Simulation of Arctic climate response to high- and low-latitude volcanic eruptions during the late 13th Century: Possible early onset of the Little Ice Age

David P. Schneider, Caspar M. Ammann, Bette Otto-Bliesner
National Center for Atmospheric Research
Climate and Global Dynamics Division
Boulder, CO
dschneid@ucar.edu

Funded by:
History of radiative forcing shows extreme volcanic perturbations in the 1200s

(Mount Pinatubo, courtesy Wikipedia)

(IPCC, 2007; Ammann et al., 2007)
Eruptions leave spikes in sulfate concentration in ice cores, but the source of volcanic sulfate from 1250 – 1300 AD has not been definitively attributed to specific volcanoes.

(IPCC, 2007; Ammann et al., 2007)
Volcanic simulations with the NCAR CCSM3 (climate model)

• Used fully coupled NCAR CCSM3;
  - same model as in IPCC AR4; well-validated
  - atmosphere at T42 resolution (2.75 X 2.75 degree grid)
  - ocean at 1 X 1 degree resolution
  - includes sea-ice and land models

• Two sets of simulations (sorry, only first set for this talk…)
  • 3, 50-year long ensemble members representing the pre-industrial climate of the 1200s, perturbed by 4 tropical eruptions from 1250AD to 1300AD
  • Same, except we assume that the eruptions occurred at high latitudes in both hemispheres
Motivations for these simulations with the NCAR CCSM3 (climate model)

• Volcanic eruptions as an explanation for Arctic climate change, especially from the warmer conditions (MWP) to colder conditions (LIA) of the last millennium
• Support the attribution of source volcanoes (tropical or high latitude) based on patterns of climate response
• Good test of models’ response to perturbations in radiative forcing
• Volcanic eruptions as analogs for climate geo-engineering schemes
Volcanic aerosol prescription

• Zonal-mean aerosol mass prescribed; Follows Ammann et al. (2007)

March 1258, 5 months following eruption
Surface radiative response and temperature response
Surface temperature response, years 0-4 after eruptions

Composites of DJF TREFHT anoms following 4 volcanic eruptions

Composites of JJA TREFHT anoms following 4 volcanic eruptions

WINTER

SUMMER

deg C
Surface temperature response, long-term

Control run 2 sigma bound for Arctic, NH

Seasonal avgs of NH and Arctic regions

Temperature anomaly (°C)

WINTER

SUMMER
Precipitation response, water year (Oct-Sep) after eruptions

Observed after Pinatubo (Trenberth and Dai, 2007)

CCSM3 simulations (this study)
Precipitation response, water year (Oct-Sep) after eruptions

(a) Precipitation Anomaly (mm/day), 10/1991 - 9/1992

ENSO precipitation (Trenberth and Caron, 2000; IPCC AR4)
Dynamical response, winters following the eruptions

After simulated eruptions

The model’s internal Arctic Oscillation
Dynamical response, winters following the eruptions

Composites of DJF [u] following 4 volcanic eruptions

AO Positive

AO Negative

After simulated eruptions

The model’s internal Arctic Oscillation
Temperature reconstructions

(D’Arrigo et al, 2006)
Temperature reconstructions

(D’Arrigo et al, 2006)

New data!

2000 years of Climatic Variability from Arctic Lakes
Summary

• Largest temperature response to the tropical eruptions is in the high Arctic in winter

• The model simulates a positive phase Arctic Oscillation in the winter as observed; this weakens the cooling over northern Europe and Asia

• Strong summer cooling is produced over the mid-latitude continents, so we’d expect to see this signal in tree-ring based reconstructions

• Among the first simulations to show reduced precipitation over the continents, especially in the tropics, as observed after Pinatubo
Summary

• Largest temperature response to the tropical eruptions is in the high Arctic in winter

• The model simulates a positive phase Arctic Oscillation in the winter as observed; this weakens the cooling over northern Europe and Asia

• Strong summer cooling is produced over the mid-latitude continents, so we’d expect to see this signal in tree-ring based reconstructions

• Among the first simulations to show reduced precipitation over the continents, especially in the tropics, as observed after Pinatubo

FUTURE WORK

• Missing role of solar forcing, internal variability, THC variations, etc.

• How do these results compare to high-latitude eruptions?

• How do these results compare to climate and paleoclimate data?
The End