Oxygen Isotopic Expression of Volcanic Climate Signatures

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Mt. Pinatubo, Philippines, 1991

(a) Observed and CMIP5 simulated global mean surface air temperature
Past eruptions: even larger than Pinatubo

Information on pre-industrial volcanoes: reconstructions from ice cores
Otto-Bliesner et al. (2016)

NCAR Community Earth System Model Last Millennium Ensemble (LME)
Multiple ensembles, varying sizes: different combinations of climate forcings
850-2005 for most ensembles, 1850-2005 for ozone/aerosol only
Some extensions to 2100 (full-forcing ensemble)
Isotope-Enabled Last Millennium Ensemble (iLME)

Table 1
Simulations Completed to Date as Part of the Isotope-Enabled Last Millennium Ensemble

<table>
<thead>
<tr>
<th>Ensemble</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full forcing</td>
<td>3</td>
</tr>
<tr>
<td>Volcano only</td>
<td>2</td>
</tr>
<tr>
<td>Orbital only</td>
<td>1</td>
</tr>
<tr>
<td>Solar only</td>
<td>1</td>
</tr>
<tr>
<td>Greenhouse gas only</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. All simulations cover the 850–2005 period.

Stevenson et al. (2019)
Precip $\delta^{18}O$: DJF following tropical eruptions (Year 0-1)

Stevenson et al. (2019)
Anomalies in temperature (Paleoceanography) and Precip δ¹⁸O.

DJF following tropical eruptions (Year 0-1)

Top row (a,d,g) shows composites for DJF +0-1; middle row (b,e,h), for JJA +1; and bottom row (c,f,i), for DJF +1-2.

Figure 1.

Temperature (°C) and Precipitation (mm/day).

Stippling indicates values which are insignificant at 90% using a Wilcoxon rank-sum test.
Top row (a,d,g) shows composites for DJF +0-1; middle row (b,e,h), for JJA +1; and bottom row (c,f,i), for DJF +1-2.

Anomalies in total precipitable water (colors) and 850-hPa winds (vectors) for the 2 years following Tropical eruptions. Stippling indicates values which are insignificant at 90% using a Wilcoxon rank-sum test. Top row (a,d,g) shows composites for DJF +0-1; middle row (b,e,h), for JJA +1; and bottom row (c,f,i), for DJF +1-2.

Figure 2. Anomalies in P-E (mm/day), for the 2 years following Tropical (a–c), Northern (d–f), and Southern (g–i) eruptions. Top row (a,d,g) shows composites for DJF +0-1; middle row (b,e,h), for JJA +1; and bottom row (c,f,i), for DJF +1-2. Figure 6. Temperature (ºC) and Precipitation (mm/day).

There are other features of interest in the high latitudes: for instance, the strong warming over Eurasia associated positive phase of the North Atlantic Oscillation, bringing warmer air from the North Atlantic lies, however (Figure 2c). We hypothesize that the increase in vapor and isotopic distillation upstream (Figures 4c, 4g, and 4k) or from a change in the moisture source over Aus-

We hypothesize that the increase in vapor (18O enrichment) is driven by the strong aerosol-driven 18O (and thus 18O through modification of the degree of evaporative fractionation. 18O (18O) is driven by the strong aerosol-driven 18O enrichment is observed throughout the cen-

18Op response in monsoon Asia is quite interesting as well. 18Op exists throughout the cen-

18Op depletion over Greenland/North America does not seem to correspond precisely to temperature, as the largest cooling occurs over the North American landmass yet
DJF following tropical eruptions (Year 1-2)

Precip $\delta^{18}O$

Vapor $\delta^{18}O$

850 hPa wind (vectors), total precipitable water (colors)

El Niño initiation after eruptions depends on latitude.
Precip $\delta^{18}O$ during DJF following eruptions (Year 1-2)

Tropical

Northern

Southern

Stevenson et al. (2019)
Precip $\delta^{18}$O: a volcano fingerprinting tool??

[all data in iLME simulations]
Precip δ¹⁸O: a volcano fingerprinting tool?

Precip δ¹⁸O projection: Tropical eruptions

Stevenson et al. (2019)
Figure 14. (a–c) Projection time series of precipitation/\delta^{18}O fields onto the composite anomalies associated with Tropical, Northern, and Southern eruption classes, respectively. Arrows indicate the occurrence years of the eruptions within the appropriate class. Solid black line indicates ensemble median; colored envelopes indicate the interquartile range. (d) Aerosol mass mixing ratio time series from the Gao et al. (2008) data set, used to force the Community Earth System Model new, isotope-enabled Last Millennium Ensemble simulations.

P-E in this region (Figure 6c) are also consistent with a dominance of evaporation at these latitudes in Tropical DJF +1–2. In the western Pacific, positive anomalies in seawater/\delta^{18}O are driven by a combination of evaporative enrichment, and an enrichment in precipitation/\delta^{18}O.

6. Spatial Fingerprints of Eruption Latitude

In addition to describing the climatic response to volcanic eruptions, an understanding of the dynamics responsible for generating/\delta^{18}O anomalies can aid in the use of/\delta^{18}O records to reconstruct characteristics of past eruptions. This conceptual approach has previously been used to infer properties of eruptions in other contexts; for instance, Lavigne et al. (2013) concluded that the 1258 eruption of Mt. Samalas occurred in boreal summer based on the pattern of tephra deposits. In this case, the most obvious application is the identification of eruption hemisphere based on the spatial pattern of/\delta^{18}O, since many of the isotopic responses described above are strongly hemispherically dependent.

We have performed a spatial pattern correlation analysis, to infer the ability of/\delta^{18}O records to correctly identify the hemispheric structure of volcanic aerosol loading. The running DJF and JJA/\delta^{18}O anomaly fields are projected onto patterns of/\delta^{18}O anomaly during DJF +0–1, JJA +1, DJF +1–2, and JJA +2 seen in Figure 5 for each iLME ensemble member, yielding time series of pattern correlation values which vary according to the spatial structure of/\delta^{18}O. Patterns showing more similarity to Figure 5 will thus yield higher correlation values; the results are seen in Figure 14. It is apparent that volcanic eruptions (as identified directly from the aerosol forcing time series; as in Stevenson et al., 2016) do indeed coincide with high pattern correlations, although there are many periods with high correlation which are

Stevenson et al. (2019)
“Success rate”: # eruptions with significant pattern correlation ONLY in the correct hemisphere category

Tropical: 25%  
Northern: 66%  
Southern: 100%
Conclusions

• The isotope-enabled Last Millennium Ensemble will be a valuable tool for understanding LM proxy signatures (now publicly available!!)

• Oxygen isotopic anomalies record temperature, hydroclimate signatures of eruptions

• Vapor $\delta^{18}O$ significantly influences precipitation $\delta^{18}O$ in many locations, moisture source changes appear significant

• Precipitation $\delta^{18}O$ patterns can uniquely identify eruption hemisphere! (sometimes)