Air-Sea interaction over the Gulf Stream in an ensemble of HighResMIP present climate simulations

by **A. Bellucci**[1] and the PRIMAVERA group (2)

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Scientific Goal

Aim of this study is to assess the role of model resolution in the representation of air-sea interactions over the eddy-rich Gulf Stream region, through an analysis of the lead-lag SST/turbulent heat fluxes (THF) covariance patterns, following the methodology outlined in Bishop et al. (2017).

HighResMIP/PRIMAVERA Multi-Model Ensemble

Model	Nominal Resolution (Km)
HadGEM3-GC31-LL	A: 250 O: 100
HadGEM3-GC31-MM	A: 100 O: 25
HadGEM3-GC31-HM	A: 25 O: 25
ECMWF-IFS-LR	A:60 O: 100
ECMWF-IFS-HR	A: 25 O: 25
CMCC-CM2-HR4	A: 100 O:25
CMCC-CM2-VHR4	A: 25 O:25
EC-Earth3P	A: 100 O:100
EC-Earth3P-HR	A: 50 O:25
MPI-ESM-XR	A: 50 O:40
MPI-ESM-HR	A: 100 O:40
CNRM-CM6-1	A: 250 O: 100
CNRM-CM6-1-HR	A: 50 O:25

For the analysis, a multi-model ensemble of 100-yr present climate (control-1950) simulations have been used, performed at standard (LR) and high resolution (HR) following the HighresMIP protocol (Haarsma et al., 2016). Steady forcings representative of the present-day (1950) climate are used.

HighResMIP: Monthly mean SST and turbulent surface heat fluxes (THF; sum of latent and sensible heat fluxes).

Observations: monthly SST and turbulent (latent and sensible) heat flux (THF) from daily ¼º J-OFURO3 dataset (Tomita et al. 2019).

Theoretical Background [Bishop et al. 2017]

As shown in Bishop et al. (2017; B17) a simple Energy Balance model (equations 1 and 2) of the coupled ocean-atmosphere system reveals a distinctively different lead-lag covariance pattern between SST (and SST tendency) and THF, depending on whether SST variability is dominated by intrinsic atmospheric (synoptic weather) or oceanic (mesoscale eddies) variability.

$$\frac{dT_a}{dt} = \alpha(T_o - T_a) - \gamma_a T_a + N_a, \quad \text{and} \qquad (1)$$

$$\frac{dT_o}{dt} = \beta(T_a - T_o) - \gamma_o T_o + N_o, \qquad (2)$$

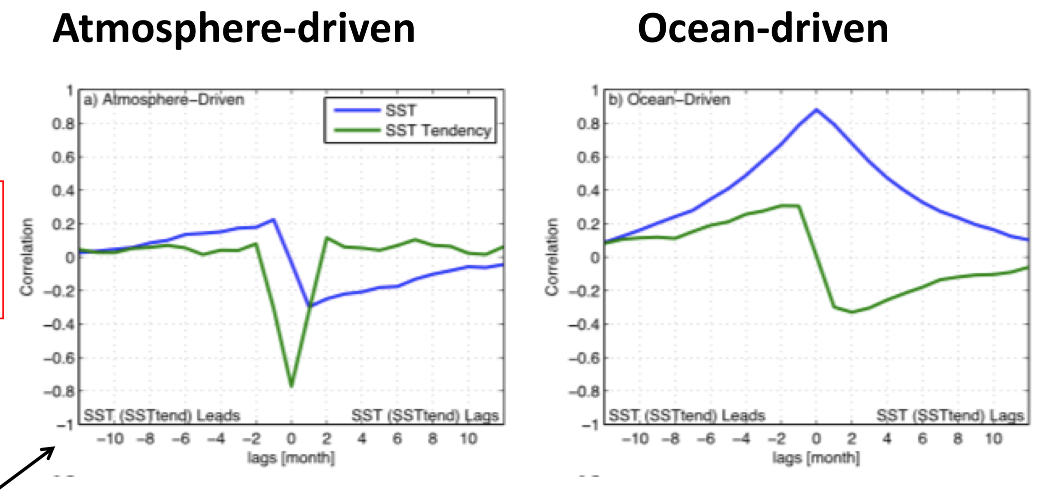
N_a, N_o: Stochastic forcings arising from weather or turbulent eddies in the atmosphere and ocean

Atmosphere-driven: N_o=0 – SST and THF are in quadrature and positive SHF (ocean cooling) is associated with negative SST tendency.

Ocean-driven: N_a=0 – THF is acting to damp the upper-ocean heat content anomalies generated by interior ocean processes, with the flux directly proportional to the SST itself.

Atmosphere-driven **Ocean-driven**

Open ocean (far from WBCs)



Energetic WBC

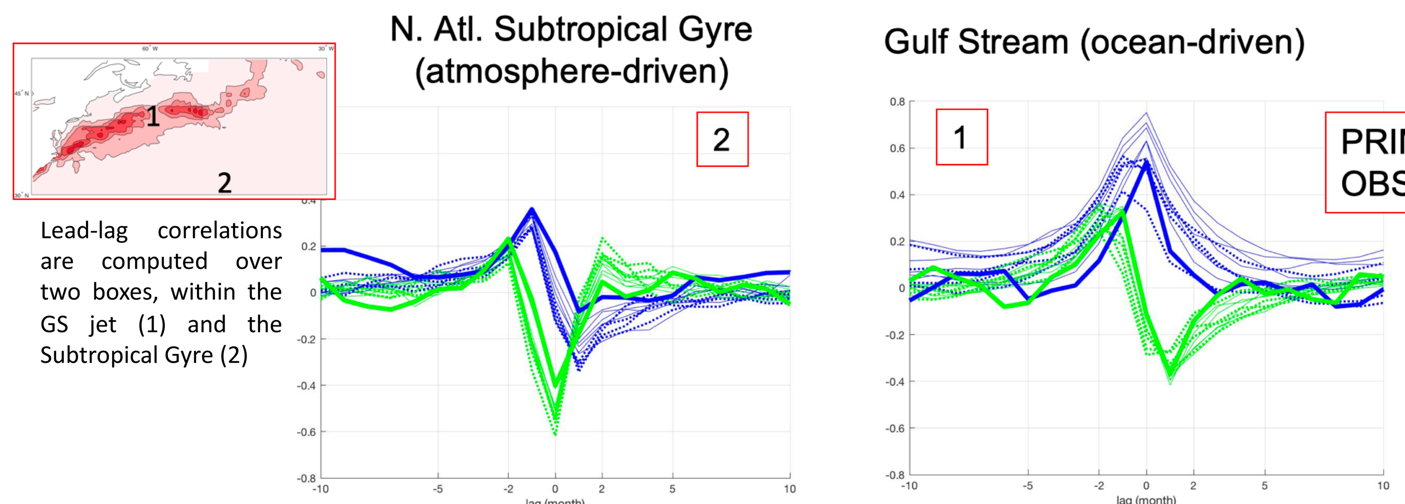
Hasselmann (1976) paradigm: all stochastic forcing arises in the atmosphere

Alternative paradigm: intrinsic ocean variability acting as the driver of surface variations

Lead-lag SST (SST_t)/THF correlations

N. Atl. Subtropical Gyre (atmosphere-driven)

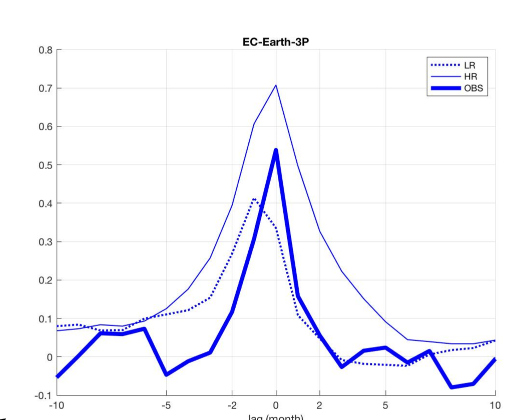
Gulf Stream (ocean-driven)

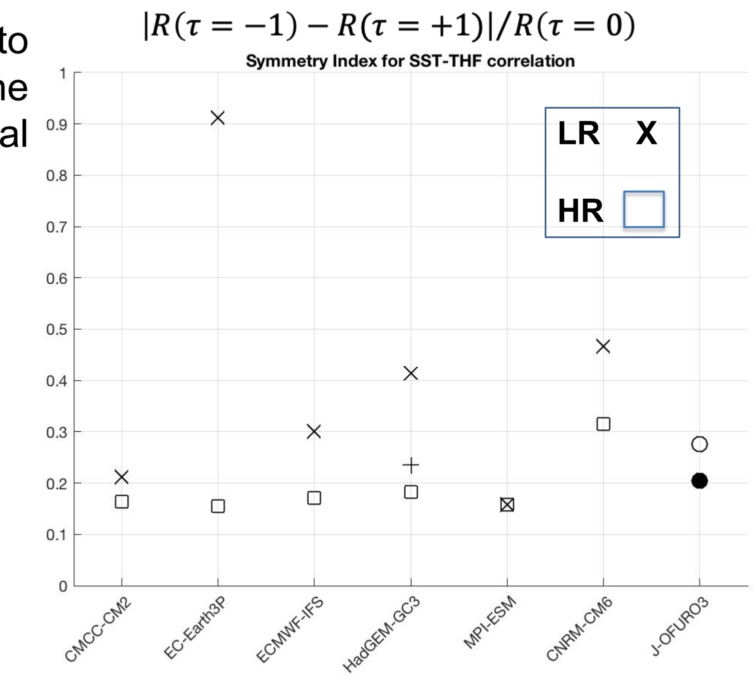


Lead-lag correlations are computed over two boxes, within the GS jet (1) and the Subtropical Gyre (2)

A **symmetry index** is defined to evaluate the deviation of the lead-lag correlation functional shape from symmetry

$$|R(\tau=-1) - R(\tau=+1)|/R(\tau=0)$$

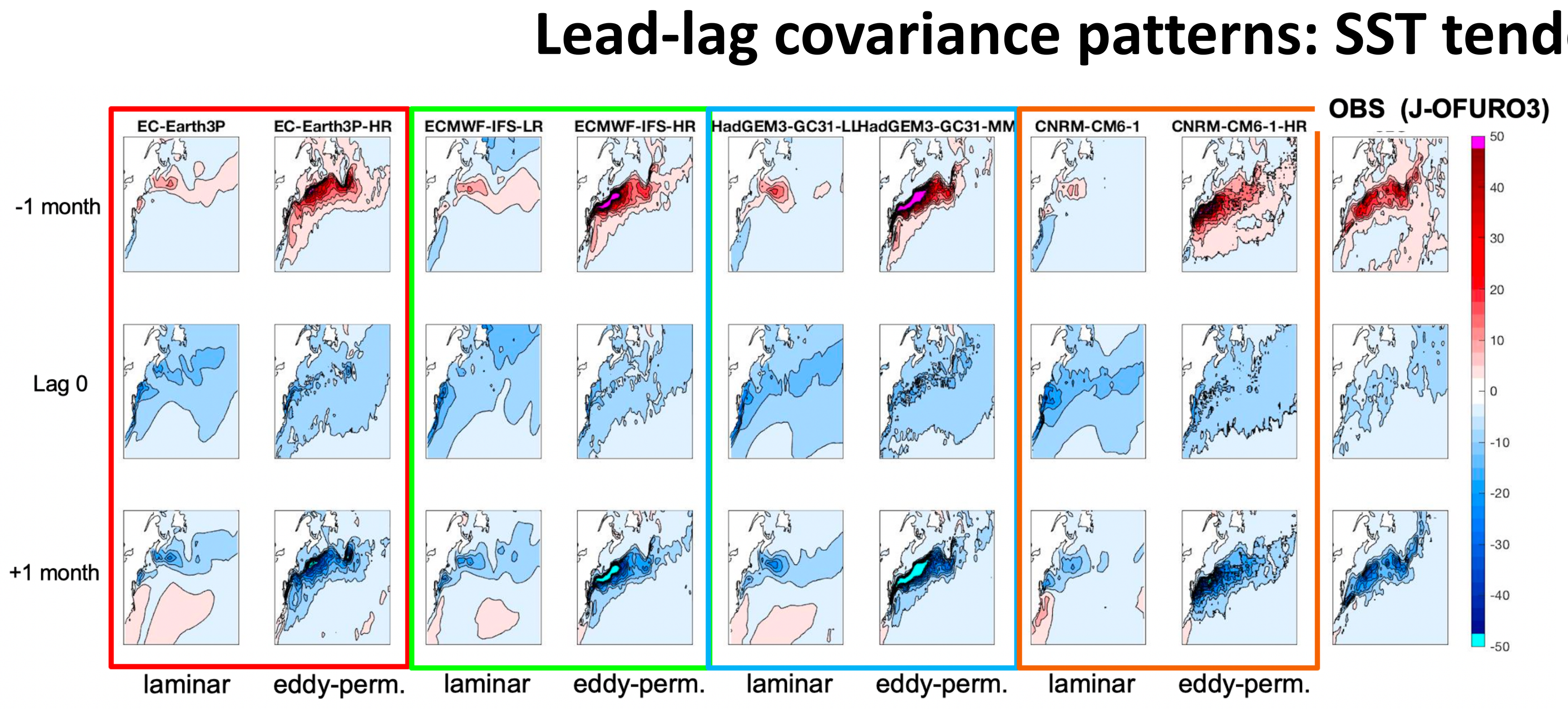




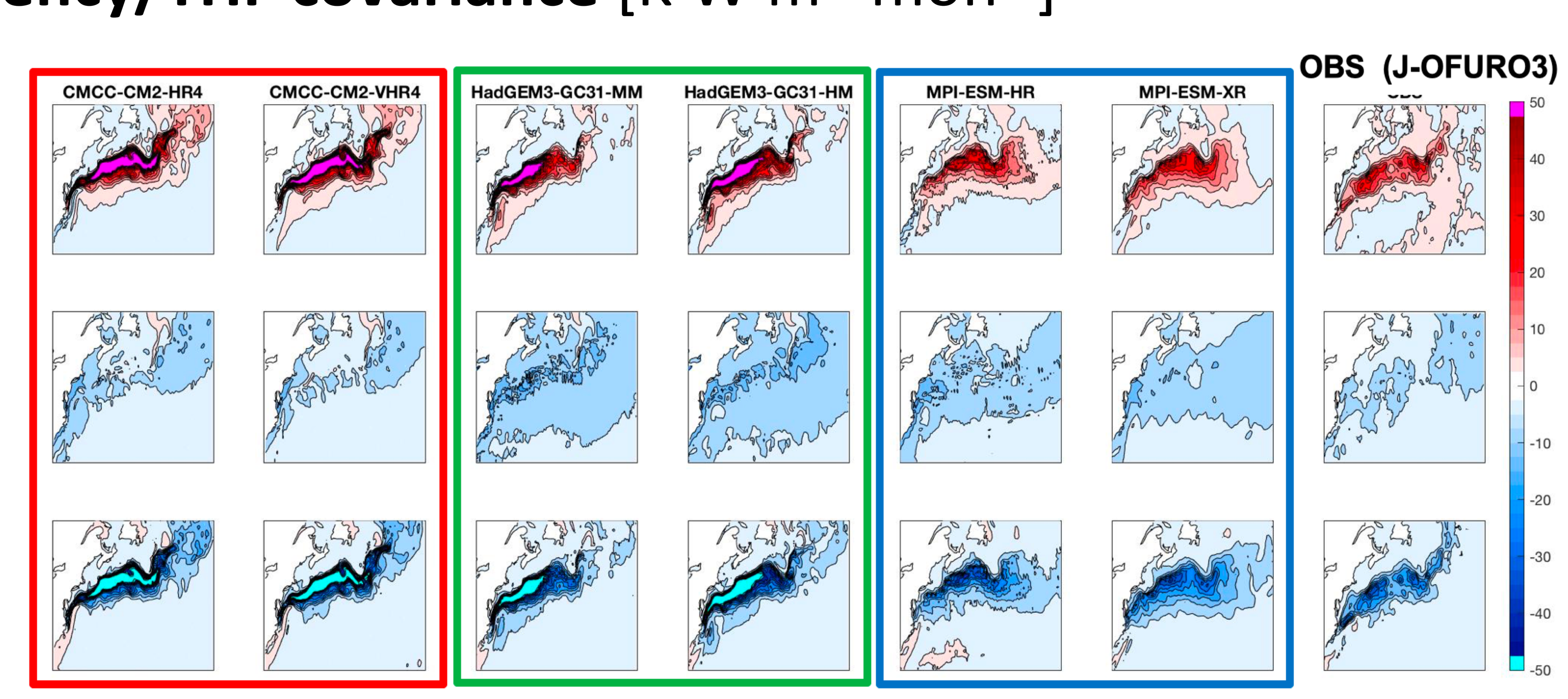
Models reproduce the theoretically predicted (EBM) functional laws for SST (SST-tend.)-THF lead-lag correlations over the Gulf Stream (WBC) and Subtropical Gyre (open ocean) **with a different degree of realism**: **eddy-parametrised models deviate from the symmetric functional shape over the GS. This bias is corrected in eddy-permitting models (e.g., see EC-Earth3).**

LR models show a systematically lower degree of symmetry (i.e., larger SI values) compared to HR

Lead-lag covariance patterns: SST tendency/THF covariance [K W m^{-2} mon^{-1}]



Models changing both oceanic AND atmospheric grid resolution



Same ocean but different atmospheric resolution

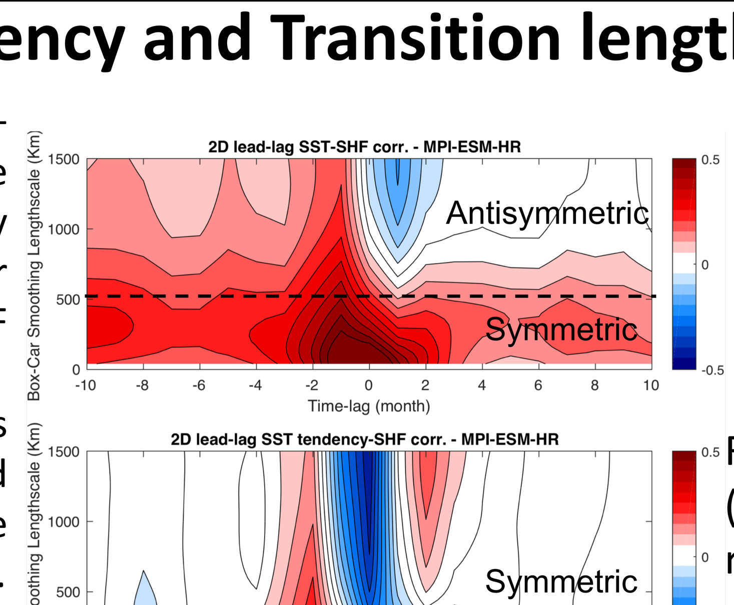
- Increasing the **ocean model resolution** from "laminar" (100 km) to "turbulent" (eddy-permitting; 25 km) has a **beneficial impact** on the representation of the covariance patterns over GS.

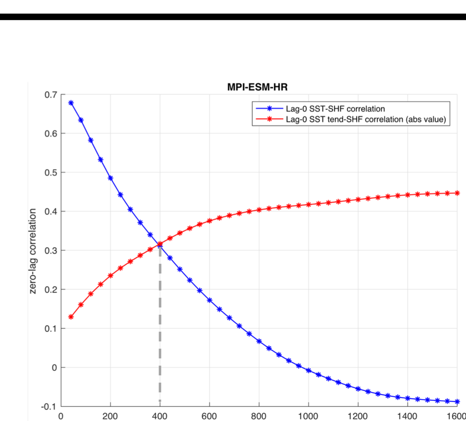
The ocean model resolution plays a primary role: there is a critical threshold in the grid resolution placed around the eddy-permitting (~25 Km) range leading to a step-change in the degree of realism of the simulated air-sea interaction.

Scale-dependency and Transition length

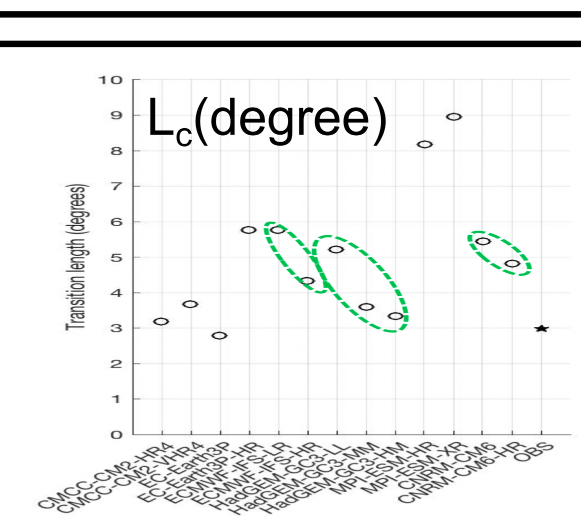
Space-depency of lead-lag correlation over the GS is inspected by applying a box-car filter to smooth SST/THF fields.

Lead-lag correlations are then re-calculated as a function of the smoothing length scale. (MPI-ESM model is shown as an example)





Following B17 a **transition lengthscale** (L_c) from ocean- to atmosphere-driven regime is identified as crossing point smoothing-length value between R(SST,THF) and |R(SST_t,THF)| at lag-0.



Modeled L_c exceed the observed estimate. Three models show a bias reduction with resolution.

References and Acknowledgements

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