What controls the variability of CO_2 fluxes in Eastern Boundary Upwelling Systems?

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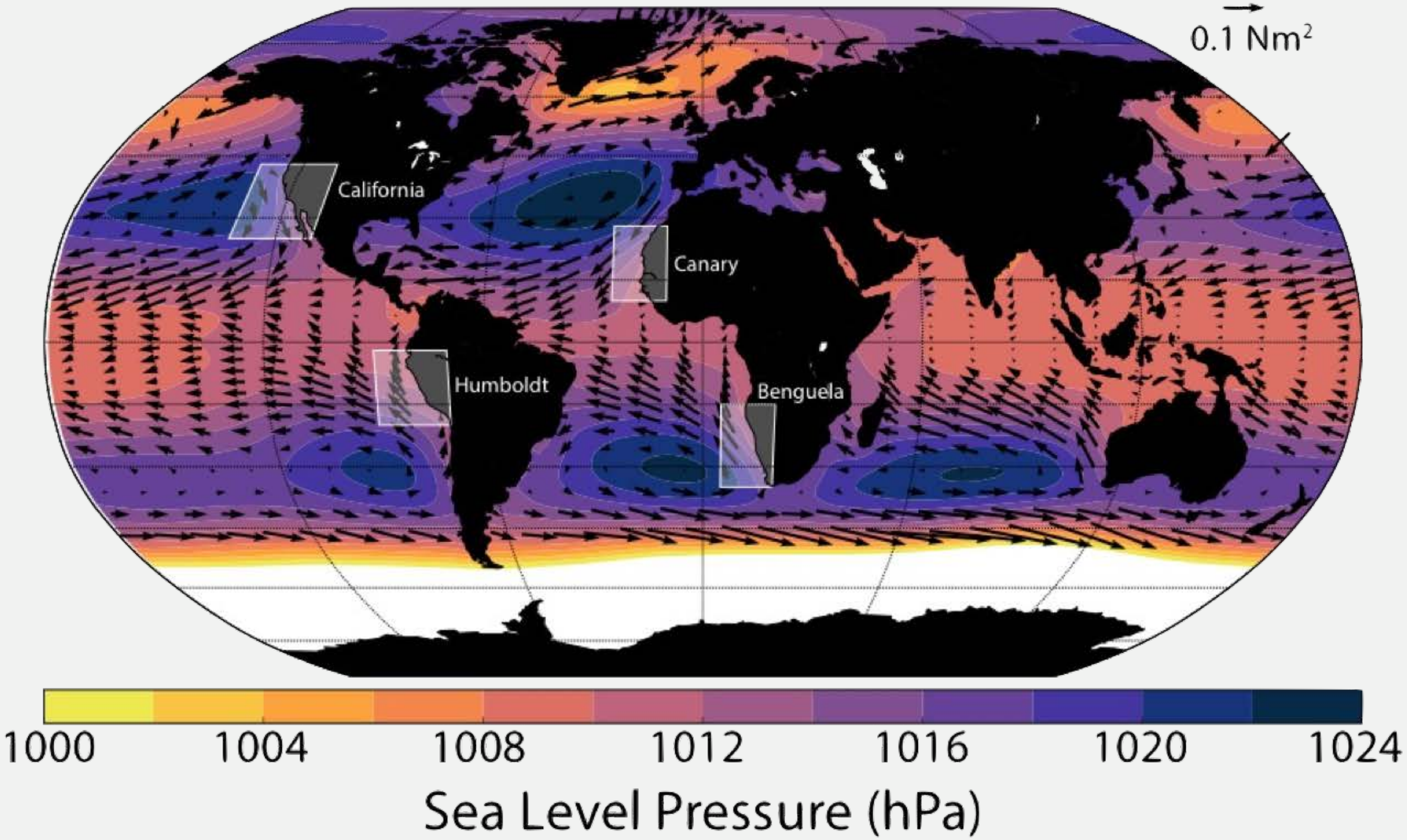
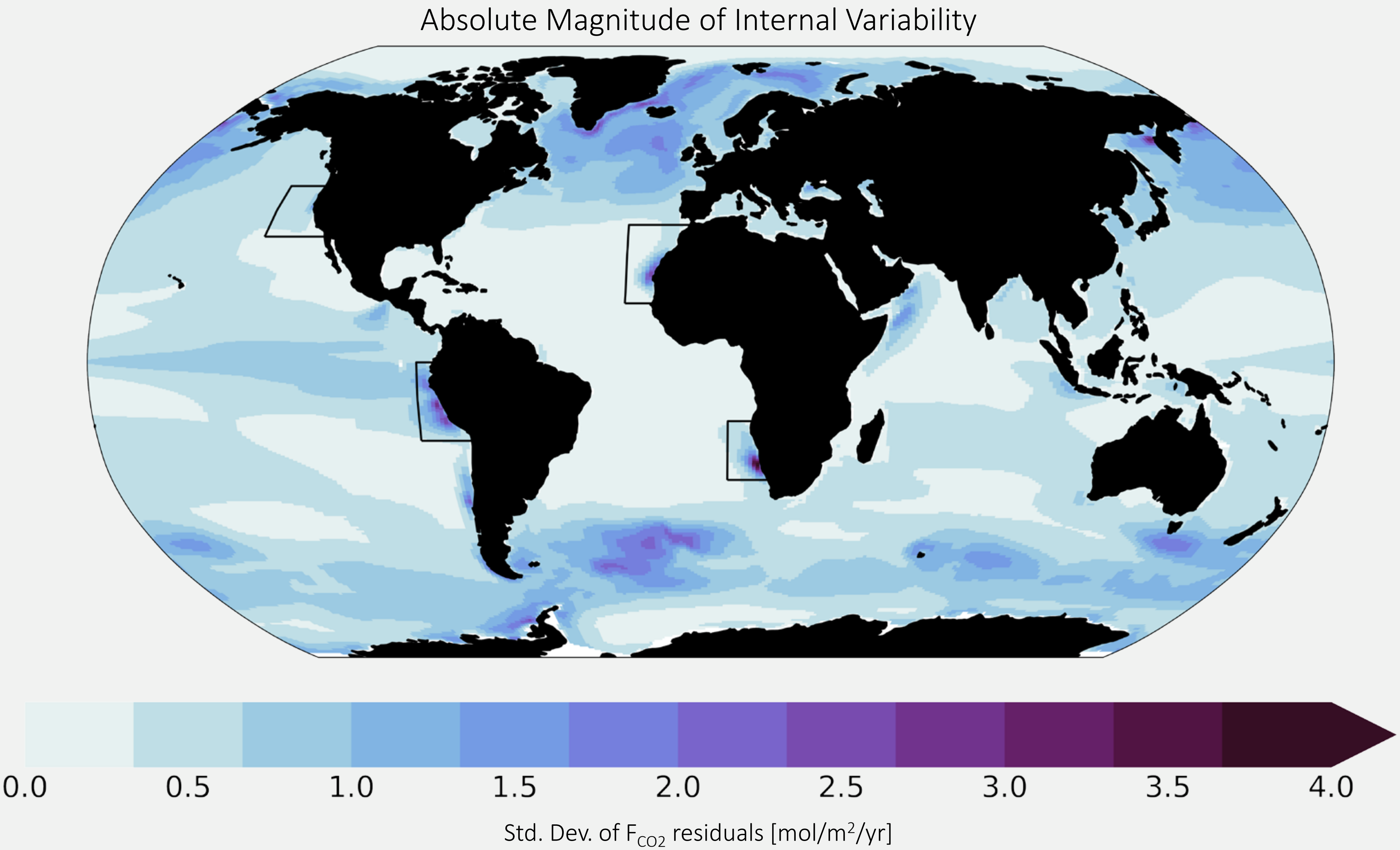
Eastern Boundary Upwelling Systems (EBUS) are highly productive regions characterized by coastally driven and curl-driven upwelling. This supplies the surface with nutrient- and carbon-enriched waters.

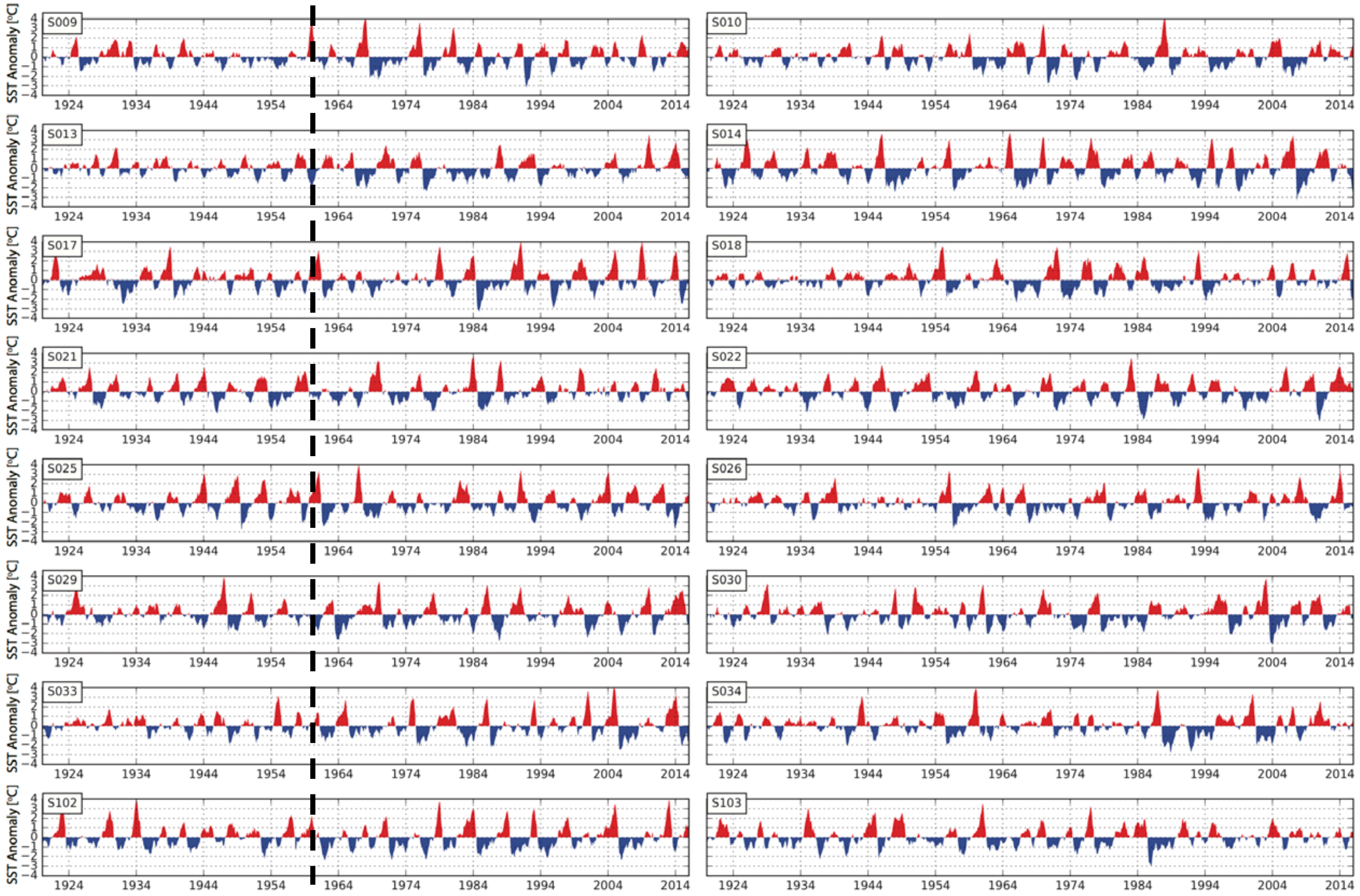


CO$_2$ fluxes in upwelling systems are characterized by significant internal variability that tends to be larger than the seasonal cycle.

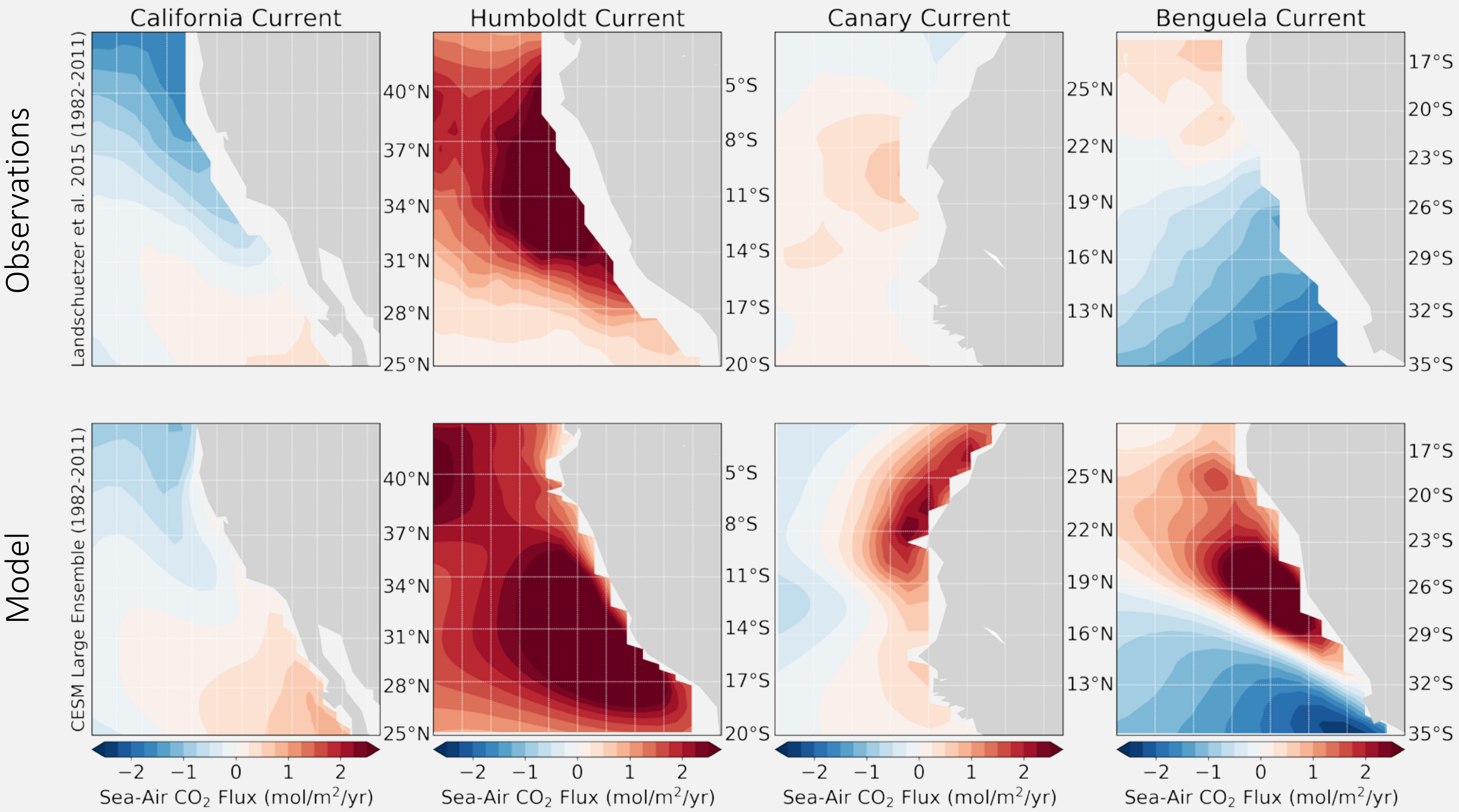


What controls this CO_2 flux variability?

The CESM Large Ensemble provides 34 independent simulations with a unique representation of the natural climate system.

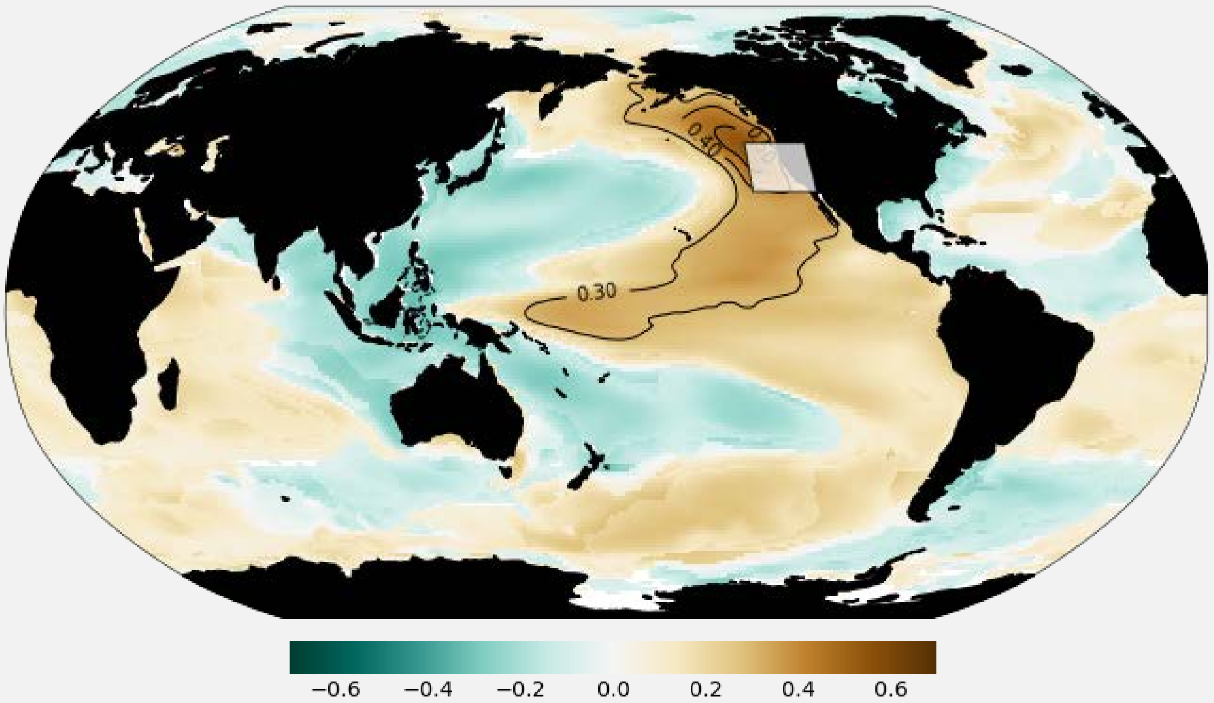


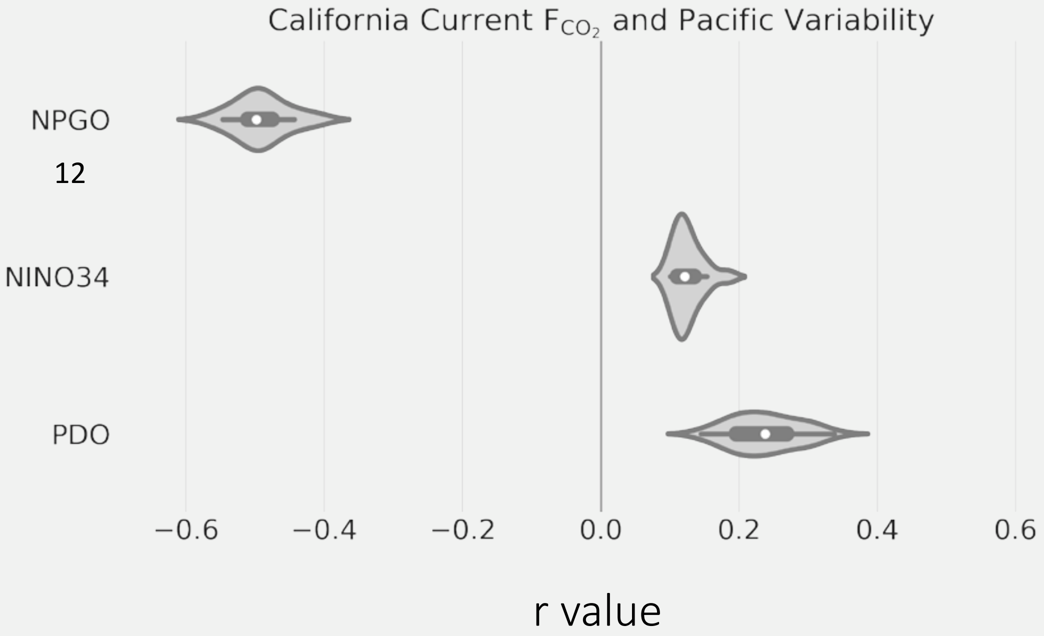
CESM-LENS captures the general characteristics of CO_2 fluxes in EBUS.



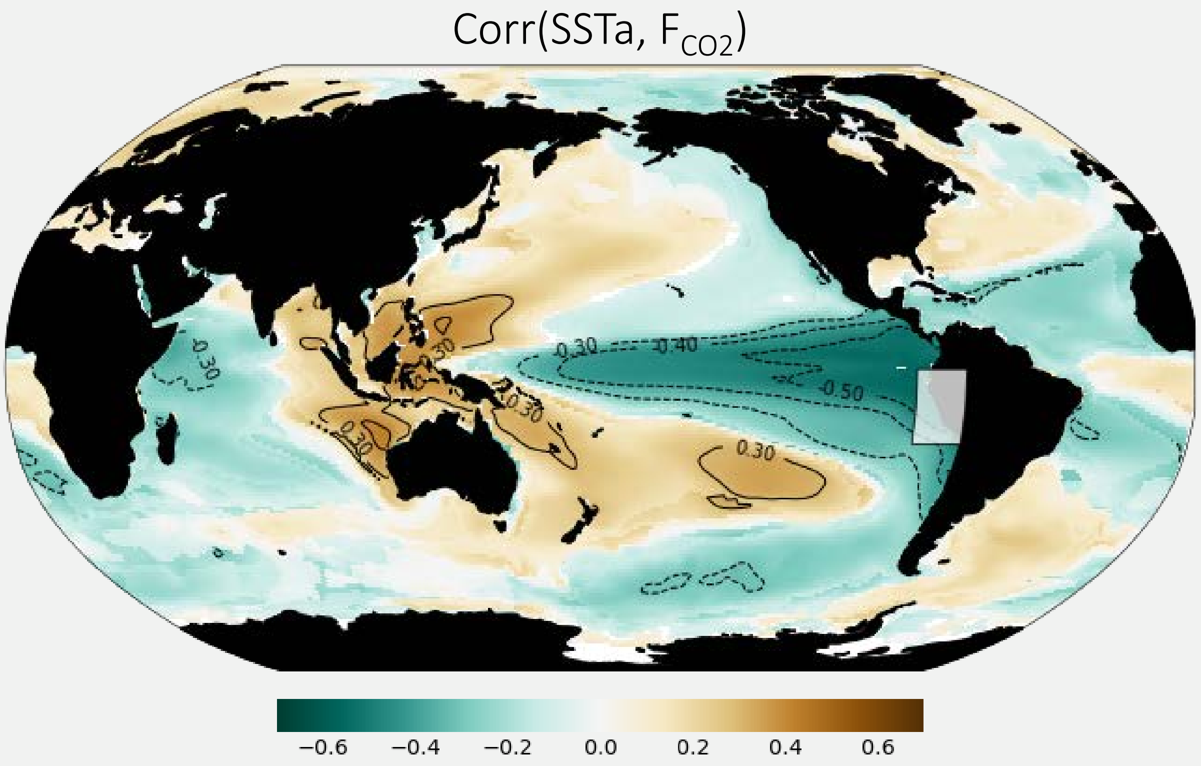
The North Pacific Gyre Oscillation (NPGO) is the primary driver of California Current variability.

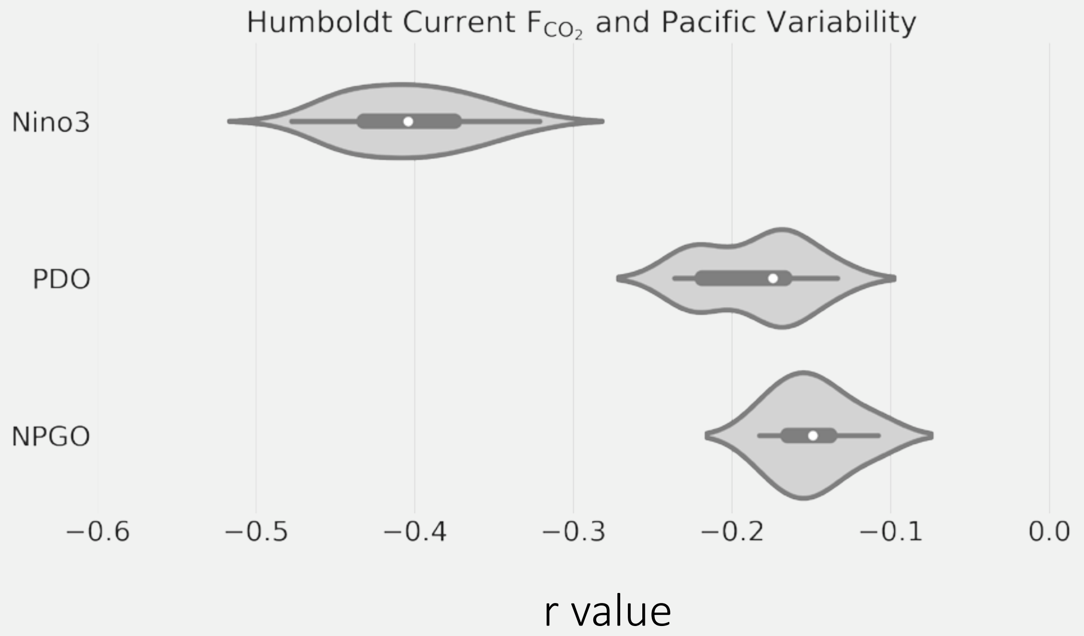
Corr(SSTa, F_{CO2})



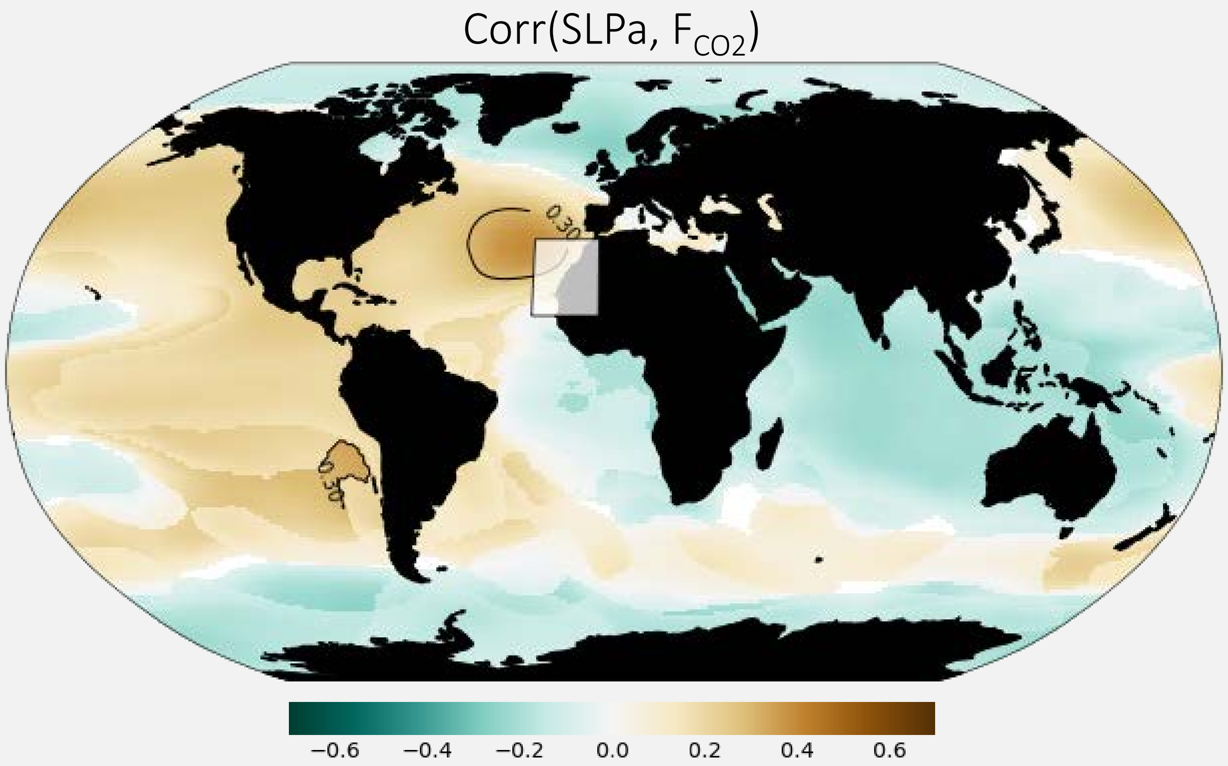


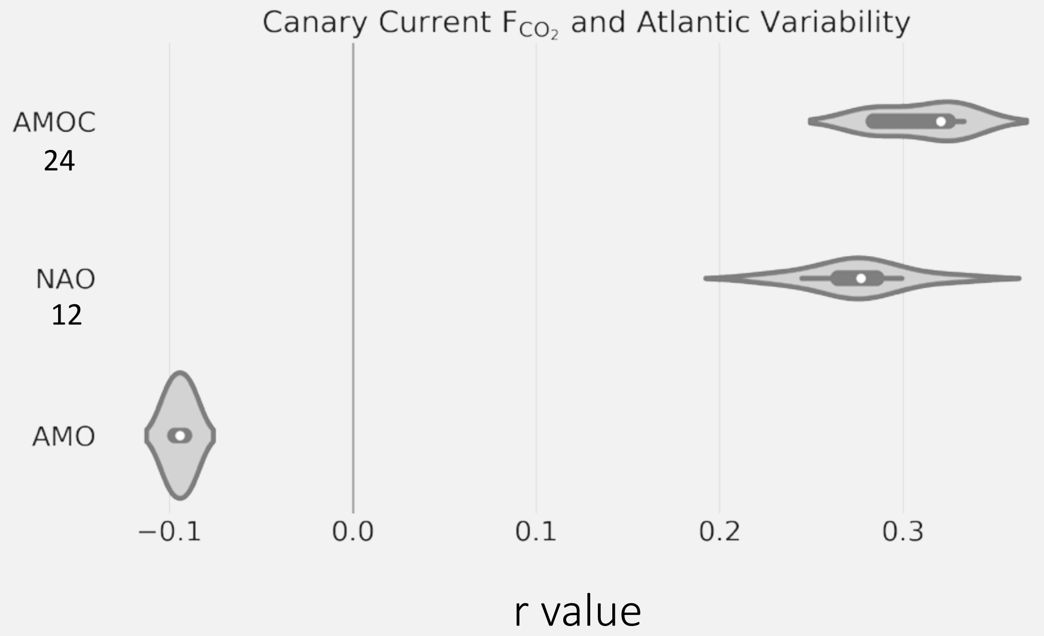
El Niño modulates CO_2 fluxes in the Humboldt Current.



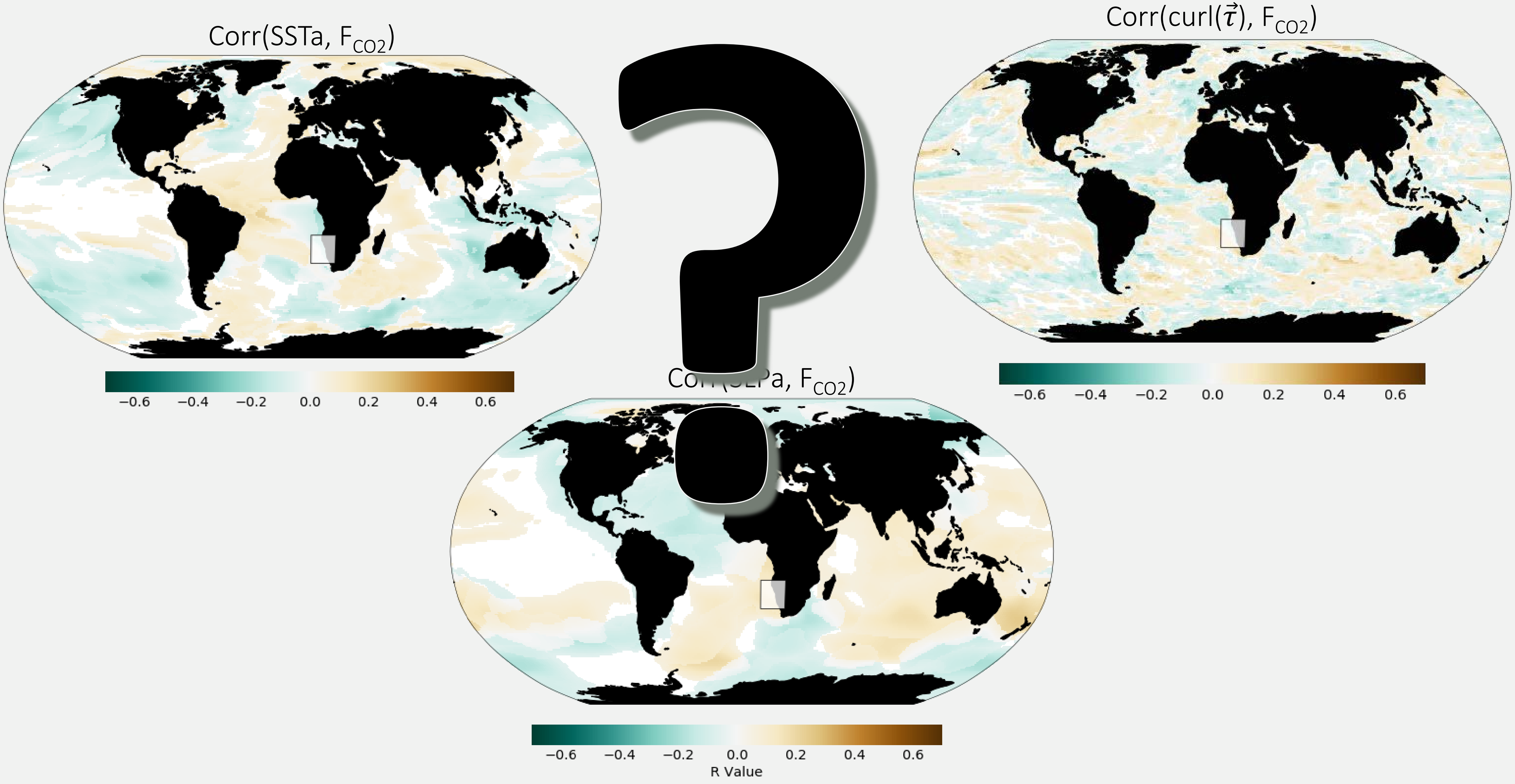


AMOC and the NAO control the variability of the Canary Current.





The Benguela Current remains a mystery.



What are the mechanisms that control the CO_2 flux anomalies?

CO_2 flux is complex and is driven by a myriad of factors, including ocean state, circulation, biology, and chemistry.

$$F_{CO_2} = k \cdot \left(pCO_2^{oc} - pCO_2^{atm}\right)$$

Gas transfer velocity

(Wind Speed)^2

pCO_2 gradient

↑SST

↑Salinity

↑Total Carbon

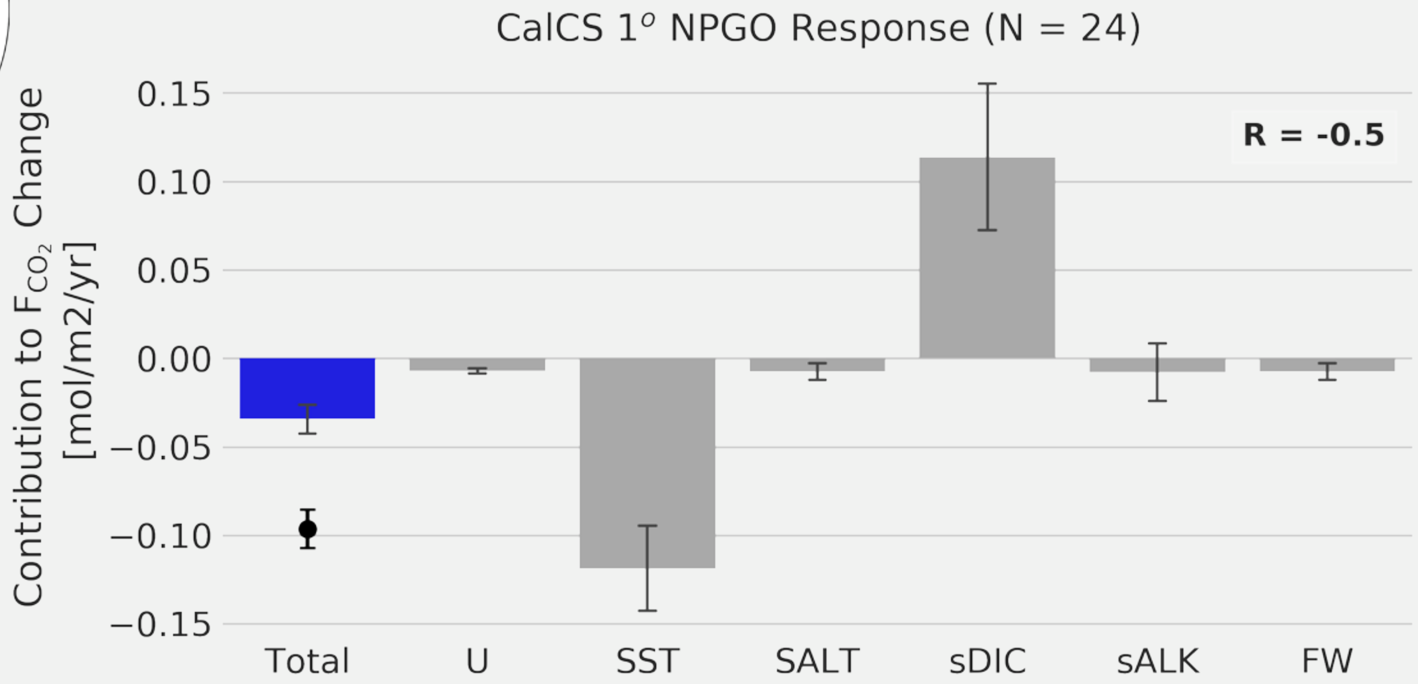
Alkalinity↓

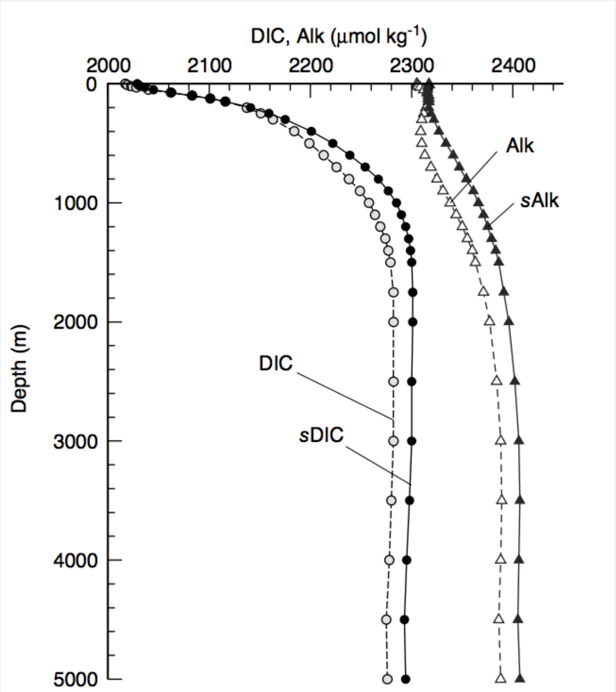
Freshwater

Anomalous outgassing occurs in the California Current during a positive NPGO. SST and smaller positive factors outweigh the reduction in DIC.

1 std. dev.

Direct ΔF_{CO2}

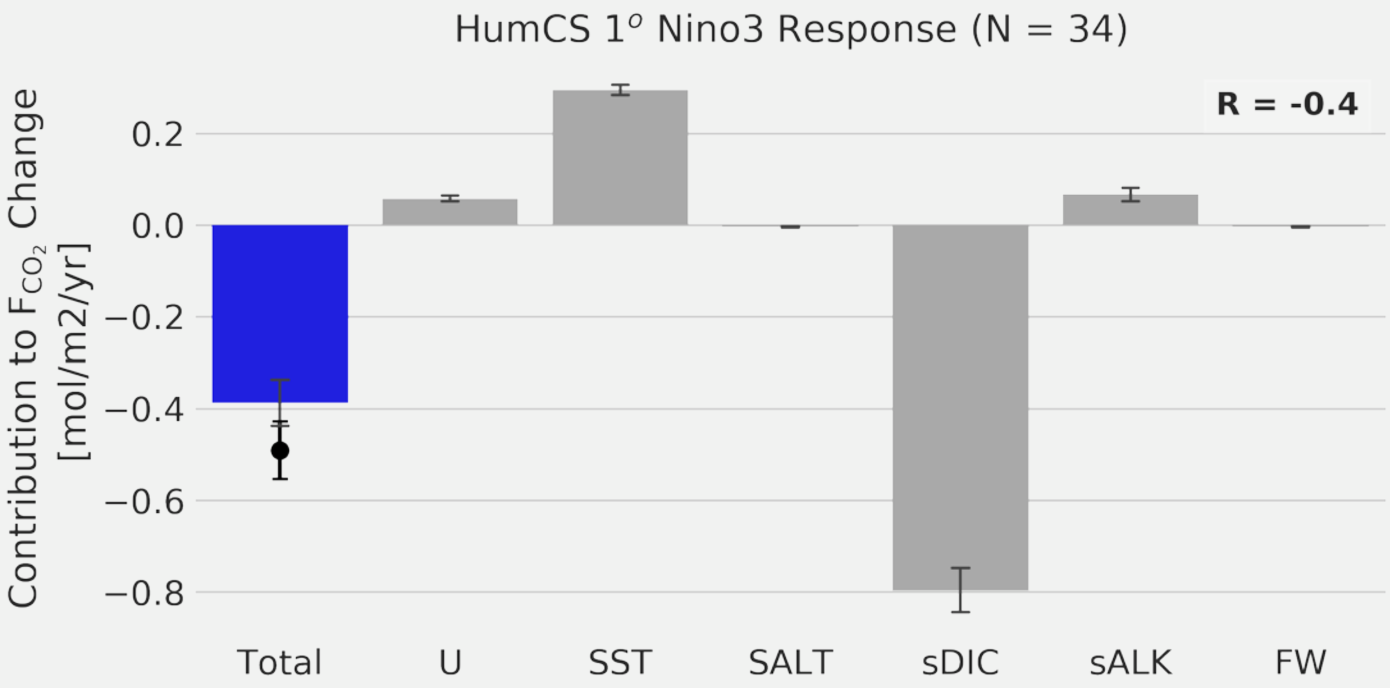




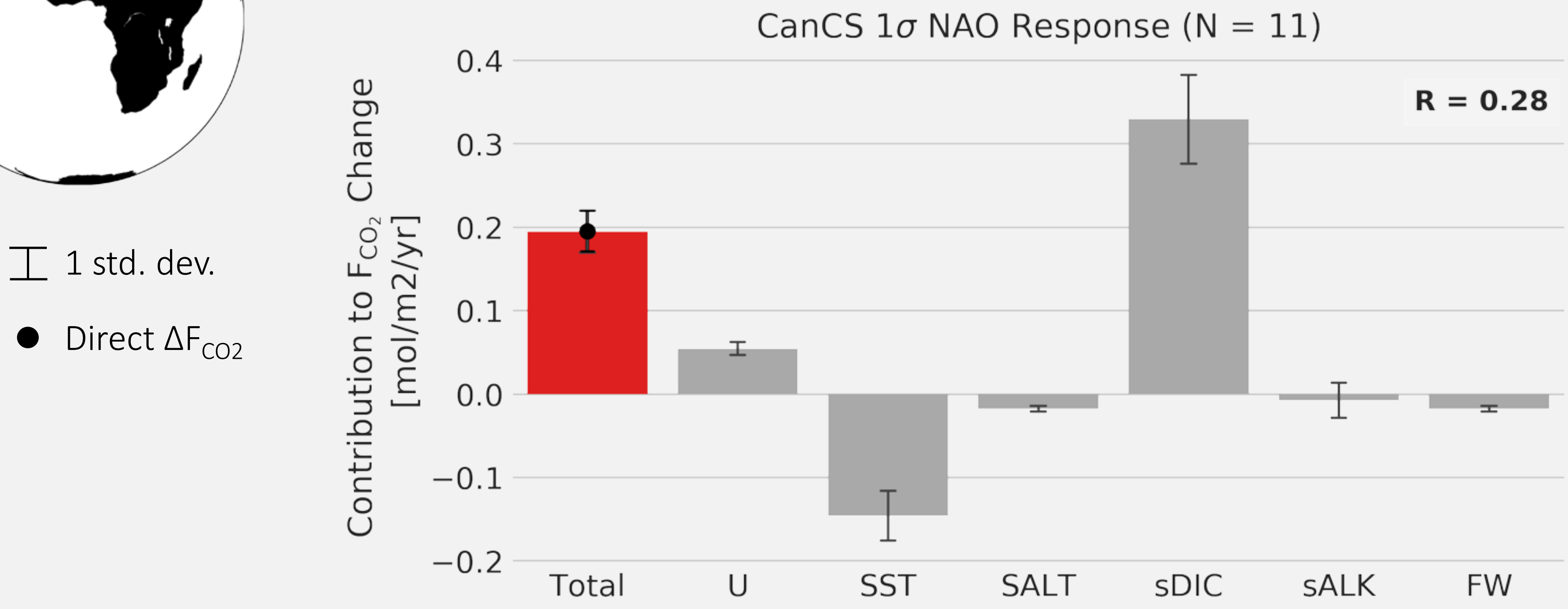
The Humboldt Current experiences anomalous uptake during El Niño. The large reduction in DIC is the dominating term.

1 std. dev.

● Direct ΔF_{CO2}



Anomalous outgassing in the Canary Current occurs during a positive NAO. Increased winds and the supply of DIC drive this change.



Conclusions

EBUS have significant internal variability in F_{CO2} relative to the coastal oceans and much of the global oceans. This internal variability tends to be larger than the seasonal cycle

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California Current F_{CO2} anomalies are most prominently driven by the NPGO (R = -0.5). Colder SSTs and smaller negative terms outweigh DIC enhancement to promote anomalous uptake during positive events.

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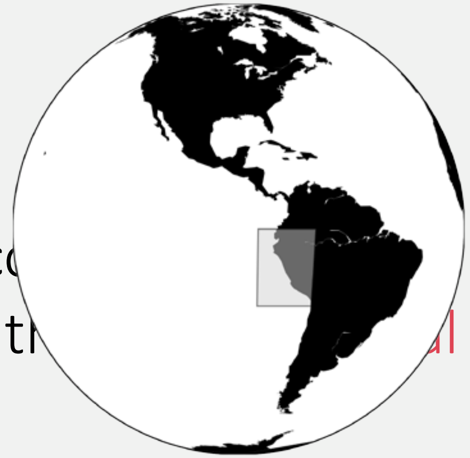

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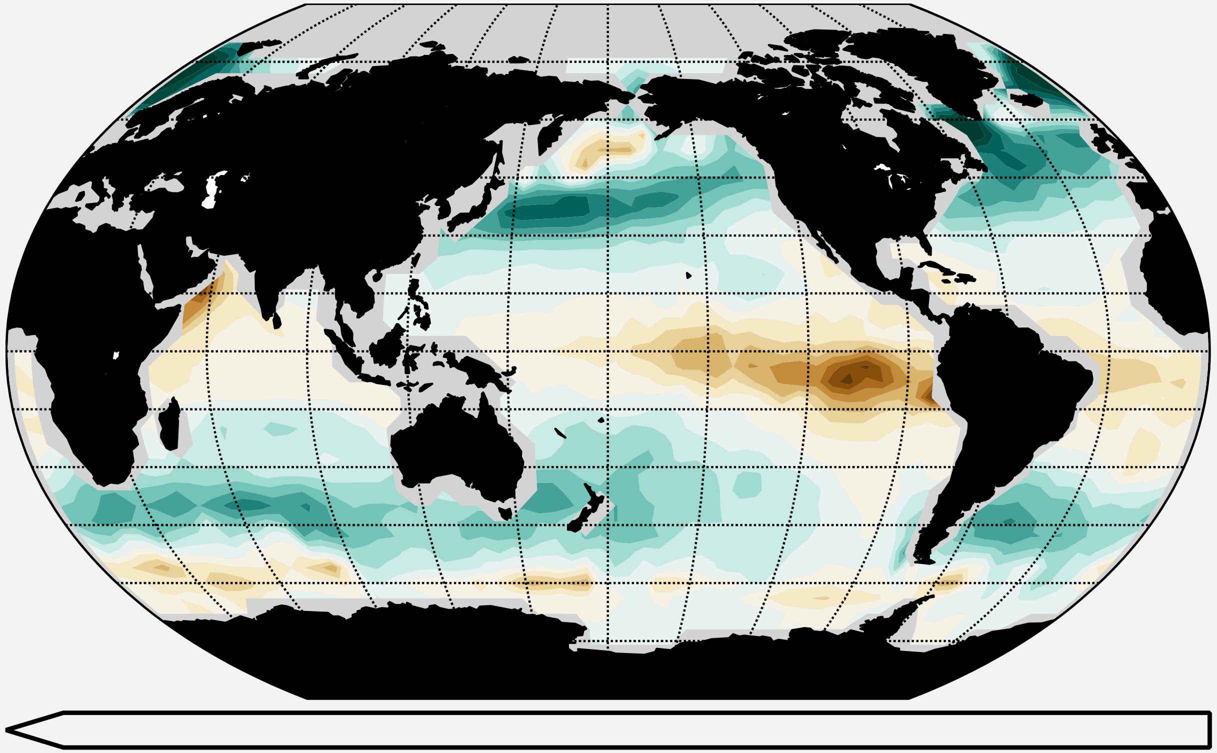
Humboldt Current anomalies are modulated by ENSO (R = -0.42). Large reductions in DIC cause anomalous uptake during El Niño.

Canary Current anomalies are produced by the NAO (R = 0.28) and AMOC (R = 0.31). A strong Azores High supplies more DIC to the system, causing anomalous outgassing.

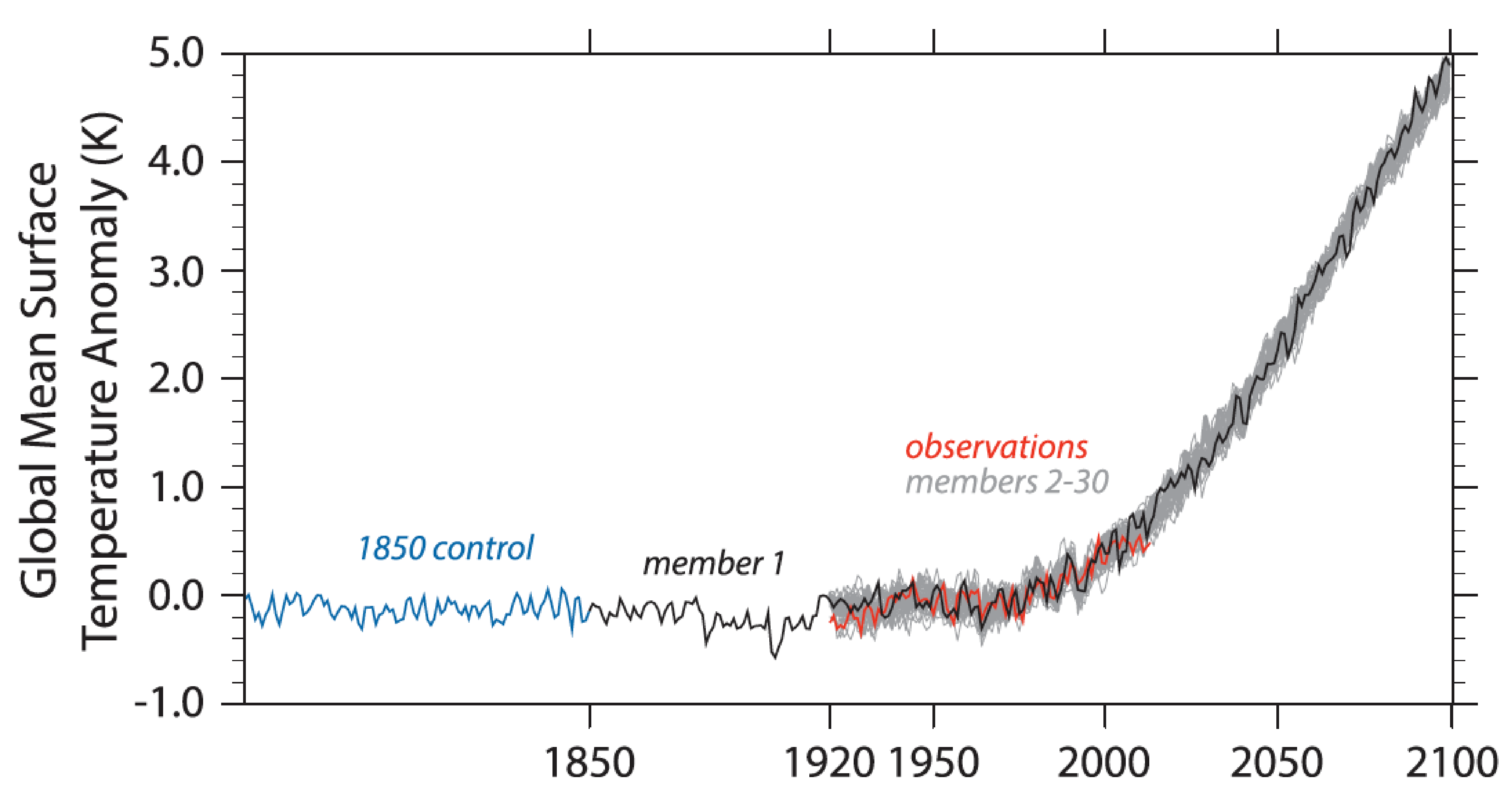
Supplemental

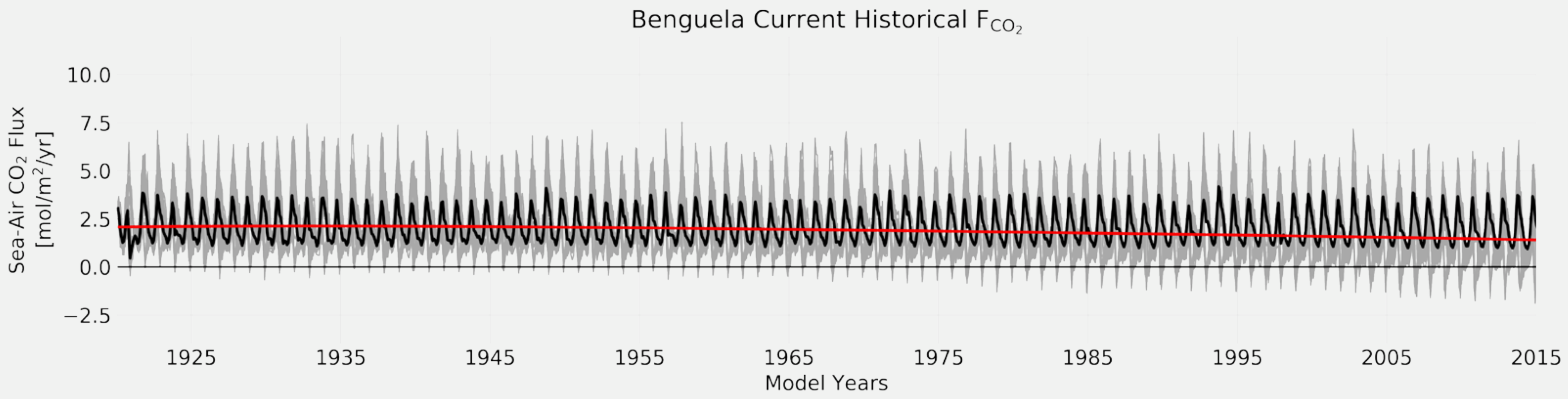
Regional variability in surface ocean pCO_2 drives carbon fluxes between the ocean and atmosphere.



O_2 Flux [mol/m^2/yr]

The CESM Large Ensemble is generated from round-off perturbations to the initial conditions, leading to an ensemble that approximates internal variability.





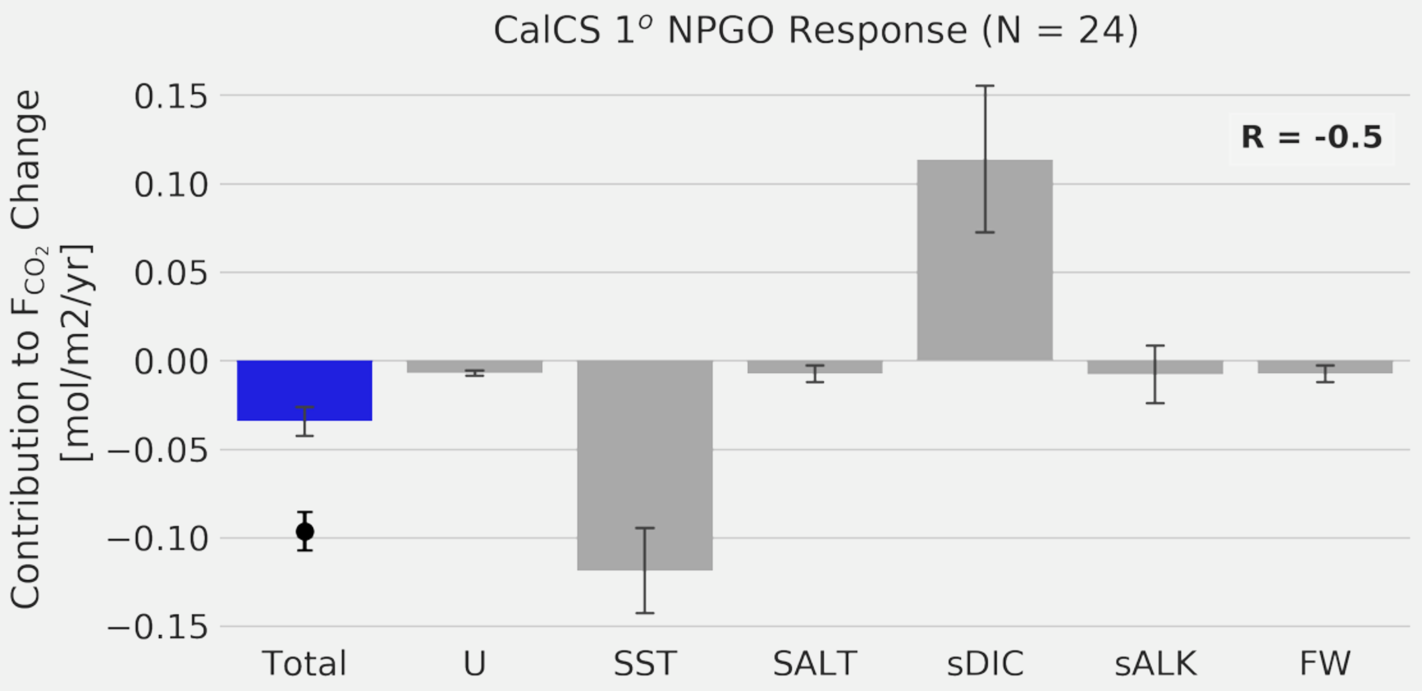
Benguela Current Historical F_{CO_2}
Sea-Air CO_2 Flux [mol/m^2/yr]
10.0
7.5
5.0
2.5
0.0
−2.5
1925
1935
1945
1955
1965
1975
1985
1995
2005
2015
Model Years

$$\Delta F = \frac{\partial F}{\partial U}\Delta U + \frac{\partial F}{\partial T}\Delta T + \frac{\partial F}{\partial S}\Delta S + \frac{\partial F}{\partial DIC}\frac{S}{S_0}\Delta sDIC + \frac{\partial F}{\partial ALK}\frac{S}{S_0}\Delta sALK + \frac{\partial F}{\partial FW}\Delta FW$$

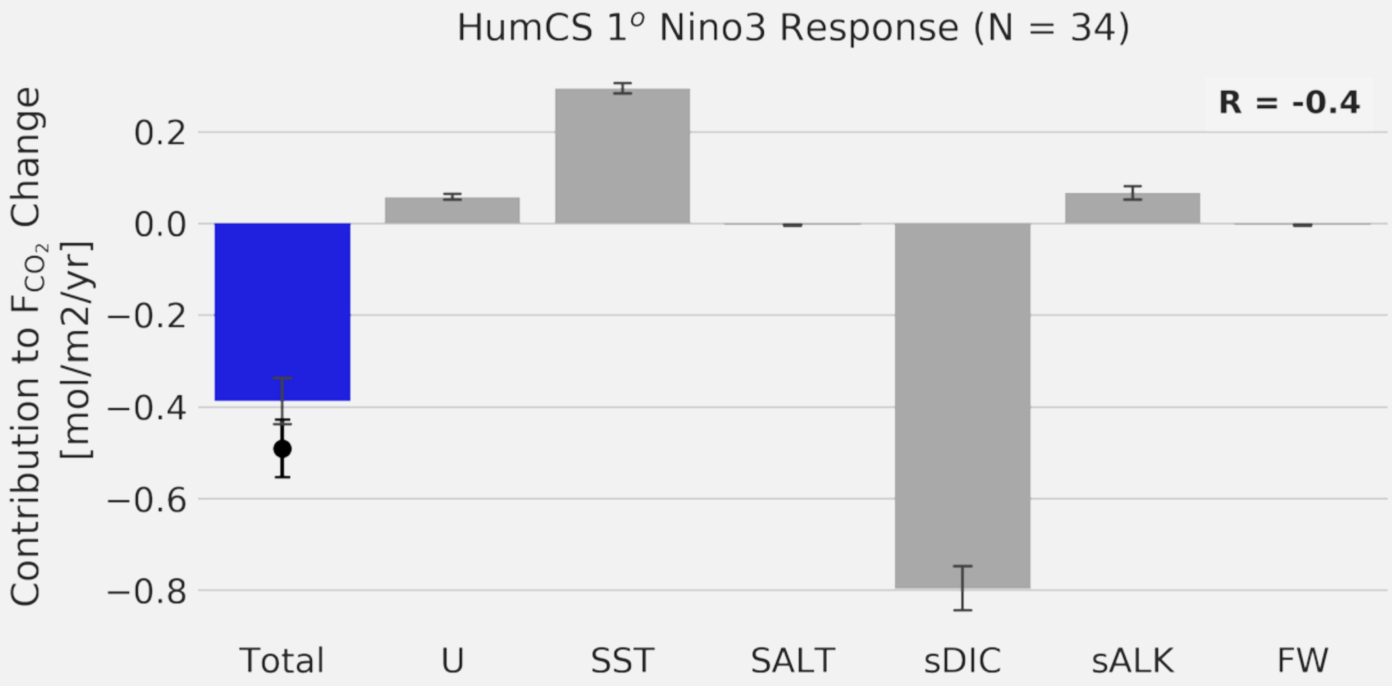
Regression of CO_2 flux onto climate predictor.

Empirical or model-derived sensitivity.

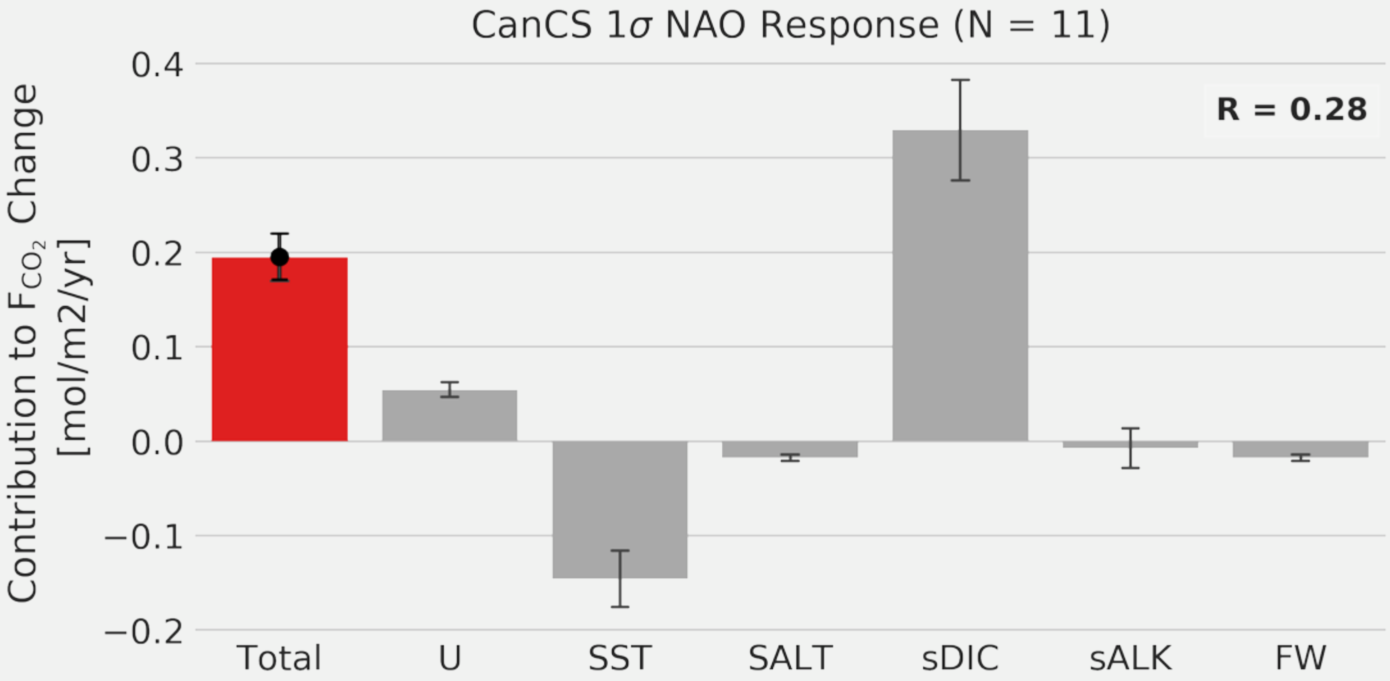
Regression of variable onto climate predictor.



	Sensitivity	Δ	Term
U	-	+	-
SST	+	-	-
SALT	+	-	-
sDIC	+	+	+
sALK	-	+	-



	Sensitivity	Δ	Term
U	+	+	+
SST	+	+	+
SALT	+	-	-
sDIC	+	-	-
sALK	-	-	+



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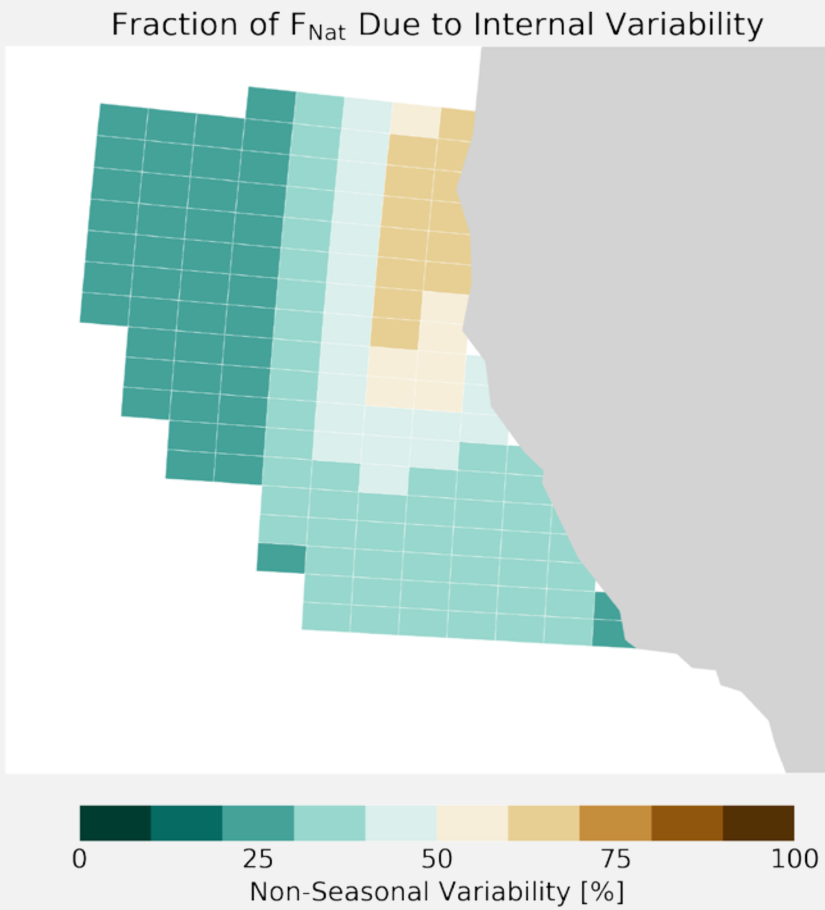
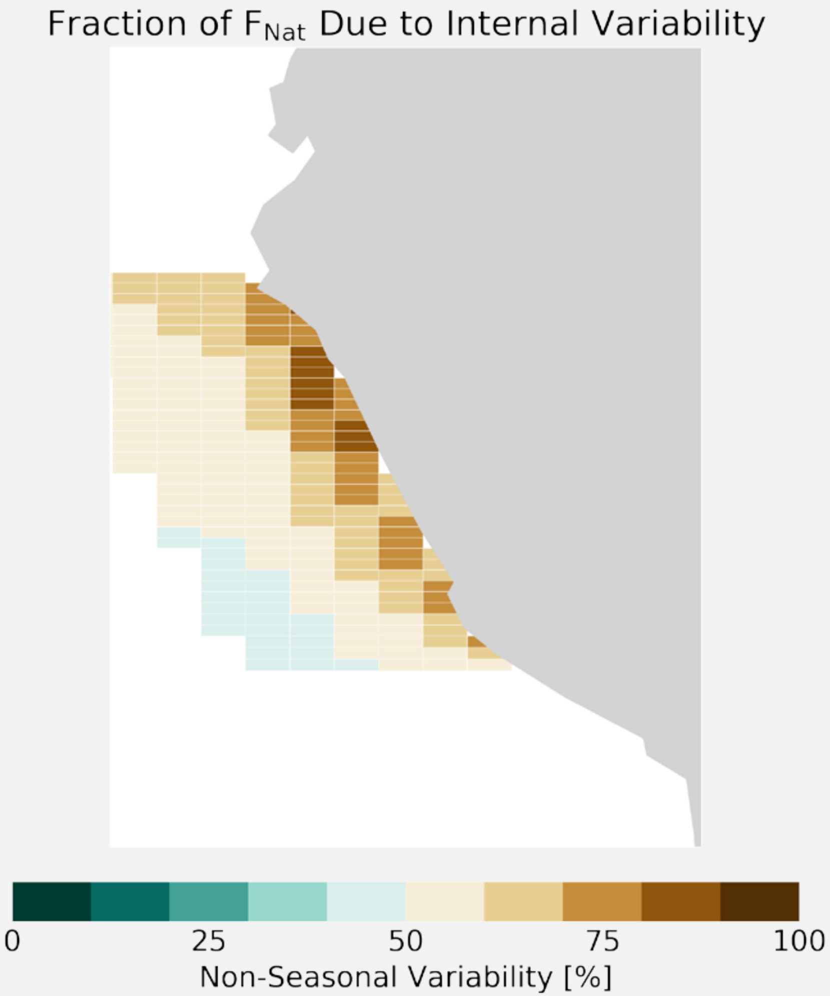

Fraction of F_{Nat} Due to Internal Variability
0
25
50
75
100
Non-Seasonal Variability [%]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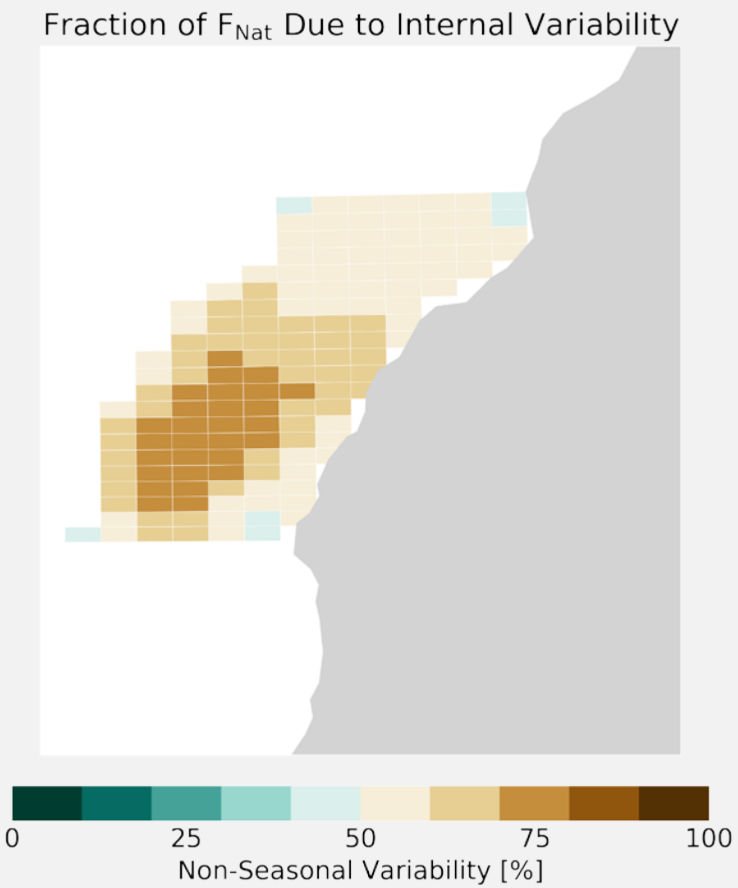

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