

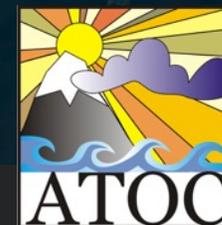


# Forced Changes in the Arctic Freshwater Budget Emerge in the Early 21st Century

ALEXANDRA JAHN AND RORY LAIHO



Published as: Jahn  
and Laiho, 2020, GRL



# The Arctic FW budget

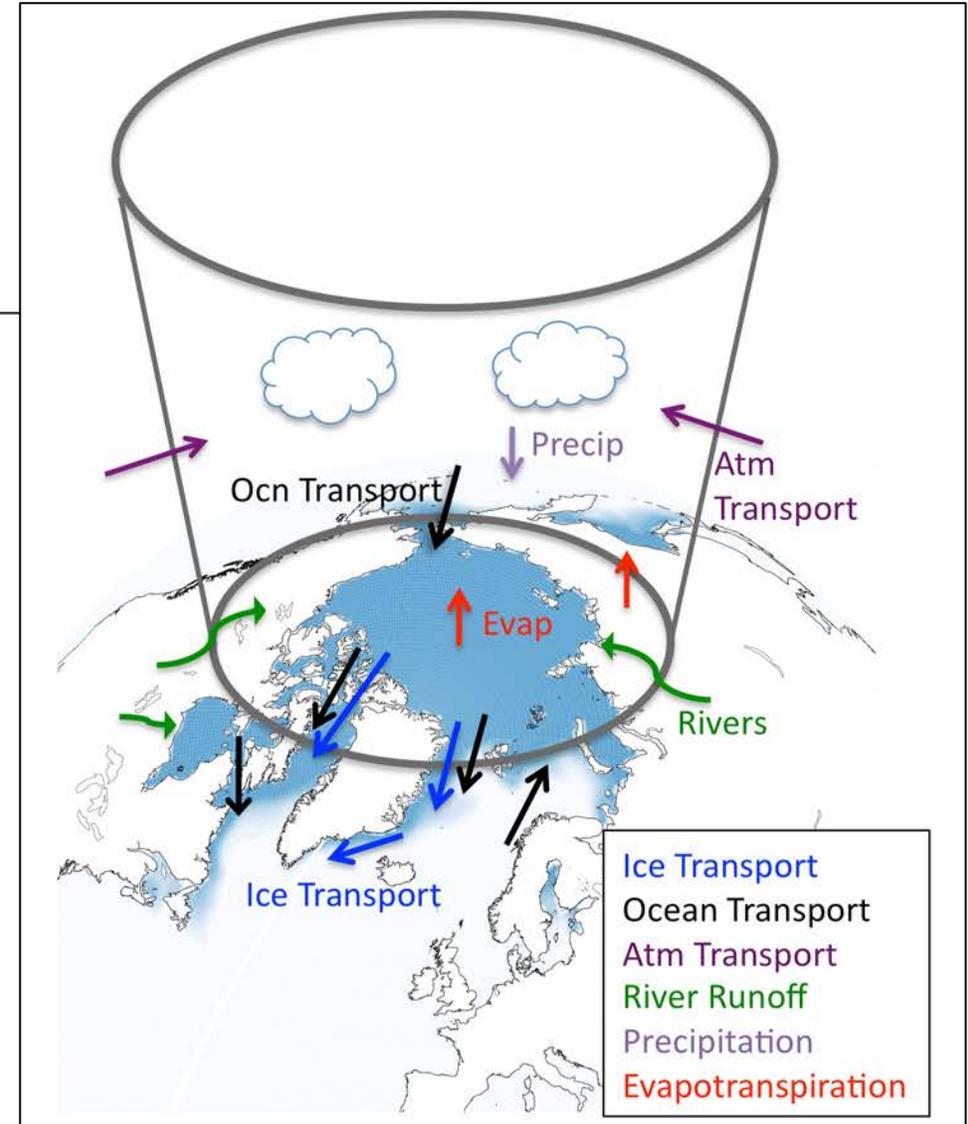


## FW sources:

- Bering Strait inflow
- River runoff
- P-E over the Arctic

## FW sinks:

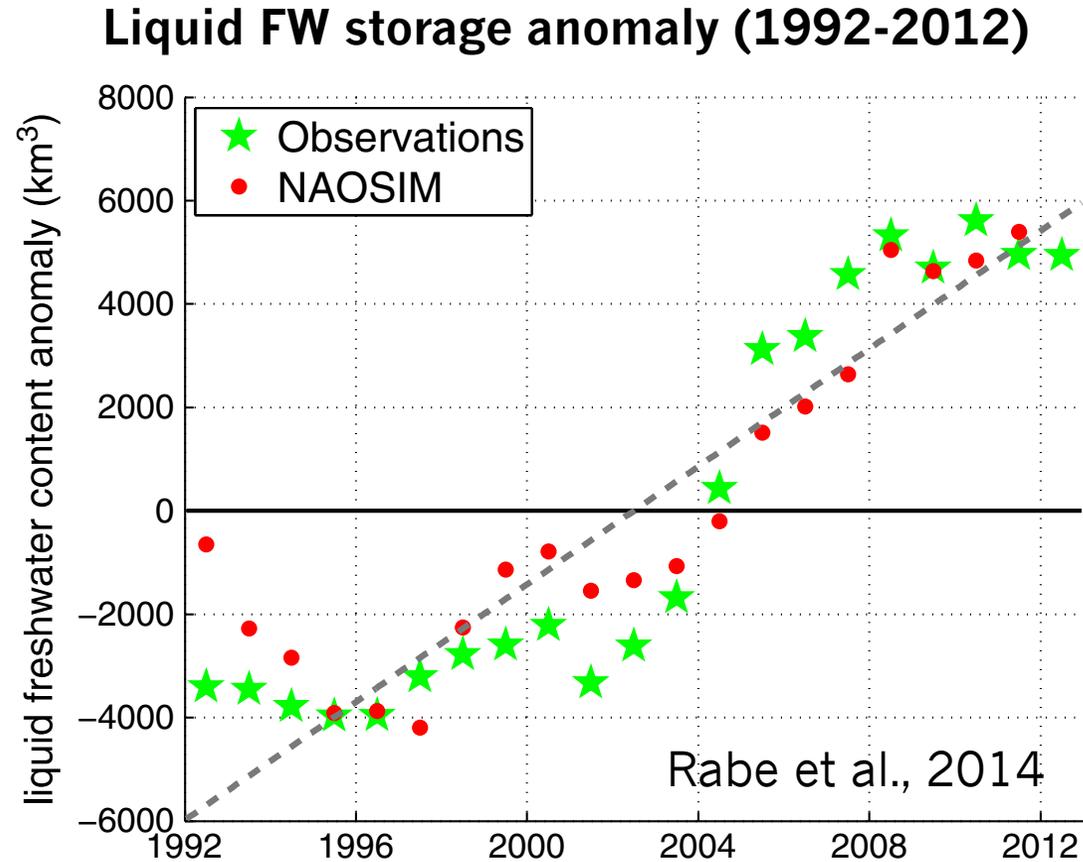
- Liquid and Solid FW exports through
  - Fram Strait
  - The channels of the CAA
  - (Barents Sea Opening)



Lique et al., 2016

All FW fluxes calculated relative to 34.8 in this study

# Motivation



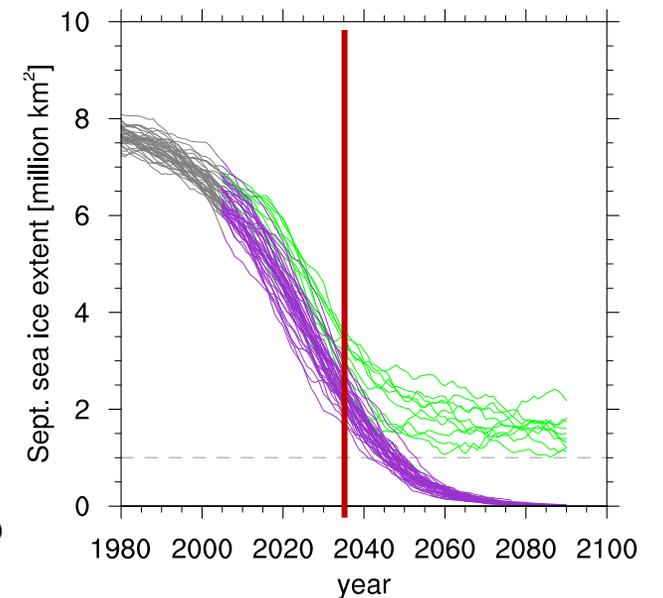
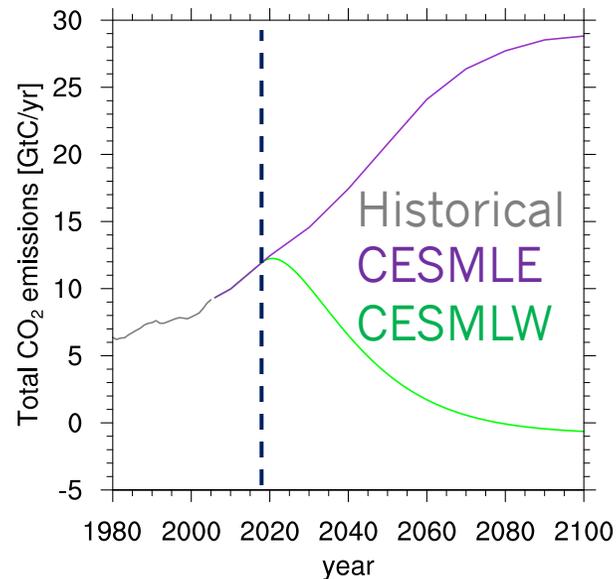
- Arctic liquid FW storage has been increasing since the mid 1990s
  - Solid FW storage has decreased over the same time, as sea ice volume has decreased
  - But oceanic gateway exports to the North Atlantic have not yet shown any trends, even though we expect them to eventually
- **When can we expect a forced signal to emerge in different parts of the Arctic freshwater budget?**
- Here we use two large ensembles to answer this question which bracket the expected warming ( $2^\circ\text{C}$  to  $4.5^\circ\text{C}$  in 2100)
- These ensembles are from the Community Earth System Model Version 1 (CESM1)

# CESM model simulations

CESM Large Ensemble (CESM LE, using 15 members, forced by RCP8.5, Kay et al., 2015)

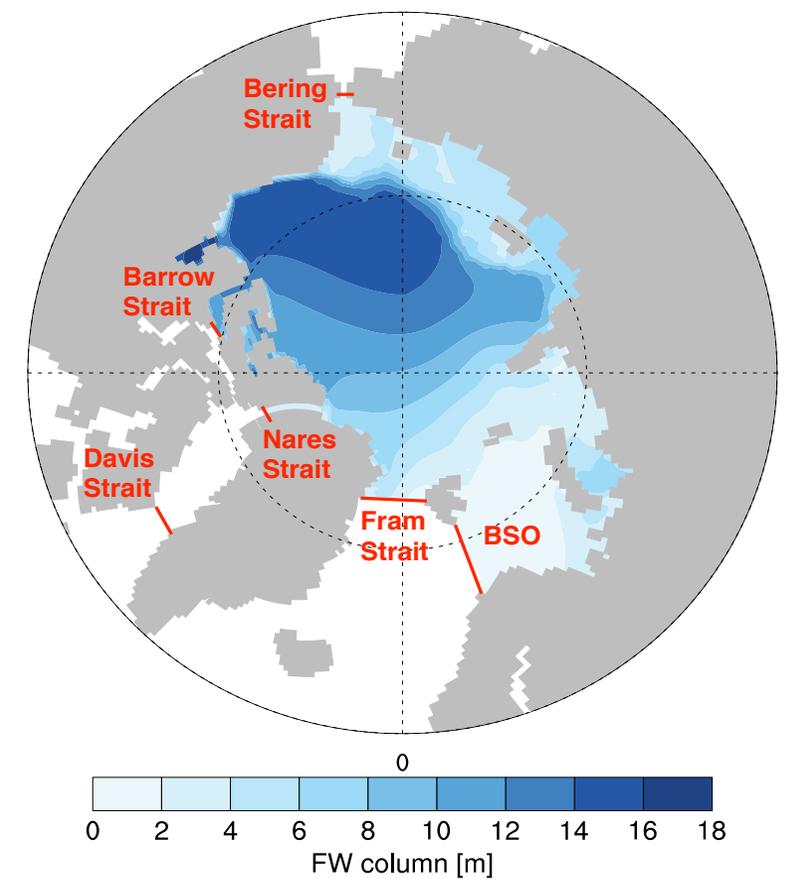
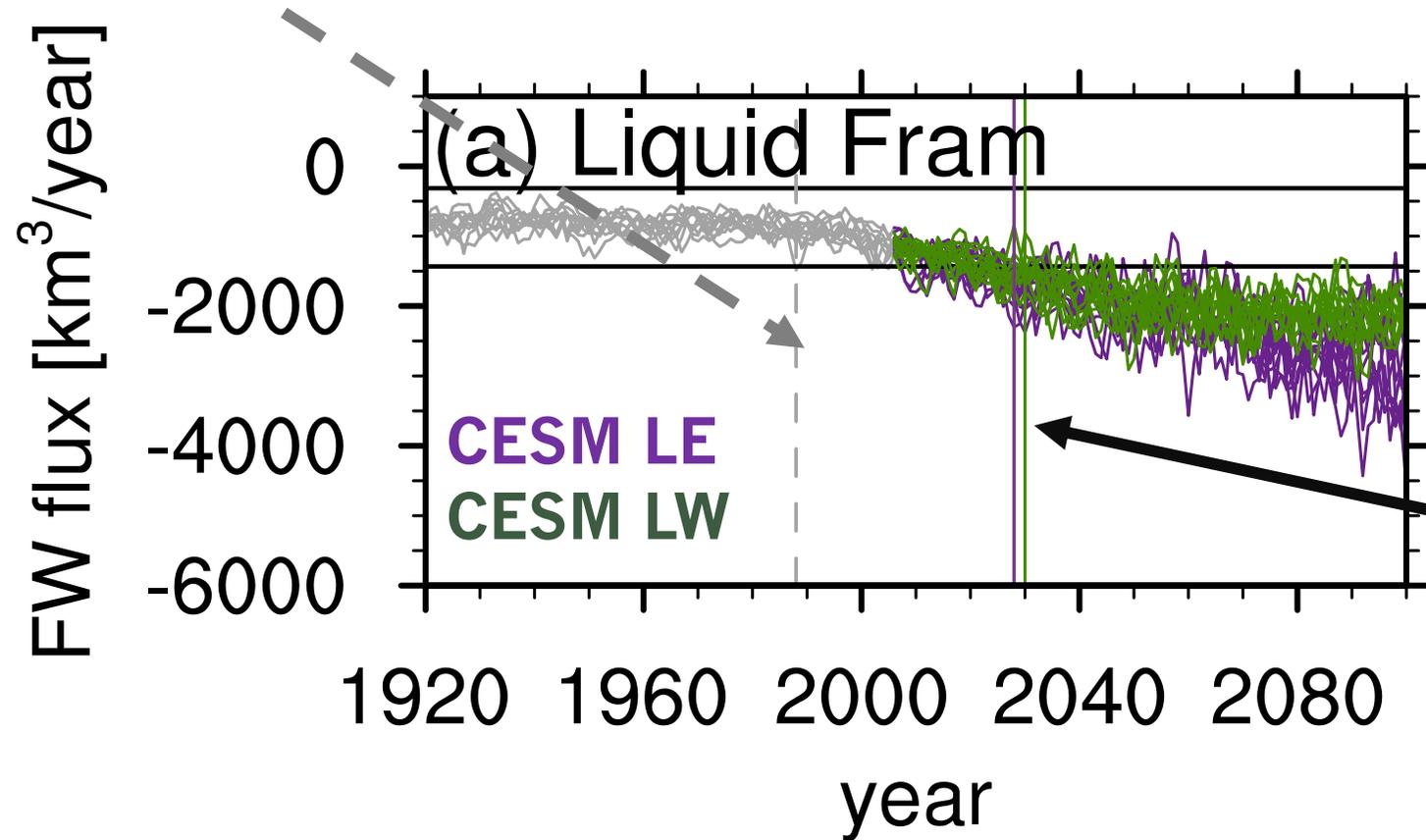
CESM Low Warming ensemble (CESM LW, 15 members, warming limited to 2°C by 2100, Sanderson et al., 2017)

- Both start in 2006 from the end of the historical simulation, but have the same forcing until 2017, when their forcing diverges
- But we don't see a clear scenario difference in the Arctic sea ice until ~ 2035



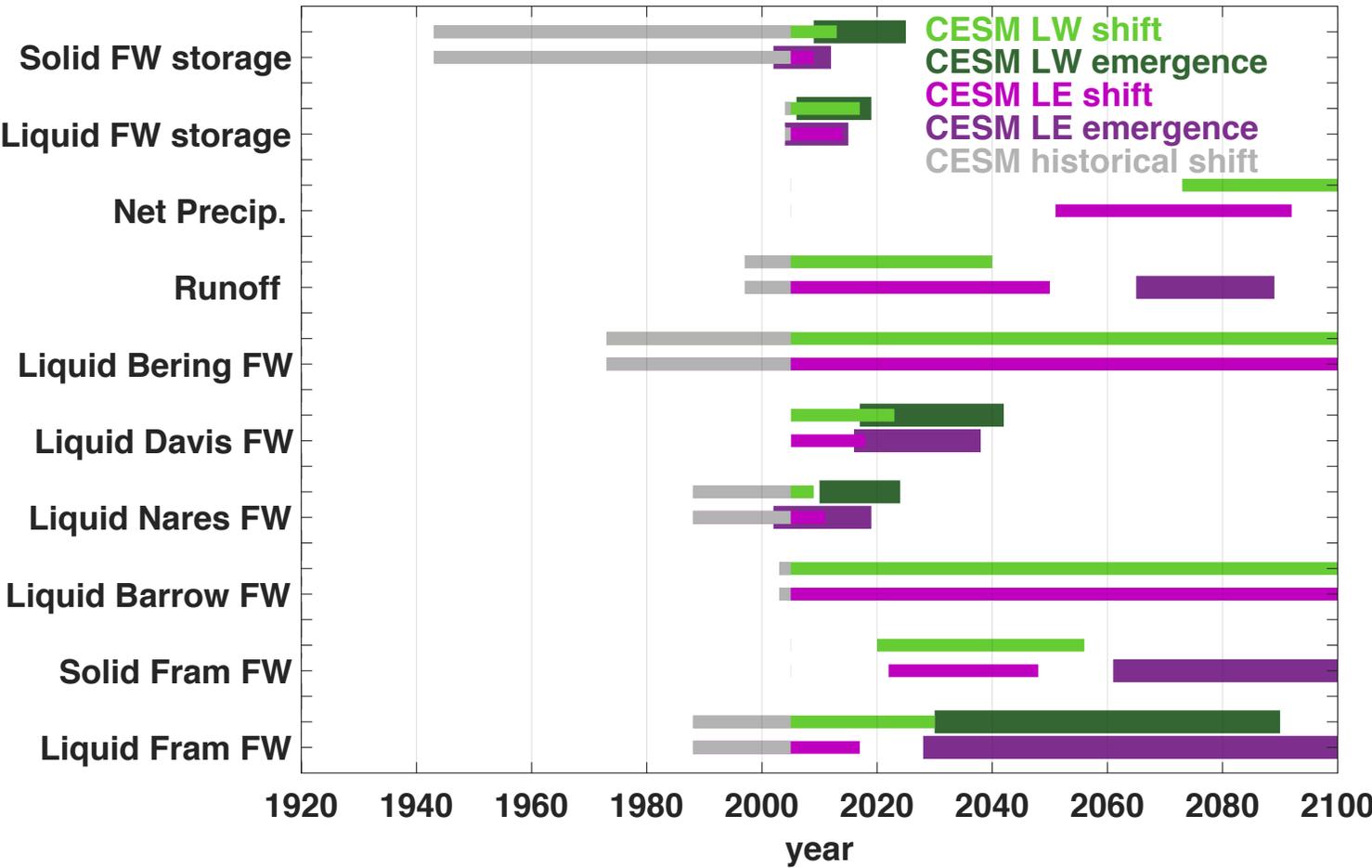
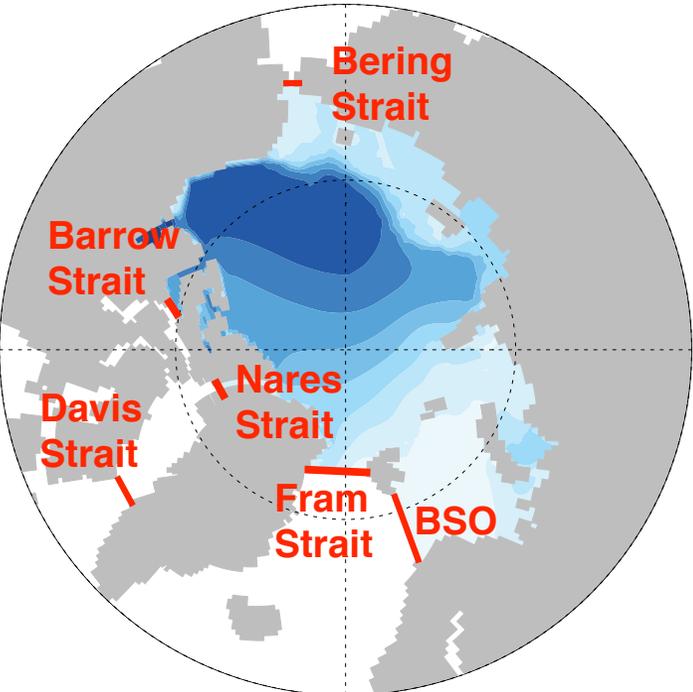
# Shift and Emergence

**Shift:** First time a FW term is outside the pre-industrial background Internal Variability from the CESM (Threshold= $\pm 3.5$  standard deviations). May cross back into background variability after



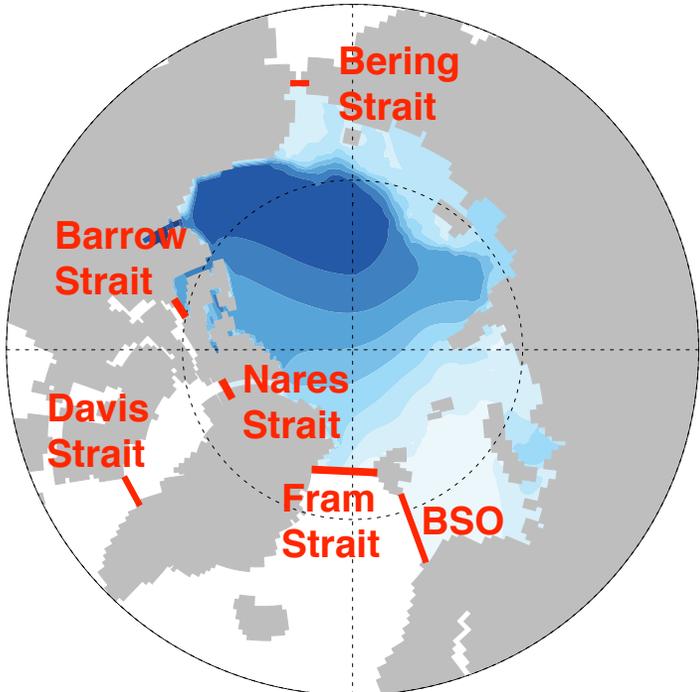
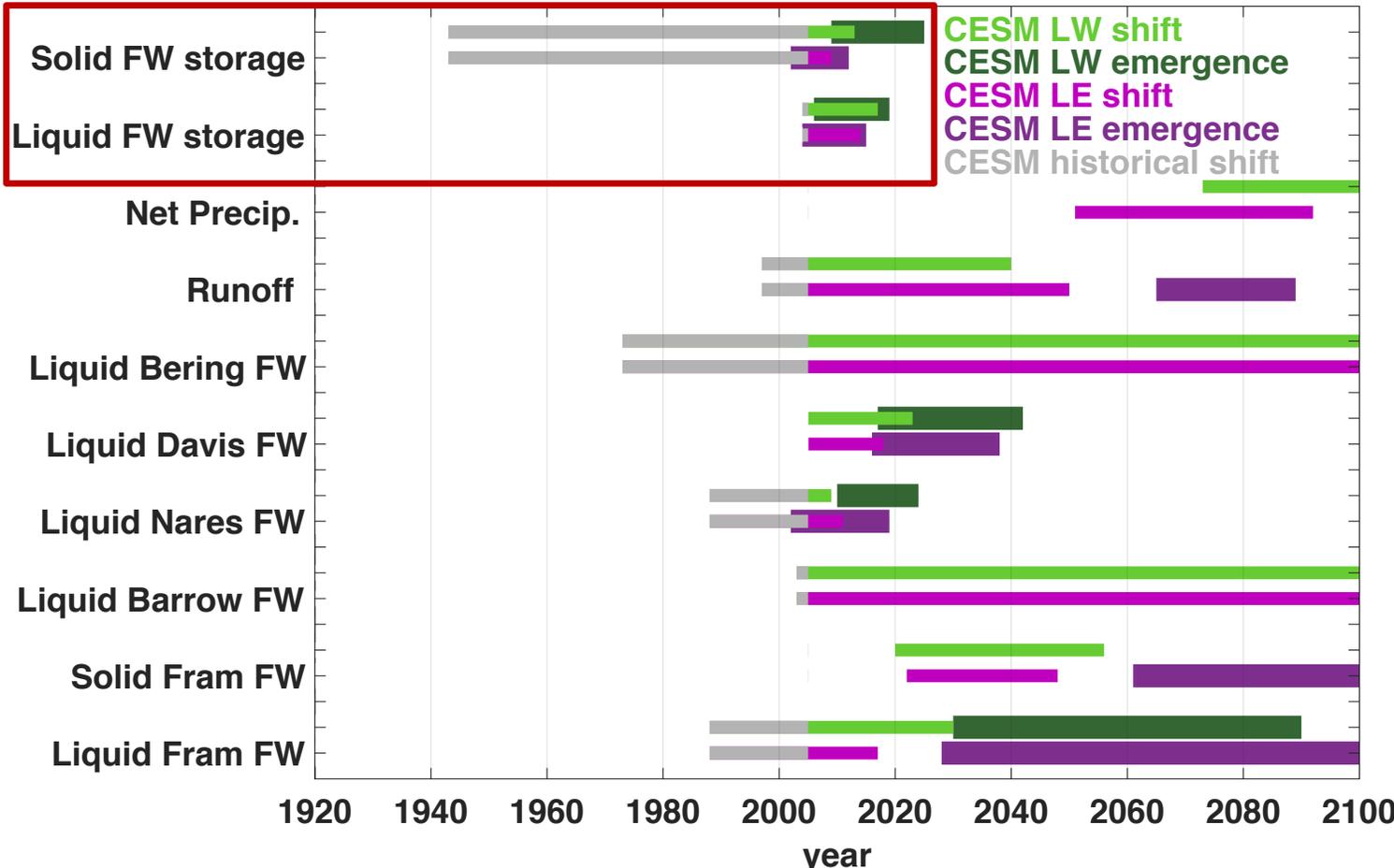
**Emergence:** A simulated FW term stays outside the CESM background variability till 2100  $\rightarrow$  no overlap with the pre-industrial state  $\rightarrow$  Can only be caused by a forced change

# Timing of the Emergence of a forced signal



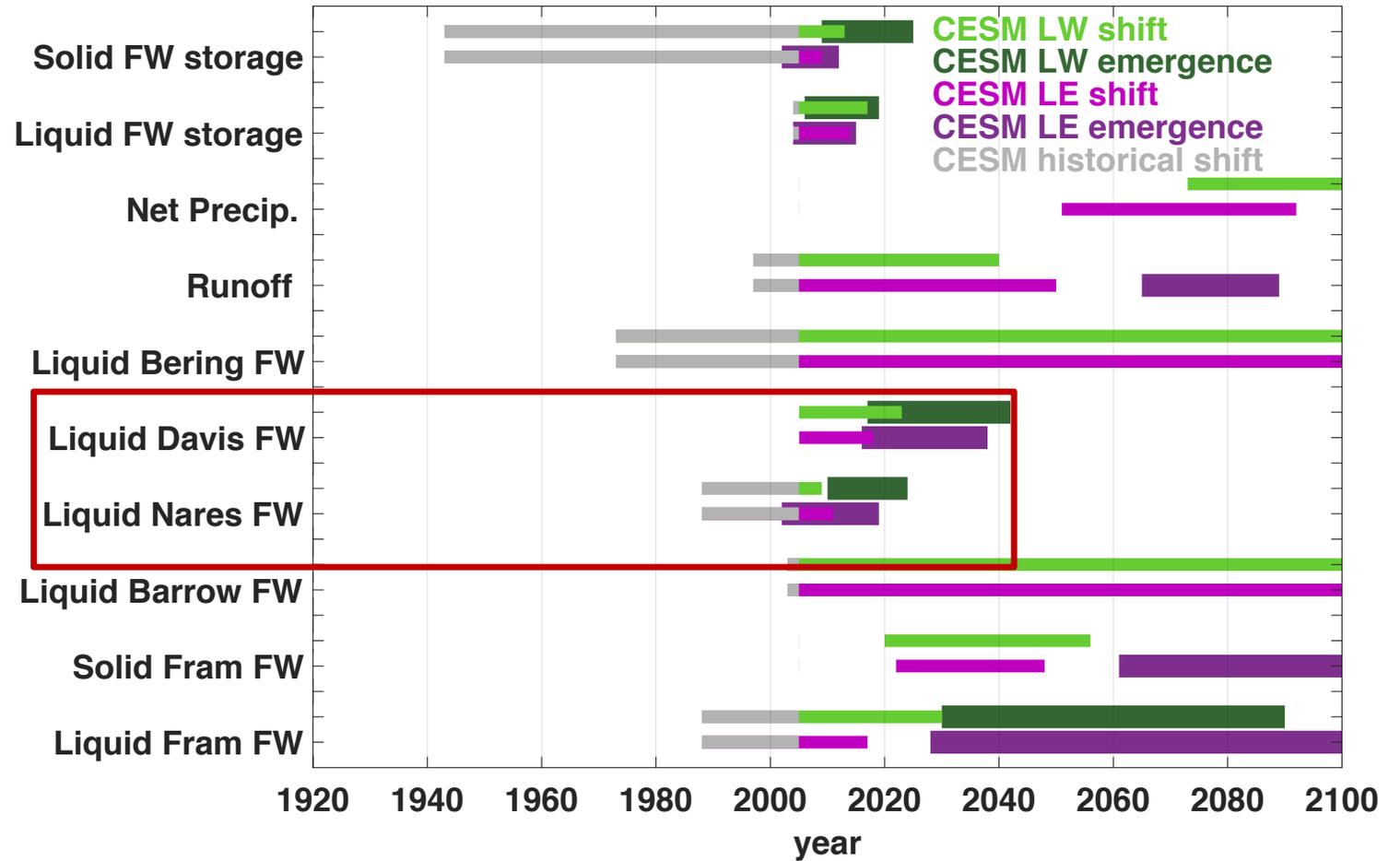
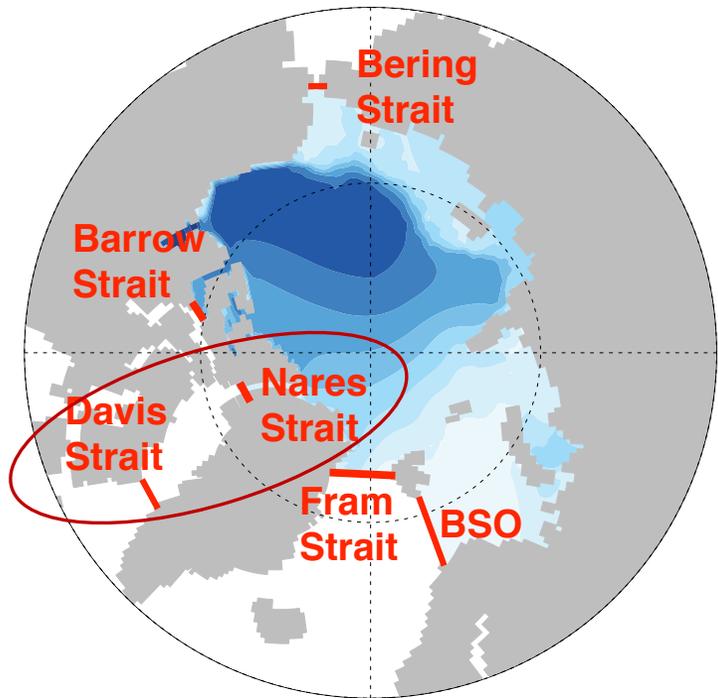
# Timing of the Emergence of a forced signal

•FW storage terms show the earliest complete emergence → observed increase in liquid FW storage may already be a forced change



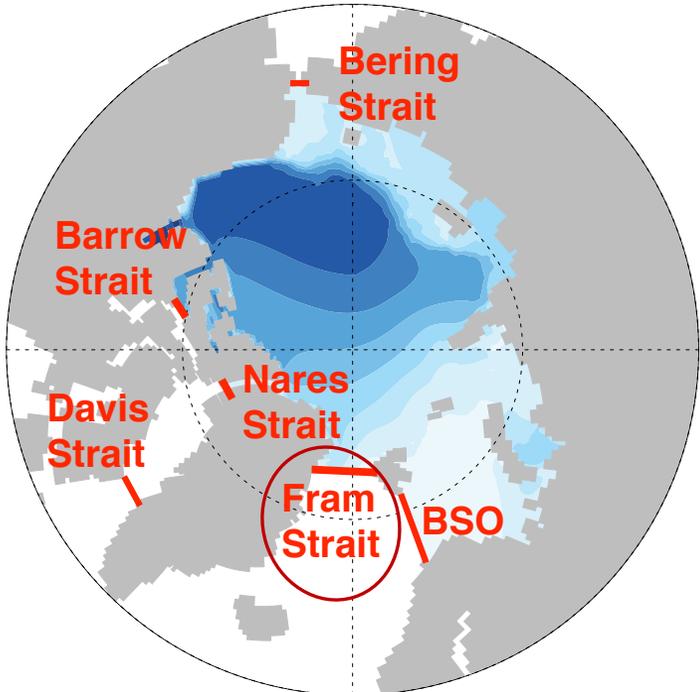
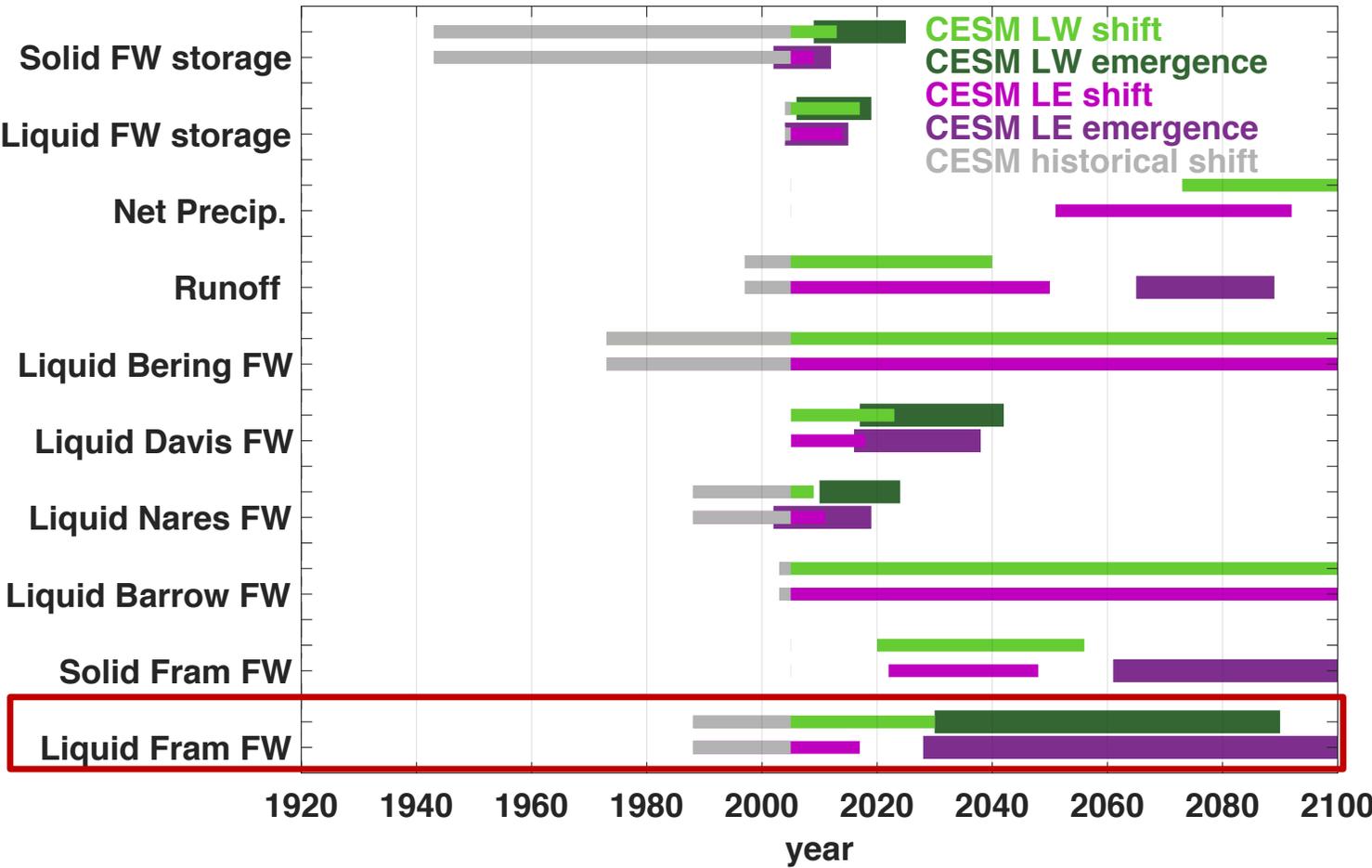
# Timing of the Emergence of a forced signal

•Nares Strait and then Davis Strait are the first fluxes to emerge, with emergence potentially already ongoing → Davis Strait monitoring was restarted in 2020, so we hopefully will be able to observe this



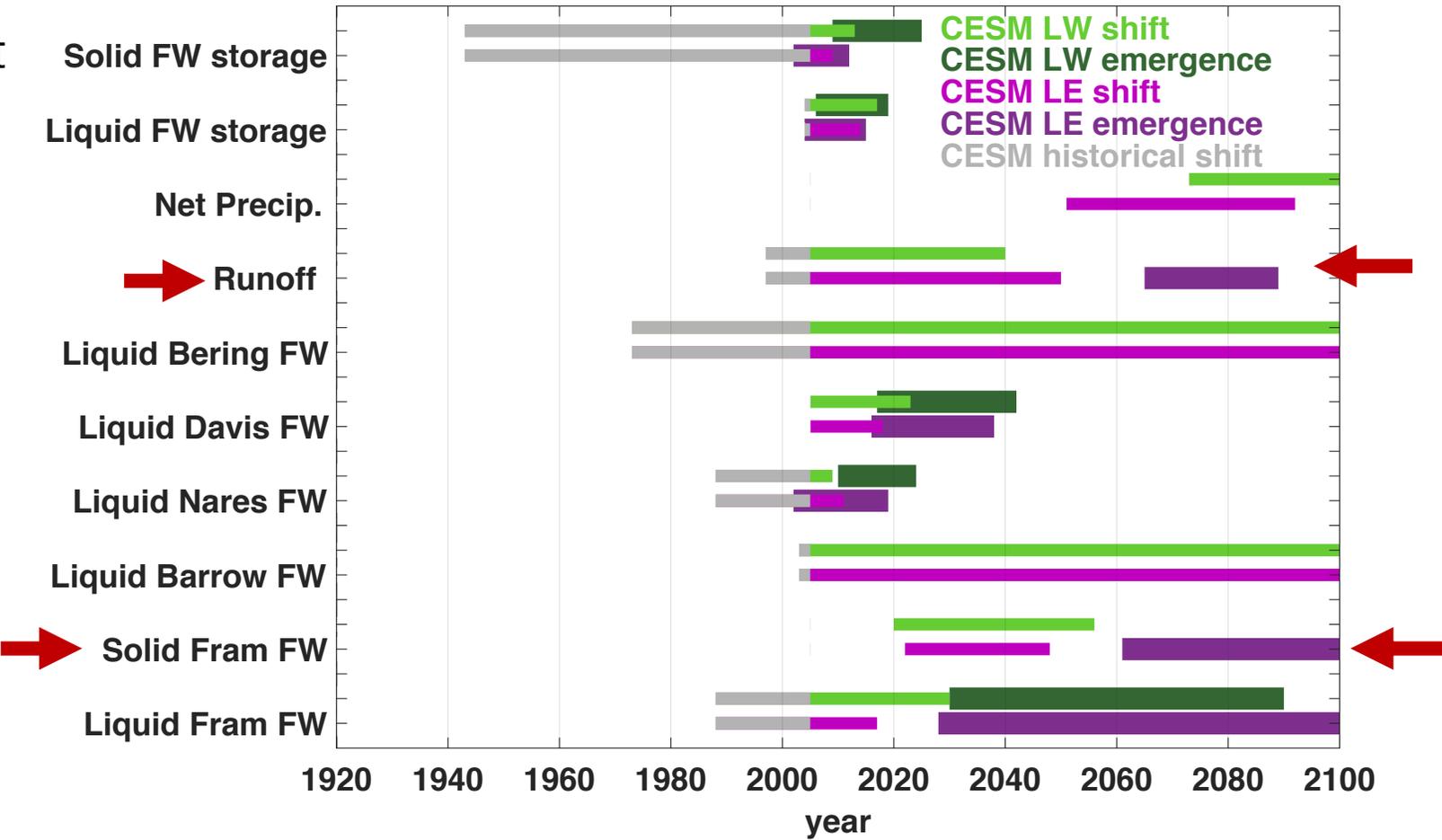
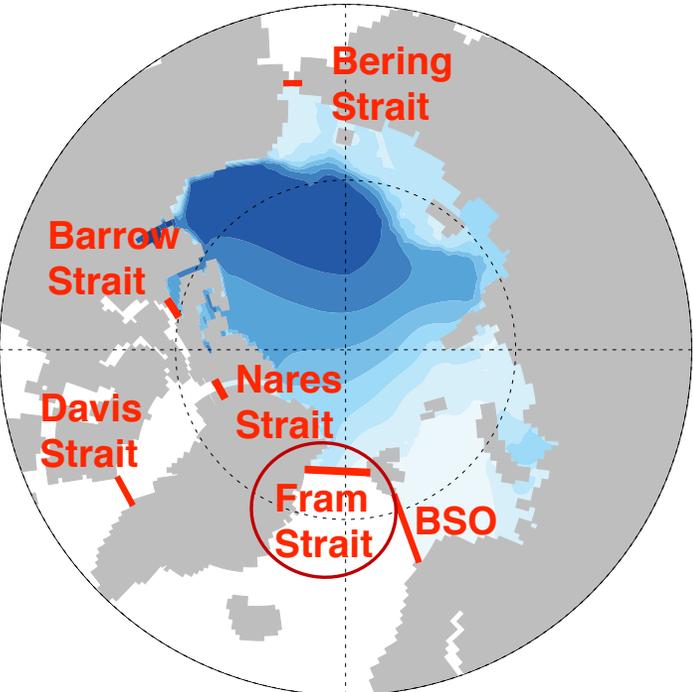
# Timing of the Emergence of a forced signal

•Fram Strait liquid FW export is the next to show emergence in the CESM1



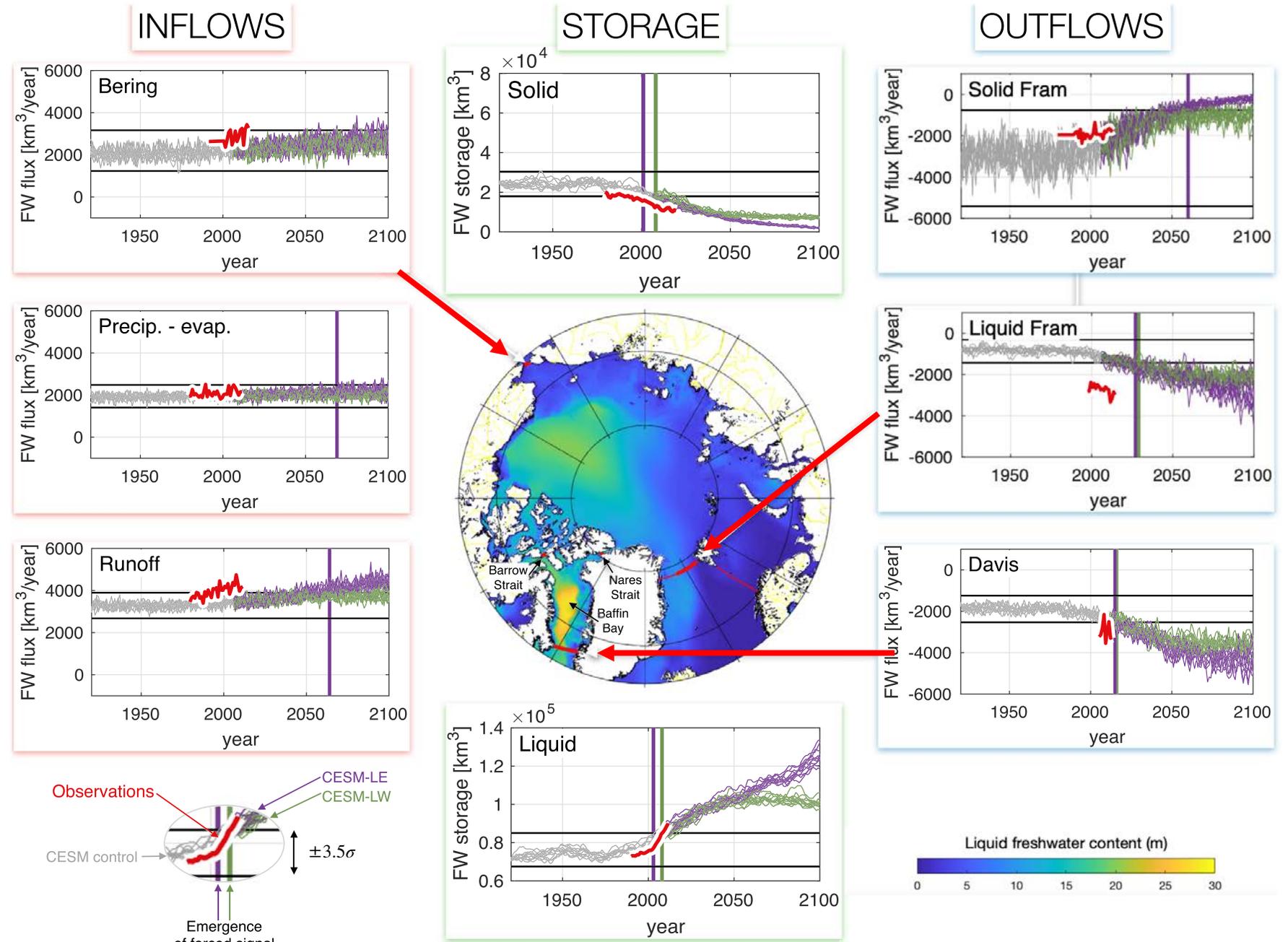
# Timing of the Emergence of a forced signal

•Future emission choices may prevent runoff and solid Fram Strait FW export to reach full emergence



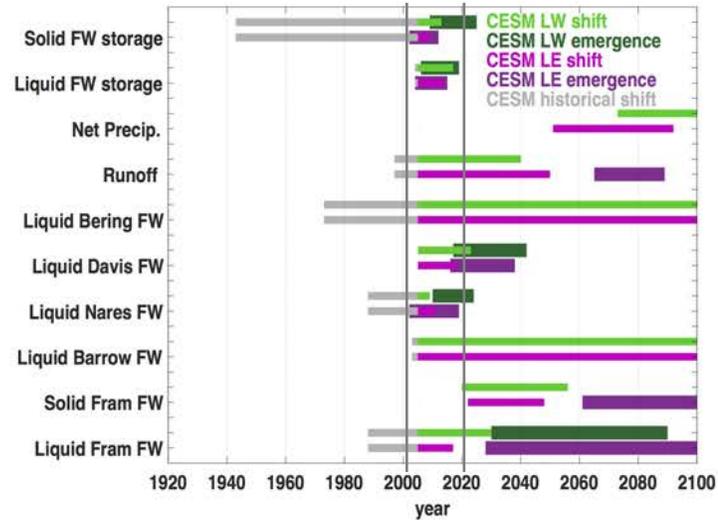
# When can we expect to detect the emergence of a forced signal from observations?

Detecting emergence of a climate change signal from the observational time series is more challenging than from model simulations, due to short timeseries that capture a system that is already responding to climate change

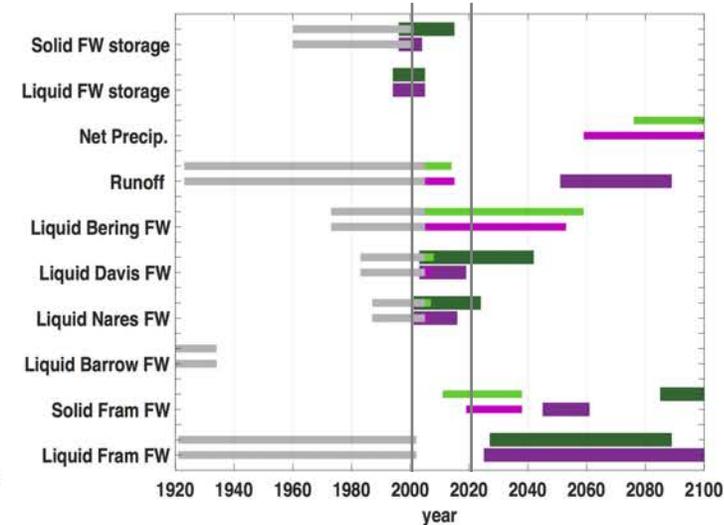


# When can we expect to detect a forced signal from observations?

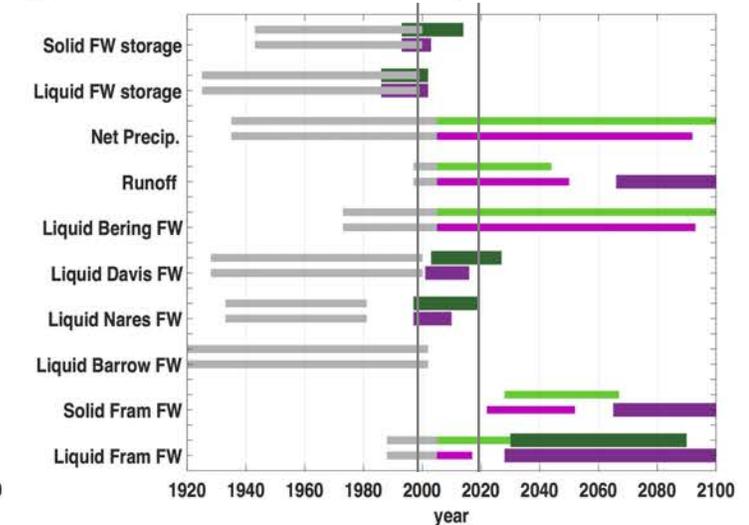
(a) Based on 1800 years of the control



(b) Based on 20 years of the control



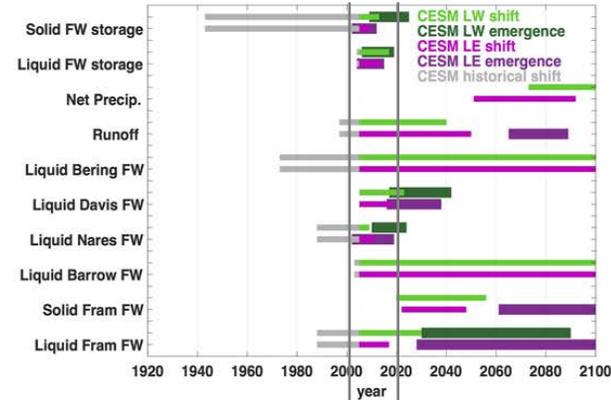
(c) Based on another 20 years of the control



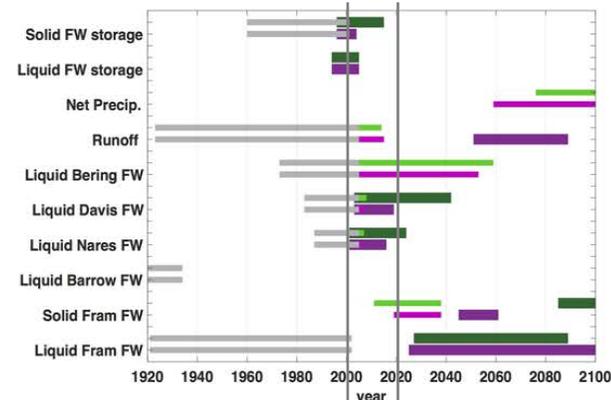
**A much shorter base period (20 years) tends to lead to earlier emergence, due to sampling fewer extreme events, but does not change the order of the FW terms that emerge**

# When can we expect to detect a forced signal from observations?

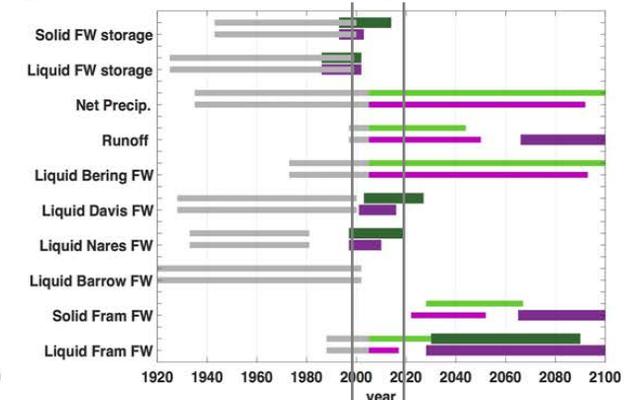
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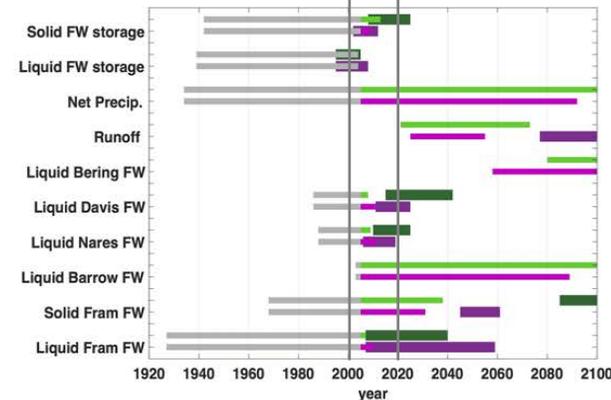
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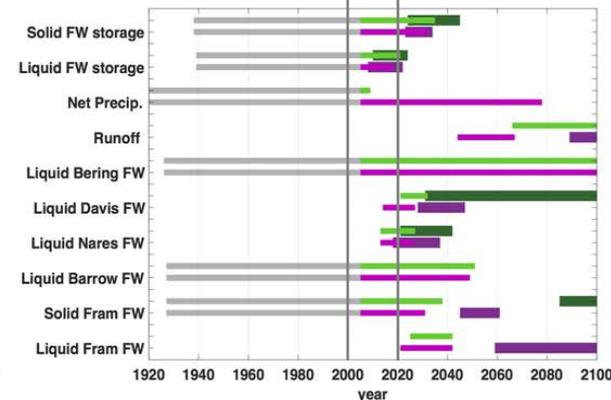
(c) Based on another 20 years of the control



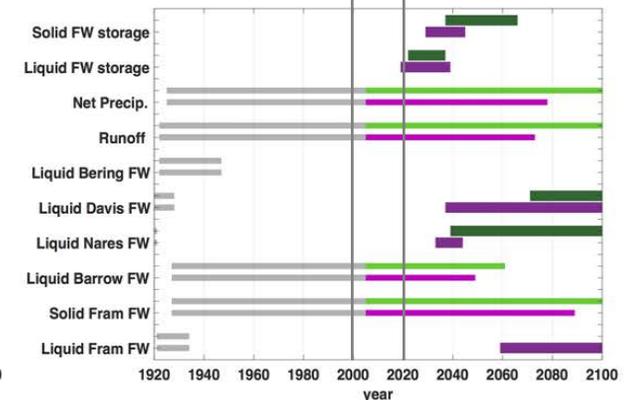
(d) Based on 1980-1999 from member 1



(e) Based on 1990-2009 from member 1

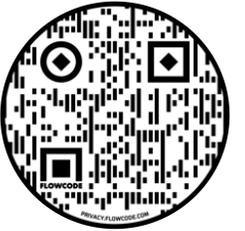


(f) Based on 2000-2019 from member 1

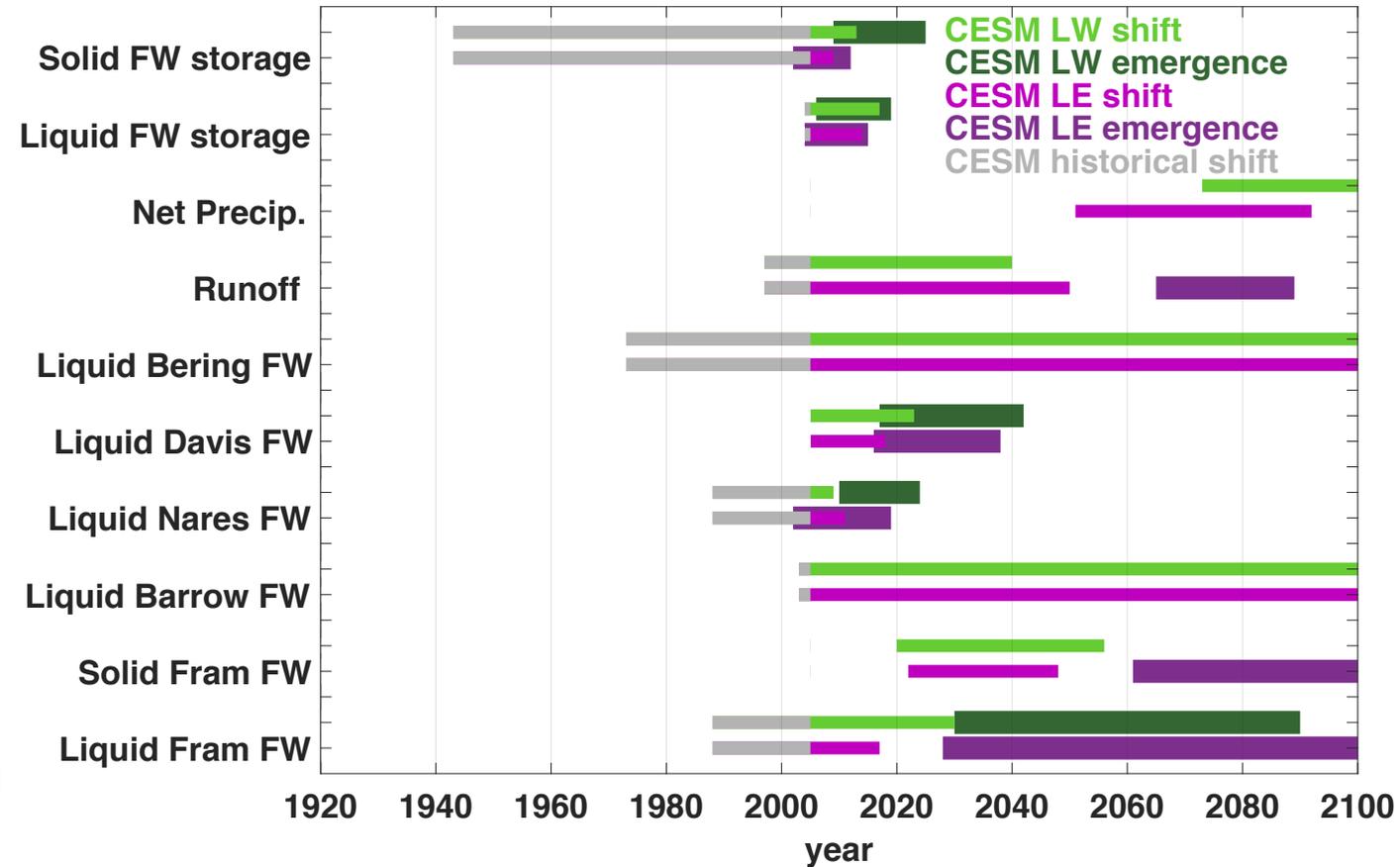


The changing nature of the FW budget terms during the base period delays the diagnosis of emergence

# Summary



- FW storage terms show the earliest complete emergence → **observed increase in liquid FW storage may already be a forced change**
- Nares Strait and then Davis Strait are the first fluxes to emerge in the CESM1, with emergence potentially already ongoing or imminent, and independent of future emissions
- Continued observations of changes in the storage and fluxes are crucial to capture these changes in the Arctic Ocean over the next few decades
- Similarly robust statistical detection of these changes in observations compared to models will likely be delayed, as observations sample an already changing system



# How does this look in other models?

- The exact same analysis hasn't been done on the CMIP6 models (yet), and emergence depends on the signal-to-noise ratio
- But many CMIP6 models project changes in the Arctic FW budget by the end of the 21<sup>st</sup> century, which can be summarized as **“Declining Sea Ice, Increasing Ocean Storage and Export”**

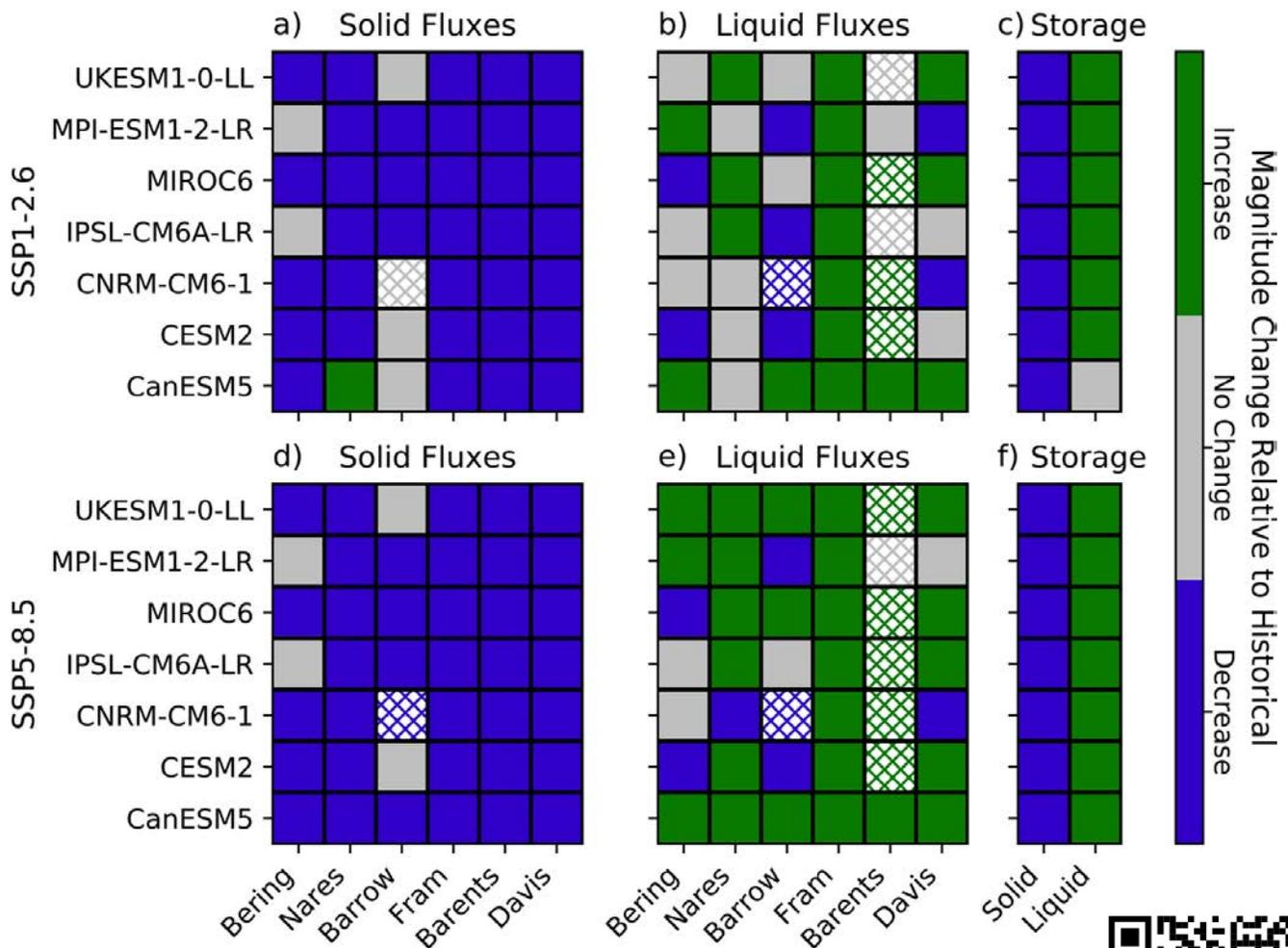


Research Article

Arctic Ocean Freshwater in CMIP6 Ensembles: Declining Sea Ice, Increasing Ocean Storage and Export

Hannah Zanowski ✉, Alexandra Jahn, Marika M. Holland,

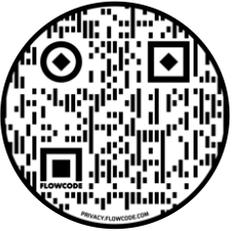
First published: 20 March 2021 | <https://doi.org/10.1029/2020JC016930>



# Future/ongoing related work

- Analysis of the Davis Strait fluxes, using models and the mooring data as part of the ongoing Davis Strait Observing NSF award (with Craig Lee and Paul Myers) → You'll hear from that at OSM22 and/or the next ASOF meeting by Jed Lenetsky

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