Revisiting the Role of Ocean Circulation Changes in Arctic Ocean Heat Transport Anomalies under Global Warming

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01 Introduction

In response to quadrupled CO_2, the northward ocean heat transport (OHT) into the Arctic increases[1]. However, the relative roles of ocean circulation changes and ocean temperature changes in the increased Arctic OHT remain uncertain. The standard approach to evaluating the individual roles of the ocean circulation and ocean temperature changes in OHT anomaly is to decompose these changes into dynamic ($v'\bar{T}$), thermodynamic ($\bar{v}T'$) and nonlinear ($v'T'$) components[1,2]:

$$OHT' = vT - \bar{v}\bar{T} = \bar{v}T' + v'\bar{T} + v'T'$$

However, ocean circulation changes can influence the ocean temperature change through redistribution effect and by changing air-sea interaction, i.e.,:

$$T' = T'_{passive} + T'_{active}$$

where $T'_{passive}$ represents the ocean temperature change caused by atmospheric forcing, T'_{active} represents the ocean temperature change induced by changes in ocean circulation. The thermodynamic component ($\bar{v}T'$) thus includes contributions from ocean circulation changes. That is, the standard decomposition method fails to effectively isolate the contributions of ocean circulation changes to the OHT anomaly. Using a set of climate model experiments incorporating a partial coupling technique[3], we can separate $T'_{passive}$ from T'_{active}. Then, we can separate the contributions of oceanic processes (active component) and passive ocean temperature responses to OHT anomaly more accurately, providing a novel perspective on the role of ocean circulation changes in anomalous OHT:

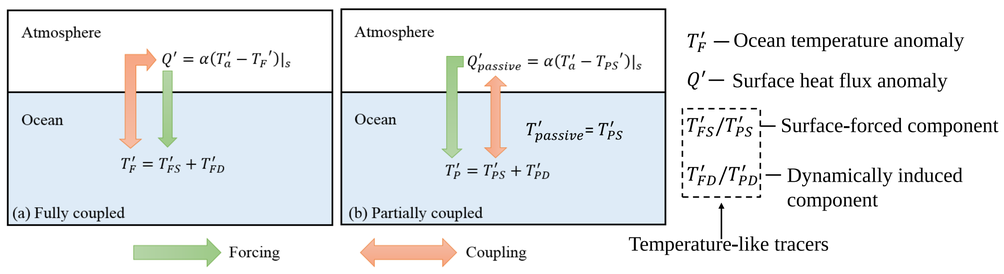
$$OHT' = \underbrace{\bar{v}T'_{passive} + v'T'_{passive}}_{\text{Passive}} + \underbrace{v'\bar{T} + \bar{v}T'_{active} + v'T'_{active}}_{\text{Active}}$$

02 Experiments

Model experiments with CESM1

Name	Run (yrs)	Description
CTRL	150	fully coupled simulation (Preindustrial CO_2)
FULL	150	Perturbed fully coupled simulation ($4\times CO_2$)
PART	150	Perturbed partially coupled simulation ($4\times CO_2$)

Schematics of air–sea surface coupling



$$\frac{\partial T'_{passive}}{\partial t} = Q'_{passive} - v\cdot\nabla T'_{passive} \quad \text{—— Passive component}$$

$$\frac{\partial T'_{active}}{\partial t} = Q'_{active} - v'\cdot\nabla\bar{T} - v\cdot\nabla T'_{active} \quad \text{—— Active component}$$

03 Results

Decomposition of Ocean Heat Transport with Standard Method

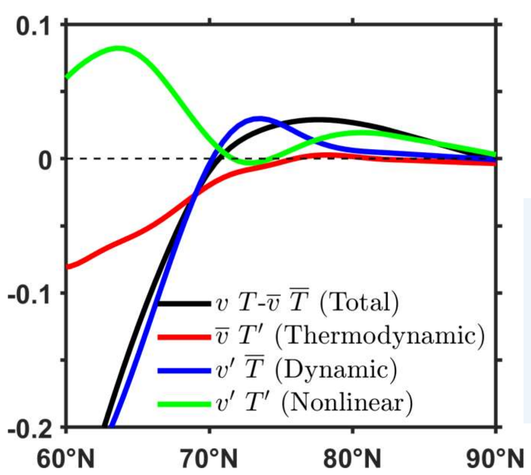


Fig.1 Changes of the OHT in abrupt CO_2 quadrupling simulation of the CESM.

The increased northward OHT is determined by the dynamic and nonlinear components, while the contribution of the thermodynamic component is negligible.

Contributions of passive and active ocean temperature anomalies

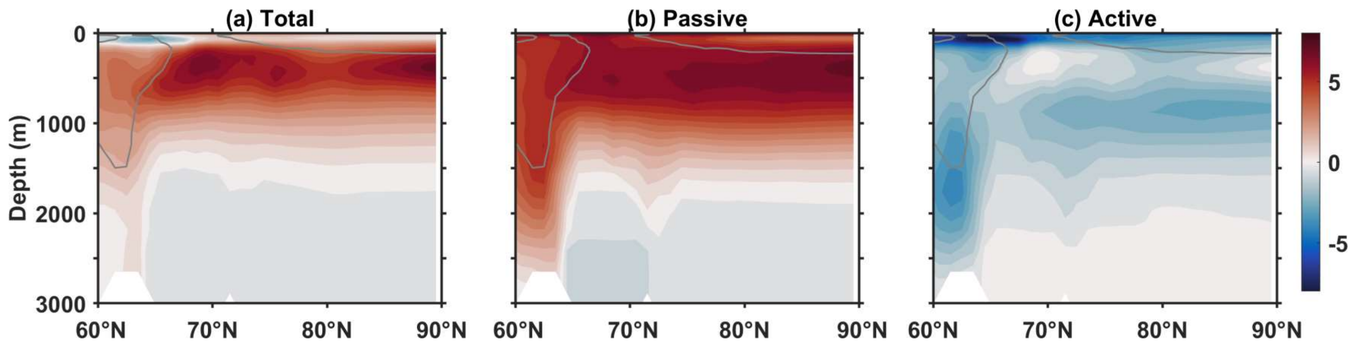


Fig. 2 Changes of the zonal mean temperature (℃) in Arctic: (a) the total response and (b) passive and (c) active components.

The changes in ocean circulation play a significant role in ocean temperature change. The ocean temperature change caused by atmospheric forcing and ocean circulation changes shows opposite results.

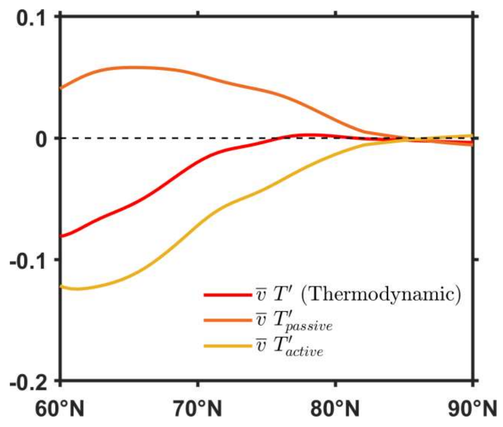


Fig. 3 Decomposing the thermodynamic component of OHT anomaly into components associated with the passive and active temperature anomaly.

The advection of the *passive* temperature anomaly by mean ocean circulation is almost entirely offset by the advection of the *active* temperature anomaly, resulting in a weak role of the thermodynamic component.

Decomposition of Ocean Heat Transport with Novel Method

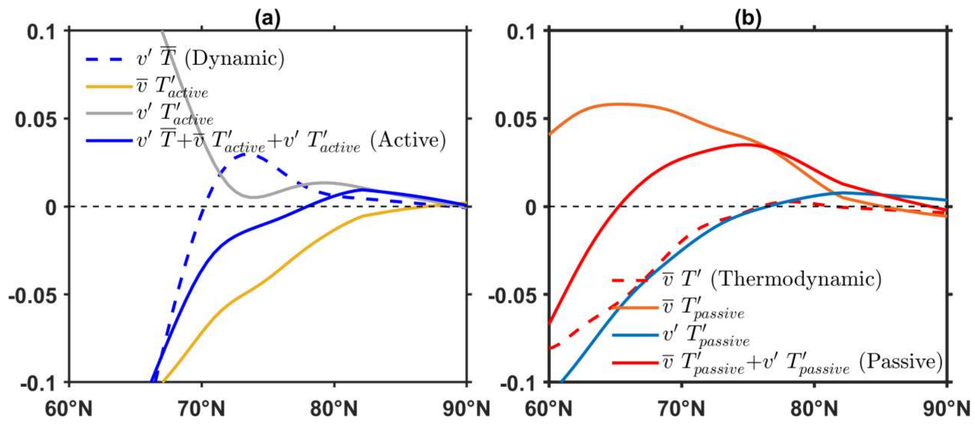


Fig. 4 The different components of OHT anomaly that resulted from (a) ocean circulation change and (b) atmospheric thermally forcing.

Both the atmospheric forcing (*passive* component) and ocean circulation changes (*active* component) contribute to the increased OHT north of 70°N.

Surface heat flux

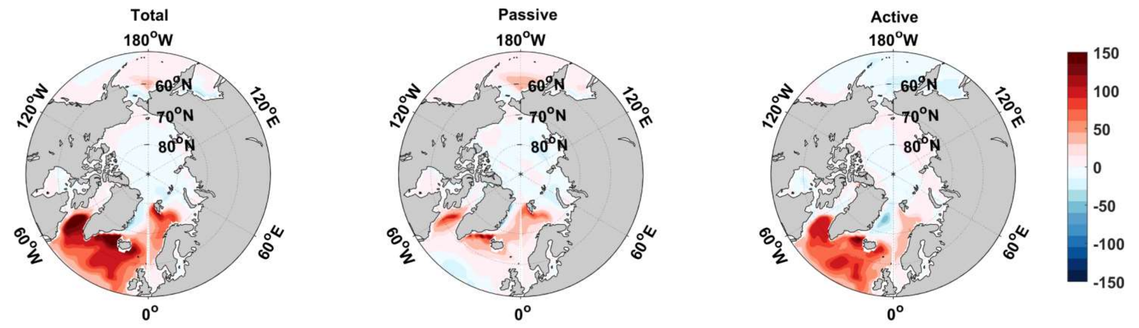


Fig. 5 Changes of the surface heat flux (positive into ocean) in the total response and its passive and active components.

The anomalous surface heat loss in the Arctic due to increased northward OHT is determined by both its *passive* and *active* component, with the *passive* component playing more important role.

04 Conclusion

- The standard decomposition methods cannot precise separate the roles of passive ocean temperature changes and ocean circulation changes in OHT anomaly.
- The advection of the *passive* temperature anomaly by mean ocean circulation is almost entirely offset by the advection of the *active* temperature anomaly.
- The new decomposition method shows both the atmospheric forcing (*passive* component) and ocean circulation changes (*active* component) contribute to the increased OHT in the Arctic.
- Both atmospheric forcing and changes in ocean circulation lead to anomalous heat loss in the Arctic, corresponding to both *passive* and *active* heat transport towards the Arctic.

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