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Atlantic Multidecadal Variability and Tropical Cyclones in Last Millennium Climate

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1. Background

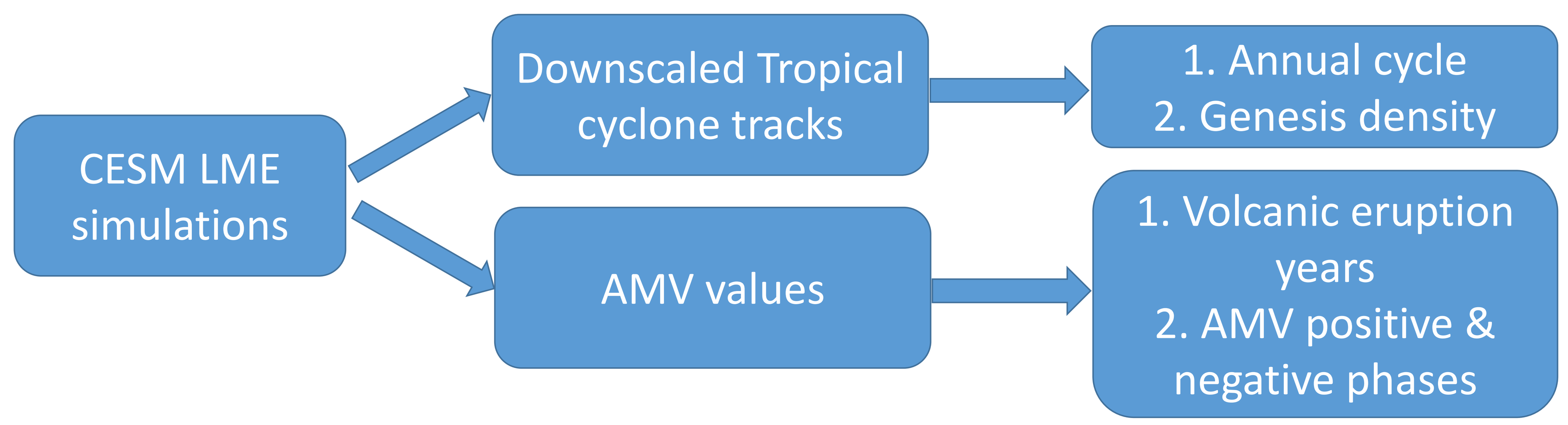
Atlantic Multidecadal Variability (AMV) refers to patterns of variability over the North Atlantic basin on decadal and longer timescales. Related to what was historically called the Atlantic Multidecadal Oscillation (AMO), it is defined by anomalies of sea surface temperature (SST) in the North Atlantic basin from a detrended long-term signal.

Past studies have shown that tropical cyclone activity is enhanced during the warm phase of the AMV in the North Atlantic. However, the physical forcing of AMV remains debated. Past research considered mechanisms arising from both internal forcing and external forces. Natural internal forcing includes the Atlantic Meridional Overturning Circulation (AMOC) and natural red-noise stochastic forcing of the ocean by the atmosphere. External forces include volcano, aerosols, and greenhouse gases. Recently, Mann et al. (2021) argued that the AMV is an artifact of pulses of volcanic activity during the last millennium and concluded that there is no compelling evidence for internal multidecadal oscillations in the climate system.

We study the response of tropical cyclones (TCs) downscaled from global simulations using conditions over North Atlantic Ocean. We focus here on storms that form in years with and immediately following volcanic eruptions, and compare with those from positive and negative phases of the AMV. The purpose is to examine whether the AMV impacts on TCs are mainly caused by volcano eruptions.

2. Data and Methods

- We apply the tropical cyclone (TC) downscaling technique developed by Emanuel (2006) to Community Earth System Model-Last Millennium Ensemble (CESM-LME) simulations.
- CESM-LME simulations are conducted at NCAR as contributions to the Paleoclimate Intermodal Comparison Project (PMIP). There are 36 ensemble members, about 1/3 of which use the full set of forcings and the remainder test responses to individual forces (e.g., greenhouse gas, solar, volcanism, etc.).
- We have downscaled 100,000 TCs for one full forcing ensemble member and another 100,000 TCs for a second forced only by volcanic eruptions (solar irradiance and other time varying forces all set to their 1850 values)
- We study their responses to Atlantic Multidecadal Variability (AMV), defined as an index computed using the method as used by Sutton et al. (2005)



3. Results

Coherence of AMV years

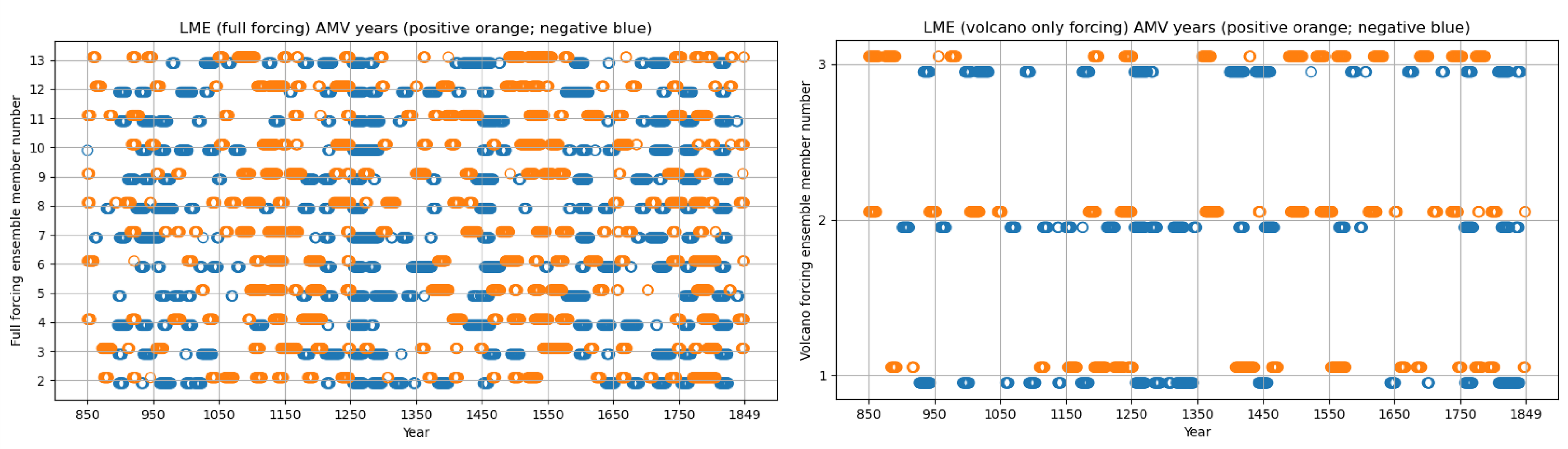


Fig. 1 Top 200 Atlantic Multidecadal Variability (AMV) years (in orange) and bottom 200 AMV years (in blue) for full forcing ensemble member 2-13 (left) and volcano only forcing ensemble member 1-3 (right.)

Fig. 1 shows the **coherence** of AMV years in different ensembles. For example, AMV in almost all full forcing ensembles are in positive phase in around 1150 and in negative phase in around 1260. This implies that there are some common drivers of AMV among these ensembles.

AMV time series

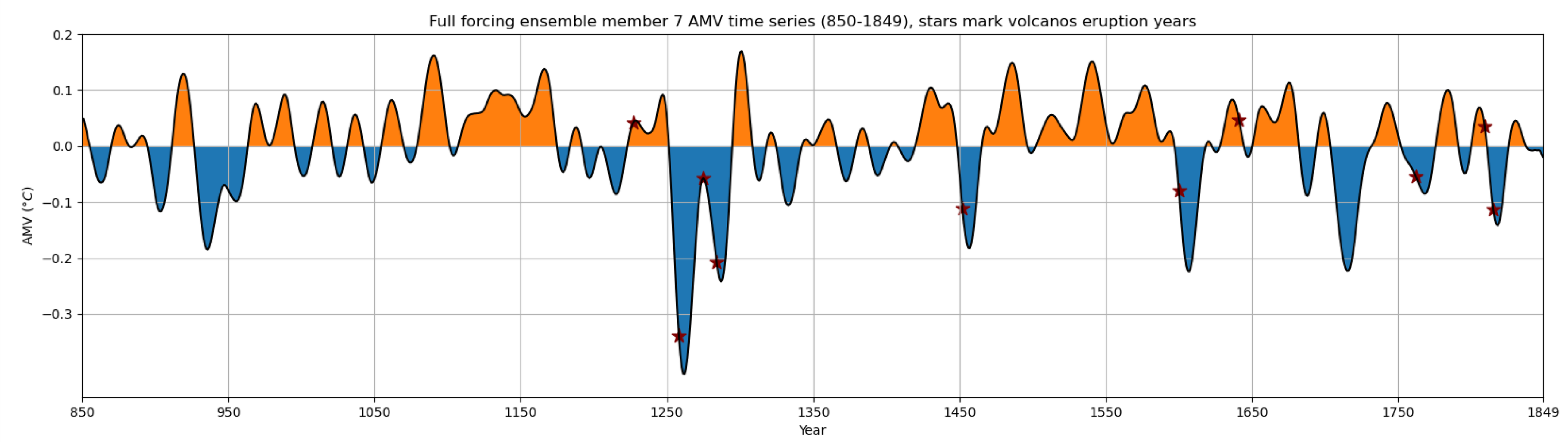


Fig. 2 Time series of Atlantic Multidecadal Variability (AMV) in CESM-LME full forcing ensemble member 7. The stars in maroon color mark the 10 volcanos eruptions years and the corresponding AMV values.

Fig. 2 shows that most of the volcano eruptions (7 out of 10) lead to a negative phase of AMV. After a few years of eruption, the AMV reaches to a low extreme value.

Annual cycle of storms

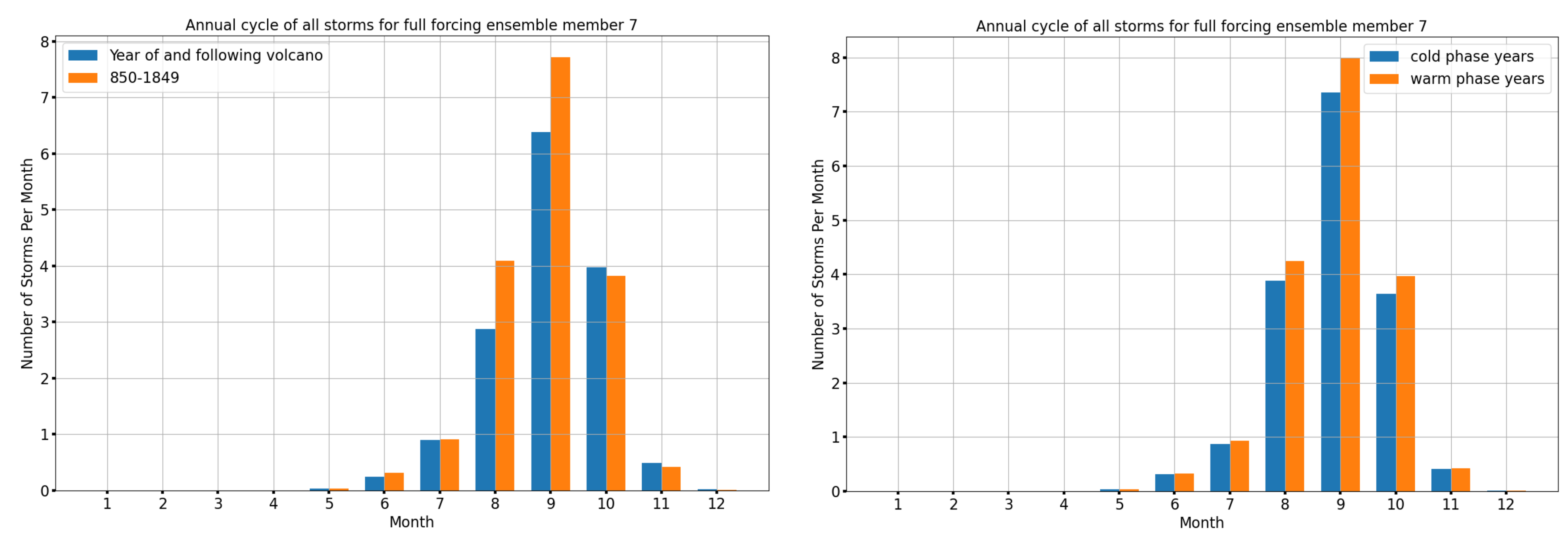


Fig. 3 Annual cycle of storms in year of and following volcano compared to all 1000 years in CESM-LME full forcing ensemble member 7 (left) and storms in AMV warm phase years compared to cold phase years (right.)

Fig. 3 shows there are less storms in year of and following volcano in Aug. and Sep. There are also less storms in cold phases years than in warm phase years.

Genesis density map

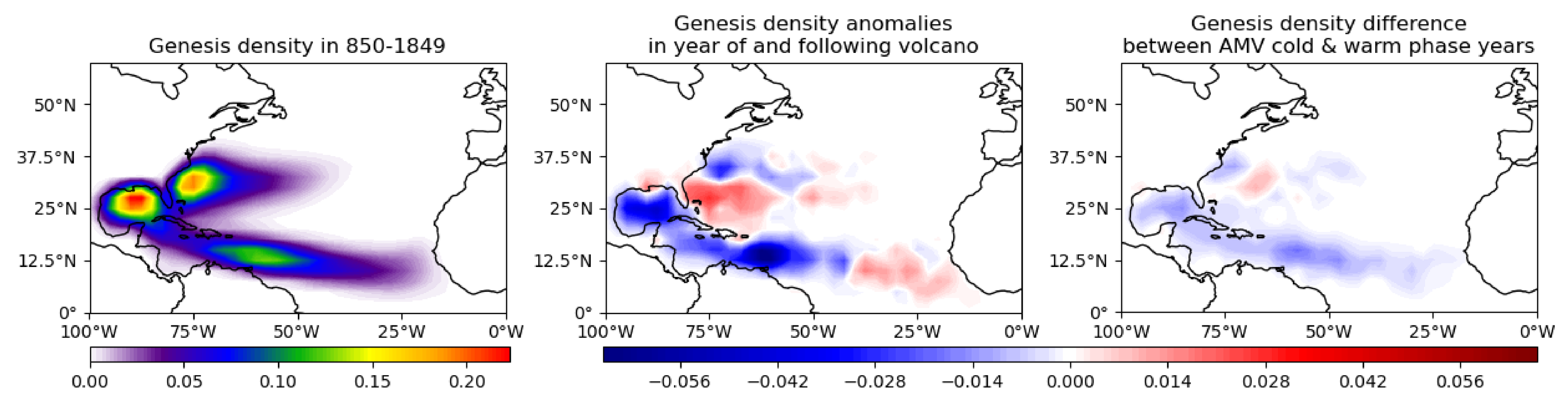


Fig. 4 Left: genesis density (2.5 deg * 2.5 deg) of all storms for CESM-LME full forcing ensemble member 7 in the whole 1000 years over North Atlantic Ocean; Middle: genesis density anomalies (2.5 deg * 2.5 deg) in year of and following volcano; Right: genesis difference between AMV cold & warm phase years for CESM-LME full forcing ensemble member.

Fig. 4 shows genesis density anomalies in the year of and following volcano eruptions have broadly similar patterns as the cold phase of AMV, although activity in the far eastern Atlantic is elevated (also evident in track density [not shown]).

Annual downscaled hurricanes

	ntc	nhur	ncat1	ncat2	ncat3	ncat4	ncat5	hur%	major%	4/5%
All years	17.5635	6.7539	4.2773	1.1825	0.7319	0.3994	0.1627	38.45%	7.37%	3.20%
AMV warm	18.1667	7.0011	4.4169	1.2307	0.7569	0.4248	0.1717	38.54%	7.45%	3.28%
AMV cold	16.7573	6.4251	4.0900	1.1189	0.6985	0.3666	0.1511	38.34%	7.26%	3.09%
Volc years	15.1246	5.5518	3.7463	1.0141	0.4584	0.2183	0.1148	36.71%	5.23%	2.20%

Table 1 Left to right columns show the averaged annual number of all downscaled storms (ntc), hurricanes (nhur), categories 1-5 hurricanes (ncat1-ncat5), percentage of storms that become hurricanes (hur%), percentage of storms that become major hurricanes (major%), percentage of storms that become category 4/5 hurricanes (4/5%) in all years, in AMV warm phase years, in AMV cold phase years, and during and after the years of 10 large volcanic eruptions in CESM-LME full forcing member 7.

4. Summary and Conclusions

1. Most major volcanic events coincide with years featuring negative AMV phase. There is coherence across the CESM-LME: each member drops into negative AMV phase in the volcanically active late 13th century.
2. During and after the 10 largest volcanic eruptions, genesis of downscaled TCs decreases during Aug. and Sept. Genesis density also decreases in most region.
3. The spatial pattern of genesis density changes following volcanic eruptions is similar to that of the difference between AMV cold & warm phases, but with larger amplitudes following volcanos.
4. The frequency of the strongest events (defined as those reaching major hurricanes or of the smaller subset that reach Category 4+ intensity) are lower following volcanic eruptions as well as the cold AMV phase.

Acknowledgements and References

This work is supported by NSF Award 1854917.

1. Mann et al., (2021), *Science*, **371(6533)**, 1014-1019.
2. Emanuel, (2006), *Journal of Climate*, **19(19)**, 4797-4802.