Do Clouds Affect Ocean Carbon Uptake?

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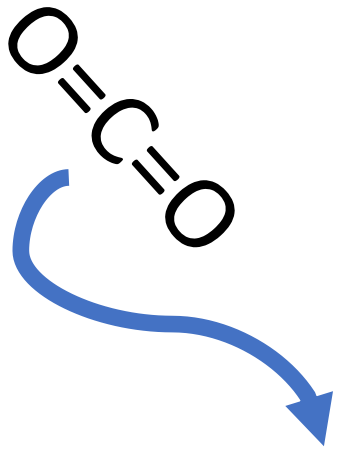
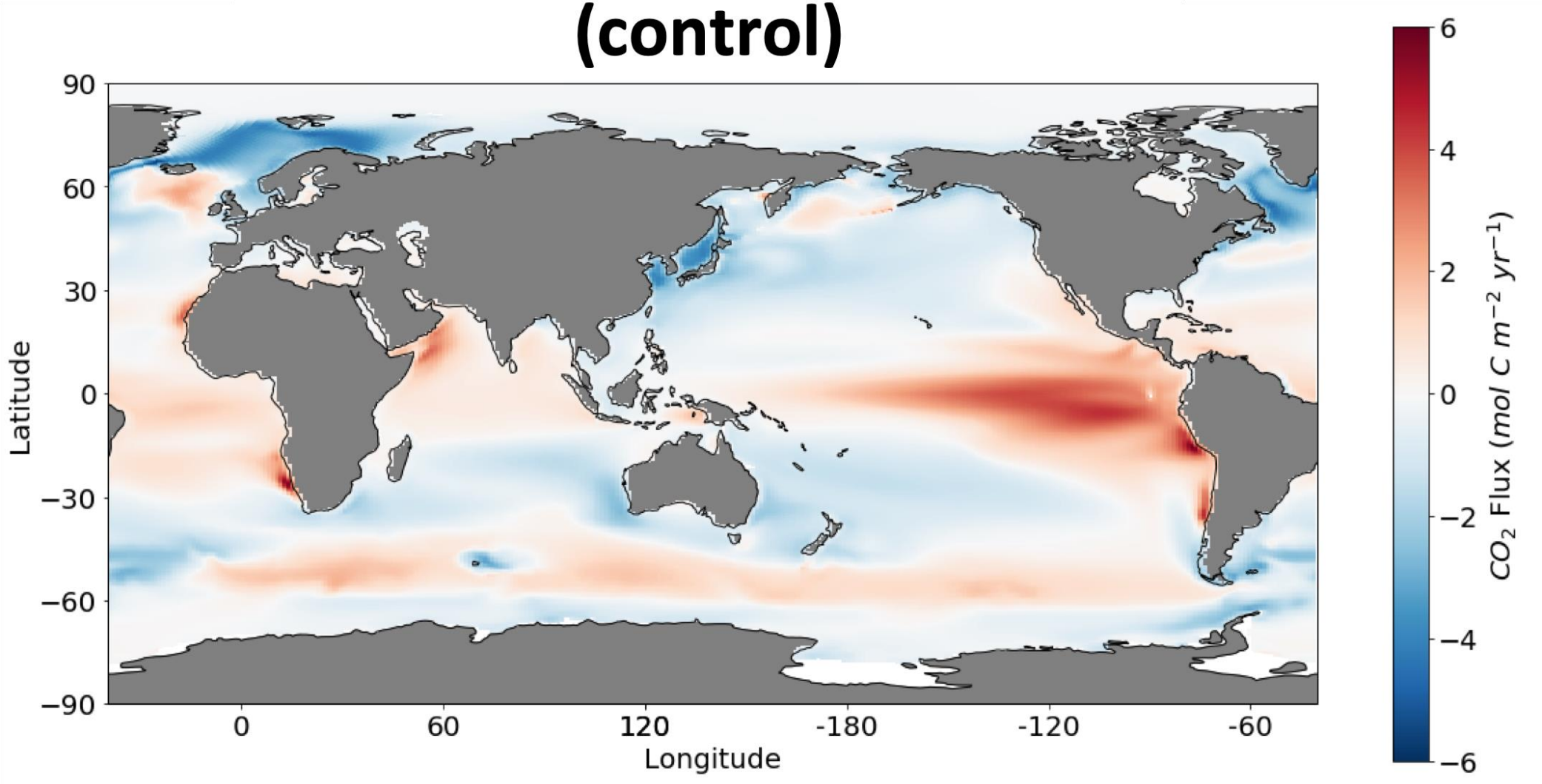


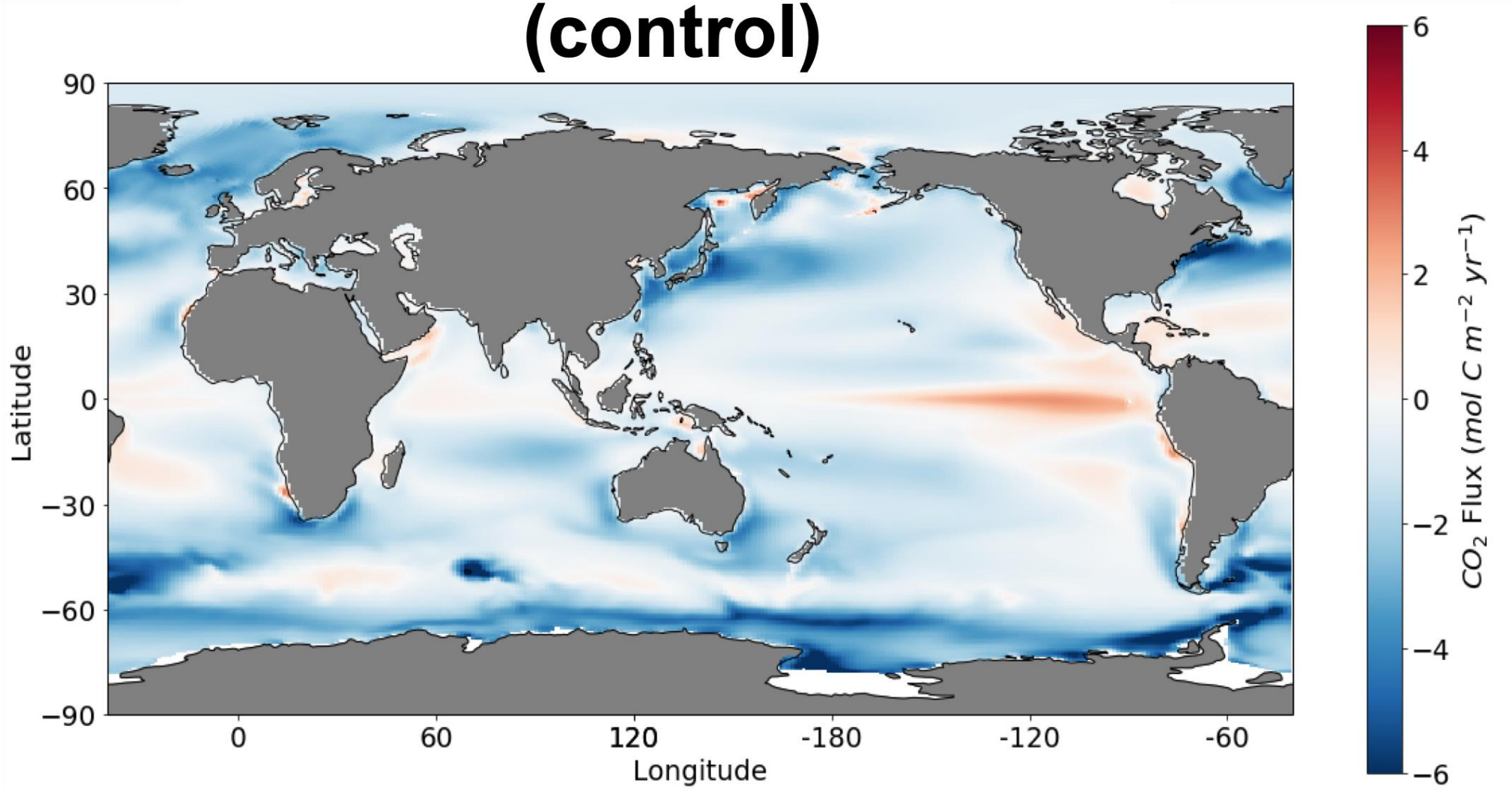
$CO_2 \leftrightarrow CO_3^{2-}$

(yes, they do!)

Preindustrial sea-air CO_2 flux (control)



End-of-century sea-air CO_2 flux (control)



Drivers of Sea-Air CO_2 Flux, φ

$$\phi = k([CO_2]_{ocn} - [CO_2]_{atm})$$

Causes of surface disequilibrium ($[CO2]_{oc} \neq [CO2]_{atm}$):

1) Surface heating or cooling
2) Biology (photosynthesis or respiration)
3) Circulation

Effects on the gas exchange velocity, k :

1) Wind stress increases k by increasing turbulent mixing.
2) Temperature can affect k by changing the viscosity of water.

Global Climate Impacts of Fixing the Southern Ocean Shortwave Radiation Bias in the Community Earth System Model (CESM)

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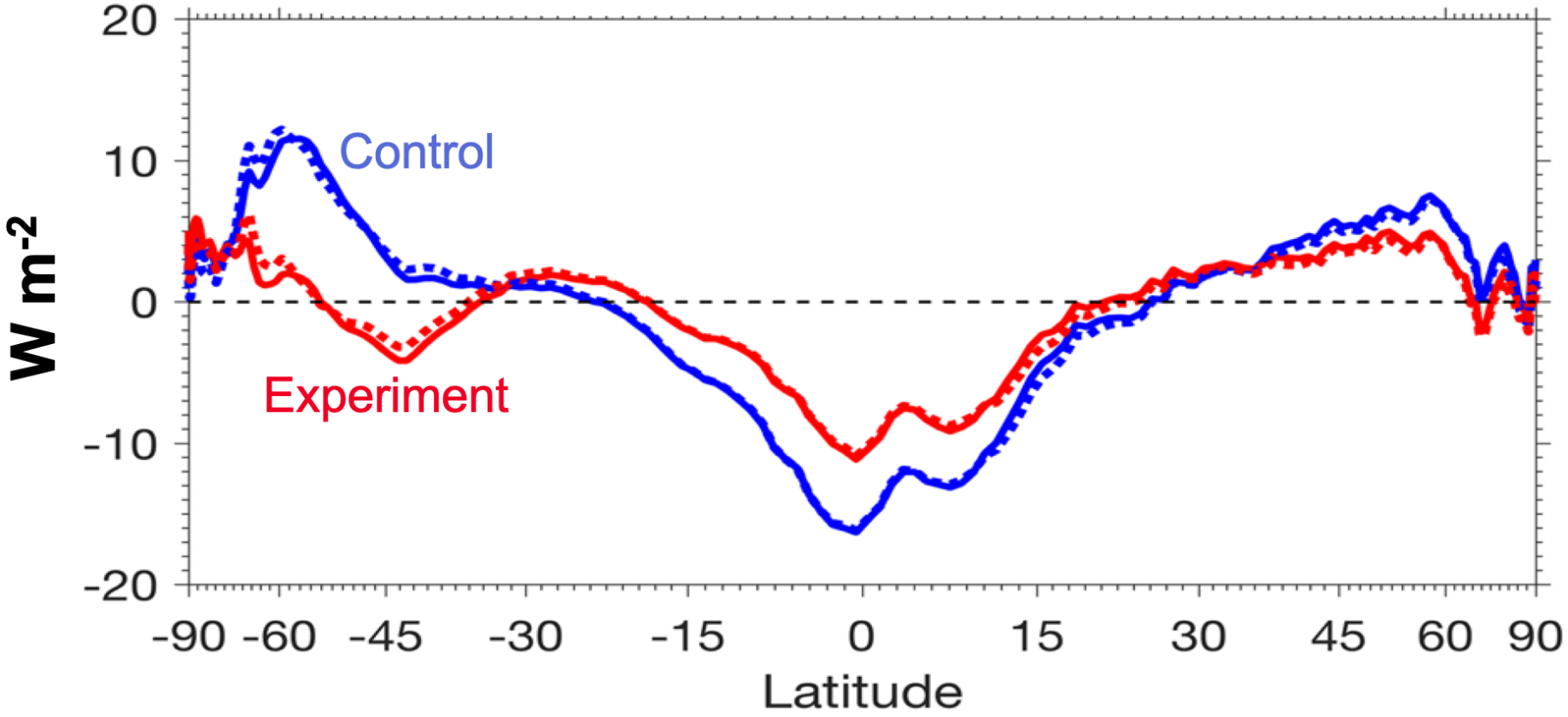
ABSTRACT

A large, long-standing, and pervasive climate model bias is excessive absorbed shortwave radiation (ASR) over the midlatitude oceans, especially the Southern Ocean. This study investigates both the underlying

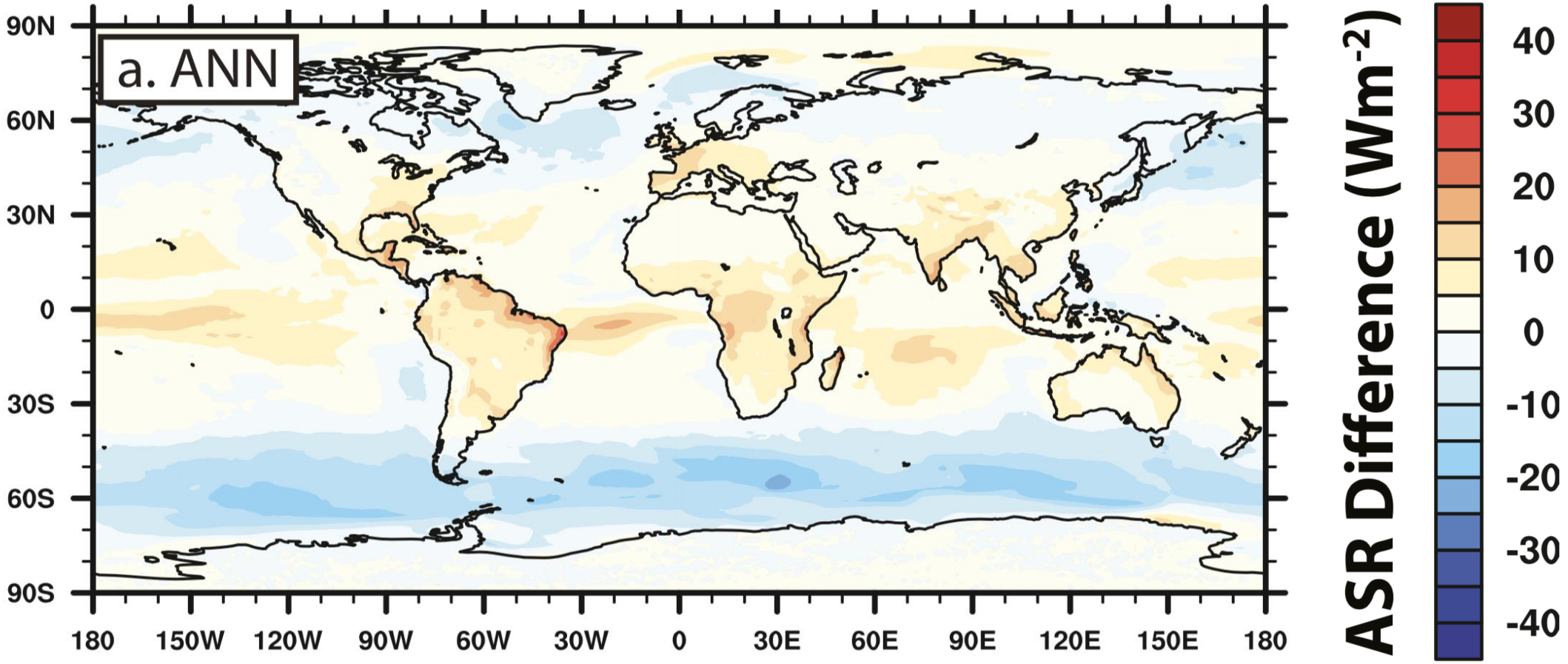
The Modeling Experiment

Absorbed Solar Radiation at the Surface Relative to Satellite Observations



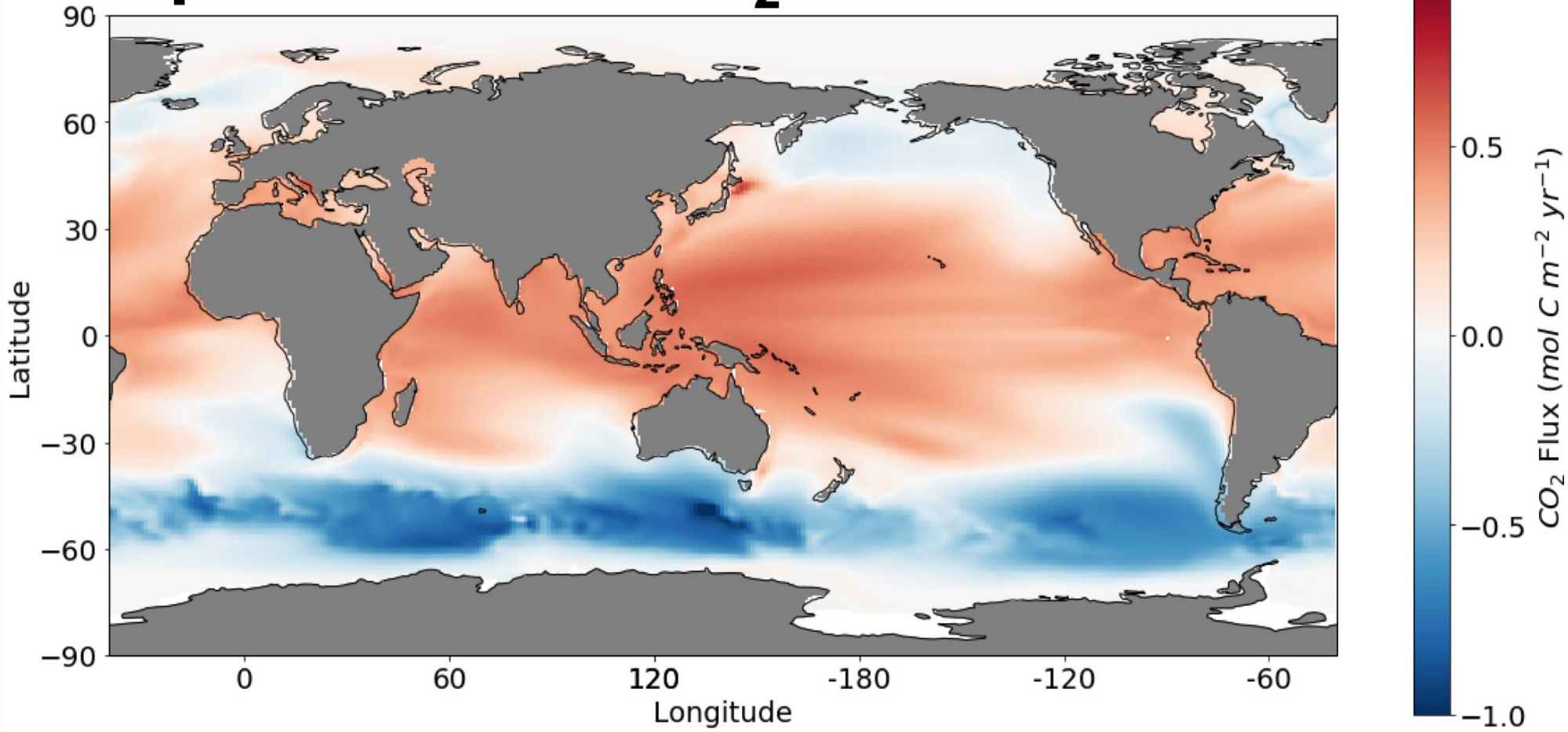
Frey and Kay 2017
Kay et al. 2016

Difference in solar radiation absorbed at the surface (experiment – control)

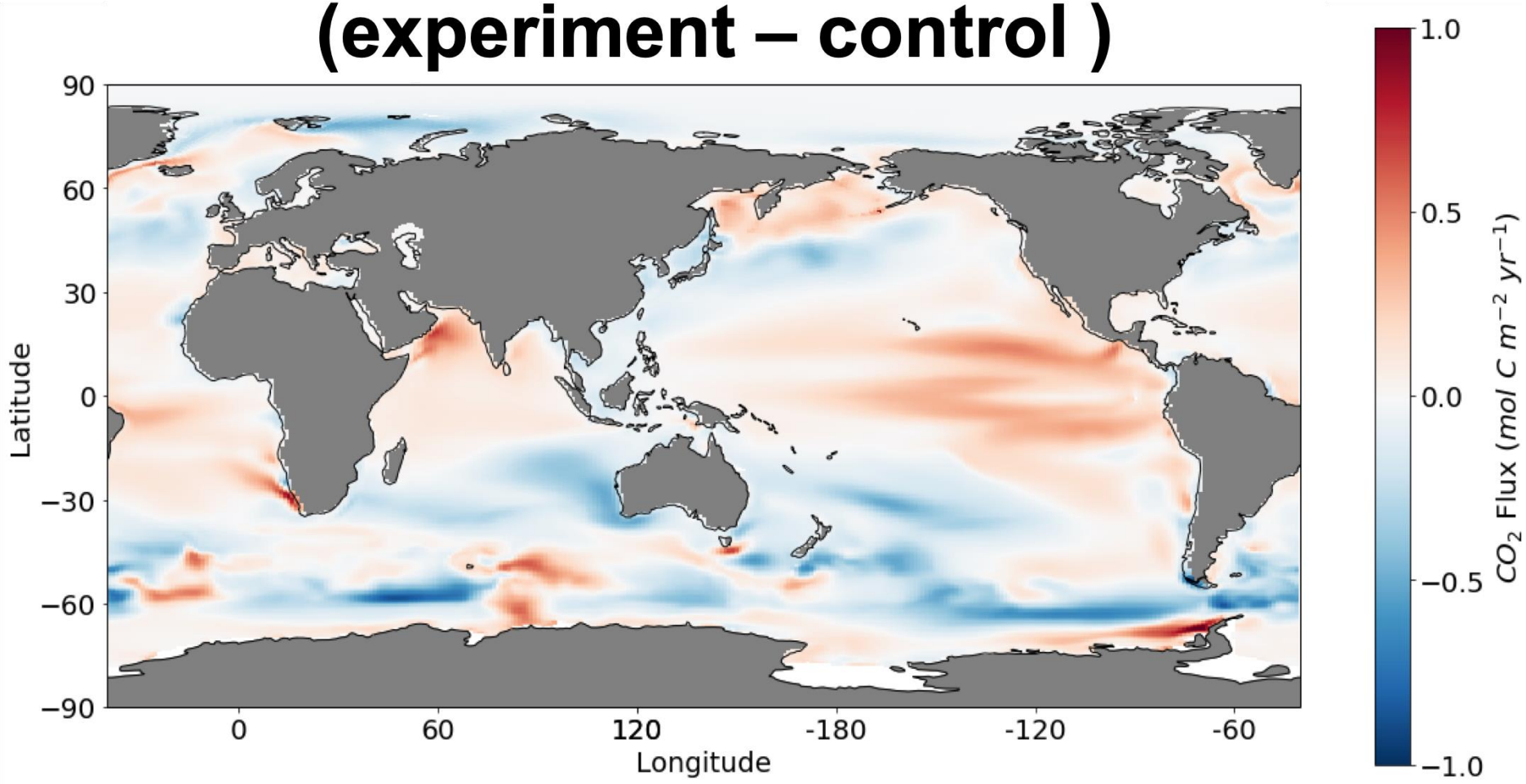


Kay et al. 2016

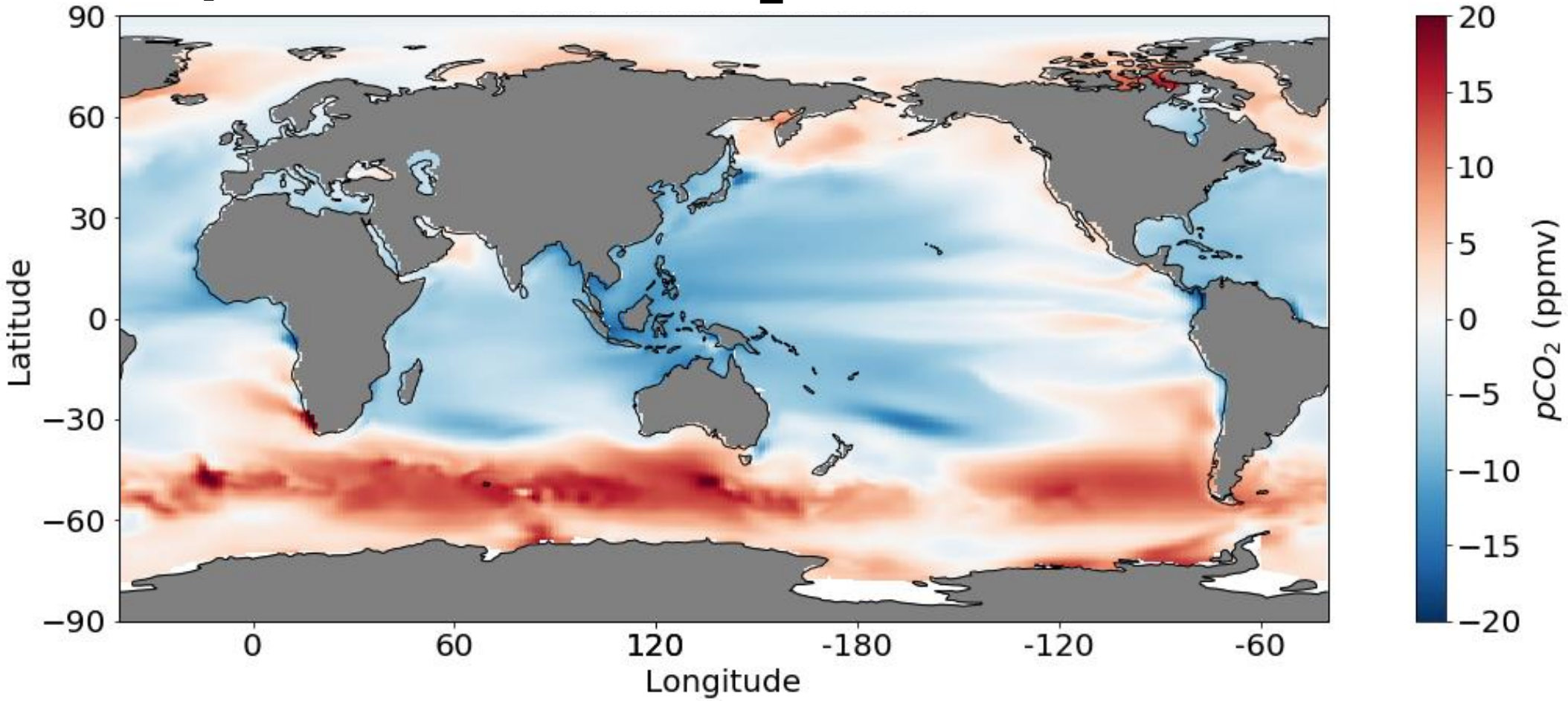
Thermal component of the preindustrial CO_2 flux difference



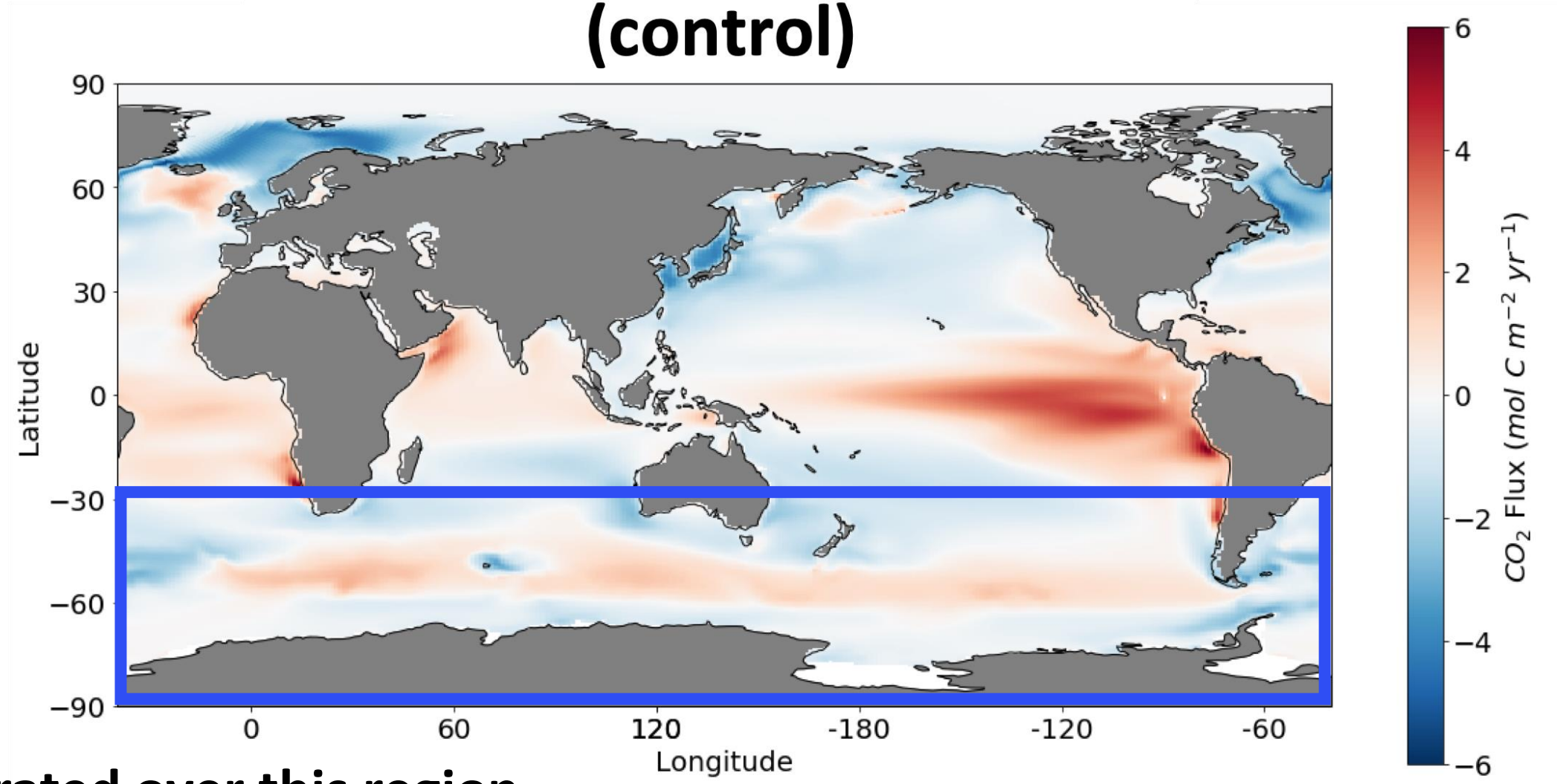
Preindustrial sea-Air CO_2 flux difference due to cloud changes (experiment – control)



Non-thermal component of the preindustrial CO_2 flux difference

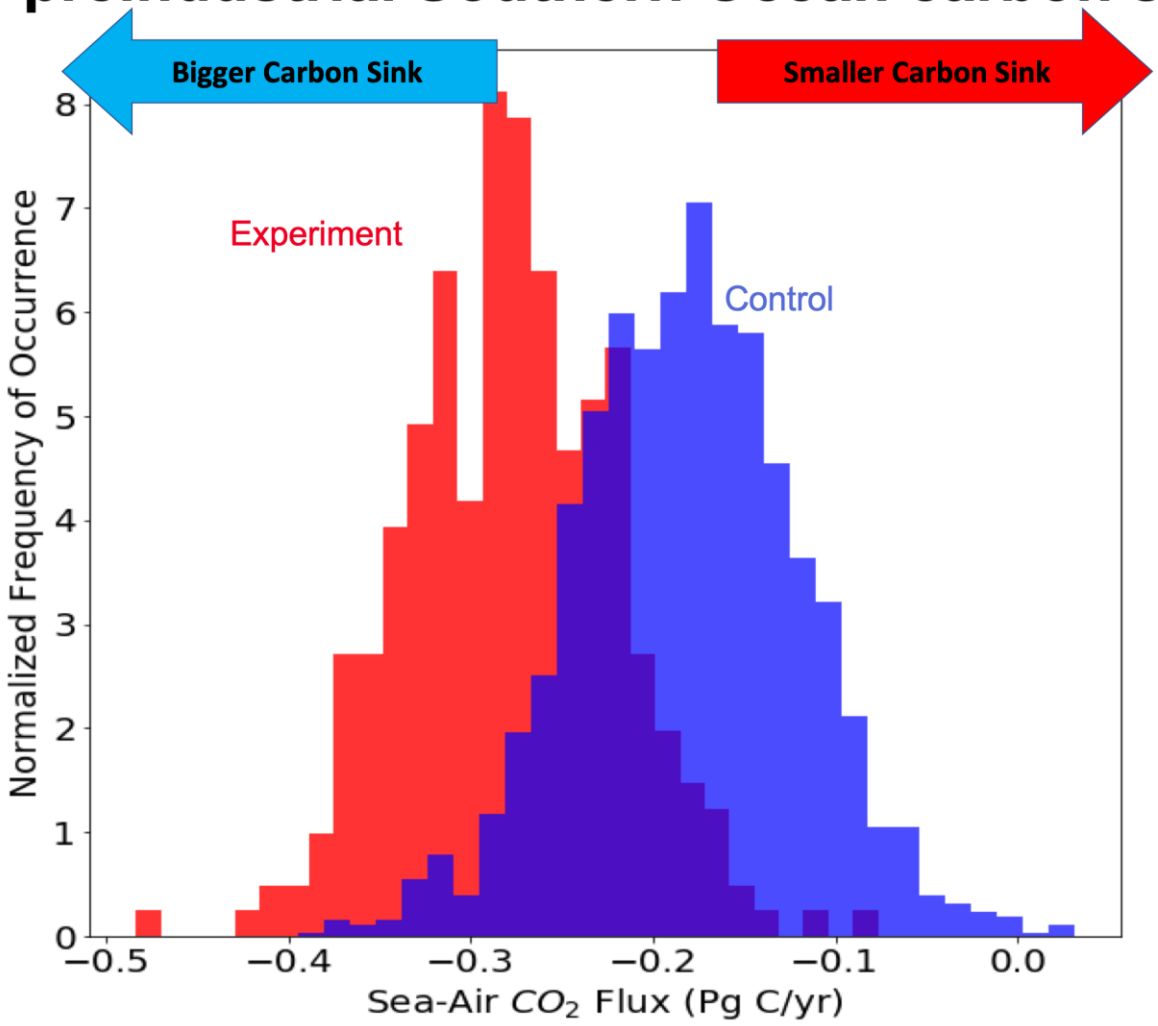


Preindustrial sea-air CO_2 flux (control)



Integrated over this region

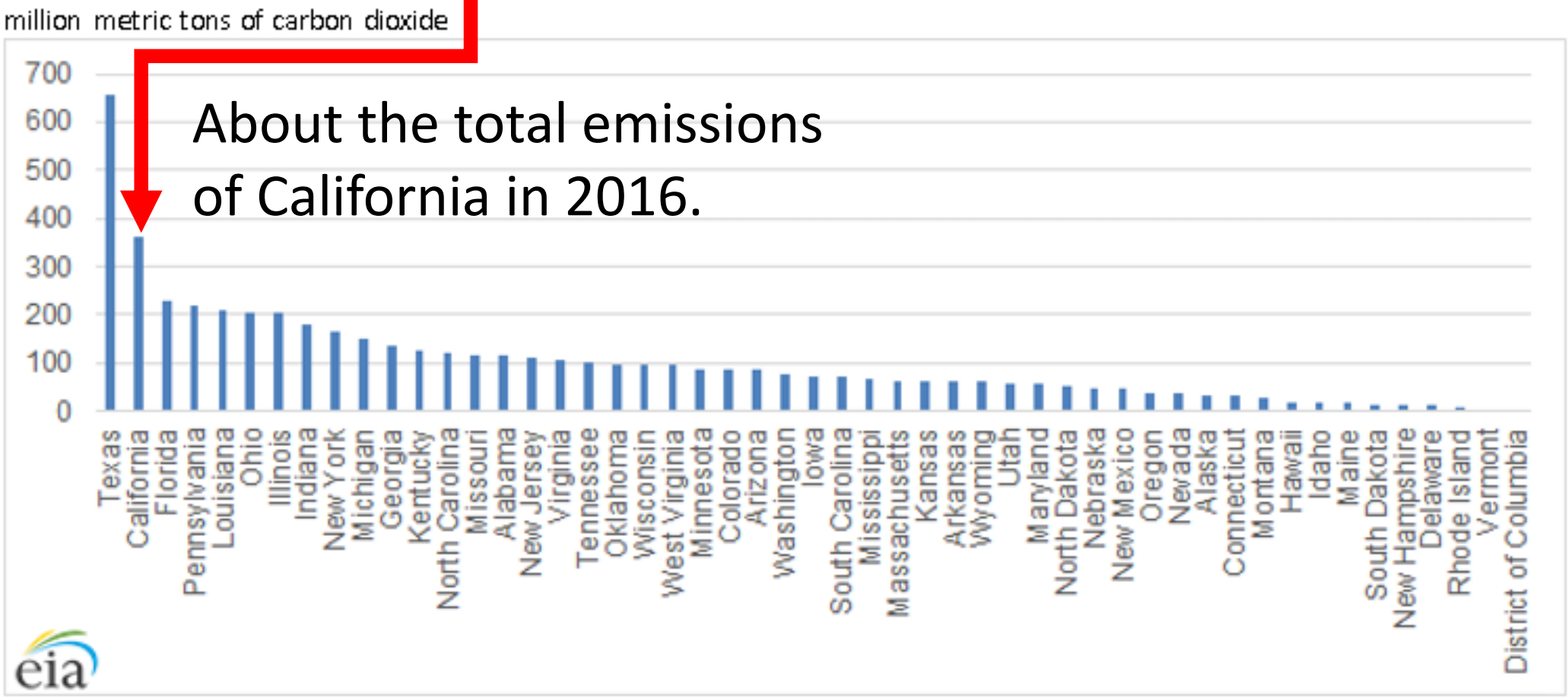
Brightening clouds increases the preindustrial Southern Ocean carbon sink



~0.1 Pg = 100 million metric tons

100 million tons C = ~370 million tons of CO_2

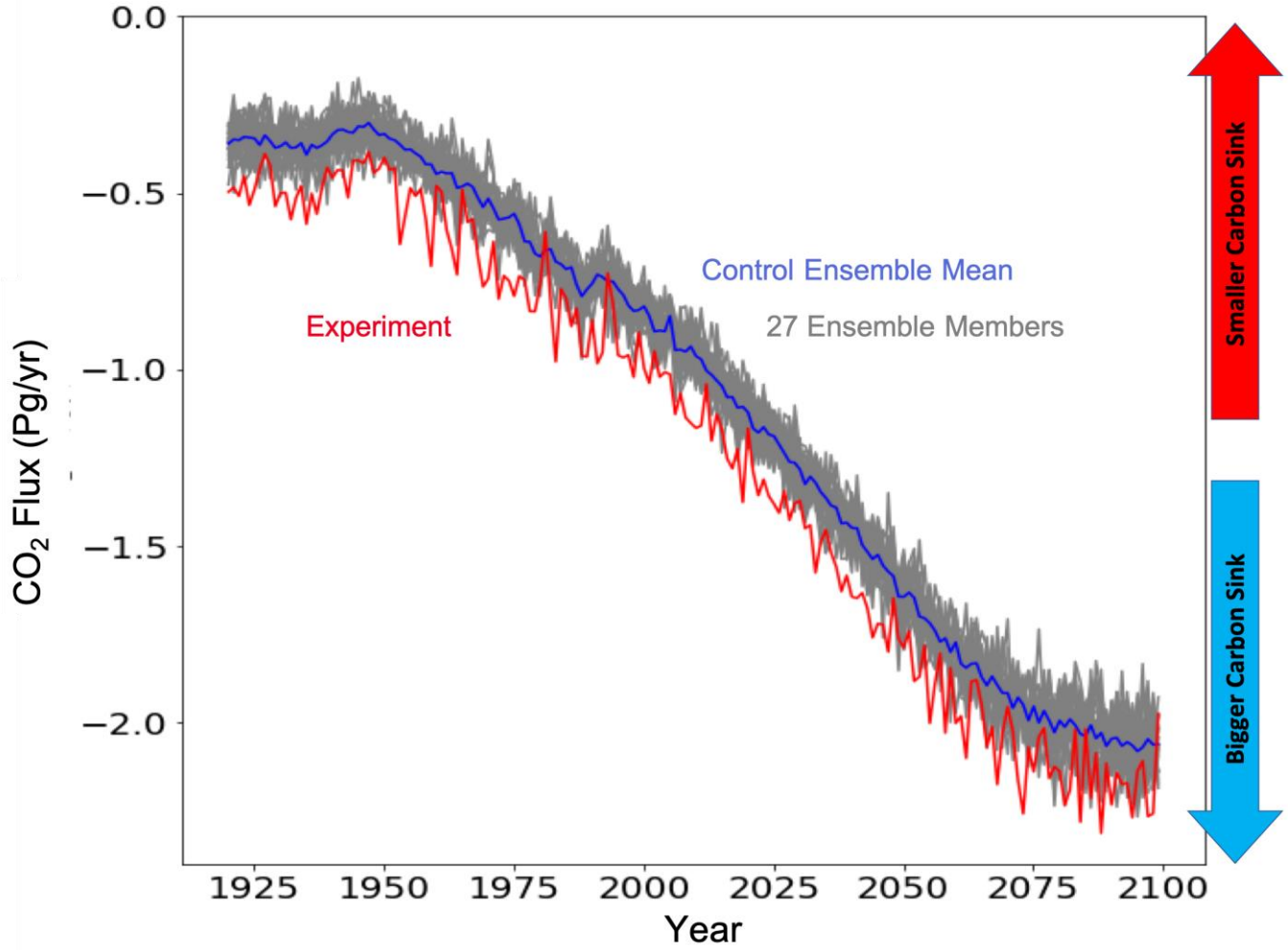
Figure 1. Energy-related carbon dioxide emissions by state, 2016



About the total emissions of California in 2016.

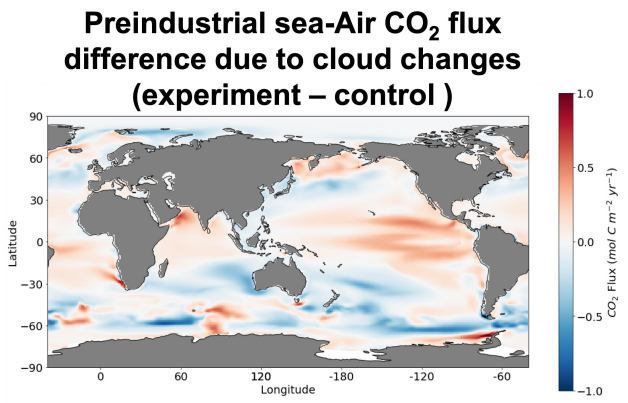
Source: EIA, State Energy Data System and EIA calculations made for this analysis.

The Southern Ocean CO_2 flux is similarly increased in the 21st century



Summary

1) Changes to the clouds in CESM1 alter the spatial distribution of the sea-air CO2 flux while maintaining a globally integrated flux of zero.



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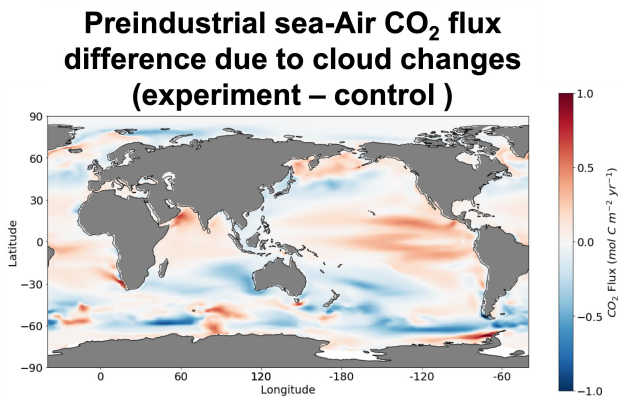
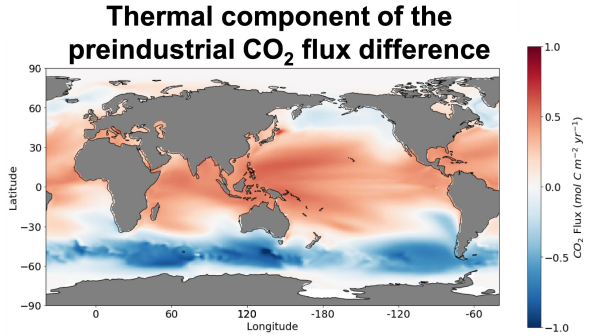


2) While the net flux difference resembles the thermal component, non-thermal effects compensate strongly for the thermal effects.



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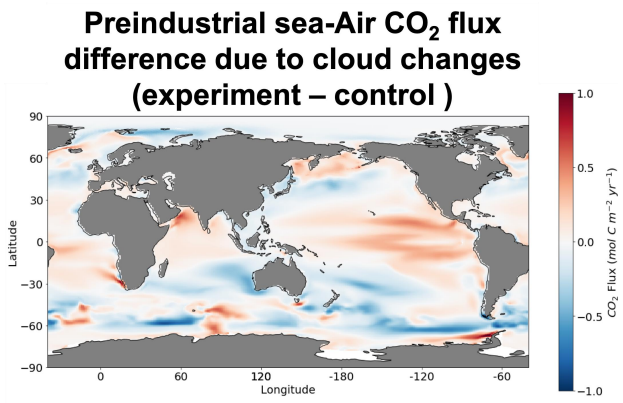

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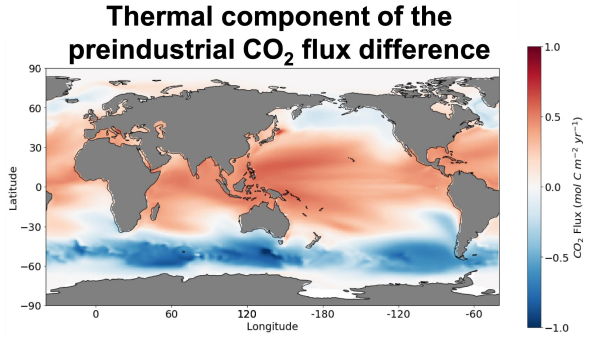
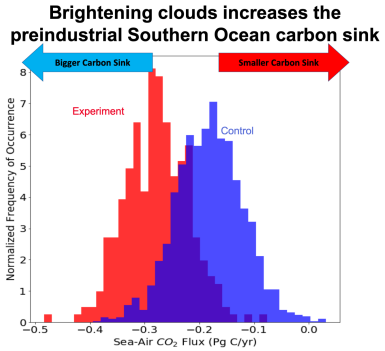


3) Integrated over the Southern Ocean, the cloud changes result in a flux into the ocean that is 0.1 Pg/year larger. This difference is maintained through simulations of the 21st century.



$$\Phi = kS_A(pCO_2^{atm} - pCO_2^{ocn})$$

Decomposition of carbon fluxes into components

The thermal component of the flux is given by:

$$\frac{\partial \Phi}{\partial T}\Delta T = \frac{\partial \Phi}{\partial pCO_2}\Delta pCO_2 = \frac{\partial \Phi}{\partial pCO_2}\frac{\partial pCO_2}{\partial T}\Delta T \tag{2.3.1}$$

The sensitivity of pCO_2 to temperature is known (Takahashi et al. 1993):

$$\frac{\partial pCO_2}{\partial T} \approx pCO_2 0.0423^o C^{-1} \tag{2.3.2}$$

And the sensitivity of the flux to pCO_2 cxan be obtained by taking the derivative of equation 1.0.1 with respect to pCO_2^{ocn}:

$$\frac{\partial \Phi}{\partial pCO_2} = k(1 - I)S \tag{2.3.3}$$

where $k = \frac{\Phi}{(1-I)\ \Delta CO_2^*}$ such that

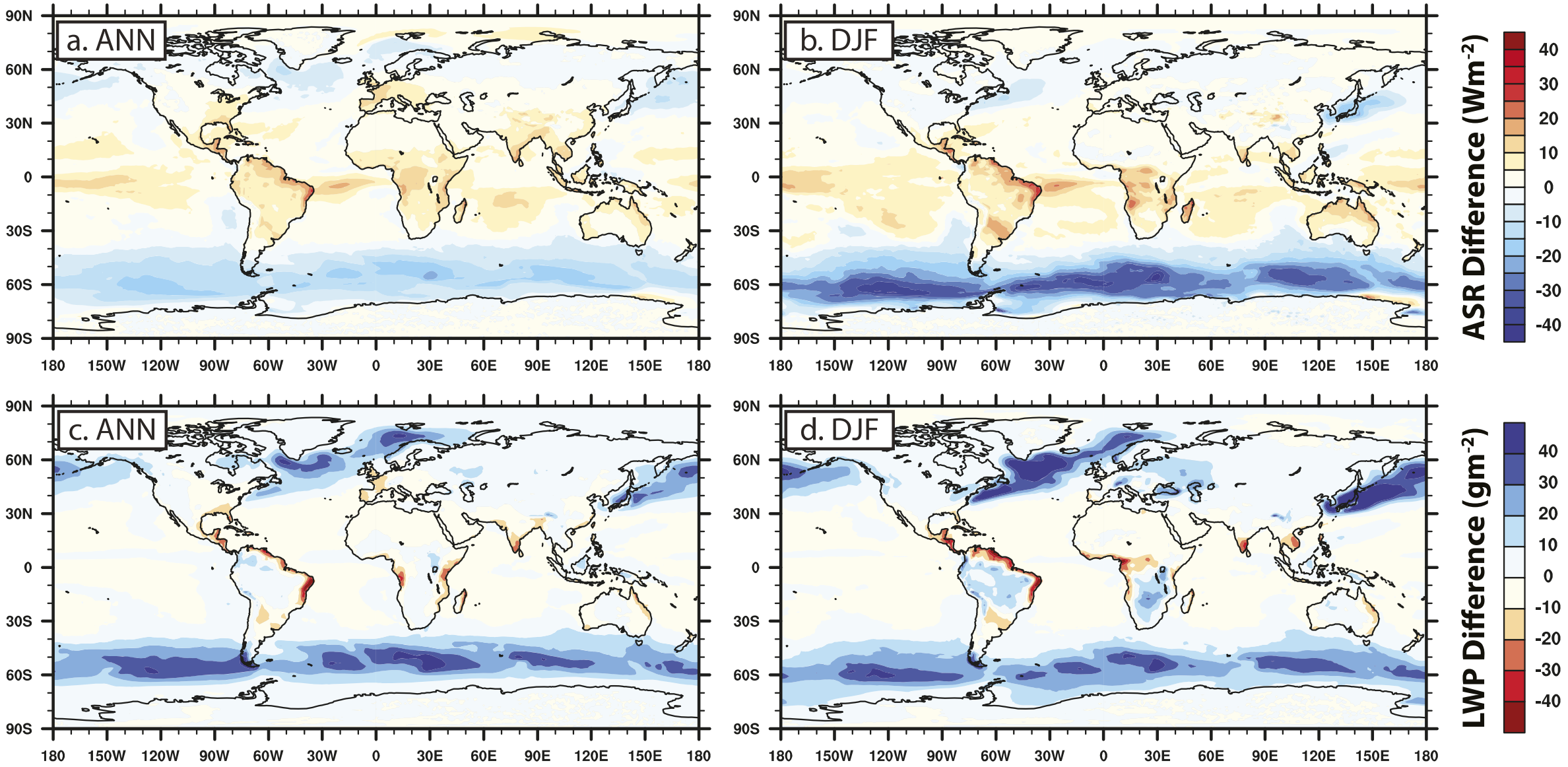
$$\frac{\partial \Phi}{\partial pCO_2} = \frac{\Phi}{\Delta CO_2^*} S \tag{2.3.4}$$

ΔCO_2^* is the difference in CO2 concentrations (not partial pressures) between the ocean and the atmosphere. The solubility, S, is a function of temperature and salinity and is obtained empirically:

$$S = exp\big[- 162.8301 + (218.2968/T) + 90.9241 * log(T)$$

$$-1.47696 * T^2 + SALT * (0.025695 - 0.025225 * T + 0.0049867 * T^2)\big]$$

Solar Radiation and Liquid Water Path (Experiment – Control)



Kay et al. 2016