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Geophysical Research Letters

RESEARCH LETTER
10.1029/2022GL097794

Key Points:

- Linearly detrending North Atlantic sea surface temperatures conflate variability unique to the Atlantic with aliased residual, nonlinear, global warming
- The role of external forcing on Atlantic Multidecadal Variability (AMV) is greatly diminished when global forcing signals are sufficiently removed
- Roles for historical forcing on AMV previously identified with the linear detrending method are likely an unphysical artifact

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

S. H. Baek,
seunghun.baek@yale.edu

Citation:

Baek, S. H., Kushnir, Y., Ting, M., Smerdon, J. E., & Lora, J. M. (2022). Regional signatures of forced North Atlantic SST variability: A limited role for aerosols and greenhouse gases. *Geophysical Research Letters*, *49*, e2022GL097794. https://doi.org/10.1029/2022GL097794

Received 11 JAN 2022
Accepted 26 MAR 2022

Regional Signatures of Forced North Atlantic SST Variability: A Limited Role for Aerosols and Greenhouse Gases

Seung H. Baek[1], Yochanan Kushnir[2], Mingfang Ting[2], Jason E. Smerdon[2], and Juan M. Lora[1]

[1]Department of Earth and Planetary Sciences, Yale University, New Haven, CT, USA, [2]Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA

Abstract

Prior studies that argue external forcings drive Atlantic Multidecadal Variability (AMV) use linear detrending to remove the global warming trend from North Atlantic sea surface temperatures (SSTs). The linear detrending method, however, aliases residual nonlinear, global-scale warming, affecting the interpretation of results. Here we revisit the role of external forcing in AMV using large climate model ensembles, examining the influences of greenhouse gases (GHGs) and industrial aerosols—the two dominant 20th-century external forcing agents—on North Atlantic SSTs separately from their respective global response. Our approach shows that GHGs have little to no influence unique to the North Atlantic, while industrial aerosols exert only modest influences as part of a broader loading over the Northern Hemisphere. We demonstrate that a prominent role for external forcings on AMV is an artifact of the linear detrending method that disappears when their global responses common to the World Ocean are correctly accounted for.

Plain Language Summary

The origin of Atlantic Multidecadal Variability (AMV) is widely debated, with discussions focused on whether it is an internal mode of the coupled climate system or a response to external radiative forcings. Most studies that identify a dominant role for external forcings in driving AMV apply linear detrending to remove the global warming trend from North Atlantic SSTs. This is problematic because the linear detrending method does not sufficiently remove the global warming signal. In this study, we re-examine the role of external forcing in 20th-century AMV, correctly accounting for global forcing influences common to the entire World Ocean. Separate analysis of the roles of greenhouse gases (GHGs) and industrial aerosols on AMV, independent of their respective planetary influence, shows that GHGs have little to no influence unique to the North Atlantic, while industrial aerosols exert only modest influences as part of a broader impact on the Northern Hemisphere oceans. Our results suggest that linear signal separation methods that do not fully isolate the influences of global forcing on North Atlantic temperatures incorrectly inflate the role played by external forcing. When these approaches are avoided, our results indicate that external forcing has little influence on AMV compared to variability internal to the climate system.

1. Introduction

During the 20th century, North Atlantic sea surface temperatures (SSTs) displayed a basin-wide, multidecadal oscillation superimposed on to a century-scale warming tendency associated with a global response to external radiative forcing. The slow, oscillating part of basin-wide SST variations, separate from the century-scale warming, has been considered unique to the North Atlantic and became known as the Atlantic Multidecadal Oscillation or Variability (AMO or AMV; Enfield et al., 2001; Kerr, 2000; Schlesinger & Ramankutty, 1994; Ting et al., 2009). AMV is thought to orchestrate similarly paced climatic variations in the Northern Hemisphere (Knight et al., 2006; Sutton & Hodson, 2007; Zhang & Delworth, 2006). For instance, AMV has been associated with variability of the northward penetration and intensity of the African summer monsoon, including the occurrence of devastating droughts in the Sahel (Zhang & Delworth, 2006), periods of prolonged dry spells in North America (Enfield et al., 2001; Hu et al., 2011; Kushnir et al., 2010; Sutton & Hodson, 2005), summer temperatures in Europe (Sutton & Hodson, 2005), and hurricane activity in the North Atlantic (Goldenberg et al., 2001; Ting et al., 2015, 2019).

The conventional explanation for AMV is that ocean-atmosphere interactions internal to the climate system drive slow changes in ocean heat transport that ultimately lead to basin-wide SST changes (with strong oceanic heat transport into the subpolar gyre triggering warm phases of AMV and vice versa; Bjerknes, 1964; Buckley &

Marshall, 2016; Delworth & Mann, 2000; Zhang et al., 2019). Several studies have, however, highlighted the role of external forcings on AMV, emphasizing instead the contributions of anthropogenic and natural external radiative forcing to the amplitude and multidecadal departures of North Atlantic SSTs from climatology (Bellomo et al., 2018; Booth et al., 2012; Haustein et al., 2019; Murphy et al., 2017, 2021; Otterå et al., 2010; Watanabe & Tatebe, 2019). Murphy et al. (2017), for instance, compared preindustrial and historical model ensembles and concluded that 20th-century forcings were essential to models simulating the temporal features of observed AMV. Bellomo et al. (2018) reached a similar conclusion in their analysis of the Community Earth System Model 1 (CESM1) large ensemble, suggesting that (a) historical greenhouse gases (GHGs) and tropospheric aerosols were the main drivers of 20th-century AMV and that (b) the spatial pattern of forced North Atlantic SST was indistinguishable from internally generated AMV.

Most studies that identify a prominent role for radiative forcing in AMV apply linear detrending in time, to remove the secular, centennial-scale warming tendency from North Atlantic basin-mean SSTs (e.g., Bellomo et al., 2018; Murphy et al., 2017, 2021; Otterå et al., 2010; Watanabe & Tatebe, 2019). This is problematic because the linear detrending method does not sufficiently remove the global warming signal; the linear detrending method does not account for the nonlinear increases in GHGs (Andrews et al., 2020; Deser & Phillips, 2021; Yan et al., 2019; Zhang et al., 2013) nor the regionally selective impacts of aerosol forcing (Baek & Lora, 2021; Bauer et al., 2020; Persad & Caldeira, 2018). Moreover, it does not discriminate between (a) the global forced response common across the entire World Ocean and (b) the specific forced response unique to the North Atlantic (Andrews et al., 2020; Yan et al., 2019; Zhang et al., 2013). The role of external forcings could, for instance, be limited to the part of North Atlantic SST variability that changes together with the World Ocean, in which case it would not be the North Atlantic specifically that external forcings modulate.

Given these considerations, the predominant role of external forcing on AMV in climate models identified using the linear detrending method may be misconstrued. What Murphy et al. (2017), Bellomo et al. (2018), and others have isolated and analyzed, for instance, may not be the AMV in its original sense (i.e., the slow, oscillating basin-wide SST variations separate from the century-scale warming), but rather the amalgamation of (a) a phenomenon unique to the Atlantic (be it internal variability or a basin-specific response to external forcing) and (b) an aliased residual (global) century-scale warming because of unphysical detrending (Deser & Phillips, 2021). Though subtle, this conflation is an important detail requiring careful attention, as it ultimately has implications for understanding the role of external forcing on AMV compared to processes internal to the coupled ocean-atmosphere system.

Challenges associated with linear detrending nevertheless do not, in and of themselves, preclude the possibility of external forcings modulating AMV. A significant role for external forcings in AMV could still exist if external forcings affected the slow, oscillating part of basin-wide SST variations separately from the global warming signal. In this study, we address how much North Atlantic SST variability, independent of global changes, is explained by external forcing in climate models. Specifically, we use large ensembles of historically forced, coupled atmosphere-ocean models and companion "all but one" experiments to delineate and re-examine the individual roles of GHGs, aerosols, and other external forcings on 20th-century North Atlantic SST variability intrinsic to the North Atlantic basin.

2. Data and Methods

2.1. Fully Coupled Model Experiments

We examine SSTs from a 20-member ensemble (members #2–21) of the CESM1 Large Ensemble, which forces the fully coupled CESM1 model (Kay et al., 2015) with historical radiative forcing from 1920 to 2005 (herein HIST experiments). Note that the Large Ensemble comprises a 40-member HIST ensemble, of which we use 20 members to maintain consistency with the 20-member ensemble sizes of the "Single Forcing" experiments described below. The HIST experiment includes the influences of historical radiative forcing and internal variability of the global, coupled ocean-atmosphere system. Taking the ensemble mean across the HIST experiments drastically reduces the impacts of internal atmosphere-ocean variability, such that the (a) ensemble mean and (b) deviations from the ensemble mean can be attributed to the forced response and internal variability, respectively.

We employ two additional 20-member ensemble experiments from the "Single Forcing" Large Ensemble Project (Deser et al., 2020). The first 20-member "all-but-one" ensemble is otherwise identical in experimental setup to the HIST ensemble but keeps GHGs fixed at 1920 conditions (all-but-GHG; herein XGHG). The second 20-member "all-but-one" ensemble is also otherwise identical to HIST but keeps industrial aerosols fixed at 1920 conditions (all-but-AER; herein XAER). All other natural and anthropogenic forcings in XGHG and XAER follow their historical evolutions (see Deser et al., 2020 for details). The influence of GHGs and industrial aerosols on SSTs is deduced by subtracting the respective ensemble means of XGHG and XAER from the ensemble mean of HIST. The influence of other "residual" 20th-century forcings is deduced by subtracting out the influence of GHGs and industrial aerosols from HIST. We note that the "all-but-one" experimental setup is unique in accounting for heterogeneous, nonlinear interactions between aerosols and GHGs (as opposed to single forcing experimental setups with GHG-only and aerosol-only forcing; Eyring et al., 2016).

2.2. Model Analyses of AMV

We define the AMV index as the area-weighted, annual average SST anomalies over the North Atlantic (0°–60°N and 0°–80°W) and apply a third order, 10-year Butterworth filter to the index to isolate decadal to multidecadal variability. We first investigate AMV spatial patterns associated with (a) internal variability + 20th-century historical forcing (from the HIST ensemble), (b) 20th-century forcing alone (from the HIST ensemble mean), and (c) internal variability alone (from HIST members—HIST ensemble mean). To identify the AMV-related SST change within the Atlantic associated with the components defined in (a), (b) and (c) above, we regress the raw annual global SST field onto standardized AMV indices (associated with the respective internal and/or external influences). The standardization of the AMV index allows for an unbiased comparison of the AMV-response pattern between model representations of internal variability and external forcing and between the response to the different external forcing agents. For fields that include internal variability, we regress global SSTs of each respective ensemble member onto the AMV indices generated in that same ensemble member and then average the regression fields across the ensemble. For AMV fields associated with historical radiative forcing only, both the AMV index and the regressions are calculated on ensemble mean SST fields.

We also investigate AMV spatial patterns associated with 20th-century industrial aerosols and GHGs but after removing their respective global forced influences (see Miller et al., 2014 for forcing data and description thereof). To do this for GHGs, we regress annual SST changes forced by GHGs at each grid point (i.e., HIST ensemble mean—XGHG ensemble mean) onto global radiative forcing due to well-mixed GHGs (WMGHG; Figure S1 in Supporting Information S1); we then multiply the representative global forcing pattern by the WMGHG forcing time series to reconstruct the year-by-year evolution of this signal at each grid point; finally, we remove this annual reconstructed pattern and its year-by-year evolution from the full annual SST changes forced by GHGs. Likewise for industrial aerosols, we regress annual SST changes forced by aerosols at each grid point (i.e., HIST ensemble mean—XAER ensemble mean) onto global radiative forcing due to tropospheric aerosols (the sum of direct and indirect forcing; Figure S1 in Supporting Information S1); we multiply the representative global forcing pattern by the tropospheric aerosol forcing time series to reconstruct the year-by-year evolution of this signal at each grid point; we remove this annual reconstructed pattern and its year-by-year evolution from the full annual SST changes forced by aerosols. We calculate AMV indices (applying the third order, 10-year Butterworth filter) from these respective global forcing-removed SST fields and regress standardized AMV indices onto the respective data components. This allows for an examination of AMV-related SST change driven by GHGs and industrial aerosols that is unique to the North Atlantic sector. While instructive, we note (as in Deser et al., 2020 and Deser & Phillips, 2021) that the use of a single time period to reconstruct spatial influences does not account for any aerosol and GHG-induced SST response patterns that may change with time (either due to changes in the regional distribution of aerosols or to time lags within the climate system such as the delayed response to GHGs in regions of ocean heat uptake).

We compare the variances of AMV time series, which represent the actual magnitude of the patterns in the different data components, separately. We specifically investigate the temporal features of AMV by examining the (non-standardized) AMV indices generated by (a) internal variability alone, (b) internal variability and industrial aerosols, and (c) internal variability and GHGs. We furthermore compute Thomson's multitaper power spectral density (Thomson, 1982) on the raw AMV indices from the XGHG and XAER ensembles to examine their spectral characteristics. We remove beforehand from each member of the XGHG ensemble (which has the influences of internal variability, residual 20th-century forcing, and industrial aerosols) its response to the globally averaged radiative forcing from tropospheric aerosols, using similar steps as outlined above (but done member by member

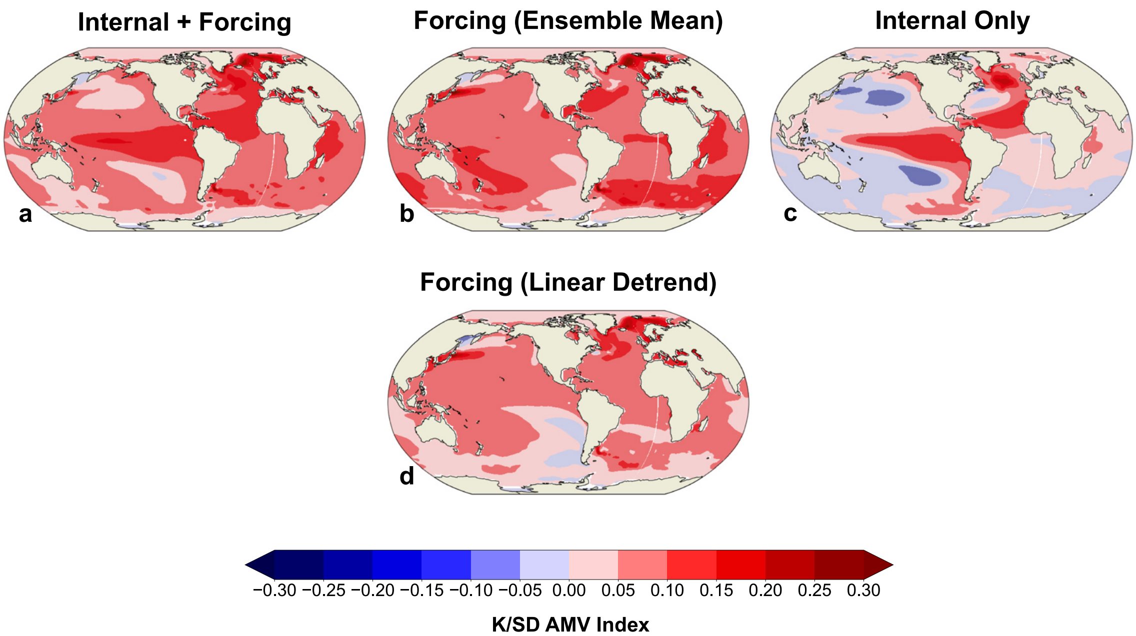

Figure 1. Regressions of simulated sea surface temperatures (SSTs) onto standardized Atlantic Multidecadal Variability (AMV) indices associated with the influence of (a) internal variability + forcing; (b) forcing only; and (c) internal variability only in the 20-member Community Earth System Model 1 large ensemble (1920–2005). No detrending is applied in (a–c). (d) Regressions of simulated SSTs onto standardized, linearly detrended AMV associated with the influence of forcing only.

as opposed to the difference between the ensemble means of the HIST and XGHG fields). That is, we (a) regress global aerosol radiative forcing onto each XGHG member, (b) multiply the member-specific resultant forced pattern by the aerosol forcing time series, and (c) subtract the reconstructed year-by-year evolution of the aerosol signal from each XGHG member. We similarly remove from each member of the XAER ensemble (which has the influences of internal variability, residual 20th-century forcing, and GHGs) its member-specific response to the globally averaged radiative forcing from WMGHG.

2.3. Observed SSTs and Analyses

We use observed SSTs (1880–2016) from the Extended Reconstructed SST version 5 (ERSSTv5) data set (Huang et al., 2017). As we do with the models, we define the AMV index as the area-weighted, annual average SST anomalies over the North Atlantic (0°–60°N and 0°–80°W) and apply a third order, 10-year Butterworth filter to the index to isolate for decadal to multidecadal variability.

3. Results and Discussion

We decompose the SST patterns of simulated AMV into components from internal variability and radiative forcing (Figures 1a–1c; the forced response in Figures 1a–1b is not detrended and thus retains the secular centennial warming trend). When isolated, internal variability drives the AMV horseshoe pattern over the North Atlantic (Figure 1c), while radiative forcing produces a near-uniform global warming pattern (Figure 1b). Notably, the internal variability pattern is devoid of any uniform warming, indicating that our analysis procedure provides a clean and complete separation of internal variability and radiative forcing. The tropical portion of the internally driven AMV pattern shows strong connections to the Pacific (Figure S2 in Supporting Information S1); the extratropical portion of the AMV, however, is regionally contained (Figure S2 in Supporting Information S1), suggesting that the commonly used definition of the AMV as the basin-wide North Atlantic average of SST anomalies may overly emphasize the role of the tropical Pacific on the tropical North Atlantic (particularly in models with very strong and regular eastern equatorial Pacific SST variability). This discrepancy also highlights an additional need to abandon the conceptualization of the AMV as a single phenomenon that can be captured by a single, area-averaged SST index.

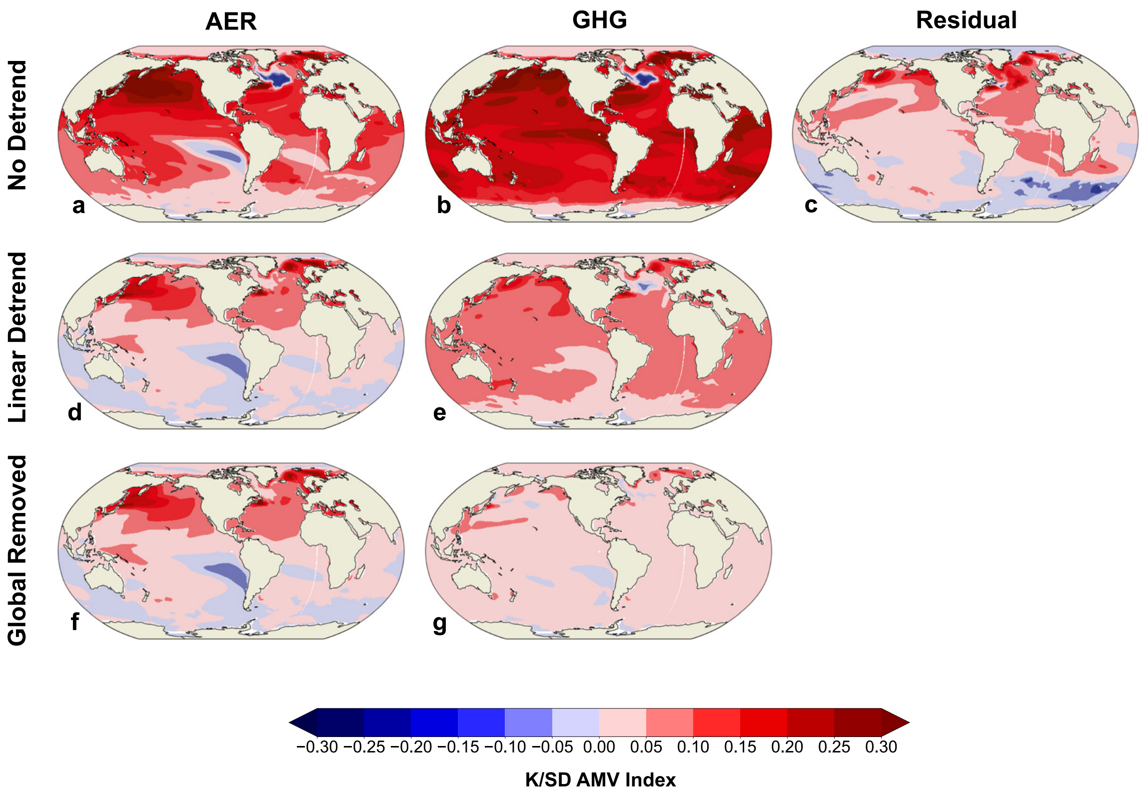

Figure 2. Regressions of simulated sea surface temperatures onto standardized Atlantic Multidecadal Variability (AMV) indices associated with the influence of (a) industrial aerosols only; (b) greenhouse gases (GHGs) only; and (c) residual 20th-century forcing only (deduced by subtracting out the influence of GHGs and industrial aerosols from HIST ensemble mean) without removing their respective global-averaged radiative forcing in the 20-member Community Earth System Model 1 ensemble (1920–2005). (d–e) Same as (a–b) but when the AMV index is linearly detrended. (f) Same as (a) but when global radiative influences from tropospheric aerosols are removed from the AMV index. (g) Same as (b) but when the global radiative influences from WMGHG are removed from the AMV index.

We apply linear detrending to the model forced response (which is devoid of the influences of internal variability) to assess whether it effectively removes the secular global warming signal. Regressions of simulated SSTs onto the standardized AMV index after linear detrending (Figure 1d) show that residual and/or nonlinear external influences project broadly over the World Ocean, much like what is seen in the forced response without any detrending (Figure 1b). Linear detrending of the observed AMV index yields similar global loadings (Figure S3 in Supporting Information S1), with the caveat that observations conflate the influences of internal variability and external forcing. Note, for instance, that the presence of the AMV horseshoe pattern seen in observations is absent in the model forced response (and instead present in the internal variability plot). Nevertheless, the strong resemblance of the linearly detrended AMV forced response to the full forced response indicates that the linear detrending method does not effectively isolate the forced response specific to the North Atlantic.

We decompose the forced response of AMV into components associated with industrial aerosols and GHGs, respectively, using the "all but one" experiments (Figure 2; see Methods). When global forcing *is not* removed, industrial aerosols and GHGs each project broadly over the globe (Figures 2a and 2b), consistent with their respective global cooling and warming influences (aerosols do appear to force the Northern Hemisphere more than the Southern Hemisphere). Residual influences (which we define as historical forcing exclusive of industrial aerosols and GHGs) produce a pattern concentrated over the North Atlantic, though there are modest loadings over the Pacific and Southern Atlantic Oceans (Figure 2c). When the global signal is removed, industrial aerosols produce a more hemispheric SST pattern with contributions from both the North Pacific and North Atlantic but concentrated over the North Pacific (Figures 2d and 2f). For aerosols, linear detrending and removal by regression of the global-average radiative forcing produces nearly identical AMV patterns (Figures 2d and 2f). For GHGs, however, the AMV pattern is sensitive to how the global signal is removed: with linear detrending, the role of GHGs on simulated AMV is part of a broadly uniform, globally forced variability (Figure 2e; consistent with Figure 1d); when the global-average WMGHG forcing is regressed out from basin-wide North Atlantic

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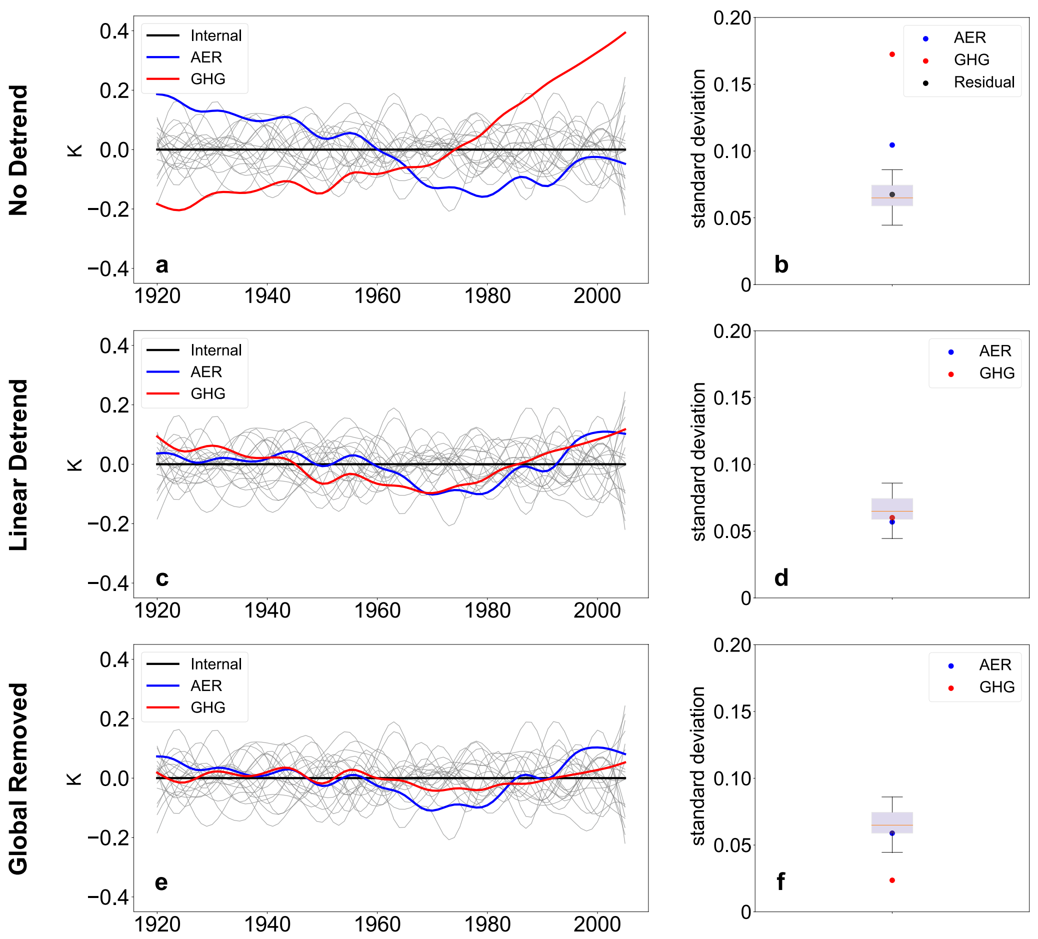

Figure 3. (a) Time series of the Atlantic Multidecadal Variability (AMV) indices generated by (black) internal variability only; (blue) industrial aerosols only; and (red) greenhouse gases (GHGs) only for the 20-member Community Earth System Model 1 ensemble over 1920–2005. (b) Boxplots (center line, median; box limits, upper and lower quartile; whiskers, range) of the standard deviations of the AMV indices generated by internal variability. Blue dot shows the standard deviation of AMV induced by industrial aerosols. Red dot shows the standard deviation of AMV induced by GHGs. Black dot shows the standard deviation of AMV induced by residual 20th-century forcing. No detrending is applied to AMV indices in (a) and (b). (c–d) Same as (a–b) but when linear detrending is applied to the AMV index generated by industrial aerosols and GHGs, respectively. (e–f) Same as (a–b) but when the global radiative influences of tropospheric aerosols and WMGHG are removed, respectively, from each AMV index. All AMV time series in Figure 3 are low-pass filtered.

SST, however, the forced pattern from GHGs all but disappears (Figure 2g), indicating that GHGs have little to no influence unique to the North Atlantic. Furthermore, we note that neither the forcing pattern from industrial aerosols nor residual 20th-century forcing resembles the canonical AMV horseshoe pattern.

We next examine the time series of the simulated AMV (Figure 3), which represent the magnitude of the patterns of variability. With their respective global radiative forcing included, GHGs and industrial aerosols alone generate AMV time series with standard deviations of 0.17 and 0.10 K, respectively, both exceeding the standard deviations of AMV generated by internal variability (0.052–0.086 K; Figures 3a and 3b). When the global signal is removed (either by linear detrending or removal by regression), industrial aerosols generate AMV standard deviations comparable to those generated by internal variability (Figures 3c and 3d; 0.057 K when linearly detrended and 0.059 K when global-average radiative forcing is regressed out). Although the two detrending methods produce nearly identical AMV amplitudes for aerosols, they produce substantially different AMV amplitudes for GHGs (consistent with the spatial analyses of Figure 2). With linear detrending, the standard deviation of AMV generated by GHGs (0.060 K) is comparable in magnitude to those of AMV generated by internal variability (Figures 3e and 3f). When the global-average WMGHG forcing is regressed out, however, the standard deviation of AMV generated by GHGs is reduced to very low levels (0.024 K), below even the minimum of what

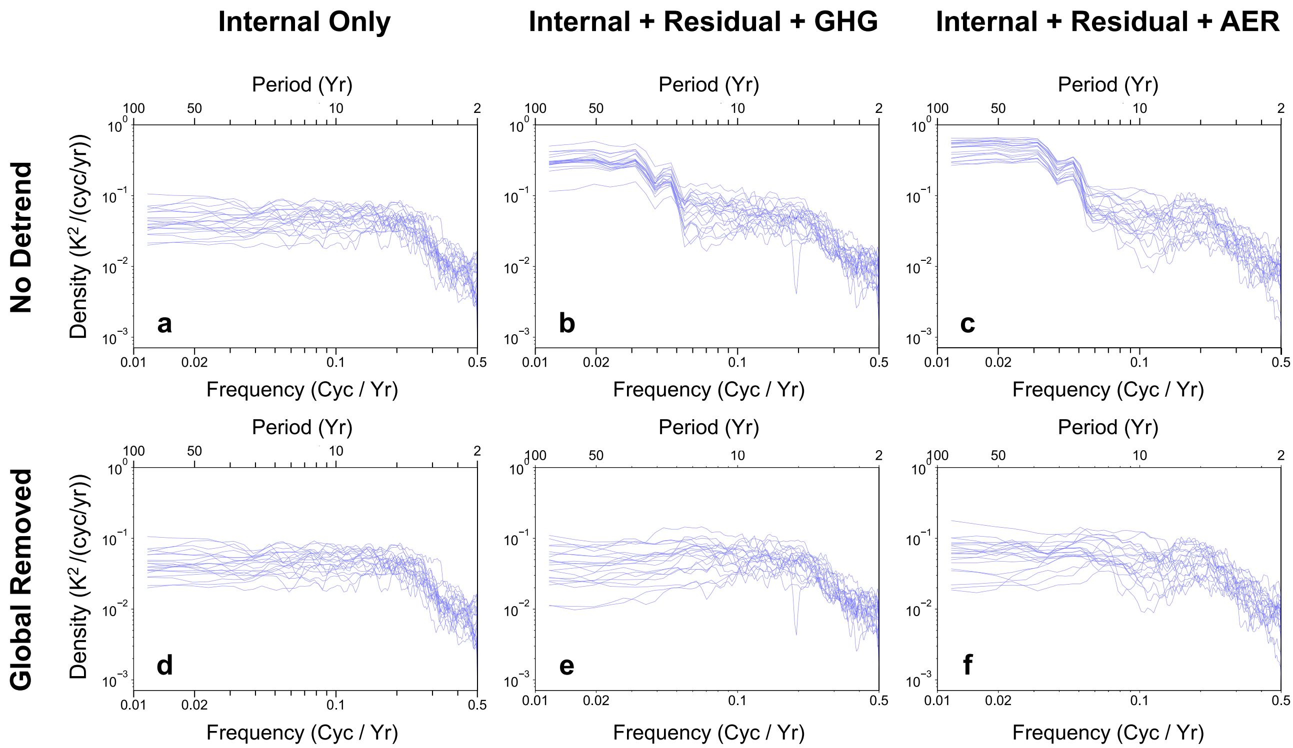

Figure 4. (a–c, left to right) Thomson's multitaper power spectral density plots of the Atlantic Multidecadal Variability (AMV) indices associated with the influence of (a) internal variability only; (b) internal variability + residual 20th-century forcing + greenhouse gases (GHGs; i.e., XAER ensemble); (c) internal variability + residual 20th-century forcing + industrial aerosols (i.e., XGHG ensemble). No detrending is applied to AMV indices in (a–c). (d–f) Same as (a–c) but when the global radiative influences of WMGHG and tropospheric aerosols are removed from the AMV index of each member in (e) and (f), respectively. None of the AMV timeseries used in this figure are low-pass filtered.

internal variability alone generates in a 20-member ensemble (Figures 3e and 3f). Our analyses thus suggest that (a) the influence of GHGs on AMV is largely limited to the global warming signal and (b) prior roles for GHGs identified with the linear detrending method are likely to be an artifact of aliasing nonlinear influences of GHGs.

We also examine the power spectral density of simulated AMV time series (Figure 4; see Mavilia et al., 2018 for uncertainties related to non-stationary behavior and the AMV spectrum). With global radiative forcing, AMV in both the XAER and XGHG ensembles demonstrates substantial increases in power spectral density over multidecadal periods, beyond what internal variability alone can generate. However, when the globally averaged radiative forcing from WMGHG and tropospheric aerosols is removed from each member of the XAER and XGHG ensembles, respectively, AMV in the XAER ensemble (i.e., influences of internal variability, residual 20th-century forcing, and GHGs) and the XGHG ensemble (i.e., influences of internal variability, residual 20th-century forcing, and industrial aerosols) do not yield increases, increased spread among the ensemble members notwithstanding. Parallel plots for when the AMV indices from each member in the respective ensembles are linearly detrended generate similar results (Figure S4 in Supporting Information S1). Collectively, these results suggest that, beyond their respective global influences, North Atlantic SST multidecadal variability generated by (a) GHGs + residual 20th-century forcing or (b) industrial aerosols + residual 20th-century forcings do not superimpose onto North Atlantic SST multidecadal variability generated by internal variability. Our analyses thus indicate a limited role for 20th-century external forcing, raising questions as to whether the respective influences of GHGs, industrial aerosols, and other residual forcing are a coherent component of North Atlantic SST multidecadal variability inherent to the North Atlantic (consistent with the conclusions of Zhang et al., 2013, 2019).

Our results contrast with those of prior studies that identify (using the linear detrending method) a strong role for external forcing on AMV. Murphy et al. (2017) for instance argue that historically forced AMV exhibits higher variance than AMV in preindustrial control simulations. Similarly, Bellomo et al. (2018) show AMV in historical simulations have higher power spectral density over multidecadal periods than AMV generated by internal

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variability alone (also corroborated in Figure S5 in Supporting Information S1, where we repeat power spectra analyses for the HIST ensemble using linear detrending to derive the AMV indices). Our results show that GHGs, aerosols, and other residual 20th-century forcing do not meaningfully influence North Atlantic SST variability apart from their respective global influences. As such, it is likely that the predominant role of external forcing previously identified is an artifact of spurious associations between external forcing and AMV arising from the linear detrending method rather than any real forced response specific to the North Atlantic.

4. Conclusions

Using CESM1 ensembles of forced atmosphere-ocean models and companion "all but one" experiments, we have re-examined the role of 20th-century external forcing on AMV. In agreement with previous studies, we refer to AMV as the quasi-oscillatory SST variations that are inherent to the North Atlantic, whether driven by internal variability or external forcing. The coherent planetary global impact of external forcing is, according to this definition, excluded. When defined this way, we find that industrial aerosols exert broad (weak) loadings over the Northern Hemisphere but in a pattern deviating from the canonical horseshoe AMV structure, while GHGs have little to no influence unique to the North Atlantic.

Most studies that argue that external forcing drives AMV apply linear detrending to remove secular global warming from the North Atlantic. This is problematic, as the linear detrending method does not sufficiently remove the global warming signal; any such forced response will change coherently over the global oceans and is not inherent to the North Atlantic, though it may have (in the case of anthropogenic aerosols) a larger than average response in the North Atlantic. Importantly, we demonstrate that a dominant role for external forcing in AMV is an artifact of the linear detrending method that disappears when global forcing is sufficiently characterized. We note that our study does not preclude the overall impact GHGs and/or industrial aerosols may have on North Atlantic SST-forced climate impacts over land; such "ocean mediated" climate influences over remote regions, for instance, may not be distinctly different whether external forcing is unique to the North Atlantic or not. However, our results do suggest that 20th-centuy external forcings have limited influence on North Atlantic SSTs other than their coherent global impact, indicating that internal processes dominate AMV.

Data Availability Statement

All CESM1 model data are publicly available through the Casper cluster (/glade/campaign/cesm/collections/cesmLE/CESM-CAM5-BGC-LE/) or through the Climate Data Gateway (https://www.cesm.ucar.edu/projects/community-projects/LENS/data-sets.html). Global radiative forcing data for WMGHG and tropospheric aerosols are available at (https://data.giss.nasa.gov/modelforce/Miller_et_2014/Fi_Miller_et_al14_upd.txt). The observed SSTs are available at (https://www.ncei.noaa.gov/products/extended-reconstructed-sst).

Acknowledgments
This work was supported by the Flint Fellowship of Yale University. J. E. Smerdon was supported in part by NSF grants OISE-1743738 and AGS-2101214.

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