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

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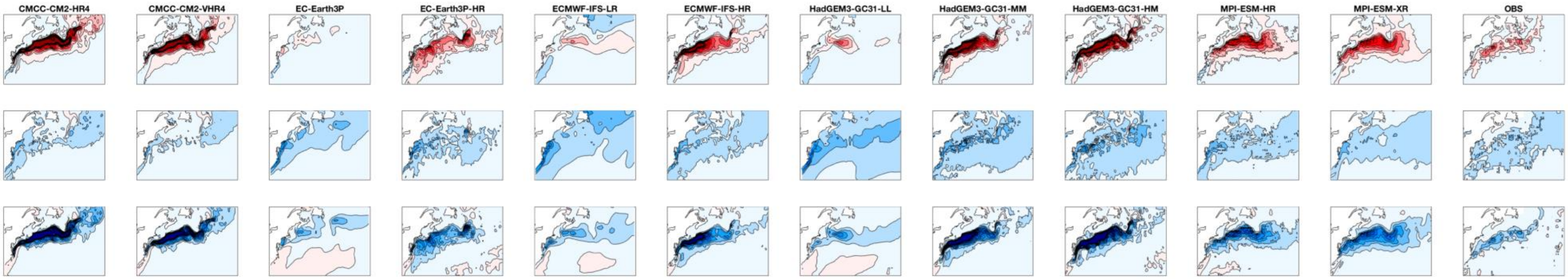


## THEORETICAL BACKGROUND

According to a simple local **Energy Balance Model** of the coupled ocean-atmosphere system, the statistical relationship between SST and Surface Heat Fluxes (SHF) features well distinguishable functional forms, depending on the relative roles played by atmospheric intrinsic variability (synoptic weather) and oceanic intrinsic variability:

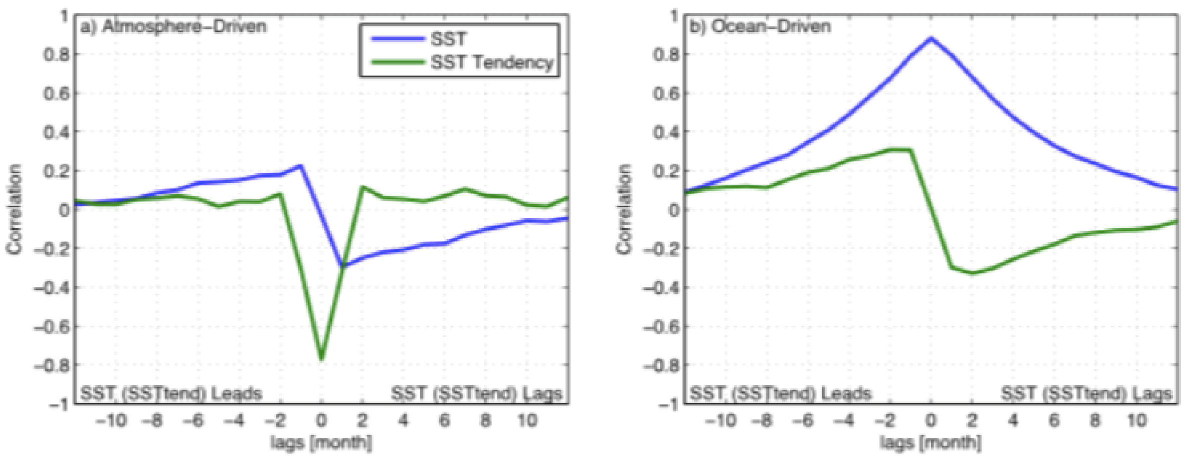
$$\frac{dT_a}{dt} = \alpha(T_o - T_a) - \gamma_a T_a + N_a \quad \text{and} \qquad (1)$$

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

**Na,No:** Stochastic forcing arising from weather or turbulent eddies in the atmosphere and ocean.

**Atmosphere-driven: No=0** - we expect the SST and SHF to be roughly in quadrature with each other and positive SHF (ocean cooling) to be associated with negative SST tendency.

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




(Bishop et al., 2017)

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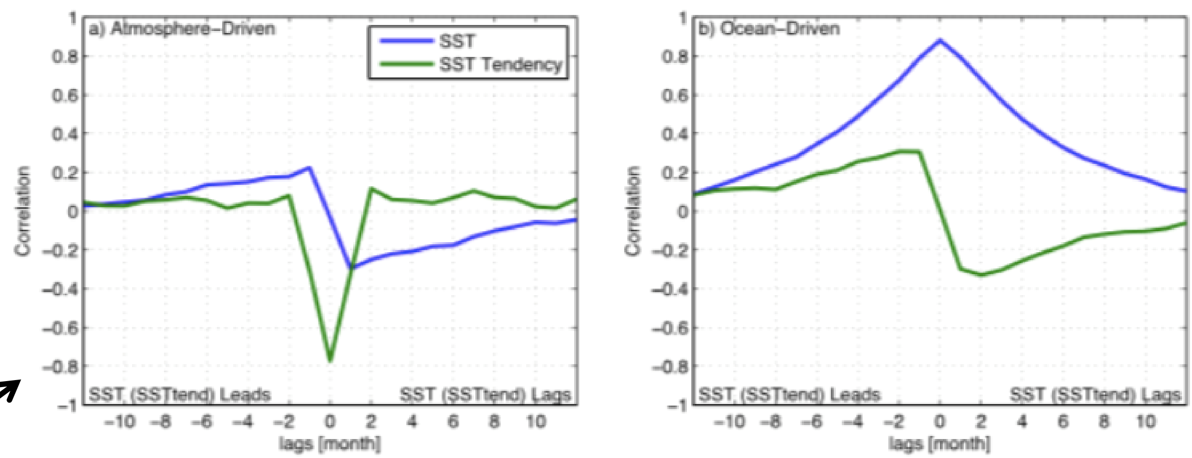
Open ocean (far from WBC)




Energetic WBCs

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

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

(Bishop et al., 2017)

Moving from zero-dimensional EBM to more complex dynamical systems

What is the ability of current current GCMs in reproducing the theoretically predicted SST-SHF covariance patterns in WBC (GS) vs open ocean?

What is the role of model resolution?
(laminar vs eddy-permitting oceans coupled with atmospheres with different resolutions)

Scrutinize HighResMIP

# HighResMIP models

| Model | Nominal Resolution (Km) | Category (O\|A) |
|---|---|---|
| HadGEM3-GC31-LL | A: 250 O: 100 | L (Loce Latm) |
| HadGEM3-GC31-MM | A: 100 O: 25 | M (Hoce Latm) |
| HadGEM3-GC31-HM | A: 25 O: 25 | H (Hoce Hatm) |
| ECMWF-IFS-LR | A:60 O: 100 | L (Loce Latm) |
| ECMWF-IFS-HR | A: 25 O: 25 | H (Hoce Hatm) |
| CMCC-CM2-HR4 | A: 100 O:25 | M (Hoce Latm) |
| CMCC-CM2-VHR4 | A: 25 O:25 | H (Hoce Hatm) |
| EC-Earth3P | A: 100 O:100 | L (Loce Latm) |
| EC-Earth3P-HR | A: 50 O:25 | H (Hoce Hatm) |
| MPI-ESM-HR | A: 100 O:40 | L (Loce Latm) |
| MPI-ESM-XR | A: 100 O:40 | L (Loce Latm) |

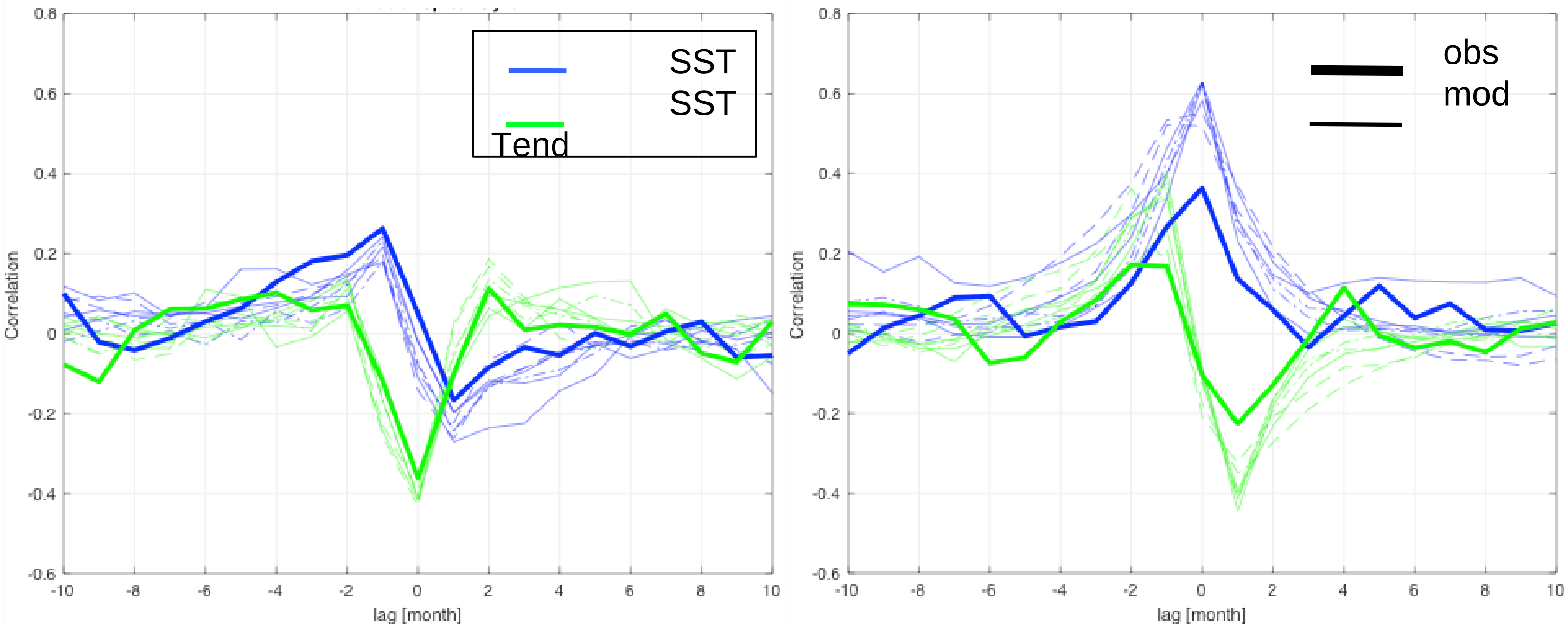
**HighResMIP models**: monthly-mean SST and SHF from present-climate (CTRL-1950) 100-yr control simulation. Forcings are held fixed at 1950.
**OBS**: daily ¼$^o$ OISST (SST) and monthly 1$^o$ OAFLUX (Latent and Sensible HF: SHF)

# SST-SHF and d(SST)/dt-SHF lead-lag correlation in GS and STG regions in HighResMIP

# Lead-lag SST/SST$_t$-SHF correlation

N. Atl. Subtropical Gyre

Gulf Stream




Lead-lag correlation between SST and SHF (blue) and SST tendency and SHF (green) over the subtropical gyre (left) and within the Gulf Stream (right).

**Thick lines identify OBS** (OISST/OAFLUX) while **thin lines refer to HighResMIP** models at different resolutions.

# Lead-lag SST/SST$_t$-SHF correlation

N. Atl. Subtropical Gyre

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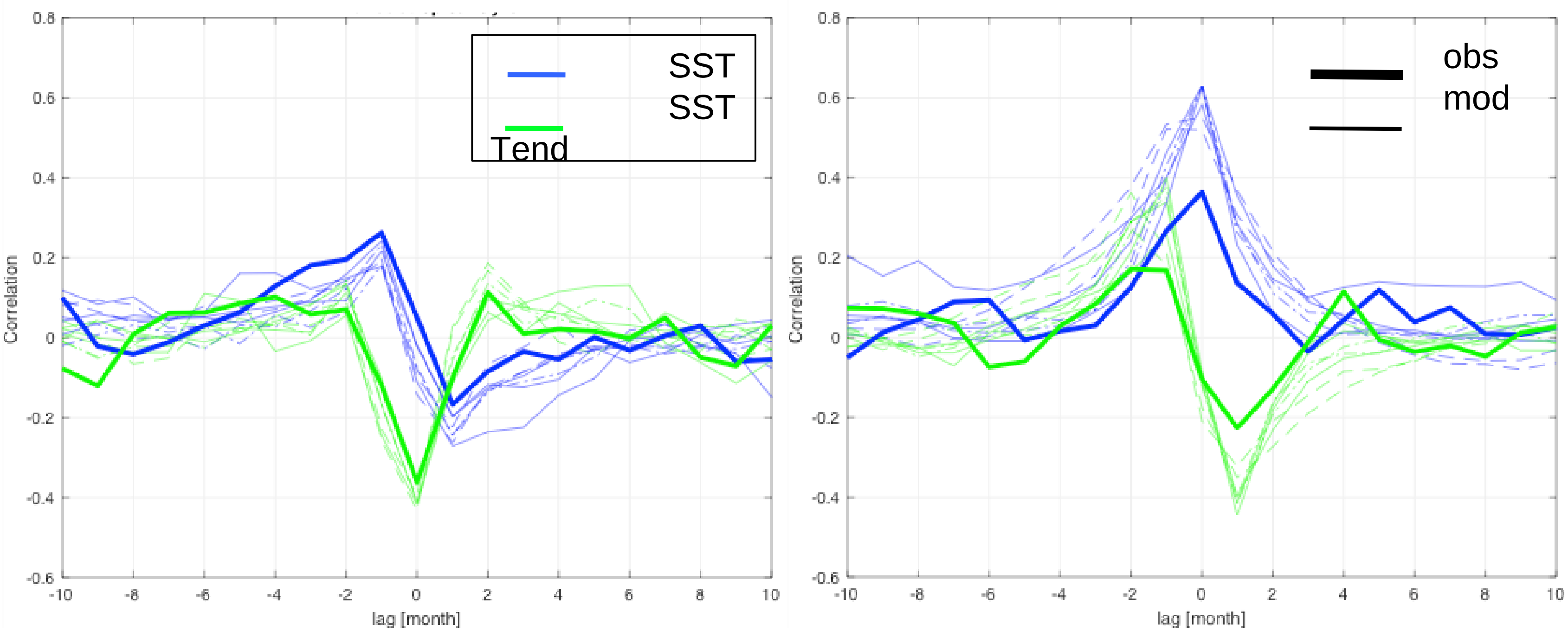


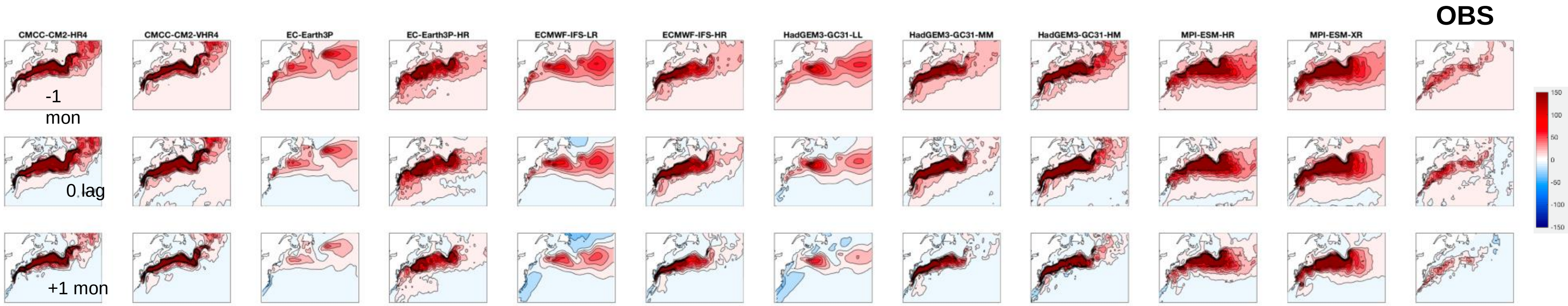

All model configurations (regardless of their resolution) faithfully capture observed and theoretically predicted air-sea interaction regimes: atmosphere-driven over Subtropical Gyre vs ocean-driven over the GS area

Lead-lag correlations are overestimated (compared to OBS) in GS jet – dominated by ocean-weather driven fluxes - while fit well the observed pattern in the more atmosphere-driven Subtropical Gyre region.

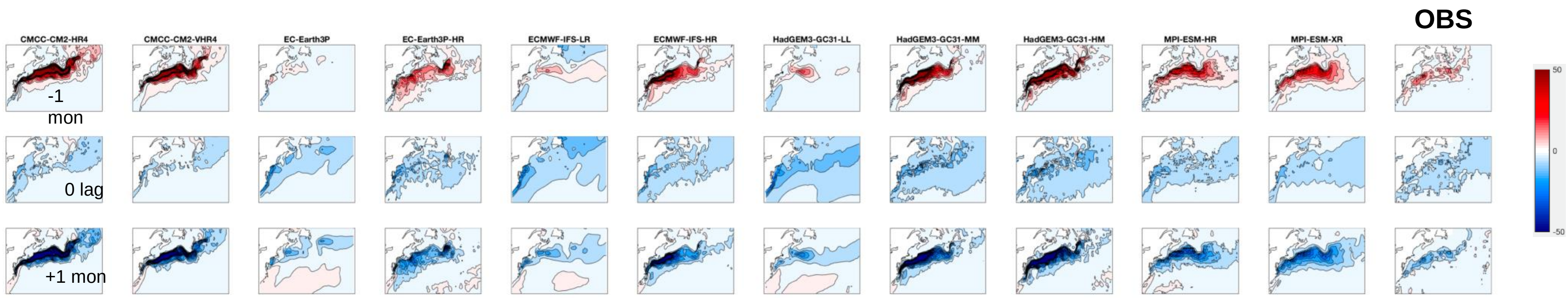
Phase relationships show weak dependency on the model resolution

# SST-SHF and d(SST)/dt-SHF COVARIANCE PATTERNS

# SST/SHF covariance [K W $m^{-2}$]




# SST tendency/SHF covariance [K W $m^{-2}$ $mon^{-1}$]



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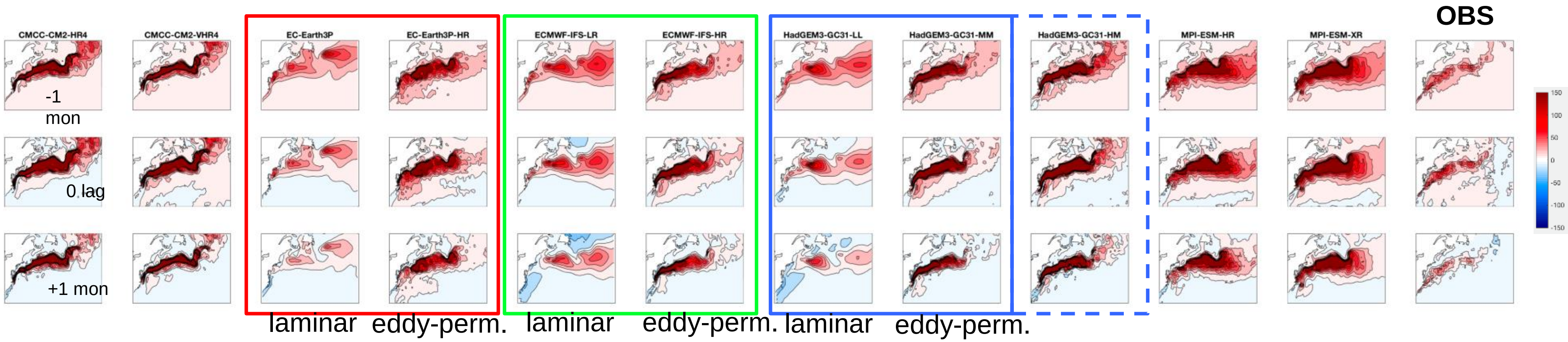


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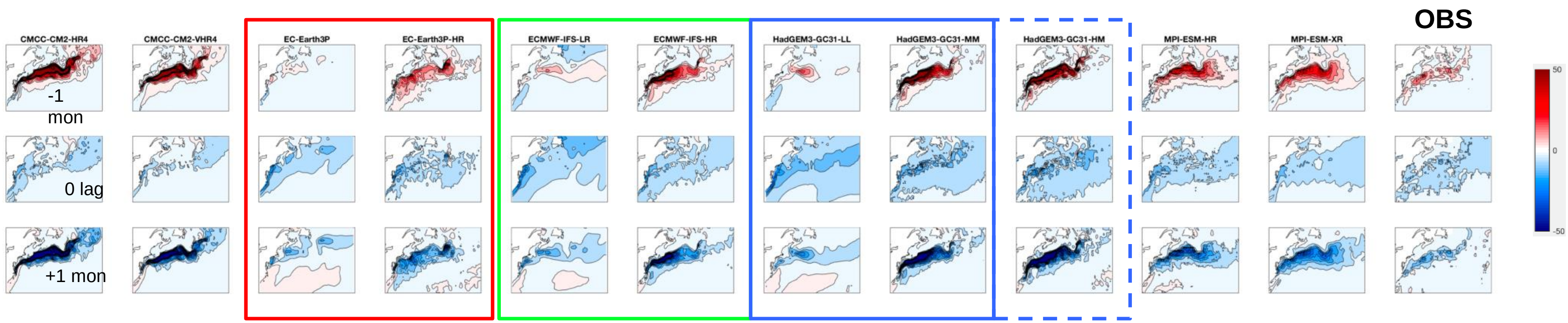
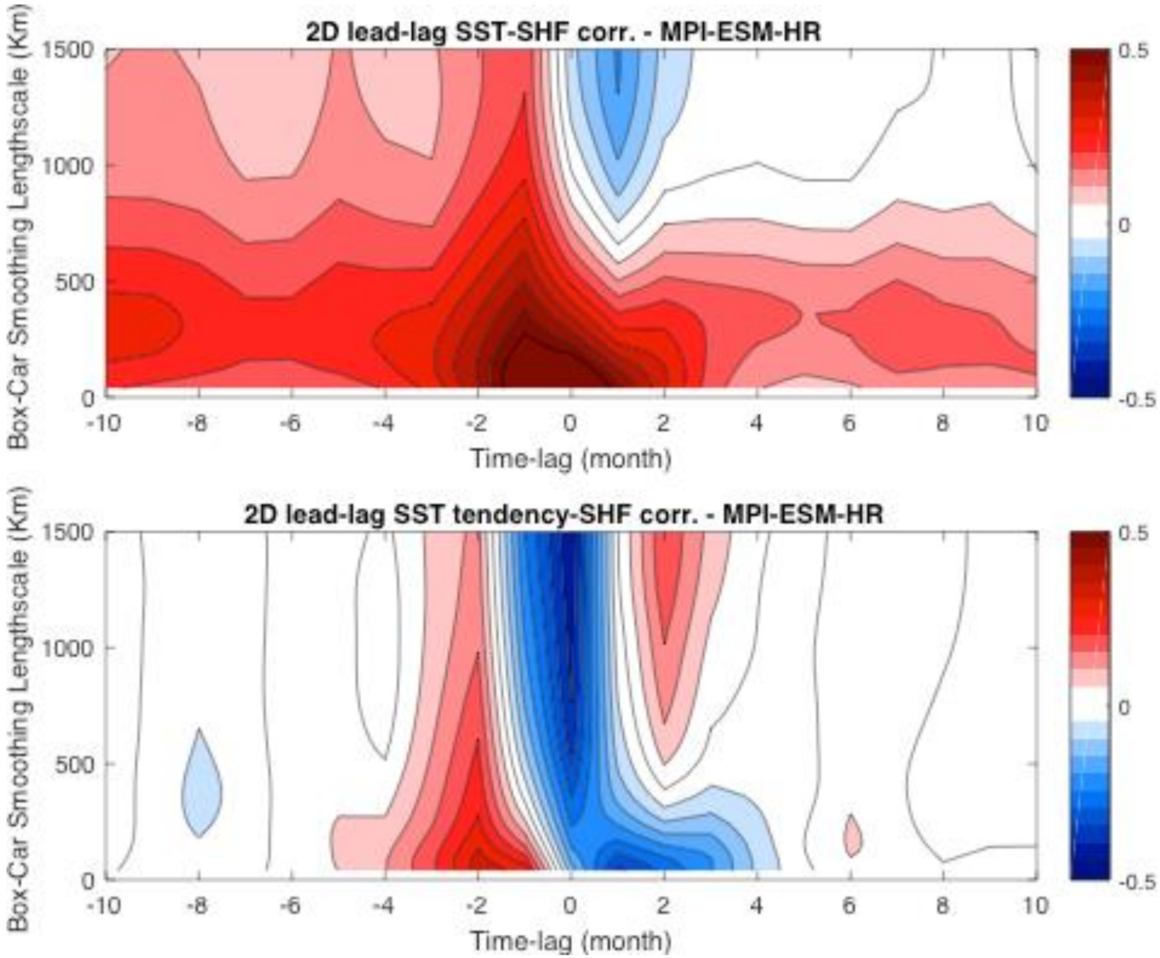


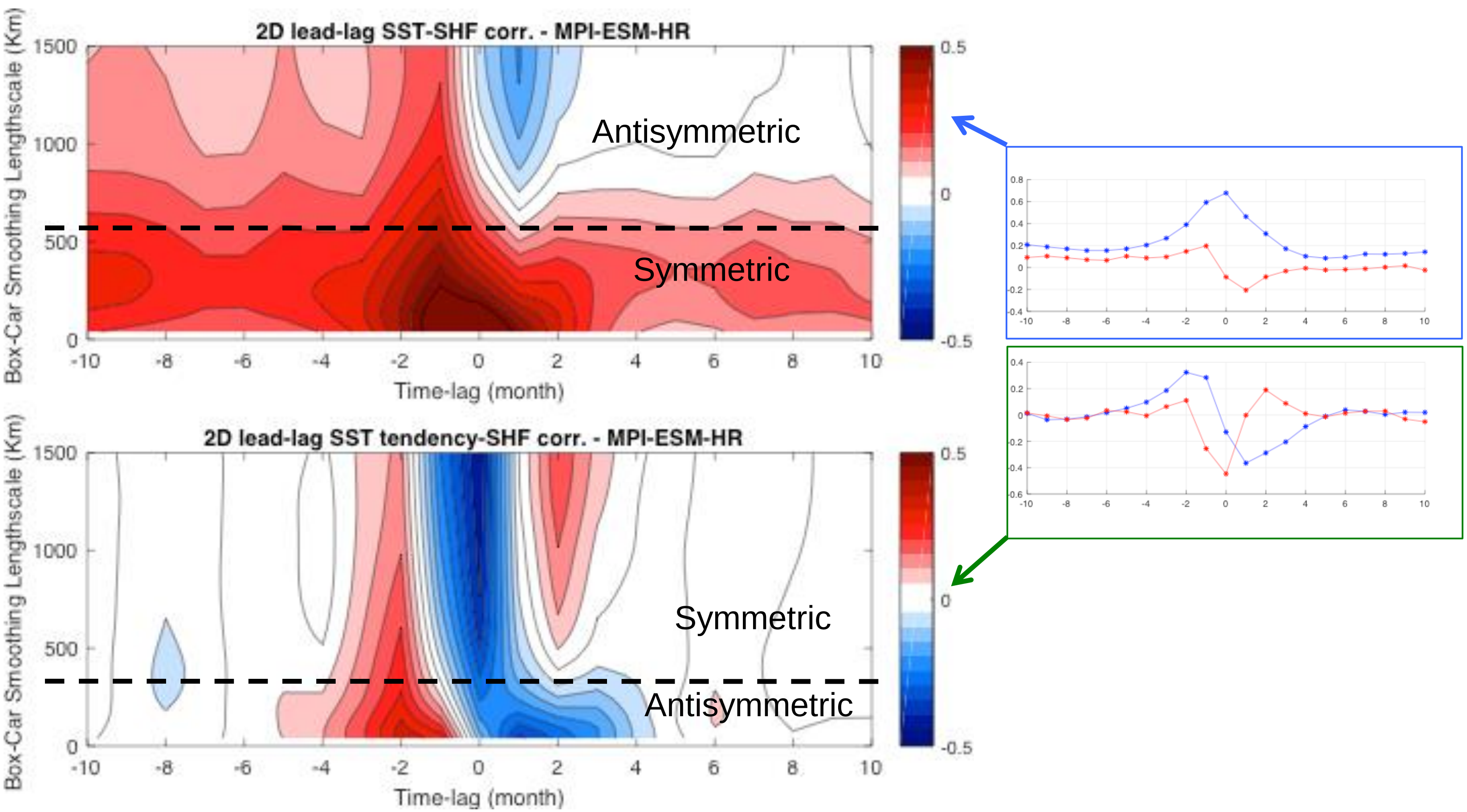

Even laminar oceans able to reproduce the observed ocean-driven regime over the GS
High res leads to an overestimation of covariance strength but improved pattern

# Space-scale dependency



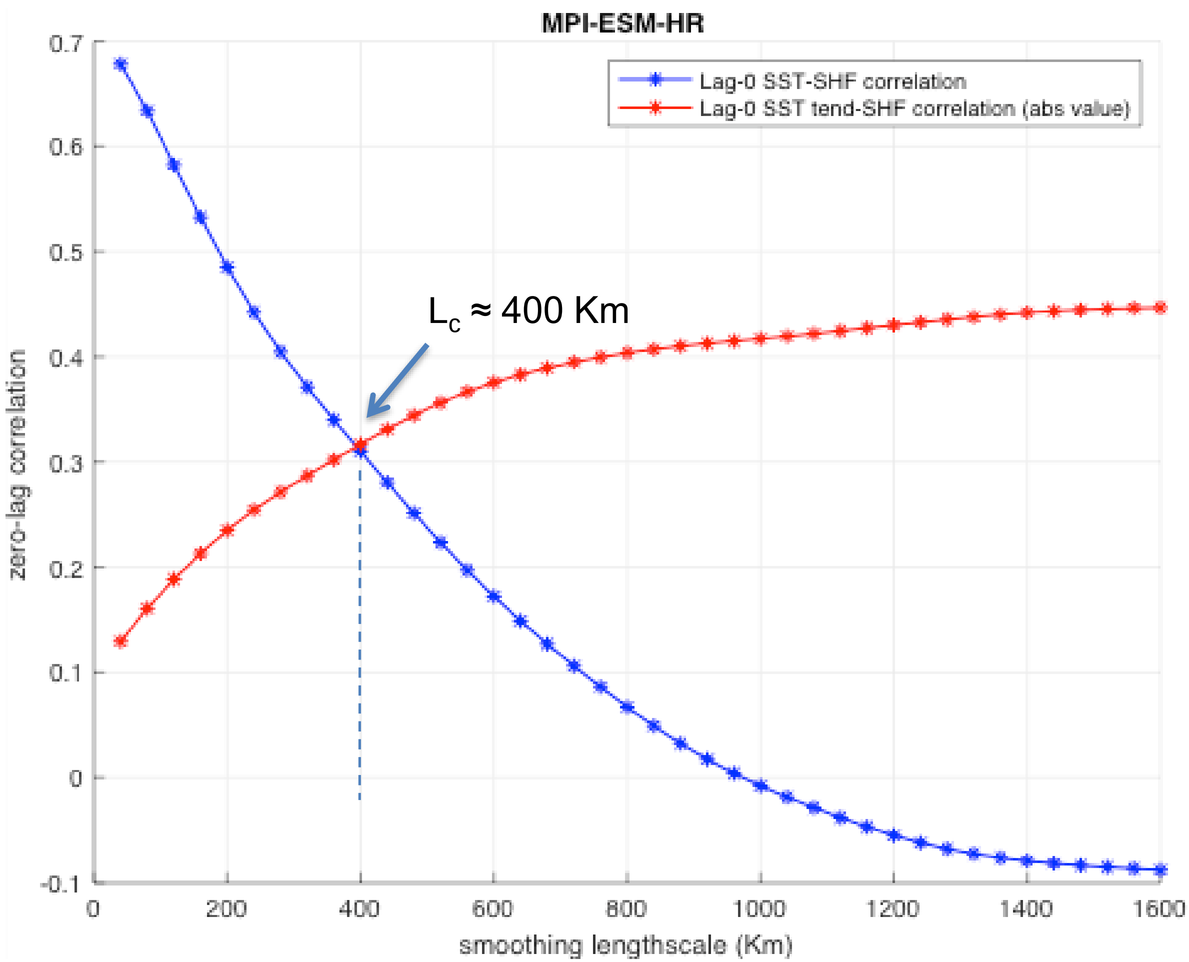

We check for space-scale dependency by applying a box-car filter to smooth SST/SHF and recalculate lead-lag correlation as a function of the smoothing lengthscale.

# Transition length-scale



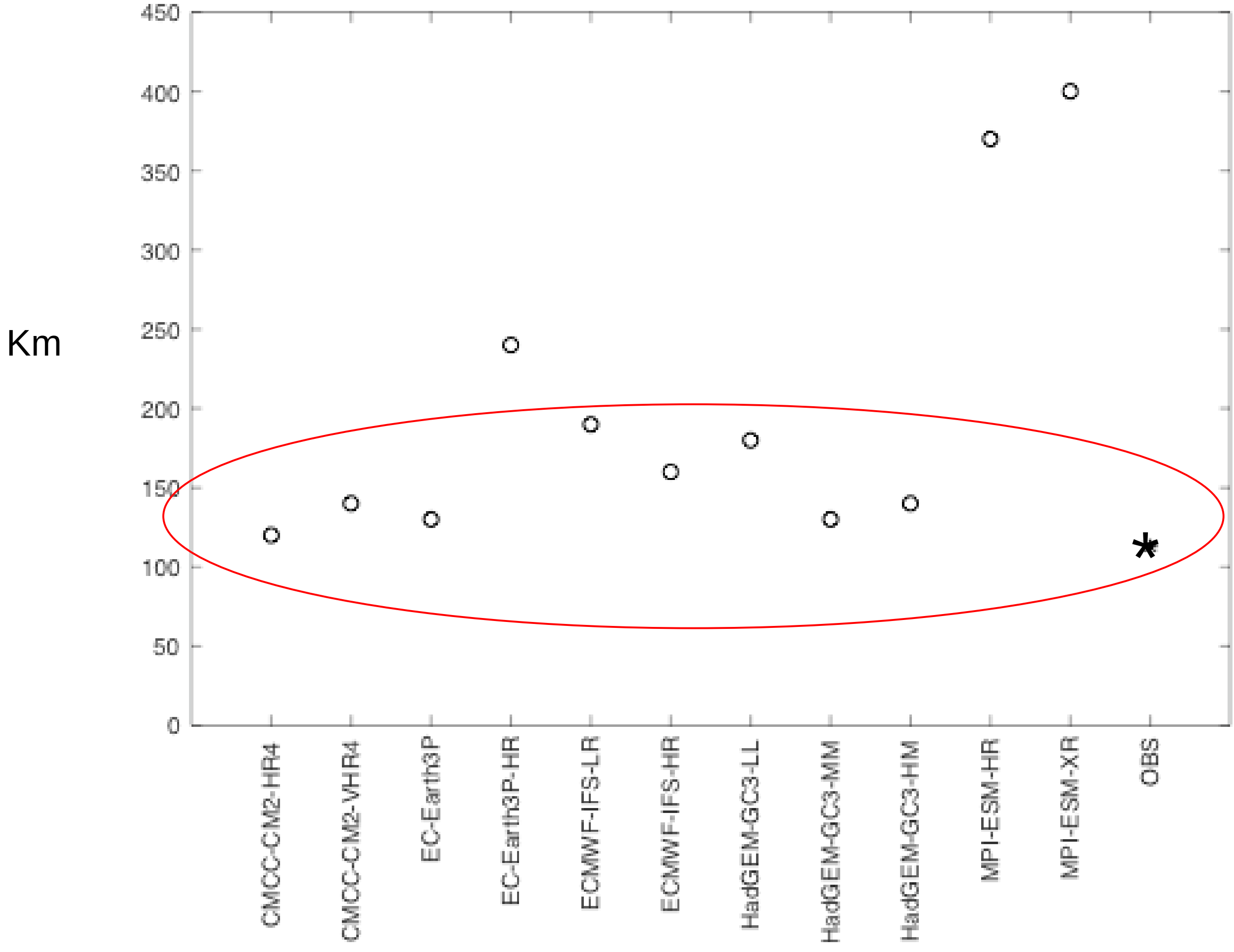

A **transition lengthscale** emerges, beyond which the initial ocean-driven regime (symmetric SST-SHF & antisymmetric SSTt-SHF turns) into a more atmosphere-driven regime.

# Transition length-scale




A **multivariate criterion** is used to identify the **transition lengthscale** ($L_c$ ) here defined as crossing point (in the smoothing-length domain) for R(SST,SHF) and |R($SST_t$,SHF)| at lag-0.

# Transition length-scale



# Summary

- Laminar oceans reproduce the observed and theoretically predicted lead-lag SST-SHF covariance patterns
- Non-eddy driven oceanic variability in low-res models over the GS mimics the "ocean weather" stochastic forcing?
- Eddy-permitting oceans improve the spatial structure (tilted, narrower jet) but overestimate the covariance strength
- Scale-dependency and regime transition well reproduced in most of the models

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