Evaluating climate sensitivity on different time scales and its relation with base climate

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Outline

- Motivation
- Model and experiment setup
- Climate sensitivity and base state
- Climate sensitivity and time-scale
- Summary and discussion

1. Introduction

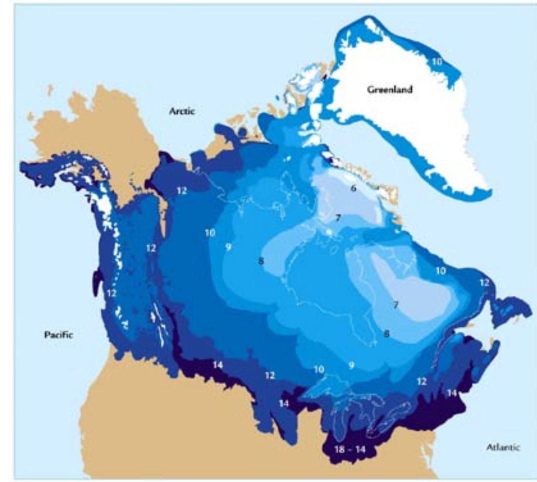
- Climate model sensitivity to CO_2 doubling: 1.5-4.5 °C
- Deficiency of instrumental observations
- Alternative: to use paleoclimate reconstructions, e.g. LGM and YD
- Two issues:

  1) How much is the sensitivity derived from the glacial climate representative of the modern warm climate?

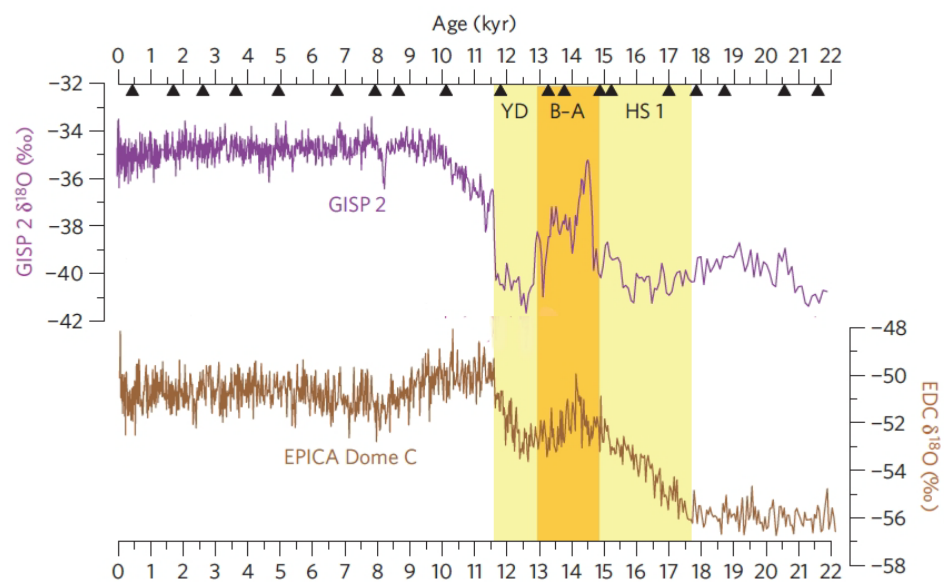
     → "base state issue"

  2) How to relate the long-term climate sensitivity to the short-term one?

     → "time-scale issue"

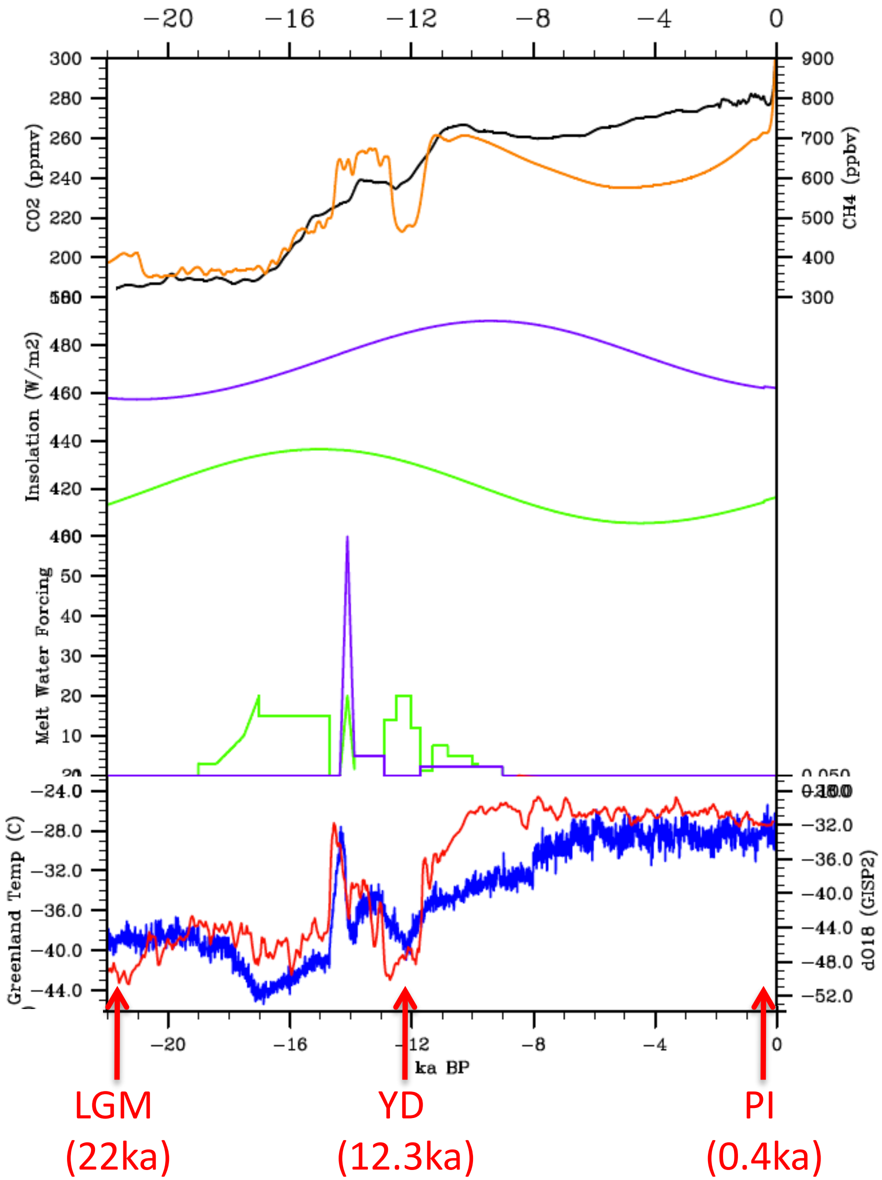


(Ruddiman, 2008)



(Mohtadi et al., 2011)

2. Model and experiment setup



Trace21 transient simulation

- CCSM3, T31x3
- Time-varing a) greenhouse gases, b) solar insolation, c) ice-sheet topography and d) meltwater discharge
- Covers 22ka-0ka

Sensitivity Experiment setup

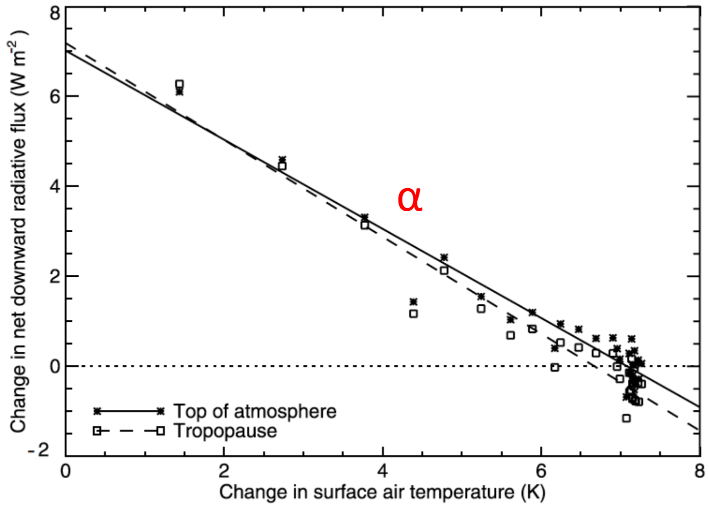
- Branched from three different base states of Trace21 (LGM, YD and PI)
- Instantaneous doubling of CO_2
- Integrated for 90 yr

3. Climate sensitivity and base state

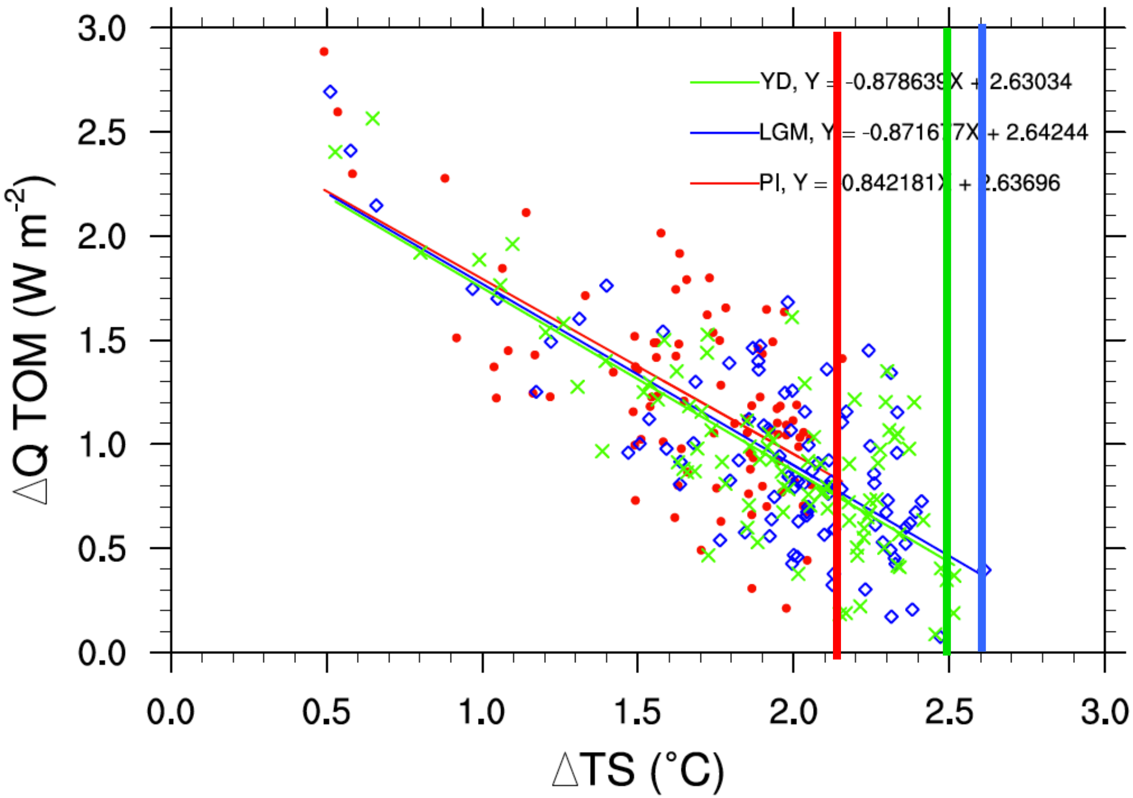
$$\Delta Q = \Delta F - \alpha \Delta TS$$

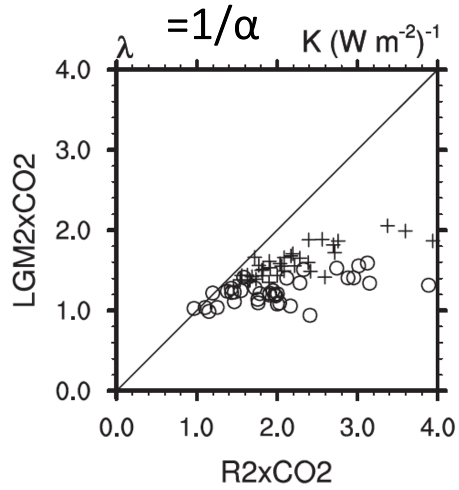
- ΔQ – net heat flux anomaly at the top of atmosphere (TOA)
- ΔF – net radiative forcing
- ΔTS – global mean surface temperature change
- α – climate feedback parameter (W m^{-2}/K),
  equals to ΔF/ΔTS at equilibrium, when ΔQ = 0.

- Gregory et al. (2004) proposed a method to find ΔTS at equilibrium, by regressing ΔQ against ΔTS to obtain a 'projected' equilibrium temperature change, ΔTS_{eqr}, as the ΔTS-intercept of the regression line found by least squares fit (ie, where ΔQ=0).



3. Climate sensitivity and base state

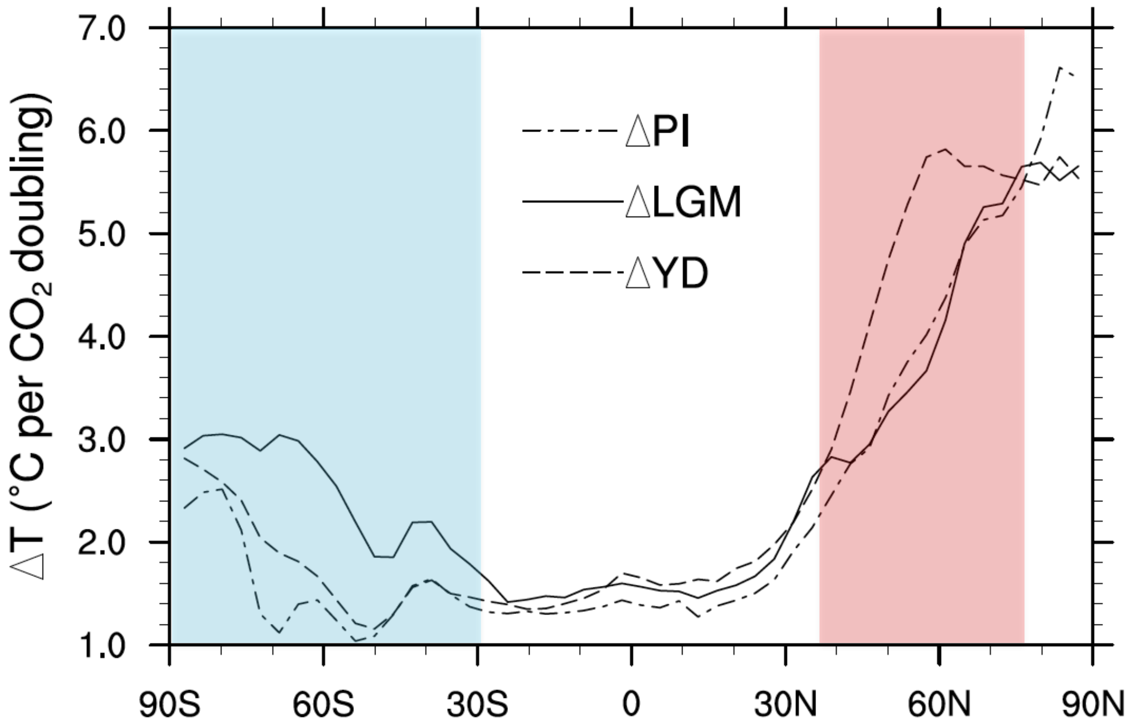




(Yoshinori et al., 2011)

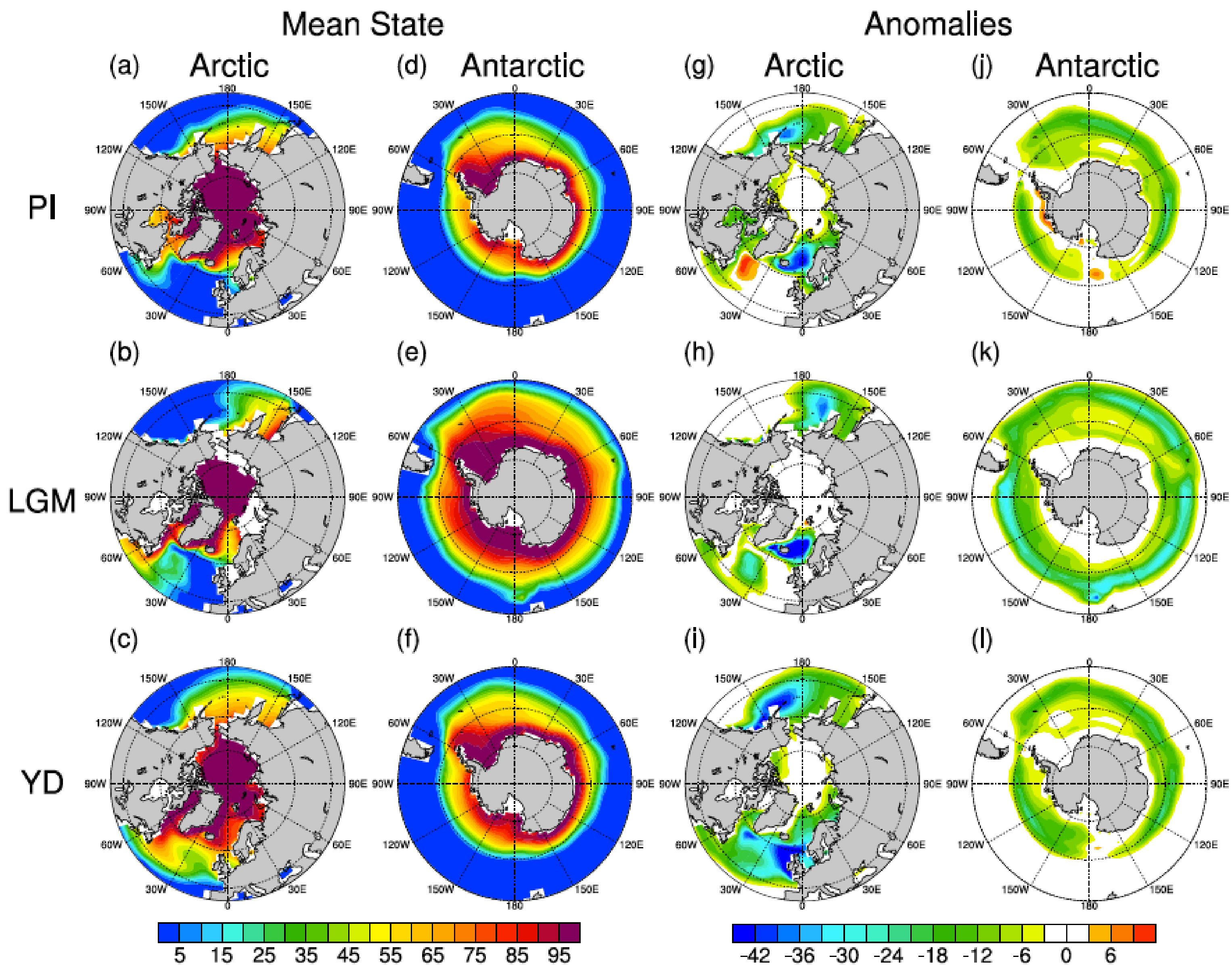
- Feedback coefficient (α) does not rely on base states.
- Climate does respond in different speeds with different base states
  - → key to short-term climate sensitivity, because we care about "how fast" the climate responds in the next few decades.
- Why does glacial climate respond faster?

3. Climate sensitivity and base state

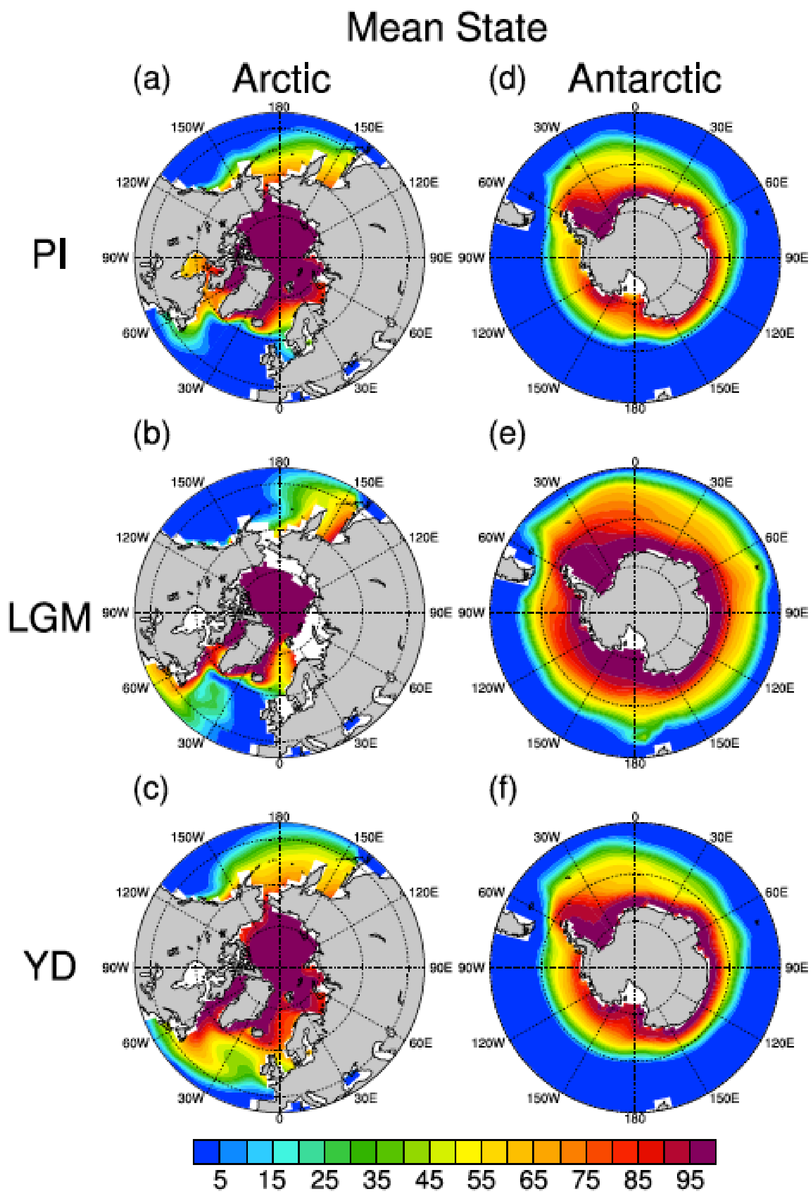


- Average of the last 40 yr (total is 90 yr)
- Polar amplification
- Response in tropics is virtually identical for three cases, despite dramatically different base states.
- LGM-2CO2: stronger response in SH
- YD-2CO2: stronger response in NH

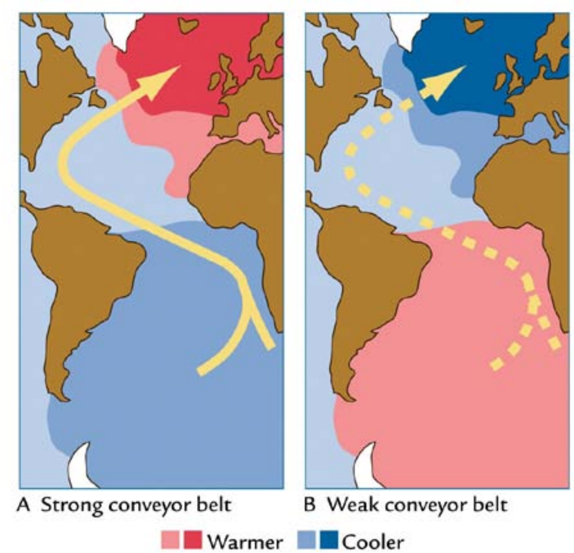
3. Climate sensitivity and base state



3. Climate sensitivity and base state



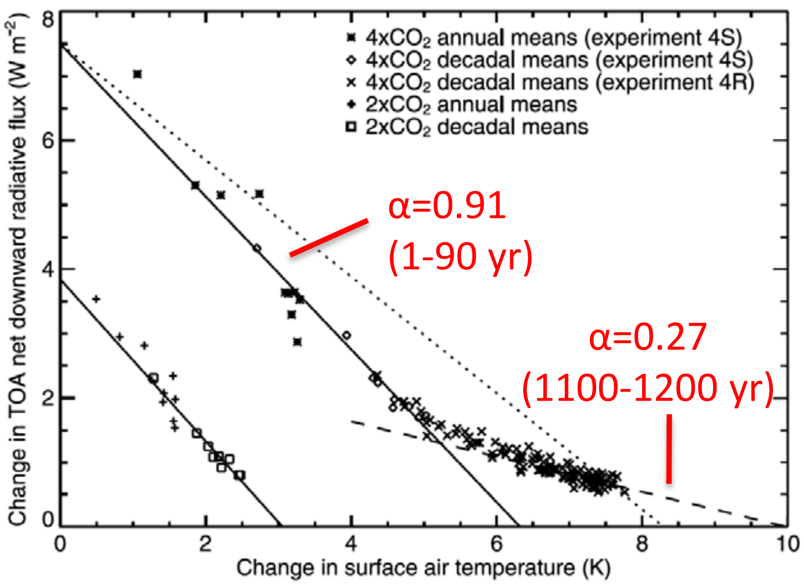
	PI	LGM	YD
$CO_2(ppmv)$	280	185	240
AMOC (Sv)	11.1	12.6	4.0
A_{global} (%)	43.7	62.8	52.3
A_{arc} (%)	62.6	60.3	77.0
A_{ant} (%)	33.1	63.9	39.3
ΔT_{global} (°C)	1.92	2.23	2.25
ΔT_{arc} (°C)	4.49	4.33	5.46
r_{arc}	2.34	1.94	2.43
ΔA_{arc} (%)	-8.49	-8.33	-14.85
ΔT_{ant} (°C)	1.38	2.60	1.68
r_{ant}	0.72	1.17	0.75
ΔA_{ant} (%)	-4.18	-9.57	-5.15



(Ruddiman, 2008)

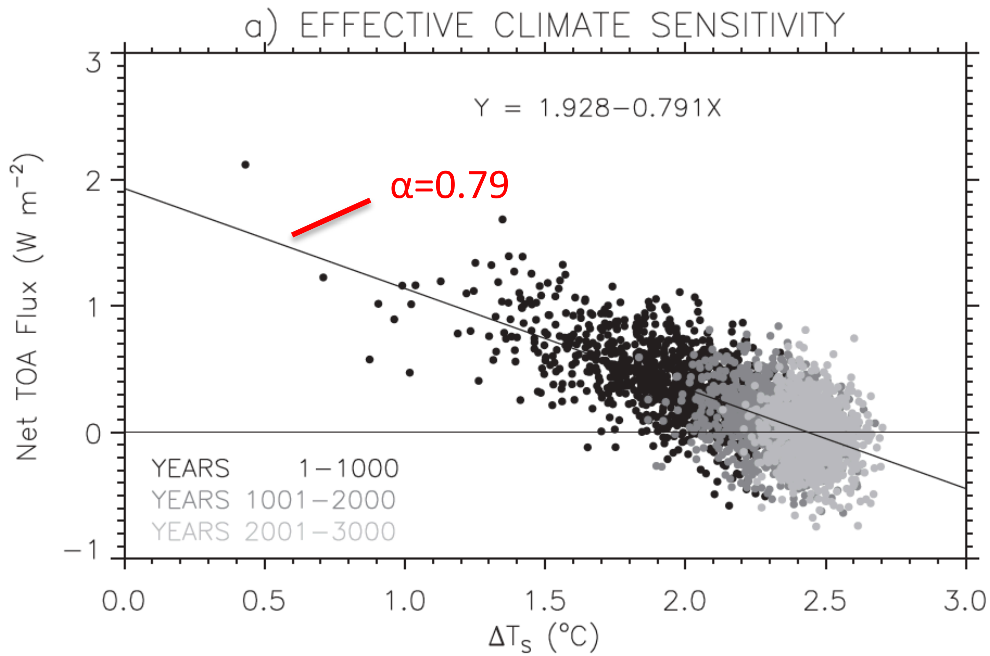
4. Climate sensitivity and time scale

HadCM3



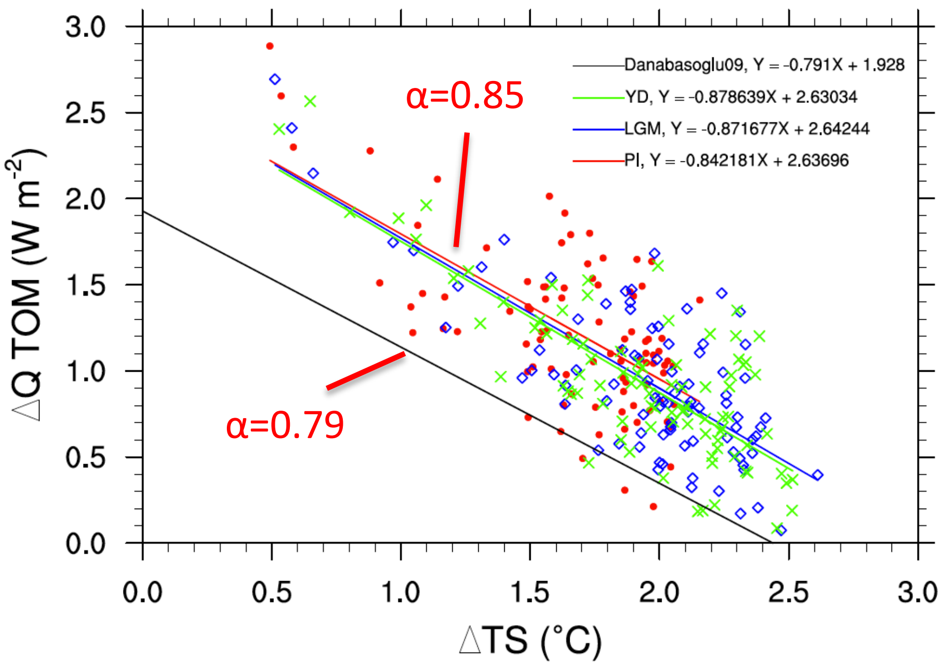
(Gregory et al., 2004)

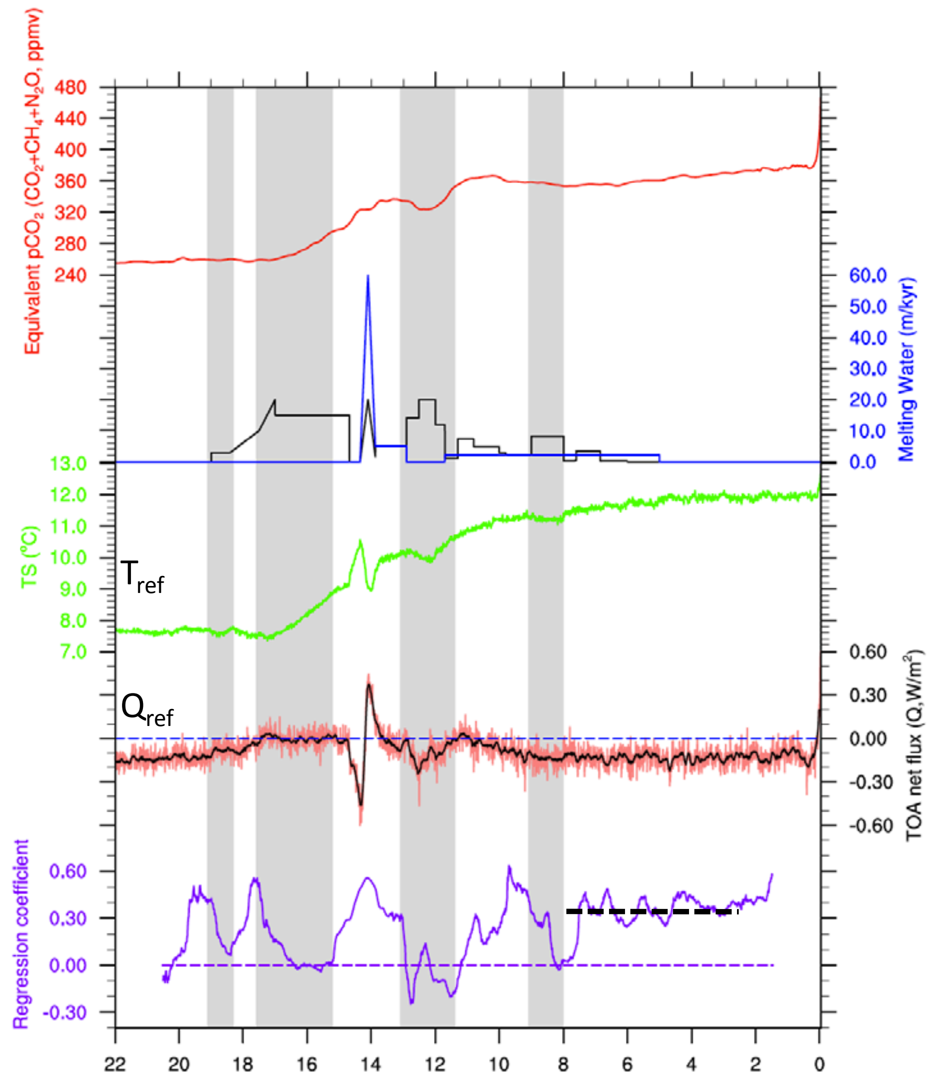
CCSM3 T31x3



(Danabasoglu et al., 2004)

4. Climate sensitivity and time scale

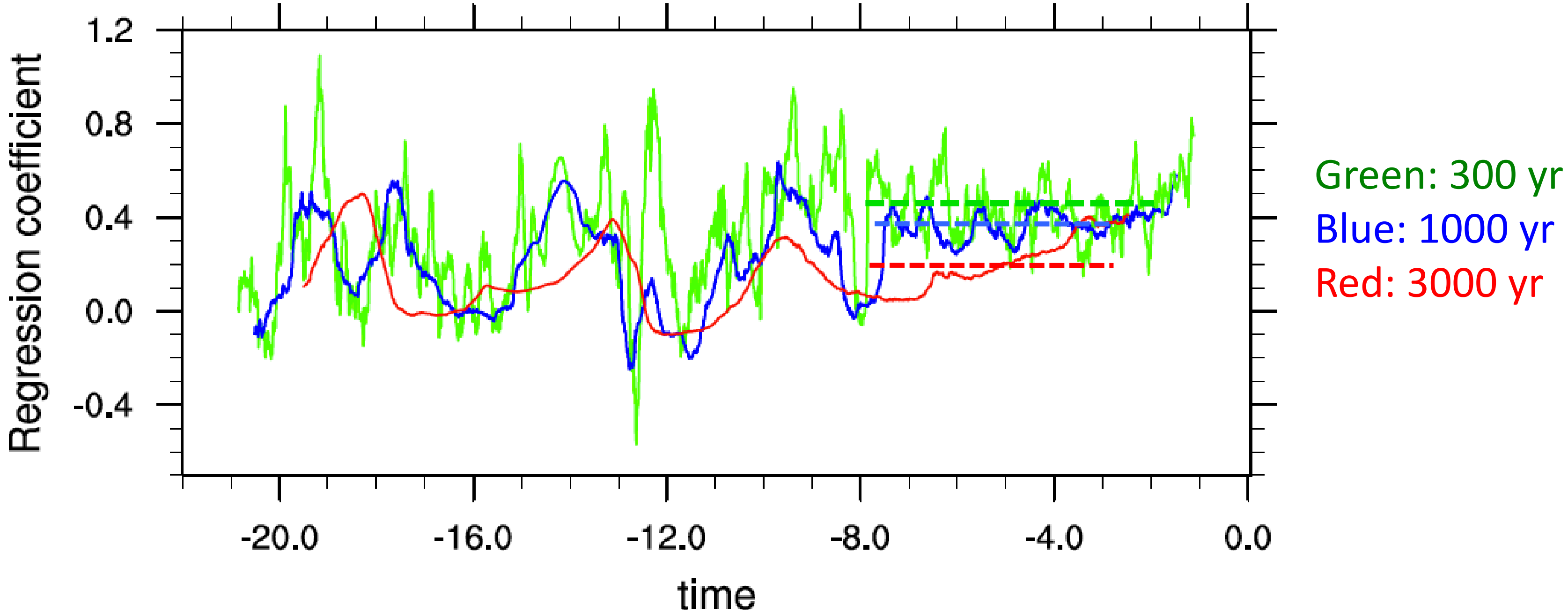




- Short-term, α ~ 0.85
- Long-term, statistic, α ~ 0.40

$$\Delta Q = \Delta F - \alpha \Delta TS$$

4. Climate sensitivity and time scale



- 300 yr regression: α ~ 0.47
- 1000 yr regression: α ~ 0.40
- 3000 yr regression: α ~ 0.21
- Feedback coefficient becomes smaller when estimated over longer time-scale (with the same forcing).
- Small α implies larger ΔTS.

$$\Delta Q = \Delta F - \alpha \Delta TS$$

- Short-term feedbacks: changes in water vapor, clouds, snow and sea ice
- Long-term feedbacks: dynamic vegetation, ocean circulation (melting water), ice sheets.
- Using LGM data to constrain model performance?

5. Summary and discussion

- Short-term climate feedback coefficient (α) does not rely on base states.
- Glacial climates respond to CO_2 doubling faster than warm climates, due to different sea ice extent.
- Long-term (millennium) sensitivity is twice the size of short-term (centennial) sensitivity based on Trace21 simulation.