The Evolving Role of Volcanic Forcing in the AMV

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Abstract

External forcing offers a meaningful contribution to North Atlantic SST variability. Using the CESM Last Millennium Ensemble (CESM-LME) we find that prior to 1850, volcanic forcing accounts for nearly 2/3 of Atlantic Multidecadal Variability (AMV). This implies that internal variability accounts for 1/3 of AMV variance, as it does in the industrial period (Bellomo et al. 2017). Further, the inclusion of variable volcanic forcing allows for more realistic model runs, relative to proxy observations. However, after 1850 the influence of volcanic forcing on the AMV wanes. Even when accounting for eruption size and the potential influence of consecutive eruptions, there appears to be an important role for anthropogenic forcing.

Background

After 1850, external forcing (e.g. GHGs, aerosols, eruptions) may contribute up to two-thirds of AMV index variance (Bellomo et al. 2017). Further, climate models require external forcing to reproduce the phasing of the post-1850 AMV (Booth et al. 2012; Murphy et al. 2017; Undorf et al. 2018; Watanabe and Tatebe 2019). A recent study suggests that the industrial AMV is paced by volcanic forcing (Fig. 1; Birkel et al. 2018). Were eruptions also responsible for AMV phasing in the prior to 1850?

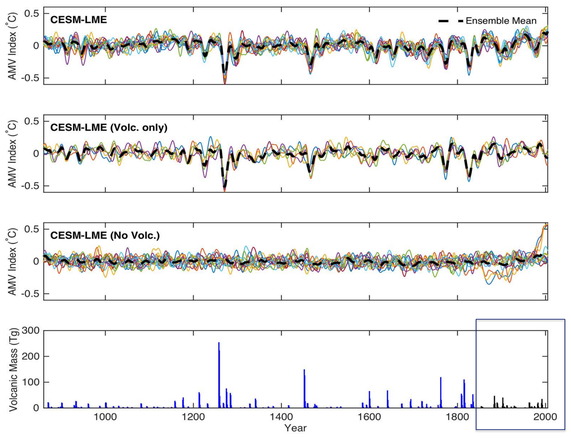

Figure 2: Timeseries of AMV indices from the CESM-LME and the volcanic forcing data used in the ensemble. The AMV index is calculated as the linearly detrended, spatially-weighted average SST between 0° - 60°N and 0° - 80°W. (*Top*) AMV indices from the "all forcing" experiments in the CESM-LME. (*Second panel*): AMV indices from the "volcanic forcing only" experiments of the CESM-LME. (*Third panel*): AMV indices from the single-forcing experiments of the CESM-LME that exclude volcanic forcing. (*Bottom*): Spatially-weighted average volcanic aerosol column mass (60°S - 60°N) used to force the CESM-LME.

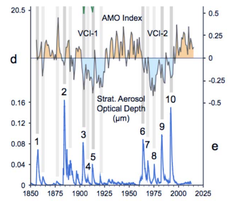

Figure 1: Reproduced from Birkel et al. 2018. (*d*) Observed AMV index. (*e*) NASA GISS record of global average stratospheric aerosol optical depth.

The phasing of the AMV timeseries shows noticeable influence of eruptions both before and after 1850 (Fig. 2).

Variable external forcing is a key component of the pre-1850 AMV

Prior to 1850, external forcing accounts for roughly 2/3 of AMV variance in the CESM-LME (Table 1). The average AMV variance is 0.014°C^2; the forced AMV variance is 0.010°C^2. In fact, volcanic forcing is nearly the sole contributor to forced AMV variance during this time period. Ensemble mean AMV variance from the CESM-LME "volcanic aerosols only" single-forcing run is 0.009°C^2. After 1850, the influence of volcanic forcing relative to the total forced component of the AMV diminishes, particularly at multidecadal timescales (Fig. 3).

	Pre-1850		Post-1850	
	Average total multidecadal AMV variance	Forced multidecadal AMV variance	Average total multidecadal AMV variance	Forced multidecadal AMV variance
All Forcings	0.014 (± 0.001)	0.010	0.014 (±0.007)	0.009
Volcanic Only	0.013 (± 0.001)	0.009	0.008 (±0.005)	0.003
PI Control	0.005	-	0.005	-
ERSST	-	-	0.023	-
	Average total multidecadal GMSST variance	Forced multidecadal GMSST variance	Average total multidecadal GMSST variance	Forced multidecadal GMSST variance
All Forcings	0.013 (± 0.002)	0.007	0.013 (±0.009)	0.007
Volcanic Only	0.012 (± 0.002)	0.007	0.008 (±0.008)	0.003
PI Control	0.005	-	0.005	-
ERSST	-	-	0.012	-
	Average total multidecadal NHSST variance	Forced multidecadal NHSST variance	Average total multidecadal NHSST variance	Forced multidecadal NHSST variance
All Forcings	0.005 (± 0.001)	0.003	0.004 (± 0.003)	0.002
Volcanic Only	0.005 (± 0.001)	0.003	0.002 (± 0.002)	0.001
PI Control	0.001	-	0.001	-
ERSST	-	-	0.010	-

Table 1: Total and forced variance from the CESM-LME. All timeseries were first filtered with Matlab's implementation of a 4th order Butterworth filter with a 1/10 year half-power frequency to isolate multidecadal variability. "Average total multidecadal variance" is defined as the average variance of each individual ensemble member's index, plus-or-minus two standard deviations of the ensemble spread. "Forced multidecadal variance" is the variance of the ensemble mean index. The AMV is defined as in Figure 1. GMSST is global mean SST between 60°S - 60°N and NHSST is Northern Hemisphere mean SST between 0° - 60°N.

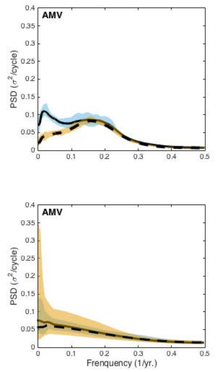

Figure 3: Spectra of SST indices from the CESM-LME with and without volcanic eruptions (similar to Otto-Bliesner et al. 2016). We grouped all model runs, including the single-forcing experiments into two categories: those that include variable volcanic forcing and those that do not. (*Top*) Spectra of indices prior to 1850. (*Bottom*): Spectra of indices after 1850.

Generally, the AMV index in CESM-LME runs with variable external forcing can produce higher correlations with a recent AMV reconstruction than PI control runs (Fig. 4; Wang et al. 2017). However, the signal is not as clear when comparing to two older records (Mann et al. 1998; Gray et al. 2004).

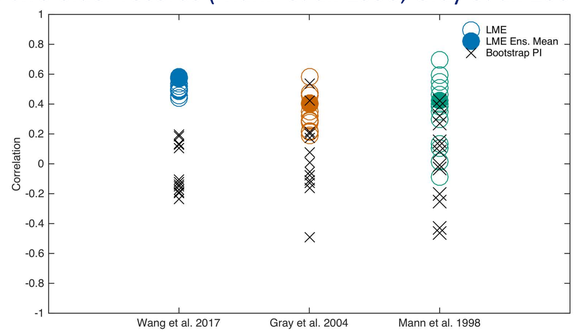

Figure 4: Correlation between CESM-LME index and four proxy AMV timeseries. All timeseries were first low-pass filtered with a half-power frequency of 30 years. Open circles represent individual ensemble members. Closed circles represent the CESM-LME ensemble mean. Crosses represent random subsections of a PI control run, where each subsection is equal to the length of the proxy record.

What's different about the post-1850 AMV?

Between 850 and 1850, there were 18 years with larger volcanic aerosol column mass than in the largest eruption year after 1850 (Fig. 5; compare black triangles). Large eruptions are more consistently linked to larger temperature responses than smaller eruptions.

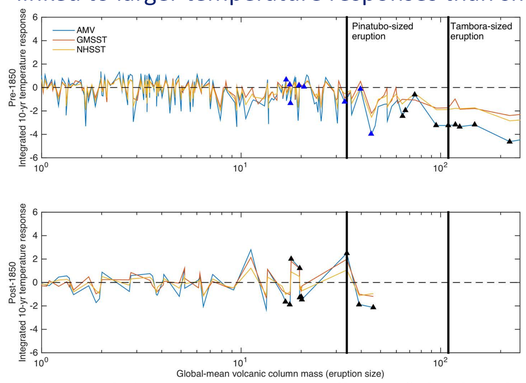

Figure 5: Integrated temperature response versus eruption size. The temperature response for each index is defined as the average sum of the composite temperature response (as in Fig. 5) for the first ten years following an eruption. Eruption size if defined as global mean volcanic aerosol column mass. Black triangles are the ten largest eruptions in each subsection of the ensemble. Blue triangles are the ten eruptions in prior to 1850 that are most similar in size to the ten largest eruptions in the industrial period. (*Top*) The period 850 – 1850. (*Bottom*) The period 1851 – 2005.

This result is consistent regardless of the level of pollution in the ambient environment (cf. Shindell et al. 2009). Equivalent eruptions, by magnitude, before and after 1850 have similar temperature responses (Fig. 5 blue triangles; Fig. 6). Consecutive eruptions or "clusters" of eruptions induce a more consistent AMV response before 1850 than after despite the noise fraction remaining constant (Fig. 7).

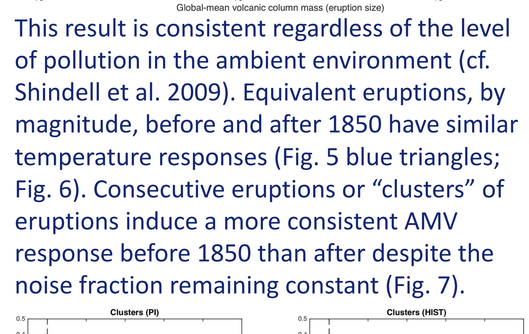

Figure 6: Composite AMV index response to the ten largest eruptions in each run for the time period specified. "PI-as-HIST" are composites following the 10 eruptions prior to 1850 that are most similar to the 10 largest eruptions in the industrial period.

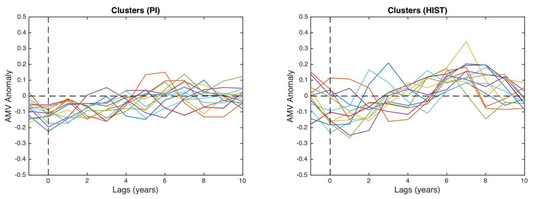

Figure 7: The composite response to the largest "clusters" of eruptions in each run. "Clusters" are defined as maxima in the 20-year moving average of global mean volcanic aerosol column mass.

Key Points

- Roughly 2/3 of the AMV is externally-forced from 850 – 2005.
- This is consistent with proxy records that show constant multidecadal variance pre- and post- 1850, despite including anthropogenic forcing.
- Prior to 1850, volcanoes are the primary source of the external contribution to AMV variance.
- After 1850, there is a role for both eruptions and anthropogenic forcing
- Smaller eruptions after 1850 explain some of the diminished explanatory power of volcanic forcing.

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