Observations on the cyclonic circulation and retroflection of the Cheju Warm Current in the southern front of the warm-tongue in the northern East China Sea

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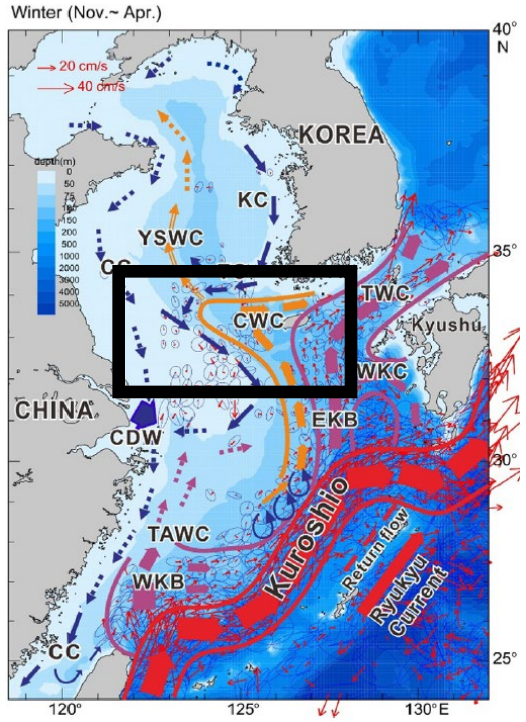
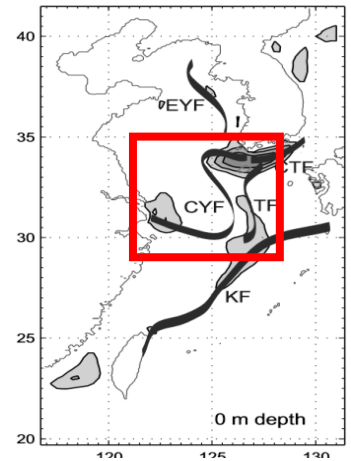
Introduction – study area & research key word

Winter surface circulation

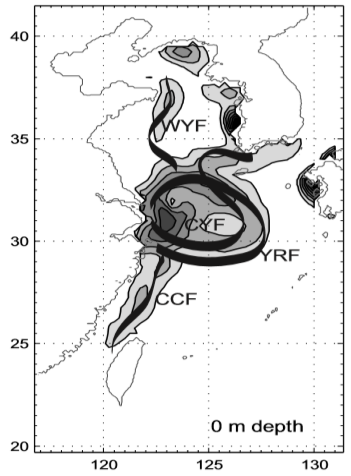


[Lee and Cho, 2016]

nECS



Temp. front



Sal. front

[Park and Chu, 2006]

Why the northern East China Sea (nECS)?

- **The active exchange of heat and material** between the open Pacific and the neighboring marginal seas such as the Yellow Sea, East China Sea, and the southern sea of Korea

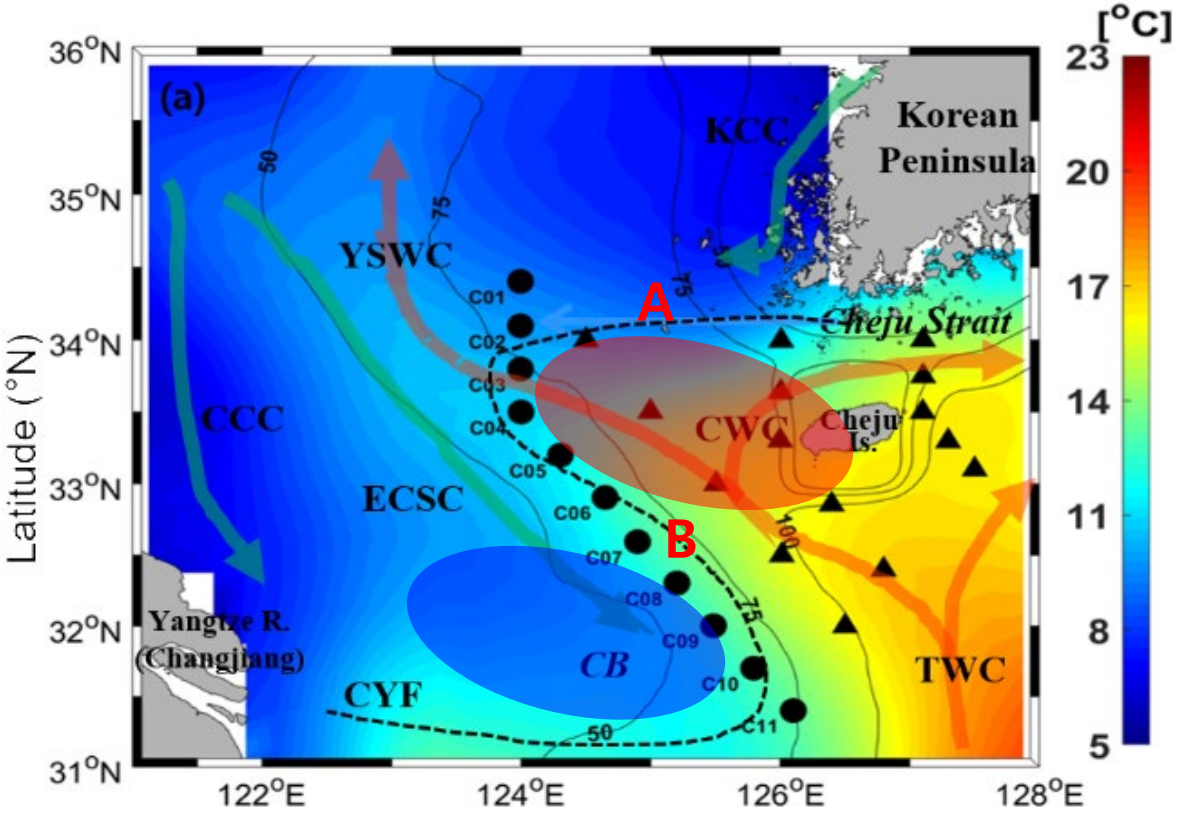
Why thermohaline front in nECS?

- The formation and dissipation of **the thermohaline fronts** are closely linked with the variation of the seasonal currents

- Especially during the winter, forming **a very strong slanted S-shaped thermohaline front (CYF)** connecting Cheju Island and the Changjiang river mouth

- **It is very important to figure out the structure of the CYF and associated circulation** in order to understand the exchange of heat and material between the open Pacific water and the shelf water

Introduction – Changjiang Yangtze Front (CYF)



Color : SST average from January to March 2017

※ Acronyms of currents
- **YSWC : Yellow Sea Warm Current**
- **ECSC : East China Sea Current**
- **CCC : Chinese Coastal Current**
- **KCC : Korean Coastal Current**
- **CWC : Cheju Warm Current**
- **TWC : Tsushima Warm Current**

About the CYF

- Slanted **S-shape**
- **Well developed** by the ECSC, CWC, YSWC **in winter**
- Warm-tongue and Cold-tongue
- The front around the warm-tongue is divided into **a northern front (A)** and **a southern front (B)**
- In winter, **geostrophically cyclonic circulation pattern** around the warm-tongue, namely, westward along the northern front and southeastward along the southern front
- The ECSC strengthens the southeastward outflow along the southern front
- Retreat eastward in spring, disappear in summer

Introduction – Previous studies and aim of this study

- Previous studies have mainly focused on the northern front of the warm-tongue by using hydrographic and satellite observations and numerical models

  - Episodic large **temperature inversion** structures along the northern front during winter [*Lie et al.* 2015; *Hao et al.* 2010; *Lie et al.* 2019]
  - **Physical connection** between the westward shift of the warm-tongue and the northern front [*Wang et al.* 2012]
  - **Frontal circulation of the warm-tongue** during the winter monsoon [*Lie et al.* 2013]

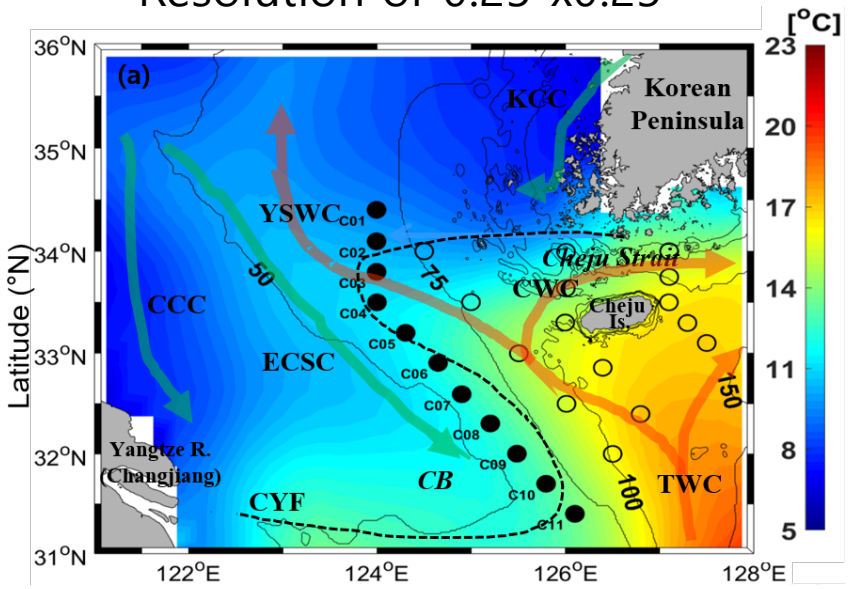
- However, **the southern front of the warm-tongue** remains largely unexplored though its significance for heat and material exchanges between the open Pacific and shelf seas

- **The aim of this study** is
  (1) analyse the structures of the southern front of the warm-tongue
  (2) identify relavant frontal circulation from the perspective of heat and material exchanges based on in-situ hydrographic observations during two cruises, historical hydrographic observations, and supplementary satellite observations

Data and Methods

Data

- **In-situ hydrographic data**
  - Periods : Feb. 6-14, 2017, Apr. 20-30, 2018
  - Temp. Sal. dissolved oxygen (CTD), currents (ADCP)
- **Historical hydrographic data (NIFS, 1963-2019)**
  : Temp. Sal. (CTD)
- **Supplementary satellite data (2017-2018)**
  : SSH, SST (provided by CMEMS)
  - Daily and monthly data
  - Resolution of 0.25°x0.25°



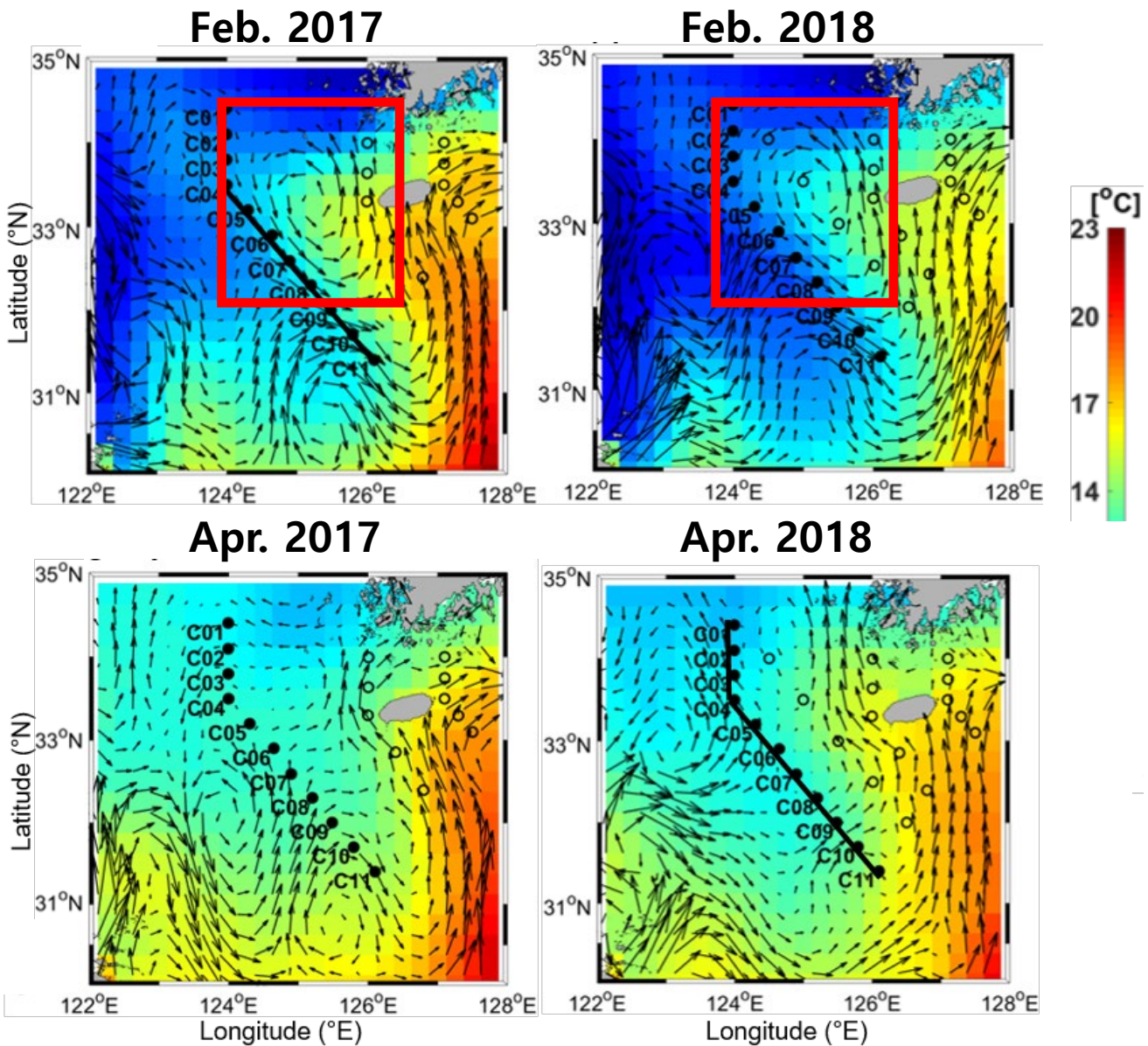
In-situ observation station map

Method

- **Detided currents (tidal correction)**
  = ADCP currents – Tidal currents (Tidal model)
  ※ TPXO8v.1 (global barotropic tidal model)
  - horizontal resolution of 1/30°
- **Water properties along the isopycnal surfaces**
  : Spiciness (π)
  ※ warm and saline → high π
- **Conservative Temperature (Θ) and Absolute Salinity (S_A)**
  : TEOS-10
  (International Thermodynamic Equation of Seawater)

Results

Satellite-derived monthly mean SST (color), surface geostrophic currents (vectors)



Well-developed S-shape front

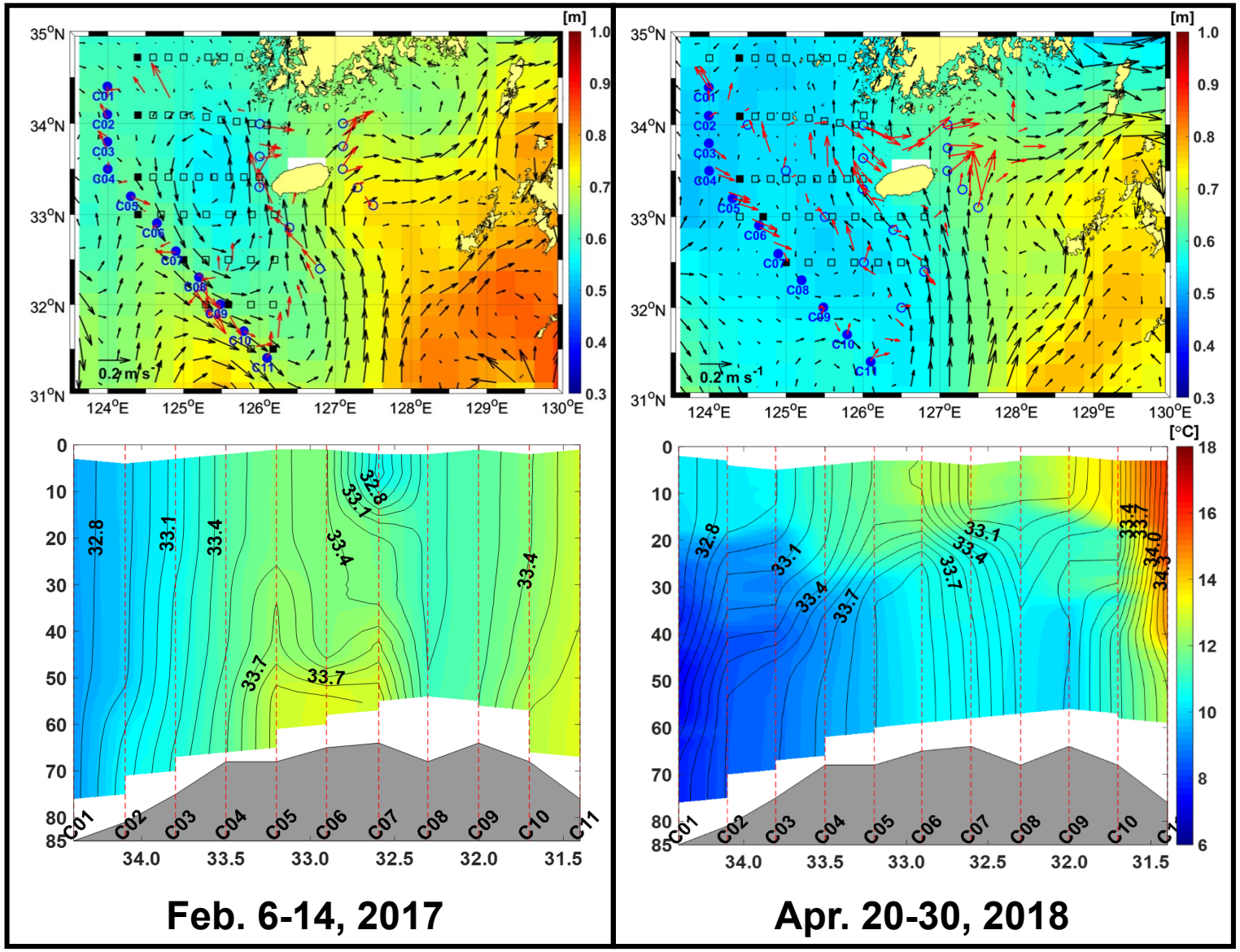
Cyclonic circulation at surface

Dim S-shape front

no cyclonic circulation at surface

Results

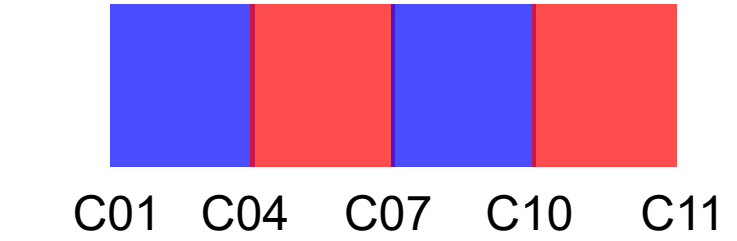
SSH (color), surface geostrophic currents (black arrows), and detided currents at 40m (red arrows)
Temperature (color) & Salinity (contour)



- **Cyclonic circulation pattern in**
  → surface geostrophic currents in Feb. 2017
  → detided currents (at 40m depth) in Feb. 2017 and Apr. 2018

- **An alternate intruding frontal structure**

<Schematic>

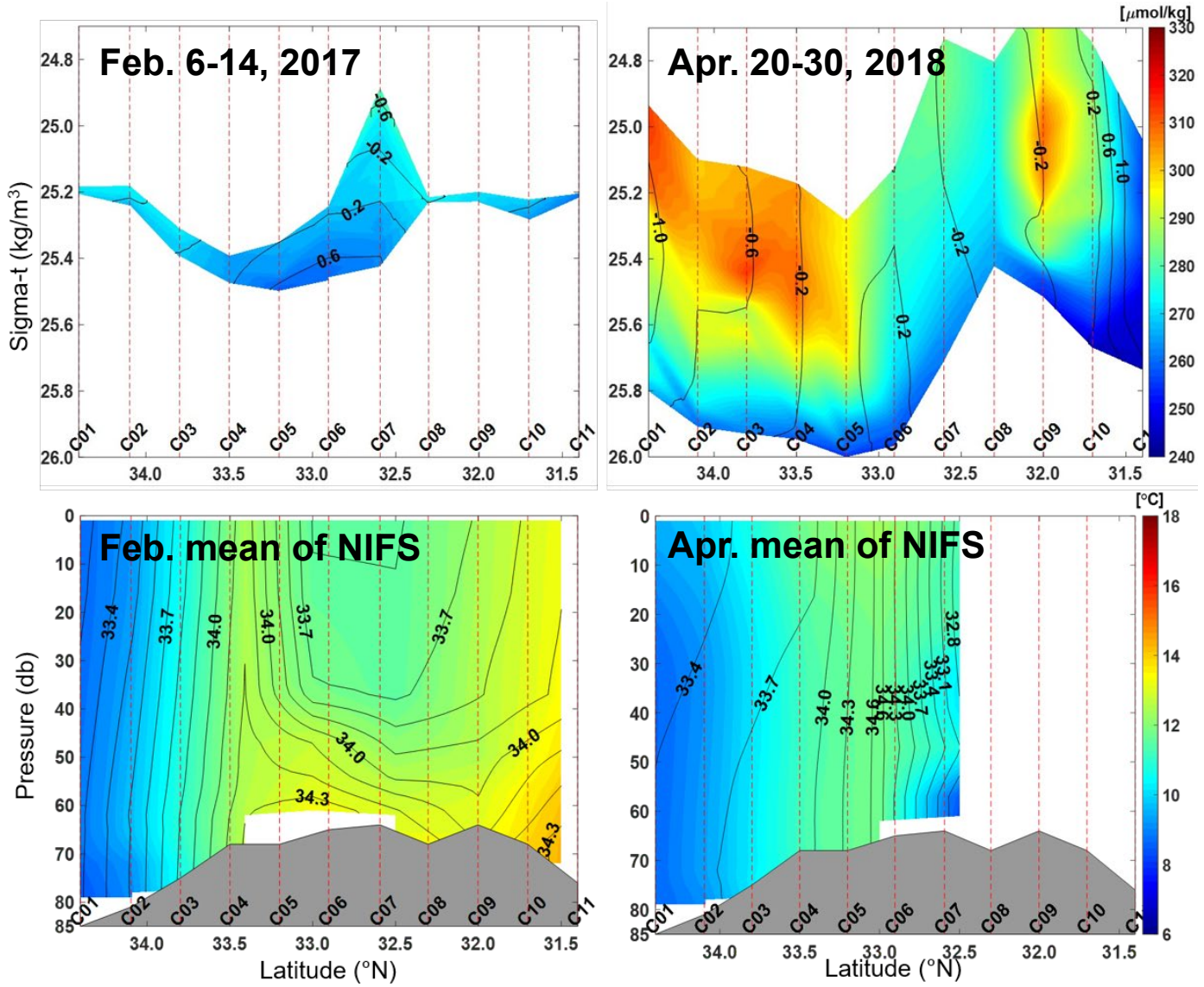


→ Low Temp **(<10.5 ℃)** & Low Sal water **(<33.4 g/kg)**

→ High Temp **(>10.5℃)** & High Sal water **(>33,4 g/kg)**

Results

Dissolved oxygen (DO) (color) & π (contour)
Temperature (color) & Salinity (contour) in historical (NIFS) data (1963-2019)

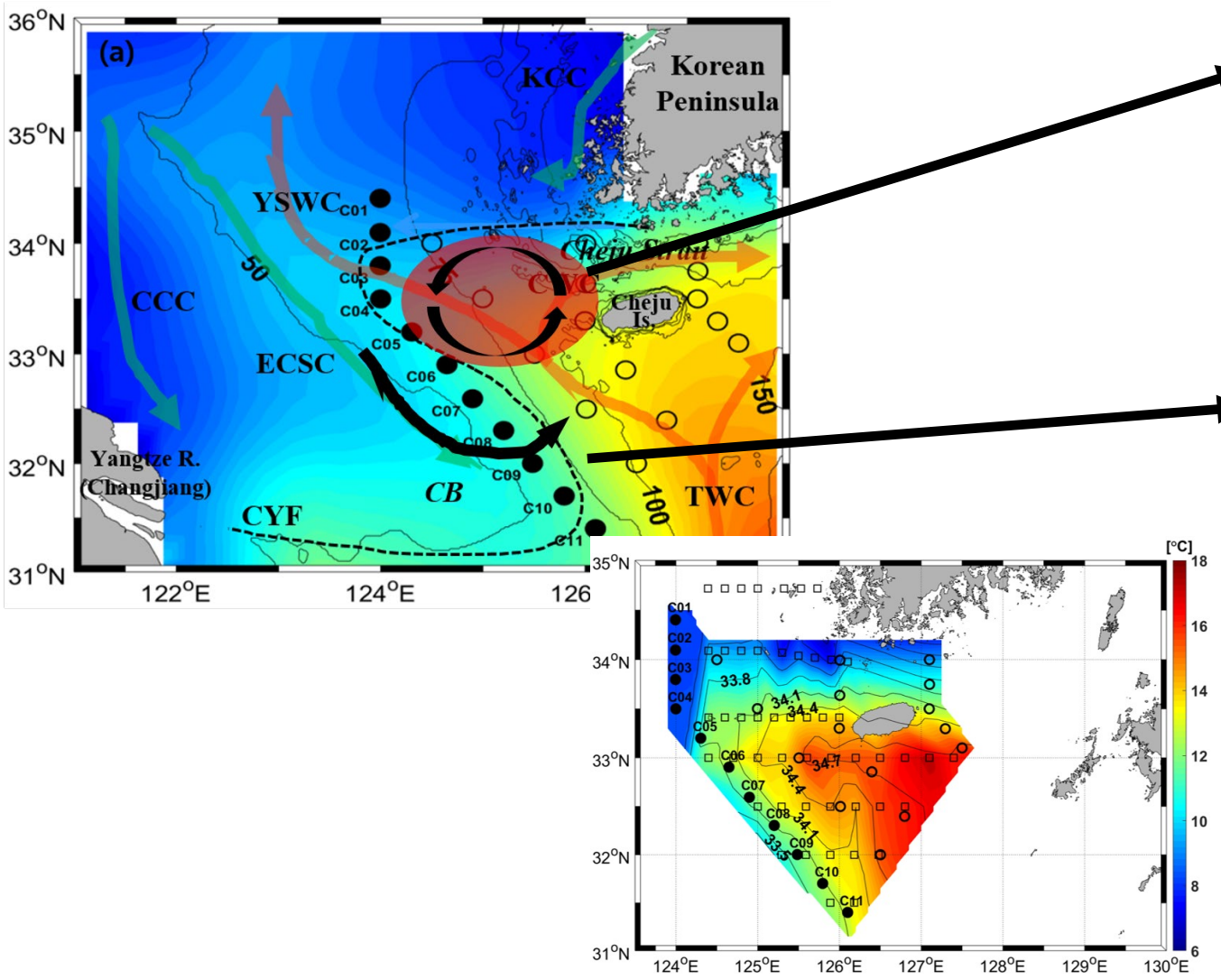


- **Alternate intruding frontal structure** distinguished also from DO, π

- NIFS historical data also showing the alternate intruding frontal structure consistent with in-situ observations

Discussions

Possible mechanism of cyclonic circulation



Feb. mean of Temp. and Sal. at 40m depth of NIFS data

- Geostrophically cyclonic circulation

High-density water formed via diapycnal mixing between low-temperature water of northern origin and high-salinity water of southern origin

- Potential vorticity conservation

The bottom relief becomes significant from C04 to C09, inducing cyclonic circulation to conserve the potential conservation due to water column stretching (increasing relative vorticity)

$$\frac{\Omega + \xi \uparrow}{H \uparrow} = constant$$

Ω : planetary vorticity **H : water depth**
ξ : relative vorticity

Summary and Conclusion

- A subsurface thermohaline front semi-permanently formed in association with **near-bottom cyclonic circulation** in the nECS was newly found from detailed hydrographic data collected during two cruises in February 2017 (winter) and April 2018 (spring) along with supplementary satellite and hydrographic data

- **An alternate intruding frontal structure** in water properties was observed across the cyclonic circulation in both seasons as formed by two contrasting water masses

- Consistent structures were confirmed from current observations during the two cruises, historical hydrographic observations, and satellite altimetry-derived sea surface height and surface frontal structure

- These results reveal significant heat and material exchanges between the open Pacific and the broad shelf, particularly via diapycnal mixing and cross-front transports associated with across-front flow and cyclonic circulation, in the northern East China Sea

References

•Chen, C.-T. A. Chemical and physical fronts in the Bohai, Yellow and East China seas. *J. Mar. Syst.* 78, 394–410 (2009).
•Son, Y.-T., Park, J.-H. & Nam, S. Summertime episodic chlorophyll a blooms near the east coast of the Korean Peninsula. *Biogeosciences* 15, 5237–5247 (2018).
•Park, S. & Chu, P. C. Thermal and haline fronts in the Yellow/East China Seas: Surface and subsurface seasonality comparison. *J. Oceanogr.* 62, 617–638 (2006).
•Hickox, R., Belkin, I., Cornillon, P. & Shan, Z. Climatology and seasonal variability of ocean fronts in the East China, Yellow and Bohai seas from satellite SST data. *Geophys. Res. Lett.* 27, 2945–2948 (2000).
•Li, G. et al. Monthly variations of water masses in the East China Seas. *Cont. Shelf Res.* 26, 1954–1970 (2006).
•Lie, H.-J. & Cho, C.-H. Seasonal circulation patterns of the Yellow and East China Seas derived from satellite-tracked drifter trajectories and hydrographic observations. *Prog. Oceanogr.* 146, 121–141 (2016).
•Lie, H.-J. & Cho, C.-H. Recent advances in understanding the circulation and hydrography of the East China Sea. *Fisheries Oceanography* 11, 318–328 (2002).
•Lie, H.-J. et al. Does the Yellow Sea Warm Current really exist as a persistent mean flow? *J. Geophys. Res. Oceans* 106, 22199–22210 (2001).
•Yu, F., Zhang, Z., Diao, X. & Guo, J. Observational evidence of the Yellow Sea Warm Current. *Chinese Journal of Oceanology and Limnology* 28, 677–683 (2010).
•Yuan, D. & Hsueh, Y. Dynamics of the cross-shelf circulation in the Yellow and East China Seas in winter. *Deep Sea Research Part II: Topical Studies in Oceanography* 57, 1745–1761 (2010).
•Yuan, D., Zhu, J., Li, C. & Hu, D. Cross-shelf circulation in the Yellow and East China Seas indicated by MODIS satellite observations. *Journal of Marine Systems* 70, 134–149 (2008).
•Lie, H.-J. et al. Seasonal variation of the Cheju warm current in the northern East China Sea. *J. Oceanogr.* 56(2) 197-211 (2000).
•Li, G. et al. Monthly variations of water masses in the East China Seas. *Cont. Shelf Res.* 26, 1954–1970 (2006).
•Park, S. & Chu, P. C. Thermal and haline fronts in the Yellow/East China Seas: Surface and subsurface seasonality comparison. *J. Oceanogr.* 62, 617–638 (2006).
•Son, Y-T., Lee, S.-H., Lee, J.-C. & Kim, J.-C. Water masses and frontal structures in winter in the northern East China Sea. *J. Korean Soc. Oceanogr. (The Sea)* 8(3), 327-339 (2003).
•Lie, H.-J., Cho, C.-H. & Lee, S. Frontal circulation and westward transversal current at the Yellow Sea entrance in winter. *J. Geophys. Res. Oceans* 118, 3851–3870 (2013).
•Xie, S.-P. et al. Bathymetric effect on the winter sea surface temperature and climate of the Yellow and East China Seas. *Geophys. Res. Lett.* 29, (2002).
•Lie, H.-J., Cho, C.-H. & Lee, S. Tongue-shaped frontal structure and warm water intrusion in the southern Yellow Sea in winter. *J. Geophys. Res.* 114, (2009).
•Lie, HHao, J., Chen, Y. & Wang, F. Temperature inversion in China seas. *J. Geophys. Res.* 115, (2010).
•Lie, H.-J., Cho, C.-H. & Jung, K. T. Occurrence of large temperature inversion in the thermohaline frontal zone at the Yellow Sea entrance in winter and its relation to advection. *J. Geophys. Res. Oceans* 120, 417–435 (2015).
•Hao, J., Chen, Y. & Wang, F. Temperature inversion in China seas. *J. Geophys. Res.* 115, (2010).
•Lie, H. J., Oh, K. H., Cho, C. H. & Moon, J. H. Wintertime large temperature inversions in the Yellow Sea associated with the Cheju and Yellow Sea Warm Currents. *Journal of Geophysical Research: Oceans* (2019). doi:10.1029/2019jc015180
•Wang, F., Liu, C. & Meng, Q. Effect of the Yellow Sea warm current fronts on the westward shift of the Yellow Sea warm tongue in winter. *Continental Shelf Research* 45, 98–107 (2012).
•Lie, H.-J. et al. Seasonal variation of the Cheju warm current in the northern East China Sea. *J. Oceanogr.* 56(2) 197-211 (2000).
•Lie, H.-J. et al. Does the Yellow Sea Warm Current really exist as a persistent mean flow? *J. Geophys. Res. Oceans* 106, 22199–22210 (2001).
•Pollard, R. T. & Regier, L. Large variations in potential vorticity at small spatial scales in the upper ocean. *Nature* 348, 227–229 (1990).
•Taburet, G., & Pujol, M. I. Sea Level TAC-DUACS products. (2018).
•Stammer, D. et al. Accuracy assessment of global barotropic ocean tide models. *Reviews of Geophysics* 52, 243–282 (2014).
•Carrère, L. & Lyard, F. Modeling the barotropic response of the global ocean to atmospheric wind and pressure forcing - comparisons with observations. *Geophysical Research Letters* 30, (2003).
•Mensah, V., Menn, M. L. & Morel, Y. Thermal mass correction for the evaluation of salinity. *J. Atmos. Oceanic Technol.* 26, 665–672 (2009).
•Morison, J., Andersen, R., Larson, N., Dasaro, E. & Boyd, T. The correction for thermal-lag effects in Sea-Bird CTD data. *J. Atmos. Oceanic Technol.* 11, 1151–1164 (1994).
•Kim, K., Cho, Y. K., Ossi, H., & Kim, Y. G. CTD data processing for CREAMS expeditions: Thermal-lag correction of Sea-Bird CTD. *Ocean Sci.* 35(4), 192-199 (2000).
•Getting started with TEOS-10 and the Gibbs Seawater (GSW) oceanographic toolbox. *SCOR/IAPSO WG*, 127, 1-28 (2011).
•Egbert, G. D. & Erofeeva, S. Y. Efficient inverse modeling of barotropic ocean tides. *J. Atmos. Oceanic Technol.* 19, 183–204 (2002).
•Flament, P. A state variable for characterizing water masses and their diffusive stability: Spiciness. *Prog. Oceanogr.* 54, 493–501 (2002).

Thank you