Distributions of the Pacific-origin Waters in the Chukchi Borderland, 2010-2014

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ABSTRACT: From 2010 to 2014 intensive Arctic summertime cruises were conducted to investigate temporal and spatial distributions of the Pacific-origin waters in the Chukchi Borderland. Five-time expeditions with the icebreaker R/V Araon led us to understand that heat transport from the Pacific-origin waters is one of the primary processes to explain rapid sea ice reduction and changes in water column structure in the Chukchi Borderland. We present recent distributions of the Pacific-origin waters observed from the Arctic cruises with CTD, expendable CTD, lowered-ADCP, and other sensors. It is found that the Pacific Summer Water (PSW) in summer 2012 passed through the vicinity of the Northwind Ridge and extended toward the west of the Ridge. In summer 2014, potential temperature of PSW in the Chukchi Plateau where the maximum sea ice retreat happened was substantially lower than the surrounding area. Remarkable feature of the Pacific Winter Water (PWW) pathway is represented as well. From 2011 to 2013, PWW tends to reach northern Chukchi Sea via the Herald Canyon and turn its direction to the east. In summer 2014, however, PWW was present on the western flank of the Chukchi Plateau, nearly the same pattern as what observed in 2008. This appears to be related with large sea ice motion in the preceding winter. Furthermore, how distribution of surface heat content is correlated with sea ice reduction will be discussed.

INTRODUCTION

◆Motivation and Prior Studies

1) In 2007 and 2012 summers, there were tremendous sea ice retreat events in the Pacific sector of the Arctic Ocean. The September monthly average trend is -13.7% decade^{-1} relative to the 1981-2010 average (Fig.1a). The summer minimum ice extent reached 4.3 M km^2 in Sep 2007 (Fig.1b), and 3.41 M km^2 in Sep 2012 (Fig.1c).

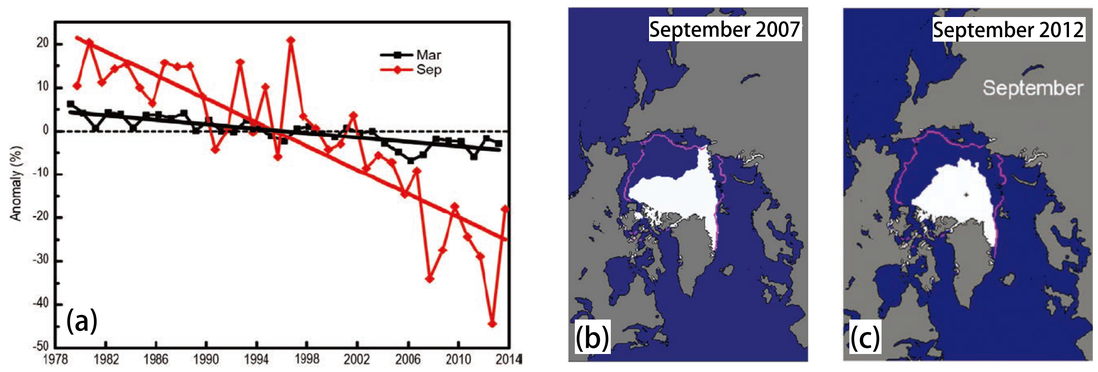

Fig.1. (a) Time series of sea ice extent anomalies (in %) relative to the average values for the period 1981-2010 (*Perovich et al., 2014*); (b) Sea ice extent in Sep 2007 (*Richter-Menge et al., 2008*), and (c) Sea ice extent in Sep 2012 (*Perovich et al., 2013*). The magenta lines indicate the median ice extents during the period 1979-2007.

2) The maximum temperature of the Pacific Water layer increased by about 1.5°C over this time with corresponding increases in heat content (*Timmermans et al., 2013*). The surface layer water in the Beaufort Gyre accumulated a significant amount of heat in 2007 due to the significant retreat of the ice cover causing its exposure to the direct solar heating. About 25% more heat on average in the summer 2012 compared to 1970s values (Fig.2a). The center of the freshwater maximum in 2007 shifted toward Canada whereas that in 2012 shifted to the northwest (Fig.2b), consistent with the large-scale wind forcing (*Timmermans et al., 2012*). However, distributions of freshwater content in summer 2008 and 2013 showed different patterns. In addition, heat content and FW content on the Chukchi Borderland have not been discussed yet.

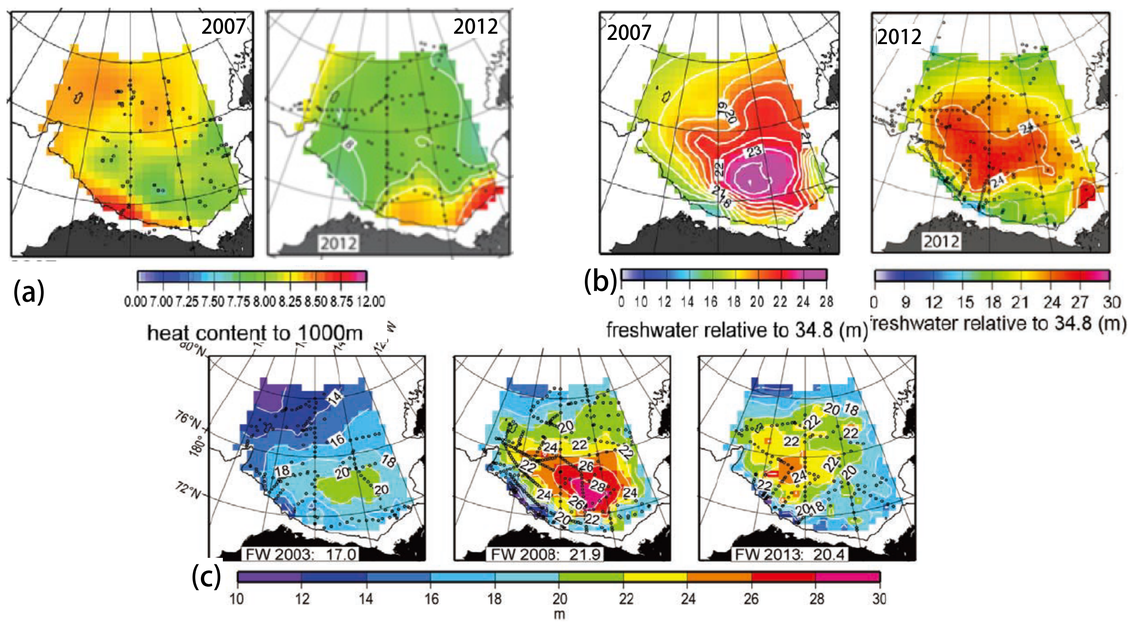

Fig.2. (a) Summer heat content (1 x 10^9 J m^{-2}) in 2007 and 2012, (b) Summer freshwater content (m) in 2007 and 2012; (c) Summer freshwater content (m) in 2003, 2008, and 2013 (inset numbers at the bottom give total FW volume (x10^3 km^3)). Heat content is calculated relative to freezing temperature in the upper 1000 m of the water column and freshwater content is calculated relative to a reference salinity of 34.8. The figures are excerpted from the reference (*Proshutinsky et al., 2008; Timmermans et al., 2012; Timmermans et al., 2014*).

◆Research Objective

Therefore, this study aims to investigate spatial and temporal variations of the Pacific-origin waters and their distributions on the Chukchi Borderland using hydrographic data obtained by the Araon Arctic Summer Surveys from 2010 to 2014.

ARCTIC OCEAN SURVEYS & DATA COLLECTION

◆Hydrographic Surveys from 2010 to 2014

1) Equipment used on the Ice Breaker R/V ARAON
- CTD, lowered ADCP, XCTD
- Ocean Mooring System
- Bio/Geo/Chemical equipment

	2010	2011	2012	2013	2014
CTD	38	18	44	16	32
XCTD	*	33	48	36	51
Duration	07/20~08/10	08/02~08/16	08/04~09/06	08/24~09/01	08/01~08/23

Table 1. A number of CTD and XCTD stations and duration of each survey.

2) Observed Items
- Temperature, salinity, DO, fluorescence, PAR, water velocity, transmission, backscatter,
- Atmospheric components,
- Primary production and new production,
- Chlorophyll-a and HPLC,
- Phytoplankton, Zooplankton compositions
- Nutrients, POC, PON, DOC, DON, DOP,
- N2O gas, pCO2, DIC, pH, SS, TA,
- Micro-zooplankton biomass, composition, and grazing,
- Bacterial and virus biomass

3) Other items collected
- Sea ice concentration
- Sea ice thickness
- Sea ice coverage
- Sea ice motion vector
- Optimal Interpolated SST
- NCEP wind

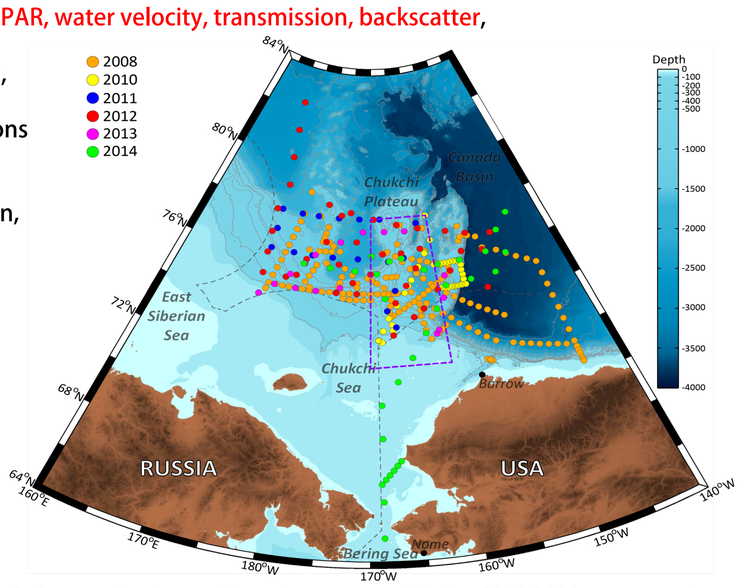

Fig.3. A map of hydrographic stations surveyed during 2010-2014 summer cruises, including 2008 survey stations (not used here).

RESULTS

◆Horizontal distributions

1) Potential Temperatures at S=31.3 (psu): It represents the distribution of PSW in summers 2010-2014 (Fig.4a). PSW in summer 2012 passed through the vicinity of the Northwind Ridge and extended toward the west of the Ridge. PSW in summer 2014 has a lower Pot. T on the south of the Chukchi Plateau.
2) Potential T at S=33.1 (psu): It represents PWW distribution in summers 2010-2014 (Fig.4b). PWW from 2011 to 2013 tends to reach northern Chukchi Sea via the Herald Canyon and turn its direction to the east. However PWW in summer 2014 was present on the western flank of the Chukchi Plateau.
3) Heat content (calculated as *Jackson et al., 2010*) in the upper ocean: High core of HC in 2012 was present in the Beaufort Sea and it tends to disappear (Fig.4c).
4) Freshwater content (calculated as *Carmack et al., 2008*): FWC in 2012 has a similar pattern as HC in 2012 but FWC is still high in 2014 (Fig.4d).

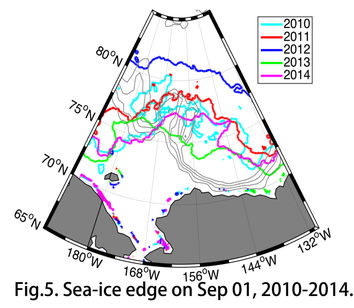

Fig.5. Sea-ice edge on Sep 01, 2010-2014.

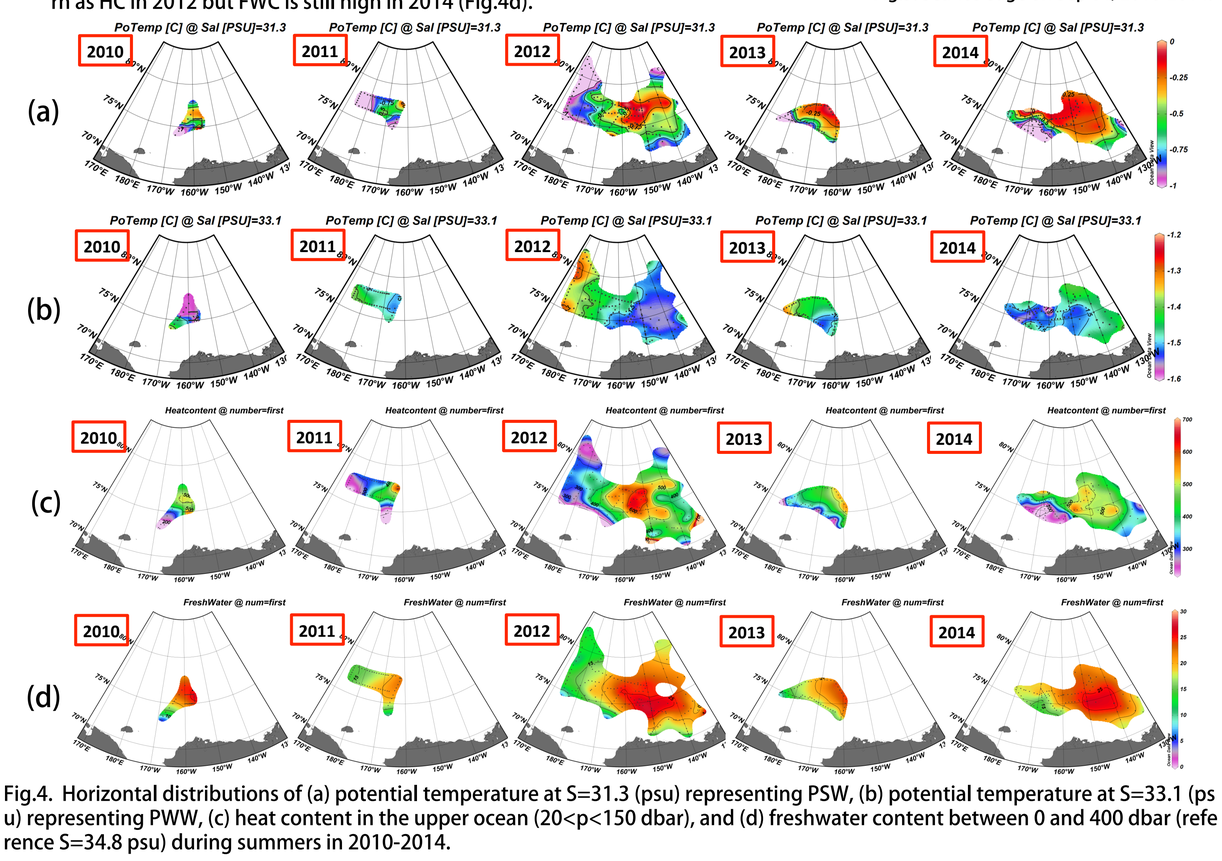

Fig.4. Horizontal distributions of (a) potential temperature at S=31.3 (psu) representing PSW, (b) potential temperature at S=33.1 (psu) representing PWW, (c) heat content in the upper ocean (20<p<150 dbar), and (d) freshwater content between 0 and 400 dbar (reference S=34.8 psu) during summers in 2010-2014.

◆Vertical profiles at the transects

1) θ, S at North-South and East-West transects

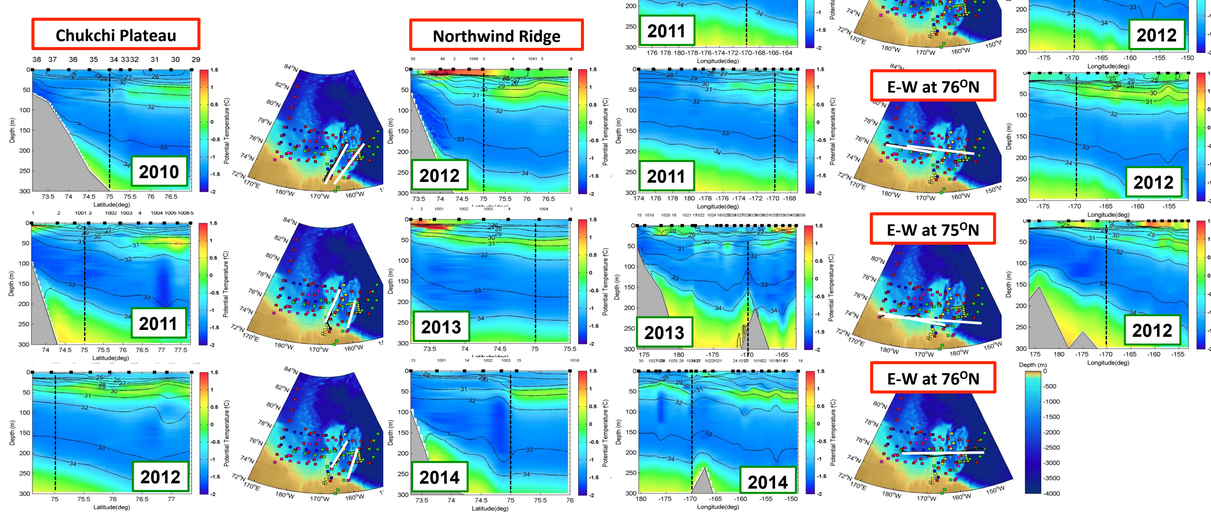

Fig.6. Vertical profiles of potential temperature and salinity along N-S transects of the Chukchi Plateau and the Northwind Ridge (left), and along E-W transects at different latitudes (right) during summers in 2010-2014.

2) θ, S Anomalies near the Chukchi Borderland (170~160°W, 74~78°N)

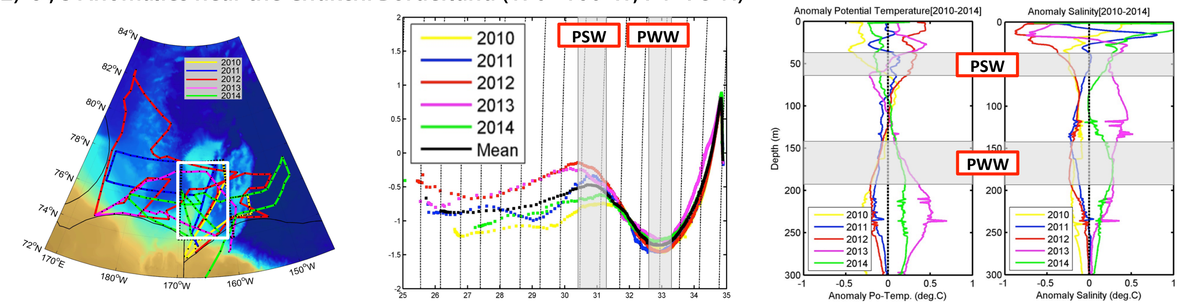

Fig.7. (a) A map of hydrographic stations with the area of the Chukchi Borderland (white), (b) diagrams of θ-S averaged over the area in 2010-2014, and (c) vertical structures of θ (left), S(right) anomalies. Shading boxes indicate PSW (~50 m) and PWW(150~200 m).

Summary

- ◆ PSW in summer 2012 passed through the vicinity of the Northwind Ridge and extended toward the west of the Ridge. PSW in summer 2014 has a lower θ on the south of the Chukchi Plateau. PWW from 2011 to 2013 tends to reach northern Chukchi Sea via the Herald Canyon and turn its direction to the east. However PWW in summer 2014 was present on the western flank of the Chukchi Plateau.
- ◆ High core of HC in 2012 was present in the Beaufort Sea and it tends to disappear. FWC in 2012 has a similar pattern as HC in 2012 but FWC is still high in 2014.
- ◆ PSW extended to south in 2012 and further extended until 2013 but it was only shown above 75°N in 2014. PSW appears to exist in the eastern side of the Chukchi Plateau in 2011, PSW in 2012 tends to mainly pass through the Northwind Ridge reaching 170°W, but PSW in 2014 does not reach 170°W.
- ◆ PSWs of 2010 and 2014 were colder than the mean value whereas those of 2011 to 2013 were warmer. However, PWWs of 2010 to 2012 were colder than the mean value whereas those of 2013 and 2014 were warmer.

Acknowledgement

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