Predicting the Atlantic Multidecadal Variability from Initialized Simulations

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ABSTRACT

In contrast to dominant interannual time-scale variability in other ocean basins, the leading observed mode variability in the Atlantic is characterized as a basinwide seesaw-like sea surface temperature variability between the North and South Atlantic on a multidecadal time scale (approximately 60–80 years), known as the Atlantic multidecadal variability (AMV). AMV has been identified as a key driver for climate shifts that occurred in the mid-1960s and late 1990s. Here we attempt to predict the summer AMV by analyzing decadal prediction experiments from two climate models. Results show that these climate models with proper initialization do a better job than uninitialized historical runs, and are capable of predicting the observed AMV time evolution. Our models predict that the AMV will be in a neutral to slightly negative phase, leading to a warm–dry trend over western Europe and North Africa and a cold–wet trend (cold relative to the warming trend) over southeastern China and Indochina in the next few years.

1. Introduction

Conventional wisdom indicates that the Atlantic multidecadal variability (AMV) is an internally generated variability associated with the multidecadal fluctuations of oceanic processes, such as the Atlantic meridional overturning circulation (AMOC) (Delworth et al. 1993; Delworth and Mann 2000; Latif et al. 2004; Knight et al. 2005; Zhang et al. 2016), and with stochastic atmospheric processes (e.g., Clement et al. 2015) and air–sea coupling (Wills et al. 2019). During the twentieth century, AMV

might have been strongly modulated by both anthropogenic (Mann and Emanuel 2006; Booth et al. 2012) and volcanic aerosols (Otterå et al. 2010), as indicated by a recent study (Si and Hu 2017). Sun et al. (2015a, 2019) found that there is a strong dynamical coupling among the North Atlantic Oscillation (NAO), AMOC, and AMV. The accumulated effect of the NAO-related atmospheric forcing causes multidecadal variations of the AMOC-/AMV-like SST anomalies (Li et al. 2013). The purpose of this research is not to further investigate the driving mechanisms of the AMV, but to focus on whether it can be predicted on a decadal time scale using simulations from two climate models, a topic that has not been thoroughly studied.

Many previous studies have indicated that AMV can cause significant regional climate fluctuations in the Northern Hemisphere (e.g., Sutton and Hodson 2005;

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Zhang and Delworth 2006, 2007; Sun et al. 2009, 2015b; Sutton and Dong 2012; Sun 2013; Han et al. 2018). To generate these hemispheric-scale influences, AMV in fact acts as a source of multidecadal climate variability in the Northern Hemisphere through exciting a circumglobal stationary baroclinic atmospheric teleconnection as identified in an observation-based study (Si and Ding 2016).

A realistic prediction of AMV and the associated teleconnections is essential to facilitate a reliable and robust provision of interdecadal information to society and policymakers. The initialized near-term prediction from coupled models demonstrates substantial skill in hindcasting subpolar North Atlantic SST anomalies (van Oldenborgh et al. 2012; Marotzke et al. 2016), while the hindcast skill over the entire North Atlantic is much lower, with even lower skill for the adjacent land (Doblas-Reyes et al. 2013; Meehl et al. 2014). The better skill in hindcasting subpolar North Atlantic SST is proposed to be benefitting from better predictability of the AMOC (Yeager et al. 2012). The relatively low predictability over land may be associated partly with the systematic errors in hindcasting the North Atlantic SSTs (or the AMV), and partly with weaker-than-observed atmospheric teleconnections in model simulations, which prevents the successful propagation of the oceanic signals to the adjacent land area (Eade et al. 2014; Qasmi et al. 2017). A recent study reveals that the simulated atmospheric response over land is not only weaker than observed, but sometimes also model dependent, particularly for summer (Ghosh et al. 2018).

To further assess the capability of the climate models in hindcasting AMV, we will analyze the initialized ensemble decadal prediction simulations (or decadal hindcast simulations) and the corresponding free-run twentieth-century all-forcing ensemble simulations from two state-of-art coupled climate models.

The paper is organized as following: section 2 introduces the observed datasets, models, and experiments used in this study; section 3 examines the changes of the AMV index for both observations and model hindcasts; section 4 analyzes the contribution of AMOC to a better AMV prediction in the initialized decadal simulation than that in the uninitialized twentieth century historical run; section 5 gives a prediction of AMV in the next few years; and section 6 is a brief summary.

2. Data, models, and experiments

a. Observational datasets

The SST dataset used here is a merged product based on the monthly mean Hadley Center Sea Ice and Sea Surface Temperature dataset (HadISST), version 1, from 1870 to 1981 and version 2 of the National Oceanic and

Atmospheric Administration (NOAA) weekly Optimum Interpolation (OI) SST analysis from 1981–2016 (Hurrell et al. 2008). The observed meridional overturning circulation index at 26.5°N in the Atlantic since 2004 is from the Rapid Climate Change (RAPID) program and the following on RAPID-MOCHA program (Smeed et al. 2017). The observed sea surface salinity (SSS) data in the Labrador Sea from 1959 to 2013 are provided by Friedman et al. (2017).

b. Models

Both CCSM4 (Gent et al. 2011) and CESM1 (Hurrell et al. 2013) are coupled climate models developed at National Center for Atmospheric Research (NCAR) in collaboration with scientists from universities and the laboratories of the U.S. Department of Energy. The CESM1 is the successor of the CCSM4. The horizontal resolution for both models is nominal 1° resolution with enhanced meridional resolution in the ocean at equatorial region. The component models for CCSM4 are the Community Atmosphere Model, version 4 (CAM4), Parallel Ocean Program, version 2 (POP2), Community Land Model, version 4 (CLM4), and Community Sea Ice Code (CICE4). The component models for CESM1 are the same as CCSM4 except the atmospheric model, which is the Community Atmosphere Model, version 5.2 (CAM5.2), and the POP2 ocean model includes ocean biogeochemistry.

c. Decadal prediction simulations

The decadal prediction simulations used here are initialized, coupled ensemble simulations contributing to phase 5 of the Coupled Model Intercomparison Project (CMIP5) as the “near-term” prediction experiments (Taylor et al. 2012). For each starting year, all ensemble members are forced by the identical observed time-dependent external forcings, and identical ocean–sea ice initial conditions are used with small perturbations in the atmospheric initial conditions. The ocean and sea ice initial conditions are derived from forced ocean–ice simulations using observed/reanalyzed atmospheric conditions from 1955 to 2016. For the CCSM4 decadal prediction (CCSM4-DP) experiment, the surface fluxes used in the forced ocean–ice simulation are calculated with bulk formulas using atmospheric fields from the Coordinated Ocean–Ice Reference Experiment (CORE) forcing data. This CORE-forced simulation shows a spurious weakening trend in the zonal SST gradient along the tropical Pacific compared to the observed over the late twentieth century. To avoid this spurious weakening trend, a new CORE-forced simulation is carried out with certain corrections to the CORE forcing in order to provide a better ocean–sea ice initial condition for CESM1 decadal prediction (CESM1-DP) experiments

(Yeager et al. 2018). The atmospheric and land initial conditions are taken from the corresponding year of the twentieth-century free-run simulations from each model. These simulations are branched from 1850 control simulation and have run from 1850 to 2016 with time-evolving observed external forcings, such as CO₂, CH₄, solar, and volcanoes from 1850 to 2005, but representative concentration pathway 8.5 (RCP8.5) from 2006 to 2016.

These two sets of ensemble simulations are initialized every year on 1 January from 1955 to 2014 for CCSM4-DP, and on 1 November from 1954 to 2015 for CESM1-DP. These simulations are integrated for 10 years with 10 and 40 ensemble members for CCSM4-DP and CESM1-DP experiments, respectively. These ensemble members were generated by adding random round-off level perturbations into the atmospheric initial fields. For CESM1-DP, 10 members were completed on National Energy Research Scientific Computing Center (NERSC), and another 30 members were completed on the NCAR–Wyoming Supercomputer Center (NWSC).

In this study, the predicted quantity as the 5-yr mean centered at year 5 is used to compare to the corresponding observations and is represented as the averages of years 3–7 in each hindcast simulation (e.g., 1959 is represented by the average of 1957–61 in the prediction, which is initialized on 1 January 1955 for CCSM4-DP or 1 November 1954 for CESM1-DP). Although the CESM1-DP is initialized on 1 November of the previous year, hereafter, we always used the following year as the starting year to keep consistent with the CCSM4-DP simulations; for example, we refer to the CESM1-DP experiment initialized on 1 November 1954 as the experiment starting at 1955.

d. Twentieth-century historical simulations

The CCSM4 twentieth-century all-forcing simulations include five ensemble members and were run from 1850 to 2005 with time-dependent all known external forcings (Gent et al. 2011). To extend these runs to 2016, RCP8.5 forcing is used for 2006–16 (Meehl et al. 2012). Hereafter, these simulations are collectively called CCSM4-his. The external forcings include both natural and anthropogenic forcings. The solar output anomaly time series from Lean et al. (2005) is added to the climatological mean value of 1360.9 W m^{-2} , which is used in the preindustrial control run. The CCSM4-his volcanic activity is based on Ammann et al. (2003) with time-dependent aerosol optical depths. The anthropogenic forcings in CCSM4-his include time-evolving greenhouse gases, as well as prescribed time- and space-evolving concentrations of tropospheric and stratospheric ozone, the direct effect of sulfate aerosols, and black and primary organic carbon aerosols (Lamarque et al. 2010, 2011). Time-evolving land use and land cover change are also included (Lawrence et al. 2012).

FIG. 1. The decadal-filtered AMV index (K). Blue and red lines represent the ensemble means of CCSM4-DP and CESM1-DP runs, respectively. Light blue and pink shading represents the ensemble spread of CCSM4-DP and CESM1-DP runs, respectively. Black line represents the observation.

The CESM1 large-ensemble twentieth-century all-forcing simulations (referred to as CESM1-LE) includes a 40-member ensemble simulation from 1920 to 2100 forced by twentieth-century observed time-evolving external forcing from 1920 to 2005 and by RCP8.5 scenario from 2006 to 2100 (Lamarque et al. 2010, 2011; Kay et al. 2015). The specified ozone forcing in all simulations is calculated using a high-top coupled chemistry–climate model, the Whole Atmosphere Community Climate Model (WACCM) (Marsh et al. 2013). Of these 40 ensemble members, only one ensemble member was branched from the 1850 control run (1 January of year 402) and run from 1850 to 2100. All other members are branched from this ensemble member on 1 January 1920 with a round-off level of perturbation added in the atmospheric temperature field, but keeping the initial conditions in other model components identical, and were run to 2100 (Kay et al. 2015).

3. Changes of the AMV index for both observations and model hindcasts

The summer AMV for both observations and model simulations used in this research is defined via a three-step process: 1) the area-weighted average of the SST in June–August (JJA) over the North Atlantic between equator and 65°N (Delworth and Mann 2000; Enfield et al. 2001) is calculated; 2) to exclude the possible influence of global warming on AMV, the global mean SST time series is removed from the area-weighted North Atlantic mean SST based on the suggestion of previous study (Trenberth and Shea 2006); and 3) to obtain the AMV multidecadal time scale signal, a decadal filter (Trenberth et al. 2007) is applied to the residue SST anomaly after the first two steps.

As shown in Fig. 1, the observed summer AMV experiences two positive phases (1959–64 and 1997–2013) and two negative phases (1965–96 and 2014–present)

FIG. 2. The SSS condition (g kg^{-1}) used to initialize the (top) CCSM4-DP and (bottom) CESM1-DP runs for (a),(d) 1955–64, (b),(e) 1962–71, and (c),(f) 1988–97. The anomalies are calculated relative to the climatology of 1955–2013. The stippling indicates statistically significant at 95% confidence level according to a Student's t test.

during 1959–2016. For the ensemble-mean model hindcasts (hereafter we discuss only the ensemble-mean model hindcasts), the AMV in both ensembles shows similar phase changes as the observed. The correlation coefficient between the unfiltered observed and hindcasted AMV indices is 0.35 and 0.39 for CCSM4-DP and CESM1-DP, respectively, which both are statistically significant at a 99% level based on the Student's t test. For the decadal-filtered indices, the correlation coefficients reach 0.41 and 0.51, respectively. However, the exact timing of the phase transition is delayed by 7 years for the first positive to negative transition, such that instead of a phase transition in 1965 as the observed, the models produce a phase transition in 1972 (Fig. 1). The models did a much better job in hindcasting the late 1990s' negative to positive transition, with a delay by only 2 years in comparison to observations. Although the models failed to hindcast the latest positive to negative transition that occurred in observations in 2014, the models do hindcast a downward AMV trend, especially in CCSM4-DP.

To explore the mechanism involving AMV's phase transitions in model hindcasts, we study the role of

AMOC and ocean–sea ice initial conditions in these hindcast simulations. Previous modeling results suggest that AMOC is one of the major drivers for AMV and upper ocean temperature (e.g., Delworth et al. 1993). Studies also show that the salinity-induced density anomalies in the subpolar gyre region tend to lead AMOC variability. By analyzing the contributions of thermal and saline effects on density in the subpolar convection zone and the associated AMOC changes in eight coupled general circulation models (CGCMs), Ba et al. (2014) found that the salinity anomalies in seven out of the eight CGCMs play the most important role in determining the density anomalies in the subpolar deep convection regions. These salinity anomalies tend to lead the change of AMOC, with the maximum correlation occurring when the salinity leads AMOC by 1–10 years. Here we also examine the anomalous initial SSS and SST condition during the period prior to the AMV transitions by 1–10 years (Figs. 2 and 3). Prior to the mid-1960s, the positive SSS anomalies over the subpolar basins (SPB) and Nordic seas (NS) are consistent with an enhanced AMOC, leading to an increased

FIG. 3. The SST condition ($^{\circ}\text{C}$) used to initialize the (top) CCSM4-DP and (bottom) CESM1-DP runs for (a),(d) 1955–64, (b),(e) 1962–71, and (c),(f) 1988–97. The anomalies are calculated relative to the climatology of 1955–2013. The stippling indicates statistically significant at 95% confidence level according to a Student's t test.

northward heat transport that contributes to a positive phase of AMV (Figs. 2a,d). The anomalous SST pattern is well coherent with the anomalous SSS pattern, showing a significant positive anomalies in the SPB-NS regions (Figs. 3a,d). Since the SSS in SPB-NS regions is an important precursor for the AMOC, positive SSS anomalies in the SPB-NS regions prior to the mid-1960s favor an enhanced deep convection and a stronger AMOC, and thus a positive phase of AMV during this time. However, during the period prior to 1972, the SSS anomalies in the SPB-NS regions change from positive to negative (Figs. 2b,e), while the SST over the SPB is still warm (Figs. 3b,e). This means that the change of SSS leads the change of SST over the SPB. The change of SSS anomalies in the SPB-NS regions from positive to negative pre-1972 favors a weakening of AMOC and transition of AMV to its negative phase around 1972. This implies that the initial SSS condition used in the CCSM4-DP and CESM1-DP decadal predictions might be the ultimate cause of the delayed AMV phase transition in 1972. Until the 1990s, the SSS anomalies become positive again

over the SPB-NS regions, resulting in a strengthening in AMOC and a transition to AMV positive phase in the late 1990s (Figs. 2c,f and 3c,f). This result is consistent with the findings of Ba et al. (2014). In summary, a better initial ocean condition is needed to improve hindcast/prediction of the AMV. With a proper initial ocean condition, both models are able to hindcast/predict the AMV for at least 5 years. The salinity anomalies in the SPB-NS regions tend to lead AMOC and govern the phase transition of AMV.

The next question to be naturally asked is whether these initialized decadal hindcast/prediction simulations can do better than the uninitialized free-run twentieth-century all-forcing simulations in determining the AMV variations. By comparing Figs. 1 and 4, the ensemble-mean AMV phase transitions of the CESM1-LE uninitialized simulations are closer to observed than the initialized CESM1-DP for the mid-1960s transition, but worse for the 1990s transition. For CCSM4, the uninitialized simulations almost totally failed to reproduce the observed AMV time evolution. Therefore, we conclude that the initialized decadal hindcast simulations

FIG. 4. The decadal-filtered AMV indices derived from the uninitialized (a) CCSM4-his and (b) CESM1-LE runs (K). Lines represent the ensemble mean, and shading represents the ensemble spread.

generally perform better than the uninitialized twentieth-century historical simulations. It is especially true for CCSM4 that the model simulations change from lowest skill in reproducing the observed AMV time evolution for the uninitialized simulations to a reasonably good skill in the initialized hindcasts. These results further imply that a properly initialized coupled model hindcast can raise the model's prediction/hindcasting skills significantly, agreeing with many previous studies (Keenlyside et al. 2008; Meehl et al. 2016). It worth noticing that the amplitudes of ensemble-mean AMV predicted by the initialized decadal prediction runs are higher than those simulated by the uninitialized historical runs. For the uninitialized runs, the weaker amplitude of ensemble-mean AMV largely represents the externally forced AMV due to the elimination of internal climate variability since the phase of AMV is different from one ensemble member to another. For the initialized runs, the memory of the ocean states from subsurface ocean after the initialization enables a better hindcast of not only the observed AMV time evolution, but also its amplitude.

4. Contribution of AMOC to a better AMV prediction

Results shown above raise a question regarding what the models have done right to enable them to hindcast the observed AMV evolution in the initialized simulations better than the uninitialized ones. Two of the mechanisms governing AMV proposed by previous studies

will be examined here: the oceanic control of the Atlantic SST through a modulated AMOC and the changes of the external forcings (Vecchi et al. 2017) with special focus on the former. Because both initialized and uninitialized simulations have experienced the same observed twentieth-century time-evolving external forcings, the lack of skill in reproducing the observed transient AMV in the uninitialized runs, especially the CCSM4 run, and the much better skill for the initialized hindcasts suggest that on pentadal to decadal time scales the changes of the external forcing might not be the deterministic forcing in controlling the transient behavior of the AMV and the internal variability must have played a more dominant role. With a close-to-reality ocean initial state, the state-of-art coupled climate models are capable of making skillful hindcasts/forecasts of the AMV on decadal time scales (Fig. 1). Here we investigate the role of the proposed AMOC mechanism in affecting AMV in more detail.

Owing to the scarcity of long-term continuous direct measurements, the observed AMOC is only available for recent decades (Cunningham et al. 2007; McCarthy et al. 2015). To derive the observed AMOC variability since 1955, we opt to use another line of evidence—the SSS in the Labrador Sea—to approximately represent the variations of the observed AMOC. Changes in SSS will lead to a fresher or saltier subpolar North Atlantic, which in turn will suppress or enhance the deep convection there, resulting in a weaker or stronger AMOC. As shown in Fig. 5, the SSS in Labrador Sea varies in a similar way as the observed AMV, reflecting the phase transition in the mid-1960s and late 1990s and a downward trend since early 2010s. The low SSS periods in the late 1960s, 1980s, and 1990s are the reoccurrence of the great salinity anomaly in the subpolar North Atlantic as indicated by previous studies (Dickson et al. 1988; Belkin 2004). In these low SSS years, the AMV index is also mostly lower. The direct observations from the RAPID program (Cunningham et al. 2007; McCarthy et al. 2015) match well the change of SSS in Labrador Sea from 2004 to 2016, also indicating a downward trend since 2004 and a transition from a saltier to fresher upper ocean in subpolar North Atlantic in the early 2010s. Moreover, Sun et al. (2018, 2019) proposed a dynamical AMOC index defined as the accumulative effects of the NAO-associated atmospheric forcings, and this dynamical AMOC index also shows a similar temporal evolution as the Labrador SSS since the late 1950s.

As the decadal prediction runs are initialized using ocean and surface atmosphere states, both the CCSM4-DP and CESM1-DP hindcast well the reconstructed AMOC changes, especially for the two phase transitions in the 1960s and 2010s (Figs. 5c,e). Because AMOC has

FIG. 5. Variations of the AMOC index (Sv ; $1 \text{ Sv} = 10^6 \text{ m}^3 \text{ s}^{-1}$). (a) The directly observed annual mean AMOC index from 2004 to 2016. (b) Observed annual mean SSS anomalies in the Labrador Sea region. (c),(e) The detrended annual mean AMOC index hindcasted by CCSM4-DP and CESM1-DP, respectively. (d),(f) The detrended annual mean AMOC index simulated by CCSM4-his and CESM1-LE, respectively. The curve with fill is the decadal filtered index.

strong memory after the initialization, this memory enables skillful decadal predictions of North Atlantic SST, which eventually leads to a successful hindcast of the observed AMV change. Contrary to the initialized prediction runs, the uninitialized twentieth-century historical CCSM4-his and CESM1-LE simulations fail to produce the observed AMOC variability (Figs. 5d,f), which may have contributed to the failure to simulate the observed AMV time evolution, especially for CCSM4-his. As indicated by Yan et al. (2019), the relationships between externally forced AMV and AMOC are opposite to the relationship of the internally generated AMV and AMOC. In fact, the ensemble-mean AMV and AMOC shown in Figs. 4 and 5d,f are externally forced. In Si and Hu (2017), when the AMOC index from each individual ensemble member of the CESM1_LE is regressed onto the SST of the same ensemble member, the resulting ensemble-mean regression pattern resembles the AMV pattern very well. This may suggest that the internally generated AMV is well related to the AMOC, agreeing with many previous studies (Zhang et al. 2016;

Yan et al. 2019). Therefore, our results emphasize that the proper ocean initialization might be the key for a successful decadal climate prediction due to a slowly evolving processes, such as AMOC.

5. Predictions of AMV in the next few years

Previous studies reveal that the negative phase of AMV in the 1960s leads to a warmer and drier North Africa and western Europe, and a “north dry–south wet” rainfall pattern in China, but the positive phase of AMV in the 1990s leads to anomalies in these regions opposite to what have mentioned above (e.g., Sutton and Hodson 2005; Zhang and Delworth 2006; Liu and Chiang 2012; Sutton and Dong 2012; Si and Ding 2016; Dong et al. 2016).

As discussed earlier, the hindcast simulations from both models are capable of hindcasting the AMV time evolution. To predict the AMV and its climate impact for the near future, the ensemble-mean prediction of the AMV index and the regional patterns can be used. As shown in Fig. 1, the observed AMV is trending downward

FIG. 6. Initialized predictions of summer AMV index (K). Individual model ensemble spreads are in pink shading; ensemble average is solid black line. Predictions are by (a) CCSM4-DP, initialized 1 Jan 2014; (b) CESM1-DP, initialized 1 Nov 2013; (c) CESM1-DP, initialized 1 Nov 2014; and (d) CESM1-DP, initialized 1 Nov 2015.

and the hindcasted AMV is also trending downward with a phase delay. The ensemble-mean AMV prediction initiated in 2014 (1 January) for CCSM4-DP and 2014–16 (1 November of the previous year) for CESM1-DP suggests a neutral or slightly negative AMV phase for the next 10 years (Fig. 6). Note that the prediction is bias-adjusted following Yeager et al. (2012) in order to remove systematic errors. Moreover, in Fig. 1 the AMV index is the 5-yr-mean ensemble mean, but the AMV index in Fig. 6 is only the ensemble mean for each individual year. Thus, a larger AMV variability is shown in Fig. 6 than Fig. 1. Based on Fig. 6, we would predict that the AMV will be in a neutral to slightly negative phase in the next few years. To better predict the AMV regional impacts, here we will use the observed AMV regional impact patterns in combination with the model predicted AMV index. As the AMV has been trending downward after 2010 in both observations and the model hindcasts and predicted to have a neutral to negative phase in next few years, the corresponding regional surface air temperature (SAT) and precipitation trends will resemble the observed negative AMV pattern, such that a below-normal precipitation trend and an above-normal SAT trend will be experienced in western Europe, North Africa, regions between the Yangtze River and Huanghe River in China, the Guangdong and Fujian provinces in China, and the western and southern parts of India. However, above-normal precipitation and

below-normal SAT (relative to the warming trend) will be found in southern Europe south of 42°N , regions south of the Yangtze River and north of Guangdong and Fujian provinces of China, and the part of China north of the Huanghe River.

As seen in Fig. 6, the prediction of AMV is sensitive to the initialization dates and the ensemble spread is large, indicating a high level of uncertainty in the prediction. Therefore, the regional summer climate prediction is just based on the neutral or slightly negative AMV phase in the next few years.

6. Summary

By analyzing the initialized and uninitialized simulations from CCSM4 and CESM1, we found that the initialized decadal prediction runs did a better job in hindcasting the AMV evolution than the uninitialized runs. Our analysis also show that the better reproduction of the observed AMV time evolution in the initialized hindcast runs is due to a closer-to-observed ocean state, specifically the AMOC in these initialized simulations. Moreover, the salinity anomalies in the subpolar North Atlantic basins and Nordic seas tend to lead AMOC and possibly govern the phase transition of AMV. Finally, based on the observed and hindcasted AMV, we predict that AMV will be in its neutral to slightly negative phase in next decade or so, leading to general

climate anomalies opposite to what we have experienced in the last couple of decades in the Eurasia region.

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