# NCAR Paleoclimate Group

# Last Millennium climate and its variability in the CESM-CCSM4

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## Key Points

**The CCSM4 LM simulation:**

• Reproduces many large-scale climate patterns suggested by historical and proxy-data records, including a cooling from the Medieval Climate Anomaly (950-1250 CE) to the Little Ice Age (1400-1700 CE) and a pronounced increase in surface temperatures from 1850-2005 CE.

• Has similar spectral peaks for the El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) modes of variability, and significant increases in low-frequency power in sea surface temperature based modes; the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO) compared to the Pre-Industrial (PI) control run, suggesting long-term oceanic response to solar and volcanic forcing.

• Shows a decrease in winter-time precipitation in the southwestern North America during the Medieval Climate Anomaly, in general agreement with paleoclimate precipitation records.

• Displays broad cooling with a delayed La Nina- type of pattern in the tropical Pacific along with related teleconnected responses to large volcanic events

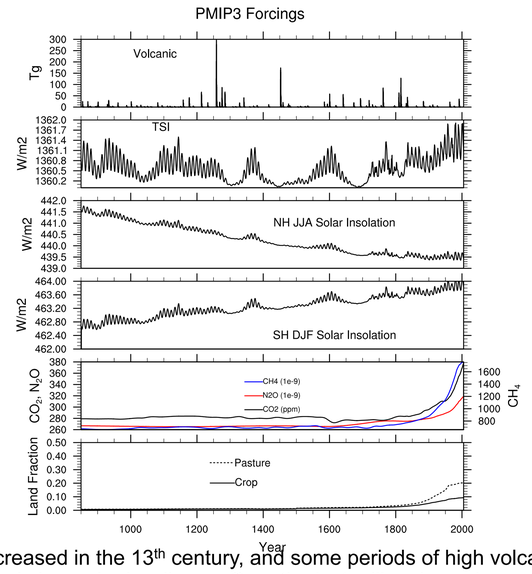
## Background and Forcing

The purpose of the Last Millennium experiment is three-fold:

- Evaluate the ability of models to capture observed variability on multi- decadal and longer time-scales.
- Determine fractions of the variability attributable to "external" forcing vs. internal variability.
- Provide a longer-term perspective for detection and attribution studies.

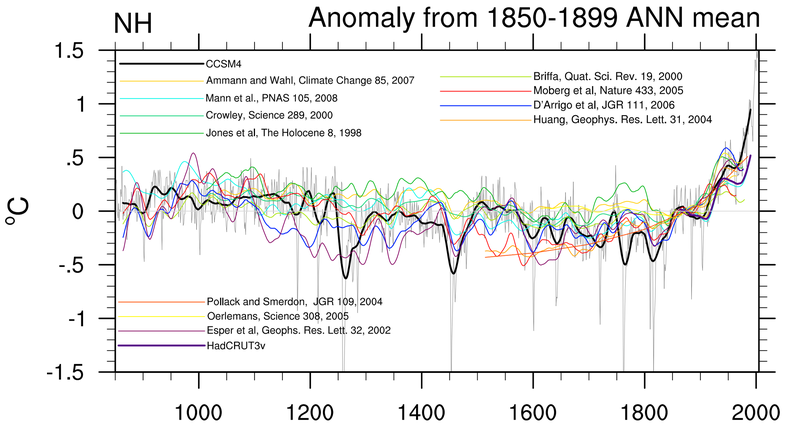
Forcings and boundary conditions follow CMIP5/PMIP3 protocols (https://pmip3.lsce.ipsl.fr/wiki/doku.php/pmip3:design:lm:final and discussed by Schmidt et al., 2011).

We extended the Last Millennium run from 1850-2005 using the same forcings prescribed for 20thC runs by the CMIP5 experiments plus a transient orbital forcing.

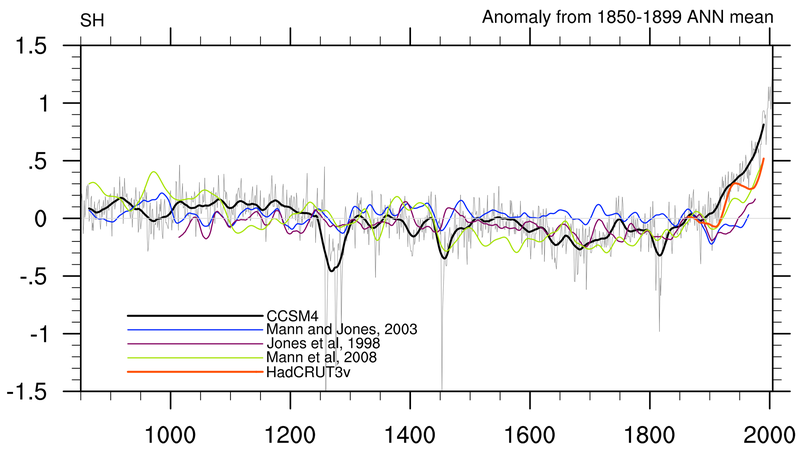



Volcanic activity increased in the 13th century, and some periods of high volcanism coincide with relatively low solar irradiance. Over the last millennium, changes in the earths orbital parameters have led to decreased/increased insolation in the NH/SH. Greenhouse gas concentrations increase rapidly after 1850.

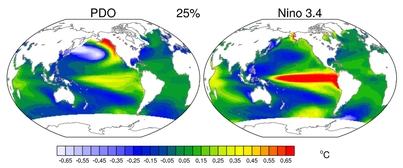
## Large-scale Temperature Response

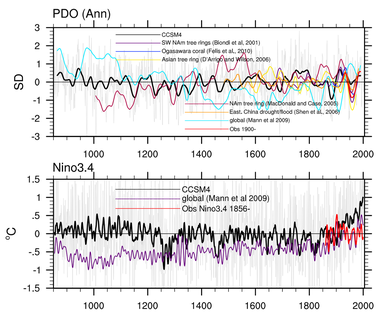


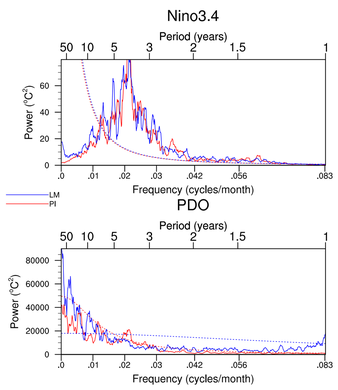

Simulated hemispheric mean temperatures (annual values in light gray; 30-yr Gaussian smoothed in black) are warmer prior to the 13th century, cooler from 1400-1800 CE, and increase rapidly in the 20th century, in general agreement with nearly all of the proxy records. The CCSM4 LM simulation tends to show a greater response to volcanoes than the proxy-records, and a greater warming in the latter half of the 20th century than in the observations. NH temperatures after 1950 are greater in both the model and all proxy records than at any other time in the last millennium.



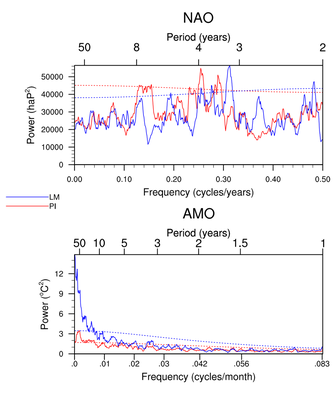

## Modes of Variability

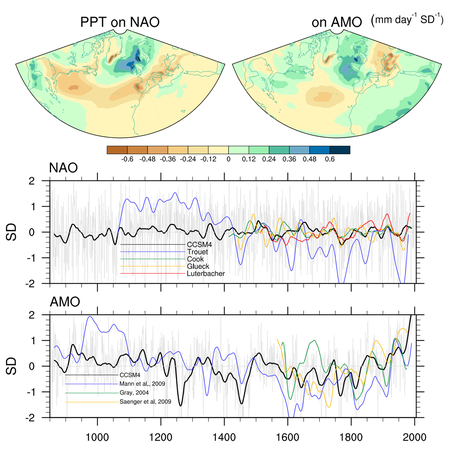


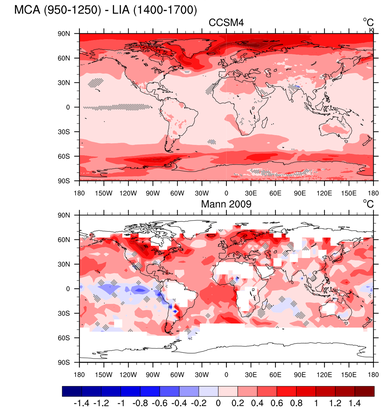



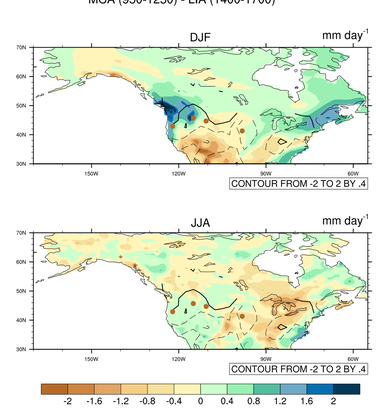

The spectra of both Nino3.4 and the NAO are similar in the LM and PI control run, however the PDO and AMO show marked increased at low frequencies in the LM simulation (upper right and lower left; dashed lines show 95% confidence levels). There is a great deal of spread in proxy-based reconstructions of these indices. Regressions of SSTs on the LM PDO and Nino3.4, as well as regressions of precipitation on the LM NAO and AMO show some similarities in their patterns.



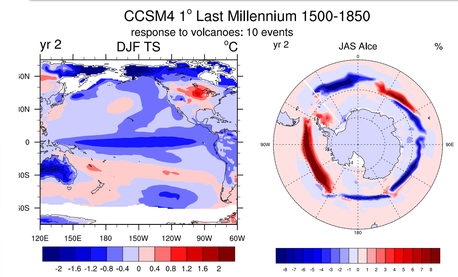

## Medieval Climate Anomaly and the Little Ice Age




Temperatures during the Medieval Climate Anomaly (950-1250 CE) were warmer than during the Little Ice Age (1400-1700 CE) in the CCSM4 simulation (upper left) and the Mann et al., 2009, proxy-based reconstruction (lower left), although the LM simulation does not reproduce La Nina type conditions in the equatorial Pacific. The LM simulation does show dry conditions in Southwestern North America (right panels), in agreement with proxy-based estimates of PDSI (contour overlay; dashed lines indicate negative PDSI; Cook, E.R., et al. 2008, Version 2a, IGBP PAGES/World Data Center Series # 2008-046.). Charcoal and lake salinity records suggesting dry Medieval conditions are shown by brown markers.

## Composite Response to Volcanoes




Superposed epoch analysis (SEA) composite response to volcanoes, year 2, of surface temperatures show a La Nina type pattern in the Pacific, with a teleconnected response in winter Antarctic ice cover.

SEA composite response (year 3) for North American FM temperature in both CCSM4 (left) and proxy-reconstructions (right; Wahl and Ammann) both show a strong latitudinal gradient, although the region of warming extends further north in the LM simulation.