To eddy resolve or not to eddy resolve?

Do we need high resolution ocean models to adequately simulate marine heatwaves in the Northwest Atlantic?

(In preparation)

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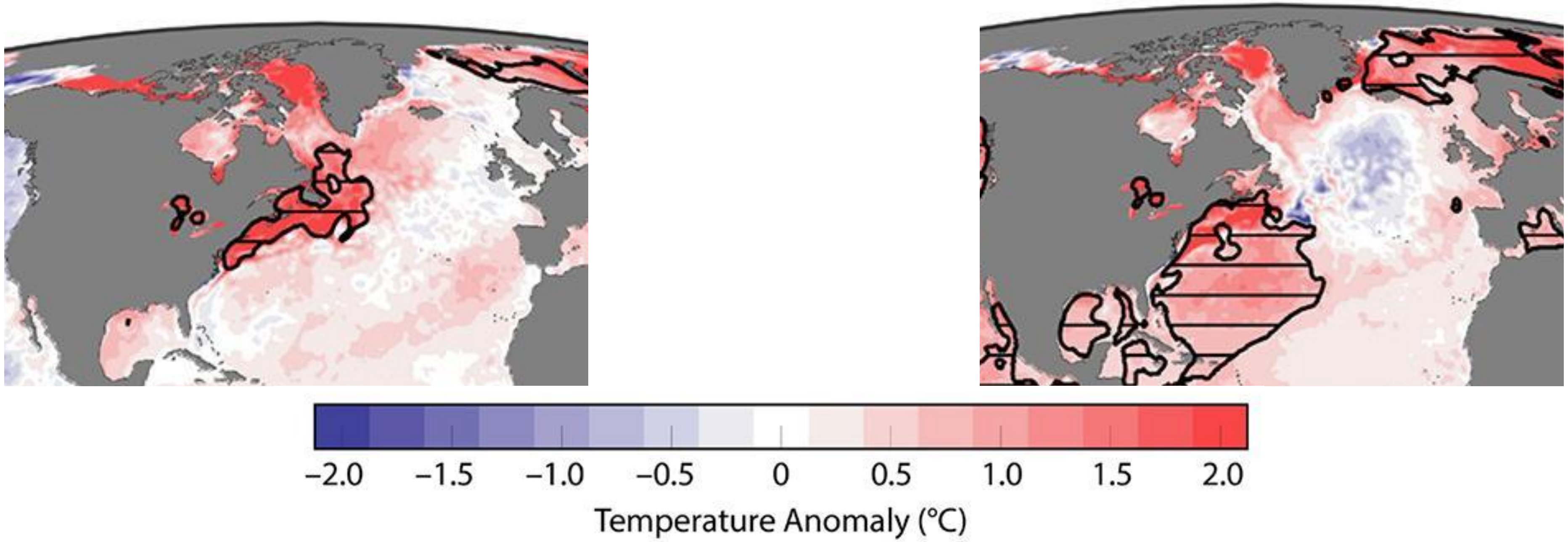
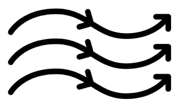
Marine Heatwaves in Northwest Atlantic (NWA)

Marine Heatwaves are extended periods of extreme temperature in Oceans.

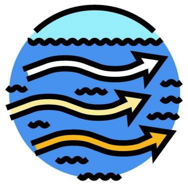
Northwest Atlantic MHWs
Driven by jet stream anomalies
Sustained by warm core eddies and Gulf Stream meanders

(a) 2012 (b) 2016



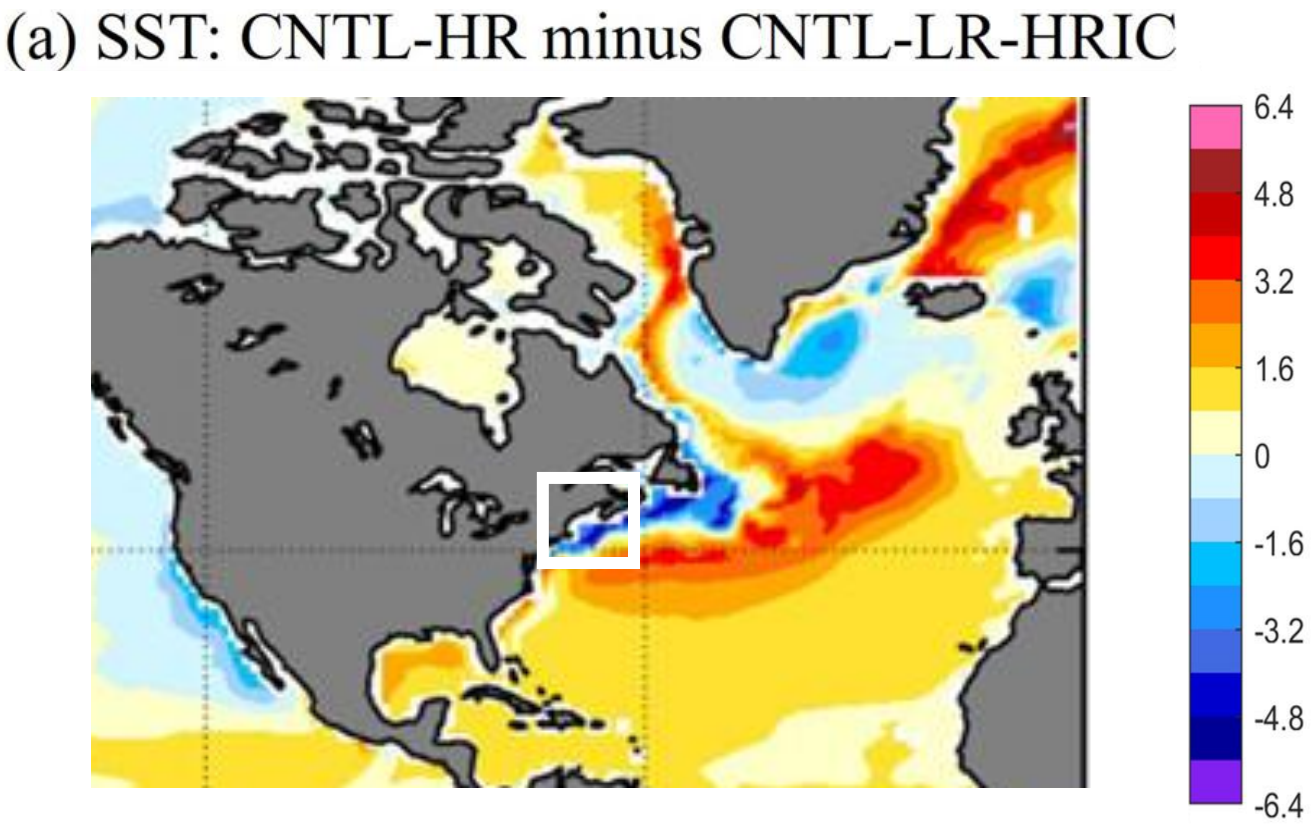


Northward shift in jet stream.
(E. Perez et al. 2021, Chen et al. 2014, 2015)



Ocean advection due to warm core eddies and Gulf Stream meanders. *(E. Perez et al. 2021)*

HOW and WHY do Marine Heatwaves differ in eddy resolving and non-eddy resolving ocean models in NW Atlantic?



Xu et al. 2022

Gulf Stream detaches further poleward in Low Res compared to High Res

Colder and Fresher Gulf of Maine in High Res

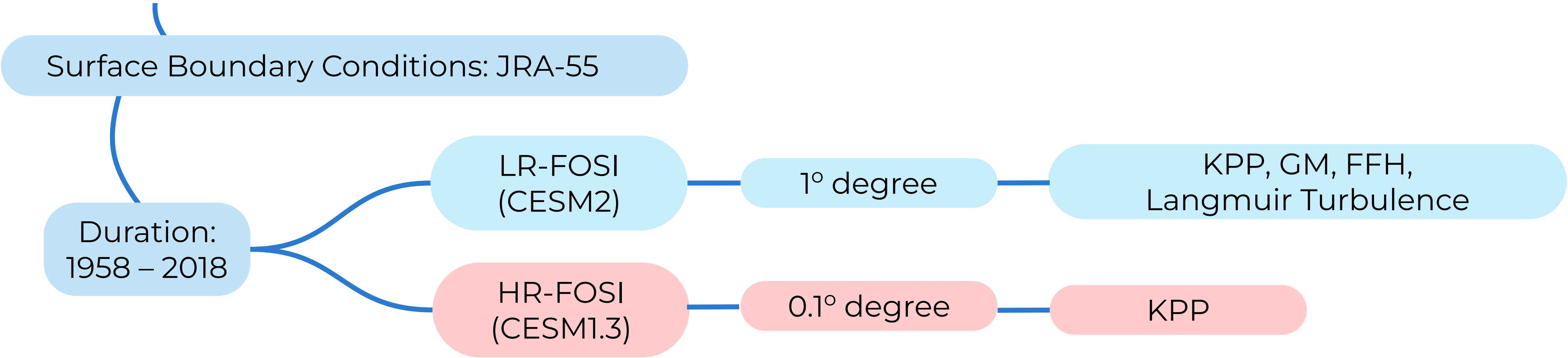
Impacts Stratification

We compare NW Atlantic MHWs in High Res and Low Res Community Earth System Model (CESM)

Forced Ocean Sea Ice (FOSI) Simulations

Following OMIP Protocol (second last cycle)

(Yeager et al., 2018, Chang et al., 2020, Danabasoglu et al., 2020, Yeager et al., 2023)



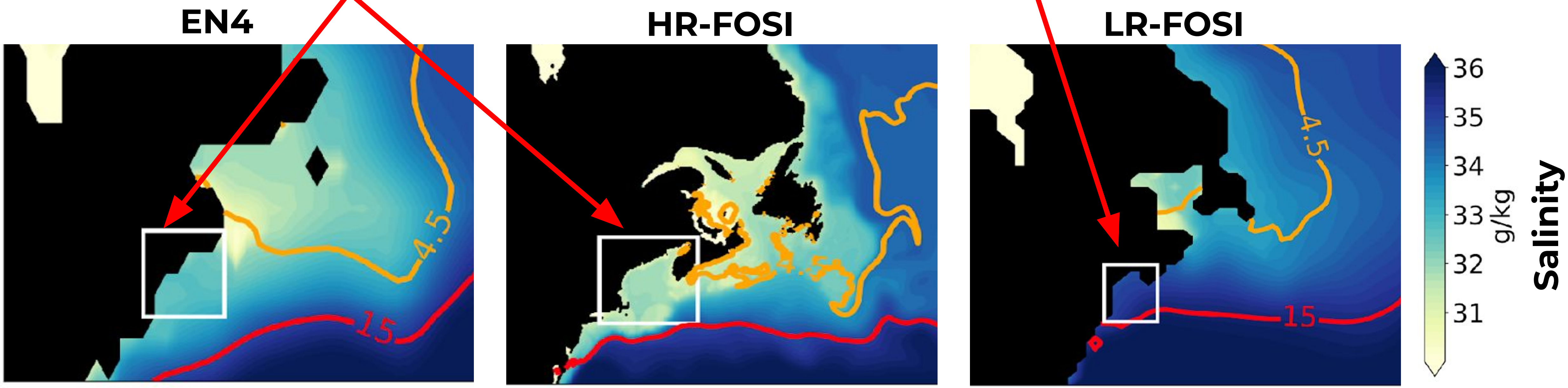
OISST: Optimum Interpolation Sea Surface Temperature *(Huang et al., 2021)*

EN4: EN4 Monthly Objective Analysis v4.2.1 *(Good et al., 2013)*

HR-FOSI has better water mass placements climatologically

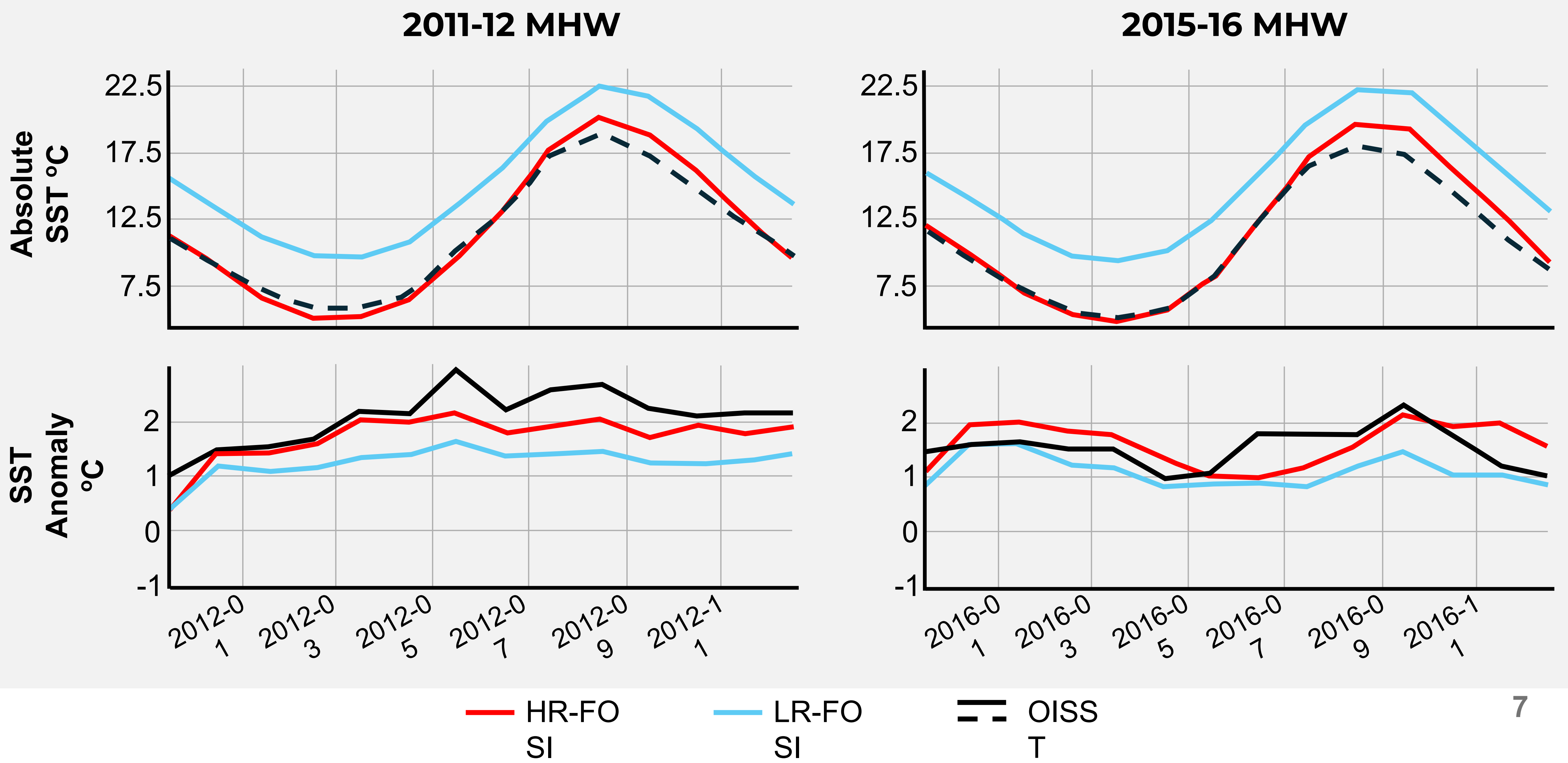
HR-FOSI water masses more similar to EN4.

LR-FOSI is warmer and saltier in Gulf of Maine.

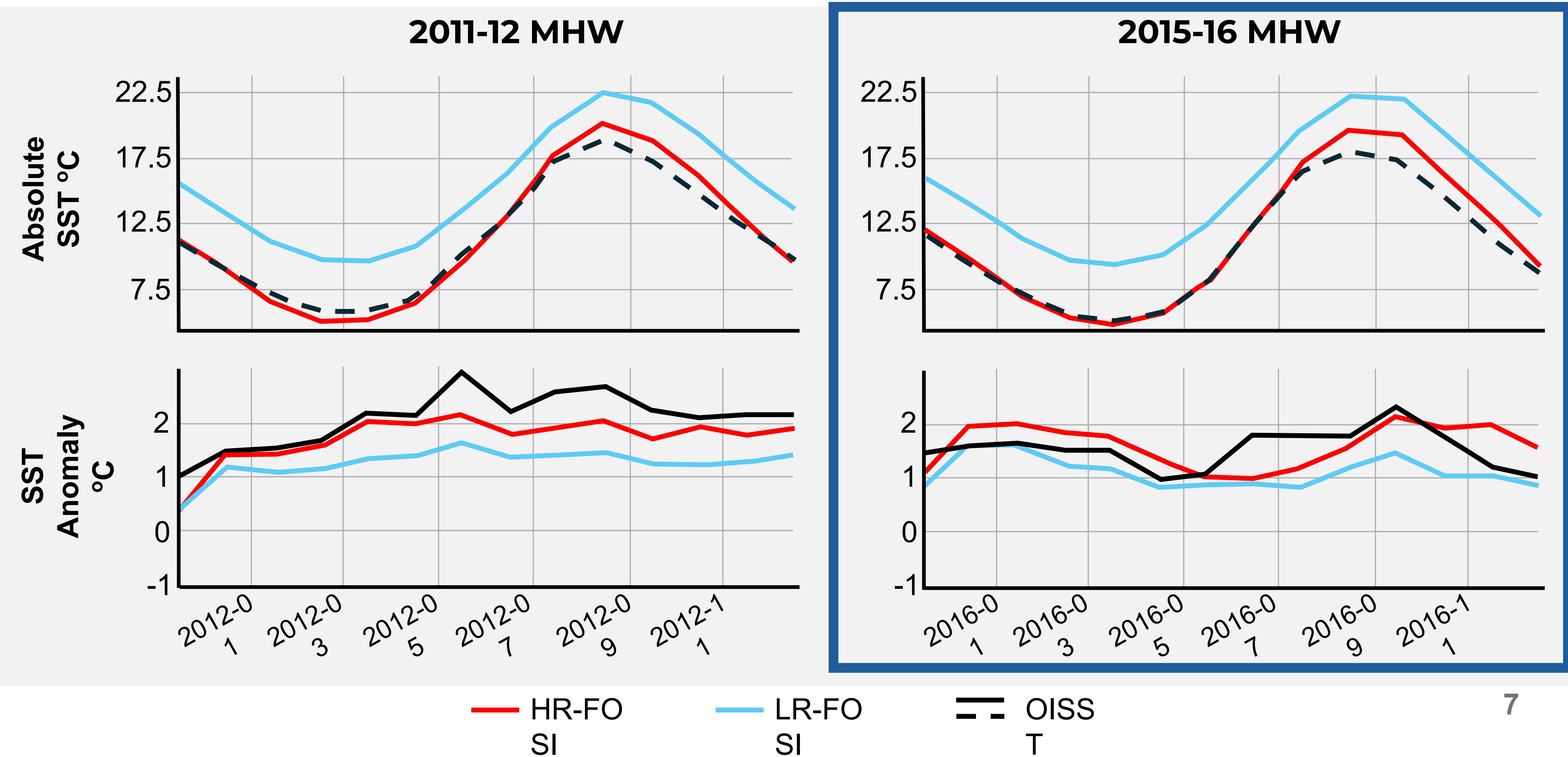


Salinity and Temperature averaged across 110 meters depth.
Averaged over 1983-2018

High Res better represents MHWs than Low Res.



High Res better represents MHWs in Gulf of Maine than Low Res



Heat Budget Decomposition

110 meters depth
Anomaly based on 1983-2014 climatology

Temperature Tendency = **Turbulent and Radiative Heat Fluxes** + **Total Resolved Advection** + **Sub Grid Scale Processes***

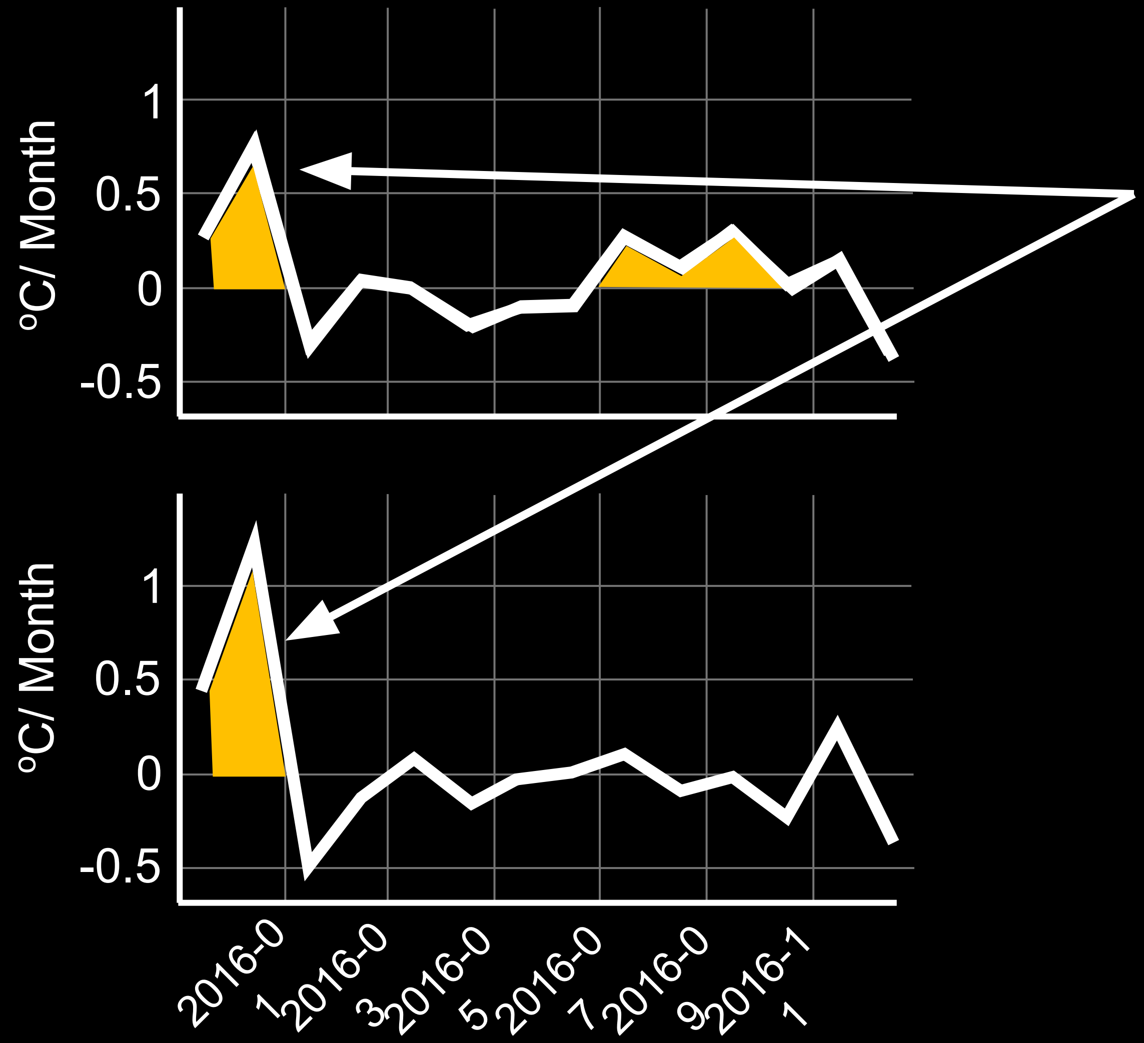
Sub Grid Scale Processes* (Parameterizations)

Low Res : KPP + Diffusion + GM + FFH
High Res: KPP + Diffusion

Temperature Tendency = **Turbulent and Radiative Heat Fluxes** + **Total Resolved Advection** + **Sub Grid Scale Processes***

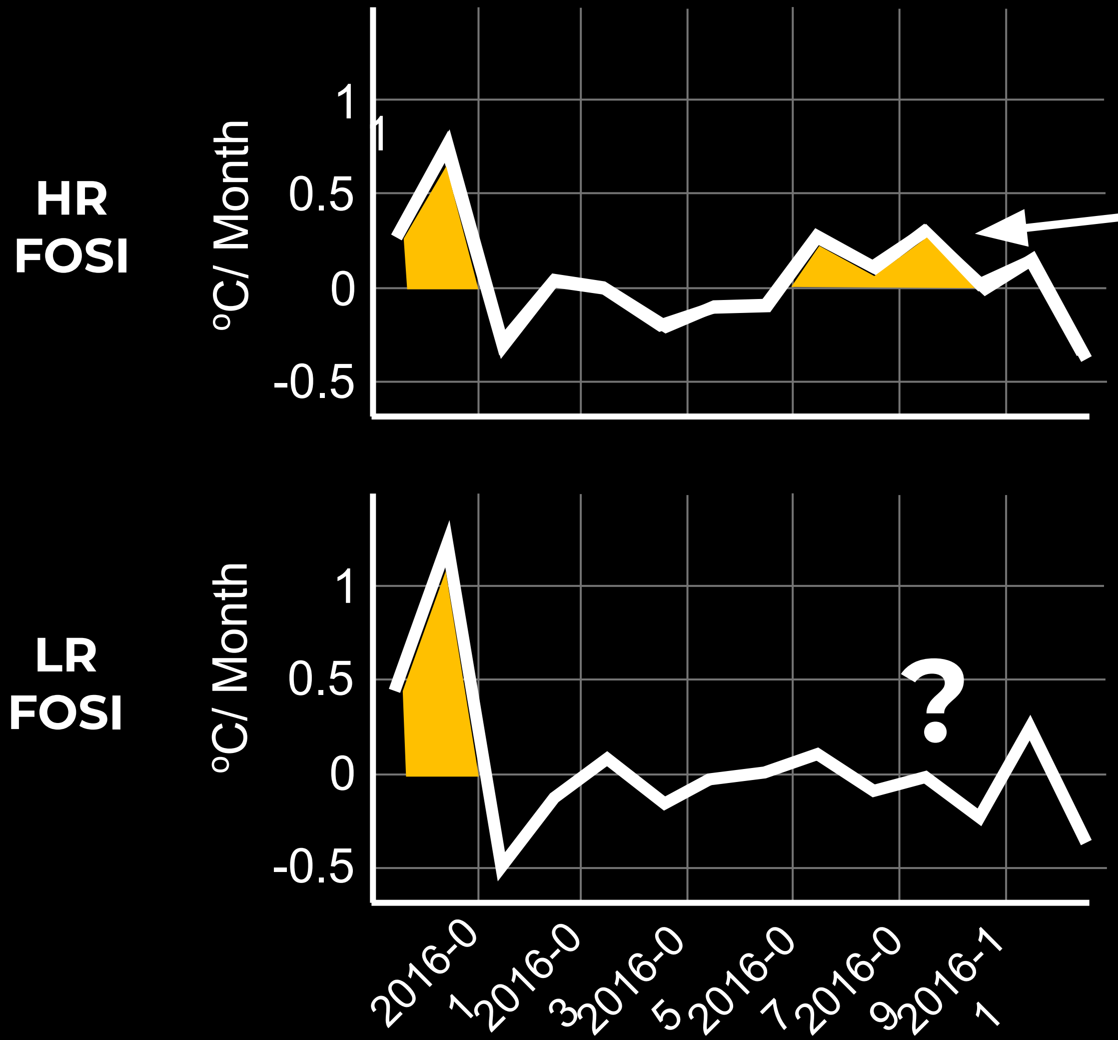
HR FOSI

LR FOSI



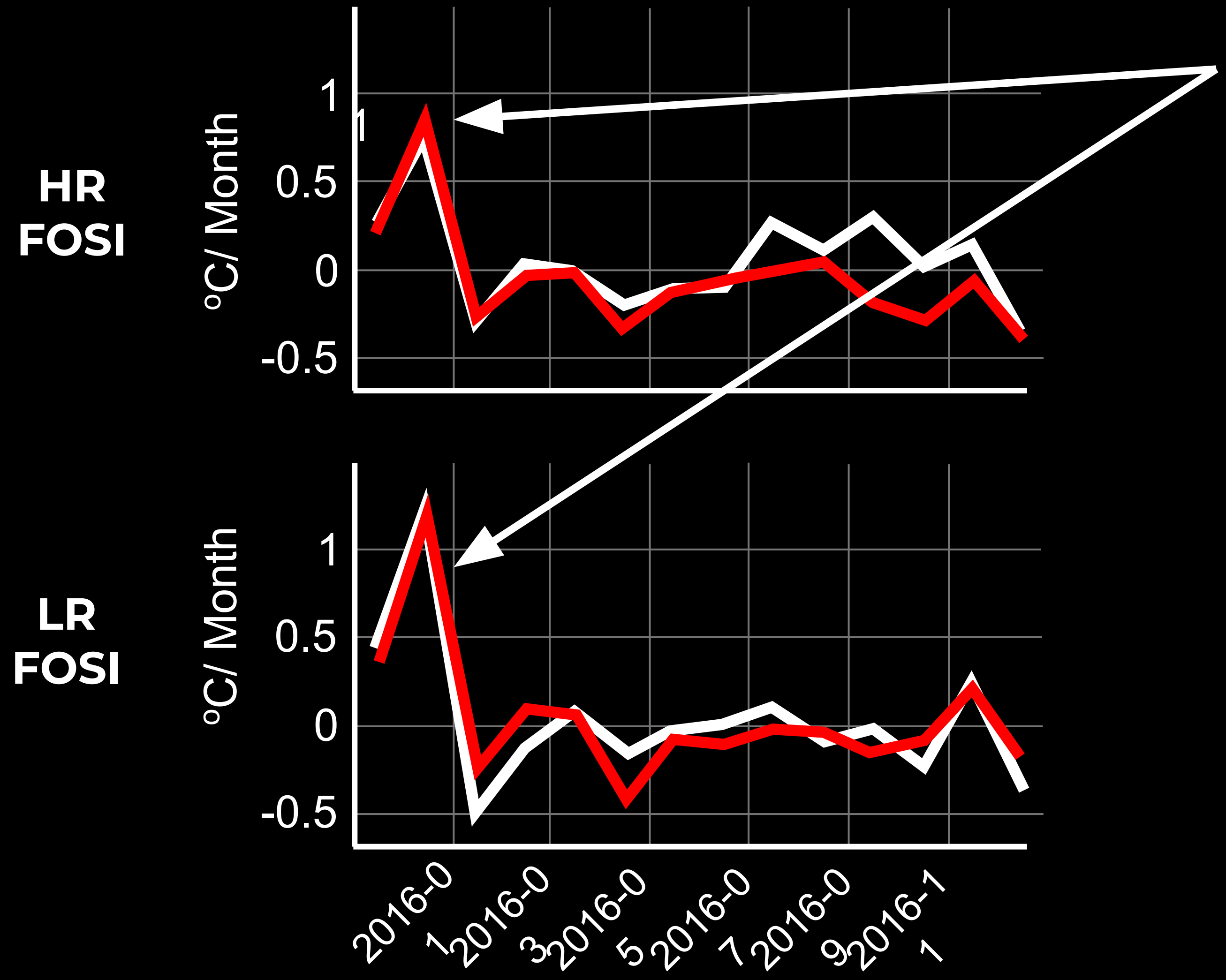
Higher tendencies in LR-FOSI

Temperature Tendency = Turbulent and Radiative Heat Fluxes + Total Resolved Advection + Sub Grid Scale Processes*



Growth of MHW magnitude in HR-FOSI

Temperature Tendency = Turbulent and Radiative Heat Fluxes + Total Resolved Advection + Sub Grid Scale Processes*

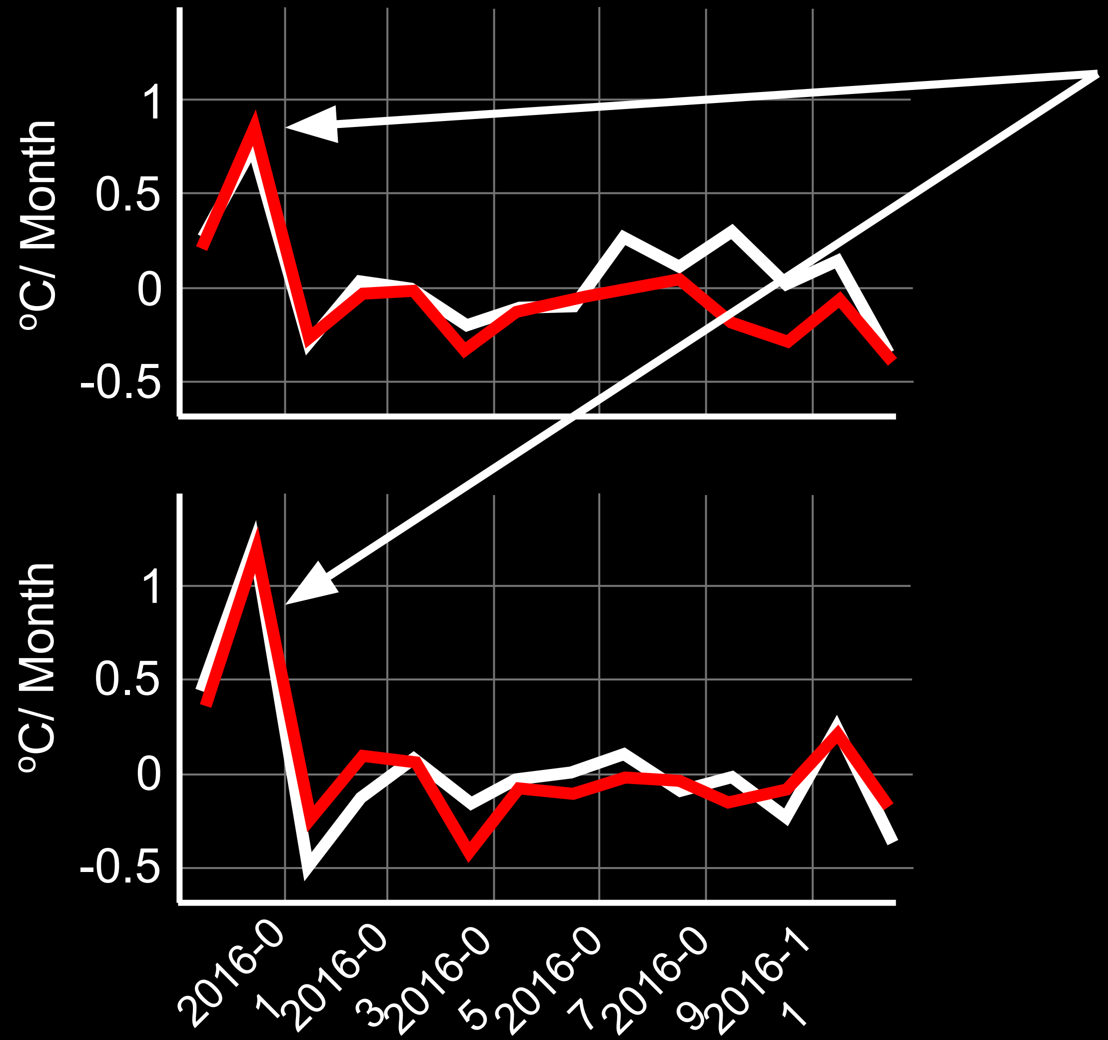


Major warming due to jet stream weakening

Temperature Tendency = Turbulent and Radiative Heat Fluxes + Total Resolved Advection + Sub Grid Scale Processes*

HR FOSI

LR FOSI

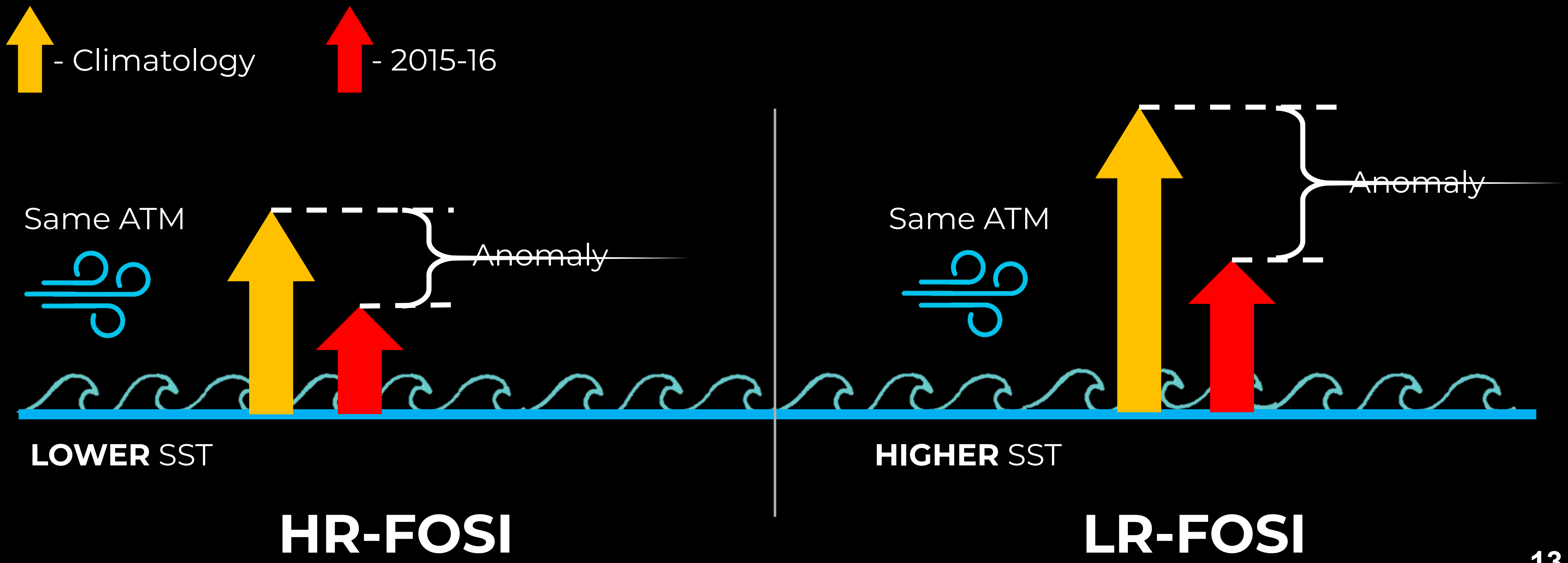


Major warming due to jet stream weakening

Largely due to anomalous turbulent heat flux

Why does LR-FOSI have larger anomalous fluxes in winter?

Turbulent Heat Flux - DJF

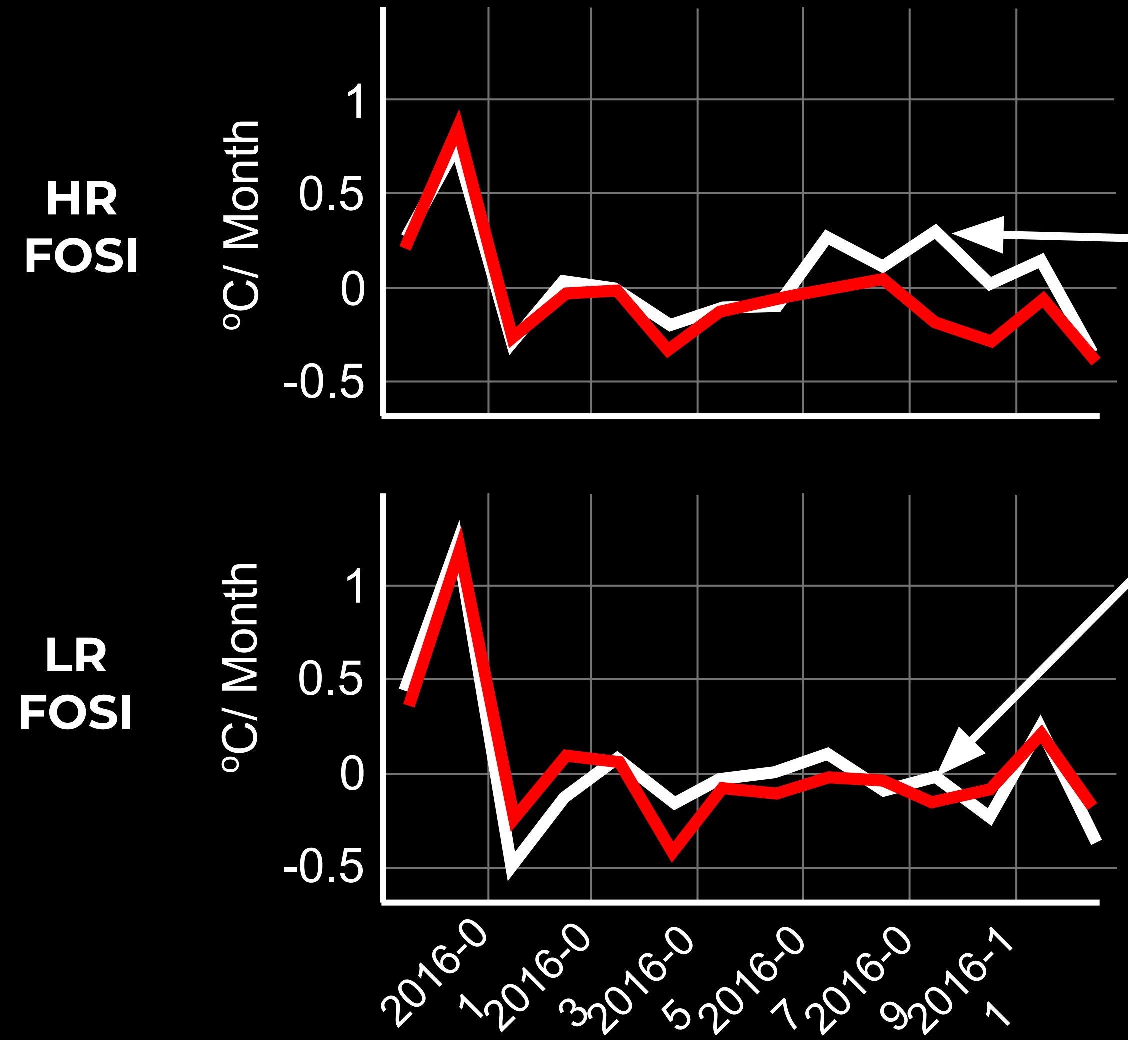


Same changes in wind
+
LR-FOSI having Higher SST

Greater reduction in heat flux out of the ocean

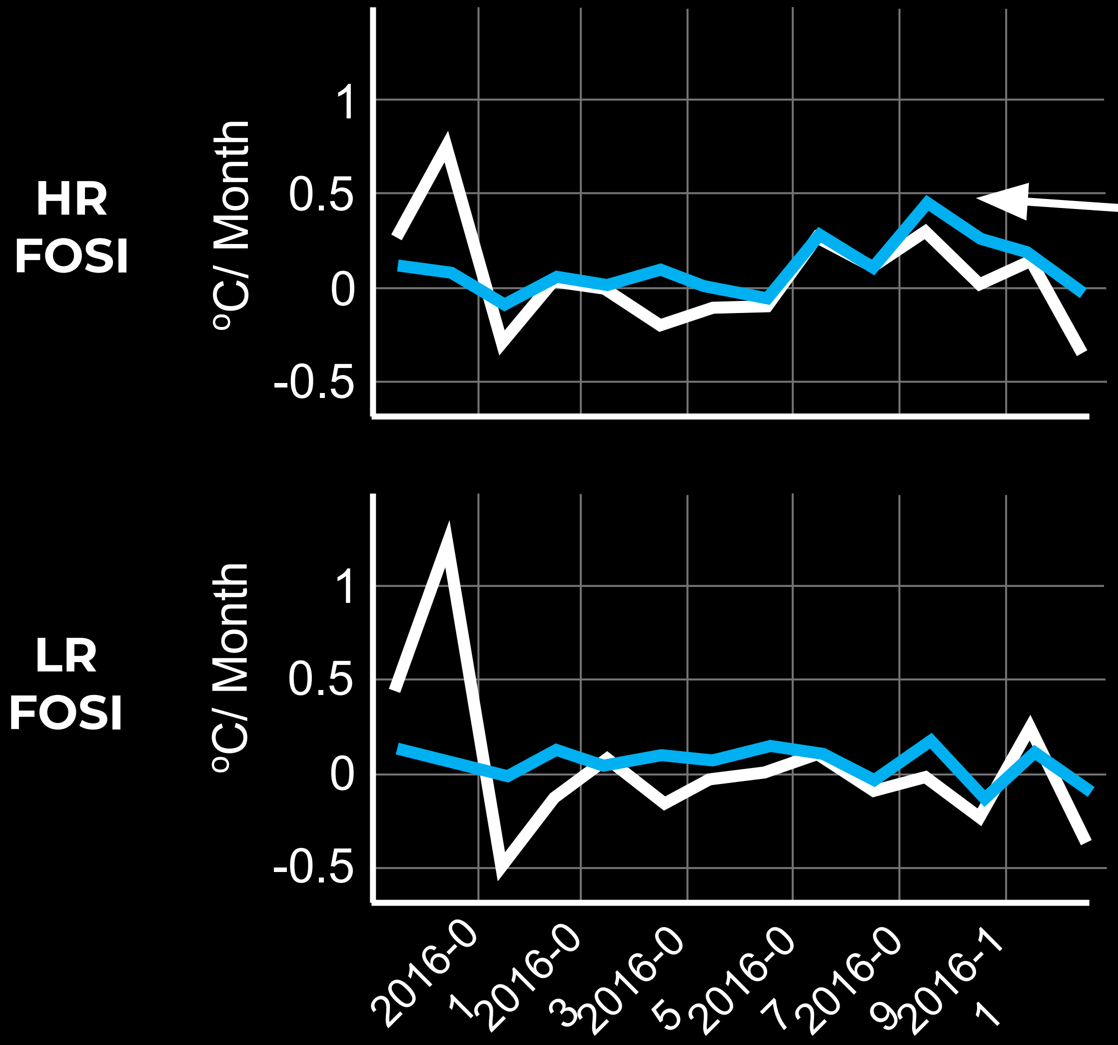
Greater anomalous heat gain in LR-FOSI due to turbulent fluxes

Temperature Tendency = Turbulent and Radiative Heat Fluxes + Total Resolved Advection + Sub Grid Scale Processes*



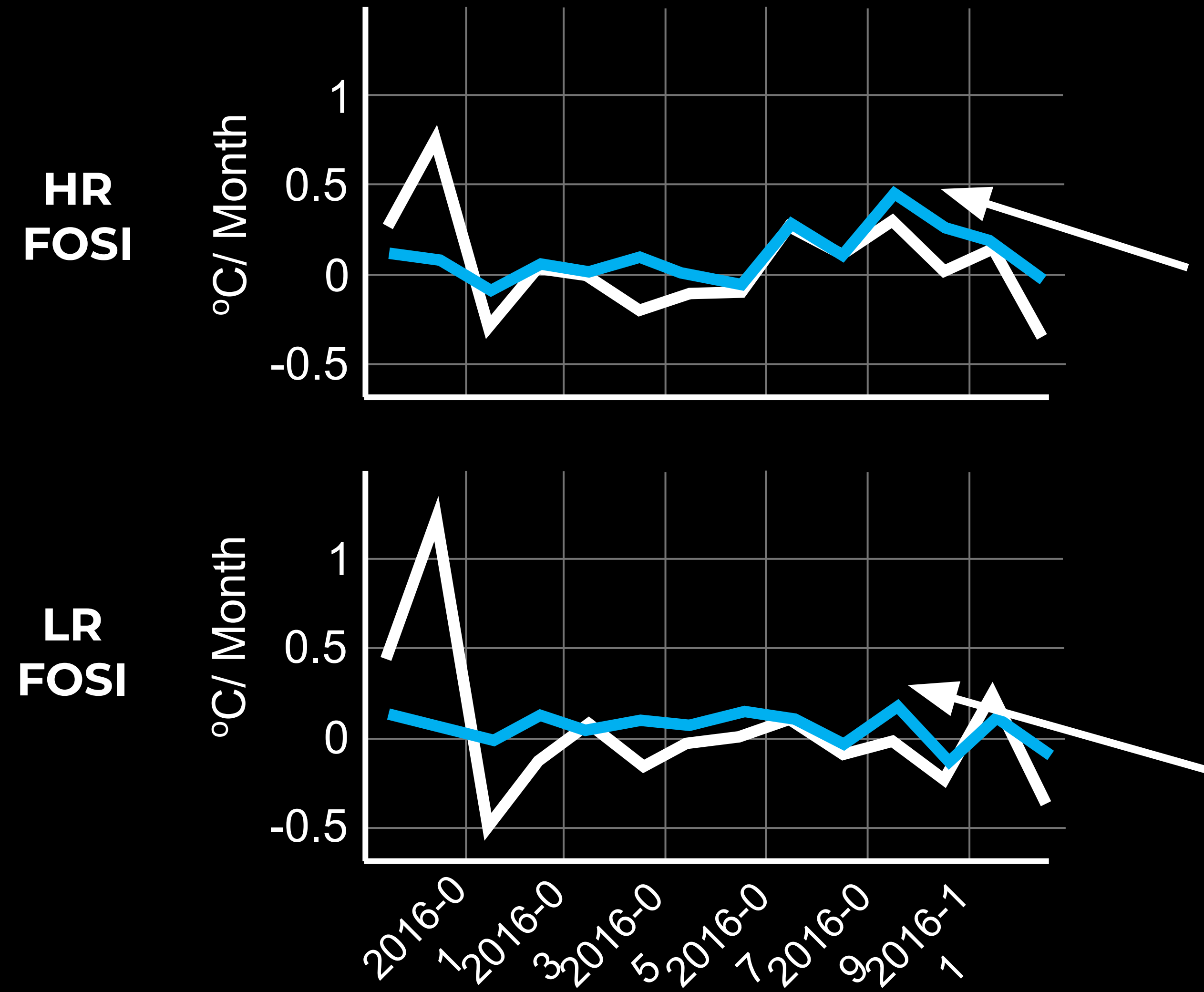
Surface heat fluxes not responsible for growing MHW magnitude in high res.

Temperature Tendency = **Turbulent and Radiative Heat Fluxes** + **Total Resolved Advection** + **Sub Grid Scale Processes***



Advection grows the MHW magnitude in High Res

Temperature Tendency = Turbulent and Radiative Heat Fluxes + Total Resolved Advection + Sub Grid Scale Processes*

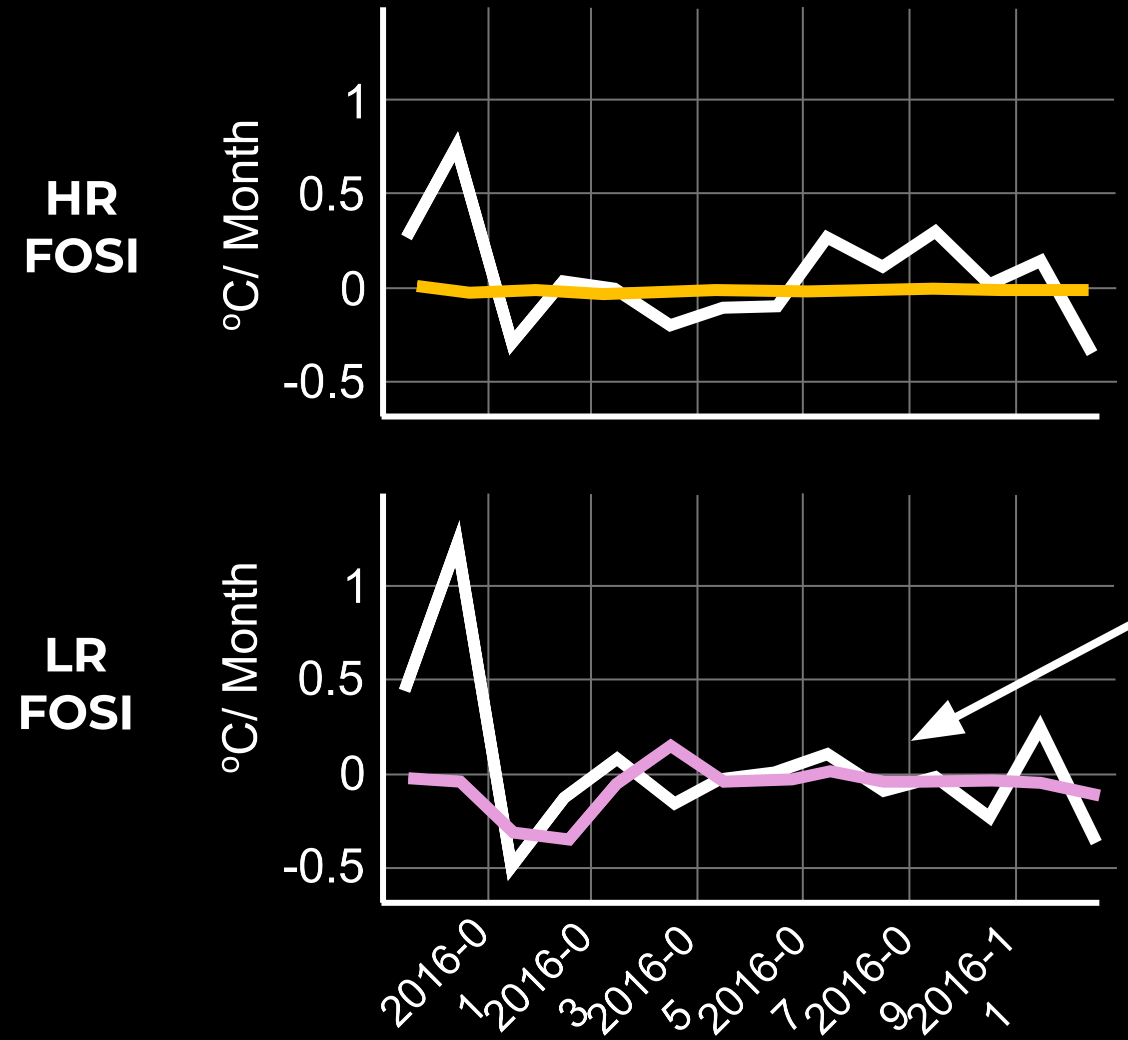


Advection grows the MHW magnitude in High Res

HR-FOSI resolves eddies.

Eddies parameterized
Eddy contribution instead included in Sub Grid Scale Processes

Temperature Tendency = Turbulent and Radiative Heat Fluxes + Total Resolved Advection + Sub Grid Scale Processes*

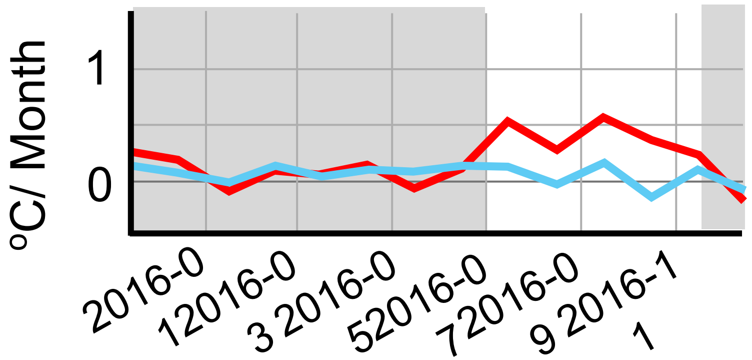


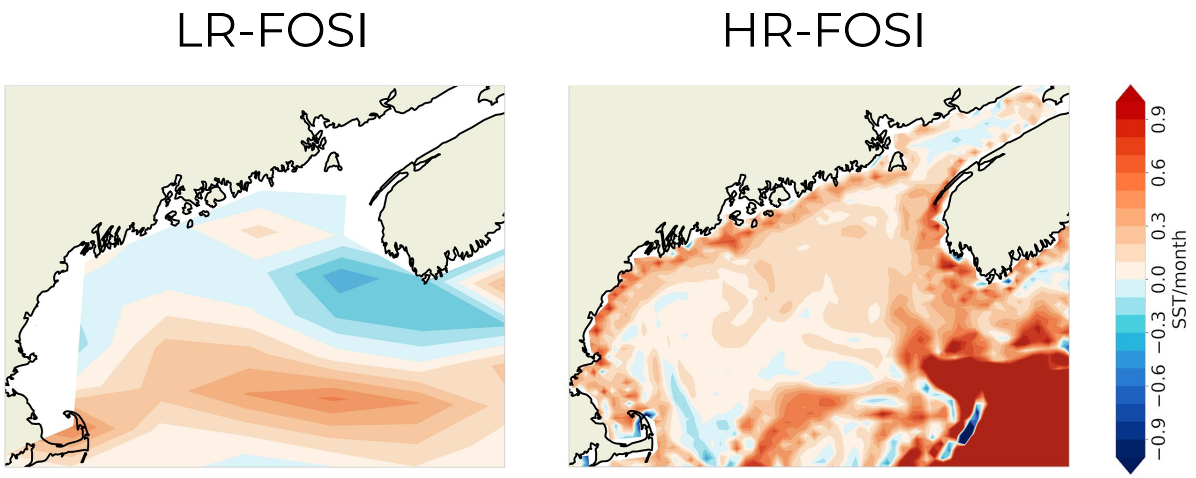
Low Res : KPP + Diffusion + GM + FFH
High Res: KPP + Diffusion

Parameterized eddies have minimal effect in LR.
:(

Resolving eddies in High Res FOSI -> a better MHW representation

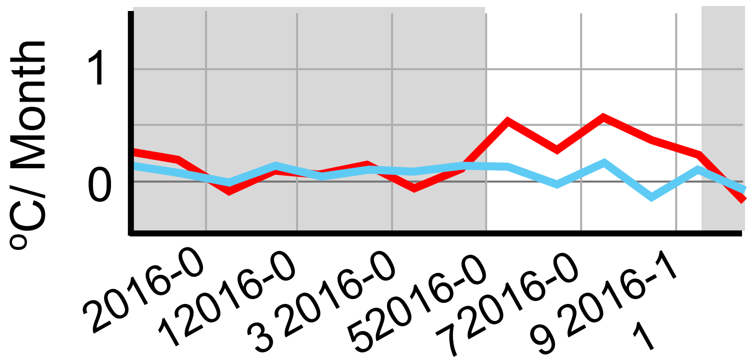
Total Resolved Advection



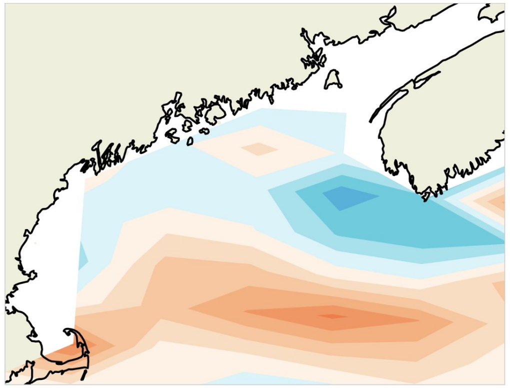


Resolving eddies in High Res FOSI -> a better MHW representation

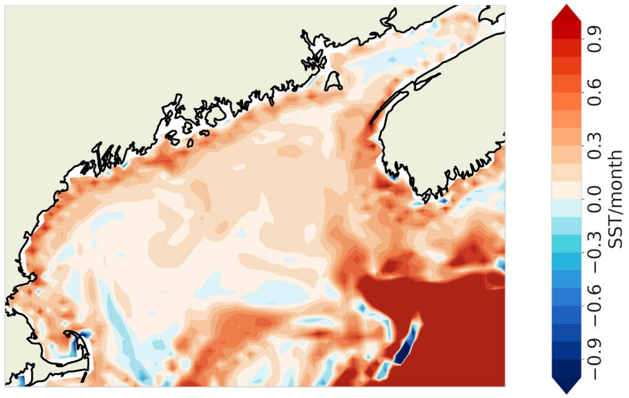
Total Resolved Advection



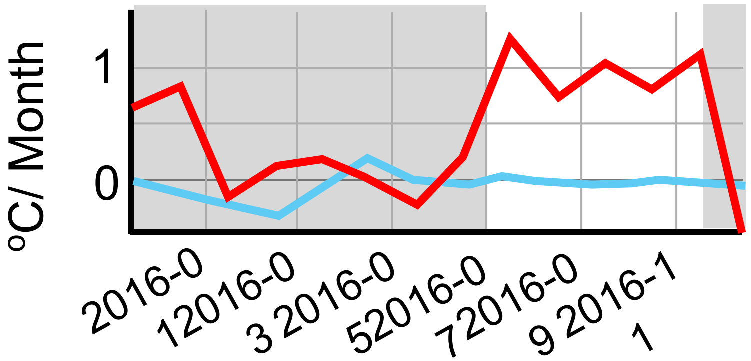
LR-FOSI



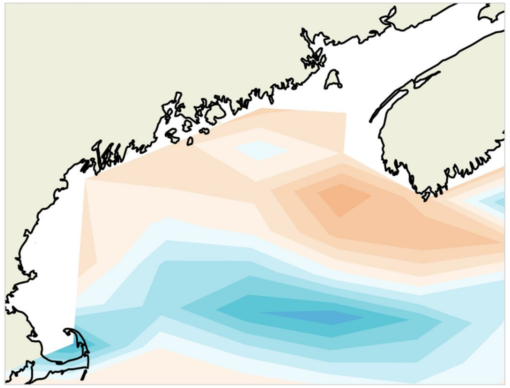
HR-FOSI



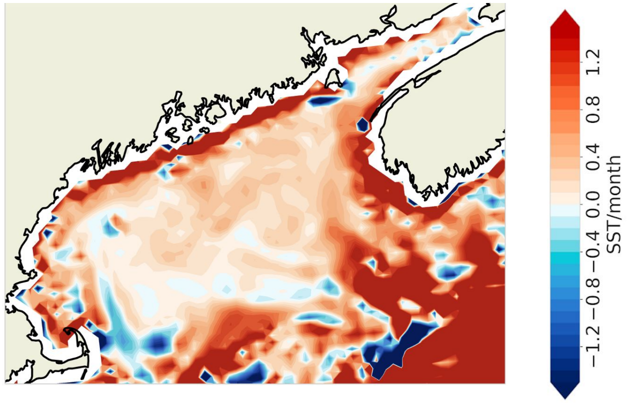
Contribution of Eddies*



All parameterization
-
KPP

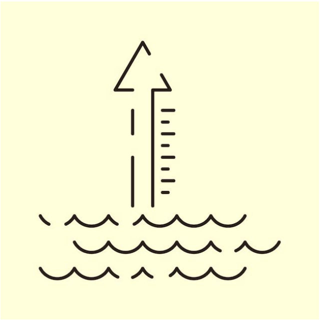


Total Advection
-
Mean Advection



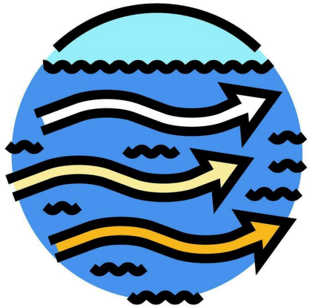
SUMMARY

CESM FOSIs are great "tools" to understand **MHW evolution** from heat budget analysis.



HR-FOSI better captures the **mean state water masses** resulting in more **realistic Marine Heatwave** simulations.

Warmer SST in LR-FOSI lead to **larger anomalous turbulent heat fluxes** during the 2015-16 MHW over winter.



Resolving mesoscale eddies improves marine heatwave representation in the Gulf of Maine **by capturing Gulf Stream variations** that could drive and intensify these events.

References

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QUESTIONS ?

To eddy resolve, or not to eddy resolve, that is the question:

Whether 'tis nobler in the model to have
The currents and eddies in outrageous resolution,
Or to coarsen and use that parameterization of eddies
Which opposes gradients.

To resolve—to parameterize, No more;
and by parameterize to save core hours;
Greater computational efficiency and the saved carbon emissions,
That it is heir to: 'tis a desire Devoutly to be wish'd.

To resolve, to parameterize; To resolve, perchance to dream—ay,
there's the rub: For with high resolution is an ocean simulation from what dreams may come,
When we have moved beyond 1 degree,
Must give us joy—there're the integrations
That will make a career of so long life.

E. Maroon adapted from Shakespeare's Hamlet

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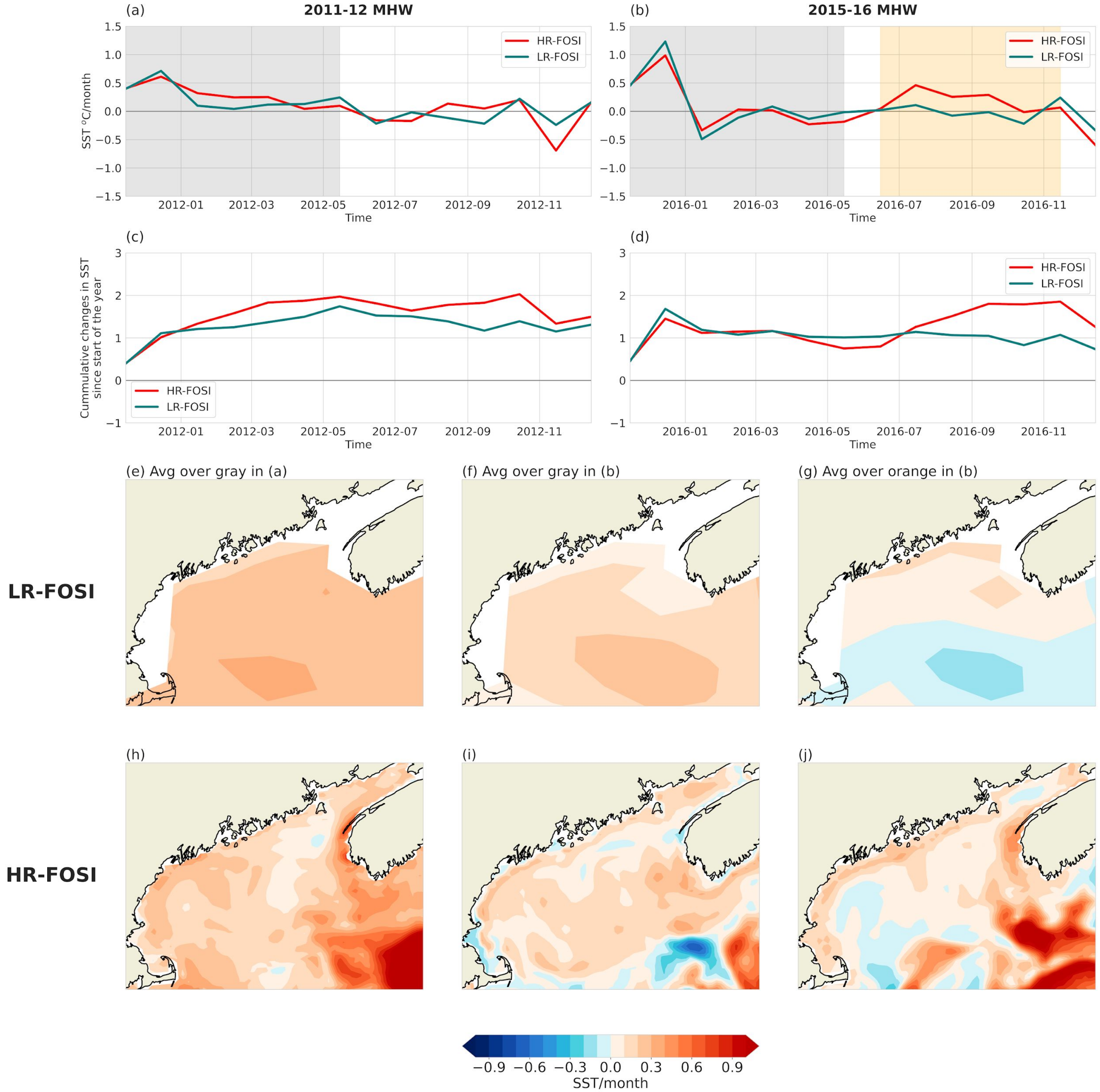
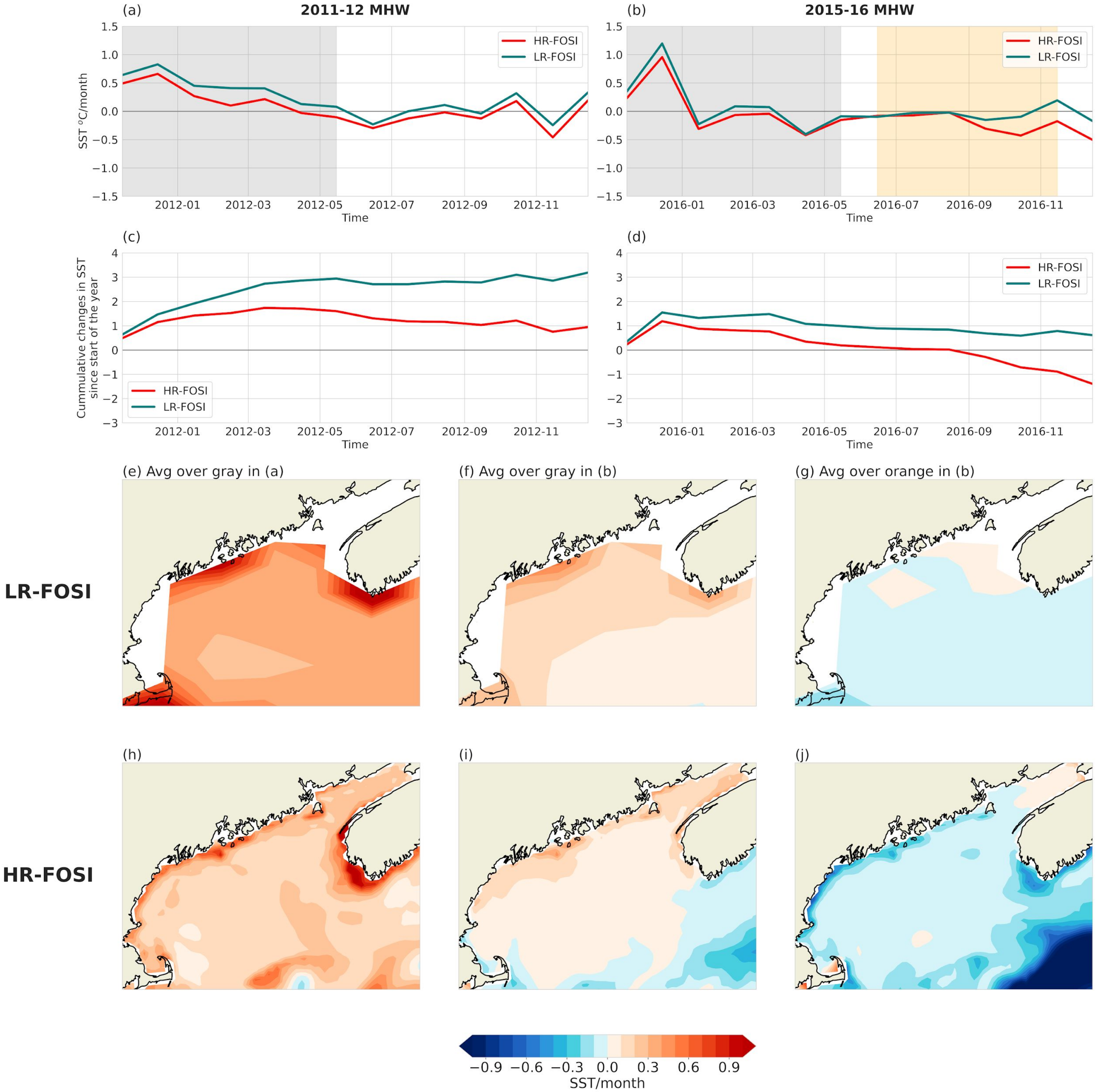
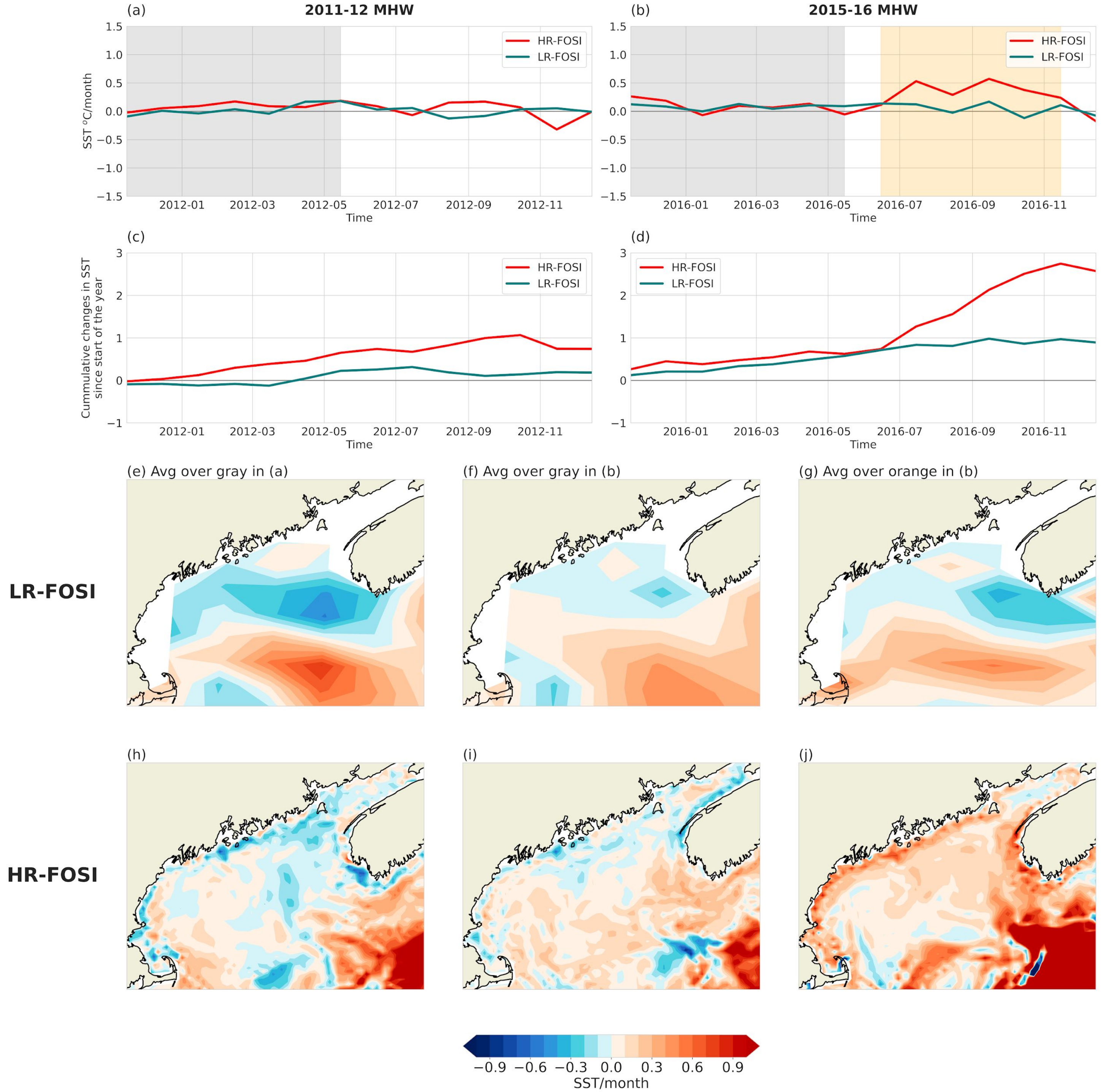
Temperature Tendencies



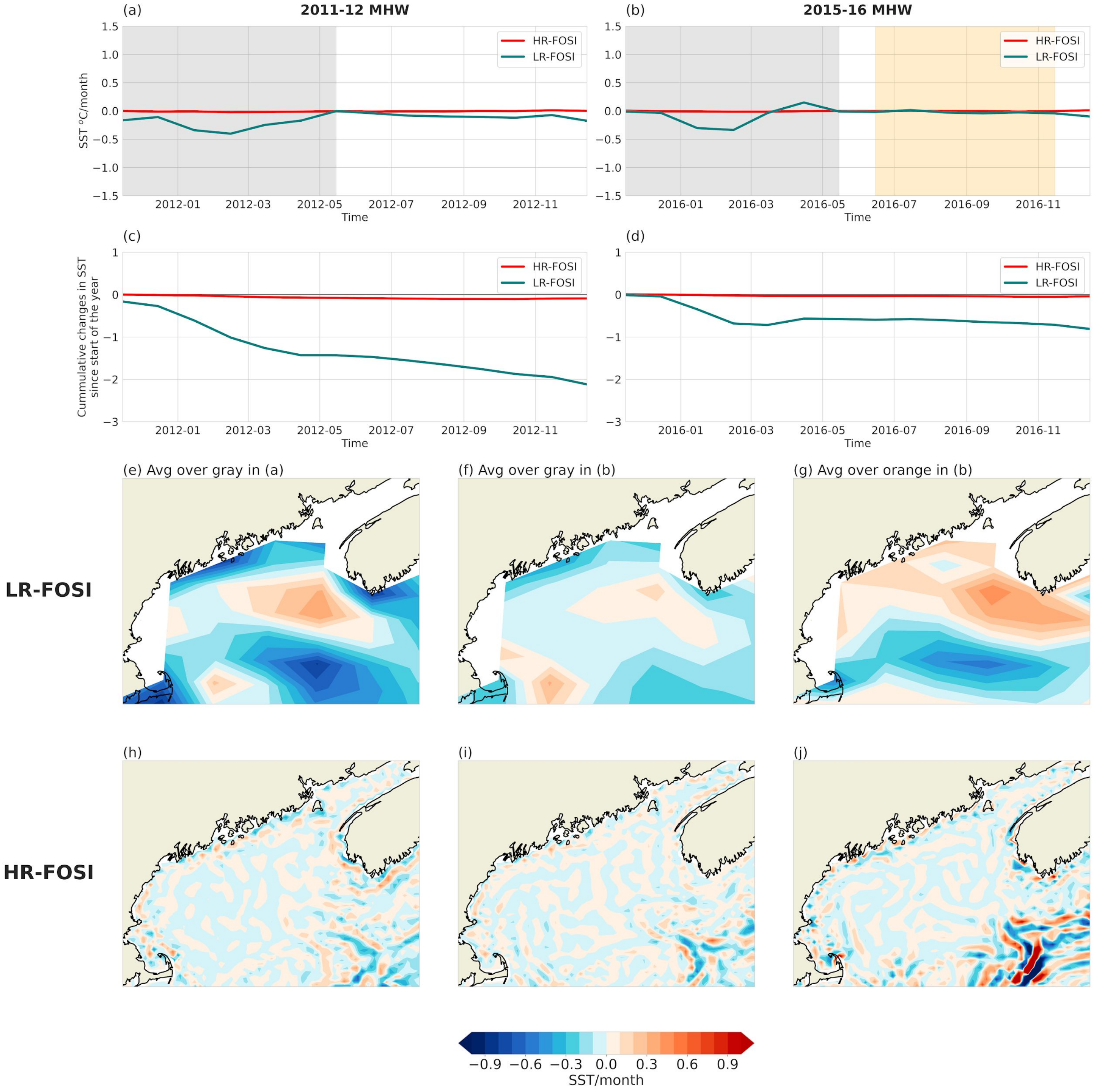
Turbulent and Radiative Heat Flux



Total Resolved Advection



Sub Grid Scale Parameterization



Eddy contribution