Atlantic Multidecadal Variability: What are the roles of external forcing and ocean circulation?

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Atlantic Multi-decadal Variability (AMV)

Average North Atlantic SST (ERSST v4), detrended
What is the role of external forcing?

What is the role of the ocean?
**CESM simulations**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Duration</th>
<th>Members</th>
<th>Forcing Period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preindustrial Control</strong></td>
<td>2200 years</td>
<td>10 members (1920-2005)</td>
<td>42 members (1920-2005)</td>
</tr>
<tr>
<td><strong>Last Millenium</strong></td>
<td>1000 years</td>
<td>??</td>
<td>10 members (1920-2005)</td>
</tr>
<tr>
<td><strong>Historical Forcing</strong></td>
<td></td>
<td></td>
<td>5 members (2005-2100)</td>
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<tr>
<td><strong>RCP8.5</strong></td>
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*Mixed layer depth is same as coupled model but fixed in time. Qflux is prescribed and does not vary with time.*
What is the role of external forcing?
CMIP5 models produce more multi-decadal variance with forcing

Murphy et al. (2017)
The chance of an unforced PI run correlating as well with the observed AMO as the historical run is very small.

Murphy et al. (2017)
Ensemble mean signal is larger than internal variability

Bellomo et al. (2018)
What is the role of external forcing?

Models need external forcing to simulate the observed magnitude and timing of the observed AMV

What is the role of the ocean?
AMO (0-60°N, 80°W-0°E)

- LENS-SOM
- LENS-fully coupled
- Observed
Correlation is better with SOM ensemble mean

*correlation is higher in CESM LME 1850-2005 and for 1930-2005 due to warm start in 1920
The ocean modulates the magnitude of variability (internal and forced)
This is especially prominent in mid-latitudes, and less so in tropics (because of ENSO)
The statistics of atmospheric variability (here, NAO) are the same in SOM and coupled
Is the ocean modulating the surface signature of the forcing by the correct amount?*

* a plug for developing a model tool to develop this
Future AMV
Key takeaway: Historical forcing is an important driver of AMV and the ocean modulates its amplitude

• Models need external forcing to explain the magnitude and timing of the observed twentieth century AMO. In CESM, forcing explains half to 2/3 of the variance.

• Interactive ocean heat transport modulates the forced signal in CESM, and damps everywhere. We hypothesize that this is due to mixing heat below the mixed layer.

• There are significant differences between the fully coupled and SOM in the future (and likely Last millennium as well). What is the correct amount of modulation by ocean?
How does the inclusion of **forcing** affect the simulation of AMV and associated impacts

- Improves the simulated magnitude of AMV and the timing of the observed shifts (Murphy et al. 2017, Bellomo et al. 2017)
- Improves the connection between AMV with N African rainfall (Group)
- Improves the connection between AMV and wind shear (S. Kramer)
- Can explain paleo AMV (Klavans, Swart et al. 2019)
- Obscures the relation between SST and NAO (Klavans et al. 2019)
- Does not produce the relation with salinity (Yu et al. 2018)
- Degrades the connection with FL rainfall (Klavans)
- Does not simulate the downturn in AMV after 2000 (Yu et al. 2017)
- European climate?? (Maroon et al., O’Reilly??)

*Ongoing
*Ongoing, but lower priority (?)
How does the inclusion of interactive ocean dynamics affect the simulation of AMV and associated impacts

• Weakens the magnitude of AMV, lowers the correlation in CESM (Murphy et al. 2019)
• Weakens future Atlantic warming (Klavans)
• Produces a future warming hole (but not required to get the 20th century warming hole) (Klavans/Clement)
• Degrades the relation between AMV and wind shear (S. Kramer)
• Produces a delayed response to NAO (Delworth)
• *can* change the ACF of temperature (in some models) – Zhang (2017)
• Changes the relation between SST and sfc heat flux in some regions (Oreilly et al. 2016, Zhang 2017, Cane et al. 2017)
SOM is more variability than coupled everywhere
**LP Filt. Correlation Coeff.**

- **LENS-SOM**
- **LENS-fully coupled**

**LP Filt. Variance**

- **LENS-SOM**
- **LENS-fully coupled**

**Graphs a. and b.**

- **Correlation Coefficient**
  - Ensemble Size range: 0 to 45
  - Ensembles sizes: 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75

- **Variance**
  - Ensemble Size range: 0 to 45
  - Ensembles sizes: 0.005, 0.01, 0.015, 0.02, 0.025, 0.03, 0.035, 0.04, 0.045
all 42 members

10 members (ens2-11)

10 members (ens12-21)

10 members (ens22-31)
Vertical mixing?
Atlantic Multi-decadal Variability (AMV)

Regression of local SST on index

Average North Atlantic SST (ERSST v4), detrended

Extended reconstructed SST anomalies

Jan 1860, Jan 1880, Jan 1900, Jan 1920, Jan 1940, Jan 1960, Jan 1980, Jan 2000
Figure 3: Variance of AMV index ($K^2$)

AMV-mid: 40-60N

AMV-tropics: 0-20N

Legend:
- LENS-SOM
- LENS
- LENS-SOM Ens mean
- LENS Ens mean
- Observations