Resolving weather fronts increases the large-scale circulation response to Gulf Stream SST anomalies

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Key Points

- There is a large NAO-like response to Gulf Stream SST anomalies in an atmospheric model with 14-km regional grid refinement
- This response is weaker or absent in simulations with 28-km or coarser resolution, which do not fully resolve mesoscale frontal processes
- Transient-eddy fluxes of heat and momentum are modified as fronts pass over warm SSTs, leading to a large-scale circulation response

Variable Resolution Simulations

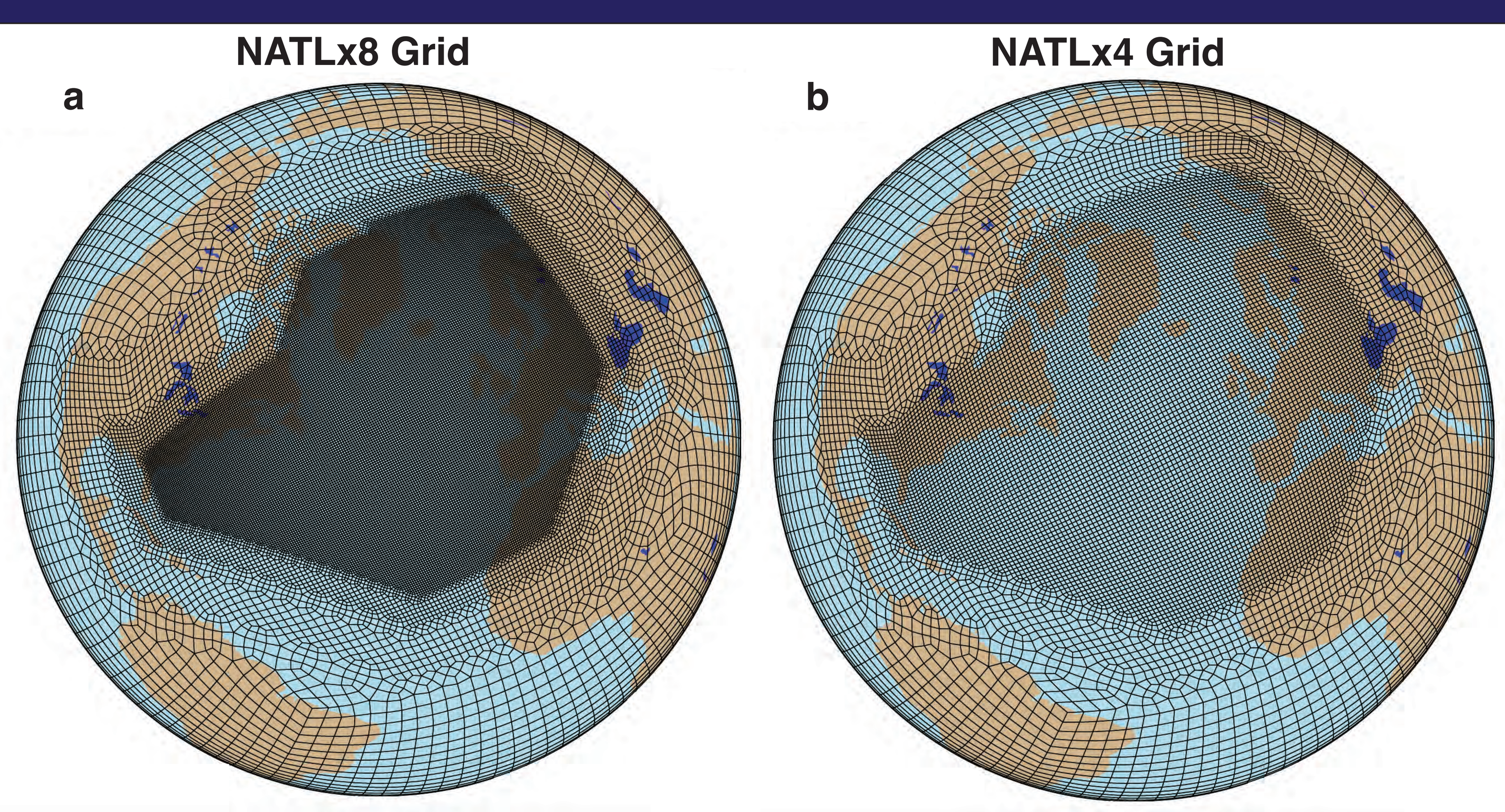


Figure 1. Variable resolution North Atlantic grids for CAM-SE: (a) The NATLx8 grid, with horizontal resolution varying from 14 km resolution in the North Atlantic to 111 km in the far field; (b) the NATLx4 grid, with horizontal resolution varying from 28 km resolution in the North Atlantic to 111 km in the far field. Note that what is shown is the element grid; the computational grid has 3 x 3 independent grid points per element.

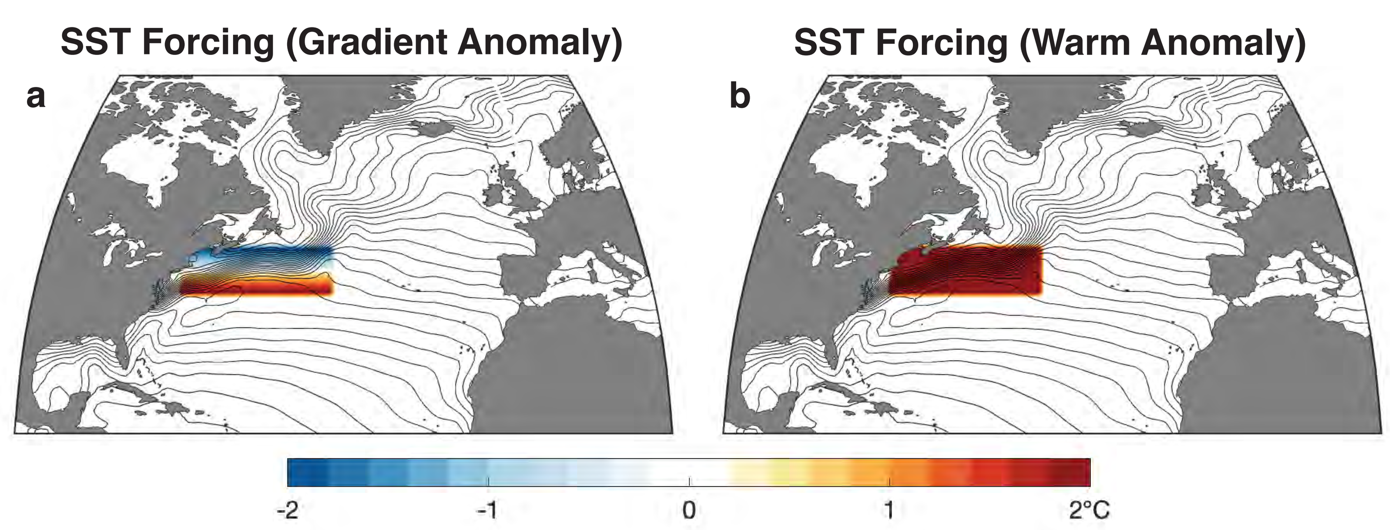


Figure 2. SST anomalies (shading) imposed in each month in the two idealized experiments: (a) The SST gradient anomaly experiment; (b) the warm SST anomaly experiment. The DJF-mean SST climatology is shown in contours, with a contour interval of 1°C.

- **SSTs are specified at 1° resolution.**
- **All results are averaged over 15+ years of simulation.**
- **Anomalies relative to simulation with climatological SSTs.**

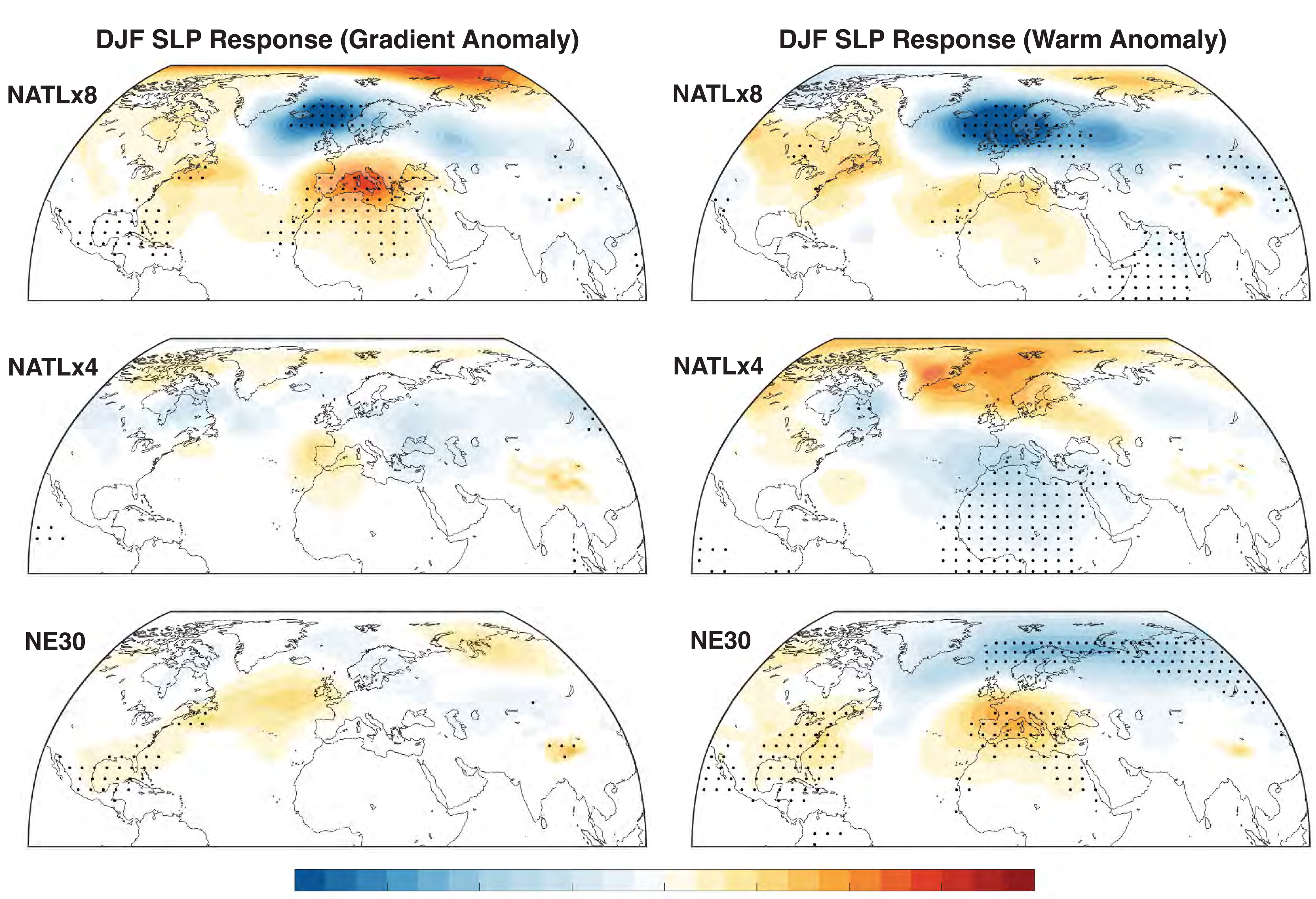


Figure 3. DJF Sea-level pressure (SLP) response to an SST gradient anomaly (left) and a warm SST anomaly (right) in the Gulf Stream, in 3 different configurations of CAM-SE: (top) NATLx8, with 14-km resolution in the North Atlantic, (middle) NATLx4, with 28-km resolution in the North Atlantic, and (bottom) NE30, with 111-km resolution in the North Atlantic. Anomalies are the difference of 15-year averages in NATL and 45-year averages in NE30. Stippling denotes anomalies that are significant compared to internal variability, diagnosed by bootstrap sampling an equivalent number of independent seasonal averages, accounting for the autocorrelation between seasonal averages.

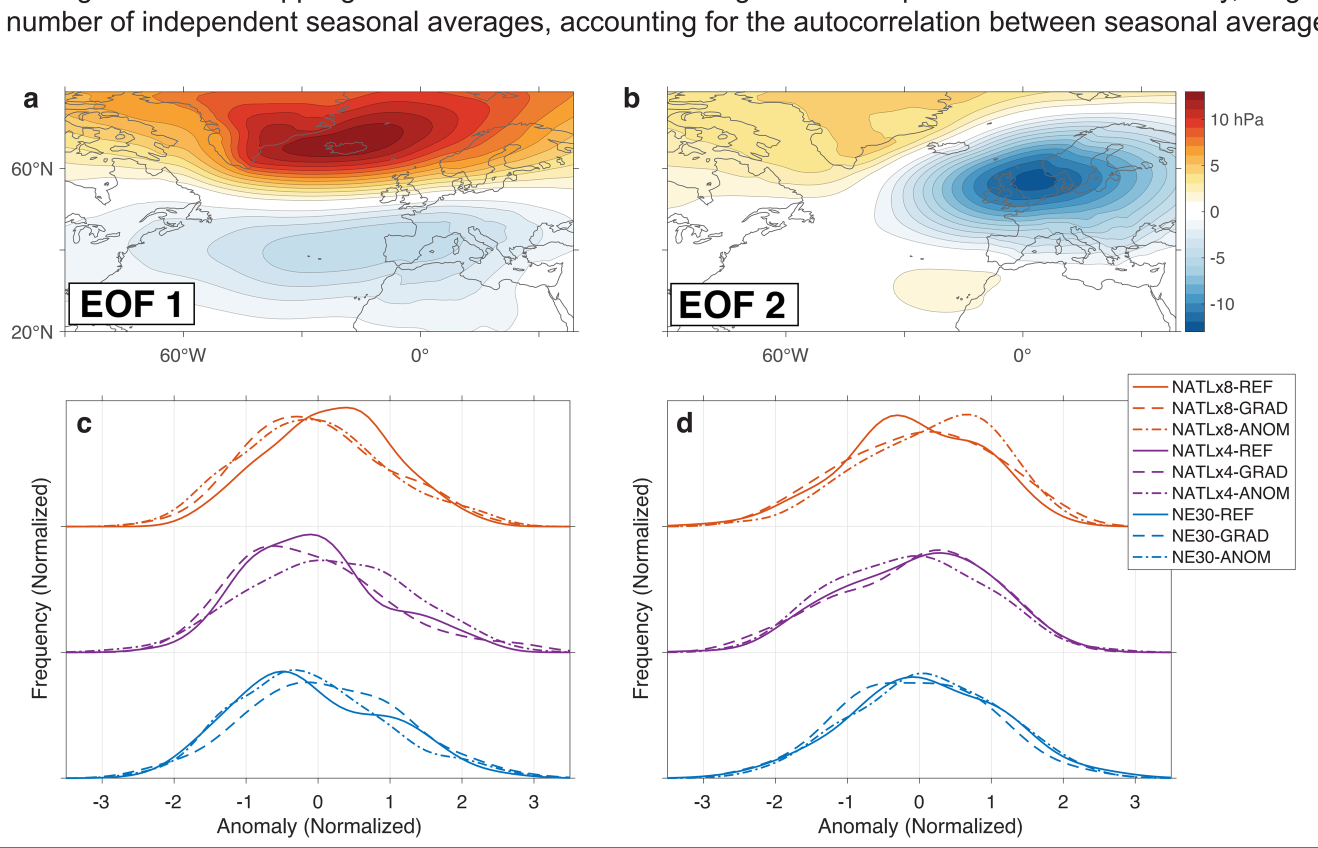


Figure 4. Empirical orthogonal functions (EOFs) of pentad-mean sea-level pressure (SLP) anomalies across all 9 simulations, where anomalies are with respect to the average climatology over all 9 simulations and thus include climatological differences. (a) EOF 1, (b) EOF2, (c) probability distribution of principal component 1 in each simulation, (d) probability distribution of principal component 2 in each simulation. The EOFs shown in (a) and (b) are equivalent to the anomaly when the associated principal component is equal to 1.

Mesoscale Influence on Large Scale

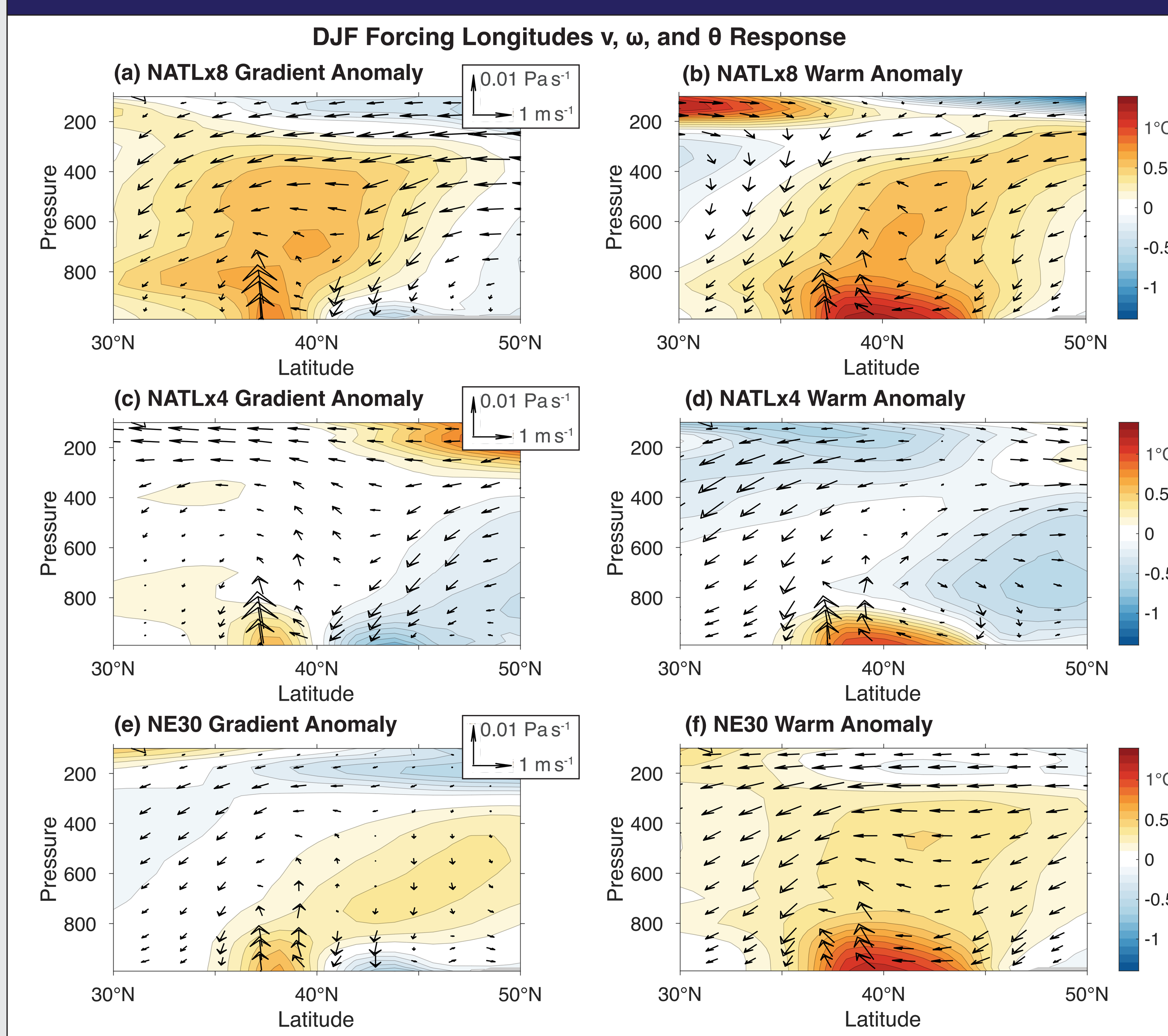


Figure 5. Average over the forcing longitudes (42-72°W) of the DJF response of v, ω (vectors), and potential temperature (shading) to an SST gradient anomaly (left) and a warm SST anomaly (right) in the Gulf Stream, in 3 different configurations of CAM-SE: (top) NATLx8, with 14-km resolution in the North Atlantic, (middle) NATLx4, with 28-km resolution in the North Atlantic, and (bottom) NE30, with 111-km resolution in the North Atlantic. Anomalies are the difference of 15-year averages in NATL and 45-year averages in NE30.

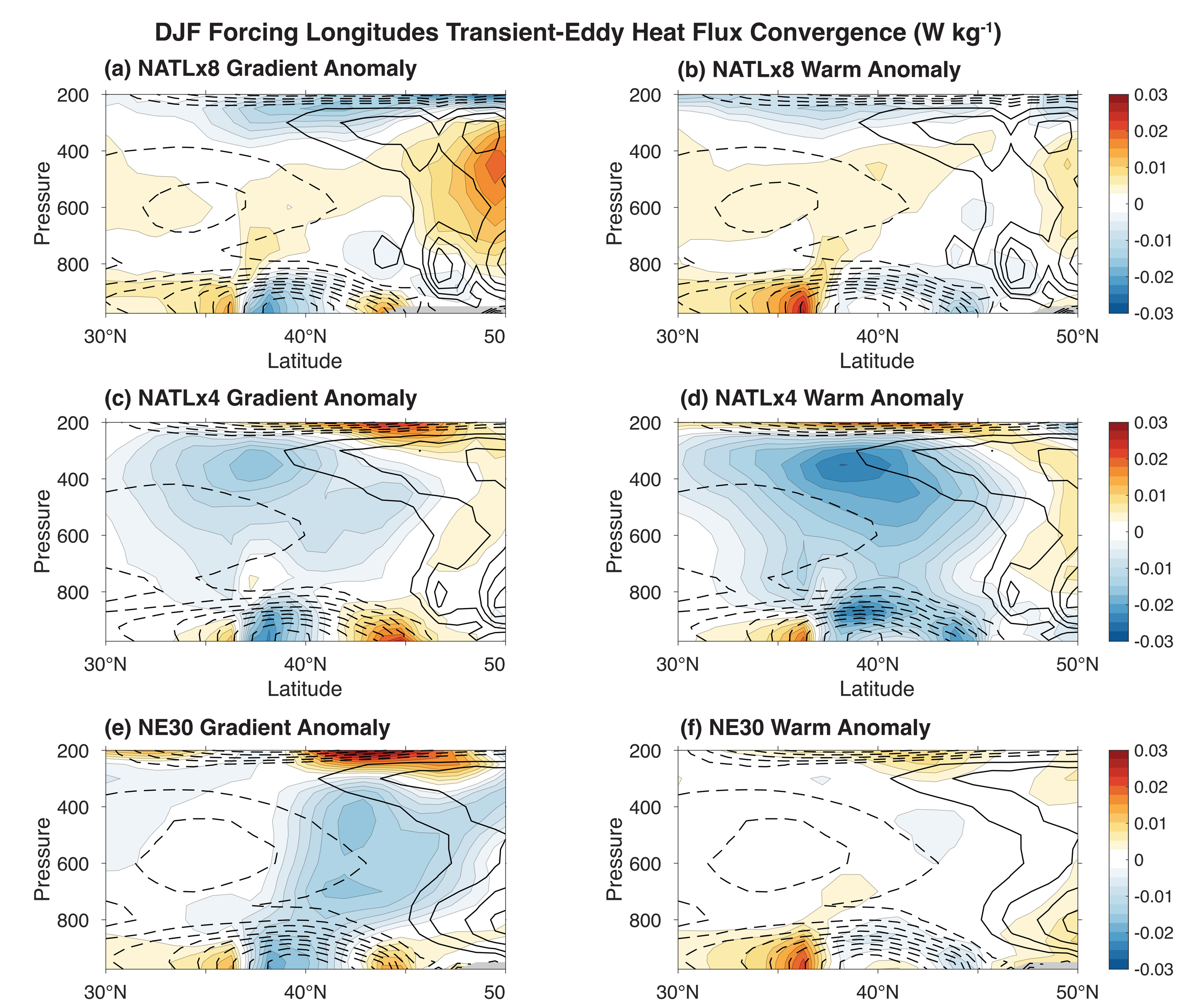


Figure 6. Average over the forcing longitudes (42-72°W) of the DJF climatology of the total transient-eddy heating tendency (contours) and its response (shading) to an SST gradient anomaly (left) and a warm SST anomaly (right) in the Gulf Stream, in 3 different configurations of CAM-SE.

Where in cyclones ascent occurs changes transient eddy statistics

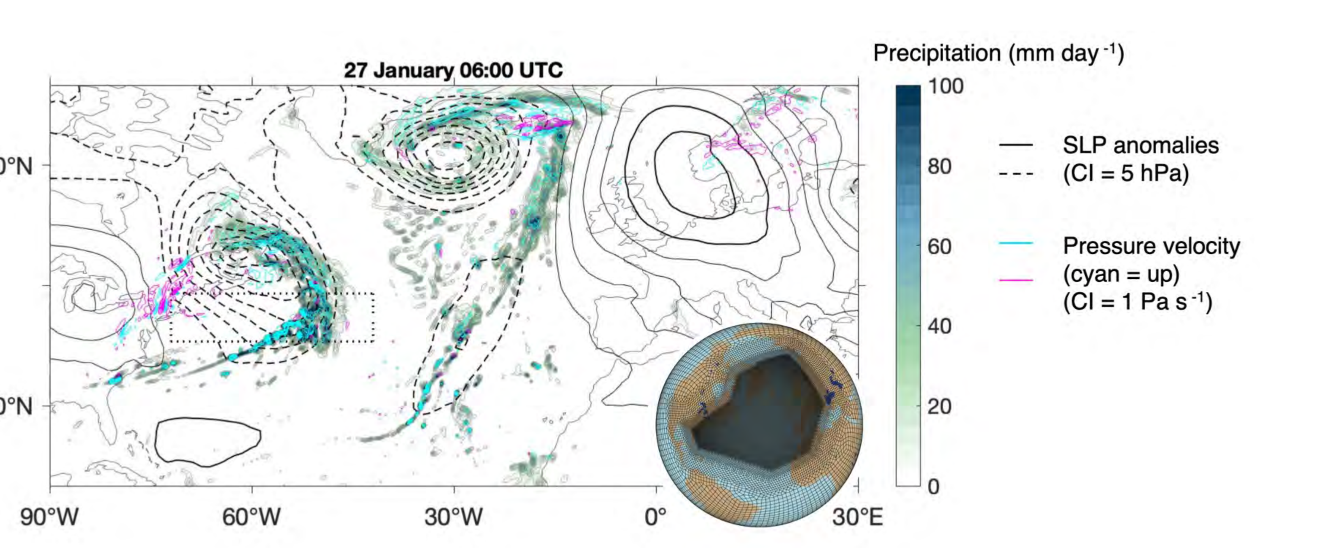
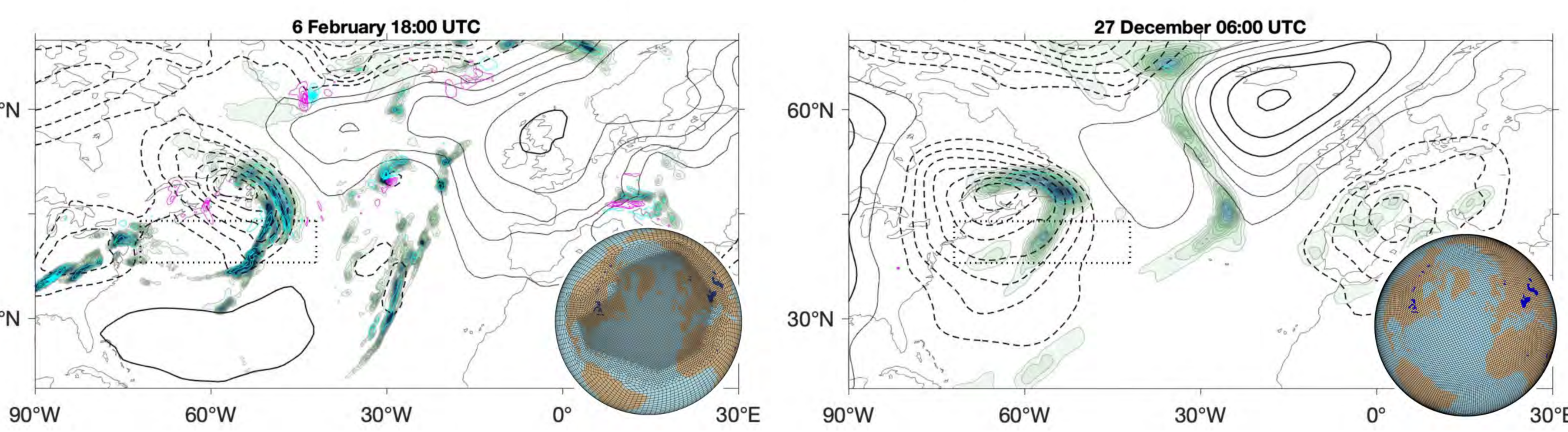


Figure 7. Snapshots of instantaneous SLP (black contours), precipitation (shading), and ω (colored contours) from simulations with an SST anomaly in the Gulf Stream in 3 difference configurations of CAM-SE.



Conclusions, Implications, Open Questions

- 14-km resolution regionally refined CAM6 simulations show a LARGE (~2 hPa per °C) positive NAO-like response to warm Gulf Stream SST anomalies that is weaker, absent, or of opposite sign in lower resolution simulations.
- There is a large increase in resolved ascent within midlatitude cyclones, leading to a deeper influence of SST anomalies on transient-eddy fluxes and free-tropospheric temperature. Opposite response at 28-km resolution appears to result from preferring warm sector (vs. cold sector) ascent pathway, following less steep isentropic slopes

Implications: Much more climate predictability from predictable decadal variability of North Atlantic SSTs; atmospheric response could influence further SST evolution

Open Questions: What aspect of SST pattern matters? Dependence on model and parameterization choices? Realism compared to observations? Much more...