An observationally constrained assessment of the northern high latitude coupled energy budget

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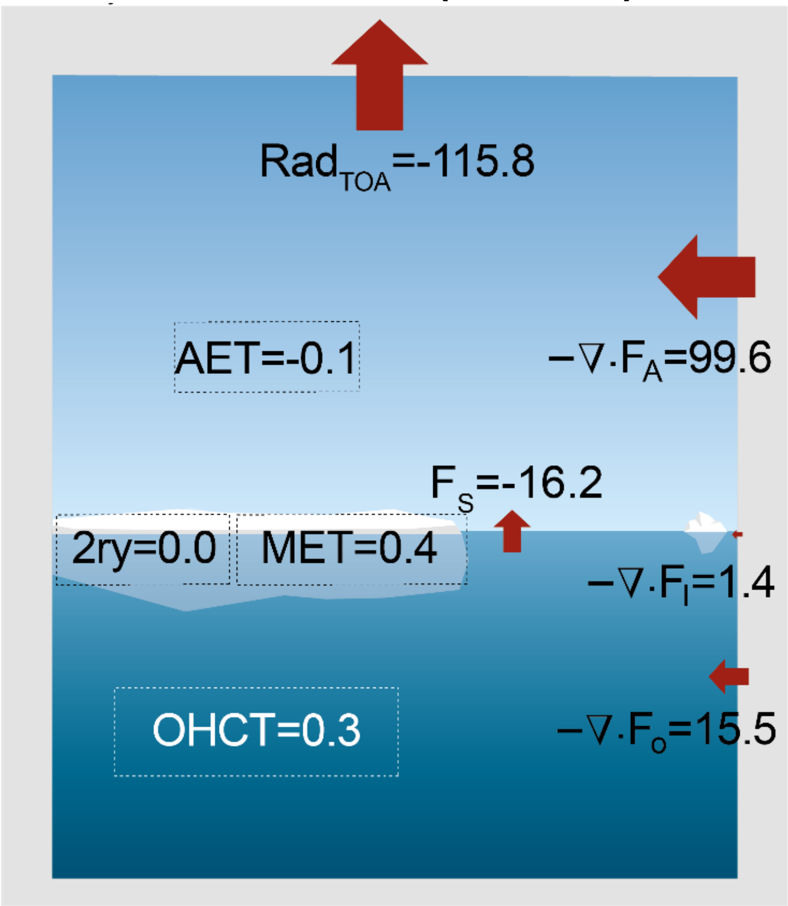
Introduction

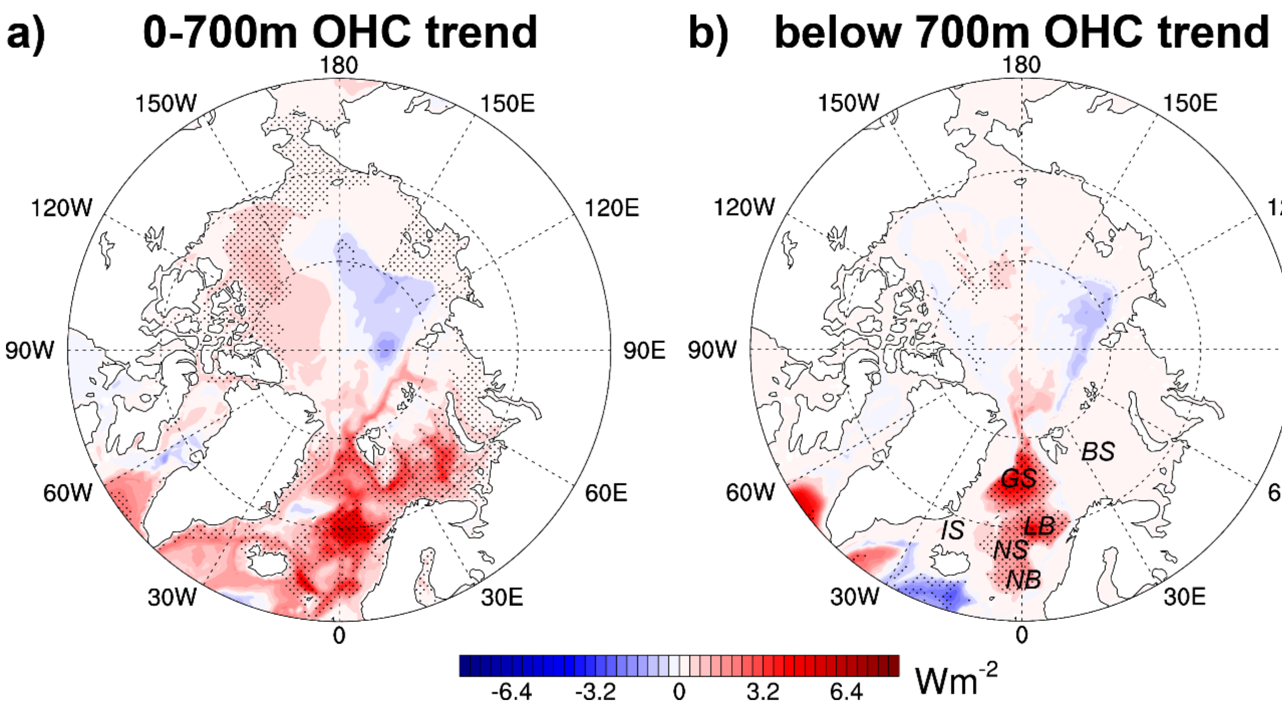
- Combine satellite data (CERES-EBAF, Cryosat2…), oceanic insitu-observations (T/S/V from moorings), and reanalyses (C3S ERA5; CMEMS GREP, …) to obtain a consistent estimate of the Arctic energy budget
- Largely independent estimates of various budget terms are already highly consistent - full budget closure obtained through a variational approach
- **In this presentation:**
  1) Different perspectives on Arctic Ocean warming
  2) Monitoring of high-latitude oceanic transports

Mean Arctic Energy budget 2005-2009 (in Wm^{-2})



Mayer et al. (2019)

Arctic Ocean warming 1993-2019



OHC data from 4 ocean reanalyses

- Large spatial variability in oceanic warming
- Long-term warming over 60-90N is ~0.8 Wm^{-2} plus 0.2 Wm^{-2} when taking sea ice melt into account – similar to global average ocean heat uptake
- How can this be reconciled with Arctic amplification?

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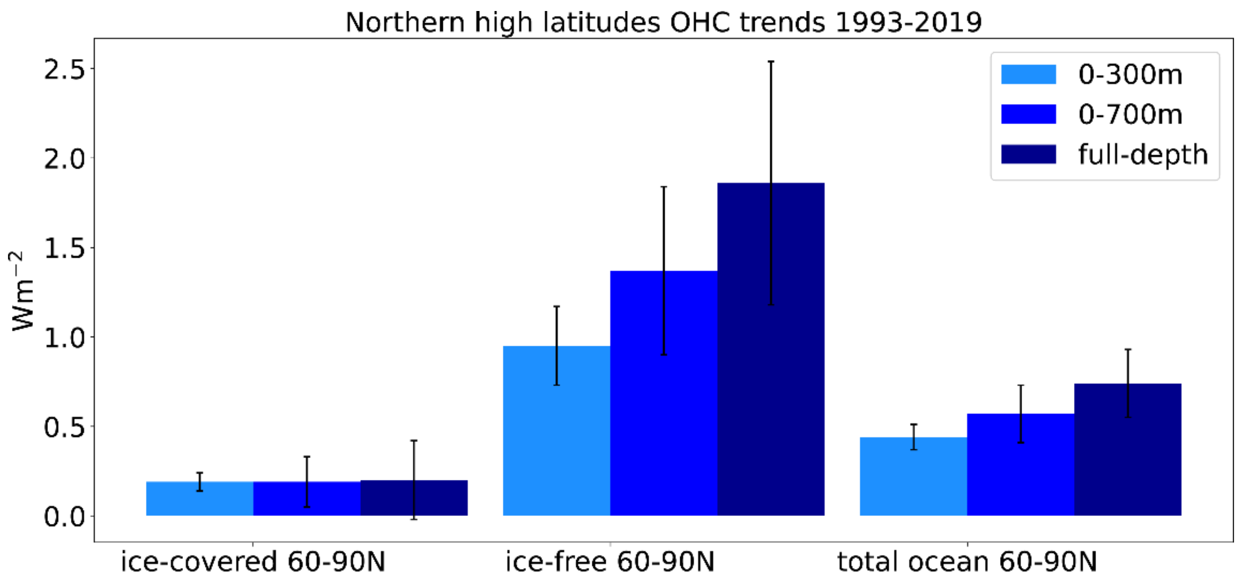
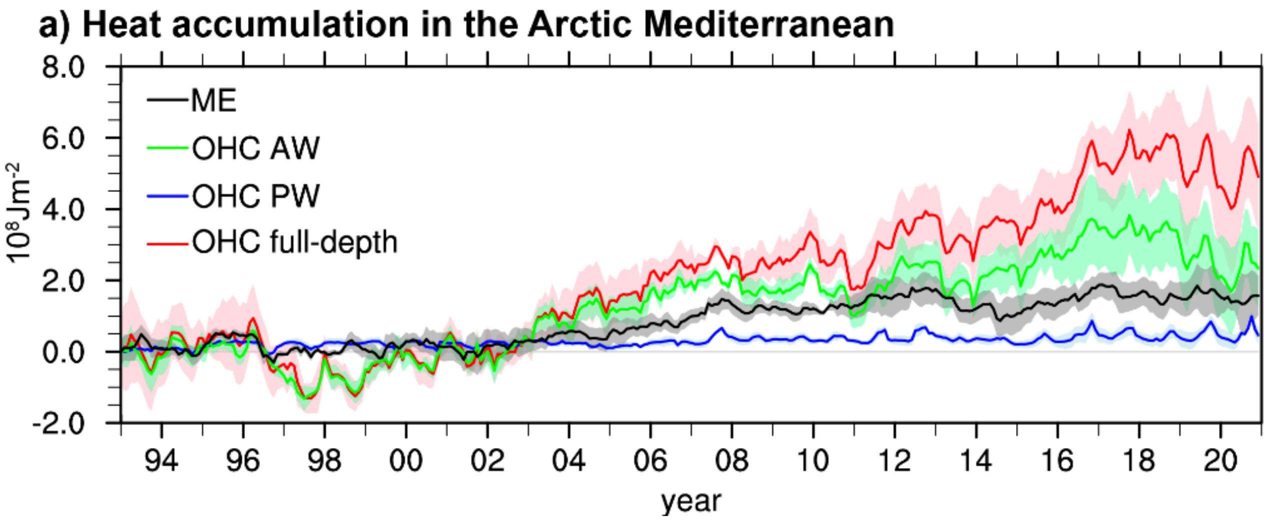
Ocean warming 1993-2019 – stratified by surface conditions

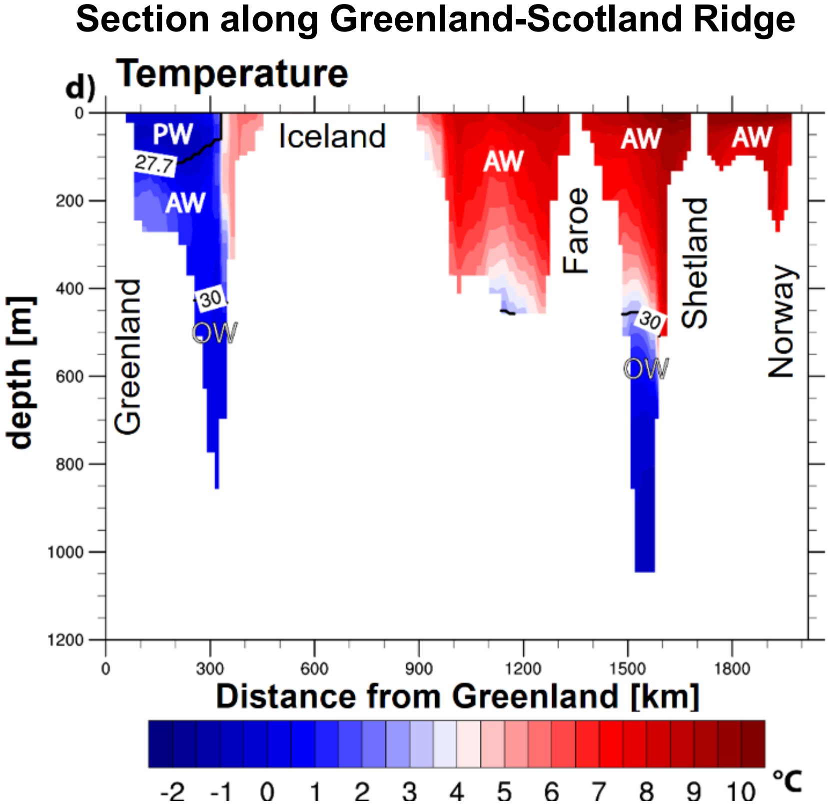


- Warming of ice-free Arctic ocean much faster than global average, but little warming underneath sea ice

	Fraction of warming	Fraction of area
Ice-covered	17%	63%
Ice-free	83%	37%

Ocean warming – stratified by water masses





- Strongest ocean warming in Atlantic Water (AW) layer: exposed to surface and strongly linked to changes in AW inflow
- Rapid warming ~2002-2016, but weak warming in recent years

	Fraction of warming	Fraction of volume
AW	64%	18%
PW	5%	5%
Deeper layers	31%	77%

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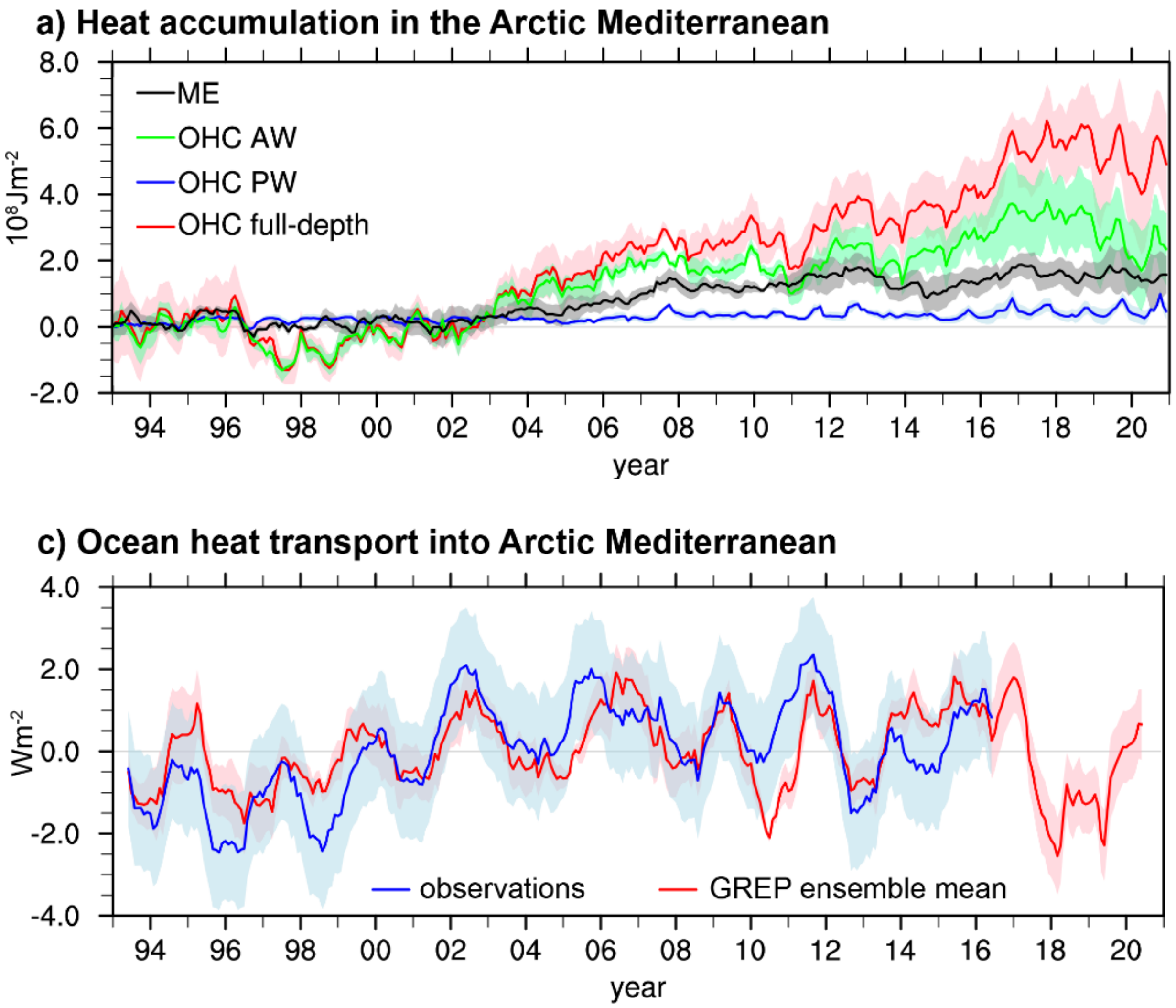
Oceanic transports and ocean warming



- Periods of enhanced warming in AW layer coincide with stepwise changes in heat transport
- Good agreement of insitu-based and reanalysis-based oceanic transports

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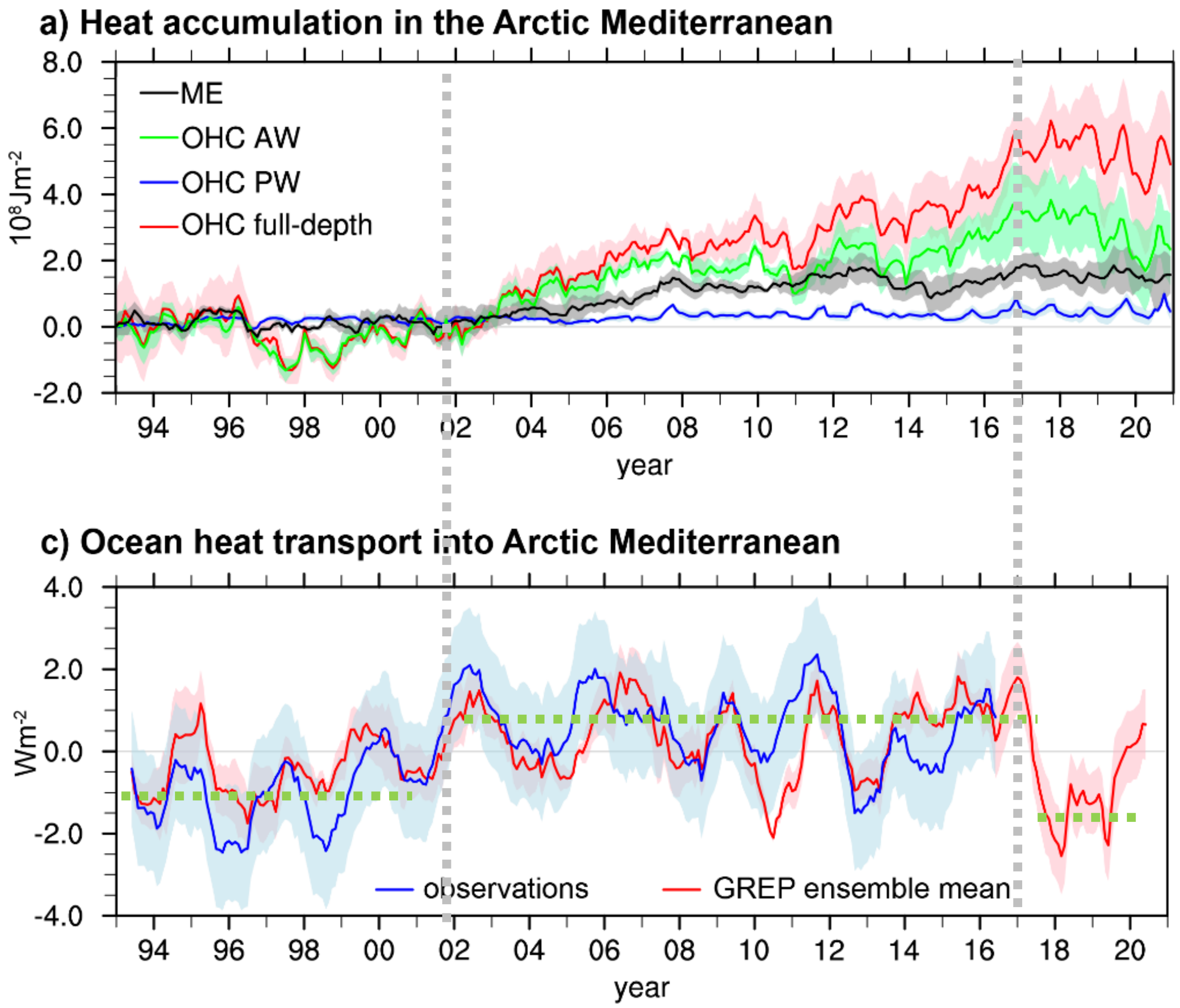
Oceanic transports and ocean warming



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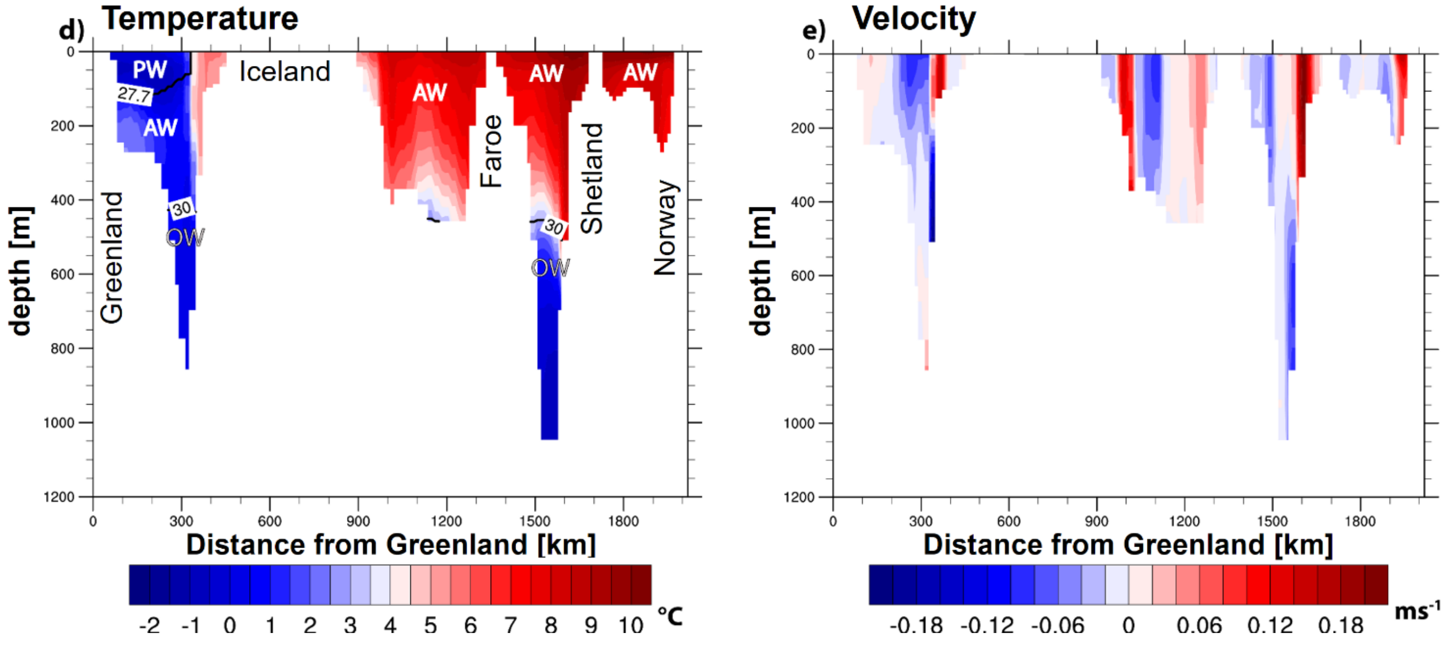
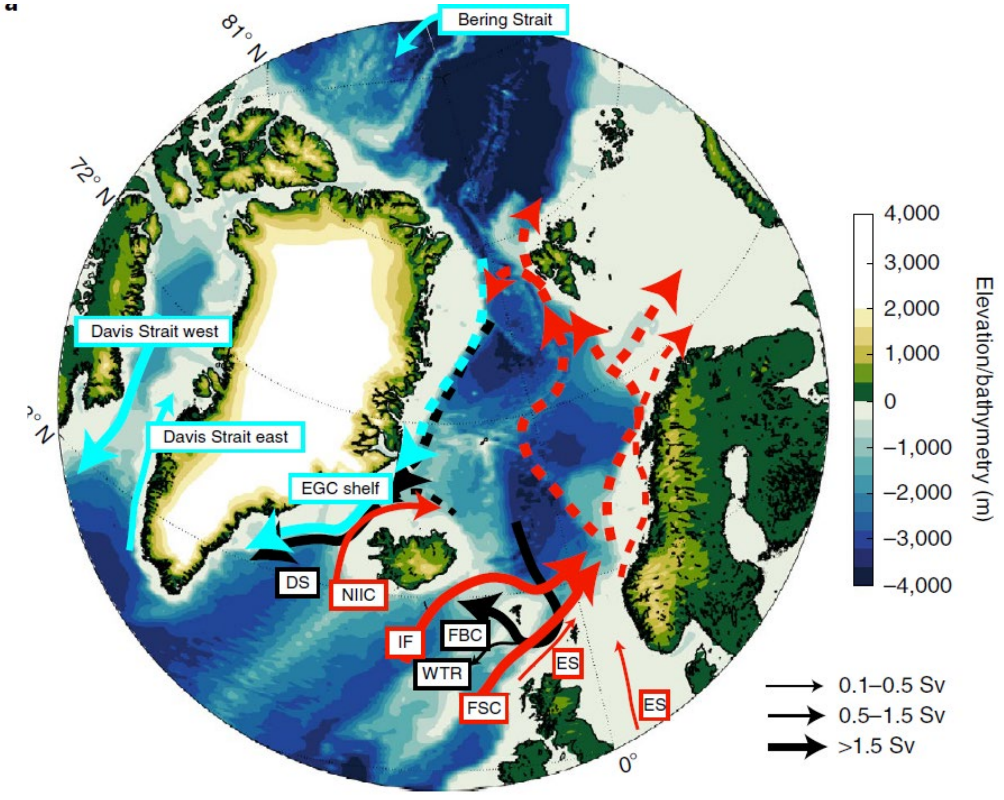
Focus on Greenland-Scotland-Ridge oceanic transports

- How well can current reanalysis products reproduce the zonal structure of observed oceanic exchanges at GSR?

Zonal-depth sections based on oceanic reanalyses





Red arrows: main AW inflow branches
Blue arrows: Polar water outflow
Black arrows: overflow water outflow

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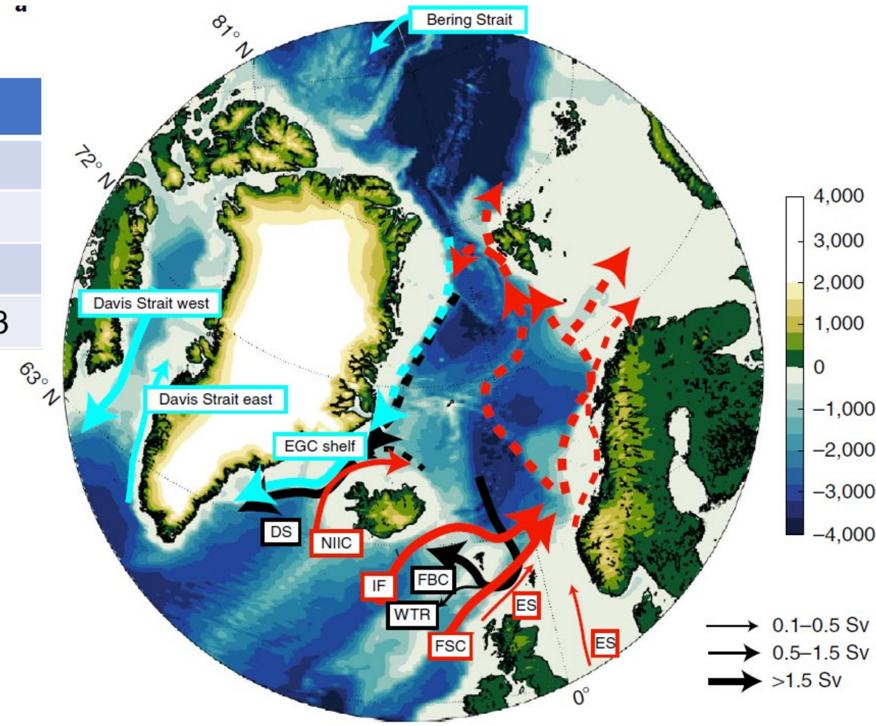
Greenland-Scotland-Ridge oceanic transports - validation

Volume flux 1993-2021 averages [Sv]

	GSR Total	PW	OW	AW	AW NIIC	AW IF	AW FS	shelf
GREP (4 reanalyses)	1.2 ± 0.5	-1.3 ± 0.6	-5.1 ± 0.4	6.9 ± 0.6	1.0 ± 0.2	1.9 ± 0.4	3.4 ± 0.7	0.6
GLORYS12	1.1	-0.7	-5.3	7.4	1.1	3.4	2.3	0.6
GLOB16	-0.2	-2.6	-4.7	7.1	0.6	3.4	2.6	0.5
OBS	0.7	-1.7	-5.6 ± 0.4	8.0 ± 0.7	0.9 ± 0.1	3.8 ± 0.4	2.7 ± 0.4	0.6 ± 0.3

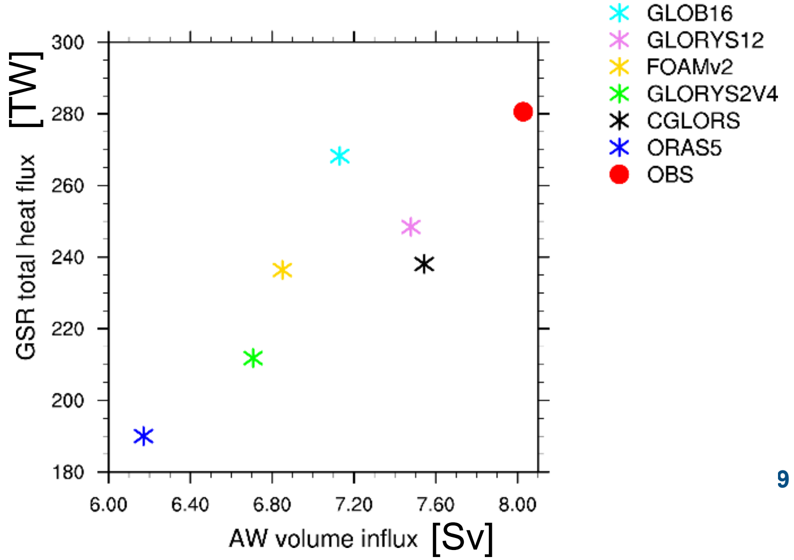


- Most branches are quantitatively well represented by ocean reanalyses – best performance by high-resolution products

heat flux 1993-2021 averages [TW]

	GSR Total	Arctic Mediterranean
GREP (4 reanalyses)	219 ± 23	232 ± 21
GLORYS12	248	258
GLOB16	268	278
OBS	280	304
Energy-budget based	-	343

- All reanalyses underestimate oceanic heat transport – related to too weak AW inflow



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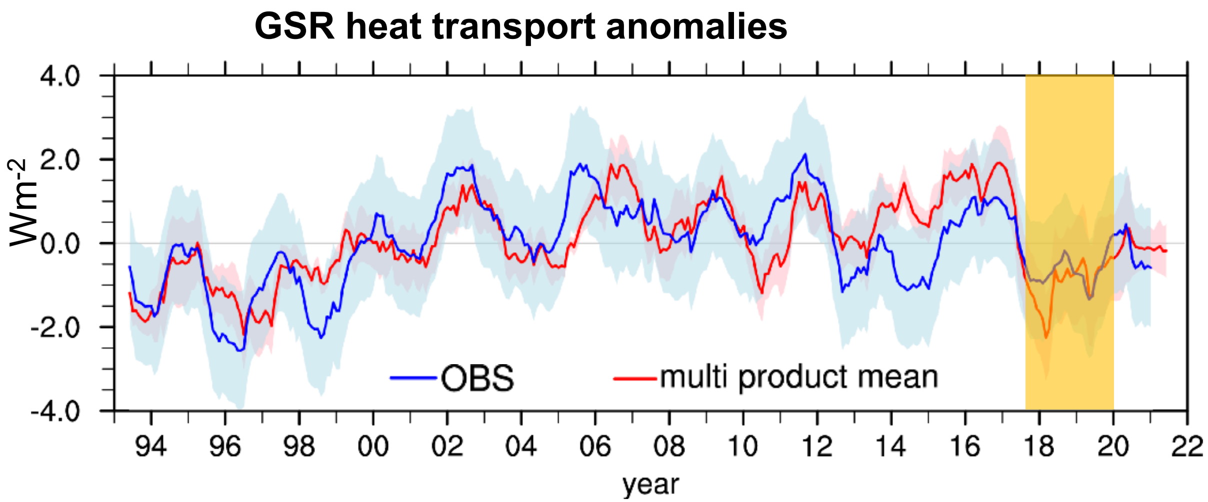
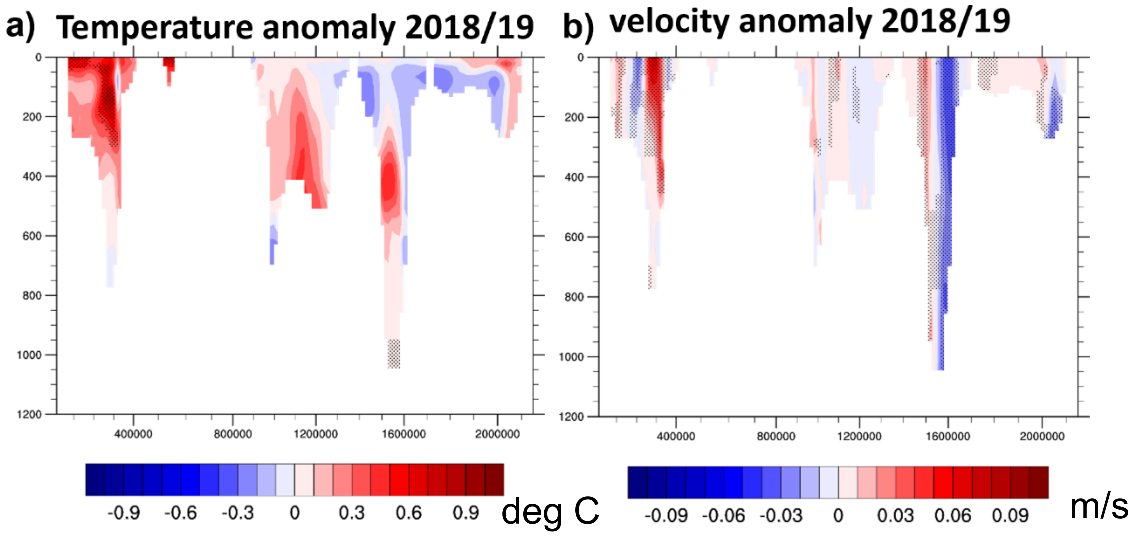
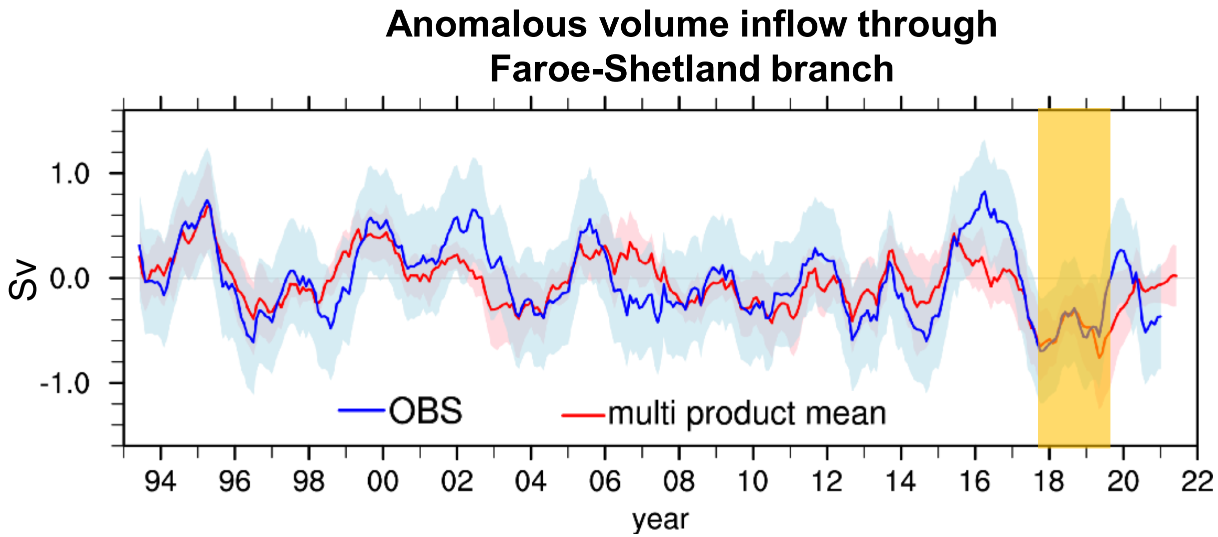
Variations in oceanic transports – interannual time scale





- The reduction of heat transport in 2018/19 was mainly related to reduced inflow in Farow-Shetland Channel – consistent in observations and model-based products



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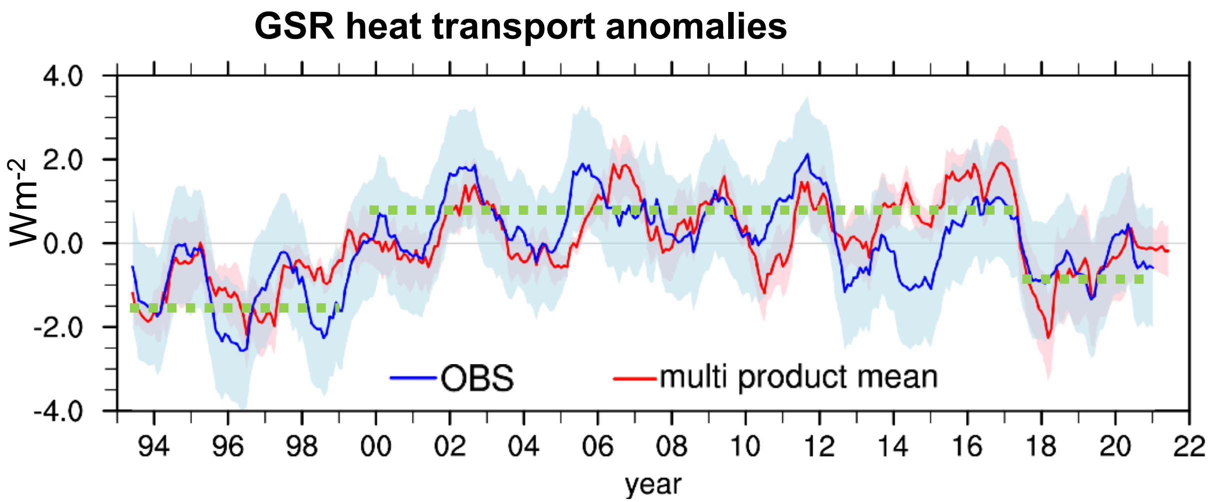
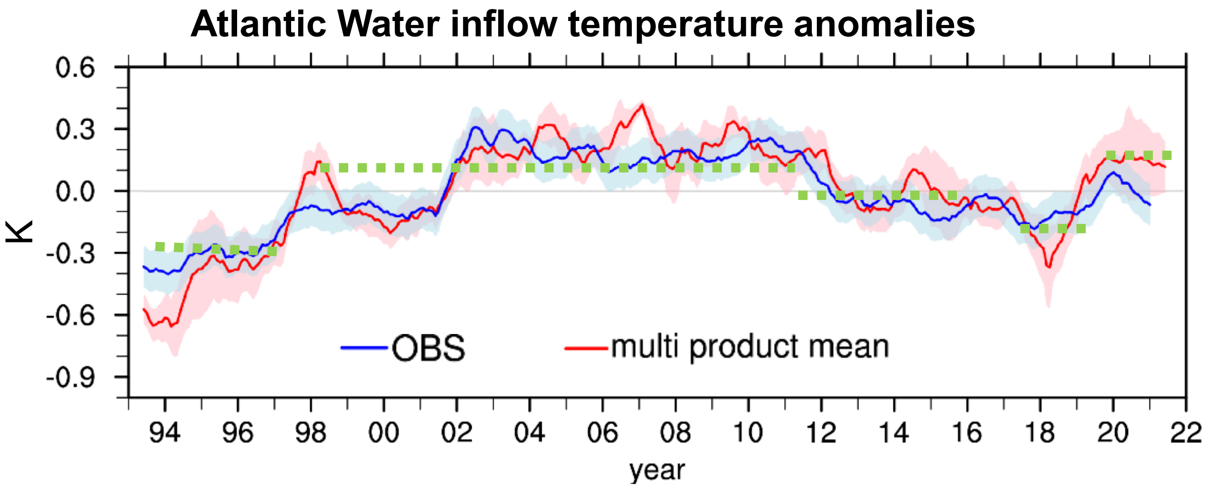
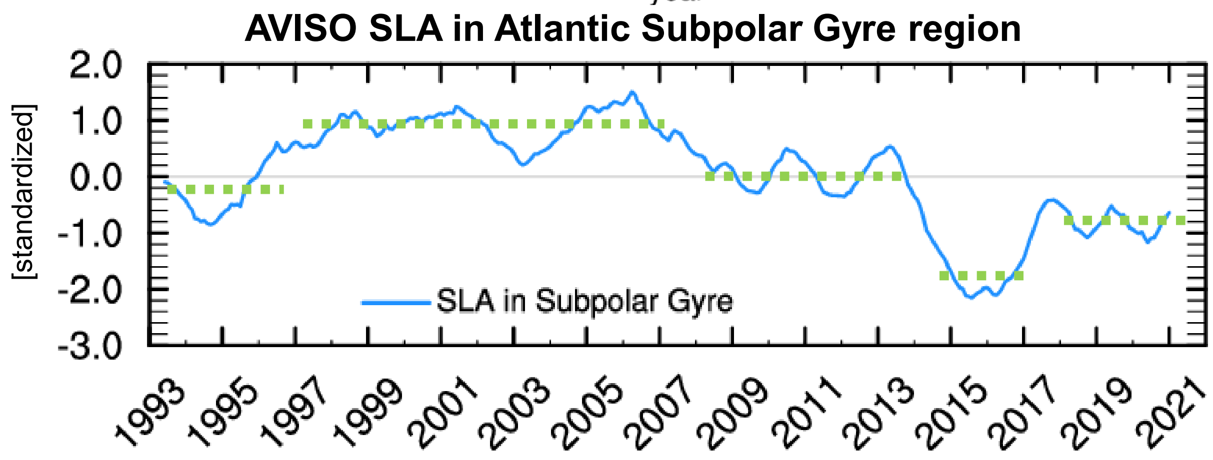
Variations in oceanic transports – decadal time scales







- On decadal timescales heat transport covaries with inflow temperatures at GSR
- Inflow temperatures appear to show a delayed response to variations in the Subpolar Gyre, with warmer inflow during weak SPG phases

High SLA → weak SPG
Low SLA → strong SPG

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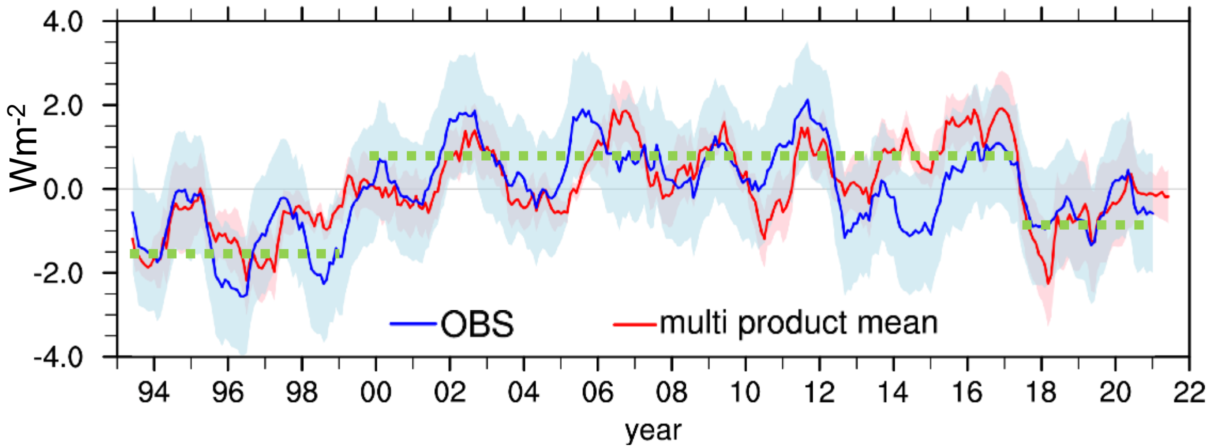
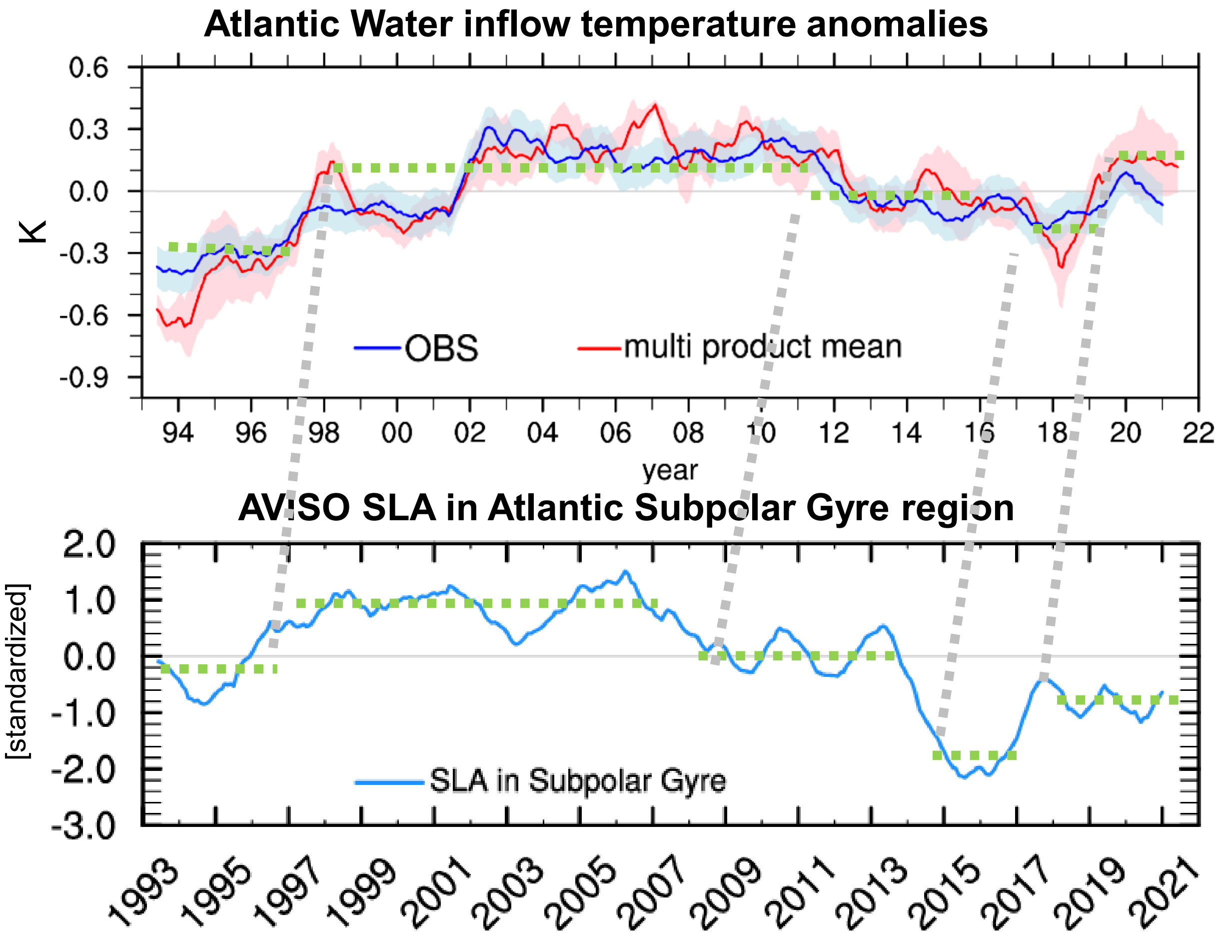
Variations in oceanic transports – decadal time scales

GSR heat transport anomalies





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Summary

- Arctic Ocean contributes ~4% to global ocean heat uptake – similar to its area relative to the global ocean
- But: ice-free Arctic ocean warms much faster than the global average
- Reanalysis-based oceanic transports into Arctic agree well with observations on branch scale → great tool for Arctic climate monitoring
- Oceanic transports modulate Arctic Ocean warming on interannual (related to wind-driven SLA variations in Nordic Seas) and decadal scale (related to strength of Subpolar Gyre).
- Recently reduced rates of Arctic Ocean warming linked to currently strengthened SPG via oceanic transports

References

- *Mayer, M., Tietsche, S., Haimberger, L., Tsubouchi, T., Mayer, J., & Zuo, H. (2019). An Improved Estimate of the Coupled Arctic Energy Budget, Journal of Climate, 32(22), 7915-7934.* https://doi.org/10.1175/JCLI-D-19-0233.1
- *Mayer, M., V.S. Lien, K.A. Mork, K. von Schuckmann, M. Monier, E. Greiner (2021): Ocean heat content in the High North, in CMEMS Ocean State Report Vol 5, Journal of Operational Oceanography 14:sup1, 1-185, DOI: 10.1080/1755876X.2021.1946240.*
- *Mayer, M., Tsubouchi, T., von Schuckmann, K., Seitner, V., Winkelbauer, S., Haimberger, L., (2022). Atmospheric and oceanic contributions to observed Nordic Seas and Arctic Ocean Heat Content variations 1993-2020, accepted for publication in Journal of Operational Oceanography, to be included in CMEMS Ocean State Report Vol 6.*