Abrupt shift of the Atlantic Ocean circulation induced by atmospheric blocking

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Introduction:

Fram Strait sea ice export from the Arctic represents a key source of fresh water for the North Atlantic. Although variations in the ice export may have a strong influence on the Atlantic meridional overturning circulation (AMOC), their causes and consequences are not yet fully understood. Using a global ocean-sea ice model with increased resolution over the Arctic and northern hemisphere deep-water formation areas, here it is shown that enhanced blocking activity over Greenland and the northern North Atlantic during the period 1962-1966 favored sea ice accumulation in the Arctic. Whereas the period 1967-1971 was characterized by weak blocking activity in the region, leading to intensified Arctic sea ice export and, hence, reduced Labrador Sea surface salinity and a weakened AMOC. These results indicate that AMOC shifts toward weak states, as the one emphasized here in the 1970s, may be induced by rapid sea ice flushes from the Arctic after periods of enhanced blocking activity over Greenland. They imply also that an important part of the atmosphere-ocean dynamics at mid- and high latitudes requires a proper representation of the Fram Strait and associated sea ice transport as well as synoptic scale variability such as atmospheric blocking, which is a challenge for current coupled climate models. In this study we investigate the potential driving role of the atmospheric blocking activity for FSSIE as well as the associated consequences for the North Atlantic freshwater budget and ocean circulation in this sector.

Methodology:

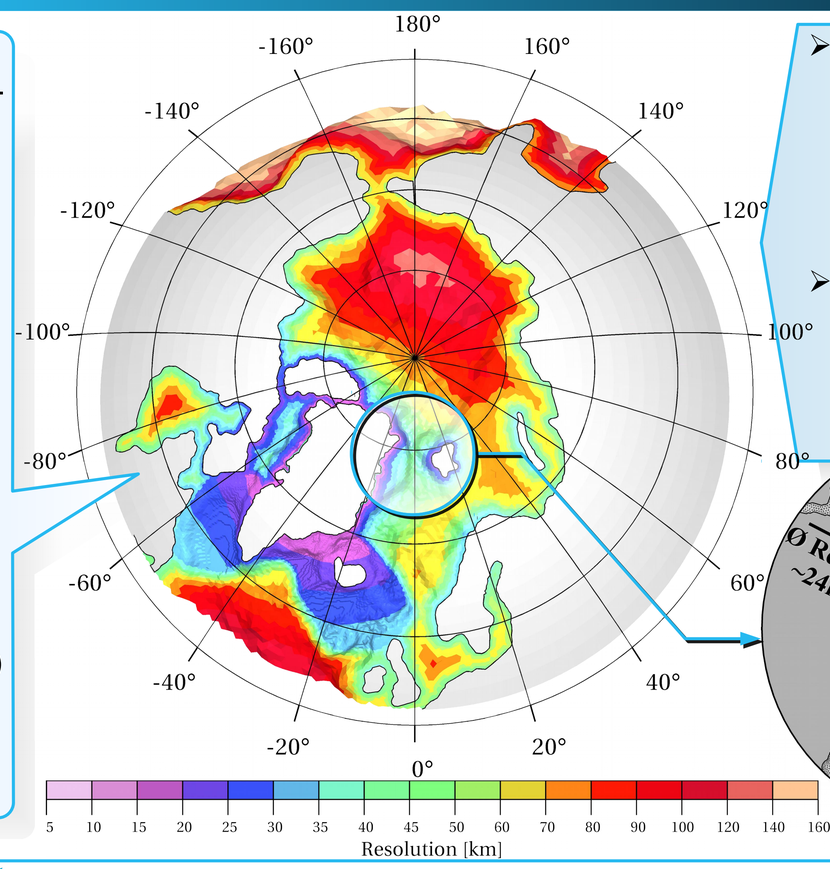
- Use Finite Element Sea Ice-Ocean Model (FESOM, developed at Alfred Wegener Institute)
- Solve primitive equation under Boussinesq approximation

Forcing:

- COREv2.0 (tair,specific humidity, precipitation, wind speed, radiation flux, SSS climatology)

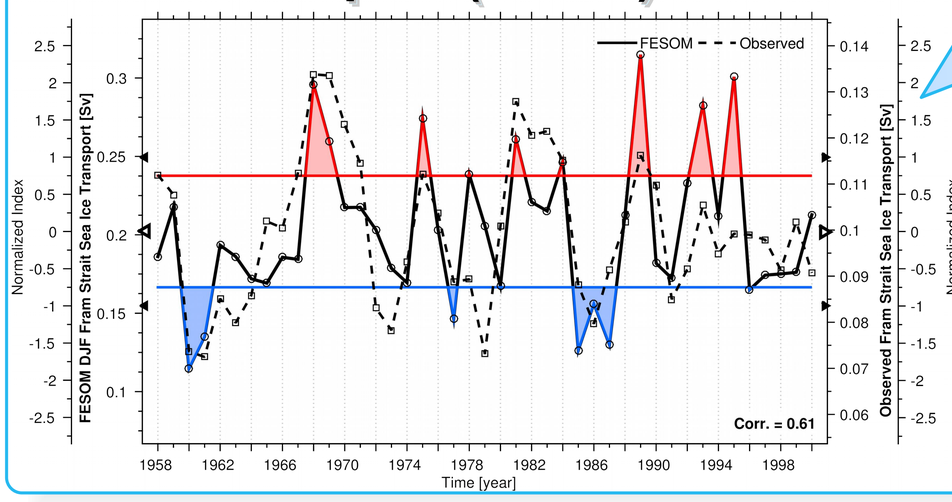
Mesh:

- Unstructured triangular surface mesh (53.382 surface nodes, 101.827 triangular surface elements)
- 41 vertical levels
- 3D tetrahedral elements (~1 Mio. 3D nodes, ~6 Mio 3D elements)



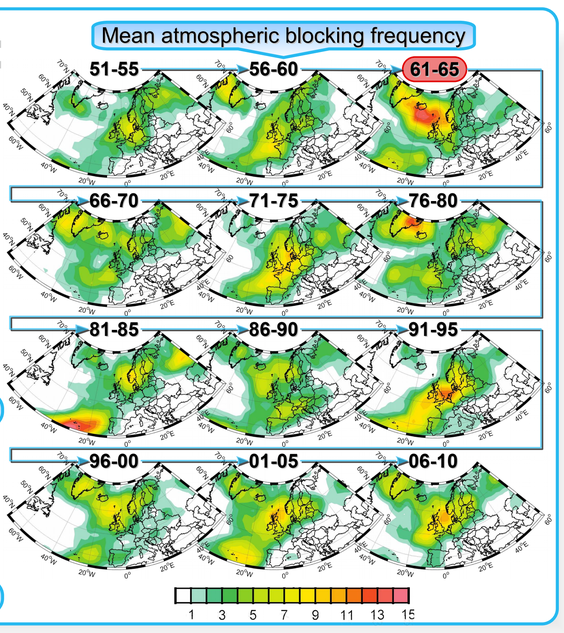
- Regional resolution of the global model setup in the Northwest Atlantic Ocean. The dashed line marks the position of the AR7W cruise line
- The resolution in Labrador Sea varies between 15 km in the North and 30 km in the South

Modeled & observational derived Fram Strait Sea Ice Export (FSSIE):



- Modeled (solid) and observational derived (dashed, Schmith and Hansen 2003) time-series of FSSIE.
- Correlation 0.61 (Significance level 99.9%)
- Modeled FSSIE **above**/**below** 75% of standard deviation

Atmospheric Blocking:



2d Blocking Index:

- Scherrer et al. 2006, based on data of geopotential height

$$GHG_S = \frac{Z(\varphi_0) - Z(\varphi_S)}{\varphi_0 - \varphi_S}$$

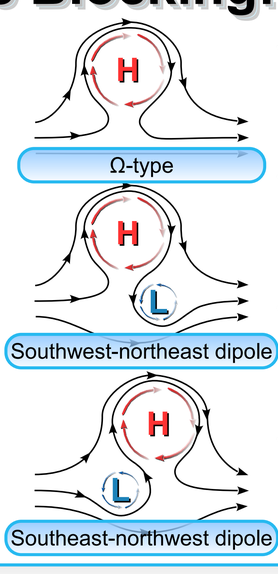
$$GHG_N = \frac{Z(\varphi_N) - Z(\varphi_0)}{\varphi_N - \varphi_0}$$

$\varphi_N = \varphi_0 + 15°$, $\varphi_S = \varphi_0 - 15°$

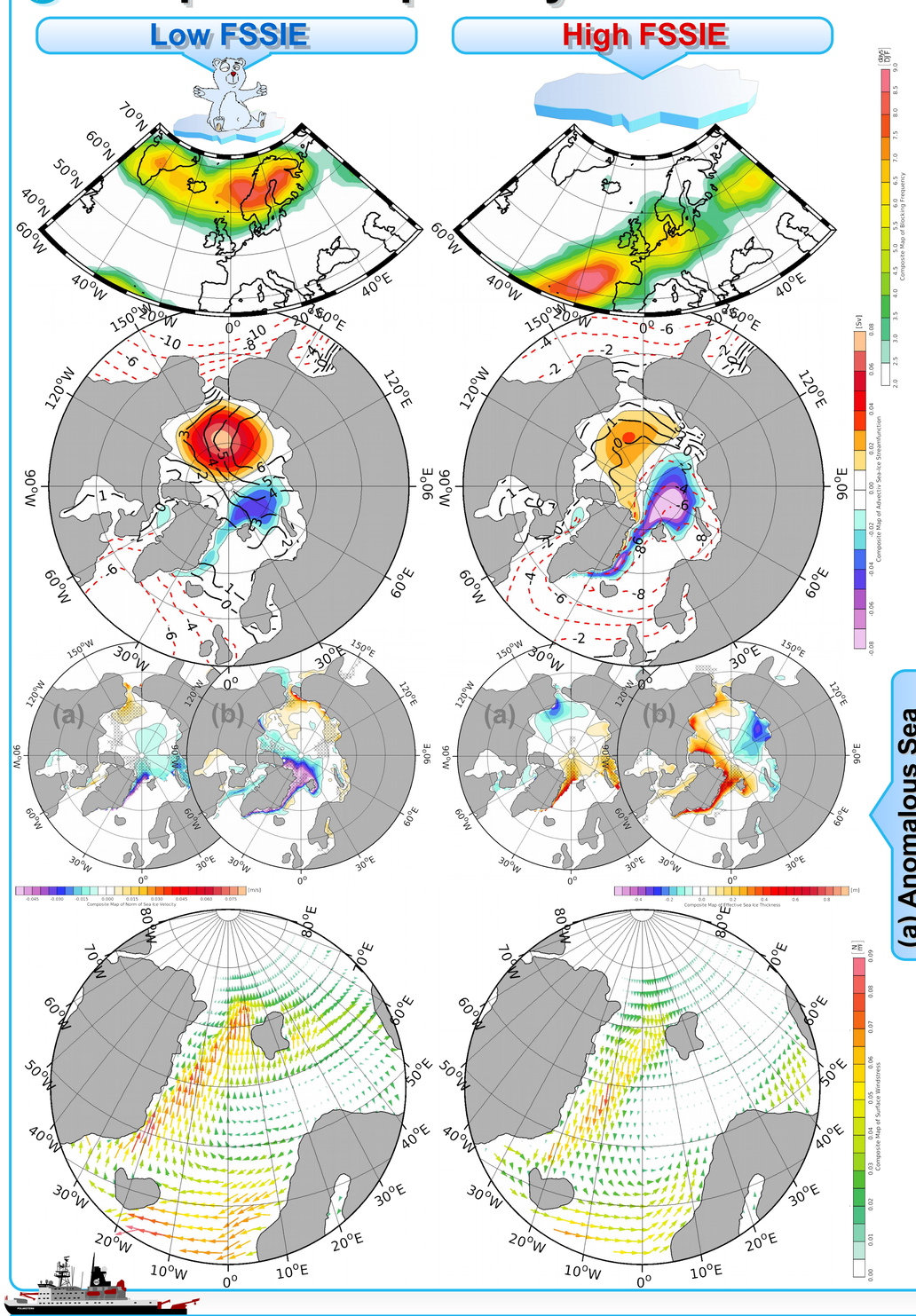
$\varphi_0 = grid\ point\ latitude$

- Blocked grid point when at least five consecutive days fulfill the condition

$$GHG_S > 0\ ,\ GHG_N < -10\ ^{m}/_{deg_{lat}}$$

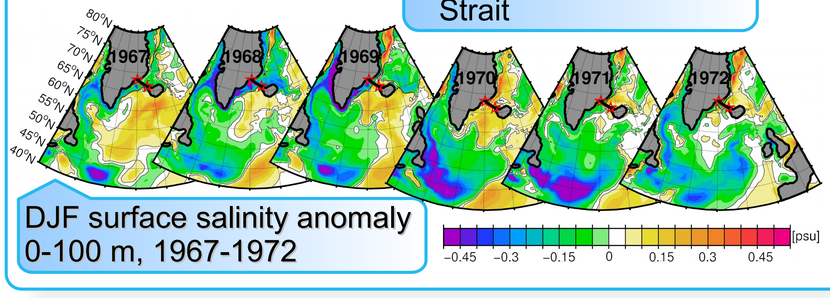


Composite Map Analysis of FSSIE:

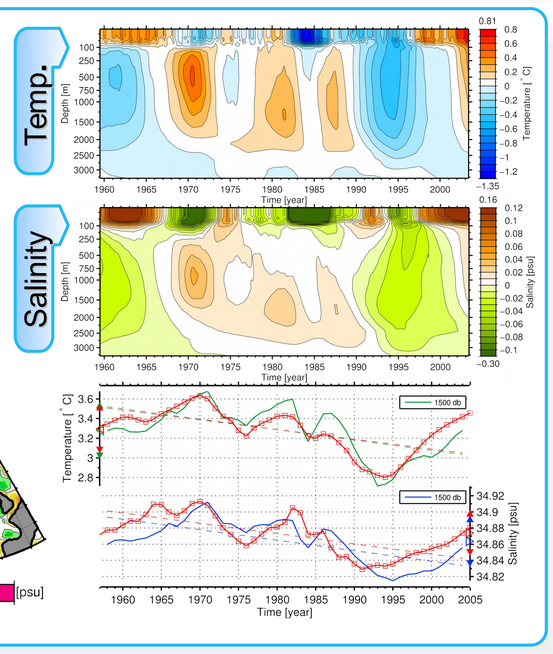


Modeled Great Salinity Anomaly (GSA):

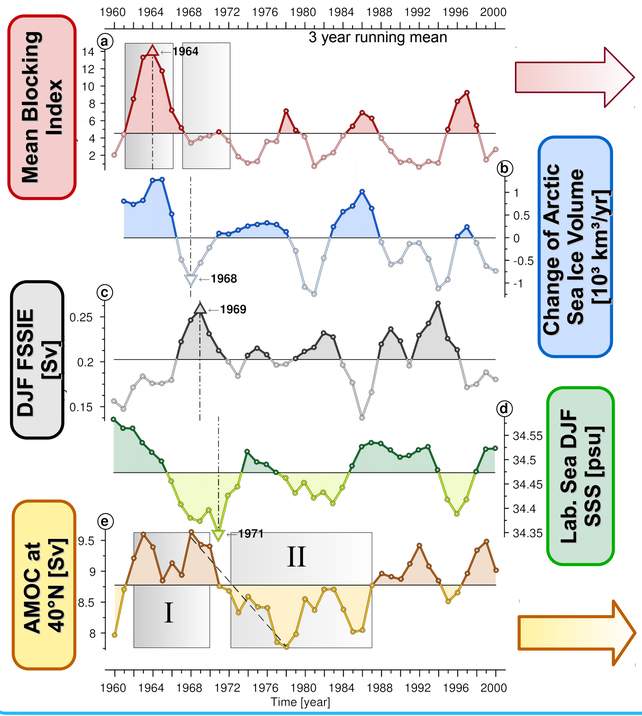
- Surface fresh water anomaly that occupied central Labrador Sea for several years
- Known GSA events, **~1970** (Dickson et al. 1988), **~1982** and **~1988** (Belkin et al. 1998 & 2004)
- Linked with increased sea ice transport through Fram or Davis Strait



DJF surface salinity anomaly 0-100 m, 1967-1972

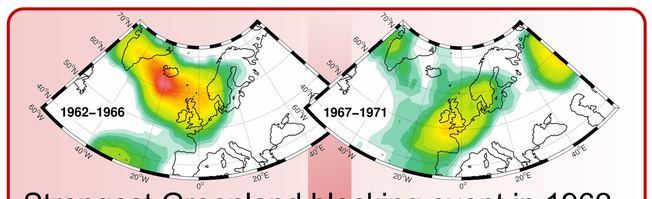


Causes and consequences of the late 1960s GSA event ?!



Change of Arctic Sea Ice Volume [10³ km³/yr]

Lab. Sea DJF SSS [psu]



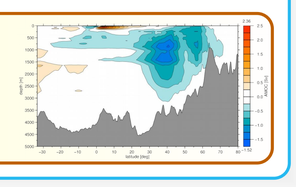
Strongest Greenland blocking event in 1962-1966, reduced meridional air mass exchange

Accumulation of Arctic sea ice volume until 1966, afterwards decrease in sea ice volume

Flush out of Arctic sea ice by increased sea ice export through Fram Strait ~ 1968/69. Creates freshwater anomaly by sea ice melting

Surface freshwater anomaly occupies ~1971 the central Labrador Sea and creates strongest GSA event of the last 5-6 decades.

Reduced deep ventilation in the central Labrador Sea leads to a drop in AMOC around 1971



References

[*] M. Ionita, P. Scholz,et al. (2015), Abrupt shift of the Atlantic Ocean circulation during the 1970s induced by atmospheric blocking. Under review in Nature Climate Change

[1] Scholz, P. et al. (2014), Evaluation of Labrador Sea water formation in a global finite-element sea-ice ocean model setup based on a comparison with observational data, J. Geophys. Res. Ocean, 119, DOI: 10.1002/2013JC009232

[2] Scholz, P., et al. (2013), Evaluation of a Finite-Element Sea-Ice ocean model (FESOM) setup to study the interannual to decadal variability in the deep-water formation rates, Ocean Dynamics, 63 (4), 347-370

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