Origin of Decadal-Scale, Eastward-Propagating Heat Content Anomalies in the North Pacific

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Introduction

- Decadal climate prediction using climate models with initialized ocean states

- Subsurface ocean conditions such as sea surface height (SSH) and ocean heat content (OHC) are keys for assessing and improving decadal prediction experiments

- Observations and modeling outcomes suggest a dichotomy in the mid-lat. Pacific Ocean:
  - SSH signals often propagate westward as equivalent barotropic Rossby waves (RWs)
  - OHC signals that propagate eastward are associated with higher baroclinic Rossby waves and spiciness anomalies

- Test the hypothesis on the propagation features, distinguish two processes support OHC signal propagation, and the origin of the waves and linkage between two signals

Method

➢ Model Description

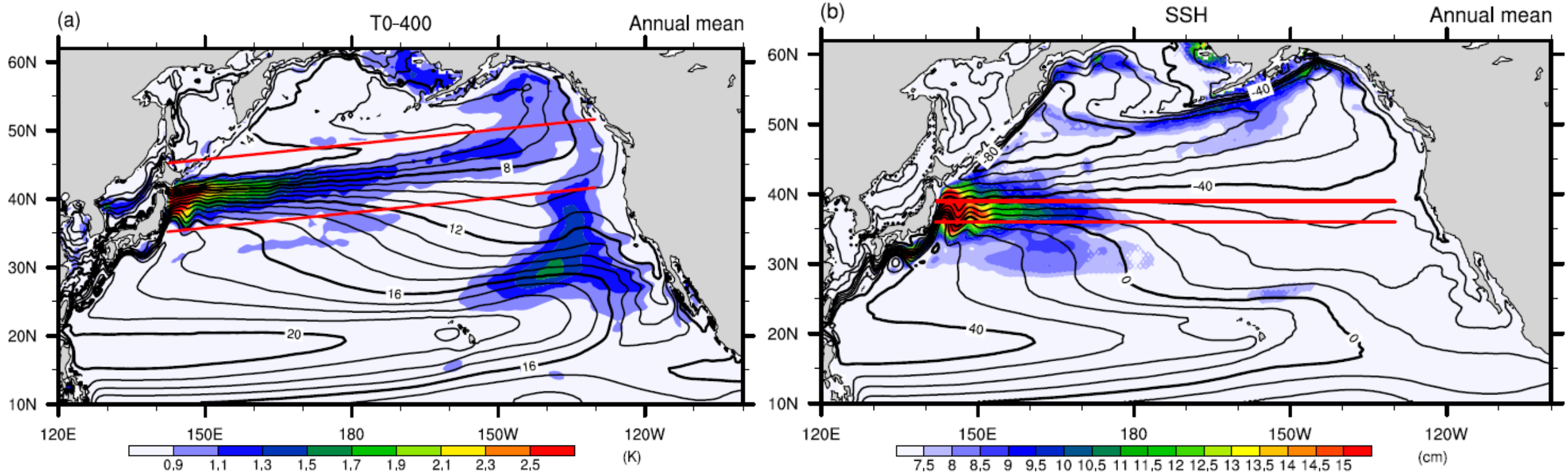
- CGCM for the Earth Simulator (CFES) 150 years control simulation
  - atm: Atmospheric GCM (AGCM) for the ES (AFES)

    based on the Center for the Climate System Research (CCSR)-National Institute for Environmental Studies (NIES) AGCM, ver. 5.4.02
  - ocn: Coupled Ocean-Sea Ice Model for the ES (OIFES)

    based on the Modular Ocean Model, ver. 3 (MOM3)
- Resolution:
  - atm: T119 spectral truncation (~100 km) grid, 48 vertical σ levels
  - ocn: 0.5° horizontal grid, 54 z-coordinate levels
- Initial condition:
  - atm: 40-yr ECMWF Re-Analysis (ERA-40) January 1 climatology
  - ocn: *World Ocean Atlas 1998* January climatology
- Coupling interval: 1 hour

Result

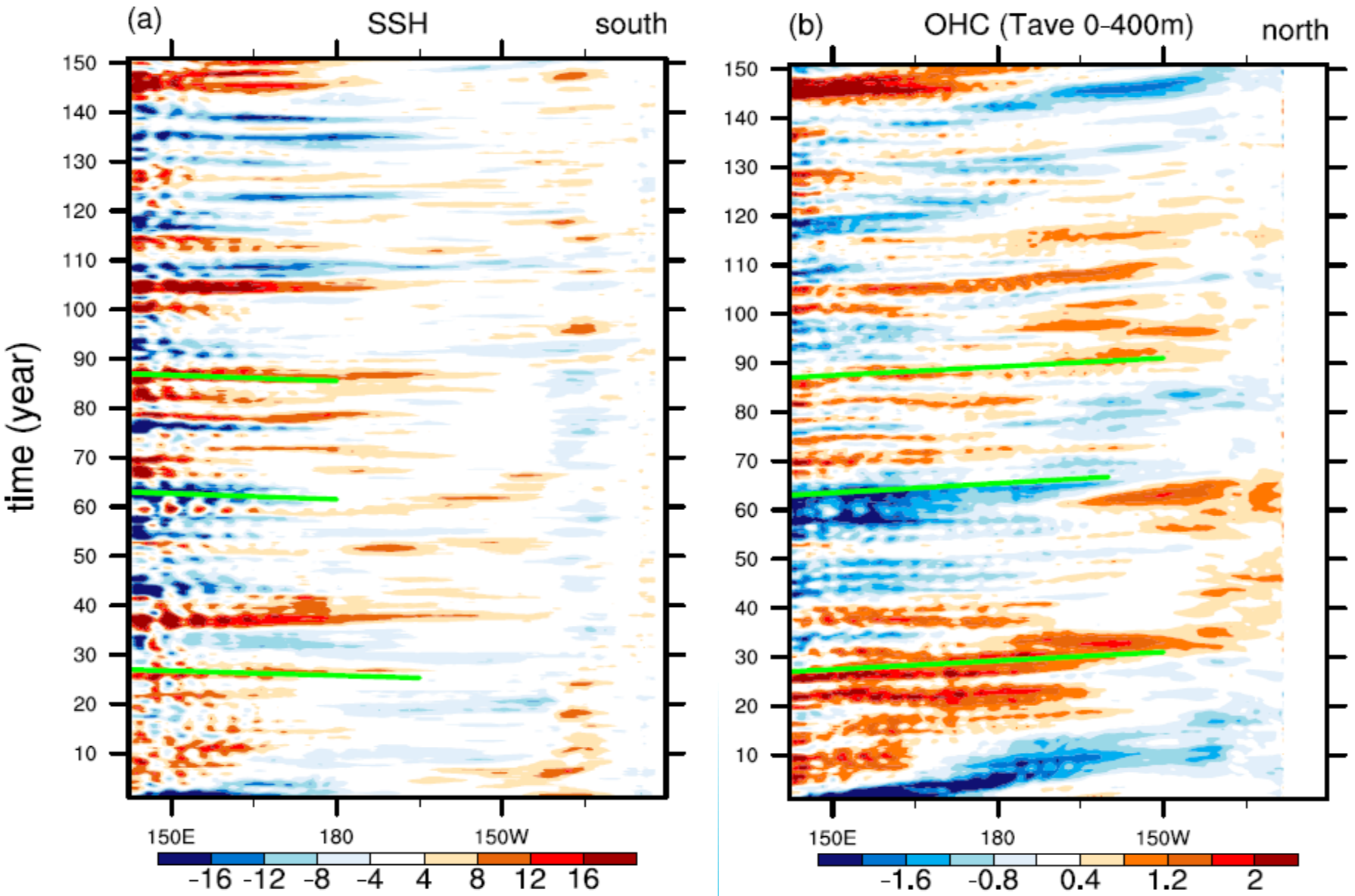
➢ Propagating Signals and Vertical Structures



- Kuroshio-Oyashio Extension (KOE) region:
  - Northern band: the subarctic front (SAF)
  - Southern band: the Kuroshio Extension (KE)

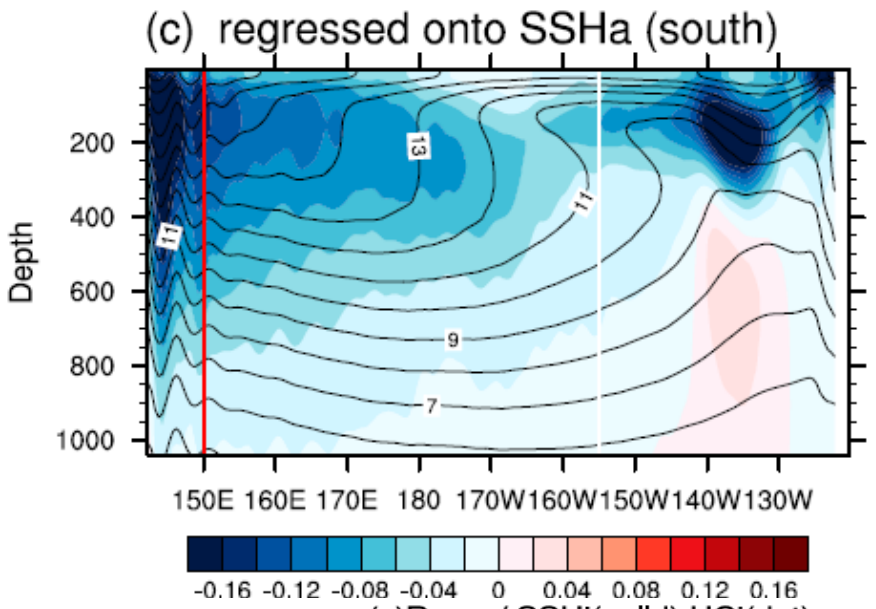
Result

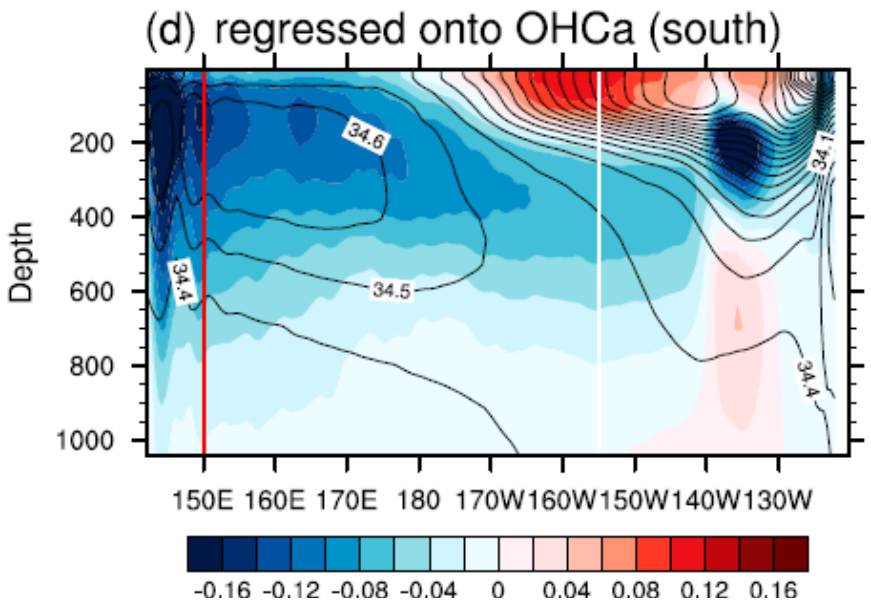
➢ Propagating Signals and Vertical Structures

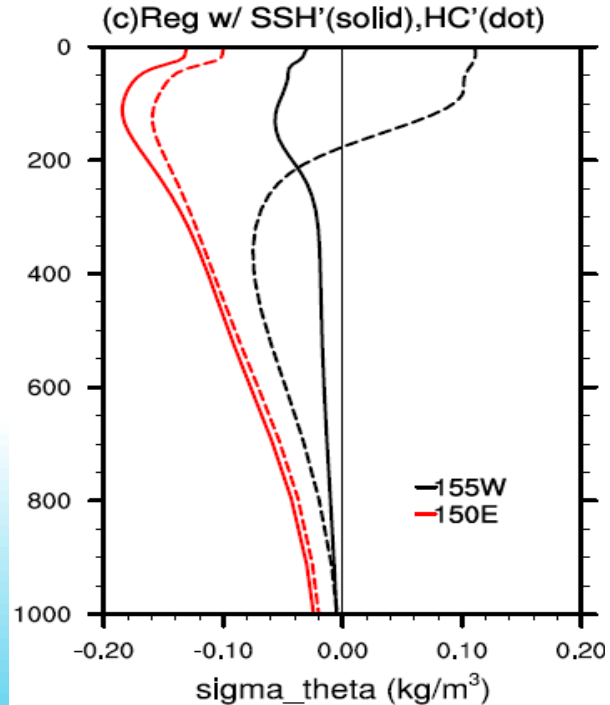


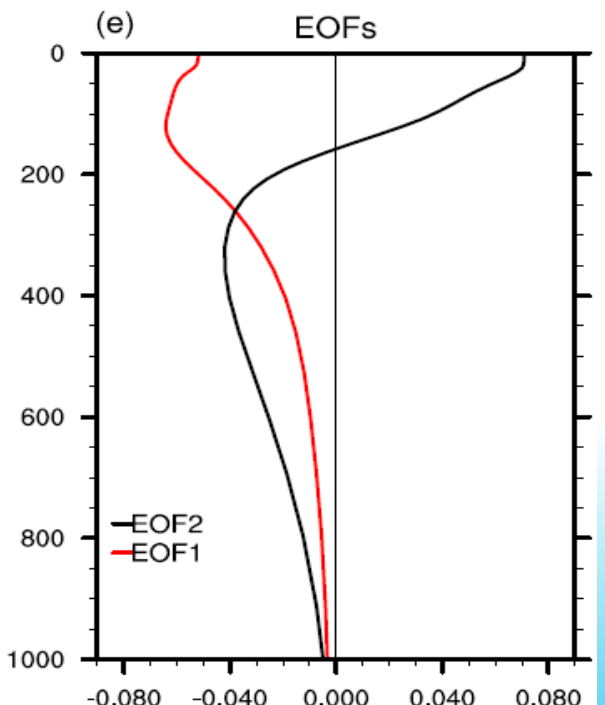
- SSH signals along the southern band are dominated by westward propagation
  - Equivalent barotropic RWs
  - Ekman pumping associated with wind stress curl
- OHC signals along the northern band displays a distinct eastward propagation
  - Matching the zonal current average velocity
- Coupling of these eastward-propagating OHC signals and the westward-propagating SSH signals

Result









➢ Propagating Signals and Vertical Structures

- SSH anomalies
  - Associated with a single-signed vertical structure
  - Maximum loading at the depth of the pycnocline
  - Equivalent barotropic RWs
  - EOF1 (50.6%)

- OHC anomalies
  - West of the date line: equivalent barotropic modes
  - Central to the eastern basin: sign reversal in the vertical depth of lower pycnocline, suggesting higher baroclinic modes
  - West: EOF1; East: EOF2 (25.1%)

Result

➢ Density and Spiciness Components of OHC

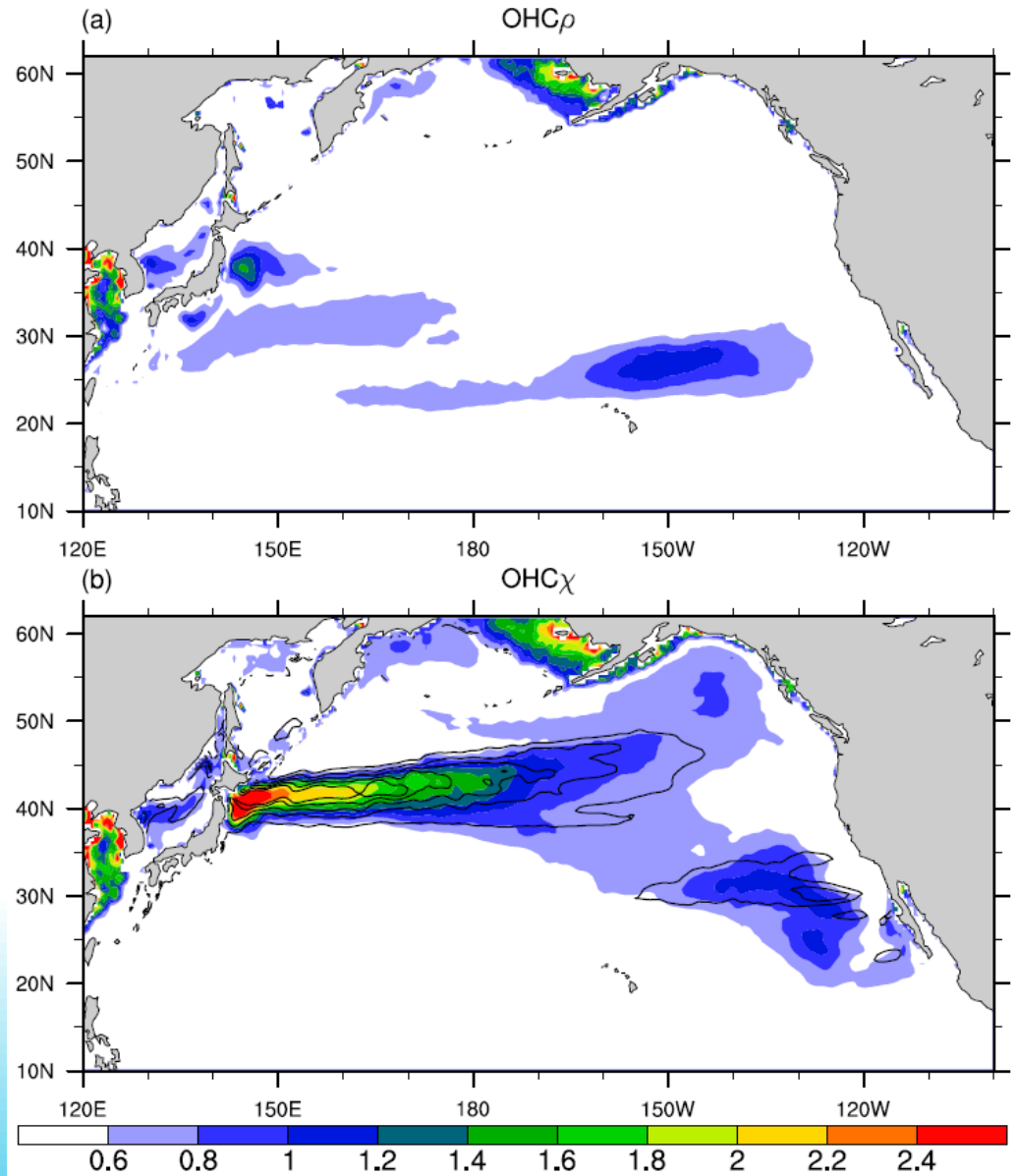
▸ Spiciness (anomalies)

- Changes of temperature along isopycnals
- The subduction and propagation of density-compensated temperature and salinity water-mass perturbations (Sasaki et al., 2010)
- $X_{y\sigma}{}' = X_{y\sigma} - < X >_{y\sigma}$,
  $X: tracer\ T\ or\ S, \sigma: isopycnal, y: year$ (Luo et al., 2005)

Result

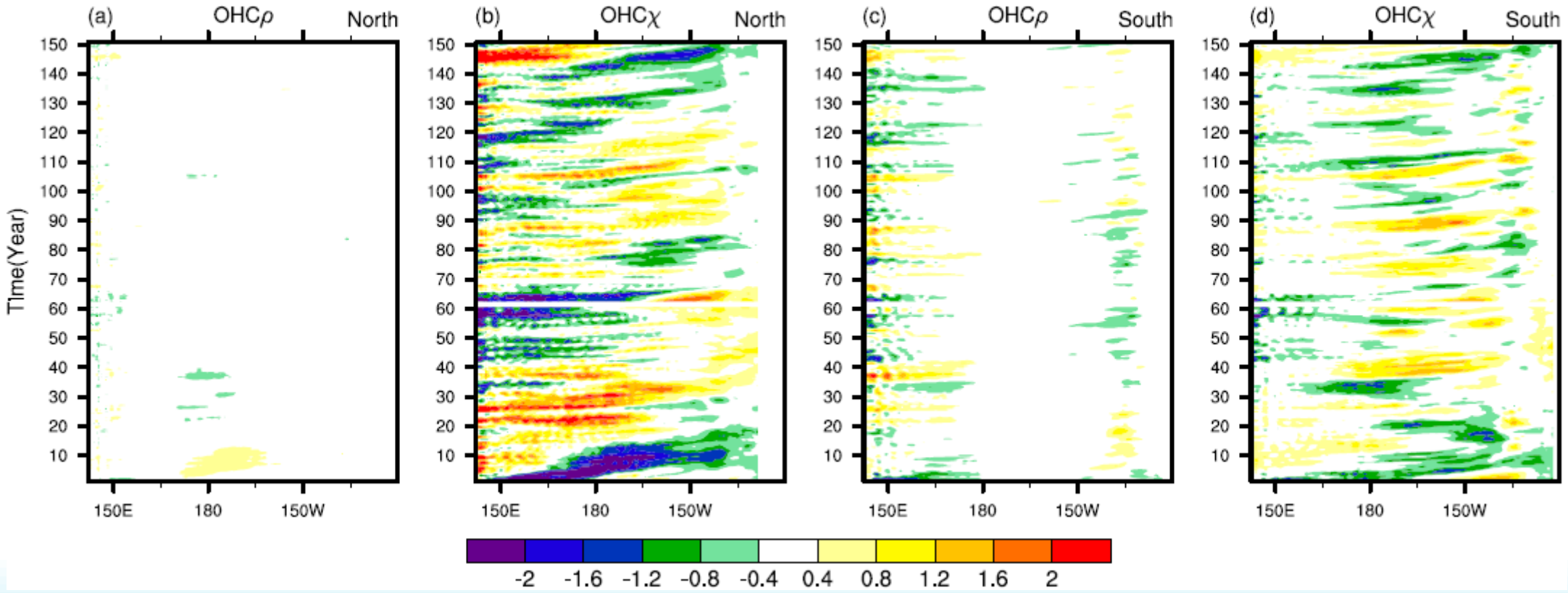
- **Density and Spiciness Components of OHC**
  - **Temperature anomaly decomposition**
    - $\delta T = \frac{\nabla \bar{T} \cdot \nabla \bar{\rho}}{|\nabla \bar{\rho}|^2} \delta\rho + \delta T_\chi$

      $= \delta T_\rho + \delta T_\chi$
    - $OHC = OHC_\rho + OHC_\chi$



Result

- **Density and Spiciness Components of OHC**
  - $OHC = OHC_\rho + OHC_\chi$



- The spiciness component δT_χ dominates the eastward-propagating upper ocean OHC anomalies

Result

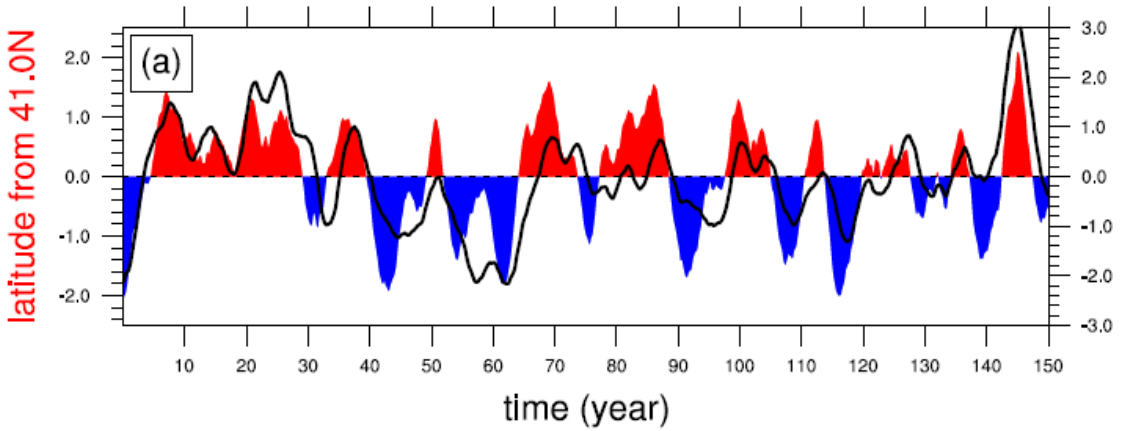
➢ Origin of Eastward-Propagating Signals

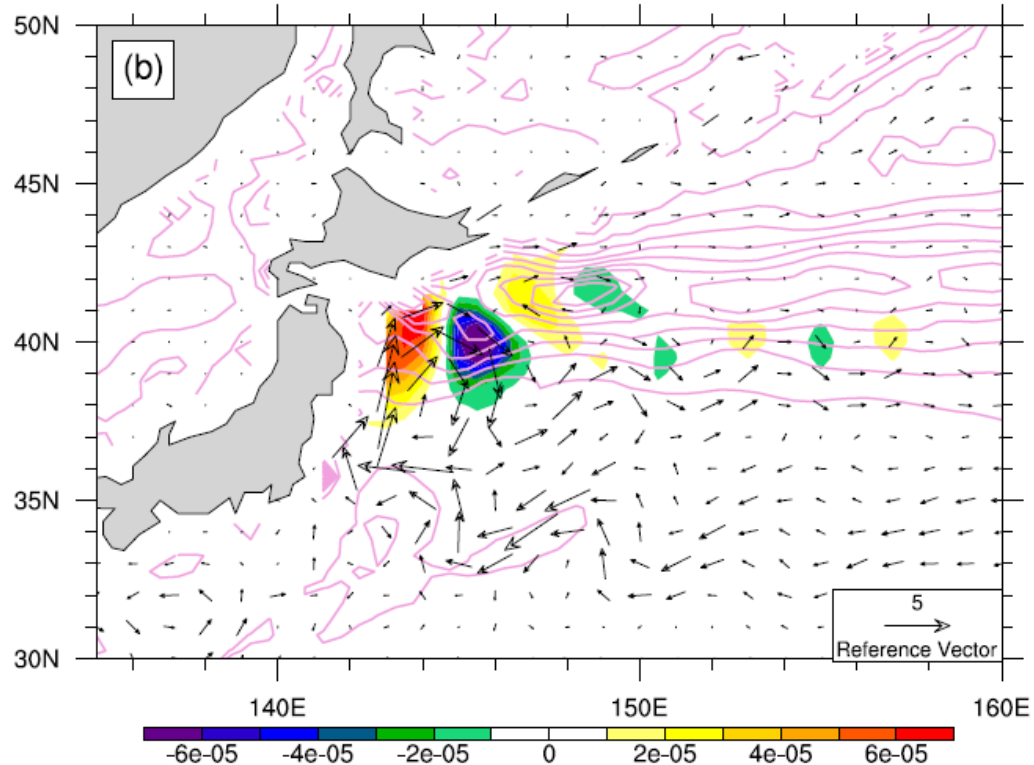
- Spiciness anomaly are generated in the northwestern Pacific Ocean (KOE region)

- Anomalous advection across mean spiciness gradients generates the anomalous advection of the spiciness anomalies

  - Northward component of anomalous currents associated with the axial variability of the subarctic front

  - Large mean spiciness gradients off northern Japan

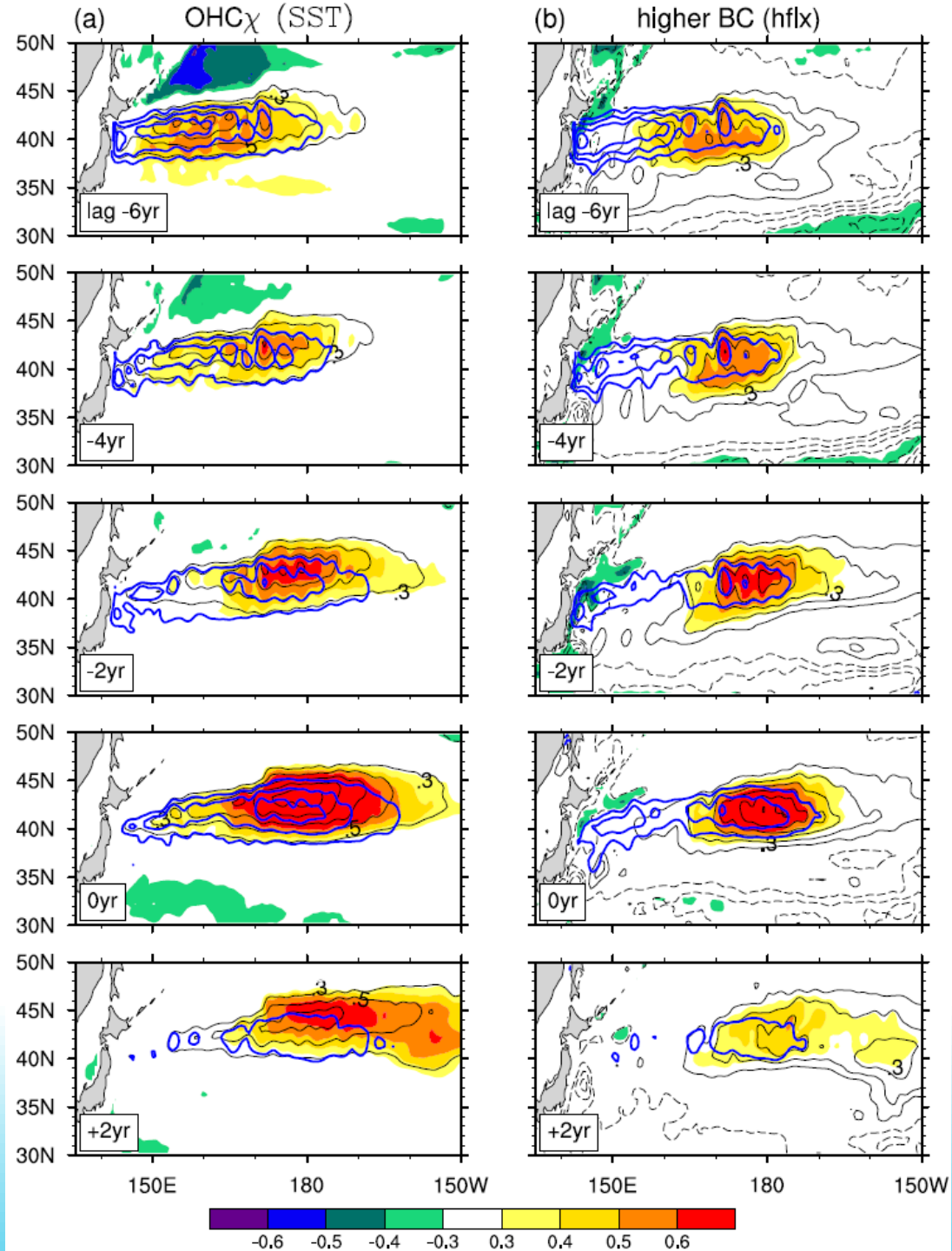




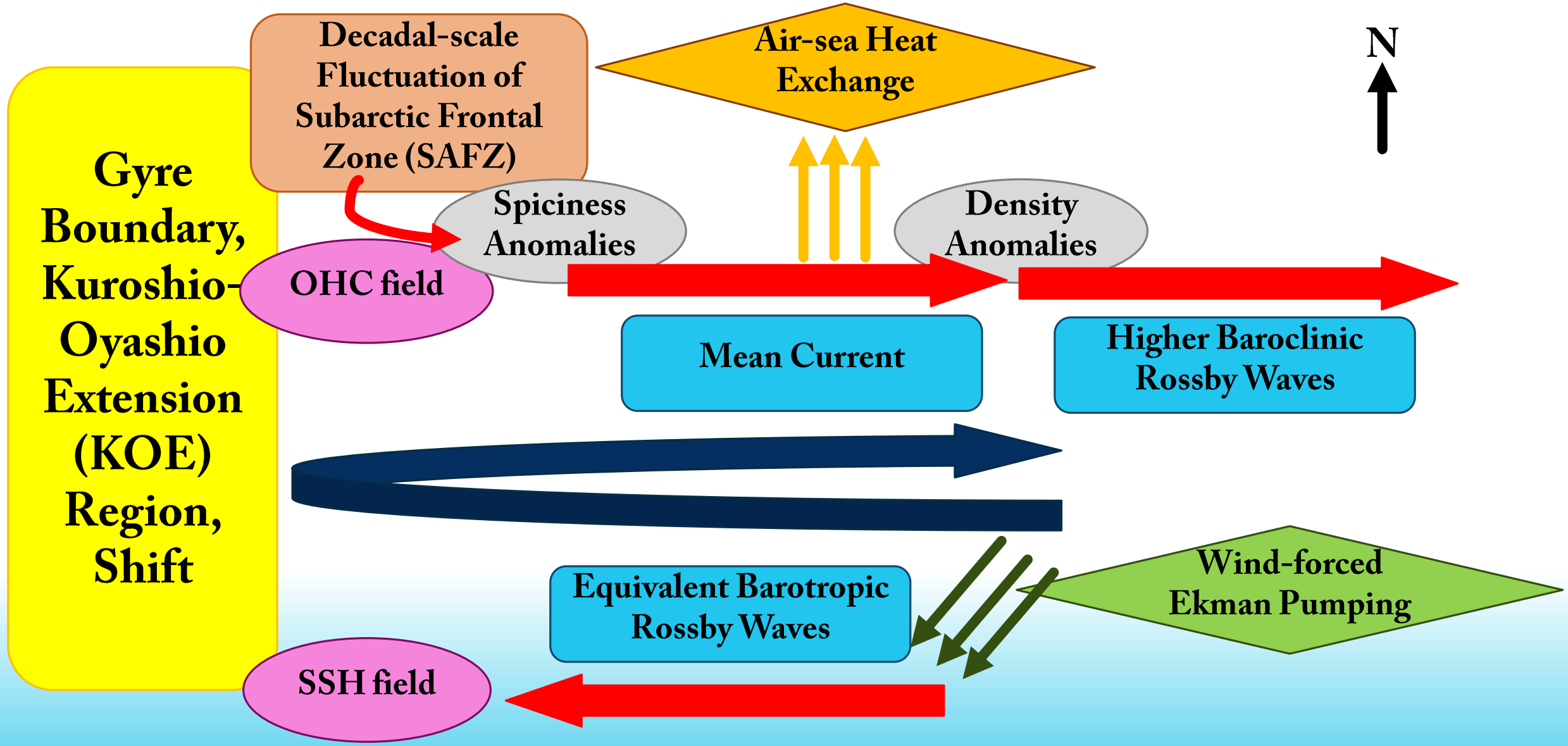
Result

➢ Origin of Eastward-Propagating Signals

- Eastward-propagating OHC_χ anomalies originate from the KOE region at a -6-yr lag
- OHC_χ is associated with SST anomalies that are damped by air-sea heat flux anomalies
- Air-sea heat flux disrupts the density compensation in the spiciness anomalies
- Higher baroclinic mode RWs can be detected downstream of the heat flux anomalies



Summary and Discussion



Summary and Discussion

- The dynamics of the decadal-scale propagating signals of sea surface height (SSH) and upper ocean heat content (OHC) anomalies in the North Pacific simulated in a 150-yr coupled atmosphere-ocean general circulation model (CGCM) integration

- Decadal-scale latitudinal displacement of the SAFZ to transform the wind-forced westward-propagating SSH signals into the eastward-propagating OHC signals

Reference

- Luo, Y., Rothstein, L. M., Zhang, R. H., & Busalacchi, A. J. (2005). On the connection between South Pacific subtropical spiciness anomalies and decadal equatorial variability in an ocean general circulation model. *Journal of Geophysical Research: Oceans*, *110*(C10).

- Sasaki, Y. N., Schneider, N., Maximenko, N., & Lebedev, K. (2010). Observational evidence for propagation of decadal spiciness anomalies in the North Pacific. *Geophysical Research Letters*, *37*(7).

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Thanks for Listening