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Decadal Variability of the upper-ocean heat content in the Northwestern Pacific

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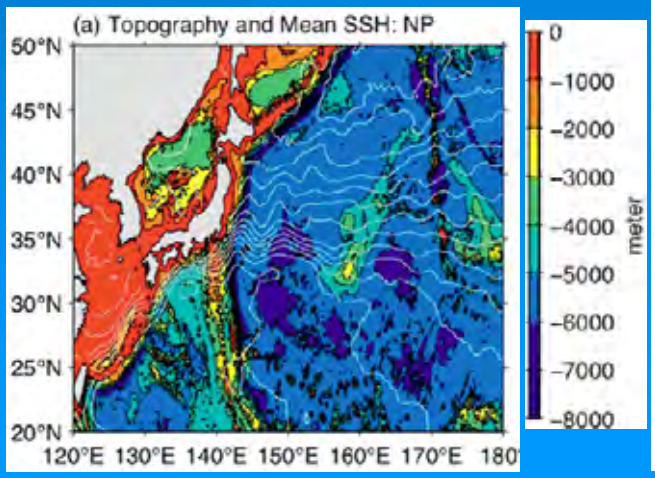
Introduction

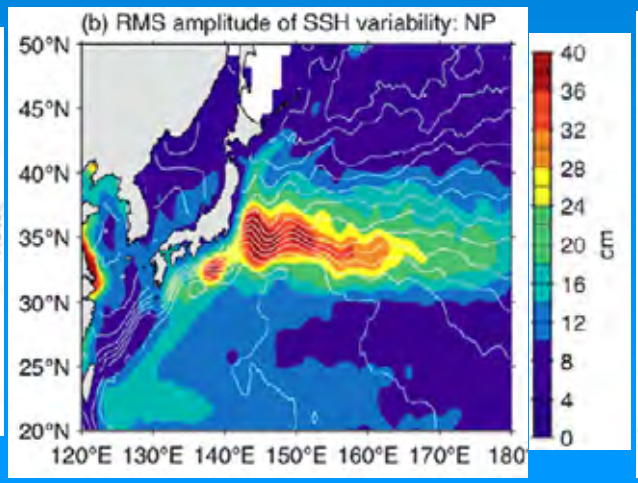
❖ Northwestern Pacific

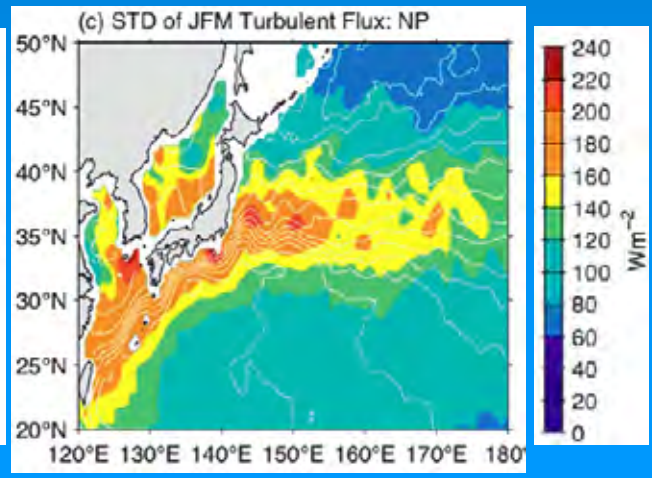
- Large variability related to the western boundary current system, Kuroshio and Kuroshio Extension
- Complex interaction between dynamics and thermodynamics and between atmosphere and ocean
- Understanding long-term variability in the Northwestern Pacific greatly contributes to understand the climate system

Topography and mean SSH



Variability in sea surface height and turbulent heat flux





Kelly et al., 2010

Introduction

- Extensive studies on the long-term variability in the Northwestern Pacific were based on the SST analysis.
- It has been argued that *Sea Surface Temperature (SST) is more a consequence of air-sea interaction* than of ocean dynamics [Sutton and Mathieu, 2002].
- Neither SST nor air temperature in the ocean boundary layer is representative of ocean or atmospheric states [Kelly et al., 2010].
- *Ocean heat content is a better climate predictor than SST* because SST anomalies decorrelate rapidly on seasonal time scales [Deser et al., 2003].
- Analyses of the upper-ocean heat budget show that while air-sea fluxes dominate on seasonal time scales, the *ocean contribution becomes increasingly important on longer time scales* [Qiu and Kelly, 1993; Kelly and Qiu, 1995].

Objectives

Understanding *decadal* variability

in the *Northwestern Pacific*

by investigating

upper-ocean heat content variability

Data

- **SODA (Simple Ocean Data Assimilation Reanalysis)**
  - monthly means: 40 years from 1967 to 2006
  - spatial resolution: 0.5°
  - depth: 19 levels from 5.01 m to 465.91 m
    - 5.01, 15.07, 25.28, 35.76, 46.61, 57.98, 70.02, 82.92, 96.92, 112.32, 129.49, 148.96, 171.4, 197.79, 229.48, 268.46, 317.65, 381.39, 465.91 [m]
  - temperature, salinity: heat content
  - Sea Surface Height (SSH)

Upper-ocean heat content

- **Vertically integrated heat content (upper 400 m)**

$$Q = \int_{-400}^{0} \rho(T,S,0)\, c_p(T,S,0)\, T(z)\, dz$$

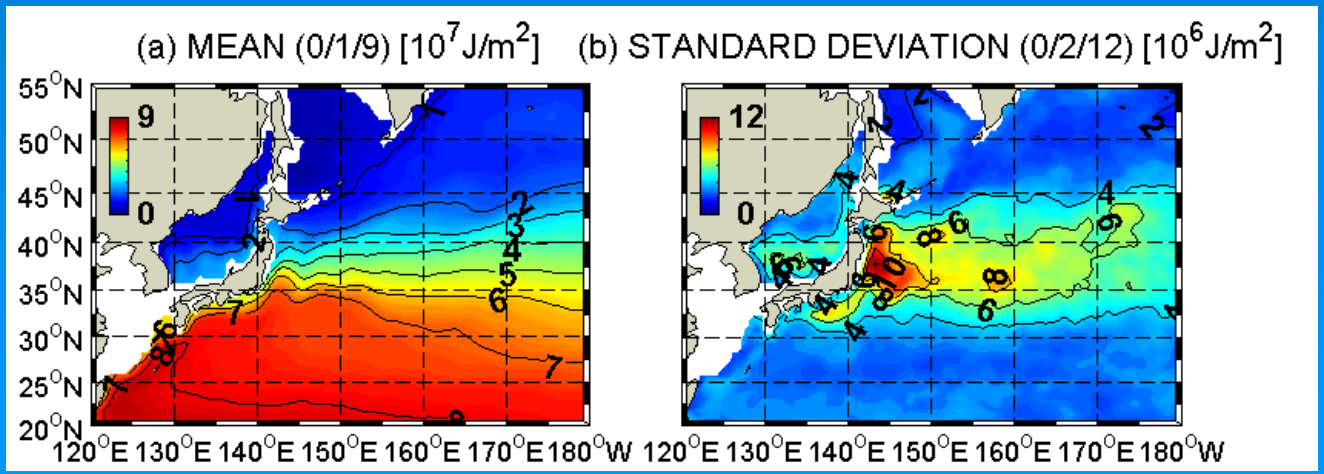
ρ : density

c_p: specific heat capacity

T: temperature

S: salinity

mean

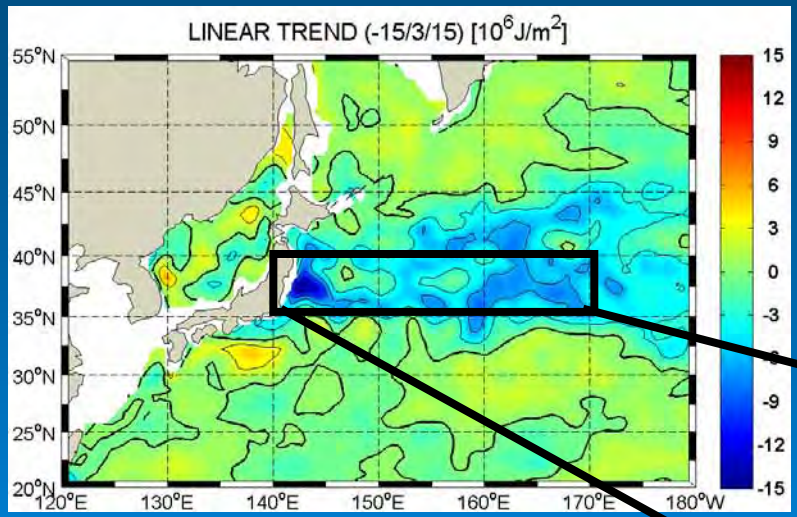


standard deviation

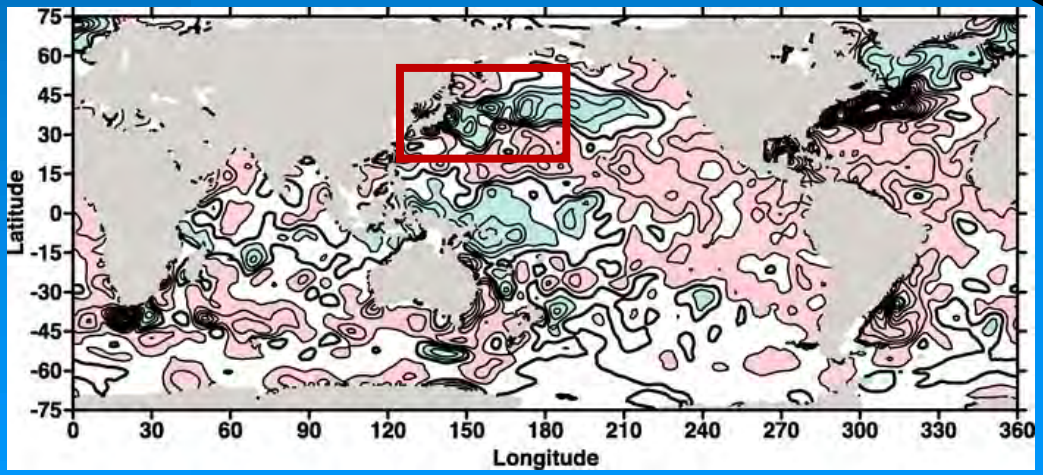
Monthly for 40 years from 1967 to 2006, 0.5°×0.5°

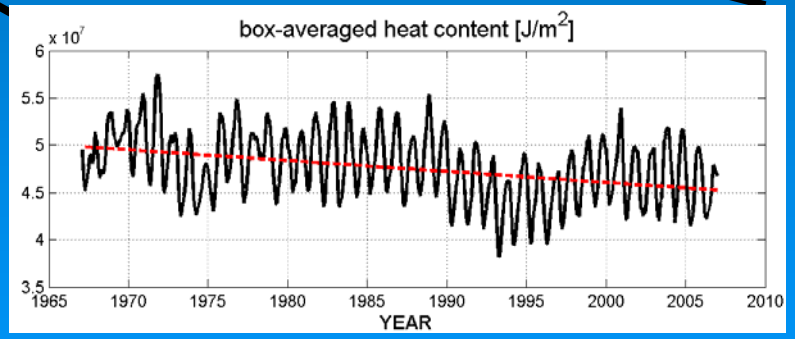
Upper-ocean heat content

Linear trend in 40 years



Long-term variability rather than a linear trend





- from the IPCC Fourth Assessment Report: Climate Change 2007
- Linear trends (1955–2003) of change in ocean heat content per unit surface area (W/m2) for the 0 to 700 m layer, based on the work of Levitus et al. (2005)

Method

- **CSEOF (Cyclostationary EOF) Analysis**

$$T(r,t) = \sum_n CSLV_n(r,t) PC_n(t)$$

$$CSLV_n(r,t) = CSLV_n(r,t+d)$$

$CSLV_n(r,t)$: physical process (e.g. El Niño, seasonal cycle)

$PC_n(t)$: PC (amplitude) time series

$CSLV_n(r,t) = CSLV_n(r,t+d)$; covariance statistics is periodic

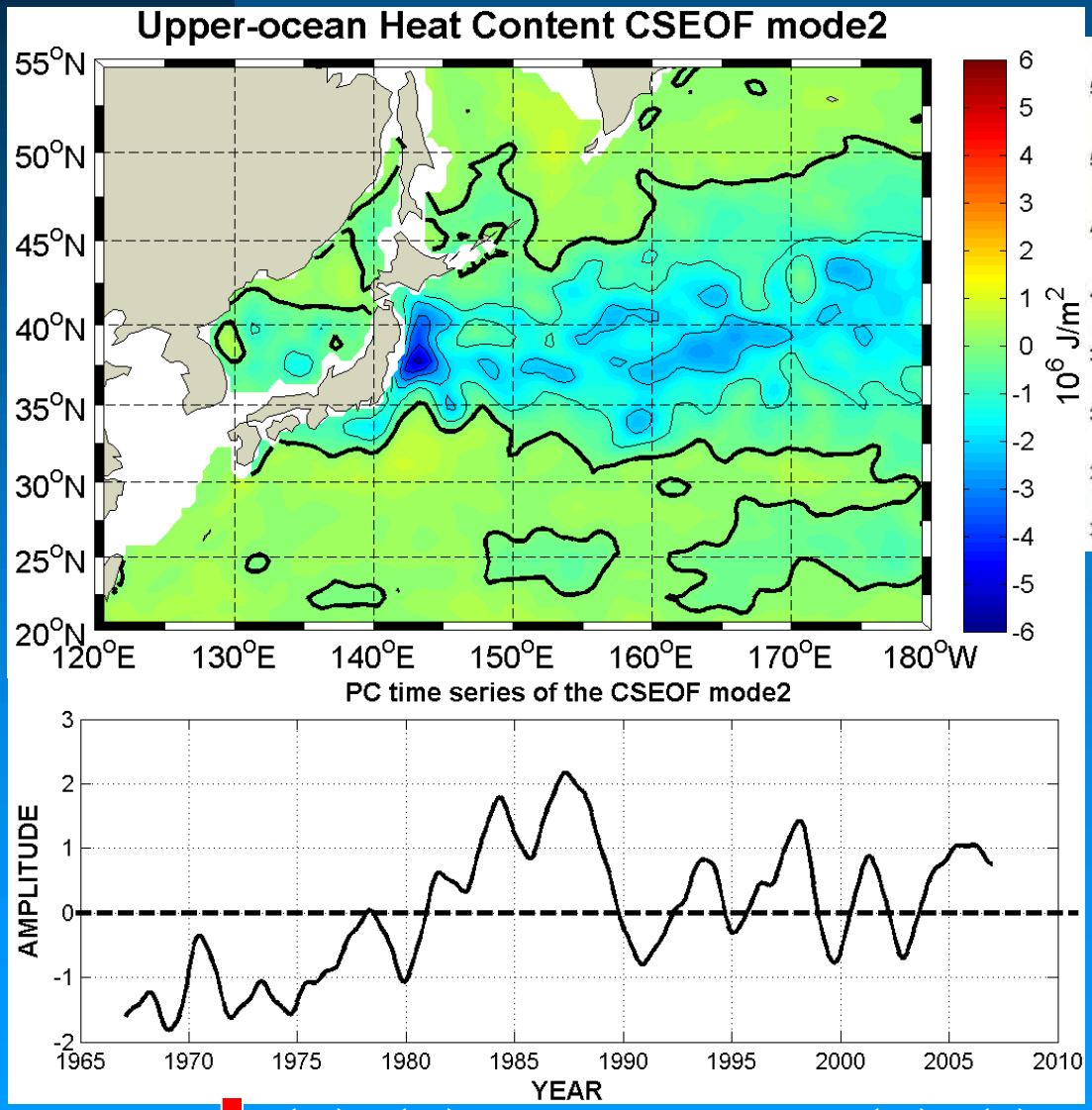
d: nested period (12 months)

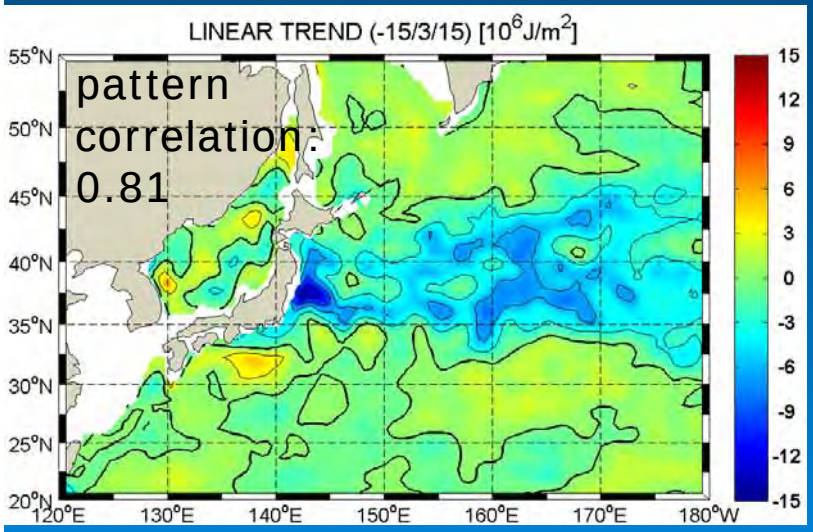
- **Multiple Regression analysis**

$$PC_i^{(T)}(t) = \sum_n a_n PC_n^{(P)}(t) + \varepsilon(t)$$

$$CSLV_i^{(PR)}(r,t) = \sum_n a_n CSLV_n^{(P)}(r,t)$$

Upper-ocean Heat Content Mode 2



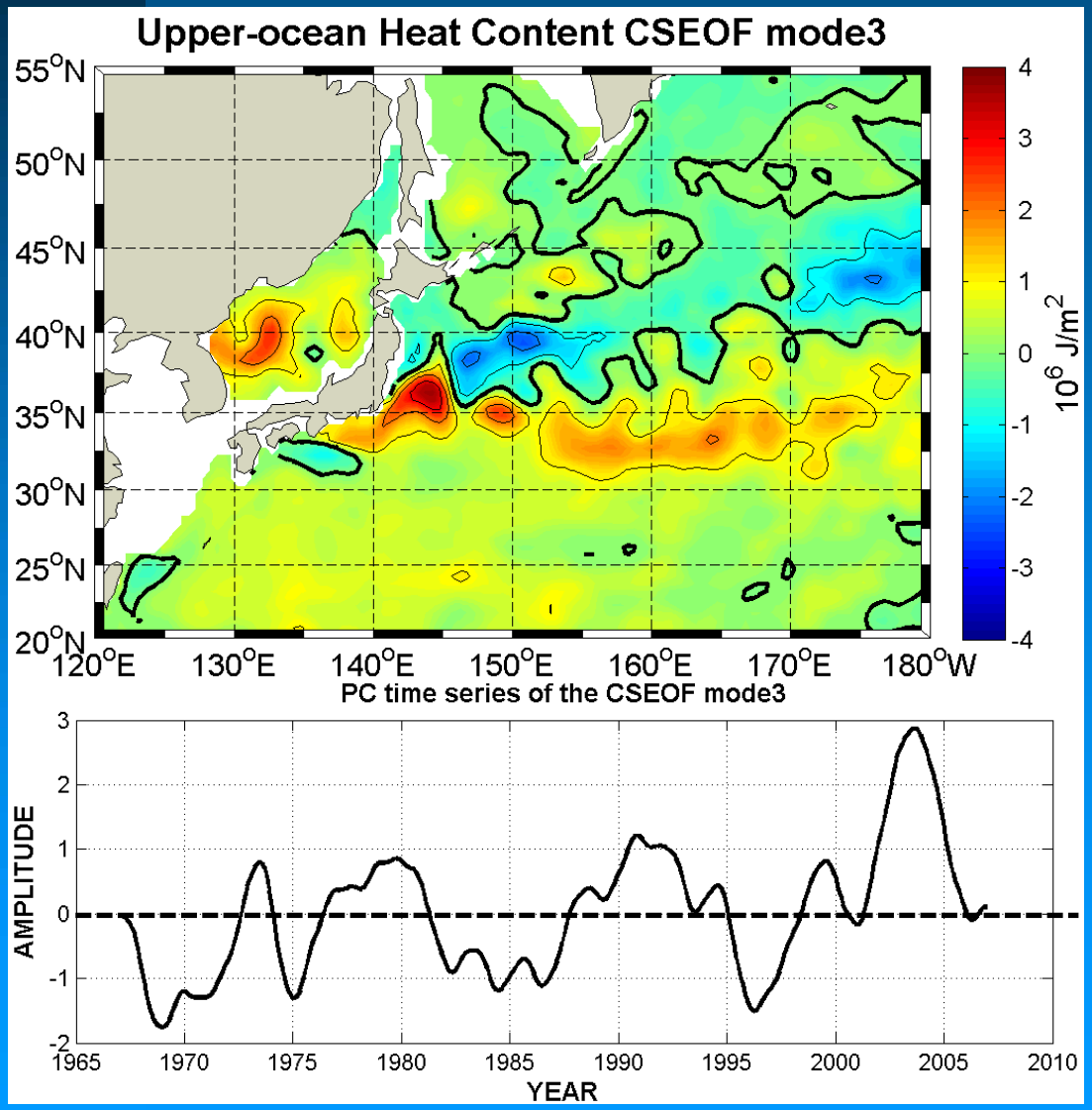


Slight cooling along the latitude band between 30°N and 45°N

Related to the negative trend along the Kuroshio Extension

Interdecadal transition of the interannual variability

Upper-ocean Heat Content Mode 3



positive/negative anomalies in different regions of the Northwestern Pacific

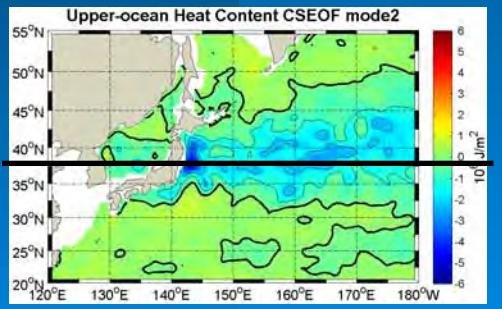
southern regions to the south of ~ 35°N including the East/Japan Sea vs. northern regions

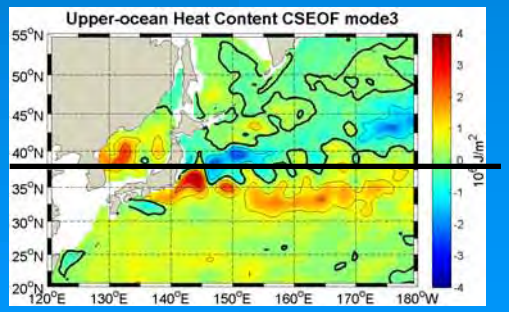
decadal variability during the 40 years

Regression of upper-ocean temperature

38°N zonal section

target: heat content

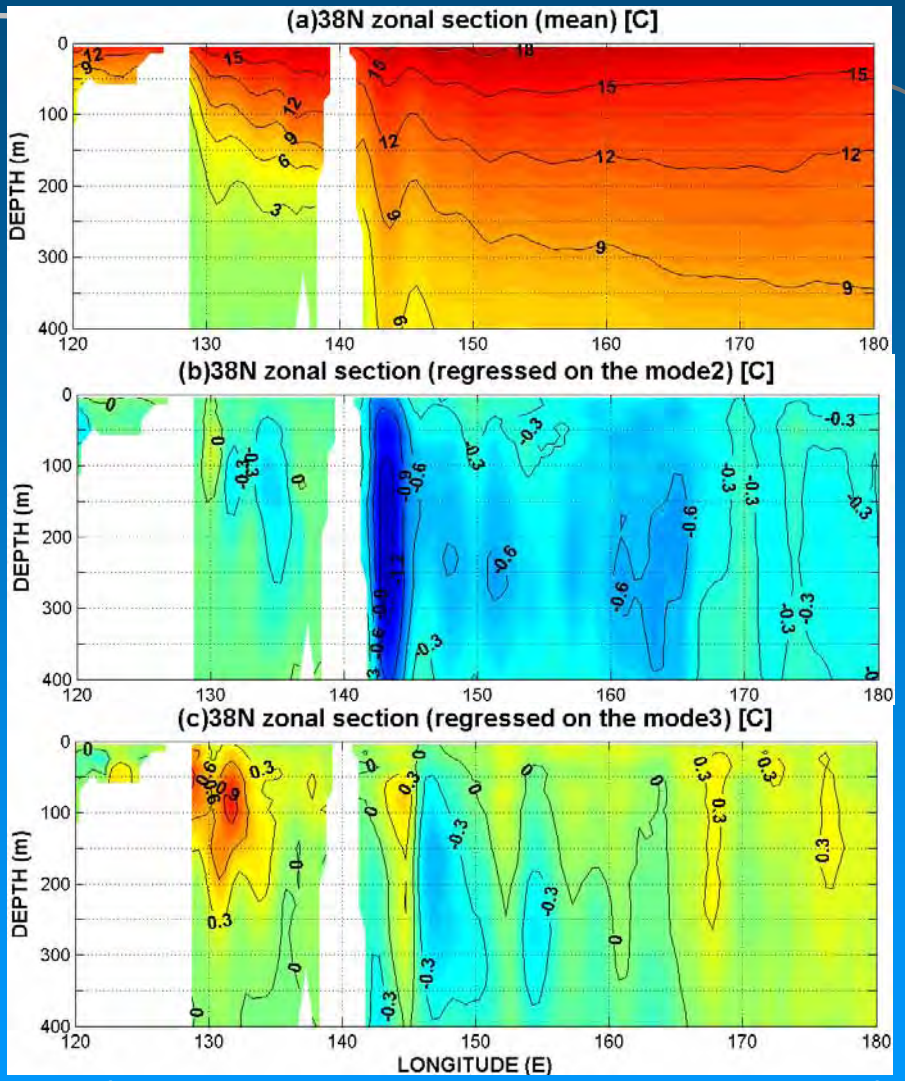




Mean temperature

Regressed temperature anomaly (target: mode 2)

Regressed temperature anomaly (target: mode 3)



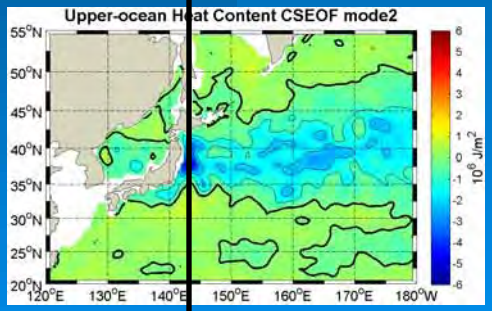
west east

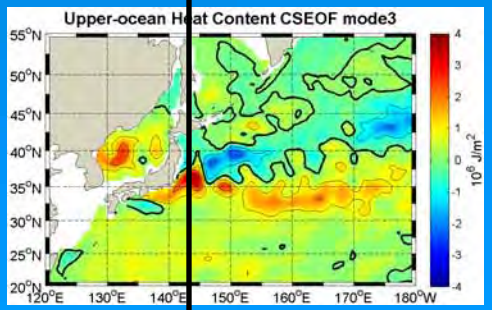
The regressed temperature anomalies show how temperature variability in the upper-ocean contributes to the heat content variability.

Regression of upper-ocean temperature

143°E meridional section

target: heat content

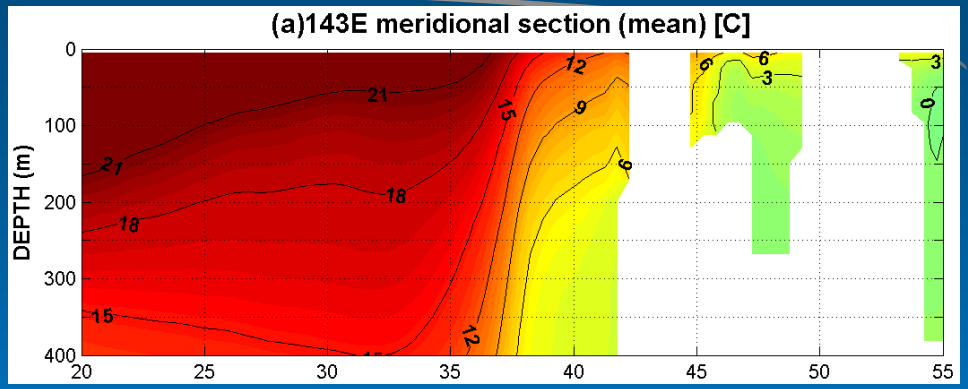


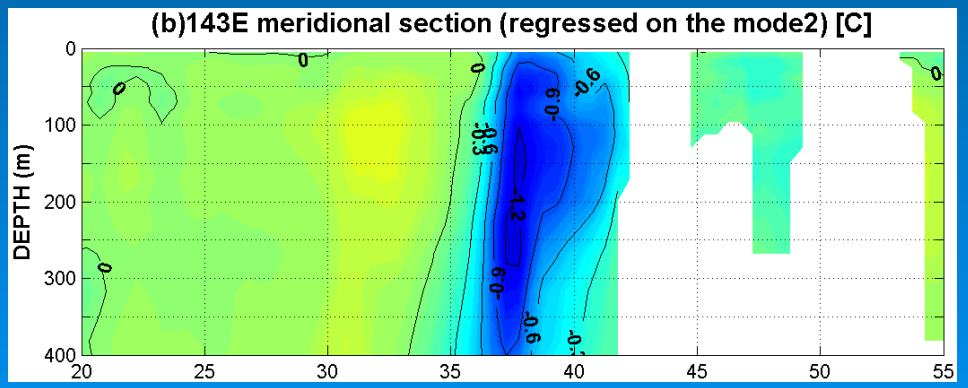


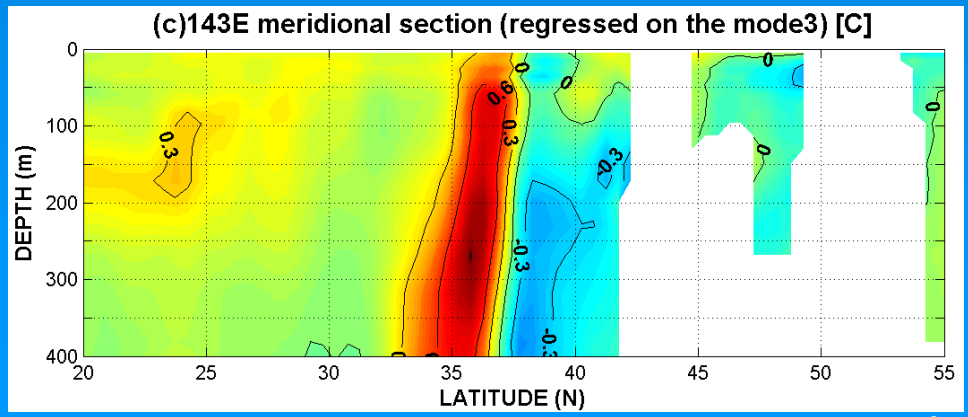
Mean temperature

Regressed temperature anomaly (target: mode 2)

Regressed temperature anomaly (target: mode 3)



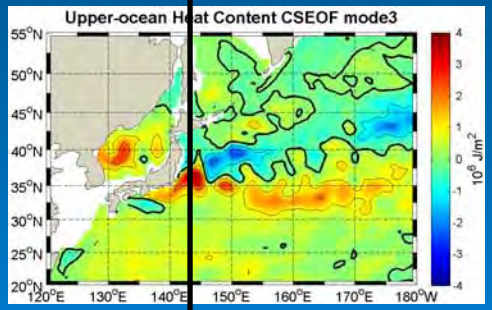




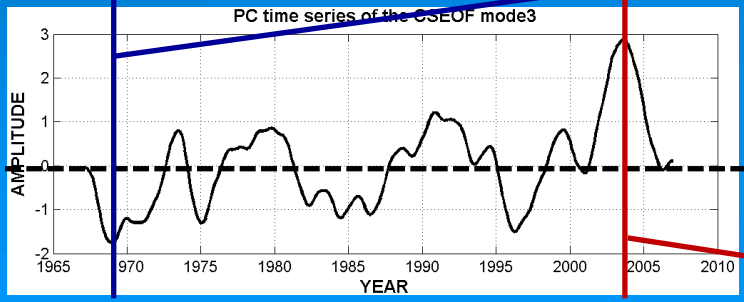
south north

Regression of upper-ocean temperature

143°E meridional section

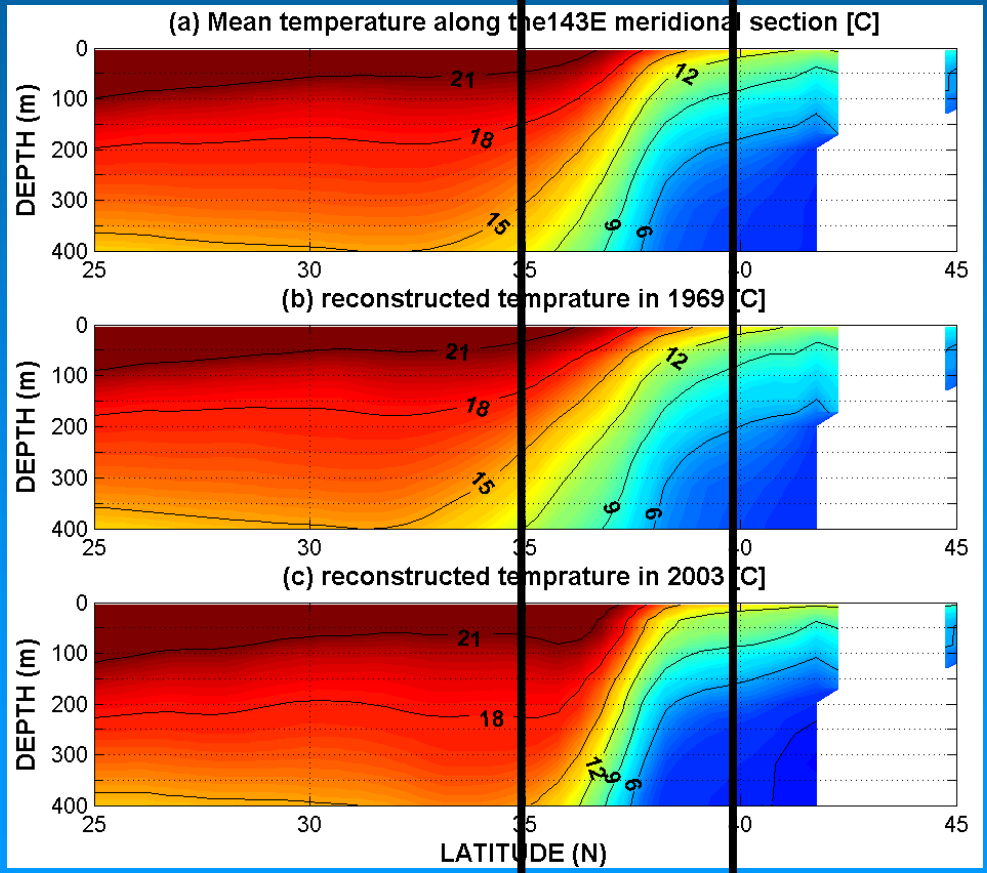


target: heat content mode 3



Differences in steepness of the isotherms and meridional temperature gradient

Mean temperature
+
Reconstructed regressed temperature anomaly

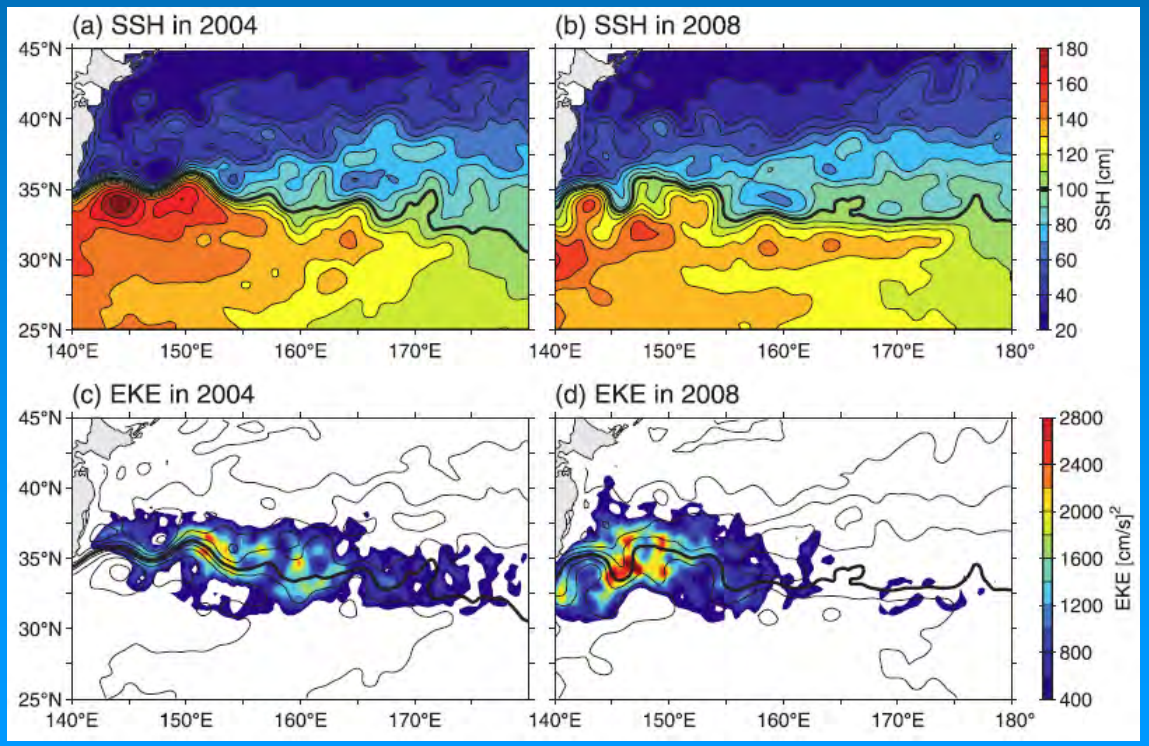


Discussion - Kuroshio Extension

- **Two dynamic states**
  - elongated (stable) state: intense jet, northerly zonal mean path, well-defined southern recirculation gyre
  - contracted (unstable) state: reduced eastward transport, more southerly flow path
  - Qiu and Chen, 2005; Kelly et al., 2007; Qiu and Chen, 2011

elongated state

- Transport ↑
- Southern recirculation gyre strength ↑
- Latitudinal position ↑
- EKE in the upstream KE region ↓



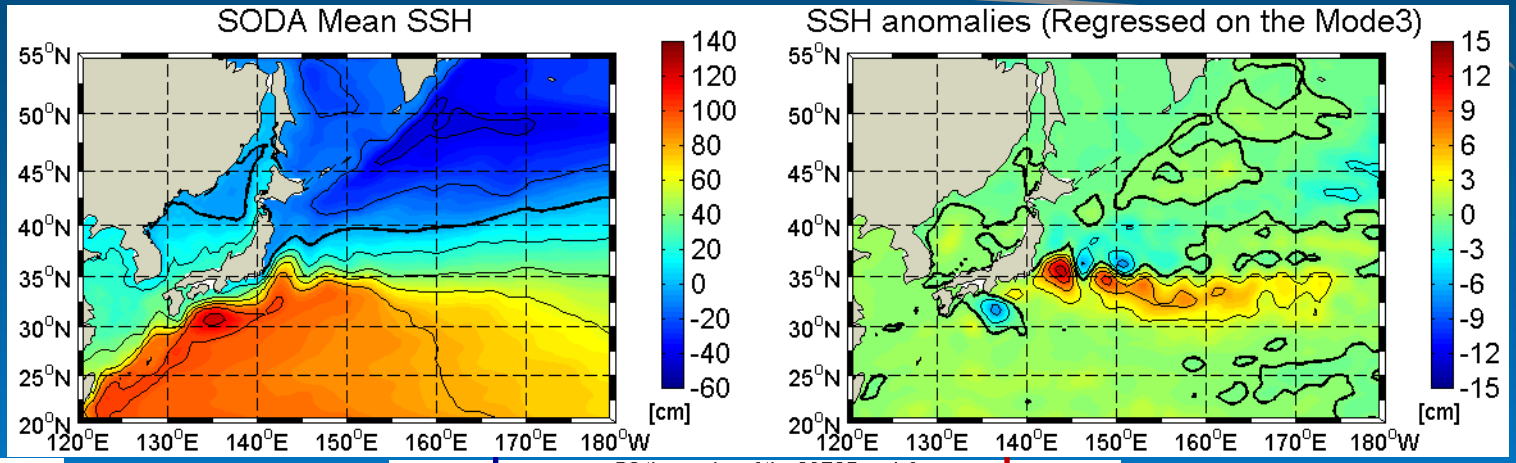
contracted state

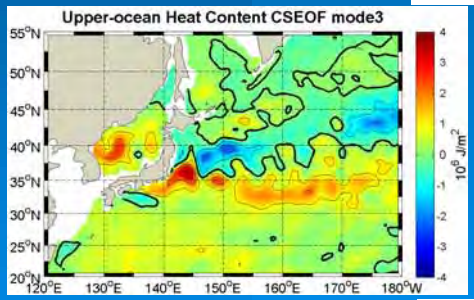
- Transport ↓
- Southern recirculation gyre strength ↓
- Latitudinal position ↓
- EKE in the upstream KE region ↑

Qiu and Chen, 2011

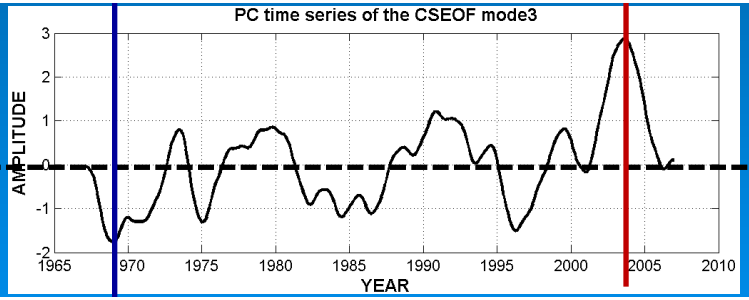
Discussion - Regression of SSH

Target:
heat content
mode 3





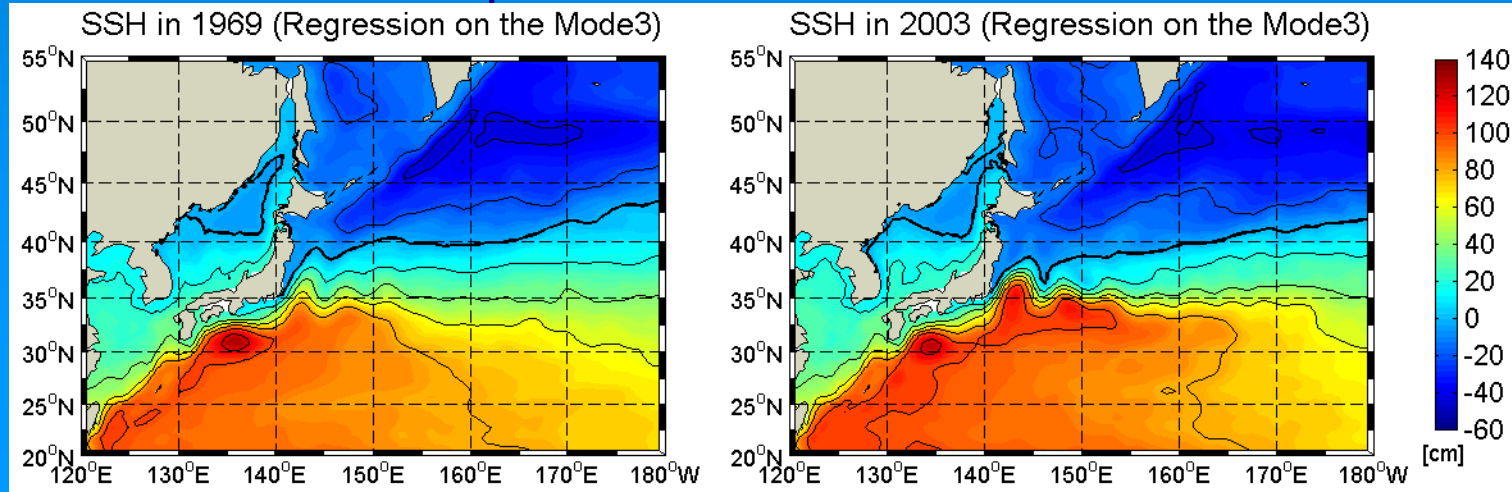
contracted state



R-squared:
0.87

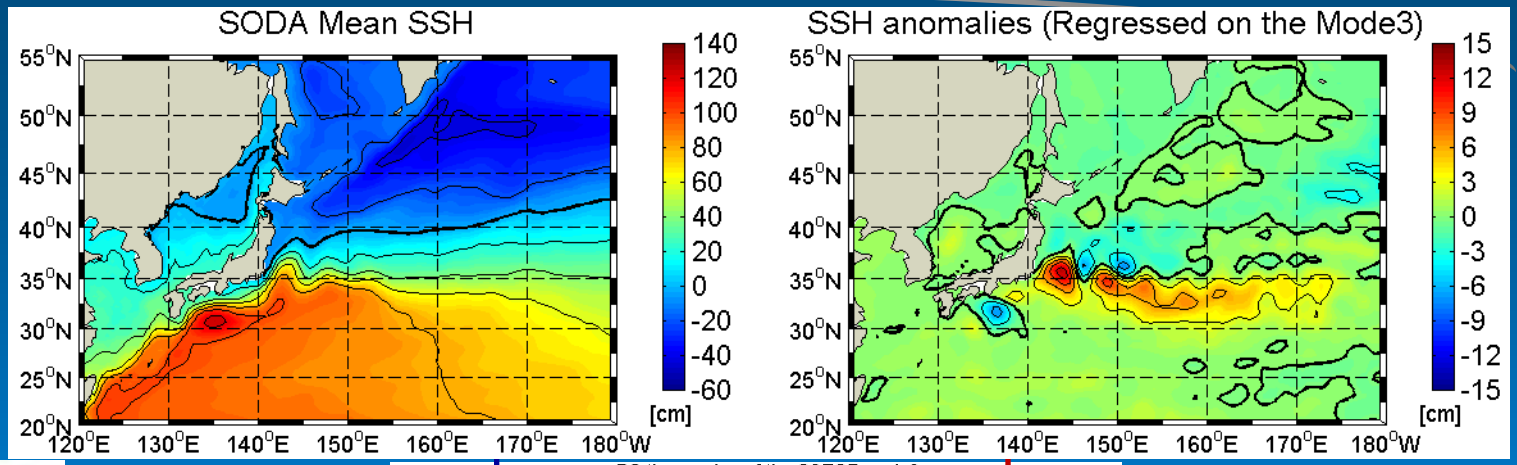
elongated state

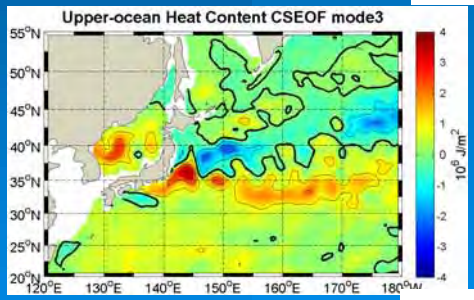
Jet intensity
&
Southern
Recirculation
Gyre



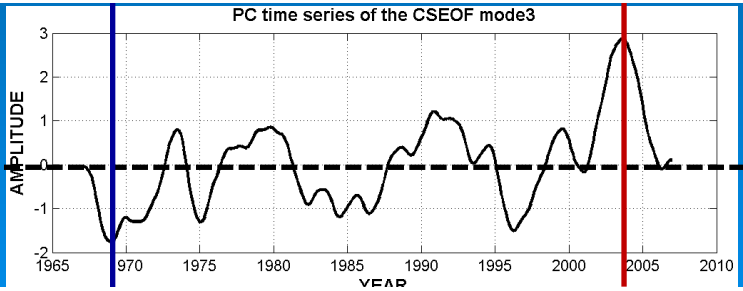
Discussion - Regression of SSH

Target:
heat content
mode 3





contracted state



R-squared:
0.87

elongated state

Jet intensity
&
Southern
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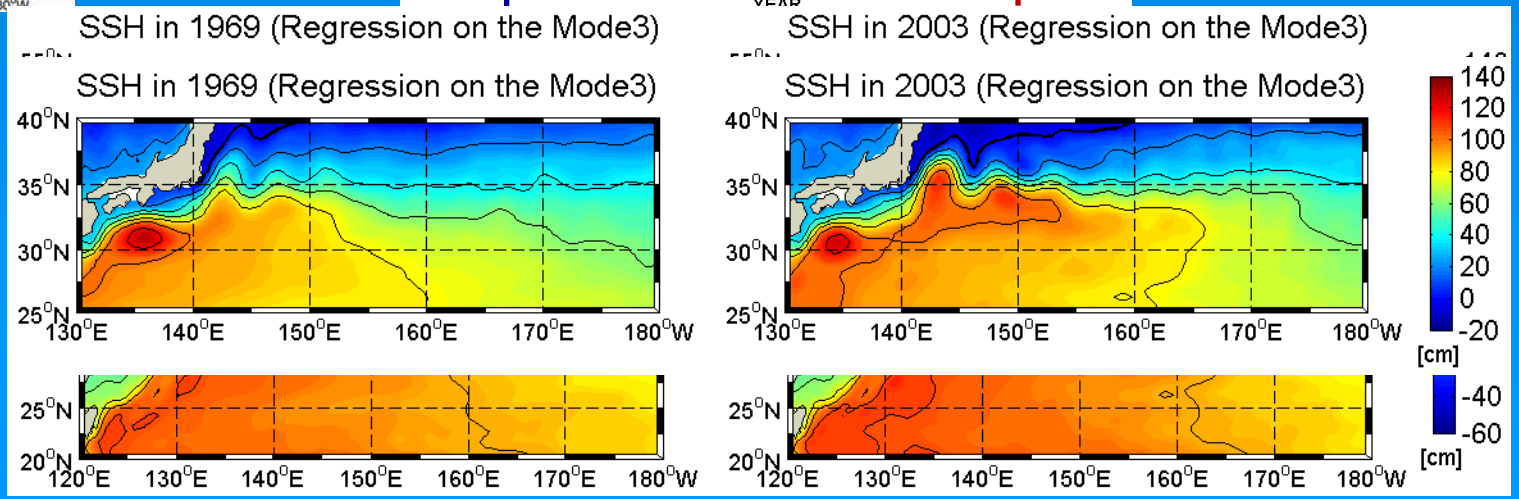
Gyre



Summary

- **Upper-ocean heat content variability in the Northwestern Pacific**
  Monthly means during 40 years from 1967 to 2006
- **Interdecadal transition of the interannual variability (Mode 2)**
  Related to negative trend along the Kuroshio Extension
  Seems to be originated from surface forcing, e.g. air-sea interaction (further investigation is needed)
- **Decadal variability (Mode 3)**
  Positive anomalies in the southern region including the East/Japan Sea and negative anomalies in the northern region (in case of the positive PC time series)
  Related to the meridional temperature gradient and steepness of the isotherms
  Related to the two dynamic states (elongated vs. contracted) of Kuroshio Extension
  Related to the SSH variability (intensity of jet & strength of the recirculation gyre) over the Kuroshio Extension region