Investigating the Climate Sensitivity Differences between CESM1 and CESM2

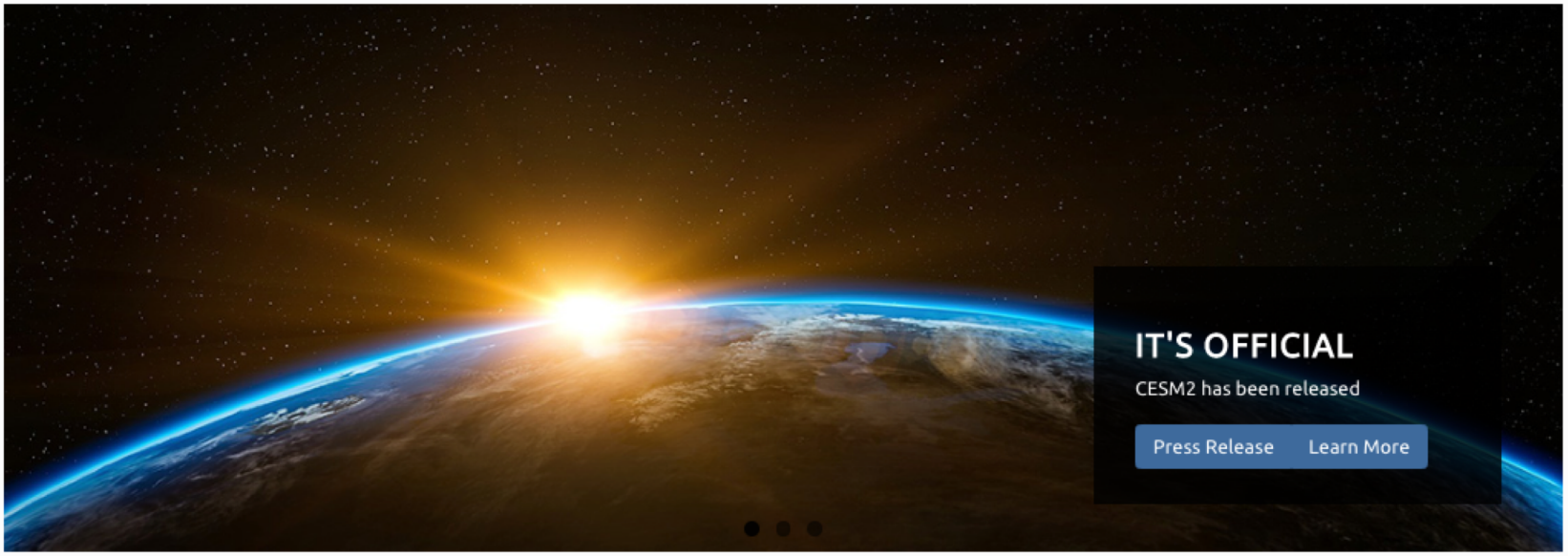
Cécile Hannay, Julio Bacmeister, Rich Neale, Andrew Gettelman,
National Center for Atmospheric Research

and Minghua Zhang*
Stony Brook University

Community Earth System Model (CESM)

CESM is a fully-coupled global climate model
CESM is maintained at the National Center for Atmospheric Research
CESM is sponsored by NSF and DOE

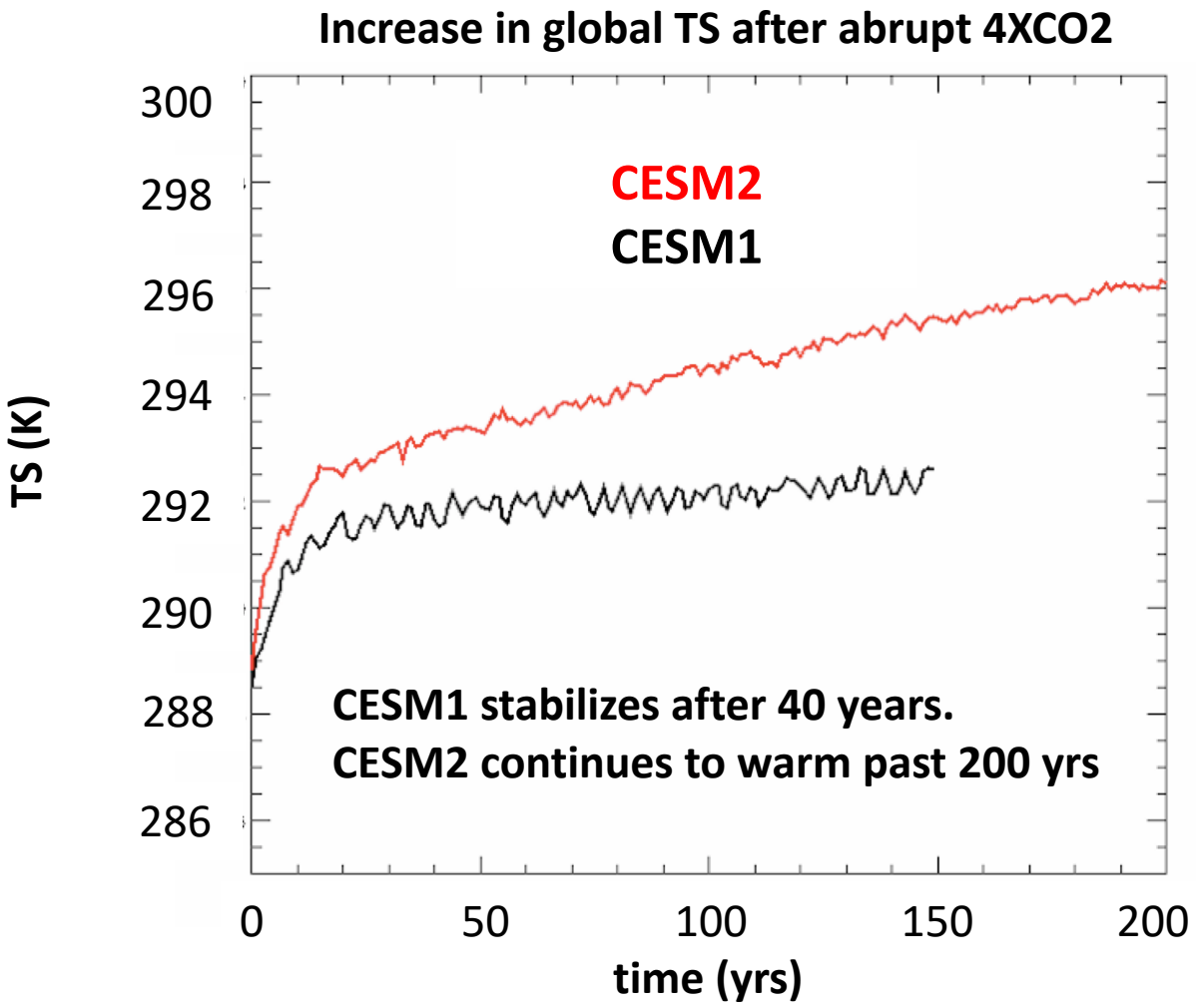
Major Releases: CESM1 (2010) and CESM2 (2018)



Find out more at: www.cesm.ucar.edu

Motivation

Abrupt 4xCO2 runs => behavior is different in CESM1 and CESM2



Motivation

- **Equilibrium Climate Sensitivity (ECS) is larger in CESM2 than in previous versions of the model.**

Equilibrium Climate Sensitivity	
CCSM3 (CAM3)	2.9 K
CCSM4 (CAM4)	3.2 K
CESM1 (CAM5)	4.1 K
CESM2 (CAM6)	5.3 K

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

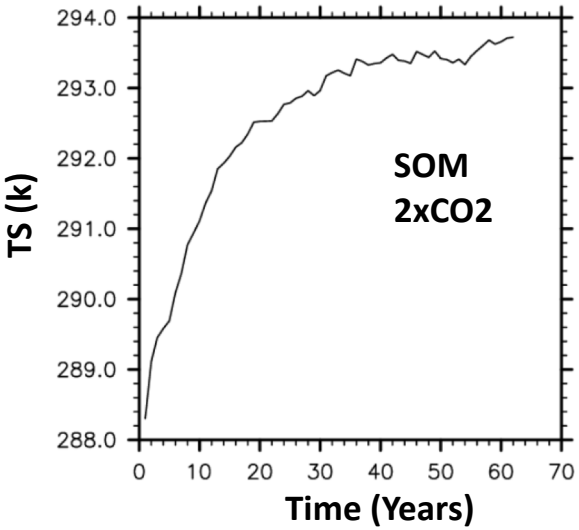
- **Why is ECS larger ?**

Climate sensitivity: Cheat-sheet

Climate sensitivity = **Equilibrium temperature change in response to abrupt 2 x CO_2.**

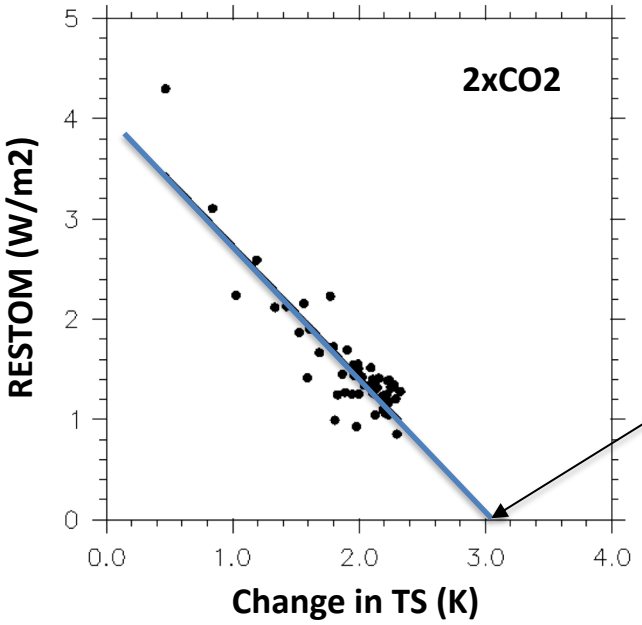
Run to a steady state

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



Gregory method (2004)

- SOM run or coupled run



X-Intercept: ECS

$\Delta TS = ECS + a*RESTOM$

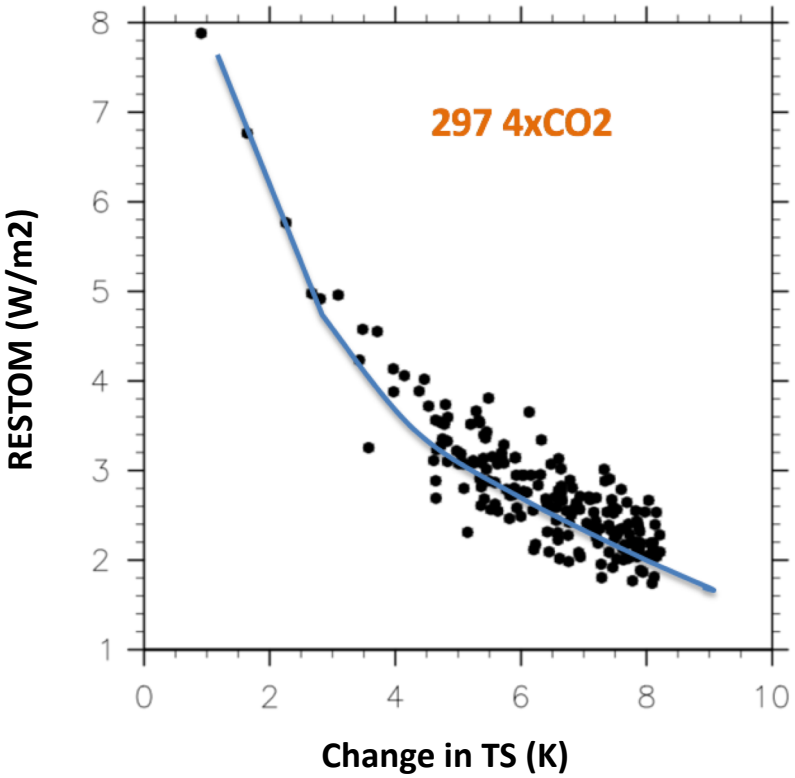
Advantage: Doesn't need to reach a steady state

Caveat: Use linear fit between RESTOM and ΔT

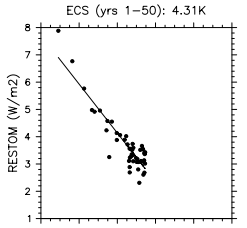
+ Other methods

Gregory method's caveat for coupled run

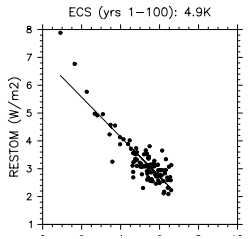
Gregory method: Use linear fit between RESTOM and ΔT



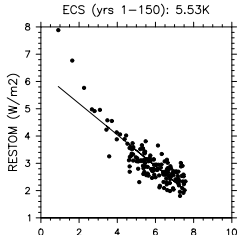
Yrs 1-50
ECS = 4.31 K



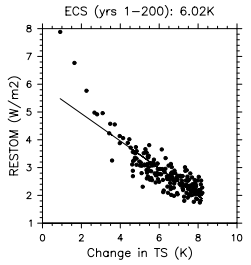
Yrs 1-100
ECS = 4.9 K



Yrs 1-150
ECS = 5.5 K



Yrs 1-200
ECS = 6.0 K

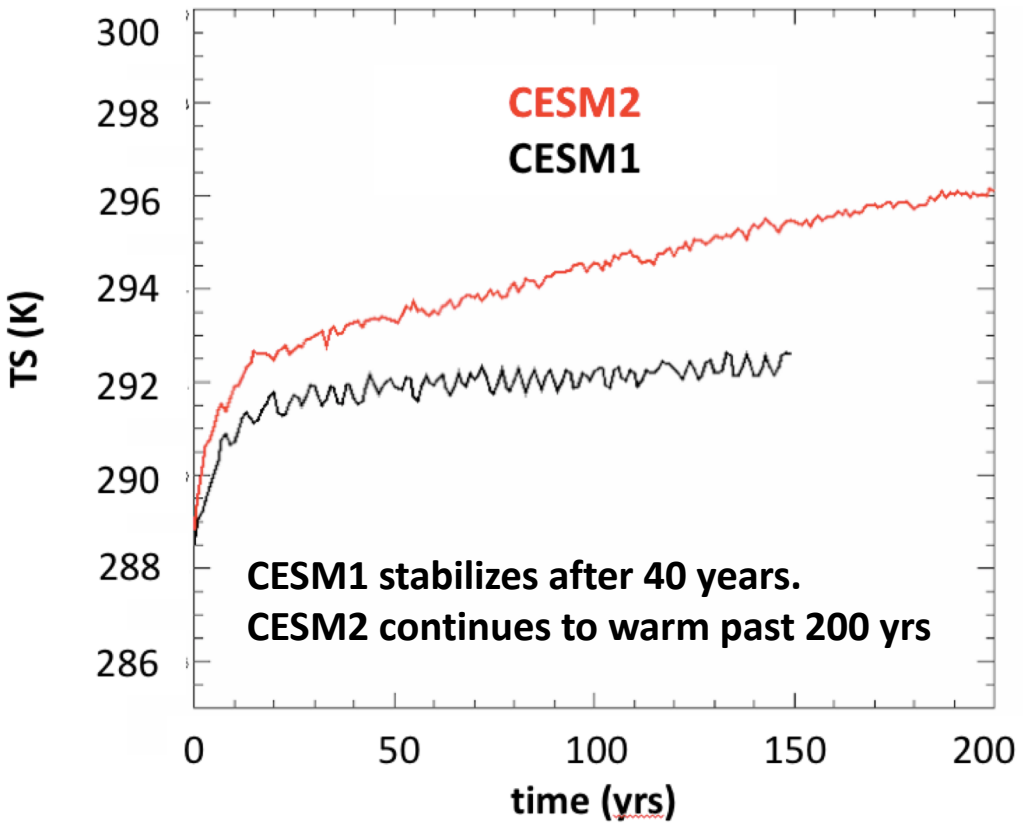


If non linear relationship,
ECS strongly depends on the chosen period
=> It is hard to give a number for ECS

What can we learn from 4XCO2 runs ?

We cannot give an exact number for climate sensitivity
Nevertheless the 4xCO2 behavior is different in CESM1 and CESM2

Increase in TS after abrupt 4XCO2



Can we identify the changes responsible for this ?

The long road from CESM1 to CESM2

Development individual model components

⇩

First coupled simulation in Nov 2015

⇩

We evaluate 297 configurations
(Thousands of simulated years and diagnostics)

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CAM1_5 Development

MENU

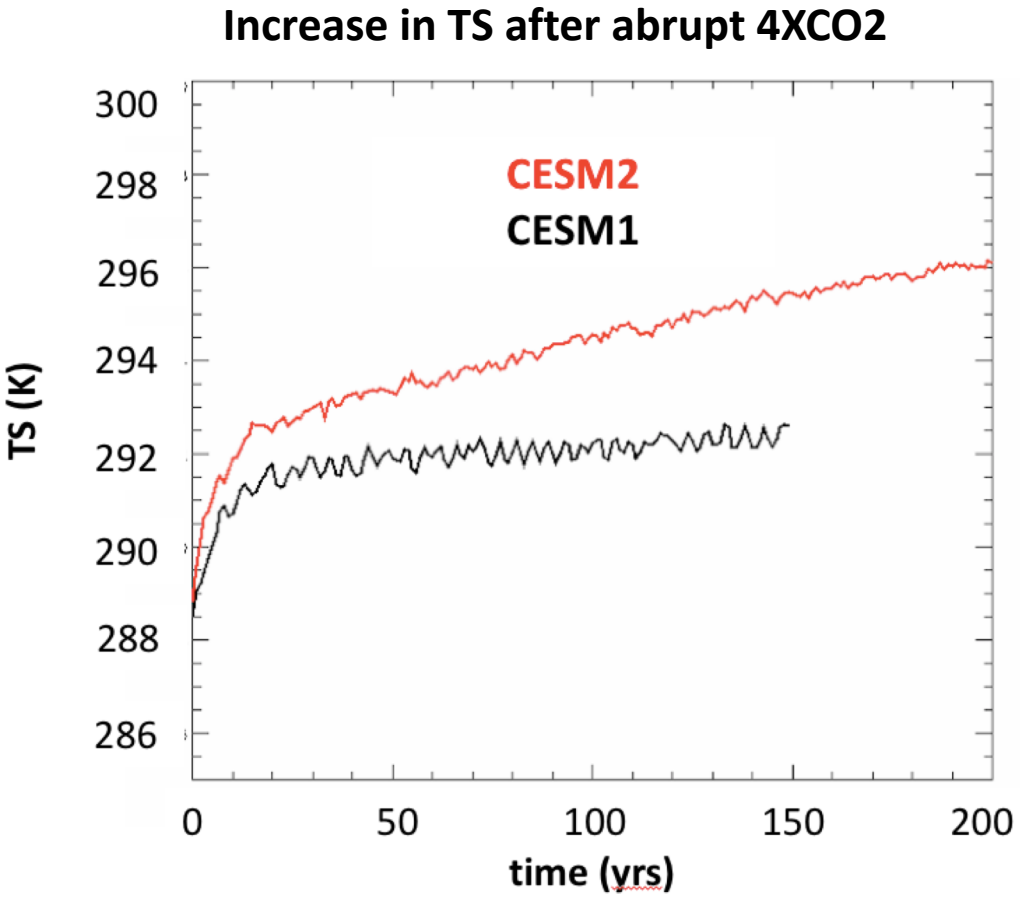
- CESM1.5 simulations (go to most recent simulation)
- List of bugs and features
- Dust: assessing dust change seen in cesm1.5

CESM1.5 SIMULATIONS

diags

ID	Case Description	ATM	OCN	ICE	LND	CVDP	comments
01	1st simulation IC: Levitus	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Known bug and bugfixes: Problem with cooling and salinity drift in the coupled runs due to an inconsistency in sea ice related fluxes between the ice and ocean models => fixed in 05 Land group looked at river discharge and found a bug (a missing term in the runoff being sent from CLM to the river model) => fixed in 03 Double counting for glacier melt => fixed in 08 Ocn heat budget: imbalance in the short wave (SW) heat fluxes of ~ 0.02 W/m^2 (due to code change in solar zenith angle) For reference, the LENS control shows a total heat flux imbalance of order 0.0005 W/m^2.
03	same as 01 + cice4 + clm bugfix (missing term when sending run-off to the river model). IC: Levitus	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Bugfix for missing term in the runoff being sent from CLM to the river model
04	same as 03 + spinup ocean IC: camclubb_B1850CN_f09g16_n27_camS_3_77_159 at yr 150	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Stabilizes faster than Levitus start up
05	same as 02 + cice5 + sea-ice bugfix IC: Levitus	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Bugfix for inconsistency in sea ice related fluxes between the ice and ocean models Ocn heat budget: imbalance in the short wave (SW) heat fluxes of ~ 0.02 W/m^2 (due to code change in solar zenith angle) Dust twice as big as in the LENS or in Pete's previous run (see: experiments below to assess origin of dust differences)
06	same as 05 + new mapping RTM->OCN (no masked runoff cells) IC: Levitus	atm diags	ocn diags	ice diags	lnd diags	cvdp diags	Stabilizes after 30 years SSTs about 0.3K colder than LENS SSTs about 0.2K colder than previous CAM5.5 (despite postive RESTOM). Dust twice as big as in the LENS or in Pete's previous run (see: experiments below to assess origin of dust differences) Pete run: zmconv_c0_lnd = 0.0075D0 zmconv_c0_ocn = 0.0450D0

Abrupt 4xCO2 in CESM1 and CESM2

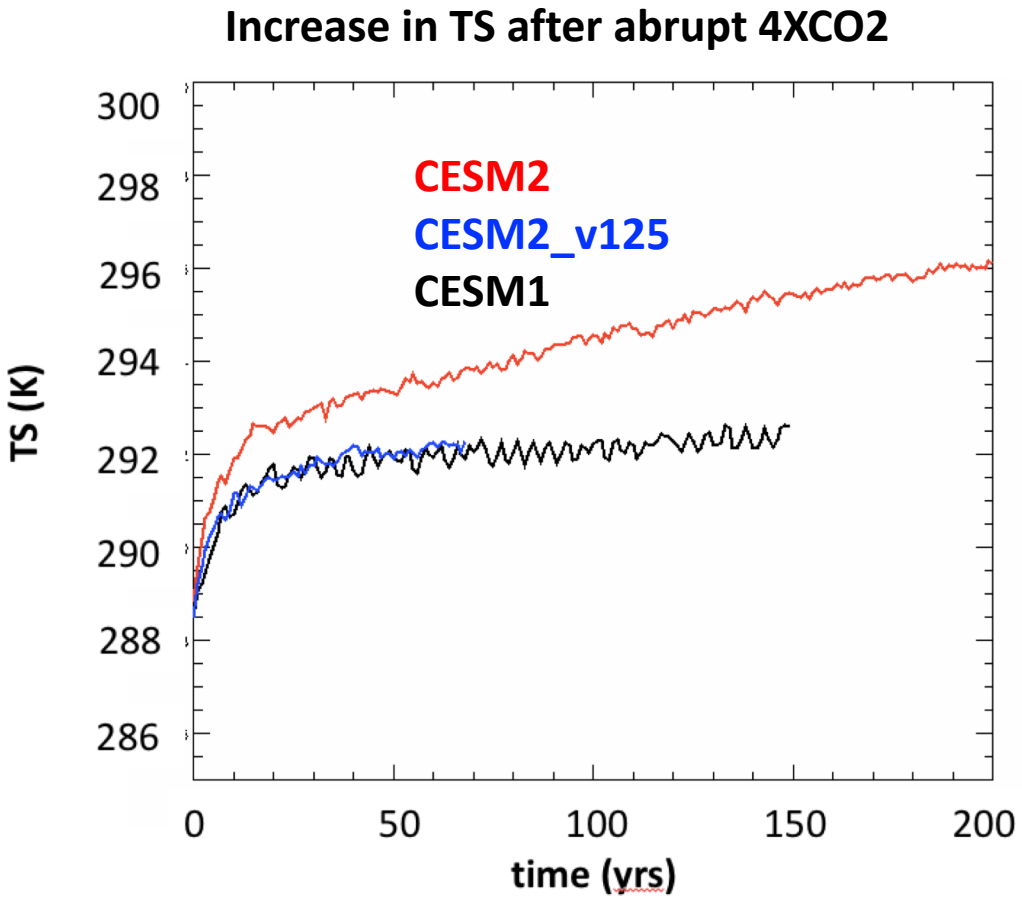


The behavior is different in CESM1 and CESM2

Can we identify the changes responsible for this ?

297 development configurations
CESM2_v1 => first coupled run
CESM2_v297 => official CESM2

Abrupt 4xCO2 in intermediate configurations



Abrupt 4xCO2 in some intermediate configurations
CESM2_v125 similar to CESM1

CESM2 ⇔ CESM2_v125
Differences in atm, lnd, ocn, sea-ice.

Revert the atmosphere to CESM2_v125

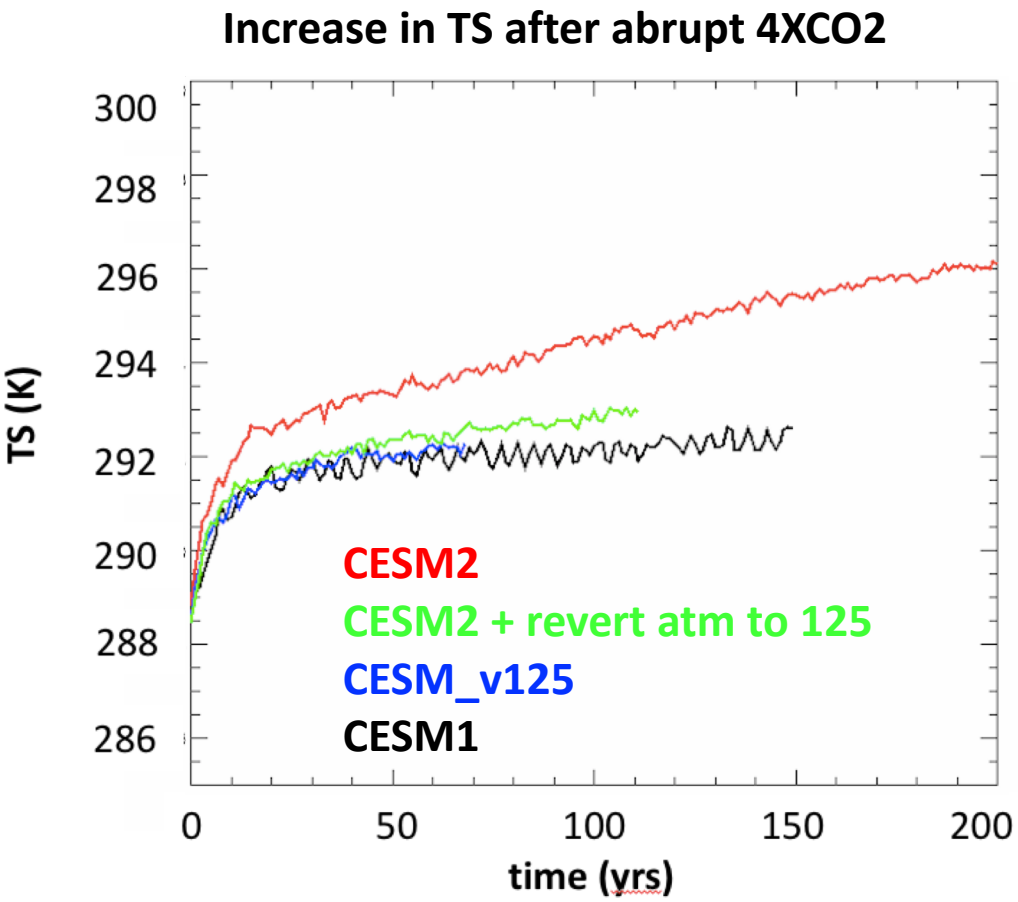
Step 1: Identify atm-only mods between CESM2_v125 and CESM2

- 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 the atmosphere to 125

Atmosphere changes explains part of the culprit



Reverting the atmosphere to CESM2_v125

⇒ bring us back part way to CESM1 behavior

Can we narrow down the list ?

List of mods to revert atm to CESM2_v125

- 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,
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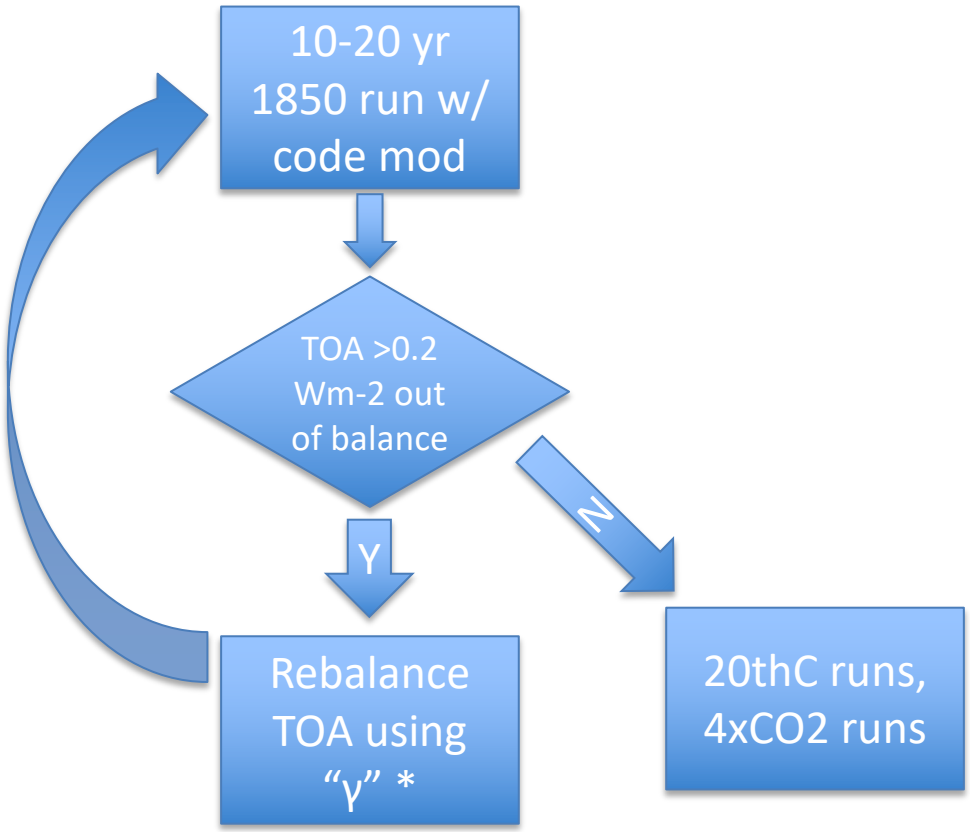
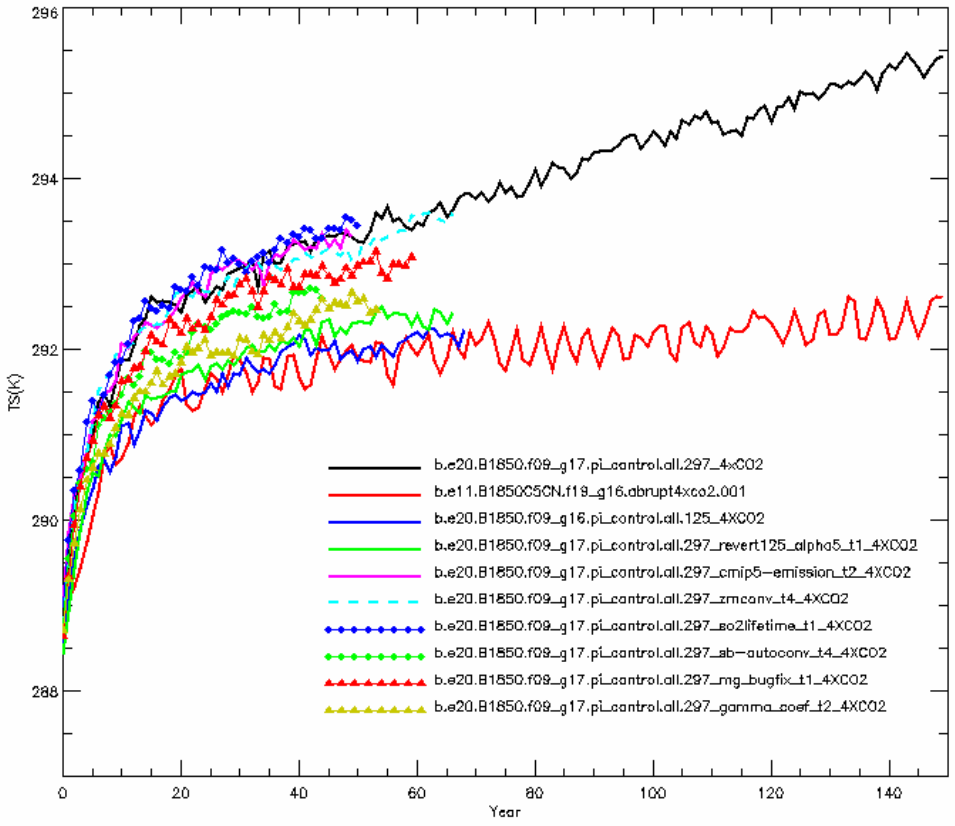
  - Bergeron Factor
  - zmconv_ke
  - Dcs

Usual CESM2 tuning cycle



* γ is a CLUBB parameter used to control low clouds

Preliminary results



What seems to make a difference ?

Makes a difference

- **Autoconversion (KK/SB)**
- **MG2 bugfix (+zmconv_ke)**
- **gamma_coeff**

Makes no difference

- **zmconv_ke**
- **So2 lifetime**
- **CMIP6 emissions**

Caveat

- **gamma_coeff retuning**

Slab Ocean Model experiments

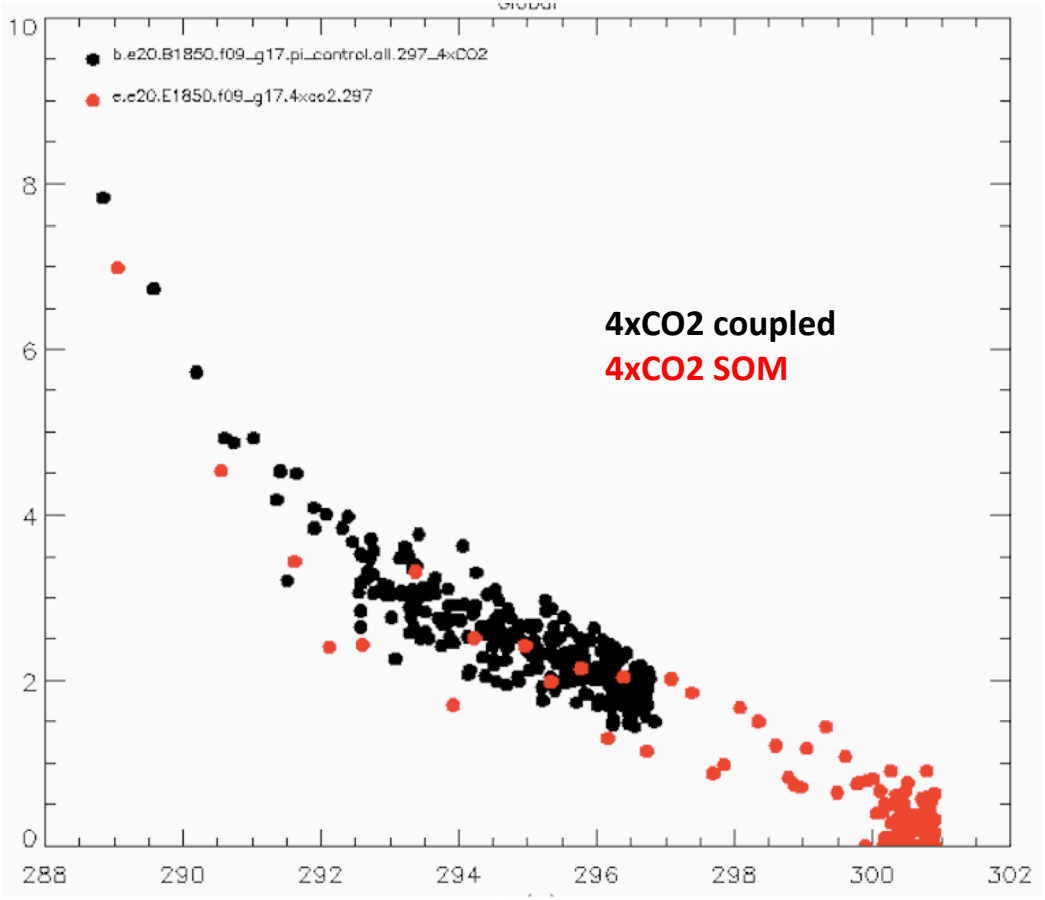
Slab Ocean Model (SOM)

- Ocean = static layer of water with some heat capacity but no motion.
- Net heat transport by ocean currents is prescribed => “q-flux"
- Reduces the time required for the model to reach equilibrium.

Q-flux

- Derived from 50 years of B1850 (to capture Arctic variability)
- Time invariant but geographically-varying mixed layer depth
- Global mean of Q_dp zero by construction

Gregory Plots for SOM runs

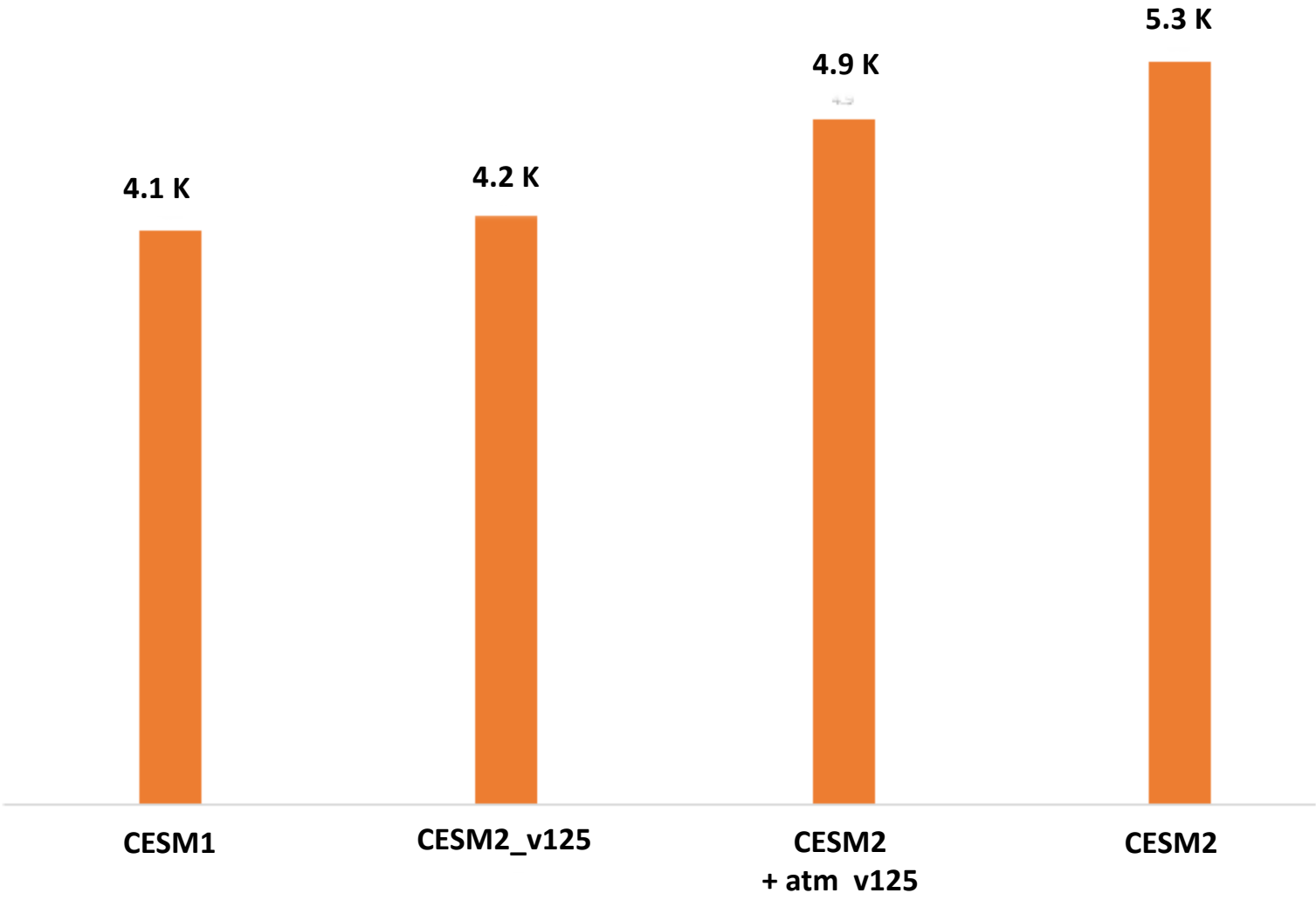


SOM runs reach equilibrium faster

Gregory plot for SOM run is similar to the coupled run

The ocean dynamics has minimal impact ?

Equilibrium Climate Sensitivity



Change in the atmosphere are part of the culprit

Conclusions

- **CESM2 has a higher sensitivity**

- **Abrupt 4xCO2 behavior is different in CESM1 and CESM2**
  CESM1 stabilizes after 40 years.
  CESM2 continues to warm past 200 yrs

- **Gregory plots for 4xCO2 SOM and 4xCO2 coupled are similar**
  Only the timescale is different
  Ocean dynamics has minimal impact

- **Equilibrium Climate Sensitivity consistent with 4XCO2 coupled runs**

- **What is the culprit ?**
  Atmosphere is part of the culprit
  Next: we are looking at the impact of the ocean coupling frequency