2016 PICES Annual Meeting

November 8, 2016
San Diego, CA, USA

Mesoscale-eddy-induced variability of flow through the Kerama Gap between the East China Sea and the western North Pacific

Hanna Na[1], Jae-Hun Park[2], Mark Wimbush[3], Hirohiko Namakuma[4], Ayako Nishina[4], and Xiao-Hua Zhu[5]

[1]Korea Institute of Ocean Science and Technology (KIOST), Korea

[2]Inha University, Korea, [3]University of Rhode Island, USA

[4]Kagoshima University, Japan, [5]Second Institute of Oceanography, China

A frequent PICES meeting attendee as a graduate student

- 14th in Vladivostok, Russia (2005);
  my first international conference

- 16th in Victoria, BC, Canada (2007)
- 18th in Jeju, Korea (2009)
- 19th in Portland, OR, USA (2010)
- 20th in Khabarovsk, Russia (2011)
- 25th in San Diego, CA, USA (2016)

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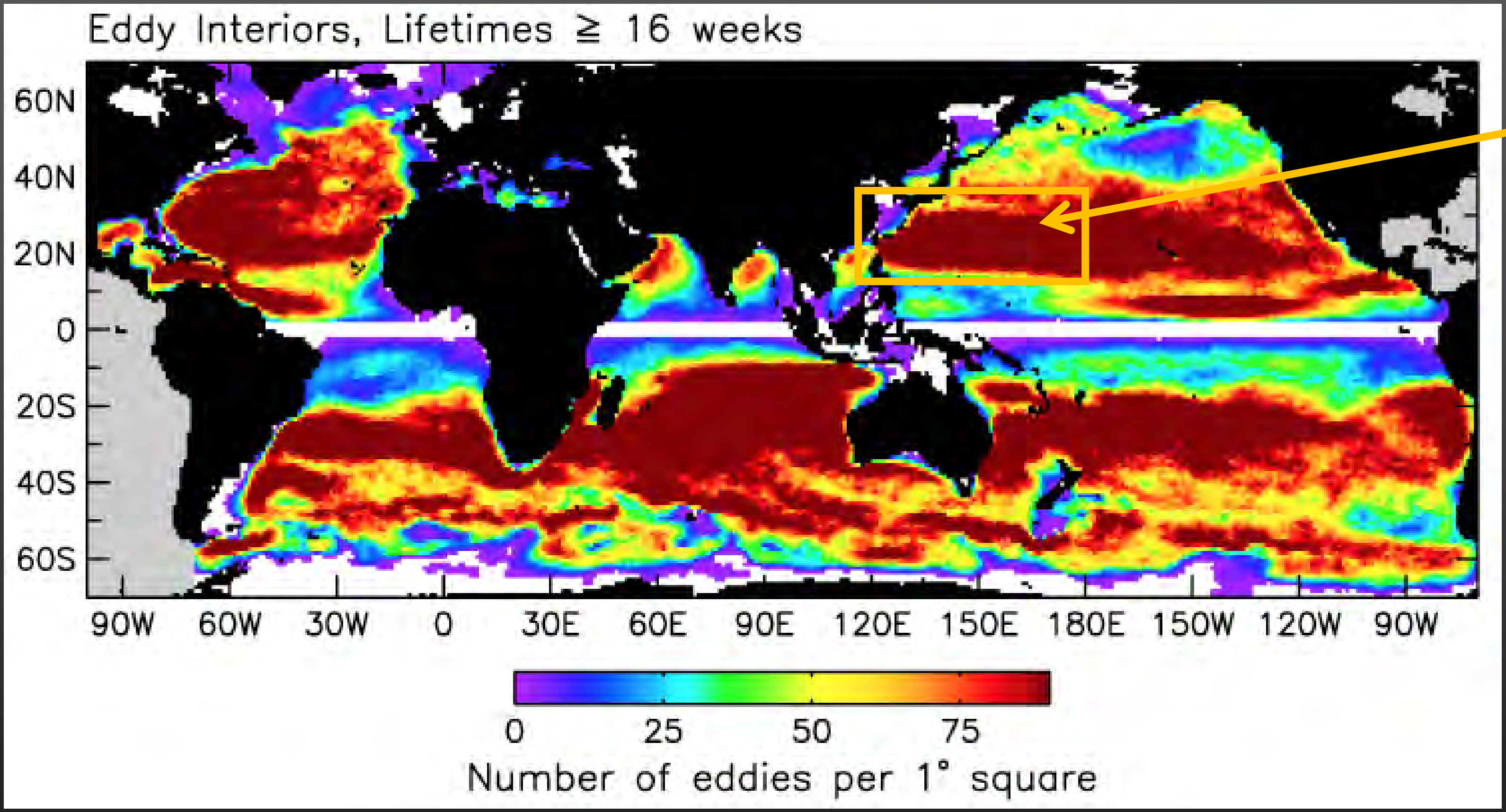
Number of eddies (lifetime >= 16 weeks)



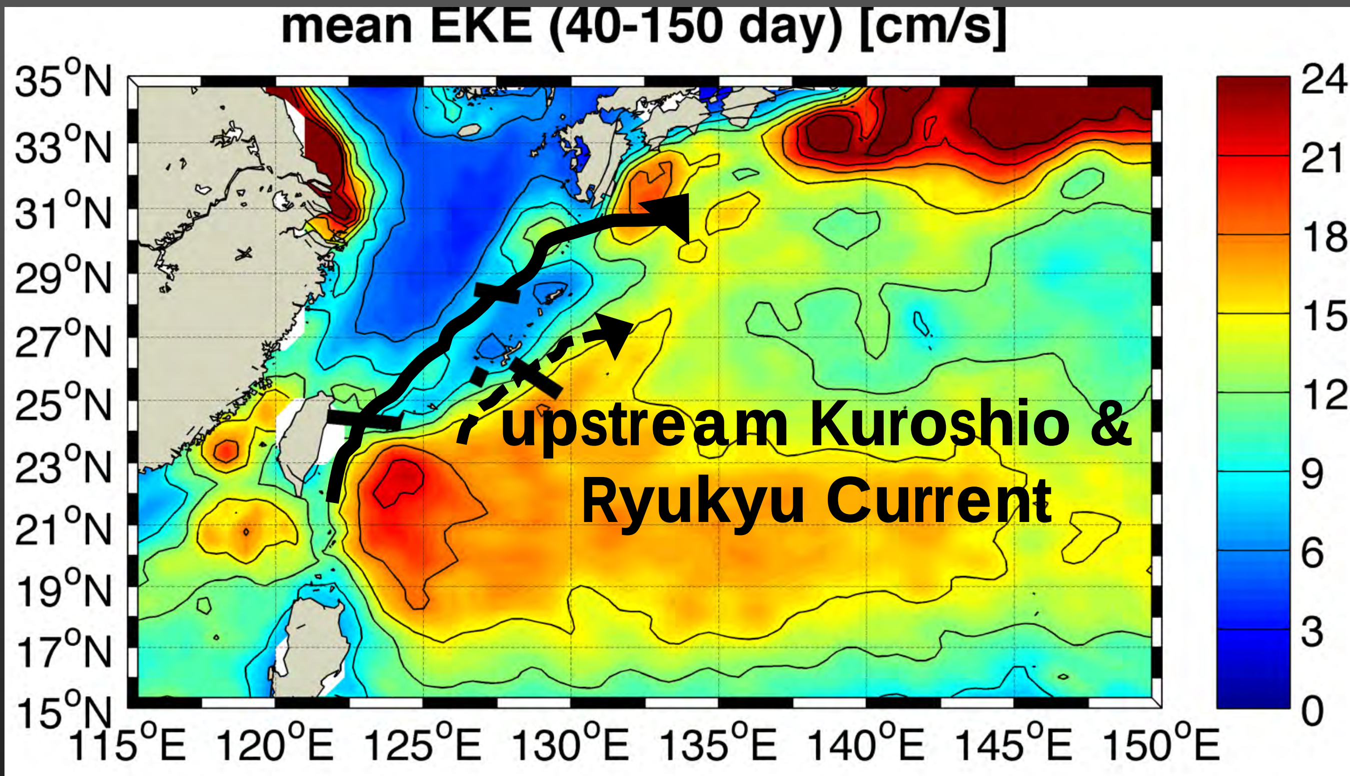
western North Pacific

abundant mesoscale eddies in the mid-latitude ocean

Chelton's new version of the eddy dataset from the new 22-year AVISO daily SSHa (January 1993 - April 2015)

http://wombat.coas.oregonstate.edu/eddies/

Mesoscale eddy variability in the western North Pacific



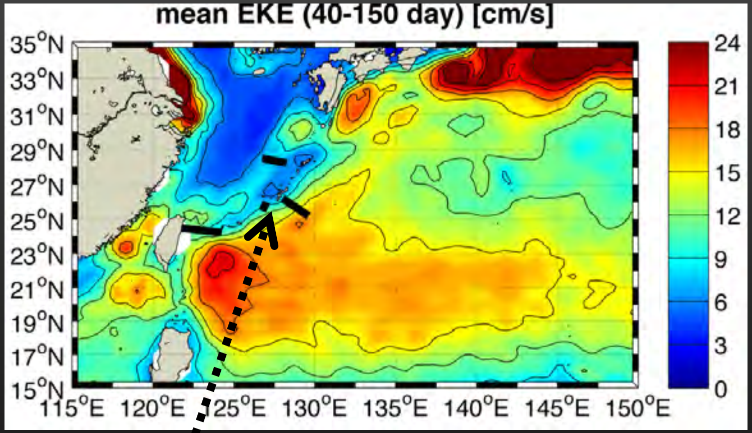
40–150 day
Eddy Kinetic
Energy (EKE)

from AVISO 7-day interval gridded geostrophic velocity anomalies

http://www.aviso.altimetry.fr/en/data/products.htm

Outline

- Large mesoscale eddy variability in the western North Pacific
- Review of observation-based studies
  - east of Taiwan
  - east of Ryukyu Islands
  - inside the East China Sea



- Observation at the Kerama Gap

Eddy **influence** on the Kuroshio east of Taiwan

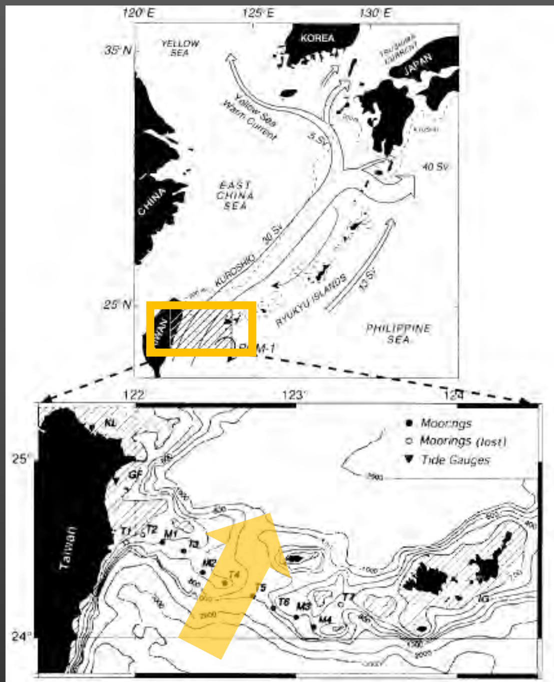


Fig. 1. (a) Schematic of the western boundary currents with estimated mean transports in the vicinity of the East China Sea (after Nitani 1972). The striped area east of Taiwan marks the East Taiwan Channel, where the WOCE PCM-1 moored current meter array was deployed. (b) Moorings and tide gauge locations on the topography of the Ilan Ridge. Shaded area indicates depth less than 200 m.

current meter array mooring between September 1994 and May 1996

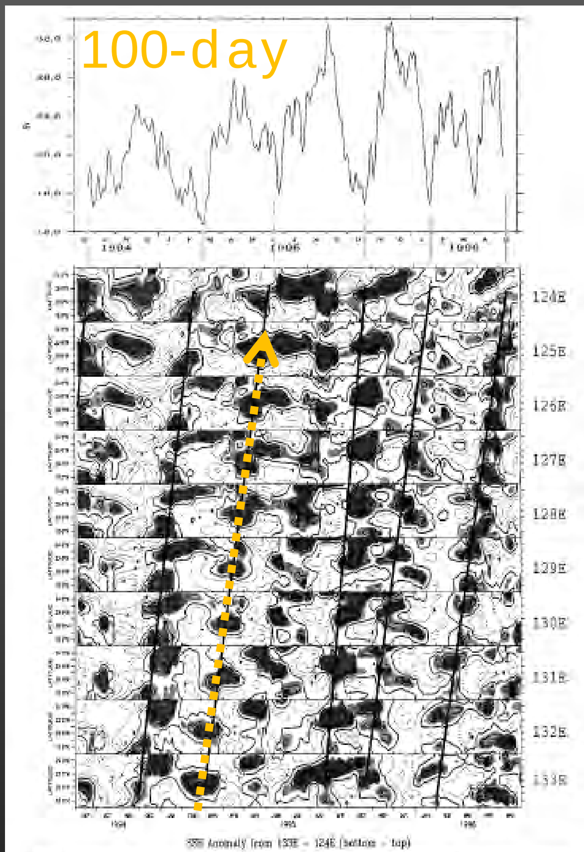


Fig. 11. Five-day low-passed Kuroshio transport time series measured by PCM-1 array (upper panel) and latitude–time plots of TOPEX/Poseidon sea surface height anomaly (SSHA) for longitudes 133°–124°E. The tilted lines indicate phase propagation of those features tracked from the interior ocean to the western boundary. The contour interval is 8 cm. The shaded area indicates the region where SSHA is larger than 5 cm, the darker area indicates SSHA larger than 10 cm.

Kuroshio transport & mesoscale eddies

west

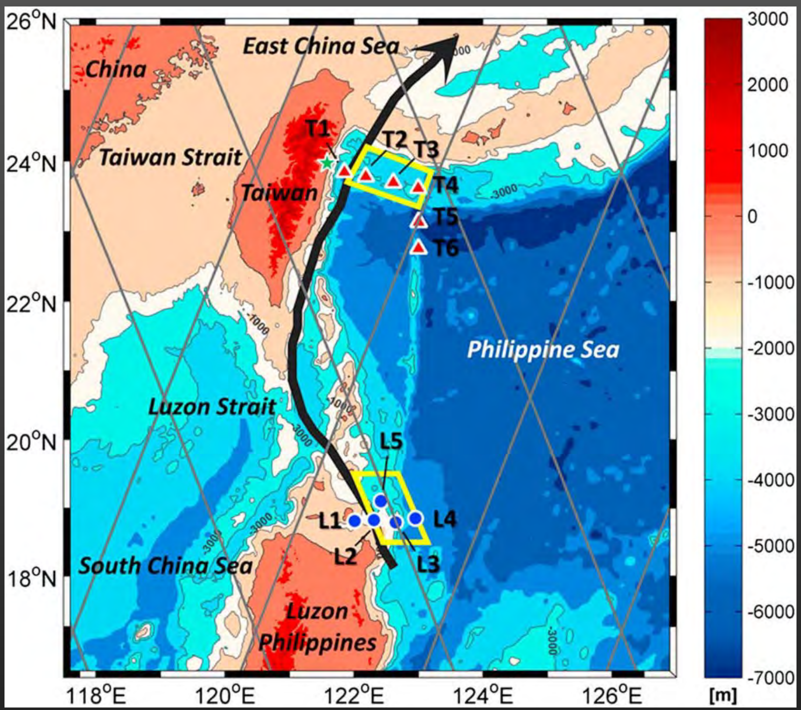
westward propagation of anticyclonic eddies

east

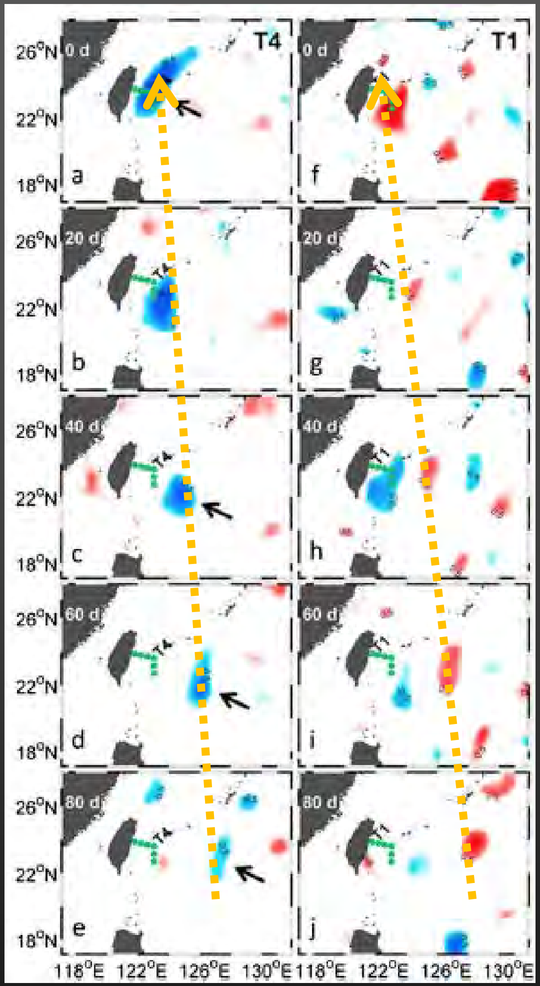
On the 100-day timescale, the Kuroshio transport entering the East China Sea is strongly related to meandering of the Kuroshio, which in turn is caused by westward propagating anticyclonic eddies from the interior ocean, the North Pacific

Zhang et al. 2001, JPO

Eddy-Kuroshio interaction east of Taiwan



PIES mooring from November 2012 to October 2014



lagged correlation between the acoustic travel time and SSHa

dynamical link between variations in pycnocline depth and propagating SSHa; eddy influence is weakened across the Kuroshio

Tsai et al. 2015, GRL

Eddy influence on the Ryukyu Current

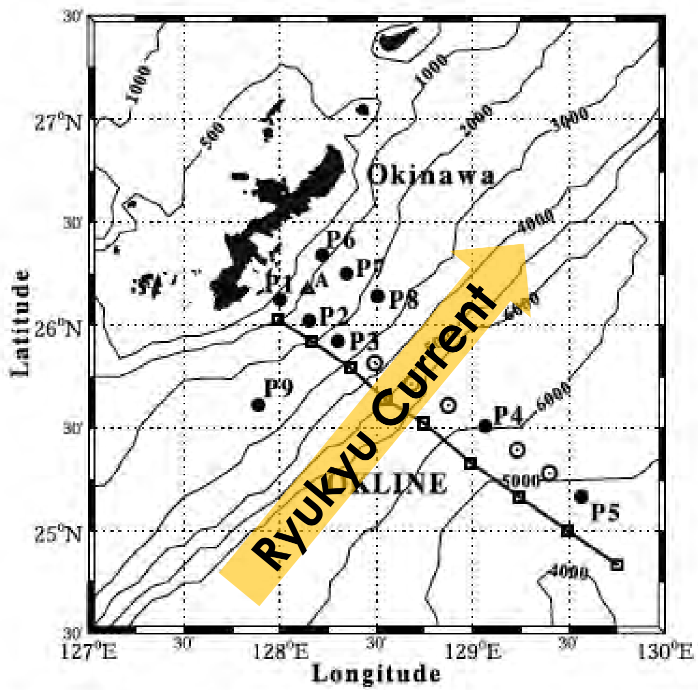
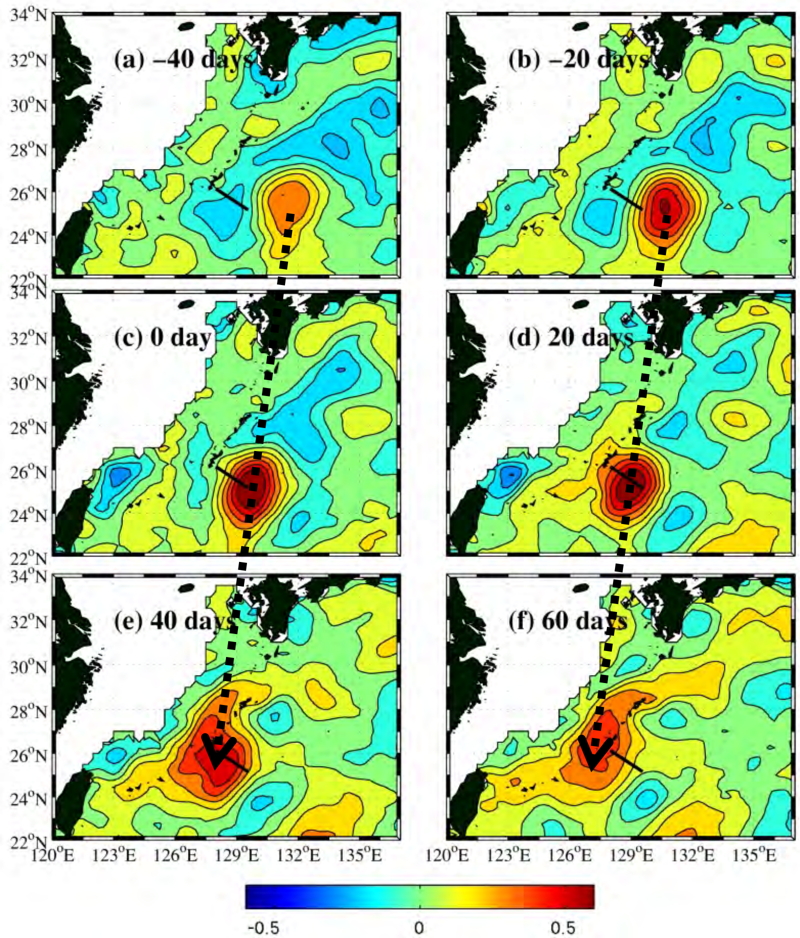


Figure 1. Location map of the observation sites. Solid circles (P1 – P9), open circles and solid triangle (A) indicate the locations of PIES, interpolated data points and the MADCP, respectively. The open squares along solid line are the hydrographic survey stations along the OK-Line on which the shipboard ADCP measurements were conducted. The bathymetric contours are drawn in unit of meter.

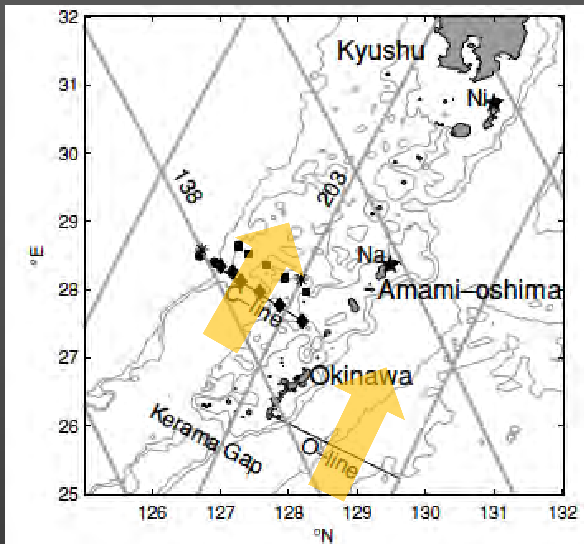
PIES and ADCP mooring during November 2000 to August 2001

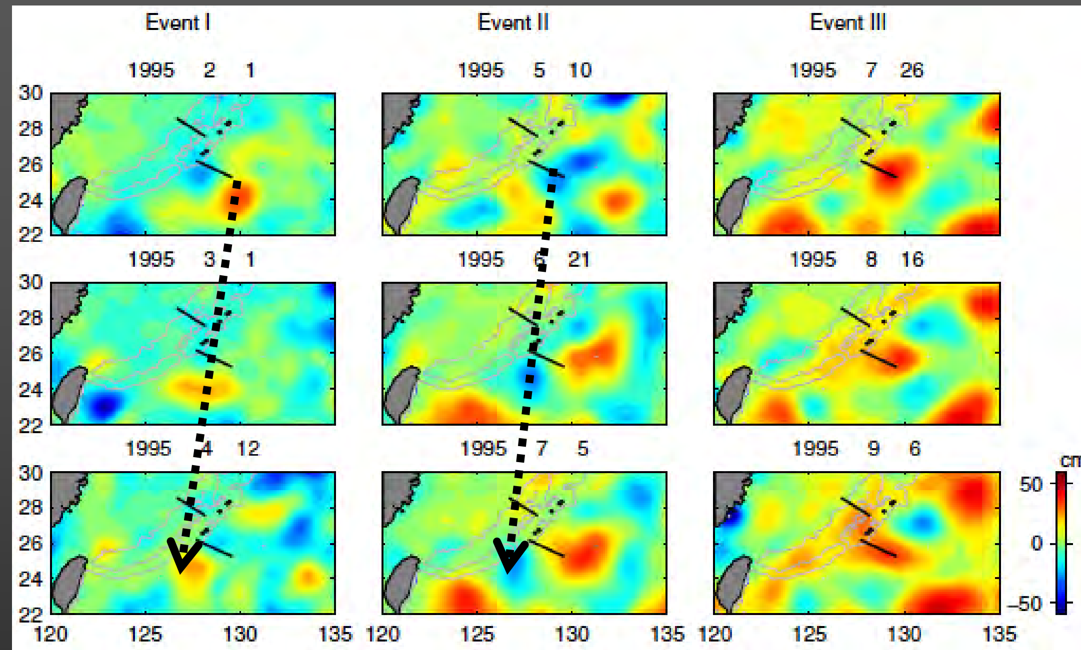


correlation coefficients between the transport and the SSHA

Zhu et al. 2003, GRL; Zhu et al. 2004, JO

Eddy-Ryukyu Current-Kuroshio





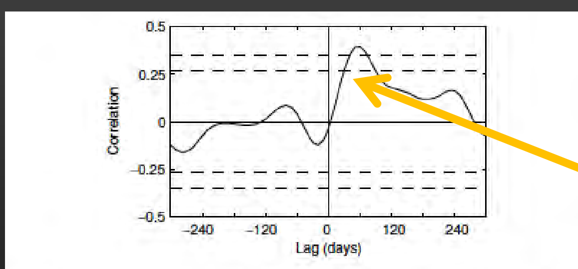


Fig. 8. Cross correlation function of KT and RT with time lag. Positive lag indicates KT lagging RT. The RT time series has 54 degrees of freedom (DOF) while the KT time series has 73 DOF. Dashed lines show the 95% and 99% confidence levels (±0.273 and ±0.354, respectively) for a correlation with 50 DOF (Emery and Thomson, 2001).

lag correlation between the Kuroshio and Ryukyu Current

the effect of mesoscale eddies is transmitted to the ECS via the Kerama Gap southwest of Okinawa

C-line: CPIES and ADCP mooring during December 2002 until November 2004

Andres et al. 2008, JO

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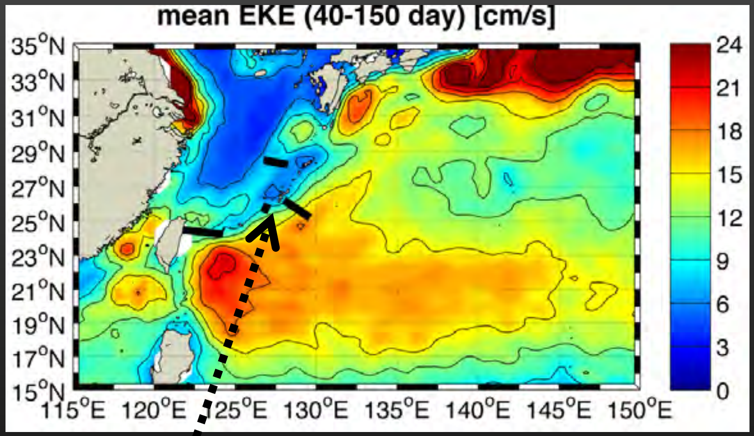
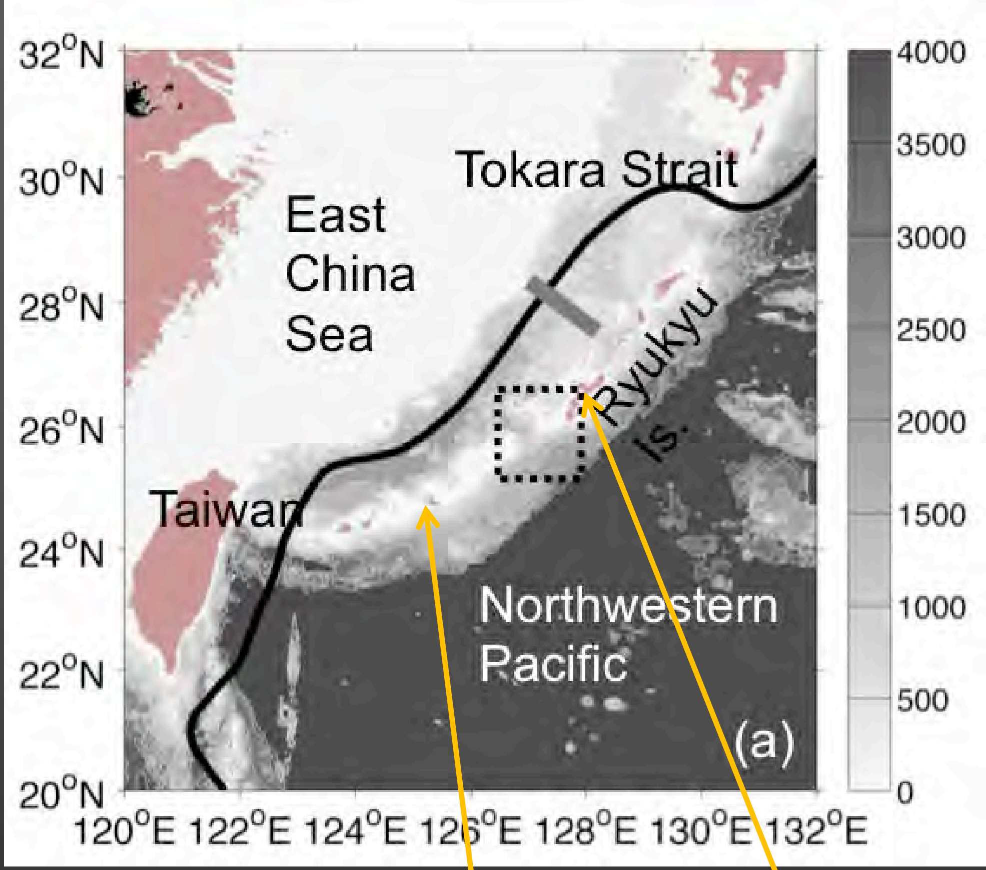


- Observation at the Kerama Gap

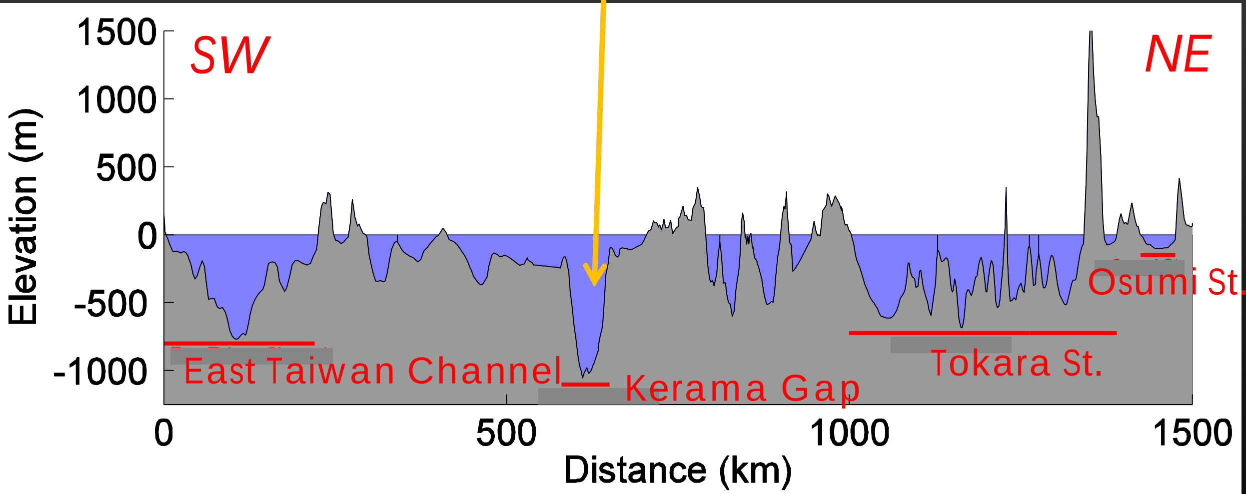
Kerama Gap

- width: 5o km
- sill depth: 1050 m, the deepest channel along the Ryukyu Ridgeline



Okinawa

Miyakojima



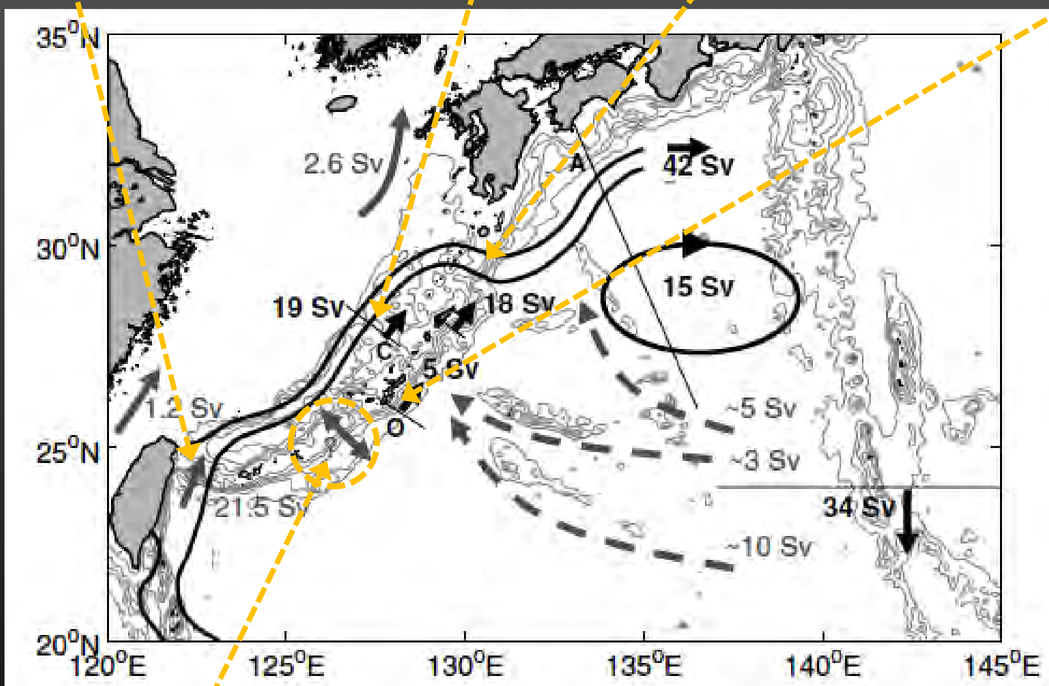
Mean transports of the Kuroshio/Ryukyu Current System

East of Taiwan

ECS-Kuroshio (PN-line)

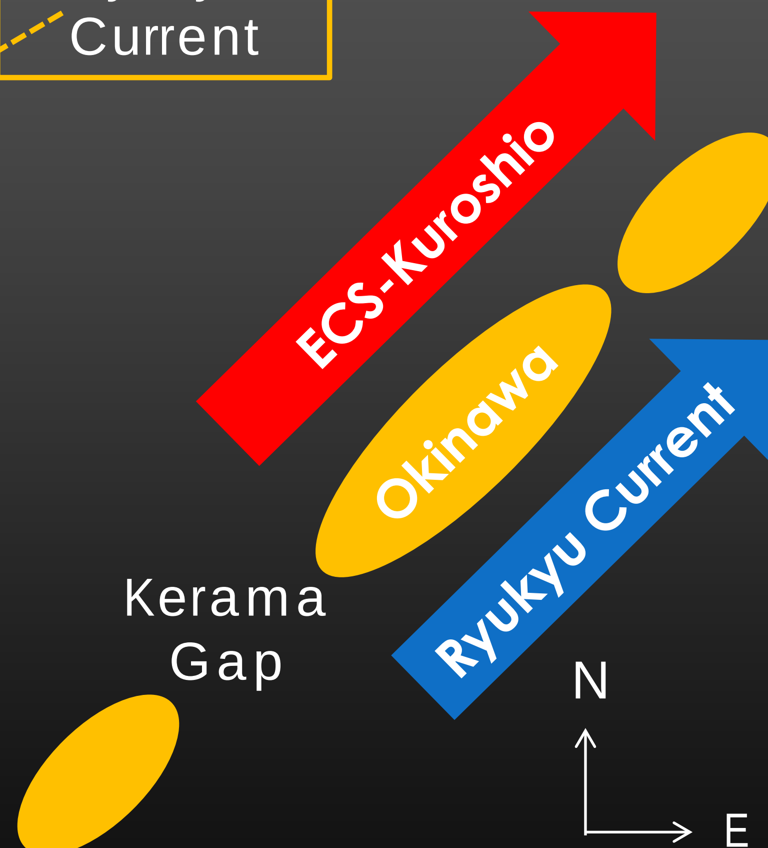
Tokara Strait

Ryukyu Current

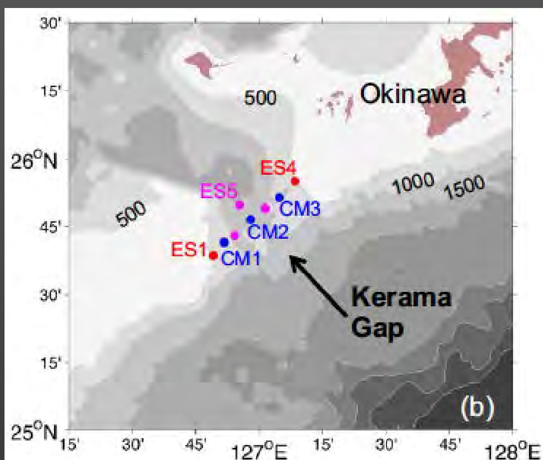


Kerama Gap: ?

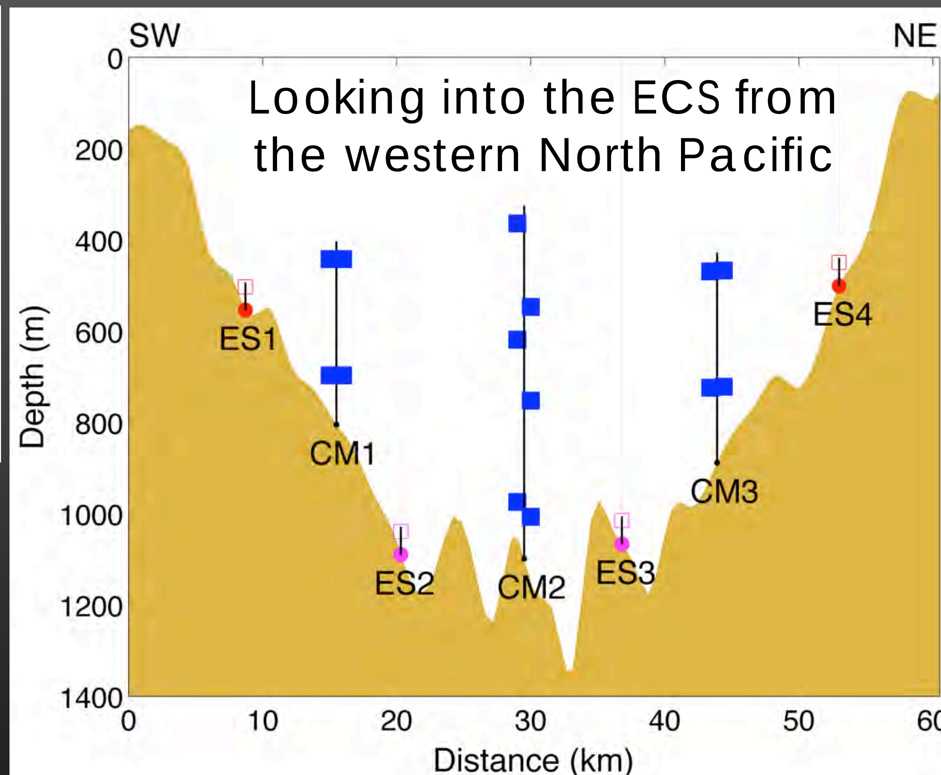
Andres et al., 2008



2-year (June 2009 – June 2011) observation across the Kerama Gap



blue: Current Meter (CM)
red & magenta: CPIES



first direct and continuous observation of the Kerama Gap transport

T/V Kagoshima-maru

Year 1: Jun 2009 – Jun 2010

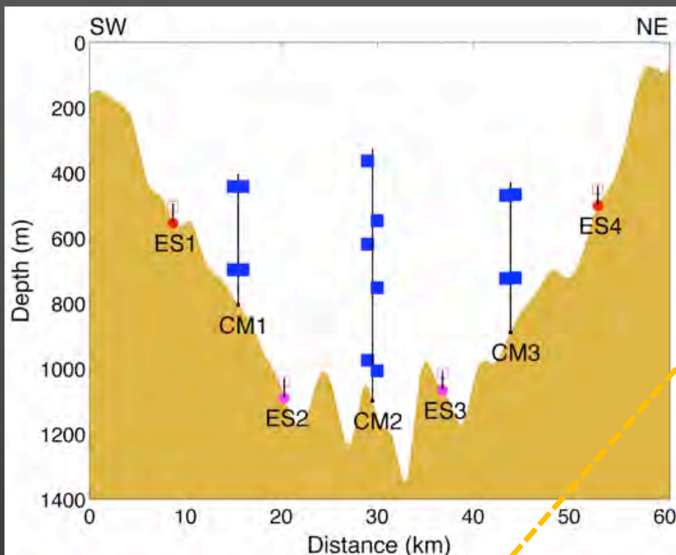
Year 2: Jun 2010 – Jun 2011

red: CPIES (ES1, ES4), 2-year

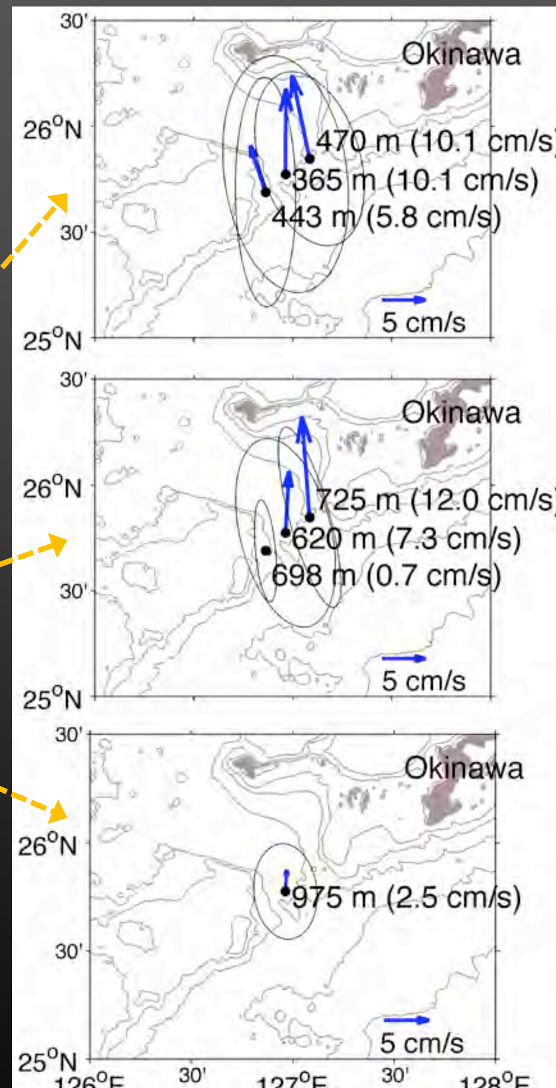
blue: CM (CM1, CM2, CM3), Year 1 (left), Year 2 (right)

The University of Rhode Island group was supported by the U.S. Office of Naval Research grant.
The Kagoshima University group was supported by JSPS KAKENHI grants.

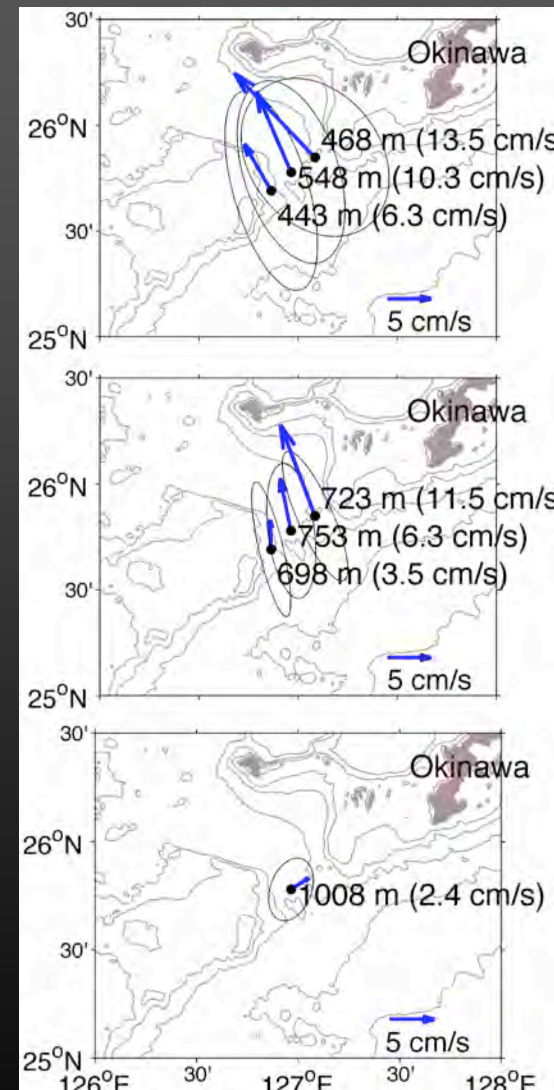
Mean currents and standard deviation ellipses from Current Meter (CM) measurements



Year 1



Year 2



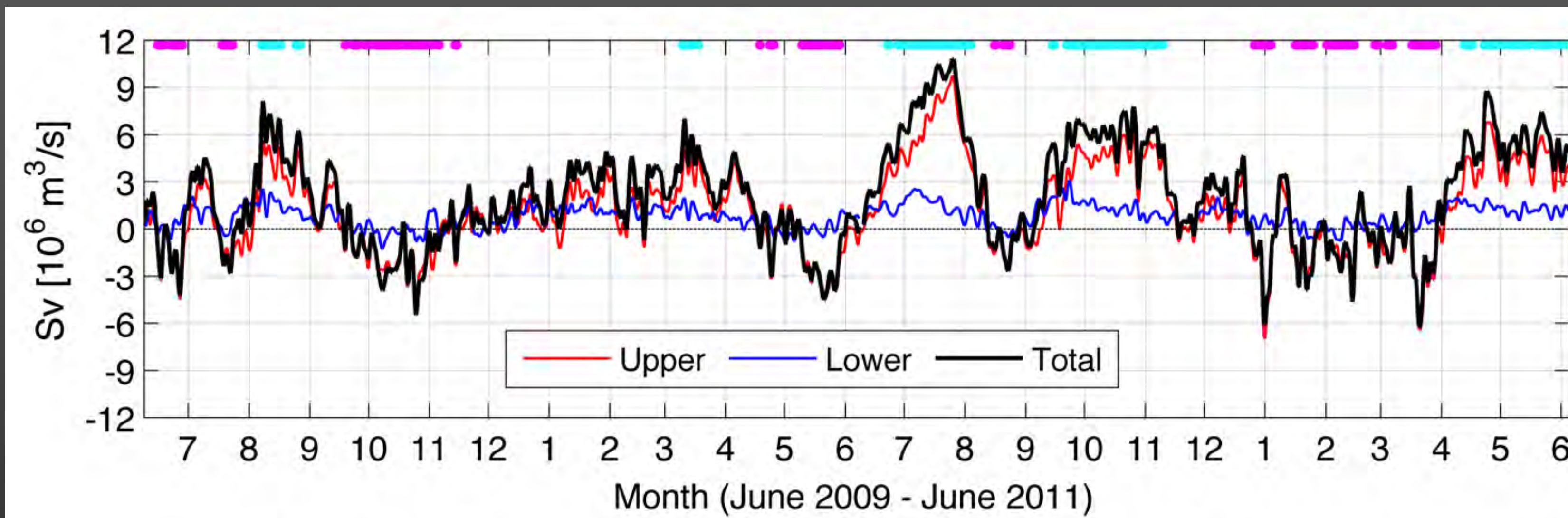
Top (~500 m)

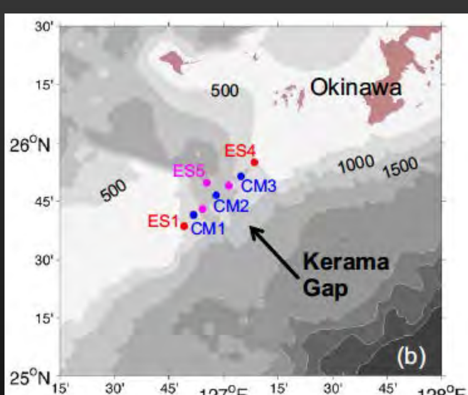
Middle (~700 m)

Bottom (~1000 m)

into the ECS and stronger toward the northeastern side of the Kerama Gap

Time series of volume transport (VT) through the Kerama Gap for 2 years

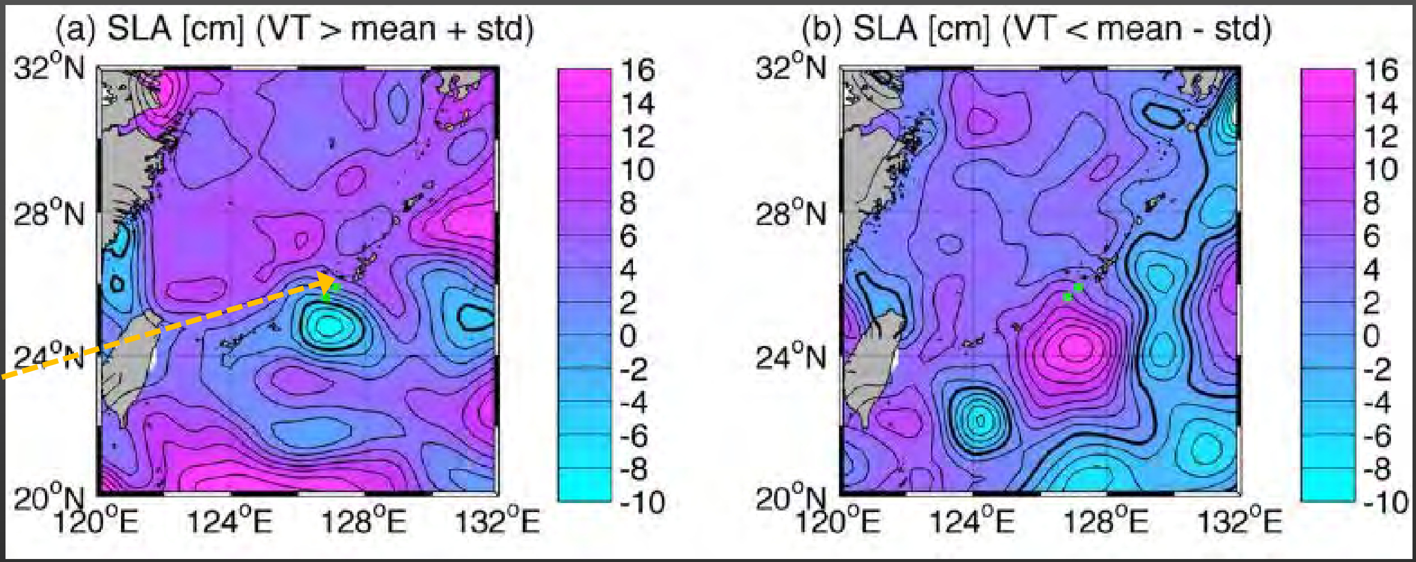




- mean: 2.0±0.7 Sv (+: into the ECS)
- sub-inertial standard deviation: 3.2 Sv (large temporal variability)
- spectral peak: about 100-day (mesoscale-eddy related)

Composite maps of Sea Level Anomalies (SLA) from satellite altimetry for the 2-year observation period

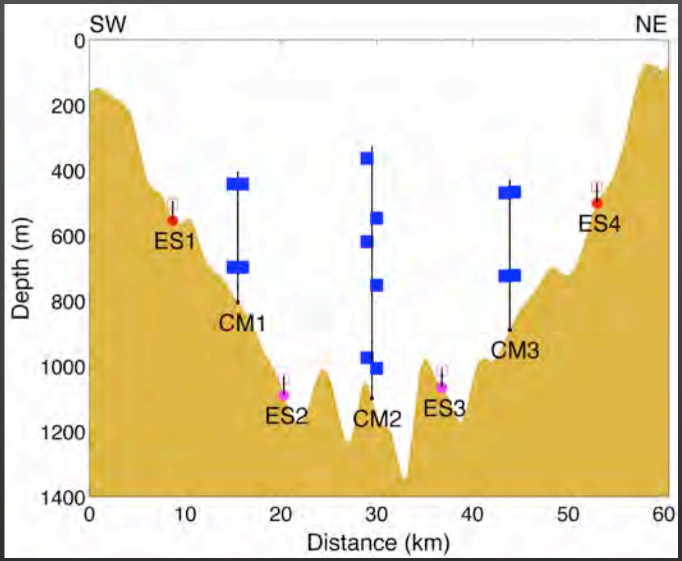
green dots:
Kerama Gap



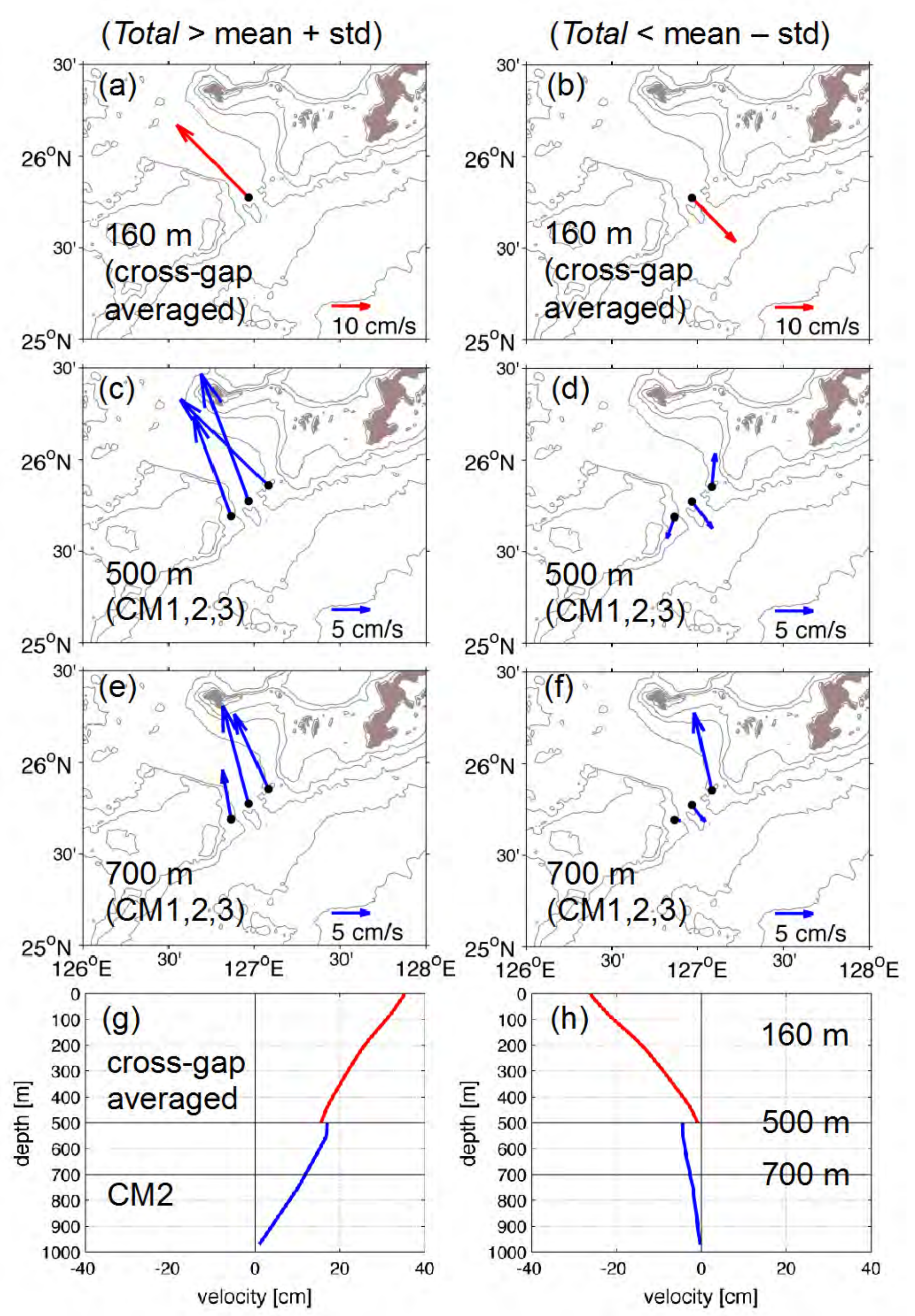
high VT (inflow into the ECS): negative sea level anomalies (cyclonic eddies)

low VT: positive sea level anomalies (anticyclonic eddies)

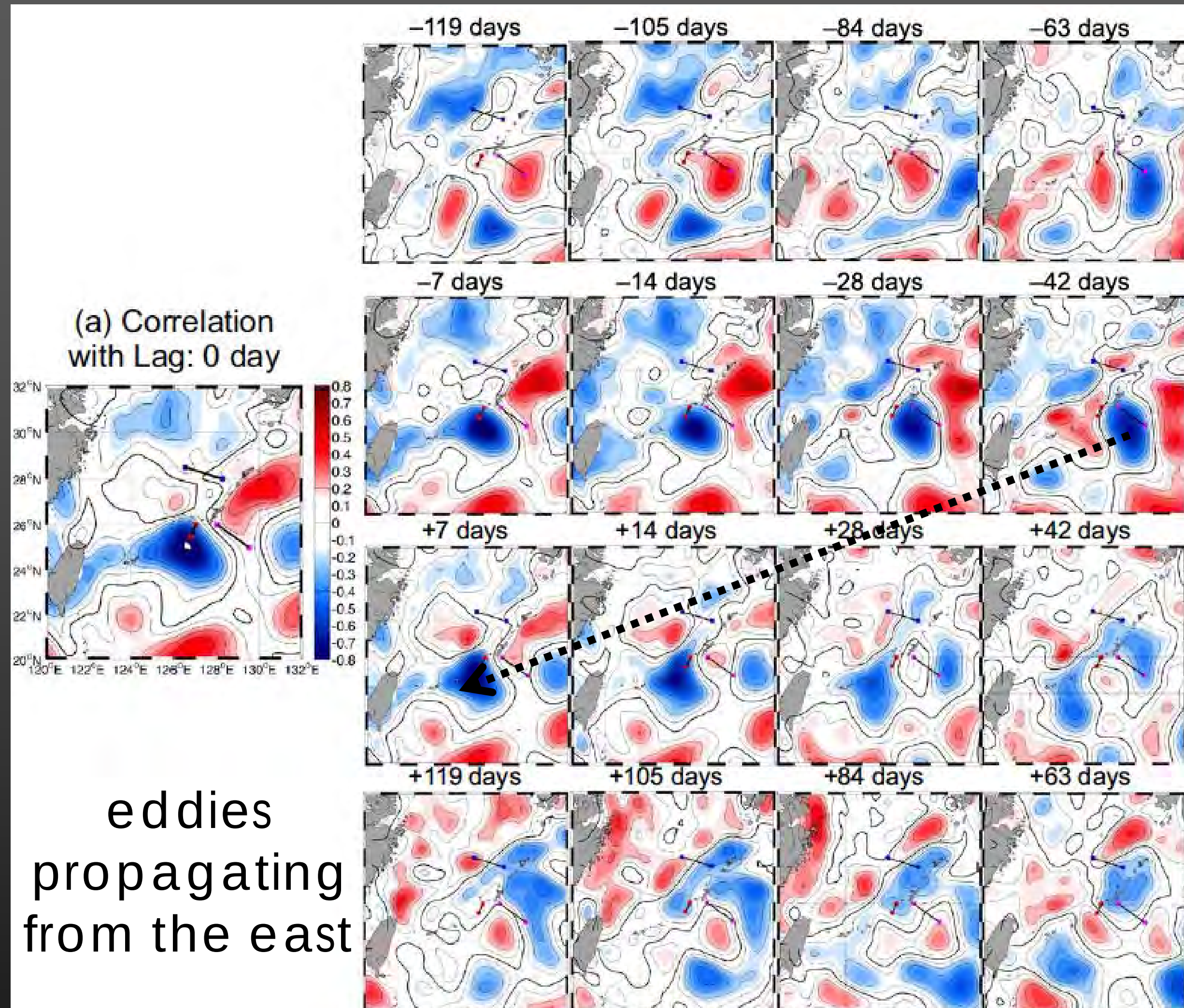
2-year observation composites



During times of high transport into the ECS currents at 160, 500, and 700 m are all into the ECS.

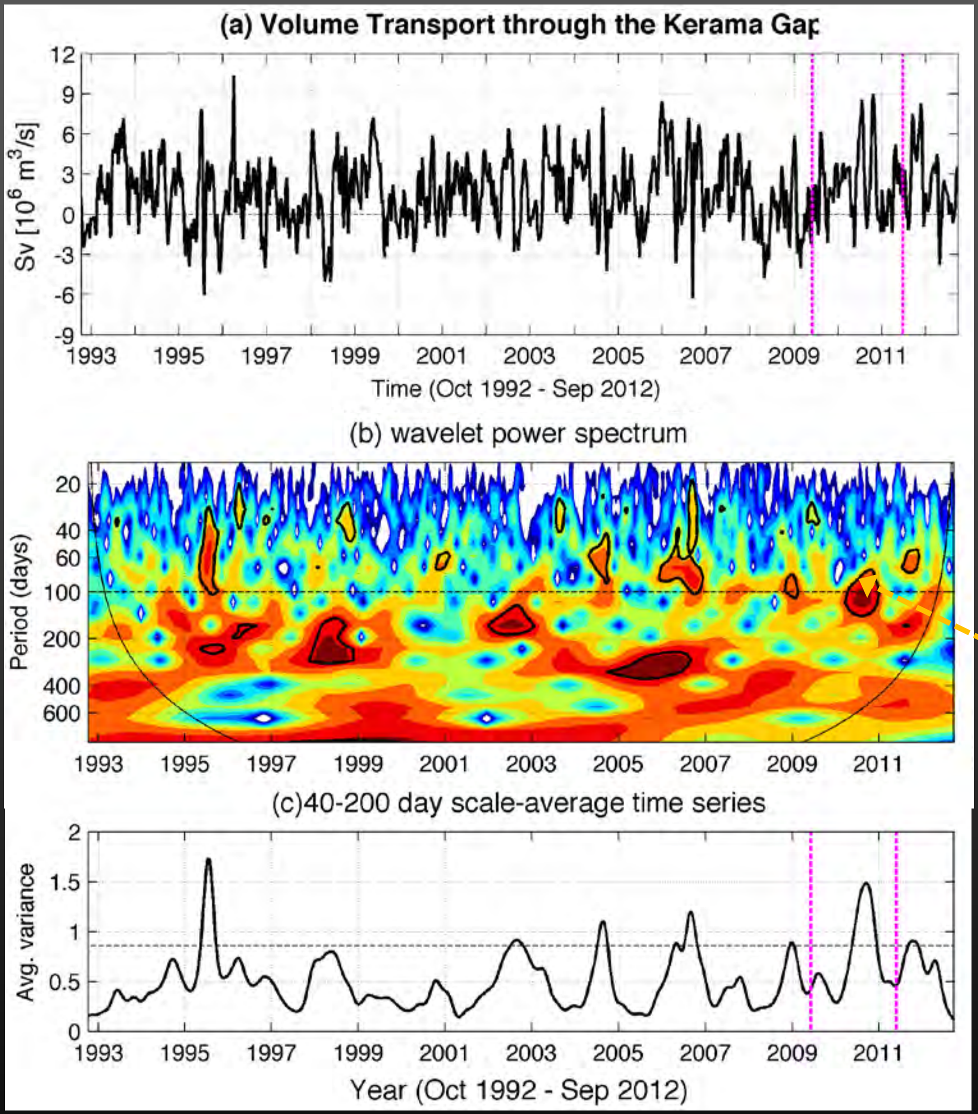


Lag correlations between Kerama Gap transport and sea level anomalies for the **2-year observation period**



cyclonic/ anticyclonic eddies → Ryukyu VT → Kerama Gap VT → SLA in the ECS → ECS-Kuroshio VT

20-year time series of the Kerama Gap transport



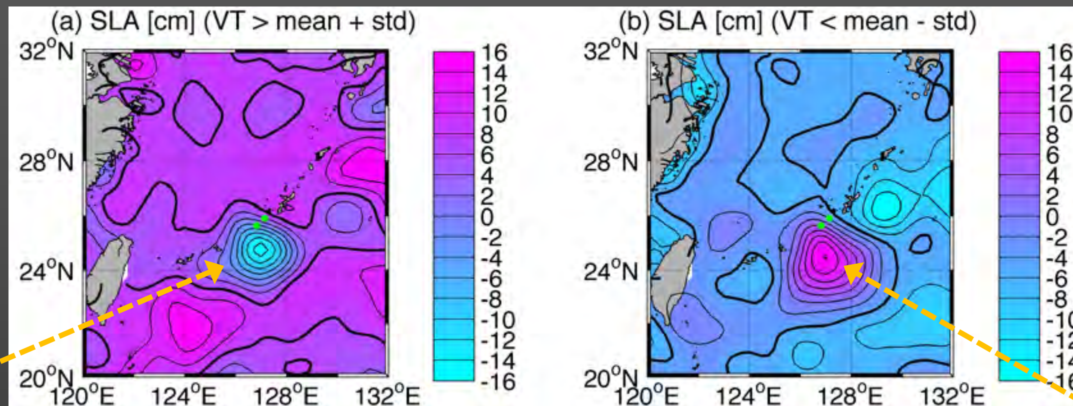
[Sv]	mean	standard deviation (7-day interval)
20 years	1.5 ±0.2	2.6
2-year observation period	2.1 ±0.5	2.5

variance on the mesoscale-eddy related period (40–200 day) exhibits strong interannual to decadal variability

Positive and negative composites of SLA and geostrophic currents (20-year)

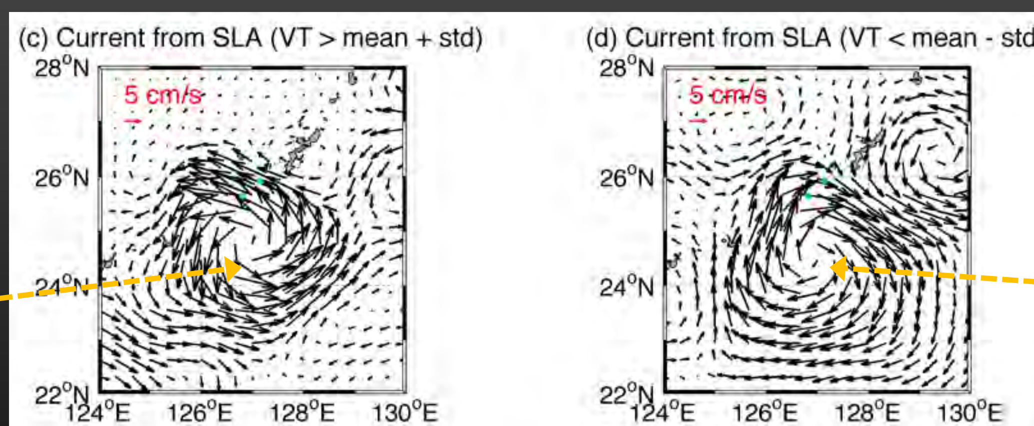
positive composite

negative composite



negative sea level anomalies & cyclonic eddies

positive sea level anomalies & anticyclonic eddies



Although the mesoscale variability exhibits strong interannual to decadal variability, the relationship between the Kerama Gap transport and the eddies is consistent throughout the 20 years.

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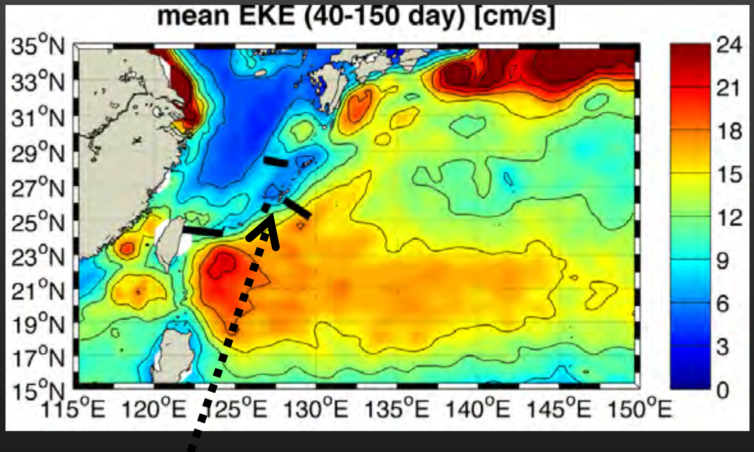
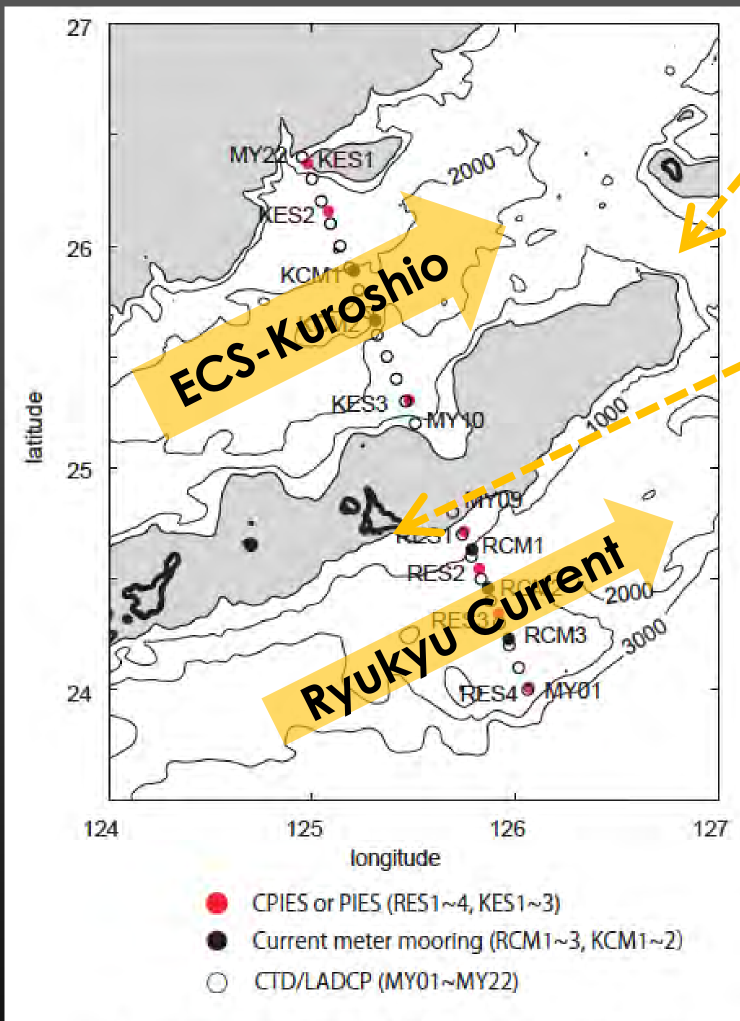


- Observation at the Kerama Gap

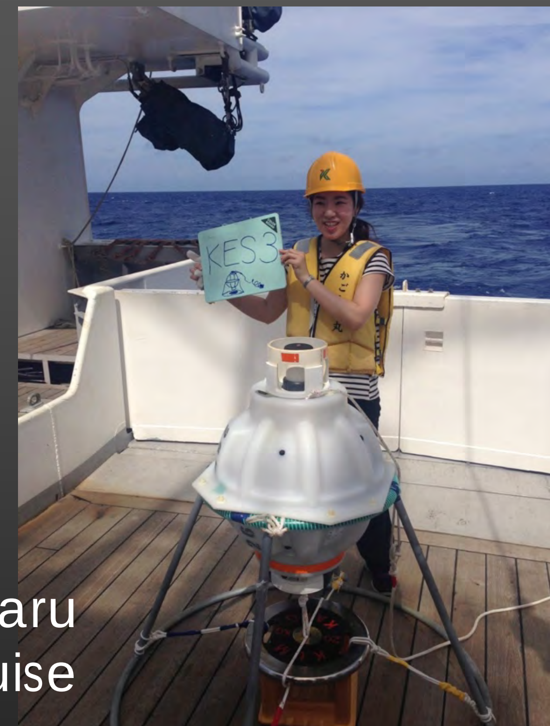
Joint Kuroshio and Ryukyu Current System Study (JKRYCSS)



Ryukyu Current and Kuroshio measuring arrays

Kerama Gap

Miyakojima



Karoghima-maru cruise

mooring arrays of PIES, CPIES, current meters and ADCP to measure the ECS-Kuroshio and the Ryukyu Current simultaneously (June 2015–June 2017)

Thank you!

hanna@kiost.ac.kr; http://hanna-ocean.net

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