Climate forcing of the mid-Pliocene in three versions of the Community Earth System models

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Mid-Pliocene

- 3.3 – 3.0 Millions of years ago
- Last pro-longed warm interval with low Glacial-interglacial variability
- 400 ppm CO_2
- Limited Greenland and Antarctic ice sheet
- Expansive boreal forests, Green Sahara, reduction in desert extent
- Well-studied paleoclimate interval for understanding future climate change

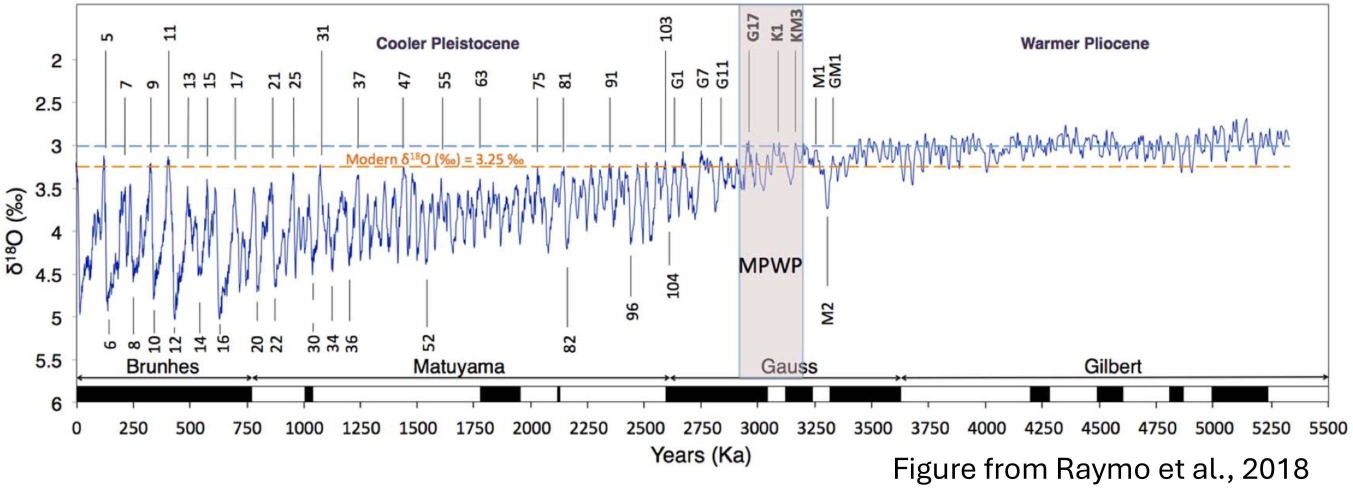

Figure from Raymo et al., 2018

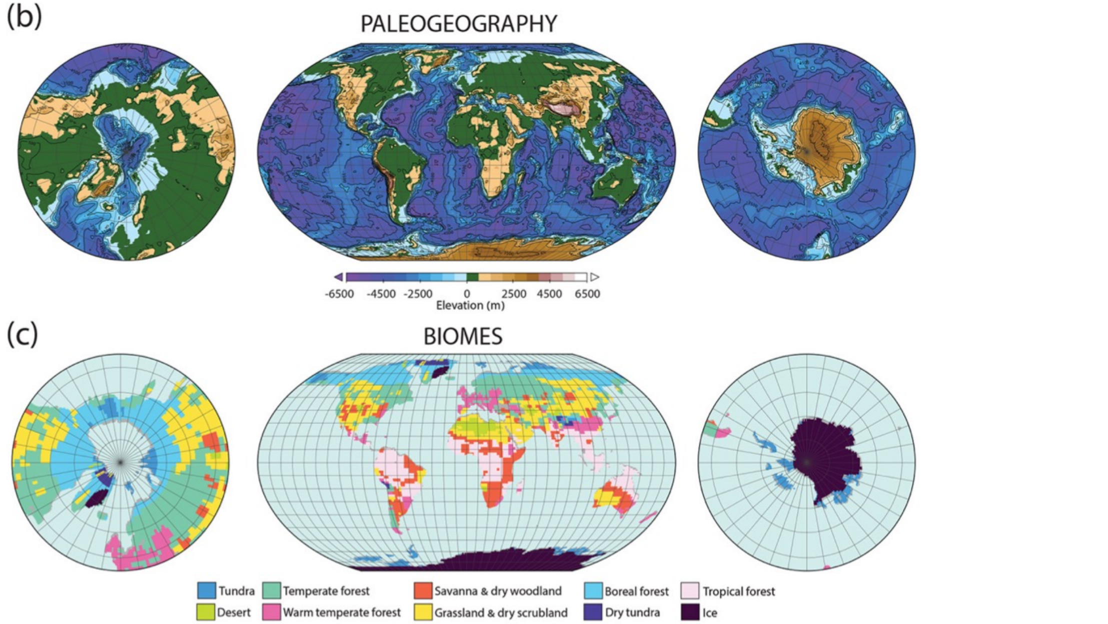

Figure from Dowsett et al., 2016

Pliocene Model Intercomparison Project

- Substantially warmer mid-Pliocene climate than what is expected from CO_2 forcing alone
  - forcing from boundary condition changes?
- Models diverge substantially in simulating mid-Pliocene warmth
  - 1.7 to 5.2 °C warming
- Climate forcing strength of the mid-Pliocene?

Model name	ECS	Eoi400 SAT	E280 SAT	Eoi400-E280 SAT
CCSM4-Utrecht	3.2	18.9	13.8	4.7
CCSM4	3.2	16.0	13.4	2.6
CCSM4-UoT	3.2	16.8	13.0	3.8
CESM1.2	4.1	17.3	13.3	4.0
CESM2	5.3	19.3	14.1	5.2
COSMOS	4.7	16.9	13.5	3.4
EC-Earth3.3	4.3	18.2	13.3	4.8
GISS2.1G	3.3	15.9	13.8	2.1
HadCM3	3.5	16.9	14.0	2.9
IPSLCM6A	4.8	16.0	12.6	3.4
IPSLCM5A2	3.6	15.3	13.2	2.2
IPSLCM5A	4.1	14.4	12.1	2.3
MIROC4m	3.9	15.9	12.8	3.1
MRI-CGCM2.3	2.8	15.1	12.7	2.4
NorESM-L	3.1	14.6	12.5	2.1
NorESM1-F	2.3	16.2	14.5	1.7
MMM	3.7	16.5	13.3	3.2

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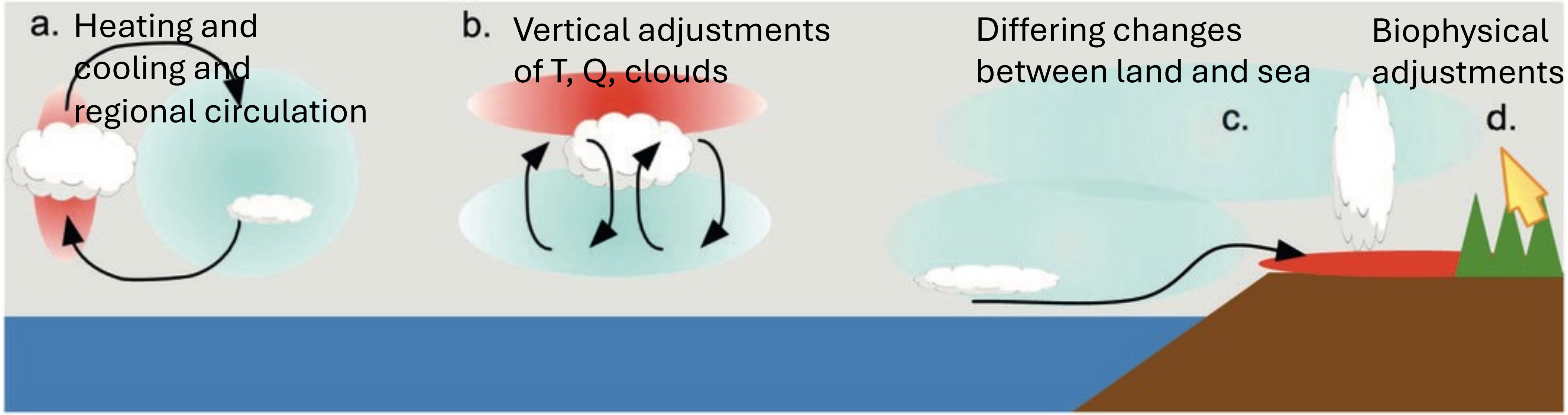
Effective radiative forcing and adjustments

- Effective radiative forcing and adjustments: "*changes that occur directly due to the forcing, without mediation by the global-mean temperature, as "**adjustments**" and the accordingly modified top-of-atmosphere radiative imbalance as the "**effective" radiative forcing**" (e.g., Sherwood et al., 2015)



Diagnose effective radiative forcing and adjustments

- Fixed SST simulations with three groups of forcing agents
  - CO_2
  - Vegetation + Ice sheets
  - Geography + topography
  - Combined forcing
- SSTs and sea ice from coupled simulations of the same model
  - CCSM4
  - CESM1.2
  - CESM2 (only has CO_2 and combined forcing)
- Run for ~30 years, last 20 years for average

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- ERF =

$(FSNT – FLNT)_{Pert}$ - $(FSNT – FLNT)_{PI}$

- Adjustments = $K_x(X_{pert} – X_{PI})$

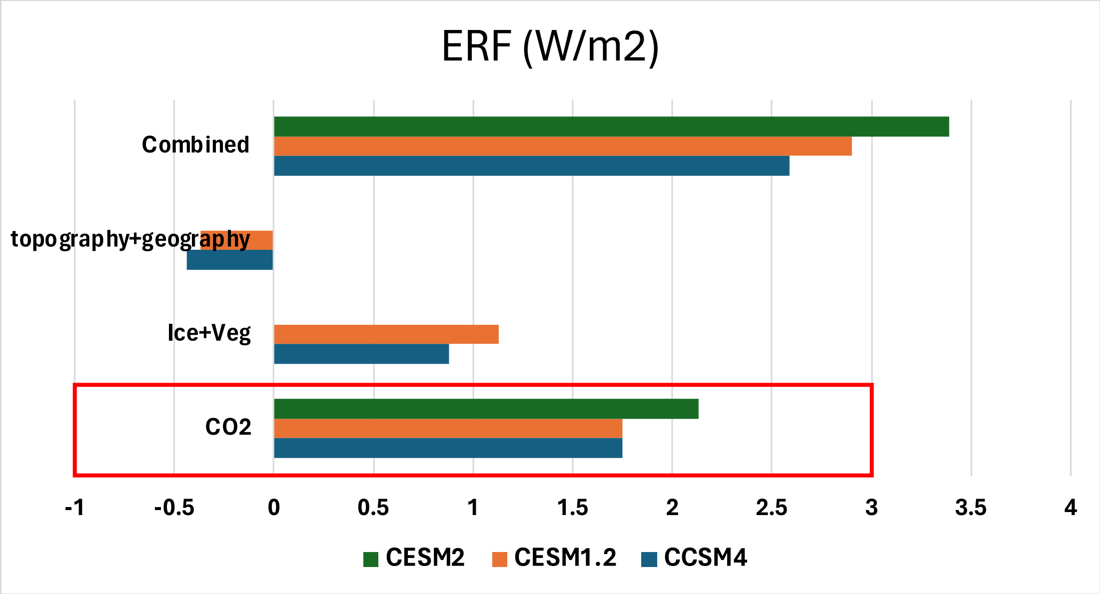
  K_x: radiative kernel coefficient

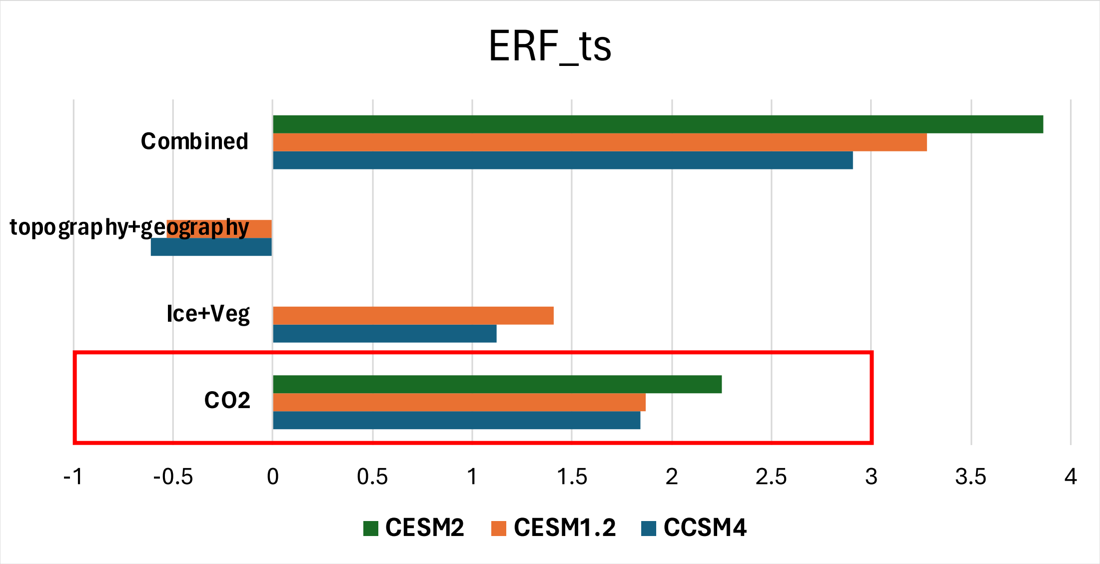
  X: T, T_s, q, α (Pendergrass et al., 2018)

- ERF_ts = ERF - $K_x(Ts\_land_{pert} – Ts\_land_{PI})$
  - correct for land T changes

ERF estimates

- CO_2 accounts for 60 to 68% of the total ERF, or 57% to 63% of the total ERF_ts.





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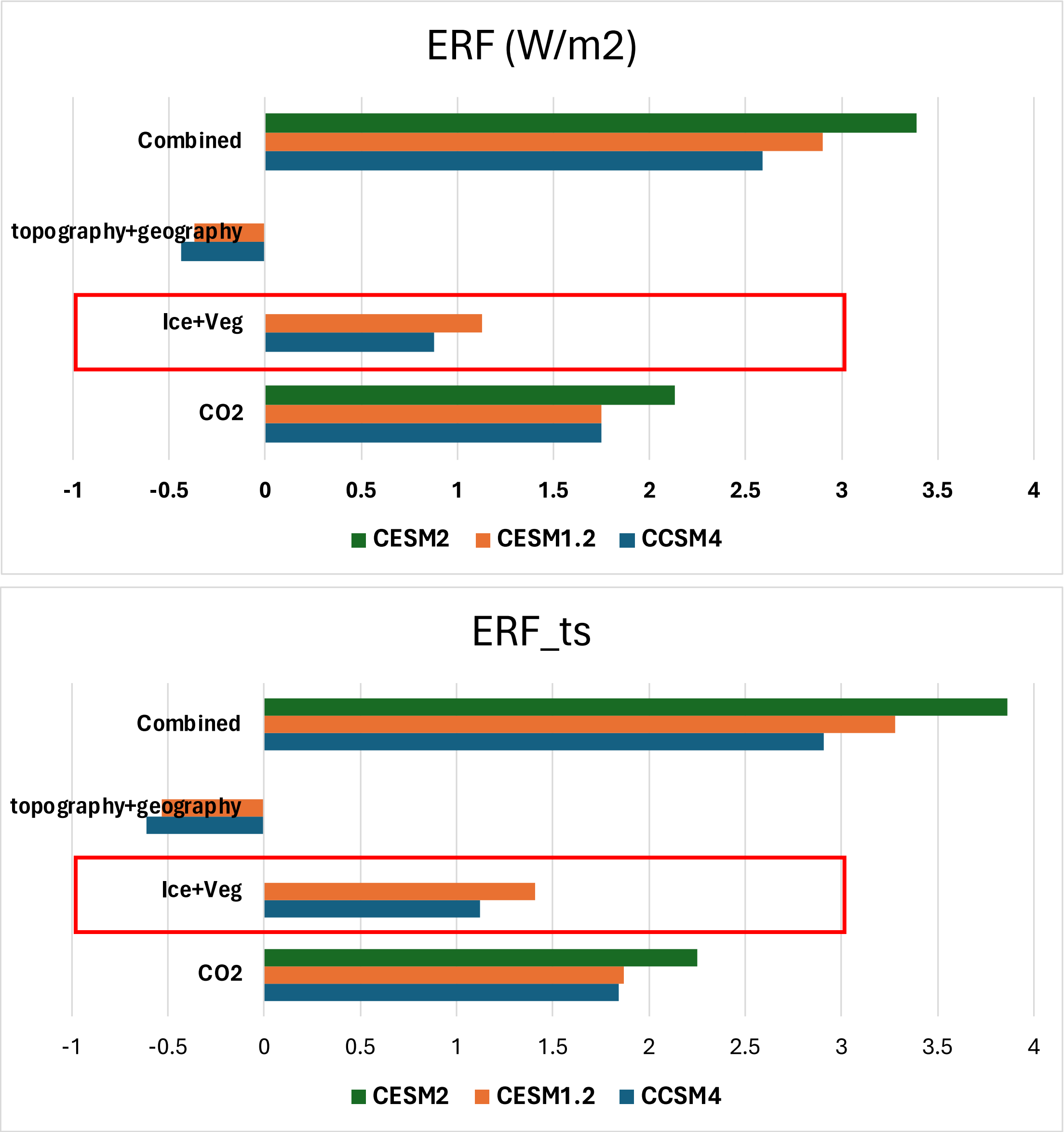
- CO_2 accounts for 60 to 68% of the total ERF, or 57% to 63% of the total ERF_ts.
- Contribution from Ice+Veg is about 2/3 of that of CO_2
  - Partially compensated by topo+geo changes



ERF estimates

- CO_2 accounts for 60 to 68% of the total ERF, or 57% to 63% of the total ERF_ts.
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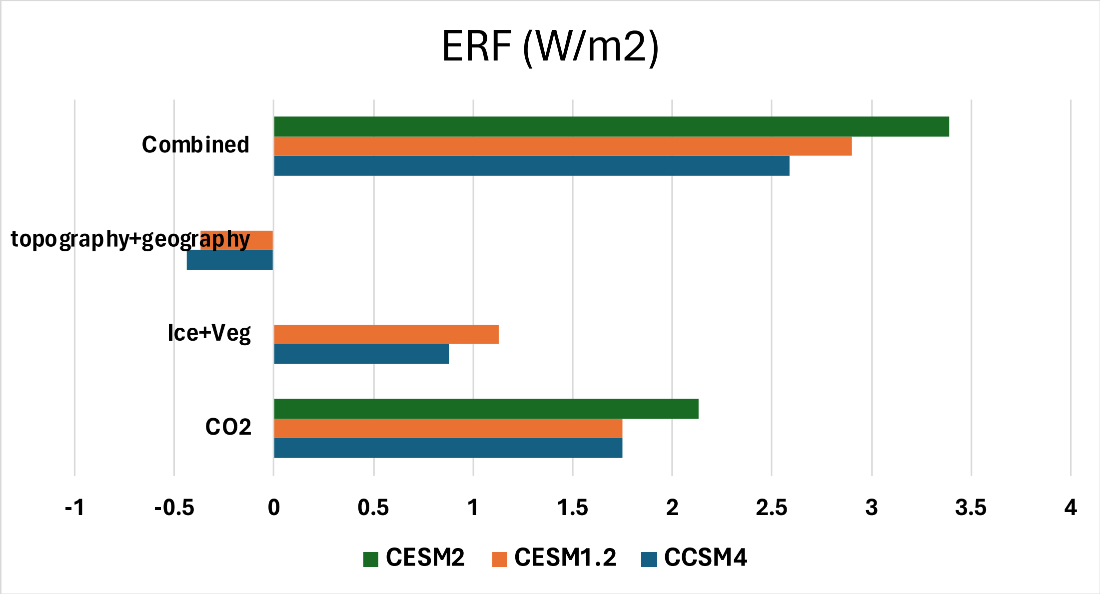
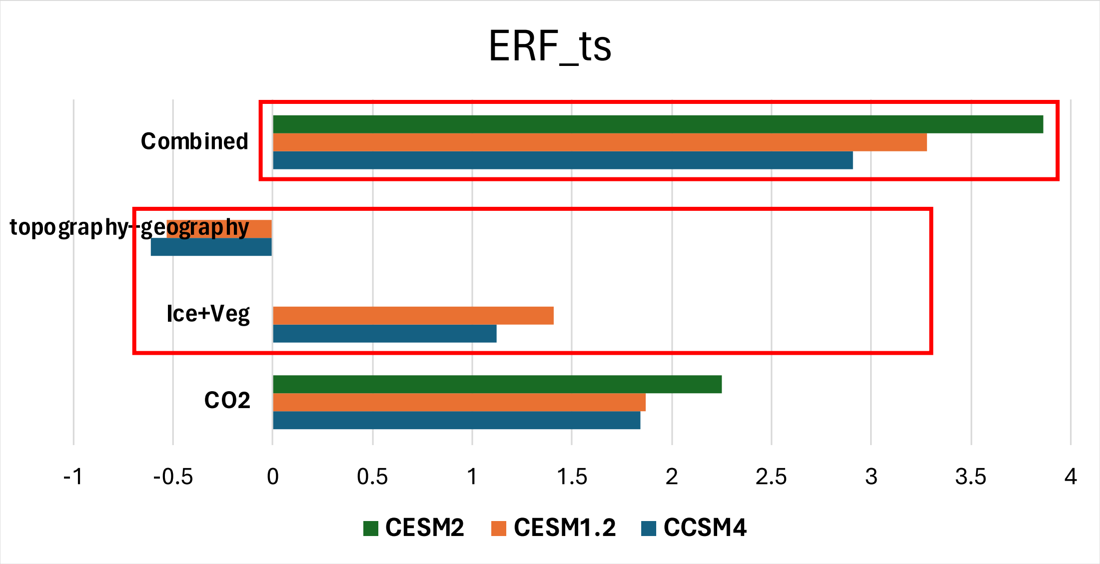
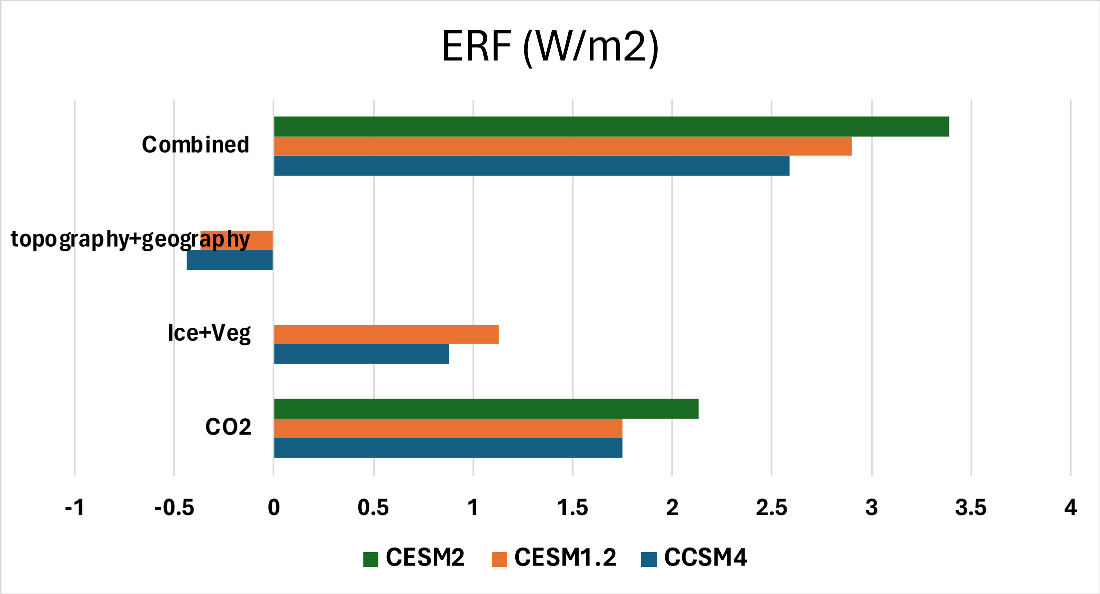
- Forcing increase from CCSM4 to CESM1 is driven by amplified non-CO_2 forcing

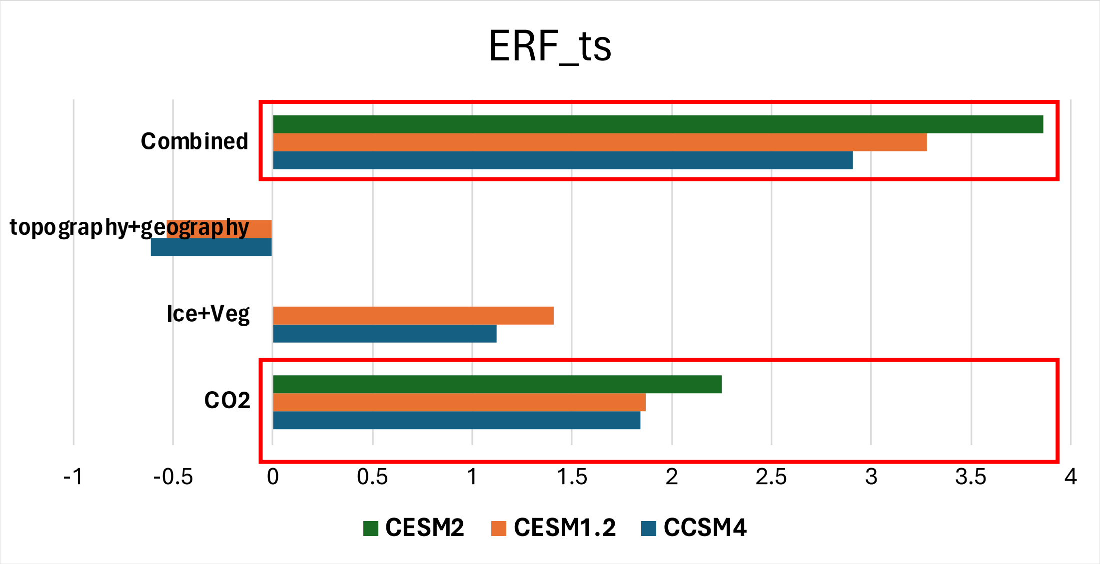




ERF estimates

- CO_2 accounts for 60 to 68% of the total ERF, or 57% to 63% of the total ERF_ts.
- Contribution from Ice+Veg is comparable to CO_2
  - Partially compensated by topo+geo changes
- Forcing increase from CCSM4 to CESM1 is driven by amplified non-CO_2 forcing, from CESM1 to CESM2 is driven by CO_2 forcing.





Adjustments

- In the case of CO_2, the net adjustments is negligible for CCSM4, but ~20% in CESM2 due primarily to cloud adjustment.
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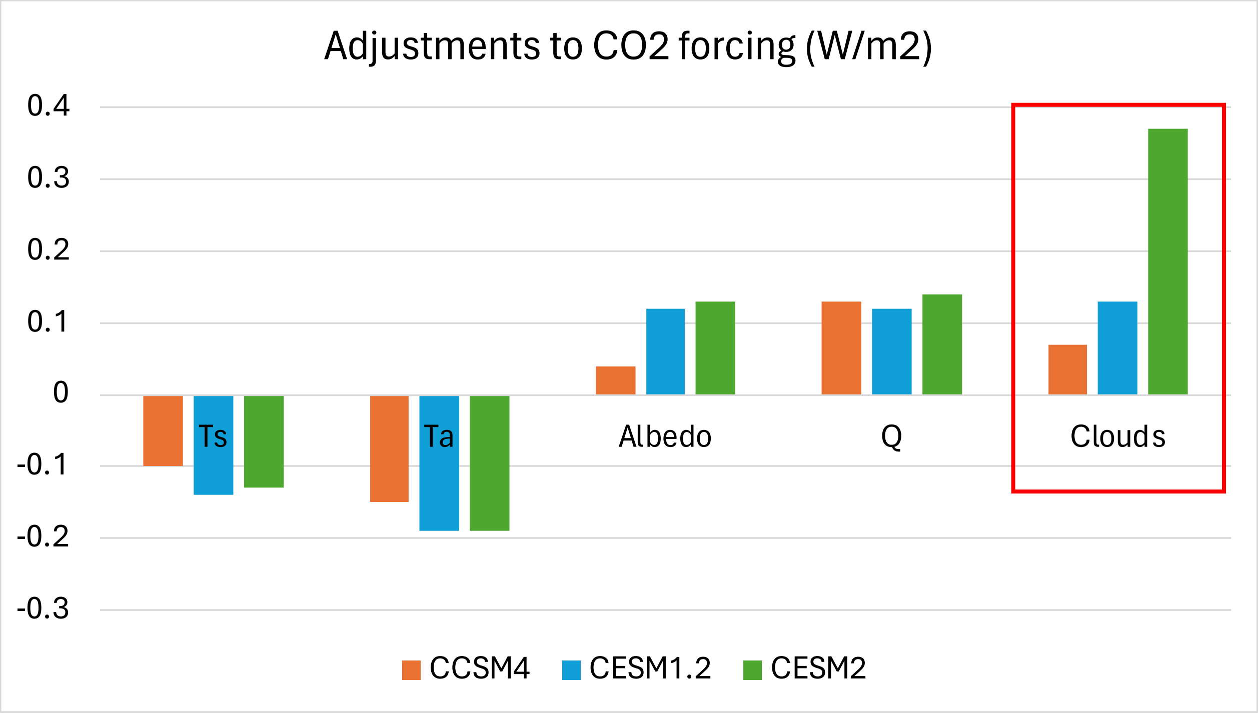
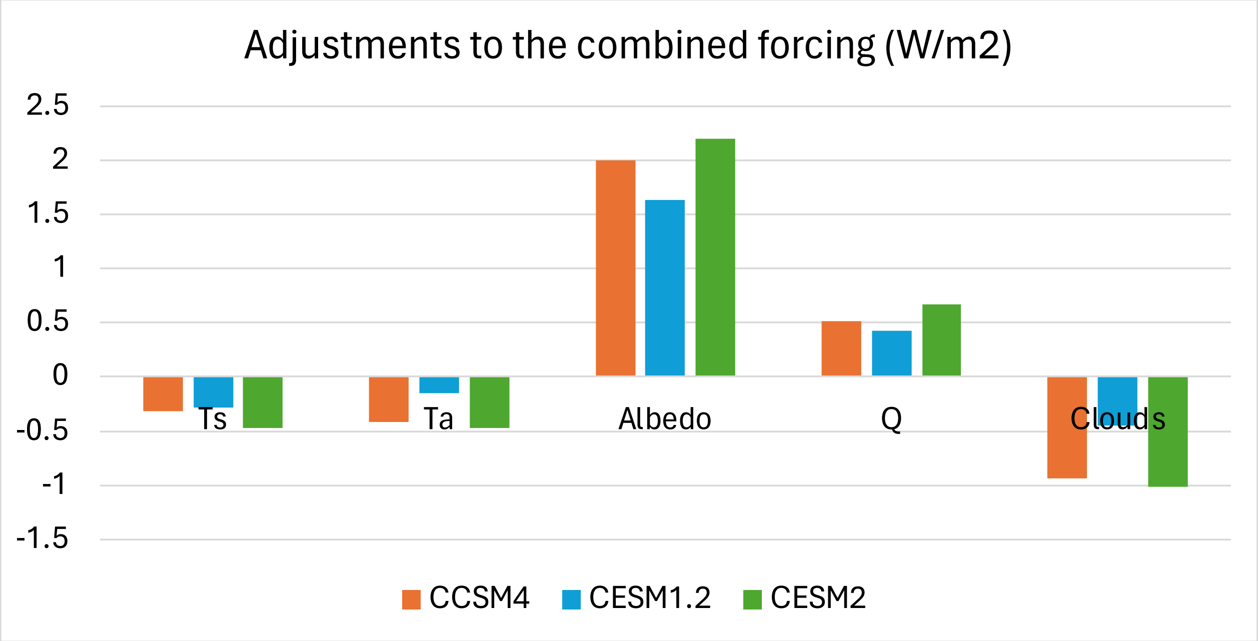
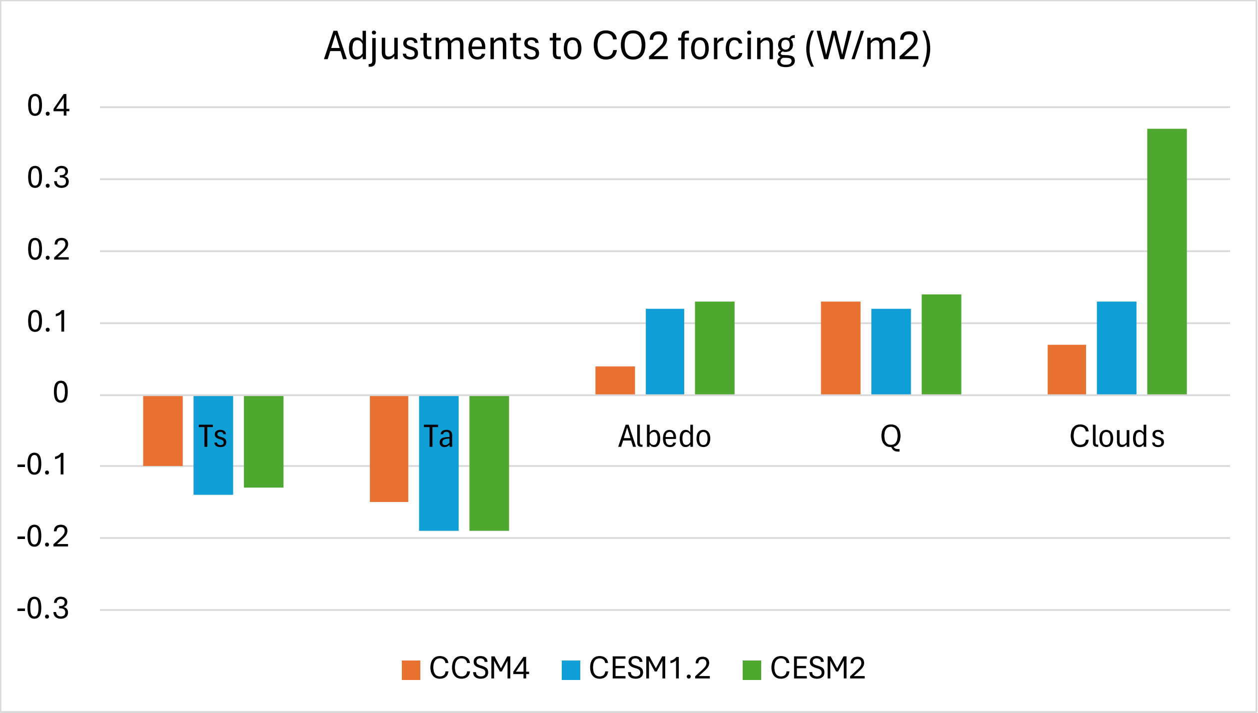
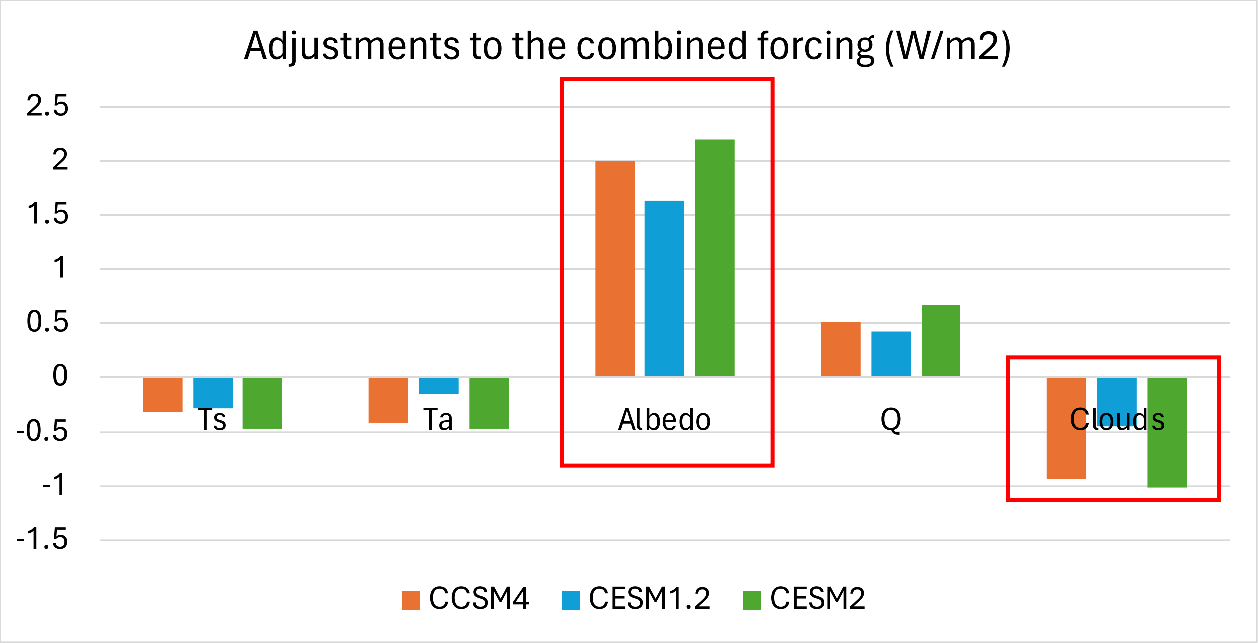




Adjustments

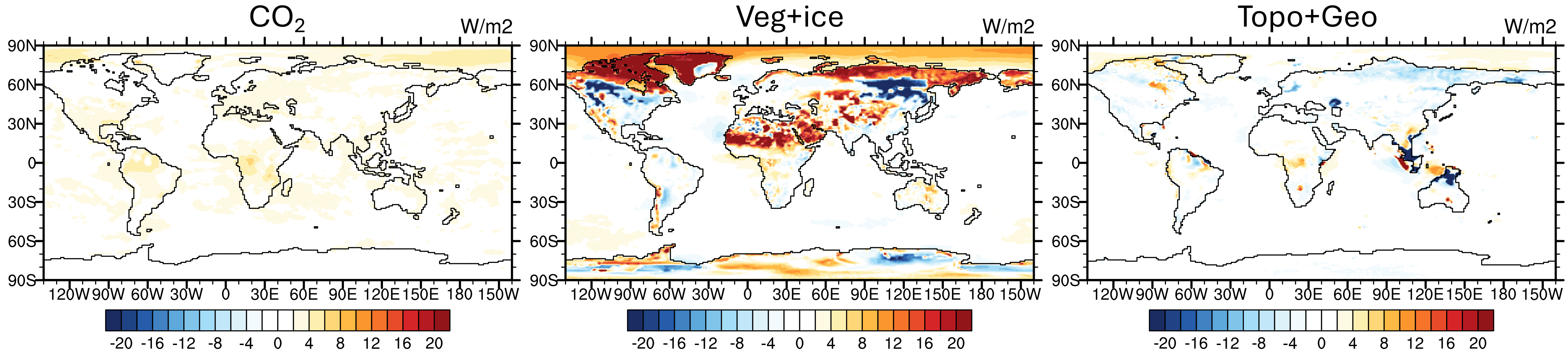
- In the case of CO_2, the net adjustments is negligible for CCSM4, but ~20% in CESM2 due primarily to cloud adjustment.
- Combined forcing mainly comes from surface albedo changes (direct forcing from veg+ice)
    - Negative contributions from cloud adjustments





Spatial distribution of the ERF

- CO_2 forcing is the strongest in the tropics and Arctic region.
- Forcing from veg+ice, topo+geo mainly reflects surface albedo changes.



Preliminary results

- CO_2 perturbation provides ~60% forcing for mid-Pliocene climate.
- Combined forcing increases with increasing climate model sensitivity
  - from different sources
- Adjustments to the combined forcing differs from CO_2 forcing
  - cloud adjustments switch signs

Questions?