Atmospheric Response to Mesoscale SST Variability in the North Atlantic

European Eddy-Rich ESMs

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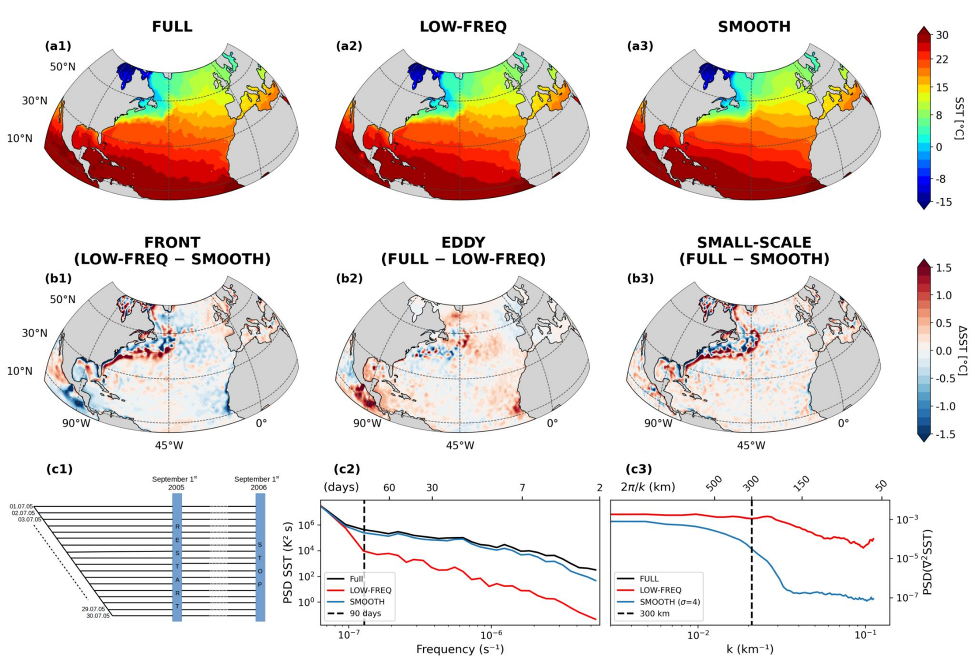

Fig. 1: **Top**: SST fields (1 Feb 2006) for FULL, temporally filtered (LOW-FREQ), and spatially filtered (SMOOTH) simulations.
Middle: SST differences defining EDDY (FULL − LOW-FREQ), FRONT (LOW-FREQ − SMOOTH), and SMALL-SCALE (FULL − SMOOTH) components.
Bottom: Ensemble spinup design (c1); power spectral densities showing the impact of temporal and spatial filtering. The dashed vertical line marks 90 days for the temporal spectra (c2) and 300 km for the spatial spectra (c3).

Motivation and Method

Motivation

Mesoscale eddies exchange energy with the atmosphere through air–sea heat fluxes[1,7,10], while oceanic fronts intensify boundary-layer circulation and precipitation[1,2,3,5,9]. These processes influence energy distribution, precipitation and the structure of atmospheric jets.

Objective

- Quantify how components of mesoscale SST variability influence:
  - Surface fluxes and precipitation
  - Vertical structure of temperature and moisture
  - Polar jet intensity

Approach

- **Region:** North Atlantic / Gulf Stream
- **Season:** DJF 2005-2006 (maximum baroclinic activity)
- **Model:** 30-member WRF ensemble[4]
- **Boundary forcing:** CFSR SST[6]
- Two filtering strategies isolate SST scales[8]:
  - Temporal smoothing (> 90 days)
  - Spatial smoothing (~ 300 km)
- Three Ensembles: Full, Low-Frequency, Smooth
- **Decomposition:**

EDDY = FULL − LOW-FREQ
FRONT = LOW-FREQ − SMOOTH
SMALL-SCALE = FULL − SMOOTH

Enhanced Low-Level Precipitation

- SST fronts over the Gulf Stream create strong temperature gradients (Fig. 1), boosting latent heat flux and moisture in the lower troposphere (Fig. 2).
- This drives a 12.1% increase in cumulative DJF precipitation over the Gulf Stream (+43.5 mm) for FRONT, and 13.3% (+48.7 mm) for SMALL-SCALE (Fig. 5) — amplifying existing convection rather than generating new precipitation in dry regions.
- Fast-moving eddies produce a weaker response (+2.2%, +7.5 mm), confirming that steady, persistent fronts — not transient eddies — anchor precipitation to the Gulf Stream.

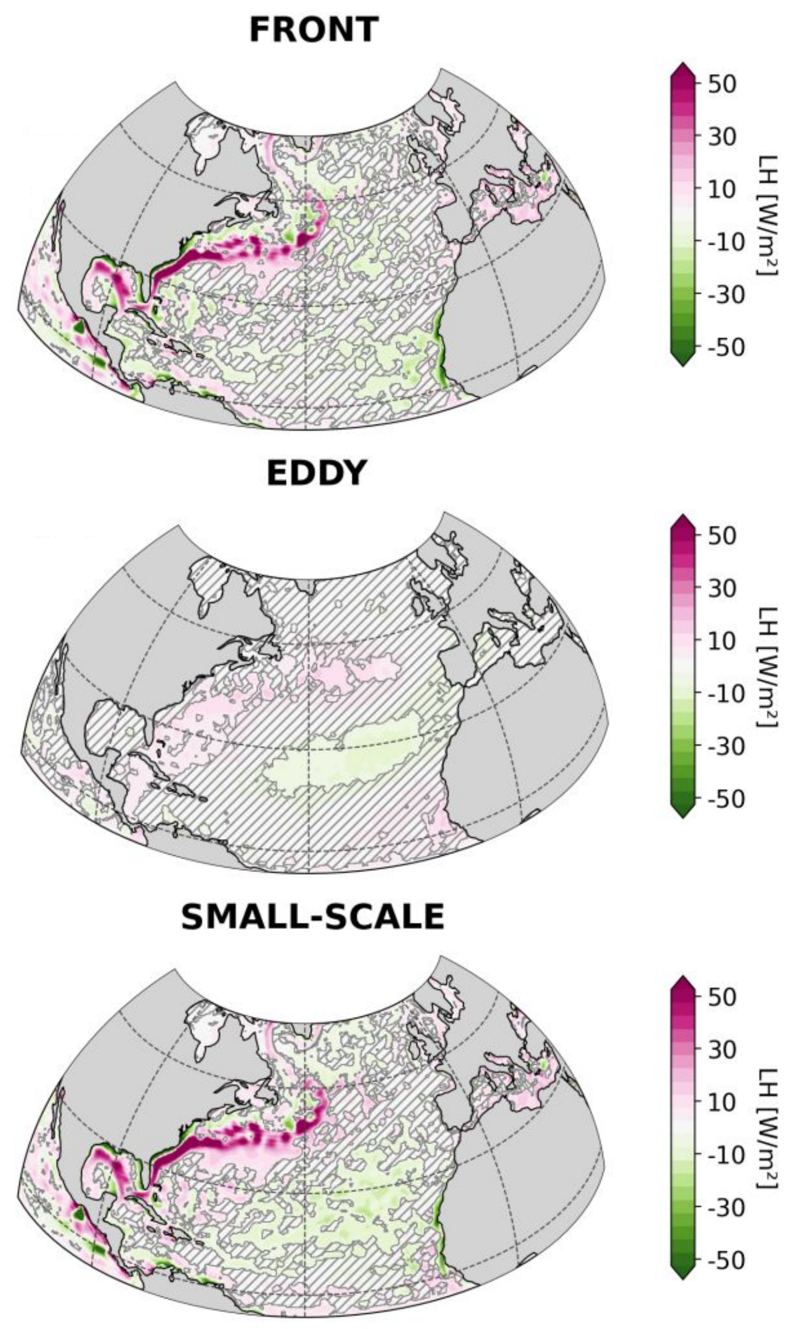

Fig. 2: Latent heat flux contributions from fronts, eddies, and small-scale features shown by colored contours (W m⁻²); shading shows where differences are statistically significant at a 95% confidence level. Black contours give the full-resolution latent heat flux. Fronts (+7.0%, +11.8 W m⁻²) and small-scale features (+9.9%, +17.1 W m⁻²) produce the strongest increases above the Gulf Stream, while eddies are weaker (+3.9%, +7.0 W m⁻²) but more spatially coherent. All contributions peak along the Gulf Stream and decline southeastward.

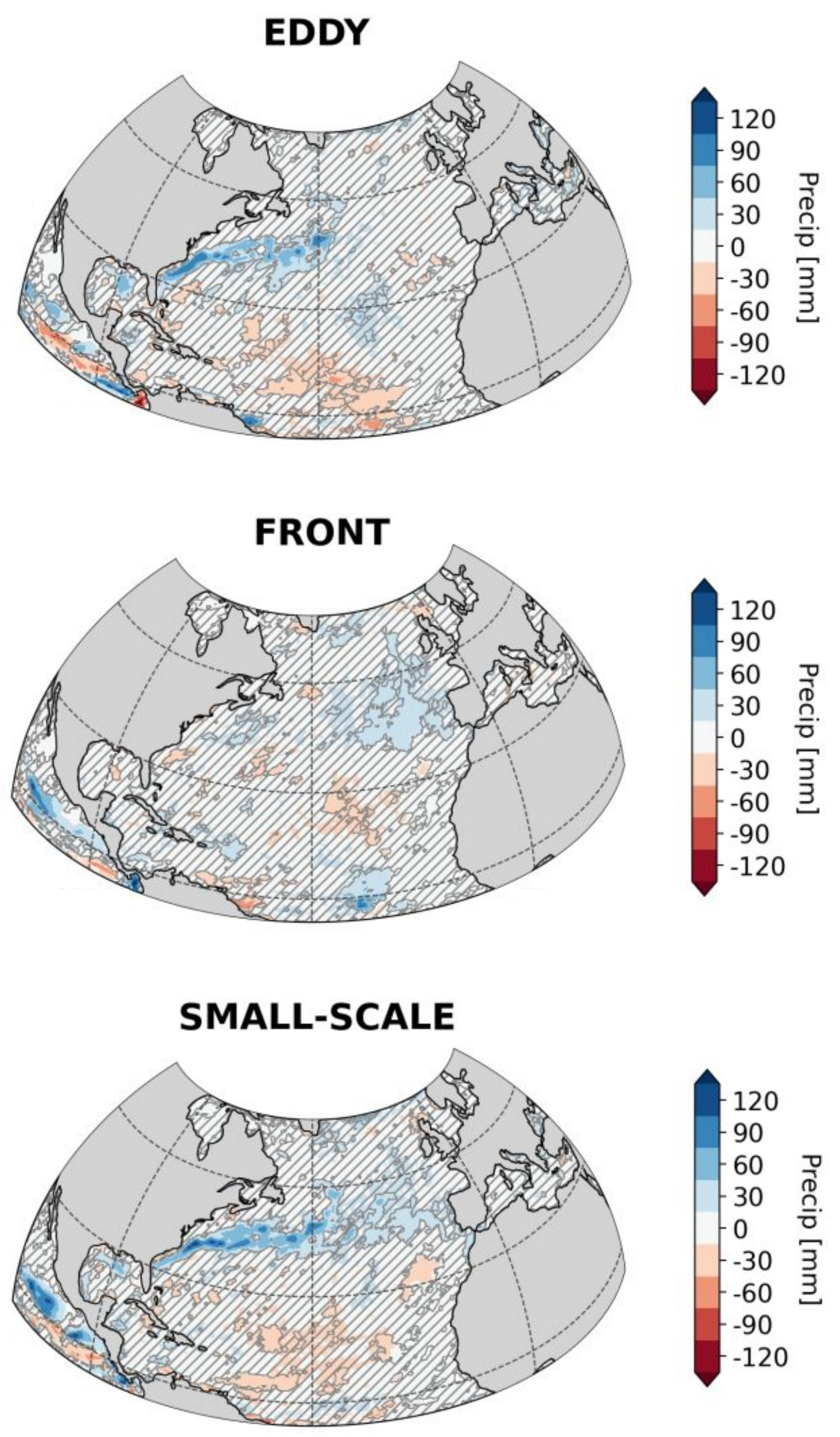

Fig. 3: DJF cumulative precipitation contributions from fronts, eddies, and small-scale features (colored contours, mm); shading shows where differences are statistically significant at a 95% confidence level. Black contours show full-resolution DJF cumulative precipitation. Fronts (+12.1%, +43.5 mm) and small-scale features (+13.3%, +48.7 mm) produce the strongest increases above the Gulf Stream, with local peaks exceeding 30%. Eddies have a much weaker impact (+2.2%, +7.5 mm) and lack spatial coherence.

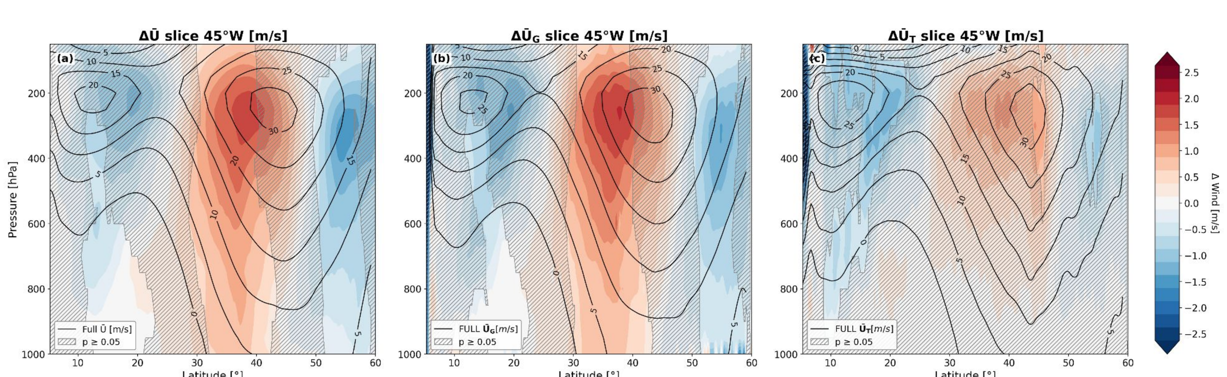

Fig. 4: Zonal slice of DJF zonal wind change attributed to eddies at 45°W. (a) WRF zonal wind response. (b) Geostrophic wind response, closely matching WRF (+0.8 m/s at jet level). (c) Thermal wind response, weaker and confined to the jet core. The match between (a) and (b) points to a diabatic, not baroclinic, pathway. Hatching = not significant (p>0.05).

Polar Jet Intensification

- Eddies and small-scale features enhance latent heat flux (Fig. 2), producing warmer, moister air that penetrates higher into the troposphere (Fig. 5b).
- Warming increases baroclinic energy conversion (+51%) and eddy heat flux convergence (+74%) between 30°N–45°N at 850 hPa, lifting geopotential levels and accelerating the geostrophic wind; matching the WRF response (+0.8 m/s at 45°W, Fig. 4).
- Fronts generate stronger but more localized latent heat flux anomalies (Fig. 2); this heating stays confined to the lower troposphere and precipitates rapidly (Fig. 3) rather than warming the column.
- As a result, fronts have limited influence on the jet, while eddies and small-scale features drive polar jet intensification of 9.8% (+1.8 m/s) through this diabatic heating path.

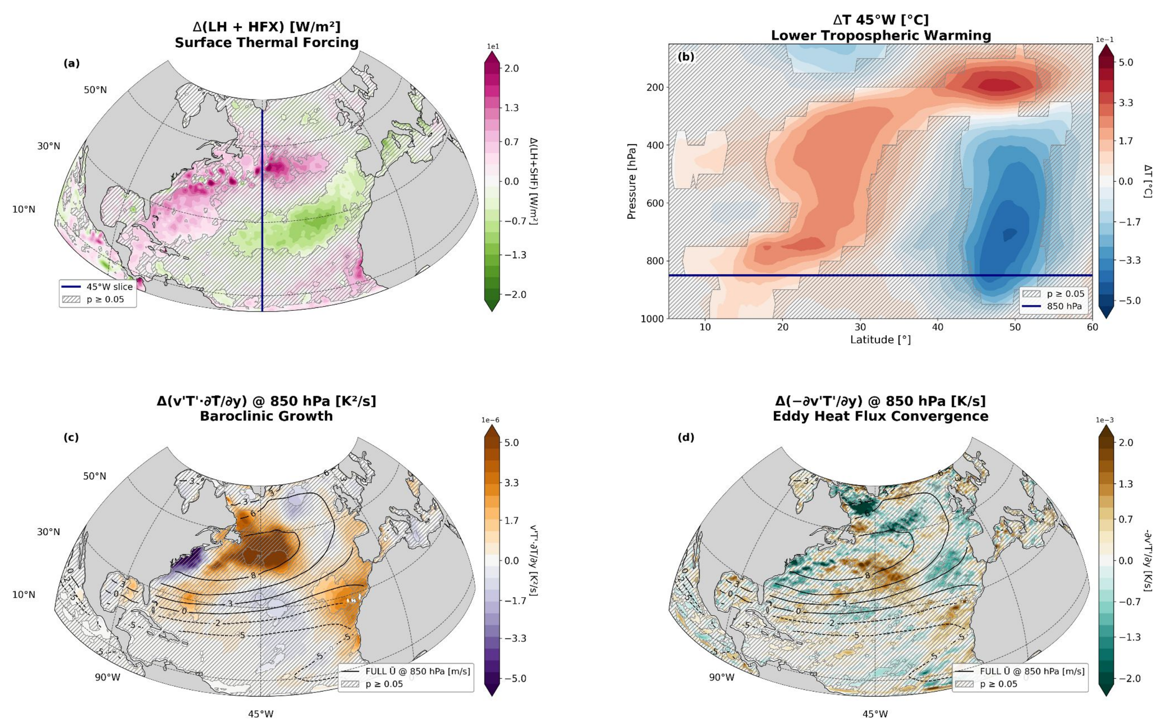

Fig. 5: Diabatic heating path for the eddy contribution to the jet (DJF). (a) Surface thermal forcing anomaly over the Gulf Stream (+10.5 W m⁻²). (b) Lower-tropospheric warming at 45°W, +0.27°C between 10° N–40°N. (c) Baroclinic energy conversion at 850 hPa, +51% between 30°N–45°N. (d) Eddy heat flux convergence at 850 hPa, +74% in the same region. Heating lifts geopotential levels and accelerates the geostrophic wind, driving jet intensification. Hatching = not significant (p>0.05).

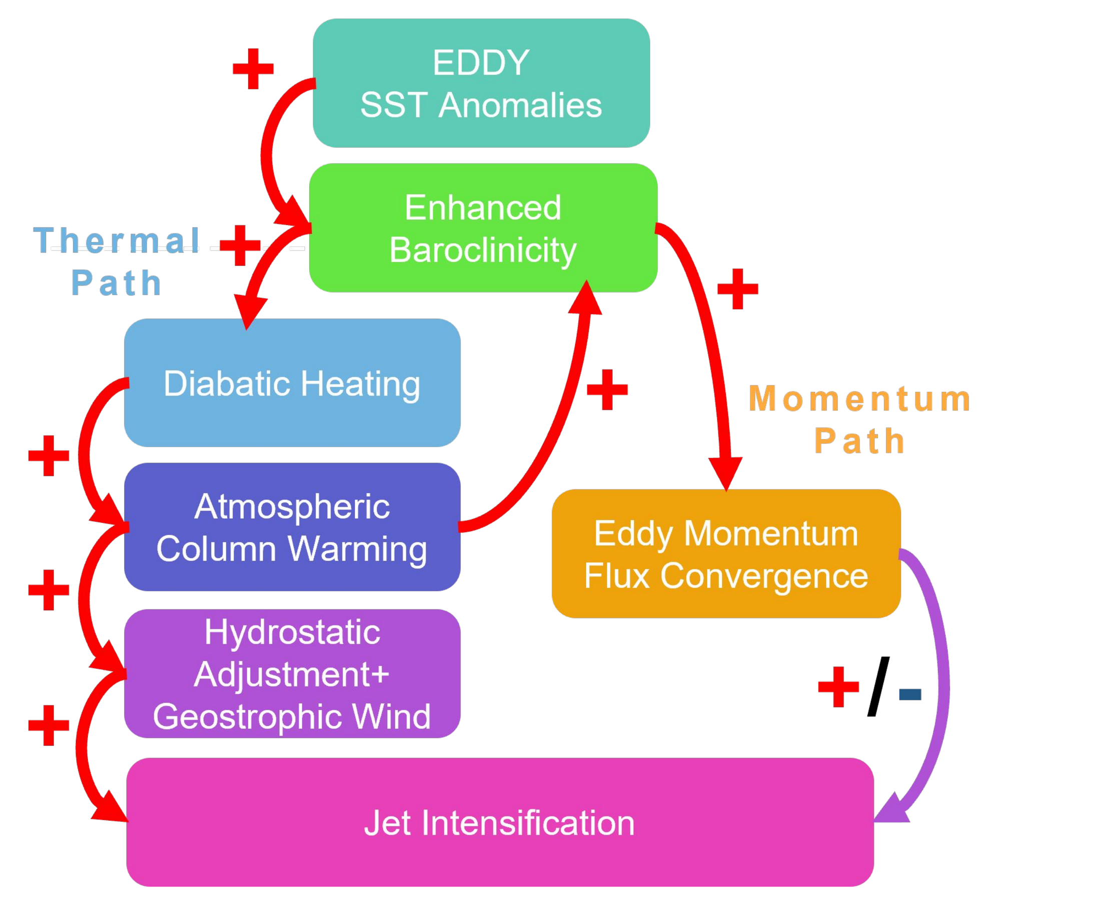

Fig. 6: Schematic of the pathways linking eddy SST anomalies to jet intensification. The thermal path — heating the atmospheric column, driving hydrostatic adjustment and accelerating the geostrophic wind — is the dominant mechanism discussed in this poster. A secondary momentum path, driven by enhanced eddy momentum flux convergence, also modulates jet position and strength.

Conclusions

- Vertical structure of latent heating controls the response: shallow heating reinforces precipitation; deeper heating strengthens the jet.
- SST fronts anchor precipitation to the Gulf Stream and intensify regional rainfall trends.
- Eddies intensify the polar jet through enhanced upper-tropospheric warming, whereas front-induced heating remains shallow and does not strengthen the jet.
- The thermal and eddy-momentum paths (Fig. 6) together link SST anomalies to jet intensification, with the thermal path dominant.
- Small-scale features reflect the combined effects of eddies and fronts.

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