

# 20<sup>th</sup> Century temperatures and climate sensitivity in the Community Earth System Model version 2 (CESM2)

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# Background: CESM2.x

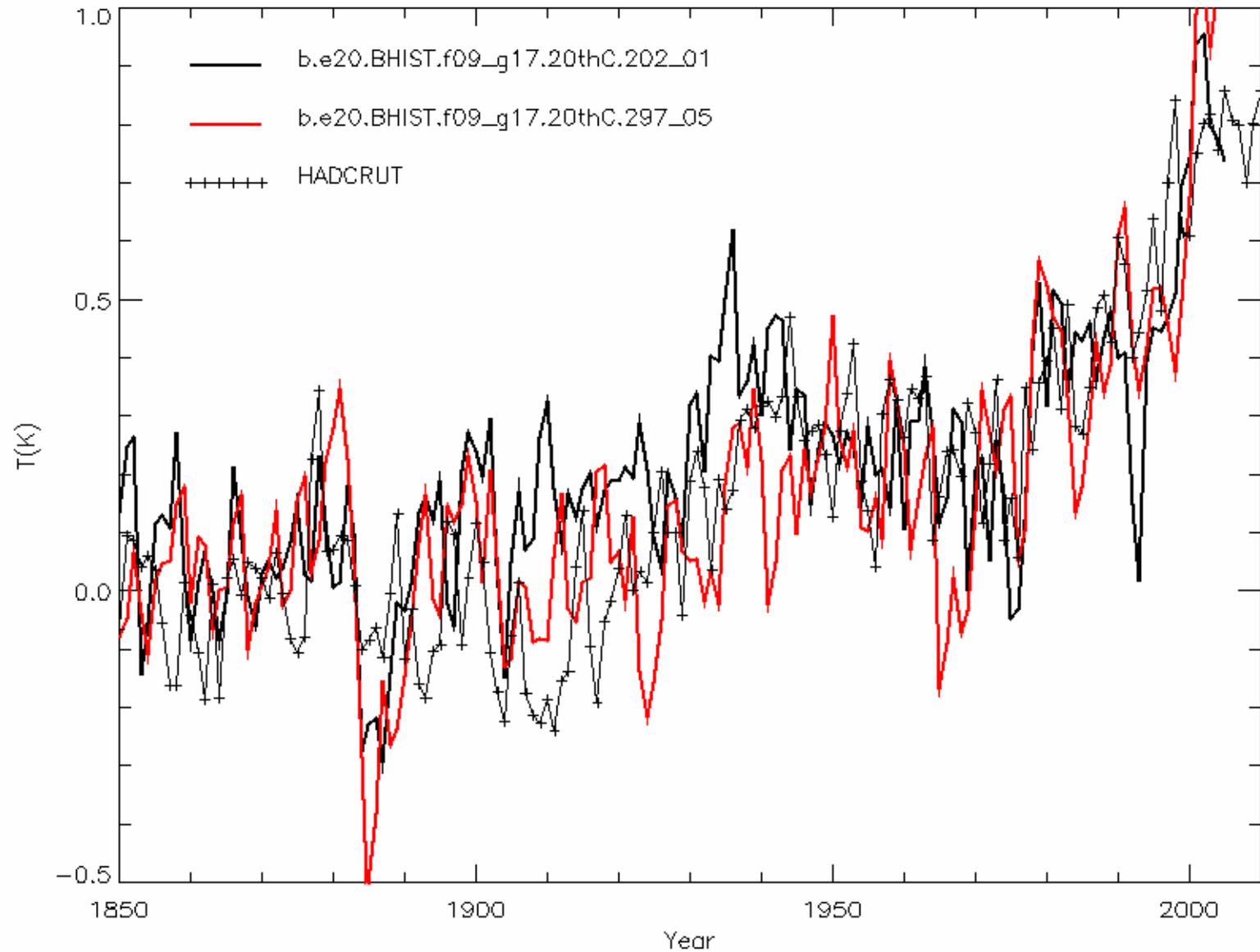
- CESM2 atmosphere includes massive parameterization changes w/ respect to CESM1
- CESM2.0 frozen in June
- Initial CMIP6 “DECK” simulations underway
- Bit-for-bit CESM2.1 to be released later this fall. *Mods for output, experimental setups requested by individual MIPs*

# Background: Experimental setups

- **1850 “pre-industrial (PI)” control:** Fix greenhouse gases, aerosol emissions, land use etc. at someone’s best guess of conditions in 1850 (and before). Run long enough that stable climate is obtained – no global TS trends, TOA rad balance near zero.
- **20<sup>th</sup> Century “historical” run:** Initialized from stable 1850 control. Forcings, aerosols, GHGs, land-use, volcanoes ... specified according to estimates of actual historical evolution from 1850 to present. *“Nice” if model reproduces observed/estimated record of global temperatures.*
- **2xCO<sub>2</sub>, 4xCO<sub>2</sub> runs:** Initialized from stable 1850 control. Atmospheric CO<sub>2</sub> concentrations doubled/quadrupled. Run for 10-100 years.

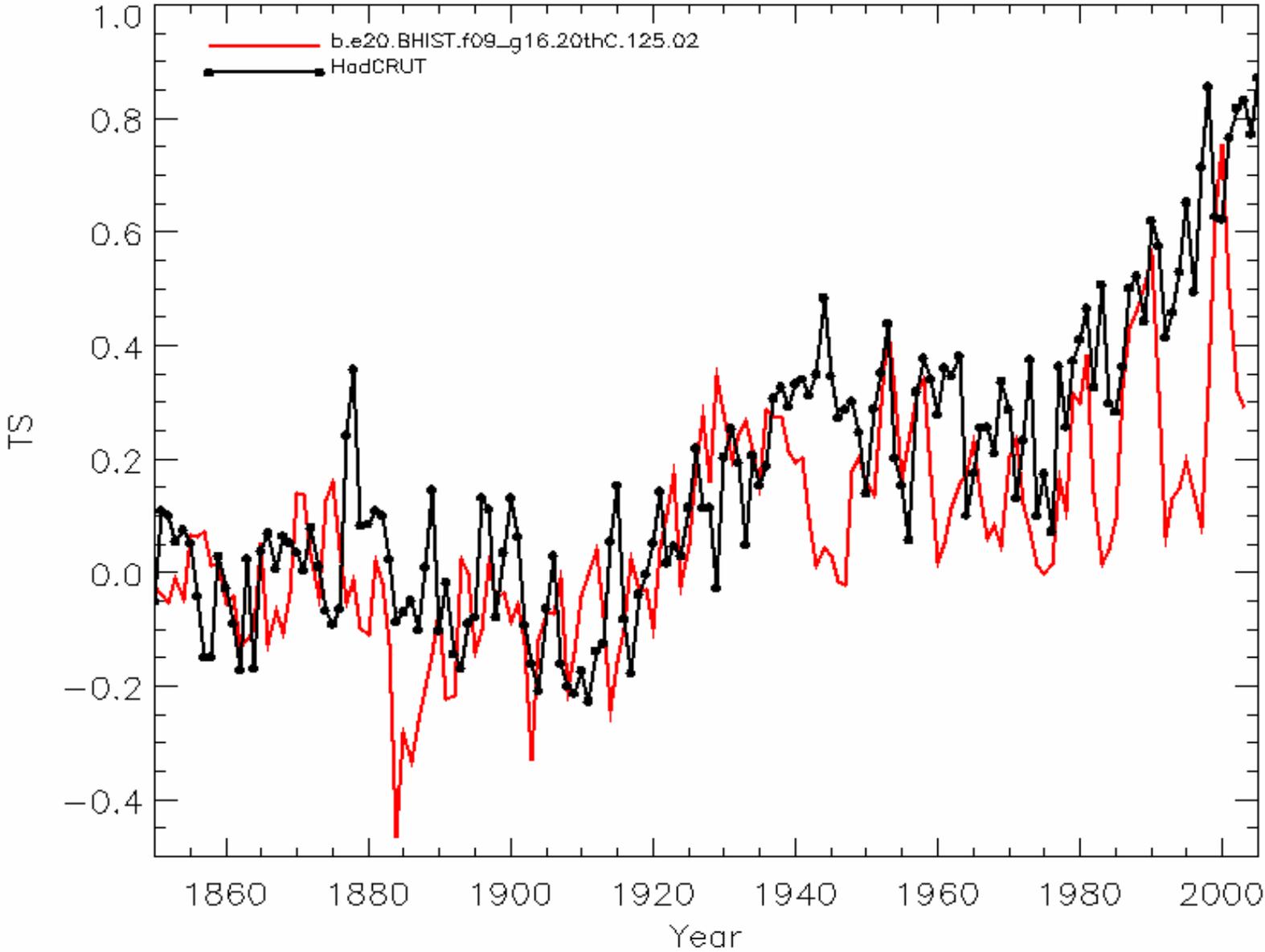
Where we are now

**297 = 202 + numerous fixes, incl. CLUBB water vapor flux for conservation, solubility changes, surface flux modifications ...**

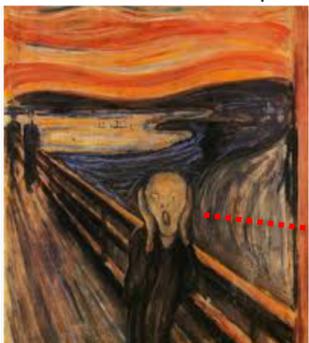
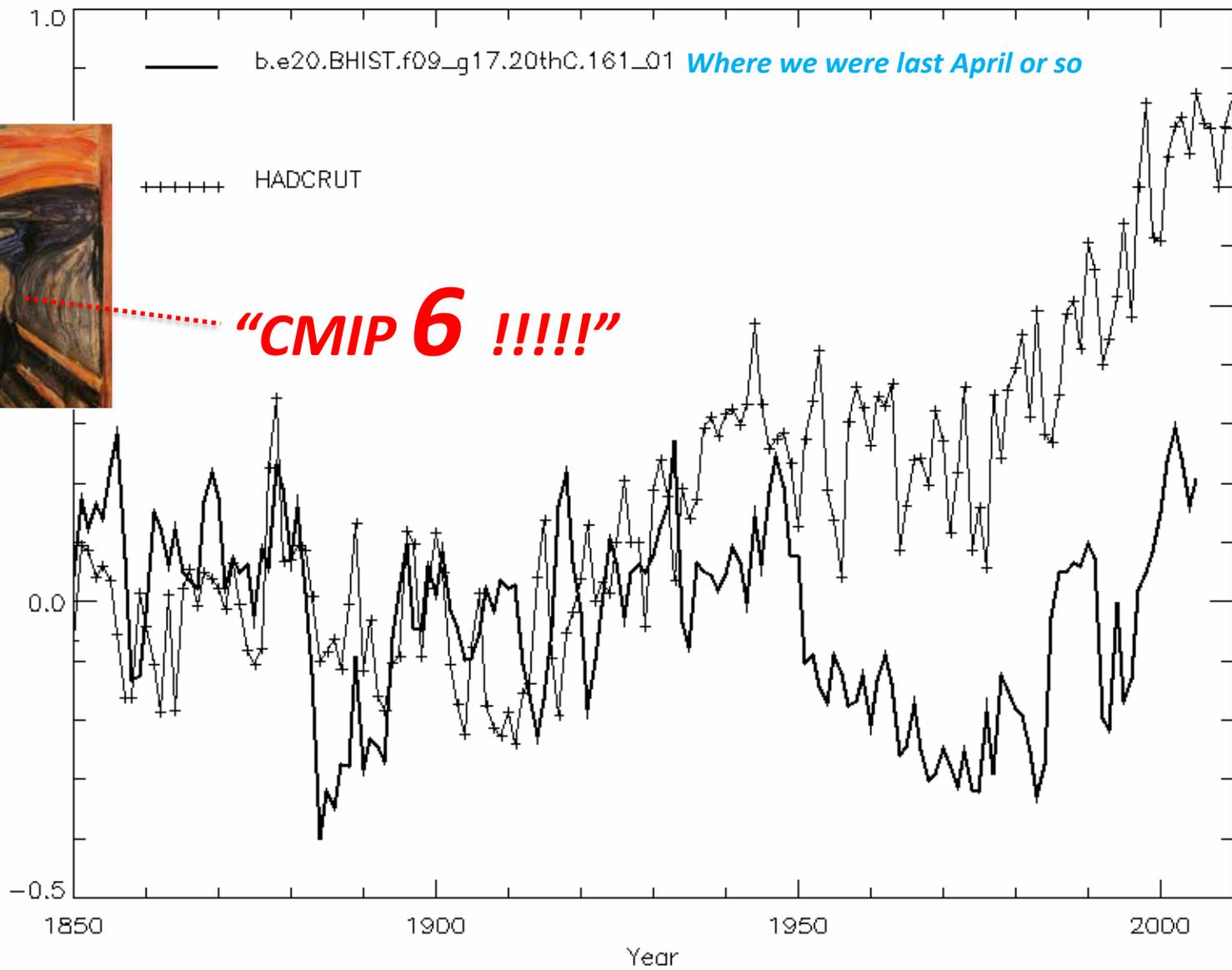


Where we were in March 2017 (18+ months ago)

### Annual mean TS Global



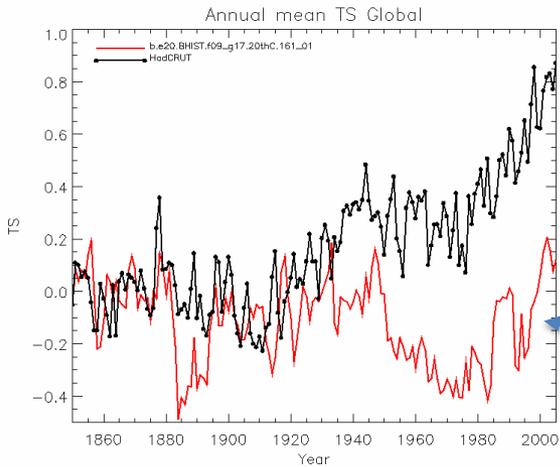
Where we were in April 2017 (18+ months ago)



**“CMIP 6 !!!!!”**

*Where we were last April or so*

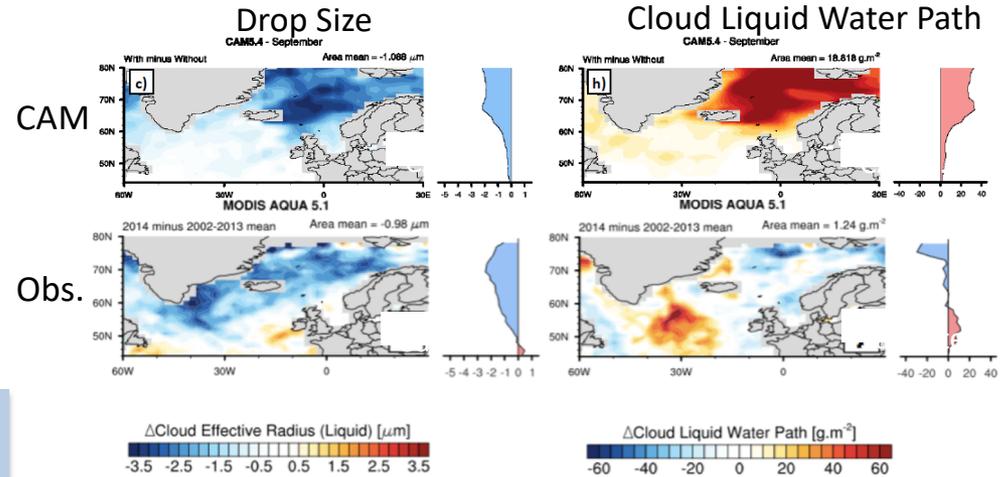
**Exp. 161 (Model ca. 5/2017;  
emissions=CMIP6**



!!!

**Possible Culprit: 2<sup>nd</sup> aerosol (aka “lifetime”) effect overestimated in CAM**

Figure from Malavelle et al 2017, Nature



Anomalies of Drop Size and Cloud Water for October 2014 from long term mean. CAM5.4 and CAM5.5 show big increases in cloud water with elevated aerosols. Here: an example from the Holuhraun eruption in Iceland in 2014. Smaller drops are seen, but no increase in cloud water from Satellites (MODIS)

$$Au = kL^a N^b$$

$Au$ =autoconversion rate

$L$ =cloud liquid (kg/kg)

$N$ =droplet number (#/kg)

Seifert&Beheng (SB):  $a=4, b=-2$

Khairoutdinov&Kogan (KK);  $a=2.67, b=-1.79$

*In consultation with panel of microphysics experts CAM6 SB autoconversion scheme was replaced with KK and retuned. E3SM approach followed*

- **R. Wood:**  $b$  in KK could be as weak as -0.9.
- Current compromise  $b=-1.1$ .

Other tunable numbers (KK)

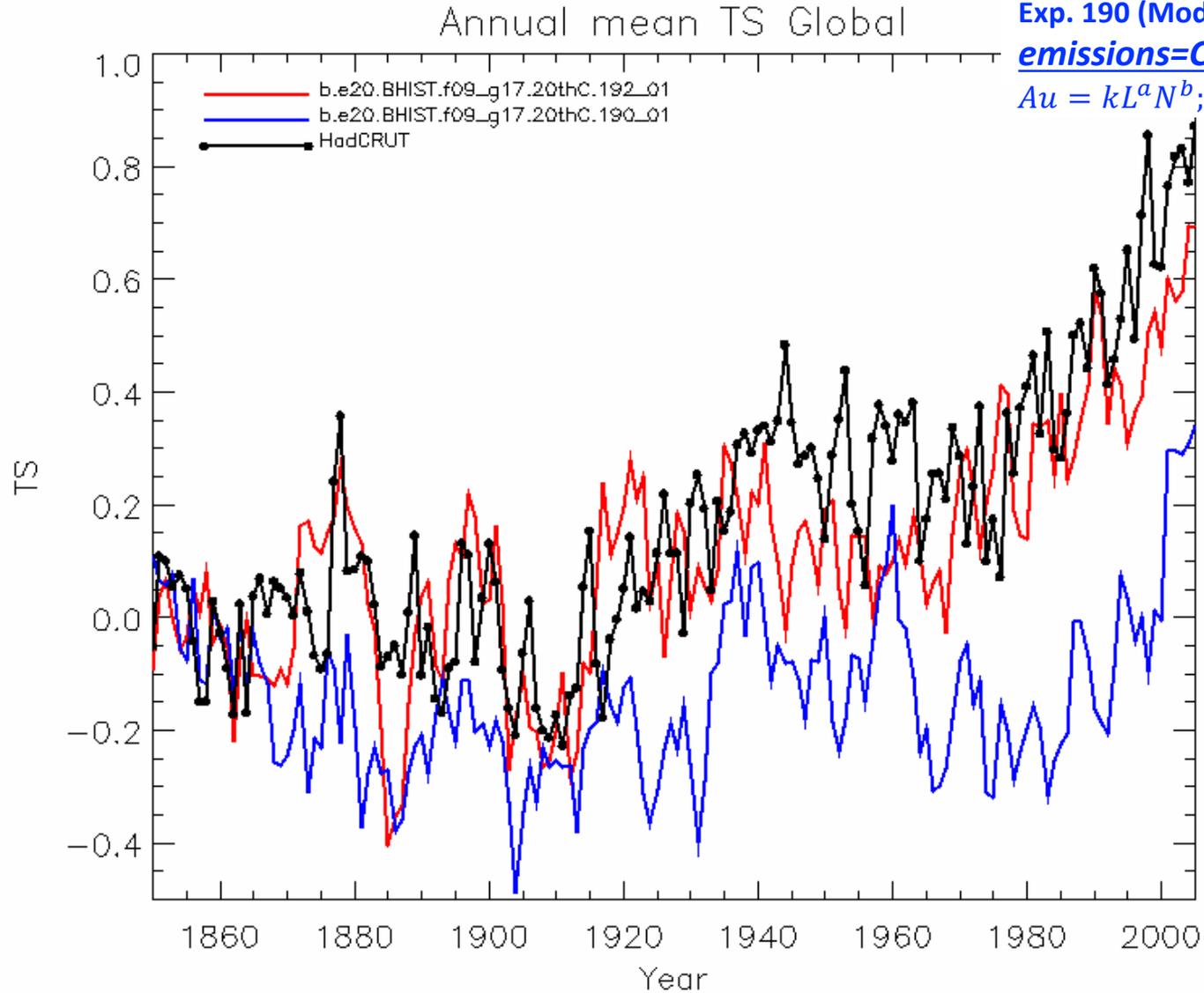
$k=0.01k_0, k=0.02k_0$  ( $k_0=1350$ )

“relative dispersion” can affect  $N$  entering  $Au$  calculation

... but simulation forced with CMIP6 emissions  
still doesn't warm enough (w/resp HadCRUT)

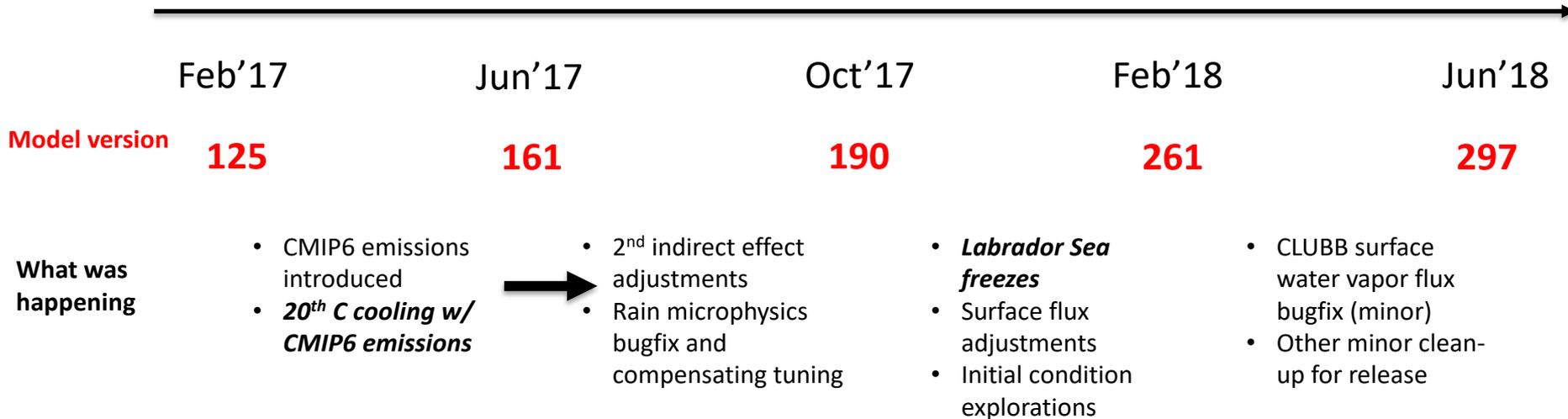
Exp. 192 (Model ca. 9/2017;  
*emissions=CMIP5*  
 $Au = kL^a N^b$ ; with  $b = -1.1$ )

Exp. 190 (Model ca. 9/2017;  
*emissions=CMIP6*  
 $Au = kL^a N^b$ ; with  $b = -1.1$ )



# Results from CESM(2- $\epsilon$ ) $_{\epsilon \rightarrow 0}$

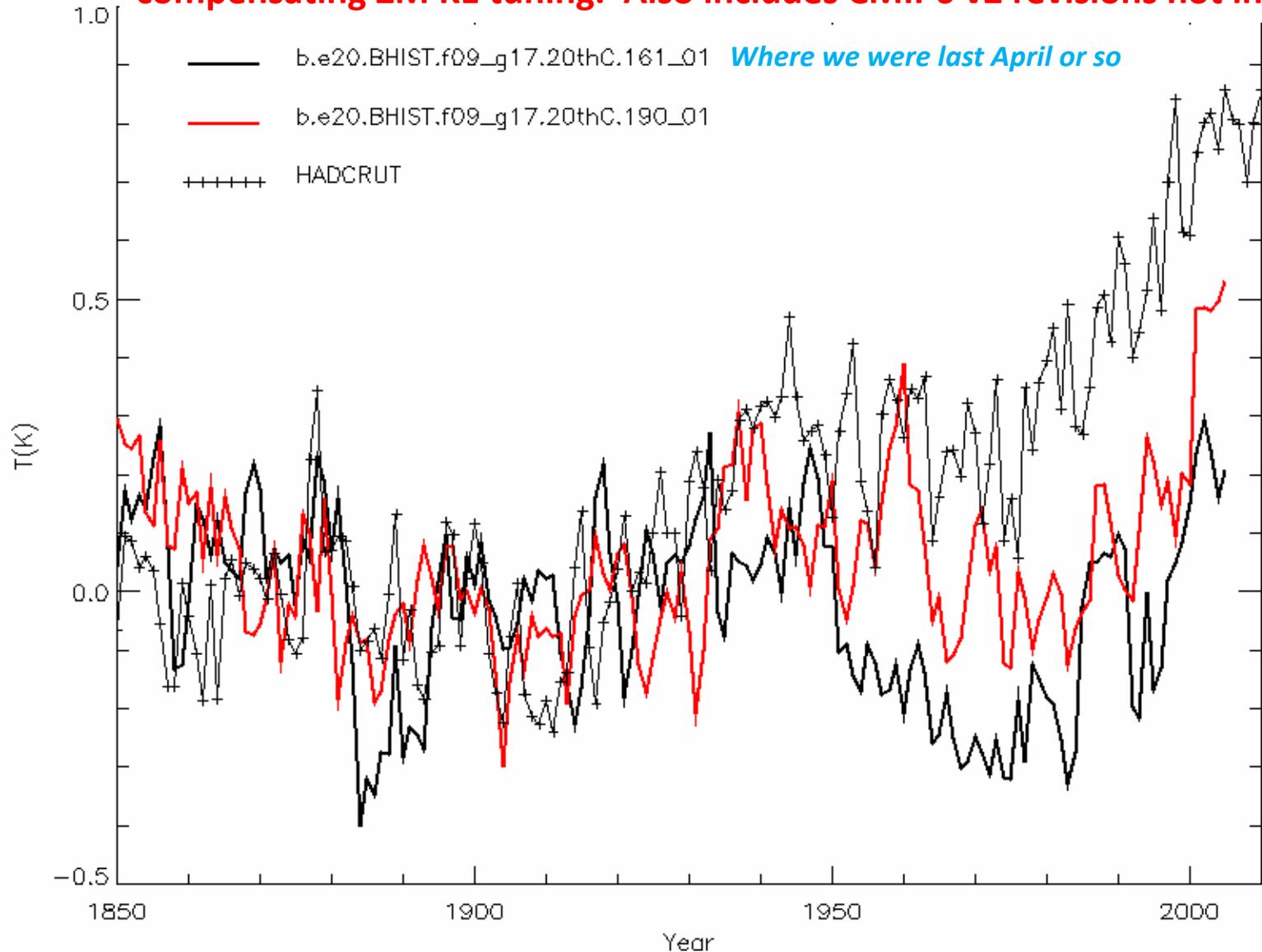
## Approximate Timeline



125 w/ CMIP5 emissions data produced very good simulations

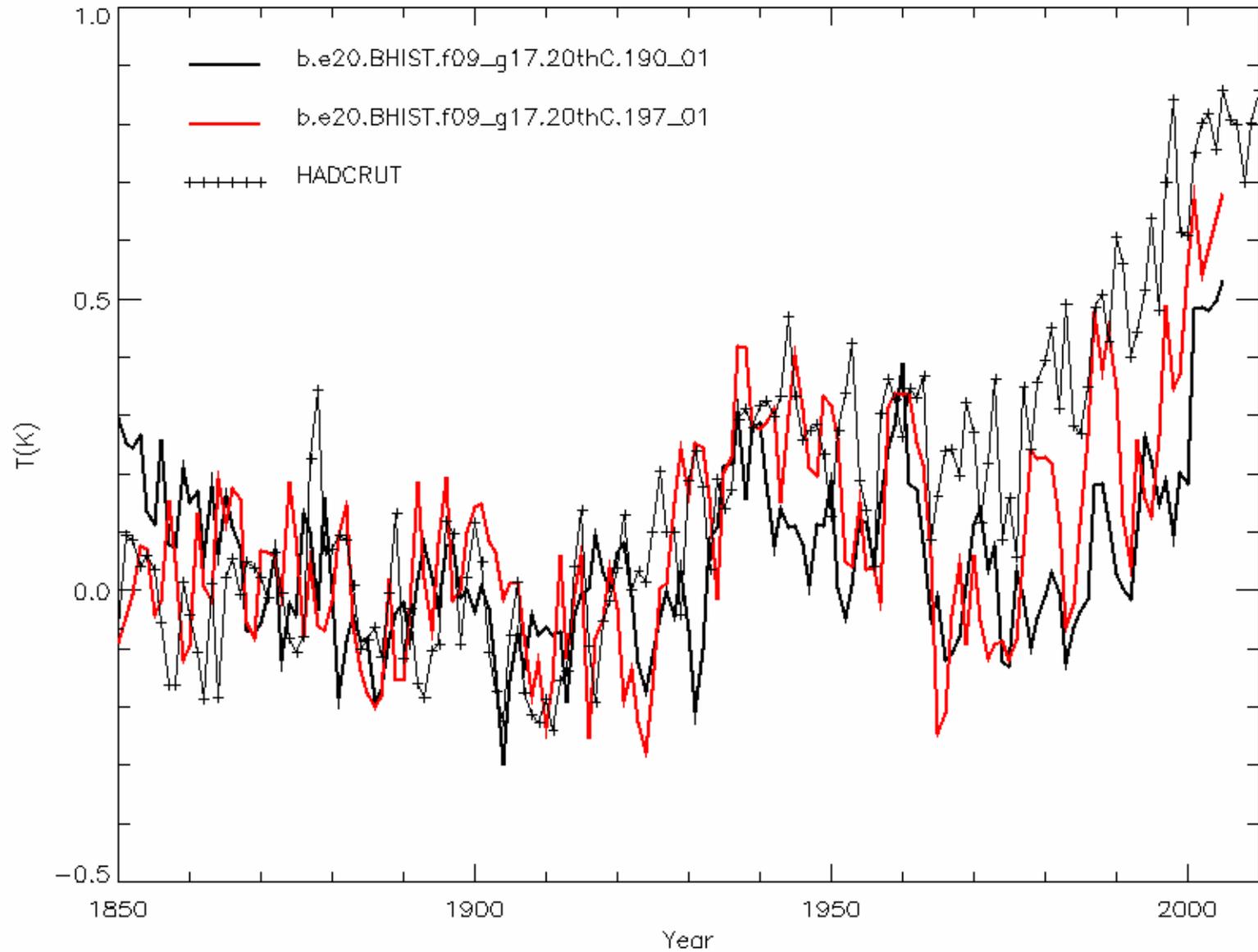
**Significant steps in evolution of 20th C global TS.  
Following slides show evolution from 161. **Red  
curve shows effect of modification** w/ respect to  
previous model (black curve)**

**190 = 161 + All autoconversion mods added, MG2 bug fixed, but no compensating ZM KE tuning. Also includes CMIP6 v2 revisions not in 161**

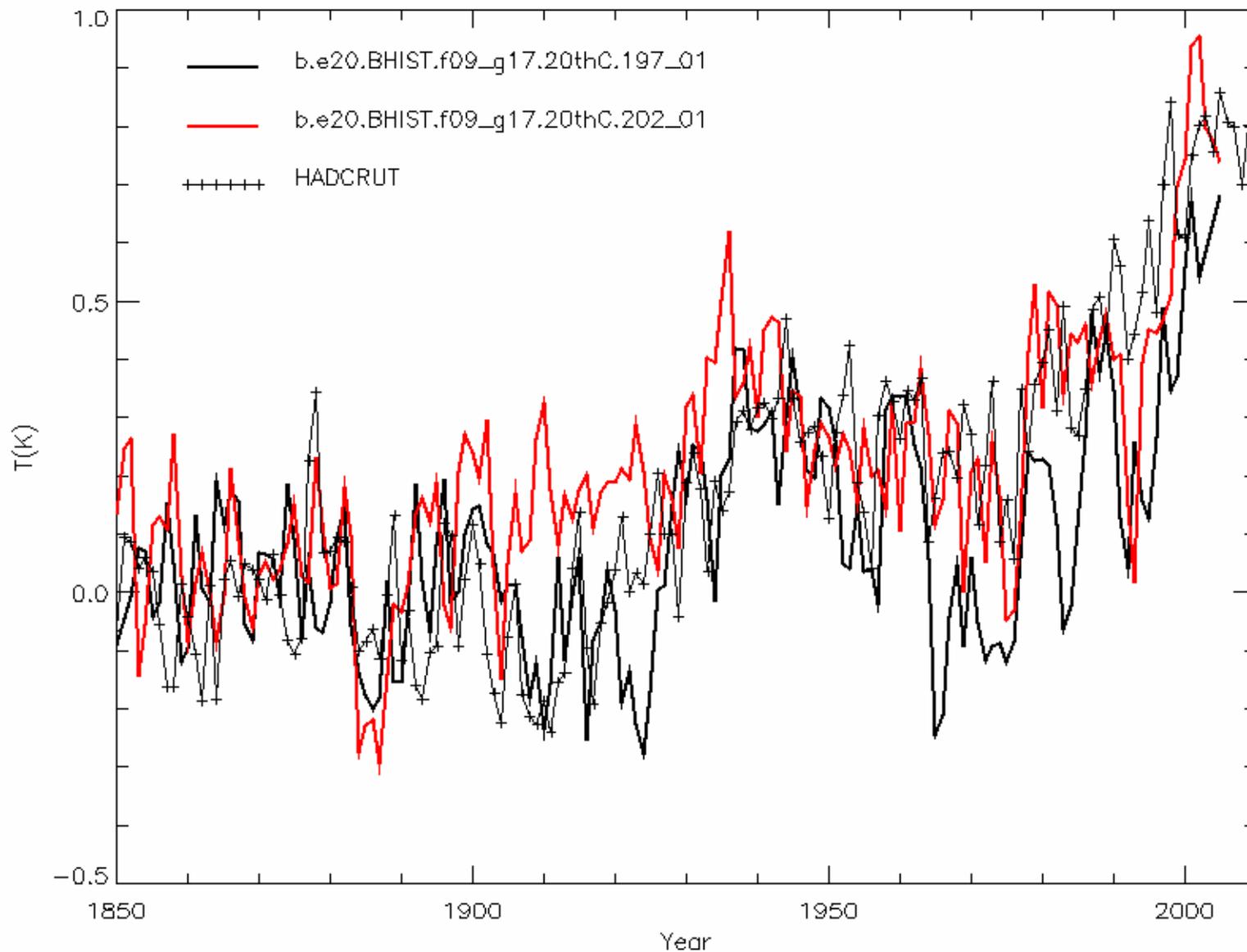


We need a clean test separating the autoconversion mods and CMIP6 emissions changes. Does not exist currently (Cecile?).

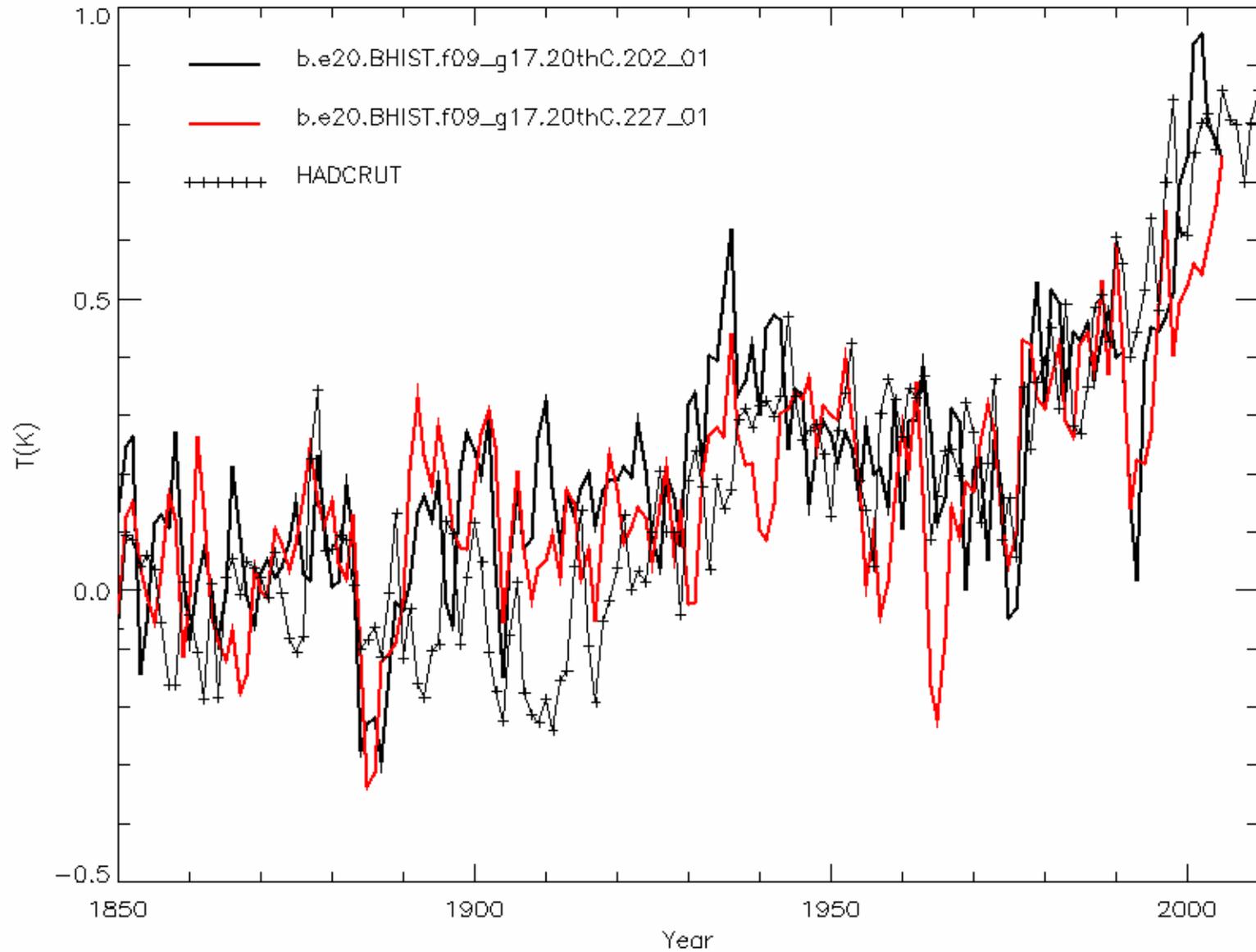
**197 = 190 + ZM KE tuning to compensate for MG2 bugfix**



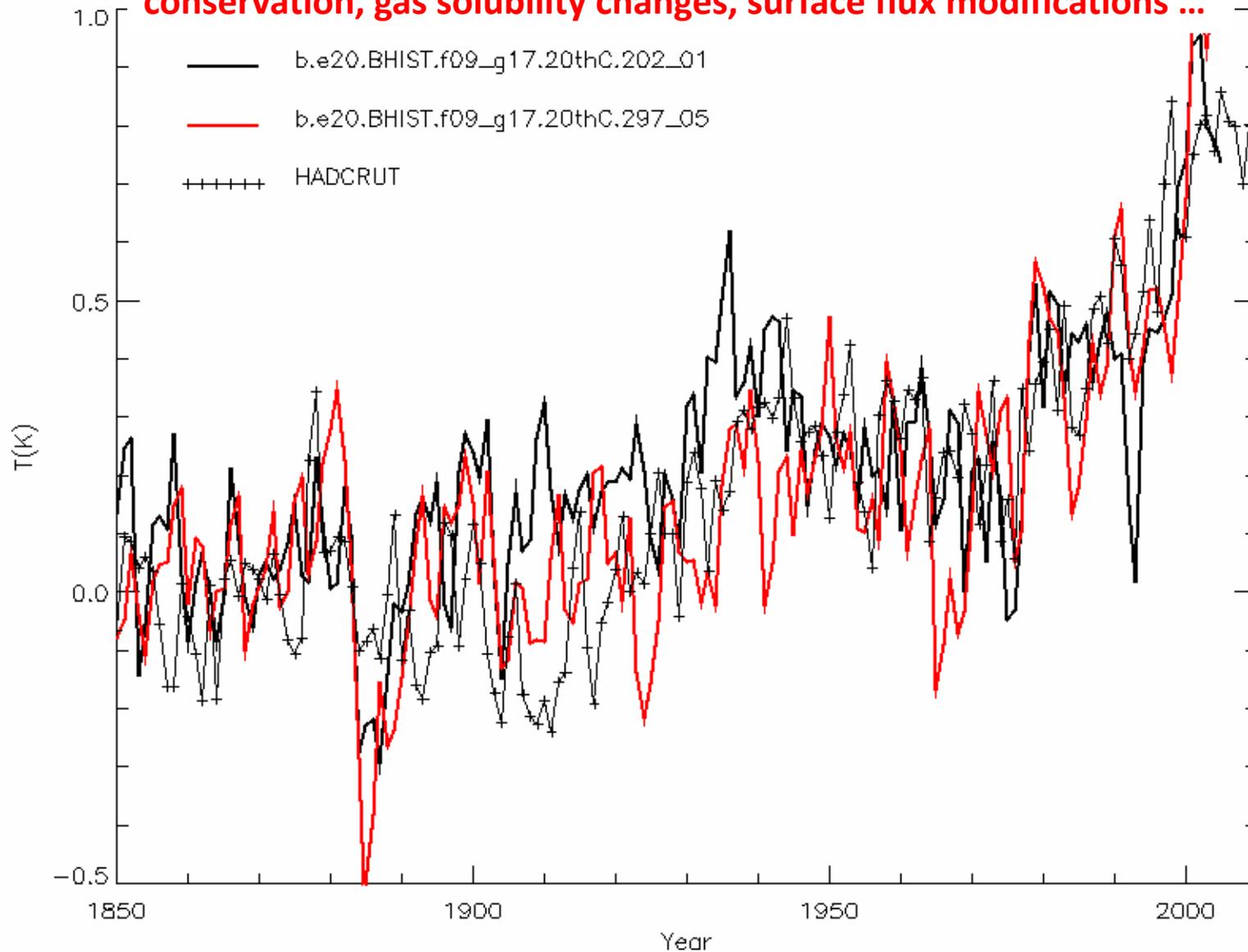
**202 = 197 + SO2 lifetime change, seasalt tuning, sea-ice albedo change**



**227 = 202** with “same physics, different tag” (ensemble var?)



**297 = 202 + numerous fixes, incl. CLUBB water vapor flux for conservation, gas solubility changes, surface flux modifications ...**



# Climate Sensitivity has also changed in CESM2

- **Equilibrium Climate Sensitivity (ECS) is larger in CESM2.**

Courtesy: Gokhan Danabasoglu

**Equilibrium Climate Sensitivity**  
**Nominal 1° resolution with a Slab Ocean Model (SOM)**

CCSM3:	2.9°C
CCSM4 (CAM4):	3.2°C
CESM1 (CAM5):	4.1°C
CESM2.0:	5.3°C

*IPCC (AR5): ECS is likely between 1.5°C and 4.5°C*

# Abrupt CO2 x2, x4 runs

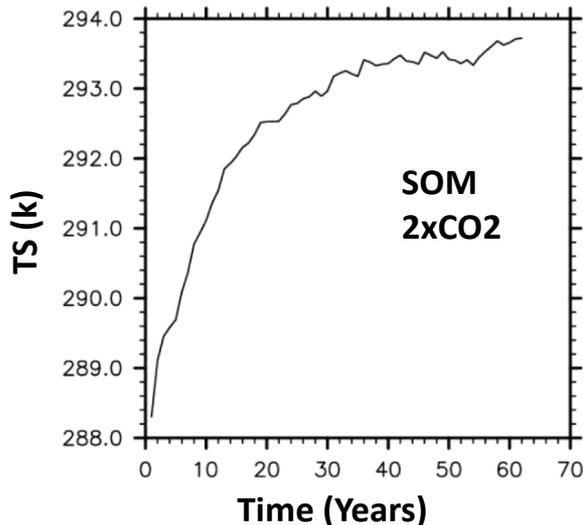
- Run 1850 experiment to equilibrium
- Instantaneously increase CO2, holding everything else fixed

# Climate sensitivity: Definitions

Climate sensitivity defined as: Equilibrium temperature change in response to abrupt 2x CO<sub>2</sub>.

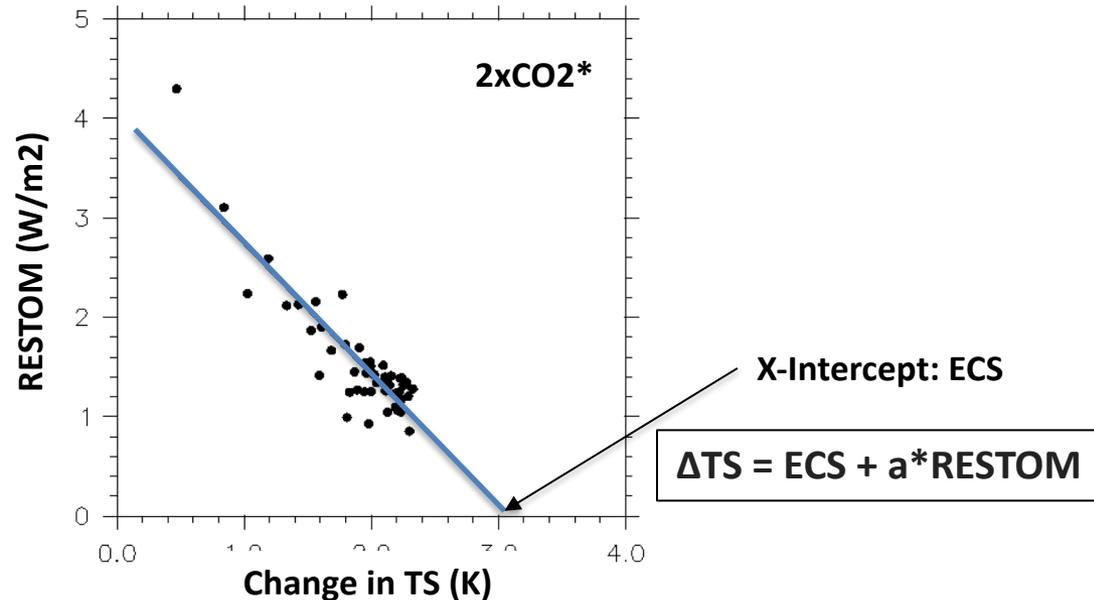
## Run to a steady state

- SOM run (60+ yrs)
- Fully coupled run (1000 yrs?)



## Gregory method (2004)

- SOM run or coupled run



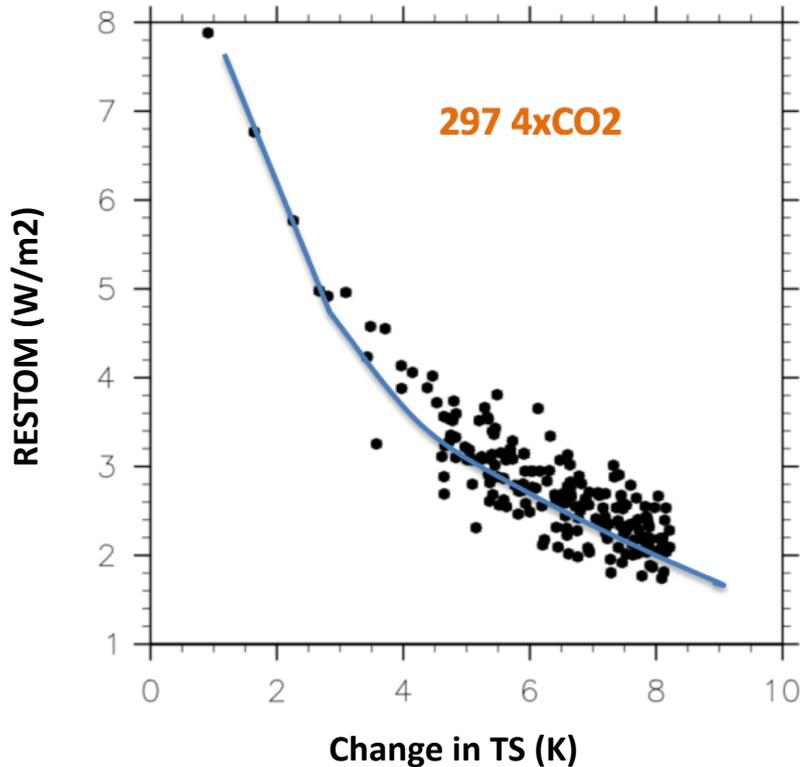
Advantage: Doesn't need to reach a steady state

Caveat: Uses linear fit between RESTOM and  $\Delta T$

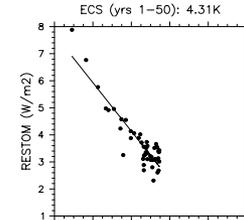
\*Note: 4xCO<sub>2</sub> often used to amplify model response. Assume:  
 $ECS(4xCO_2) = 0.5 * ECS(2xCO_2)$

# Gregory method caveat for coupled runs

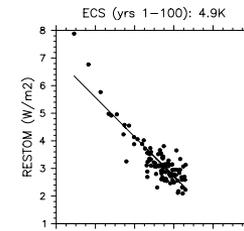
## Linear fit between RESTOM and $\Delta T$



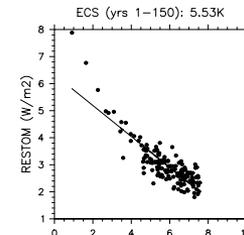
Yrs 1-50  
ECS = 4.31 K



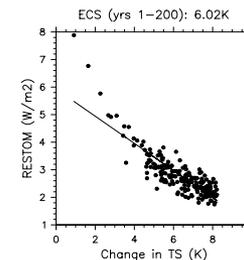
Yrs 1-100  
ECS = 4.9 K



Yrs 1-150  
ECS = 5.5 K



Yrs 1-200  
ECS = 6.0 K



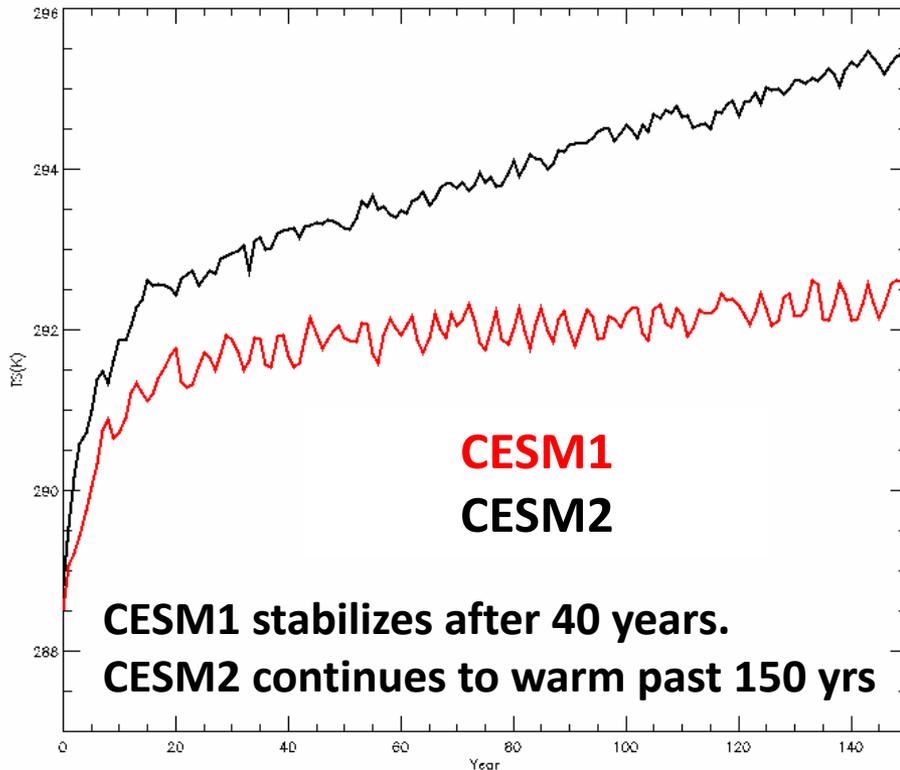
If non linear relationship,  
ECS strongly depends on the chosen period  
=> It is **hard to give a number** for ECS

# We can still learn a lot from 4XCO<sub>2</sub> runs

Simple set up. Less likely to be sensitive to emissions details.

Even if an exact number for climate sensitivity is problematic, **simulation behavior is qualitatively different** in CESM1 and CESM2 4xCO<sub>2</sub> runs.

## Increase in TS after abrupt 4XCO<sub>2</sub>



## Questions:

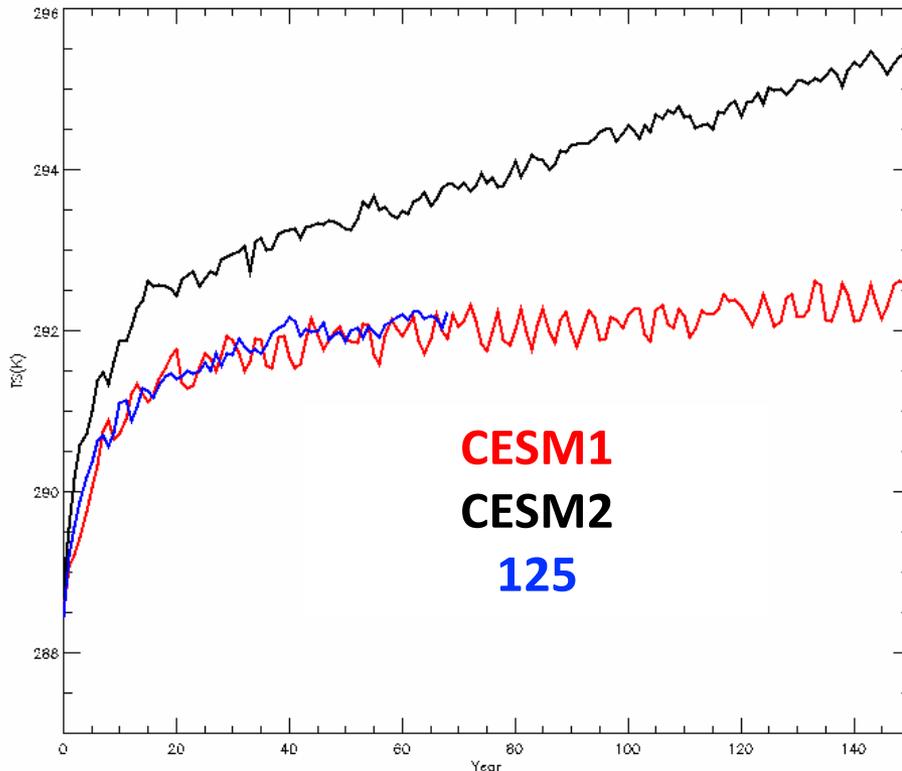
- When did this behavior change in the model?
- Does the change coincide with warming 20thC simulations?

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Development Version 125 of CESM2 looks just like CESM1. This means none of the major physics in CESM2, CLUBB, MG2 ... etc. are responsible for the high ECS. *Note 125 contains some ocean, land, and ice mods w/ respect to current model (299).*

# Code archaeology to identify possible culprits.

## Step 1: Identify CAM-only mods between 125 and 297

- New topography
- Dust tuning
- C mip6 emissions
- Orbital change
- WACCM forcing 3-mode
- WACCM forcing (ozone, stratospheric aerosol, tracer)
- Bugfix for vertical remapping
- Bugfix for MG2
- Bugfix for water conservation
- Background volcanoes
- New autoconversion (KK)
- Decrease so2 lifetime
- Increase iterations for sfc fluxes
- Mahrt and Sun sfc flux adjustment
- new H2O external forcing
- washout fix for SO2
- fix for O3 above the CAM top,
- Tuning parameters
  - gamma coeff
  - Bergeron Factor
  - zmconv\_ke
  - Dcs

## Step 2: Take CESM2 and revert to 125 in current code (CAM-only)

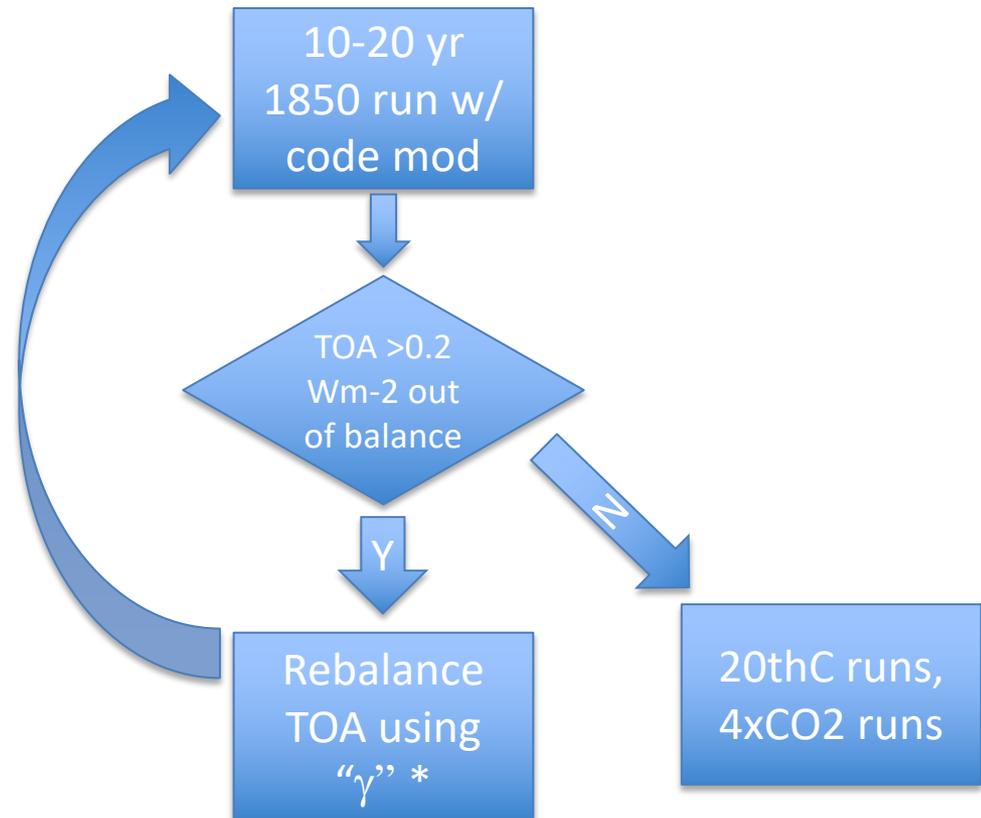
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### *CESM2 tuning cycle*



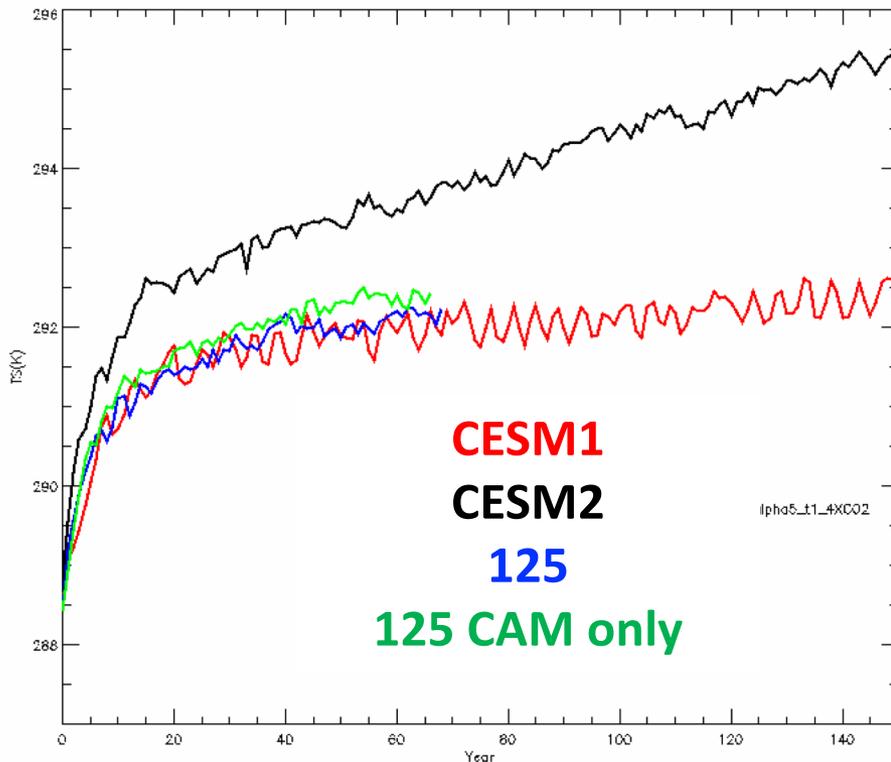
\*  $\gamma$  is a CLUBB parameter used to control low clouds

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Increase in TS after abrupt 4XCO2



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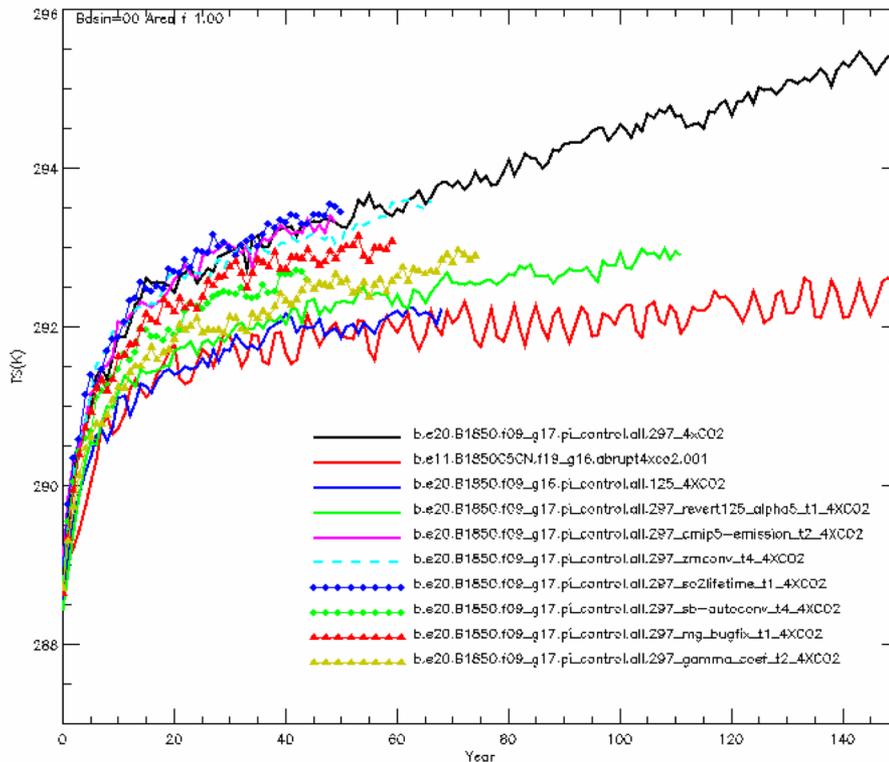
“CAM-only” 125 gets most of the way to CESM1.

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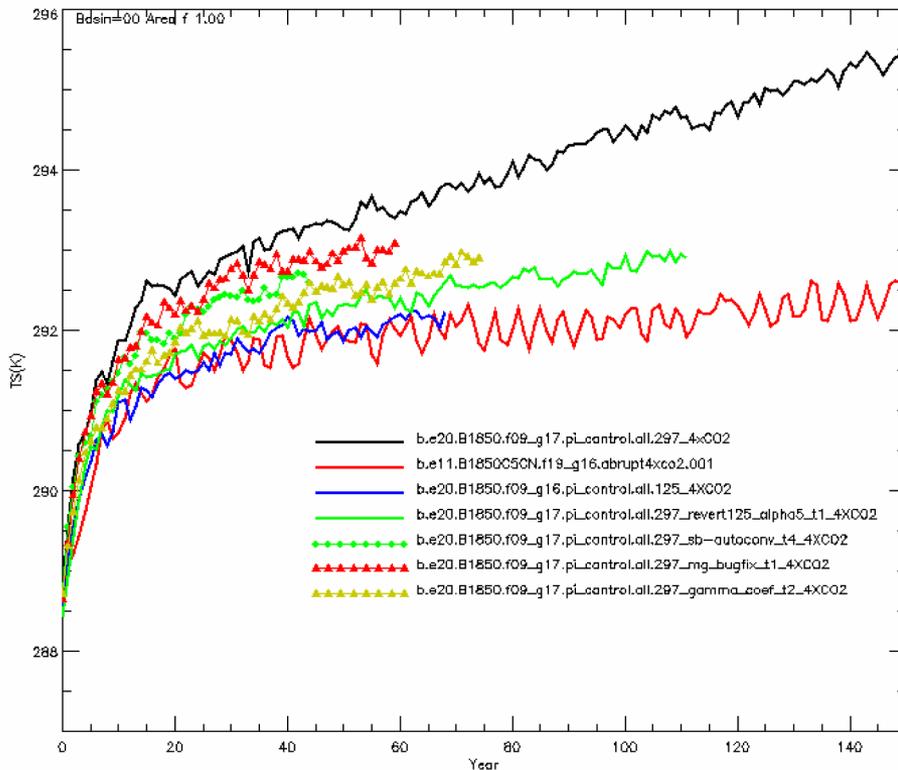
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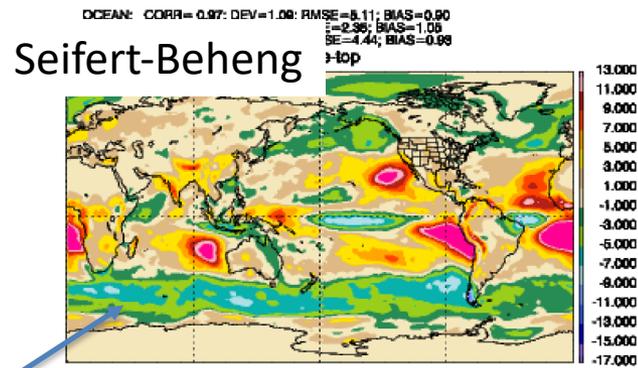
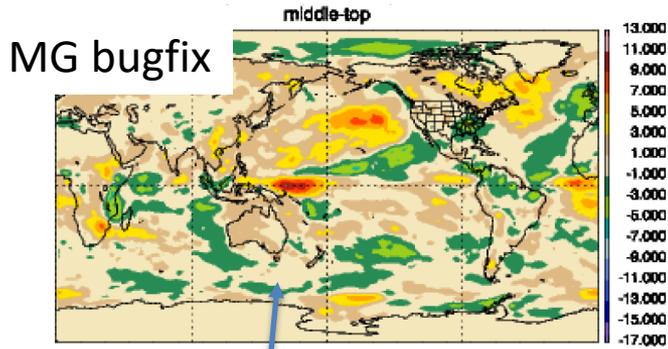
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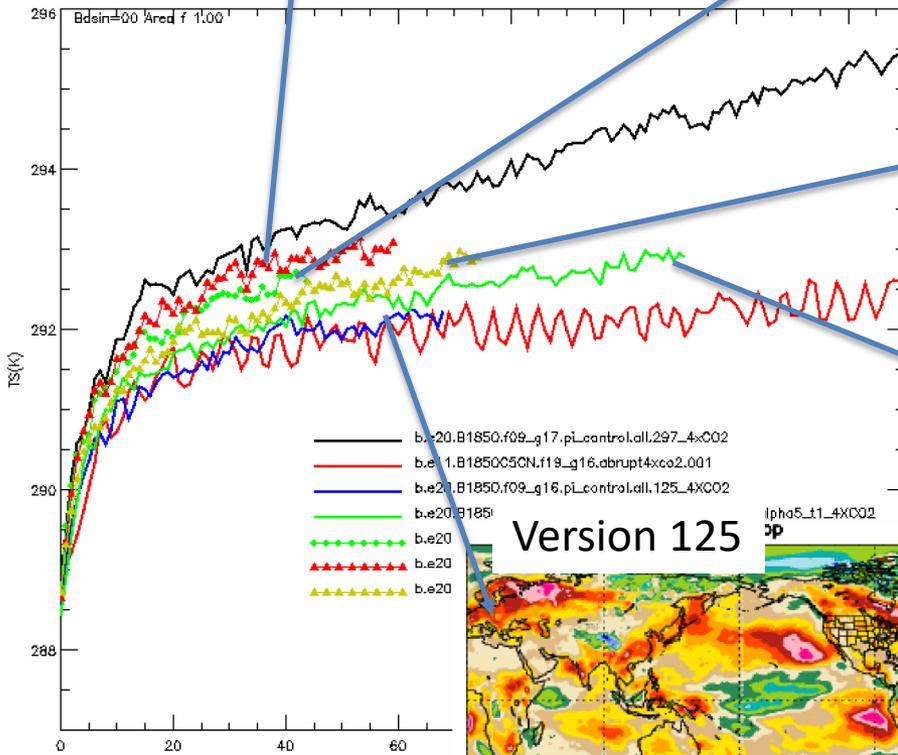
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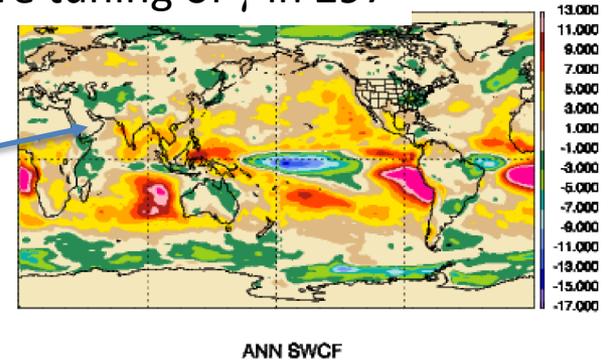
# Diffs in SWCF from 297 – red means brighter clouds in modified run. Years 1-20 4XCO2



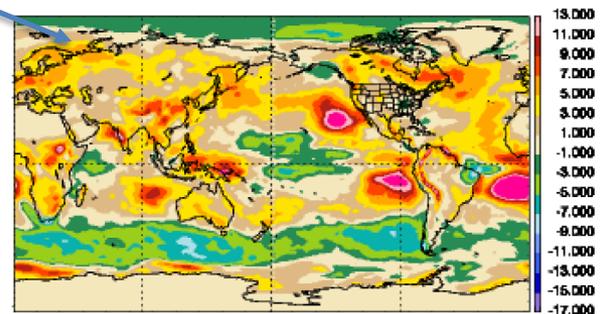
ANN SWCF  
 Increase in TS after abrupt 4XCO2



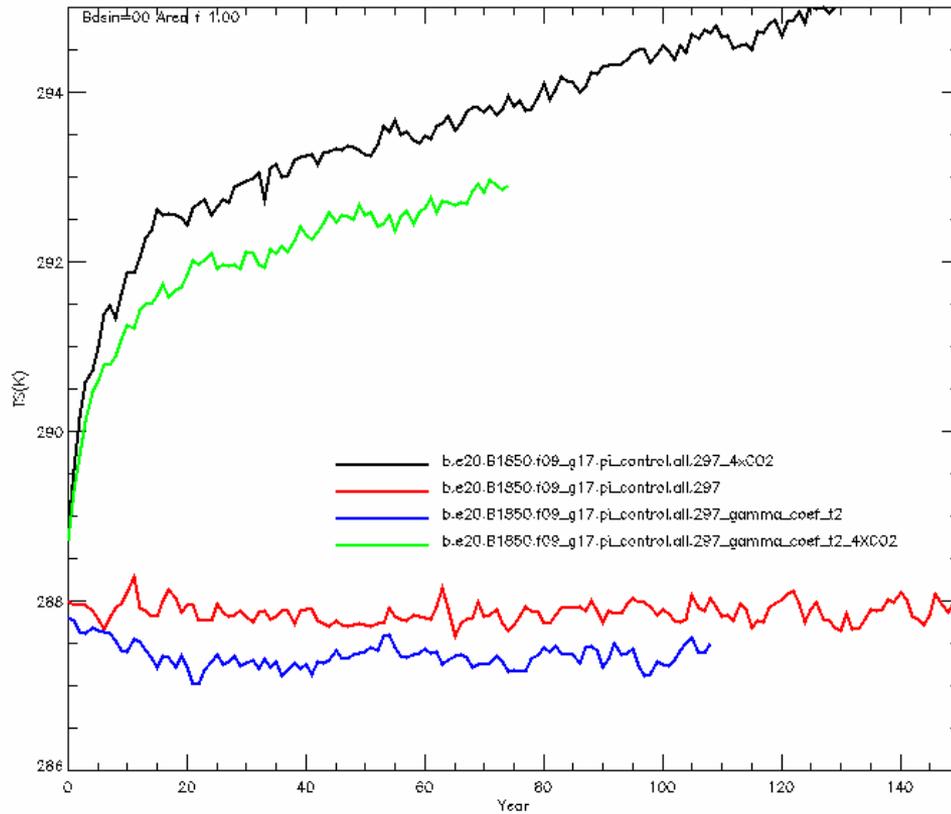
Pure tuning of  $\gamma$  in 297



CAM only revert to 125



# Should we be more patient?



# Summary

- Seems to be a relationship between low-cloud brightness and 4xCO<sub>2</sub> behavior
- Changes to land and ocean could be playing a role, although smaller than atmosphere's
- Ancillary changes to CLUBB  $\gamma$  may be as important as primary physics modifications
- Connection of 4xCO<sub>2</sub> behavior and 20<sup>th</sup>C simulations has not been established for CESM2

# Future

- Establish connection of 4xCO<sub>2</sub> behavior and 20<sup>th</sup>C simulations
  - Other setups, 1850 IC+4xCO<sub>2</sub>+2000 aerosols(could look at CMIP6 vs CMIP5)?
- Compare carefully with SOM runs
- Track down impacts of land and ocean changes

Thank you