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Aerosol Forced Multidecadal Variability in CMIP6 Historical Simulations

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Abstract

The Atlantic Multidecadal Oscillation (Atlantic Multidecadal Variability) has been, and will continue to be a key factor in the modulation of climate change both locally and globally. However, there remain considerable uncertainties in its amplitude, spatial extent, and in the role of the anthropogenic aerosol forcing. Here, we analyze the multimodel mean (MMM) anthropogenic aerosol (AA) forced SST variability in the Coupled Model Intercomparison Project Phase 6 (CMIP6) Historical Simulations. The MMM AA response is found to be dominated by a multidecadal timescale response in the North Atlantic which is consistent in sign with observations and is forced by a change in the strength of the Atlantic meridional overturning circulation. Therefore, the multidecadal variability in the North Atlantic is forced by AA emissions and not by internal variability. However, observational constraints—including a historical sea surface temperature reconstruction—suggest that the MMM response is too weak and too zonally elongated. Nevertheless, the AMOC response may be overestimated.

1 Introduction

The Atlantic Meridional Overturning Circulation (AMOC) represents the Atlantic branch of the global thermohaline circulation. It is responsible for the northward transport of heat and freshwater across the Atlantic Ocean and has been implicated in the modulation of anthropogenic climate change on decadal to multidecadal timescales (Buckley & Marshall, 2016). Changes in the strength of the AMOC have been linked to changes in Atlantic Multidecadal Variability (AMV) (Knight et al., 2005; Zhang, 2008; Zhang et al., 2019; Menary & Wood, 2018). The AMV is also thought to be sensitive to a range of other natural and anthropogenic external forcings (Menary & Scaife, 2014; Ottera et al., 2010; Booth et al., 2012; Zhang et al., 2013; Menary et al., 2015). However, there remains a lot of doubt in the strength of the AMOC and its role in the AMV. Changes in anthropogenic aerosol emissions are thought to have been the dominant forcing of the AMV over the 20th century (Booth et al., 2012; Dittus et al., 2020; Menary & Wood, 2018). The Coupled Model Intercomparison Project Phase 5 (CMIP5) Historical Simulations suggest that the AMOC response to anthropogenic aerosol forcing is too weak and too zonally elongated (Wang et al., 2016; Menary & Wood, 2018). However, there remains a lot of uncertainty in the AMOC response to anthropogenic aerosol forcing (Menary et al., 2018). There is large uncertainty in the simulated strength and spatial extent of the AMOC response to aerosol forcing, which is a key factor in the modulation of climate which leads to uncertainty in future climate change. This uncertainty in the AMOC response is also a key factor in the future changes in anthropogenic aerosol emission and related forcing (Lund et al., 2018). Observations suggest that the AMOC has been in a state of decline since the mid-20th century (Smeed et al., 2018). However, it is not clear how much of this decline is due to the global greenhouse gas forcing or to natural variability. This uncertainty in the AMOC response to anthropogenic aerosol forcing is also a key factor in our ability to predict the future evolution. This, in turn, limits our ability to predict the future evolution of the AMOC and its impacts on the climate system.

2 Methods

We compare the simulation of the AMOC in historical simulations from CMIP5 and CMIP6. We also use historical simulations from the Detection and Attribution Model Intercomparison Project (DAMIP) (Gillett et al., 2016). We use the following variables: sea surface temperature (tos), geographical pole (latitude, longitude), sea surface height above geoid (zos), meridional ocean heat transport (hfbasin), and changes in anthropogenic ocean drive (dcfo03). The data we use are obtained from the Earth System Grid Federation (ESGF) and are from the first ensemble member in each simulation. Ensembles, as AMOC error, are discussed in Section 3.3. We use the multimodel mean (MMM) for CMIP6 and (when still meaningful) for the CMIP5 DAMIP ensembles only those models with the relevant variables available are included in the MMM. We use the Hadley Centre Sea Ice and Sea Surface Temperature version 2 (HadISST2) (Kennedy et al., 2019) for observations of SST. We use the Ocean Reanalysis System 5 (ORA-S5) (Zuo et al., 2019) for observations of ocean heat transport (OHT). We use observations of AMOC at 26°N from the RAPID-MOCHA-WBTS array (Smeed et al., 2018) and AMOC at 26°N from the Ocean Reanalysis System 5 (ORA-S5) (Zuo et al., 2019). We use the Kaplan SST (Kaplan et al., 1998) to compare the global mean SST. We use the Hadley Centre Sea Ice and Sea Surface Temperature version 2 (HadISST2) (Kennedy et al., 2019) for observations of SST. We use the Ocean Reanalysis System 5 (ORA-S5) (Zuo et al., 2019) for observations of ocean heat transport (OHT). We use observations of AMOC at 26°N from the RAPID-MOCHA-WBTS array (Smeed et al., 2018) and AMOC at 26°N from the Ocean Reanalysis System 5 (ORA-S5) (Zuo et al., 2019). We use the Kaplan SST (Kaplan et al., 1998) to compare the global mean SST.

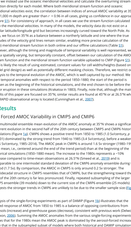

Figure 1
Open in figure viewer | PowerPoint
Historical AMOC change in SMT (Sverdrup) over CMIP6 (A), CMIP5 (B), CMIP5 with CMIP6 ensemble (C), CMIP6 minus CMIP5 (D), CMIP6 minus CMIP5 (E), CMIP6 minus CMIP5 (F), CMIP6 minus CMIP5 (G), CMIP6 minus CMIP5 (H), CMIP6 minus CMIP5 (I), CMIP6 minus CMIP5 (J), CMIP6 minus CMIP5 (K), CMIP6 minus CMIP5 (L), CMIP6 minus CMIP5 (M), CMIP6 minus CMIP5 (N), CMIP6 minus CMIP5 (O), CMIP6 minus CMIP5 (P), CMIP6 minus CMIP5 (Q), CMIP6 minus CMIP5 (R), CMIP6 minus CMIP5 (S), CMIP6 minus CMIP5 (T), CMIP6 minus CMIP5 (U), CMIP6 minus CMIP5 (V), CMIP6 minus CMIP5 (W), CMIP6 minus CMIP5 (X), CMIP6 minus CMIP5 (Y), CMIP6 minus CMIP5 (Z), CMIP6 minus CMIP5 (AA), CMIP6 minus CMIP5 (AB), CMIP6 minus CMIP5 (AC), CMIP6 minus CMIP5 (AD), CMIP6 minus CMIP5 (AE), CMIP6 minus CMIP5 (AF), CMIP6 minus CMIP5 (AG), CMIP6 minus CMIP5 (AH), CMIP6 minus CMIP5 (AI), CMIP6 minus CMIP5 (AJ), CMIP6 minus CMIP5 (AK), CMIP6 minus CMIP5 (AL), CMIP6 minus CMIP5 (AM), CMIP6 minus CMIP5 (AN), CMIP6 minus CMIP5 (AO), CMIP6 minus 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