The Seasonal Cycle in Temperature and Salinity within the East Greenland Current at 74°N

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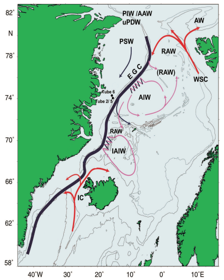
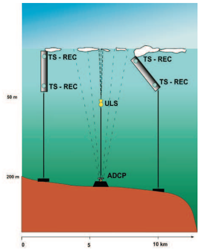
Abstract:
It is quite difficult to make measurements over the course of one year in regions which have an almost closed, thick ice-cover during winter. Instruments near the surface are easily damaged by the ice, by using a protective tube for the uppermost 40m of a mooring, we were able to collect temperature and salinity data near the surface for several years within the Polar Water (PW) on the shelf at 74°N. Moorings further offshore also collected data within the depth of the Return Atlantic Water (RAW).
The processes in this area play an important part in the deep water formation. The deep water formation is essential for the meridional overturning heat transport driven by the thermohaline circulation. In the PW we see a strong stratification in summer and almost none in winter, these changes being also correlated with the regional ice cover. A similar seasonal cycle can also be seen in results of the North Atlantic/Arctic Sea Ice Ocean Model (NAOSIM), which is forced with NCEP atmospheric data from the period 1948-2002. We will present the seasonal cycle as seen in the measurements and in the model and show differences and similarities.

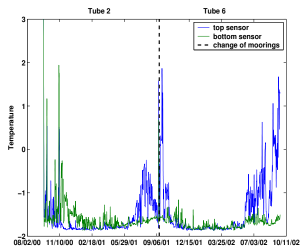


The Greenland Sea:
This map shows the water masses that mainly occur in the Greenland Sea. Warm Atlantic Water (AW) flows from the south with the North Atlantic Current along the coast of Scandinavia. A part of the current flows into the Barent Sea and some as part of the West Spitzbergen Current (WSC) into Fram Strait. There it recirculates and goes south as part of the East Greenland Current (EGC). This water mass is called Return Atlantic Water (RAW). The other part goes into the Arctic Ocean and after some mixing returns as Arctic Atlantic Water (AAW). Cold, low saline Polar Water (including ice) flows out of the Arctic southwards into the EGC. The Polar Water (PW) is divided into upper Polar Deep Water (uPDW) and Polar Surface Water (PSW).
The major water mass of the EGC is the Polar Water which comes from the Arctic Oceans and flows south along the East Greenland shelf. Along with the Polar Water comes Arctic Atlantic Water (AAW) that is Atlantic Water which mixes in the Arctic Ocean and incorporates into the Denmark Strait.

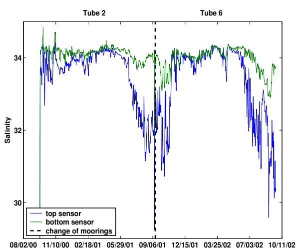


Scheme of tube mooring array (left). The approximately 40 m long tube protects the intruments against damage due to ice. An Upward Looking Sonar (ULS) was not used. There is a security line attached at the outside of the tube, in case of breaking.
Positions of tube moorings and ADCP are shown below on the East Greenland Shelf, with water depths and depths of temperature and salinity.

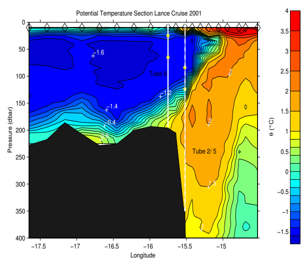
Mooring	Date	Latitude	Longitude	Water Depth (m)	Depth of TS-Sensor
Tube No. 2 Tube No. 2	Sep 2000 - Sep 2001	74° 01.716 N	15° 31.149 W	320	upper Sensor: ca. 20 m lower Sensor: ca. 60 m
Tube No. 5 Tube No. 5	Sep 2001 - Sep 2002	74° 01.678 N	15° 31.303 W	340	upper Sensor: ca. 77 m lower Sensor: ca. 117 m
Tube No. 6 Tube No. 6	Sep 2001 - Sep 2002	74° 03.956 N	15° 45.139 W	203	upper Sensor: ca. 16 m lower Sensor: ca. 56 m
ADCP	Sep 2001 - Sep 2002	74° 02.879 N	15° 38.113 W	205	



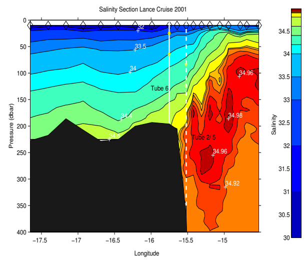
Temperature Tube No. 2 and No. 6



Salinity Tube No. 2 and No. 6



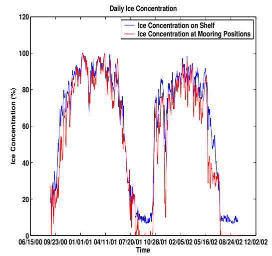
Potential Temperature hydrographic section September 2001



Salinity hydrographic section September 2001

Comparison of tube mooring temperatures and salinities with hydrographic (CTD) data:

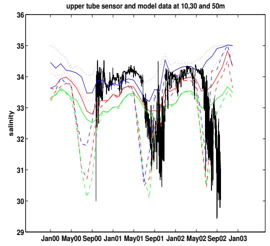
Temperature and salinity time series of tube moorings No. 2 and No. 6 (top figures).
Temperatures and salinities of the moorings agree very well with the hydrographic sections generated at the mooring position. The hydrographic sections also show the approximate mooring positions, with tube No. 6 located on the shelf and tubes No. 2 and 5 located on the shelf break. The topography is only a rough approach. Tube No. 2 and 5 were nearly on the same positions, but had the sensors in different water depths, unlike the sensors of tube No. 2 and 6. The hydrographic section was generated between the recovery of Tube No. 2 and the deployment of tube No. 5 and 6, in September 2001. On deployment of tube No. 2 in September 2000 the ice concentration was about 25%. The mooring stayed within the ice border during the whole summer, clearly visible in the ice diagram (upper right). The top salinity did not fall below 32.6. The following summers this area was ice free, which made a strong stratification of the upper layers possible. The upper sensors salinity of tube No. 2 and 6 droped down to 31.15 respectively 30.74 in summer 2001 and the temperature rose up to -0.2°C respectively 1.87°C. Lower sensors temperatures and salinities differed scarcely from winter values.
During the winter the water column is homogenous, with temperatures around freezing point and salinities that oscillate around 34.2. The freshening of the surface layer in summer 2002 is greater, visible in higher temperatures and lower salinities before the recovery of tube No. 6.
The generated CTD section reveals a warmer and less saline surface layer. Salinities on the shelf are equally stratified unlike the temperatures, which show a thick layer of cold water (PW) at depths of approximately 40 to 150 m. At the surface a slightly warmer layer is found. This layer was also measured by the upper sensors of the tube moorings. A tongue of warm (2°C) and saline (34.96-34.98) water lies above the slope of the shelf. This is RAW that approaches the shelf break and has its branches propagate onto the shelf, also visible in the lower sensor of tube mooring No. 5.



Ice concentration per month in percentage

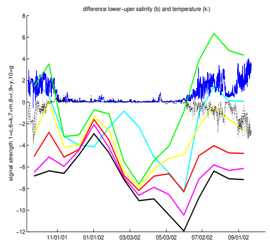
Ice concentration on mooring position compared with salinities of upper sensor:
The ice concentration (upper right figure) has a great influence on the stratification of the water on the East Greenland shelf. Changes in the ice concentration influence temperatures and salinities measured by the tube moorings.
In 2000 the first mooring was deployed within the ice, with an ice concentration of about 25%. During winter time the concentration oscillates around 85%. A decline in the concentration during winter time is only visible in the measurements of the upper salinity sensors.

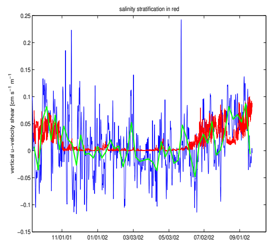
By the end of May the ice concentration starts to drop and some days later, visible in the temperatures and salinities of the tube moorings. In summer 2001 and 2002 the ice melted away completely at the mooring positions, but not further west on the shelf, where it never went below 10%. Temperatures, but especially salinities of the tube moorings correlate well with the ice concentration and a seasonal cycle in the ice concentration is clearly visible.



Upper sensors salinities of tube No. 2 and 6 (black line). Modelled salinity data of 3 grid points: red close to mooring, green more on the shelf, blue further away (1 grid point each). Solid line 30m, dashed line 10m and dotted line 50m.

Comparison of modelled salinity data with salinities measured by the tube moorings (figure above right):
A seasonal cycle is apparent in the modelled salinity data. When modelled salinities drop during the summer, moored salinities drop too, but always with a delay. Though it is not apparent, which line is the most accurate (blue or red). In winter time moored salinities seem to be close to the blue line, in summer time more to the red line. Modelled salinities more on the shelf (green line) hardly ever correlate with measured salinities.





The model used for the numerical experiment (left) is NAOSIM (North Atlantic/ Arctic Sea-Ice Ocean Model), a coupled ocean-ice model developed at the AWI, Bremerhaven. The ocean part derives from the Geophysical Fluid Dynamics Laboratory modular ocean model MOM-2 [Pakanowski, 1985], enclosing the northern North Atlantic, the Nordic Seas and the Arctic Ocean. The horizontal resolution is approximately 28 km on a rotated spherical grid. In the vertical, the model has 30 unevenly spaced levels.
The ocean model is coupled to a dynamic-thermodynamic sea ice model [Hibler, 1979; Harder et al., 1998] which employs a viscous-plastic rheology. The thermodynamics follow Semtner [1976]. The Atmosphere is forced by NCEP reanalysis data with a period from 1948 to 2002. A detailed description of the model can be found in Karcher et al. [2003] and Kauker et al. [2003].

The temporal changes in the salinity and temperature stratification are also correlated with changes in the velocity field (above). Although the velocity shear (roughly between 180m and 25m depth) shows large changes on short timescales, the shear is larger during the times of salinity stratification.
Also the ADCP signal strength (above left) is increased, the near bottom (bin1=183m) to mid-depth (bin9=44m) shows a minimum just before the salinity stratification starts and then increases sharply. The reason why the 26 and 44m bin start to increase 2 months before is still not clear. We hoped to identify the layer of strong salinity stratification due to an higher signal strength, but the main signal seems to arise from other scatteres (plankton?)

Conclusions:
For the first time we measured the near surface stratification of salinity and temperature in a mostly ice covered region. At the mooring position on the shelf at 74°N this stratification is well correlated with the ice cover. The seasonal cycle is therefore primarily given by ice melting and formation and advection plays only a minor role.
Moored temperatures and salinities correlate well with the hydrographic (CTD) measurements. The tube moorings produced a nice two year long time series, with a seasonal cycle.
In a first comparision with an numerical model, the near surface amplitude of the seasonal cycle was similar in magnitude, although the model salinity preceeded the measured one. This has to be looked on in near future.
Changes in the stratification correlate with changes in the velocity field.

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