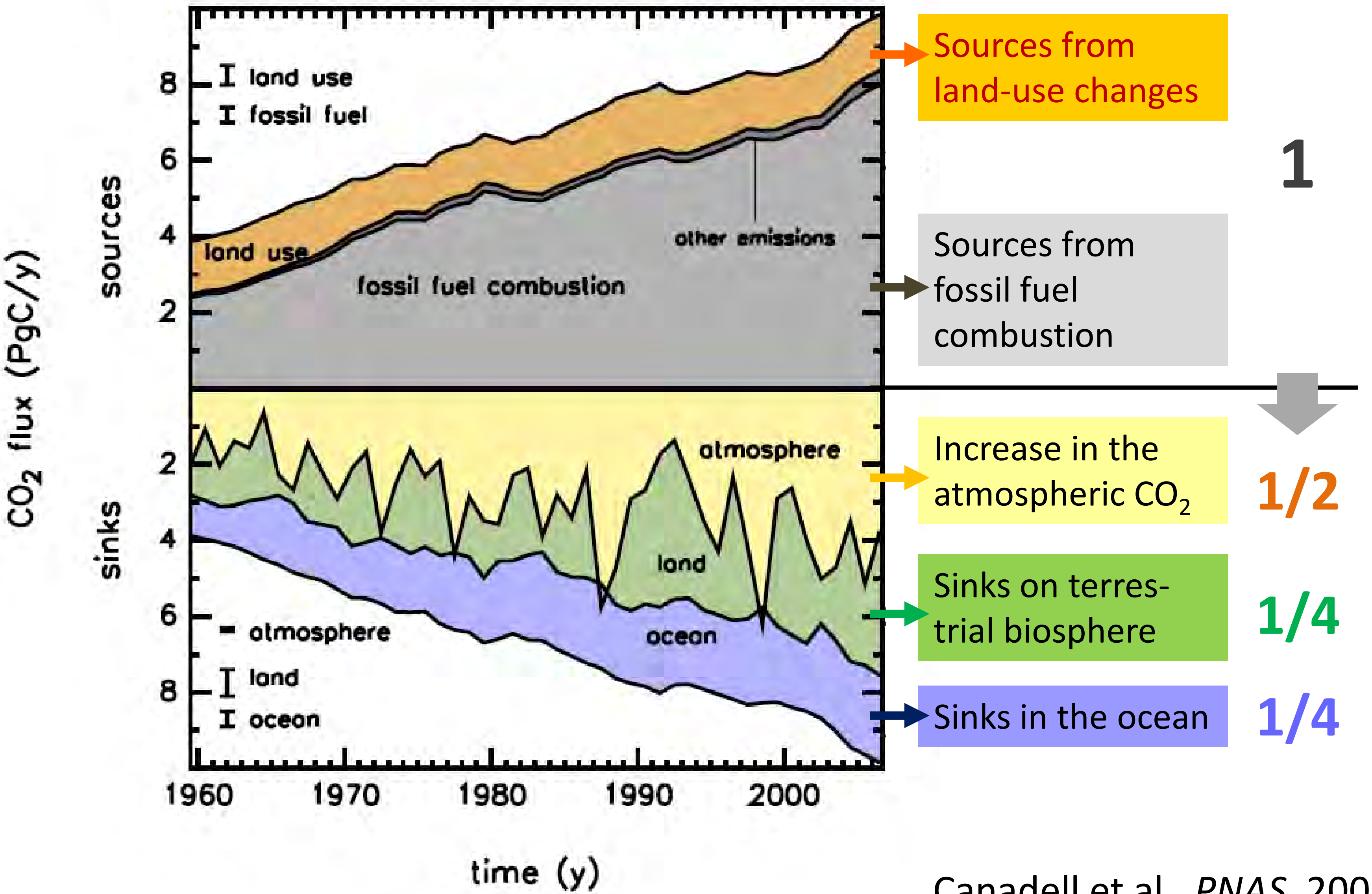
Background:

Ocean is a major sink of the anthropogenic CO_2



Canadell et al., *PNAS*, 2007

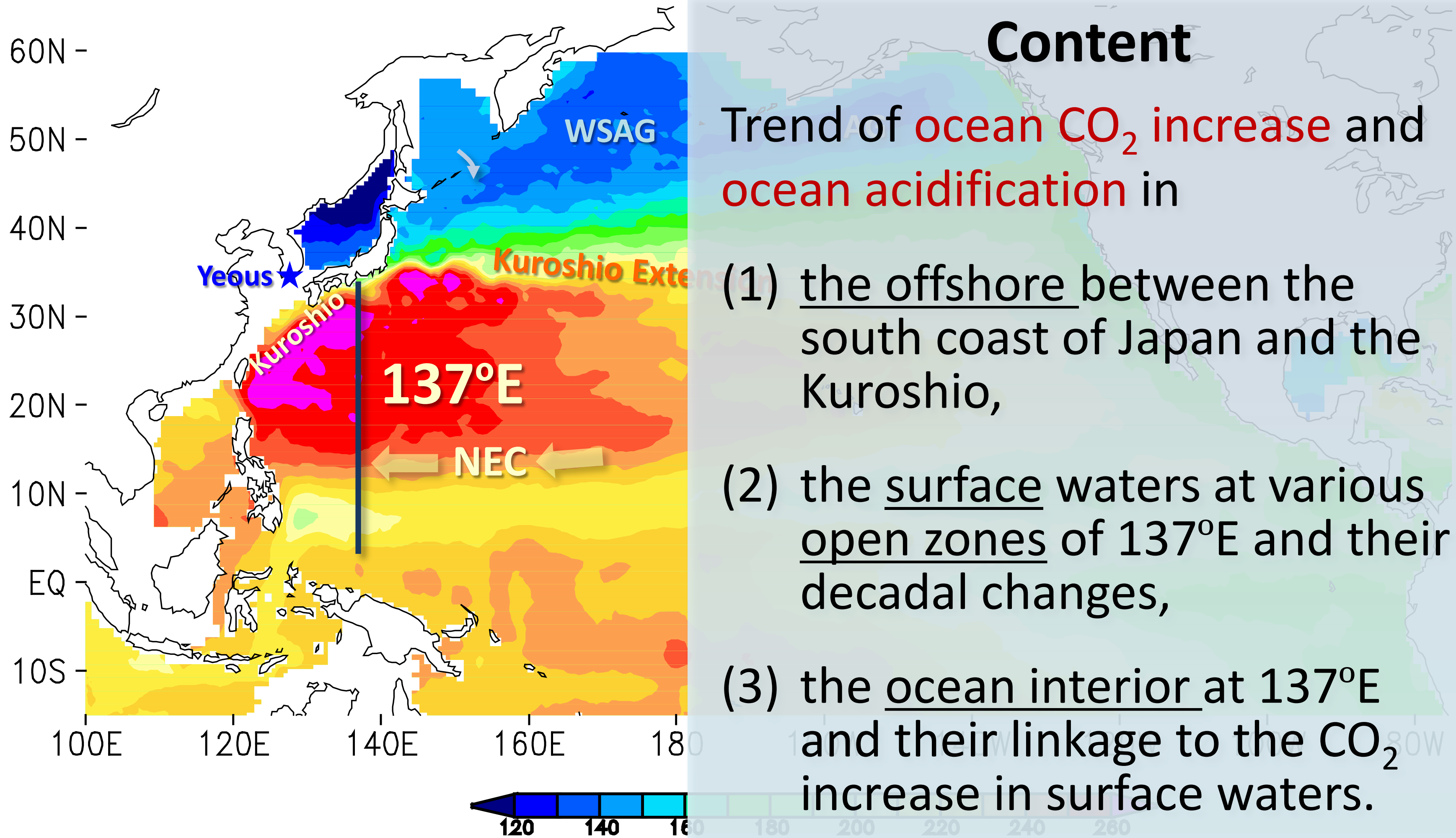
Seawater becomes less basic by absorbing CO_2

This phenomenon is caused by the anthropogenic CO_2 increase in the atmosphere and is referred to as **"ocean acidification"**.

$$CO_2(g)$$
$$\downarrow\uparrow$$
$$H_2O + CO_2(aq)$$
$$\downarrow\uparrow$$
$$H_2CO_3(aq)$$
$$\downarrow\uparrow$$
$$H^+ + HCO_3^-(aq)$$
$$\downarrow\uparrow$$
$$2H^+ + CO_3^{2-}(aq)$$

- CO_2 reacts with water molecule to form carbonic acid and release hydrogen ion (H^+) to seawater .
- The increase in the concentration of H^+ (reduction of pH) results in the decrease in the carbonate ion (CO_3^{2-}) concentration.
- This makes calcifying organisms difficult to form carbonate shell, and leads to serious consequence for marine biodiversity and ecosystems.

Japan Meteorological Agency's repeat section at 137ºE



Sea Surface Dynamic Height (average 2000-2004)

Content

Trend of ocean CO_2 increase and ocean acidification in

(1) the offshore between the south coast of Japan and the Kuroshio,

(2) the surface waters at various open zones of 137ºE and their decadal changes,

(3) the ocean interior at 137ºE and their linkage to the CO_2 increase in surface waters.

Ocean acidification in the offshore zone
between the south coast of Japan and the Kuroshio

MODIS-Aqua (2005.05.04)
http://www.frontier.tuis.ac.jp/modis/
frontier/index.html

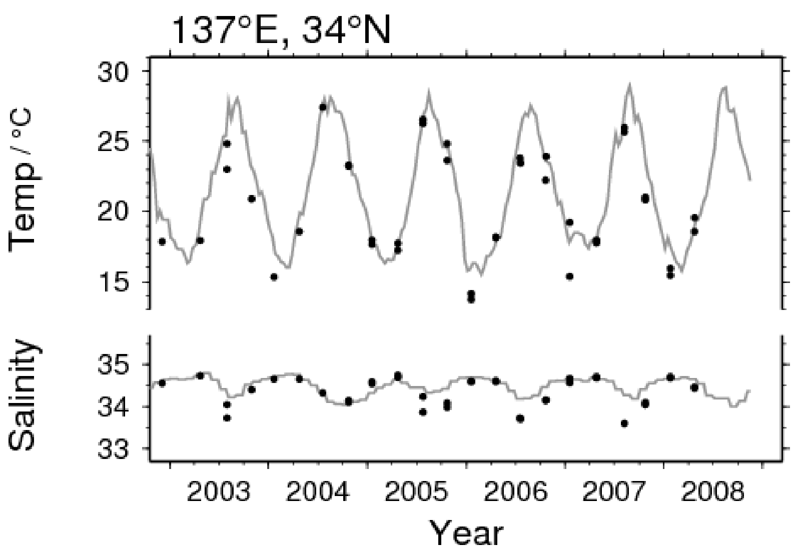
Physical

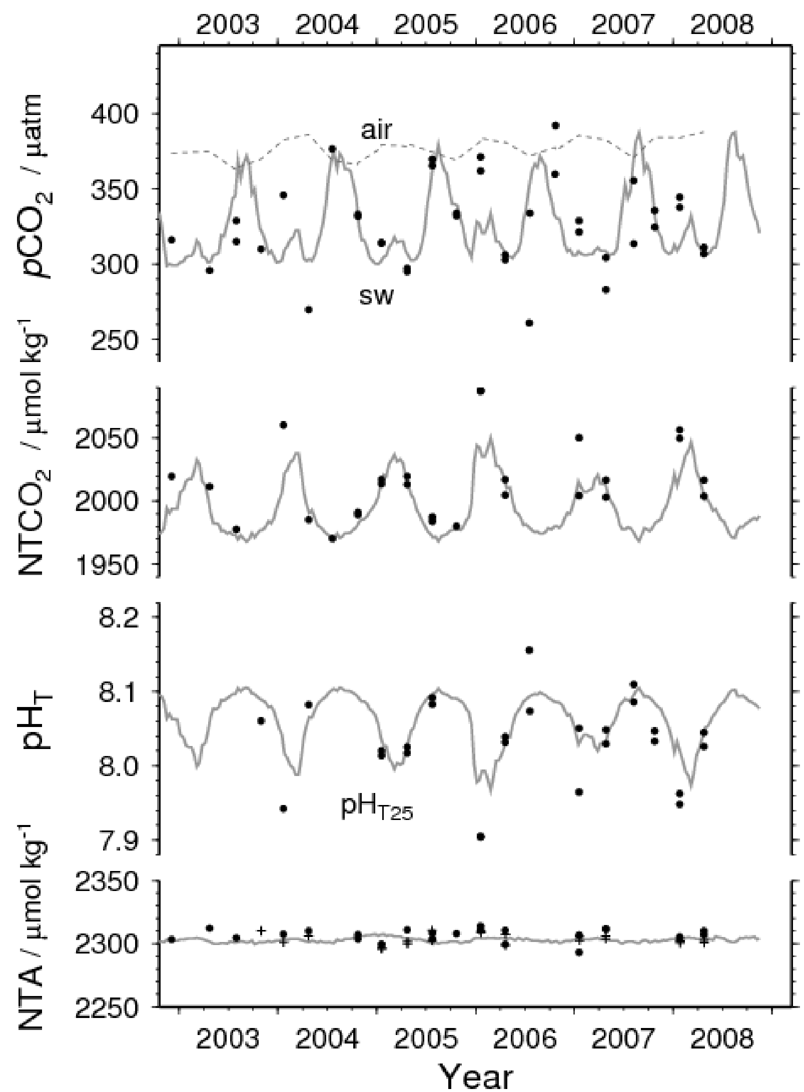
- Large influence on the coastal waters by tidal mixing.
- Large seasonal and regional SST variations.
- Meandering of Kuroshio also have a large effect on the variation of SST.

Biological

- High primary productivity
  (> 200 gC m^{-2} yr^{-1}) (Yokouchi et al., 2006)
- Large fish catch and the crop of aquaculture (MAFF, 2009)
  (470,000 tons in 2009 incl. 5,000 *t* of oyster)
- Habitat of a cocolithophore
  Gephyrocapsa oceanica (Kai et al., 1999)
- The northern limit of tropical reef corals' habitat in the N. Pacific
  (Yamano et al., 2010).

Large seasonal and regional variations in carbonate parameters in the offshore region



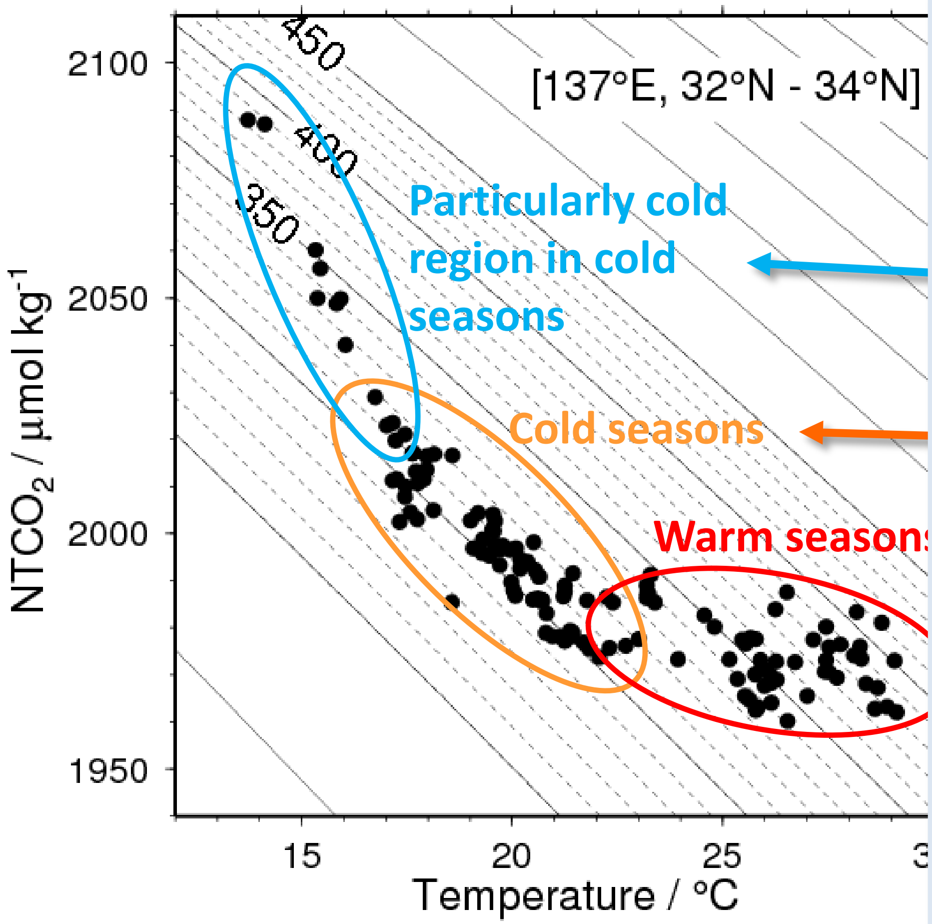


Satellite-derived SST (10-days mean, 1°x1°).
Salinity from MOVE-G ocean data assimilation (monthly, 1°x1°)

Results from multi-regressions. (10-days mean)

Ishii et al., *J. Geophys. Res.*, 116, 2011

A good correlation between $NTCO_2$ and SST



Multi-parameters regressions (1994-2008)

$NTCO_2$ / µmol kg^{-1}

$= 1980.1\ (\pm 4.0)\ +1.23\ (\pm 0.40) \cdot yr$

$-\ 6.61\ (\pm 0.69) \cdot sst + 1.05\ (\pm 0.08) \cdot sst^2$

$-\ 0.072\ (\pm 0.019) \cdot sst^3$

$-\ 13.0\ (\pm 5.6) \cdot sss \quad + \varepsilon$

NTA / µmol kg^{-1}

$= 2301.1\ (\pm 2.8)\ +0.13\ (\pm 0.29) \cdot yr$

$-\ 0.43\ (\pm 0.17) \cdot sst - 6.1\ (\pm 2.7) \cdot sss + \varepsilon'$

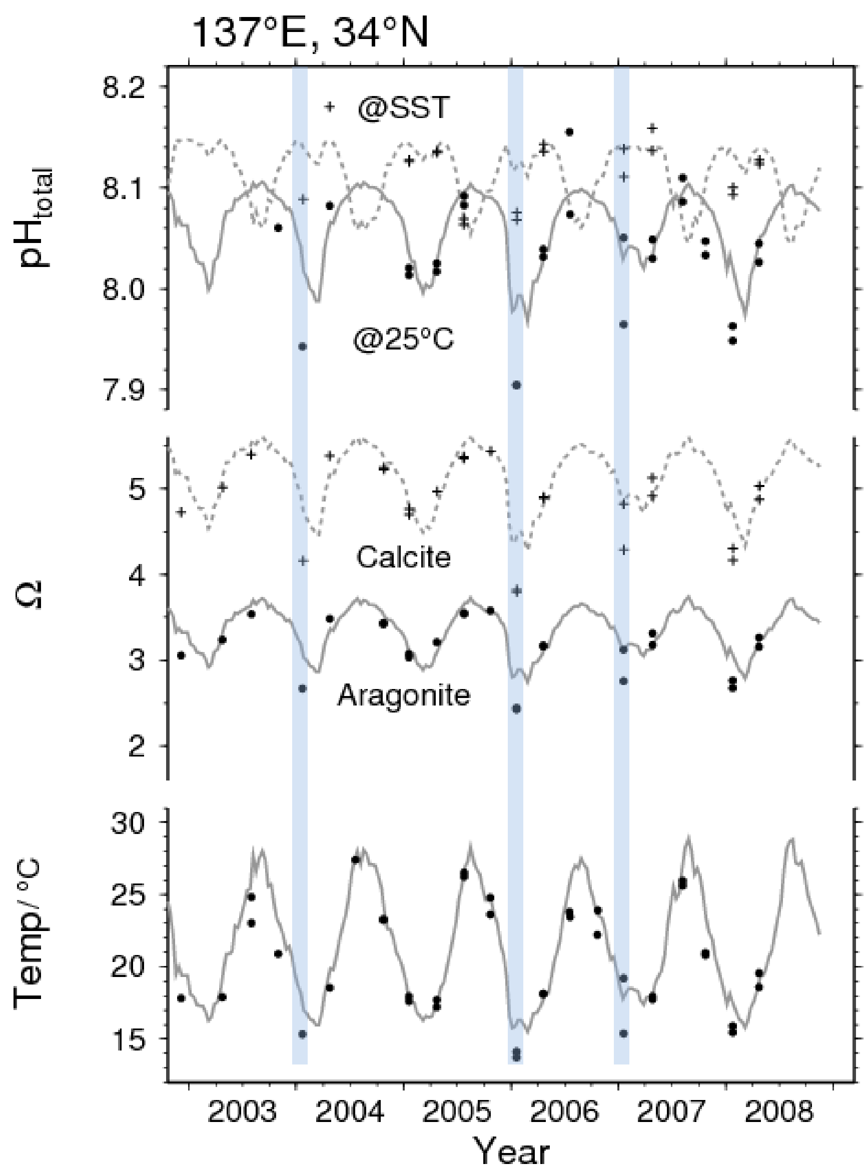
yr = Year – 2000, *sst* = temp./°C – 20.0, *sss* = salinity – 35.0.

Large seasonal and regional variations in pH and Ω

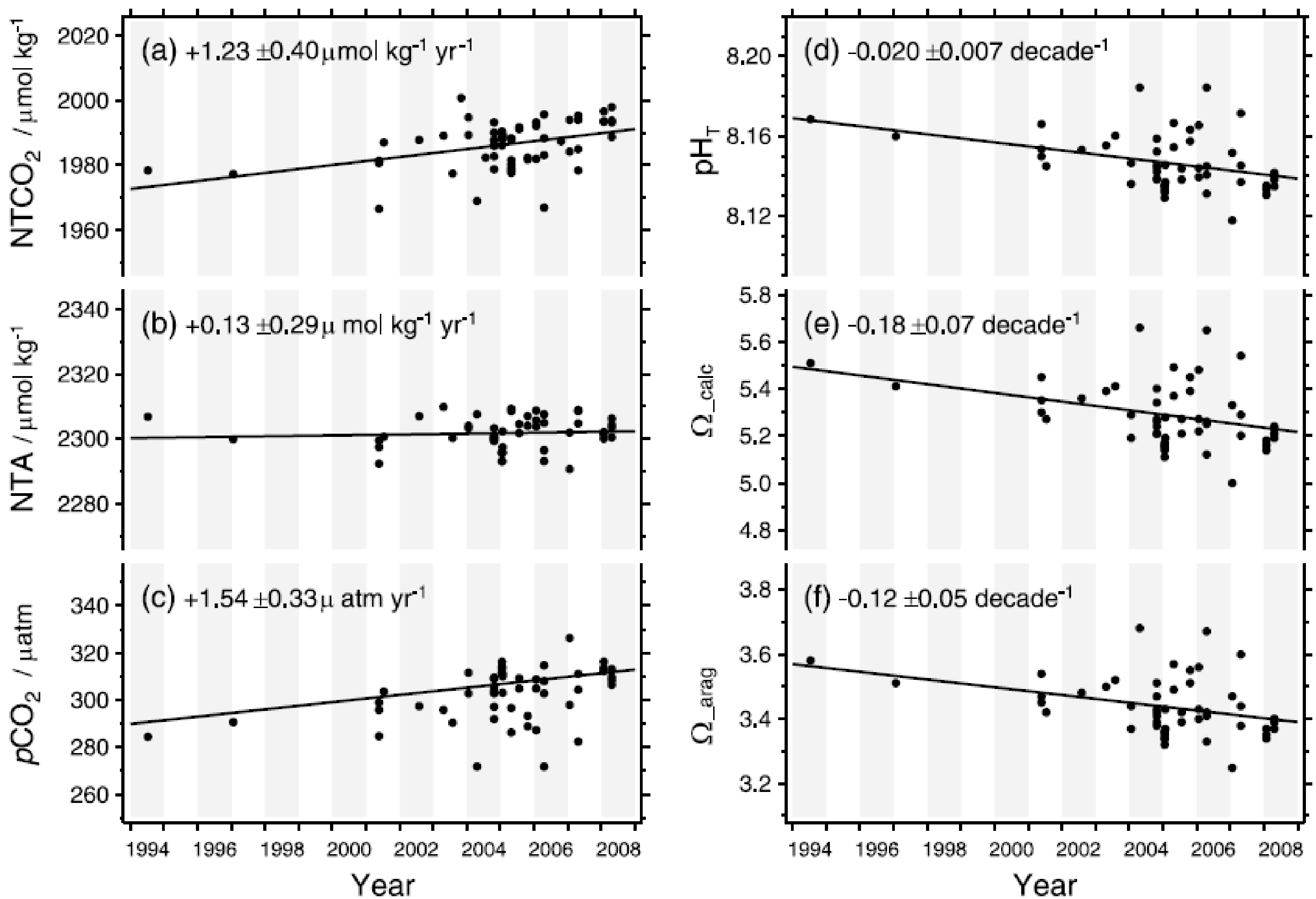
Ω : index of carbonate saturation
$= [Ca^{2+}][CO_3^{2-}] / K_{sp}'$

Carbonate saturation index Ω becomes lower in winter, because $NTCO_2$ becomes higher due to the enhanced vertical mixing.

In the cold events (SST ≤ 15°C) that are observed near the coast in winter, Ω becomes even lower ($2.5 < \Omega_{arag} < 3.0$).

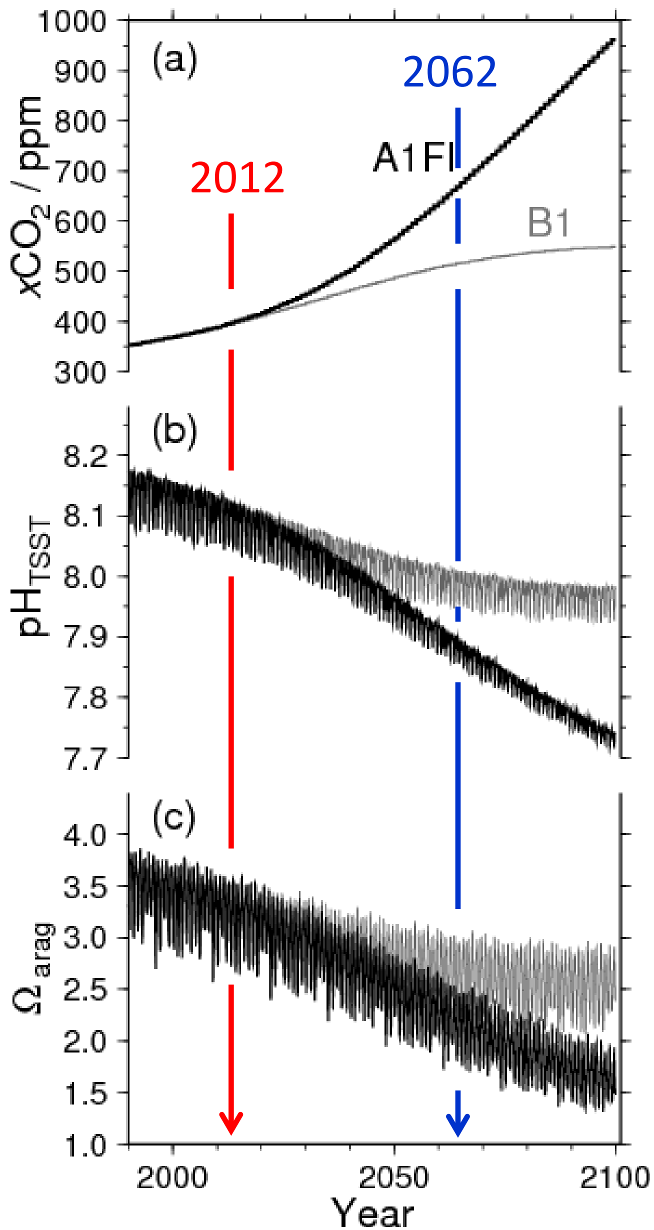


Seasonally detrended time series data indicate long-term trend of ocean acidification



Some spring data outlay because of the uncoupling of seasonal warming and biological net community production.

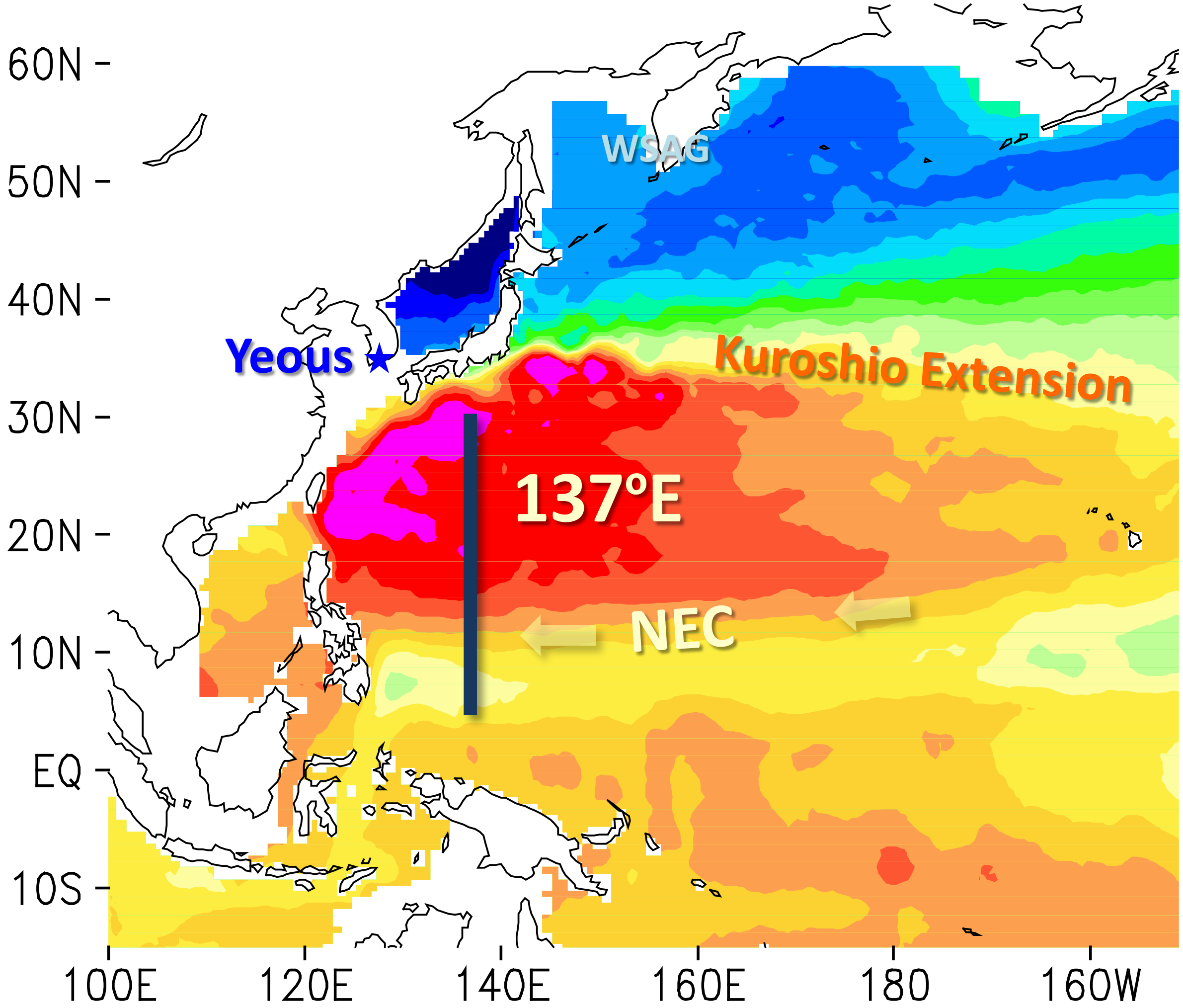
Ishii et al., *J. Geophys. Res.*, 116, 2011



Future projections

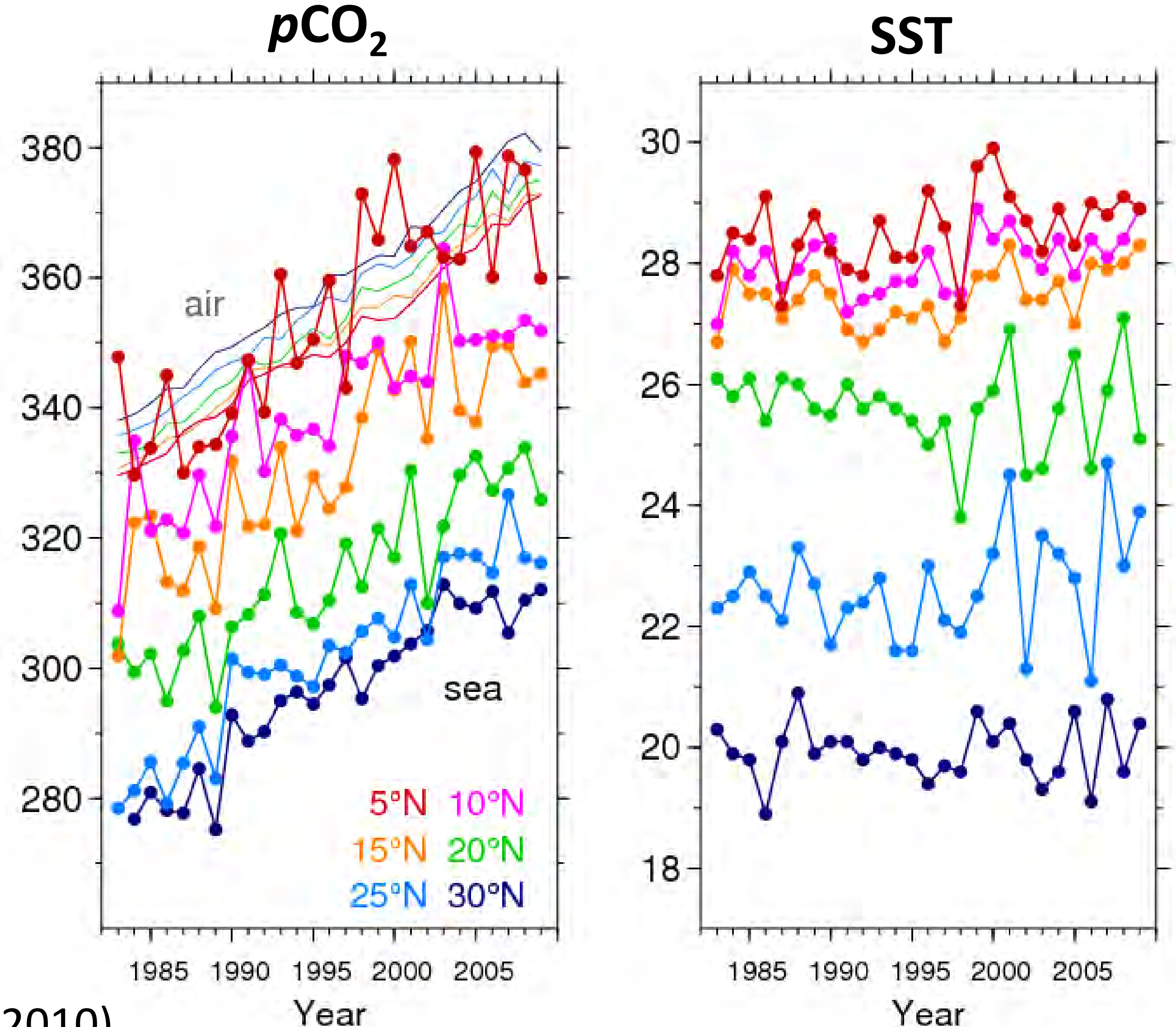
- Annual CO_2 emission by fossil fuel combustion is currently increasing in a similar curve as has been predicted from the A1FI scenario of IPCC SRES with fossil fuel intensive very rapid economic growth in IPCC SRES.
- On this scenario, Ω_{arag} could fall by 0.9 for the next 50 years. In a normal winter, Ω_{arag} could reach to 2 by the year 2045.

Ocean acidification in the surface waters of the 137°E open zones (3°N – 30°N)



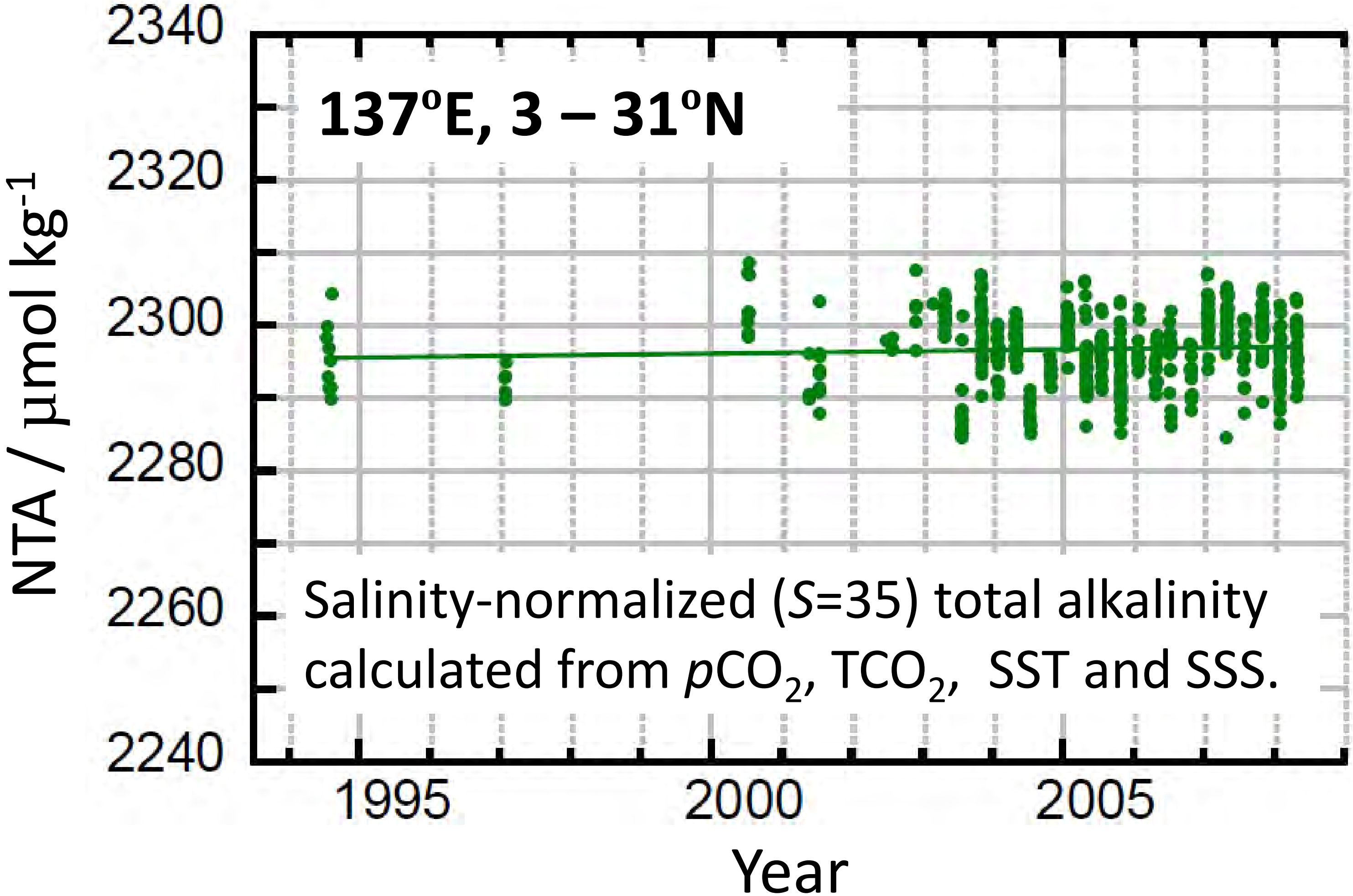
Trend of pCO_2 increase in surface water (1983 -)

137°E
Winter
(Jan.-Feb)



Midorikawa et al.,
Tellus, **62B**, 649-659. (2010).

No significant decadal changes has been observed for salinity-normalized total alkalinity (1994-)



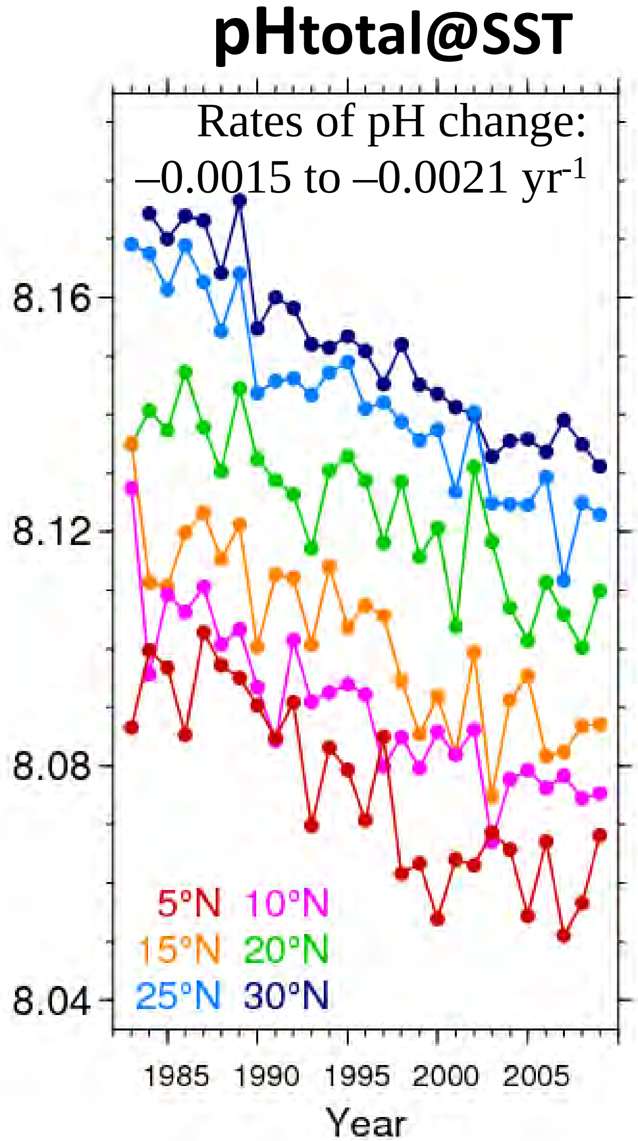
Trend of ocean acidification (1983-)

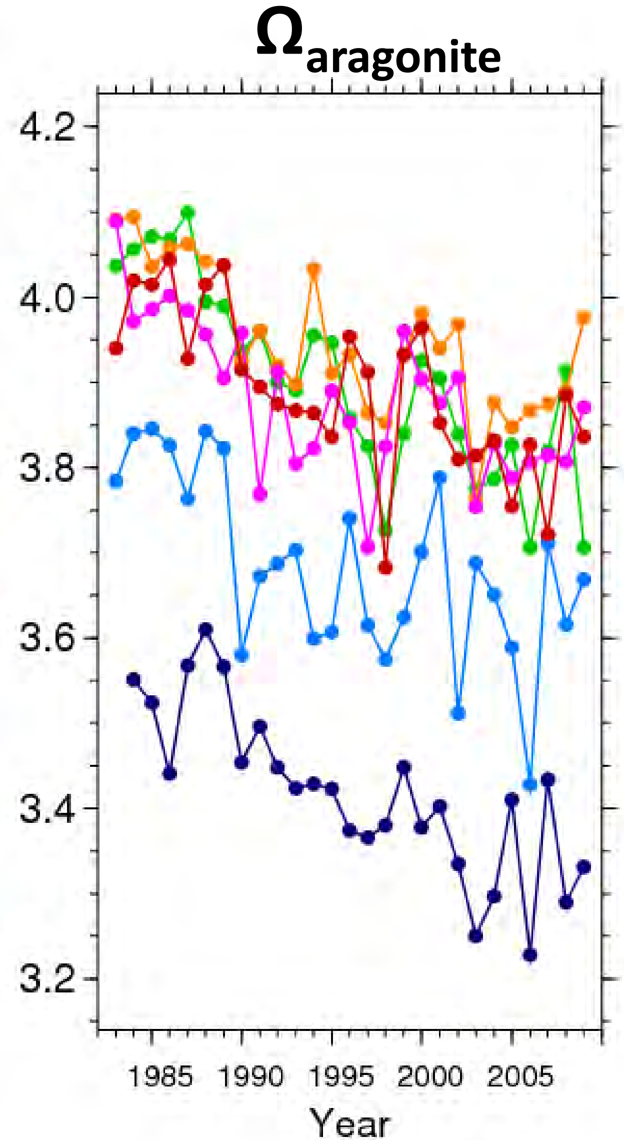
137°E

Winter

(Jan.-Feb)

Calculated from pCO$_2$, SST and SSS at a constant NTA of 2295 μmol kg^{-1}.

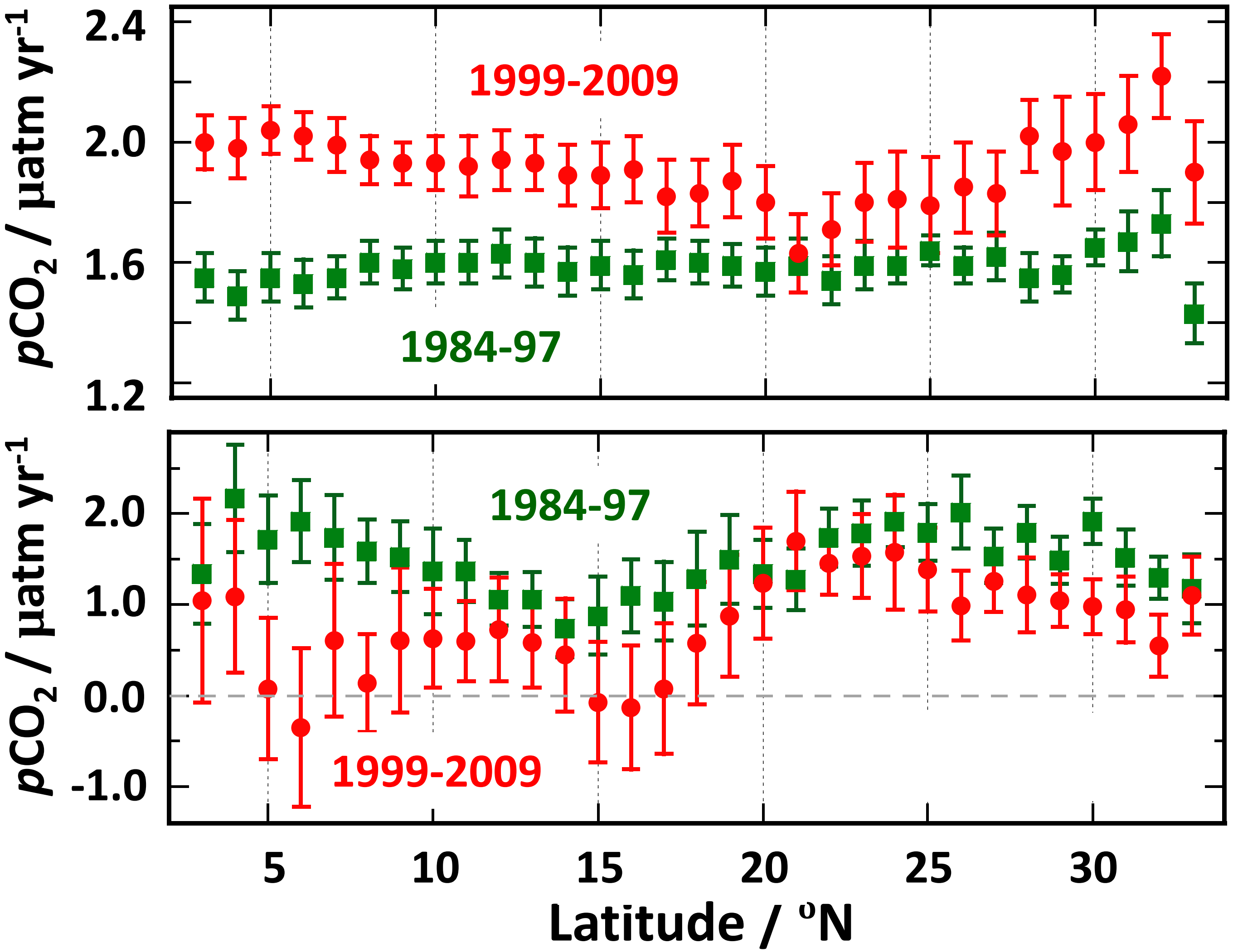




Slowdown of pCO$_2$sw increase is significant after late 1990s in the southern subtropics and tropics

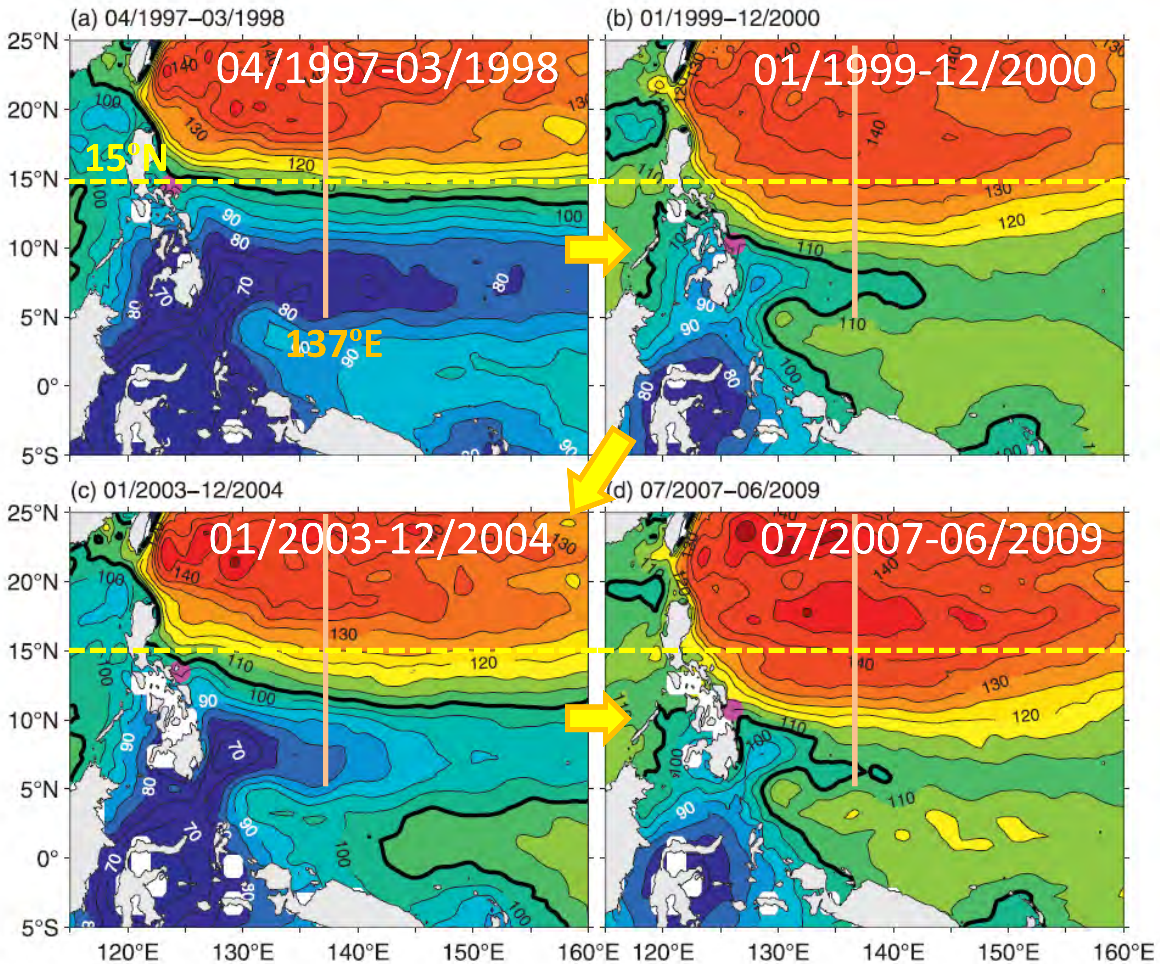
Air

Seawater



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

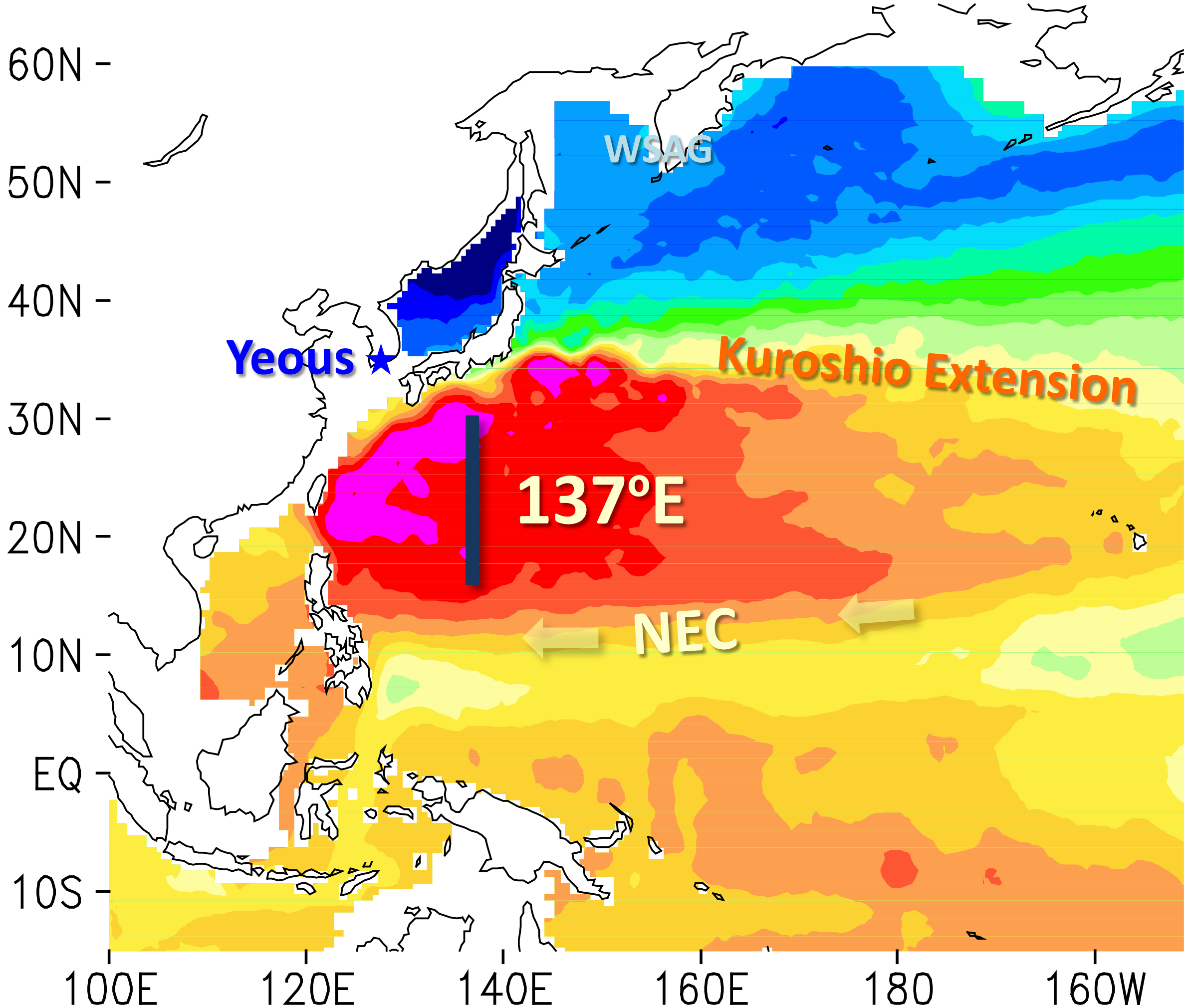
Deepening of thermocline due to the southward expansion of the subtropical gyre is likely to be a controlling factor



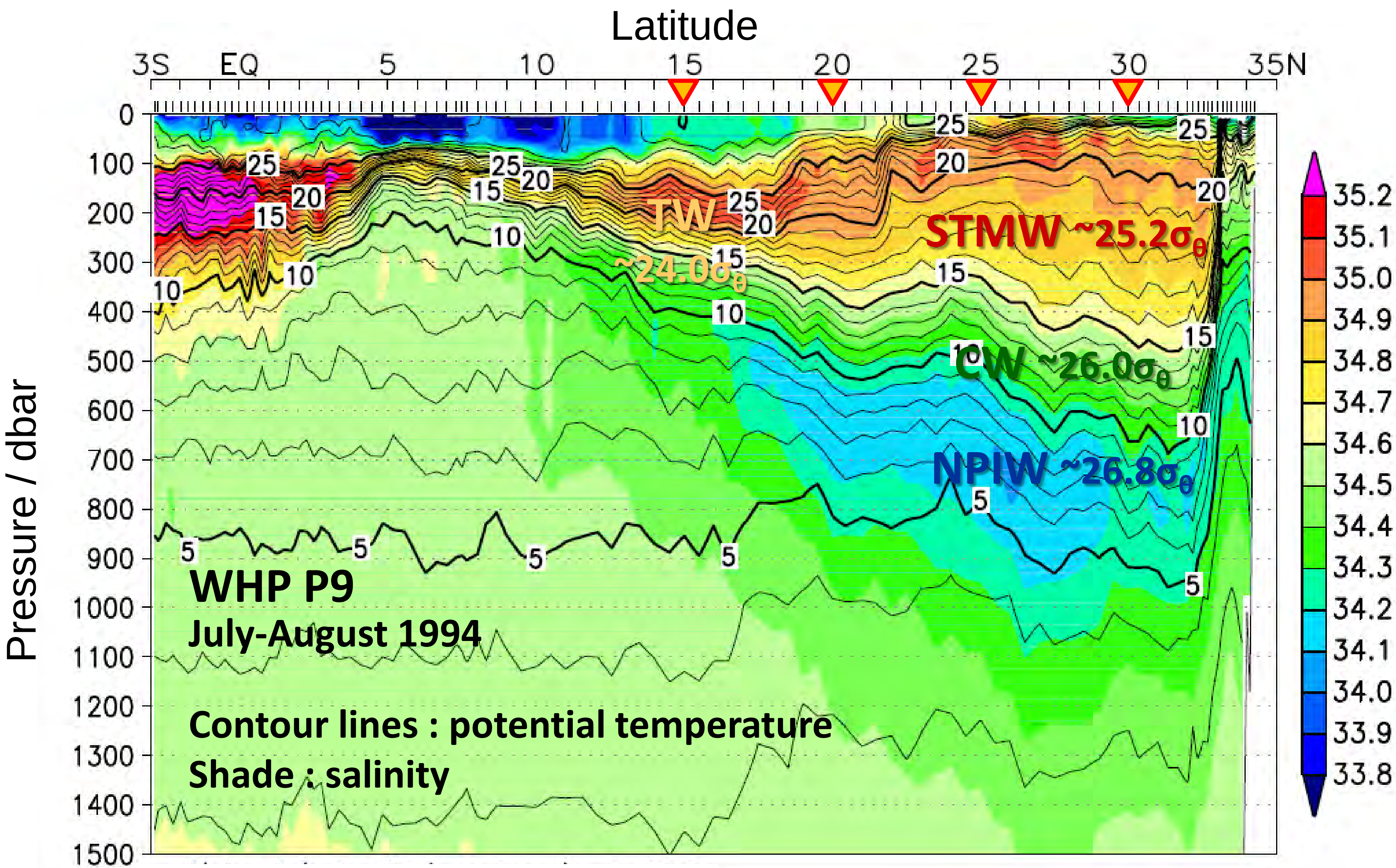
Sea surface height maps of the low-latitude western Pacific

(Qiu and Chen, *J. Phys. Oceanogr.*, 2010)

Ocean acidification in the interior of the subtropical gyre at 137ºE (15ºN – 30ºN)

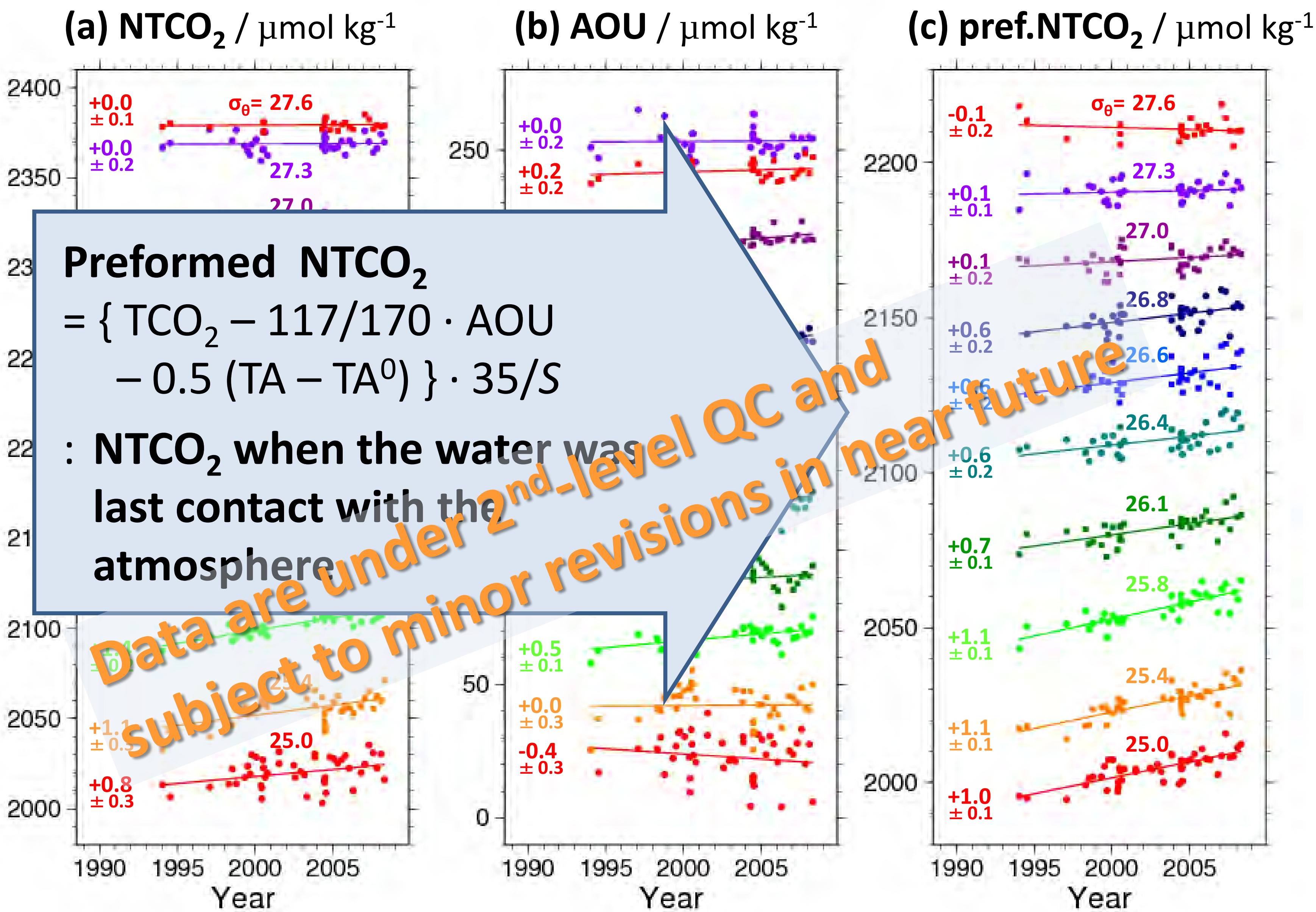


Ventilation of the western North



STMW : Subtropical Mode Water
CW : Central Water
NPIW : North Pacific Intermediate Water

Trends on isopycnals at 137°E, 30°N



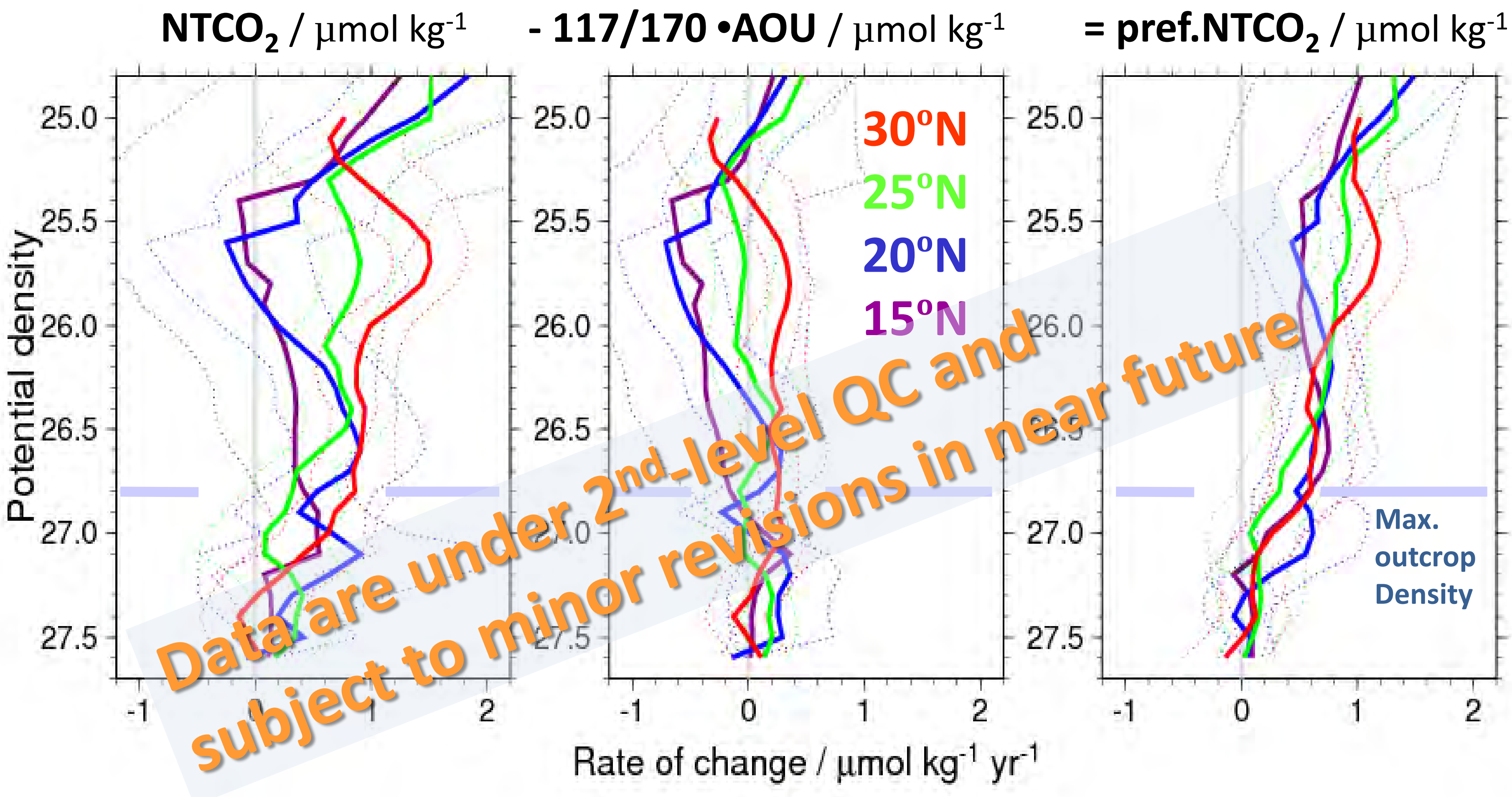
Preformed $NTCO_2$

$$= \{ TCO_2 - 117/170 \cdot AOU - 0.5\,(TA - TA^0) \} \cdot 35/S$$

: **$NTCO_2$ when the water was last contact with the atmosphere**

Data are under 2nd-level QC and subject to minor revisions in near future

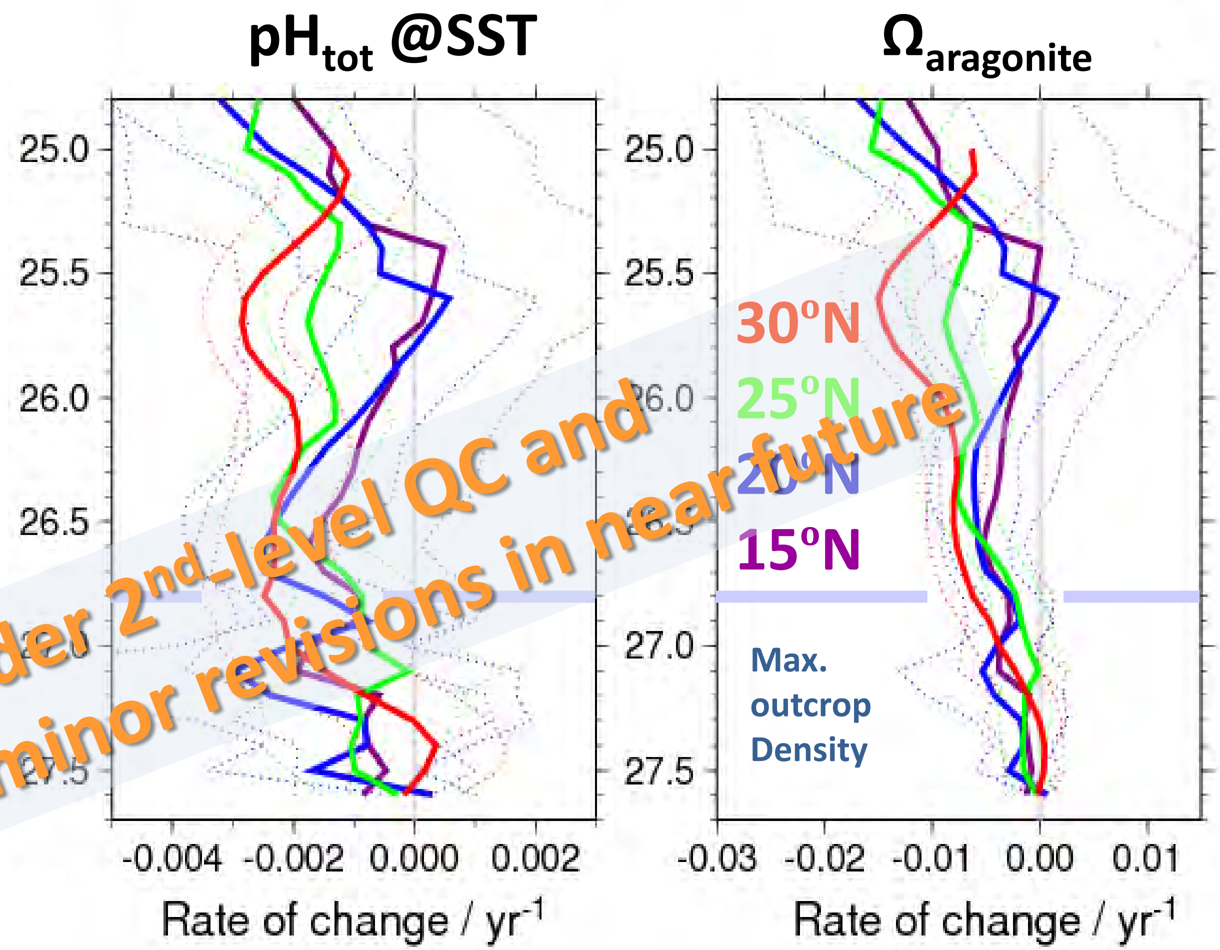
Rate of change at various latitudes and densities (1994-2008)



Rates of pref. $NTCO_2$ change are consistent with those calculated from the buffer factor and the rate of atmospheric CO_2 rise prior to the apparent CFC age.

Rate of acidification at various latitudes and densities (1994-2008)

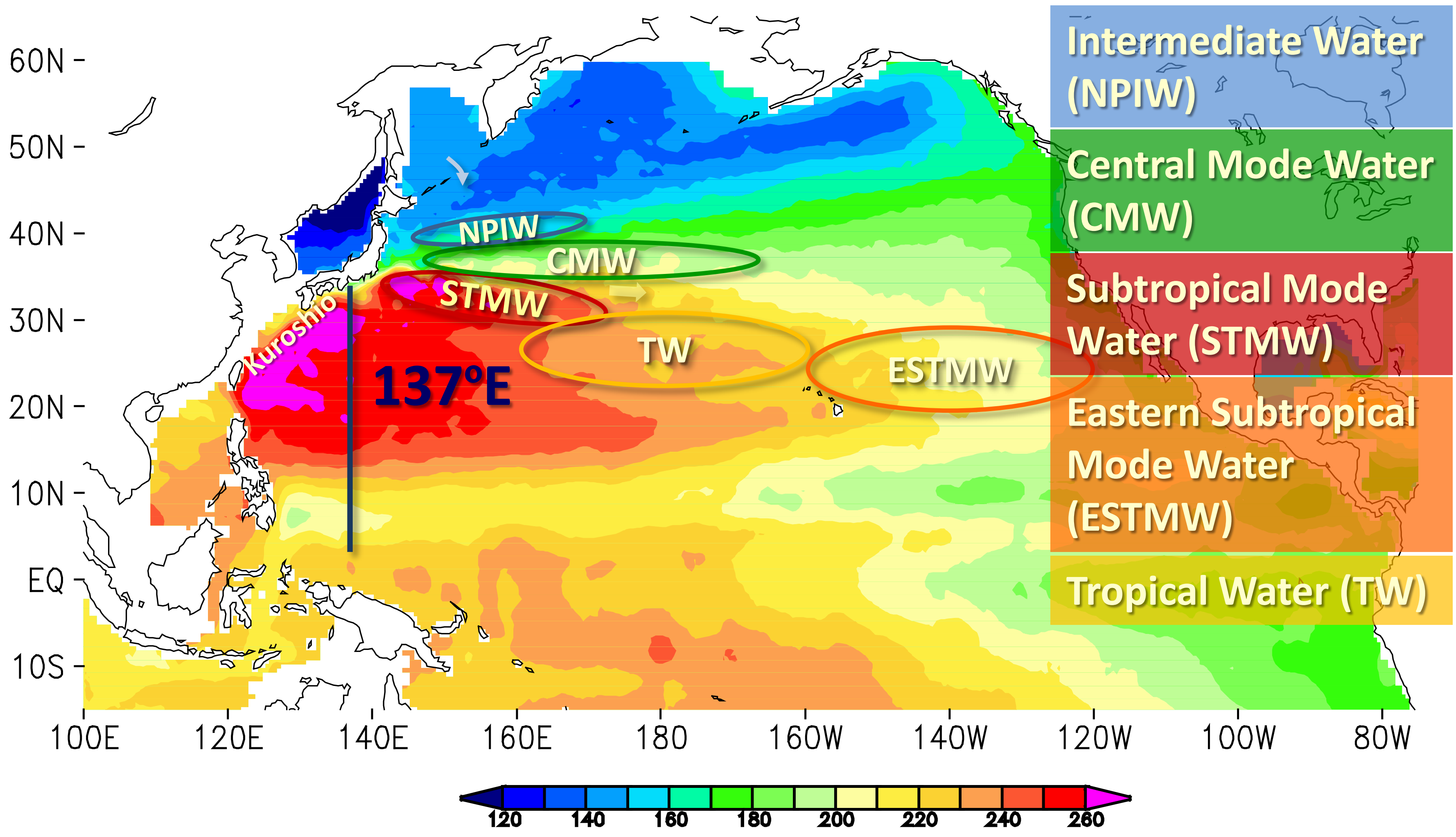
Storage of anthropogenic CO_2 is the main reason for the acidification. Contributions from short-term and long-term change in TCO_2 due to ocean circulation and/or biological activity change that are accompanied by the oxygen change are also significant.



How are the CO_2 increases in the surface and in the interior connected to each other?

- How is the anthropogenic (excess) carbon being transported from ocean surface into the ocean interior? Are the water-mass formation zones are the “hot spots” of CO_2 uptake into the ocean interior?

Regions of water-mass formation in the North Pacific



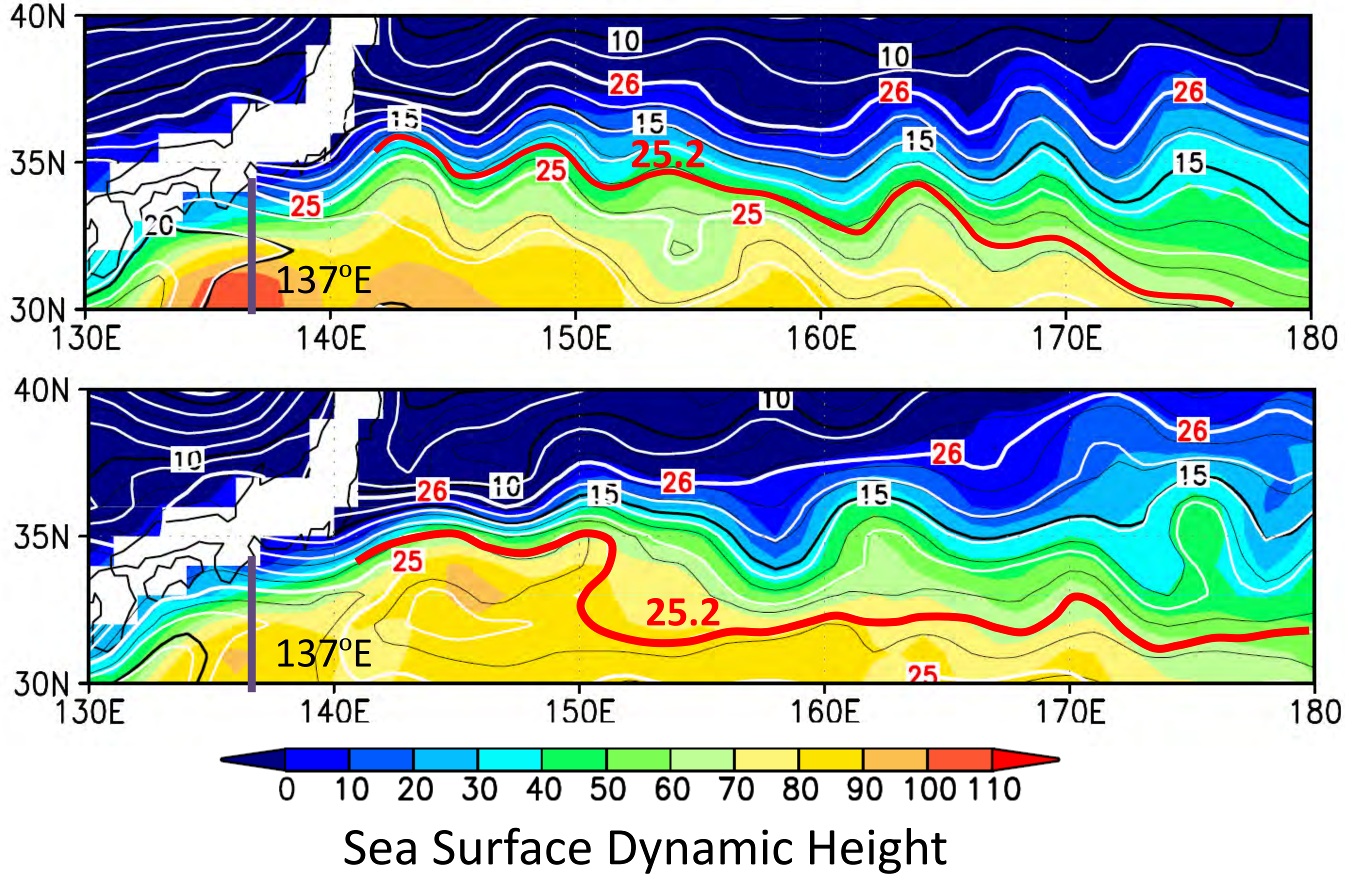
Sea Surface Dynamic Height (average 2000-2004)

Variability of SST, density and SSH around the Kuroshio Extension

Subtropical Mode Water (σ_θ~25.2), which is also called "18^{o}C water", is formed just to the south of Kuroshio Extension. Its formation region changes with the change in the path of Kuroshio Extension.

February 1998

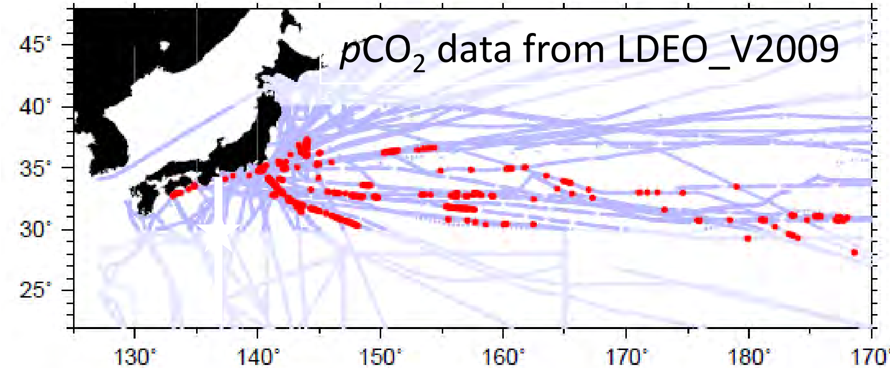
February 2004



Trend of pCO_2 and $NTCO_2$ in the STMW formation region

at σ_t = 25.200 ±0.025

17.35 ≤ SST/°C ≤ 18.05

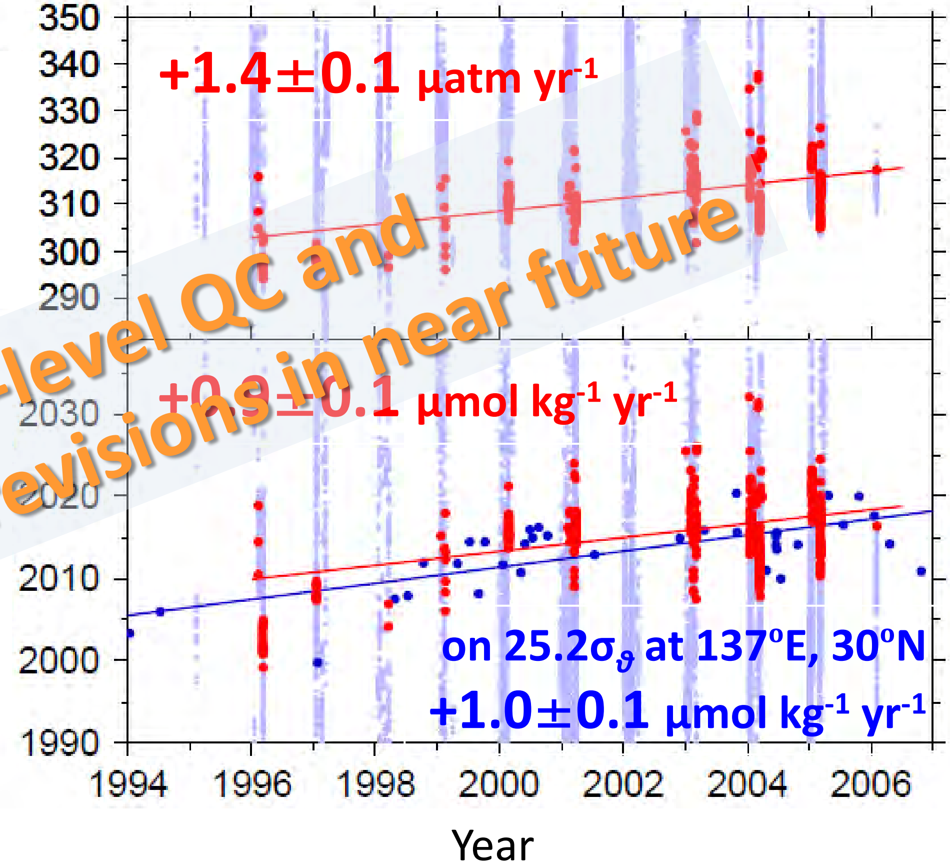


pCO_2

NTA = 2301 µmol kg^{-1}

from underway concurrent pCO_2 and TCO_2 measurements in 2006

$NTCO_2$



$NTCO_2$ and its rate of increase in surface water of the STMW formation region is consistent with preformed $NTCO_2$ and its rate of increase at 25.2σ_θ in the interior at 137°E, 30°N.

Conclusion

- In the offshore between the south coast of Japan and the Kuroshio, large seasonal and regional variations of CO_2 parameters are superposed on the trend of ocean acidification. The rate of pH reduction (-0.020±0.007 per decade) is consistent with the rate of atmospheric CO_2 increase.

  This result demonstrates that the ocean acidification can be another serious threat for coastal ecosystem.

- In surface waters of the open zones, CO_2 is increasing and ocean acidification is in progress. But these changes slowed, in particular, in the southern subtropics and tropics after late 1990s presumably because of the changes in the circulation of subtropical gyre.

- In the interior of the subtropical gyre, acidification is also in progress above the maximum density of winter-outcrop in the North Pacific. The contribution of the change in the ocean circulation and/or biological activity to the rate of acidification is also significant.

  They suggest the importance of physical and biological changes for the progress of acidification in regional and basin scales.

Thank you!

Acknowledgments

Officers and crew of the R/V Ryofu Maru and R/V Keifu Maru, and members of Climate and Marine Department, Japan Meteorological Agency, who have been involved in the JMA's shipboard long-term ocean monitoring program in the western Pacific.