CESM Tutorial 2011
Application: Paleoclimate Modeling

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• Drivers of past climate changes
• Time scales of climate component changes
• Simulation of transient climate change of the last 21,000 years
  - Combining model results with information from data
  - Understanding mechanisms
• Summary of other paleo applications with CCSM/CESM
External Forcings
- Seasonal and interannual solar variations
- Greenhouse gases
- Aerosols
- Volcanic eruptions
- Continental drift
- Sea level and ice sheets
- Vegetation

Paleo Climate Model Simulations

CCSM/CESM

Atmosphere
T85, T42, T31, FV1

Temperature
Precipitation
Snowcover
Winds

Vegetation
Soil Moisture
Runoff

Ocean
x1°, x3°

Extents
Motion
Basal Melting

Land
T85, T42, T31, FV1

Currents
Salinity
Temperature

Sea Ice
x1°, x3°

Coupler

....
The Earth’s climate system

Time scales:
- Atmosphere - days
- Sea ice – days to centuries
- Vegetation – days to centuries
- Oceans – months to centuries
- Ice sheets – centuries to millennia

Need to consider these time scales when designing a simulation

Karl and Trenberth, 2003; Bamber and Payne, 2004
Modeling the Climate Evolution and Abrupt Changes over the Last 21,000 Years

**Inputs:**
Earth’s orbital configuration
Atmospheric composition of GHGs
Amount of water tied up in ice sheets:
  - Ice sheet extent: albedo
  - Ice sheet height
Sea level / geography
Meltwater from ice sheets freshening oceans

**Model:**
CCSM3 T31x3 with predictive vegetation
~100 simulation years / calendar day

Ruddiman, 2000
Orbital Variations of Incoming Solar Radiation

Fig. 4a. Solar radiation departures (past-minus-present, in W m⁻²) for July and January as a function of latitude and time (18 kyr BP to 0 kyr BP). The numbers in parentheses are the departures from present expressed in percent.

Kutzbach and Guetter, 1986; Ruddiman, 2000
Greenhouse Gases: CO\textsubscript{2}, CH\textsubscript{4}, N\textsubscript{2}O

IPCC AR4 WG1, 2007
Ice Sheet Extents and Heights

Peltier, 2004

21 ka

14.5 ka

10 ka
Meltwater History During the Deglaciation?

- Sea level records
- Marine cores: concentrations of lithic grains, detrital carbonate, geochemical proxies
- Stratigraphic evidence of ice margin retreat and drainage outlets
Freshwater Forcing:
Leading EOFs of Surface Temperature (Decadal)

CO₂/Orbital/Icesheet/Veg Effect
“Antarctic”

N. Atl Meltwater Effect
“Greenland”
Transient “forcings”
Orbital Insolation
Greenhouse Gases: CO₂, CH₄, N₂O
Ice Sheet Extents and Heights
Meltwater Fluxes ***

Transient responses
Atlantic Ocean Overturning
Greenland Temperature
(model offset by -3°C)
Antarctic Temperature
Iberian Margin SST
Cariaco Basin SST
(model offset by 4°C)
Cariaco Basin Precipitation

*** Gray: Proxy data estimates
Attribution

Liu, Otto-Bliesner et al., 2009
Leading EOFs of Precipitation (Decadal)

**EOF 1**

- CO₂/Orbital/Icesheet/Veg Effect
- “Monsoon”

**EOF 2**

- N. Atl Meltwater Effect
- “Greenland”

**Graphs:**
- **EOF 1** and **EOF 2** showing patterns over the world with temperature gradients.
- Time series for **EOF 1** and **EOF 2** showing changes in mm/month over Kyr (B.P.).
Northern Africa Hydrologic Cycle

CCSM3 transient simulation
Sahel (12.9-16.7°N, 11.25-22.5°E)

Otto-Bliesner et al., in prep.

deMenocal et al., 2000; Hoelzmann et al., 2004; Liu et al., 2007
CCSM can also predict vegetation changes

21 ka

10 ka
Transient Simulations: Last Millennium

CCSM4  1° x 1°

Black line: Smoothed CCSM4 simulation
Colored lines: Reconstructions from data
Many more CCSM/CESM Paleoclimate Snapshot Simulations

CCSM3
Low Resolution (T31)
Atm/land: 3.75°
Ocn/ice: ~3°

CESM1
High Resolution (FV1)
Atm/land: ~1°
Ocn/ice: ~1°
Applying CESM to Paleoclimate is a science problem

- Quaternary simulations: Nan Rosenbloom (nanr@ucar.edu)
- Pre-Quaternary simulations: Christine Shields (shields@ucar.edu)