What drives surface convergence over the Gulf Stream - atmosphere fronts, ocean fronts, or both?

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Abstract:

The western boundary currents are key regions of air-sea interaction in the Extratropics. A striking example is the occurrence of near-surface convergence, and enhanced rain rate, over the Gulf Stream in time-averaged fields. The paper of Minobe et al. (2008, Nature) related these features to responses of the boundary layer to SST gradients via adjustments of surface pressure. However, more recent papers note that typical (e.g. median) conditions over the Gulf Stream are surface divergence, and the convergence seen in the time-mean is due to a few high amplitude convergence events (O'Neill et al 2017, J. Clim.), and Parfitt and Seo (2018, GRL) further revealed that atmospheric fronts provided the vast majority of the convergence. In this poster we examine the time-and-space-scale dependence of the surface convergence to determine the relative roles of these processes.

Models, Data and Methods:

We use the ERA5 dataset for most analysis (Hersbach et al. 2020, QJRMS). ERA5 is a state of the art atmosphere reanalysis, with model grid spacing 31 km (spectral TL639), and 137 levels in the atmosphere. Data assimilation is a 4D VAR ensemble. Among the many datasets ingested are satellite scatterometer near-surface winds. Prior to September 2007, the boundary SST is from HadISST2.1.0.0 on a 0.25deg. Grid, and afterwards from OSTIA (0.05deg. Grid, Donlon et al. 2012). We analyze hourly output data. The results are highly consistent with those from a high resolution coupled simulation of CESM (Small et al. 2014, JAMES) indicating that the lack of coupling to the ocean in ERA5 is not a drawback for this work. For this poster we employ snapshots in time, monthly averages, and spectral techniques to analyze co-variability of atmosphere and ocean properties.

Case Study 1. Monthly-mean, Dec. 2018.

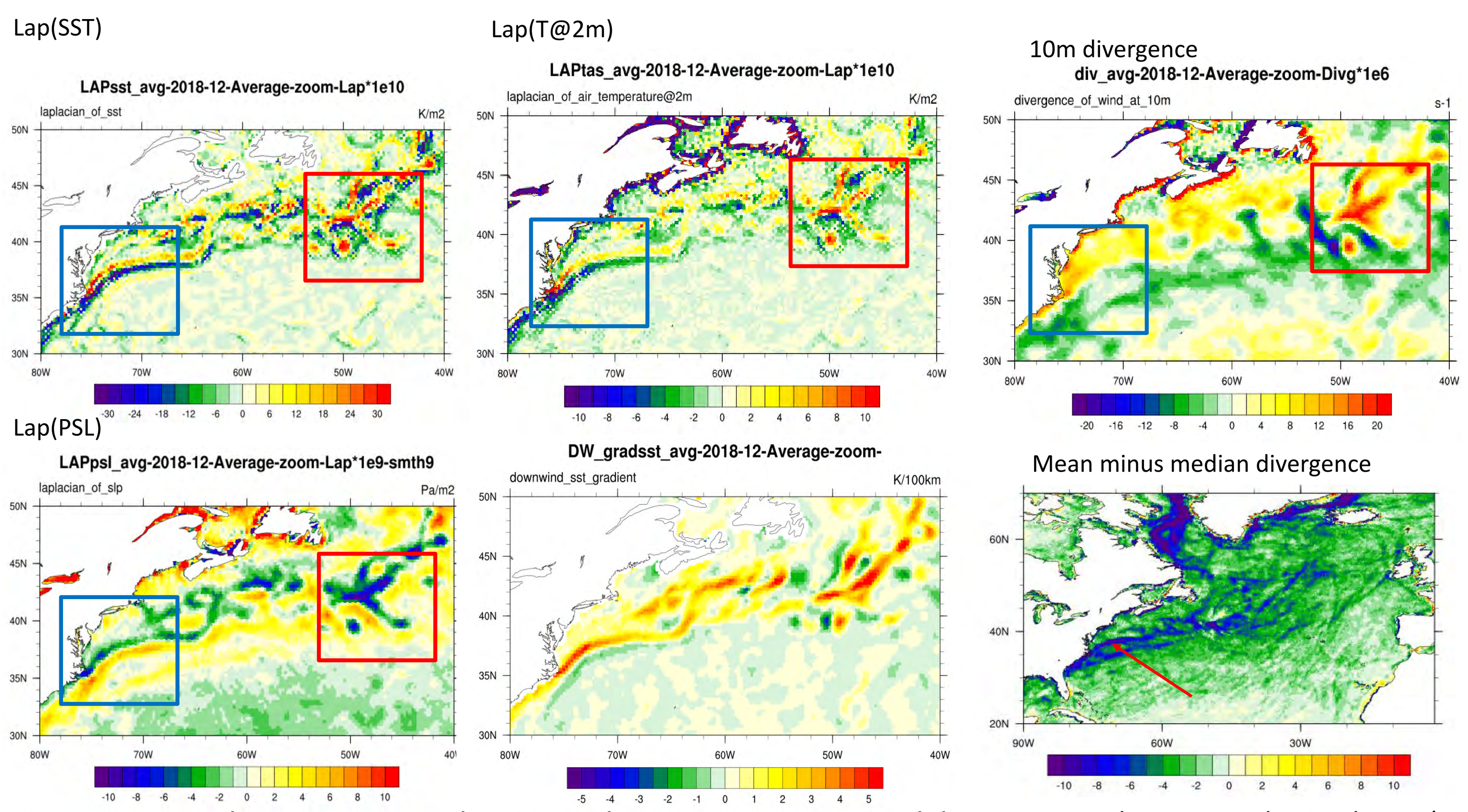


Fig. 1. One-month average, December 2018. The time-mean 10m wind divergence is shown at right. Laplacian(air temperature at 2m, Ta) is clearly similar to Lap(SST). Also some features in the divergence field relate to Lap (Ta), (e.g. red box), but not all (in blue box the convergence field over Gulf Stream is much broader than the negative lap(Ta)). The Lap(sea level pressure, PSL) is mostly the sign-reverse of the divergence. The downwind SST gradient also shows similar structures to Lap(Ta) and to 10m wind divergence, although downwind SST gradient is more positive-signed, which would encourage wind divergence. Meanwhile, a measure of extremes (mean minus median for the month) shows enhancement over the Gulf Stream.

Case Study 2. Hourly snapshot, Dec. 2018.

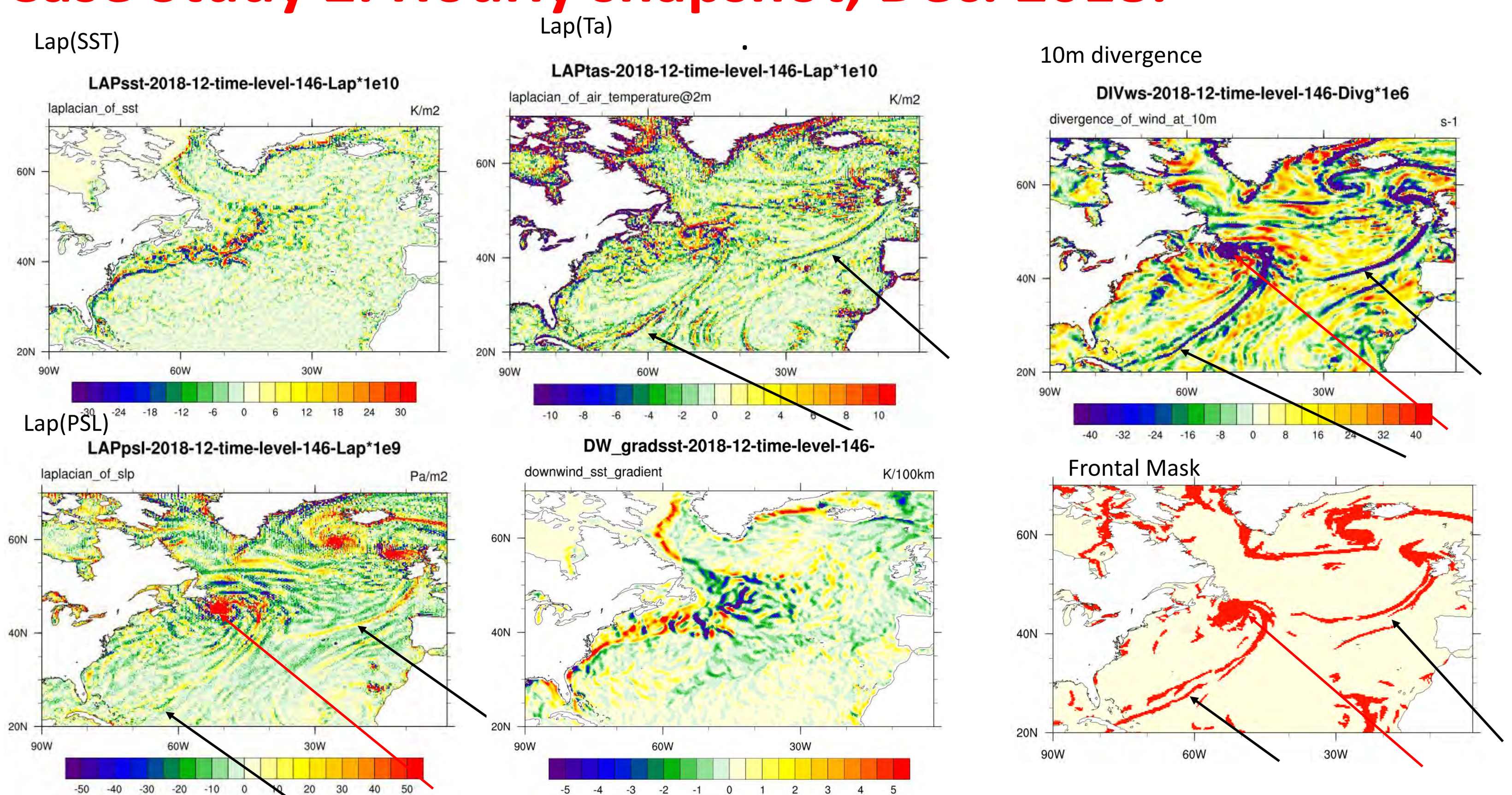
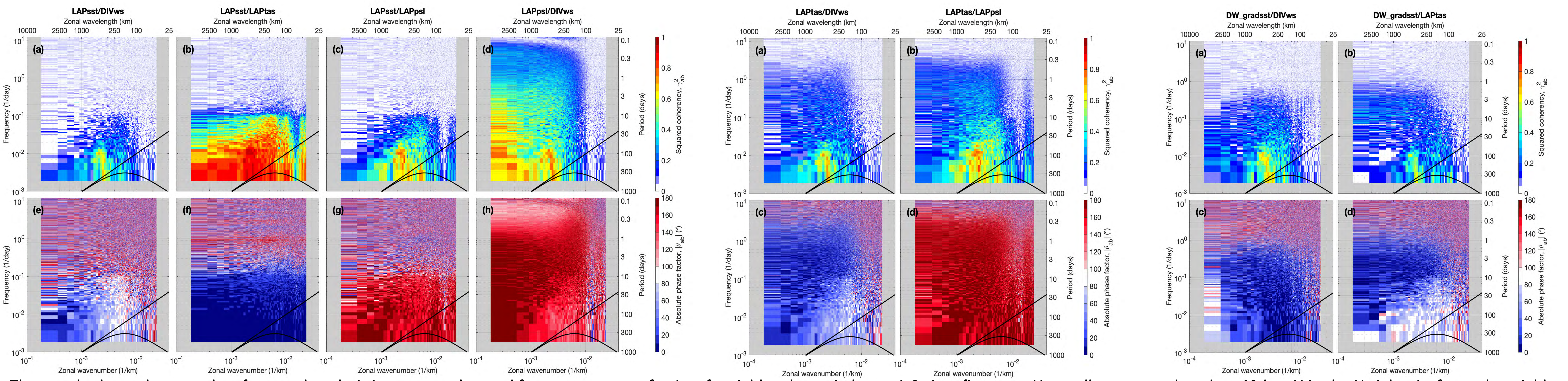


Fig. 2 Hourly-snapshot in December 2018. The 10m wind divergence is shown at right. Laplacian (Ta) shows structures also seen in the divergence field (i.e. atmosphere fronts, see black arrows and red arrows). Lap(Ta) also has some structure similar to Lap(SST), but not so obvious as in monthly mean. Divergence and Lap(SST) have no obvious relationship. Lap(PSL) also shows atmosphere front signatures. The downwind SST gradient shows maximum magnitude in the ocean front region, and also shows wide bands of alternating sign which likely correspond to changing wind direction in sectors of storms. A frontal-detection mask (Parfitt et al 2017, https://doi.org/10.1002/2017GL073662) confirms the location of the atmosphere fronts (in dark red).

Box 3. Spectral coherence analysis. Zonal-temporal Hovmoller diagrams at 40deg.N are analysed using spectral methods.



The panels above show results of spectral analysis in wavenumber and frequency space of pairs of variables shown in boxes 1-2. As a first step, Hovmollers are produced, at 40deg. N in the N. Atlantic, for each variable (longitude vs time), and then spectral (Fourier) coherence techniques are applied. In the above, the top panels are squared coherency (range 0 to 1), and the bottom panel the phase relationship (zero to 180deg., zero implying in phase, 180deg. is out of phase). Axes show frequency (left axis) and Period (right), and zonal wavenumber (bottom) and wavelength (top). The 10m wind divergence (DIVws) is strongly related to Laplacian of sea level pressure (LAPpsl) and also to Laplacian of 2m air temperature (LAPtas), at low and high frequency. Meanwhile Laplacian of SST (LAPsst) and downwind SST gradient (DW_gradsst) both influence divergence at low frequencies, while Laplacian of air temperature and downwind SST gradient are themselves related, as shown in recent papers by Foussard et al.

Conclusions:

The surface convergence over the Gulf Stream is indeed driven by both atmosphere fronts, and ocean fronts, and they interact, with extreme events and atmosphere fronts clustering over the Gulf Stream front. Two different regimes of air-sea interaction over the Gulf Stream are identified. At short time periods (less than 10 days) atmosphere fronts and synoptic systems dominate the surface convergence field. They leave distinct signatures in convergence, Laplacian (sea level pressure) and Laplacian (air temperature). At longer periods of 10 days or more, the ocean SST imprint in Laplacian(SST), Laplacian(air temperature), Laplacian (sea level pressure) and downwind SST gradient dominates. In turn this leads to an imprint on the surface convergence field. This is consistent with earlier findings by Brachet et al. 2012 (JCLIM).

Current work by the authors aims to quantify the contribution of atmosphere fronts (including extremes) as well as the background, boundary layer response to SST in driving the time-mean convergence field. *Small, R. J, et al., 2023. Near-surface wind convergence over the Gulf Stream – the role of SST revisited. Under revision, J. Clim.*

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