Increases in Northern Hemisphere vegetation cover as a potential solution to the Holocene Temperature Conundrum

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CESM Workshop
June 17, 2020
Holocene Temperature Conundrum

- Since early and middle Holocene...
  - Global temperature proxies suggest ~0.5°C cooling
  - Climate model simulations suggest ~0.5°C warming
Recent updates to Holocene temperature proxies

Kaufman et al. (2020)

1319 Records from 679 sites
51% lake sediment, 31% marine sediment, 18% peat, glacier ice, and other natural archives
What factors are driving the model and proxy signals?
Proxies resembles Northern Hemisphere insolation signal

Liu et al. (2014)

Kaufman et al. (2020)

Data from Berger & Loutre (1991)
Largest temperature response occurs in Northern Hemisphere high-latitudes

- Global temperature during the Holocene is driven by Northern Hemispheric temperatures
Models are sensitive to GHG, orbital, and ice sheet dynamics

Liu et al. (2014)
Which is to blame: models or proxies?
Proxies? It is unlikely.

• With updated global data, the proxy record represents over 1,000 individual records

• New studies show consistent, logical results

• Possible bias in proxy record toward summer season (JJA) based on record locations
Models? More likely!

• May be missing a mechanism for warming

• Must be able to amplify the Northern Hemisphere insolation signal that is not strong enough on its own

Liu et al. (2014)
Are models missing a mechanism for warming?

• Adding a mechanism to the models can work:
  
  • *Liu et al. (2018)*
    • Completely removed global dust during early- and mid-Holocene \(\rightarrow\)
      overestimation!
  
  • *Park et al. (2019)*
    • In mid-Holocene, Arctic amplification increases global temperature \(\rightarrow\)
      global temperature response is too weak
  
• Need to find the correct mechanism!
Vegetation warms the climate through...

- **Albedo** (Swann et al., 2014)

- **Transpiration effects** (Swann et al., 2010)

- Northern Hemisphere vegetation can amplify insolation signal

Swann et al. (2014)
Missing mechanism? Vegetation!

- Pollen records show increased vegetation cover in the early- and mid-Holocene in the African Sahara and Northern Hemisphere high-latitudes (Bartlein et al., 2011; COHMAP, 1988)
Fully coupled iCESM1 Time-slice Simulations

Model specs
- 1.9°x2.5° atm/land resolution
- 1°x1° ocean resolution
- Each base simulation run for 900 years
- Calendar effect (Bartlein & Shafer, 2019)
Model Forcings (GHGs, Ice Cover, Orbital)
Prescribed Vegetation Modifications

- Pre-industrial conditions:
  - Desert Sahara and Arctic tundra
• For 6ka and 9ka simulations:
  • Green Sahara and Arctic boreal forest expansion

Sahara set to shrub and C₄ grass

Arctic C₃ grass set to boreal tree
Sensitivity Experiments

Holocene Insolation

- + Green Sahara and Boreal Forest
- + Green Sahara
- PI vegetation

Time (years BP)

Insolation (W/m²)

Thompson, CESM Workshop 2020
Results

Data from Kaufman et al. (2020)
With no vegetation change…
Adding a Green Sahara...
Adding Boreal Forest...
Conclusions

• Increased vegetation cover is promising as a missing mechanism in models that can help resolve the Holocene Temperature Conundrum

• Broadly, resolving model-proxy discrepancy in past climates can give us confidence in model projections of the future

• Must account for future land surface change
Thank you! Questions?

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