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On the effect of atmospheric forcing on the upper heat content variability in the Japan/East Sea from 1948 to 2009

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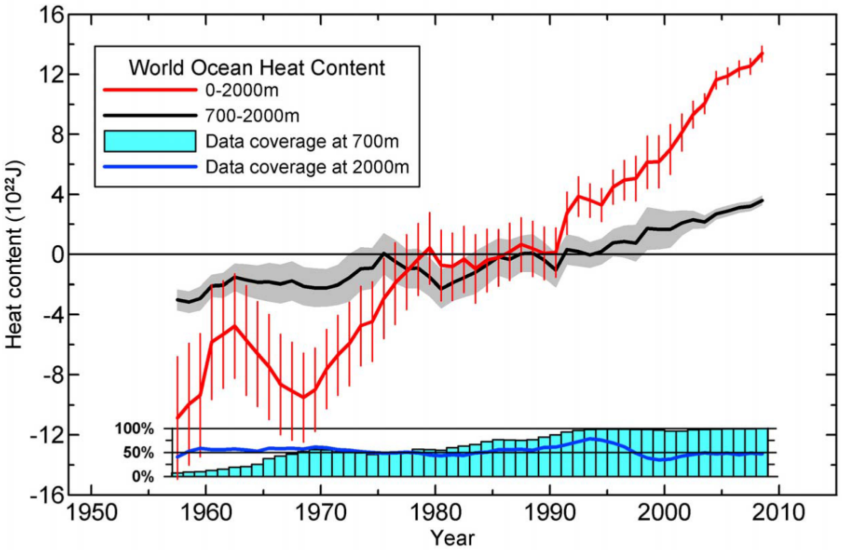
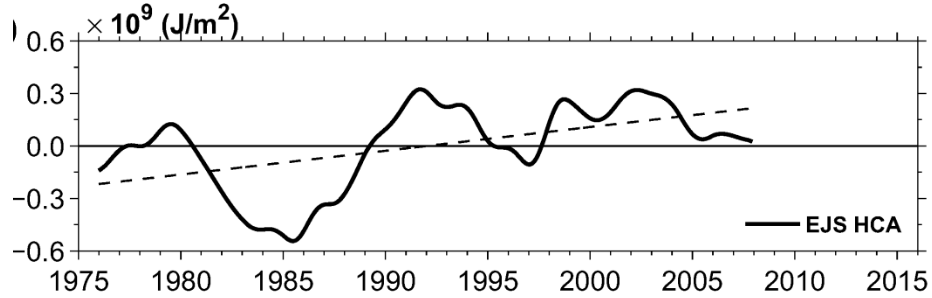
World Ocean heat content and Japan/East Sea heat content

$$HC = \int_V c_p \rho_0 \left(T - T_{\text{clim}}\right) dV$$



Time series of ocean heat content (Levitus S. et al. GRL. 2012)



Heat content variability in the southeastern Japan/East Sea (Na H. et al. JGR 2012; Yoon S. et al. JGR 2016)

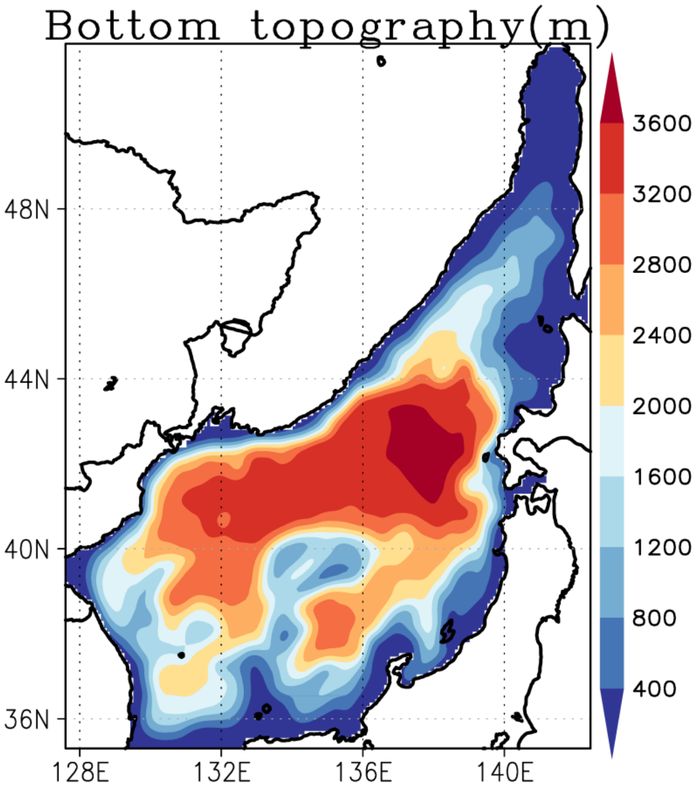
At studying the Japan/East Sea heat content, we face the problem of separating the atmospheric forcing impact from the strait impact on its variability.

High-resolution retrospective numerical simulations are used to investigate the upper layer (0-300 m) heat content variability in the Japan/East Sea and the atmospheric forcing impact on this variability.

Outline

1. Model configuration description
2. Validation of the simulated circulation. Heat budget, mean state and variations of the upper heat content in the Japan/East Sea.
3. Spatial and temporal upper heat content variability and the mechanisms responsible for this variability.
4. Conclusions

Model configuration



INMOM is a sigma-coordinate model based on the primitive equations of ocean dynamics with hydrostatic and Boussinesq approximations.

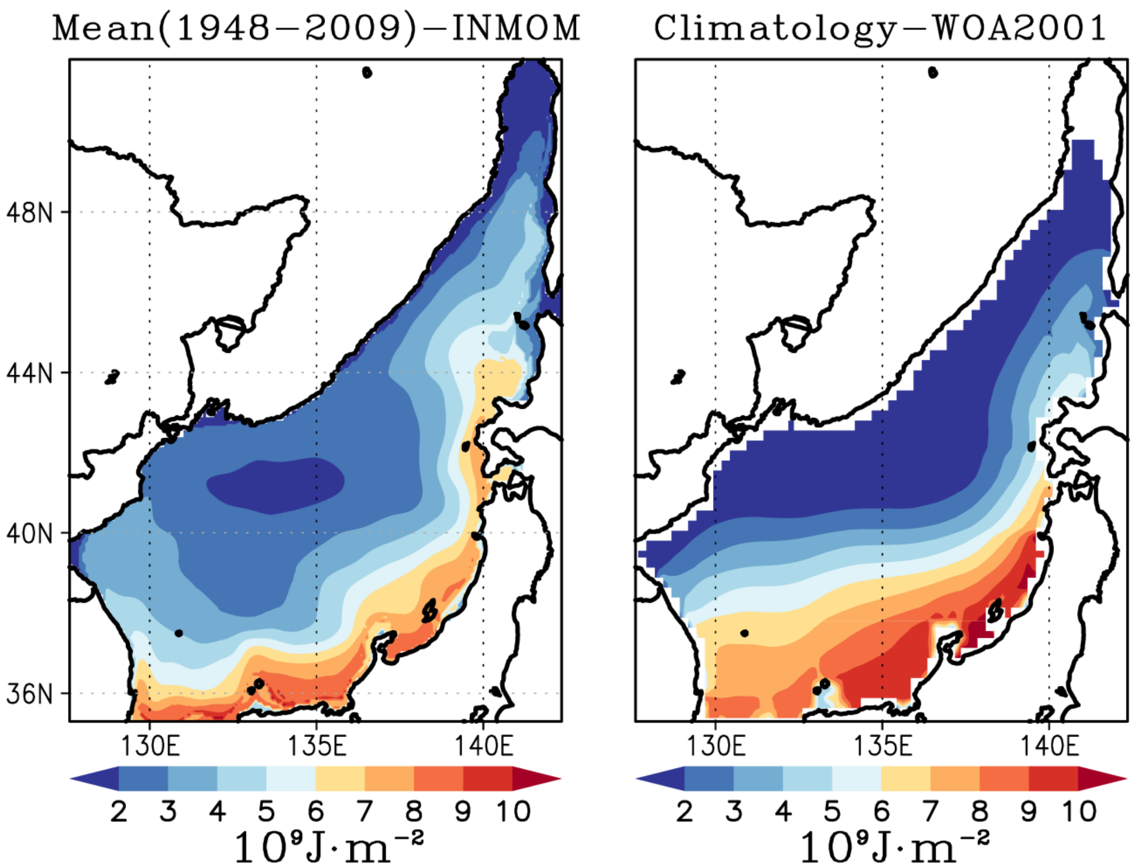
Model Parameters and Boundary conditions

The model is implemented with a horizontal resolution of $1/12^0$ and 30 sigma-levels in the vertical direction. Parameterizations include a Laplacin mixing of temperature and salinity along the geopotential surfaces, a horizontal biharmonic viscosity. Vertical mixing is parameterized according to the Kochergin parametrization and convective mixing is parameterized by enhanced vertical viscosity and diffusivity. Initial temperature and salinity were extracted from the WOA 2001. Temperature and salinity are nudged to their climatological values in the region of the straits.

Atmospheric forcing

Atmospheric parameters are extracted from the CORE phase II dataset. The data with the spatial resolution of about 1.9^0 were collected from 1948 to 2009. The computation of heat, salt and momentum fluxes is done using the bulk-formulae. Our experiment runs from 1948 to 2009 and time of spin-up amounts to 4 years.

Mean upper heat content in the Japan/East Sea



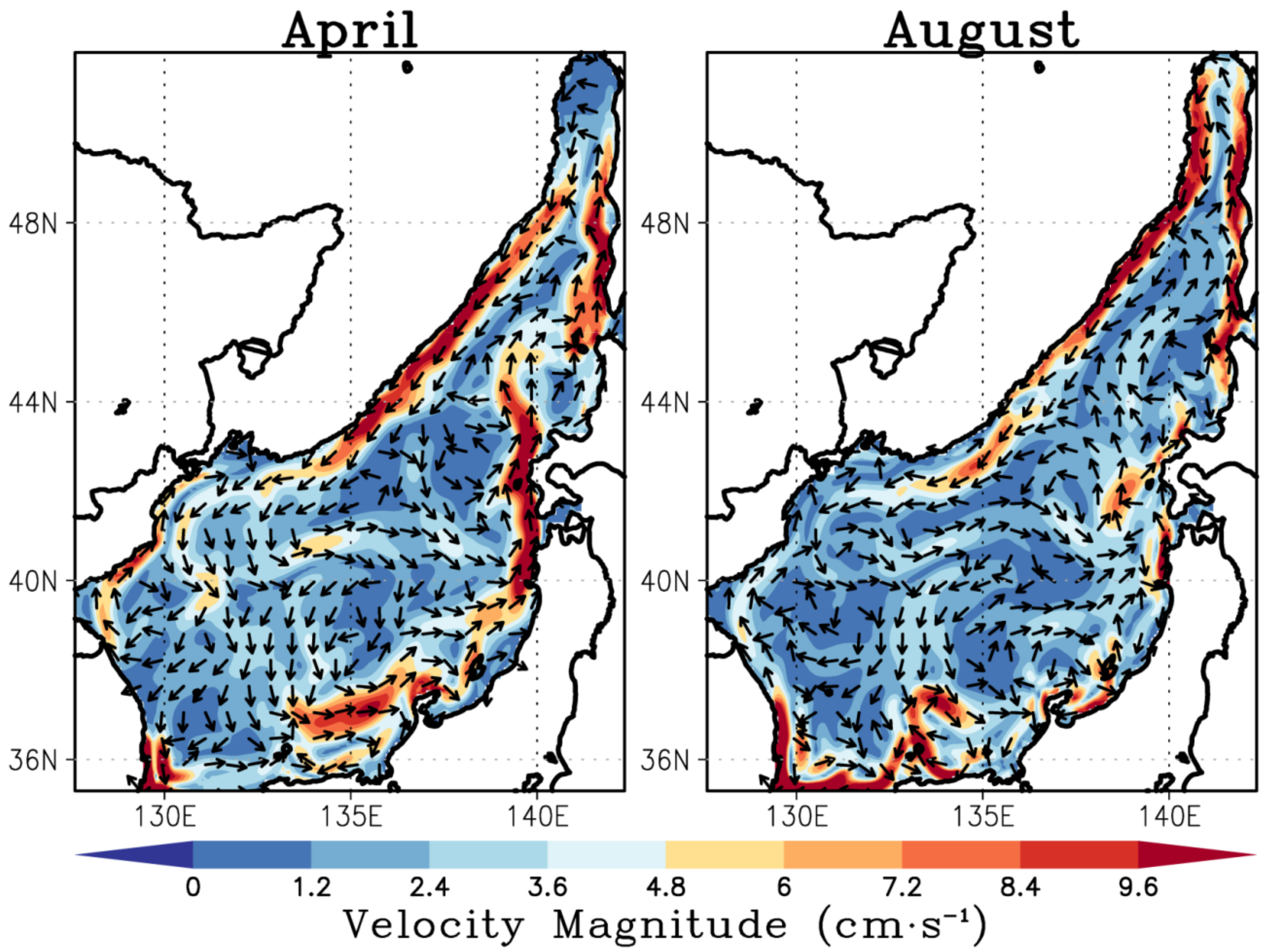
$$HC_c = \int_0^{300} c_p \rho_0 \left(T_{\text{clim}} - \overline{\langle T_{\text{clim}} \rangle} \right) dz,$$

$$\langle T_{\text{clim}} \rangle = \frac{1}{V} \int_V T_{\text{clim}} \, dV,$$

$$c_p = 4000 \, J / (kg \cdot K), \;\; \rho_0 = 1025 \, kg / m^3$$

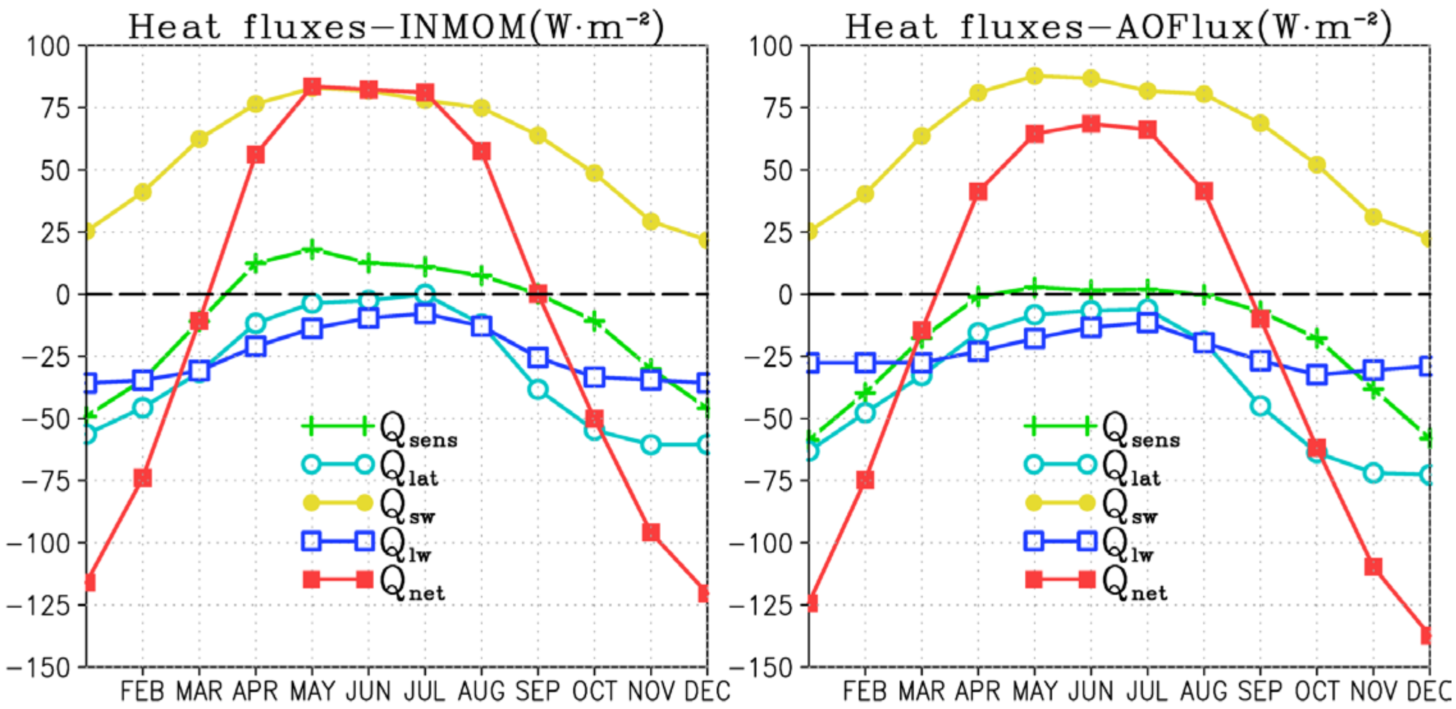
Mean (1948-2009) heat content, integrated in the top 300 m, calculated from numerical simulation outputs and World Ocean Atlas 2001 climatology.

Simulated Circulation in the Japan/East Sea, 1948-2009



Mean velocity field averaged in the top 300 m.

Mean heat fluxes over the Japan/East Sea, 1948-2009



Q_{net} = – 9 W/m^2

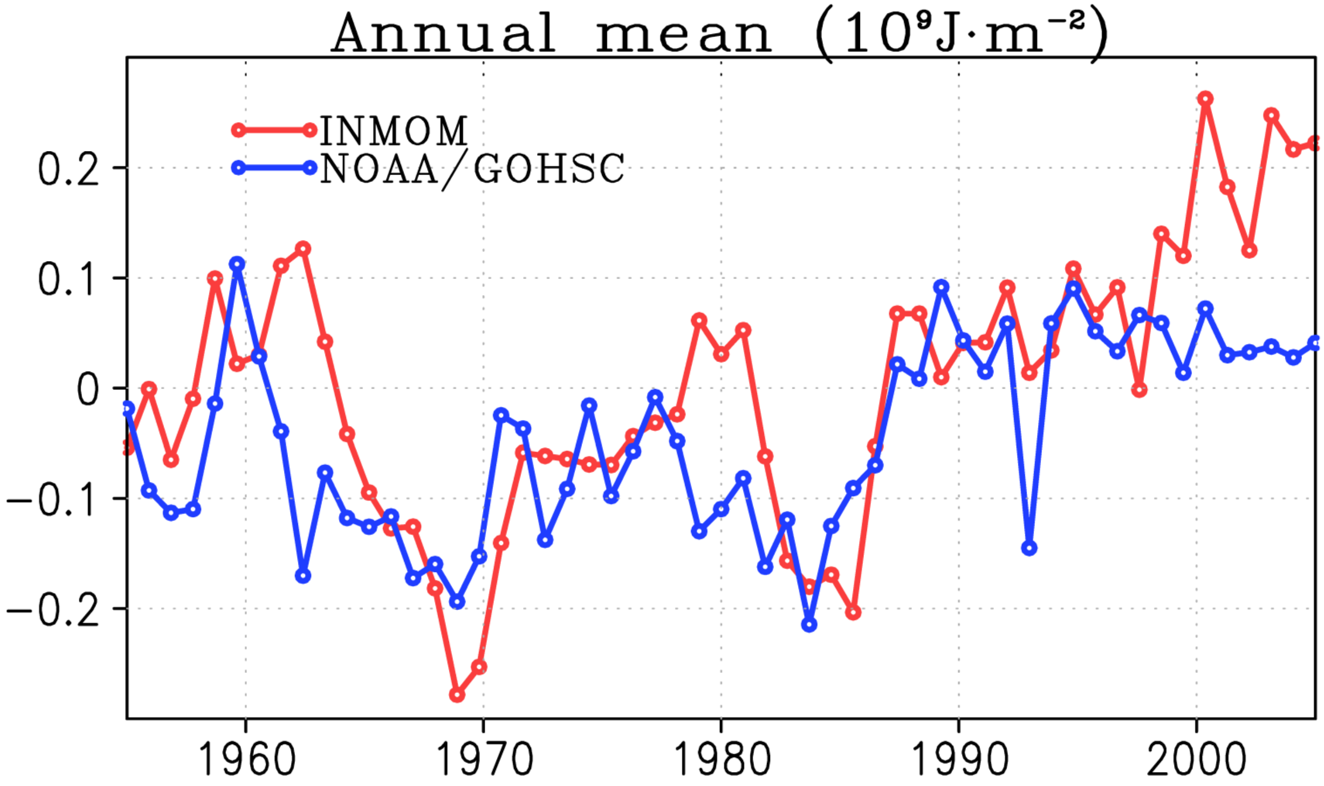
Q_{net} = – 21 W/m^2 (AOFlux Yu et al. BAMS 2007)

Q_{net} = – 53 W/m^2 (Hirose N. et al. J. Oceanogr. 1996)

Mean seasonal variations of the heat fluxes from the model configuration and the AOFlux dataset. Positive value indicates that the sea gains heat from the air.

The Japan/East Sea Heat Content Variability

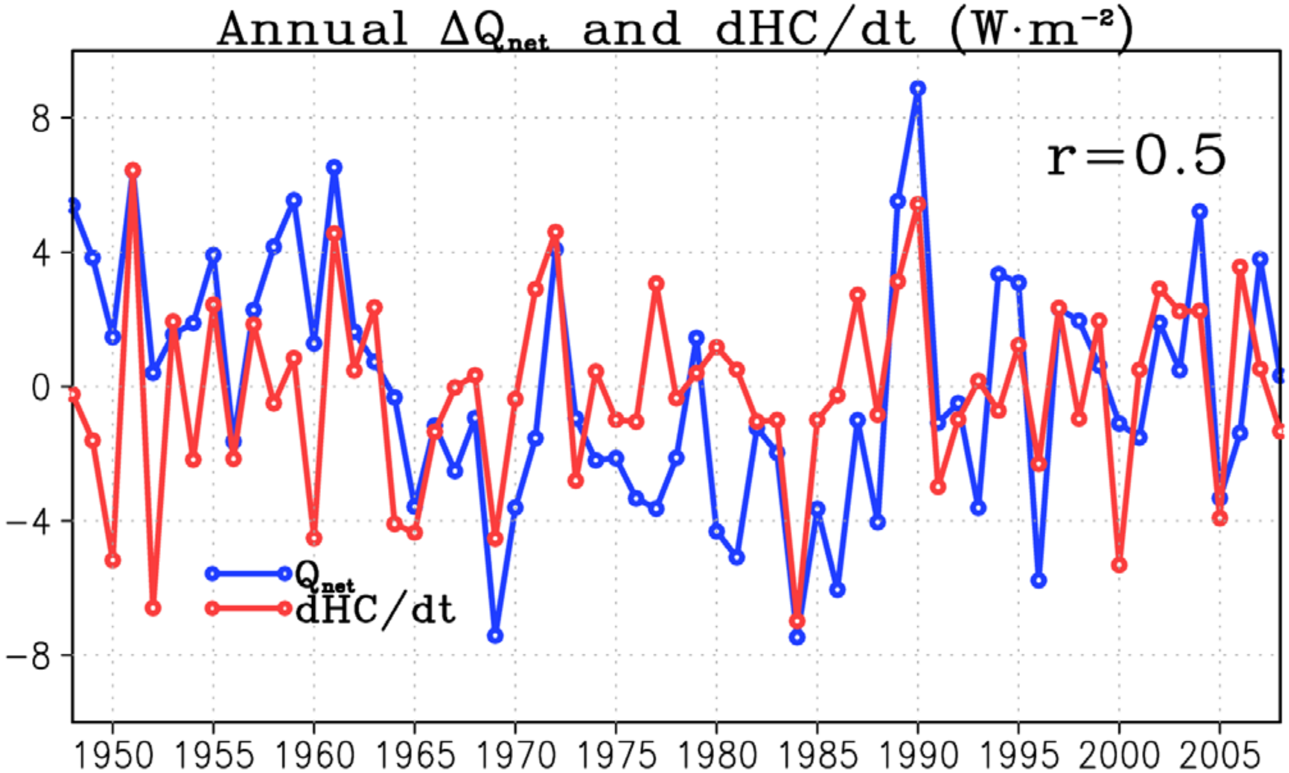
$$\langle HC \rangle = \frac{1}{V_2} \int_{V_2} c_p \rho_0 (T - T_c)\, dV$$



Time series of the annual variations of the Japan/East Sea heat content, integrated in the top 700 m, calculated from the model outputs (red line) and the NOAA dataset (blue line).

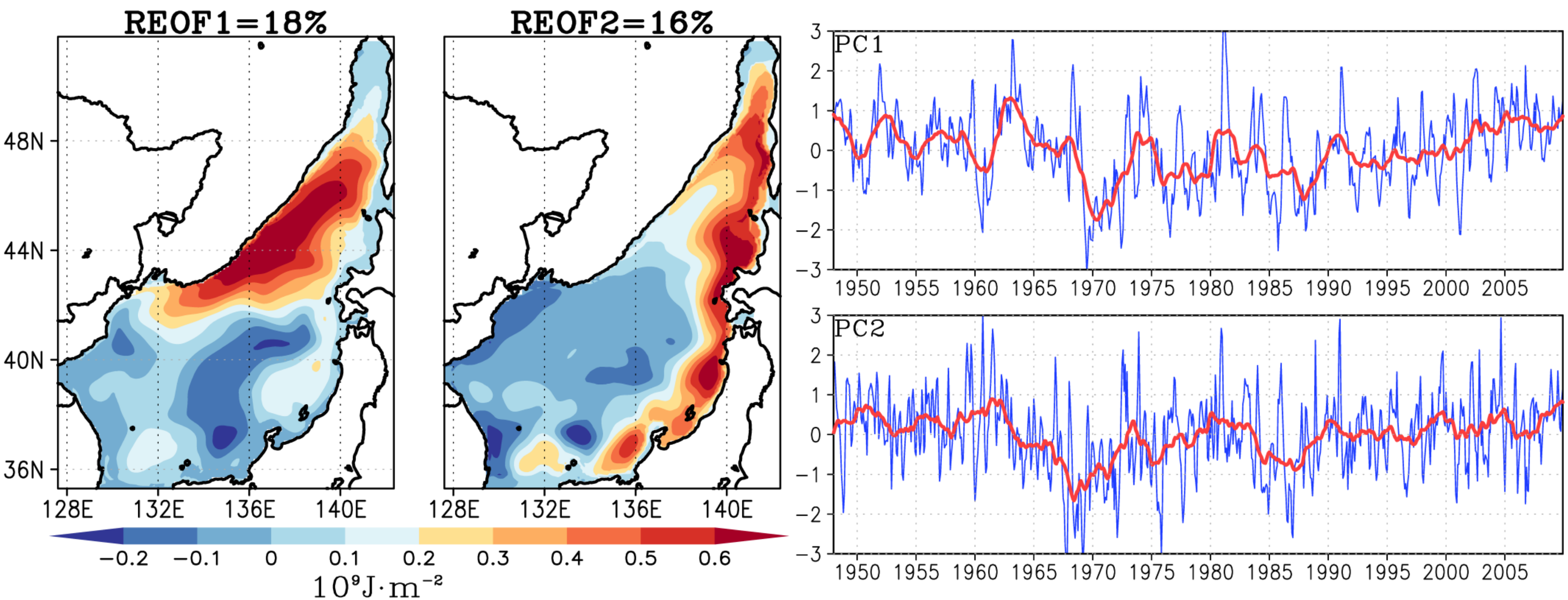
Heat budget in the Japan/East Sea, 1948-2009
Upper layer

$$\frac{\partial \langle HC \rangle}{\partial t} = \langle Q_{net} \rangle + D$$



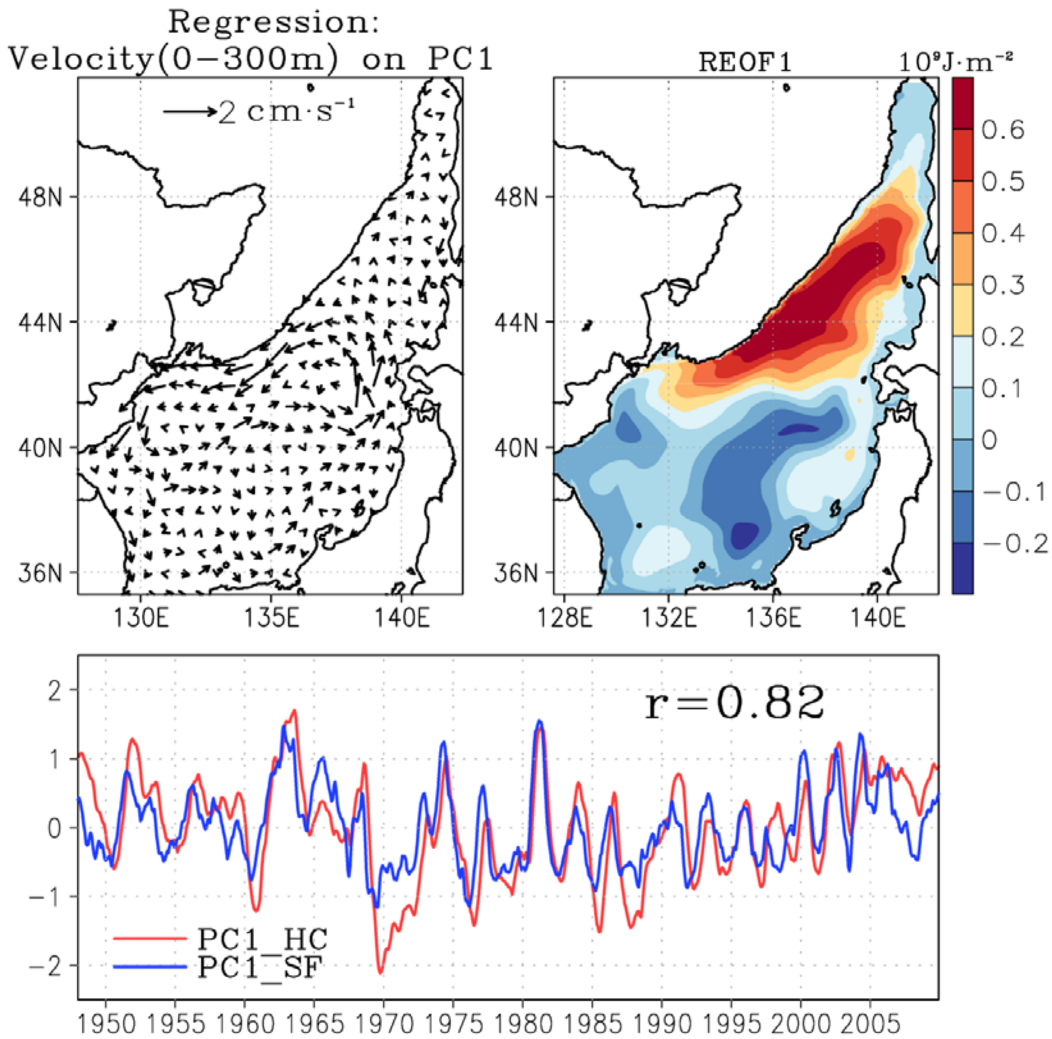
Time series of the annual anomalies of the net heat flux (blue line) and the upper heat content temporal derivative (red line) integrated over the Japan/East Sea.

Dominant modes of spatio-temporal variability of the upper heat content in the Japan/East Sea
REOF - analysis



Spatial patterns of the leading REOF modes of monthly mean heat content detrended anomalies over 1948–2009. The percentage of variance for each mode is also indicated. Time series of PC1 and PC2 (blue lines). A running mean with a 25 month window has been applied to the time series and the time series have then been normalized (red lines).

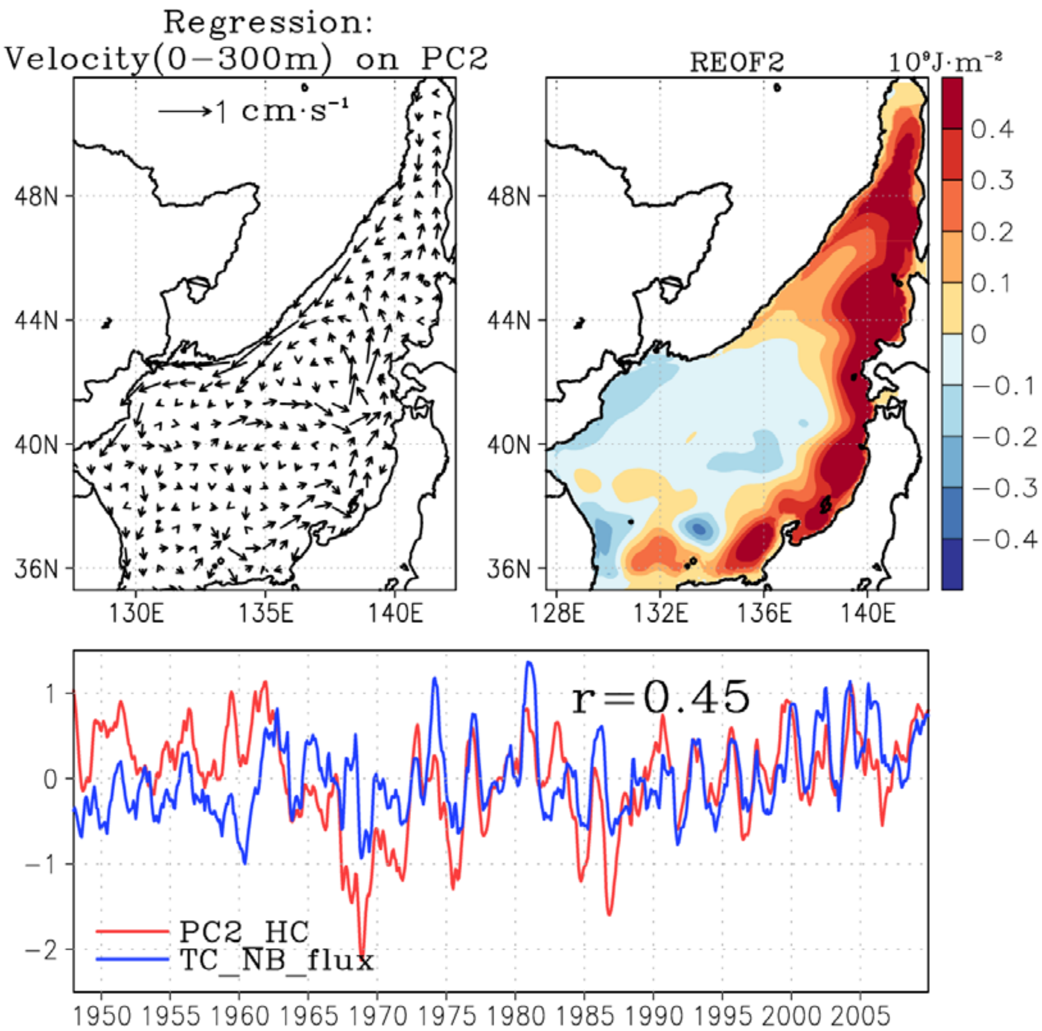
First REOF mode of the upper heat content variability
Regression analysis



Detrended velocity averaged between the surface and 300 m projected on PC1 and the first REOF mode of the upper heat content are shown.

Time series of PC1 (red line) obtained with a 25 month window running mean. PC1_SF (blue line) denotes the low-frequency principal component of the first REOF mode of the barotropic stream function of the cyclonic gyre in the Japan/East Sea. The PC1_SF was obtained with a 25 month window running mean.

Second REOF mode of the upper heat content variability
Regression analysis



Detrended velocity field averaged between the surface and 300 m projected on PC2 and the second REOF mode of the upper heat content are shown.

The low-frequency time series of the PC2 (red line) obtained with a 25 month window running mean. TC_NB_flux (blue line) denotes the low-frequency component of the monthly mean anomalies of the Nearshore Branch of the Tsushima Current transport.

Conclusions

- Based on the high-resolution retrospective numerical simulations, the upper heat content (0-300 m) and its spatial and temporal variability are examined in the Japan/East Sea. Given that the long-term mean net heat flux amounts to -9 W/m^2 and the heat transport variability across the Korea Strait is artificially underestimated, the heat content in the Japan/East Sea does not decrease during the time integration.
- It was shown that temporal variability of the heat content was weakly driven by solely net heat flux over the Japan/East Sea. An analysis of the upper heat content variability showed that its significant variability is associated with the northern part and the eastern boundary of the Japan/East Sea.
- In the northern Japan/East Sea, the upper heat content increase is driven by the intensification of the cyclonic gyre and the influence of net heat flux over the Japan/East Sea is insignificant. In particular, the upper heat content increase from the 1990s is associated with intensification of the cyclonic gyre over the Japan Basin. In the southern Japan/East Sea, the upper heat content increase is driven both the net heat flux and the intensity of the Nearshore Branch of the Tsushima Current.