# ECS and TCS in CESM

# CESM1 (CMIP5) vs CESM2 (CMIP6)

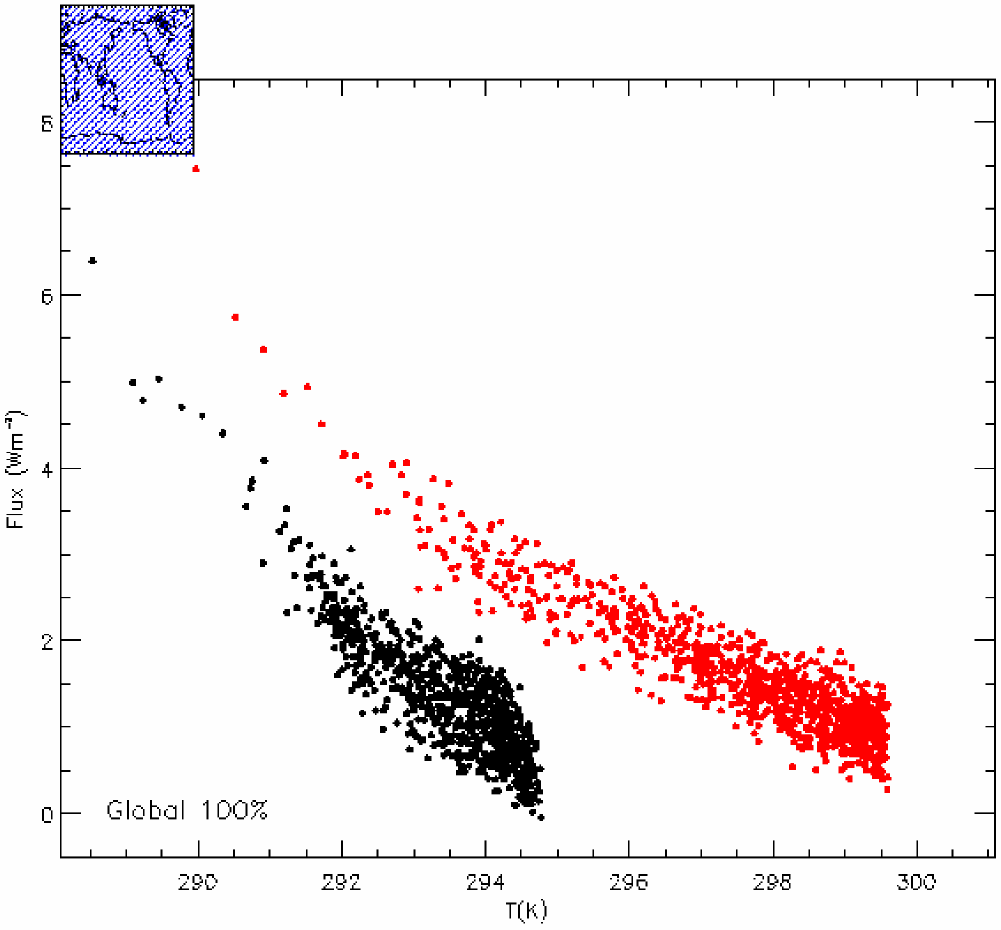
- Equilibrium climate sensitivity (ECS) went from ~4K to ~5.5K
- Time evolution of $4xCO_2$ experiment has changed

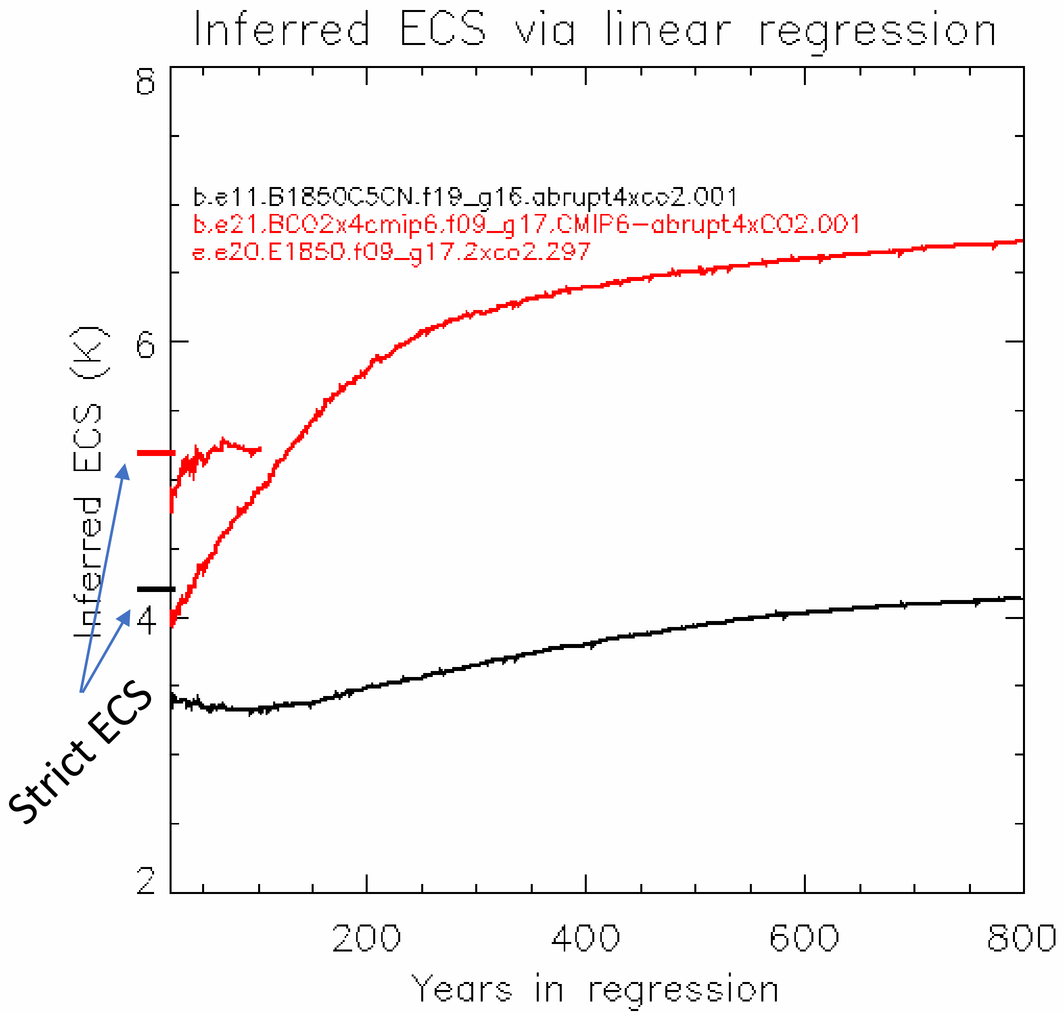
**CESM1**

**CESM2**

ECS is calculated from equilibrated 2xCO2 slab-ocean model (SOM) run

Transient climate sensitivity (TCS) –inferred ECS – calculated from linear fit of TOA radiation imbalance *(R)* vs global mean $T_s$ "Gregory plot" (divided by 2 for 4xCO2)



**CESM1**

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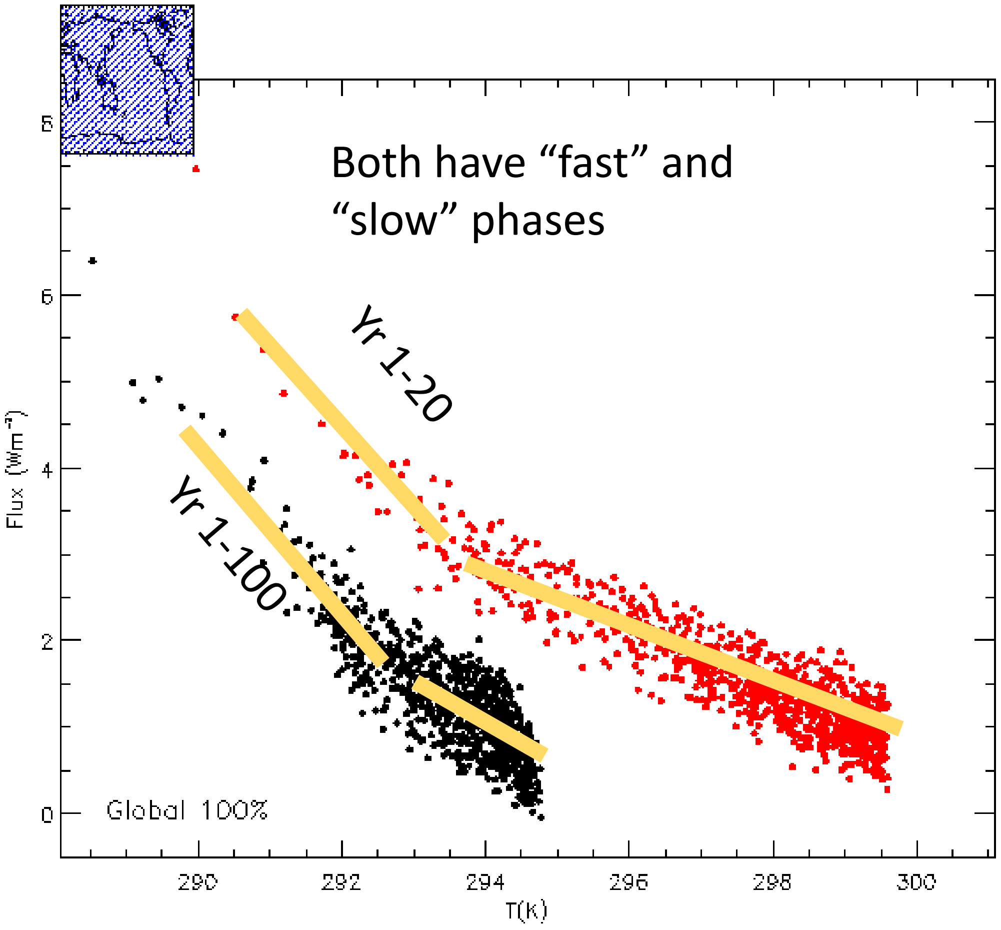
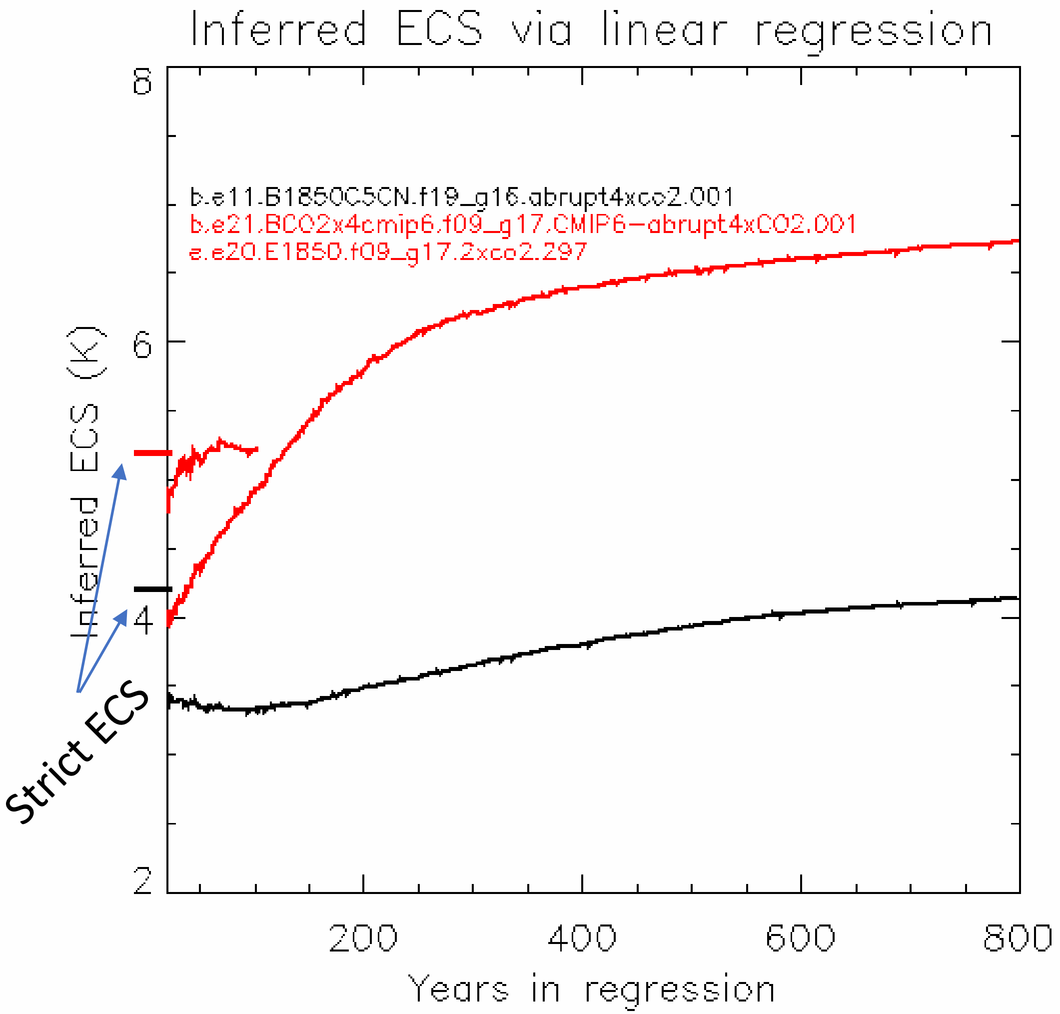
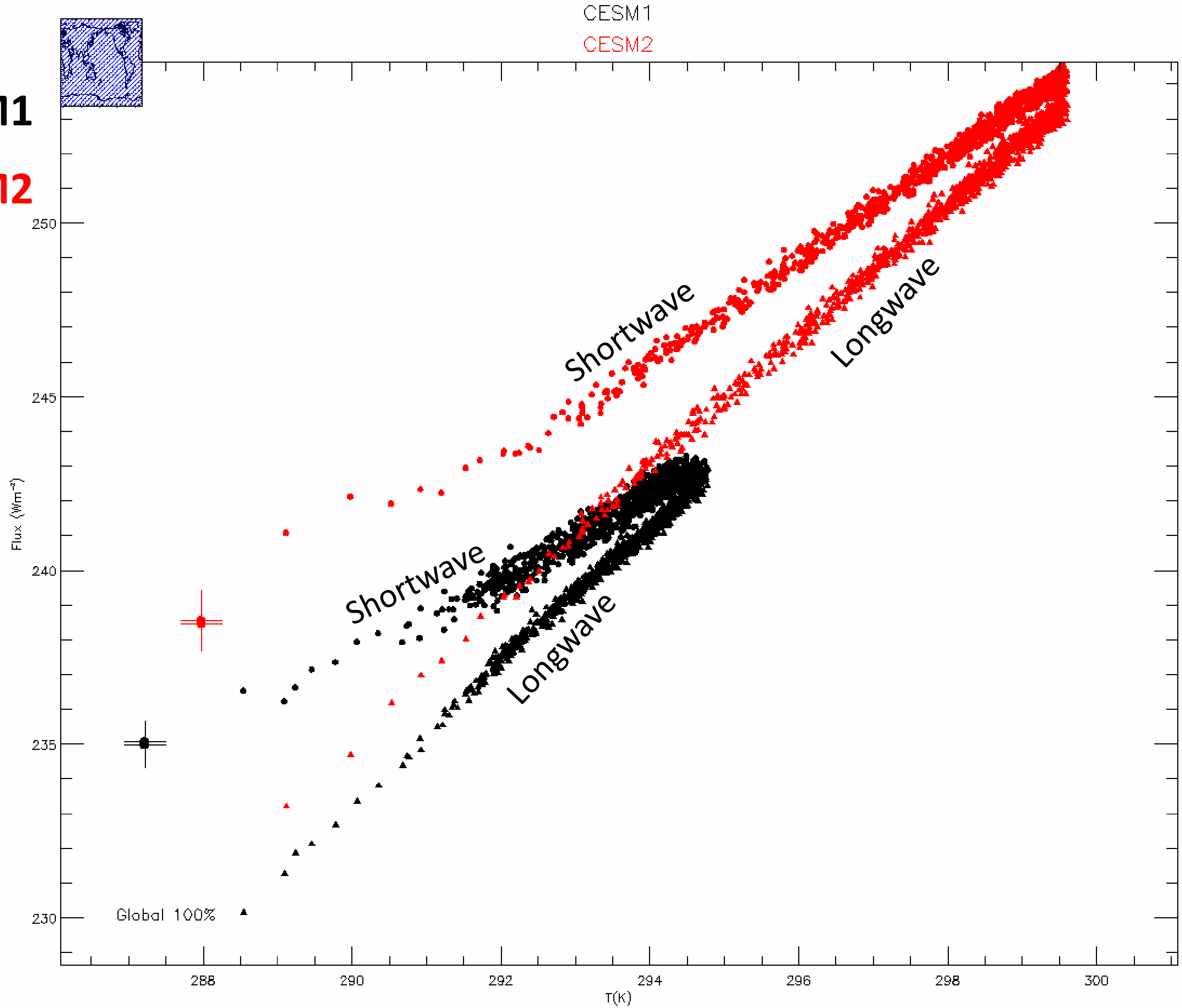


**CESM1**

**CESM2**



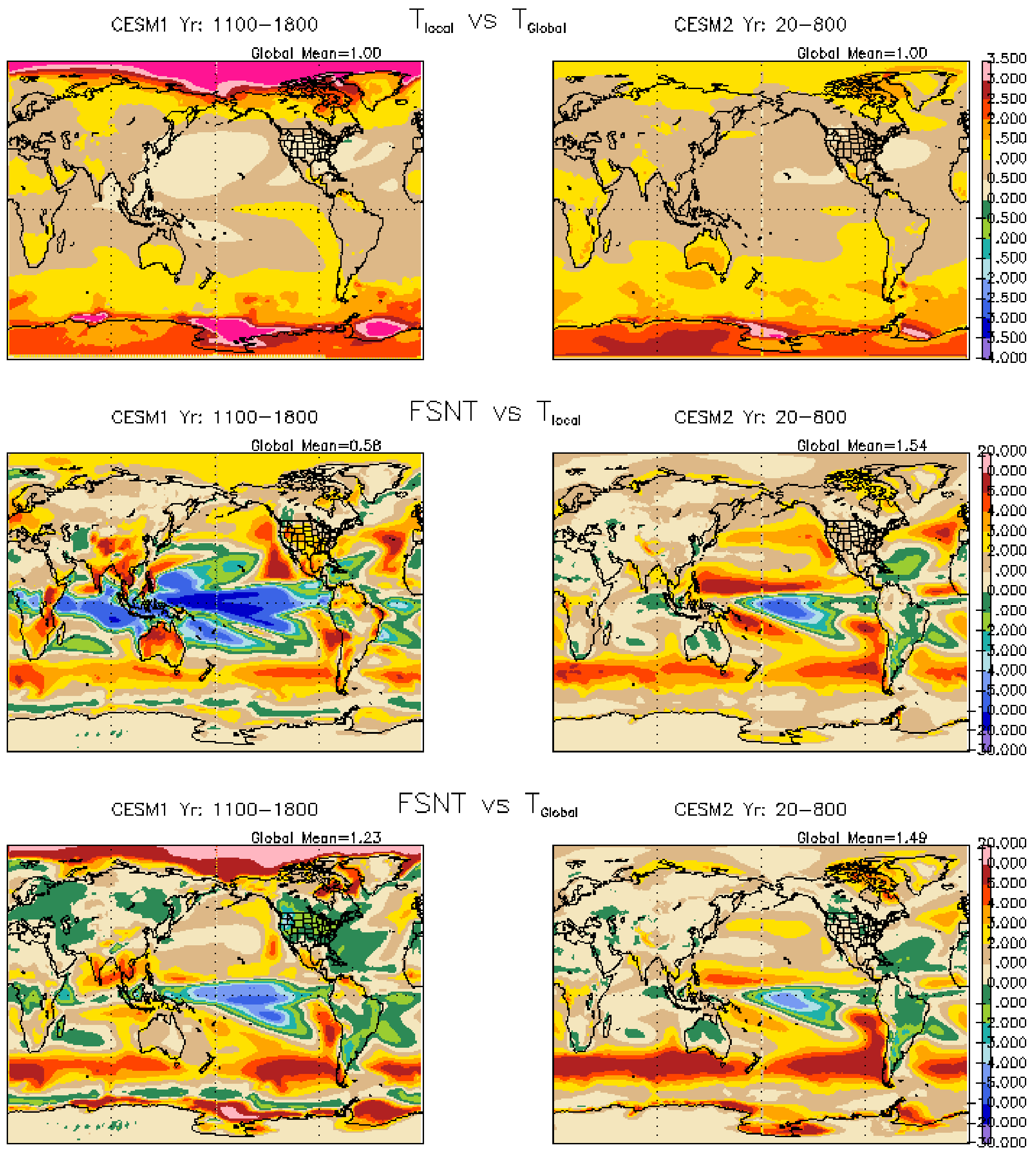
CESM1
CESM2
Flux (Wm⁻²)
T(K)
Shortwave
Longwave
Shortwave
Longwave
Global 100%

# “Slow” adjustment phase

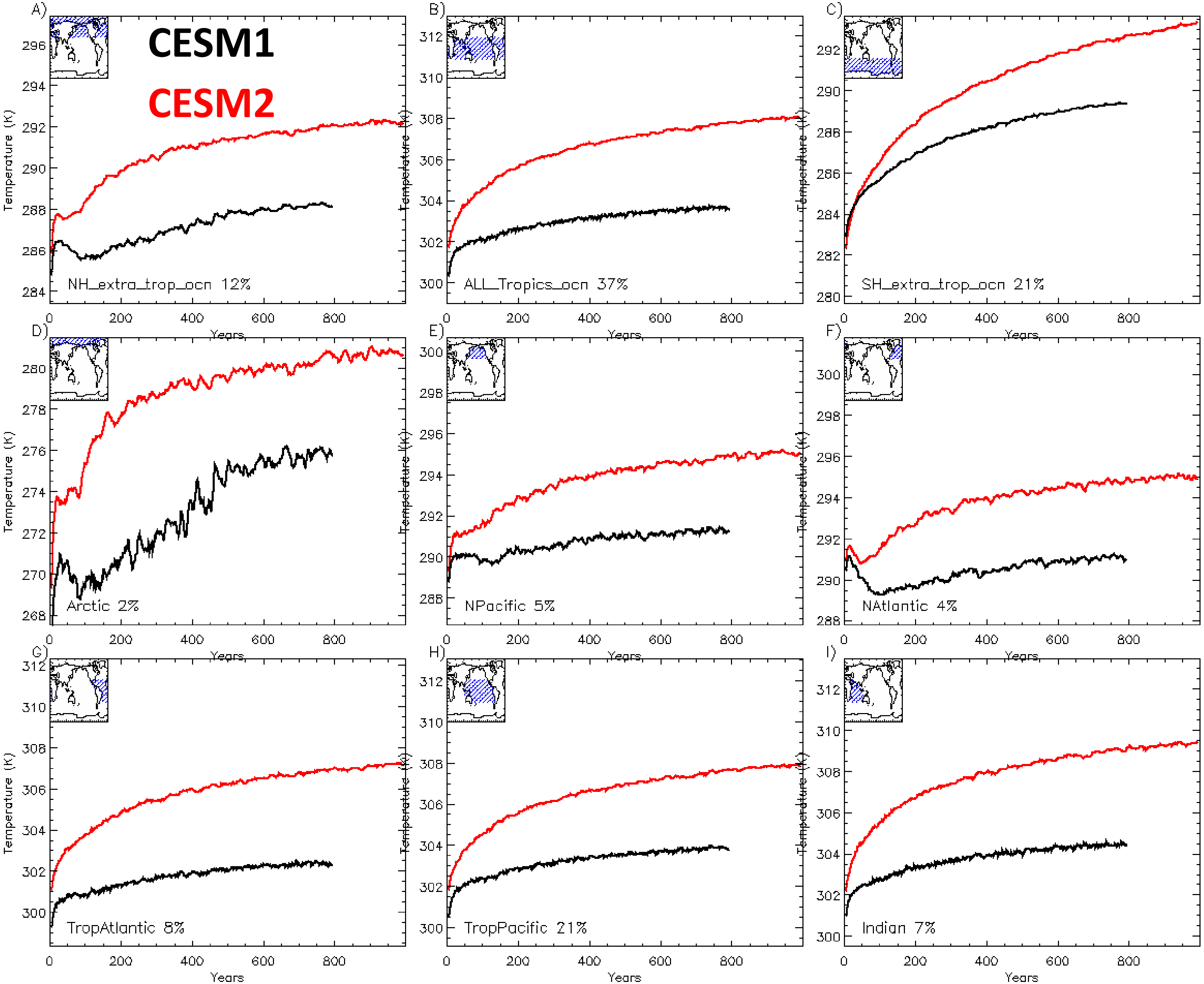
Regression of local $T_s$ vs global $T_s$

Regression of local $SW_{net}$ vs local $T_s$

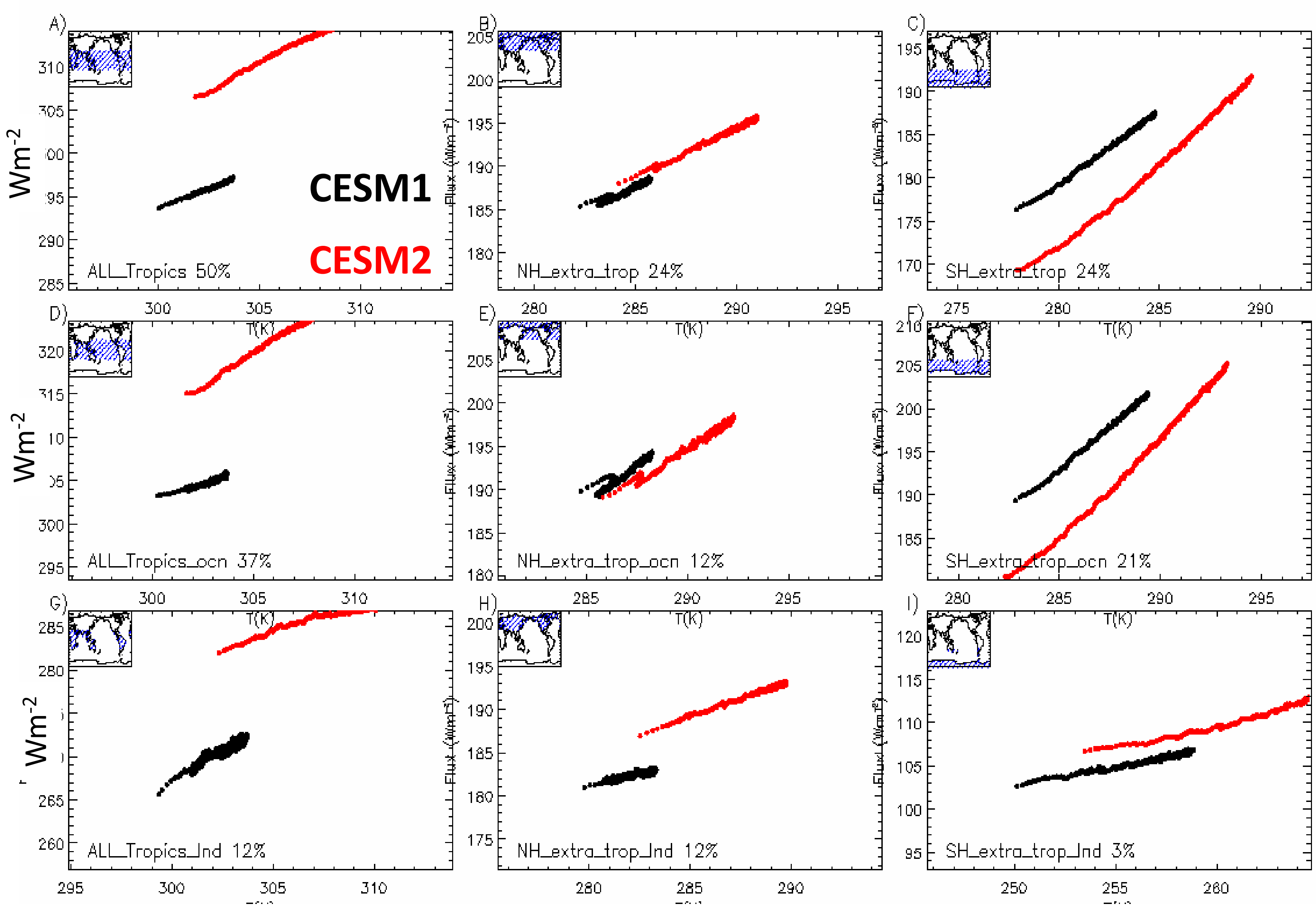
Regression of local $SW_{net}$ vs global $T_s$



Regional time-series of $T_s$



$SW_{net}$ vs $T_s$ (regional)



Global mean S

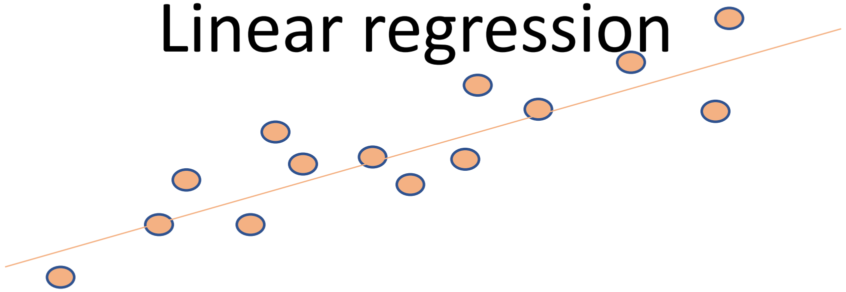
$$\overline{\mathcal{S}} = \sum_{k}^{N} a_k \tilde{\mathcal{S}}_k(\tilde{T}_{s;k}, \quad , \dots )$$

Regional flux, e.g. net SW $\tilde{\mathcal{S}}_k$, depends on regional $T_k$ and possibly other variables. $a_k$ is areal fraction of region $k$.

$$\frac{\delta \overline{\mathcal{S}}}{\delta \overline{T}_s} \approx \frac{\sum_k^N a_k \frac{\partial \tilde{\mathcal{S}}_k}{\partial \tilde{T}_{s;k}} \frac{\partial \tilde{T}_{s;k}}{\partial u} \delta u}{\sum_l^N a_l \frac{\partial \tilde{T}_{s;l}}{\partial u} \delta u}$$

Global “sensitivity” ($Wm^{-2}K^{-1}$) depends on regional sensitivities and regional trends of $T_k$ . $u$ is parameter e.g. time or global mean T.

Linear regression



$$B \approx \frac{\sum_k^N a_k \; B_k \; C_k}{\sum_l^N a_l C_l}$$

$B_k$ is regression slope of $S_k$ vs $T_k$. $C_{k,l}$ are slopes of $T_{k,l}$ vs global T. ***B*** is global regression slope.

$$B \approx \sum_{k}^{N} \left( \frac{a_k \; C_k}{\sum_l^N a_l C_l} \right) B_k$$

Global regression slope ***B*** ends up as weighted sum of regional $B_k$’s

Global mean S

$$\overline{\mathcal{S}} = \sum_k^N a_k \tilde{\mathcal{S}}_k(\tilde{T}_{s;k}, \quad , \dots )$$

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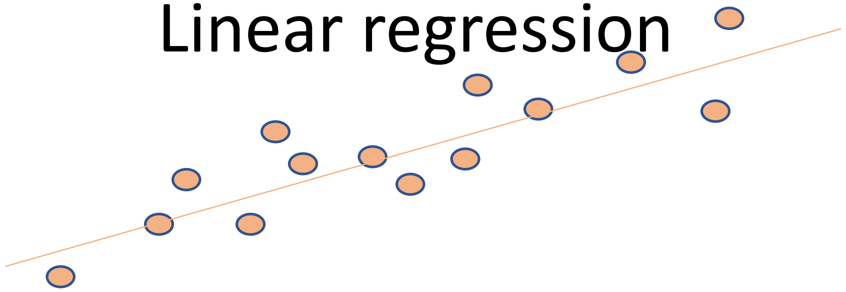
## Linear regression



$$B \approx \frac{\sum_k^N a_k B_k C_k}{\sum_l^N a_l C_l}$$

$B_k$ is regression slope of $S_k$ vs $T_k$. $C_{k,l}$ are slopes of $T_{k,l}$ vs global T. ***B*** is global regression slope.

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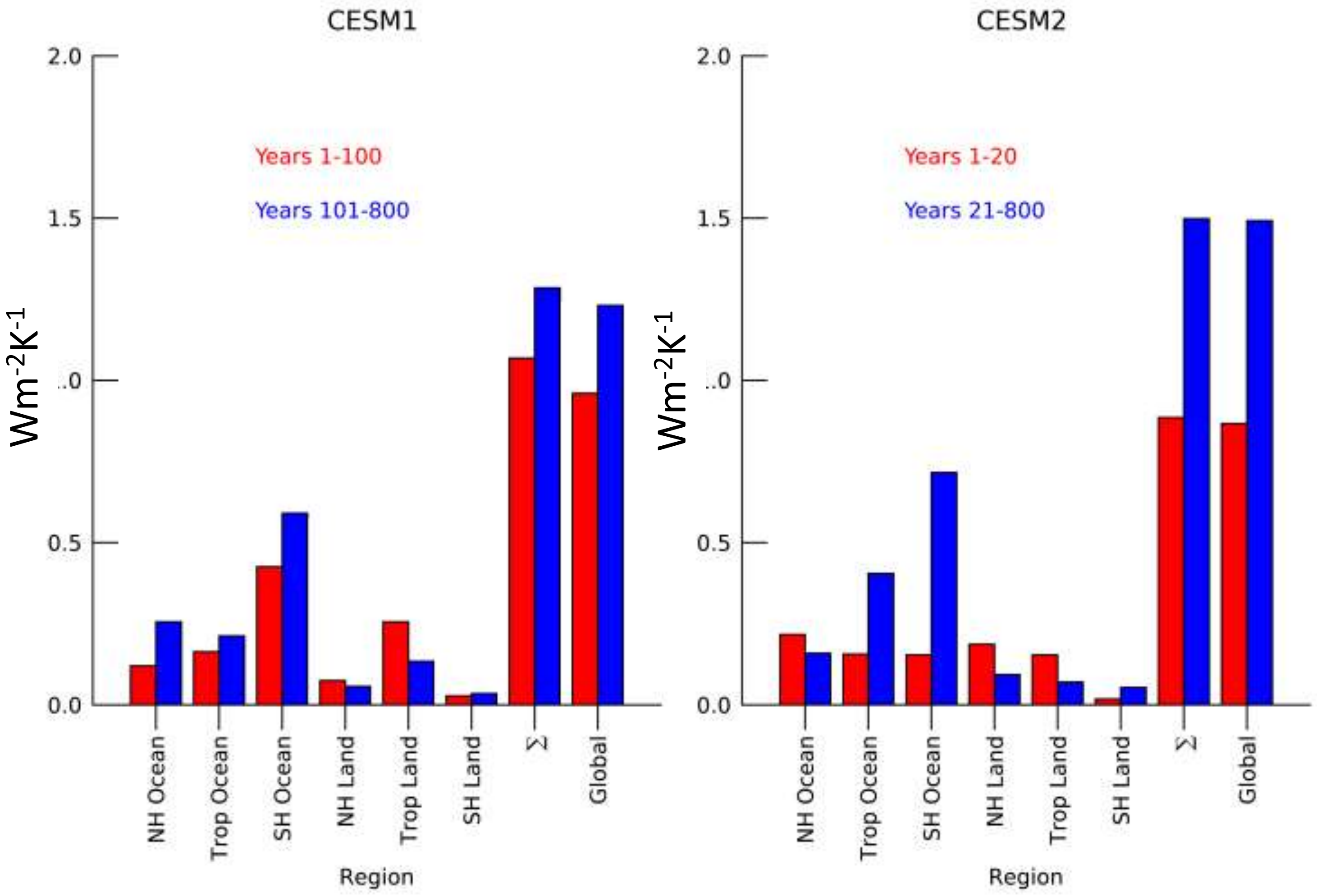
Global regression slope ***B*** ends up as weighted sum of regional $B_k$'s

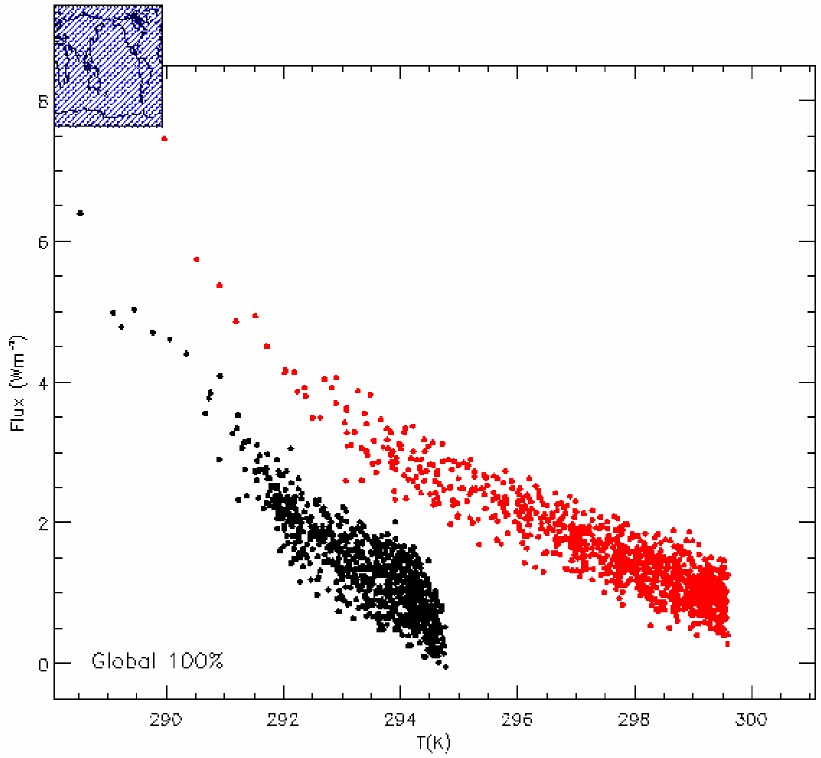
$$\left(\frac{a_k\ C_k}{\sum_l^N a_l C_l}\right) B_k$$

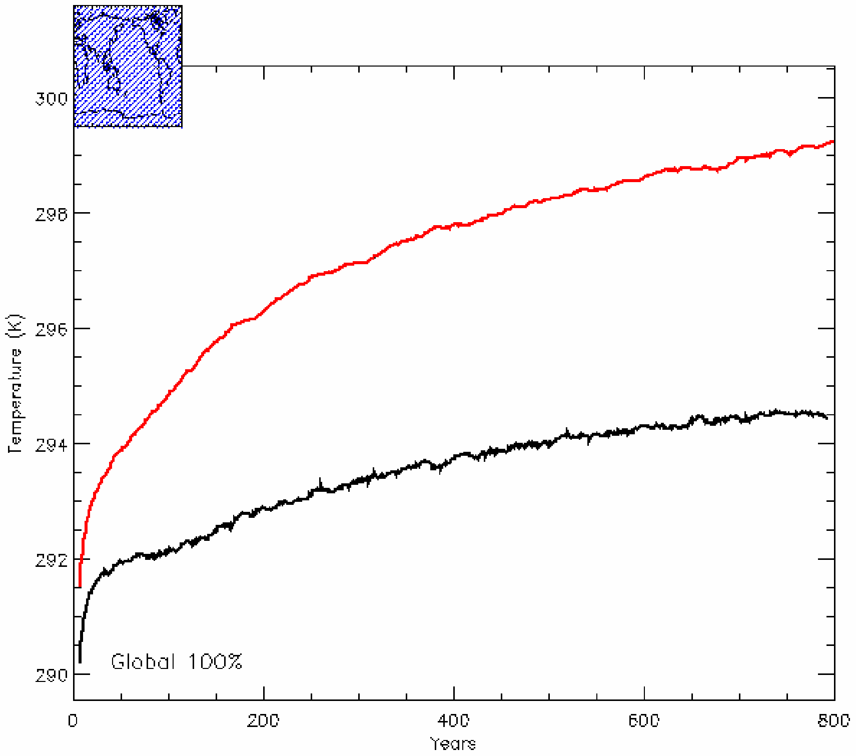


# Time evolution of $T_s$

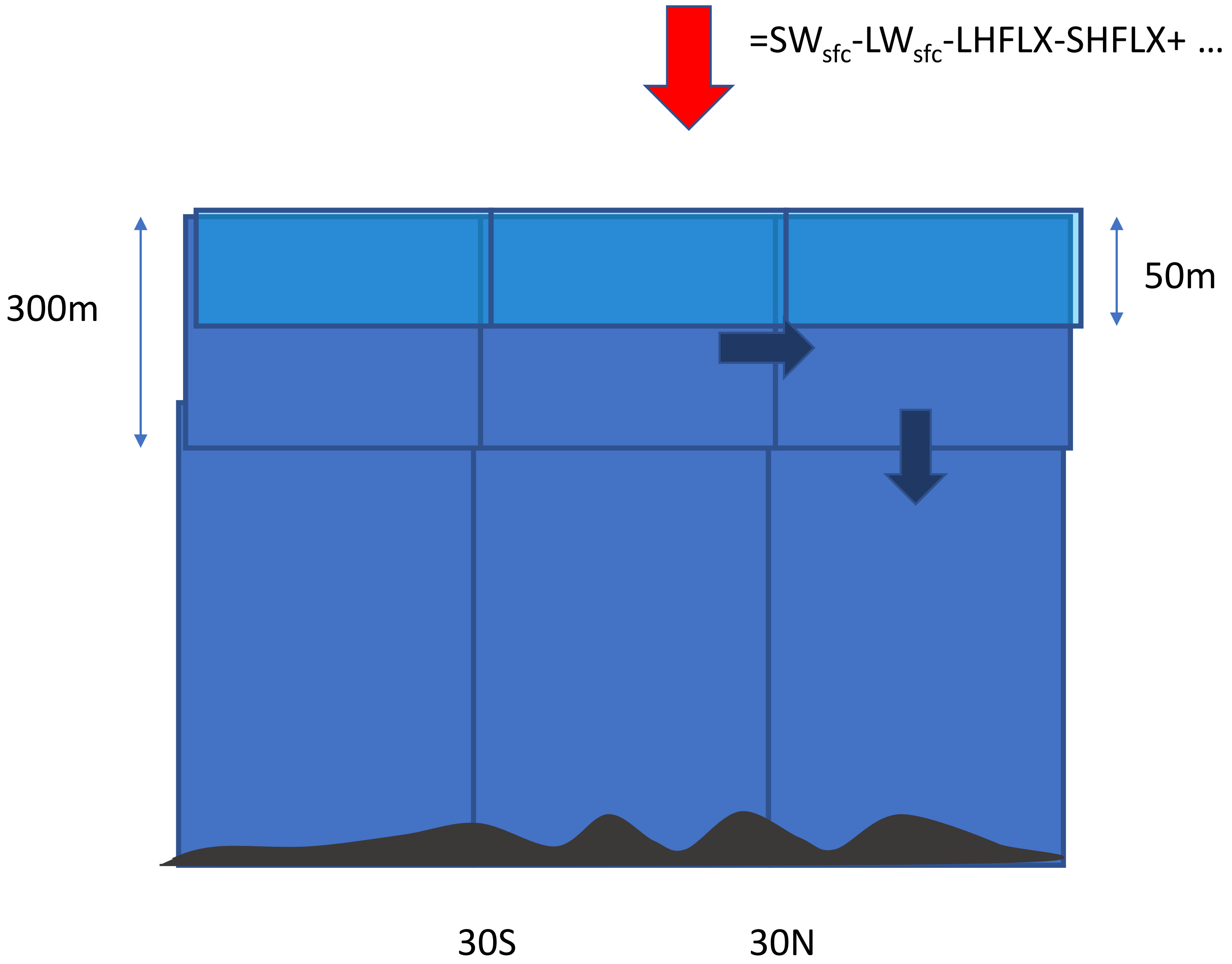
**CESM1**

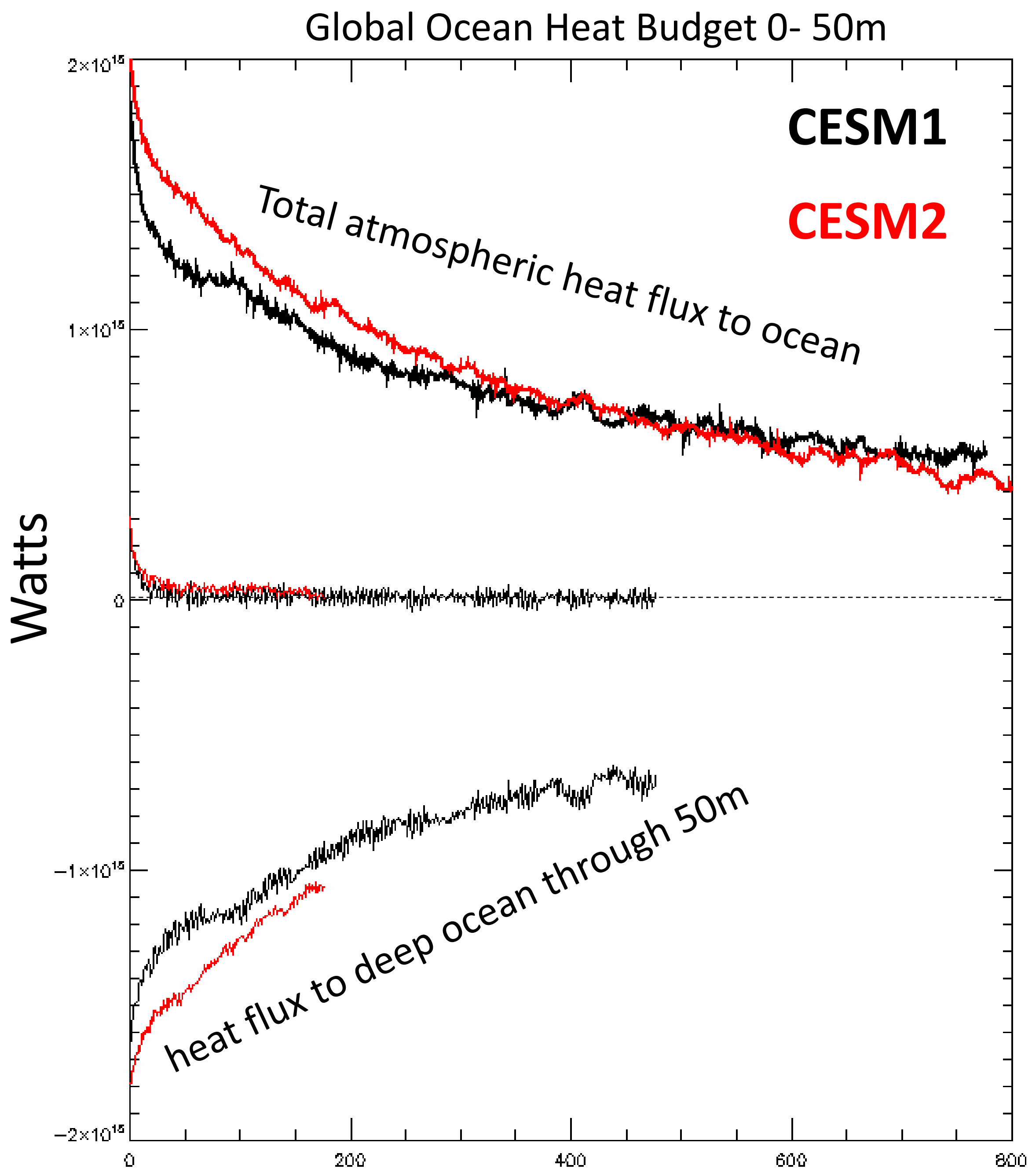
**CESM2**



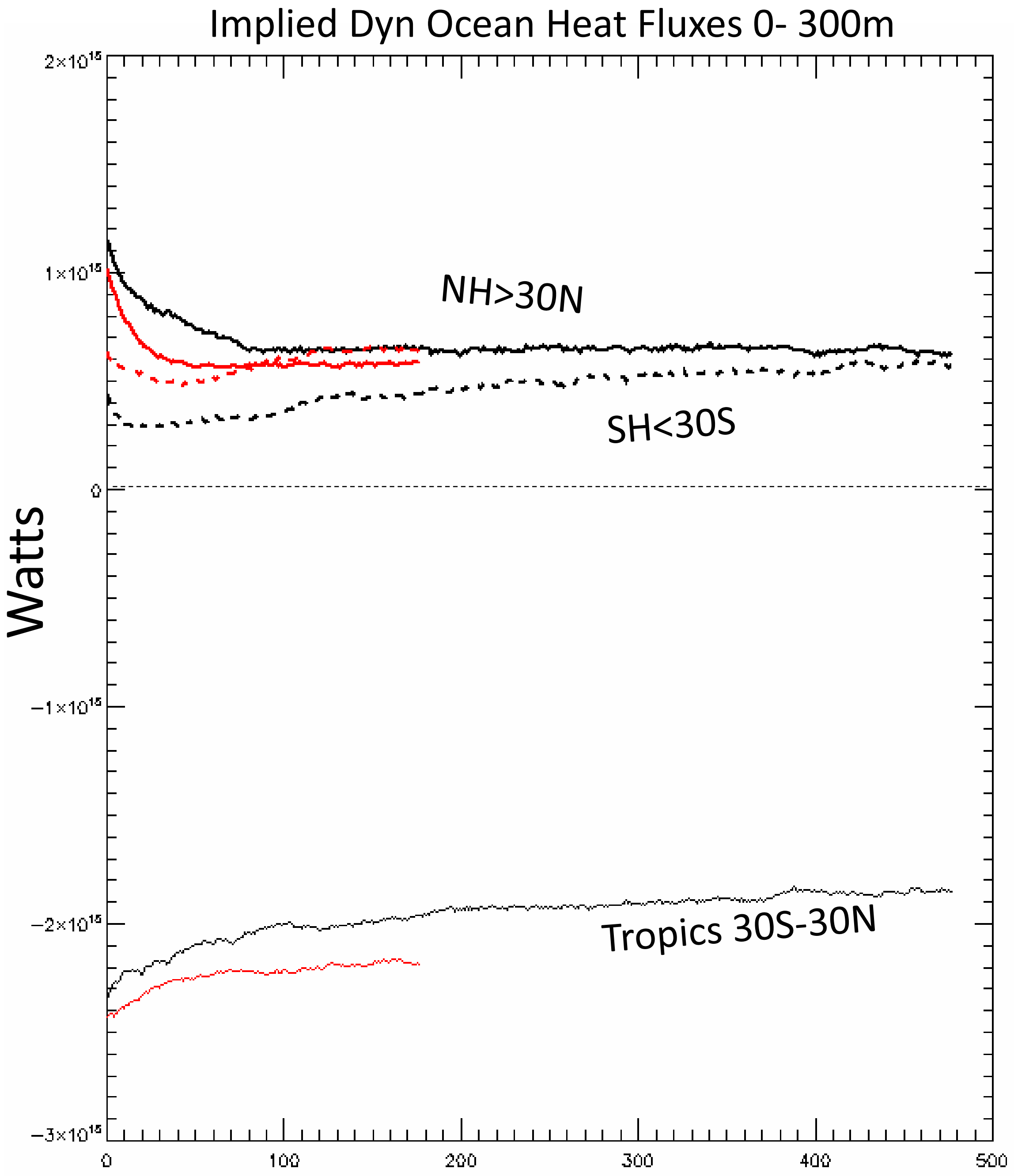



# Ocean heat budget and fluxes



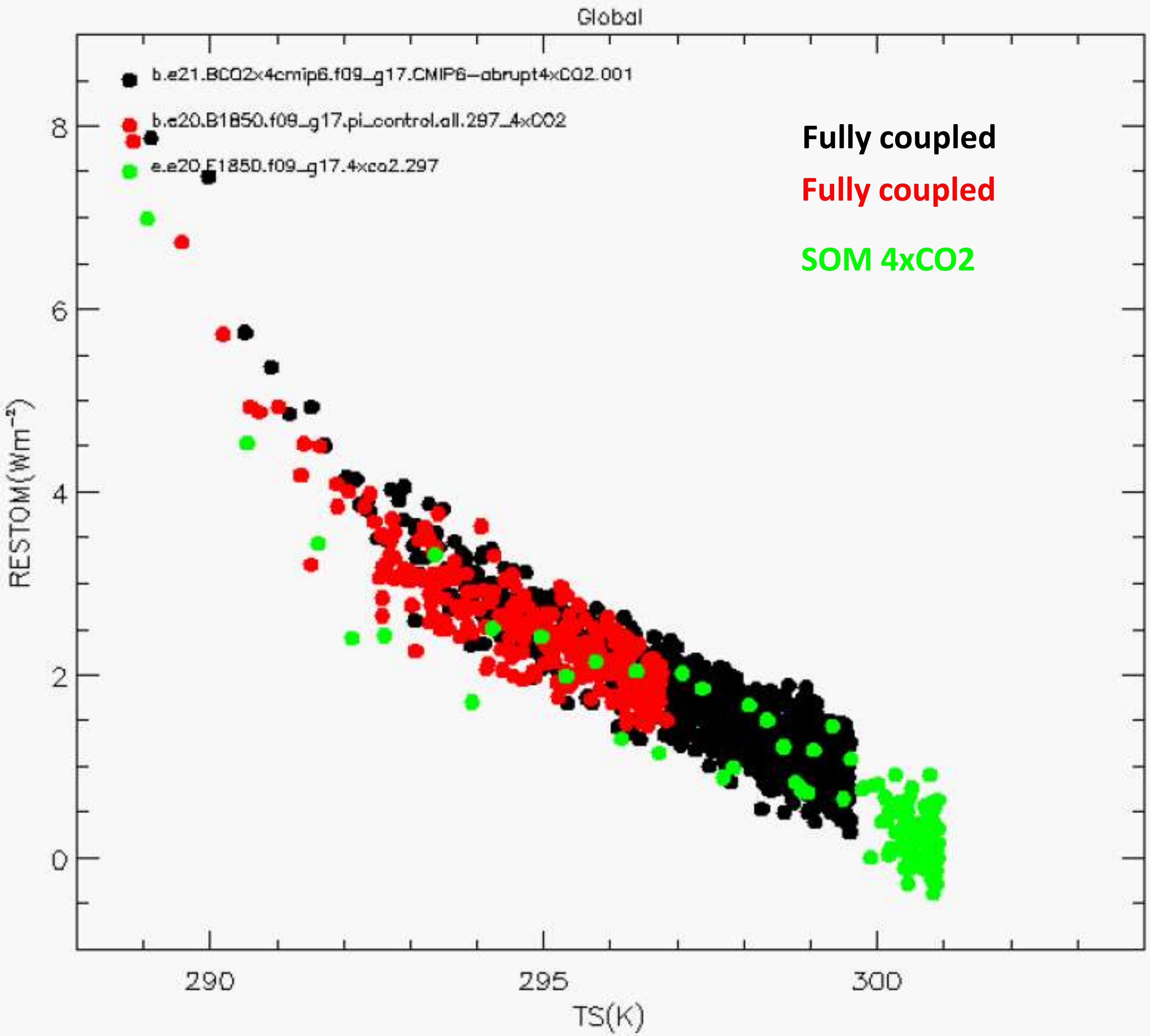


Global Ocean Heat Budget 0- 50m
CESM1
CESM2
Total atmospheric heat flux to ocean
heat flux to deep ocean through 50m
Watts
2×10^15
1×10^15
0
−1×10^15
−2×10^15
0
200
400
600
800

Implied Dyn Ocean Heat Fluxes 0- 300m
NH>30N
SH<30S
Tropics 30S-30N
Watts
2×10^15
1×10^15
0
−1×10^15
−2×10^15
−3×10^15
0
100
200
300
400
500

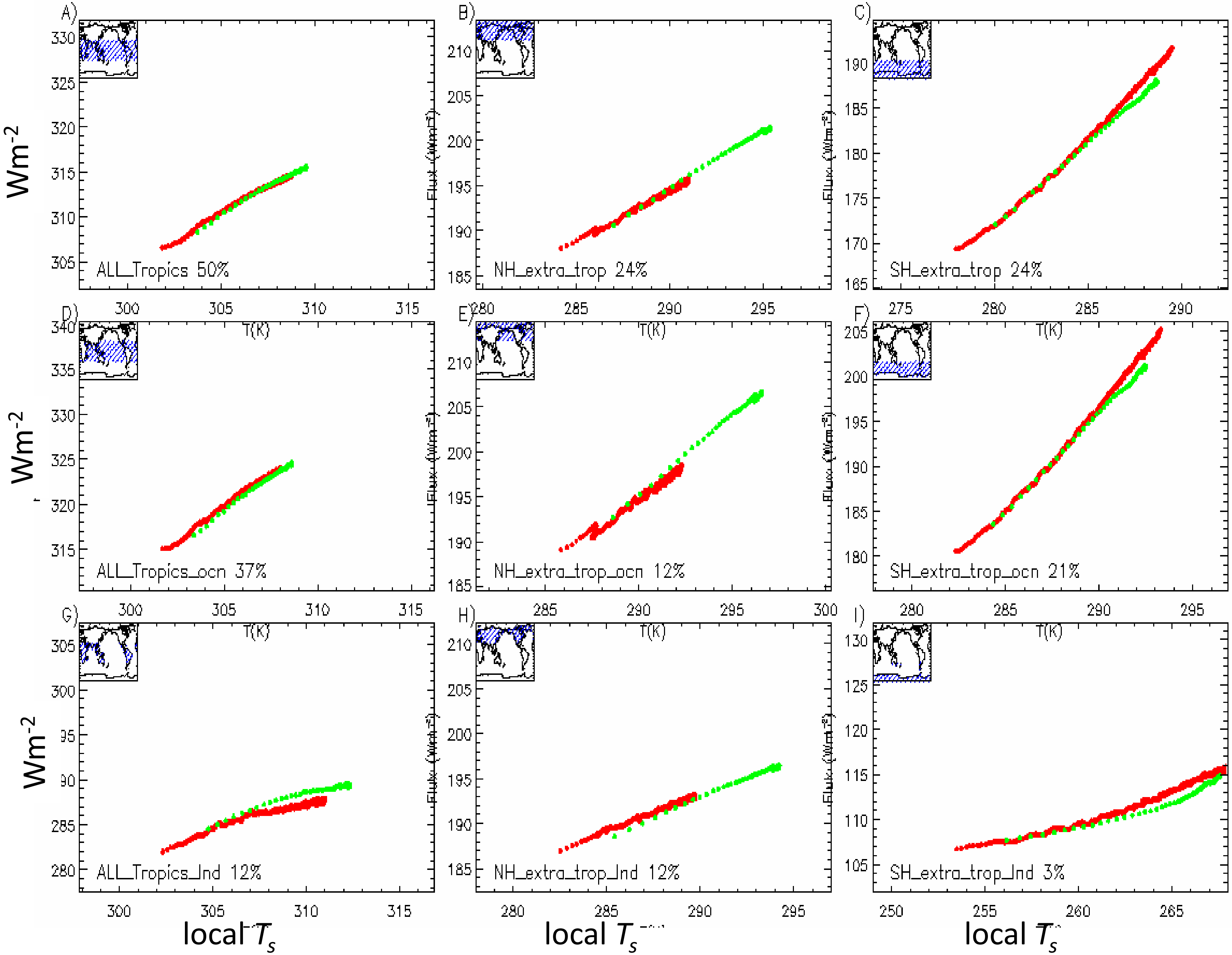
# But does the ocean matter in the end?

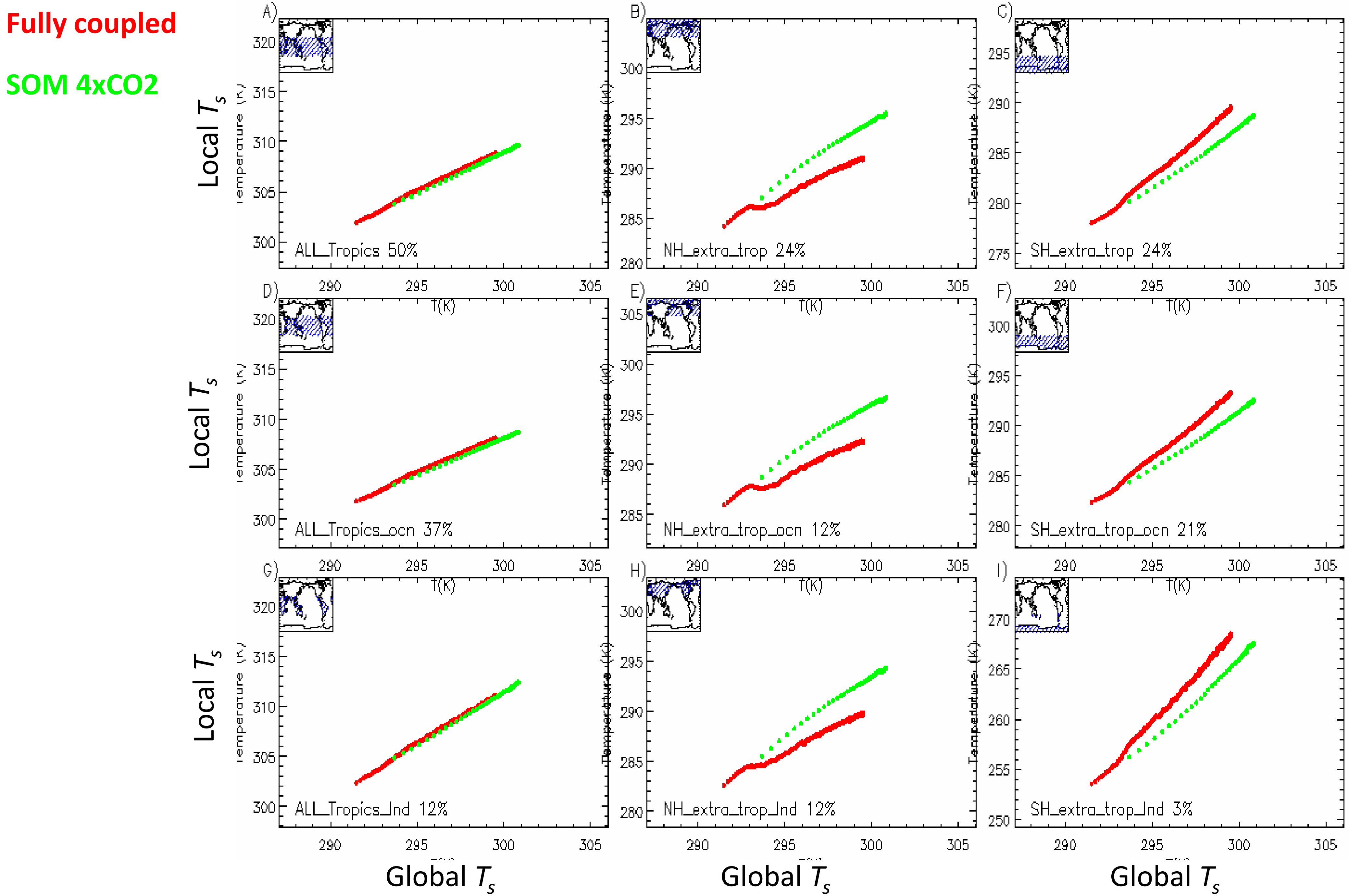

Global
b.e21.BCO2x4cmip6.f09_g17.CMIP6-abrupt4xCO2.001
b.e20.B1850.f09_g17.pi_control.all.297_4xCO2
e.e20.E1850.f09_g17.4xco2.297
Fully coupled
Fully coupled
SOM 4xCO2
RESTOM(Wm⁻²)
TS(K)
0
2
4
6
8
290
295
300

**Fully coupled**

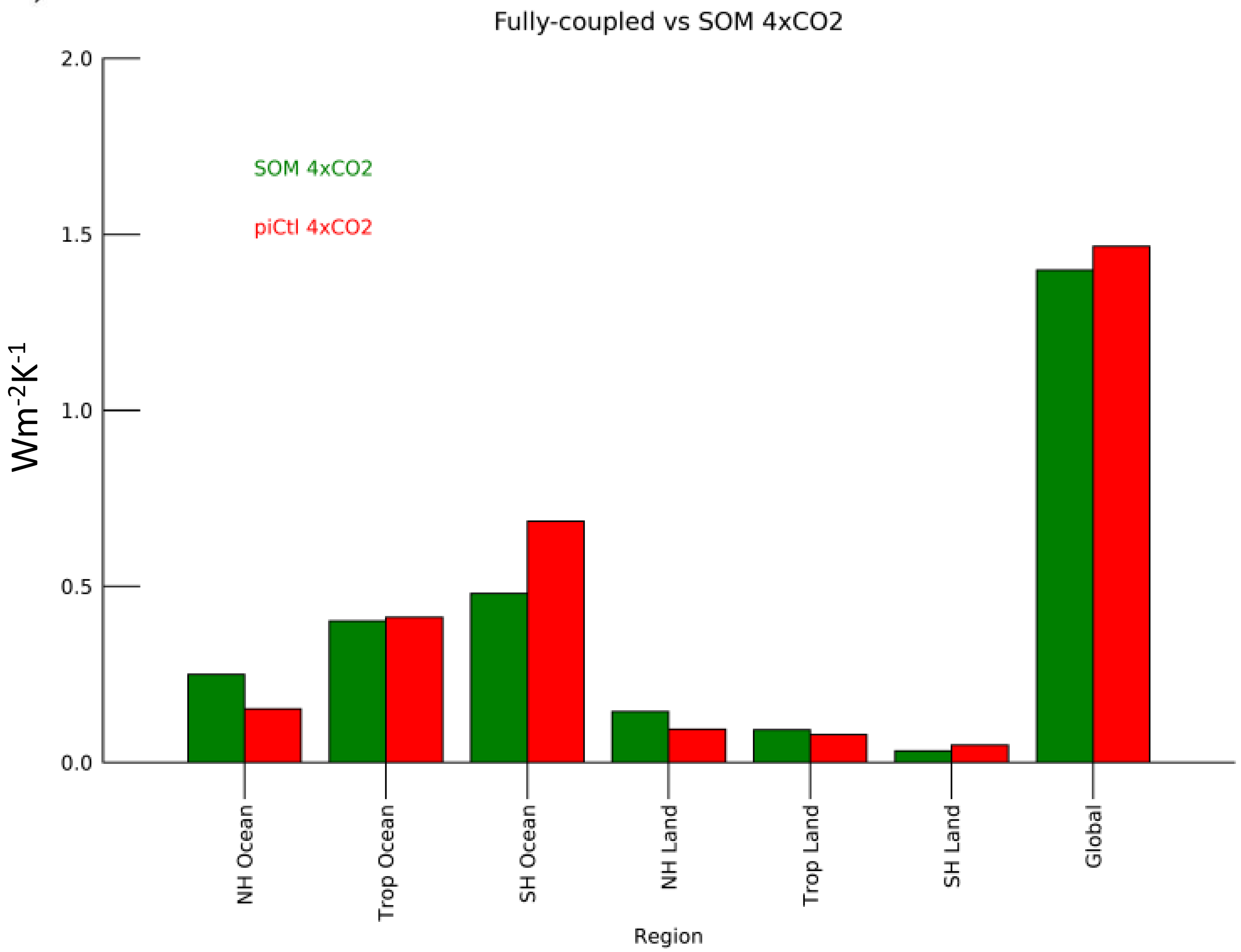
**SOM 4xCO2**

Shortwave vs Local T




Fully coupled
SOM 4xCO2
A)
ALL_Tropics 50%
B)
NH_extra_trop 24%
C)
SH_extra_trop 24%
D)
ALL_Tropics_ocn 37%
E)
NH_extra_trop_ocn 12%
F)
SH_extra_trop_ocn 21%
G)
ALL_Tropics_lnd 12%
H)
NH_extra_trop_lnd 12%
I)
SH_extra_trop_lnd 3%
Local $T_s$
Global $T_s$
T(K)

$$\left(\frac{a_k\ C_k}{\sum_l^N a_l C_l}\right) B_k$$

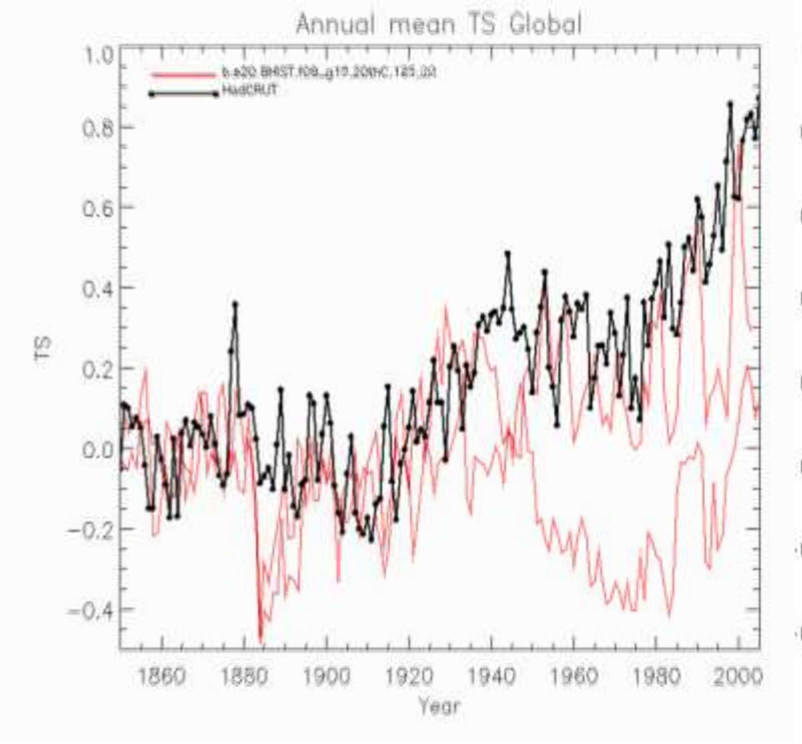


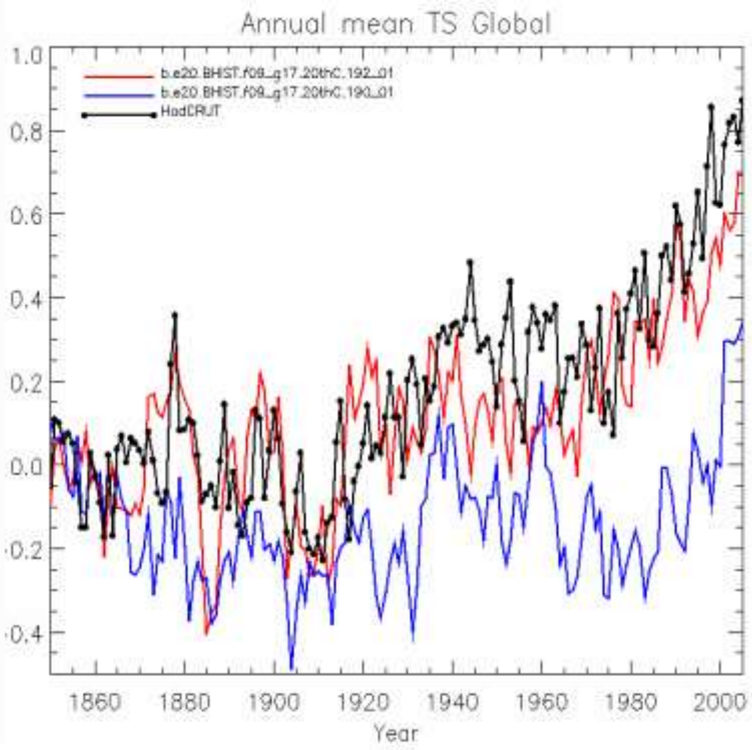
# How did this happen?

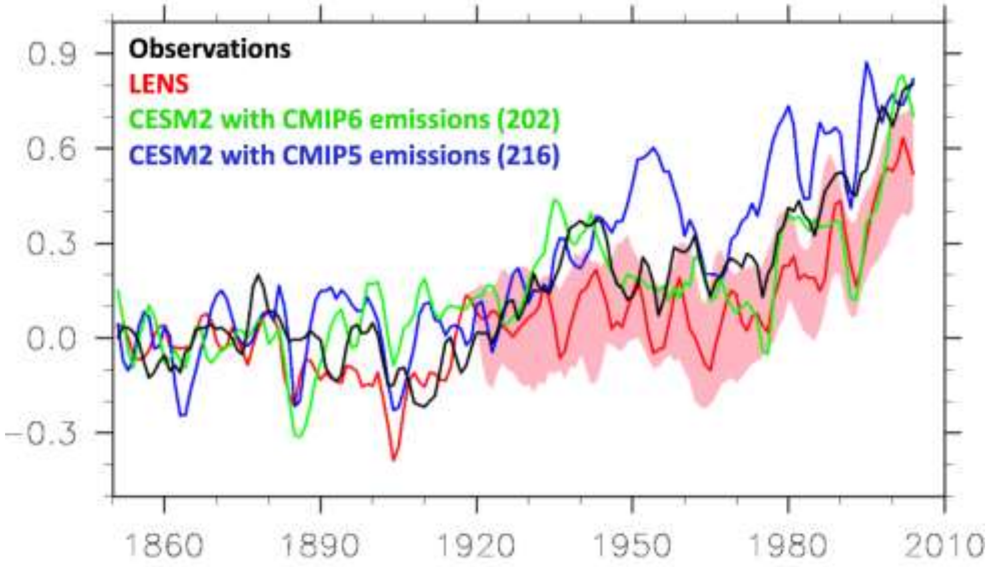
- Earlier development versions of CESM2 had much lower climate sensitivity (~4.2K)
  - These had CLUBB MG2 microphysics etc., but different atmosphere and land tuning.

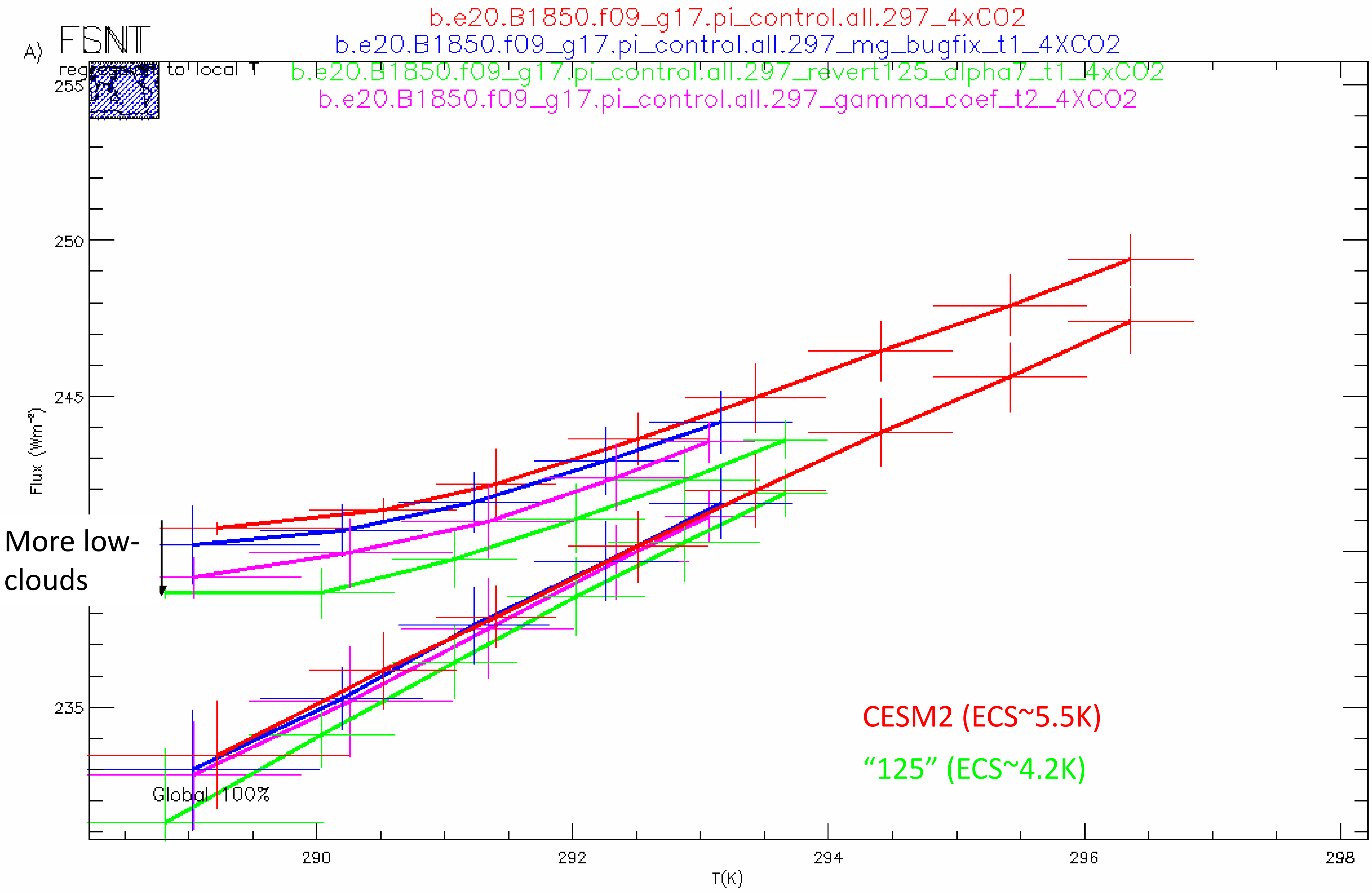
# Pairs of runs with CESM2 development versions swapping CMIP5 and CMIP6 aerosol forcing data

| | | | |
|---|---|---|---|
| **Radiation Balance point:** | **236.5 Wm-2** | **236.4 Wm-2** | **238.6 Wm-2** |
| **ECS:** | **4.2K** | **?? K** | **5.5K** |




A) FSNT
regression to local T
b.e20.B1850.f09_g17.pi_control.all.297_4xCO2
b.e20.B1850.f09_g17.pi_control.all.297_mg_bugfix_t1_4XCO2
b.e20.B1850.f09_g17.pi_control.all.297_revert125_alpha7_t1_4xCO2
b.e20.B1850.f09_g17.pi_control.all.297_gamma_coef_t2_4XCO2
255
250
245
235
Flux (Wm⁻²)
More low-clouds
Global 100%
CESM2 (ECS~5.5K)
“125” (ECS~4.2K)
290
292
294
296
298
T(K)

# Summary

- CESM2 behavior different from CESM1 (but not as much as we thought)
- Ocean transport controls time evolution of $4xCO_2$ coupled runs
- Net warming amount ***not*** controlled by ocean (at least not in CESM2)
- Is increased sensitivity simply caused by thinner low clouds?