The origin of along-shelf pressure gradient (ASPG) in the Middle Atlantic Bight (MAB)

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IWMO-2010, ODU, May 24
Why is the ASPG important?

The ASPG exists to account for the mean along-shelf circulation.

Momentum Balance:

\[
g h \frac{\partial \eta}{\partial x} = \frac{\tau^x_{\text{wind}}}{\rho_0} - \tau^x_b \approx -ru
\]

ASPG $10^{-8}$-$10^{-7}$ drives mean along-shelf flow towards the southwest (Stommel and Leetmaa, 1972; Csanady, 1976; Lentz, 2008);
16-yr (1993-2008) run:
10km & 25 sigma levels
Qscat winds
Daily rivers
M2 tide
SSHA (H>1000m) & SST assimilations

Mean
ASPG
\[ R = -0.5 \]

\[ \text{ASPG} = 8.4 \times 10^{-8}, \quad \text{Std} = 8.6 \times 10^{-8} \]

Distance from Cape Hatteras

Years
Tide-gauge sea level data: demeaned

EOF mode 1: 67%
Previous Works:

• Due to offshore pressure field (Beardsley and Winant, 1979)?
  But, pressure field not likely to penetrate onto the shelf (Wang, 1982; Chapman et al. 1986);

• Due to be rivers?
  This was questioned by Csanady (1979);

• Upstream transport? (Wang, 1982; Chapman et al. 1986).

The origin of (mean) ASPG remains unclear (Lentz, 2008)…
  What is its origin?

What drive the seasonal and inter-annual variations?
  how and why?

Possible candidates:

Winds GS path Rings
Rivers Labrador transport
The base case

River only

River and transport

Wind only
Correlation coefficient (R) and lags

<table>
<thead>
<tr>
<th>R/Lag in month</th>
<th>ASPG</th>
<th>Wind curl</th>
<th>GS shifts</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS shifts</td>
<td>0.57 / 4</td>
<td>0.40 / -6</td>
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</tr>
<tr>
<td>Wind curl</td>
<td>---</td>
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</tr>
<tr>
<td>N - EKE</td>
<td>0.41 / 5</td>
<td>0.33 / -4</td>
<td>0.30 / 0</td>
</tr>
<tr>
<td>Transport</td>
<td>---</td>
<td>-0.65 / 0</td>
<td>---</td>
</tr>
<tr>
<td>River input</td>
<td>0.19 / 0</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>N - EKE</td>
<td>0.52</td>
<td>0.33</td>
<td>0.27</td>
</tr>
</tbody>
</table>
The EKE estimated from satellite geostrophic currents (Aviso)

Black line: 16-year mean of GS path
An Idealized simulation with warm-core rings injected every 360 days

SSH

ASPG = -1.5e-8
Std = 2.3e-8
Summary

Rivers and Labrador transport → Mean ASPG

GS shifts and Warm core rings → ASPG Seasonality

Wind → Warm core Rings → ASPG Inter-annual Variability
Thank you! Questions?
Along-shelf momentum balance

\[ \rho_0 f v = -P_x + \tau_z^x \]

\[ \int f v d\eta = -\frac{1}{\rho_0} \int P_x d\eta + \frac{1}{\rho_0} \int \tau_z^x d\eta \]

\[ \frac{1}{\rho_0} \int P_x d\eta = gH \frac{\partial \eta}{\partial x} \]

\[ \frac{1}{\rho_0} \int \tau_z^x d\eta = \tau_{\text{wind}} - \tau_{\text{bottom}} \approx -r u \]

So,

\[ u \approx -\frac{gH}{r} \frac{\partial \eta}{\partial x} \]
### Inter-annual Correlation coefficient

<table>
<thead>
<tr>
<th>R/lags</th>
<th>ASPG</th>
<th>GS latitude shifts</th>
<th>Wind stress curl</th>
<th>Transport</th>
<th>River Input</th>
<th>Model EKE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASPG</td>
<td>---</td>
<td>0.15/0.25</td>
<td>-0.07/0.12</td>
<td>-0.06/0.1</td>
<td>0.09/0.18</td>
<td>0.52/0.19</td>
</tr>
<tr>
<td>GS latitude shifts</td>
<td>0.15/0.25</td>
<td>---</td>
<td>-0.11/0.18</td>
<td>0.40/0.16</td>
<td>---</td>
<td>0.27/0.16</td>
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<tr>
<td>Wind stress curl</td>
<td>-0.07/0.12</td>
<td>-0.11/0.18</td>
<td>---</td>
<td>-0.48/0.14</td>
<td>---</td>
<td>0.33/0.15</td>
</tr>
<tr>
<td>Transport</td>
<td>-0.06/0.1</td>
<td>0.40/0.16</td>
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<tr>
<td>Model EKE</td>
<td>0.52/0.19</td>
<td>0.27/0.16</td>
<td>0.33/0.15</td>
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</table>
POM
Princeton Regional Ocean Forecast System (PROFS)

- Curvilinear grid
- Grid size:
  - Horizontal: ~10km
  - Vertical: 25 $\sigma$ levels

Mid-Atlantic Model:
- Winds, rivers & tides
- Nesting from PROFS
- Finer grid size: ~5km
- DA for GS & Eddies
Seasonal mean CCMP winds
Summary

1. The NWAOM produced the mean along-shelf circulation southwestward. The model dynamics produce an ASPG, $8.4 \times 10^{-8}$, consistent with the value inferred by previous studies.

2. The total freshwater discharge and upstream transport mainly contribute to the mean ASPG setup.

3. The wind stress may not affect the ASPG directly, but the upstream transport and GS path shifts are deeply influenced by wind. So the wind is important to the ASPG.

4. The westward propagating Rossby waves and warm-core rings can influence ASPG in both seasonal and inter-annual time scale.
1. The variability of Gulf Steam path
2. Wind stress curl: \((\partial \tau_y / \partial x - \partial \tau_x / \partial y) / \rho\)
3. The Gulf Stream warm-core rings
4. Upstream Transport: \[ \int \overline{UH}dy \]
5. Rivers
Hypothesis

- The ASPG is affected by westward Rossby waves and Gulf Stream (GS) warm-core rings (WCR).

WCR->SSH near shelf break->ASPG
River only

River with reduced transport 34%

Wind only

Reduced transport 17%
NWAOM: Along shelf currents and Along shelf pressure gradient (ASPG)

\[ R = -0.52, \quad S = 0.33 \]

\[
\begin{align*}
\text{ASPG} &= 8.4 \times 10^{-8}, \\
\text{Std} &= 8.6 \times 10^{-8} \\
\bar{U} &= -0.015 \text{ m s}^{-1}, \\
\text{Std} &= 0.03 \text{ m/s}
\end{align*}
\]
Rivers: 1992-2008
## R for monthly data

<table>
<thead>
<tr>
<th>R/lags</th>
<th>Alongshore currents</th>
<th>ASPG</th>
<th>GS latitude shifts</th>
<th>Wind stress curl</th>
<th>Transport</th>
<th>River Input</th>
<th>Model EKE</th>
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<tr>
<td>Alongshore</td>
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<tr>
<td>GS latitude</td>
<td>0.32/0.12</td>
<td>-0.21/0.17</td>
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<tr>
<td>Wind stress</td>
<td>-0.34/0.09</td>
<td>0.18/0.12</td>
<td>-0.24/0.07</td>
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<tr>
<td>Transport</td>
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<td>-0.09/0.27</td>
<td>0.41/0.15</td>
<td>-0.35/0.11</td>
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</tr>
<tr>
<td>River input</td>
<td>-0.41/0.10</td>
<td>0.16/0.13</td>
<td>-0.34/0.09</td>
<td>0.23/0.06</td>
<td>-0.46/0.12</td>
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<tr>
<td>Model EKE</td>
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<td>-0.10/0.04</td>
<td>0.21/0.05</td>
<td>0.04/0.03</td>
<td>0.003/0.05</td>
<td>-0.05/0.06</td>
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