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Impact of Atlantic water variability on sea ice changes in the Fram Strait and north of Svalbard

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sea ice, Atlantic Water variability, Fram Strait, north of Svalbard

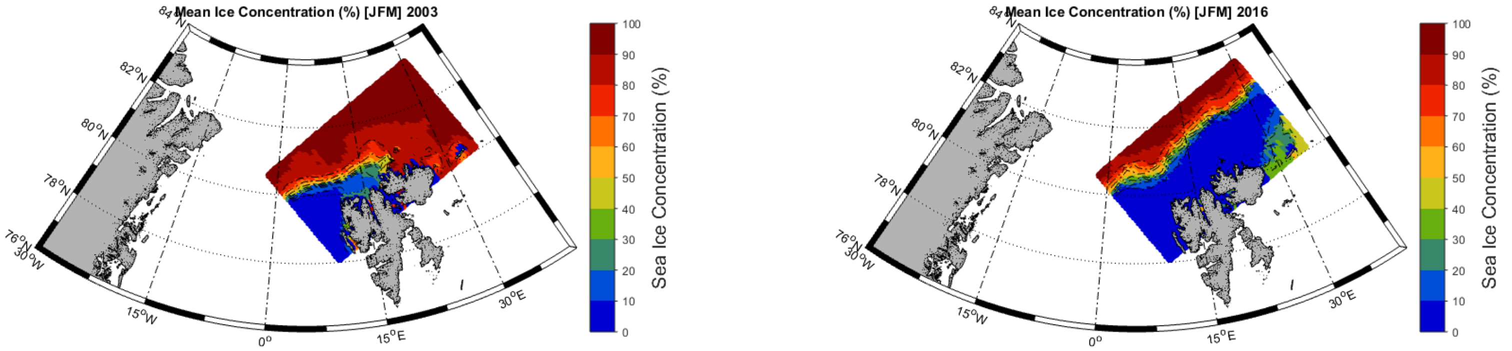

Fig. Specific evolution of sea ice concentration in winter (January-March [JFM]) in 2003 and 2016.

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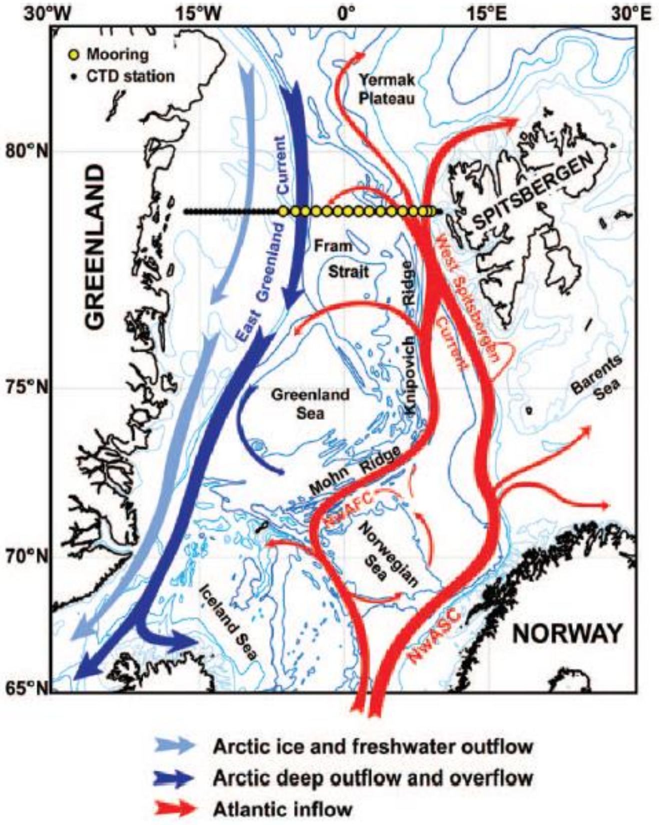

***Fig. 1**. A circulation scheme for the Nordic Seas and Fram Strait; main pathways of the Atlantic water circulation (**Beszczynska-Möller et al., 2011**).*

Research area:

- North of Svalbard
- Fram Strait

play a key role for the Atlantic Water inflow to the Arctic Ocean,
which is one of the main drivers of sea ice variability

Main objective of the research:

analyze and explain the sea ice variability along main pathways of the Atlantic origin water in the context of observed warming of Atlantic layer and change of local atmospheric conditions

Hypothesis of the research:

summer-to-summer variability in the Atlantic Water sector provides conditions for loss and shifted northeastward sea ice cover, generally in the winter season

LOSS OF SEA ICE DURING WINTER NORTH OF SVALBARD

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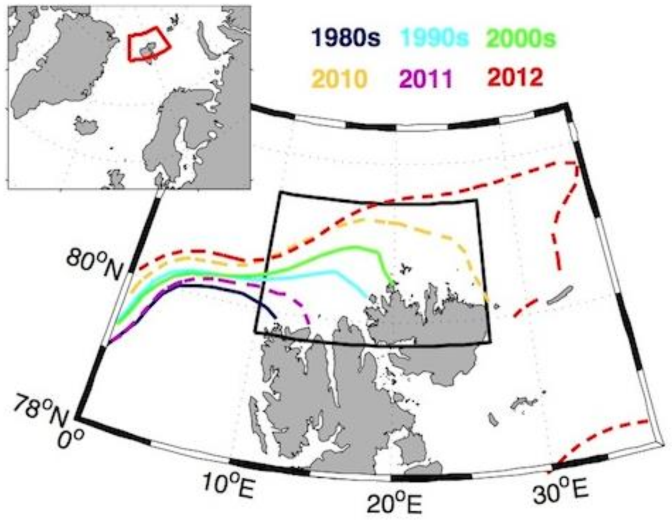

Fig.2 *Contour lines of the 40% winter (**DJFM)** ice concentration north of Svalbard during the 1980s (dark blue), 1990s (light blue), and 2000s (green). The most recent winters are also included with dashed lines (2010: yellow, 2011: purple, and 2012: red). Onarheim, I. H, et al., 2014*

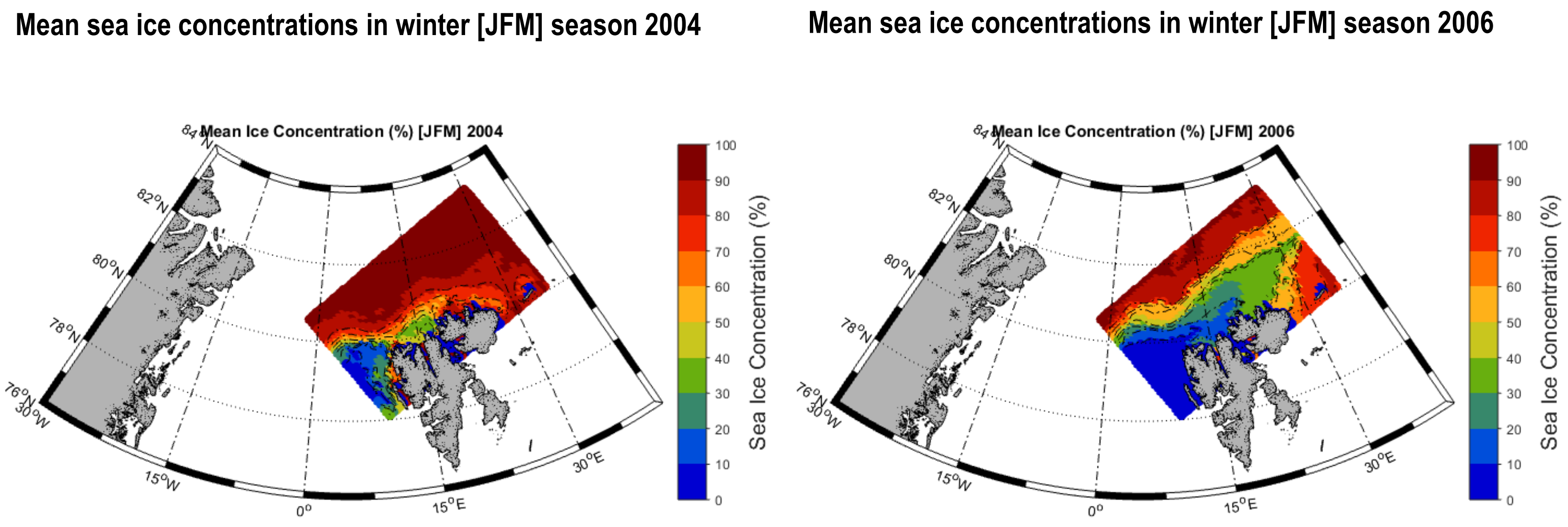

Fig.3 *Specific winter evolution of sea ice concentration in the Atlantic section in winter: January-March [JFM] in 2004 and 2006.*

- warming of winter mean surface air temperature observed north of Svalbard
- withdrawal of the sea ice cover towards the northeast, along with the pathways of water inflow in the Atlantic sector of the Arctic Ocean
- winter JFM (January-March) and autumn OND (October-December) mean ice concentration demonstrate the biggest reductions of sea ice

OCEANOGRAPHIC MEASUREMENTS DURING THE AREX CRUISE (1996-2019)

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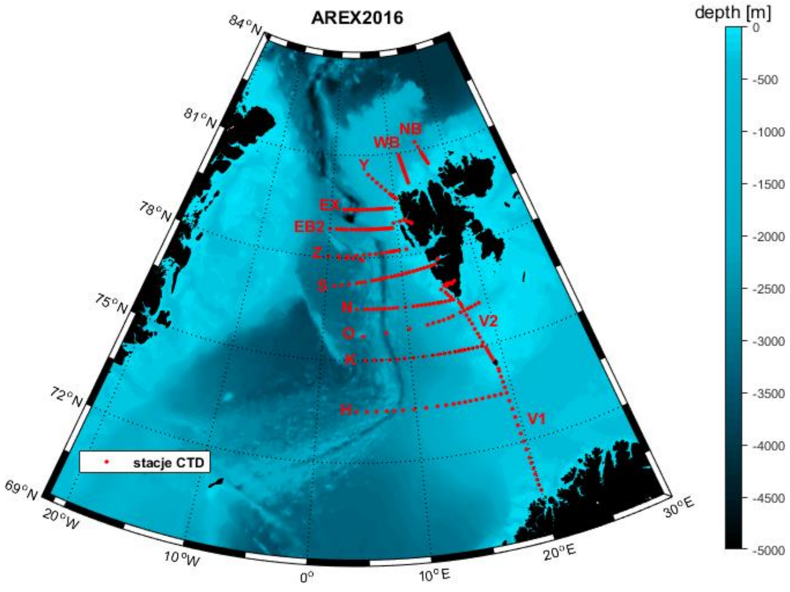

Fig.4 Location of CTD stations measured during the open ocean part of AREX 2016 (June 21—July 24, 2016). Red dots mark CTD stations

- time period of measurements - 20 June to 20 July (each year)
- conductivity-temperature-depth (CTD) full-depth stations within the geographical area 70°30' - 81 ° 15' N and 0 - 20 ° E
- Lowered Acoustic Doppler Current Profiler (LADCP)
- cross-sections perpendicular to presumed direction of current
- transects arranged along parallels intersected the most important bottom structures

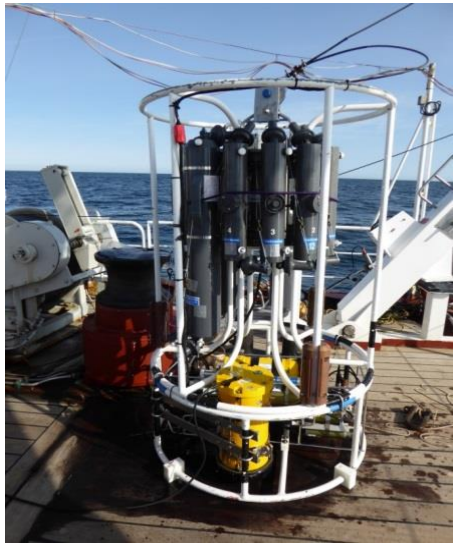

Photo by A. Beszczyńska-Möller

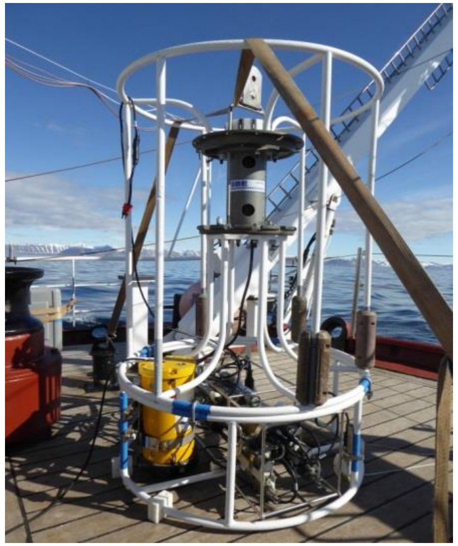

Photo by A. Beszczyńska-Möller

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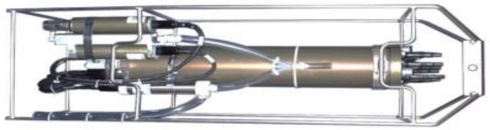

SBE 911plus CTD; www.seabird.com

- System Seabird 9/11+ (24 Hz, 4 cm, 0–3400 m)
  - double pairs of temperature (SBE3) and conductivity (SBE4) sensors
  - Digiquartz pressure sensor (410K-105)
  - two dissolved oxygen sensors (one standard SeaBird sensor SBE43 and additional Rinko optode, connected directly to the CTD registration system)
  - SeaPoint fluorescence sensor
  - Benthos altimeter Benthos PSA-916
- Acoustic Doppler Current Profiler *ADCP* (150 kHz, 350 m)
- SeaBird bathymetric rosette (carousel): 9 large Nansen bottles (12 l each) and 3 small bottles (1.75 l each)

SEASONAL, INTERANNUAL AND DECADAL VARIABILITY OF SEA ICE CONCENTRATION

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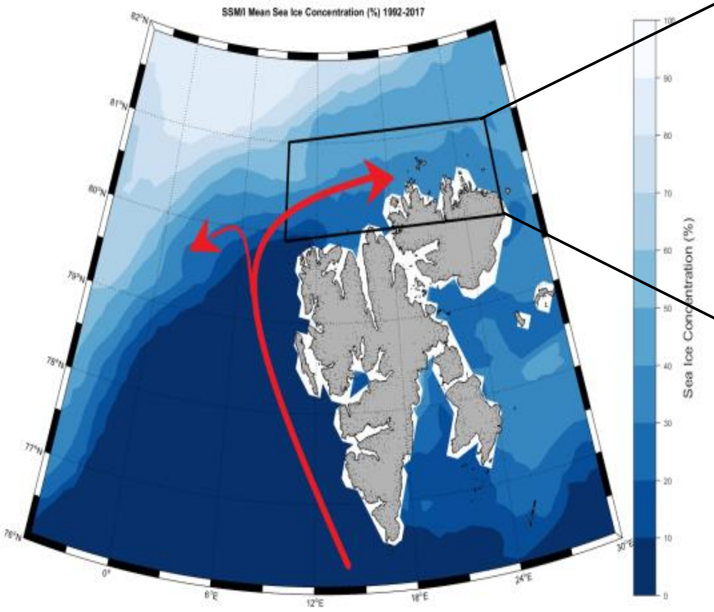

Fig. 4. Mean ice concentration field from 1992 to 2017. The solid black box shows the study region north of Svalbard. The red arrow indicates the pathway of the Svalbard Branch of the WSC and RAC.

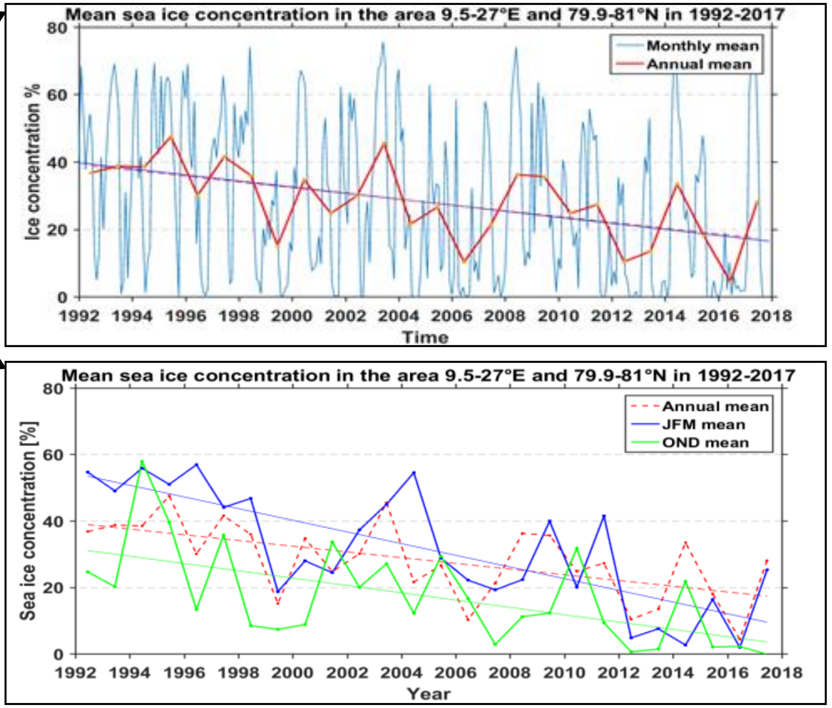

Fig.5 Time series of the annual and monthly means in the study regions north of Svalbard between 1992-2017.

The average yearly sea ice concentration has decreased at a linear rate of 12% per decade over the satellite record with minima in 1999, 2006, 2012, 2016 and 2018. The yearly mean ice concentration in the study region (9.5-27° E and 79.9-81° N) between 1992 and 2018 was estimated on 39.4%. Negative trends in sea ice extent are now statistically significant in all months of the year, although generally less extensive in summer and autumn. The sea ice concentration in study regions reaches its maximum in June and minimum in September. The monthly September sea ice concentration shows a linear rate of decline of 3.46 % per decade. Record low seasonaly summer [AMJJ] sea ice extents were reached in 2006 and 2016 and the lowest winter [DJFM] and autumn [ASON] sea ice extents have all occurred during the last 10 years.

In 2018, when the largest sea ice reduction was observed (annual mean in 2018 was 5.68% and 2017 was 43.58%), winter and autumn mean values of the ice concentration were respectively 5.74% and 0.26%. In the same time, sea ice extent was shifted from 80.5° N (in 2017) to 82° N (in 2018).

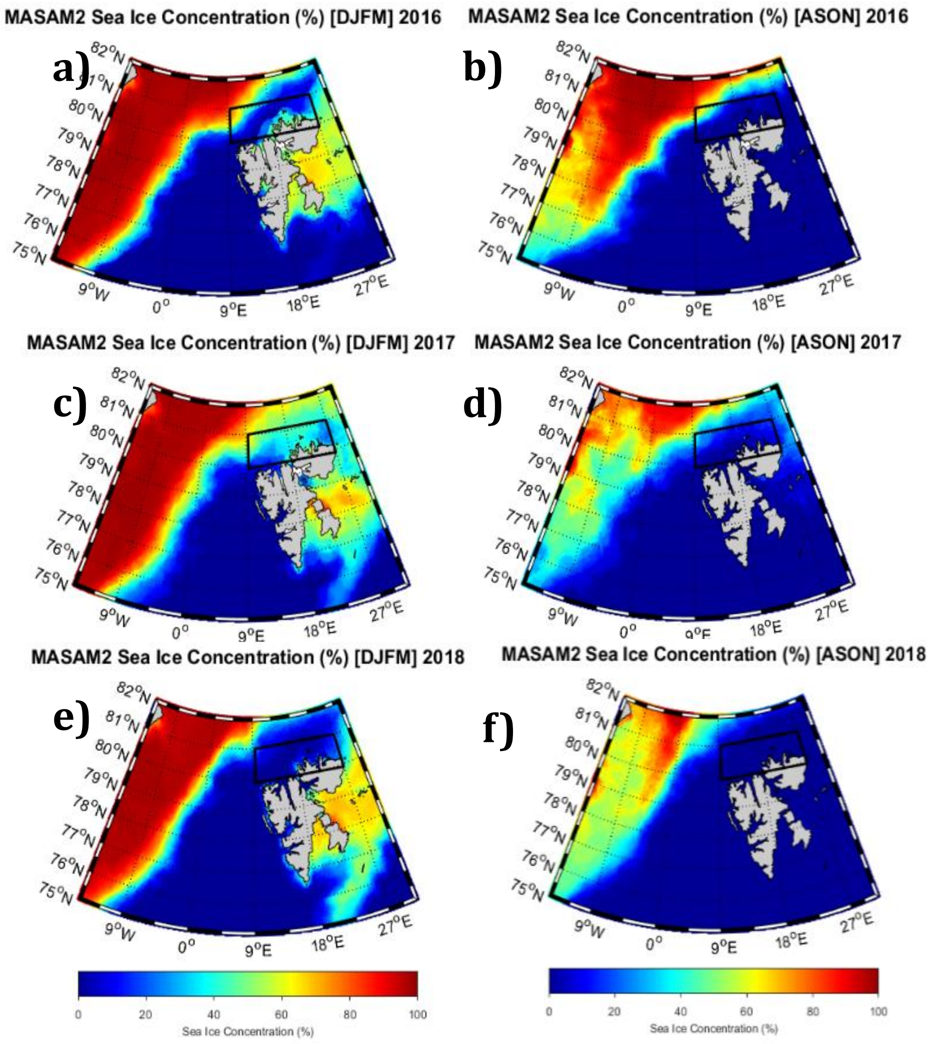

*Fig.6 Specific evolution of sea ice concentration in winter (**a,c,e**) [DJFM] and autumn (**b,d,f**) [ASON] in 2016, 2017 and 2018. Black box shows the study region from ice averages were calculated.*

OBSERVATIONS OF ATLANTIC WATER VARIABILITY DURING THE AREX SUMMER CAMPAIGNS: IMPACT ON SEA ICE CONCENTRATION NORTH OF SVALABRD

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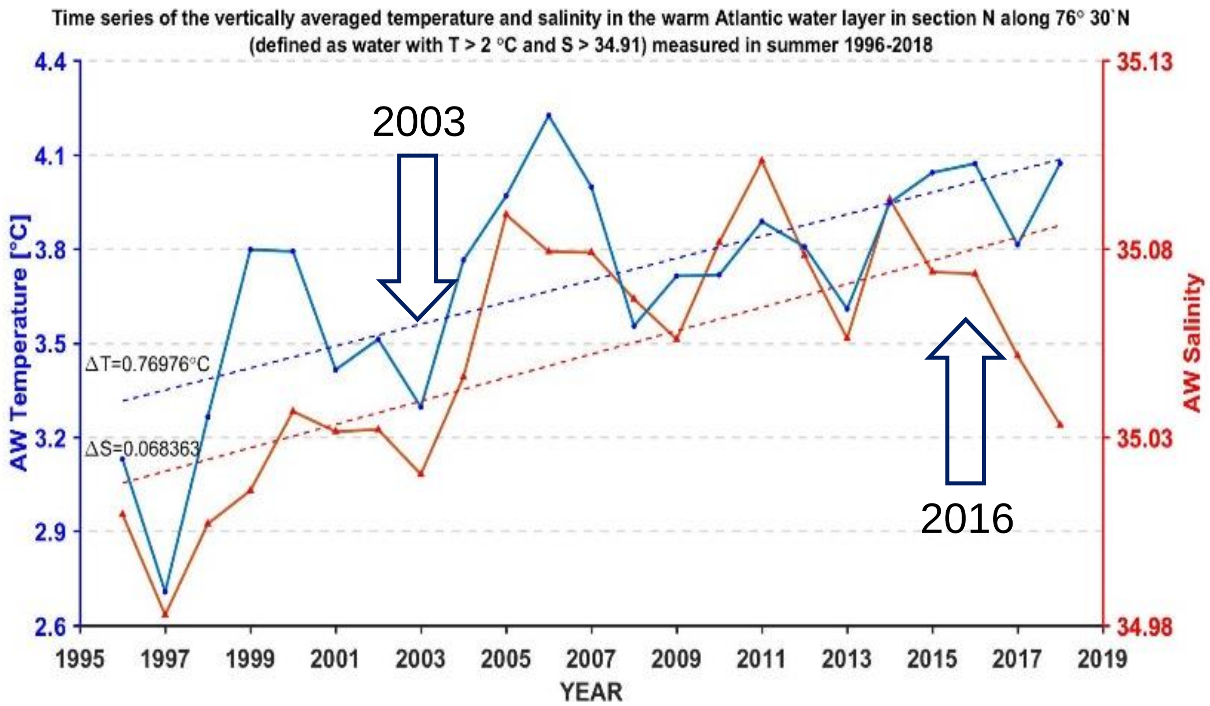

Fig.7 Time series of the vertically averaged temperature and salinity of the Atlantic water layer at the section N measured in summers of 1996—2018.

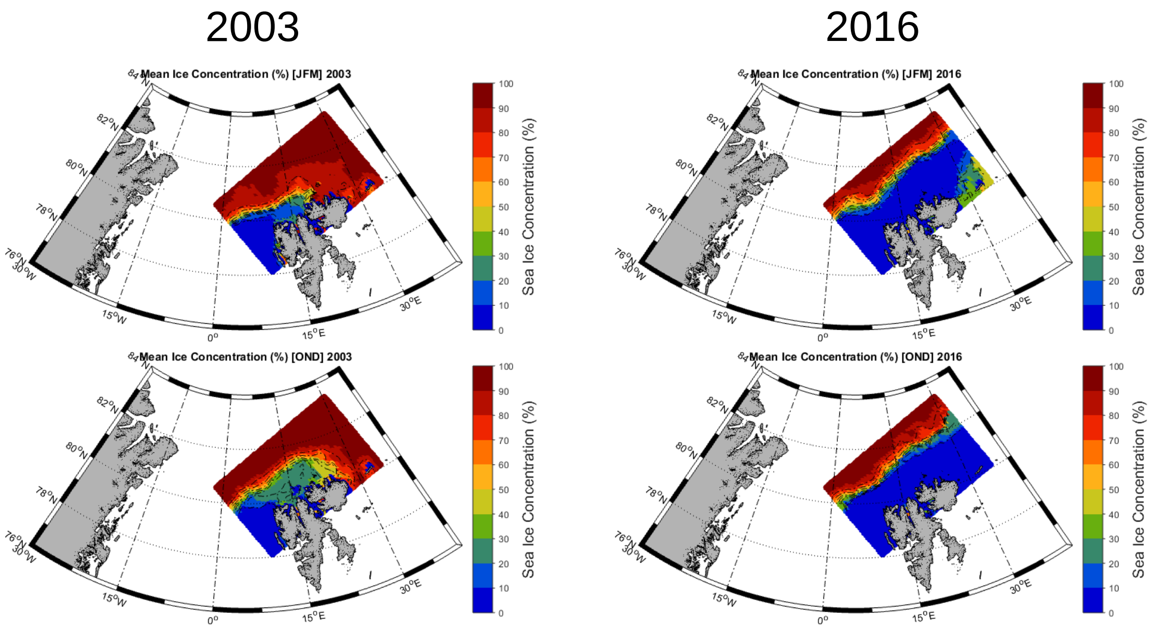

Fig.8 Specific evolution of sea ice concentration in winter (**a,b**): January-March [JFM] and autumn (**c,d**): October-December [OND] in 2003 and 2016.

- The longest observation record from the **section N** along 76°30′N reveals a steady **increase of Atlantic water salinity**, while temperature trend depends strongly on parametrization used to define the Atlantic water layer.
- The spatially averaged temperature at different depths indicate an **increase of Atlantic water temperature** in the whole layer.
- The mean AW temperature and salinity increased significantly in section N between 1996 and 2018. The maximum temperature was observed in 2006 (4.25°C) and 2018 (4.1°C). Maximum AW mean salinity of 35.13 was observed in 2011 and its minimum of 35.00 in 1997.

CONCLUSIONS:

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- During the last two decade, the West Spitsbergen Current has carried warmer than long-term mean AW northwards. A possible impact of AW warming causes a winter increase of open water extent in the area north of Svalbard. Atlantic water parameters, averaged on the section measured since 1996, are characterized by an increase of temperature and compensated by the increase of salinity.
- The ice loss is now visible for all months and in all regions, but varies substantially between regions and time of year. The sea ice decline in the Arctic Ocean is the strongest in summer seasons but in the Atlantic sector (north of Svalbard) is larger during winter and autumn.
- The results show that changes in AW temperature affect the of sea ice cover north of Svalbard, but the effect is not detectable during the summer (AMJJ). The greatest influence on ice cover occurs during the winter (DJFM) following the AW temperature measurements.
- During the summer the ice cover changes are more impacted by other factors (solar radiation, wind stress, air temperature) and AW temperature is less important driver of sea ice changes. Oceanic temperature is important factor for ice evolution in the Atlantic sector during the winter, and its variability correlates well with the changes in ice cover (not show).
- The decreasing sea ice concentration (6.94% in DJFM) observed in 2016 year is generally associated with higher (4.08°C) AW temperature, mainly in the upper layer, and larger open water areas in the Atlantic sector. However, decrease in sea ice (near to zero) observed in 2018 is accompanied by a similar AW temperature as found in the last four years (around 4.05°C) and a decrease in salinity (35.04). This means that temperature (similar in both years) was not one of the shaping factors affecting the variability of the ice cover in the study region in 2018, and the atmospheric drivers were potentially responsible for the most recent minimum.