Studies on Ocean Acidification in the Western North Pacific and Arctic Ocean

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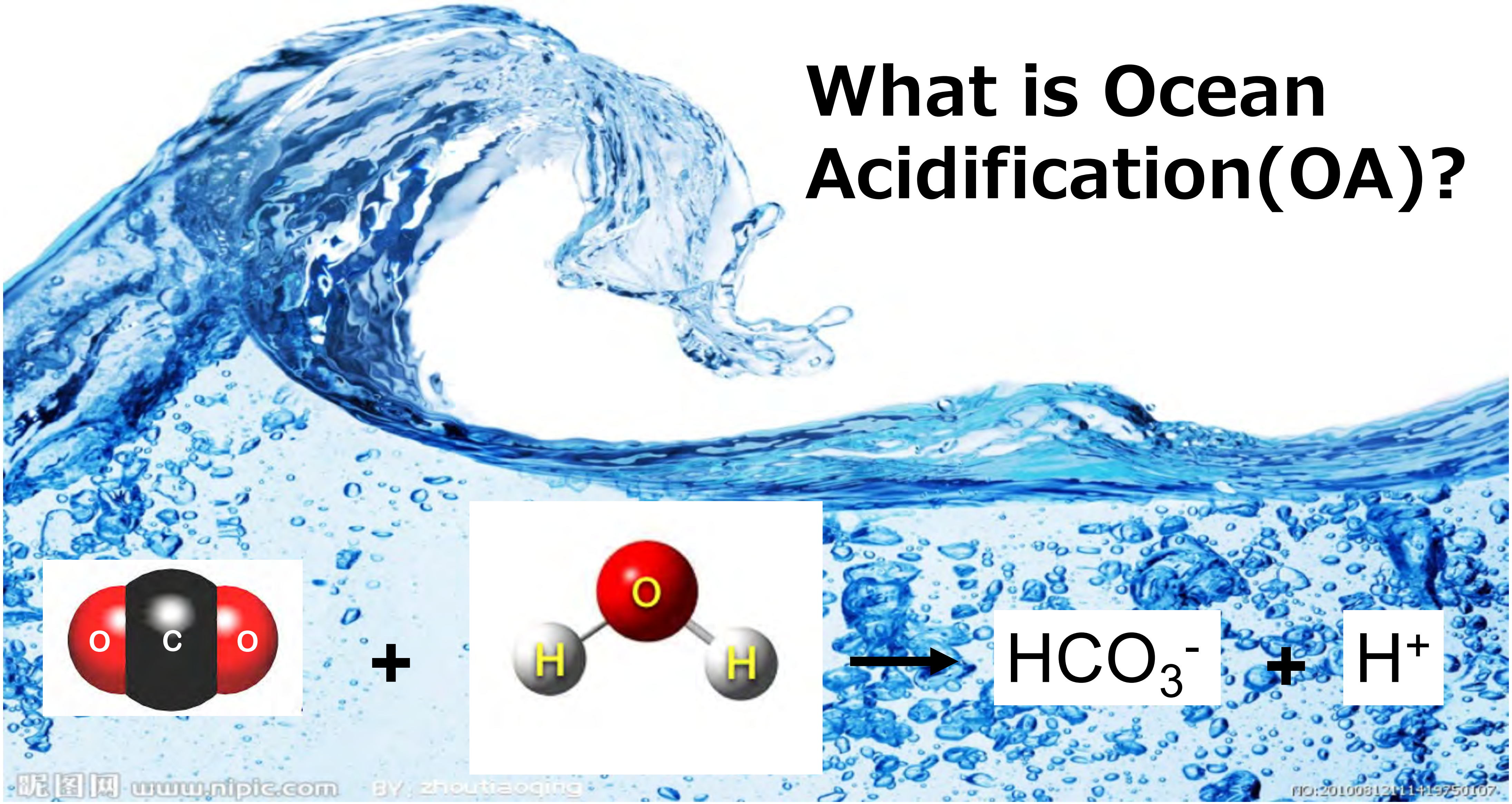
What is Ocean Acidification(OA)?

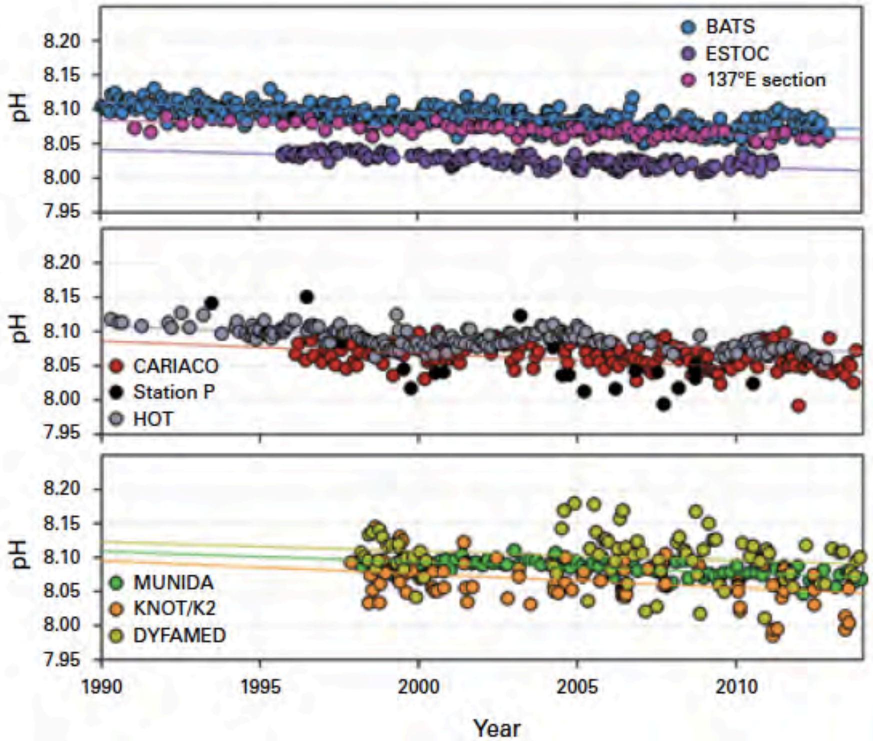


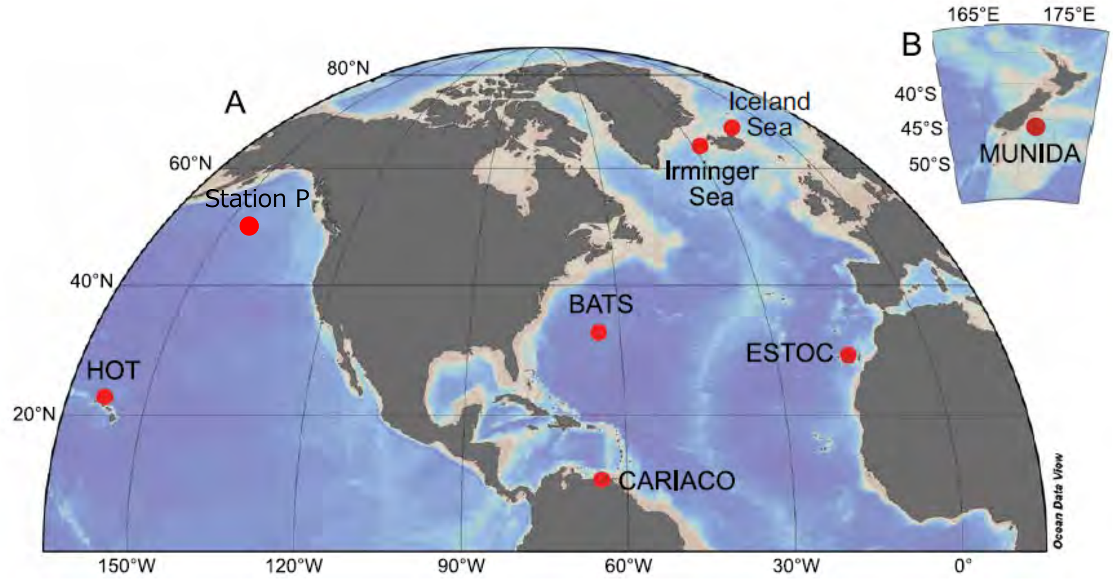
WMO GREENHOUSE GAS BULLETIN

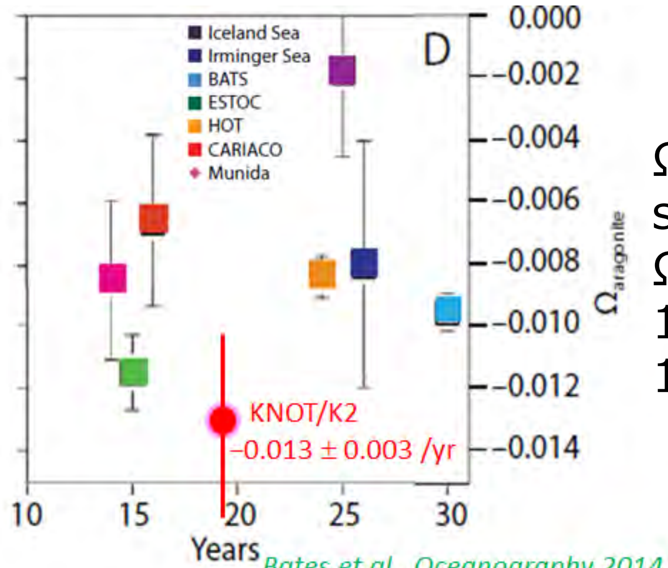
The State of Greenhouse Gases in the Atmosphere
Based on Global Observations through 2013

No. 10 | 6 November 2014

Surface pH: -0.0011~-0.0024/yr







Bates et al., Oceanography 2014

Ω: $CaCO_3$ Saturation state

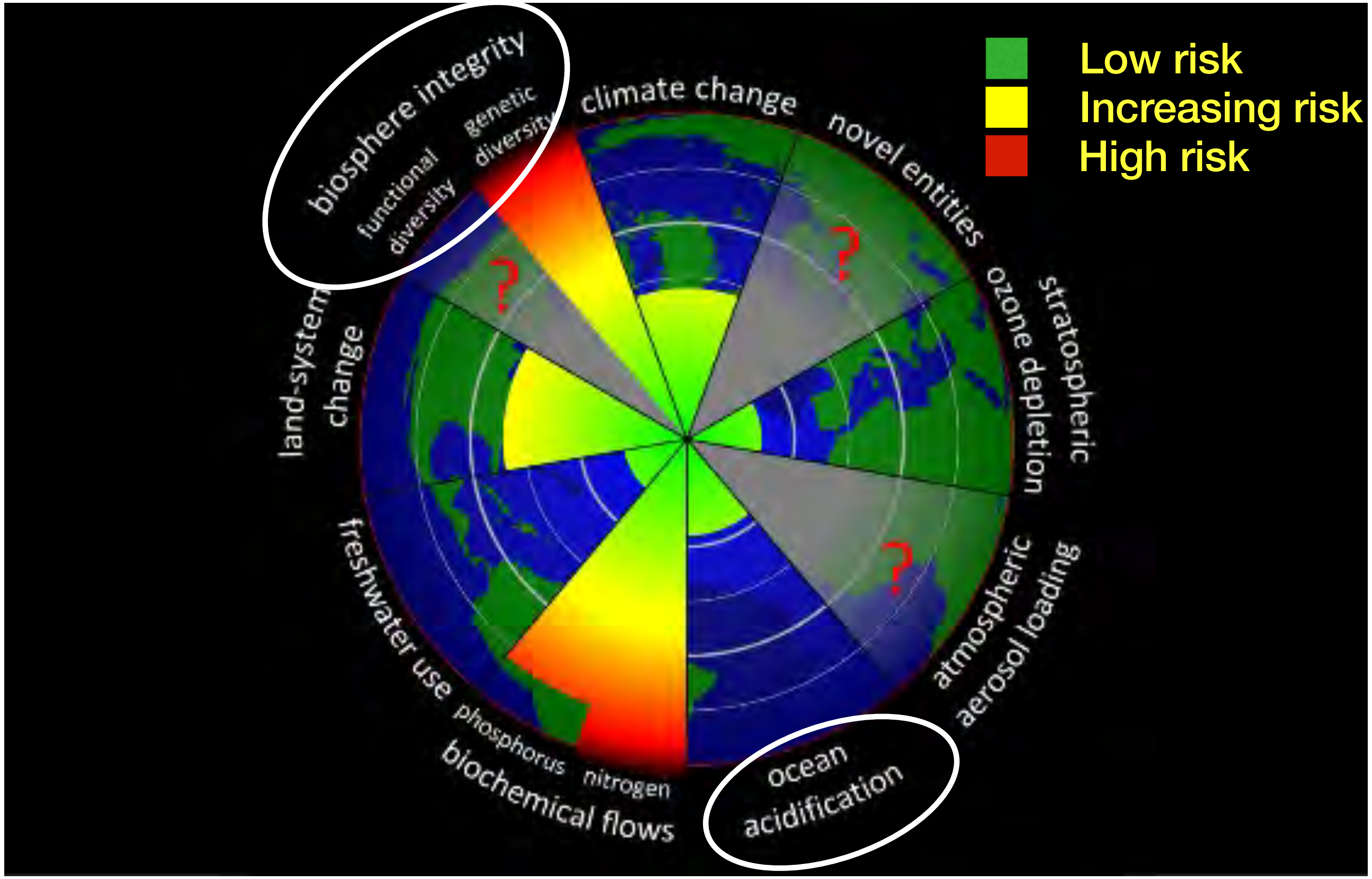
$\Omega = [Ca^{2+}]\,[CO_3^{2-}] / K'_{sp}$

1> Super saturation

1< Under saturation

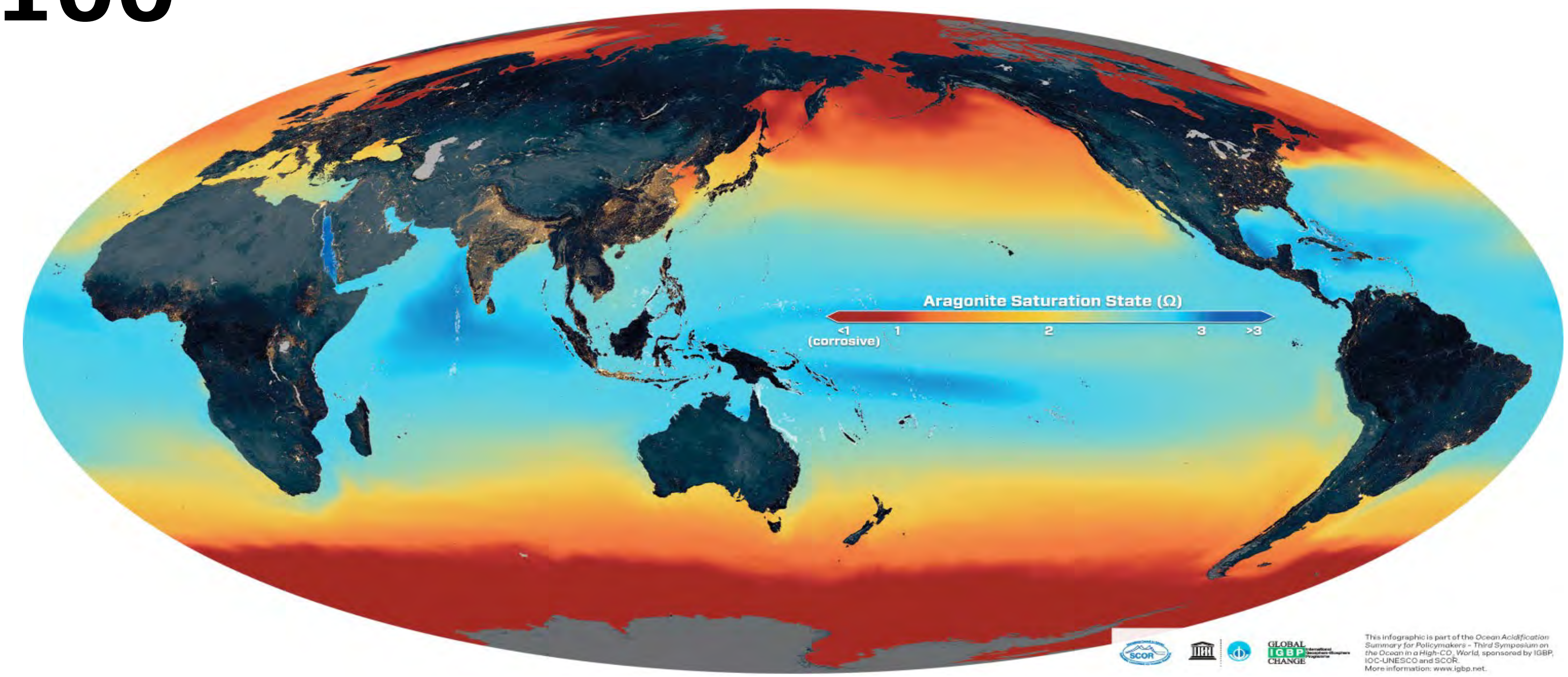
Limit of Earth

Steffen et al., Science 347, 2015 doi:10.1126/science.1259855



IGBP Ocean acidification summary for policymakers (2013)
3rd Symposium on the Ocean in a High-CO2 World

Aragonite saturation state (Ωar) in 2100



Sub-Arctic and Polar Seas: Low CO_3^{2-} brings low Ω

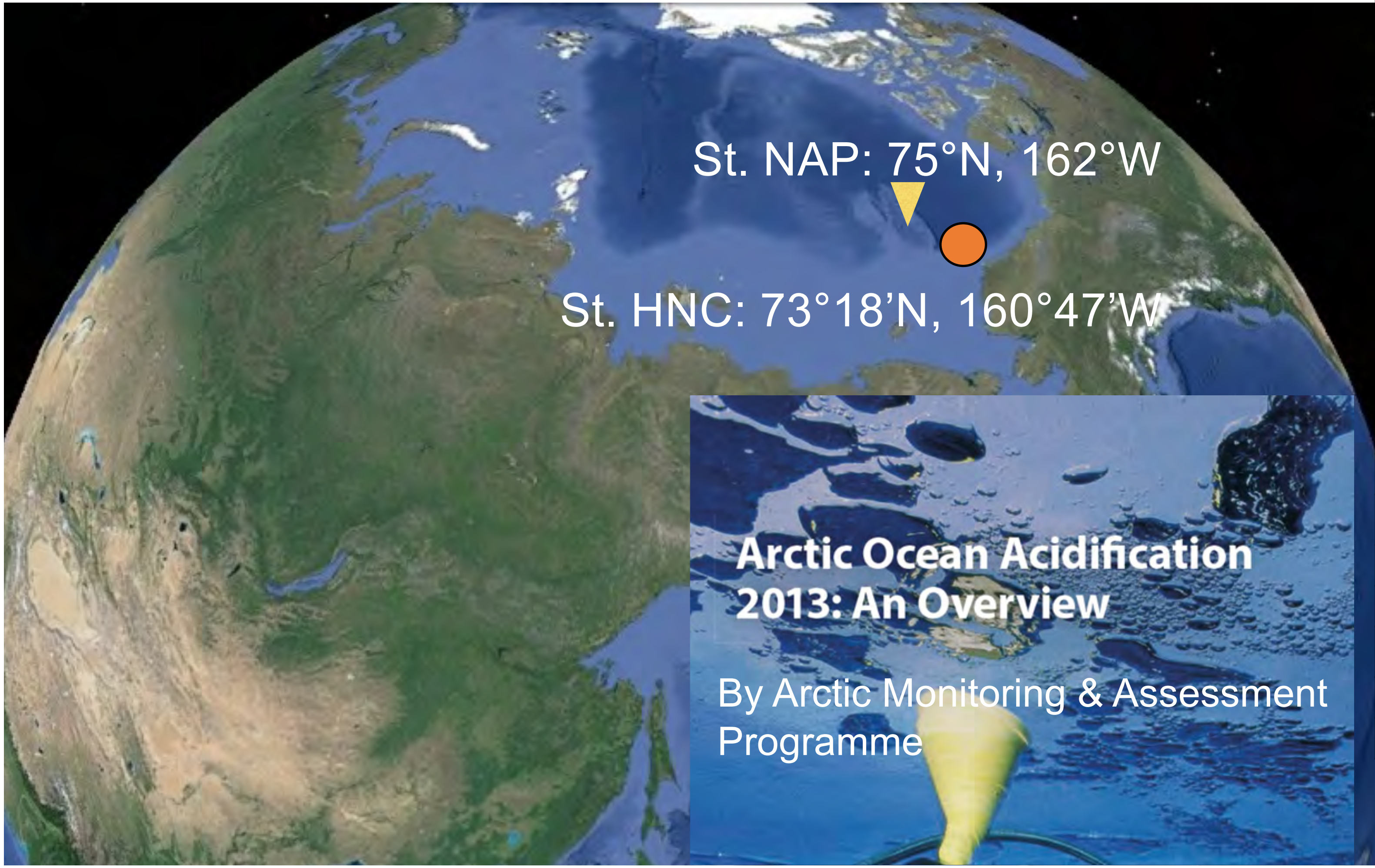
$$\Omega = [Ca^{2+}]\,[CO_3^{2-}]\,/\,K'_{sp}$$

K'_{sp} : solubility product of calcite/aragonite

Ω>1: precipitation(shell preserved)

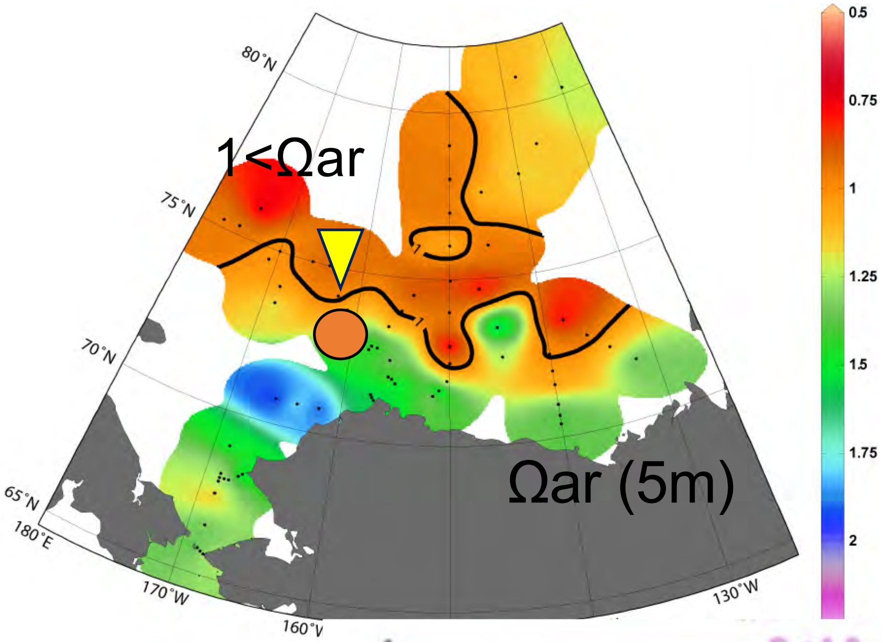
Ω<1: undersaturation (shell dissolved)

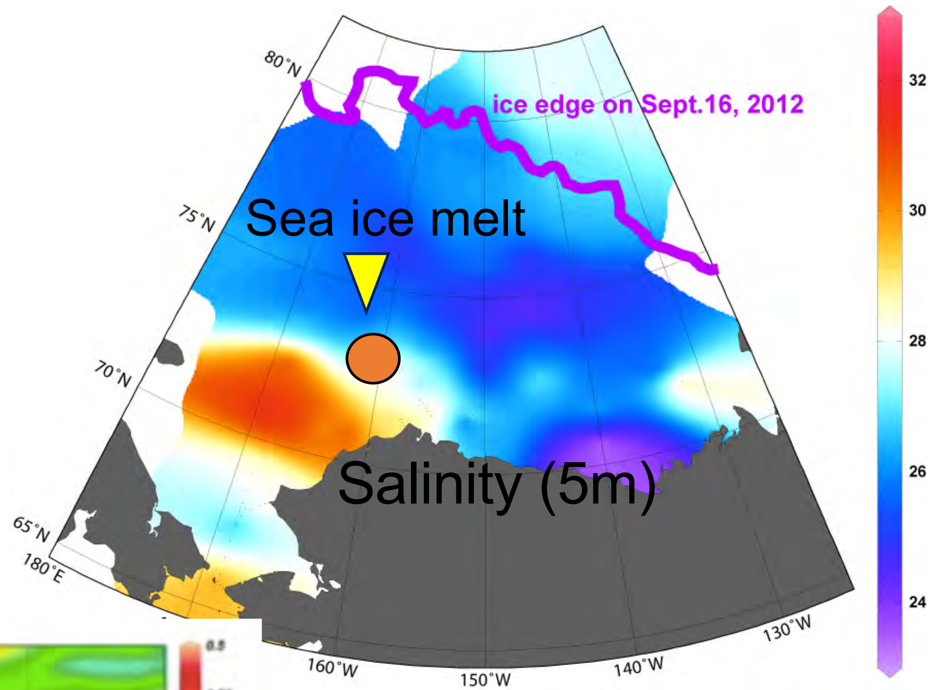
Observation sites in the Pacific side of the Arctic Ocean



Area	pH	Ω
Nordic Seas		
Surface	8.1-8.4	1.5-3.5
Bottom	7.9-8.3	0.7-2.2
Bering Sea		
Surface	7.9-8.3	0.7-2.9
Bottom	7.0-7.7	0.1-2.0
Siberian Shelves		
Surface	7.5-8.1	0.2-2.5
Bottom	7.4-7.9	0.2-1.4
Chukchi & Beaufort shelves		
Surface	7.9-8.4	0.8-2.0
Bottom	7.8-8.1	0.8-2.0
Canadian Archipelago		
Surface	8.0-8.3	0.8-2.2
Bottom	7.6-8.1	0.8-2.0
Central Arctic		
Surface	8.0-8.2	1.3-1.8
Bottom	~8.1	0.6-1.0

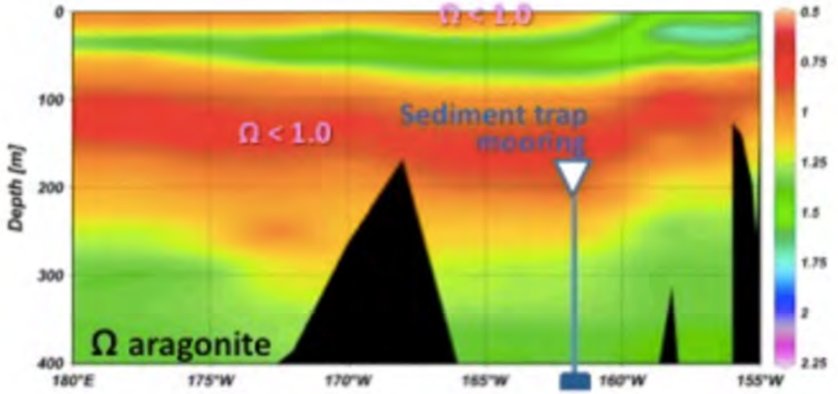
Decreasing Ωar by sea ice melt (Sep. 2012)





St.NAP

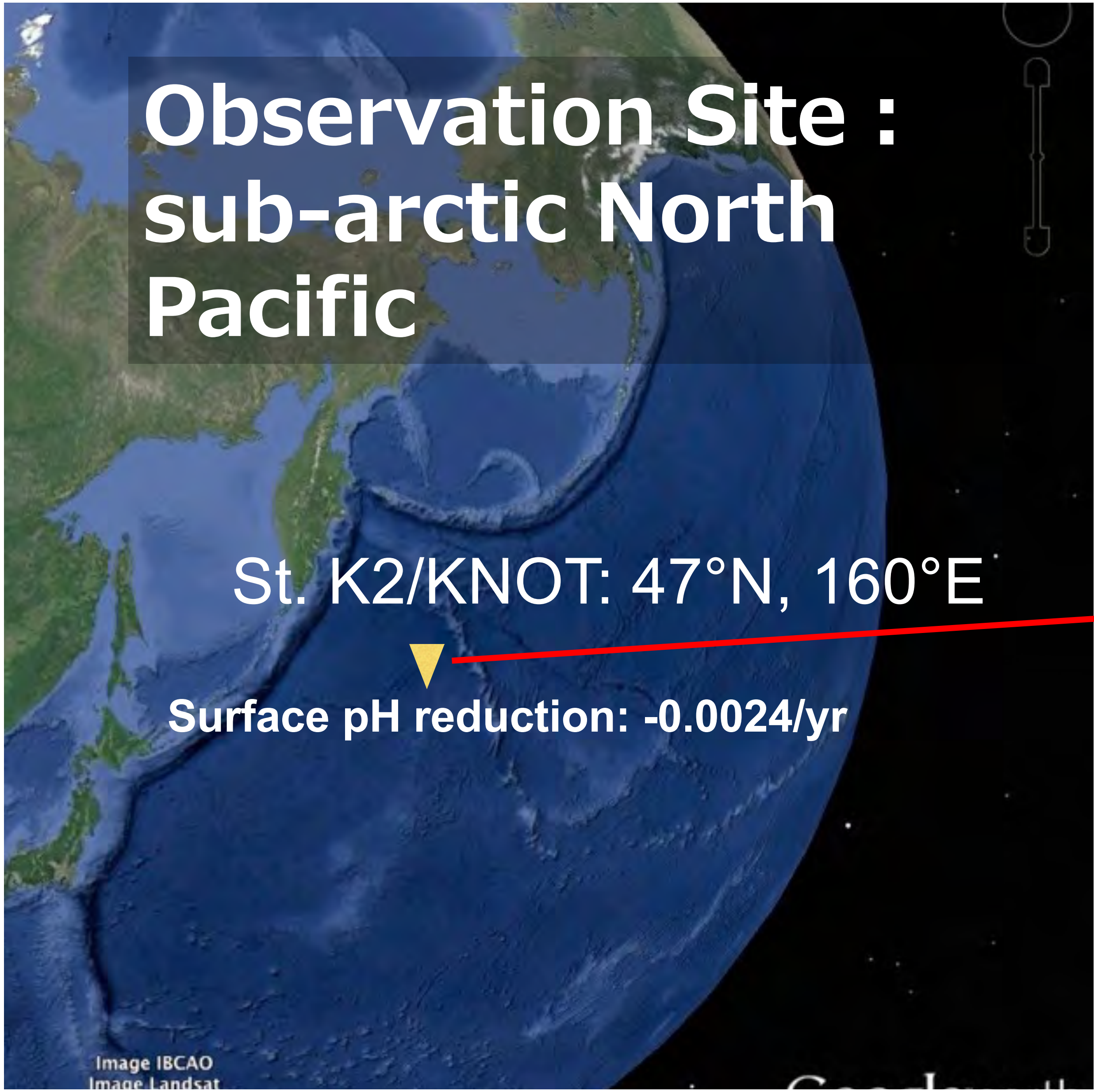
St.NHC



Undersaturated subsurface water for aragonite dissolved living pteropods shells?

Yamamoto-Kawai et al., 2016 Biogeosciences,
doi:10.5194/bg-13-6155-2016

Observation Site : sub-arctic North Pacific



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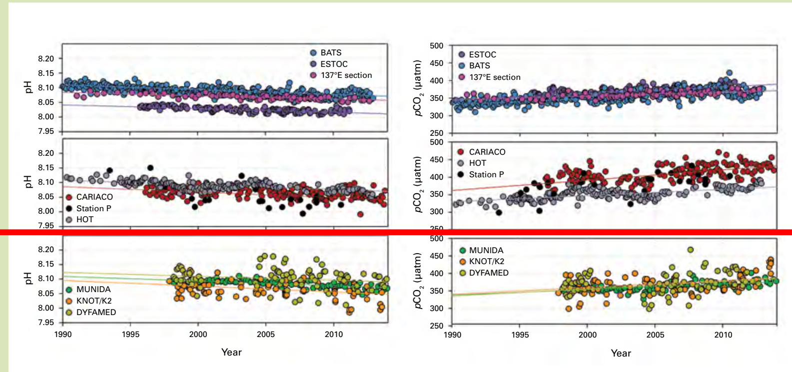


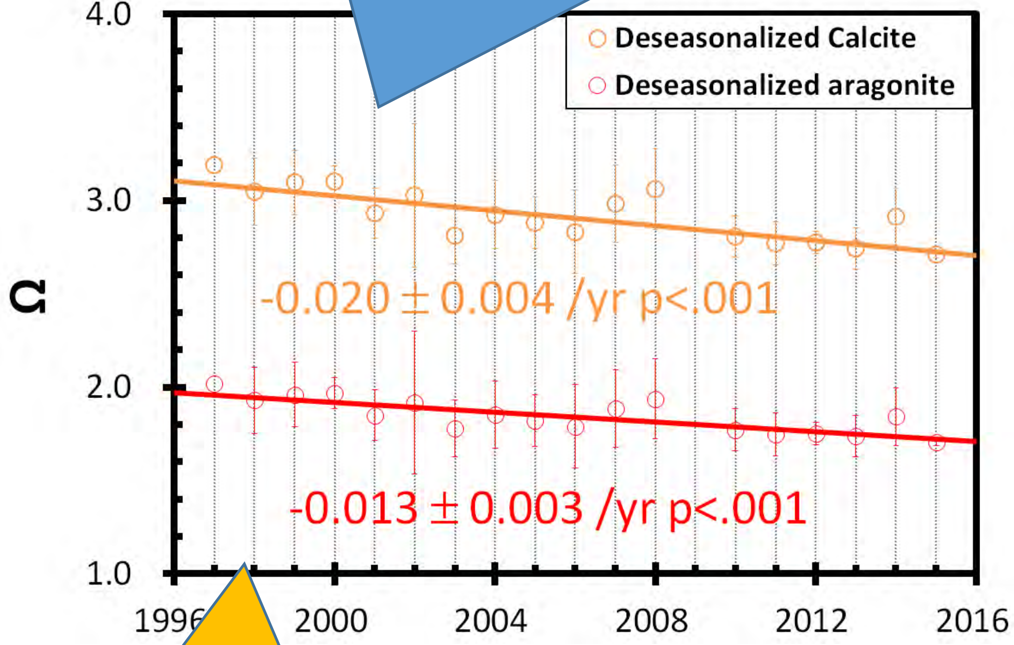
Figure 6. Time series of de-seasonalized surface seawater pH and respective trendlines (left) and of de-seasonalized surface pCO_2 (µatm) and respective trendlines (right). Featured time series include the Bermuda Atlantic Time-series Study (BATS; blue) the European Station for Time Series in the Ocean near the Canary Islands (ESTOC; purple), the Hawaii Ocean Time-series (HOT; grey); CARIACO (red); Station P (black); MUNIDA (green); the Kyodo North Pacific Time series (KNOT; orange); the station known as the Dynamics of Atmospheric Fluxes in the MEDiterranean Sea (DYFAMED; yellow); the Japan Meteorological Agency 137°E section repeat hydrographic line at 10°N, 137°E (137°E section; pink). The locations of the featured time series are shown in Figure 2. Temporal sampling resolution varies from monthly to annually.

Table 2. Linear trends and standard errors for surface pH[a] and pCO_2 at the nine featured ocean time series

Time series	pH (yr^{-1})	pCO_2 (µatm yr^{-1})	***Reference***
BATS[b]	−0.0017±0.0001	1.75±0.08	Bates et al., 2014
ESTOC[b]	−0.0014±0.0001	1.78±0.15	Bates et al., 2014 González-Dávila et al., 2010
HOT[b]	−0.0017±0.0001	1.89±0.15	Bates et al., 2014 Dore et al., 2009
CARIACO[b]	−0.0024±0.0003	2.79±0.37	Bates et al., 2014 Astor et al., 2013
DYFAMED[b]	−0.0019±0.0009	2.56±0.85	Touratier and Goyet, 2011
MUNIDA[b]	−0.0016±0.0003	1.55±0.24	Bates et al., 2014

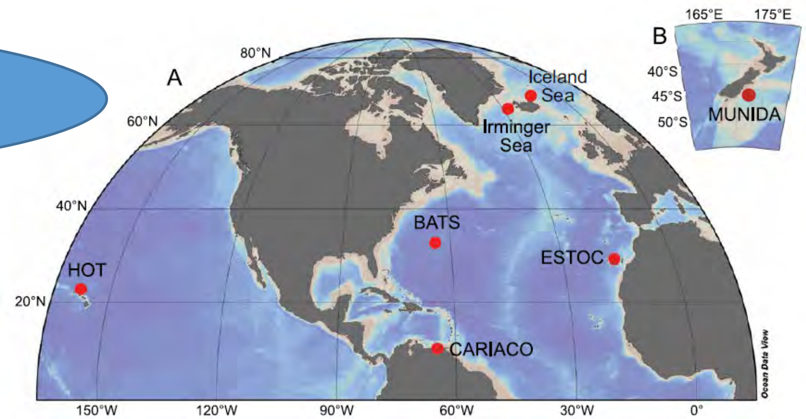
Ωar in the mixed layer at St. K2

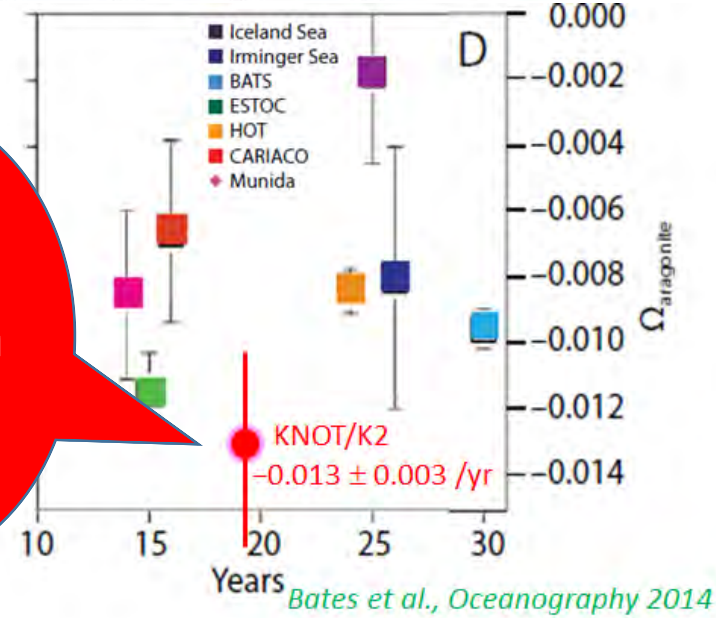
Aragonite saturation horizon: 120m
Calcite saturation horizon: 150m



Less than 1 after ~2100?

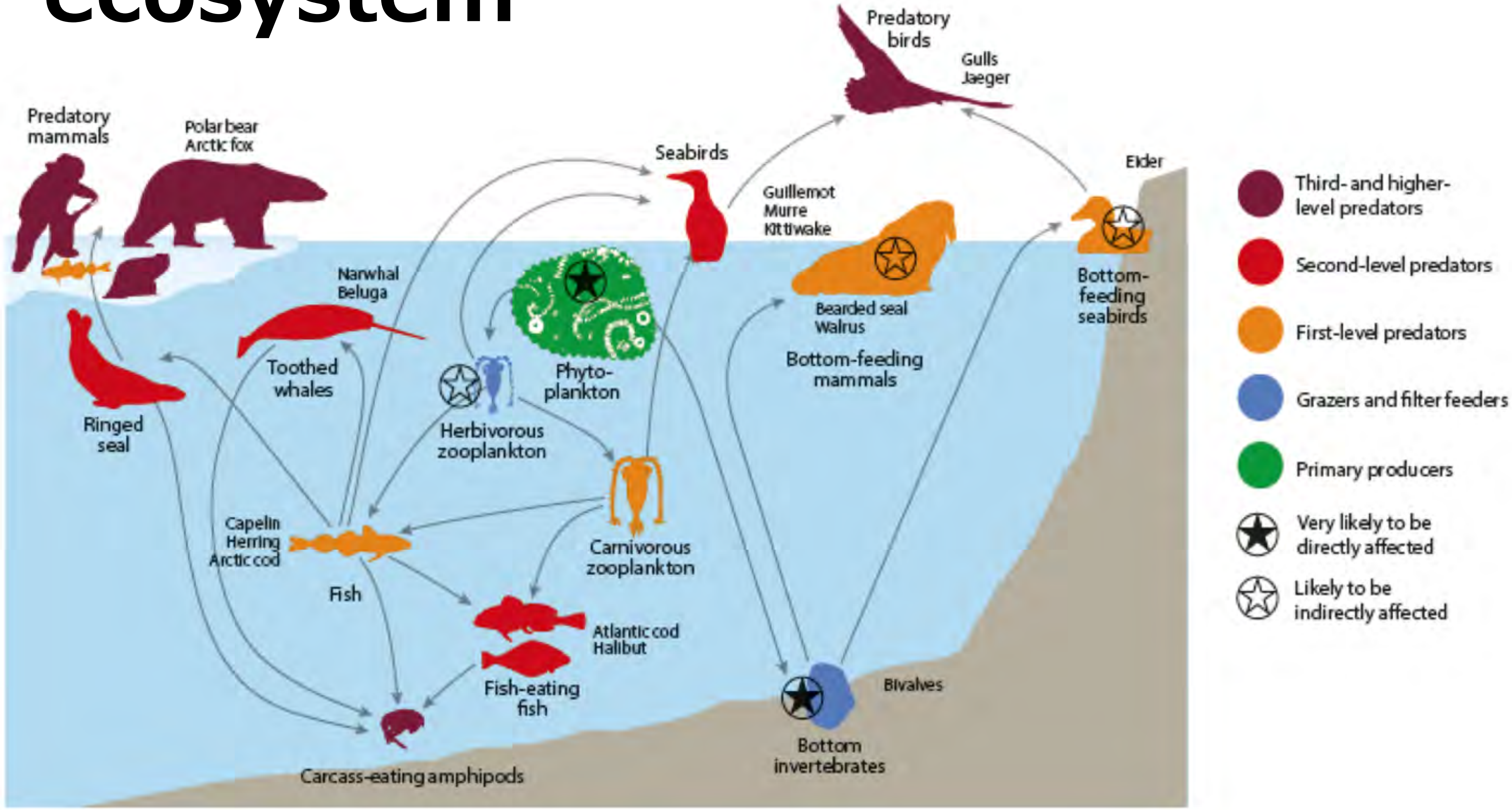
Wakita et al., 2016 JO, doi10.1007/s10872-016-0379-8





Largest annual reduction rate at K2

Influence of OA to marine ecosystem

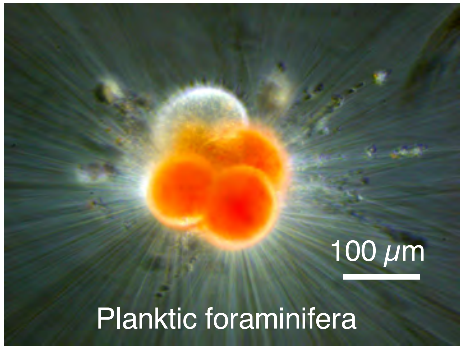


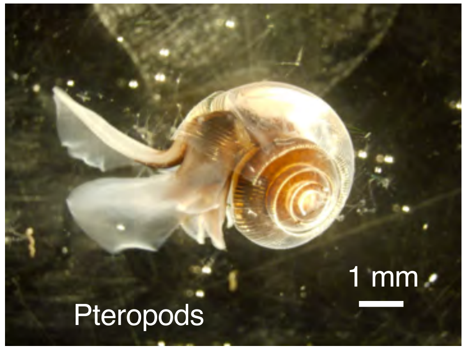
Development of new technique to evaluate OA impact on marine plankton

- Marine plankton is the largest carbonate producer in the world. Especially, the global planktic foraminiferal flux to the ocean floor of 0.36–0.88 GTC y^{-1} accounts for 32–80% of the total deep marine calcite budget (Schiebel, 2002) .

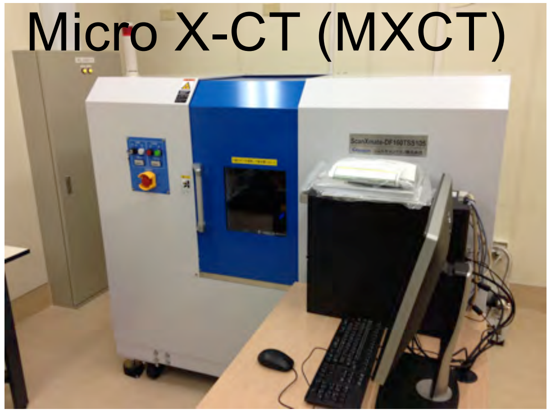
- Serious damage of marine plankton due to OA potentially give a negative impact on food web.

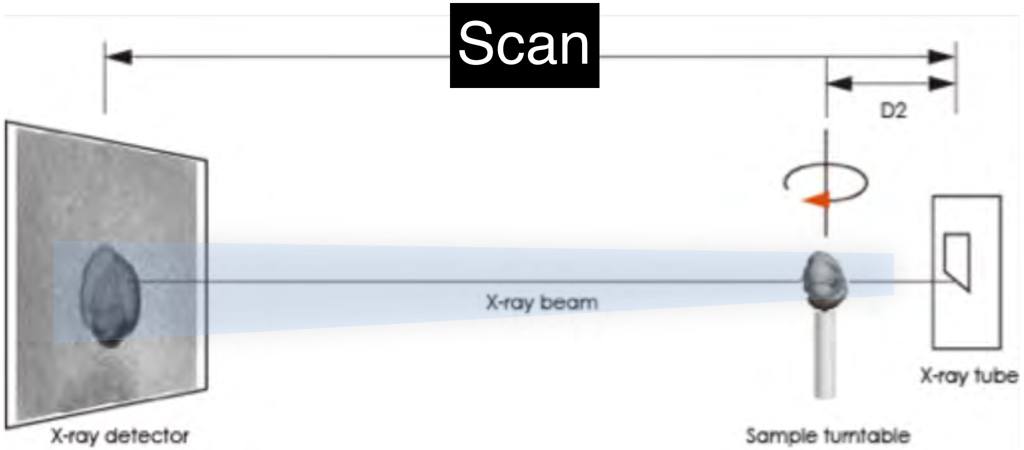
- There is no well quantitative and comparable estimation method to evaluate impacts (damages) of the ocean acidification on marine plankton. So, we have developed new technique to quantify carbonate density.



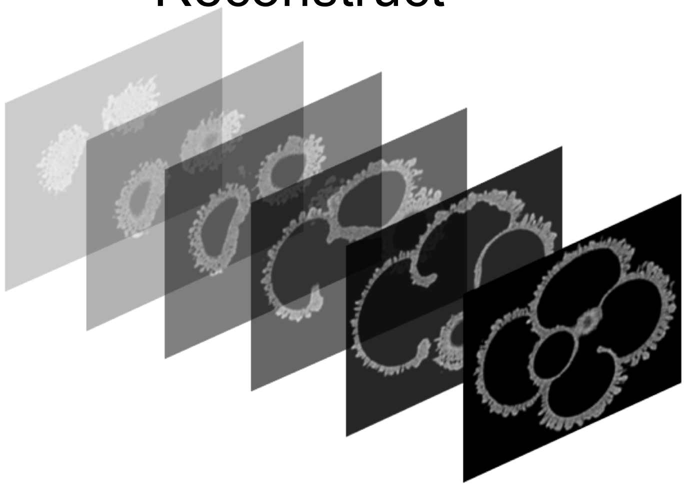


Micro focus X-ray Computing Tomography method

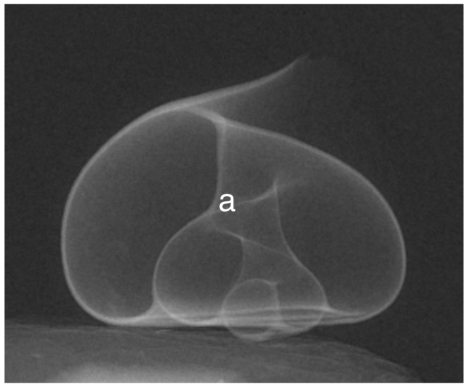




Reconstruct



Fluoroscopic image

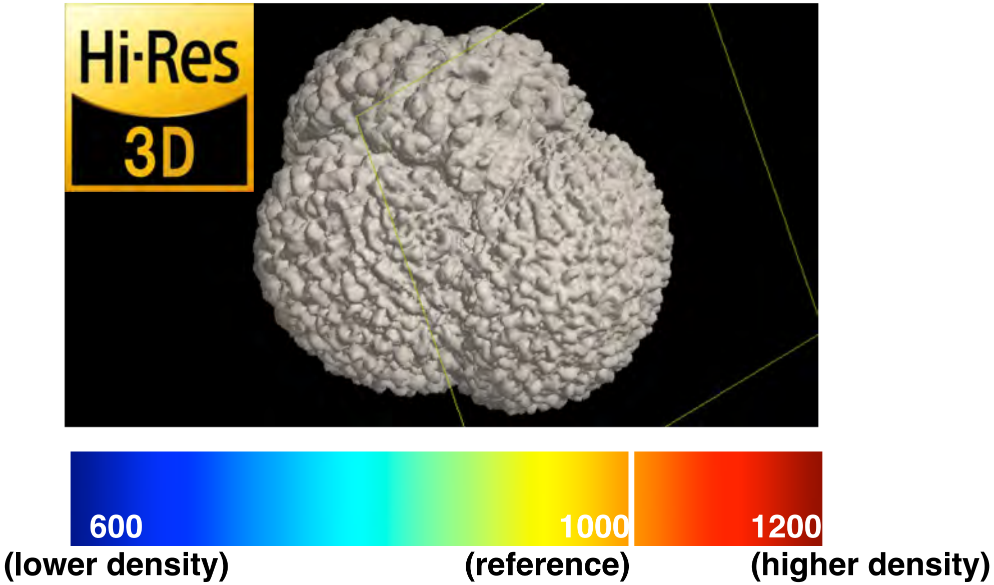


<u>Calcite CT Number</u> as a shell density index

relative value of X-ray attenuation coefficient in each voxels

$$\text{Calcite CT Number} = \frac{\mu_{sample} - \mu_{air}}{\mu_{calcite} - \mu_{air}} \times 1000$$

μsample: X-ray attenuation coefficient of samples
μair: X-ray attenuation coefficient of the surrounding air = -1000
μcalcite: X-ray attenuation coefficient of calcite (standard material:Calcite or Aragonite) = 1000

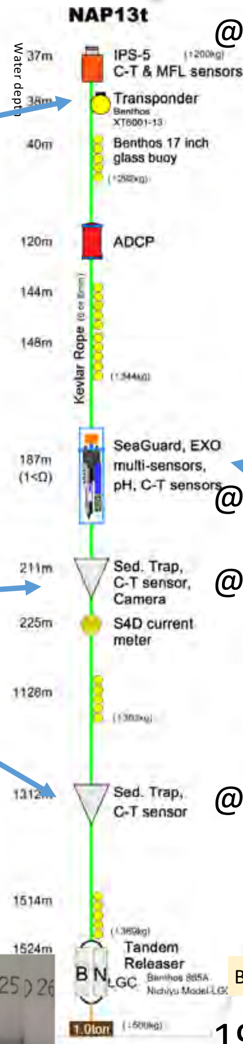


Kimoto et al., submitted

Time-series sediment trap mooring system (Oct. 2013-Sep. 2014)

Multi-wave length excitation fluorescence photometer

@ 38m



@ 37m

Ice profiling sonar

Sediment trap with 26 bottles (Oct. 2010-Sep.2014)

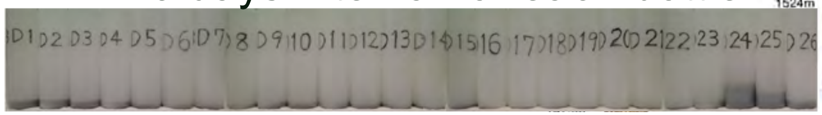
@ 170m

@ 200m

@ 1300m

EXO advanced water quality monitoring platform

10 days interval for each bottle



Battery Life: 2 years

1975 m water depth

Summary

- Micro-Focus X-ray Computing Tomography (MXCT) technique can be applied successfully to evaluate the impact of OA for marine calcifiers quantitatively.
- In the Pacific side of Arctic Ocean, subsurface pH changed seasonally with dynamic range.
- Carbonate density of marine calcifiers (pteropods and planktic forams) also changed seasonally and maximum 40-50% of density reduced associated with low pH and omega condition.
  - It seems likely that when pteropods and planktic forams are exposed by water mass having quite low pH, shell density would immediately drop. It is critical for the marine calcifiers that their habitat become often under the thresholds of pH and Ω (omega).

Next challenge

- Robust species against OA also exist in nature, although majorities are expected to be vulnerable against OA. Behavior of key species are required to brought out for OA in the marine ecosystem.
- Based on the quantitative evaluation of carbonate density loss of marine calcifiers measured by MXCT, the impact of carbonate reduction on marine carbonate cycle could be estimated.