Surface controls of freshwater export through Denmark Strait

Emma Boland **emmomp@bas.ac.uk**

Dani Jones, Yavor Kostov

20th March 2024, ECCO Annual Meeting 2024

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

CANARI

POLAR SCIENCE FOR PLANET EARTH

Background

Extreme weather events lead to substantial socioeconomic impacts in the UK and Europe:

- UK flooding in winter 2019/20 resulted in **£150 million** of damage, and extreme central Europe flooding in summer 2021 resulted in **243 fatalities** and **€10 billion** of damage.
- In February 2021, the UK experienced a succession of winter storms – Dudley, Eunice, and Franklin – that led to damages of **£3 billion**.
- The heatwave of summer 2022 led to UK temperature records exceeding 40C for the first time, resulting in over **3,200 excess deaths**.

Background

CANARI is a five year research programme funded by the UK's Natural Environment Research Council.

It seeks to understand how climate change in the Arctic and North Atlantic region will impact the United Kingdom, with a focus on extreme weather and the potential for rapid, disruptive change.

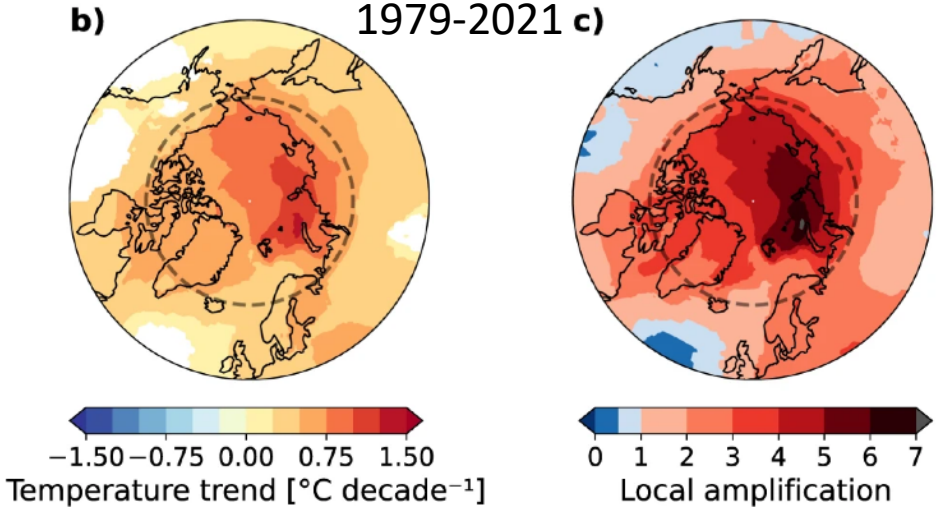
Background

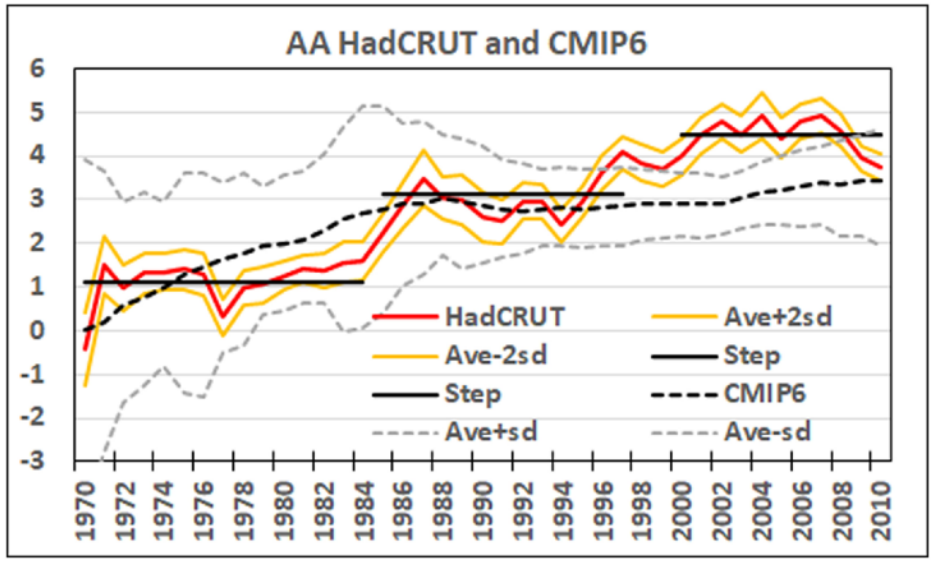
One of the possible* causes of disruptive change to weather and climate in the UK is **rapid Arctic warming** and **loss of sea ice**.

The Arctic has been warming at nearly **four** times faster than the rest of the globe since 1979

Models are getting better at reproducing **Arctic Amplification**, but still need improvement -> we need to better understand possible physical processes.

Rantanen et al. 2022

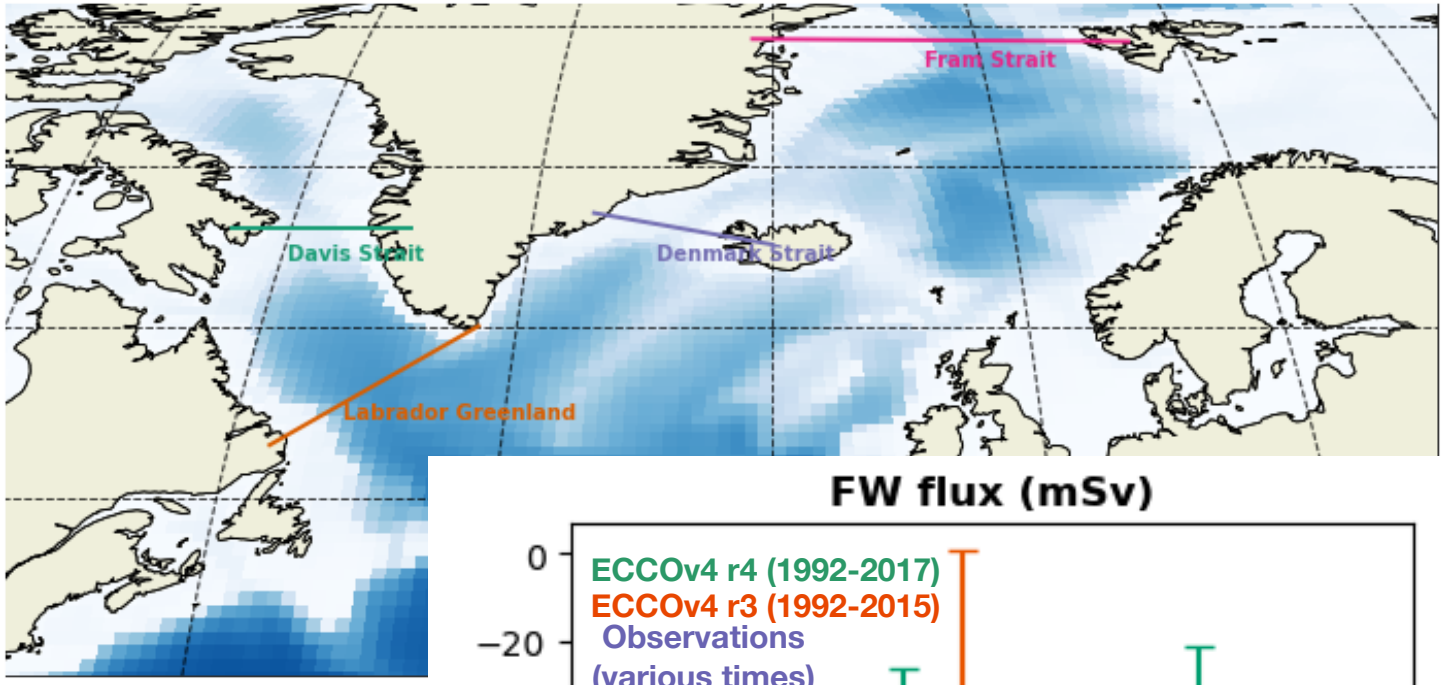


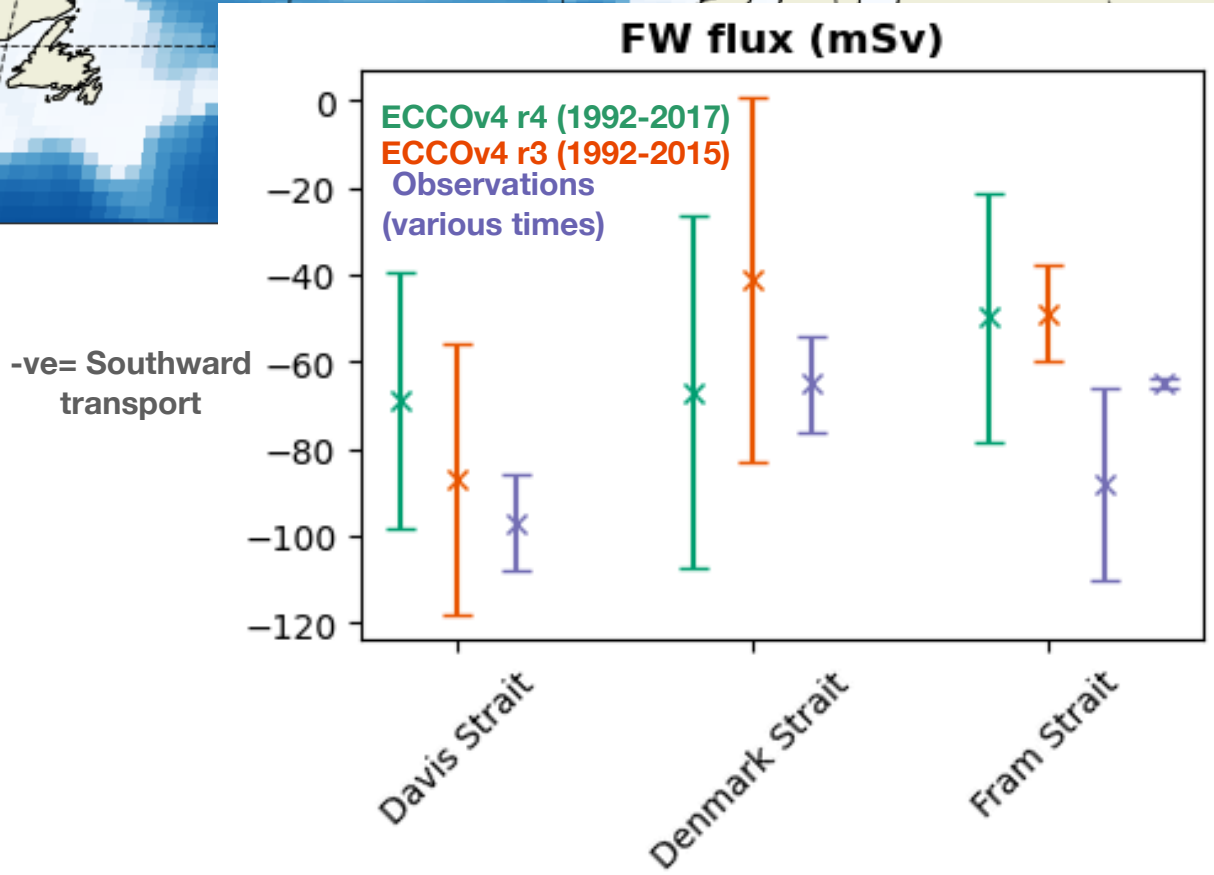


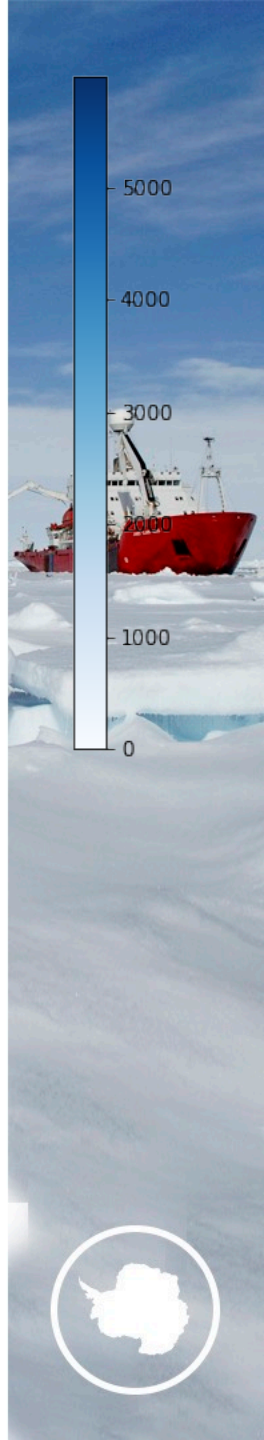
Chylek et al. 2022

This study

- Aim: Identify Arctic-origin pathways of influence on lower latitudes
- Plan: identify surface controls of freshwater export from the Arctic
- Tool: ECCOv4 r4 state estimate (1992-2017), using adjoint sensitivity experiments



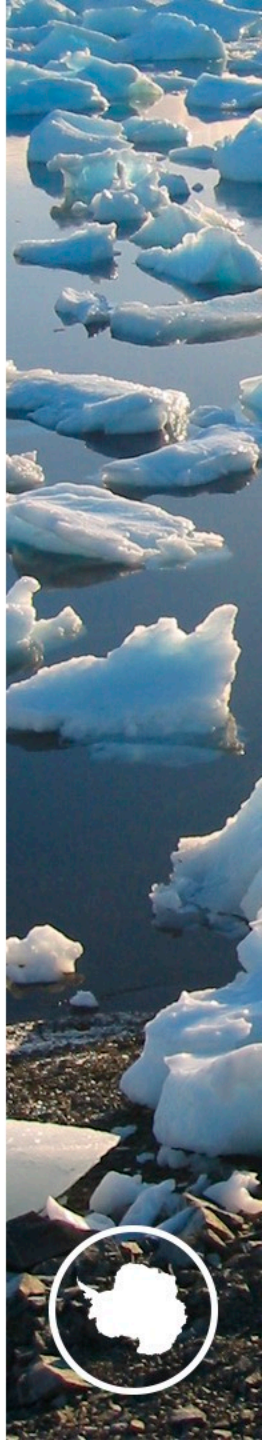




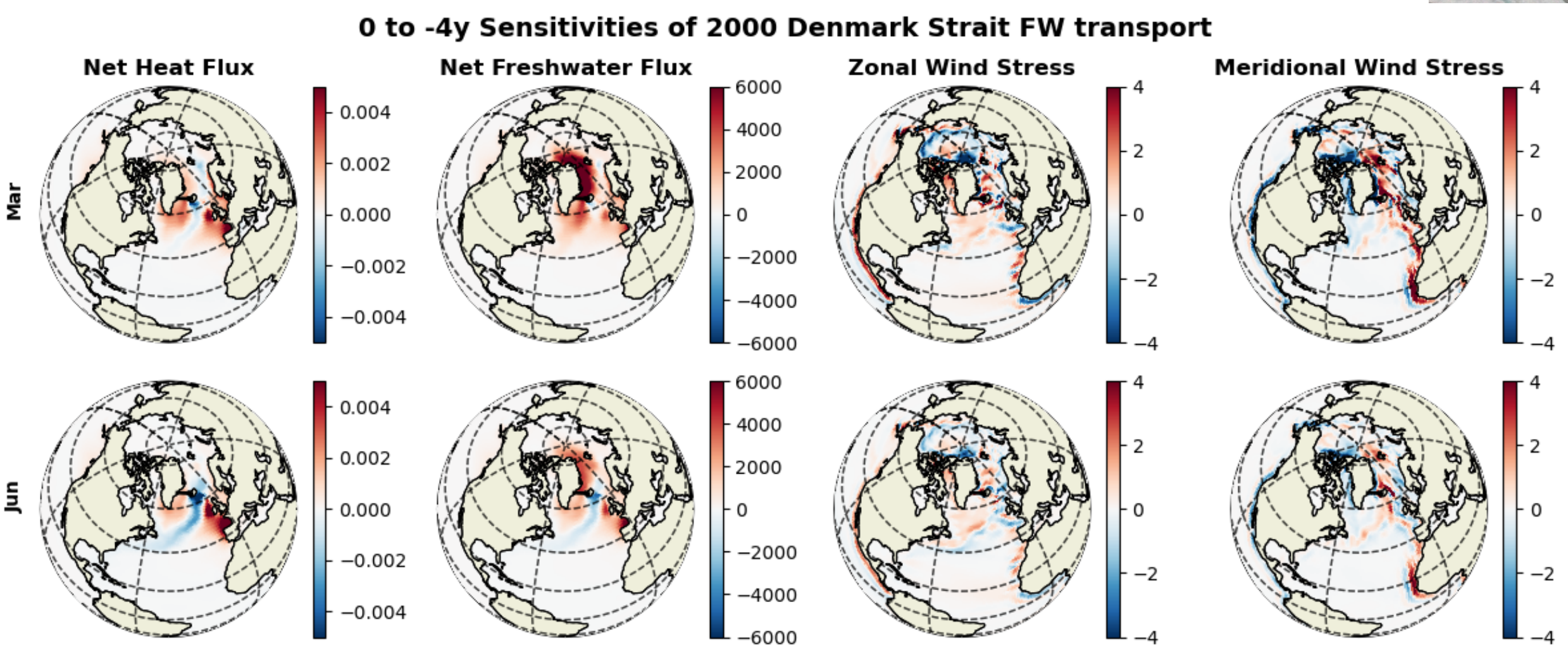
Adjoint Setup

- ECCOv4 r4 1992 - 2017
- Objective function: Monthly mean freshwater flux through Denmark Strait J
- Four experiments - March, June, September and December 2000
- Weekly averaged sensitivities output: $\frac{\partial J}{\partial F_i}(\mathbf{x}, t)$
- Modifications: Bulk formulae used in forward model but not differentiated in adjoint (as in Kostov et al. 2019)
- Reconstruct objective function by convolving sensitivities with forcing anomalies:

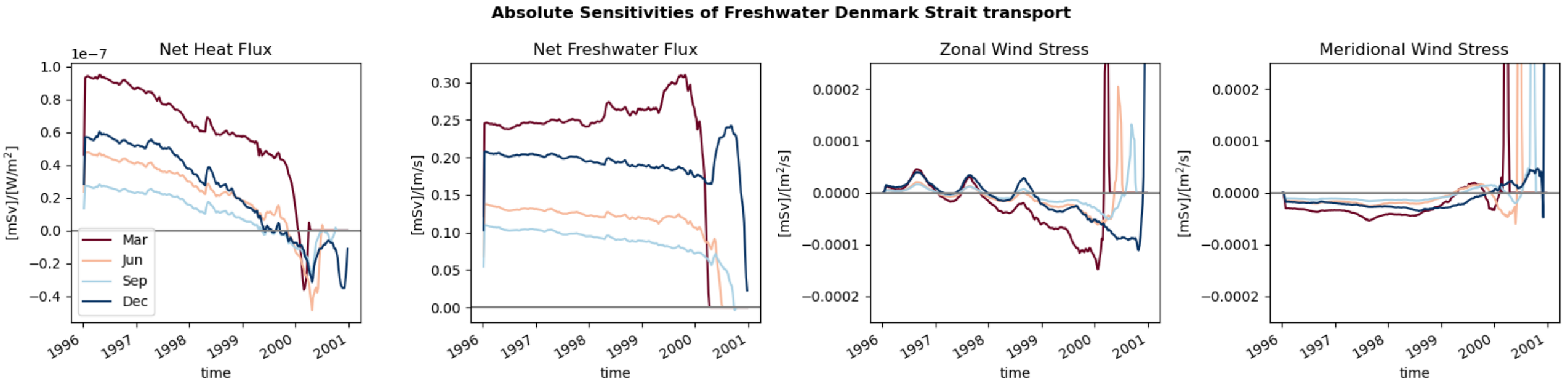
$$J(t) \approx \sum_i \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial J}{\partial F_i}(\mathbf{x}, \Delta t)\, \delta F_i(\mathbf{x}, t - \Delta t)$$



Results: sensitivities



Results: sensitivities

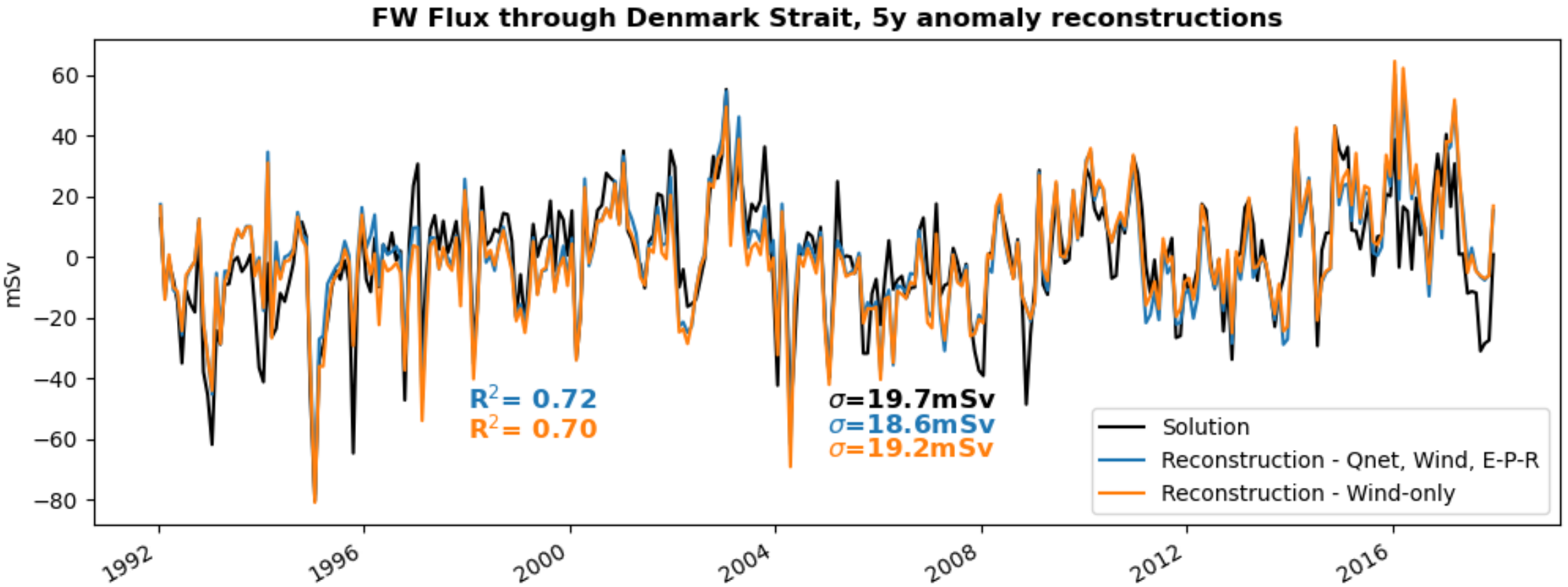


Buoyancy fluxes show sustained seasonal differences in sensitivity

Momentum fluxes show short-lived seasonal differences in sensitivity

Reconstruction

Up to 5 year lagged sensitivities, using March sensitivities for Feb and Apr, etc:



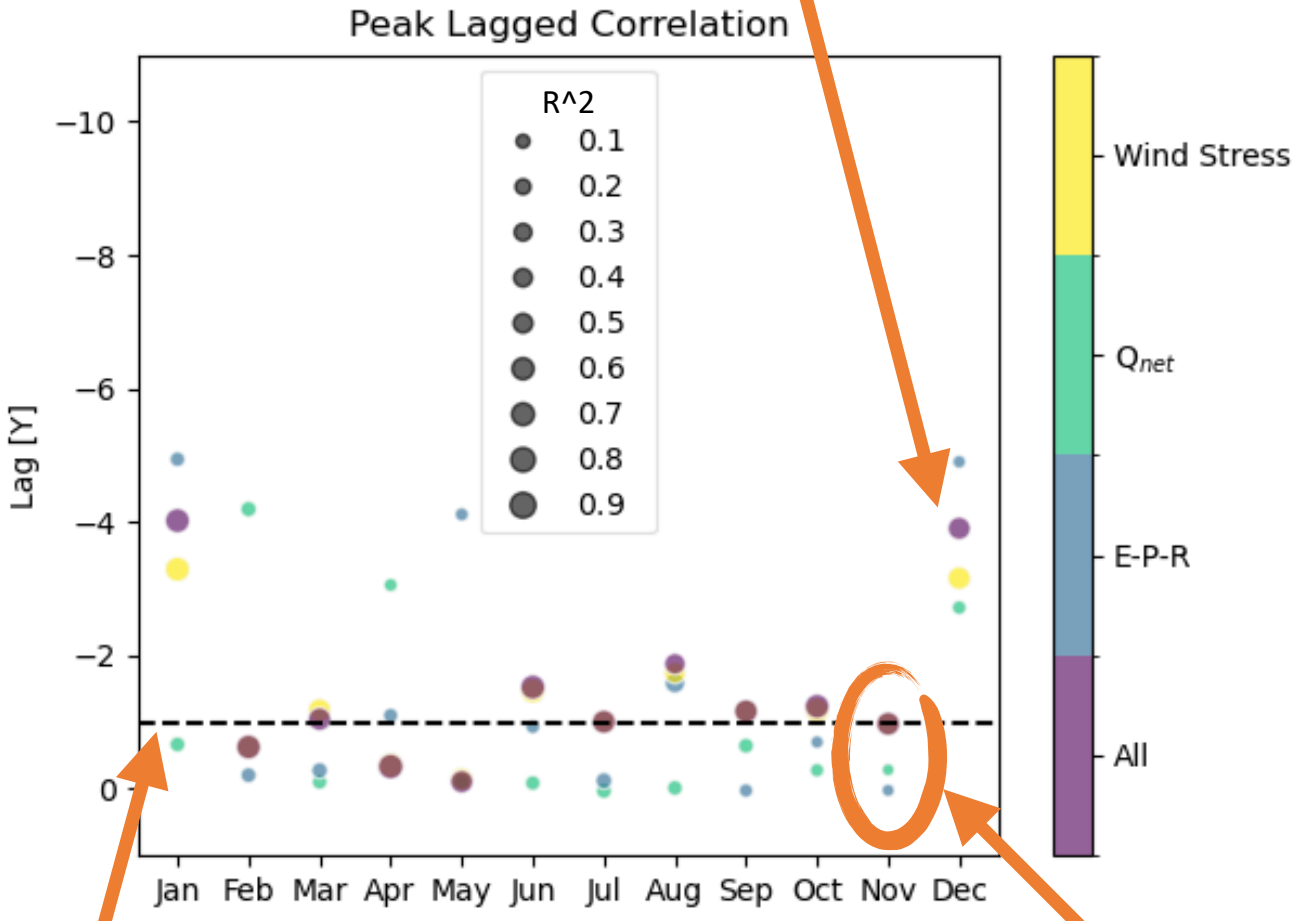
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

POLAR SCIENCE FOR PLANET EARTH

Reconstruction

$$J(t) \approx \sum_{i} \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial J}{\partial F_i}(\mathbf{x}, \Delta t)\, \delta F_i(\mathbf{x}, t - \Delta t)$$

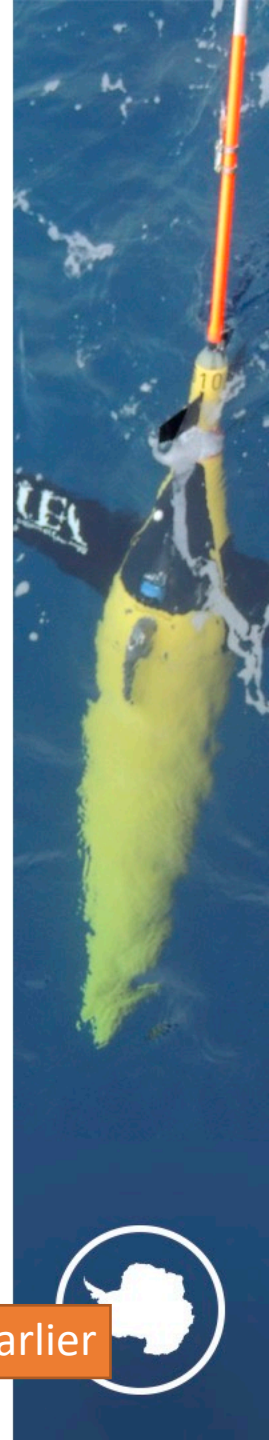
- Can determine the optimal ‘memory’ by finding the peak correlation with increasing integrated lag Δt
- Significant seasonal variation in optimal memory, from a few weeks to 4 years, by comparing monthly time series.



Peak correlation of Dec & Jan ~4y

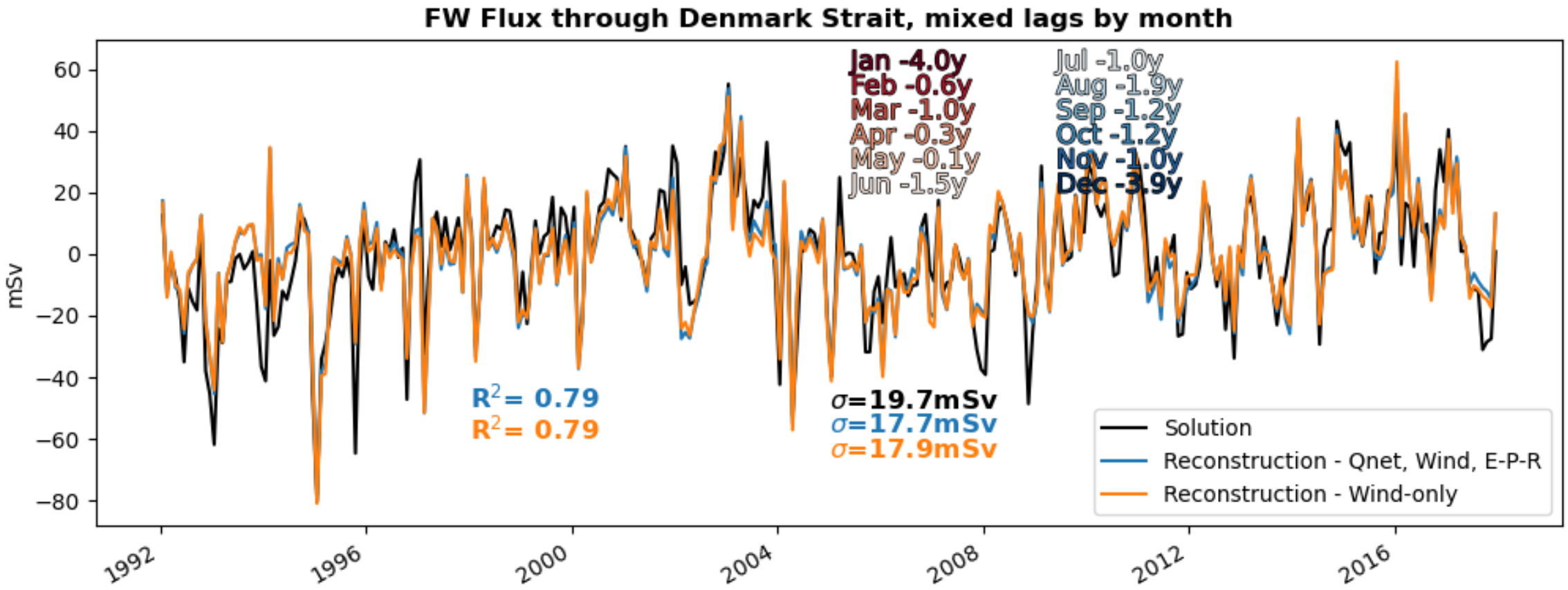
Peak correlation of full time series ~1 year

Nov uses Dec sensitivities but peaks earlier



Reconstruction

Using optimal memory to reconstruct each month increases explained variance from **72%** to **79%**



Summary

- **Successful reconstruction** of Denmark Strait Freshwater Transport possible using 5 year adjoint sensitivity experiments based on a single year.
- Reconstruction extremely dominated by **wind contributions.**
- Significant **seasonal variation** in **optimal memory** of the reconstruction - December and January in particular have a longer memory of around 4 years.
- Further investigations planned, including perturbation experiments.
- Comparison with other gateways planned.

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

POLAR SCIENCE FOR PLANET EARTH