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Impact of Gulf Stream SST biases on the global atmospheric circulation

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Background

Atmospheric climate model biases have been shown to be sensitive to large-scale sea surface temperature (SST) biases [1,2]. Despite improvements on the large-scale, smaller regions of SST biases remain. When these are located in regions of deep atmosphere-ocean interactions, there is potential for a propagation of biases.

In general, the local response mechanism to dissipate anomalous diabatic heating in the mid-latitudes may be via any of the following mechanisms:

1. meridional heat advection by a mean wind anomaly [3];
2. meridional heat advection by the transient eddies [4];
3. ascent [5] and the associated adiabatic cooling if over the western boundary currents.

In this study, the role of winter Gulf Stream biases from a high resolution fully coupled global climate model (HadGEM3-GC2) are examined with a focus on the tropospheric response in the atmospheric model component, by performing three sensitivity experiments.

Data

- ECMWF Interim Reanalysis (ERA-Interim) [6]
  T255 horizontal resolution (~79 km), 60 vertical levels (0.1 hPa top)
- UK Met Office Unified Model, Global Coupled model version 2.0 (GC2) [7]
  Used for the seasonal forecast system (GloSea5), decadal prediction system (DePreSys3), and climate projection system (HadGEM3); comprises the following components:
  - Global Atmosphere version 6.0 (GA6) – semi-implicit semi-Lagrangian dynamical core; here with N216 horizontal resolution (60 km in the mid-latitudes), 85 vertical levels (85 km top)
  - Global Land version 6.0 – four soil levels
  - Global Ocean version 5.0 – 75 levels (1 m top level), here uses ¼° resolution on a tri-polar grid
  - Global Sea Ice version 6.0 – five sea-ice thickness categories

The winter (DJF) season: from 1981–2008 is used for ERA-Interim and GA6; 27 years of the GC2 simulation are also used, with perpetual present-day forcing.

The significance of differences has been assessed by using a Monte-Carlo method with 10,000 trials, two tailed.

Experimental design

The ¼° coupled ocean used in GC2-Coupled (GC2-C) has a spatially small, but large in magnitude bias (~7 K) where the Gulf Stream separates from the US eastern sea board at Cape Hatteras (Fig. 1). The three sensitivity experiments are created by imposing the warm SST bias from GC2-C onto the atmosphere-only configuration (GC2-A) over differing areas, here named: 'small' (GC2-S), 'medium' (GC2-M) and 'large' (GC2-L). All horizontal boundaries are linearly tapered by two gridpoints (1° in latitude; 1.67° in longitude) each side.

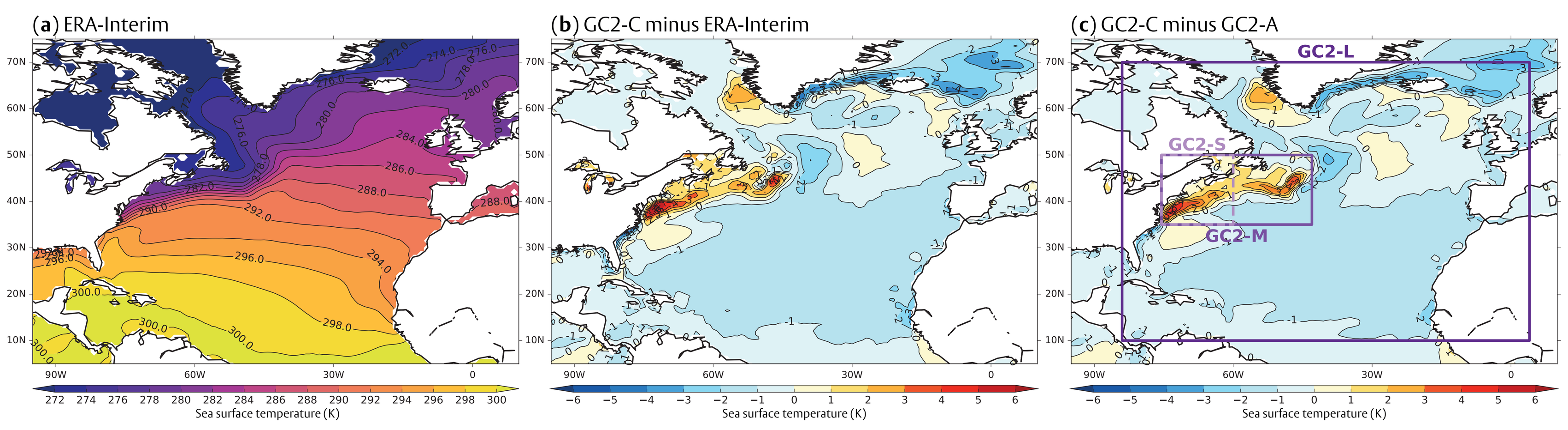

FIG. 1. Sea surface temperatures (*shading*; K), including in (**c**) the sensitivity experiments boundaries: GC2-S, GC2-M and GC2-L.

Results

The surface flux response is consistent with the biases and imposed biases (Fig. 2). Enhanced upwards surface heat fluxes occur over the warm biased SSTs.

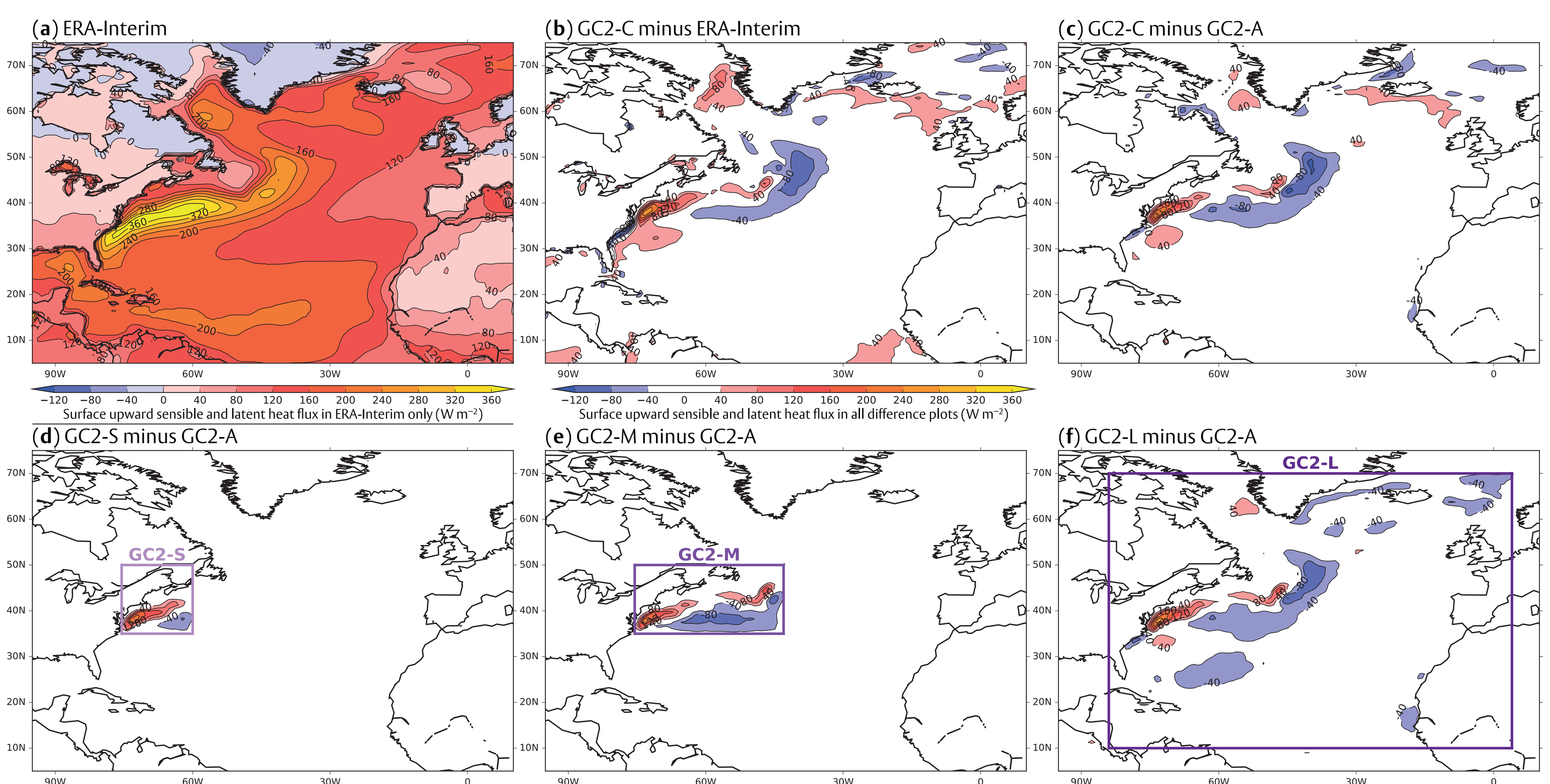

FIG. 2. Surface upward sensible and latent heat flux (*shading*; W m^{-2}), and the sensitivity experiments boundaries.

The anomalous heating imposed over the Gulf Stream is balanced not by meridional heat transport (not shown), either mean or eddy, but by enhanced ascent (Fig. 3). This deep ascent is up to twice as strong over the SST biases, and is mostly made up of ascent which is over the fronts as seen in the transient field (not shown), steeper than the isentropes in the lower troposphere, and slantwise ascent along the isentropes in the upper troposphere. All three experiments (Fig. 3g–i) consistently reproduce the anomalously strong ascent just over the imposed SST bias.

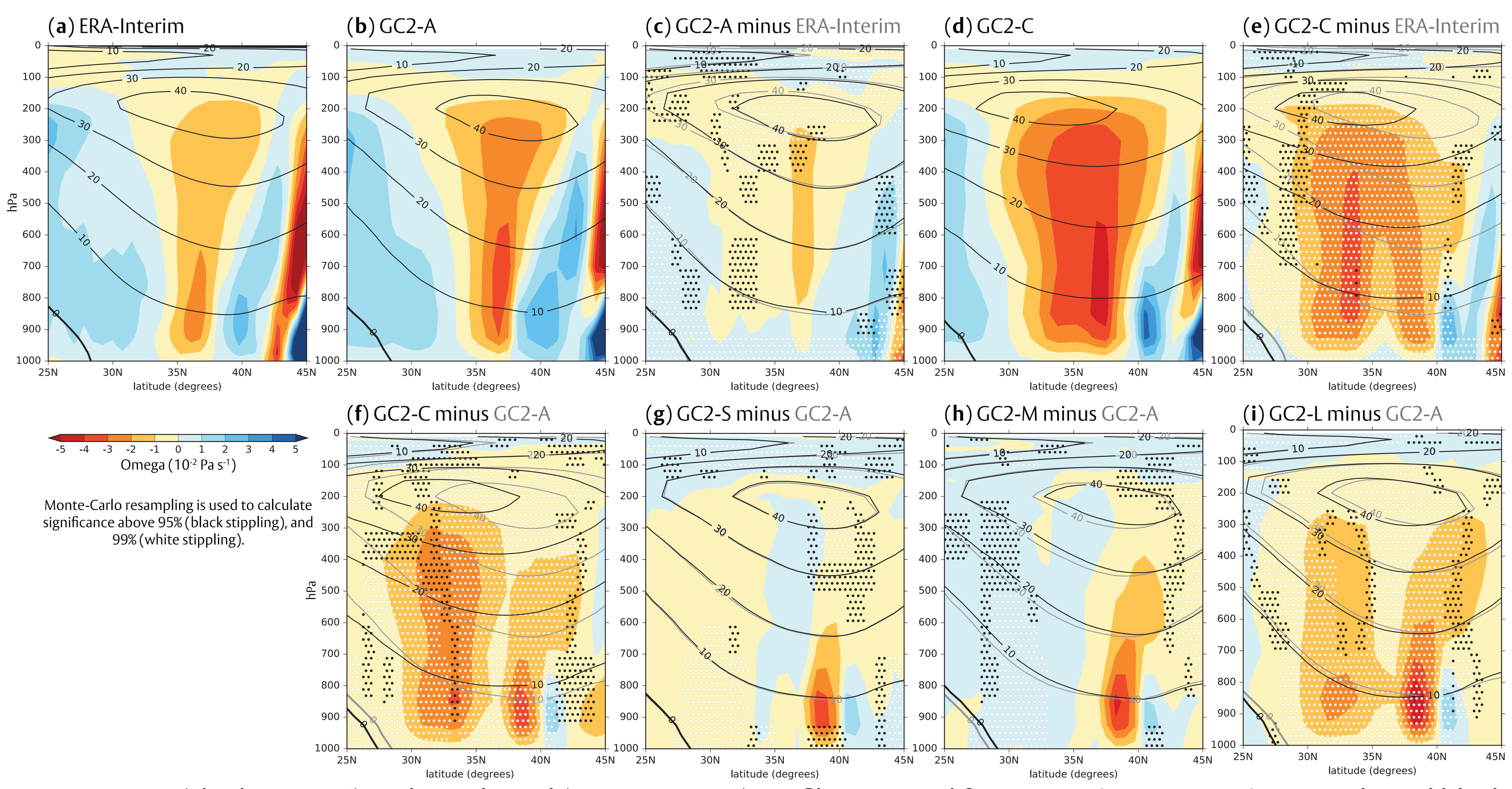

FIG. 3. Omega (*shading*; Pa s^{-1}) and zonal wind (*contours*; m s^{-1}) profile averaged from 69.75°W to 68.25°W. Zonal wind black contours correspond to the data labelled in black, and grey contours correspond to the data labelled in grey.

The increased ascent is not a constant perturbation, but rather occurs during periods of transient ascent. Hence the distribution of vertical velocity is broadened rather than shifted over the large SST bias in GC2-C and the three experiments (Fig. 4c), and small Sargasso Sea bias in GC2-C and GC2-L (Fig. 4a).

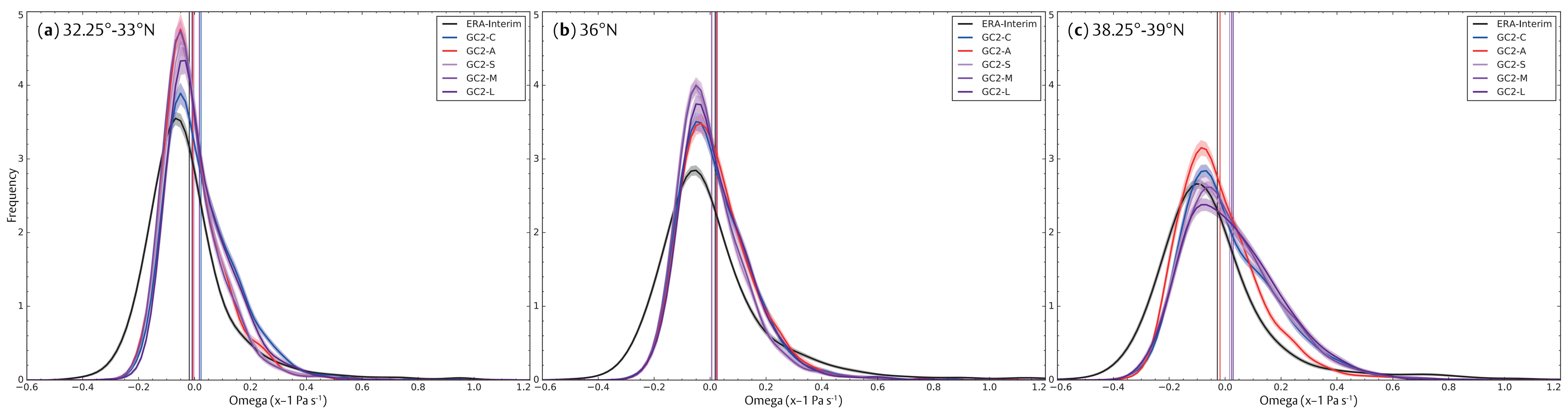

FIG. 4. Omega frequency distributions (*lines*; Pa s^{-1}) and one-sigma envelope from 1000 bootstraps of the seasons (*shading*), averaged from 69.75°W to 68.25°W for three latitude bands. Thin vertical lines indicate the mean of each distribution.

The response affects the troposphere not only locally but also in remote regions of the Northern Hemisphere via a quasizonal planetary barotropic Rossby wave response (Fig. 5), at wavenumber 5, triggered by the increased ascent over the Gulf Stream, consistent with other studies [5,8]. This planetary response is able to partially account for some of the coupled model biases in jets, troughs and ridges throughout the hemisphere (not shown).

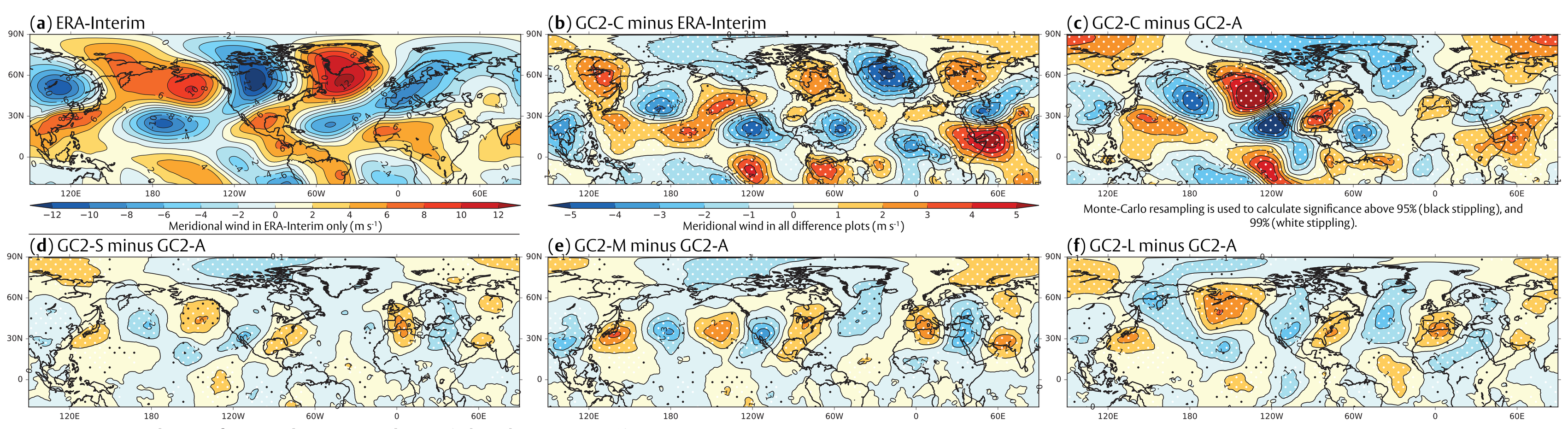

FIG. 5. Meridional wind at 250 hPa (*shading*; m s^{-1}).

The transient ascent, and wave response pathways may have implications for the ability of the model to respond correctly to variability or changes in the Gulf Stream.

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