UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE

An Investigation Into the Role of External Forcing and Ocean Coupling on the Relationship Between the AMV and Vertical Wind Shear in the Main Development Region

Sydney Kramer[1], Lisa Murphy[1], Amy Clement[1], Jeremy Klavans[1]

1. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida

Abstract

Observations show that multidecadal variability in vertical wind shear over the historical period coincides with changes in sea surface temperature (SST). It has previously been suggested that the cause of this correlation is changes in ocean circulation. Here we test the roles of internal atmospheric and oceanic circulation changes, as well as transient historical forcing (i.e. CO2 and aerosols). We analyze large ensembles using the National Center for Atmospheric Research (NCAR) Community Earth System Model (CESM). The fully coupled model consists of a 42- member ensemble (LENS-Fully Coupled), while the slab ocean model (SOM) consists of a 10-member ensemble (LENS-SOM) simulated over the historical period, from 1920-2005. We examine the role of ocean circulation by comparing the relationship between vertical wind shear in the Main Development Region (MDR) (80°W-20°W, 10°N-20°N) and the AMV in the LENS-Fully Coupled and LENS-SOM experiments. The role of forcing on vertical wind shear is examined by comparing the ensemble mean to the ensemble spread. We find that the model produces a correlation between the AMV and vertical wind shear variability that is comparable to observations, but the correlation appears to be mainly driven by transient historical forcing. The inclusion of ocean circulation in the Fully-Coupled ensembles does not improve the correlation values, but instead, degrades the relationship. This occurs particularly at high frequencies, which suggests that it is mainly due to ENSO.

Introduction

Yan et al. (2017) states that ocean circulation (AMOC) influences the AMV which can modulate hurricane activity through its impact on Vertical Wind Shear variability (Fig. 1). Clement et al. 2015 shows that the AMV can exist in the absence of AMOC and Murphy et al. 2017 shows transient historical forcing is the main driver of the AMO in the historical period. The correlation between the AMV and Vertical Wind Shear translates to warmer sea surface temperatures occurring simultaneously with lower vertical wind shear, two optimal conditions for hurricane development and increased hurricane intensity. In this study we explore whether the AMOC must be present in order for Vertical Wind Shear variability to occur.

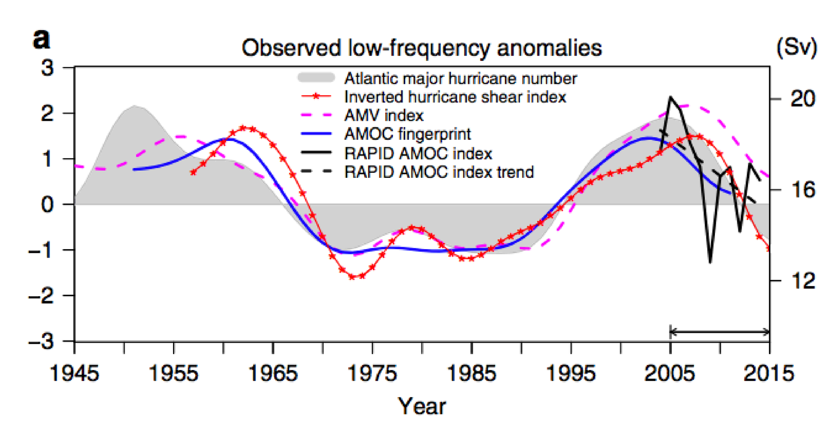


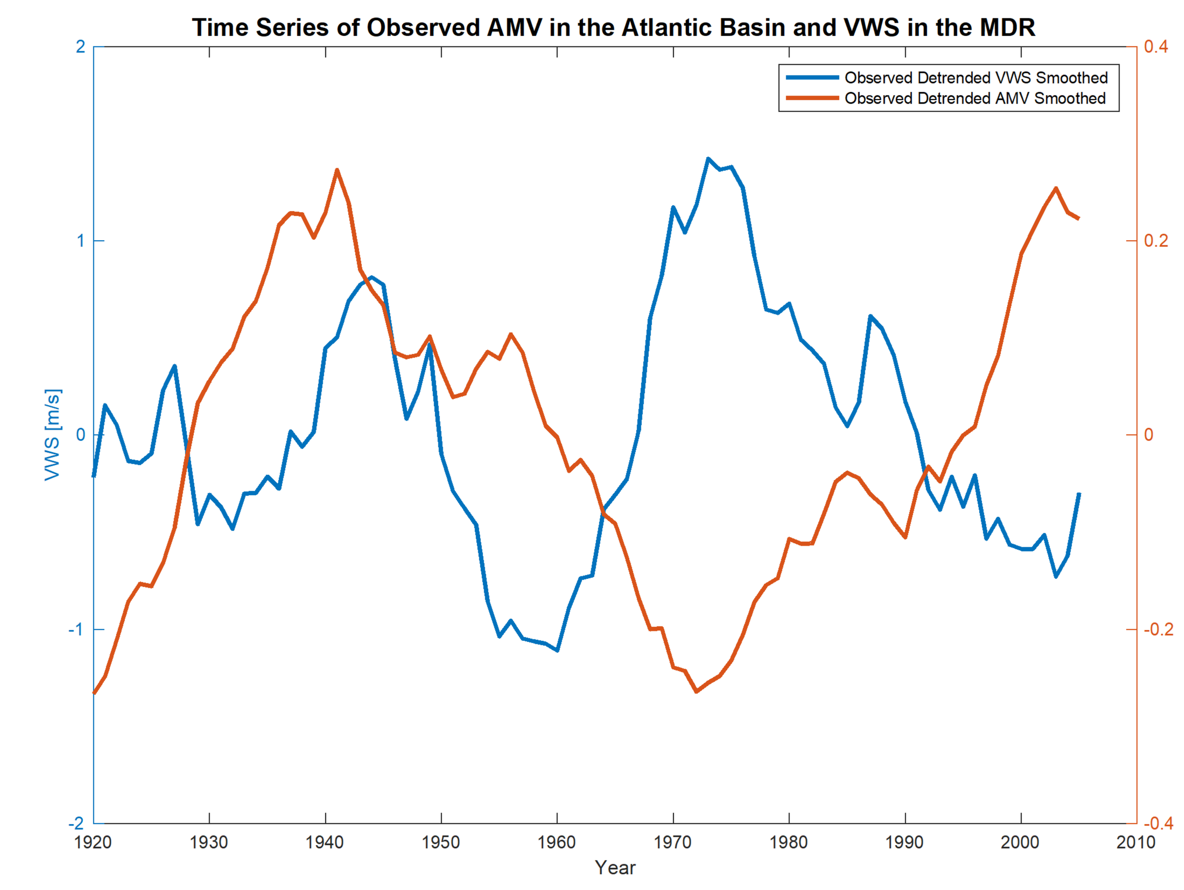
Figure 1: Yan et al. (2017): Observed low frequency anomalies in Atlantic major hurricane frequency and associated climate variables. (a) Coherent variations are shown for Atlantic major hurricane frequency (grey shading), Inverted Hurricane Shear Index during the Atlantic hurricane season (JJASON) (solid red with stars), Atlantic Multidecadal Variability (AMV) Index (dashed magenta) and Atlantic Meridional Overturning Circulation (AMOC) Fingerprint (solid blue). The AMOC Fingerprint is shifted backward by 4 years to represent the AMOC anomalies at mid-high latitudes. Also shown are the unfiltered annual mean RAPID AMOC Index at 26 ° N for 2004-2014 (solid black line) and its linear trend (dashed black line) with a unit Sverdrup (Sv, right y-axis)

Methods: LENS-SOM

We perform several climate model experiments following the methodology of the CESM Large Ensemble Project (LENS-Fully Coupled; Kay et al., 2015), which is a 42-member ensemble of fully coupled climate model simulations that cover the historical period (1920-2005). Each member differs only in that they were forced with small perturbations in the atmospheric initial conditions. In our new simulations we replace the dynamical ocean model with a slab ocean model (LENS-SOM), where the ocean heat transport convergence is prescribed as a q-flux. The q-flux is calculated using output from the last 100 years of an 1800-year long CESM fully coupled pre-industrial (PI) control simulation. Here we compare a ten-member ensemble of the LENS-SOM to the 42-member ensemble from LENS-Fully Coupled. Vertical wind shear is found by calculating the difference in U-Zonal Wind at 200mb and 850mb using the NCEP/NCAR Reanalysis 1 (Kalnay et al. 1996). The Observed Sea Surface Temperature used to calculate the AMV and Nino3.4 Index was found with the NOAA Extended Reconstructed Sea Surface Temperature (SST) V5 data set (Huang et al. 2014). The smoothed correlation was found by using the ten-year running mean in order to remove high frequency variability. We removed the signature of ENSO in the coupled model by linear regression of the Nino3.4 index on vertical wind shear. Once calculating vertical wind shear without ENSO the timeseries is smoothed and then detrended, and correlation values are calculated between the detrended smooth vertical wind shear without ENSO and the detrended smooth AMV. Pre-Industrial (PI) control run distributions were calculated by subsampling the long run into 10,000 86-year segments with replacement.

Results

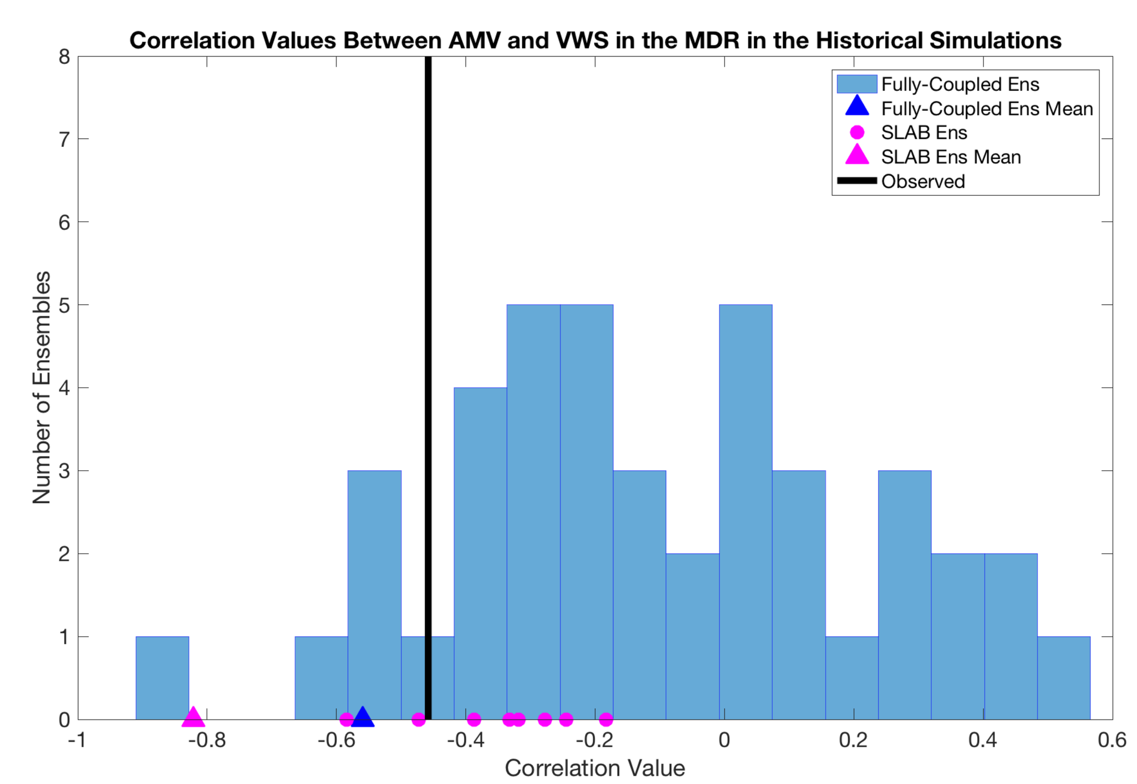
Figure 2: Observed JJASO Smoothed and Detrended VWS (200-850mb) over the MDR and AMV over the Atlantic Basin



Key point:

→ Smoothing and Detrending both the Observed AMV and VWS timeseries show a stronger multidecadal pattern.

Figure 3: Detrended and Smooth Correlation Values between the AMV in the Atlantic Basin and VWS in the MDR JJASON



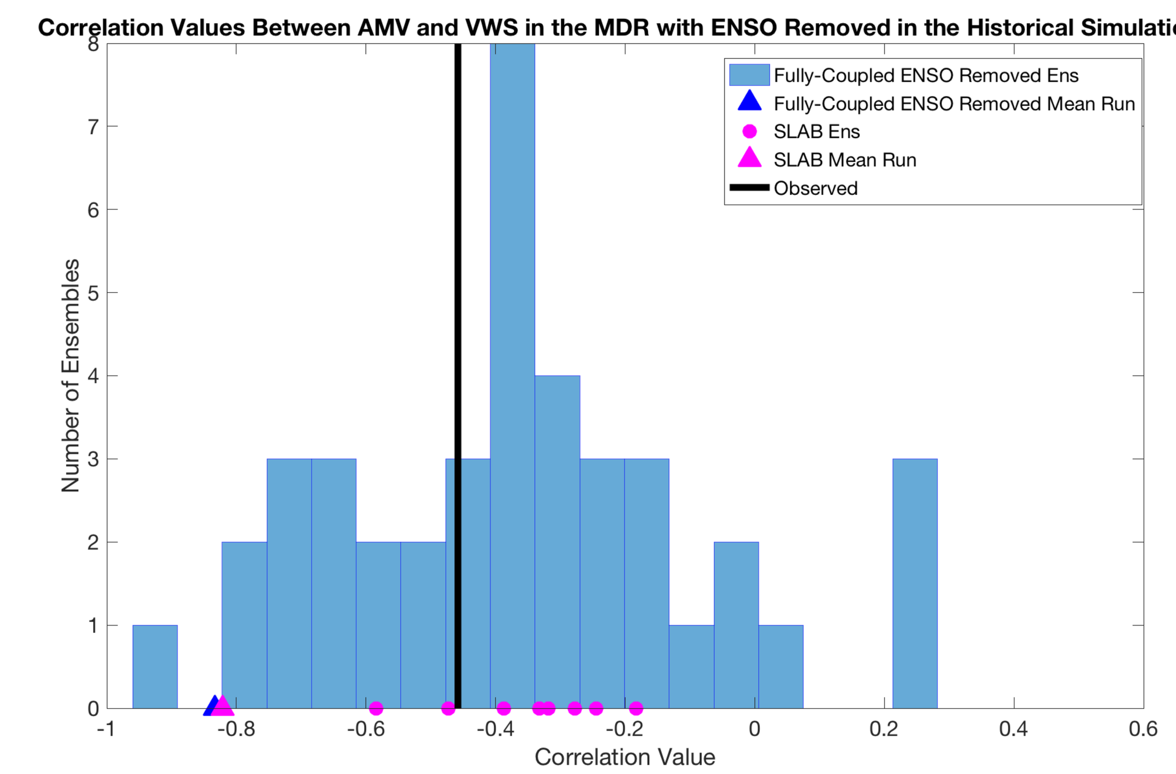
Key points:

→ The fully-coupled model shows both positive and negative correlation values between the AMV and vertical wind shear. The LENS-SOM model only shows negative correlation values. This suggests that ocean coupling can interrupt the local relationship between SST and wind-shear.

→ The ensemble mean negative correlation value for both the fully-coupled model and the LENS-SOM model is larger indicating that this is a response to historical forcing rather than due to internal variability alone.

→ The negative correlation indicates that historical transient forcing is leading to weaker wind shear when the AMV is positive.

Figure 4: Detrended and Smooth Correlation Values between the AMV in the Atlantic Basin and VWS in the MDR ENSO Removed JJASON

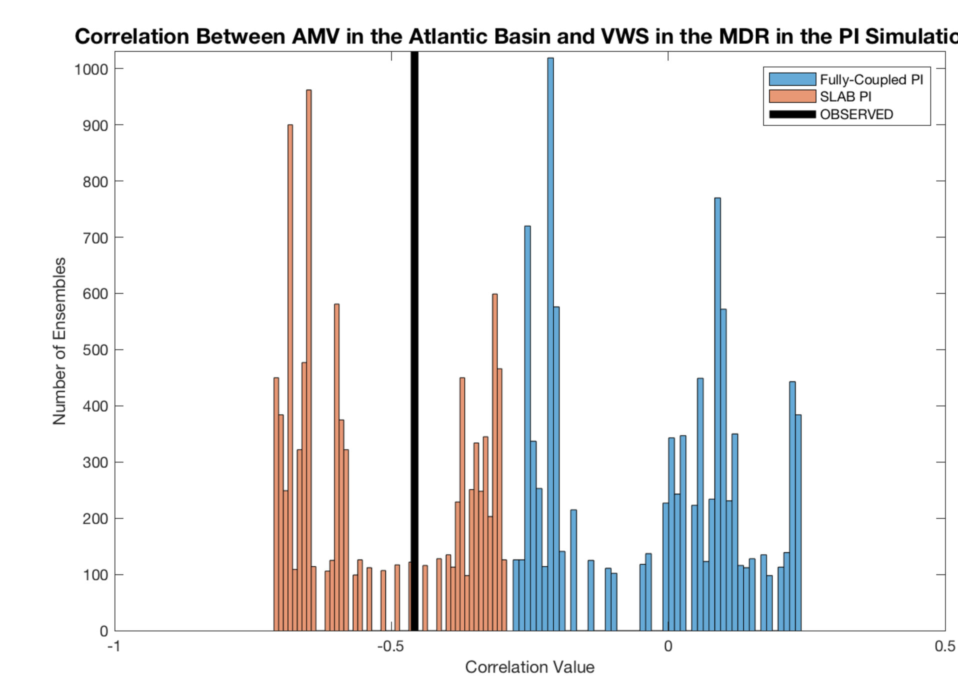


Key points:

→ Linearly removing ENSO from the fully-coupled model brings the coupled and LENS-SOM model into good agreement with each other.

→ This indicates that the main difference between the two models is caused by ENSO, and that ENSO interrupts the relationship between local SST and VWS in the fully-coupled model.

Figure 5: Detrended and Smooth Bootstrapped Pre-Industrial Control Run Correlation Values



Key points:

→ Observed correlation value is not simulated by the fully-coupled model without forcing

→ The SLAB (SOM) model both with and without forcing produces a negative correlation consistent with observations.

Conclusions

→ Because Low vertical wind shear variability is correlated with warmer AMV variability, the relationship provides two favorable conditions for more frequent and more intense hurricane activity in the Atlantic.

→ Our simulations show that the transient historical forcing, namely from greenhouse gases and aerosols, plays a role in producing a relationship between the AMV and vertical wind shear closer to what is seen in observations.

→ The observed correlation is within both the SLAB and fully-coupled ensembles, but is weaker than the forced correlation. This indicates that internal variability is playing some role.

→ Ocean circulation does not appear to be responsible for the negative correlation between the AMV and vertical wind shear in this model. Instead, ENSO disrupts the local relationship between the AMV and VWS in the coupled model. By removing ENSO from the fully-coupled model, we reproduce the results found with the SLAB model and find a better agreement with observations.

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