Can an Interactive Ocean Impact the Indian Ocean-NAO teleconnection?
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Introduction
Changes in sea surface temperature (SST) can drive both changes in local weather and shifts in atmospheric circulation patterns, with non-local effects typically called teleconnections. SST changes in the Indian Ocean are known to drive changes in sea level pressure (SLP) in the North Atlantic associated with the North Atlantic Oscillation (NAO) (Li and Forest, 2014), which in turn impacts the development of strong storms in Europe.

In this study, we want to test how teleconnections will change when atmosphere-ocean feedbacks are considered. Rather than directly changing SSTs (Barsugli and Sardeshmukh, 2002), we add heat fluxes (via Q-fluxes) to induce SST changes and allow the slab-ocean mixed-layer model to respond in contrast to the fixed SST studies. We will examine the differences in these two methodologies and how they affect the Indian Ocean-NAO teleconnection.

Take-Away Message
Although the Indian Ocean-NAO teleconnection is still present, some of the signal is lost due to a response to ocean-atmosphere circulation and feedback. Therefore, an interactive ocean reduces the strength of the Indian Ocean-NAO teleconnection.

Methodology

a. Q-flux Patch method (Barsugli and Sardeshmukh, 2002; Bailey et al, 2003)
• We create a Q-flux heating anomaly over the Indian Ocean. This was designed to create an SST anomaly of 2°C.
• Q-flux equation:
  \[ Q_{flux} = -\frac{\partial B}{\partial t} \rho c_p \frac{\partial}{\partial \phi} \left[ \frac{1}{2} \sum_{j=0}^{J} \int_{\lambda_1}^{\lambda_2} \left( \cos^2\phi \phi \cos^2\xi \lambda \right) d\lambda d\phi \right] \]
where \( B \) is the temperature anomaly over time, \( \phi \) is latitude, \( \lambda \) is longitude, \( k \) indicates the center of the patch, \( w \) indicates the width of the patch, \( \rho \) is the density of salt water, \( c_p \) is the specific heat capacity of salt water, and \( h \) is the ocean mixed layer depth at each specific grid point (used to define the water mass, m). Figure 1 shows our Qflux patch and an SST patch:

![Figure 1: SST and Qflux anomaly patches.](image1.png)

b. Community Earth System Model (CESM) Specifications
• Preindustrial
• CAMS physics
• Atmosphere, land, and slab ocean models
• Carbon-nitrogen cycle
• Approximately 1 degree grid
• Runs submitted on ACI computing system

References

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Results

a. Indian Ocean SSTs
During the first year, the average SST anomaly in the Indian Ocean is approximately 1°C (Figure 2). Although the entire 2°C anomaly did not form, we hypothesize that this is because of a significant response to atmospheric circulation. This implies that the expected temperature change was probably limited by increased surface winds, more clouds, or other processes that cool the ocean surface. Given the resulting SST anomaly, it was still sufficient to affect the NAO SLP patterns discussed below. Over the 10 year period, Indian Ocean SSTs (Figure 3) still follow the typical season cycle, with anomalies ranging from 0.5 to 1°C.

![Figure 2: Year 1 SST Mean Differences](image2.png)

b. NAO SLP Patterns
In our analysis, we examine wintertime SLP patterns (December, January, February) over 10 years, with Year 2 including December from Year 1. As used in Li and Forest (2014), we characterize the NAO as the difference in SLP between Lisbon, Portugal (38.75°N, 9°W) and Stykkisholmur, Iceland (65°N and 22.7°W) (Figure 4). Our time series shows minimal differences between the control and modified runs, with only Year 4 in particular exhibiting a positive index when the control is negative. With 5 years exhibiting a distinct low pressure anomaly near Iceland, the mean wintertime differences in SLP generally indicate a positive NAO signal (Figure 5). Although the yearly wintertime averages demonstrate that the teleconnection is present, we argue that both the SST forcing and the teleconnection response are weaker than expected due to the interactive ocean model.

![Figure 3: Indian Ocean SST](image3.png)

![Figure 4: NAO Index](image4.png)

![Figure 5: Changes in SLP over 9 winters (DJF)](image5.png)