Why is a global approach needed ?

Processes are occurring at global scales; therefore we need to go beyond local measurements and **observe on global scales in order to understand OA and its drivers correctly.**

We need information and data products that can **inform policy and the public with respect to global status of OA and implications** for overall ecosystem health (status) of the planet.

We need sufficient data and understanding to **develop predictive skills and early warning systems**. This requires coverage at appropriate scales, nesting local observations within global context.

OA is
a global condition with local effects

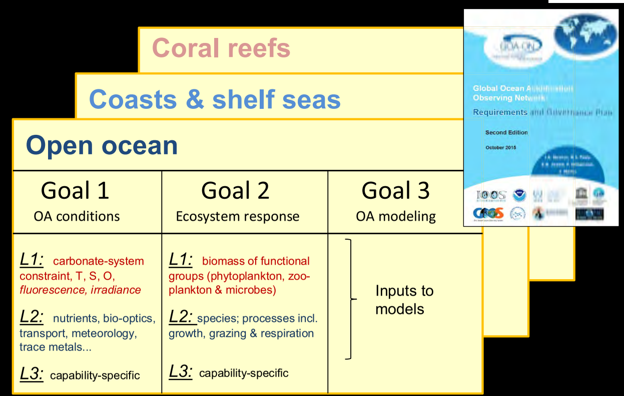
- We need local through global scale observations **in order to get either correct**
- This issue **demands our coordination**, networked skill, and open analysis

Designing GOA-ON

In 2012-2013, two international workshops, with ~100 participants from ~30 countries, defined an approach to build a coordinated, integrated global observing network for ocean acidification:

- *Rationale*
- *Goals*
- *Design*
- *Suite of measurement parameters*
- *Data quality and data distribution strategies*
- *International program integration*

Data Requirements



GOA-ON defined two data quality objectives:

- '**Climate data**': of sufficient and defined quality to assess long term trends with defined level of confidence
  Detection of changes in OA state over multi-decadal timescales
- '**Weather data**': of sufficient and defined quality to identify relative spatial patterns and short-term changes
  Mechanistic interpretation of the ecosystem response to local, immediate OA dynamics

GOA-ON requirements:

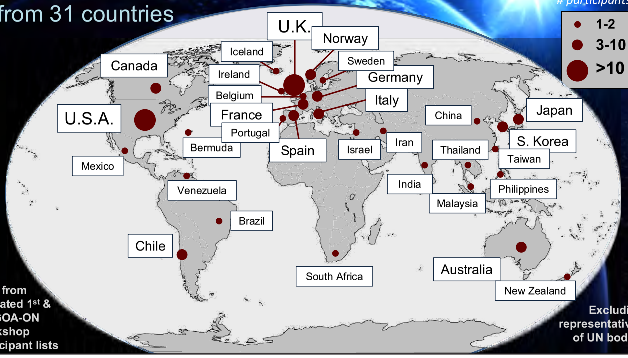
Capacity for

- Physical infrastructure
- Intellectual infrastructure
- Operations and maintenance
- Data QA/QC
- Analytical and synthesis activities

GOA-ON Workshops 1 & 2

- **Seattle, WA, USA (2012)**
- **St. Andrews, UK (2013)**

Network of ~150 scientists from 31 countries



Data from validated 1st & 2nd GOA-ON Workshop participant lists

Excluding representatives of UN bodies

GOA-ON Workshop 3

- **Hobart, TAS, AUS (2016)**

Pier 2 Peer

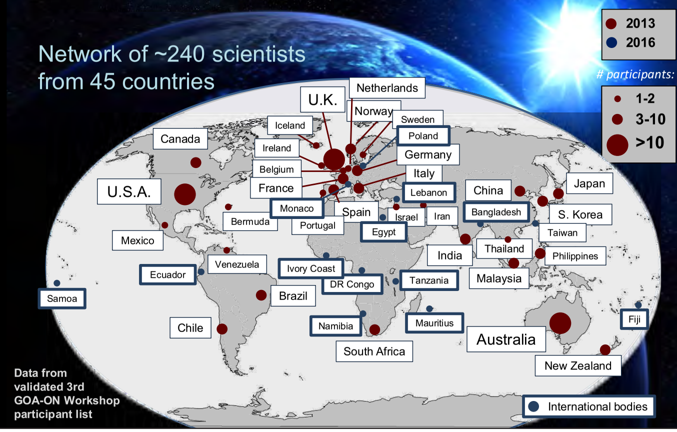
GOA-ON Global Ocean Acidification Observing Network

- Connects scientist to scientist
- Provides training opportunities
- Strengthens relationships across countries and continents

GOA-ON Workshop 3

➢ Hobart, TAS, AUS (2016)

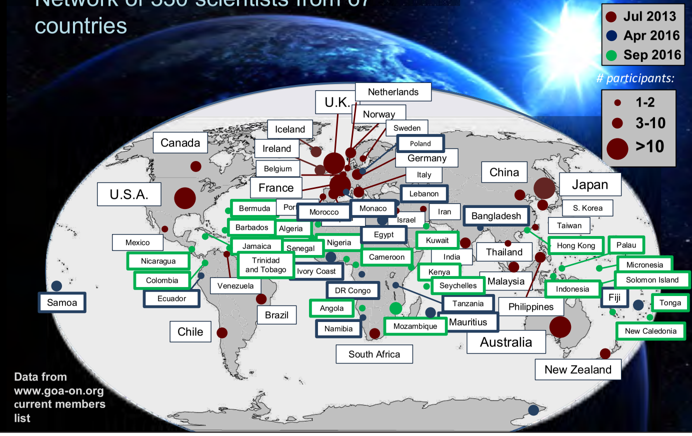
Network of ~240 scientists from 45 countries



Data from validated 3rd GOA-ON Workshop participant list

GOA-ON…as of Sept 2016

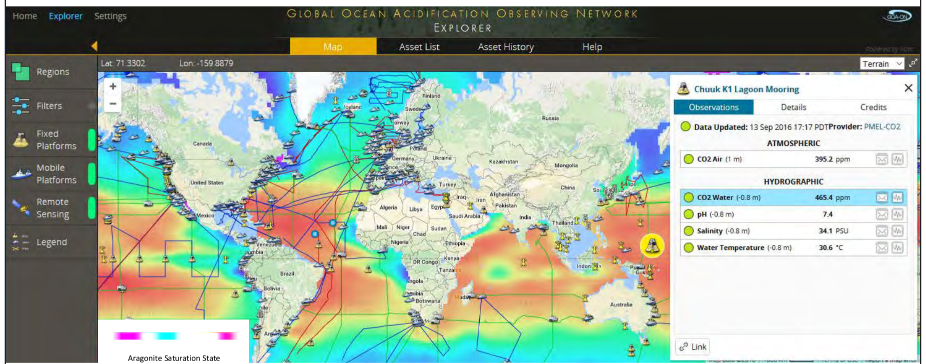
Network of 330 scientists from 67 countries



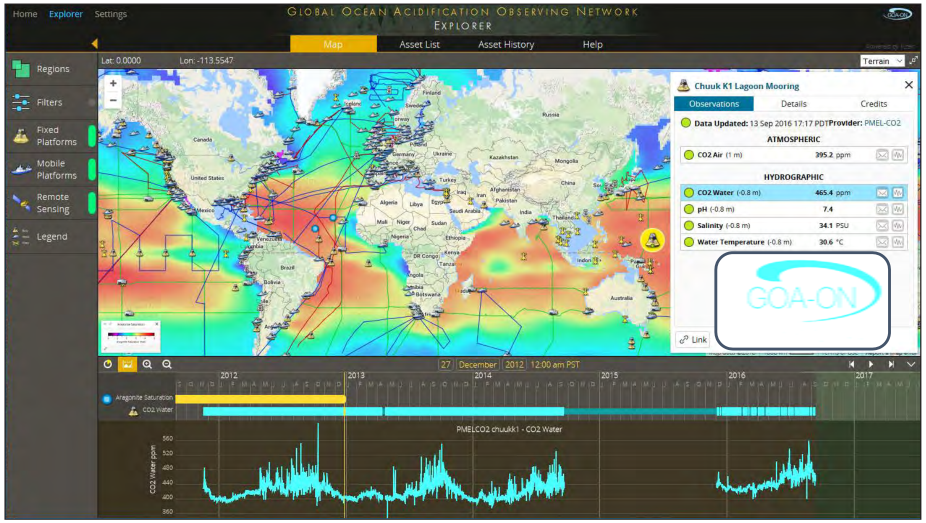
Data from www.goa-on.org current members list

GOA-ON provides:

The GOA-ON interactive data portal



Featuring global OA data, asset inventory, metadata, data synthesis products, etc.

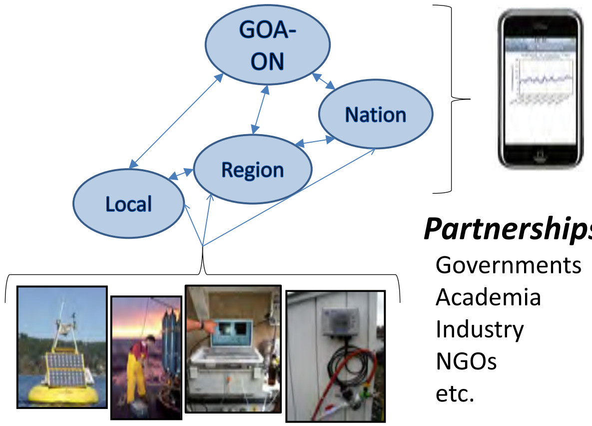


Outcomes from GOA-ON:

Globally distributed, high quality data, near-real-time data, and data synthesis products that:

- Facilitate research (new knowledge) on OA
- Communicate status of OA and biological response
- Enable forecasting/prediction of OA conditions

Integration of local through global



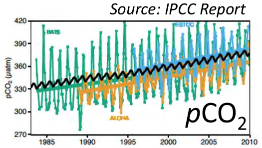
Partnerships:

Governments
Academia
Industry
NGOs
etc.

End-uses of GOA-ON information:

- **International policy** including carbon emission policies
- **Food security and livelihoods**
  - **Fisheries**
  - **Shellfish aquaculture**
  - **Coral reefs**
- **Shore protection, tsunami protection** from coral reefs
- **Cultural identity**
- **Tourism**

Source: IPCC Report



OA is
a global condition
with
local effects

Session 1-1

"The Status of Ocean Acidification in the Subtropical Pacific Region"

Chen-Tung Arthur Chen
Professor,
Department of Oceanography, National Sun Yat-sen University

Professor Chen has been a Professor of the Department of Oceanography since 1984. He has sat on numerous international committees, including the International Geoshpere-Bioshpere Programme, the IGBP/IHDP/WCRP/DIVERSITAS GCP, MAIRS, SCOR and WOCE. He also served as one of the executives of the JGOFS SSC between 1992–1995. Just prior to that, he had helped to form the Joint JGOFS/LOICZ Marginal Seas Task Team in 1991, and served as its chairman until 1995.

Prof. Chen is at present an associate editor of Mar. Chem. (since 1993), Cont. Shelf Res. (Since Oct. 2016), Acta Oceanol. Sin. (Since Oct. 2016), and a member of the editorial board of J. Marine Syst. (since 2001), Acta Oceanol. Sin. (2004 – Sept. 2016) and Cont. Shelf Res. (2007 – Sept. 2016), all SCI journals. He also served as an editor of the J. Oceanogr. between 1998 and 2010. Prof. Chen's specialty is on the nutrients and carbon cycle in the oceans, ocean acidification (including hydrothermal systems), global change (including paleoclimates) and sediment heavy metals. His recent work is across disciplines toward integrated Earth System science on the regional to global scales. Besides having 350 of his own scientific papers published (http://ctchen.ocean.nsysu.edu.tw/Biography--English.htm), He was awarded the highly-coveted 5M¥ Biwako Prize for Ecology from Japan in 1997 and is a Chair Professor of the NSYSU since 2006.

The status of ocean acidification in the subtropical Pacific Region

Chen-Tung Arthur Chen[1], Hon-Kit Lui[2]

1 Department of Oceanography, National Sun Yat-sen University, Kaohsiung, Taiwan. E-mail: ctchen@mail.nsysu.edu.tw

2 National Applied Research Laboratories, Taiwan Ocean Research Institute (TORI). E-mail: hklui@narlabs.org.tw

Abstract

Because of the penetration of the anthropogenic CO_2 the world oceans have been acidifying. Feely and Chen (The effect of excess CO_2 on the calculated calcite and aragonite saturation horizons in the northeast Pacific, GRL, 1982, 9, 1294-1297) reported for the first time that the aragonite and calcite saturation horizons will become shallower, thus threatening biota with calcium carbonate skeletons and shells. Indeed it has been observed that waters at the shelf break of the East China Sea (ECS) and in the Okinawa Trough have been acidifying between 1982 and 2007 (Lui et al., Acidifying intermediate water accelerates the acidification of seawater on shelves: An example of the East China Sea, CSR, 2015, 111, 223-233). The use of apparent oxygen utilization (AOU) data to quantify the change in pH due to physical changes and changes in biological activities is demonstrated. The results thus obtained reveal that the drop in pH of the Kuroshio Intermediate Water (KIW) in the ECS is a result of not only the intrusion of atmospheric CO_2, but also an increase in AOU concentration. The acidification rates caused by the increasing AOU concentration could contribute up to −0.00086±0.00017 pH unit yr^{-1} at 900 m in the Okinawa Trough and −0.00082±0.00057 pH unit yr^{-1} on the shelf break of the ECS. These values are equivalent to 54% and 51%, respectively, of the acidification rate of −0.0016 pH unit yr^{-1} based on an assumption of the air–sea CO_2 equilibrium. When the effects of changing AOU and θ are eliminated, the acidification rate in the basin of the ECS captures the rate of change that is caused by an increase in anthropogenic CO_2 concentration. In contrast, when the effects of changing AOU and θ are eliminated, the acidification rate at the shelf break is 69% higher than the rate based on an assumption of the air–sea CO_2 equilibrium. Since the seawater on the shelf contains a higher proportion of the South China Sea (SCS) seawater and coastal water than does that in the Okinawa Trough, the result herein may imply that the SCS seawater, coastal water, or a combination of them suffered a higher acidification rate during the studied period. This study demonstrates that changing the carbonate chemistry of both incoming offshore intermediate seawater and coastal water results in the acidification of seawater on a continental shelf. The results herein reveal a situation in which the acidification of coastal seawater may be faster than expected when the reduction of pH of the incoming offshore seawater is considered along with the increasing atmospheric CO_2 and terrestrial nutrient fluxes.

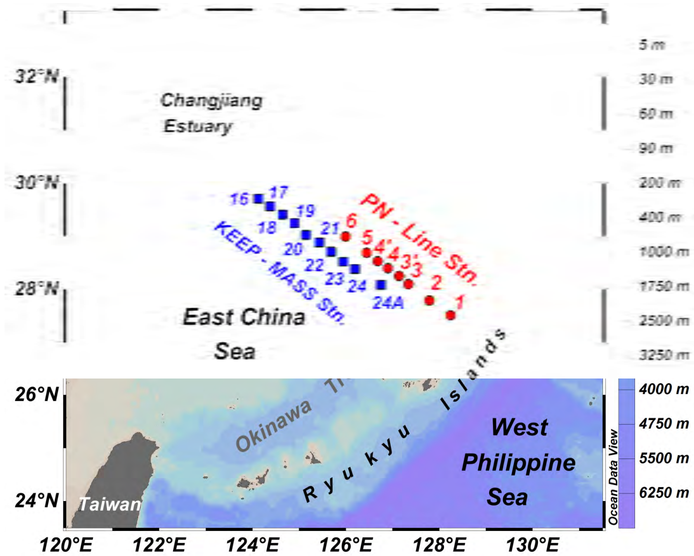
Acidification in the SCS and the West Philippine Sea will also be presented.

The status of ocean acidification in the subtropical Pacific Region

Chen-Tung Arthur Chen[1], Hon-Kit Lui[2]

1 Department of Oceanography, National Sun Yat-sen University, Kaohsiung, Taiwan. E-mail: ctchen@mail.nsysu.edu.tw
2 National Applied Research Laboratories, Taiwan Ocean Research Institute (TORI). E-mail: hklui@narlabs.org.tw

1



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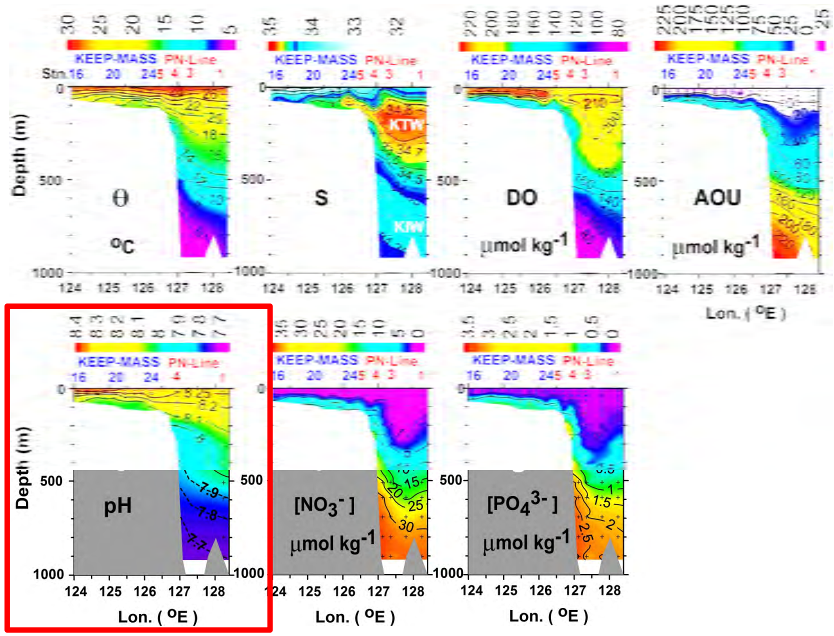

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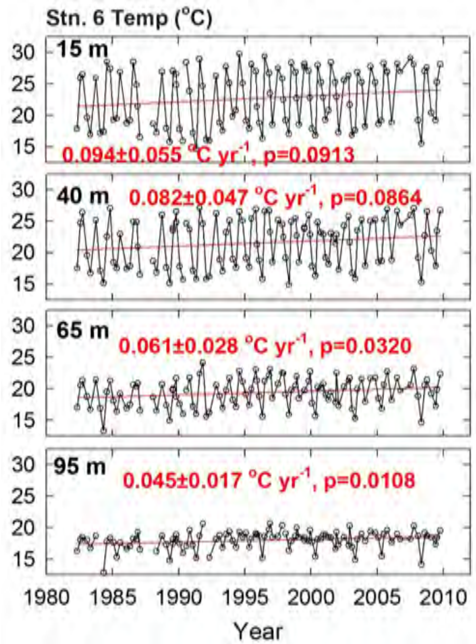

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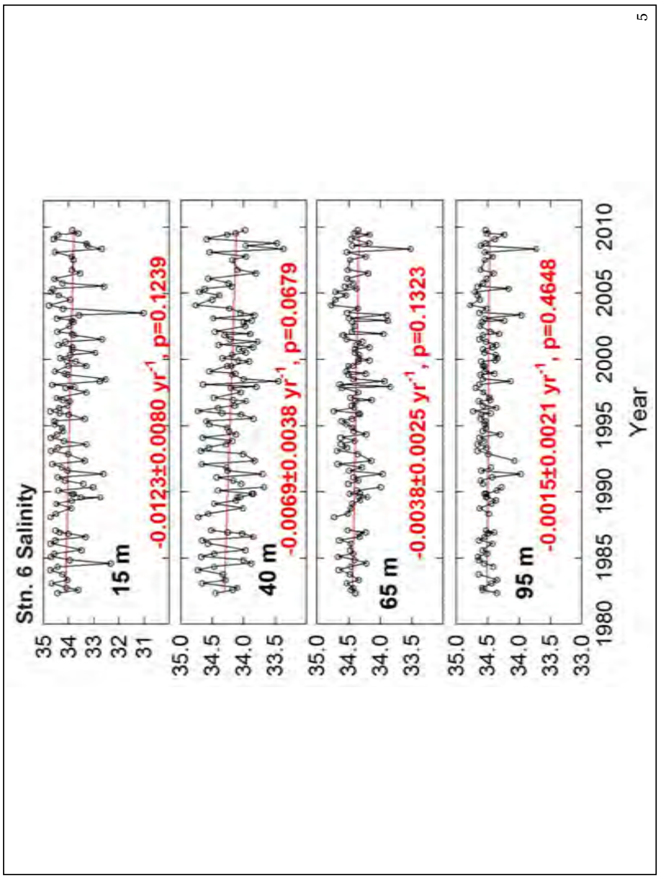
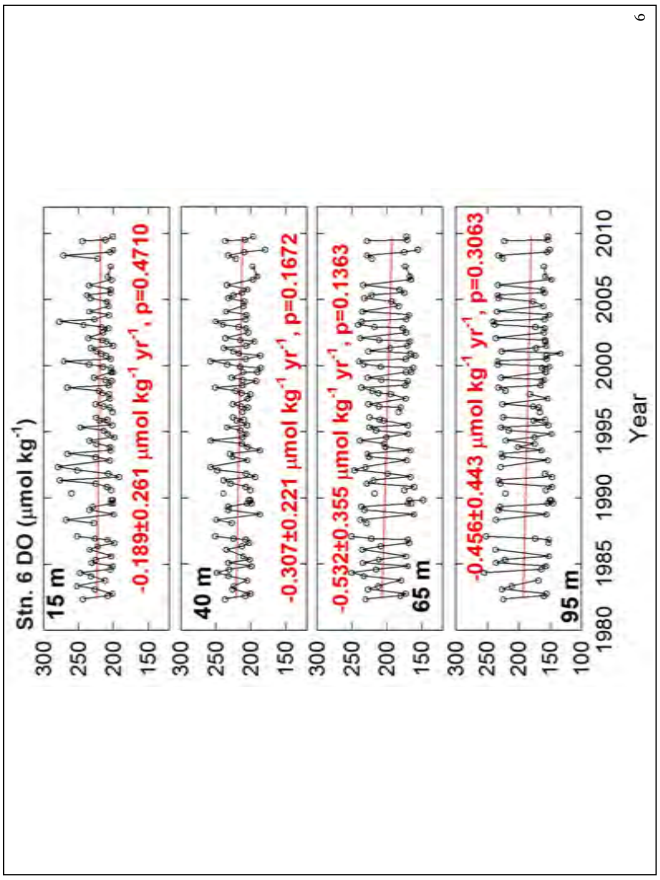
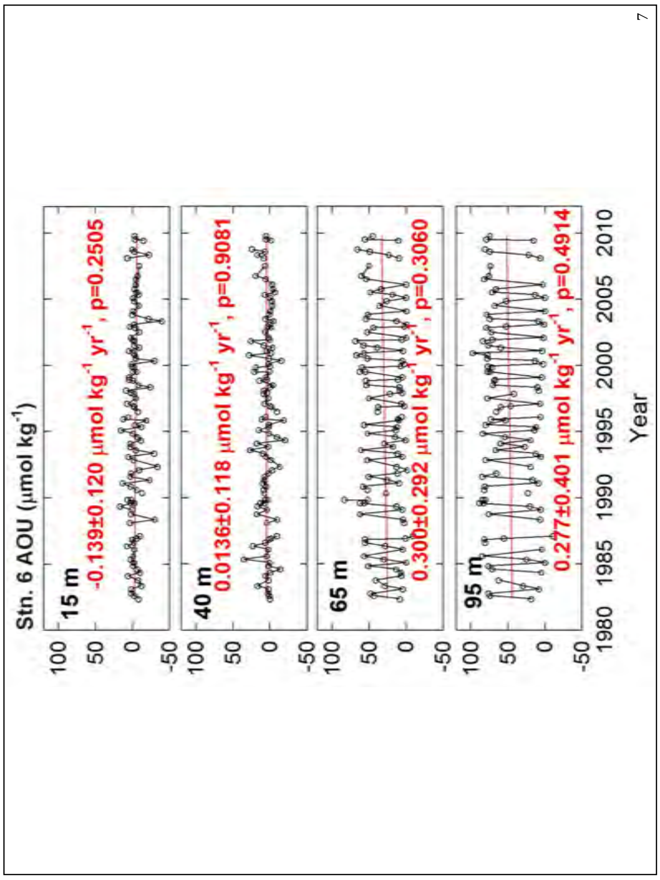
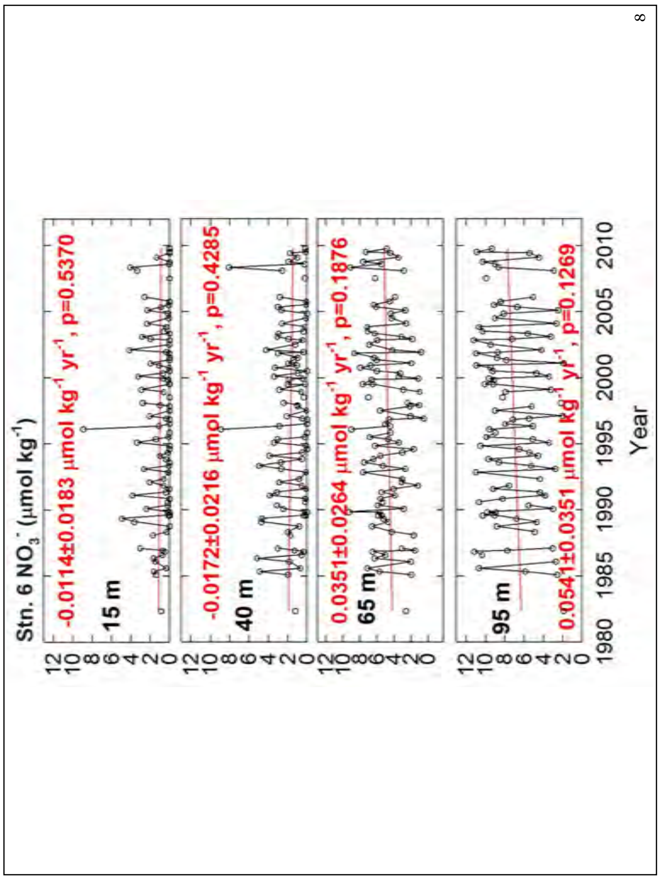
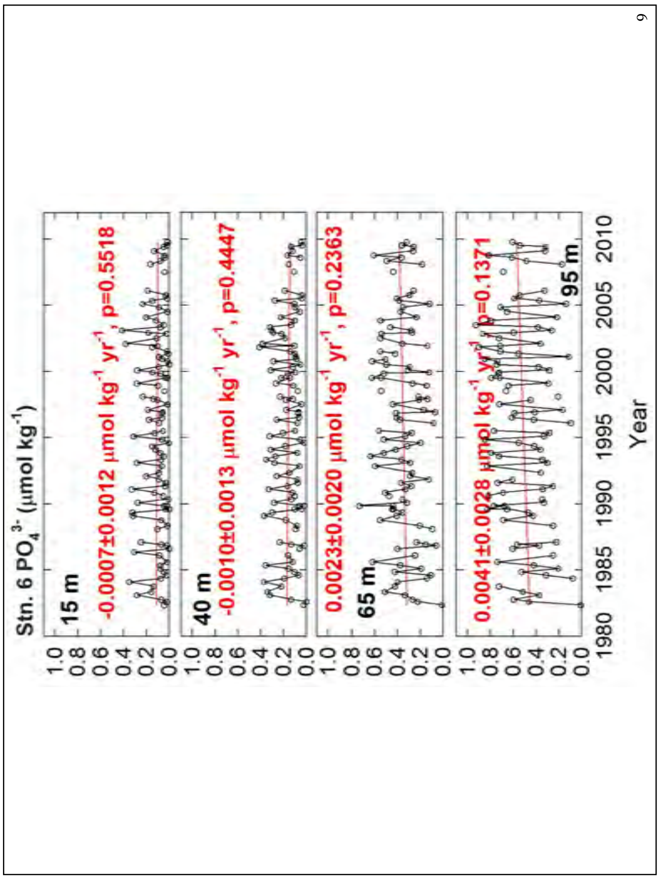
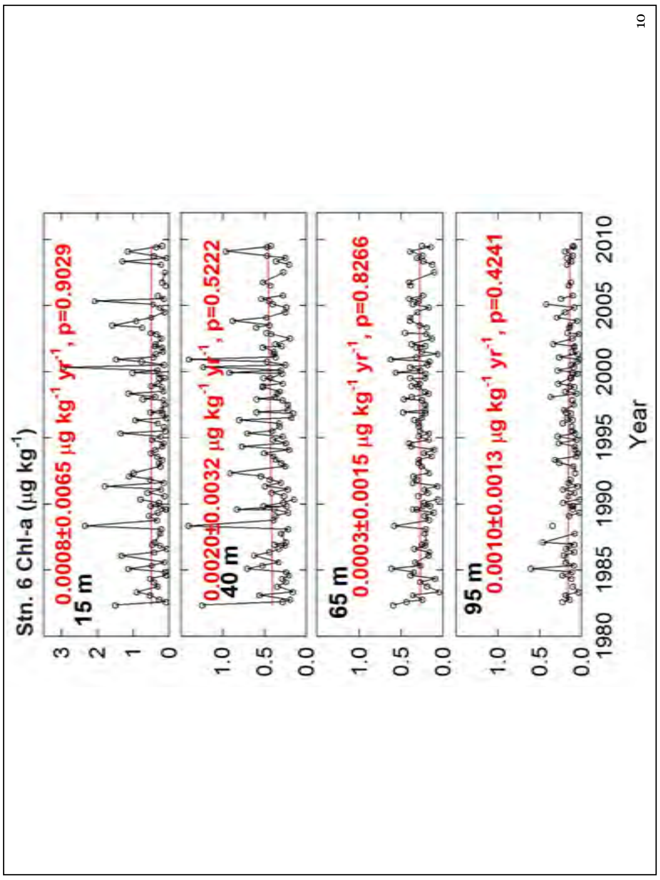

Stn. 6 Salinity
15 m
-0.0123±0.0080 yr-1, p=0.1239
40 m
-0.0069±0.0038 yr-1, p=0.0679
65 m
-0.0038±0.0025 yr-1, p=0.1323
95 m
-0.0015±0.0021 yr-1, p=0.4648
Year
5

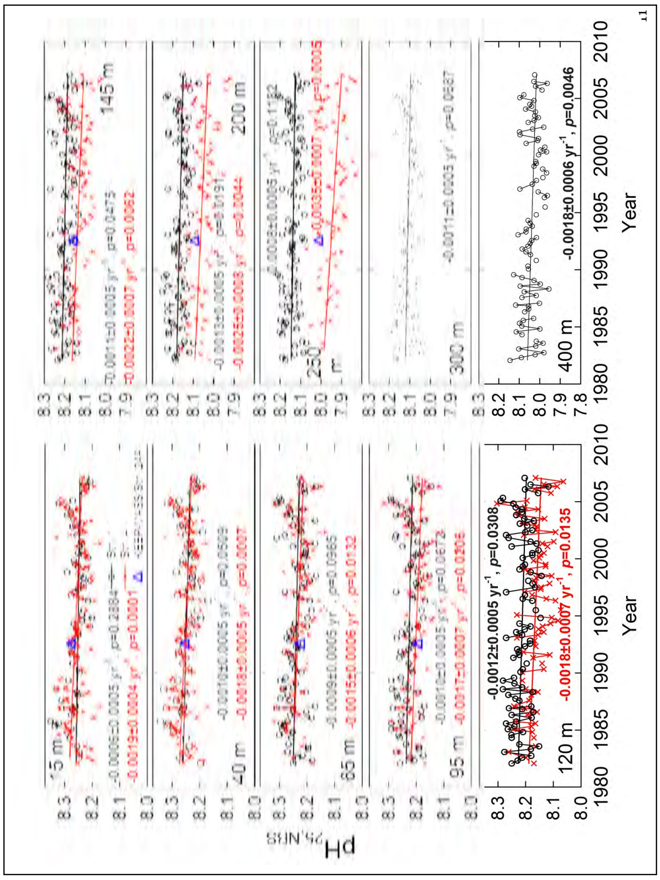

Stn. 6 DO (μmol kg-1)
15 m
-0.189±0.261 μmol kg-1 yr-1, p=0.4710
40 m
-0.307±0.221 μmol kg-1 yr-1, p=0.1672
65 m
-0.532±0.355 μmol kg-1 yr-1, p=0.1363
95 m
-0.456±0.443 μmol kg-1 yr-1, p=0.3063
Year
6

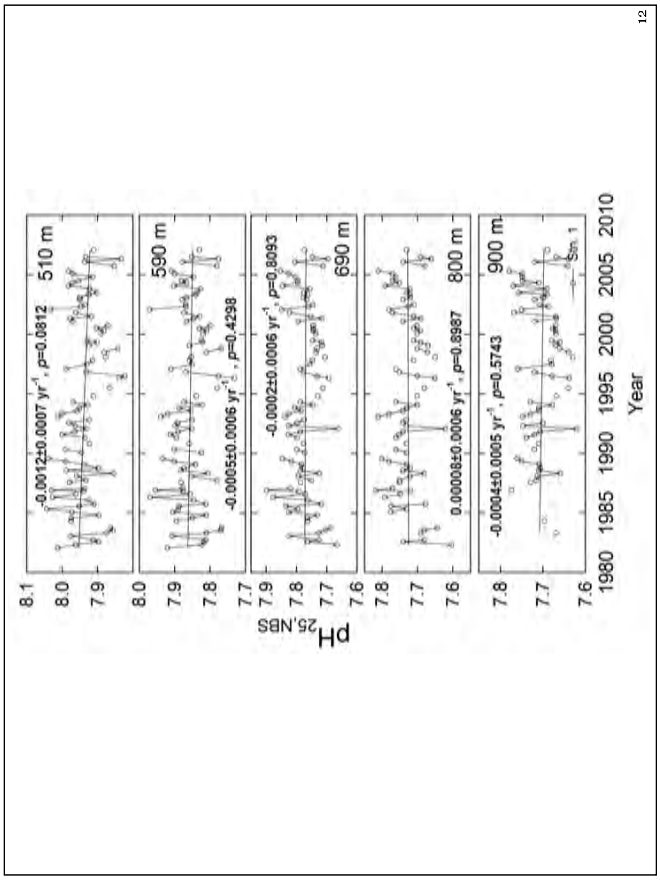

Stn. 6 AOU (μmol kg-1)
15 m
-0.139±0.120 μmol kg-1 yr-1, p=0.2505
40 m
0.0136±0.118 μmol kg-1 yr-1, p=0.9081
65 m
0.300±0.292 μmol kg-1 yr-1, p=0.3060
95 m
0.277±0.401 μmol kg-1 yr-1, p=0.4914
Year
7

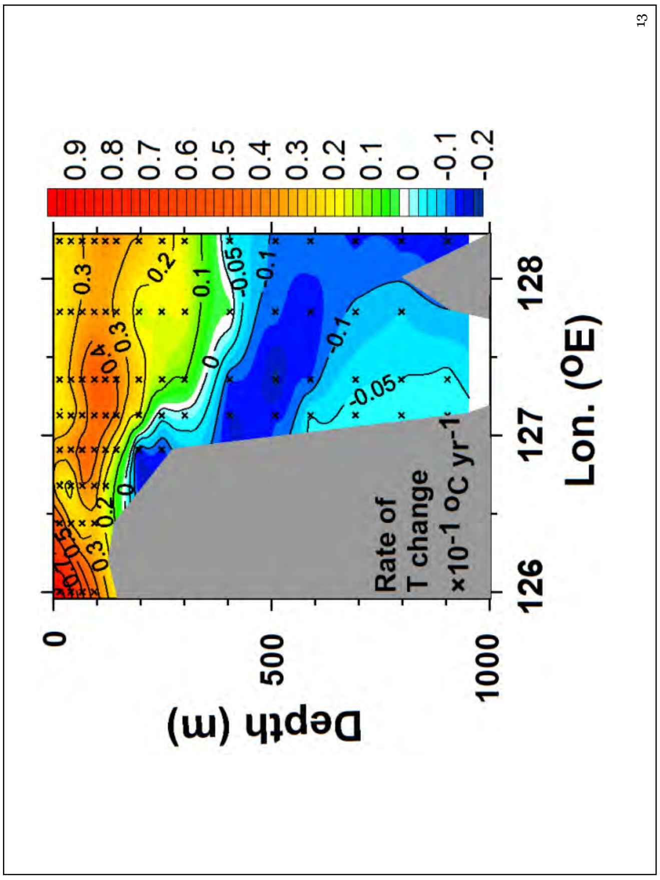

Stn. 6 NO3- (μmol kg-1)
15 m
-0.0114±0.0183 μmol kg-1 yr-1, p=0.5370
40 m
-0.0172±0.0216 μmol kg-1 yr-1, p=0.4285
65 m
0.0351±0.0264 μmol kg-1 yr-1, p=0.1876
95 m
0.0541±0.0351 μmol kg-1 yr-1, p=0.1269
Year
8

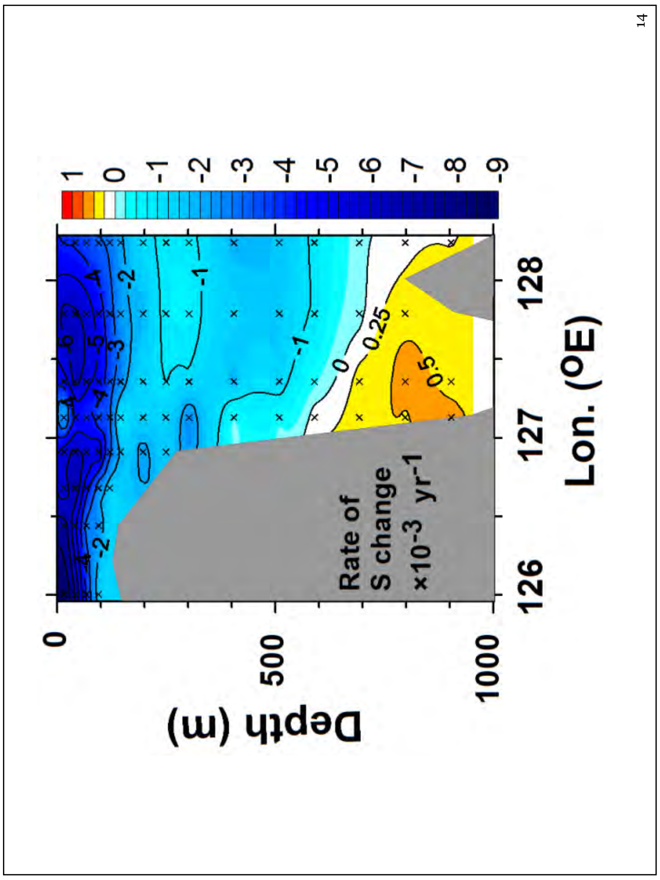

Stn. 6 PO4 3- (μmol kg-1)
15 m
-0.0007±0.0012 μmol kg-1 yr-1, p=0.5518
40 m
-0.0010±0.0013 μmol kg-1 yr-1, p=0.4447
65 m
0.0023±0.0020 μmol kg-1 yr-1, p=0.2363
95 m
0.0041±0.0028 μmol kg-1 yr-1, p=0.1371
Year
9

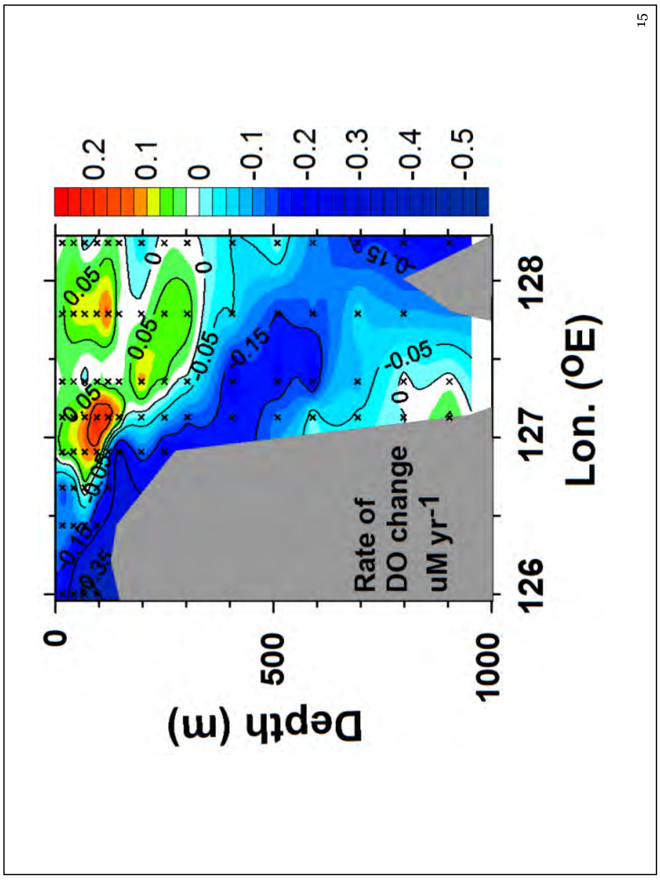

Stn. 6 Chl-a (μg kg-1)
15 m
0.0008±0.0065 μg kg-1 yr-1, p=0.9029
40 m
0.0020±0.0032 μg kg-1 yr-1, p=0.5222
65 m
0.0003±0.0015 μg kg-1 yr-1, p=0.8266
95 m
0.0010±0.0013 μg kg-1 yr-1, p=0.4241
Year
10

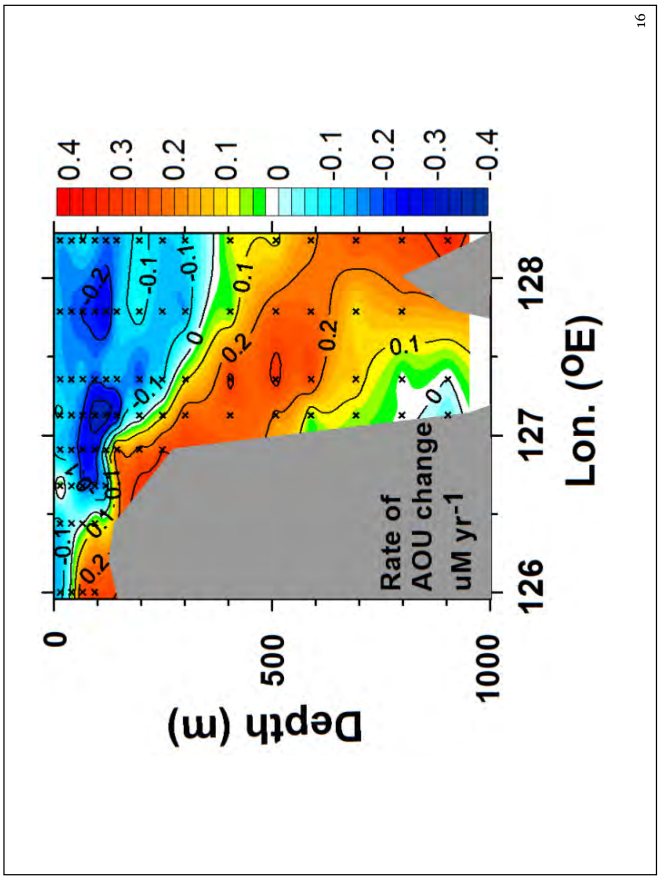

pH25,NBS
-0.0012±0.0005 yr-1, p=0.0308
-0.0018±0.0007 yr-1, p=0.0135
120 m
400 m
-0.0018±0.0006 yr-1, p=0.0046
Year
11

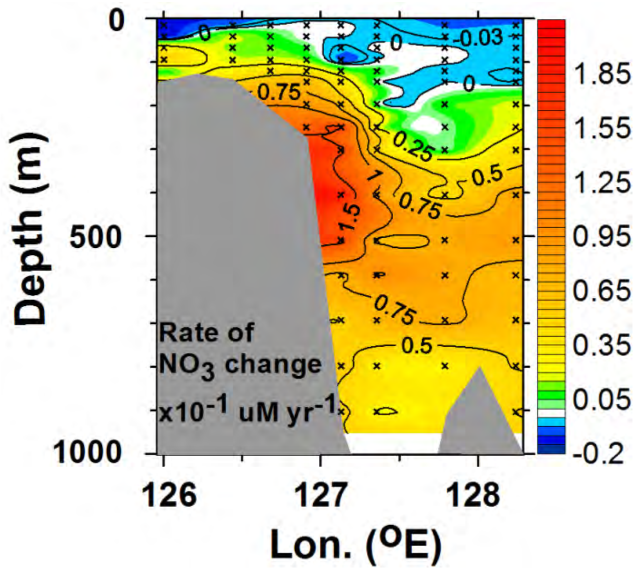

pH25,NBS
510 m
-0.0012±0.0007 yr-1, p=0.0812
590 m
-0.0005±0.0006 yr-1, p=0.4298
690 m
-0.0002±0.0006 yr-1, p=0.8093
800 m
0.00008±0.0006 yr-1, p=0.8987
900 m
-0.0004±0.0005 yr-1, p=0.5743
Year
12


13
Rate of
T change
×10-1 oC yr-1
Depth (m)
Lon. (oE)

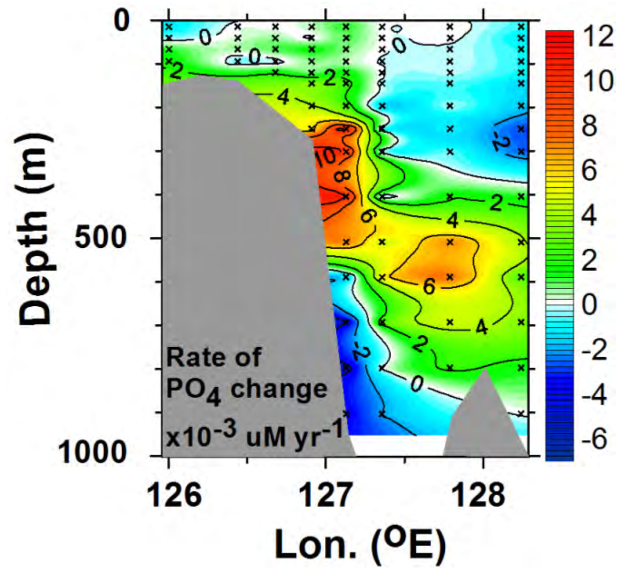

14
Rate of
S change
×10-3 yr-1
Depth (m)
Lon. (oE)


15
Rate of
DO change
uM yr-1
Depth (m)
Lon. (oE)

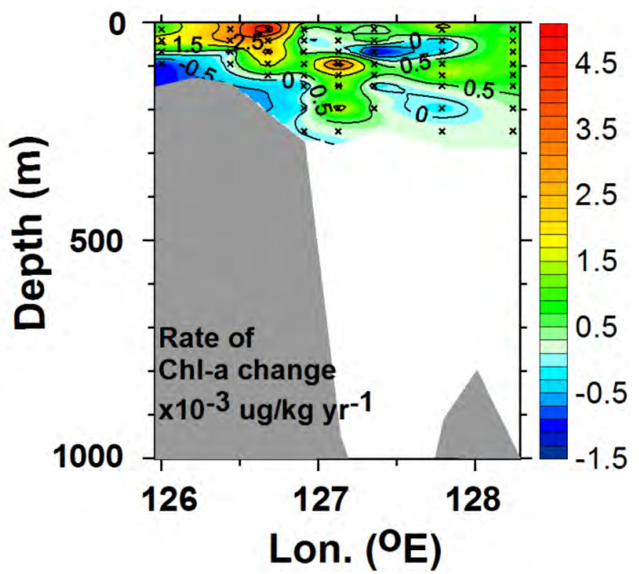

16
Rate of
AOU change
uM yr-1
Depth (m)
Lon. (oE)


Depth (m)
Lon. (ºE)
Rate of
NO3 change
x10-1 uM yr-1
1.85
1.55
1.25
0.95
0.65
0.35
0.05
-0.2

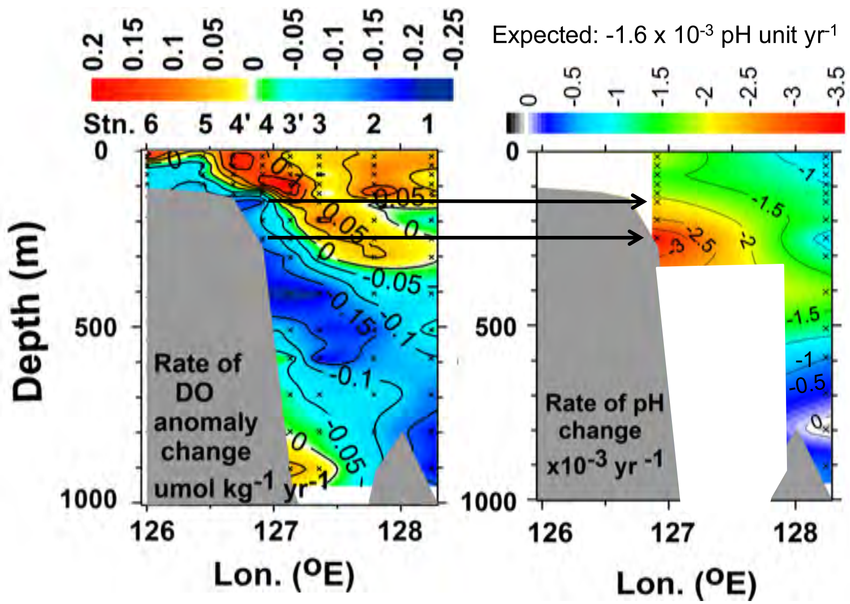
17


Depth (m)
Lon. (ºE)
Rate of
PO4 change
x10-3 uM yr-1
12
10
8
6
4
2
0
-2
-4
-6

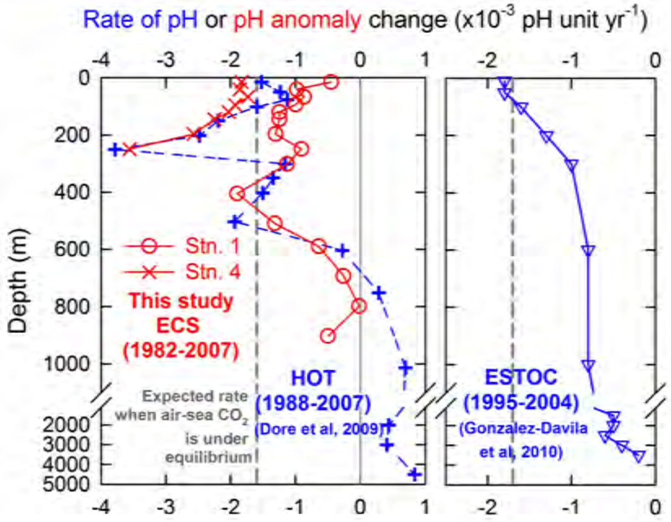
18


Depth (m)
Lon. (ºE)
Rate of
Chl-a change
x10-3 ug/kg yr-1
4.5
3.5
2.5
1.5
0.5
-0.5
-1.5

19


Expected: -1.6 x 10-3 pH unit yr-1
Stn. 6 5 4' 4 3' 3 2 1
Depth (m)
Rate of
DO
anomaly
change
umol kg-1 yr-1
Lon. (ºE)
Rate of pH
change
x10-3 yr-1
Lon. (ºE)

20



Dore J E, Lukas R, Sadler D W, Church M J and Karl D M 2009 Physical and biogeochemical modulation of ocean acidification in the central North Pacific *Proc. Natl. Acad. Sci. U. S. A. 106*(30) 12235-12240.

Gonzalez-Davila M, Santana-Casiano J M, Rueda M J and Llinas, O 2010. The water column distribution of carbonate system variables at the ESTOC site from 1995 to 2004.*Biogeosciences* **7**(10) 3067-3081.

21

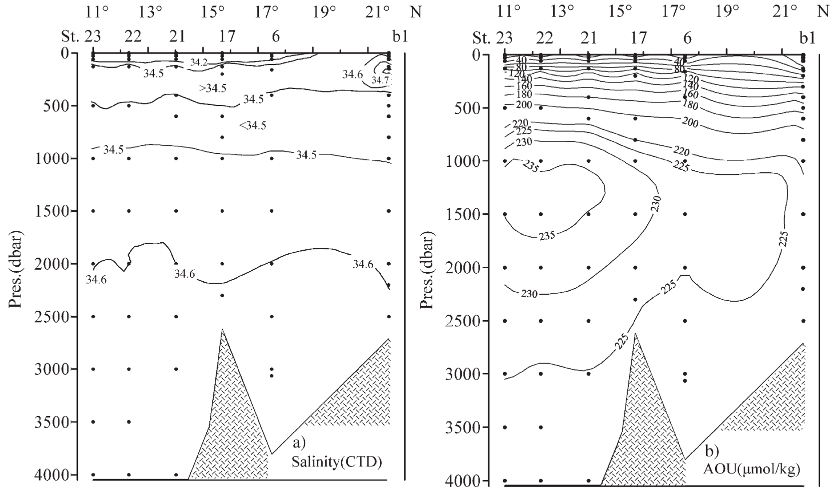
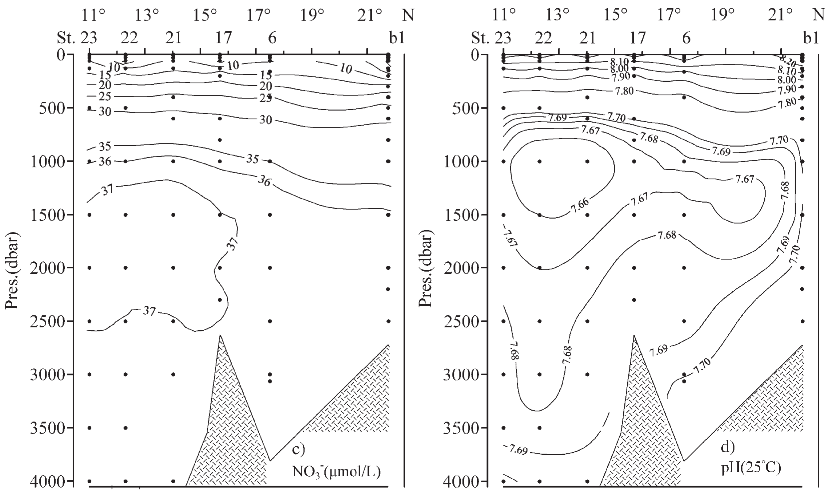


Fig. 2. North-South cross-sections of **(a) *S*, (b) AOU**, (c) NO_3, (d) pH, (e) NTA and (f) $NTCO_2$ in the western part of the SCS.

Taken from Chen et al. (2006). Marine Chemistry, 101, 277-305, doi: 10.1016/j.marchem.2006.01.007.

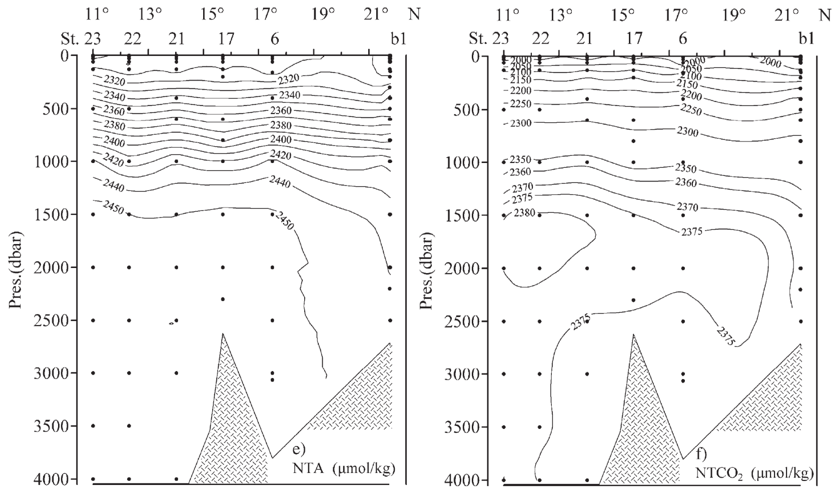
22



(Cont.)
Fig. 2. North-South cross-sections of (a) *S*, (b) AOU, **(c) NO_3, (d) pH**, (e) NTA and (f) $NTCO_2$ in the western part of the SCS.

Taken from Chen et al. (2006). Marine Chemistry, 101, 277-305, doi: 10.1016/j.marchem.2006.01.007.

23



(Cont.)
Fig. 2. North-South cross-sections of (a) *S*, (b) AOU, (c) NO_3, (d) pH, **(e) NTA and (f) $NTCO_2$** in the western part of the SCS.

Taken from Chen et al. (2006). Marine Chemistry, 101, 277-305, doi: 10.1016/j.marchem.2006.01.007.

24

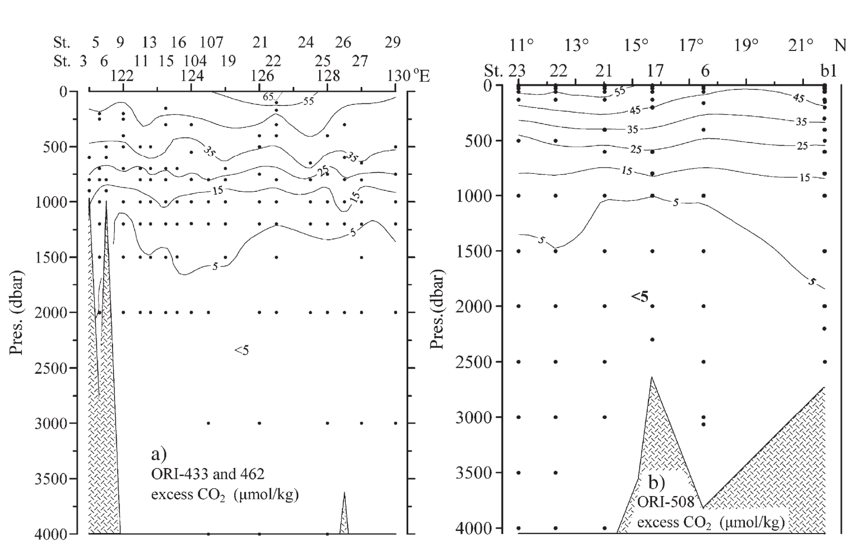


Fig. 9. Cross-sections of anthropogenic CO_2 in the (a) West Philippine Sea and (b) the South China Sea.

Taken from Chen et al. (2006). Marine Chemistry, 101, 277-305, doi: 10.1016/j.marchem.2006.01.007. 25

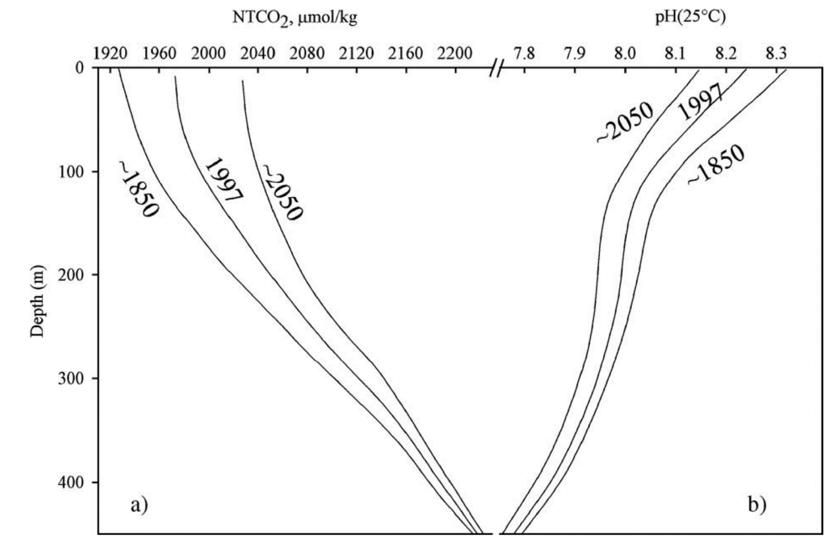


Fig. 11. Typical pre-industrial (~ 1850), present (1997) and projected (~ 2050) (a) $NTCO_2$ and (b) pH vertical profiles of seawater in the SCS.

Taken from Chen et al. (2006). Marine Chemistry, 101, 277-305, doi: 10.1016/j.marchem.2006.01.007. 26

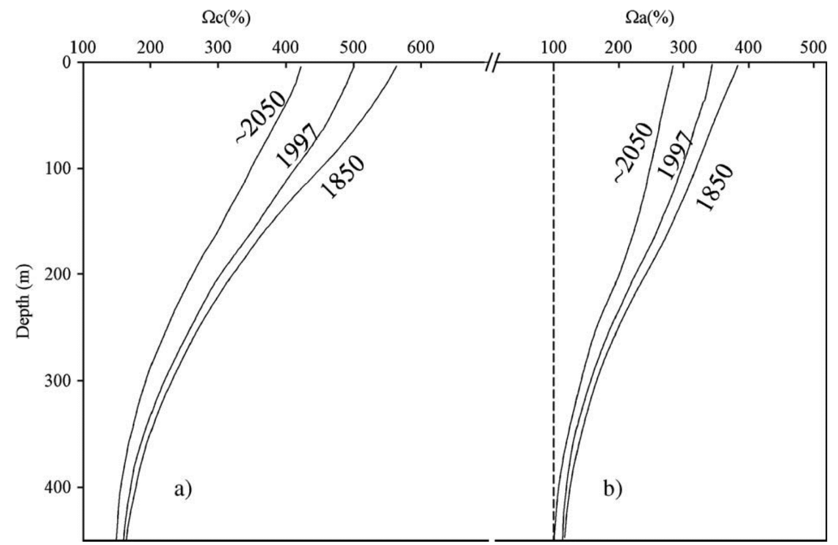


Fig. 12. Typical pre-industrial (~ 1850), present (1997) and projected (~ 2050) (a) Ωc and (b) Ωa vertical profiles of seawater in the SCS.

Taken from Chen et al. (2006). Marine Chemistry, 101, 277-305, doi: 10.1016/j.marchem.2006.01.007. 27

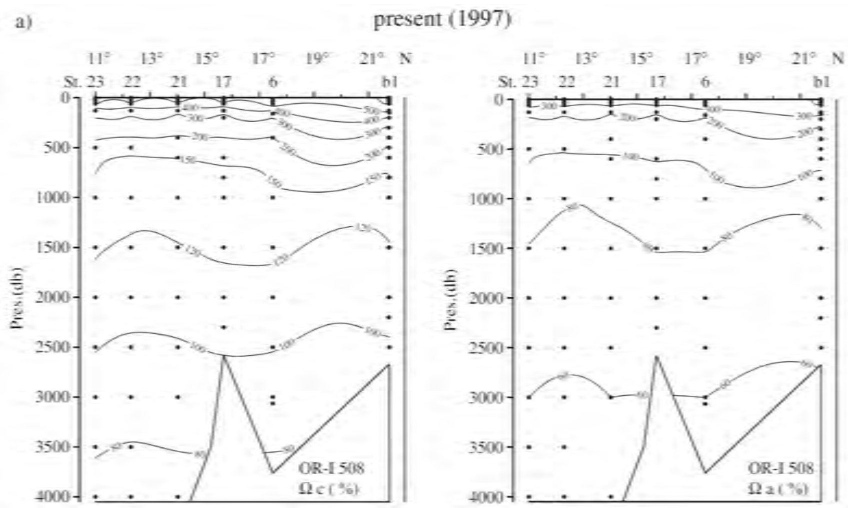
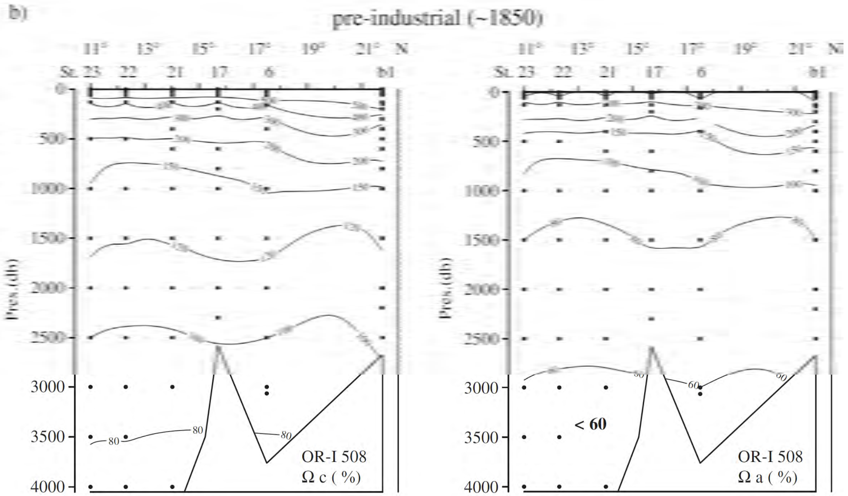


Fig. 13. North–south cross-sections of **(a) present (1997) Ωc and Ωa** and (b) pre-industrial (~ 1850) Ωc and Ωa in the western part of the South China Sea.

Taken from Chen et al. (2006). Marine Chemistry, 101, 277-305, doi: 10.1016/j.marchem.2006.01.007. 28



(Cont.)
Fig. 13. North–south cross-sections of (a) present (1997) Ωc and Ωa and **(b) pre-industrial (~ 1850) Ωc and Ωa** in the western part of the South China Sea.

Taken from Chen et al. (2006). Marine Chemistry, 101, 277-305, doi: 10.1016/j.marchem.2006.01.007.

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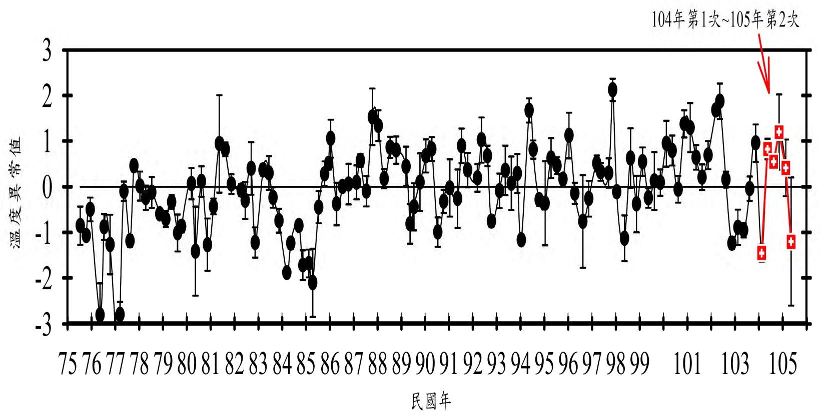

圖2-3 75年7月~105年5月第三核能發電廠附近海域溫度距平值(當月測值-歷年月平均值)之變化圖

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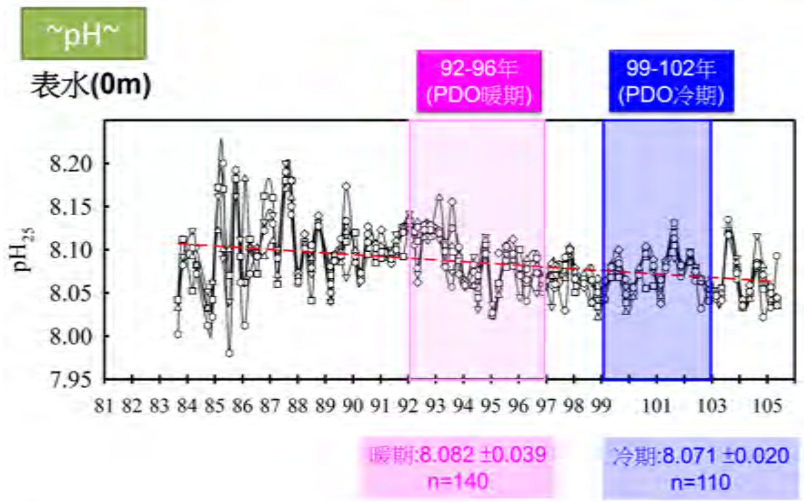

圖6-2-4 本海域於92~96年PDO暖相以及99~102年PDO冷相之pH變化圖

31

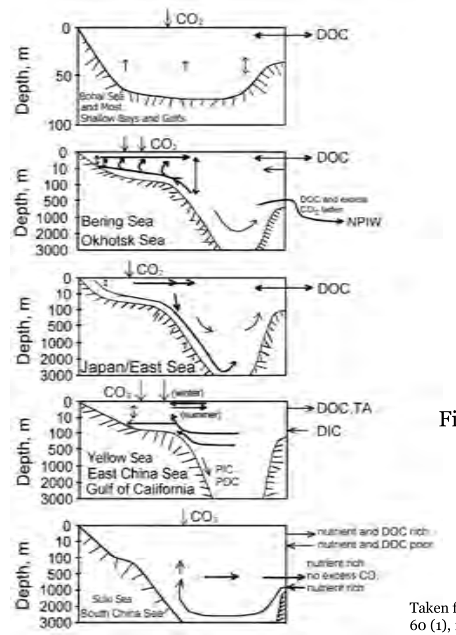

Fig. 12. Schematic diagrams of flow patterns in the Bohai Sea, Bering and Okhotsk Seas, Japan/East, Yellow and East China Seas, Gulf of California, and the Sulu and South China Seas.

Taken from Chen et al. (2004). Journal of Oceanography, 60 (1), 17-44.

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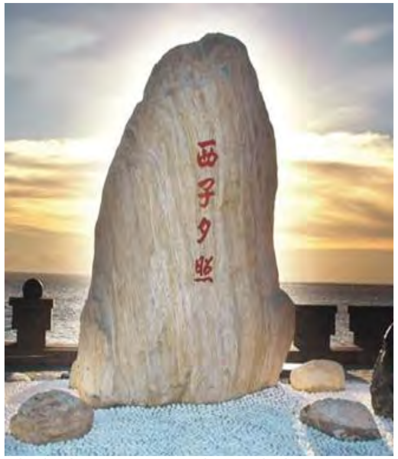
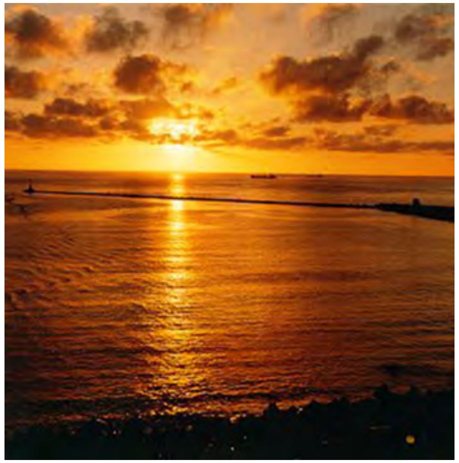
Welcome to visit
National Sun Yat-sen University





Taken from http://www.uu1.com/sight/cq1486.html

Session 1-2

"Progress of Ocean Acidification in the western North Pacific"

Masao Ishii

Head of 3rd Laboratory,

Oceanography and Geochemistry Research Department,

Meteorological Research Institute, Japan Meteorological Agency

Education:

Ph.D. in Science (Chemistry), Nagoya University, 1989

Expertise:

Ocean Carbon Cycle and Biogeochemistry

Measurements of CO2 system variables in seawater

Appointments:

2013- Head Scientist of 3rd Laboratory, Oceanography and Geochemistry Research Department, Meteorological Research Institute, Japan Meteorological Agency

International activities:

2017- UNESCO/IOC and SCOR International Ocean Carbon Coordination Project (IOCCP) - Global Ocean Observing System (GOOS) Biogeochemical Panel, co-chair.

2015- Integrated Marine Biogeochemistry and Ecosystem Research (IMBER), member of Scientific Steering Committee.

2008- North Pacific Marine Science Organization (PICES), member of Section on Carbon and Climate (S-CC)

温暖化・海洋酸性化の研究と対策に関する国際会議
2017年1月18・19日　笹川平和財団

Progress of Ocean Acidification in the western North Pacific

北西太平洋における海洋酸性化の進行

Masao ISHII
石井 雅男

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Co-chair, SCOR-IOC International Ocean Carbon Coordination Project

Special thanks to

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T. Nakano, Y. Takatani, Y. Iida, A. Kojima, S. Masuda, K. Enyo, K. Nemoto et al. (JMA)

M. Wakita, N. Harada, T. Kawano (JAMSTEC), I. Asanuma (TUIS)

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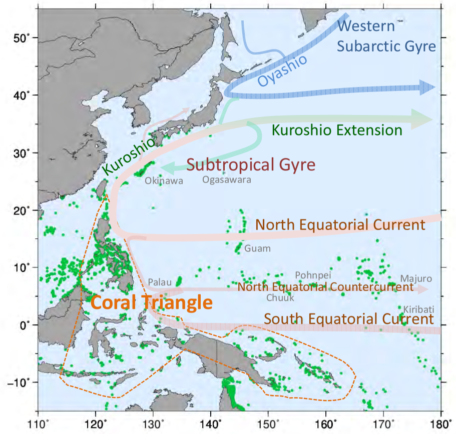
K.B. Rodgers (Princeton U.), D. Iudicone (SZAD), B. Blanke (Ifemer), O. Aumont (LOCEAN)

SOCAT team, PACIFICA team

Officers and crew of *RV Ryofu Maru, RV Keifu Maru* (JMA),
RV Hakuho Maru (U.Tokyo, JAMSTEC), *RV Natsushima, RV Kaiyo, RV Mirai* (JAMSTEC)

Western North Pacific



• Coral reef habitats

Subarctic

- High productivity in summer
- Large catch of fish

Subtropics and Tropics

- Accommodating many coral reef habitats and marine biodiversity hotspots (e.g., 75% of the world's coral species and more than 3000 species of fish).

Photo by WWF

"Is ocean acidification in fact occurring in the western North Pacific?"

Contents

Trends of oceanic CO_2 increase and ocean acidification over the past decades in :

(1) 137°E repeat line between Japan and Indonesia (3°N – 34°N) across subtropical and tropical zones.

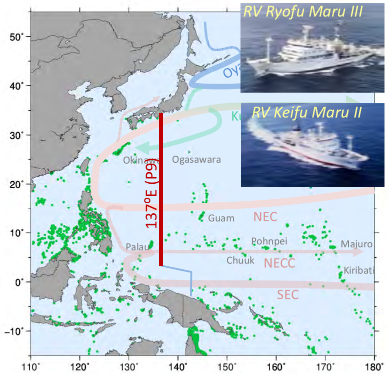
- Surface layer
- Ocean interior

(2) Surface layer of the western equatorial Pacific warm pool (130°E – 180°, 5°S – 5°N).

(3) Surface layer in the western subarctic at

- Stations KNOT (155°E, 44°N) and K2 (160°E, 47°N)
- 155°E – 165°E, 34°N – 50°N and Oyashio region off of northern Japan

Subtropics and Tropics - 137ºE Repeat Line by JMA



Shower-head type equilibrator for pCO_2

Automated measuring system for DIC & TA

Repeat measurements at 137ºE

1967 – *T*emp., *S*alinity, oxygen and nutrients.

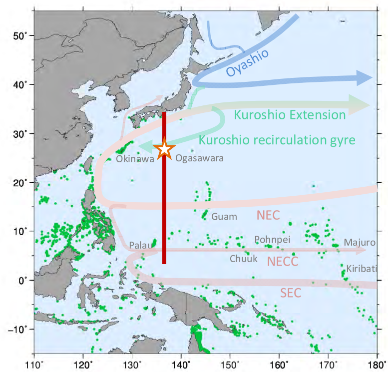
1983 – Partial pressure of CO_2 in surface water (pCO_2^{sw}) and in the atmosphere (pCO_2^{air}) .

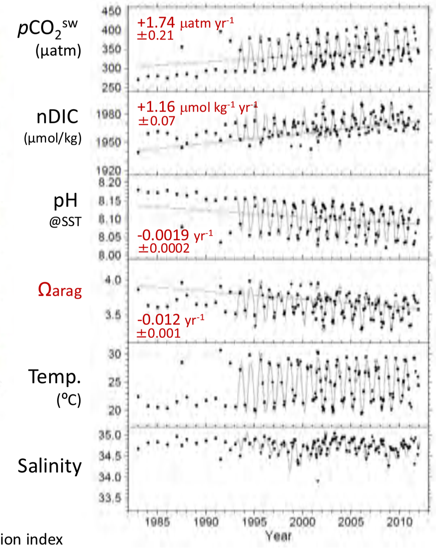
1994 – total dissolved inorganic carbon (DIC) at depths.

2010 – total alkalinity (TA) and pH at depths

- Saturation level of CO_2 in surface water
  - > Sea-air CO_2 flux
- DIC increase in surface water and in the ocean interior
  - > Anthropogenic CO_2 accumulation and carbon cycle / ocean circulation changes
  - > Ocean acidification

Trends in the surface of the subtropics at 137ºE, 27ºN

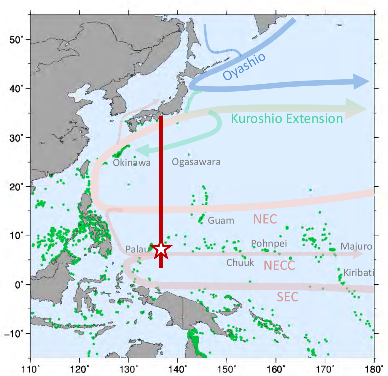


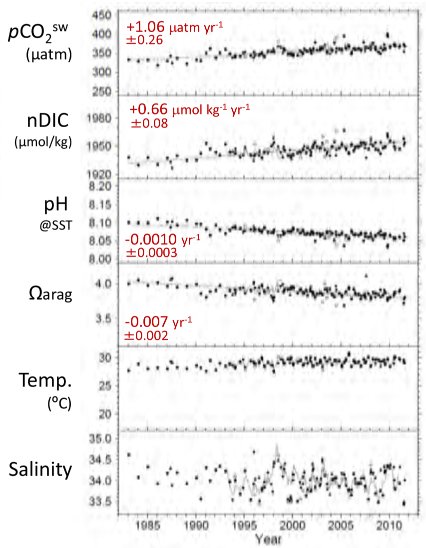


- Despite large seasonal and year-to-year variations, trends of CO_2 increase and acidification are significant.

Ωarag : Calcium carbonate mineral "aragonite" saturation index

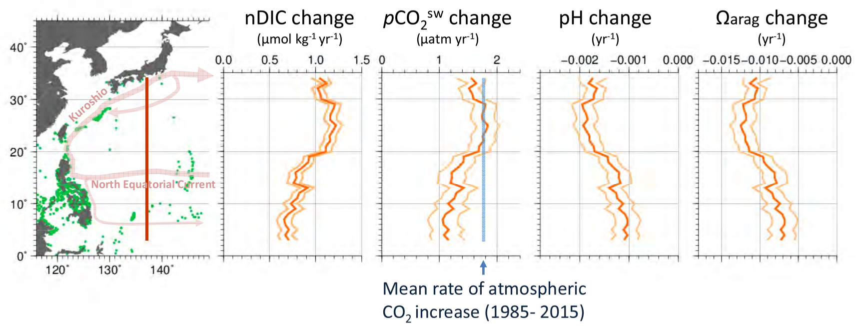
Trends in the surface of the tropics at 137ºE, 7ºN





- Trends of CO_2 increase and acidification are clear, but their rates of change are lower than in the subtropics and than the rates under the condition of air-sea CO_2 equilibrium.

Meridional distributions of the linear rate of ocean CO_2 increase and acidification at 137ºE



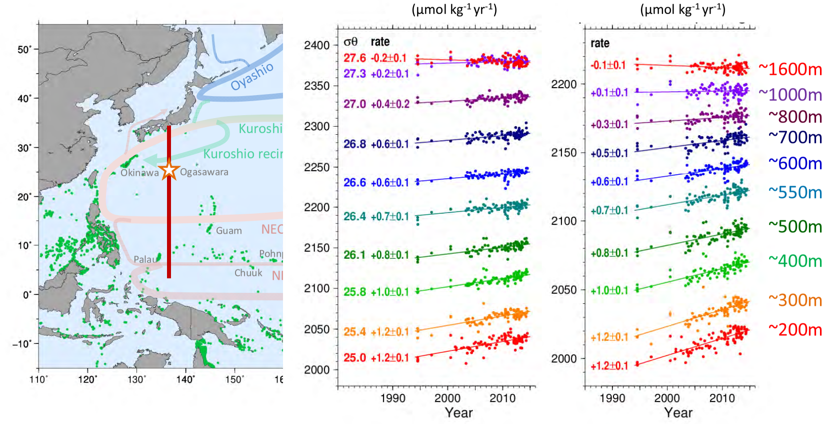
- Rates of DIC increase and acidification are consistent with those expected from the rate of atmospheric CO_2 increase in the subtropics (20ºN-34ºN), but are lower in the tropics (3ºN-18ºN).
- From the biogeochemical point of view, marine ecosystems in the subtropics are more vulnerable to ocean acidification.

Trends of CO_2 increase and acidification in the ocean interior of the subtropical gyre at 137°E

"How deep have the anthropogenic CO_2 penetrated into the ocean interior?"

RV Ryofu Maru and CTD/multi-sampler.

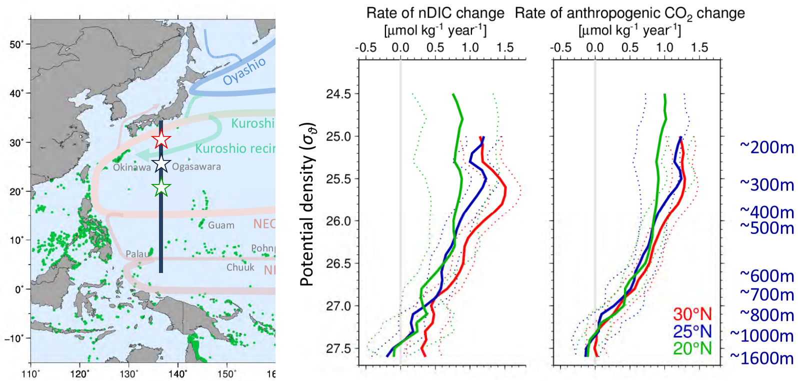
Trends in the interior of the subtropical gyre at 137°E, 25°N



- Upward trend of nDIC has been detected down to the layer of 27.0σ_θ (~800m).
- These DIC increases at depths are primarily attributable to the invasion of anthropogenic CO_2.

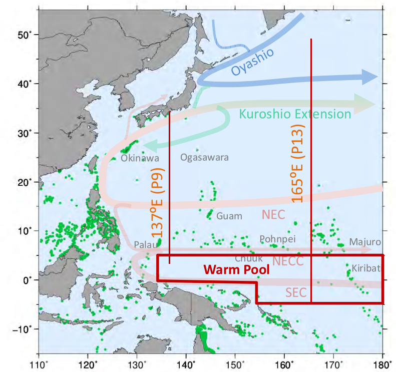
Preformed nDIC : nDIC when the water was last contact with the atmosphere
= {DIC – 117/170 (O_2sat- O_2)}·S/35 : changes due to $CaCO_3$ dissolution not taken into account

Trends of nDIC increase in the interior of the subtropical gyre at 137°E



- Rate of anthropogenic CO_2 (preformed nDIC) increase is the highest in the surface layer and lower in the deeper layers.
- Vertical profiles of the anthropogenic CO_2 increase with respect to water density show little latitudinal variation.

Oceanic CO_2 measurements in the western equatorial Pacific



1987 –2003 MRI-JAMSTEC collaborative studies on ocean CO_2 in the western equatorial Pacific.

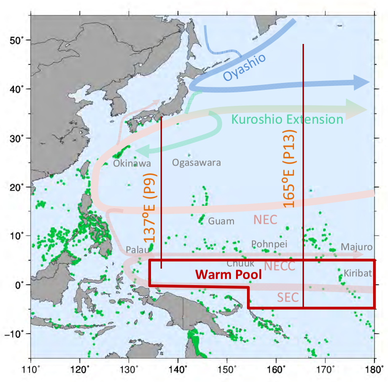
1996 – JMA's repeat line at 165E.

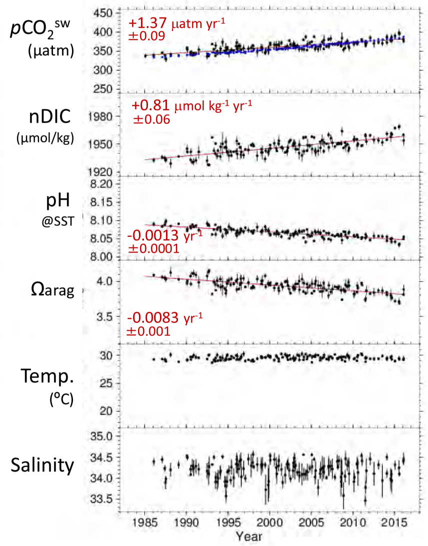
and many others cruises by Japan, USA and France. Data of pCO_2sw taken in these cruises have been stored in "Surface Ocean CO_2 Atlas"

- Here, we define the "warm pool" as the region where t>28.7°C, S<34.6 in the western equatorial Pacific (5°S-5°N).

The pCO_2sw measurements in the equatorial Pacific have originally been made in order to understand the variability in sea-air CO_2 flux associated with El Nino Southern Oscillation.

Trends in the warm pool





- Rate of CO_2 increase and acidification in the warm pool are also slower than the rates expected under the conditions of air-sea CO_2 equilibrium.

Mechanism of ocean acidification in the equatorial Pacific: excess CO_2 uptake in extratropics and its equatorward transport through the ocean interior

1) Excess CO_2 uptake from the atmosphere into the surface of the vast extratropics

2) Subduction into the ocean interior

10 ~ 15 years

3) Equatorial Undercurrent (EUC)

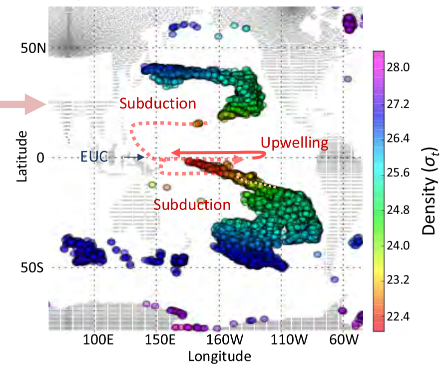
< 2 years

4) Upwelling to the surface in the central equatorial Pacific

+ excess CO_2 uptake in the equatorial zone

5) Westward transport to the warm pool

Model: NEMO-LIM2-PISCES
Origins of 165E EUC water (Ariane backward)



Transports originated from
North: 4.8 Sv (24.2%)
South: 15.0 Sv (75.8%) → Increasing?

Courtesy of K.Toyama

Why ocean acidification is slower in the warm pool?

1) Excess CO_2 uptake from the atmosphere into the surface of the vast extratropics

2) Subduction into the ocean interior

10 ~ 15 years

3) Equatorial Undercurrent (EUC)

< 2 years

4) Upwelling to the surface in the central equatorial Pacific

+ excess CO_2 uptake in the equatorial zone

5) Westward transport to the warm pool

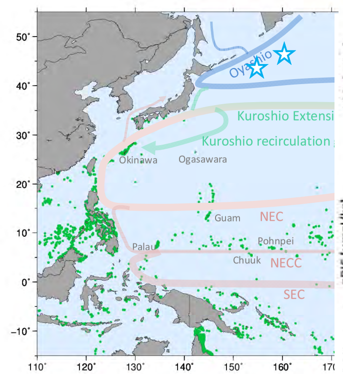
a) Smaller CO_2 buffering capacity (smaller physico-chemical ability to absorb CO_2) of surface seawater in higher latitude

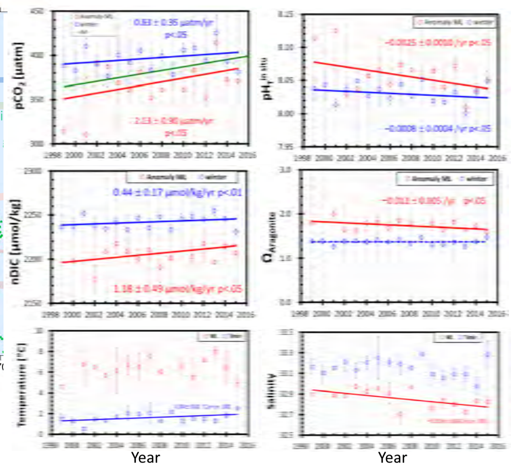
b) Time-lag of CO_2 increase in the warm pool after the atmospheric CO_2 growth

c) Increasing transport from the South Pacific with naturally lower preformed nDIC?

= Negative feedback from the climate variability/change?

Trends in the surface of the western subarctic at stations KNOT (155°E, 44°N) and K2 (160°E, 47°N)



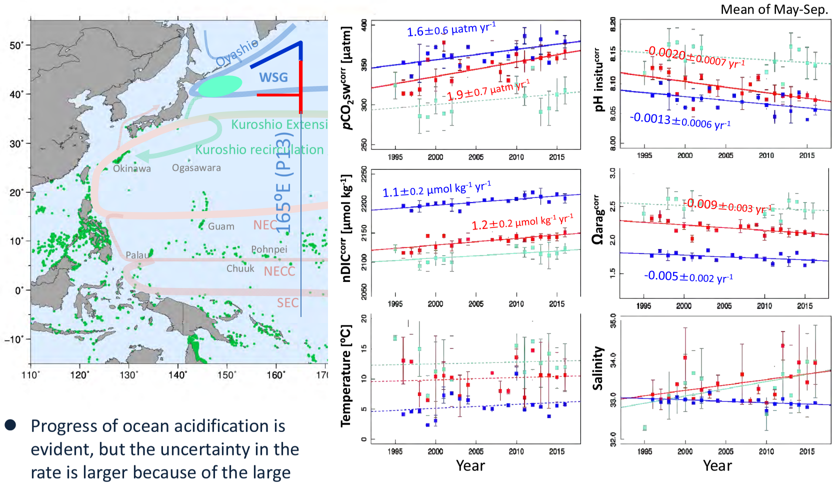


- Different trends in different seasons, i.e., slower rate of CO_2 increase and acidification in winter.

Winter (from winter water observed in summer)
Annual mean (seasonally-detrended)

Courtesy of M.Wakita and N. Harada

Trends in the surface of the western subarctic and subtropical-to-subarctic zones and of the Oyashio region



- Progress of ocean acidification is evident, but the uncertainty in the rate is larger because of the large spatial and seasonal variations.

$nDIC^{corr} = nDIC - a \cdot SST^{anomaly} - b \cdot \log(Chl.a)$

(The rates indicated are preliminary)

Courtesy of Y. Iida

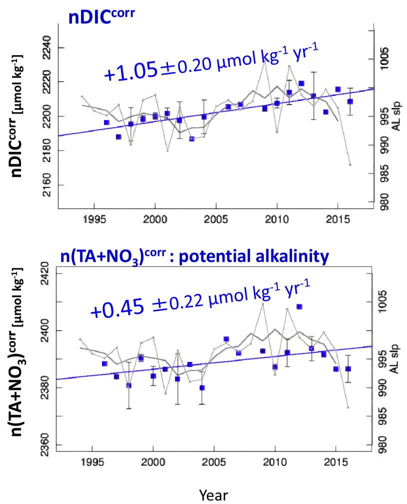
Perturbation by climate variability?

nDIC *vs* Sea level Pressure
R = 0.42
(significant at 90% confidence intervals)

—— **Sea level pressure** at the center of the **Aleutian Low** (3-year running mean)

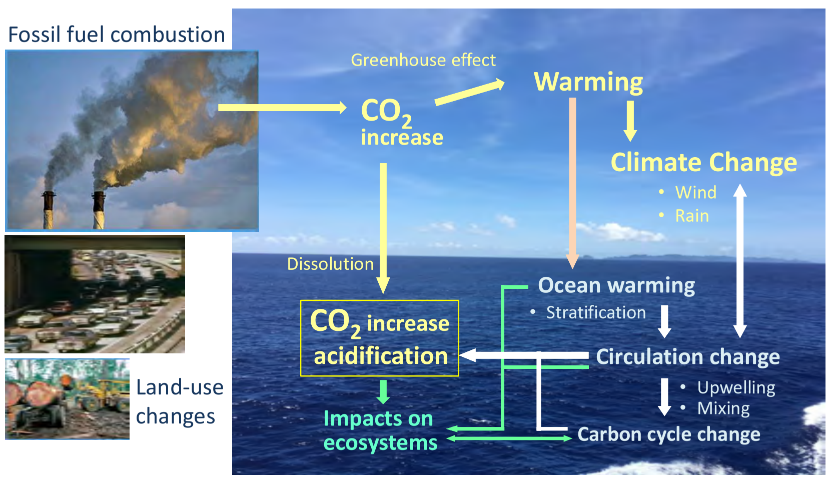
n(TA+NO_3) *vs* Sea level Pressure
R = 0.59
(significant at 99% confidence intervals)

- Variability in potential alkalinity that is associated with the sea level pressure suggests that changes in ocean circulation and vertical mixing in the upper subarctic gyre are playing a role for the variability in ocean CO_2 system and thereby the rate of ocean acidification.



Courtesy of Y. Iida

Anthropogenic CO_2 invasion into the sea and carbon-climate feedback



Conclusion

- Progress of OA have been distinctly observed for the past decades at a variety of location in the tropical, subtropical and subarctic zones of the western North Pacific.
- Rate of OA in the surface layer has been primarily controlled by the growth rate of the atmospheric CO_2 concentration.
- In the tropics, rate of OA appears to be 10-15 years behind the rate that corresponds to the growth of the atmospheric CO_2. This is because the OA in the tropical Pacific is primarily controlled by the transport of anthropogenic CO_2 from the extratropics through the ocean interior.
- Climate variability/change is likely to have a significant impact on the rate of OA in the tropics and in the subarctic.

Session 1-3
“Ocean Acidification Studies in the Seas around Japan”

Tsuneo Ono
Chief Scientist,
Japan Fisheries Research and Education Agency (FRA)

Research Interests

*Temporal variation of physical/chemical ocean environment both by natural and by anthropogenic forcings, such as PDO and/or global warming
*Response of oceanic ecosystems to ocean environmental changes
*Carbon and nutrient cycles within North Pacific Ocean

Education

1997	Ph.D. in Fisheries Sciences, Hokkaido Univ.

Synergistic Activities

2004-2006	Contributing Author for IPCC Fourth Assessment Report
2006-present	Member of PICES Section for Carbon and Climate (co-chair from 2015)

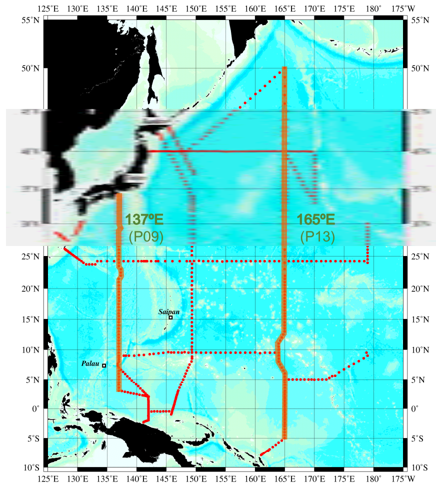
Ocean acidification studies in the seas around Japan
日本周辺海域における酸性化とモニタリングの現状

Tsuneo Ono (Fisheries Research Institute)
小埜恒夫（水産研究・教育機構）

Japan Ocean Acidification Network

気象庁 Japan Meteorological Agency; National Institute for Environmental Studies, Japan; FRA; HIROSAKI UNIVERSITY; 筑波大学 University of Tsukuba; 国立大学法人 東京海洋大学; University of the Ryukyus; 京都大学 KYOTO UNIVERSITY; AIST; NiPR; OPRI THE OCEAN POLICY RESEARCH INSTITUTE

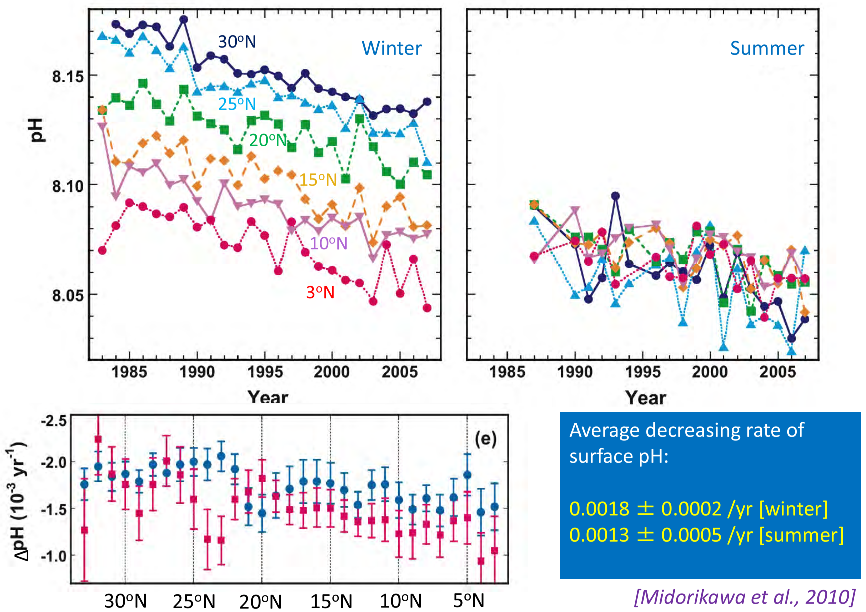
Overall trends of pCO_2 and pH in western North Pacific : Japan Meteorological Agency monitoring along 137E & 165E



JMA high-frequency hydrographic sections

- 137°E (P09) : Seasonal to annual 1967 -
  - pCO_2 (NDIR, shower-head) 1983 -
  - DIC (coulometric) 1994 -
  - pH (spectrophoto.) 2003 -
  - TA (spectrophoto.) 2010 -
- 165°E (P13) : Annual 1997 -

Long-term trends in the surface water along 137°E

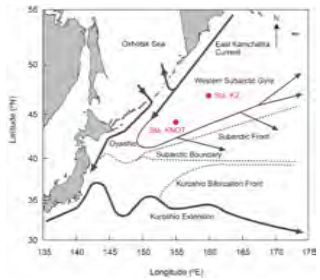


Average decreasing rate of surface pH:

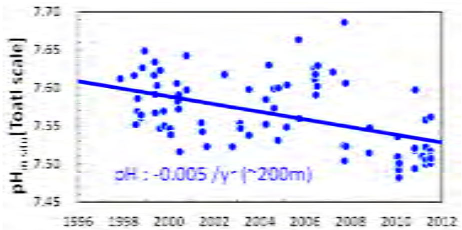
0.0018 ± 0.0002 /yr [winter]
0.0013 ± 0.0005 /yr [summer]

[Midorikawa et al., 2010]

Long-term decreasing trend of pH are also observed in subarctic North Pacific

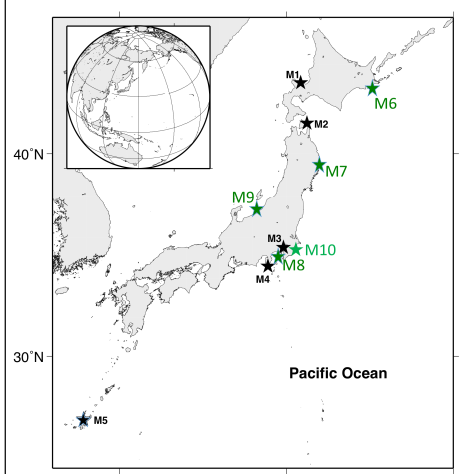


Long-term ocean monitoring stations in western subarctic North Pacific:
Sta. KNOT (44°N, 155°E)
Sta. K2 (47°N, 160°E)



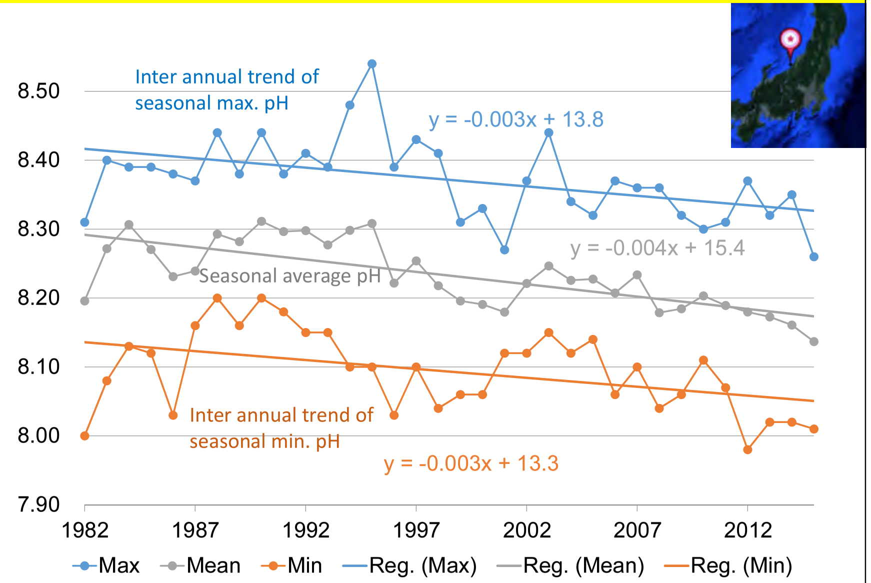
Time series of pH observed in KNOT and K2: averaged data from sea surface to 200m depth
[adapted from Wakita et al. 2013, Biogeosciences]

ongoing Japan-coast pH monitoring sites *[after S. Takao/WESTPAC 2015]*

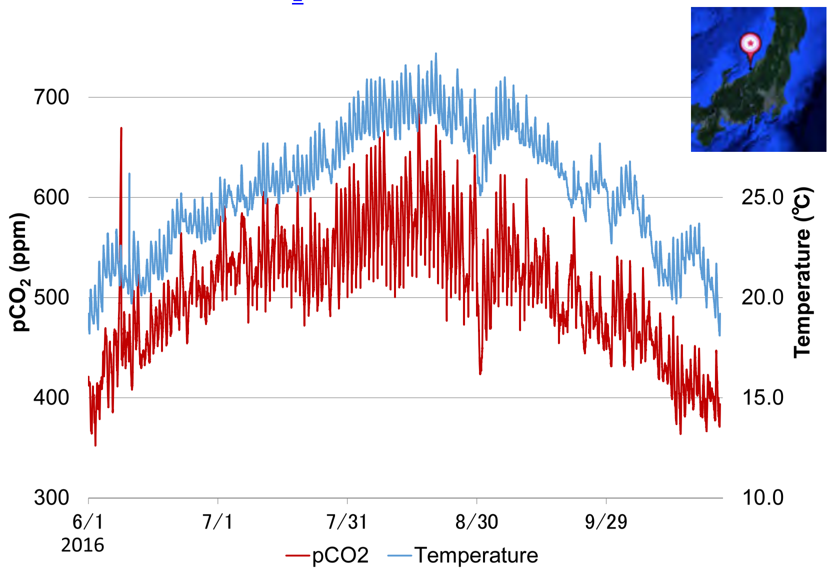


M1: Oshoro Bay [Japan Sea & origotrophic; 2013 – present]
M2: Tsugaru Straight [transition & origo-trophic; 2014 – present]
M3: Tateyama Bay [subtropic & eutrophic; 2011 – present]
M4: Shimoda Bay [Subtrophic & oligo-trophic; 2011 – present]
M5: Nago Bay [Coral coast; 2000 – present]
M6: Akkeshi Bay [subarctic eelgrass swamp; 2014 – present]
M7: Miyako station [transition & oligo-trophic; 2014 – present]
M8: Arasaki Station [Subtrophic & oligo-trophic; 2009 - 2011]
M9:Kashiwazaki Station [Subtrophic & oligo-trophic; 1982 –present]
M10:Onjuku Station [Subtrophic & oligo-trophic; 1982 –present]

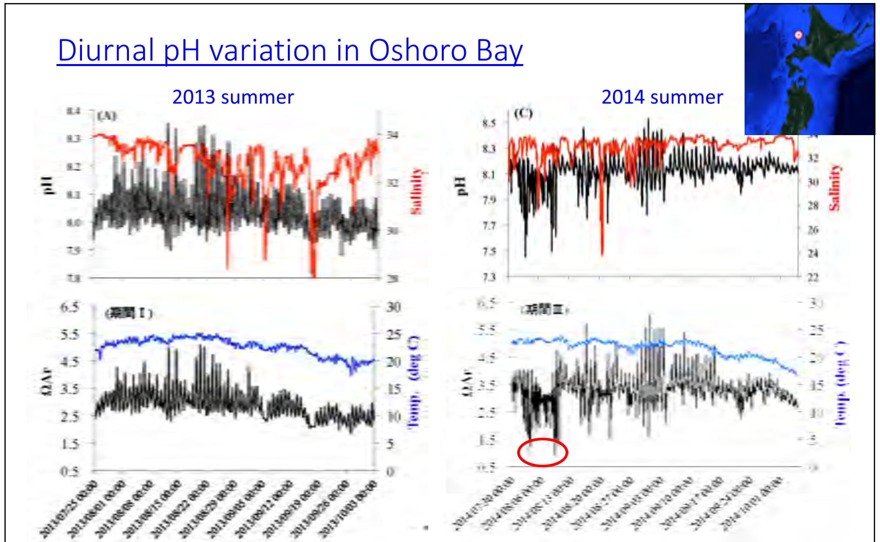
long term pH trend observed at Kashiwazaki site (1982-2015)



Diurnal / seasonal pCO_2 variation in kashiwazaki district



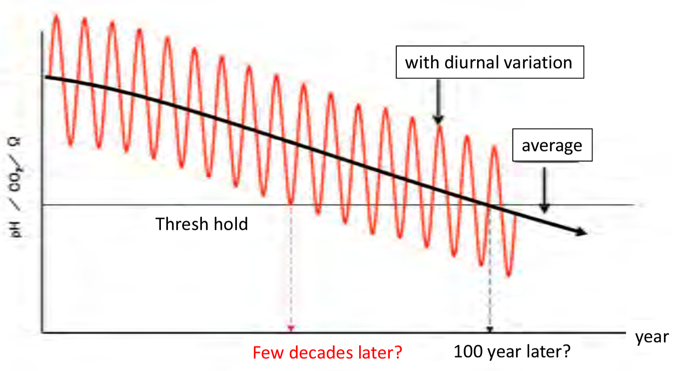
Diurnal pH variation in Oshoro Bay



pH amplitude:
avg. 0.18 ± 0.08
max 0.44
min 0.08

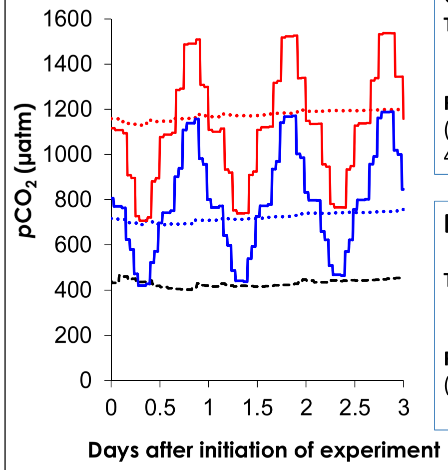
pH amplitude:
avg. 0.28 ± 0.19
max 0.83
min 0.05

Consequence of diurnal/seasonal variation of pH in coastal area:
What does biota respond to? Average or Minimum?



modified from Yamamoto-Kawai et al.

Effects of diurnally-variable pCO_2 on ezo-abalone larvae by culture experiment *[Onitsuka et al., submit.]*



Constant treatments

Targeted *p*CO_2
400 μatm, 800 μatm, 1200 μatm

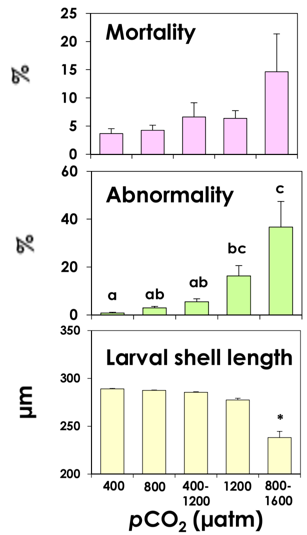
Results of monitoring
(Dotted lines)
430±15, 732±19, 1175±20 μatm

Diel cycle treatments

Targeted *p*CO_2
400-1200 μatm, 800-1600 μatm

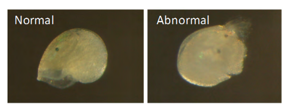
Results of monitoring
(Solid lines)
420-1189 μatm, 739-1537 μatm

Results : Effects on larval fitness



There were no significant differences in mortality rate among all the *p*CO_2 treatments.

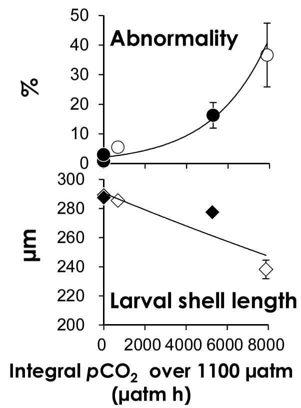
Abnormality rate was significantly higher in the 1200μatm, and more in 800-1600 μatm



Shell length in the 800-1600 μatm was significantly shorter but not in the 1200μatm.

[Onitsuka et al., submit.]

Results 2: Effect of integral *p*CO_2 on larval fitness



Open markers: diel cycle treatments
Solid markers: constant treatments

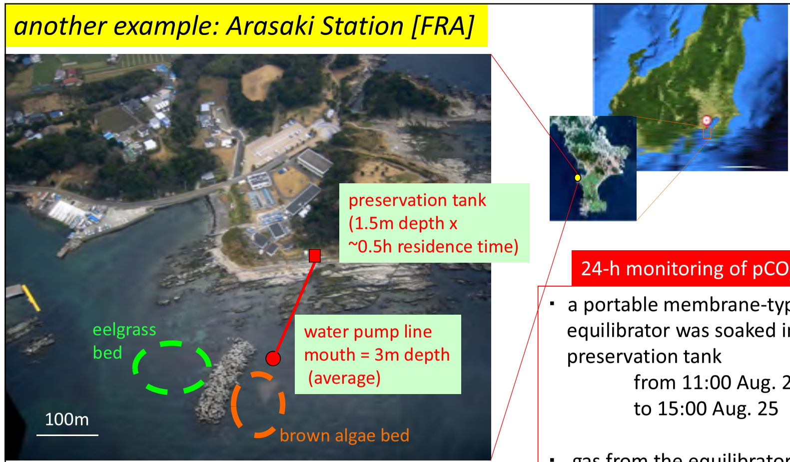
The aragonite saturation state around Ω=1.0 is equivalent to 1100 μatm *p*CO_2.

Integral *p*CO2 over 1100 μatm
$=\sum(P-1100)i$
***P*: *p*CO_2 over 1100 μatm**
***i*: exposed hours to *p*CO_2 over 1100 μatm**

Abnormality rate increased with increment of integral *p*CO_2 over 1100 μatm .

Larval shell length decreased as integral *p*CO_2 over 1100 μatm increased.

another example: Arasaki Station [FRA]



1-year composite pCO_2 variation

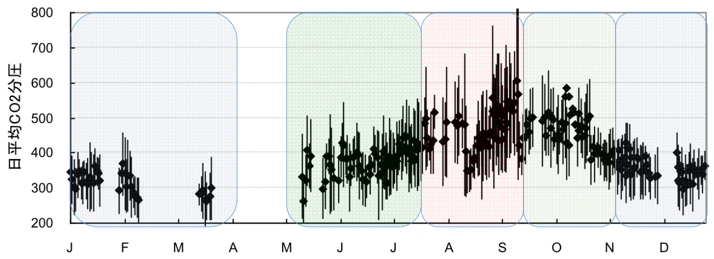
similar pCO_2 monitoring (without water sampling) was continued intermittently until Mar. 2011 to obtain composite 1-year monitoring data.

©KIMOTO electolonic

24-h monitoring of pCO_2

- a portable membrane-type gas equilibrator was soaked into the preservation tank
  from 11:00 Aug. 24
  to 15:00 Aug. 25
- gas from the equilibrator was measured once an hour by NDIR
- water samples were taken from the tank every 3hour and measured DIC and Talk.

1-year composite data

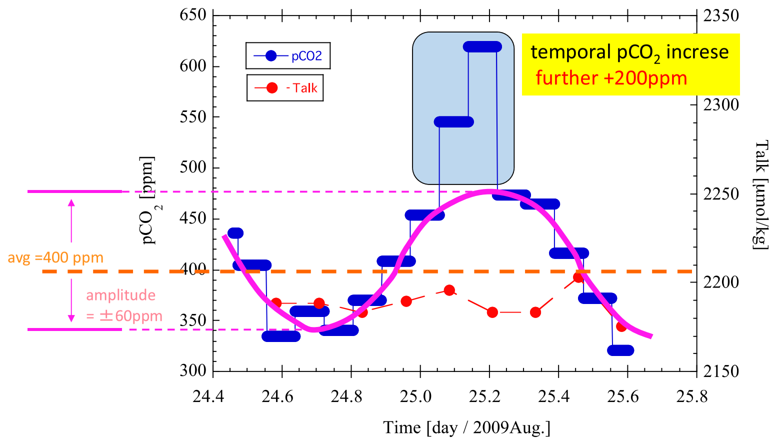


- significant seasonal dependence in the amplitude of diurnal pCO_2 variation

#winter (Nov. – Mar.)	~150 ppm
#spring (May –mid July)	~200ppm
#summer (mid July – early Sept.)	>300ppm (max. 400)
#autumn(mid Sept.-Oct.)	~200ppm

- Annual pCO_2 maximum: daily avg. 600ppm
  with diurnal variation: >800ppm

result of 24-hour pCO_2 monitoring

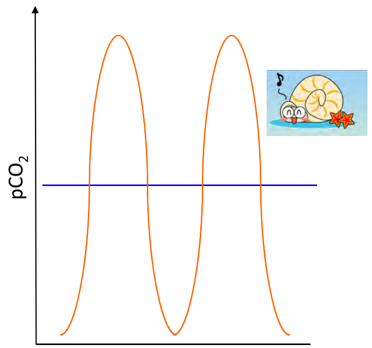


total diurnal pCO_2 variation........about 300 ppm

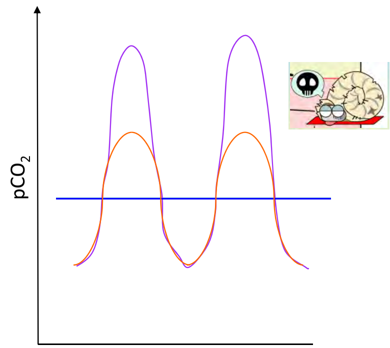
Existence of local hot spot of pH and pCO_2 among the Arasaki station

different biotic response between "natural eutrophication" and "polluted eutrophication"

natural eutrophication
(inner-Bay, estuary etc.)



polluted eutrophication
(arasaki district)



Summary: present knowledge on ocean acidification In the waters around Japan

1] observed pH decrease in open ocean: -0.0013 〜 -0.0018/y (subtropical surface)
-0.005/y (subpolar surface)

2] pH decrease in Japan coast: -0.003/y at one station, but
should be subject to high local variation
(more long-term data needed!)

3] existence of high diurnal / seasonal variation of pH even in one site, and

4] some biota exhibit high sensibility not against daily average but daily minimum pH
(or daily integral pH-excess from the level equivalent to Ω_{ara} =1)

5] existence of eutrophication-oriented ocean acidification in parallel with anthropogenic CO_2 - oriented ocean acidification : This may more cause severe effect to local biota when considering historical biological adaptation.

Session 1-4

“Ocean Acidification and its Effects on Pacific Island States”

Tommy S. Moore
Pacific Islands Global Ocean Observing System Officer,
Secretariat of the Pacific Regional Environment Programme (SPREP)

Professional Interests

Climate Change and Oceans; Bridging the Gap Between Science and Policy/Resource Managers; Geochemistry; Chemical Oceanography; Ocean Observing; Coupling of Physical, Chemical, and Biological Measurements; Environmental and Marine Conservation

Professional Experience

Secretariat of the Pacific Regional Environment Programme	Apia, Samoa
Pacific Islands Global Ocean Observing System Officer	July 2014 to Present

Project manager for the Pacific Partnership on Ocean Acidification. Supporting and developing ocean observing programmes in the Pacific Islands region. Supporting international efforts such as the Argo programme. Raising awareness of ocean acidification in the region and seeking funding for adaptation efforts. Working as a member of the Pacific Meteorology Desk Partnership to enhance meteorology and marine forecasting in the region. Chair of the Pacific Islands Marine and Ocean Services Panel.

Pacific Islands Conservation Initiative	Rarotonga, Cook Islands
Lead Science Officer	Sep 2013 to Dec 2013
IMEDEA	Esporles, Balearic Islands, Spain
Post-Doctoral Researcher	Dec 2011 to Aug 2013
University of Montana	Missoula, MT, USA
Post-Doctoral Researcher	Feb 2009 to Mar 2011

Education

University of Delaware	Lewes, DE, USA
Ph.D., Oceanography	July 2003 to Aug 2008

Dissertation Topic: Time-series electrochemical studies in the lower Delaware Bay and at the 9°50’N East Pacific Rise hydrothermal vent field

Boston University	Boston, MA, USA
M.A., Earth Sciences	Sept 2001 to May 2003
University of Montana	Missoula, MT, USA
B.Sc., Geology	Sept 1996 to May 2001

Ocean Acidification and its Effects on Pacific Island States

OPRI International Conference

19-20 January, 2017
The Sasakawa Peace Foundation Building, Tokyo, Japan

PROTECT PACIFIC WHALES – OCEAN VOYAGERS

PI-GOOS

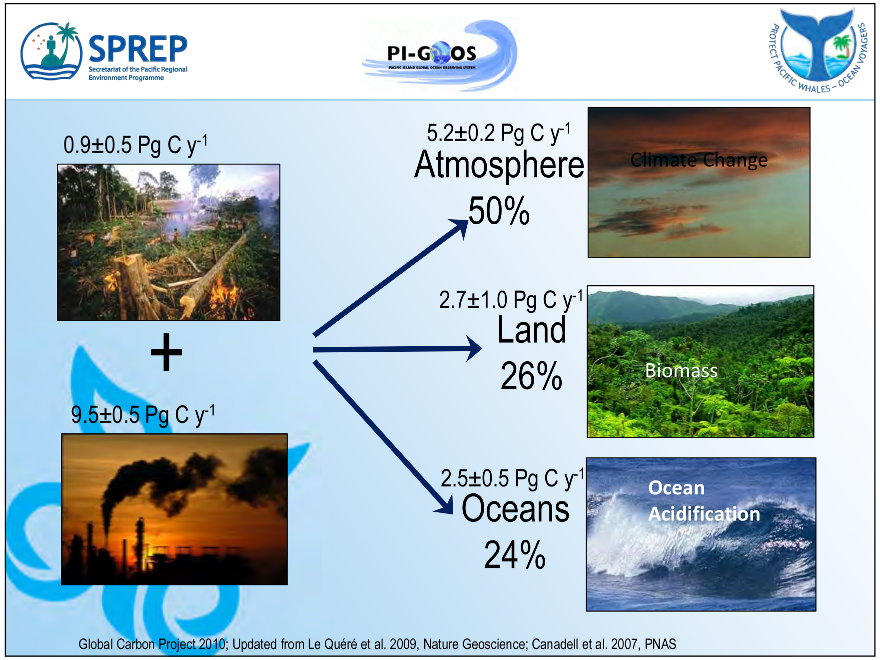
SPREP
Secretariat of the Pacific Regional Environment Programme

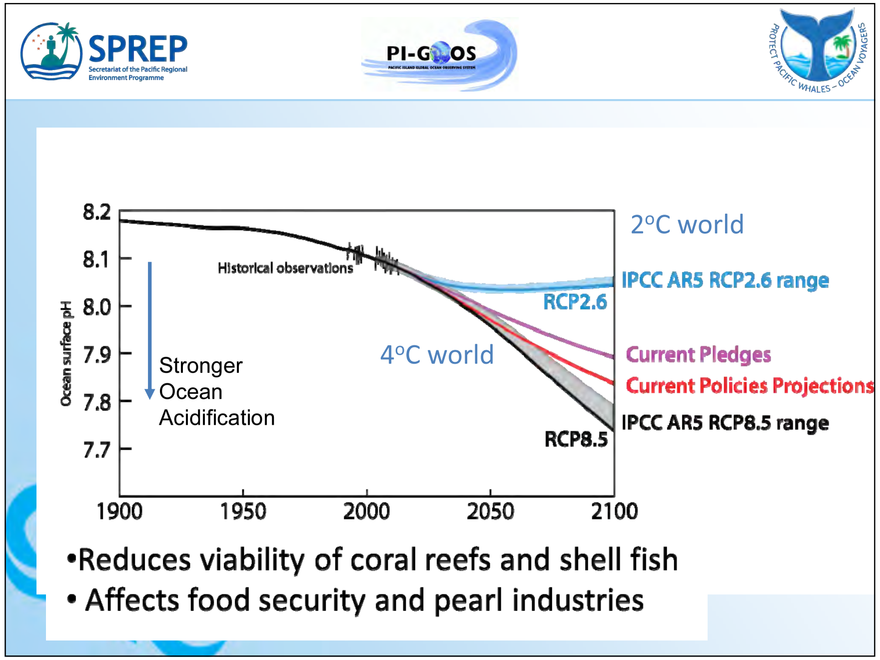
SPREP PI-GOOS PROTECT PACIFIC WHALES – OCEAN VOYAGERS

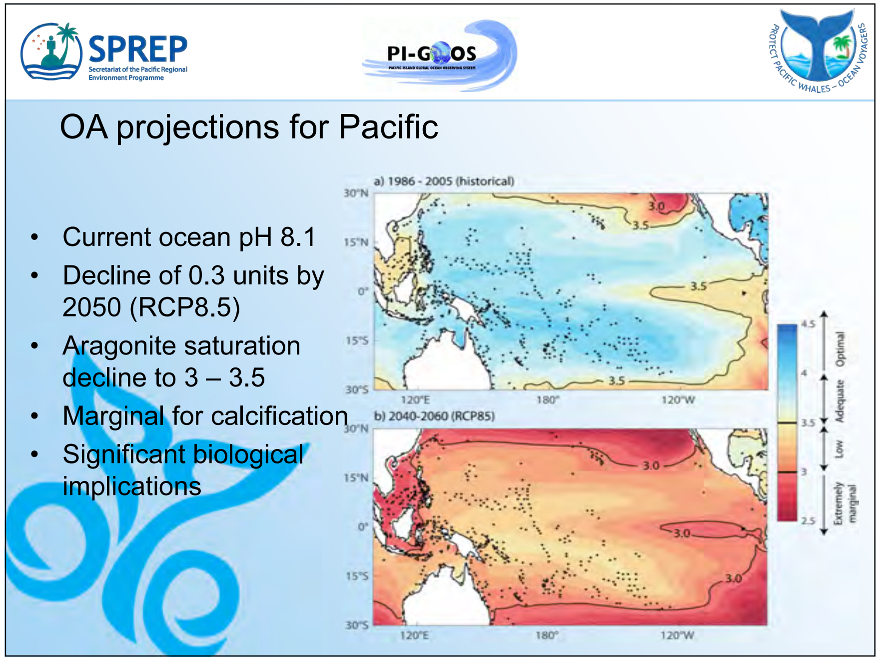
SPREP PI-GOOS PROTECT PACIFIC WHALES – OCEAN VOYAGERS

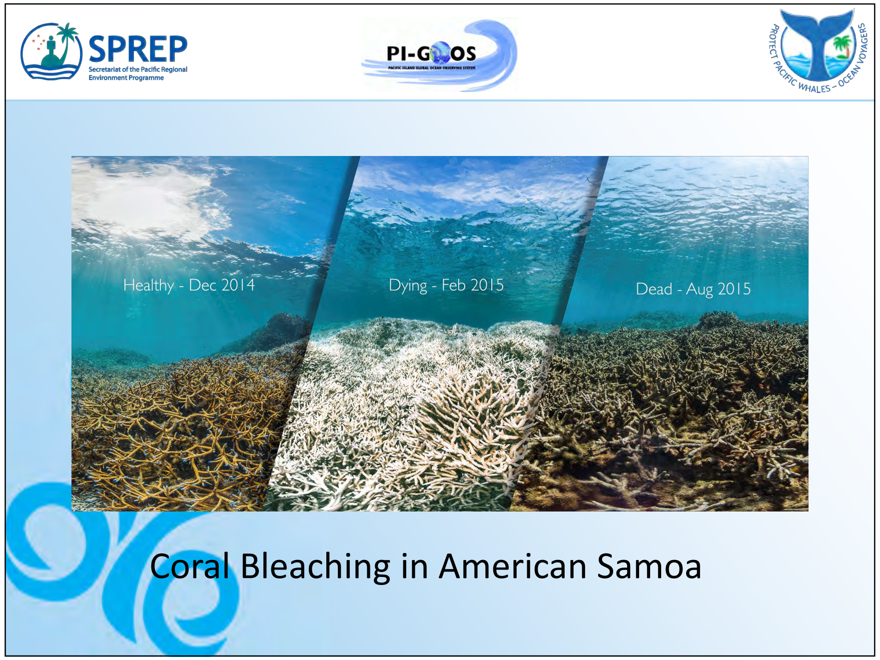
SPREP PI-GOOS PROTECT PACIFIC WHALES – OCEAN VOYAGERS

What is Ocean Acidification?


SPREP
PI-GOOS
0.9±0.5 Pg C y-1
+
9.5±0.5 Pg C y-1
5.2±0.2 Pg C y-1
Atmosphere
50%
Climate Change
2.7±1.0 Pg C y-1
Land
26%
Biomass
2.5±0.5 Pg C y-1
Oceans
24%
Ocean Acidification
Global Carbon Project 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS


SPREP
PI-GOOS
Ocean surface pH
8.2
8.1
8.0
7.9
7.8
7.7
1900
1950
2000
2050
2100
Historical observations
Stronger Ocean Acidification
4°C world
2°C world
IPCC AR5 RCP2.6 range
RCP2.6
Current Pledges
Current Policies Projections
IPCC AR5 RCP8.5 range
RCP8.5
•Reduces viability of coral reefs and shell fish
• Affects food security and pearl industries


SPREP
PI-GOOS
OA projections for Pacific
• Current ocean pH 8.1
• Decline of 0.3 units by 2050 (RCP8.5)
• Aragonite saturation decline to 3 – 3.5
• Marginal for calcification
• Significant biological implications
a) 1986 - 2005 (historical)
b) 2040-2060 (RCP85)
Optimal
Adequate
Low
Extremely marginal


SPREP
PI-GOOS
Healthy - Dec 2014
Dying - Feb 2015
Dead - Aug 2015
Coral Bleaching in American Samoa

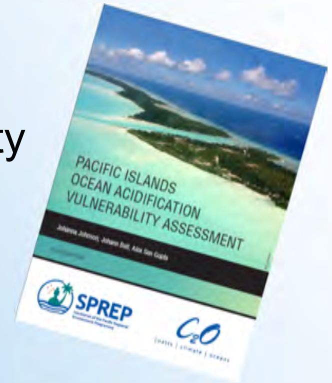
Taxon	No. of studies	No. of para-meters studied	Total no. of species studied	pCO_2 where the most vulnerable species is negatively affected or investigated pCO_2 range* (μatm)	Assessment of tolerance to RCP 6.0 (*confidence*)	Assessment of tolerance to RCP 8.5 (*confidence*)
Cyanobacteria	17	5	9+	180-1250*	Beneficial (*low*)	Beneficial (*low*)
Coccolithophores	35	6	7+	740	Tolerant (*low*)	Vulnerable (*medium*)
Diatoms	22	5	28+	150-1500*	Tolerant (*low*)	Tolerant (*low*)
Dinoflagellates	12	4	11+	150-1500*	Beneficial (*low*)	Tolerant (*low*)
Foraminifers	11	4	22	588	Vulnerable (*low*)	Vulnerable (*medium*)
Seagrasses	6	6	5	300-21000*	Beneficial (*medium*)	Beneficial (*low*)
Macroalgae (non-calcifying)	21	5	21+	280-20812*	Beneficial (*medium*)	Beneficial (*low*)
Macroalgae (calcifying)	38	10	36+	365	Vulnerable (*medium*)	Vulnerable (*high*)
Warm-water corals	45	13	31	467	Vulnerable (*medium*)	Vulnerable (*high*)
Cold-water corals	10	13	6	445	Vulnerable (*low*)	Vulnerable (*medium*)
Annelids	10	6	17+	1200	Tolerant (*medium*)	Tolerant (*medium*)
Echinoderms	54	14	35	510	Vulnerable (*medium*)	Vulnerable (*high*)
Mollusks (benthic)	72	20	38+	508	Vulnerable (*medium*)	Vulnerable (*high*)
Mollusks (pelagic)	7	8	8	550	Vulnerable (*low*)	Vulnerable (*medium*)
Mollusks (cephalopods)	10	8	5	2200 (850 for trace elements)	Tolerant (*medium*)	Tolerant (*medium*)
Bryozoans	7	3	8+	549	Tolerant (*low*)	Vulnerable (*low*)
Crustaceans	47	27	44+	700	Tolerant (*medium*)	Tolerant (*low*)
Fish*	51	16	40	700	Vulnerable (*low*)	Vulnerable (*low*)

Tolerances to ocean acidification in marine taxa, assessed from laboratory and field studies of species in the *pCO2* range from <650 to >10 000 μatm, compared to present day atmospheric levels (400 μatm).

Variables studied include growth, survival, calcification, metabolic rate, immune response, development, abundance, behavior and others.

Confidence is based on the number of studies, the number of species studied and the agreement of results within one group.
WGII Ch 6

Regional Ocean Acidification Vulnerability Assessment



Available at: http://www.sprep.org/attachments/Publications/CC/ocean-acidification.pdf

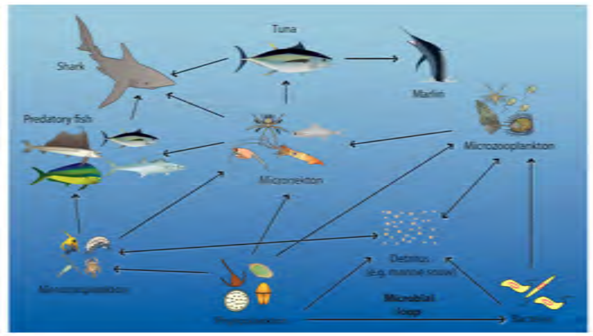
Vulnerability of reef habitats

- Lower aragonite saturation reduces calcification rates by ~10%
- Scleractinian corals, certain plankton (pteropods), molluscs, crustaceans, sea cucumbers
- Reduced coral reef growth and structural integrity; eventually bioerosion exceeds growth
- Increased susceptibility to other disturbances (e.g. storms, disease, borers)

Vulnerability of reef fisheries

- Loss of reef habitat & structure (indirect)
- Laval stages – reduced survival, growth, metabolism
- Larval reef fish loss of olfactory senses (detecting settlement habitat & predators)
- Reduced growth and more shell deformities in molluscs
- Altered sea cucumber larval survival and spicule strength
- Declining productivity

Vulnerability of ocean habitats



- Decreased calcification of some plankton and micronekton
- Changes in oceanic food web (abundance of grazers and microbes)
- Minor indirect effects on tuna – skipjack, albacore, yellowfin & bigeye

Vulnerability of tuna: prelim

- Reductions in yellowfin tuna larval growth and survival, and deformities
- Possible narrowing of optimal thermal performance window altering resistance, metabolic rate and behaviour of tuna
- Additional energy required to compensate for acidosis could lower growth rates and egg production
- Altered growth and formation of the aragonite ear bones (otoliths)

Vulnerability of aquaculture

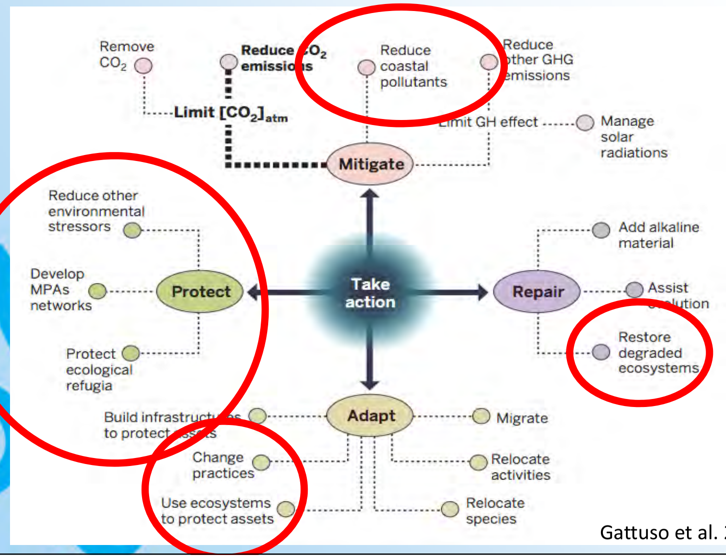
- Pearl oysters – reduced survival and growth of wild spat; weaker shells and reduced pearl quality
- Shrimp – possible deformities in blue shrimp due to thinner shell
- Seaweed - growth enhanced by higher CO_2, however, likely to be offset by other climate impacts
- Marine ornamentals – weaker shells and deformities (giant clams), reduced growth and density (corals)

Vulnerability Assessment findings

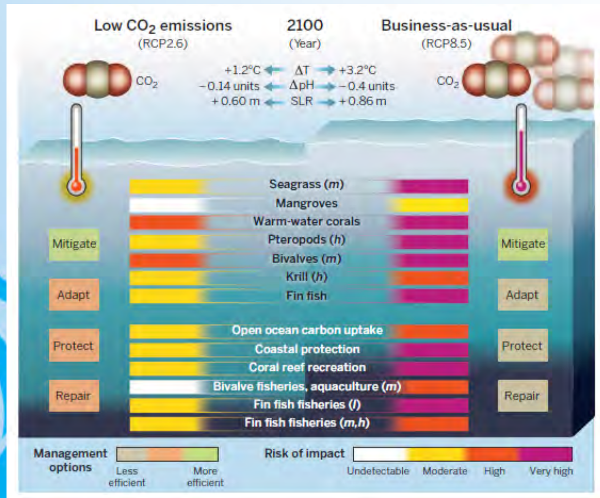
- Key drivers: high reef area, high household income dependence, poor governance and small economies
- Lack of provincial & local scales data (including coastal nutrient loading)
- Highlights the need for incorporating other livelihoods (e.g. aquaculture) and economic revenue (e.g. from tourism)

Regional hot-spots

- American Samoa, CNMI, Fiji, Guam, Nauru, PNG, Samoa, Solomon Islands, Vanuatu for food security adaptations
- High vulnerability reef-dependent communities (Kiribati, Marshall Is, FSM, PNG, American Samoa, Solomon Is) for community-based adaptations that target food security, livelihoods and reef services (e.g. coastal protection)
- Cook Is, Fiji, French Polynesia, FSM, Kiribati, New Caledonia, Marshall Is, Palau, Solomon Is, Tonga, Vanuatu for aquaculture adaptations
- Case studies to improve understanding of OA vulnerability of key resources (e.g. pearl oysters in French Polynesia)



Gattuso et al. 2015



Gattuso et al. *Science* 2015

Thank You

tommym@sprep.org

Session 1-5　Moderator Speech

Discussion
"Issues in the West Pacific Region"

Yukihiro Nojiri
Professor,
Department of Earth and Environmental Sciences, Hirosaki University

1975-1981	Chemistry Department, Faculty of Science, University of Tokyo
1981-1995	Researcher, National Institute for Environmental Studies (NIES)
1995-2006	Head, Global Warming Mechanism Research Laboratory
2001-2006	Head, Carbon Cycle Research Laboratory, NIES
1993-2003	Associate Professor, Department of Biology, University of Tsukuba
2004-2006	Counselor, Secretary for Council of Science, Technology and Policy, Cabinet Office, Government of Japan
2006-2011	Vice Director, Center for Global Environmental Research (CGER), NIES
2008-2013	Professor, Graduate School of Science and Technology, Tokyo Institute of Technology
2011-2015	Principal Senior Researcher, CGER, NIES
2015-present	Professor, Graduate School of Science and Technology, Hirosaki University

Research Interest
Ocean carbon cycle and related biogeochemical parameters
Biological impact of ocean acidification
Methodology of national and regional greenhouse gas inventory

Activity in international research
Lead author and review editor, IPCC AR4 and AR5
Co-chair PICES WG 13 & 17
SSC member IOCCP (2007-2012), SOLAS (2010-2015)

Discussion Topics of Session 1:

1. Impacts on our oceans and corresponding issues
   - Subarctic region
   - Subtropical region
   - Pacific island States

2. Impacted areas and corresponding issues
   - Coastal environment
   - Ecosystems of offshore regions

3. Necessary measures
   - Increase observations
   - Information dissemination
   - Creation of research partnerships

Session 2-1

"Social Regional Impacts of Ocean Acidification in Japan"

Masahiko Fujii

Associate Professor,

Faculty of Environmental Earth Science,

Graduate School of Environmental Science, Hokkaido University

Education

2001	Ph.D., Environmental Earth Science, Hokkaido University, Japan "A marine ecosystem modeling applied to the subarctic time series observation"
1998	M.Sc., Environmental Earth Science, Hokkaido University, Japan "Roles of biogeochemical productivity in the carbon cycle using a simple global ocean model"
1996	B.Sc., Earth and Planetary Sciences, Kyushu University, Japan "Estimation of diabatic meridional circulation based on the UARS data"

Employment

Jun 2008 - Present:	Associate Professor, Graduate School of Environmental Science, Hokkaido University, Japan
Aug 2006 - May 2008:	Associate Professor, Sustainability Governance Project, Center for Sustainability Science, Hokkaido University, Japan
Jan 2006 - Jul 2006:	Research associate, School of Marine Sciences, University of Maine, USA
Aug 2003 - Dec 2005:	Postdoctoral research scholar, School of Marine Sciences, University of Maine, USA
Jan 2002 - Jul 2003:	Domestic postdoctoral research fellow of Japan Society for the Promotion Science, National Institute for Environmental Studies, Japan

Language skills: Japanese (mother tongue), English

Specific skills: PADI Master Scuba Diver

Research interests

・Future Projection and mitigation/adaptation of effects of global warming and ocean acidification

・Education and research for developing renewable energy

Anticipated impacts of ocean acidification on local societies in Japan

Masahiko Fujii
Faculty of Environmental Earth Science, Hokkaido Univ.
E-mail: mfujii@ees.hokudai.ac.jp

Outline
1. Introduction
2. Impacts on coral reefs in Japan
3. Impacts on Japanese fisheries and aquaculture

Industries that may be affected by ocean acidification in Japan (million USD per year)

(cf. annual GDP of Japan in FY2014: 5,248,740 million USD[1])

Fisheries & Aquaculture (14,107)[2]

Tourism & Recreation in coral reefs (779[3])-2,399[4])

Jewelry coral fisheries (85)[4]

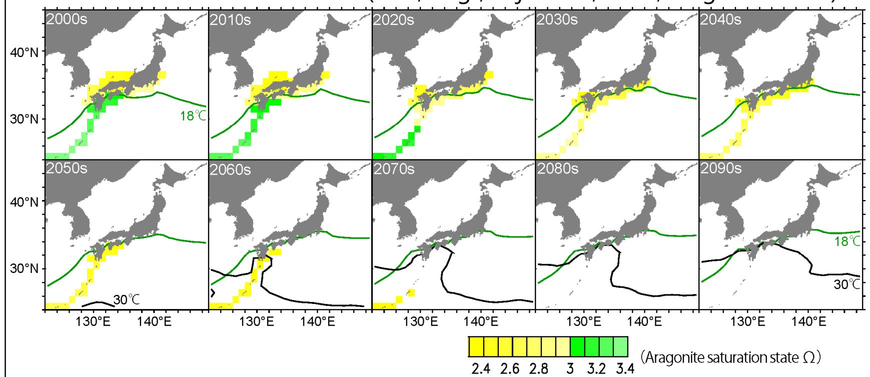
Coastal defense services provided by coral reefs (75-839)[3), 4)]

1)Cabinet Office, Government of Japan
2)Ministry of Agriculture, Forestry and Fisheries (農林水産省統計部　漁業・養殖業生産統計年報)
3)Cesar et al. (2003), The economics of worldwide coral reef degradation, WWF and ICRAN, 23pp.
4)サンゴ礁保全行動計画策定会議サンゴ礁価値評価分科会 (https://www.env.go.jp/nature/biodic/coralreefs/pdf/project/development/210312_mat01.pdf)
5)http://www.hirobata.com/coral/

Outline

- Impacts on coral reefs in Japan
- Impacts on Japanese fisheries and aquaculture

Projected coral habitats in response to global warming and ocean acidification (Yara, Vogt, Fujii et al., 2012, Biogeosciences)



Green lines: Northern limit of subtropical corals regulated by temperature (defined by annual minimum temperature of >18℃)
Black lines: Northern limit of bleaching occurrence regulated by temperature (defined by annual maximum temperature of <30℃)
Shades: Suitable coral habitats regulated by $CaCO_3$ saturation state (defined by annual minimum Ω of >2.3)

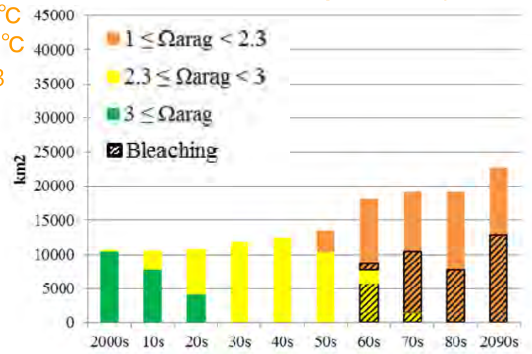
To estimate future change in economic values of Japanese coral reefs

Change in economic values = $\int_{2000s}^{2090s} \Delta A(t) \times \Delta H(t) dt$

$\Delta A(t)$: change in the area of coral reefs (km^2) regulated by:

- Annual min. SST of >18℃
- Annual max. SST of <30℃
- Annual min. Ω_{arg} of >2.3

(Yara et al., 2012; 2016)

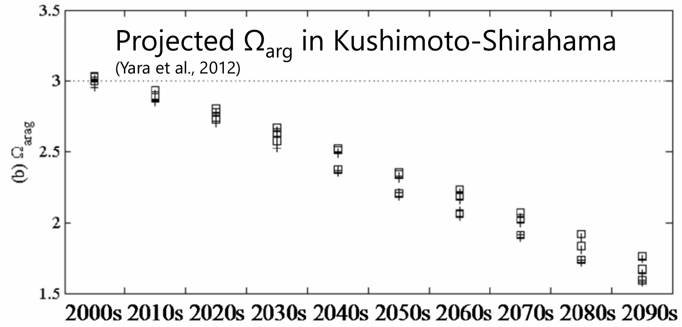


To estimate future change in economic values of Japanese coral reefs

Change in economic values = $\int_{2000s}^{2090s} \Delta A(t) \times \Delta H(t) dt$

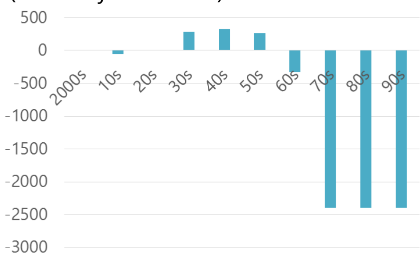
$\Delta H(t)$: change in health condition of coral reefs

- Decrease by 15% per Ω_{arg} (Chan and Connolly, 2013; van Hooidonk et al., 2004)

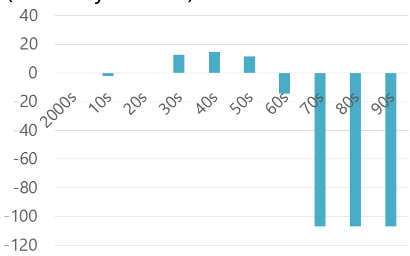


Estimated future change in economic values of Japanese coral reefs

Tourism (million USD/year)
(currently 779-2399)



Fisheries (million USD/year)
(currently 89-107)



Estimated total economic loss in the 21st century

- Tourism: 22-67 billion USD
- Fisheries: 5-6 billion USD

Outline

- Impacts on coral reefs in Japan
- Impacts on Japanese fisheries and aquaculture

Fish catch in Japan (of FY2014)

Total catch: 14,107 (million USD per year) (~0.3% of total GDP)

Fisheries (69%)

Shellfish (7%) / Shrimps (2%) / Crabs (2%) / Sea urchins (1%) / Non-calcifiers (57%)

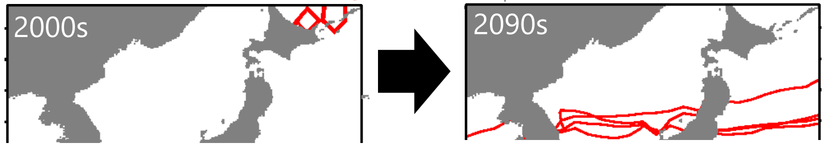
Aquaculture (31%)

Shellfish (6%) / Pearls (1%) / Shrimps (1%) / Non-calcifiers (24%)

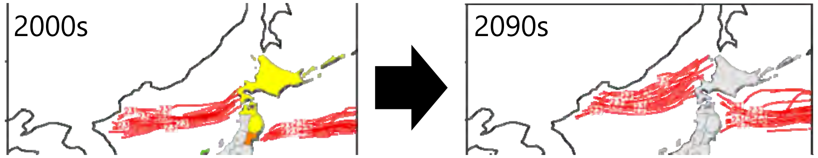
Source: Ministry of Agriculture, Forestry and Fisheries
(農林水産省統計部 漁業・養殖業生産統計年報)

Suitable scallop culture areas regulated by ocean acidification and warming

Southern shift of suitable areas regulated by OA
(defined by annual minimum Ω_{arg} of > 1) (Yara et al., 2012)



Northern shift of suitable areas regulated by warming
(defined by annual maximum temperature of <23℃) (Shibano et al., 2014)



No suitable scallop culture areas by the end of this century

How about sushi in future？

Salmon egg
Sea urchin
Eel
Surf clam
Abalone
Shrimp
Scallop
Crab
Tuna

(http://www.ees.hokudai.ac.jp/carbon/mfujii/en/research/)

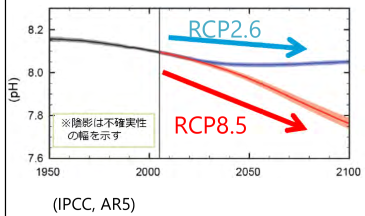
How about sushi in future？

Present / by OA? / by global warming?

by overfishing？ / by OA + global warming + overfishing?

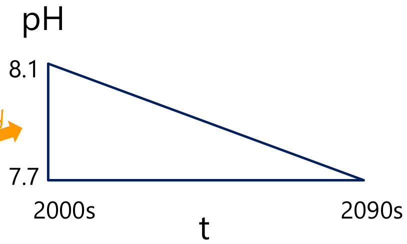
(http://www.ees.hokudai.ac.jp/carbon/mfujii/en/research/)

To estimate future change in economic values of Japanese fisheries and aquaculture



(IPCC, AR5)

Simplify

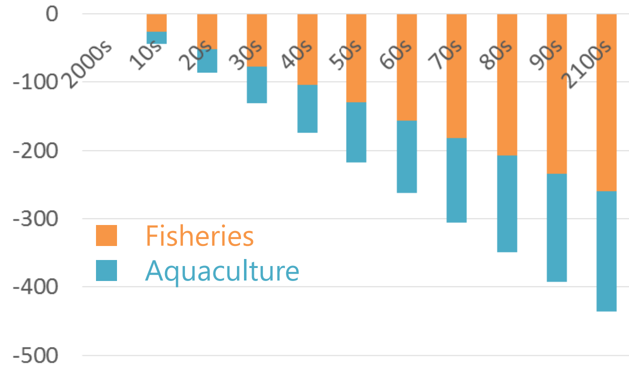


$$\text{Economic change} = \int_{2000s}^{2090s} \Delta G(t)\,dt$$

$$\Delta G(t) = \alpha \times \Delta pH(t)$$

α = -0.1 through -0.4 (Wootton et al., 2008)

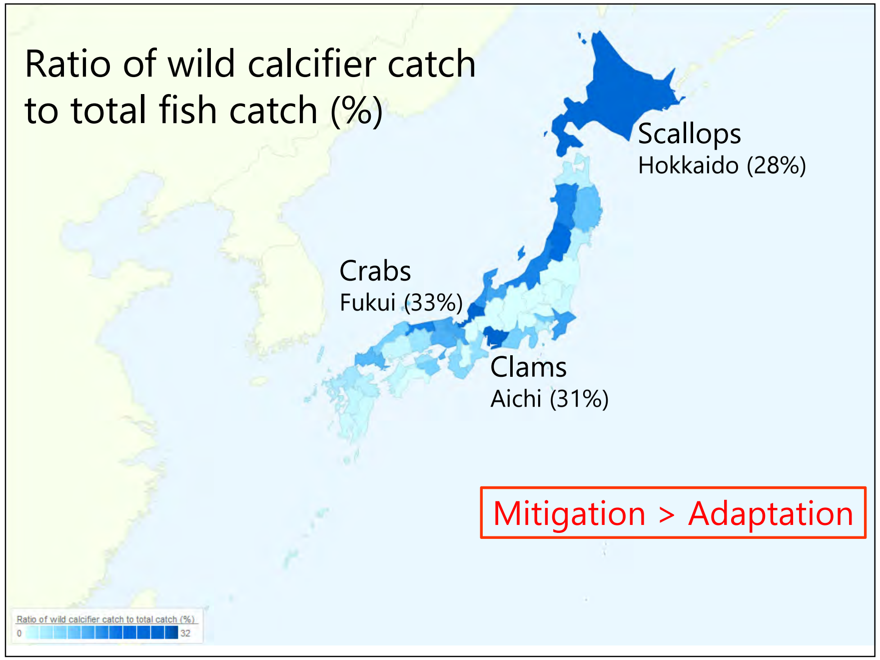
Estimated future change in economic values of Japanese fisheries (million USD/year)



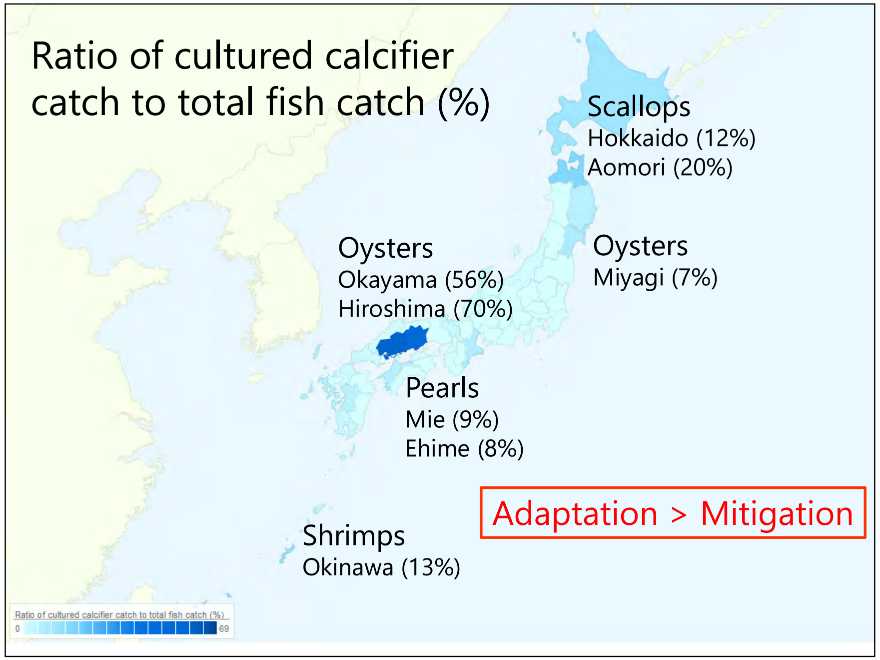
Estimated total economic loss in the 21st century

- Fisheries: 9-22 billion USD
- Aquaculture: 6-15 billion USD

Ratio of wild calcifier catch to total fish catch (%)



Ratio of cultured calcifier catch to total fish catch (%)



Conclusion and Remarks

Estimated OA-derived economic loss in Japan in the 21st century

- Tourism in coral reefs: 22-67 billion USD
- Fisheries in coral reefs: 5-6 billion USD
- Fisheries and aquaculture in Japan: 15-37 billion USD

→ Relatively large economic loss in coral reefs due to the extinction in future

Adaptation needed for aquaculture, esp. scallops, oysters, pearls and shrimps, all of which are very important to the local industries (for tourism as well as fisheries)

- Such as to raise larvae with lower-CO_2 conditions

Many uncertainties in future projection to be reduced, esp. for those caused by:

- Climate model structure
- Future scenario of greenhouse gas emissions
- Biological adaptation to changing environments
- Other human impacts (population growth, overfishing etc.)

Session 2-2

“Mitigation Options - CCS and the Marine Environment”

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Academic Background

B.S. Fisheries Science, National University of Fisheries, Yamaguchi, Japan, 1986
M.S. Marine Biology, Kyushu University, Fukuoka, Japan, 1988
Ph.D. Marine Biology, Kyushu University, Fukuoka, Japan, 1991

Area of Expertise

A. Marine environmental impact assessment
B. Physiology of marine organisms
C. Chemical and physical coastal marine monitoring
D. Carbon dioxide capture and storage under the seabed
E. Ocean acidification