Temporal variation of the saturation state of carbonate in intermediate waters of western North Pacific

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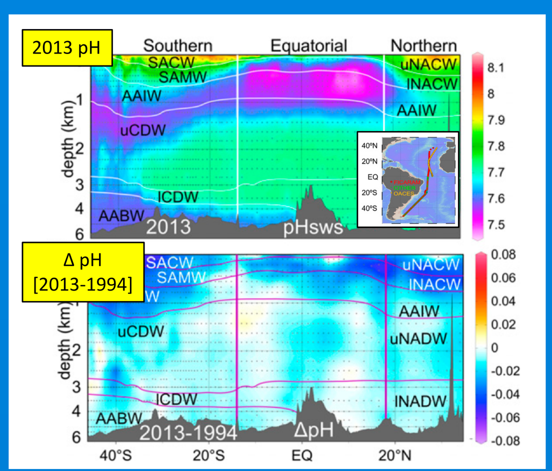
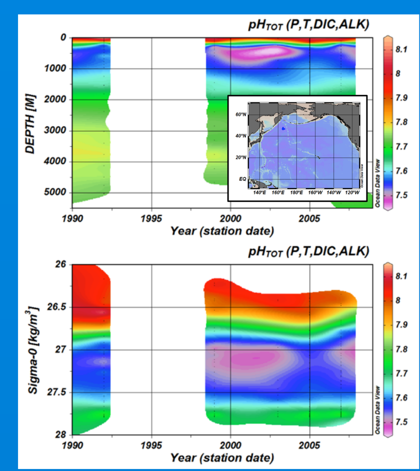
1. Background and Objective

It is recently found that acidification of seawater is ongoing even in ocean interior, but few information is provided so far about the extent of water acidification (e.g., Ω drawdown) and responses of mesopelagic organisms therein.



Cross section of pH (upper) and its temporal change from 1994 to 2013 (lower) along a north-south transect of Atlantic Ocean. [Rios et al., 2015. PNAS]



Temporal variation of vertical pH distribution observed from 1990 to 2010 in Station K2 [Susuki et al., 2010]. Upper and lower: depth [m] and sigma-0 as Y-axis.

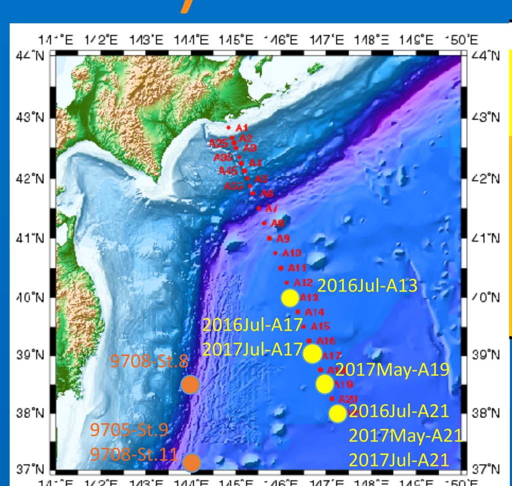
Main objective:

・Assess detailed extent of water acidification in each density range in subsurface layer of western Subarctic North Pacific (Oyashio-Kuroshio Mixed water Region, hereafter O/K region)

・Assess response of mesopelagic organisms against observed water acidification, taking an example of planktonic foraminifera *Globorotalia scitula*.

2. Repeat observation of carbonate species and *G. scitula* in western subarctic North Pacific (1997 – 2017)

A hydrographic observation for carbonate species has been made as well as vertical distribution and molphologic characteristics of G. scitula in O/Kregion in 1997 [Itou et al., 2001; hereafter IT01]. We carried out re-observation of IT 01, to investigate inter-annual changes of carbonate properties and any corresponding changes of G. Scitula. Outlines of the investigation for each property are as follows:



year	month	Cruise name	Station	Latitude [N]	Longitude [E]
1997	May	SY9705	S09	37°00.00'	144°00.00'
1997	Aug	SY9708	S08	38°30.00'	144°00.00'
1997	Aug	SY9708	S11	37°00.00'	144°00.00'
2016	July	WK1607	A13	40°00.00'	146°15.00'
2016	July	WK1607	A17	39°00.00'	146°45.00'
2016	July	WK1607	A21	38°00.00'	147°15.00'
2017	May	WK1705	A19	38°30.00'	147°00.00'
2017	May	WK1705	A21	38°00.00'	147°15.00'
2017	July	WK1707	A17	39°00.00'	146°45.00'
2017	July	WK1707	A21	38°00.00'	147°15.00'

Map and list of hydrographic / MOCNESS observations occupied in O/K region in 1997 and in 2016-2017. Data and detailed sampling method for the 1997 observation are described in Itou et al. (2001), Mar. Micrpaleont. 42. 189-210.

Stations:

・1997: along 144°E [SAGE line]

・2016-2017: 146-148°E [along A-line]

all stations are confirmed to locate within the O/K region based on water temperature on 100m and 200m isobath.

Hydrographic observation (same both in IT1997 and 2016-2017)

・CTD 0 - 3000m with 15-layer water sampling (every 100m in 100-600m and every 200m in 600-1200m)

・measured palameters T,S, DO, Talk and DIC

All values of Talk and DIC were collected its offset against PACIFICA climatology in 2000-3000 m.

MOCNESS sampling:

・1/4 m^2 MOCNESS with 64μm-mesh net (both in 1997 and 2016-2017)

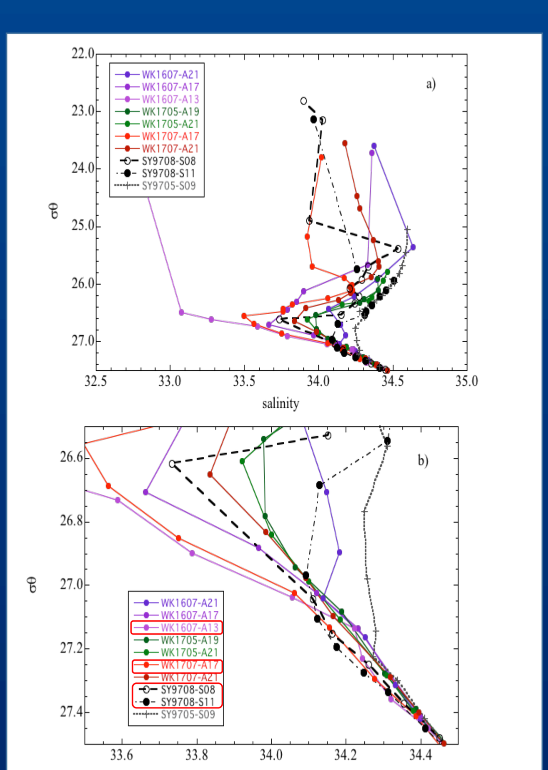
・sampling layers:

1997: 100m interval from 100m to 800m

2016-2017: 0.1 σ_θ interval from 26.8 to 27.4

In this study, vertical distribution of 1997 samples were converted to 0.1 σ_θ interval based on CTD-observed density profile, assuming uniform biomass distribution within a sampling layer.

3. Assessment of watermass structure

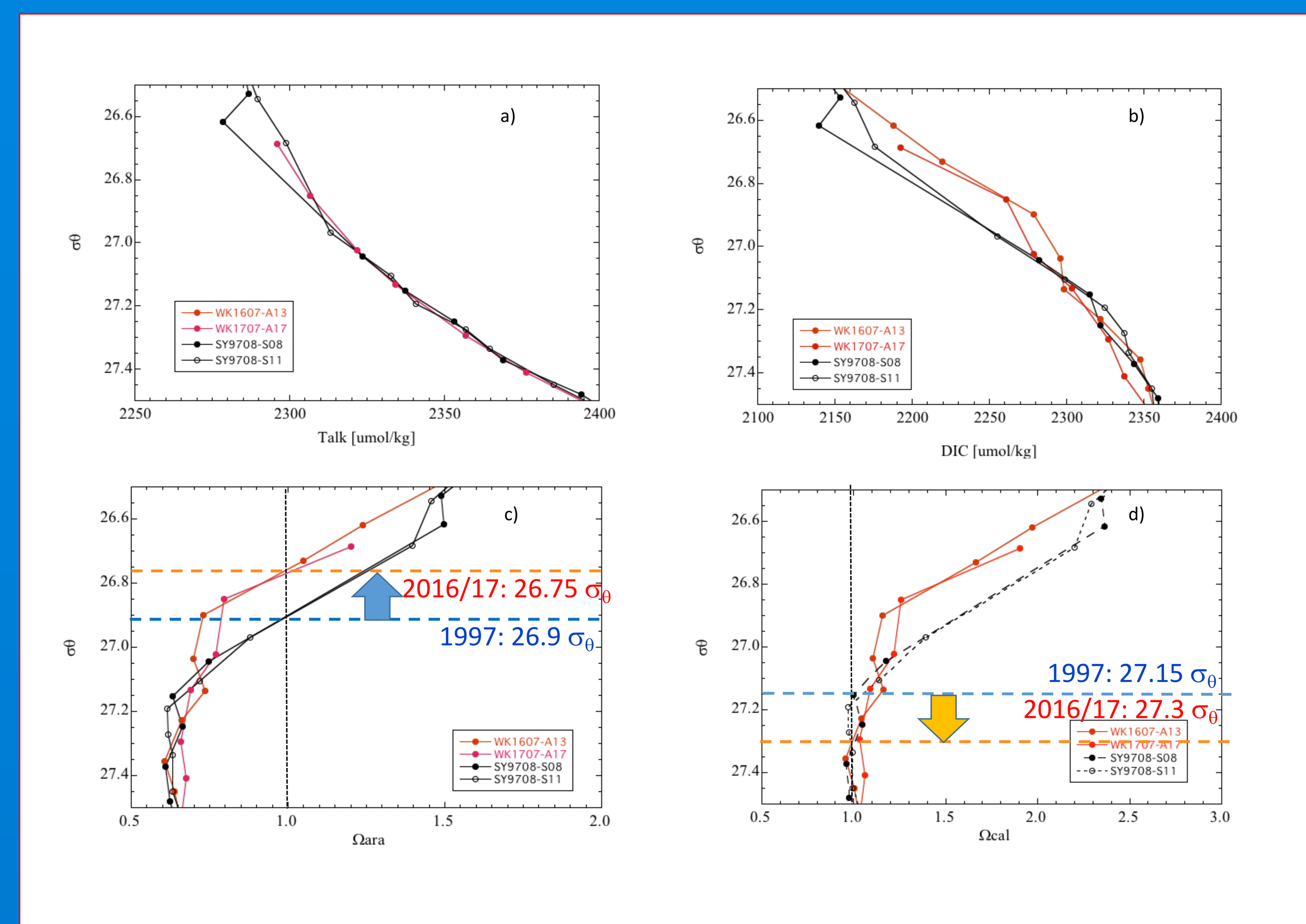


a) Profile of salinity vs water density for each sampling station and b) its enlarged view in the density range of 26.5 - 27.5 σ_θ. Red boxes indicate stations selected for inter-annual comparison analysis based on relative similarity of S profile in the density range of 27.0 – 27.5 σ_θ.

Beforehand of the analysis of inter-annual variation, similarity of watermass structure among stations were assessed based on the salinity – density plot. The result show that stations were divided into two groups: four stations have relatively low salinity in the density range of 27.0 – 27.5 σθ (SY9708-S08, SY9708-S11, WK1607-A13, and WK1707-A17) while the others have relatively high salinity.

As "high salinity" group involves only one station observed in 1997, we decided to use four "low salinity" stations in the following inter-annual comparison analysis. Also, we decided to make inter-annual comparison analysis only for the density layers below 26.5 σ_θ, as watermass structure becomes too variable between stations above this density surface.

4. Temporal change of carbonate properties in the mid-depth layer of western North Pacific



Profiles of a) Talk, b) DIC, c) Ω aragonite, and d) Ω calcite against water density. Red and black profiles represent those observed in 2016-2017 and in 1997, respectively. In Fig c) and d), saturation depth of each crystal form in 1997 and in 2016-2017 are shown by blue and red dashed line, respectively.

While Talk showed almost same vertical profile between 1997 and in 2016-2017, DIC showed significant increase in the density range above 27.1 σ_θ. The largest increase of DIC, over 50 μmol/kg between 1997 and 2016-2017, was observed in the density range of 26.7 - 26.9 σ_θ.

The observed rate of DIC increase in this density range is even higher than that observed in surface water (1.18 μmol/kg/y in Stastion K2, Wakita et al., 2017), suggesting that main cause of DIC increase is declined ventilation in recent North Pacific due to global warming (e.g., Stramma et al., 2012).

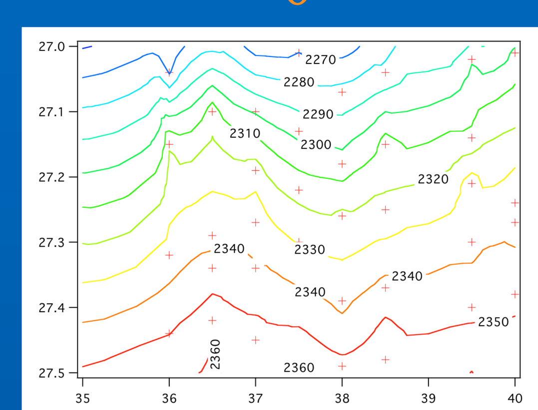
In the density range of 27.1 – 27.5 σ_θ, on the other hand, we observed almost similar, or slightly smaller, DIC values compared to 1997. Reflecting these DIC variation, both Ωara and Ωcal showed significant decrease in the density range above 27.1 σ_θ while they showed slight increase in the density range of 27.1 – 27.5 σ_θ. As the consequence, saturation depth of aragonite and calcite had changed in opposite direction, i.e.,

Temporal change of isopycnals corresponding to saturation depth:

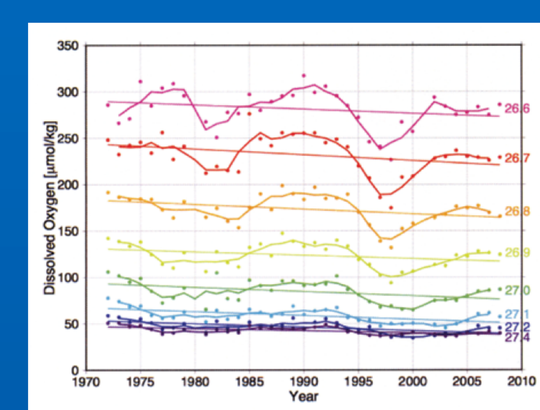
Aragonite: 26.9 σ_θ (1997) => 26.75 σ_θ (2016-2017) [shoaling]

Calcite: 27.15 σ_θ (1997) => 27.3 σ_θ (2016-2017) [deepening]

5. Why DIC *decrease* in the density range of 27.1 – 27.5 σ_θ ?



Latitudinal transect of DIC along 144°E Plotted against water density (σ_θ). Reproduced from the data of IT01.



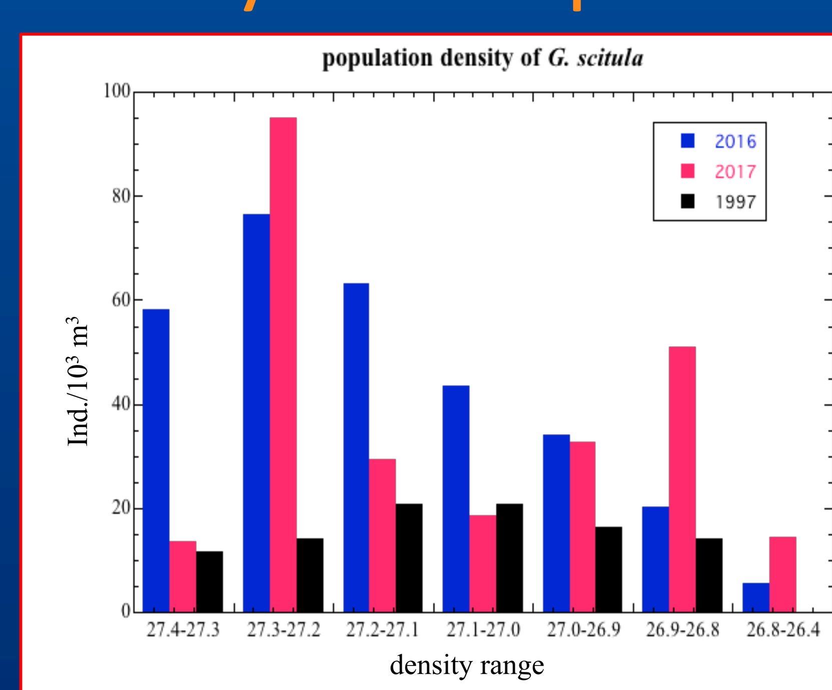
Temporal variation of DO on isopycnals from 26.6 to 27.4 σ_θ observed at 41.5°N, 146-147°E (just north of the study area). Sited from PICES NPESR 2010.

Several potential cause can be considered for observed DIC decrease in the 27.1 – 27.5 σ_θ waters:

1] There are slight latitudinal fluctuations of DIC on these isopycnals in O/K region. DIC becomes high both in Oyashio region and in Kuroshio extension region, while it becomes low in between them. Although we eliminated affection of watermass differences between the observed periods, some differences may be remained and cause DIC difference.

2] Dissolved oxygen provides good index of water-age variation, and its time series in western North Pacific show both long-term decreasing trend and bidecadal-scale oscillation. Especially in deep density surface (ca, 27.4 σ_θ), long-term trend is very small and hence bidecadal oscillation frequently induces short-term DO increase. It may be possible that DIC in O/K region also showed similar short-term decrease due to the bidecadal-scale oscillation of water age, is spite of its slight long-term increasing trend.

6. Vertical distribution of *G. scitula* population density: a temporal change



Vertical maximum of *G. scitula* population had moved from the density range of σ_θ = 27.0 – 27.2 in 1997 to that of σ_θ = 27.2 – 27.3 in 2016-2017. This movement corresponds to the observed downward shift of Ωcal. (27.15 => 27.3 σ_θ during 1997 => 2016-2017)

This may indicate that G. scitula had changed its main habitat along with the shift of saturation depth of calcite. We are now examining affection of other parameters such as age, body size etc. to the habitat depth. For more information for G. scitula vertical distribution as well as their morphological characteristics, please see poster of Kimoto et al. [S3-P13]

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