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Warming signal in the upper layers of the East/Japan Sea

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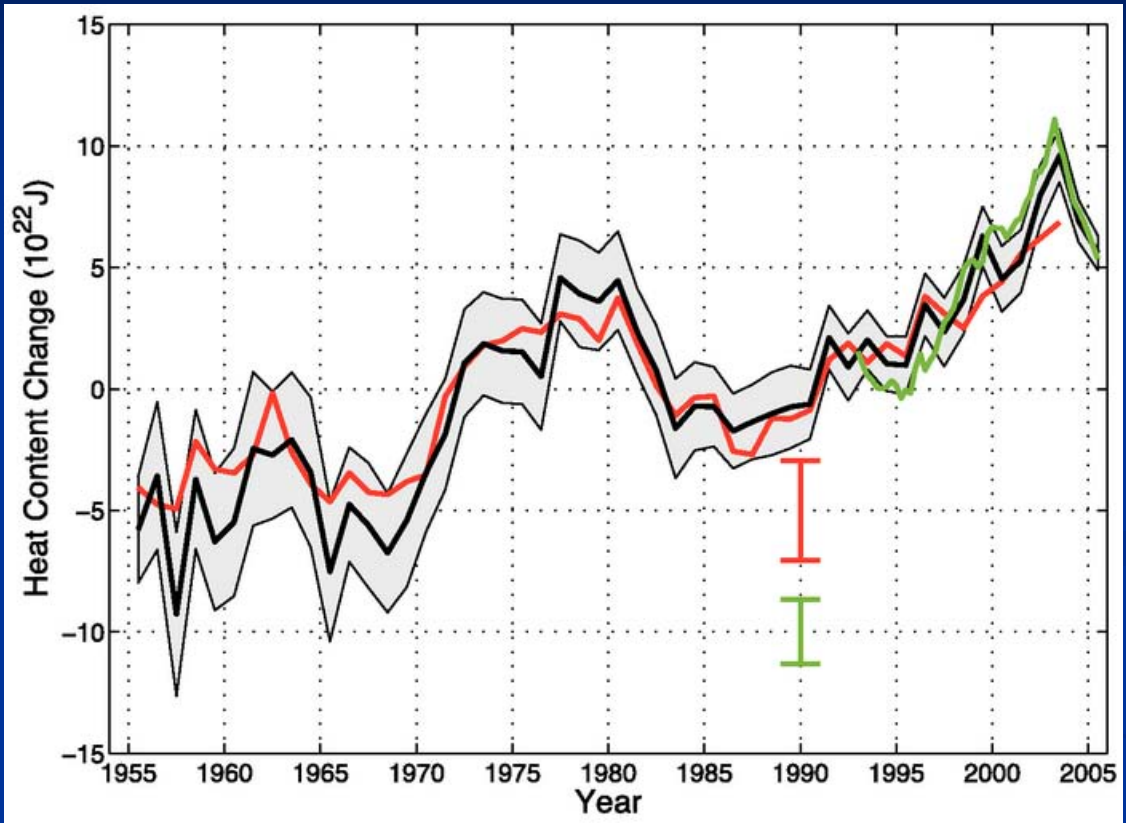
Global Annual Ocean Heat content

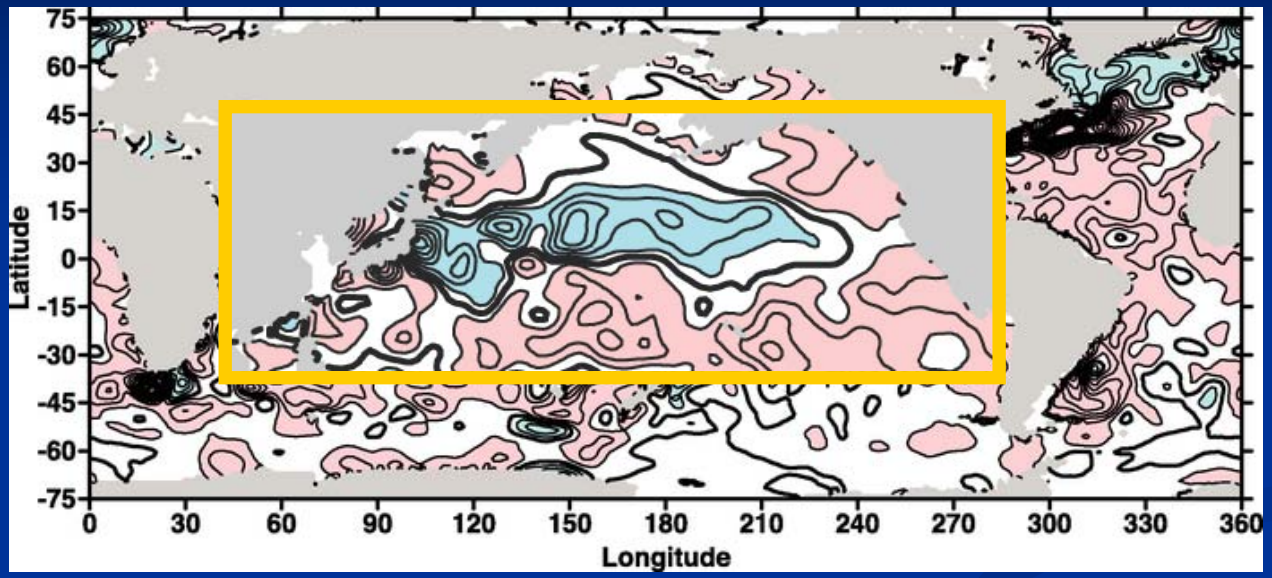


IPCC Fourth Assessment Report: Climate Change 2007

References: Levitus et al. (2005), Ishii et al. (2006), Willis et al. (2004)

- Time series of globally-averaged annual ocean heat content anomalies for the 0 to 700 m layer
- Decadal variations on top of an increasing trend

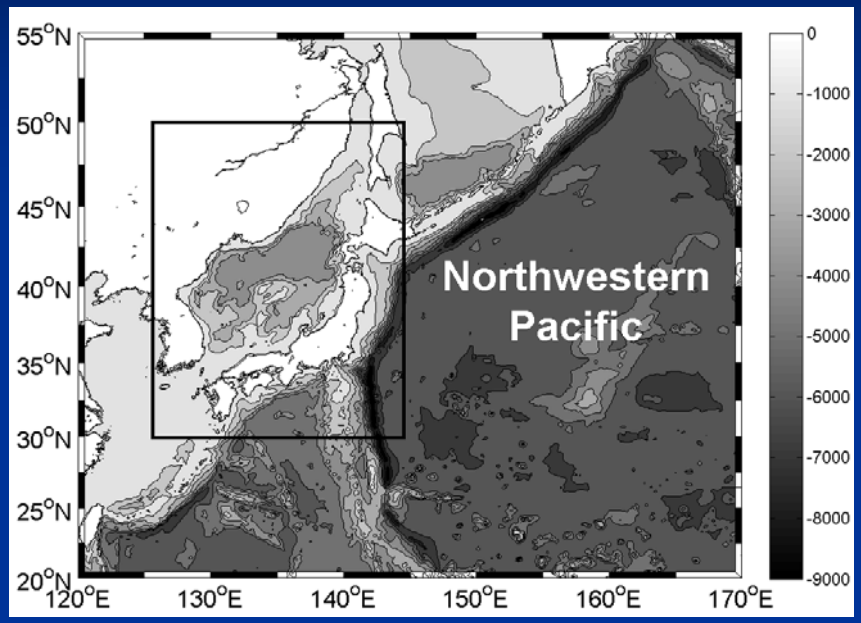
Linear trends (1955–2003) of change in ocean heat content

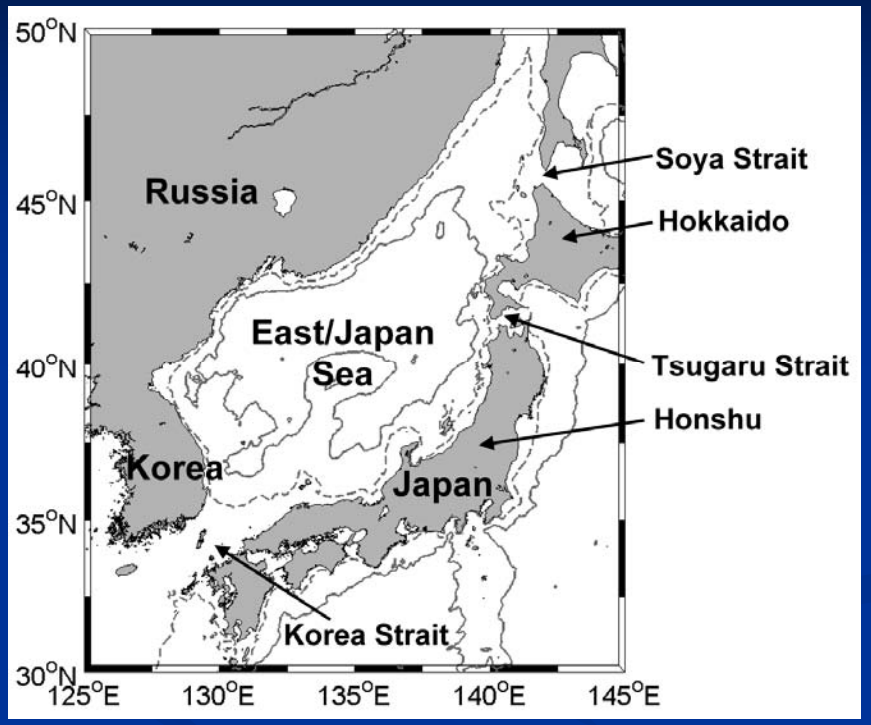


IPCC Fourth Assessment Report: Climate Change 2007

- Linear trends (1955–2003) of change in ocean heat content per unit surface area (W/m^2) for the 0 to 700 m layer, based on the work of Levitus *et al.* (2005).
- The linear trend is computed at each grid point using a least squares fit to the time series at each grid point.
- Positive or negative trends depending on locations
- Warming in the marginal seas needs to be investigated from a regional point of view and compared with the warming signal in the larger ocean basins

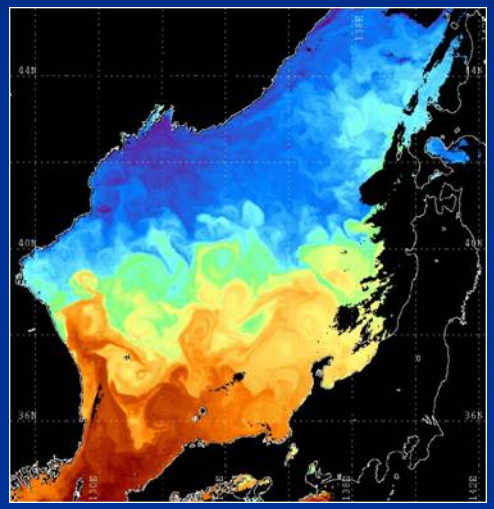
East/Japan Sea





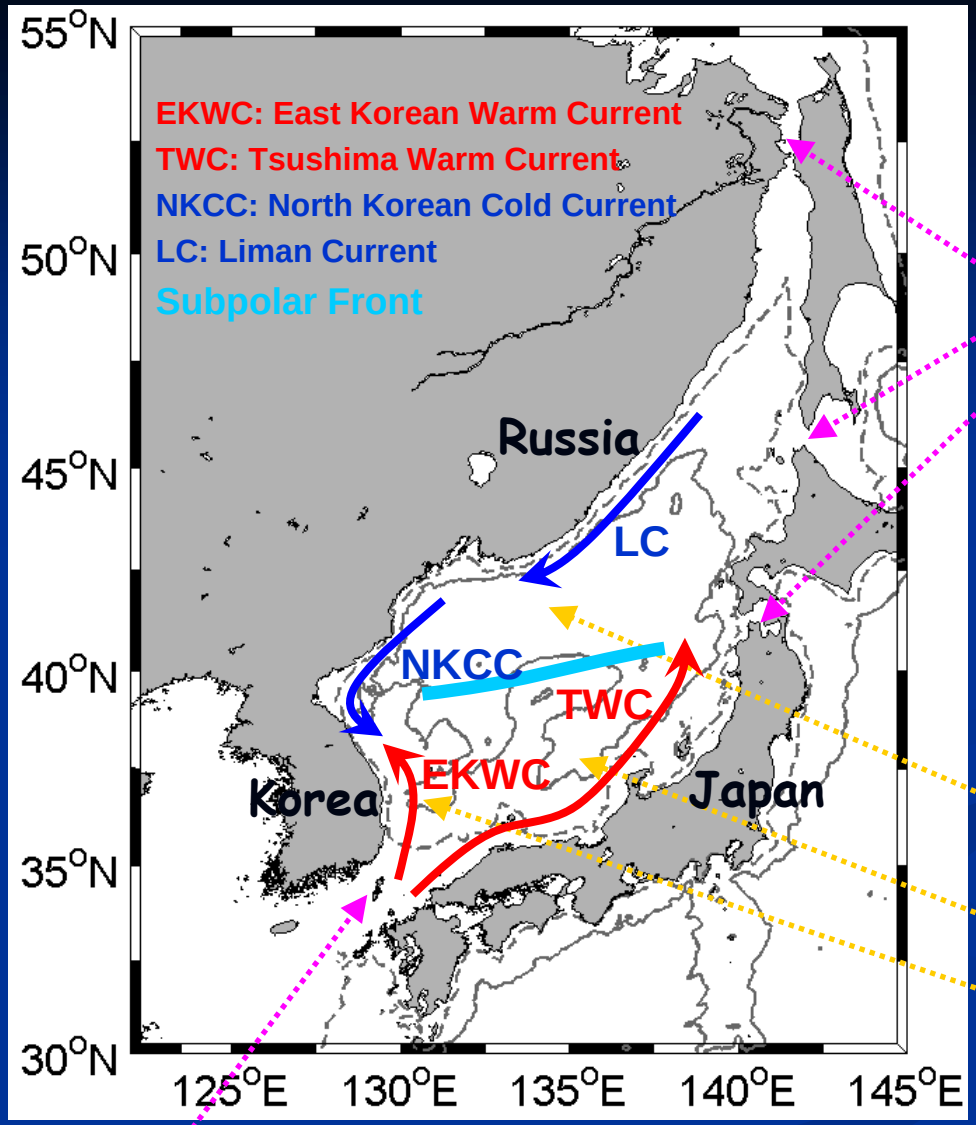
- a semi-enclosed marginal sea in the Northwestern Pacific
- surrounded by Korea, Japan, and Russia
- deep basins (>3000 m) vs. shallow straits (<300 m)
- warm inflow through the Korea Strait (Tsushima Warm Current)
- outflow through the Tsugaru Strait and the Soya Strait

East/Japan Sea



SST

- Effects of warm inflow
- the Subpolar Front



Tatar Strait

Soya Strait

Tsugaru Strait

Japan Basin

Yamato Basin

Ulleung Basin

Korea Strait

- Lack of long-term observational data
- Lack of clear understanding of the long-term variability of the upper-ocean hydrography

Objectives

- Warming signal in the upper East/Japan Sea
  - by examining the upper-ocean heat content in the past 40 years
- Relationship with warming in the Northwestern Pacific
  - Upper-ocean heat content
  - Sea Level Anomalies (SLA)
  - Sea Surface Temperature (SST)

Data

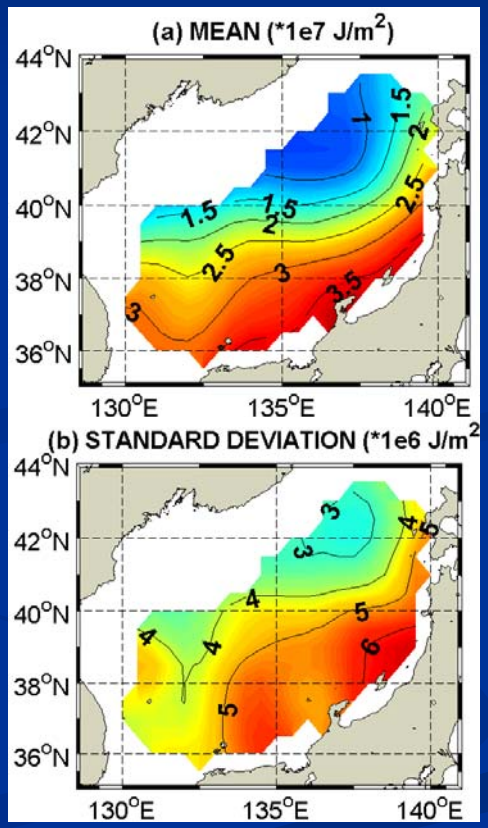
- Gridded temperature and salinity in the East/Japan Sea
  - Optimally interpolated dataset same as in Minobe et al., (2004) and Na et al. (2010)
  - Monthly means: 40 years from 1968 to 2007
  - Spatial resolution: 0.5°
  - Depth: 14 levels
    - 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500 (m)
- AVISO Merged Sea Level Anomaly (1993-2007)
- ERSST.v3b (1968-2007)
- SODA (Simple Ocean Data Assimilation Reanalysis)
  - Monthly means: 40 years from 1968 to 2007
  - Spatial resolution: 0.5°
  - Depth: 17 levels from 5.01 m to 317.65 m

Methods

- Vertically integrated heat content (upper-300m)

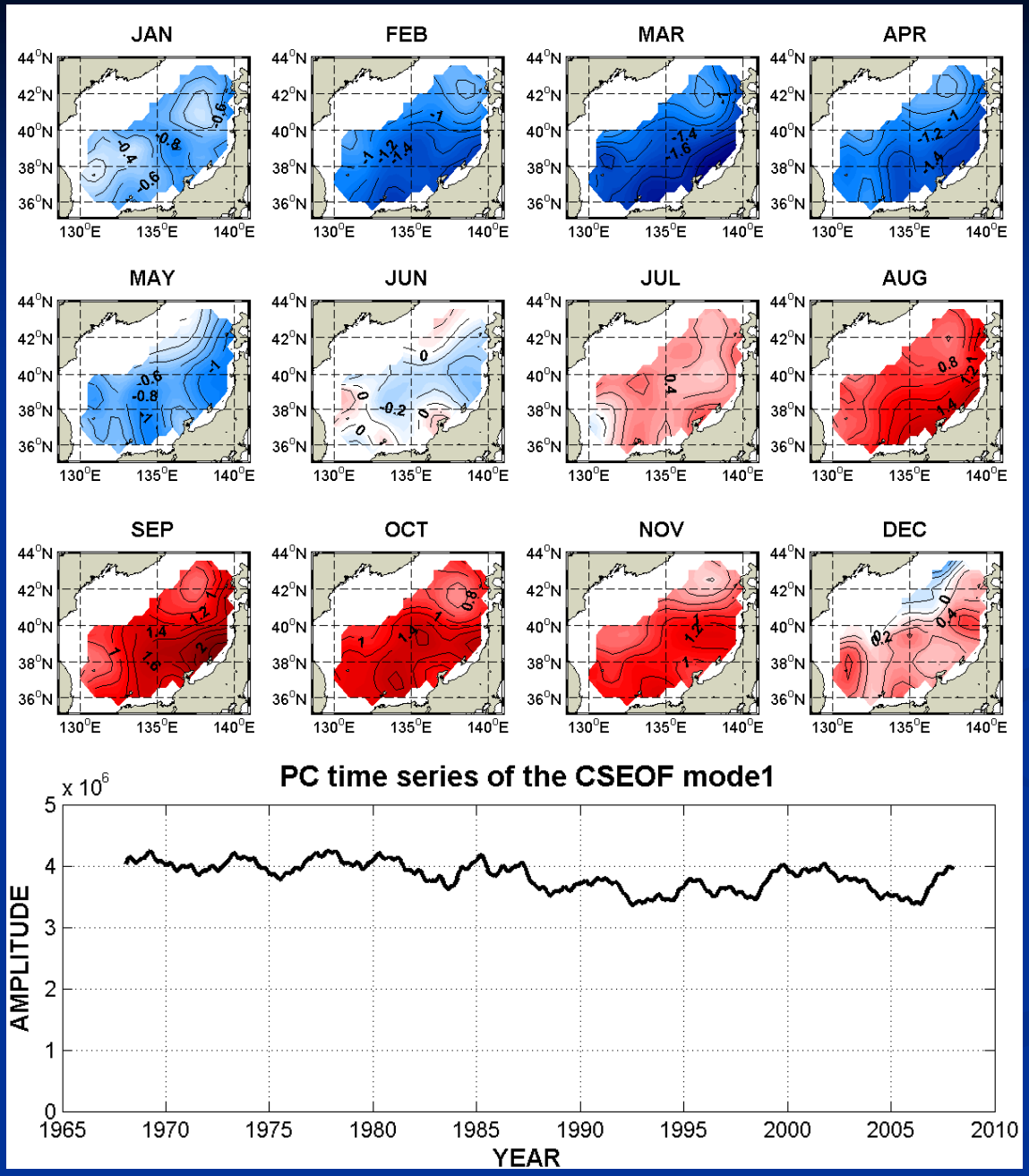
$$Q = \int_{-300}^{0} \rho(T,S,0) c_p(T,S,0) T(z) dz$$

  - ρ : density
  - c_p: specific heat capacity
  - T : temperature



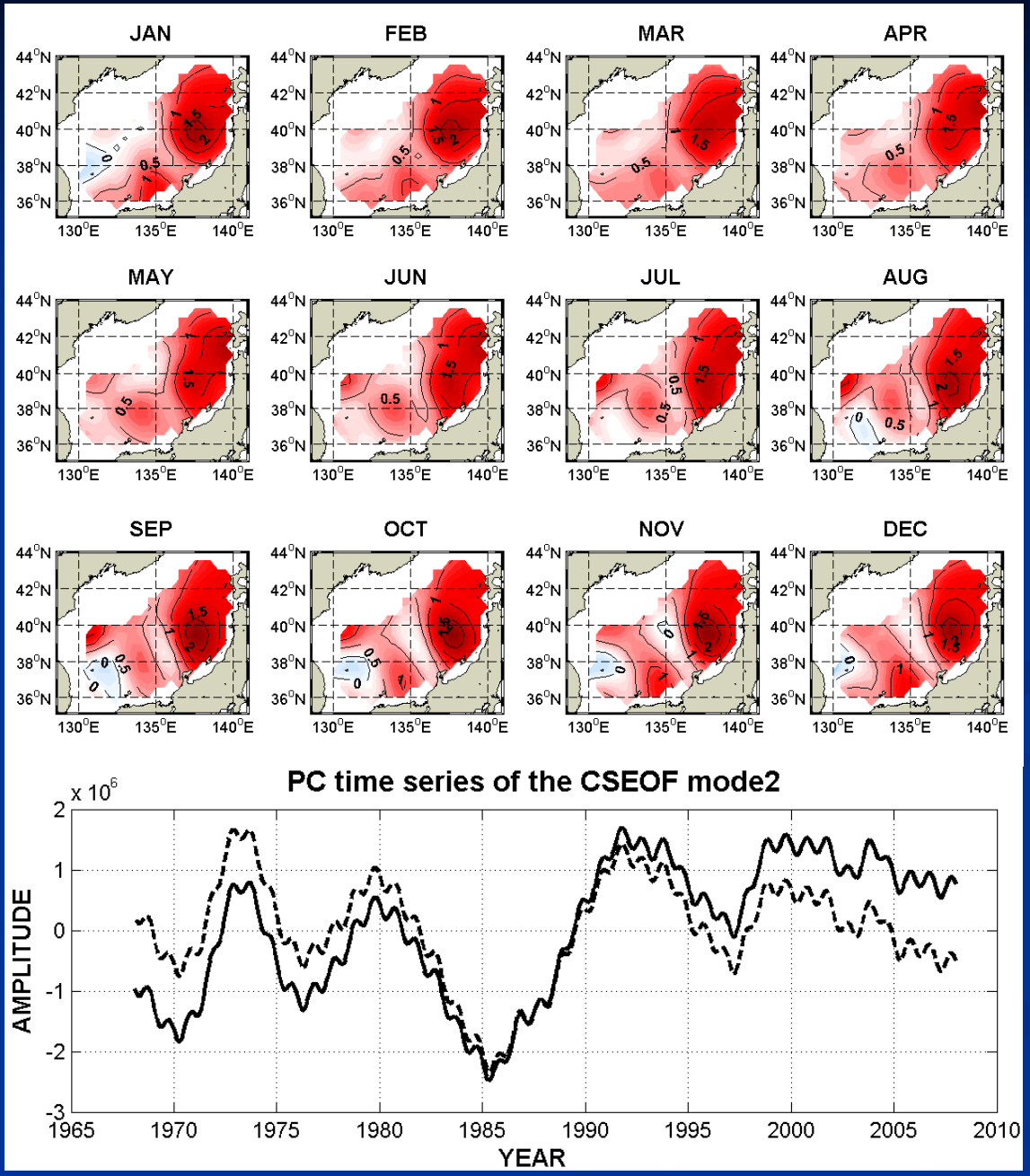
- Cyclostationary EOF (CSEOF) analysis
  - Upper water heat content
- Multiple regression analysis
  - Relationship with the warming signal

Heat Content CSEOFs



- CSEOF mode 1 (83%)
- Annual cycle
  - Positive anomalies during summer and fall
  - Negative anomalies during winter and spring
- Effects of the Tsushima Warm Current
  - Large variance along the west coast of Japan
  - Maximum in September-October and minimum in February-March

Heat Content CSEOFs

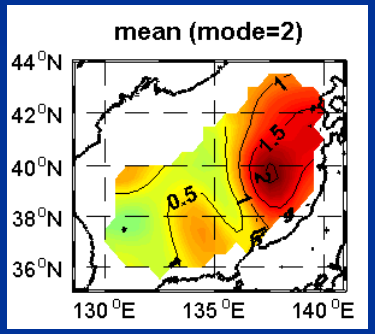


- CSEOF mode 2
- 7 % (~40 % aside from the annual cycle)
- Generally positive anomalies throughout the year
- Large positive anomalies to the west of northern Honshu, western end of the Tsugaru Strait, and west of southern Hokkaido
- Major spectral peak: ~10 years
- Increasing trend: about 25% of the decadal fluctuation range

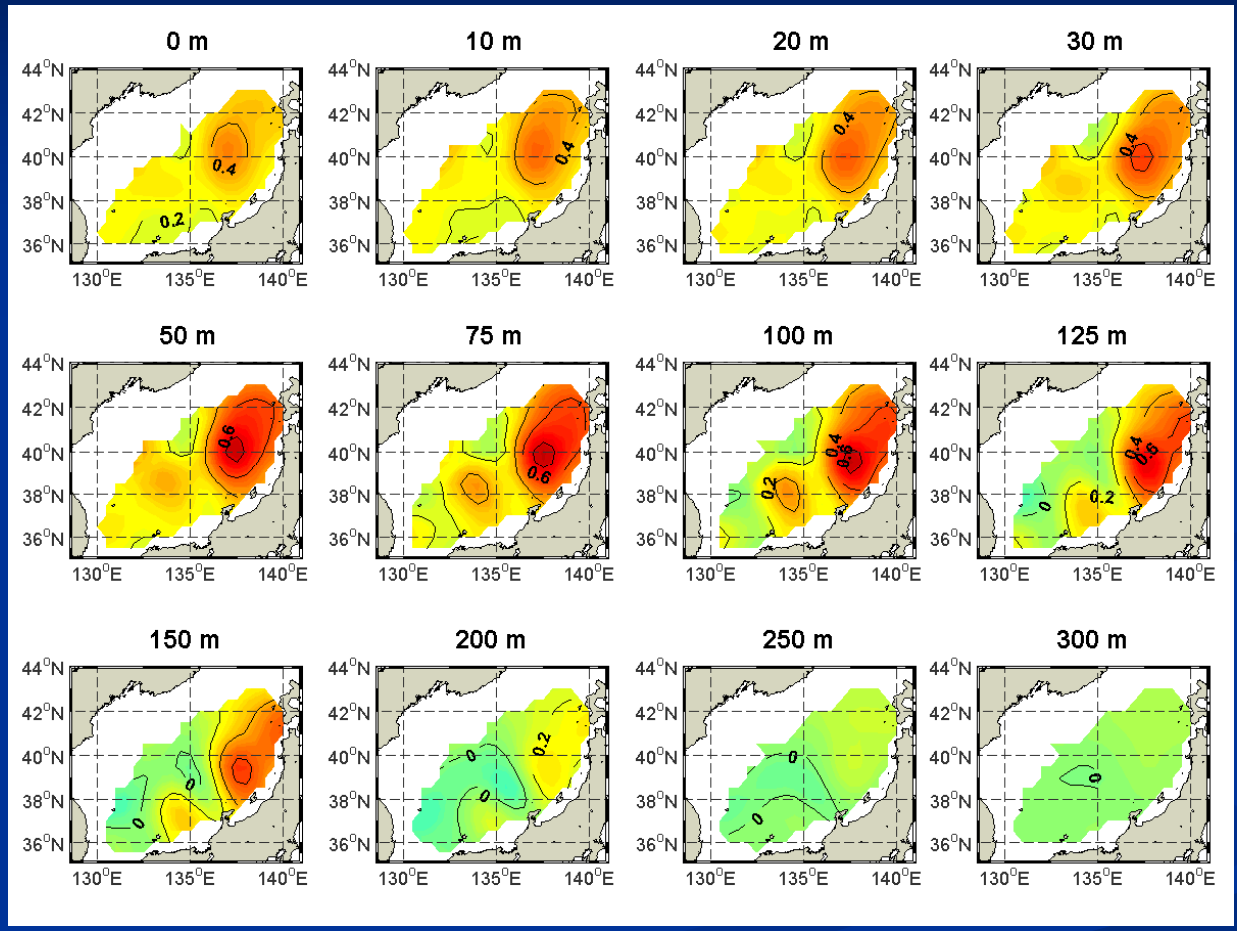
warming mode

Temperature anomalies at each depth regressed on the warming signal in upper-ocean heat content

target

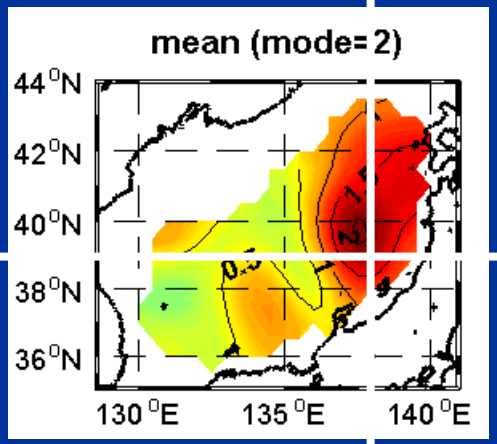


R-square values of regression at all levels: > 0.9



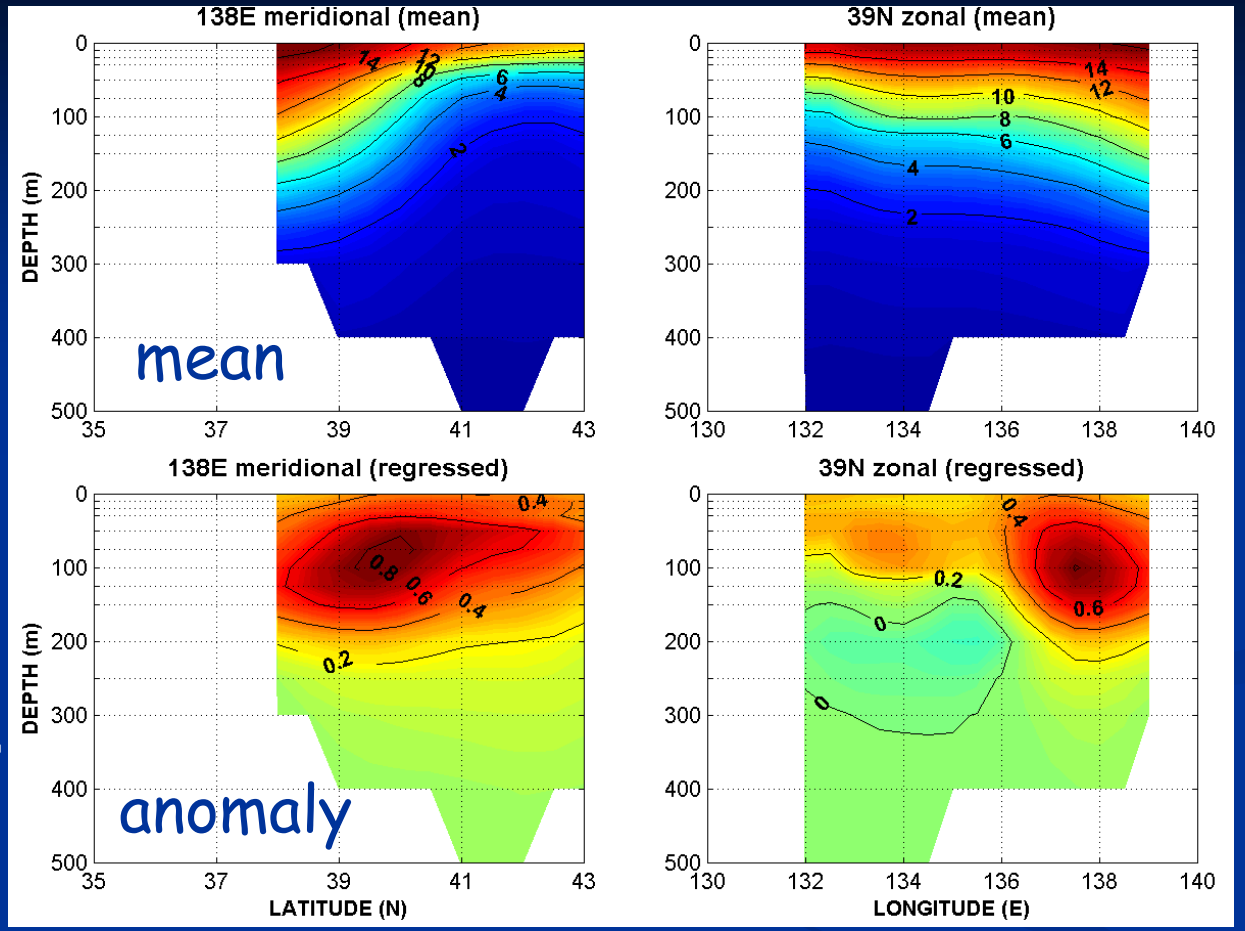
- warming over most of the domain up to 150 m depth
- positive anomalies: 0-30 m < 50-125 m
- primary source of warming: Tsushima Warm Current

Mean temperature and temperature anomalies regressed on the warming signal in upper-ocean heat content



138°E meridional

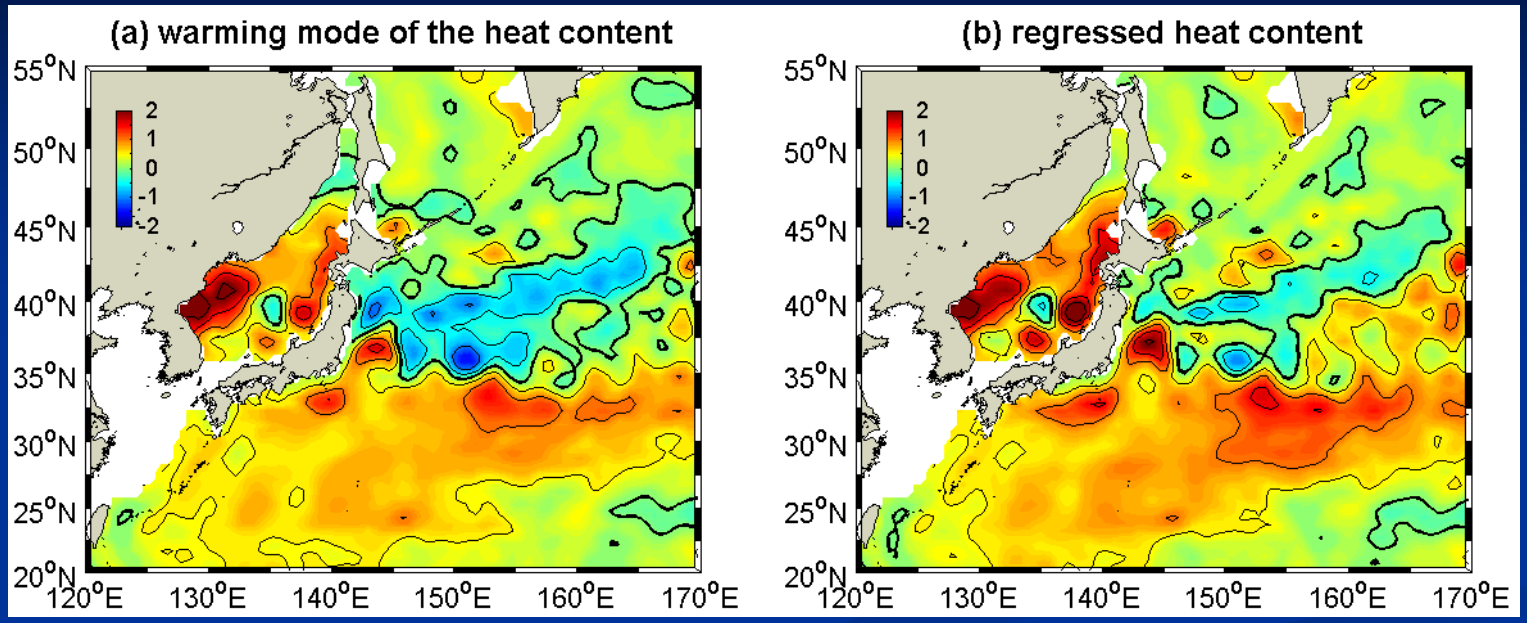
39°N zonal



- large positive anomalies in the upper 200 m depth
- location of core in the temperature anomalies
- temperature increase of the Tsushima Warm Current is primarily responsible for the increased upper-ocean heat content

Relationship with the Northwestern Pacific

Upper-Ocean Heat Content



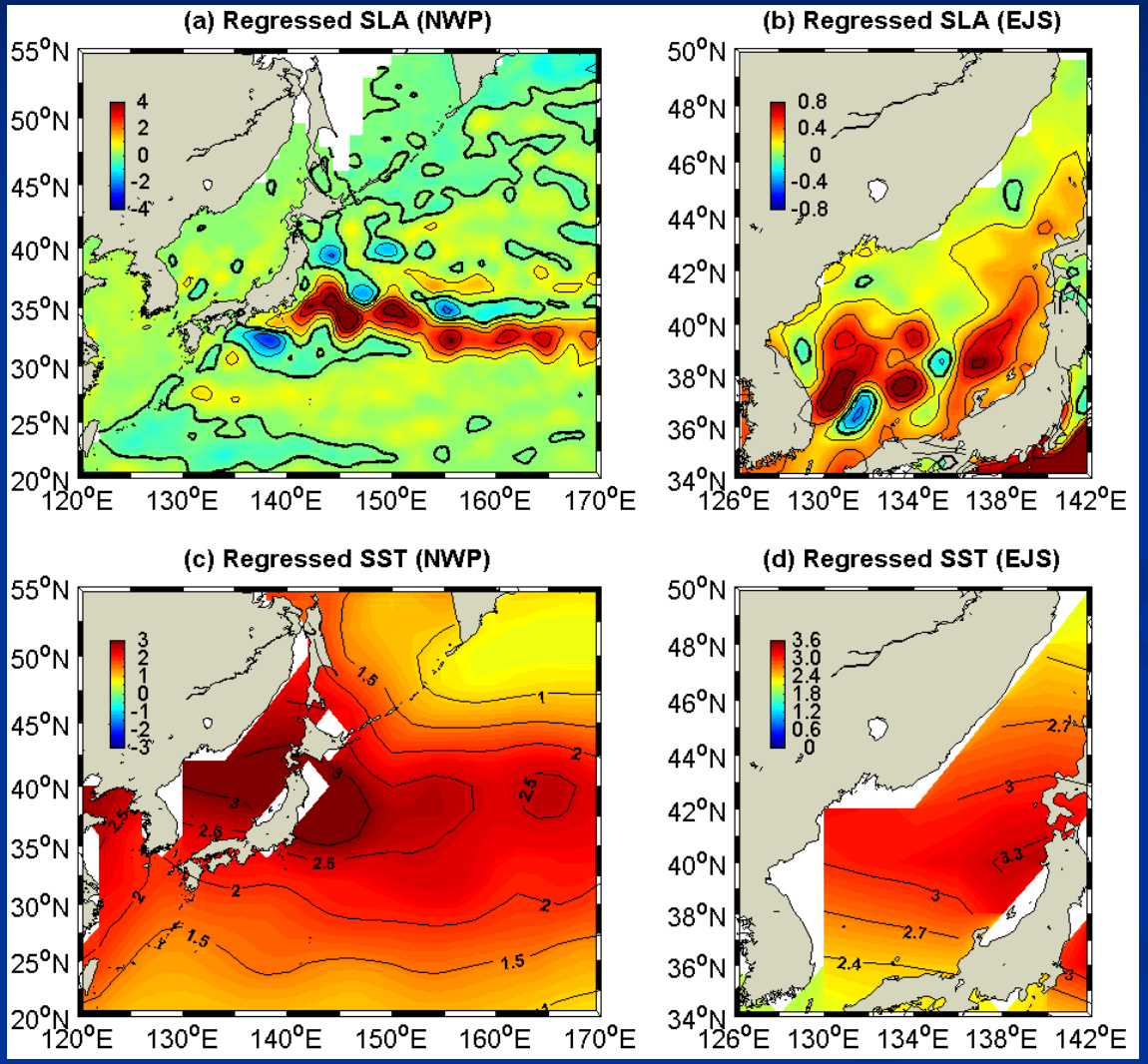
(a) Warming mode of the upper-ocean heat content in the Northwestern Pacific (CSEOF mode 3)

(b) Upper-ocean heat content in the Northwestern Pacific regressed on the second CSEOF mode of the upper-ocean heat content in the East/Japan Sea (warming mode), R-squared value: ~0.87

- Warming signal in the East/Japan Sea is significantly correlated with the heat content variation in the Northwestern Pacific.
- Upper-ocean heat content increase in the East/Japan Sea is a part of much larger-scale heat content change in the Northwestern Pacific

Relationship with the Northwestern Pacific

Sea Level Anomalies



(a) Sea level anomalies in the Northwestern Pacific regressed on the warming mode in the East/Japan Sea (regression period: 1993-2007)

(c) Sea surface temperature anomalies in the Northwestern Pacific regressed on the warming mode in the East/Japan Sea (regression period: 1968-2007)

Sea Surface Temperature anomalies

Summary

- Upper-ocean (0-300 m) heat content variability by analyzing the 40-year long temperature and salinity dataset
- Warming signal in the decadal variations with major spectral peak at ~10 years
- Strong warming to the west of northern Honshu, west of the Tsugaru Strait, and west of southern Hokkaido
- Large contribution of the temperature anomalies in 50-125 m levels to the upper-ocean warming
- Induced by warmer inflow of the Tsushima Warm Current
- Related to the warming in the Northwestern Pacific

Thank you.