Using remote sensing from *below* (and above) to study the dynamics of the PAMS region

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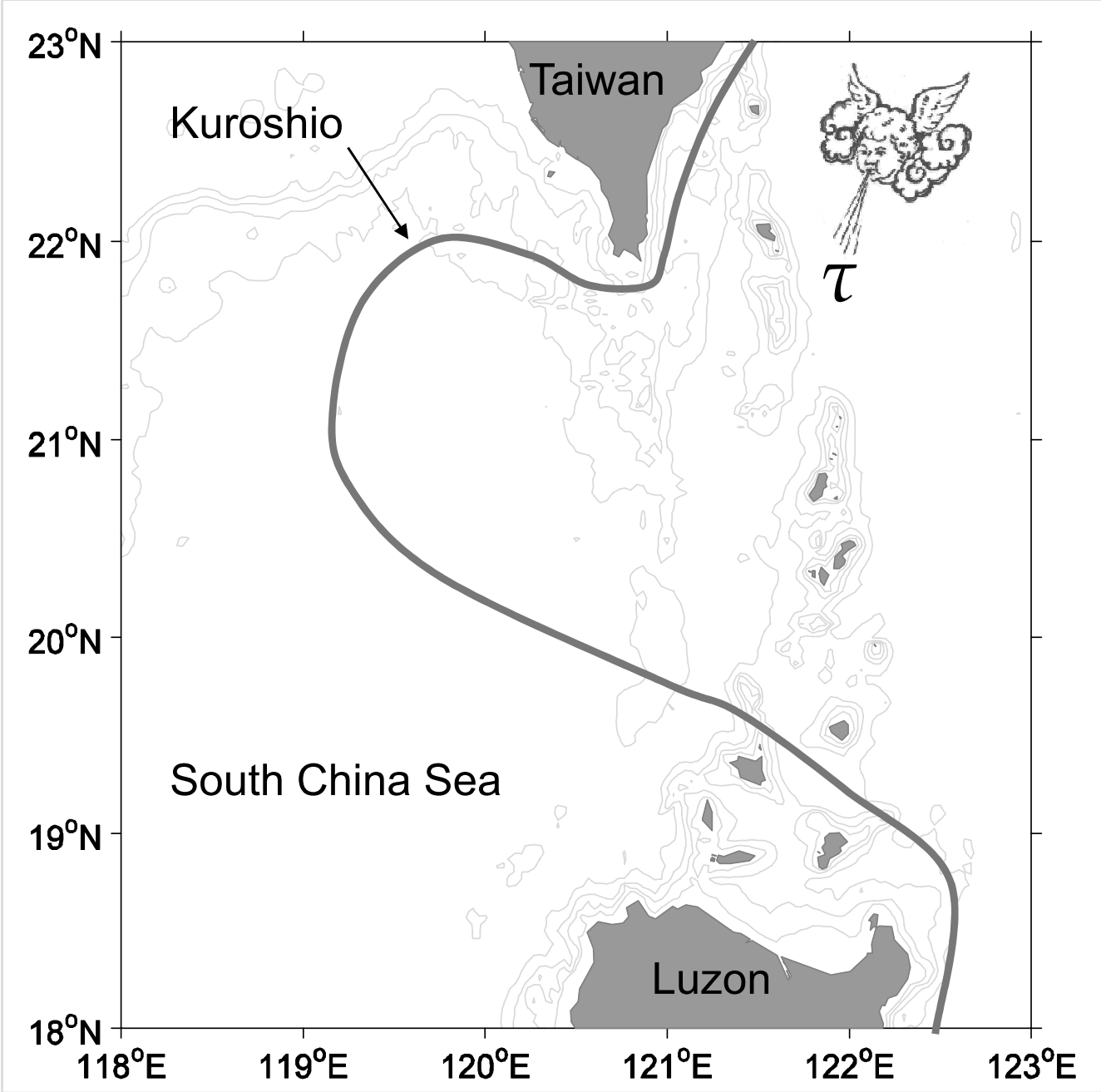
and many others.

Main objectives of the talk:

- Give an overview of PAMS region research in which I have been involved during the past two decades.
- Explain the effectiveness and versatility of the Inverted Echo Sounder (“IES”) as a research instrument for PAMS region research.

Kuroshio Loop Current in the SCS



Loop-current stage **(determined from satellite SST images)**

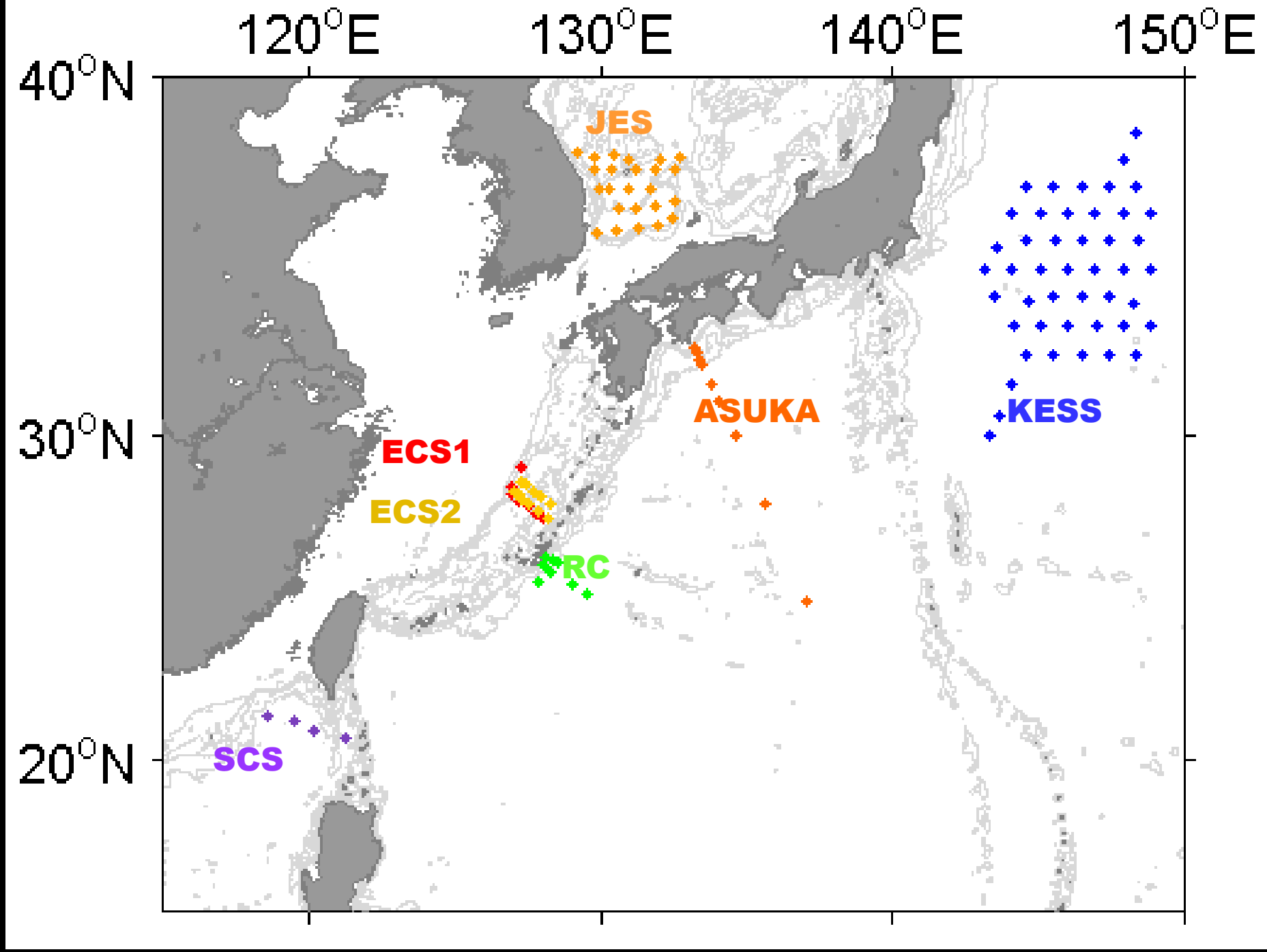
$$\Omega(t) = \int_{t_c}^{t} \Re_{1/2}(\tau - \tau_c)\,dt$$

Time since mean τ over past 4 days was $< \tau_c$

Critical wind stress

Half-wave rectifier function

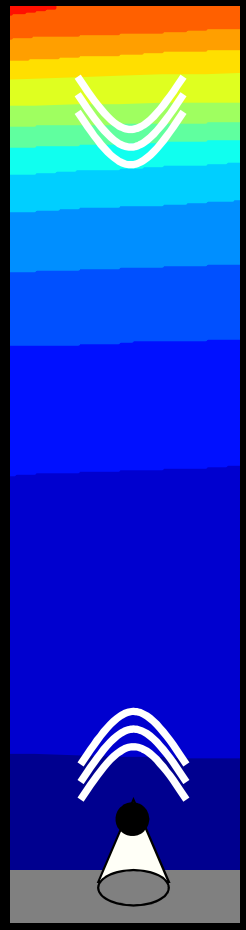
Farris & Wimbush (1996)



IES arrays in the PAMS region

Inverted Echo Sounder (IES) operation

IES

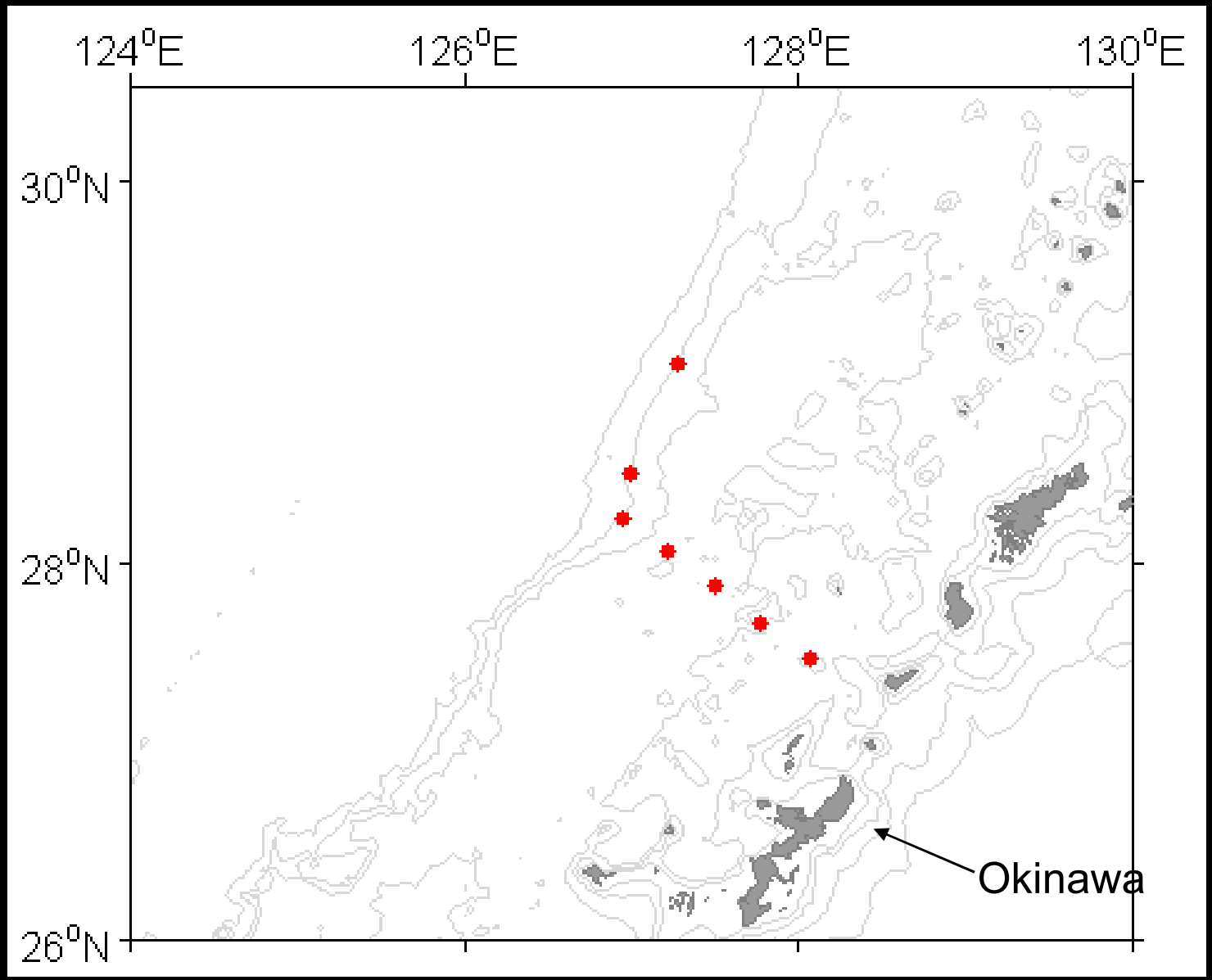


12kHz acoustic echo time

IES enhancements:

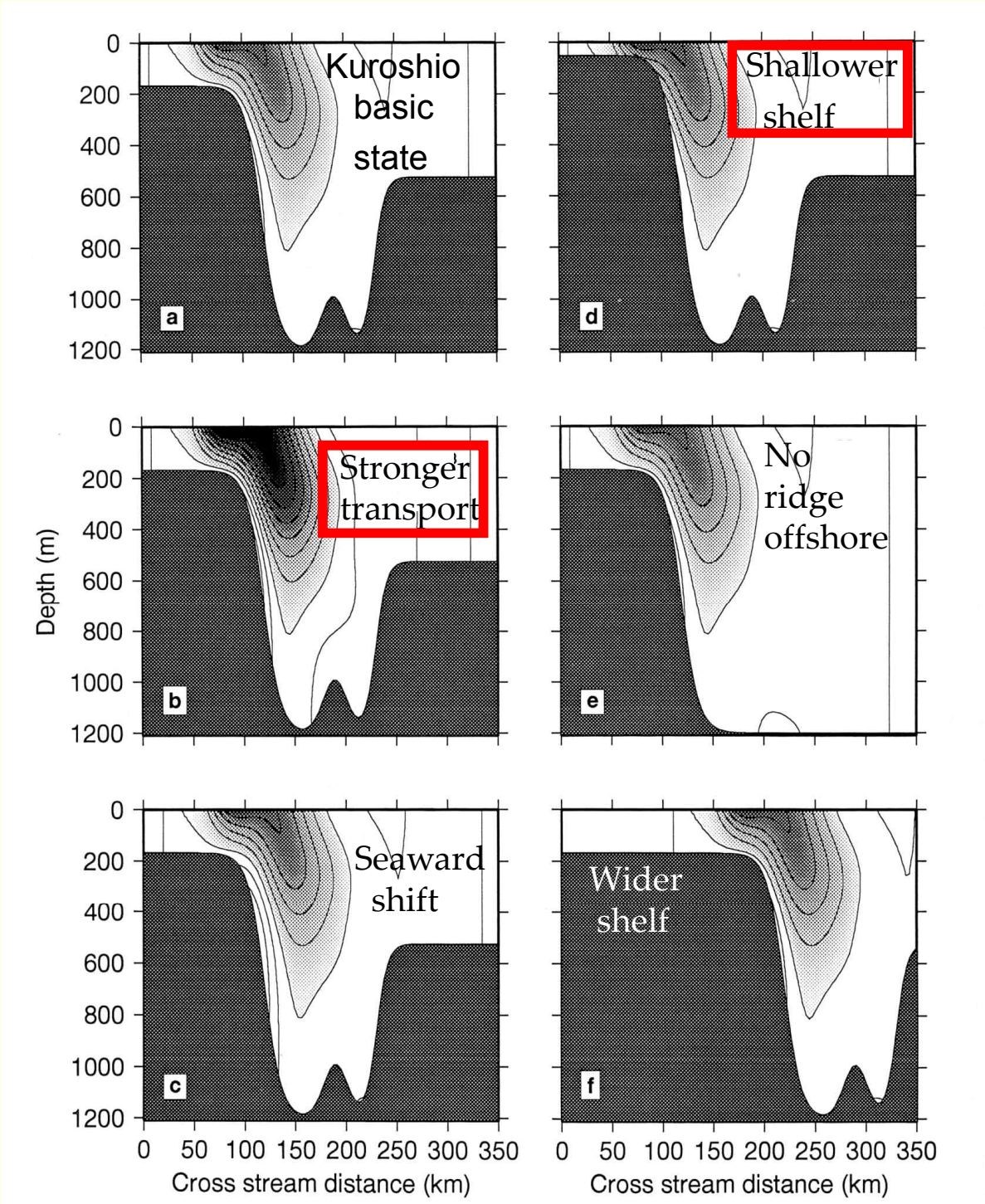
- IES + Pressure sensor = “PIES”
- PIES + Current sensor = “CPIES”

ECS1 PIES array (1991-92)



ECS1 Results

- Persistent Kuroshio meanders with **period 11 days**, propagating downstream at **phase speed 20 km/day.**
- Kuroshio meanders compared with Gulf Stream off the southeast U.S. (Xue & Mellor, 1993):
  - **meander period = 2 × Gulf Stream value**
  - **meander phase speed = ½ × Gulf Stream value.**
- Why these differences?
  Investigated with a **numerical model**.

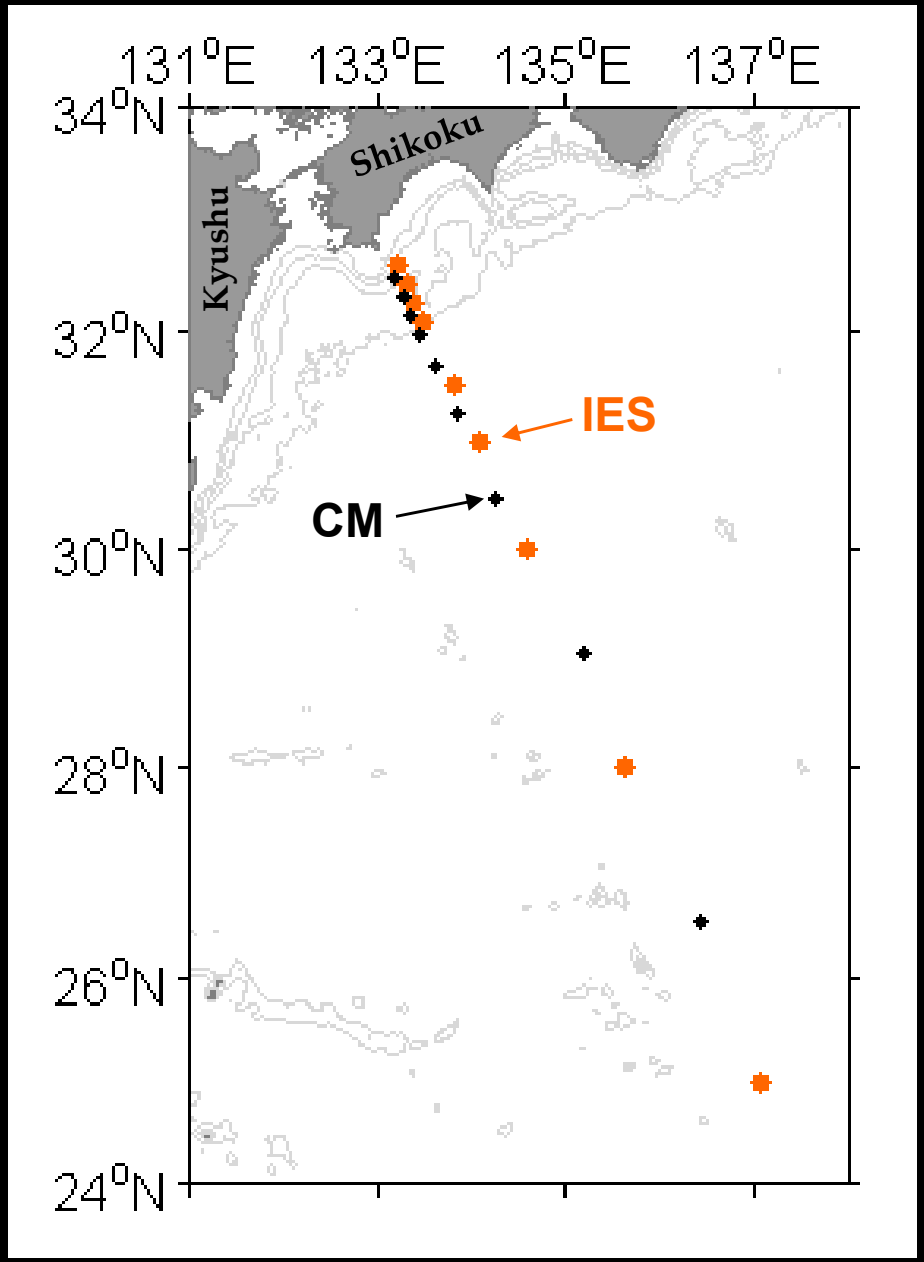


ECS-Kuroshio velocity cross-sections

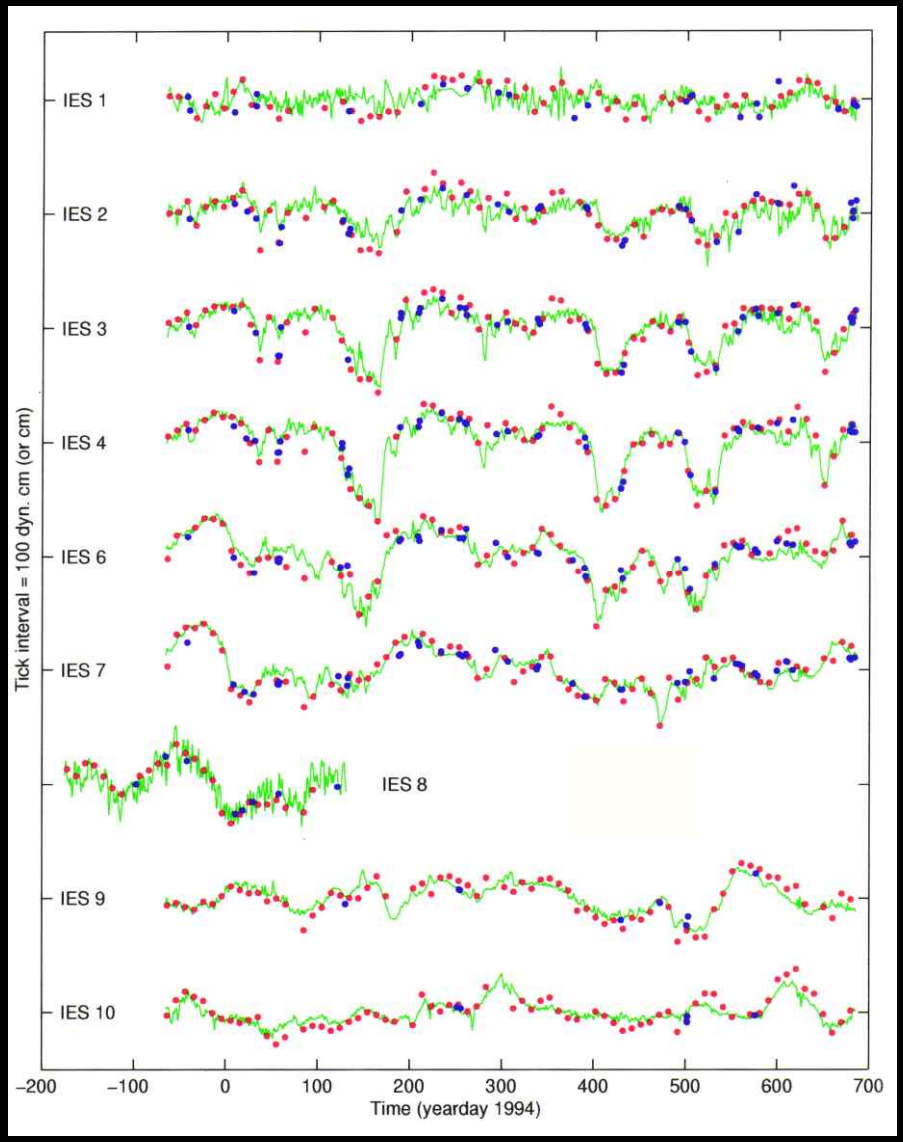
(0.2 m/s contours)

James et al. (JPO, 1998)

ASUKA line IES array (1993-95)

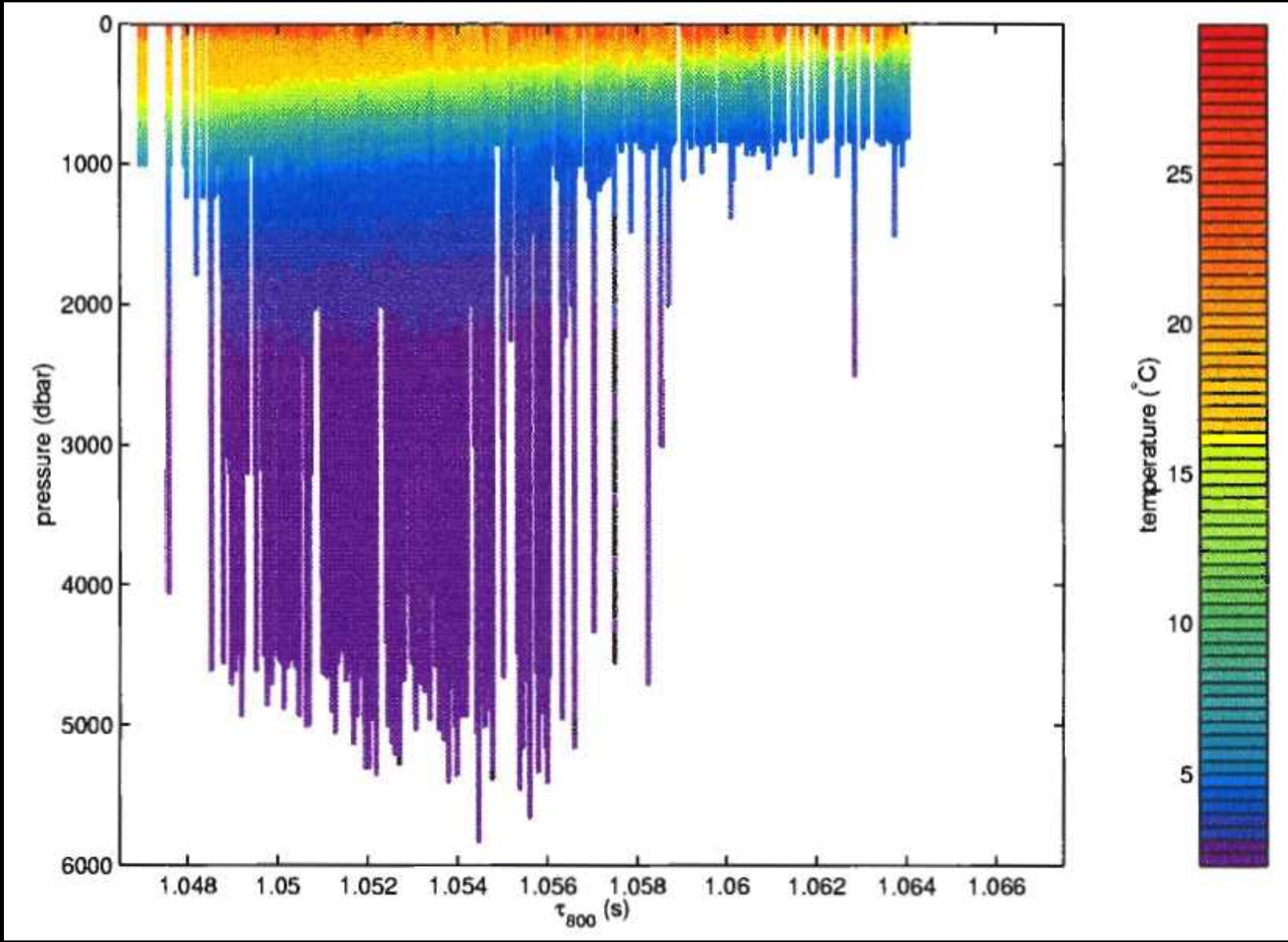


ASUKA line comparisons



- TOPEX/Poseidon
- CTD/XBT
- IES

Developing the Gravest Empirical Mode (GEM)



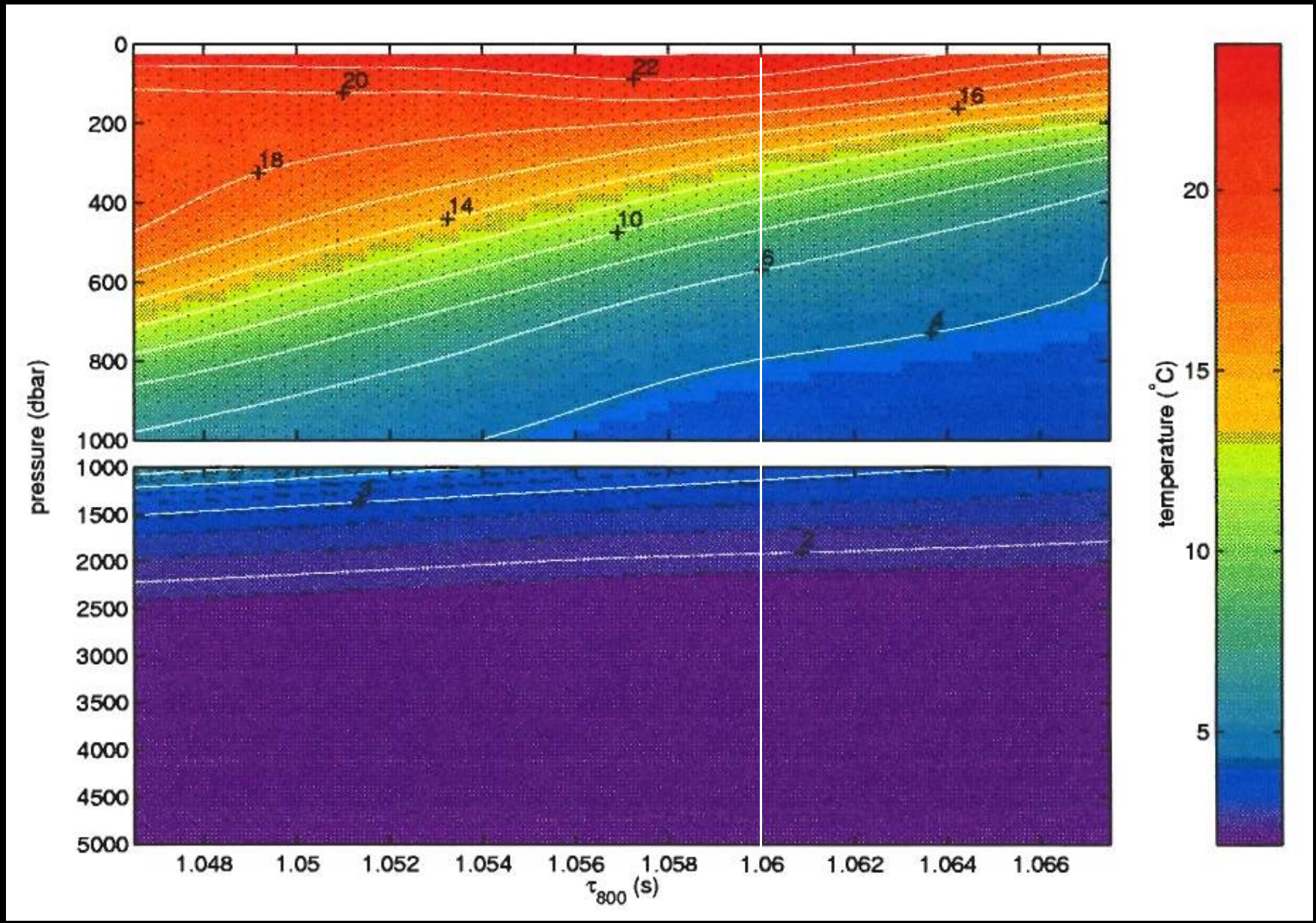
Hydrocast $T(z)$ profiles, positioned according to τ computed from the hydrocast data.

Acoustic echo time

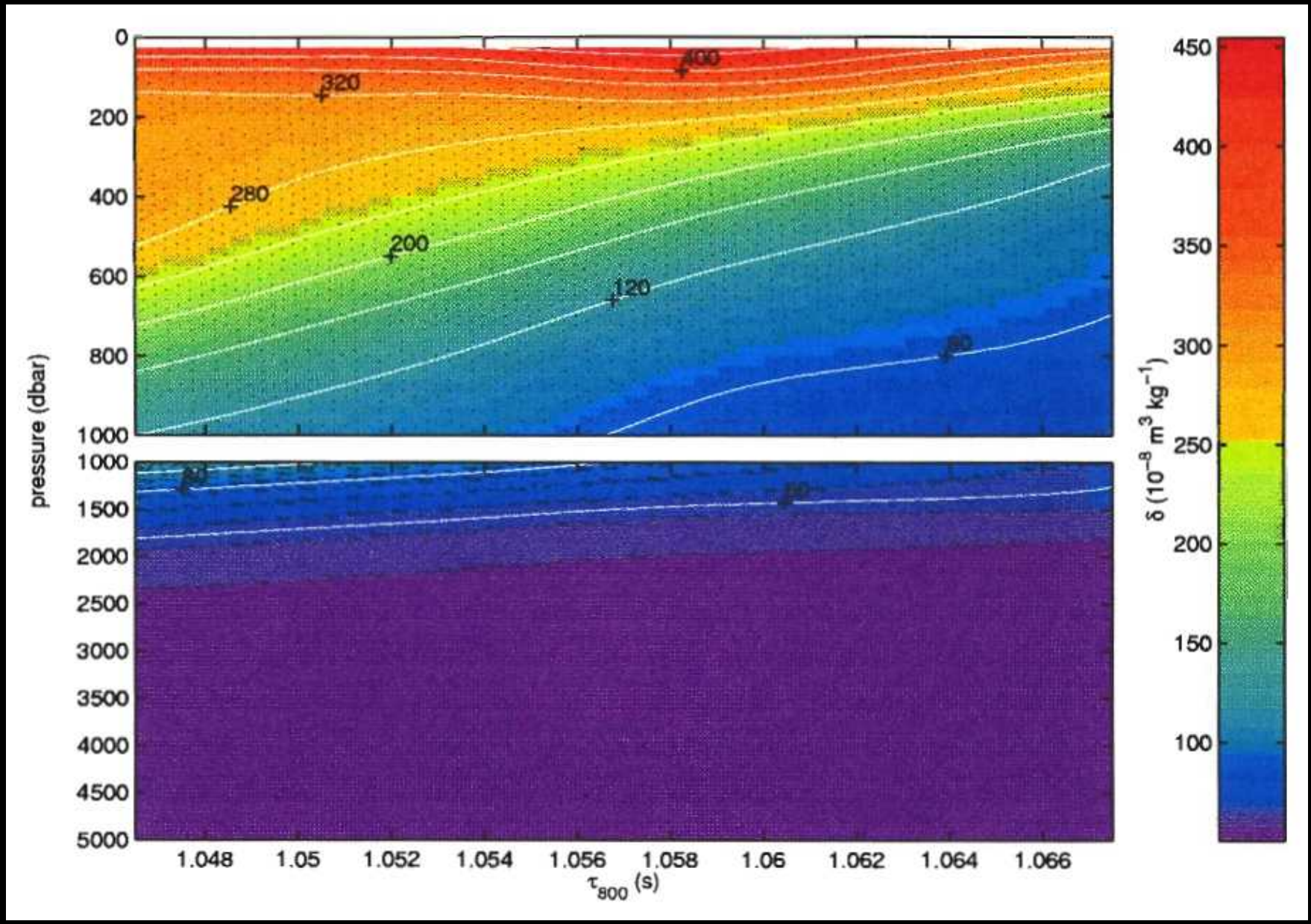
$$\tau = 2 \int_{z_{bottom}}^{z_{surface}} \frac{dz}{c(z)}$$

X-axis = τ, *Y*-axis = pressure, Color = *T* (temperature)

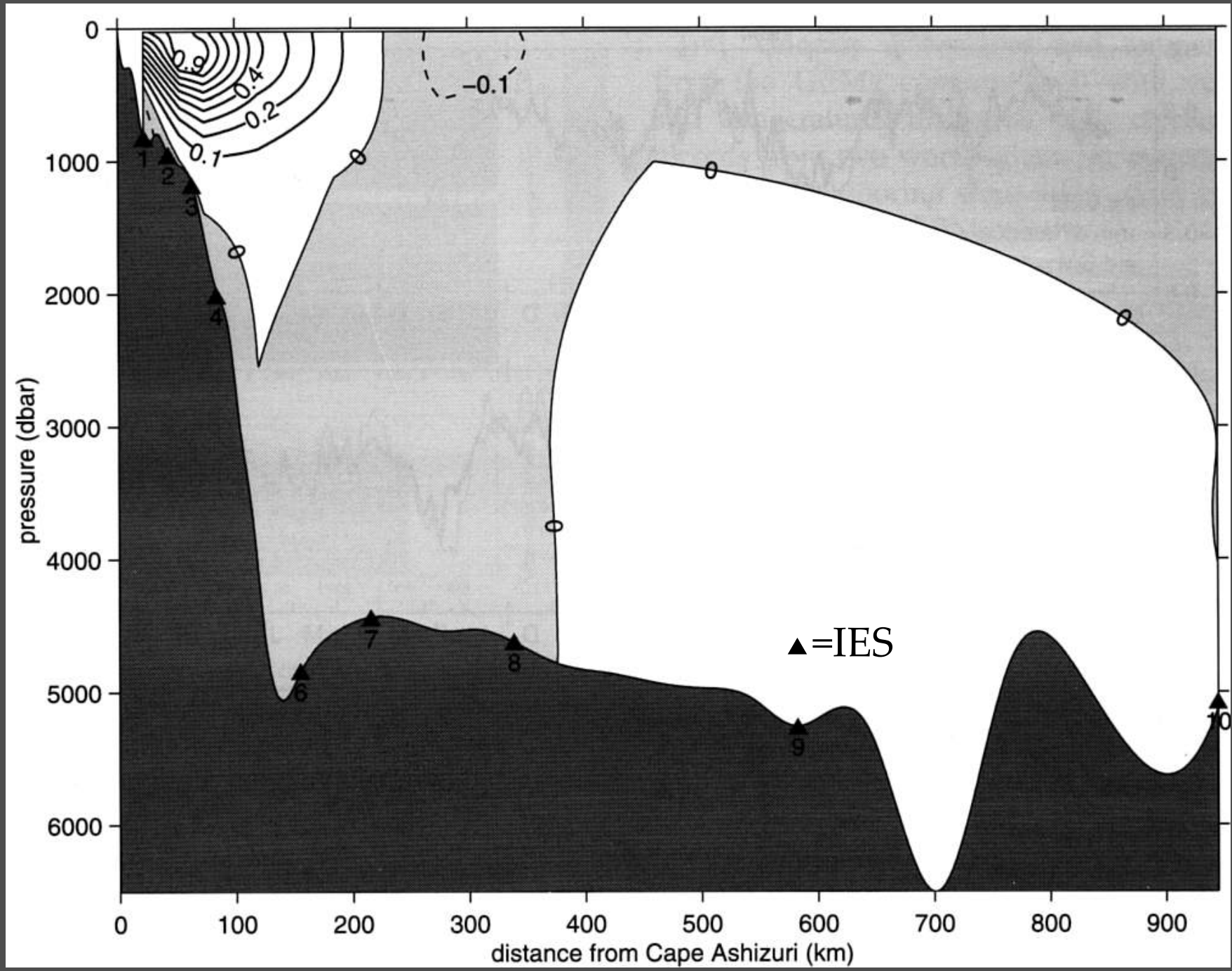
ASUKA Temperature GEM



ASUKA Specific-volume-anomaly GEM

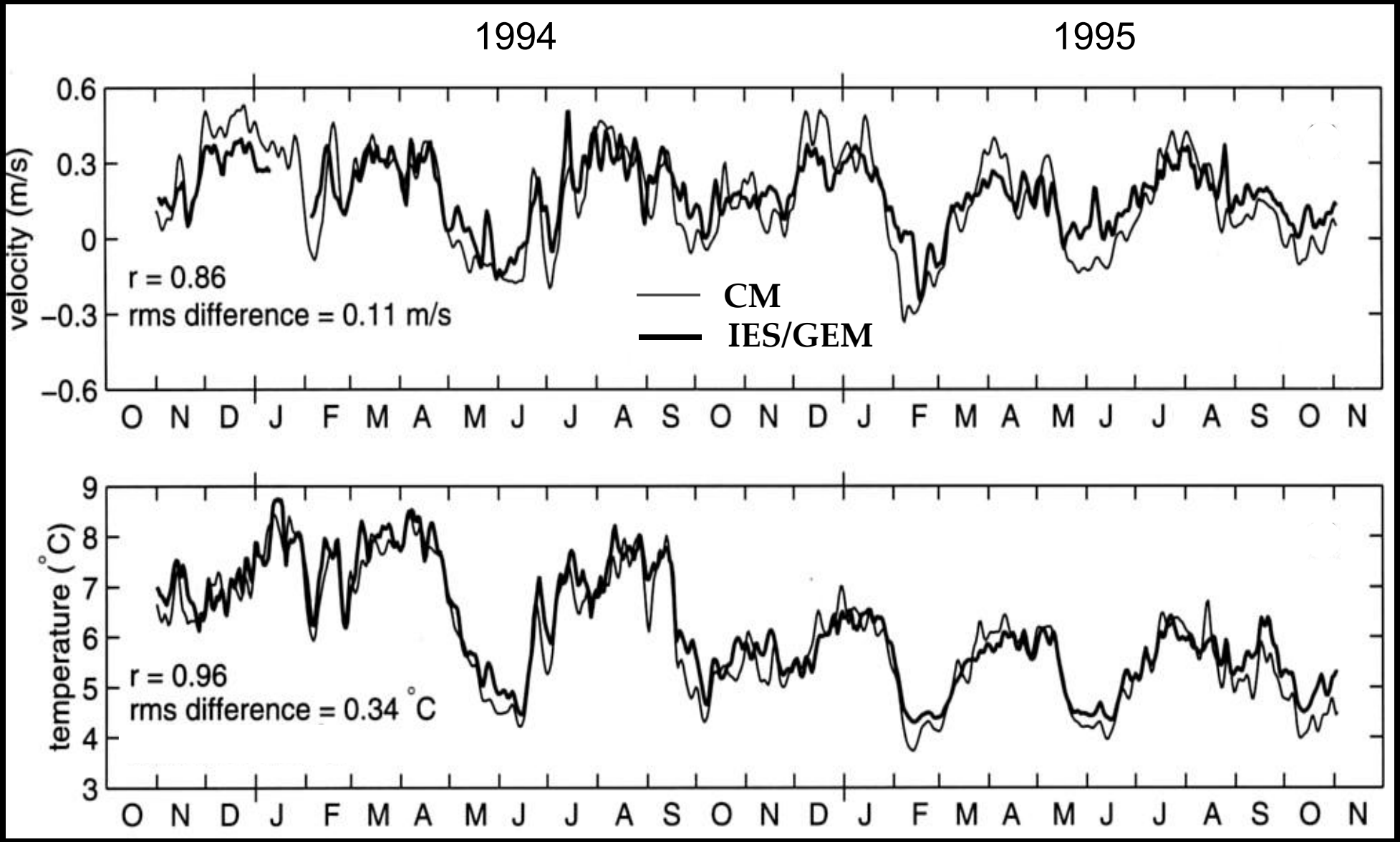


ASUKA line mean velocity cross-section (m/s)



Book et al. (JGR, 2002)

Comparison of directly-measured and IES/GEM-determined quantities at ~650 m depth: **Current Velocity** (top), **Temperature** (bottom)

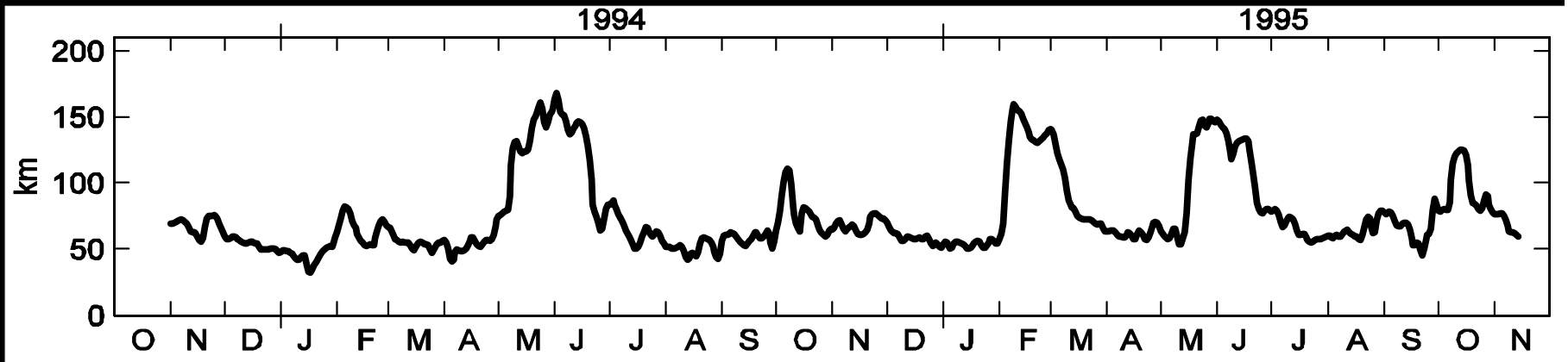


Book et al. (JGR, 2002)

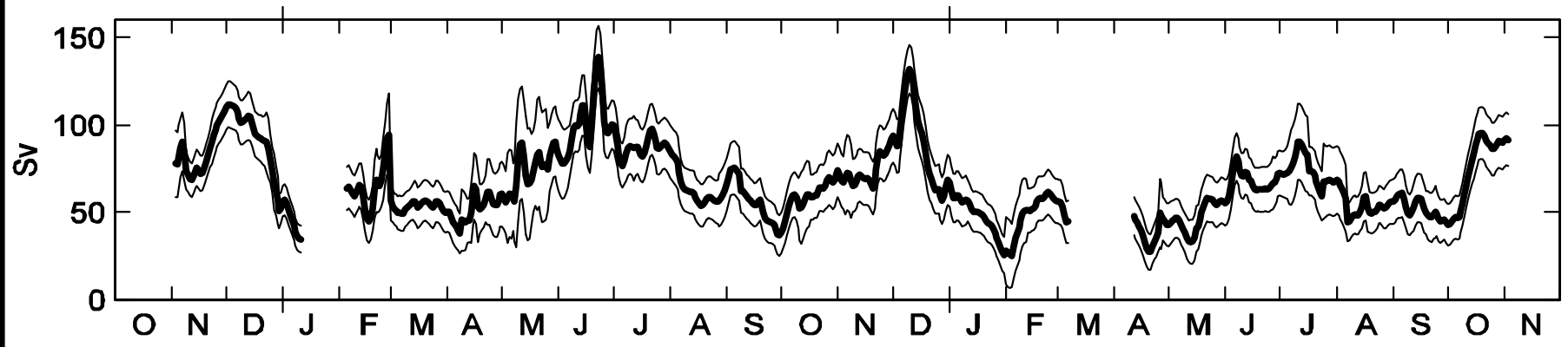
Kuroshio at the ASUKA line

Core position

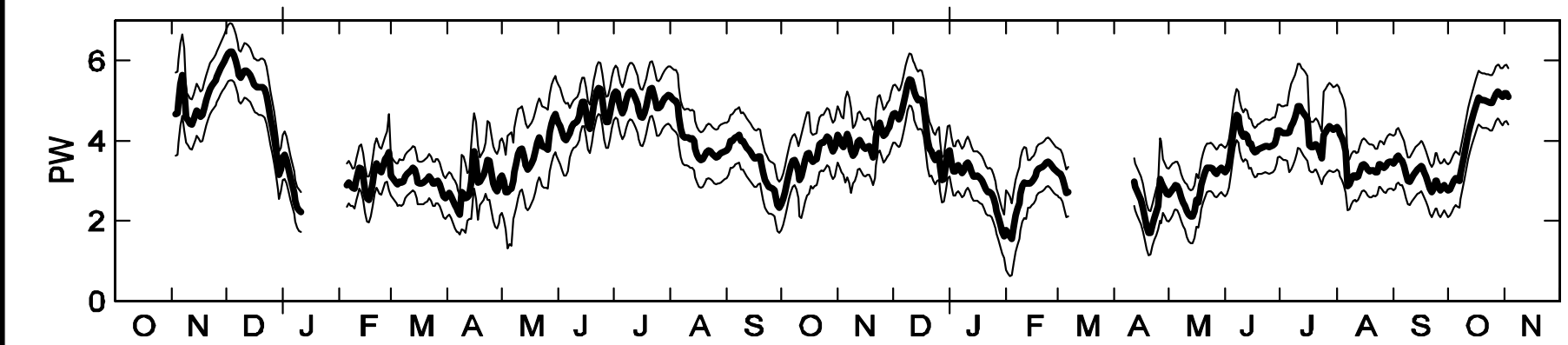
15˚C @ 300m



Volume transport

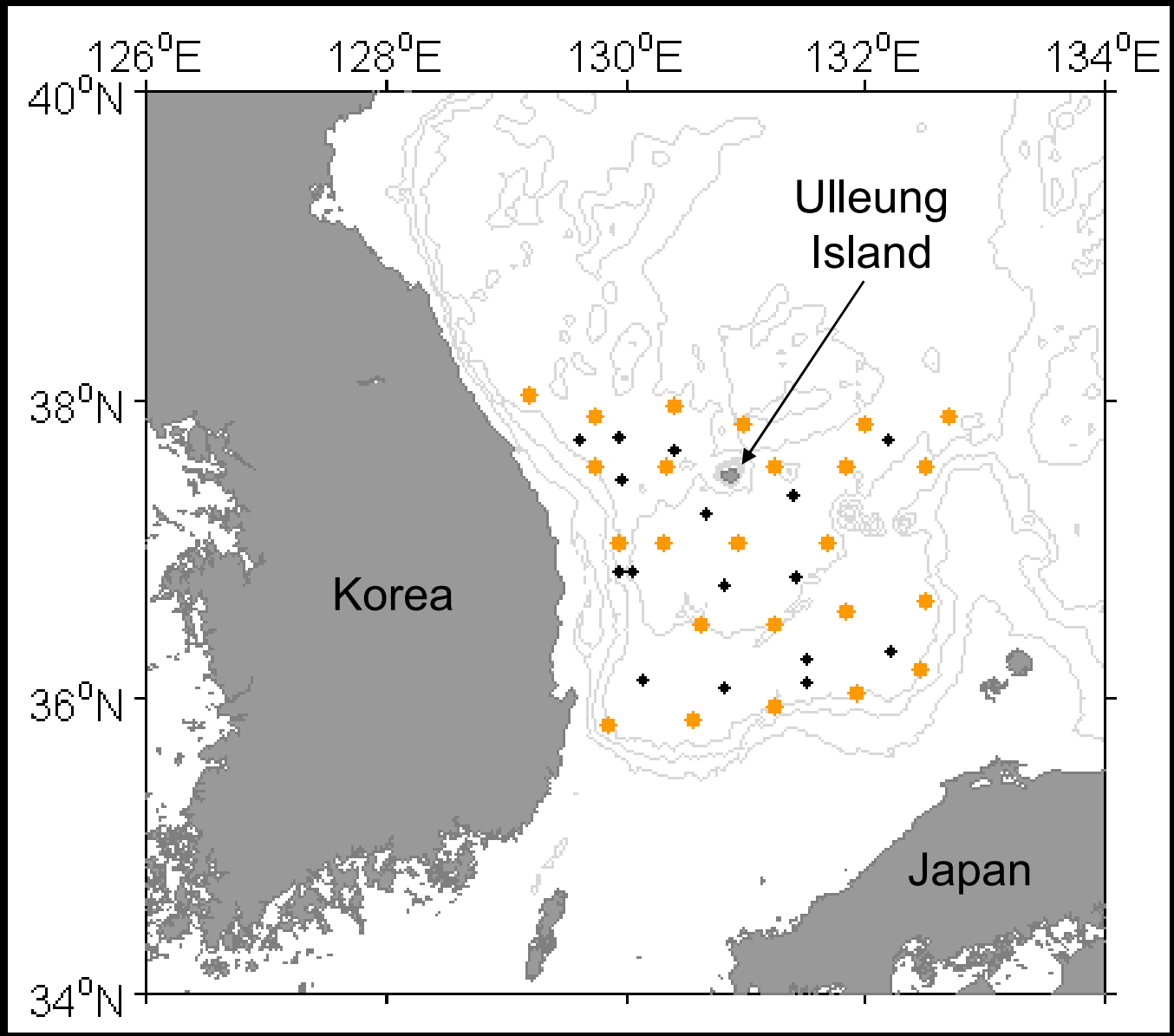


Temperature transport



Book et al. (JGR, 2002)

JES PIES array (1999-2001)



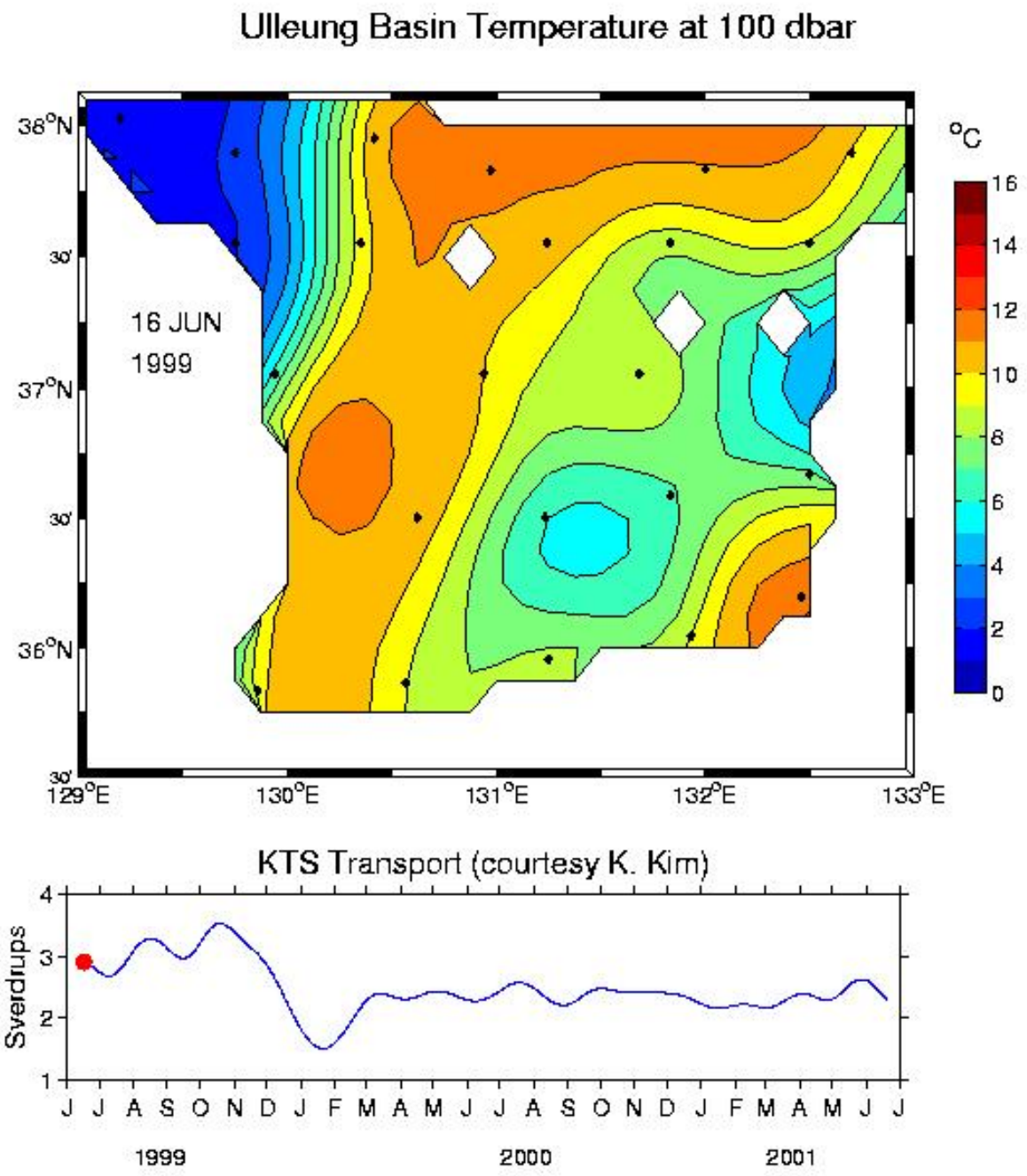
Principal results of JES study:

Obtained $4-\mathrm{d}$ fields of $T(x,y,z,t)$ and $\vec{U}(x,y,z,t)$ allowing us to study mean and variability of

- deep (sub-thermocline) circulation

- upper-layer circulation, including
  - East Korean Warm Current
  - Ulleung Warm Eddy
  - Offshore Branch (near Japan shelf-break)
  - Dok Cold Eddy

  E.g., movie of $T(x,y,t)$ at z = 100 m depth . . . . . .

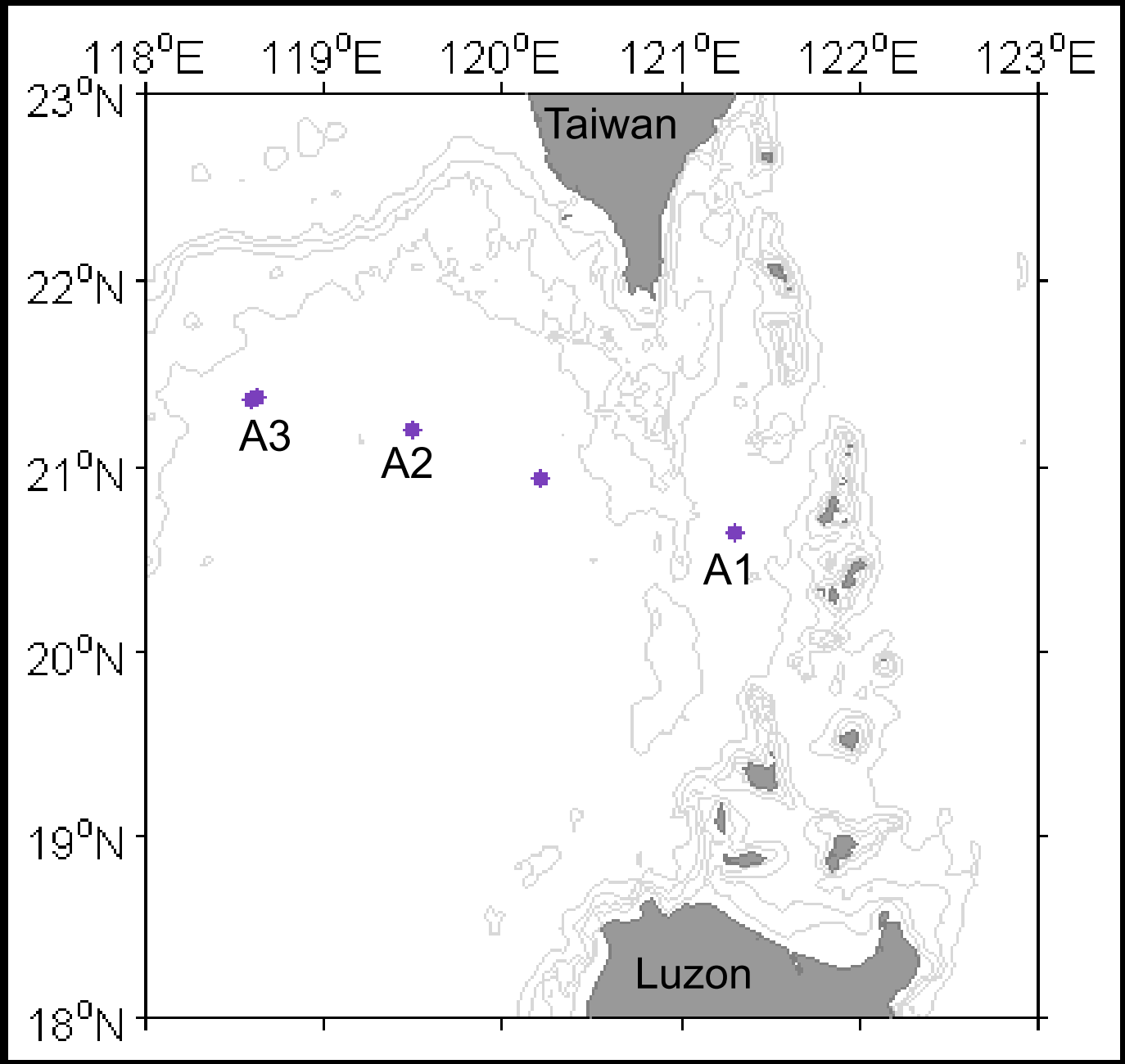

Ulleung Basin Temperature at 100 dbar
38°N
30'
37°N
30'
36°N
30'
129°E
130°E
131°E
132°E
133°E
16 JUN
1999
°C
16
14
12
10
8
6
4
2
0
KTS Transport (courtesy K. Kim)
Sverdrups
4
3
2
1
J J A S O N D J F M A M J J A S O N D J F M A M J J
1999
2000
2001

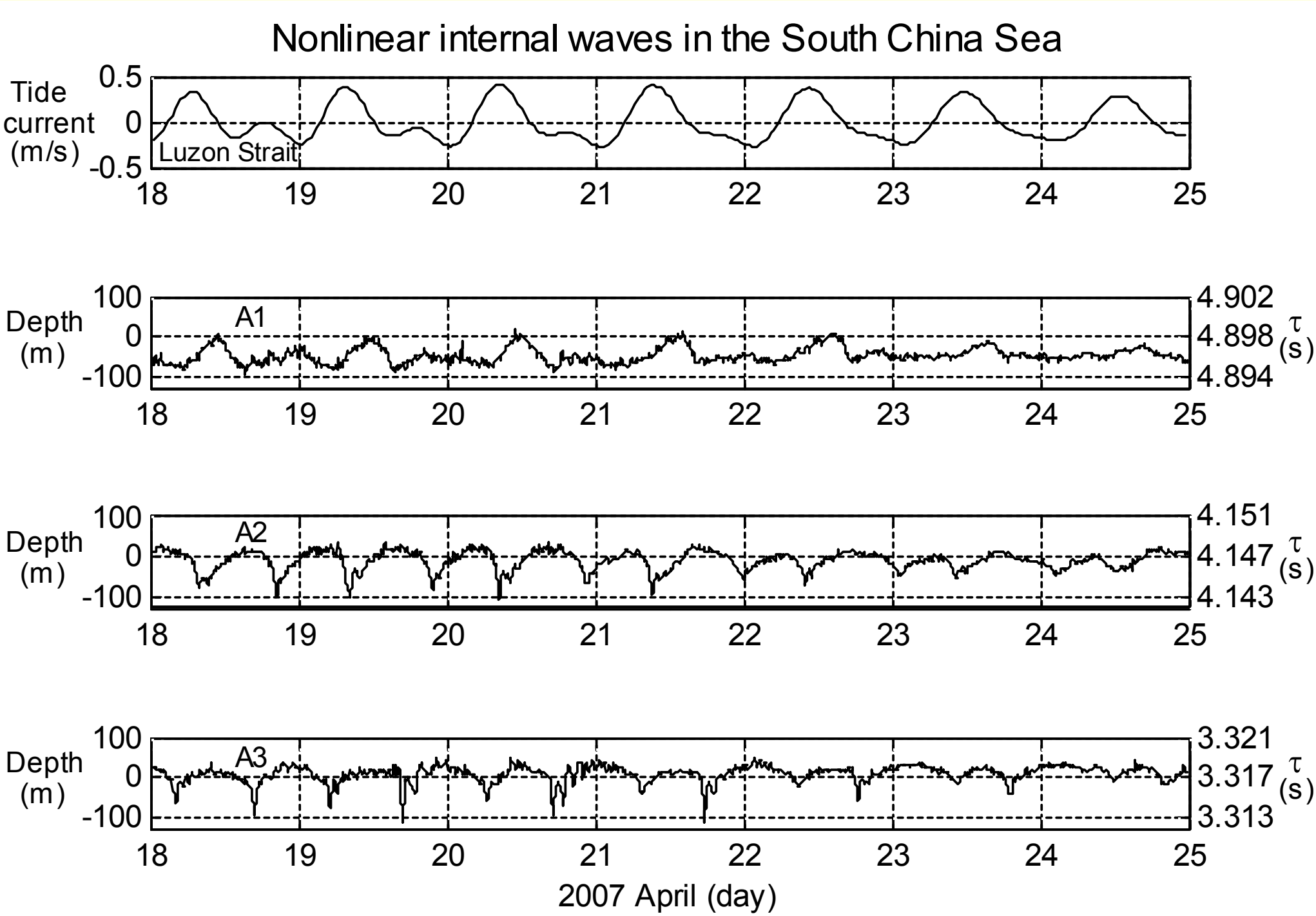
- Such a 4-d data set (lasting 2 years) of temperature and current fields permits the study of *many* processes.

- For example, PIES sampling was at $\Delta t = 1$ hour, allowing study of higher-frequency JES phenomena:
  - distribution of near-inertial internal-wave energy
  - propagation of internal and surface tides
  - resonance oscillations of the JES.

- Another example of PIES high-frequency sampling: a study of internal solitons in the SCS ($\Delta t = 1$ hour) . . .

SCS PIES array 2005, 2007

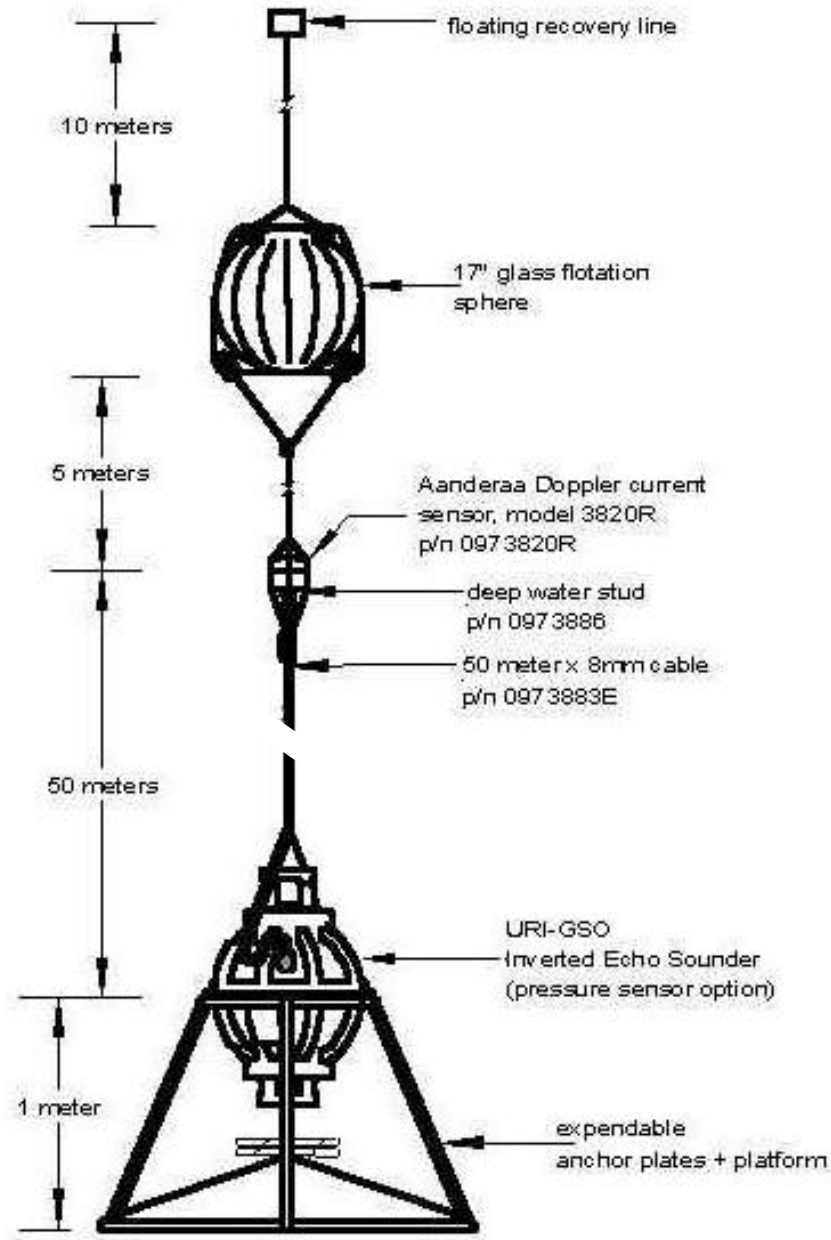




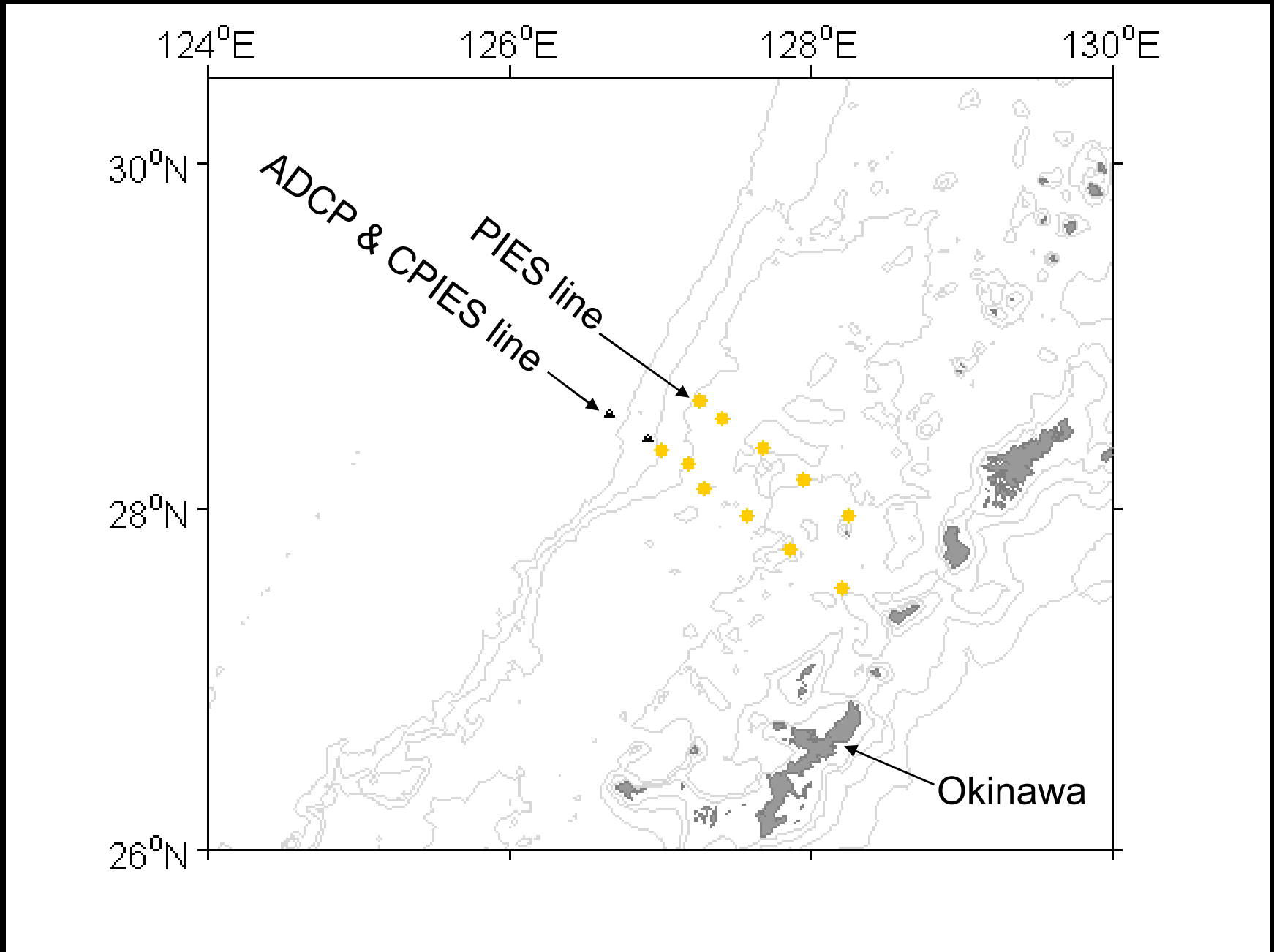
Farmer et al. (Atmosphere-Ocean, in review)

CPIES – Current and
Pressure recording
Inverted Echo Sounder

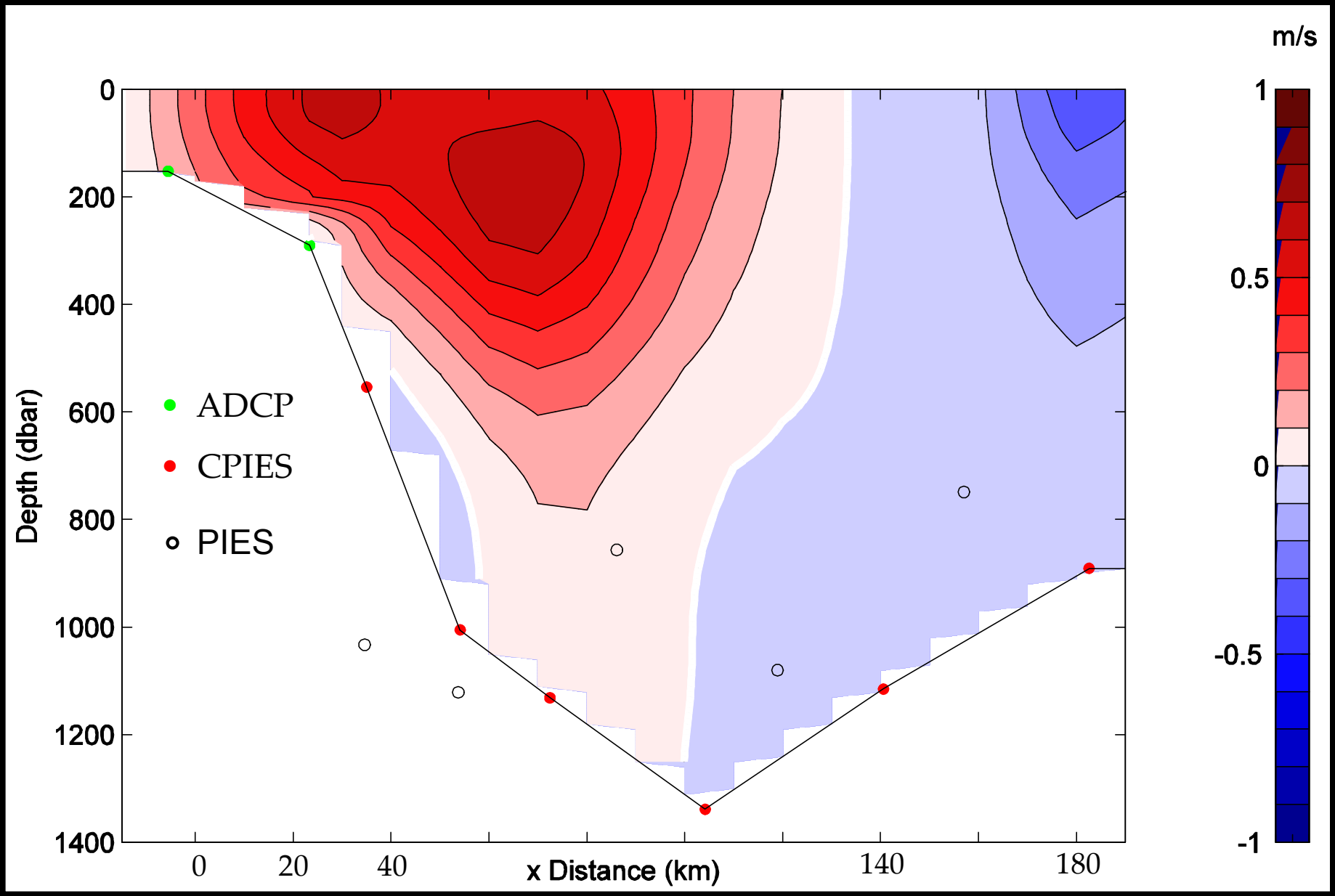
(has acoustic
telemetering
capability)



ECS2 CPIES+PIES array 2002-04

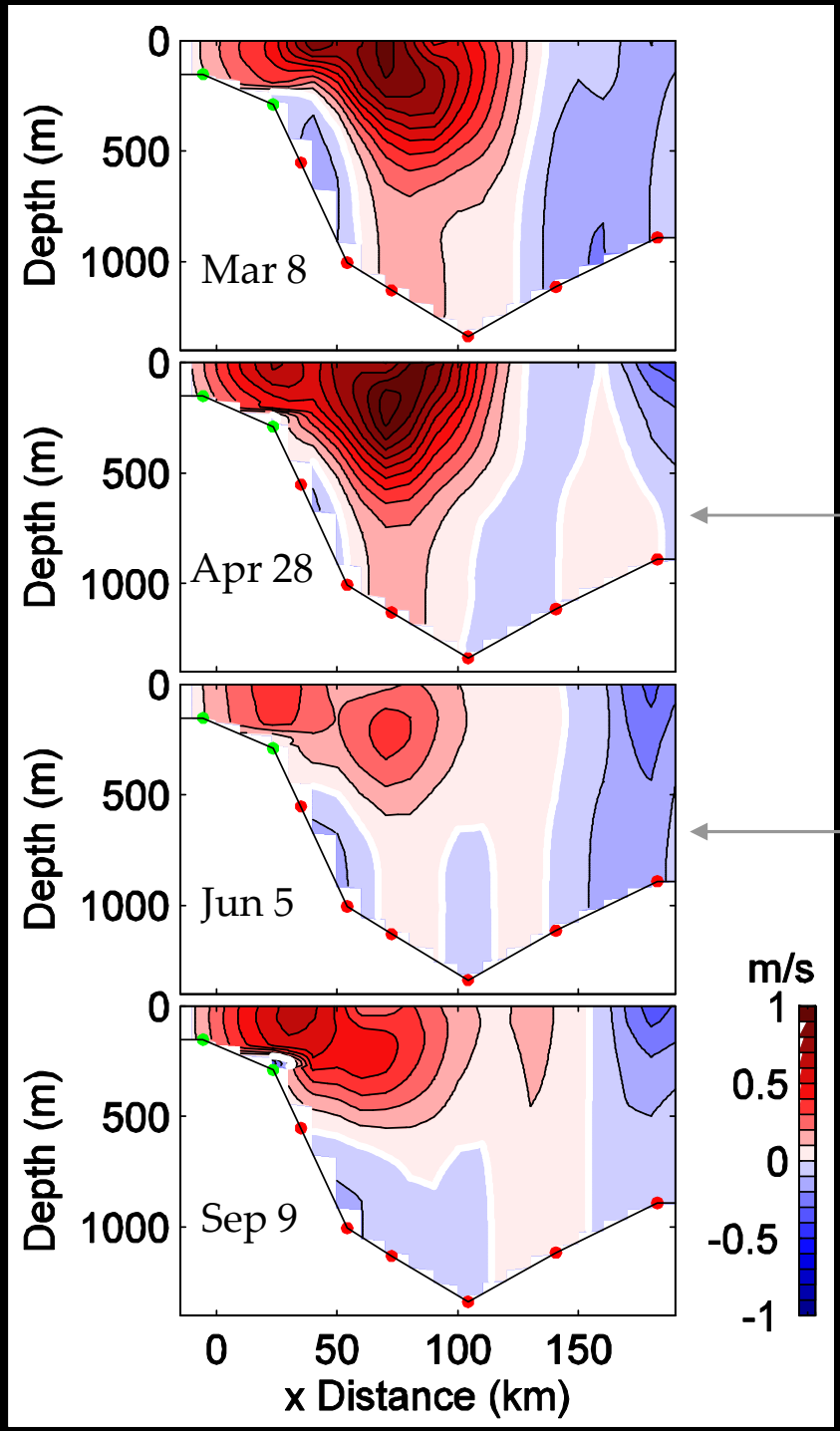


ECS mean along-slope current velocity



Andres et al. (JGR, 2008)

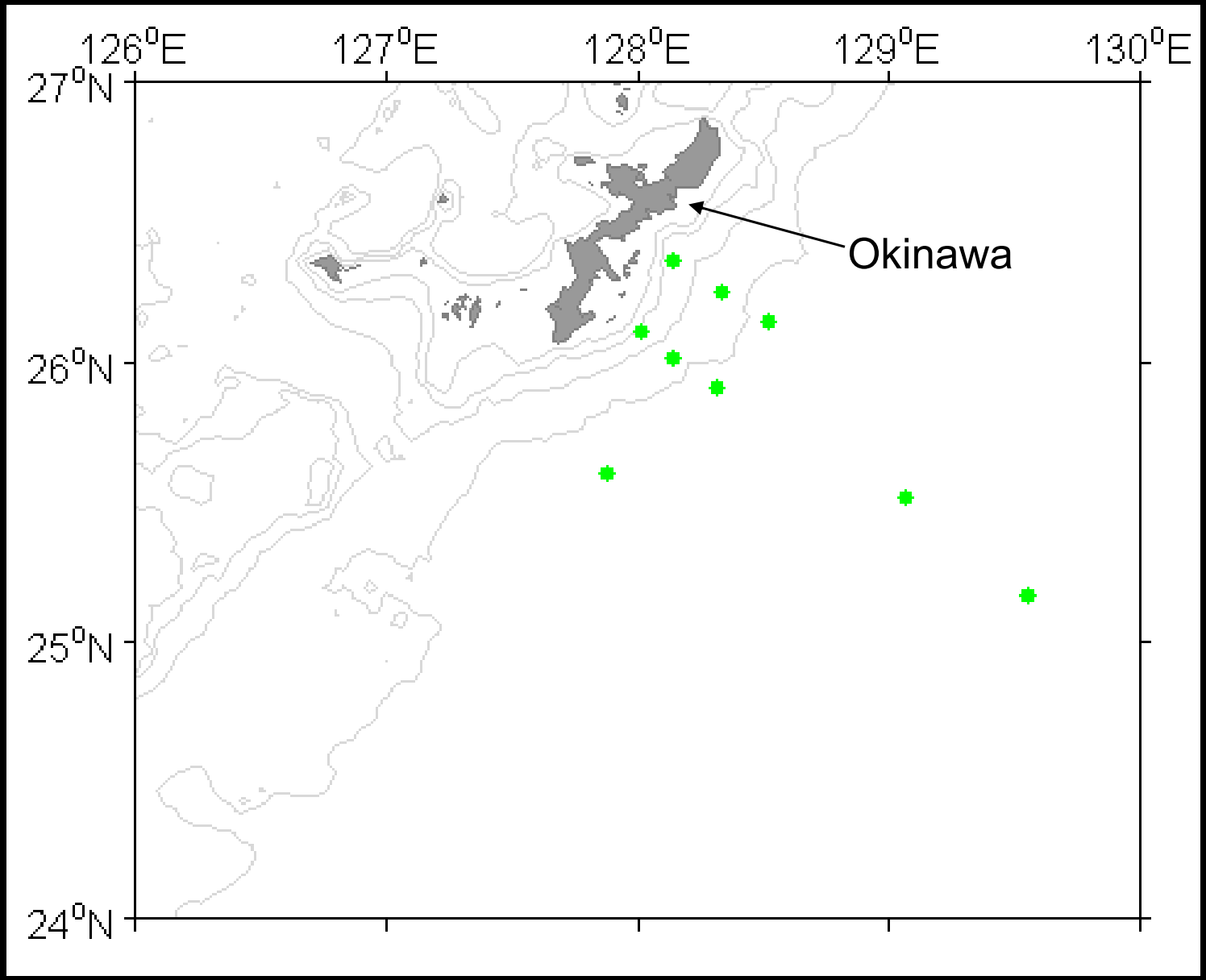
Velocity sections on four days in 2004.



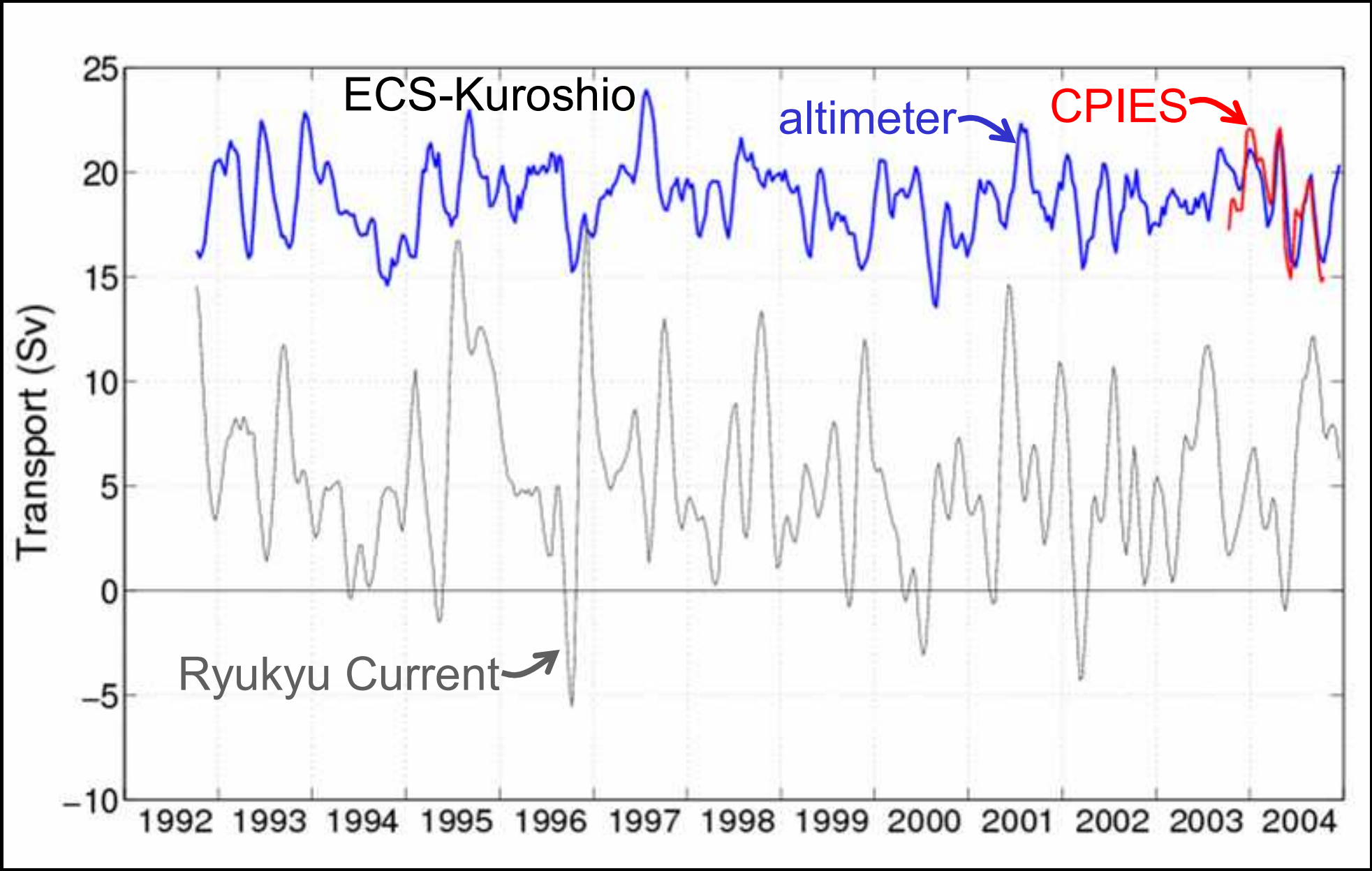
Day of maximum transport (29.5 Sv)

Day of minimum transport (4 Sv)

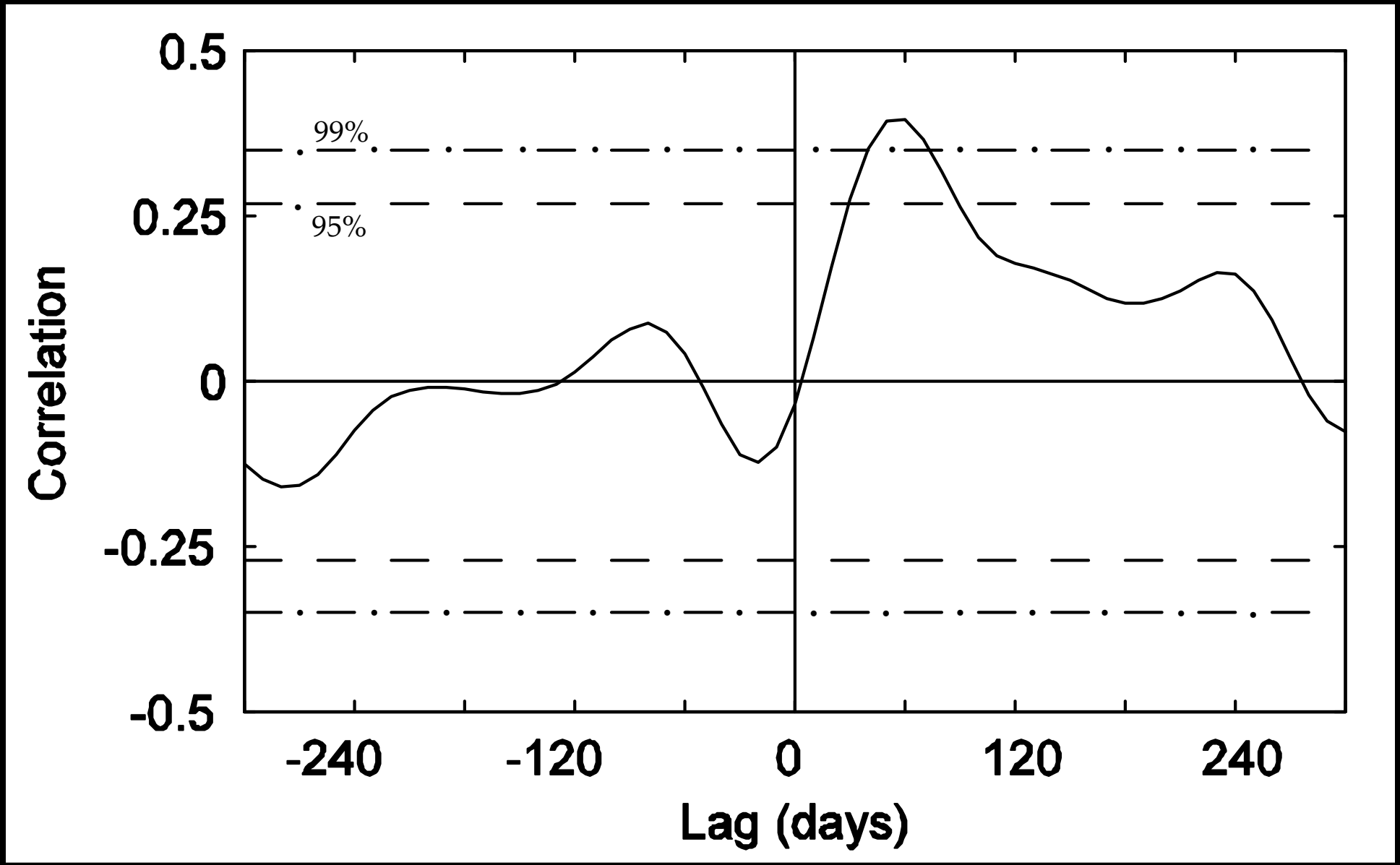
RC PIES array (JAMSTEC, 2000-01)



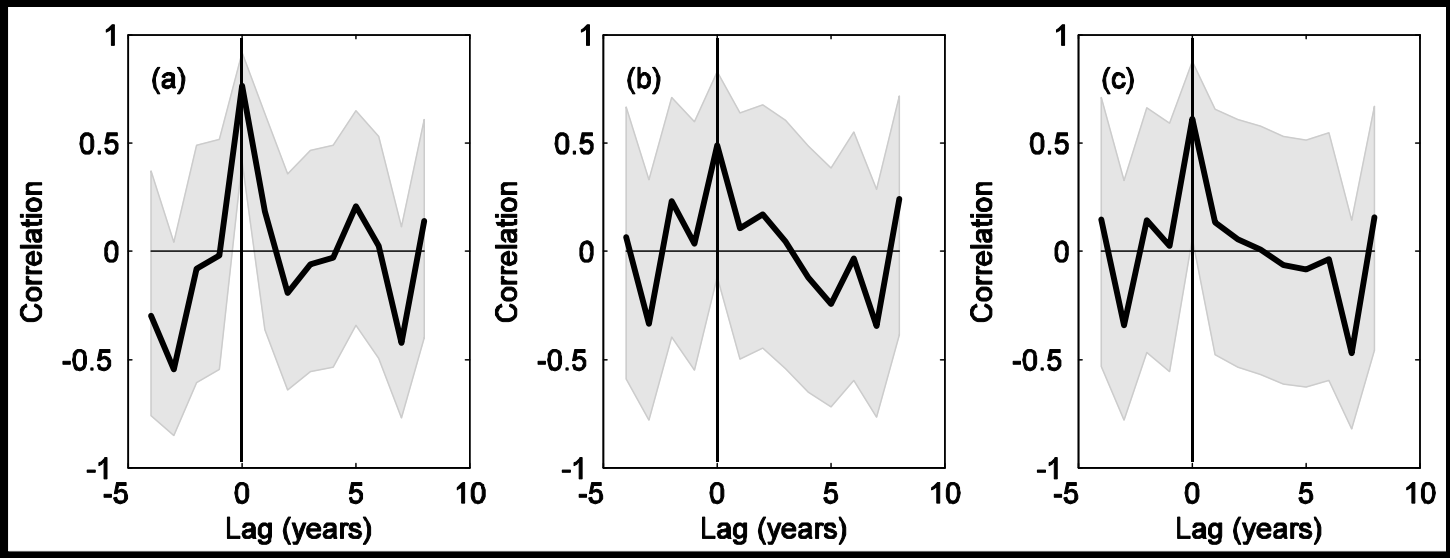
12-year transports of ECS-Kuroshio (red & blue) and Ryukyu Current (gray)



Transport lag of Kuroshio behind Ryukyu Current



Transport correlations with PDOI



Kuroshio

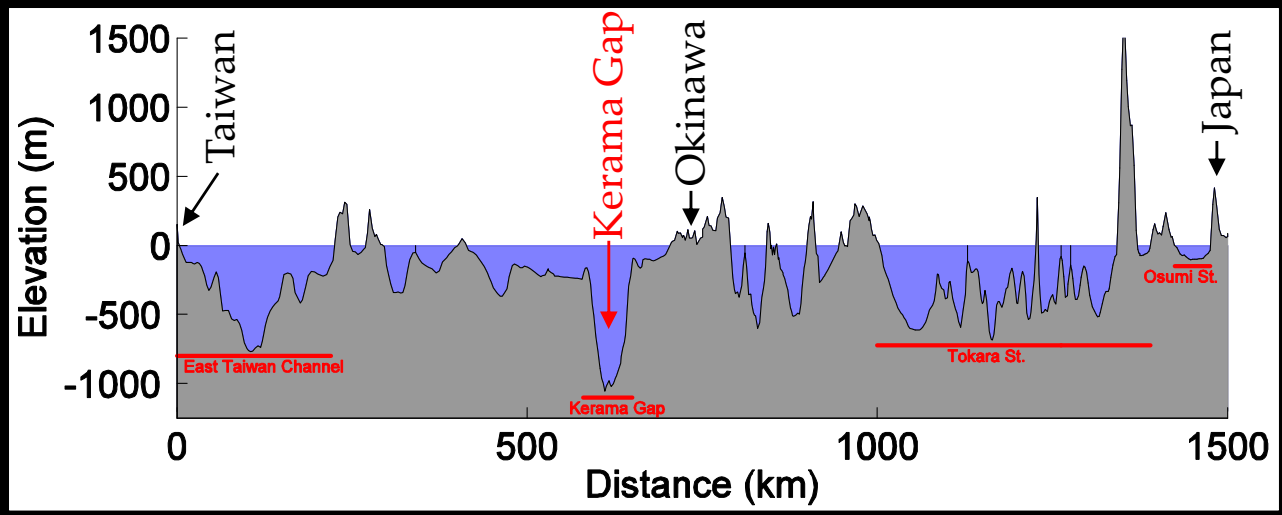
Ryukyu Current

Kuroshio + Ryukyu Current

- Correlations highest at ZERO lag.
- But Kuroshio Extension transport correlation with PDOI highest at 4-5 years lag (e.g., *Qiu, JPO 2003*).

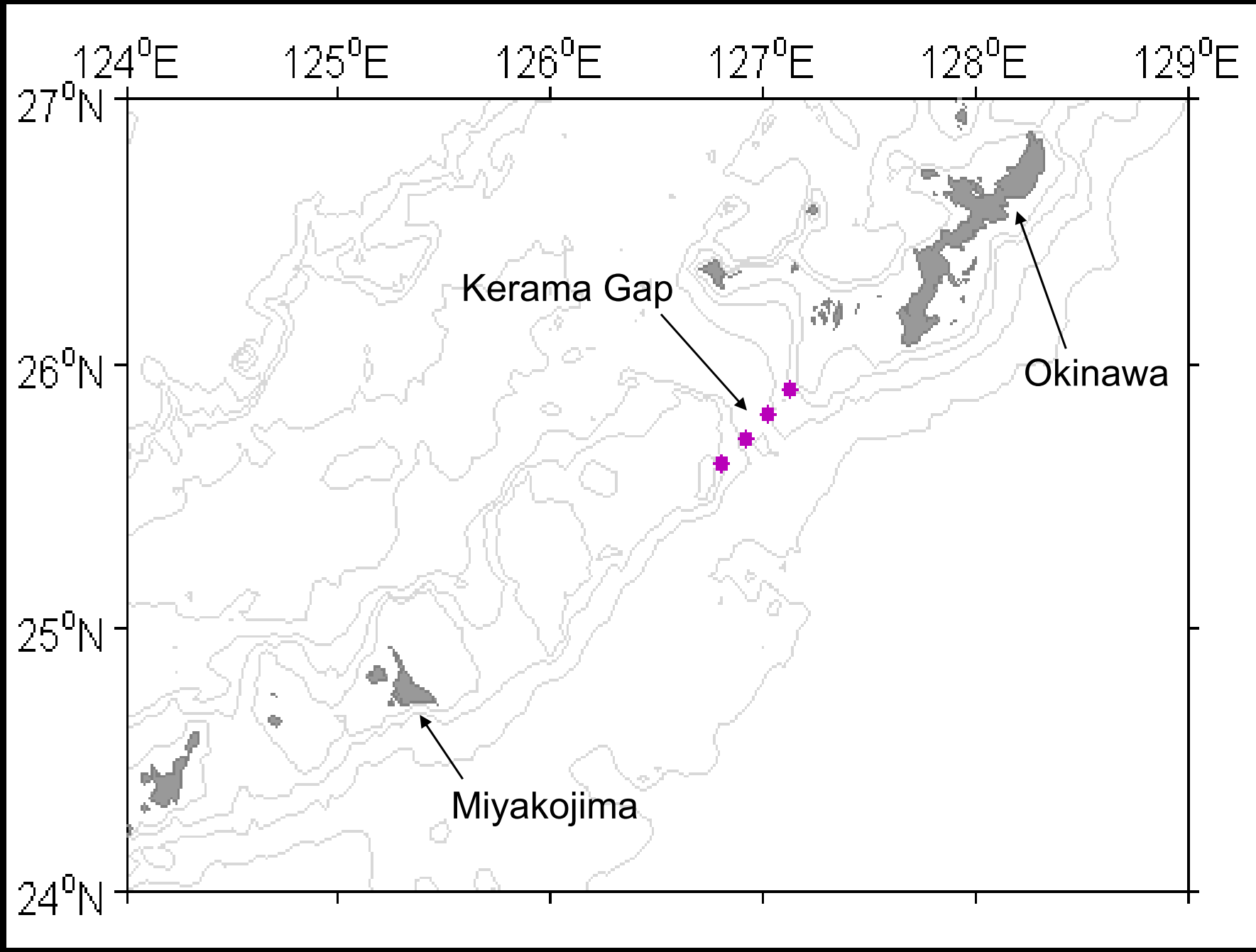
The Future

- Immediate: Flow through the Kerama Gap

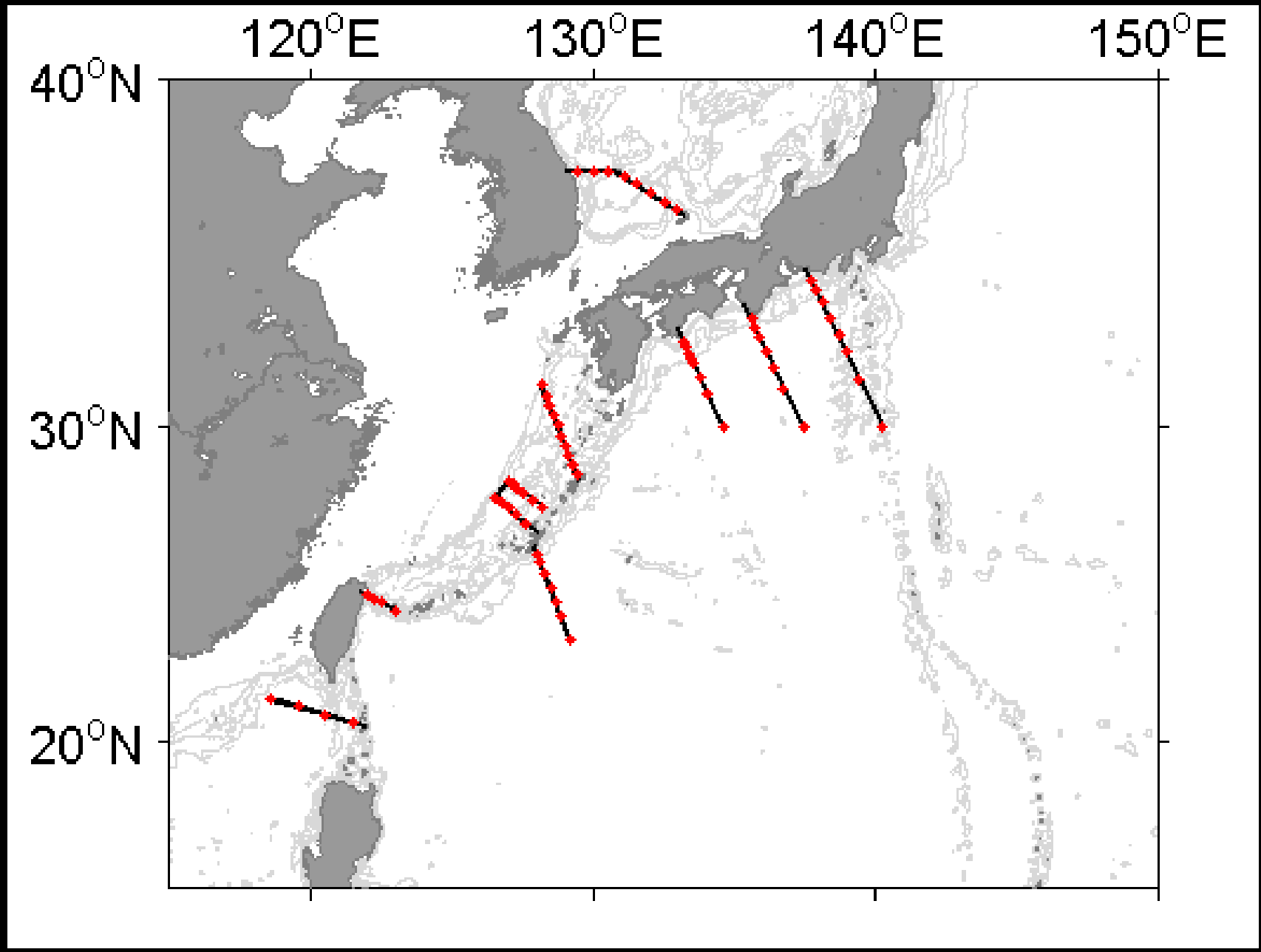


- Longer-term: Cabled CPIES arrays?

Kerama Gap CPIES array 2009-11



The Future? Cabled CPIES arrays



Thank you for your attention!

Questions?