



Ocean heat uptake slows 21st century surface warming driven by extratropical cloud feedbacks

William Frey

Elizabeth Maroon, Angeline Pendergrass, Jennifer Kay



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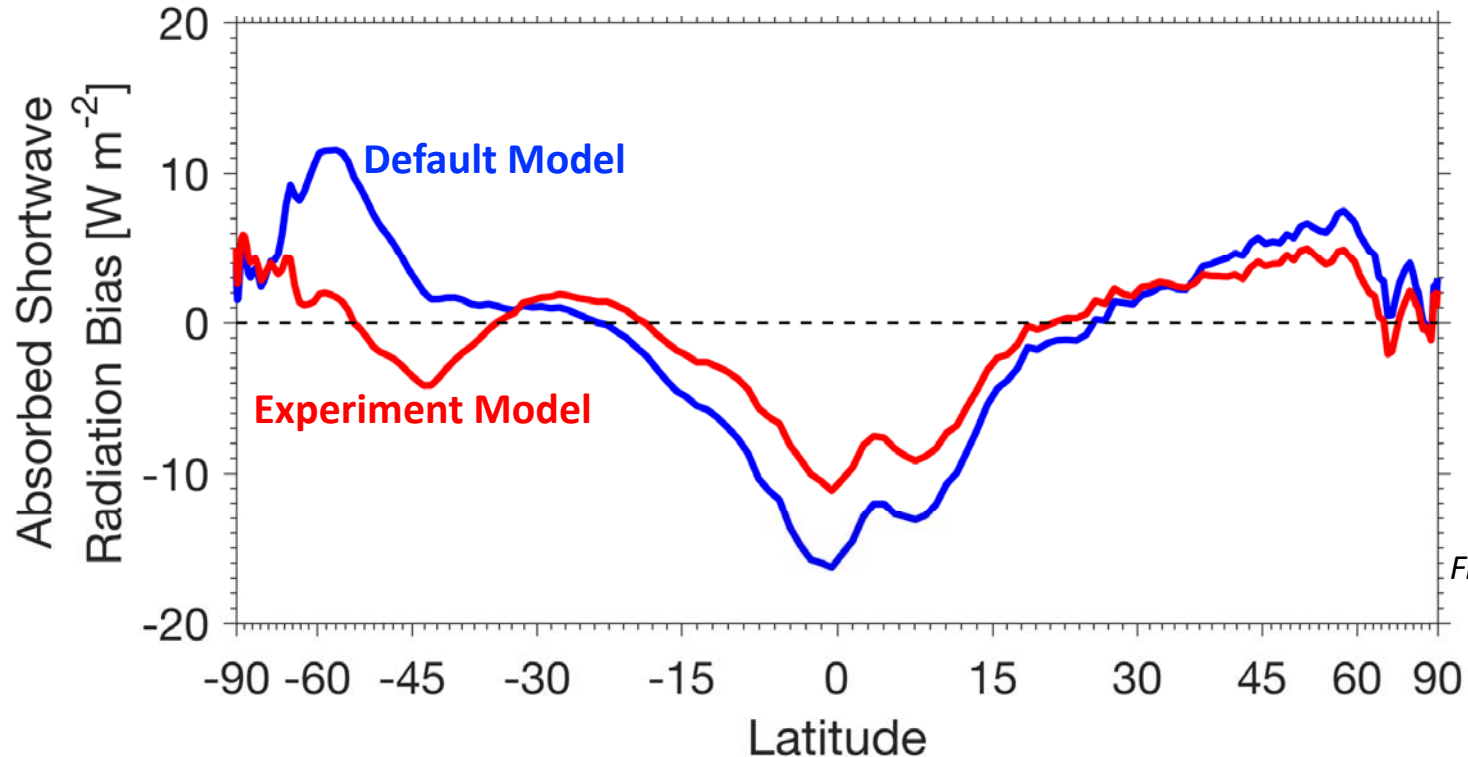




Reducing Radiation Biases



**Absorbed Shortwave Radiation Bias:
Model minus Observations**



Frey and Kay, 2017

Control:
CESM Large Ensemble

Experiment:
Decreased radiation biases via
modified cloud phase partitioning

See Kay et al (2016), *JClim* for details

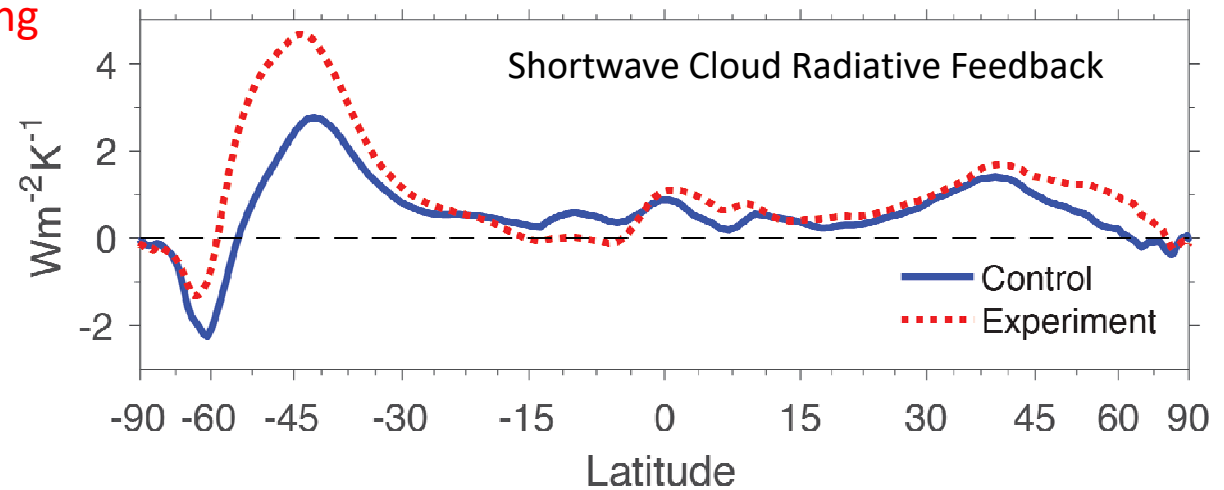
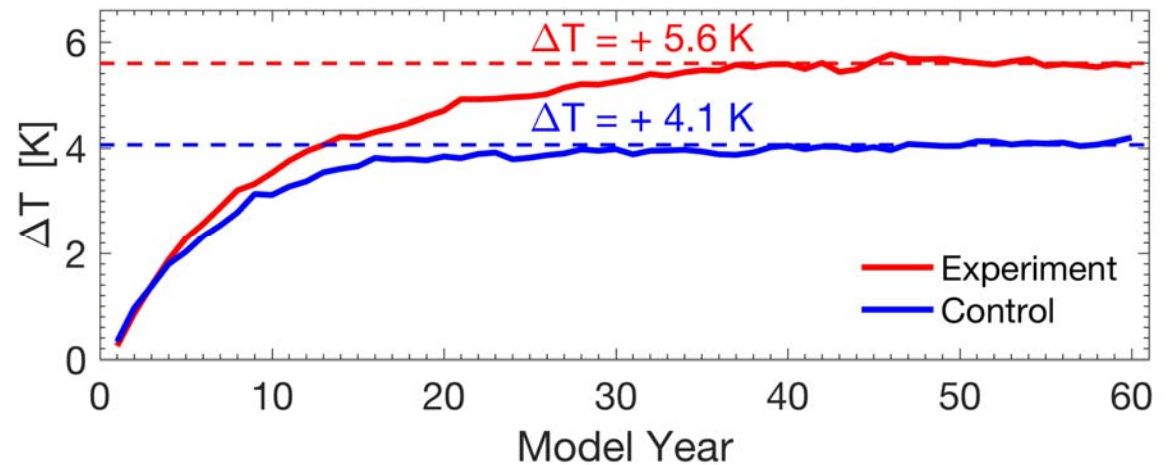


Extratropical cloud radiative feedbacks increase climate sensitivity



Control:
CESM Large Ensemble

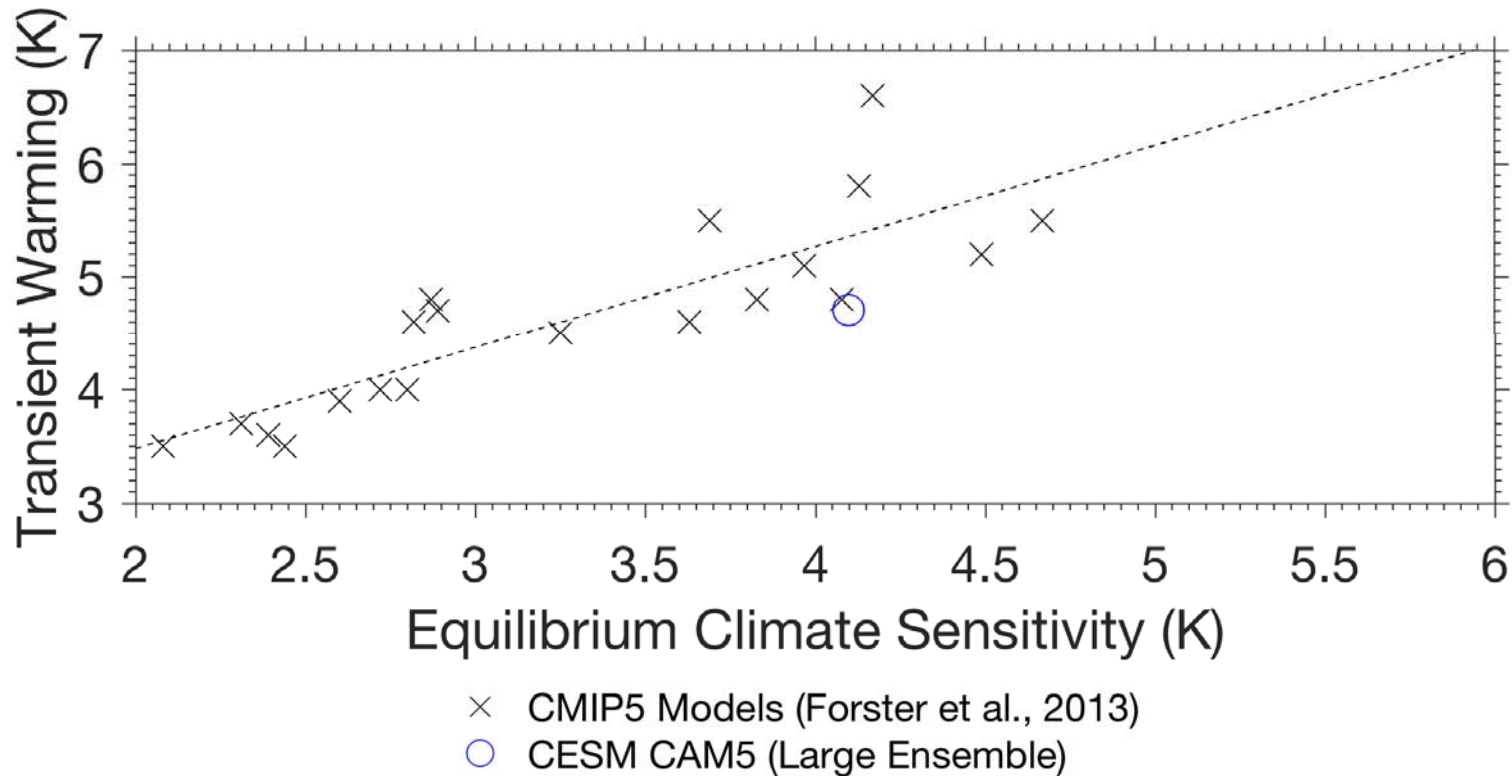
Experiment:
Decreased radiation biases via
modified cloud phase partitioning



Frey and Kay (In Review)



Climate Sensitivity correlated with transient warming

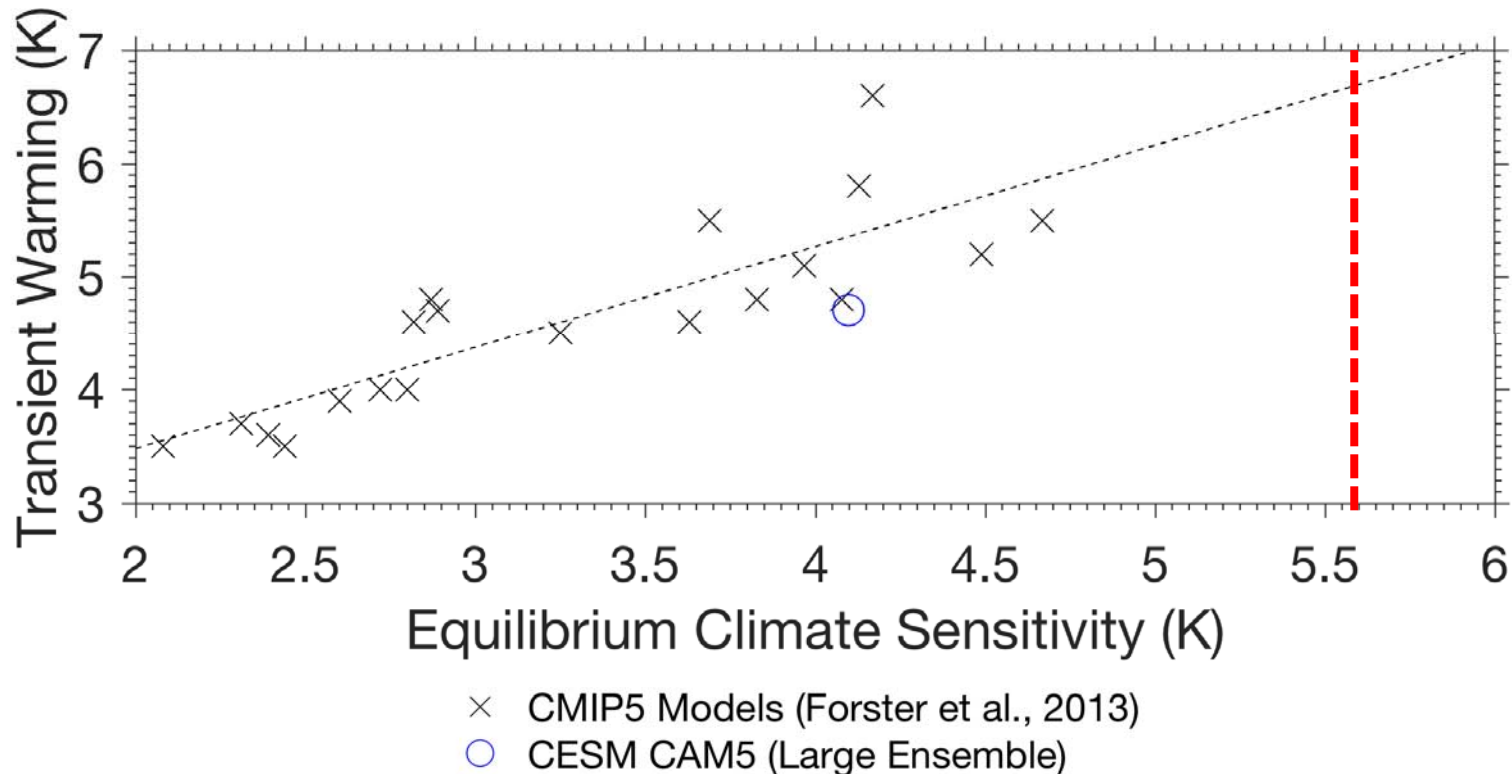




Climate Sensitivity correlated with transient warming

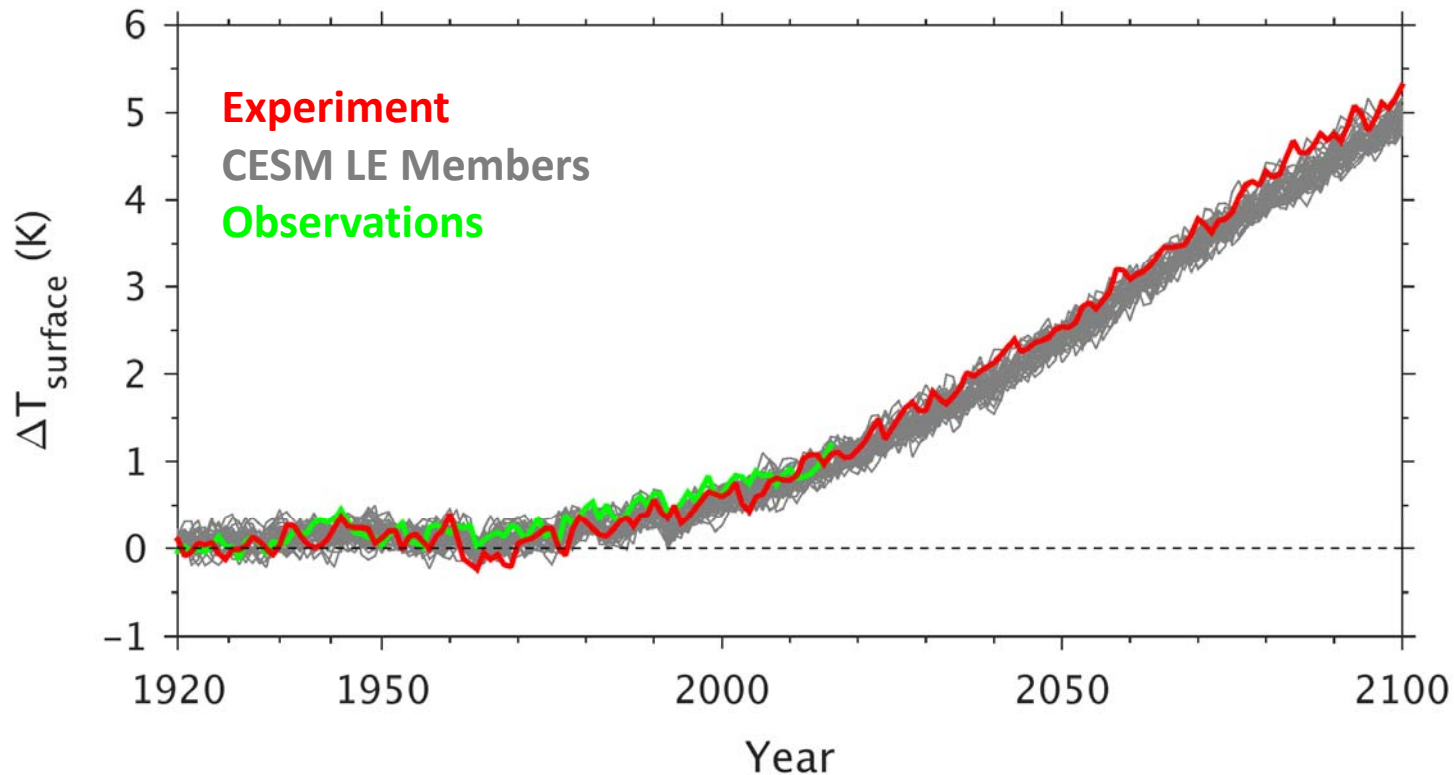


Does the large (1.5K) increase in ECS imply a large difference in 21st Century Warming?





Little Change in 21st Century Warming



Late 21st Century Warming

Experiment: 4.78 K

Large Ensemble Max: 4.72 K

Large Ensemble Mean: 4.50 +/- 0.03 K

Large Ensemble Min: 4.38 K

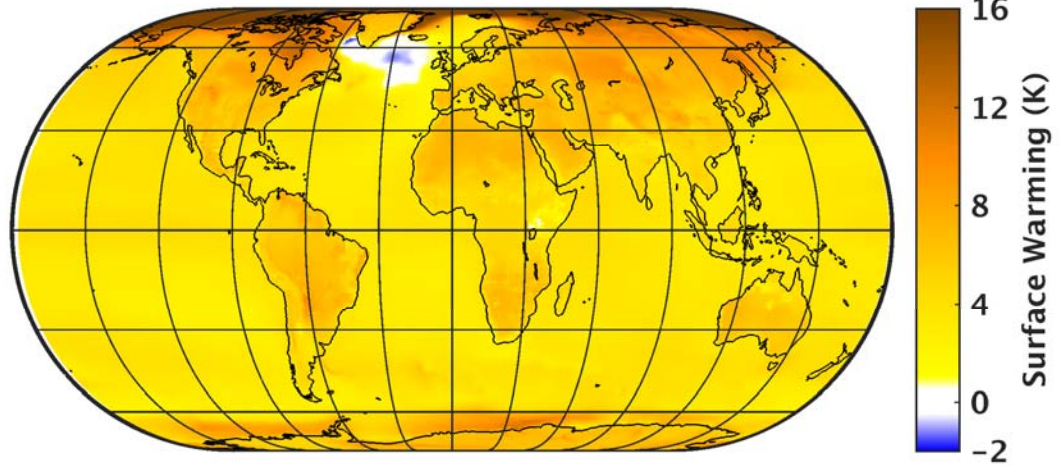
Frey et al., in prep



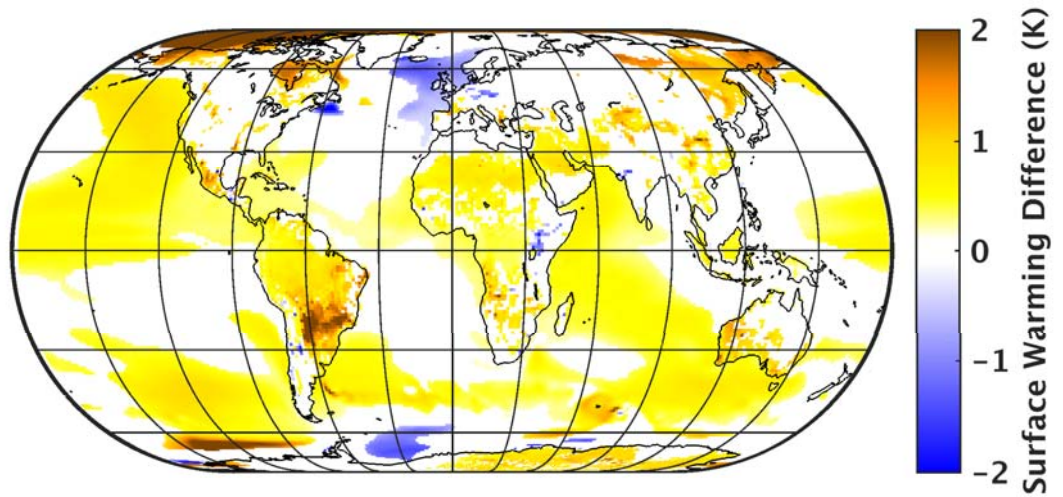
Little Change in 21st Century Warming



Experiment

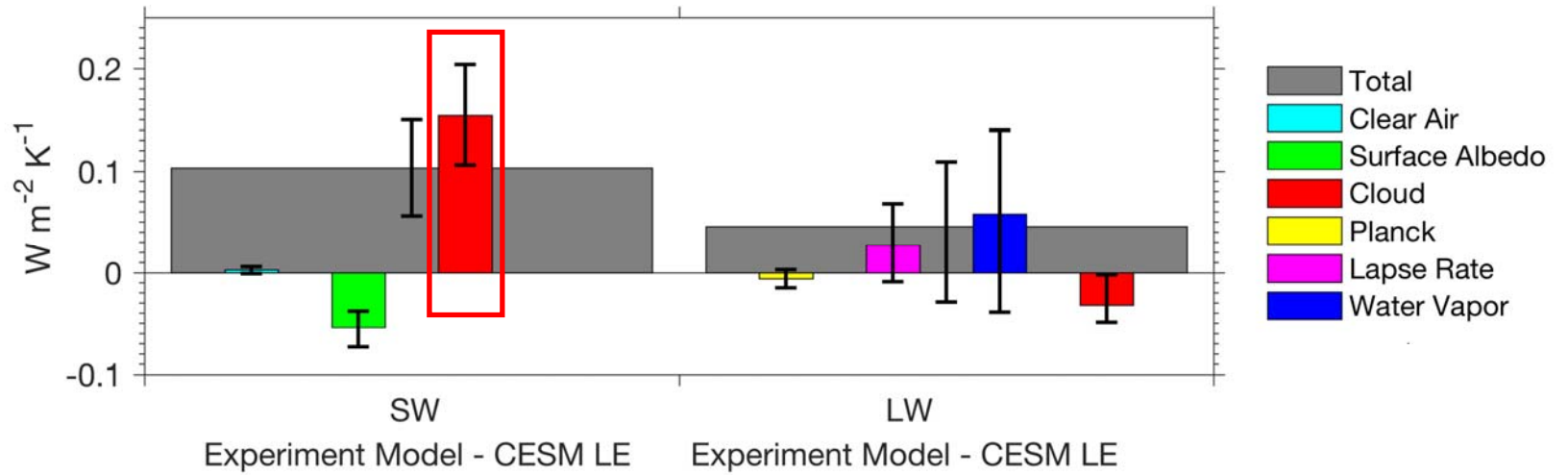


Experiment - Large Ensemble



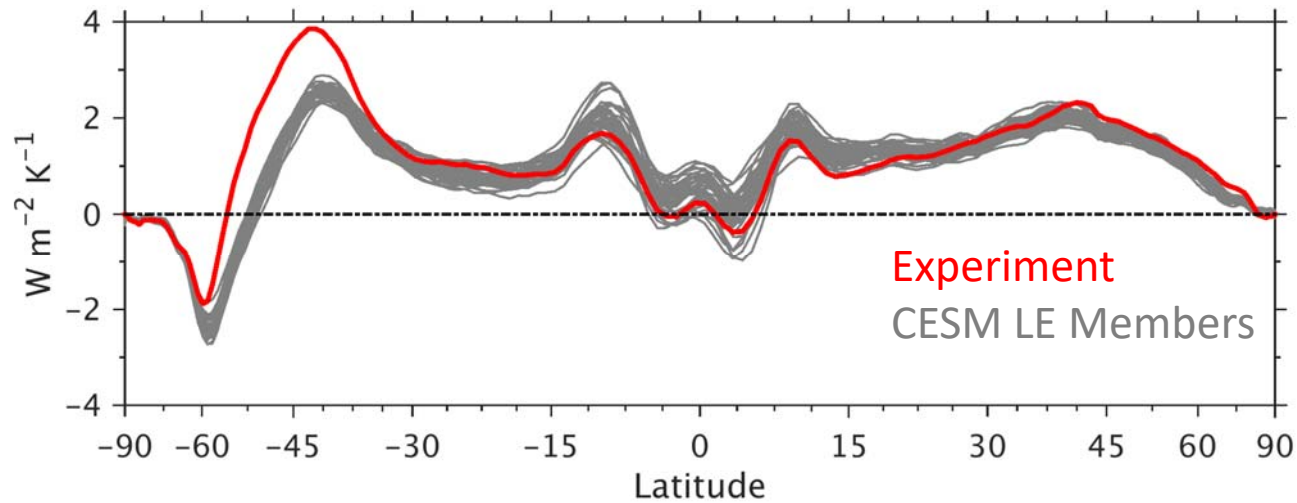
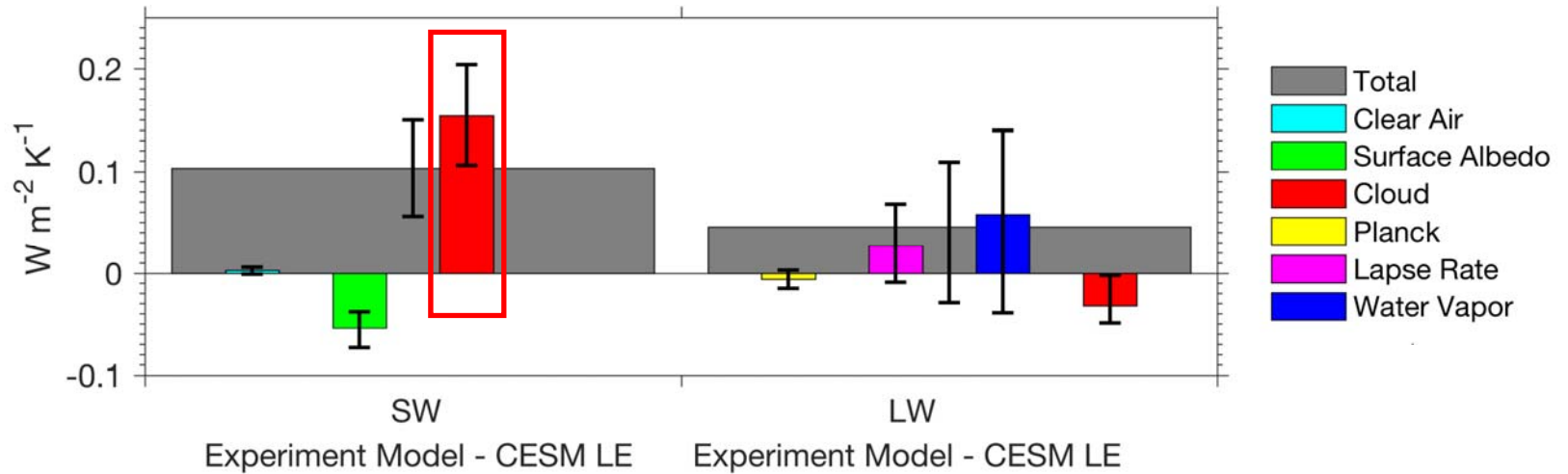


Increased Shortwave Cloud Feedback





Increased *Extratropical* Shortwave Cloud Feedback

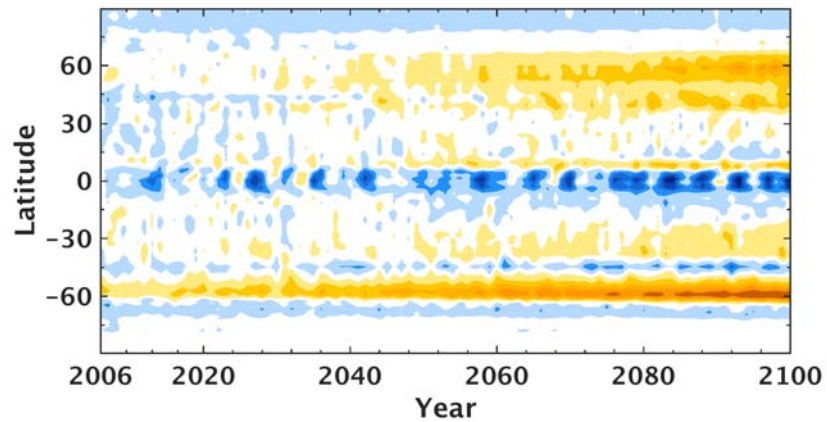




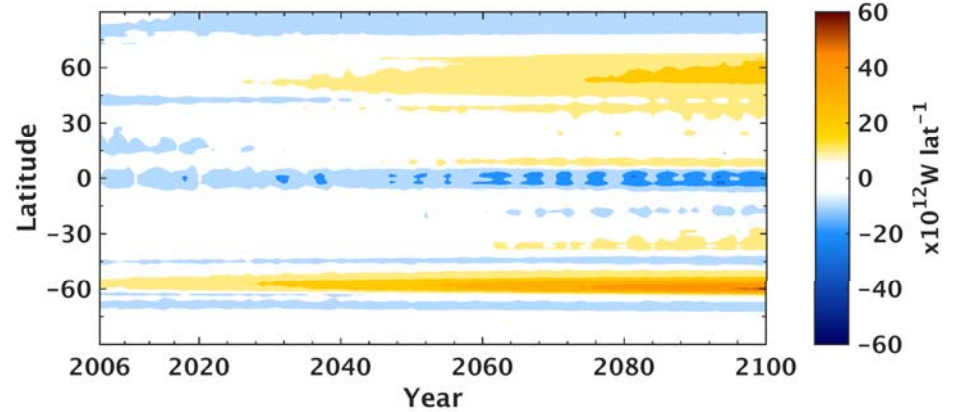
Ocean takes up heat in the Extratropics



Experiment



CESM Large Ensemble

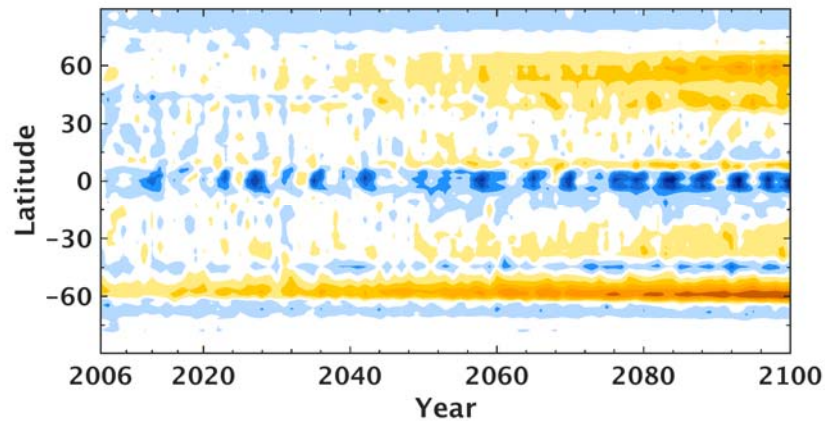




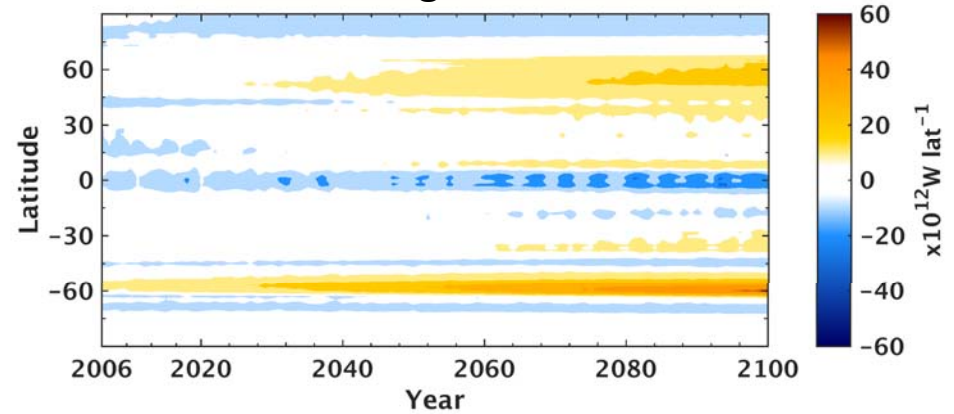
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Experiment

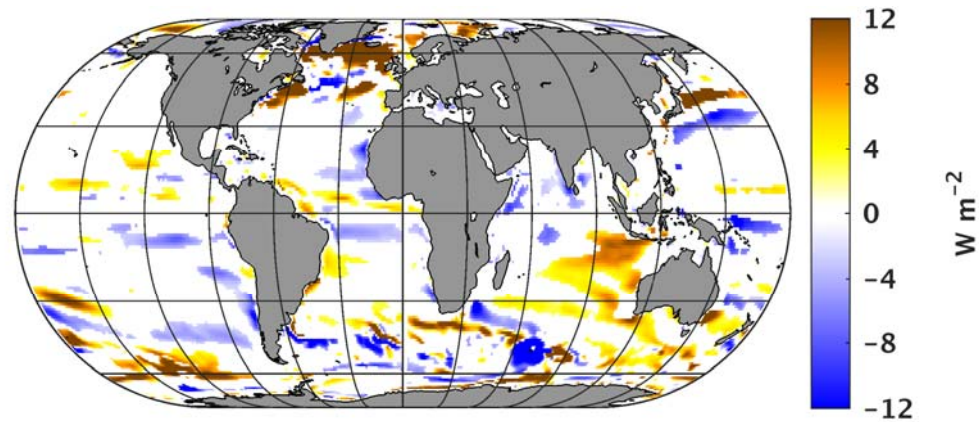


CESM Large Ensemble



Experiment - CESM Large Ensemble

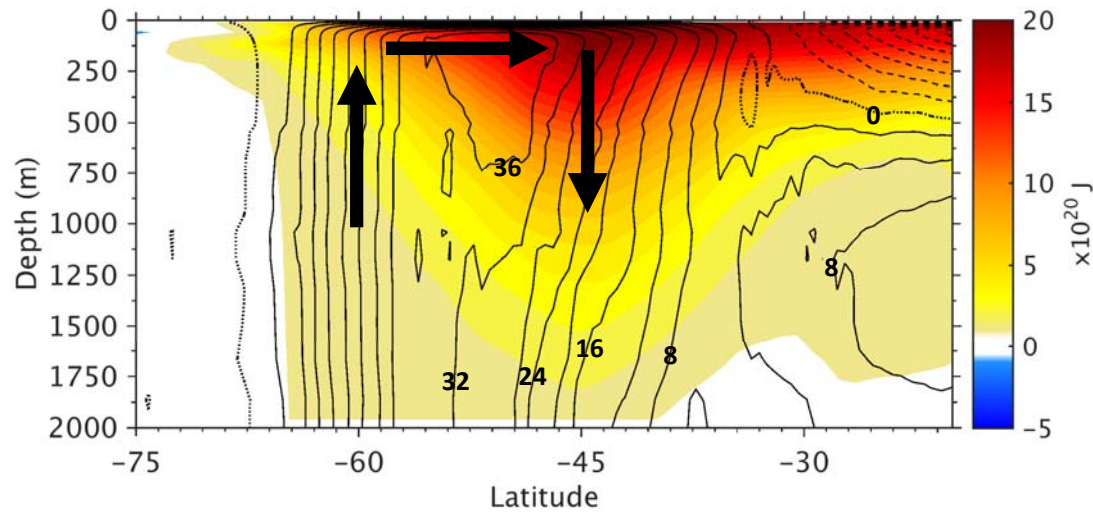
Δ Surface Heat Flux Anomaly



Frey et al., in prep



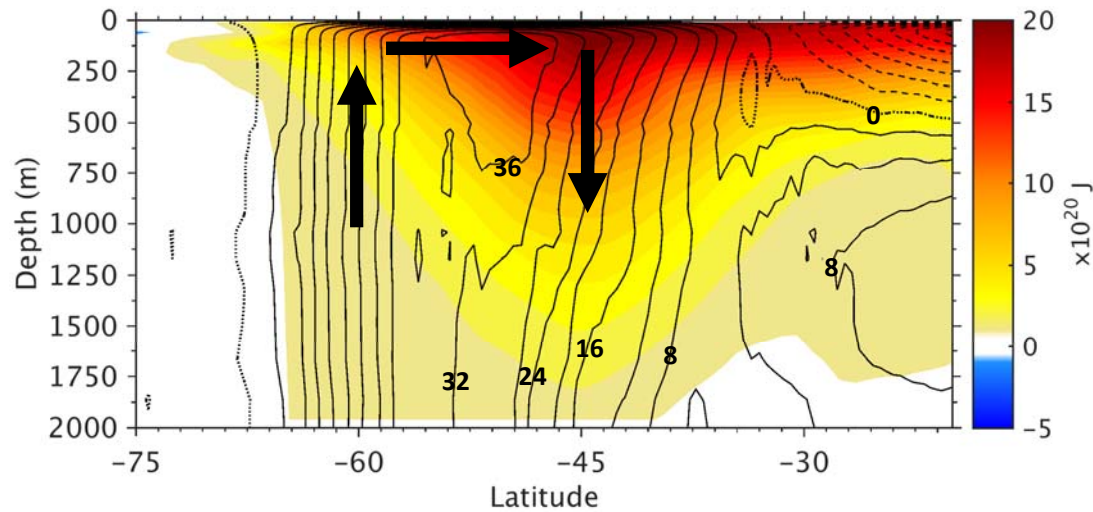
Southern Ocean Mean state circulation takes up heat



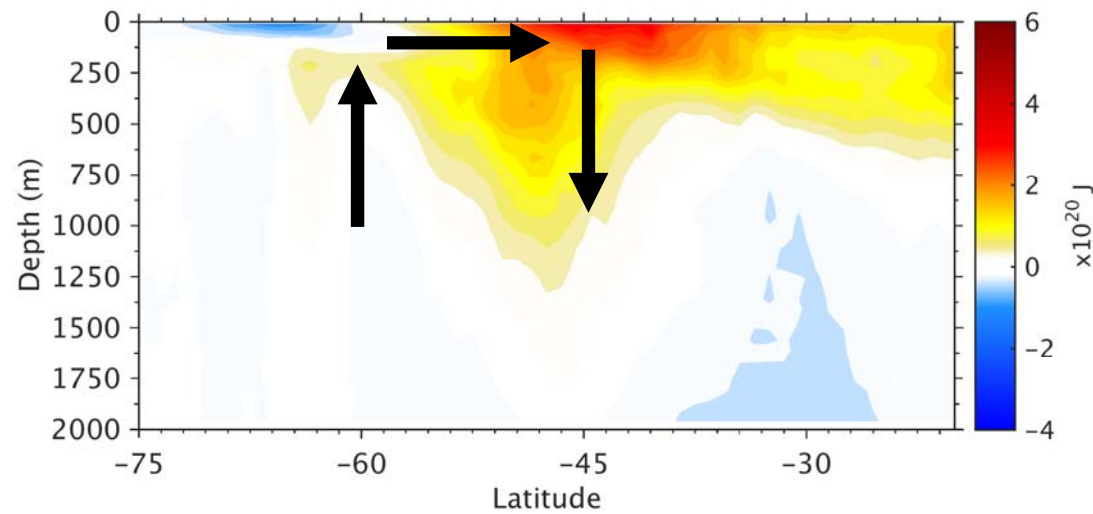
Ocean Heat Content Anomaly



Southern Ocean Mean state circulation takes up heat



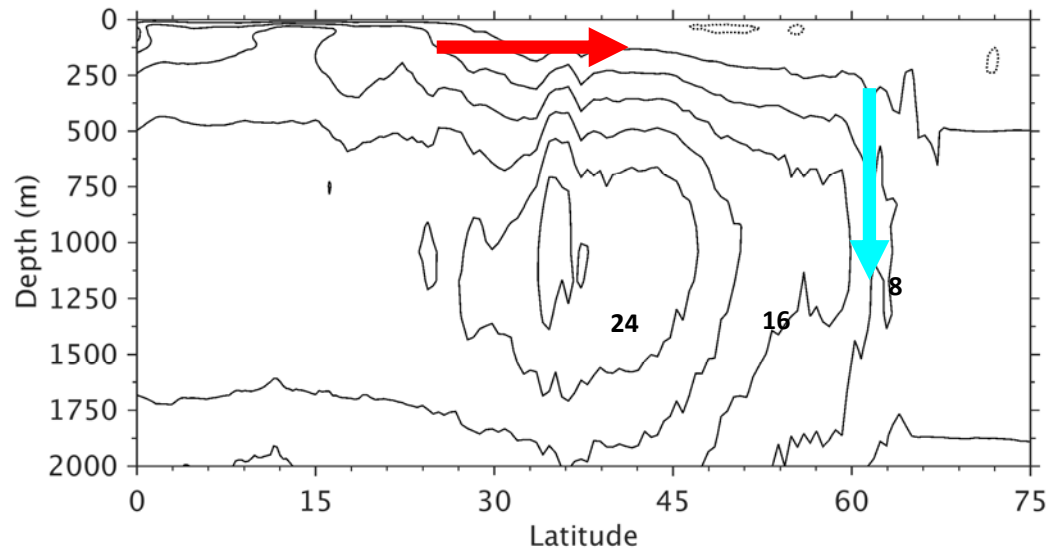
Ocean Heat Content Anomaly



Δ Ocean Heat Content Anomaly
Experiment – Large Ensemble



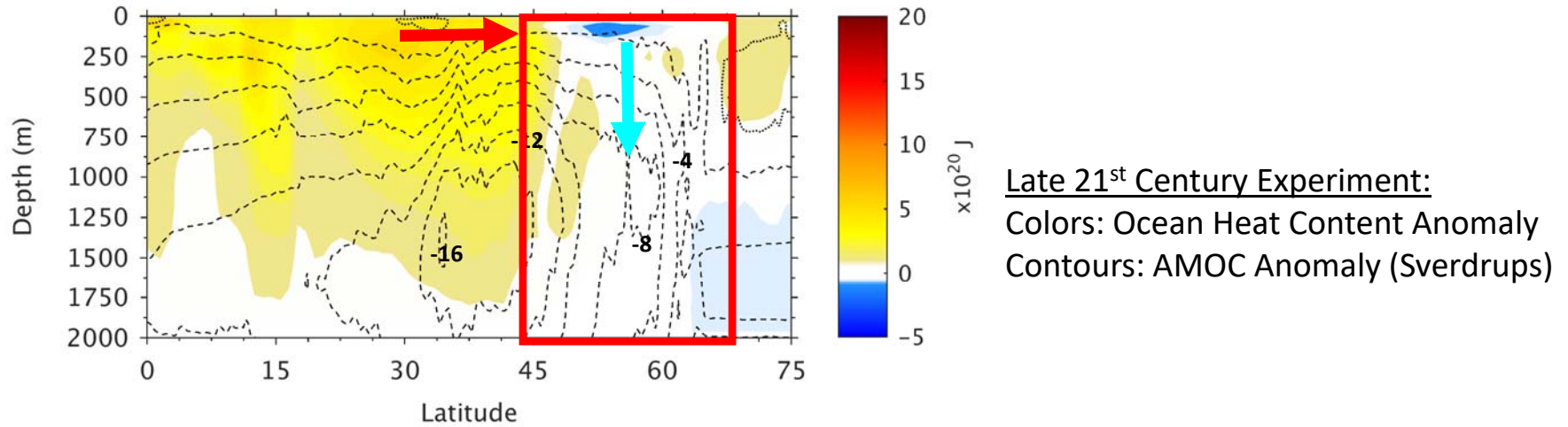
North Atlantic AMOC



Experiment Pre-Industrial AMOC (Sverdrups)

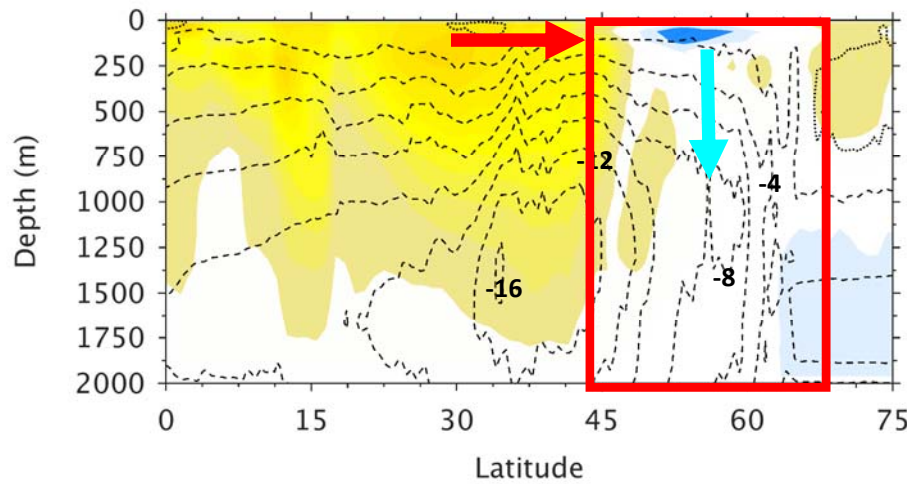


North Atlantic Slowdown of the AMOC takes up heat

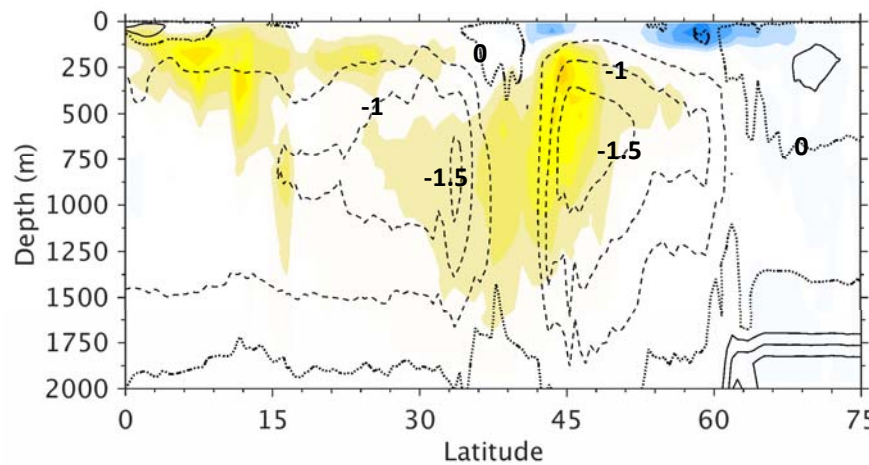




North Atlantic Slowdown of the AMOC takes up heat



Late 21st Century Experiment:
Colors: Ocean Heat Content Anomaly
Contours: AMOC Anomaly (Sverdrups)




Late 21st Century Experiment – CESM LE:
Colors: Δ Ocean Heat Content Anomaly
Contours: Δ AMOC Anomaly (Sverdrups)

Frey et al., in prep



Conclusions





-  Modified extratropical cloud radiative feedbacks increase equilibrium climate sensitivity by 1.5 K, but have a small impact on 21st century warming



Conclusions






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-  Modified extratropical cloud radiative feedbacks increase equilibrium climate sensitivity by 1.5 K, but have a small impact on 21st century warming
 -  Energy input by extratropical cloud radiative feedbacks is taken up by the ocean and moved to depth, slowing transient surface warming



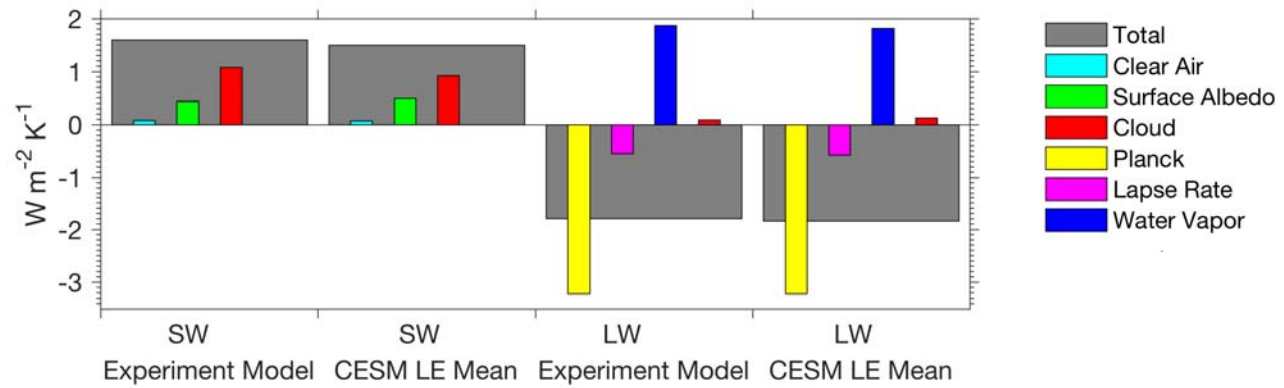
Conclusions



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-  Modified extratropical cloud radiative feedbacks increase equilibrium climate sensitivity by 1.5 K, but have a small impact on 21st century warming
 -  Energy input by extratropical cloud radiative feedbacks is taken up by the ocean and moved to depth, slowing transient surface warming
 -  Equilibrium warming cannot be used to infer transient warming when it is driven by extratropical feedbacks



Radiative Feedbacks



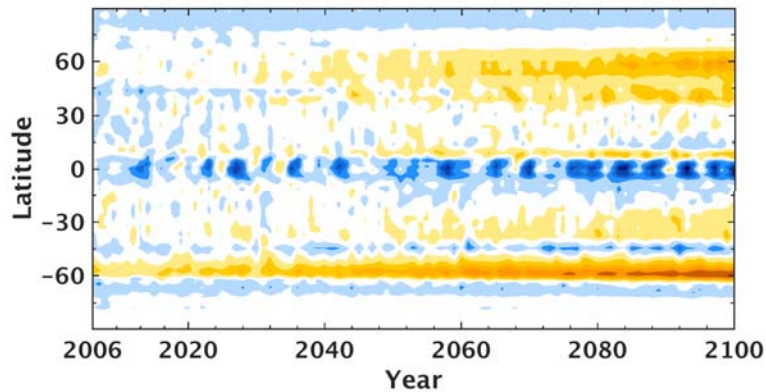
Frey et al., in prep



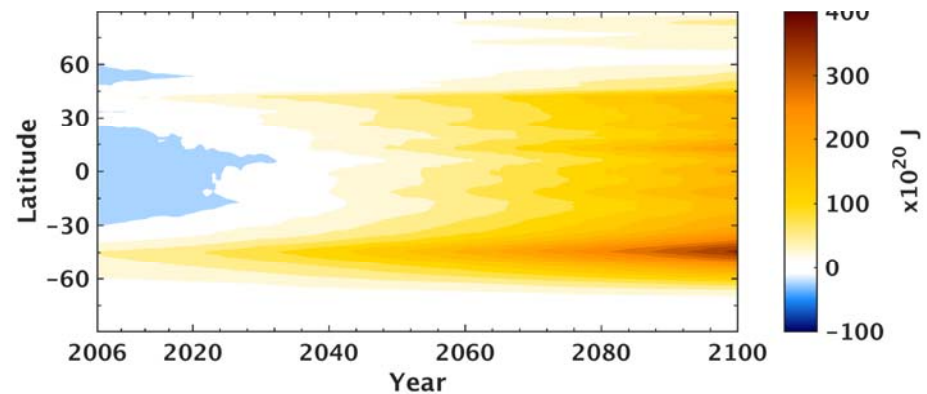
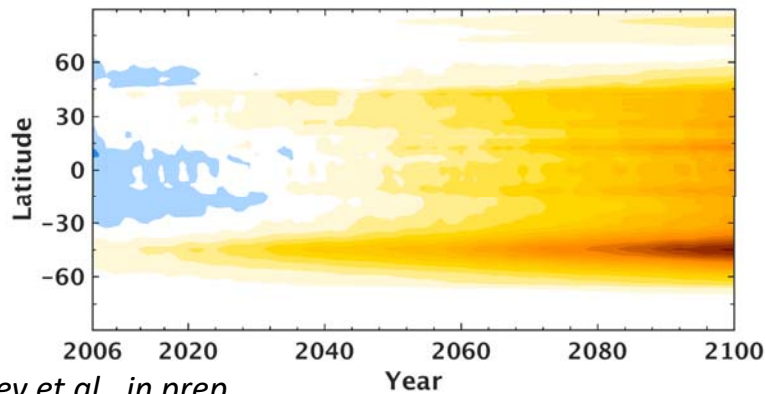
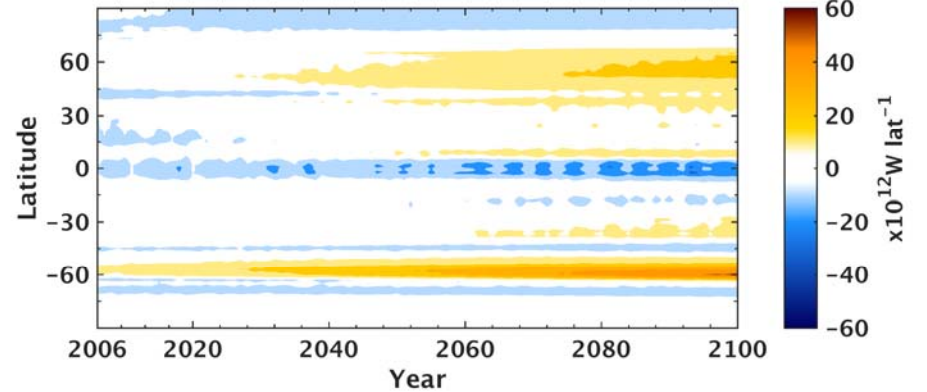
Ocean takes up heat in the Extratropics Stores heat further equatorward



Experiment



CESM Large Ensemble



Frey et al., in prep

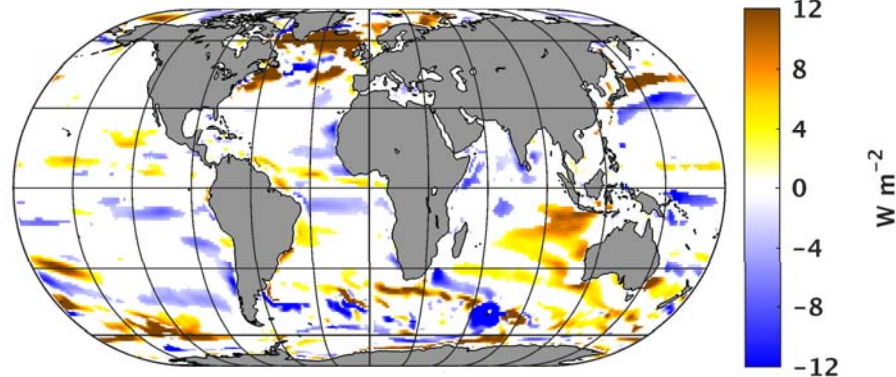


Ocean takes up heat in the Extratropics Stores heat further equatorward

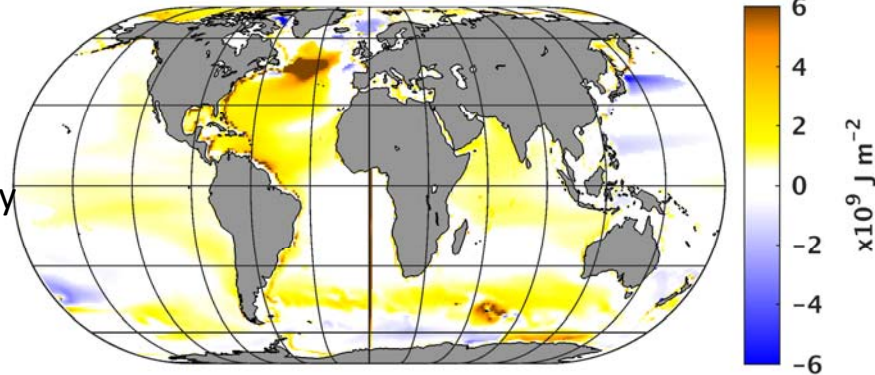


Experiment - CESM Large Ensemble

Δ Surface Heat Flux Anomaly



Δ Ocean Heat Content Anomaly



Frey et al., in prep