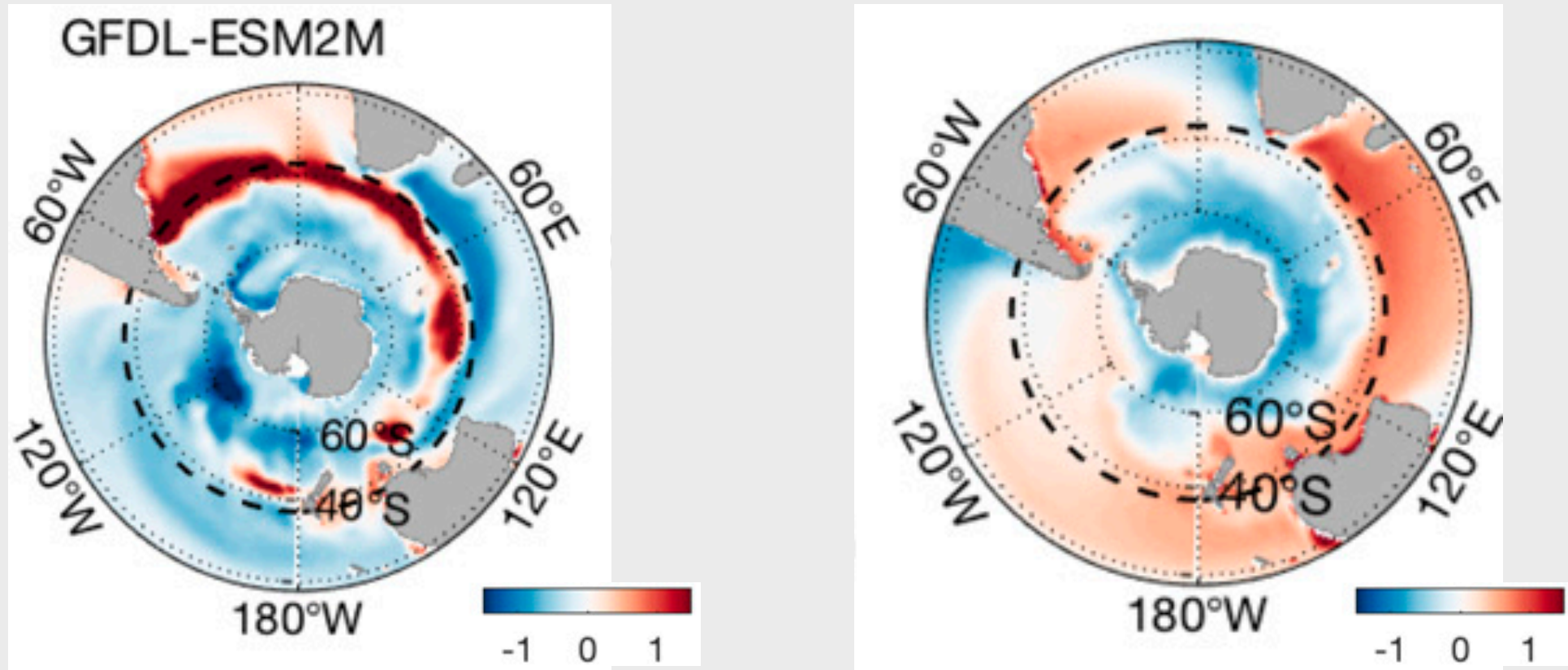


How do heat and carbon anomalies compare in climate model projections for the Southern Ocean?

EGU21-3153 Vassil Roussenov, Ric Williams, and Anna Katavouta

1. Low heat & carbon storage relative to global mean in 1% projections

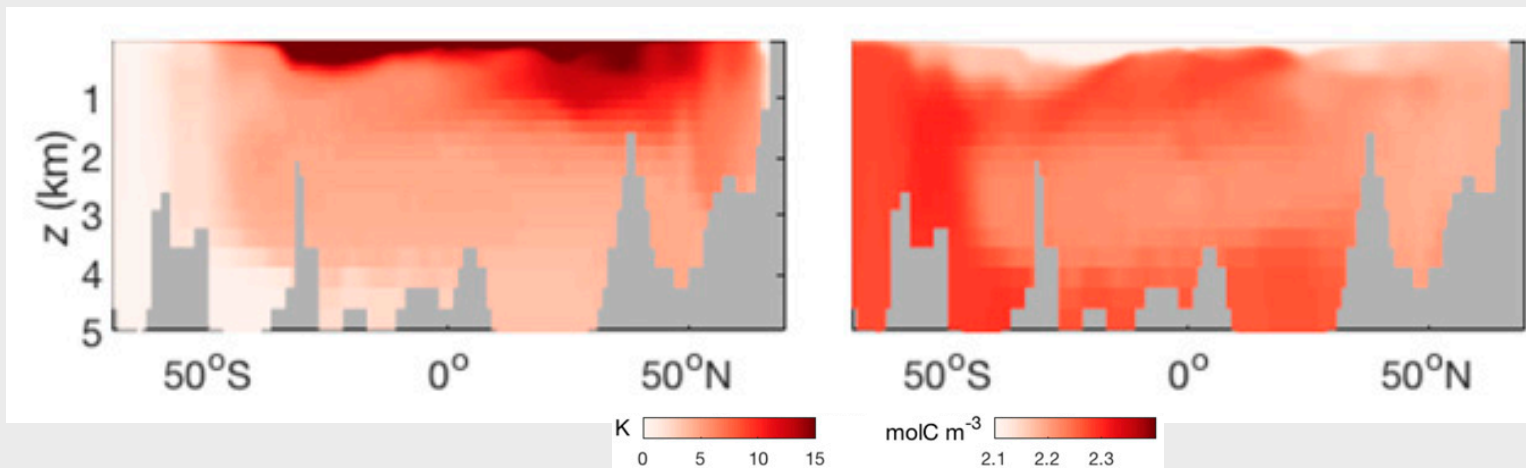


normalised T' and DIC' anomalies for 1% projections after 100 y over upper 1 km (cyan is less than global mean)

4. Key mechanisms

- 1. Heat & carbon added in similar manner & transported north
- 2. Heat & carbon redistributed in *opposite* manner due to opposing vertical pre-industrial gradients
- 3. Stronger residual circulation, upwells cold, DIC rich waters

pre-industrial T and DIC anomalies along Atlantic section



2. Tracer response viewed as added + redistributed

evolution of anthropogenic tracer

$$\frac{\partial c'}{\partial t} = \underbrace{S'}_{\text{added tracer}} - \underbrace{\mathbf{u} \cdot \nabla c' + \mathbf{u}' \cdot \nabla c_o}_{\text{redistributed tracer}}$$

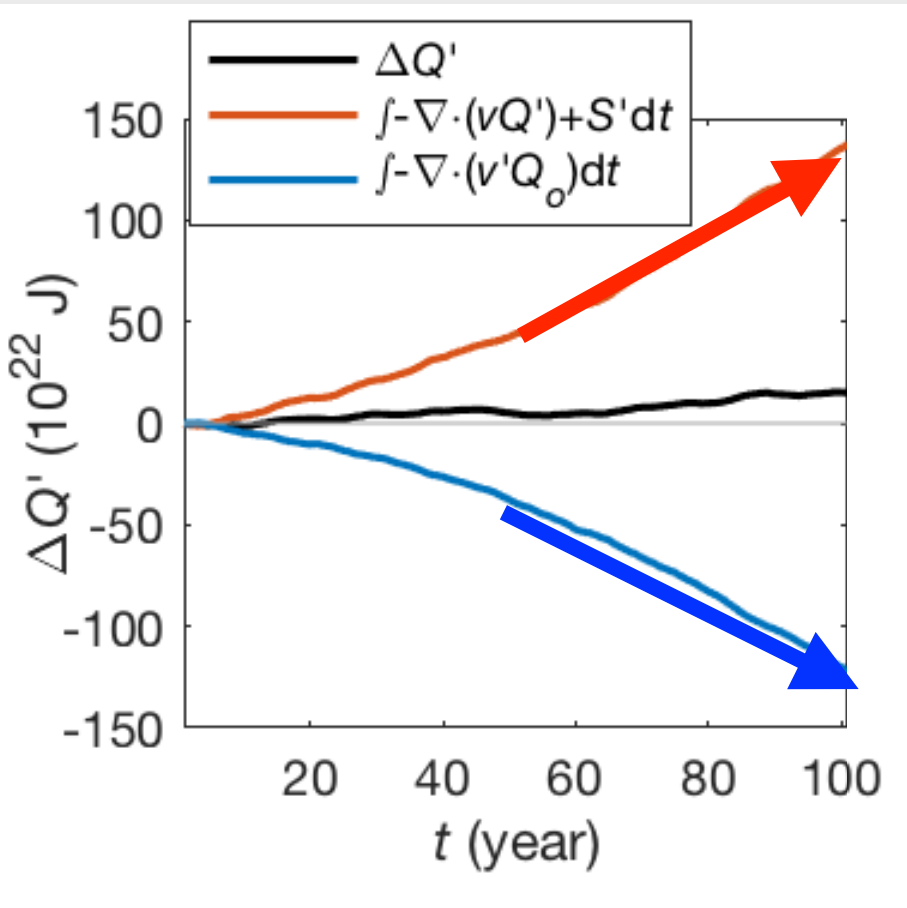
tracer anomaly c'
pre-industrial tracer c_o

net tracer source from atmosphere and mixing, S'

added tracer

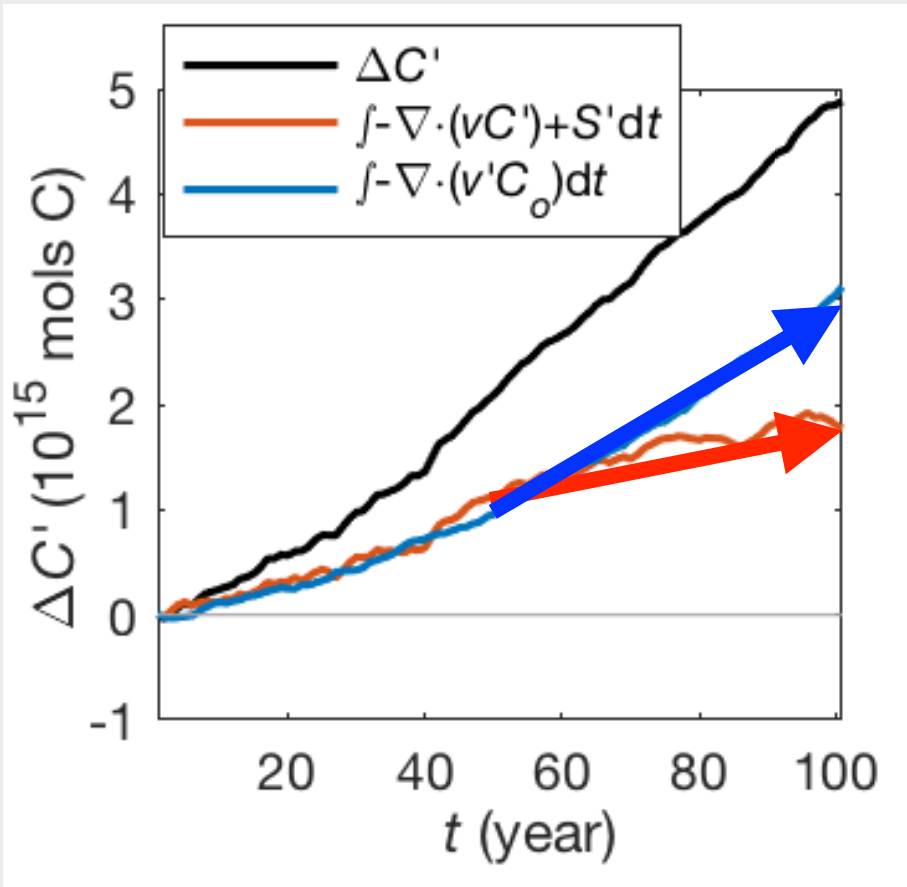
redistributed tracer

3. Heat & carbon increase in different ways over S. Ocean



added heat > 0

redistributed heat < 0



added carbon > 0

redistributed carbon > 0

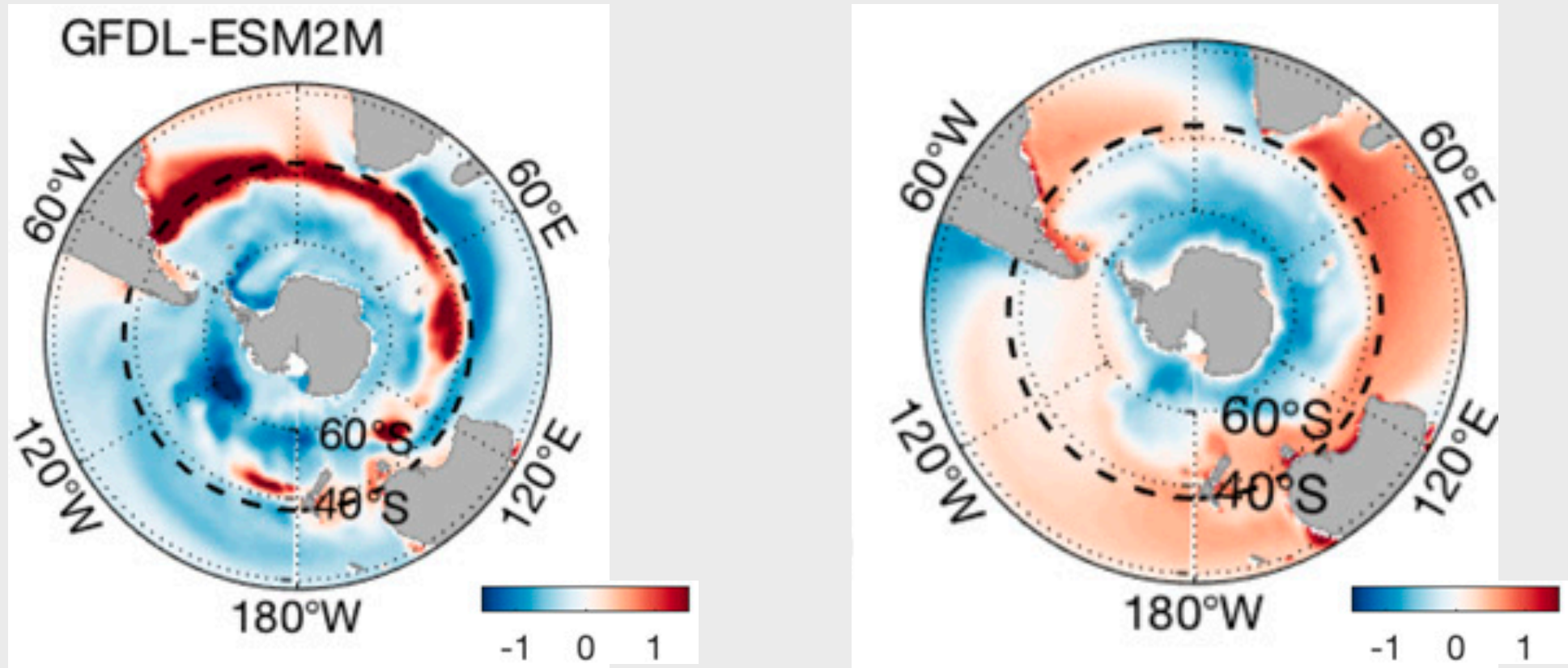
5. Summary for high latitude response

- 1. Heat anomalies of variable sign due to opposing added & redistributed heat
- 2. Carbon anomalies of similar sign due to reinforcing, comparable added & redistributed carbon

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1. Low heat & carbon storage relative to global mean in 1% projections

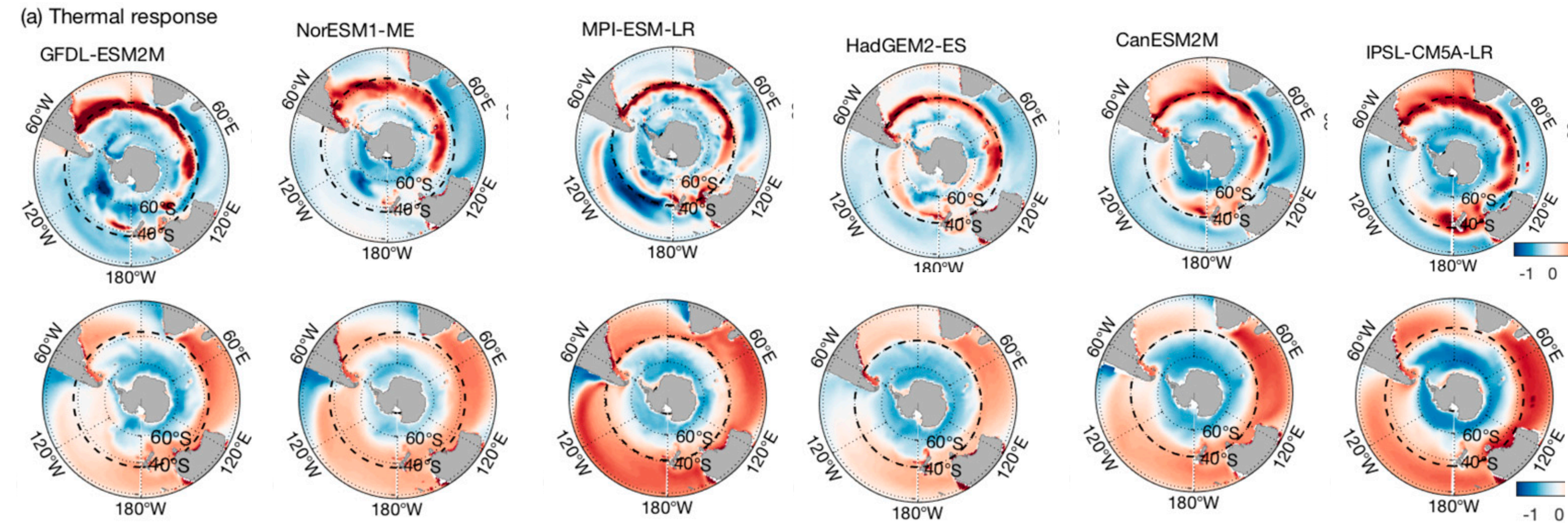


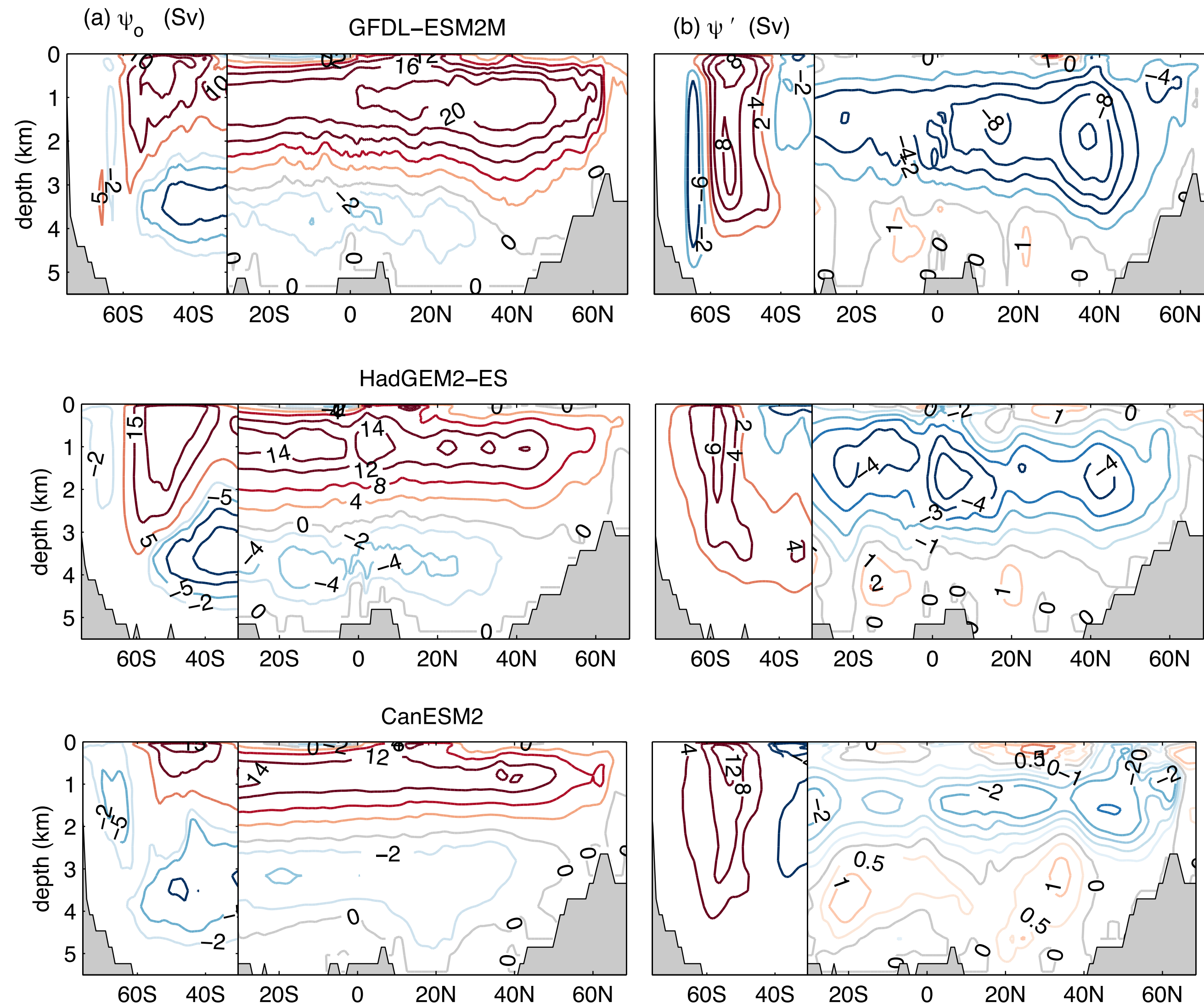
normalised T' and DIC' anomalies for 1% projections after 100 y over upper 1 km (cyan is less than global mean)

Fig 1. Modeled normalised change over the upper 1000 m for (a) upper ocean temperature anomaly $T'(x, y, t)$, (b) dissolved inorganic carbon anomaly $DIC'(x, y, t)$, for an annual 1% increase in CO_2 projections from GFDL-ESM2M,

The normalization for a tracer anomaly c' is defined by the tracer value minus the global mean, divided by the standard deviation. The normalization reveals whether more tracer (in red) is locally stored than the global mean or whether less tracer (in blue) is locally stored than the global mean.

Also for NorESM1-ME, MPI-ESM-LR, HadGEM2-ES, CanESM2M, and IPSL-CM5A-LR, averaged from years 100 to 140. The first three models have strong preindustrial Atlantic overturning, and the last two models have weak overturning.





The meridional overturning streamfunction(Sv) for the Atlantic basin and the residual overturning for the entire Southern Ocean (domains separated by the thin line) for GFDL-ESM2M, HadGEM2-ES, and CanESM2M, for (a) the preindustrial ψ_0 and (b) the perturbation at year 100, ψ' . The residual overturning includes the Eulerian-mean overturning and the parameterized eddy-driven circulation.

2. Tracer response viewed as added + redistributed

evolution of
anthropogenic
tracer

$$\frac{\partial c'}{\partial t} = \underbrace{S'}_{\text{added tracer}} - \underbrace{\mathbf{u} \cdot \nabla c'}_{\text{redistributed tracer}} - \underbrace{\mathbf{u}' \cdot \nabla c_o}_{\text{redistributed tracer}}$$

added tracer

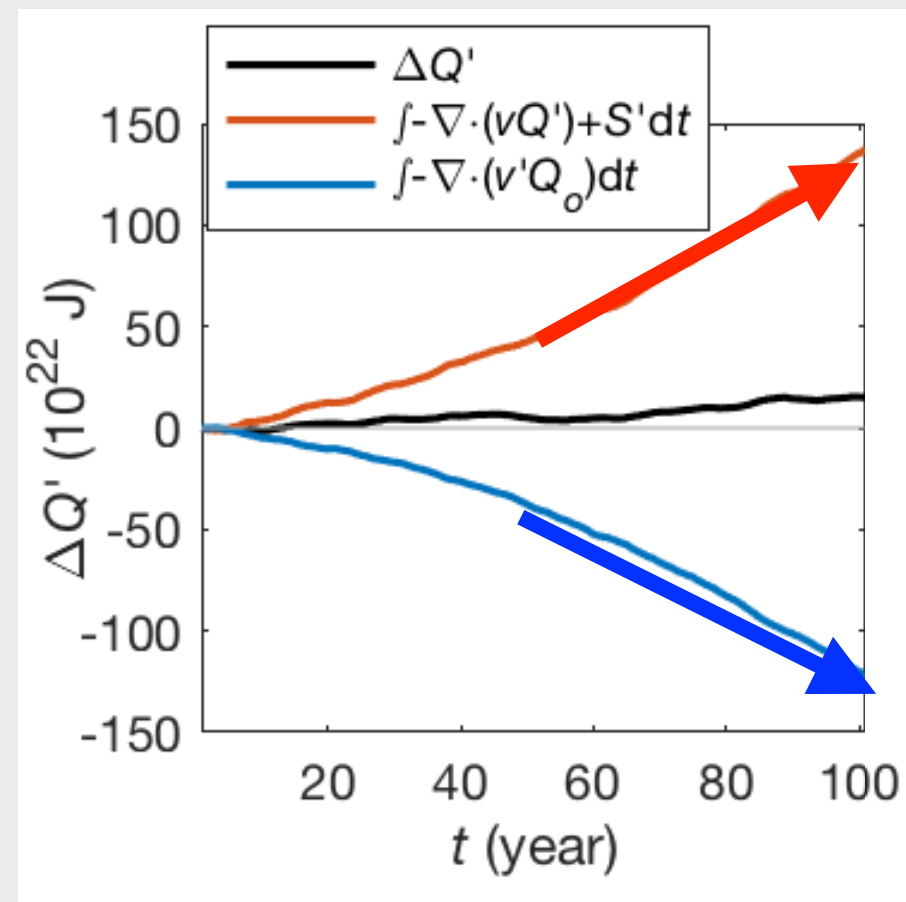
redistributed tracer

tracer anomaly c'
pre-industrial c_o
tracer

net tracer source from
atmosphere and mixing, S'

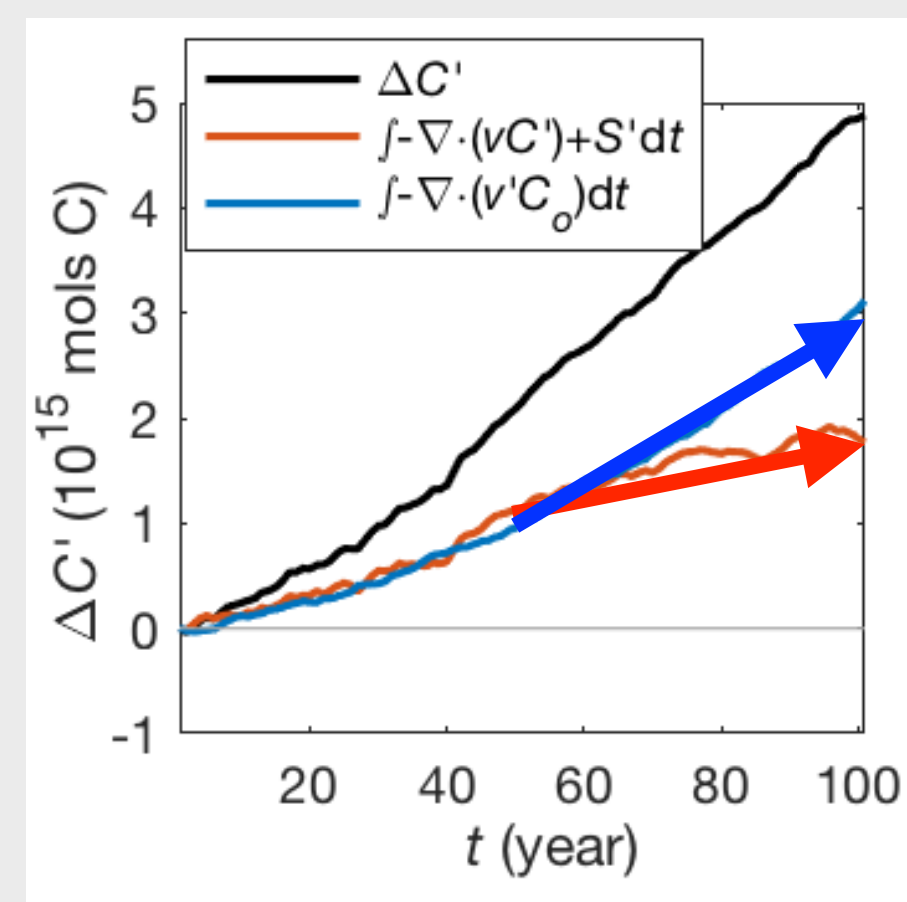
total flow, $\mathbf{u}$
time-dependent anomaly $\mathbf{u}'$

3. Heat & carbon increase in different ways over S. Ocean



added heat > 0

redistributed heat < 0



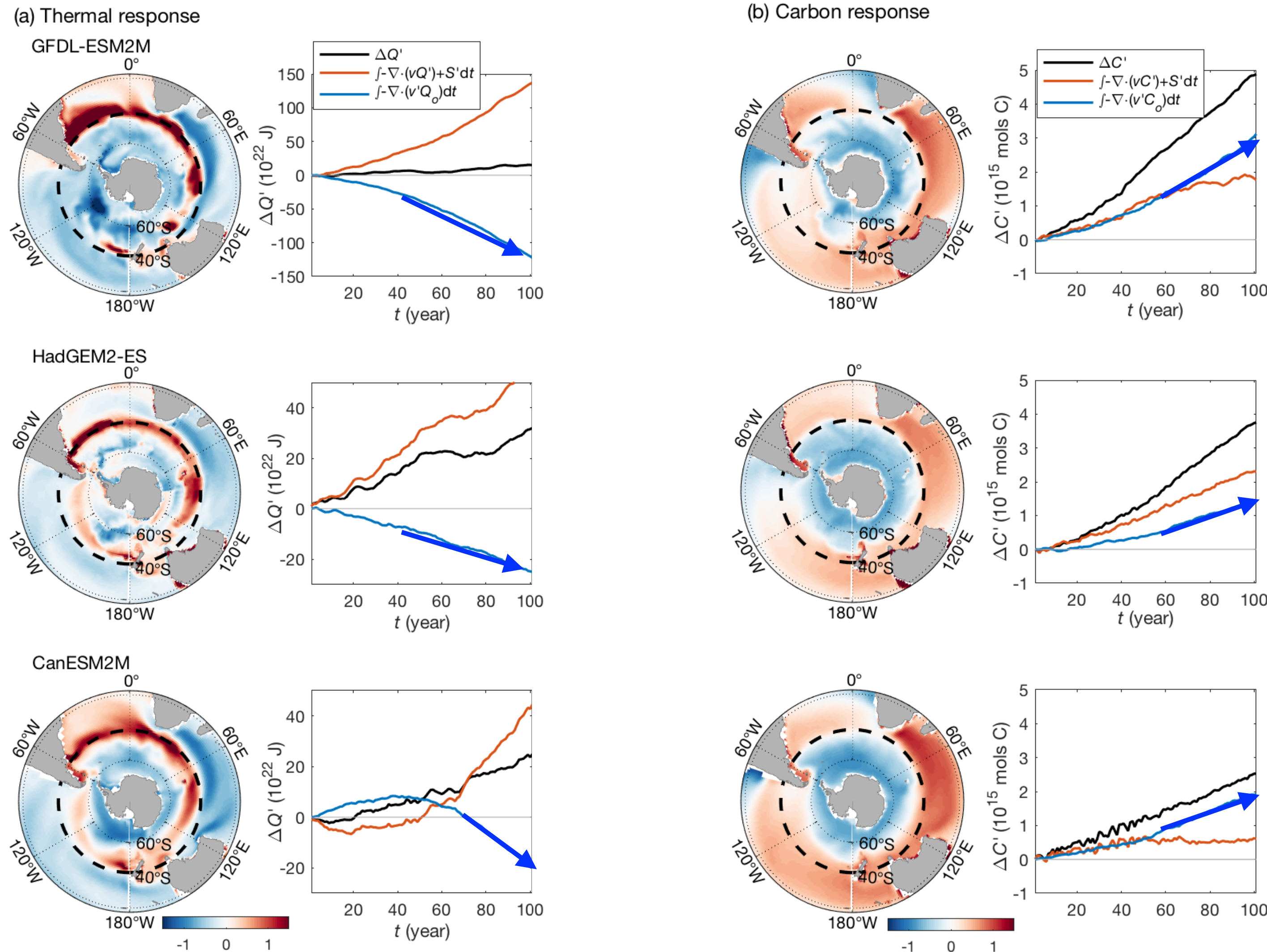
added carbon > 0

redistributed carbon > 0

A tracer budget for the upper 1000m of the S. Ocean (dashed black lines in Fig.1), the tracer anomaly (black line) is made up of the added tracer (red line) and redistributed tracer (blue line).

The added tracer includes contributions from the time integral of the net source and the advection of added tracer.

3. In the Southern Ocean, broadly similar storage for the models



The normalized anomalies for the temporal change in (a) heat and (b) carbon over the upper 1000 m for the Southern Ocean for GFDL-ESM2M, HadGEM2-ES and CanESM2M.

In the tracer budget for the upper 1000m of the domain (dashed black lines), the tracer anomaly (black line) is made up of the added tracer (red line) and redistributed tracer (blue line). The added tracer includes contributions from the time integral of the net source and the advection of added tracer.

so overall heat storage involves *opposing* contributions

overall carbon storage involves *reinforcing* contributions

added heat is positive
redistributed heat is negative

added carbon is positive
redistributed carbon is positive

Abstract

Projected changes in ocean heat and carbon storage are assessed in terms of the added and redistributed tracer using a transport-based framework for 6 CMIP5 Earth system models following an annual 1% rise in atmospheric CO₂.

Heat and carbon budgets for the added and redistributed tracer are used to compare the reasons for the relatively-reduced storage of heat and carbon within the Southern Ocean. Here the added tracer takes account of the net tracer source and the advection of the added tracer, while the redistributed tracer takes account of the time-varying advection of the pre-industrial tracer distribution.

The added heat and carbon are nearly always positive over the Southern Ocean with the net source acting to supply tracer. However, there is a relatively-reduced local storage of heat and carbon in the Southern Ocean due to the passive northward transport of heat and carbon by the overturning, which is augmented by a passive northward carbon transport for the gyre circulation.

In contrast, the redistributed heat is usually negative and the redistributed carbon is positive over the Southern Ocean due to the transport effects of a strengthening residual circulation and the opposing gradients in the pre-industrial temperature and carbon.

Hence, climate projections for the Southern Ocean are expected to have heat anomalies of a variable sign and carbon anomalies of a consistently positive sign, since the effects of added and redistribution heat are opposing in sign, while the effects of added and redistributed carbon reinforce each other.

Ref: Williams, R.G., A. Katavouta and V. M. Roussenov, 2021. Regional asymmetries in ocean heat and carbon storage due to dynamic redistribution in climate model projections. J. Climate, doi: 10.1175/JCLI-D-20-0519.1.

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Regional Asymmetries in Ocean Heat and Carbon Storage due to Dynamic Redistribution in Climate Model Projections

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ABSTRACT: Projected changes in ocean heat and carbon storage are assessed in terms of the added and redistributed tracer using a transport-based framework, which is applied to an idealized climate model and a suite of six CMIP5 Earth system models following an annual 1% rise in atmospheric CO₂. Heat and carbon budgets for the added and redistributed tracer are used to explain opposing regional patterns in the storage of ocean heat and carbon anomalies, such as in the tropics and subpolar North Atlantic, and the relatively reduced storage within the Southern Ocean. Here the added tracer takes account of the net tracer source and the advection of the added tracer by the circulation, while the redistributed tracer takes account of the time-varying circulation advecting the preindustrial tracer distribution. The added heat and carbon often have a similar sign to each other with the net source usually acting to supply the tracer. In contrast, the redistributed heat and carbon consistently have an opposing sign to each other due to the opposing gradients in the preindustrial temperature and carbon. These different signs in heat and carbon redistribution can lead to regional asymmetries in the climate-driven changes in ocean heat and carbon storage. For a weakening in the Atlantic overturning and strengthening in the Southern Ocean residual circulation, the high latitudes are expected to have heat anomalies of variable sign and carbon anomalies of a consistently positive sign, since added and redistributed tracers are opposing in sign for heat and the same sign for carbon there.

KEYWORDS: Meridional overturning circulation; Upwelling/downwelling; Anthropogenic effects/forcing; Climate change; Climate models