Weather Noise Forcing of Low Frequency Variability in the North Atlantic

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Collaborators

• Meizhu Fan - many of the results come from her PhD thesis.

• Ben Kirtman - developer of the “Interactive Ensemble”
Motivation

• Diagnose and understand the mechanisms of observed low frequency observed (1951-2000) North Atlantic SST variability.

• In particular, what were the roles of weather noise forcing, coupled feedbacks, and ocean dynamics?

• What are the implications for “decadal” predictability?
Tripole

Index: area average SST difference
(Czaja and Marshall 2001, QJRMS)
Approach

• Simulate the observed 1951-2000 tripole index using a CGCM class model forced by observed weather noise.

• Try to understand the results in the framework of the simple model of Frankignoul and Hasselmann (1976) as extended by Marshall et al. (2001):
  – Weather noise
  – Atmospheric feedback to SSTA
  – Gyre circulation
  – AMOC
Data and Models

• NCEP reanalysis 1951-2000, monthly means

• COLA CGCM
  – COLA V2 AGCM (T42, L18)
  – MOM3 OGCM (1.5º, finer meridional near equator) non-polar domain
  – Anomaly coupled
  – (RIP)
Mechanisms of Low Frequency Climate Variability (Sarachik et al., 1996)

- Forced by atmospheric weather noise (Hasselmann 1976)
- Forced by oceanic “weather noise”
- Intrinsic coupled variability (e.g. coupled ocean-atmosphere) that is not forced by weather noise
- Externally forced
Weather Noise

• **What is this “weather noise?”**
  - Atmospheric motions that are NOT the response to the evolving surface boundary conditions (SST, etc.) or external forcing.
  - Unpredictable more than ~1 week in the future.
  - Properties of random (white) noise?

• **Determination of weather noise**
  - Although unpredictable it is straightforward to determine weather noise that has already occurred and been observed.
  - Subtract the atmospheric motions that ARE the response to the surface evolution (SST, etc.) or external forcing, as evaluated from an “AMIP ensemble,” from the total.
Response N = SST forced signal + Noise\textsubscript{N}

Noise\textsubscript{N} is distinct for each N

AMIP/GOGA Ensemble
Determination of Weather Noise Surface Fluxes

Observed SST, sea ice

Surface flux 1
AGCM 1

Surface flux 2
AGCM 2

... Surface flux N
AGCM N

Ensemble Mean Surface Fluxes (=EMSF)

Noise = "OBS" - EMSF

Surface Fluxes from Analysis (="OBS")
Variance Ratio $\text{Noise} : \text{Total}$
Monthly Weather Noise Surface Flux
1951-2000
Example of Noise Evaluation: North Atlantic

**Total**
-NAO

**Feedback**
-NAO

**Noise**
-NAO

**+NAO**

Anti-cyclonic over warm
Cyclonic over cold
What is the SST Response to Weather Noise?

- Force a coupled model which has no weather noise with the “observed weather noise” surface fluxes as determined from the NCEP reanalysis.
  - Reproduce (or don’t reproduce) the observed SST evolution
  - Additional simulations to isolate the mechanisms responsible for the simulated SST evolution
Tool: Interactive Ensemble CGCM (IE CGCM; B. Kirtman)

- Couple an OGCM to a parameterized atmospheric model (as in an Intermediate Coupled Model).
  - The parameterized atmosphere is an AGCM ensemble.
  - The ocean sees the AGCM ensemble mean surface fluxes.
  - Each AGCM ensemble member sees the OGCM SST.
Interactive Ensemble CGCM

Interactive Ensemble Approach
Properties of IE CGCM

1. Atmospheric weather noise filtered out by ensemble mean

2. Internal variability is due to only ocean weather noise, coupled instability
   - Potentially much reduced low frequency variability

3. Response of SST to a specified surface flux forcing (heat, wind stress, or fresh water) will be quasi-deterministic

4. Includes full coupled feedbacks calculated from state-of-the-art parameterizations
Experiments

• Force Interactive Ensemble (IE) CGCM with weather noise surface fluxes for 1951-2000.

• If the SST variability was the response to the weather noise, it will be reproduced.
  – Further experiments will then isolate the role of various processes in the SST variability (e.g. ocean dynamics, location and type of weather noise forcing, …)

• Diagnostic only (“additive noise”).
Noise Forced Interactive Ensemble
Another Way to Think About Weather Noise Forced IE CGCM:

• It is an **OGCM simulation** forced by observed fluxes but *without the double counting* of the surface fluxes.
  – “OGCM” simulations typically include atmospheric feedbacks (e.g. damping) as well as specified observed fluxes. This is inconsistent.
Understand Model Internal Variability

• Perfect model, perfect data
  – Done
  – Perfect results
Experiments to Diagnose Observed Variability

- Bad model, inaccurate data, no external forcing in model or analysis
- Forcing Data: 1951-2000 NCEP reanalysis monthly surface fluxes and SST

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Forcing Noise</th>
<th>Forcing Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gctl</td>
<td>all</td>
<td>Global ocean</td>
</tr>
<tr>
<td>NActl</td>
<td>all</td>
<td>North Atlantic 15°N~65° N</td>
</tr>
<tr>
<td>NAh</td>
<td>heat</td>
<td>...</td>
</tr>
<tr>
<td>NAm</td>
<td>momentum</td>
<td>...</td>
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</tbody>
</table>

Note: all ~ freshwater, heat, and momentum
Tripole Index

![Graph showing JFM Tripole Index 7 Year Running Mean (Detrended)]
Tripole Index

JFM Tripole Index 7 Year Running Mean (Detrended)

Index (°C)

-1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0


- Observed
- NAm
- NActl
- Gctl
- NAh
• The tripole index is locally forced by the weather noise heat flux (Gctl, NActl, NAh).

• Momentum flux weather noise forces a tripole response that damps/lags the full response.
Extract Model Patterns by Regression of Simulation Results against Observed: Tripole Index

Observed

Gctl

NActl

NAh

NAm
Gyre Circulation and Variability in NActl

Mean Gyre

EOF 1 (31%) (“Intergyre Gyre”)

PC1 of EOF1 (gyre index); NAO Index (observed)
Tripole and Gyre Indices NActl

Gyre index: area avg. streamfn., 60°W-40°W, 35°-45°N
NActl Tripole Index (JFM) and AMOC Index (annual)
COLA Model Diagnosis of the Observed North Atlantic SST Variability

- The later 20th century North Atlantic SST variability is predominantly forced by the weather noise, for both of the two major low frequency patterns of variability
  - Tripole mode: it can be reproduced reasonably well both for its spatial pattern and its time evolution.
    - Local heat flux weather noise provides the major forcing.
    - Ocean dynamics/wind stress feedback is negative (from NAh).
    - The MOC is forced by weather noise. Its variability appears to be associated connected to the tripole, which it damps.
    - Parameters have been determined for Marshall et al. (2001) model, which can then be used for some crude predictability estimates.
Wind Stress Feedback

- **Obs (total)**

- **COLA_V2**
  - Negative
  - Weak

- **CAM3.0**
  - Positive
  - Weak
For Additional Details


