Inferring the AMOC from Surface Observations

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July 21, 2018

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To What Extent Can the AMOC be Inferred From Surface Information?

Past Work

Latif et al., 2004; J. Climate: Reconstructing, Monitoring, and Predicting Multidecadal-Scale Changes in the NA Thermohaline Circulation with SST

Hirschi and Marotzke 2007; JPO: Reconstructing the Meridional Overturning Circulation from Boundary Densities and the Zonal Wind Stress

Zhang, 2008; GRL: Coherent surface-subsurface fingerprint of the AMOC

Zhang, Rosati, Delworth, 2010; J. Climate: The Adequacy of Observing Systems in Monitoring the AMOC and North Atlantic Climate

Mahajan et al. 2011; Deep-Sea Res. II: Predicting AMOC variations using subsurface and surface fingerprints

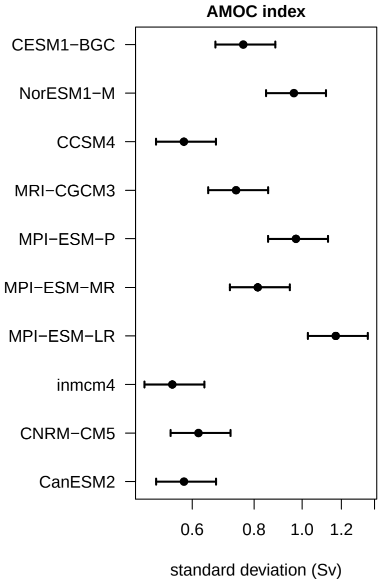
Lopez et al., 2017; GRL: A reconstructed South Atlantic Meridional Overturning Circulation time series since 1870

No study has shown that a reconstruction method works in a suite of coupled atmosphere-ocean models.

New Analysis with CMIP5

- Analyze CMIP5 simulations
- Only piControl simulations at least 500 years long
- 5-year running mean SST North Atlantic basin (0-60N).
- AMOC index: maximum streamfunction at 40N
- AMOC index is 5-year running mean
- Only 11 models have 500-year control, AMOC index, and SST.
- MIROC5 has SST discontinuity, leaving 10 models.

Variance of AMOC



Linear Regression

Assume reconstruction model of the form

$$\text{reconstructed AMOC}(t) = w_1 X_1(t) + w_2 X_2(t) + \cdots + w_M X_M(t)$$

Least squares: select the weights **w** to minimize

$$\Bigg\| \underset{\textit{AMOC}}{\mathbf{y}} - \underset{\textit{SST}}{\mathbf{X}} \; \underset{\textit{weights}}{\mathbf{w}} \Bigg\|^2$$

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Problem: Not enough data.
There are more SST grid points than data.

Approach: impose constraints on the equation.

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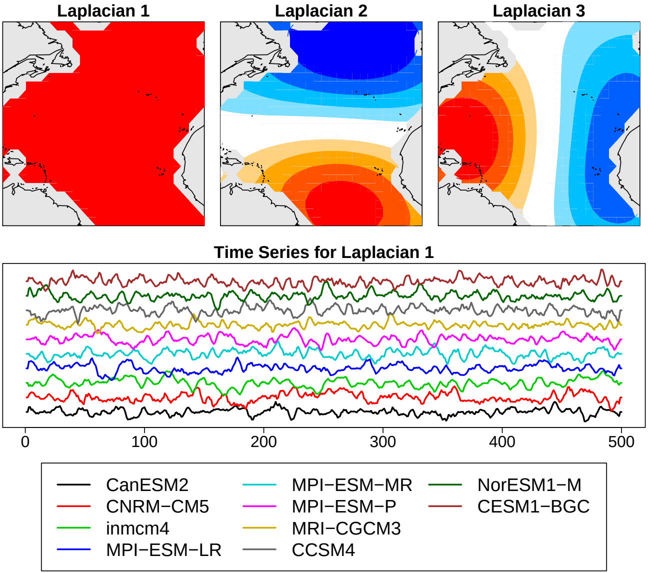
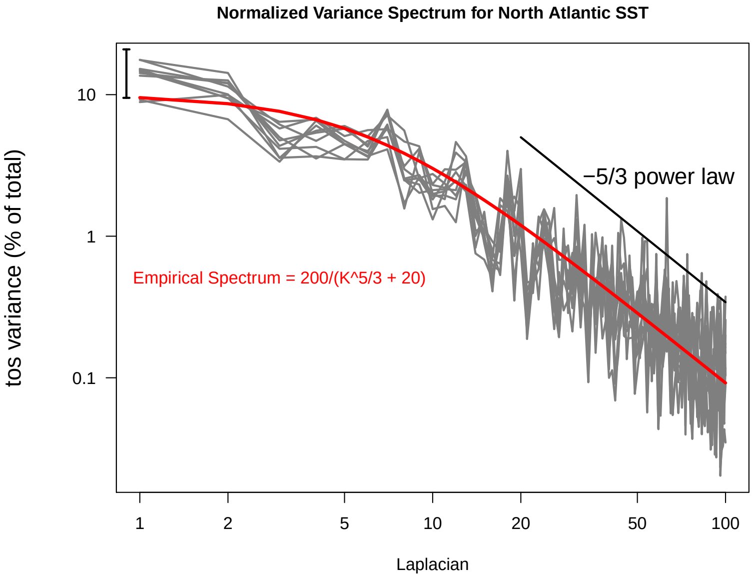
A priori assumption:
AMOC affects the large-scale SST.

Laplacians


Laplacian 1
Laplacian 2
Laplacian 3
Time Series for Laplacian 1
0
100
200
300
400
500
CanESM2
CNRM−CM5
inmcm4
MPI−ESM−LR
MPI−ESM−MR
MPI−ESM−P
MRI−CGCM3
CCSM4
NorESM1−M
CESM1−BGC

Normalized Variance Spectrum for N. Atlantic SST



Constrained Least Squares

Constrained least squares is equivalent to minimizing the function

$$\left\| \underset{AMOC}{\mathbf{y}} - \underset{SST}{\mathbf{L}} \; \underset{weights}{\mathbf{w}} \right\|^2 + \lambda R(\mathbf{w}),$$

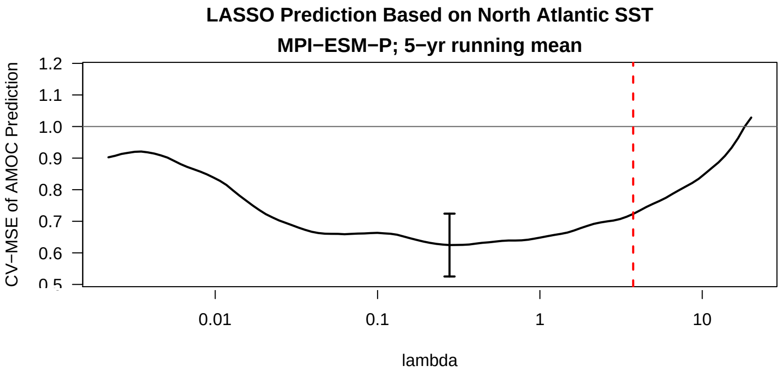
where $R(\mathbf{w})$ is a non-negative "penalty" function of the weights.

LASSO corresponds to $R(\mathbf{w}) = \sum_i |w_i|$. It tends to sign zero weight to high-wavenumbers because they have small variance.

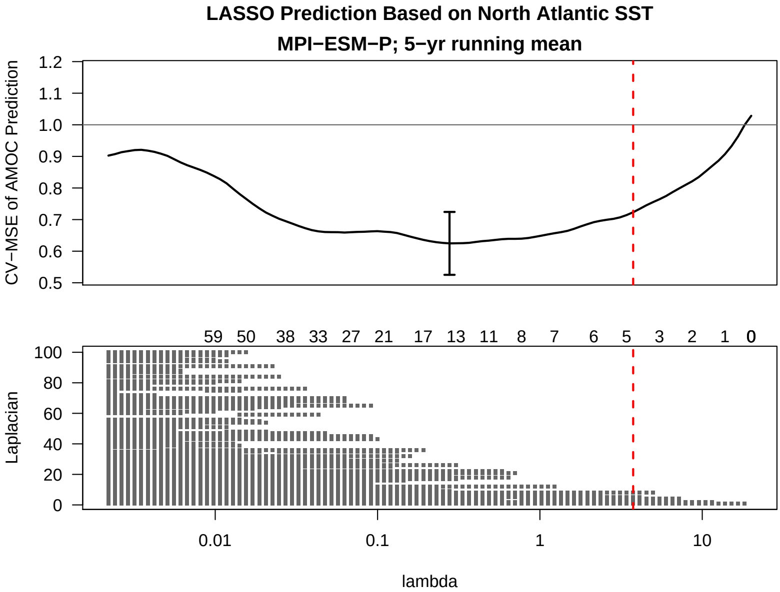
λ controls the strength of the penalty:

- large λ means most w's are zero: field is smooth
- small λ means more w's are non-zero: field can be noisy.

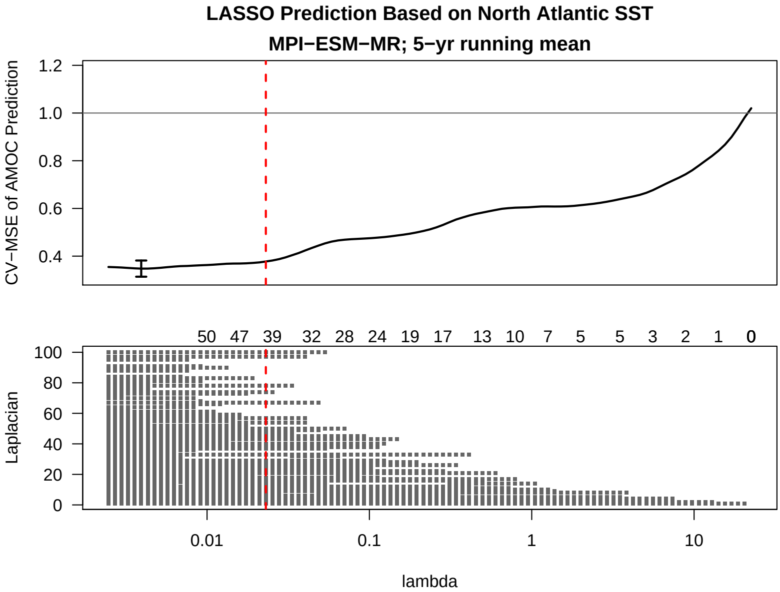
AMOC Prediction



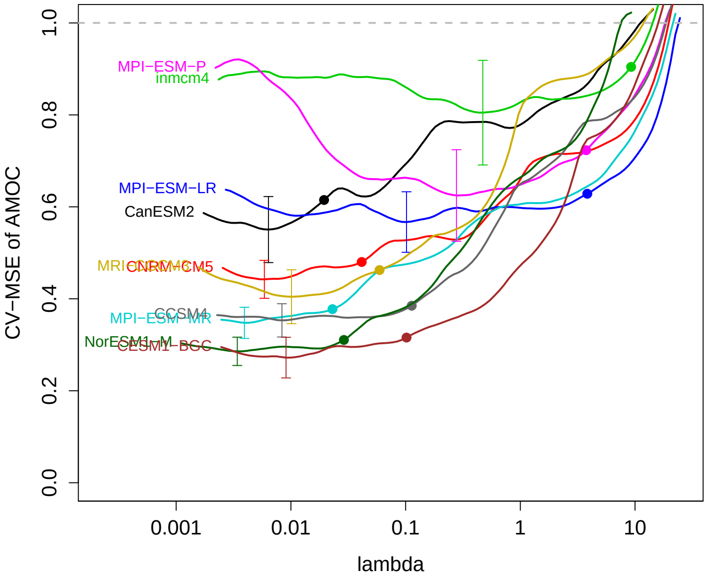
AMOC Prediction



AMOC Prediction

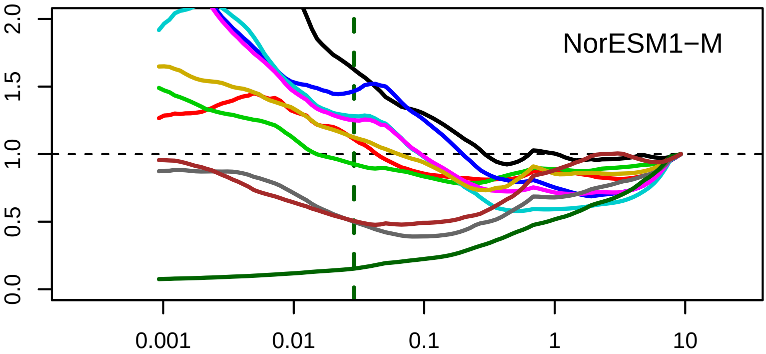


AMOC Prediction

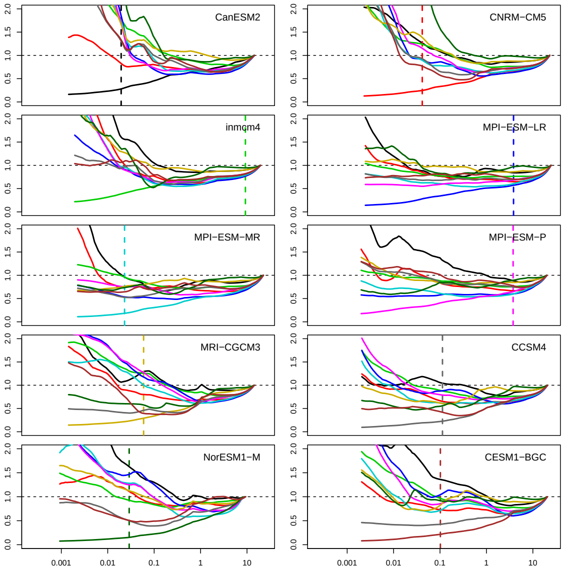


Cross-Model Predictions

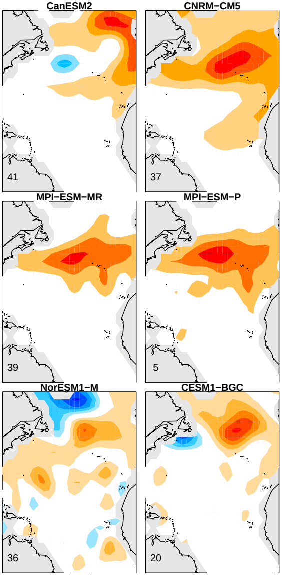
Train on one model, test in another model.



AMOC Prediction



SST that Co-Varies with AMOC (λ = optimal)



Conclusions

1. We reconstruct the AMOC based on surface observations using a combination of regularized regression and Laplacian basis functions.
2. Fraction of AMOC that is predictable from Atlantic SST: 10-70%.
3. A reconstruction equation that works well in one climate model can perform poorly in other climate models.
4. Reconstructions at $\lambda = 1$ tend to have skill in all models.
5. Reconstructions at $\lambda = 0.1$ suggest model clusters:
   - CCSM4, CESM1-BGC, NorESM1-M
   - MPI models
   - CanESM2, CNRM-CM5
   - INMCM4
   - MRI-CGCM3

Next step: include time lags and other variables (e.g,. SSS).
Optimal Fingerprinting.