An observational analysis of coupling between the ocean and the Atmosphere in the subtropical North Atlantic

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Net surface flux from the atmosphere to the oceans Watt/m$^2$: implied ocean heat transport convergence, maximum around 30-40N
Role of heat transport: mean balance

Heat is lost from the Gulf Stream to the atmosphere (about 0.2 PWatts)

Dong and Kelly (2004) show that heat transport convergence forces heat storage which in turn controls the net surface heat flux that damps the heat anomalies. Holds on interannual time scales
Barsugli and Battisti (1998) ocean-atmosphere interaction

$$\gamma_a \frac{dT_a}{dt} = -\lambda (T_o - T_a) - \lambda_a T_a + N_a$$  \quad \text{Atmosphere noise}

$$\gamma_o \frac{dT_o}{dt} = \lambda (T_o - T_a) - \lambda_o T_a + N_o$$  \quad \text{Ocean noise}

\begin{tabular}{|c|l|}
\hline
$T_a$ & Air Temperature \\
$T_o$ & Sea surface Temperature \\
$\gamma_a$ & Atmosphere heat capacity \\
$\gamma_o$ & Ocean heat capacity \\
$N_a$ & Atmospheric Noise \\
$N_o$ & Ocean Noise \\
$\lambda_a$ & Atmosphere radiational cooling \\
$\lambda_o$ & Ocean radiational cooling \\
$\lambda$ & Coefficient for air-sea turbulent flux of heat \\
\hline
\end{tabular}
Barsugli and Battisti (1998) ocean-atmosphere interaction

Lagged correlations of SST/Q_{turb} with normally distributed noise

Q_{turb} is the sum of latent and sensible heat flux. negative when it cools the ocean

![Graph showing correlations over time with month on the x-axis and correlation on the y-axis.](image-url)
Ocean-atmosphere interaction can be examined via SST/heat flux lagged correlations.

Here we also examine sea surface height (SSH, upper ocean heat content).

SSH/heat flux gives information about how heat stored below the seasonal mixed layer interacts with the atmosphere.
Using observations to look at the relationship between the heat content and surface flux

Smooth both with 400 km full width at half max Gaussian smoother

Removing seasonal cycle and lowpass

<table>
<thead>
<tr>
<th>Observational Analysis variables</th>
<th>Source</th>
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<tbody>
<tr>
<td>Sea surface height (SSH)</td>
<td>Monthly maps of sea level anomaly from Ssalto/Duacs 1/3° x 1/3°, Mercator grid, Aviso</td>
<td>Used as proxy for upper ocean heat content</td>
</tr>
<tr>
<td>Turbulent heat flux $Q_{turb}$ And net surface heat flux $Q_{net}$ And SST on the same grid</td>
<td>OAflux: Objectively Analyzed air-sea fluxes for the Global Oceans (Yu and Weller, 2007)</td>
<td>Fluxes are positive for warming the ocean.</td>
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</table>
Consider two locations

1. In the Gulf Stream
   Strong Advection
2. In the Eastern Basin
   weak Advection

Mean turbulent heat flux out of the ocean.
What can we learn from $\text{SST/Q}_{\text{turb}}$ and $\text{SSH/Q}_{\text{turb}}$ lagged correlations?

Mixed ocean-atmosphere
Gulf Stream

Atmosphere forcing
Eastern Basin
SSH leads $Q_{\text{turb}}$ in Gulf Stream
SST/Q lagged correlation more symmetric
a. SSH leads Q

b. SSH lags Q

Maximum mixed-layer Depth

Evidence for role of heat stored below mixed-layer

1. Atmosphere forcing in shallow mixed-layer
2. Ocean releases heat in deep mixed-layer
Evidence for role of heat stored below mixed-layer

Atmosphere forcing

Ocean forcing downstream
What is the connection to AMOC?

Look for a connection between RAPID/MOCHA Meridional heat transport and heat content (SSH) in Gulf Stream

Standard deviation SSH 4.4 cm, $Q_{\text{turb}}$ 18 Watts/m$^2$
What is the connection to AMOC?

RAPID/MOCHA MHT leads SSH in Gulf Stream (but short times series)
Conclusions

1. The 20 year satellite altimeter record allows investigation of the role of regional upper ocean heat content in ocean-atmosphere interactions.

2. SST follows the model of atmospherically forced anomalies that are then damped by surface fluxes throughout most of the basin.

3. SSH is forced regionally by “ocean noise”.

4. Gulf Stream: warm upper ocean heat content leads to turbulent surface flux out of the ocean.

5. There is evidence for heat content anomalies forced by the atmosphere upstream in the North Atlantic Current and the Gulf Stream.

6. Heat content released to the atmosphere where flow enters deeper maximum mixed-layer depth.

7. Some evidence for connection between MHT at 26N and Gulf Stream heat storage.
What does this mean for understanding the influence of AMOC on the atmosphere?

1. Variations in AMOC Meridional Heat Transports may be linked to local heat transport convergence.

2. On interannual time scales heat transport convergence drives heat into or out of the ocean in the Gulf Stream.

3. On going work: The release of heat to the atmosphere in the Gulf Stream occurs primarily in December/January/February.

4. Evidence for mid-level cloud fraction increase when $Q_{turb}$ is out of the ocean and heat content is high (see Koehler poster). Consistent with Minobe et al (2008) mid-level cloud fraction large over the Gulf Stream in winter.

5. Ocean only models do not show the correlations found here: coupled model analysis is needed to investigate further (also underway).