Simulating Climate Response to Changes in Paleogeography through the Cretaceous

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Motivation

• Most of the Cretaceous was a greenhouse climate
  – No continental ice sheets
  – Weak equator to pole temperature gradient

• Cretaceous CO$_2$ reconstructions suggest concentrations similar to RCP 8.5 for the 2100

• Climate models have difficulty simulating the high-latitude warmth
Experiment Design

- Detailed Cretaceous topographies
  - Berriasian (145-140 Ma)
  - Cenomanian (100-94 Ma)
  - Maastrichtian (72-66 Ma)
- Fixed GHG concentrations
  - $\text{CO}_2 = 1120$ ppm
- Adjusted solar constants
  - $\sim 1\%$ per 100 Myr
Climate Models

• CESM1.2
  – Components:
    • CAM5
    • CLM4
    • POP2
    • CICE4
  – Resolution:
    • Atm / Lnd – 1.9 x 2.5°
    • Ocn / Ice - ~1°
  – Run:
    • 500 years

• HadCM3
  – Components:
    • HadAM3
    • TRIFFID
    • HadOM3
  – Resolution:
    • Atm / Lnd – 3.75 x 2.5°
    • Ocn / Ice – 1.25°
  – Run:
    • >2000 years
Topics

• I: CESM1.2 cretaceous temperature change due to different paleogeography

• II: Similarities and differences between CESM1.2 and HadCM3 Cenomanian surface temperatures
• Global average surface warming over the Cretaceous
  – ~1.8°C
• Different from proxy temperature reconstructions
  – GHG changes?
Surface Temperature Differences

- Large scales differences between Berriasian and Maastrichtian surface temperatures
  - especially in equatorial and southern high-latitudes
Equatorial SST Differences

- Berriasian has a cooler equatorial ocean and greater E-W temperature gradient
  - No equatorial land barrier
Equatorial Pressure and Wind Differences

- Berriasian has stronger surface winds and E-W sea level pressure gradient
Walker Circulation Differences

- Berriasian has stronger Walker circulation
  - Limits N-S transport and equatorial precipitation

Berriasian EW Clouds and Streamlines

Maastrichtian EW Clouds and Streamlines

Cloud Fraction:

- 0.1
- 0.13
- 0.16
- 0.19
- 0.22
- 0.25
- 0.28
Berriasian has colder high-latitude surface temperatures due to greater land cover.
• Berriasian has higher surface albedo and greater snow cover.
Topics

• I: CESM1.2 cretaceous temperature change due to different paleogeography

• II: Similarities and differences between CESM1.2 and HadCM3 Cenomanian surface temperatures
Sea Surface Temperature Differences

- CESM1.2 produces warmer ocean surface temperatures than HadCM3
  - Especially in high-latitudes during winter months
Sea Ice Differences

- HadCM3 produces more sea ice than CESM1.2
  - Contributes to the high-latitude temperature difference
Land Surface Temperature Differences

- HadCM3 produces warmer land surface temperatures than CESM1.2
  - Most pronounced during spring months in the high-latitudes
Vegetation Cover Differences

- HadCM3 has higher, more dense vegetation that CESM1.2 in the high-latitudes
  - Masks snow cover and lowers albedo
CENOMANIAN: CESM ANNUAL AVERAGE SURFACE TEMPERATURE

Data from:
Huber et al. 2002 (and source therein)
Schouten et al. 2003
Forster et al. 2007
Puceat et al. 2007 (and source therein)
Sinninghe Damsté et al. 2010
Spicer et al. 2010
Linnert et al. 2014
Conclusions

• Paleogeography causes large-scale climate differences over the Cretaceous
  – Cannot explain proxy reconstructed temperature trend

• Large temperature differences exist between models and proxies
  – Model configuration refinement and new proxy reconstructions are promising
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Questions?
Hadley Circulation Differences

• Stronger Walker circulation seems to affect strength of Hadley circulation