Response of the Atlantic Ocean Circulation to Greenland Ice Sheet Melting

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Weijer et al., GRL 2012

Atlantic Meridional Overturning Circulation (AMOC)

- **How sensitive is AMOC to GrIS freshwater input?**
- **2007 mass deficit: 267 ± 38 Gt/yr (Rignot et al. 2008)**
  - ~ 0.01 Sv
  - Freshwater input expected to increase
    - Surface melting
    - Precipitation
    - Calving
- **Studied exclusively in low-resolution ocean models**
  - No explicit eddies, effects parameterized
  - Sluggish, broad boundary currents
  - Freshwater input over large area Greenland Ice Sheet

Research Question

- **Does enhanced model resolution modify AMOC sensitivity?**
  - More accurate representation of ocean transports
    - Boundary currents
    - Eddy fluxes
  - Less reliance on parameterizations
- **Does result depend on spatial pattern of freshwater forcing?**
- **Approach**
  - Perform freshwater sensitivity studies in hierarchy of models
    - 1 degree and 0.1 degree
  - Different freshwater flux patterns
    - Realistic distribution of freshwater around Greenland
    - Hosing

The Model

- **Los Alamos' Parallel Ocean Program (POP 2.0)**
  - Global domain
  - Ocean-only
- **2 configurations**
  - 1^{o} ("by-one")
    - non-eddying
    - IPCC class
    - 40 levels
    - Dipole, displaced pole over Greenland
  - 0.1^{o} ("point-one")
    - strongly eddying
    - 42 levels
    - tripole

Forcing

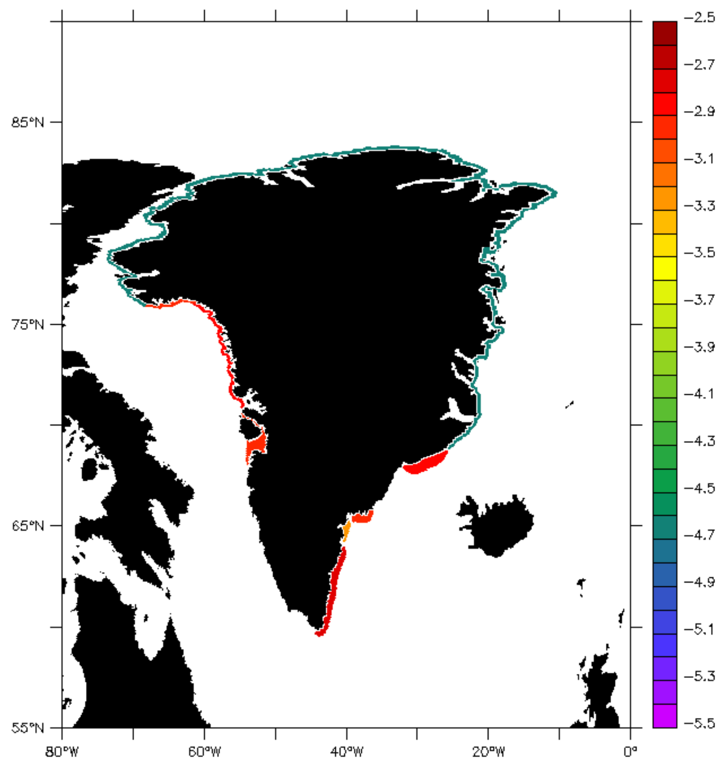
- **CORE monthly-mean normal-year atmospheric climatology**
  - Large & Yeager (2004) data
  - Standard bulk formulae
- **SST**
  - Latent heat flux
  - Sensible heat flux
  - Radiation
- **SSS**
  - Precipitation
  - Evaporation
  - Run-off
  - Flux correction
    - Mixed boundary conditions
    - No relaxation

Experimental Procedure: Spin-up + 3 Branches

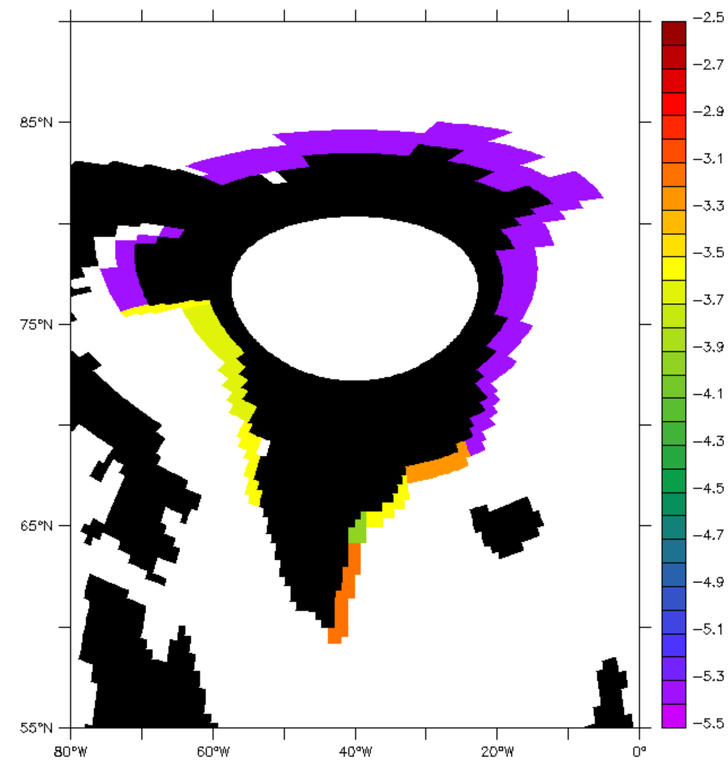
- **C-Mixed: Control Integration**
- **E-Greenland: Greenland Freshwater**
  - 'Realistic' near-coastal distribution around Greenland *(Rignot & Kanagaratnam 2006)*
  - Time-mean amplitude 0.1 Sv *(Gerdes et al. 2006)*
  - Seasonal variation
- **E-Hosing: Traditional Hosing**
  - Distribution North Atlantic 50^o-70^oN (CMIP)
  - Constant 0.1 Sv flux

E-Greenland Freshwater Perturbation

0.1°



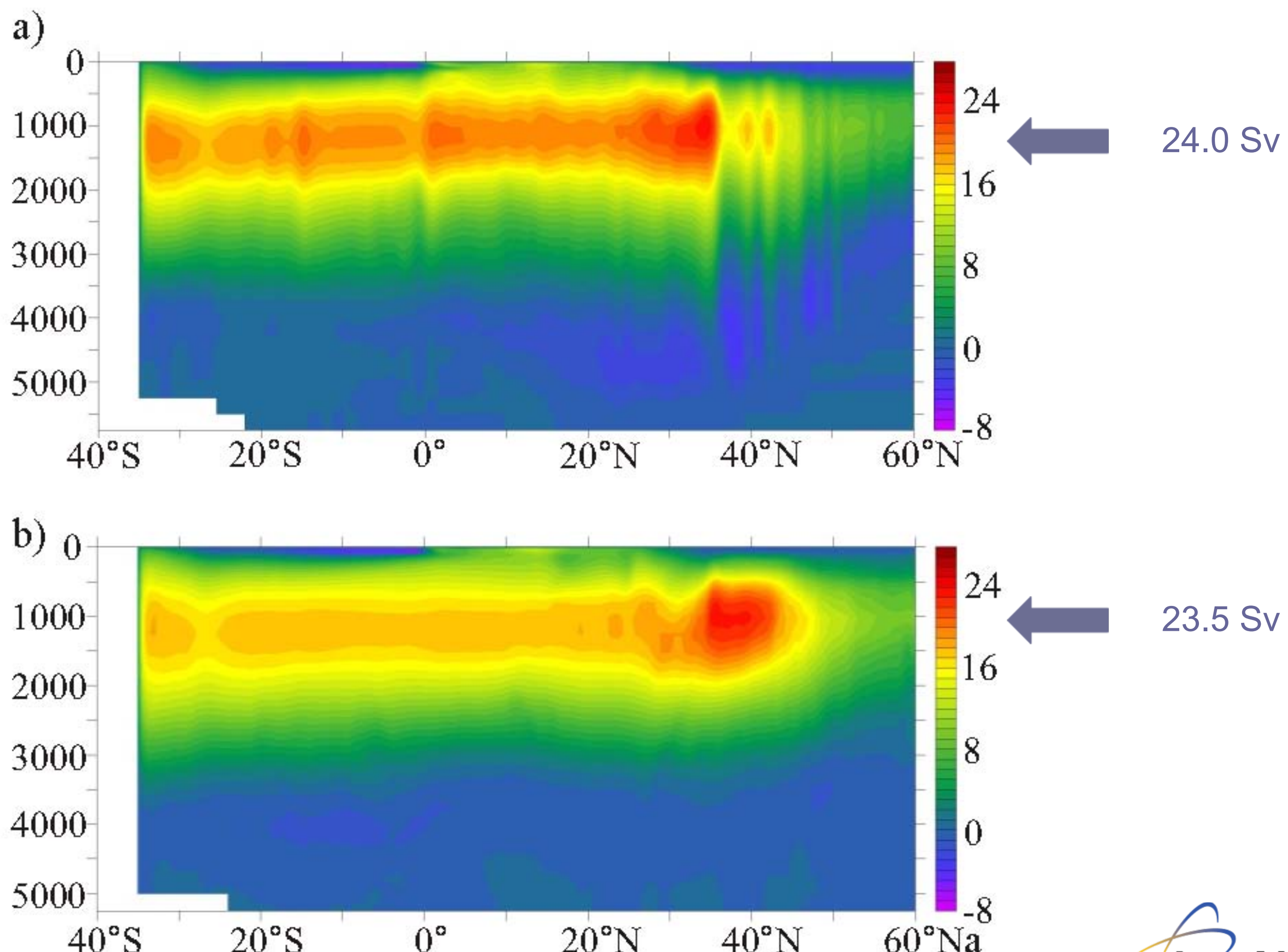
1.0°



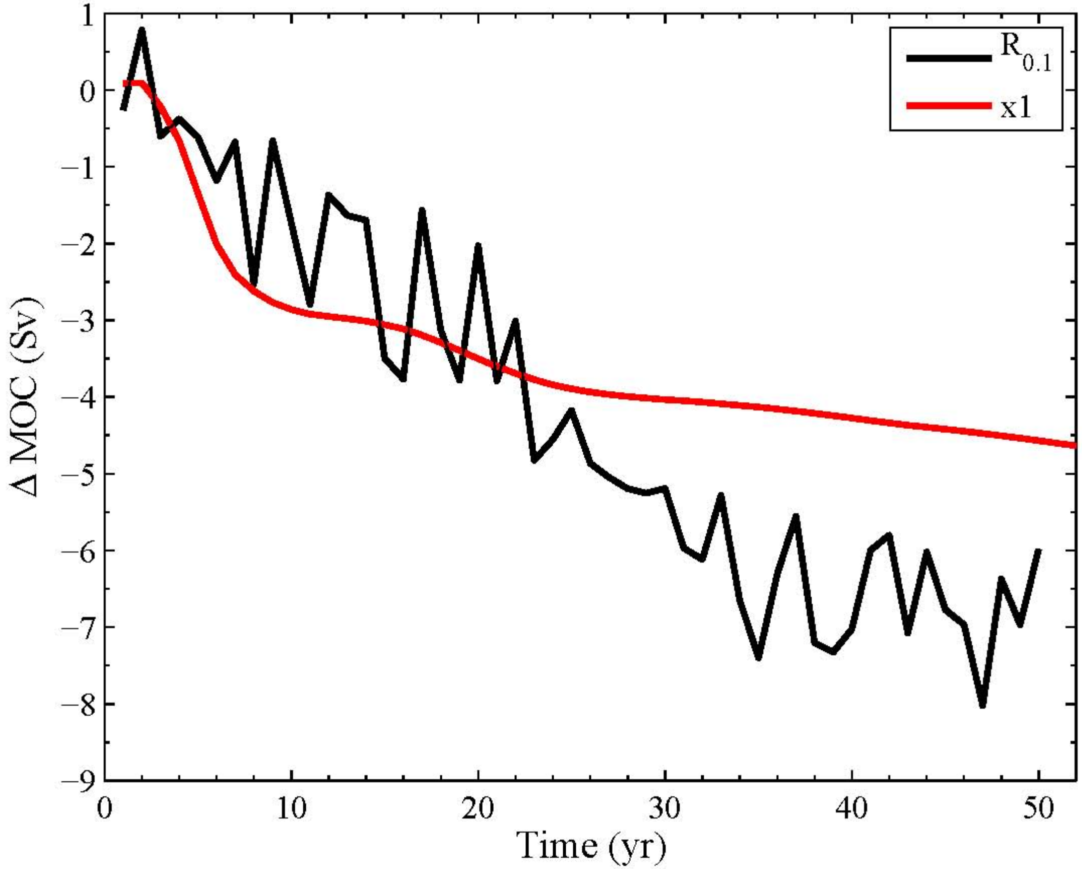
Overturning Streamfunction

0.1°

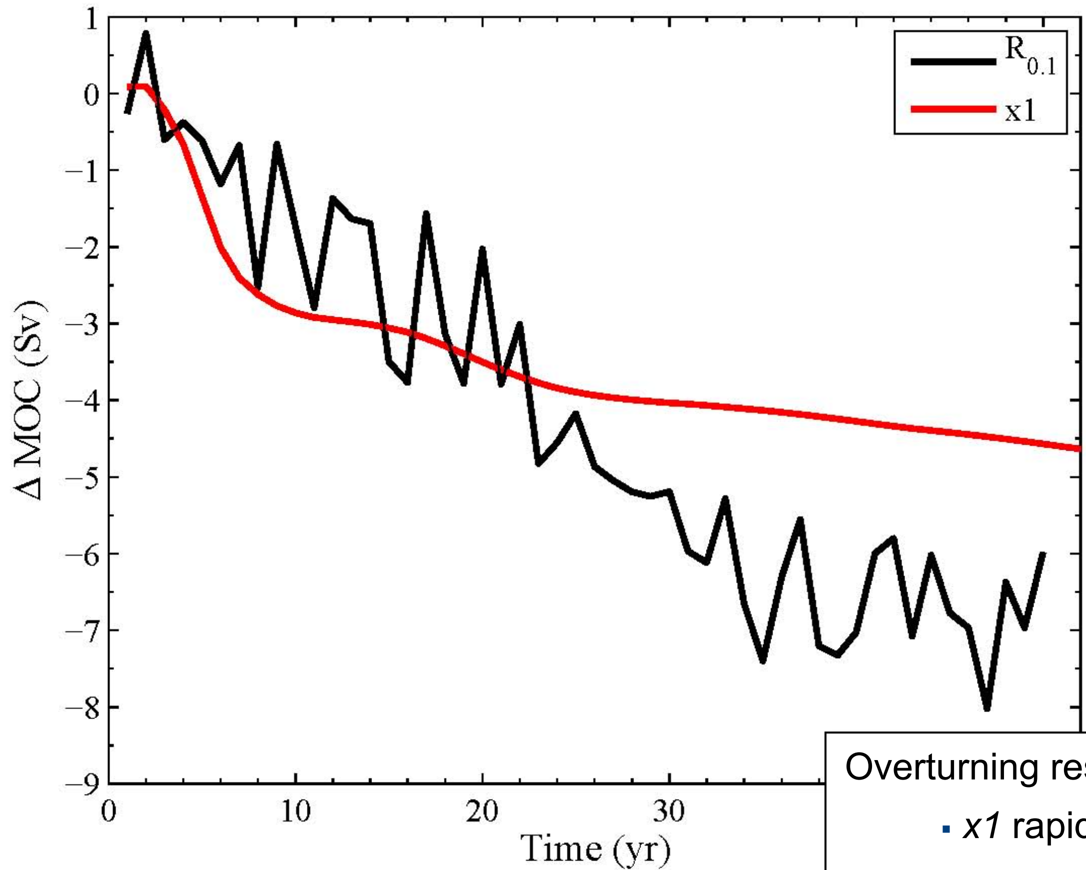
1.0°



Overturning Response: E-Greenland



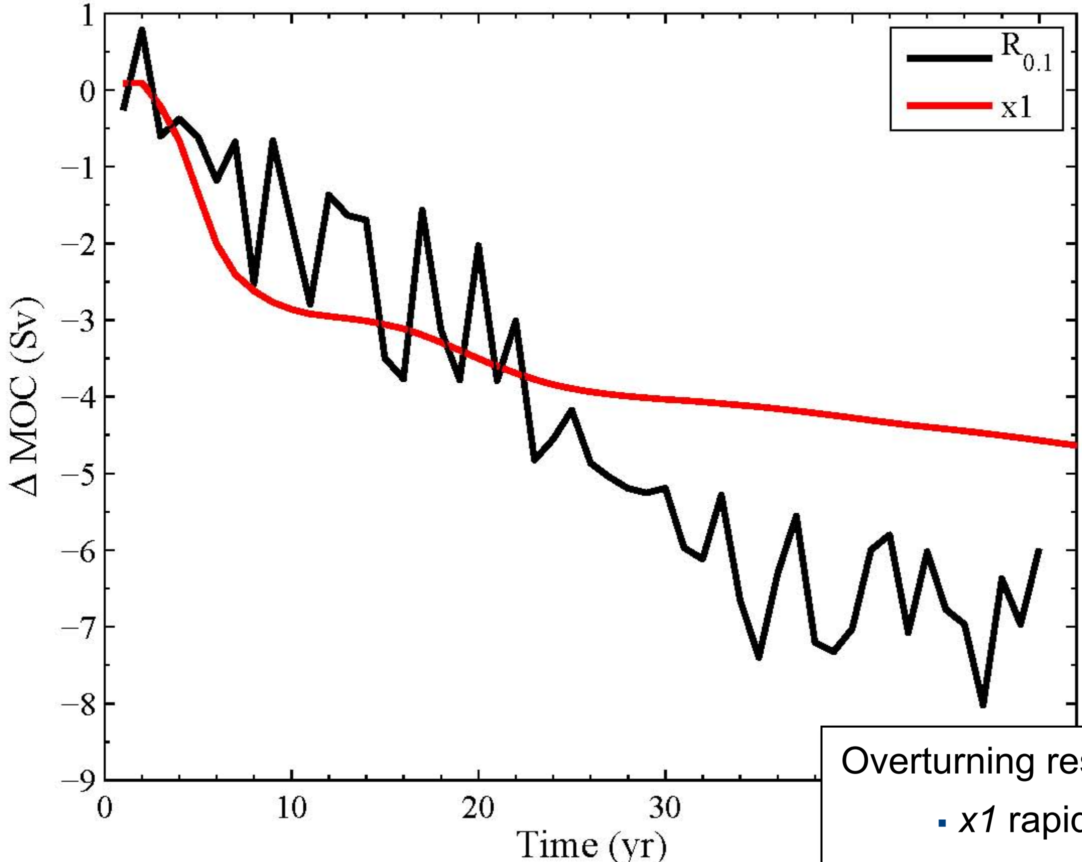
Overturning Response: E-Greenland



Overturning response:

- *x1* rapid initial adjustment

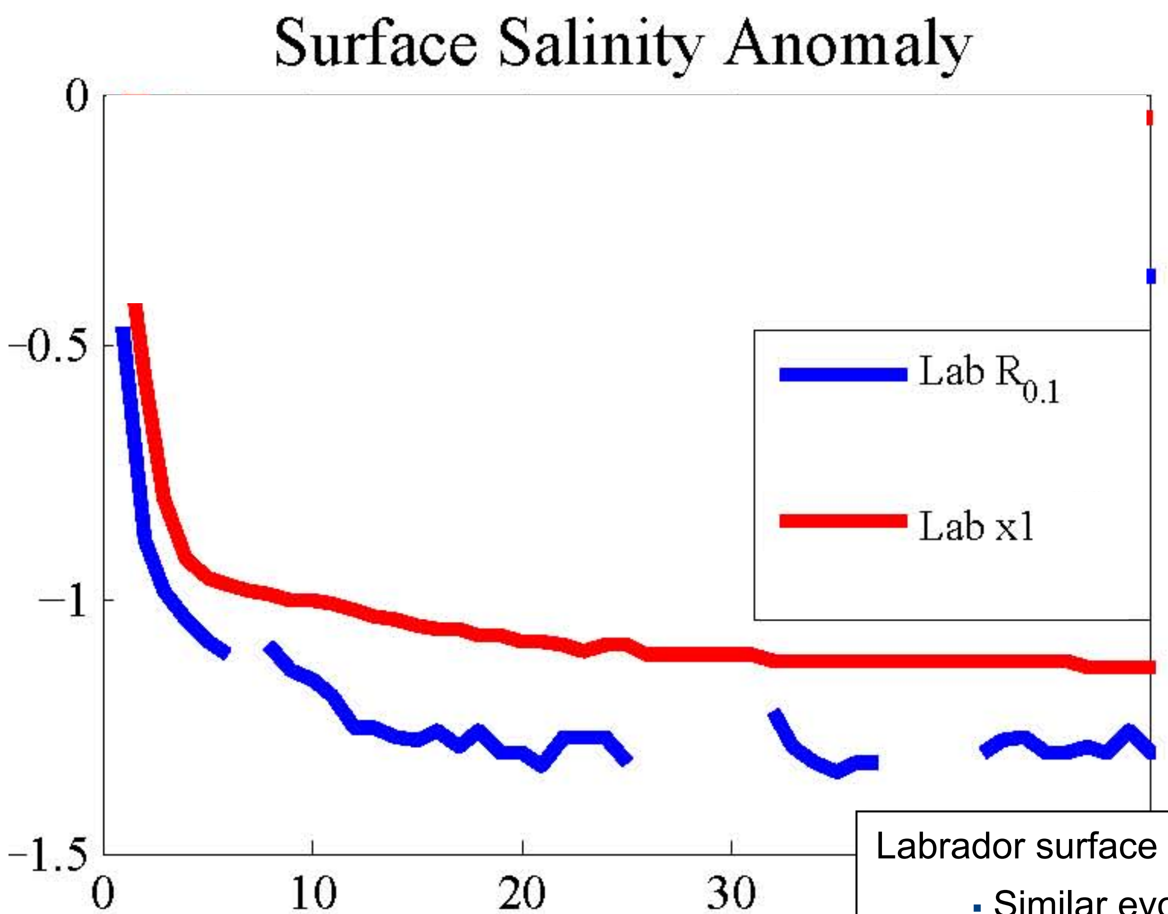
Overturning Response: E-Greenland



Overturning response:

- *x1* rapid initial adjustment
- $R_{0.1}$ more gradual, persistent

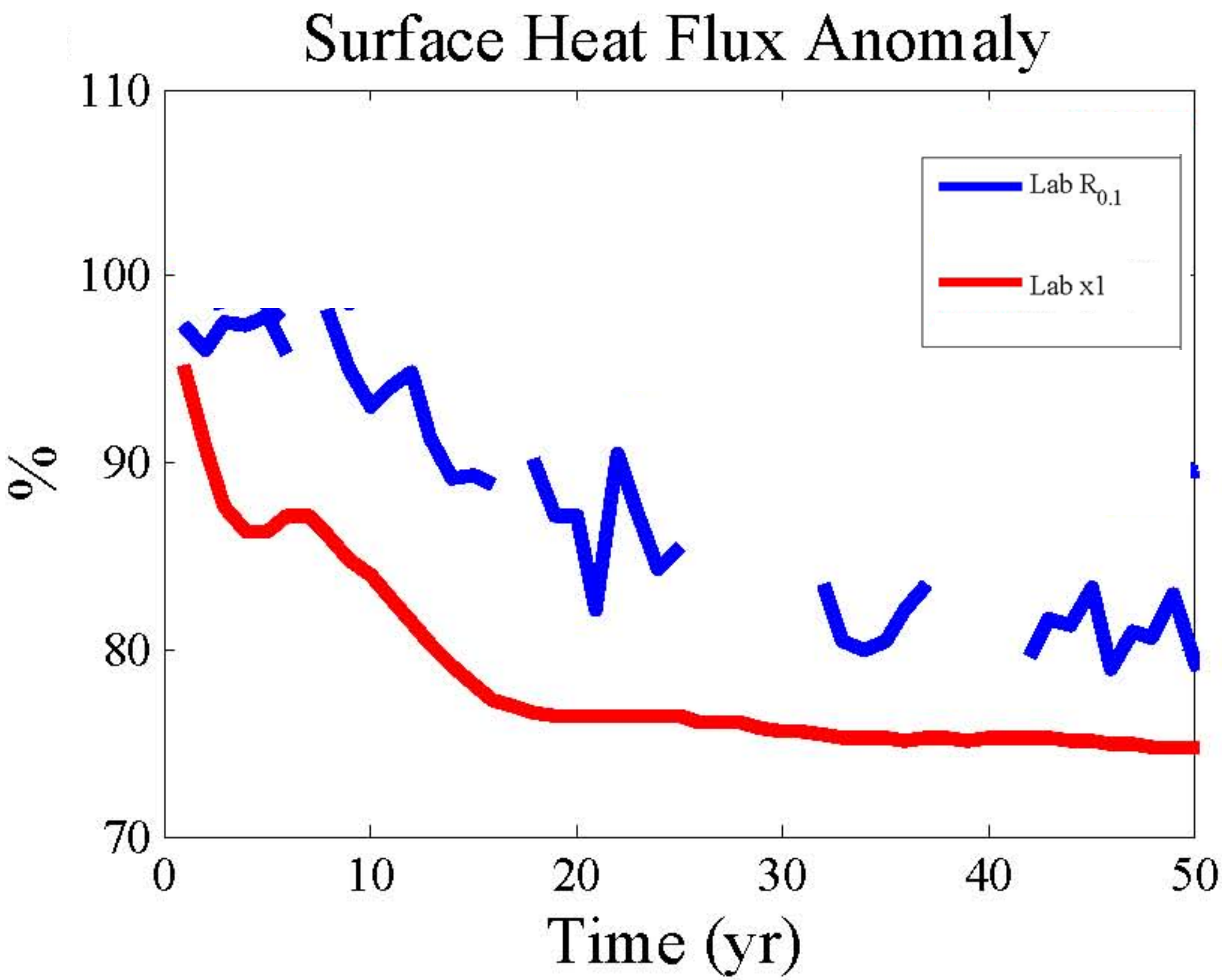
Surface Salinity: E-Greenland



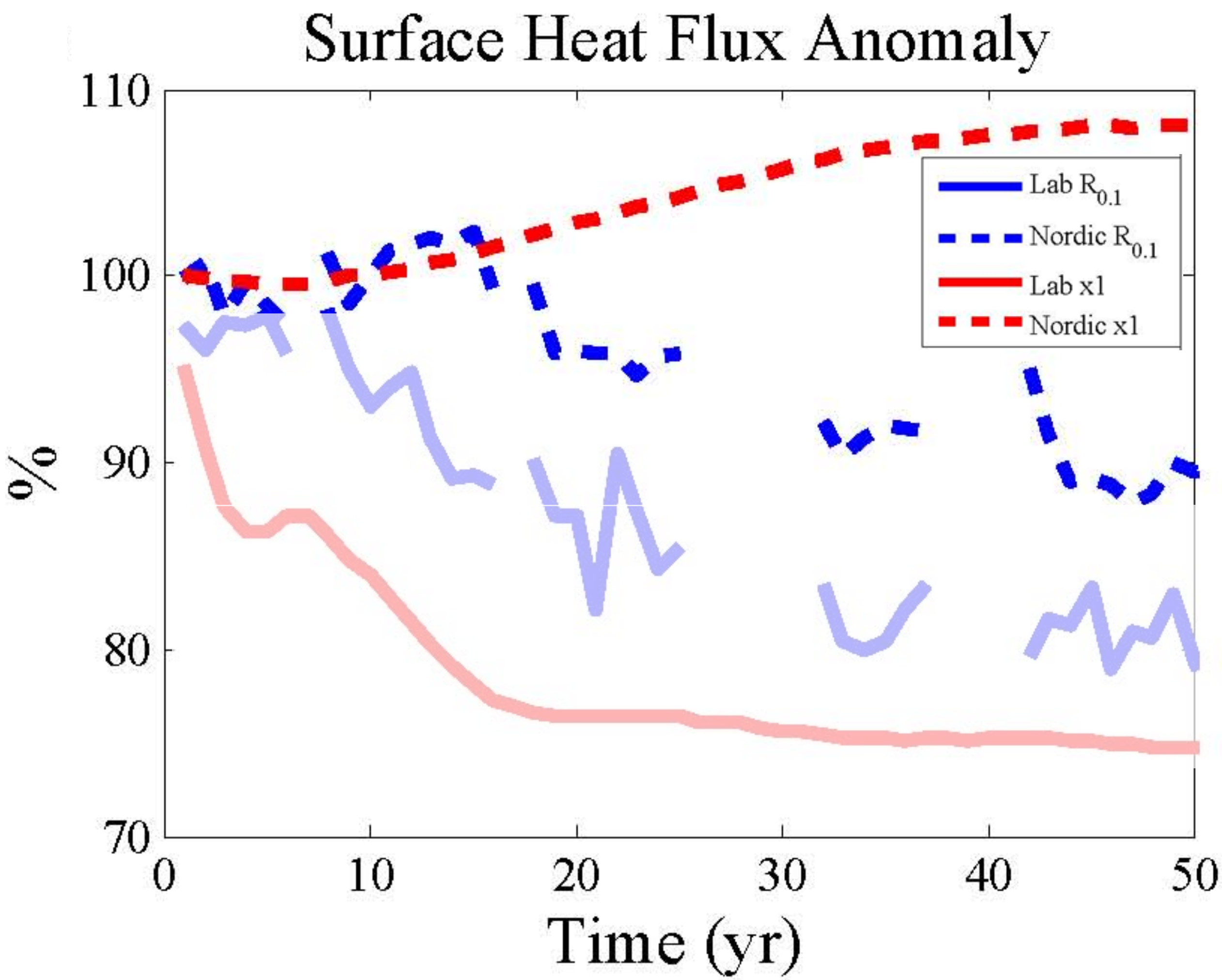
Labrador surface salinity:

- Similar evolution

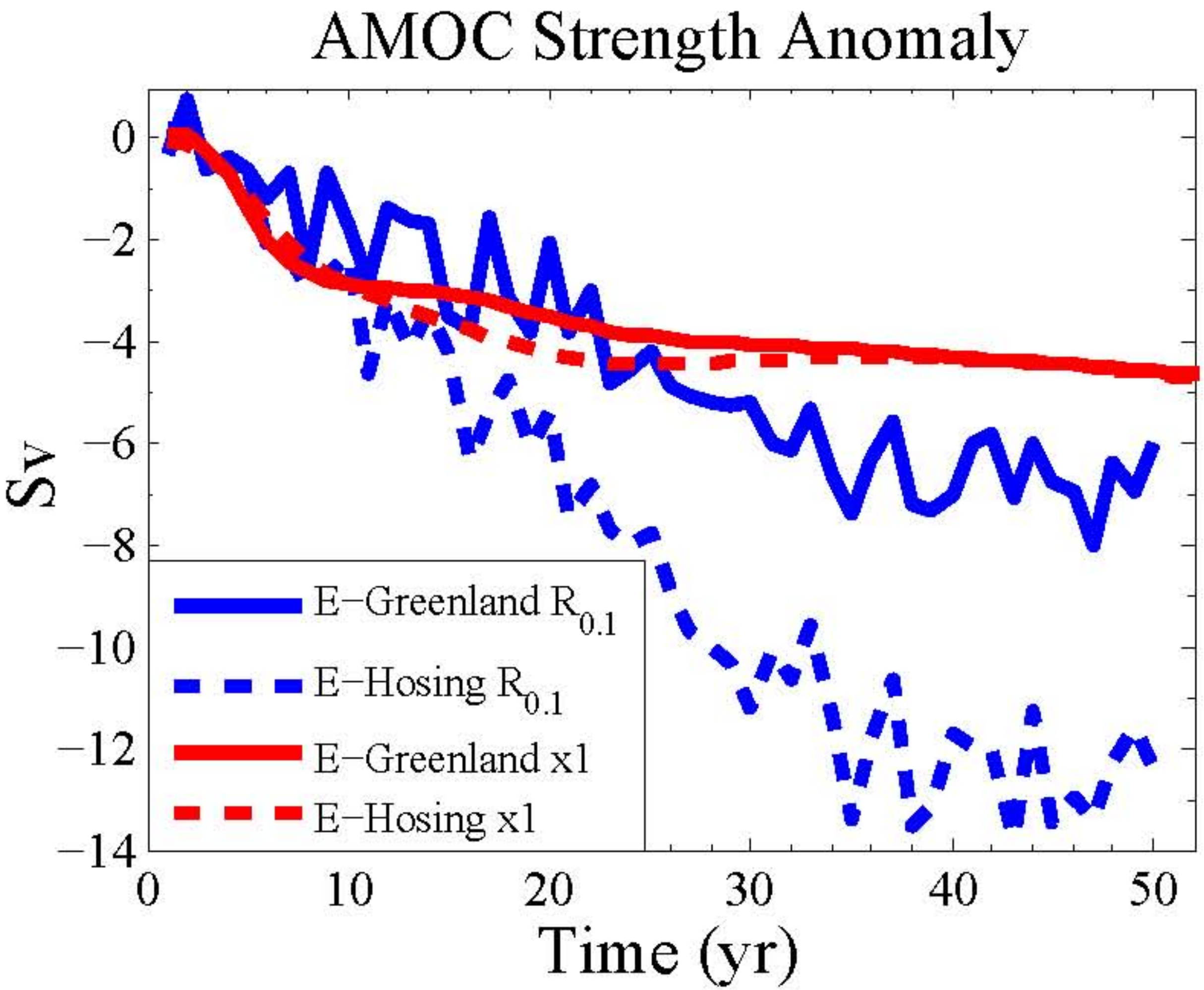
Surface Heat Flux: E-Greenland



Surface Heat Flux: E-Greenland



Overturning Response: Hosing



New Results: 0.5 Sv Perturbation

Den Toom et al. (in prep.)

$$\psi(\varphi,b,t) = -r_0 \cos\varphi \int_{\lambda_W}^{\lambda_E} \int_{-H}^{\zeta(\lambda,\varphi,b,t)} v(\lambda,\varphi,z,t)\, dz\, d\lambda$$ *Streamfunction*

$$V(\varphi,b,t) = r_0 \cos\varphi \int_{\varphi}^{90N} \int_{\lambda_W}^{\lambda_E} \int_{-H}^{\zeta(\lambda,\varphi,b,t)} dz\, d\lambda\, d\varphi$$ *Volume*

$$G(\varphi,b,t) = \psi(\varphi,b,t) + \frac{\partial V(\varphi,b,t)}{\partial t}$$ *Transformation streamfunction*

e.g., Marsh et al. (2000); Wolfe & Cessi (2011)

New Results: 0.5 Sv Perturbation

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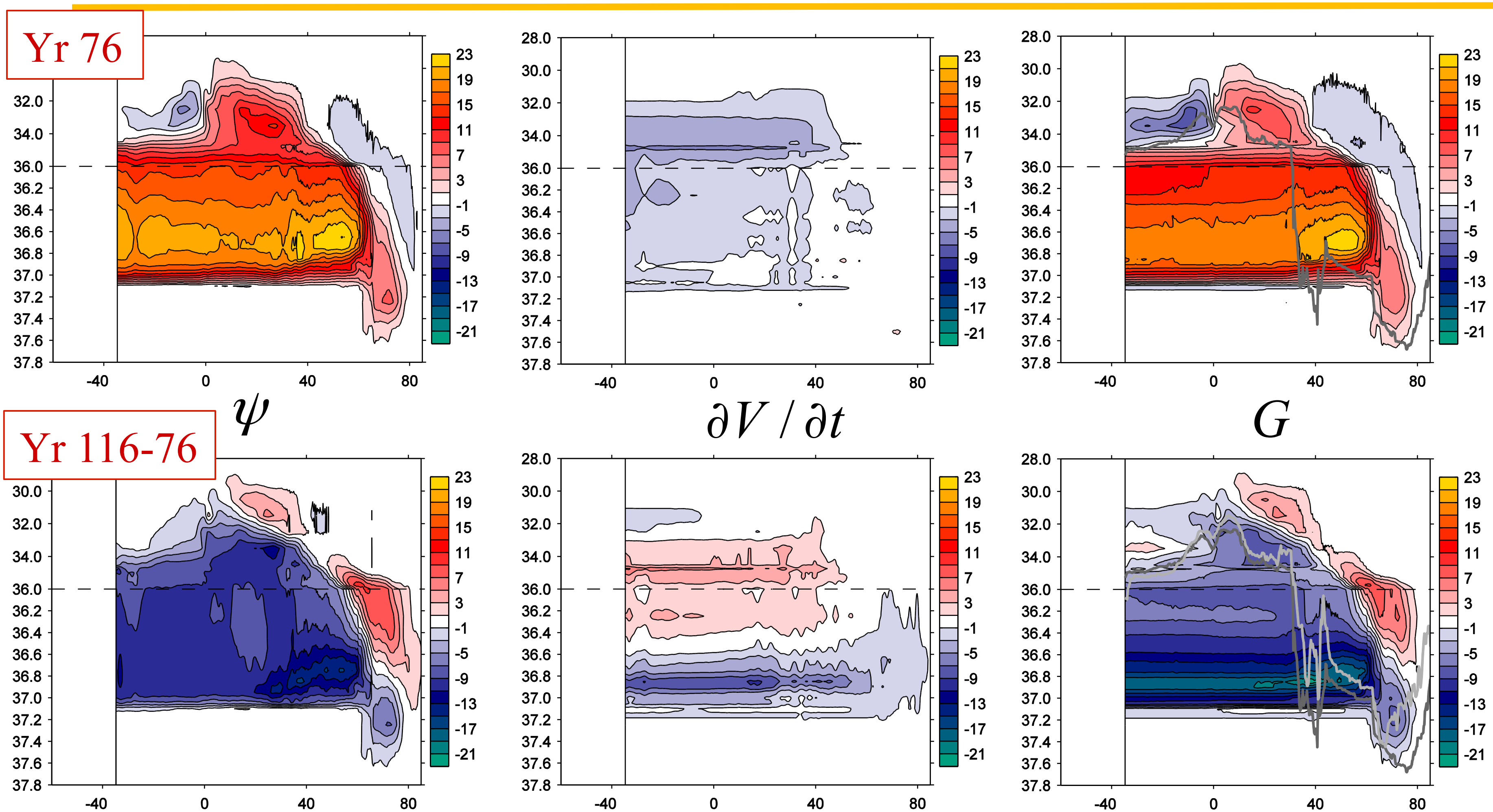

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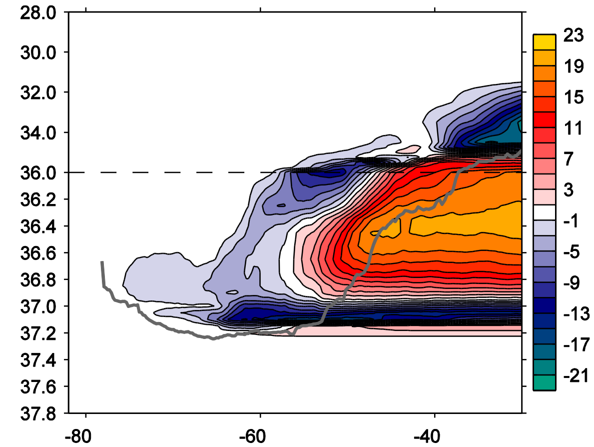
Den Toom et al. (in prep.)

Yr 76



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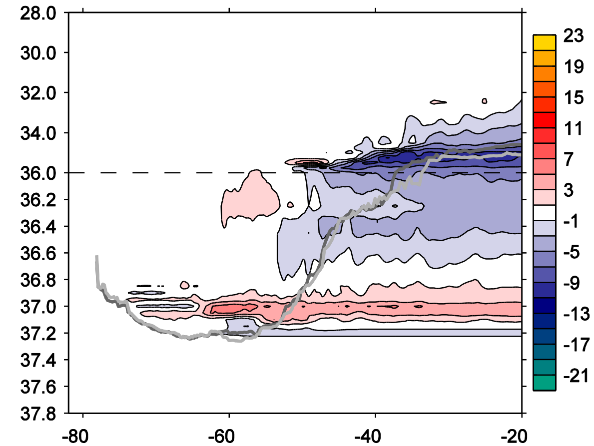
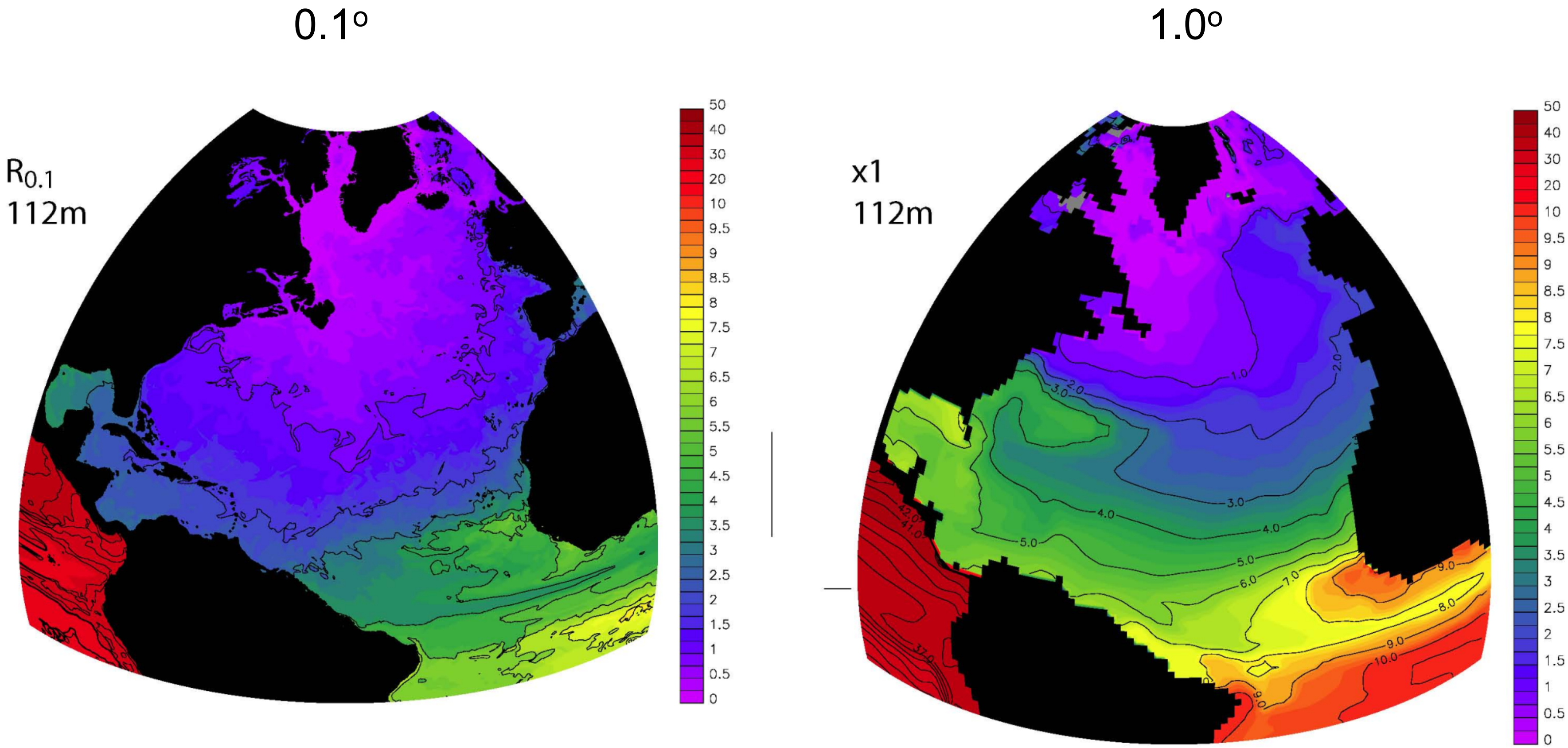


Conclusions

- **Greenland freshwater flux perturbations**
  - No quantitative difference in MOC response
  - Qualitative differences
    - Rapid initial adjustment in *x1*
    - Gradual, more persistent in $R_{0.1}$
      - Deep convection more resilient to freshwater perturbation
      - Increase of Nordic Seas ventilation in *x1*
- **E-Greenland vs. E-Hosing**
  - No difference in *x1*
  - $R_{0.1}$ much more sensitive to *spatial distribution*
- **Adiabatic pole-to-pole: limited predictive value for transient response**

Dye Arrival Time (112 m)



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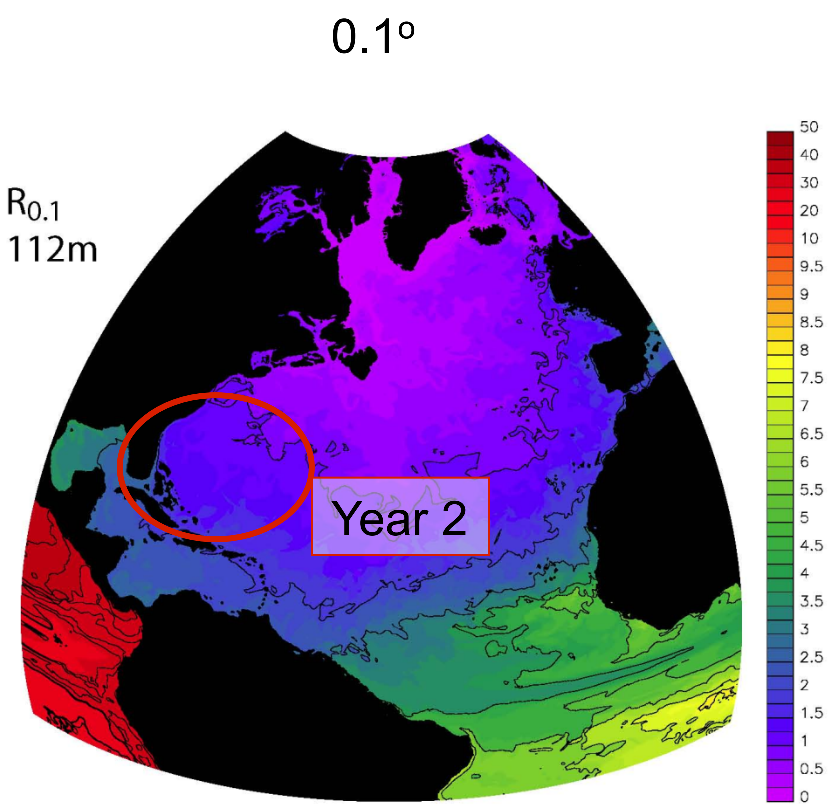

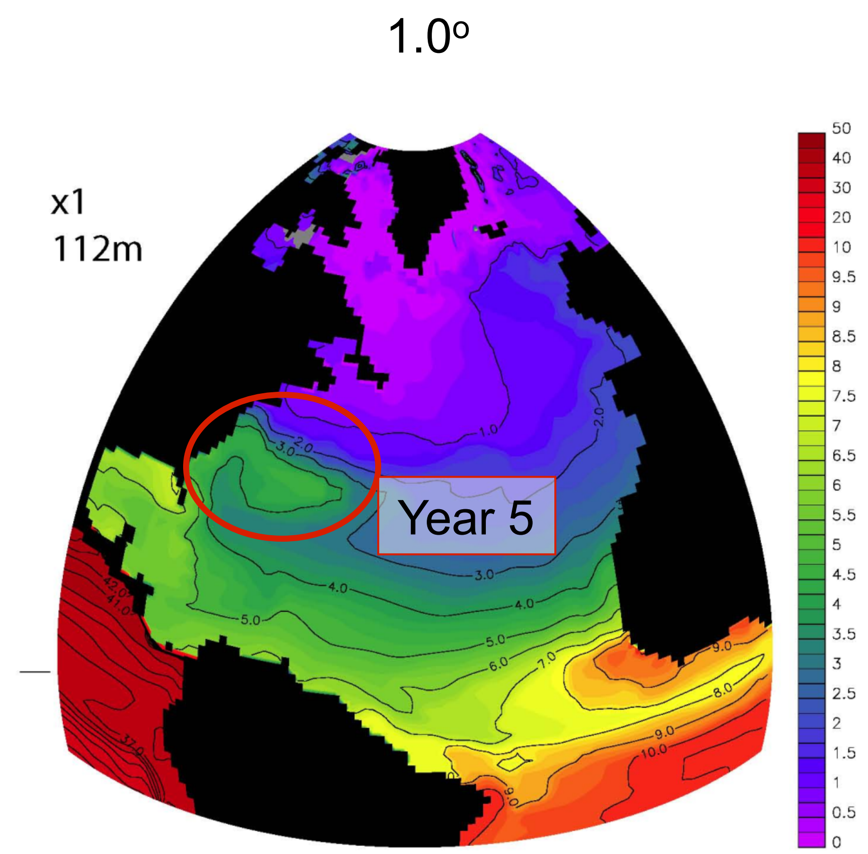

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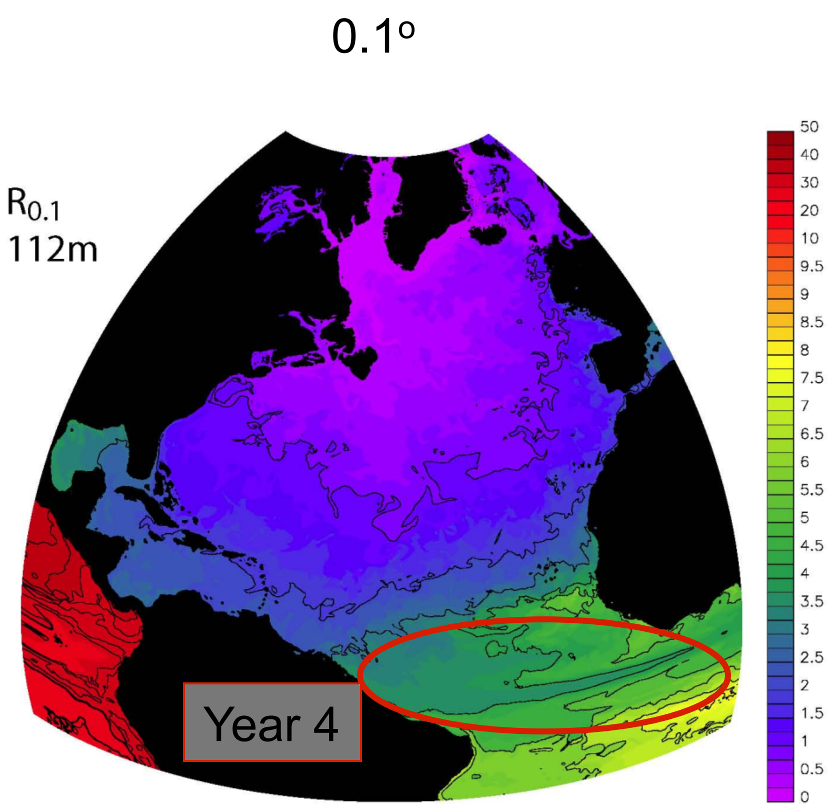

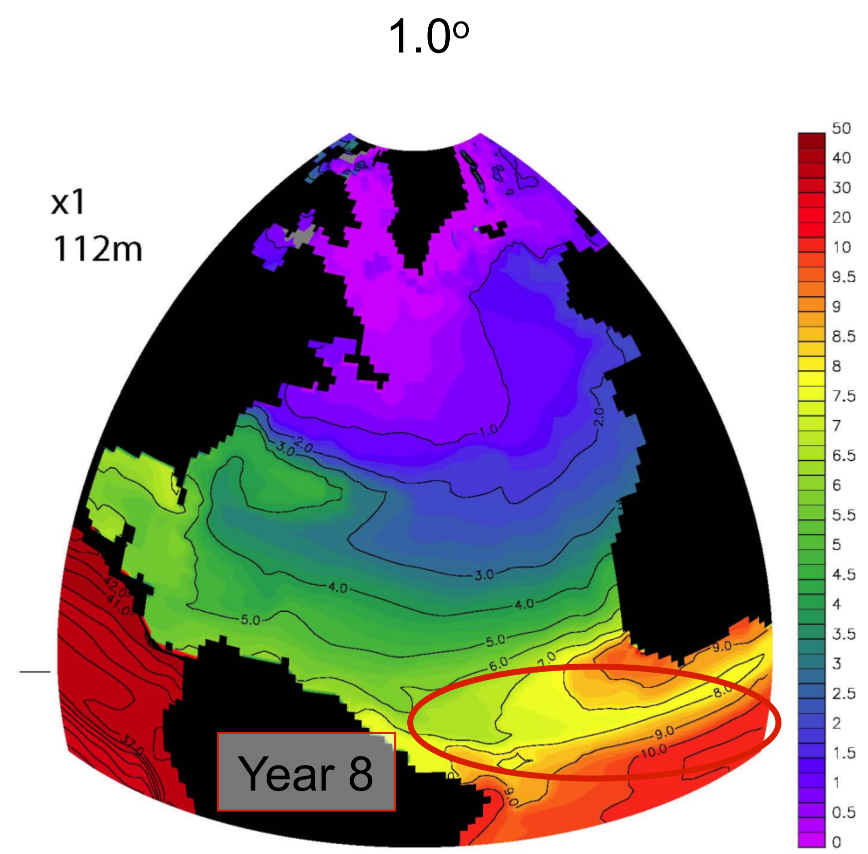

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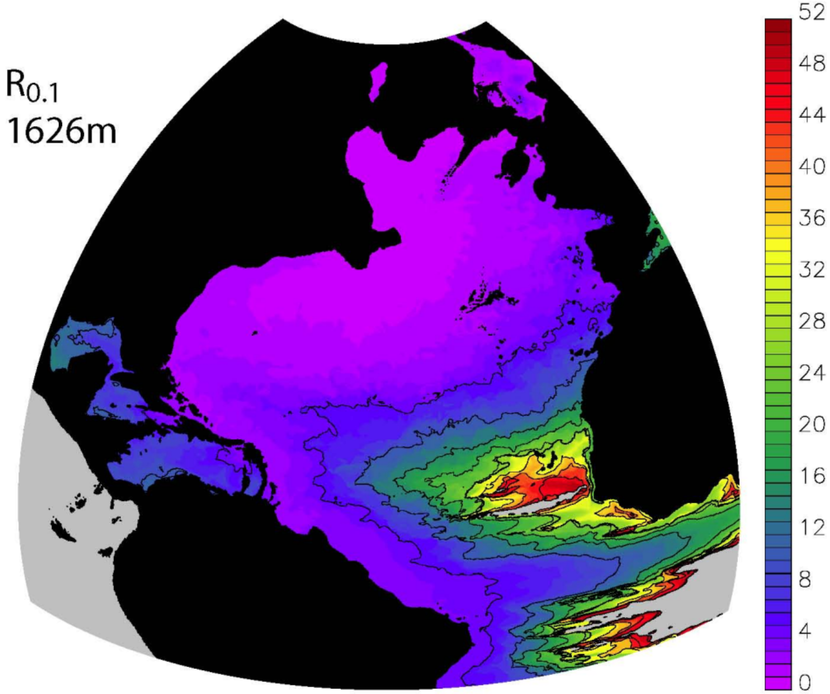
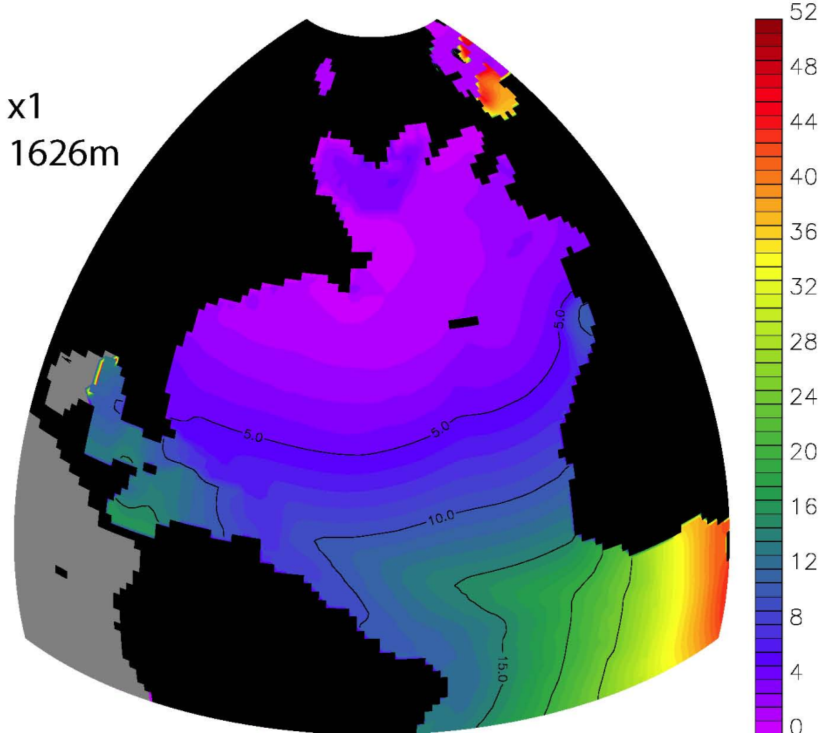
Dye Arrival Time (1626 m)

0.1°



1.0°



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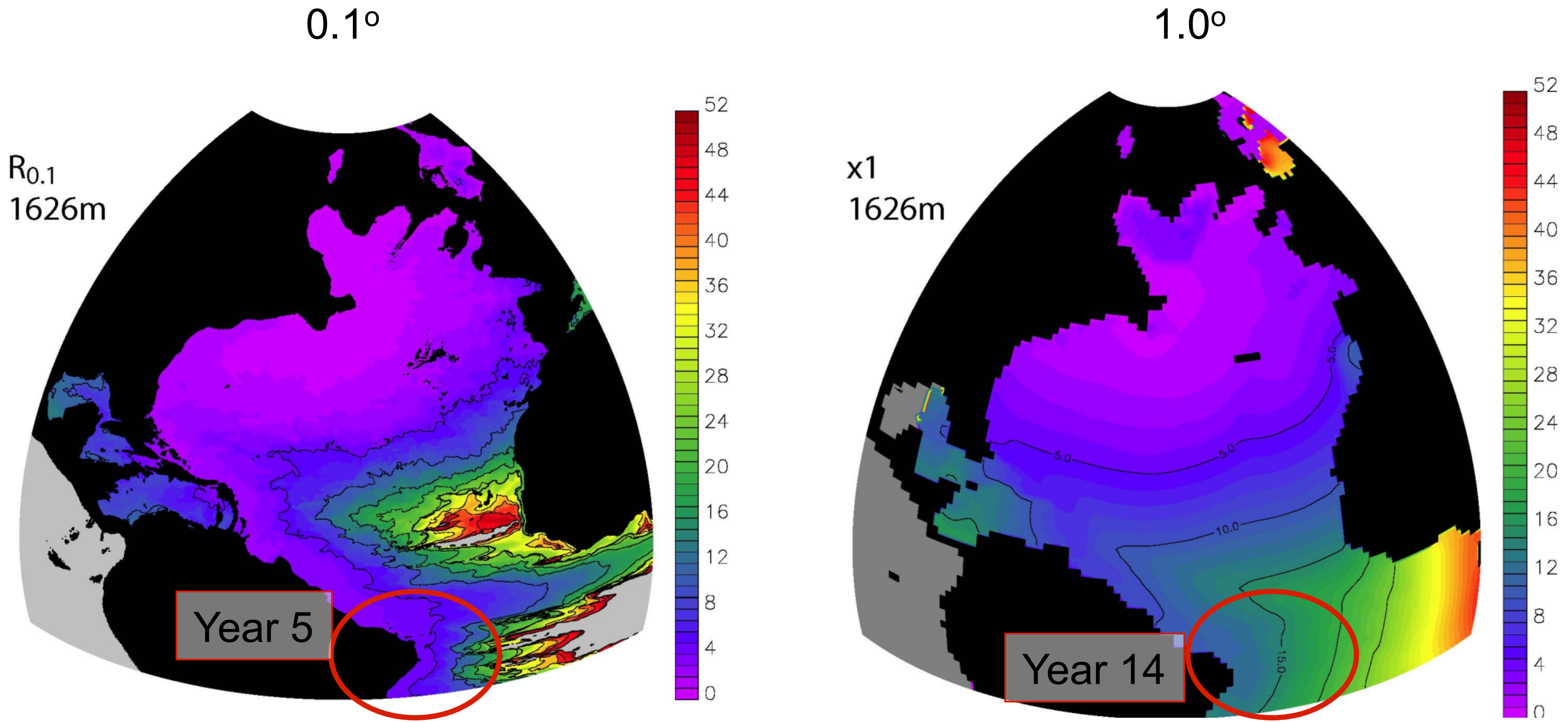

Dye Arrival Time (1626 m)