Late Holocene Climate Change: Astronomical vs. Anthropogenic Forcing

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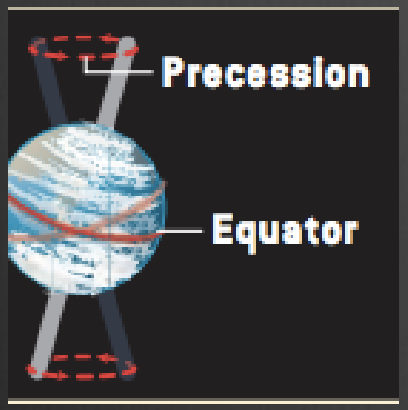
Astronomical vs. Anthropogenic Forcing

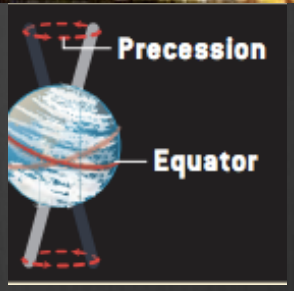
Two Views of Pre-Industrial Holocene climate changes

Traditional view



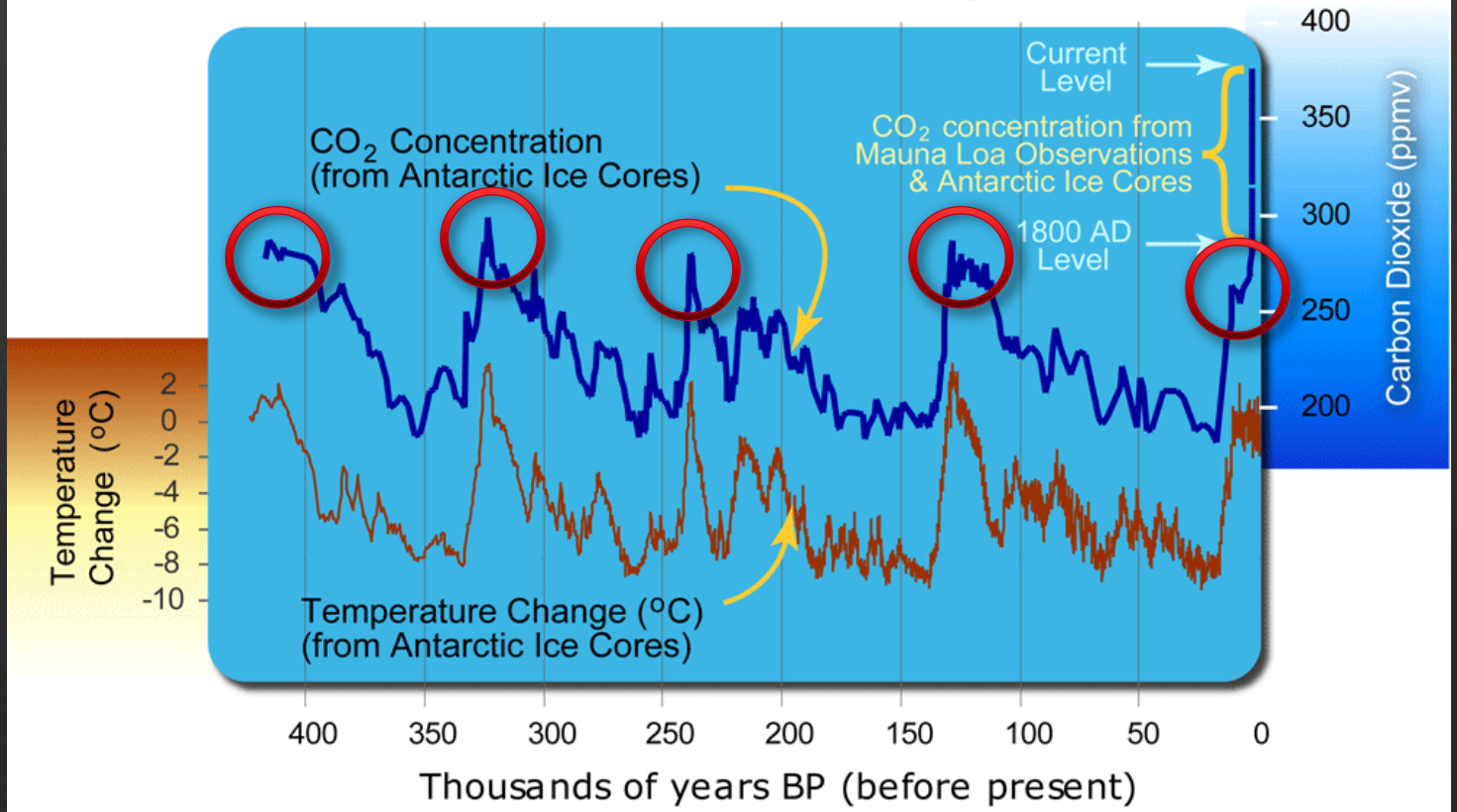
Natural climate variability
(Astronomical & Volcanic forcing)

Early Anthropogenic view



Early agriculture +
Natural climate
variability
(Ruddiman 2003)

400 Thousand Years of Atmospheric Carbon Dioxide Concentration and Temperature Change

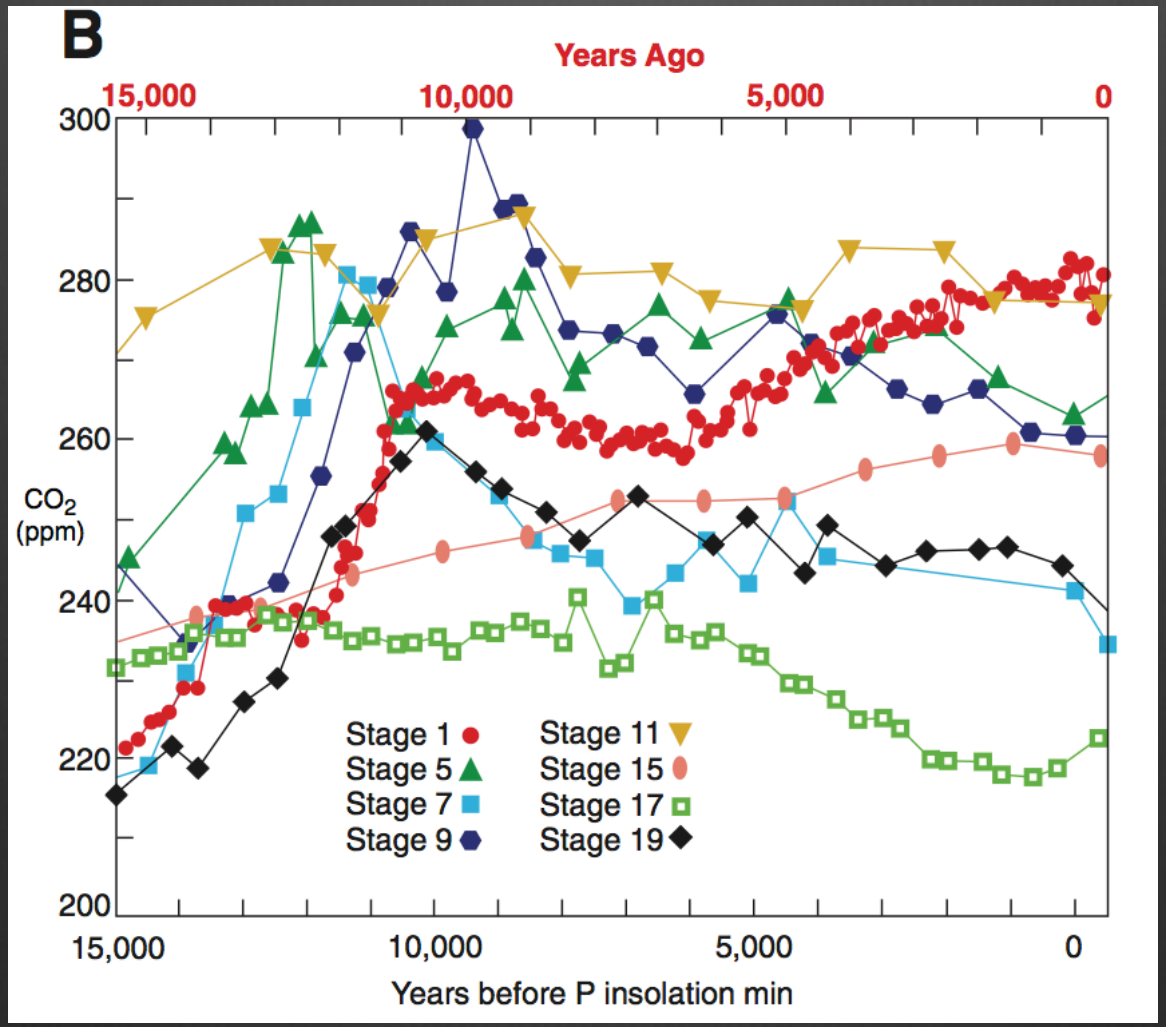


Data Source CO2: ftp://cdiac.ornl.gov/pub/trends/co2/vostok.icecore.co2
Data Source Temp: http://cdiac.esd.ornl.gov/ftp/trends/temp/vostok/vostok.1999.temp.dat

Graphic: Michael Ernst, The Woods Hole Research Center

Past Interglacial CO_2 Variations

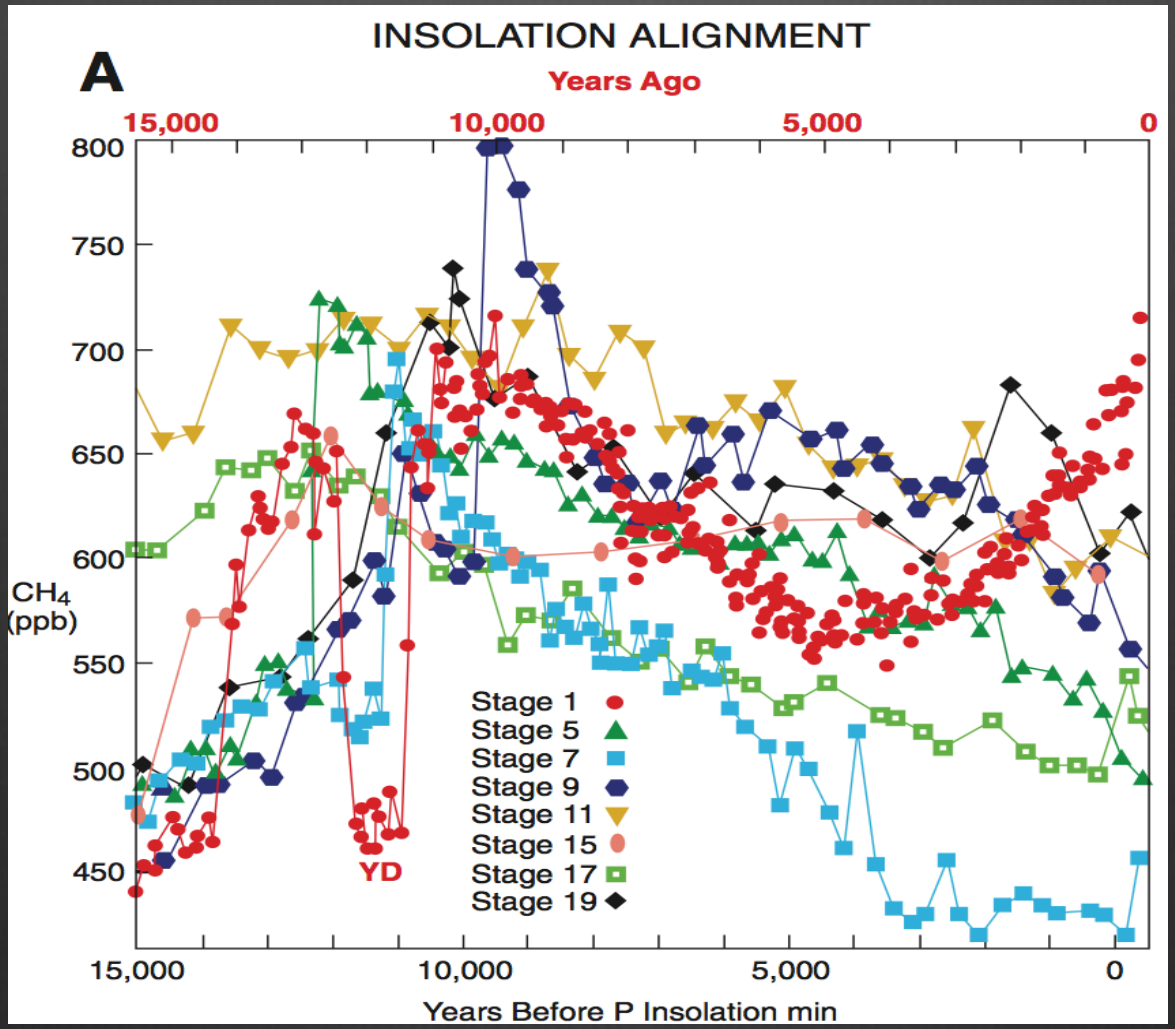
CO_2



Ruddiman et al, 2011

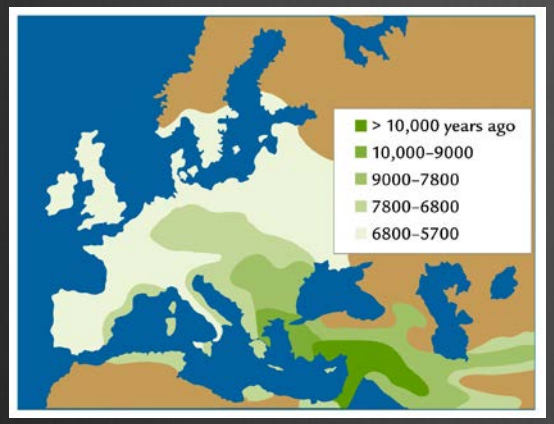
Past Interglacial CH_4 Variations

CH_4

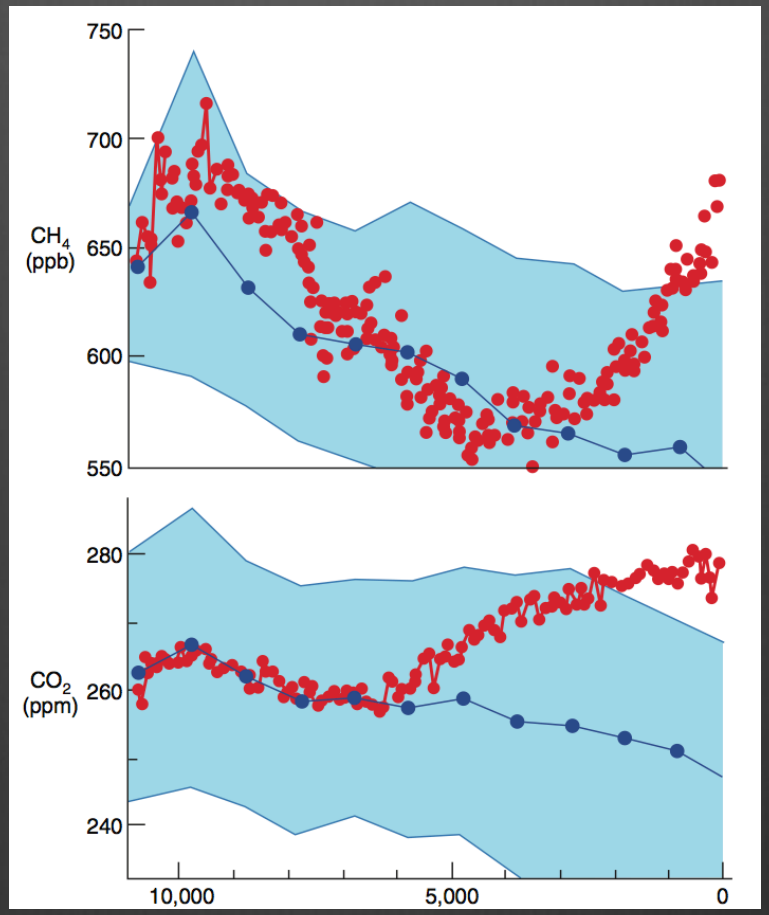


Ruddiman et al, 2011

Early Anthropogenic Hypothesis

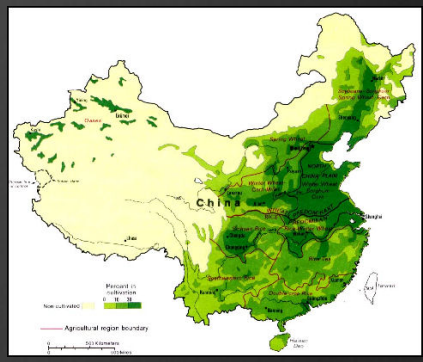


8,000 years ago
Deforestation in Europe
(CO_2)



Ruddiman, 2003

5,000 years ago
Rice cultivation in China
(CH4)



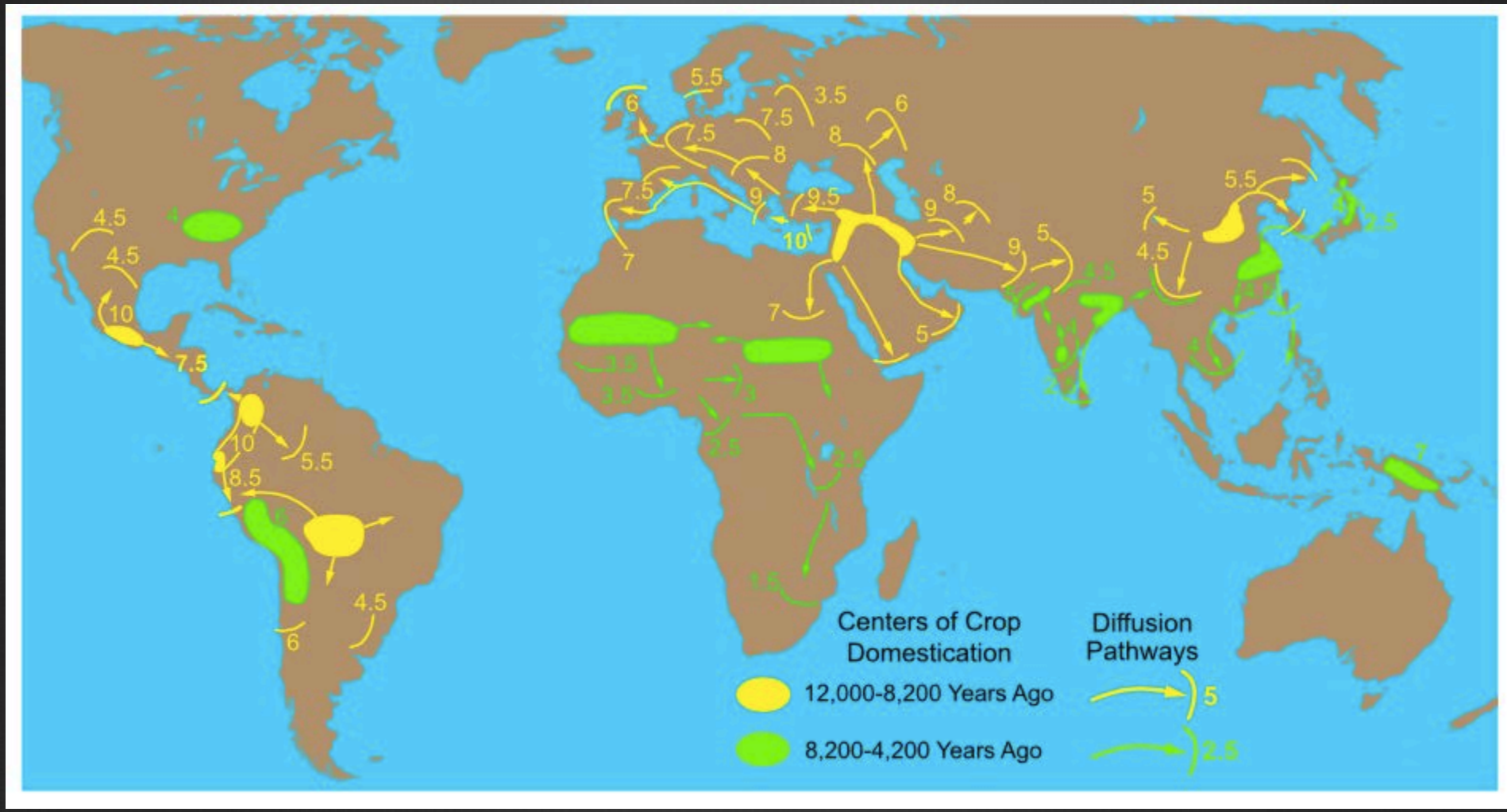
Agriculture development in the Holocene
Neolithic Revolution
12,000–5,000 years ago

1. The first agricultural revolution.
2. It was the transition from hunting and gathering to agriculture and settlement.
3. The start of the domestication of various plant and animal species

http://arkeofili.com/wp-content/uploads/2016/03/Neolithic-Farming-Communities-lesson-2.jpg

The spread of agricultural crops

~9,000 years ago in Europe/Middle East and Central America, ~5,000 years ago in China



Fuller et al., 2014; Larson et al., 2014; Ruddiman et al., 2016

Carbon emissions from the current agriculture

nature International weekly journal of science

NATURE | NEWS

One-third of our greenhouse gas emissions come from agriculture

Farmers advised to abandon vulnerable crops in face of climate change.

Natasha Gilbert

31 October 2012

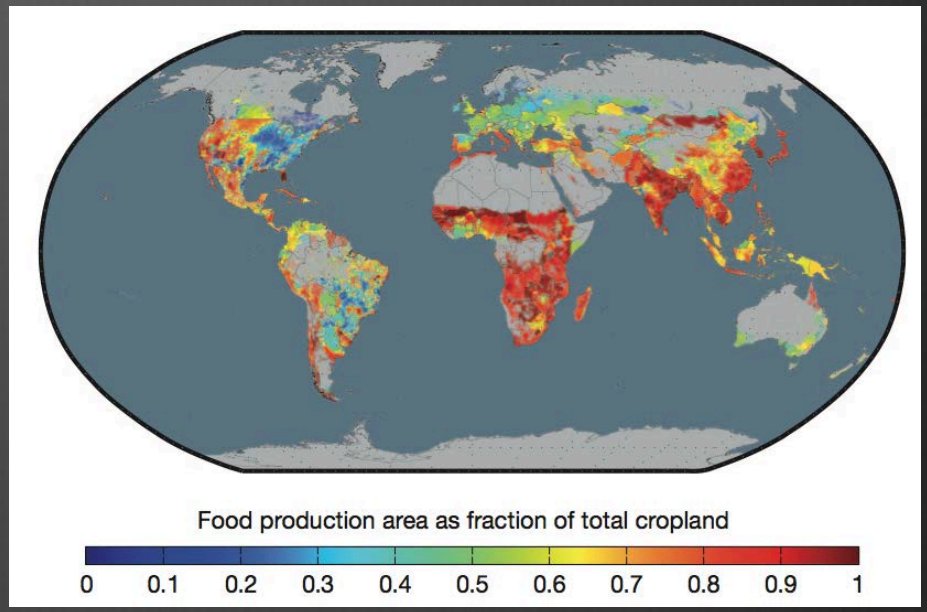
Carbon emission from agriculture: up to 4.6 GtC (2.3 ppmv CO_2) in 2008

The global food system, from fertilizer manufacture to food storage and packaging, is responsible for up to one-third of all human-caused greenhouse-gas emissions, according to the latest figures from the Consultative Group on International Agricultural Research (CGIAR), a partnership of 15 research centres around the world.

Agricultural production is the main emitter of carbon dioxide in the global food system.

A. SACKS/GETTY

In two reports published today[1,2], the CGIAR says that reducing agriculture's carbon footprint is central to limiting climate change. And to help to ensure food security, farmers across the globe will probably have to switch to cultivating more climate-hardy crops and farming practices.

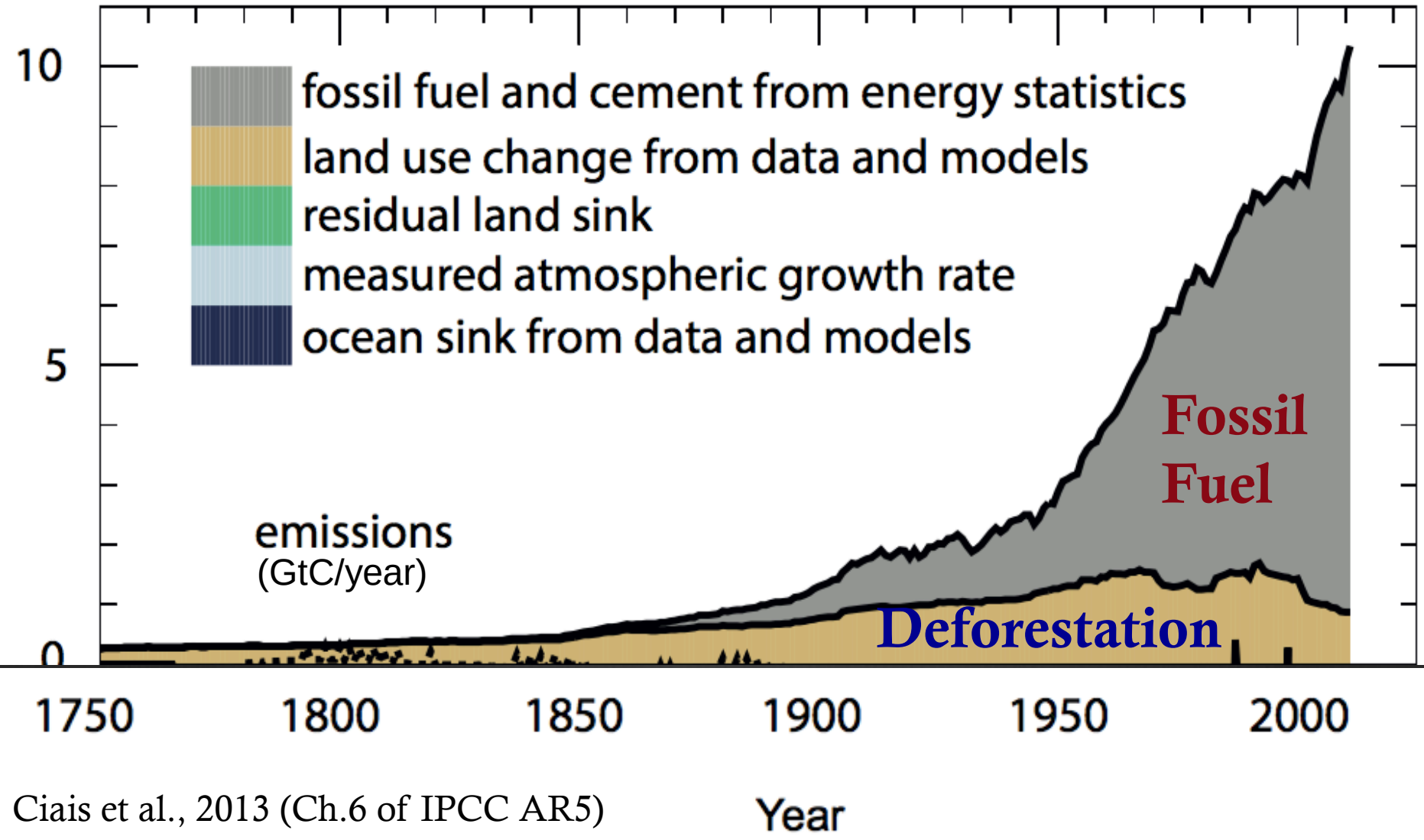


Agriculture occupies about 40% land surface.

Agriculture have cleared 70% grassland, 50% savanna, 45% temperate deciduous forest, and 27% tropical forest. 70% global freshwater withdraw is used for irrigation.

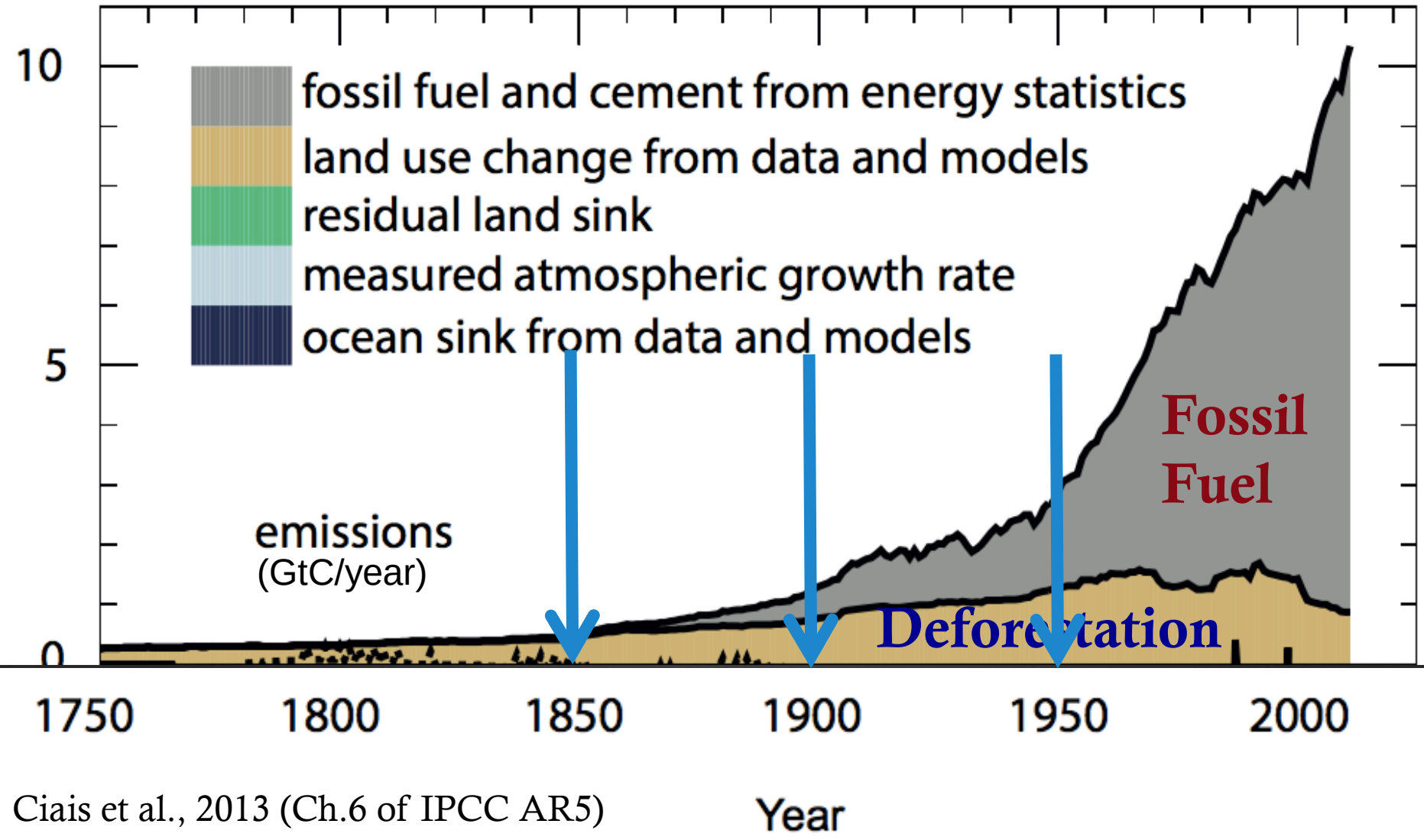
Foley et al., 2011

Carbon emissions: Fossil fuel vs. Deforestation



Ciais et al., 2013 (Ch.6 of IPCC AR5)

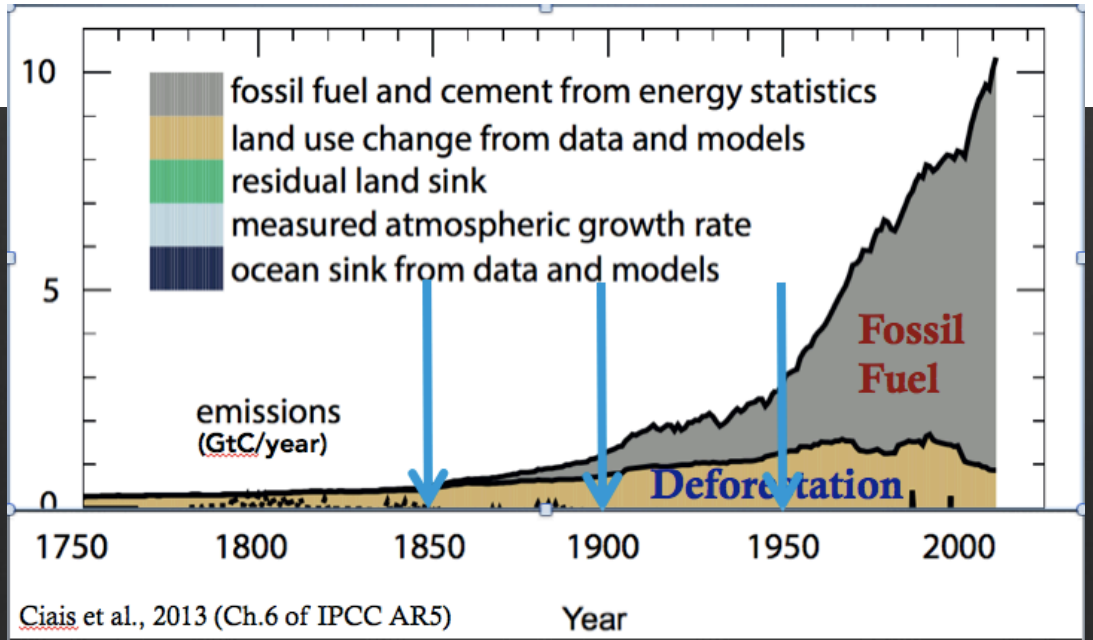
At 1950, half of A.C.E. is from deforestation
Before 1850, almost all A.C.E. is from deforestation



Ciais et al., 2013 (Ch.6 of IPCC AR5)

At 1950, half of A.C.E. is from deforestation
Before 1850, almost all A.C.E. is from deforestation

The Holocene epoch (~11,500 years) is ~75 times longer than the Industrial Times (~150 years).
So it's entirely possible
the cumulative anthropogenic carbon emissions
during the Holocene were as much as
that in the Industrial Times



Summary #1:
Greenhouse gases and land cover changes
(Anthropogenic forcing in the Holocene)

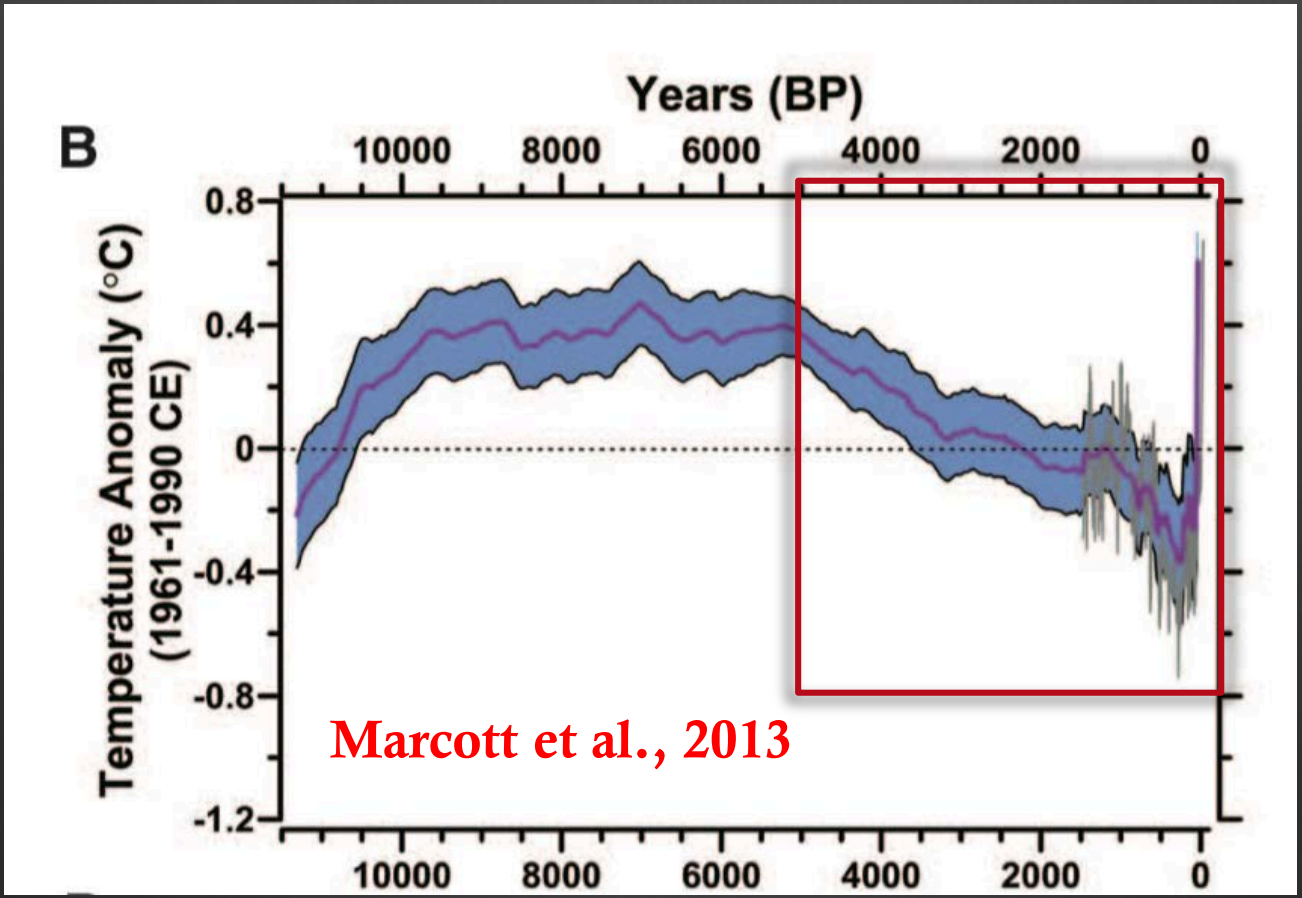
1. In the mid-late Holocene, greenhouse gases show significantly different trends from previous interglacials.

2. Paleoecological and archaeological syntheses show the development of the Early Agriculture during the Neolithic Revolution predated or coincided with the abnormal Holocene climate trends.

1. The Holocene deforestation from the development of the Early Agriculture has the capacity to alter the Holocene carbon cycle and cause the increase of atmospheric CO_2

Simulating Late Holocene Climate Change: Astronomical vs. Anthropogenic Forcing

Motivation:
Reconstructed Global Temperature Evolution during the Holocene



A cooling trend between 5K and Pre-industrial times

But climate models have some difficulties in reproducing this cooling trend with CO_2 rise in late Holocene (e.g., Liu *et al., 2014*)

Snapshot simulations of the late Holocene climate in high-resolution CCSM4

Model: 1-degree fully-coupled atmosphere-ocean-land-sea-ice CCSM4

Astronomical Forcing: Orbital variations (ORB)

Anthropogenic Forcing:

- Greenhouse gases (GHG)
- Land Cover Changes (LCC)

Snapshot simulations of the late Holocene climate in high-resolution CCSM4

Simulation ALL: 7 simulations with all-varying Holocene forcing (GHG, LCC, ORB)

Simulation ORB: 6 simulations with single-varying Holocene orbital forcing

Simulation GHG: 6 simulations with single-varying Holocene orbital forcing

Simulation LCC: 6 simulations with single-varying Holocene orbital forcing

The length of each simulation is ~200 years

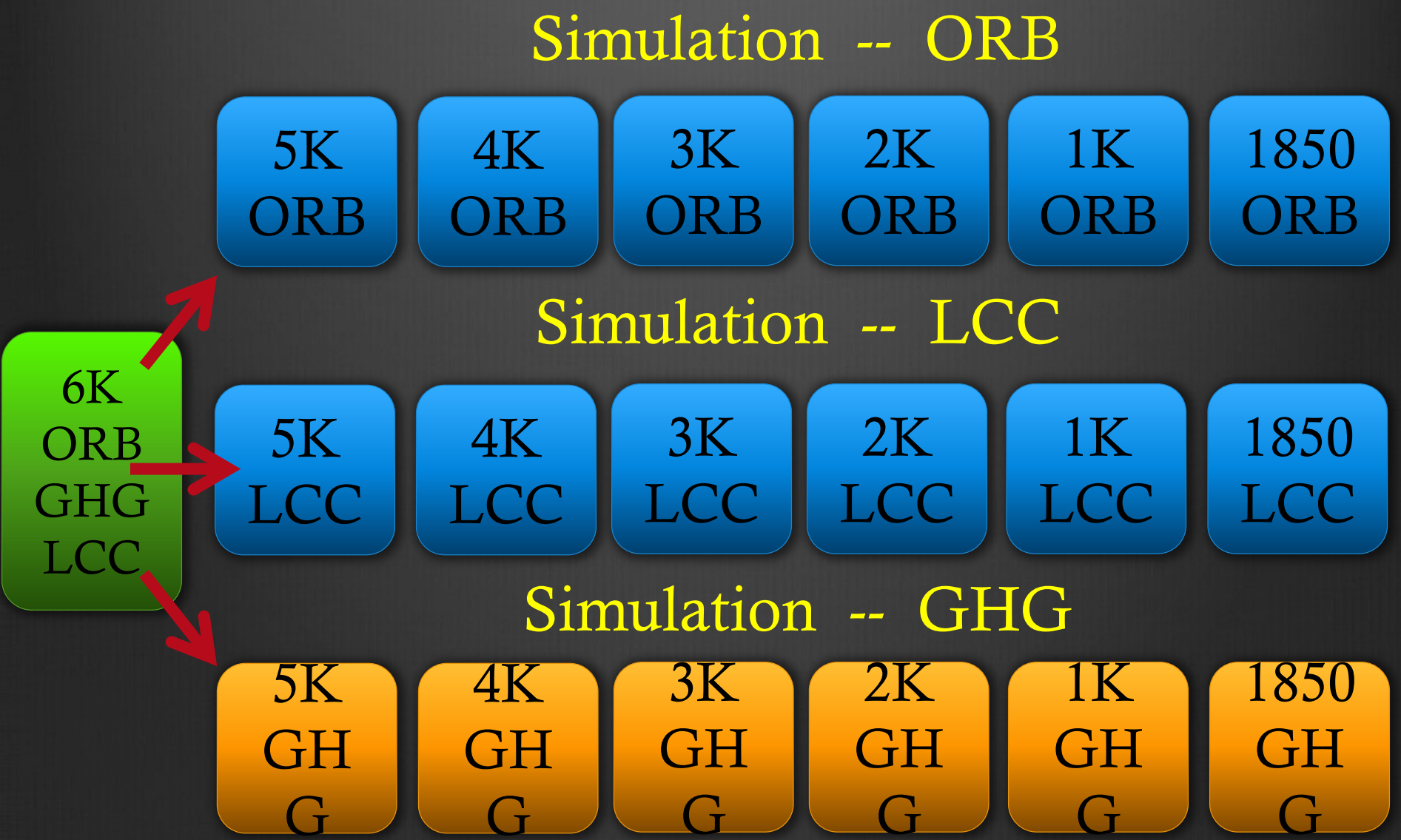
Seven Snapshot Simulations of Late Holocene with ALL Holocene forcing

Simulation ALL:

7 simulations with all-varying Holocene forcing (GHG, LCC, ORB)

6K	5K	4K	3K	2K	1K	1850
ORB	ORB	ORB	ORB	ORB	ORB	ORB
GHG	GHG	GHG	GHG	GHG	GHG	GHG
LCC	LCC	LCC	LCC	LCC	LCC	LCC

Single-forcing Simulations of Late Holocene



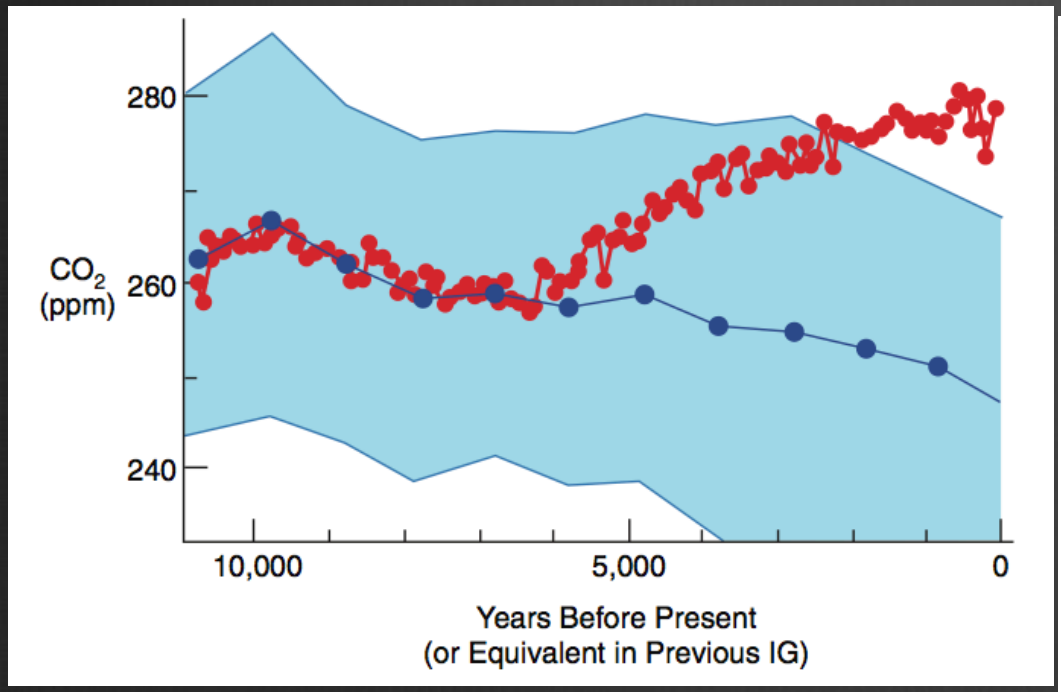
Simulation results

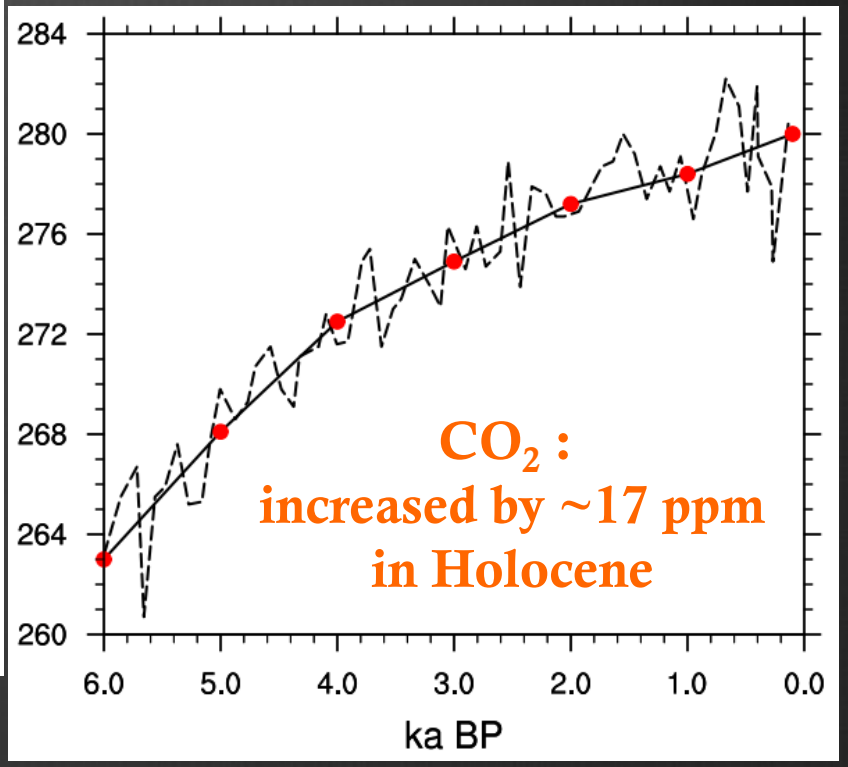
Simulation -- Greenhouse Gases

6K ORB GHG LCC

5K GHG | 4K GHG | 3K GHG | 2K GHG | 1K GHG | 1850 GHG

CO_2 variations during the late Holocene





Ruddiman *et al,* 2011

Simulation -- Greenhouse Gases

6K ORB GHG LCC

5K GHG

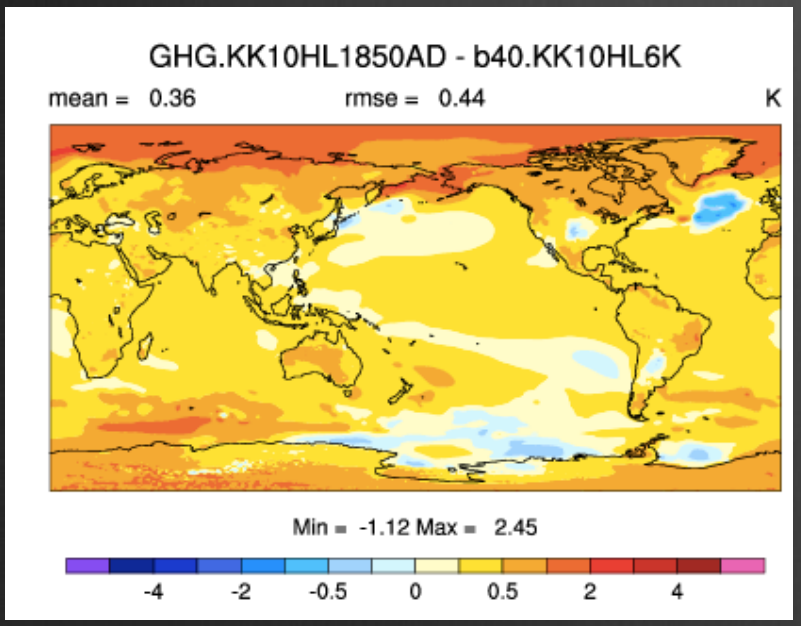
4K GHG

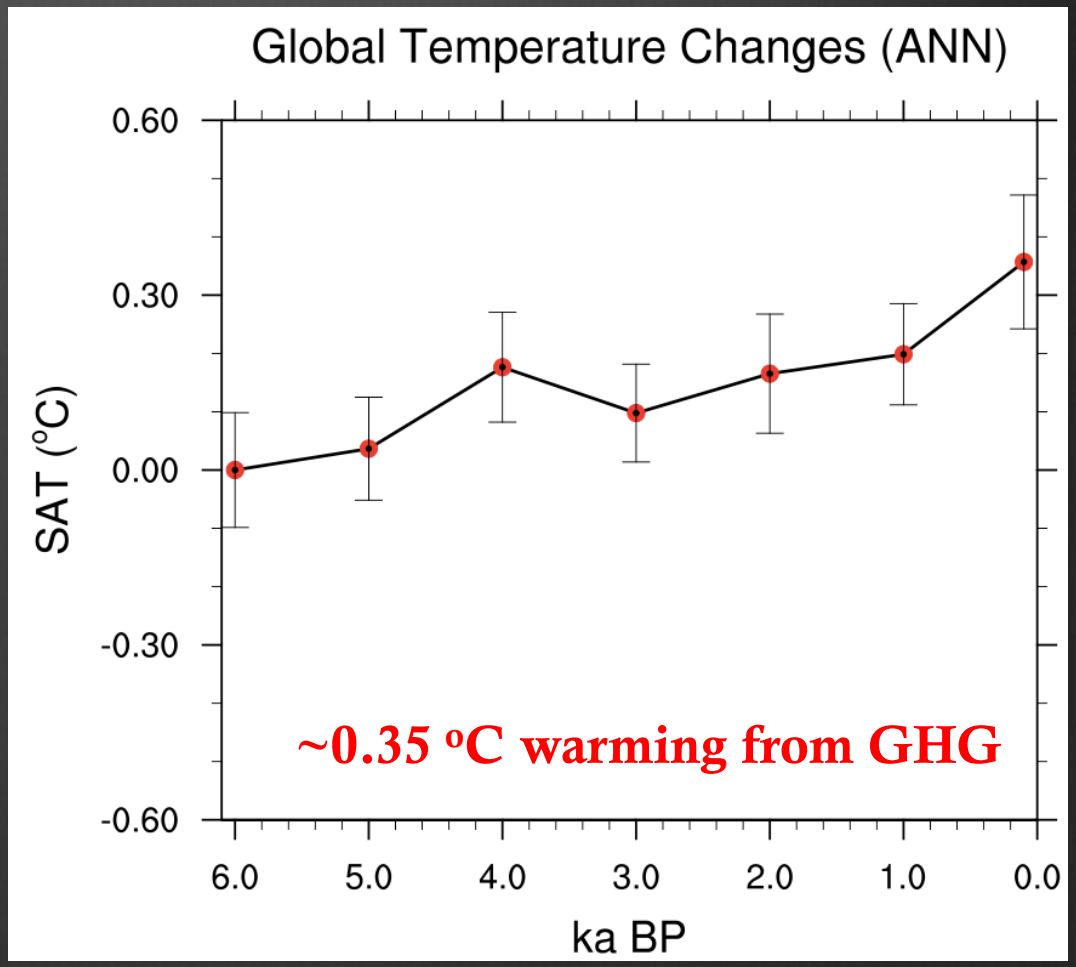
3K GHG

2K GHG

1K GHG

1850 GHG

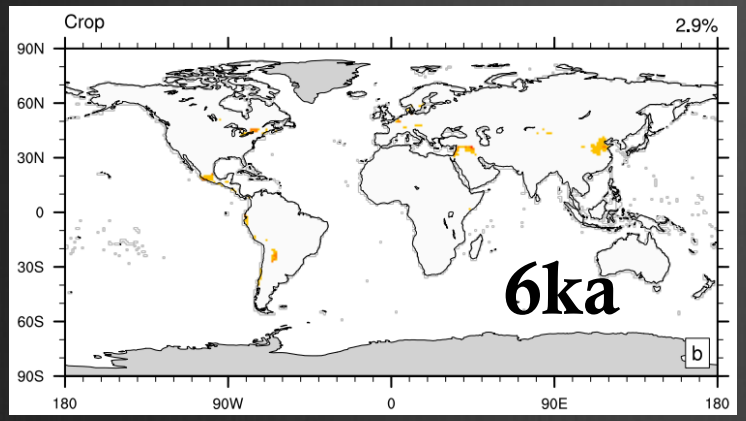


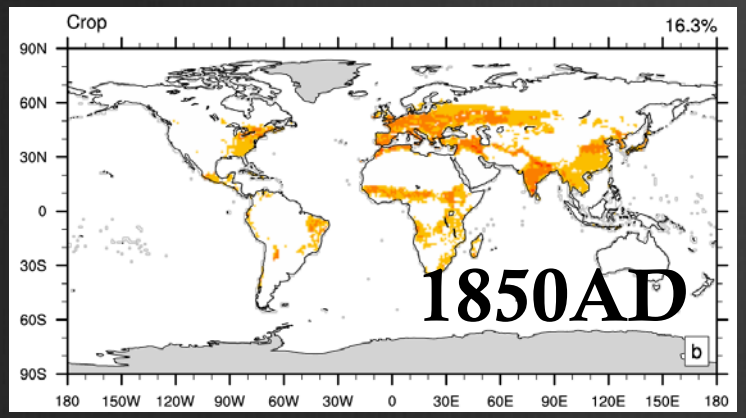


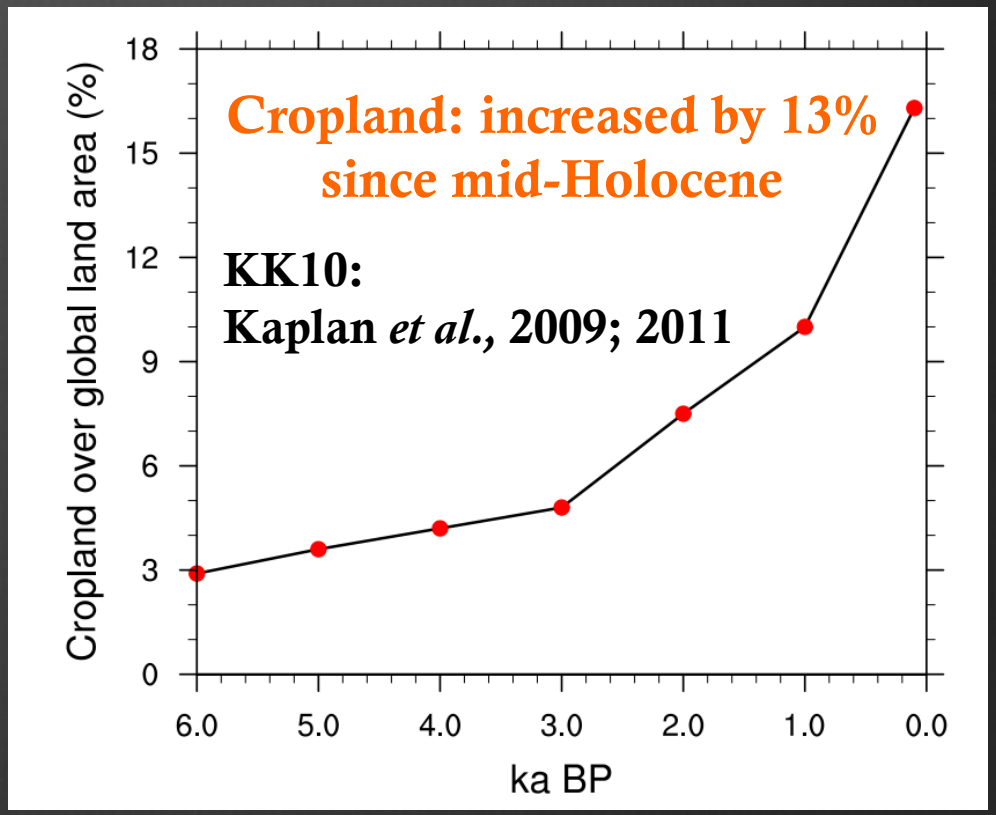
Simulation -- Land Cover Changes

6K ORB GHG LCC

5K LCC | 4K LCC | 3K LCC | 2K LCC | 1K LCC | 1850 LCC



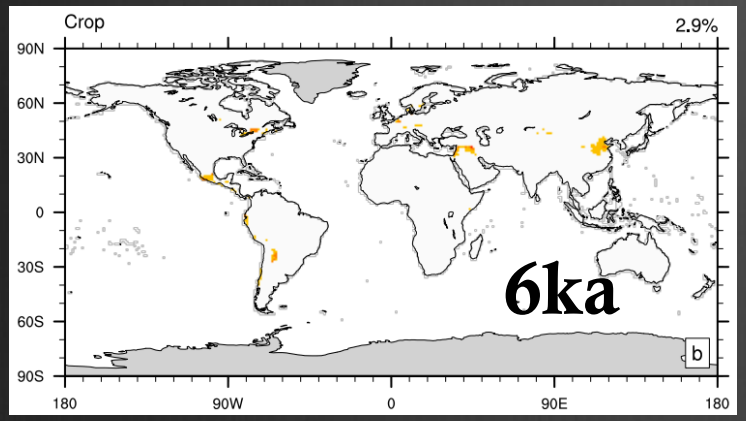


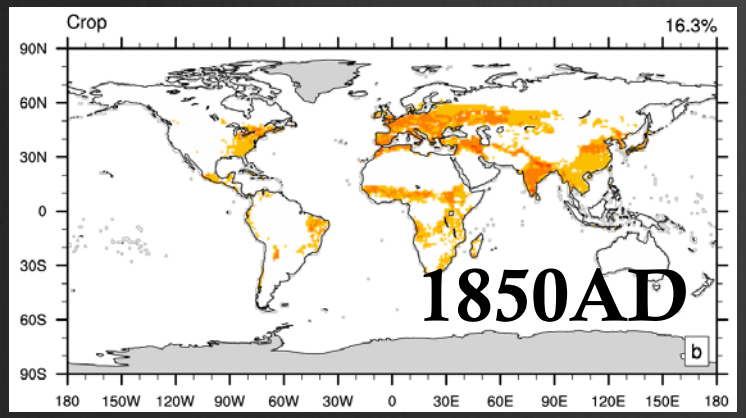


Simulation -- Land Cover Changes

6K ORB GHG LCC

5K LCC | 4K LCC | 3K LCC | 2K LCC | 1K LCC | 1850 LCC



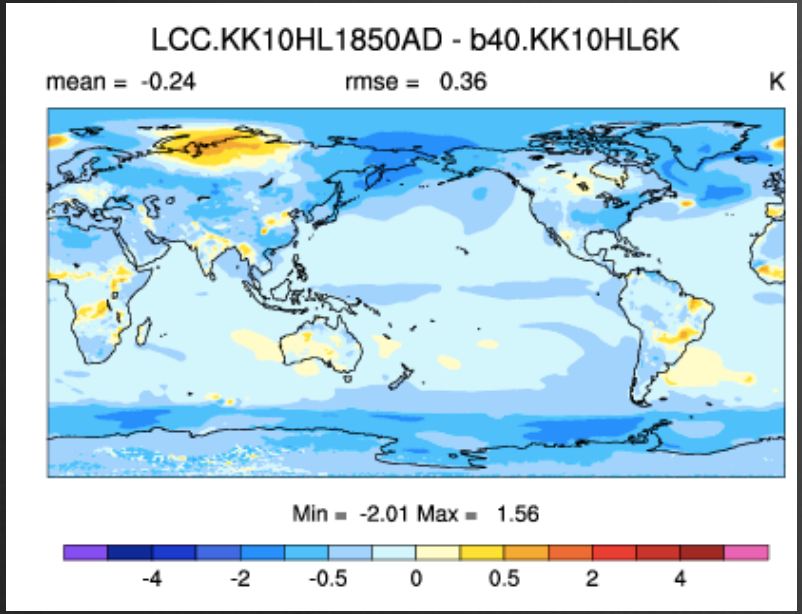


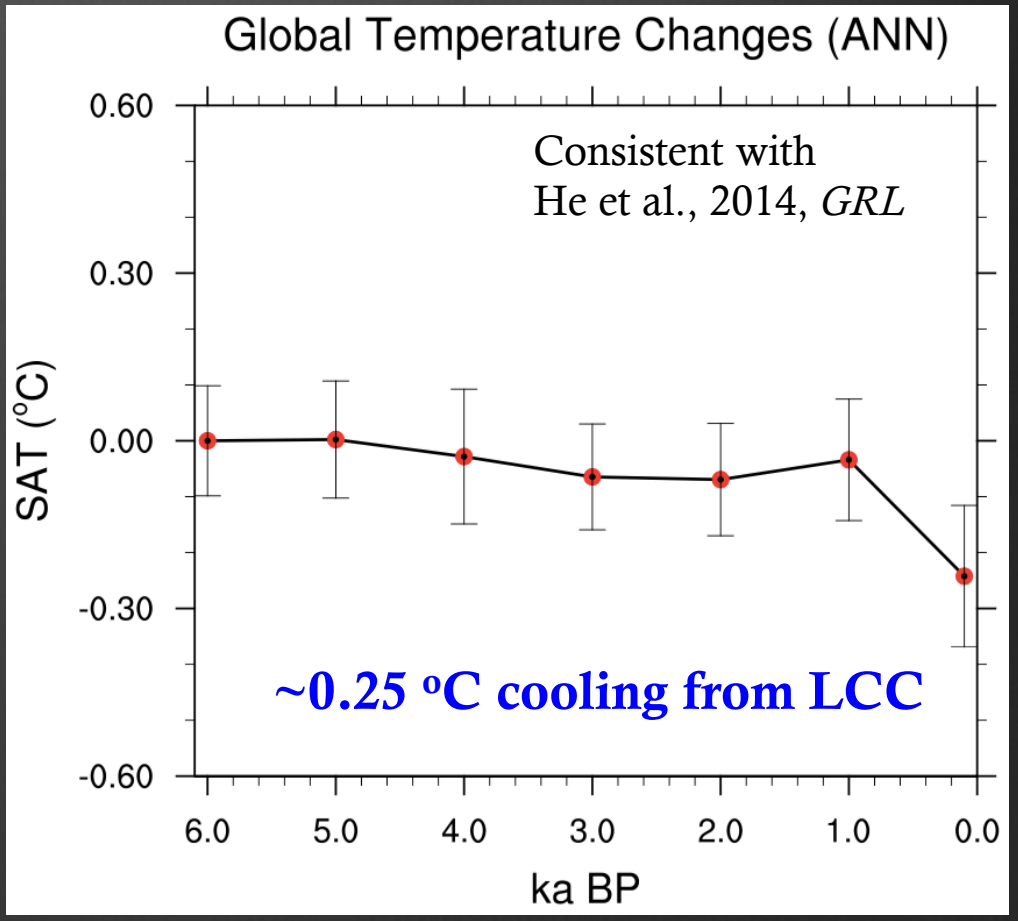
Deforestation increases wintertime Albedo, produces global cooling

Simulation -- Land Cover Changes

6K ORB GHG LCC

5K LCC | 4K LCC | 3K LCC | 2K LCC | 1K LCC | 1850 LCC





Simulation -- Orbital forcing

6K
ORB
GHG
LCC

5K
ORB

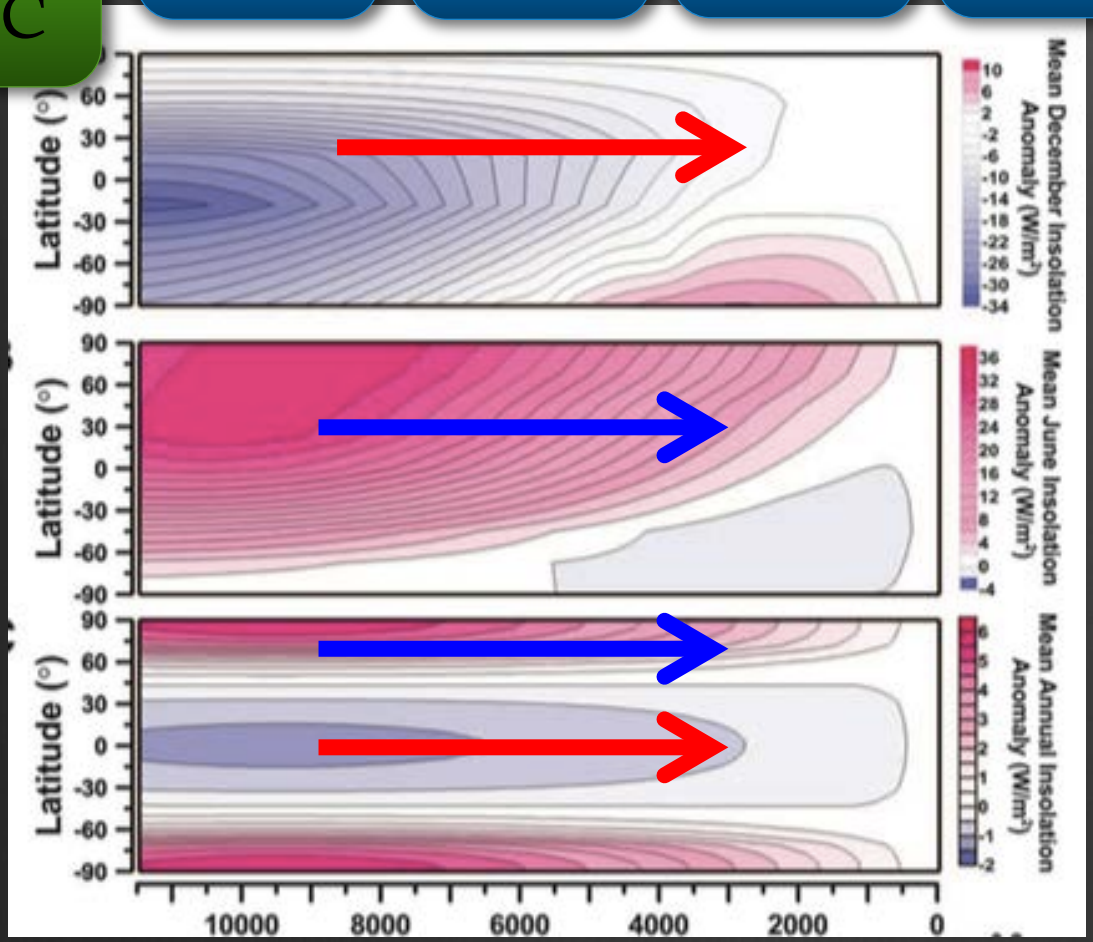
4K
ORB

3K
ORB

2K
ORB

1K
ORB

1850
ORB



Marcott *et al.*, 2013

Insolation:

Winter: increase

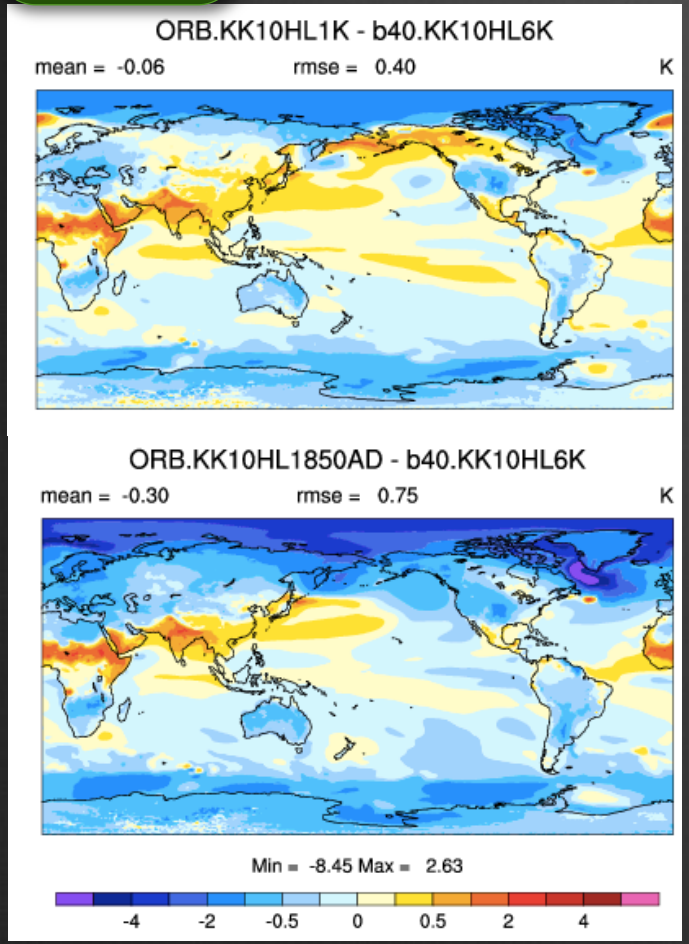
Summer: decrease

Annual:
decrease in polar region
increase in Tropics

Simulation -- Orbital forcing

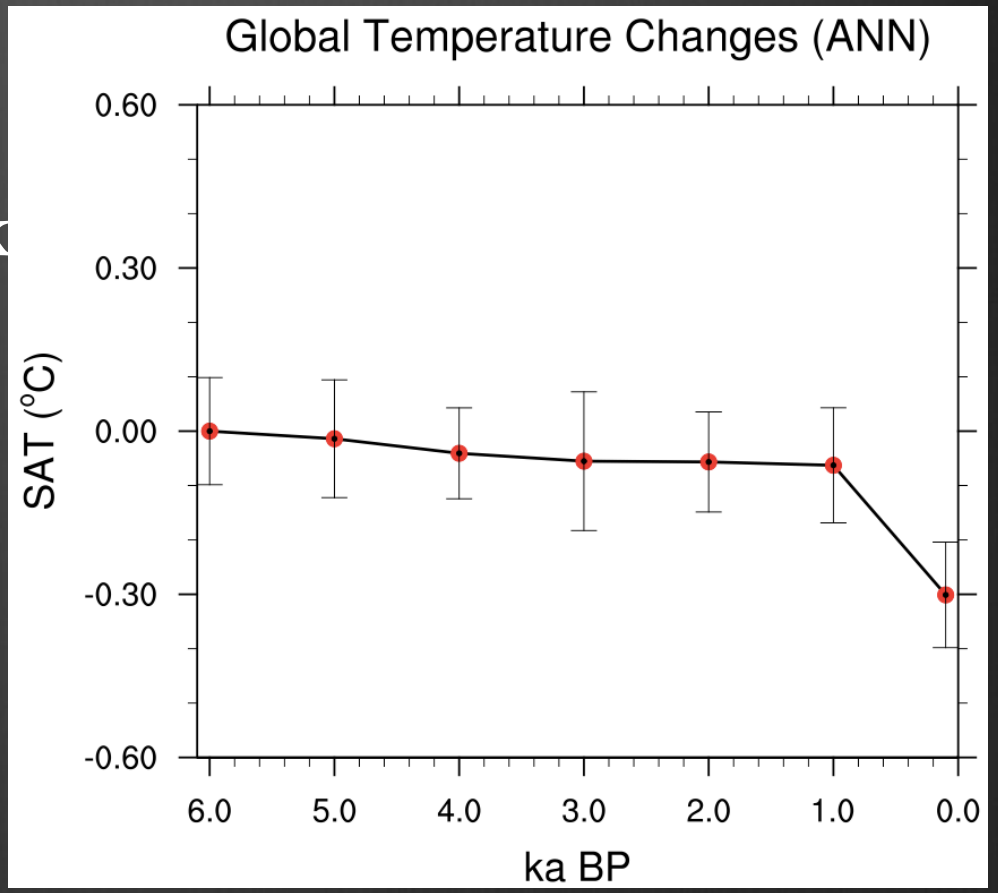
6K ORB GHG LCC

5K ORB | 4K ORB | 3K ORB | 2K ORB | 1K ORB | 1850 ORB



1k-6k

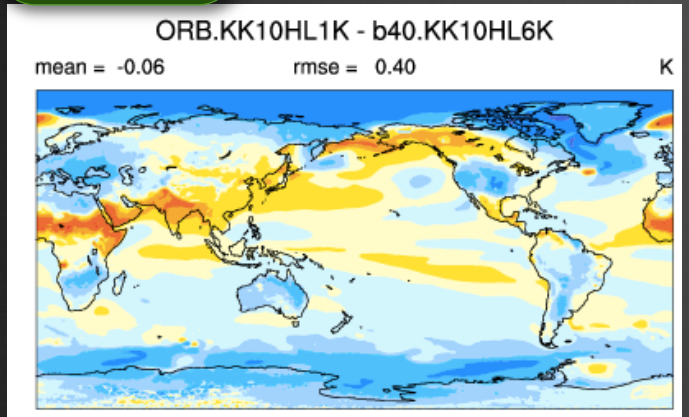
1850 - 6k



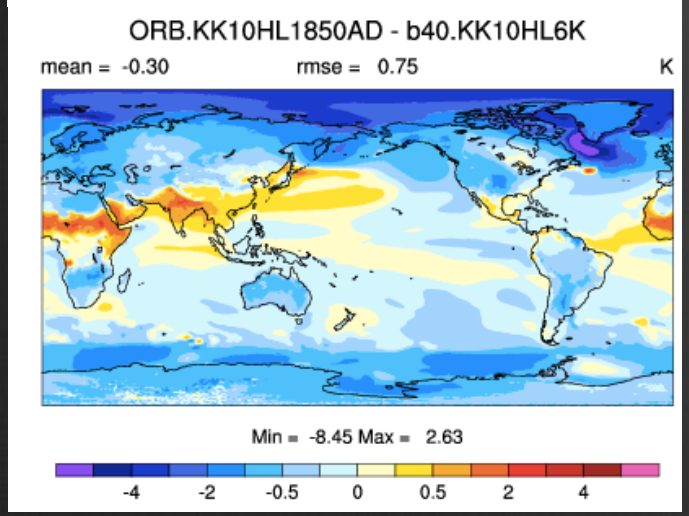
Simulation -- Orbital forcing

6K ORB GHG LCC

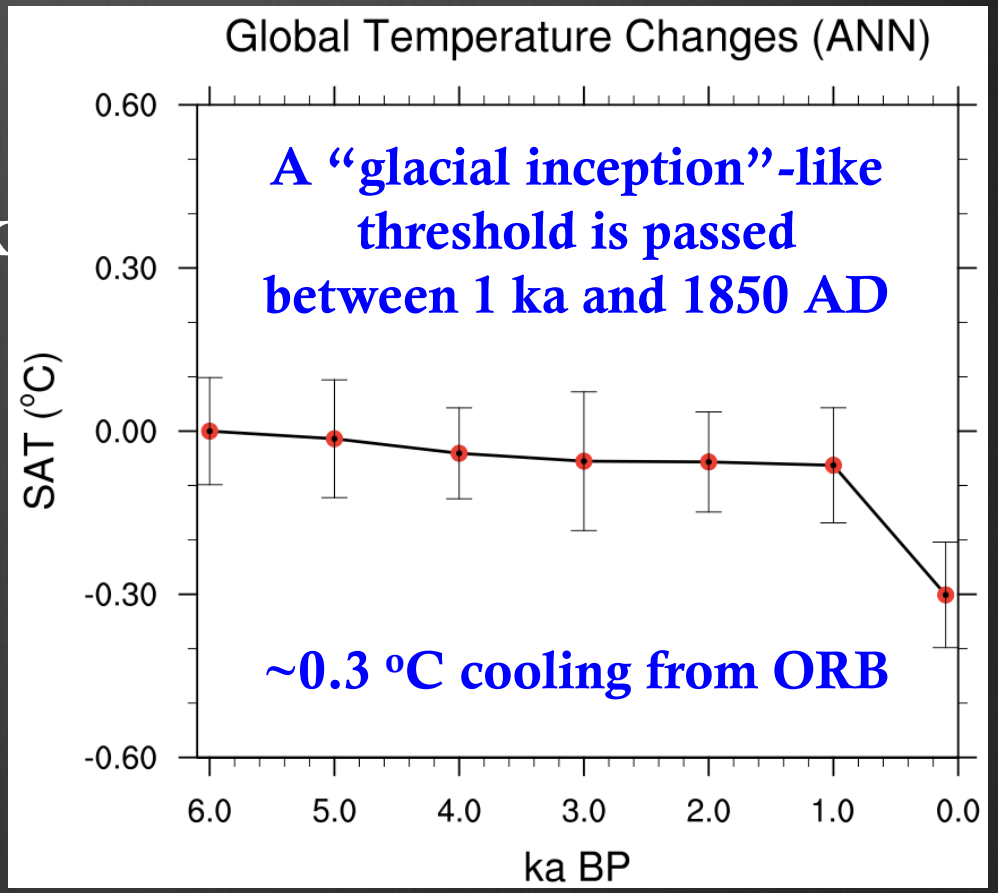
5K ORB | 4K ORB | 3K ORB | 2K ORB | 1K ORB | 1850 ORB



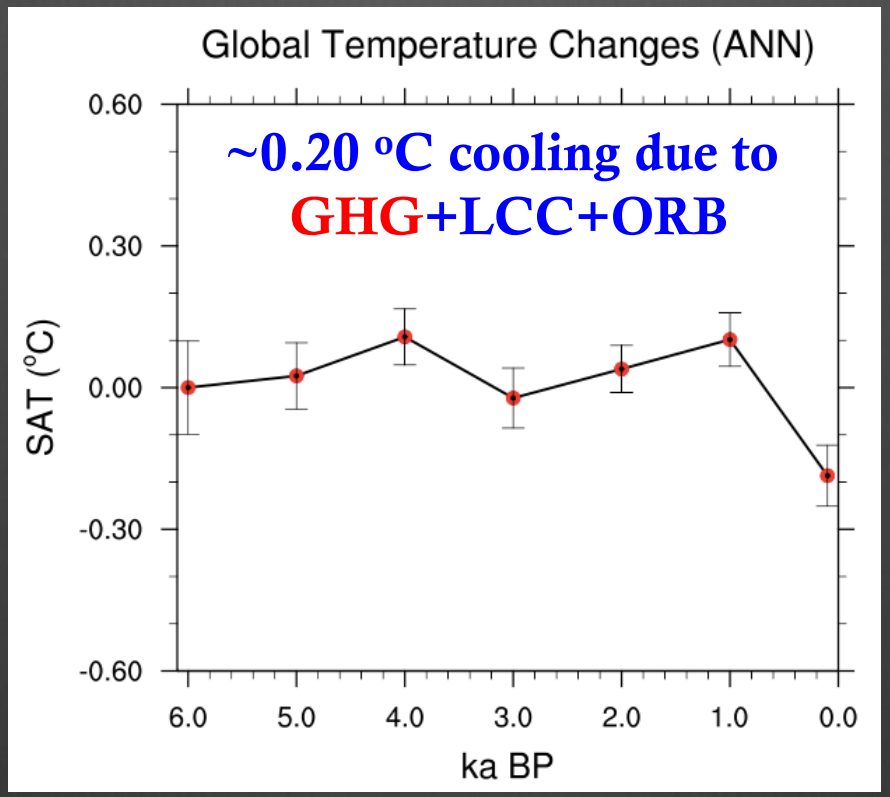
1k-6k

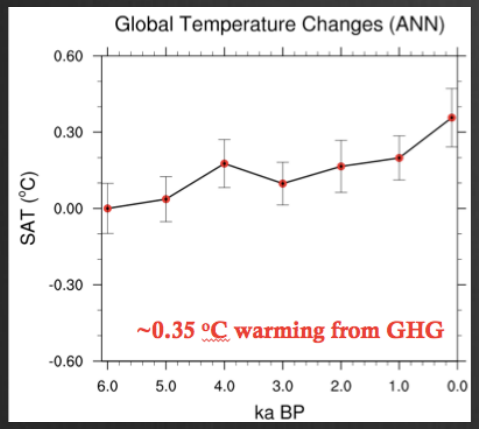


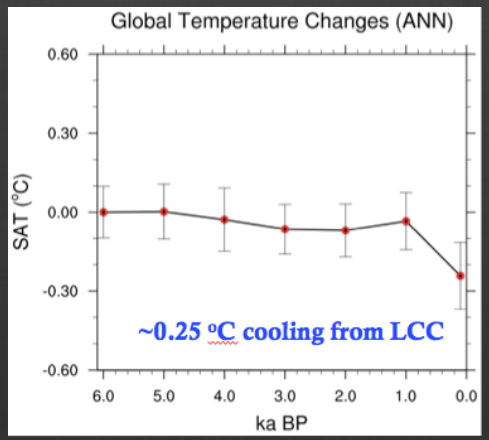
1850 - 6k

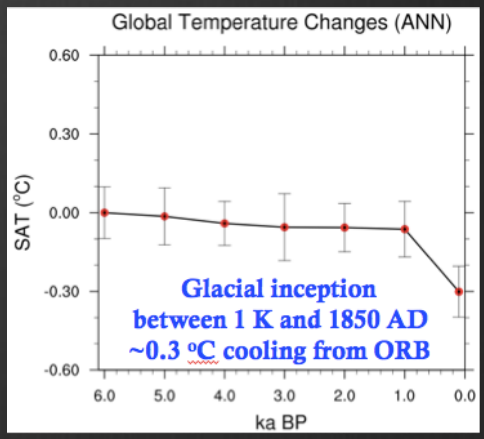


Sum of Single-forcing Simulation GHG+LCC+ORB

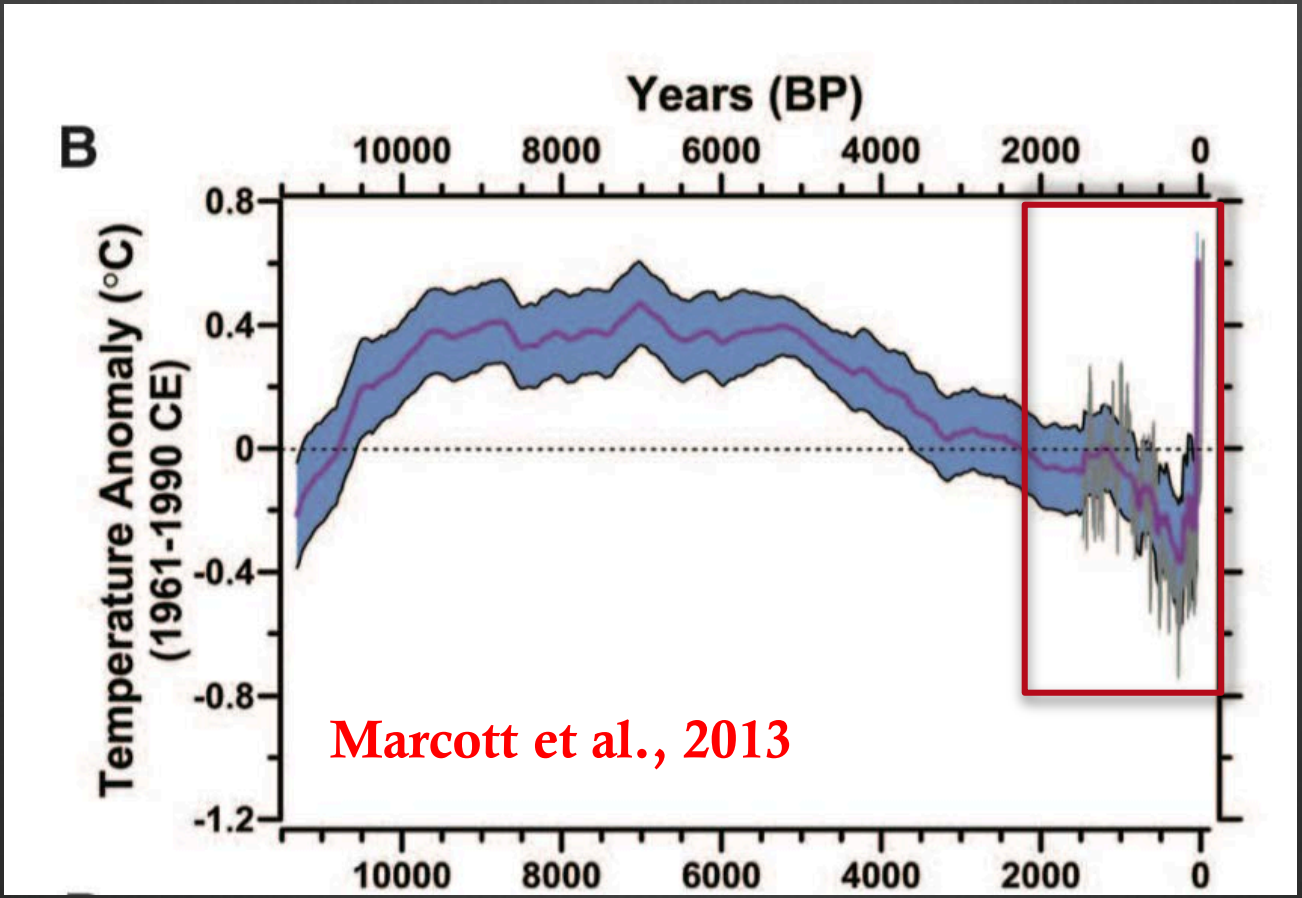








Reconstructed Global Temperature Evolution during the Holocene



A stronger cooling trend between 1K and Pre-industrial times

Similar cooling trend is found in simulation GHG+LCC+ORB

Summary #2: **Astronomical vs. Anthropogenic Forcing**

Simulated Late Holocene climate change in 1-degree CCSM4:

Compared to 6K climate:

Astronomical forcing produces ~0.3 ^{o}C cooling

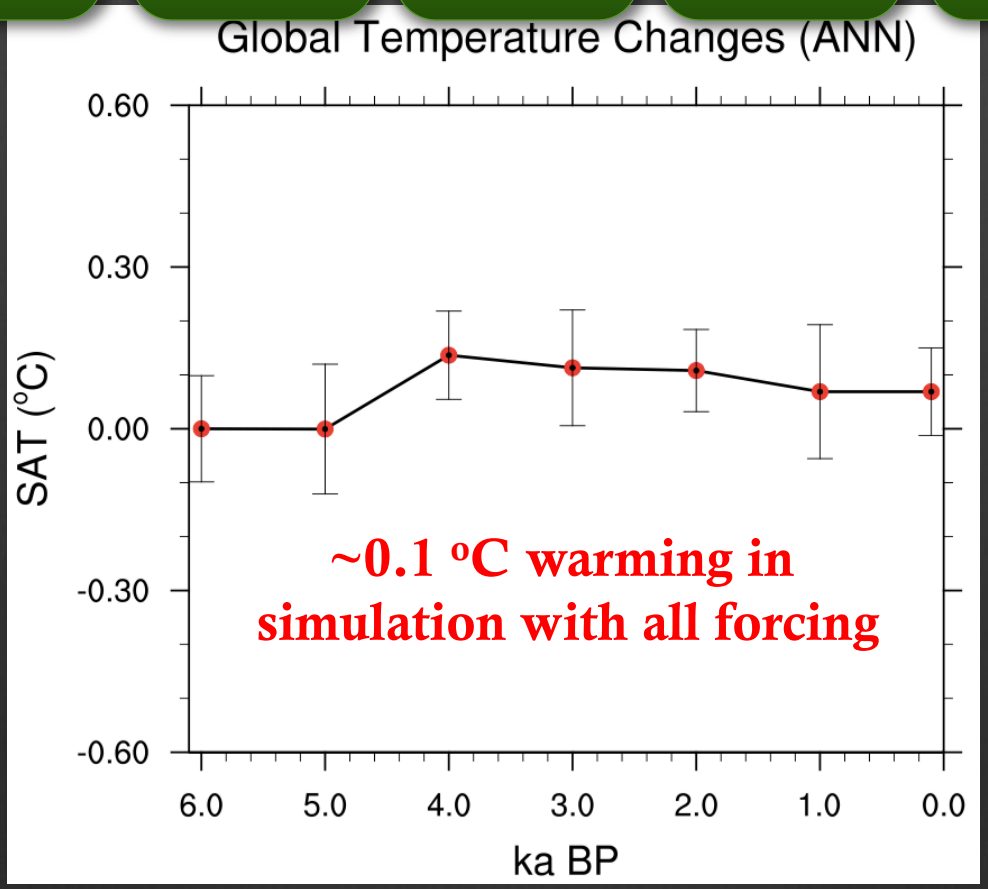
Anthropogenic Greenhouse Gases produces ~0.35 ^{o}C warming, while Anthropogenic Land Cover produces ~0.25 ^{o}C cooling.

Total anthropogenic forcing produces ~0.1 ^{o}C warming

Astronomical forcing (~0.3 ^{o}C) dominates anthropogenic forcing (~0.1 ^{o}C) and produces a net ~0.2 ^{o}C cooling.

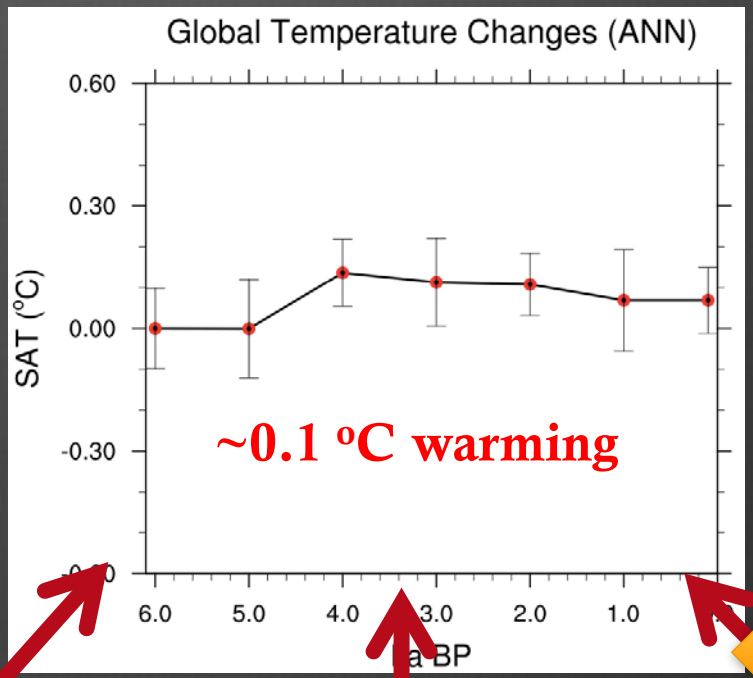
But the cooling trend is missing in Simulation - ALL

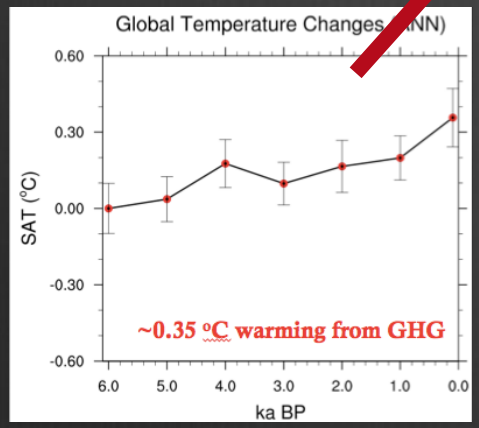
6K	5K	4K	3K	2K	1K	1850
ORB	ORB	ORB	ORB	ORB	ORB	ORB
GHG	GHG	GHG	GHG	GHG	GHG	GHG
LCC	LCC	LCC	LCC	LCC	LCC	LCC

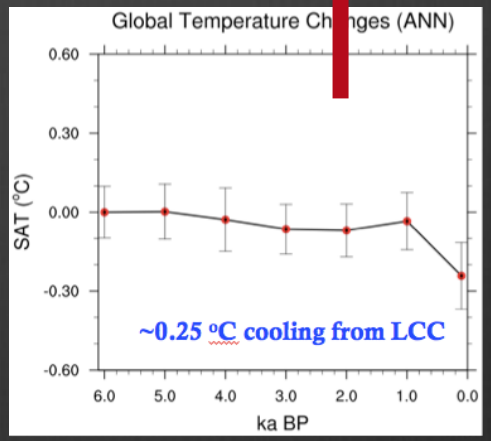


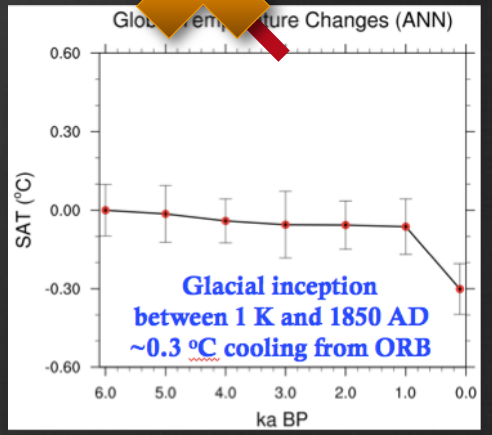
CCSM4 with all Holocene forcing underestimates the cooling from orbital forcing

Orbital cooling was missing in simulation with ALL forcing because of the elevated threshold with higher CO2









Summary #3

1. The inclusion of Land Cover Changes in CCSM4 could produce ~0.20 global cooling, and therefore reconcile the seemingly data/model mismatch between rising CO_2 and reconstructed global cooling in the late Holocene.

2. CCSM4 with all Holocene forcing (GHG+LCC+ORB) underestimates the cooling from orbital forcing because the model fails to cross the threshold for the "glacial inception" due to the higher CO_2 from the Anthropogenic Land Cover Changes.