13 Climatic Data for Logistics

13.1 West Greenland Meteorology

13.1.1 Introduction

Surrounded by steep coasts, Davis Strait/Baffin Bay forms a channel that provides ideal conditions for outbreaks of cold air southward, as well as for the injection of warm subtropical air deep into the Arctic Basin. Both patterns are driven by disturbances of the polar front zone. This exchange of air masses within the lower part of the troposphere largely determines the weather and climate of the area. Another essential feature is the all year round low sea surface temperatures, causing the West Greenland waters to be part of the arctic zone with summer temperatures below 10°C.

The upper flow of the troposphere largely controls the movement of surface weather phenomena, such as migrating cyclones and anticyclones.

13.1.2 Sea level pressure

The sea level pressure (slp) pattern is strongly influenced by the distribution of cold and warm surfaces (Figure 13.1), although in an opposite direction. The slp pattern is essentially different from the upper level pattern, particularly during winter, when an area of high pressure occurs over the northernmost part of Greenland and northerly winds (a winter monsoon) prevail in the West Greenland waters. A low pressure area extending from Newfoundland via Iceland to the Norwegian Sea, with a trough northward along the west coast of Greenland reflects the main zone of cyclonic activity. It appears that Greenland generally receives its weather from the southwest. About 60-70 percent of all cyclones approaching South Greenland arrives from between west and south-southeast.

In summer, the mean slp gradient around Greenland is slack, and no prevailing wind direction is discernible. Cyclonic activity may occur anywhere in the Greenland area. During the year, atmospheric pressure is highest (most settled weather) normally occur around April. Atmospheric pressure is lowest in September/October over Canada and in December/January over Greenland.

13.1.3 Surface winds

Three main factors affect wind speeds:

1. The pressure gradient associated with cyclones and anticyclones.
The intensity of pressure systems (particularly cyclones) is greatest in winter. Southern Greenland in particular is influenced by severe weather that is connected with the North Atlantic winter cyclones. The northern part of the Davis Strait has the lightest winds due to the moderating effect of high pressure systems. Although the main track of cyclones is south of Greenland in summer, cyclonic activity may occur anywhere in the Greenland.

2. The static stability of the air near the surface.
Stable layering or inversions impede vertical motions. In the coastal area, orographic influences on the direction and speed of low level air flow are reinforced. On the open sea, the surface wind speed are reduced under stable conditions. With the movement of cold and stable air over snow/pack ice to open water, there is a rapid destabilisation taking place due to warming from

below. Vertical exchange (convection) results in an increase in the speed and gustiness of the surface wind.

3. Influence of topography (local winds).
Surface winds and pressure patterns are also substantially modified by the steep coasts surrounding the Davis Strait, particularly that of Greenland.

Down directed (katabatic) offshore winds may reach the sea level as outbursts of dry and (due to compression) relatively warm air (a foehn wind) accompanied by falling pressure, causing a trough of low pressure to develop. Foehn winds are rather frequent in southern Greenland, however, their frequency declines northward along the coast. In the fjords and in the inner part of Disko Bay (e.g. Ilulissat/Jakobshavn), the Foehn winds may be very strong with gusts of hurricane force; their occurrence is not known in detail. At sea (or the outer coast, e.g. Aasiaat/Egedesminde), the warm wind is usually insufficient to supersede the cold air near the sea surface, resulting in the formation of a pronounced low level inversion (and a wind minimum).

Onshore winds are diverted along the coast towards lower pressure and are reinforced. A ridge of high pressure develops. Maximum winds occur in the coastal areas, particularly around the protruding coastline (e.g. Cape Farewell, Nunarsuit). The coastal jet or barrier wind propagates more or less northwards along the coast (like a surge), causing a rapid and often dramatic change from ’foehn conditions’ (broken clouds and good visibility) to ’barrier wind conditions’ (strong wind, snow or rain with poor visibility and low clouds). The surge also propagates seawards, although in a weakened form.

With cold air aloft (in an unstable air mass), the orographic influence upon flow patterns are less evident. Most essential, katabatic winds from the ice cap are likely to be of the bora type. In defiance of the warming by compression, a still cold and strong easterly wind, which, contrary to foehn winds, will spread far out over the sea . Strong winds of the bora type are infrequent in the West Greenland area. Their occurrence in the form of a cold north-easterly gale or storm is known from Disko Bay and the Nuuk/Godthåb area. At present, there is no model available to explain the extremely high winds that occur very locally in the fjords and over the archipelago, or the high winds that occur for short periods of time and extend (e.g. in heavy showers) out to the open sea.

In the northern part of the area, north of lat. 65°N, the annual mean wind speed is 5-6 m/s, increasing south of lat. 65° N to 7-8 m/s and south of Cape Farewell to almost 10 m/s. It appears that maximum wind speeds occur in the northernmost part of the area as early as October/November, and in midwinter for other areas. The minimum wind speeds occur in midsummer all over the area.

Gale force winds
The geographical distribution of gale force winds (above 13.8 m/s) in winter and summer is shown in Figure 13.2. The percentage of gale force winds is relatively low in the northern part of the area, less than 5% in winter and 1% in summer, increasing southward to a maximum of 30% in winter and 4% in summer in the southernmost part.

Most of the cyclones affecting West Greenland arrive from between south and west. Weather systems approaching from directions between north-east and south-east are essentially modified by the passage of the ice cap, however, they may regenerate over the Davis Strait.

In winter, southern Greenland in particular is influenced by severe weather connected with the North Atlantic cyclones. Figure 13.3 outlines typical tracks for major cyclones. Cyclones approaching southern Greenland from south-west or south usually split in the vicinity of Cape Farewell with one part moving northward along the west coast, while the other moves off toward

Iceland. In summer, eastward moving cyclones often develop along the boundary line between the cold Canadian archipelago and the warm continent to the south of it, affecting the Davis Strait region. Therefore, West Greenland weather, although less severe, often appears more unsettled in summer than in winter.

Cyclones may develop locally on a small scale any time of the year. Often they will be the result of topographic influence, i.e. lee lows. Another type is the polar low. In this case the cyclone develops over open water with very cold air aloft. The diameter of a polar low is generally 200-300 km. Wind speeds exceed (as per definition) gale force, 15 m/s, and the system is accompanied by heavy snow showers. Occasionally, polar lows can be rather intense with a structure in their mature stage resembling that of a tropical cyclone. The lifetime of a polar low is limited, usually less than 24 hours, and it dies rapidly when making landfall.

13.1.4 Air temperature

The sea west of Greenland belongs to the Arctic region, with mean air temperatures at two meters above the sea surface of below 10°C all year round. The coldest month is February and the warmest month August (in the coastal area: July). The distribution of mean air temperatures for the two months is shown in Figure 13.4.

To the north (with sea ice occurring much of the year) the pattern is of the continental or high arctic type (cool summers and very cold winters), with temperatures ranging by as much as 30°C between the coldest and warmest month . To the south (over open water) the pattern is oceanic (cool summers and relatively mild winters) with a temperature range of less than 10°C.
[figures]

In summer, temperatures close to the sea surface will deviate little from those of the seawater. Freezing temperatures may occur over sea ice and/or within fog. In winter, very low temperatures occur over snow covered areas due to radiation cooling of the surface. Over open water, air temperatures are normally below those of the sea surface due to advection of cold air. In the coastal zone, temperatures may reach 15°C or more in summer and, under foehn conditions, even in winter. Away from the coast, the warm air mass is generally incapable of displacing the cool air nearest to the surface.

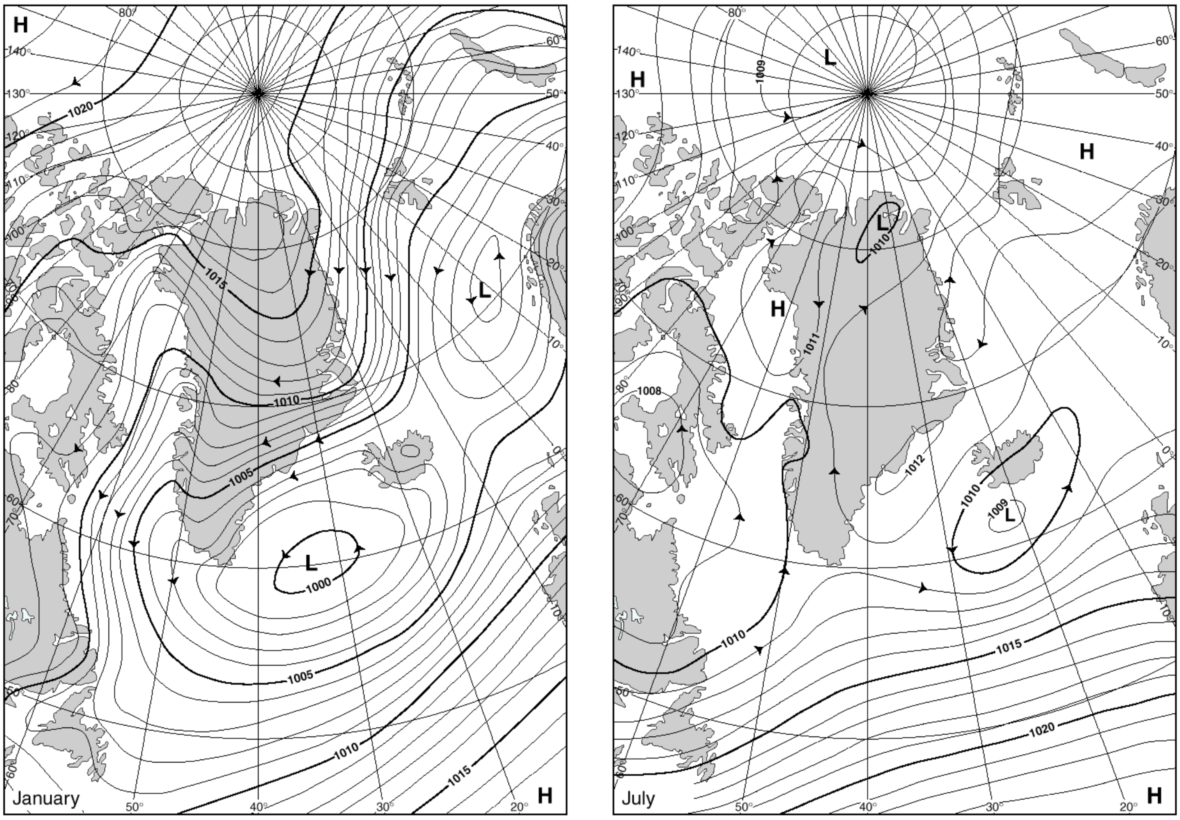

Figure 12.1. Mean atmospheric pressure (hPa) at sea level in winter (left) and summer (right).

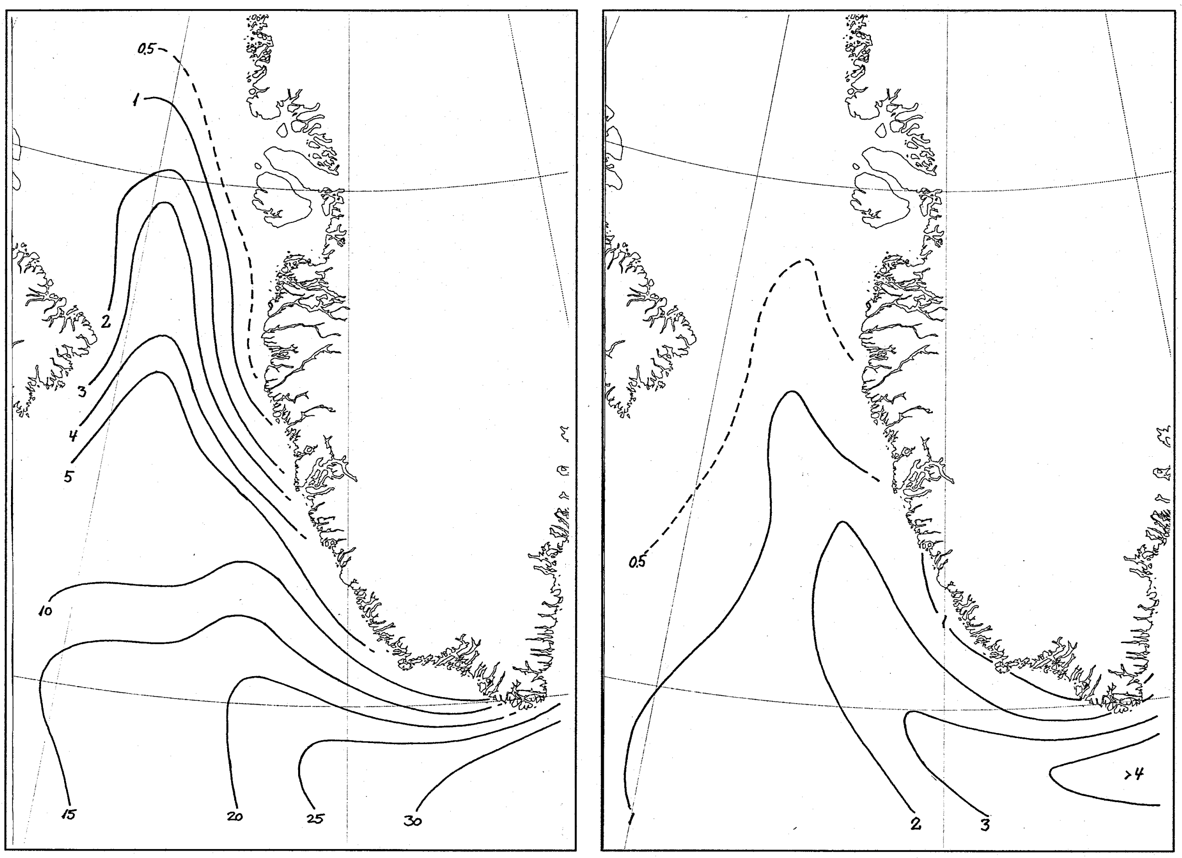

Figure 12.2. Geographical distribution in percentages of gale force winds (above 13.8 m/s). Left: winter. Right: summer. (ECMWF-data, 1980-93).

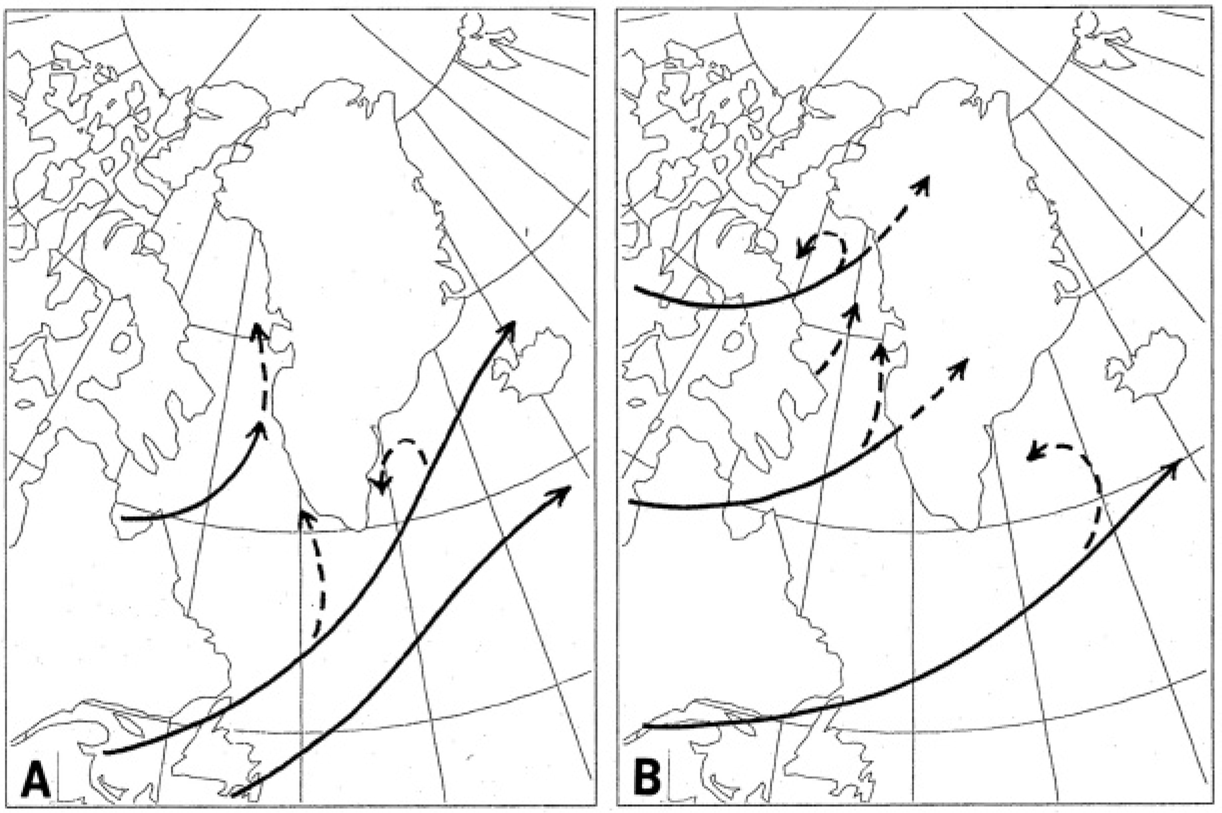

Figure 12.3. Typical tracks for major cyclones, (A) in winter and (B) in summer.

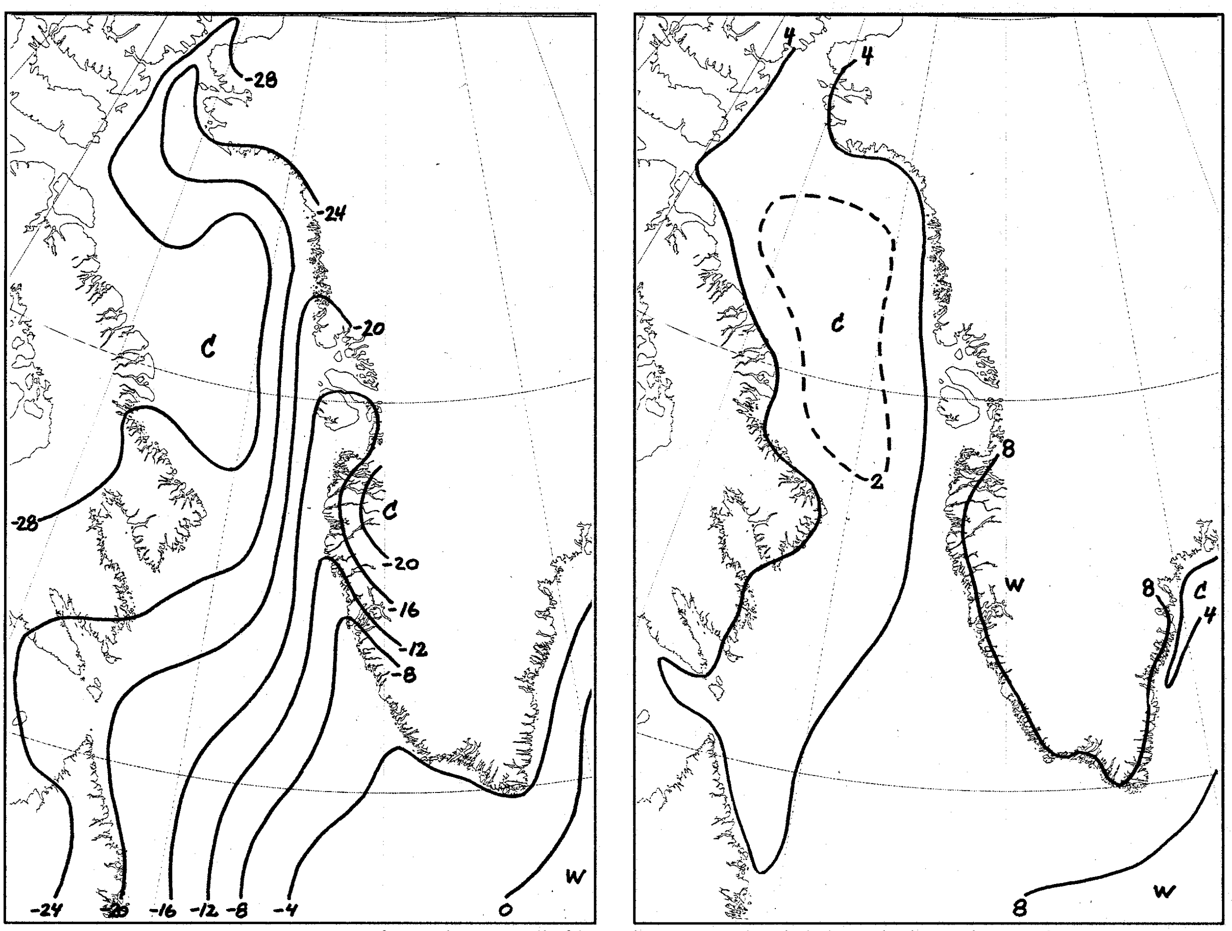

Figure 12.4.Mean temperatures for February (left) and August (right) (partly based on ECMWF-data).

13.1.5 Fog and precipitation

Visibility is reduced mainly by the occurrence of fog, although precipitation, snow in particular, is another important cause. Fog (visibility less than 1 km) is primarily a summer phenomenon. The frequency of fog increases during May, and peaks in June/July, when the temperature contrast between the cool sea surface and the relatively warm atmosphere is at a maximum. It fades out in late August. The frequency of fog in July is 20-30% of the total time over the coldest parts of the sea area (Figure 13.5).

Fog is less frequent over the coast land,. It is often within sight, when facing west from the inhabited places of West Greenland. Summer fog is of the advection type. It typically develops with moist air drifting slowly across a water surface with (not necessarily large) temperature variations, which occur almost everywhere in the West Greenland waters. The sun will often be visible through the fog. Once formed, fog may persist even with increasing wind, however, it will gradually become patchy. Advection of an air mass to a warmer surface causes the fog to evaporate or lift to low clouds.

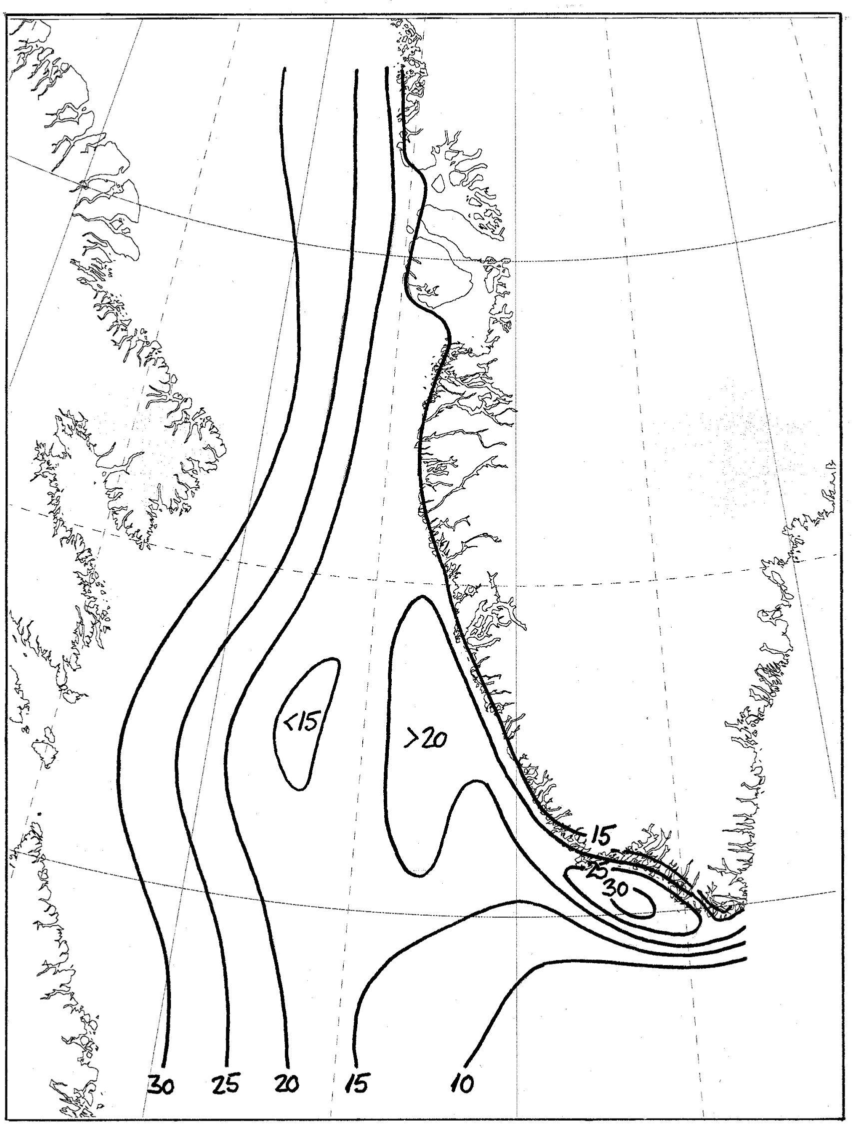

Figure 13.5. Geographical distribution of fog in July - percentage of time.

When there are clear skies above, temperatures within fog are , often a few degrees below that of the sea surface, due to radiation cooling. Freezing temperatures within fog over a cold water surface are not unusual, and icing with rime ice or clear ice may occur. In winter, advection fog may occasionally form within a warm and moist air mass advected from the south. Fog may even form with a warm foehn wind blowing aloft. Radiation fog may develop under clear calm conditions over snow covered and solid pack ice. However, the air will often be too dry for the fog formation, unless there is a source of moisture (an open lead in the ice) nearby, due to sublimation of rime on the cold surface. Steam fog (sea smoke) forms within cold air flowing from pack ice or from cold land out over open water. The occurrence of steam fog is often very localised, however, it may be more widespread in a very cold air mass.

Visibility may also be reduced more or less by precipitation (particularly snow) and drifting snow. In winter, snow showers are present much of the time over open water causing moderate or poor visibility. The amount of precipitation is known only from coastal stations. It is high in the south due to open water and frequent cyclonic activity. Precipitation is low in the north, where the moisture content of the air is low, particularly in winter and spring. The annual precipitation ranges from 200-300 mm in the Disko area to more than 1000 mm in southernmost Greenland. In Nuuk/Godthåb it is about 600 mm. **[figures]**

With winds blowing onshore, orographic intensification takes place in the outer coastal areas. On the other hand offshore winds tend to reduce precipitation. Winterly showers over open water are very frequent; often kept away from the coast by the land breeze, they contribute to the amount of precipitation at sea. Most of the precipitation falls in late summer or in autumn, due to maximum occurrence of open water combined with high cyclonic activity. In winter, precipitation is usually in the form of snow.

13.2 Oceanography

13.2.1 Introduction

The oceanographic conditions in the West Greenland Waters are dominated by the following water masses:

- Polar Water, originating from the Arctic Ocean and carried to West Greenland by the East Greenland Current. This component is dominating the surface waters closest to the shore, bringing water of polar origin northward along the West Greenland coast. On its way, this water is diluted by run-off water from the fjords. The East Greenland Current component looses its momentum as it moves northwards. At the latitude of 'Fyllas Banke', the current turns westward towards Canada, where it joins the Labrador Current.
- Irminger Water, Irminger Mode Water and North Atlantic Mode Water, all originating from the North Atlantic Current. This current is made up of relatively warm and salty water, which can be traced all the way along West Greenland from Cape Farewell to Thule. It is found below the Polar Water.

The Polar Water inflow is strongest during spring and early summer (May - July) and since the East Greenland Current carries large amounts of Polar Ice with it, the distribution of Polar Ice ('Storis') along the coasts of West Greenland is at a maximum during the same period. The inflow of the water masses of Atlantic origin is strongest during autumn and winter, explaining why the waters of Southwest Greenland are normally ice free during winter.

A fifty year long time-series of temperature and salinity measurements from West Greenland oceanographic observation points reveal strong inter-annual variability in the oceanographic conditions off West Greenland as well as some distinct climatic events of which three cold periods within the last thirty years are the most dominant. Inter-annual variability is caused by changes in atmospheric circulation, or by variations in the strength of the ocean currents transporting water to the West Greenland area. Both seem to be related to the North Atlantic Oscillation Index (NAO-index), reflecting the difference in mean sea level air pressure between the Icelandic Low and the Azores High.

13.2.2 Circulation

The ocean currents around Greenland are an integral part of the circulation and water mass balance of the North Atlantic and the arctic regions, where the bottom topography is of vital importance to the circulation and the distribution of water masses. **[map]**

The North Atlantic Current, a continuation of the Gulf Stream, enters the area from the west. It flows northward along the west coast of Great Britain, through the Faroe-Shetland Channel, and continues along the continental slope off Norway. At around 70^{o}N the current splits up into two components: one continuing along the west coast of Norway into the Barents Sea and the other following the continental slope northwards to the Spitsbergen region, where it converges with the colder, less saline arctic surface water, sinks and continues as a subsurface current into the Arctic Ocean. Before entering the Arctic Ocean part of the North Atlantic Current branches off westwards into the East Greenland Current, where it is found below the Polar Water from 150 m to approximately 800 m.

Before entering the Faroe-Shetland Channel, part of the North Atlantic Current turns westward as the Irminger Current south of Iceland. Part of this current follows the Icelandic coastline to the north through the Denmark Strait and continues along the north coast of Iceland, where it meets the cold, less saline East Icelandic Current. The other part of the Irminger Current turns towards Greenland south of the Denmark Strait, where it flows southward along the east coast of Greenland. Some of this water continues to, and around Cape Farewell, while a second portion remains within the Irminger Sea, where it recirculates in a cyclonical gyre.

The cold water originates from the Arctic Ocean, which throughout the year is supplied with fresh water primarily from the large Russian rivers. This surplus of water leaves the area mainly at two locations:

a. Through the Fram Strait i.e the area between Greenland and Spitsbergen.

b. Through the Canadian Arctic Archipelago i.e the area between Greenland and Canada.

The Fram Strait is by far the most important of the two outflow regions, making up about 75% of the water outflow from the Arctic basin. This water is transported southward along the east coast of Greenland and constitutes the East Greenland Current. This current flows on top of the Greenlandic shelf from the Fram Strait to Cape Farewell, rounds the Cape and continues northward along the west coast of Greenland up to a latitude of about 65^{o}N -66^{o}N, where it turns westward and unites with the south flowing current off the Canadian east coast. This current, called the Baffin Current, also transports water from the Arctic Ocean, leaving the area through the second major outflow region, the Canadian Arctic archipelago. It follows the Canadian coast, continues into the Labrador Current, which meets the North Atlantic Current at around 40^{o}N - 45^{o}N.

The water south of the Cape Farewell area is relatively stagnant. In the southern part of the area, water from the Labrador Current is swept east to northeast by the North Atlantic Current. It flows side by side, gradually mixing with the North Atlantic Current and later the Irminger Current in the

Irminger Sea, and returns to the area south of Cape Farewell. The current system in this area can therefore be regarded as a great cyclonic gyre, in which the velocities are relatively small.

This picture of the surface circulation in the ocean off Greenland reflects average conditions, and as described below large seasonal and inter-annual variations occur.

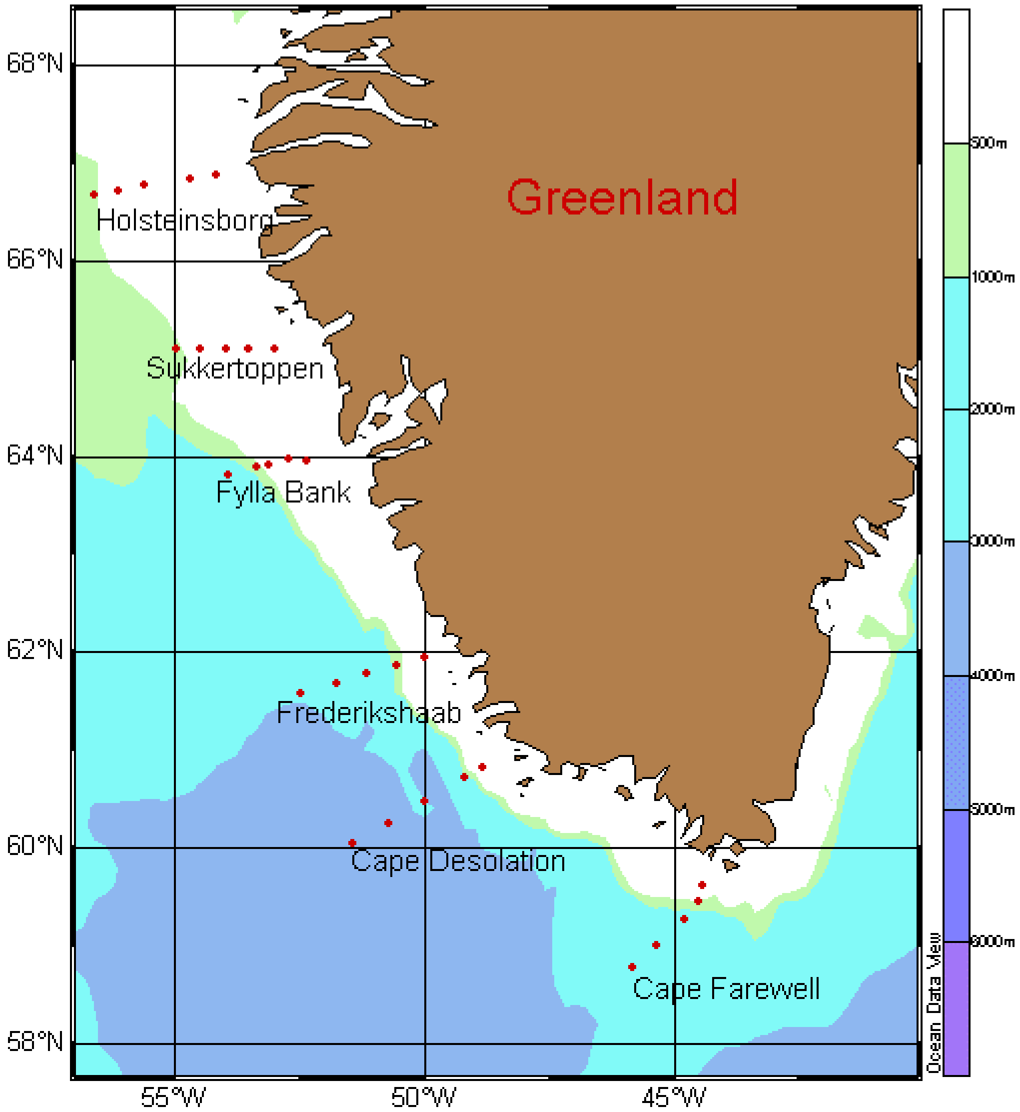

Figure 13.7 Map showing the position of standard sections and stations off West Greenland.

13.2.3 Water masses

The waters off West Greenland are dominated by four water masses, all formed outside the Davis Strait:

- Cold and low saline water Polar Water is found in the surface layer close to the coast. The East Greenland Current carries this water to West Greenland.
- Water originating from the North Atlantic Current is found below and west of the Polar Water
- North East Atlantic Deep Water

- Northwest Atlantic Bottom Water are found at great depths.
-

The two deep water masses are not discussed in the present context since they are found at great depths.

Polar Water, as it is found in the East Greenland Current, is characterised by temperatures generally below 0°C, although they may rise to 3-5°C in the surface layer during the summer. Salinity is below 34.4 psu. Buch (1990) however showed that the temperature and salinity (T/S)-characteristics of Polar Water are altered on the way to West Greenland due to mixing with surrounding water masses. Along the West Greenland banks the Polar Water is characterised by temperatures below 1°C, but may be heated to 3-5°C during summer, and salinities below 33.75 - 34.0 psu.

The Atlantic water component has, until recently, been referred to as Irminger Water, however, a more detailed analysis questions this conclusion. Lee (1968) and Clarke (1984) have defined Irminger Water as a mixture of Irminger Sea Water, formed in the Irminger Sea during winter, and North Atlantic Water. Furhtermore, they characterised Irminger Water to have temperatures between 4 and 6°C and salinities between 34.95 and 35.1 psu.

Buch (1990) studied the water masses of Atlantic origin in more detail using T/S-plots of observations from 'Fyllas Banke' from 1950 to 1988. Due to the seasonal variability of the inflow of Atlantic water, T/S-diagrams have been prepared for each of the four seasons (Figure 13.8 a-d).

These T/S-diagrams clearly indicate the presence of Irminger Water (T~4.5°C, S>34.95 psu) during all seasons. It is, however, striking to see how few observations of salinities above 34.95 psu that were actually made over the almost forty-year observation period. This is partly due to the fact that the vertical spacing between the observation points during bottle casts was 100 - 200 m in the depth interval where Irminger Water is found, and partly because Irminger Water is not always present at the latitude of Fyllas Banke.

Figure 13.8 shows that throughout the year there is a body of water in the West Greenland area with salinities above 34.85 psu and temperatures around 4°C. It is most likely that this body of water is formed by the Irminger Water mixing with the surrounding water as it flows towards West Greenland, resulting in a decrease in temperature and salinity. Water off West Greenland with temperatures above 4°C and salinities between 34.85 and 34.95 psu may therefore be named **Irminger Mode Water**. This water mass can always be observed off West Greenland, while pure Irminger Water (T around 4.5°C; S>34.95) is only occasionally observed in the area, and even then primarily in the southernmost parts.

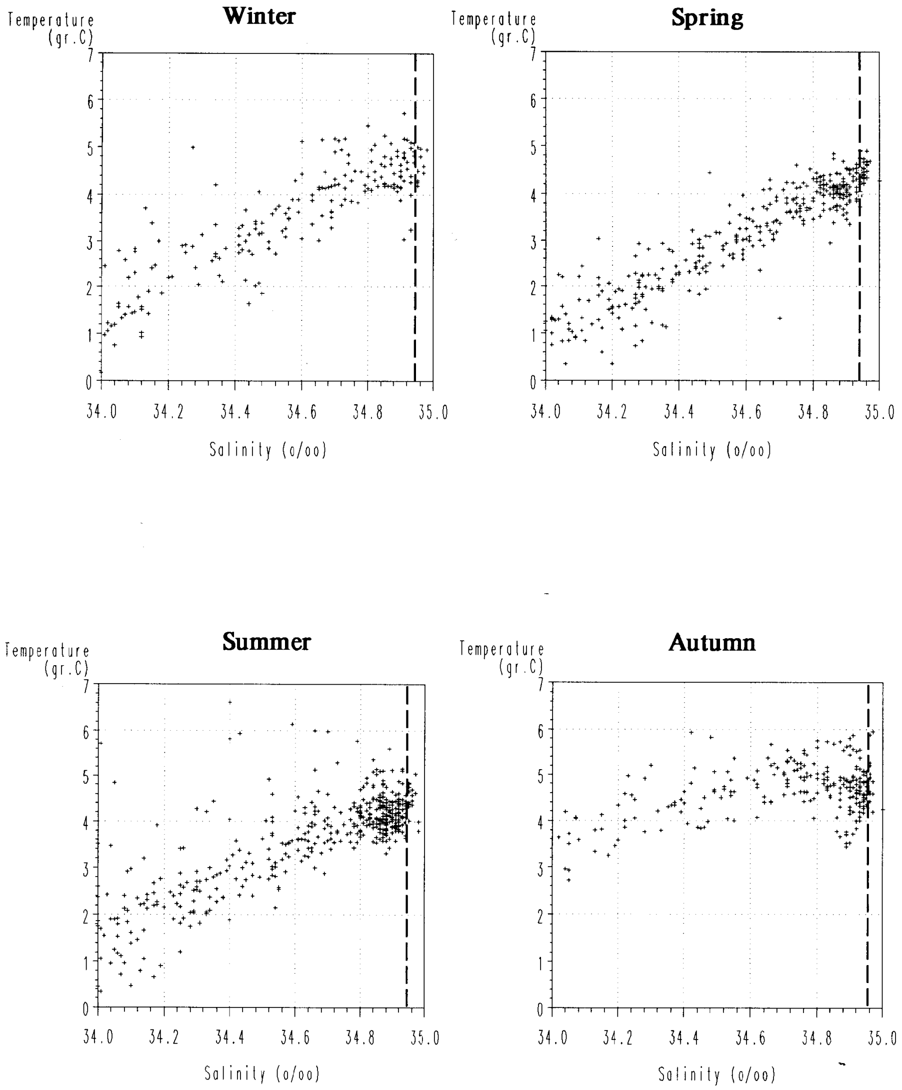

Figure 13.8. Seasonal T-S plots using data from Fyllas Banke st.4 and 5 from 1950 - 1998.

The T/S plots in Figure 13.8 and the example of a vertical temperature and salinity distribution plot in Figure 13.9 show that a huge volume of water exists with temperatures above 2.5°C and salinities in the interval 34.50 - 34.85. Additionally, as is seen in Figure 13.8, the water temperature increases during autumn. Waters with salinities above 34.5 are found at great depths, excluding the possibility of a temperature rise due to atmospheric heating. The high temperatures, especially during autumn, supports the assumption that water with salinities in the interval 34.5 - 34.85 originates from the North Atlantic Current. This water mass is called "**Northwest Atlantic Mode Water"**. A possible path by which this water comes to West Greenland could be that it branches off towards the west in the area Southeast - East of Cape Farewell, rounds Cape Farewell and enters the Davis Strait.

The analysis of T/S data from West Greenland therefore indicates the presence of three water masses of Atlantic origin:

- **Irminger Water** - temperature around 4.5°C and salinity above 34.95 psu
- **Irminger Mode Water** - Irminger Water mixed with surrounding water masses on it way to West Greenland - temperature around 4°C and salinities between 34.85 and 34.95 psu.

- **Northwest Atlantic Mode Water** - Temperature above 2.5°C and salinities between 34.5 and 34.85 psu. In late autumn the temperatures rise to above 5°C.

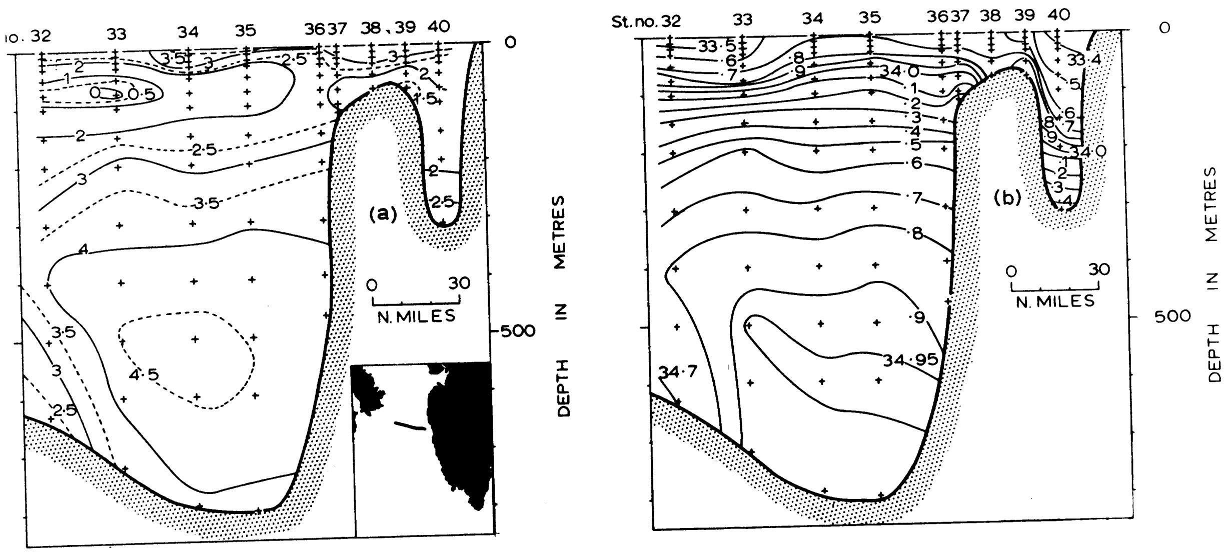

Figure 13.9. Vertical temperature and salinity distribution at NORWESTLANT 3, section 13. From Lee (1968)

13.2.4 Seasonal variability

During winter the surface layer cools, reaching temperatures below - 1°C and a cold, homogenous upper layer with a thickness of approximately 50m develops due to vertical convection. By April the temperature of the atmosphere begins to rise and the winter cooling stops. Nevertheless, the surface water remains cold until the middle of June, with temperatures below 1°C, and the cold layer grows in thickness reaching depths of 150 m. This is due to intensification of the East Greenland Current component.

During spring and early summer the surface layer is slowly heated by solar radiation The avarage temperature over the shallow parts of the West Greenland banks may reach values of 2-3°C as early as mid-June. On its course along West Greenland, the Polar Water is subject to the action of the Coriolis Force. In years with normal or strong current velocities, the Polar Water is pressed so strongly towards the outer slopes of the banks that it interferes with the heating of the surface layer. Observations from the Fyllas Banke area indicate that the East Greenland Current component attains its greatest intensity off West Greenland - and thereby its highest cooling power - in June and July. This is additionally reflected by the fact that the 'Storis' has its most northerly distribution in this period.

The inflow of warm water from the North Atlantic Current has a distinct annual periodicity. During spring and first part of the summer the intensity is only appreciable at the southern part of West Greenland. In July the current intensifies and is deflected towards the coast due to the action of the Coriolis Force. The boundary between warm and cold water rises along the outer slopes of the banks, reaching its highest level around November - December. The strong inflow of warm Atlantic Water during winter is the reason why the waters off Southwest Greenland are not ice covered during most winters.

13.2.5 Inter annual variability

The longest oceanographic time series of temperature measurements from West Greenland is the mid-June mean temperature on top of Fyllas Banke (st. 2, 0 - 40 m), Figure 13.10. These measurements have been maintained by the Greenland Institute of Natural Resources due to their importance to cod stock assessments.

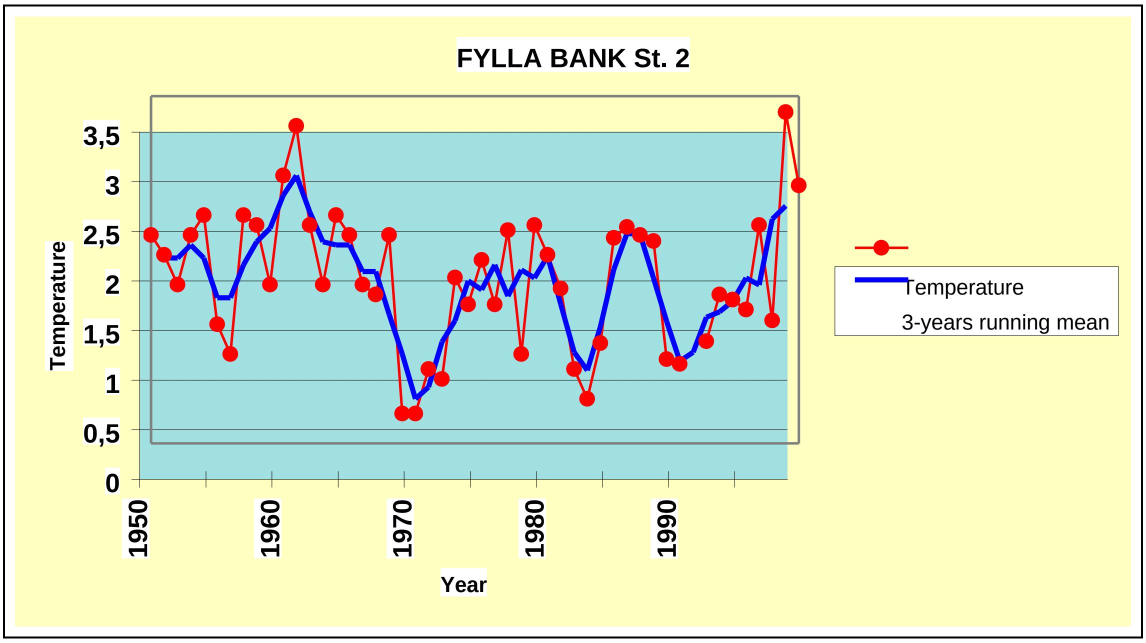

Figure 13.10. Mean temperatures of the upper 40 m on Fyllas Banke St. 2, mid-June 1950 - 1999.

Temperatures may vary quite drastically from one year to the next, often by more than 1°C, reflecting the variability of both the atmospheric influence and the inflow of Polar Water. The curve showing the 3-year running mean values naturally smoothens out the variations, and is therefore more a reflection of the large scale climatic variability.

The almost 50 year long temperature time-series reveals some very distinct climatic events:

- The 1950 - 1968 period generally showed high temperatures around 2°C.
- Around 1970 a cold period - the coldest - was experienced. The cold climate of this period was due to a anomalous high inflow of Polar Water, which was closely linked to the 'Great Salinity Anomaly' (Dickson et al. 1988), which again is reflected in the NAO negative index (difference in mean atmospheric pressure at sea level between the Icelandic Low and the Azores High) changing to positive indices.
- During the early 1980'ies and early 1990'ies, two extremely cold periods were observed reflecting the cold atmospheric conditions over the Davis Strait area due to the high NAO indices during these years.
- A remarkably low temperature was observed in 1997 although the atmospheric conditions were quite warm, indicating a high inflow of Polar Water, Figure 13.10.

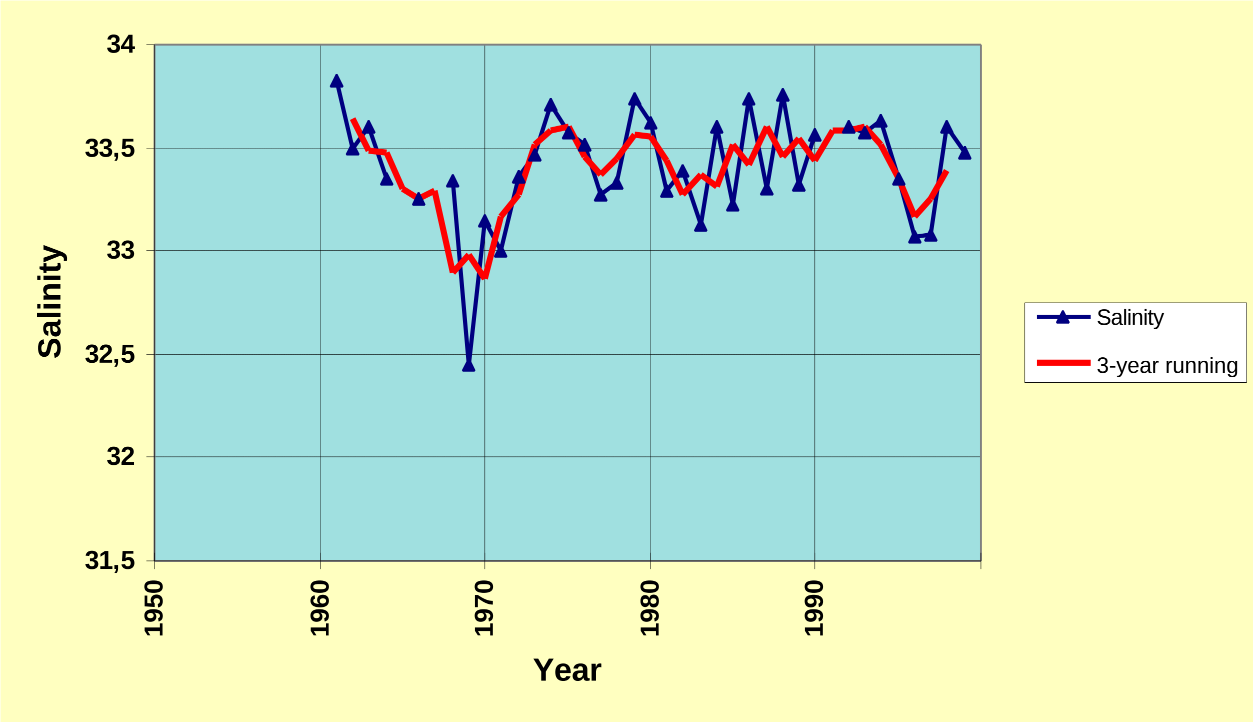

Figure 13.11. Mean salinity of the upper 40 m on Fyllas Banke St. 2, mid-June 1961 - 1999.

Figure 13.11 shows the time-series of the Mid-June salinity on top of Fyllas Banke (actual observations as well as a 3 years running mean). The 'Great Salinity Anomaly' around 1970 is clearly reflected in this data set. The climatic anomalies in the early 1980'ies and 1990'ies are not evident from the surface salinities at Fyllas Banke, but this could not expected because these cold periods was due to atmospheric cooling.

Relatively low salinities were observed in 1996 and 1997, indicating that the inflow of Polar Water was above average in these years.

A relatively long time series of temperature and salinity measurements during July exists for an area further offshore just west of the banks . The mean salinity of the upper 50 m at Fyllas Banke St. 4 from 1970 to 1997 is shown in Figure 13.12. A tendency analysis shows that there is a general increase in the salinity during this period, which, according to Blindheim et al. (1999) is a result of changes in the oceanic circulation of the North Atlantic that can be related to the rise in the NAO-index since 1970.

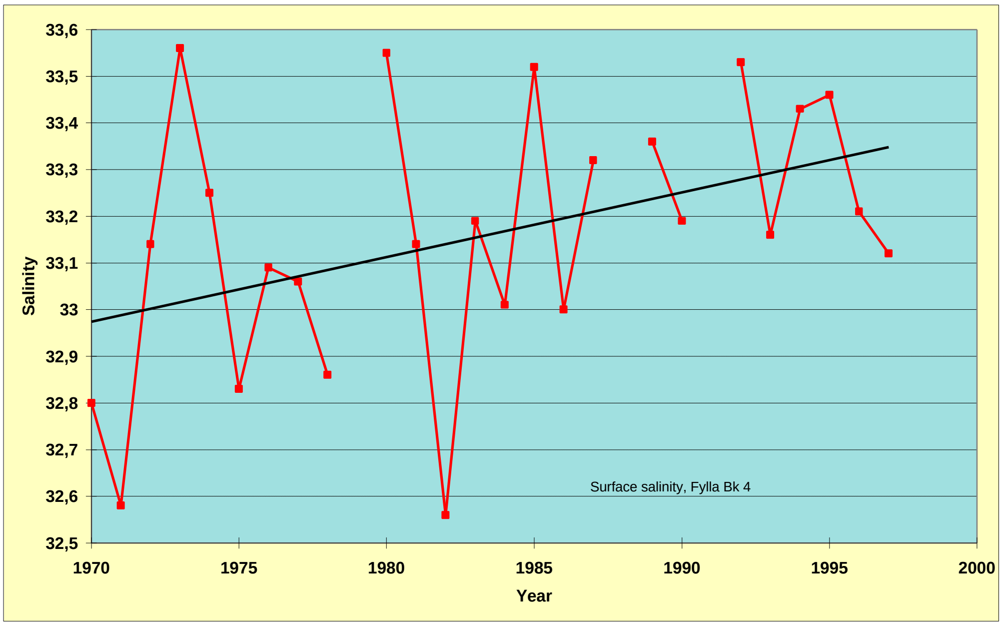

Figure 13.12. Mean salinity of the upper 50 m on Fyllas Banke St.4, July 1970 -1997.

The large variability in the oceanographic conditions off West Greenland has a strong impact on the living conditions for a number of fish stocks occurring close to the limit of their distribution in this area. The cold conditions experienced in this area during the recent two to three decades have caused a dramatic change in the ecological balance. Cod were found in great abundance from the 1920'ies up until 1970, but since then the stock has declined drastically. In recent years, after the latest cold period, cod is almost absent along the West Greenland fishing banks. The disappearance of the most important fish stock has seriously affected the Greenland economy.

13.2.6 Tides

The average period between high and low tide on the west coast of Greenland is 13.4h (24.8h in some places). Locally, the period between tides varies by an hour or so on either side of the average, and the rise and fall sequence shows an almost infinite variety around the globe. Tides are a consequence of the simultaneous action of the moon's, sun's and earth's gravitational forces and the revolution of the earth-moon and the earth-sun about one another. The strongest tidal signal - Spring tide - is experienced when the Sun, Earth and Moon are on aligned, which happens every 14 days with new Moon and full Moon. The lowest tidal signal - Nip tide - is experienced 7 days after Spring tide at half moon (when the line between the Moon and Earth is perpendicular to the line between the Sun and Earth). The difference between high and low tide at a few locations along the west coast of Greenland at spring tide and Nip tide are given in the table below.

	Difference in water level between high and low water	
Location	Spring tide	Nip tide
Nanortalik	2.7 m	0.9 m
Paamiut	3.3 m	1.0 m
Nuuk	4.6 m	1.5 m
Maniitsoq	4.3 m	1.2 m
Sisimiut	4.3 m	1.2 m
Aasiaat	2.5 m	0.8 m

The fact that the paths of the rotation of the sun and the moon about the earth are not circles, but ellipses, and that the planes of rotation are not always in the equatorial plane, but move north and south with the annual cycle of the sun and a monthly cycle for the moon add further complications to the resultant tide producing forces. The motions of the sun and moon are known very exactly, and it is possible to express the resultant tide producing forces as the sum of a number of simple harmonic constituents, each of which has its own characteristic period, phase and amplitude - the most important is given in the table below.

Name	Symbol	Period (solar hours)	Relative size
Semi-diurnal			
• Principal lunar	M_2	12.42	100
• Principal solar	S_2	12.00	47
• Large lunar elliptic	N_2	12.66	19
• Luni-solar	K_2	11.97	13
Diurnal			
• Luni-solar	K_1	23.93	58
• Principal lunar	O_1	25.82	42
• Principal solar	P_1	24.07	19
• Larger lunar elliptic	Q_1	26.87	8
Long period			
• Lunar fortnightly	M_f	327.9	17
• Lunar monthly	M_m	661.3	9
• Solar semi-annual	S_{sa}	4383	8

The most important tidal constituent in the Davis Strait- Baffin Bay area is the semidiurnal M_2 with a amphidromic[1] point at about 70°N (almost in the middle of the Baffin Bay) Figure 13.13. Along West Greenland the greatest amplitude (120 cm) is found in the Nuuk area, decreasing to around 40 cm north of Disko Island.

[1] Amphidromic Point = point with no tidal amplitude around which cotidal lines rotate in anti-clockwise

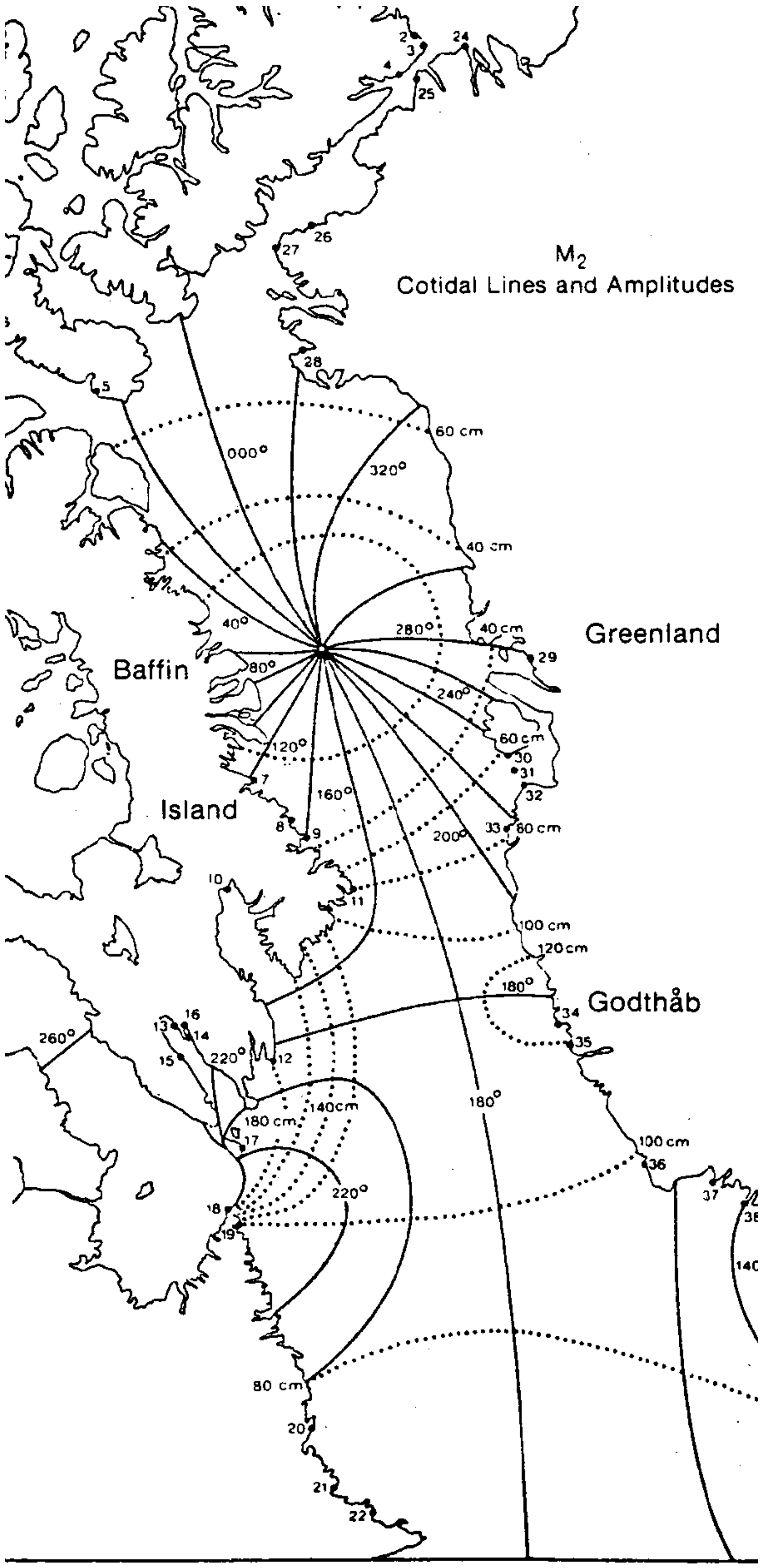

Figure 13.13. M_2-cotidal lines and amplitudes based on coastal observations

13.2.7 Fjord oceanography

Most fjords in West Greenland are sill fjords i.e. resulting in strong limitations to the exchange of water between the deeper parts of the fjord and the open ocean, Figure13.14.

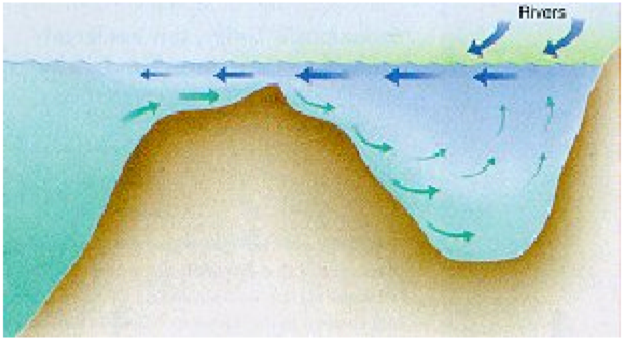

Figure 13.14 Large-scale fjord circulation.

The large scale circulation in a fjord depends on three factors: bottom conditions, water exchange with the open ocean and the supply of fresh water from land. Schematically, the circulation consists of a surface current with brackish water that flows out of the fjord, and a current in deeper layers with more saline water going in the opposite direction. The fresh water largely comes from rivers in the drainage area, an area that is normally several times larger than the fjord itself. Direct precipitation on the sea surface is of minor importance.

The inflow of fresh water to the fjord may be described as the engine that drives the large-scale circulation. The inflow generally causes a higher water level in the fjord than outside. This difference in water level forces the brackish surface water out of the fjord. On its way to the mouth of the fjord the brackish water becomes increasingly saline since the surface water mixes with the underlying water. The water entrained into the surface current is replaced by an undercurrent of more saline water that flows into the fjord at intermediate depth levels. During winter, the fresh water inflow to Greenland fjords is reduced to almost zero because lakes and rivers freeze, and the precipitation on land falls as snow. The surface salinity in the fjords will therefore increase to the level found in the coastal waters outside the fjord. Thus the circulation in the fjord will decrease to a minimum. These conditions will facilitate convection in the fjord.

The deep water in West Greenland fjords are renewed through two different mechanisms:

- Inflow of water from the open ocean with higher density than the deep water of the fjord. This process normally requires strong northerly winds along the west coast of Greenland, which causes high density water to rise above the sill level outside the fjord.
- Vertical convection during autumn, and winter cooling and freezing of the surface water causing salt rejection from the freezing water.

The latter mechanism occurs every winter, and it is therefore anoxic conditions are seldomly seen in the deep water of Greenland fjords.

13.2.8 References

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