Taking the pulse of the Gulf Stream through variational inverse methods: is the North Atlantic Oscillation teasing it?

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26 apr 2018 - FOCUS Young Scientists Day
Background and motivation

- 2008–2011: Bachelor in Physics at FUNDP (now UNamur)
- 2011–2013: Master in Climatology at ULg (now ULiège)
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Funding?

Motivation:
- Freedom of research
- Transversal topic
- Many trips abroad
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- What about FRIA?
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FNRS?
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What about FRIA?
- Good things come in threes, didn’t dare to check it!

Motivation:
- Freedom of research
- Transversal topic
- Many trips abroad
My expectations with respect to FOCUS

- Job offers, job days?
- How to highlight PhD valuable experience (CV,...)?
- Make the PhD guidelines more accessible/visible (FOCUS website)?

Information about PhD spread among many websites

Centralise the information at [http://www.focus.uliege.be](http://www.focus.uliege.be)?
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The Gulf Stream

The North Atlantic Oscillation (NAO)

NAO +

NAO -

(Source: Martin Visbeck et Heidi Cullen, Lamont Doherty Earth Observatory, NOAA)
Is there a link?

(Near-)consensus on

- the influence of NAO on the GS
  - NAO+ ⇒ stronger GS ; NAO– ⇒ weaker GS
  - NAO+ ⇒ GS shifts northward ; NAO– ⇒ GS shifts southward

No clear consensus on

- the existence of a time lag between NAO and GS
- the assessment of this lag

Uncertainties due to

- short time series
- coarse resolution models
- subjective methods
- small data sets
- absence of error estimates
### Method - 1. Data acquisition

<table>
<thead>
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<th>Database</th>
<th>No. of obs.</th>
<th>Total</th>
<th>No. of duplicates</th>
<th>Total without dup.</th>
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<td>Salinity</td>
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- Collecting a maximum of data (T/S)
- Duplicates handling & quality control
- Production of an homogeneous data base (∼40 M)
Method - 2. Data analyse

- Production of a **continuous field** from discrete measurements

**Variational Inverse Method (VIM)**

\( \varphi \) is the analyzed field,
\( N_d \) the number of data points,
\( d_j \) the data value in \((x_j, y_j)\),
\( D \) the region of interest.

We search for \( \varphi \) minimizing \( J \) on \( D \):

\[
J[\varphi] = \sum_{j=1}^{N_d} \mu_j [d_j - \varphi(x_j, y_j)]^2 + \|\varphi\|^2
\]

where

\[
\|\varphi\| = \int_D \left( \alpha_2 \nabla \nabla \varphi : \nabla \nabla \varphi + \alpha_1 \nabla \varphi \cdot \nabla \varphi + \alpha_0 \varphi^2 \right) dD
\]
- Monthly diva analyses of SST since 1900
- Fit by err fct for 81 lon
- Longitudinal filtering acc. quality of fit
- 81 lat. of highest gradient
- 1st EOF (N-S movement)
- GSNW between 1900 and 2012
- Correlation with NAO (lag 0,1,2 years)
Correlations NAO-GSNW

GSNW index
NAO index (-1 yr)

<table>
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<tr>
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<th>NAO</th>
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<th>NAO (-2 yr)</th>
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<td>0.1812</td>
<td>0.3692 (S)</td>
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Sylvain Watelet

Gulf Stream and NAO
Correlations NAO-GSNW

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Gulf Stream Delta index: measures the T diff. across GSNW

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<th>NAO (-2 yr)</th>
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</thead>
<tbody>
<tr>
<td>GSG (1940-2014)</td>
<td>0.2077</td>
<td>0.1667</td>
<td>0.2069</td>
</tr>
<tr>
<td>GSG (1960-2014)</td>
<td>0.4964(S)</td>
<td>0.2838</td>
<td>0.4297(S)</td>
</tr>
</tbody>
</table>
Comparison with satellite data and Taylor GSNW index

GSNW Diva (red), GSNW sat (black), Taylor (blue)

GSD Diva (red), GSD sat (black)

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<th>GSNW sat</th>
<th>GSD sat</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSNW Diva</td>
<td>0.7336</td>
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</tr>
<tr>
<td>Taylor GSNW</td>
<td>0.4331</td>
<td>0.4458</td>
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</tr>
<tr>
<td>GSD Diva</td>
<td>0.7559</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GS speed and transport

- T and S diva maps at 15 depths (0-3000 m)
- Speeds from geostrophic equilibrium

Average speeds (ms\(^{-1}\)) along the GS in March 2014

<table>
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<tr>
<th>GST</th>
<th>NAO</th>
<th>NAO (-1 yr)</th>
<th>NAO (-2 yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940-2014</td>
<td>0.3476 (S)</td>
<td>0.1620</td>
<td>0.2202</td>
</tr>
<tr>
<td>1960-2014</td>
<td>0.3030 (S)</td>
<td>0.1119</td>
<td>0.2239</td>
</tr>
</tbody>
</table>

Correlations between NAO-GSD (black) and between NAO–GST (red) on 1960–2014
1. Extend the GSG index to a real transport index (3D)
2. Increase the reliability of DIVA analyses
   1. Weighting too close data
   2. Use of variable correlation length (from sat. data)
3. Other developments of DIVA (eg. detrending option)
4. Other variables (salinity, currents)
5. ...
Thank you for your attention!

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Fit by err fct for 81 lon
Longitudinal filtering acc. quality of fit
81 values of highest gradient
Average
GSG index between 1900 and 2012
Correlation with NAO (lag 0,1,2 years)
From 1st analyses err fct fits, creation of new ref monthly fiels
New estimation of parameters CL & SN
Analyses
=> GSNW index not affected
Handling of duplicates

1. Immediate removal of exact duplicates

2. Longer procedure for near duplicates:
   - $\triangle lon < 0.1^\circ$
   - $\triangle lat < 0.1^\circ$
   - $\triangle time < 1h$

$\Rightarrow$ candidates duplicates

1. If $\triangle val < 0.1$ then
   - averaging the candidates

2. Else
   - averaging + low weight on this observation
1. Sea ice concentration since 1870 from Walsh and Chapman (2013)
2. Average on 1900-2011 & interpolation on DIVA grid
3. hshs

Pixels > 15% of sea ice are replaced by Levitus (2010) climatology (1°)
Variational Inverse Method (VIM)

Parameters:

1. $\alpha_0$ penalizes the field itself (anomalies)
2. $\alpha_1$ penalizes the gradients
3. $\alpha_3$ penalizes the variability
4. $\mu$ penalizes the error of the analysis