JULIUS BUSECKE | ARNOLD GORDON | RYAN ABERNATHEY

TEMPORAL VARIABILITY IN SURFACE EDDY MIXING

WHOI SSS WORKSHOP MAY 2017

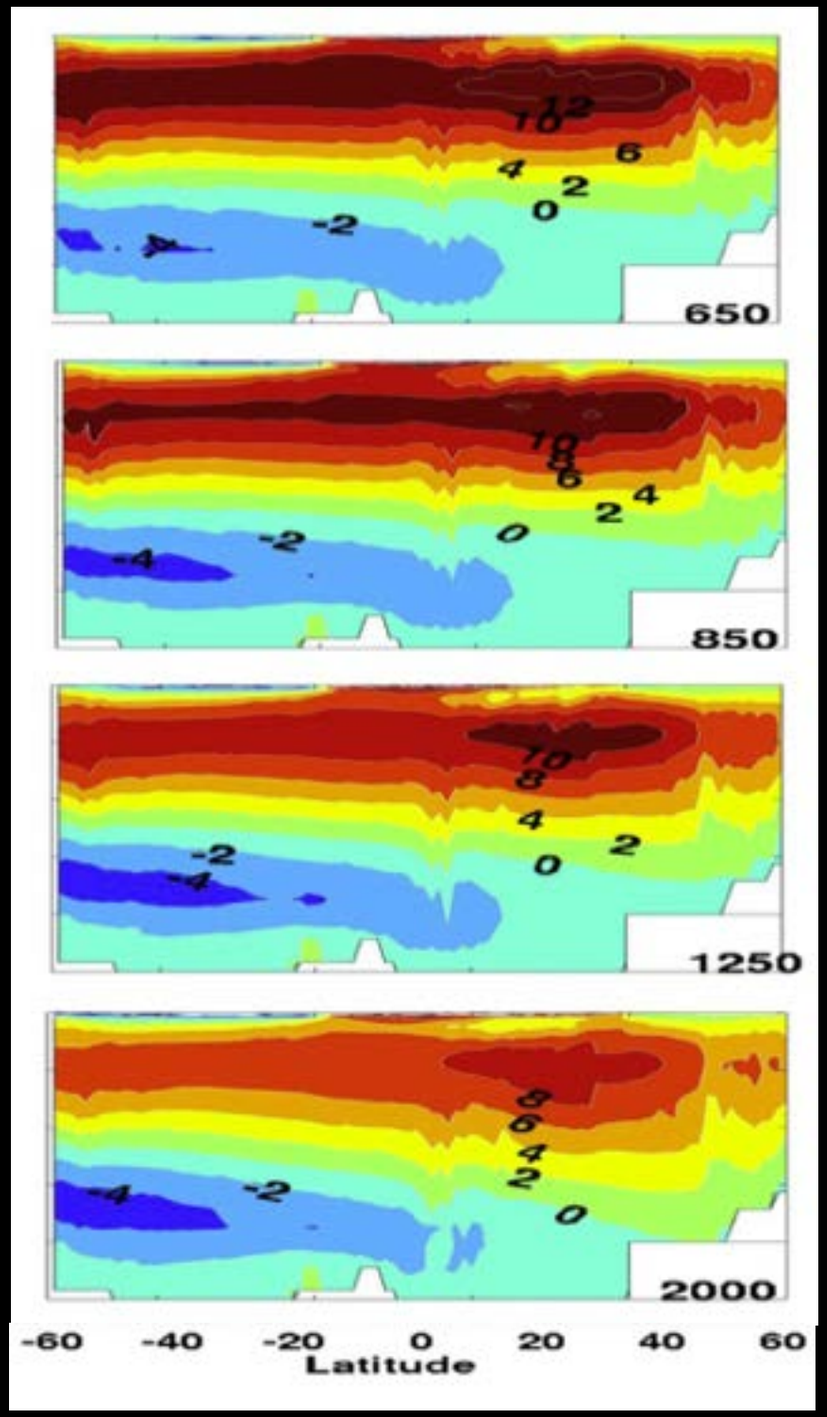
Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

Eddies mixing is important for the global climate:

The global ocean circulation

Tracer transports (heat, freshwater, carbon and **SALINITY**)

GLOBAL MOC (MITGCM)



MARSHALL ET AL. 2017

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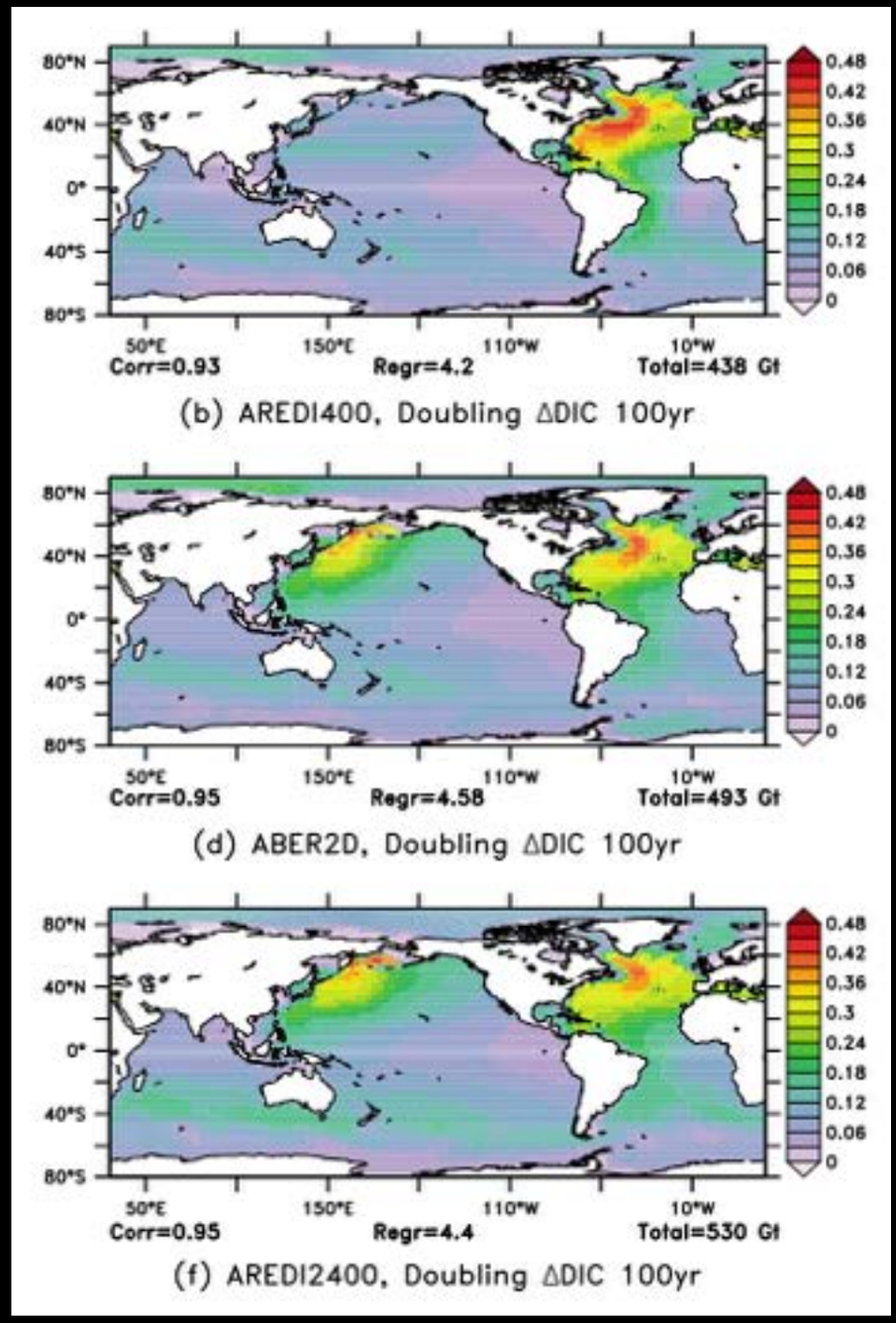
CARBON UPTAKE
100YR AFTER CO2 DOUBLING



DIFFUSIVITY

GNANADESIKAN ET AL. 2015

GOAL

Investigate **temporal variability** in eddy mixing and the connection to climate variability

SPURS specific message:
Watch the K in your salinity budget! Particularly when residuals are interpreted as a physical process.

$$-\nabla \cdot (K \nabla S)$$

SALINITY TENDENCY DUE TO EDDY MIXING

MODEL SETUP

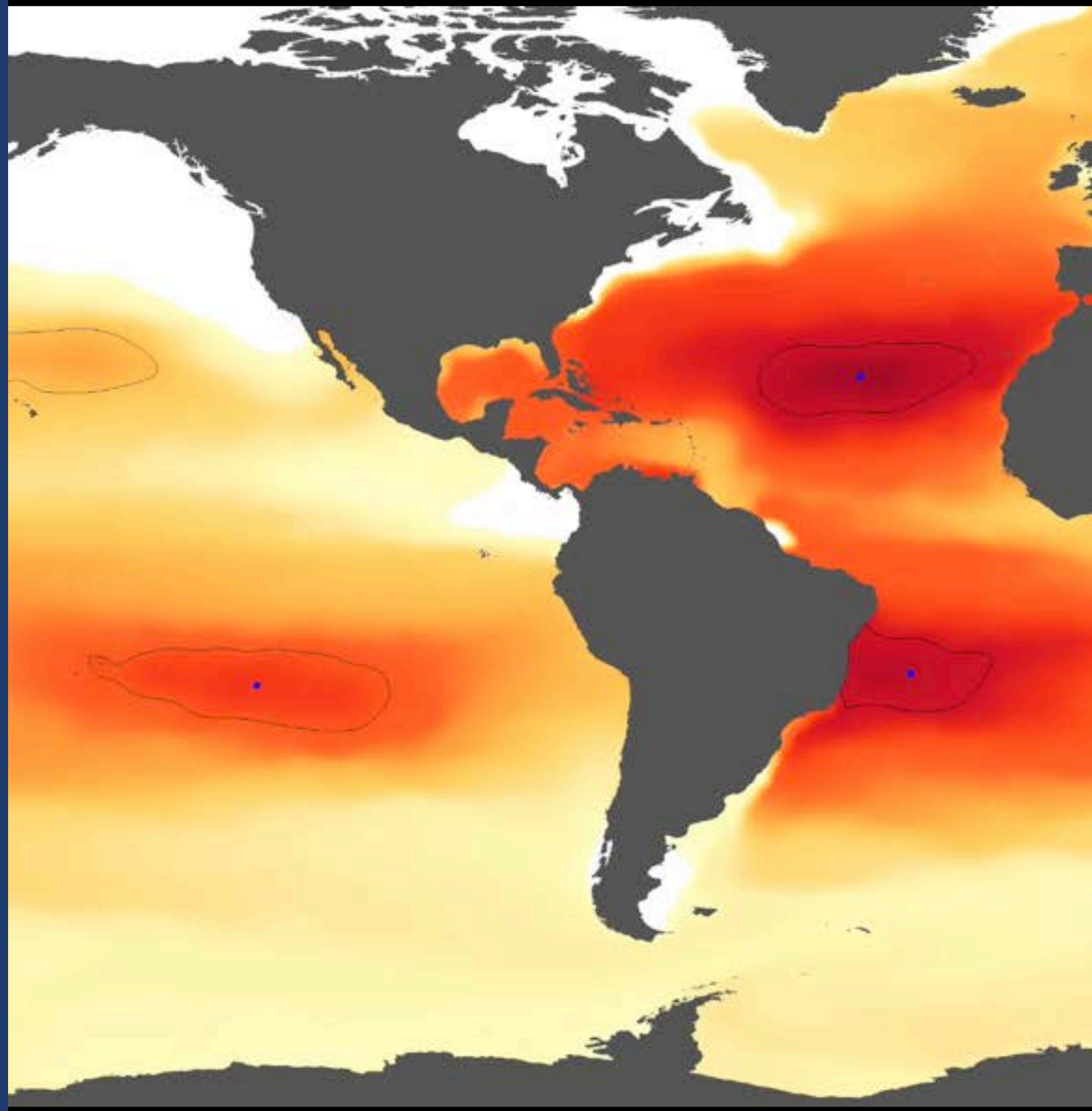
1/10° surface setup (MITgcm[1]).

AVISO velocities advect passive tracer field.

No surface forcing or vertical processes to isolate effect of eddies

Initial conditions are reset in regular intervals to preserve large scale characteristics.

Diffusivity and transport dominated by velocity characteristics not sub-grid scale diffusivity[2].



[1]ABERNATHEY AND MARSHALL 2013
[2]MARSHALL ET AL. 2006

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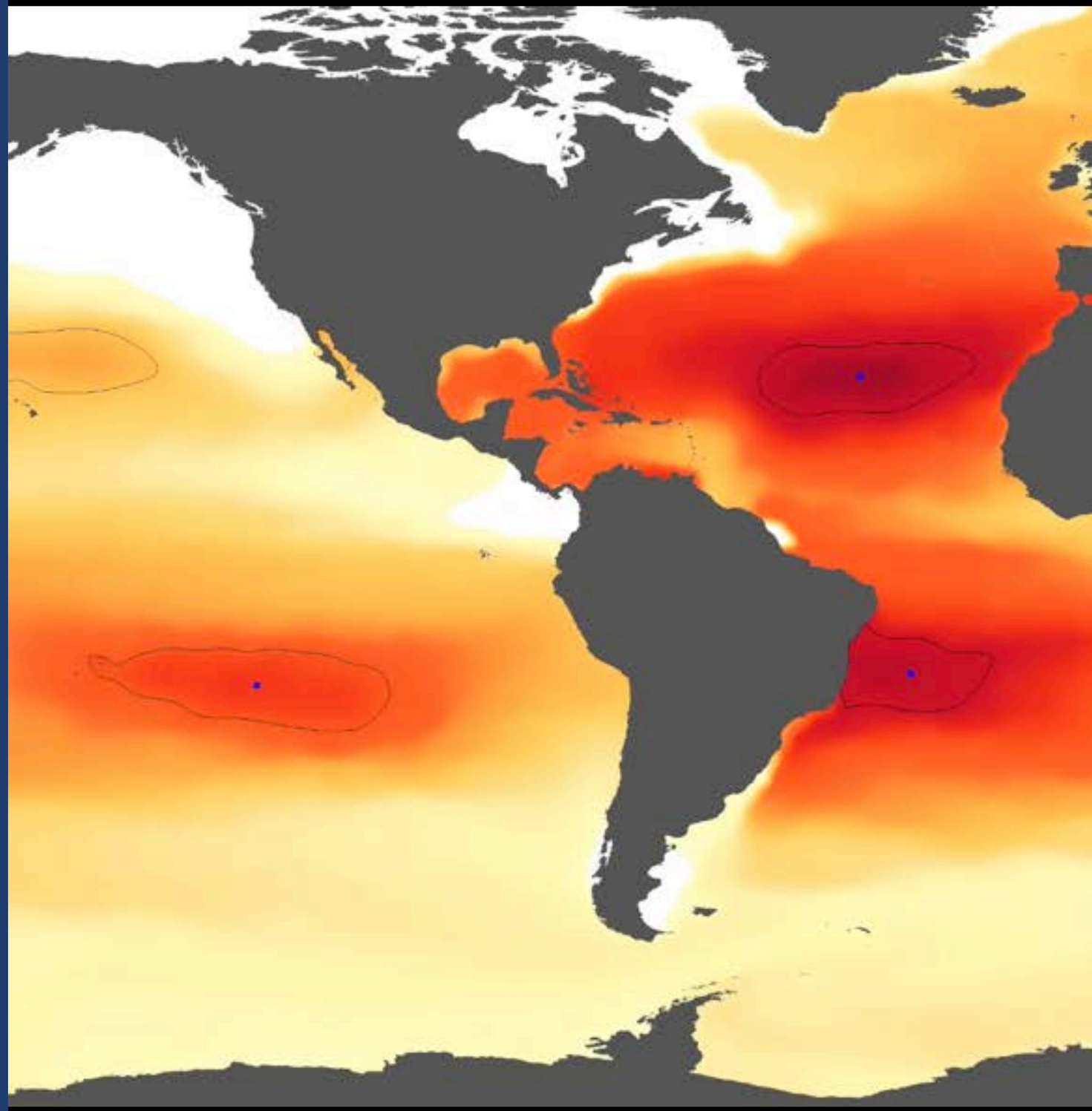

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Eddies v’ ~ 100 km / weeks-months

Eddies diffuse tracer fields by enhancing the ‘contact area’ of an isohaline

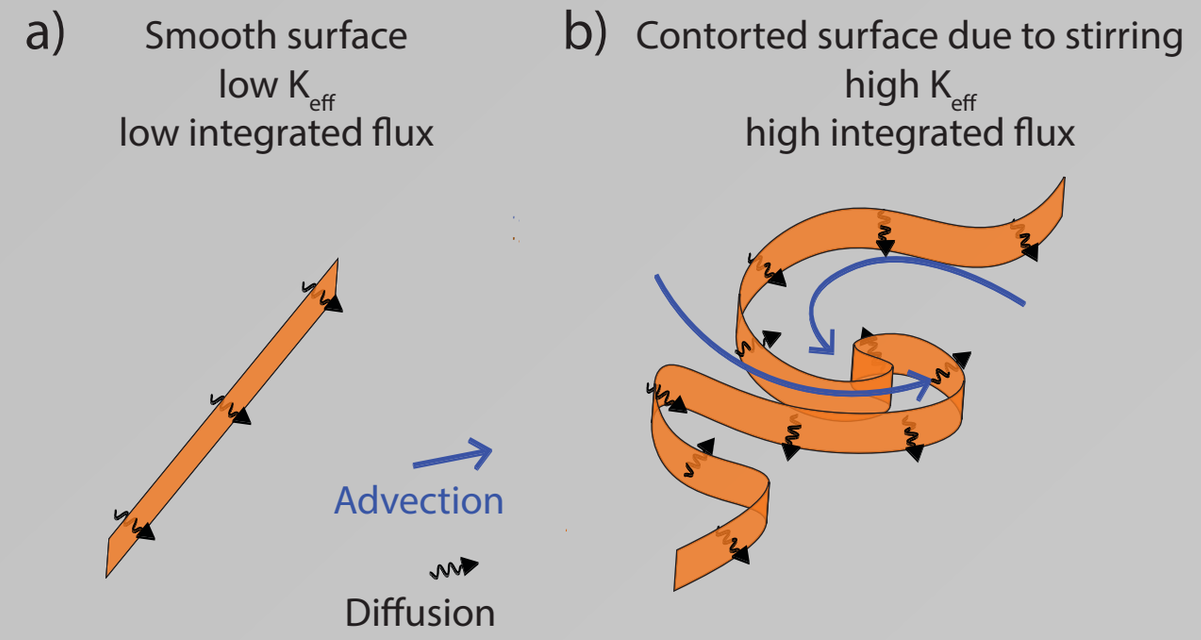
Water mass coordinate system - Advection does not affect the budget

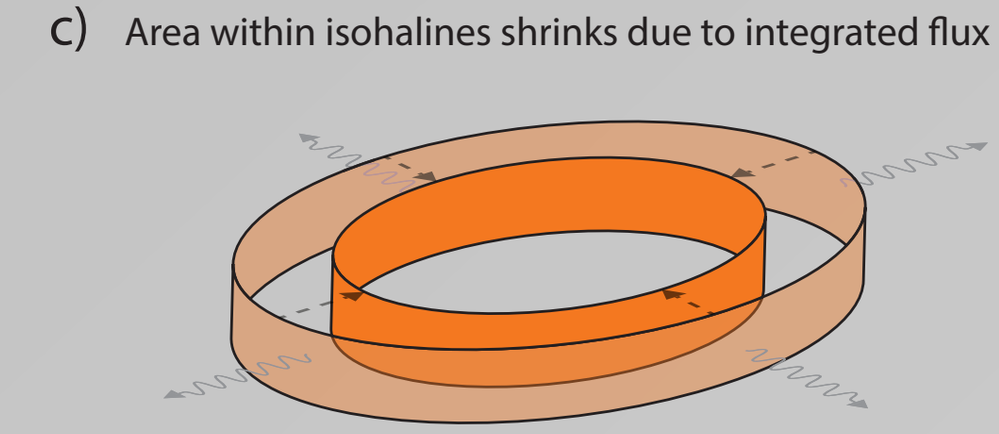
Eddy diffusivity (velocity field)

$$K_{eff} = \kappa \frac{L_e^2}{L_{min}^2}$$

Eddy mixing (velocity + tracer field)

$$TFR(S_0, t) = \frac{\partial}{\partial t} \iint\limits_{(S>=S_0)} dA \, \overline{MLD}(S_0)$$





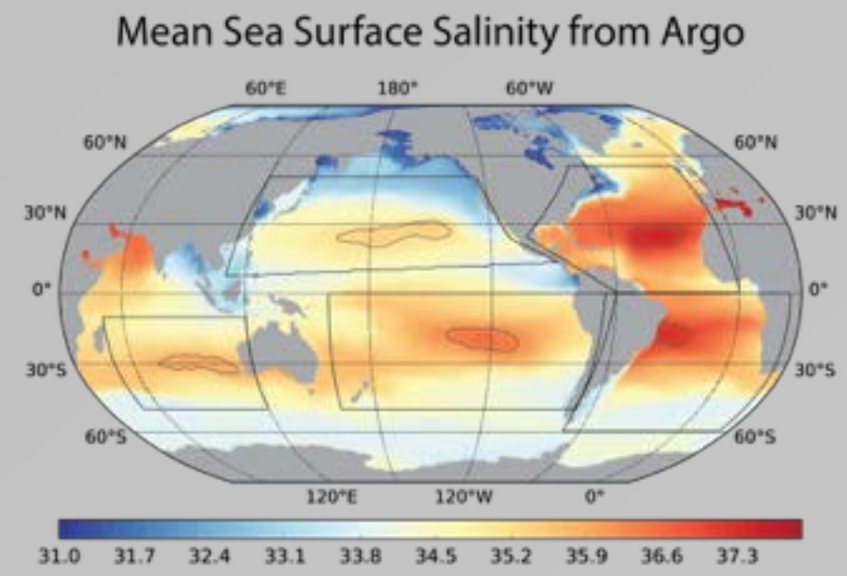
BUSECKE ET AL. 2017, JPO

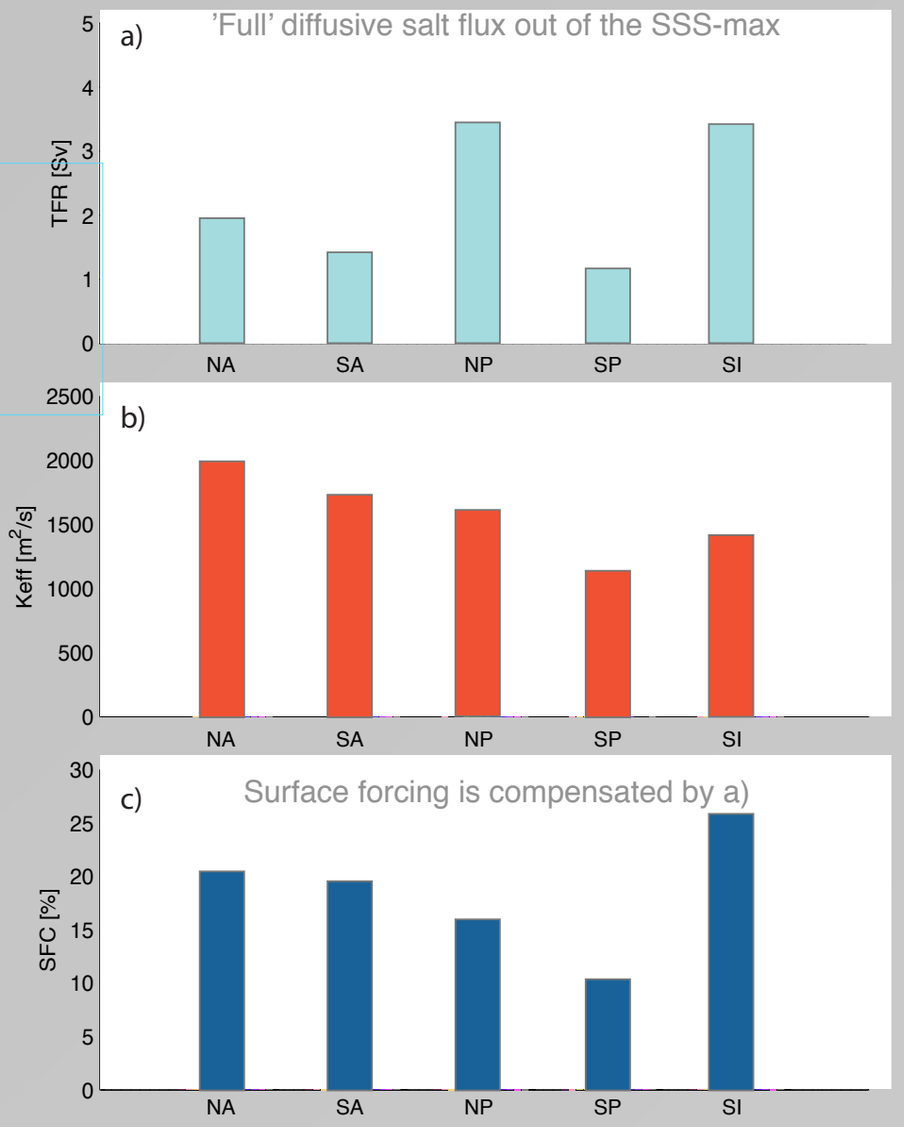
Reference isohalines from Gordon et al. 2015

Eddy mixing does matter in all ocean basins

Regional differences in the importance of eddy mixing for the mixed layer salinity budget

But what about temporal variability?





TOTAL DIFFUSIVE FLUX

DIFFUSIVITY

SURFACE FORCING COMPENSATED

BUSECKE ET AL. 2017, JPO

TEMPORAL VARIABILITY

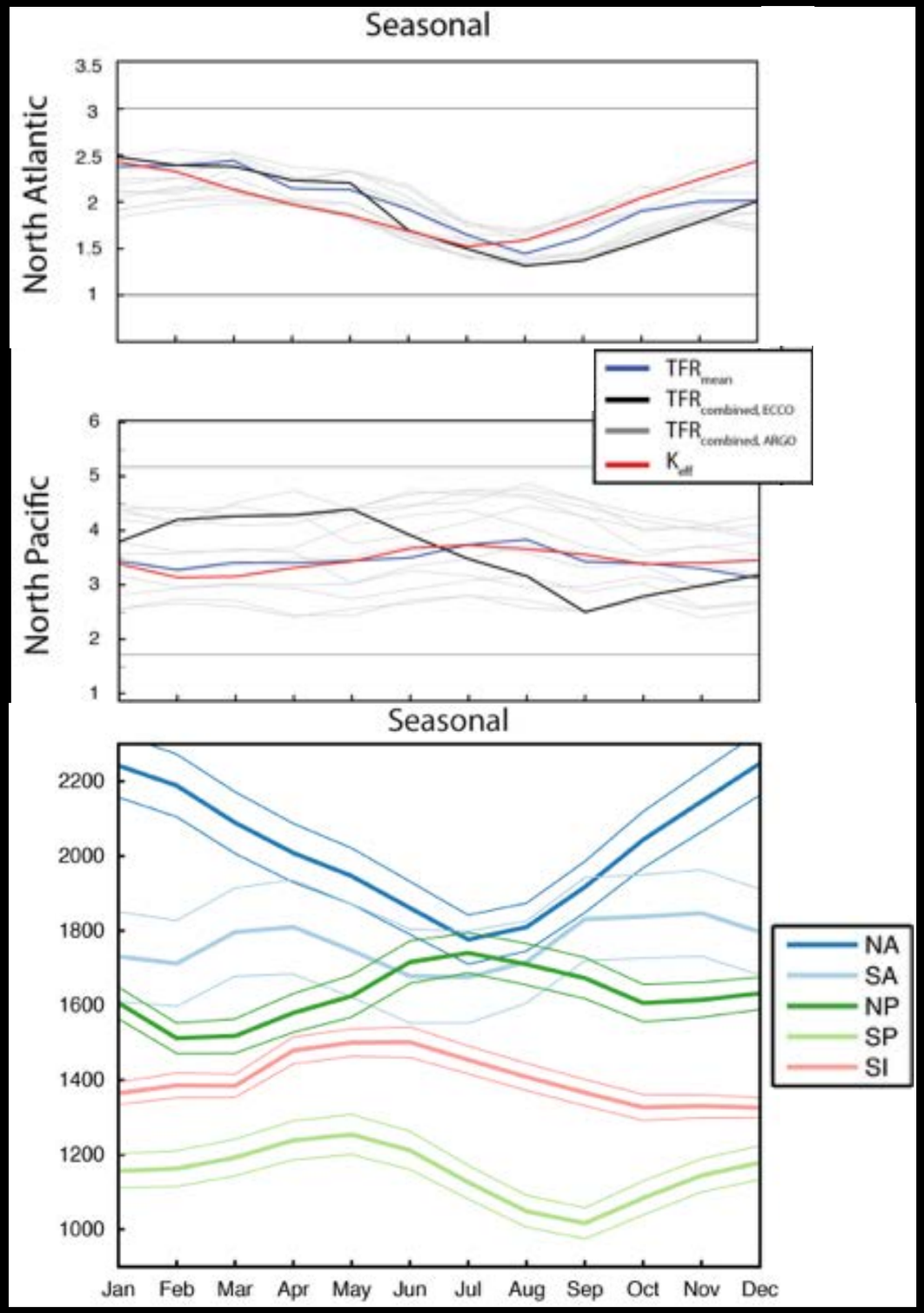
Multiple experiments with seasonal/ interannual SSS fields as initial conditions reveal **sensitivity to position of SSS-max**

North Atlantic and Pacific show a seasonal cycle in eddy mixing.

North Atlantic dominated by **diffusivity** (velocity field)

North Pacific dominated by **initial conditions** (large scale SSS)

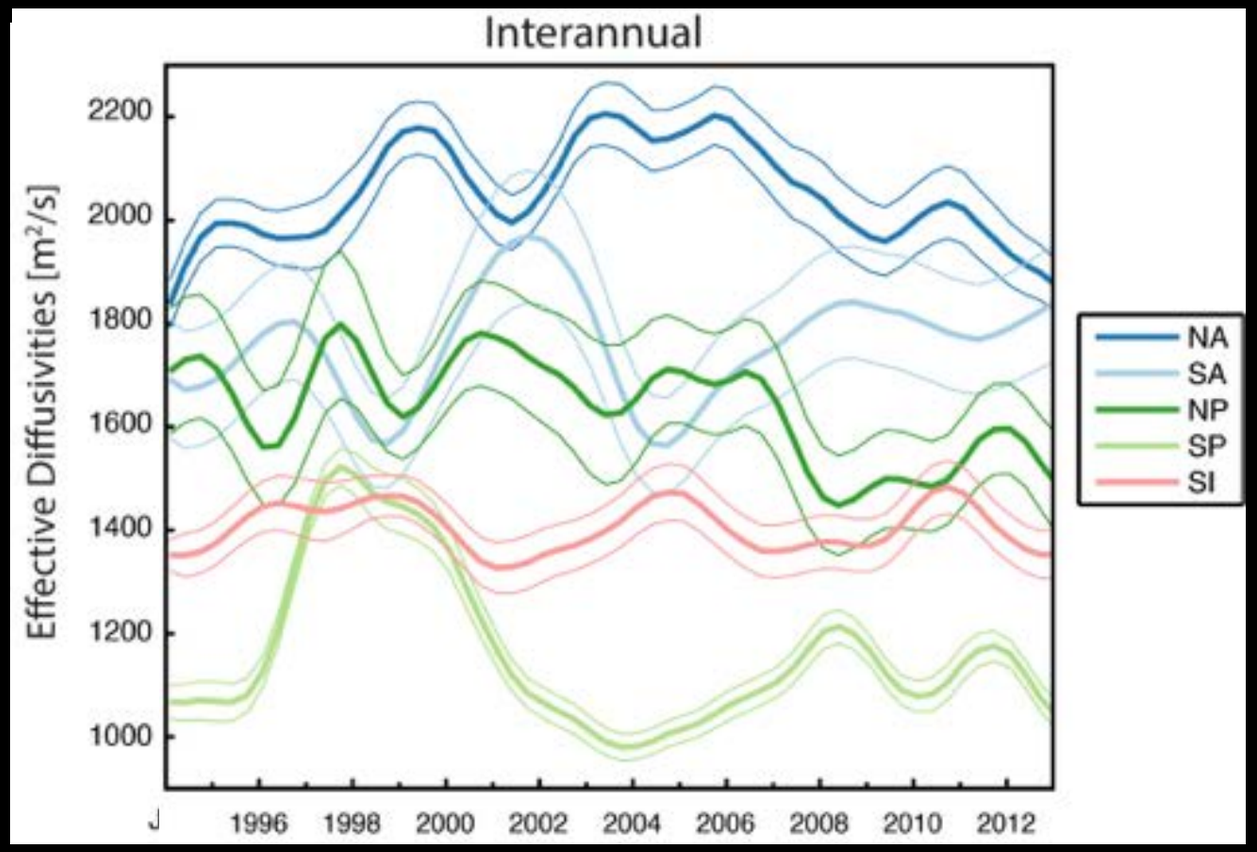
TOTAL DIFFUSIVE FLUX INTO SSS-MAX

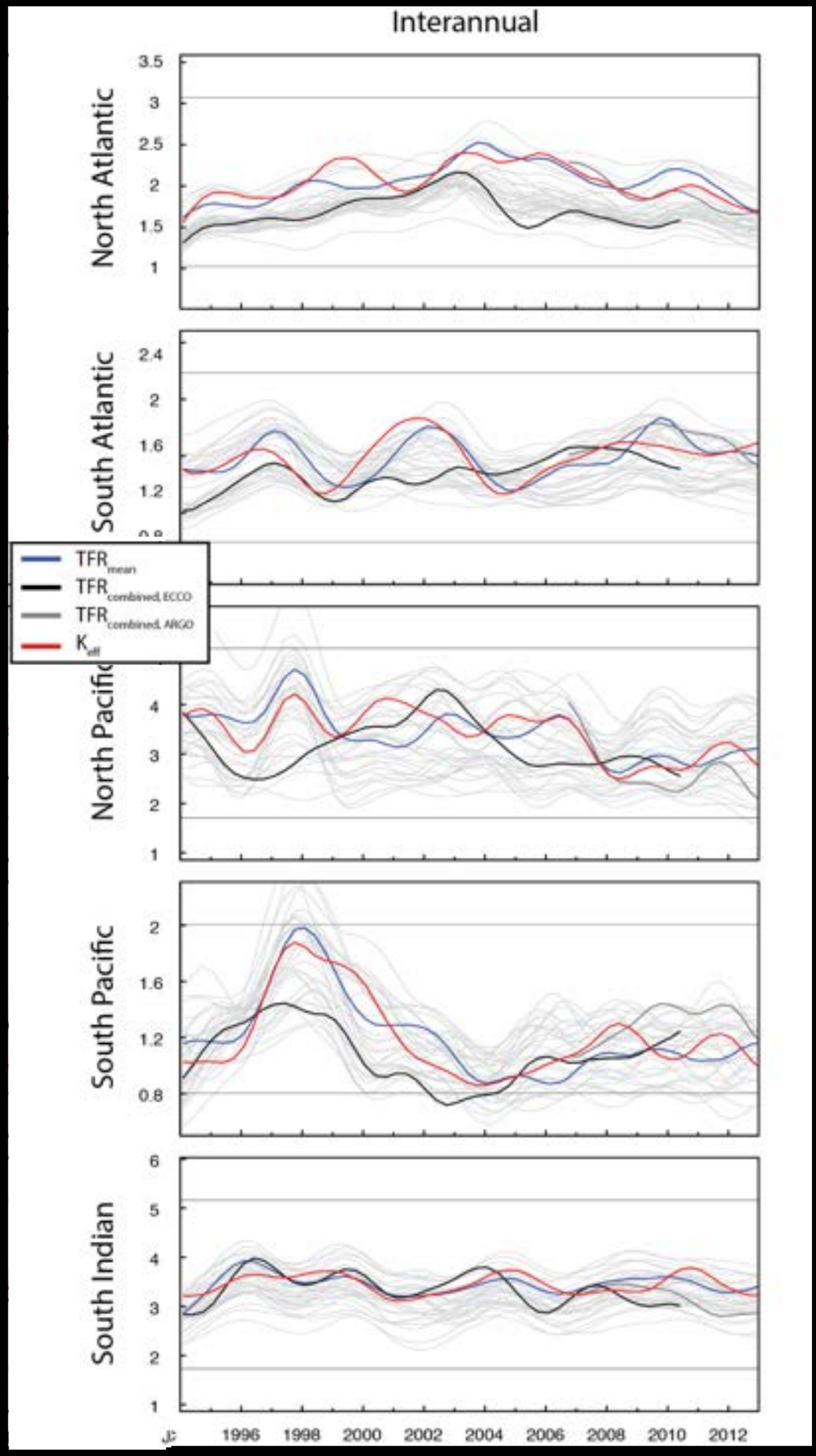


CROSS CONTOUR DIFFUSIVITY

Regional differences in mechanism might influence how each region ‘reacts’ to a changing climate.

In the South Pacific strong peaks around 97/98 suggest a coupling of eddy mixing/diffusivities to large scale climate variability

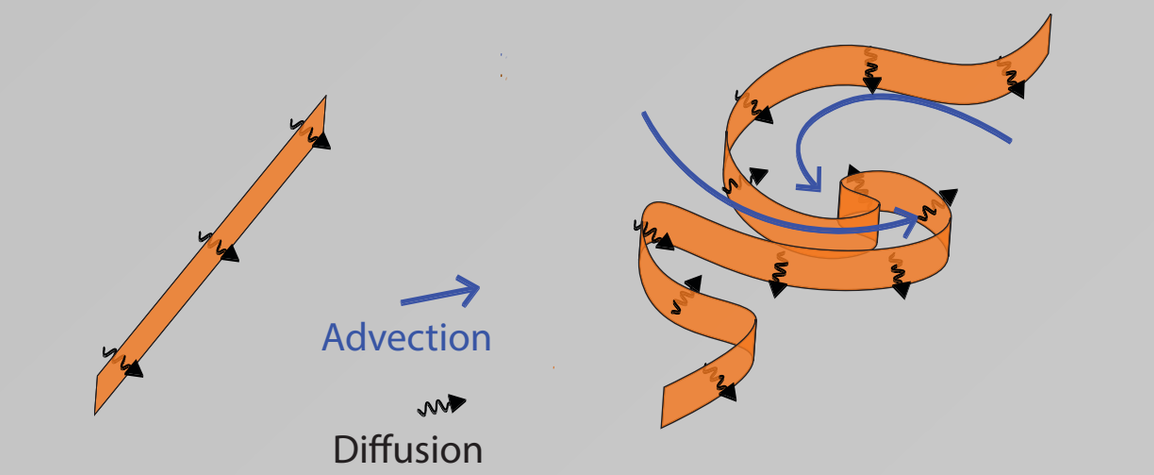




Both diffusivity and total diffusive flux are regionally and temporally variable - ‘Character’ of SSS-maxima also manifest in the eddy mixing characteristics

Water mass framework is well suited to investigate the salty water masses but not able to localize the results

Stretching of isolines corresponds to increased lateral tracer gradients



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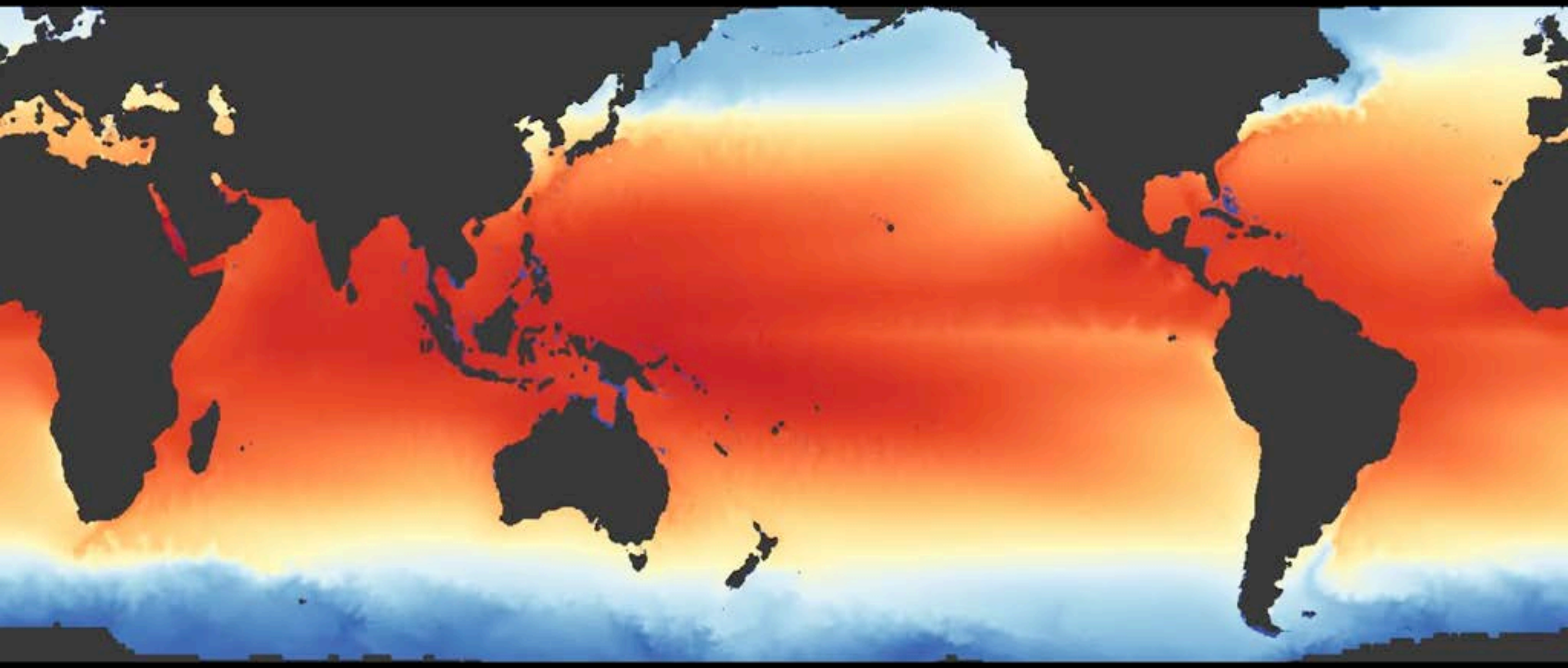
SST Tracer



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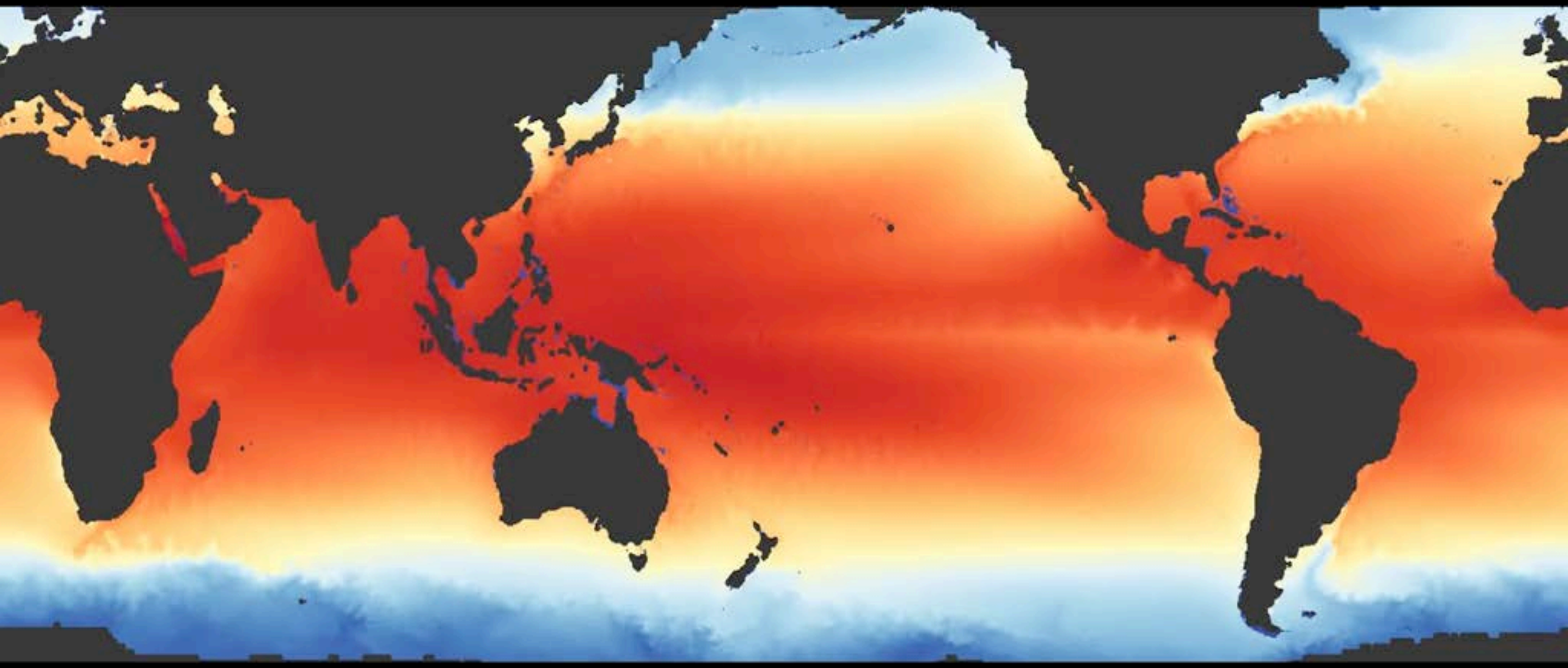


OSBORN COX DIFFUSIVITY

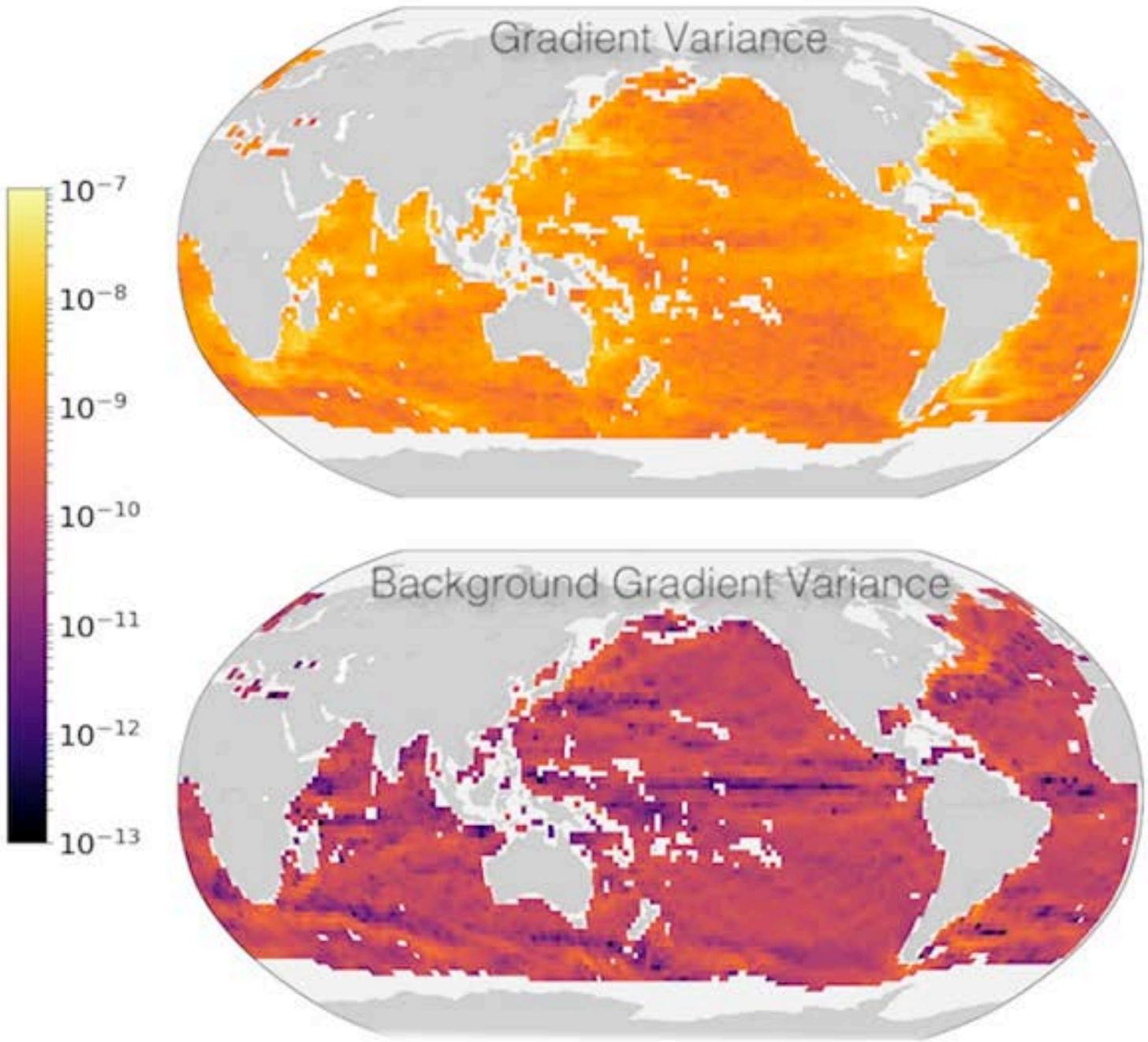
$$K_{OC} = \kappa \frac{\overline{|\nabla q'|^2}}{|\nabla \overline{q}|^2}$$

Eulerian Diagnostic - Results in monthly map of diffusivities ($K_{OC}(x,y,t)$)

Represents the **local destruction of tracer variance** by small scale diffusion

Mesoscale eddies form filaments and fronts, thus increasing the tracer gradient variance over the background gradient variance

1993-06-30



$$\kappa \frac{\overline{|\nabla q'|^2}}{|\nabla \overline{q}|^2} = K_{OC}$$

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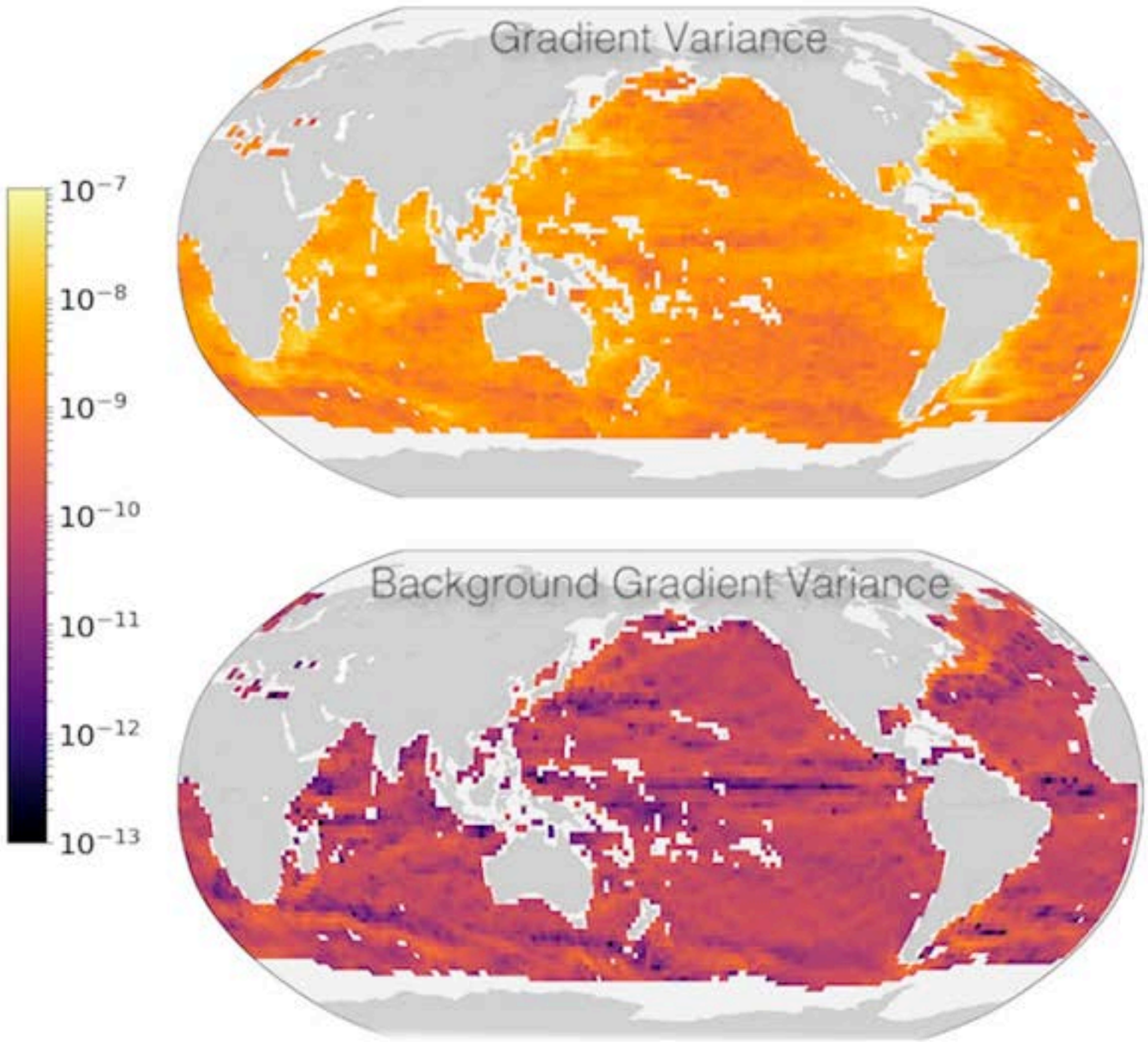


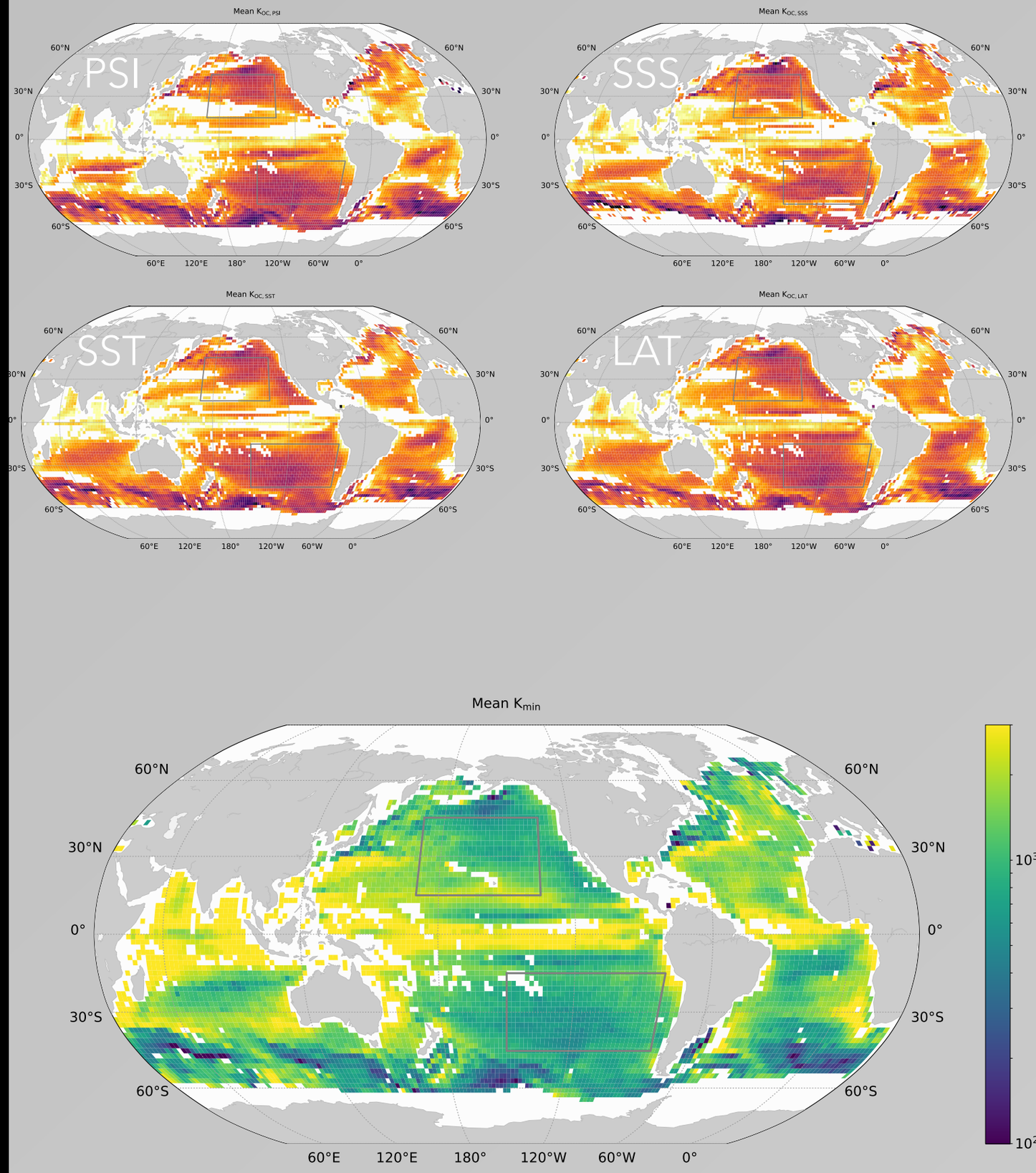
$$\kappa \frac{\overline{|\nabla q'|^2}}{|\nabla \overline{q}|^2} = K_{OC}$$

KMIN

K_{OC} is a scalar diffusivity, relevant to the background tracer field.

The actual diffusivity tensor is anisotropic - Use multiple initial conditions to cover different projections of the diffusivity tensor onto the background gradient

K_{min} : The minimum diffusivity at each grid point, representing the minor axis of the diffusivity tensor - Important for transport barriers



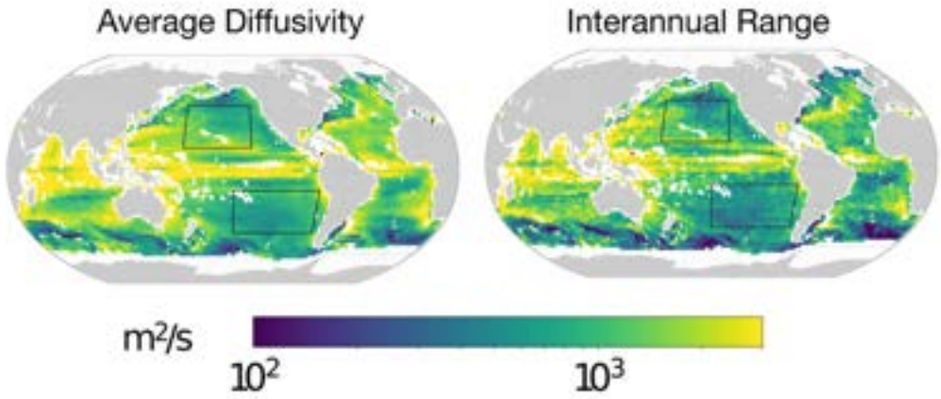
BUSECKE AND ABERNATHEY, IN PREP

RESULTS

Large spatial variability of K_{min}. In agreement with previous studies (Abernathey et al. 2013, Cole et al. 2015)

Interannual range of K_{min} is very large compared to the mean (80% of the global ocean have a ratio above 0.5)

In the subtropical Pacific surface diffusivities show high correlation to ENSO index, suggesting a potential feedback mechanism.



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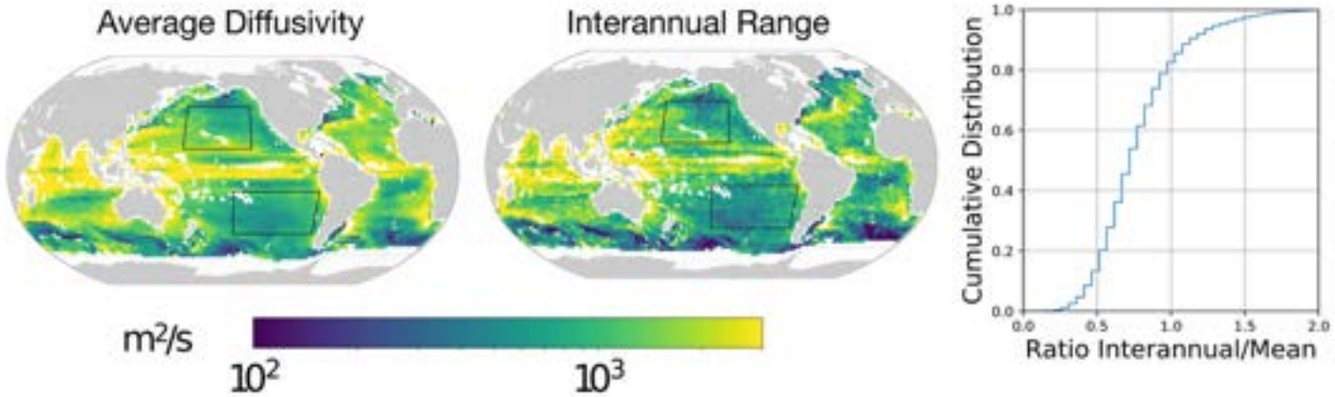

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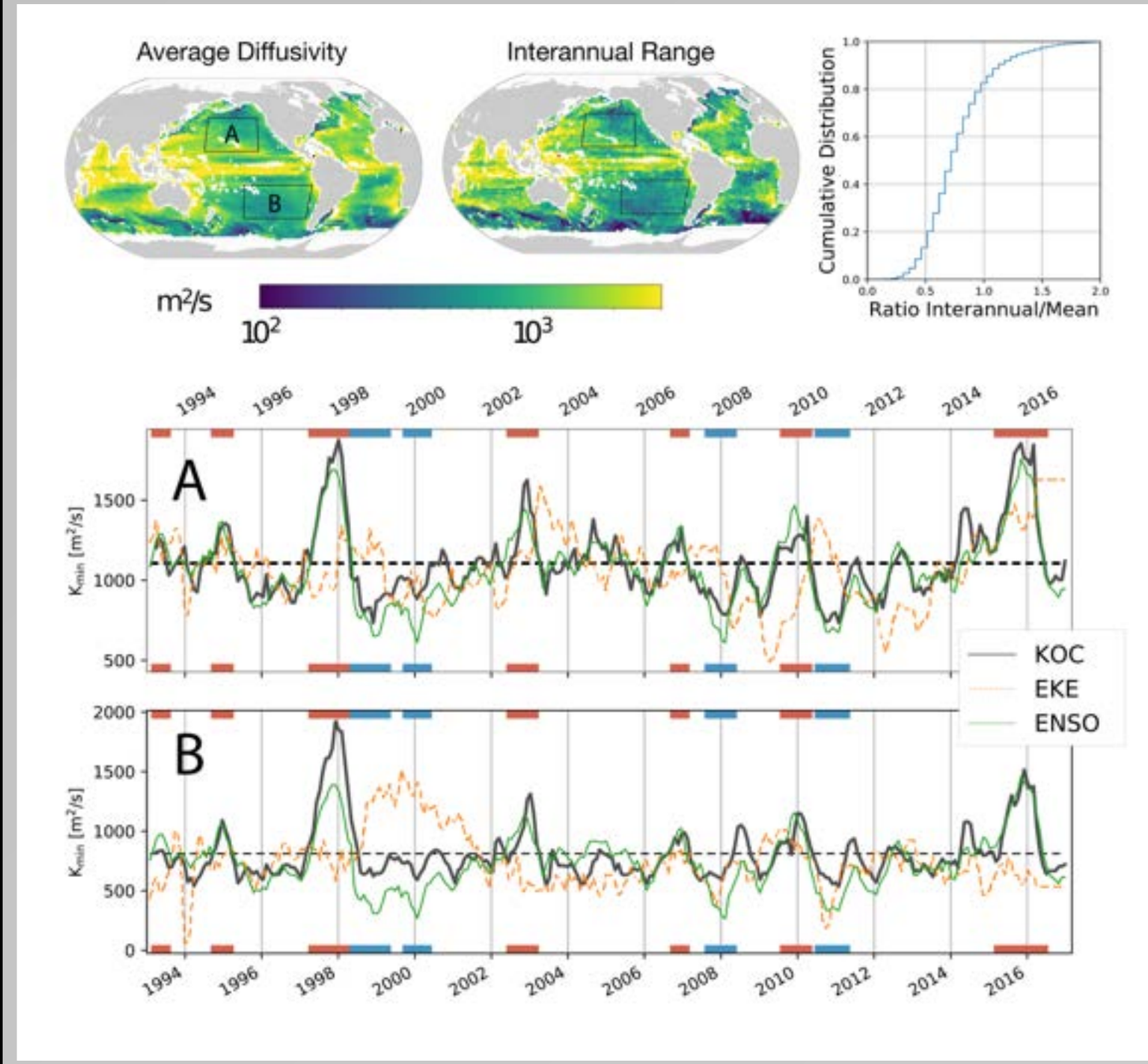


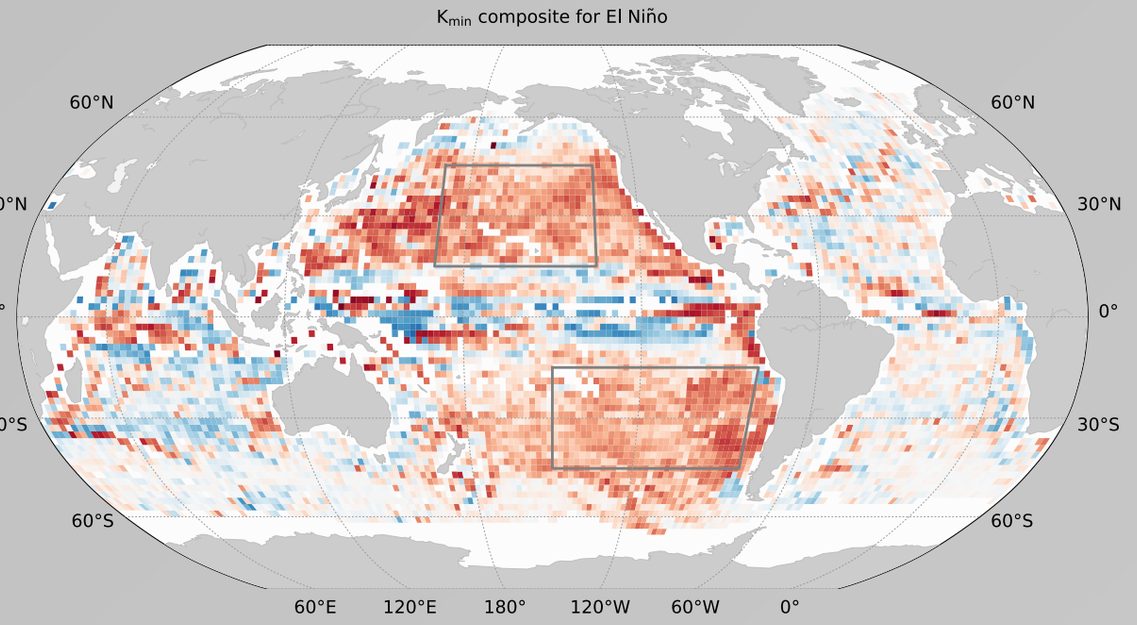
BUSECKE AND ABERNATHEY, IN PREP

Surface Diffusvity

K_{min} is elevated over most of the Pacific during high ENSO periods

Particularly relevant since the diffusivity in the subtropics is generally low.

El Niño



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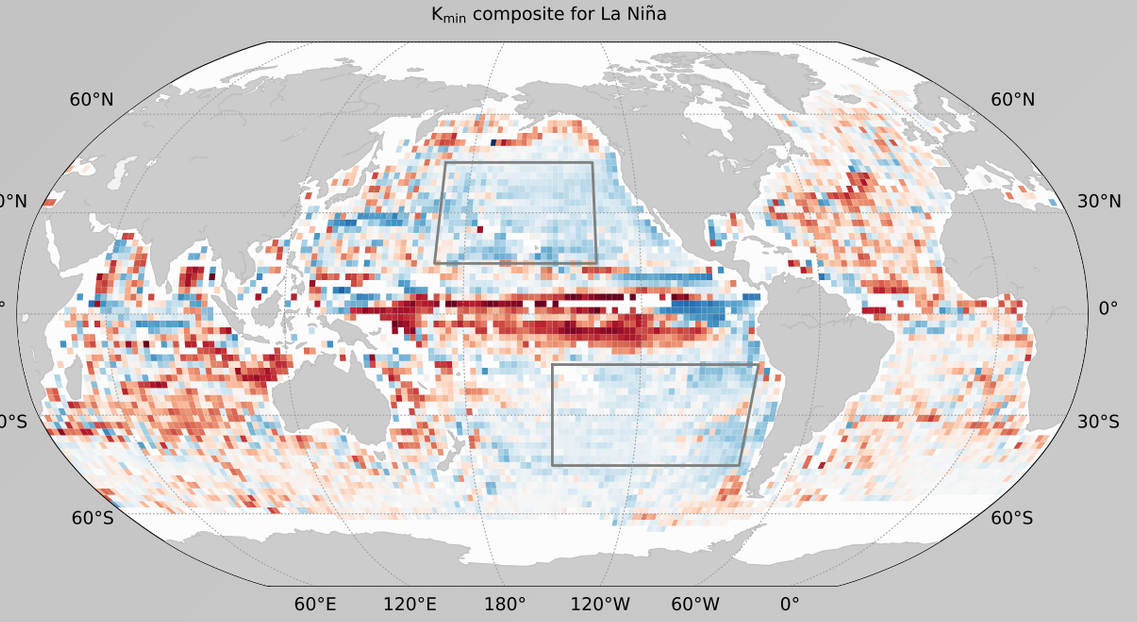


BUSECKE AND ABERNATHEY, IN PREP

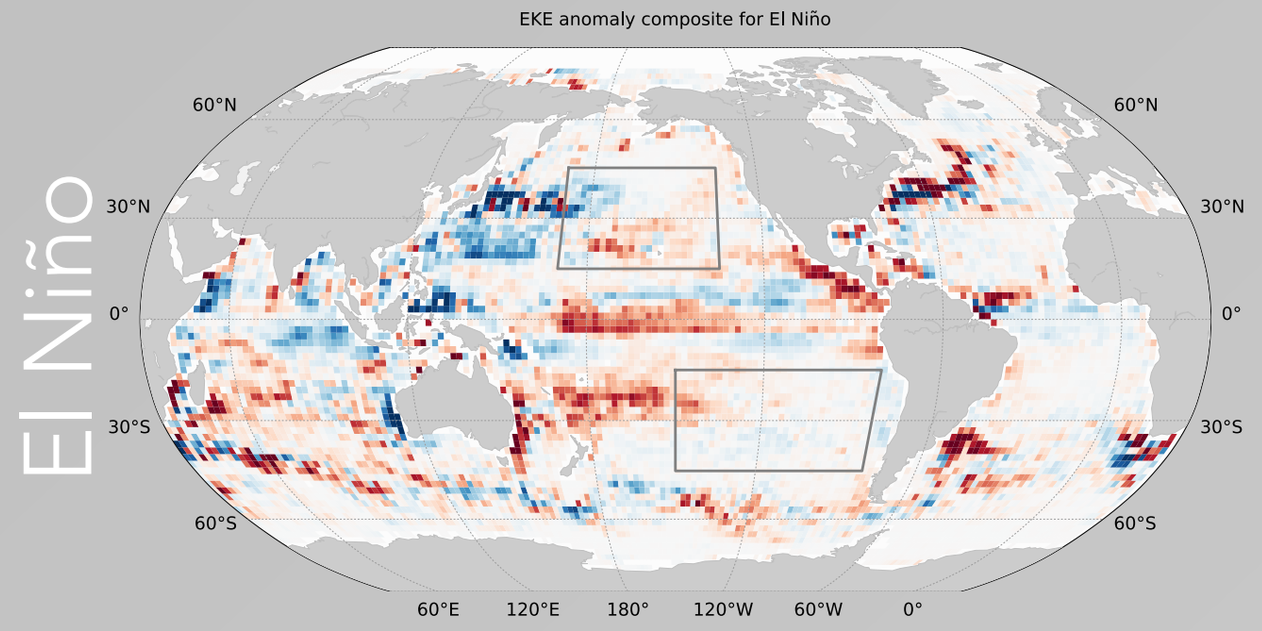
K_{min} is not well correlated to to the EKE

Interaction with the large scale flow field could have a primary role in modulating the surface diffusivities in the Pacific Ocean.

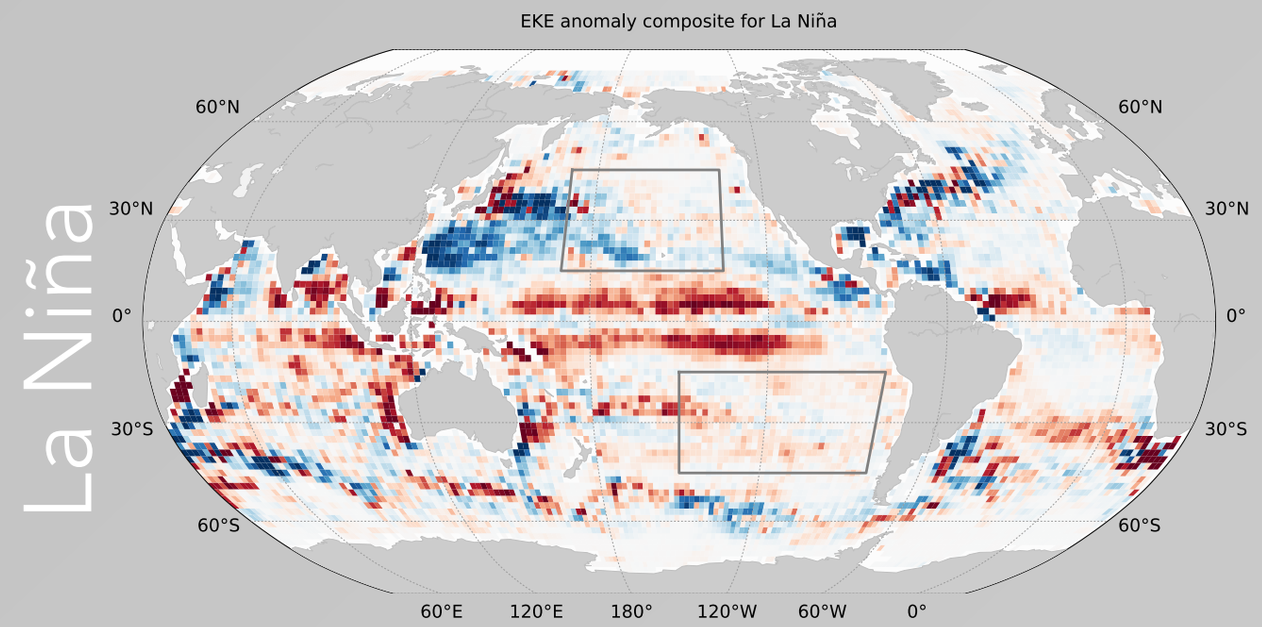
Mixing length shows similar response

EKE

El Niño



La Niña



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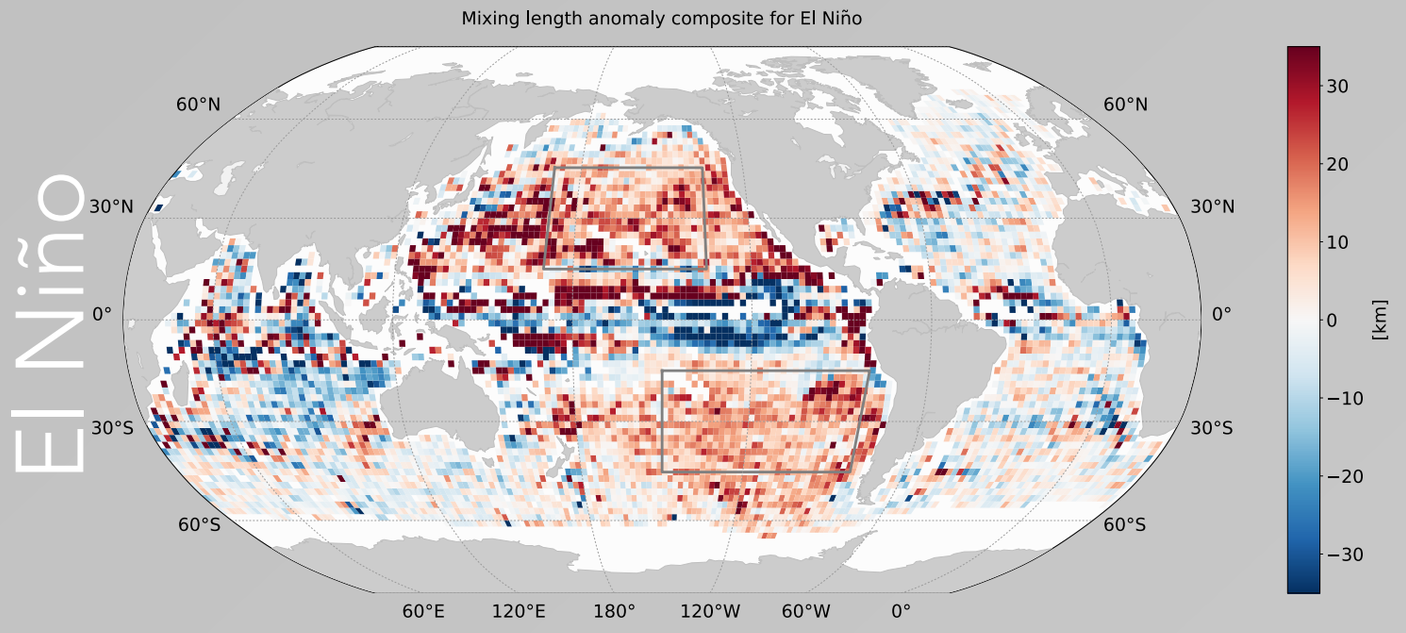

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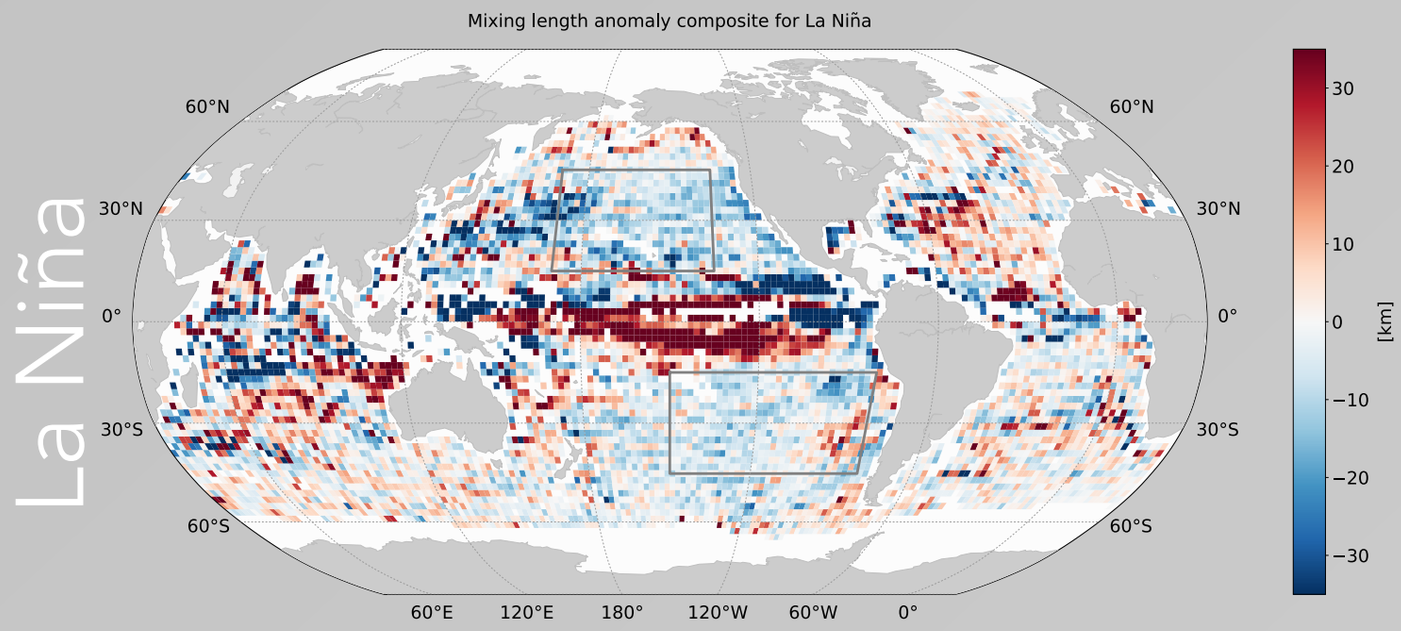


BUSECKE AND ABERNATHEY, IN PREP

CONCLUSIONS

These studies suggest that **surface eddy diffusivity/eddy mixing vary in time** in most areas of the global ocean

> This has **implications for surface tracer budgets.** Careful consideration of eddy diffusivities (including NOT applying it to ‘partially mesoscale resolving’ fields) might help reconcile different approaches for salinity budgets within SPURS

The dominant **mechanisms for temporal variability in eddy mixing differ regionally**.

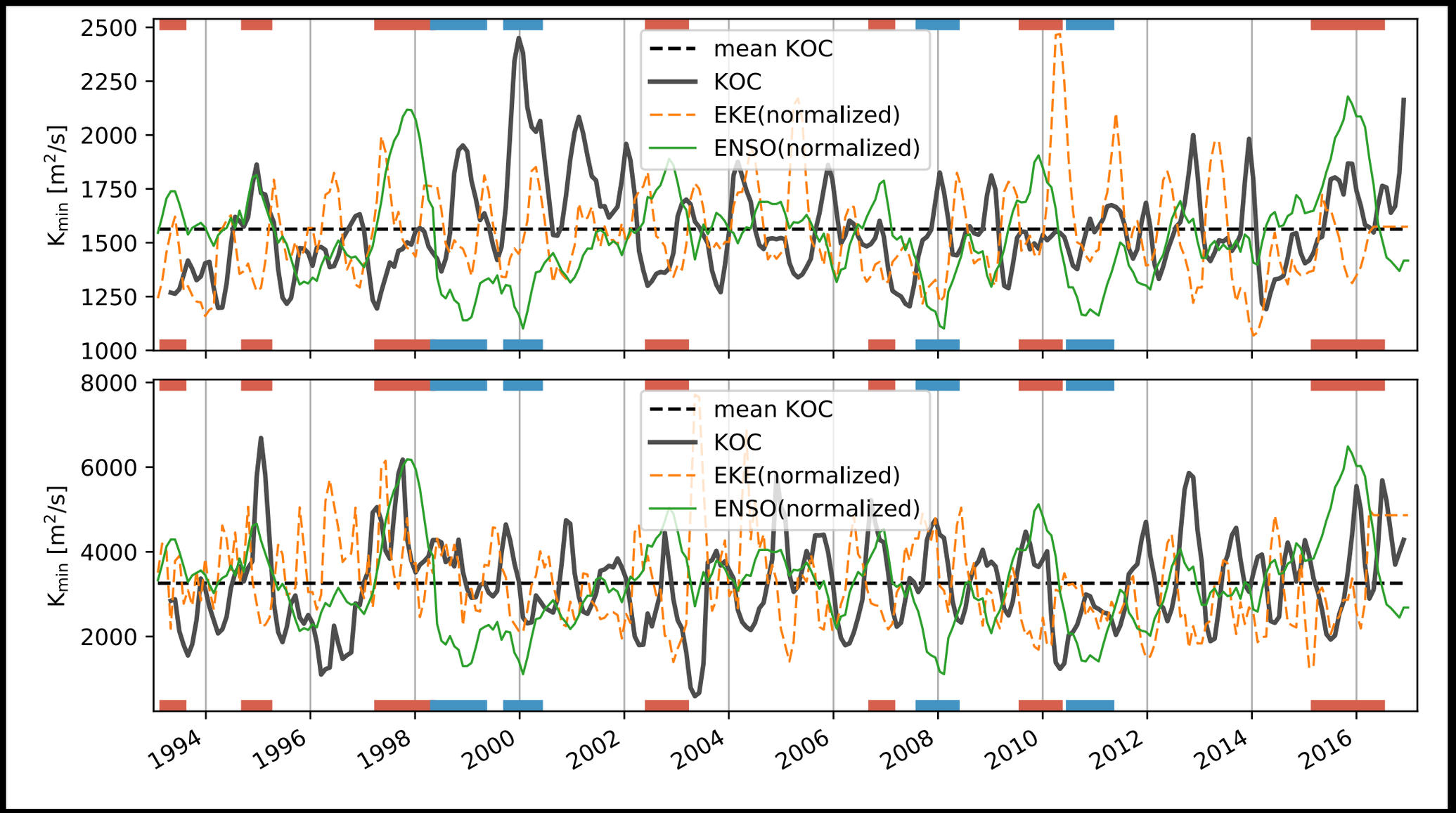
> This should be taken into account when relating the SSS fields to a change in the hydrological cycle - particularly on ‘shorter’ (interannual - decadal) time scales

Eddy diffusivities seem connected to large scale climate variability, possibly representing an important climate feedback.

> The strong variability in the Pacific is not related to EKE implying the **importance of eddy mean flow interaction (Ferrari and Nikurashin 2010, Klocker and Abernathey 2014, Bates 2014)**

SPURS 1

SPURS 2

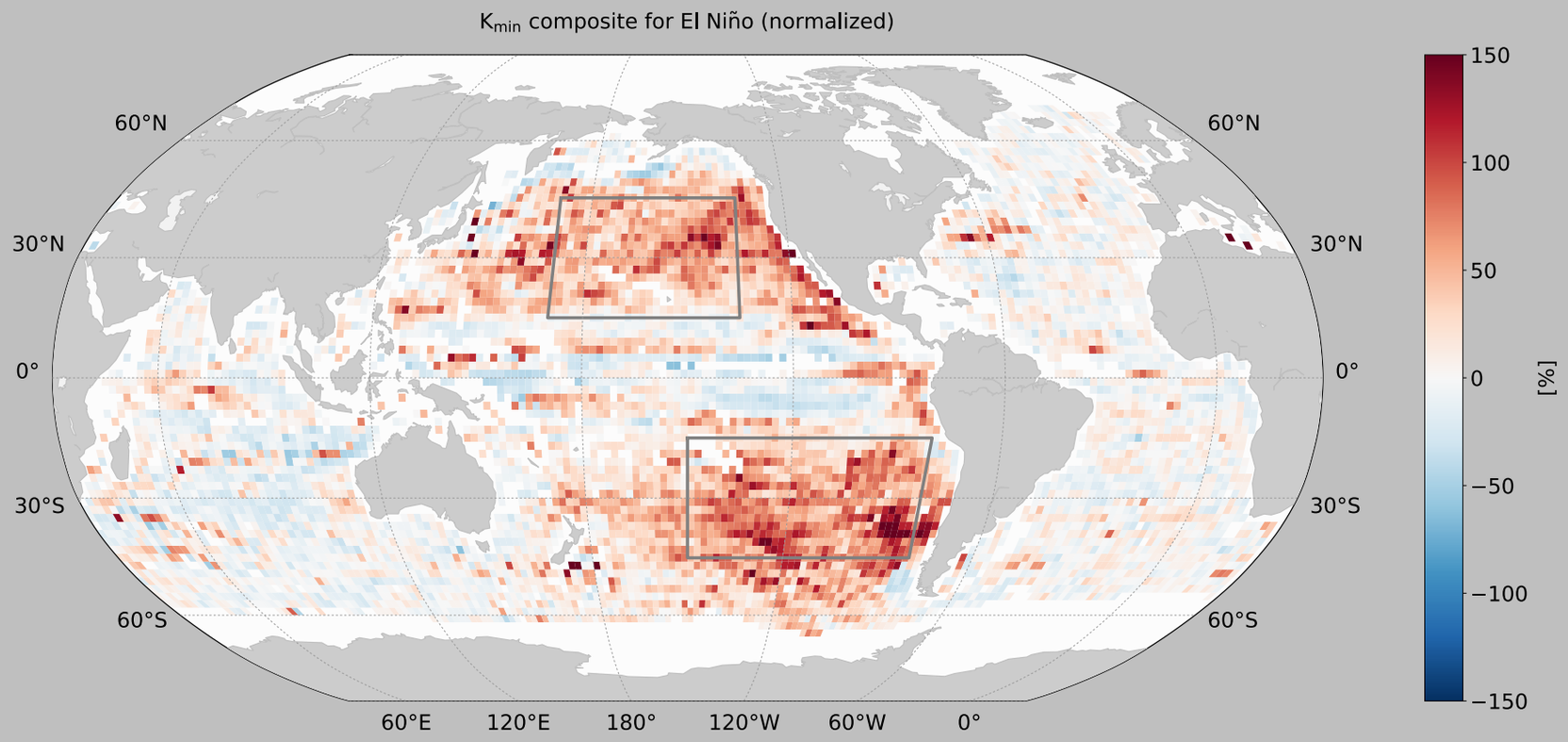


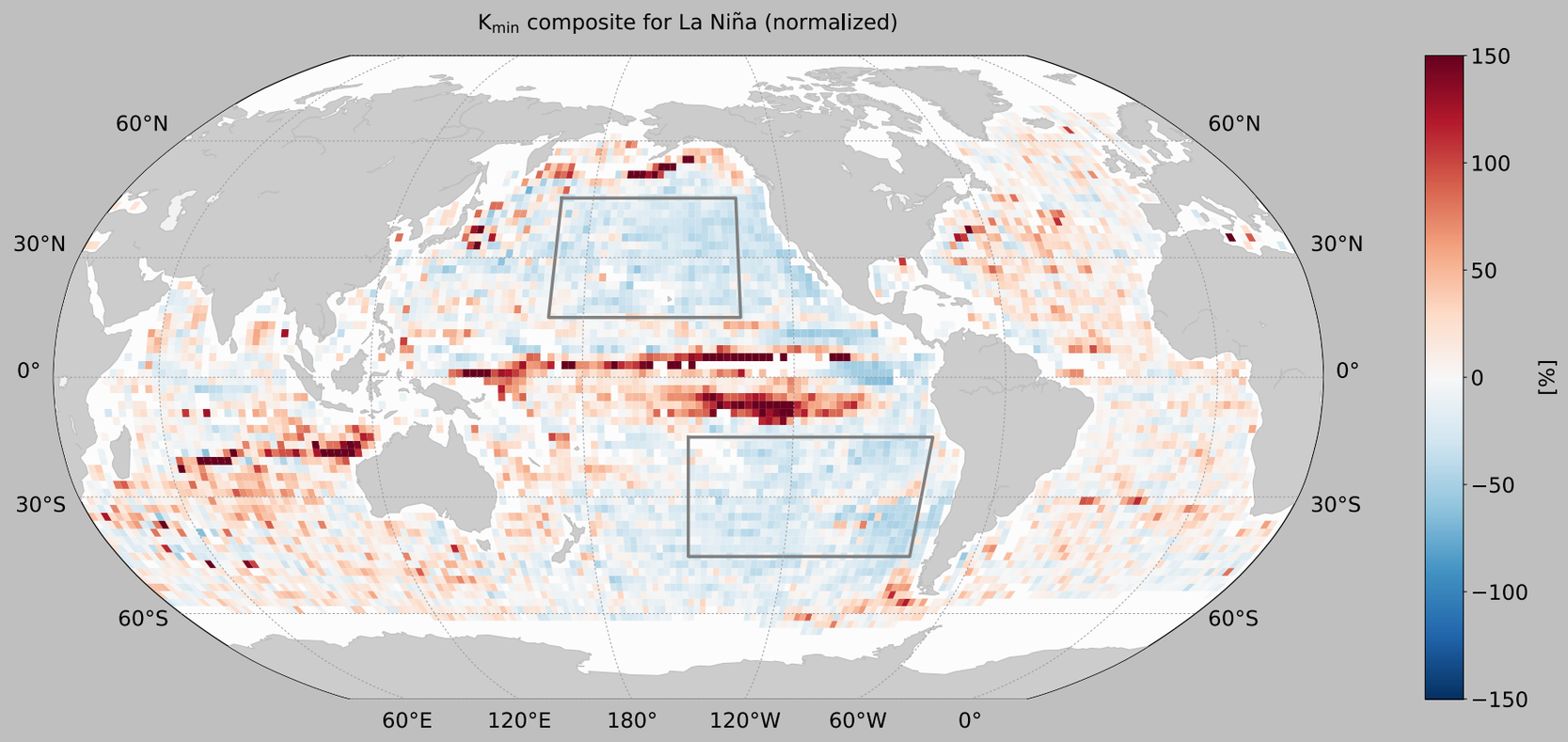
The data set will be made available including all code…soon

OUTLOOK

Investigating of the physical mechanisms coupling the large scale climate to the surface diffusivities

Comparison of "hybrid" results to high resolution models and observations


K_{min} composite for El Niño (normalized)
60°N
30°N
0°
30°S
60°S
60°E
120°E
180°
120°W
60°W
0°
150
100
50
0
−50
−100
−150
[%]


K_{min} composite for La Niña (normalized)
60°N
30°N
0°
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120°W
60°W
0°
150
100
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−50
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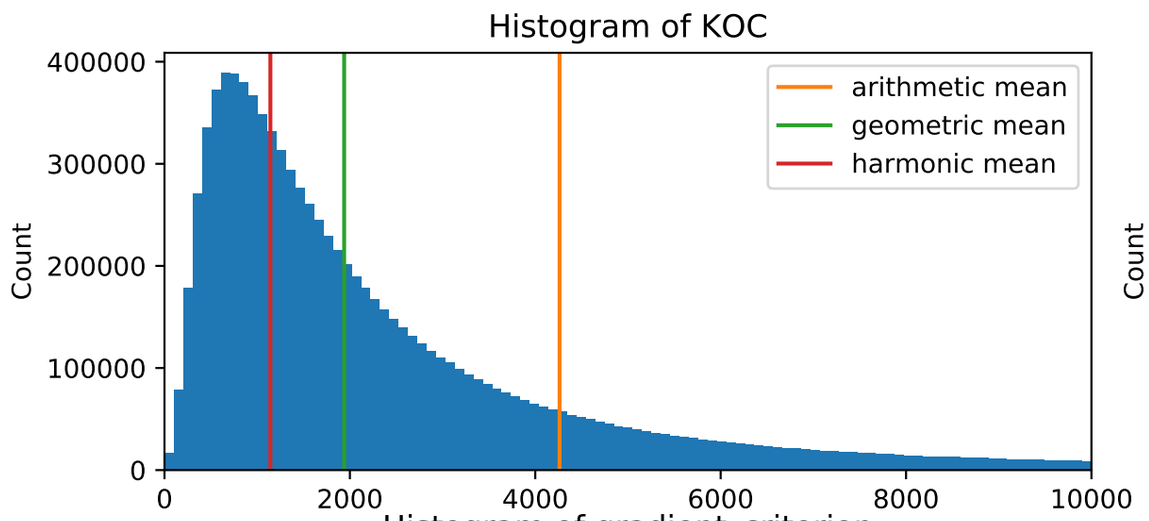
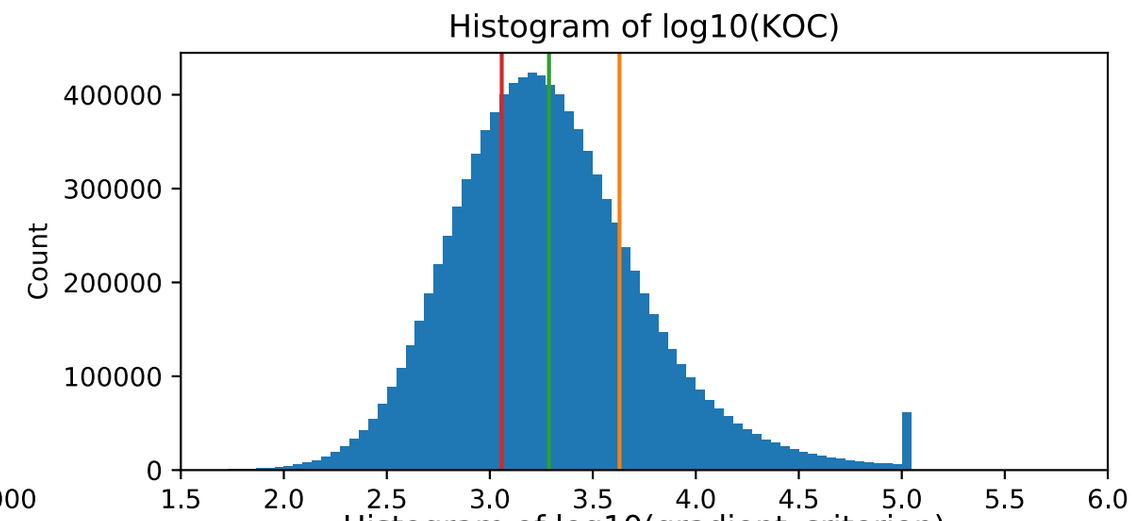
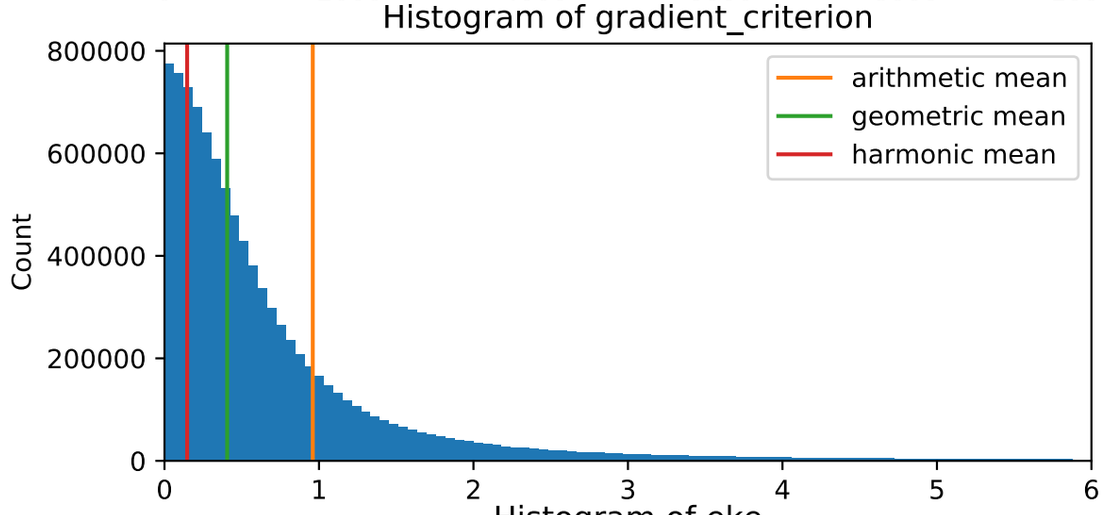
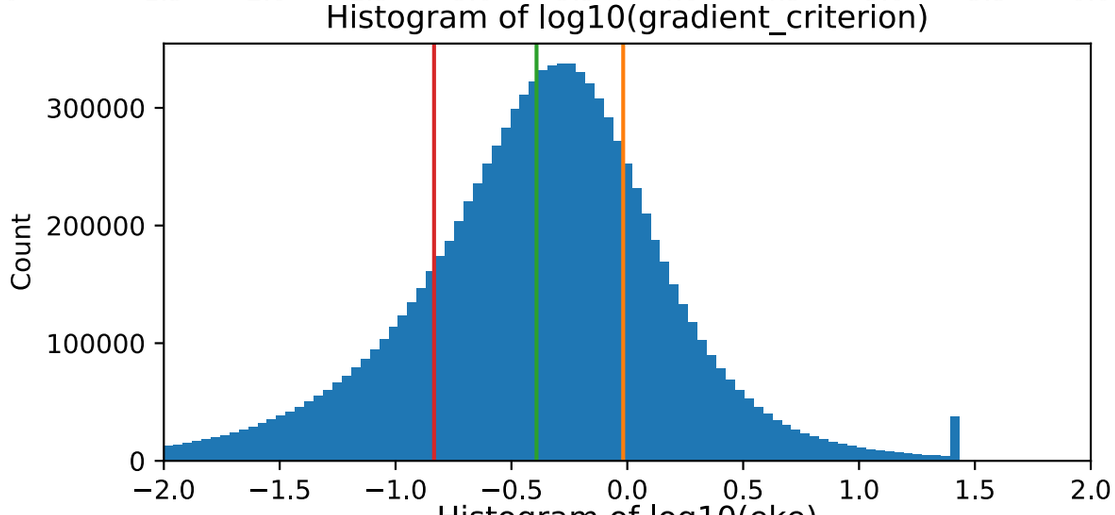
[%]

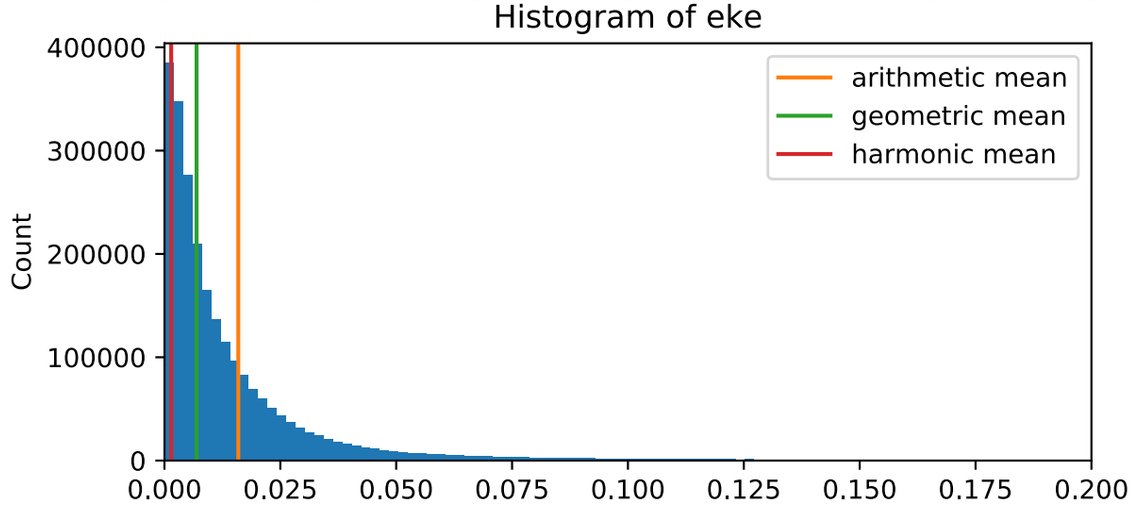
AVERAGING METHOD

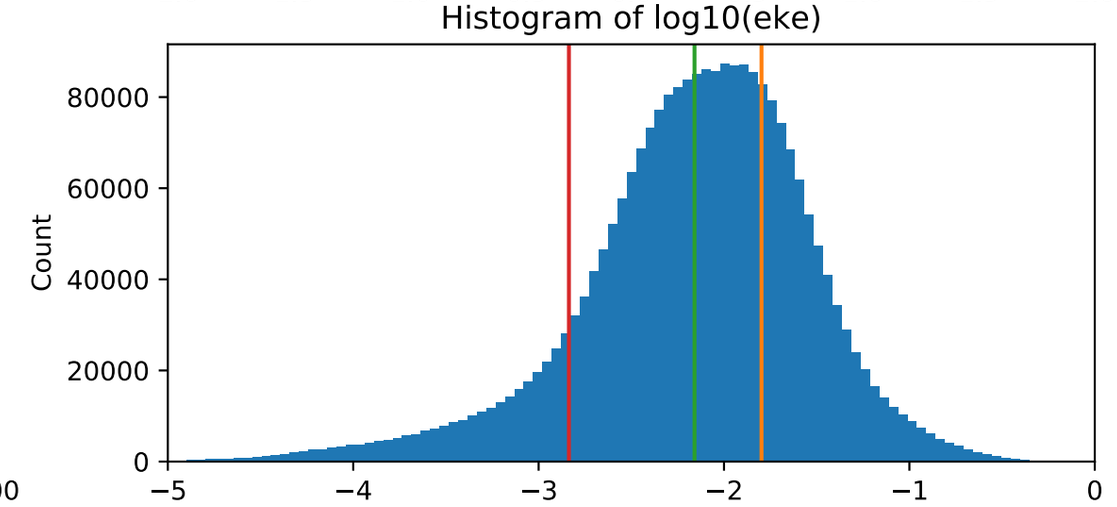




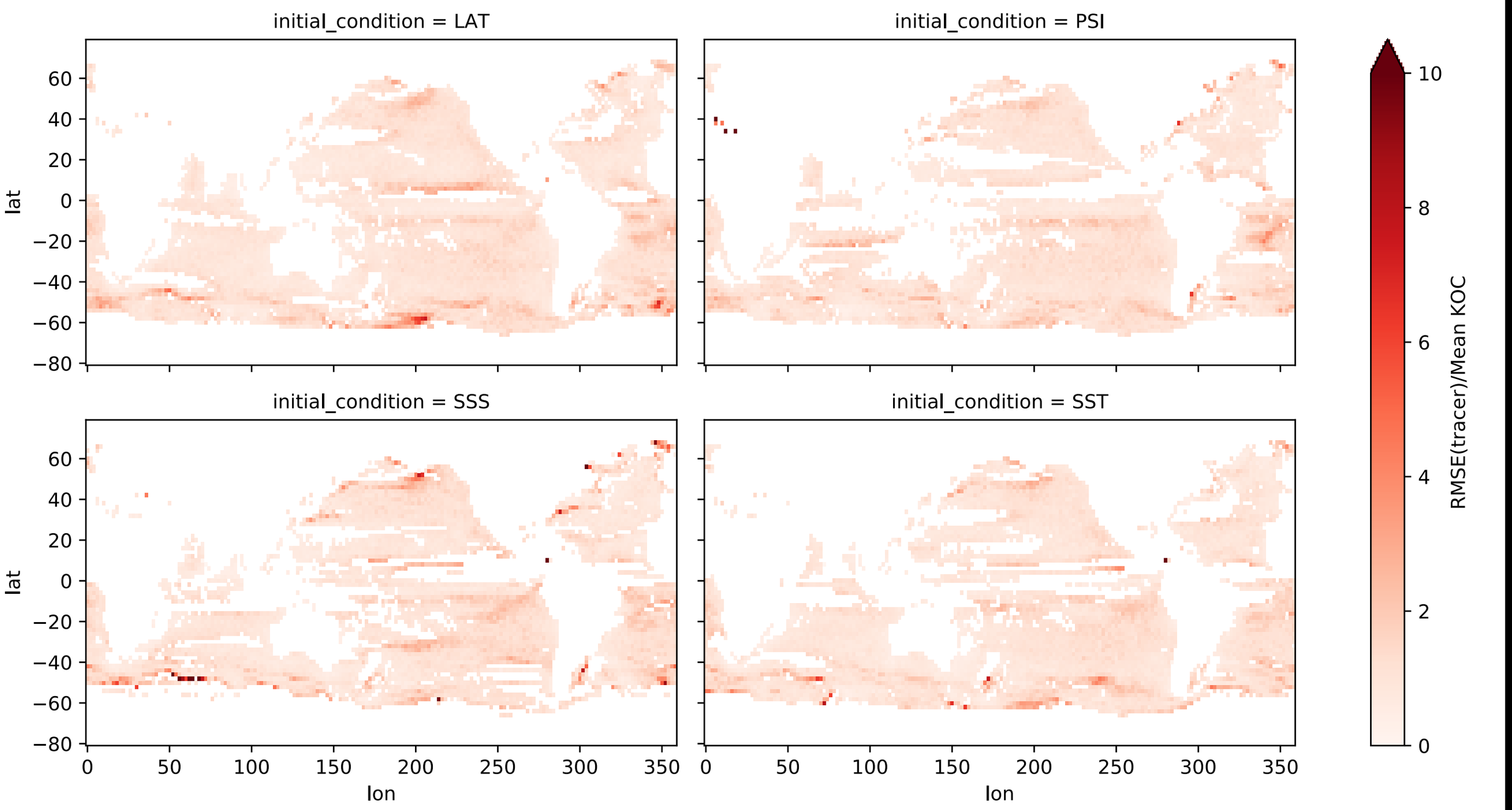




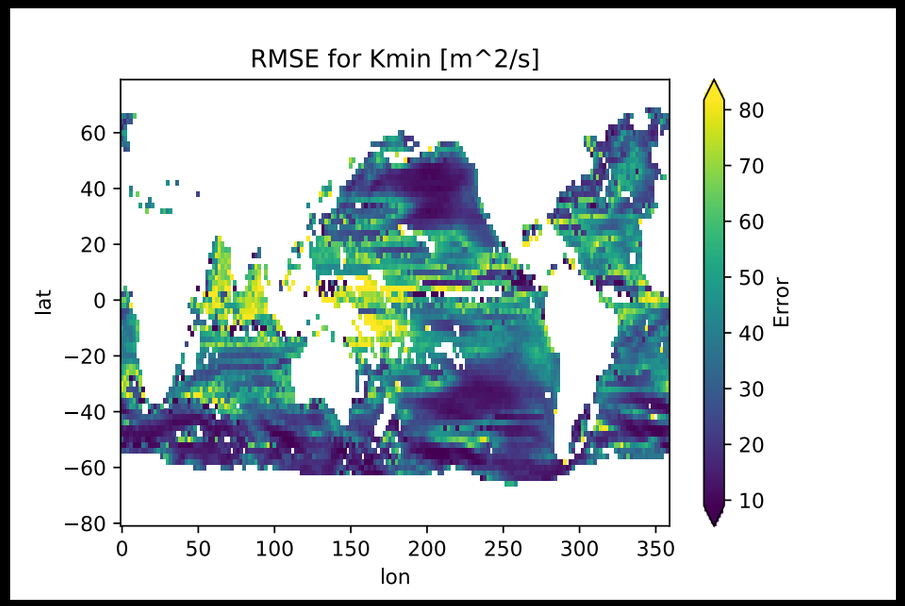


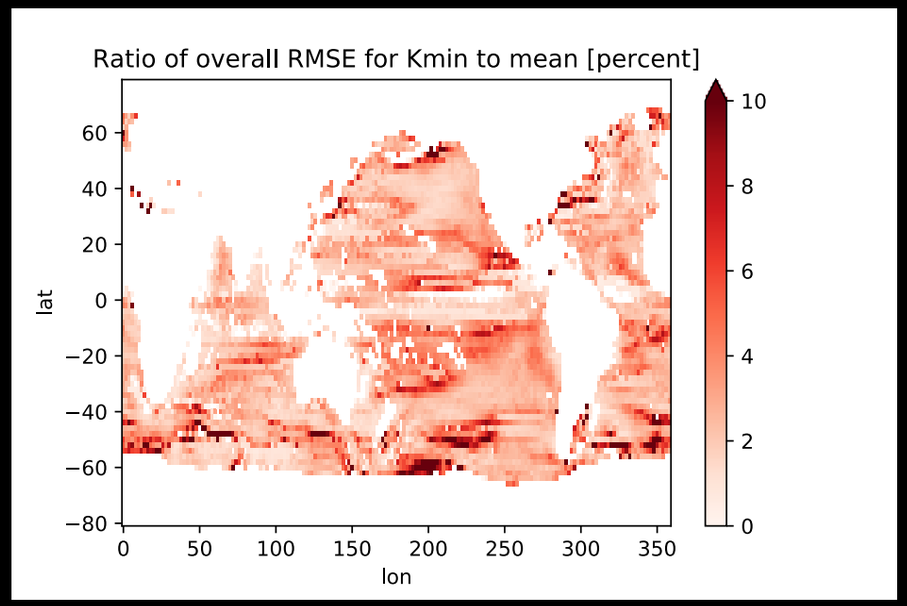


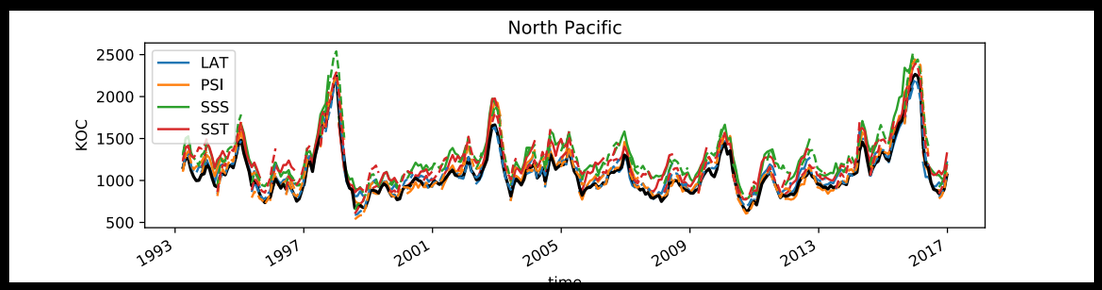
ERROR ESTIMATES (RESET)

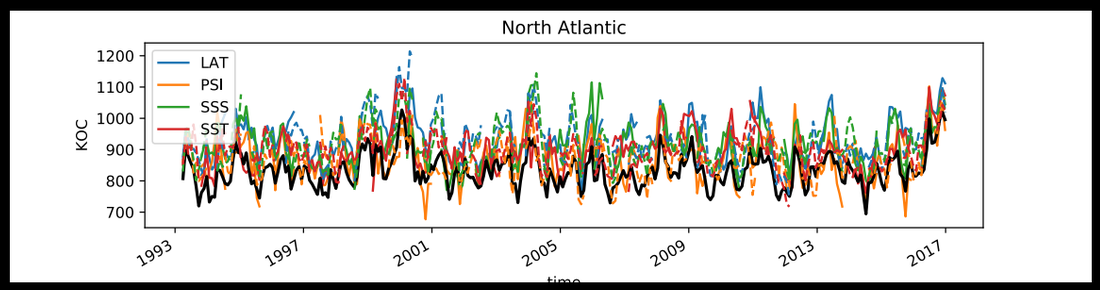


ERROR (INITIAL CONDITIONS)





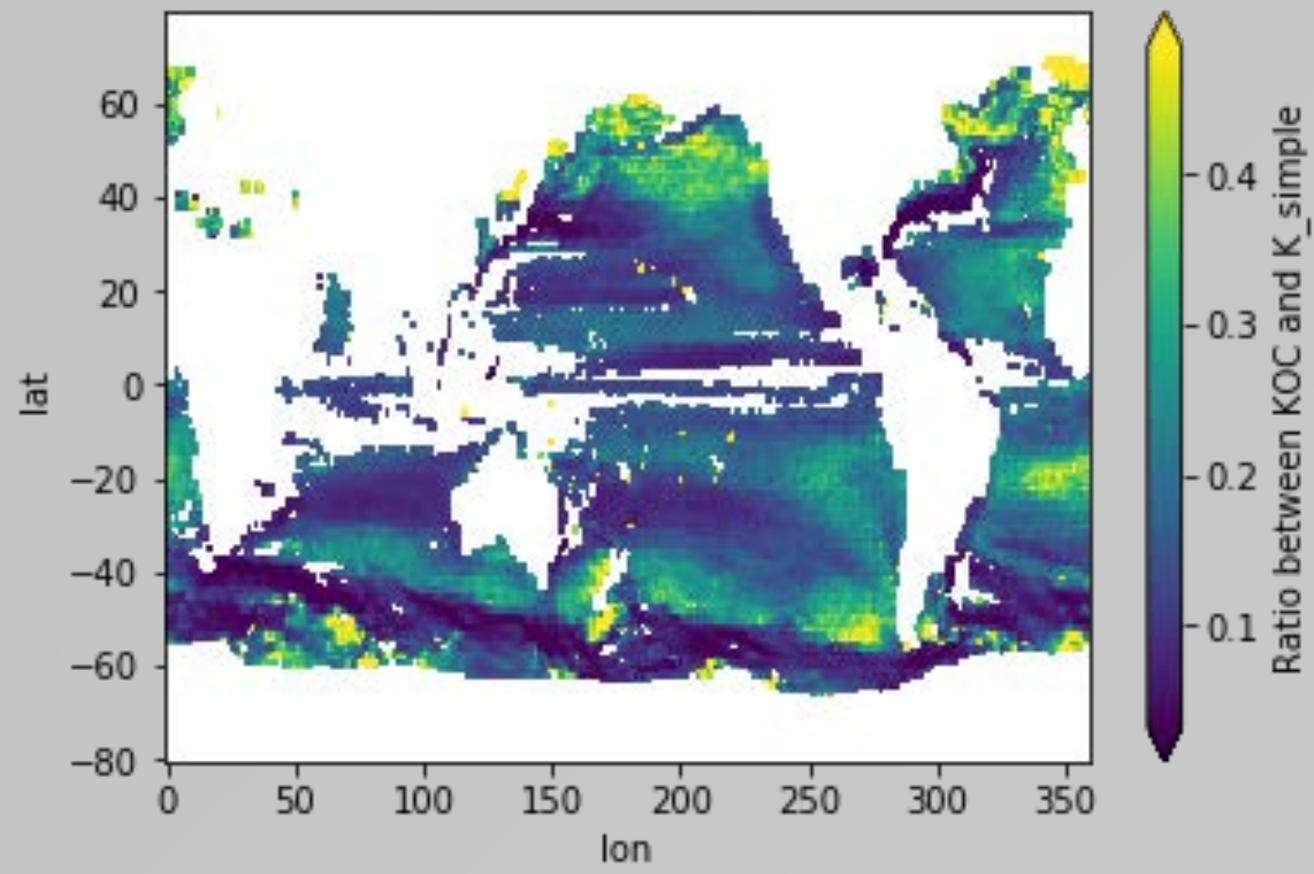




GRADIENT CRITERION

$$l_{mix} = \frac{\sqrt{\frac{(c')^2}{2}}}{|\nabla \bar{c}|}$$

$$l_{curv} = \frac{|\nabla \bar{c}|}{|\nabla^2 \bar{c}|}$$

$$1 >> cr = \frac{l_{mix}}{l_{curv}} = \frac{\sqrt{\frac{(c')^2}{2}}|\nabla^2 \bar{c}|}{|\nabla \bar{c}|^2}$$

MIXING EFFICIENCY?