Was the Great Salinity Anomaly in the 1970s Induced by an Extreme Fram Strait Sea Ice Export?

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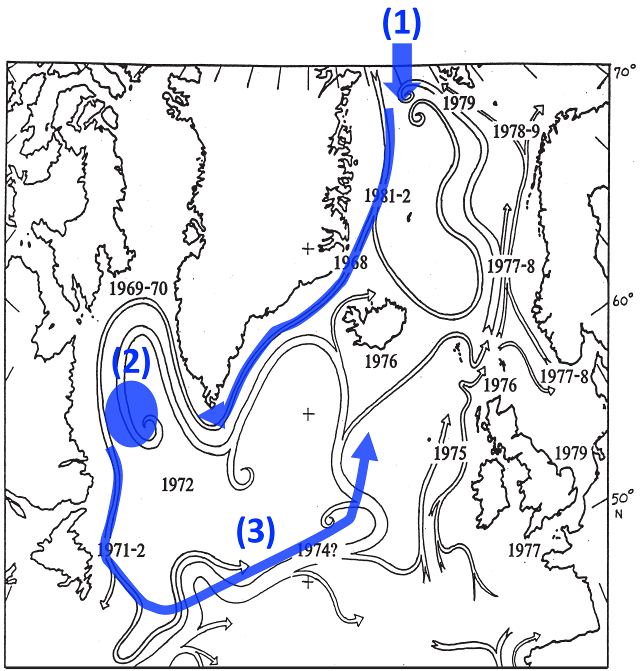
HiLAT RASM

Great Salinity Anomaly of the 1970s

- There has been decadal-scale low salinity events in the subpolar North Atlantic (SPNA), first emerging in the sub-Arctic seas, entering the North Atlantic, and moving along the subpolar gyre
- The most pronounced event: during the late 1960s and 1970s, called **Great Salinity Anomaly (GSA)**
- **Conventional view of GSA (*Dickson et al. 1988*):**

1) Enhanced Fram Strait sea-ice export (FSSIE) in the late 1960s
2) Freshwater anomaly advected to the Labrador Sea, shutting down deep convection during 1969-1971
3) Continued to move following the subpolar gyre and returned back to sub-Arctic seas a decade later

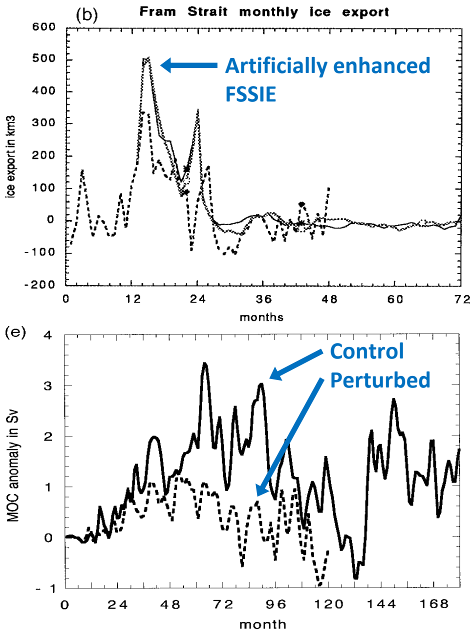


Belkin et al. (1998)

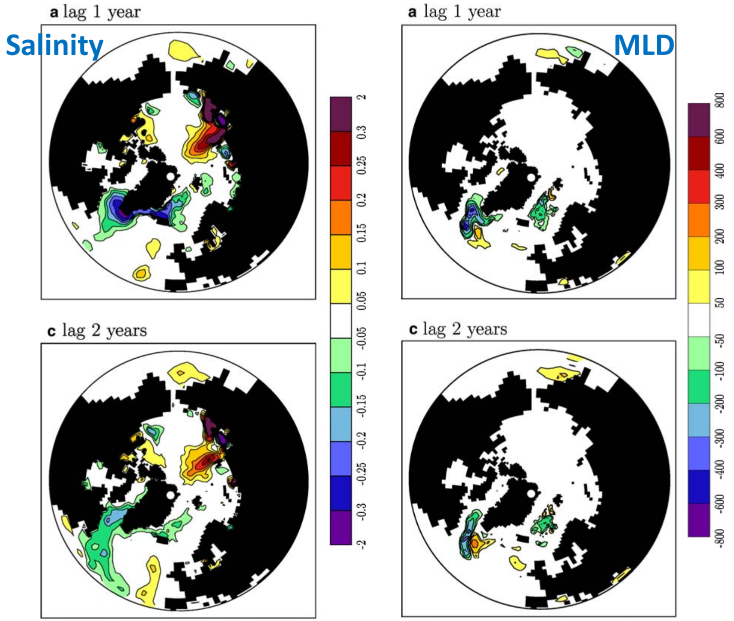
Great Salinity Anomaly of the 1970s

- GSA has received attention because of a potential role of Arctic-origin freshwater in shutting down deep convection
- Several modeling studies support the conventional view

Hakkinen (1999)

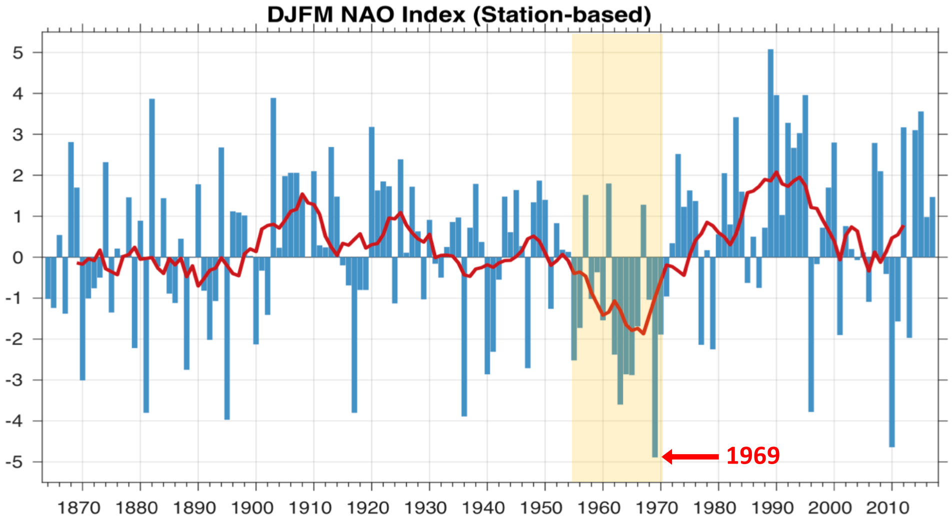


Koenigk et al. (2006) - Composite analysis using CGCM



Motivations

- However, the winter NAO was overall negative during 1960s and was the record low in 1969 (when the shutdown of deep convection occurred)
- NAO-related surface buoyancy forcing predominantly controls the strength of deep convection, thermohaline circulation (buoyancy-driven AMOC and subpolar gyre circulation), and thereby northward transport of heat and salt from subtropics.



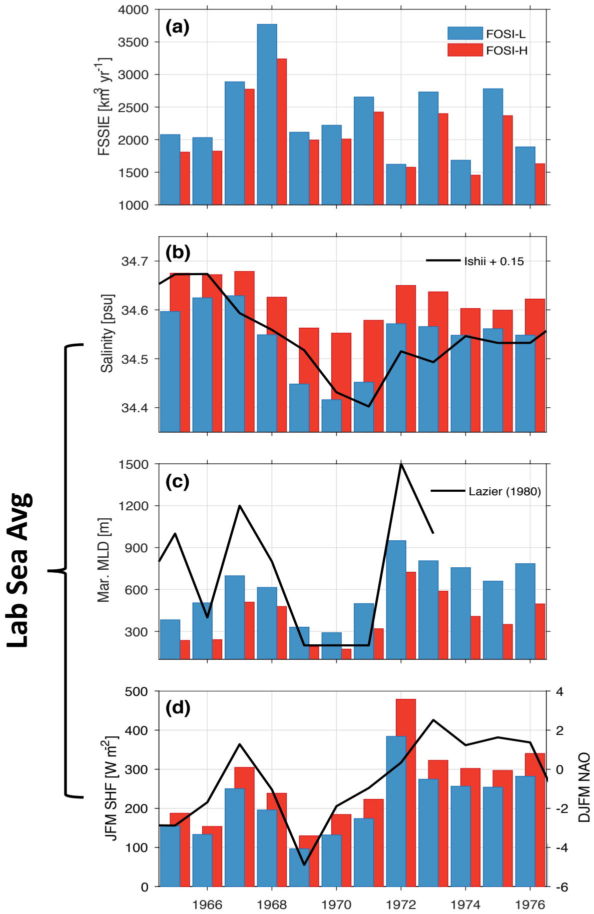
Motivations

- **However,** the winter NAO was overall negative during 1960s and was the record low in 1969 (when the shutdown of deep convection occurred)
- It is well known that NAO surface buoyancy forcing predominantly controls the strength of deep convection, thermohaline (AMOC) circulation, and thereby northward transport of heat and salt from subtropics.
- **No modeling studies have so far systematically compared the relative contribution of FSSIE and NAO buoyancy forcing to GSA**
  - ➢ Gelderloos et al. (2012) found roughly equal contributions using observations and 1-D mixed layer model
- Also, the models used in previous studies (mostly early 2000s) are almost two decades old

Model Simulations (CESM)

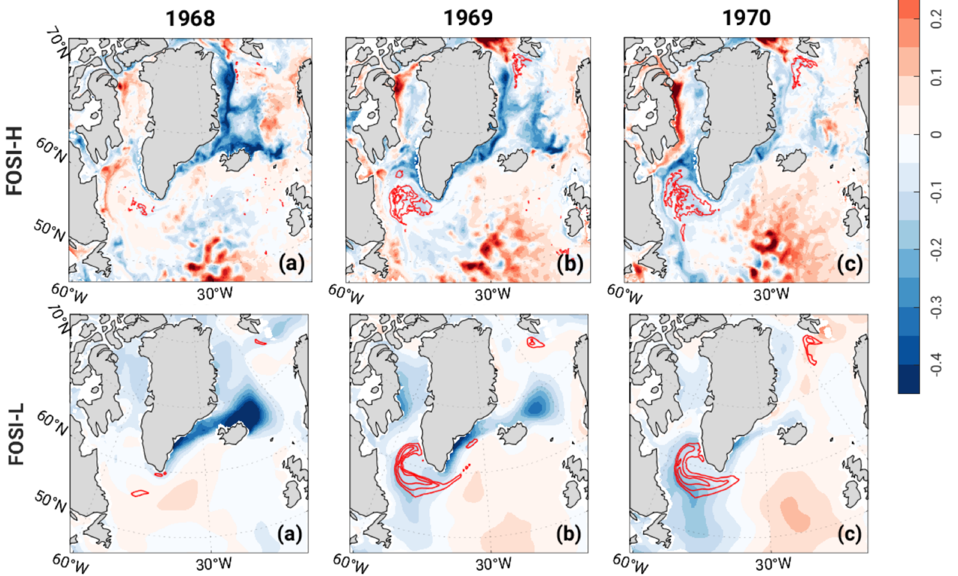
- **CESM1 (LENS) preindustrial control simulation (2200 year long)**
  - Later 1800 years are used for composite analyses
- **1° and 0.1° forced ocean – sea-ice simulations (FOSI-L and FOSI-H)**
  - Forcing: JRA55-do (1958-2018; *Tsujino et al. 2018*)
  - FOSI-L: Long spin-up cycles (5 times) and 5th cycle is used for analysis
  - FOSI-H: Only the first cycle is available (possible drift)
  - anomalies are relative to the 1962-1976 reference period
- **CESM1 NAO surface heat flux forcing experiments (*Kim et al. 2020*)**
  - Used to investigate the role of a decade long NAO surface buoyancy forcing
- **CESM1 physics- and initial condition-perturbed experiments (*Danabasoglu et al. 2019*)**
  - Used to examine the dependency of the results on temperature bias in the Labrador Sea

Simulated GSA in FOSIs

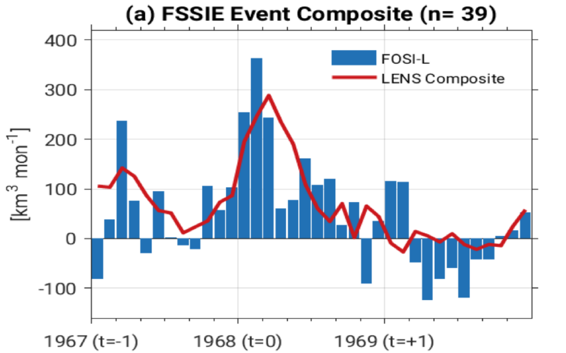


FSSIE

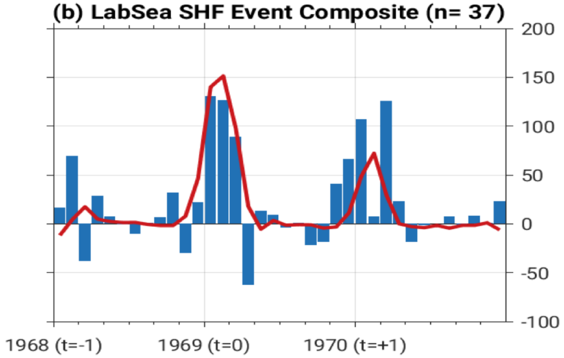
	FOSI-L	FOSI-H	Obs
Average (1991-1998)	2470 km³ /yr	1950 km³/yr	2220 km³/yr (Kwok et al. 2004)
1967-1968 Anomalies	2070 km³	1960 km³	2300 km³ (Vinje 2001)



Composite Analysis

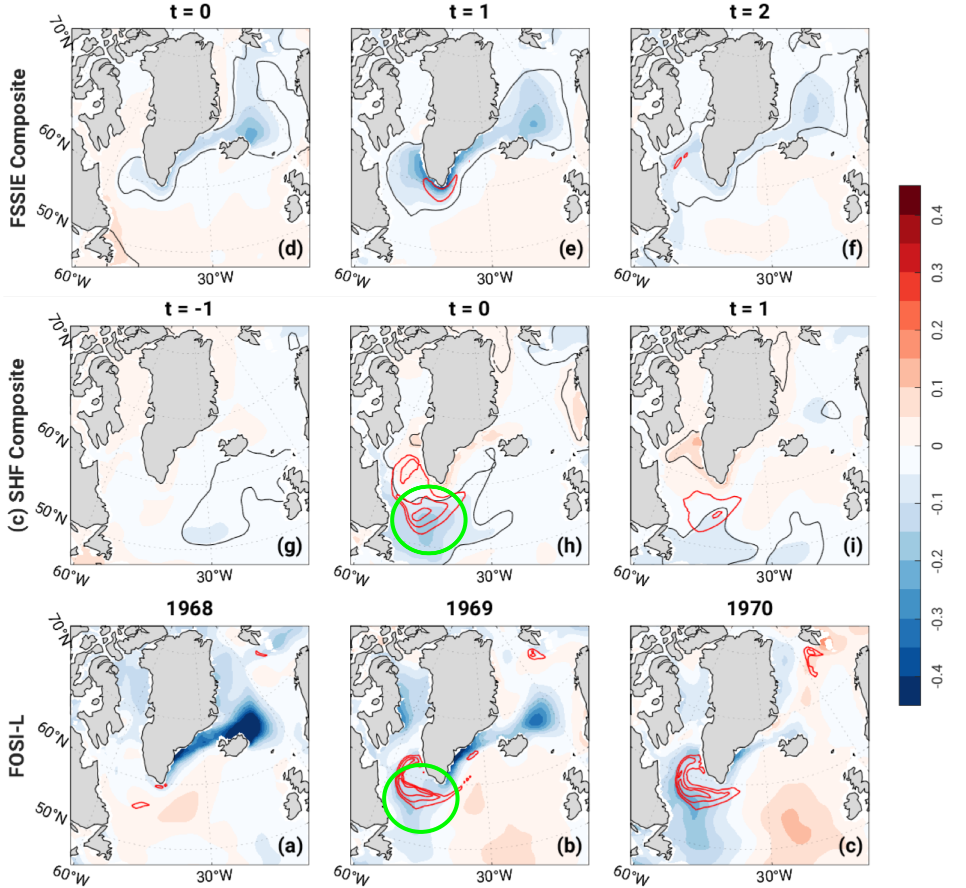


Jan-Jun (t=0) > 1.8 s.d. & Jan-Mar (t=-1) > 0

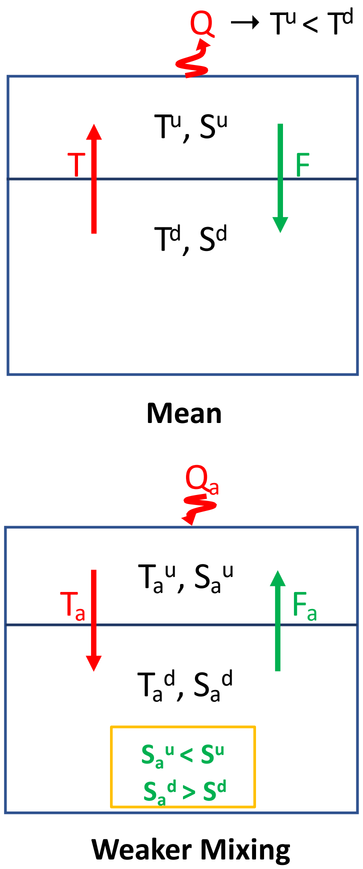


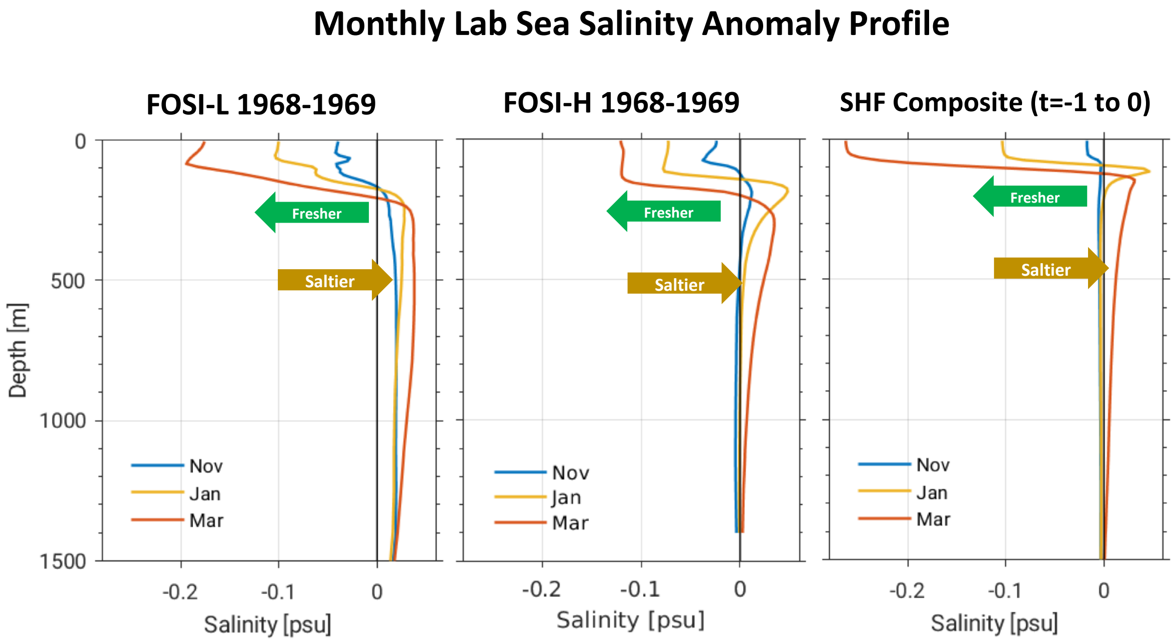
Jan-Mar (t=0) > 1.8 s.d. & Jan-Mar (t=+1) > 0

Salinity (<100m; shading)/Mar. MLD (contours) Anomaly Composites

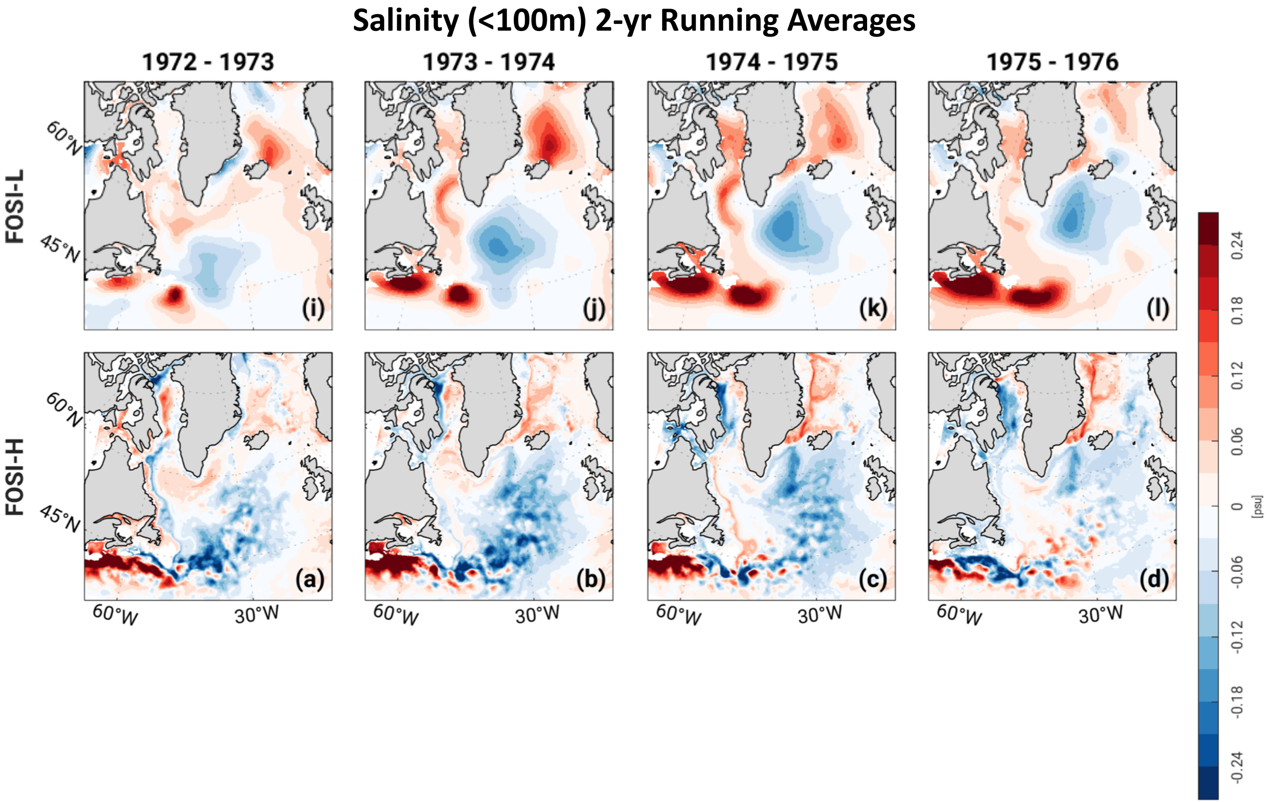


Freshening due to Suppressed Convection



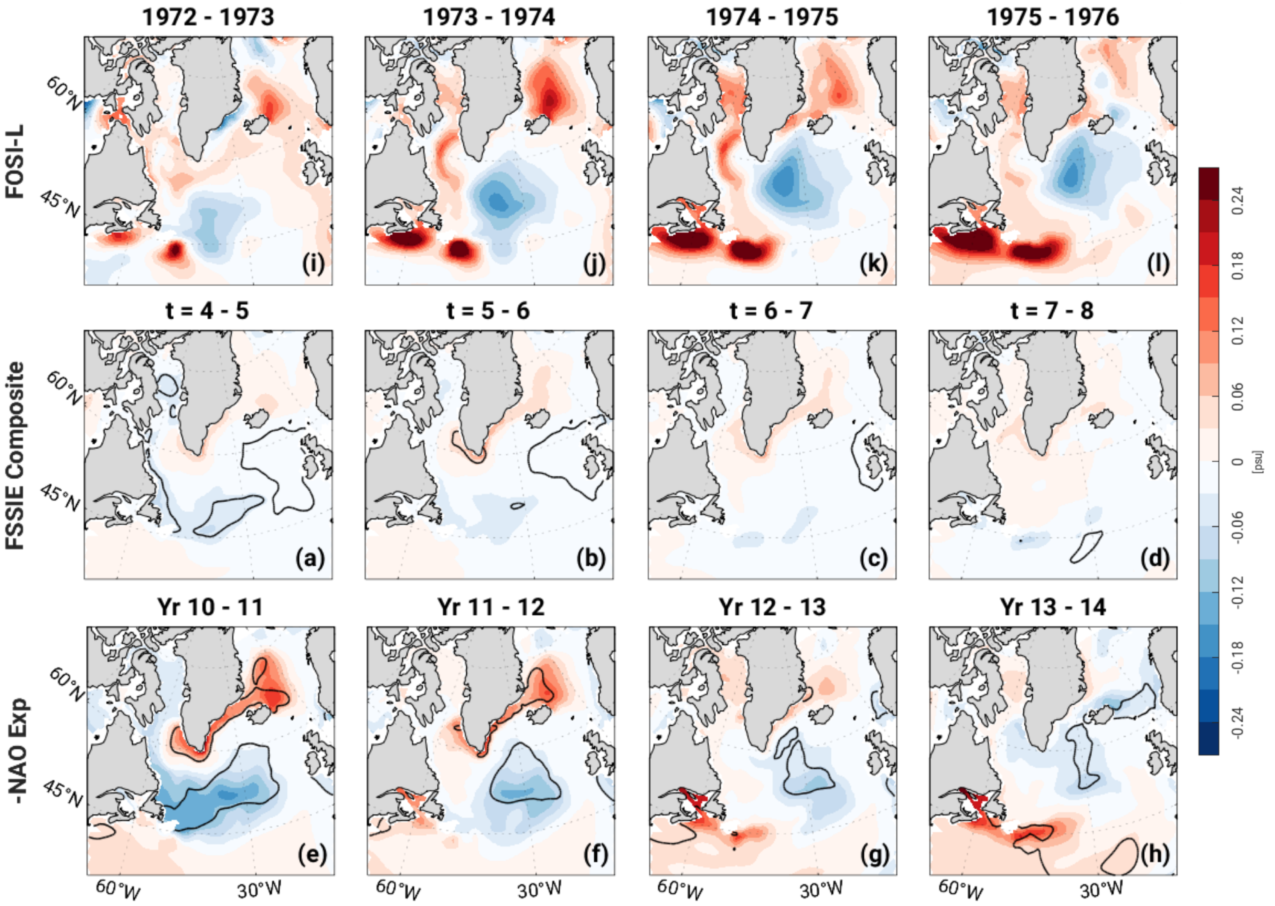


Downstream Advection

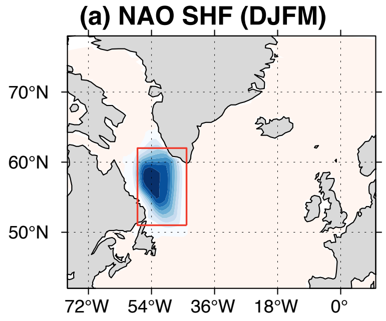


Downstream Advection

Salinity (<100m) 2-yr Running Averages

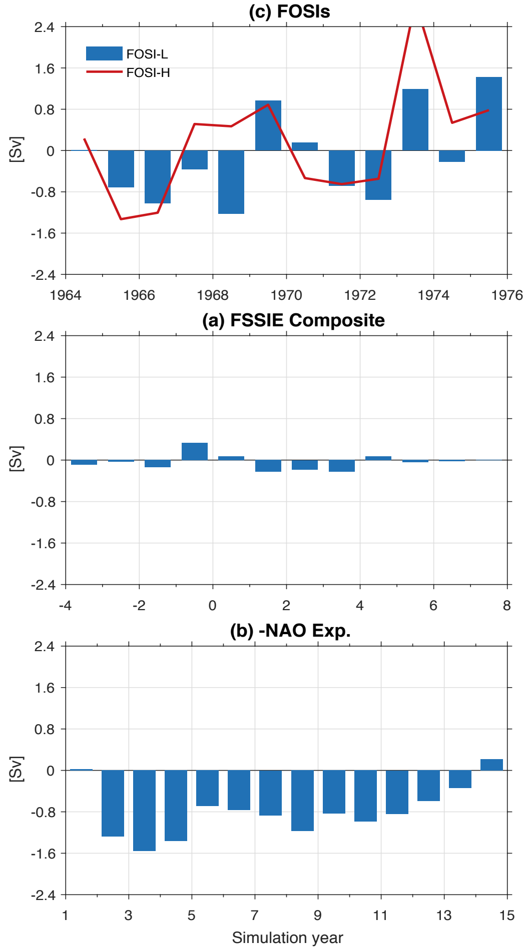


Lab Sea -NAO Heat Flux Forcing Experiments



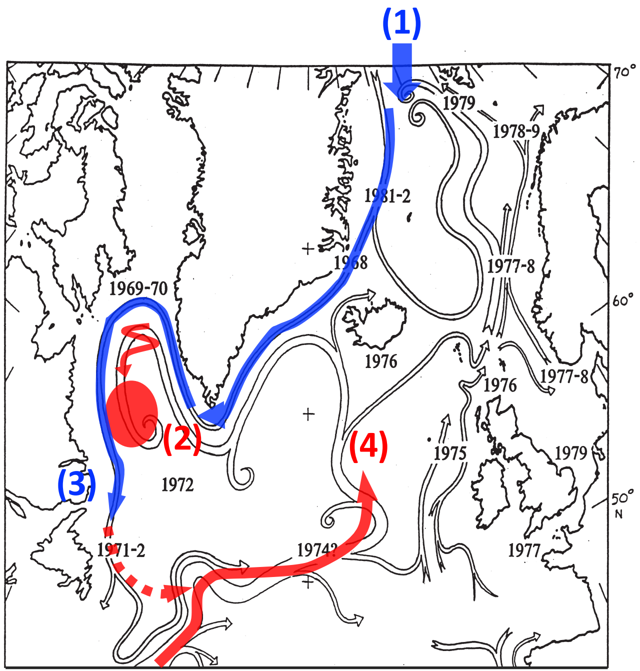
- Fully coupled CESM simulations
- 10 ensemble members
- 20-year simulations with the forcing applied for the first 10 years (winter only)
- Originally performed to study AMV mechanisms and climate impacts (*Kim et al. 2020,* https://doi.org/10.1175/JCLI-D-19-0530.1)

AMOC


(c) FOSIs
FOSI-L
FOSI-H
[Sv]
2.4
1.6
0.8
0
-0.8
-1.6
-2.4
1964
1966
1968
1970
1972
1974
1976
(a) FSSIE Composite
[Sv]
-4
-2
0
2
4
6
8
(b) -NAO Exp.
[Sv]
1
3
5
7
9
11
13
15
Simulation year

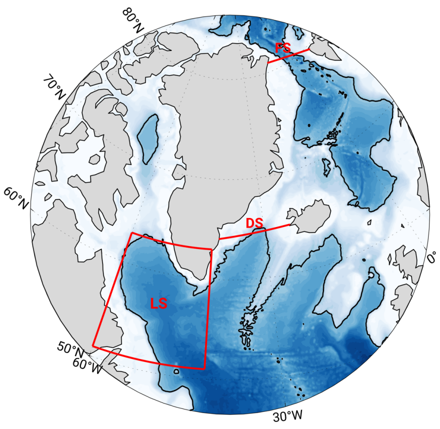
Revised GSA Mechanisms

1) Enhanced Fram Strait sea-ice export (FSSIE) in the late 1960s
2) ~~Freshwater anomaly advected to the Labrador Sea, shutting down deep convection during 1969-1971~~
2) **The shutdown of deep convection and freshening in the interior Labrador Sea due to strong anomalous heat gain**
3) **FSSIE-induced fresh anomaly propagated along the boundary currents to the gyre boundary, but dissipated there**
3) ~~Continued to move following the subpolar gyre and returned back to sub-arctic seas a decade later~~
4) **The propagation of the fresh anomaly along the subpolar gyre coming from the subtropics due to weaker thermohaline circulation**

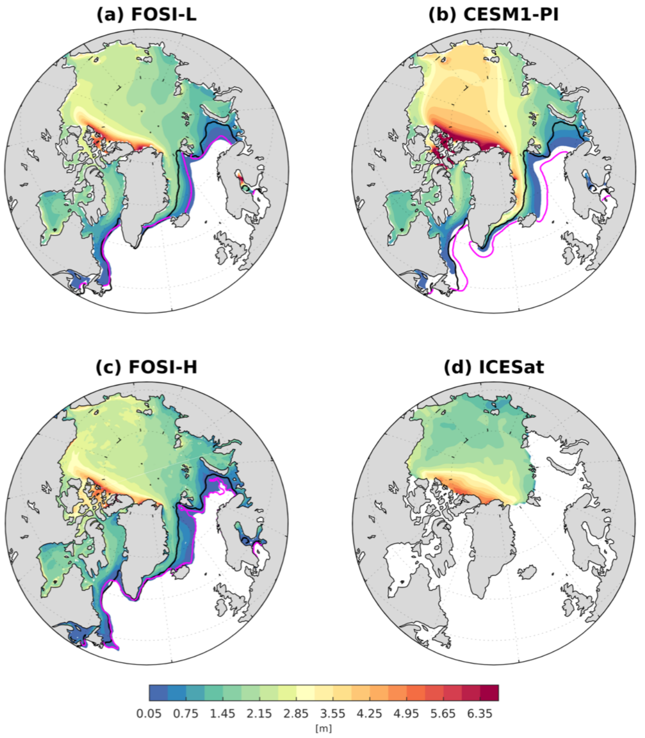


Belkin et al. (1998)

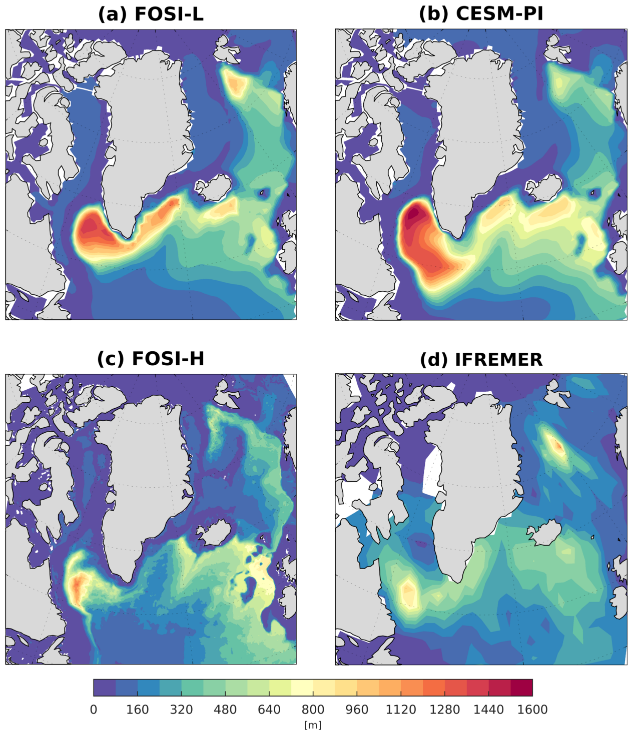
Climatologies



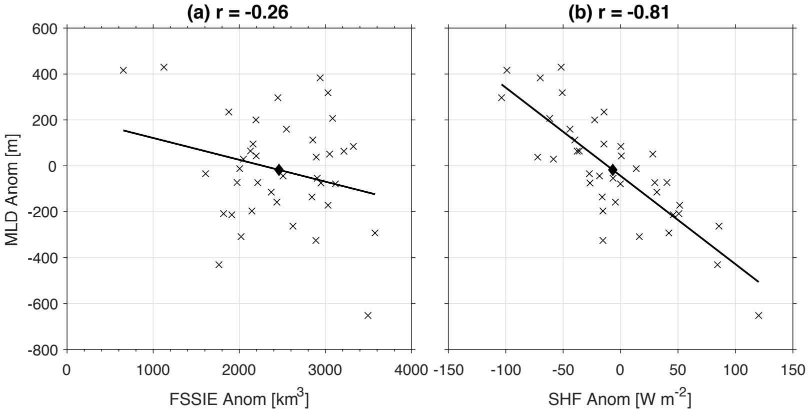
March Sea-Ice Thickness



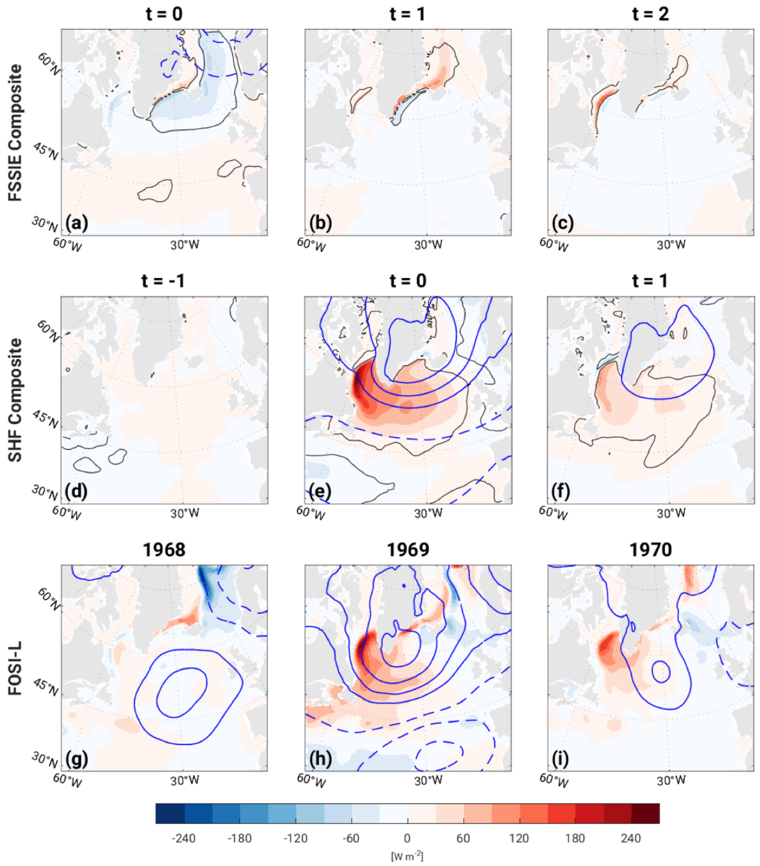
March MLD



Individual MLD anomalies of the FSSIE events

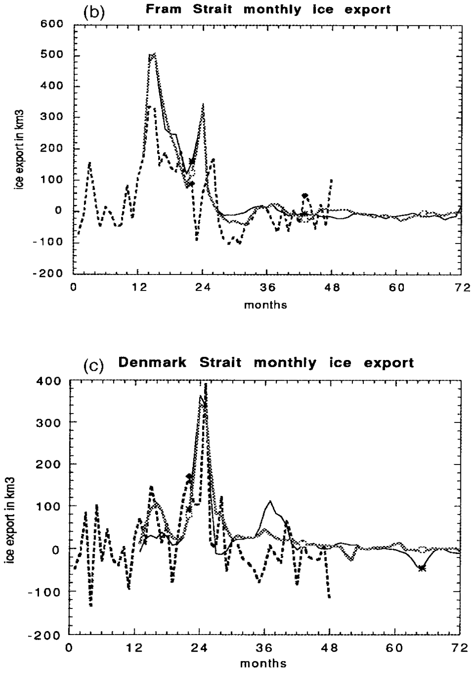


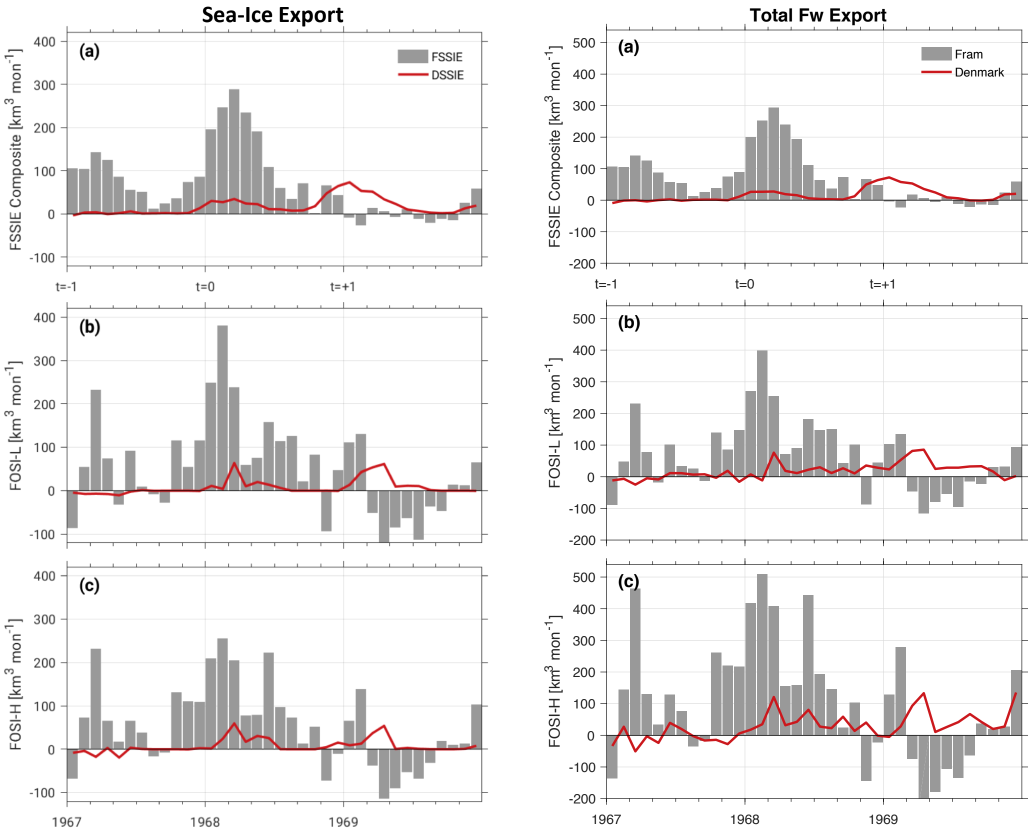
JFM SHF (shading)/SLP (con) Anomaly Composite



Comparison to Hakkinen (1999)

Hakkinen (1999)

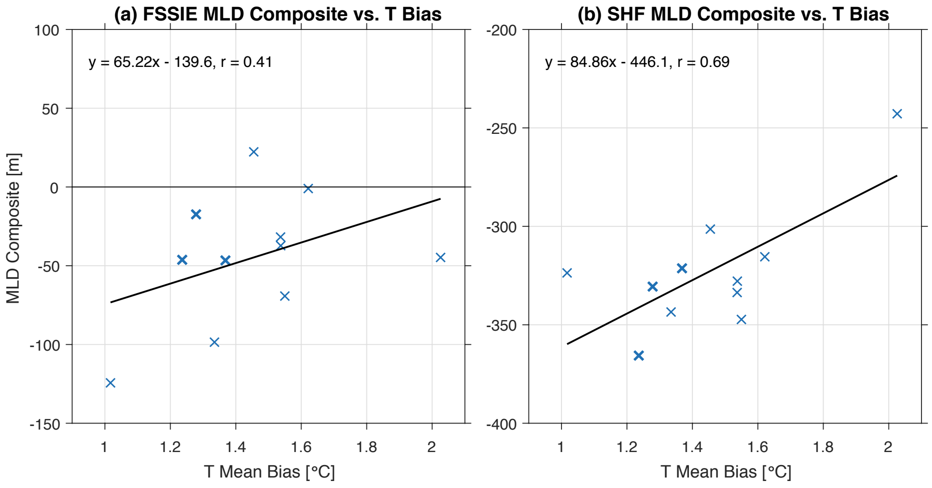




Dependency on Lab Sea Temperature Bias

- Because of the nonlinearity of the equation of state, a density change is greater at colder temperature and Lab Sea salinity bias is positive in CESM1
- Similar composite analysis performed from physics- and initial condition-perturbed experiments (8 experiments) using the same CESM1 (*Danabasoglu et al. 2019*)

Composite Analysis from Perturbed Experiments



Dukhovskoy et al. (2016)

- Realistic Greenland meltwater is released along with a passive tracer in three different models (1/12, 1/4 and 1/2º)
- Only 1-2% of the passive tracer ends up in the interior Lab Sea