20th Century temperatures and climate sensitivity in the Community Earth System Model version 2 (CESM2)

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Background: CESM2.x

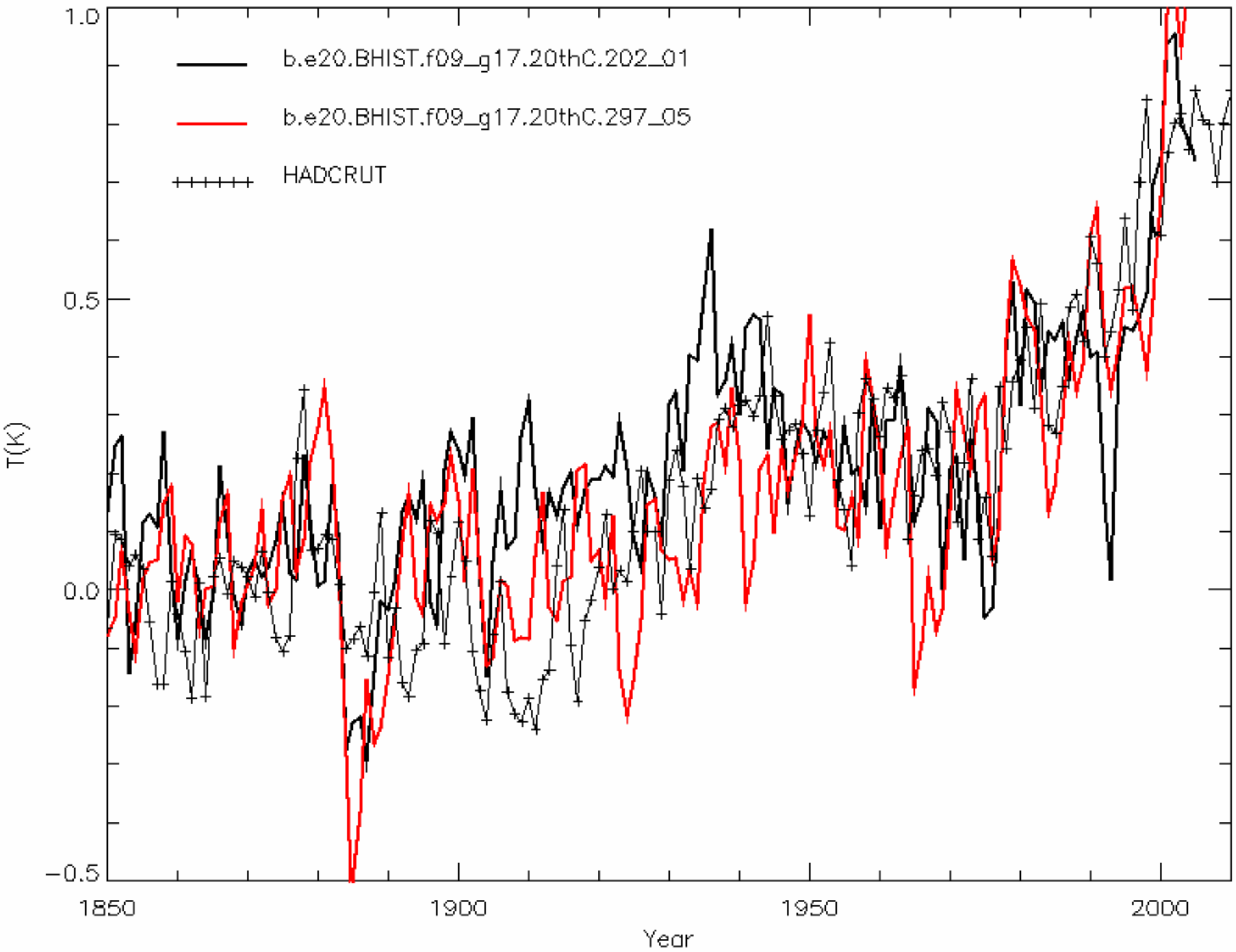
- CESM2 atmosphere includes massive parameterization changes w/ respect to CESM1
- CESM2.0 frozen in June
- Initial CMIP6 “DECK” simulations underway
- Bit-for-bit CESM2.1 to be released later this fall. *Mods for output, experimental setups requested by individual MIPs*

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.
- **20th 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.*
- **2xCO2, 4xCO2 runs:** Initialized from stable 1850 control. Atmospheric CO2 concentrations doubled/quadrupled. Run for 10-100 years.

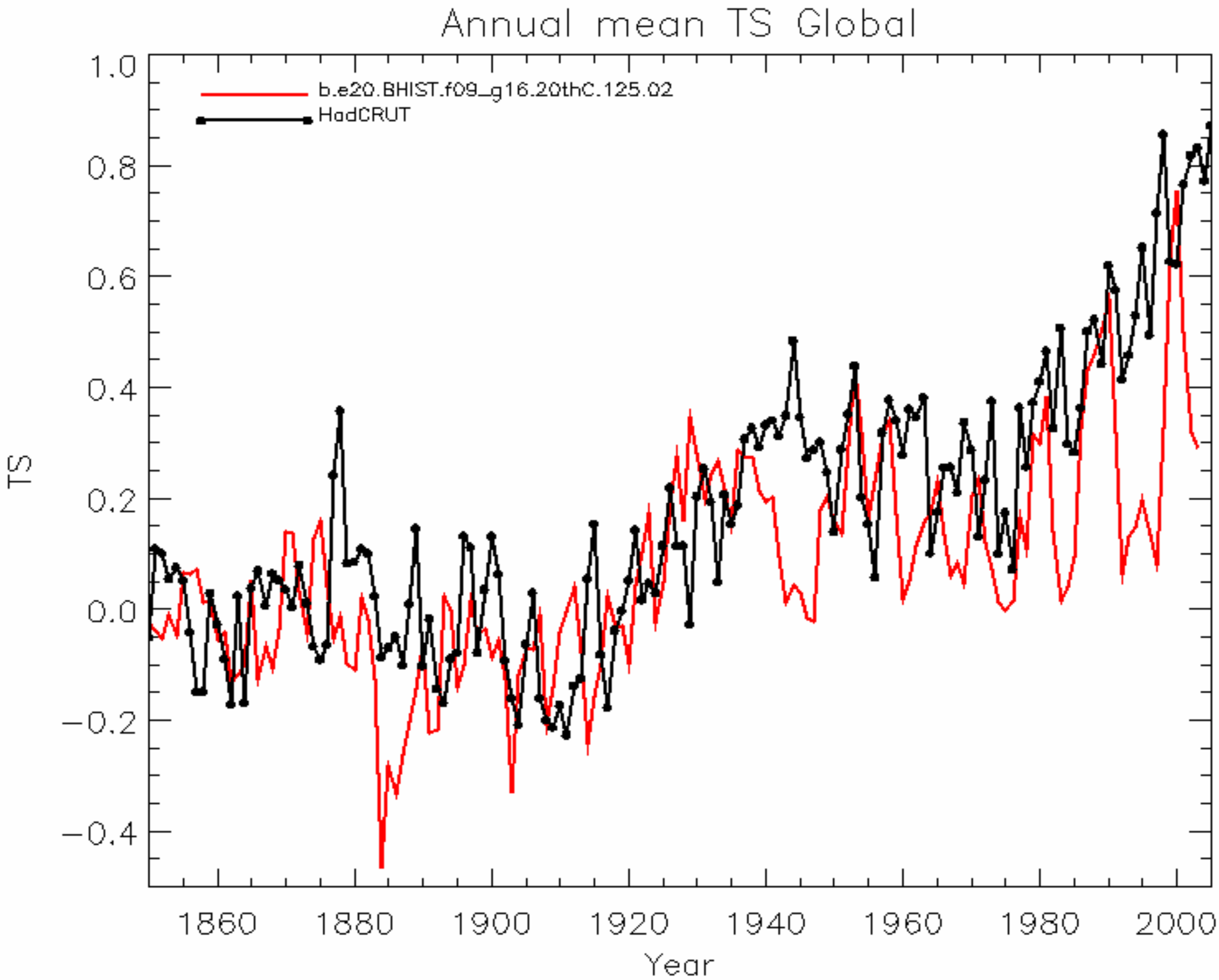
Where we are now

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

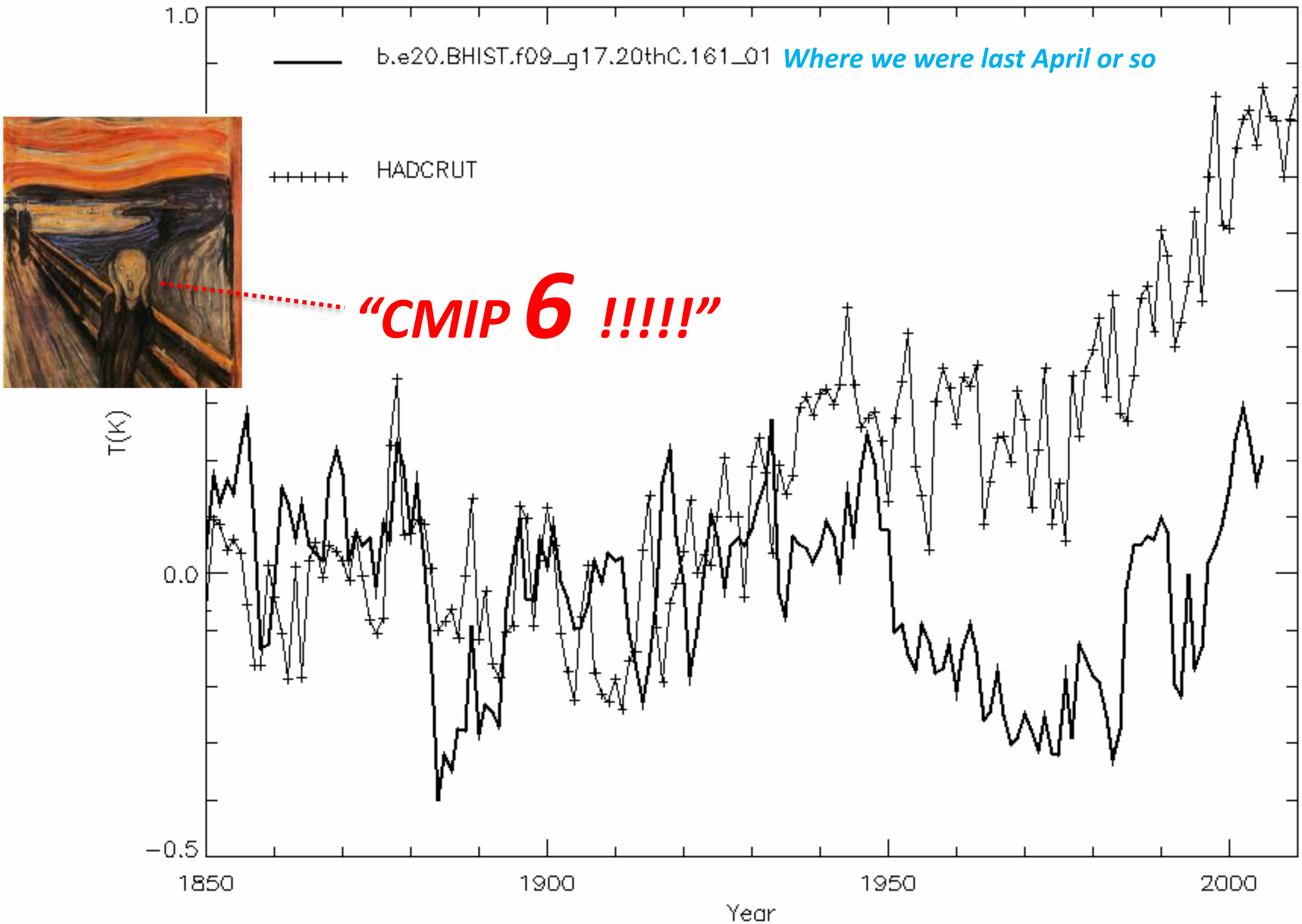


Where we were in March 2017 (18+ months ago)

Exp. 125 (Model ca. 3/2017;
emissions=CMIP5

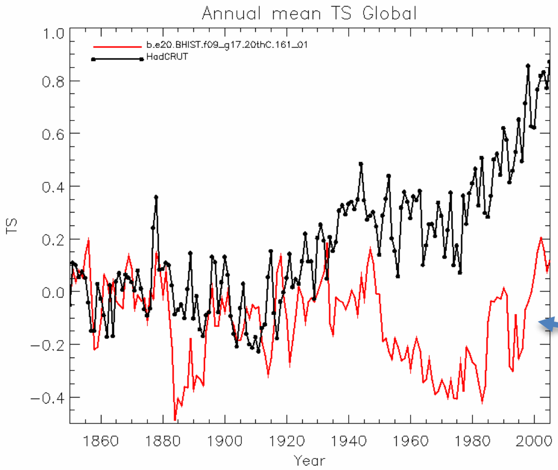


Where we were in April 2017 (18+ months ago)



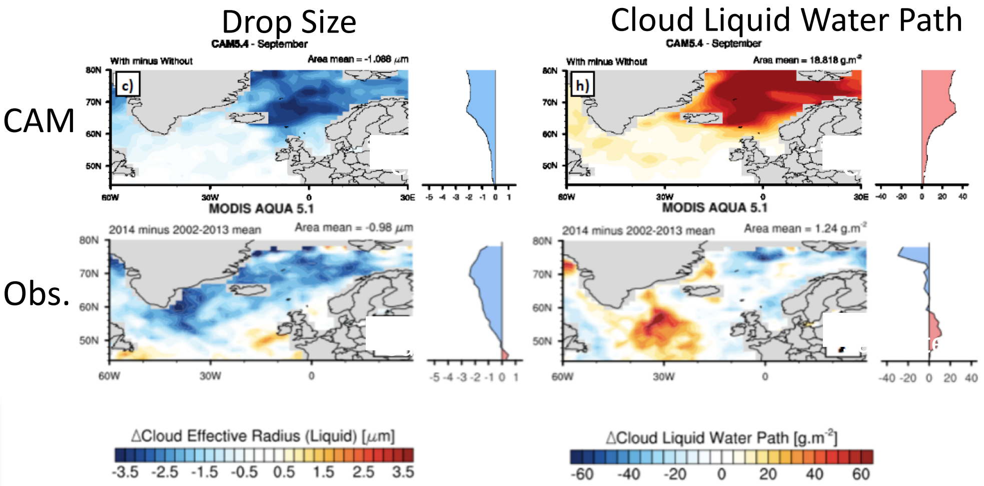
b.e20.BHIST.f09_g17.20thC.161_01
Where we were last April or so
HADCRUT
"CMIP 6 !!!!!"
1.0
0.0
−0.5
T(K)
1850
1900
1950
2000
Year

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



Possible Culprit: 2nd 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)

$$Au = kL^aN^b$$

Au=autoconversion rate
L=cloud liquid (kg/kg)
N=droplet number (#/kg)

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

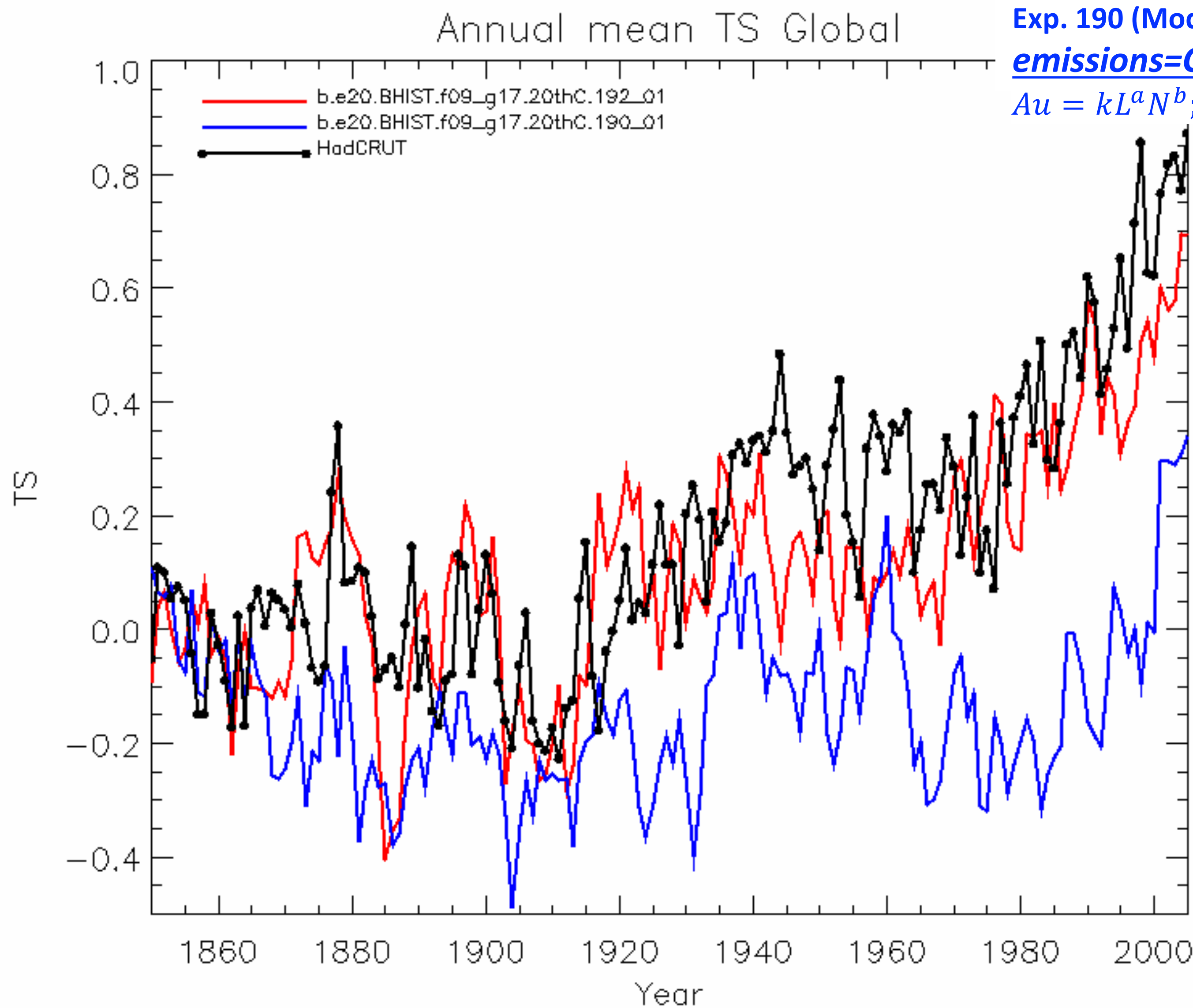
- ***R. Wood***: b in KK could be as weak as -0.9.
- Current compromise b=-1.1.

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*
$Au = kL^aN^b$; with $b = -1.1$

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



Results from CESM(2-ε)$_{\varepsilon \rightarrow 0}$

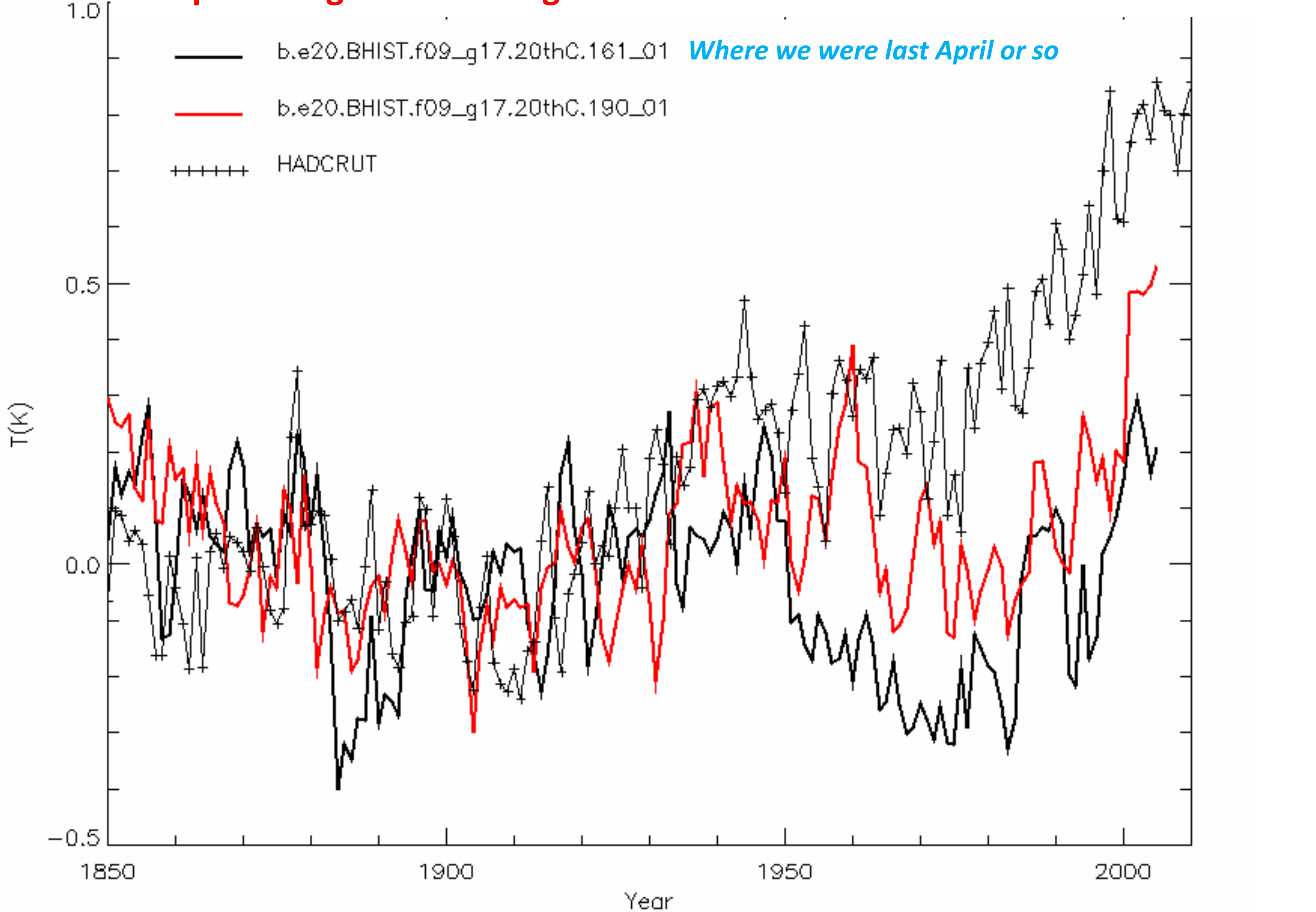
Approximate Timeline

	Feb'17	Jun'17	Oct'17	Feb'18	Jun'18
Model version	**125**	**161**	**190**	**261**	**297**
What was happening	• CMIP6 emissions introduced • ***20th C cooling w/ CMIP6 emissions*** →	• 2nd indirect effect adjustments • Rain microphysics bugfix and compensating tuning	• ***Labrador Sea freezes*** • Surface flux adjustments • Initial condition explorations	• CLUBB surface water vapor flux bugfix (minor) • Other minor clean-up for release	

125 w/ CMIP5 emissions data produced very good simulations

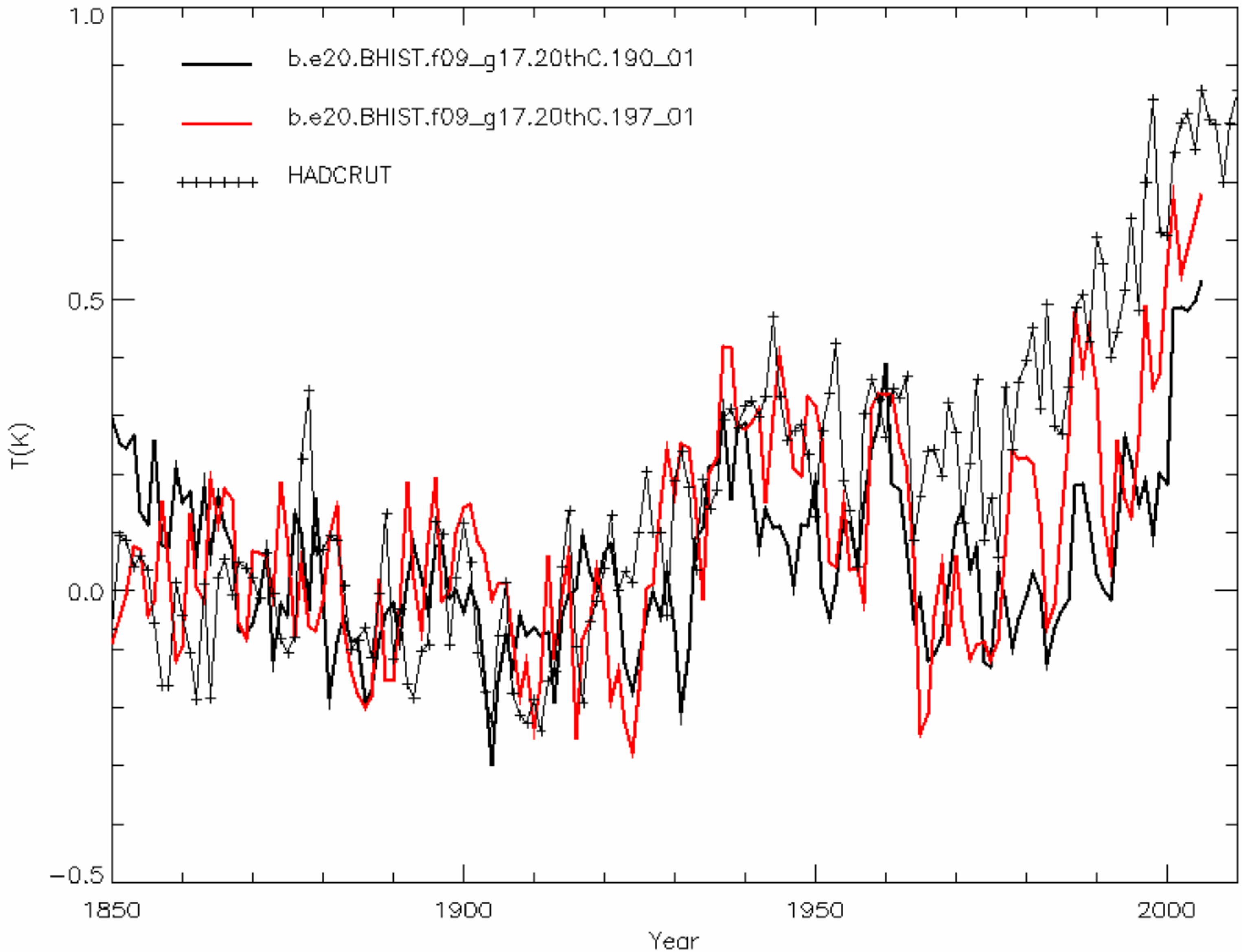
Significant steps in evolution of 20th C global TS. Following slides show evolution from 161. Red curve shows effect of modification w/ respect to previous model (black curve)

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

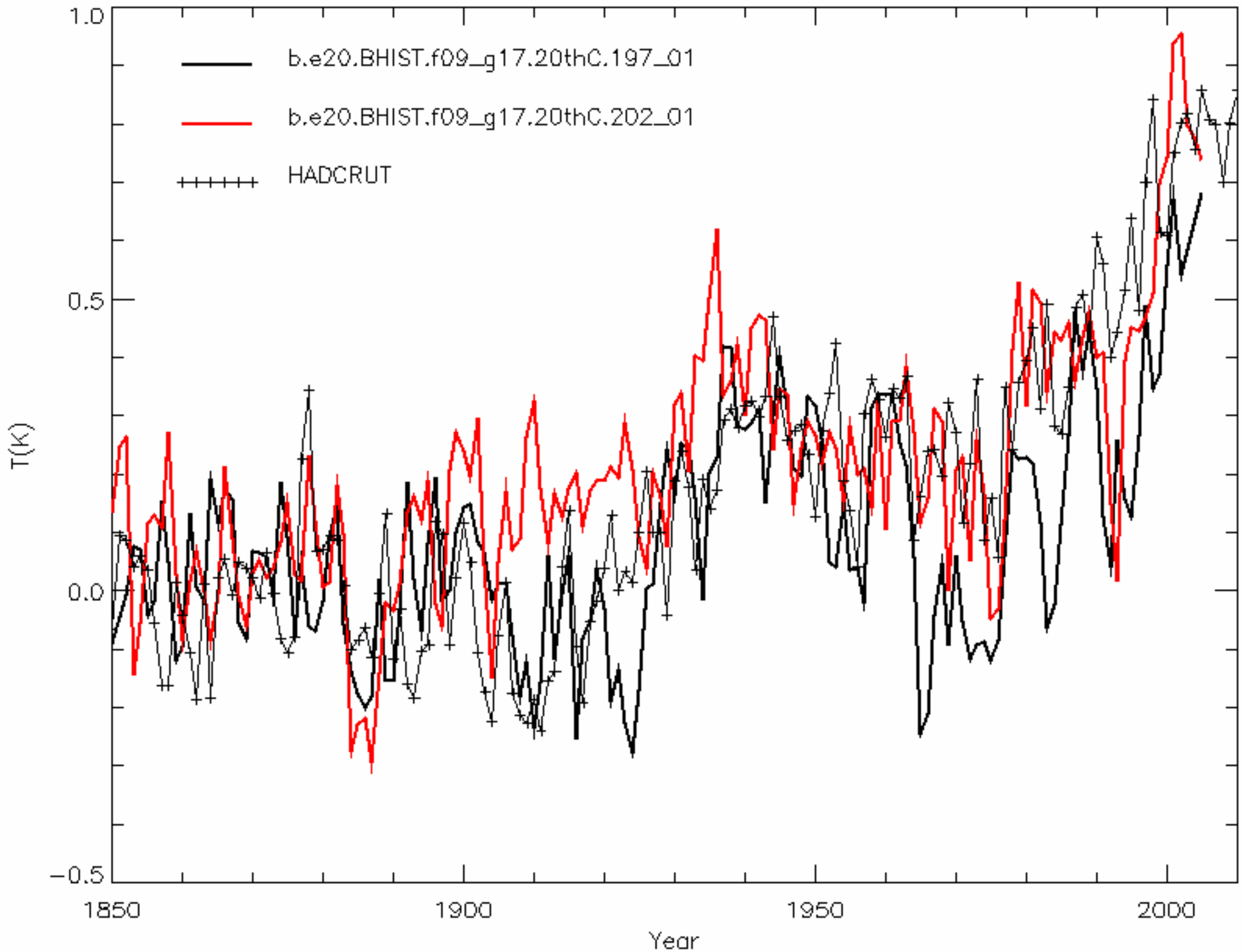


We need a clean test separating the autoconversion mods and CMIP6 emissions changes. Does not exist currently (Cecile?).

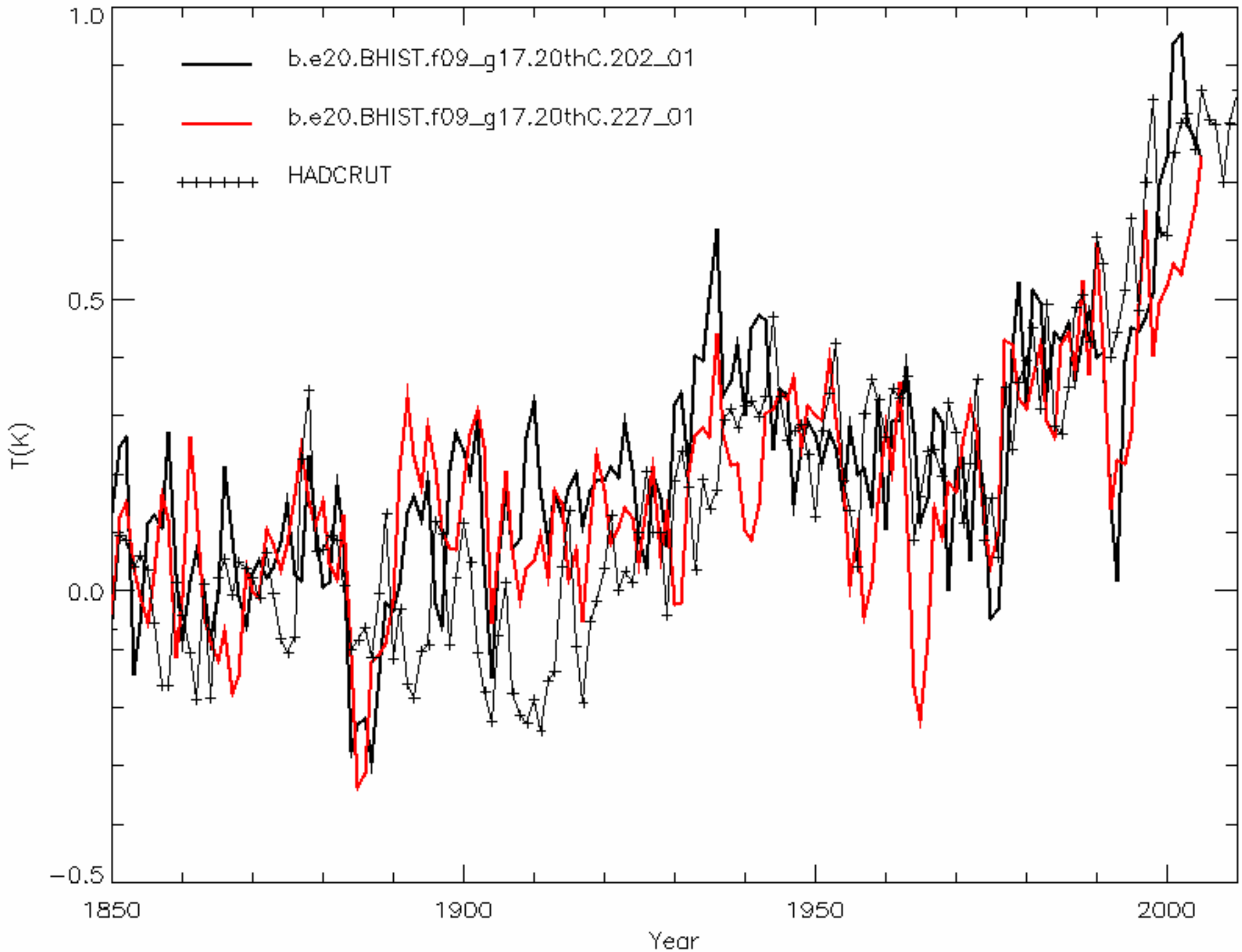
197 = 190 + ZM KE tuning to compensate for MG2 bugfix



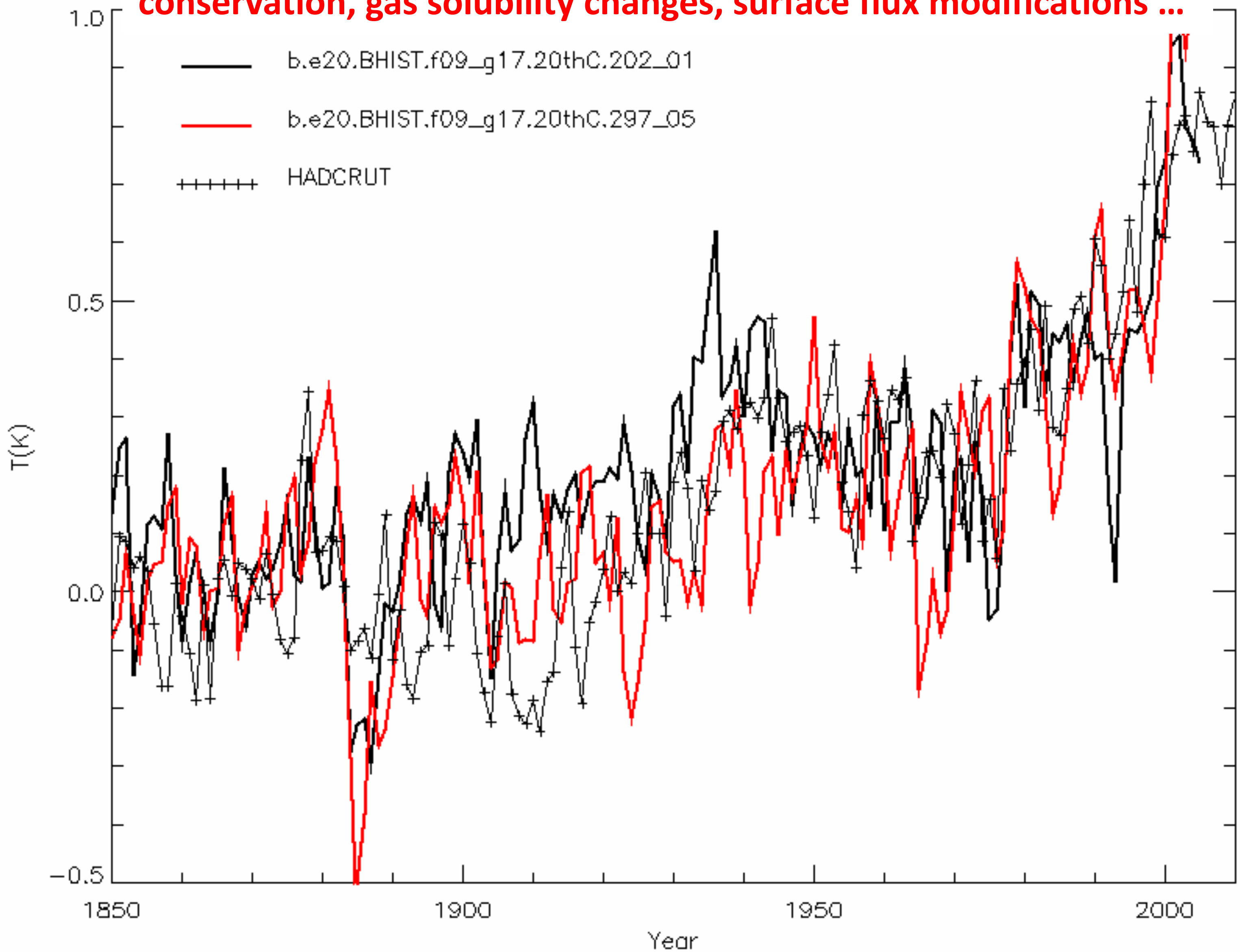
202 = 197 + SO2 lifetime change, seasalt tuning, sea-ice albedo change



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

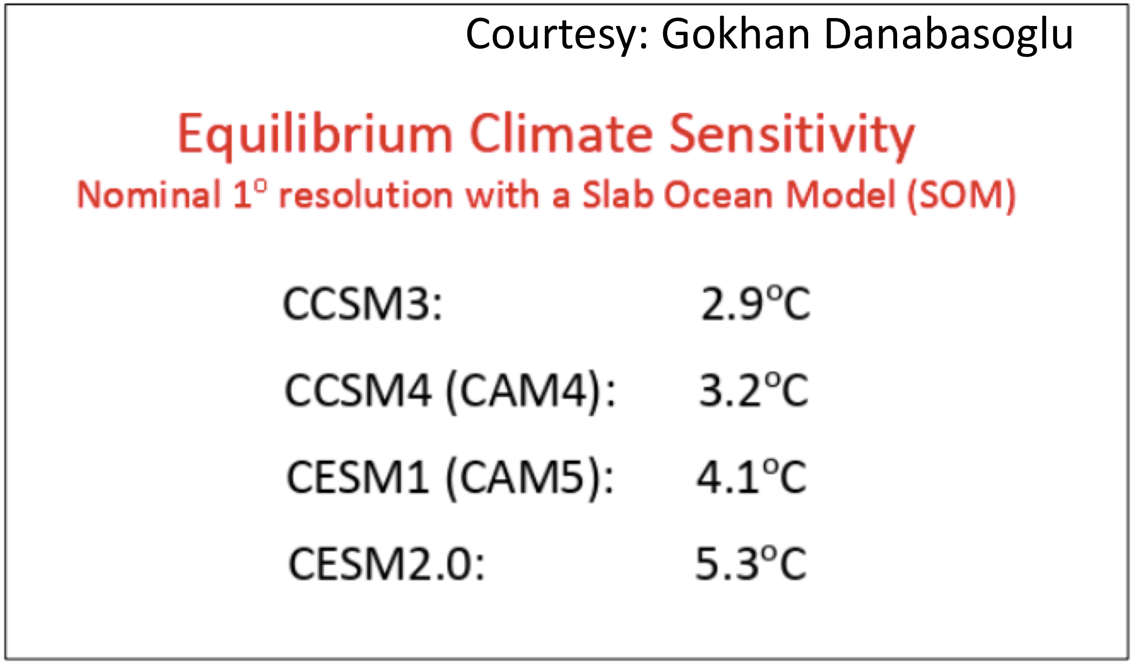


297 = 202 + numerous fixes, incl. CLUBB water vapor flux for conservation, gas solubility changes, surface flux modifications …



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 CO_2 x2, x4 runs

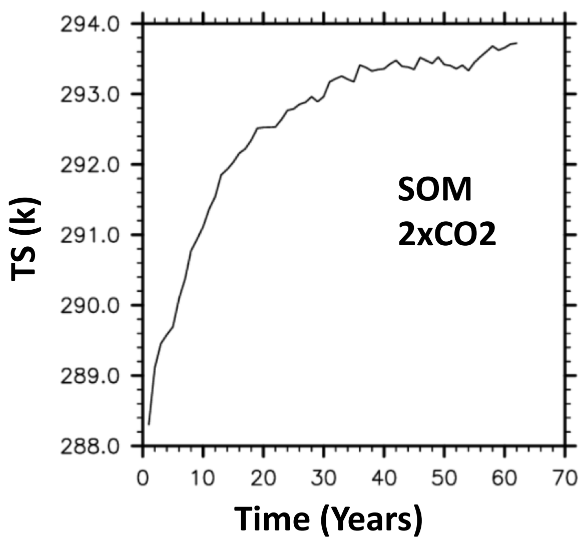
- Run 1850 experiment to equilibrium
- Instantaneously increase CO_2, holding everything else fixed

Climate sensitivity: Definitions

Climate sensitivity defined as: Equilibrium temperature change in response to abrupt 2x CO_2.

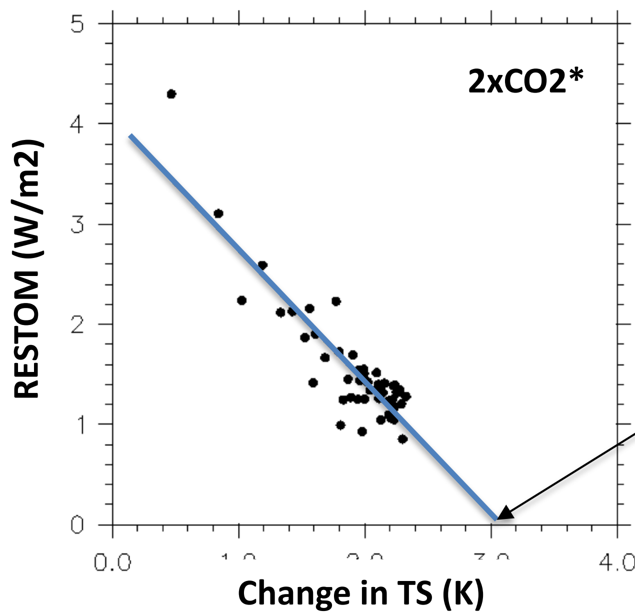
Run to a steady state

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



Gregory method (2004)

- SOM run or coupled run



X-Intercept: ECS

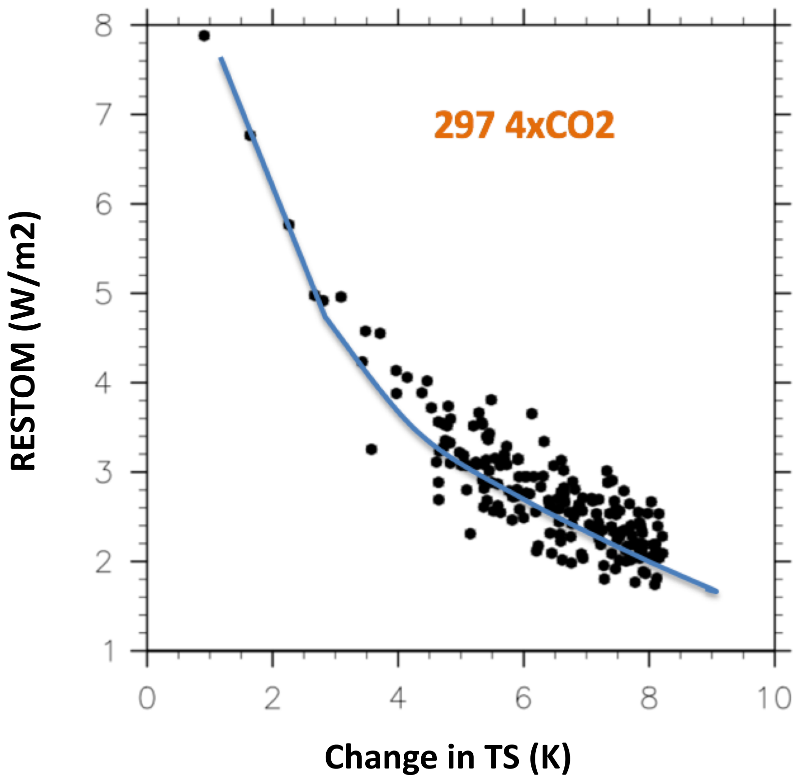
$\boxed{\Delta TS = ECS + a*RESTOM}$

Advantage: Doesn't need to reach a steady state
Caveat: Uses linear fit between RESTOM and ΔT

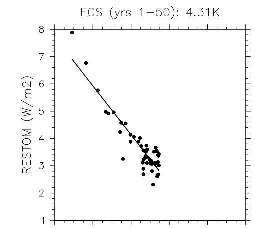
***Note: 4xCO2 often used to amplify model response. Assume:**
ECS(4xCO2) = 0.5*ECS(2xCO2)

Gregory method caveat for coupled runs

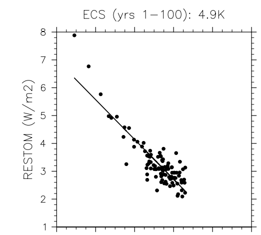
Linear fit between RESTOM and ΔT



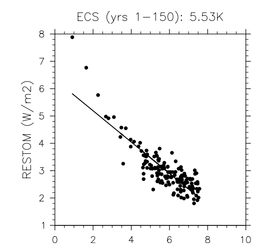
Yrs 1-50
ECS = 4.31 K



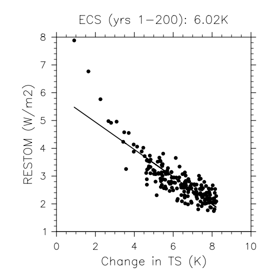
Yrs 1-100
ECS = 4.9 K



Yrs 1-150
ECS = 5.5 K



Yrs 1-200
ECS = 6.0 K



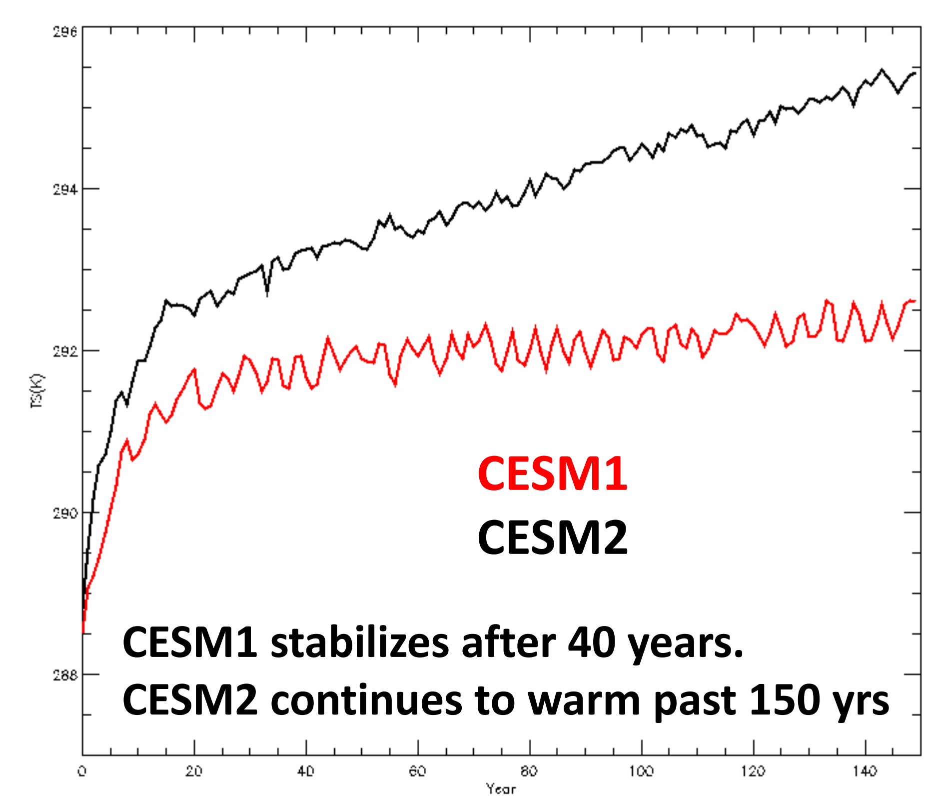
If non linear relationship,
ECS strongly depends on the chosen period
=> It is hard to give a number for ECS

We can still learn a lot from 4XCO2 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 4xCO2 runs.

Increase in TS after abrupt 4XCO2



Questions:

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

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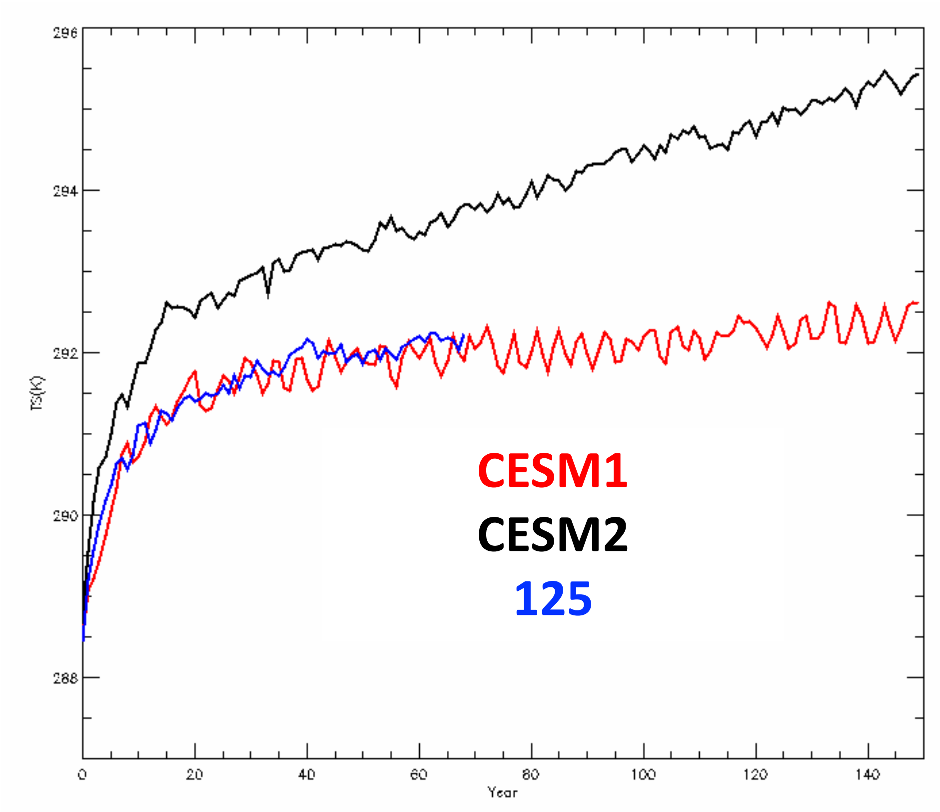

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Development Version 125 of CESM2 looks just like CESM1. This means none of the major physics in CESM2, CLUBB, MG2 … etc. are responsible for the high ECS. ***Note 125 contains some ocean,land, and ice mods w/ respect to current model (299).***

Code archaeology to identify possible culprits.

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

- **New topography**
- **Dust tuning**
- **Cmip6 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 adjustement**
- **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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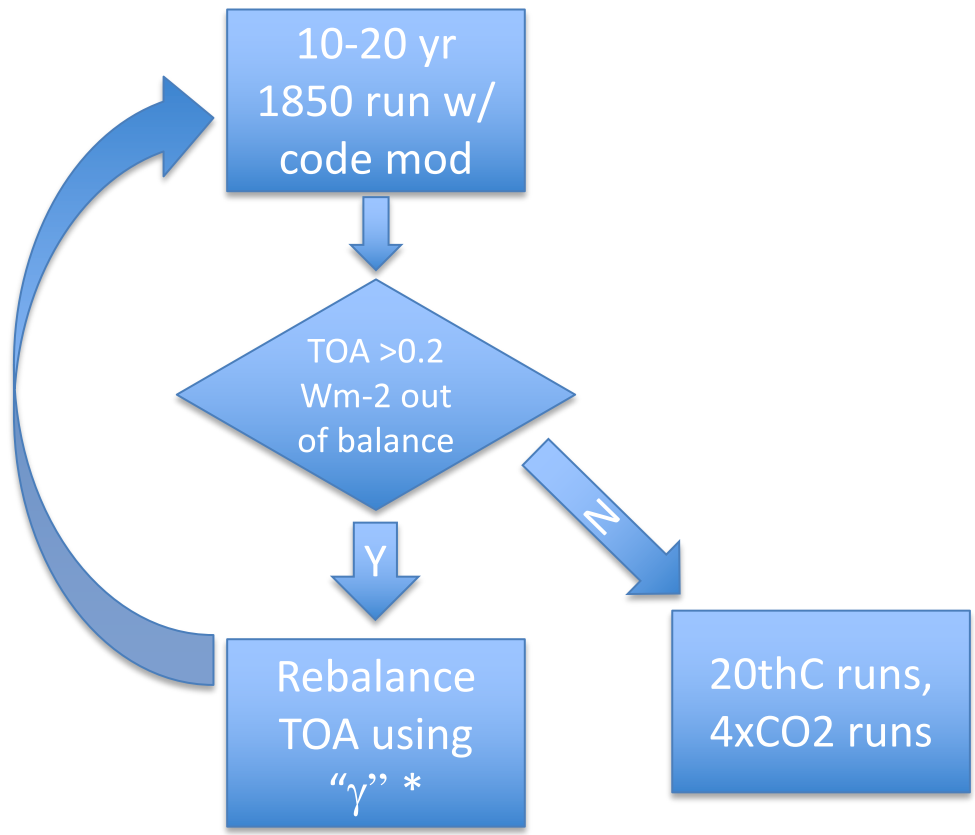
CESM2 tuning cycle



* γ is a CLUBB parameter used to control low clouds

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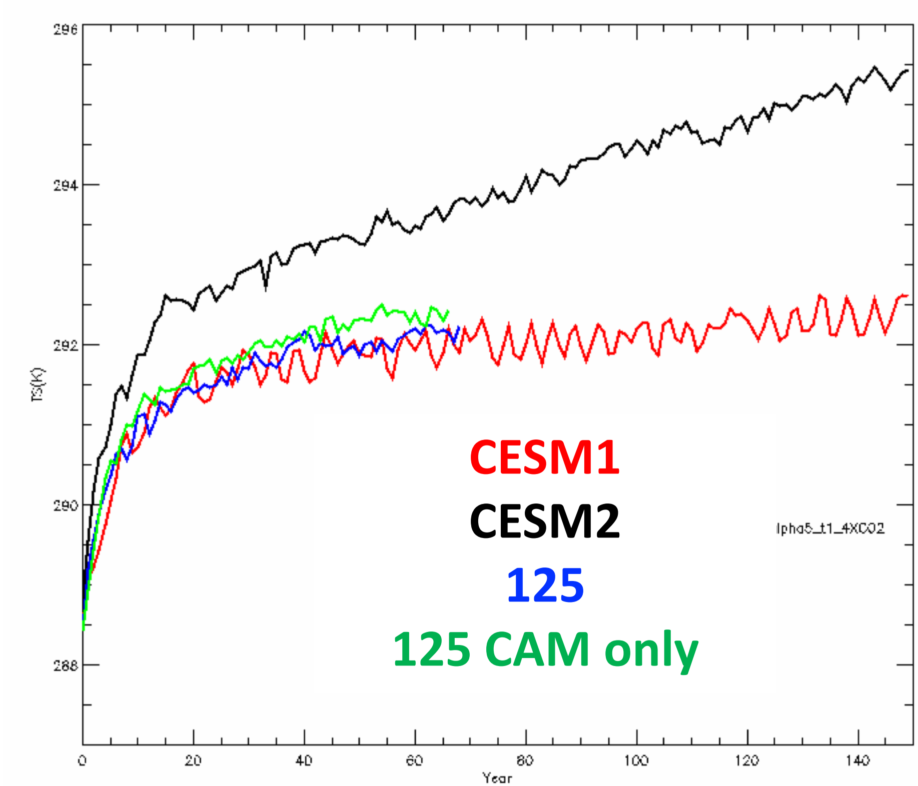
Increase in TS after abrupt 4XCO2



Questions:

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

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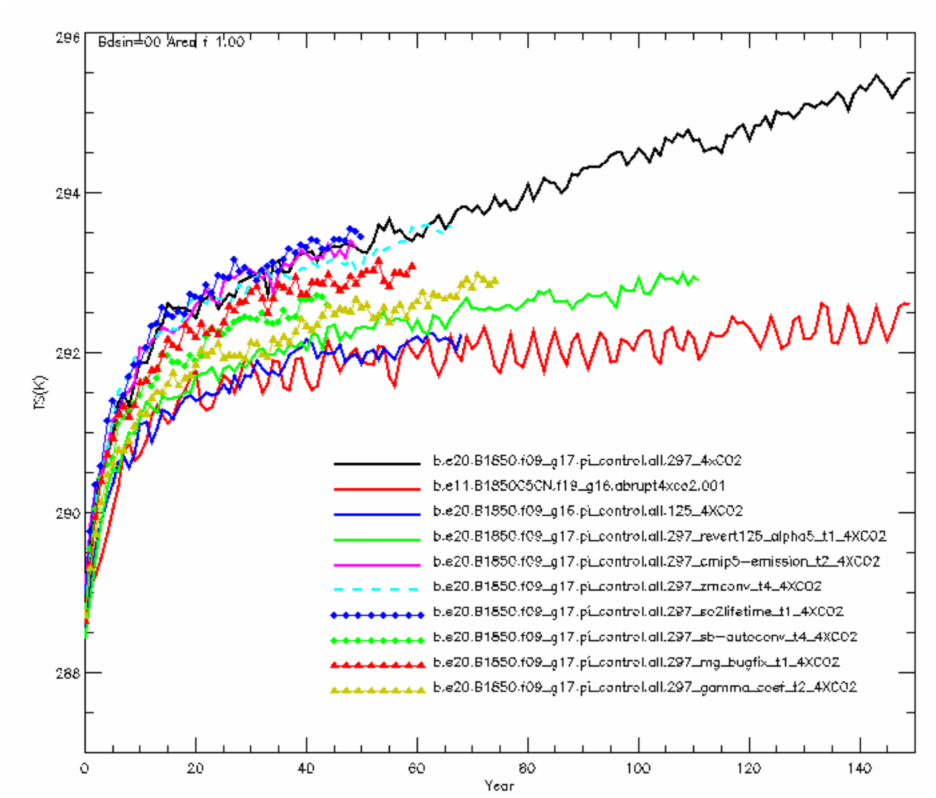

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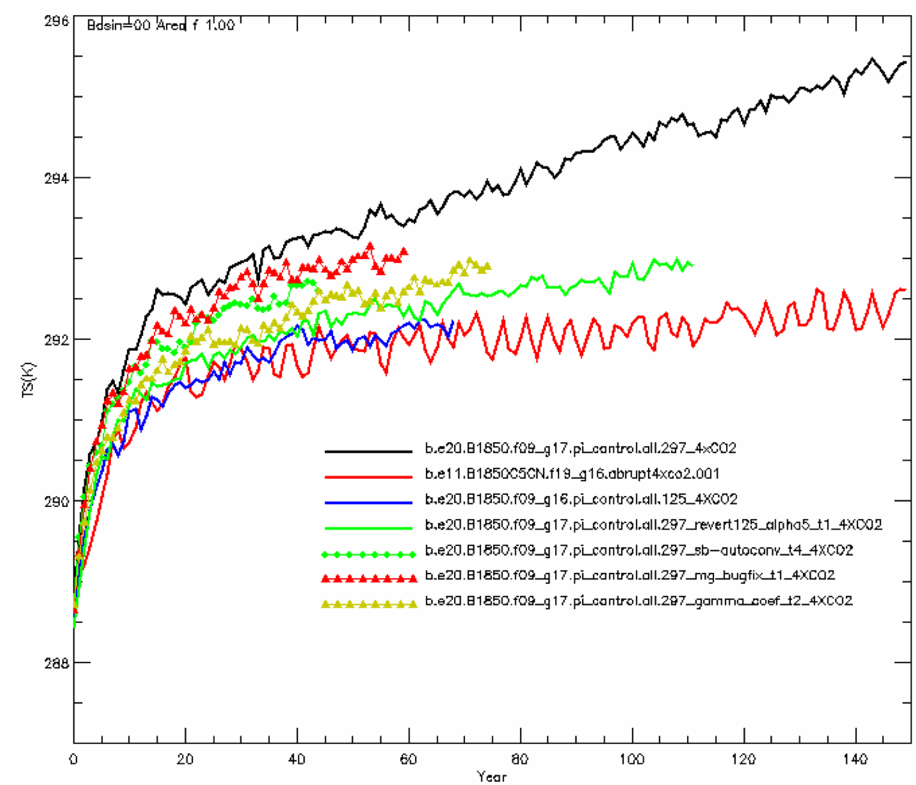

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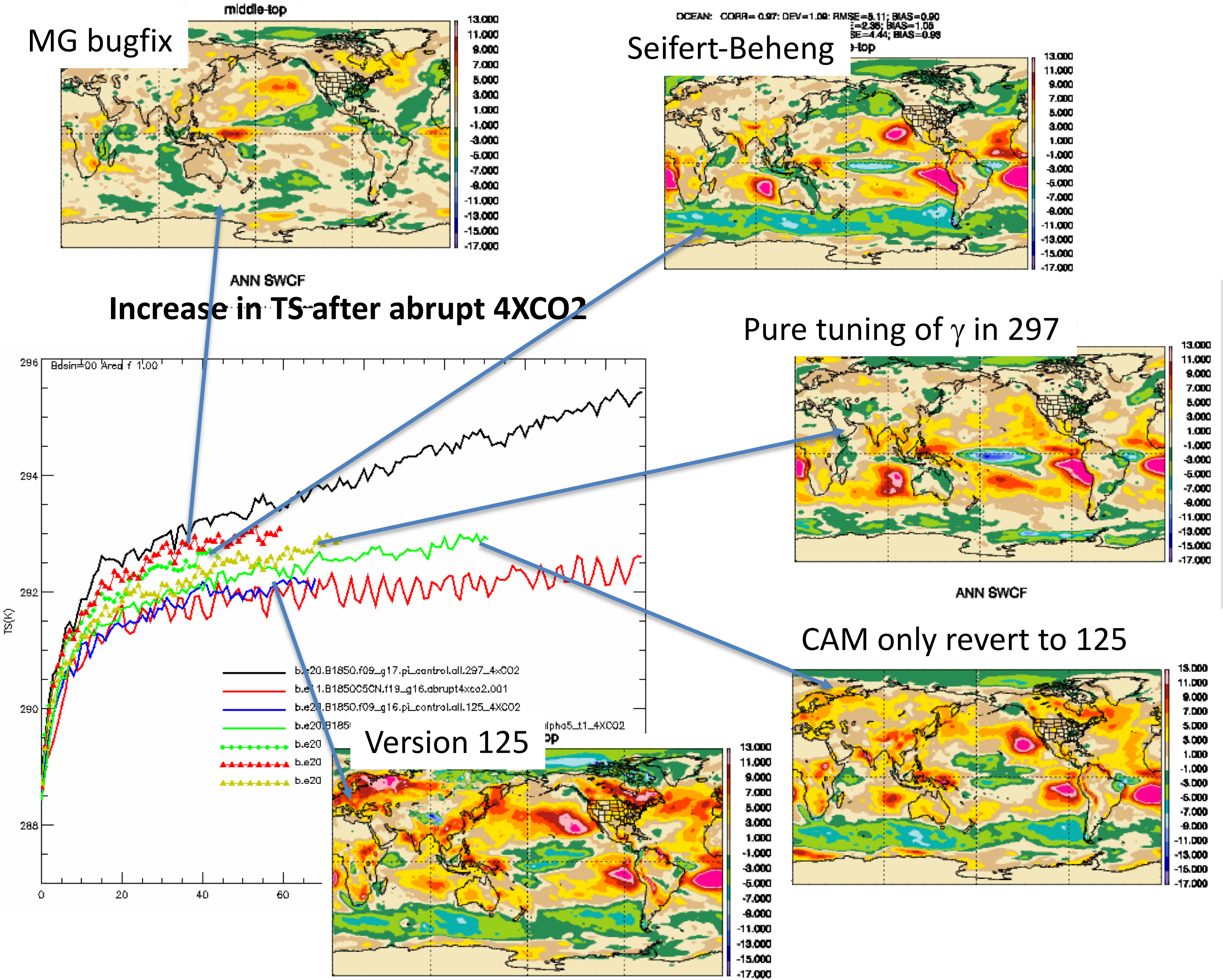
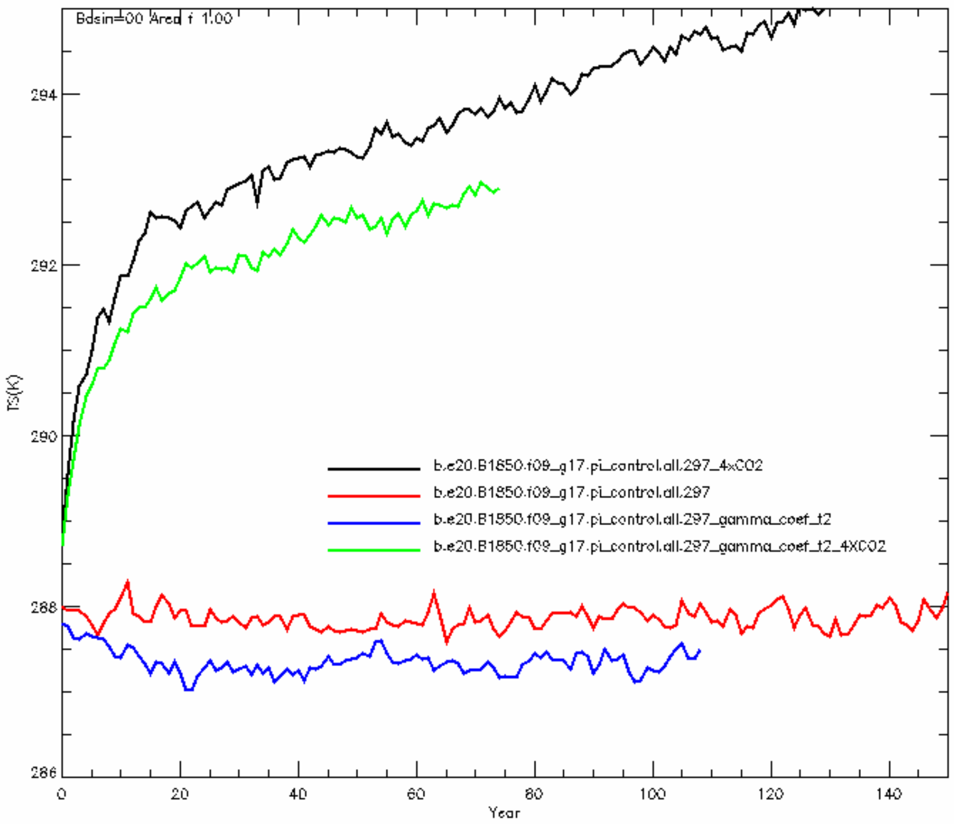
Diffs in SWCF from 297 – red means brighter clouds in modified run. Years 1-20 4XCO2



Should we be more patient?



Summary

- Seems to be a relationship between low-cloud brightness and 4xCO2 behavior
- Changes to land and ocean could be playing a role, although smaller than atmosphere's
- Ancillary changes to CLUBB γ may be as important as primary physics modifications
- Connection of 4xCO2 behavior and 20thC simulations has not been established for CESM2

Future

- Establish connection of 4xCO2 behavior and 20thC simulations
  - Other setups, 1850 IC+4xCO2+2000 aerosols(could look at CMIP6 vs CMIP5)?
- Compare carefully with SOM runs
- Track down impacts of land and ocean changes

Thank you