UNIVERSITY OF TROMSØ UIT

FACULTY OF BIOSCIENCES, FISHERIES AND ECONOMICS
DEPARTMENT OF ARCTIC AND MARINE BIOLOGY

Hydrophysical characteristics of the northern Norwegian coast and fjords

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A dissertation for the degree of Philosophiae Doctor

August 2013

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> The sailing is coming to an end and the ship is reaching the shore... It is the time to thank and appreciate the fellow sailors for an adventurous and exciting voyage!

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ABSTRACT

It is evident that, both due to the large water volumes they hold and that they stretches from coast to inland, it is to be expected that the northern Norwegian fjords plays an important role in a climatic scientific context. Also generally northern regions are considered as a choke point in the regional as well as the global climate. In my opinion it is therefore surprising to find thorough physical oceanographical examinations of these areas are scarce or missing. Since large data sets are compiled in the present thesis, it is my hope that it will contribute and trigger further investigations and interpretations. Due to the large spread of data in time and space, it is clear that my physical oceanographical interpretations are far from comprehensive.

The periodic collection of hydrophysical data along the northern Norwegian coast (from Malangen to Porsangerfjord) started in the beginning of the 20^{th} century and some of the oldest stations are still in operation by the "Havmiljødata" sampling programme organized by BFE/UIT. One of the the main aims of the current PhD project was to organize and systematize the datasets and analyze for long term trends and also aspects of shorter period variations. The complete database from 1920–2012 has been digitalized and presented to the general public and scholars on the website http://purl.org/hmd.

The results of the research demonstrates some significant differences in the hydrophysical characteristics between the investigated fjords. There are also hydrographic variations between Inner fjords and Outer fjords. The hydrographic features of the fjords of northern Norway notably differ from the Arctic and Southern ones in many ways. The peak surface temperatures in the northern Norwegian fjords were recorded in July–August whereas the highest bottom temperatures were measured in November–December.

In terms of temperature and salinity variations, Balsfjord demonstrates the highest range of temperature and salinity among the fjords, followed by Altafjord. Malangen shows a narrower distribution in both parameters whilst Porsangefjord is considerably colder (has the lowest temperatures) and also operates at the narrowest salinity range.

According to the computations Altafjord has the least water exchange, followed by Malangen and Balsfjord, whereas Porsangerfjord has the most heat and water advected into the fjord. The outer and coastal stations are affected by Atlantic Water (AW), however the inner stations in Porsangerfjord and Altafjord and other locations are not. The overall heat content and the temperature anomalies for 5m at stations Outer Malangen (open fjord), Inner Balsfjord (closed fjord), Refsbotn (coastal station) and Outer Porsangefjord (northern open fjord) have been calculated. They demonstrate no significant heating or cooling trends during the period of 1920–2012.

Main warm periods during the winter season were 1929–1930, 1990–1992 and 2000 in all the stations (Malangen, Balsfjorden, Refsbotn Skipsholmen and Outer Porsangerfjorden). Also Outer Malangen and Inner Balsfjorden were warmer in 1938. Malangen and Balsfjorden experienced another warm period during 2005 followed by a constant cool-

ing trend until 2012 whereas in Altafjorden and Porsangerfjorden the warm period was in 2007 before it started cooling.

The correlation between interannual variability of temperature in Inner Balsfjorden and NAO index has been discovered. The changes of the NAO index parameters cause the subsequent temperature shift in the fjord that may occur after a considerable time.

1 INTRODUCTION

1.1 GENERAL ASPECTS OF GEOGRAPHY, WATER MASSES AND CLIMATOLOGY

Northern Norway is the large geographical region of Norway comprising the three northernmost counties, i.e. Nordland, Troms and Finnmark, covering ca. six degrees of latitude (65° 30′N–71° 10′N , Figure 1). The coastline is highly fragmented by a multitude of islands and fjords. Northern Norway is generally defined as the area from Helgeland, south of the Arctic Circle (66°33′ 44″) to the North-cape. It covers almost one third of the total area of the Norwegian mainland. The role of the fjords and coastal shelf of northern Norway, in a climatic, oceanographic and fisheries scenario is crucial and sensitive. There are a great topographical, climatological and dynamical variations between the fjords in this region. Moreover the vastness and the diversity of the aquatic life of this zone and the fisheries activities make this area a zone, which has been marked in the Norwegian marine resources distribution map as biologically potent. So, a better understanding of the marine environment of the northern Norwegian coastal shelf and its fjords is really important.

Northern Norwegian fjords and coastal areas are significantly influenced by the northward flowing Norwegian Coastal Current (NCC) containing Norwegian Coastal Water (NCW) (Sætre and Mork, 1981). The Baltic outflow in Skagerrak between Denmark and Sweden is the origin of the Norwegian Coastal Current (NCC) that flows northwards along the western coast of Norway. The Norwegian Coastal Water (NCW) continuously mixes with the warmer and more saline Atlantic Water with the result that less saline (∼34.5‰) and colder (∼5.5°C) NCC flows northwards (Eilertsen and Skarðhamar, 2006; Sætre, 2007) .

The North Atlantic Oscillation (NAO) is a dominant source of inter-annual changes in the atmospheric circulation. The Atlantic Ocean and the northern hemisphere are influenced by the North Atlantic Oscillation. The North Atlantic Oscillation is the most adapted index of Arctic and high latitude climates and it can force some climatic features in these regions (Dickson, 1999; Hurrell and Deser, 2009). More detailed this also means that the major part of the north flowing Atlantic Water (AW) that continues as a Norwegian Atlantic Current (NWAC) along the coast of Norway may vary in temperature and salinity and may also cause local variations in inflowing water (Sætre and Mork, 1981). Large-scale wind fields are also governed by NAO, and is one of the factors controlling the mixing and exchange processes in northern fjords (Wassmann et al., 1996). Off the Lofoten islands in the southern part of Northern Norway both the NWAC and NCC are narrow, deep and strong and follow the bathymetry of the north Norwegian coastal zone. Both water masses enter trenches which are extensions of the longitudinal axes of the major fjords.

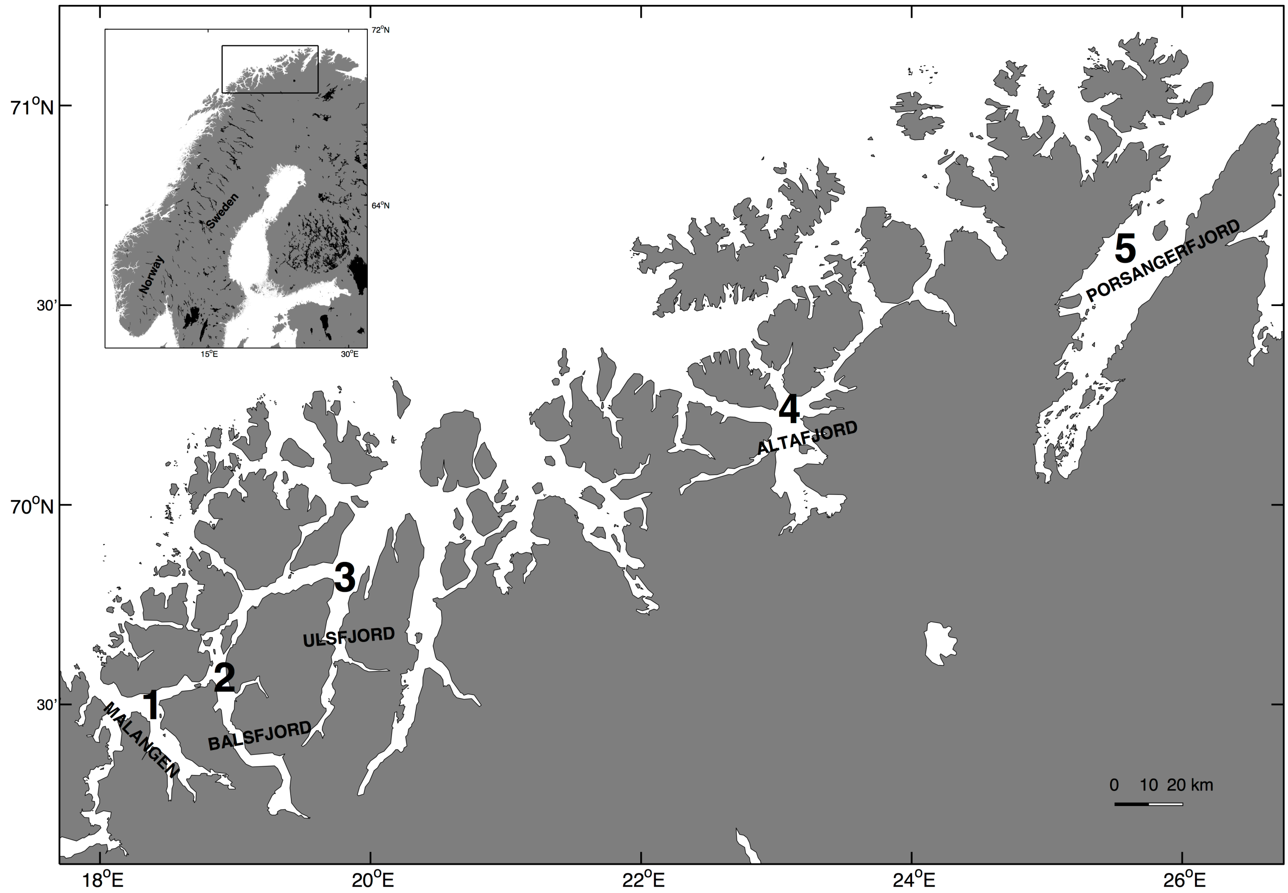


Figure 1: Map of the Northern Norwegian coast. (1) Malangen, (2) Balsfjord, (3) Ulsfjord , (4) Altafjord and (5) Porsangerfjord

The northern coastal areas interacts heavily with the outer lying Atlantic and Arctic Barents Sea situated further north (Loeng, 2007). The area is also influenced by the formerly mentioned climatic variations governed by the North Atlantic Oscillation (NAO), in addition to climatic oscillations in the Baltic area (Aure and Saetre, 1981; Hurrell and Deser, 2009). As mentioned large heat quantities are transported northwards and this equator to pole transport may vary both on long and short time scales (Barron, 1987).

During the last decades the amount of literature dealing with the physics of climate change has had a sharp increase (e.g. Bengtsson et al. (2004); Zhang et al. (1998); Clement et al. (2010); Lucarini et al. (2010); Blöschl and Montanari (2010)). The normal conception up till now has been that eventual climate changes will first be noticed in northern areas (Dickson, 1999) and that there has been a weak increase in mean air and ocean temperatures the last decades. This is though disputed by some, and it is e.g. argued that measurements may have large uncertainties (Cane et al., 1997; Folland et al., 2001). According to Quadfasel et al. (1991) there is a warming of the Atlantic layer of the Arctic Ocean, similar to what was observed during a former (1918-1940) warming period (Scherhag, 1937).

On the other side, in a study by Kahl et al. (1993), after analysing more than 27000 temperature profiles, they concluded that there are no pronounced surface warming trends. They though detected some significant surface cooling trends over the western Arctic Ocean during winter and autumn (Kahl et al., 1993). Chylek et al. (2006) analyzed Greenland temperature records between 1995–2005 and 1920–1930 warming period to compare the Greenland warming trends. According to them Greenland warming is not uncommon in the history. Even though the warming period between 1920–1930 and 1995–2005 were similar in magnitude, the former period were 50% higher than that of the later (Chylek et al., 2006). Many research articles was reporting the effect of the mass balance of the Greenland ice sheet that range between an increasing e.g (Zwally and Giovinetto, 2000; Johannessen et al., 2005; Zwally et al., 2005) and decreasing total mass (Krabill et al., 2000; Thomas et al., 2000). The common conclusion is that the interior of the ice sheet is thickening and thinning close to the margins. Moreover, some studies show that there is an increase in the ice sheet melt area during last decade (Abdalati et al., 2001; Steffen et al., 2004). There are diverse reports suggesting of shorter warming periods of Greenland temperature and a long term cooling period (Box, 2002; Polyakov et al., 2002; Hanna and Cappelen, 2003; Chylek et al., 2004). One central issue in this is therefore, in either case, the important role of the northern and Arctic region in global regulation of temperature and climate related events (Johannessen et al., 2004).

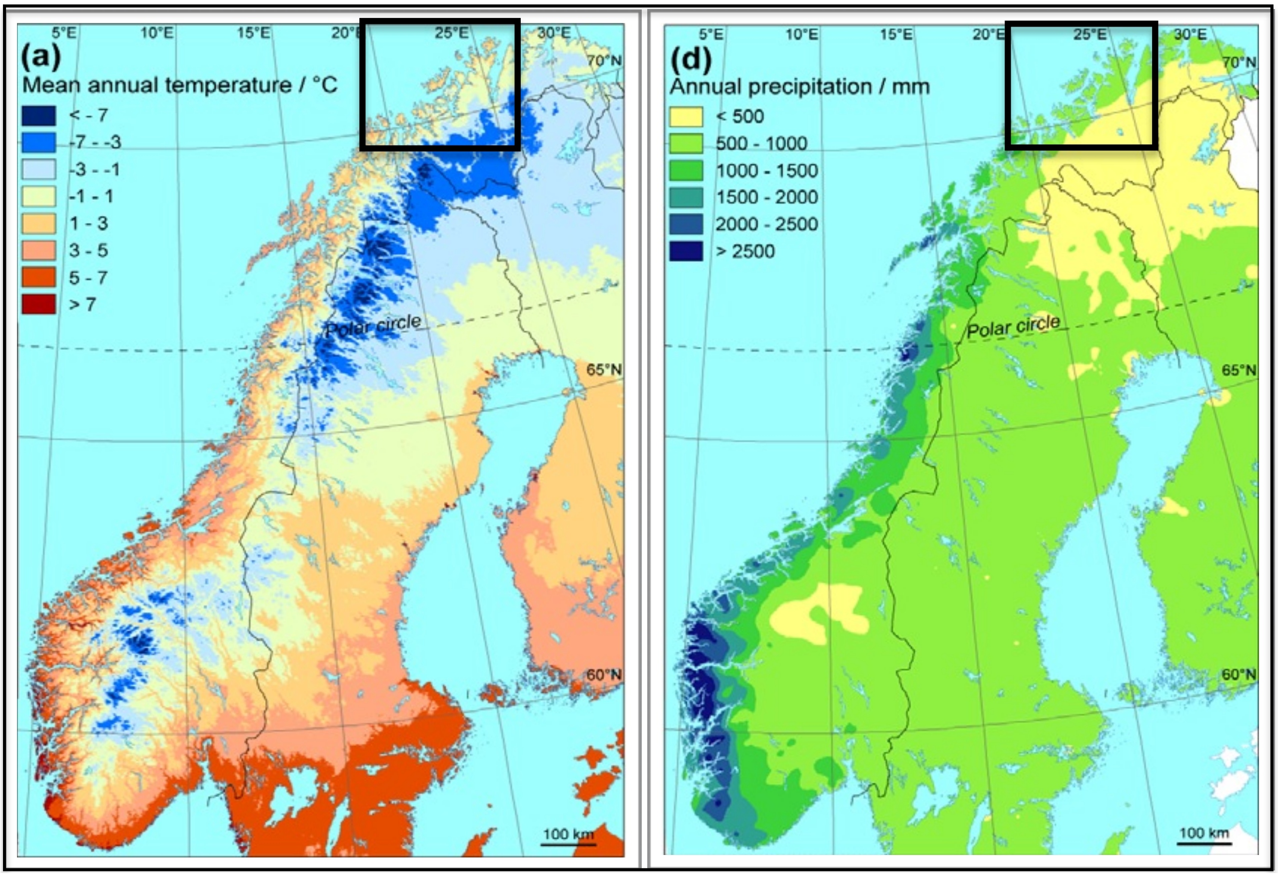


Figure 2: Mean annual air temperatures and precipitation in Norway (Tveito et al., 2001))

Table 1: Position, maximum depth, maximum width and sill depth of some northern Norwegian fjords from (Hegeseth et al., 1995)

Fjord	Position	Length (km)	Width (km)	Max. depth	Sill depth
Porsangerfjord	70.0°N–71.0°N	100	15–20	230	no outer sill
Altafjord	70.0°N–70.3°N	30	4–14	450	190
Malangen	69.0°N–69.4°N	60	3–6	400	200
Balsfjord	69.0°N–69.4°N	45	2–3	190	30

Warming of the oceans is also claimed to have many biological effects (Key et al., 2010). One main mechanism through which climate change may affect biological systems is that altered stratification structures in the water columns may lead to changes in primary production patterns (Behrenfeld et al., 2006; Levitus et al., 2000). There is in fact a bewildering amount of literature on these topics, naturally following the increased focus on climate related issues. Two recent frequently cited works (Chavez et al., 2011; Boyce et al., 2010) dealing with these climate and biology issues argue that worlds oceans primary production has changed the last decades . According to Chavez et al. (2011) the primary production has increased while Boyce et al. (2010) argues that it has decreased.

It is therefore, regardless of eventual discrepancies, that an understanding of the dynamics of the physics of northern ocean areas is of great importance in order to understand the dynamics of the global climate. The climate is greatly influenced by the Gulf Stream that transports substantial energy as heat from the south into the region. This stabilises the climate, especially along the outer coast, and reduces the seasonal amplitude in temperature variations (MacKay and Ko, 2001; Eilertsen and Skarðhamar, 2006).

In terms of terrestrial climatology Northern Norway belongs to the “northern boreal” region (Moen, 1999) where annual mean temperatures at the coast is around 0°C and 1–4°C in the inland areas (Tveito et al., 2001). Annual precipitation in the area is substantially lower than further south along the coast of Norway, i.e. 500 – 1000 mm year^{-1} (Figure 2). The large part of the precipitation falls as snow during winter (November to April). Along the coast the period with the largest precipitation is the autumn (Norwegian Meteorological Institute). The northern coastal area also traditionally hosts large fisheries. Some of the fish stocks here migrate to and from the northern Barents Sea area. The distribution in time and space of these fishes, especially cod *(Gadus morhua)*, may largely be determined by inter-annual variations in sea temperatures and salinity (Sundby and Nakken, 2008). This works partly directly on vital rates in cod, and indirectly through trophic transfer by regulating zooplankton amounts or primary production through variable watercolumn stratification (Brander, 1995; Sundby, 2000). Aquaculture have also become increasingly important the last decades. In 2011 the aquaculture production of salmon and trout in the two northernmost counties (Troms and Finnmark) amounted to ca. 170000 tonnes (Krogstad, personal communication) divided on 183 localities. Variations in fish diseases as well as general stock size variations are also most often explained by variations in hydrophysical parameters, especially temperature (Perry et al., 2005), i.e. by the action of so called physical–biological interactions (Cushing, 1978). This therefore also makes this region important in terms of management of valuable natural resources.

1.2 GEOPHYSICAL ASPECTS OF NORTHERN FJORDS

1.2.1 *Topography, heat budgets, ice cover, temperatures, salinities, densities, runoff and circulation*

Northern fjords are geophysically highly diverse. The lengths vary considerably, with Porsangerfjorden being the longest (<100 km, Table 1). The southernmost fjords (Malangen, Balsfjorden and Ullsfjorden) are all sill fjords. Some of the northern fjords have no sill and communicates freely with outer lying coastal waters, having the appearance of bights (e.g. Porsangerfjorden). Balsfjorden in Troms on the other hand has narrow sills and acts more like an enclosed water basin (Sælen, 1950; Eilertsen et al., 1981; Wassmann et al., 1996). In general the southern fjords are also more narrow than the northern ones. The fjords in the northernmost county (Finnmark) are also generally the largest ones.

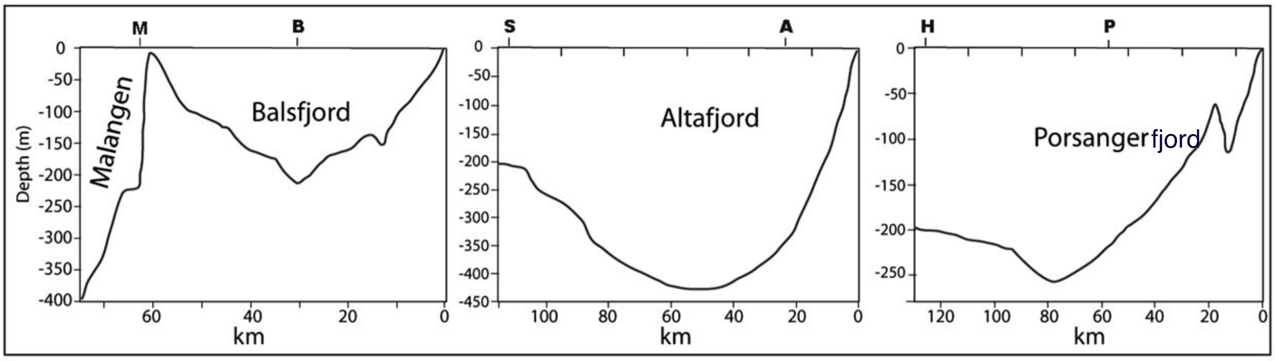


Figure 3: Vertical cross sections of Balsfjorden, Altafjorden and Porsangerfjorden

The communication between the fjords and the outer coast is, during winter, controlled by offshore geostrophic and wind induced circulation (Klinck et al., 1981; Svendsen, 1995). In fjords with sills this also regulates renewal of (deep) basin water. The exchange of basin water most often takes place during the early spring and is indicated by increased bottom water salinities (Eilertsen et al., 1981; Wassmann et al., 1996). The exchange may also be sporadic, determined by the conditions in the watercolums outside the fjords. The boundary between coastal water that lies on top of the Atlantic water may oscillate so that heavier Atlantic water can cross the fjord sill and penetrate the fjord basin. The processes regulating this may be caused by changed wind fields or density variations, i.e. by pressure driven circulations (Svendsen, 1995).

Annual mean sea temperatures are lower than further south, mainly resulting from lower summer maxima in the north and not lower winter minima. There are though, as can be expected, differences in this in the inner parts of fjords where temperatures some years may be close to the freezing point of seawater. The heat transported from the south with the Gulf Stream is released into the air in the north (Takahashi et al., 2009). Annual mean heat flux is therefore negative in the area, and the higest mean annual release of heat from sea to air is in the north in Porsangerfjord, i.e. -45 Wm^{-2} (Eilertsen and Skarðhamar, 2006). At the more southern and oceanic location Malangen, mean annual heat flux is four times lower, i.e. -9.8 Wm^{-2}. During winter the highest mean monthly heat flux from sea to air is in Porsanger in January (-177 Wm^{-2}) while the highest mean monthly heating of the sea surface layers is in Malangen in June (+ 155 Wm^{-2}). Resulting from the transport of heat from sea to air during the long winters, the annual mean sea surface temperatures are therefore always substantially higher than the annual mean air temperatures. Typical temperature regimes are, for e.g. Malangen in the south and Porsangerfjord in the north respectively: Annual means 5.87°C and 5.33°C; monthly maxima 9.38°C and 10.04°C (Sælen, 1950; Eilertsen and Skarðhamar, 2006). An overview of mean sea surface and air temperatures and heat fluxes along the northern coast, from Malangen to Porsanger/Helnes, is in Table 2.

Generally these northern fjords are not ice-covered during winter. Exceptions may be inner parts of fjords during short periods with extreme cooling. The reason for this is that surface salinities remain high during the winter due to negligible winter runoff (Figure 4). The inner Porsangerfjord (Østerbotn) is the only fjord with true arctic environment where temperatures below ca. 20-30m are always below zero (Wassmann et al., 1996).

Runoff in the northern area of the Norwegian coast is normally lower than further south (Skofteland, 1985). The northern fjords and coastal areas therefore have higher surface salinities and hence are generally weaker stratified than further south along the Norwegian coast (Skofteland, 1985; Eilertsen and Skarðhamar, 2006). Typically surface salinities during winter when salinities approach NCC values are 33.2-33.8‰, more seldom values may approach 34.0‰. Runoff is normally totally absent during winter since freshwater is stored on land as snow and ice, and therefore the fjords are vertically unstratified during this period, i.e. estuarine circulation only prevails during summer (Wassmann et al., 1996; Sælen, 1950; Svendsen, 1995). Runoff starts early in April and peaks considerably later than at southern Norwegian sites, i.e. in June or early in July (Figure 4). Less incoming radiation leading to (weaker thermoclines) also contributes somewhat to this, and the winter period with unstratified waters (surface cooling with formation of heavy water) and high wind overturning therefore lasts substantially longer than further south (Eilertsen and Skarðhamar, 2006).

The largest rivers running displacing water into fjords in the area are Målselva (Figure 4) and Altaelva with maximum discharge volumes 400-500 $m^{-2}s^{-1}$. Runoff can influence fjord circulation either by direct pressure driven forcing or indirectly through changed stratification patterns. The relative importance of the two processes is regulated by the width of the fjord and the runoff pattern in the adjacent areas (Svendsen, 1995).

Table 2: Monthly mean of cloud cover (0-9), air and sea surface temperatures and modelled heat flux (Q_t) for each month (W m^{-2}). Positive Q_t means heating of sea. At bottom of table is shown Q_t when cloud cover, wind and sea temperatureswere increased to values comprising 75% of the data for the period 1980-2003, i.e. ca. 10% CC, +20% wind and 20% increased sea temperature (from Eilertsen and Skarðhamar (2006)).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Mean
Malangen cloud cover	5.68	5.22	5.06	4.56	4.82	3.57	3.93	3.9	3.46	4.26	5.02	5.88	4.6
Malangen, sea temperature	3.5	3.05	3.19	3.69	4.97	6.64	8.32	9.38	9.3	7.32	5.67	5.46	5.87
Malangen, air temperature	-1.51	-1.43	-0.4	2.09	5.71	9.06	11.4	11.4	8.35	4.4	1.11	-0.92	4.11
Malangen Q_t	-99	-94	-67	5	78	155	148	86	-24	-85	-103	-117	-9.8
Balsfjord cloud cover	5.76	6	5.85	5.7	6.74	4.22	5.49	5.49	3.75	5.96	5.75	6.42	5.6
Balsfjord Q_t	-112	-90	-64	-6	37	135	120	74	-27	-84	-115	-120	-21
Balsfjord, sea temperature	2.66	1.33	1.46	2.48	4.54	7.17	8.56	8.56	8.28	6.53	5.13	4.14	5.07
Balsfjord, air temperature	-3.74	-3.56	-2.26	0.66	4.91	9.29	11.8	11	7.09	2.65	-1.06	-3.11	2.81
Skips olmen cloud covere	5.8	6.52	6.89	6.5	7.39	4.98	6.26	5.36	4.4	5.9	6.91	6.71	6.1
Skipsholmen, sea temperature	4.52	3.67	3.44	3.63	4.22	5.84	7.85	8.93	8.71	7.58	6.63	5.91	5.91
Fruholmen, air temperature	-1.89	-1.78	-0.97	0.84	3.77	6.84	9.71	9.97	7.63	4.15	0.75	-1.05	3.16
Skipsholmen Q_t	-116	-97	-72	-26	13	99	79	52	-25	-80	-106	-119	-33
Altafjord cloud cover	5.61	6.13	5.64	5.14	6.53	4.73	6	5.48	4.42	5.66	6.23	5.53	5.6
Altafjord, sea temperature	3.56	2.59	2.19	2.66	4.33	7.18	9.27	10.5	8.67	7.4	6.06	5.24	5.81
Altafjord, air temperature	-7.43	-6.6	-4.24	-0.06	4.84	10	13.5	12.2	7.6	2.05	-3.76	-6.38	1.82
Altafjord Q_t	-163	-137	-96	-13	43	136	131	65	-26	-107	-155	-176	-42
Porsanger, cloud cover	5.18	5.95	5.08	4.37	6.41	4.38	5.6	4.72	4.52	5.63	5.67	5.57	5.3
Porsanger, sea temperature	3.28	2.46	1.95	2.3	3.45	6.15	8.41	10.4	8.24	7.05	5.58	4.71	5.33
Porsanger, air temperature	-9.03	-7.89	-5.36	-0.81	4.12	9.37	12.7	11.2	6.9	1.41	-4.77	-7.67	0.85
Porsanger Q_t	-177	-149	-106	-10	47	148	136	57	-29	-110	-163	-181	-45
Helnes cloud cover	4.9	6.65	6.2	5.28	7.06	5.2	5.95	4.51	4.13	5.81	6.7	6.41	5.7
Helenes, sea temperature	4.67	4.25	3.61	3.8	4.52	5.88	7.38	9.3	8.44	7.77	6.26	5.69	5.96
Helnes, air temperature	-3.05	-3.01	-1.92	0.28	3.53	6.99	10	9.99	7.37	3.29	-0.21	-2.1	2.59
Helnes Q_t	-123	-96	-69	-10	15	77	69	38	-30	-90	-111	-124	-38
Helnes Q_t +10% cloud cover	-119	-91	-67	-14	2	66	57	32	-29	-86	-106	-119	-39.5
Helnes Q_t +20% wind	-129	-102	-73	-11	15	78	71	38	-31	-94	-118	-132	-42
Helnes Q_t +20% sea temp	-132	-101	-74	-13	9	63	56	23	-42	-102	-120	-131	-52

This has biological consequences since it shortens the phytoplankton productive season as well as that the seasonal production pattern changes, especially in the northernmost regions (Eilertsen and Frantzen, 2007; Degerlund and Eilertsen, 2010).

The prevailing winds comes from the south, and these winds peaks during winter and slackens during summer. During winter high barometric pressure centers over northern Scandinavia causes strong, cold winds ("boras") to blow out of the fjords in northern Norway. In summer these "boras" are absent, and winds of diel periodicity caused by heating of the land may blow into the fjords (Svendsen, 1977; Eilertsen et al., 1981).

During summer, after stratification has set in, the fjords experience estuarine circulation with brackish surface water being transported out of the fjord and an intermediate compensating current. The

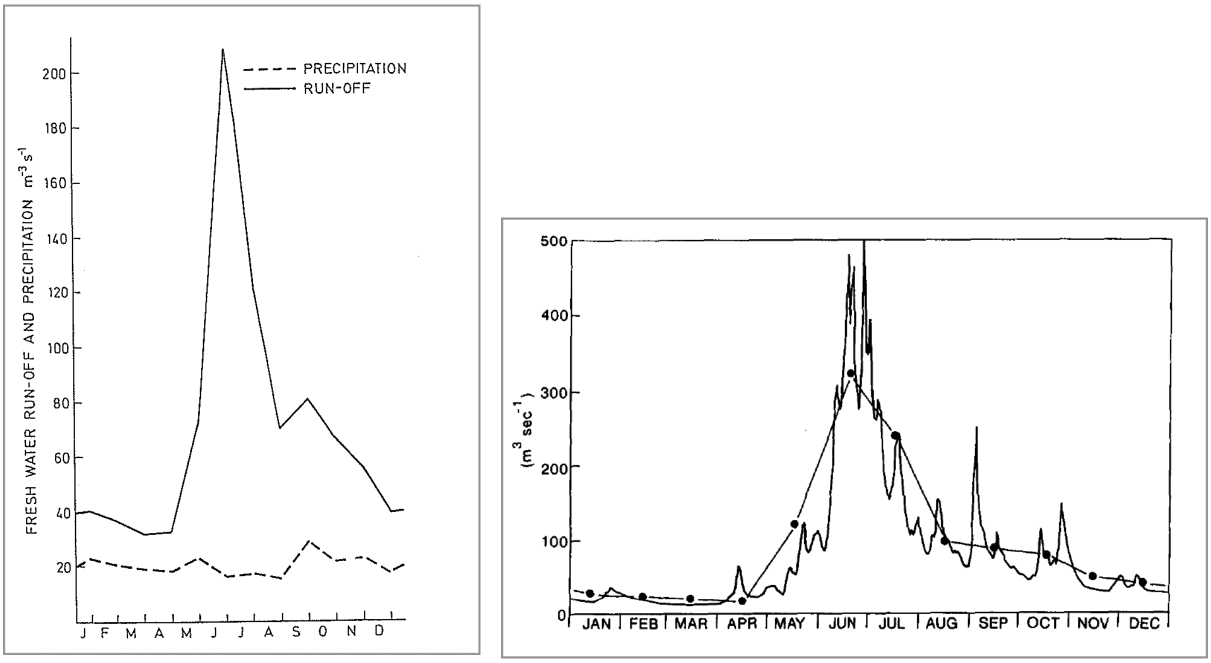


Figure 4: Runoff from Målselva into Malangen in 1991 (daily and monthly averages (right). The left figure shows runoff and precipitation to Balsfjorden in 1976. Målselv data is from Aure (1983) and Balsfjorden from Eilertsen et al. (1981)

strength of the compensating current naturally varies with the fjord width, length and runoff magnitude. Also plays a role here if there are sills present and their depth. Depending on the direction of the wind-stress generated by atmospheric pressure the fjords will experience different circulation patterns. If the wind-stress is along the fjord system, then the geostrophic circulation will either drain or flood the fjord system as a whole (Klinck et al., 1981). On the other hand, wind- induced circulation across the fjord has been shown to play a considerable role within the system in Porsangerfjorden, especially where run-off water does not possess the ability to generate the circulation by itself (Svendsen and Thompson, 1978). Strong winds have, in wide fjords, the ability to generate Ekman drift, displacing the surface water towards the right creating upwelling and downwelling (Cushman-Roisin et al., 1994). The strength of the wind is usually greater in the outer parts of the fjord systems (Eilertsen and Frantzen, 2007). When the Coriolis effect leads to upwelling and downwelling events within a fjord that is constrained by the width of the deformation radius, a separation of the sides will appear and the separated sides can start to behave as independent coastal oceans (Cushman-Roisin et al., 1994). The current will travel upfjord along the left side and downfjord on the right handed side of the fjord. This generated steady-state will be carried on for some time even after the termination of the wind-stress. However, an upwelling event within a fjord can never be compared to upwelling events along an open-ocean coastal zone (Cushman-Roisin et al., 1994).

1.2.2 *Atmospheric and subsurface irradiance*

The northern Norwegian coastline stretches northwards from the Arctic Circle (66° 33′ 44″ N), hence the area experiences midnight sun as well as winter darkness periods. In the Porsangerfjord area (70–71°N, Figure 1) the winter darkness and midnight sun periods lasts 55–66 days. In the south in Malangen and Balsfjorden the length of these periods are 48–51 days (Figure 5). Due to the compensating effect of the midnight sun, daily integrated summer radiation values are not substantially lover compared to areas further south. In the south in Malangen and Balsfjorden the length of these periods are 48–51 days (Figure 5). Integrated annual radiation in the north (Porsangerfjord) amounts to 80–85% of the radiation in Oslo that is situated at ca. 60°N, i.e. 10° further south. This comparison assumes that atmospheric and cloud cover conditions are comparable (Figure 6). Winter radiation levels are, naturally, very low due to the absence of direct sunlight, but at special cloud cover conditions backscattered light intensity (with sun under horizon) may reach 100 mWm^{-2} at 1 m depth during noon (Degerlund and Eilertsen, 2010). This type of diffuse radiation typically has a higher blue to red ratio than direct sunlight, similar to what can be observed in radiation that has travelled through clouds (Eilertsen and Holm-Hansen, 2000). The relative amount of UVR also has a tendency to be high in this type of radiation. Important to take note of is also that the areas in question are susceptible to long periods with "dusk and dawn" irradiance (Gates, 1966; Johnson et al., 1967; Degerlund and Eilertsen, 2010) since solar heights are low for longer and longer periods during early spring and late autumn. When the sun settles below the horizon there appears a sharp increase in the blue to red ratio (Johnson et al., 1967). This has effects on how deep surface irradiance penetrates into the sea since k values (diffuse attenuation coefficients) are lower for shorter wavelengths, and the transfer of these short-wave radiation values into the watercolumn may have less tendencies to cause shallow (weak) thermoclines. To this adds that during winter and early spring when phytoplabkton concentrations are negligible, before the phytoplankton spring bloom starts waters are exceptionally clear with k values down to 0.13 m^{-1} (Degerlund and Eilertsen, 2010).

1.2.3 *Historical background and knowledge base*

Norway was one of the pioneer countries that started oceanographic studies as early as in the 1800s. The early studies were chiefly confined to fisheries and explorative attempts in marine biology. The first governmental initiative in this area was the provision of a grant to marine zoologist *Georg Ossain Sars*, in 1864 for the studies of the Lofoten cod fisheries. The outcome of his studies proved to be of great importance and acted as a stepping-stone for the later developments in marine biological studies. In 1866, the Norwegian Geographical Survey acquired the combined sail and steam vessel *Hansteen*. For the following thirty years, this vessel was used to survey the seabed off Norway and also fishery

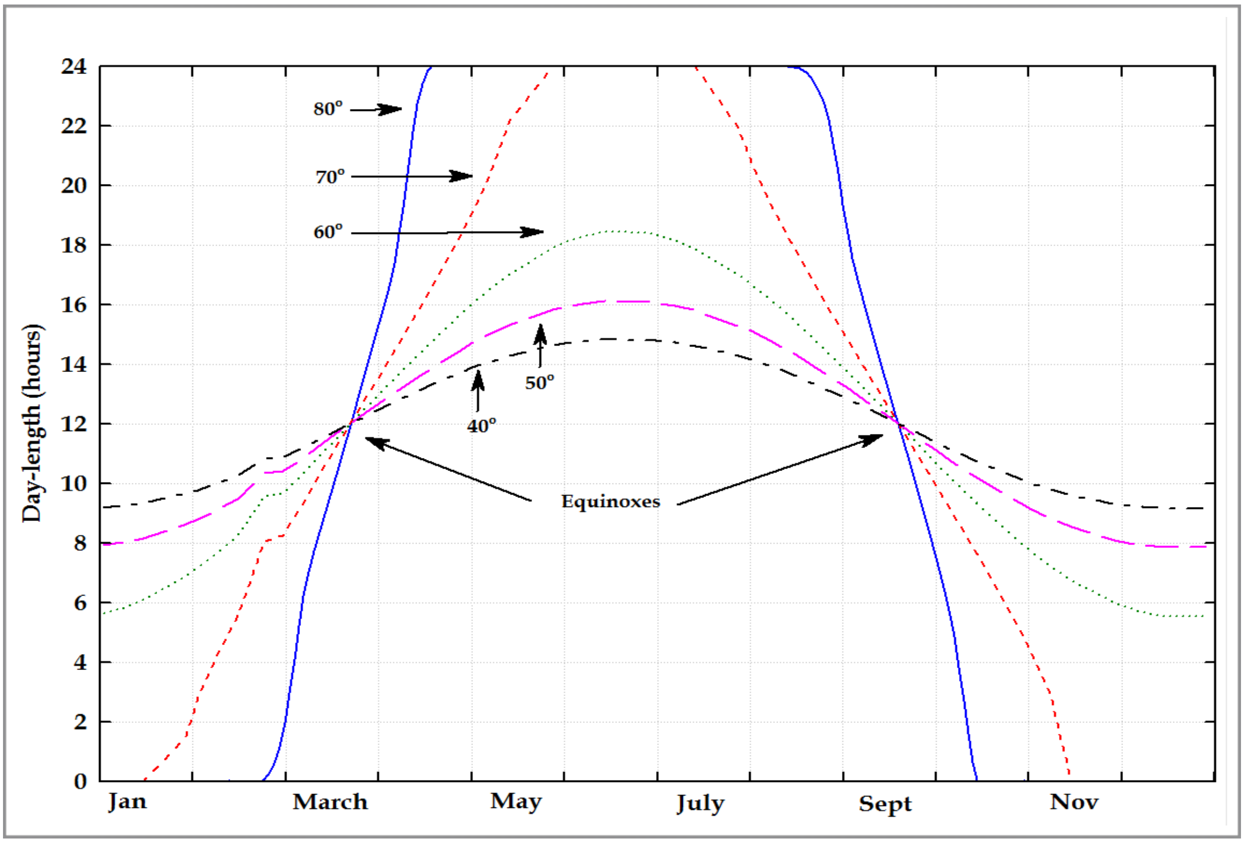


Figure 5: Seasonal daylengths on the northern hemisphere from 40°N to 80°N. Data is modelled according to method described in Eilertsen and Holm-Hansen (2000).

research studies. The remarkable incidents in the history of Norwegian marine research in that period were Norwegian North Atlantic Expedition (Wille, 1882) and Fram expedition to arctic.

It was Mohn (1887) that first attempted to make the first detailed current map of the Nordic seas. The map was calculated from data on mean winds, temperature and salinity information. He also summarized the distribution of temperatures on the Norwegian coastal banks and in the fjords on the basis of all available measurements, from both Norwegian and international surveys. Hjort and Gran (1899) studied the seasonal and inter-annual hydrographic variations in the Norwegian coastal area and presented detailed overview of the physical oceanography of the region, including the northern region. The first purpose built Norwegian research vessel “Michael Sars” was given to the Norwegian Marine and Fisheries Investigations in 1900. Based on the results from four years studies conducted using this vessel, Helland-Hansen and Nansen (1905) provided the first authentic and comprehensive information on the oceanographic features of the Nordic seas.

When Tromsø Museum was founded in 1872, marine science was of high prioritiy and was from the start incorporated in the activities (Sars, 1879; Sparre Schneider, 1881; Nordgaard, 1905). Tromsø was also a natural starting point for polar expeditions, e.g. the Nansen expeditions and the Amundsen–Sverdrup Maud expedition in 1918. Numerous international expeditions to the northern and Arctic areas also started in Tromsø, something that led to close contact with researchers from

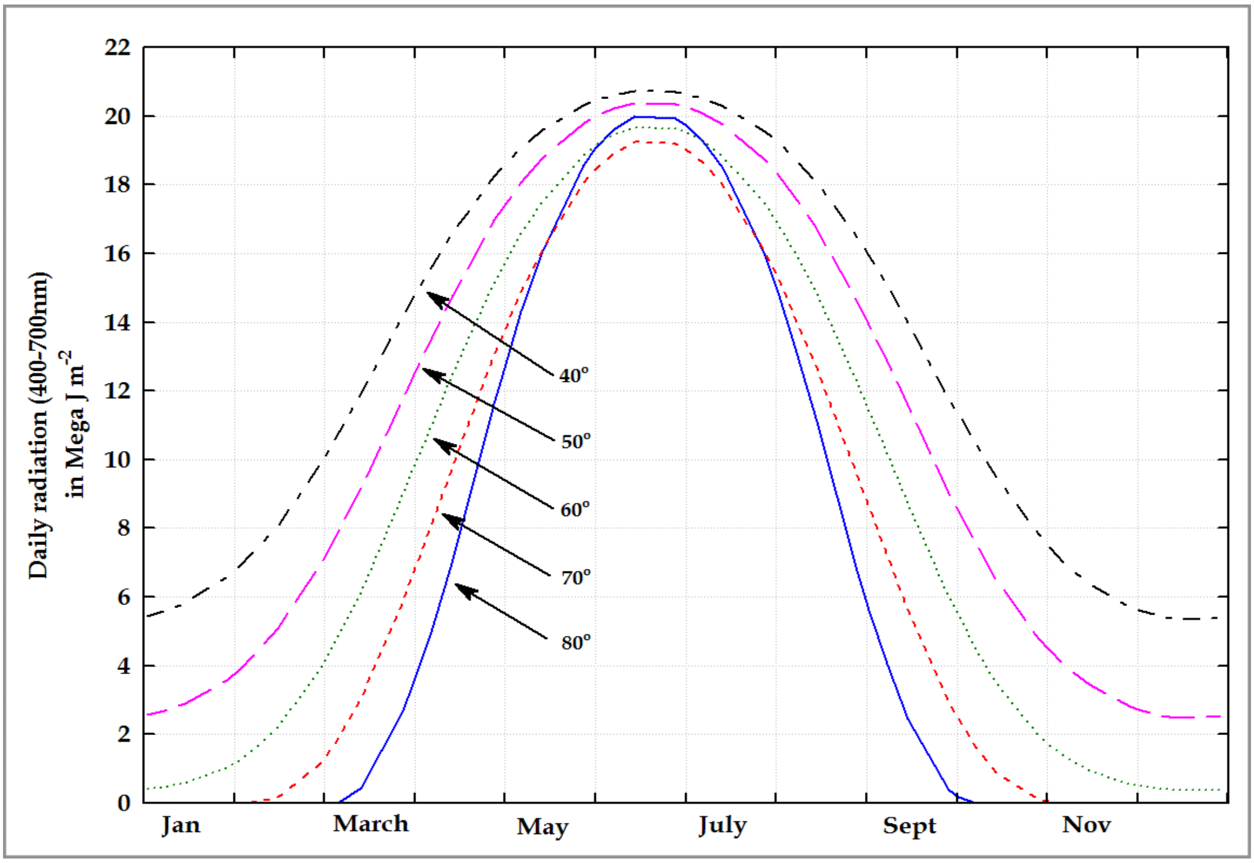


Figure 6: Seasonal daily radiation vs. latitude on the northern hemisphere from 40°N to 80°N. Data is modelled according to method described in Eilertsen and Holm-Hansen (2000) with maritime atmospheric conditions and constant cloud cover 1.0 (8-9=100% clouds/fog).

other Norwegian and also foreign institutions. Often this resulted in cooperation and publications in the Tromsø Museum's own scientific journal (Foslie, 1887; Lagerheim, 1894; Norman, 1902).

There exists several monographs dealing with the research history of Norwegian Oceanography (Broch, 1954; Sakshaug and Mosby, 1976; Hognestad, 1999; Skreslet, 2007), but it is our opinion that the role of early marine research in Tromsø is downplayed and/or overlooked.

Systematical retrieval of the physical oceanographical data during shorter periods (1–2 years) in Tromsø and north Norway goes back to ca. 1872 when Tromsø Museum was founded. The first decades sampling was performed with hired vessels, and retrieval of hydrophysical data was connected to sampling of marine organisms. During the first decades of the existence of the Museum up till ca. 1922, temperature and salinity data were during periods collected from areas adjacent to Tromsø, again as data to back up biological observations (Soot-Ryen, 1932a). Large parts of these data sets was stored at Tromsø Museum in the form of hand-written tables, or the data sets have been published in table form merely, i.e. without any kind of interpretations attached (Soot-Ryen, 1932b, 1943).

The sampling frequency increased when Tromsø Museum in 1926 got their first research vessel with hydrographic winch and water bottle systems (Soot-Ryen, 1938). This vessel was used until the start of WW2. The fate of this vessel after the start of the war is uncertain, but in 1952 it was continued with the purchase of R/V Asterias that had the name Hansnes prior to that it was converted to research purposes (Figure 11).

1.3 HAVMILJØDATA (HMD)

A large part of my PhD has been made up by work with old data tables that I have had digitised, sorting data and scrapping obvious unreliable (erroneous) measurements. Also systemising the data and constructing a database with all information (station, depth, temperature, salinity, σ_t, runoff) has been time consuming. All data after January 2009 has been collected by me on routine Havmiljødata (HMD) cruises along the coast. In sum this makes up to 170 days at sea. Further older (and for periods also newer) data on O_2, pH, nitrate, ammonia and phosphate has been digitised (not shown here) and is present in the database, this since also some of the "mission" with my PhD was to make the old data sets easily available to other researchers. The entire data set is therefore available and downloadable from a new HMD web based site, i.e. `http://purl.org/hmd` (I have used a persistent uniform resource locator (PURL) to avoid future URL changes).

2

MATERIALS AND METHODS

2.1 DESCRIPTION OF THE SAMPLING AREAS AND STATIONS

An overview map of complete havmiljødata (HMD) sampling stations are presented in Figure 8 and geographic positions in Table 3.

2.1.1 *Malangen*

Malangen is located ca 30 km southwest of Tromsø (Figure 7). Of the larger fjords in the area, Malangen is the most open fjord and has a free connection to the sea. The fjord system extends about 60 km inland in a southeast-northwest direction. The bathymetry is dominated by two basins, one in the outer part with a maximum depth of 400 m and one in the inner part (maximum depth ca. 250 m). The two basins are separated by a sill area with maximum depth 160 m situated in the in the middle and east-west oriented area. The east-west oriented area has its entrance in the southern part through the long and narrow sound Gisundet, and in the northern part through the shallow Rystraumen (maximum depth ca. 30 m). Also, 7 km outside the mouth of the fjord there is a sill with a maximum depth of 200 m, separating the outer basin from a deeper groove on the shelf. In the inner part of Malangen the big river Målselv is supplying most of the freshwater to the fjord. Malangen usually does not have a winter ice cover.

2.1.2 *Balsfjorden*

Balsfjorden is located between 69°13′ N and 69°30′ N. Its orientation is a South / South-East direction and its total length is 45 km (Figure 7). The fjord is connected with the outer lying coast through two sounds: Rystraumen towards west and Kvalsund towards north. It is separated from the outside deep waters by three relatively narrow sounds. Tromsøysundet and Sandnessundet have sill depths of 8 and 9 m respectively and Rystraumen has 30 m. The fjord does not have a winter ice-cover. The water column is vertically mixed and almost homogeneous from October until the end of April. In most years, the vertical convection reaches the bottom during late winter. In Balsfjorden, the exchange of fjord water with coastal water is limited by the sills surrounding the fjord. According to Eilertsen et al.

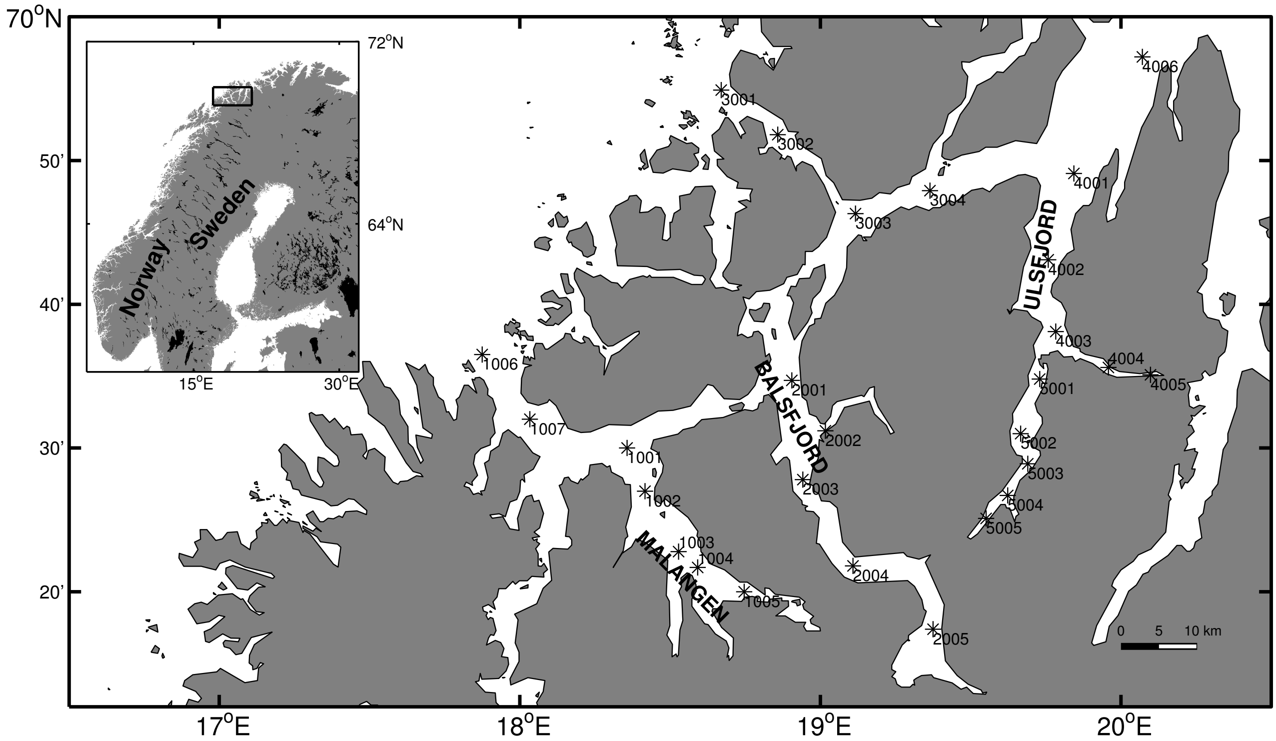


Figure 7: Map of Malangen, Balsfjorden and Ullsfjorden

(1981) the temperature of the bottom water increases until it reaches its maximum about May before decreasing it again during the summer. Salinity changes follow the same pattern as temperature in the first part of the year, i.e. increases until May, then it decreasing again. Coastal water on the Norwegian west coast lies as a wedge on top of the Atlantic water and oscillations of this wedge may at times lift heavier Atlantic water up high enough to cross the sills thus penetrating the fjord basin (Sælen, 1950). The water masses are well oxygenated and oxygen levels do not fall below 70 to 80% saturation in the bottom water (Sargent et al., 1983; Eilertsen et al., 1981). The fjord doesn't usually have winter ice cover, though during cold winters the inner part may have some thin ice sheets.

2.1.3 *Altafjorden*

Altafjorden has a length of 30 km. The width of the fjord is not uniform and varies from 4 km in the middle to 10 and 14 km at the mouth and head respectively (Figure 9). The outer part of the fjord branches into three inlets, Stjernsund, Rognsund and Vargsund. In the junction area of the fjord and the three inlets the maximum depth is ca. 450 m and inwards Altafjorden gets shallower. The minimum depth at the inlets are 190, 60 and 50 m in Stjernsund, Rognsund and Vargsund respectively. The effective sill depth preventing the Altafjorden basin water from having free exchange with the open sea is 190 m. The main fresh water source is the Altaelv situated at the head of the fjord.

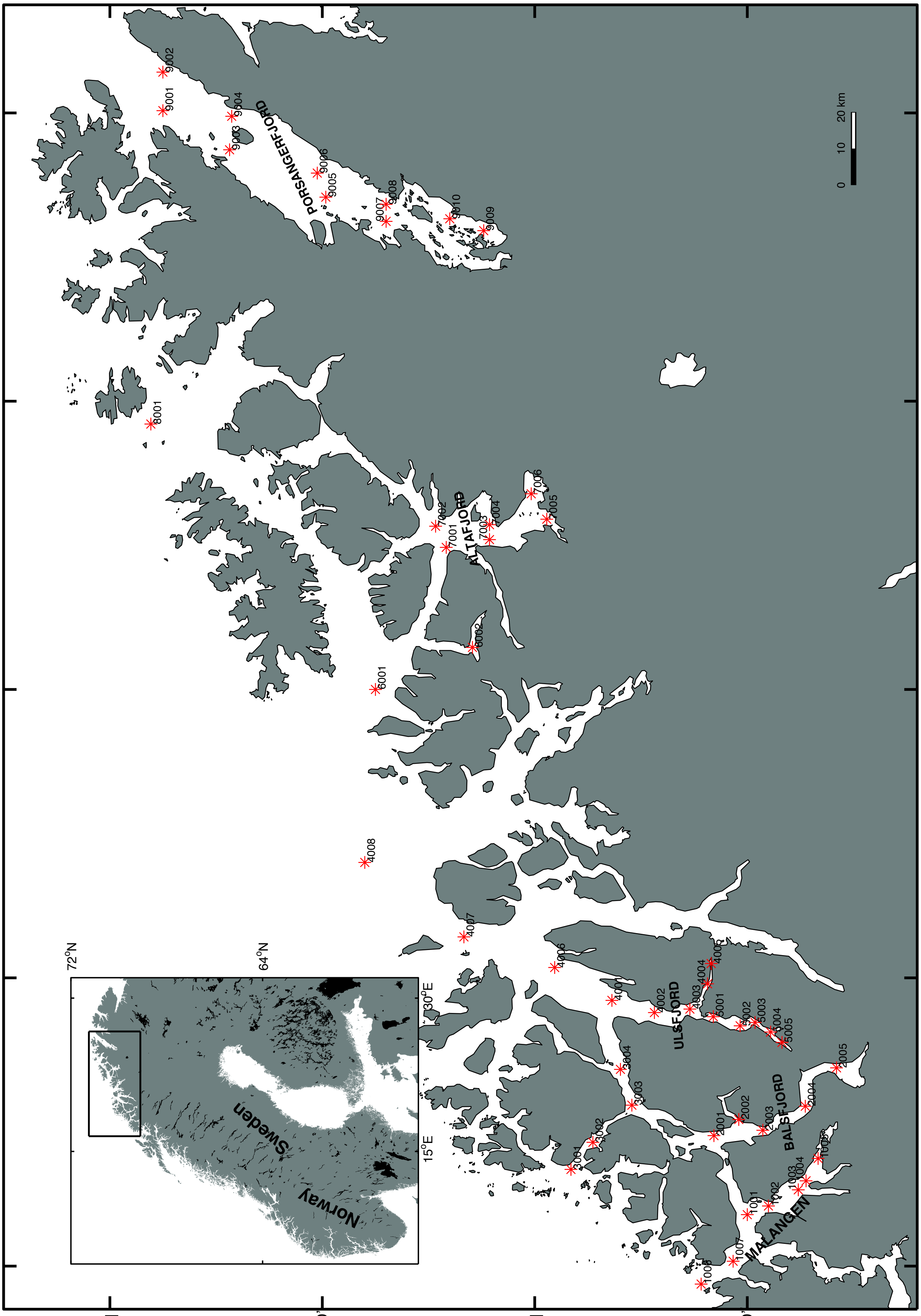


Figure 8: Overview of havmiljødata stations

Table 3: Sampling stations with positions applied after 1981

Sl No:	Station name	Standard No:	Latitude	Longitude	Old No:
1	MALANGEN YTRE	1001	$69°30.0' N$	$18°21.4' E$	1
2	MALANGEN SPILDERNES	1002	$69°27.0' N$	$18°25.0' E$	2
3	MALANGEN MÅLSJORD	1003	$69°22.8' N$	$18°31.7' E$	3
4	MALANGEN MÅLSNES	1004	$69°21.7' N$	$18°35.5' E$	4
5	MALANGEN NORDFJORD	1005	$69°20.0' N$	$18°44.8' E$	6
6	MALANGEN HEKKINGEN	1006	$69°36.5' N$	$17°52.5' E$	48
7	MALANGEN BUVIKA	1007	$69°32.0' N$	$18°02.0' E$	47
8	BALSFJORD BERG	2001	$69°34.7' N$	$18°54.3' E$	7
9	BALSFJORD HAUGBERGNES	2002	$69°31.2' N$	$19°01.0' E$	8
10	BALSFJORD STORNES	2003	$69°27.8' N$	$18°56.5' E$	9
11	BALSFJORD SVARTNES	2004	$69°21.8' N$	$19°06.5' E$	10
12	BALSFJORD TENNES	2005	$69°17.4' N$	$19°22.5' E$	11
13	KVALSUND GÅSVÅR	3001	$69°54.9' N$	$18°40.2' E$	7C
14	KVALSUND KÅRVIK	3002	$69°51.8' N$	$18°51.5' E$	7B
15	KVALSUND GRØTSUND	3003	$69°46.3' N$	$19°07.0' E$	7A
16	GRØTSUND NIPØY	3004	$69°47.9' N$	$19°21.9' E$	NA
17	ULLSFJORDMUNNINGEN	4001	$69°49.1' N$	$19°50.6' E$	15
18	ULLSFJORD NORD AV NISEGRUNN	4002	$69°43.1' N$	$19°45.5' E$	16
19	ULLSFJORD NORD AV JØVIK	4003	$69°38.1' N$	$19°47.0' E$	17
20	ULLSFJORD YTRE KJOSEN	4004	$69°35.6' N$	$19°57.5' E$	18
21	ULLSFJORD INDRE KJOSEN	4005	$69°35.1' N$	$20°05.9' E$	19
22	ULLSFJORD SØR AV KARLSØY	4006	$69°57.2' N$	$20°04.3' E$	14
23	ULLSFJORD ØST AV SPENNA	4007	$70°10.0' N$	$20°17.0' E$	13
24	ULLSFJORD NORD AV ARNØY	4008	$70°24.0' N$	$20°48.0' E$	12
25	SØRFJORD REIERVIK	5001	$69°34.8' N$	$19°43.8' E$	NA
26	SØRFJORD SOMMARBUKT	5002	$69°31.0' N$	$19°40.0' E$	NA
27	SØRFJORD NJOSKEJUFTA	5003	$69°28.9' N$	$19°41.4' E$	NA
28	SØRFJORD LAKSELVNES	5004	$69°26.7' N$	$19°37.4' E$	NA
29	SØRFJORD STORURA	5005	$69°25.1' N$	$19°33.1' E$	NA
30	LOPPA ØST AV SILDA	6001	$70°22.5' N$	$22°00.0' E$	20
31	ØKSFJORD INDRE	6002	$70°08.8' N$	$22°17.5' E$	23
32	ALTA STJERNSUND	7001	$70°12.5' N$	$22°59.2' E$	24
33	ALTA VARGSUND	7002	$70°14.0' N$	$23°08.0' E$	25
34	ALTA MIDTRE VEST	7003	$70°06.4' N$	$23°02.4' E$	26
35	ALTA MIDTRE ØST	7004	$70°06.4' N$	$23°08.6' E$	27
36	ALTA KÅFJORD	7005	$69°58.3' N$	$23°10.9' E$	28
37	ALTA RAFSBOTN	7006	$70°00.5' N$	$23°21.5' E$	29
38	REVSBOTN SKIPSHOLMEN	8001	$70°54.2' N$	$23°50.5' E$	32
39	PORSANGNES VEST	9001	$70°52.5' N$	$26°01.0' E$	36
40	PORSANGNES ØST	9002	$70°52.5' N$	$26°17.0' E$	37
41	PORSANGER YTRE VEST	9003	$70°43.1' N$	$25°44.7' E$	38
42	PORSANGER YTRE ØST	9004	$70°42.8' N$	$25°58.6' E$	39
43	PORSANGER MIDTRE VEST	9005	$70°29.5' N$	$25°25.0' E$	41
44	PORSANGER MIDTRE ØST	9006	$70°30.7' N$	$25°35.0' E$	42
45	PORSANGER INDRE VEST	9007	$70°21.0' N$	$25°14.9' E$	43
46	PORSANGER INDRE ØST	9008	$70°21.0' N$	$25°22.0' E$	44
47	PORSANGER ØSTERBOTN	9009	$70°07.2' N$	$25°11.0' E$	45
48	PORSANGER RODDENESSJØEN	9010	$70°12.0' N$	$25°16.0' E$	46

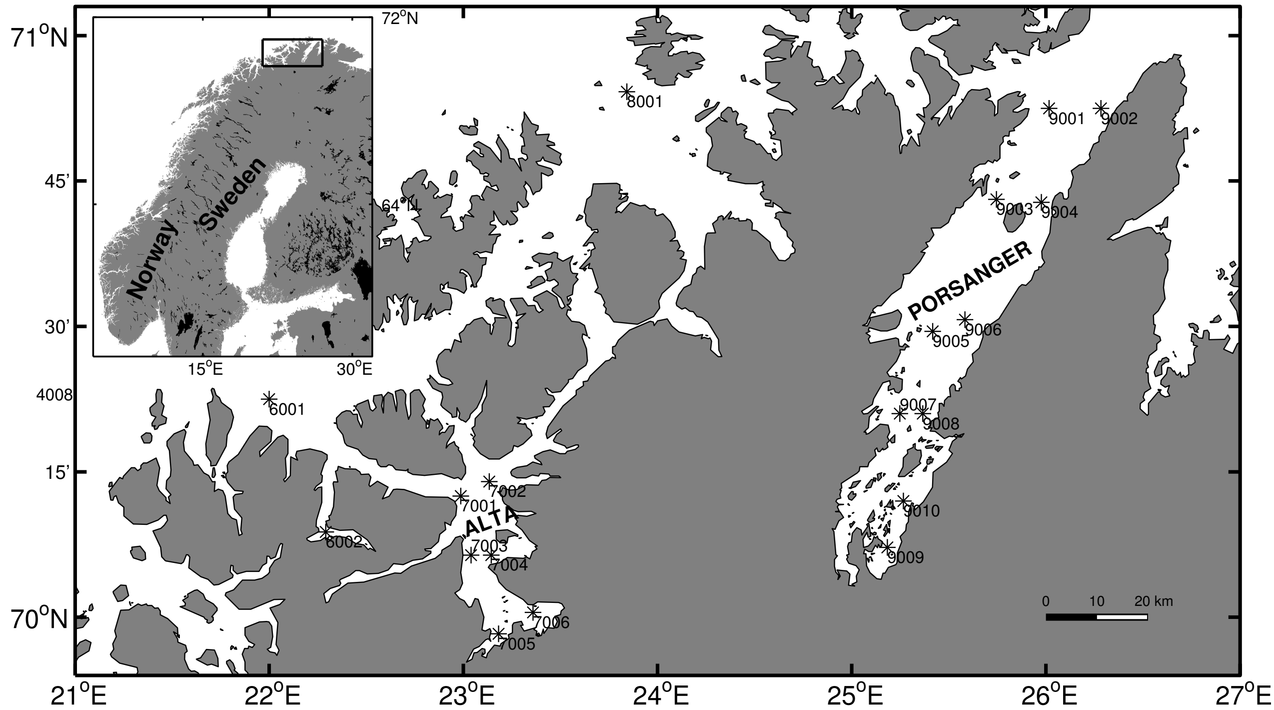


Figure 9: Map of Altafjorden and Porsangerfjorden

The Altafjorden is situated between 70° N and 70°03′ N and has lower winter temperature, higher summer temperature and lower annual precipitation than Porsangerfjorden. During the winter the inner part of Altafjorden is covered with ice. In the warmest summer period (August) the surface layer temperature is 14-16°C (Eilertsen and Skarðhamar, 2006). Strong gradients in density appear in the surface layer of the Altafjorden in the longitudinal direction, while the cross fjord gradients are weak. The strongest frontal area is normally found ca 30 km from the head of the fjord in June when it is maximum fresh water supply to the fjord, while in August the front is found in the inner part (Svendsen, 1991).

2.1.4 *Porsangerfjorden*

Porsangerfjorden is the largest north Norwegian fjord. It is located in a north-south direction between 70°N–71 °N and 25°E 26°E in the county of Finnmark. Porsangerfjorden is open to the adjacent Barents Sea (Figure 9). The length is approximately 100 km and the width varies from the broadest point of 20 km in the middle to 15 km at the head and the mouth of the fjord. The sill at the mouth is at 200 m depth. The deepest point in Porsangerfjorden is within the same depth regime as the sill. It is therefore reasonable to divide the fjord into three sections; outer, middle and inner Porsangerfjorden, and to consider the outer and middle part of the fjord as a semi-enclosed fjord system (Svendsen, 1991). Continuous or at least frequent exchange of the deep water occurs with the Norwegian Coastal Current

(NCC) (Wassmann et al., 1996; Eilertsen and Skarðhamar, 2006). The inner part of Porsangerfjorden is separated by a second sill located 30 km from the head at a depth of 60 m (Figure 3).

2.2 DATA COLLECTION AND METHODS

The data sets applied in the present work, representing the period 1876-2012, are from the former mentioned reports and old handwritten tables (that we have digitized), while data from after 1981 are from the HMD (Havmijødata) database. Data from some of the periods before 1980 are scattered in time and space, but considering the long coastline with many large and long fjords, especially the localized spatial coverage is good, i.e. if e.g. a fjord was sampled this was most often done at many other stations at approximately the same time. A complete list of the stations sampled after 1981 is in Table 2 and the sampling area with stations are shown in Figures 7 and 9. Several stations listed here are localities that were also sampled prior to 1981 and some of them date back to the 1920ties. For Balsfjorden, Malangen and the southern sampling area data coverage prior to 1981 is especially good for 1930 - 1940. Also, for samplings from before 1981 where stations were located close to (> 2 km) and not hindered by e.g. sills or obviously different water-masses, the station numbers and positions listed in Table 3 were used in the analysis instead of the original ones. The reason for this was that this would ease the analysis and plotting of the data sets.

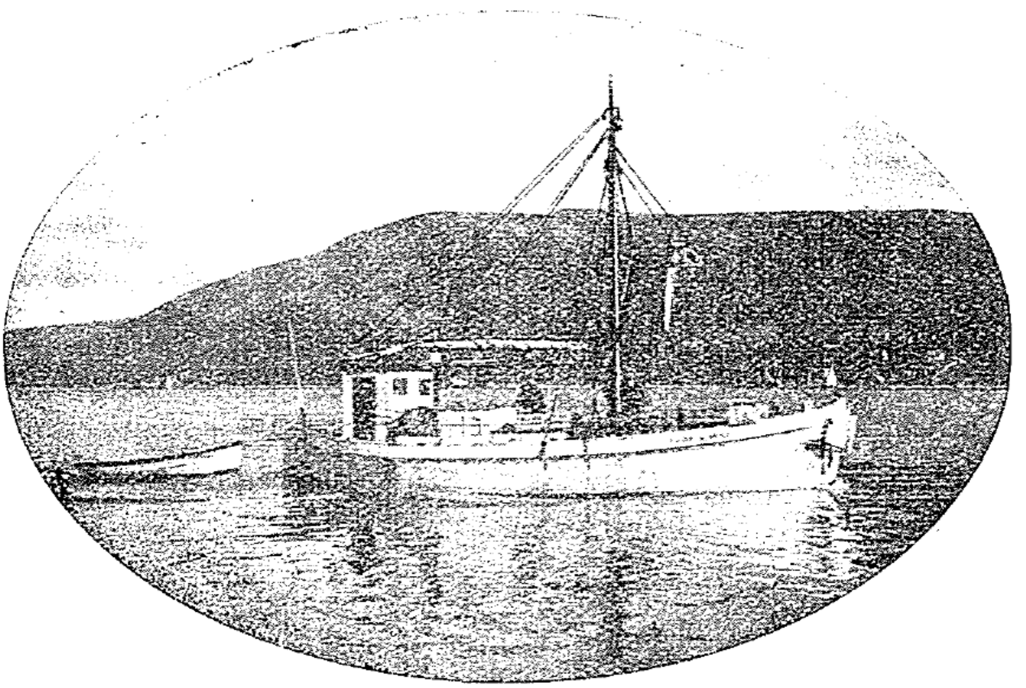


Figure 10: R/V Sparre Schneider, the first research vessel owned by Tromsø Museum (Table 4)

The data sets prior to 1981 were collected from various vessels using Nansen water bottles with two reversing thermometers (Table 4). Temperature was read in half hundredths degrees by the aid of a

Figure 11: R/V Asterias, in service 1952 – 1976 (Table 4), © *Bjørn Gulliksen*

Figure 12: R/V Johan Ruud, in service since 1976 (Table 4), © *Rahman Mankettikkara*

Figure 13: R/V Helmer Hanssen (Previous name: Jan Mayen), in service since 1992 (Table 4), © *Rahman Mankettikkara*

lens and the applied temperature was the mean of the readings from the two thermometers. During the samplings from 1924 to 1939 surface water was taken with a special sampler that was left hanging in the surface for some time before it was taken up and temperature immediately read. After 1939 surface temperatures were registered with Nansen samplers. Prior to 1975 chlorine content was determined by titration two or three times for each sample. Calculation of salinity was done with the hydrographical slide rule of Sund (1929). Descriptions of the methods used during the 1920ties and 1930ties are in Soot-Ryen (1934). After 1975 an inductive salinometer was used. The data sets also contain some few measurements retrieved with a bathythermograph during the 1920ties.

Table 4: Research vessels used in the collection of hydrophysical data in north Norway

Vessel name	Built	Ft.	HP, Engine.	Researchers	Service time	Remarks
Hired fishing vessels					1872 - 1926	
Sparre Schneider	1909	38	12 Scandia	3	1926 - ??	Former “Bjørnen”
Asterias		76	120 Normo	4	1952 - 1976	Former “Hansnes”
Johan Ruud	1976	100	1000 Wichmann	11	1976 - present	
Helmer Hanssen	1992	210	4080 Wärtsile	29	1992 - present	“Former Jan Mayen”

After 1980 all data was measured with Neil-Brown Mark II CTD sonde systems (1980-1985); EG & G Mark III (1985-1990) and Seabird 9-11 (1990-present).

A list with all sampling stations, station names, dates and positions is uploaded at http://purl.org/hmd

Data (temperature, salinity and σt at 10 m depth intervals) sampled after 1980 is downloadable from the HMD searchable database http://purl.org/hmd. As mentioned earlier reports and publications containing information on hydrophysical issues from north Norwegian coastal waters (and in some icases also from other areas) is downloadable (as .pdf) from http://www.phaeocystis.com/HMDREFWEB. Here are also included e.g. Sælen (1950) that is a comprehensive text on the physical oceanography of Balsfjorden and Malangen and areas around Tromsø during 1930-1935. Also are here e.g. included data tables from earlier periods published by Tromsø Museum (e.g. Soot-Ryen (1932b)) also containing oxygen, inorganic plant nutrients (N, P, ammonia) and pH measurements as well as selected biological monographs containing hydrophysical data.

2.2.1 *Accuracy Issues*

Presenting the results from large datasets in an understandable way is a great challenge. The dataset has during periods a very high resolution both in time and space. From early on in my thesis work a choice had to be made, i.e. either to go for a “full detail” presentation form or a more “overview” presentation. Both approaches were tested and it soon became apparent that showing all details could easily “blur” the main trends. In addition the “overview” approach allowed for more situations that varied in time and space to be compared. The reason for this is obvious since samplings were not performed at the same time between years, i.e. the autumn sampling in Balsfjorden was performed either in September or in October and spring sampling was in one or two of the months March, April and May. This was also one of the reasons why the complete datasets was uploaded and is available at http://purl.org/hmd. For these reasons an “overview” approach was chosen.

Nansen bottles attached with protected reversing thermometers were used to measure temperature on hydrographic casts (e.g. Sverdrup et al. (1942) pp 349-351). Richter and Wiese (Berlin), manufactured most of the instruments in the 1930ties. The range of those instruments were 10 to 30°C, -2 to 25°C, 3 to 13°Cand -3 to 8°C. Thermometers with ranges -2 to 30°C, -2 to 5°C, -2 to 8°C were used after 1950.

The CTD systems used were Neil Brown Instruments Mark III and Seabird 911Plus. From 1999 on the CTD systems were calibrated prior to and after each cruise. For the earlier period temperature and conductivity sensors were checked or calibrated at infrequent intervals and the data sets, if necessary, corrected for the observed drift.

Table 5: Data presentation methods

Data presentation type	Explanation
I. Measure vs. day in year for each season	Was done to find typical trend for season (decrease, increase, turning points. Also to find typical interannual variation for season
II. Two month intervals	To be used to detect differences between years and trends for period with frequent sampling
III. Seasonal intervals	To be used to detect differences between years and trends for period with infrequent sampling

Due to this variability I have chosen not to present the means with standard errors (SE) or standard deviations (SD), but rather we have analysed the data for basic statistical properties in order to find the "correct" presentation forms (Table 5).

2.3 DATA TREATMENT AND PRESENTATION

The Havmiljødata (HMD) dataset as mentioned has, during periods generally a very high resolution both in time and space. Other periods, prior to 1981, may be lacking completely. One characteristic feature is that data collection was not performed at fixed dates at each location and also new stations were added underway. This fact that sampling did not occur at fixed dates (or even months) was due to that sampling had to be performed when a vessel (and crew) was available. Seasonally the temperature and salinity in the area are, as it is all places, characterized by seasonally cooling and warming, dilution (runoff) and mixing. This leads to the conclusion that even if stations had been sampled on fixed dates the minima and maxima couldd have been missed. For example the warming of Balsfjorden during late spring can start with at least one month difference in time. In seldom cases this difference may in fact be close to two months. The graphical (and interpretional) presentation of the data was therefore done in three ways (see Table 5 above), i.e.

(i) Measure vs. day in year for each season;

(ii) At two month intervals for the whole period, i.e. measurements were plotted on a linear time scale with six "points" in each year;

(iii) At seasonal intervals for the whole period (i.e. measurements plotted on a linear scale with four "points" in each year.

The reason why a mix of seasonal and two month interval approach was chosen was that when data resolution was good this functioned best. On the other hand when certain months were missing the seasonal approach was best in order to compare long periods with many years. During the data processing it was also attempted to plot all data on a linear "true" time scale for each station, but this did not work out in that the interpretation was obscured totally since data clustered and made it impossible to see the trends.

In the following interpretation, for each parameter, data will be compared and presented successively according to the system above, and summary data compiled in Tables.

Table 6: List of adjacent stations that were merged

Locality	Merged stations
Outer Malangen	1006 — 1007
Inner Malangen	1003 —1004
Outer Balsfjorden	2001 — 2002
Inner Balsfjorden	2004 — 2005
Outer Alta	7001 — 7002
Inner Alta	7005 — 7006
Outer Porsanger	9001 — 9002
Inner Porsanger	9007 — 9008
Østerbotn	9009 — 9010

The data sets were grouped vs season for analysis by assigning the measurements to four periods, i.e. winter (November, December, January, February); spring (March, April, May); summer (June, July, August); autumn (September, October). This division of the data was based on judgment of the data sampling frequencies. Since the procedure in Table 5 was chosen, this means that in many presentations (plots, overview-tables) in the present monograph single numbers represents the mean from all samplings during each of the four seasons. To this adds that during some instances close stations (e.g. 1006 and 1007 in outer Porsangefjord) were merged too (Table 6). This leads to the conclusion that, at instances where the illustration of trends in the data (vs. time) and differences between data sets (i.e. differences between localities and seasons) was in focus the presented mean is the arithmetic mean of a variable number of measurements (from two to six).

3

RESULTS

3.1 HYDROPHYSICAL CHARACTERISTICS IN THE WINTER SEASON

A summary of temperature, salinity and density variations during the winter season are presented in Tables 7,8 and 9. Additional Tables are also provided in the Appendix. The winter season in northern Norway is substantially different from the southern regions. Northern Norway experiences long periods with winter darkness (e.g. in Tromsø from 21st November until 21st January). There are great variations in hydrophysical characteristics between the fjords during winter. The January–February mean surface temperature was 3.5°C in the southernmost fjord (Inner Malangen) and -0.57°C in the northern fjord (Østerbotn in the Inner Porsangerfjorden). At 100 m depth it was 6.01°C in Inner Malangen and -1.13°C in Østerbotn.

During November–December periods, temperatures decreased and the lowest temperatures recorded were in January and February. The inter-annul variability in temperature during November and December was less compared to January–February. Seasonal mean (November–February) surface temperature was 4.57°C in Inner Malangen and 1.34°C in Østerbotn. At 100 m it was 6.75°C and 1.34°C respectively.

All figures from the analysis are presented in Appendix chapter. Only selected figures are presented here in the Results chapter (i.e. some figures presented twice, both in Results and Appendix chapters). This means that the figures presented in the Results chapter, enclosed in square brackets, are present in the Appendix too, though with other numbers also referred in the text. In some figures, the slop of the regression line for the surface temperature can be misleading (great reduction or large increase). The procedure with regression line is though kept in lack of better, more appropriate methods.

3.1.1 *Malangen*

Malangen is the southernmost fjord in our database. Outer Malangen and Inner Malangen represent merged stations 1006—1007 and 1003—1004 respectively.

Table 7: Compilation of winter temperatures (November – February) in the sampled fjords (°C)

Locality	Depth	Mean	Minimum	Coldest Year	Maximum	Warmest Year
Inner Malangen	0 m	4.57	-0.02	1992	8.73	2006
(1003–1004)	100 m	6.75	3.54	1987	9.14	1999
Outer Malangen	0 m	4.94	1.96	1986	8.62	2011
(1006–1007)	100 m	6.25	2.9	1899	9.27	1999
Outer Balsfjorden	0 m	3.92	-0.03	1982	7.63	2011
(2001–2002)	100 m	4	0.93	1982	6.43	2005
Inner Balsfjorden	0 m	3.56	-0.55	1988	7.4	2005
(2004–2005)	100 m	3.82	0.48	1987	6.67	1933
Kvalsund	0 m	5.05	2.08	2011	7.89	1999
(3003)	100 m	6.14	2.87	2011	8.48	1990
Sørfjord	0 m	4.47	0.48	1931	7.81	1999
(5003)	100 m	2.89	0.76	1931	5.16	2000
Outer Altafjorden	0 m	4.91	1.95	1980	7.86	1999
(7001–7002)	100 m	5.42	2.14	1980	8.36	2009
Inner Altafjorden	0 m	4.17	-0.17	1983	8.38	1999
(7005–7006)	100 m	5.38	1.63	1982	8.18	1990
Refsbotn	0 m	5.42	2.25	1976	7.75	1999
(8001)	100 m	5.61	2.97	1981	7.87	2006
Outer Porsangerfjorden	0 m	4.93	0.69	1961	7.55	1958
(9001–9002)	100 m	4.91	0.71	1961	8.1	1999
Inner Porsangerfjorden	0 m	3.01	-1.61	1994	6.52	2005
(9007–9008)	100 m	3.46	-0.36	1982	7.35	1999
Østerbotn	0 m	1.34	-1.79	1983	5.3	1999
(9009–9010)	100 m	1.12	-1.13	2006	3.6	1990

3.1.1.1 *Temperature*

During the winter period, both Inner and Outer Malangen showed gradual decreases in temperature from November to February at all depths (Figures 104 [14], 105). The mean surface temperature during the winter season was 4.57°C and it was 6.75°C at 100 m depth (Table 7). The amplitude of surface the temperature changed from November to February. In Inner Malangen and Outer Malangen was 2.36°C, 2.52°C in the surface and at 100 m depth it was 1.45°C, 2.31°C respectively. The seasonal mean surface temperature in Inner Malangen were slightly warmer (0.37°C) than in Outer Malangen, whereas at 100 m depth Inner Malangen was 0.5°C warmer than the outer station (Table 7). During the winter season, Outer Malangen showed the highest mean surface winter temperature (4.94°C) among all the fjords. At 100 m depth, 6.75°C in the Inner Malangen was highest (Table 7).

The lowest surface temperature recorded in Malangen was -0.02°C in 1992 and the highest was in 2006 (8.73°C) both in the Inner Malangen stations. At 100 m depth, the lowest and highest temperature recorded were in the year 1899 (2.9°C) and year 1999 (9.27°C) at the Outer Malangen stations.

Table 8: Compilation of winter salinity (November – February) in the sampled fjords (‰)

Locality	Depth	Mean	Minimum	Least saline Year	Maximum	Most saline Year
Inner Malangen	0 m	31.95	21.49	2003	34.11	2011
(1003–1004)	100 m	34.02	33.24	1999	34.69	1959
Outer Malangen	0 m	33.27	27.66	1988	34.52	1977
(1006–1007)	100 m	33.92	33.11	2000	34.67	1997
Outer Balsfjorden	0 m	32.77	27.49	1999	33.79	1994
(2001–2002)	100 m	33.19	32.56	1983	33.83	1994
Inner Balsfjorden	0 m	32.7	23.42	1975	33.71	1994
(2004–2005)	100 m	33.21	32.71	2000	33.8	1994
Kvalsund	0 m	33.47	15.8	2008	34.19	2010
(3003)	100 m	34.03	33.33	1999	34.37	1993
Sørfjord	0 m	33.05	26.68	2011	33.69	1959
(5003)	100 m	33.63	33.14	2003	33.98	1997
Outer Altafjorden	0 m	33.78	31.87	2002	34.86	1990
(7001–7002)	100 m	34.01	33.34	1999	35.06	1990
Inner Altafjorden	0 m	33.15	10.79	2009	36.23	1988
(7005–7006)	100 m	34.01	33.41	1999	34.56	2009
Refsbotn	0 m	34.06	33	1991	34.99	1964
(8001)	100 m	34.23	33.62	2000	35.04	1965
Outer Porsangerfjorden	0 m	34.15	31.95	2006	34.88	1965
(9001–9002)	100 m	34.22	33.72	2002	34.97	1965
Inner Porsangerfjorden	0 m	33.94	31.39	2007	34.49	1994
(9007–9008)	100 m	34.08	33.69	1983	34.46	1994
Østerbotn	0 m	33.43	29.87	2007	34.83	2005
(9009–9010)	100 m	33.64	33.27	2002	34.49	1962

All other fjords showed a higher mean temperature in the outer fjord areas than in the inner fjords, but in Inner Malangen the temperature at 100 meter depth was ~0.5°C warmer than Outer Malangen.

Figures 248 [17], 249 show the inter annual variability in temperature in the Malangen during the winter season (November–February). Both Inner and Outer Malangen had similar variation patterns in temperature. The warmest years in malangen were 1930,1960,1992, 2000 and 2004. After year 2005, both the inner and outer stations showed a decreasing trend in temperature.

3.1.1.2 *Salinity*

The monthly variations in salinity during the winter period in Outer and Inner Malangen are shown in Figures 152 [15] and 153. Both stations showed gradual increases in salinity from November to February at all depth levels. Compared to Outer Malangen the surface salinity in Inner Malangen during this period was 1‰ less than the Outer station. The gradient between the surface and 50 m was ca 2 in Inner Malangen whereas in Outer Malangen it was ca 0.5. The mean surface salinity in

Table 9: Compilation of winter density (November – February) in the sampled fjords (σ_t)

Locality	Depth	Mean	Minimum	Least dens Year	Maximum	Most dens Year
Inner Malangen	0 m	25.29	17.11	2003	27.07	1981
(1003–1004)	100 m	27.14	26.17	1999	27.72	1993
Outer Malangen	0 m	26.31	21.93	1988	27.3	1977
(1006–1007)	100 m	27.12	26.15	1999	27.74	1977
Outer Balsfjorden	0 m	26.01	21.69	1999	27	1994
(2001–2002)	100 m	26.8	26.2	1983	27.52	1994
Inner Balsfjorden	0 m	25.99	18.62	1975	26.93	1994
(2004–2005)	100 m	26.83	26.35	1989	27.51	1994
Kvalsund	0 m	26.46	12.55	2008	27.28	1994
(3003)	100 m	27.22	26.38	1999	27.8	1994
Sørfjord	0 m	26.18	20.95	2011	26.97	2011
(5003)	100 m	27.27	26.88	2003	27.59	1997
Outer Altafjorden	0 m	26.72	25.18	1999	27.44	1994
(7001–7002)	100 m	27.29	26.6	1999	27.95	1990
Inner Altafjorden	0 m	26.29	8.57	2009	29.08	1988
(7005–7006)	100 m	27.3	26.63	1999	27.89	1994
Refsbotn	0 m	26.89	26.09	1991	27.65	1977
(8001)	100 m	27.45	26.77	1967	28.15	1987
Outer Porsangerfjorden	0 m	27.02	25.3	2006	27.71	1965
(9001–9002)	100 m	27.52	26.87	1999	28.26	1965
Inner Porsangerfjorden	0 m	27.03	25	2005	27.68	1994
(9007–9008)	100 m	27.55	26.94	1999	28.14	1994
Østerbotn	0 m	26.75	23.94	2007	28.03	2005
(9009–9010)	100 m	27.4	27.02	1983	27.81	1970

Inner Malangen was 31.95 and in Outer Malangen 33.27 during this period. At 100 m depth the mean was 34.02 in the Inner Malangen and 33.92 in the Outer Malangen. The maximum surface salinity in Malangen was in Outer Malangen stations in 1977 and the minimum was in Inner Malangen in 2003 (21.49). The maximum salinity recorded at 100 m was in Inner Malangen (34.69, 1959) and the minimum was at Outer Malangen in 2000 (33.11, Table 8).

3.1.1.3 *Density*

Figures 200 [16] and 201 shows the monthly variations in density during the winter period. The density gradually increases from November to February. The mean surface density in Malangen was between 25.29–26.31 and at 100 m it was between 27.12–27.14 (Table 9). Minimum surface density of 17.11 was recorded in Inner Malangen in the year 2003 and maximum surface density was recorded at Outer Malangen (27.3) in 1977. At 100 m the highest and lowest density were at Outer Malangen (27.74, in 1977 and 26.15, in 1999).

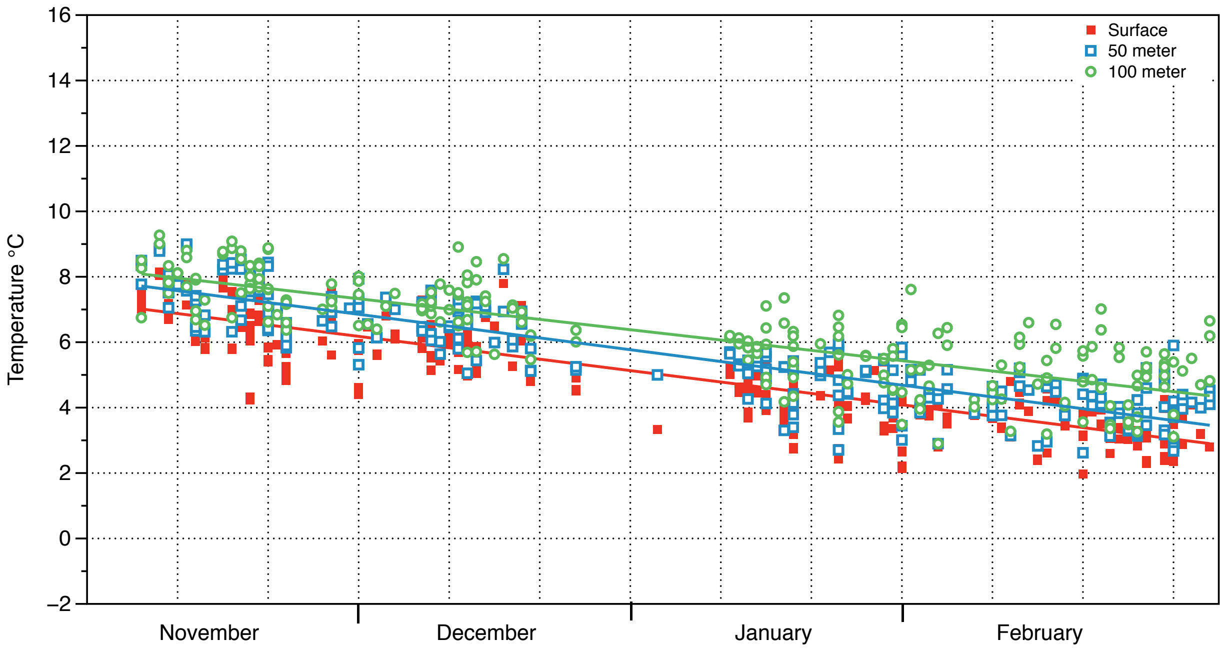


Figure 14: Monthly variability of winter temperatures (November – February) at station Outer Malangen

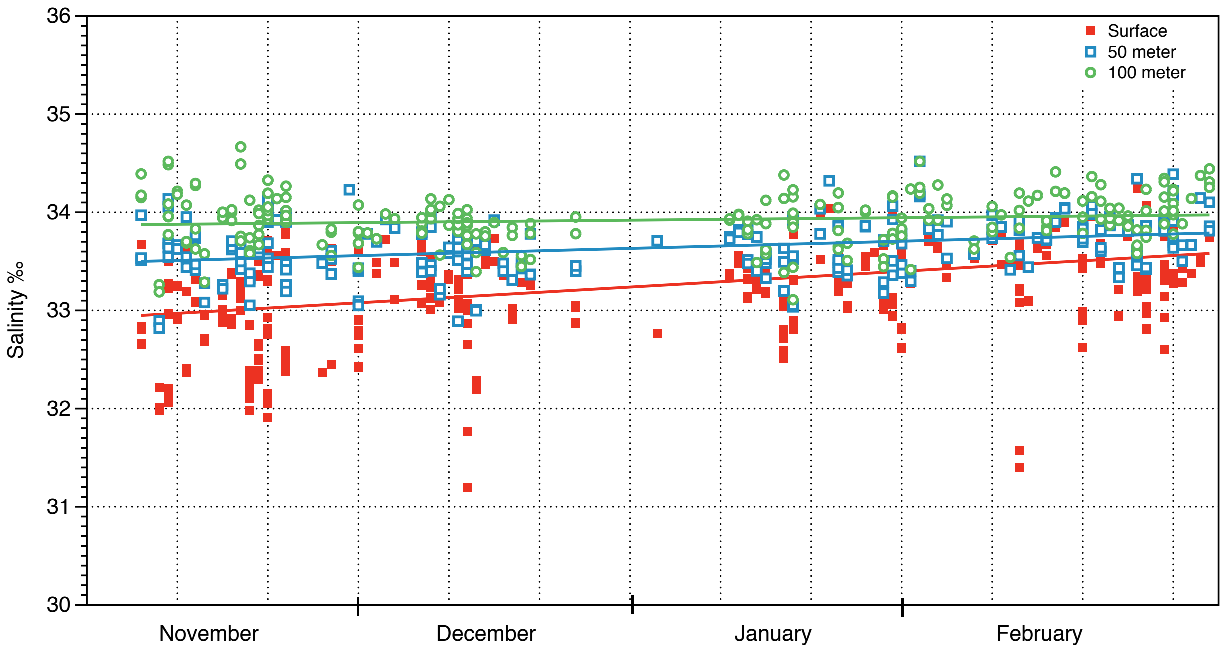


Figure 15: Monthly variability of winter salinity (November – February) at station Outer Malangen

3.1.2 *Balsfjorden*

Balsfjorden is located very close to Tromsø. It is one of the most investigated fjords in this area. Inner Balsfjorden represents stations Balsfjord Svartnes (2004) and Balsfjord Stornes (2005). Outer Balsfjorden represents stations Balsfjord Berg (2001) and Balsfjord Haugbergnes (2002).

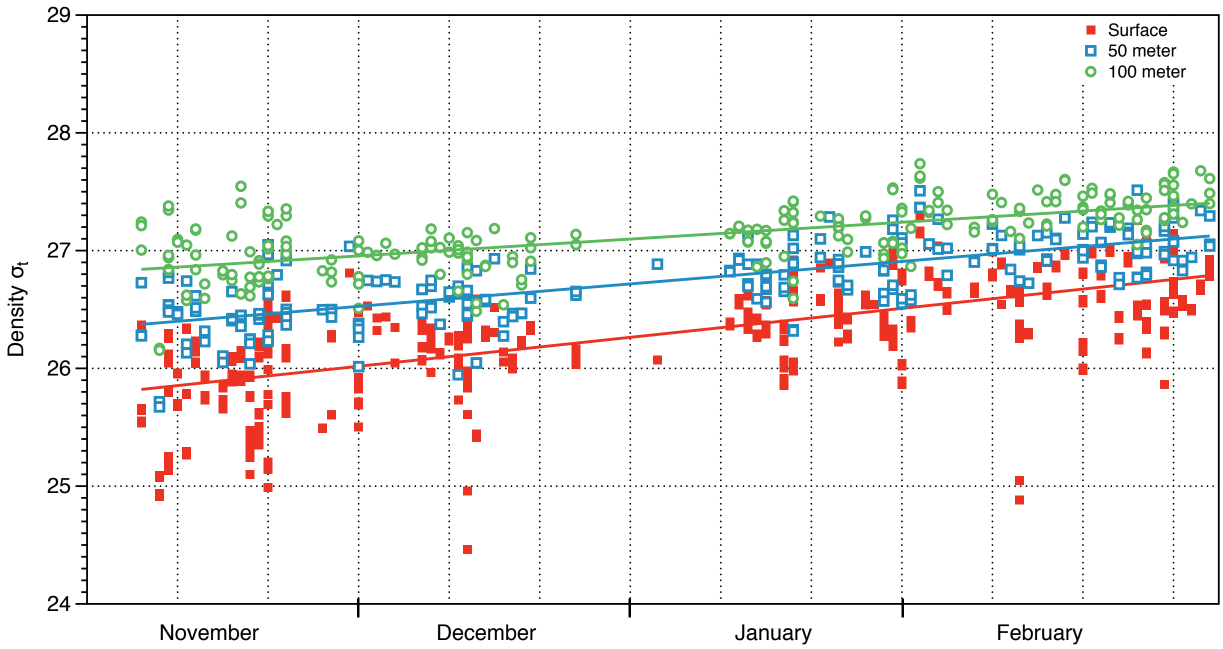


Figure 16: monthly variability of winter density (November – February) at station Outer Malangen

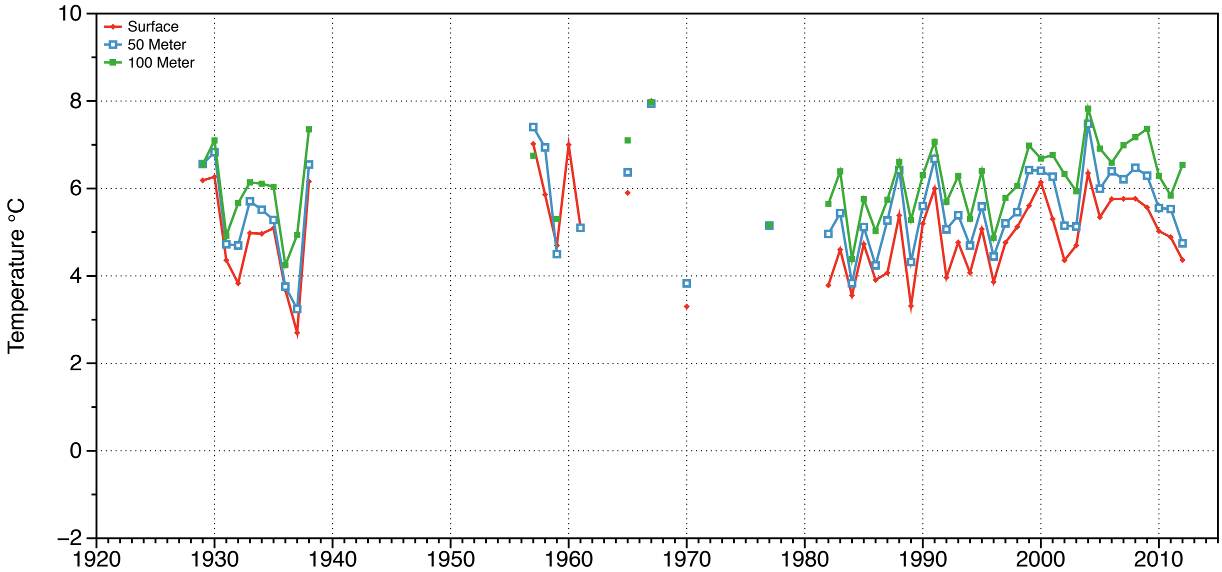


Figure 17: Interannual variability of winter temperatures (November – February) at station Outer Malangen

3.1.2.1 *Temperature*

The Seasonal variations in winter temperature in both Outer and Inner Balsfjorden showed similar trends (Figures 106, 107 [18]). In both locations the temperature at all depths showed decreasing trend. From the beginning of November to the end of February the difference in surface temperature was nearly 4°C in Balsfjord compared to 2.5°C in Malangen. During the winter season, the difference in temperature between surface and 100 m was remarkably lower than in Malangen. In Balsfjord it was nearly 1°C whereas in Malangen it was 4°C (Figures 104, 105, 106, 107). The average surface temperature in Balsfjorden during the winter period was between 3.56°C– 7.63°C and at 100 m it was between 3.82 and 6.67°C.

It is interesting to note from Table 7 that Balsfjord is generally less warm than both Altafjord and Outer Porsangerfjord. The mean temperature at 100 meteres in the Outer Balsfjord is 4.0°C and Inner Balsfjord was 3.82°C whereas in Altafjord it is 5.38°C and in Outer Porsangerfjord was 4.91°C.

Figures 250 and 251 [21] show the inter-annual variability of winter temperature in Outer and Inner Balsfjorden. Even though Balsfjorden is located much south than both Altafjorden and Porsangerfjorden, it showed lot of similarities in winter temperature. There was a remarkable decreasing trend from 2004 to 2012 similar to Altafjorden and Porsangerfjorden (Figures 254, 255, 257, 258). There was also a decreasing trend from 1933 to 1937. Both Inner and Outer Balsfjord showed an increase in temperature from 1987 to 1990 whereafter it decreased. The same trend was also seen in Porsangerfjorden (Figures 257, 258). The warmest surface temperature at Balsfjorden was in Outer Balsfjorden (7.63°C) in the year 2011 and the lowest surface temperature was in Inner Balsfjorden in the year 1988 (-0.55°C).

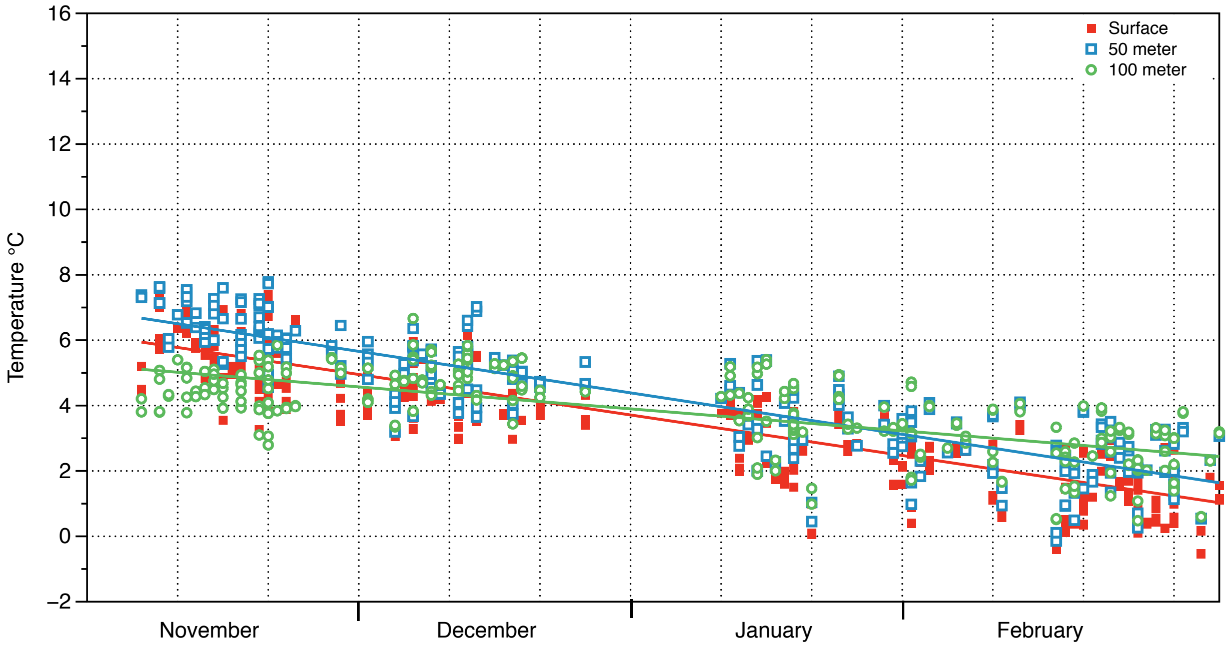


Figure 18: Monthly variability of winter temperatures (November – February) at station Inner Balsfjorden

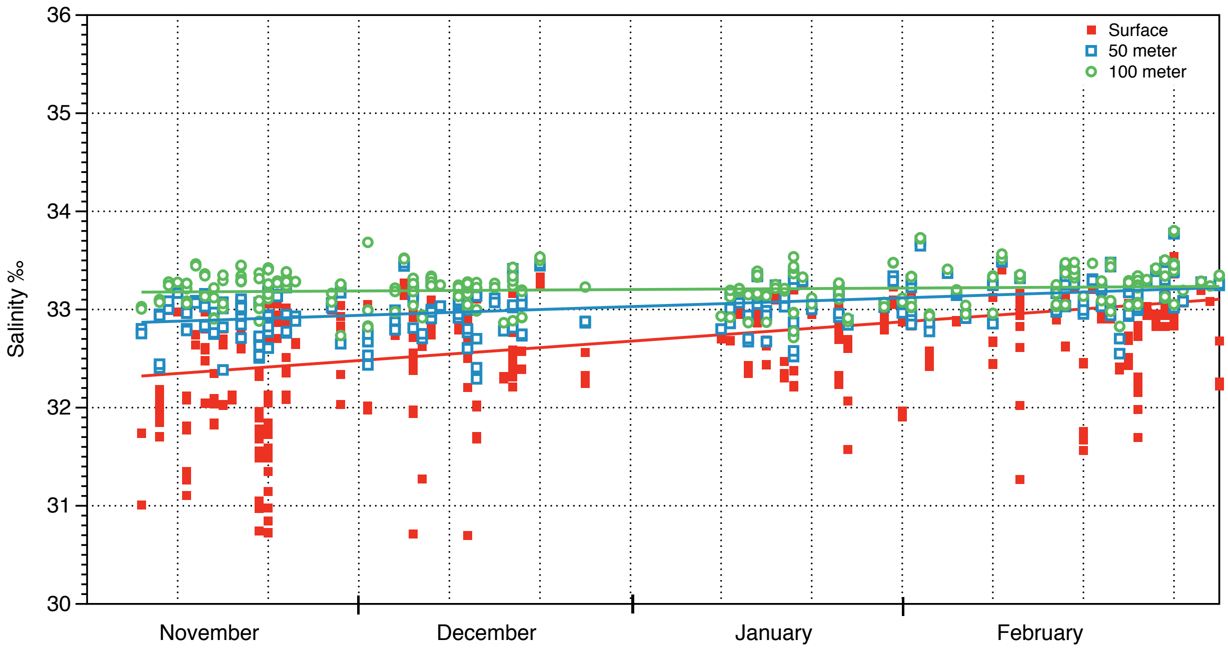


Figure 19: Monthly variability of winter salinity (November – February) at station Inner Balsfjorden

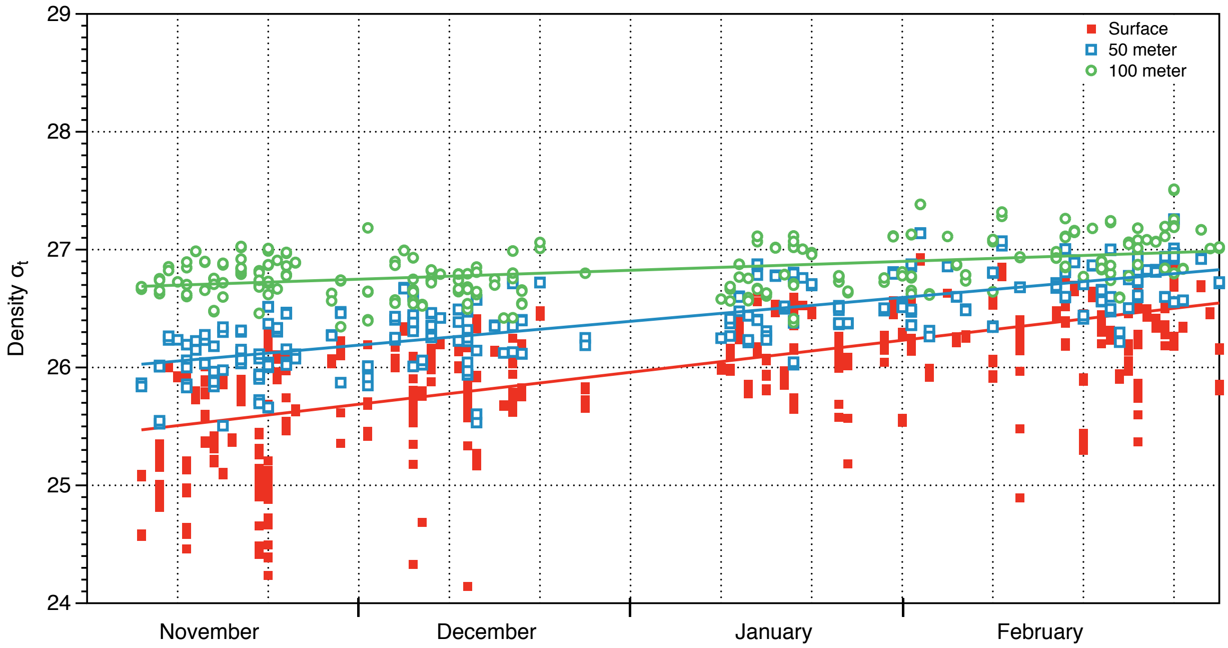


Figure 20: monthly variability of winter density (November – February) at station Inner Balsfjorden

3.1.2.2 *Salinity*

The monthly variations in salinity during the winter period in Outer and Inner Balsfjorden are shown in Figures 154 and 155 [19]. Similar to Malangen the salinity in both Inner and Outer stations in-

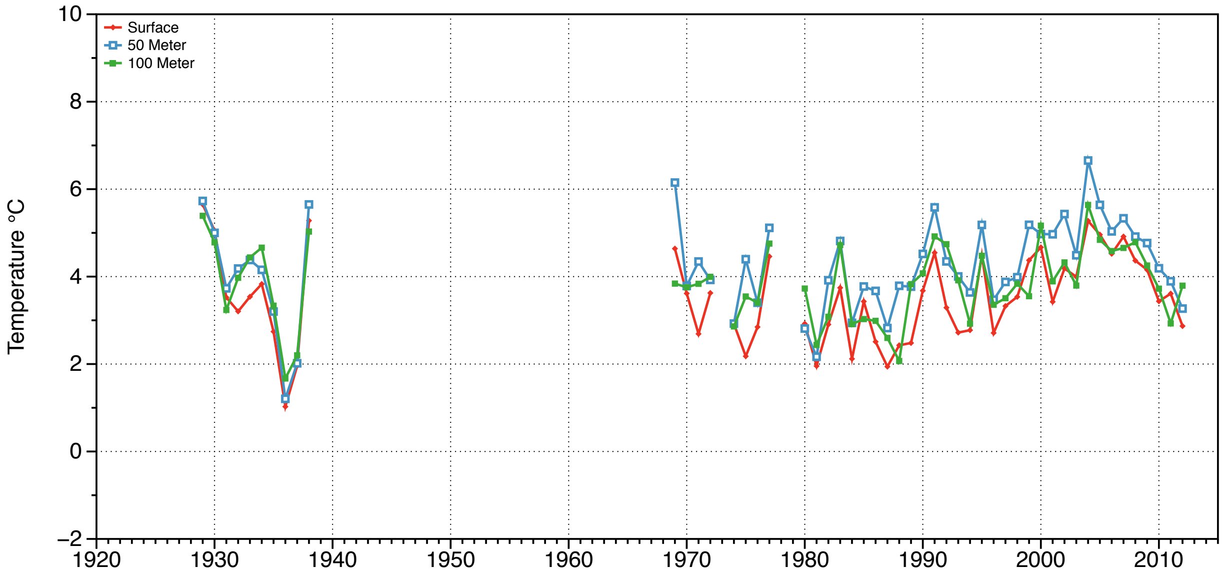


Figure 21: Interannual variability of winter temperatures (November – February) at station Inner Balsfjorden

creased in Balsfjorden too. The increasing trend were similar in Outer Balsfjorden and Inner Balsfjorden. The surface salinity in Balsfjorden increased from 32.4 in November to 33.2 at the end of February. The mean surface salinity in Inner Balsfjorden was 32.7 and in Outer Balsfjorden is 33.77 during this period. At 100 meter depth it was 33.21 in the Inner Balsfjorden and 33.19 in the Outer Balsfjorden (Table 8). Highest surface salinity recorded in Balsfjorden was in the Outer station (33.79, in the year 1994) and the lowest surface salinity was 23.42 in Inner Balsfjorden in the year 1975. The 33.83 salinity recorded in the year 1994 at Outer stations was the highest at 100 m in Balsfjorden and 32.71 in the year 2000 at Inner stations was the lowest at 100 m.

3.1.2.3 *Density*

The monthly variations in density during winter period in Balsfjorden are presented in Figures 202 and 203 [20]. Density increased from November to february during this period. No remarkable deference between inner and outer fjord were found in this season. Minimum surface density of 18.62 was recorded in Inner Balsfjorden in 1975 and maximum surface density was recorded in Outer Balsfjorden (27) in 1994. At 100 m the highest density was 27.52, in the year 1994 and lowest was 26.8, in the year 1983 (both were in Outer Balsfjorden).The mean surface density in Balsfjorden was between 25.99–26.72 and at 100 m it was between 26.83–27.29 (Table 9).

3.1.3 *Altafjorden*

In Altafjorden, station 7001 (Alta Stjernsund) and station 7002 (Alta Vargsund) represent Outer Altafjorden. The adjacent stations Alta Rafsbotn (7005) and Alta Rafsbotn (7006) represent Inner Altafjorden.

3.1.3.1 *Temperature*

Similar to Malangen and Balsfjord, the monthly variations in winter temperature in Altafjord also decreased gradually from the November to February (Figures 110 [22],111). The temperature in Altafjord was more comparable to Balsfjord than Malangen or Porsangerfjord. Figure (110 [22],111) shows that Outer Alta was nearly 1°C warmer in all depths than Inner Alta. Also the difference in surface and deep (100 m) water was less (0 to 0.5°C comapred to 1 to 1.9°C) in the Outer station.

During the winter period there were no remarkable differences noticeable from inner and outer stations in Altafjorden in temperature (Figures 254 [25], 255). From year 1976 to 1986 there was a constant increasing trend except the year 1983. Both inner and outer fjord showed a decreasing trend in temperature from 1987 to 1996. Years 1997 to 2004 were a warmer period whereafter it started cooling until 2012. The highest recorded temperature during winter in the Outer Altafjord at 100 m depth was 8.36°C (2009) and lowest was 2.14°C(1980). Inner station was slightly colder with highest and lowest winter temperature 8.18°C and 1.63°C respectively (Table 7).

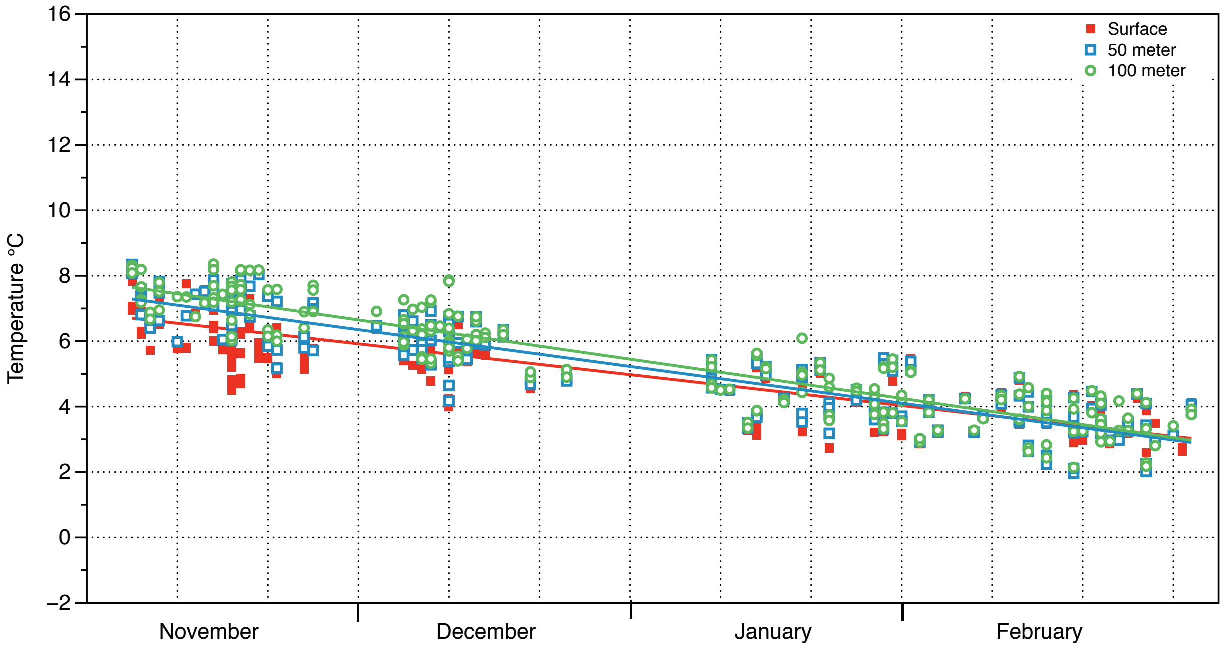


Figure 22: Monthly variability of winter temperatures (November – February) at station Outer Altafjorden

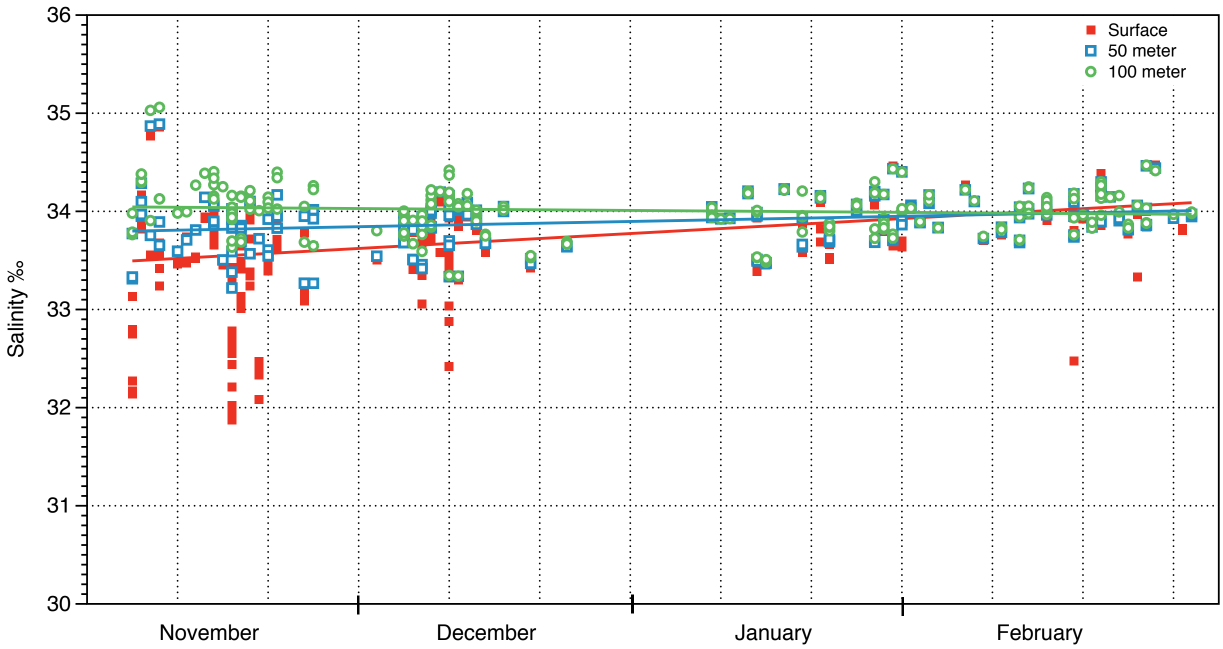


Figure 23: Monthly variability of winter salinity (November – February) at station Outer Altafjorden

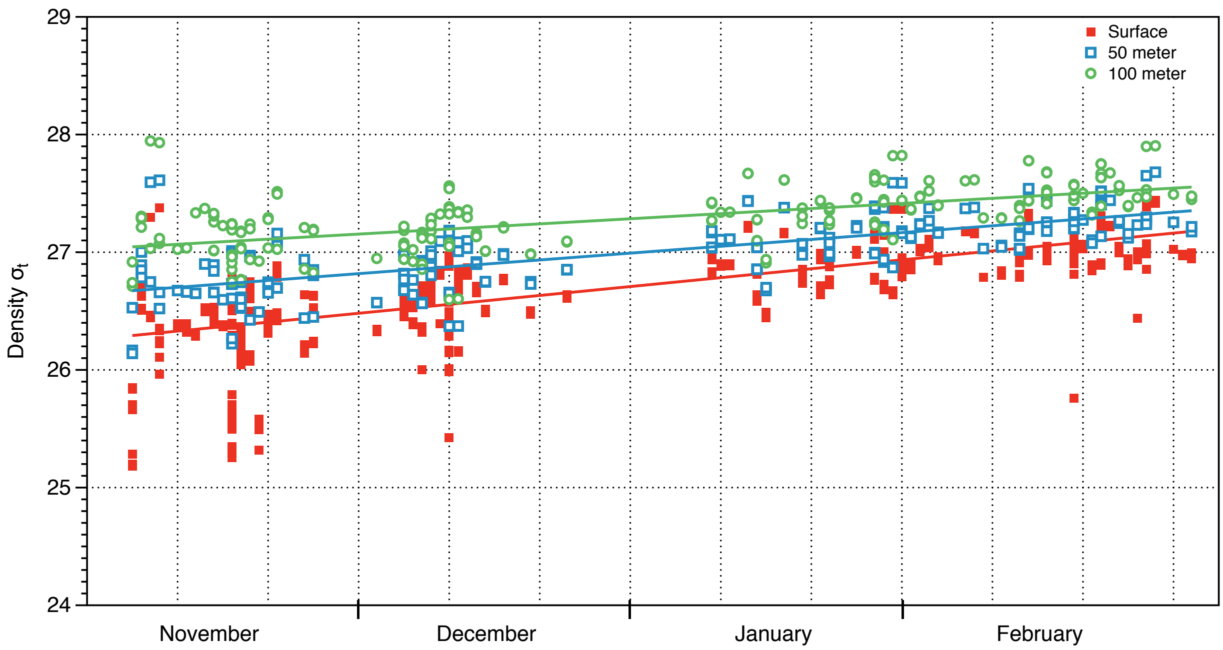


Figure 24: monthly variability of winter density (November – February) at station Outer Altafjorden

3.1.3.2 *Salinity*

Figures 158 [23] and 159 shows the monthly variations in salinity during winter period in Outer and Inner Altafjorden. The surface salinity in both Inner and Outer stations increased from November to

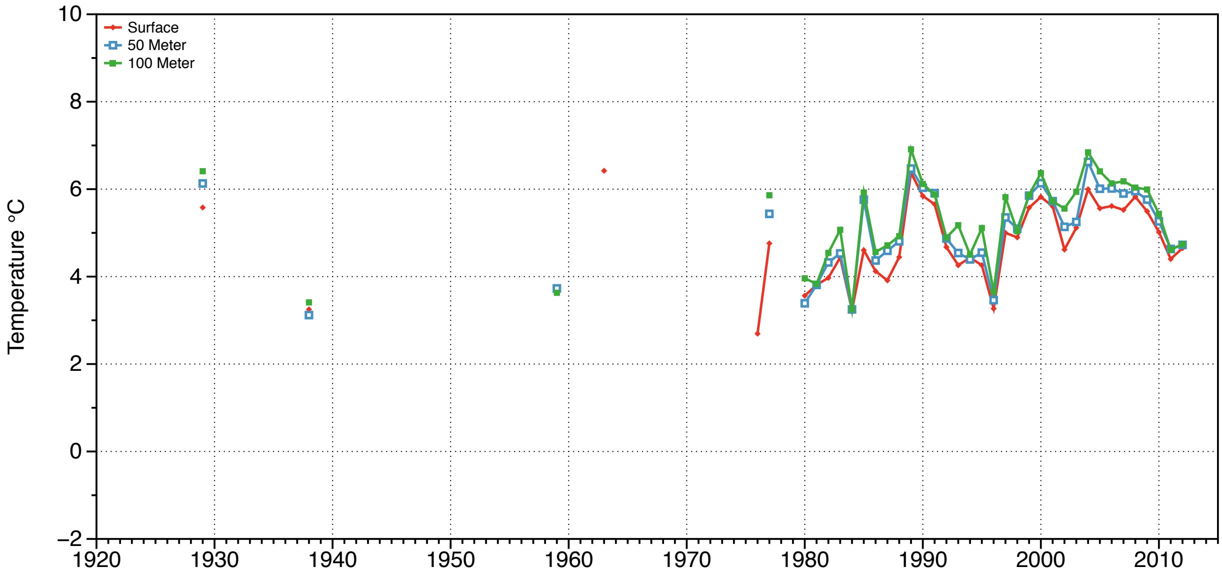


Figure 25: Interannual variability of winter temperatures (November – February) at station Outer Altafjorden

February in Altafjorden. Unlike Malngen and Balsfjorden, at 50 m and 100 m there were no increase in Salinity during this period. The surface salinity in Inner Altafjorden increased from 32.5 to 33.8 and in Outer station it increased from 33.5 to 34.1 . The mean surface salinity in Altafjorden was between 33.15–33.78 and at 100 m depth, it was 34.01. Highest surface salinity recorded in Altafjoden was in the Inner station (36.23, in 1988) and the lowest was 10.79 in Inner Altafjoden in 2009. The 35.06 salinity recorded in 1990 in Outer stations was the highest at 100 m in Altafjoden and 33.34 in the year 1999 in Outer stations was the lowest (Table 8).

3.1.3.3 *Density*

The monthly variations in density during winter period in Outer and Inner Altafjorden are shown in Figures 206 [24] and 207. Similar to Malangen and Balsfjorden, the density increased from November to February in both Inner and Outer Stations. The surface density in Inner Altafjorden were comparatively lower than that of the Outer Station. Minimum surface density of 8.57 was recorded in Inner Altafjoden in 2009 and maximum surface density was recorded in Outer Altafjoden (29.08) in 1988. At 100 m the highest density was 27.95, in the year 1990 and lowest was 26.6, in the year 1999 (both were in Outer Altafjoden).The mean surface density in Altafjoden was between 26.29–26.72 and at 100 m it was between 27.29–27.3 (Table 9).

3.1.4 *Porsangerfjorden*

In Porsangerfjorden stations 9001 (Porsangnes Vest) and 9002 (Porsangnes Øst) represent Outer Porsanger. Stions 9007, 9008 (Porsangen IndreVest, Porsanger Indre Øst) represent Inner Porsanger. Østerbotn, the innermost part of Porsangerfjorden represented by stations 9009 and 9010 (Porsanger Østerbotn, Porsanger Roddenessjøen).

3.1.4.1 *Temperature*

Figures 113 [26] and 114 shows that the temperature during the winter months in Outer Porsanger was remarkably different than southern fjords. The difference in temperature between surface and 100 m depth was very less, i.e., the water was well mixed. Inner Porsanger and Østerbotn was almost similar to Outer Porsanger.

The highest recorded winter temperature at 100 m in Outer Porsanger was 8.1°C in 1999 winter and lowest in 1961, 0.71°C (Table 7). Figures 257 [29], 258 and 259 shows the yearly variations in winter temperature in Outer Porsanger, Inner Porsanger and Østerbotn respectively. During the entire winter period, Østerbotn was much colder than the outer part. Both Outer and Inner Porsanger stations showed a decrease in temperatures at 100 m from year 2007 to 2012. Østerbotn also showed a decreasing trend from 2002. All stations show almost similar trends in temperature during the entire period except that cooling in the Østerbotn started earlier (year 2005). There was a slight increasing trend from 1960 to 1980 and after that there was no noticeable trend until 1987. From year 1987 to 1990 all stations showed an increase in temperature. After 1990 it started cooling until 1996 and then it went up again and remained stable from 1999 to 2007.

3.1.4.2 *Salinity*

The monthly variations in salinity during the winter period in Outer and Inner Porsangerfjorden and Østerbotn are shown in Figures 161 [27], 162 and 163. The variations in salinity during winter in Porsangerfjorden were very less at all levels. At Outer and Inner Porsangerfjorden, the increase in salinity was less than 0.3 and in Østerbotn it was 0.6 . Highest surface salinity recorded in Porsangerfjorden was at the Outer station (34.88, in the year 1965) and the lowest was 29.87 in Østerbotn in the year 2007. The 34.97 salinity recorded in the year 1990 in Outer stations was the highest at 100 m in Porsangerfjorden and 33.27 in the year 2002 in Østerbotn was the lowest (Table 8).

3.1.4.3 *Density*

The monthly variations in density during the winter period in Outer, Inner Porsangerfjorden and Østerbotn are shown in Figures 209 [28], 210 and 211. Similar to other southern fjords, the density in-

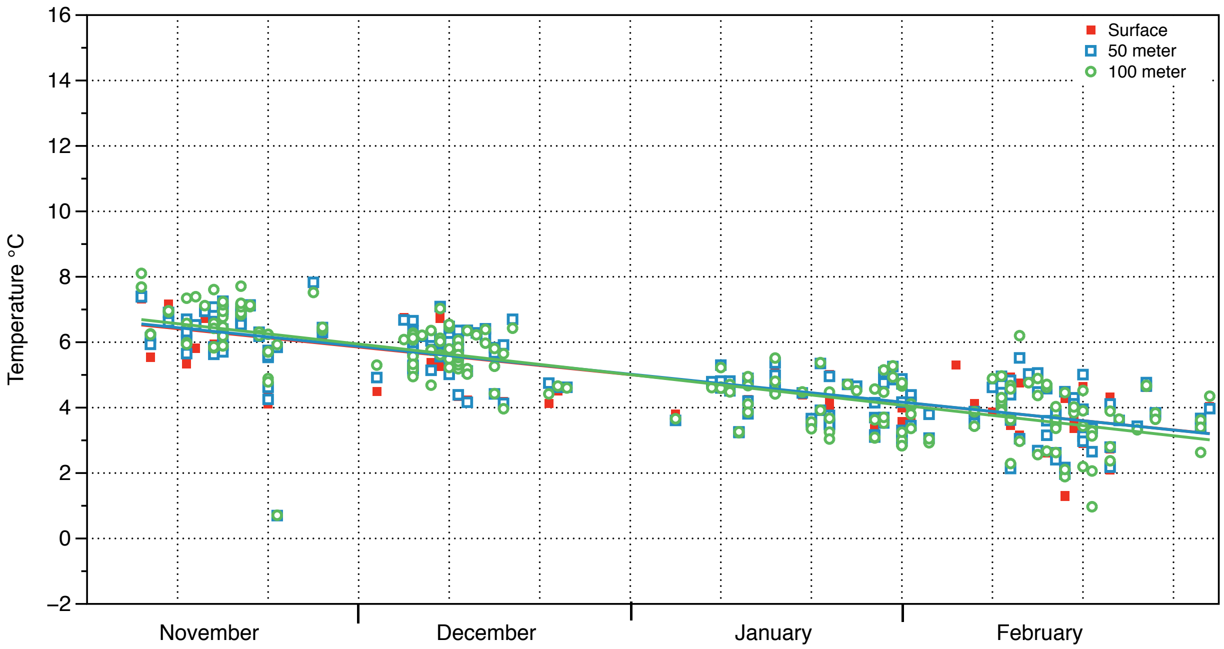


Figure 26: Monthly variability of winter temperatures (November – February) at station Outer Porsangerfjorden

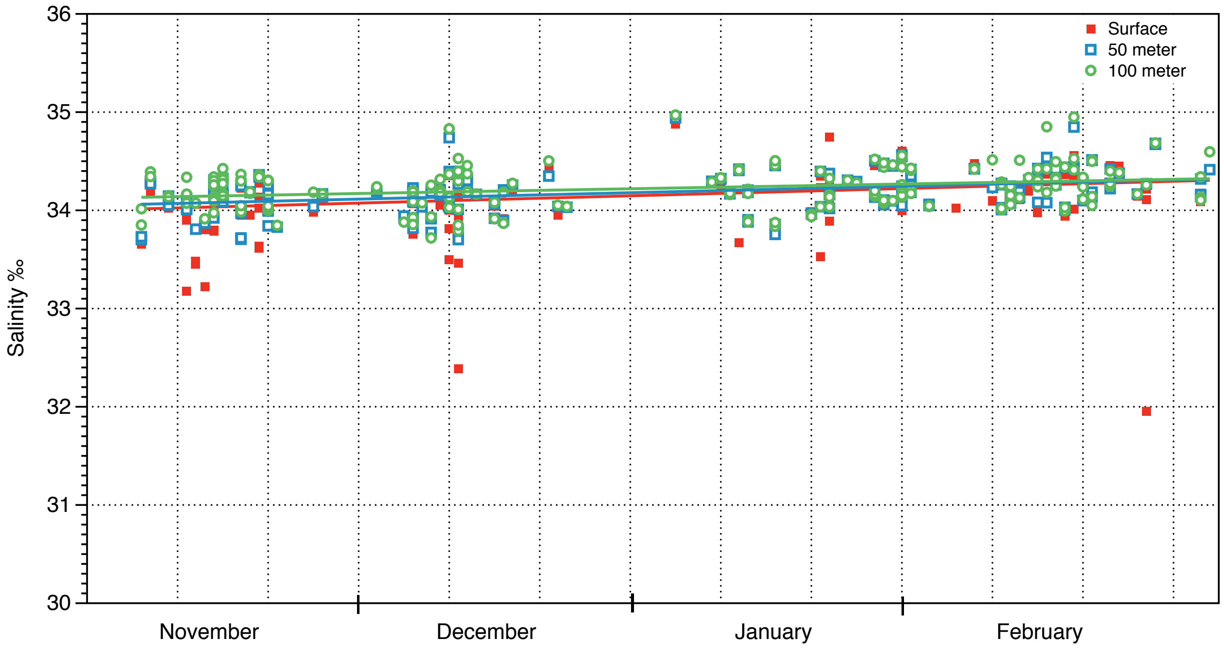


Figure 27: Monthly variability of winter salinity (November – February) at station Outer Porsangerfjorden

creased from November to February in Porsangerfjorden. All stations in Porsangerfjorden showed similar trend in density. Minimum surface density (23.94) was recorded in Østerbotn in the year 2007 and maximum surface density was recorded in Outer Porsangerfjorden (28.03) in 2005. At 100 m the highest density was 28.26, in the year 1965 and lowest was 26.87, in the year 1999 (both were

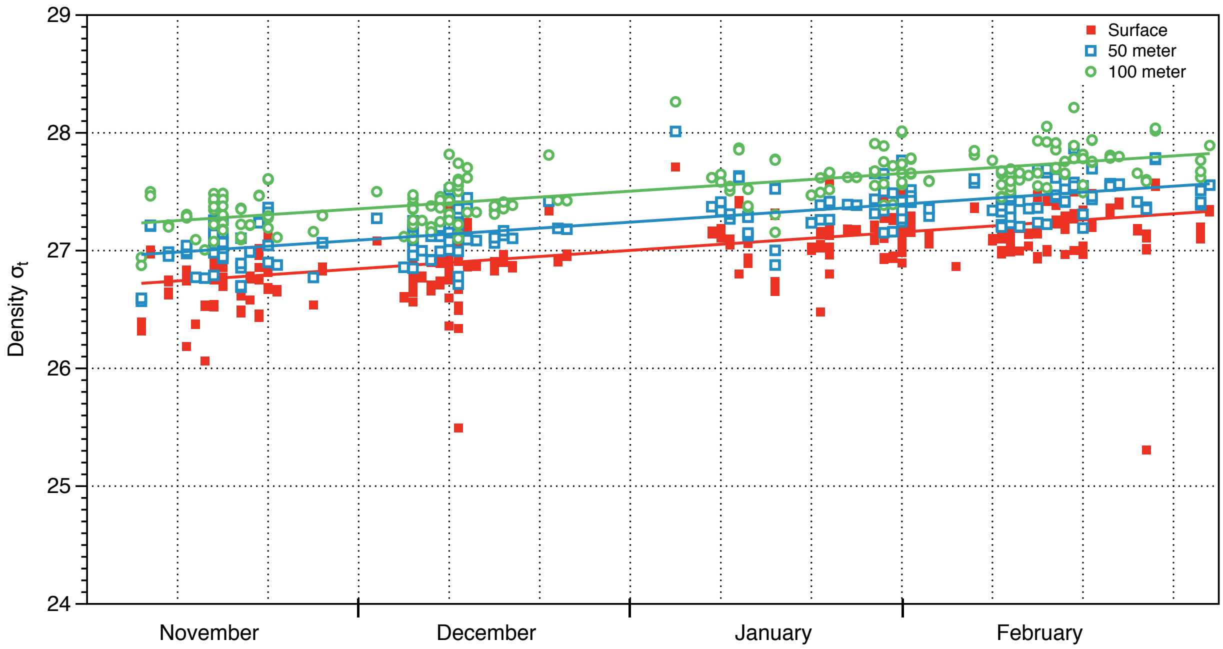


Figure 28: monthly variability of winter density (November – February) at station Outer Porsangerfjorden

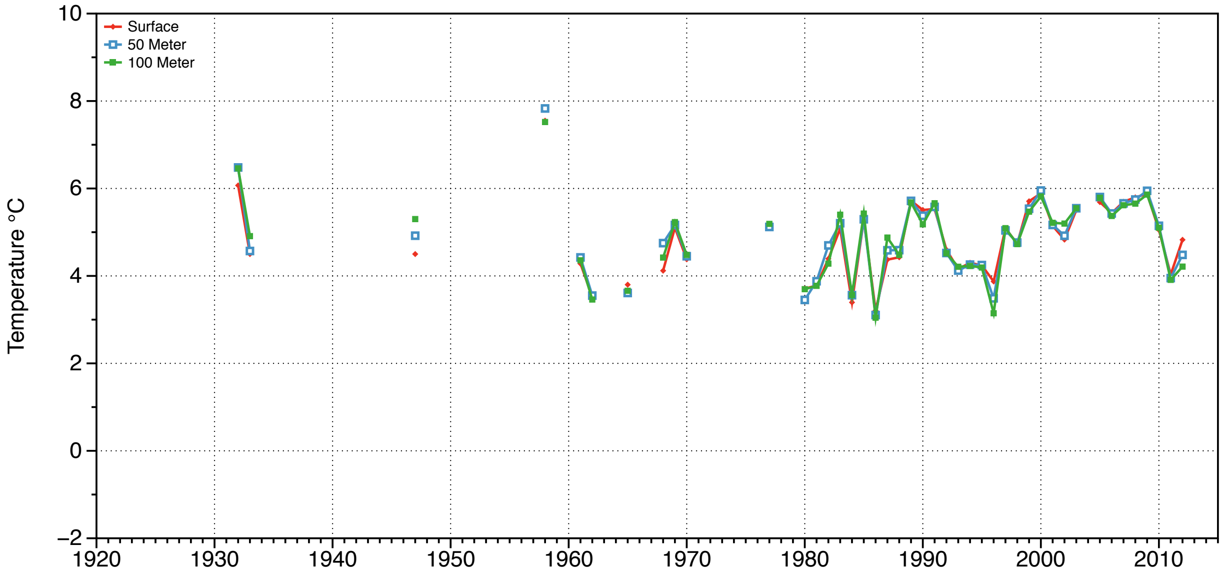


Figure 29: Interannual variability of winter temperatures (November – February) at station Outer Porsangerfjorden

in Outer Porsangerfjorden). The mean surface density in Porsangerfjorden was between 26.75–27.02 and at 100 m it was between 27.4–27.55 (Table 9).

3.2 HYDROPHYSICAL CHARACTERISTICS IN THE SUMMER SEASON

A summary of temperature, salinity and density during the summer season are presented in Tables 10, 11 and 12. Additional tables are also provided in the Appendix.

Table 10: Compilation of summer temperatures (June – August) in the sampled fjords (°C)

Locality	Depth	Mean	Minimum	Coldest Year	Maximum	Warmest Year
Inner Malangen	0 m	9.48	5.36	1981	15.28	1994
(1003–1004)	100 m	4.9	3.02	1981	6.12	1992
Outer Malangen	0 m	8.6	4.91	1931	16.3	1934
(1006–1007)	100 m	6.37	4.42	1940	9.2	1983
Outer Balsfjorden	0 m	8.43	4.34	1995	19	1934
(2001–2002)	100 m	3.17	1.41	1981	4.72	1992
Inner Balsfjorden	0 m	9.68	4.68	1994	19.2	1934
(2004–2005)	100 m	2.87	0.63	1936	4.53	1992
Kvalsund	0 m	7.68	4.92	1994	11.17	1994
(3003)	100 m	5.28	4.27	1994	6.36	1992
Sørfjord	0 m	9.12	6.66	1999	14.5	1930
(5003)	100 m	2.6	1.13	1999	3.88	2012
Outer Altafjorden	0 m	8.89	4.84	1982	14.86	1994
(7001–7002)	100 m	5	2.77	1981	6.7	1994
Inner Altafjorden	0 m	9.94	5.71	1993	16.25	1994
(7005–7006)	100 m	4.43	2.46	1982	5.99	1994
Refsbotn	0 m	7.33	1.4	1955	11.49	1937
(8001)	100 m	5.58	0.5	1955	8.04	1955
Outer Porsangerfjorden	0 m	7.56	3.42	1982	12.3	1931
(9001–9002)	100 m	5.34	2.68	1987	8.45	2006
Inner Porsangerfjorden	0 m	7.77	3.36	1980	12.64	1993
(9007–9008)	100 m	4.06	1.37	1980	7.33	1972
Østerbotn	0 m	8.38	4	1982	12.11	1994
(9009–9010)	100 m	0.01	-1.61	1969	4.32	1931

3.2.1 *Malangen*

3.2.1.1 *Temperature*

Figures 128 and 129 [30] shows monthly variation in summer temperature in Outer and Inner Malangen respectively. Both stations showed similar trends in temperature, i.e. gradual increase from June to August at all depths. surface temperature increased from 7°C in June to 11°C in August in both stations.

Table 11: Compilation of summer salinity (June – August) in the sampled fjords (‰)

Locality	Depth	Mean	Minimum	Least saline Year	Maximum	Most saline Year
Inner Malangen	0 m	26.38	8.73	1928	32.76	2006
(1003–1004)	100 m	34.05	33.66	1994	34.46	2012
Outer Malangen	0 m	31.34	10.75	1934	34.63	1965
(1006–1007)	100 m	34.36	33.92	1983	34.94	1985
Outer Balsfjorden	0 m	30.43	15.19	2011	33.21	1994
(2001–2002)	100 m	33.47	33.14	1992	33.78	1994
Inner Balsfjorden	0 m	28.52	13.17	1932	32.85	2006
(2004–2005)	100 m	33.48	33.16	1992	34.22	1970
Kvalsund	0 m	32.55	13.18	2008	33.69	2006
(3003)	100 m	34.1	33.83	1992	34.3	2012
Sørfjord	0 m	28.05	16.01	1998	31.62	2012
(5003)	100 m	33.69	33.59	1996	33.81	1998
Outer Altafjorden	0 m	31.1	15.76	1993	34.41	1980
(7001–7002)	100 m	34.19	33.88	1992	34.52	1993
Inner Altafjorden	0 m	25.46	6.83	1982	33.45	1980
(7005–7006)	100 m	34.07	33.67	1992	34.54	1944
Refsbotn	0 m	34.06	33.19	1989	35.07	1934
(8001)	100 m	34.57	34.09	1992	35.14	1956
Outer Porsangerfjorden	0 m	33.81	30.56	1993	34.78	1965
(9001–9002)	100 m	34.4	32.69	1969	34.94	1957
Inner Porsangerfjorden	0 m	31.39	21.99	1992	33.66	1993
(9007–9008)	100 m	33.75	23.1	1992	34.48	1994
Østerbotn	0 m	29.99	20.75	1992	33.24	1994
(9009–9010)	100 m	33.45	22.74	1992	34.33	1980

Outer Malangen had better data coverage in the summer season. During the periods 1935-40,1948-1950 and 1978-1980 there was a warming trend in Outer Malangen (Figures 272, 273 [33]). No remarkable difference in temperature between Inner and Outer Malangen was present during this period. Highest recorded surface temperature in the Outer Malangen was 16.3°C in the year 1934 and in the Inner Malangen 15.28°C in the year 1994 (Table 10)

3.2.1.2 *Salinity*

The monthly variations in salinity during the summer period in Outer and Inner Malangen are shown in Figures 176 and 177 [31]. Only the surface salinities varied during this season. At both stations, the variations in salinity at 50 meter and 100 meter were negligible. Highest surface salinity recorded in Malangen was in the Outer station (34.63, in the year 1965) and the lowest was 8.73 in Inner Malangen in the year 1928. The 34.94 salinity recorded in the year 1985 in Outer stations was the highest at 100 m in Malangen and 33.66 in the year 1994 in Inner Malangen was the lowest (Table 11).

Table 12: Compilation of summer density (June – August) in the sampled fjords (σ_t)

Locality	Depth	Mean	Minimum	Least dens Year	Maximum	Most dens Year
Inner Malangen	0 m	20.31	6.36	1928	25.31	1998
(1003–1004)	100 m	27.39	27.06	1992	27.6	1994
Outer Malangen	0 m	24.3	7.12	1934	27.11	1965
(1006–1007)	100 m	27.45	26.69	1983	27.92	1985
Outer Balsfjorden	0 m	23.64	11.79	2011	26.34	1994
(2001–2002)	100 m	27.11	26.7	1992	27.48	1994
Inner Balsfjorden	0 m	21.95	8.79	1934	25.89	1994
(2004–2005)	100 m	27.15	26.73	1992	27.77	1970
Kvalsund	0 m	25.4	10.38	2008	26.44	1994
(3003)	100 m	27.39	27.04	1992	27.59	1994
Sørfjord	0 m	21.67	11.64	1998	24.64	2012
(5003)	100 m	27.33	27.22	1930	27.49	2011
Outer Altafjorden	0 m	24.08	12.19	1993	26.96	1987
(7001–7002)	100 m	27.49	27.08	1992	27.77	1980
Inner Altafjorden	0 m	19.51	5.16	1982	25.87	1980
(7005–7006)	100 m	27.46	26.98	1992	27.77	1993
Refsbotn	0 m	26.65	25.57	1937	27.58	1938
(8001)	100 m	27.72	27.18	1994	28.18	1934
Outer Porsangerfjorden	0 m	26.39	23.51	1993	27.43	1965
(9001–9002)	100 m	27.62	26.41	1969	27.98	1987
Inner Porsangerfjorden	0 m	24.46	17.13	1992	26.68	1993
(9007–9008)	100 m	27.24	18.89	1992	27.91	1981
Østerbotn	0 m	23.28	15.77	1992	26.18	1994
(9009–9010)	100 m	27.33	18.7	1992	28.02	1994

Mean surface salinity were between 26.38–34.36 . The mean salinity at 100 meter depth was between 34.05–34.36 .

3.2.1.3 *Density*

Figures 224 and 225 [32] shows the monthly variations in density during the summer period. Similar to salinity the density variations from June to August were less at deeper levels but surface salinities were varied quite much. A minimum surface density of 6.36 was recorded in Inner Malangen in the year 1928 and maximum surface density was recorded in Outer Malangen (27.11) in 1965. At 100 m the highest density was 27.92 in the year 1985 and lowest 26.69 in the year 1983 (both were in Outer Malangen).The mean surface densities in Malangen were between 20.31–24.3 and at 100 m between 27.39–27.45 (Table 12).

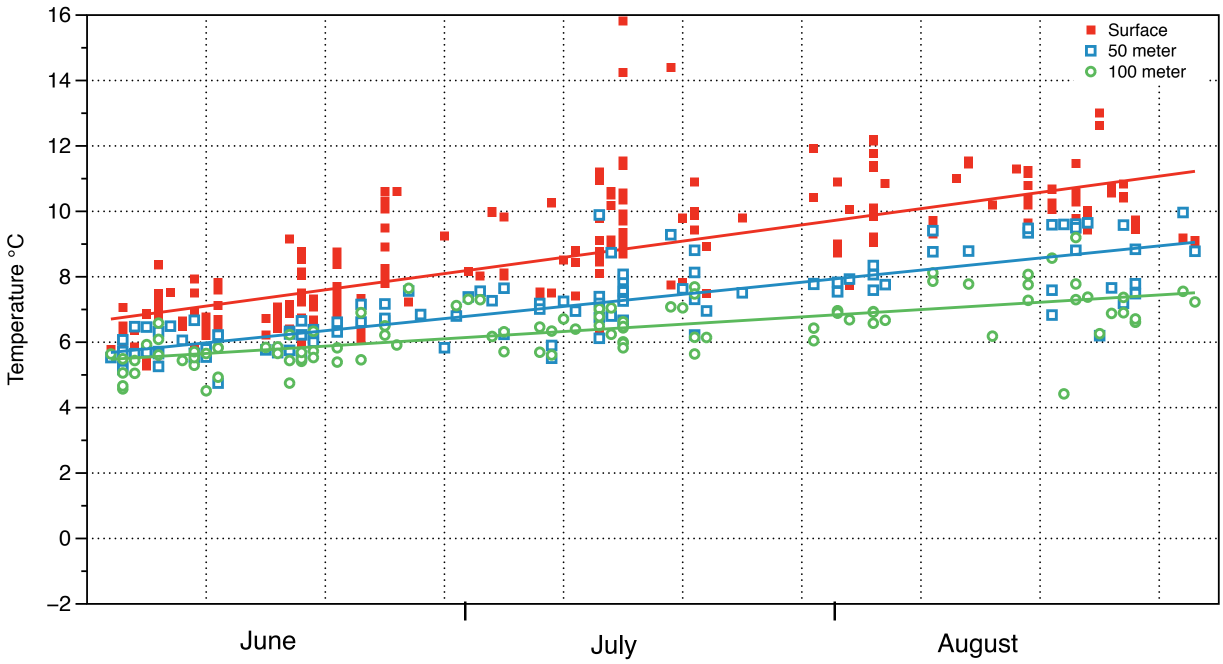


Figure 30: Monthly variability of summer temperatures (June – August) at station Outer Malangen

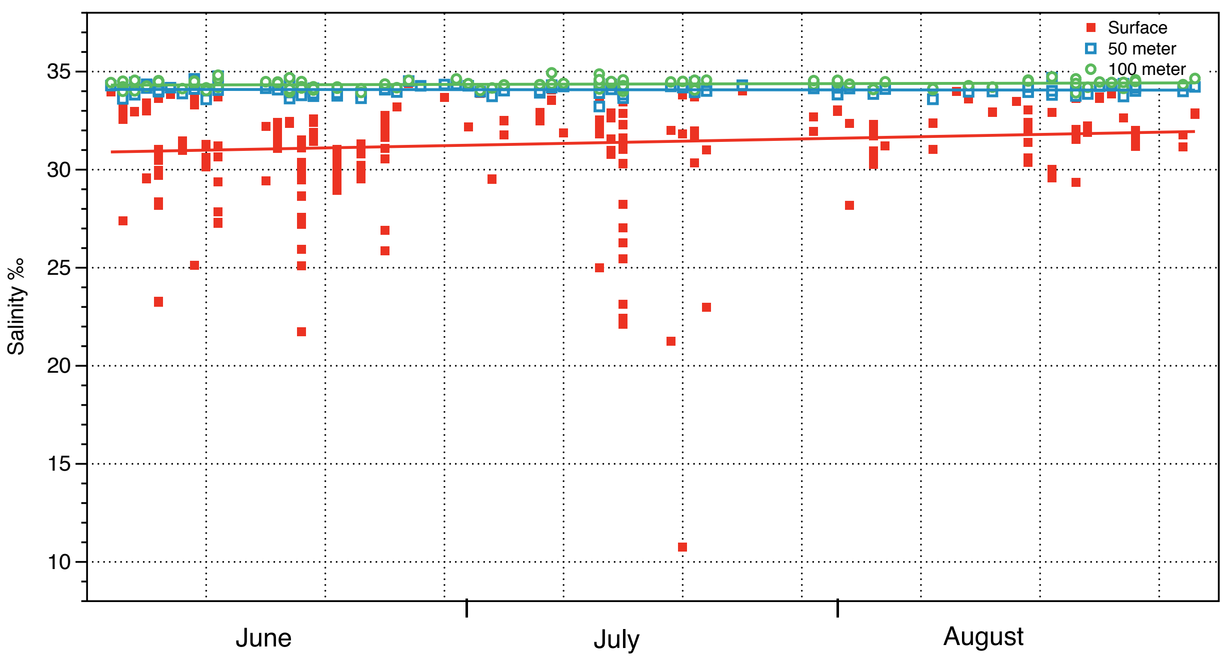


Figure 31: Monthly variability of summer salinity (June – August) at station Outer Malangen

3.2.2 *Balsfjorden*

3.2.2.1 *Temperature*

Figures 130 and 131 [34] shows the summer temperature in Outer and Inner Balsfjord. Similar to Malangen, temperatures increased from June to August in both Outer and Inner stations. At 100m the increase in temperature was less than 1°C compared to 3°C at the surface.

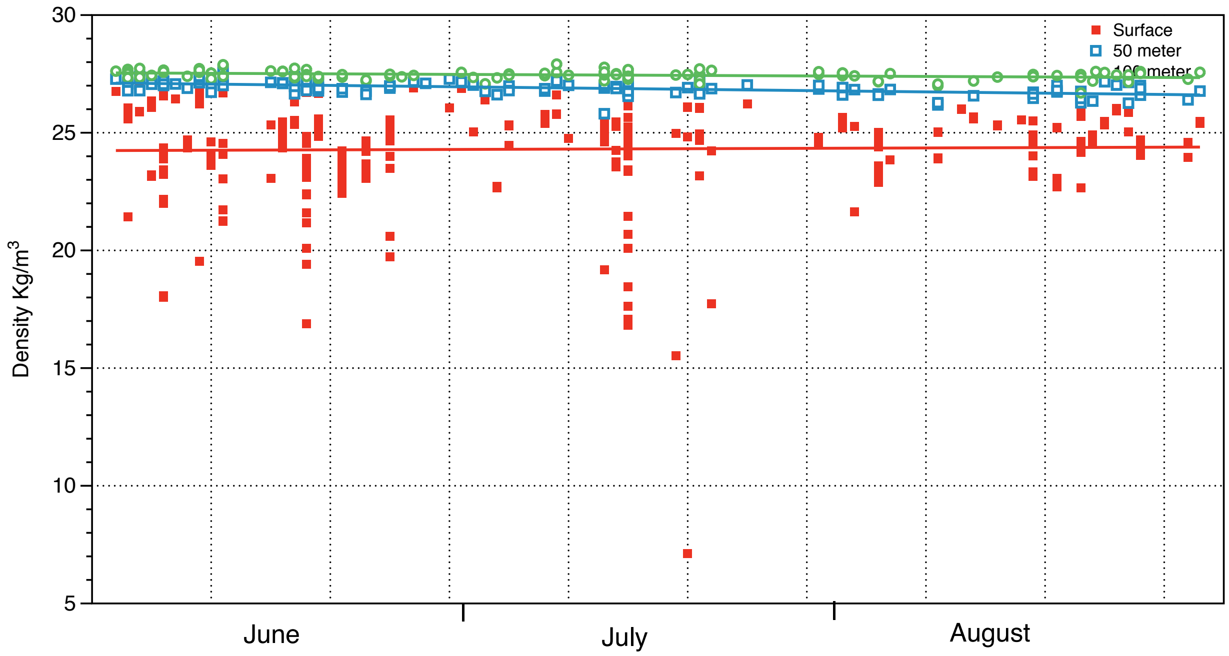


Figure 32: monthly variability of summer density (June – August) at station Outer Malangen

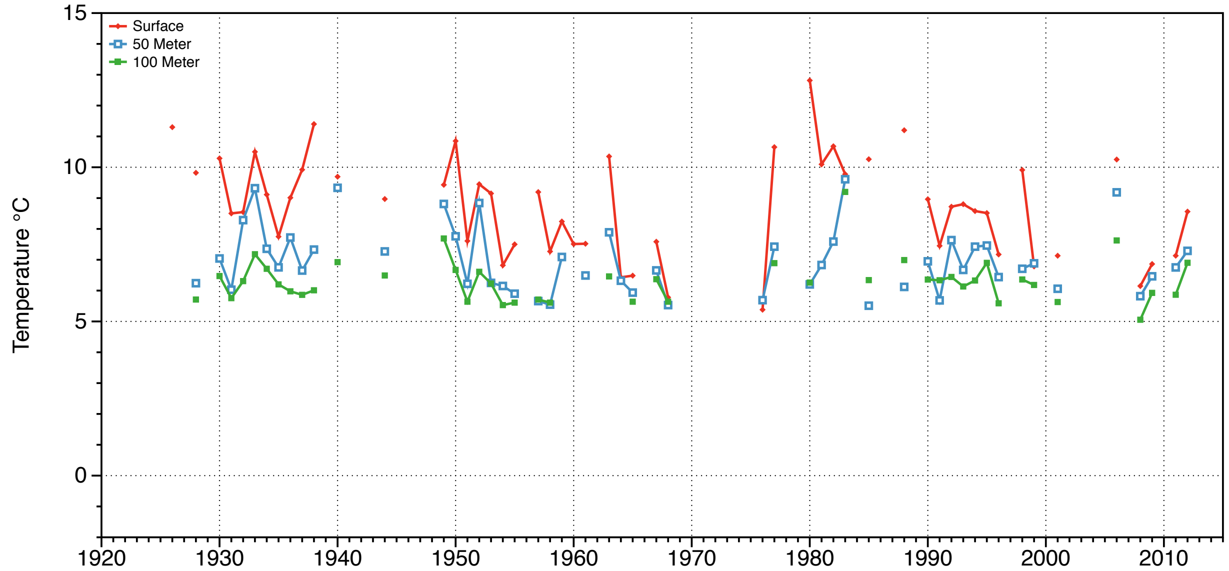


Figure 33: Interannual variability of summer temperatures (June – August) at station Outer Malangen

Both in the Inner and Outer Balsfjorden, the surface temperature during the period 1925 to 1938 were higher than during the current period (Figure 274 and 275 [37]). The highest surface temperature in Inner Balsfjorden was 19.2°C and in the Outer Balsfjorden was 19.0°C in the year 1934 (Table 10). The temperature shows similar patterns in both inner and Outer fjords. In the summer season there was a cooling tendency after year 2007 in Balsfjorden(Figure 274 and 275 [37]).

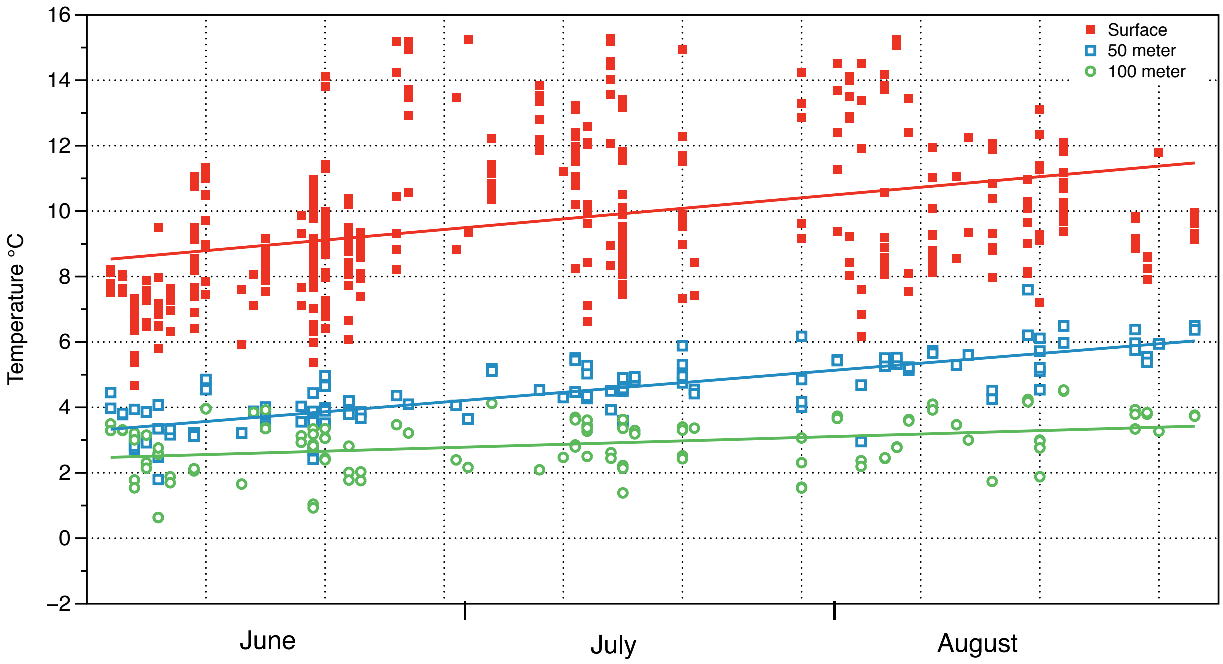


Figure 34: Monthly variability of summer temperatures (June – August) at station Inner Balsfjorden

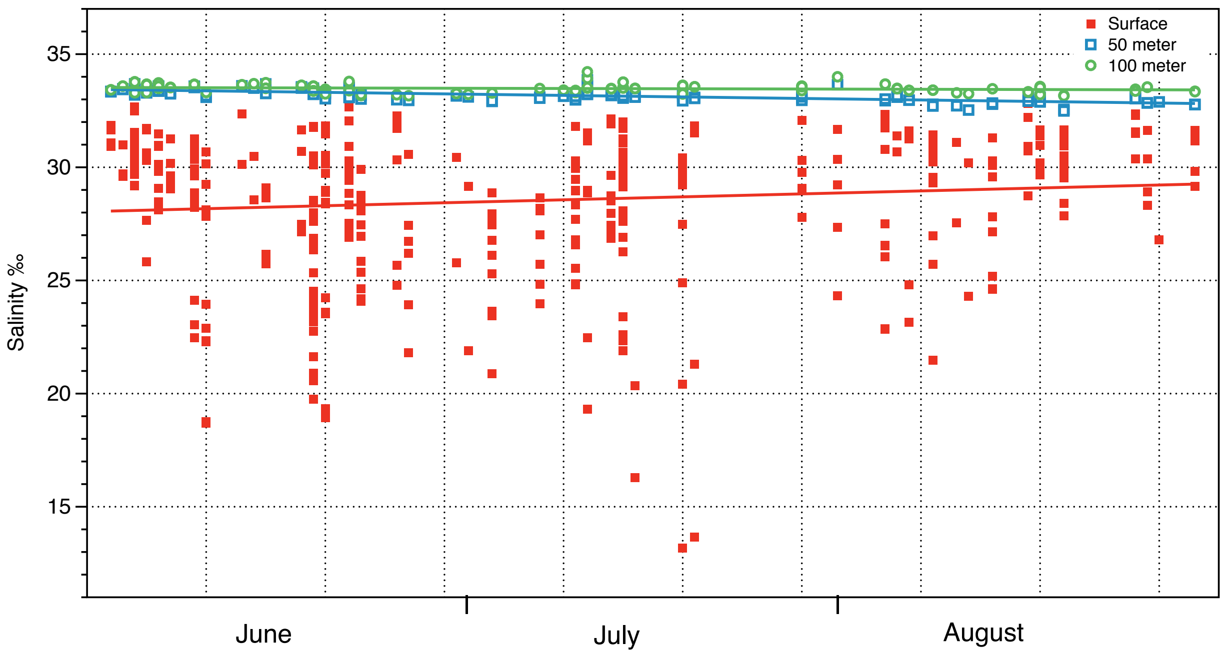


Figure 35: Monthly variability of summer salinity (June – August) at station Inner Balsfjorden

3.2.2.2 *Salinity*

The monthly variations in salinity during the summer period in Outer and Inner Balsfjorden are shown in Figures 178 and 179 [35]. Similar to Malangen there were no variations in salinity at 50 m and 100

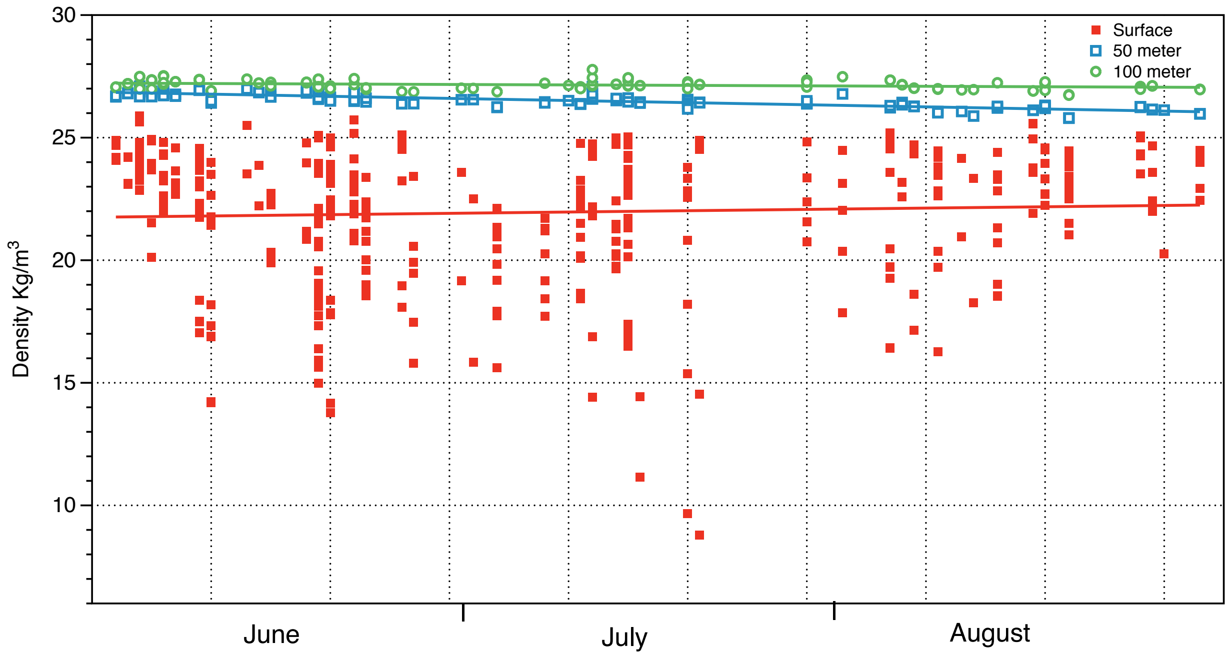


Figure 36: monthly variability of summer density (June – August) at station Inner Balsfjorden

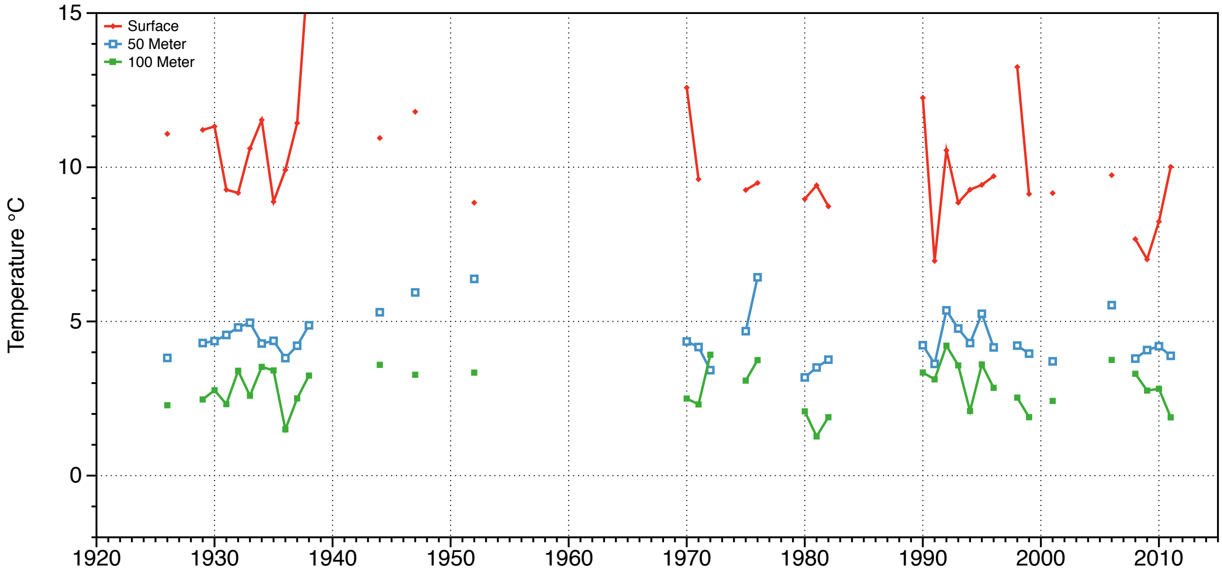


Figure 37: Interannual variability of summer temperatures (June – August) at station Inner Balsfjorden

m in both Inner and Outer Balsfjorden. Highest surface salinity recorded in Balsfjorden was in the Outer station (33.21, in the year 1994) and the lowest was 13.17 in Inner Balsfjorden in the year 1932. The 34.22 salinity recorded in the year 1970 in Inner stations was the highest at 100 m in Balsfjorden and 33.14 in the year 1992 in Outer Balsfjorden was the lowest (Table 11).

3.2.2.3 *Density*

The monthly variations in densities during the summer period in Balsfjorden are presented in Figures 226 and 227 [36]. The density at deeper layers showed a small decrease (0.1-02) in density from June to August. Similar to Malangen, the densities at surface were quite variable in both stations. A minimum surface density of 8.79 was recorded in Inner Balsfjorden in the year 1934 and maximum surface density was recorded in Outer Balsfjorden (26.34) in 1994. At 100 m the highest density was 27.77, in the year 1970 and lowest was 26.7, in the year 1992 (both were in Outer Balsfjorden).The mean surface densities in Balsfjorden were between 21.95–23.64 and at 100 m it was between 27.11–27.15 (Table 12).

3.2.3 *Altafjorden*

Figures 134 [38] and 135 shows monthly variations in temperature during summer months in Outer and Inner Alta. The trends are comparable to the southern fjords. The surface temperature in Inner Alta was comparatively warmer (1 to 2°C) during June. After June, both stations showed similar trends. Table 10 shows the summary of summer temperature in the sampled stations.

Similar to the winter months, Inner and Outer stations in Altafjorden follow the similar trend in temperature (Figures 278 [41]–279). The period 1931 to 1936 were relatively warm and then there was a cooling period until 1982. After that it gradually increased and 2003 it started decreasing again. Mean temperature in Altafjord in summer was comparable to Outer Porsangerfjord. Highest surface temperature in Inner Alta was 16.25°C and in Outer Alta it was 14.86°C in the year 1994 (Table 10).

3.2.3.1 *Salinity*

The monthly variations in salinities during the summer period in Outer and Inner Altafjorden are shown in Figures 182 [39] and 183. Inner Altafjorden showed an increasing trend in surface salinity compared to Malagen and Balsfjorden. Similar to southern fjords, at 50 m and 100 m depth, there were no variations in salinity. Highest surface salinity recorded in Altafjorden was in the Outer station (34.41, in the year 1980) and the lowest was 6.83 in Inner Altafjorden in the year 1982. The 34.54 salinity recorded in the year 1944 in Inner stations was the highest recorded at 100 m in Altafjorden and 33.67 in the year 1992 in Inner Altafjorden was the lowest (Table 11).

3.2.3.2 *Density*

The monthly variations in densities during summer period in Outer and Inner Altafjorden are shown in Figures 230 [40] and 231. Density showed similar trend as salinities in Altafjorden. Minimum

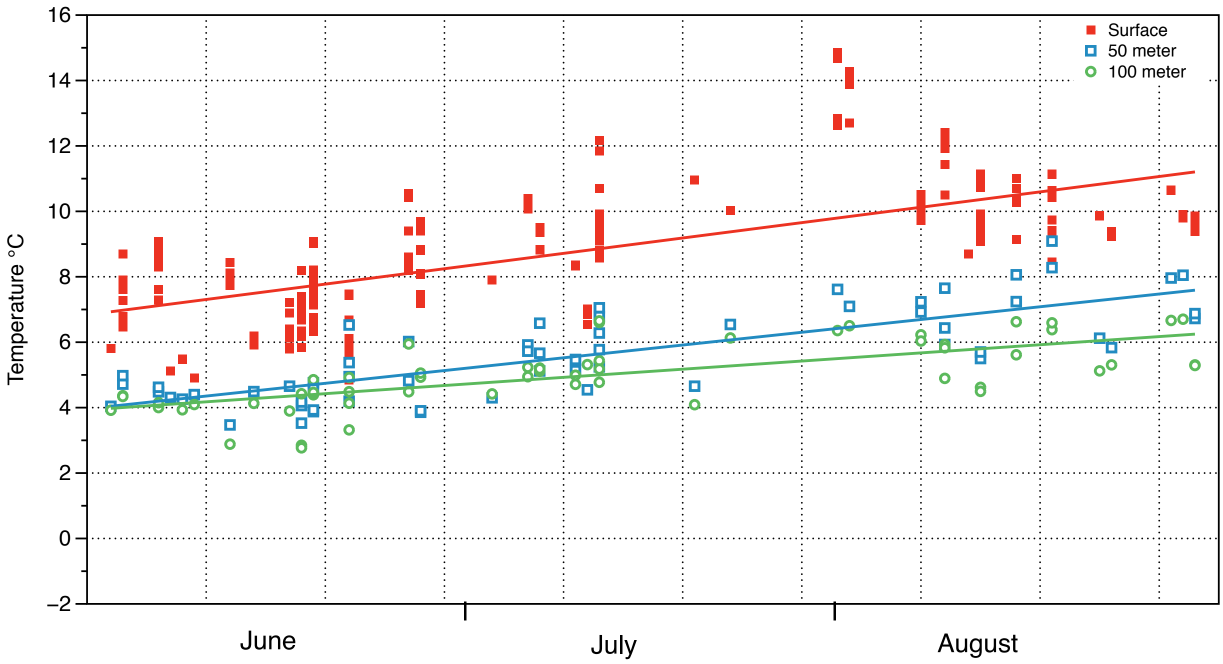


Figure 38: Monthly variability of summer temperatures (June – August) at station Outer Altafjorden

surface density of 5.16 was recorded in Inner Altafjorden in the year 1982 and maximum surface density was recorded in Outer Altafjorden (26.96) in 1987. At 100 m the highest density was 27.77 in the year 1980 and lowest was 26.98, in the year 1992 (both were in Inner Altafjorden). The mean surface densities in Altafjorden were between 19.51–24.08 and in 100 m between 27.46–27.49 (Table 12).

3.2.4 *Porsangerfjord*

Figures 137 [42], 138 and 139 shows the temperature in Outer Porsanger, Inner Porsanger and Østerbotn respectively. The temperature differences between surface and 100m increased from Outer to Inner fjord. During August, the difference between surface and 100m in Outer Porsanger was 3.6°C whereas in Inner Porsanger it was 4.6°C and Østerbotn it was 7.2°C.

During the summer months, Outer Porsanger showed more variations in temperatures at 100 m compared to Inner Porsanger and Østerbotn (Figures 281 [45], 282 and 283). At Inner Porsangerfjord, from year 1957 to 1981 there was a decreasing tendency in temperature. During 1982 to 1987 it went up and then it was stable until 1995 whereafter it slowly started decreasing. The trend was similar in Østerbotn. From 2010 both these stations showed a rise in temperature. Outer Porsangerfjord have temperature data dating back to 1870. There were three noticeable warming periods. The summers from 1939 to 1956 were 1.5 to 2.0°C warmer than mean temperature (5.34°C). The next warm period was 1958-1959 and after that temperature gradually decreased over year and reached 4.0°C in 1969.

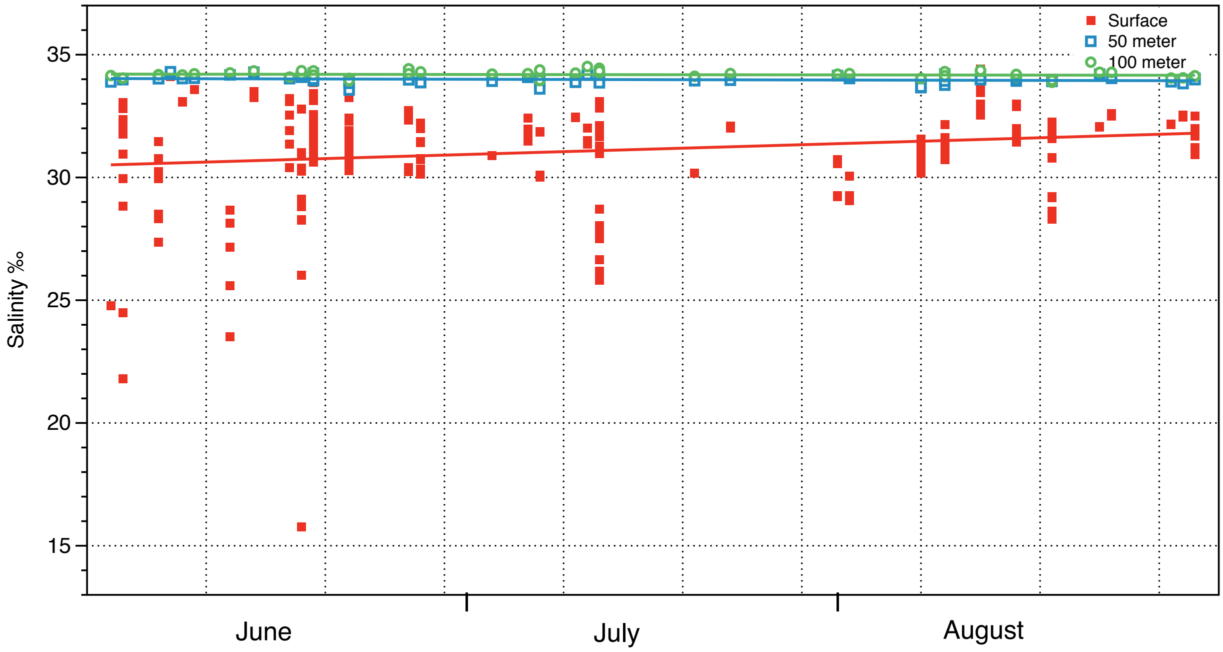


Figure 39: Monthly variability of summer salinity (June – August) at station Outer Altafjorden

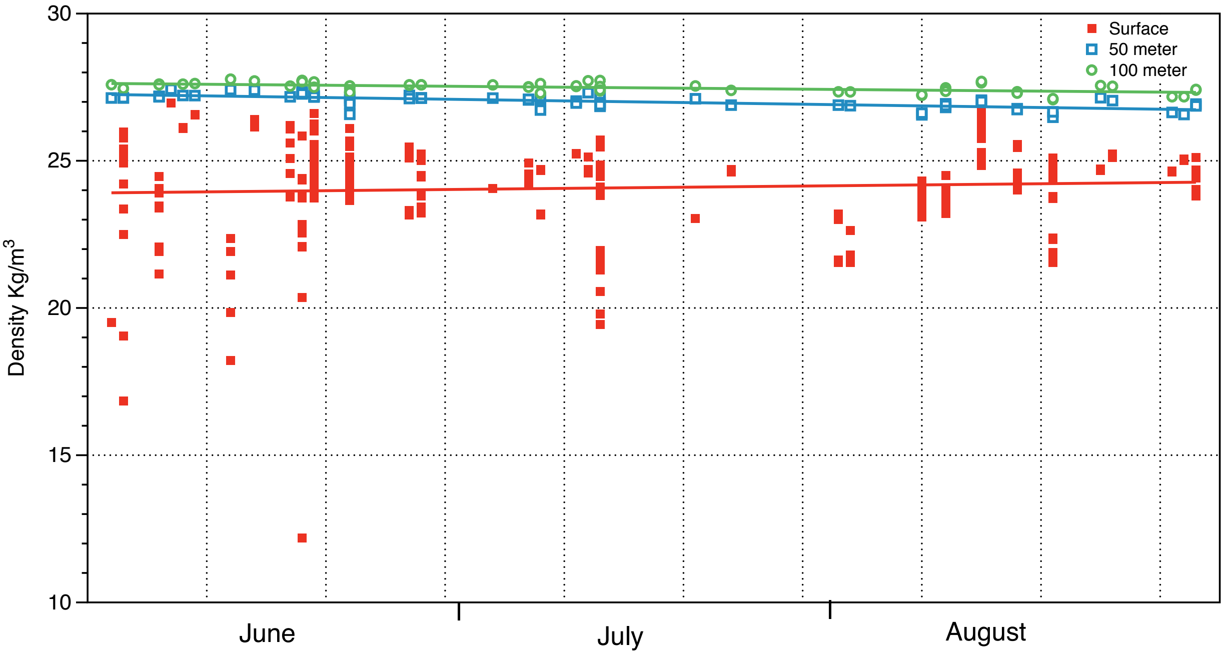


Figure 40: monthly variability of summer density (June – August) at station Outer Altafjorden

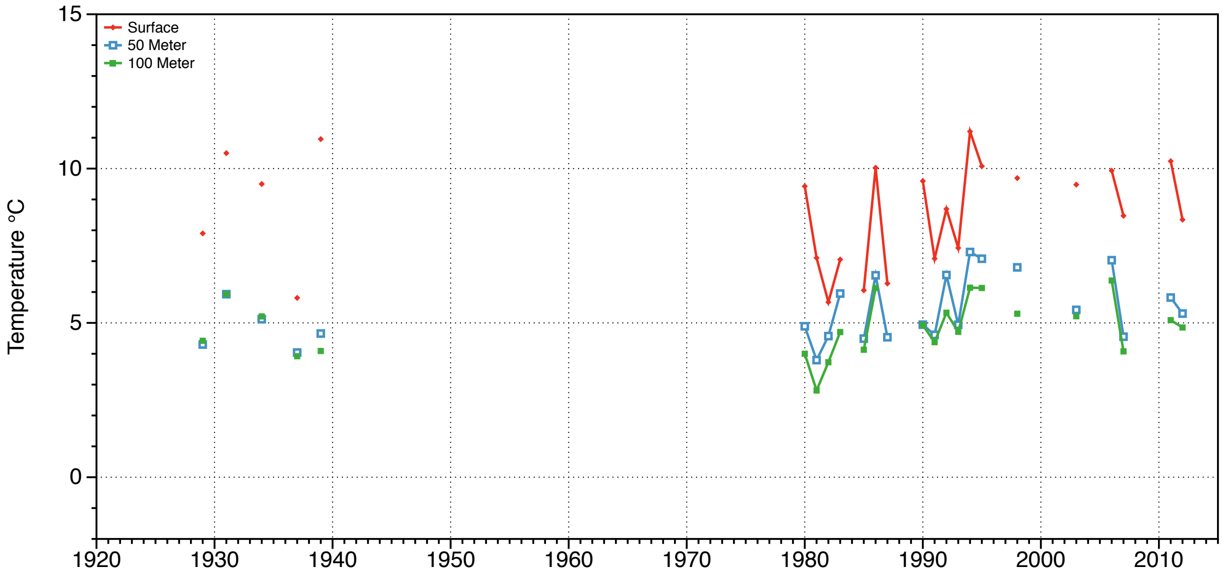


Figure 41: Interannual variability of summer temperatures (June – August) at station Outer Altafjorden

The last warmest summer period was 2006-2007. After this period it was a decreasing trend. The surface and 100m temperature in Østerbotn showed a huge difference compared to other stations in Porsangerfjord. The mean surface temperature at 0m was 8.38°C where as at 100m it was 0.01°C. The minimum recorded temperature in Østerbotn in summer was -1.61°C at 100m (Table 10). Inner and Outer Porsangerfjord showed 1.37°C and 2.68°C respectively. Østerbotn thus was comparatively colder during the summer months (Table 10).

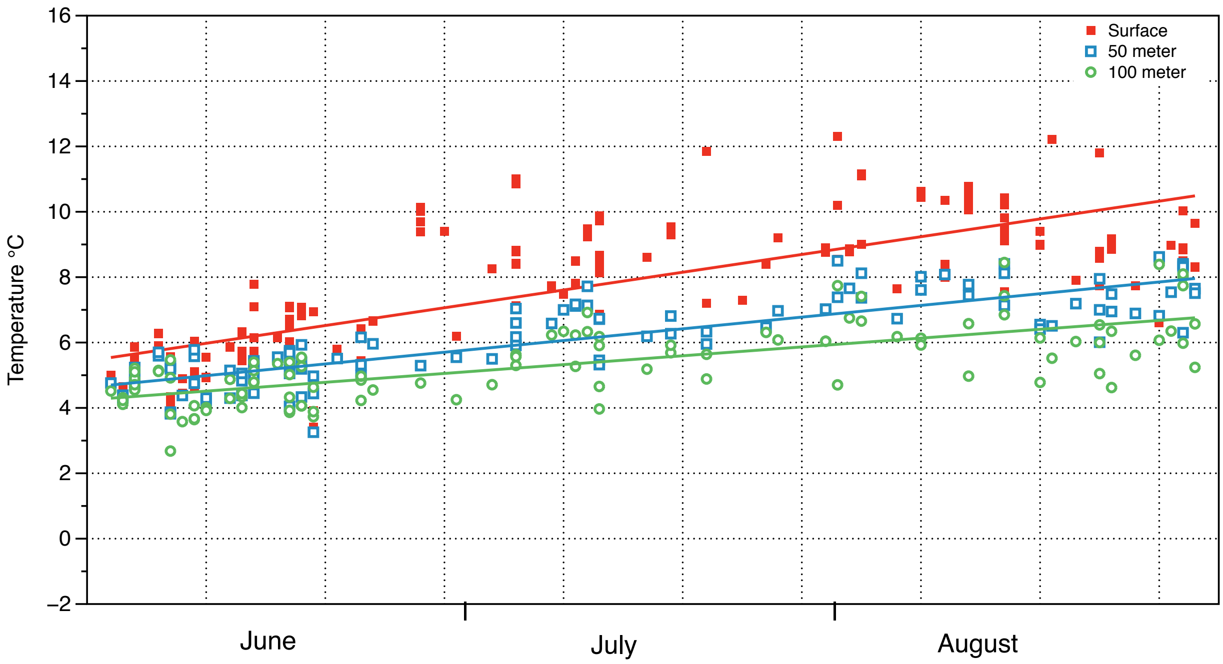


Figure 42: Monthly variability of summer temperatures (June – August) at station Outer Porsangerfjorden

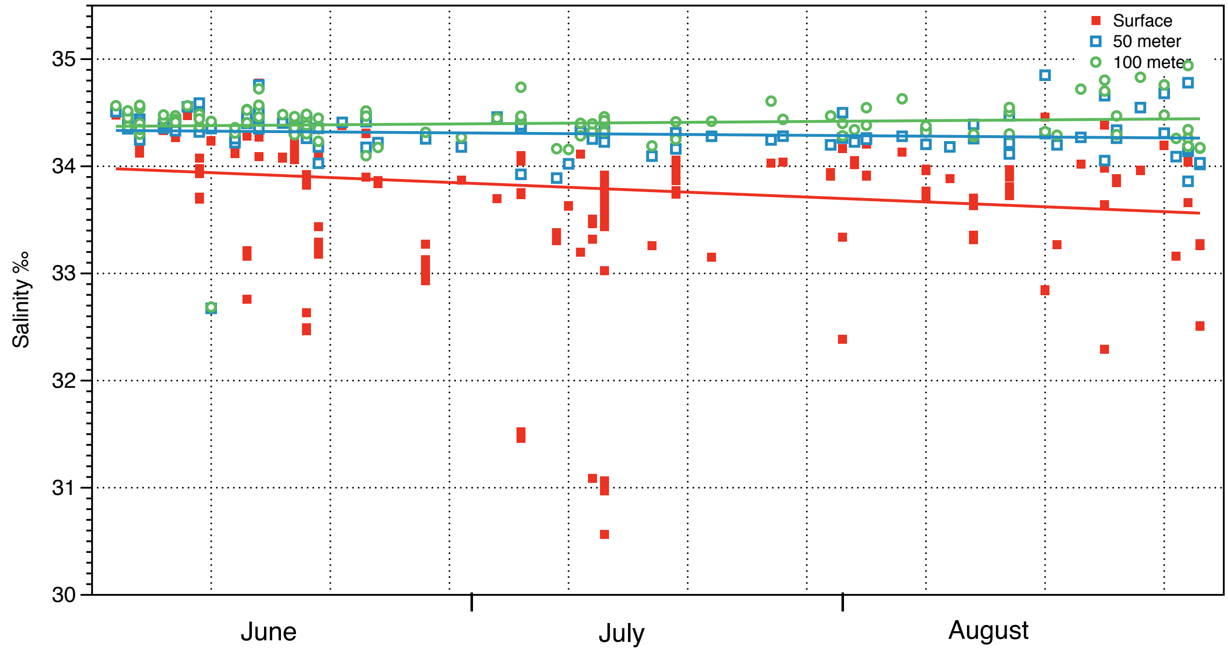


Figure 43: Monthly variability of summer salinity (June – August) at station Outer Porsangerfjorden

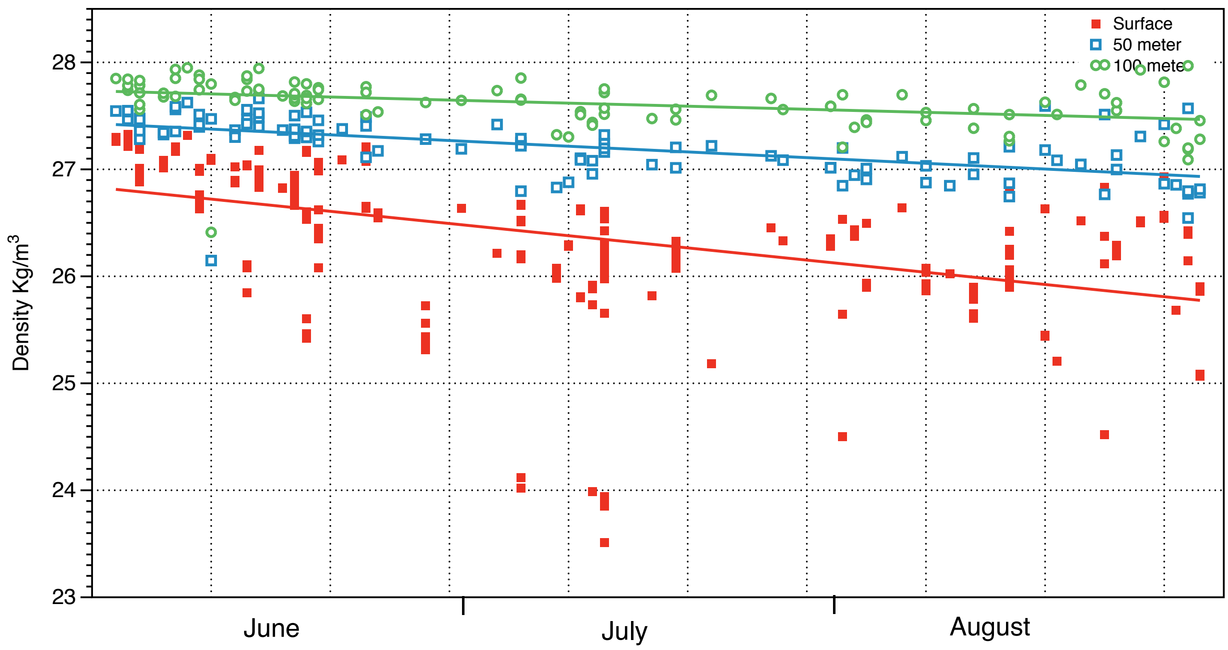


Figure 44: monthly variability of summer density (June – August) at station Outer Porsangerfjorden

3.2.4.1 *Salinity*

The monthly variations in salinities during the summer period in Outer, Inner Porsangerfjorden and Østerbotn are shown in Figures 185 [43], 186 and 187. Surface salinity in Outer Porsangerfjorden

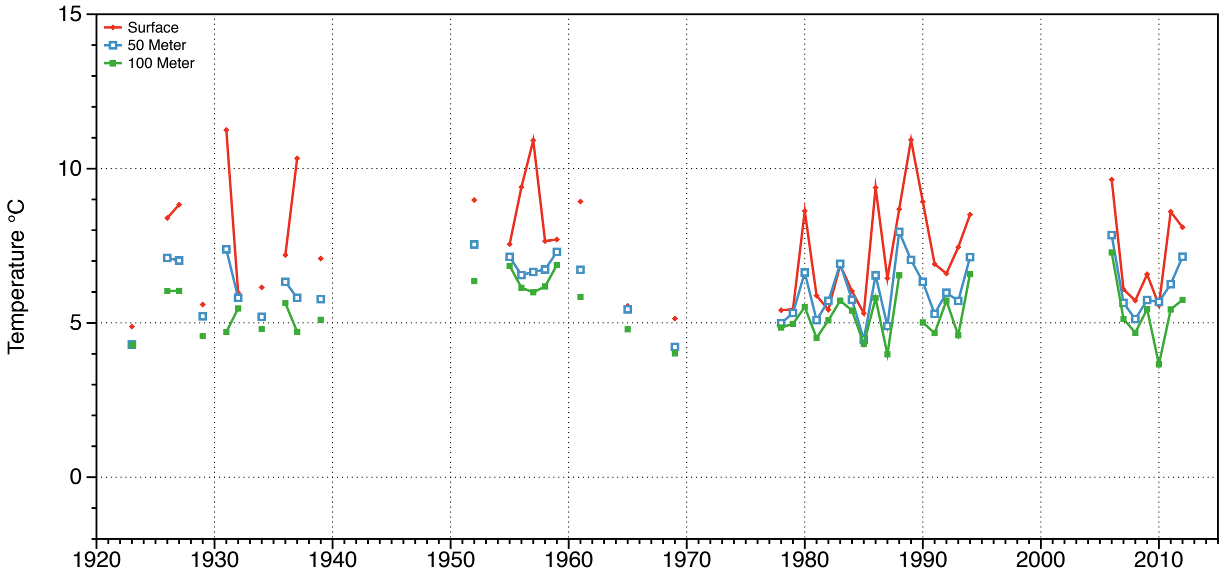


Figure 45: Interannual variability of summer temperatures (June – August) at station Outer Porsangerfjorden

decreased from June to August, but at 50 m and 100 m the variations in salinity were less. Highest surface salinity recorded in Porsangerfjorden was in the Outer station (34.78, in the year 1965) and the lowest was 20.75 in Østerbotn in the year 1992. The 34.94 salinity recorded in the year 1957 in Outer stations was the highest at 100 m in Porsangerfjorden and 22.74 in the year 1992 in Østerbotn was the lowest (Table 11).

3.2.4.2 *Density*

The monthly variations in densities during the summer period in Outer, Inner Porsangerfjorden and Østerbotn are shown in Figures 233 [44], 234 and 235. Unlike southern fjords, the density in Outer Porsangerfjord showed a decreasing trend from June to August. But the Inner Porsangerfjorden and Østerbotn showed a slight increasing trend. Minimum surface density of 15.77 was recorded in Østerbotn in the year 1992 and maximum surface density was recorded in Outer Porsangerfjorden (27.43) in 1965. At 100 m the highest density was 28.02, in the year 1994 and lowest was 18.7, in the year 1992 (both were in Østerbotn). The mean surface densities in Porsangerfjorden were between 23.28–26.39 and at 100 m between 27.24–27.62 (Table 12).

3.3 HYDROPHYSICAL CHARACTERISTICS IN THE SPRING SEASON

A summary of temperatures, salinities and densities during the spring season are presented in Tables 13, 14 and 15. Additional tables are also provided in the Appendix.

3.3.1 *Malangen*

3.3.1.1 *Temperature*

The surface temperatures during the spring season showed gradual increases in both Inner and Outer Malangen. Figures 116, 117 [46] show monthly variations in spring temperatures in Inner and Outer Malangen stations respectively. During the beginning of March to end of May the temperatures in Outer Malangen increased from 2.8°C to 4.8°C and in Inner Malangen it increased from 3°C to 5.2°C. At 50 m and 100 m, the trend were different in Inner and Outer stations. At the Inner station the temperature decreased from March to May (from 5.1°C 4.2°C at 50 m and 5.7°C to 4.8°C at 100 m) but Outer Malangen showed a slight increase (3.2°C to 4.6°C at 50 m and 4.2°C to 4.4°C at 100 m). At both stations deeper waters were warmer than the surface ones (e.g. Inner Malangen showed 2.8°C difference from surface to 100 meter in the beginning of March) until beginning of April after that surface temperature got warmer than the deeper layers. The mean surface temperatures in Malangen were between 3.76–4.11°C and at 100 m it was 4.57–5.31°C (Table13). Malangen showed the highest mean temperature in both the surface and 100 m among all fjords.

The minimum and maximum surface temperatures recorded in Inner Malangen were -1.23°C (in the year 1981) and 6.6°C (in the year 1992). At Outer Malangen it were -0.39°C (in the year 1968) and 11.51°C (in the year 1949). At 100 m depth, the minimum recorded temperatures were 3.13°C (Inner Malangen, in the year 1981) and -1.22°C (Outer Malangen, in the year 1981). The highest recorded temperatures at 100 m in the Inner and Outer Malangen were 7.07°C (in the year 2012) and 6.63°C (in the year 1939) respectively (Table 13).

Figures 260, 261 [49] show the inter annual variability of temperature in Inner and Outer Malangen respectively. Outer Malangen had more data coverage than Inner Malangen. There was no remarkable trend in long term temperature in the Outer Malangen station. The surface temperatures during the years 1950 and 1960 were somewhat warmer (above 5°C) compared to rest of the years (less than 4°C). The coldest year was 1968 in Outer Malangen. From 1990 to 2012 both Inner and Outer Malangen showed similar trends in temperature but the gradient in temperature between surface and deeper layers in both stations were completely different.

3.3.1.2 *Salinity*

The monthly variations in salinities during spring season in Outer and Inner Malangen are shown in Figures 164 and 165 [47]. Both stations showed gradual increases in salinity from March to May at 50 m and 100 m. Compared to Outer Malangen the mean surface salinity in Inner Malangen during this period was 1 decreased than the Outer station. The maximum surface salinity in Malangen was in Outer Malangen stations recorded in the year 1960 (34.7) and the minimum was in Inner Malangen in 1983 (12.77). The maximum salinity recorded at 100 m was in Inner Outer Malangen (34.92, year

Table 13: Compilation of spring temperatures (March – May) in the sampled fjords (°C)

Locality	Depth	Mean	Minimum	Coldest Year	Maximum	Warmest Year
Inner Malangen	0 m	4.11	-1.23	1981	6.6	1992
(1003–1004)	100 m	5.31	3.13	1981	7.07	2012
Outer Malangen	0 m	3.76	-0.39	1968	11.51	1949
(1006–1007)	100 m	4.57	-1.22	1949	6.63	1939
Outer Balsfjorden	0 m	3.04	0.05	1936	8.99	1983
(2001–2002)	100 m	2.87	0.89	1981	4.5	2012
Inner Balsfjorden	0 m	2.79	-1.01	1983	9	1983
(2004–2005)	100 m	2.51	0.33	1981	4.32	1934
Kvalsund	0 m	3.83	2.08	1999	5.4	2006
(3003)	100 m	4.38	2.39	1999	6.03	2012
Sørfjord	0 m	2.56	0.55	1999	7.65	2006
(5003)	100 m	2.33	0.85	1999	3.83	2012
Outer Altafjorden	0 m	3.25	1.02	1980	7.06	2006
(7001–7002)	100 m	3.37	1.42	1987	5.41	2010
Inner Altafjorden	0 m	2.92	-0.03	1987	7.6	2006
(7005–7006)	100 m	3.6	1.48	1998	5.95	2010
Refsbotn	0 m	3.95	2.55	1979	6.37	1989
(8001)	100 m	4.19	2.55	1981	6.09	1989
Outer Porsangerfjorden	0 m	3.31	0.23	1998	6.17	2006
(9001–9002)	100 m	3.37	1.24	1998	5.63	1989
Inner Porsangerfjorden	0 m	1.37	-1.44	1987	7.21	2007
(9007–9008)	100 m	1.2	-0.85	1987	3.95	1994
Østerbotn	0 m	0.64	-1.77	1995	6.94	2007
(9009–9010)	100 m	-0.83	-1.75	2001	0.84	1968

1960) and the minimum was in Outer Malangen in year 1933 (33.58) (Table 14). The mean surface salinity in Outer Malangen was 33.43 and Inner Malangen it was 31.58 .

3.3.1.3 *Density*

Figures 212 and 213 [48] show the monthly variations in density during spring season. The mean surface density gradually decrease from March to May. The mean surface density in Malangen was between 25.06-26.57 and at 100 m it was between 27.49–27.52 (Table 15). Minimum surface density of 10.16 was recorded in Inner Malangen in the year 1983 and maximum surface density was recorded in Outer Malangen (27.47) in 1970. At 100 m the highest and lowest density were at Outer Malangen (28.32, in the year 1989 and 27.16, in the year 1969).

Table 14: Compilation of spring salinity (March – May) in the sampled fjords (‰)

Locality	Depth	Mean	Minimum	Least saline Year	Maximum	Most saline Year
Inner Malangen	0 m	31.58	12.77	1983	34.3	2004
(1003–1004)	100 m	34.23	33.79	1996	34.55	1980
Outer Malangen	0 m	33.43	16.85	1934	34.7	1960
(1006–1007)	100 m	34.17	33.58	1933	34.92	1960
Outer Balsfjorden	0 m	32.52	17.96	1994	33.91	2010
(2001–2002)	100 m	33.1	18.1	1994	33.88	2010
Inner Balsfjorden	0 m	32.44	11.38	1931	35.11	1933
(2004–2005)	100 m	33.26	20.89	1994	35.22	1933
Kvalsund	0 m	33.85	32.44	2006	34.38	2010
(3003)	100 m	34.19	33.82	1999	34.53	2010
Sørfjord	0 m	33.25	30.18	2006	33.78	2009
(5003)	100 m	33.72	33.37	1996	34.05	2010
Outer Altafjorden	0 m	33.74	25.28	1989	34.52	1994
(7001–7002)	100 m	34.18	33.83	1989	34.72	2010
Inner Altafjorden	0 m	32.76	7.57	2006	34.46	1994
(7005–7006)	100 m	34.24	33.76	2012	34.82	2010
Refsbotn	0 m	34.3	33.66	1939	35.13	1948
(8001)	100 m	34.5	34	1933	35.35	1937
Outer Porsangerfjorden	0 m	34.32	33.35	2003	35.44	1968
(9001–9002)	100 m	34.41	33.94	1989	35.01	1938
Inner Porsangerfjorden	0 m	33.95	10.96	2008	34.72	1968
(9007–9008)	100 m	34.2	33.87	1989	35.1	1968
Østerbotn	0 m	33.22	27.01	1989	34.11	1960
(9009–9010)	100 m	33.83	33.52	1989	34.3	1994

3.3.2 *Balsfjorden*

3.3.2.1 *Temperature*

During the spring season both Inner and Outer Balsfjorden showed gradual increases in temperature at all levels. The surface temperature in both station in March were lower than that of 50 m and 100 m. The surface temperature increased from 1°C from the beginning of Marc to 5°C at the end of May (Figures 118, 119 [50]). The mean surface temperature in Balsfjorden was between 2.79°C and at 100 m it was 2.51°C (Table13).

The minimum and maximum surface temperatures recorded in Inner Balsfjorden were -1.01°C (in the year 1983) and 9.0°C (in the year 1983). In the Outer Balsfjorden it were 0.05°C (in the year 1936) and 8.99°C (in the year 1983) respectively (Table13). At 100 m, Inner Balsfjorden recorded a minimum temperature of 0.33°C in the year 1981 and Outer Balsfjorden 0.89°C in the year 1981.

Table 15: Compilation of spring density (March – May) in the sampled fjords (σ_t)

Locality	Depth	Mean	Minimum	Least dens Year	Maximum	Most dens Year
Inner Malangen	0 m	25.06	10.16	1983	27.1	2004
(1003–1004)	100 m	27.49	27.22	1989	27.77	1980
Outer Malangen	0 m	26.57	13.29	1934	27.47	1970
(1006–1007)	100 m	27.52	27.16	1989	28.32	1969
Outer Balsfjorden	0 m	25.9	14.36	1994	27.02	1936
(2001–2002)	100 m	26.85	14.96	1994	27.55	1994
Inner Balsfjorden	0 m	25.85	9.09	1931	28.04	1933
(2004–2005)	100 m	27	17.19	1994	28.61	1933
Kvalsund	0 m	26.9	25.71	2006	27.39	1994
(3003)	100 m	27.56	27.35	1990	27.89	2010
Sørfjord	0 m	26.53	23.55	2006	27.04	2010
(5003)	100 m	27.39	27.16	1996	27.66	2010
Outer Altafjorden	0 m	26.87	19.79	1989	27.51	1994
(7001–7002)	100 m	27.66	27.3	1989	27.96	1994
Inner Altafjorden	0 m	26.11	5.94	2006	27.55	1994
(7005–7006)	100 m	27.68	27.31	1989	28	1994
Refsbotn	0 m	27.24	26.57	1939	27.8	1970
(8001)	100 m	27.84	27.5	1933	28.56	1937
Outer Porsangerfjorden	0 m	27.32	26.53	1989	28.28	1968
(9001–9002)	100 m	27.84	27.44	1989	28.21	1956
Inner Porsangerfjorden	0 m	27.17	8.75	2008	27.79	1994
(9007–9008)	100 m	27.86	27.44	1989	28.48	1968
Østerbotn	0 m	26.63	21.31	1989	27.44	2007
(9009–9010)	100 m	27.67	27.39	1989	28.08	1994

The maximum recorded temperature in Inner Balsfjorden was 4.32°C (in the year 1934) and in Outer Balsfjorden it was 4.5°C(in the year 2012).

Figures 262, 263 [53] shows the inter annual variability of temperature in Inner and Outer Balsfjorden respectively. Both Inner and Outer stations showed similar trends in temperature. The warmest years in Balsfjorden were 1934, 1948 and 1989. Figure 263 [53] showes a decreasing trend during 1934–1936, 1983–1987, 1989–1999 and 2007–2011. Both stations showed an increase in temperature from 2011 to 2012.

3.3.2.2 *Salinity*

The monthly variations in salinities during the spring season in Outer and Inner Balsfjorden are shown in Figures 166 and 167 [51]. The surface salinity first increased and then decreased in May in both stations. The maximum surface salinity in Balsfjorden was at Inner Balsfjorden stations recorded in the year 1933 (35.11) and the minimum was also in Inner Balsfjorden in 1931(11.38). The maximum

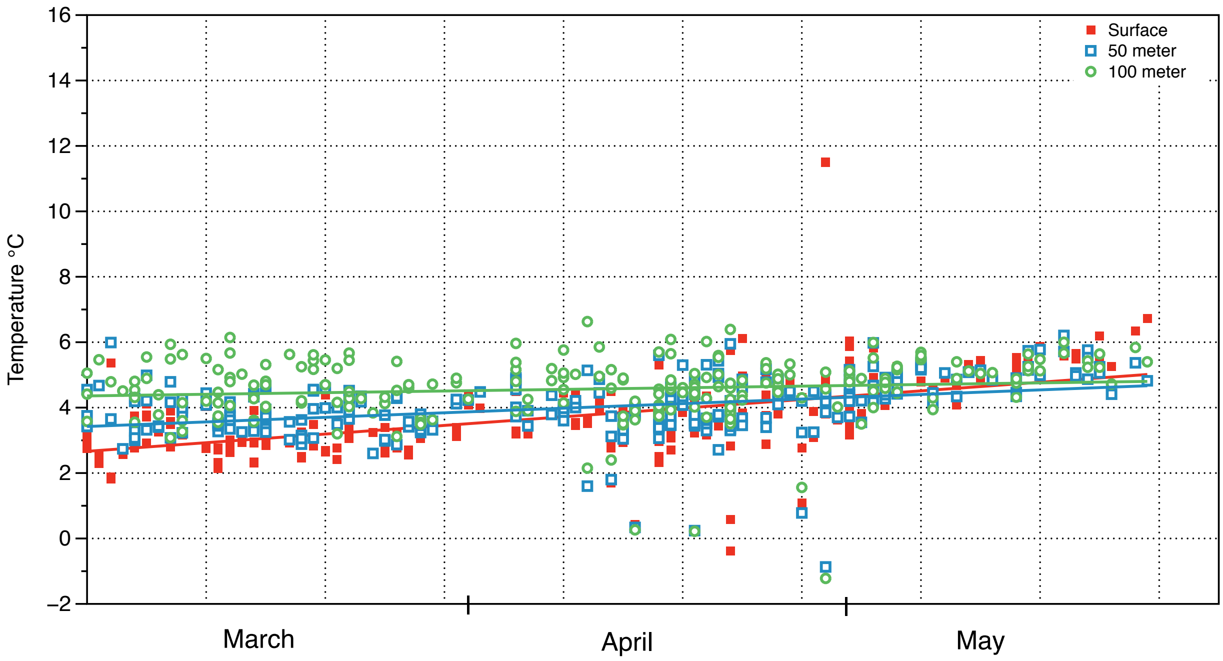


Figure 46: Monthly variability of spring temperatures (March – May) at station Outer Malangen

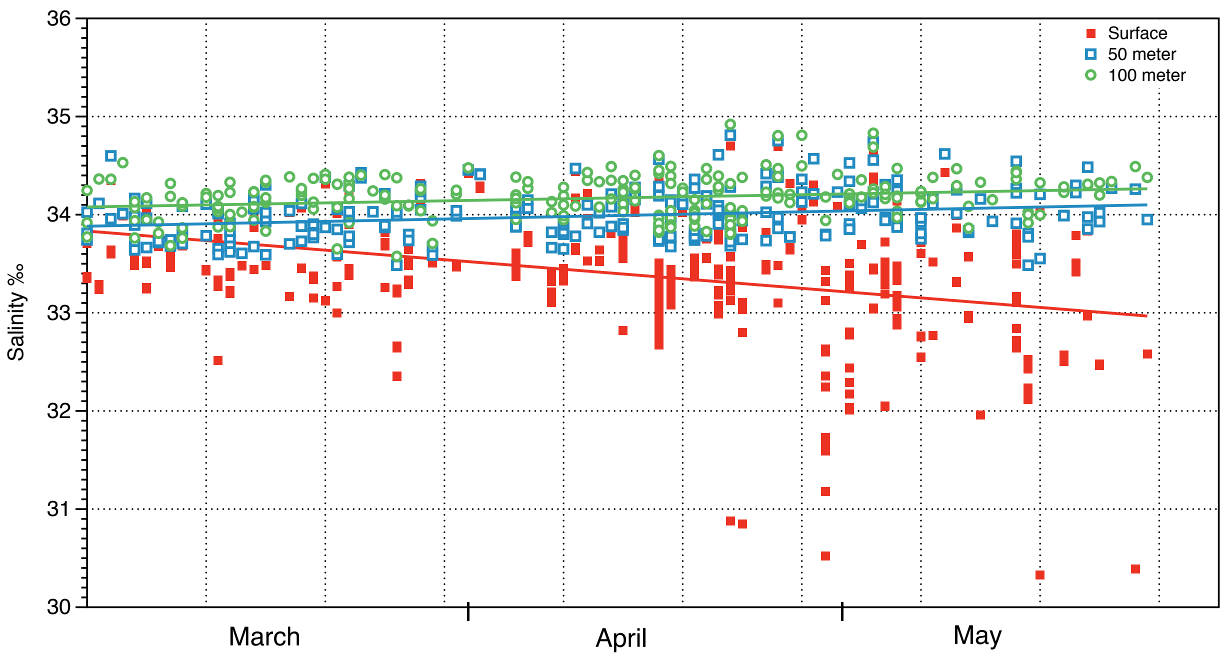


Figure 47: Monthly variability of spring salinity (March – May) at station Outer Malangen

salinity recorded at 100 m was at Inner Balsfjorden (35.22, year 1933) and the minimum was at Outer Balsfjorden in year 1994 (18.1) (Table 14). The mean surface salinity at Outer Balsfjorden was 32.52 and Inner Balsfjorden it was 32.44.

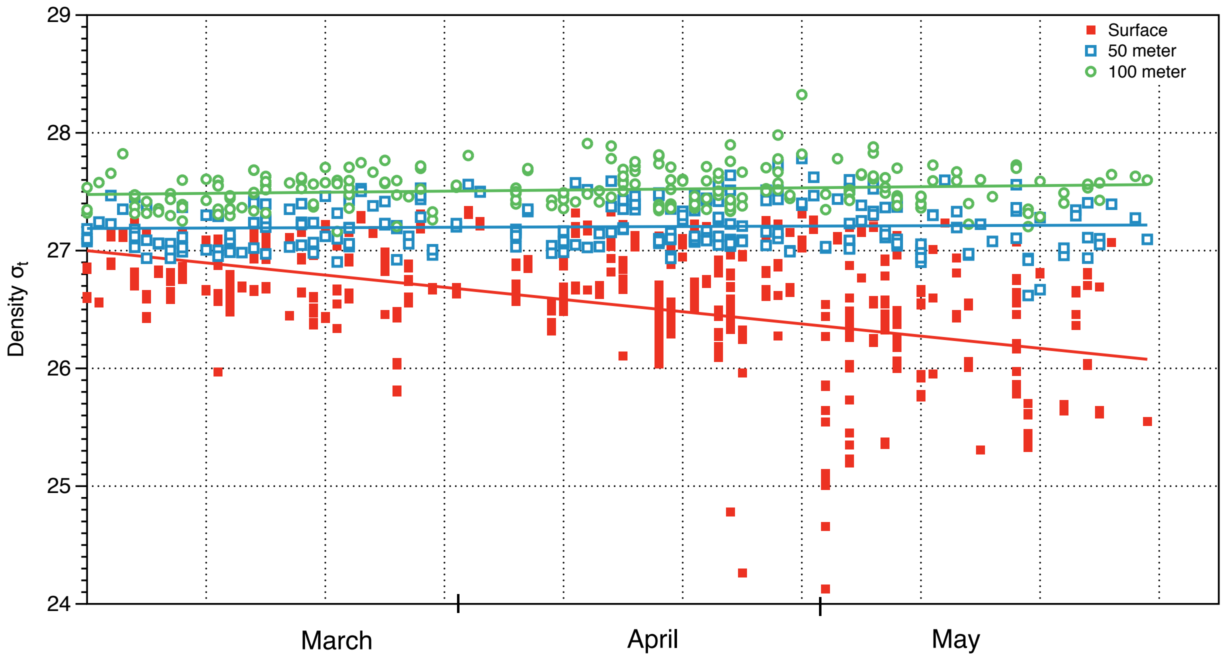


Figure 48: monthly variability of spring density (March – May) at station Outer Malangen

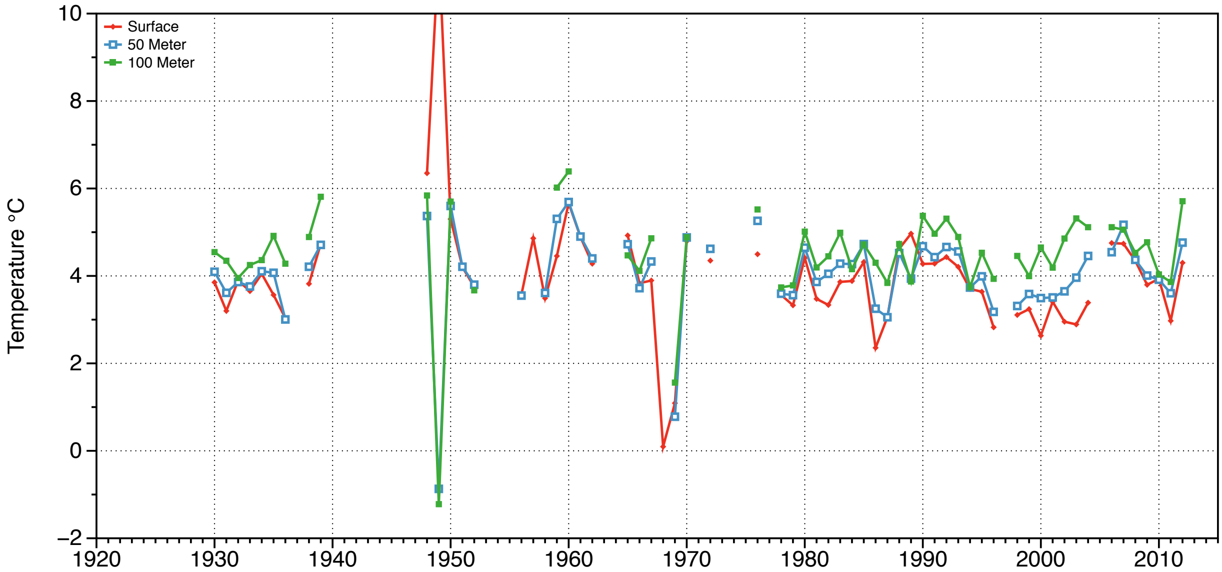


Figure 49: Interannual variability of spring temperatures (March – May) at station Outer Malangen

3.3.2.3 *Density*

Figures 214 and 215 [52] show the monthly variations in density during spring season. The mean surface density gradually decrease from March to May. The mean surface density in Balsfjorden was between 25.85–25.9 and at 100 m it was between 26.85–27.0 (Table 15). Minimum surface density of 9.09 was recorded at Inner Balsfjorden in the year 1931 and maximum surface density was recorded

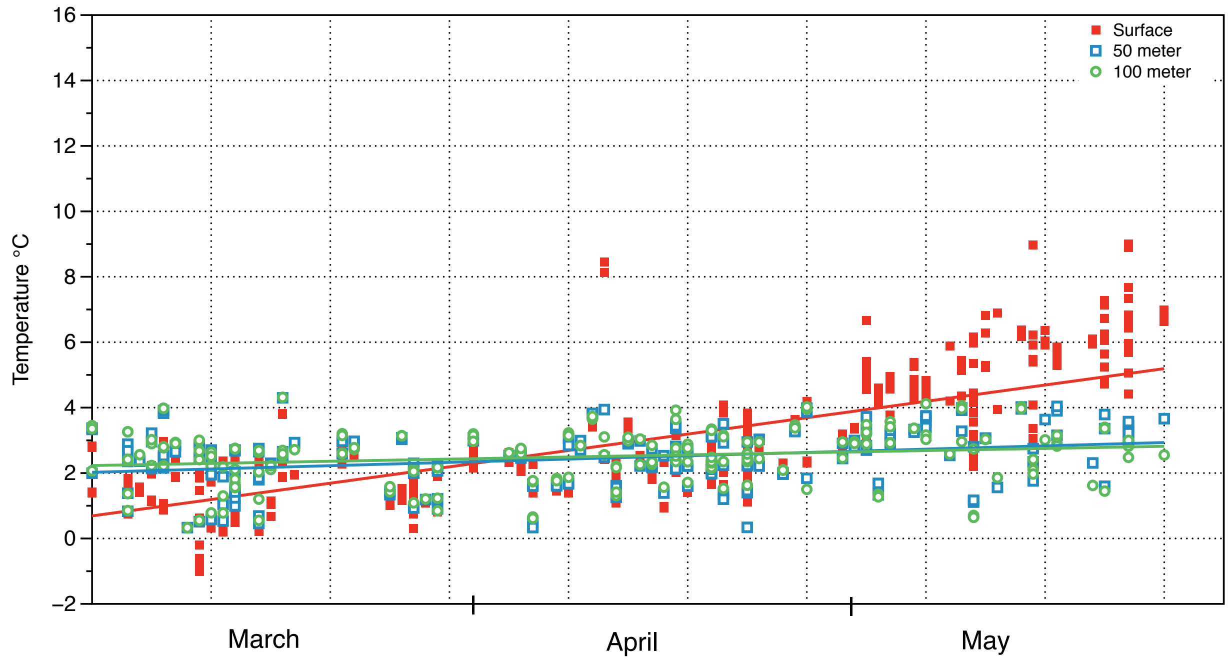


Figure 50: Monthly variability of spring temperatures (March – May) at station Inner Balsfjorden

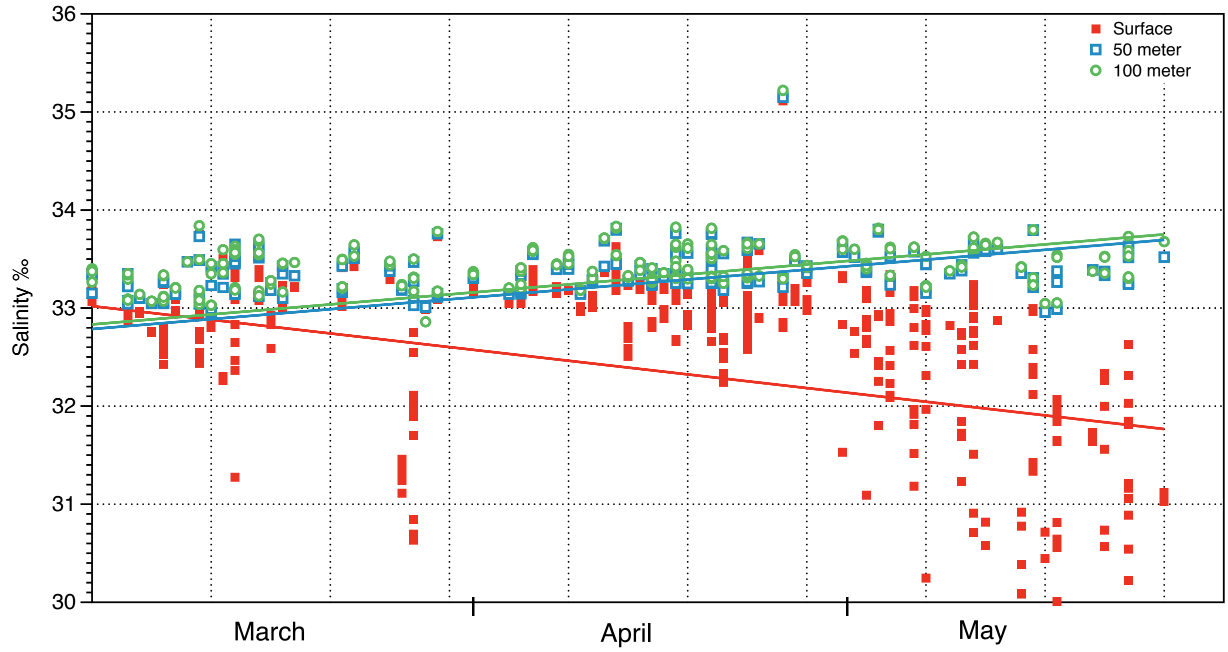


Figure 51: Monthly variability of spring salinity (March – May) at station Inner Balsfjorden

at Inner Balsfjorden (28.04) in 1933. At 100 m the highest density were at Inner Balsfjorden (28.61 , in the year 1933 and the lowest were at Outer Balsfjorden (14.96 , in the year 1994).

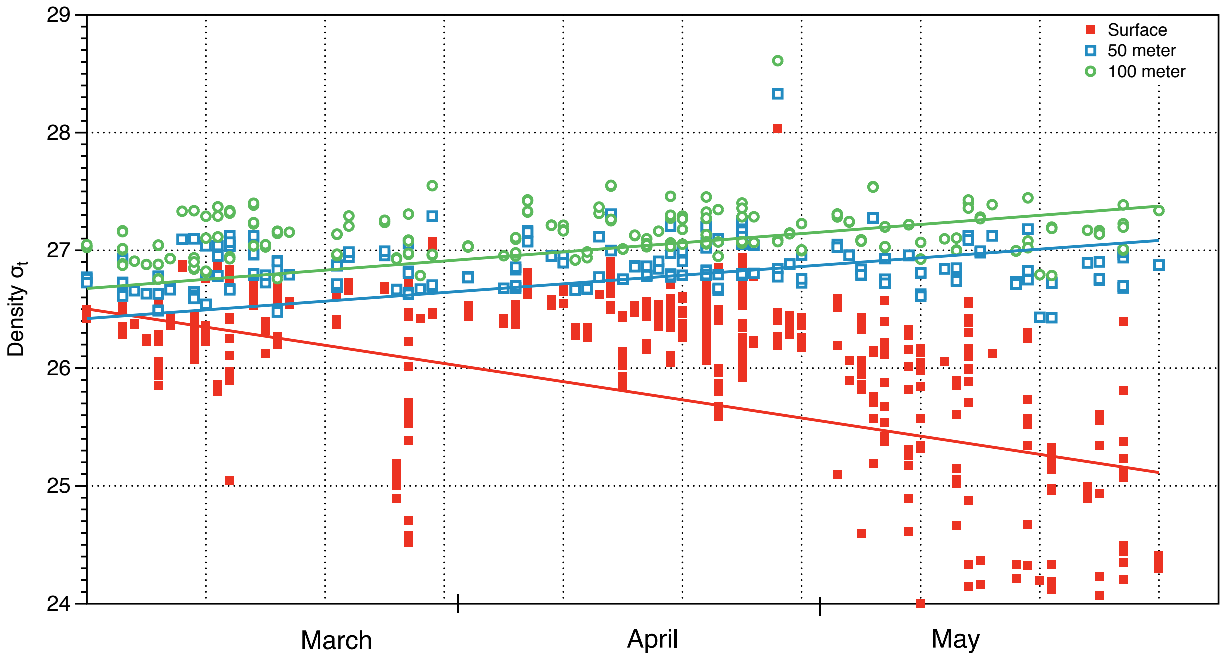


Figure 52: monthly variability of spring density (March – May) at station Inner Balsfjorden

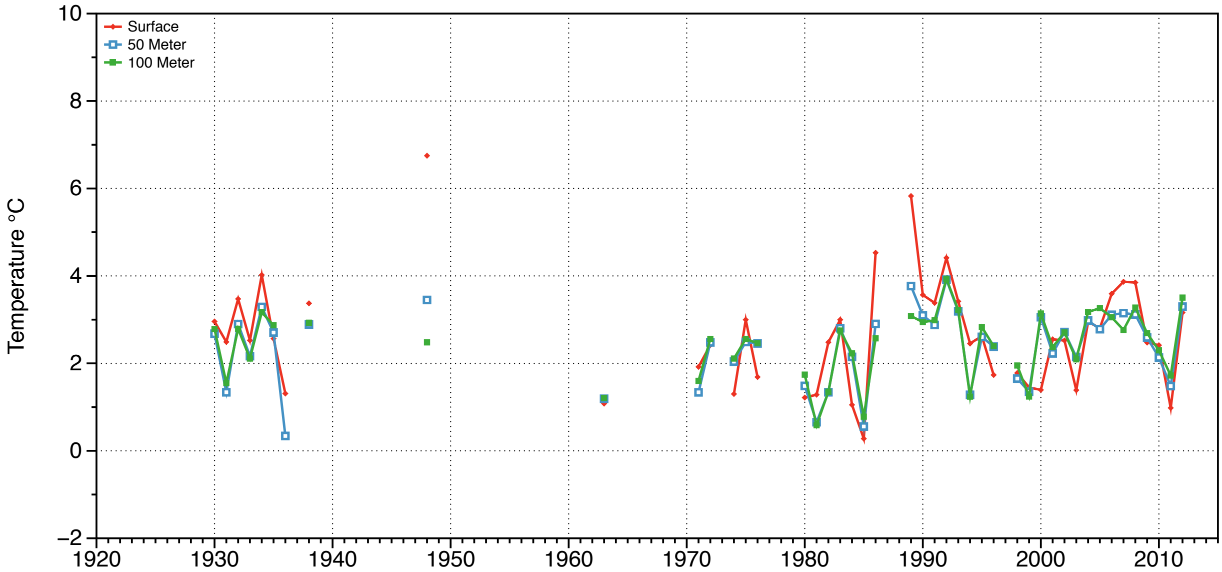


Figure 53: Interannual variability of spring temperatures (March – May) at station Inner Balsfjorden

3.3.3 *Altafjorden*

3.3.3.1 *Temperature*

Figures 122 [54], 123 shows the monthly variations in temperature at Altafjorden during the spring season. Similar to Malangen and Balsfjorden the temperature gradually increased from the beginning of March to the end of May. At the Outer station the surface temperature increased from 2°C to 4.8°C and at the Inner station it increased from 1°C to 5°C. The mean surface temperature at Altafjorden were between 2.92–3.25°C and at 100 m it were between 3.37–3.6°C (Table13).

The minimum and maximum surface temperatures recorded at Inner Altafjorden were -0.03°C (in the year 1987) and 7.6°C (in the year 2006, Table 13). At Outer Altafjorden it were 1.02°C (in the year 1980) and 7.06°C (in the year 2006). At 100 m depth, the minimum recorded temperature were 1.48°C (Inner Altafjorden, in the year 1998) and 1.42°C (Outer Altafjorden, in the year 1987). The highest recorded temperature at 100 m in the Inner and Outer Altafjorden were 5.95°C (in the year 2010) and 5.41°C (in the year 2010) respectively.

The inter annual variability of temperature at Outer and Inner Altafjorden are given in Figures 266 [57], 267. There were no remarkable difference in inner and outer stations. During 1930–1940 there was a decreasing trend. Both stations were lacking data during the period 1940 to 1980. From 1980 to 1983 the surface temperature increased and then it decreased again until 1987. There was a similar decreasing trend from 2006 to 2011. Similar to Balsfjorden after 2011 it started increasing again at both stations.

3.3.3.2 *Salinity*

The monthly variations in salinities during the spring season in Outer and Inner Altafjorden are shown in Figures 170 [55] and 171. The surface salinity in Altafjorden decreased from March to May in both Stations. Compared to the Outer station the range of surface salinity is higher Inner fjord. The mean surface salinity in Outer and Inner fjord were 33.74 and 32.76 respectively. Highest surface salinity (34.52) were at Outer Altafjorden in 1994 (Table 14).

3.3.3.3 *Density*

Figures 218 [56] and 219 show the monthly variations in density during spring season in Altafjorden. Both Inner and Outer fjords showed decrease in surface density from March to May. Maximum surface density (27.55) and maximum density at 100 m (28.0) were both in Inner Altafjorden. Mean surface density in Inner Altafjorden (26.11) is lower than the Outer Altafjorden (26.87, Table 15).

3.3.4 *Porsangerfjorden*

3.3.4.1 *Temperature*

All stations in Porsangerfjorden showed gradual increases in temperatures during the spring similar to Balsfjorden and Altafjorden. Figures 125 [58], 126 and 127 shows the monthly variations in tem-

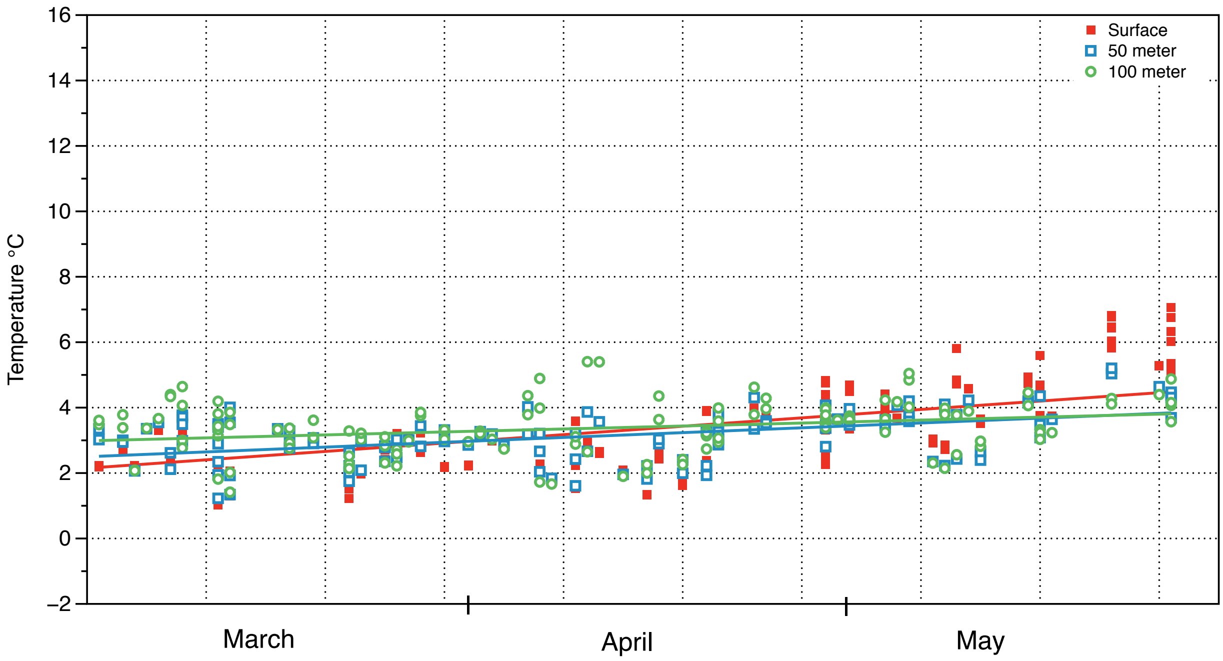


Figure 54: Monthly variability of spring temperatures (March – May) at station Outer Altafjorden

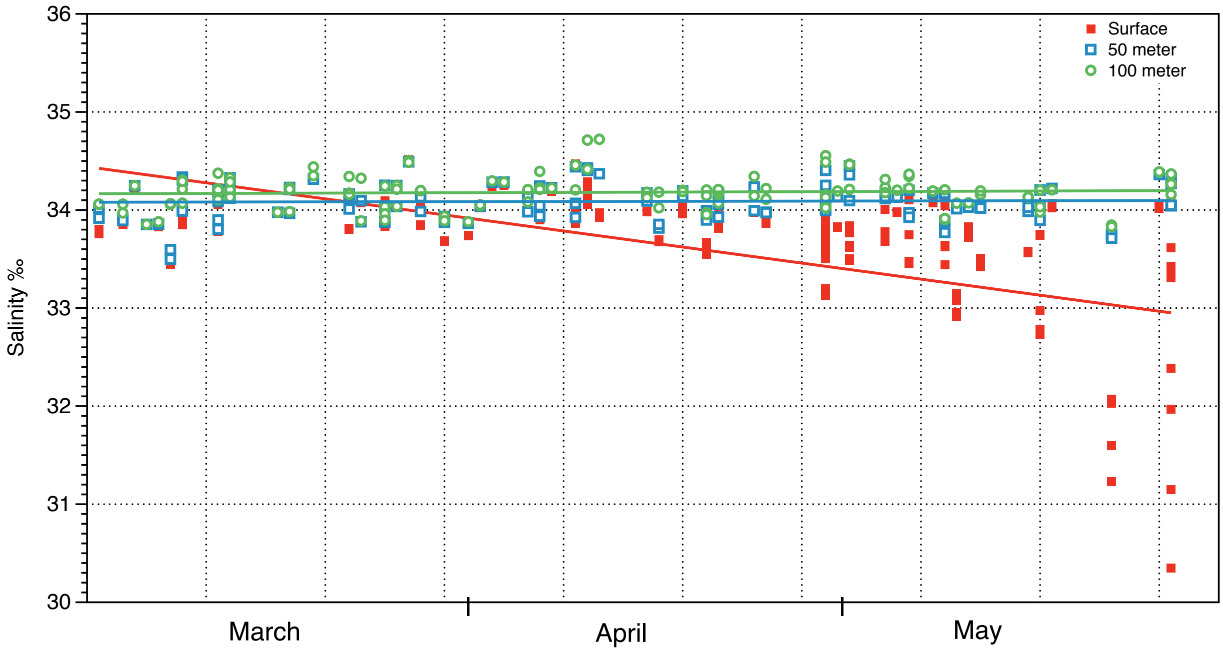


Figure 55: Monthly variability of spring salinity (March – May) at station Outer Altafjorden

perature at Outer Porsangerfjorden, Inner Porsangerfjorden and Østerbotn respectively. The Outer Porsangerfjorden showed an increase from 3°C to 4°C during this period while Inner Porsangerfjorden and Østerbotn showed an increase from -1°C to 3°C. Mean surface temperature at Outer Porsangerfjorden was 3.31°C and at Inner Porsangerfjorden it was 1.37°C. At Østerbotn it was the

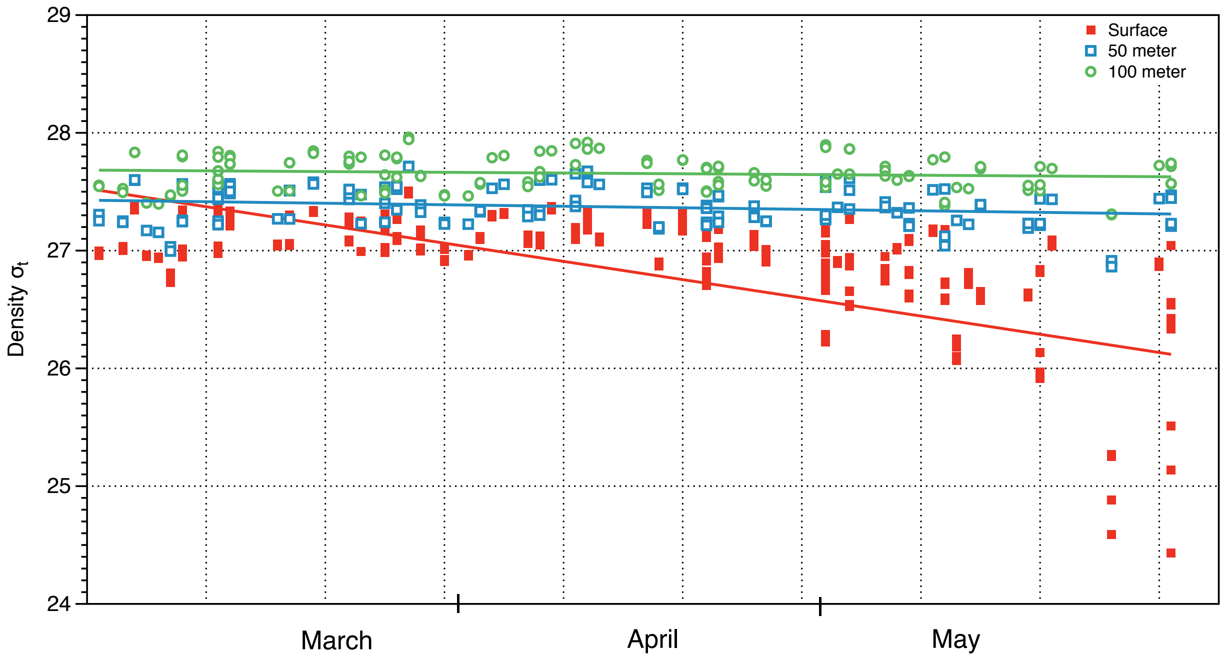


Figure 56: monthly variability of spring density (March – May) at station Outer Altafjorden

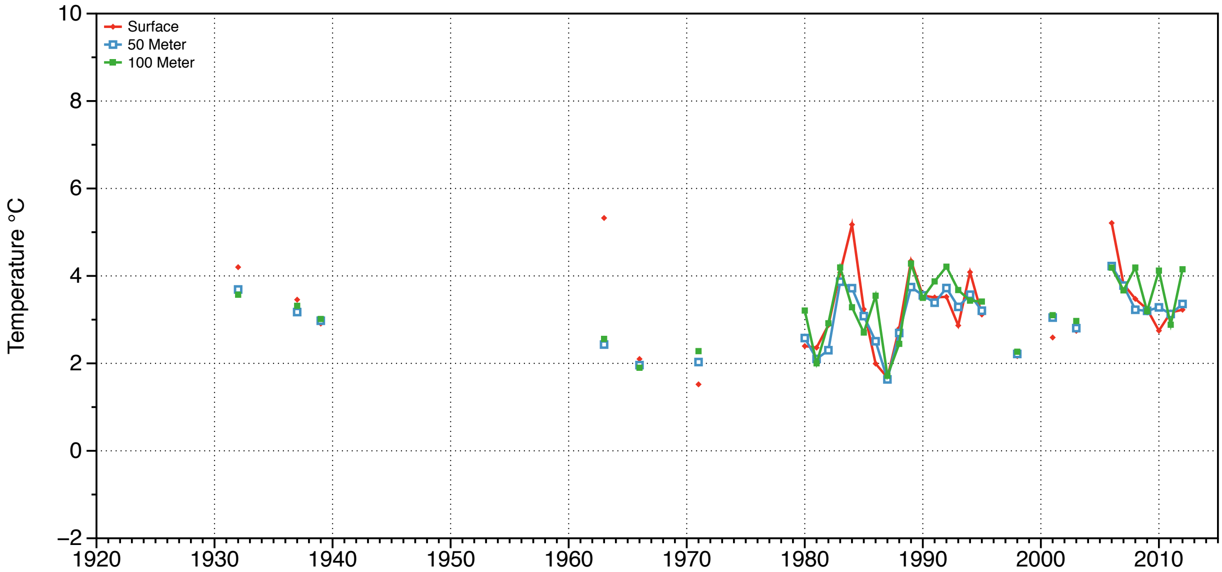


Figure 57: Interannual variability of spring temperatures (March – May) at station Outer Altafjorden

lowest among all the fjords (0.64°C). At 100 m also Østerbotn showed the lowest mean temperature (-0.83°C). At Inner Porsangerfjorden the mean temperature at 100 m was 1.2°C and at Outer Porsangerfjorden it was 3.37°C (Table 13).

The lowest surface temperature recorded at Porsangerfjorden was -1.77°C in the year 1995 at Østerbotn. The highest was in the year 2007 (7.21°C) at Inner Porsangerfjorden. At 100 m depth, the lowest and highest temperature recorded were in the year 2001 (-1.75°C, Østerbotn) and in the year 1989(5.63°C Outer Porsangerfjorden) (Table 13).

Figures 269 [61], 270 and 271 shows the yearly variations in spring temperature at Outer Porsangerfjorden, Inner Porsangerfjorden and Østerbotn respectively. Outer Porsangerfjorden has the best data coverage during this season. All three stations showed similar trend in inter annual temperature. The periods 1930–1933, 1955–1960, 1988–1991 and 2005-2006 were warm periods while1960–1967, 1985–1987, 1992–1998 and 2006–2010 had decreasing trends.

3.3.4.2 *Salinity*

The monthly variations in salinities during the spring season in Outer and Inner Porsangerfjorden are shown in Figures 173 [59] and 174. In Outer porsangerfjord the salinity variations during spring were very less. But the Inner fjord, similar to Altafjorden, showed a decrease in salinity from March to May. Mean surface salinity in Outer Porsangerfjorden was 34.32 and in Inner Porsangerfjord it was 33.95 (Table 14). Maximum surface salinity was 35.44 in Outer Porsangerfjorden in 1968.

3.3.4.3 *Density*

Figures 221 [60] and 222 show the monthly variations in density during spring season in Porsangerfjorden. Similar to salinity the variations in density in Outer station were less whereas the density in the Inner station showed a decreasing trend from March to May. Mean surface density Outer fjord was 27.32 and in Inner fjord it was 27.17 (Table 15). Highest surface density (28.28) was in Outer Porsangerfjord in 1968.

3.4 HYDROPHYSICAL CHARACTERISTICS IN THE AUTUMN SEASON

A summary of temperatures, salinities and densities during the autumn season are presented in Tables 16, 17 and 18. Additional tables are also provided in the Appendix.

3.4.1 *Malangen*

3.4.1.1 *Temperature*

During the autumn season, both Inner and Outer Malangen showed gradual decreases in surface temperature from September to October (Figures 140, 141 [62]). The amplitude of surface temperature at Inner Malangen during October was comparatively higher (8°C) than Inner Malangen (2°C). At Inner

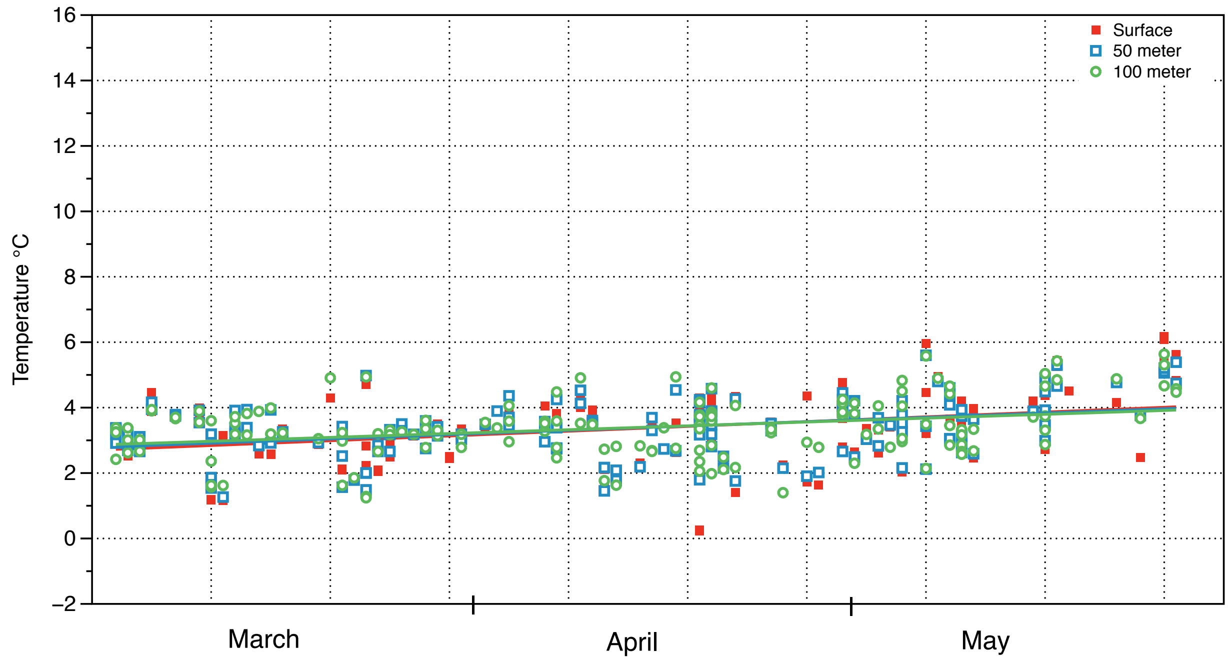


Figure 58: Monthly variability of spring temperatures (March – May) at station Outer Porsangerfjorden

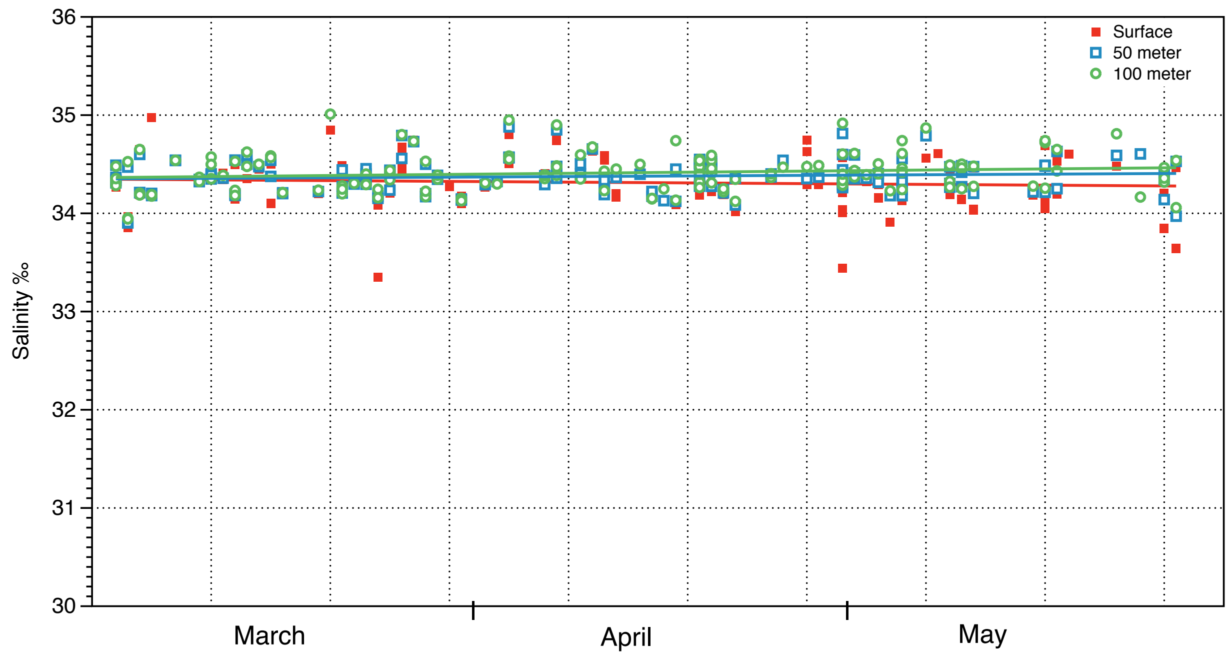


Figure 59: Monthly variability of spring salinity (March – May) at station Outer Porsangerfjorden

Malangen mean temperature at 50 m showed an increase of 1°C from September to October whereas at Outer Malangen there was no noticeable increase. Both stations showed a gradual increase at 100 m depth. The mean temperature at 100 m showed Inner stations are slightly warmer (1°C) than Outer stations.

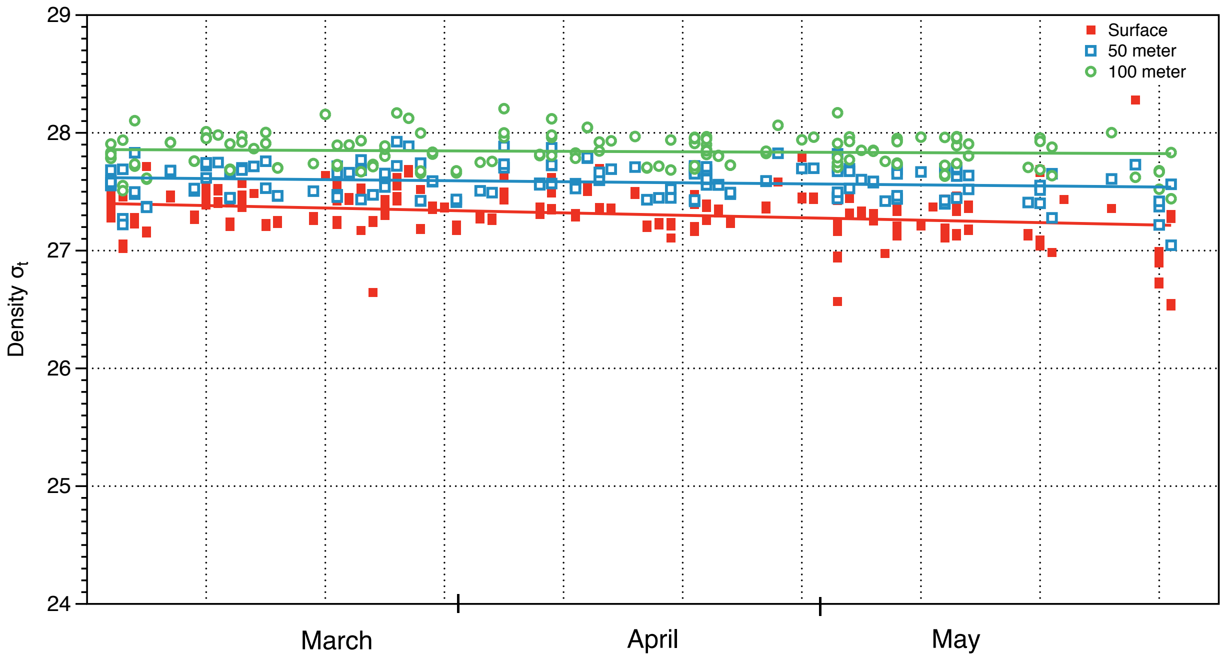


Figure 60: monthly variability of spring density (March – May) at station Outer Porsangerfjorden

The seasonal mean surface temperature during the autumn season at Inner Malangen was 7.88°C and at 100 m it was 6.78°C (Table 16). At Outer stations it was slightly higher 8.94°C at surface and 8.19°C at 100 m. During the autumn season, Outer Malangen showed the highest mean surface temperature (8.94°C) and highest mean temperature at 100 meter depth (8.19°C) among all the fjords (Table 16). The lowest surface temperature recorded at Malangen was 1.29°C (Inner Malangen, 1992) and highest was 12.53°C (Outer Malangen, 1990). At 100 m depth, lowest was 2.78°C (Outer Malangen, 1941) and highest was 9.75°C (Outer Malangen, 2009).

Figures 284, 285 [65] shows the inter annual variability of temperature at Inner and Outer Malangen respectively. Outer Malangen have more data coverage than Inner Malangen. At 50 m depth the coldest years were 1940-1942, 1978 and 1985-1986. There were no remarkable warmest years at 50 m except the year 1938. At surface, years 1938, 1965, 1967, 1968 and 19860–1990 showed temperature greater than 10°C. The main difference between the Outer and Inner Malangen were the temperature range between 50 m and 100 metres was generally 1°C higher than Outer Malangen.

3.4.1.2 *Salinity*

The monthly variations in salinity during autumn season at Outer and Inner Malangen are shown in Figures 188 and 189 [63]. There were no remarkable variations in mean salinity during autumn in any depths. The maximum surface salinity in Malangen was at Outer Malangen stations recorded in the year 1983 (34.28) and the minimum was at Inner Malangen in 2007 (9.63). The maximum salinity recorded at 100 m was at Inner Outer Malangen (34.65, year 1998) and the minimum was at Outer

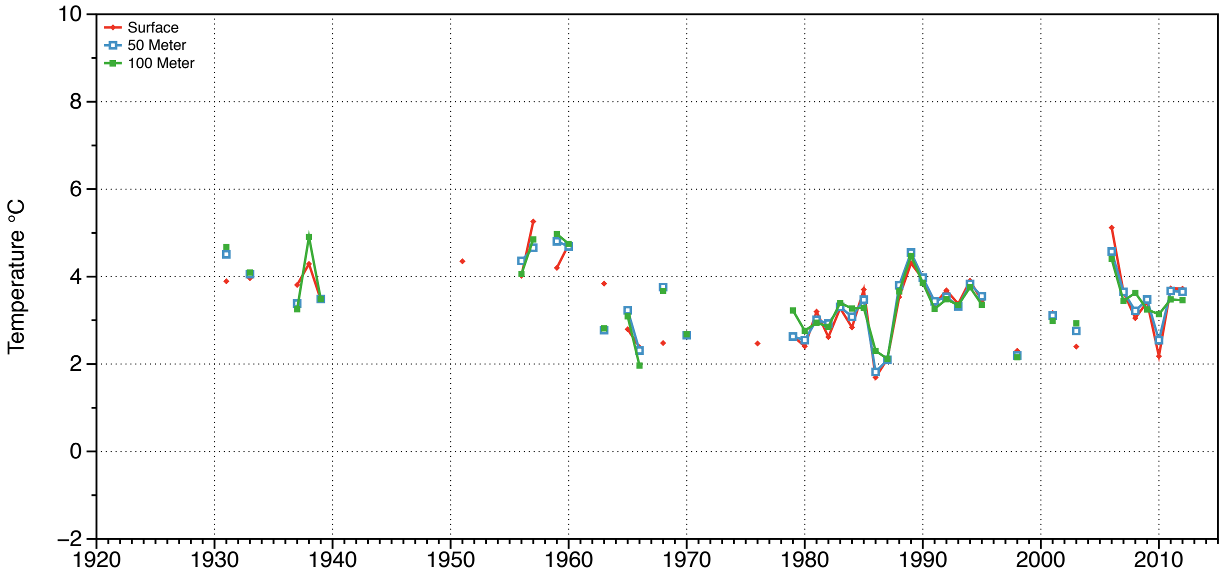


Figure 61: Interannual variability of spring temperatures (March – May) at station Outer Porsangerfjorden

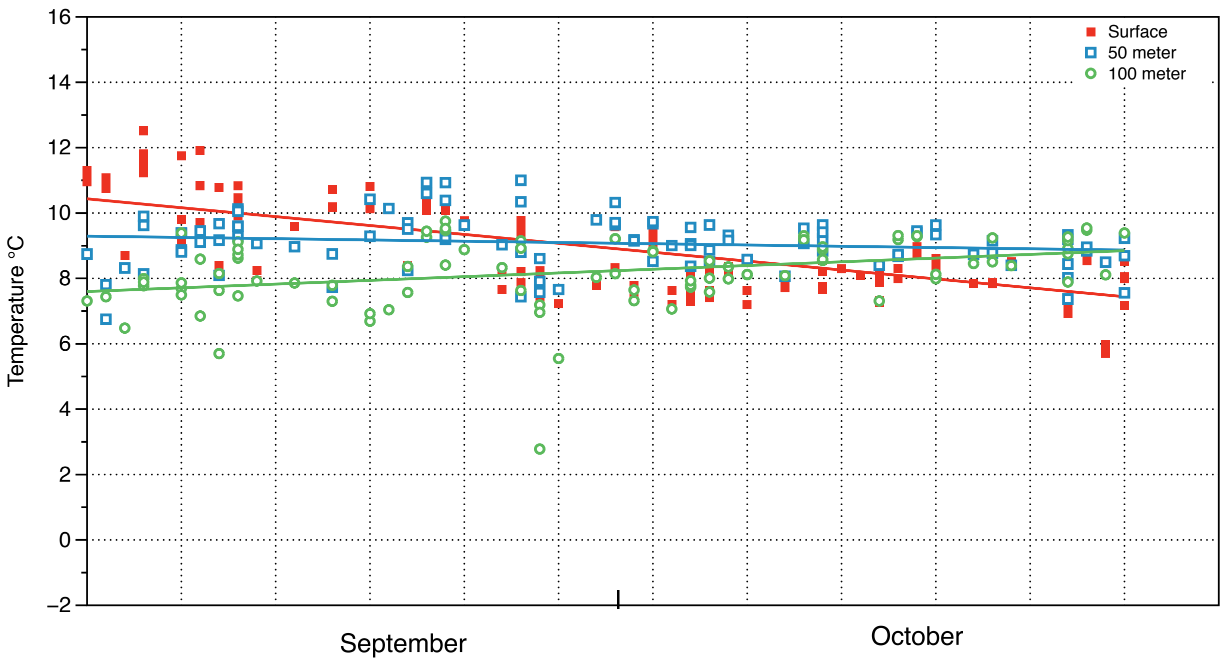


Figure 62: Monthly variability of autumn temperatures (September – October) at station Outer Malangen

Malangen in year 1990 (33.41) (Table 17). The mean surface salinity at Outer Malangen was 32.65 and Inner Malangen it was 29.86 .

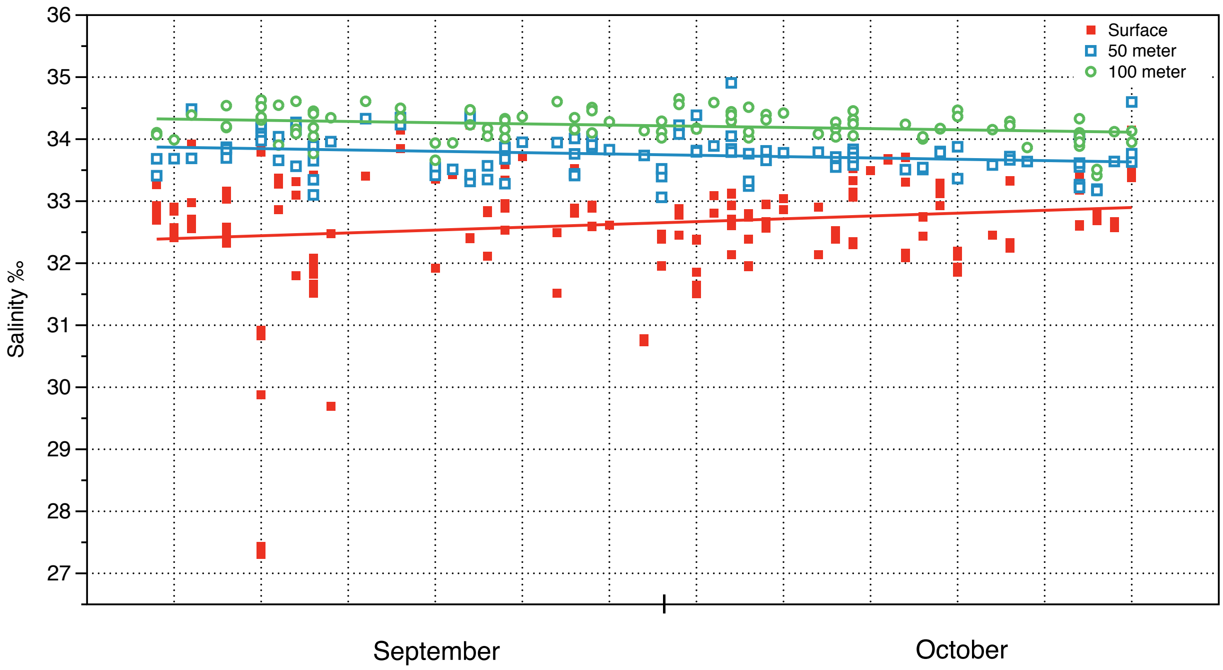


Figure 63: Monthly variability of autumn salinity (September – October) at station Outer Malangen

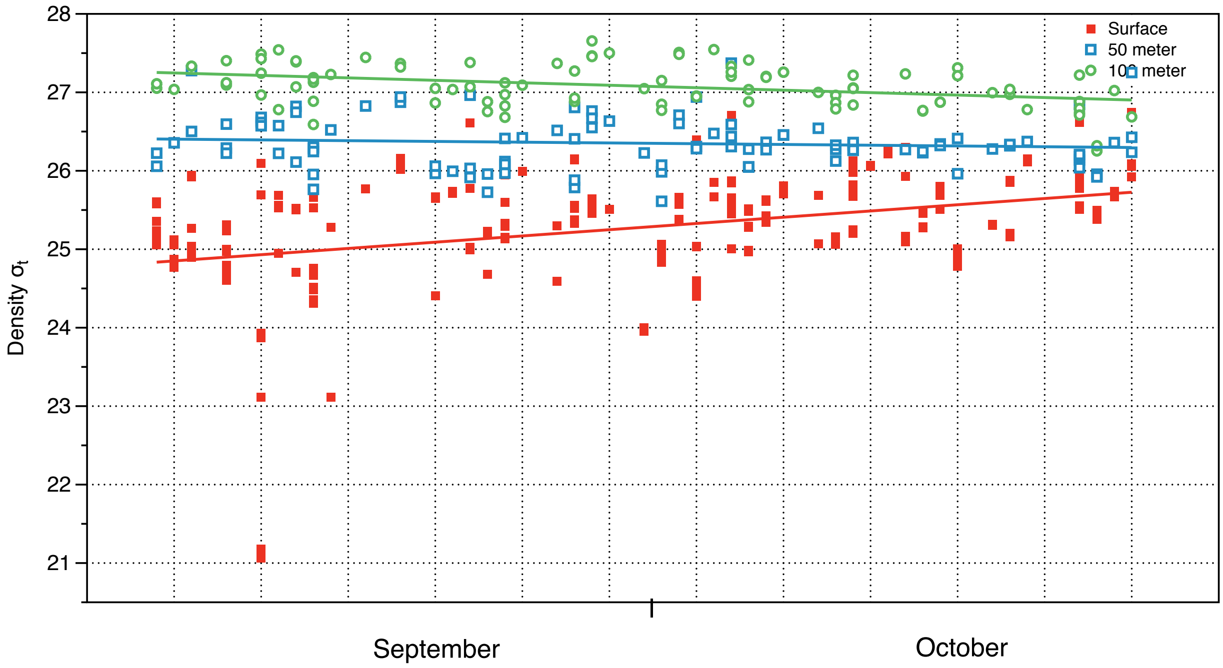


Figure 64: monthly variability of autumn density (September – October) at station Outer Malangen

3.4.1.3 *Density*

Figures 236 and 237 [64] show the monthly variations in density during autumn season. The mean surface density gradually increase from March to May. The mean surface density in Malangen was

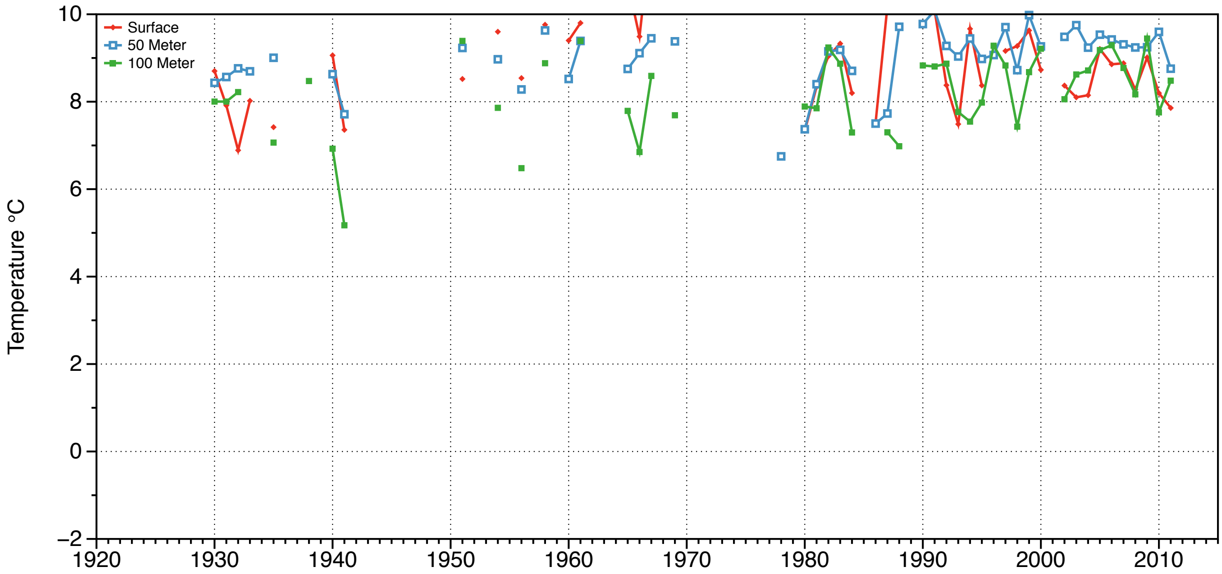


Figure 65: Interannual variability of autumn temperatures (September – October) at station Outer Malangen

between 23.25-25.29.57 and at 100 m it was between 27.08–27.09 (Table 18). Minimum surface density of 7.68 was recorded at Inner Malangen in the year 2007 and maximum surface density was recorded at Outer Malangen (26.74) in 1986. At 100 m the highest and lowest density were at Outer Malangen (27.66, in the year 1941 and 26.25, in the year 1990).

3.4.2 *Balsfjorden*

3.4.2.1 *Temperature*

Figures 142 and 143 [66] shows the temperatures at Outer and Inner Balsfjorden during autumn. Similar to Malangen, the mean surface temperature decreased from September to October in both Outer and Inner stations. The amplitude of surface temperature during this period was around 8.5°C at both stations. At Inner Balsfjorden the mean temperature at 50 m incased 0.5°C from September to October whereas at Outer Balsfjorden it decreased 0.5°C. At 100 m mean temperature slightly increased during this season (0.5-1.0°C). The amplitude of temperature at 50 m and 100 m were 2°C.

At Inner Balsfjorden, the mean surface temperature was 7.29°C and at 100 m it was 3.92°C (Table 16). At Outer Balsfjorden, it were 7.47°C and 4.54°C respectively. Balsfjorden showed the lowest mean temperature (3.92°C) at 100 m among all the fjords. The lowest temperature recorded at Balsfjorden were at Inner station 3.18°C in the year 1988. The highest temperature were at Outer Balsfjorden in the year 1990 (10.79°C , see Table 16).

The inter-annual variability of temperature during autumn at Outer and Inner Balsfjorden were shown in Figures 286 and 287 [69]. At Balsfjorden the range of average temperature at 100 meter

Table 16: Compilation of autumn temperatures (September – October) in the sampled fjords (°C)

Locality	Depth	Mean	Minimum	Coldest Year	Maximum	Warmest Year
Inner Malangen	0 m	7.88	1.29	1992	11.26	1990
(1003–1004)	100 m	6.78	4.76	1998	9.59	1990
Outer Malangen	0 m	8.94	5.71	1932	12.53	1990
(1006–1007)	100 m	8.19	2.78	1941	9.75	2009
Outer Balsfjorden	0 m	7.47	4.03	1980	10.79	1990
(2001–2002)	100 m	4.54	2.63	1981	5.68	2006
Inner Balsfjorden	0 m	7.29	3.18	1988	10.29	1990
(2004–2005)	100 m	3.92	2.34	1981	5.15	2006
Kvalsund	0 m	8.22	6.97	1988	9.64	1990
(3003)	100 m	7.68	5.51	1998	9.3	2009
Sørfjord	0 m	7.8	1.95	1998	9.47	1998
(5003)	100 m	2.79	1.52	1999	4.27	2006
Outer Altafjorden	0 m	7.99	5.6	1981	11.1	1995
(7001–7002)	100 m	7.29	4.74	1987	9.22	2009
Inner Altafjorden	0 m	7.47	2.76	1994	10.92	1995
(7005–7006)	100 m	6.38	3.83	1987	8.51	1990
Refsbotn	0 m	8.18	6.31	1980	10.56	1988
(8001)	100 m	7.5	6.27	1988	8.79	1946
Outer Porsangerfjorden	0 m	7.74	5.52	1981	9.23	1995
(9001–9002)	100 m	7.48	6.03	1963	8.73	1997
Inner Porsangerfjorden	0 m	6.73	4.37	1980	9.39	1998
(9007–9008)	100 m	6.59	4.63	1980	7.81	2002
Østerbotn	0 m	5.86	1.79	1996	9.35	1995
(9009–9010)	100 m	1.24	-0.97	1998	5.86	1981

and mean surface were 3°C which was higher than other fjords (1–1.5°C) excluding Østerbotn. The temperature at all depths were varied between years but there were no remarkable warming or cooling trend during this season. Years 1945, 1972, 1980, 1992, 2003, 2005 and 2008 were warmer (above 8°C). Temperature were less than 6°C in the years 1953, 1973, 1981 and 1982.

3.4.2.2 *Salinity*

The monthly variations in salinity during autumn season at Outer and Inner Balsfjorden are shown in Figures 190 and 191 [67]. There were no remarkable variations in mean salinity during autumn at 50 m and 100 m. The surface salinity increased from March to May at both stations. The maximum surface salinity in Balsfjorden was at Outer Balsfjorden stations recorded in the year 1980 (33.57) and the minimum was at Inner Balsfjorden in 1975 (20.87). The maximum salinity recorded at 100 m was at Inner Balsfjorden (33.78, year 1970) and the minimum was at Outer Balsfjorden in year 1988

Table 17: Compilation of autumn salinity (September – October) in the sampled fjords (‰)

Locality	Depth	Mean	Minimum	Least saline Year	Maximum	Most saline Year
Inner Malangen	0 m	29.86	9.63	2007	33.09	1998
(1003–1004)	100 m	33.97	33.5	1990	34.34	1998
Outer Malangen	0 m	32.65	27.3	1995	34.28	1983
(1006–1007)	100 m	34.22	33.41	1990	34.65	1998
Outer Balsfjorden	0 m	32	26.35	1997	33.57	1980
(2001–2002)	100 m	33.26	32.9	2002	33.57	2010
Inner Balsfjorden	0 m	31.65	20.87	1975	33.33	1980
(2004–2005)	100 m	33.3	32.69	1988	33.78	1970
Kvalsund	0 m	33.25	32.5	1988	33.79	2010
(3003)	100 m	33.97	33.64	1988	34.25	2004
Sørfjord	0 m	31.51	27.03	1998	33.32	1930
(5003)	100 m	33.67	33.37	2002	33.88	1948
Outer Altafjorden	0 m	32.92	25.12	1995	34.09	1980
(7001–7002)	100 m	34.02	33.62	1994	34.57	1980
Inner Altafjorden	0 m	31.91	20.34	1995	34.18	1986
(7005–7006)	100 m	33.93	33.6	1995	34.43	1940
Refsbotn	0 m	33.94	33.38	1947	34.88	1986
(8001)	100 m	34.37	33.8	1946	35.13	1960
Outer Porsangerfjorden	0 m	33.97	32.74	2007	34.7	1960
(9001–9002)	100 m	34.31	33.99	2001	35.12	1963
Inner Porsangerfjorden	0 m	33.44	31.51	2004	34.18	1980
(9007–9008)	100 m	34.09	33.84	2002	34.37	1970
Østerbotn	0 m	33	29.15	1971	33.94	1981
(9009–9010)	100 m	33.74	33.4	1990	34.31	1981

(32.69) (Table 17). The mean surface salinity in Outer Balsfjorden was 32.0 and Inner Balsfjorden it was 31.65.

3.4.2.3 *Density*

Figures 238 and 239 show the monthly variations in density during autumn season. The mean surface density gradually increase from March to May. The mean surface density in Balsfjorden was between 24.74–25 and at 100 m it was between 26.81–26.91 (Table 18). Minimum surface density of 16.53 was recorded in Inner Balsfjorden in the year 1975 and maximum surface density was recorded in Outer Balsfjorden (26.44) in 1980. At 100 m the highest density were in Inner Balsfjorden (27.35, in the year 1970 and the lowest were in Outer Balsfjorden (26.46, in the year 1990).

Table 18: Compilation of autumn density (September – October) in the sampled fjords (σ_t)

Locality	Depth	Mean	Minimum	Least dens Year	Maximum	Most dens Year
Inner Malangen	0 m	23.25	7.68	2007	25.89	1980
(1003–1004)	100 m	27.09	26.3	1990	27.49	1998
Outer Malangen	0 m	25.29	21.07	1995	26.74	1986
(1006–1007)	100 m	27.08	26.25	1990	27.66	1941
Outer Balsfjorden	0 m	25	20.65	1997	26.44	1980
(2001–2002)	100 m	26.81	26.46	1990	27.2	1994
Inner Balsfjorden	0 m	24.74	16.53	1975	26.32	1980
(2004–2005)	100 m	26.91	26.48	1988	27.35	1970
Kvalsund	0 m	25.88	25.37	1997	26.39	1993
(3003)	100 m	26.97	26.6	1990	27.46	1998
Sørfjord	0 m	24.57	21.59	1998	26.04	1930
(5003)	100 m	27.31	27.06	2002	27.5	1948
Outer Altafjorden	0 m	25.65	19.08	1995	26.85	1980
(7001–7002)	100 m	27.07	26.62	1990	27.65	1980
Inner Altafjorden	0 m	24.92	16.12	1995	26.82	1980
(7005–7006)	100 m	27.11	26.65	1990	27.63	1980
Refsbotn	0 m	26.43	25.91	1999	27.39	1986
(8001)	100 m	27.3	26.67	1946	28.04	1960
Outer Porsangerfjorden	0 m	26.52	25.43	2007	27.11	1980
(9001–9002)	100 m	27.27	26.91	2002	28.1	1963
Inner Porsangerfjorden	0 m	26.23	24.6	1971	27.07	1980
(9007–9008)	100 m	27.22	26.85	2002	27.65	1980
Østerbotn	0 m	26	22.77	1971	26.89	1980
(9009–9010)	100 m	27.49	27.04	1990	27.83	1969

3.4.3 *Altafjorden*

3.4.3.1 *Temperature*

Figures 146 and 147 [70] shows the monthly variations in temperature in Altafjorden during autumn season. Similar to Malangen and Balsfjorden the surface temperature gradually decreased from the beginning of September to end of October. At 50 m the mean temperature remained unchanged in Outer station and it increased 1°C during this period in Inner Altafjorden. Mean temperature at 100 m depth at both Inner and Outer Altafjorden were increased around 1°C. Figures 143, 144 shows the mean temperatures at all depths at Outer Altafjorden were warmer than Inner Altafjorden. During the month of October the amplitude of surface temperature at Inner Altafjorden was 7.5°C whereas at Outer fjord it was 3.3°C.

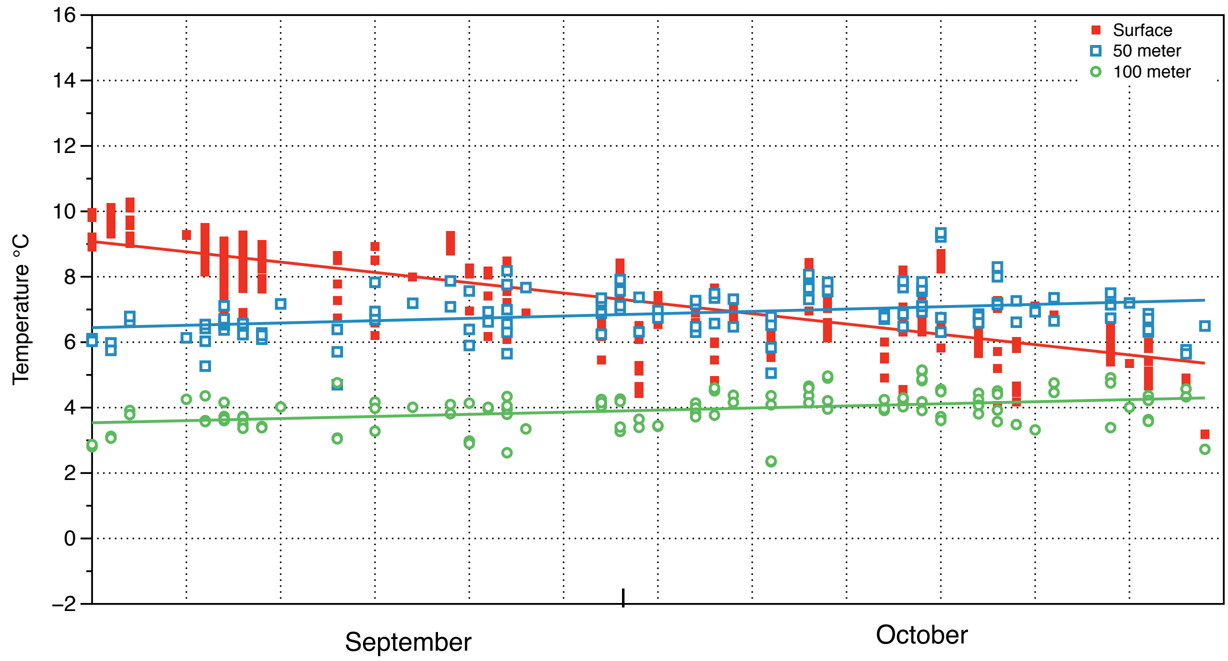


Figure 66: Monthly variability of autumn temperatures (September – October) at station Inner Balsfjorden

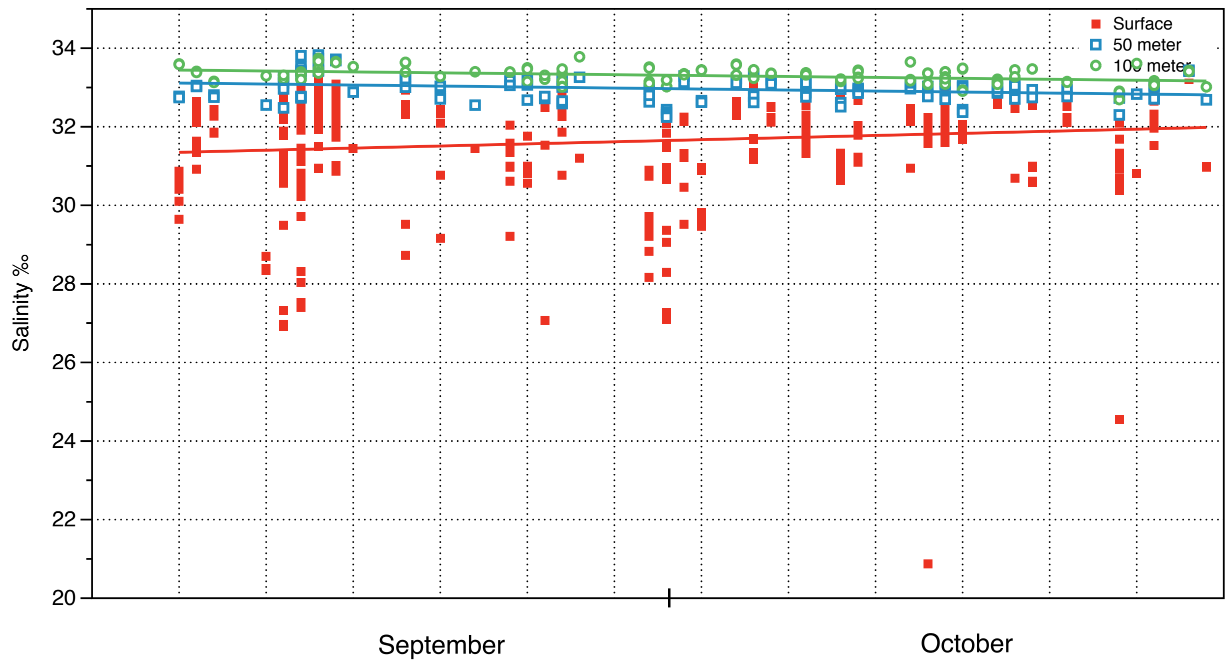


Figure 67: Monthly variability of autumn salinity (September – October) at station Inner Balsfjorden

During the autumn season, the mean surface temperature at Outer Altafjorden was 7.99°C and at 100 m it was 7.29°C. At Inner station mean temperatures were 7.47°C and 6.38°C respectively (Table 16). The lowest surface temperature was recorded at Inner Altafjorden (2.76°C, 1994) and the

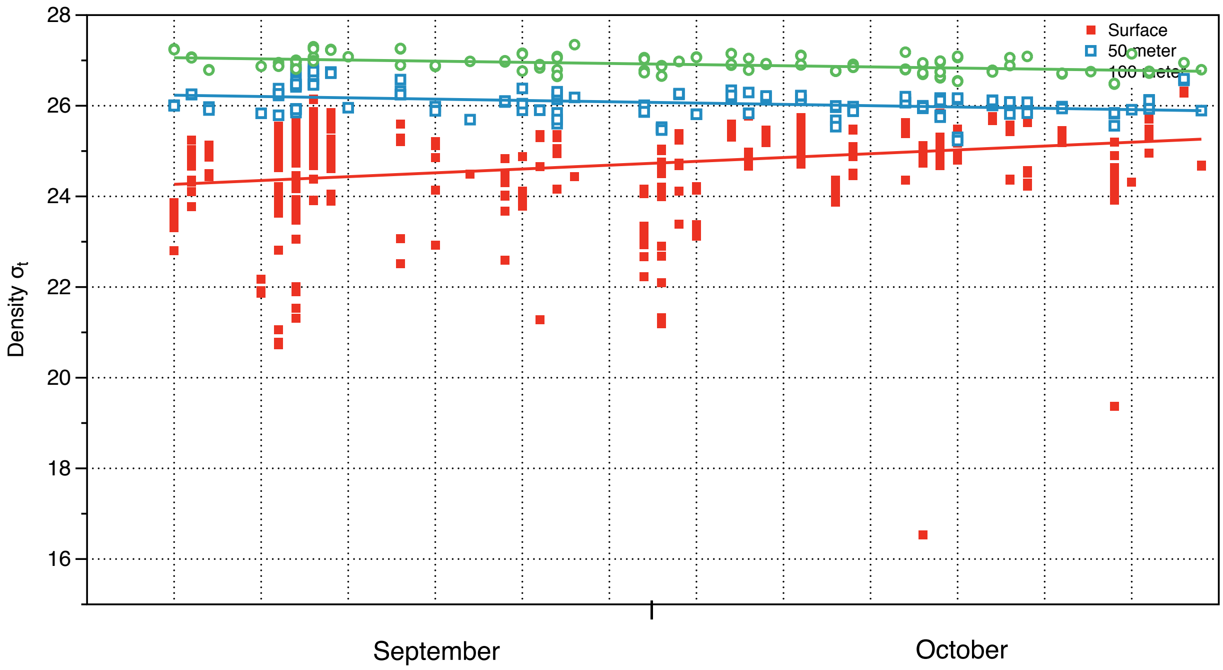


Figure 68: monthly variability of autumn density (September – October) at station Inner Balsfjorden

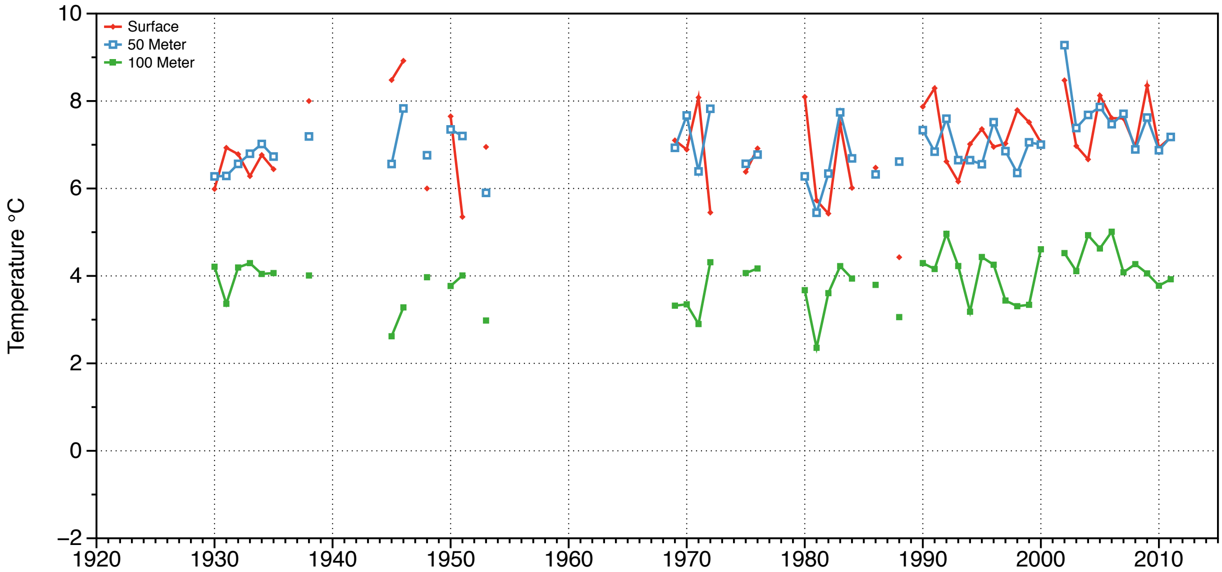


Figure 69: Interannual variability of autumn temperatures (September – October) at station Inner Balsfjorden

highest was at Outer Altafjorden (11.1°C, 1995). Similarly at 100 m the lowest temperature was at Inner Altafjorden (3.83°C, 1987) and highest was at Outer Altafjorden (9.22°C, 2009).

During the autumn season the Outer Altafjorden were comparatively warmer than Inner Altafjorden at 100 m depth (Figures 290 and 291 [73]). Interannual variability at surface and 50 m were similar at Inner and Outer stations. There were no strong cooling or warming trend noticeable during this period.

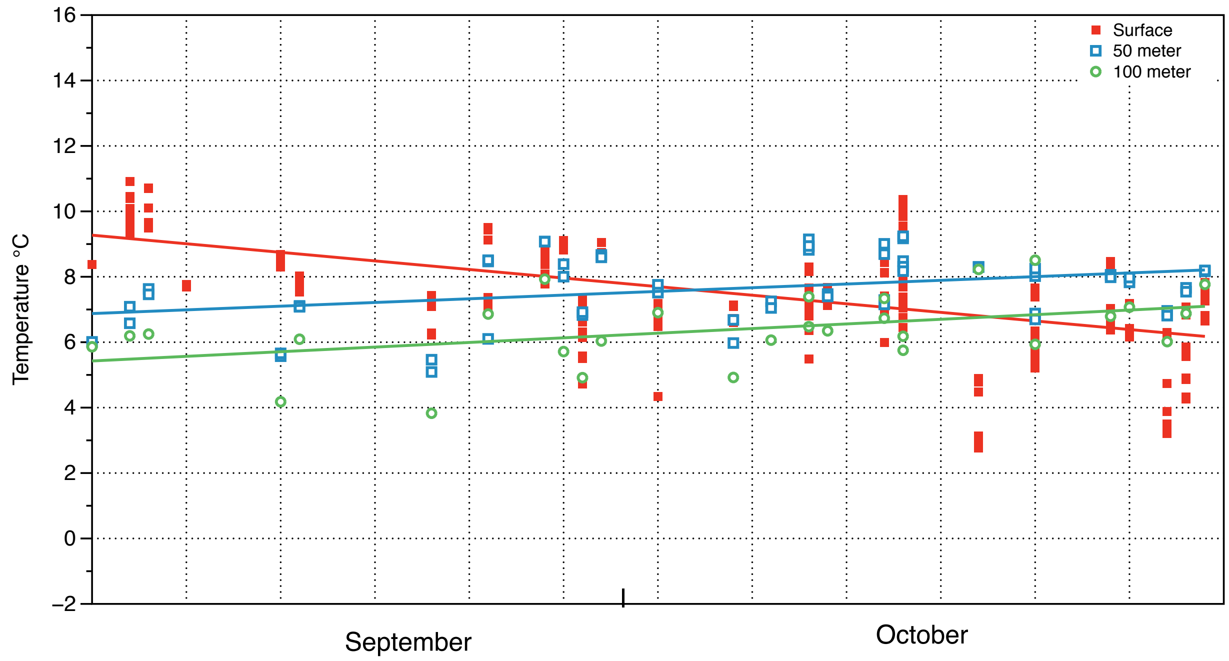


Figure 70: Monthly variability of autumn temperatures (September – October) at station Inner Altafjorden

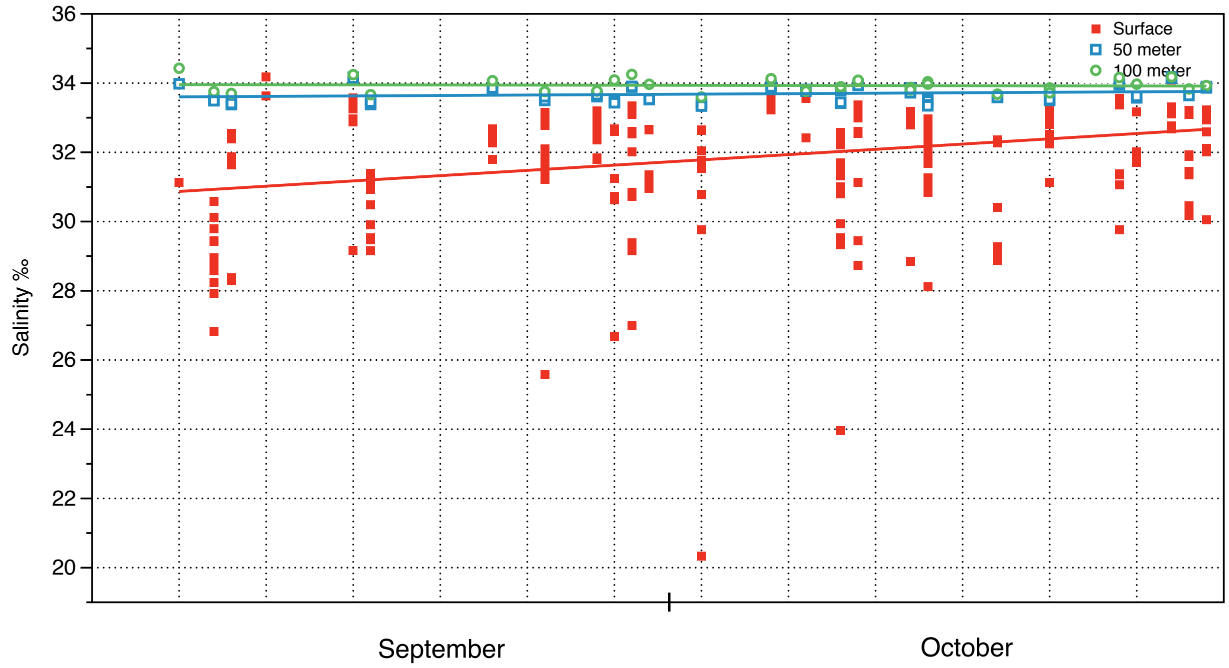


Figure 71: Monthly variability of autumn salinity (September – October) at station Inner Altafjorden

3.4.3.2 *Salinity*

The monthly variations in salinities during the autumn season in Outer and Inner Altafjorden are shown in Figures 194 and 195 [71]. The surface salinity increased from September to October in

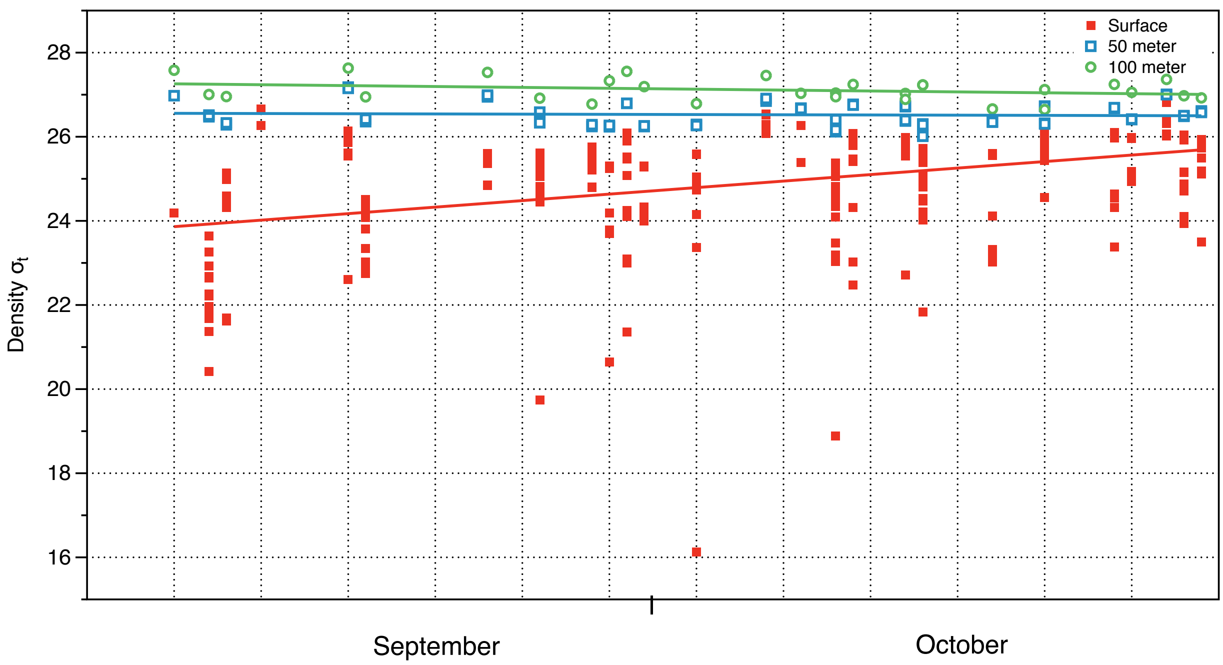


Figure 72: monthly variability of autumn density (September – October) at station Inner Altafjorden

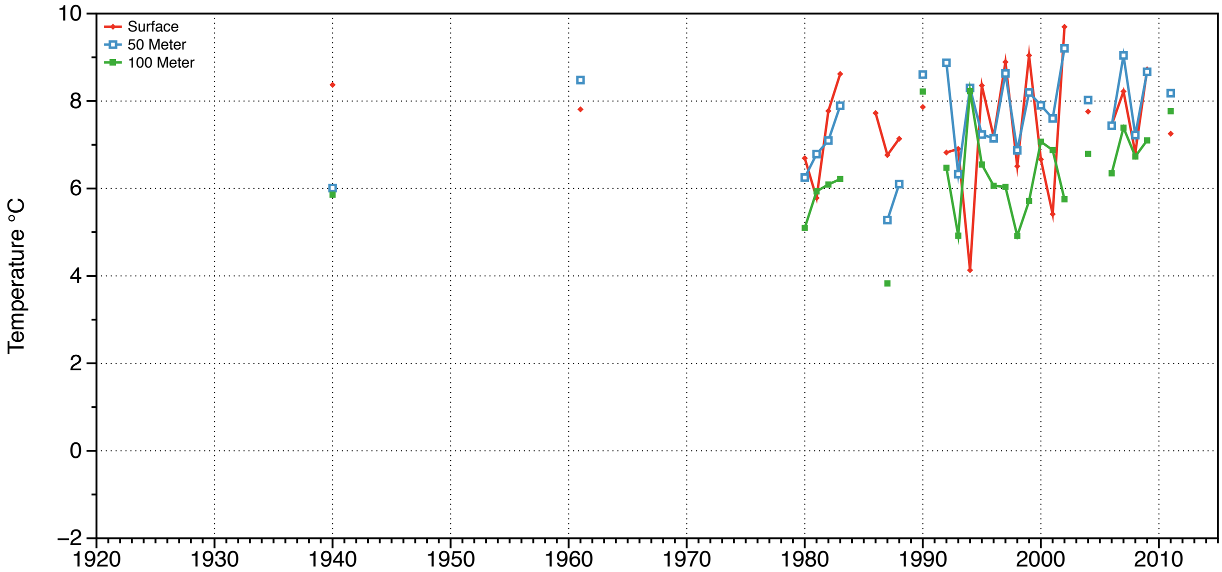


Figure 73: Interannual variability of autumn temperatures (September – October) at station Inner Altafjorden

both stations. The were no noticeable variations in salinity at 50 m and 100 m. Mean surface salinity in Outer fjord was 32.92 and in Inner fjord was 31.91 (Table 17). Highest salinity was in Inner Altafjorden (34.18) in 1986.

3.4.3.3 *Density*

Figures 242 and 243 [72] show the monthly variations in density in Altafjorden during autumn season. From September to October both Inner and Outer stations showed an increase in density. Minimum measured surface density was at Inner Altafjorden in 1995 (16.12) and the maximum surface density was at Outer fjord in 1980 (26.85, Table 18). Mean surface density in the Inner fjord was 24.92 and it was 25.65 in Outer fjord.

3.4.4 *Porsangerfjorden*

3.4.4.1 *Temperature*

Figures 149 [74], 150 and 151 show the monthly variations in temperature at Outer Porsangerfjorden, Inner Porsangerfjorden and Østerbotn respectively. The mean surface temperature at all stations in Porsangerfjorden showed similar trend like southern fjords. The mean surface temperature at Outer Porsangerfjorden decreased from 9°C to 7°C and at Inner Porsangerfjorden it decreased from 8.2°C 5.6°C from the Beginning of September to October. At Østerbotn, the decrease in surface temperature is more. It decreased from 8.2°C to 4.6°C during this season. At 50 m, Inner and Outer Porsangerfjorden showed a decrease in mean temperature but it was less than 0.5°C. Meanwhile at Østerbotn it increased 1°C during this period. The mean temperature at 100 m depth from September to October were increased by 0.5°C in Inner Porsangerfjord and Østerbotn.

The mean surface temperature and mean temperature at 100 m were decreased towards inner part of the fjord (Table 16). At Outer Porsangerfjorden, Inner Porsangerfjorden and Østerbotn the mean surface temperature were 7.74°C, 6.73°Cand 5.86°C respectively. Østerbotn showed lowest mean temperature at 100 meter (1.24°C) among all fjords.The lowest surface temperature recorded at Porsangerfjorden was 1.79°C in the year 1996 at Østerbotn. The highest was in the year 1998 (9.39°C) at Inner Porsangerfjorden. At 100 m depth, the lowest and highest temperature recorded were in the year 1998 (-0.97°C, Østerbotn) and in the year 1997(8.73°C Outer Porsangerfjorden) (Table 16).

Figures 293 [77], 294 and 295 show the yearly variations in autumn temperature at Outer Porsangerfjorden, Inner Porsangerfjorden and Østerbotn respectively. Outer and Inner Porsangerfjorden had similar trends in mean seasonal temperature. The warmest years in Outer Porsangerfjorden were 1945, 1955, 1964, 1984, 1990, 1995,1997, 1999, 2007 and 2010. The inter annual variability in seasonal temperature at Østerbotn is different from Inne and Outer Porsangerfjorden. The range of mean temperature between surface and 100 m were comparatively higher (2°C) in Østerbotn. The warmest years in Østerbotn were 1961, 1983, 1992, 1995, 1998 and 2010.

3.4.4.2 *Salinity*

The monthly variations in salinities during the autumn season in Outer and Inner Porsangerfjorden are shown in Figures 197 [75] and 198. Similar to Altafjorden, the surface salinity in Porsangerfjorden increased from September to October. Mean surface salinity in Outer Porsanger fjord was 33.97 and it was 33.44 in Inner Porsangerfjorden (Table 17). Highest measured surface salinity was in Outer Porsangerfjord (34.7) in 1960 and lowest measured surface salinity was in Inner Porsangerfjord (31.51) in 2004.

3.4.4.3 *Density*

Figures 245 [76] and 246 show the monthly variations in density during autumn season in Porsangerfjorden. The surface density in both Outer and Inner fjords showed an increasing trend from September to October in Porsangerfjorden. The mean surface density was 26.52 in Outer Porsangerfjorden and it was 26.33 in Inner Porsangerfjorden. The range of density variations were higher in Inner Porsangerfjorden. The lowest surface density was in Inner Porsangerfjord in 1971 (24.6) and highest surface density was in Outer Porsangerfjord (27.11) in 1980 (Table 18).

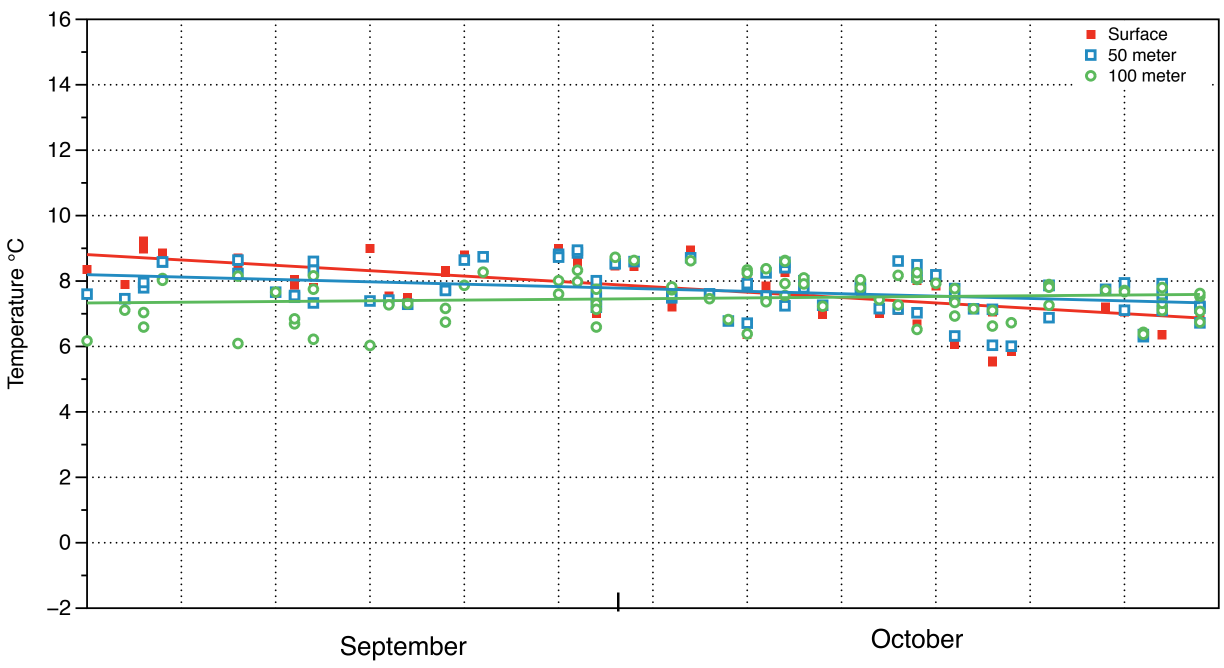


Figure 74: Monthly variability of autumn temperatures (September – October) at station Outer Porsangerfjorden

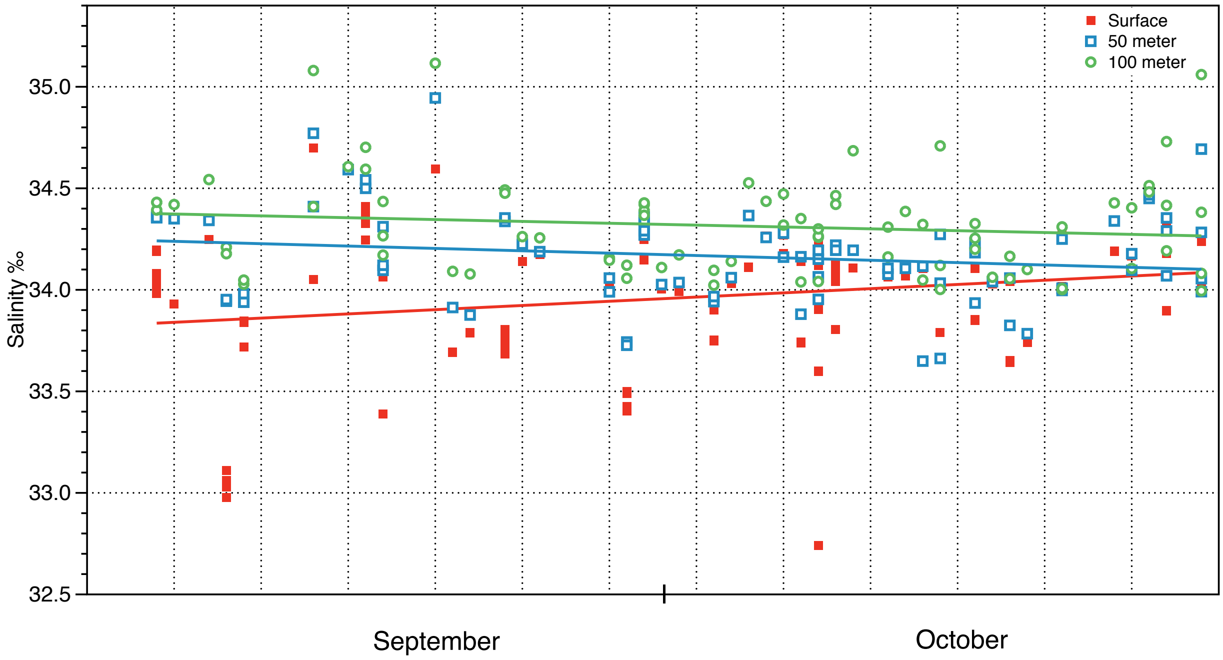


Figure 75: Monthly variability of autumn salinity (September – October) at station Outer Porsangerfjorden

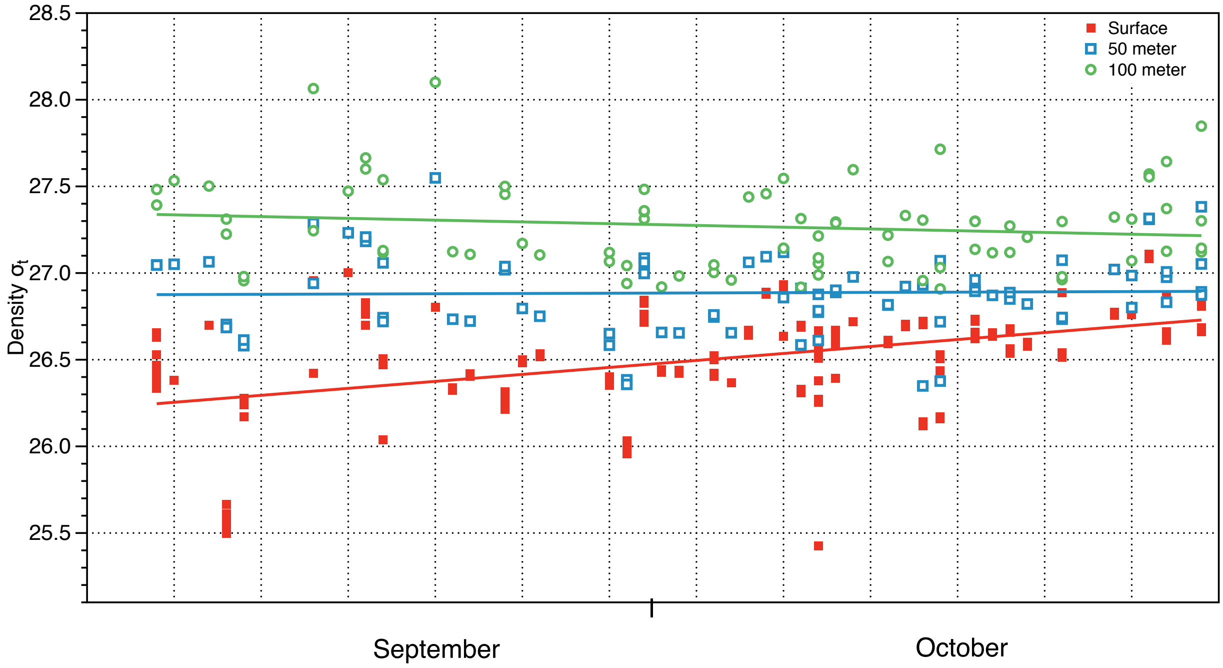


Figure 76: monthly variability of autumn density (September – October) at station Outer Porsangerfjorden

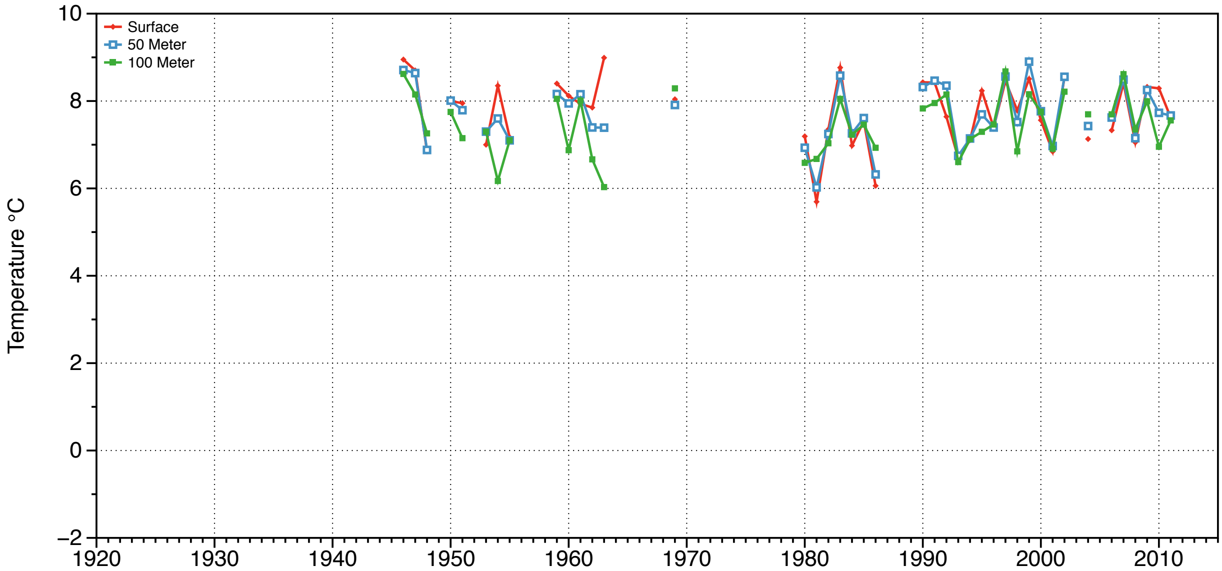


Figure 77: Interannual variability of autumn temperatures (September – October) at station Outer Porsangerfjorden

4

DISCUSSION

4.1 INTRODUCTION TO THE DISCUSSION

This PhD presentation is special in that it deals with environmental data that stretches over large areas and especially over a long period of time, i.e. in fact from 1870 until present, though with some discontuities for some locations in the data series. In terms of human comprehension of time this is maybe not so long (three generations), but in terms of evolution of science this represents quite a jump. To this enormous gain in scientific knowledge that has been achieved the last 150 years also adds a close to exponential development in instrumentation and interpretation techniques, modeling of ocean processes, satellite imagery etc (Schlee, 1975; Mills, 2011). More detailed "conceptual" models that helps the overall understanding of how the ocean systems works has also been added, e.g. the (though now disputed) Conveyor belt theory (Rahmstorf, 2003) and the North Atlantic Oscillation shifts (Hurrell, 1995).

The first data sets (from 1870, only temperature) in this presentation were collected two years before the "Challenger" (1872 – 1876) around-the-world oceanographic expedition with the focus to study grounds of the ocean floor, bottom topography in addition to biological, chemical and physical characteristics of all ocean waters. The findings of the Challenger expedition took 70 scientists 20 years to work up, and represented a new era in the understanding of the physics as well as chemistry and biology of the oceans (Hoyle, 1885). This new knowledge triggered numerous similar hydrophysical investigations. Also, several voyages to Arctic areas had indicated that in the summer period they were sometimes accessible to ships. This resulted in the defining of potential shipping routes to the Pacific. Nordenskiöld, the Swedish polar researcher successfully accomplished this navigation and from Norway to the Bering Strait he headed the expedition between 1878 and 1879 on the ship "Vega". Today this is still an issue of great interest since it potentially can shorten the travel time to Asia. For easy understandable reasons research on the physical oceanography (temperature) of northern areas have also nowadays a high priority (Carmack, 1990).

Succeeding the "Challenger" expedition, Norwegian scientists started to explore the North Atlantic. The vessel "Voringen" led by Henrik Mohn between 1876–1878 investigated the area between Iceland, Spitsbergen and Norway. Then followed e.g. the Nansen initiative to reach the Central Arctic by using the stream going from east Siberia to Greenland across the Arctic Basin. The "Fram" voyage started in 1893 and lasted three years. The scientific outcome of this expedition were enormous.

Large efforts was also put into the scientific discipline of physical oceanography since it could be used to explain changes in economically important fish stocks, e.g. the Lofoten fisheries (Sars, 1877). The underlying reasoning here was that physical changes in the water-masses influenced phytoplankton primary production (timing of and/or magnitude of blooms) and thereby food availability to zooplankton that again formed food for fish larvae or adults (Cushing, 1978).

It is also obvious that much of this early research was simply "healthy curiosity driven" and based on "the need to get an overview of the world". The late years focus on climate variations ("global warming") has led to a renewed focus on "bare bone" physical oceanography. Also an interpretation of ocean data in an atmosphere – ocean interaction context has become important.

Of special importance, of the same reason as above, temperature and salinity time series has received renewed interest (e.g. MacKay and Ko (2001); Fonselius and Valderrama (2003)). Some of these are truly unique and will be quite important in the future since they form reference points in the climate debate. To my knowledge there is though much work left to do what concerns the availability and interpretation of such data, especially what concerns coastal areas and fjords.

To the formerly mentioned issue that physical oceanography "supports" biology, it must also be added that the (rightly so) famous Norwegian physical oceanographer, Harald Ulrik Sverdrup, in fact had the clear conviction that physical oceanography was a support discipline to biological oceanography. This is also reflected in that the first comprehensive and unique "world physical oceanography" treatise "The Oceans" (Sverdrup et al., 1942) in addition to geophysical issues also dealt with other aspects (chemistry, biology) of the oceans! In many ways "The Oceans" marked a paradigm shift in the development of physical oceanography in that it was largely quantitatively oriented, and also considered the world's oceans from a holistic view. It is true that the authors (Sverdrup, Johnson and Fleming) also largely did draw on other persons research, but the unique in this project was the way they combined own (e.g. Sverdrups Indian ocean thesis) and other peoples research into new conclusions. So, in many ways this monograph still stands out today as a reference work in physical oceanography.

My present PhD thesis presents, as is stated earlier, contain much data, also in the form of figures (see Appendix chapter). It is also apparent that the period prior to 1980 that has the most data is the period around 1930. This is because during this period there occurred a substantial warming of ocean and land areas on the northern hemisphere. North America experienced extensive draughts, the Arctic ice cover was at a minimum and the Greenland ice was at levels probably lower than today (Chylek et al., 2006). In "The Oceans" the northern areas are treated in Chapter XV. "The Water Masses and Currents of the Oceans". In the introduction to this chapter it is stated that: "Within any given region, the character of the water masses depends mainly upon three factors – the latitude of the region, the degree of isolation, and the types of currents". Some focus in my thesis is, for natural reasons, on the relative importance of latitude and degree of isolation of the northern areas and of the fjords in special. This is, as will be seen later, not an easy task, but though not less important since the fjords holds large water masses and influences inland climate as well as outer water masses. Further, of interesting statements in the referred monograph, relevant to my thesis is: " The Norwegian Current and its branches are subject to variations which are related to other phenomena (Sverdrup et al., 1942). Helland-Hansen and Nansen (1905, 1920) have shown that the surface temperature of the Atlantic water off the Norwegian coast fluctuates considerably from one year to another and that high summer temperatures of the surface waters are mostly followed by high air temperatures during the subsequent winter and spring. Besides such minor fluctuations major changes take place that lead to altered conditions over a number of years (Helland-Hansen, 1934). In 1901–1905 and in 1925 and 1927 the maximum salinity of the Atlantic water off western Norway at depths greater than 50 m was between 35.30‰ and 35.35‰ , but in 1929 a maximum salinity of 35.45‰ was observed, and in 1928 and 1930 the highest values were 35.43‰ and 35.40‰ respectively. The temperatures in 1929 were higher than on any previous occasion and, in agreement with this observation, the air temperature in Norway from November, 1929, to April, 1930, was higher, on an average, than in any winter since 1900 ".

As will appear later in the present text I will have some focus on the claimed heating period of 1929 to 1940. Helland-Hansen (1934) also concluded that in addition to that Atlantic water flowing into the Norwegian Sea had higher salinities and temperatures it also had larger volumes. He further stated that this would lead to much larger ice free areas in the Barents Sea and that there would be a two years delay in this from when the warming was observed off southwestern Norway. This was indeed observed, and in agreement with this reasoning, in May, 1929, the ice-free areas in the Barents Sea east of 20°E comprised 330 km^2; in May, 1931, they extended to over 710 km^2! These events are unfortunately not thoroughly described, but Mosby (1938) stated that whereas in the years 1910, 1912, 1922, and 1923 the maximum salinities of the Atlantic water varied between 34.95‰ and 35.06‰ , it reached a value of 35.14‰ in 1931. In earlier years the maximum temperature varied between 2.57°C and 4.48°C, but in 1931 it reached 5.04°C. The inflow of the warmer water led to the return into Spitsbergen waters of the cod, which had not been caught there in commercial quantities during the preceding fifty or sixty years!

The HMD (Havmiljødata) database contains mainly stations from the fjords and few stations from the open sea. The fjords are significantly influenced by the coastal waters and it will be interesting to see if the trends in the open sea is present in the fjords. Northern Norwegian fjords and coastal areas are influenced by the northward flowing Norwegian Coastal Current (NCC) containing Norwegian Coastal Water (NCW) that has its origin in the Baltic Ocean. The heat advected into the fjords that cause large heat flux variations in the Northern Norwegian fjords. Therefore the present dataset is very important and valuable in understanding fjord ocean interactions.

4.2 SEASONAL TEMPERATURE, SALINITY AND DENSITY TRENDS BETWEEN INVESTIGATED AREAS

Although the investigated fjords are situated somewhat close each other (e.g. Malangen and Balsfjorden) they nevertheless have some individual characteristic hydrographical features. There are also hydrographic variations between inner and outer fjords. The present database showed that the mean surface temperature in Inner Malangen varied from 4.57°C in winter to 9.48°C during summer. The highest variations were in the Østerbotn (Innermost Porsangerfjorden). The mean temperature in Østerbotn during winter was 1.34°C and in summer it was 8.38°C. The amplitudes were lower in the outer fjords than in the inner fjords. For example, the mean summer temperature at Outer Balsfjorden varied from winter 3.92°C to 8.43°C in the summer whereas in Inner Balsfjorden it varied between 3.56°C and 9.86°C. Similarly the at Altafjorden the amplitudes were higher at Inner Altafjorden. Coastal station Refsbotn Skipsholmen showed the lowest amplitude (5.42°C in winter and 7.33°C in summer). According to Hegeseth et al. (1995) along the coast, temperature varied from 5–6°C in winter to 10–11°C in the summer. The temperature amplitude in the southern fjords (Malangen, Balsfjorden and Altafjorden) varied from 2–4°C in the winter to 14–15°C during summer. In the t innermost Porsangerfjorden it varied from -1.62°C in winter to 7–9°C in summer. The inner fjords were colder than the coast in winter and warmer in summer as also stated in Hegeseth et al. (1995). During the winter season the amplitude of the surface temperatures can vary very much (Table 19). For example in Inner Malangen the winter temperatures can vary between -0.02°C to 8.73°C. The range of variations are higher in the inner fjords. The coastal station Refbotn had the least amplitude, 2.25°C to 7.75°C. The range of variations for each fjords are presented in Table 19. During the summer Balsfjorden had the highest range 4.34°C to 19.0°C (14.66°C difference). In Østerbotn it was less (3.93°C to 12.10°C). The amplitude of mean temperature during winter–spring was less (<2°C compared to >5°C in summer) compare to winter–summer. The mean temperature decreased from winter to spring. The temperature at inner fjords varied less during this period. Østerbotn showed the lowest variation. The mean surface temperature in Østerbotn varied form 1.34°C in winter to 0.64°C in Spring. The range of mean temperature variation was less than 2°C at all fjords. during spring, Outer Malangen had the highest amplitude in surface temperature (from -0.39°C to 11.51°C). Refsbotn Skipsholmen and Kvalsund had the lowest range 3.82°C and 3.31°C.

The mean temperature decreased from summer to autumn, Inner Balsfjorden had highest variation. The mean temperature varied from 9.68°C to 7.29°C during this period. Mean temperature in Outer Porsangerfjorden, Outer Malangen ad Refsbotn Skipsholmen slightly (0.2–0.8°C) incread during this time. Inner Malangen had the highest amplitude of surface temperature variation during winter (1.29–11.26°C). The variations were higher at Inner fjords than outer fjords (see Table 19)

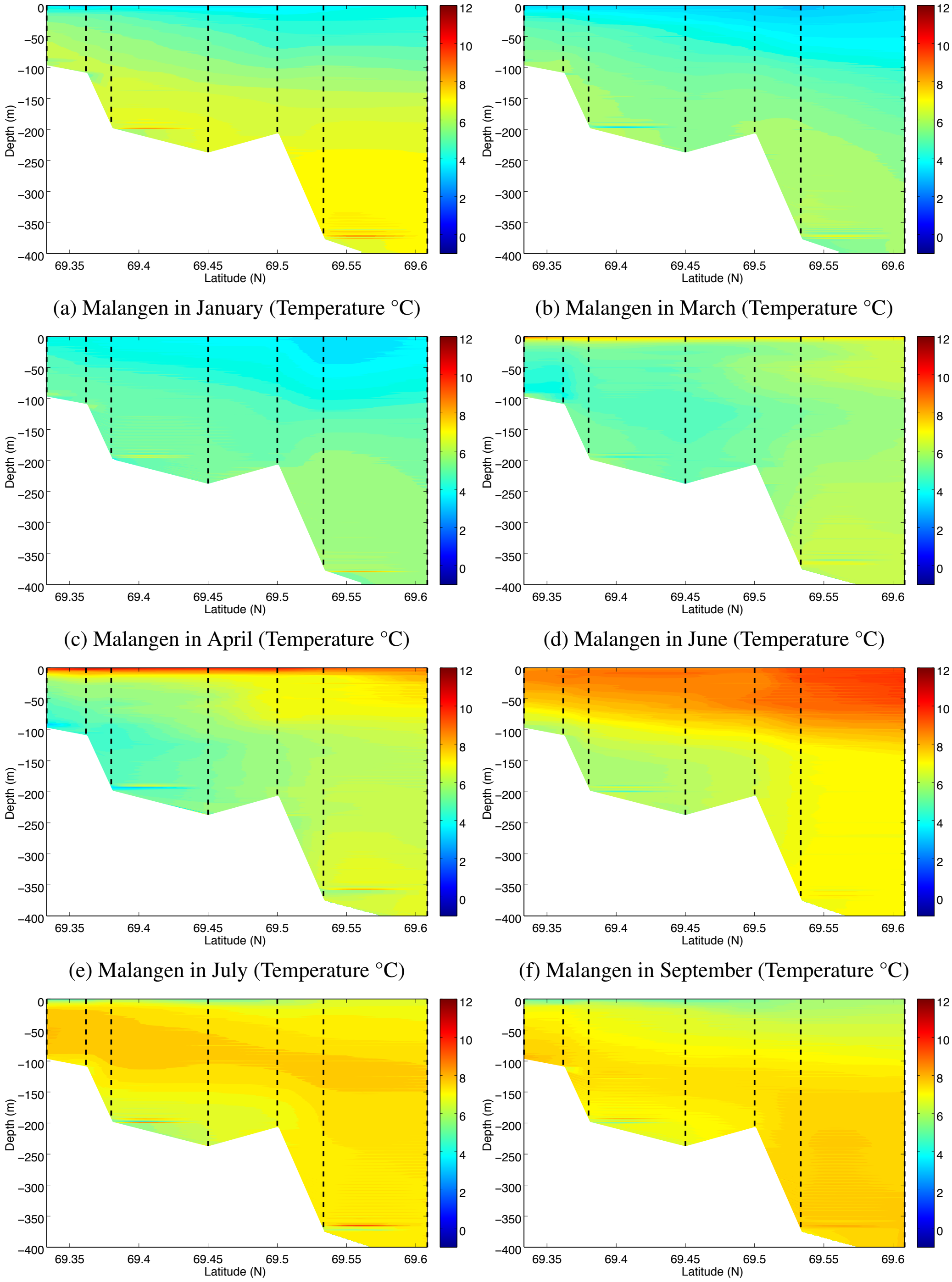
During the winter season, amongst the southern fjords (Malangen, Balsfjorden and Altafjorden), Balsfjorden had the lowest surface and bottom temperatures (Table 7, Figures 78 , 79 and 80). The mean bottom temperature at Balsfjorden was ca. 4°C (see Table 7) which was siginificantly lower

Table 19: Amplitude of surface temperature variations at investigated fjords (°C)

Locality		Winter	Spring	Summer	Autumn
Inner Malangen	Min	-0.02	-1.23	5.36	1.29
(1003–1004)	Max	8.73	6.60	15.28	11.26
Outer Malangen	Min	1.96	-0.39	4.91	5.71
(1006–1007)	Max	8.62	11.51	16.30	12.53
Outer Balsfjord	Min	-0.03	0.05	4.34	4.03
(2001–2002)	Max	7.63	8.99	19.00	10.79
Inner Balsfjord	Min	-0.55	-1.01	4.68	3.17
(2004–2005)	Max	7.40	9.00	19.20	10.29
Kvalsund	Min	2.08	2.08	4.92	6.96
(3003–3003)	Max	7.89	5.40	11.17	9.64
Sørfjord	Min	0.48	0.55	6.66	1.95
(5003–5003)	Max	7.80	7.65	14.50	9.47
Outer Alta	Min	1.95	1.02	4.84	5.60
(7001–7002)	Max	7.86	7.06	14.86	11.10
Inner Alta	Min	-0.17	-0.03	5.71	2.76
(7005–7006)	Max	8.38	7.60	16.25	10.92
Refsbotn	Min	2.25	2.55	1.40	6.31
(8001–8001)	Max	7.75	6.37	11.48	10.56
Outer Porsanger	Min	0.69	0.23	3.42	5.52
(9001–9002)	Max	7.55	6.17	12.30	9.23
Inner Porsanger	Min	-1.61	-1.44	3.36	4.37
(9007–9008)	Max	6.52	7.21	12.64	9.39
Østerbotn	Min	-1.79	-1.72	3.93	3.23
(9009–9008)	Max	6.06	7.21	12.10	9.35

than Malangen (6.25°C) and Altafjorden (5.42°C). Comparing the vertical sections of temperature for Malangen Altafjorden and Porsangerfjorden (Figures 78 , 80 and 81), it is interesting to note that Porsangerfjorden was colder longer period (until April) . Also during the November–January period the innermost Porsangerfjorden (Østerbotn) is separated by a front at from rest of the fjord around 70.3°N (Figure 81).

The minimum surface temperature occurred during March-April and there was no significant delay in the signal to reach deeper levels. This is similar to the results of Sælen (1950) and he suggested that this is due to the horizontal flow during this period. The temperature in the deeper water decreased due to cooling of the surface water and vertical mixing due to wind and tides. Balsfjorden remained the coldest fjord amongst the southern fjords during March–May. Table 13 shows that there is nearly 3°C difference in temperature between Inner Malangen and Inner Balsfjorden at 100 meters and ca 1°C between Inner Altafjorden and Inner Balsfjorden. Outer Altafjorden and Outer Porsangerfjorden were comparable whereas Østerbotn and Inner Porsangerfjorden were much colder (Table 13).



(a) Malangen in January (Temperature °C)

(b) Malangen in March (Temperature °C)

(c) Malangen in April (Temperature °C)

(d) Malangen in June (Temperature °C)

(e) Malangen in July (Temperature °C)

(f) Malangen in September (Temperature °C)

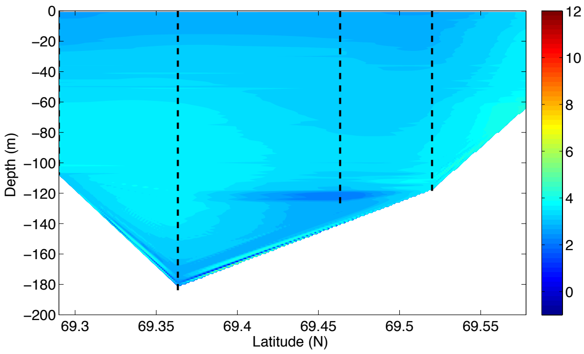
(g) Malangen in November (Temperature °C)

(h) Malangen in December (Temperature °C)

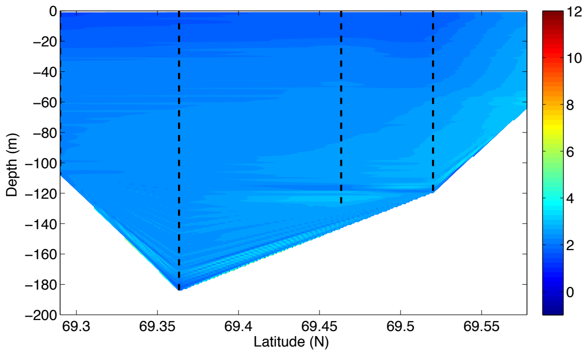
Figure 1: Vertical section of mean temperature (1920–2012) at Malangen

1

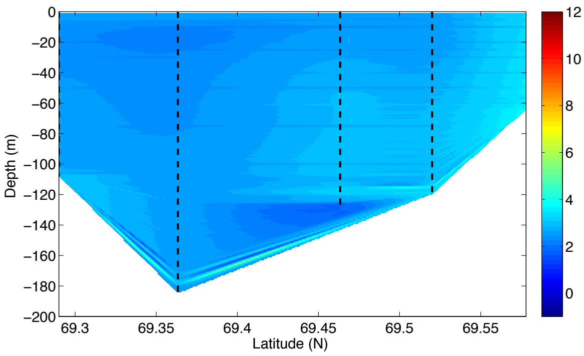
Figure 78: Vertical section of mean temperature (1920–2012) at Malangen



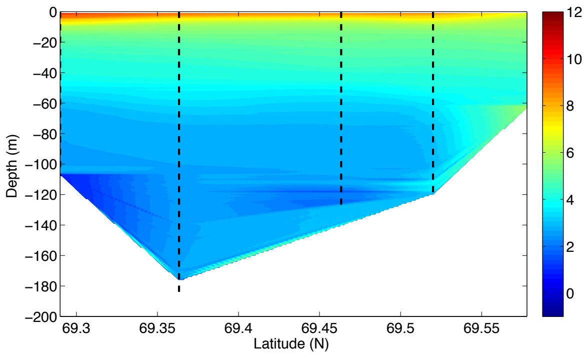
(a) Balsfjorden in January (Temperature °C)



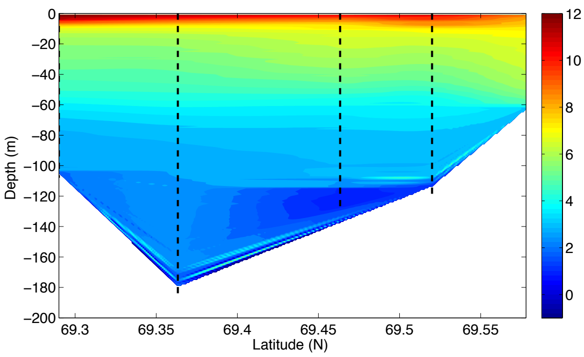
(b) Balsfjorden in March (Temperature °C)



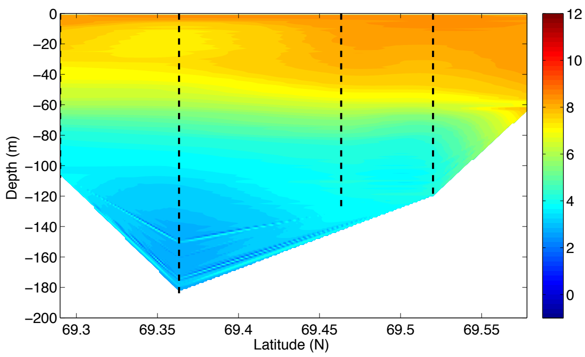
(c) Balsfjorden in April (Temperature °C)



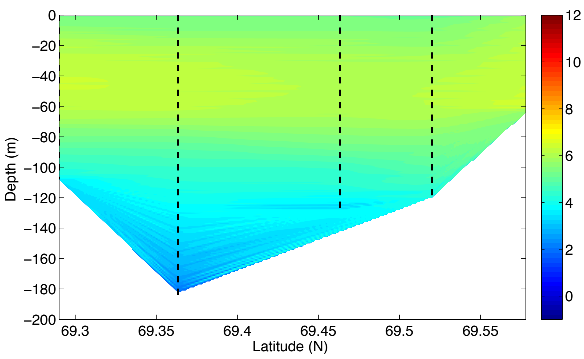
(d) Balsfjorden in June (Temperature °C)



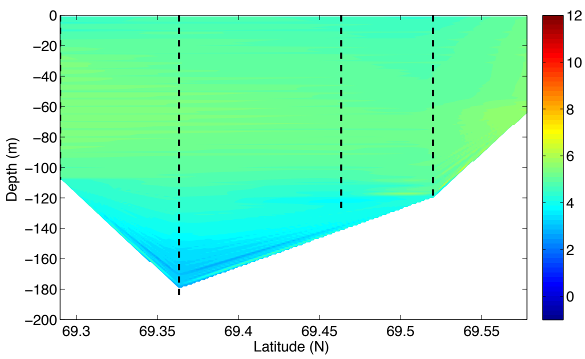
(e) Balsfjorden in July (Temperature °C)



(f) Balsfjorden in September (Temperature °C)

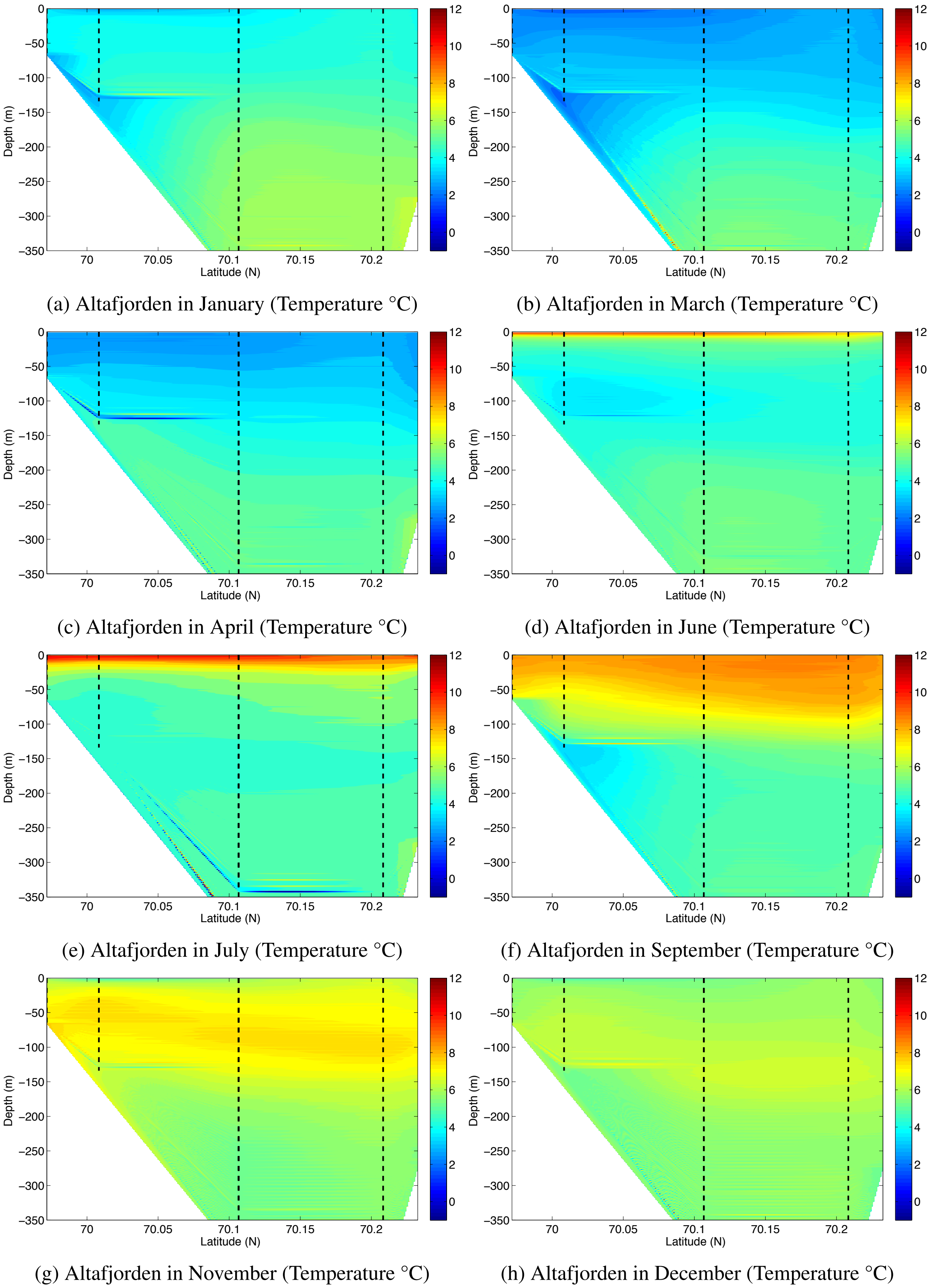


(g) Balsfjorden in November (Temperature °C)



(h) Balsfjorden in December (Temperature °C)

Figure 79: Vertical section of mean temperature (1920–2012) at Balsfjorden



(a) Altafjorden in January (Temperature °C)

(b) Altafjorden in March (Temperature °C)

(c) Altafjorden in April (Temperature °C)

(d) Altafjorden in June (Temperature °C)

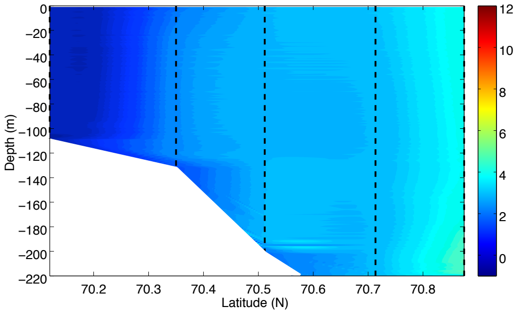
(e) Altafjorden in July (Temperature °C)

(f) Altafjorden in September (Temperature °C)

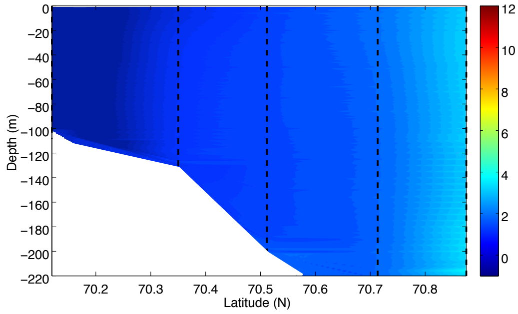
(g) Altafjorden in November (Temperature °C)

(h) Altafjorden in December (Temperature °C)

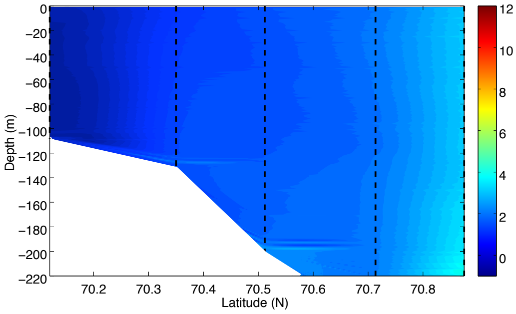
Figure 80: Vertical section of mean temperature (1920–2012) at Altafjorden



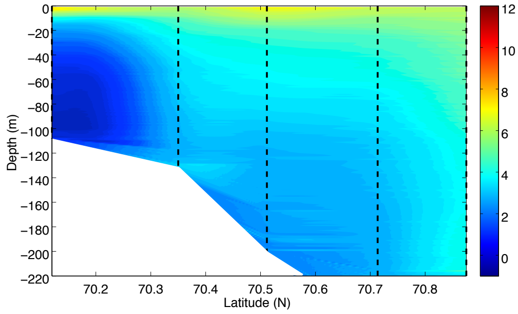
(a) Porsangerfjorden in January (Temperature °C)



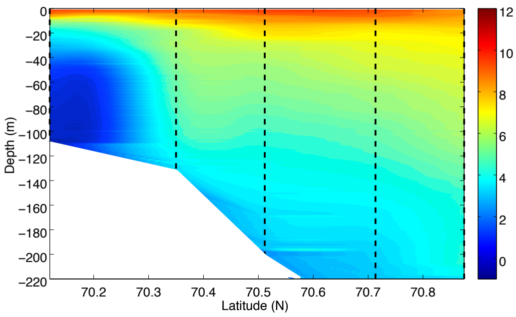
(b) Porsangerfjorden in March (Temperature °C)



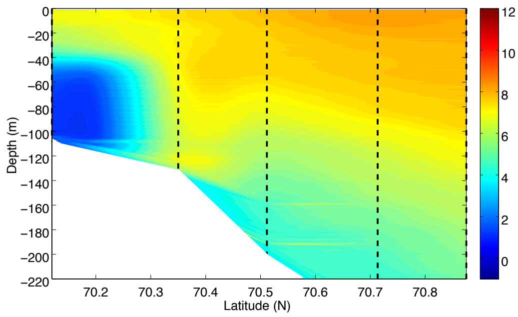
(c) Porsangerfjorden in April (Temperature °C)



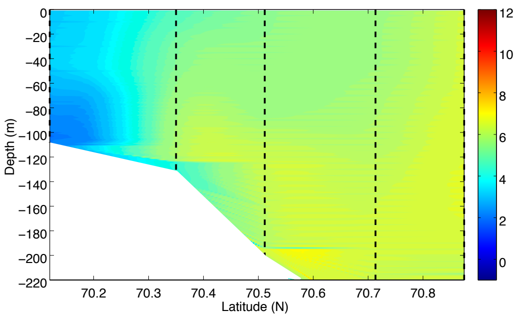
(d) Porsangerfjorden in June (Temperature °C)



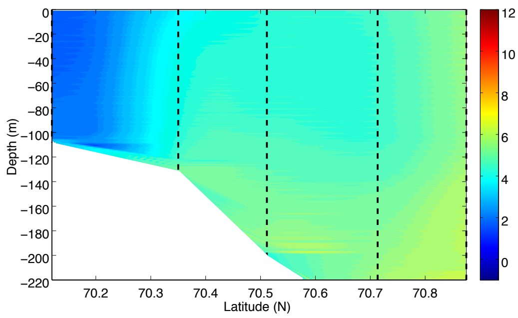
(e) Porsangerfjorden in July (Temperature °C)



(f) Porsangerfjorden in September (Temperature °C)



(g) Porsangerfjorden in November (Temperature °C)

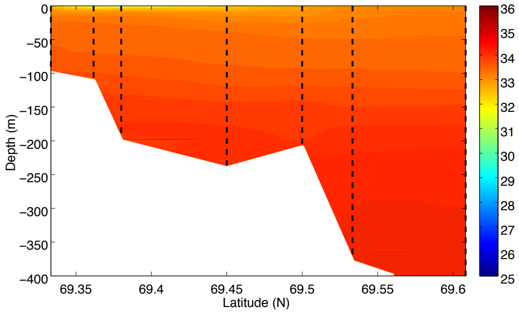


(h) Porsangerfjorden in December (Temperature °C)

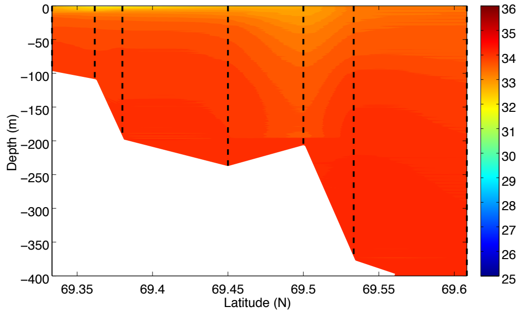
Figure 4: Vertical section of mean temperature (1920–2012) at Porsangerfjorden

4

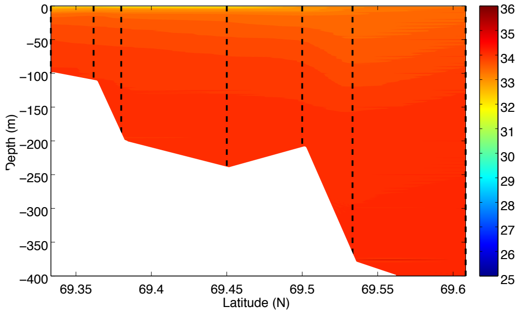
Figure 81: Vertical section of mean temperature (1920–2012) at Porsangerfjorden



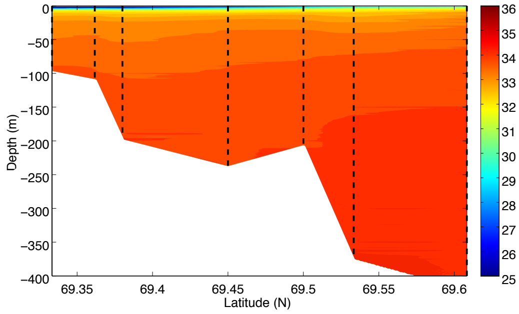
(a) Malangen in January (Salinity ‰)



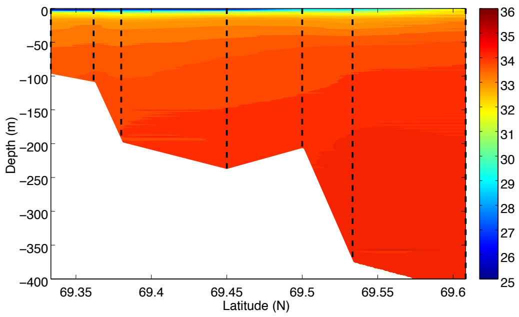
(b) Malangen in March (Salinity ‰)



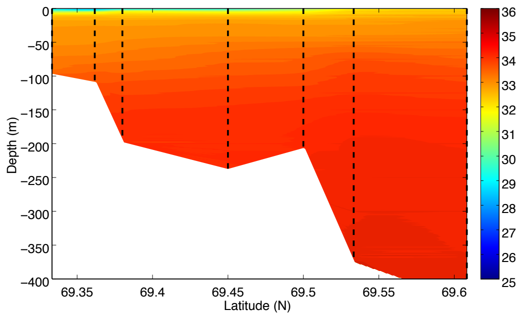
(c) Malangen in April (Salinity ‰)



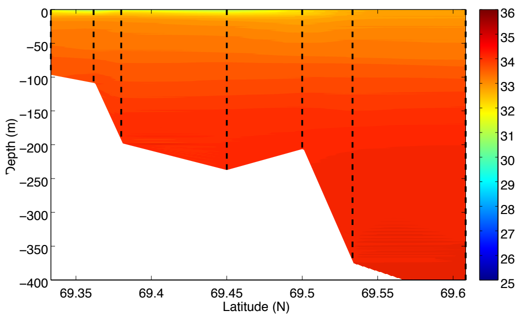
(d) Malangen in June (Salinity ‰)



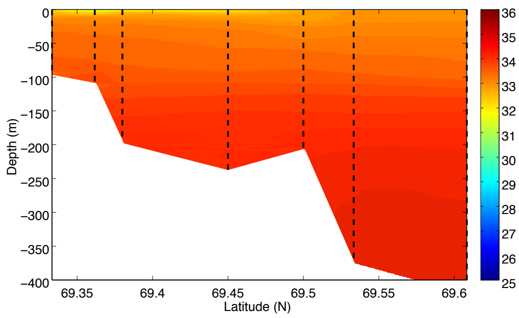
(e) Malangen in July (Salinity ‰)



(f) Malangen in September (Salinity ‰)



(g) Malangen in November (Salinity ‰)

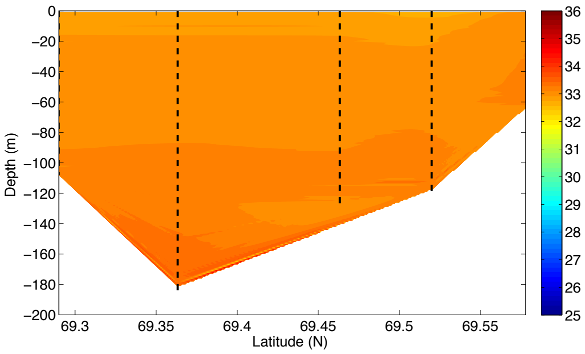


(h) Malangen in December (Salinity ‰)

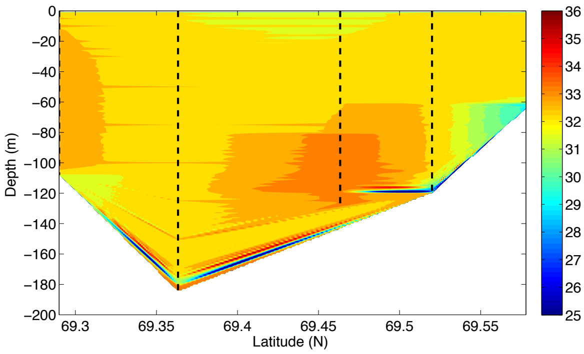
Figure 5: Vertical section of mean salinity (1920–2012) at Malangen

5

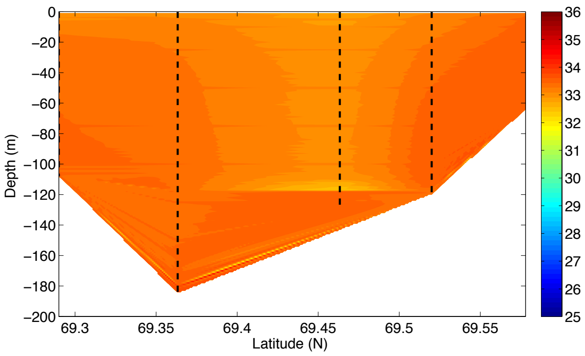
Figure 82: Vertical section of mean salinity (1920–2012) at Malangen



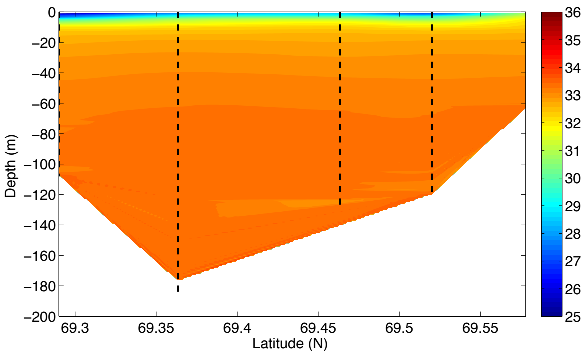
(a) Balsfjorden in January (Salinity ‰)



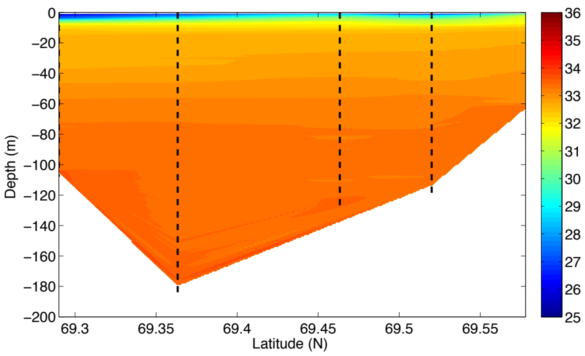
(b) Balsfjorden in March (Salinity ‰)



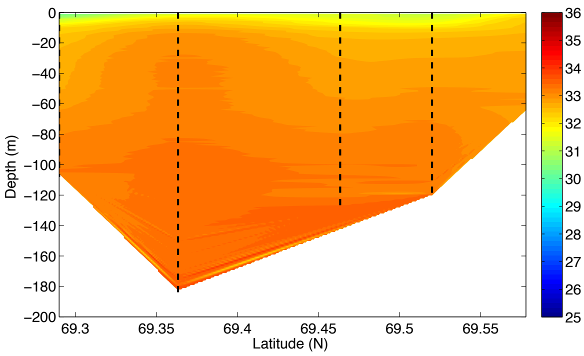
(c) Balsfjorden in April (Salinity ‰)



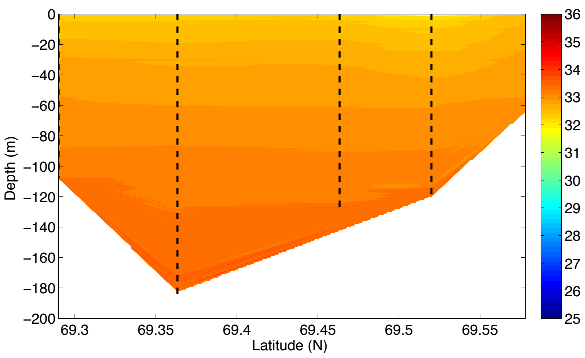
(d) Balsfjorden in June (Salinity ‰)



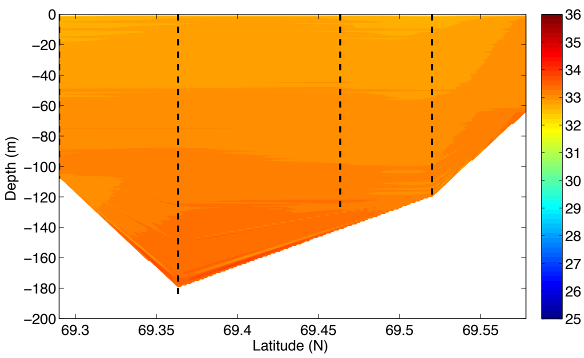
(e) Balsfjorden in July (Salinity ‰)



(f) Balsfjorden in September (Salinity ‰)

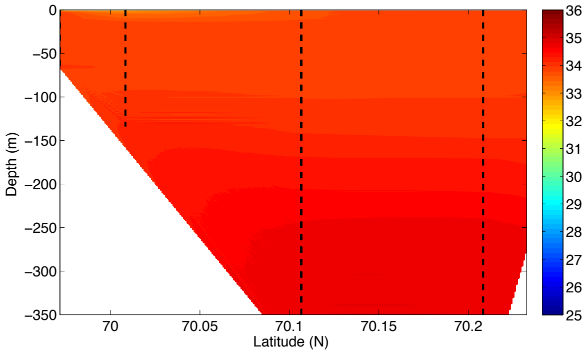


(g) Balsfjorden in November (Salinity ‰)

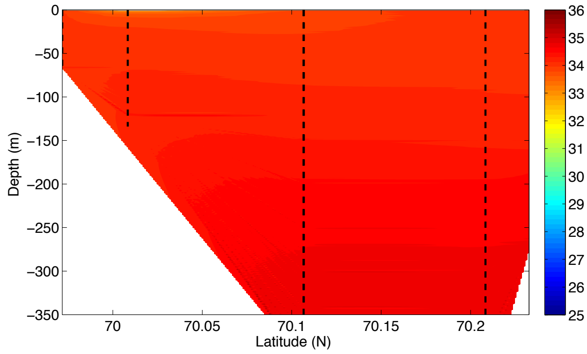


(h) Balsfjorden in December (Salinity ‰)

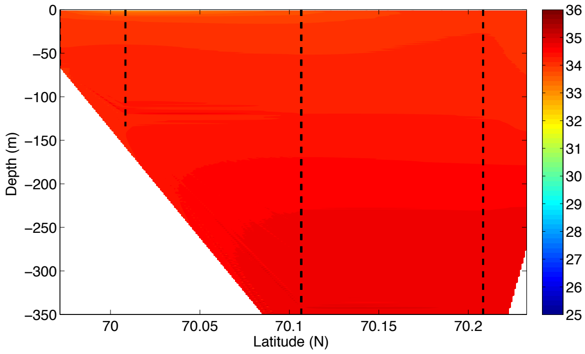
Figure 83: Vertical section of mean salinity (1920–2012) at Balsfjorden



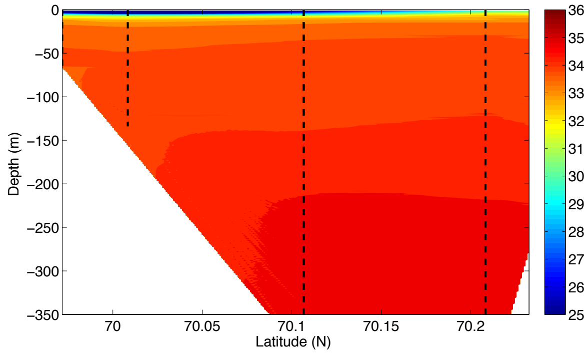
(a) Altafjorden in January (Salinity ‰)



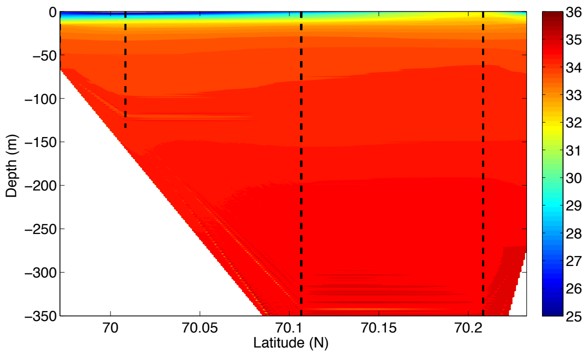
(b) Altafjorden in March (Salinity ‰)



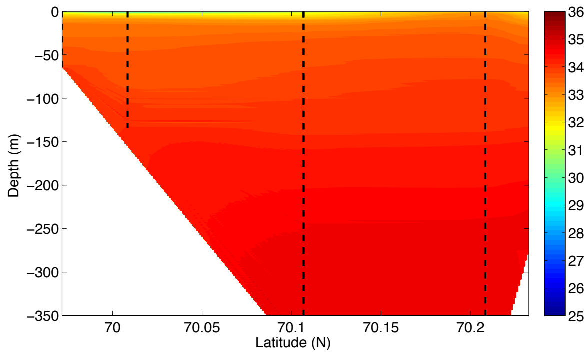
(c) Altafjorden in April (Salinity ‰)



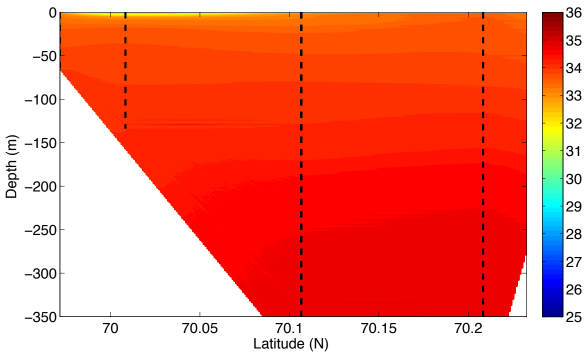
(d) Altafjorden in June (Salinity ‰)



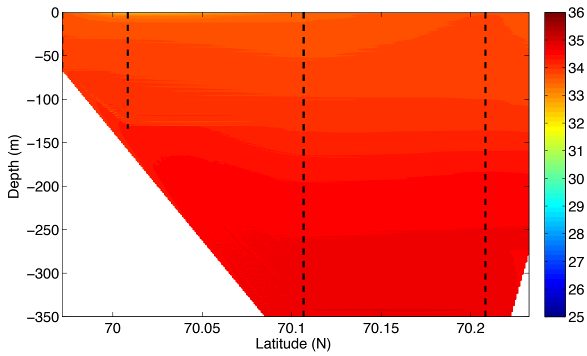
(e) Altafjorden in July (Salinity ‰)



(f) Altafjorden in September (Salinity ‰)

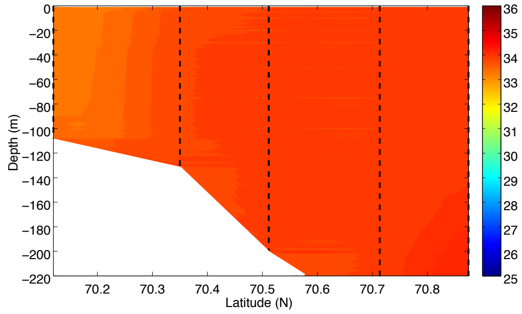


(g) Altafjorden in November (Salinity ‰)

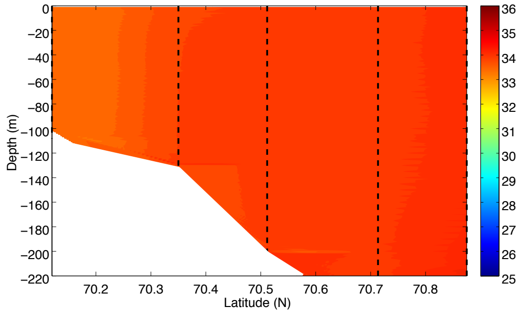


(h) Altafjorden in December (Salinity ‰)

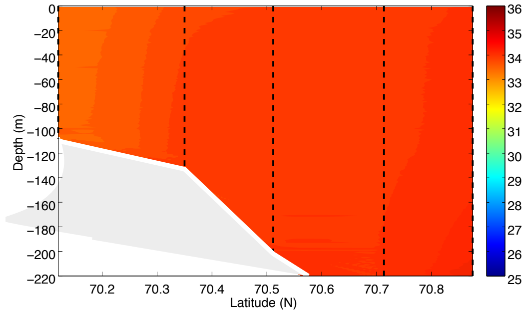
Figure 84: Vertical section of mean salinity (1920–2012) at Altafjorden



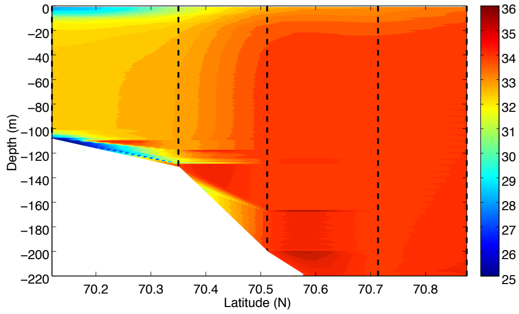
(a) Porsangerfjorden in January (Salinity ‰)



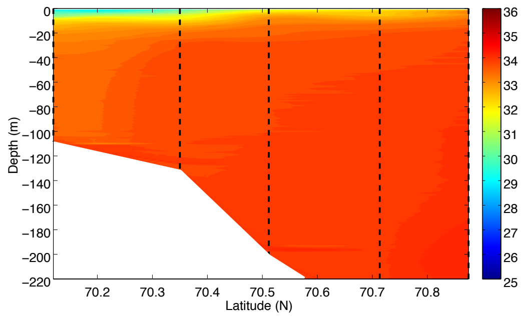
(b) Porsangerfjorden in March (Salinity ‰)



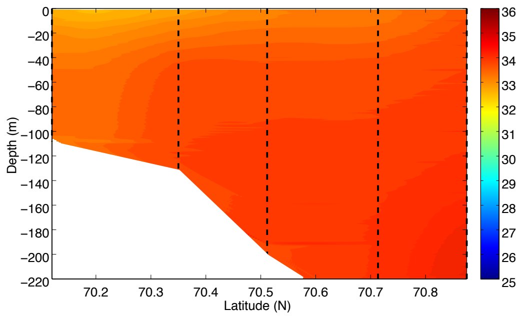
(c) Porsangerfjorden in April (Salinity ‰)



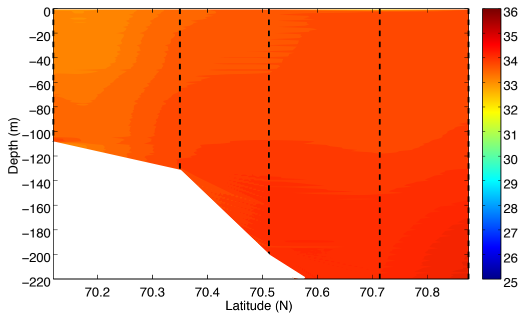
(d) Porsangerfjorden in June (Salinity ‰)



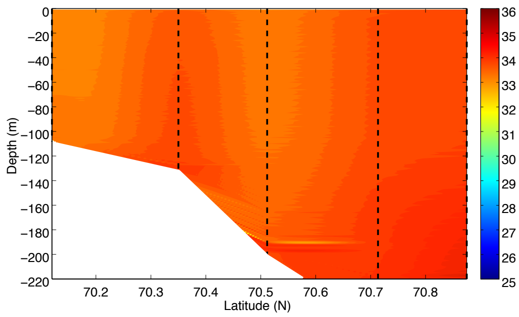
(e) Porsangerfjorden in July (Salinity ‰)



(f) Porsangerfjorden in September (Salinity ‰)



(g) Porsangerfjorden in November (Salinity ‰)

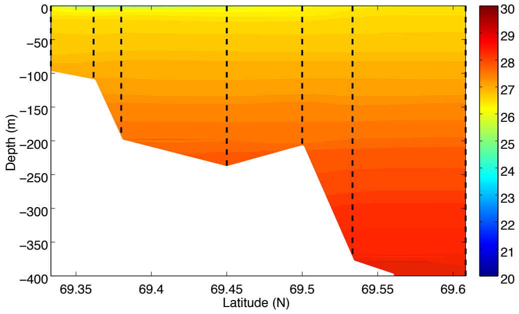


(h) Porsangerfjorden in December (Salinity ‰)

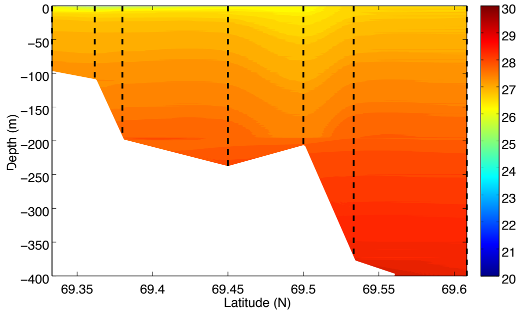
Figure 8: Vertical section of mean salinity (1920–2012) at Porsangerfjorden

8

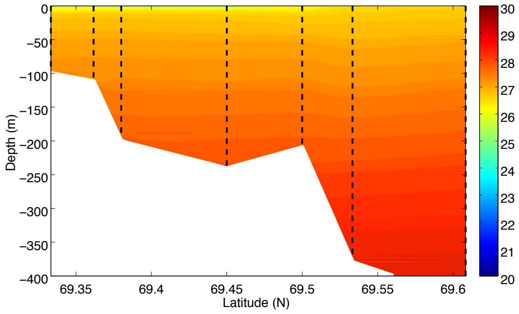
Figure 85: Vertical section of mean salinity (1920–2012) at Porsangerfjorden



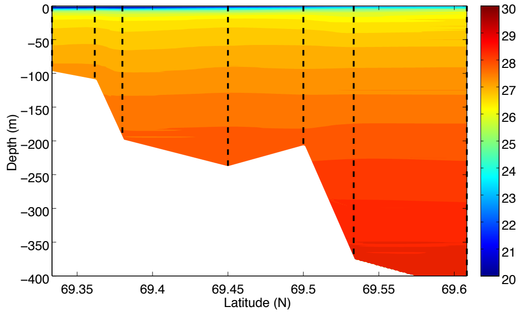
(a) Malangen in January (Density σ_t)



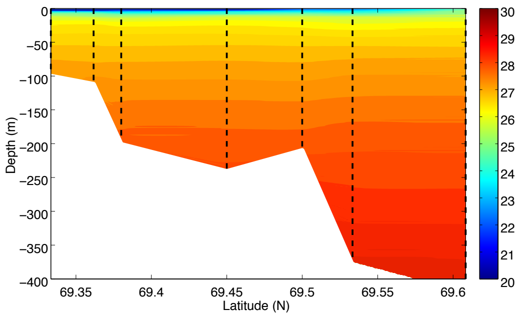
(b) Malangen in March (Density σ_t)



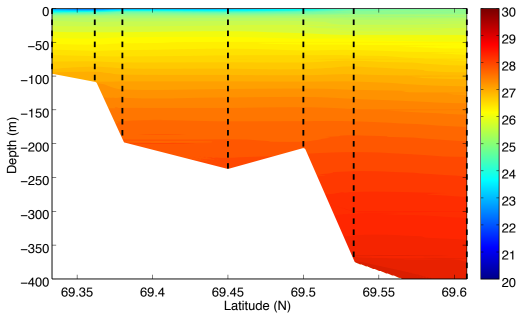
(c) Malangen in April (Density σ_t)



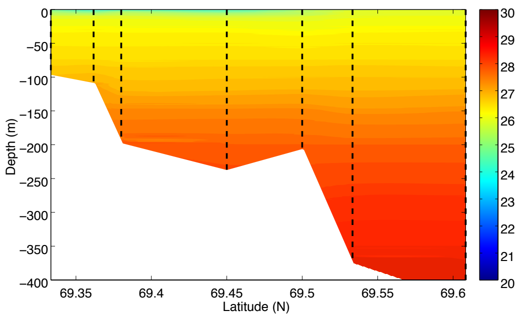
(d) Malangen in June (Density σ_t)



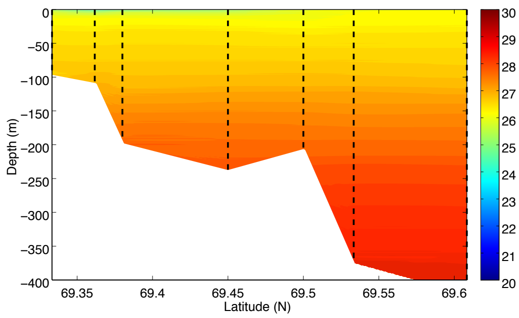
(e) Malangen in July (Density σ_t)



(f) Malangen in September (Density σ_t)



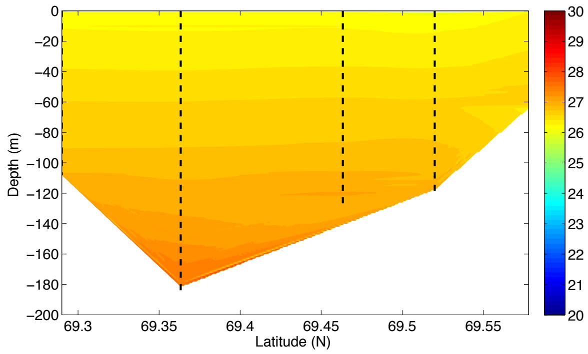
(g) Malangen in November (Density σ_t)



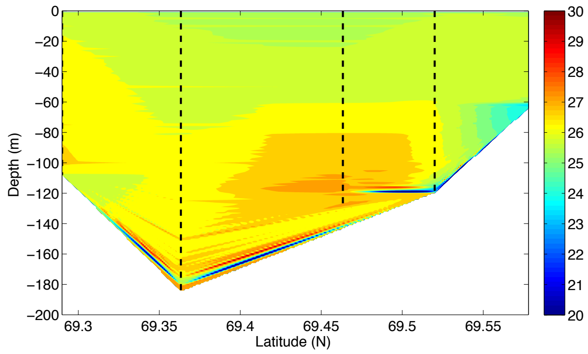
(h) Malangen in December (Density σ_t)

Figure 9: Vertical section of mean density (1920–2012) at Malangen

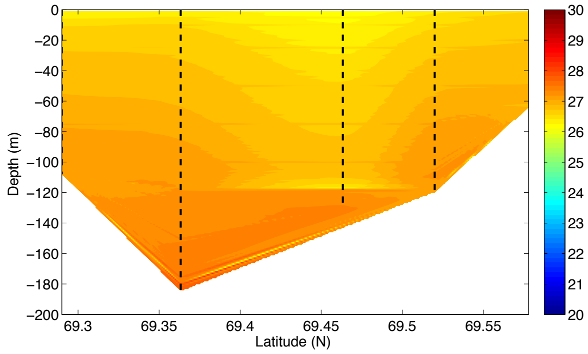
Figure 86: Vertical section of mean density (1920–2012) at Malangen



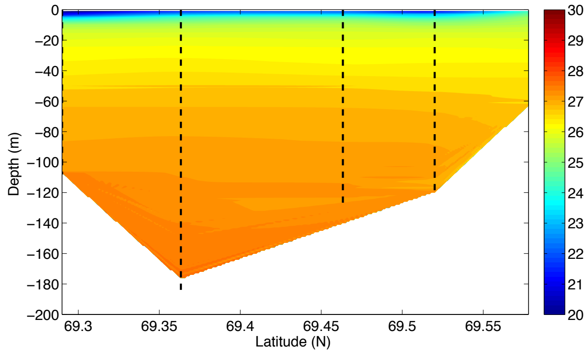
(a) Balsfjorden in January (Density σ_t)



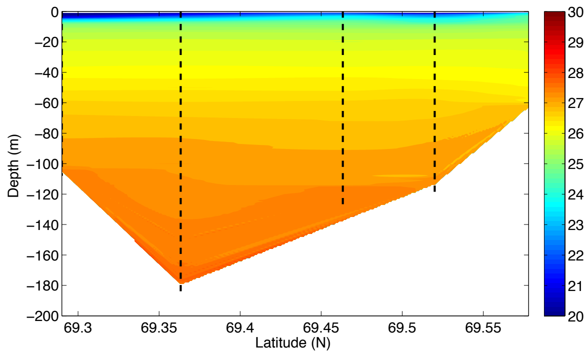
(b) Balsfjorden in March (Density σ_t)



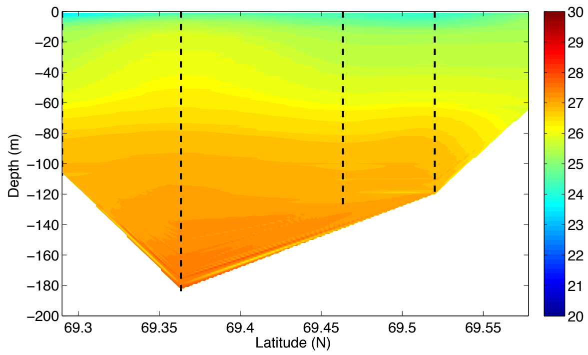
(c) Balsfjorden in April (Density σ_t)



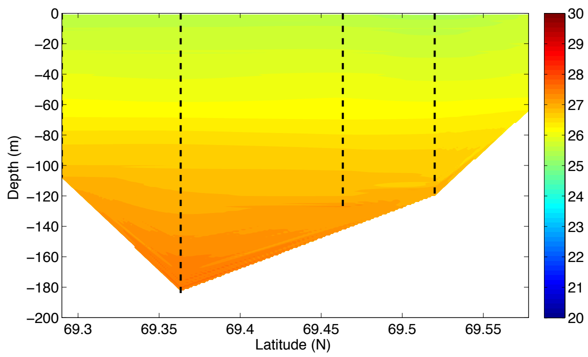
(d) Balsfjorden in June (Density σ_t)



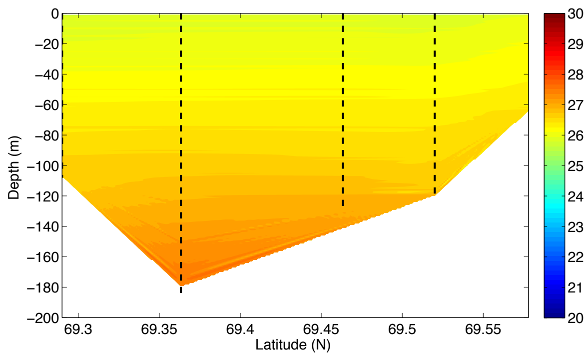
(e) Balsfjorden in July (Density σ_t)



(f) Balsfjorden in September (Density σ_t)

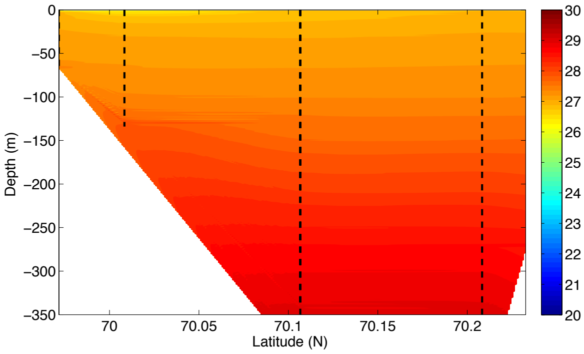


(g) Balsfjorden in November (Density σ_t)

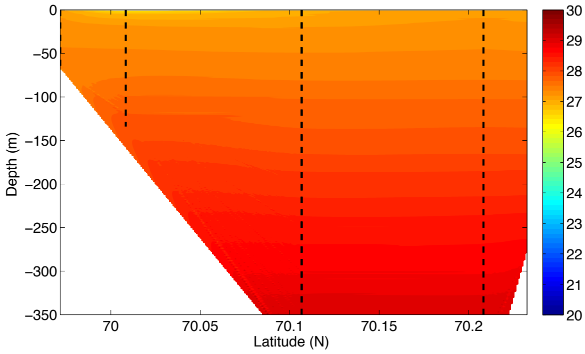


(h) Balsfjorden in December (Density σ_t)

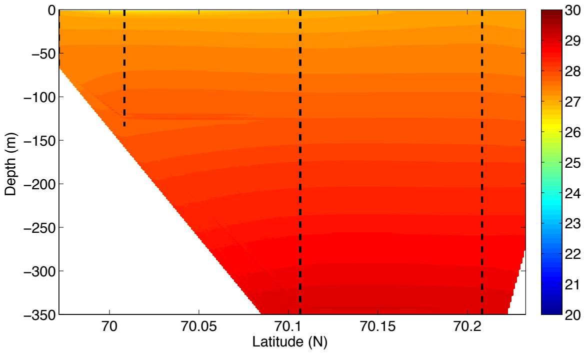
Figure 87: Vertical section of mean density (1920–2012) at Balsfjorden



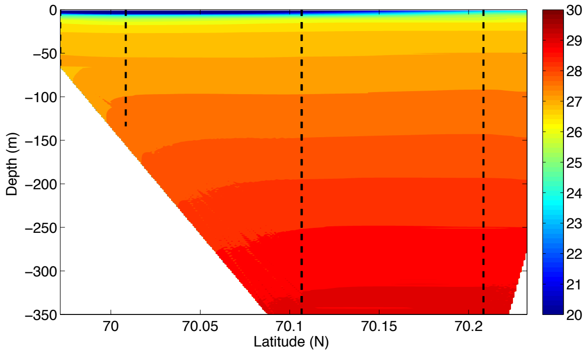
(a) Altafjorden in January (Density σ_t)



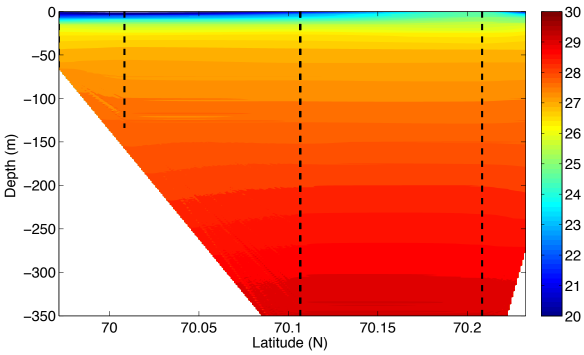
(b) Altafjorden in March (Density σ_t)



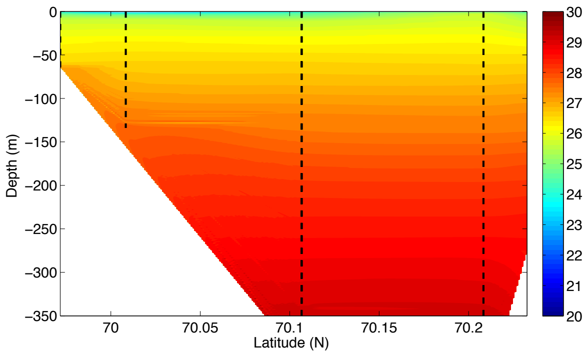
(c) Altafjorden in April (Density σ_t)



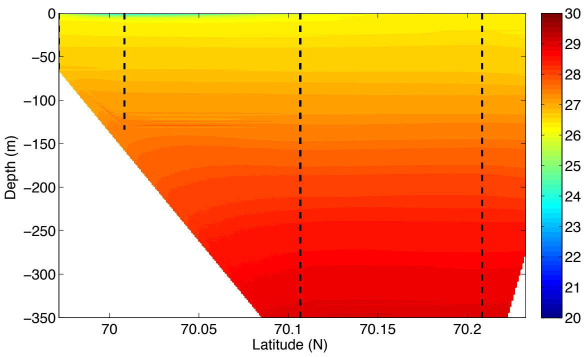
(d) Altafjorden in June (Density σ_t)



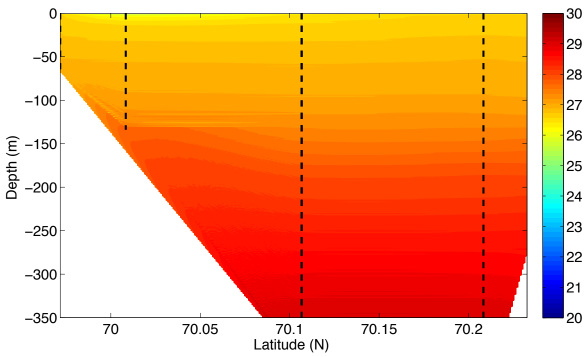
(e) Altafjorden in July (Density σ_t)



(f) Altafjorden in September (Density σ_t)

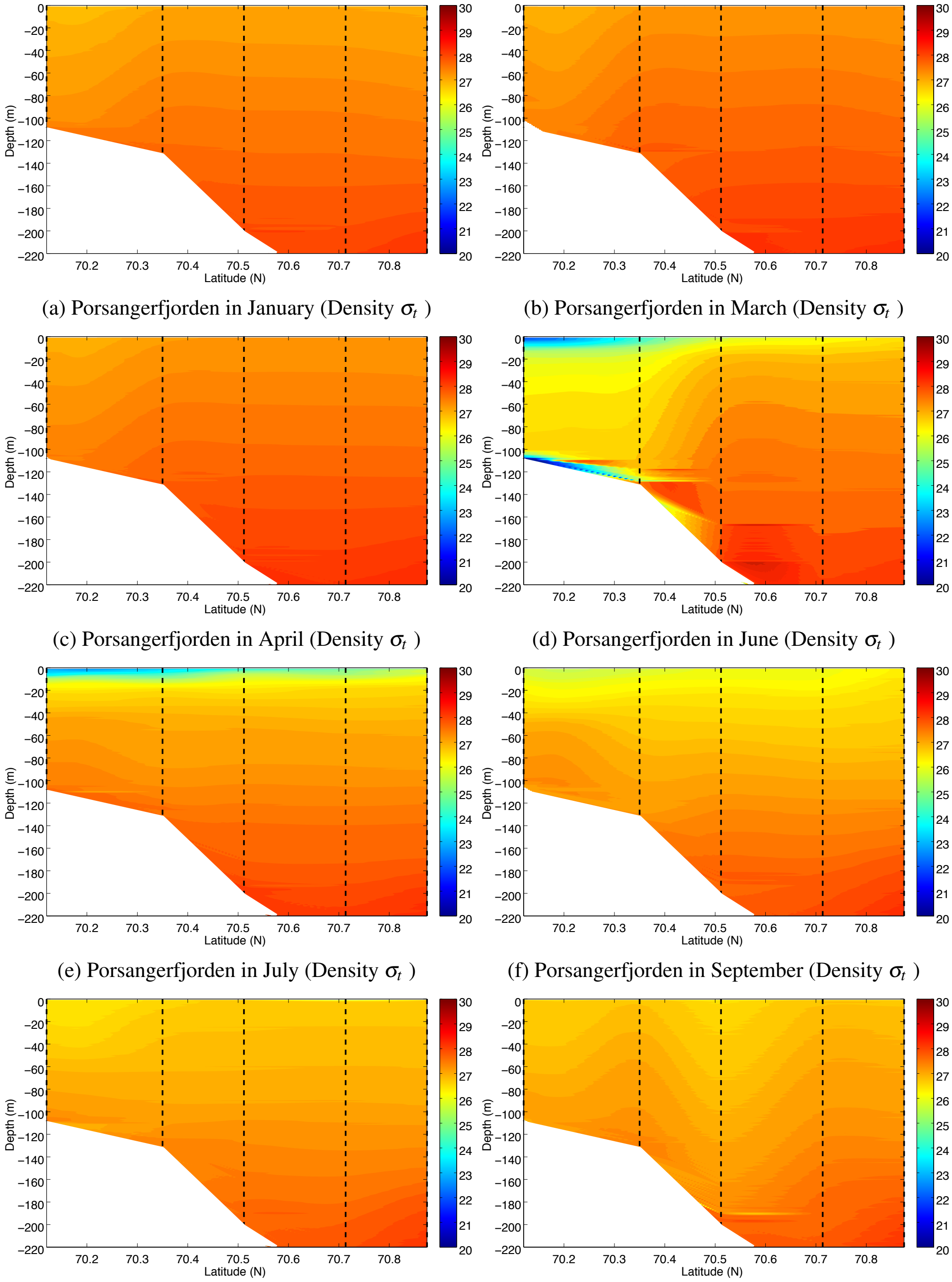


(g) Altafjorden in November (Density σ_t)



(h) Altafjorden in December (Density σ_t)

Figure 88: Vertical section of mean density (1920–2012) at Altafjorden



(a) Porsangerfjorden in January (Density σ_t)

(b) Porsangerfjorden in March (Density σ_t)

(c) Porsangerfjorden in April (Density σ_t)

(d) Porsangerfjorden in June (Density σ_t)

(e) Porsangerfjorden in July (Density σ_t)

(f) Porsangerfjorden in September (Density σ_t)

(g) Porsangerfjorden in November (Density σ_t)

(h) Porsangerfjorden in December (Density σ_t)

Figure 12: Vertical section of mean density (1920–2012) at Porsangerfjorden

Figure 89: Vertical section of mean density (1920–2012) at Porsangerfjorden

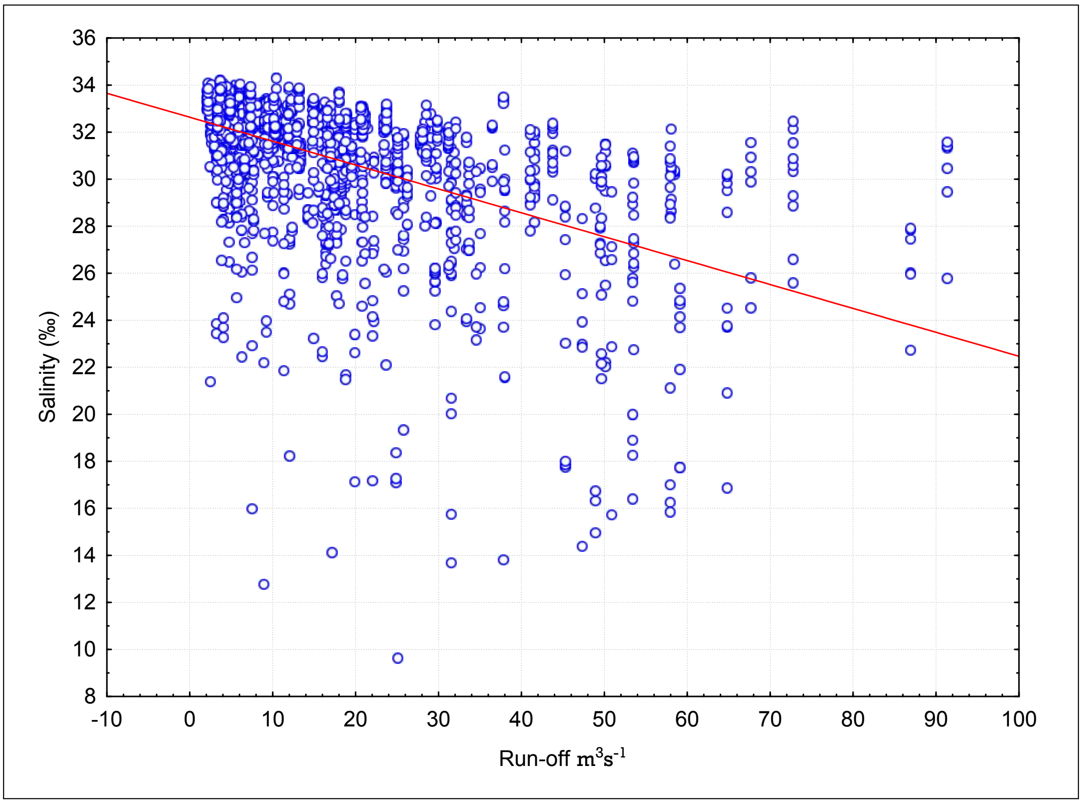


Figure 90: Surface salinity (5 m average) vs run-off in Inner Malangen

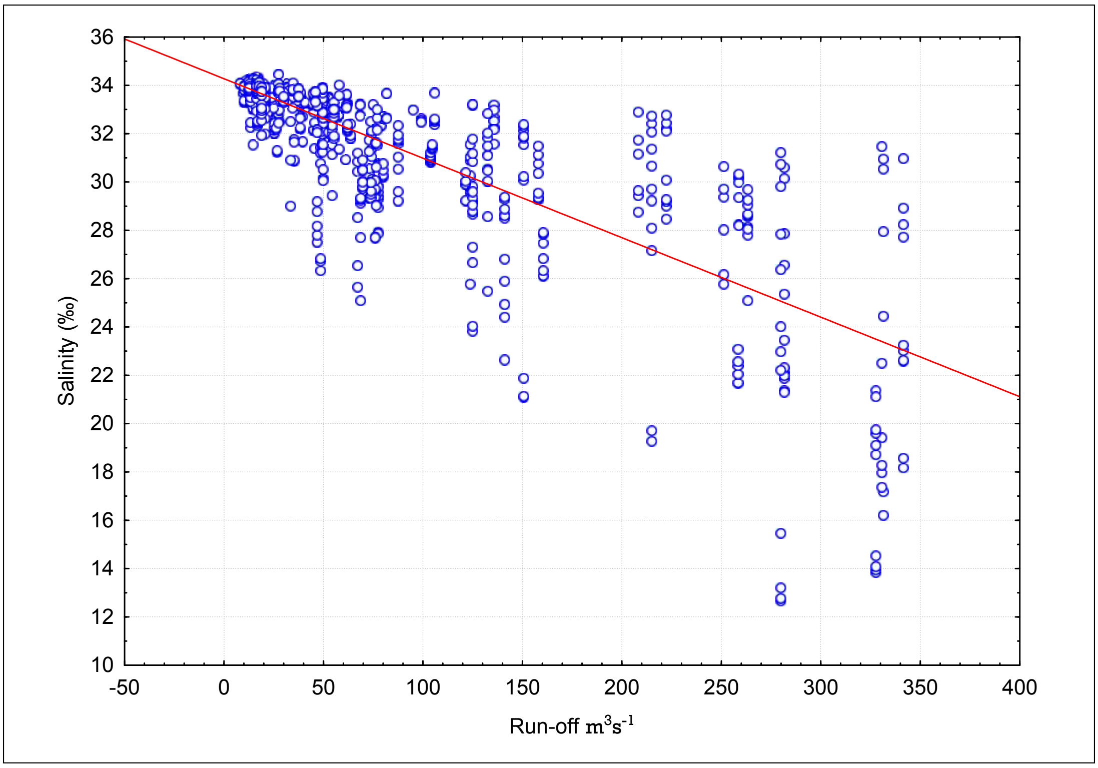


Figure 91: Surface salinity (5 m average) vs run-off in Altafjorden

The peak surface temperatures in the northern Norwegian fjords were in July–August and the highest bottom temperatures were in November-December (Table 7 and Figures 78, 79, 80 and 81). Previous studies (Sælen, 1950; Eilertsen et al., 1981; Eilertsen and Skarðhamar, 2006) also had similar conclusions. The downward heating was slow compared to winter cooling (Figures 78–81). In outer Balsfjorden which is shallower than Malangen, the highest bottom temperature occurred in September-October. In the deeper and wider fjords like Porsangerfjorden and Malangen the warming reaches up to the bottom in October. But in Balsfjorden below 75 meters, the warming effect less (Figure 79) . Time series of mean temperatures at different depths in the Bjørnøya–Fugløya section in the Barents sea, showed the mean delay in the signal from surface to 200 to 300 m depth level was three months and at 400 meters it was four months (Furevik, 2001) which is similar to Northern Norwegian fjords.

Rivers are the main freshwater sources for the north Norwegian fjords. The main rivers running into the fjords are Målselva in the Malangen, Altelva in the Altafjorden, and Lakselv in the Porsangerfjorden. Fresh water runoff to fjords have a seasonal variation and it reaches maximum during summer snow melt. Even though the melting starts in May the fresh water run off to the fjord reaches its maximum in June, while a minimum is usually found in February, but this can vary according to the weather conditions. A second maximum during autumn may appear during the periods of heavy rain (Furevik, 2001), and episodic events with high air temperatures even during winter can cause heavy anomalously runoff. The variations in salinity were larger in the inner part of the fjords than the coastal stations like Outer Malangen, Outer Porsangerfjorden and Refsbotn Skipsholmen due to the inner fjord freshwater runoff (Figures 90 and 91 show the relation between runoff and surface salinity in Inner Malangen and Innner Altafjorden). In Malangen, Balsfjorden and Altafjorden, the surface salinity during June–July were comparably less than other months due to the increased runoff (Table 11, for e.g. mean surface salinity during summer at Inner Malangen was 26.38‰ and at Inner Altafjorden it was 25.46‰. See Figure 82, 83 and 84 and) and it created a brackish top layer in the fjords during summer. In Porsangerfjorden it was limited to the inner most part of the fjord. The outer most and coastal stations were less influenced by run off than the inner part of the fjords, i.e. the influence was less when moving towards the outer fjord.

In the fjords the surface salinity and the mixed layer thickness are normally influenced by wind mixing (McClimans and Næser, 1973). By convection and diffusion warmer and heavier deep water is mixed with the overlying colder and less saline water. The surface density decreased during the summer periods due to the decrease in salinity and an increase in temperature. In most of the investigated fjords the vertical sections of mean temperature and salinity showed that density pattern were mainly determined by the salinity rather than temperature since the effect temperature variation on density is small compared to that of salinity variation (see Figures 78– 89).

The stratified period in Balsfjord, and Malangen lasted from the second week of May until late September–early October (Sælen, 1950; Skreslet, 1973; Eilertsen et al., 1981). The present database showed that the stratification in Malangen started in May and the innermost stations were more stratified than the outer stations. Stratifications weakened from September with decreasing run off and solar radiation.The patterns were different for Balsfjorden (stronger stratification) , Altafjorden and Porsangerfjorden (less stratified for a shorter period). In Balsfjorden, typical estuarine circulation with

Table 20: Amplitude of surface salinity variations at investigated fjords (‰)

Locality		Winter	Spring	Summer	Autumn
Inner Malangen	Min	21.49	12.77	8.73	9.63
(1003–1004)	Max	34.11	34.30	32.76	33.09
Outer Malangen	Min	27.66	16.85	10.75	27.30
(1006–1007)	Max	34.52	34.70	34.63	34.28
Outer Balsfjord	Min	27.49	17.96	15.19	26.35
(2001–2002)	Max	33.79	33.91	33.21	33.57
Inner Balsfjord	Min	23.42	11.38	13.17	20.87
(2004–2005)	Max	33.71	35.11	32.85	33.33
Kvalsund	Min	15.79	32.44	13.18	32.50
(3003–3003)	Max	34.19	34.38	33.69	33.79
Sørfjord	Min	26.68	30.18	16.01	27.03
(5003–5003)	Max	33.69	33.78	31.61	33.32
Outer Alta	Min	31.87	25.28	15.76	25.12
(7001–7002)	Max	34.86	34.52	34.41	34.09
Inner Alta	Min	10.79	7.57	6.83	20.34
(7005–7006)	Max	36.23	34.46	33.45	34.18
Refsbotn	Min	33.00	33.66	33.19	33.38
(8001–8001)	Max	34.99	35.13	35.07	34.88
Outer Porsanger	Min	31.95	33.35	30.56	32.74
(9001–9002)	Max	34.88	35.44	34.78	34.70
Inner Porsanger	Min	31.39	10.96	21.98	31.51
(9007–9008)	Max	34.49	34.72	33.66	34.18
Østerbotn	Min	31.39	10.96	20.75	29.15
(9009–9008)	Max	34.67	34.63	33.66	34.04

a net transport of brackish surface water out of the fjord and an intermediate compensating current in the fjord with relatively stagnant underlying basin water occurs during summer after stratification ((McClimans and Næser, 1973; Eilertsen et al., 1981). Water advected into the basin of Balsfjord derived mainly from a mixed water body in the threshold area supplied through the open fjord Malangen (Svendsen, 1995) (Figures 86 and 87)

There are great variations in hydrophysical characteristics between the investigated fjords (Northern fjords like Porsangerfjorden and Southern fjords like Malangen) There are also hydrographic variations between Inner fjords (e.g. Inner Malangen, Inner Altafjorden and Østerbotn) and Outer fjords (e.g. Outer Malangen, Outer Altafjorden and Outer Porsangerfjorden). The characteristics of Northern Norwegian fjords are much different from the Arctic fjords in a many ways . The stratification, seasonal change in salinity, temperature and circulation are different due to intense Arctic seasonality and different oceanic and atmospheric conditions experienced in the Arctic (Cottier et al., 2010). Even though the north Norwegian fjords experience an Arctic light and heat flux regime (low inland winter temperatures), the temperatures substantially warmer than “true” Arctic fjords due to the influence of the North Atlantic Current (Wassmann et al., 1996; Cottier et al., 2010). Also an issue here is that this, i.e. that fjords are warmer, varies between seasons as well as between years (Hurrell, 1995).

A comprehensive physical oceanographic investigation was carried out in the Ryfylkefjords in the west coast of Norway in 1972–1972 by Svendsen (1981). Comparing present study with those published by Svendsen (1981), it showed the water masses in the Ryfylkefjords are consisting of three layers. At the top, the upper layer, the depth of with varies in time and space. Below there is an intermediate layer down to the sill depth and then the basin water below the sill depth (Svendsen, 1981). This type of layers were not found in Northern Norwegian fjords like Porsangerfjorden Altafjorden and Malangen with deep sills. The stratifications are much shorter in the North. The circulations, exchange process and seasonal variations in hydrophysical properties are different in the Southern Norwegian fjords due to the dissimilar Air-Sea interactions and wind conditions etc. Solar heating is less effective and surface salinities are higher due to less runoff in the Northern Norway so, summer stratification is generally weaker in the north compared to southern Norway (Skofteland, 1985). Mean summer surface salinity in Inner Malangen, Inner Alta and Inner Porsangerfjorden were 26.47‰, 28.7‰ and 31.73‰ respectively whereas mean surface salinity at Jelsafjord (R9) was 20‰ and Josenfjord (R7) was 15‰ (Svendsen, 1981), which was comparatively less saline than Northern fjords.

4.3 CATEGORIZATION OF THE INVESTIGATED AREAS

Historically there are numerous systems applied in the categorization of estuaries. One method is the geomorphological one where estuaries are defined as either coastal plain or bar built ones. This was later supplemented by definitions based on hydrodynamic considerations (Cameron and Pritchard, 1963), i.e. highly stratified, partially mixed and well mixed estuaries. I though prefer, as recommended in (Svendsen, 1986), not to (over) use the term estuaries when describing the fjords. This is since both the geomorphological and hydrodynamic definitions in fact does not cover the "fjord" case. Geomorphologically the fjords originated at the end of last ice edge and is carved by ice activity, often with a moraine at the mouth. Also some fjords may be neglibly influenced by freshwater runoff, and at least during winter the northern fjords are almost vertically homogenous since all water is stored on land as snow and ice.

Porsangerfjord in the north is by far the longest fjord and also largest in terms of area and volume (length ca. 100 km), while Altafjord is the smallest one (30 km length). Balsfjord, situated right east to Malangen is as mentioned the only fjord that has shallow sills. It is therefore, a priori, to be expected that these areas will behave different in terms of general hydrophysics and also in the communication with outer waters. The observed surface temperatures in the fjord areas will be governed both by air-sea interactions (cooling heating, wind) and by water exchange with outerlying (mostly more saline water). Sælen (1950) points out that Balsfjord probably experiences more cooling (lower winter temperatures) and higher summer temperatures than the other fjords he investigated. This is also confirmed by my results.

It is reasonable to assume that the atmospheric climate, at least up to Altafjord, is relatively homogenous while Porsanger that stretches further inland is more influenced by the cold "Finnmarksvidda" winter climates (Eilertsen and Skarðhamar, 2006). This is also reflected in the outer station temperatures since while there are comparable surface temperatures in all fjords northwards (Table 7), the decrease inwards is more substantial in Porsangerfjord. Also while Malangen, Balsfjord and Altafjord stretches in a north-west direction, Porsangerfjord points in a north-east direction. Altafjord only has a width ca. one third of Balsjorden but twice as much freshwater runoff. Therefore other differences to note are that Porsangerfjord has a much weaker stratification than the other fjords and hence is more susceptible to windstress (Svendsen, 1981) while Altafjord that has more runoff (during summer) has a circulation that is more influenced by freshwater addition (Svendsen, 1991).

Balsfjorden is separated from the outside deep waters by three relatively narrow sounds. Tromseysundet and Sandnessundet have sill depths of 8 and 9 meters respectively and Rystraumen has 30 meters. Compared to the Malangen (200 meters) and Altafjorden (190 meters) the sills at Balsfjorden are narrow and very shallow which prevents it from free exchange with the coastal water. The presence of warm water in Malangen, Ullsfjorden and Altafjorden is due to the influence of Atlantic water, which flows over the sill during the spring and summer (Eilertsen et al., 1981). The Norwegian Coastal Current is broad and shallow in May to September (50-100 m), but weaker and deeper during autumn and winter (<200 m). The seasonal lateral oscillation of the coastal water has been attributed to upwelling events forced by north-westerly winds (Sætre and Mork, 1981). According Sætre and Mork (1981), along the western coast of Norway, upwelling forced by northwesterly winds causes the change in pressure field, which flushes out the upper layer of the fjords. Even though downward propagation of winter cooling is rapid, the convection is limited to the upper 100 meters, so the bottom waters are unaffected (Sælen, 1950). Porsangerfjorden, which is broad and have free connection to open sea, was much colder compared to the southern fjords. Winter surface temperatures at the outermost part of Porsangerfjorden was comparable with Altafjorden (4.93°C vs 4.91°C), whereas Inner Porsangerfjorden (3.01°C) and Østerbotn (1.34°C) were much colder. The deeper water at Østerbotn (1.12°C) and Inner Porsangerfjorden (3.46°C) indicate that the influence of warmer Atlantic water is not present in the Inner Porsagnerfjorden during the winter season.

The results from the present investigation shows that the winter surface temperatures are always lower in the inner parts of the fjords than in the outer areas (Table 7). When the ratios between surface and 100m temperatures were examined (Table 21) it shows that the largest difference was at station Inner Malangen (highest 100m temperature relative to the surface), whereas at Outer Porsangerfjord in fact it was warmer in the surface layers. This can be interpreted in terms of mixing since temperatures decreases during the wither, leading to the conclusion that Porsangerfjord had the highest vertical mixing rate during winter and that Malangen had the slowest mixing. The salinities during winter demonstrated the same trend, i.e largest difference in Malangen and lowest in Porsanger. During summer it was always warmer in the surface, and the smallest difference was at outer Malangen and outer Porsangefjord. The summer is a period with stratification and the summer differences shows that Porsangerfjord is most mixed = has a less layered structure than the other fjords.

Table 21: The difference between surface and 100m mean temperatures (surface minus 100m) at the investigated areas during the winter and summer season vs. mean heat fluxes from Eilertsen and Skarðhamar (2006). The referred heat fluxes (Q_t) are from the midst of the fjords.

Locality	Salinity difference 0–100m		Temperature difference 0–100m		Heat flux (Wm^{-2})	
	Winter	Summer	Winter	Summer	Winter	Summer
Outer Malangen (1006–1007)	-0,65	-3,02	-1.35	2.23	-103.8	130
Inner Malangen (1003–1004)	-2,07	-7,67	-2.51	4.58	-103.8	130
Outer Balsfjorden (2001–2002)	-0,42	-3,04	-0.46	5.26	-109.3	109.7
Inner Balsfjorden (2004–2005)	-0.51	-4,96	-0.89	6.81	-109.3	109.7
Kvalsund (3003)	-0,56	-1,55	-1.09	2.4	–	–
Sørfjord (5003)	-0,58	-5,64	1.58	6.52	–	–
Outer Altafjorden (7001–7002)	-0,23	-3,09	-0.18	3.89	-157.8	110.7
Inner Altafjorden(7005–7006)	-0,86	-8,61	-1,03	5.51	-157.8	110.7
Refsbotn (8001)	-0,17	-0,51	-0.19	1.75	-109.5	76.7
Outer Porsangerfjord (9001–9002)	-0,07	-0,59	0.12	2.22	-167.5	113.7
Inner Porsangerfjord (9007–9008)	-0,14	-2,36	-0.22	3.71	-167.5	113.7
Østerbotn (9009–9010)	-0,21	-3,46	-0.23	8.37	-167.5	113.7

One important property of a fjord area is its ability to communicate with outer coastal water. Earlier calculations of total heat flux in the area shows that there is a annual net release of energy from the fjords to the atmosphere in the size range -10 Wm^{-2} in the south (Malangen) to -45 Wm^{-2} in the north in Porsangerfjord (Eilertsen and Skarðhamar, 2006). If this is interpreted in terms of water exchange this means that there must be a net transport of heat into the fjords. Also, since heat fluxes are positive (from air to sea) from spring to late summer this advection of heat into the fjords must mainly take place during winter. Further the sum of the energy in terms of heat added to a fjord over a mid winter to mid summer period must be heat advected into the area plus the total net heat flux from radiation, sensible heat transfer and eventual black body radiation (see Table 21). In order to evaluate water influx/exchange in another way I have compared the energy needed to rise temperatures from winter to summer (Q_{calc}) and compared it to "actual" heat fluxes calculated from measured temperatures, wind and cloud cover

The calculated energy (Q_{calc}, Table 22) needed to increase the temperatures in the fjords were always higher than the observed (Q_{obs}) fluxes. This is since heating from the atmosphere is not large enough to reach the mid summer maximum temperatures, reflecting the fact that the Norwegian Coastal current brings heat into the area. Then, the calculated heat demand (Q_{calc}) minus the observed heat flux (Q_{obs}) will be a indirect measure of the excess energy brought into the fjord and an indirect

Table 22: Calculated energy needed (Wm^{-2}) to increase the temperature from observed winter means to observed summer means. MLD = Mixed layer depth from Appendix Tables 461-472 and 485-496. Mean MLD = mean mixed layer depth for period, Q_{calc} = calculated energy input needed to increase temperature from simplified volumetric heat capacity equation. The calculations are hence performed as if mixing and diffusion only reached down to the MLD and as if the fjord was an enclosed basin. $Q_{\text{“obs”}}$ are “observed” heat flux through surface from Eilertsen and Skarðhamar (2006). The “observed” heat flux (Q) values are from the midst of Malangen, Balsfjord, Altafjord and Porsangerfjord and these values were used both for inner an outer stations. Further the Q real values for Sørfjord are not from the cited publication but calculated from available data in the HMD database. The period from mid winter to mid summer was from 01 January to 15 July, i.e. 6.5 months. Negative heat flux means net release from sea to air.

Locality	Winter MLD	Winter MLD_t	Summer MLD	Summer MLD_t	Mean MLD	d_t	Q_{calc} Wm^{-2}	$Q_{\text{“obs”}}$ Wm^{-2}	dQ
Outer Malangen (1006–1007)	62	4.72	20	8.8	34	4.1	36.29	-3.4	29.4
Inner Malangen (1003–1004)	38	4.535	6	9.24	29	4.7	35.7	-3.4	28.8
Outer Balsfjorden (2001–2002)	43	3.76	16	9.065	30	5.3	52.4	-15.4	21.6
Inner Balsfjorden (2004–2005)	61	3.23	18	10.39	40	7.2	80.3	-15.4	51.5
Sørfjord (5003)	55	4.535	8	9.06	32	4.5	33.70	-42.7	-9.0
Outer Altafjorden (7001–7002)	111	4.705	21	8.44	66	3.7	76.4	-42.7	15.7
Inner Altafjorden (7005–7006)	43	4.134	9	9.97	26	5.8	35.9	-42.7	-6.8
Outer Porsangerfjord (9001–9002)	137	4.665	47	7.78	92	3.1	67.8	-47	20.8
Inner Porsangerfjord (9007–9008)	136	2.7	12	7.38	74	4.7	81.9	-47	34.9
Østerbotn (9009–9010)	95	1.37	21	8.19	58	6.8	93.6	-47	46.6

measure of advection of heat into the fjord. This approach is inaccurate e.g. in that MLDs (mixed layer depths) may vary in strength and hence variation in communication with underlying water is not considered, but I though mean this, somewhat controversial approach, though represents a tool to judge the relative abilities of the fjords to communicate with outer lying waters. Also the calculations are based on that the thermal volume specific heat capacity of water is 3.985 J cm^{-3}°C^{-1}. The heat capacity of seawater is both temperature and salinity dependent (Millero et al., 1980). This introduces errors below 1% and this was not taken into account. Considering the other inaccuracies involved I mean the present approach to be appropriately indicative for the purpose. Another source of error is also that air temperatures may vary inwards in the fjords, decreasing during winter and increasing during summer. An attempt to correct the heat flux calculations from Eilertsen and Skarðhamar (2006) only resulted in some few % changes in Q_{calc} so this was discarded. According to the computations

Table 23: Summary of characteristics for Malangen and Balsfjord

Fjord name	Characteristics				
Malangen	(i) Position: 69.33°N and 69.66°N. 60 km long and 3-6 km wide. Sill depth is 200m. North west direction. Free connection to coastal water. (ii) Innermost fjord are influenced by fresh water from the river Måselva and fresh water runoff during snow melt. (iii) Stratification starts in May and stratifications weakened from September with decreasing run off and solar radiation				
		Winter	Spring	Summer	Autumn
	Mean surface Temperature	4.94°C	3.76°C	9.48°C	8.94°C
	Mean surface Salinity	31.95‰	32.37‰	26.38‰	29.86‰
Balsfjord	(i) Position: 69.22°N and 69.50°N. 45 km long and 2-3 km wide. Sill depth is 30m. North west direction. Seperated from outside deep water by narrow sounds (ii) Fresh water runoff during snow melt. (iii) Stratification starts in May and stratifications weakened from September with decreasing run off and solar radiation				
		Winter	Spring	Summer	Autumn
	Mean surface Temperature	3.92°C	3.04°C	9.68°C	7.47°C
	Mean surface Salinity	32.37‰	31.52‰	28.52‰	32.0‰

Altafjord has little exchange, then follows Malangen and Balsfjord while Porsanger as mentioned earlier has most heat (and water) advected into the fjord.

The results from the calculations leads to the conclusion that advection of water during winter must increase from south to north since the largest discrepancies in demanded and observed heat flux increases northwards. If not so the temperatures of the northern fjords would have continuously decreased.

If the fjords are categorized merely from temperature and salinity variations it shows that it is Balsfjord that varies most with respect to temperature and second most (after Altafjord) in terms of salinity. Malangen shows a more narrow distribution in both parameters while Porsangefjord clearly is colder (has the lowest temperatures) and also operates at the narrowest salinity range, i.e. it is furthest away from a estuary definition in terms of salinity variations. In terms of temperatures it in fact compares to the Atlantic part of the Barents Sea or Spitzbergen fjords in that in fact temperatures and salinities in the 50–100m layer resembles the Barents Sea water (Loeng, 1991).

Table 24: Summary of characteristics for Altafjord and Porsangerfjord

Fjord name	Characteristics				
Altafjord	(i) Position: 70.00°N- and 70.20°N. 30 km long and 4-14 km wide. Sill depth is 30m. North west direction. Free connection to coastal water (ii) Innermost fjord is influenced by fresh water from the river Altelva and fresh water runoff during snow melt. (iii) Less stratified for a shorter period				
		Winter	Spring	Summer	Autumn
	Mean surface Temperature	4.91°C	3.25°C	9.94°C	7.99°C
	Mean surface Salinity	33.15‰	32.76‰	25.46‰	32.92‰
Porsangerfjord	(i) Position: 70.00°N and 71.00°N. 100 km long and 15-20 km wide. No sill. North east direction. Free connection to coastal water (ii) Wide fjord little runoff (iii) Less stratified for a shorter period				
		Winter	Spring	Summer	Autumn
	Mean surface Temperature	3.01°C	3.31°C	7.7°C	7.74°C
	Mean surface Salinity	33.94‰	34.32‰	31.39‰	33.97‰

The classical assumption that the circulation in a fjord is hydraulically controlled in the mouth of the fjord may possibly be justified in the upper layer in narrow fjords. Hydraulic controlled circulation may also exist in parts of a fjord where there are narrow passages and/or sills. The physical and dynamical processes in fjords are governed far more by exchange with coastal waters than river estuaries. Large seasonal variations of freshwater supply and air temperature occur in the fjords of north Norway. As a consequence, the stratification and circulation pattern varies considerably during the year (Svendsen, 1995; Eilertsen and Skarðhamar, 2006). The exchange in narrow fjords takes place as a pressure driven, mainly two-layer circulation. Due to the rotational dynamics the exchange in broad fjords takes place in some different way than in narrow fjords. In wider fjords, such as Porsangerfjord, rotational effects influence the dynamics significantly (Svendsen, 1995) , and may slow down the exchange of fjord water relative to more narrow fjords.

Knudsen's relation considers the integrated conservation of volume and salt in a basin that has a riverine source of fresh water and exchange flow with the ocean.The estuarine circulation was estimated by Knudsen's equations with mean values of measurements as input. Qf is the mean freshwater supply, S1 and S2 is the mean salinity down to one meter and the mean between 10 and 100 meters, respectively. The current measurements in Porsangerfjorden by Svendsen (1995) and velocity

Table 25: Velocity and transport calculated using Knudsen relationship (Upper layer 10m and Lower layer 100m) at different stations during winter.

Station No:	Velocity upper layer (*m/sec*)	Transport upper layer (m^3/sec)	Velocity lower layer (*m/sec*)	Transport lower layer (m^3/sec)
9001	-0.021	-4148.65	-0.002	-4198.65
9007	2.288	343224.22	0.229	343174.22
7001	-0.059	-5932.94	-0.006	-5982.94
7004	0.013	1820.67	0.001	1770.67
2002	0.182	4552.26	0.018	4512.26
2004	0.411	10285.19	0.041	10245.19
1007	0.082	4120.82	0.008	4080.82
1003	0.024	1189.83	0.002	1149.83

Table 26: Velocity and transport calculated using Knudsen relationship (Upper layer 10m and Lower layer 100m) at different stations during summer.

Station No:	Velocity upper layer (*m/sec*)	Transport upper layer (m^3/sec)	Velocity lower layer (*m/sec*)	Transport lower layer (m^3/sec)
9001	0.0637	12742.87	0.0063	12642.87
9007	0.0111	1669.83	0.001	1569.83
7001	0.0327	3267.19	0.0031	3067.19
7004	0.01	1405.75	0.0009	1205.75
2002	0.1634	4084.05	0.0151	3784.05
2004	0.1511	3777.64	0.0139	3477.64
1007	0.0527	2636.12	0.0049	2436.12
1003	0.0282	1409.27	0.0024	1209.27

calculated by Knudsen relationship showed (Table 25, 26) Porsangerfjorden have the lower velocities than Balsfjorden in summer. During the winter season, Outer Porsangerfjorden and Outer Altafjorden showed transport towards the fjord (Table 25), which is different from the other fjords. The net volume transport was higher in Porsagnerfjorden in both winter and summer seasons (Table 25, 26). The higher net transport in Porsangerfjorden is associated with the width of the fjord, even though the velocities were lower than the Southern fjords. Compared to other fjords Malangen showed lowest volume transport in both seasons.

The total heat flux during the winter in Porsangerfjorden was higher than Balsfjorden and Malangen during the winter season (Table 21). The calculations using Knudsen relationship showed an inward transport of water during winter season at Outer Porsangerfjorden. So, the higher heat flux could be the result of heat transport form the coastal water. At Balsfjorden, the transport of inflowing coastal water can be restricted by the sills, which results less transports into the fjord.

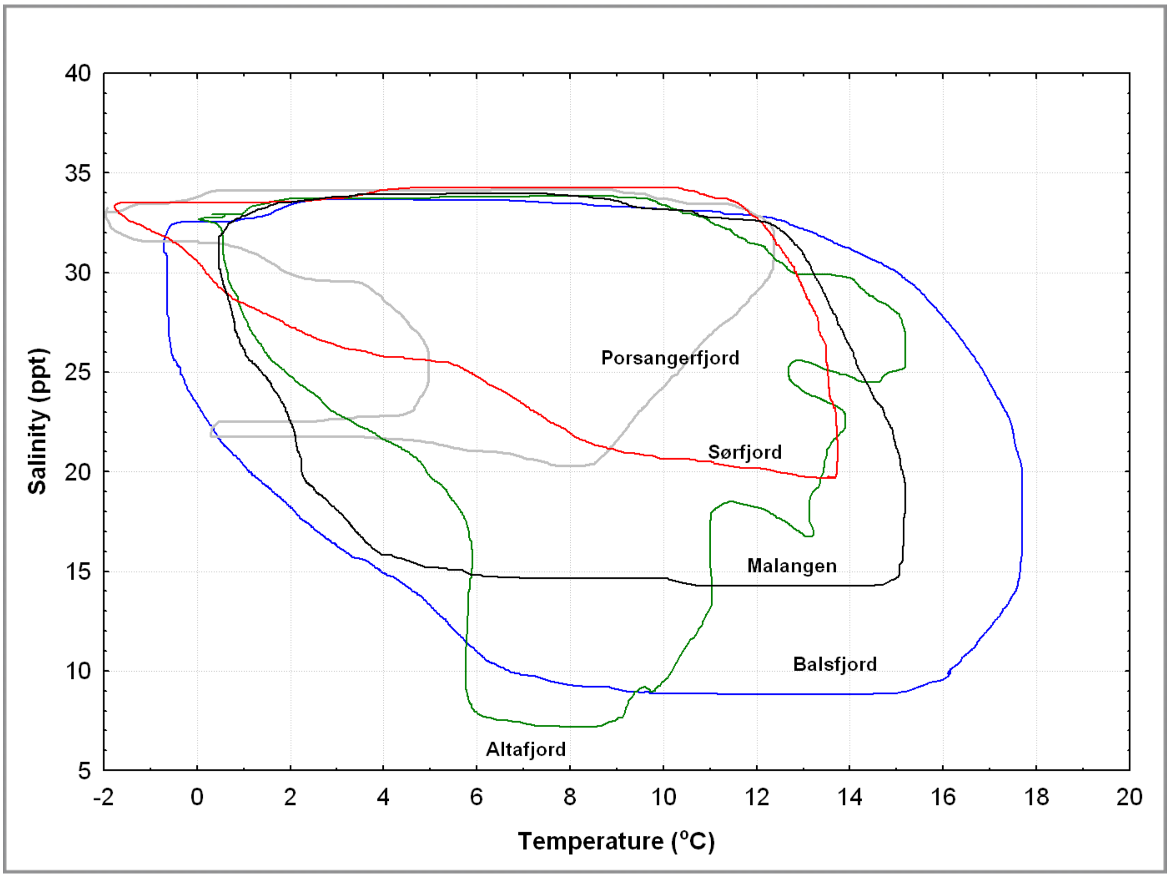


Figure 92: Temperature vs salinity relations (all depths) of the investigated fjords visualised as areas. The drawn lines embed all measured temperatures and salinities in each fjord. To avoid extremes the data sets were screened in such a manner that 0.5% of the highest and lowest temperatures and salinities were discarded, i.e. each dataset represents 99% of the total data.

4.4 INTERANNUAL TEMPERATURE, SALINITY AND DENSITY TRENDS BETWEEN INVESTIGATED AREAS (LONG TERM TRENDS) AND SEEN IN WIDER REGIONAL CONTEXT

It is a fact that combustion of fossil fuels have caused a rise in atmospheric concentrations of carbon dioxide by 25% the last 100 years (Mitchell, 1989). Also possibly other gases (methane, nitrous oxide) increased. As mentioned in the introduction there is a certain discrepancy amonst scientists whether there is a persistent warming of the earth, i.e. both atmosphere land areas and ocean, and if this is the case: is it manmade or is it an expression of natural variations in th earths climate systems (Bengtsson et al., 2004; Zhang et al., 1998; Clement et al., 2010; Lucarini et al., 2010; Blöschl and Montanari, 2010; Cane et al., 1997; Folland et al., 2001; Schneider, 1989, 1990).

It is obvious that, whether there is a manmade global warming or not, since seawater has a very high heat capacity and cover 71% of the earths surface the oceans plays a crucial role in earth's climate. It was stated by Levitus et al. (2000) that the oceans (entire watercolumn) is warming by a rate of 0.58°C per century, and it is claimed that this is continuing (Levitus et al., 2012). Most of the climate warming debate is concentrated on the atmosphere, but according to Levitus et al. (2000), this excess heat accumulated/stored by the oceans since 1955 is of immense proportions and (citation from Levitus et al. (2000))

> " We have estimated an increase of 24x1022 J representing a volume mean warming of 0.09°C of the 0-2000m layer of the World Ocean. If this heat were instantly transferred to the lower 10 km of the global atmosphere it would result in a volume mean warming of this atmospheric layer by approximately 36°C (65°F) ."

If this correct I cannot judge, but anyway it stresses the importance of the oceans in regulating the world's climate, and though this represents significant increases in global heat content it does not necessary imply that this is a manmade process. As mentioned there is an agreement that northern and Arctic areas plays an important role in the regulation of the global climate. Quadfasel et al. (1991) stated that there is a warming of the Atlantic layer of the Arctic Ocean (Quadfasel et al., 1991). This apparently also happened during 1918-1940 (Scherhag, 1937). This was though disputed by Kahl et al. (1993) that also observed significant surface cooling over the western Arctic Ocean during winter and autumn (Kahl et al., 1993).

The present dataset, representing data from a long period, offers a good opportunity to evaluate the overall heat content of the northern fjord and coastal areas. To check this I chose an approach where I computed depth averaged temperatures during the summer season (June–August) and let this represent the total heat content of the water column. This approach, rather than only inspecting temperatures from specific depths, was chosen since it is clear that there may be situations where in fact the upper water layers can, for periods, show significant increases or decreases in temperature while the total heat content of the water columns can show other trends. This was the case when surface warming of the Bering Sea occurred in 1997 and 1998 (Stabeno et al., 2007) while the total heat content of the water columns decreased. I have chosen stations Outer Malangen (open fjord), Inner Balsfjord (closed fjord), Refsbotn Skipsholmen (coastal station, 8001) and Outer Porsangefjorden (northern open fjord) to be representative of the heat content of the area (Fig 93– 96). Since data prior to ca. 1978 was collected with Nansen bottles at specific depths (0, 5, 10, 25, 50, 75, 100, 125, 150, 175m, 10m above bottom) only these depths were included in the computations. There was no clear heating or cooling trends could be detected by analysing the heat content for different locations (Fig 93– 96). The heat content for the Inner Malangen were comparatively less than Outer stations and coastal locations. All the stations follow almost the same pattern and like the surface temperature, there was a decrease in total heat content after the year 2005.

During 1990s there was a noticeable variations in the oceanographic climate of the Arctic Ocean and it has been associated with the abnormal heat and volume transport from the Nordic Seas to the Atlantic (Furevik, 2001). According to Furevik (2001), he studied the time series for mean temperatures (from the Norwegian Sea and in the Barents Sea Opening) at 10, 50, 100, 200, 300, and 400

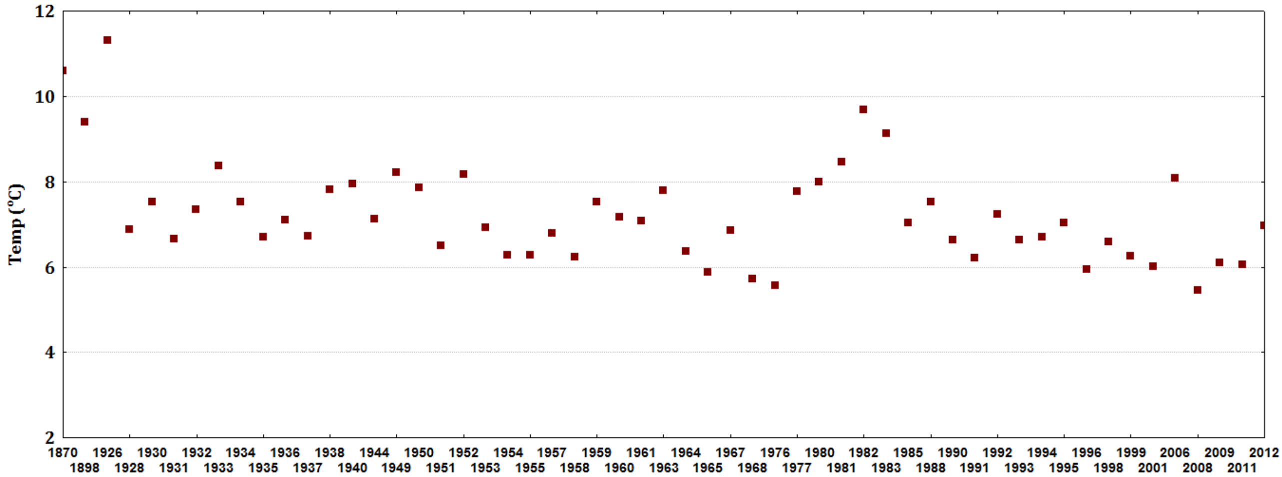


Figure 93: Depth averaged summer season (June – July –August) temperatures from station Outer Malangen

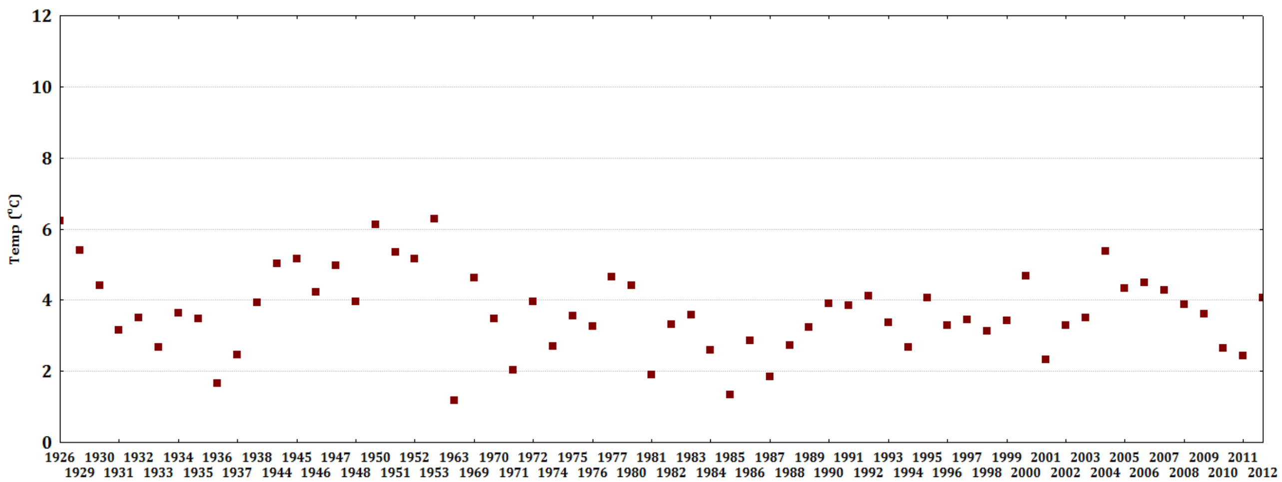


Figure 94: Depth averaged summer season (June – July – August) temperatures from station Inner Balsfjorden. station Outer Malangen. Since data prior to ca. 1978 was collected with Nansen bottles at specific depths (0, 5, 10, 25, 50, 75, 100, 125, 150, 175m, 10m above bottm) only these depths were included in the computations

m depths, there was a warm period in 1990-1992 period. I have compared the long term (1920-2012) mean temperature for Malangen, Altafjorden, and Porsangerfjorden, with mean temperature during the period 1990-1992 (Figure 97). The stations selected were outermost stations in the fjords. It is interesting to note that the warm waters are present in all the investigated fjords. The water column up to 100 meters in the summer and winter in Altafjorden and Porsangerfjorden are comparatively warmer (2°C) during this period. Even though the outer stations are affected by AW, the inner stations like inner Porsangerfjorden, Inner Altafjorden etc were not influenced.

The Arctic climate impact assessment suggests that the Polar region would have a earlier climate changes (Kattsov and Kallen, 2005; Kattsov et al., 2005). This could be affected by Pole ward Ocean heat transport that would affect the arctic temperature directly and indirectly. The direct effect could be as a result of changes in the strength and /or location of heat transport that will affect the amount

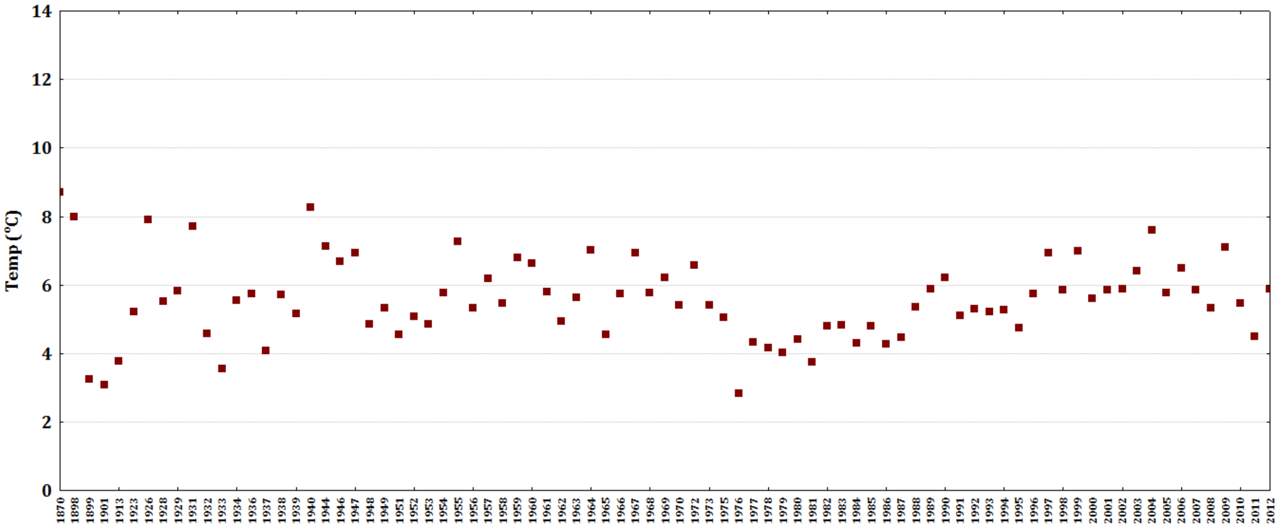


Figure 95: Depth averaged summer season (June – July – August) temperatures from station Refsbotn (Station 8001)

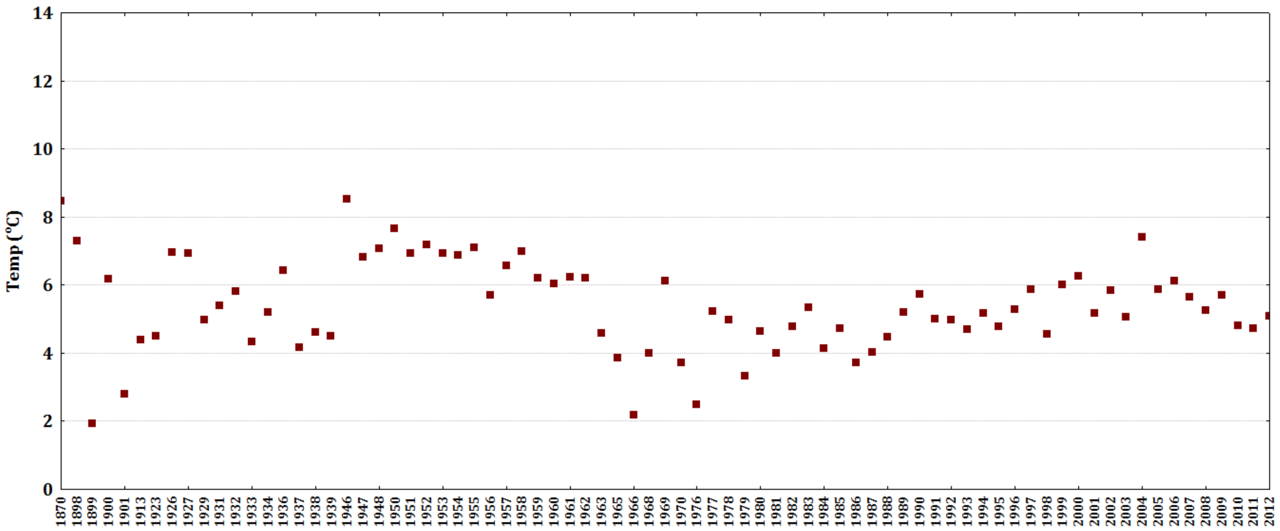
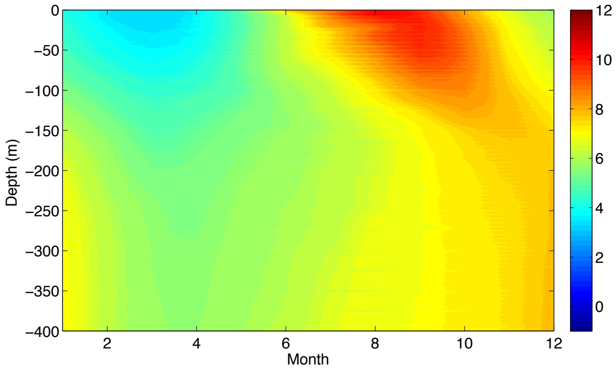
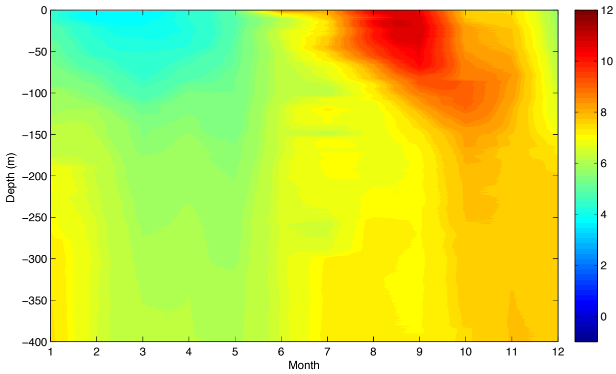


Figure 96: Depth averaged summer season (June – July – August) temperatures from station Outer Porsangerfjord

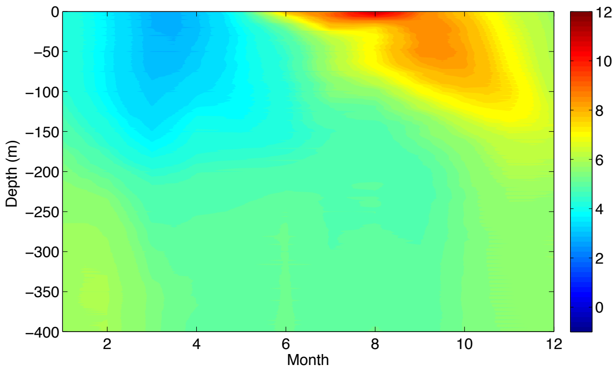
of warming whereas the indirect effect could influence the nature of sea-ice retreat (Holland and Bitz, 2003). Furthermore in 2010, Polyakov et al., they analyzed historical and modern observations for the intermediate depth (150m-900m) of Atlantic water of the Arctic Ocean that revealed an increase in the level of temperature. However, warming has been uneven, in the in the mid 1990s a 1°C maximum was observed locally then it decreased gradually and in 2007 the temperature increased 0.248°C higher than that of 1990s. Mooring and synoptic observation in the fram strait region have shown that the alternation in the temperature have been moved into the Arctic Ocean during 2000-2005 (Walczowski and Piechura, 2006). The temperature and salinity of the Atlantic water was substantially increased in 2005. Temperature anomalies for 5m at stations Outer Malangen (open fjord), Inner Balsfjord (closed fjord), Refsbotn Skipsholmen (coastal station, 8001) and Outer Por-



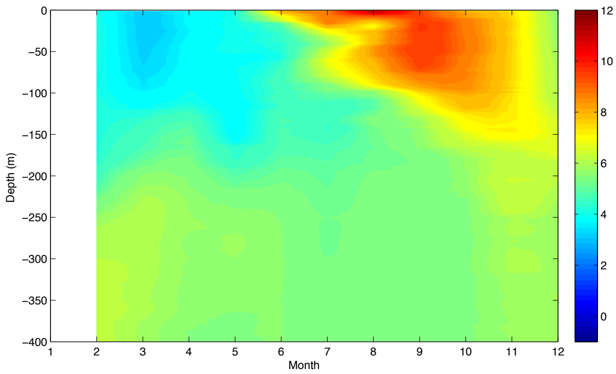
(a) Malangen (1006), Temperature °C (1920-2012)



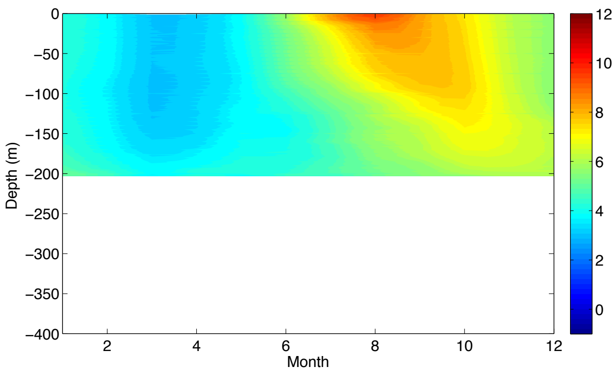
(b) Malangen (1006), Temperature °C (1990-1992)



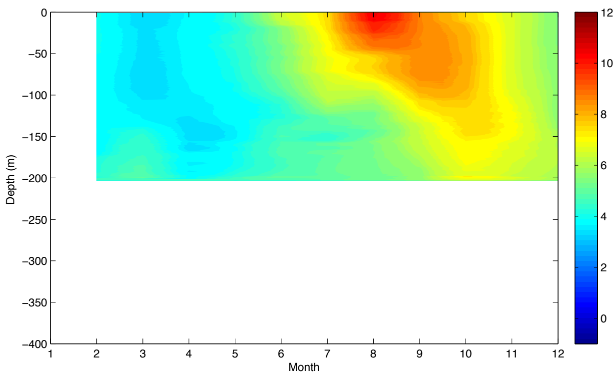
(c) Altafjorden (7001), Temperature °C (1920-2012)



(d) Altafjorden (7001), Temperature °C (1990-1992)



(e) Porsangerfjord(9001), Temperature °C (1920-2012)



(f) Porsangerfjord(9001), Temperature °C (1990-1992)

Figure 97: Monthly variations in mean temperature during 1920–2012 (left) and 1990–1992 (right) in Malangen (St: 1006), Altafjorden (St: 7001) and Porsangerfjorden (St: 9001)

sangefjord (northern open fjord) were calculated (Figure 98, 99, 100 and 101). It showed no clear long term heating or cooling trends during the period 1920–2012.

During the winter season (Figures 248 – 259) , all the stations (Malangen, Balsfjorden, Refsbotn Skipsholmen and Outer Porsangerfjorden) with data 1920-1940 showed that the years 1929–1930 were warmer. Outer Malangen and Inner Balsfjorden showed the year 1938 was warmer. There was another warm period in 1960 in Malangen, but unfortunately no data set is available to compare with other fjords. All fjords showed a warm period between 1990-1992 and 2000. Malangen and Balsfjorden experienced another warm period during 2005 followed by a constant cooling trend until 2012

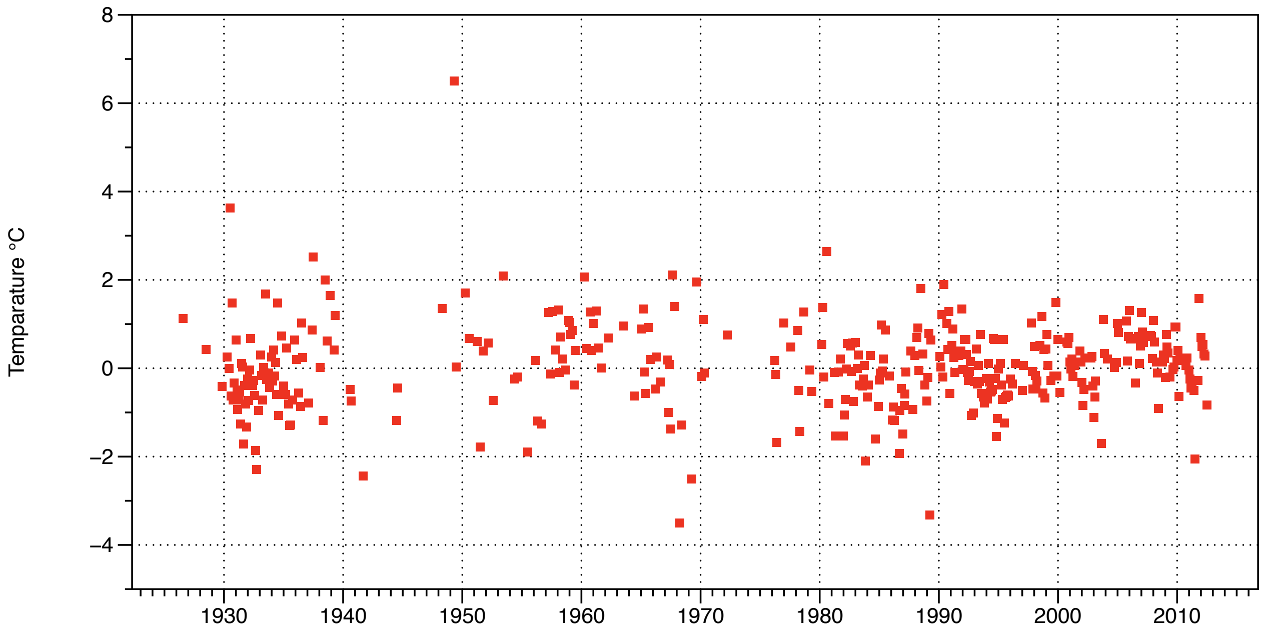


Figure 98: Temperature anomalies for 5 m at station Outer Managen

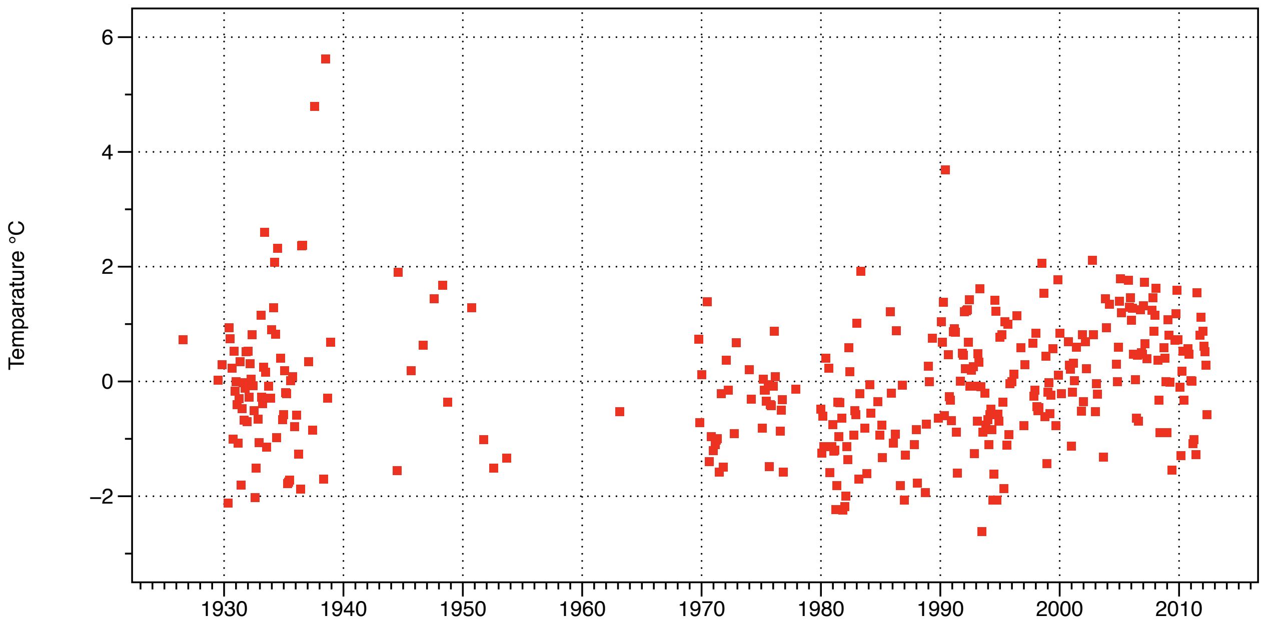


Figure 99: Temperature anomalies for 5 m at station Inner Balsfjorden

whereas in Altafjorden and Porsangerfjorden the warm period was in 2007 before it started cooling. Two months' average plots for interannual variability shows that decreasing trend is visible only during January –February period (Figures 392 – 403). Malangen and Balsfjorden had a colder period during the winter of 1937. Balsfjorden, Altafjorden and Porsangerfjorden showed lower temperatures than the previous years during 1975, 1984 and 1996. All the fjords experienced a colder year in 2011. Comapred to the winter season, the variability in temperature during spring season is less (nearly 1°C) in Malangen (Figures 260 – 271). Outer Malangen and Inner Balsfjorden showed a warm period

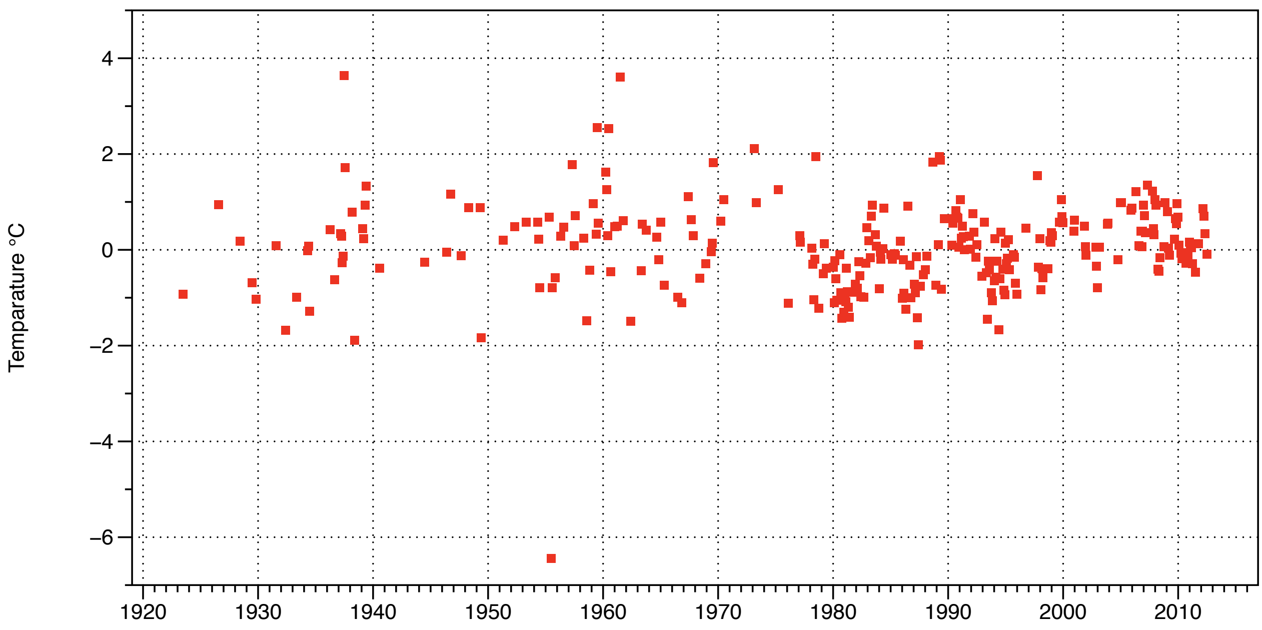


Figure 100: Temperature anomalies for 5 m at station Rafsbotn

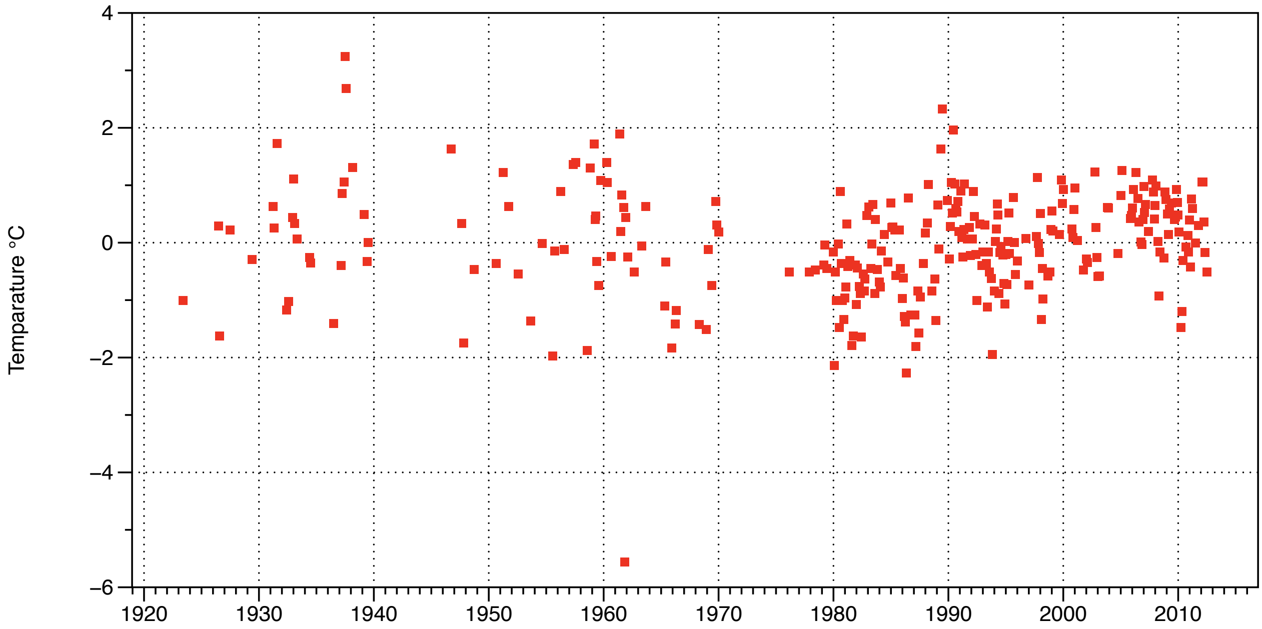


Figure 101: Temperature anomalies for 5 m at station Outer Porsangerfjorden

in 1938 in spring season. All the fjords shows a common warm period in 1988. Also all the fjords showed a warming trend from 2010. During summer (Figures 272 – 283) the variability at 100m and 50 m not that significant. The common warm period were in 1938 and 1990 in most of the fjords. The long term trends in temperature and salinity in Northern fjords did not show any clear warming trends (Figures 248 – 295).

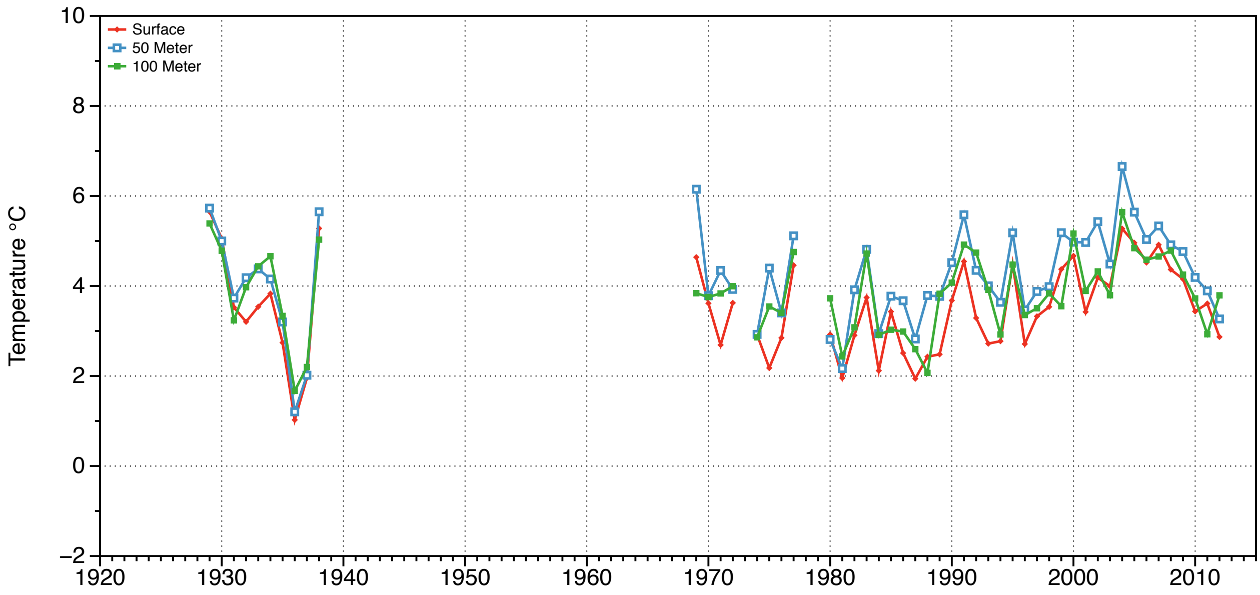


Figure 102: Interannual variation of winter temperature in Inner balsfjorden

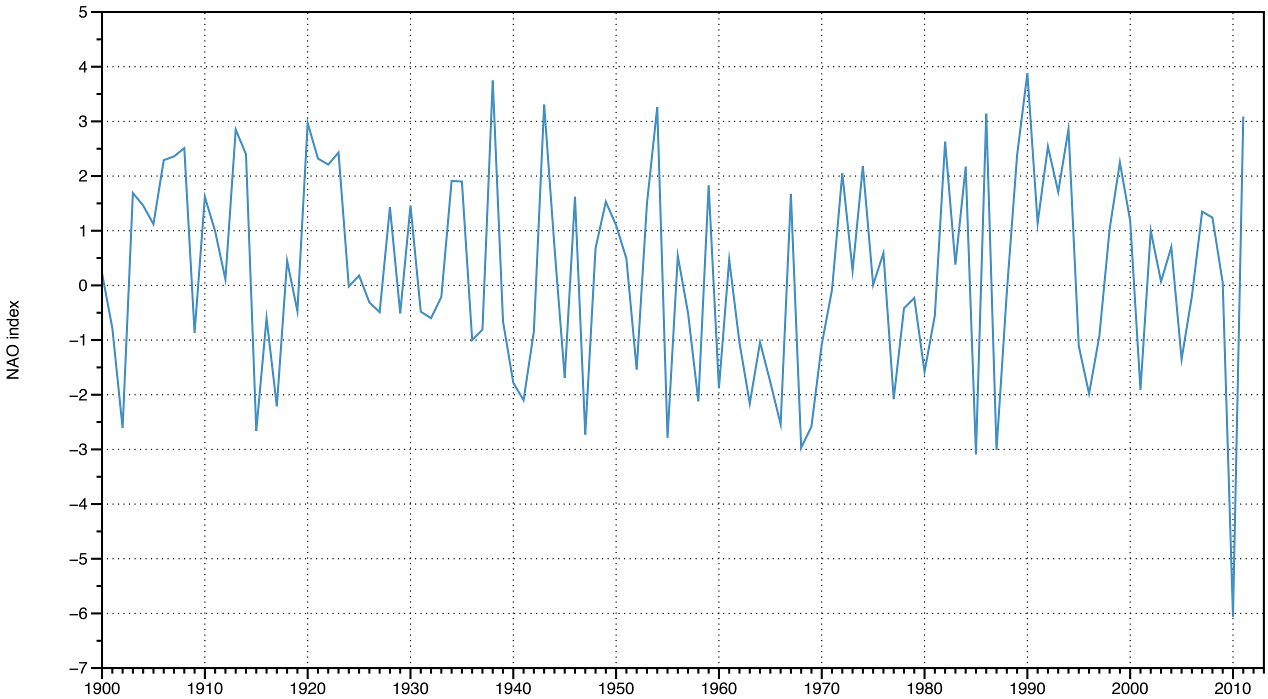


Figure 103: Interannual variation of NAO index

Hurrell (1995), proposed a correlation between the global warming and North Atlantic Oscillation. He observed a similarity between the changes in surface temperatures and NAO associated temperature variability and suggested that the changes in the temperature of the Northern Hemisphere (NH) were due to continuous effect of the NAO in its positive phase. In 1996, Hurrell added that all the observed warming over Eurasia since the mid 1970 was recognized as a result of interannual changes of the NAO (Hurrell, 1996). Figure 102 and 103 shows Interannual variability of temperature at Inner

Balsfjorden and NAO index. It shows that the warming and cooling trends in the fjords follows the NAO index. However, rather than synchronising with the NAO trend immediately, a temporal delay is observed in the fjords. For example, during year 1990 and 1998 NAO index were higher, but fjords experienced the warm periods in 1992 and 2000.

4.5 CONCLUDING REMARKS

Though Norway was one of the pioneers of oceanographic research, where oceanographic studies were implemented as early as in the mid 1800s. It is important to utilize and "remember" this legacy, especially in a context where climatic variations is in focus. Also it is worthy to remember that the early studies were, in addition to "pure" physics, also confined to explain variations in fisheries, something that is also important today when many fish stocks struggle. As is evident from several monographs dealing with the research history of Oceanography, systematical retrieval of the physical oceanographical data in Tromsø and north Norway goes back to ca. 1872 when Tromsø Museum was founded. Thus an invaluable treasure of oceanographical data has remained so far unexplored! One of the goals of my PhD has therefore been to make some of this these old data available to other researchers. As a part of my work, the entire data set has therefore been made available and downloadable from a new HMD website.

Norwegian Coastal Water (NCW) is mainly affected by the Norwegian Coastal Current (NCC), which has its origins from the Baltic Sea. The heat advected into the fjords cause large heat flux variations in the Northern Norwegian fjords which has a major influence on the Norwegian fjords and coastal regions. Therefore the present dataset is also important and valuable in understanding fjord–ocean interactions.

4.5.1 *Some of the most important observations:*

As the data shows, there was great variations in hydrophysical characteristics between the investigated fjords. There were also hydrographic variations between Inner fjords and Outer fjords. The characteristics of Northern Norwegian fjords is quite different from the Arctic fjords in a many ways. The stratification, seasonal change in salinity, temperature and circulation were different due to intense Arctic seasonality and different oceanic and atmospheric conditions experienced in the Arctic. The peak surface temperatures in the northern Norwegian fjords were recorded in July–August and the highest bottom temperatures were in November–December. The downward heating was slow compared to winter cooling.

The results from the present investigation show that the stratification in Malangen starts in May and the innermost stations are more stratified than the outer stations. Stratifications weaken from

September with decreasing run off and solar radiation. The winter surface temperatures are always lower in the inner parts of the fjords than in the outer areas. The salinities during winter demonstrate the same trend, i.e. with the largest difference in Malangen and the lowest in Porsangerfjord. This can be interpreted in terms of mixing since temperature decreases during the winter, leading to the conclusion that Porsangerfjord has the highest vertical mixing rate during winter and that Malangen has the slowest mixing. During summer it is always warmer in the surface, and the smallest difference is at outer Malangen and outer Porsangefjord. The summer is a period with stratification and the summer differences shows that Porsangerfjord is most mixed, ie, has a less layered structure than the other fjords.

To evaluate the ability to communicate with outer coastal water, being an important property of a fjord area, to compare the energy needed to rise temperatures from winter to summer (Q_{calc}) to “actual” heat fluxes calculated from measured temperatures, wind and cloud cover with a view to evaluate water influx/exchange. The calculated energy (Q_{calc}) needed to increase the temperatures in the fjords were always higher than the observed (Q_{obs}) fluxes. This is since heating from the atmosphere is not large enough to reach the mid summer maximum temperatures, reflecting the fact that the Norwegian Coastal current brings heat into the area. According to the computations Altafjord has little exchange, then follows Malangen and Balsfjord while Porsangerfjord has most heat (and water) advected into the fjord. The results from the calculations lead to the conclusion that advection of water during winter must be increasing from south to north since the discrepancies in demanded and observed heat flux increase northwards. Otherwise ,the temperatures of the northern fjords would have continuously decreased.

In terms of temperature and salinity variations among the fjords, Balsfjord varies most in temperature and second highest in salinity just following Altafjord. Malangen shows a more narrow distribution in both parameters while Porsangefjord clearly is colder (has the lowest temperatures) and also operates at the narrowest salinity range, i.e. it is furthest away from an estuary definition in terms of salinity variations.

The total heat flux during the winter in Porsangerfjorden was higher than Balsfjorden and Malangen during winter . The calculations using Knudsen relationship showed an inward transport of water during winter season at Outer Porsangerfjorden. The higher heat flux could be attributed to the heat transport from the coastal water. In Balsfjorden, the transport of inflowing coastal water is being restricted by the sills, which results in less transport into the fjords.

Temperature anomalies for 5m at stations Outer Malangen (open fjord), Inner Balsfjord (closed fjord), Refsbotn Skipsholmen (coastal station) and Outer Porsangefjord (northern open fjord) were calculated. The analysis revealed no significant long term heating or cooling trends for the period from 192–2012. The interannual variability of temperature at Inner Balsfjorden and NAO index shows the warming and cooling trend follows the NAO index but with an offset or lagging of a few years.

The years 1929–1930, 1990–1992 and 2000 were warmer in all the stations (Malangen, Balsfjorden, Refsbotn Skipsholmen and Outer Porsangerfjorden) during the winter season. Also Outer Malangen and Inner Balsfjorden were warmer in 1938. Malangen and Balsfjorden experienced another warm period during 2005 followed by a constant cooling trend until 2012 whereas in Altafjorden and Porsangerfjorden the warm period was in 2007 before it started cooling. Malangen and Balsfjorden had a colder period during the winter of 1937. Balsfjorden, Altafjorden and Porsangerfjorden showed lower temperatures during 1975, 1984 and 1996. All the fjords experienced a colder year in 2011.

The present study indicates the necessity of comprehensive field experiments being supported by the use of numerical modeling tools, as frequency of data collection is limited to once in a month and even in this scenario, data pertaining to certain months are missing for varying reasons. Thus as is the case in all scientific endeavors, the data driven empirical approach in oceanographic research needs to be supplemented with creative mathematical interpolation. And towards this end, I believe, the volume of as well as the way in which I have set out the data will prove to be beneficial.

APPENDIX

A

FIGURES

A.1 MONTHLY VARIATIONS IN TEMPERATURE

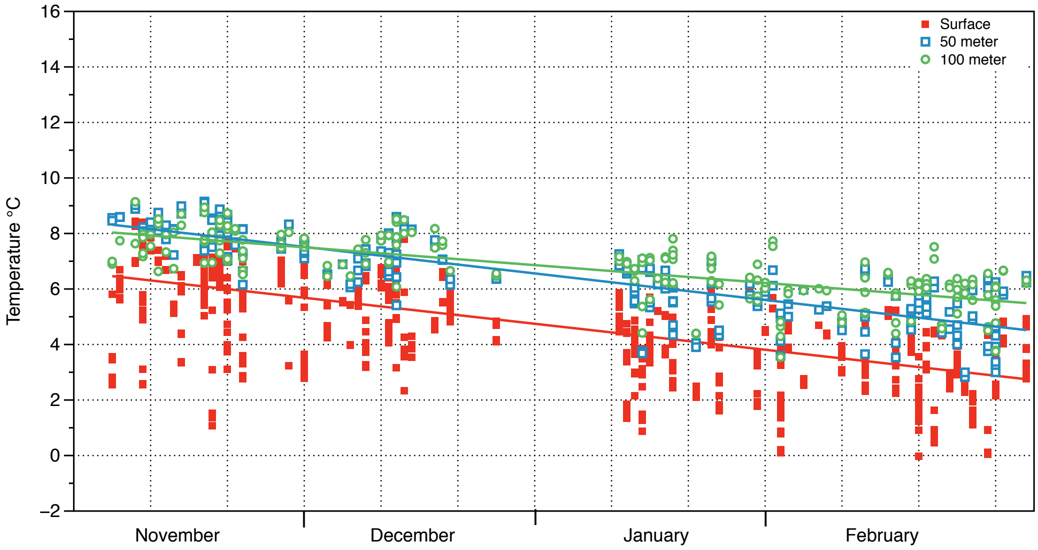


Figure 104: Monthly variability of winter temperatures (November – February) at station Inner Malangen

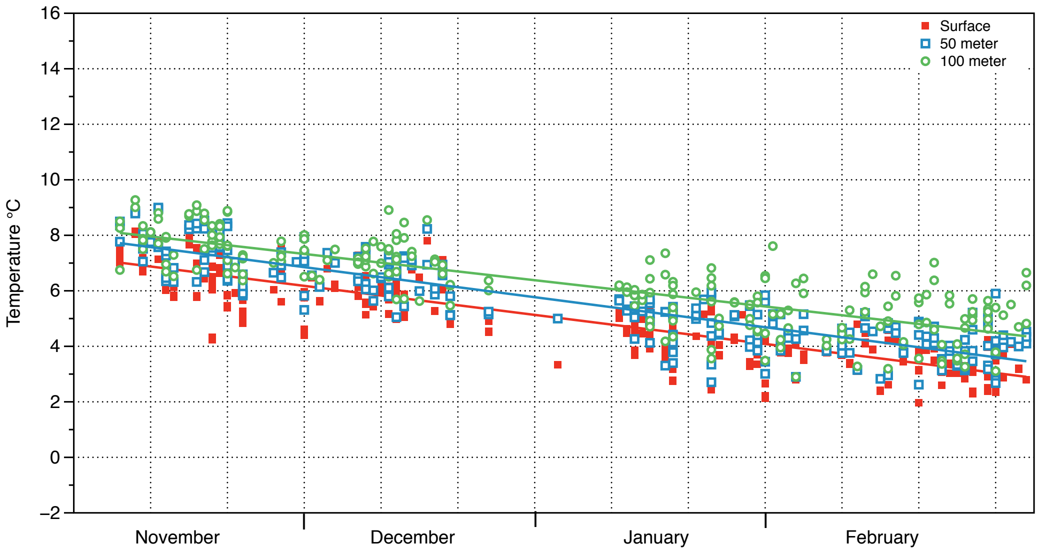


Figure 105: Monthly variability of winter temperatures (November – February) at station Outer Malangen

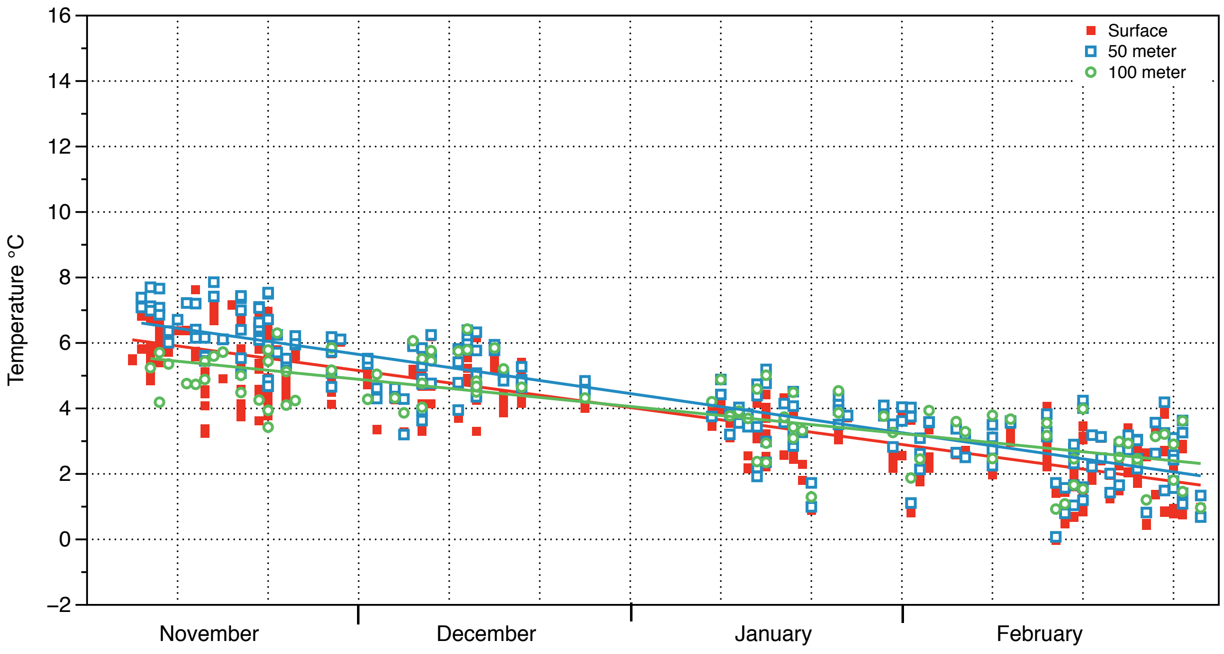


Figure 106: Monthly variability of winter temperatures (November – February) at station Outer Balsfjorden

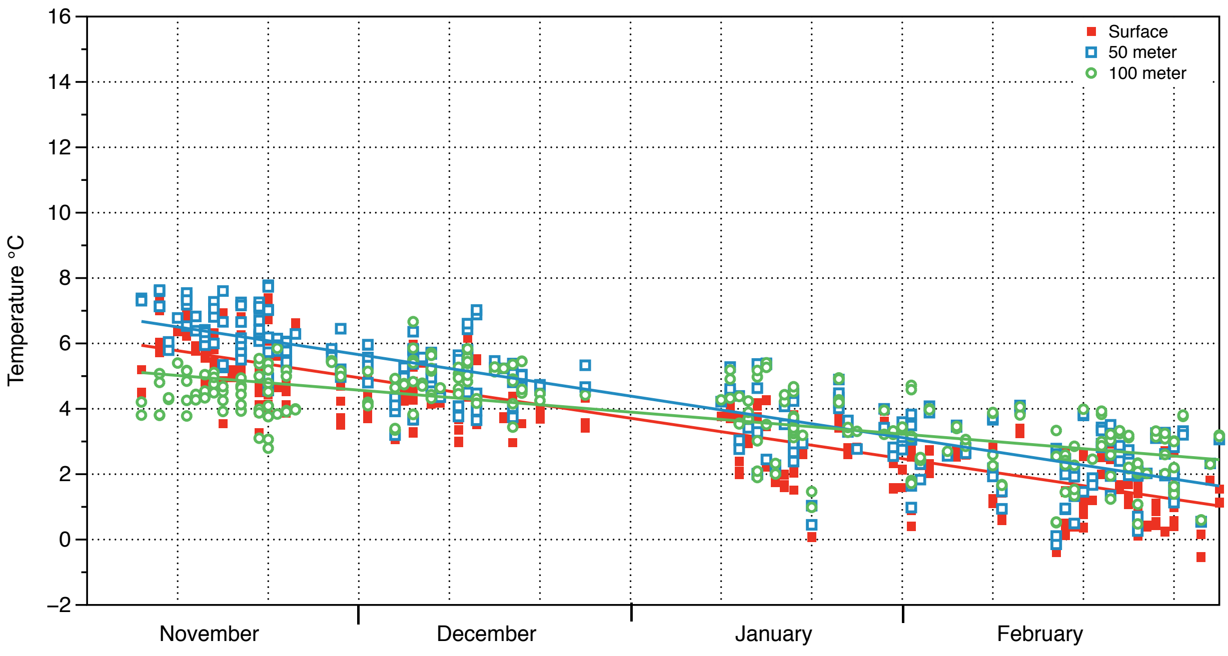


Figure 107: Monthly variability of winter temperatures (November – February) at station Inner Balsfjorden

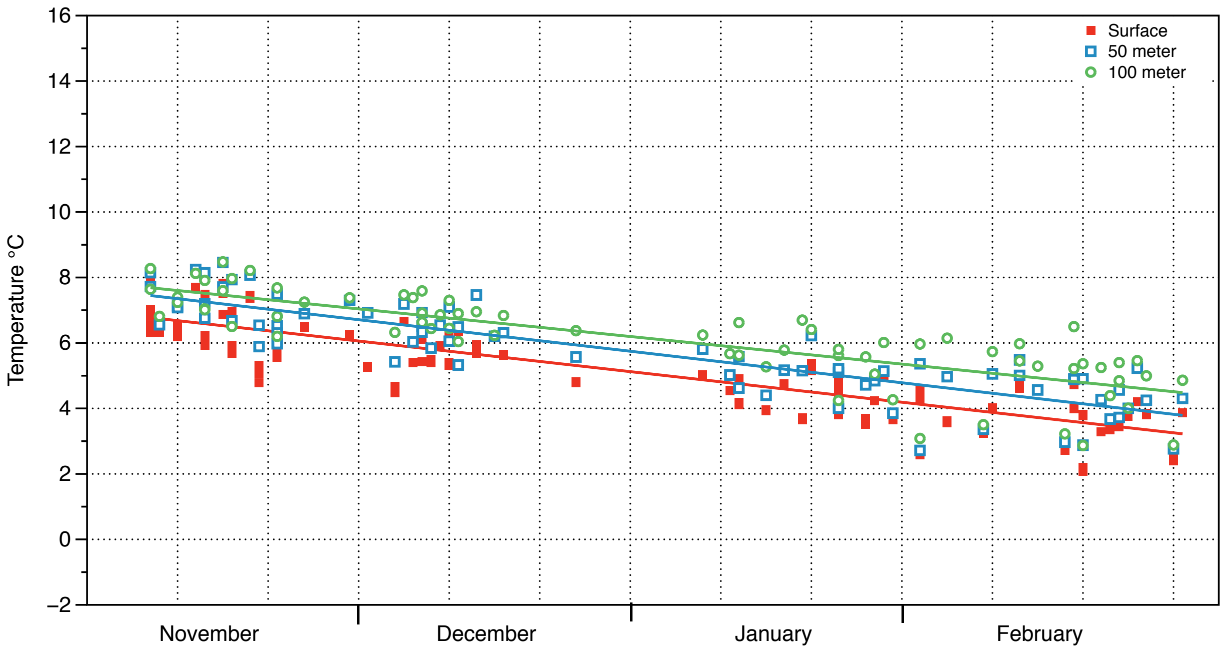


Figure 108: Monthly variability of winter temperatures (November – February) at station Kvalsund

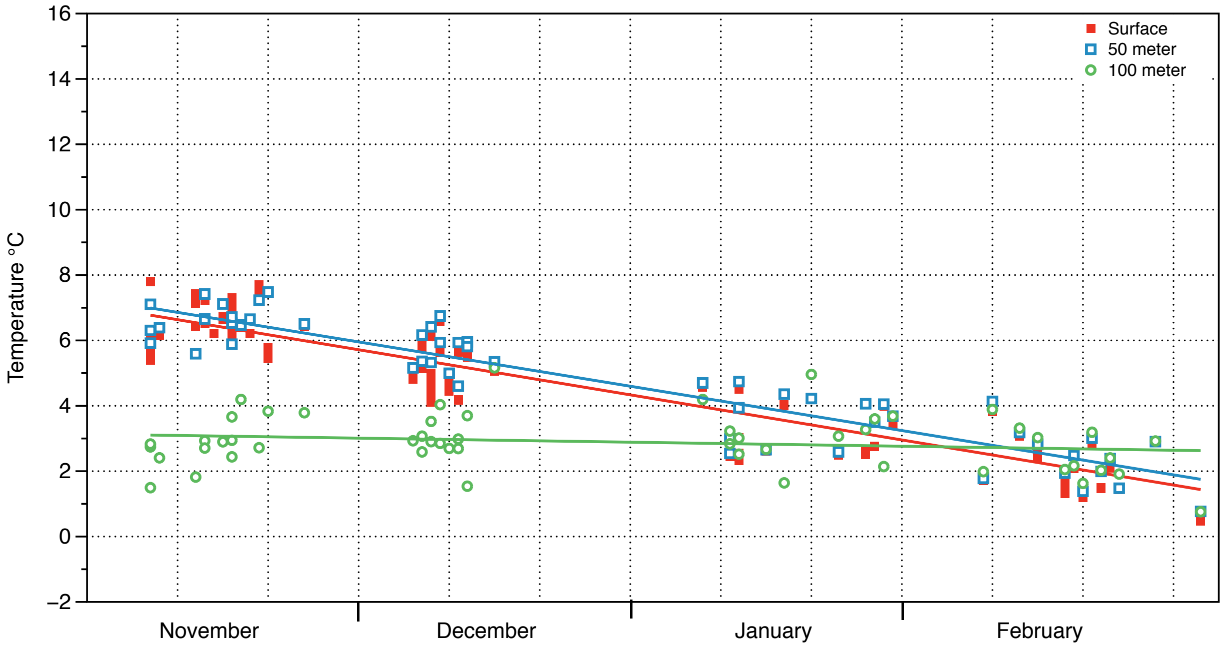


Figure 109: Monthly variability of winter temperatures (November – February) at station Sørfjord

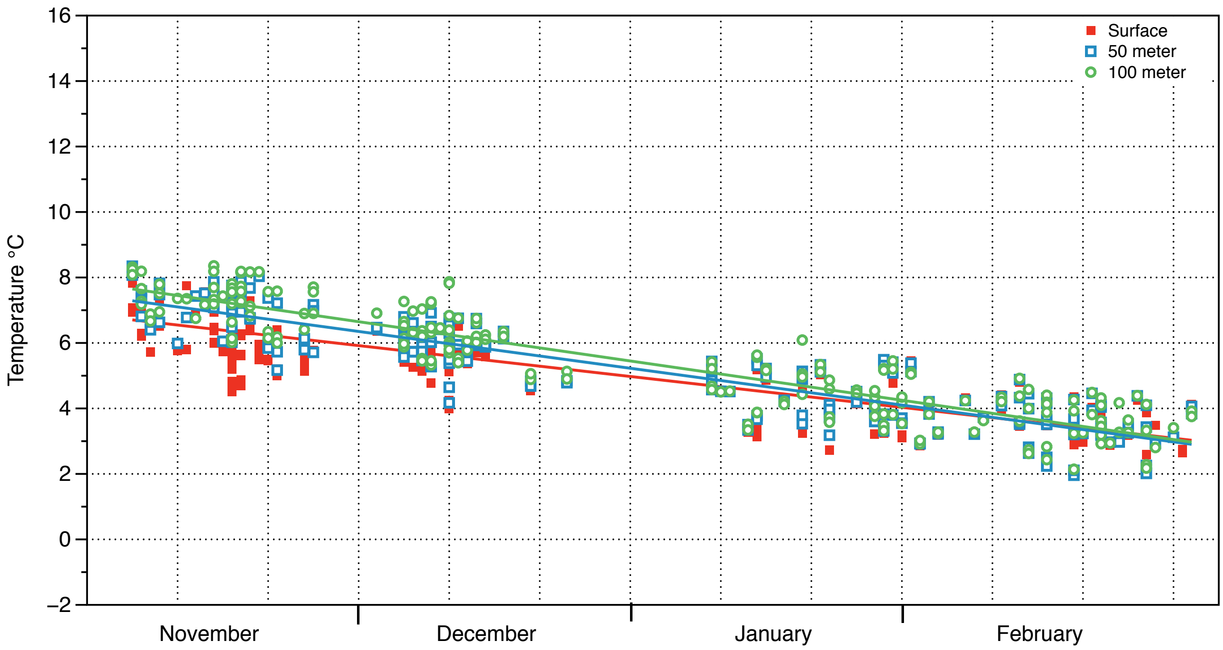


Figure 110: Monthly variability of winter temperatures (November – February) at station Outer Altafjorden

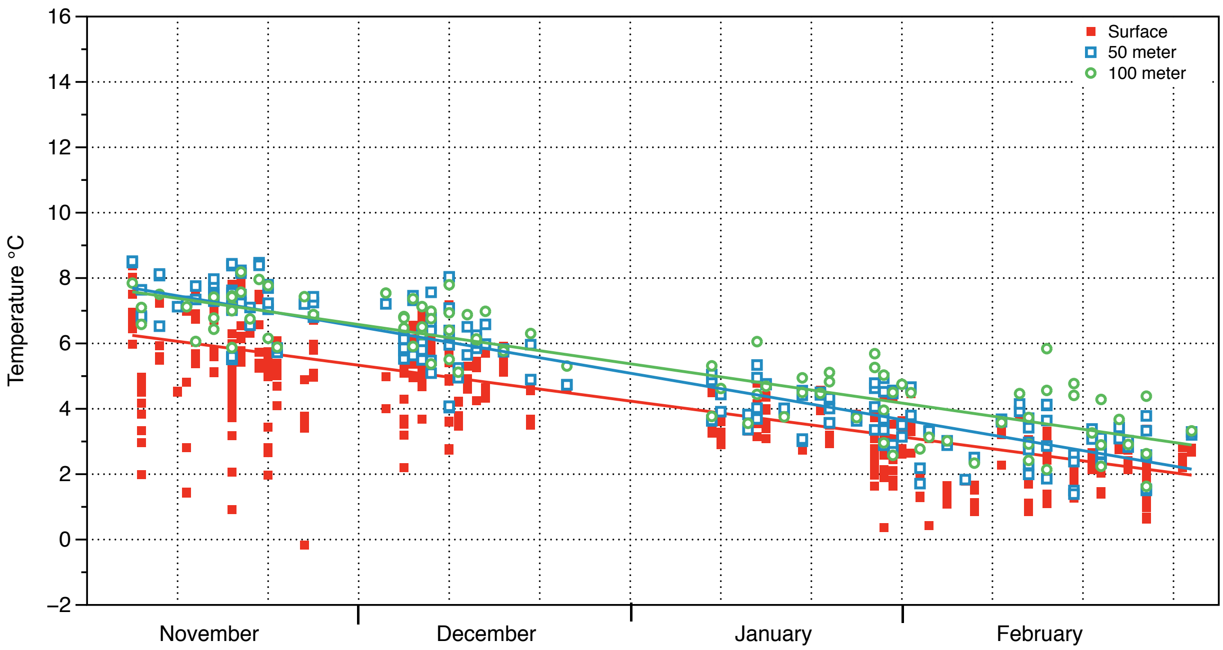


Figure 111: Monthly variability of winter temperatures (November – February) at station Inner Altafjorden

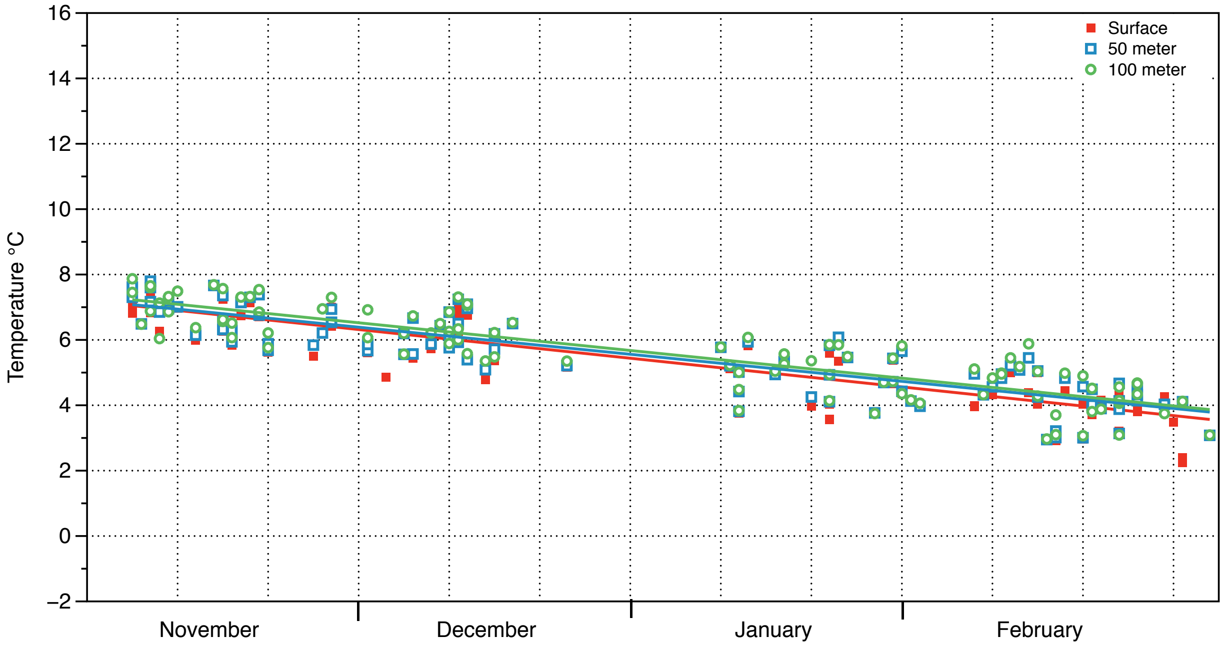


Figure 112: Monthly variability of winter temperatures (November – February) at station Refsbotn

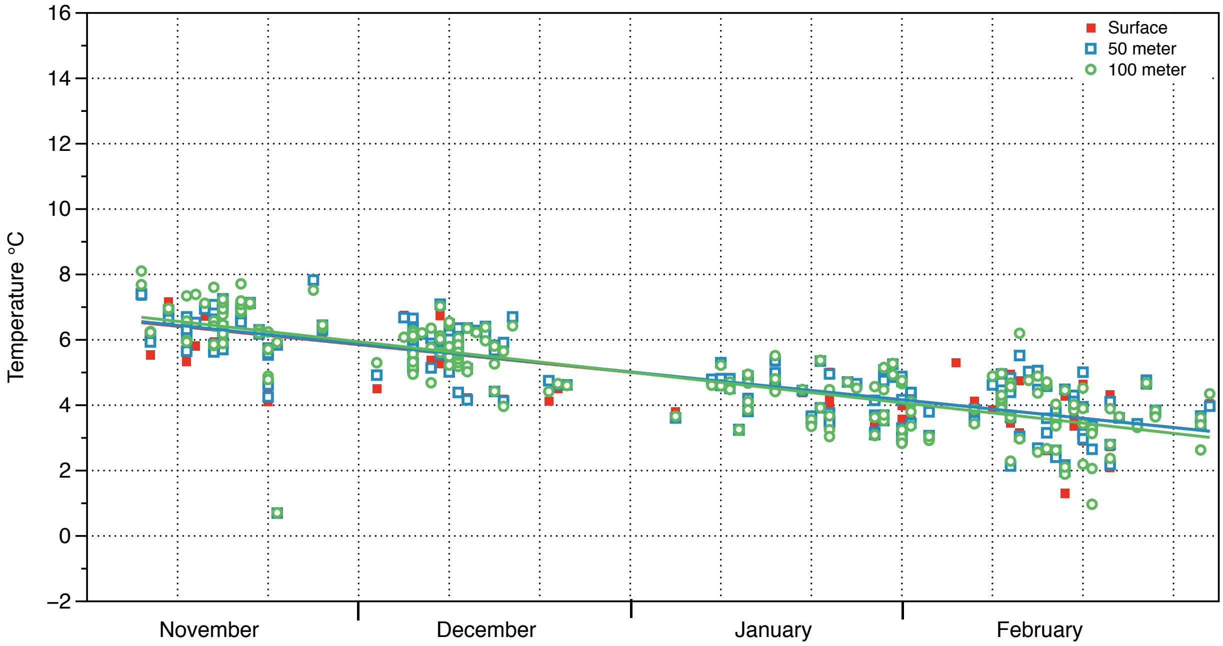


Figure 113: Monthly variability of winter temperatures (November – February) at station Outer Porsangerfjorden

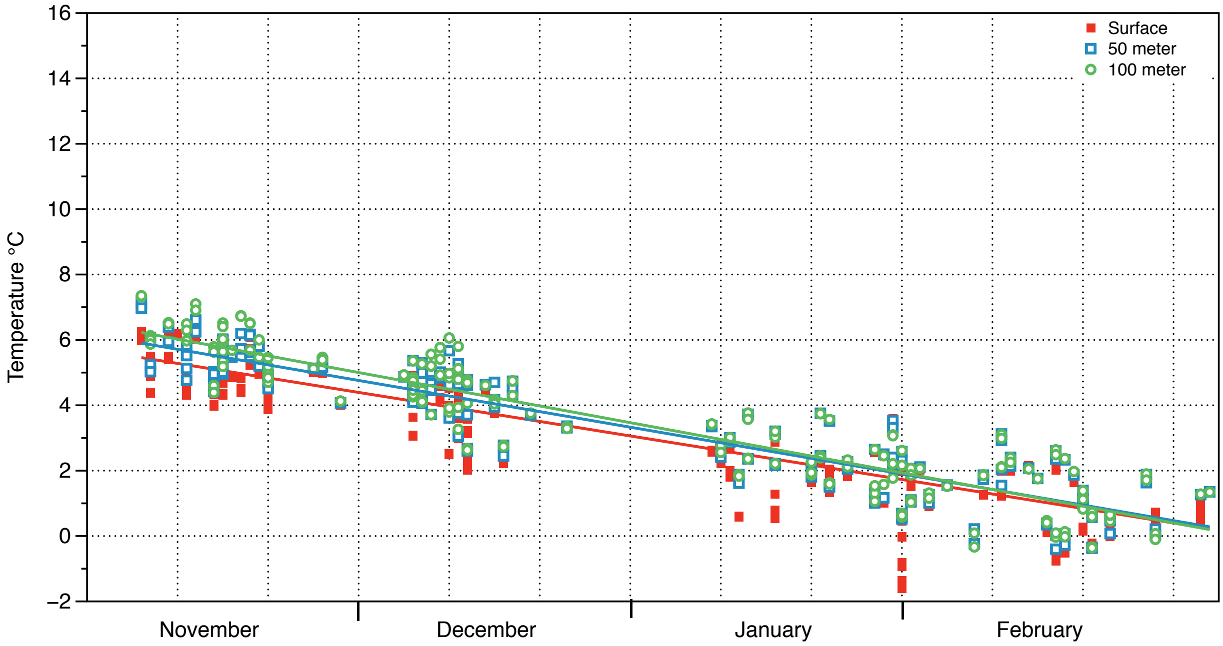


Figure 114: Monthly variability of winter temperatures (November – February) at station Inner Porsangerfjorden

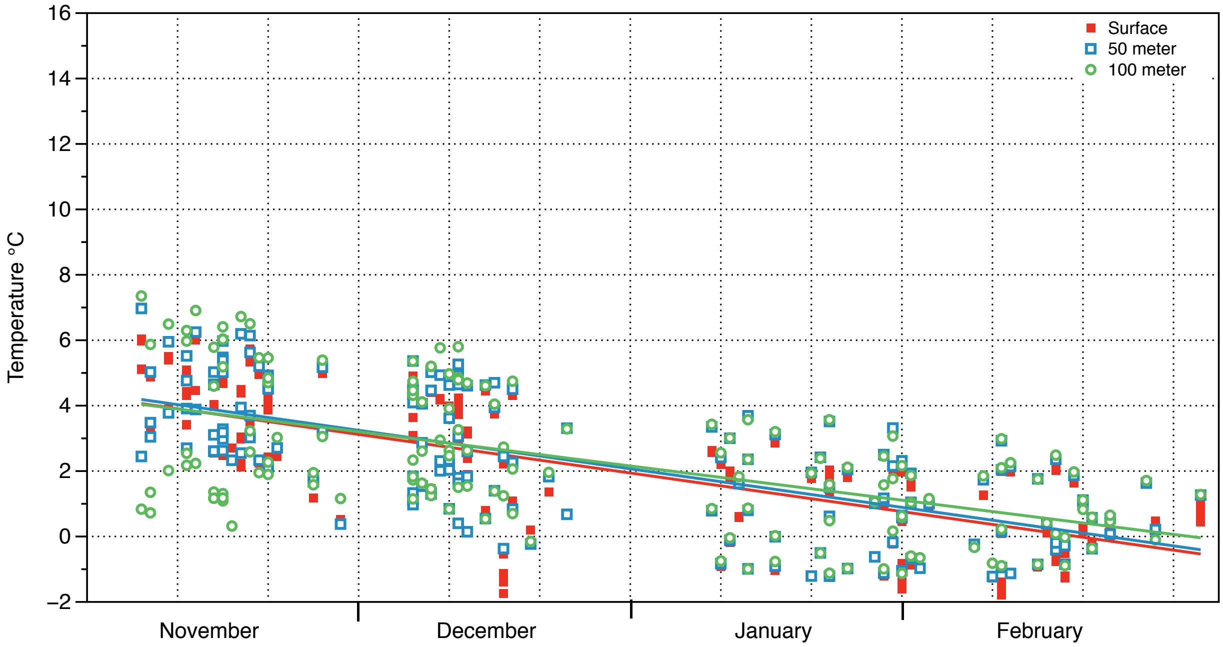


Figure 115: Monthly variability of winter temperatures (November – February) at station Østerbotn

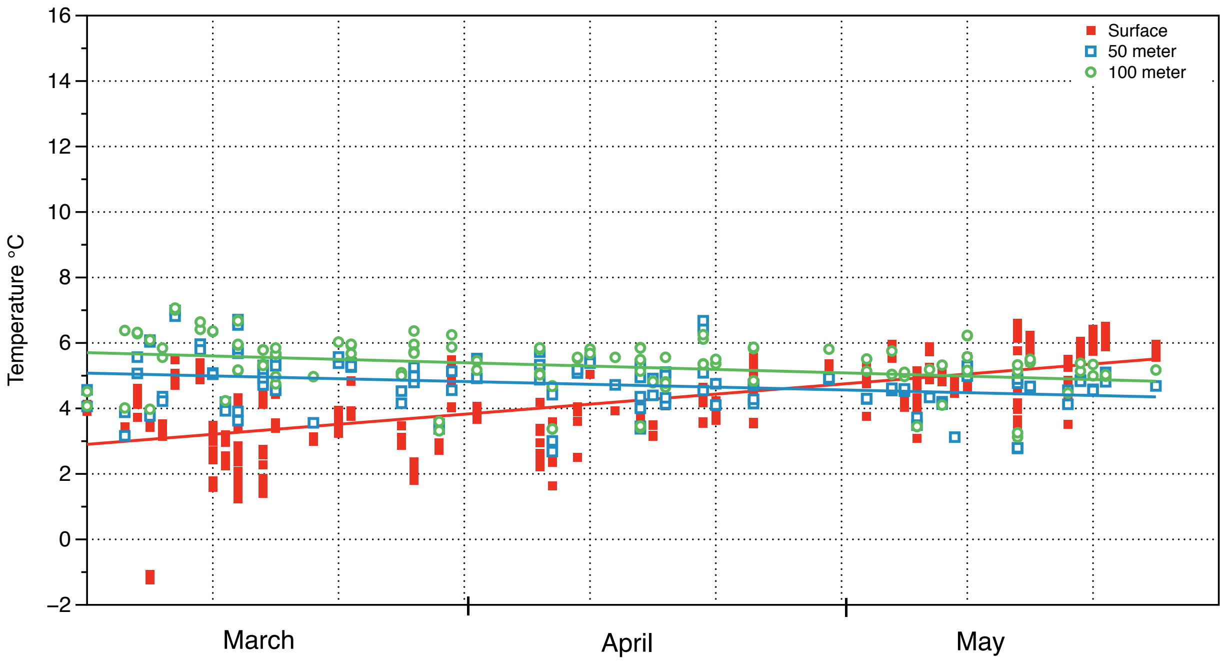


Figure 116: Monthly variability of spring temperatures (March – May) at station Inner Malangen

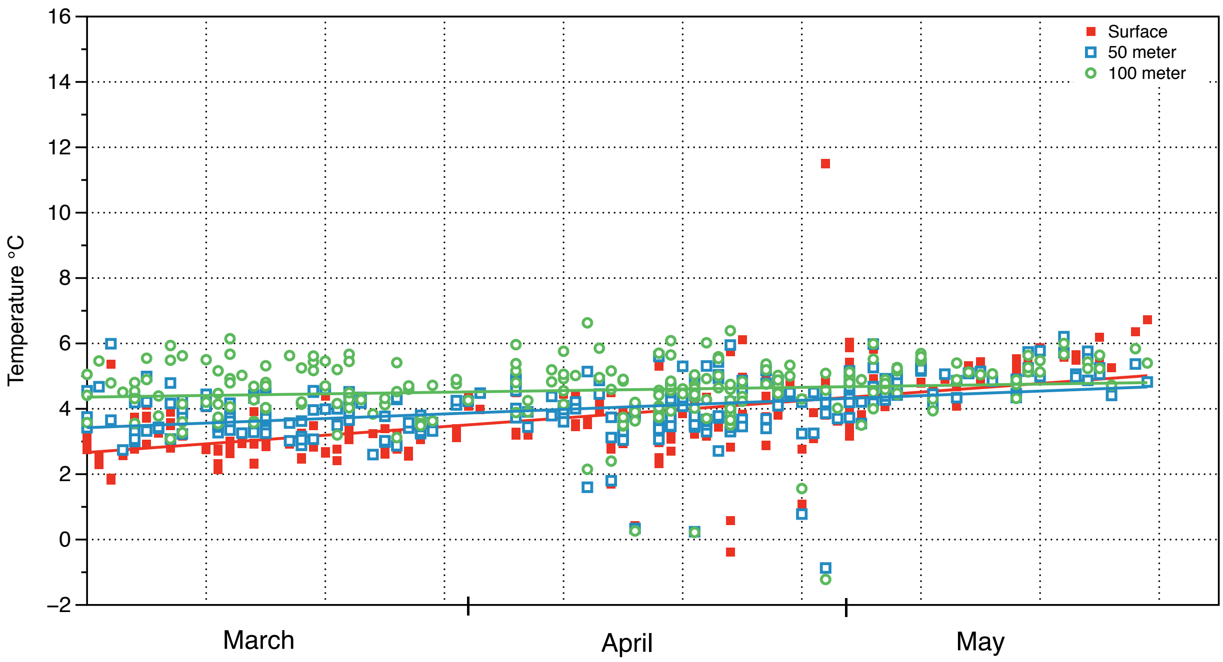


Figure 117: Monthly variability of spring temperatures (March – May) at station Outer Malangen

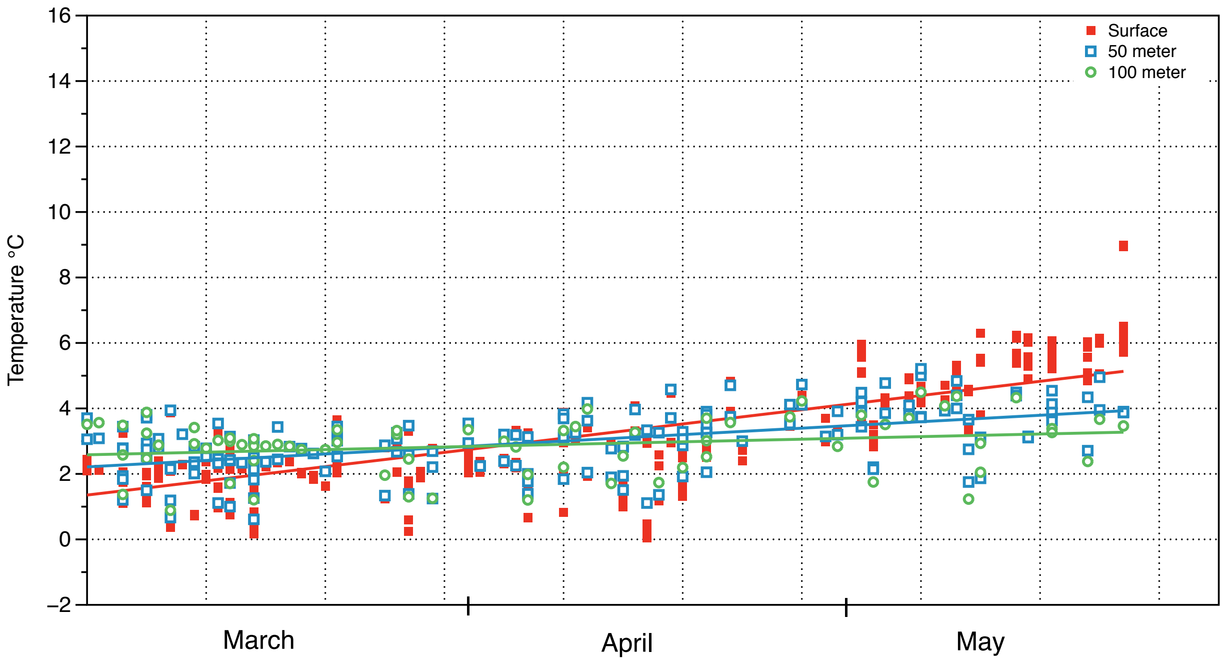


Figure 118: Monthly variability of spring temperatures (March – May) at station Outer Balsfjorden

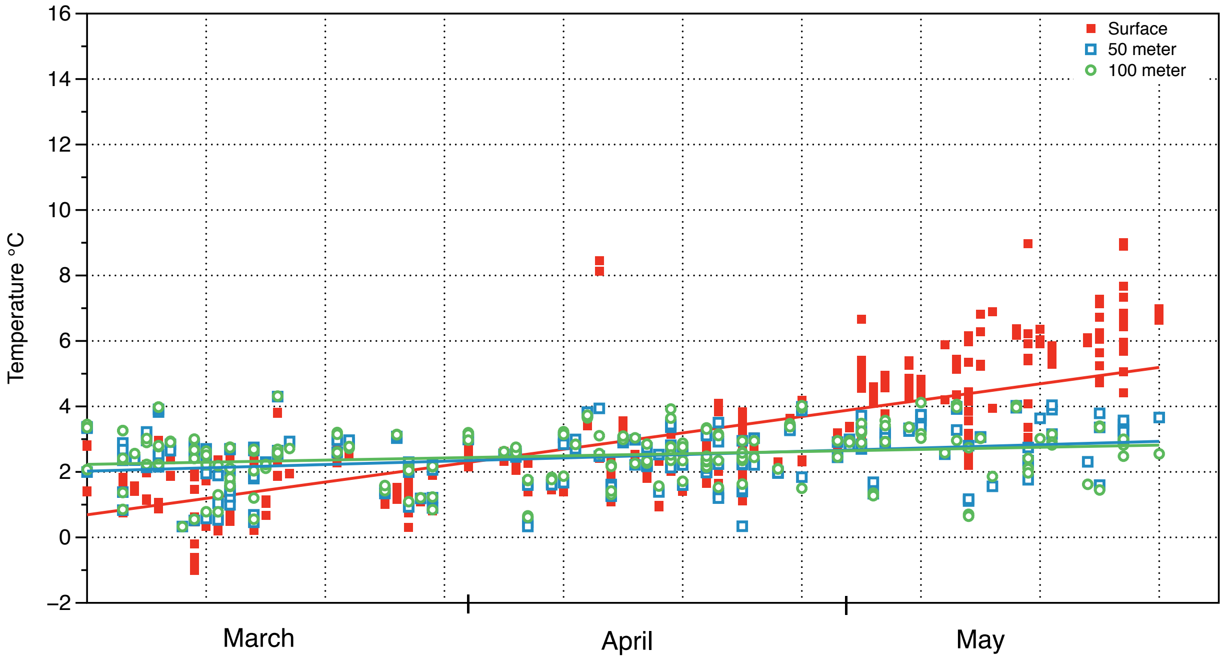


Figure 119: Monthly variability of spring temperatures (March – May) at station Inner Balsfjorden

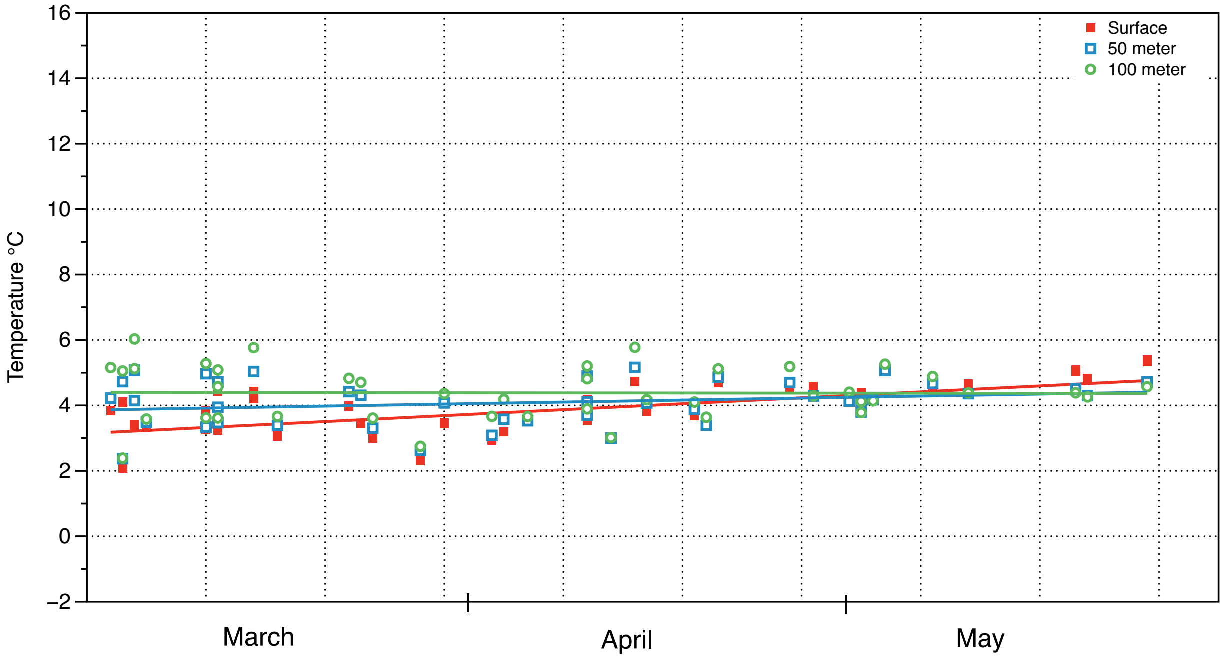


Figure 120: Monthly variability of spring temperatures (March – May) at station Kvalsund

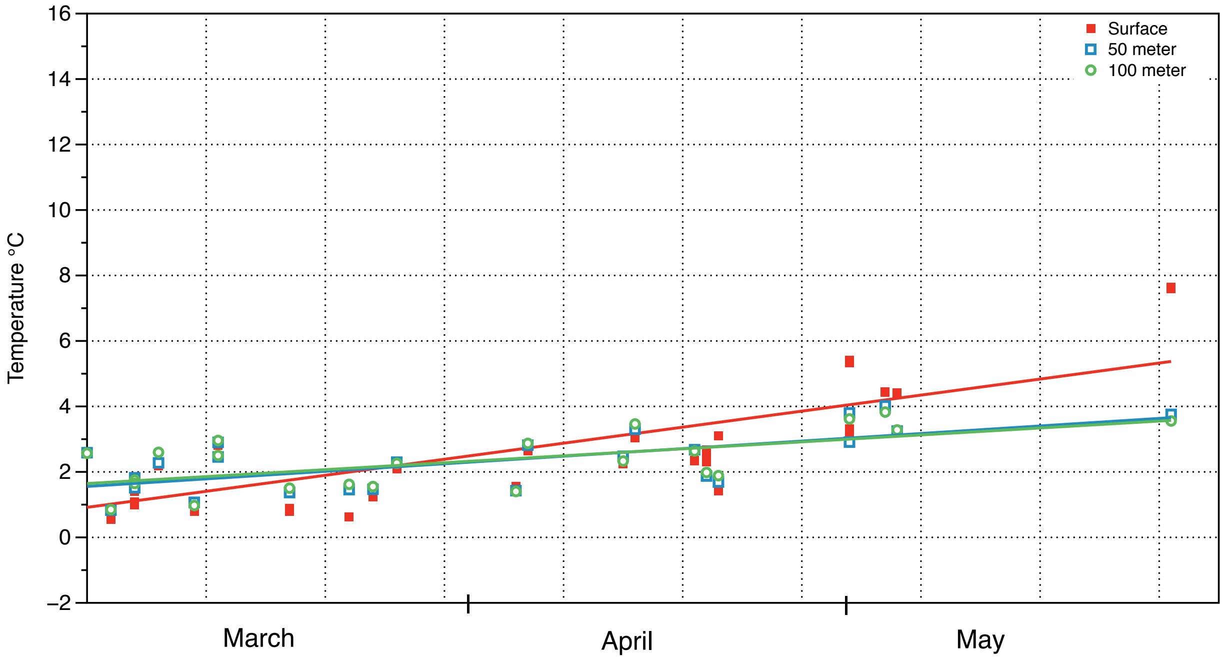


Figure 121: Monthly variability of spring temperatures (March – May) at station Sørfjord

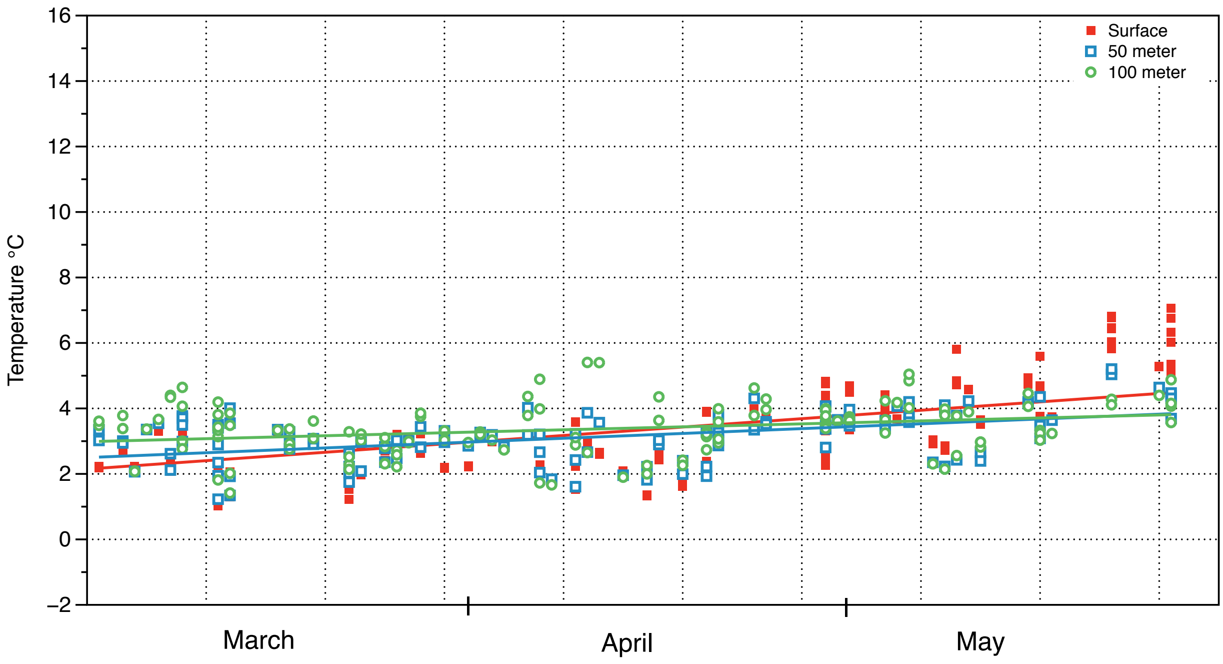


Figure 122: Monthly variability of spring temperatures (March – May) at station Outer Altafjorden

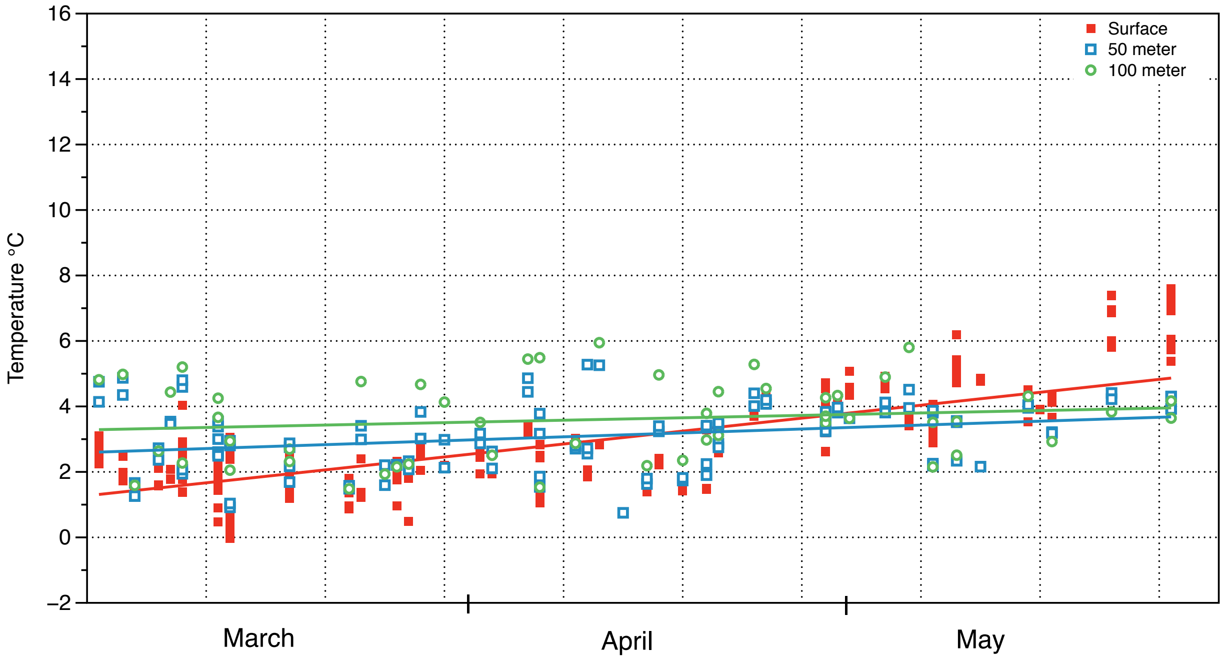


Figure 123: Monthly variability of spring temperatures (March – May) at station Inner Altafjorden

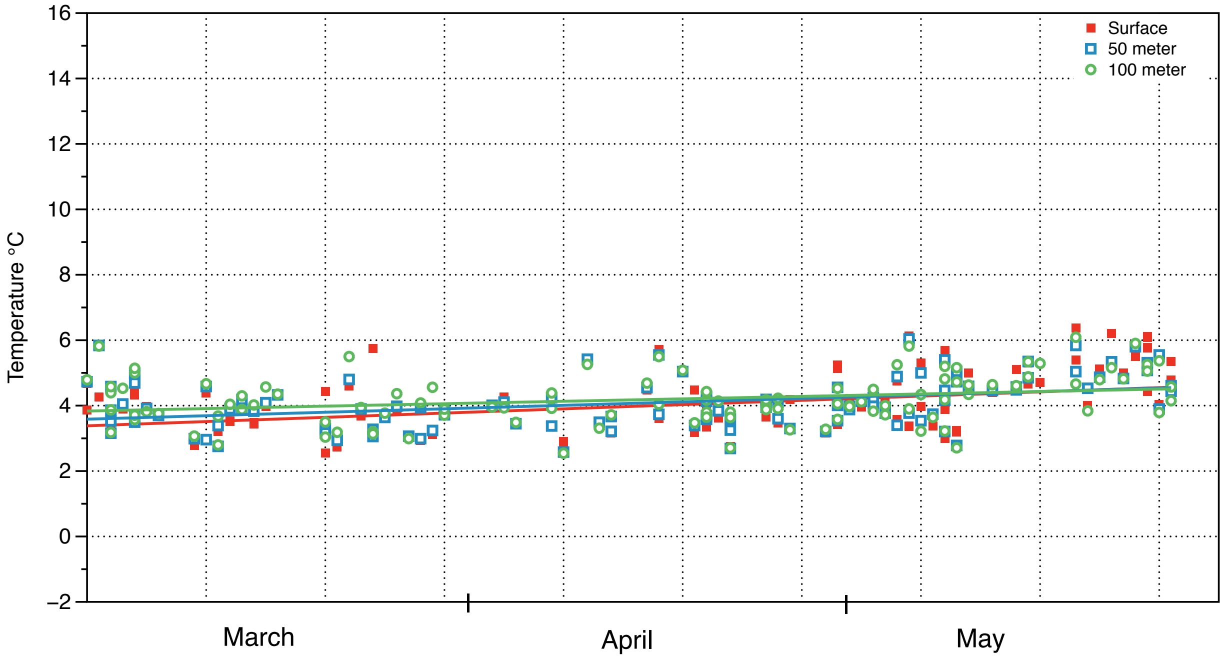


Figure 124: Monthly variability of spring temperatures (March – May) at station Refsbotn

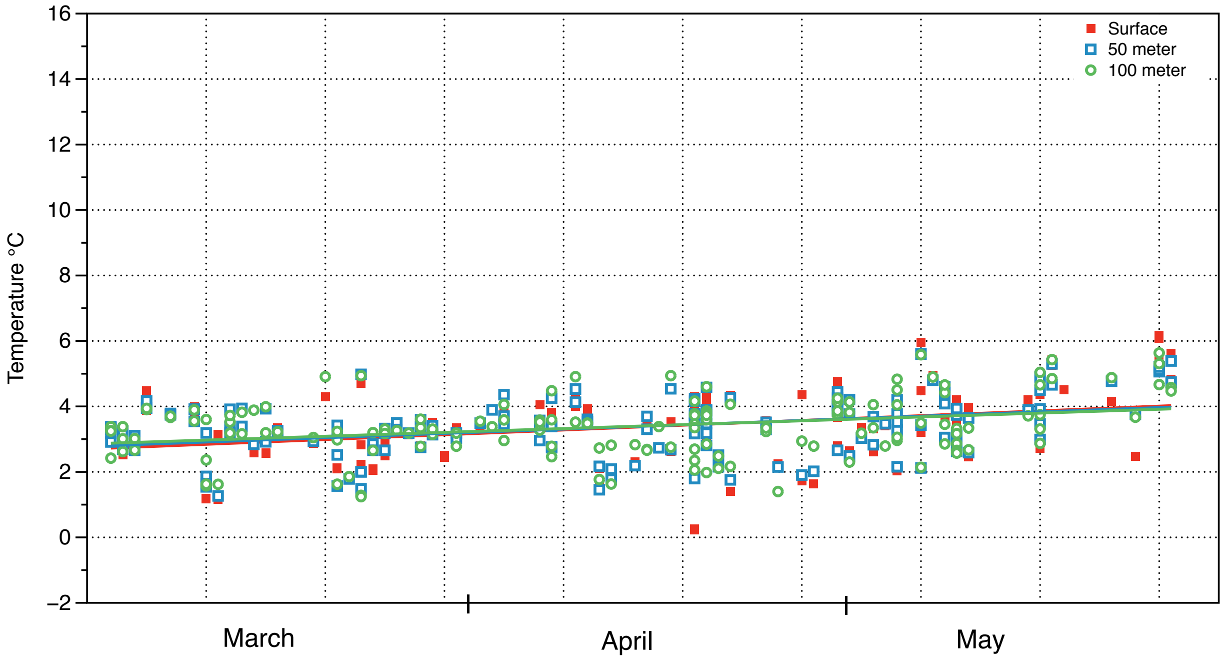


Figure 125: Monthly variability of spring temperatures (March – May) at station Outer Porsangerfjorden

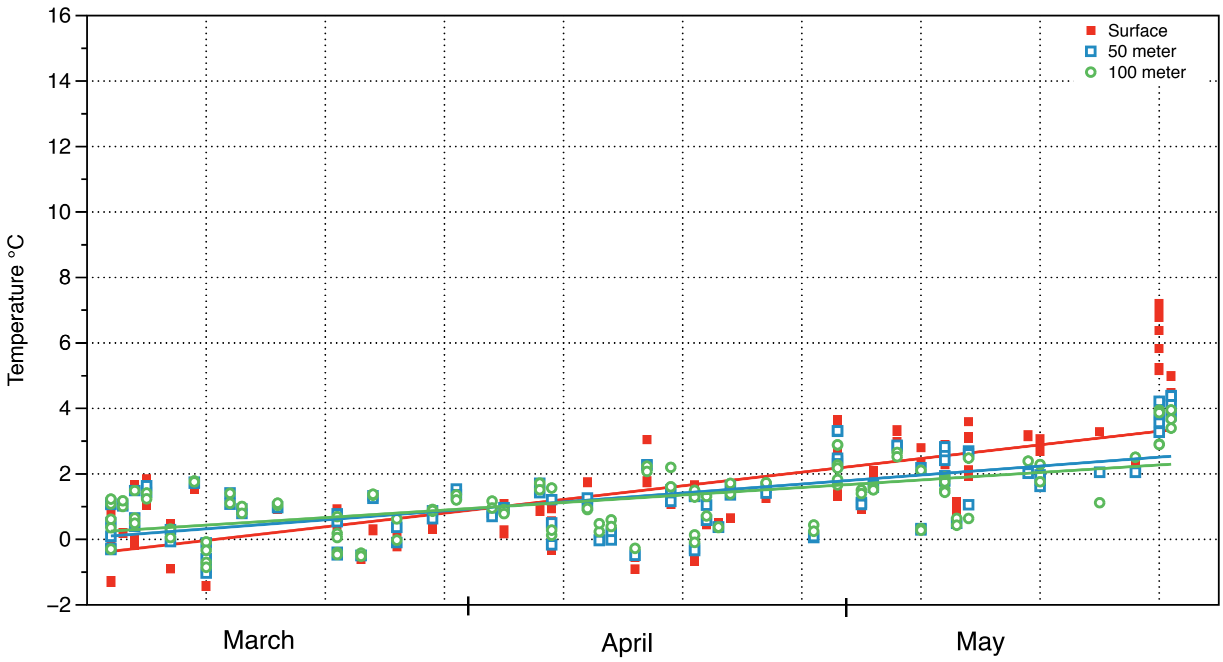


Figure 126: Monthly variability of spring temperatures (March – May) at station Inner Porsangerfjorden

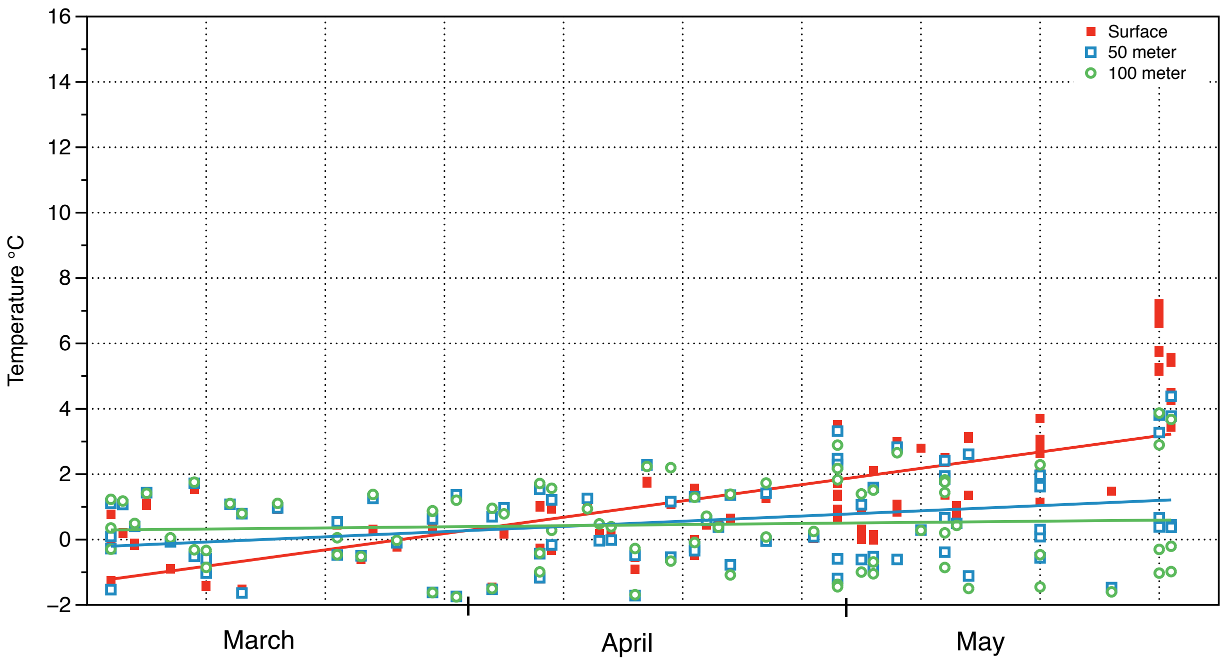


Figure 127: Monthly variability of spring temperatures (March – May) at station Østerbotn

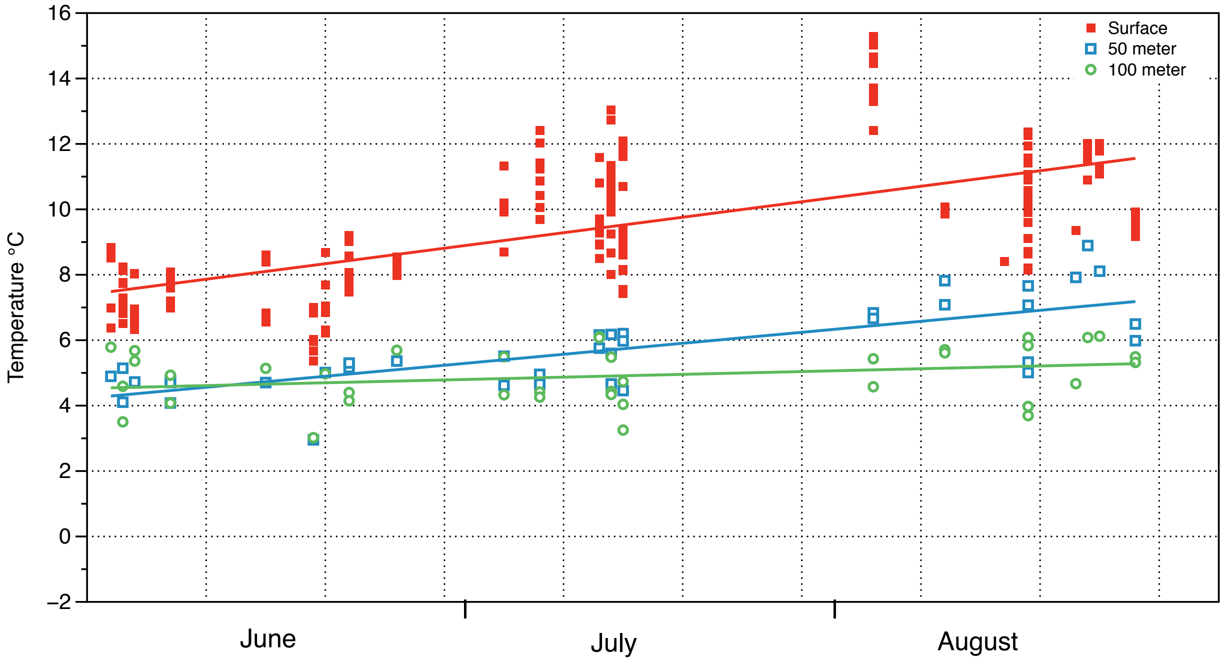


Figure 128: Monthly variability of summer temperatures (June – August) at station Inner Malangen

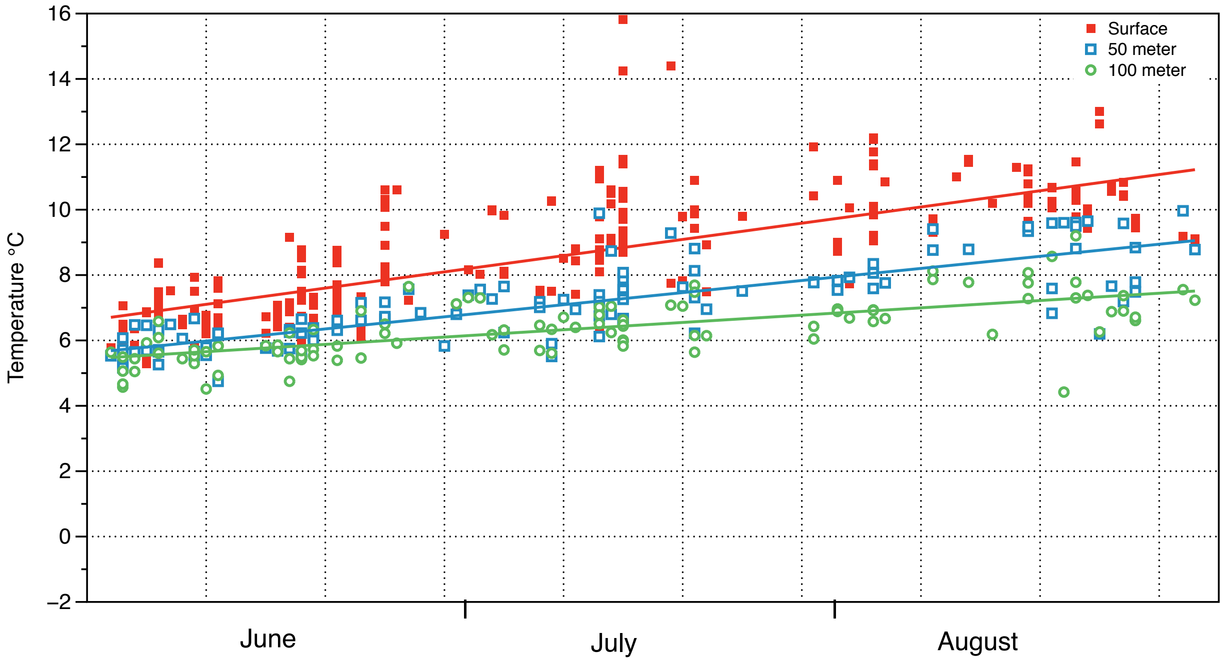


Figure 129: Monthly variability of summer temperatures (June – August) at station Outer Malangen

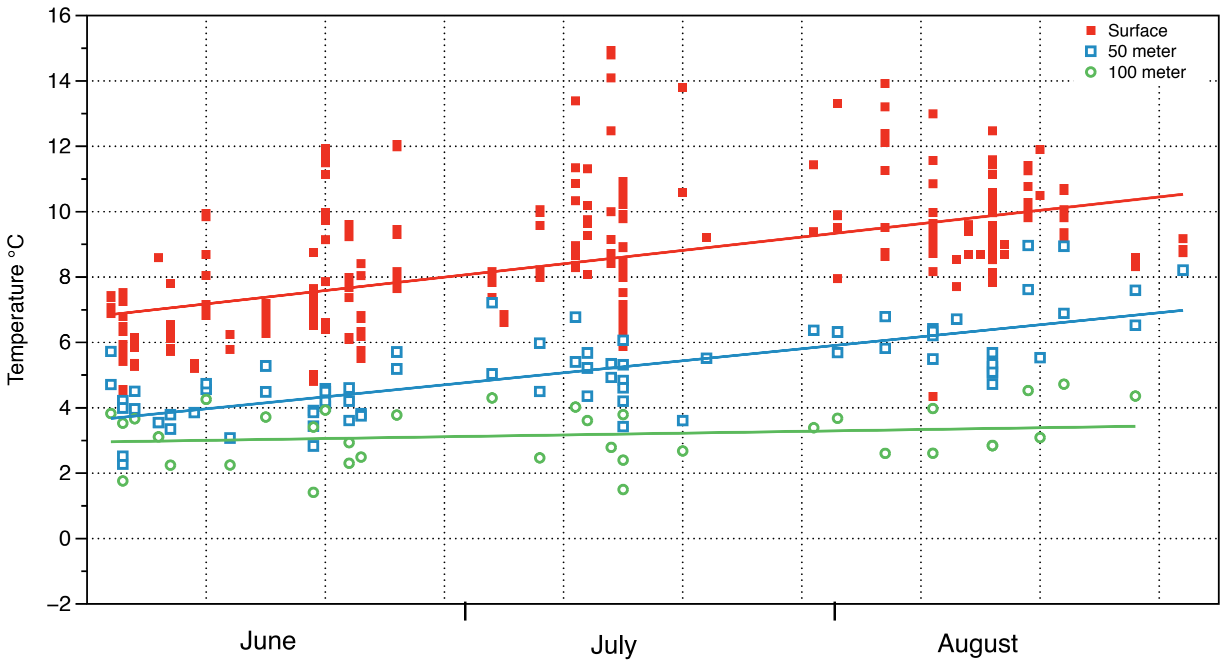


Figure 130: Monthly variability of summer temperatures (June – August) at station Outer Balsfjorden

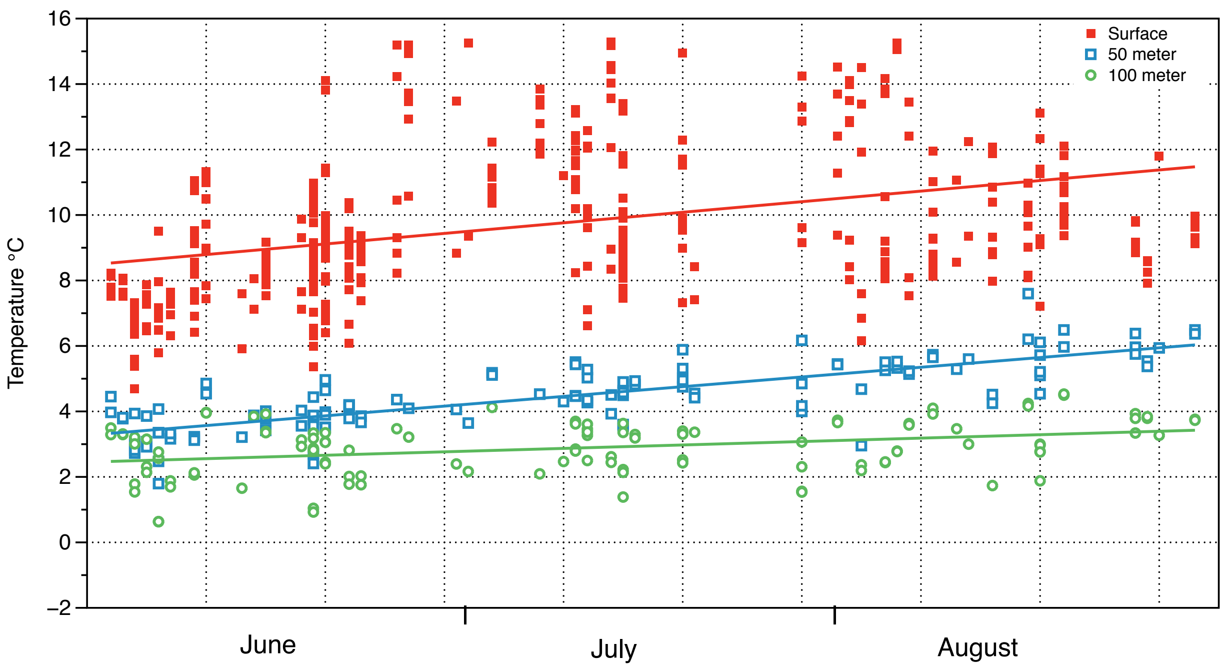


Figure 131: Monthly variability of summer temperatures (June – August) at station Inner Balsfjorden

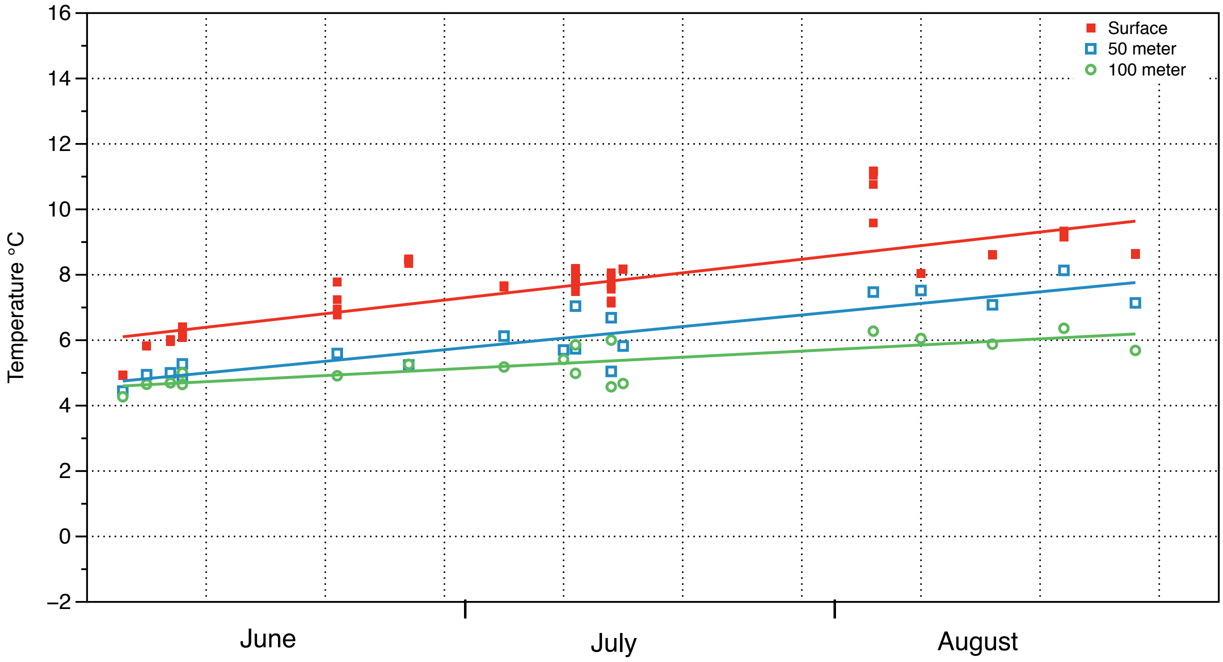


Figure 132: Monthly variability of summer temperatures (June – August) at station Kvalsund

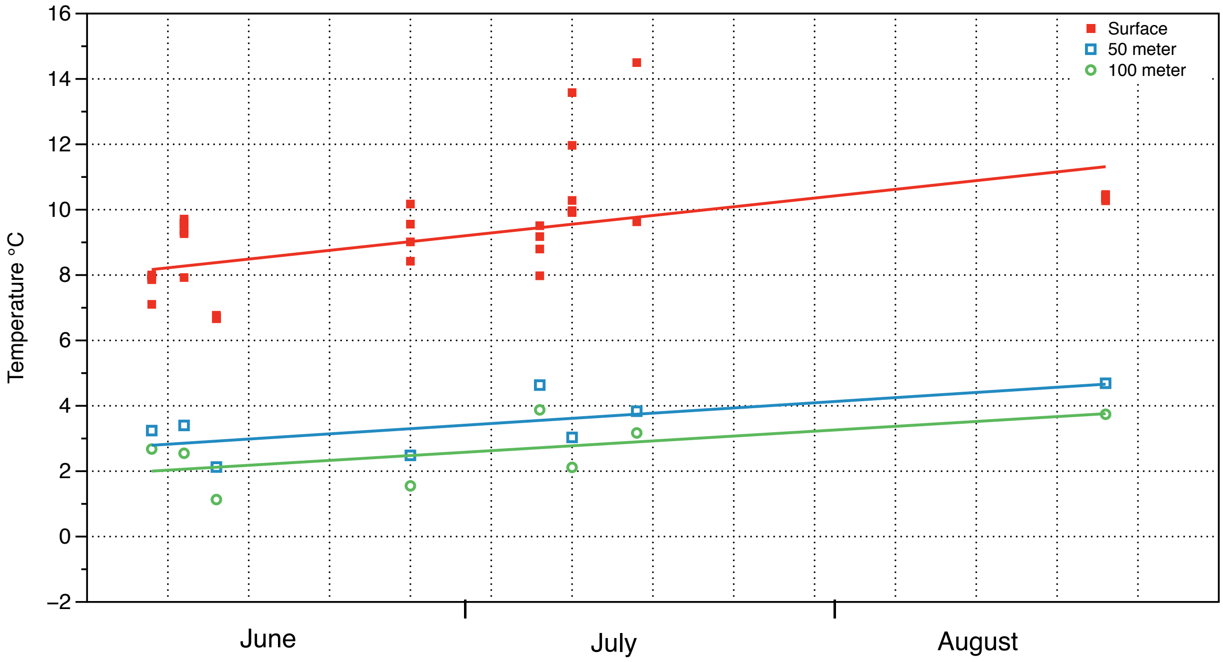


Figure 133: Monthly variability of summer temperatures (June – August) at station Sørfjord

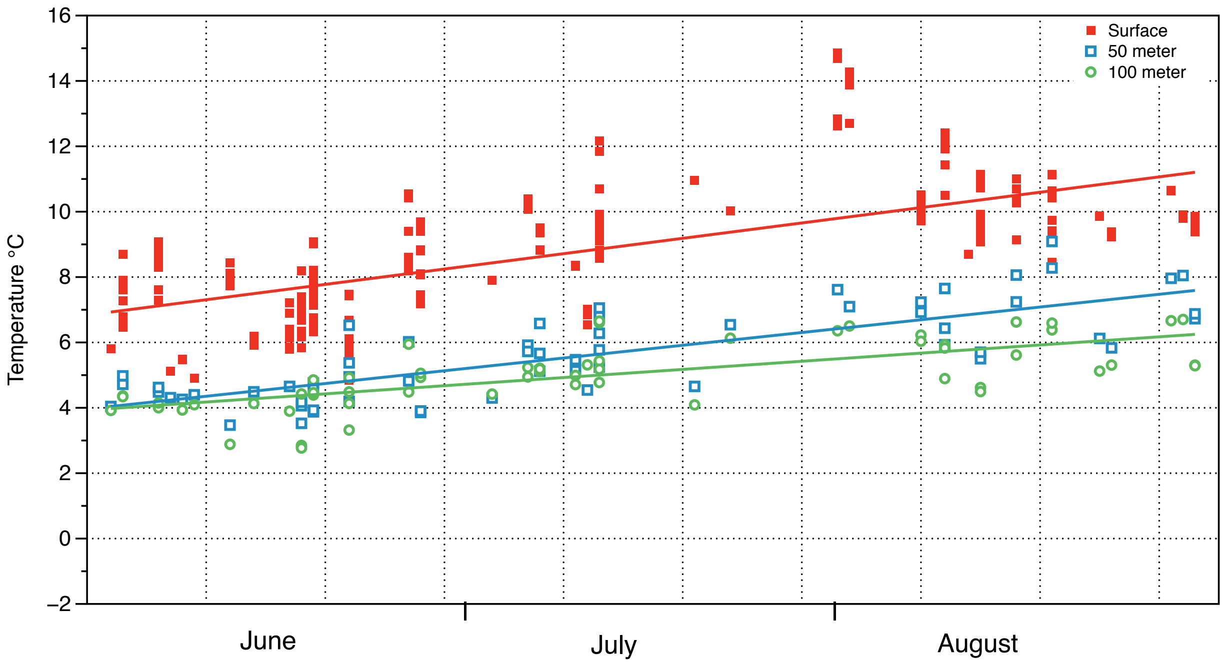


Figure 134: Monthly variability of summer temperatures (June – August) at station Outer Altafjorden

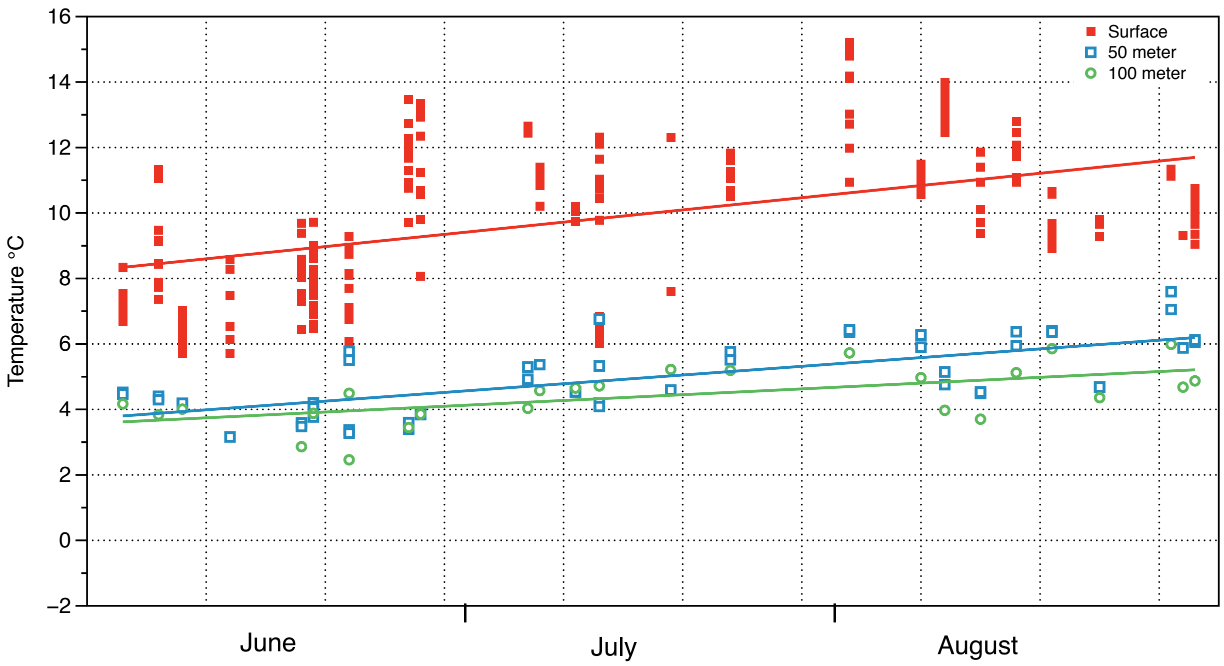


Figure 135: Monthly variability of summer temperatures (June – August) at station Inner Altafjorden

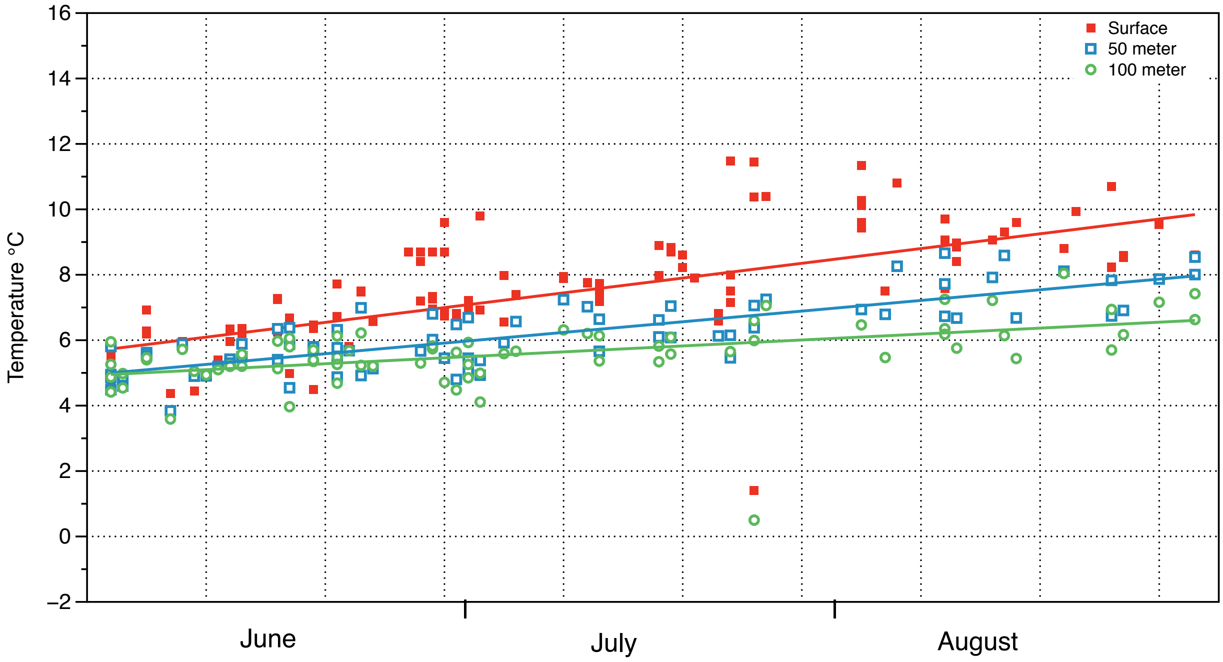


Figure 136: Monthly variability of summer temperatures (June – August) at station Refsbotn

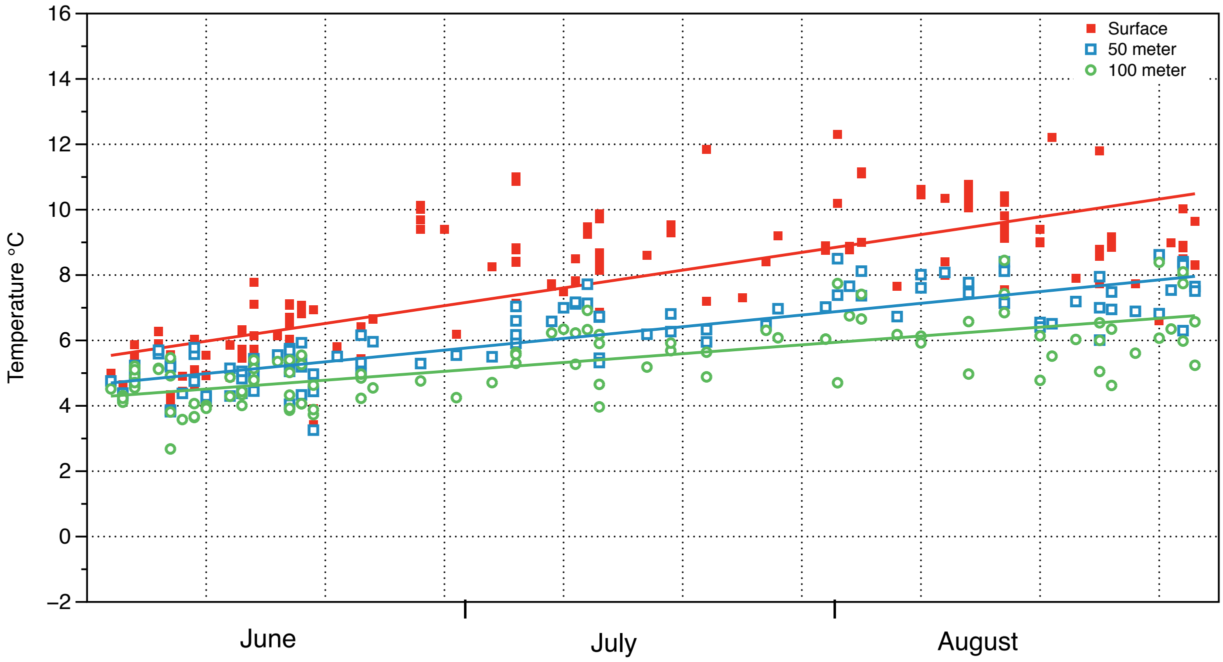


Figure 137: Monthly variability of summer temperatures (June – August) at station Outer Porsangerfjorden

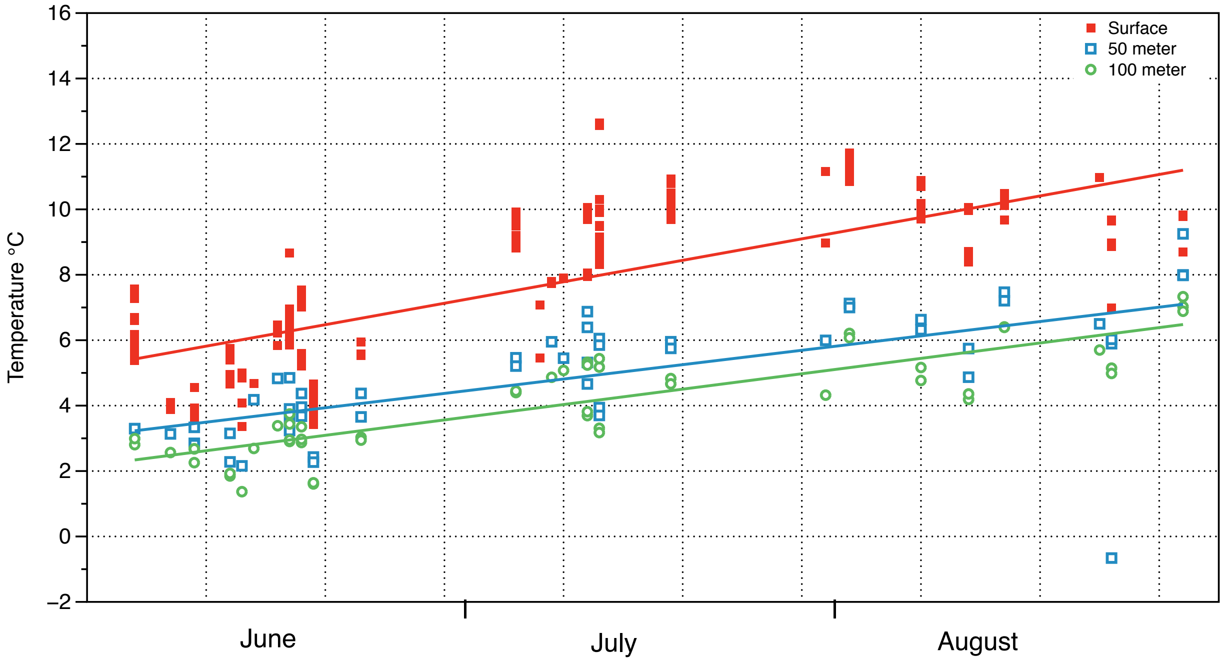


Figure 138: Monthly variability of summer temperatures (June – August) at station Inner Porsangerfjorden

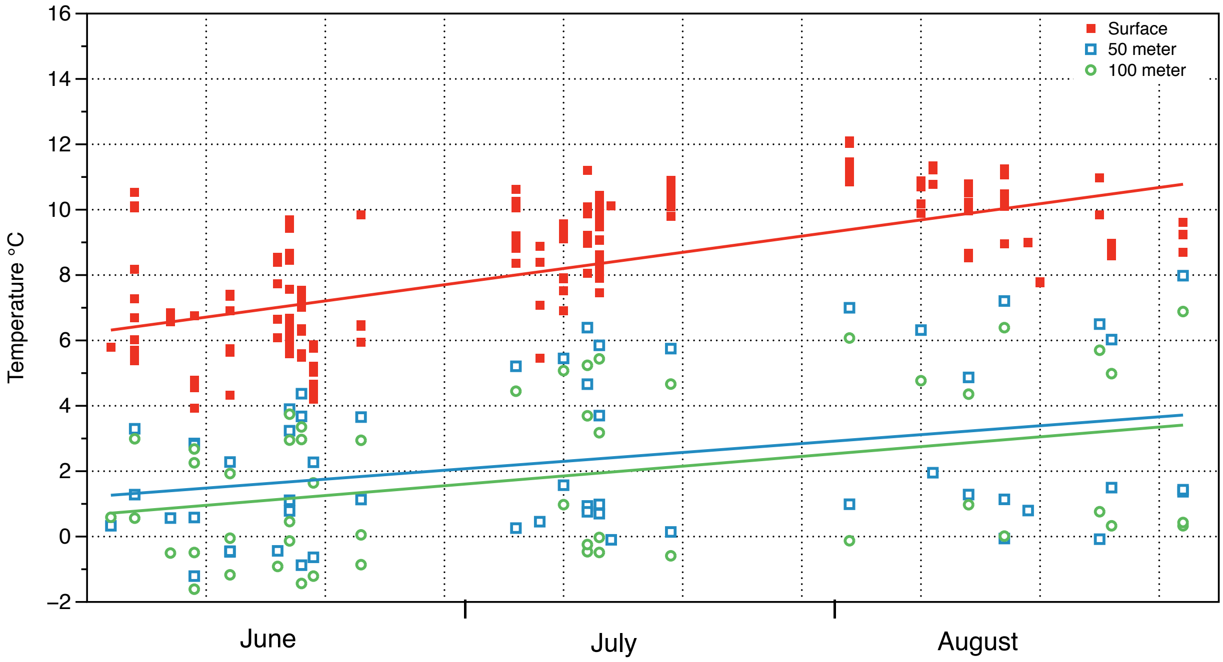


Figure 139: Monthly variability of summer temperatures (June – August) at station Østerbotn

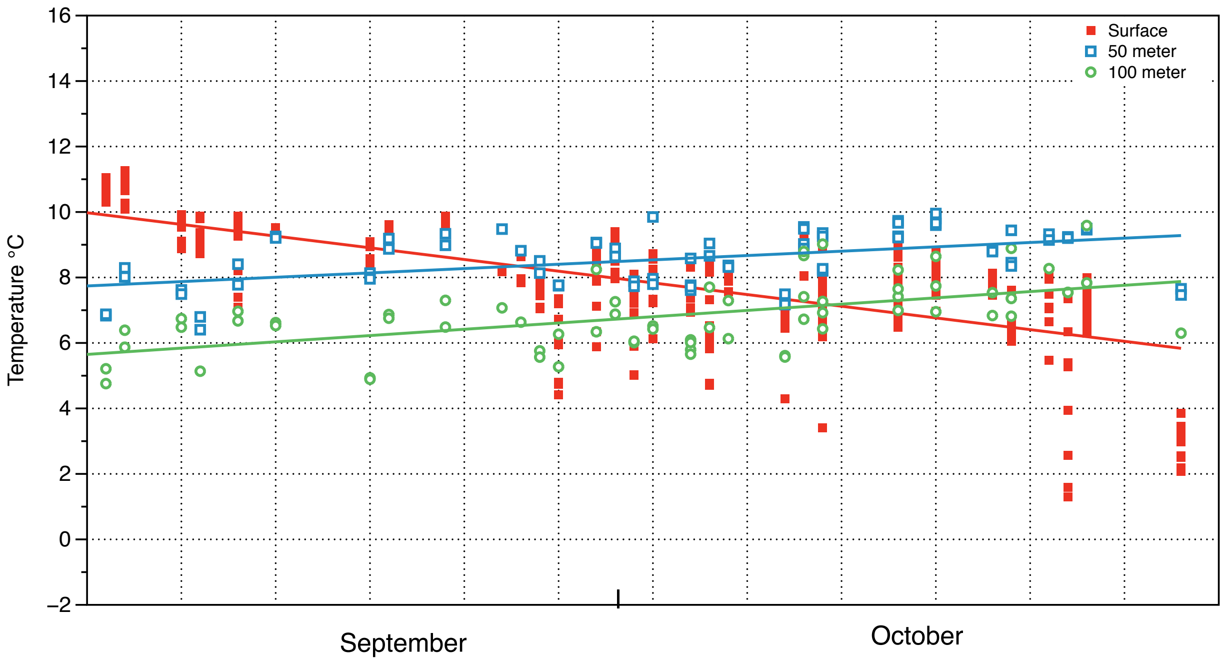


Figure 140: Monthly variability of autumn temperatures (September – October) at station Inner Malangen

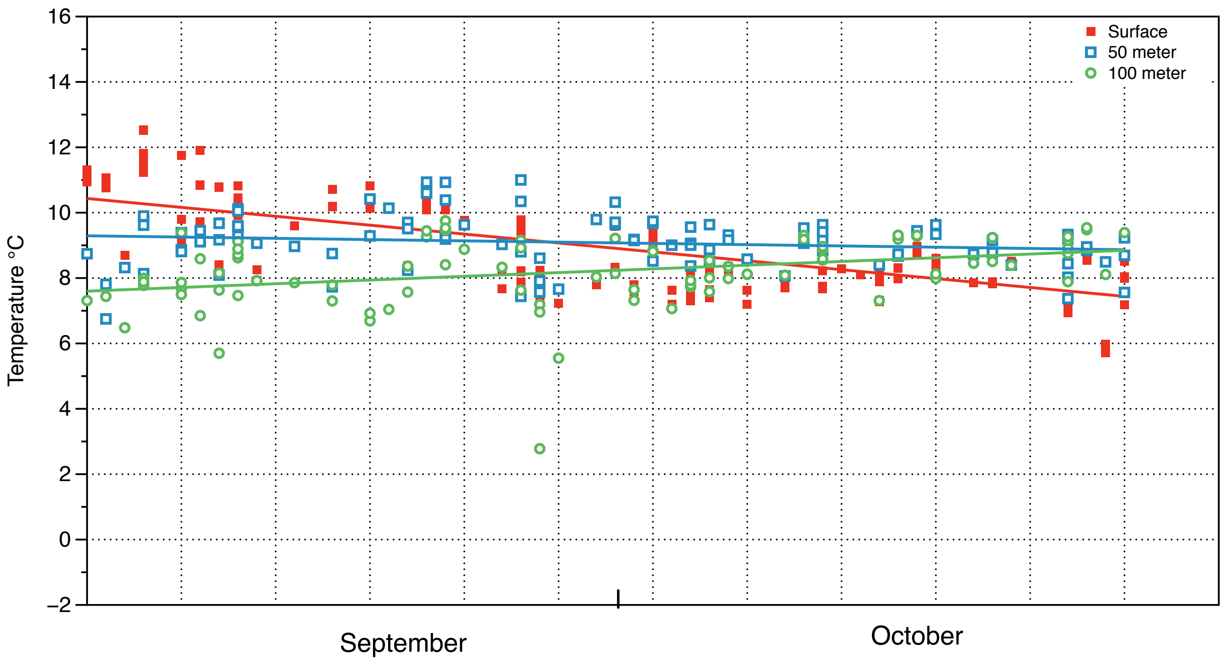


Figure 141: Monthly variability of autumn temperatures (September – October) at station Outer Malangen

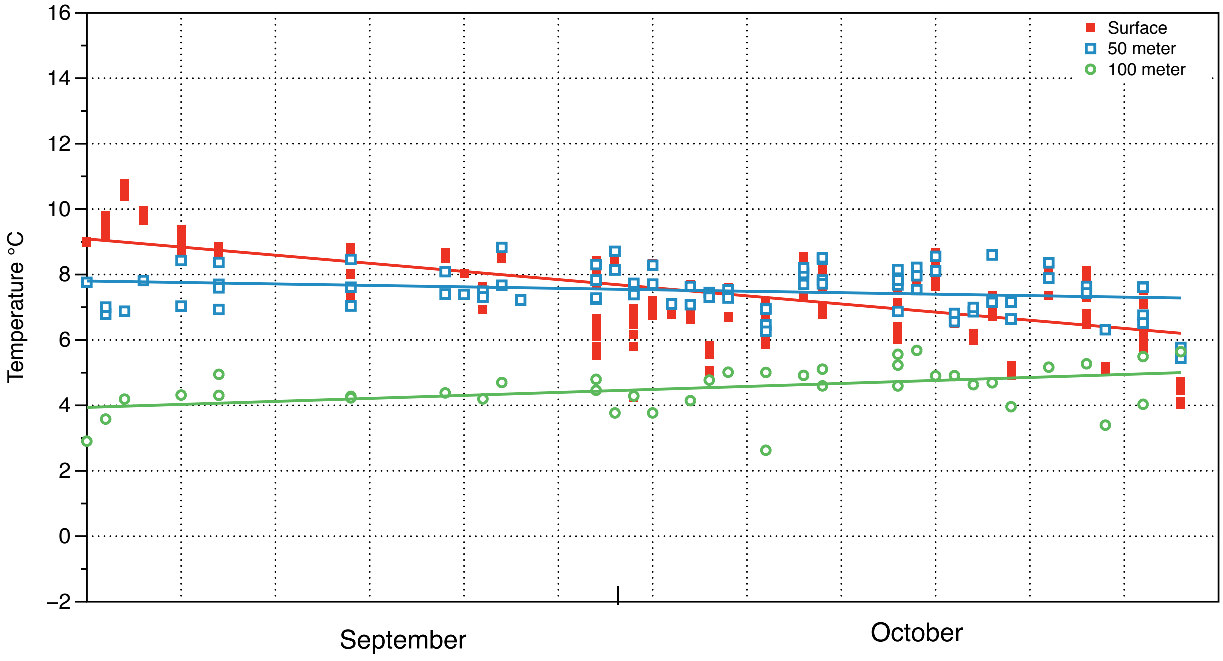


Figure 142: Monthly variability of autumn temperatures (September – October) at station Outer Balsfjorden

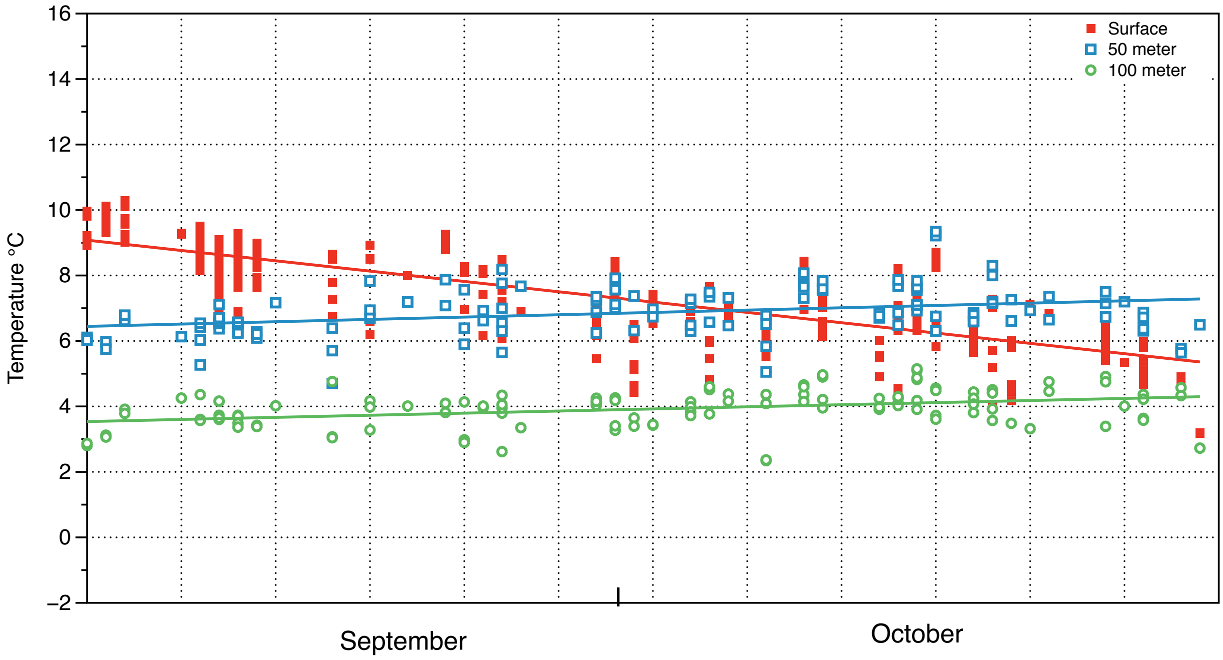


Figure 143: Monthly variability of autumn temperatures (September – October) at station Inner Balsfjorden

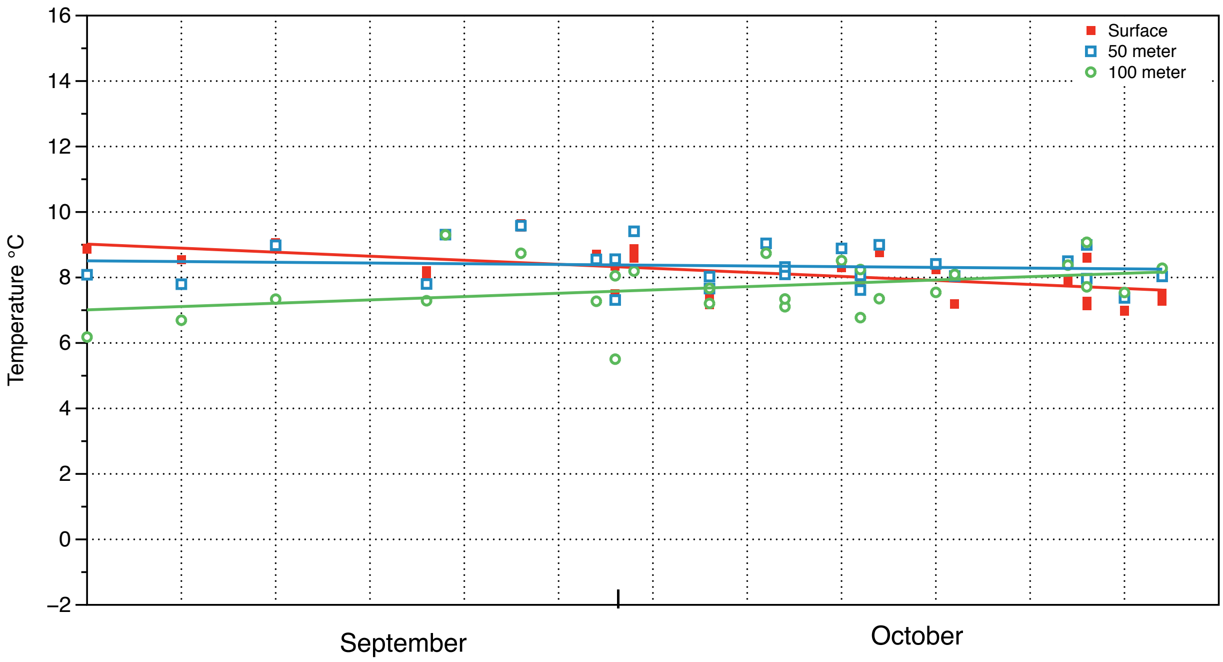


Figure 144: Monthly variability of autumn temperatures (September – October) at station Kvalsund

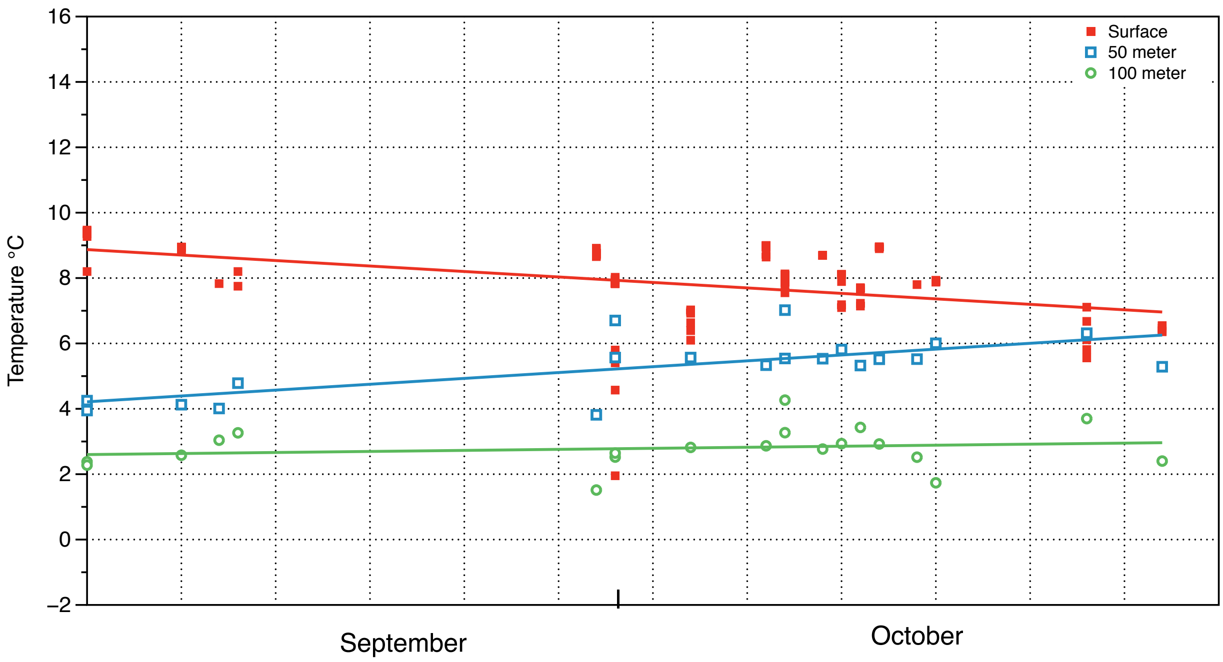


Figure 145: Monthly variability of autumn temperatures (September – October) at station Sørfjord

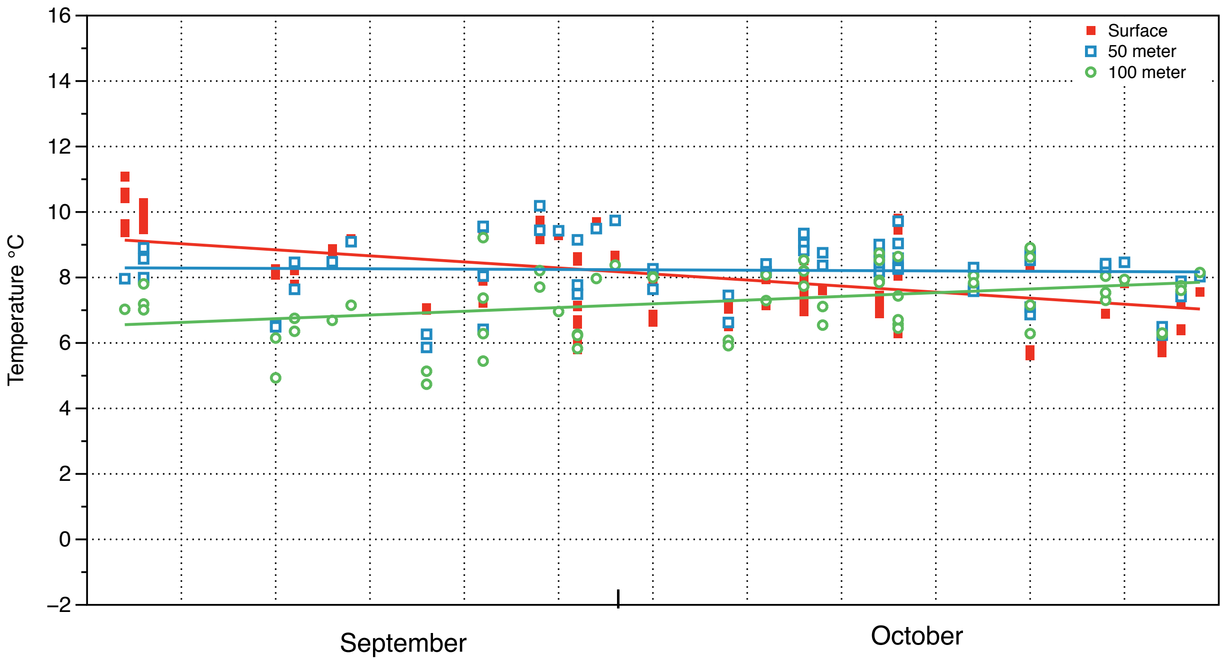


Figure 146: Monthly variability of autumn temperatures (September – October) at station Outer Altafjorden

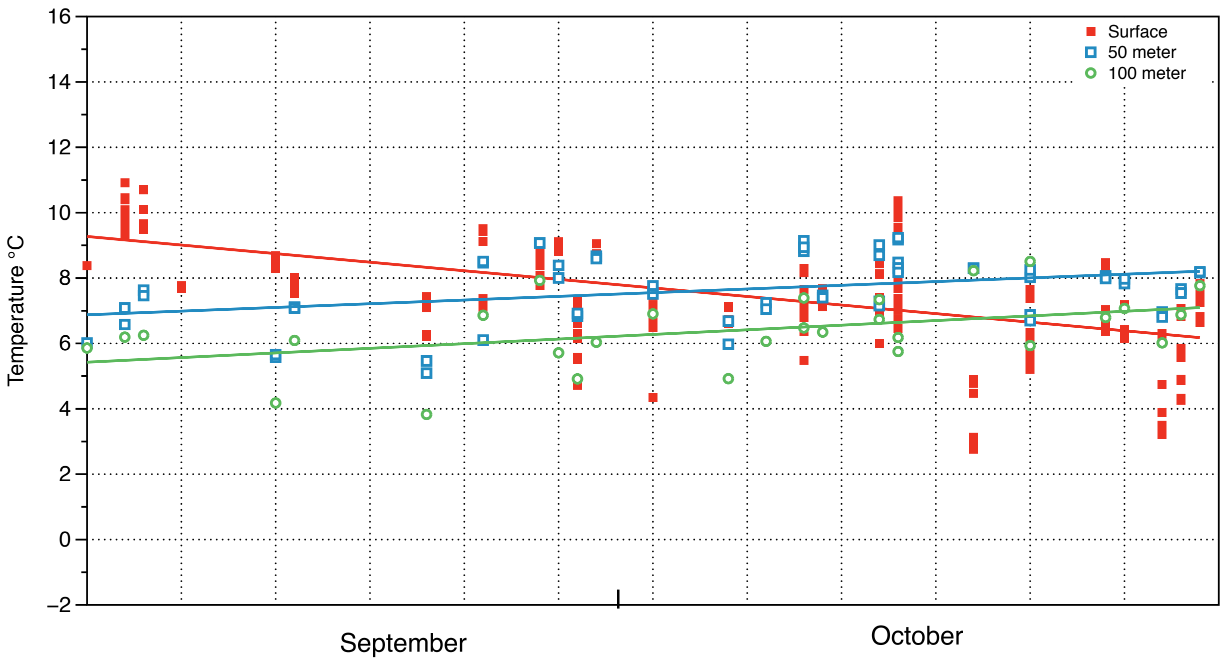


Figure 147: Monthly variability of autumn temperatures (September – October) at station Inner Altafjorden

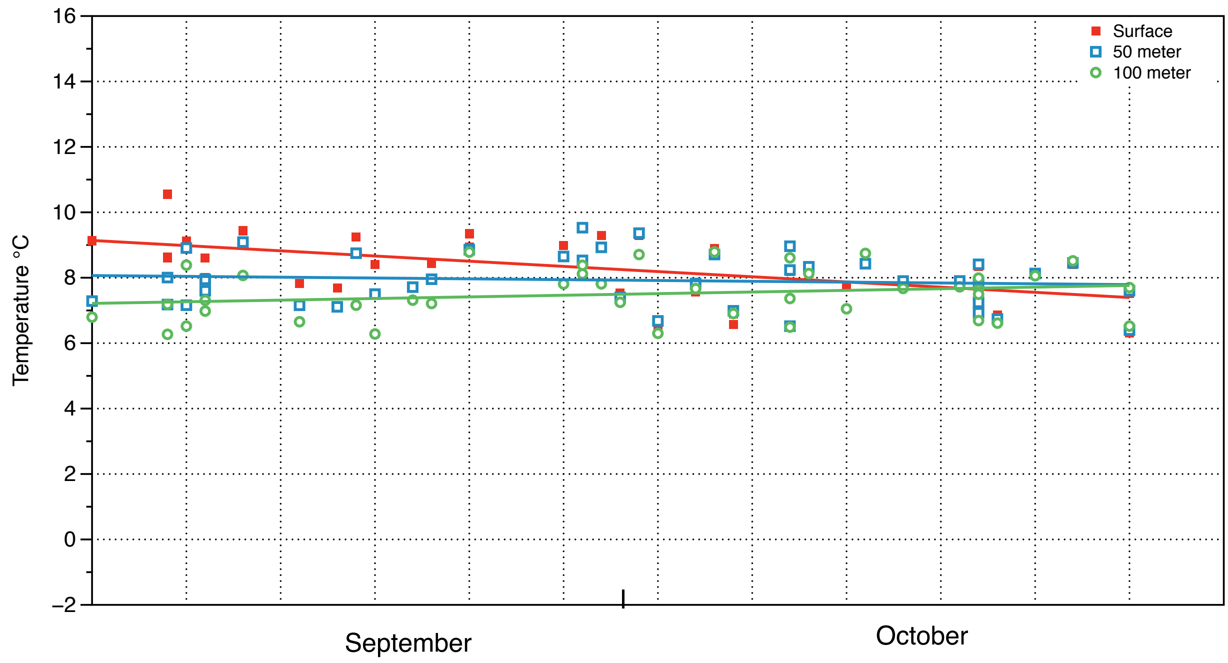


Figure 148: Monthly variability of autumn temperatures (September – October) at station Refsbotn

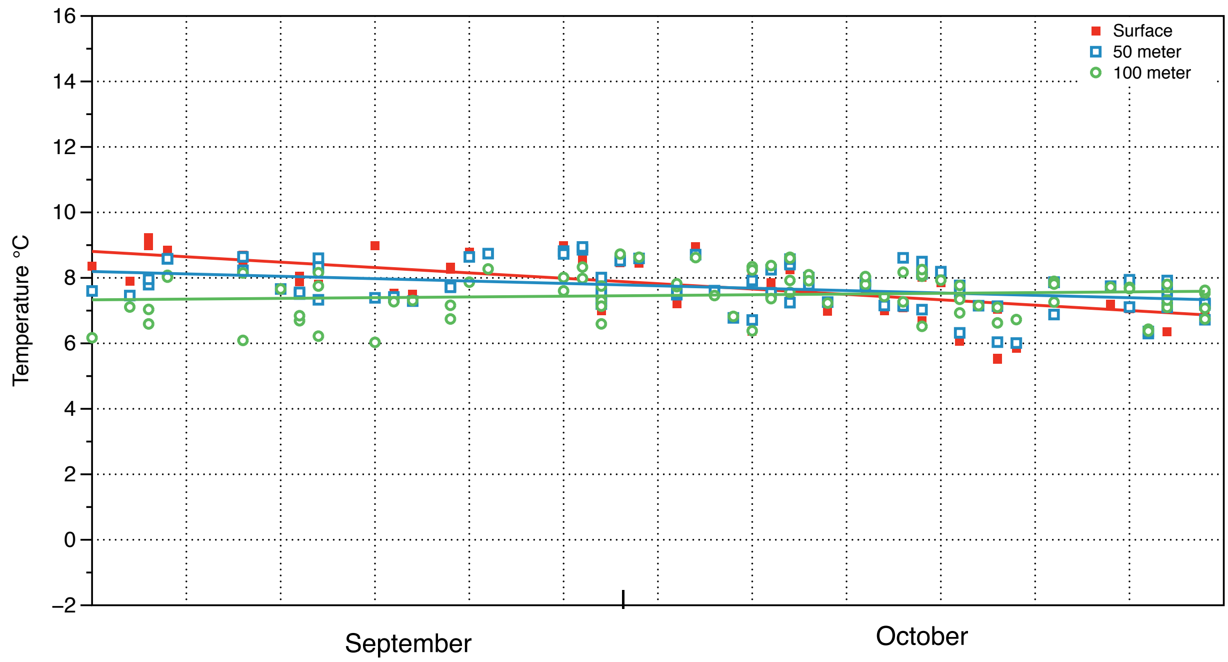


Figure 149: Monthly variability of autumn temperatures (September – October) at station Outer Porsangerfjorden

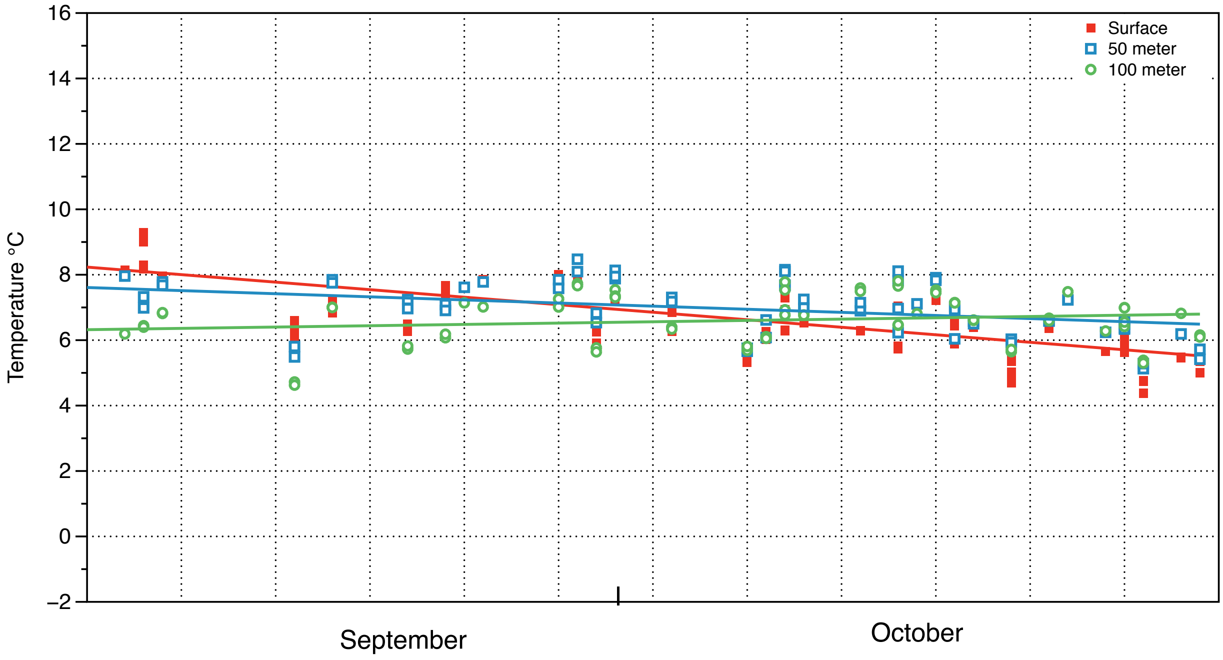


Figure 150: Monthly variability of autumn temperatures (September – October) at station Inner Porsangerfjorden

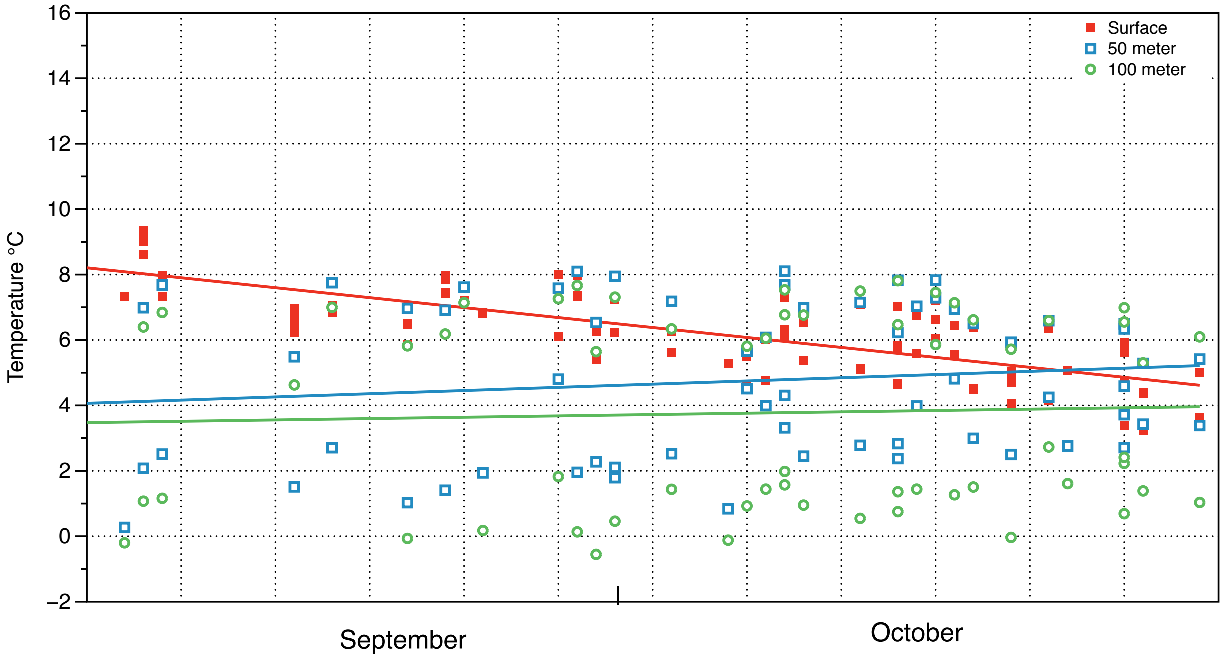


Figure 151: Monthly variability of autumn temperatures (September – October) at station Østerbotn

A.2 MONTHLY VARIATIONS IN SALINITY

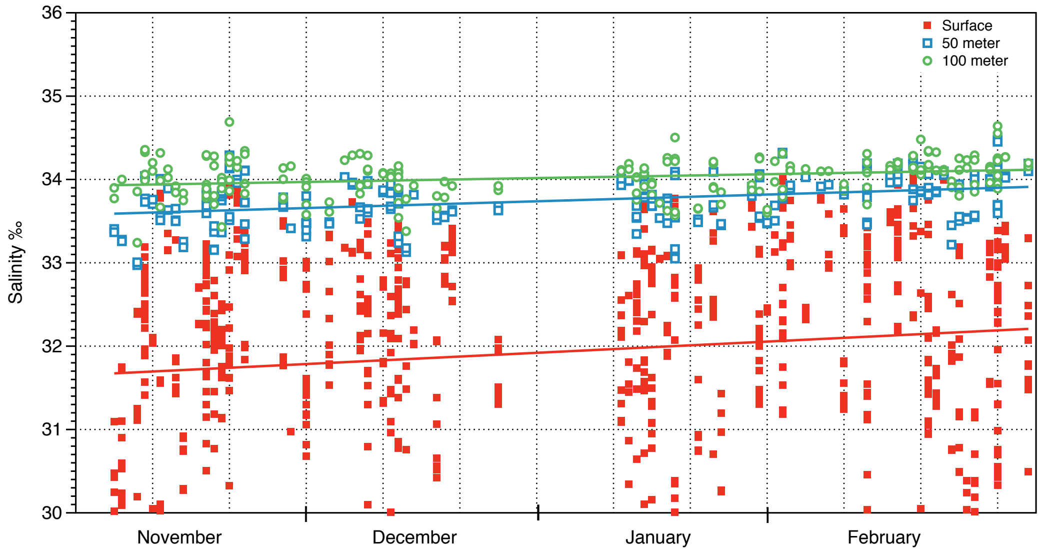


Figure 152: Monthly variability of winter salinity (November – February) at station Inner Malangen

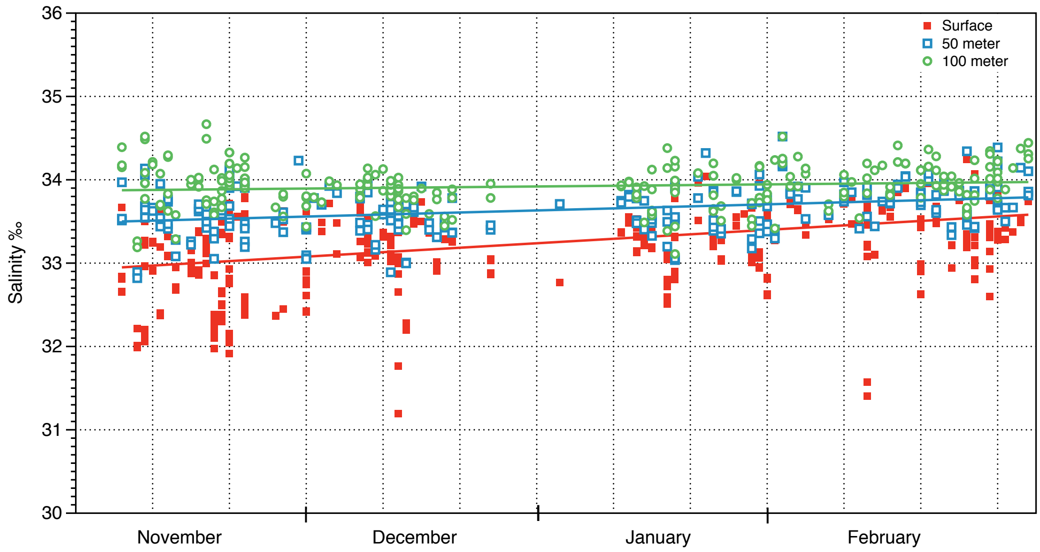


Figure 153: Monthly variability of winter salinity (November – February) at station Outer Malangen

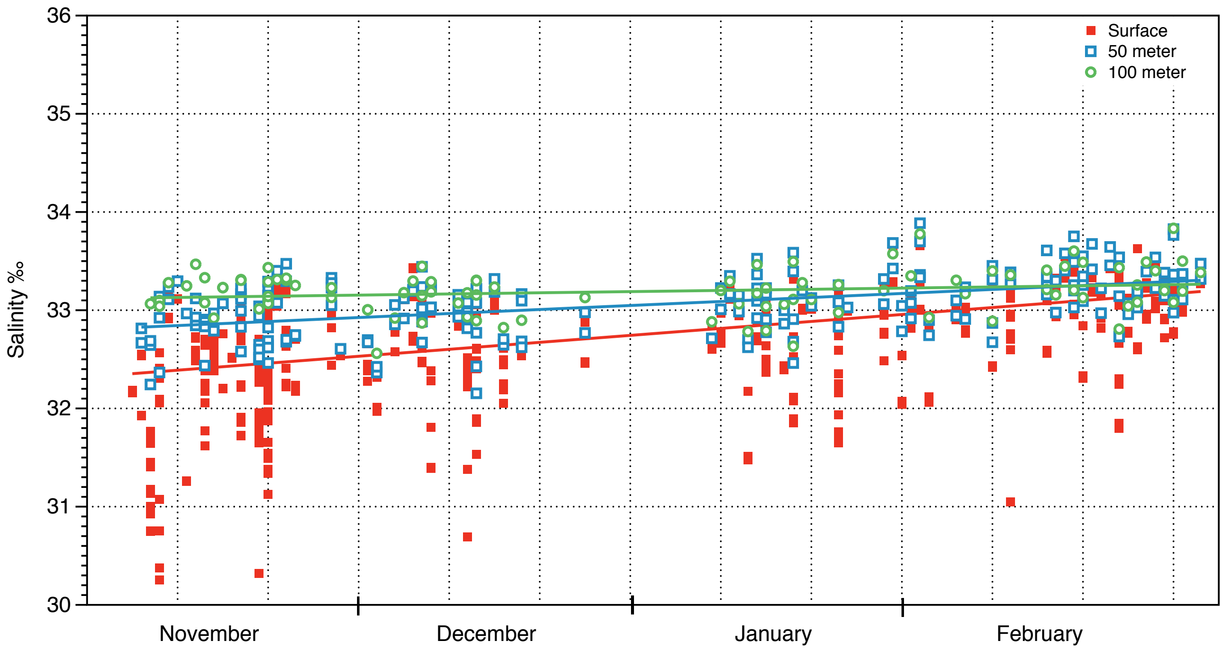


Figure 154: Monthly variability of winter salinity (November – February) at station Outer Balsfjorden

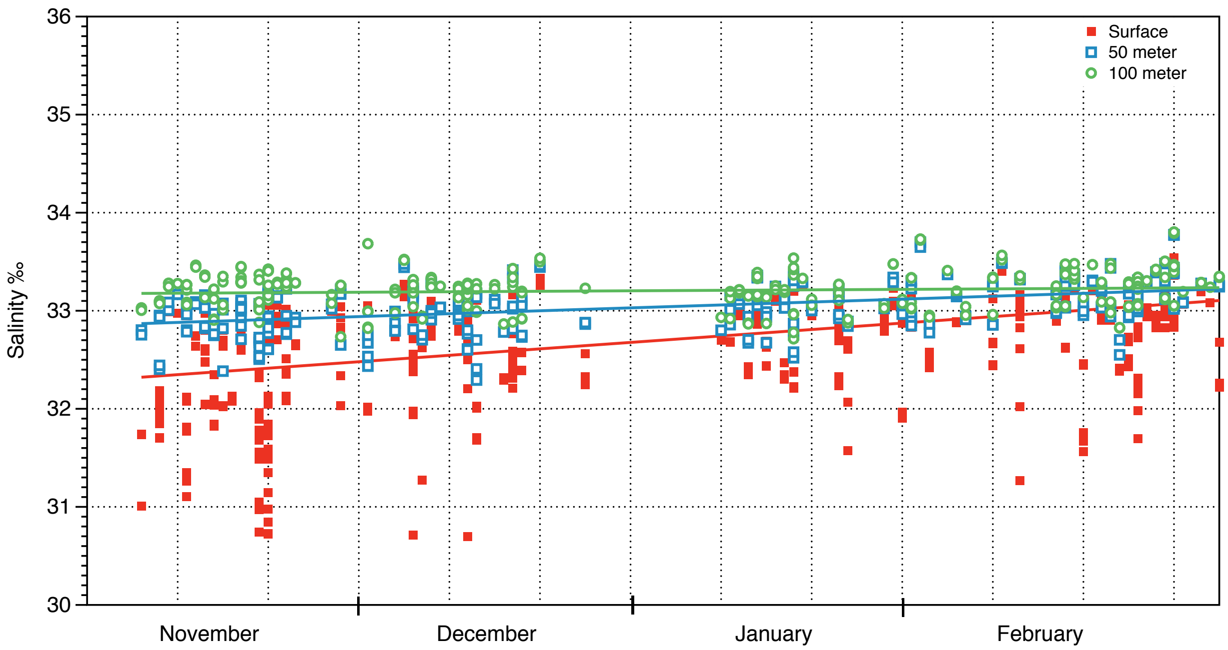


Figure 155: Monthly variability of winter salinity (November – February) at station Inner Balsfjorden

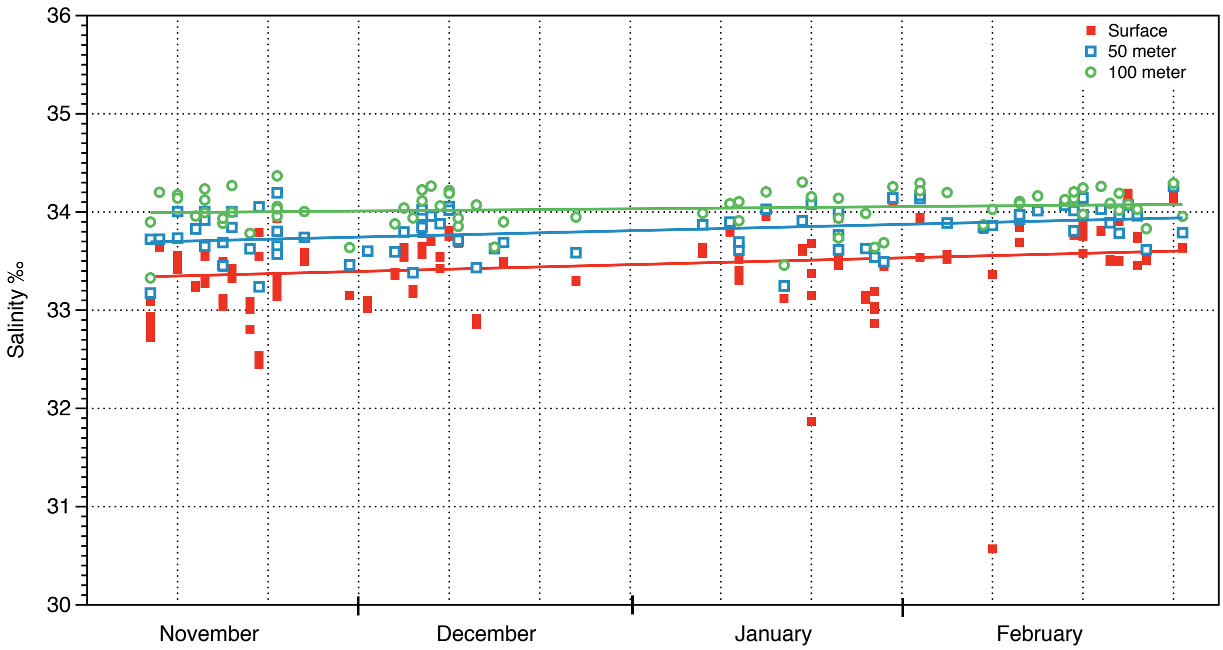


Figure 156: Monthly variability of winter salinity (November – February) at station Kvalsund

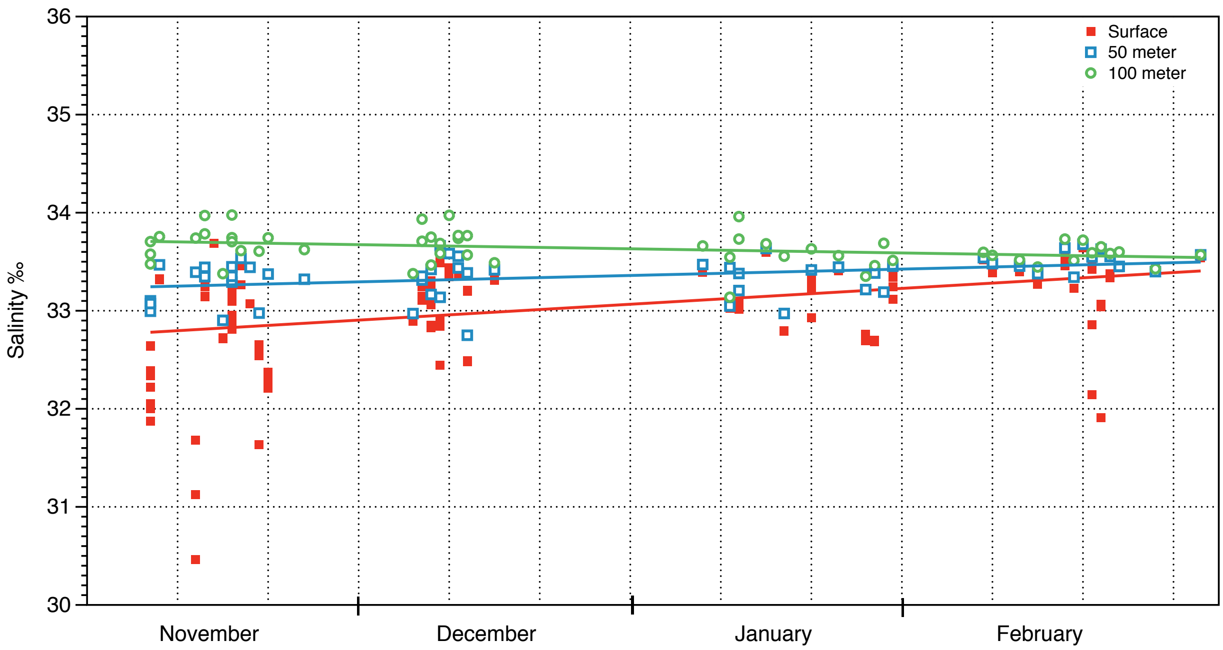


Figure 157: Monthly variability of winter salinity (November – February) at station Sørfjord

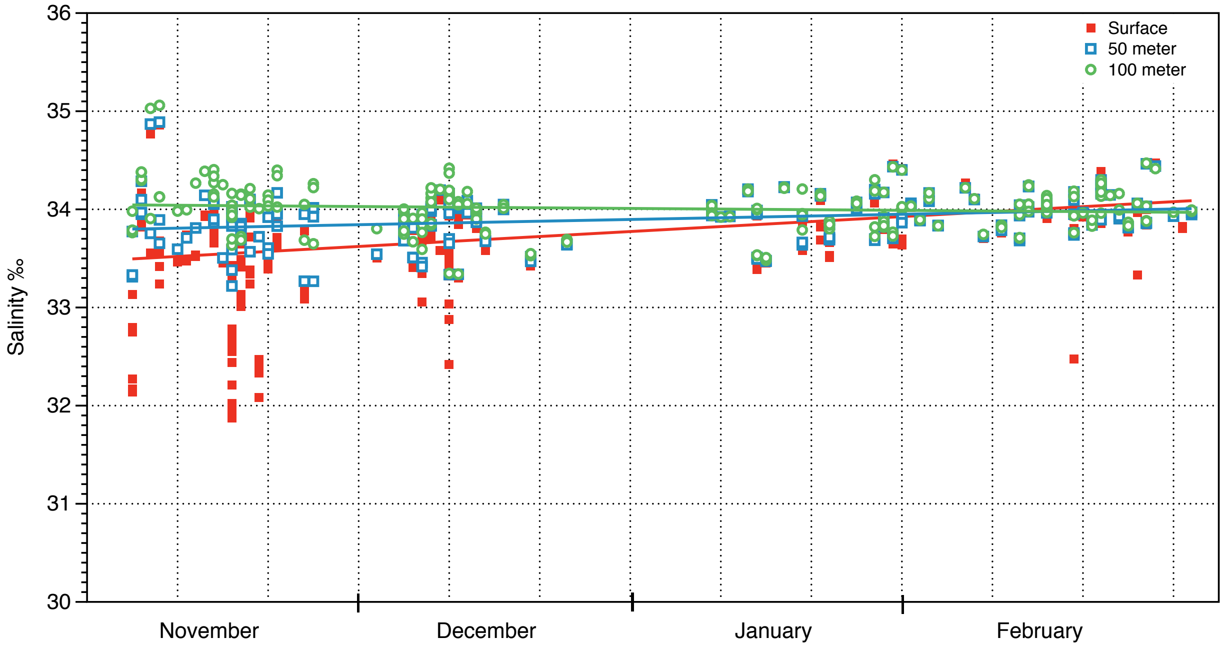


Figure 158: Monthly variability of winter salinity (November – February) at station Outer Altafjorden

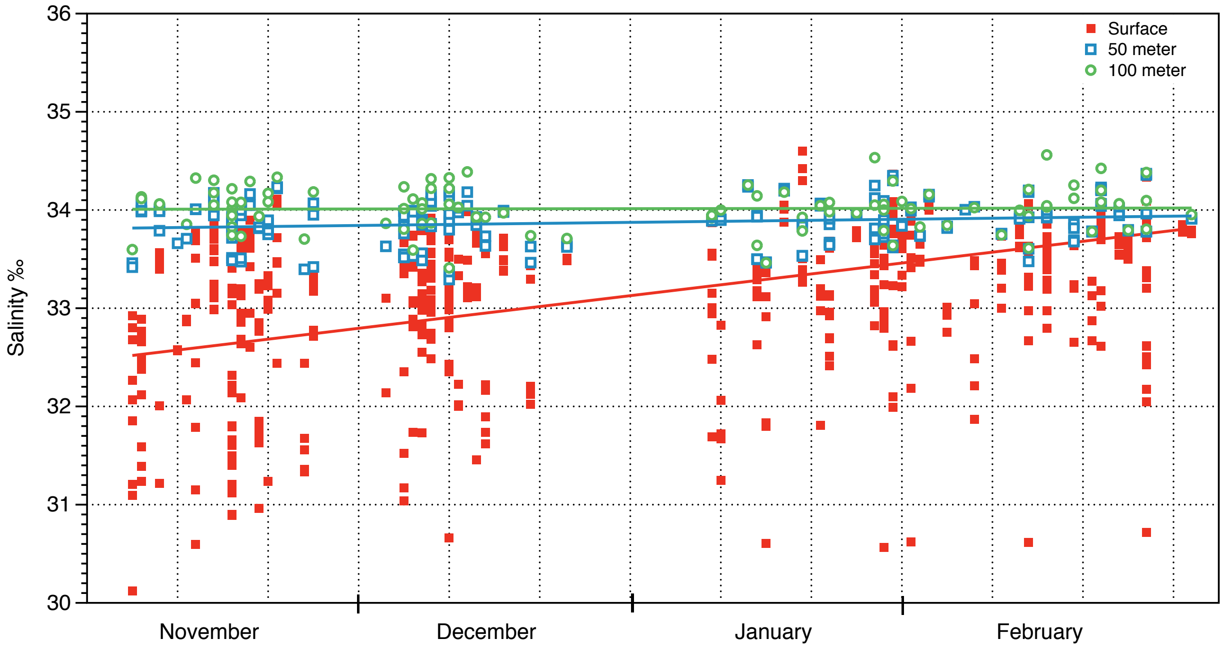


Figure 159: Monthly variability of winter salinity (November – February) at station Inner Altafjorden

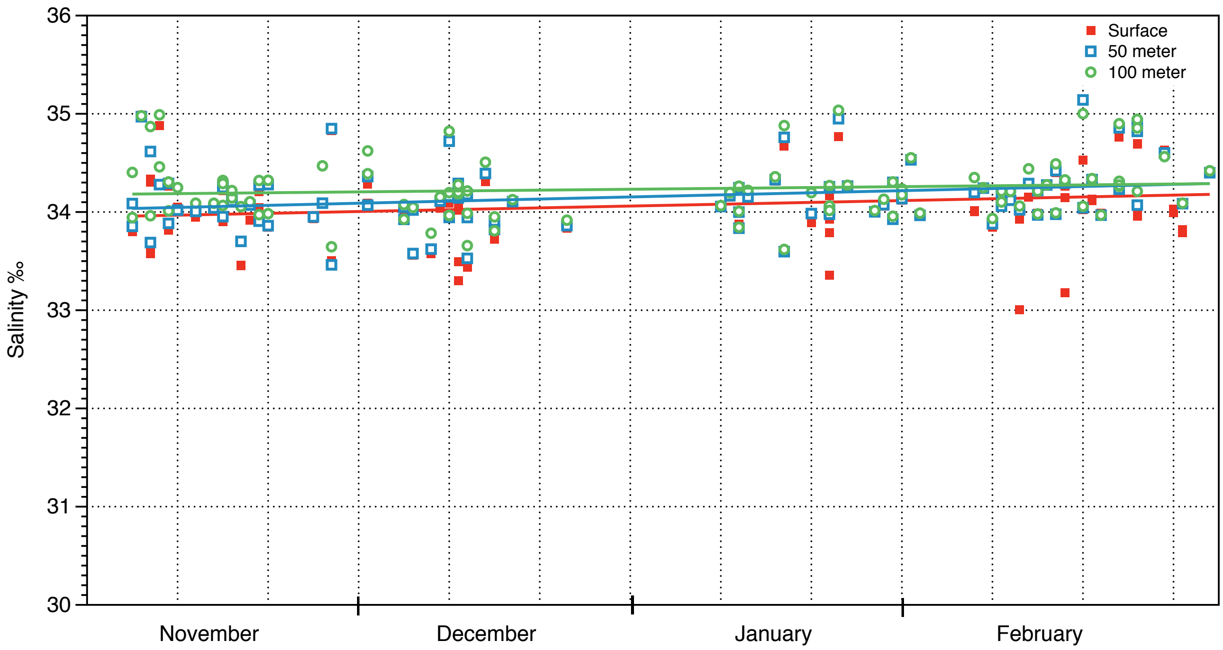


Figure 160: Monthly variability of winter salinity (November – February) at station Refsbotn

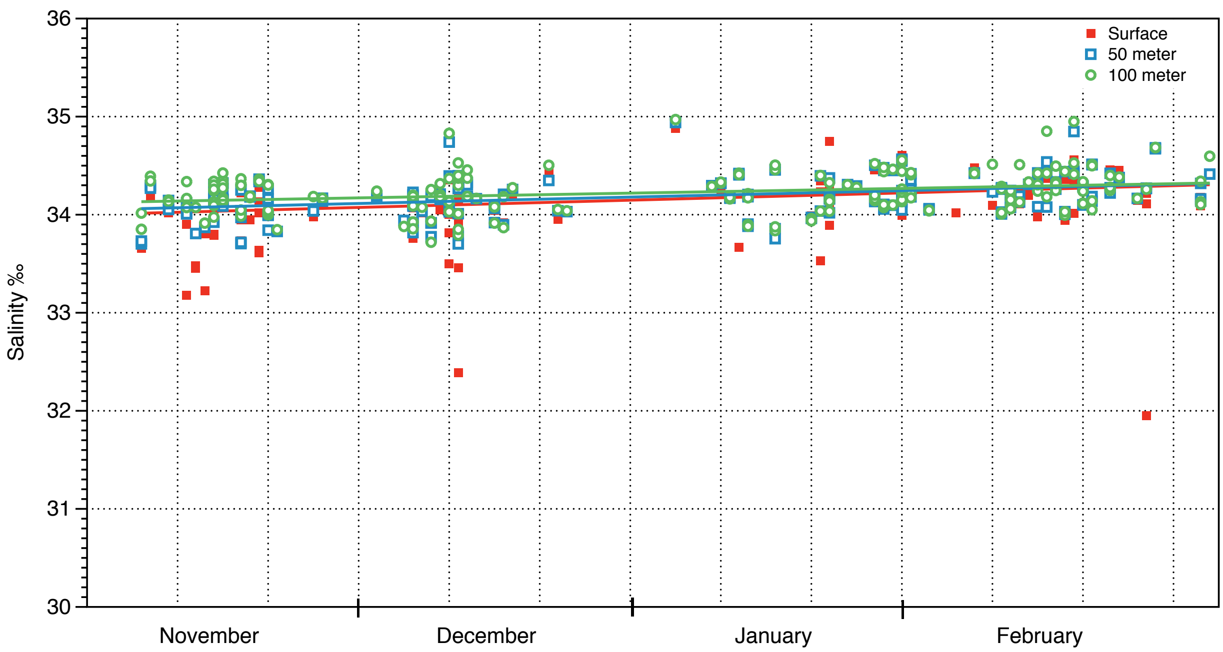


Figure 161: Monthly variability of winter salinity (November – February) at station Outer Porsangerfjorden

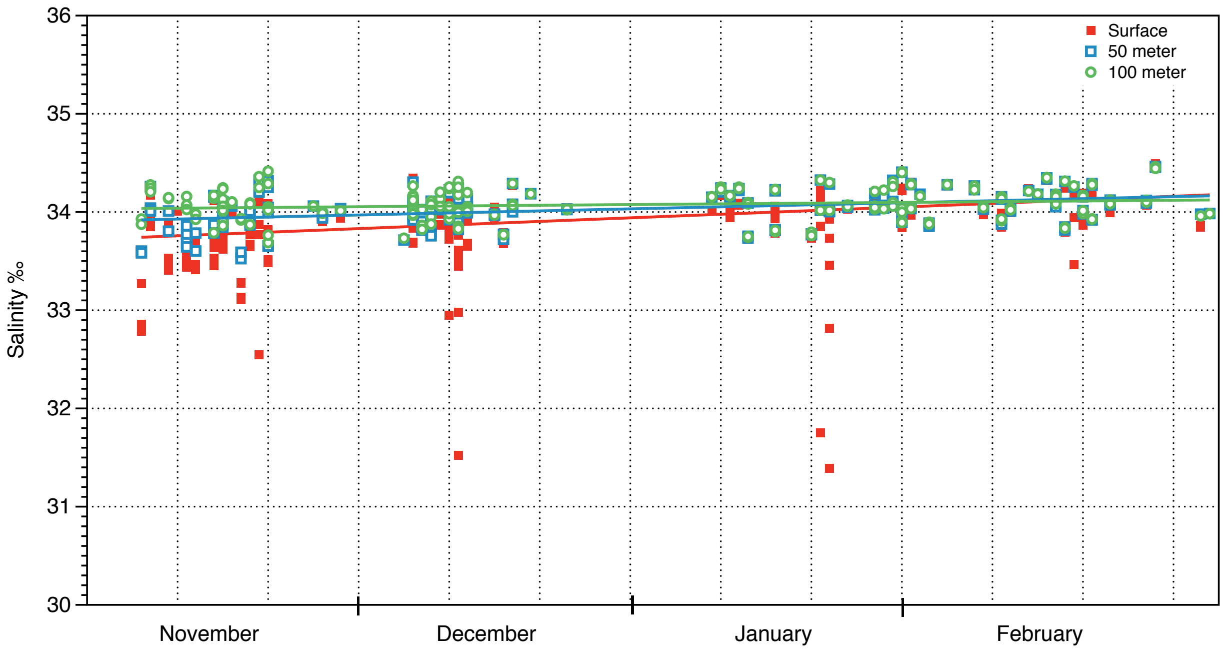


Figure 162: Monthly variability of winter salinity (November – February) at station Inner Porsangerfjorden

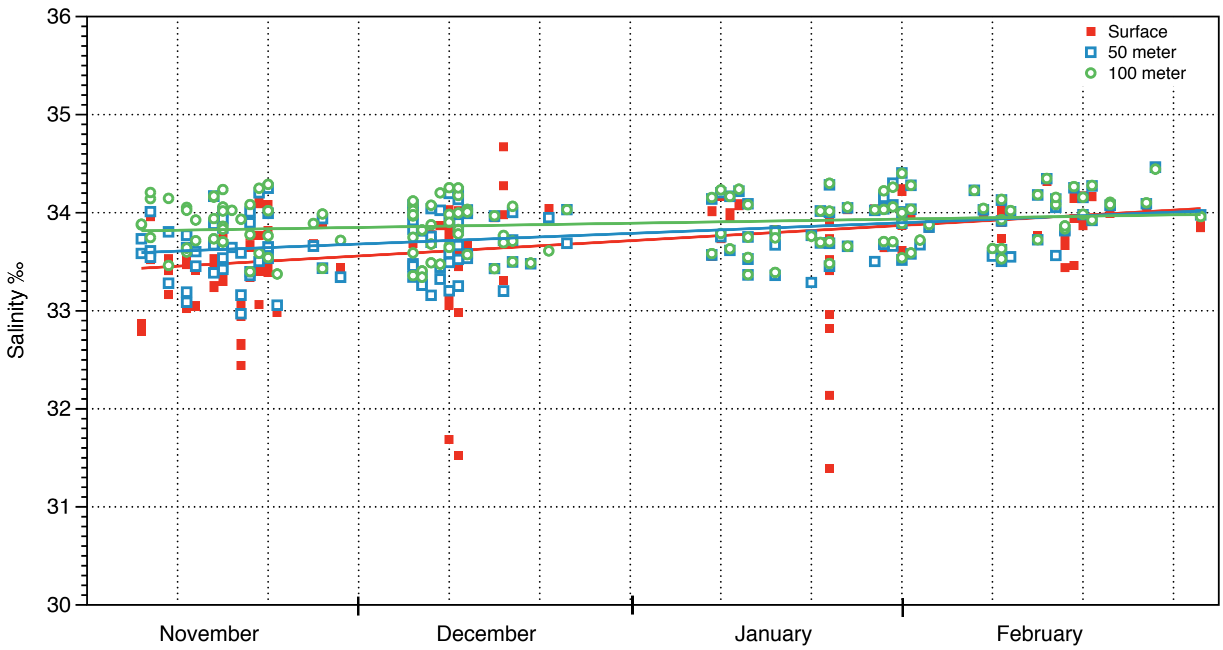


Figure 163: Monthly variability of winter salinity (November – February) at station Østerbotn

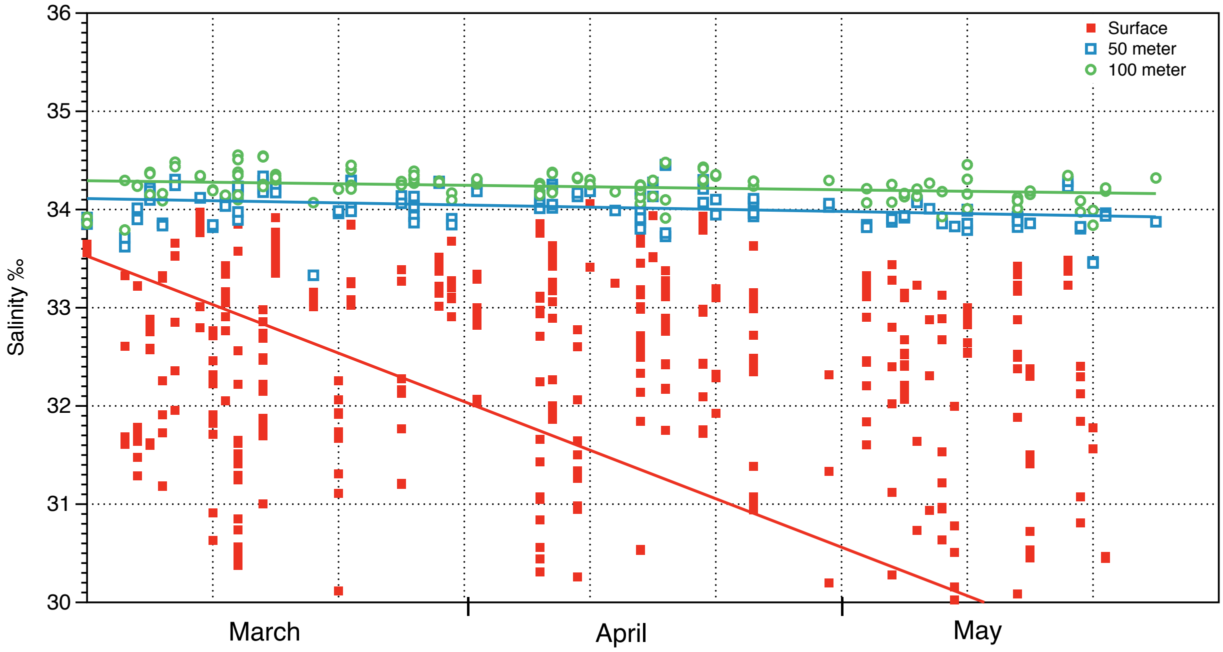


Figure 164: Monthly variability of spring salinity (March – May) at station Inner Malangen

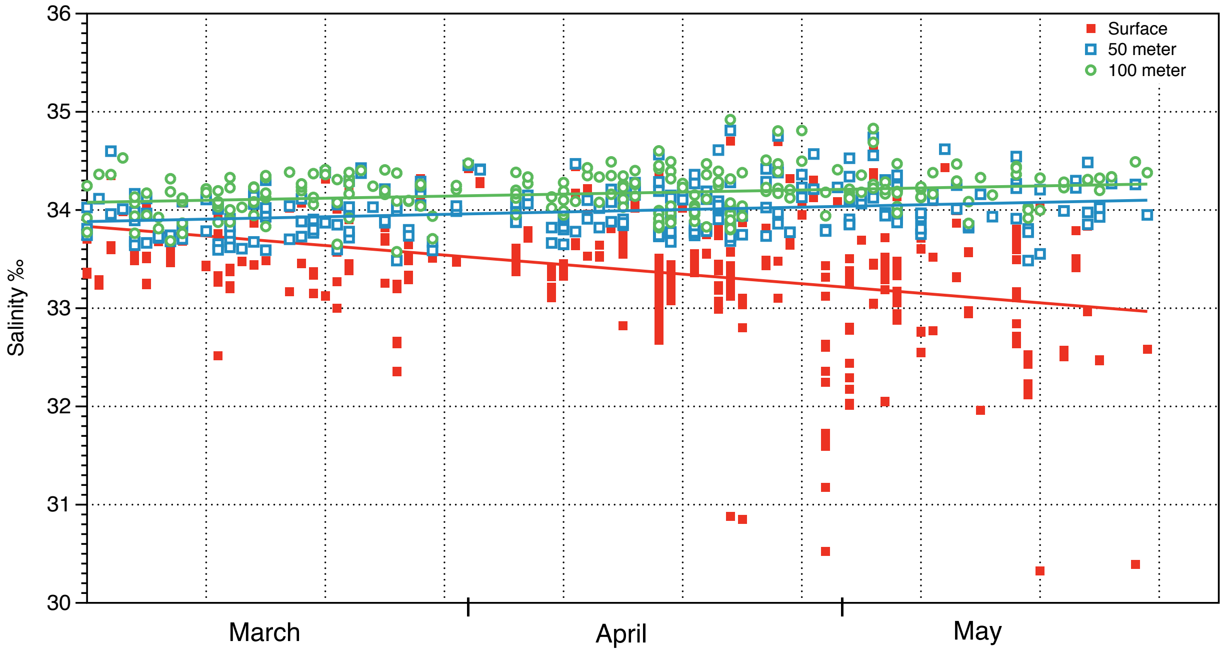


Figure 165: Monthly variability of spring salinity (March – May) at station Outer Malangen

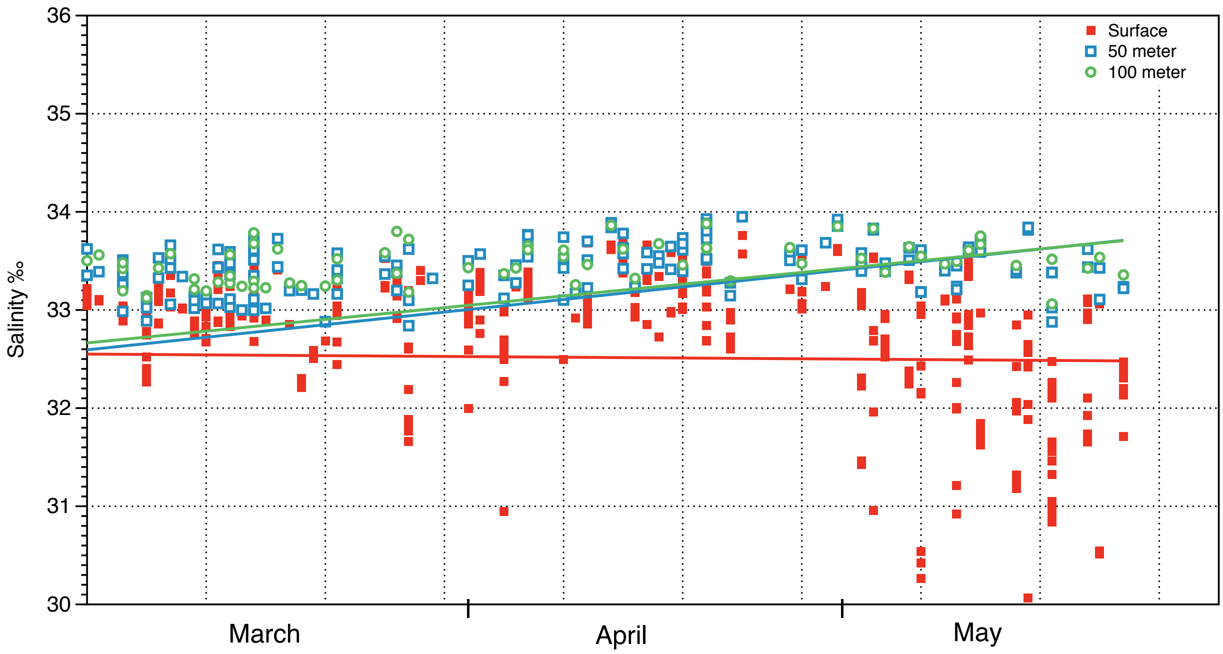


Figure 166: Monthly variability of spring salinity (March – May) at station Outer Balsfjorden

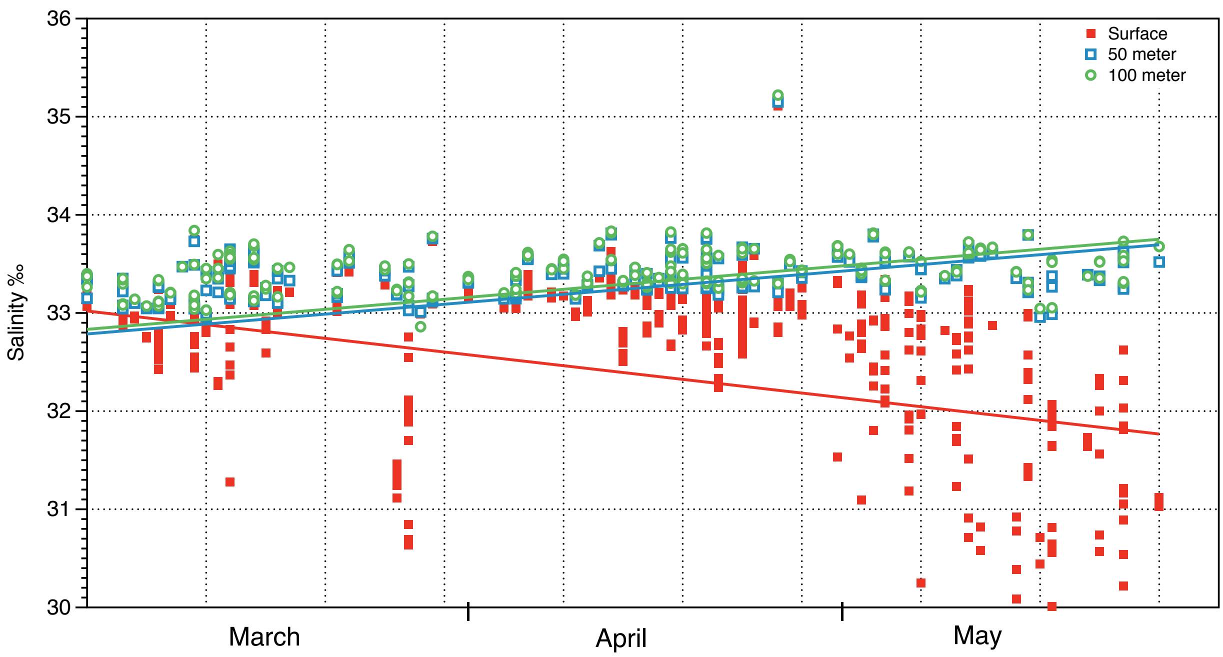


Figure 167: Monthly variability of spring salinity (March – May) at station Inner Balsfjorden

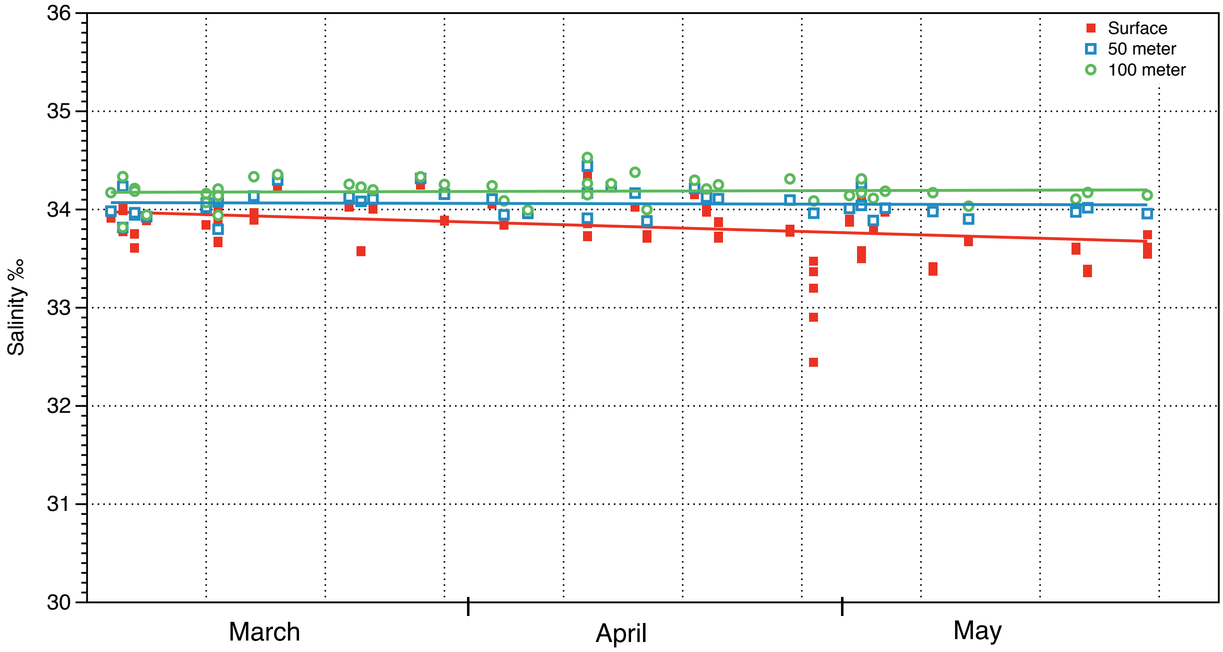


Figure 168: Monthly variability of spring salinity (March – May) at station Kvalsund

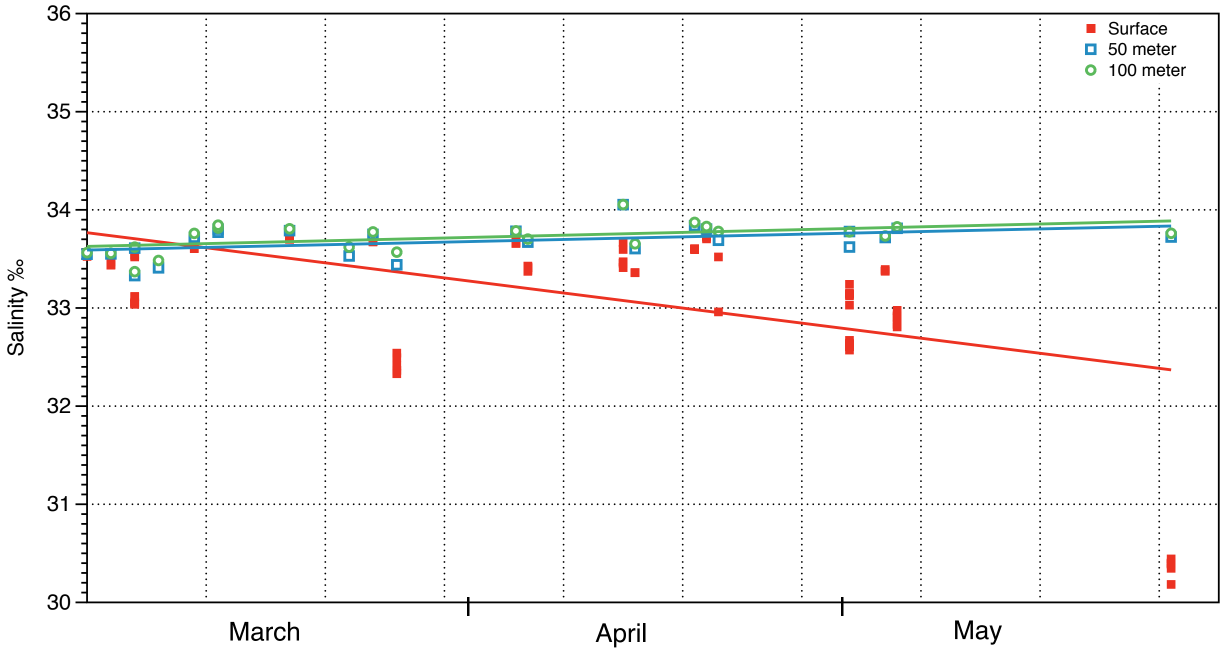


Figure 169: Monthly variability of spring salinity (March – May) at station Sørfjord

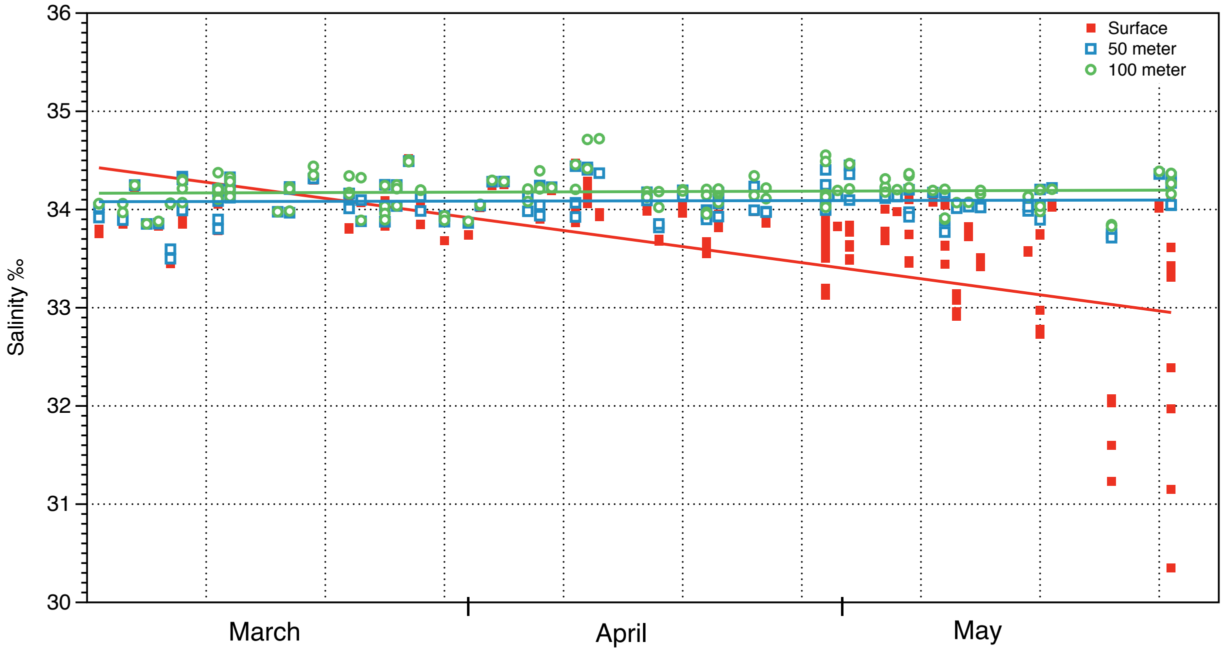


Figure 170: Monthly variability of spring salinity (March – May) at station Outer Altafjorden

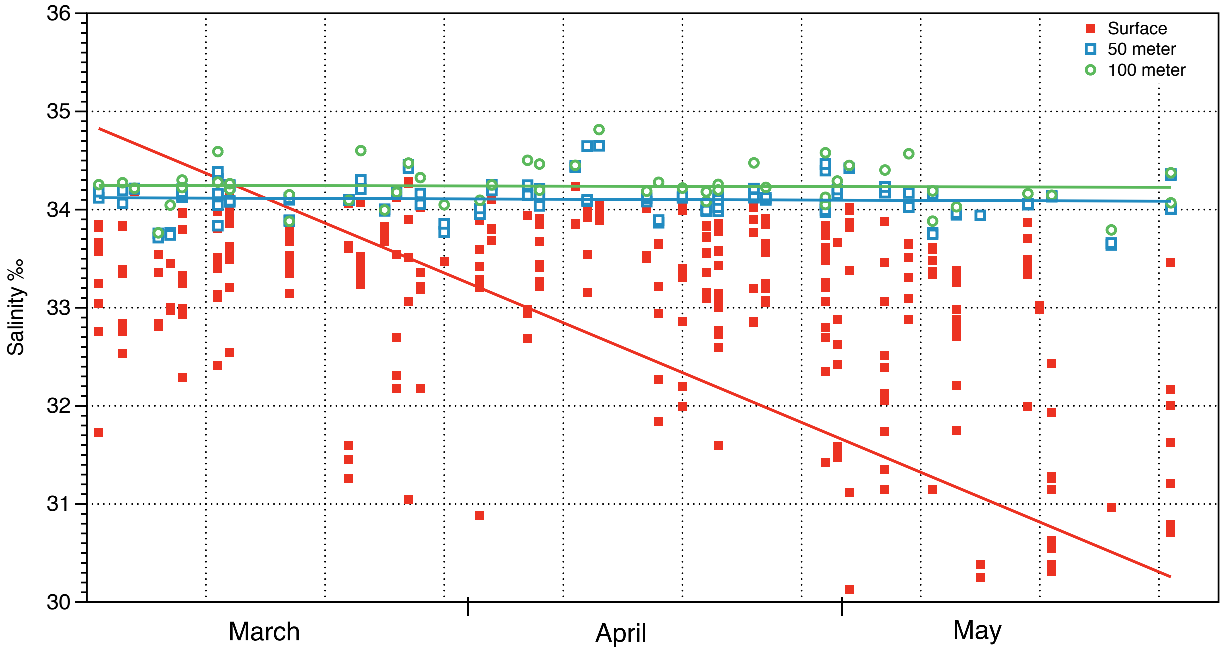


Figure 171: Monthly variability of spring salinity (March – May) at station Inner Altafjorden

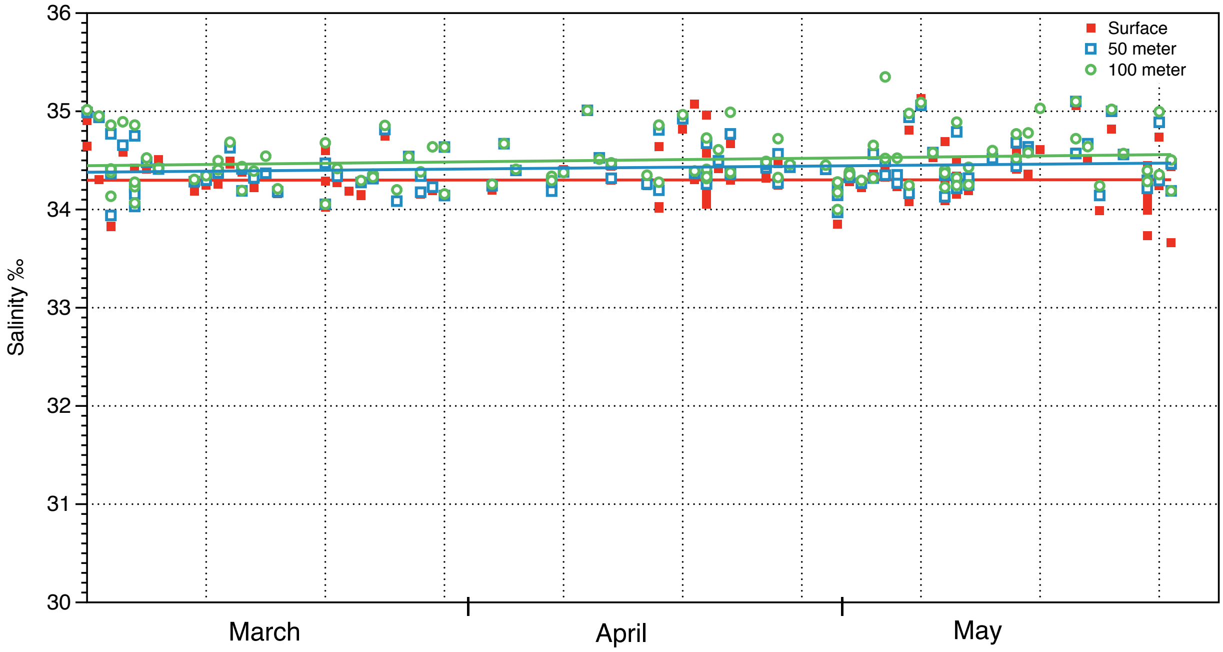


Figure 172: Monthly variability of spring salinity (March – May) at station Refsbotn

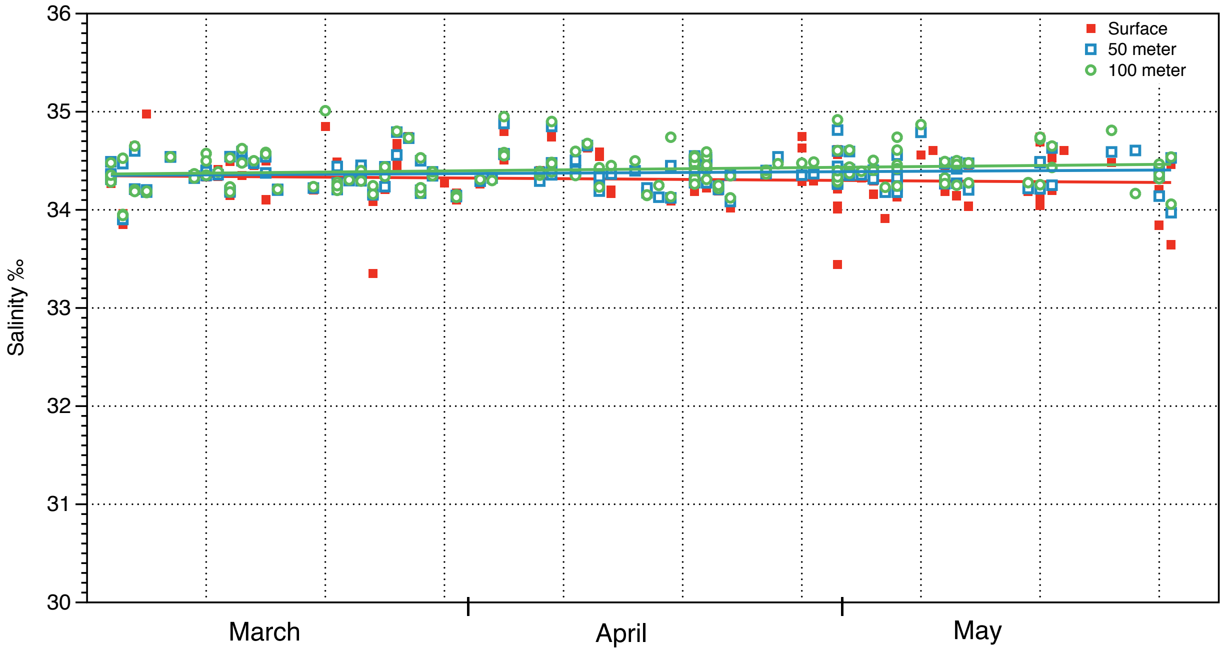


Figure 173: Monthly variability of spring salinity (March – May) at station Outer Porsangerfjorden

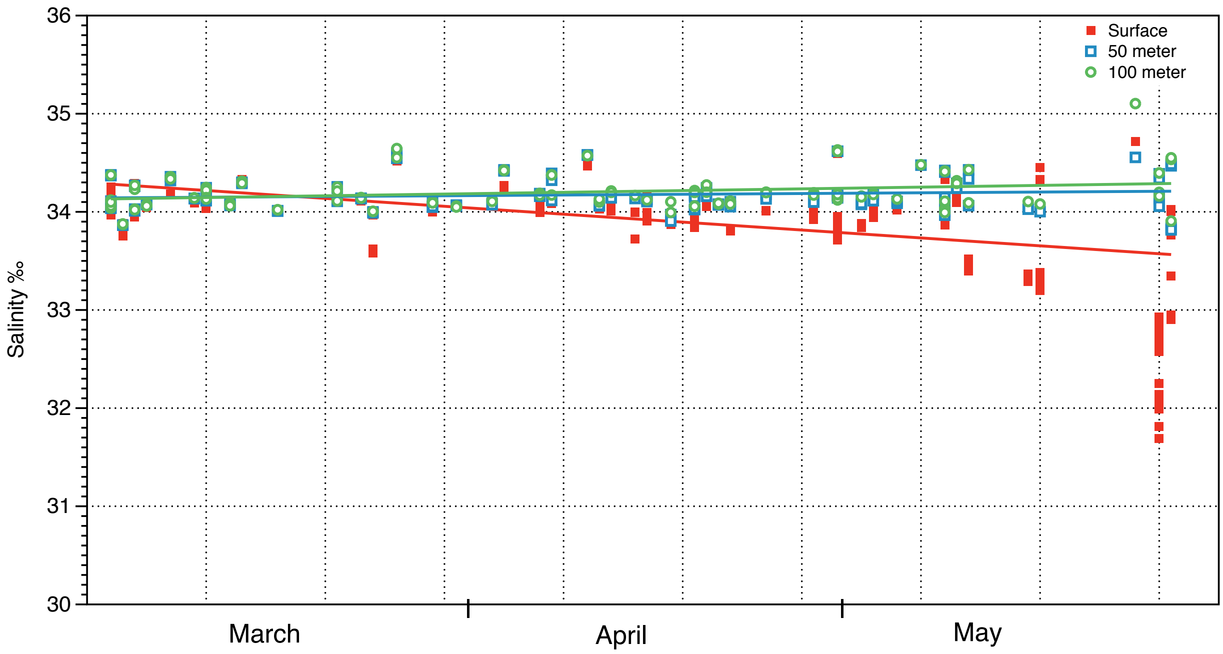


Figure 174: Monthly variability of spring salinity (March – May) at station Inner Porsangerfjorden

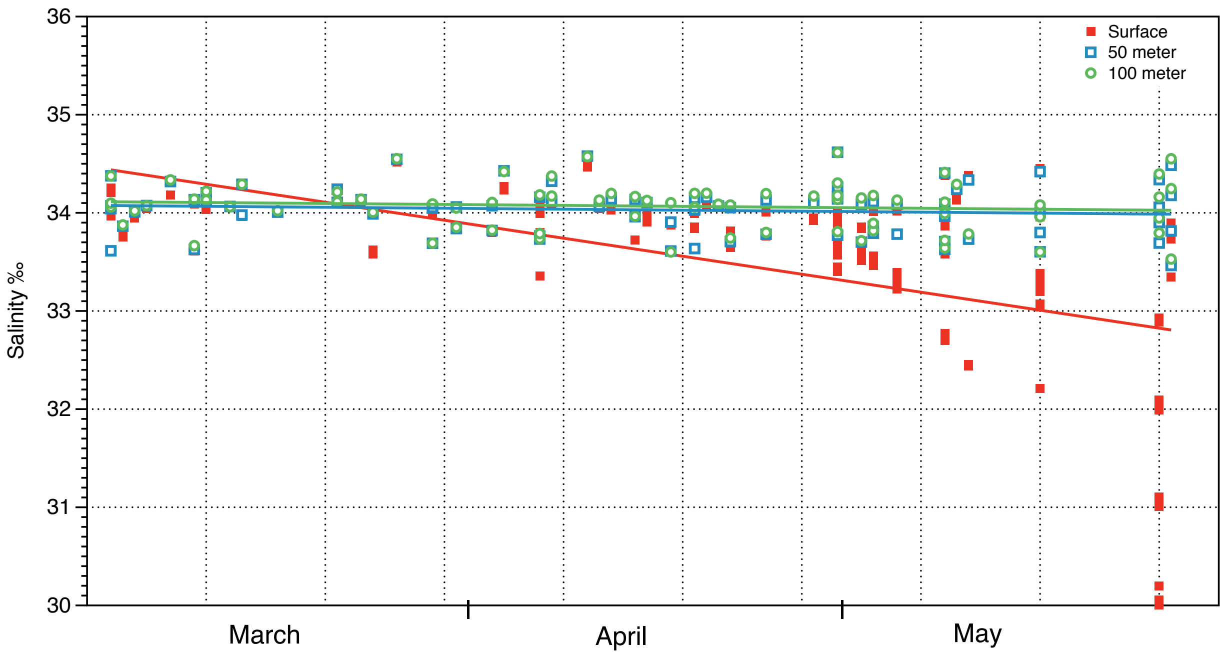


Figure 175: Monthly variability of spring salinity (March – May) at station Østerbotn

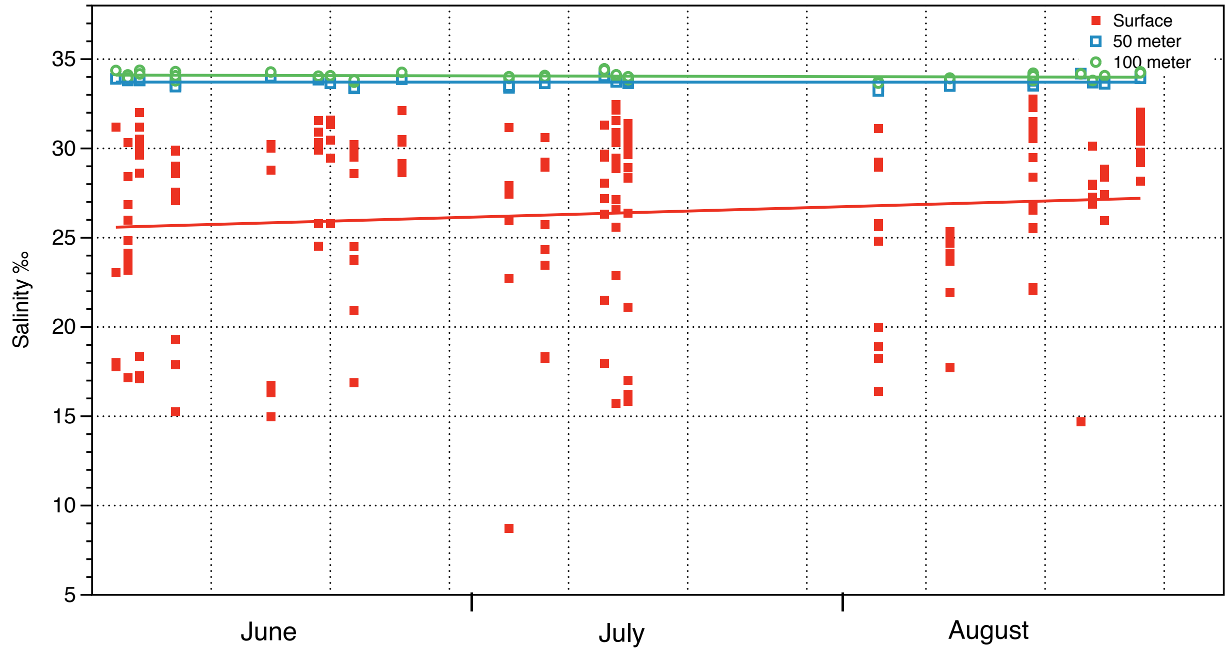


Figure 176: Monthly variability of summer salinity (June – August) at station Inner Malangen

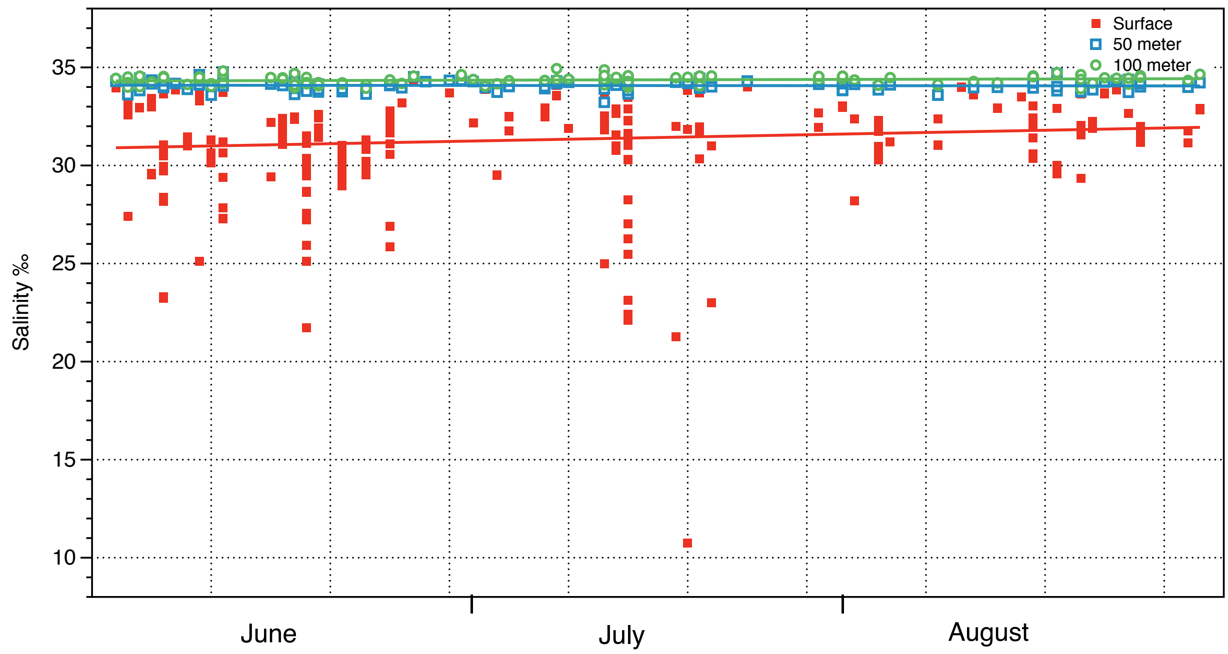


Figure 177: Monthly variability of summer salinity (June – August) at station Outer Malangen

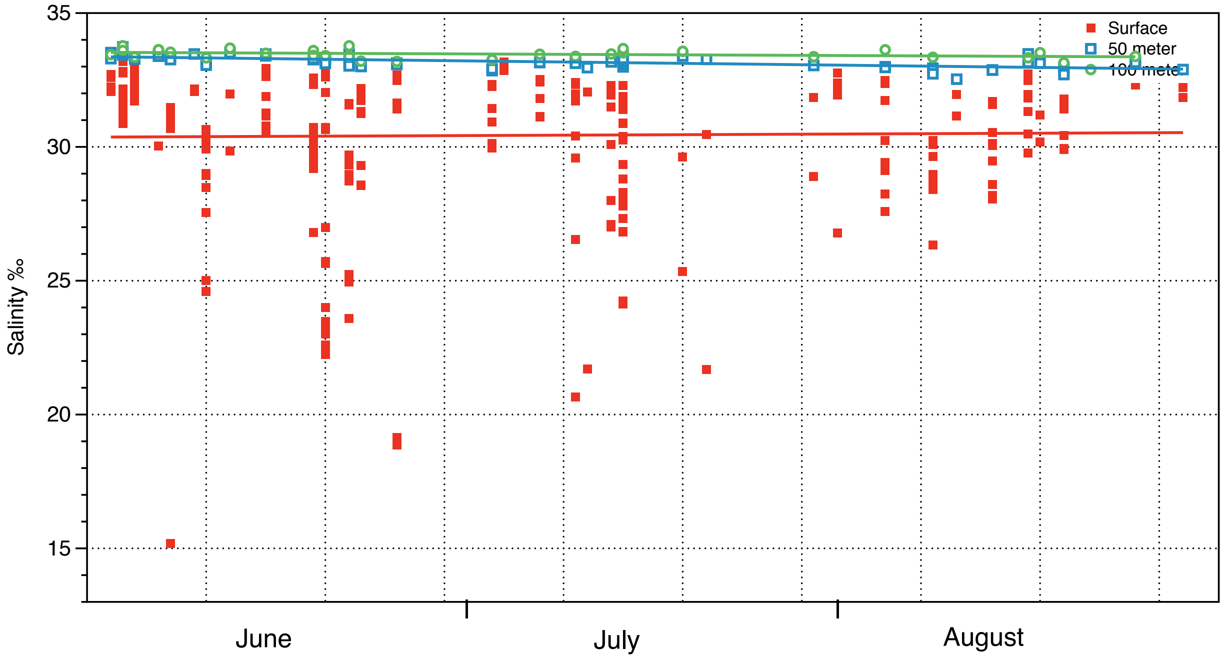


Figure 178: Monthly variability of summer salinity (June – August) at station Outer Balsfjorden

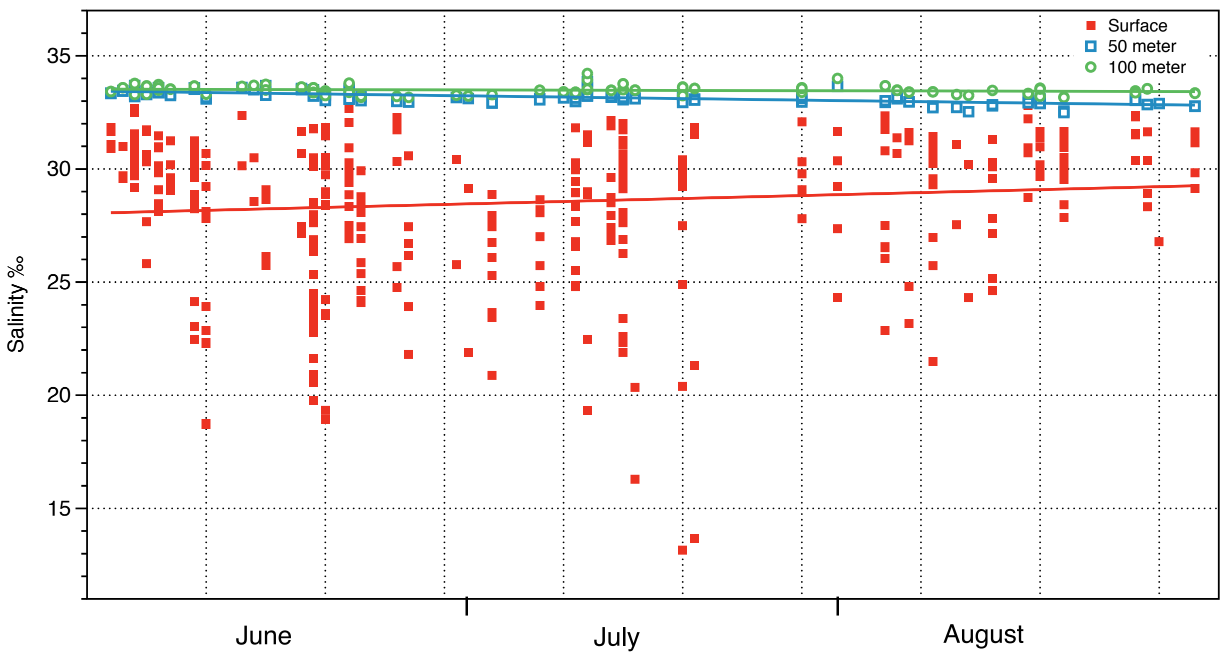


Figure 179: Monthly variability of summer salinity (June – August) at station Inner Balsfjorden

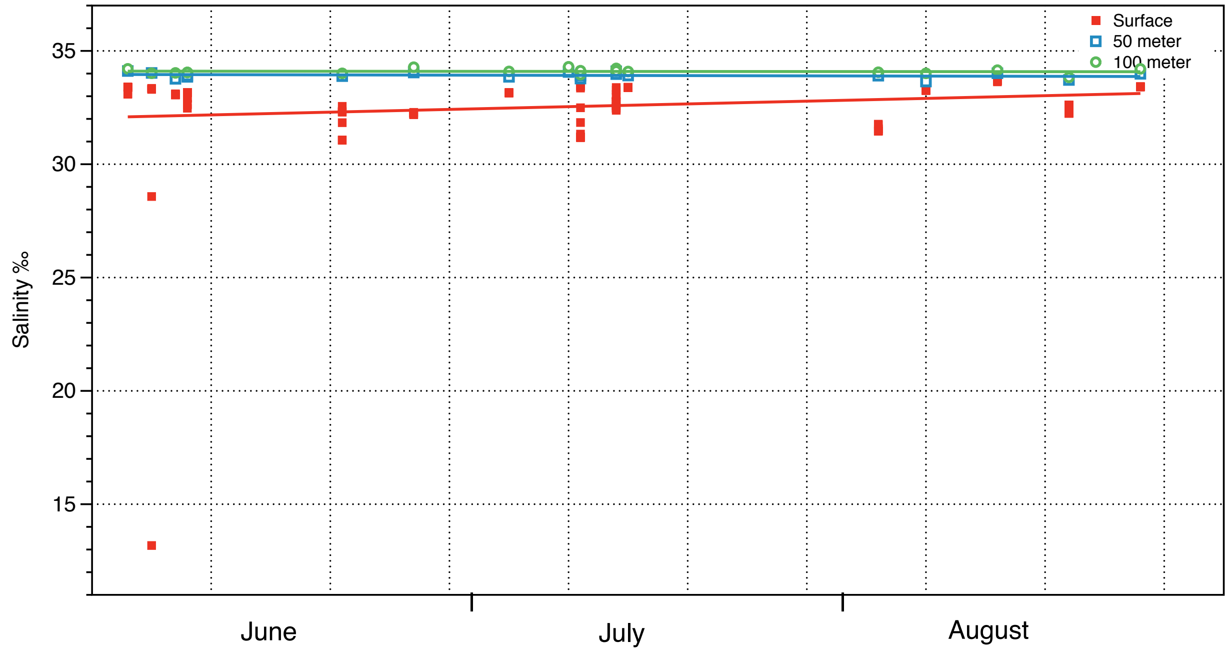


Figure 180: Monthly variability of summer salinity (June – August) at station Kvalsund

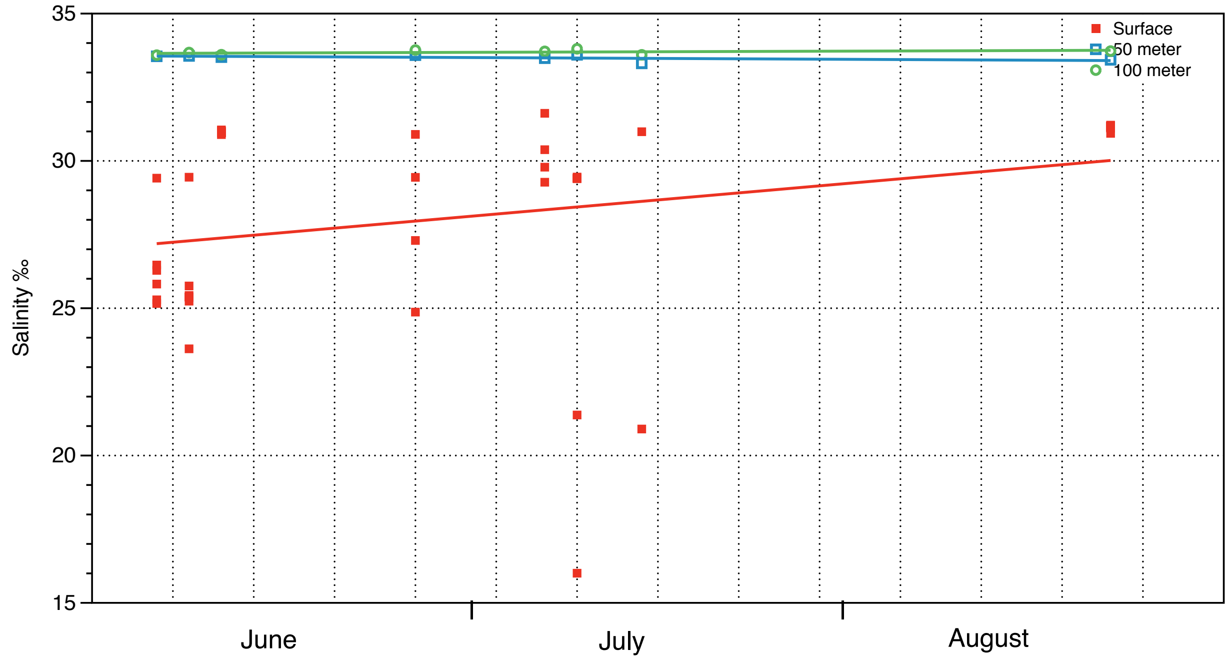


Figure 181: Monthly variability of summer salinity (June – August) at station Sørfjord

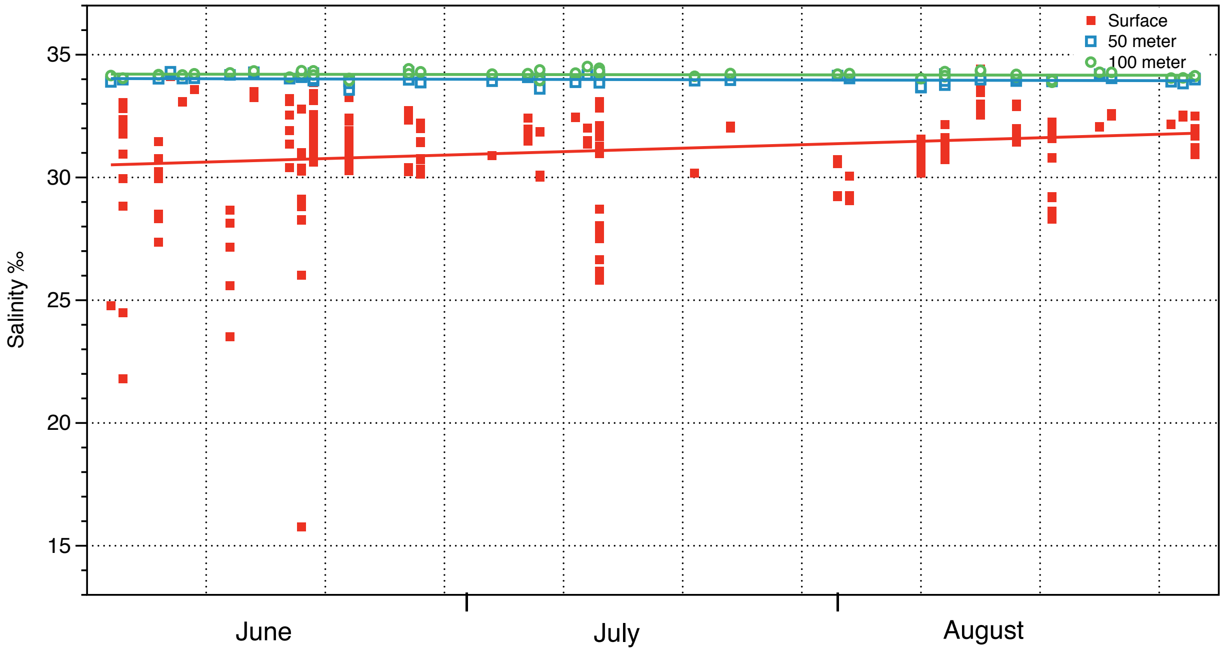


Figure 182: Monthly variability of summer salinity (June – August) at station Outer Altafjorden

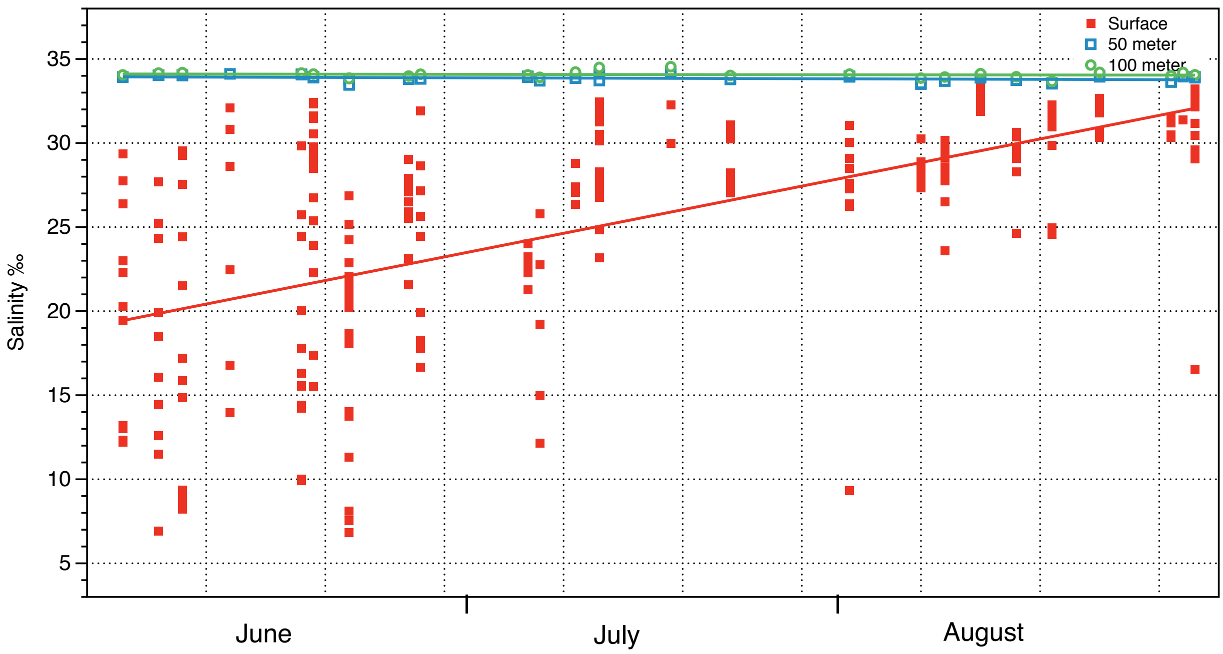


Figure 183: Monthly variability of summer salinity (June – August) at station Inner Altafjorden

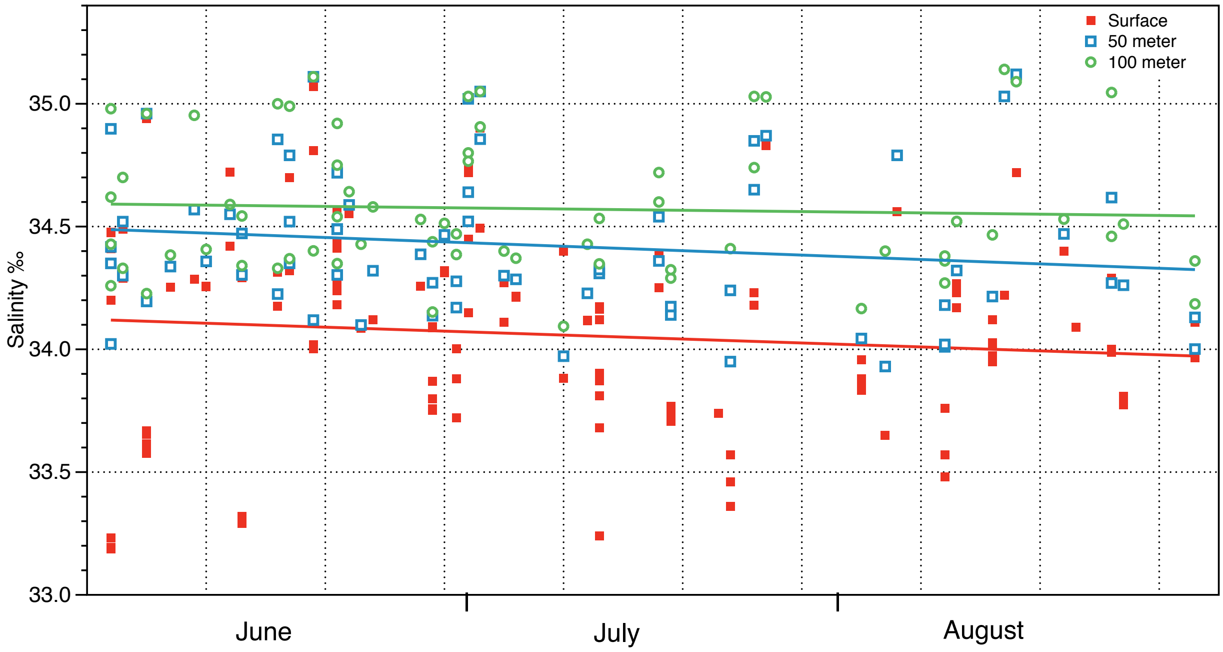


Figure 184: Monthly variability of summer salinity (June – August) at station Refsbotn

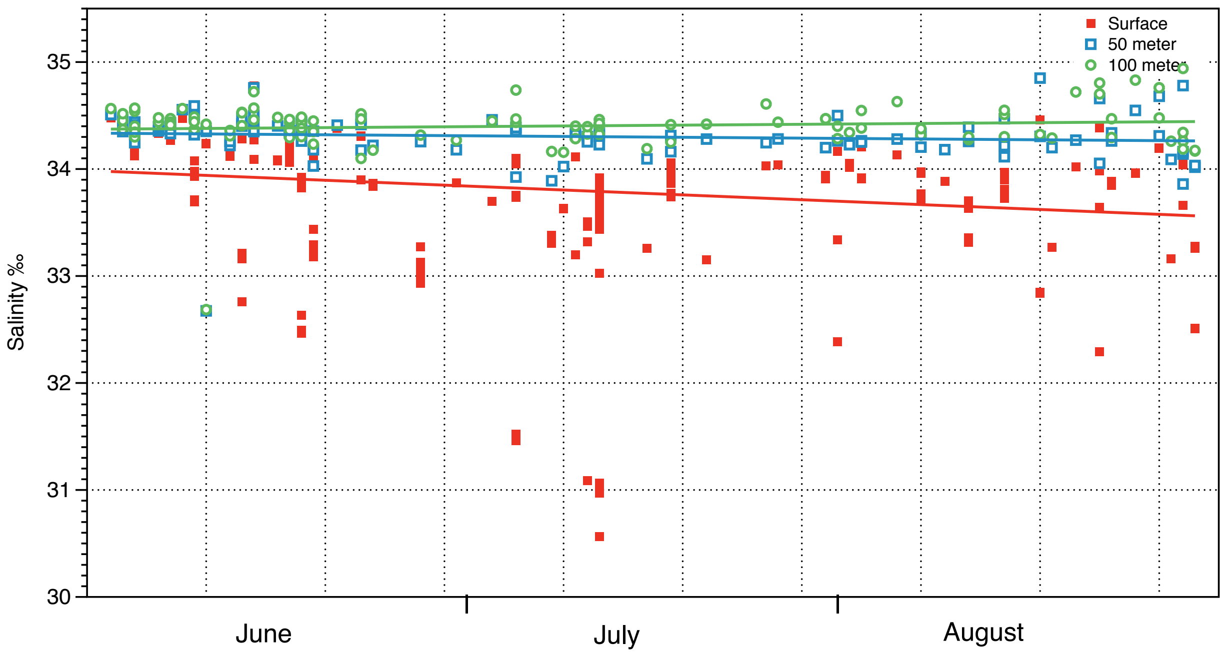


Figure 185: Monthly variability of summer salinity (June – August) at station Outer Porsangerfjorden

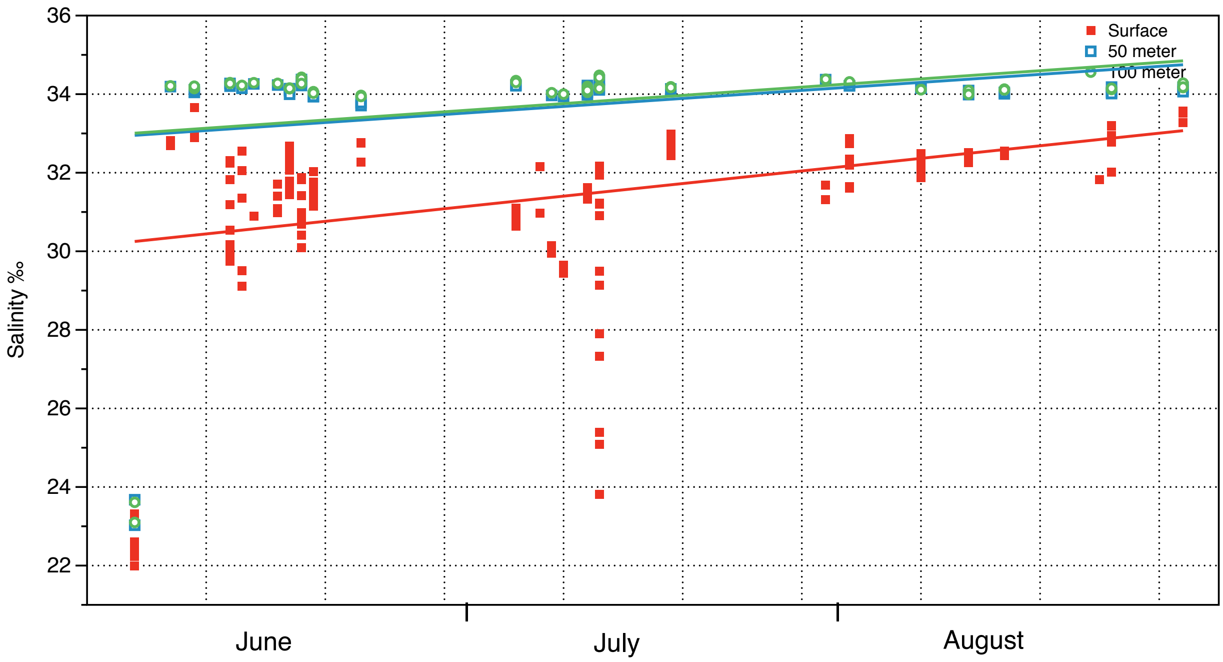


Figure 186: Monthly variability of summer salinity (June – August) at station Inner Porsangerfjorden

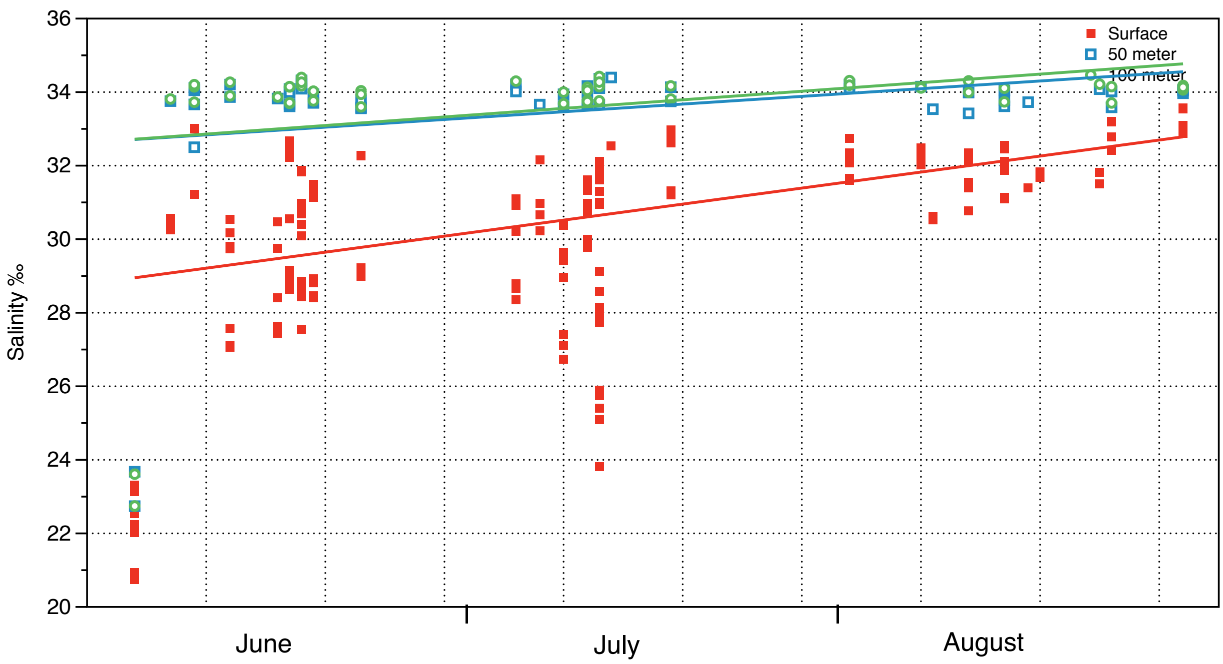


Figure 187: Monthly variability of summer salinity (June – August) at station Østerbotn

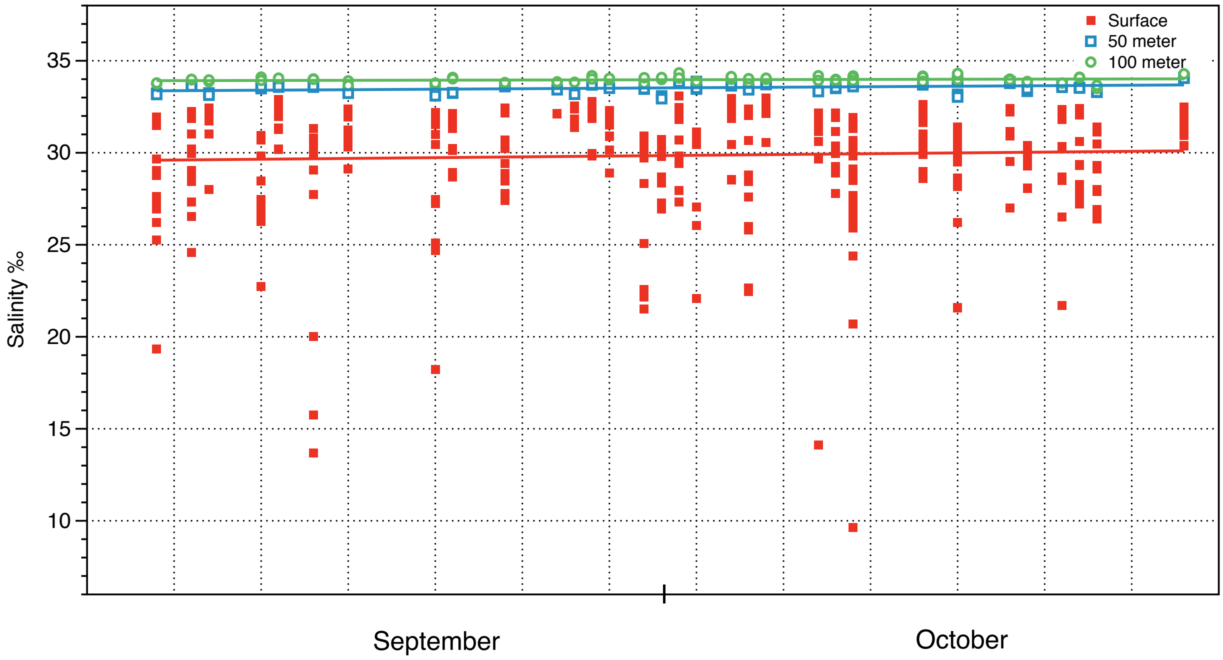


Figure 188: Monthly variability of autumn salinity (September – October) at station Inner Malangen

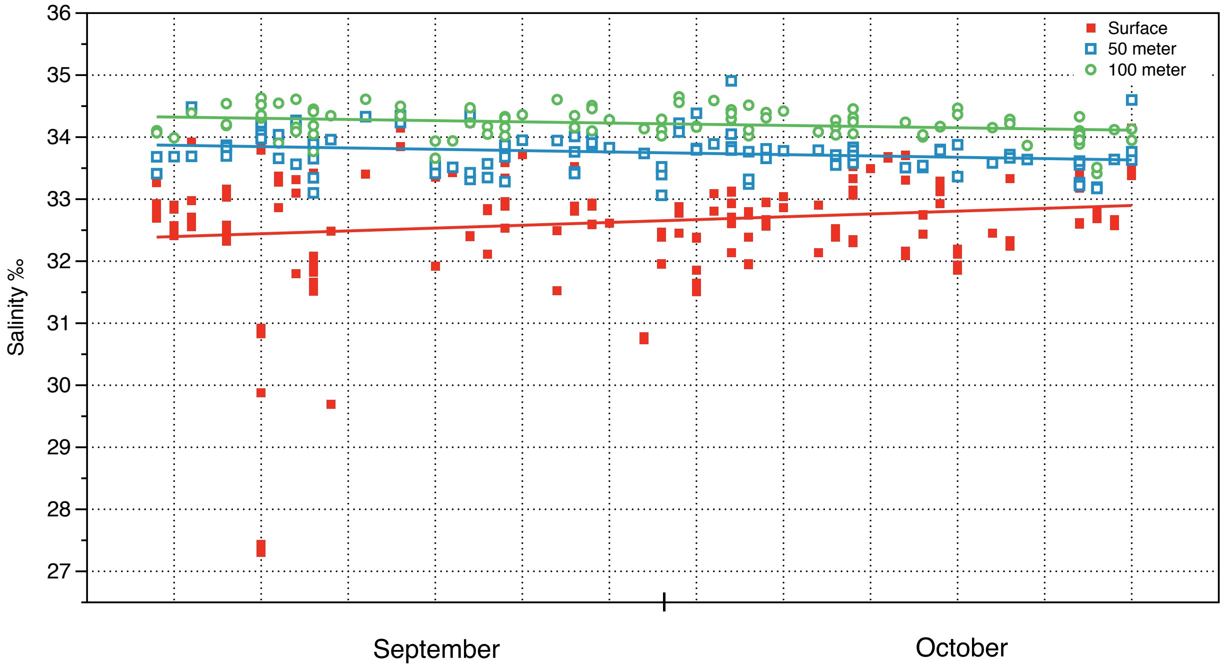


Figure 189: Monthly variability of autumn salinity (September – October) at station Outer Malangen

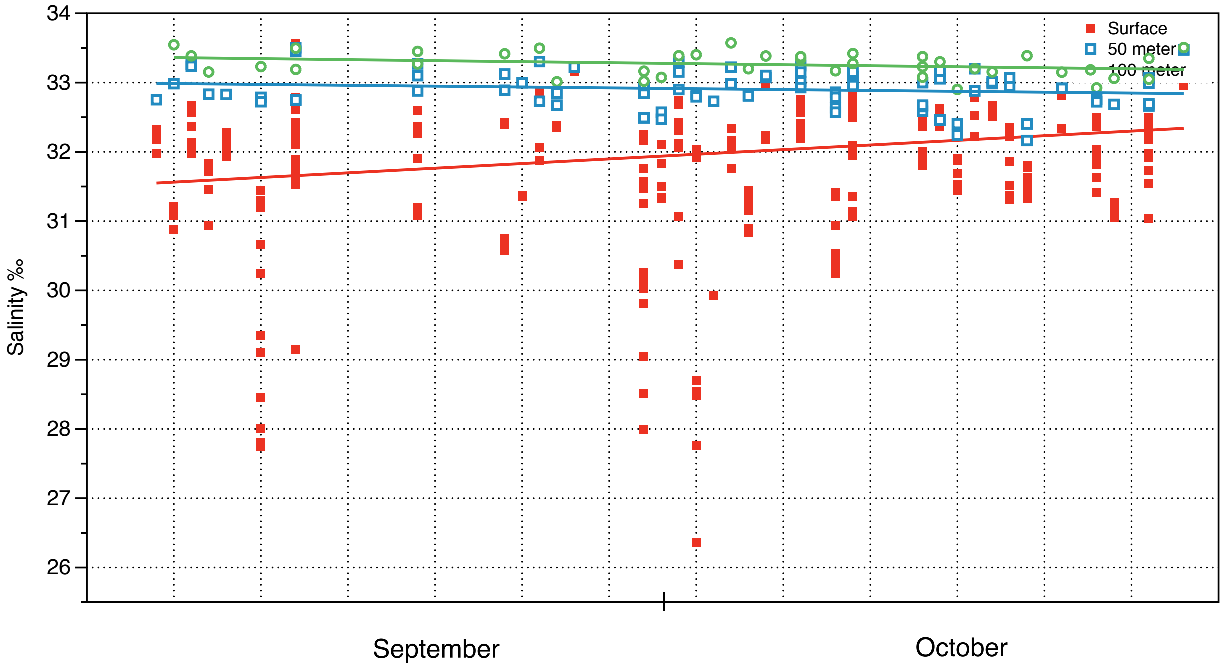


Figure 190: Monthly variability of autumn salinity (September – October) at station Outer Balsfjorden

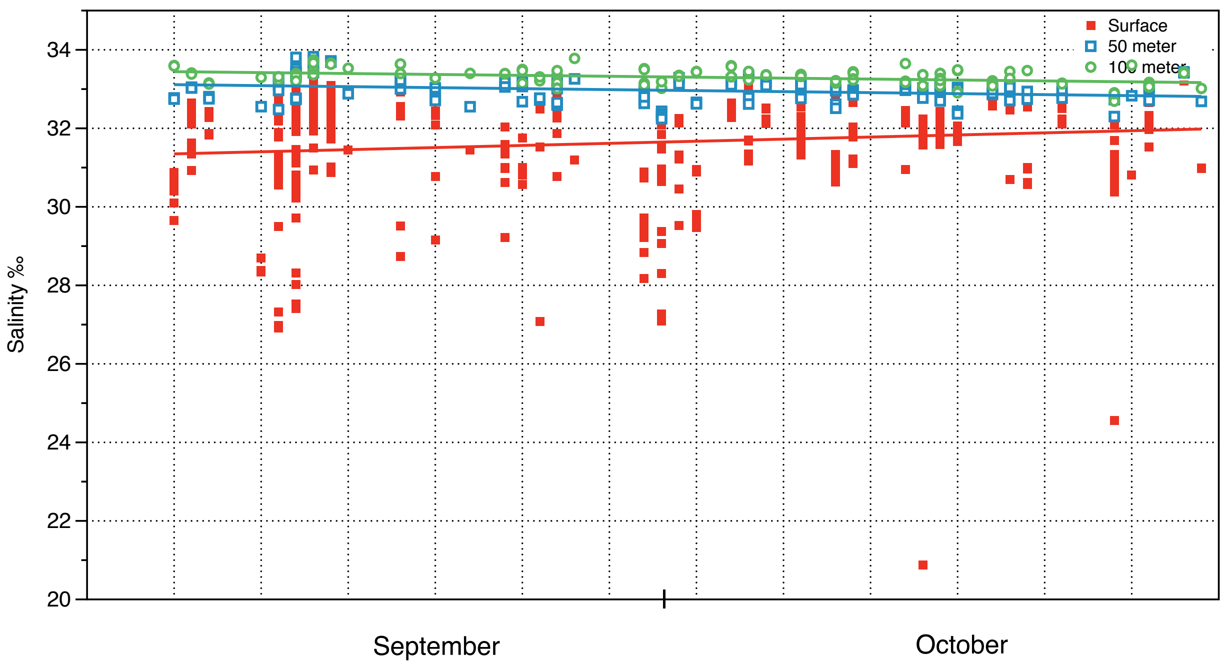


Figure 191: Monthly variability of autumn salinity (September – October) at station Inner Balsfjorden

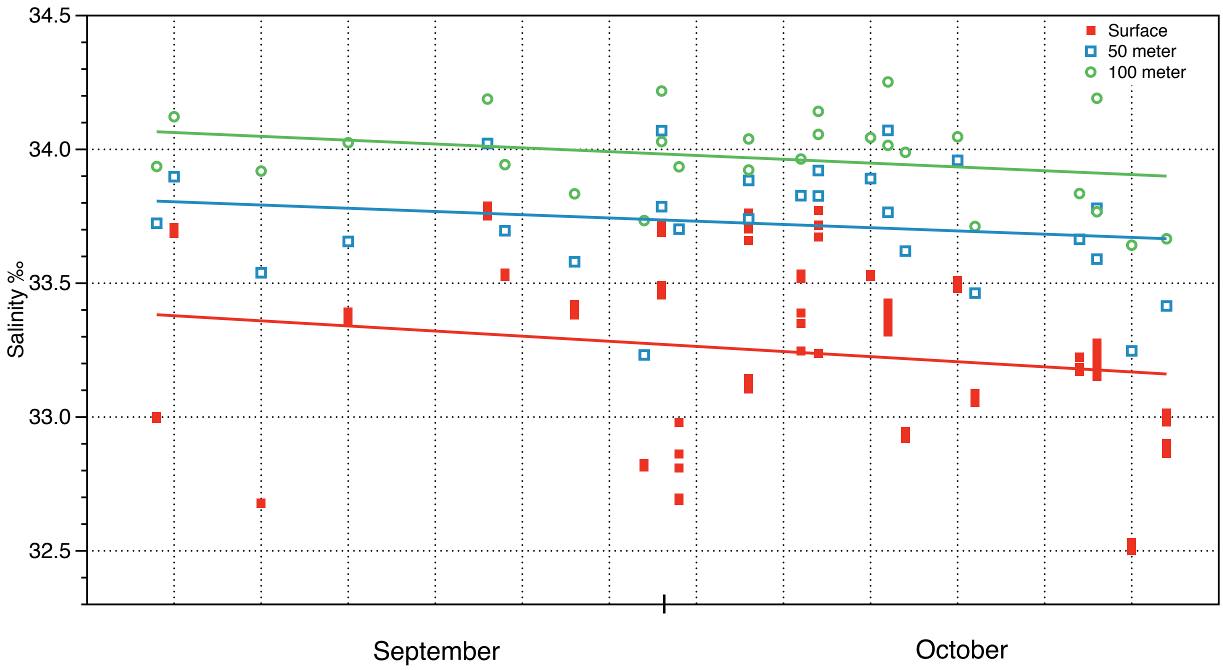


Figure 192: Monthly variability of autumn salinity (September – October) at station Kvalsund

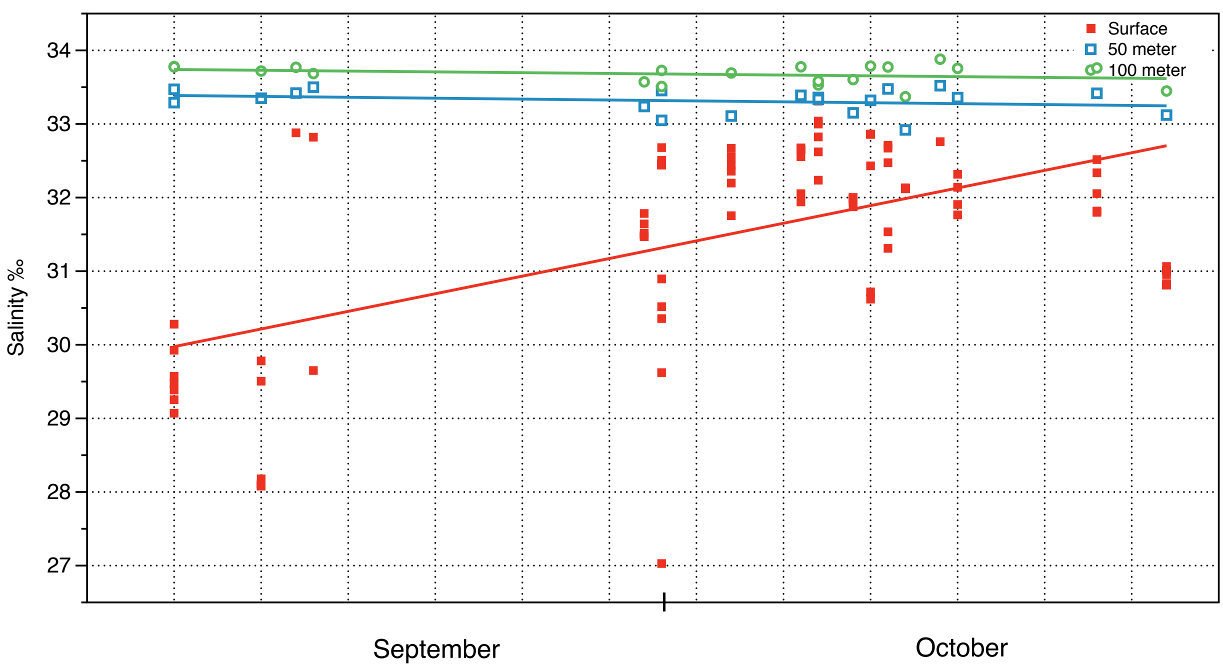


Figure 193: Monthly variability of autumn salinity (September – October) at station Sørfjord

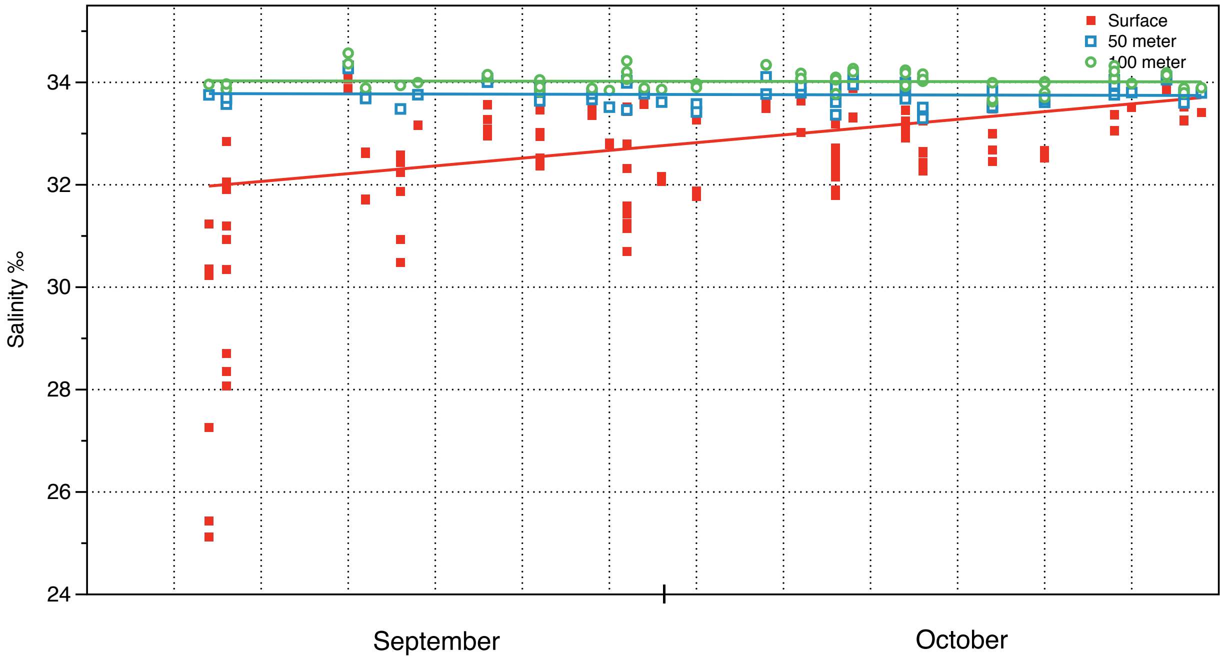


Figure 194: Monthly variability of autumn salinity (September – October) at station Outer Altafjorden

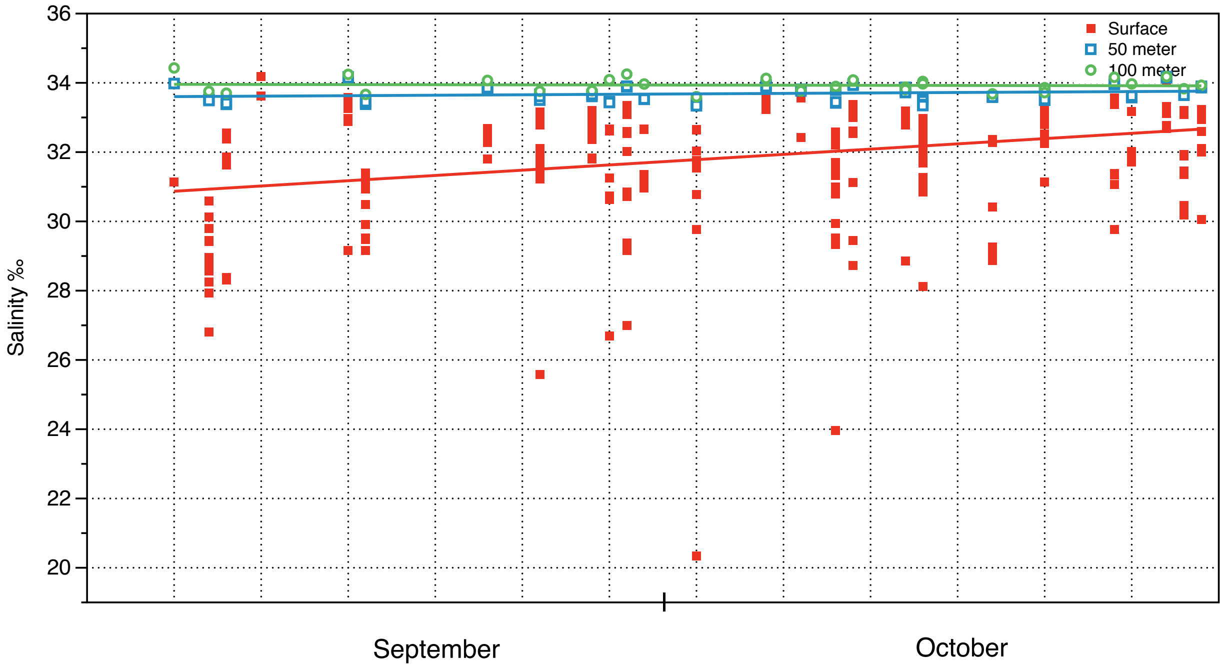


Figure 195: Monthly variability of autumn salinity (September – October) at station Inner Altafjorden

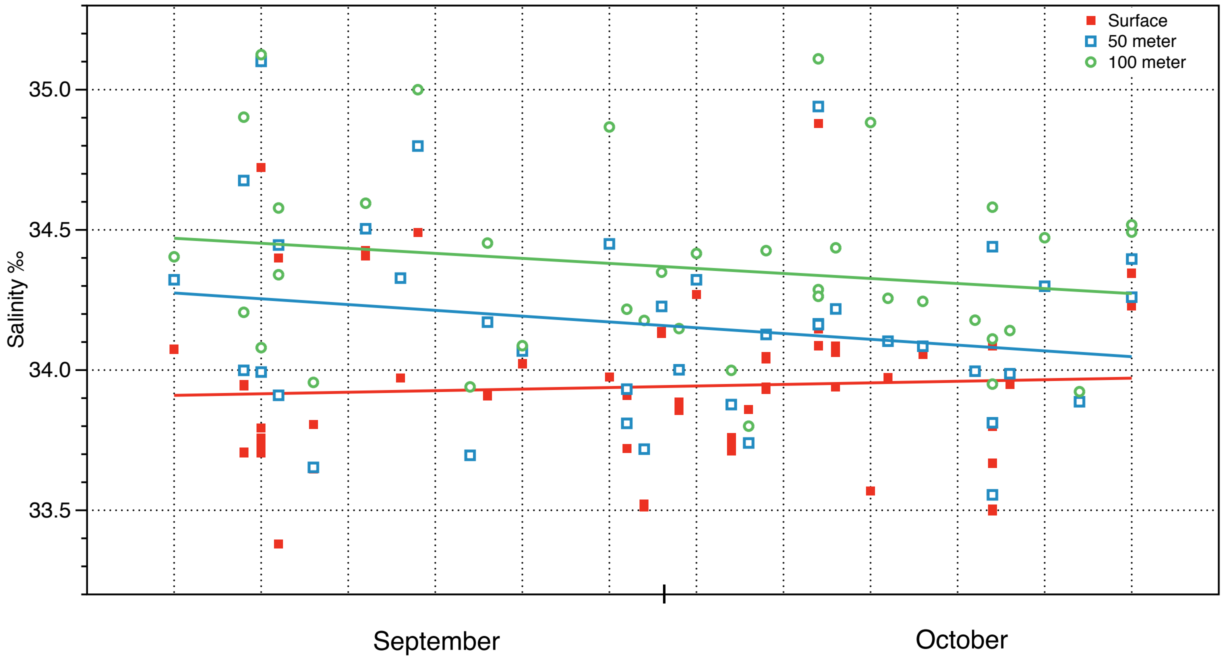


Figure 196: Monthly variability of autumn salinity (September – October) at station Refsbotn

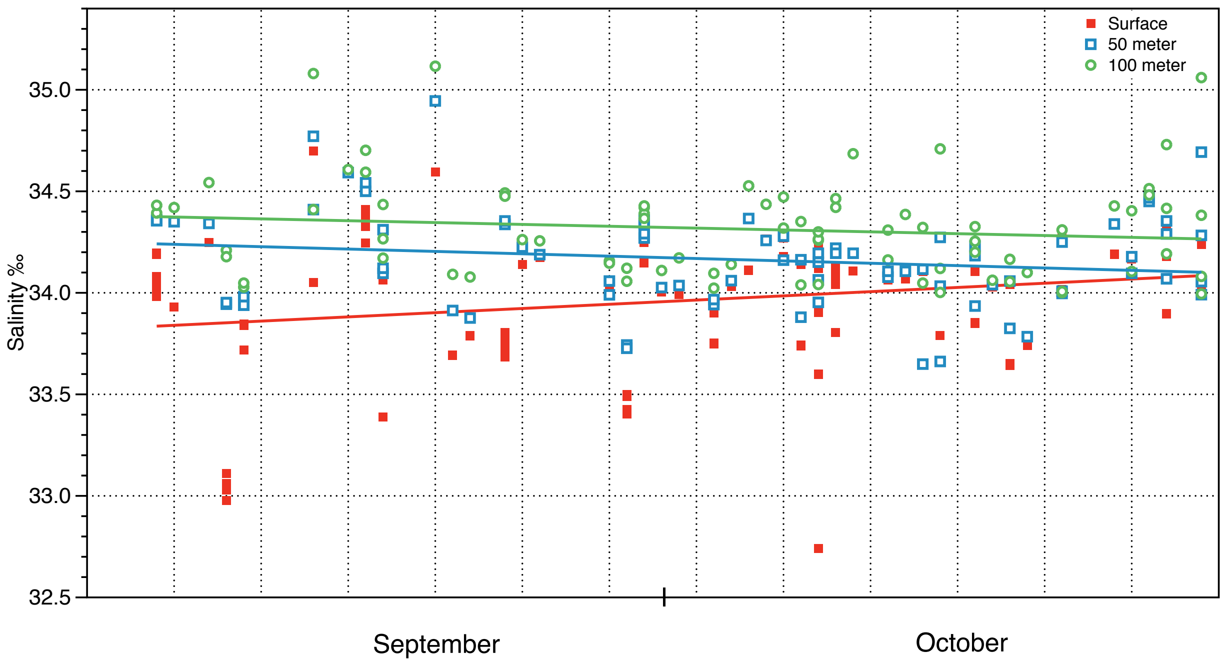


Figure 197: Monthly variability of autumn salinity (September – October) at station Outer Porsangerfjorden

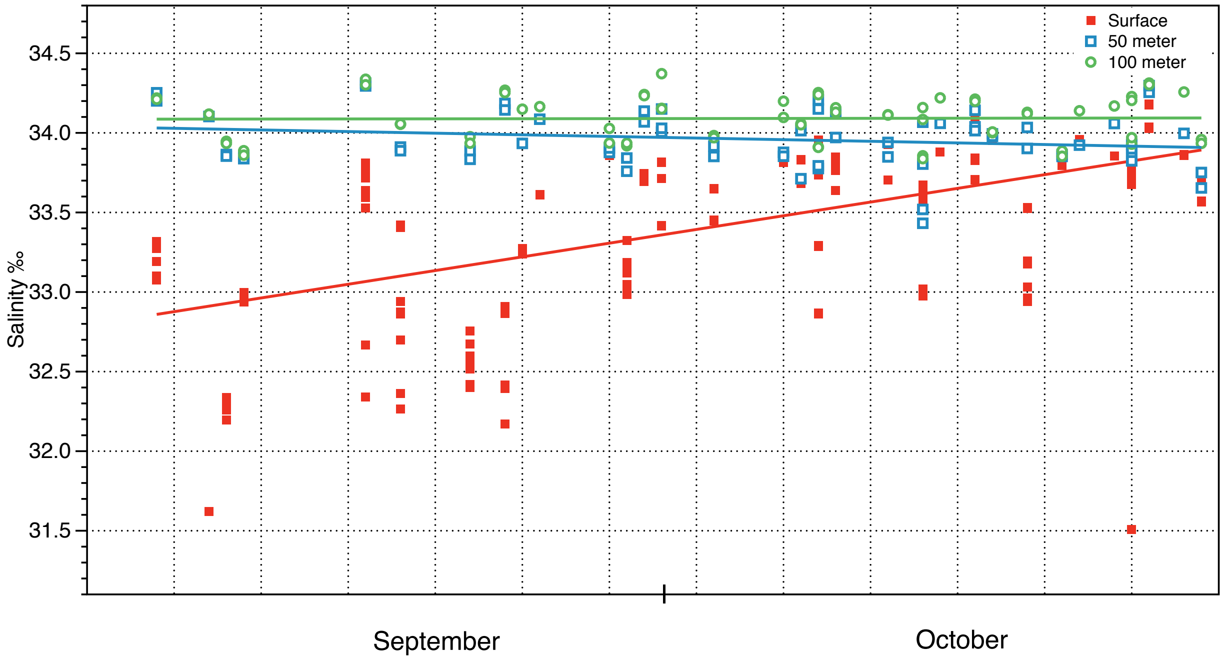


Figure 198: Monthly variability of autumn salinity (September – October) at station Inner Porsangerfjorden

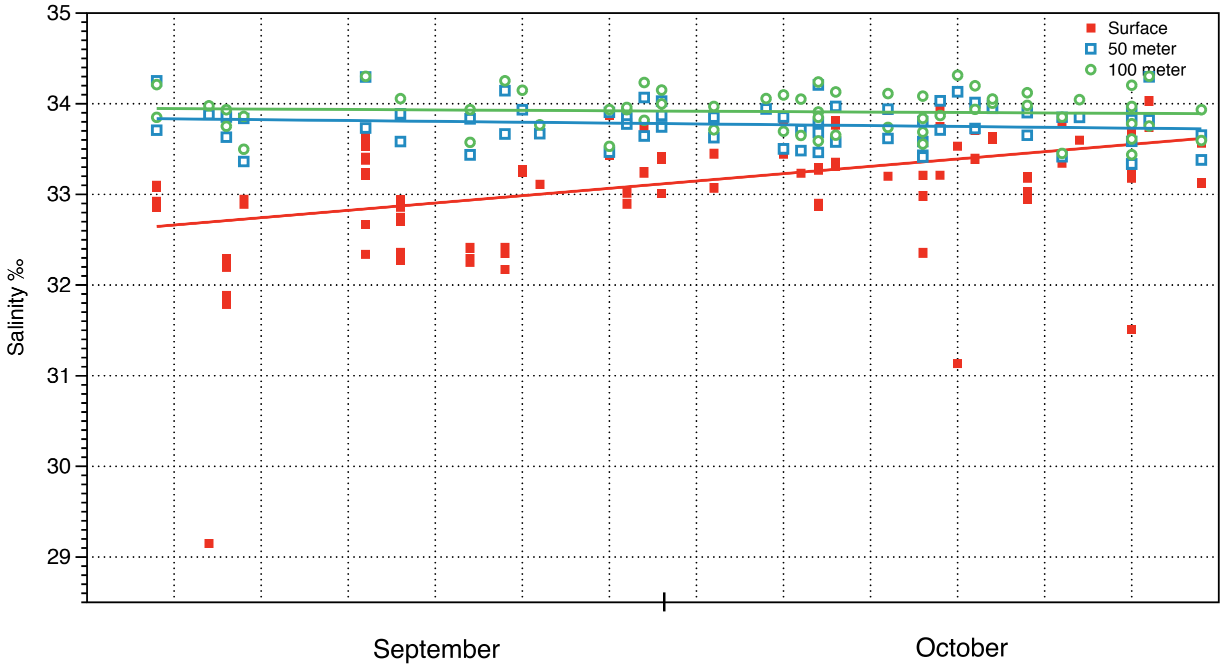


Figure 199: Monthly variability of autumn salinity (September – October) at station Østerbotn

A.3 MONTHLY VARIATIONS IN DENSITY

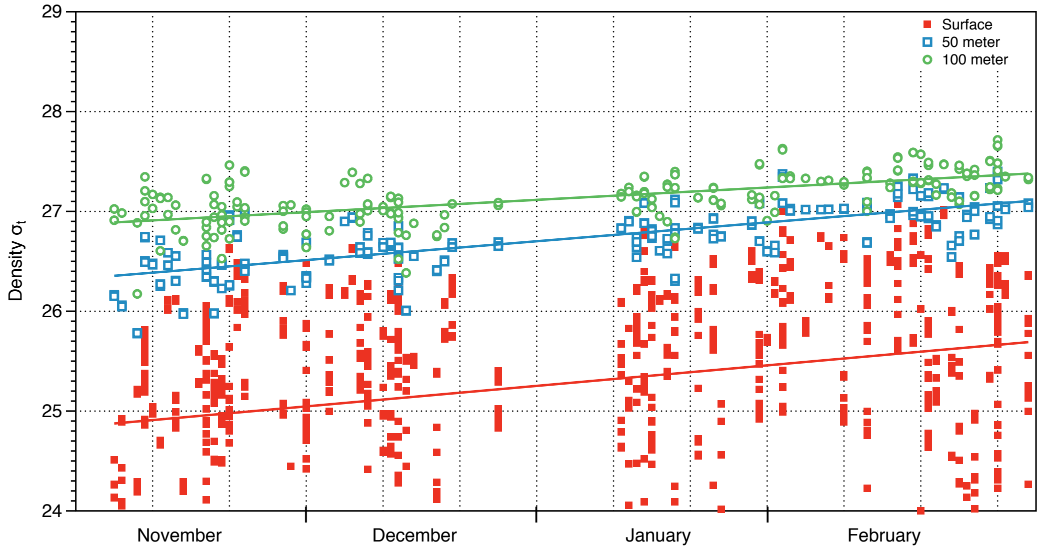


Figure 200: monthly variability of winter density (November – February) at station Inner Malangen

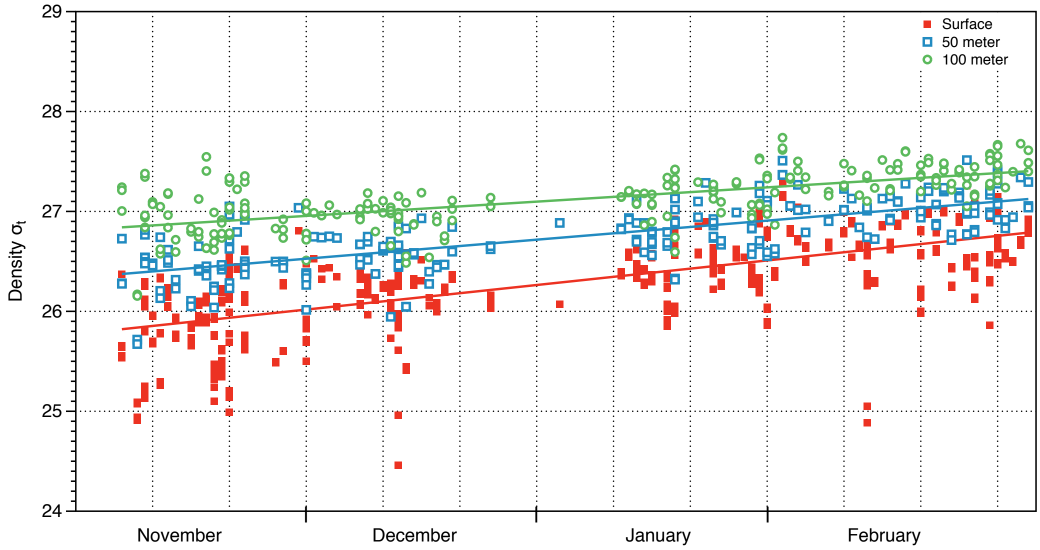


Figure 201: monthly variability of winter density (November – February) at station Outer Malangen

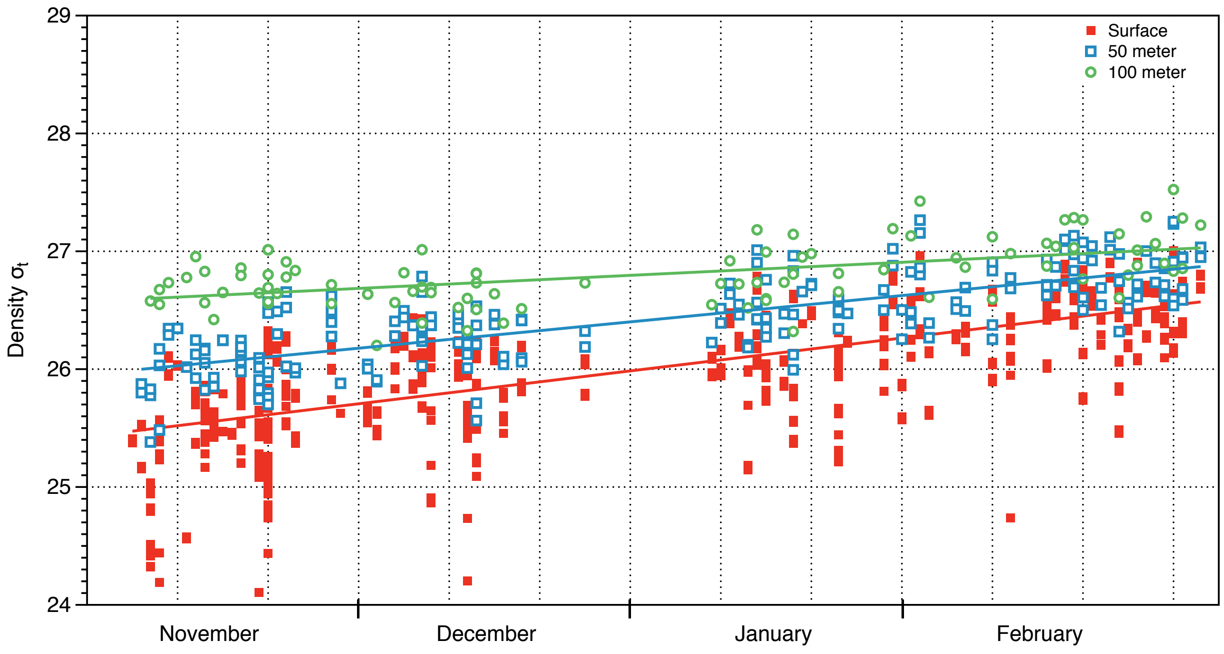


Figure 202: monthly variability of winter density (November – February) at station Outer Balsfjorden

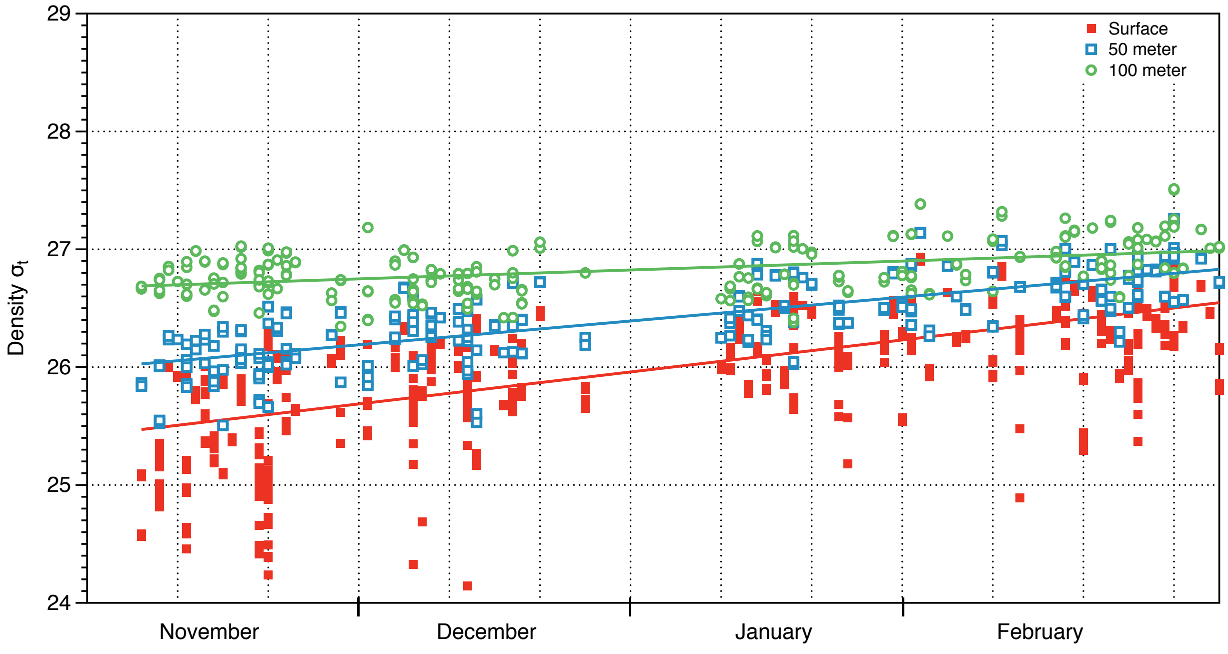


Figure 203: monthly variability of winter density (November – February) at station Inner Balsfjorden

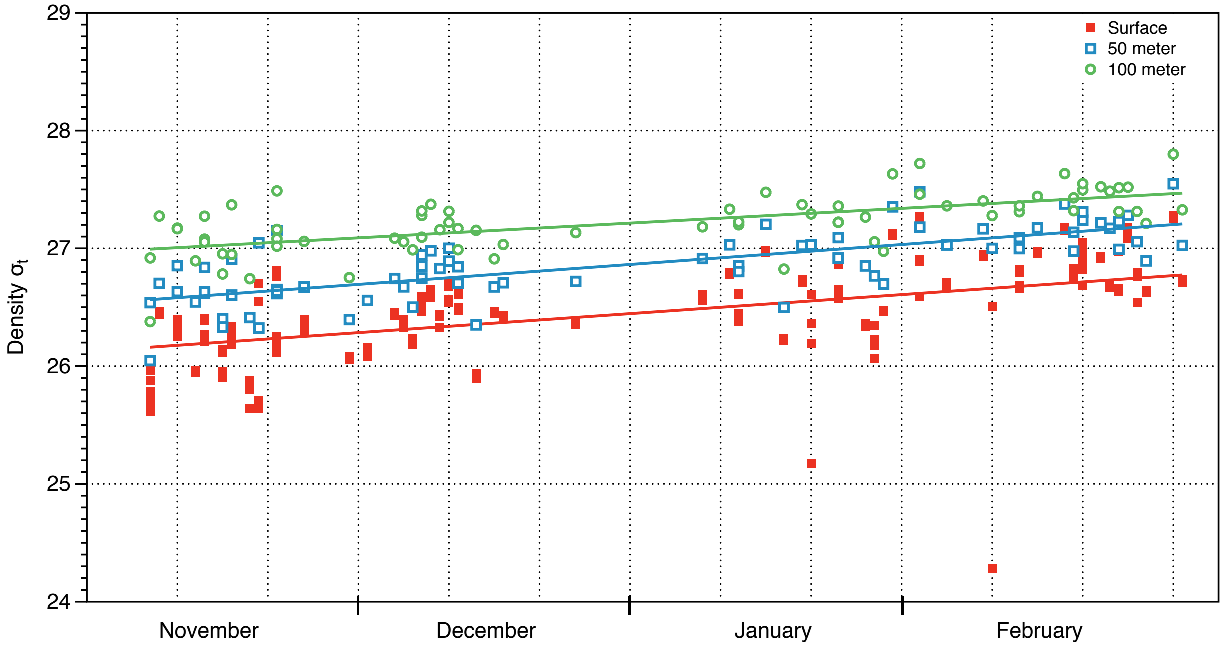


Figure 204: monthly variability of winter density (November – February) at station Kvalsund

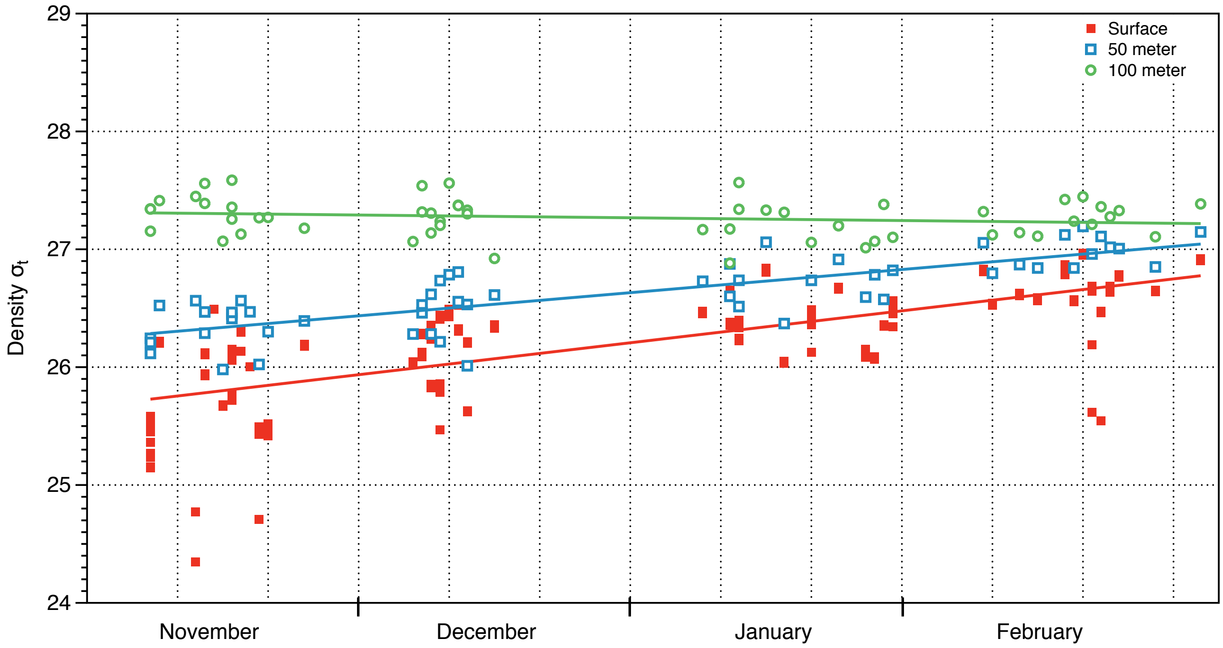


Figure 205: monthly variability of winter density (November – February) at station Sørfjord

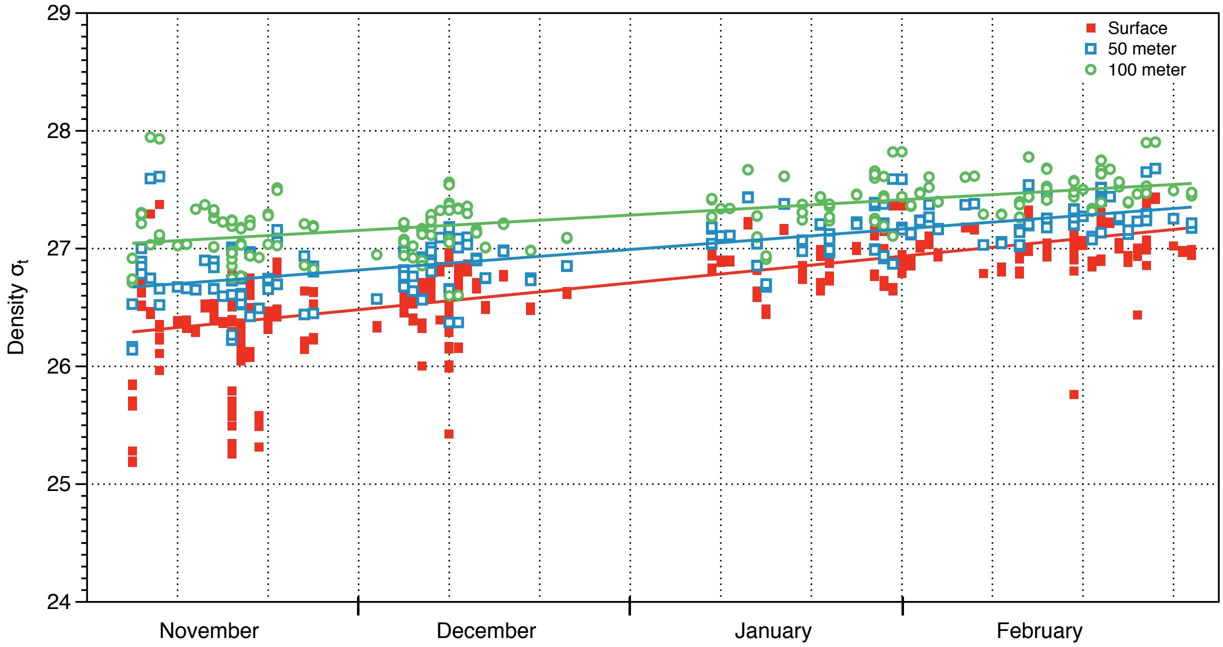


Figure 206: monthly variability of winter density (November – February) at station Outer Altafjorden

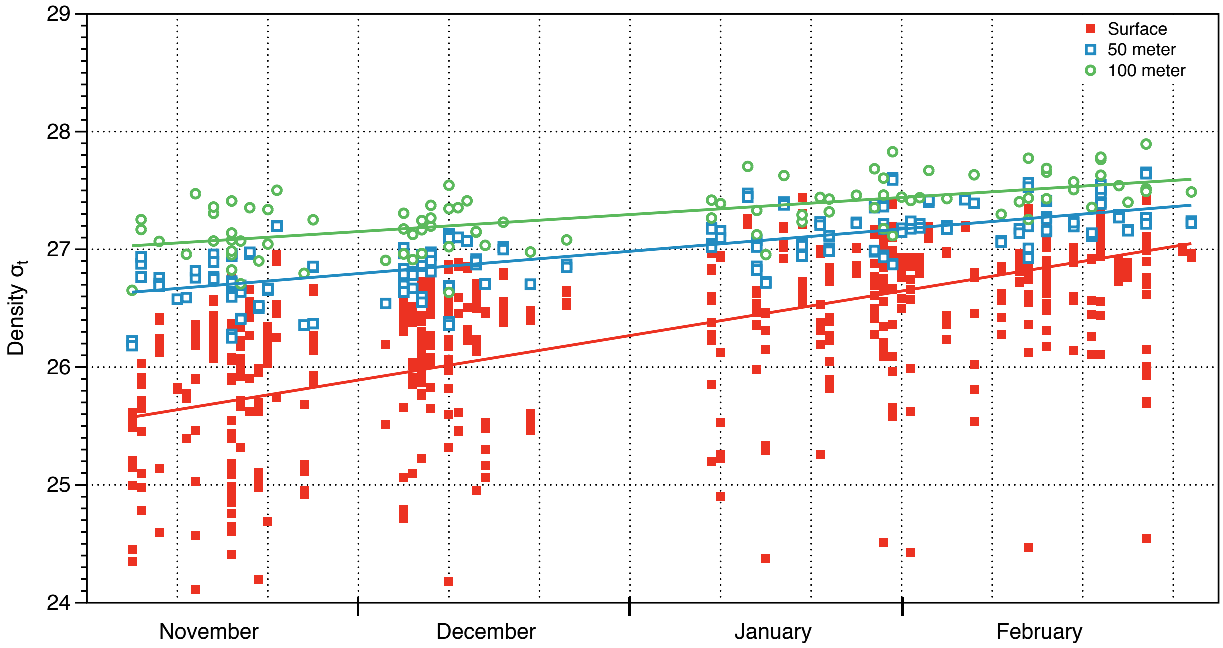


Figure 207: monthly variability of winter density (November – February) at station Inner Altafjorden

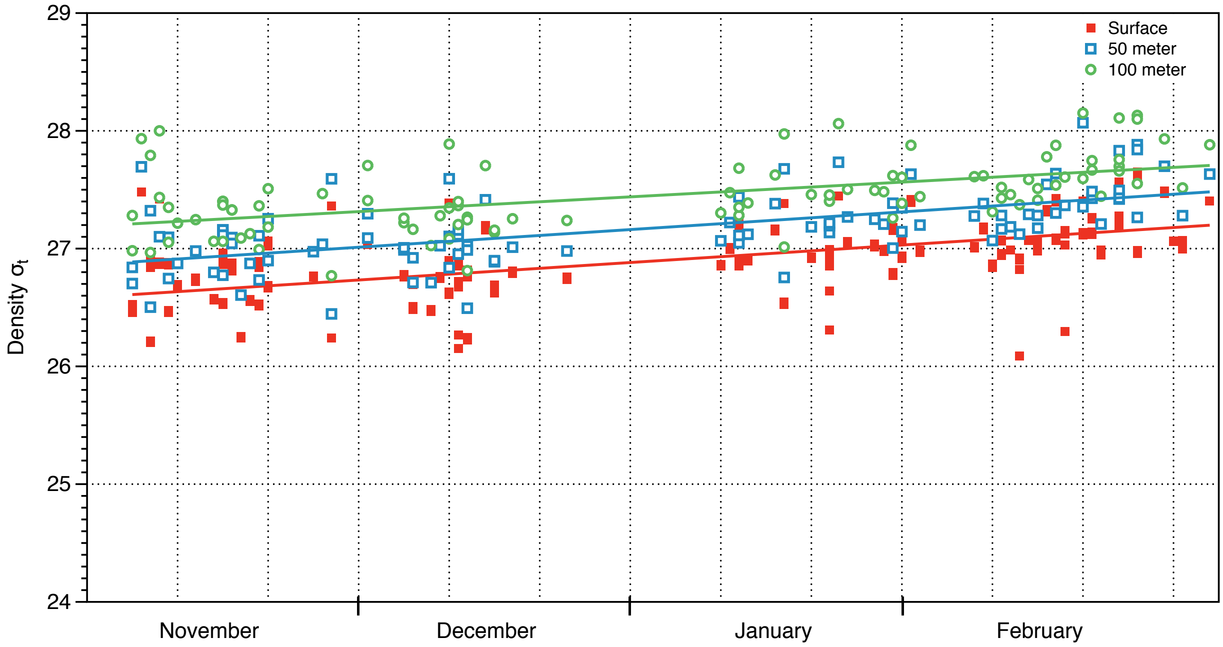


Figure 208: monthly variability of winter density (November – February) at station Refsbotn

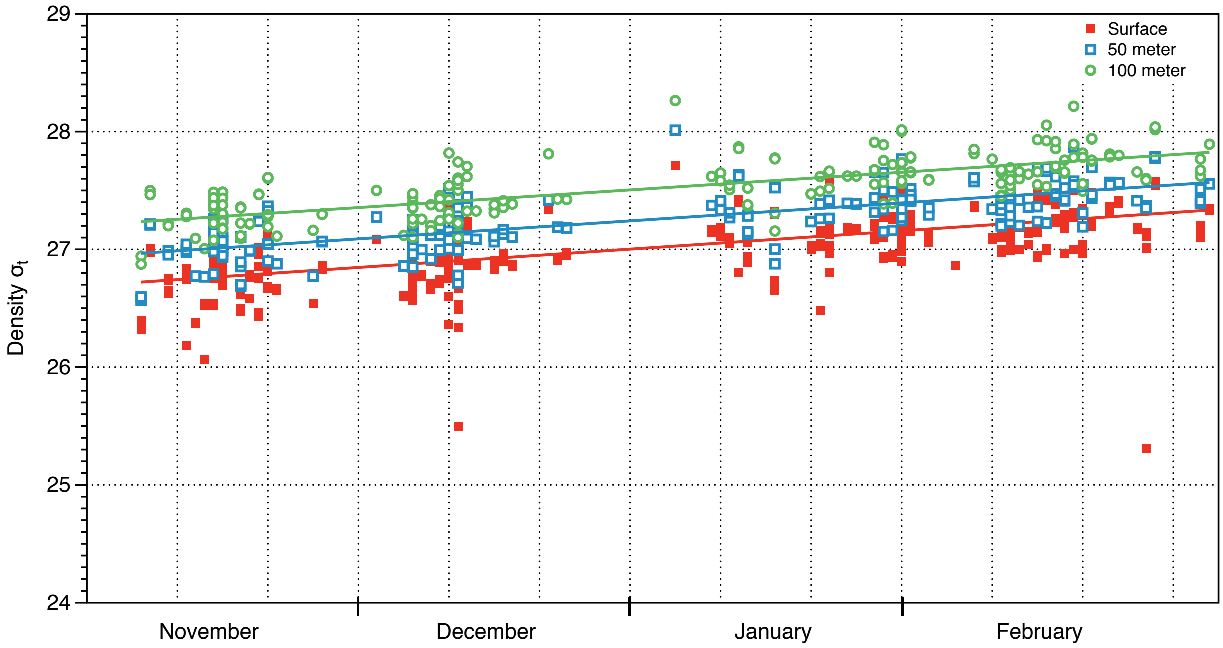


Figure 209: monthly variability of winter density (November – February) at station Outer Porsangerfjorden

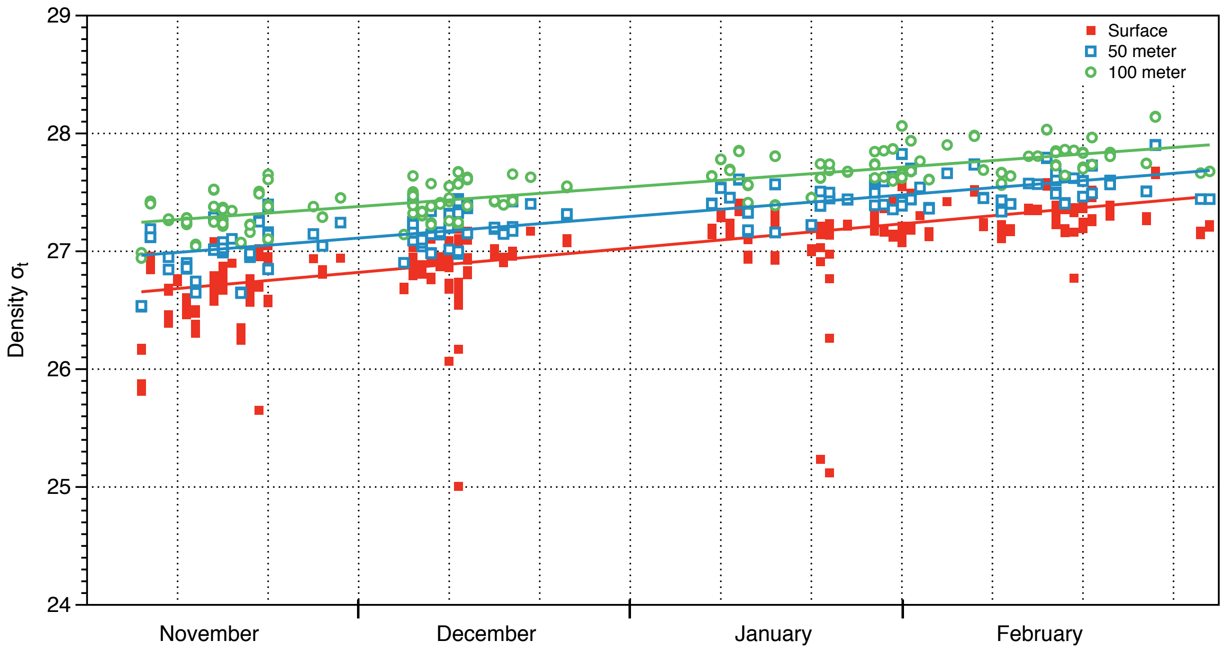


Figure 210: monthly variability of winter density (November – February) at station Inner Porsangerfjorden

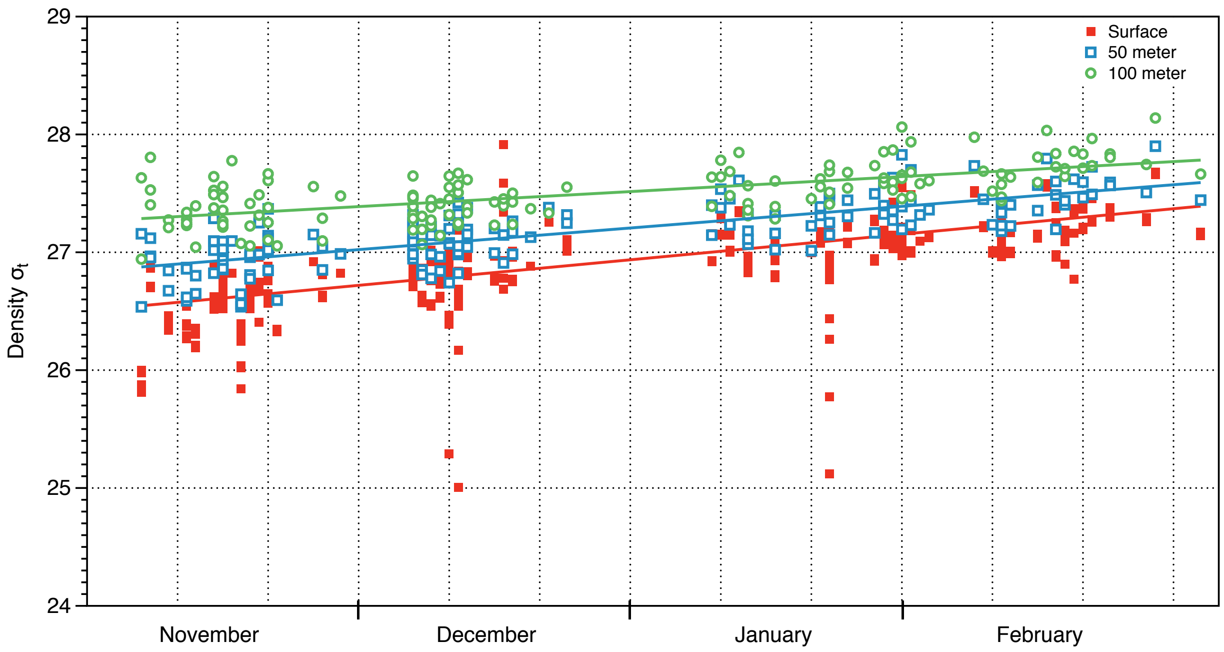


Figure 211: monthly variability of winter density (November – February) at station Østerbotn

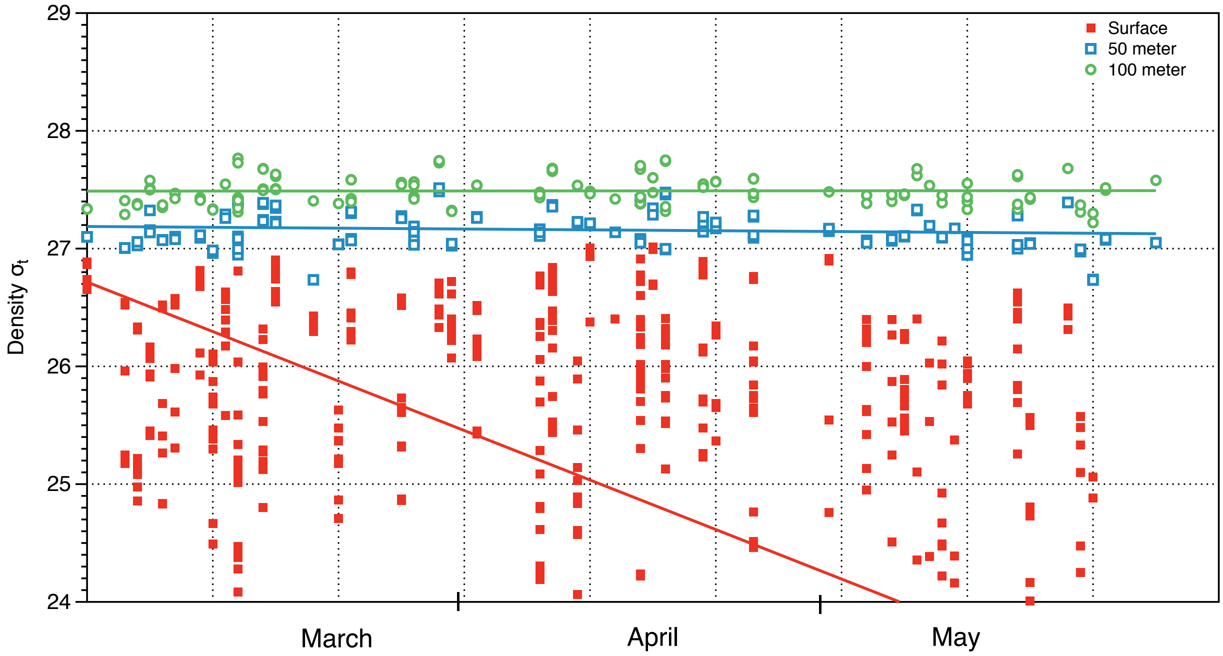


Figure 212: monthly variability of spring density (March – May) at station Inner Malangen

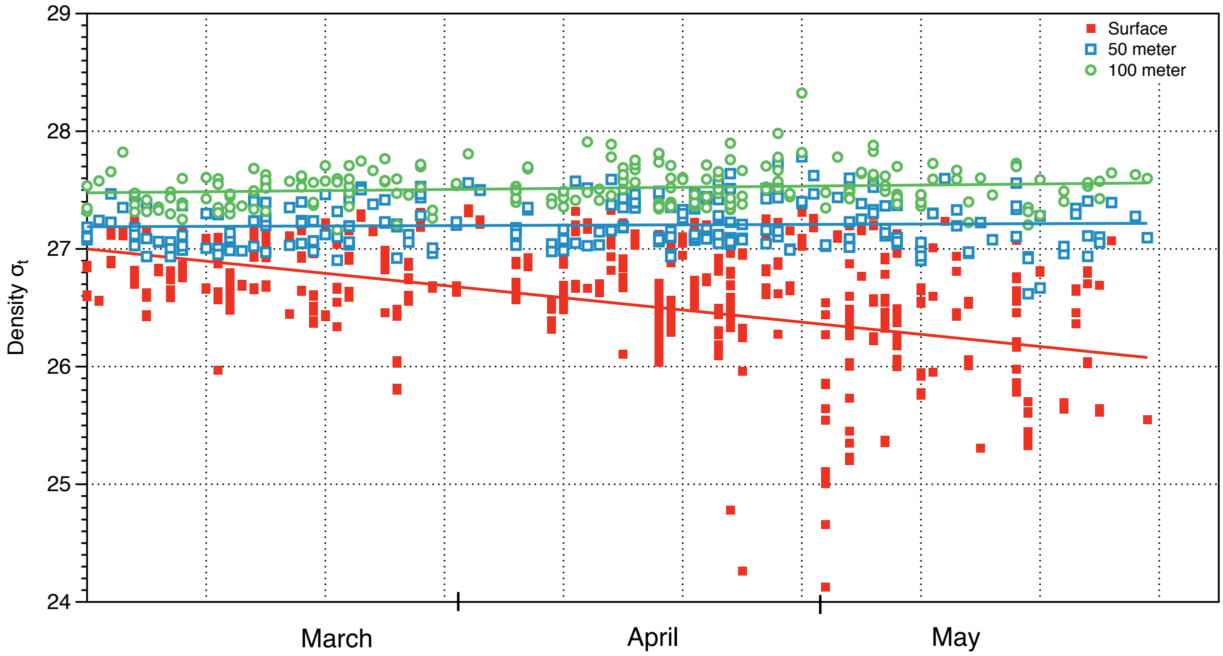


Figure 213: monthly variability of spring density (March – May) at station Outer Malangen

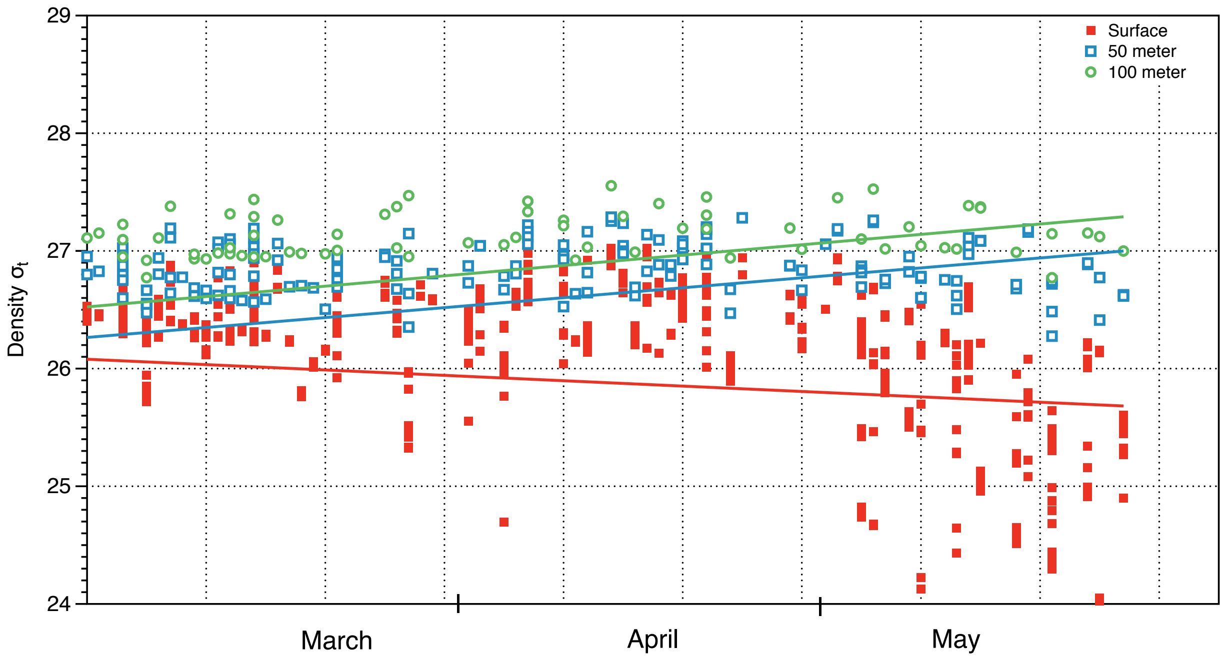


Figure 214: monthly variability of spring density (March – May) at station Outer Balsfjorden

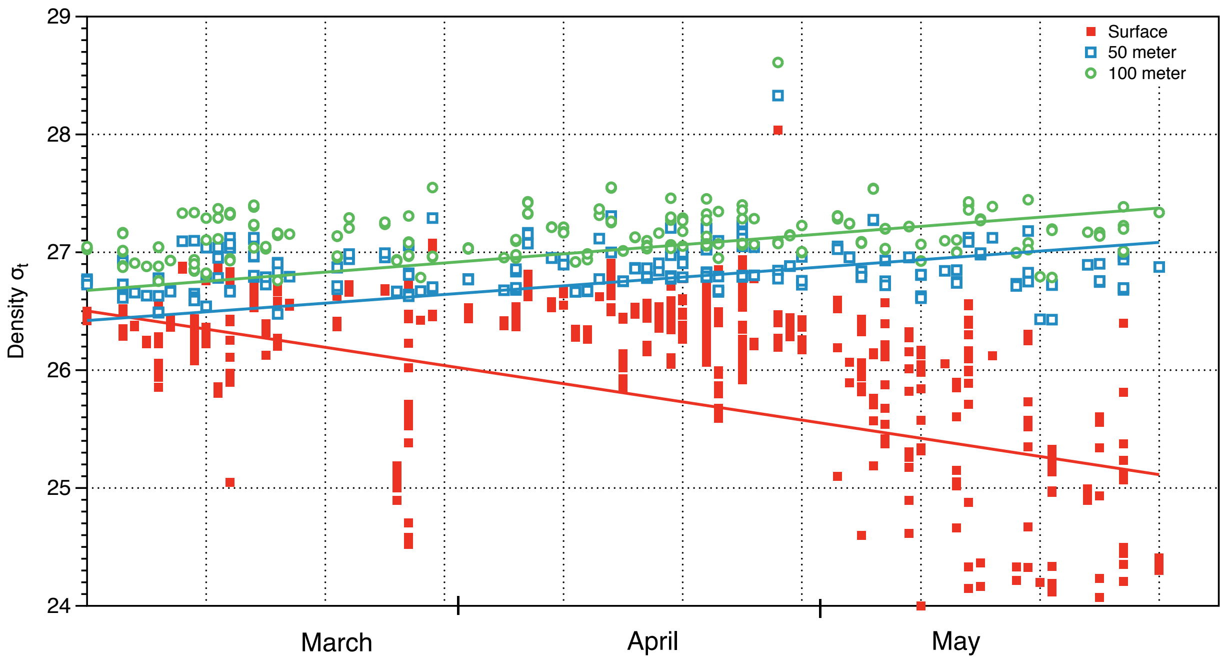


Figure 215: monthly variability of spring density (March – May) at station Inner Balsfjorden

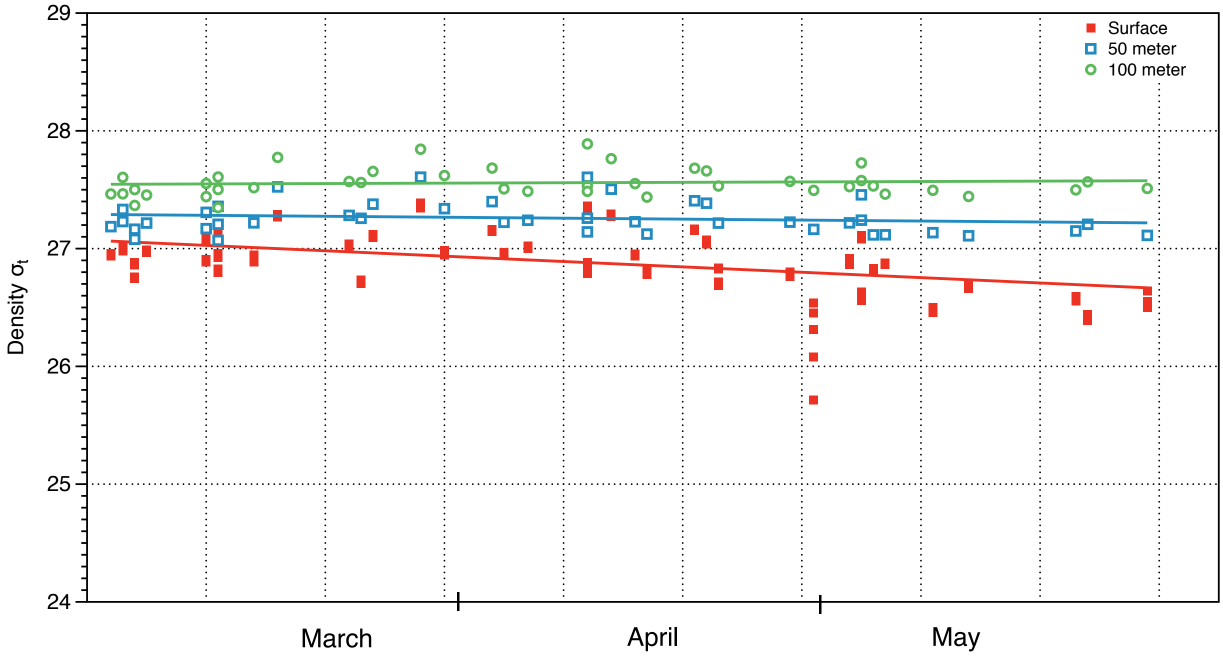


Figure 216: monthly variability of spring density (March – May) at station Kvalsund

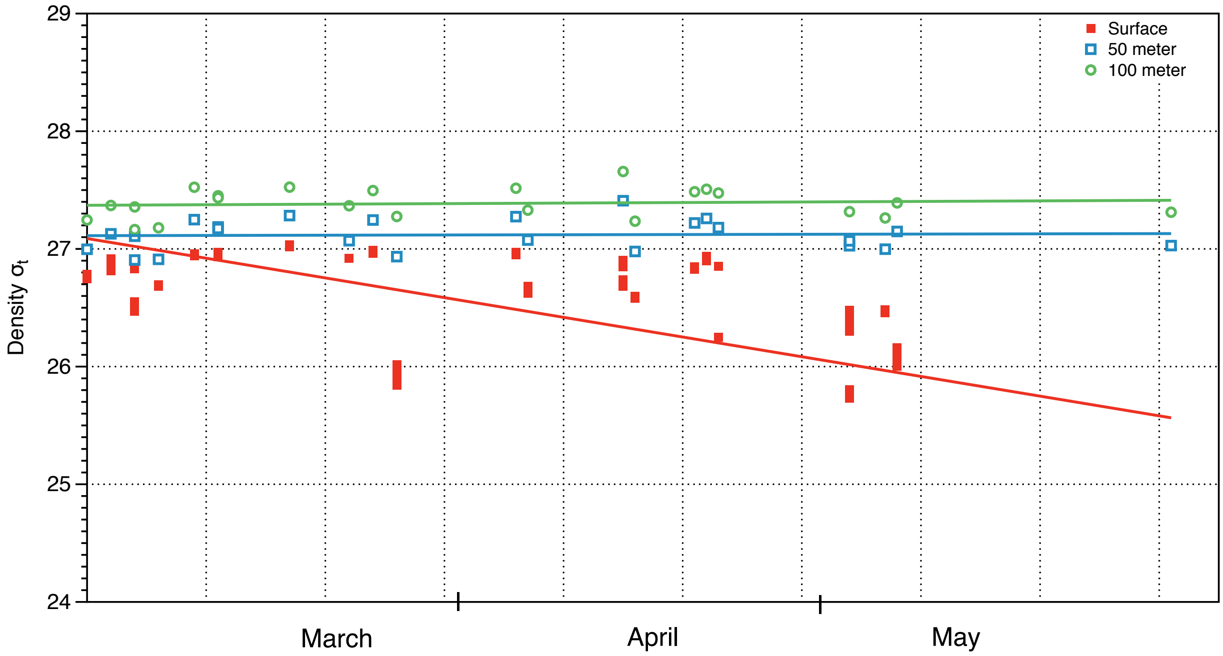


Figure 217: monthly variability of spring density (March – May) at station Sørfjord

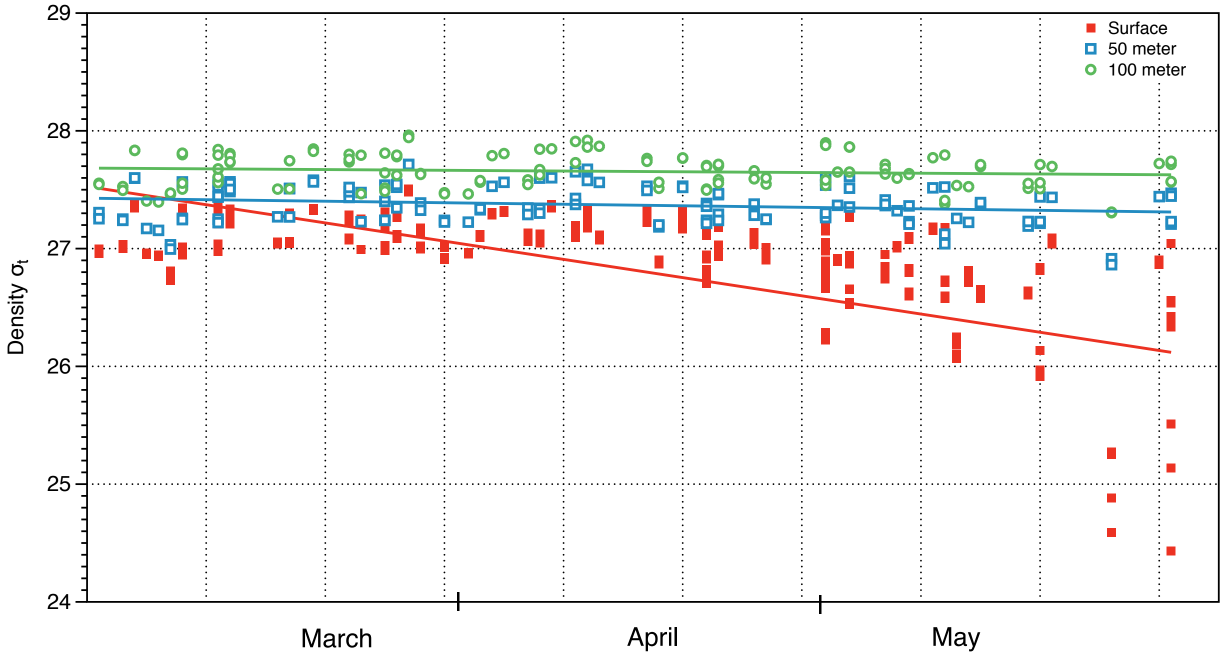


Figure 218: monthly variability of spring density (March – May) at station Outer Altafjorden

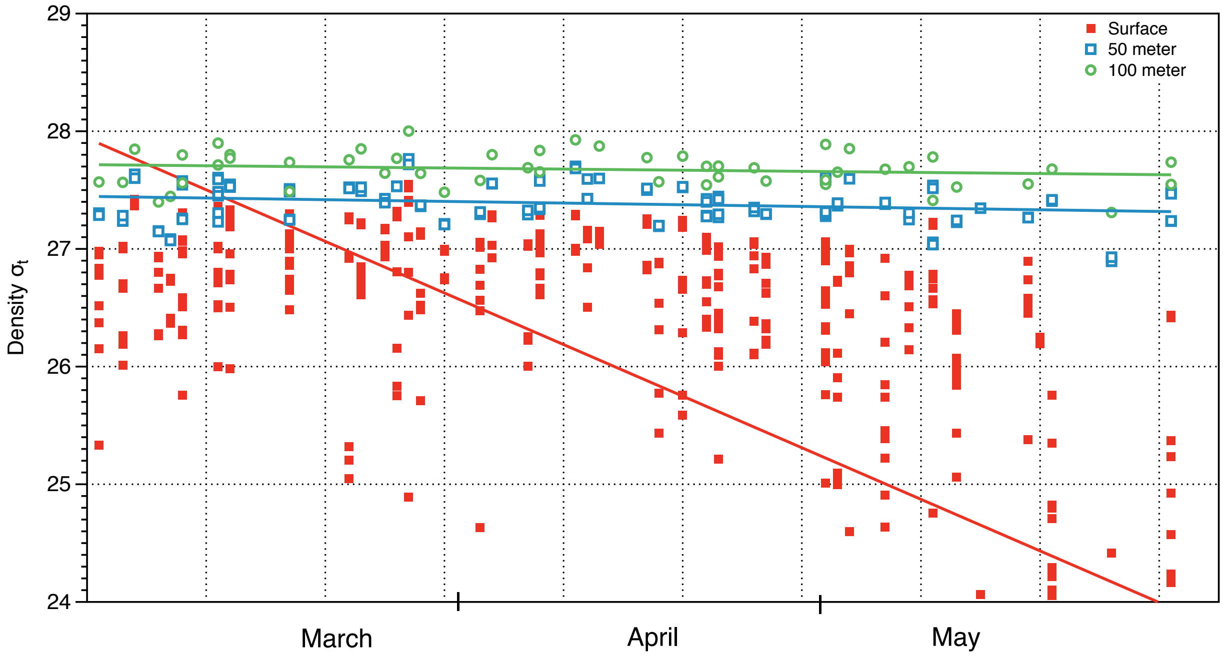


Figure 219: monthly variability of spring density (March – May) at station Inner Altafjorden

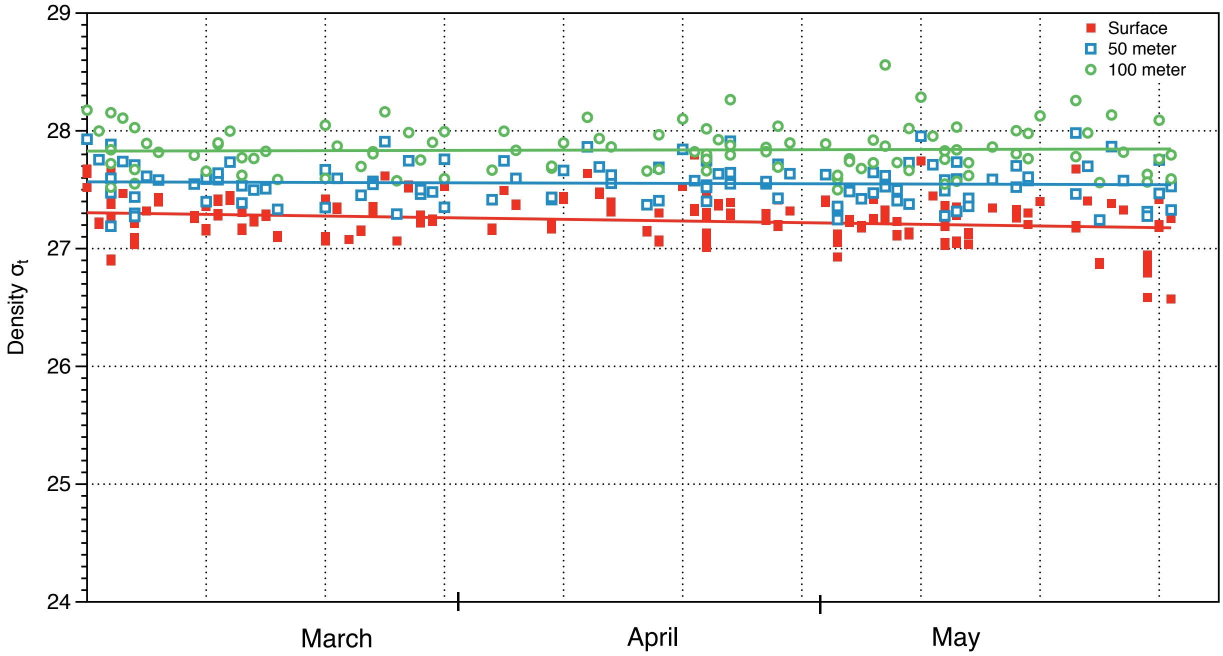


Figure 220: monthly variability of spring density (March – May) at station Refsbotn

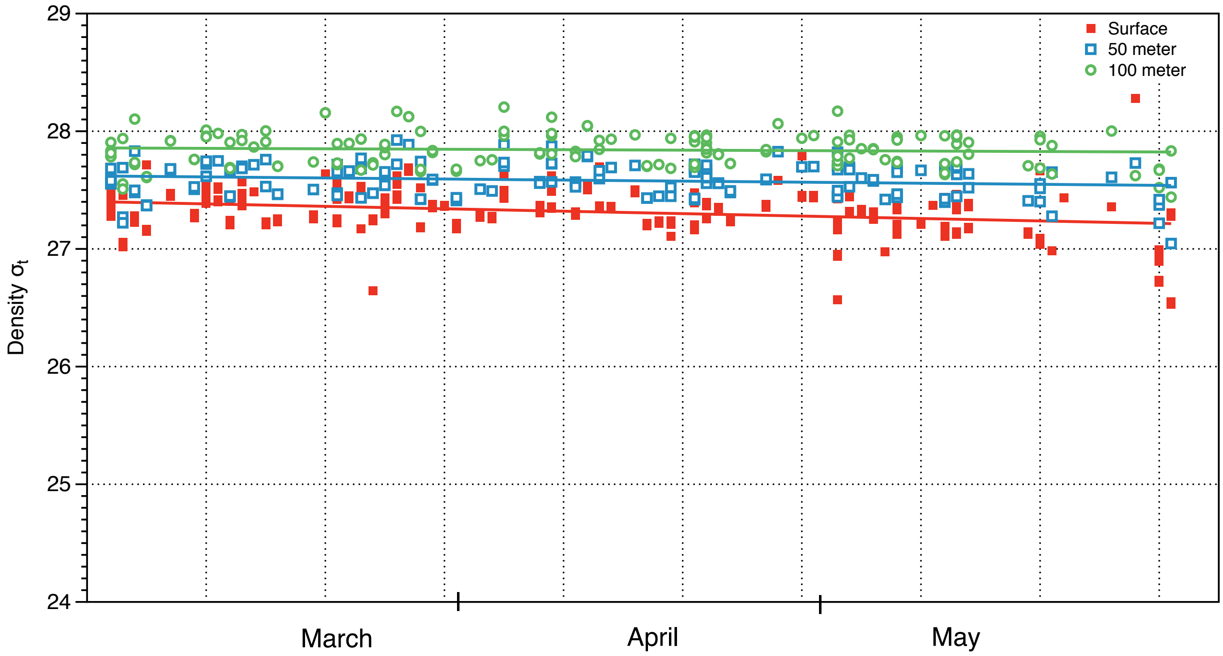


Figure 221: monthly variability of spring density (March – May) at station Outer Porsangerfjorden

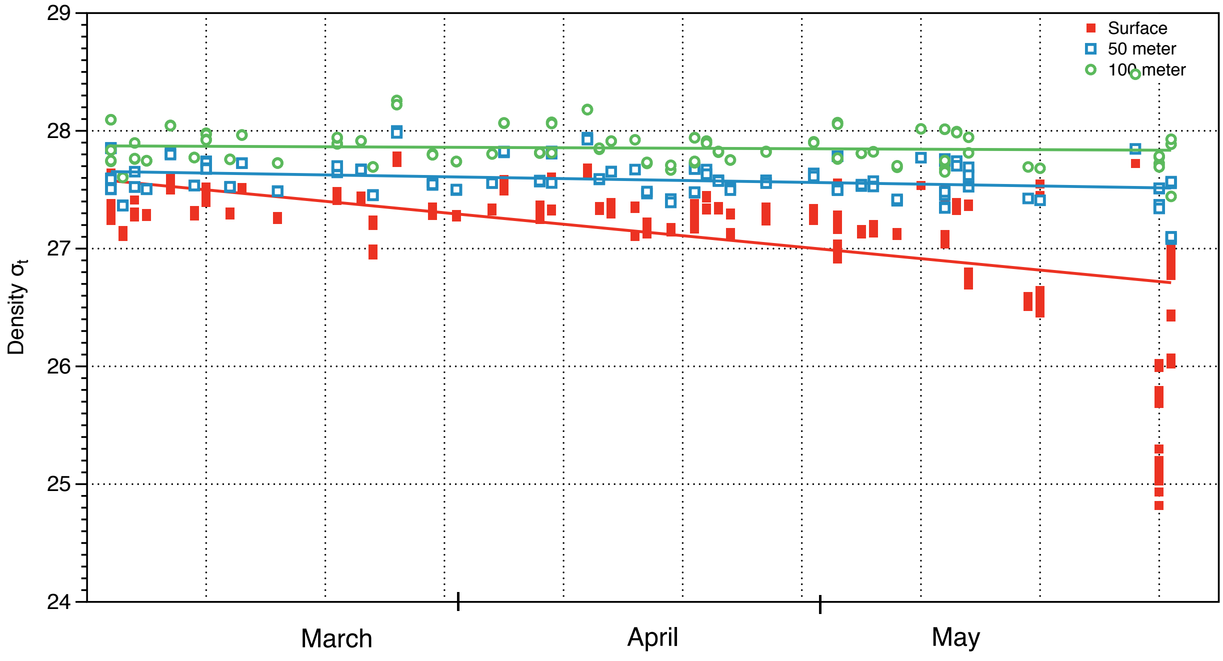


Figure 222: monthly variability of spring density (March – May) at station Inner Porsangerfjorden

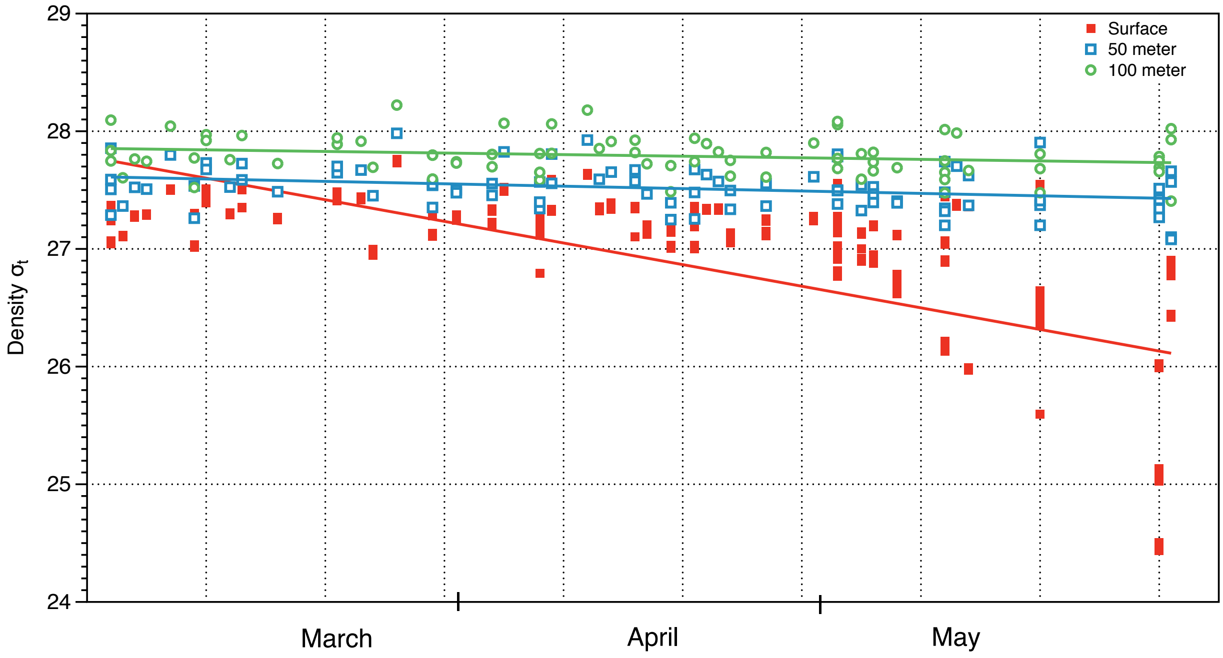


Figure 223: monthly variability of spring density (March – May) at station Østerbotn

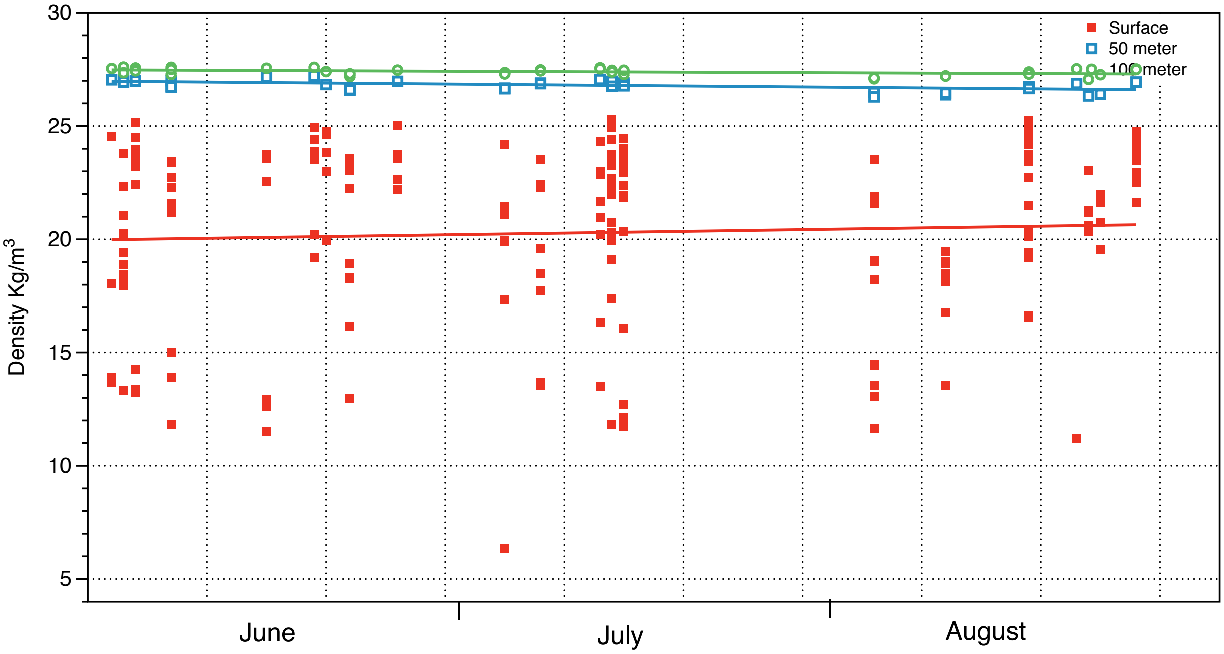


Figure 224: monthly variability of summer density (June – August) at station Inner Malangen

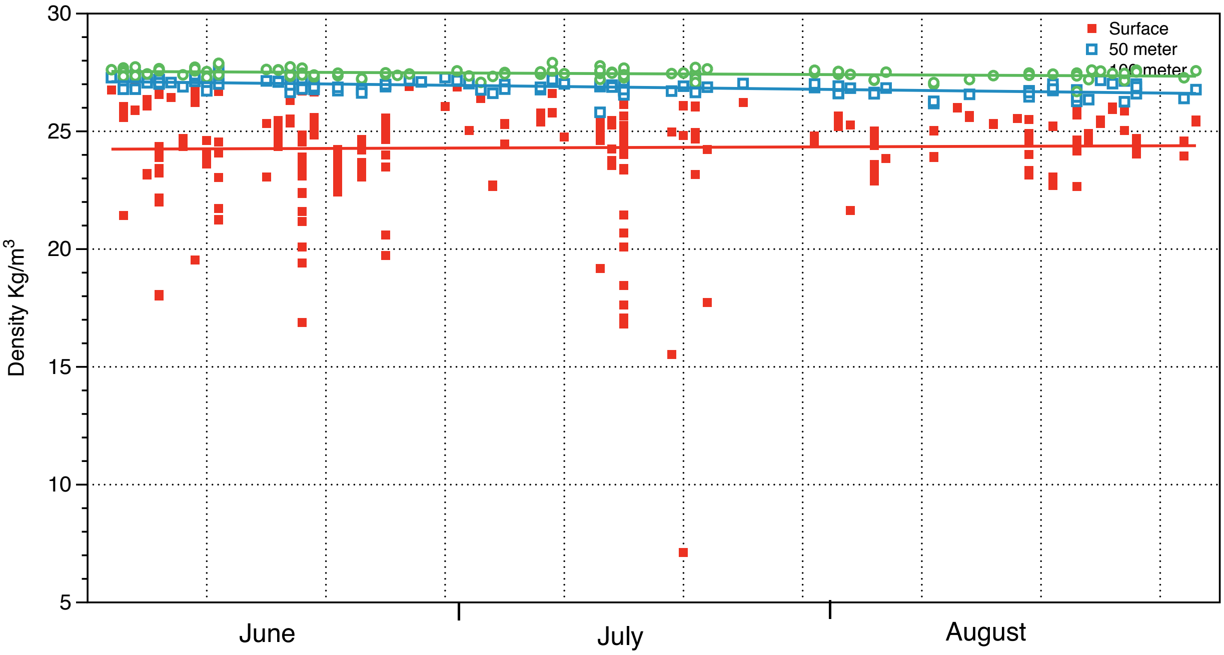


Figure 225: monthly variability of summer density (June – August) at station Outer Malangen

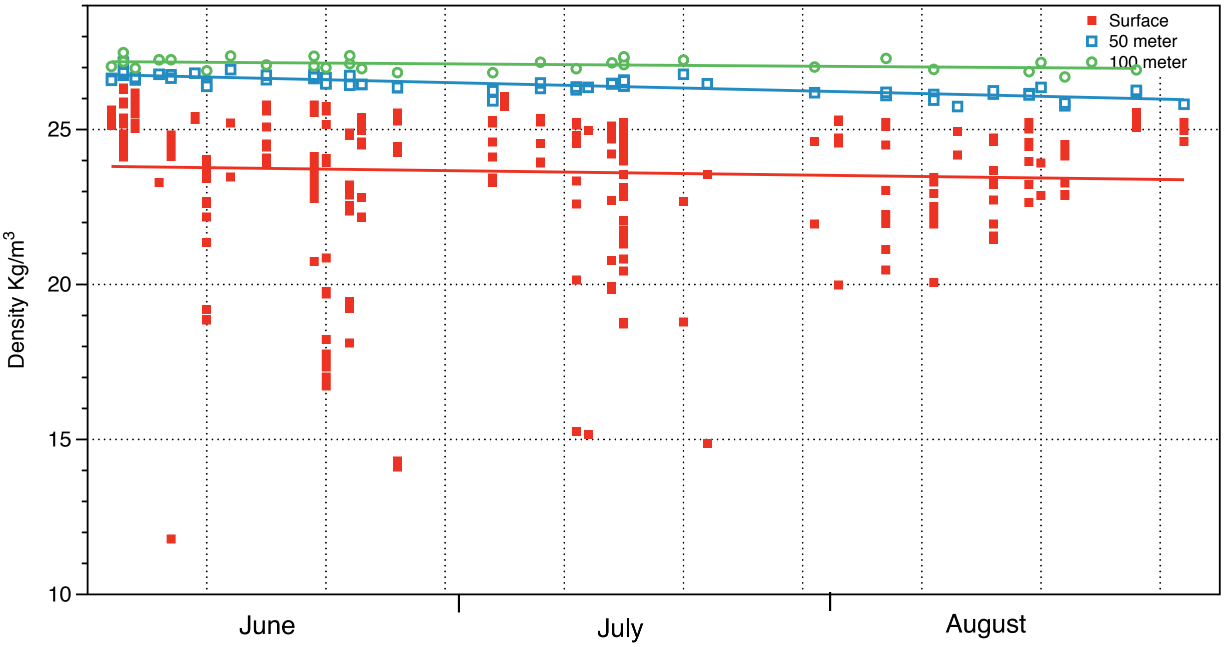


Figure 226: monthly variability of summer density (June – August) at station Outer Balsfjorden

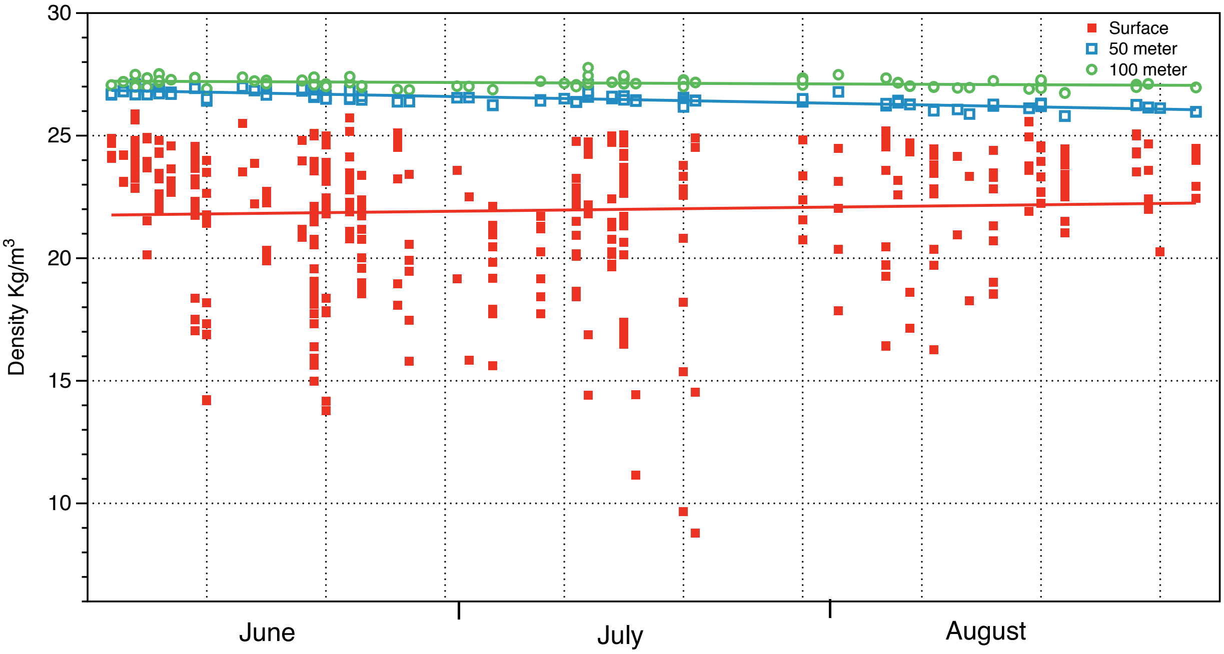


Figure 227: monthly variability of summer density (June – August) at station Inner Balsfjorden

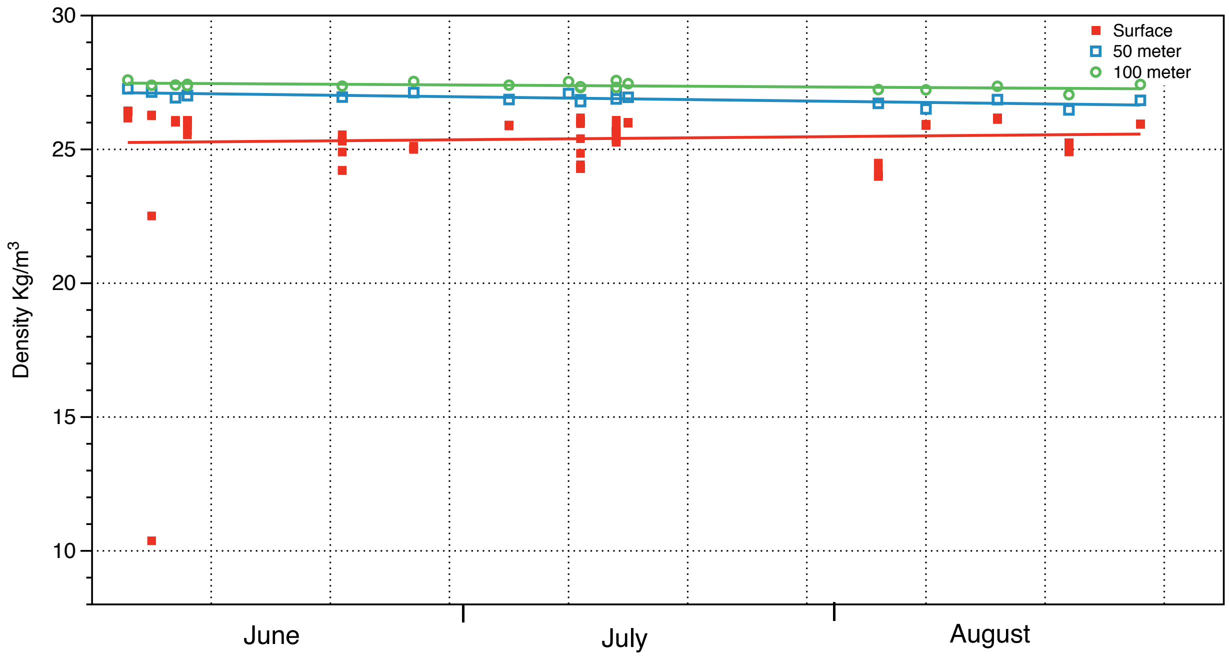


Figure 228: monthly variability of summer density (June – August) at station Kvalsund

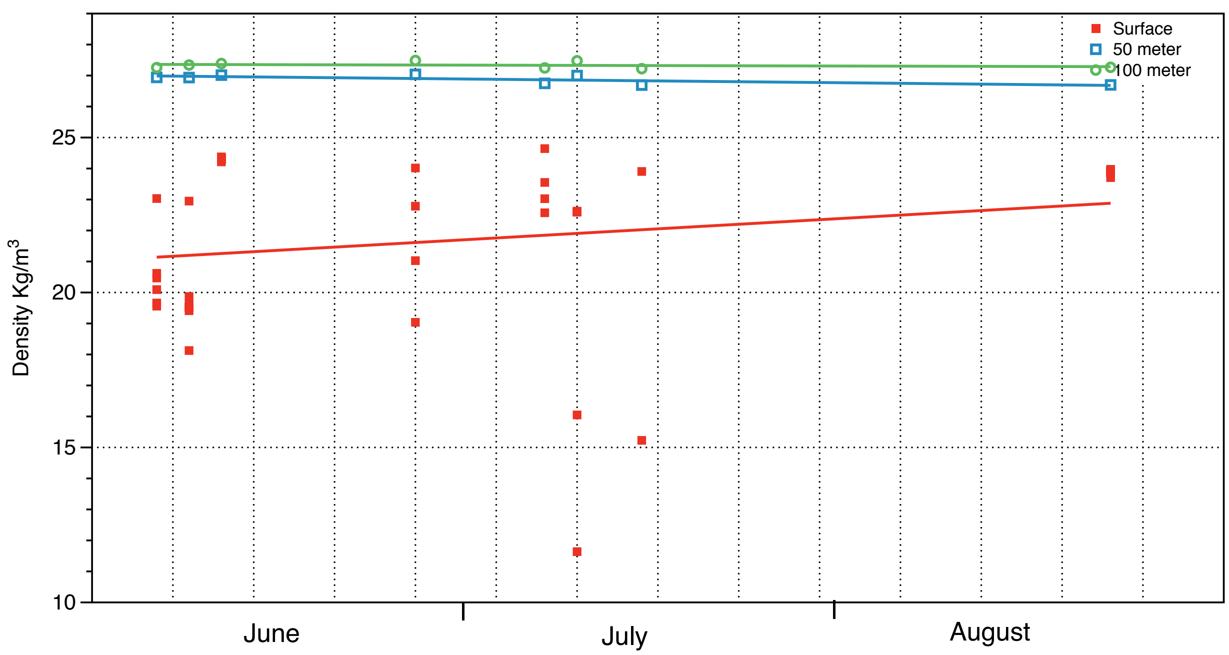


Figure 229: monthly variability of summer density (June – August) at station Sørfjord

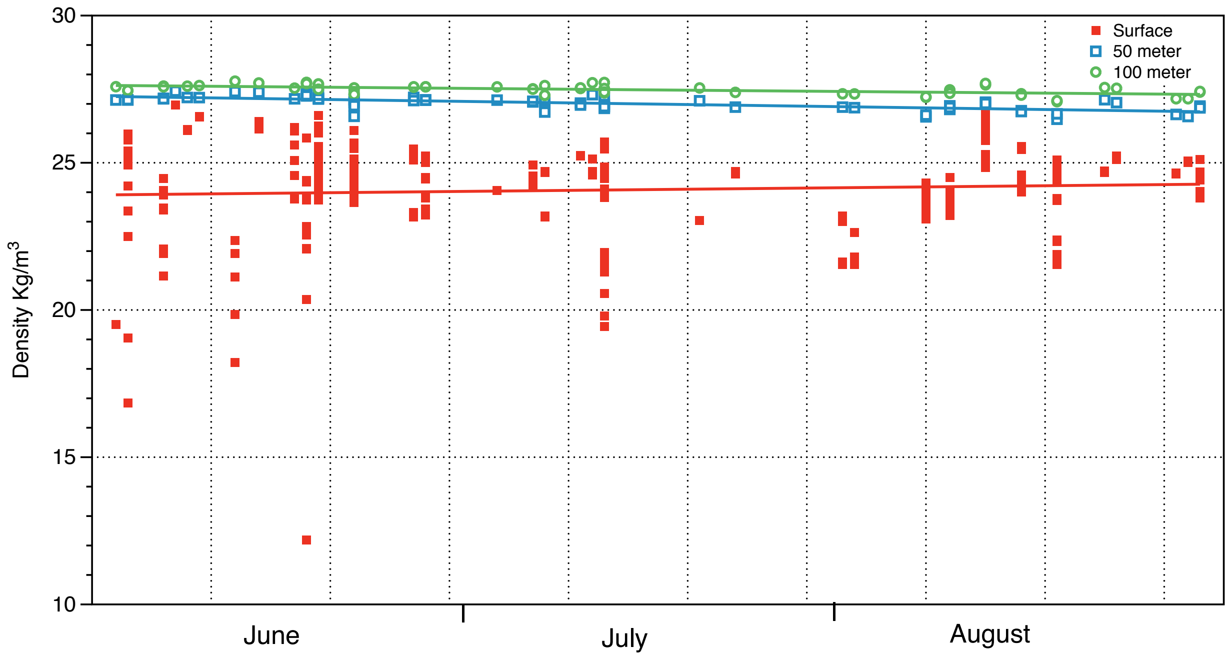


Figure 230: monthly variability of summer density (June – August) at station Outer Altafjorden

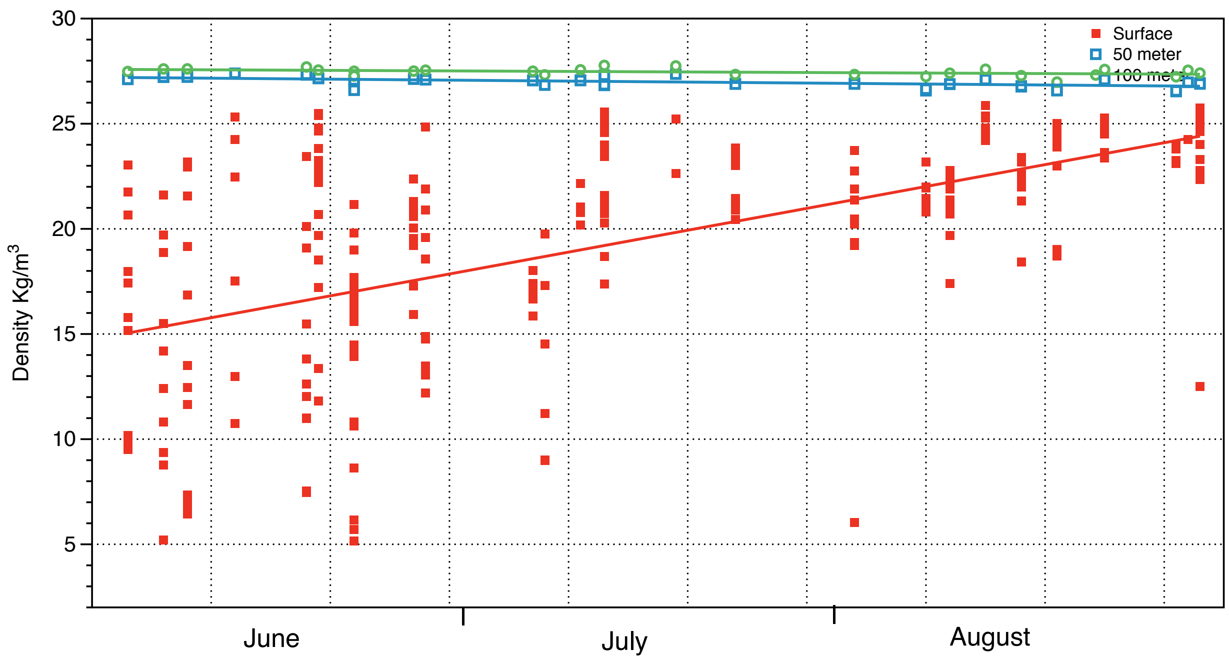


Figure 231: monthly variability of summer density (June – August) at station Inner Altafjorden

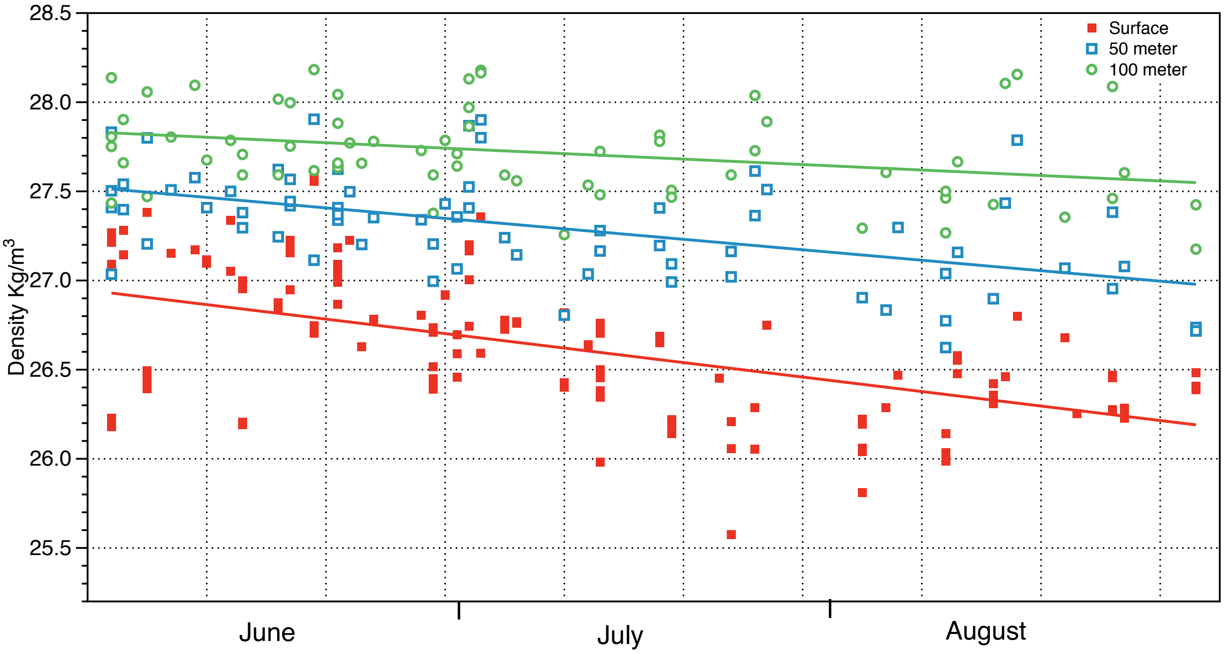


Figure 232: monthly variability of summer density (June – August) at station Refsbotn

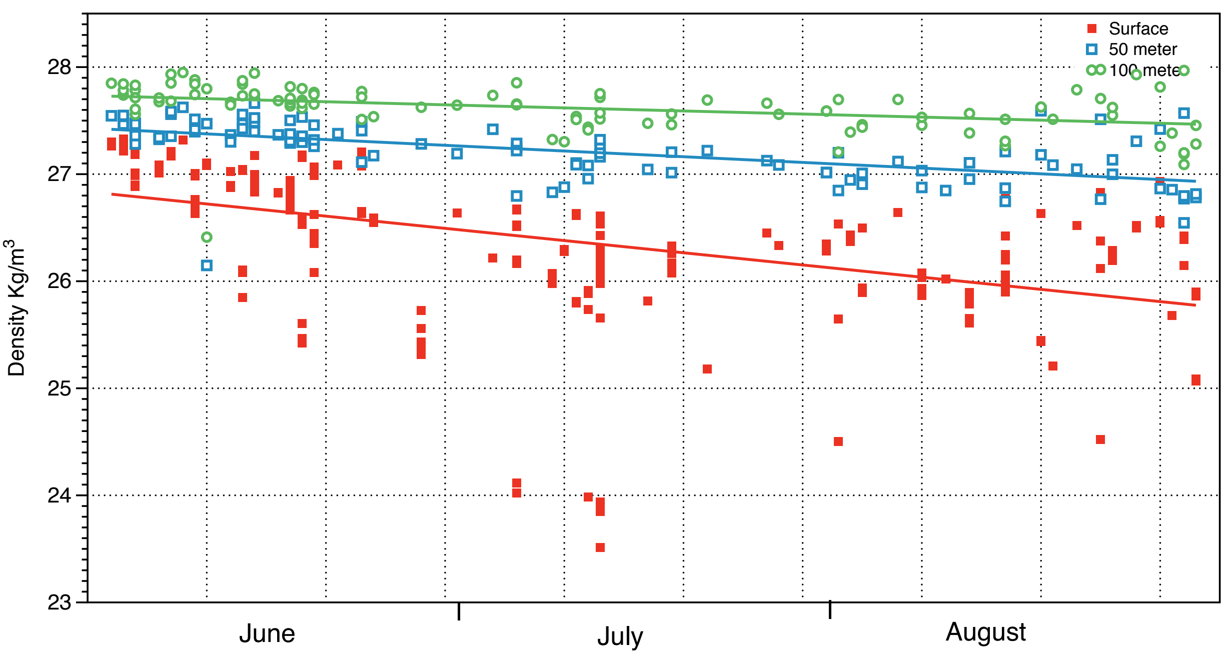


Figure 233: monthly variability of summer density (June – August) at station Outer Porsangerfjorden

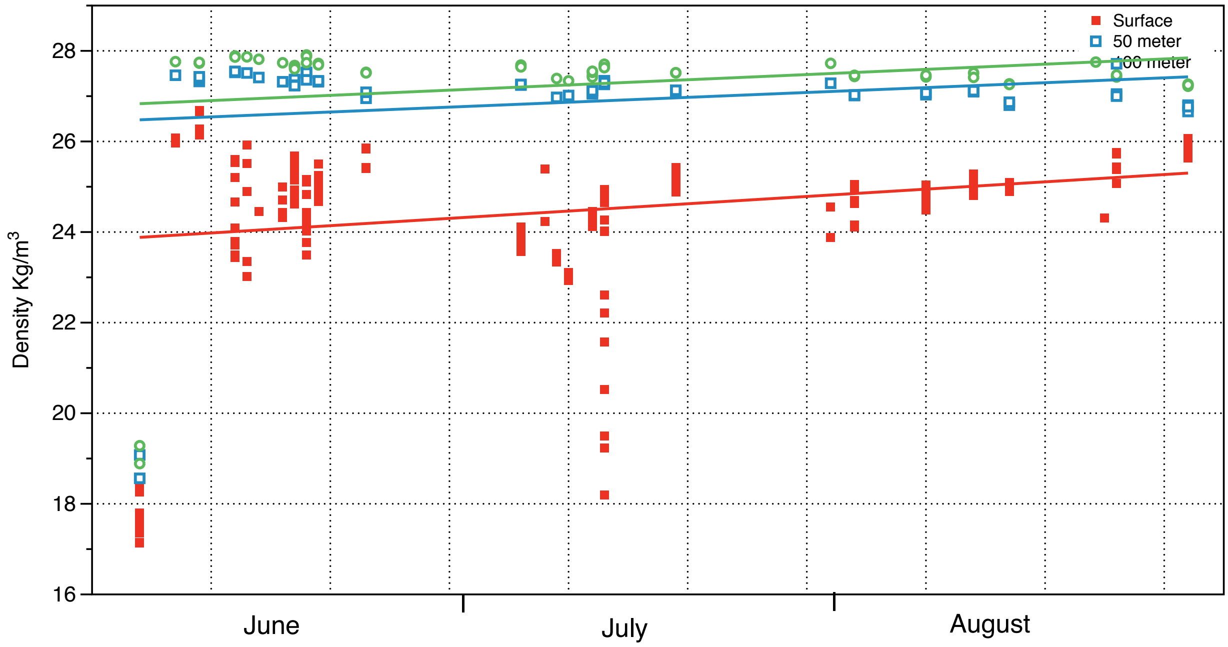


Figure 234: monthly variability of summer density (June – August) at station Inner Porsangerfjorden

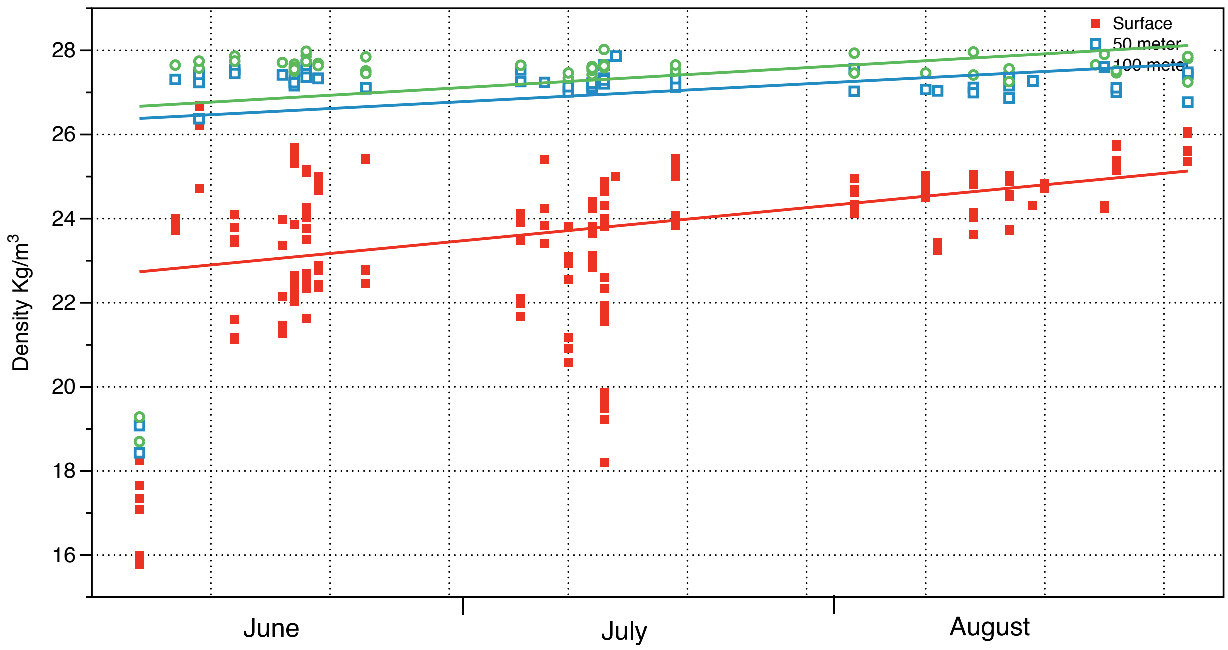


Figure 235: monthly variability of summer density (June – August) at station Østerbotn

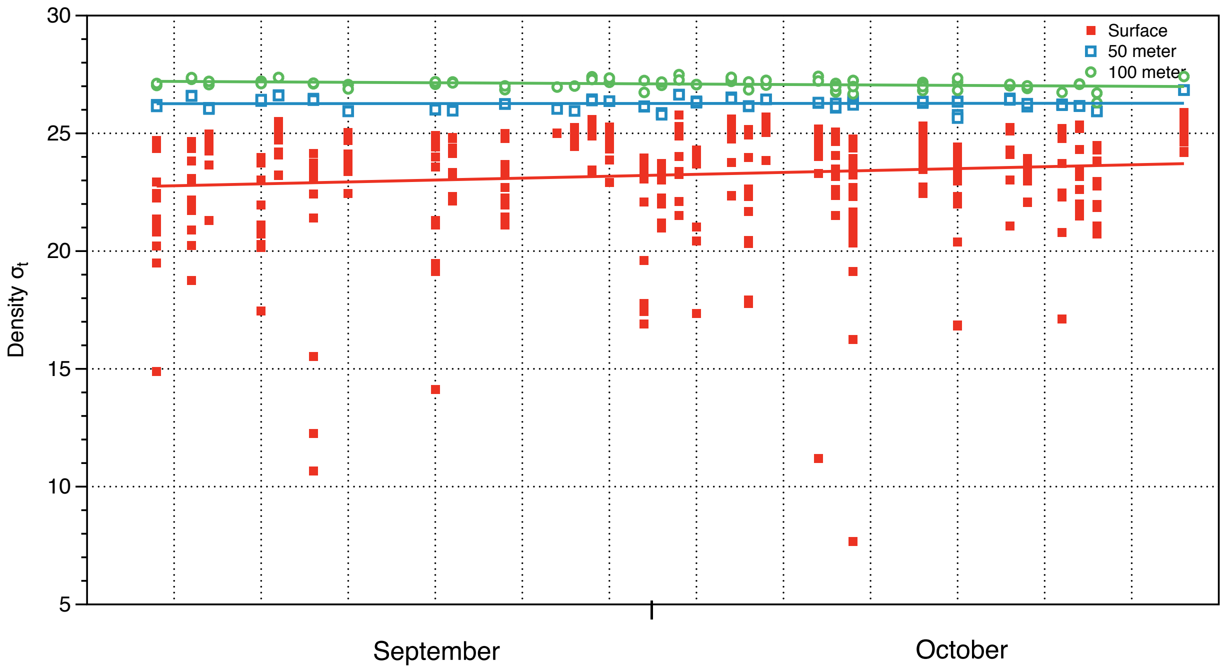


Figure 236: monthly variability of autumn density (September – October) at station Inner Malangen

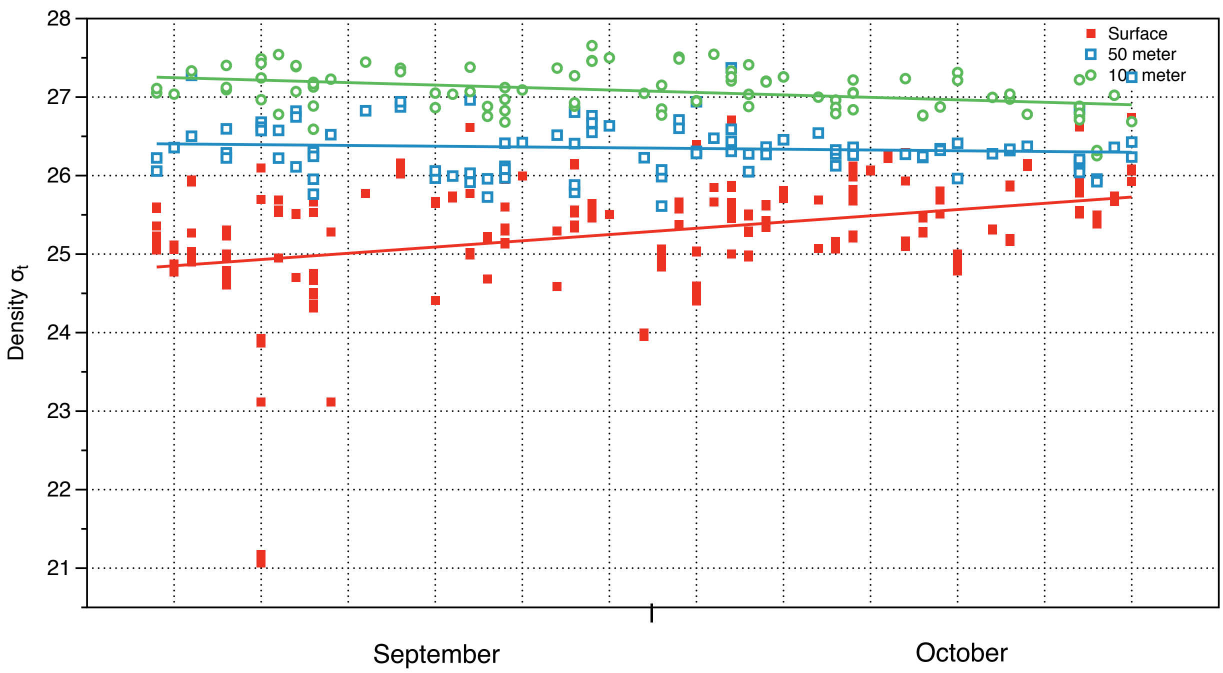


Figure 237: monthly variability of autumn density (September – October) at station Outer Malangen

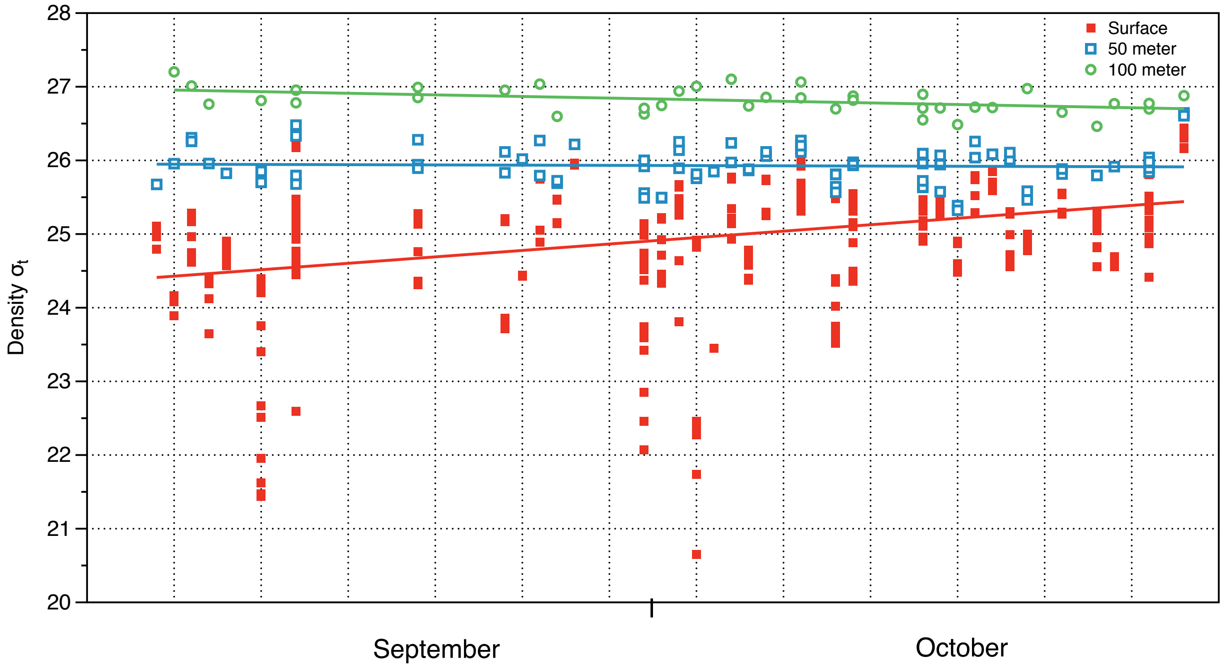


Figure 238: monthly variability of autumn density (September – October) at station Outer Balsfjorden

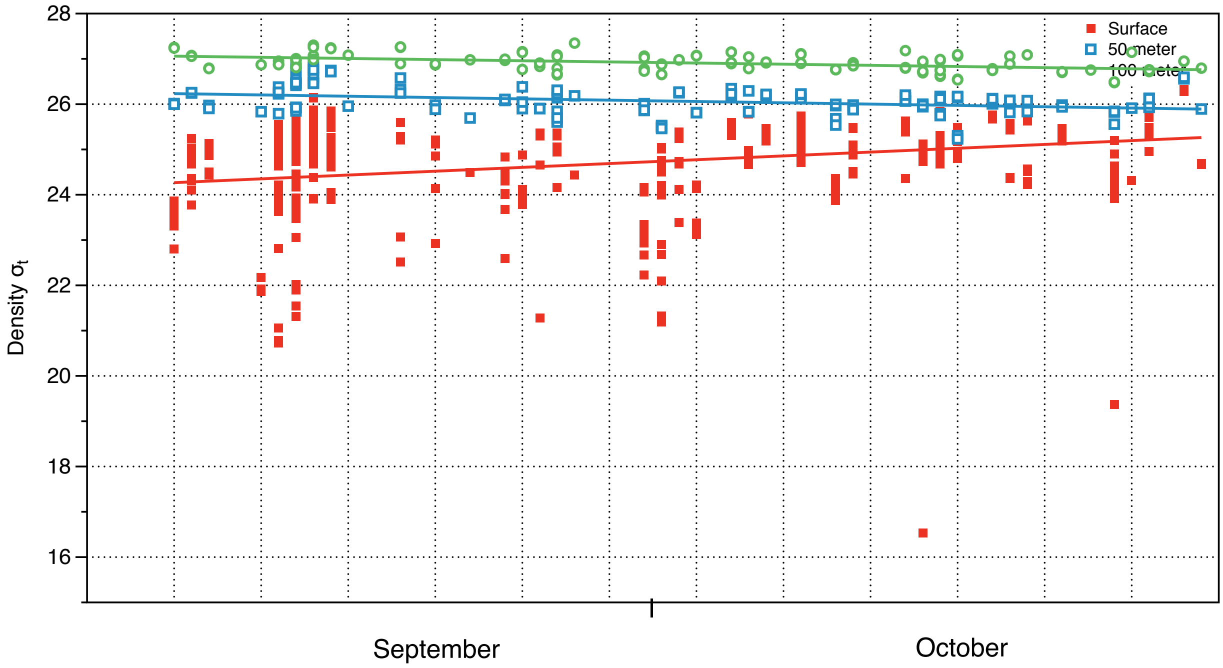


Figure 239: monthly variability of autumn density (September – October) at station Inner Balsfjorden

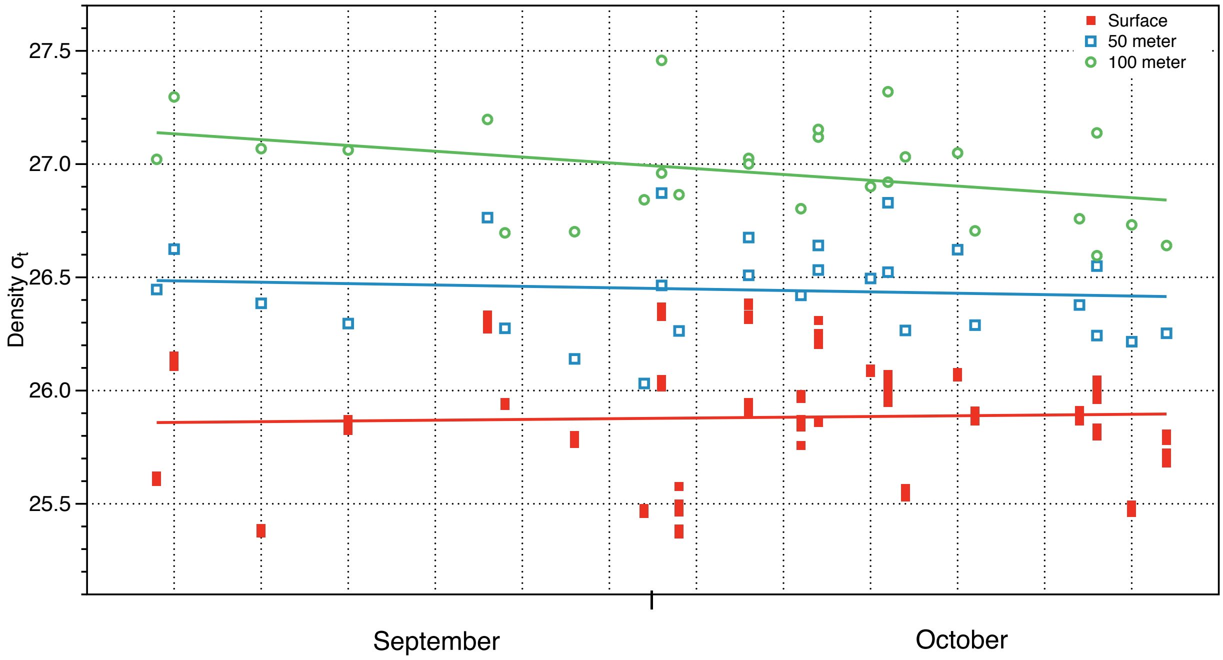


Figure 240: monthly variability of autumn density (September – October) at station Kvalsund

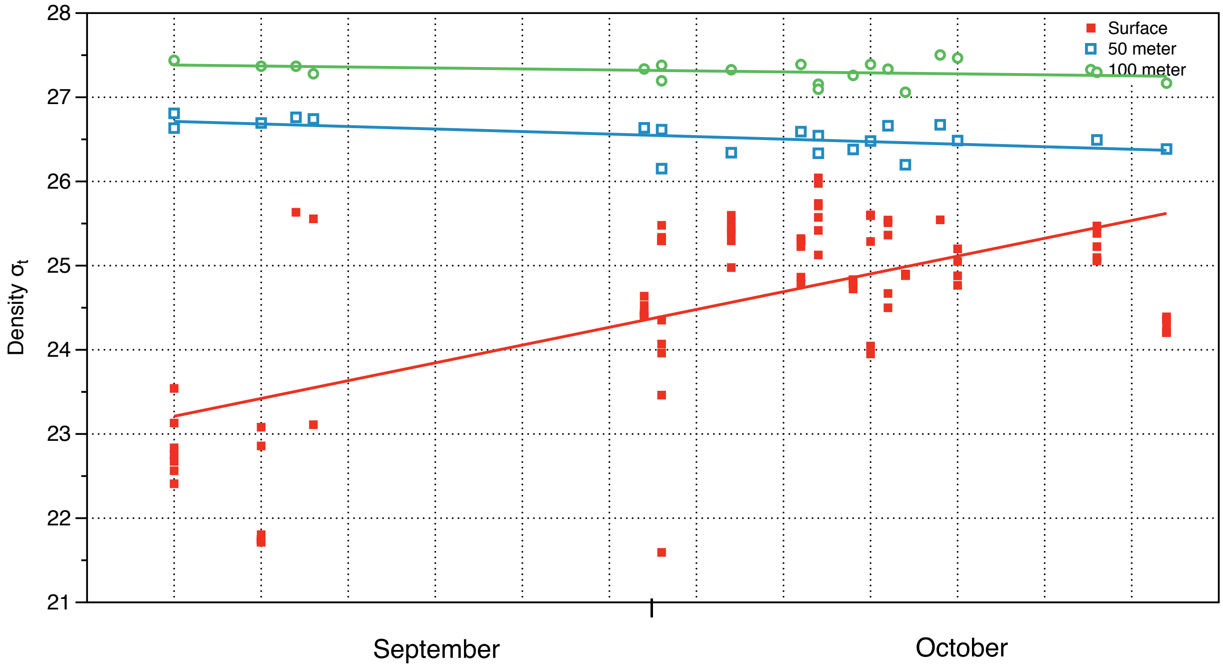


Figure 241: monthly variability of autumn density (September – October) at station Sørfjord

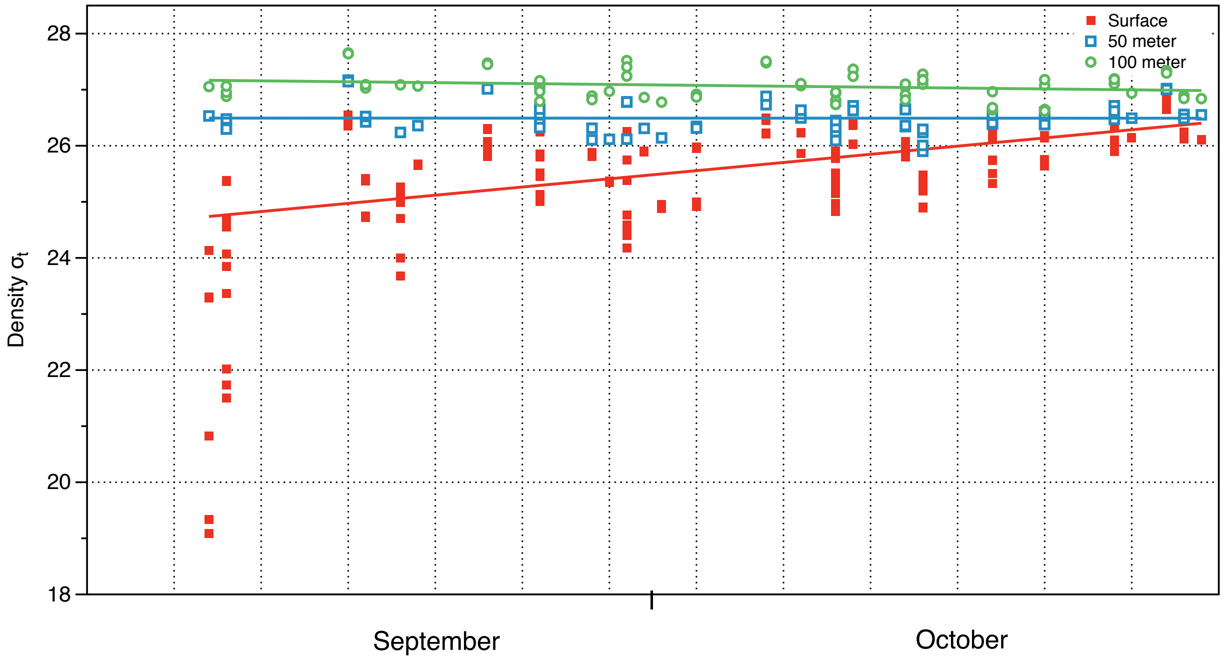


Figure 242: monthly variability of autumn density (September – October) at station Outer Altafjorden

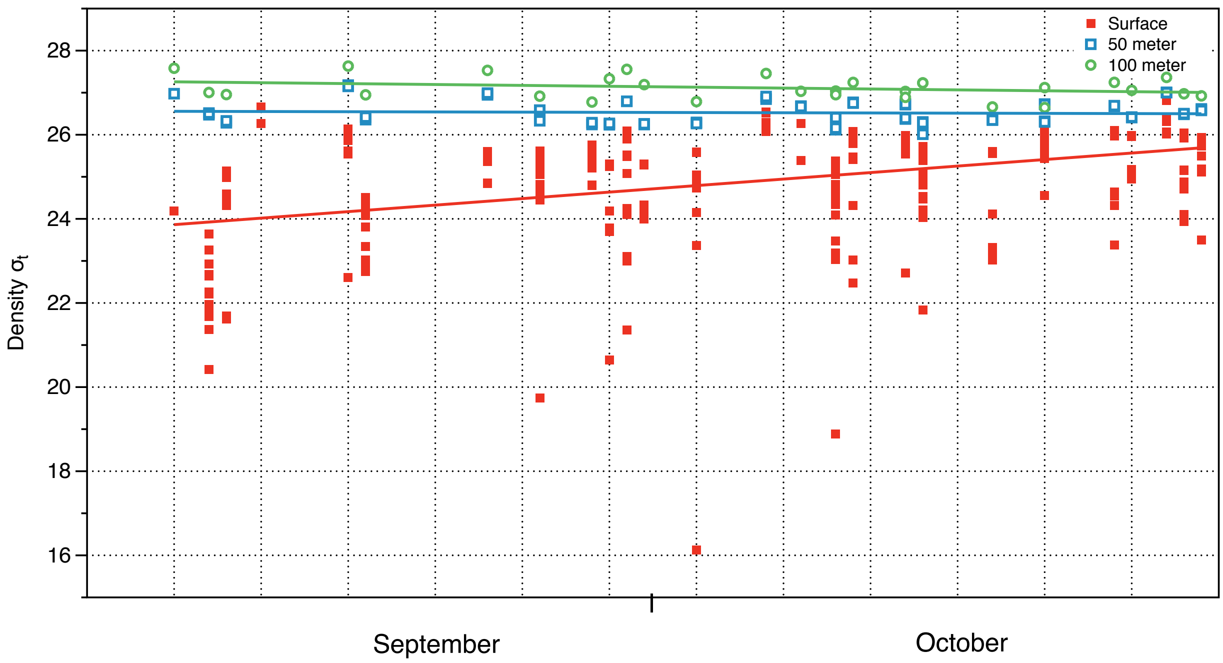


Figure 243: monthly variability of autumn density (September – October) at station Inner Altafjorden

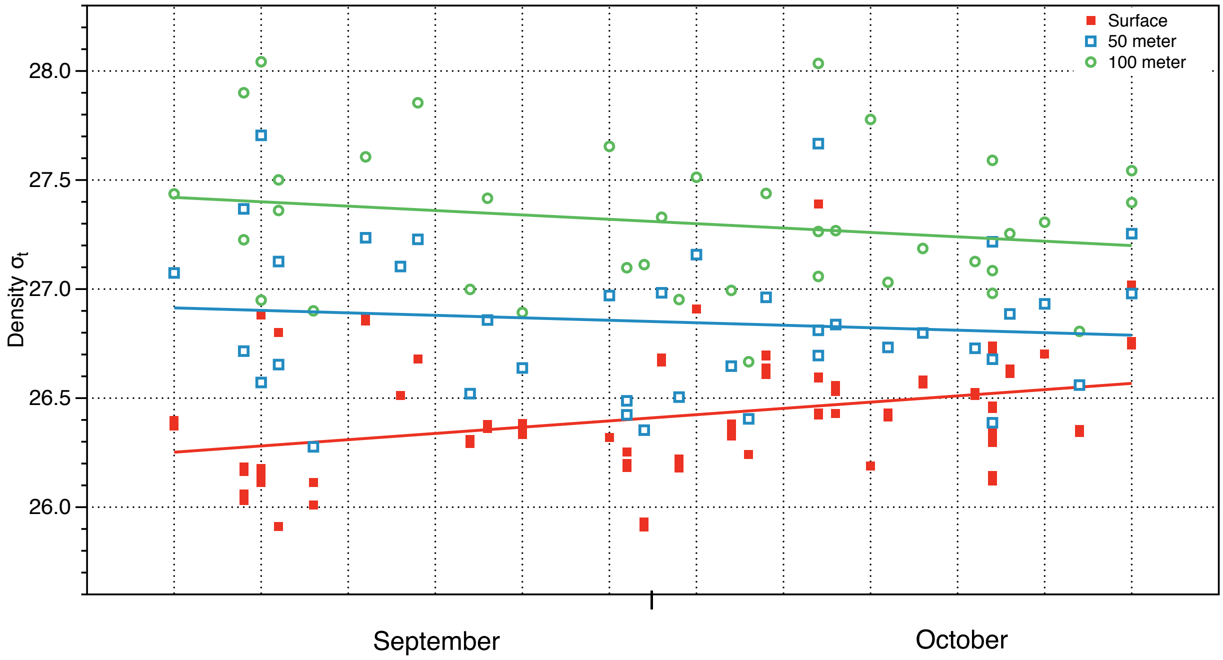


Figure 244: monthly variability of autumn density (September – October) at station Refsbotn

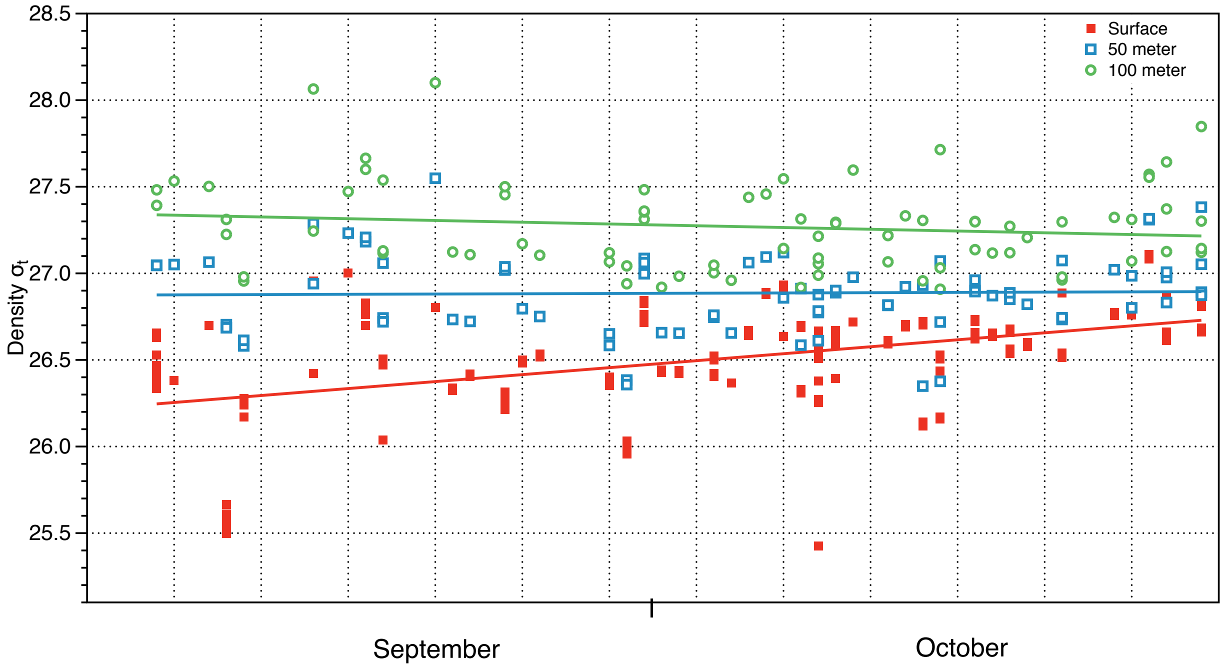


Figure 245: monthly variability of autumn density (September – October) at station Outer Porsangerfjorden

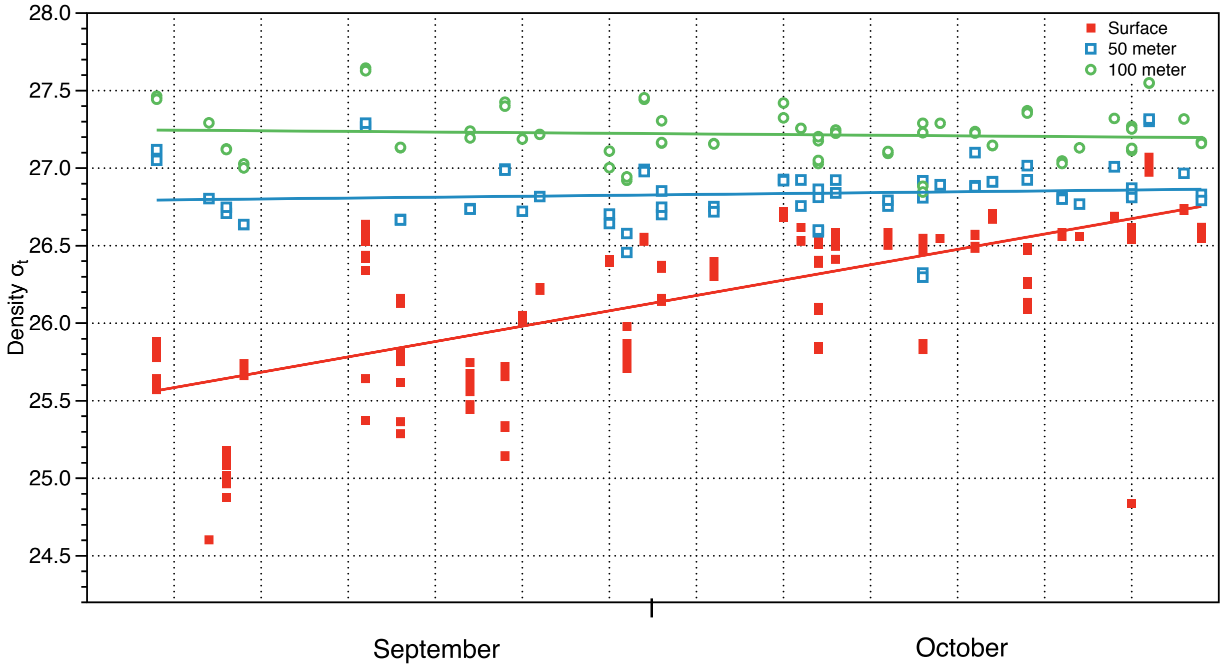


Figure 246: monthly variability of autumn density (September – October) at station Inner Porsangerfjorden

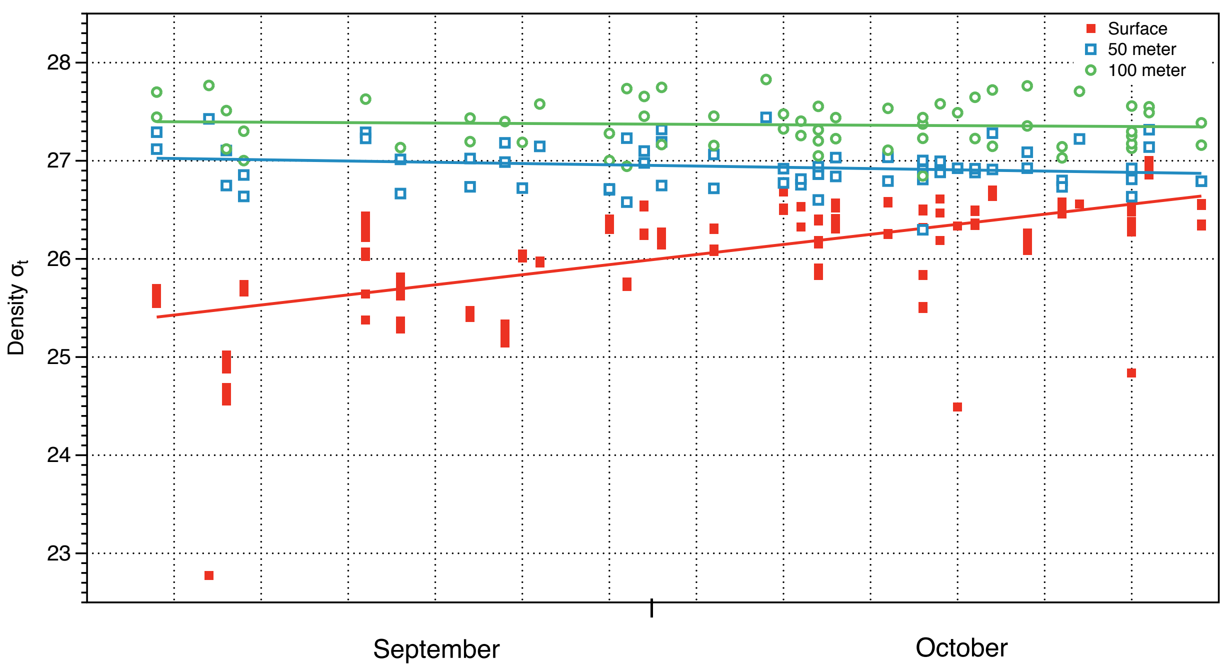


Figure 247: monthly variability of autumn density (September – October) at station Østerbotn

A.4 INTERANNUAL VARIABILITY IN SEASONAL TEMPERATURE

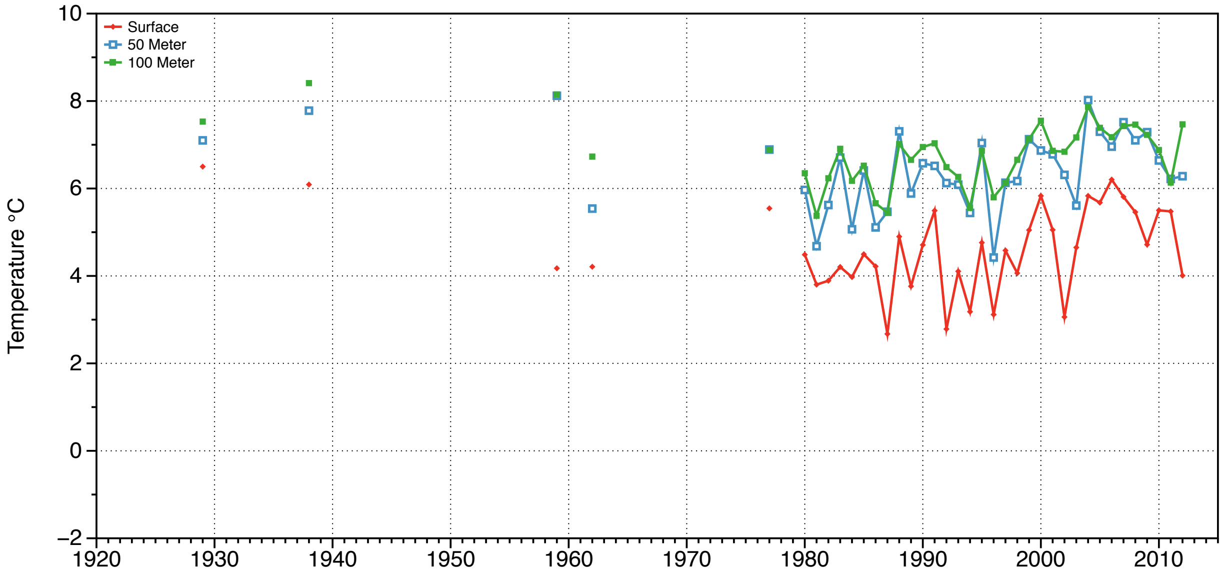


Figure 248: Interannual variability of winter temperatures (November – February) at station Inner Malangen

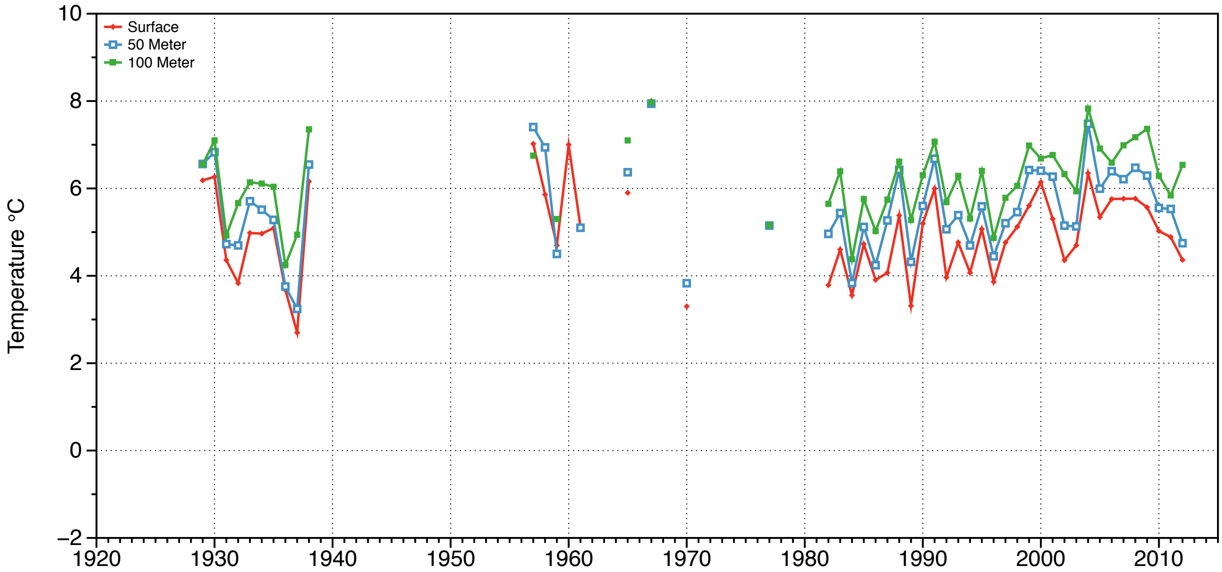


Figure 249: Interannual variability of winter temperatures (November – February) at station Outer Malangen

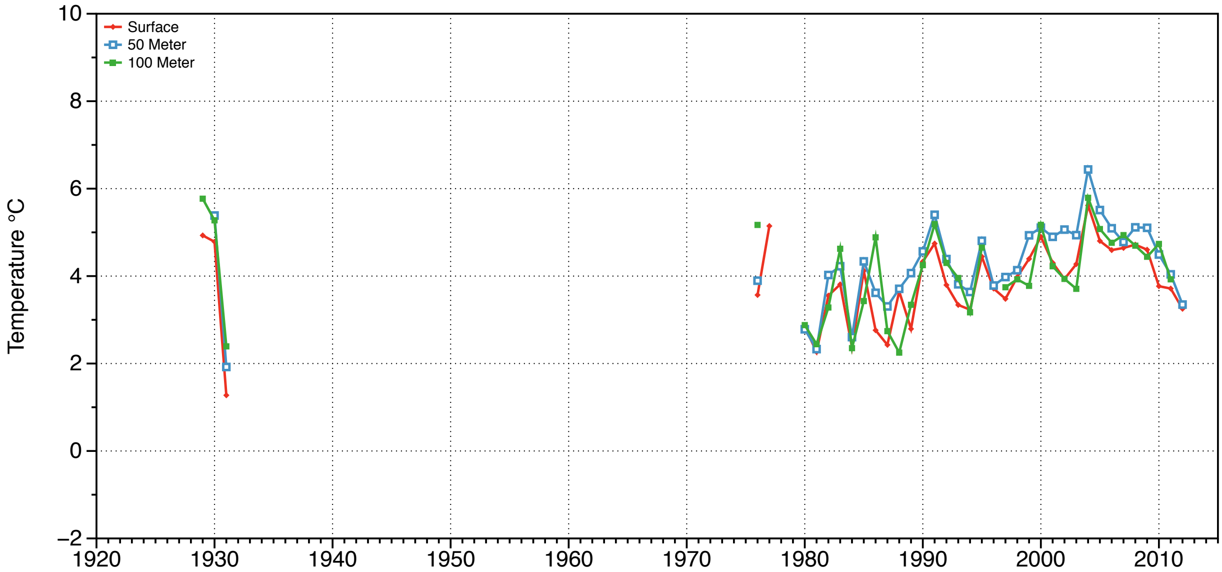


Figure 250: Interannual variability of winter temperatures (November – February) at station Outer Balsfjorden

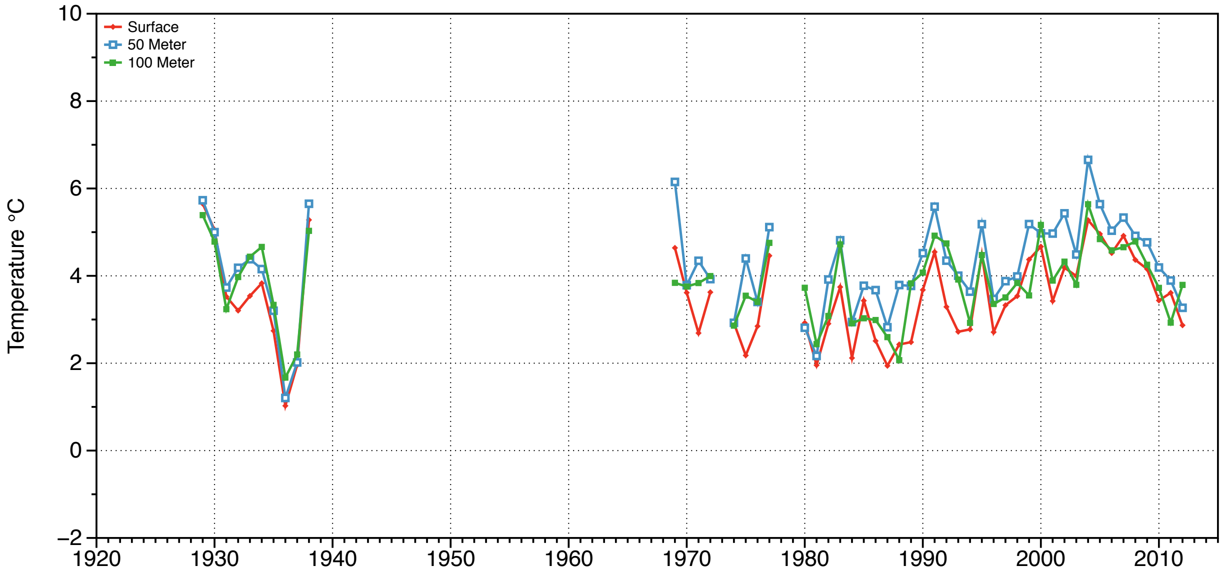


Figure 251: Interannual variability of winter temperatures (November – February) at station Inner Balsfjorden

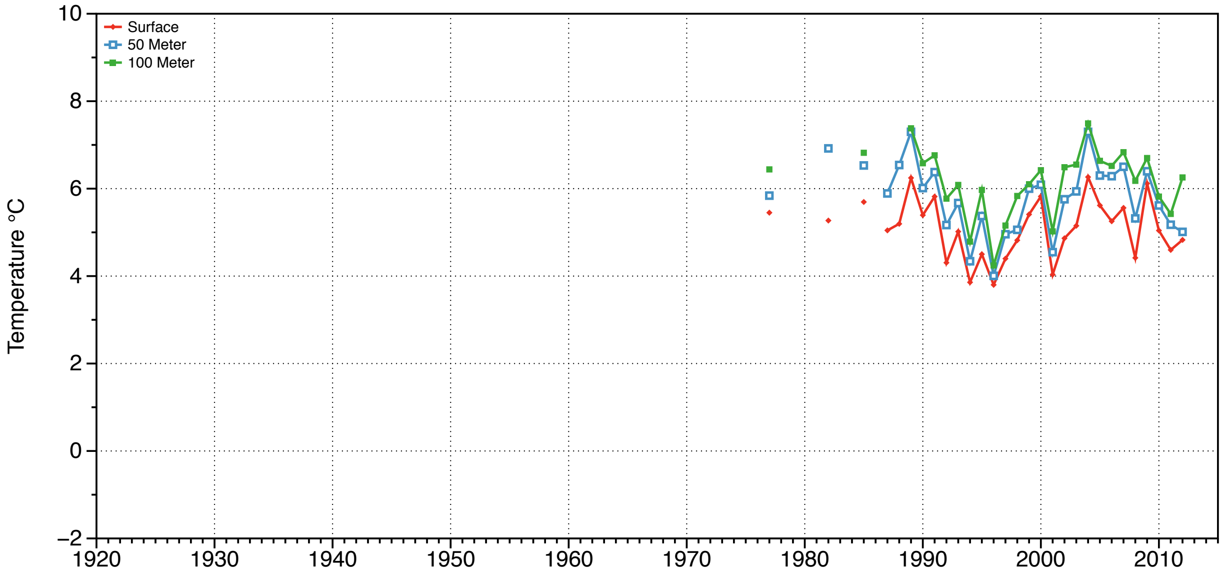


Figure 252: Interannual variability of winter temperatures (November – February) at station Kvalsund

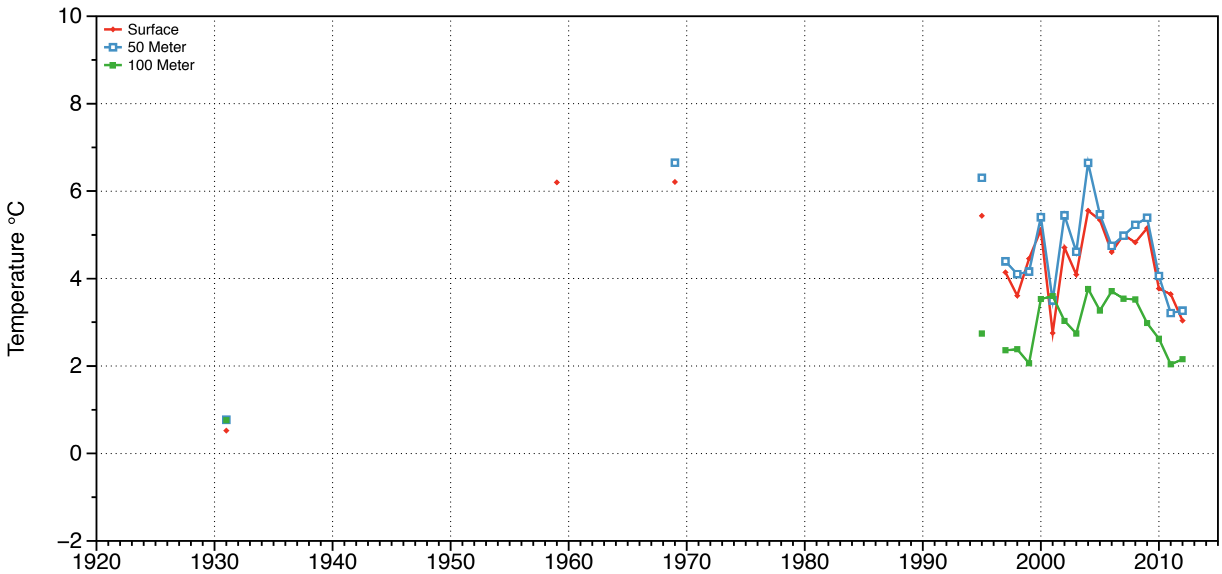


Figure 253: Interannual variability of winter temperatures (November – February) at station Sørfjord

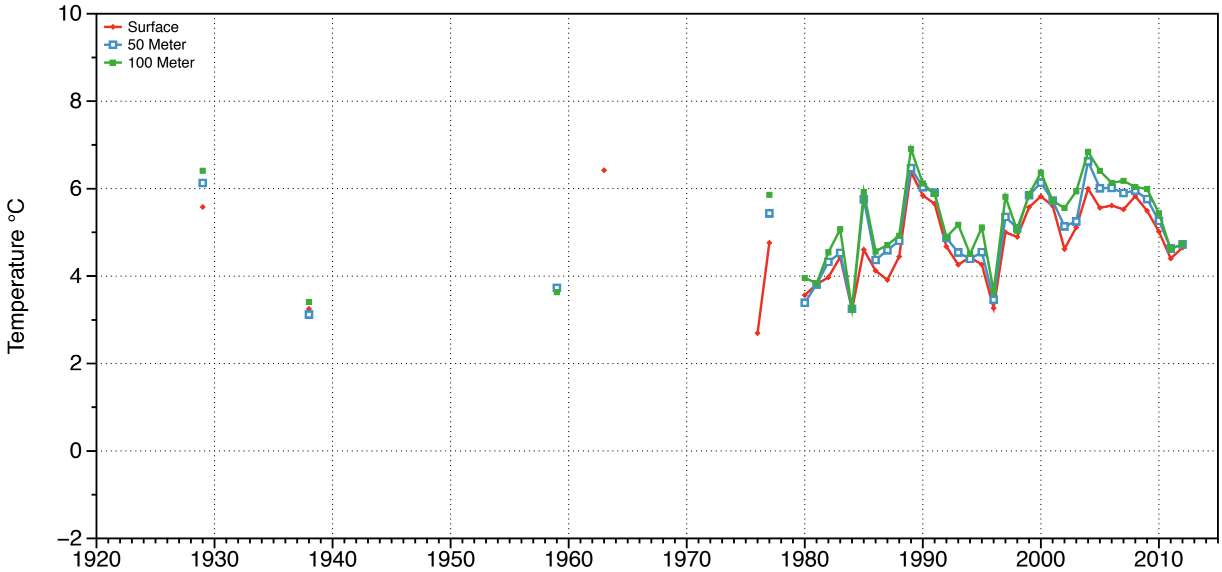


Figure 254: Interannual variability of winter temperatures (November – February) at station Outer Altafjorden

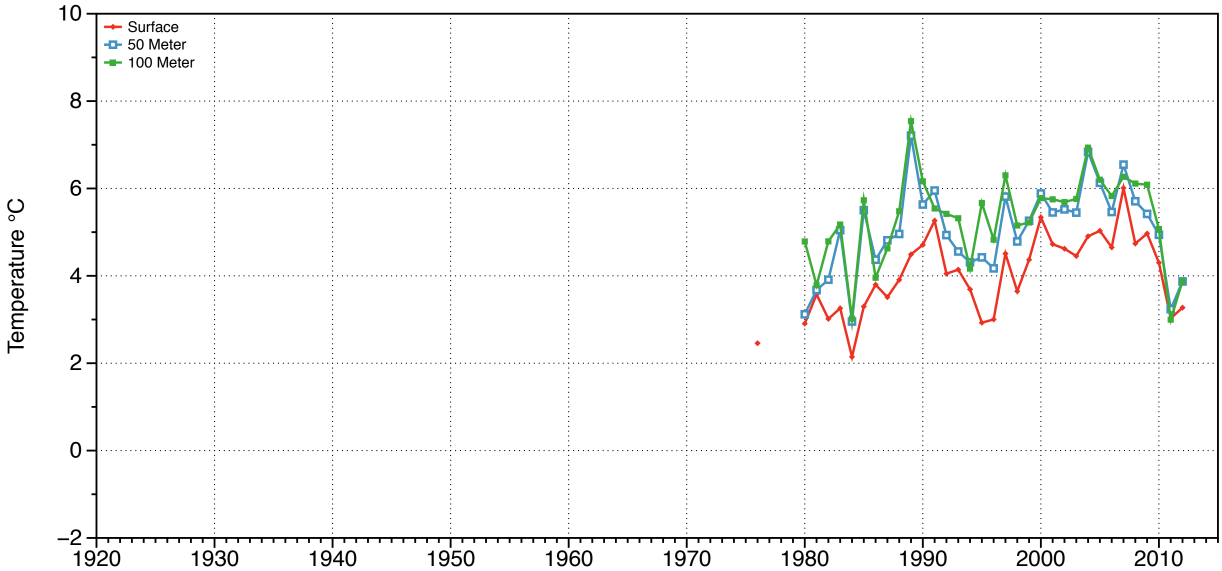


Figure 255: Interannual variability of winter temperatures (November – February) at station Inner Altafjorden

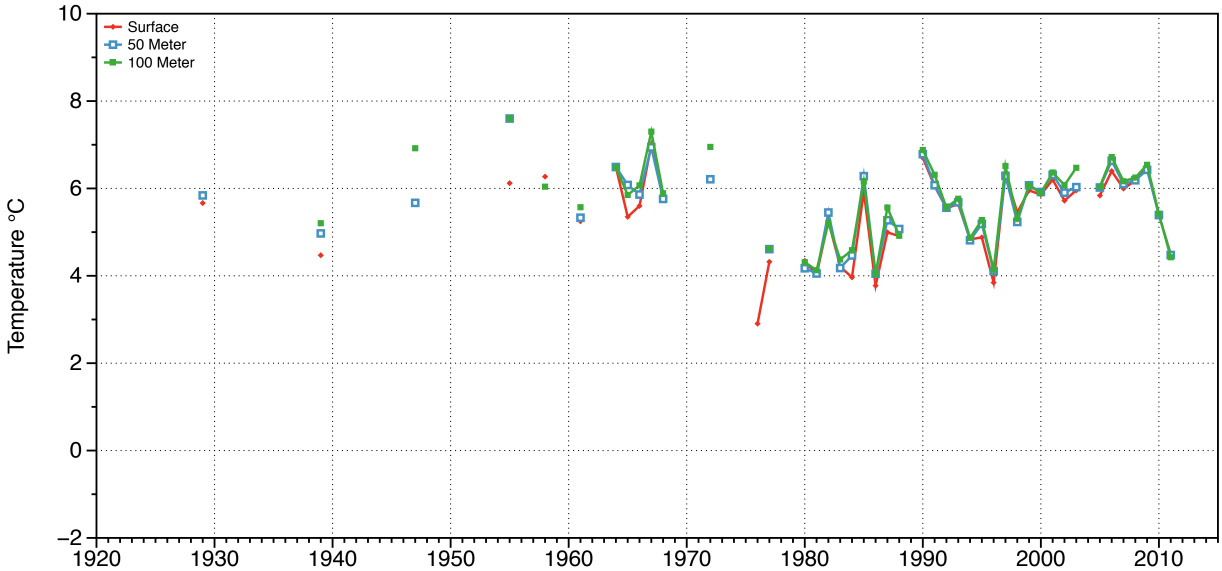


Figure 256: Interannual variability of winter temperatures (November – February) at station Refsbotn

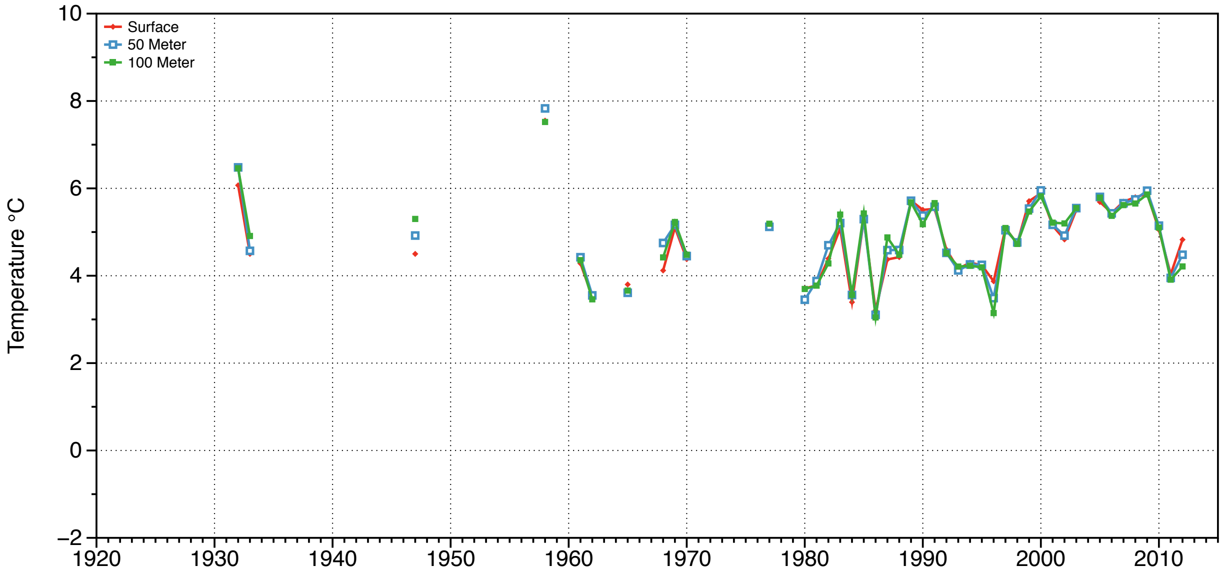


Figure 257: Interannual variability of winter temperatures (November – February) at station Outer Porsanger-fjorden

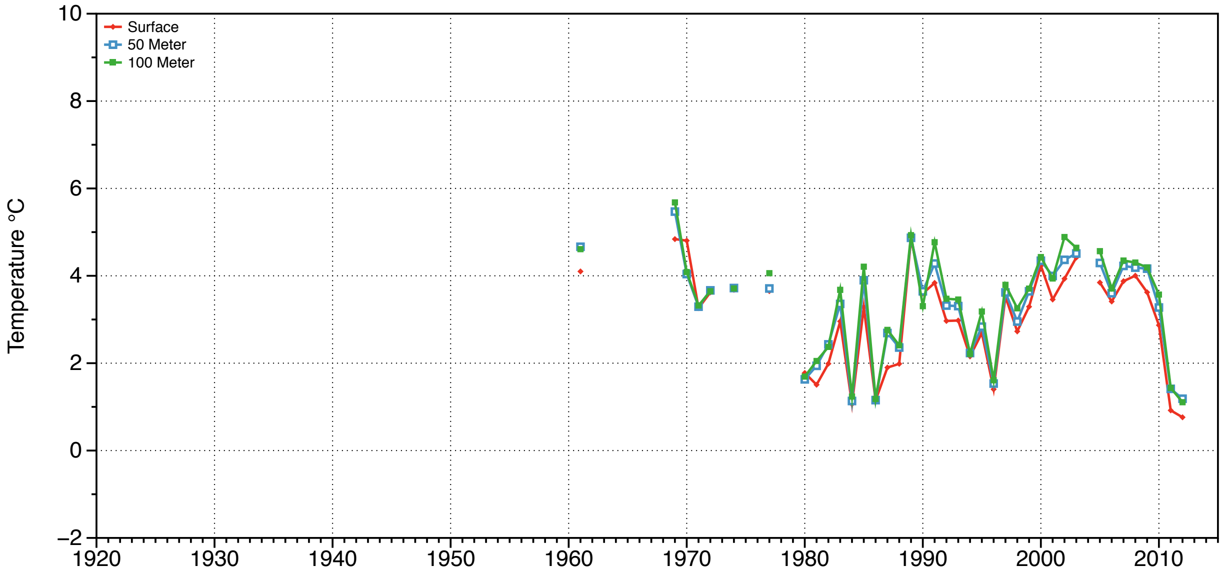


Figure 258: Interannual variability of winter temperatures (November – February) at station Inner Porsanger-fjorden

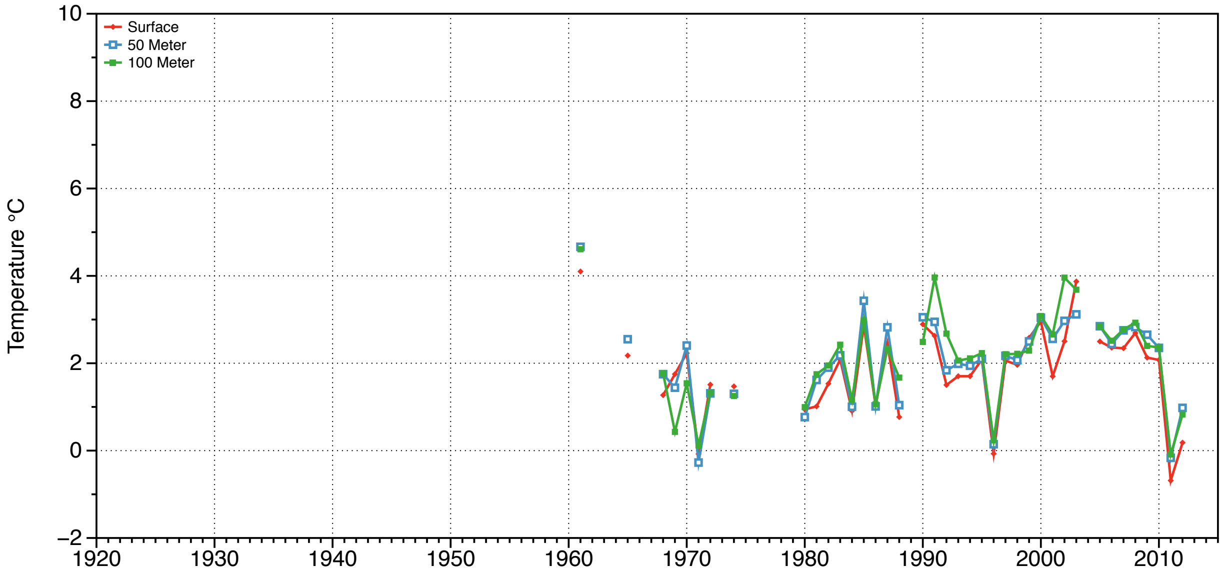


Figure 259: Interannual variability of winter temperatures (November – February) at station Østerbotn

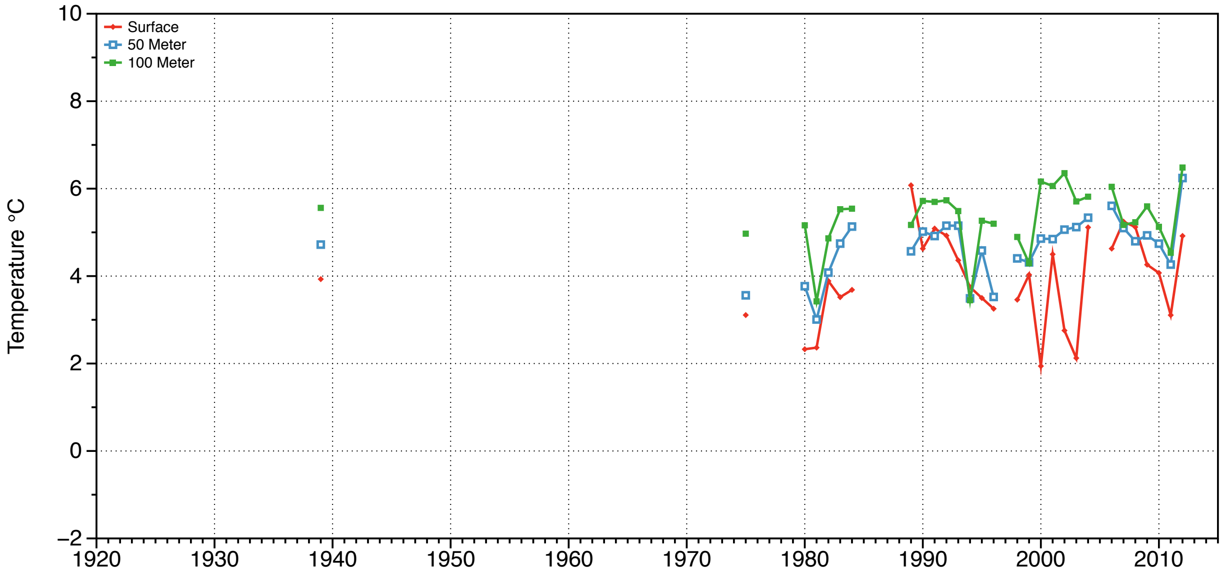


Figure 260: Interannual variability of spring temperatures (March – May) at station Inner Malangen

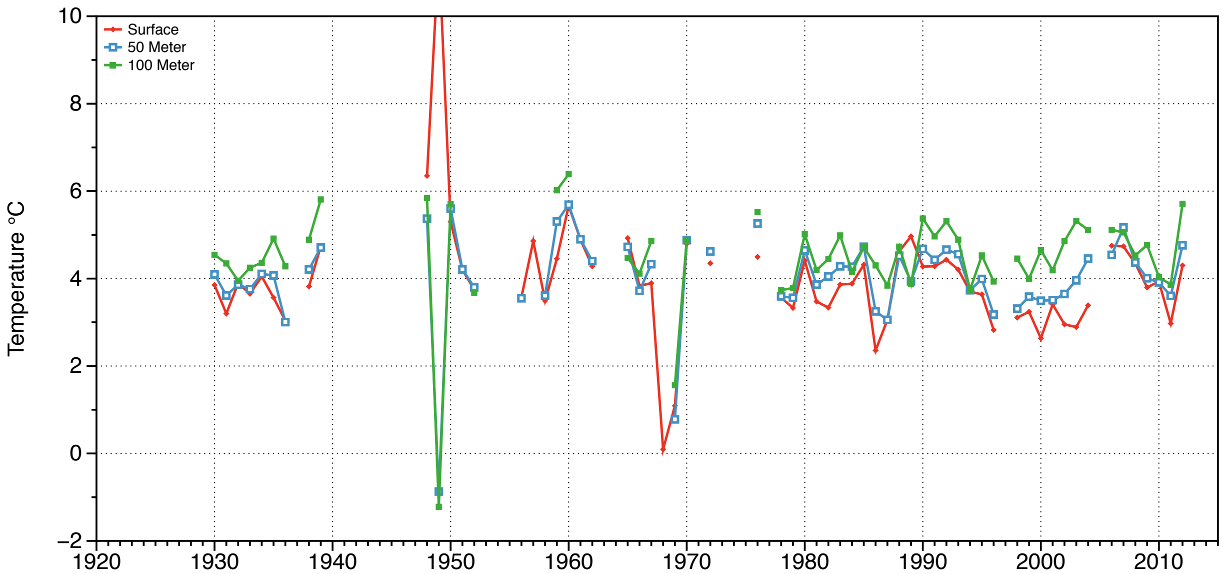


Figure 261: Interannual variability of spring temperatures (March – May) at station Outer Malangen

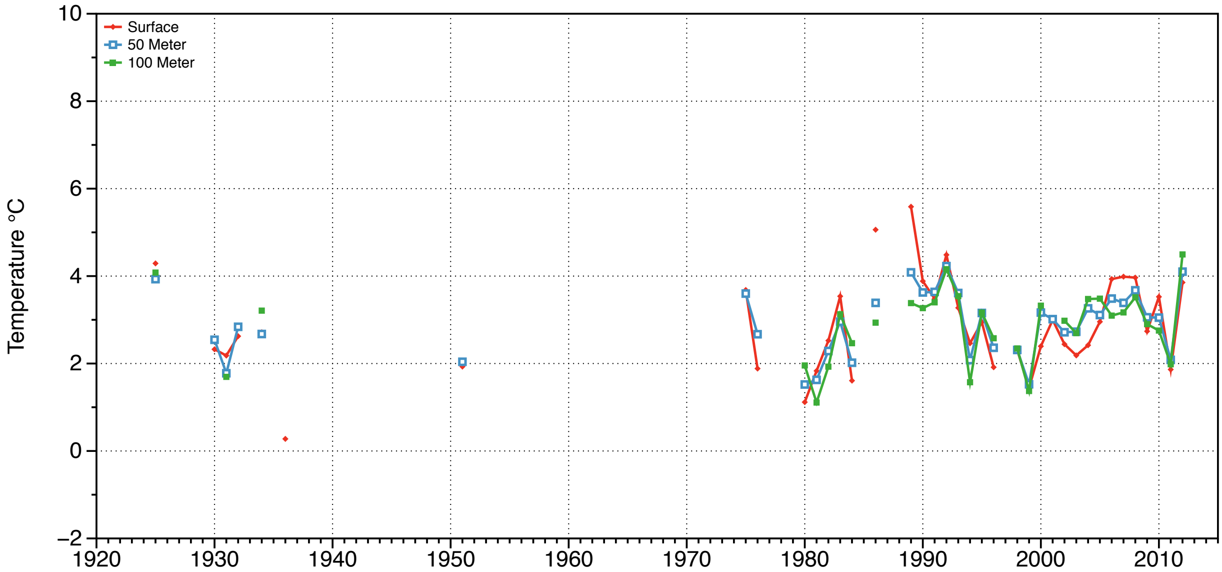


Figure 262: Interannual variability of spring temperatures (March – May) at station Outer Balsfjorden

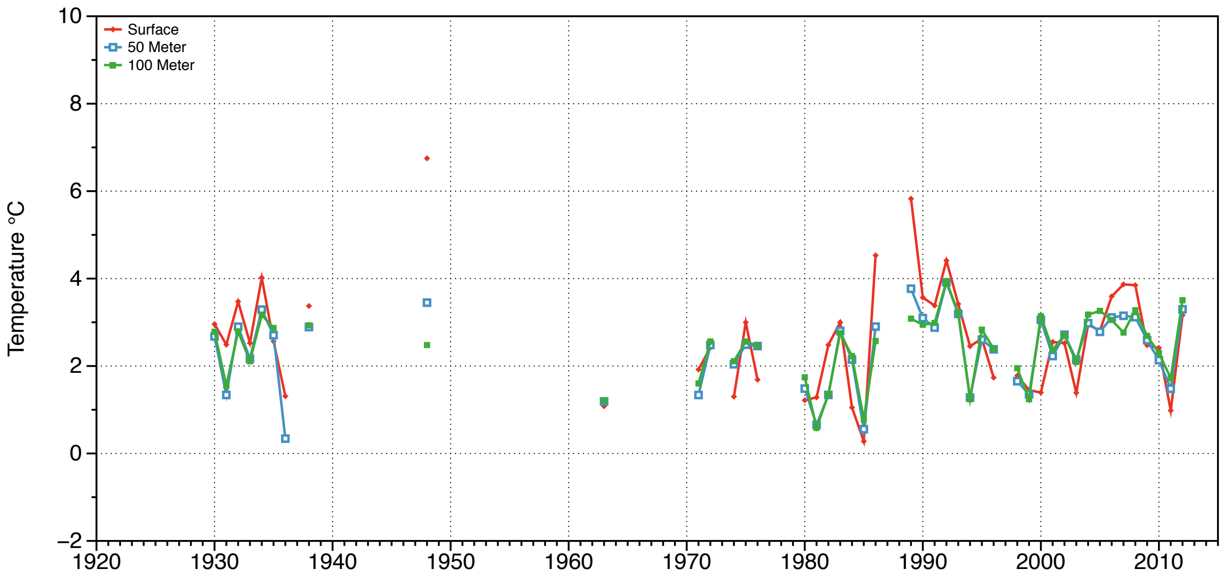


Figure 263: Interannual variability of spring temperatures (March – May) at station Inner Balsfjorden

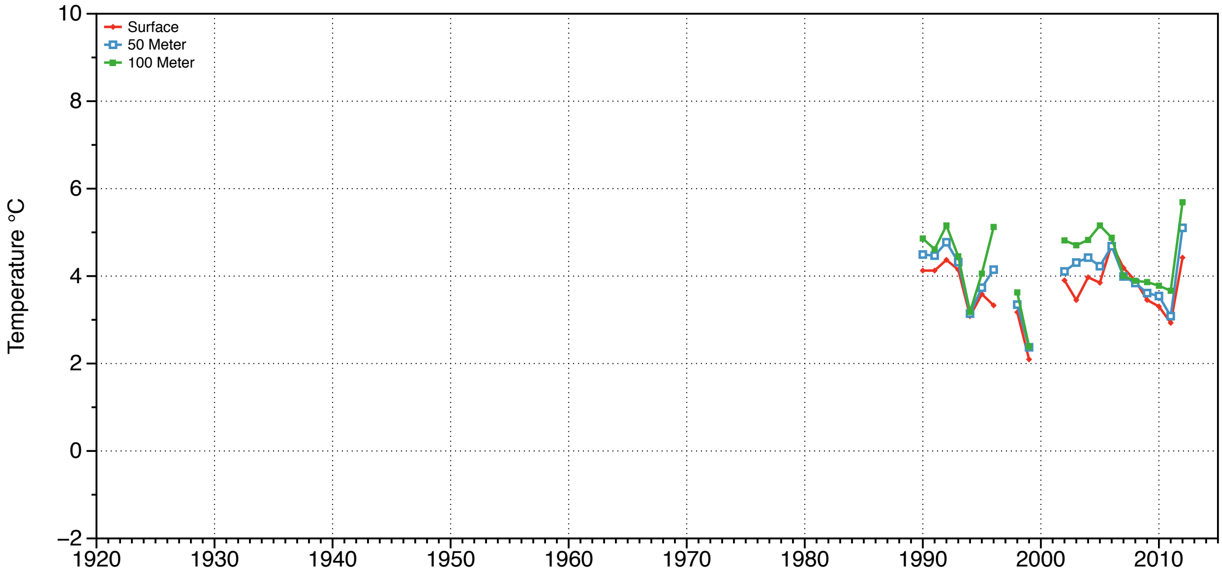


Figure 264: Interannual variability of spring temperatures (March – May) at station Kvalsund

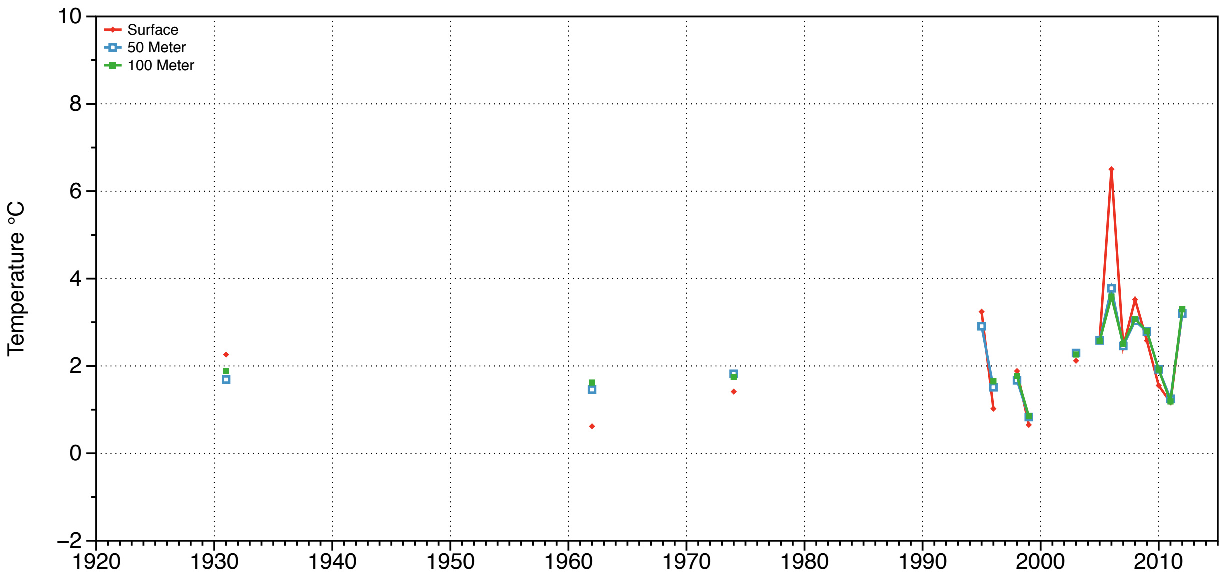


Figure 265: Interannual variability of spring temperatures (March – May) at station Sørfjord

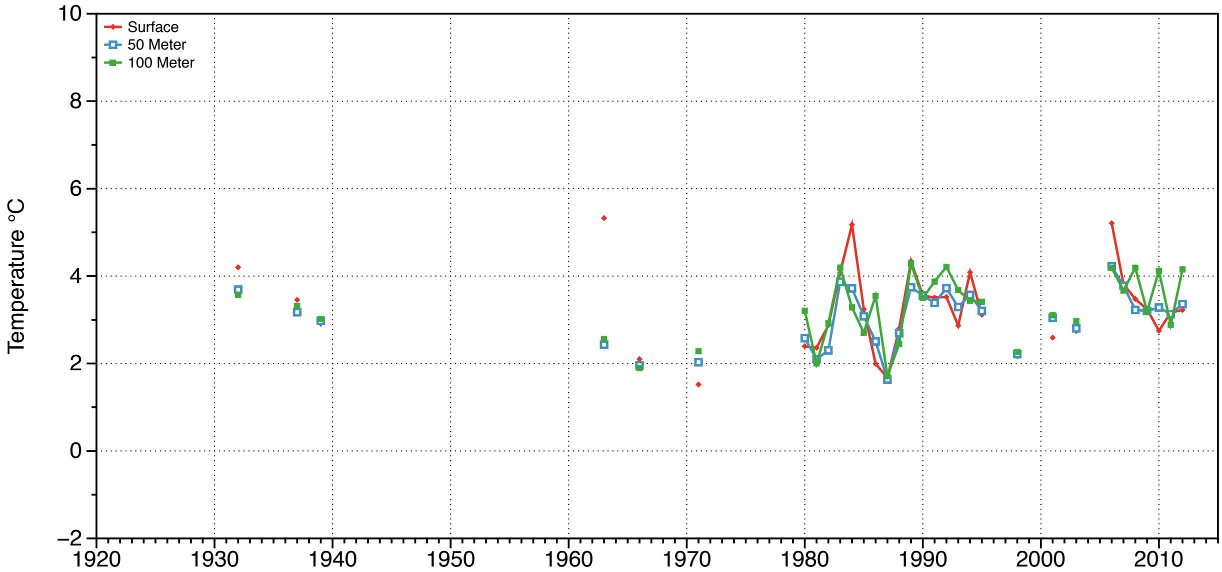


Figure 266: Interannual variability of spring temperatures (March – May) at station Outer Altafjorden

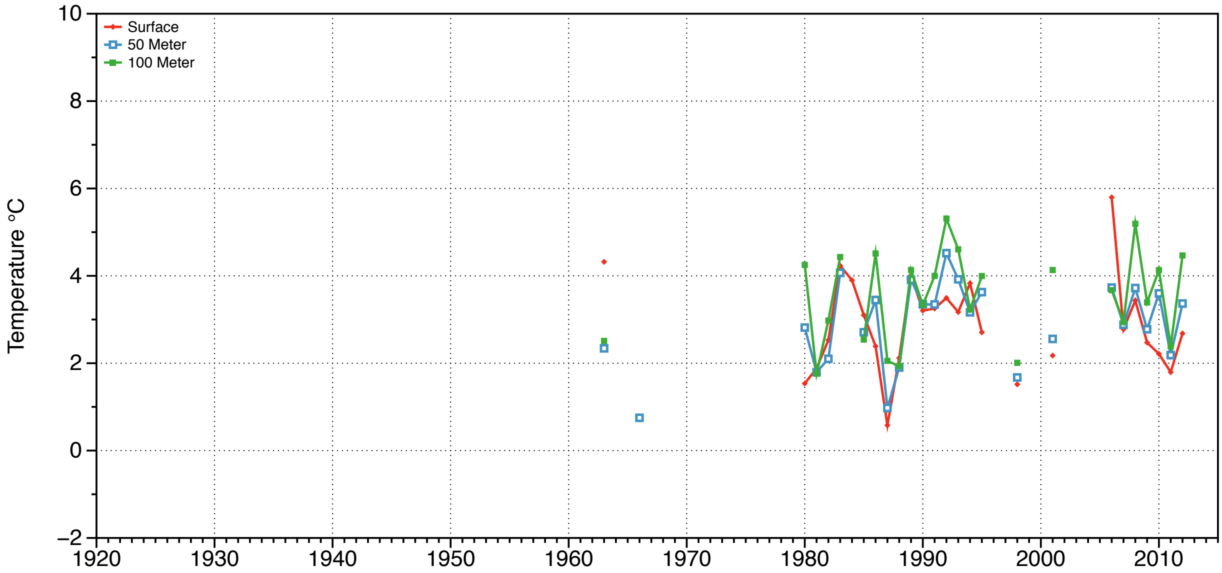


Figure 267: Interannual variability of spring temperatures (March – May) at station Inner Altafjorden

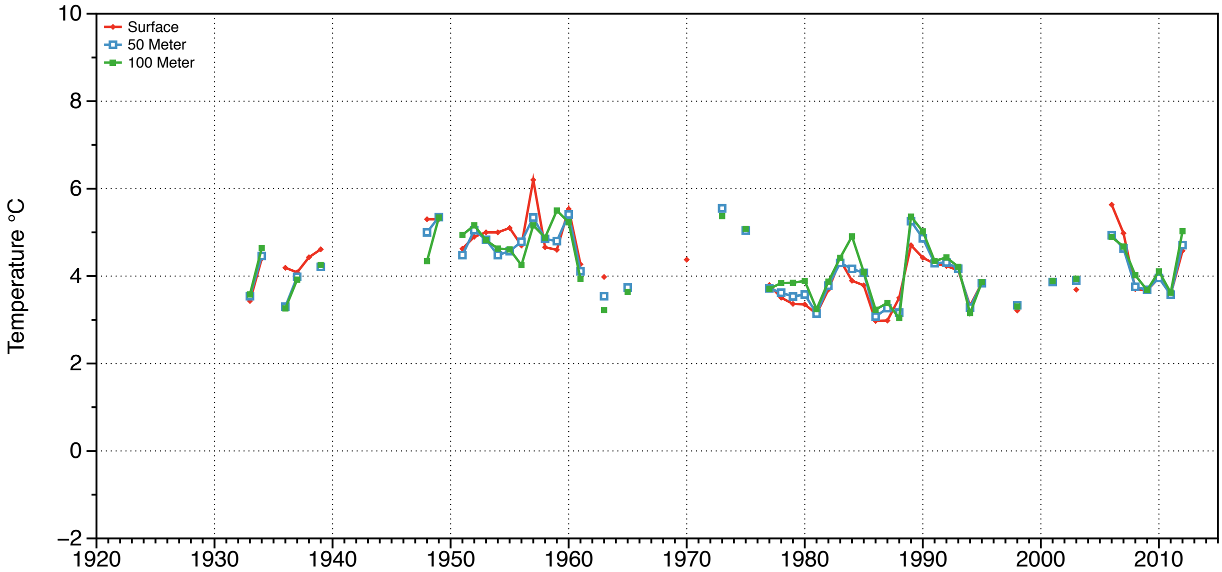


Figure 268: Interannual variability of spring temperatures (March – May) at station Refsbotn

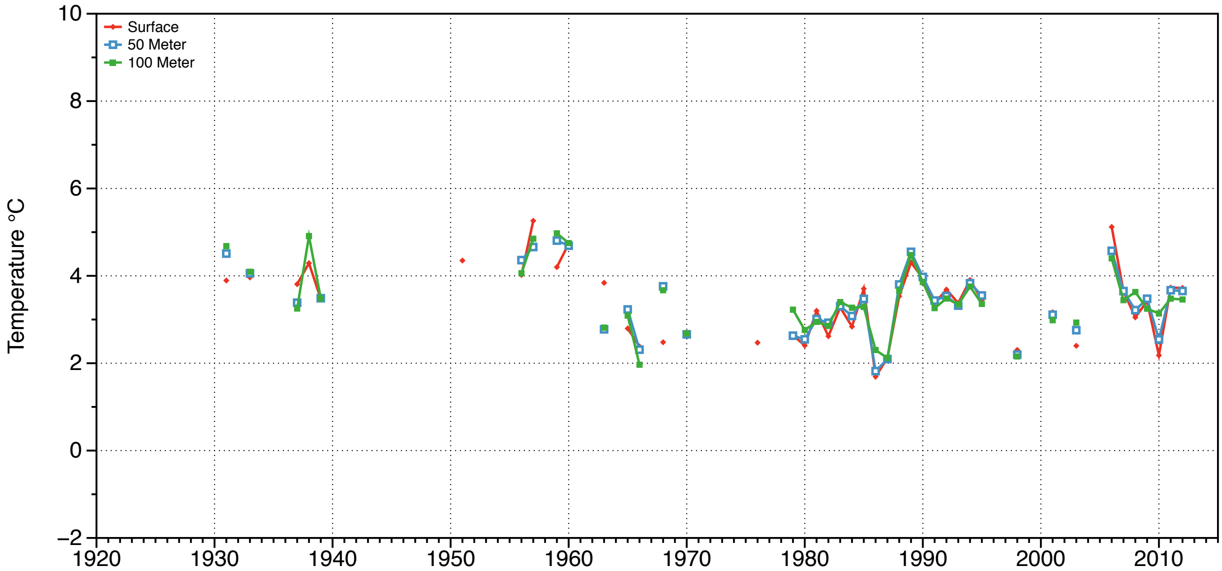


Figure 269: Interannual variability of spring temperatures (March – May) at station Outer Porsangerfjorden

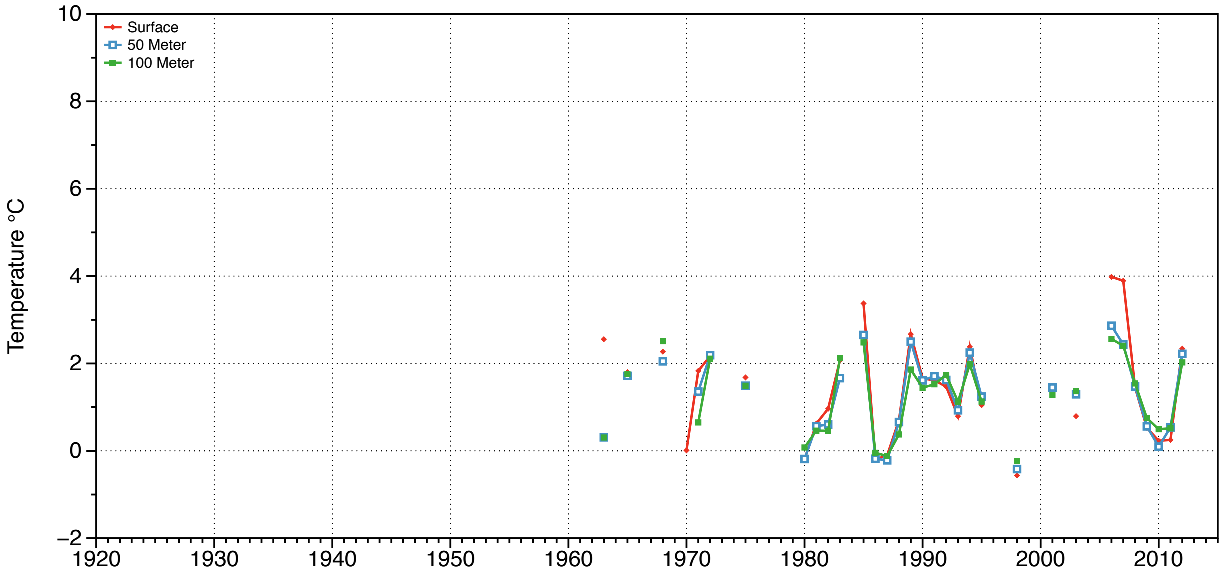


Figure 270: Interannual variability of spring temperatures (March – May) at station Inner Porsangerfjorden

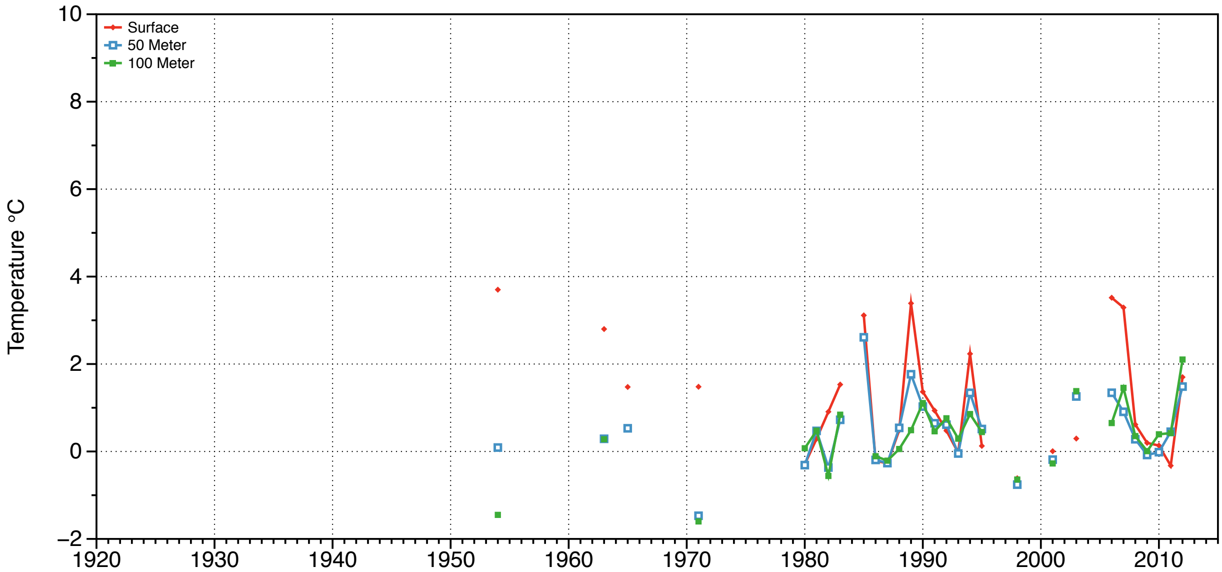


Figure 271: Interannual variability of spring temperatures (March – May) at station Østerbotn

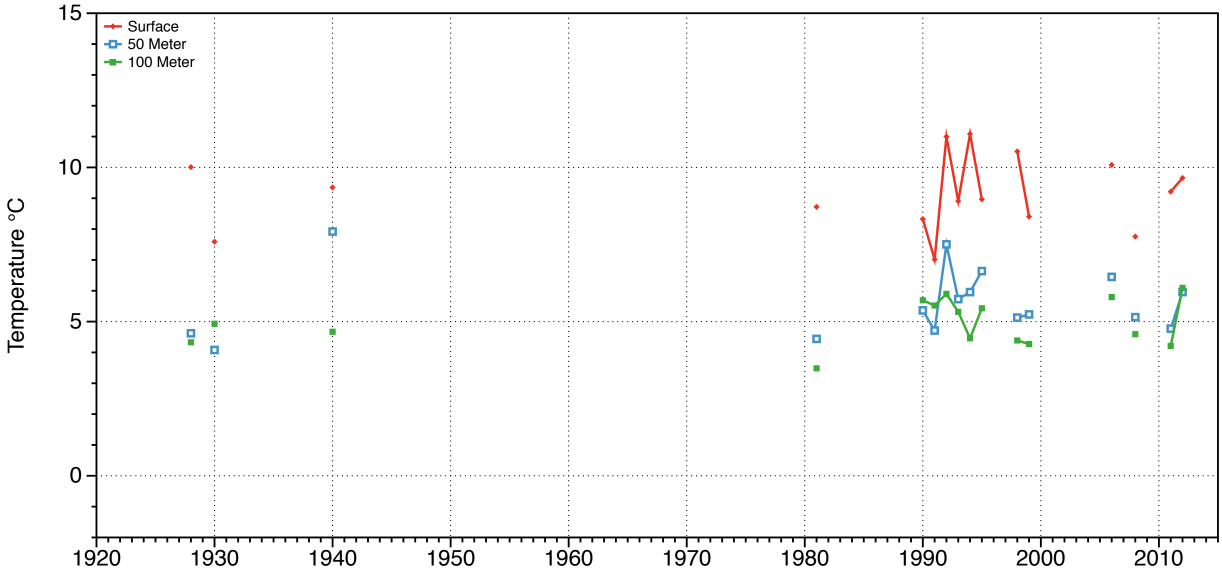


Figure 272: Interannual variability of summer temperatures (June – August) at station Inner Malangen

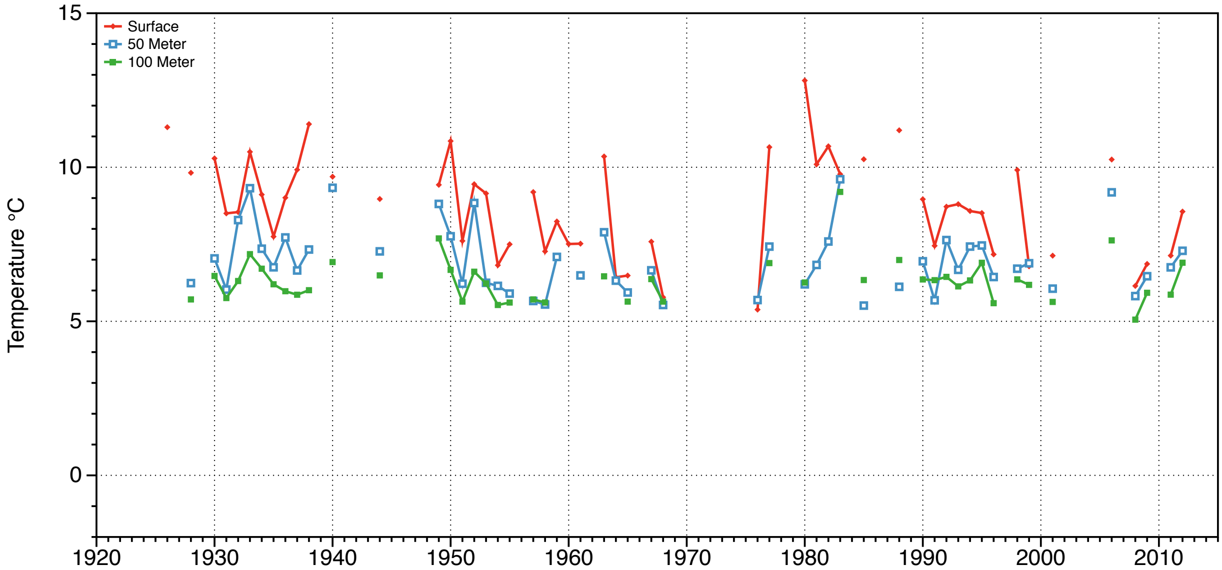


Figure 273: Interannual variability of summer temperatures (June – August) at station Outer Malangen

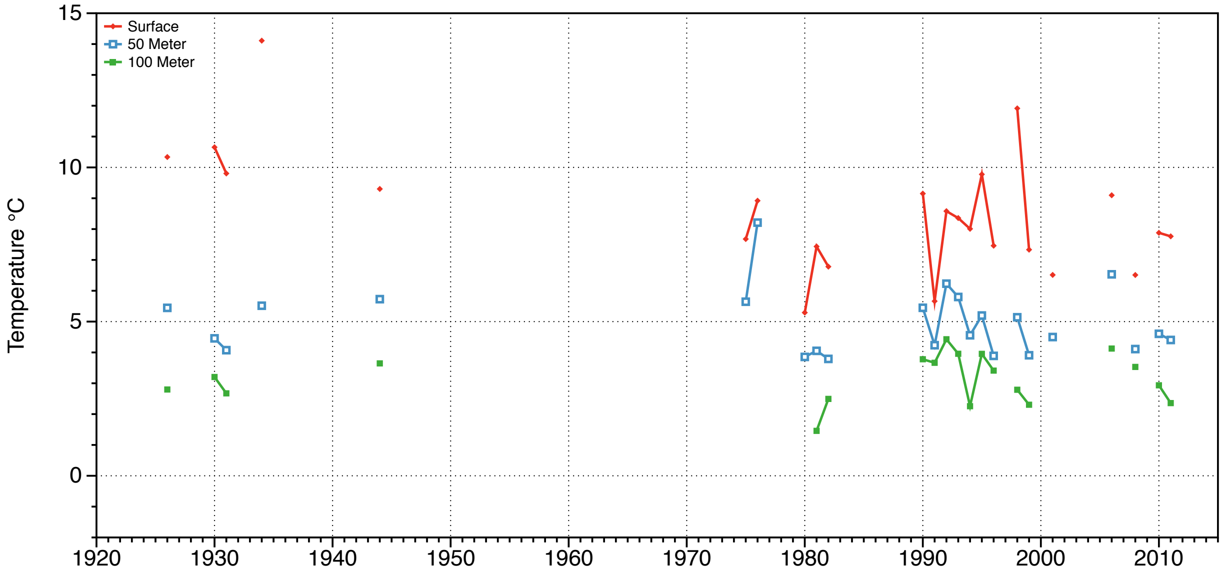


Figure 274: Interannual variability of summer temperatures (June – August) at station Outer Balsfjorden

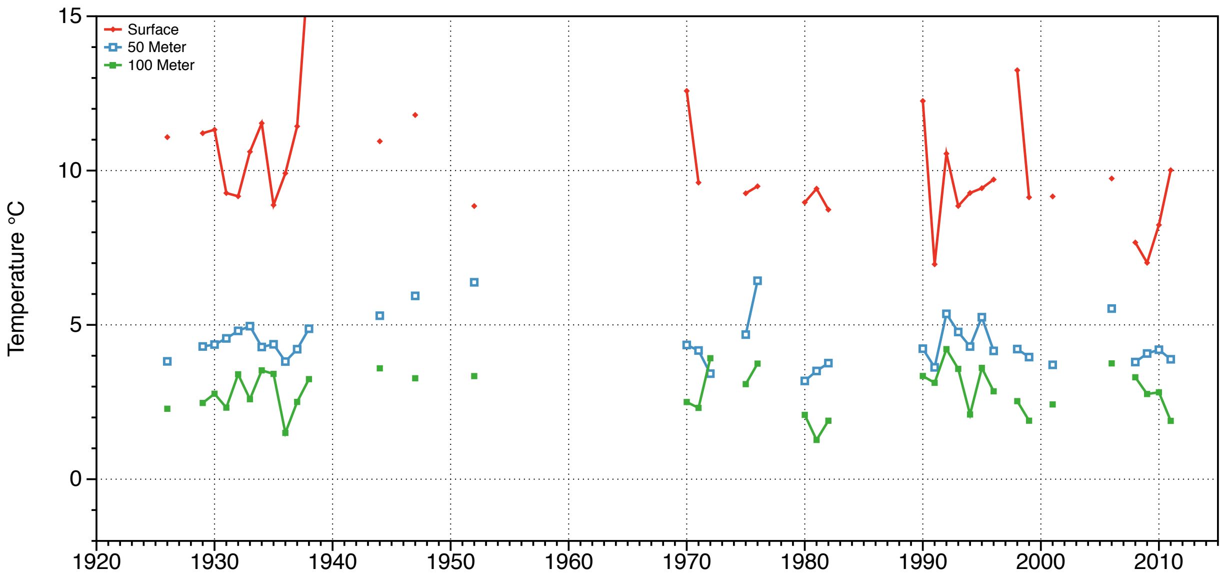


Figure 275: Interannual variability of summer temperatures (June – August) at station Inner Balsfjorden

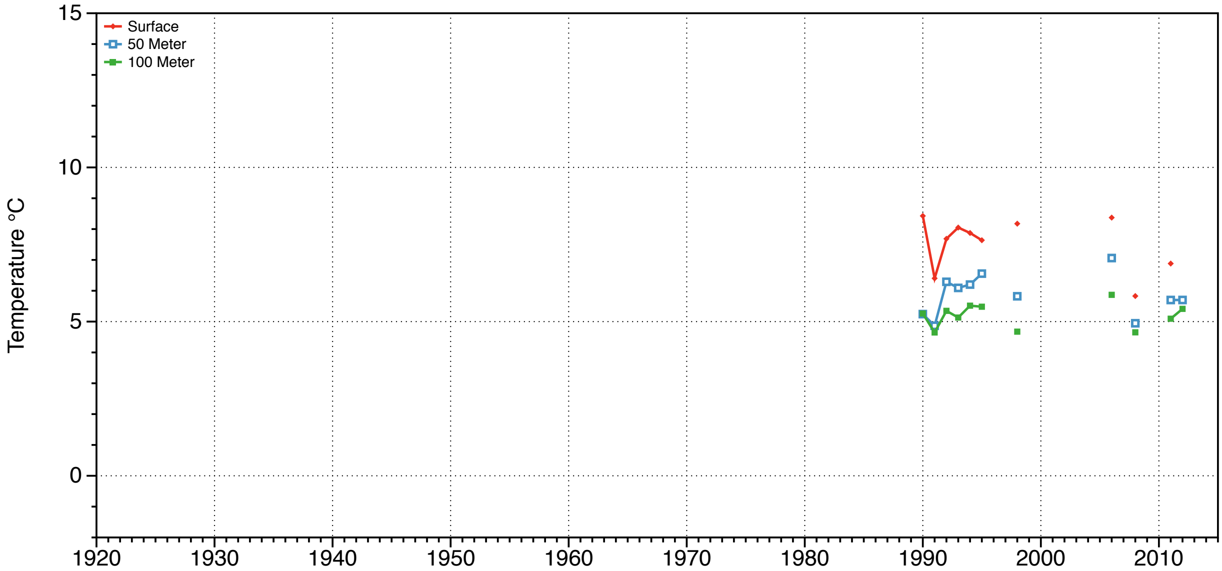


Figure 276: Interannual variability of summer temperatures (June – August) at station Kvalsund

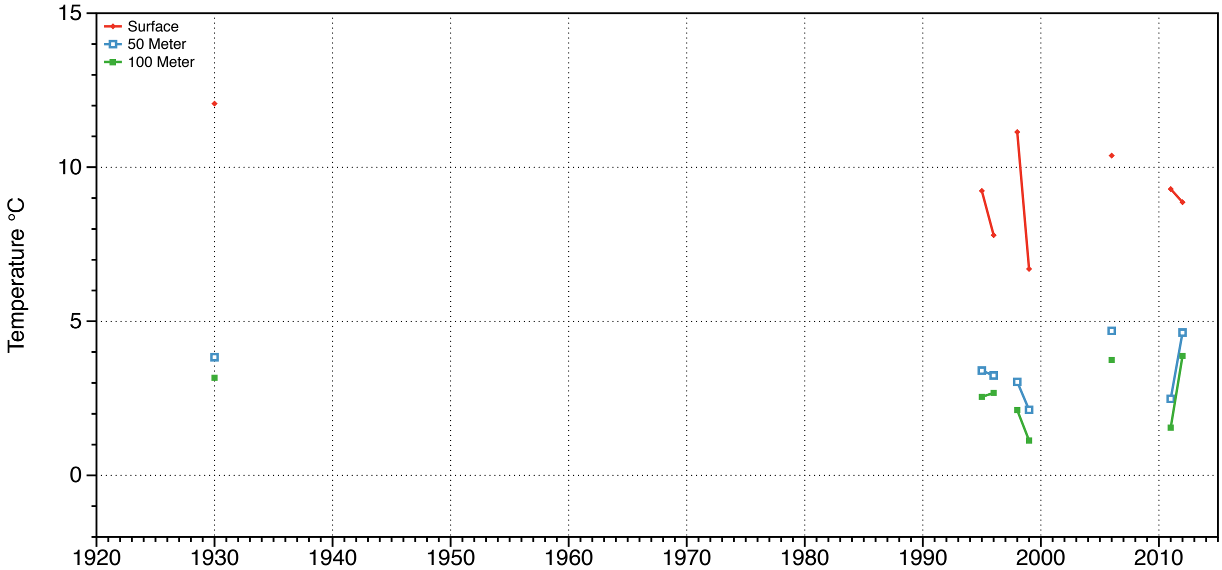


Figure 277: Interannual variability of summer temperatures (June – August) at station Sørfjord

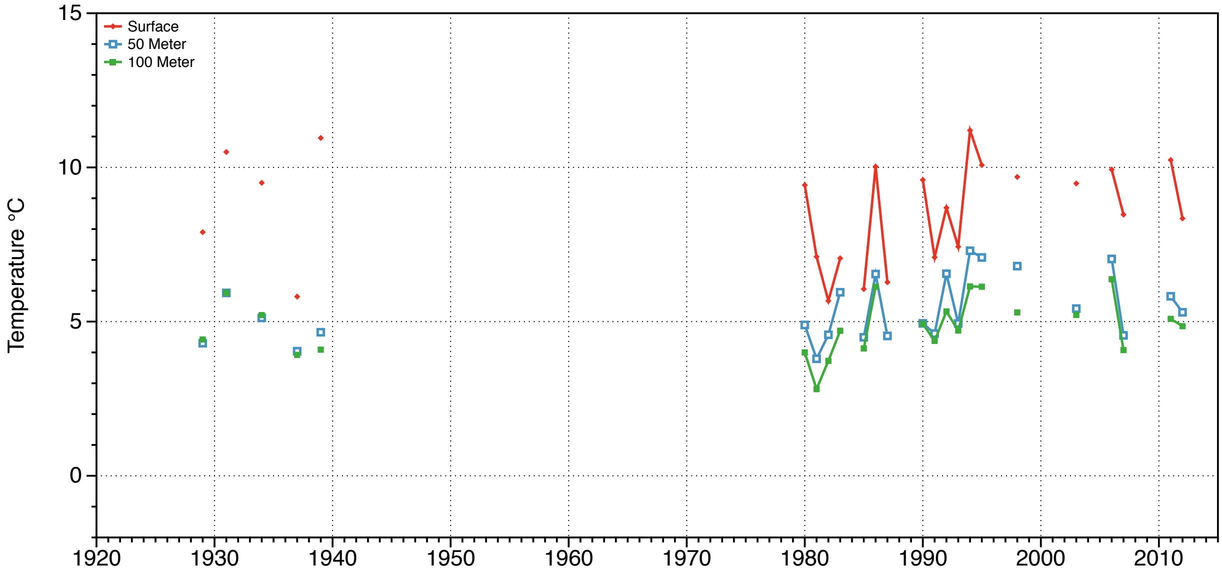


Figure 278: Interannual variability of summer temperatures (June – August) at station Outer Altafjorden

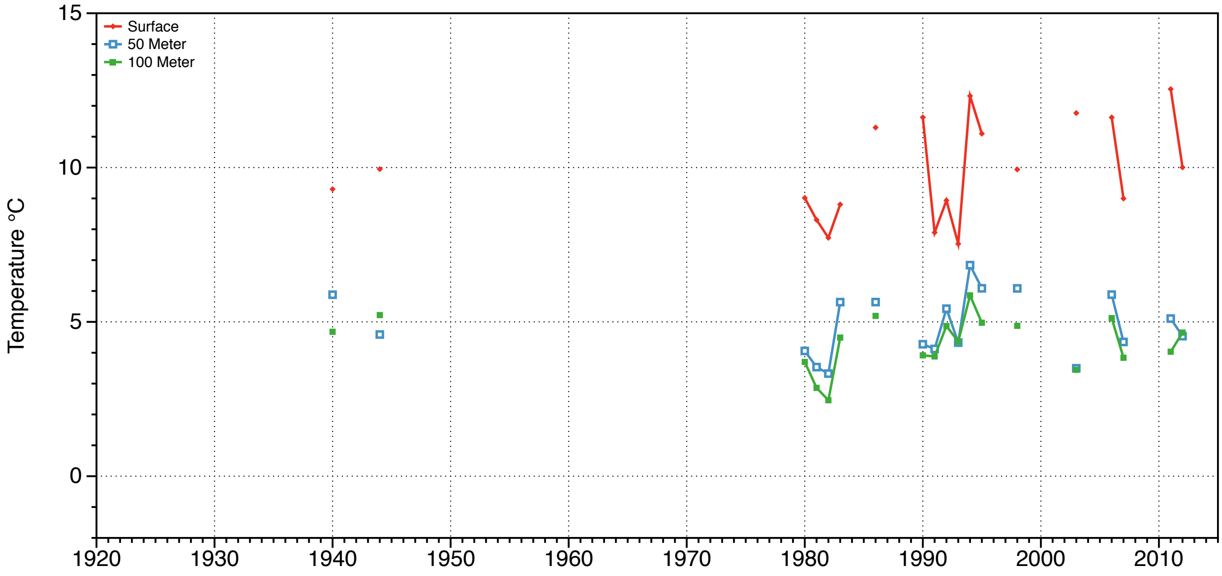


Figure 279: Interannual variability of summer temperatures (June – August) at station Inner Altafjorden

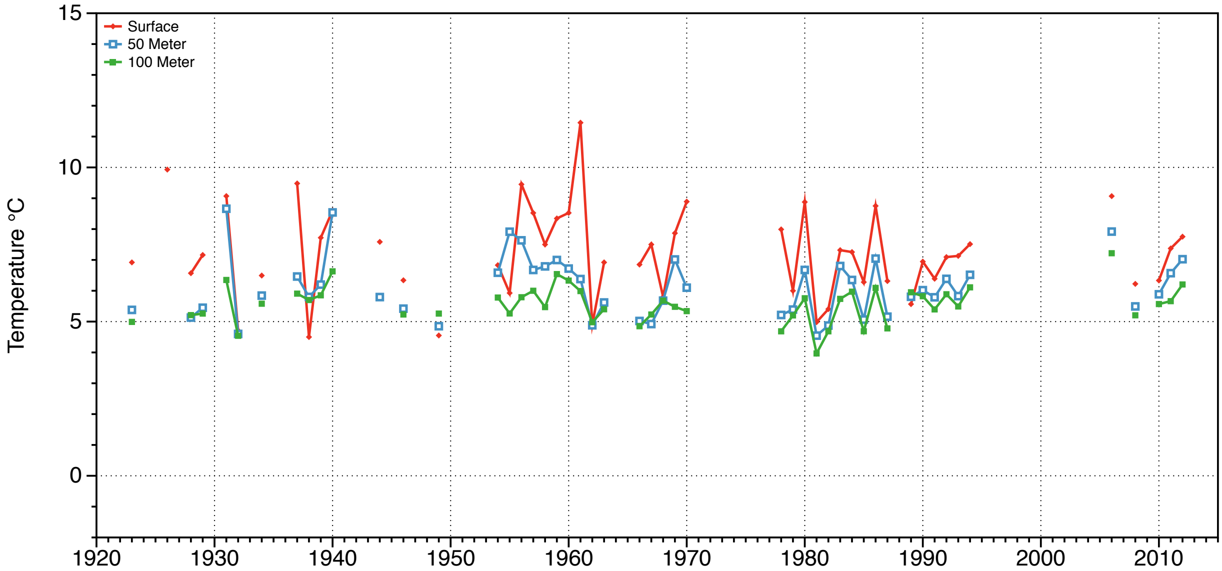


Figure 280: Interannual variability of summer temperatures (June – August) at station Refsbotn

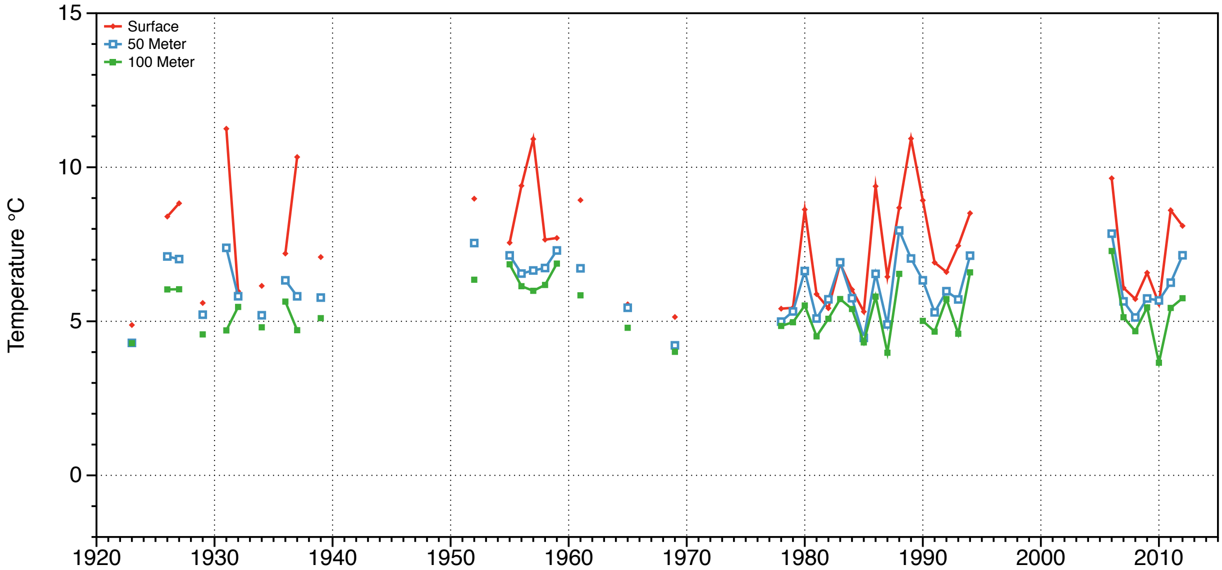


Figure 281: Interannual variability of summer temperatures (June – August) at station Outer Porsangerfjorden

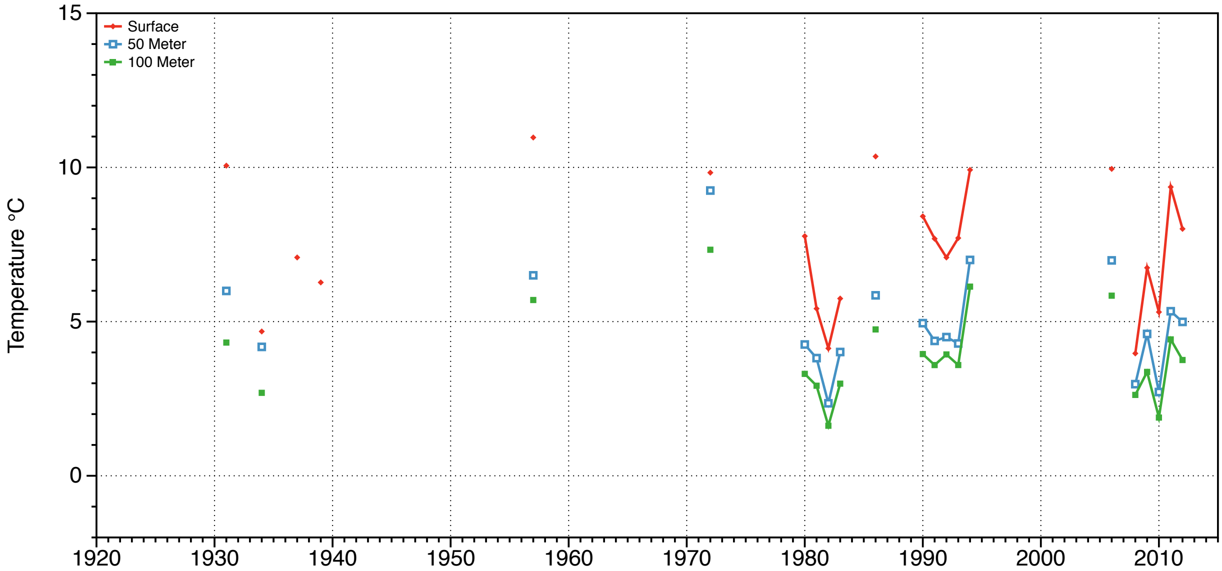


Figure 282: Interannual variability of summer temperatures (June – August) at station Inner Porsangerfjorden

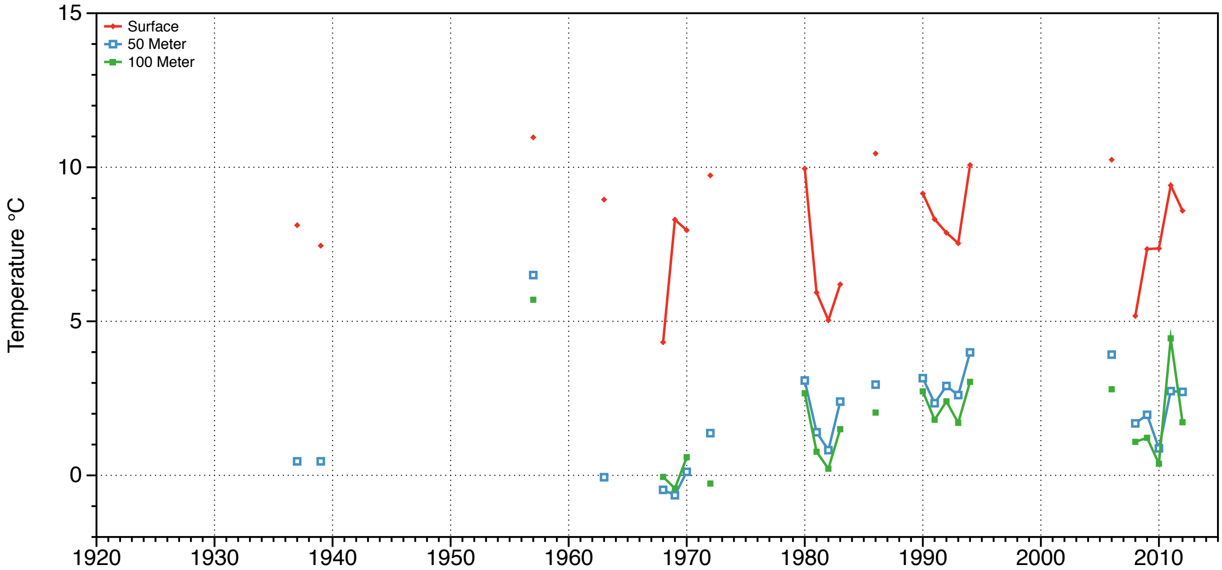


Figure 283: Interannual variability of summer temperatures (June – August) at station Østerbotn

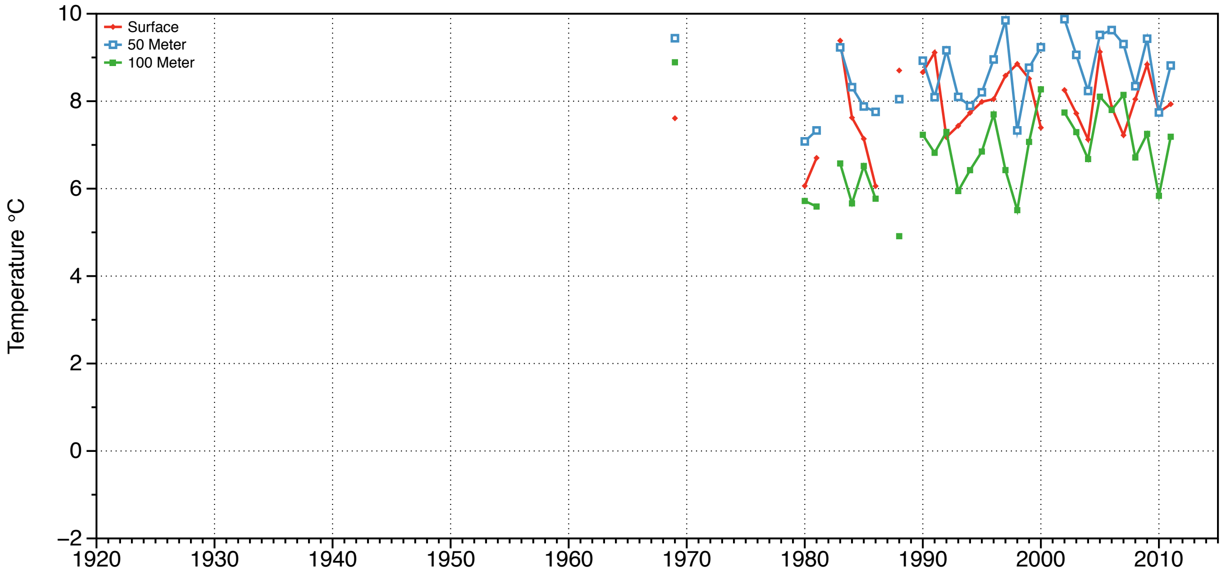


Figure 284: Interannual variability of autumn temperatures (September – October) at station Inner Malangen

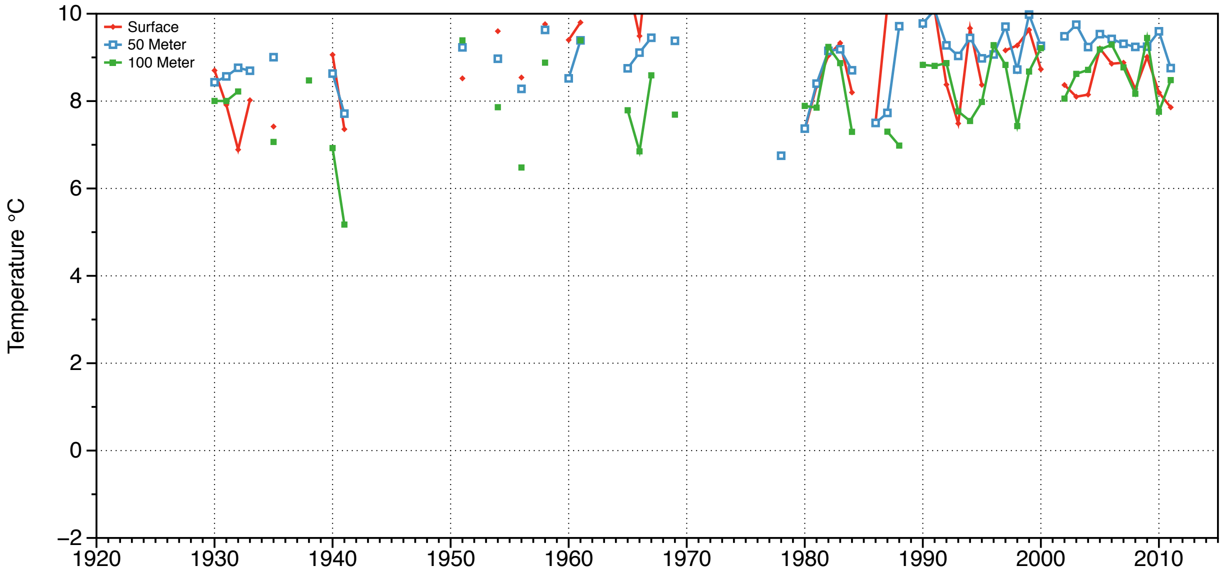


Figure 285: Interannual variability of autumn temperatures (September – October) at station Outer Malangen

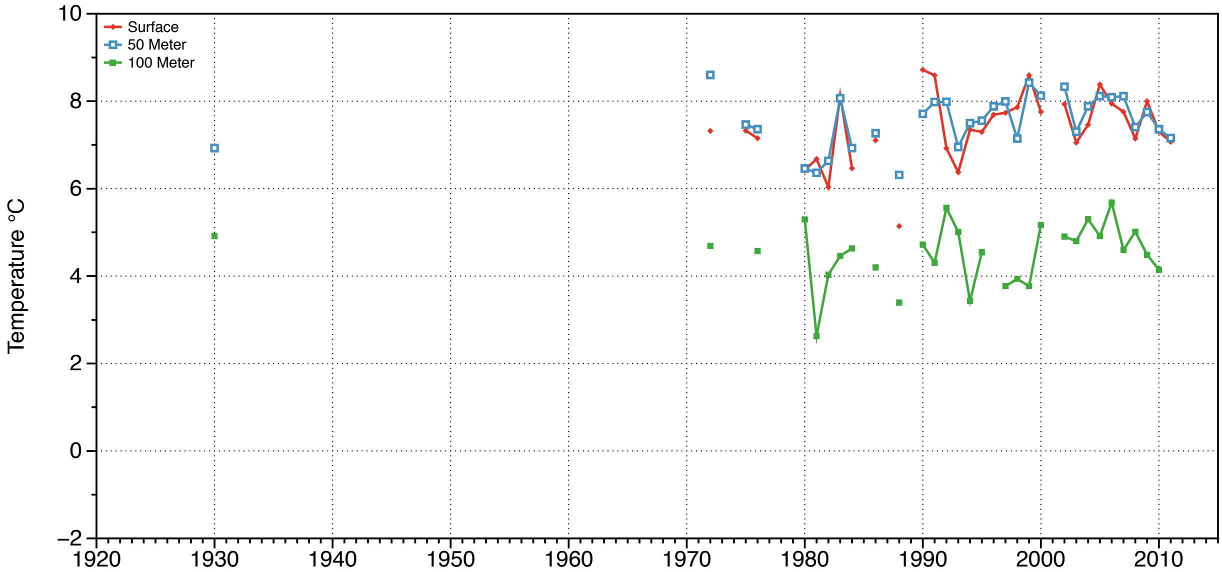


Figure 286: Interannual variability of autumn temperatures (September – October) at station Outer Balsfjorden

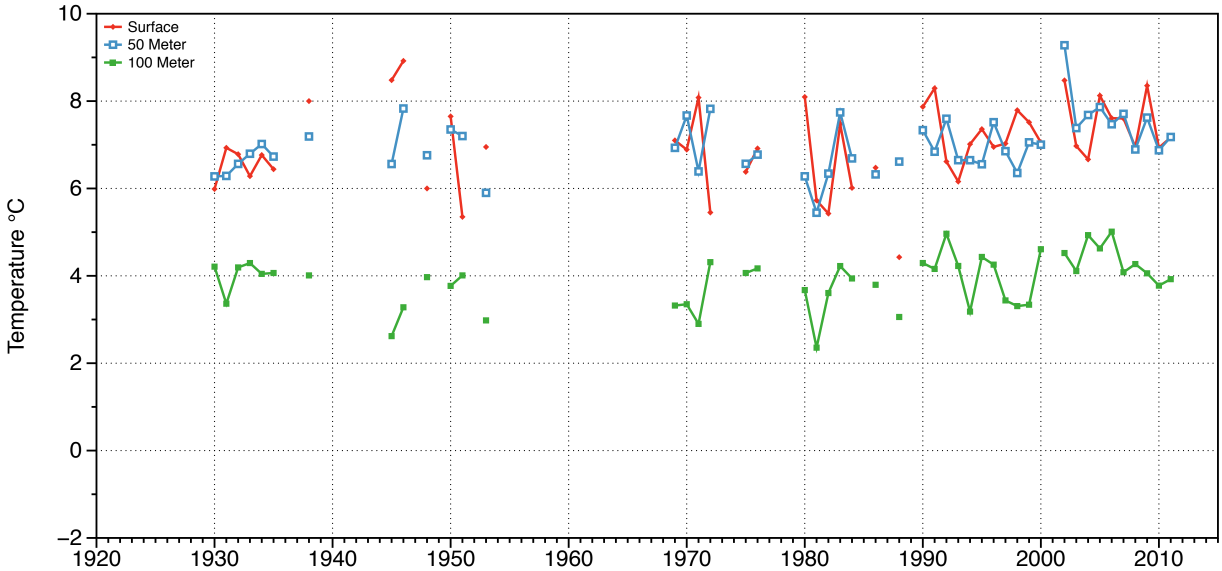


Figure 287: Interannual variability of autumn temperatures (September – October) at station Inner Balsfjorden

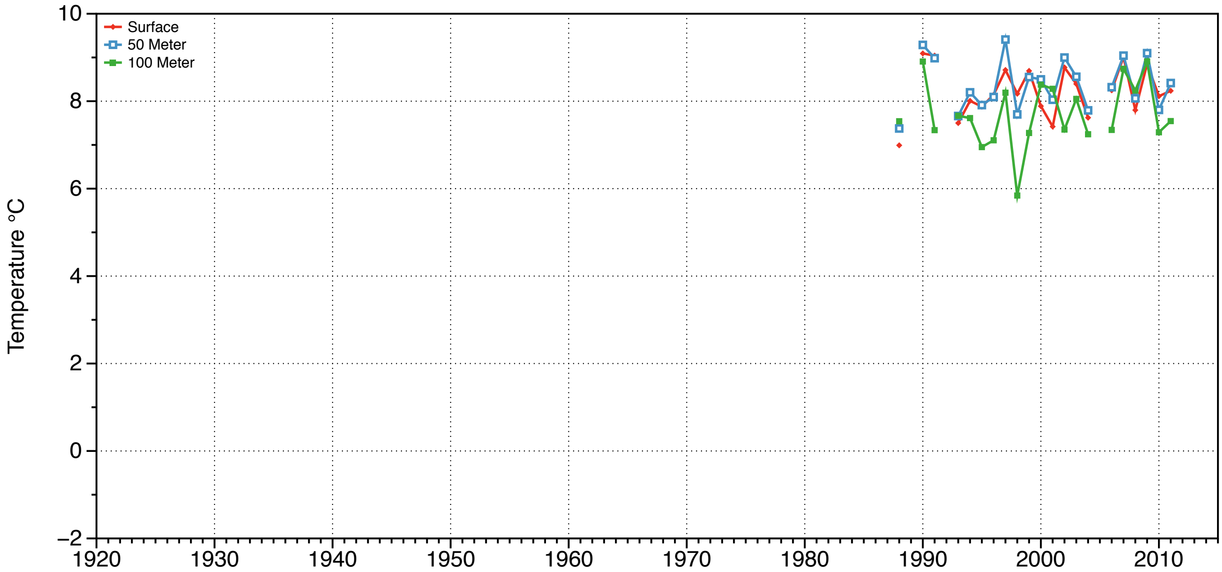


Figure 288: Interannual variability of autumn temperatures (September – October) at station Kvalsund

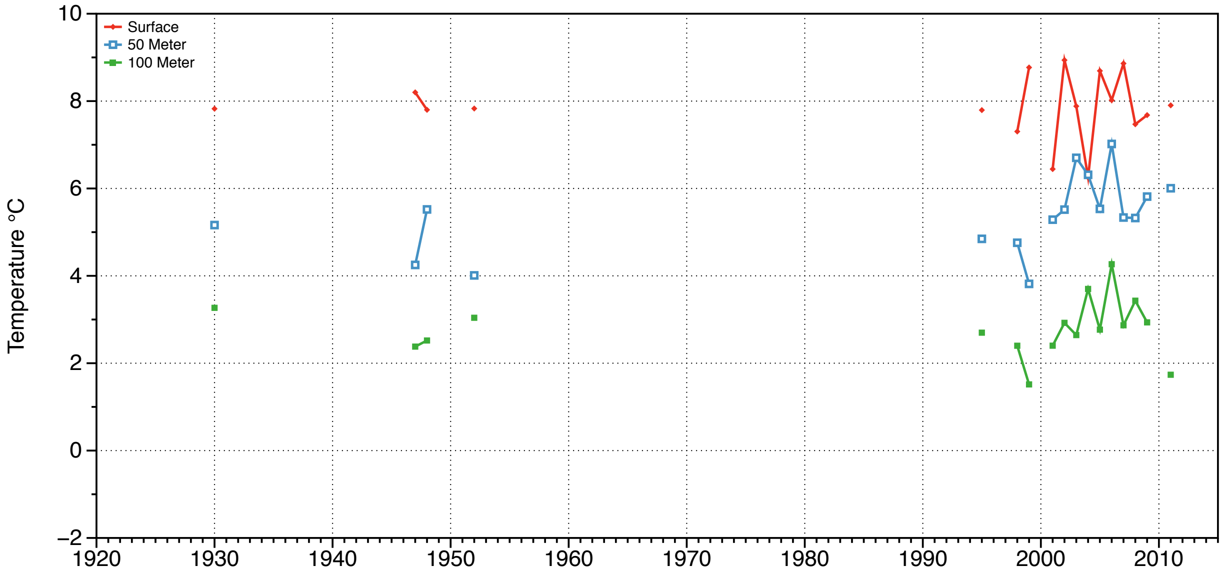


Figure 289: Interannual variability of autumn temperatures (September – October) at station Sørfjord

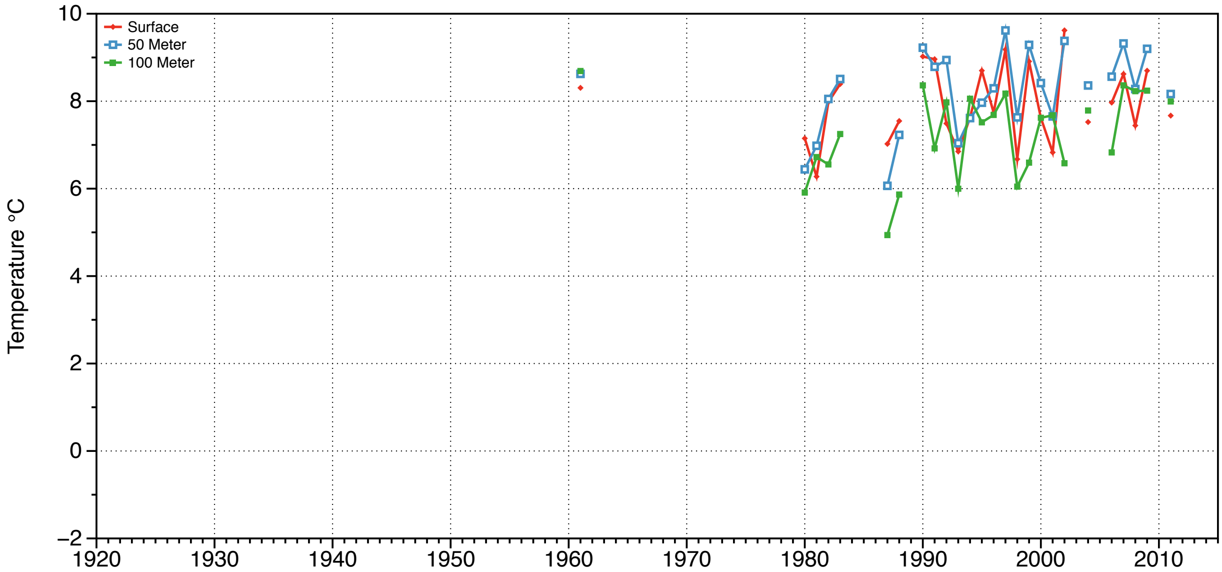


Figure 290: Interannual variability of autumn temperatures (September – October) at station Outer Altafjorden

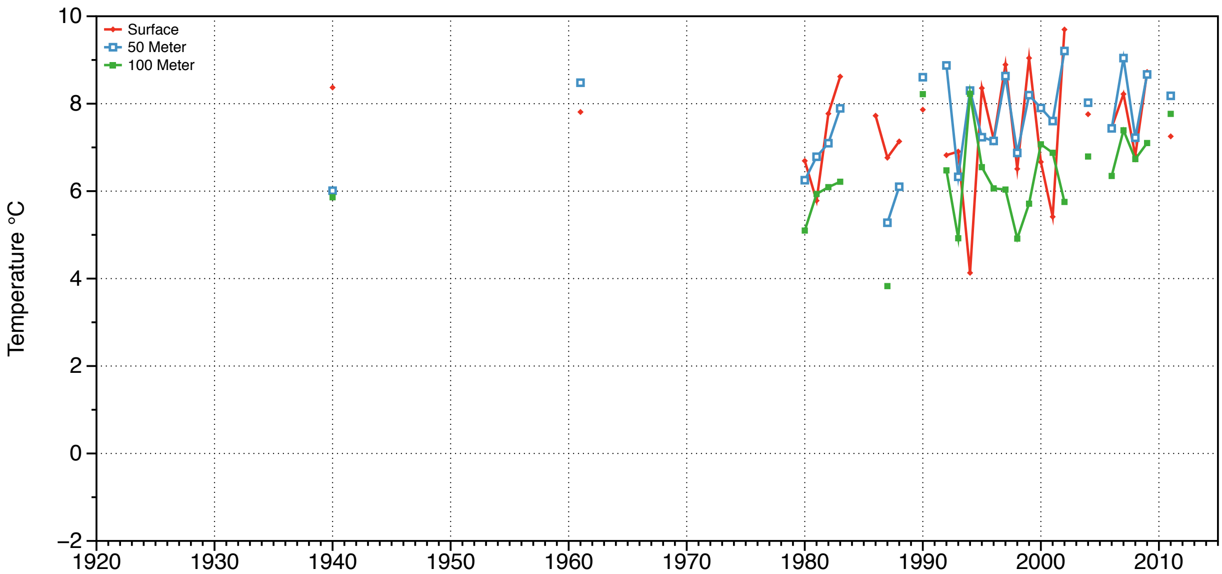


Figure 291: Interannual variability of autumn temperatures (September – October) at station Inner Altafjorden

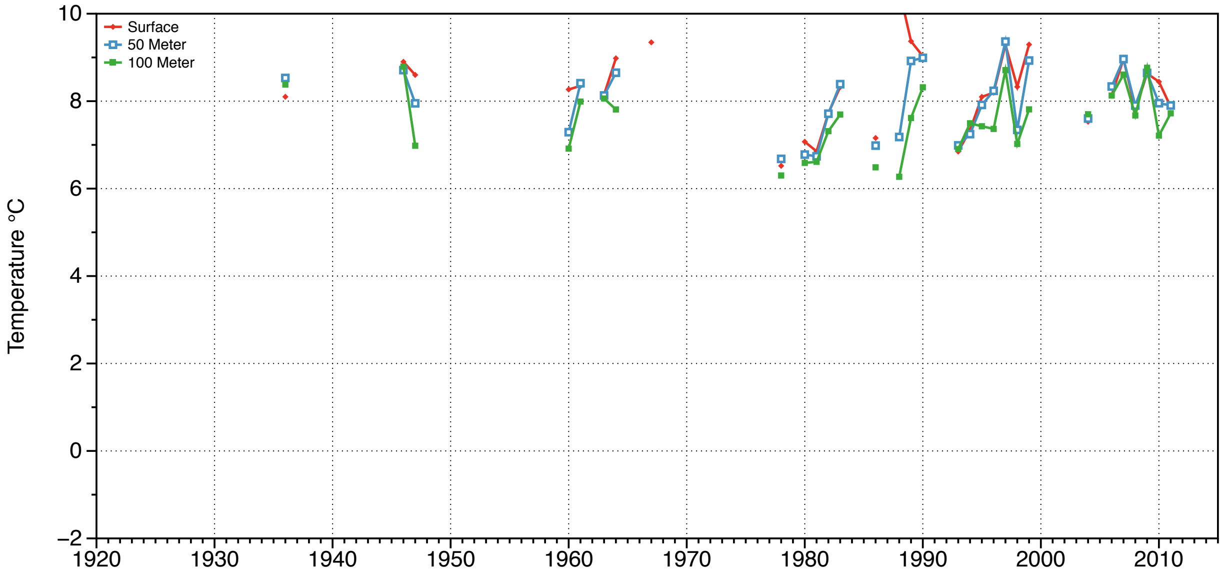


Figure 292: Interannual variability of autumn temperatures (September – October) at station Refsbotn

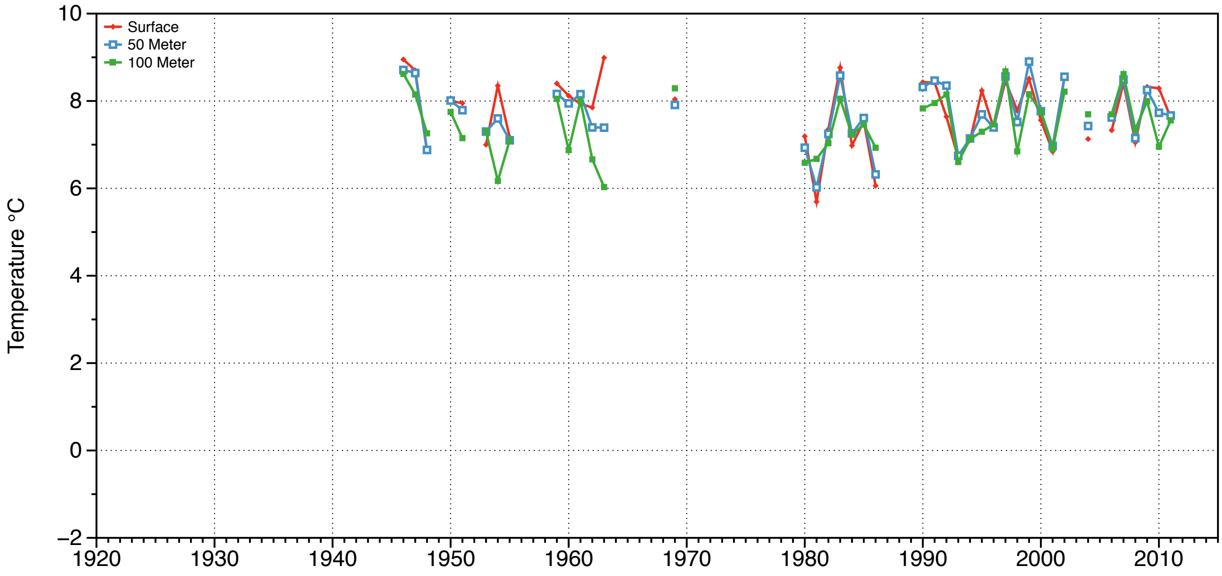


Figure 293: Interannual variability of autumn temperatures (September – October) at station Outer Porsanger-fjorden

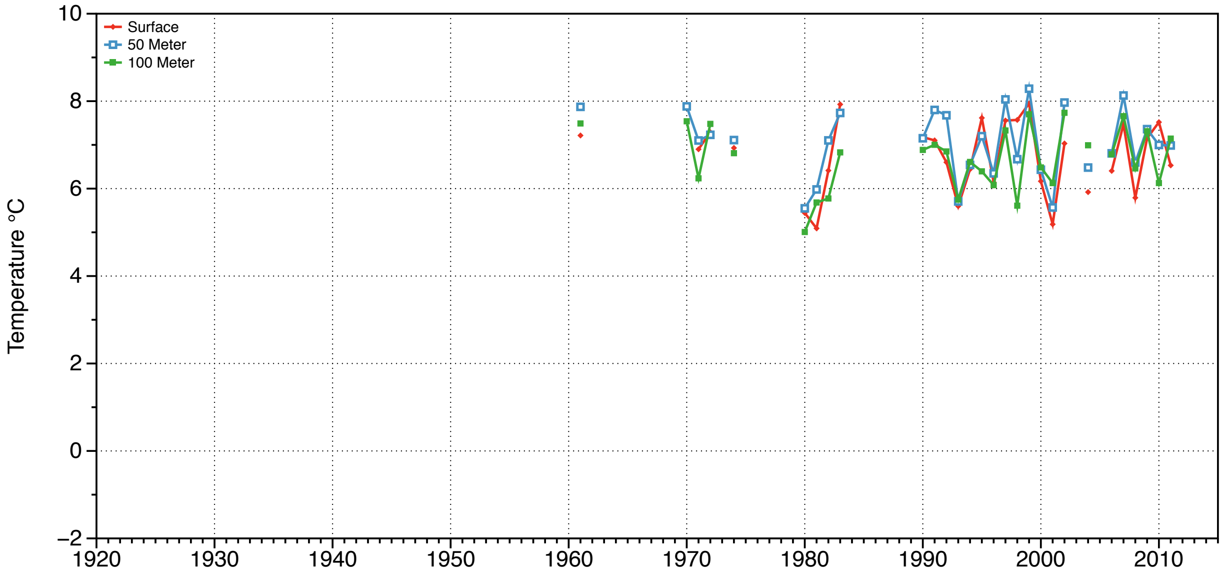


Figure 294: Interannual variability of autumn temperatures (September – October) at station Inner Porsanger-fjorden

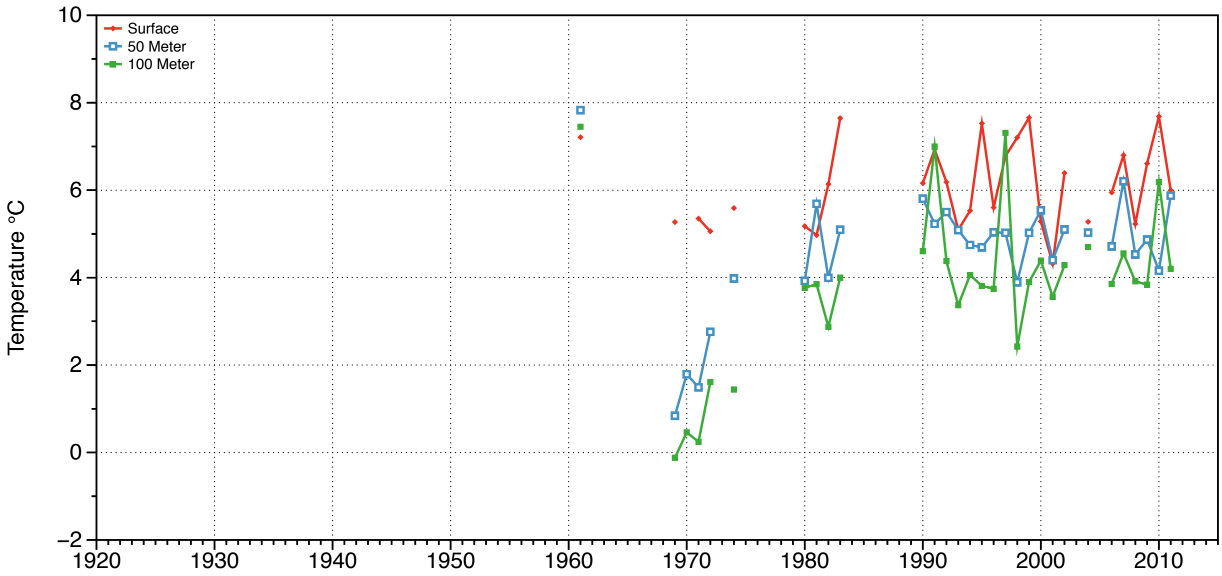


Figure 295: Interannual variability of autumn temperatures (September – October) at station Østerbotn

A.5 INTERANNUAL VARIABILITY IN SEASONAL SALINITY

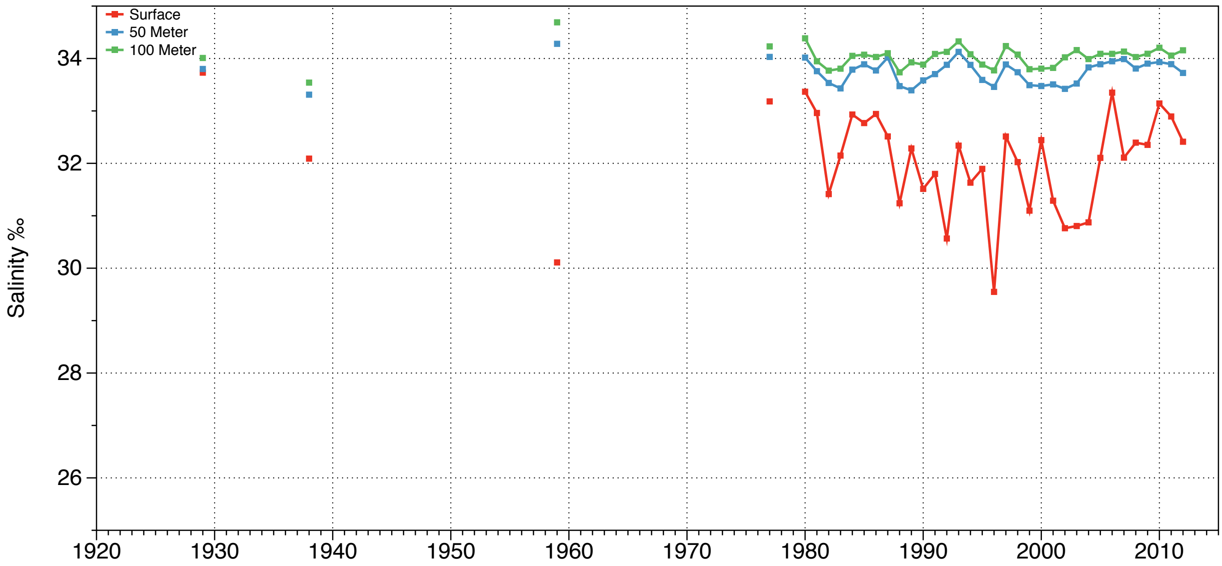


Figure 296: Interannual variability of winter salinity (November – February) at station Inner Malangen

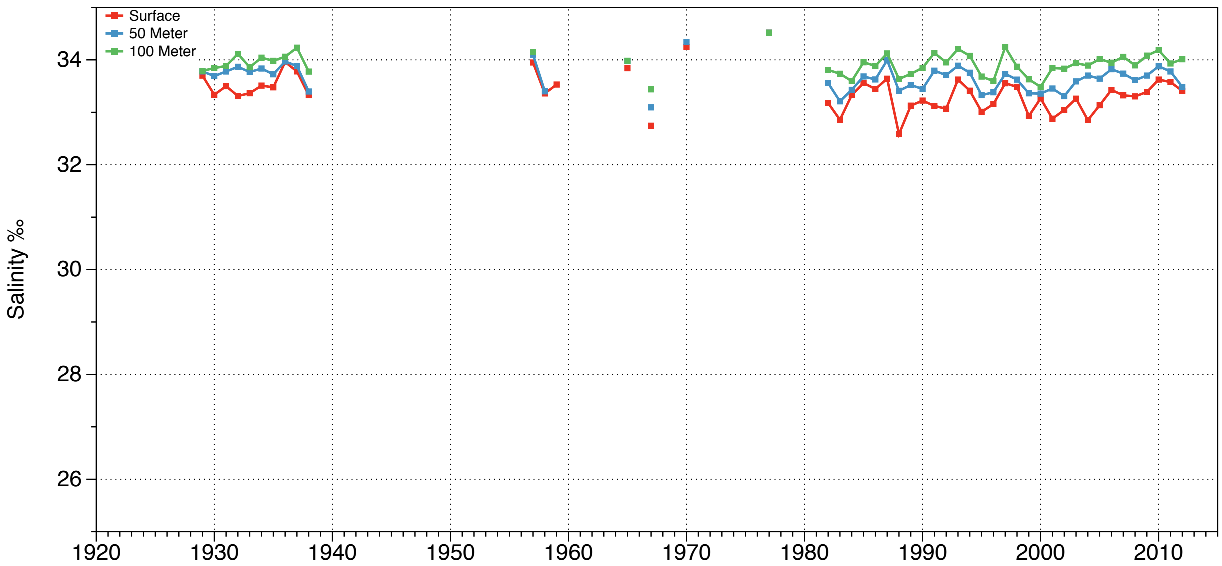


Figure 297: Interannual variability of winter salinity (November – February) at station Outer Malangen

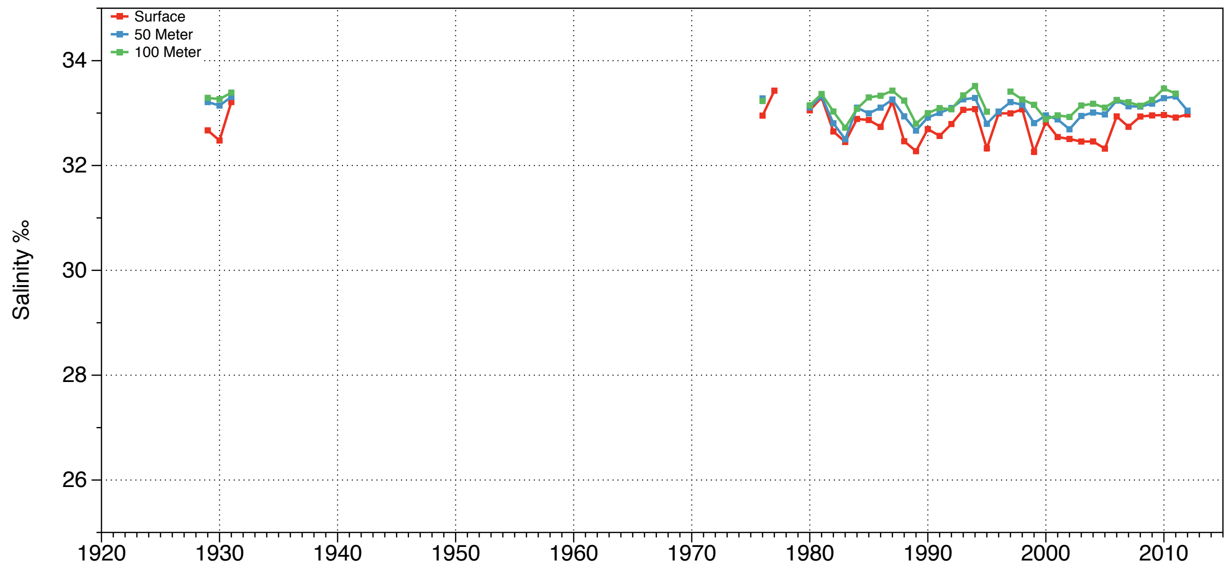


Figure 298: Interannual variability of winter salinity (November – February) at station Outer Balsfjorden

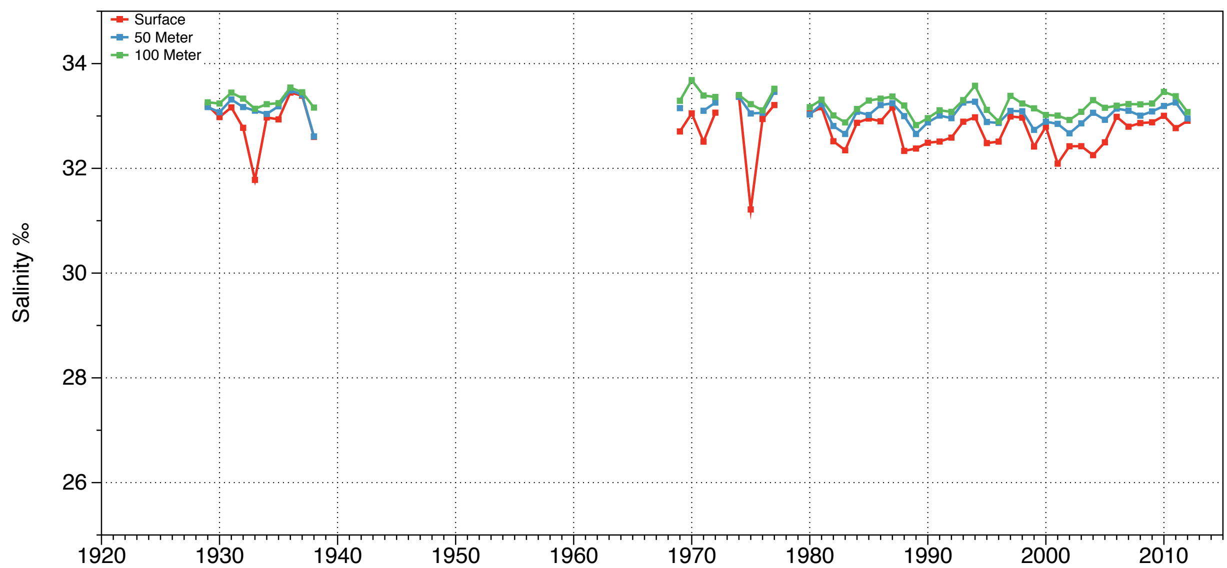


Figure 299: Interannual variability of winter salinity (November – February) at station Inner Balsfjorden

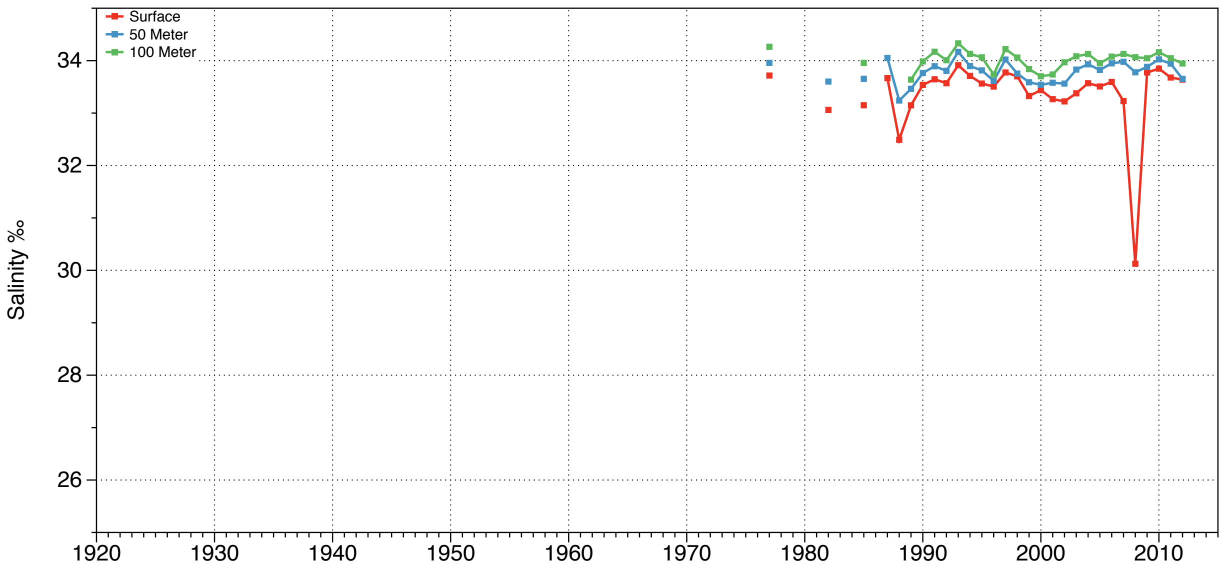


Figure 300: Interannual variability of winter salinity (November – February) at station Kvalsund

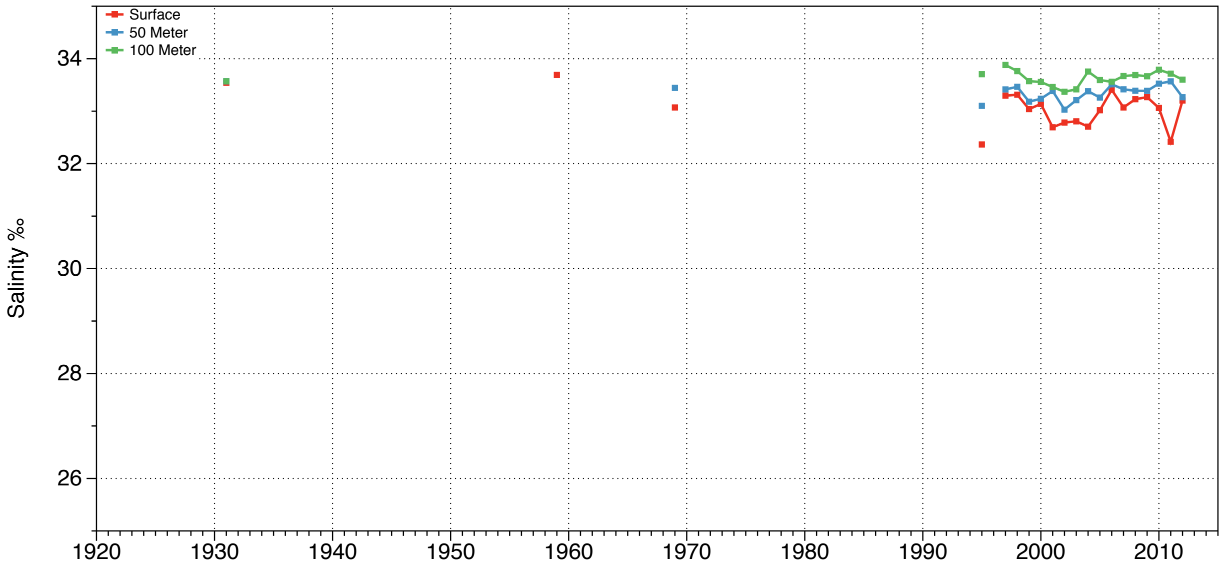


Figure 301: Interannual variability of winter salinity (November – February) at station Sørfjord

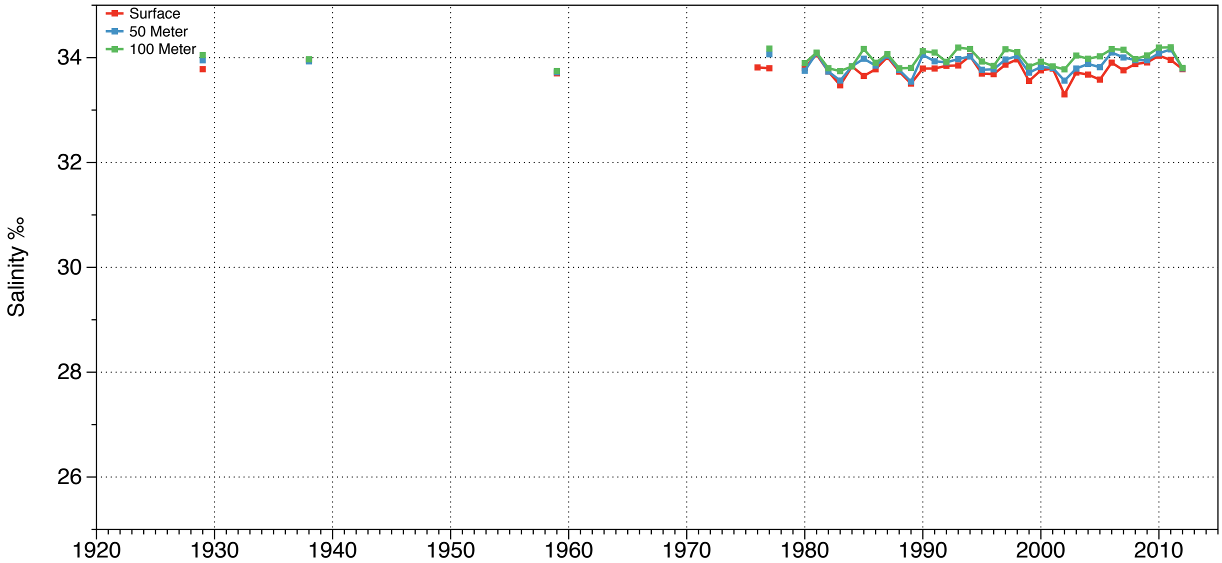


Figure 302: Interannual variability of winter salinity (November – February) at station Outer Altafjorden

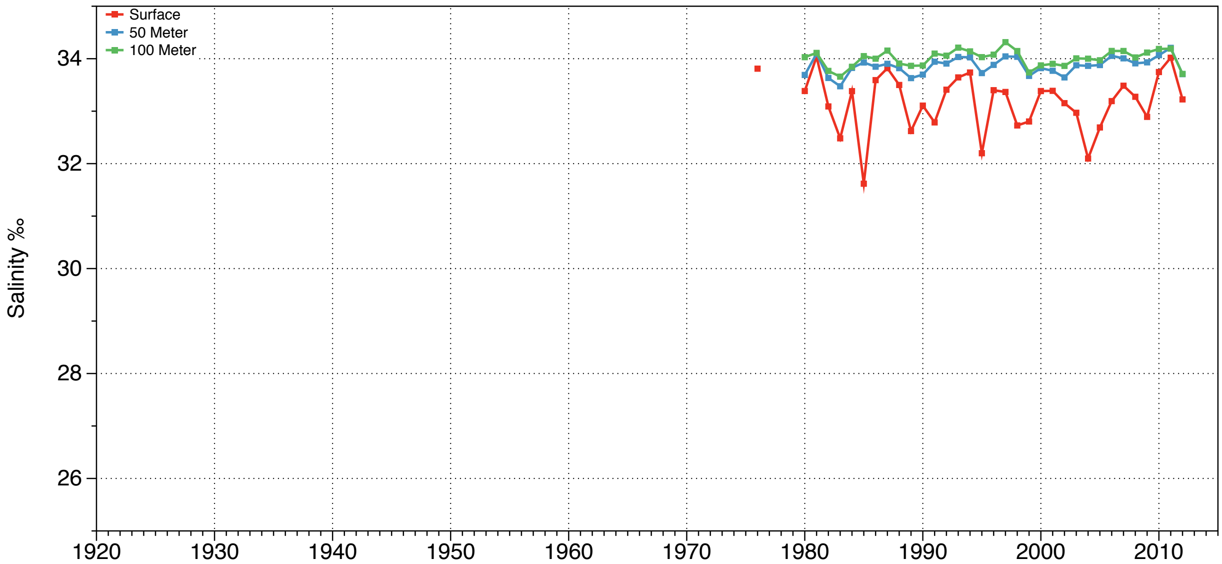


Figure 303: Interannual variability of winter salinity (November – February) at station Inner Altafjorden

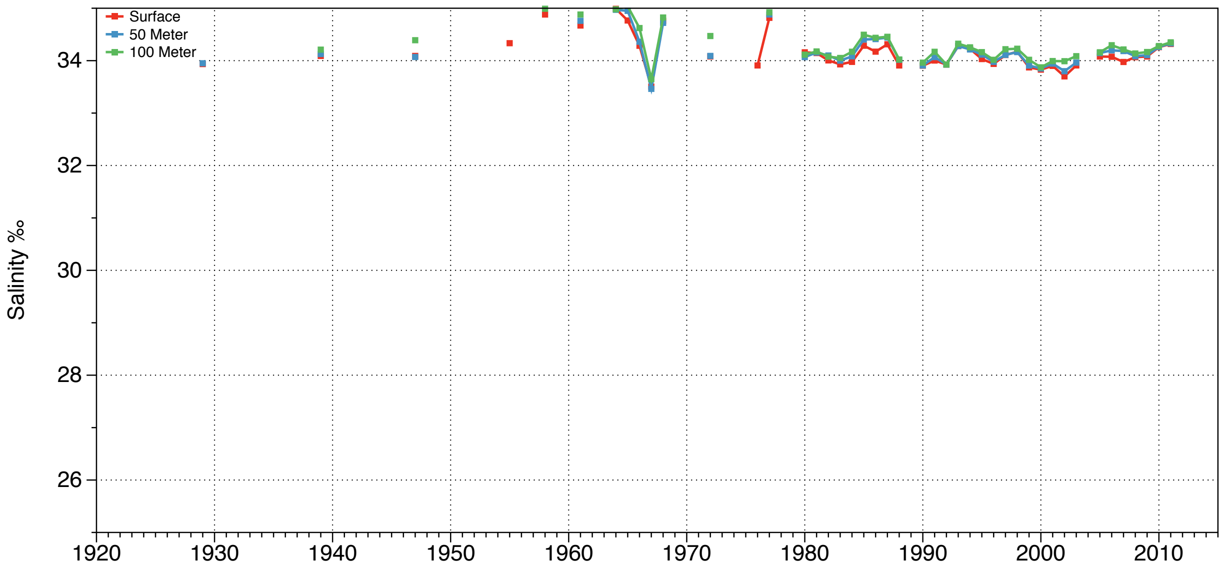


Figure 304: Interannual variability of winter salinity (November – February) at station Refsbotn

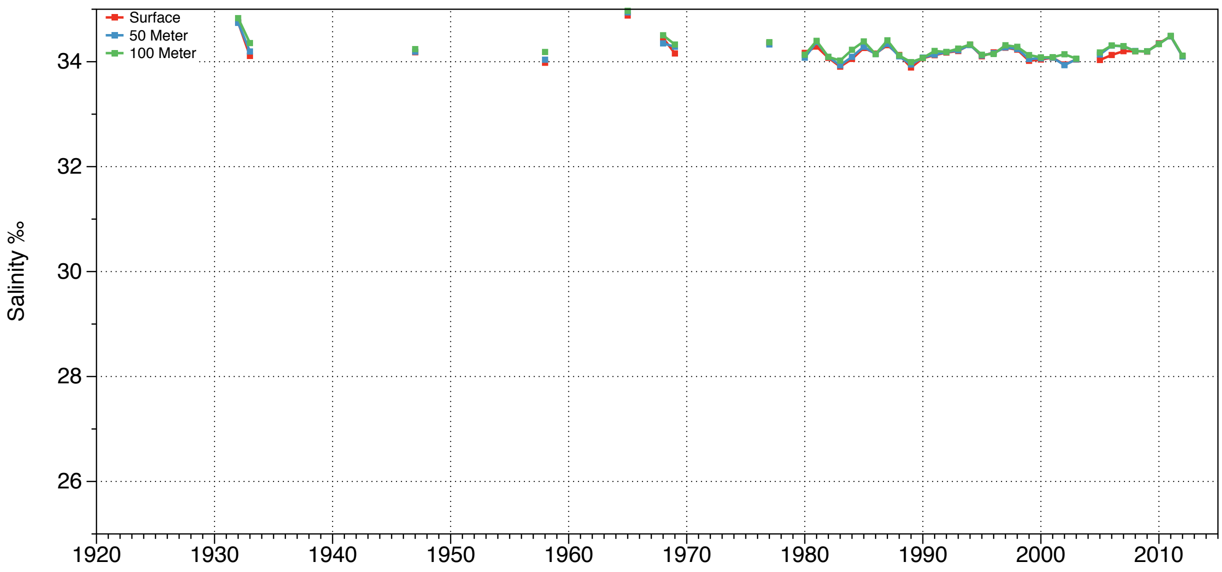


Figure 305: Interannual variability of winter salinity (November – February) at station Outer Porsangerfjorden

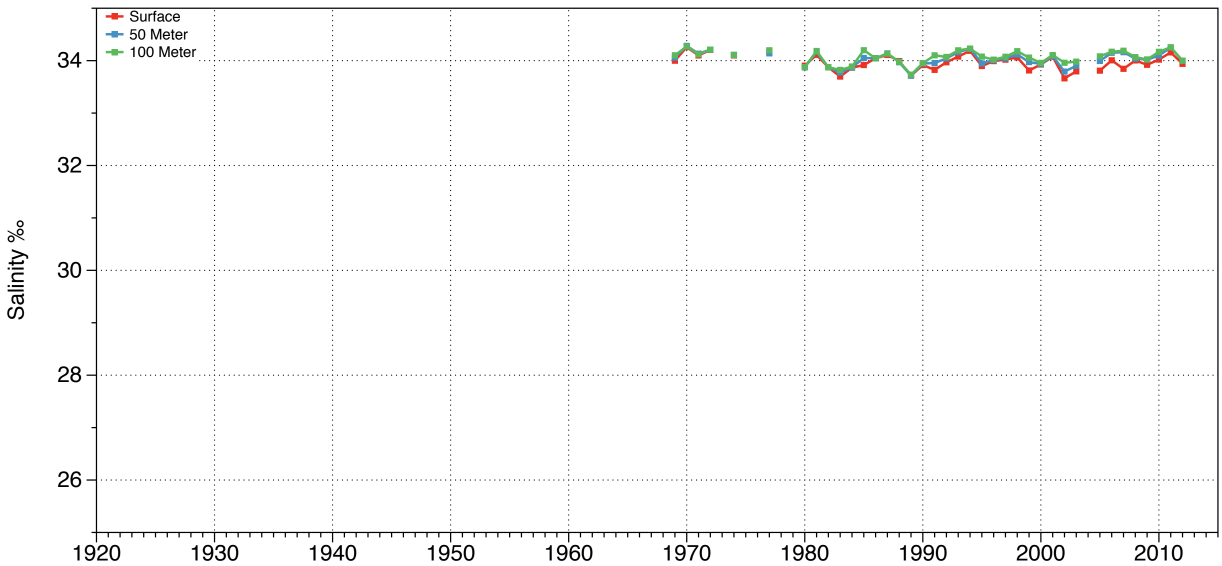


Figure 306: Interannual variability of winter salinity (November – February) at station Inner Porsangerfjorden

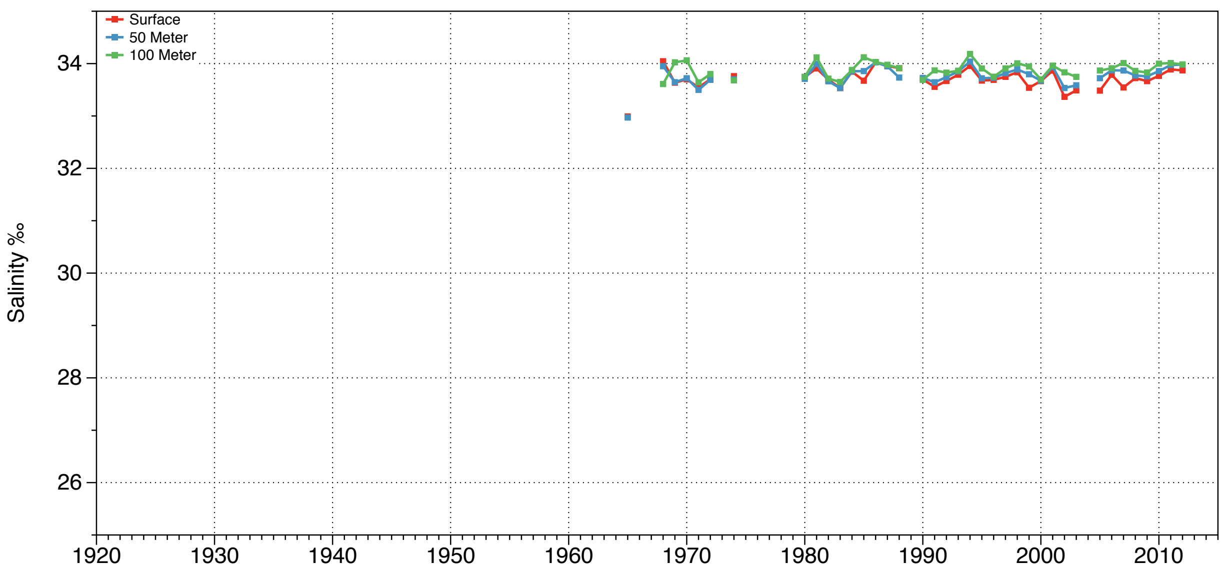


Figure 307: Interannual variability of winter salinity (November – February) at station Østerbotn

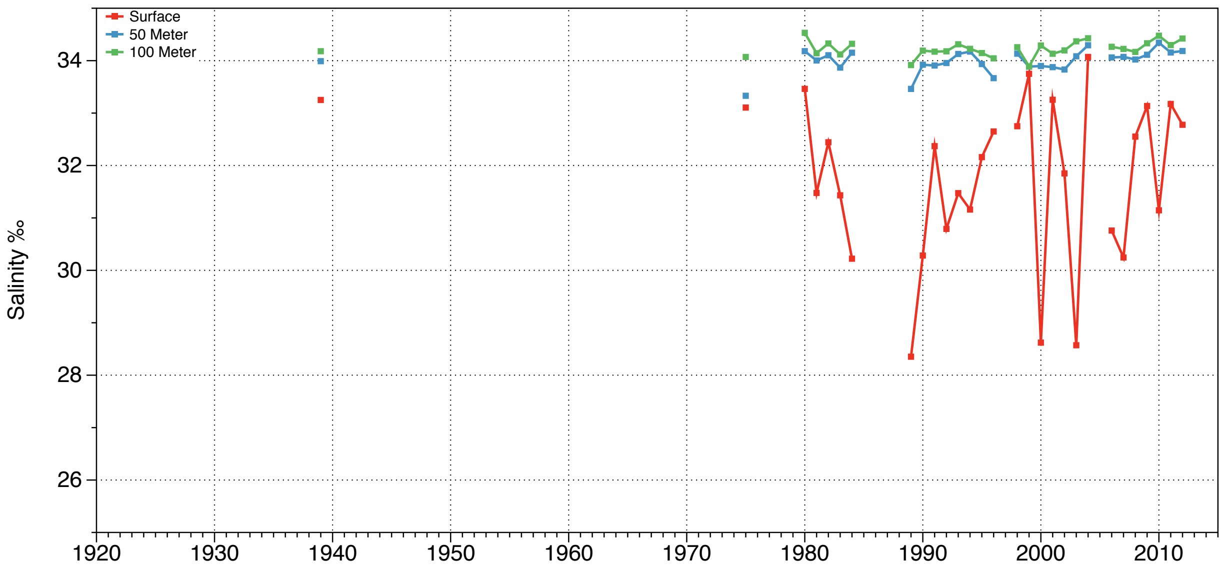


Figure 308: Interannual variability of spring salinity (March – May) at station Inner Malangen

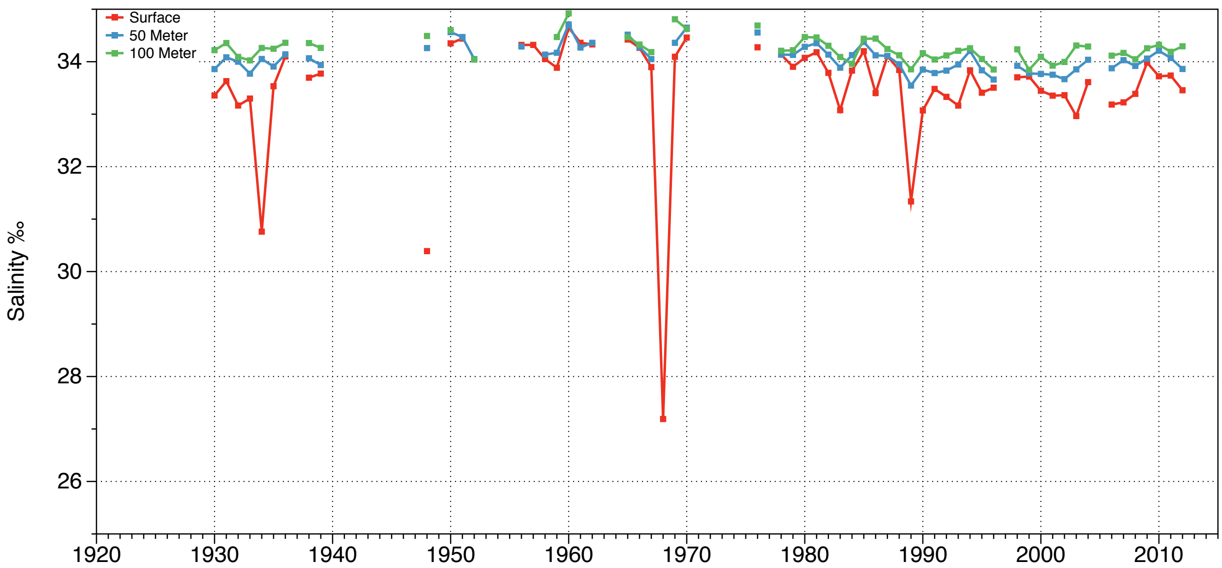


Figure 309: Interannual variability of spring salinity (March – May) at station Outer Malangen

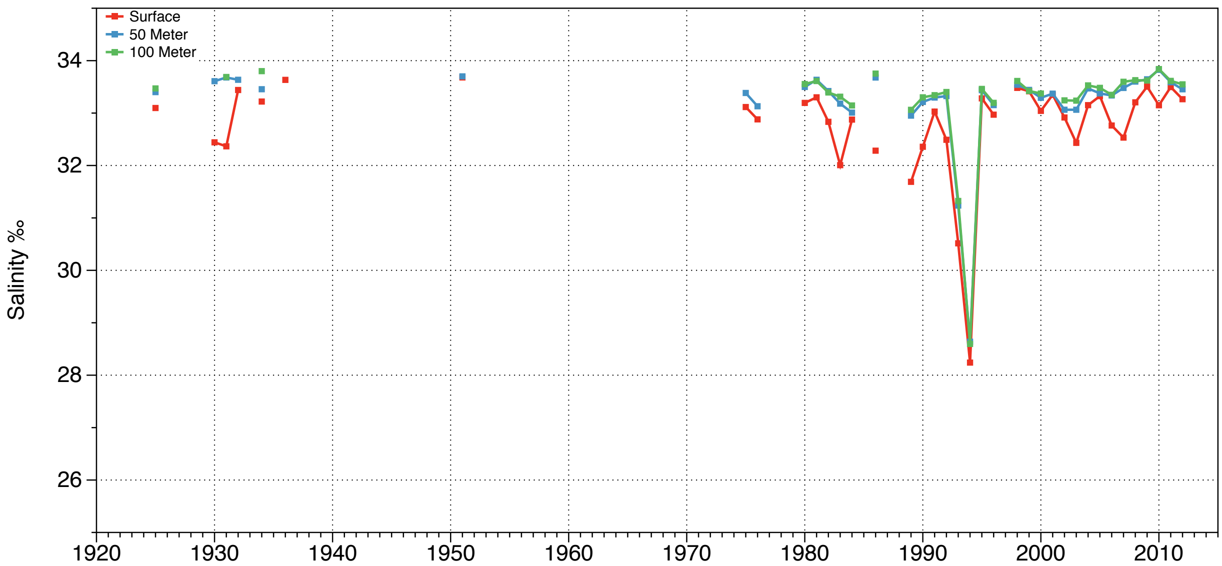


Figure 310: Interannual variability of spring salinity (March – May) at station Outer Balsfjorden

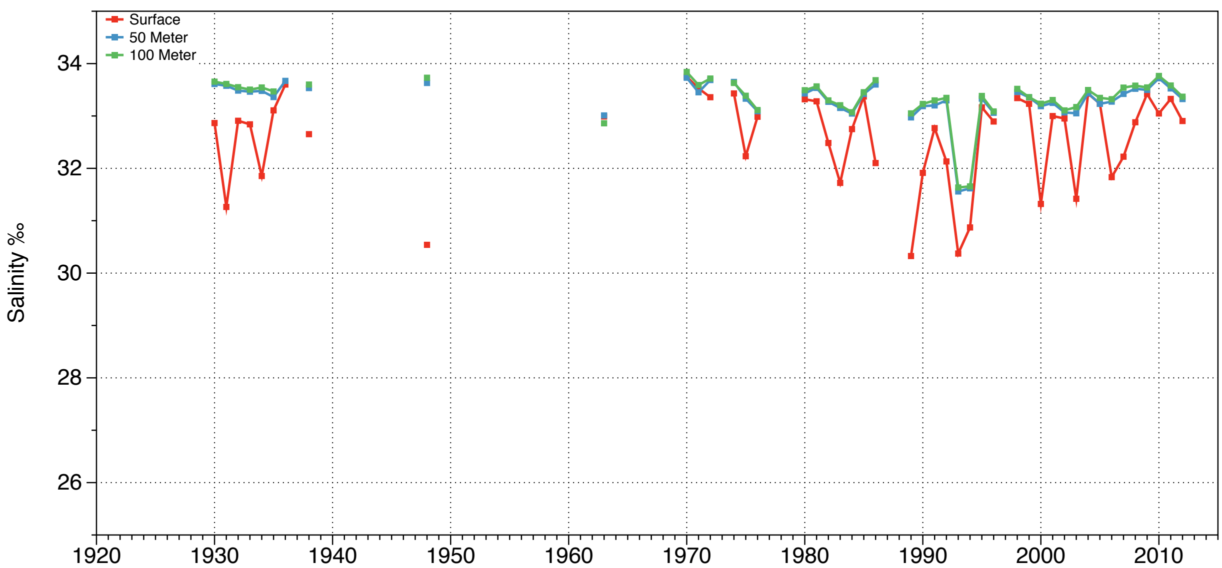


Figure 311: Interannual variability of spring salinity (March – May) at station Inner Balsfjorden

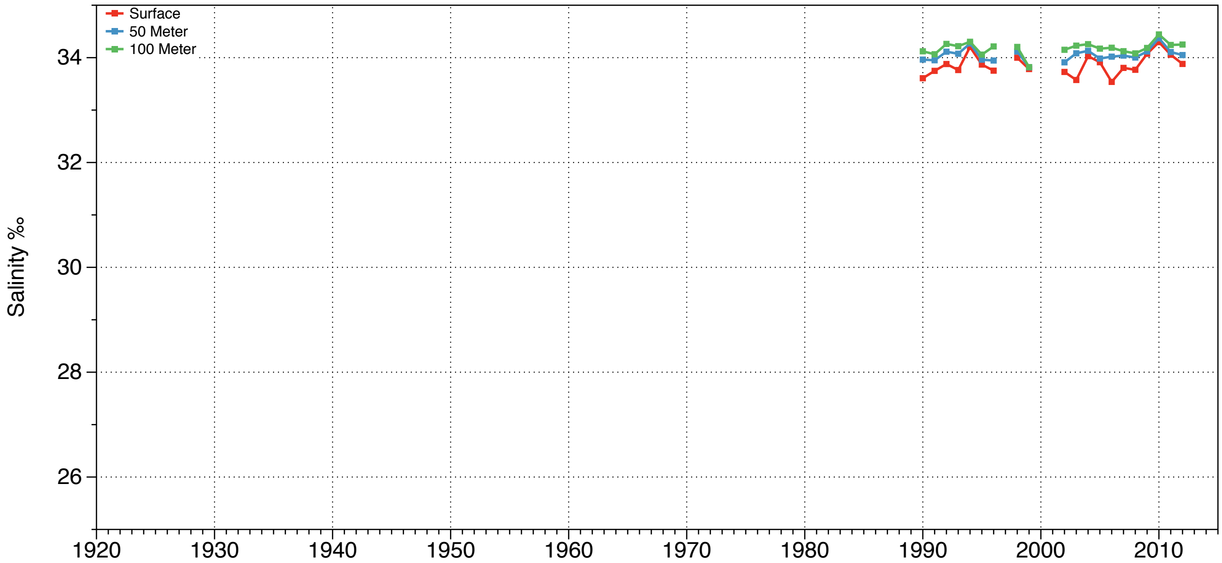


Figure 312: Interannual variability of spring salinity (March – May) at station Kvalsund

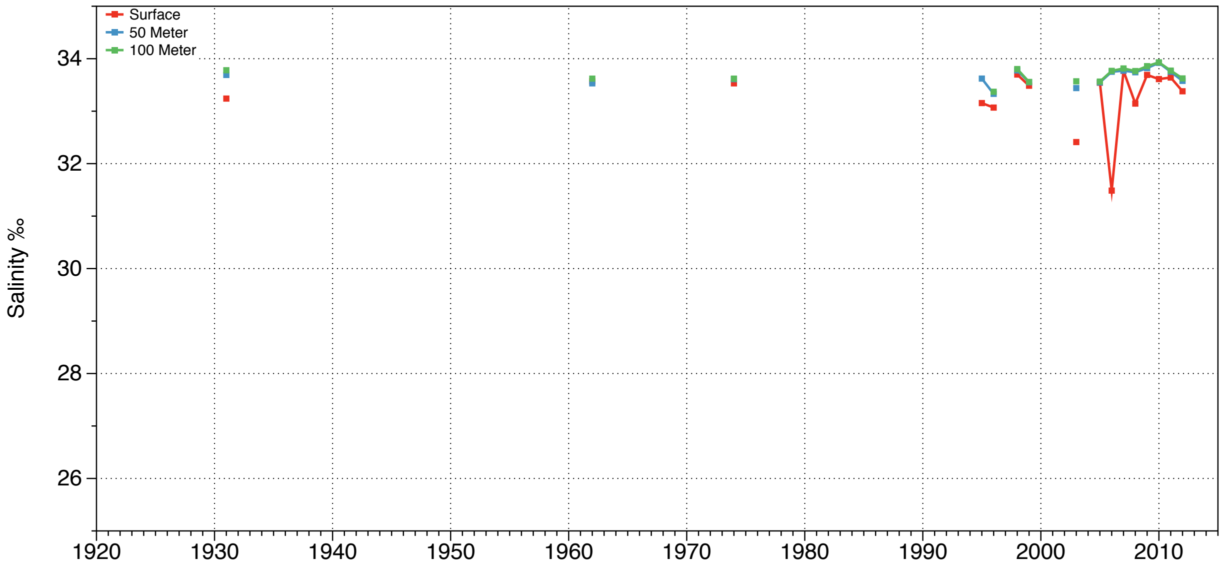


Figure 313: Interannual variability of spring salinity (March – May) at station Sørfjord

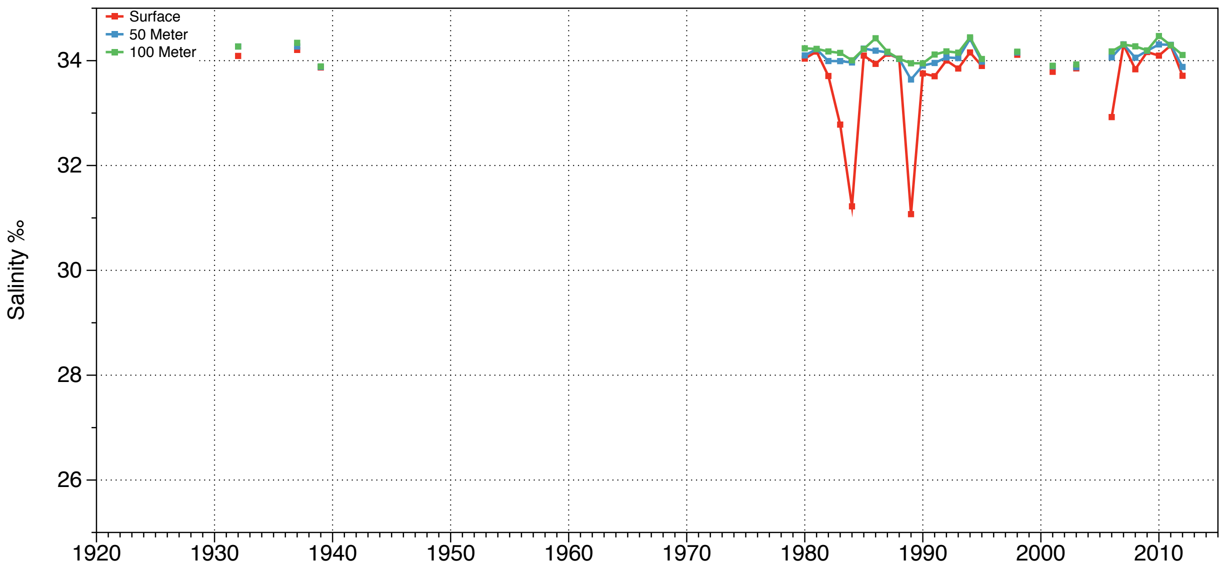


Figure 314: Interannual variability of spring salinity (March – May) at station Outer Altafjorden

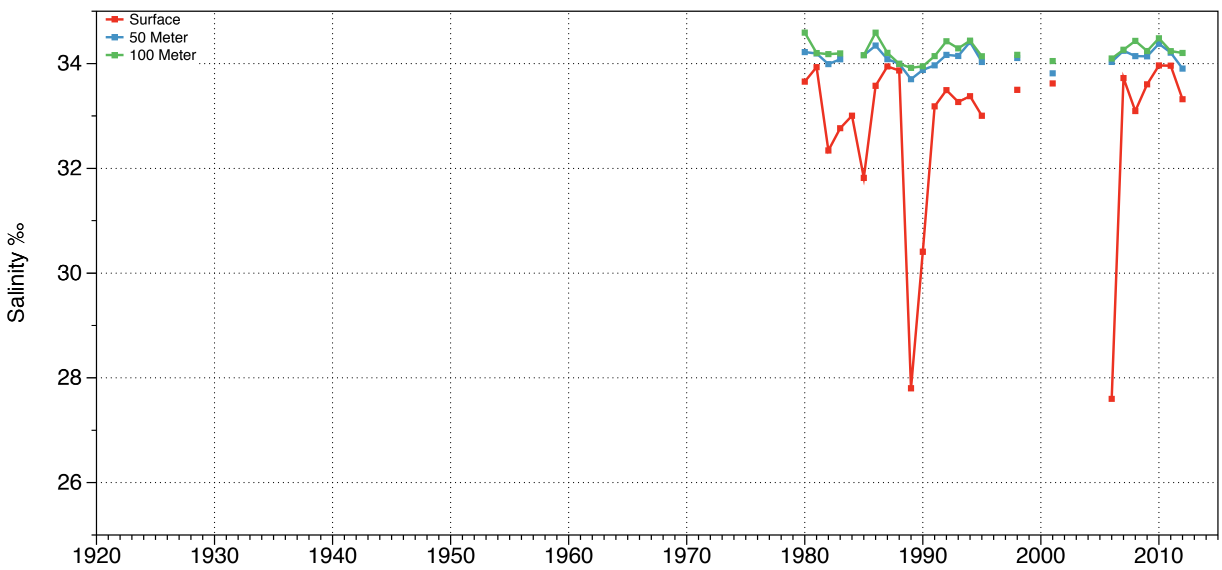


Figure 315: Interannual variability of spring salinity (March – May) at station Inner Altafjorden

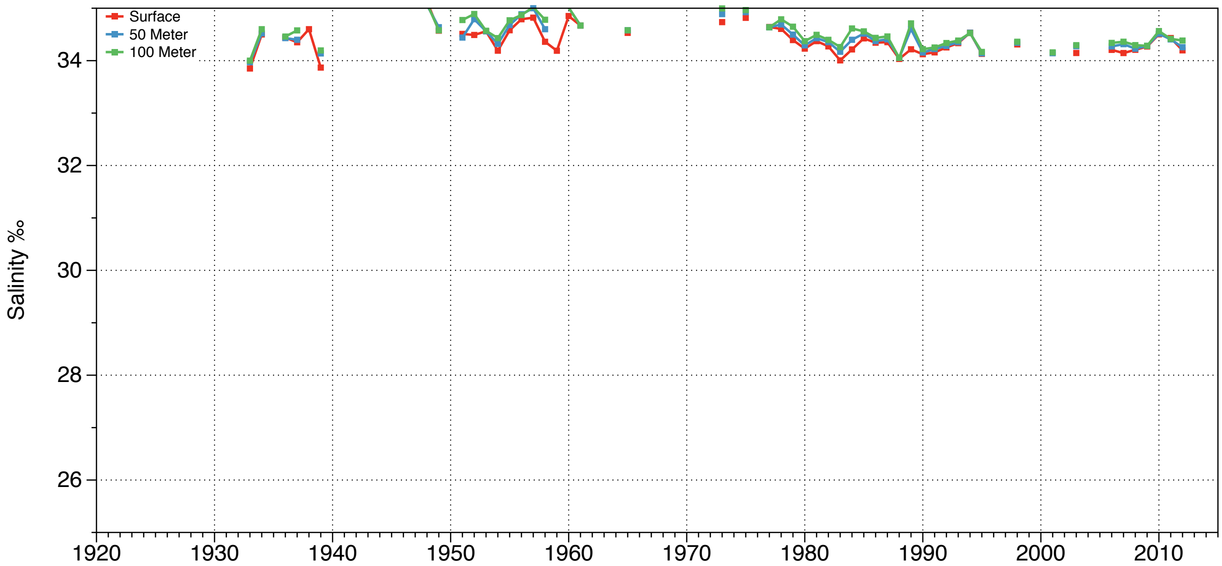


Figure 316: Interannual variability of spring salinity (March – May) at station Refsbotn

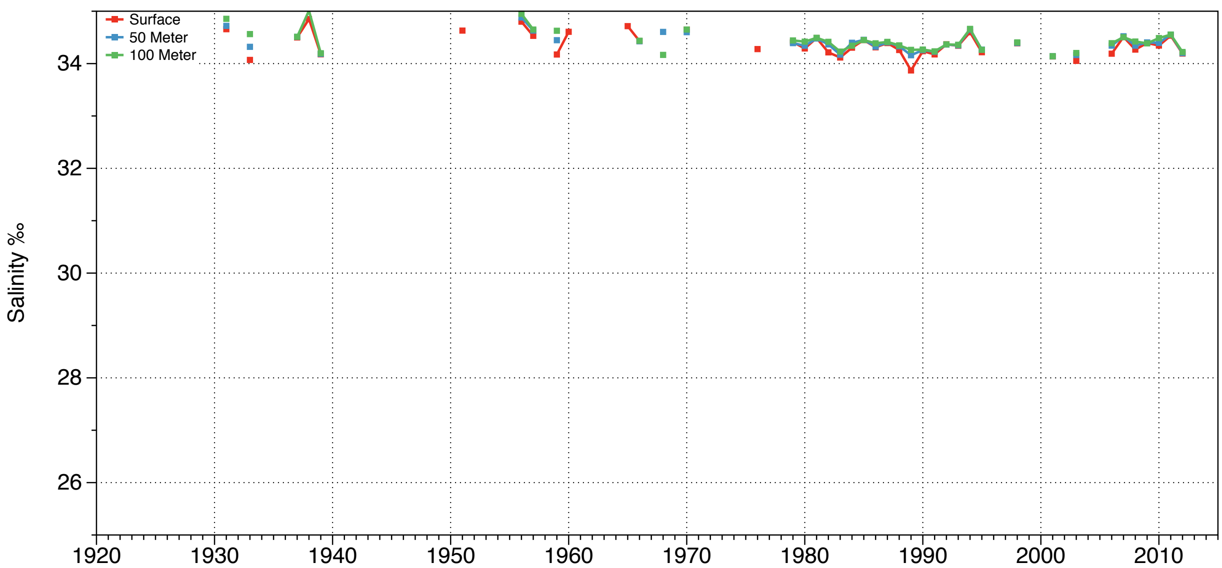


Figure 317: Interannual variability of spring salinity (March – May) at station Outer Porsangerfjorden

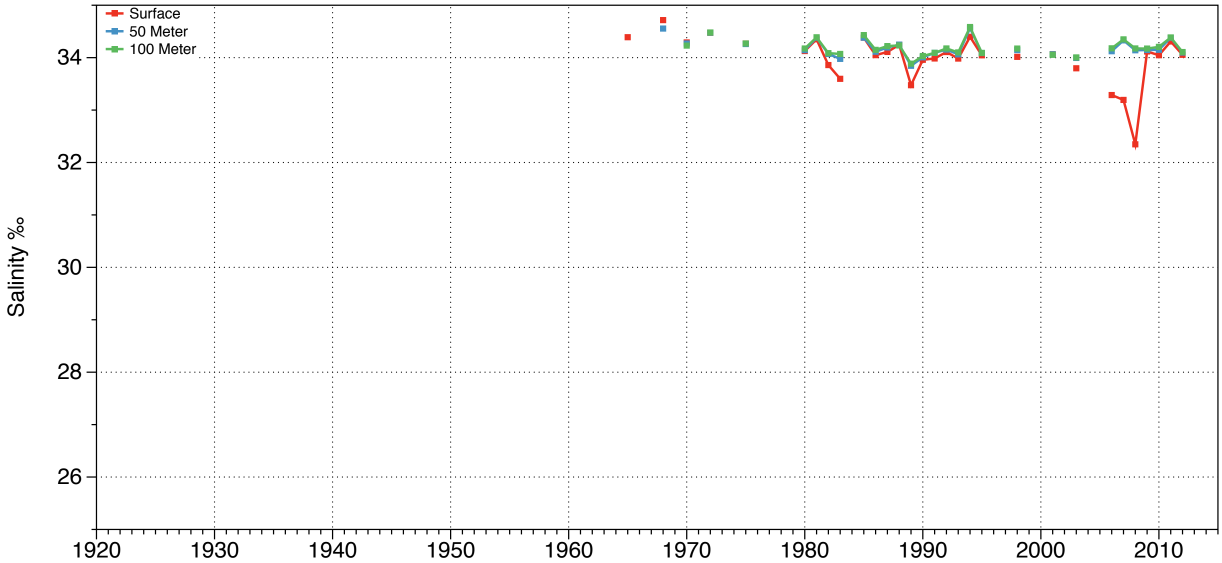


Figure 318: Interannual variability of spring salinity (March – May) at station Inner Porsangerfjorden

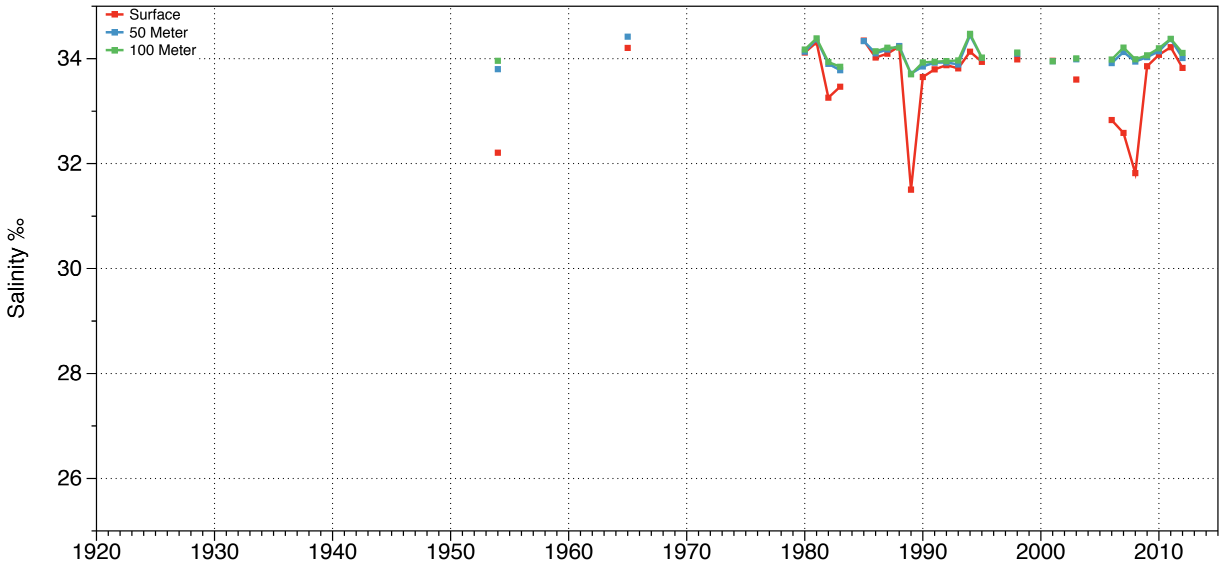


Figure 319: Interannual variability of spring salinity (March – May) at station Østerbotn

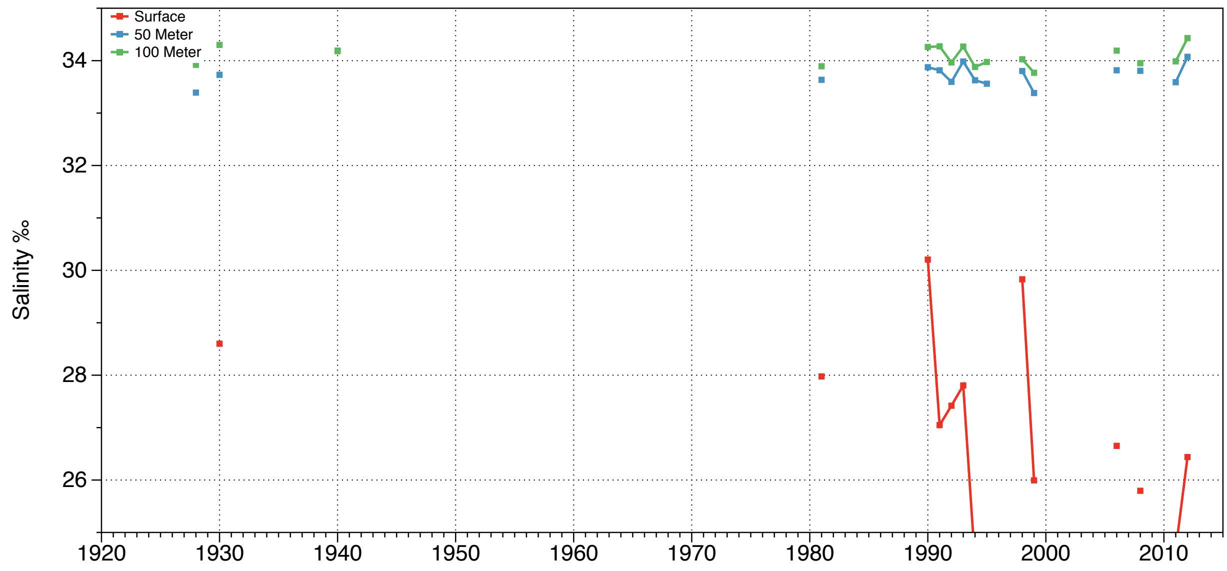


Figure 320: Interannual variability of summer salinity (June – August) at station Inner Malangen

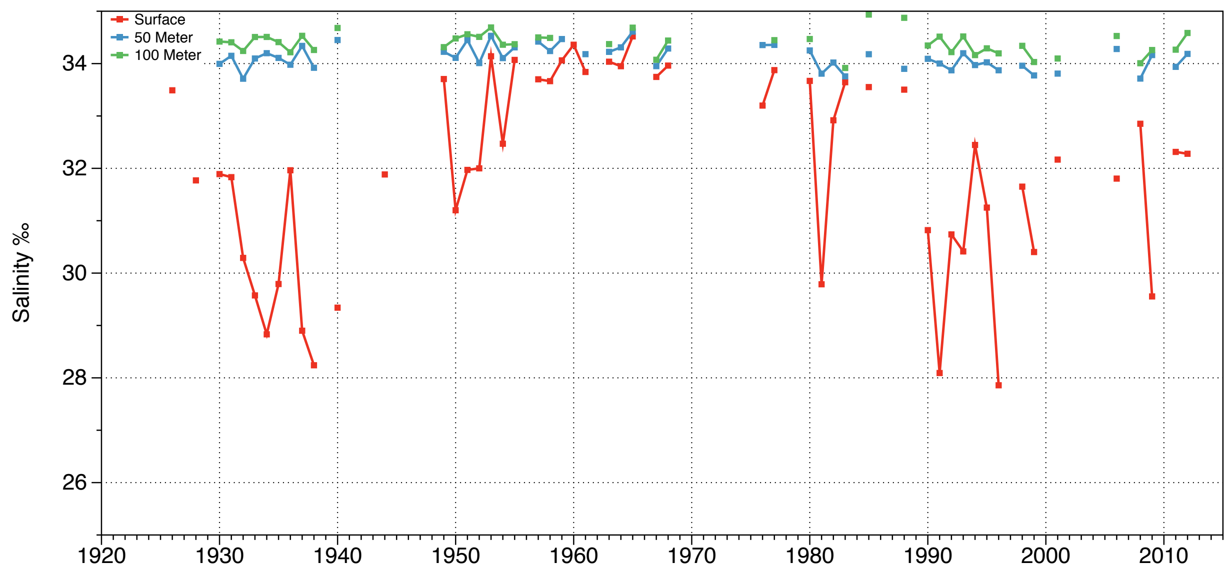


Figure 321: Interannual variability of summer salinity (June – August) at station Outer Malangen

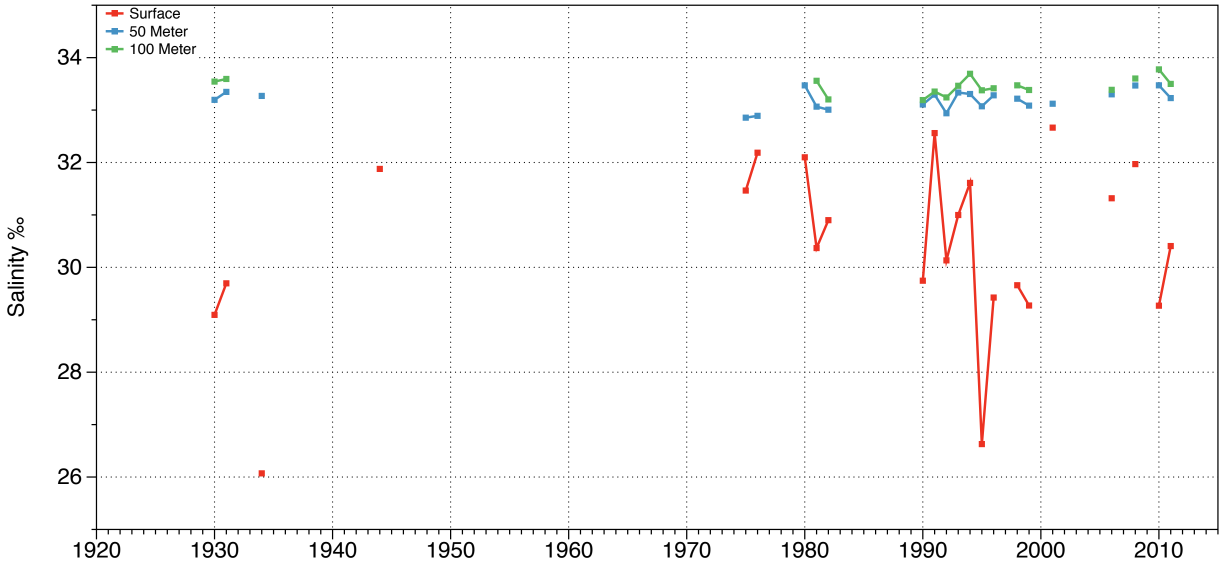


Figure 322: Interannual variability of summer salinity (June – August) at station Outer Balsfjorden

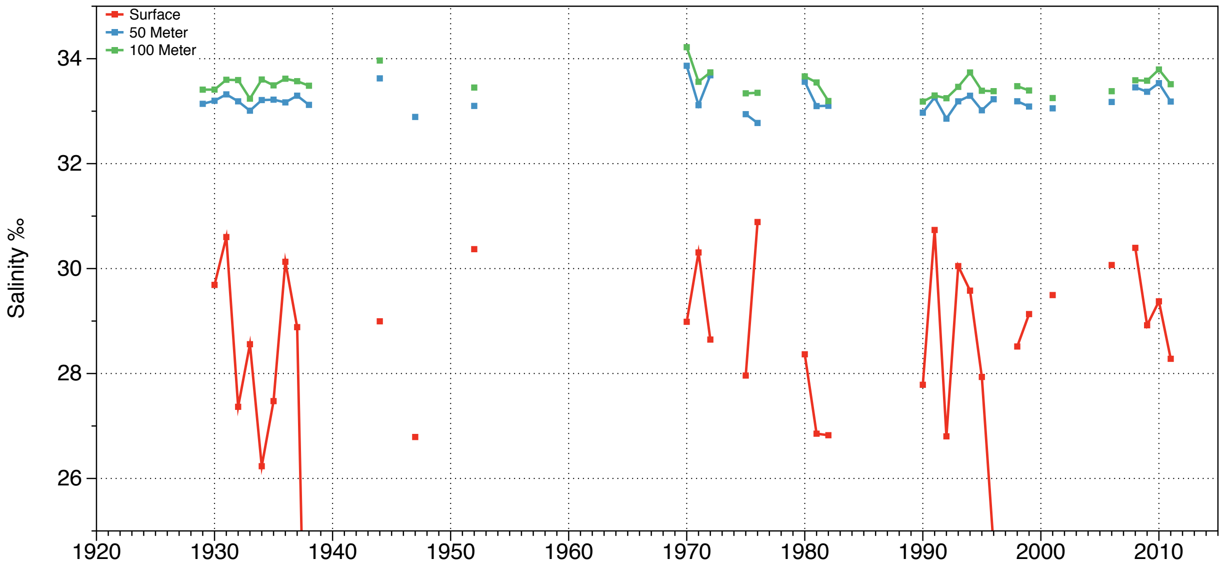


Figure 323: Interannual variability of summer salinity (June – August) at station Inner Balsfjorden

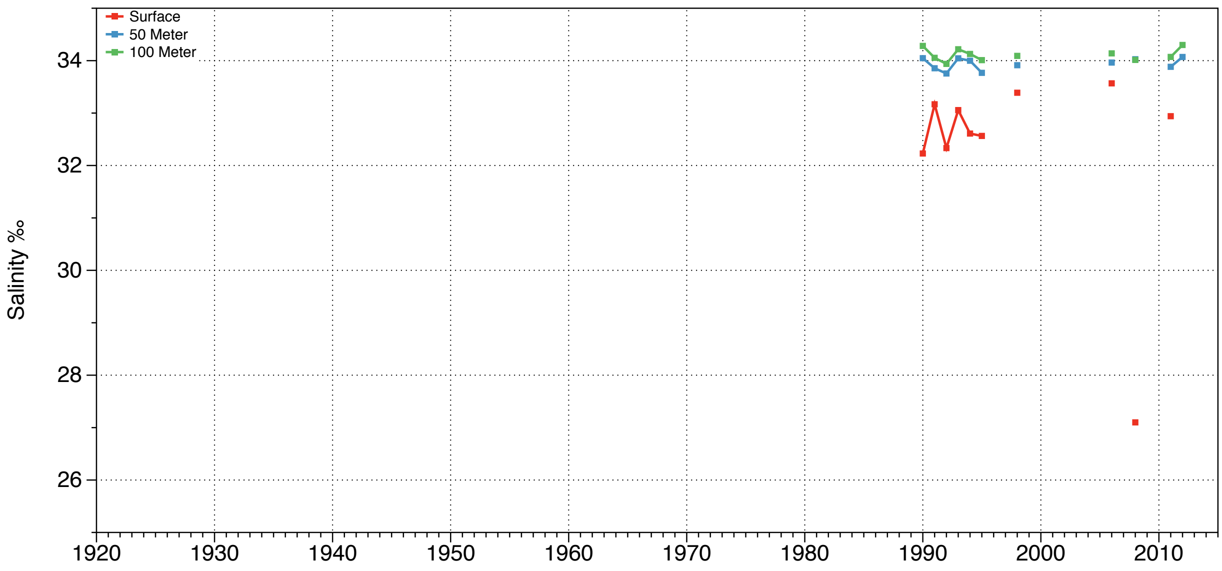


Figure 324: Interannual variability of summer salinity (June – August) at station Kvalsund

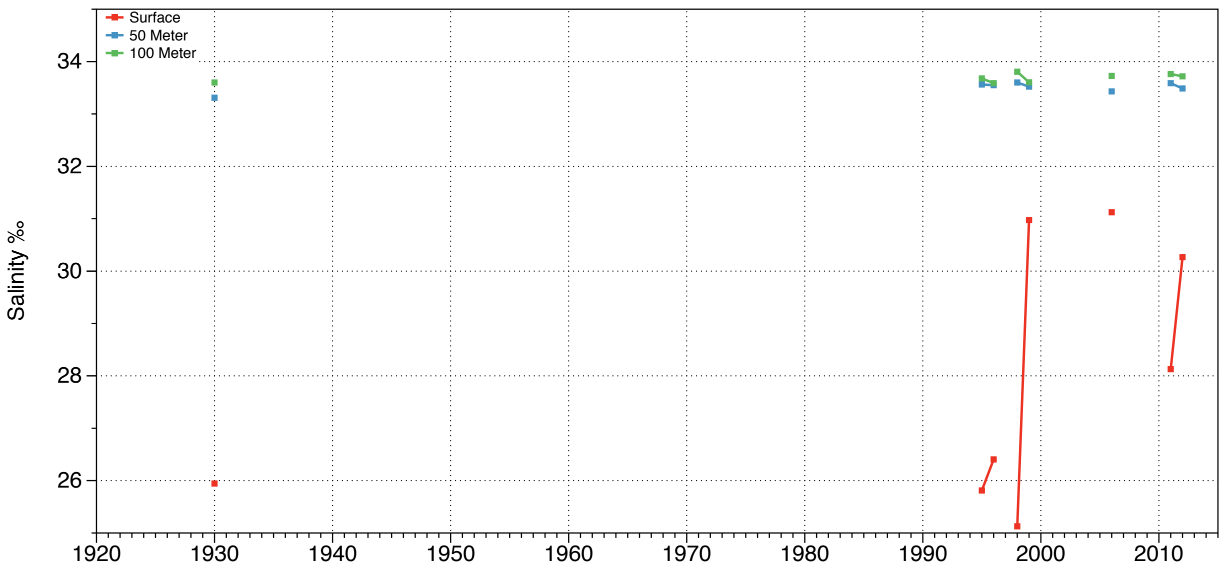


Figure 325: Interannual variability of summer salinity (June – August) at station Sørfjord

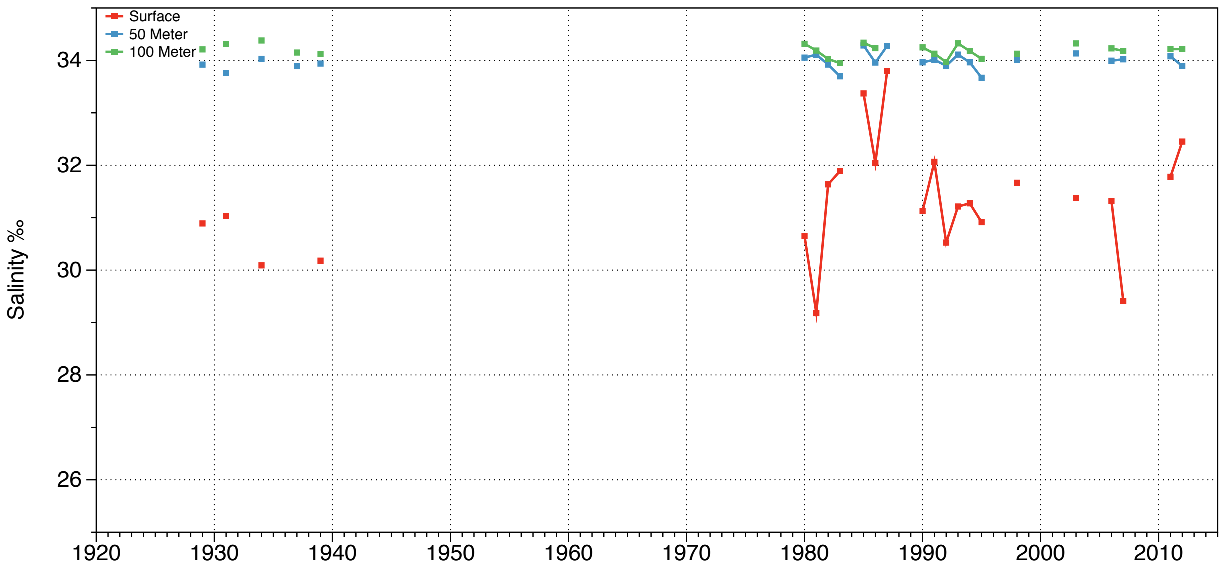


Figure 326: Interannual variability of summer salinity (June – August) at station Outer Altafjorden

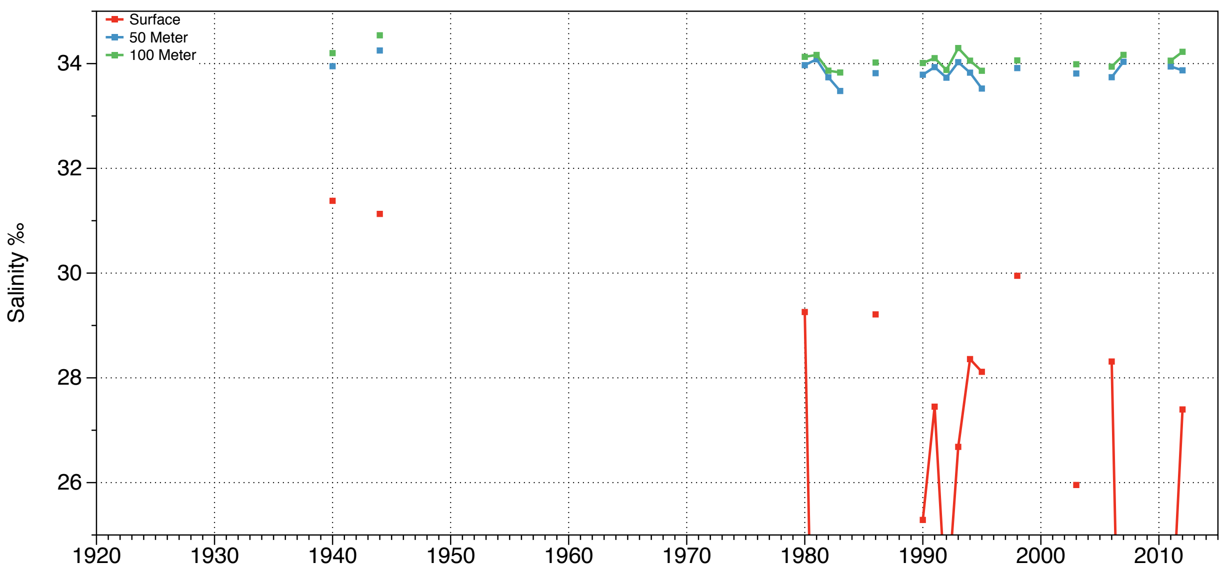


Figure 327: Interannual variability of summer salinity (June – August) at station Inner Altafjorden

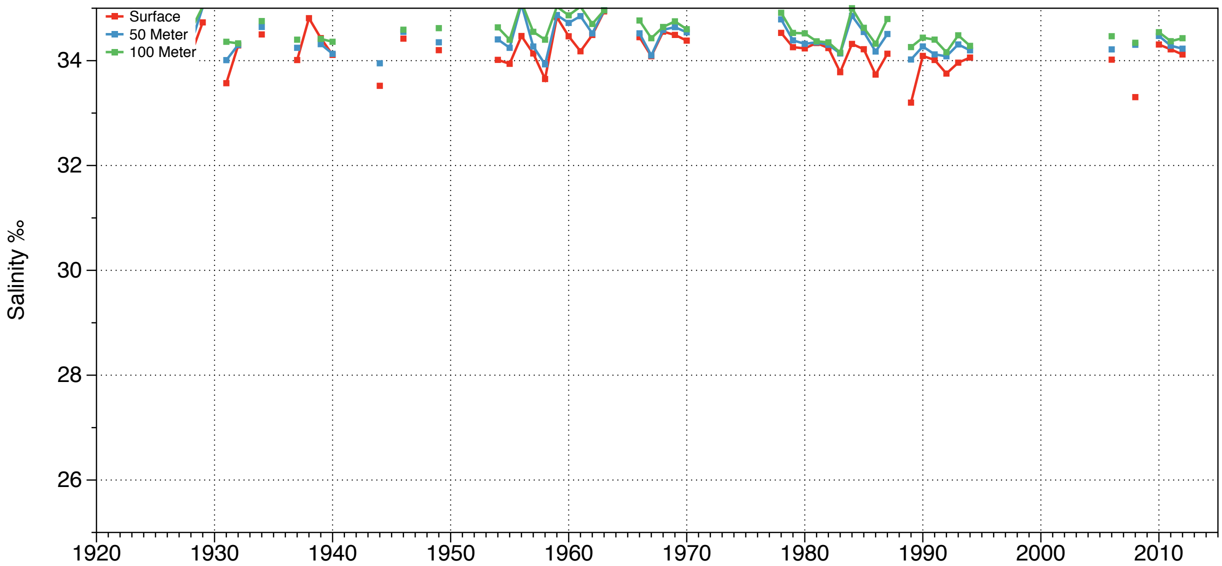


Figure 328: Interannual variability of summer salinity (June – August) at station Refsbotn

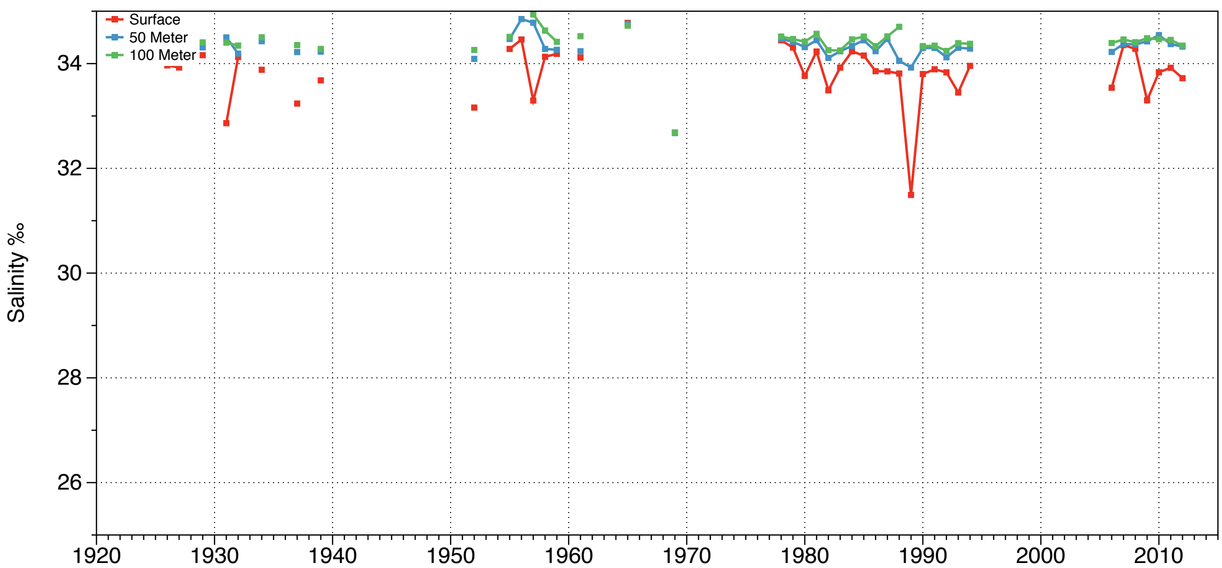


Figure 329: Interannual variability of summer salinity (June – August) at station Outer Porsangerfjorden

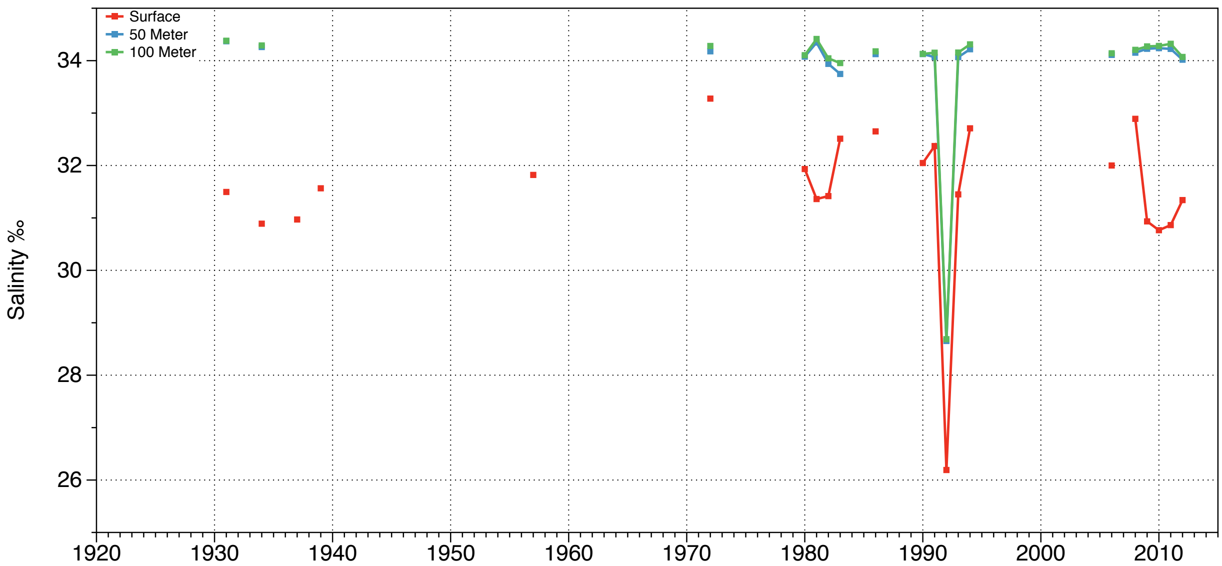


Figure 330: Interannual variability of summer salinity (June – August) at station Inner Porsangerfjorden

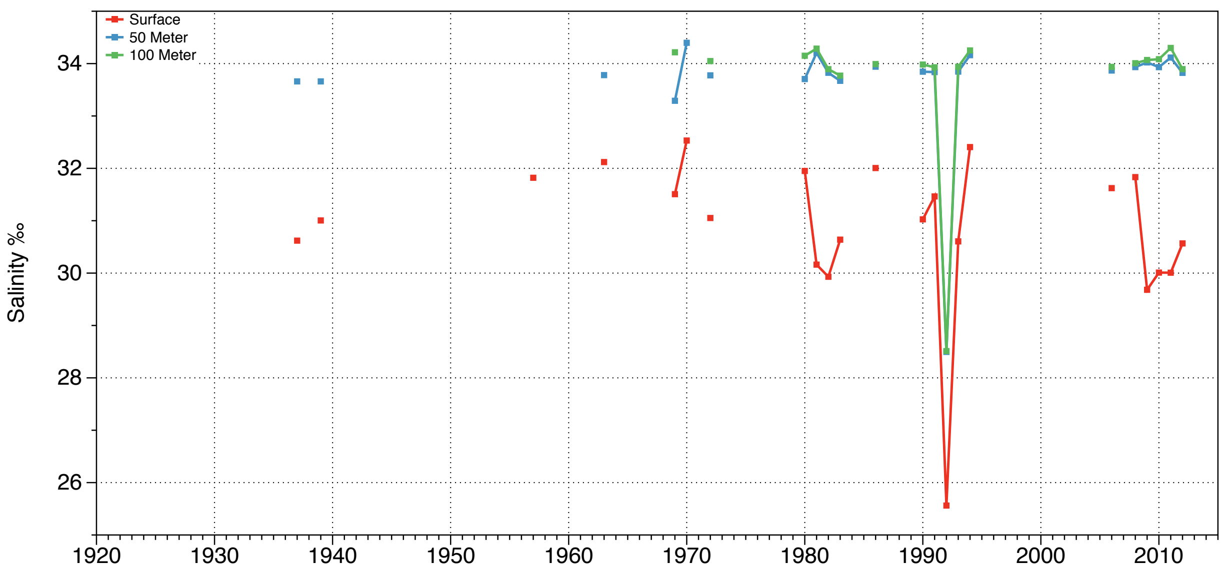


Figure 331: Interannual variability of summer salinity (June – August) at station Østerbotn

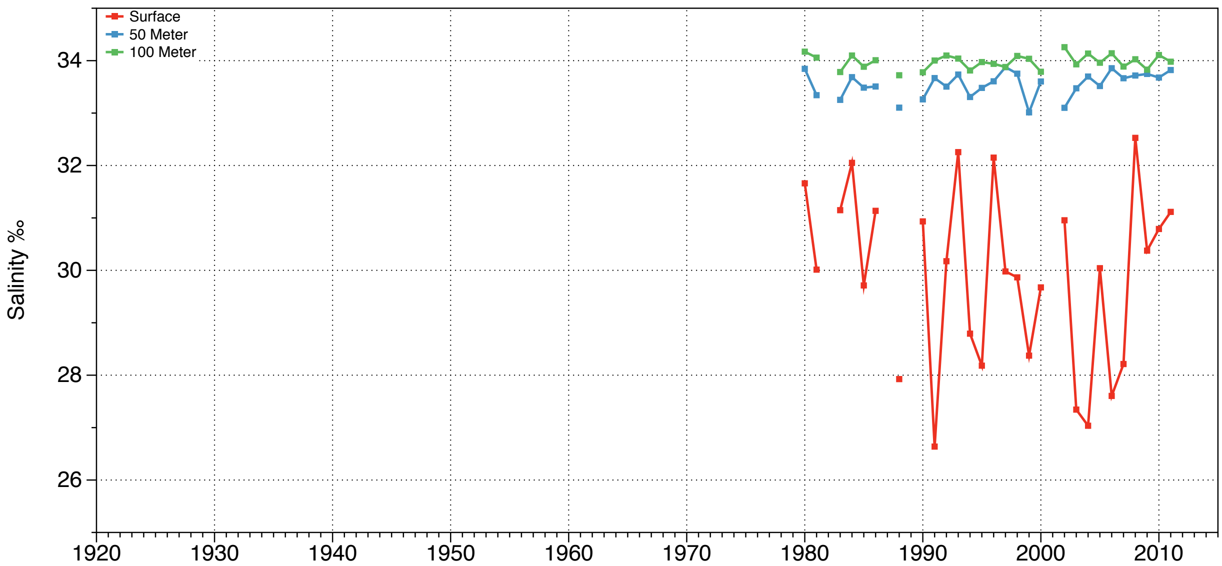


Figure 332: Interannual variability of autumn salinity (September – October) at station Inner Malangen

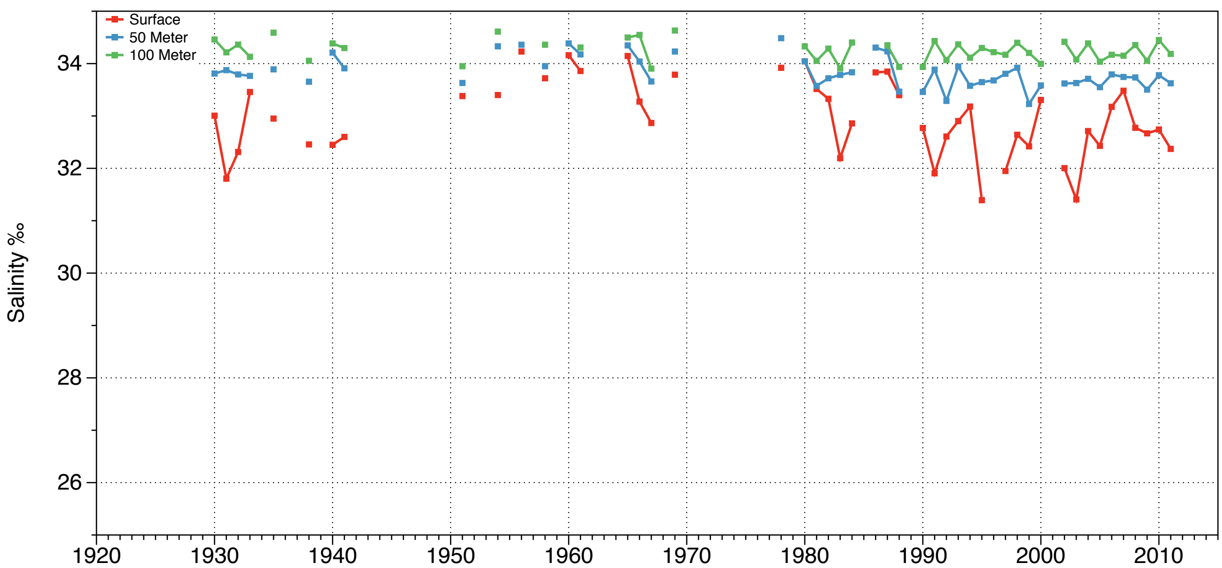


Figure 333: Interannual variability of autumn salinity (September – October) at station Outer Malangen

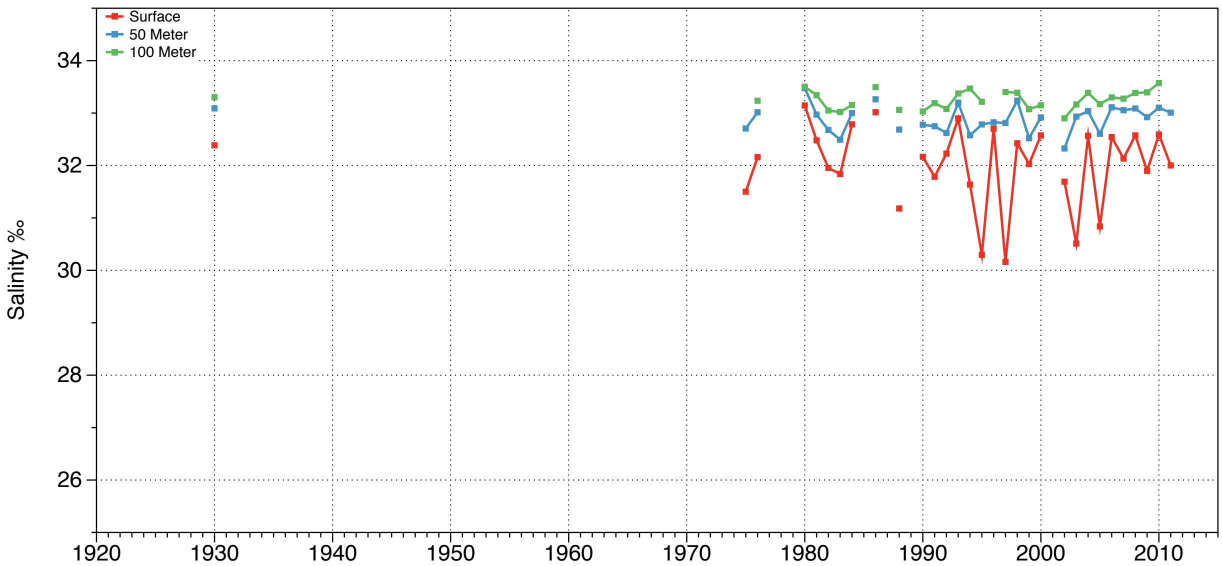


Figure 334: Interannual variability of autumn salinity (September – October) at station Outer Balsfjorden

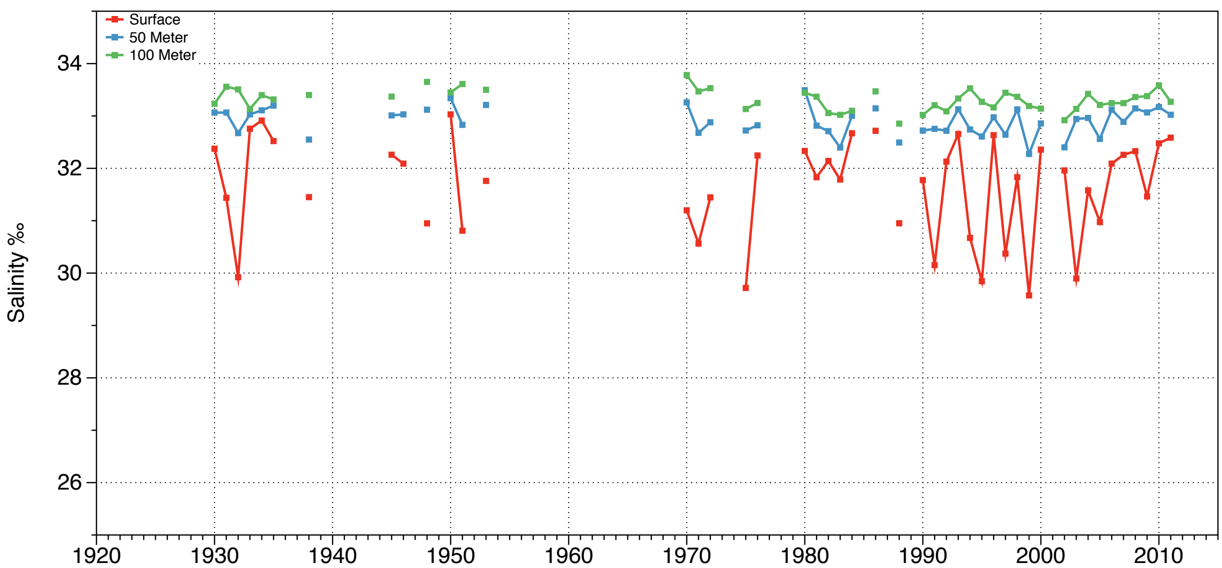


Figure 335: Interannual variability of autumn salinity (September – October) at station Inner Balsfjorden

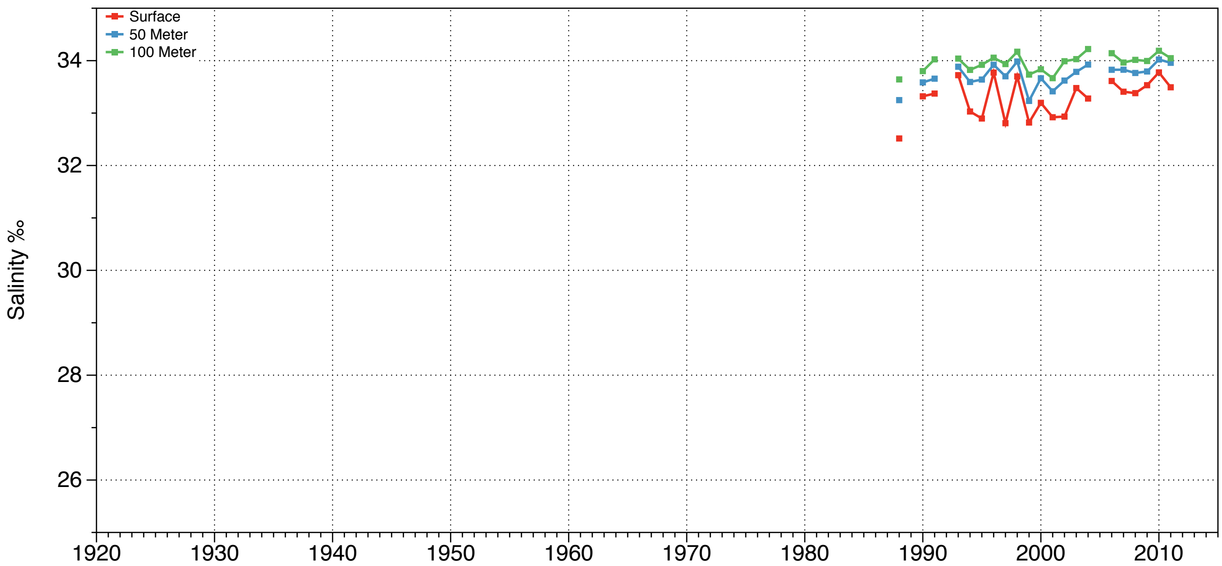


Figure 336: Interannual variability of autumn salinity (September – October) at station Kvalsund

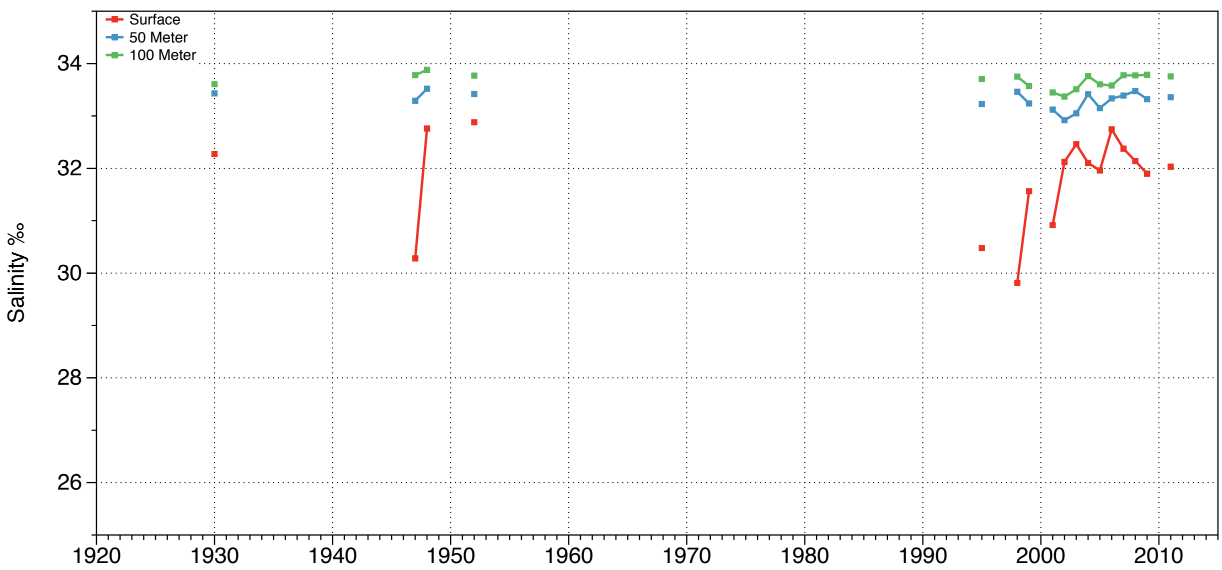


Figure 337: Interannual variability of autumn salinity (September – October) at station Sørfjord

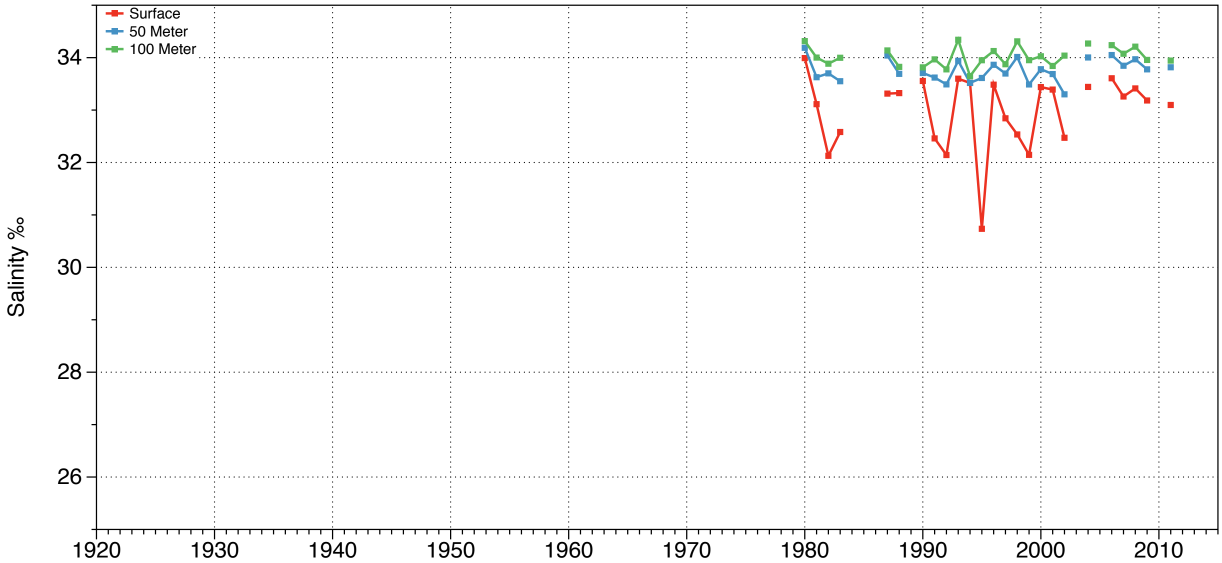


Figure 338: Interannual variability of autumn salinity (September – October) at station Outer Altafjorden

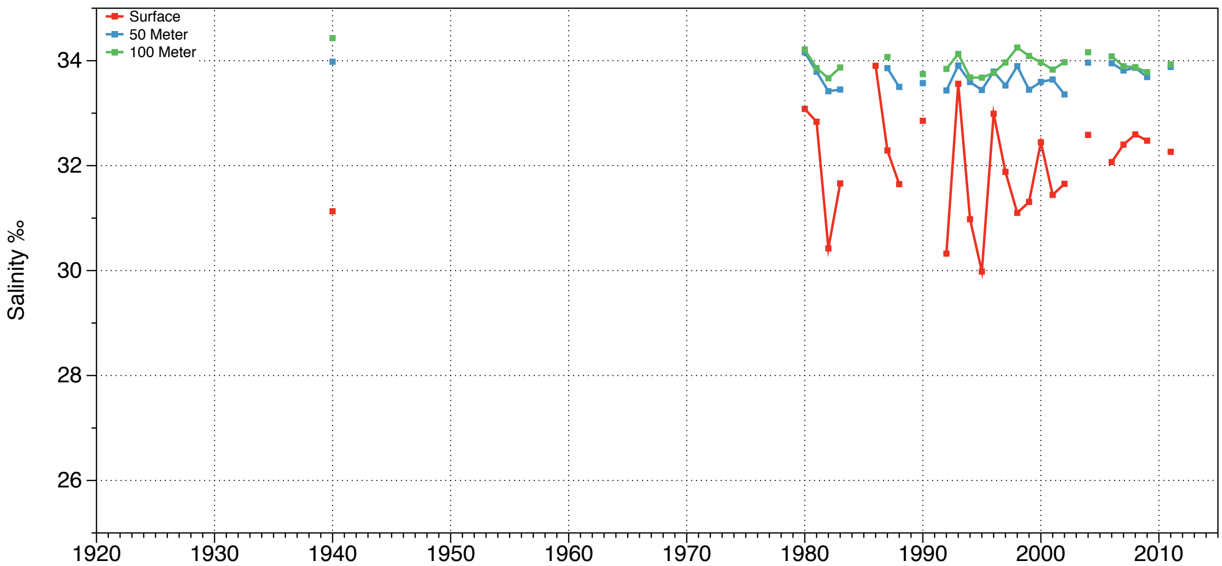


Figure 339: Interannual variability of autumn salinity (September – October) at station Inner Altafjorden

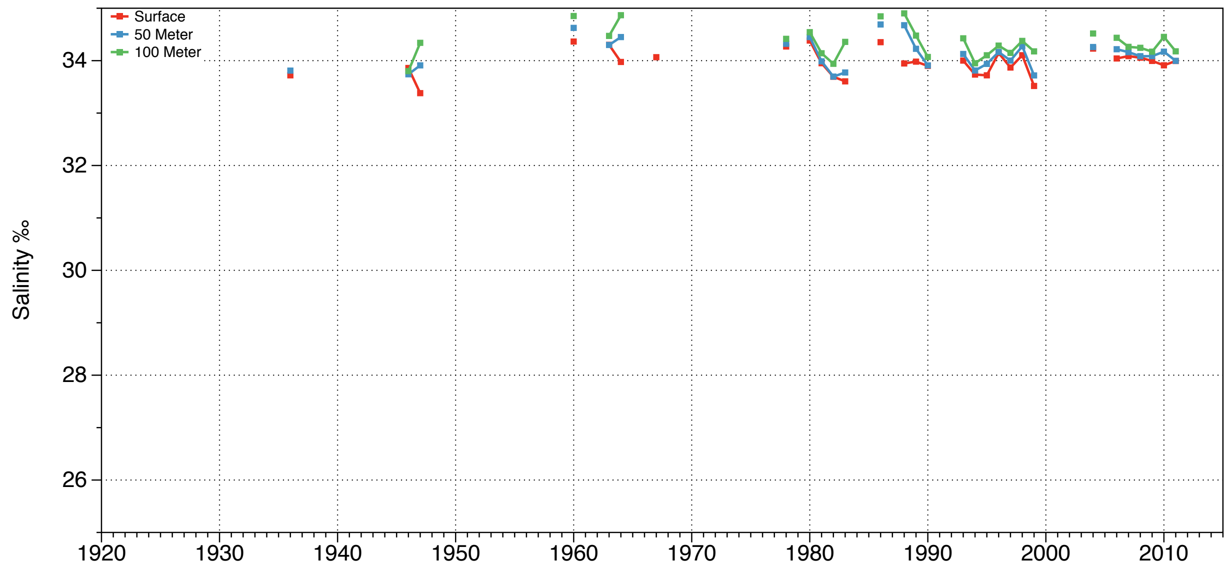


Figure 340: Interannual variability of autumn salinity (September – October) at station Refsbotn

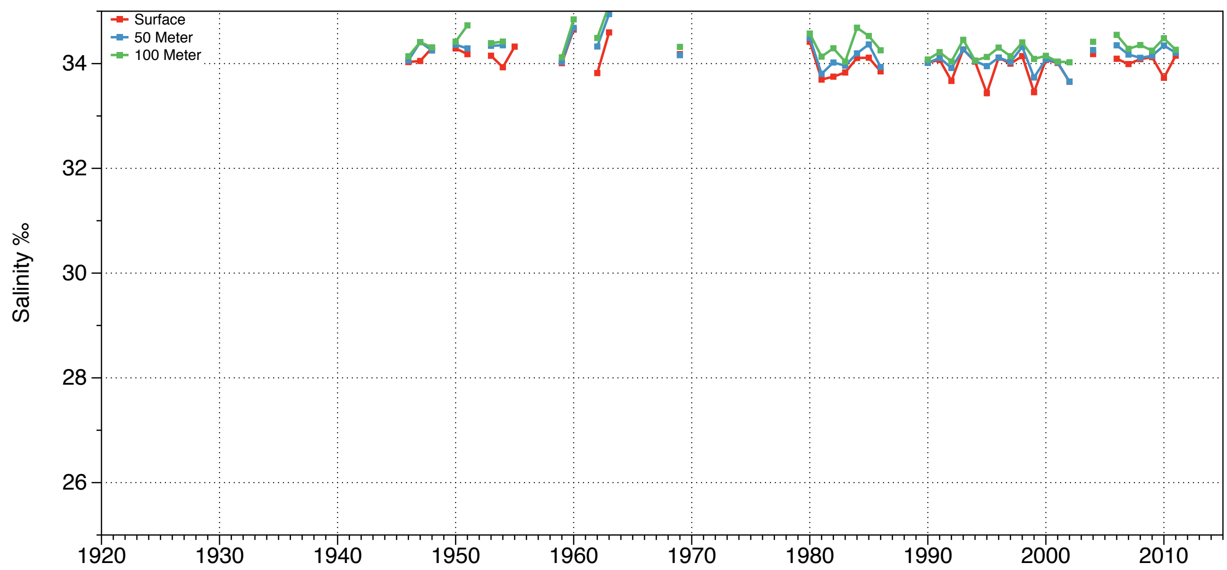


Figure 341: Interannual variability of autumn salinity (September – October) at station Outer Porsangerfjorden

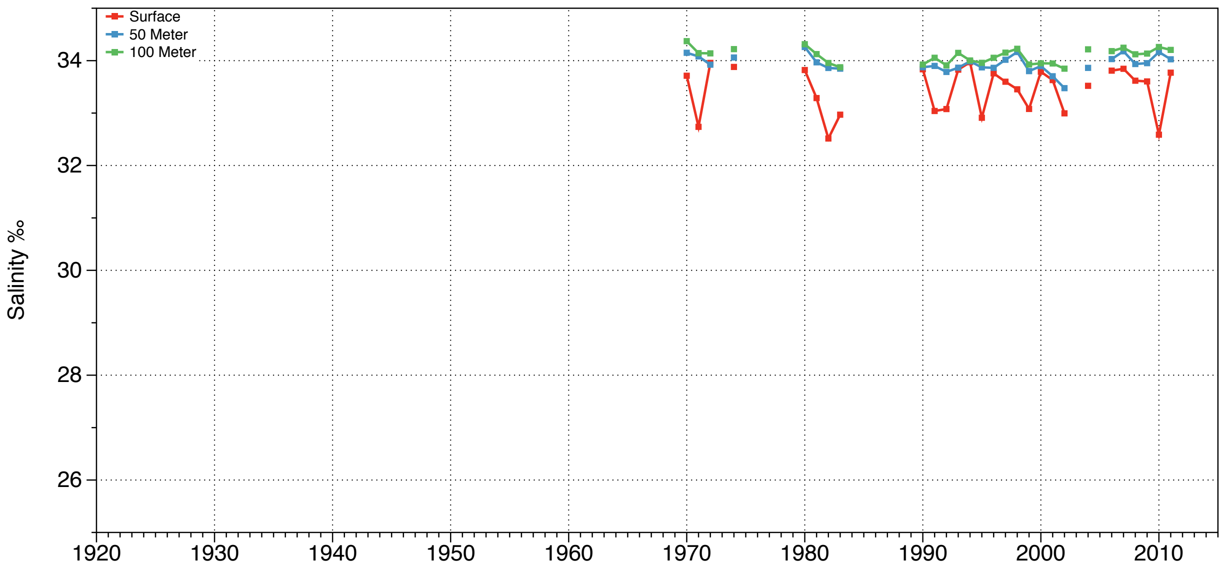


Figure 342: Interannual variability of autumn salinity (September – October) at station Inner Porsangerfjorden

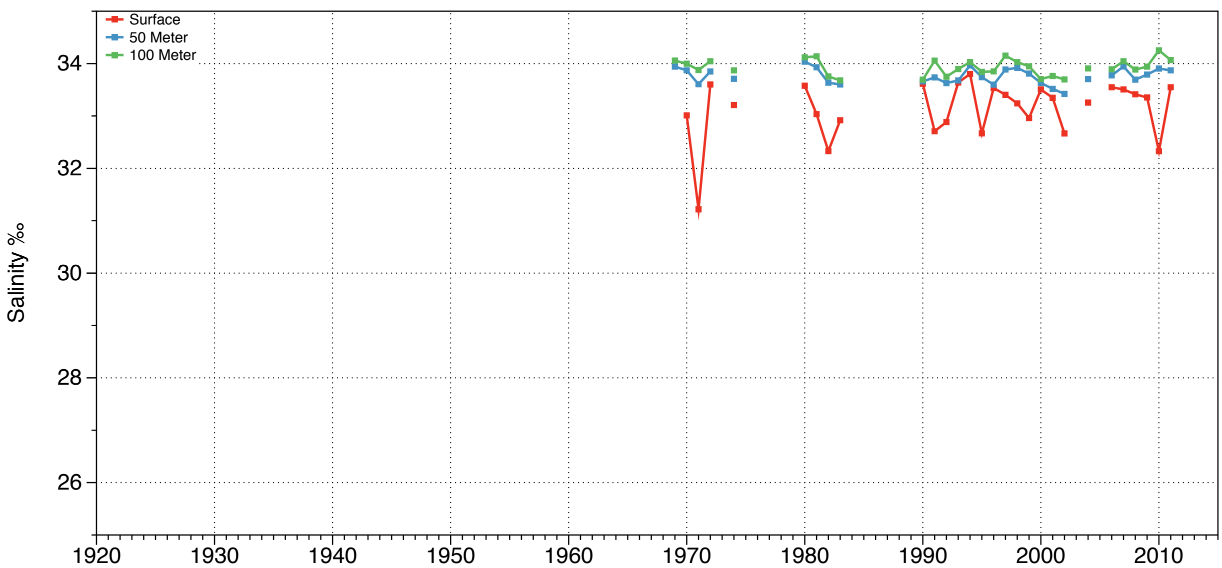


Figure 343: Interannual variability of autumn salinity (September – October) at station Østerbotn

A.6 INTERANNUAL VARIABILITY IN SEASONAL DENSITY

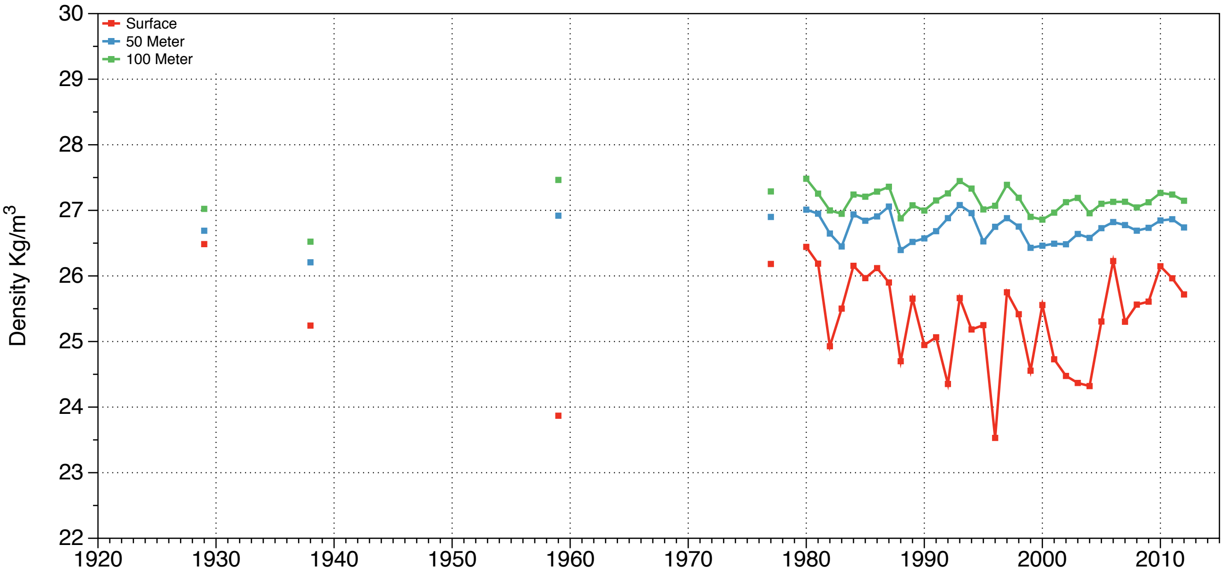


Figure 344: Interannual variability of winter density (November – February) at station Inner Malangen

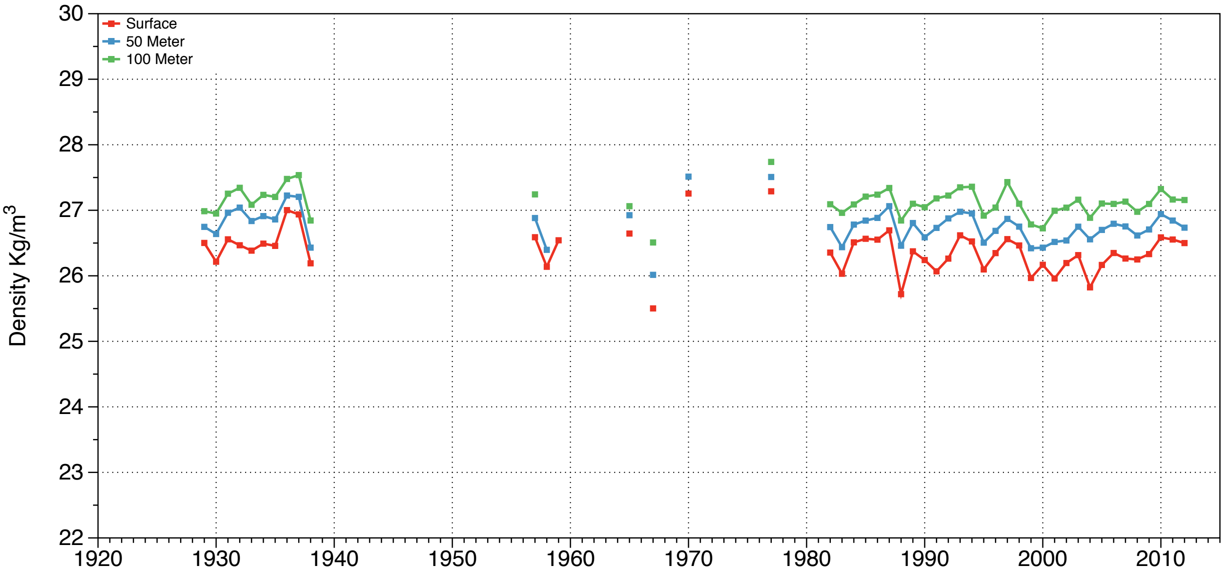


Figure 345: Interannual variability of winter density (November – February) at station Outer Malangen

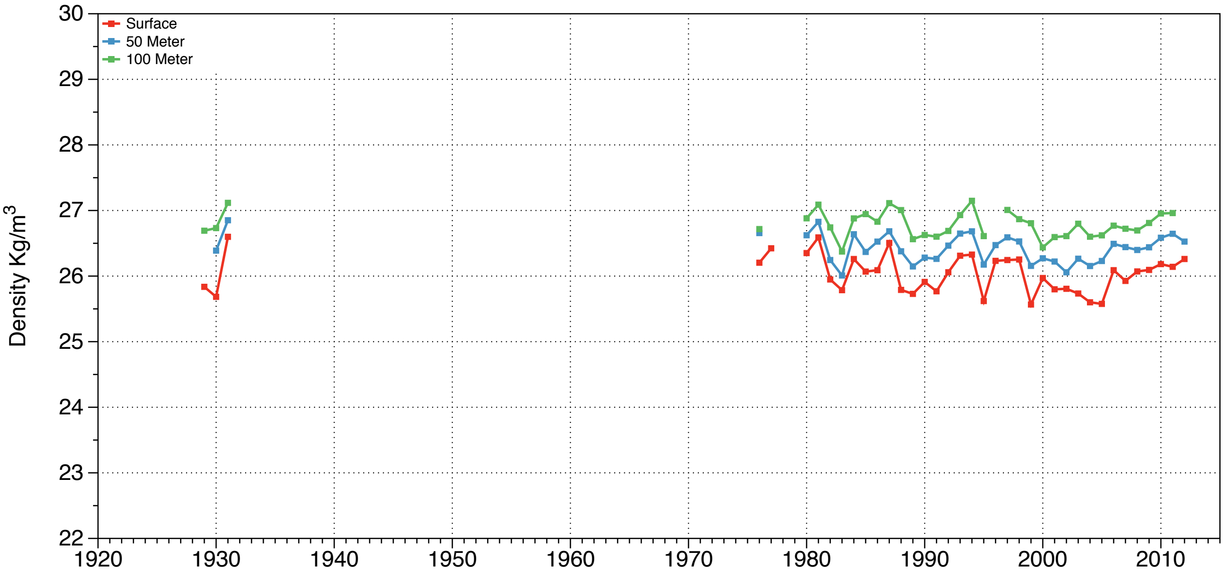


Figure 346: Interannual variability of winter density (November – February) at station Outer Balsfjorden

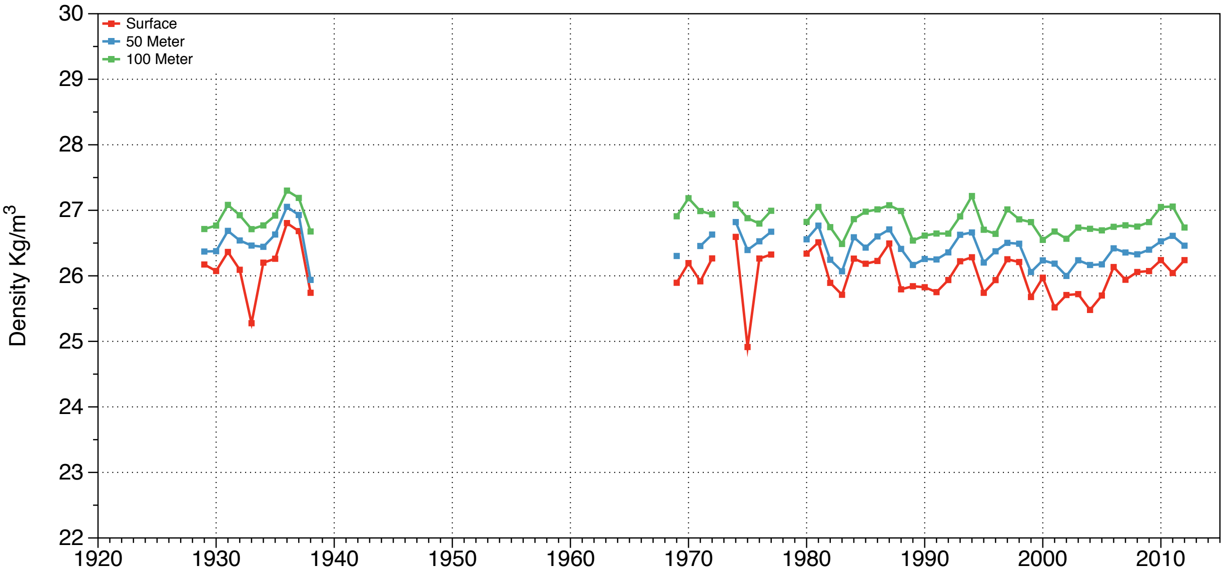


Figure 347: Interannual variability of winter density (November – February) at station Inner Balsfjorden

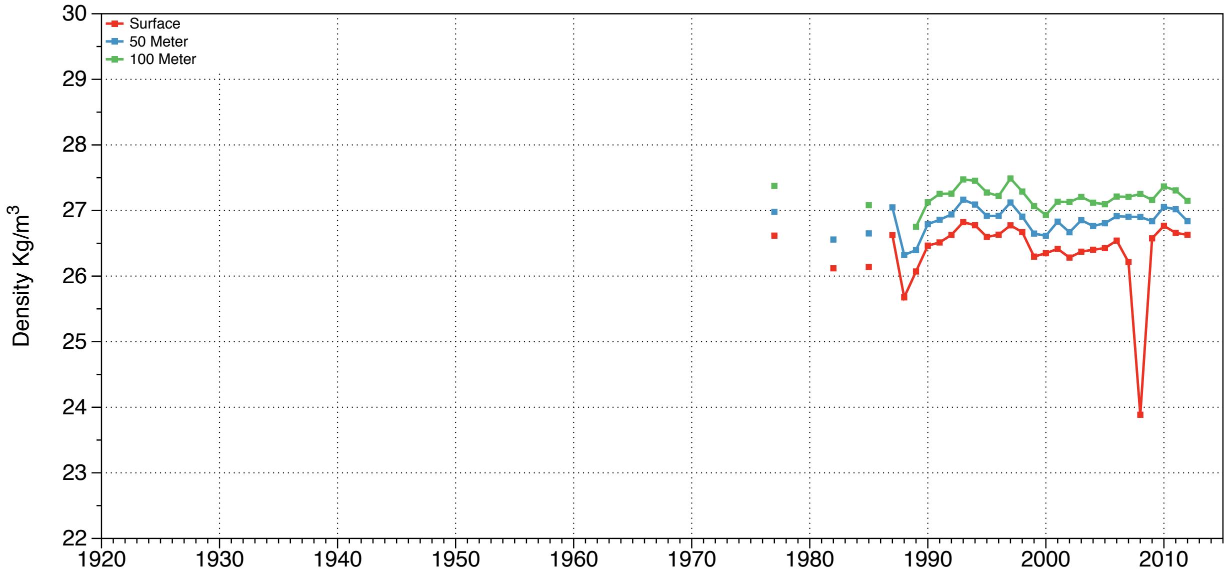


Figure 348: Interannual variability of winter density (November – February) at station Kvalsund

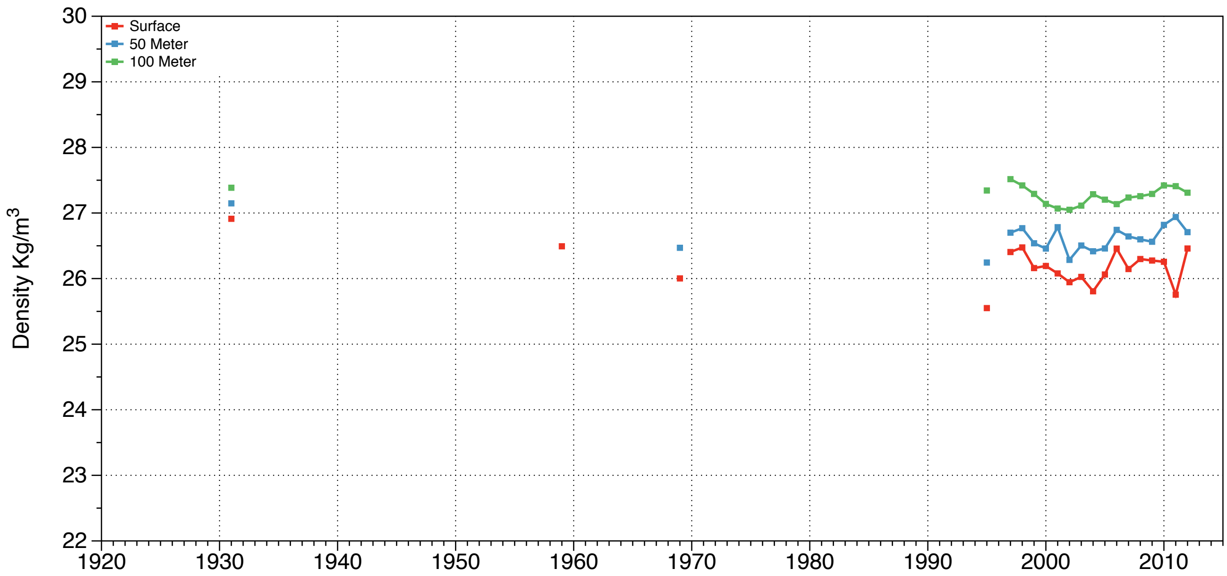


Figure 349: Interannual variability of winter density (November – February) at station Sørfjord

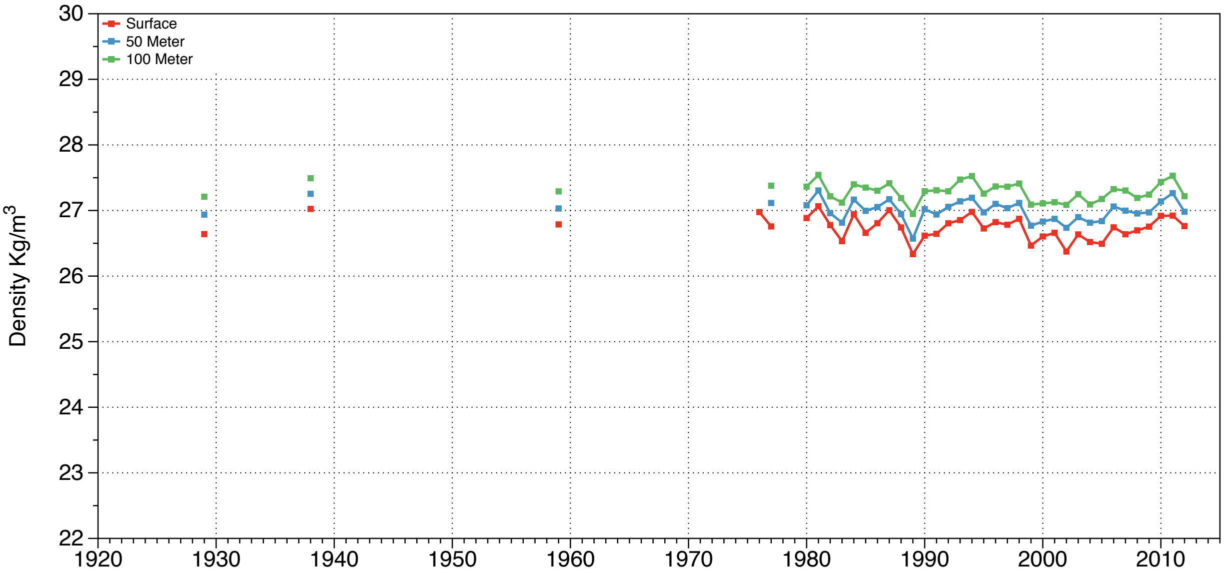


Figure 350: Interannual variability of winter density (November – February) at station Outer Altafjorden

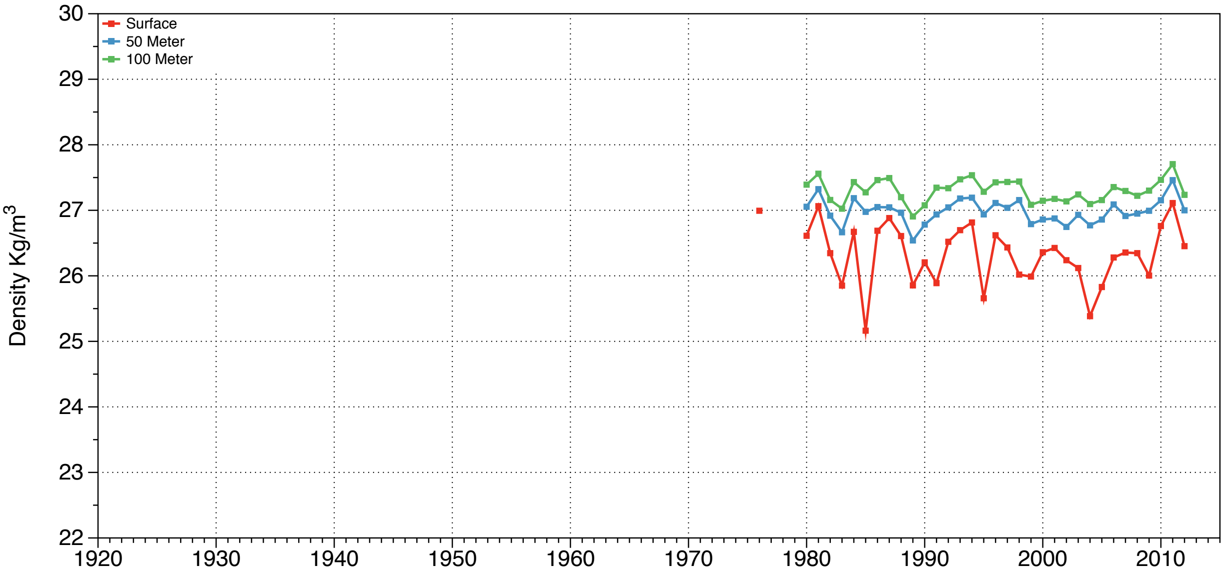


Figure 351: Interannual variability of winter density (November – February) at station Inner Altafjorden

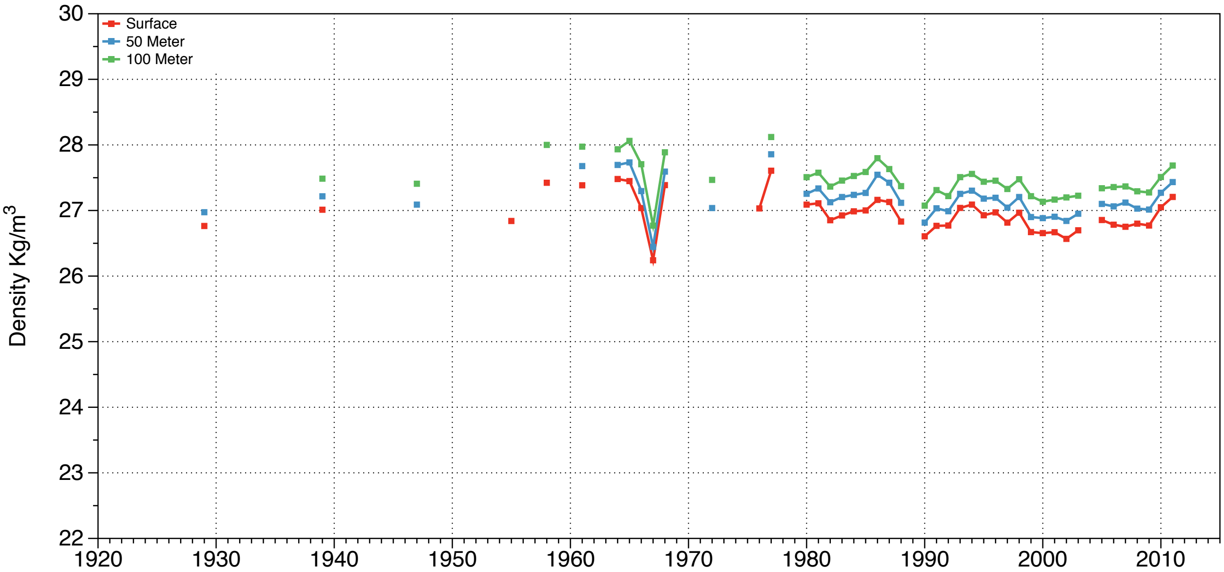


Figure 352: Interannual variability of winter density (November – February) at station Refsbotn

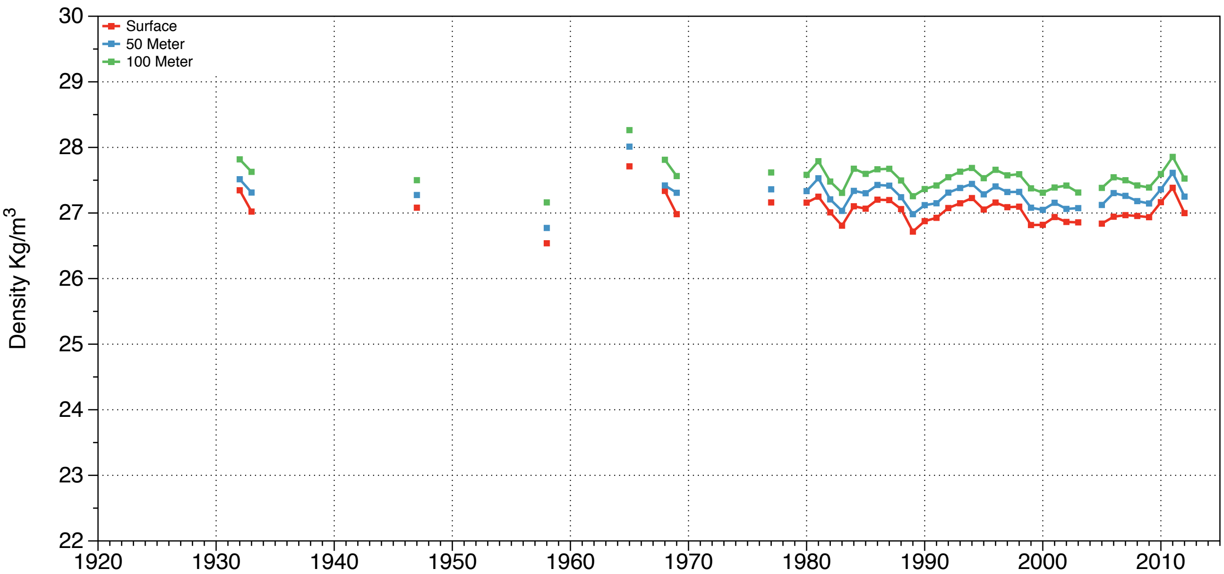


Figure 353: Interannual variability of winter density (November – February) at station Outer Porsangerfjorden

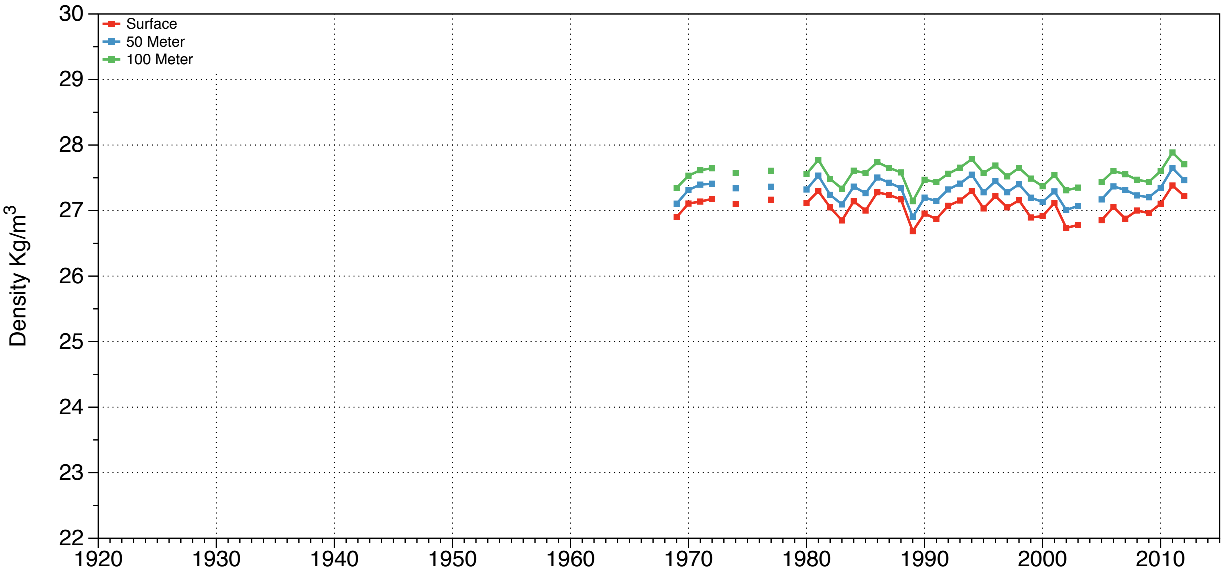


Figure 354: Interannual variability of winter density (November – February) at station Inner Porsangerfjorden

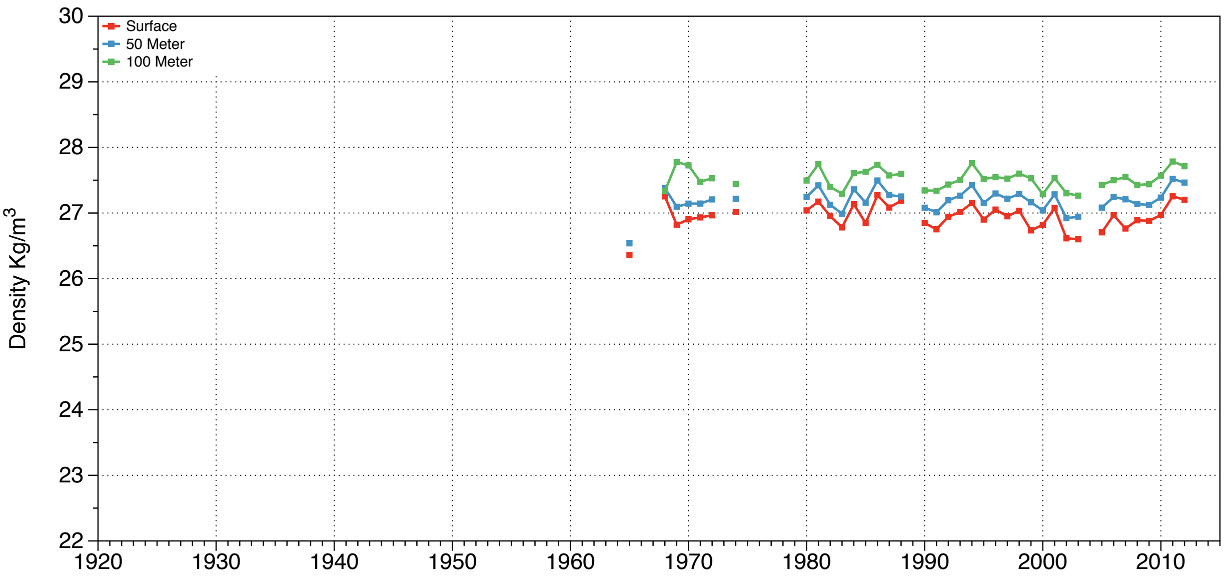


Figure 355: Interannual variability of winter density (November – February) at station Østerbotn

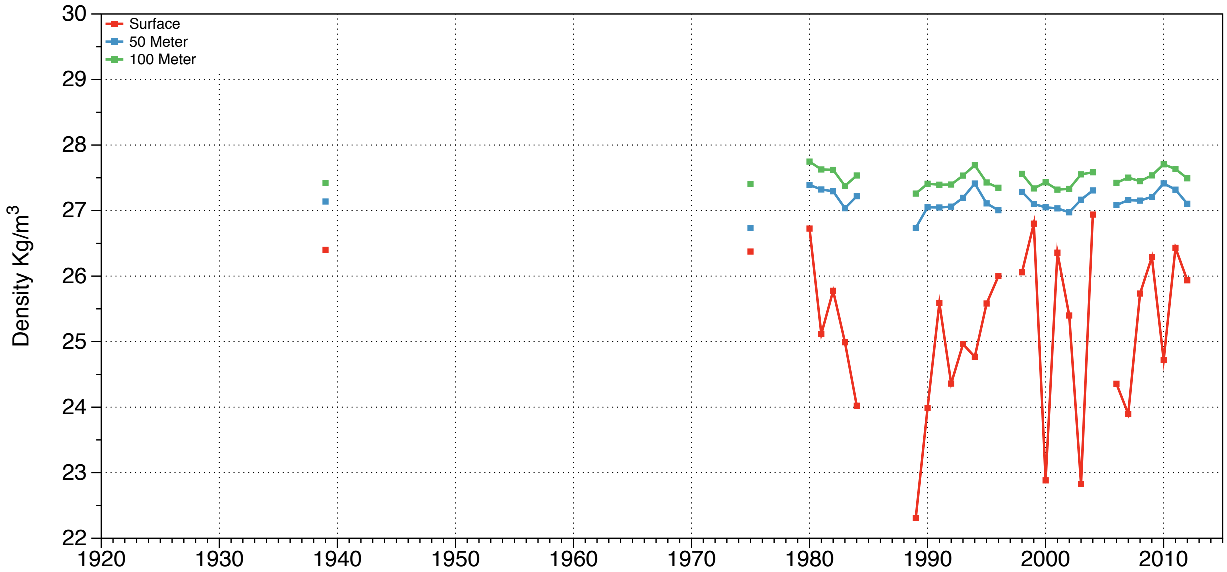


Figure 356: Interannual variability of spring density (March – May) at station Inner Malangen

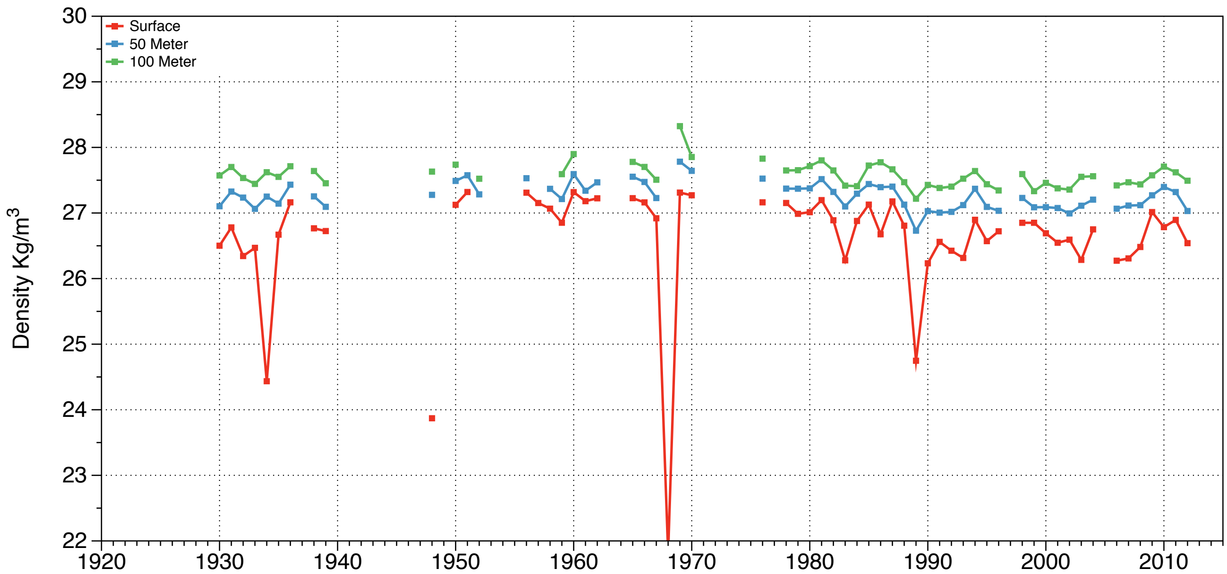


Figure 357: Interannual variability of spring density (March – May) at station Outer Malangen

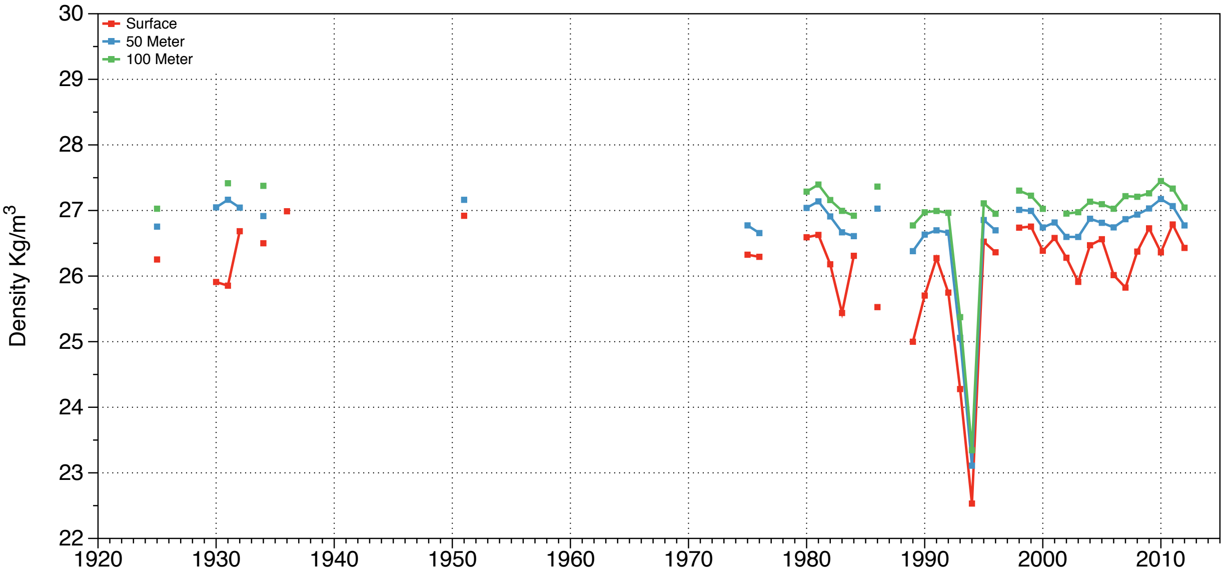


Figure 358: Interannual variability of spring density (March – May) at station Outer Balsfjorden

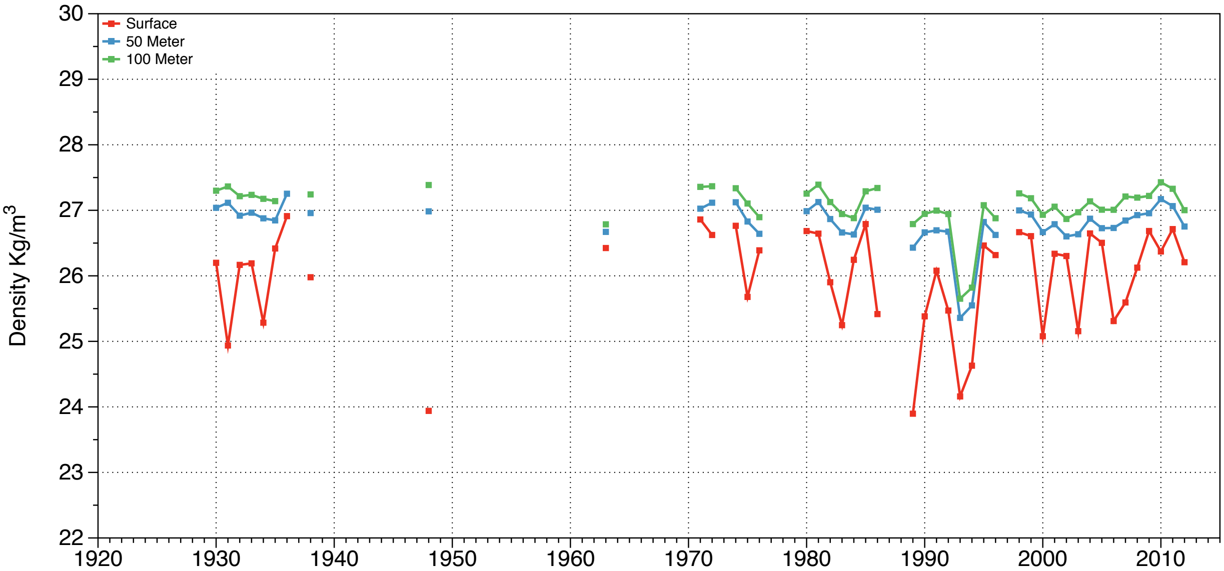


Figure 359: Interannual variability of spring density (March – May) at station Inner Balsfjorden

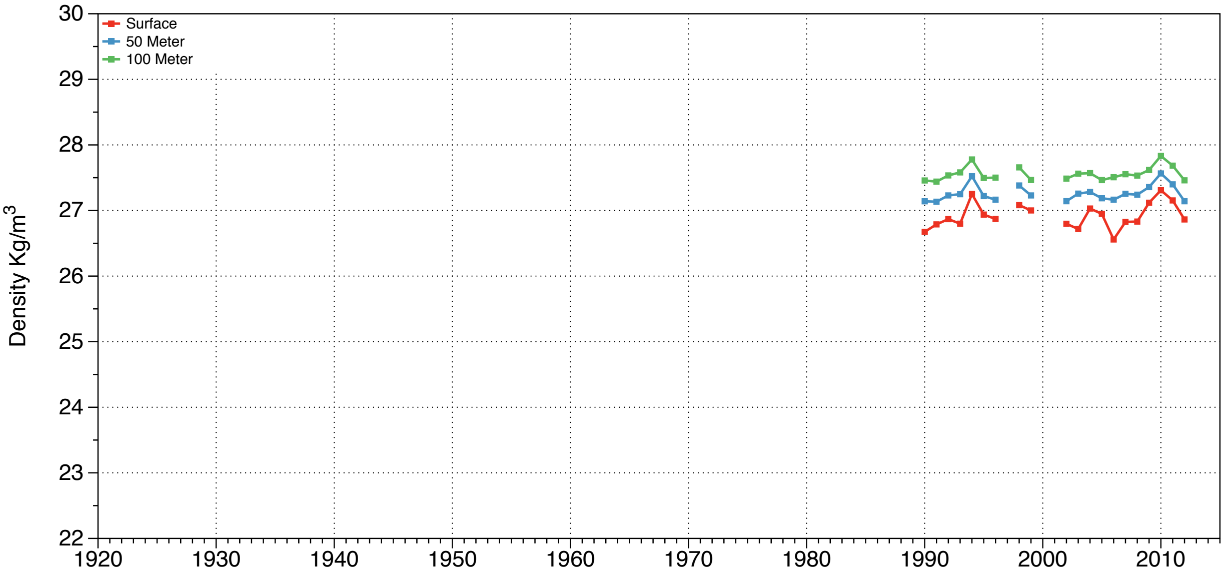


Figure 360: Interannual variability of spring density (March – May) at station Kvalsund

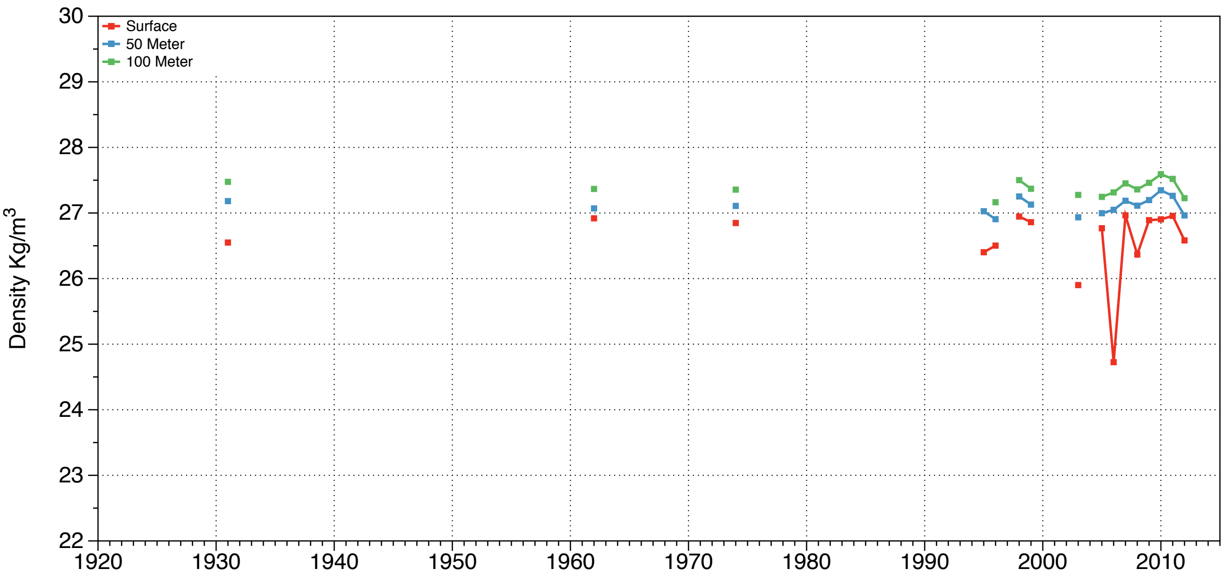


Figure 361: Interannual variability of spring density (March – May) at station Sørfjord

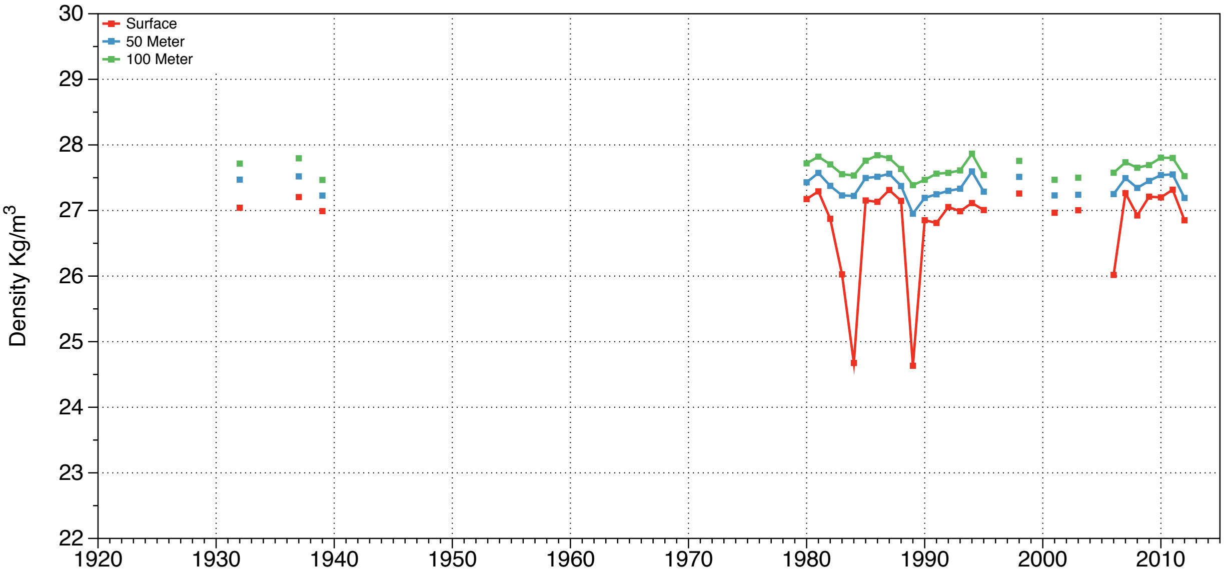


Figure 362: Interannual variability of spring density (March – May) at station Outer Altafjorden

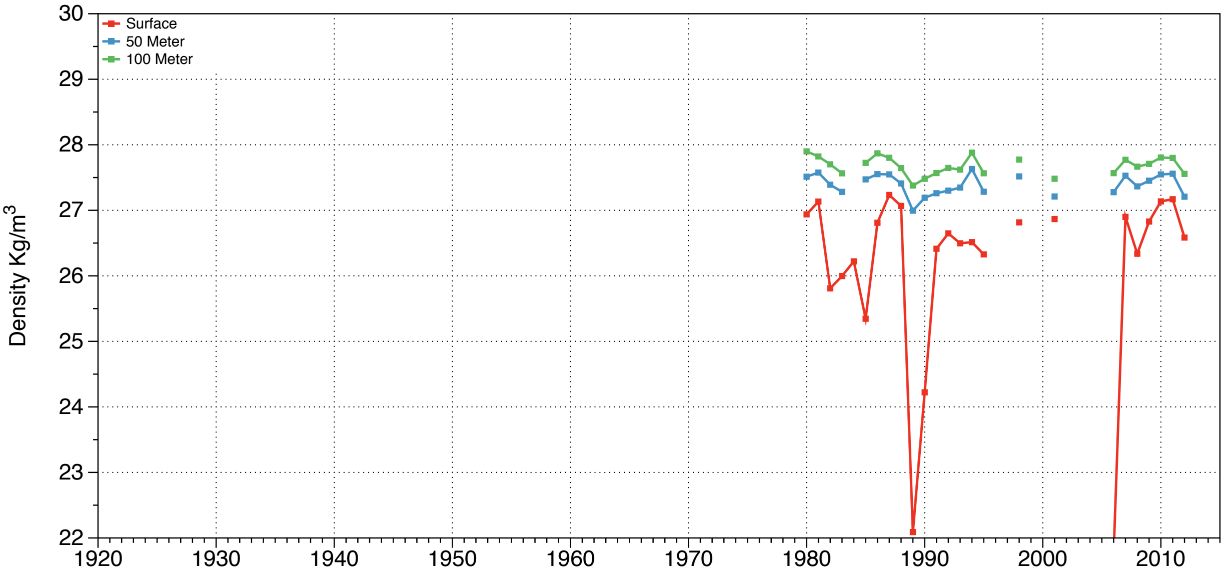


Figure 363: Interannual variability of spring density (March – May) at station Inner Altafjorden

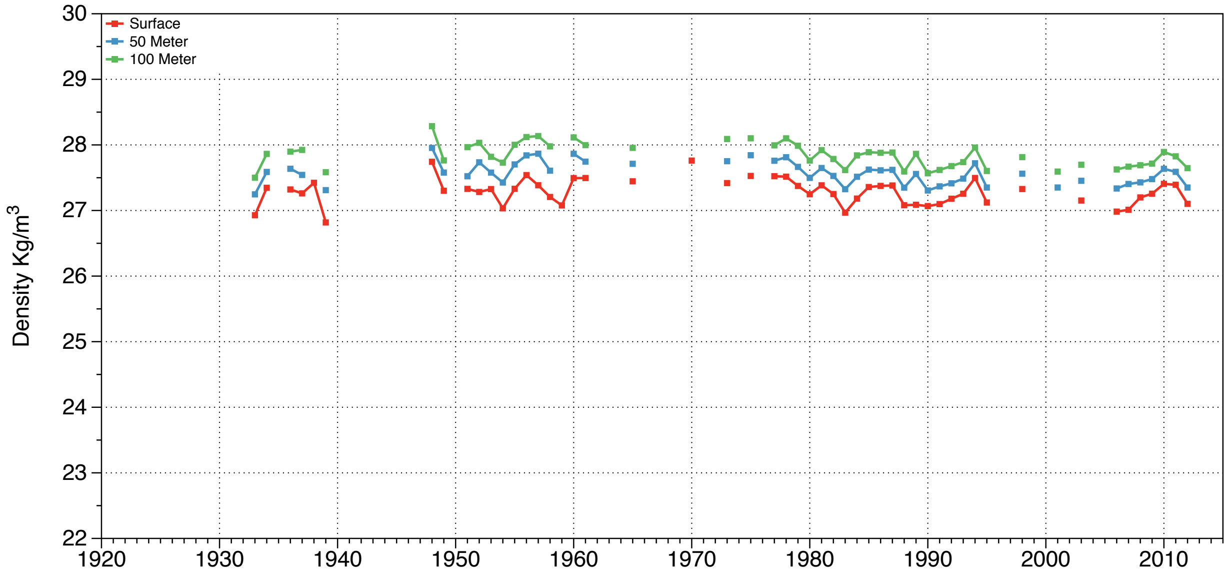


Figure 364: Interannual variability of spring density (March – May) at station Refsbotn

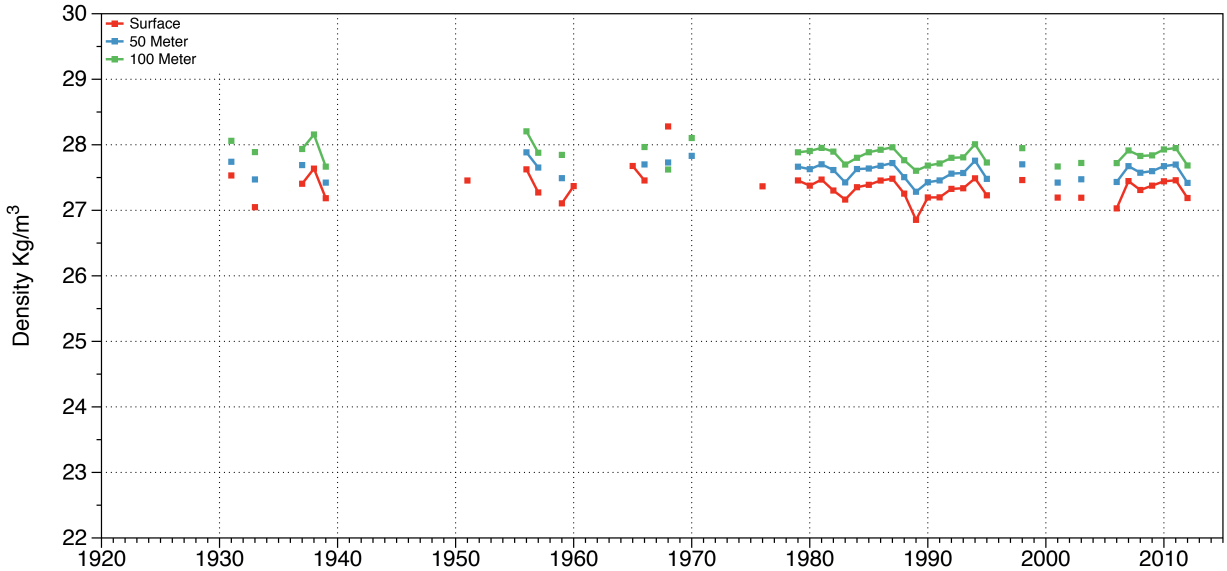


Figure 365: Interannual variability of spring density (March – May) at station Outer Porsangerfjorden

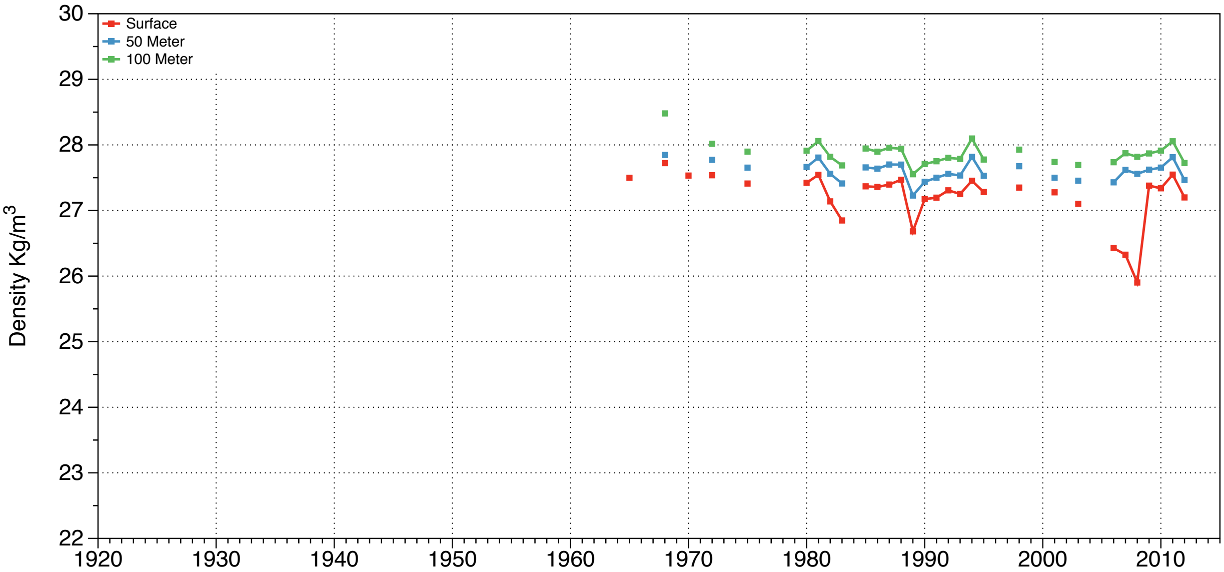


Figure 366: Interannual variability of spring density (March – May) at station Inner Porsangerfjorden

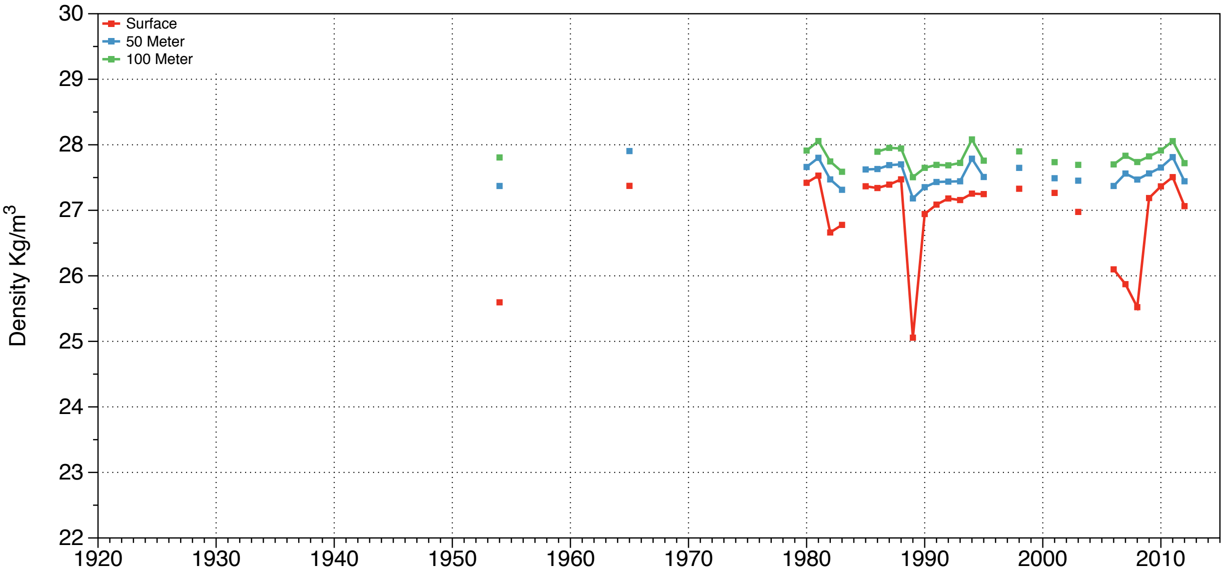


Figure 367: Interannual variability of spring density (March – May) at station Østerbotn

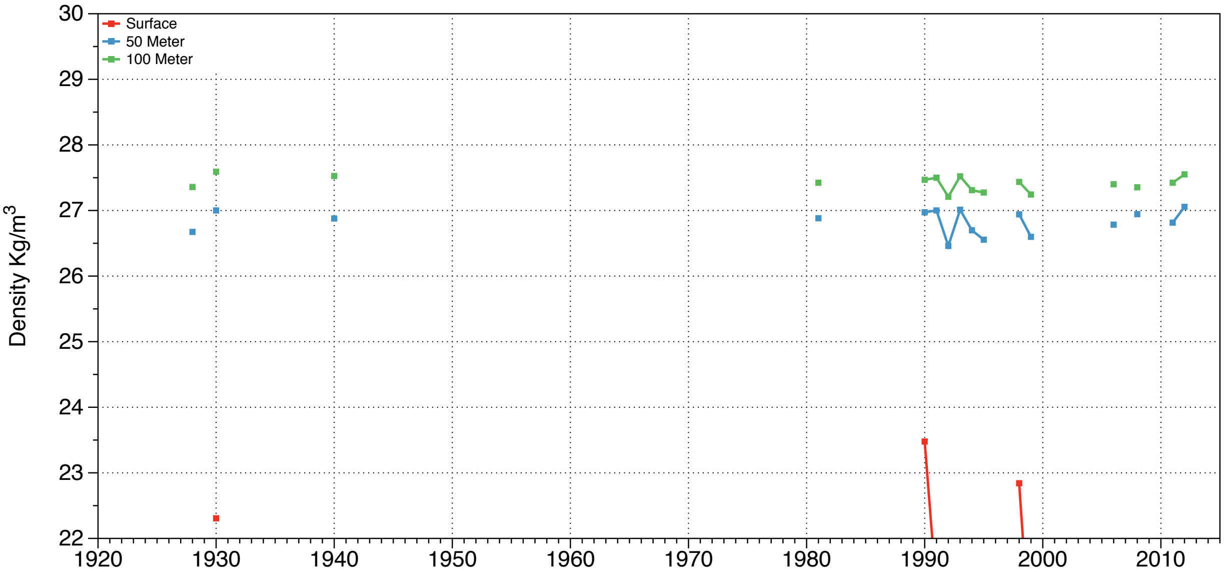


Figure 368: Interannual variability of summer density (June – August) at station Inner Malangen

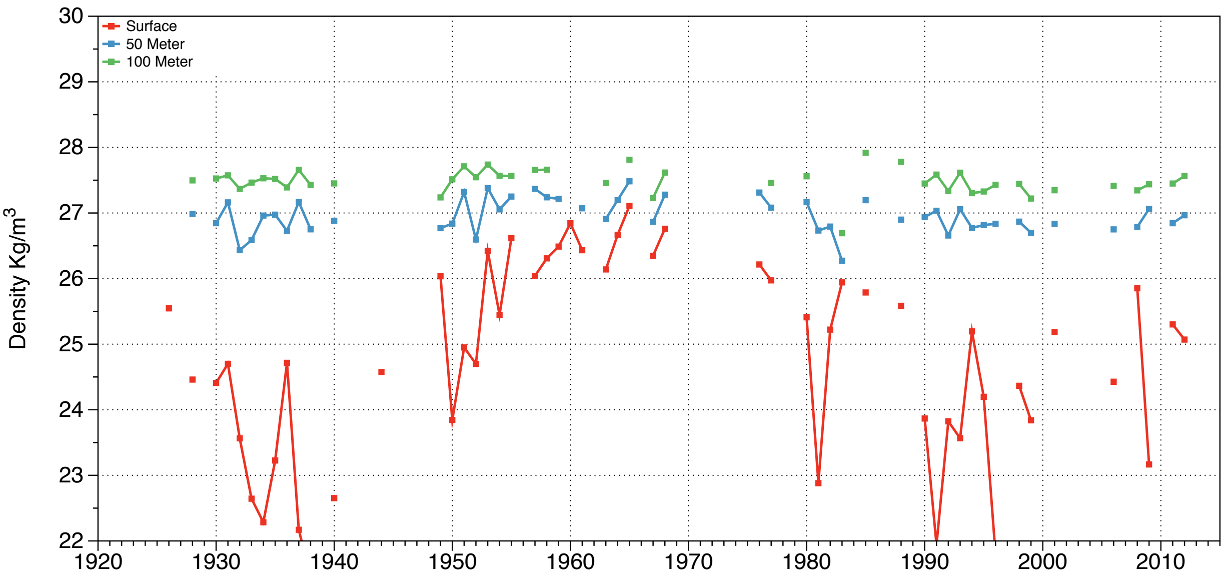


Figure 369: Interannual variability of summer density (June – August) at station Outer Malangen

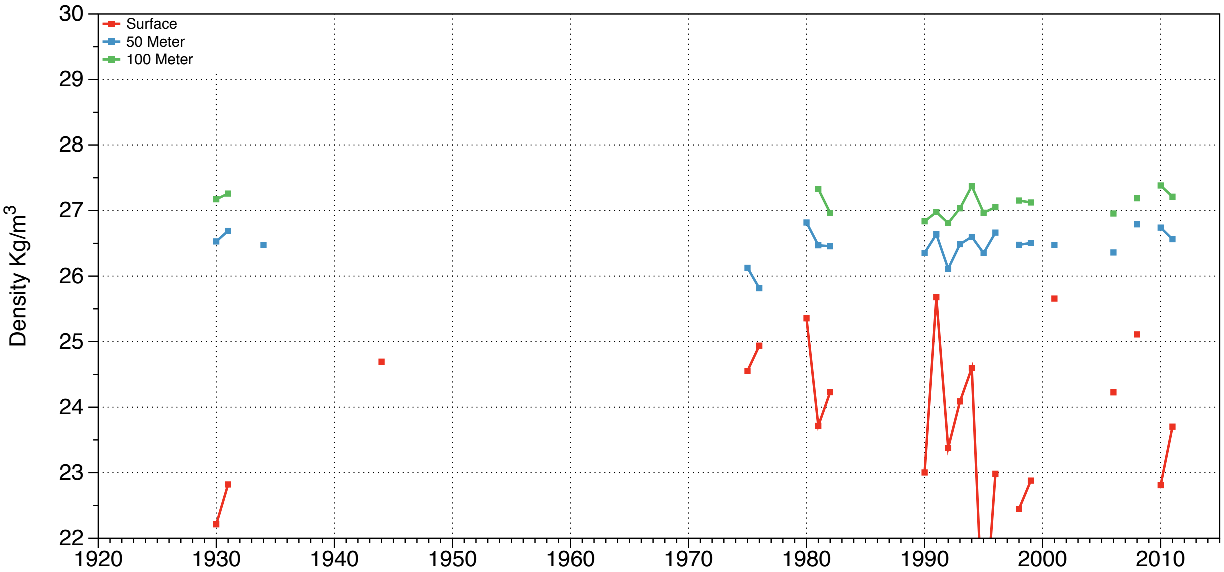


Figure 370: Interannual variability of summer density (June – August) at station Outer Balsfjorden

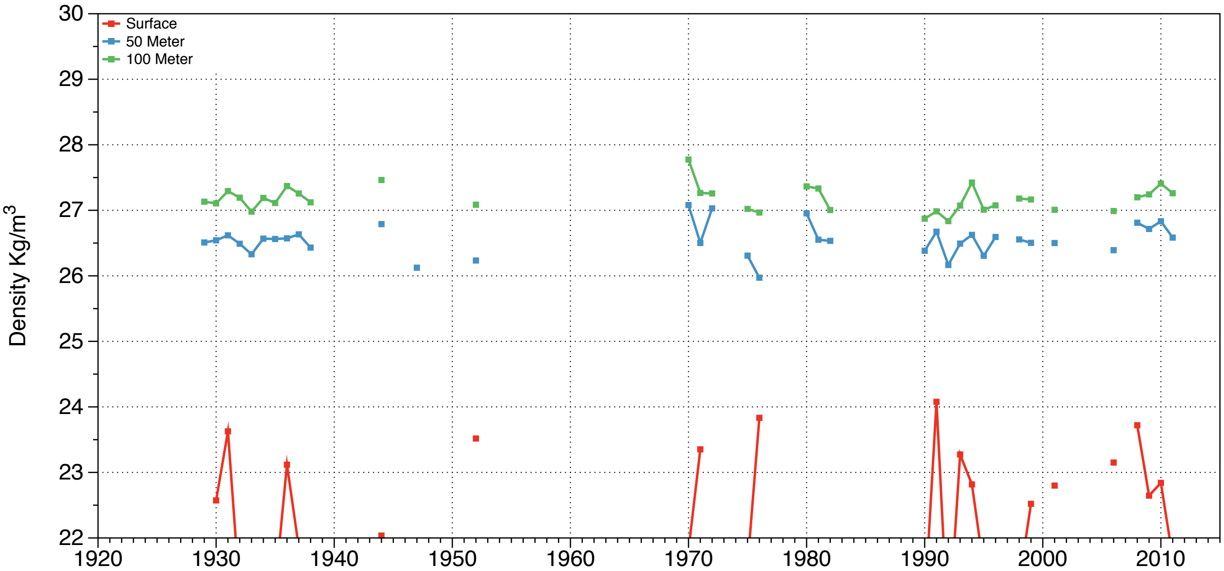


Figure 371: Interannual variability of summer density (June – August) at station Inner Balsfjorden

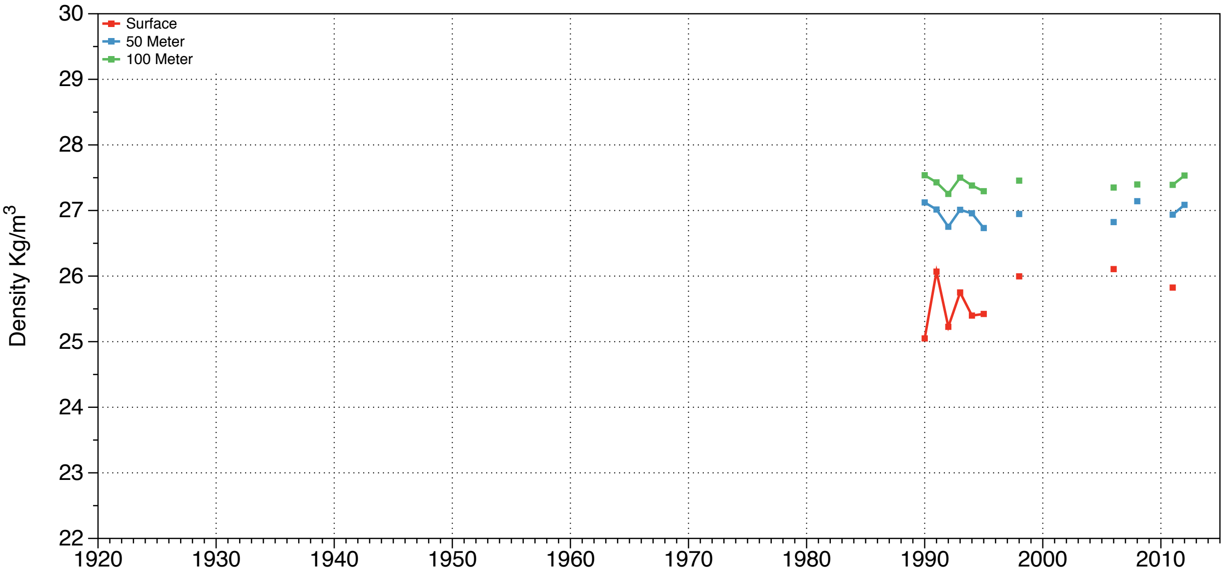


Figure 372: Interannual variability of summer density (June – August) at station Kvalsund

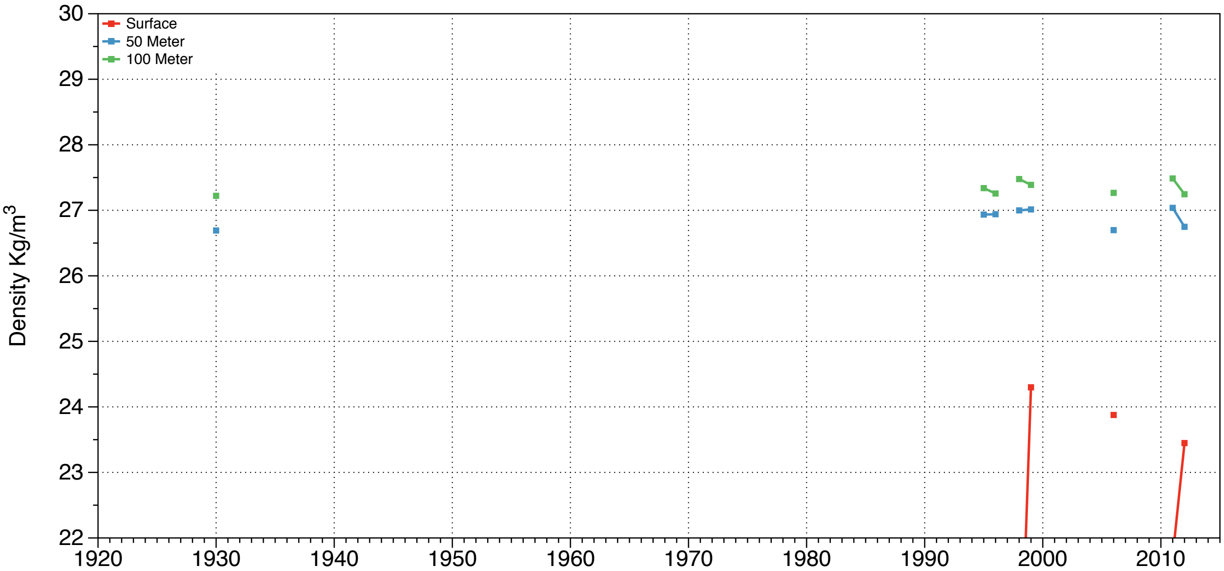


Figure 373: Interannual variability of summer density (June – August) at station Sørfjord

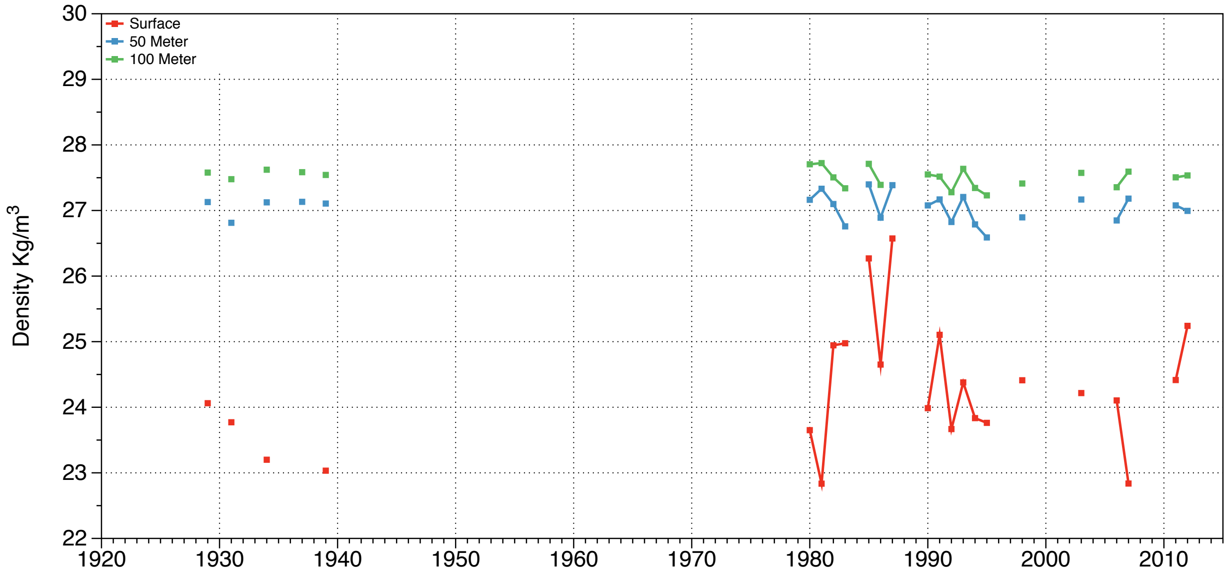


Figure 374: Interannual variability of summer density (June – August) at station Outer Altafjorden

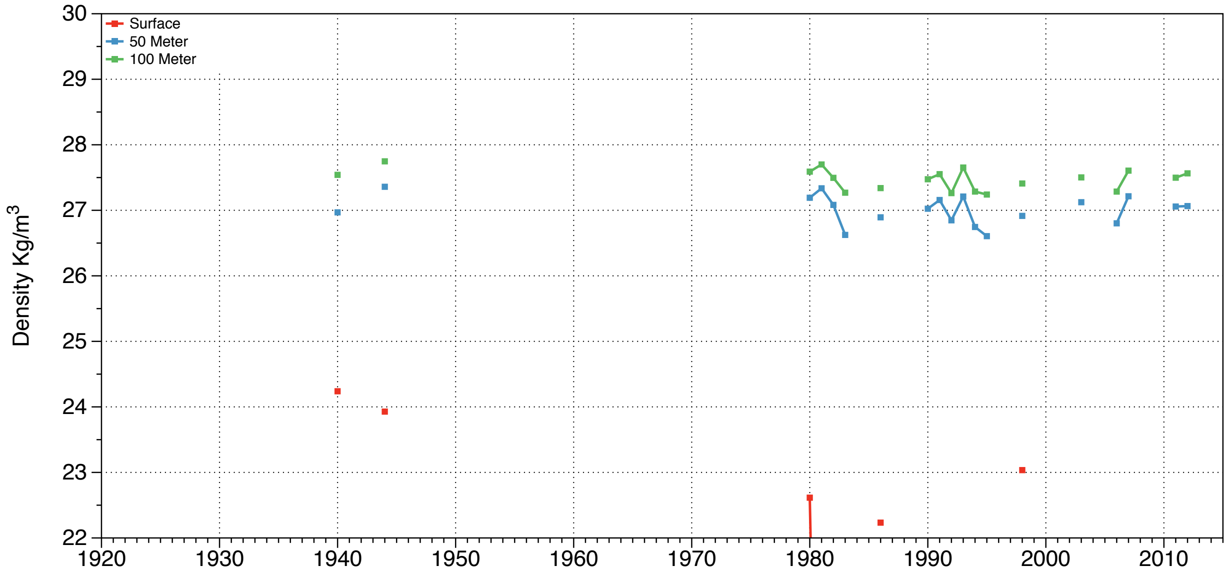


Figure 375: Interannual variability of summer density (June – August) at station Inner Altafjorden

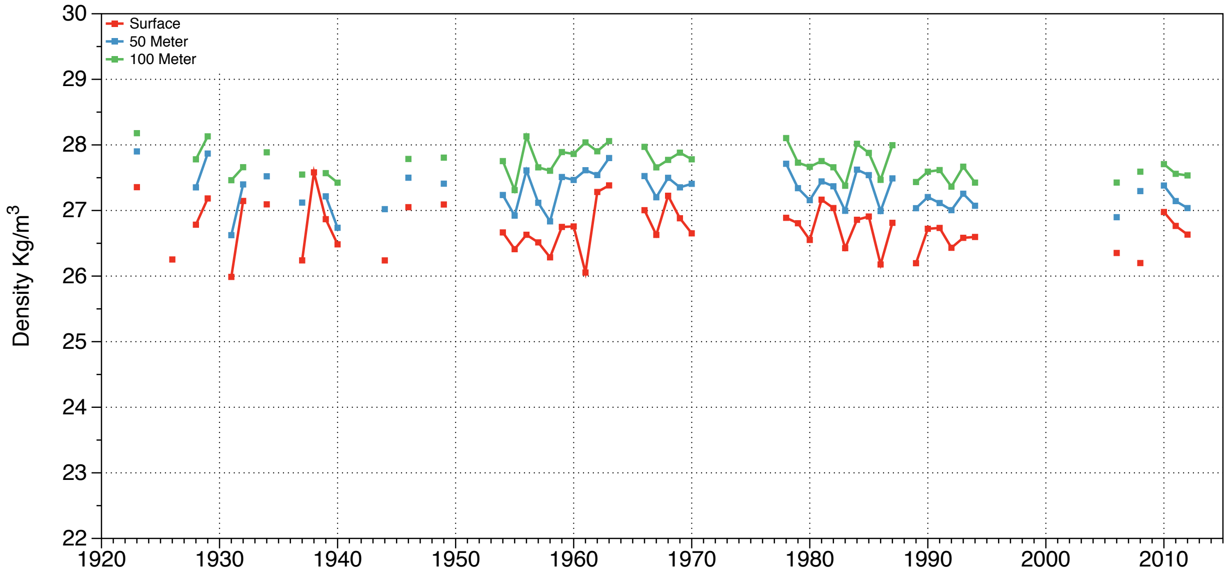


Figure 376: Interannual variability of summer density (June – August) at station Refsbotn

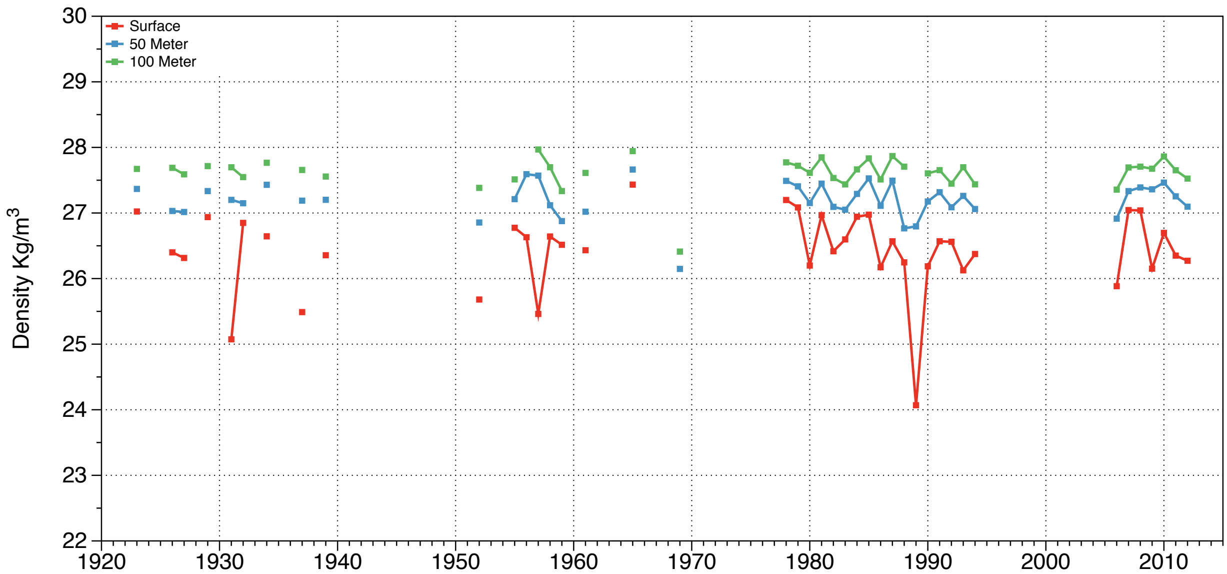


Figure 377: Interannual variability of summer density (June – August) at station Outer Porsangerfjorden

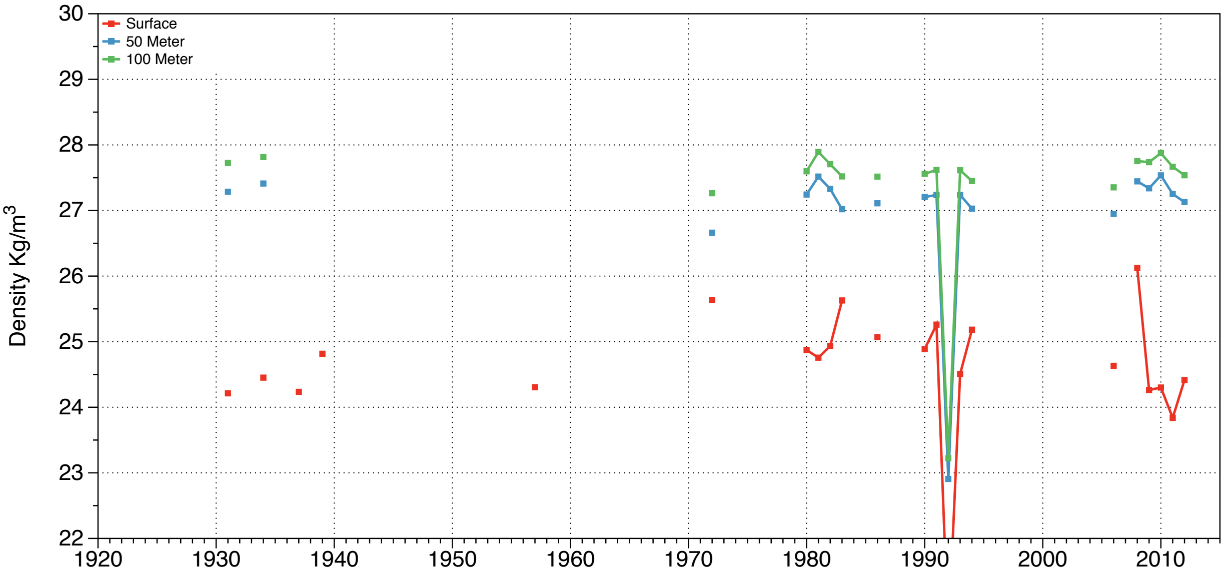


Figure 378: Interannual variability of summer density (June – August) at station Inner Porsangerfjorden

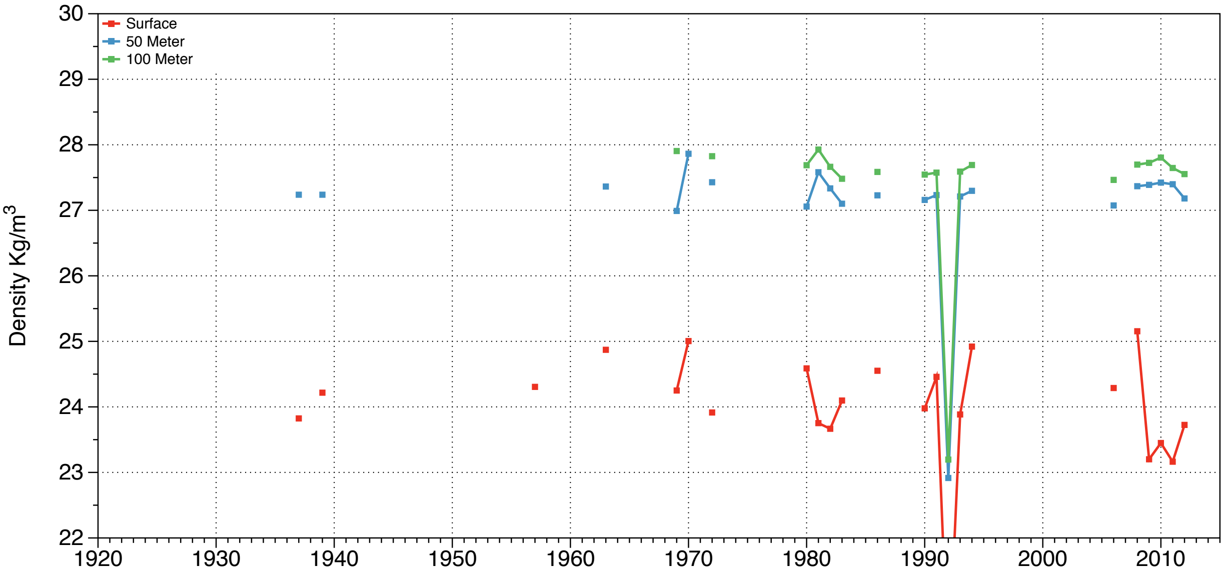


Figure 379: Interannual variability of summer density (June – August) at station Østerbotn

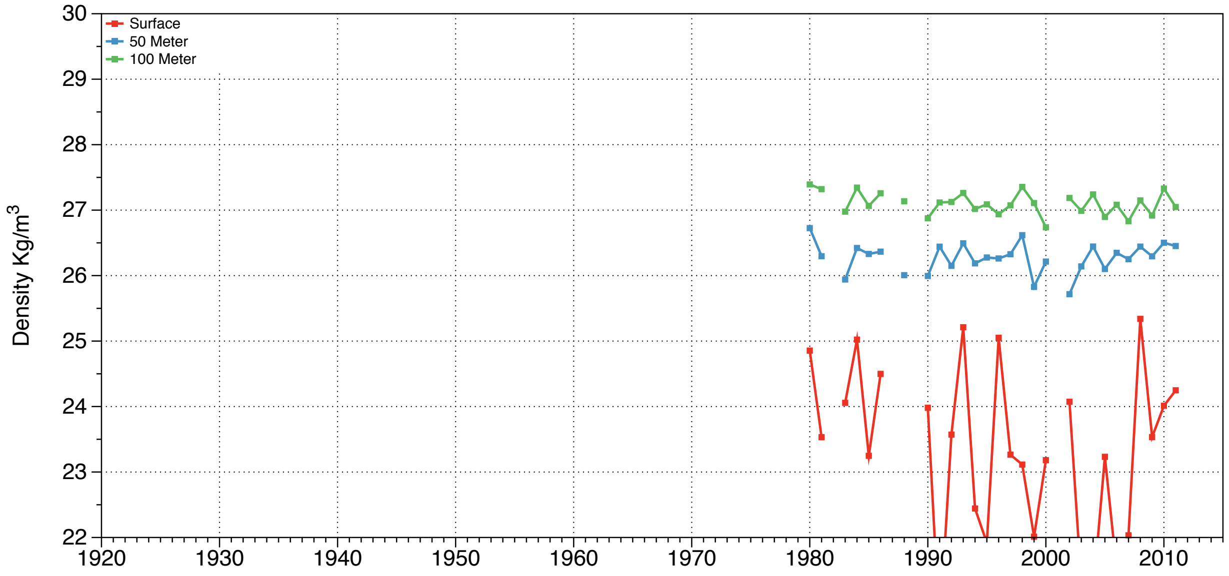


Figure 380: Interannual variability of autumn density (September – October) at station Inner Malangen

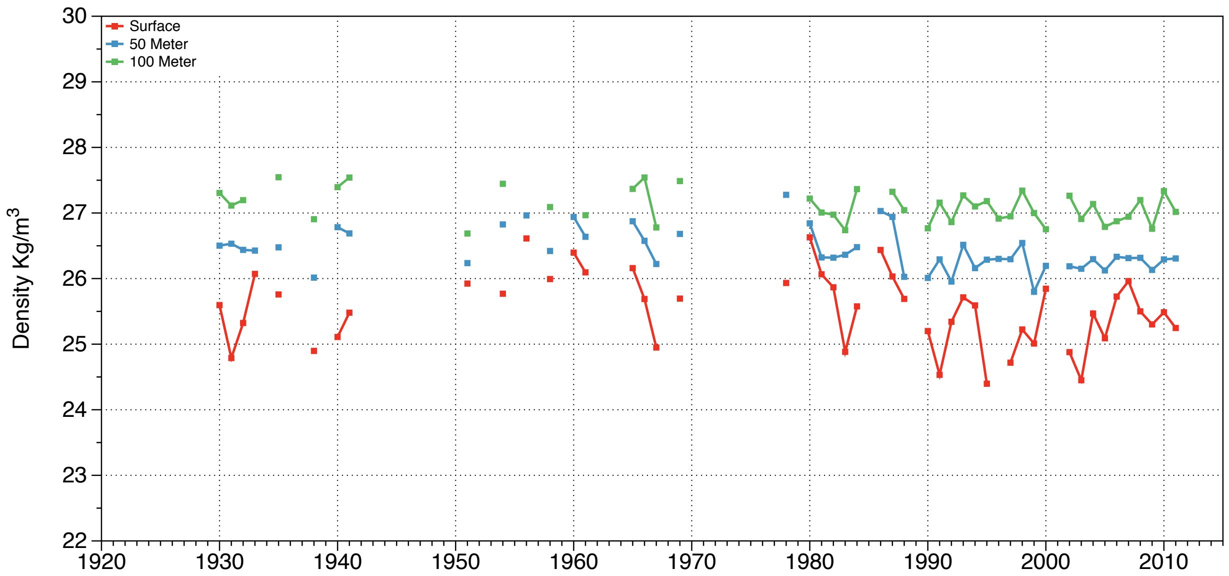


Figure 381: Interannual variability of autumn density (September – October) at station Outer Malangen

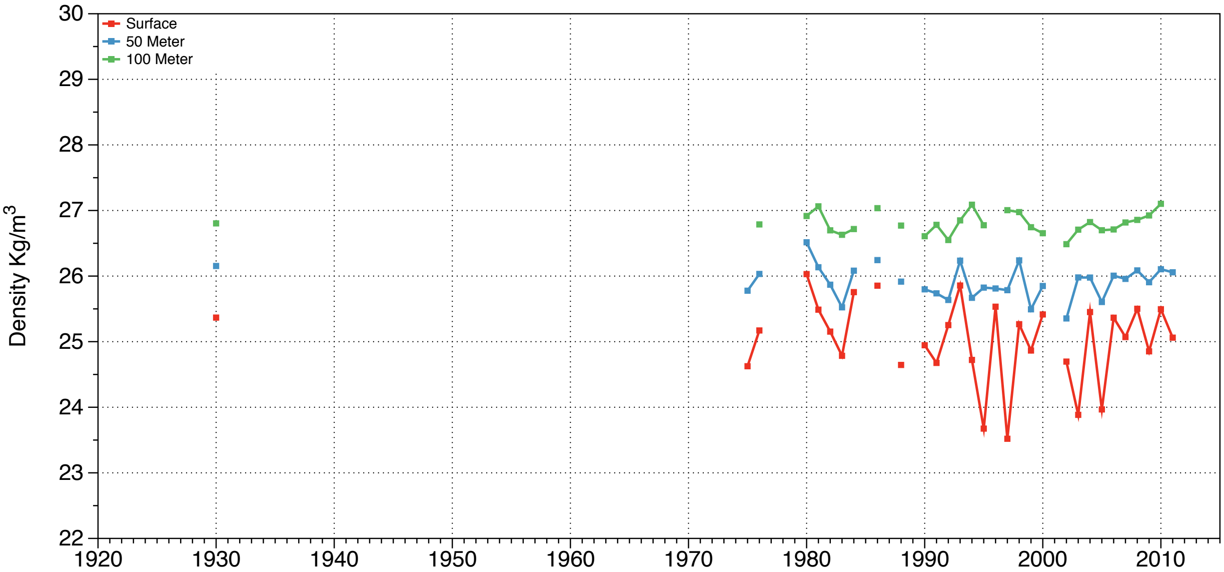


Figure 382: Interannual variability of autumn density (September – October) at station Outer Balsfjorden

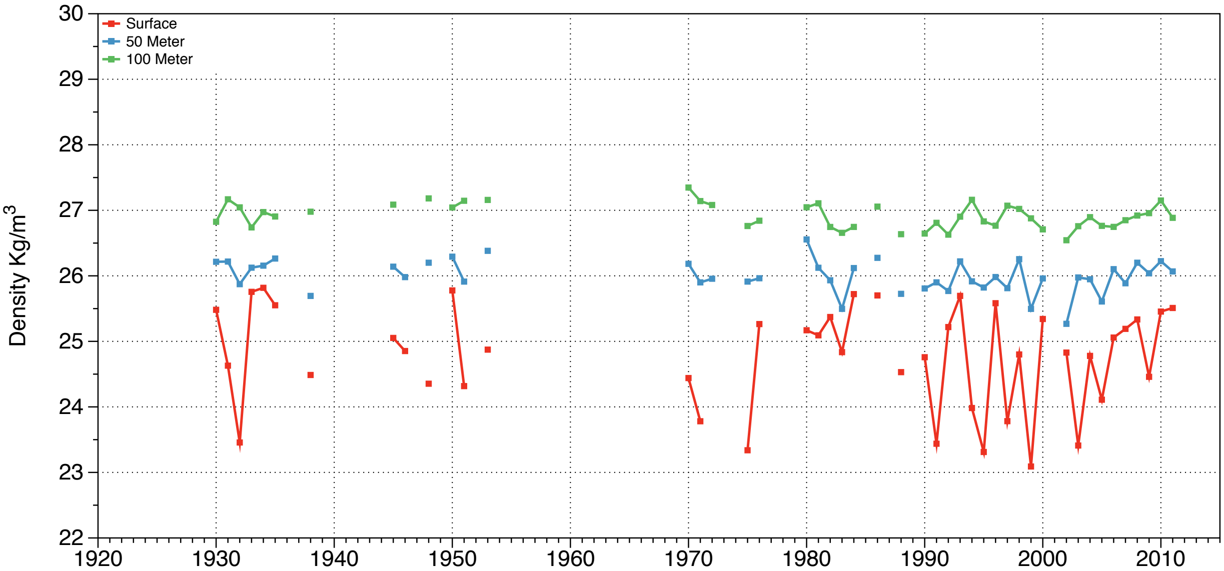


Figure 383: Interannual variability of autumn density (September – October) at station Inner Balsfjorden

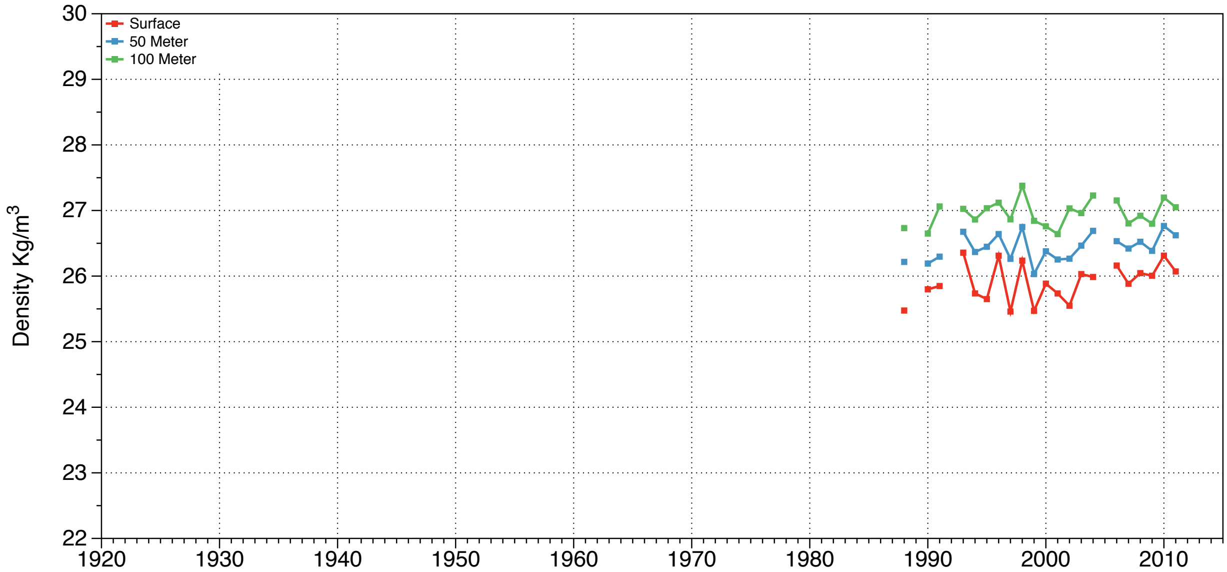


Figure 384: Interannual variability of autumn density (September – October) at station Kvalsund

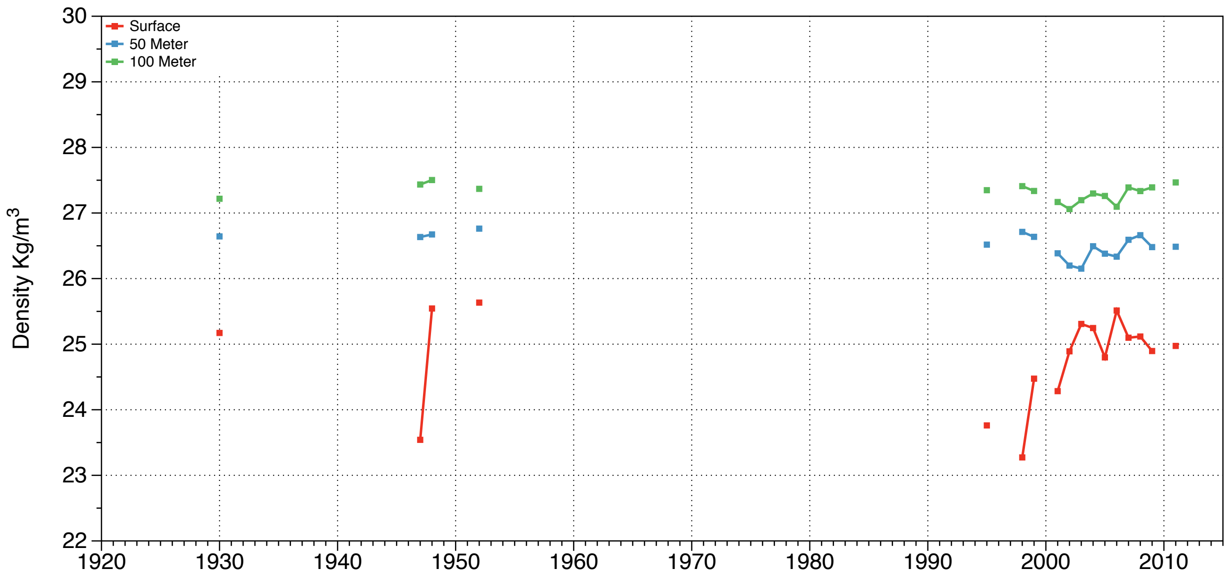


Figure 385: Interannual variability of autumn density (September – October) at station Sørfjord

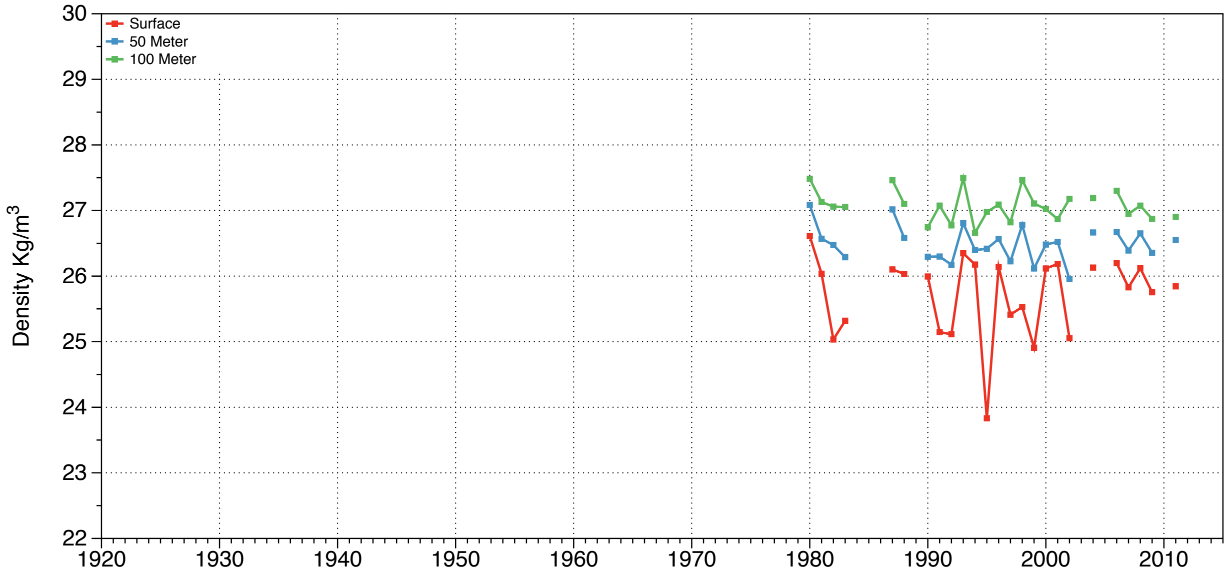


Figure 386: Interannual variability of autumn density (September – October) at station Outer Altafjorden

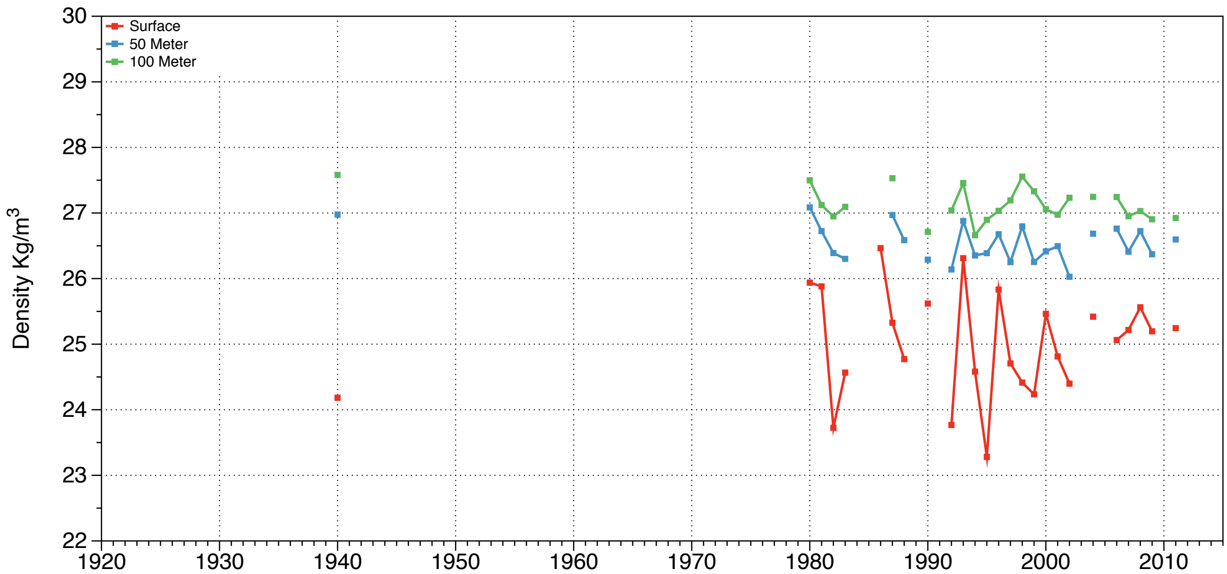


Figure 387: Interannual variability of autumn density (September – October) at station Inner Altafjorden

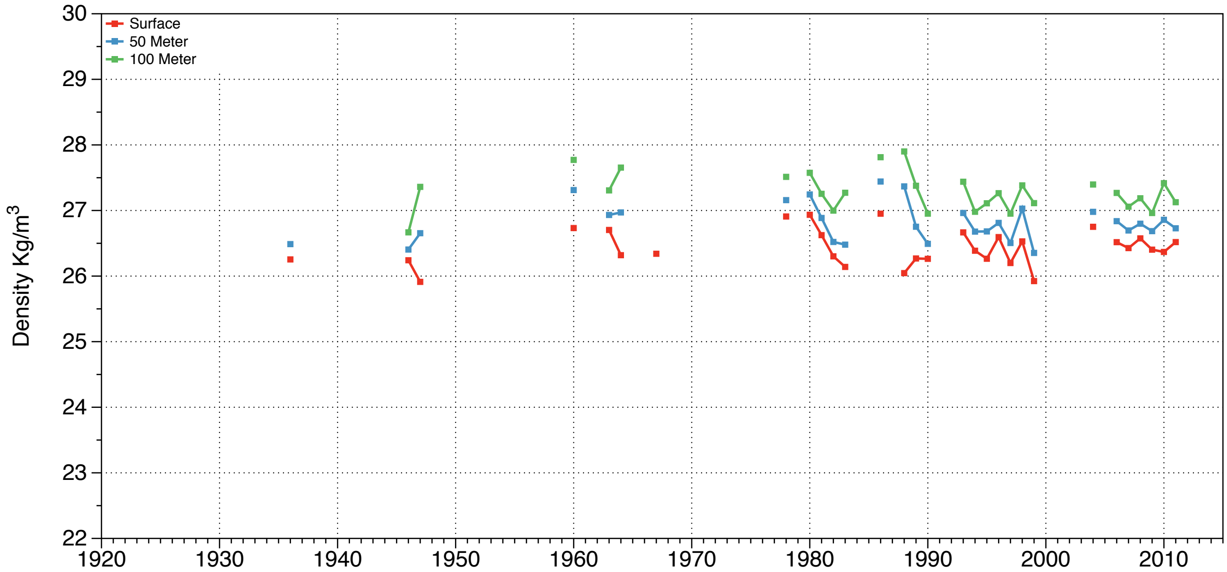


Figure 388: Interannual variability of autumn density (September – October) at station Refsbotn

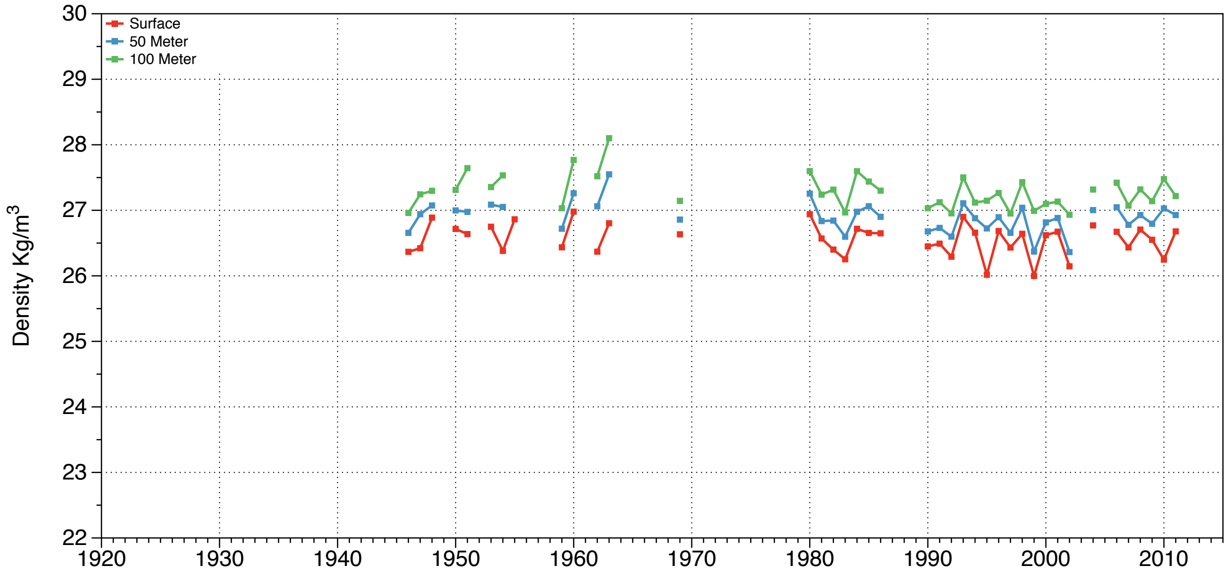


Figure 389: Interannual variability of autumn density (September – October) at station Outer Porsangerfjorden

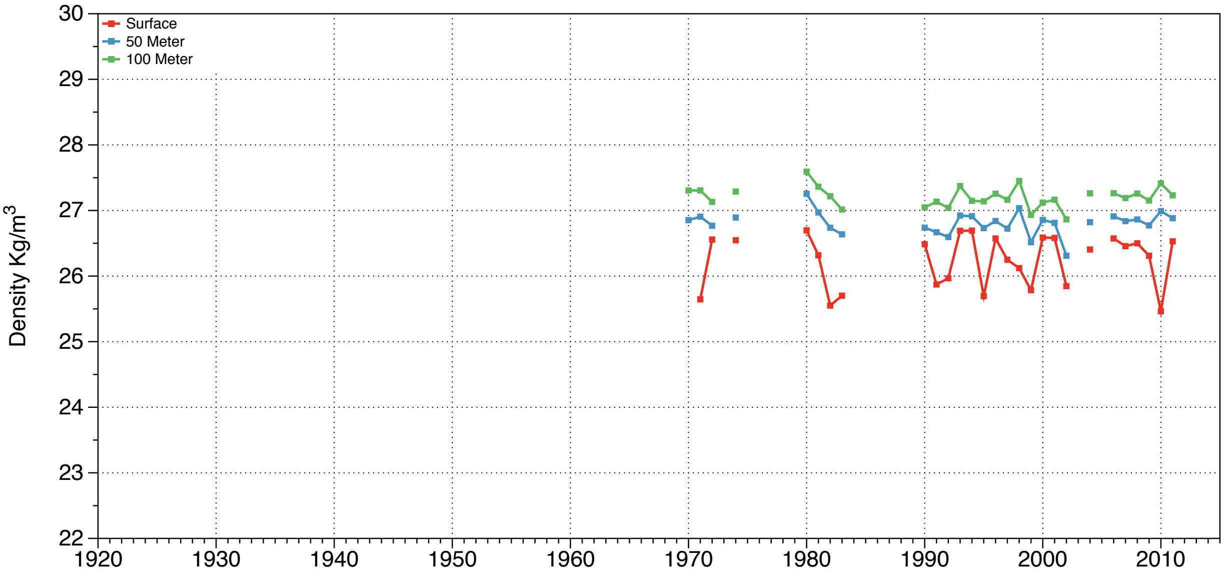


Figure 390: Interannual variability of autumn density (September – October) at station Inner Porsangerfjorden

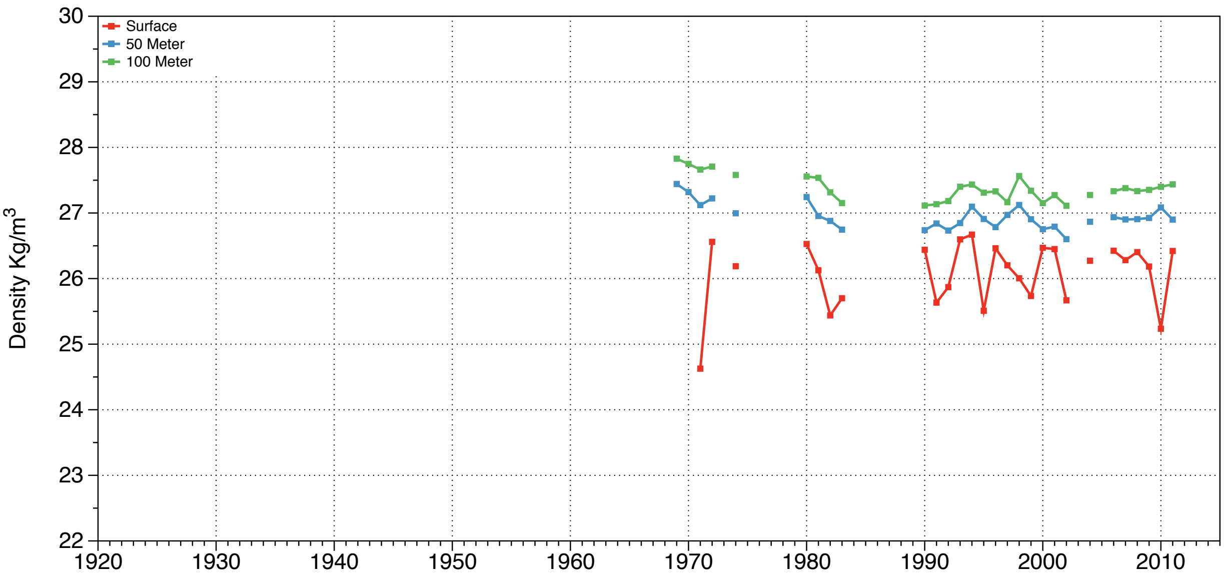


Figure 391: Interannual variability of autumn density (September – October) at station Østerbotn

A.7 INTERANNUAL VARIABILITY IN TEMPERATURE (TWO MONTHS AVERAGE)

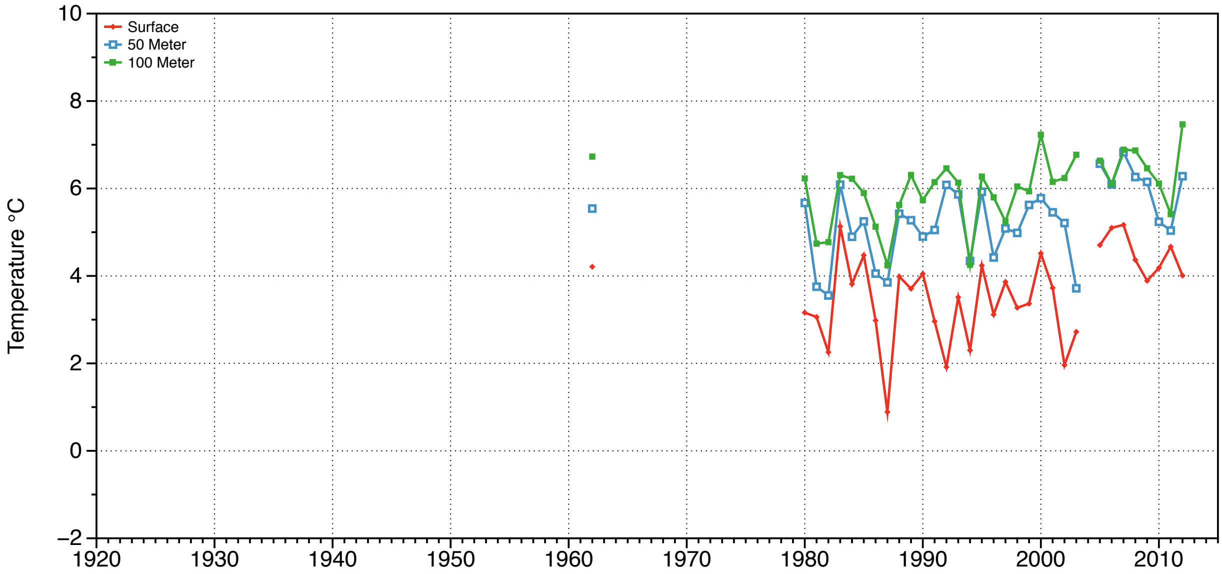


Figure 392: Interannual variability of temperatures (January – February) at station Inner Malangen

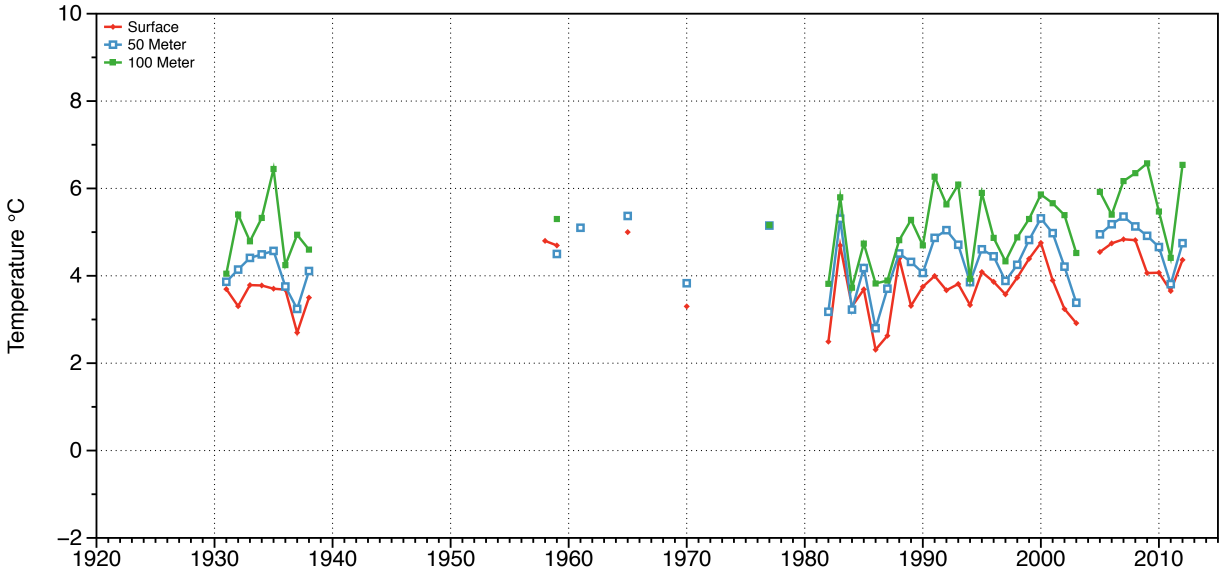


Figure 393: Interannual variability of temperatures (January – February) at station Outer Malangen

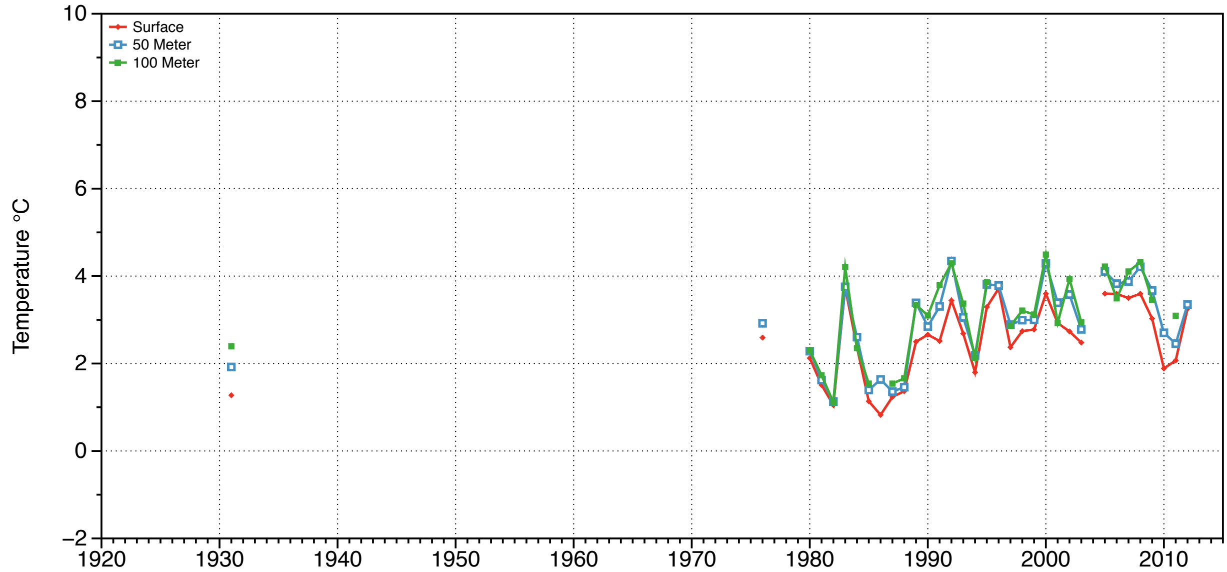


Figure 394: Interannual variability of temperatures (January – February) at station Outer Balsfjorden

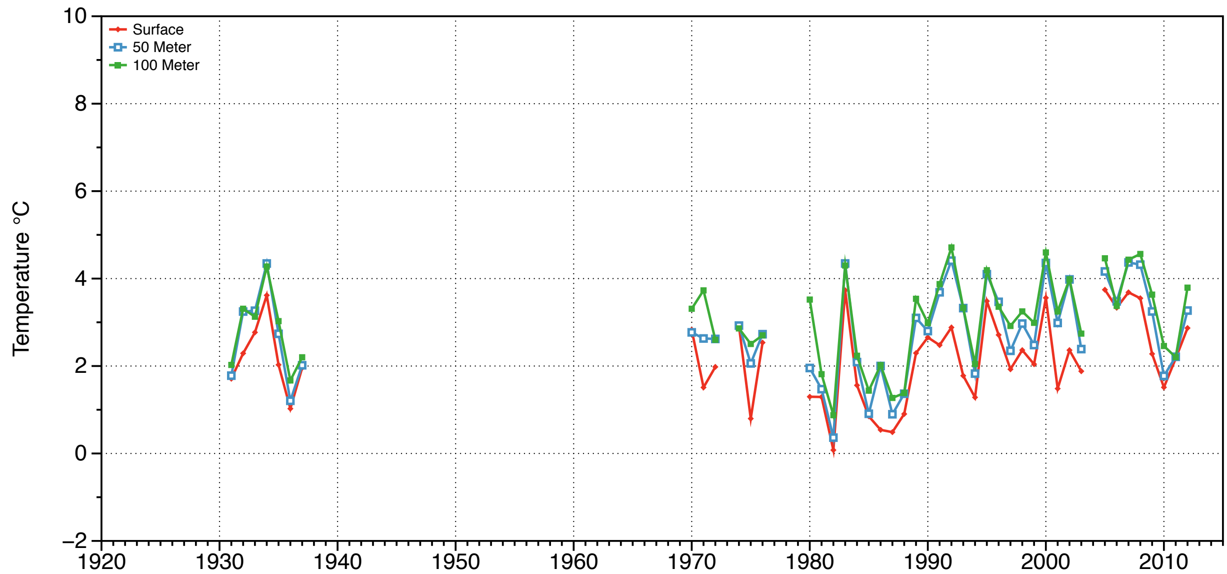


Figure 395: Interannual variability of temperatures (January – February) at station Inner Balsfjorden

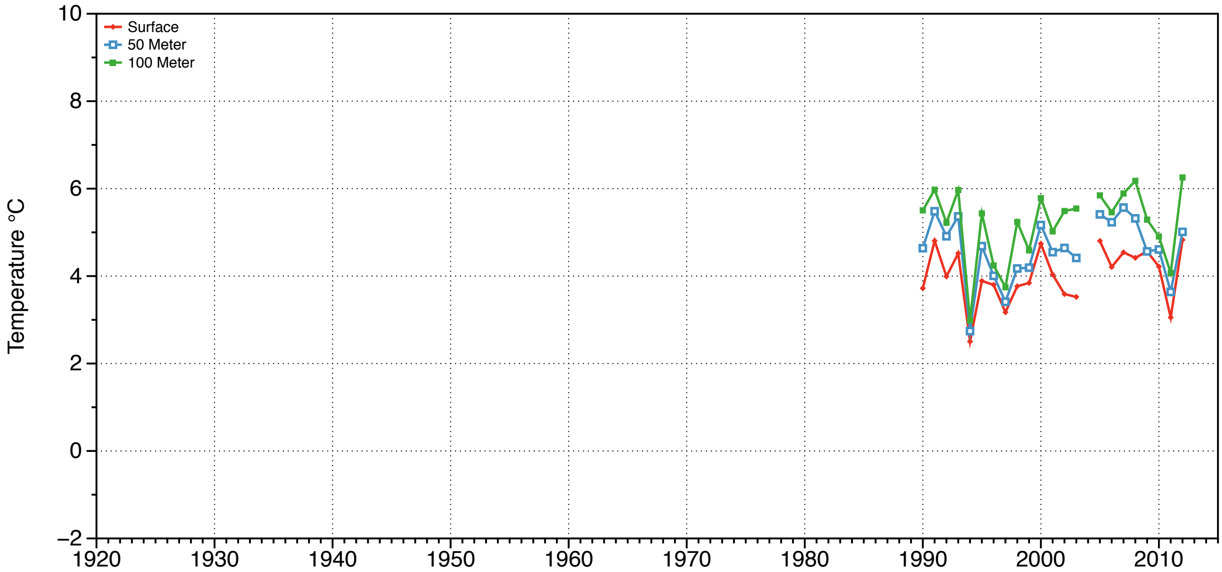


Figure 396: Interannual variability of temperatures (January – February) at station Kvalsund

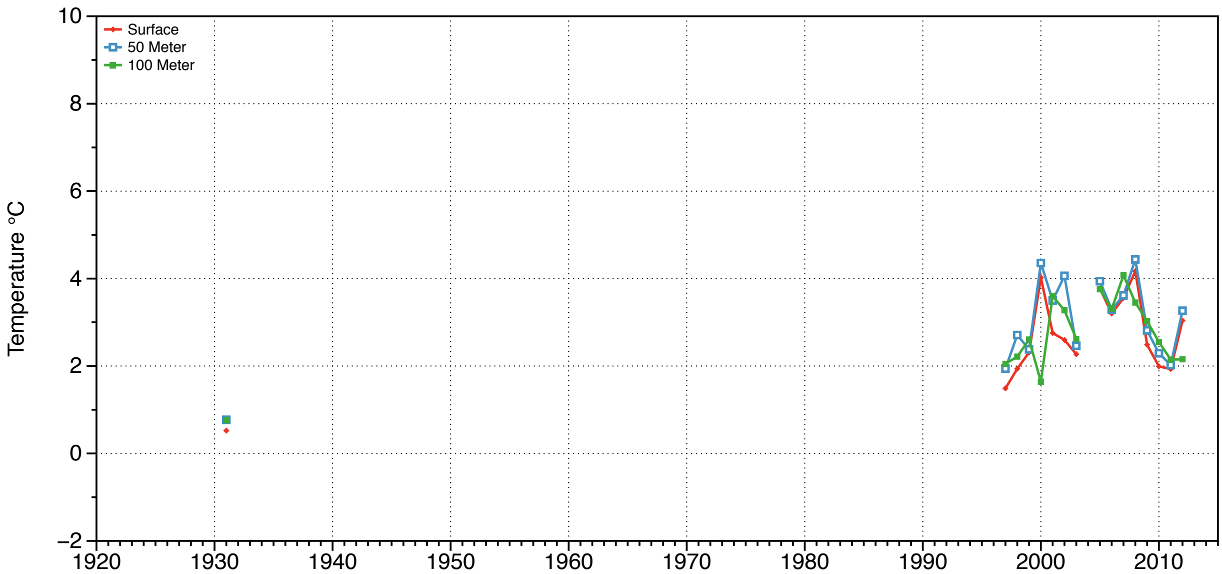


Figure 397: Interannual variability of temperatures (January – February) at station Sørfjord

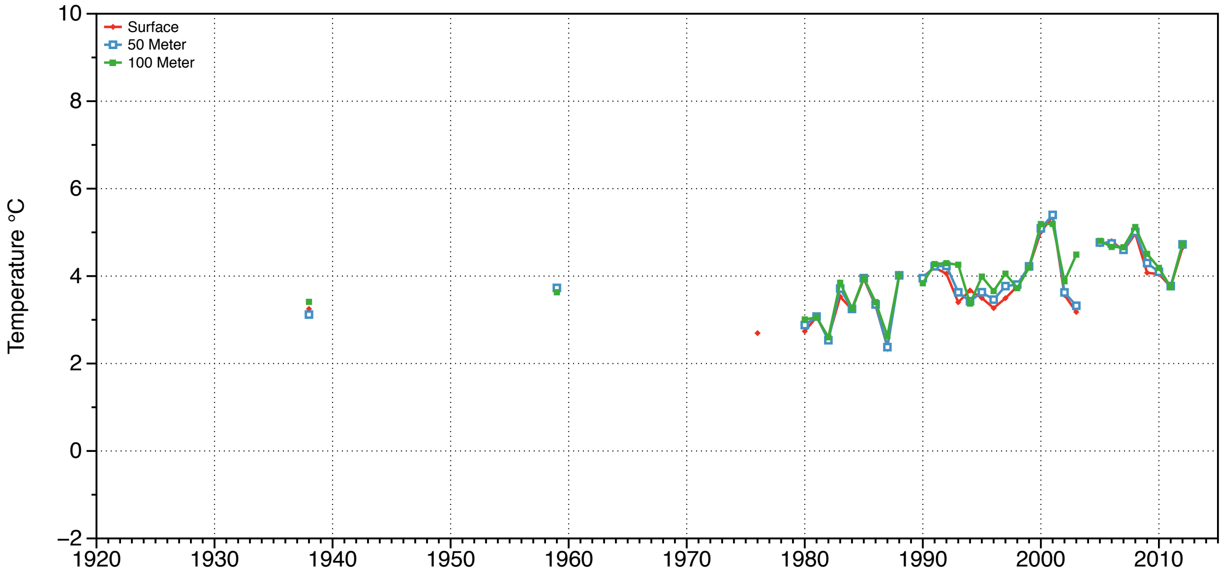


Figure 398: Interannual variability of temperatures (January – February) at station Outer Altafjorden

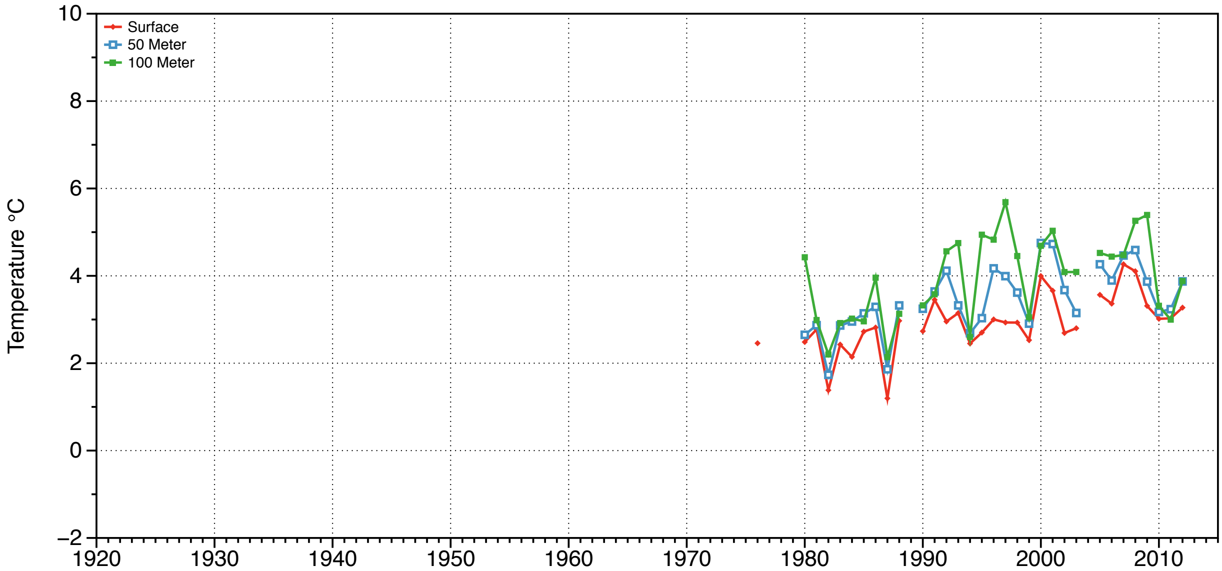


Figure 399: Interannual variability of temperatures (January – February) at station Inner Altafjorden

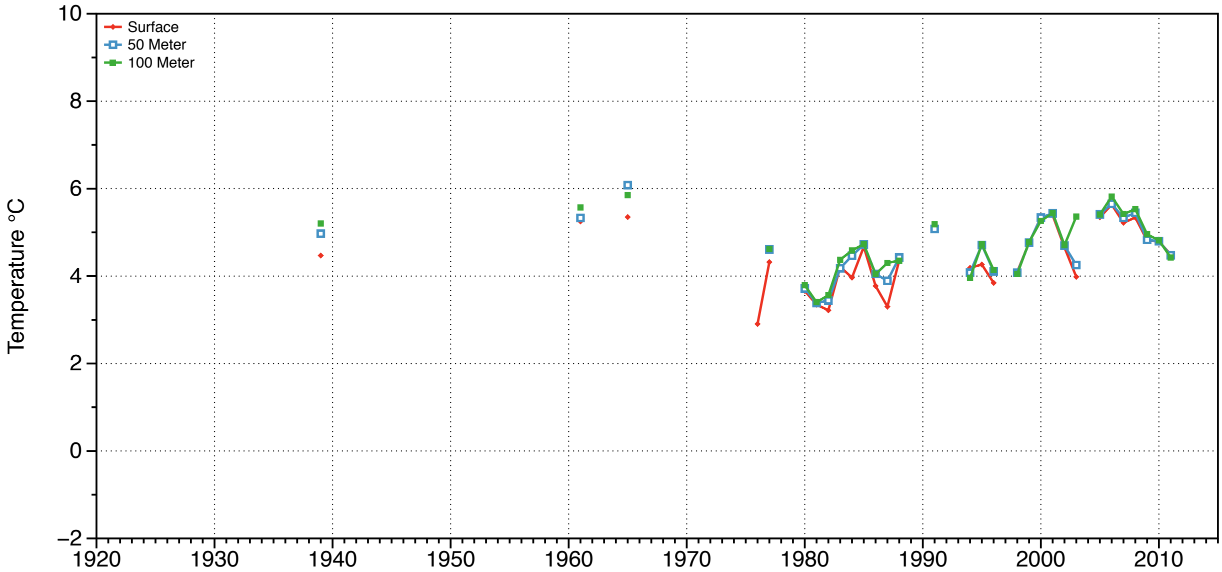


Figure 400: Interannual variability of temperatures (January – February) at station Refsbotn

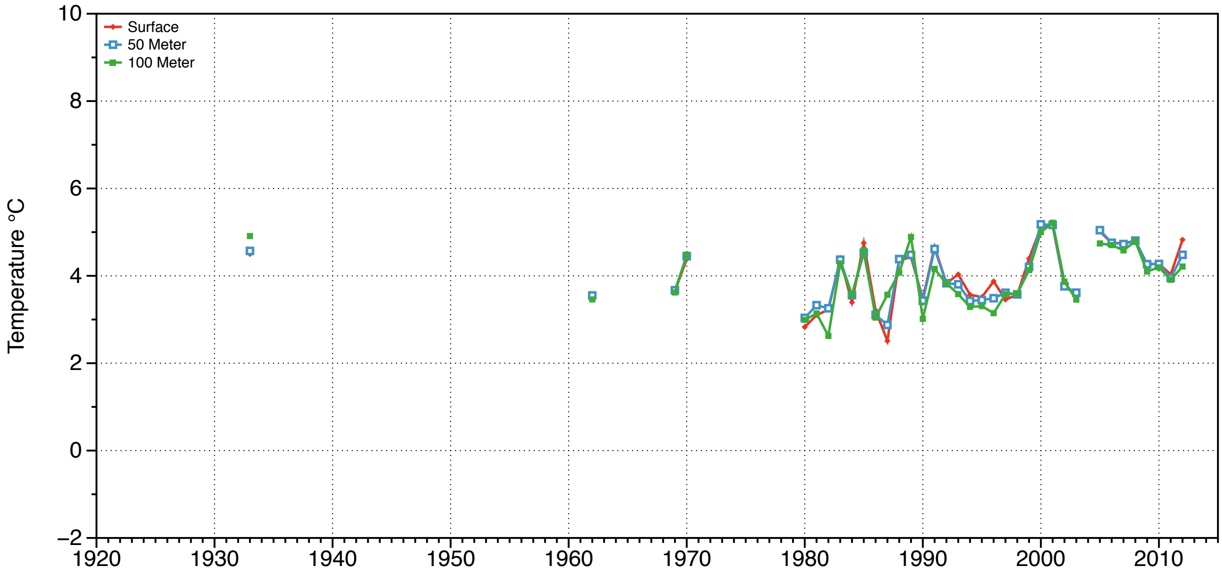


Figure 401: Interannual variability of temperatures (January – February) at station Outer Porsangerfjorden

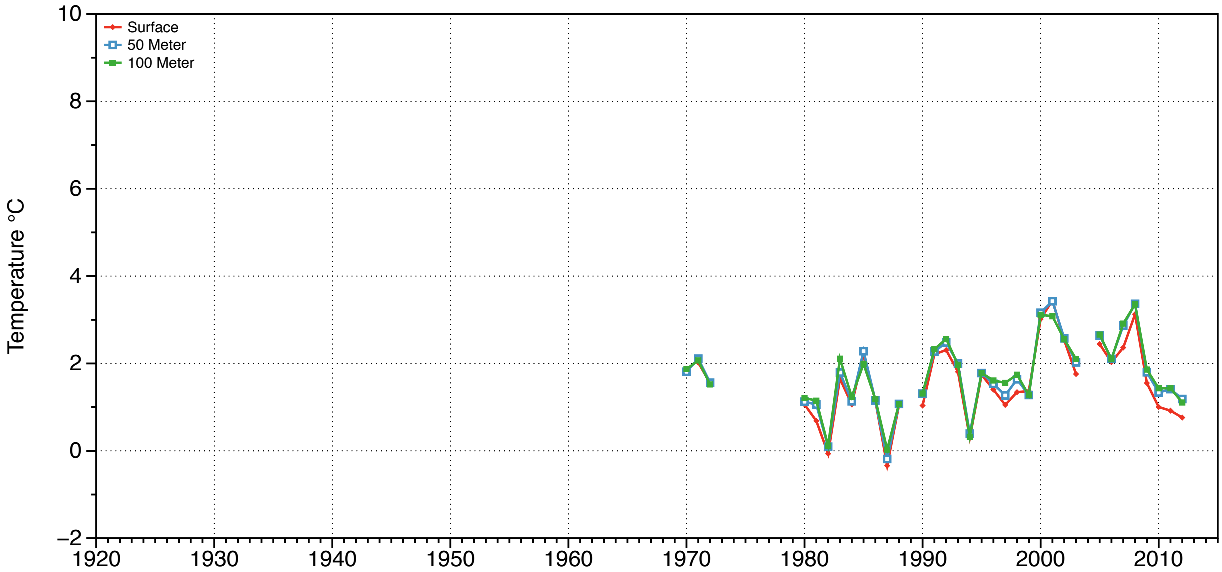


Figure 402: Interannual variability of temperatures (January – February) at station Inner Porsangerfjorden

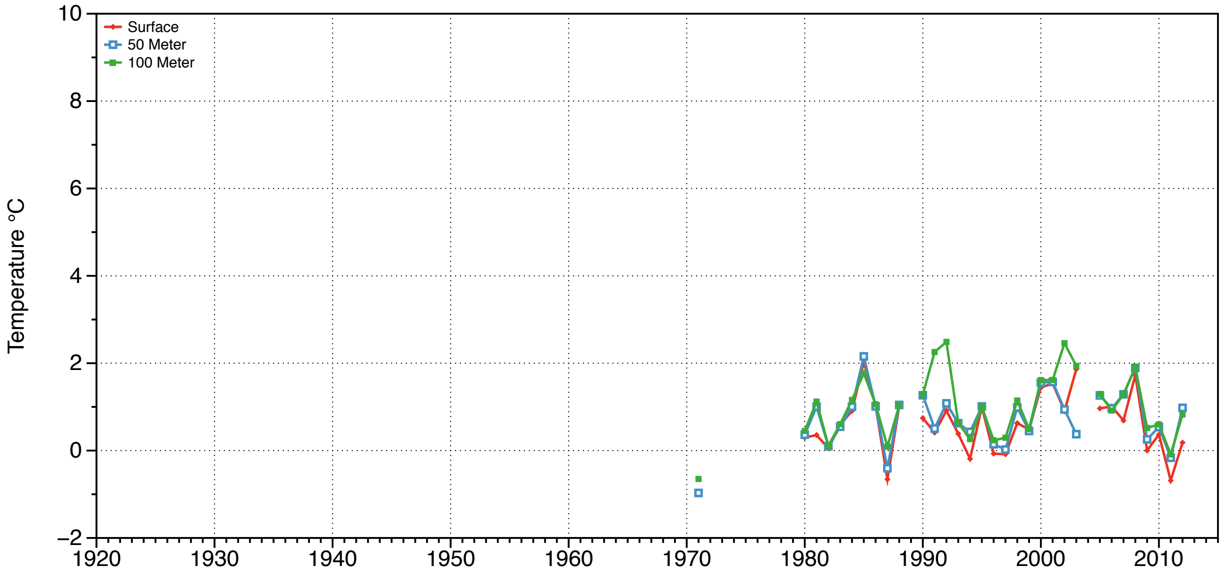


Figure 403: Interannual variability of temperatures (January – February) at station Østerbotn

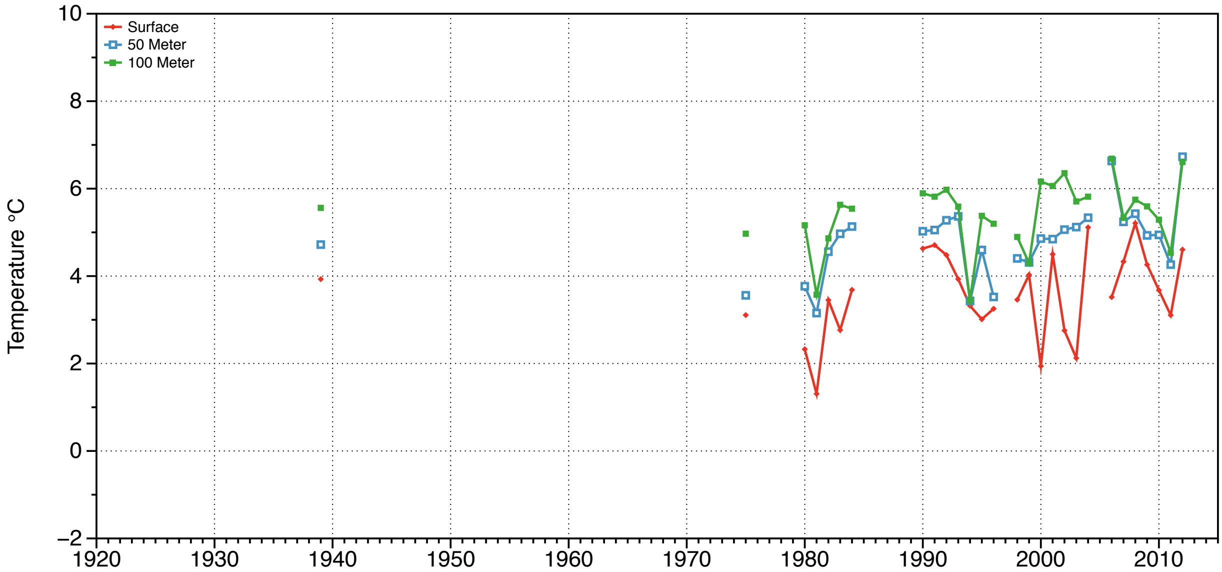


Figure 404: Interannual variability of temperatures (March – April) at station Inner Malangen

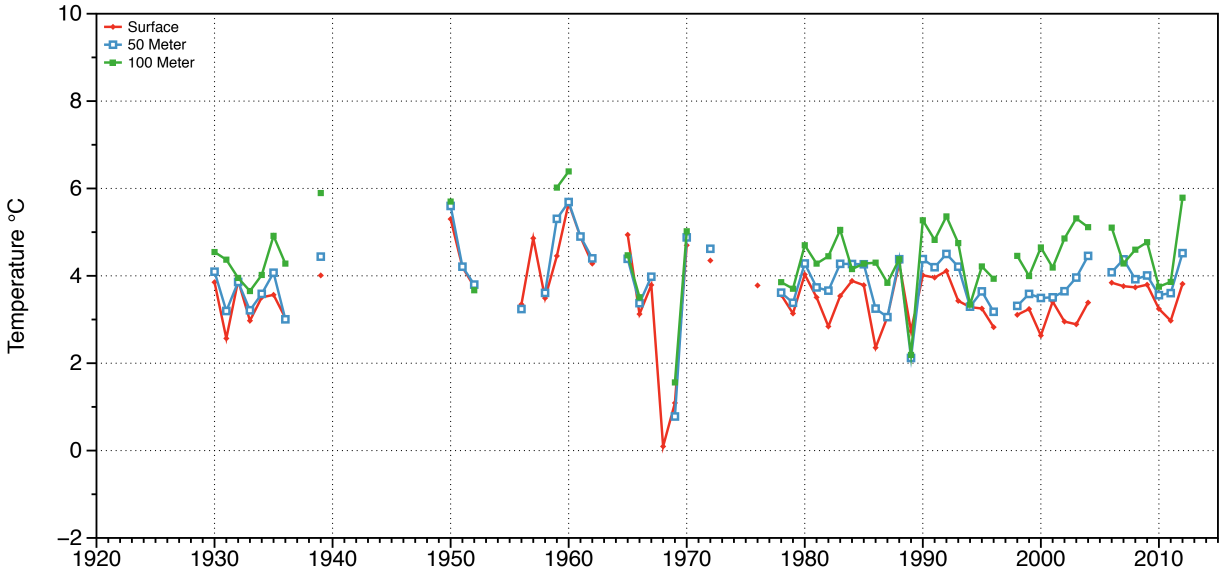


Figure 405: Interannual variability of temperatures (March – April) at station Outer Malangen

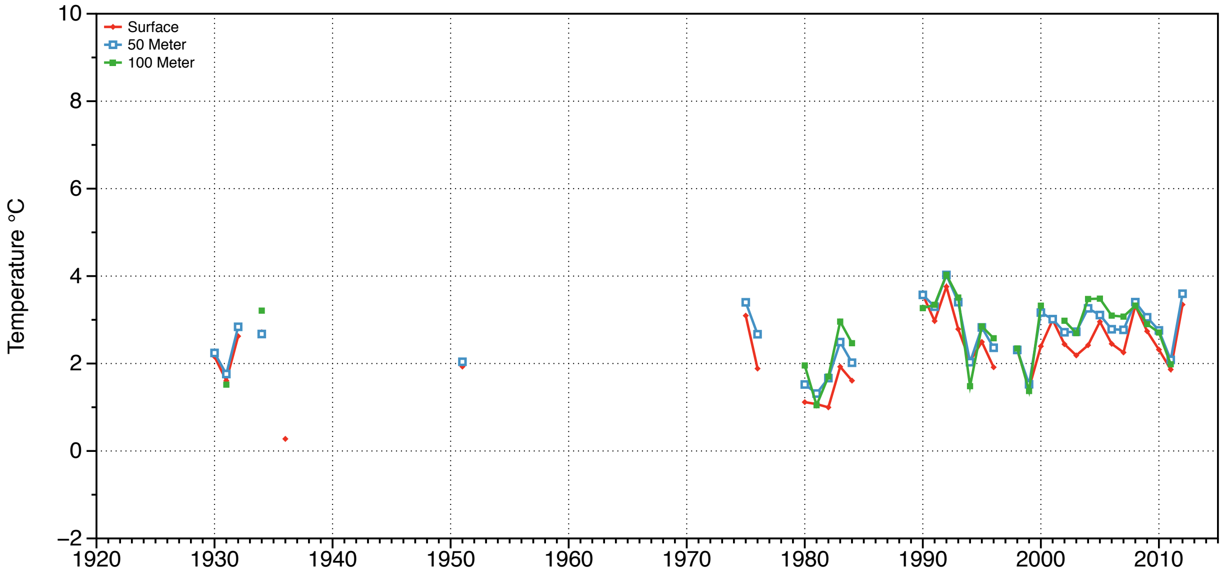


Figure 406: Interannual variability of temperatures (March – April) at station Outer Balsfjorden

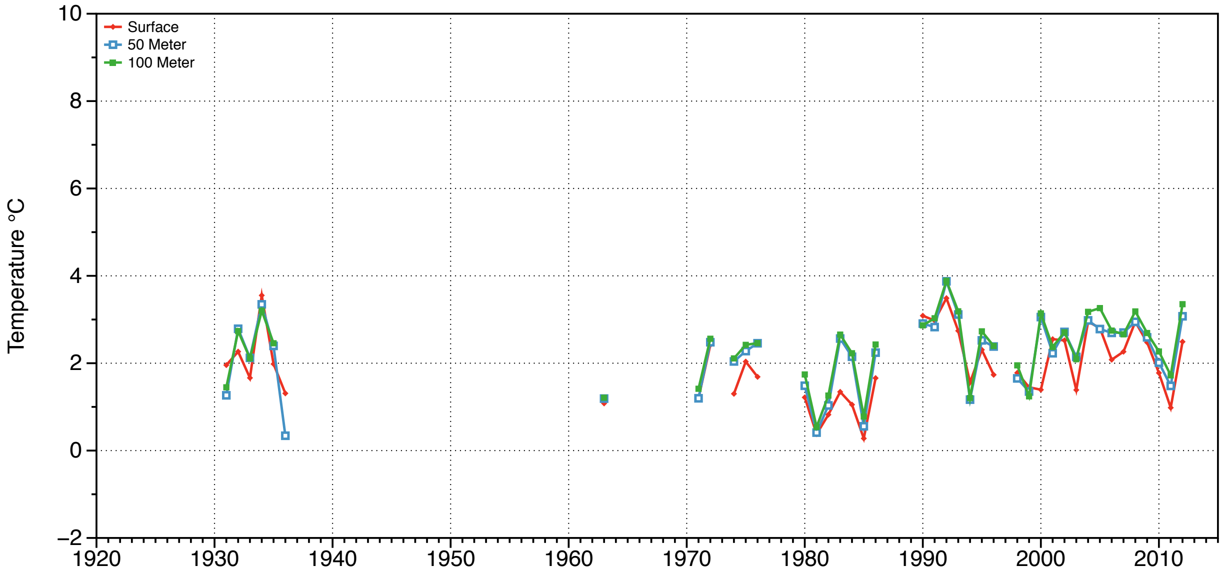


Figure 407: Interannual variability of temperatures (March – April) at station Inner Balsfjorden

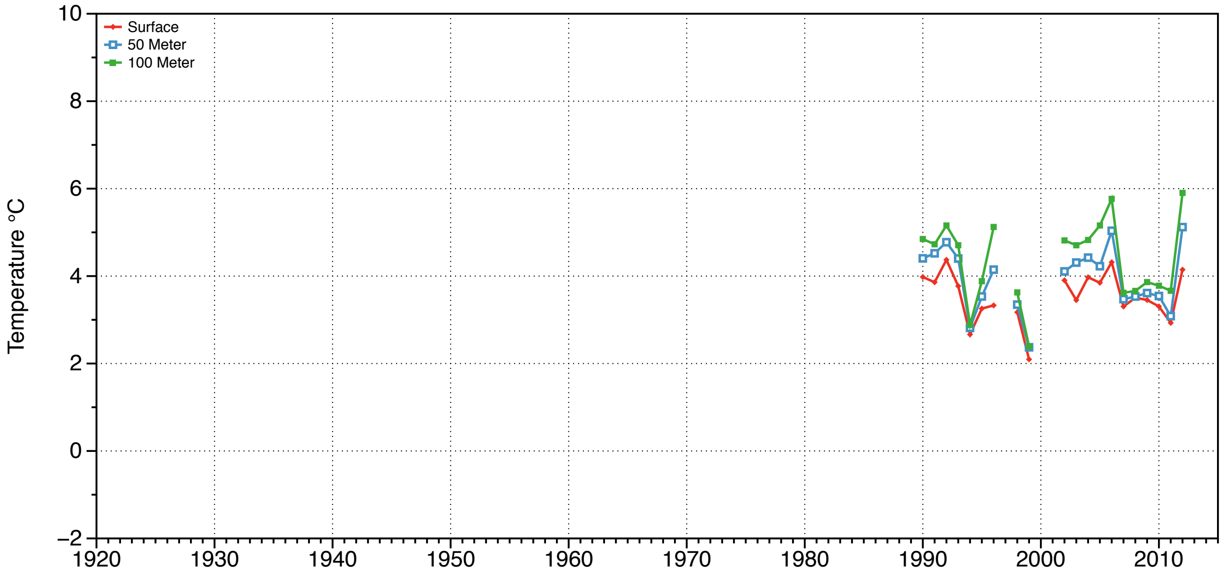


Figure 408: Interannual variability of temperatures (March – April) at station Kvalsund

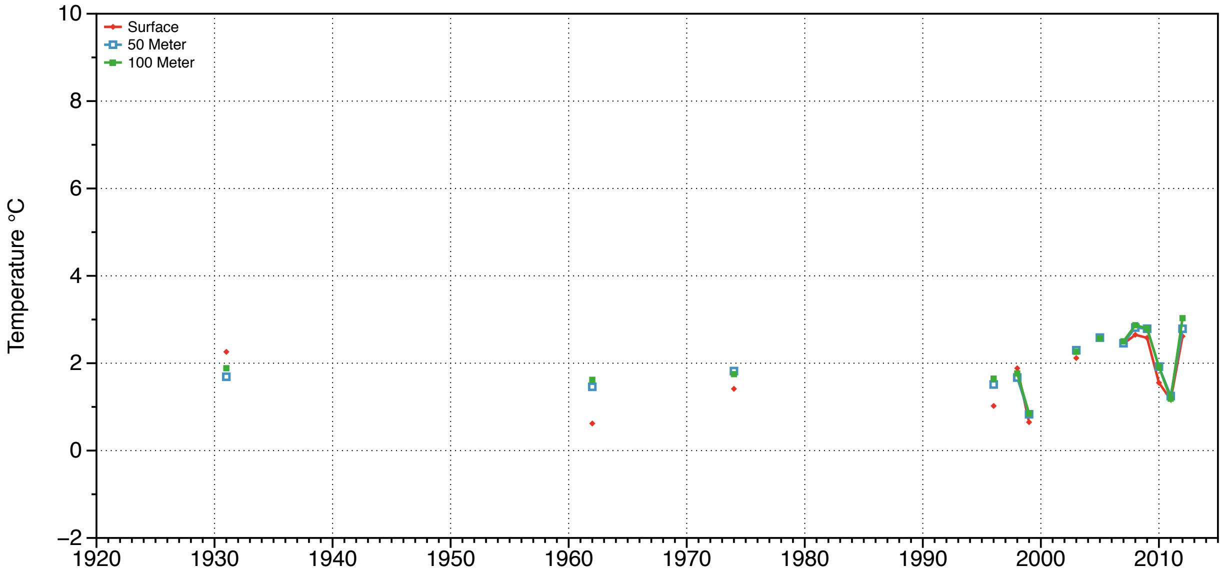


Figure 409: Interannual variability of temperatures (March – April) at station Sørfjord

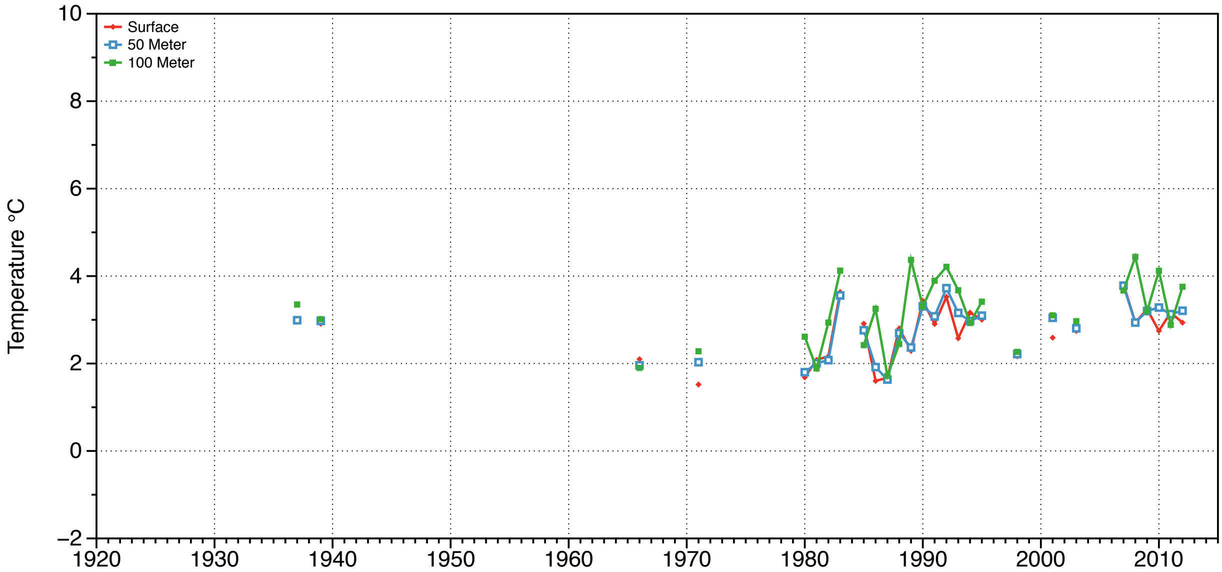


Figure 410: Interannual variability of temperatures (March – April) at station Outer Altafjorden

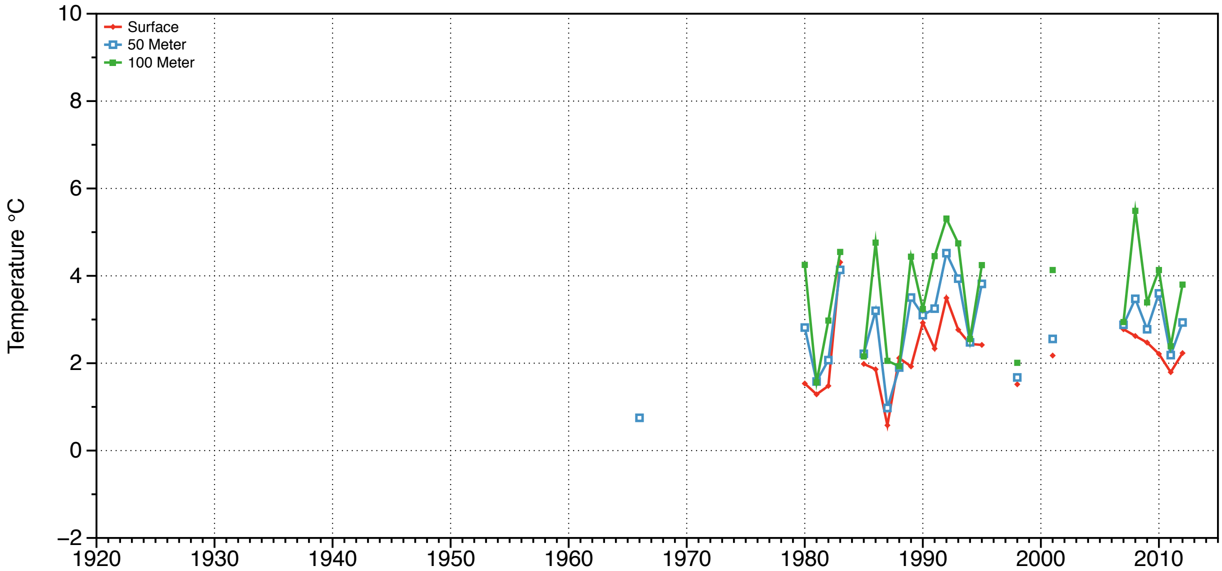


Figure 411: Interannual variability of temperatures (March – April) at station Inner Altafjorden

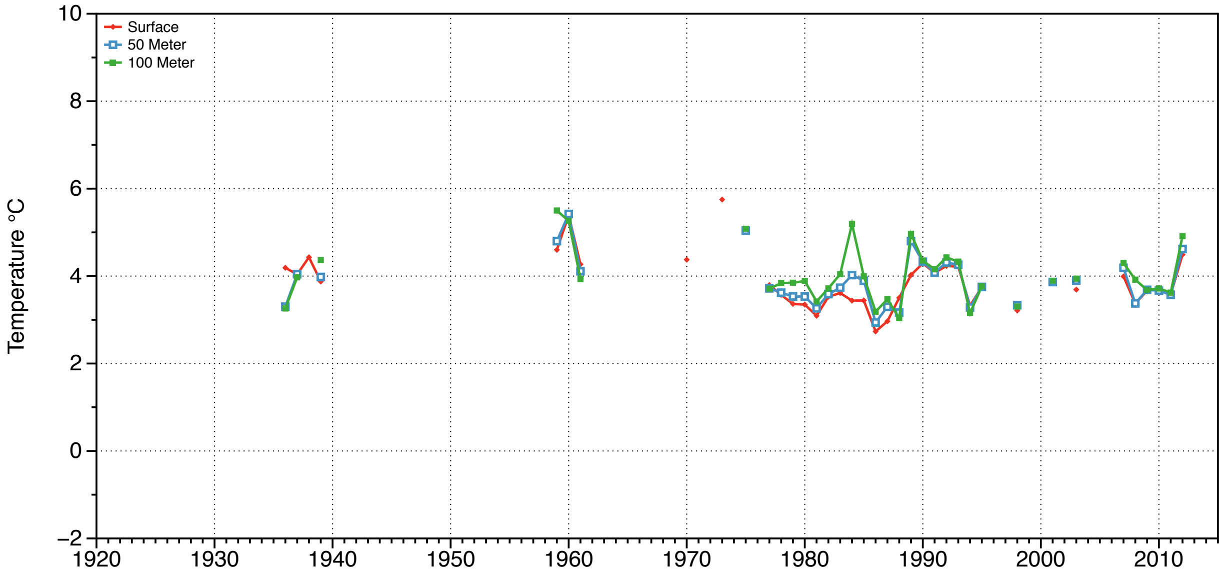


Figure 412: Interannual variability of temperatures (March – April) at station Refsbotn

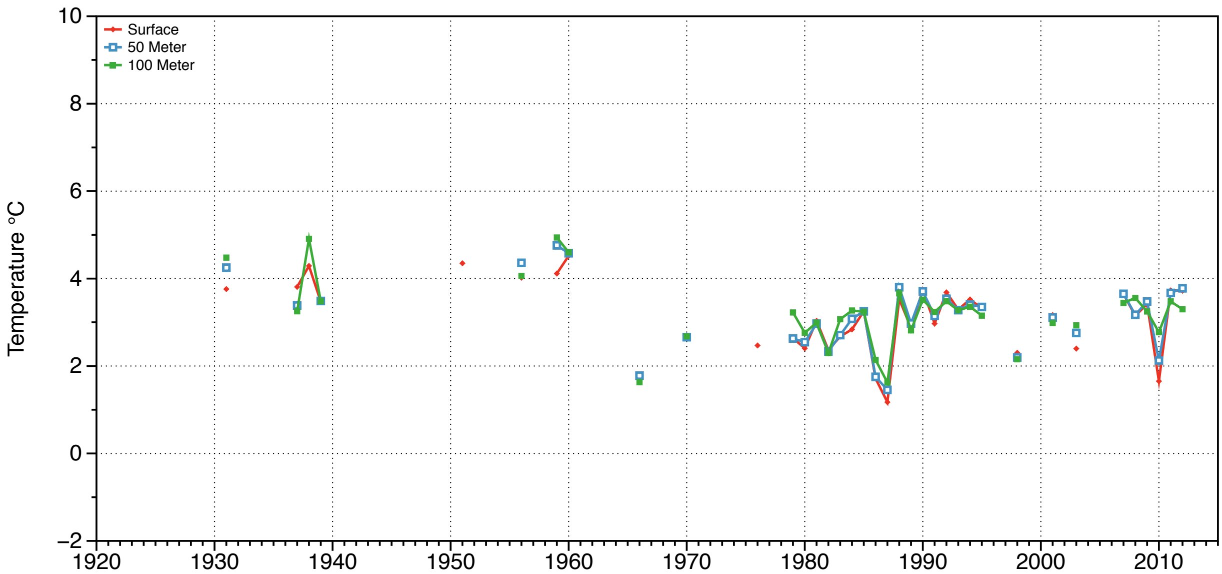


Figure 413: Interannual variability of temperatures (March – April) at station Outer Porsangerfjorden

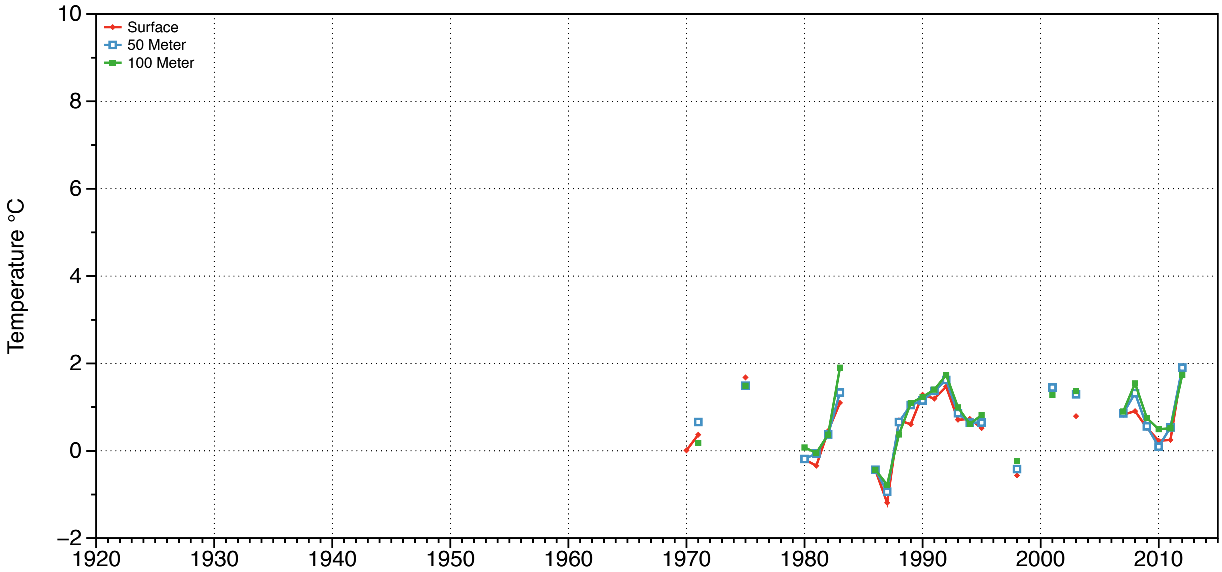


Figure 414: Interannual variability of temperatures (March – April) at station Inner Porsangerfjorden

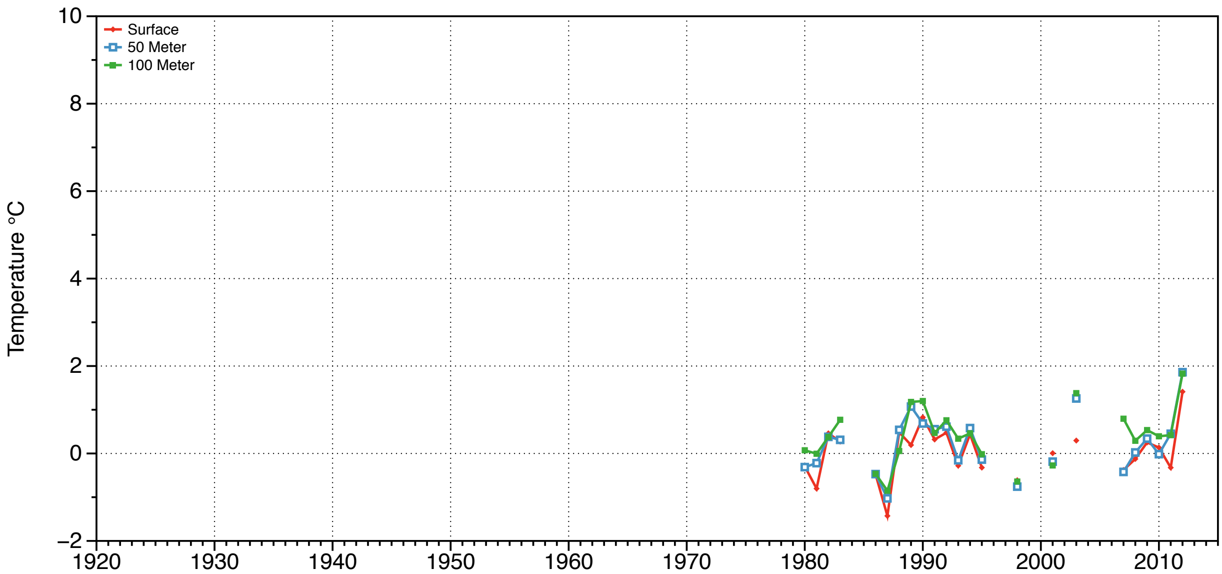


Figure 415: Interannual variability of temperatures (March – April) at station Østerbotn

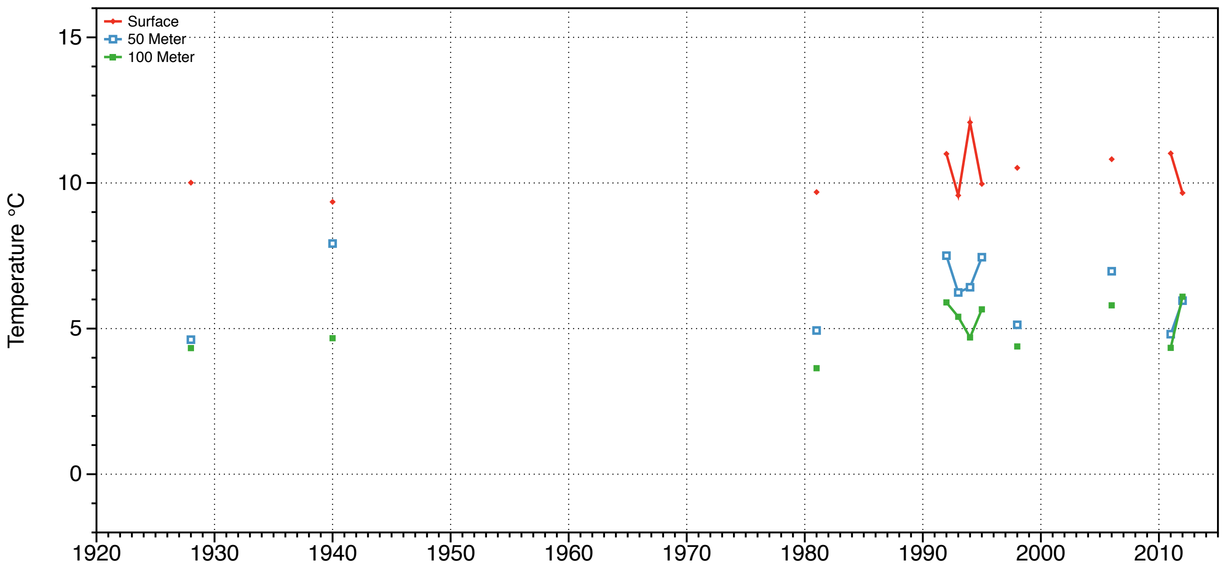


Figure 416: Interannual variability of temperatures (July – August) at station Inner Malangen

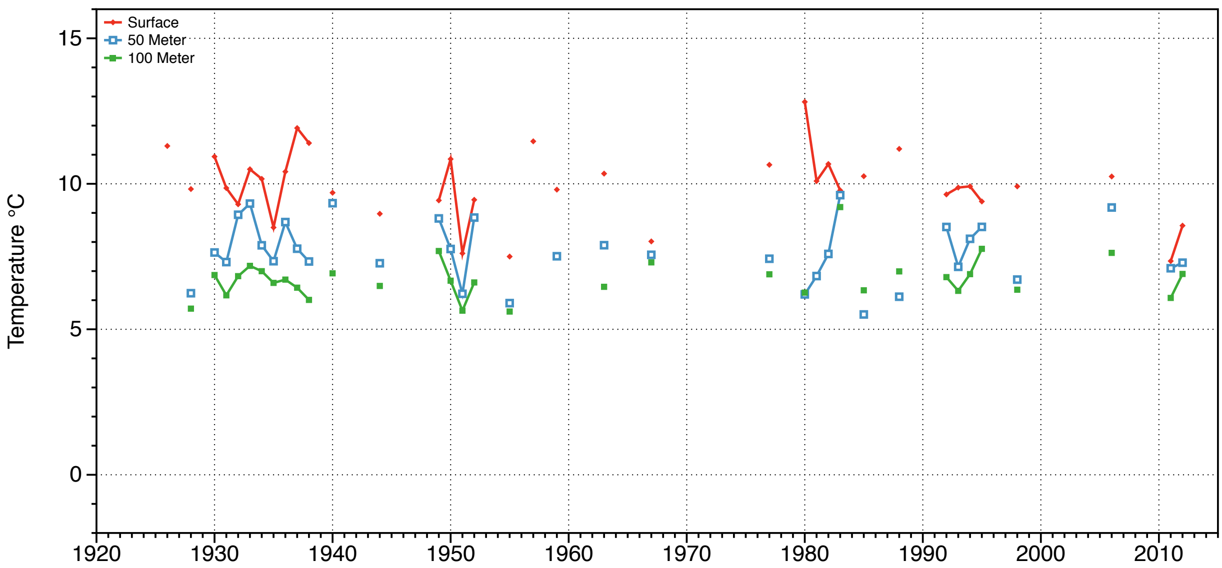


Figure 417: Interannual variability of temperatures (July – August) at station Outer Malangen

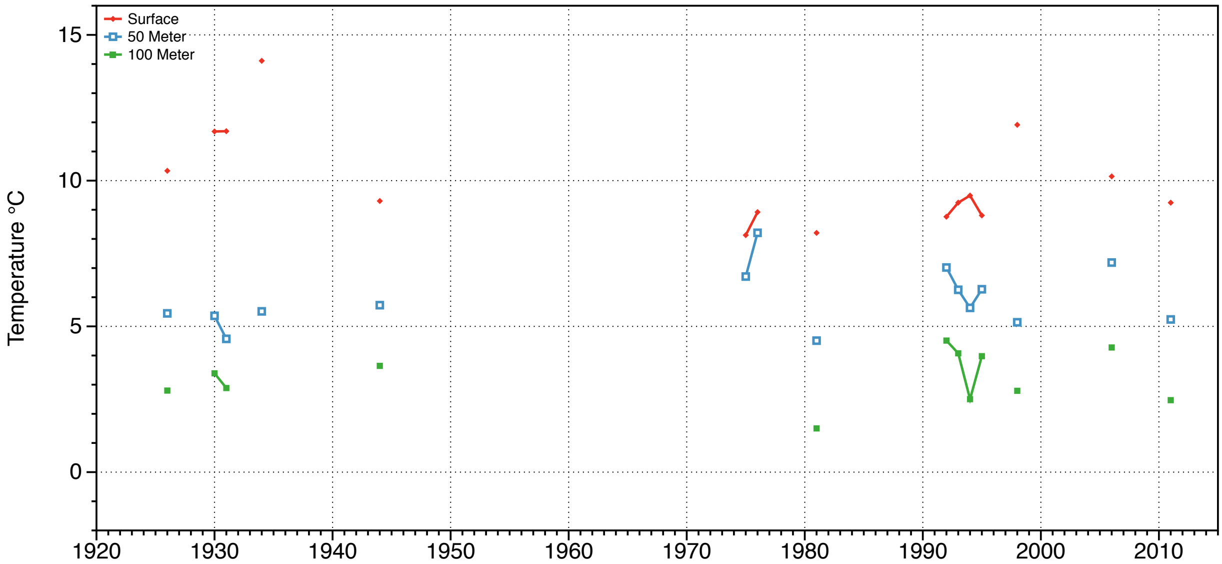


Figure 418: Interannual variability of temperatures (July – August) at station Outer Balsfjorden

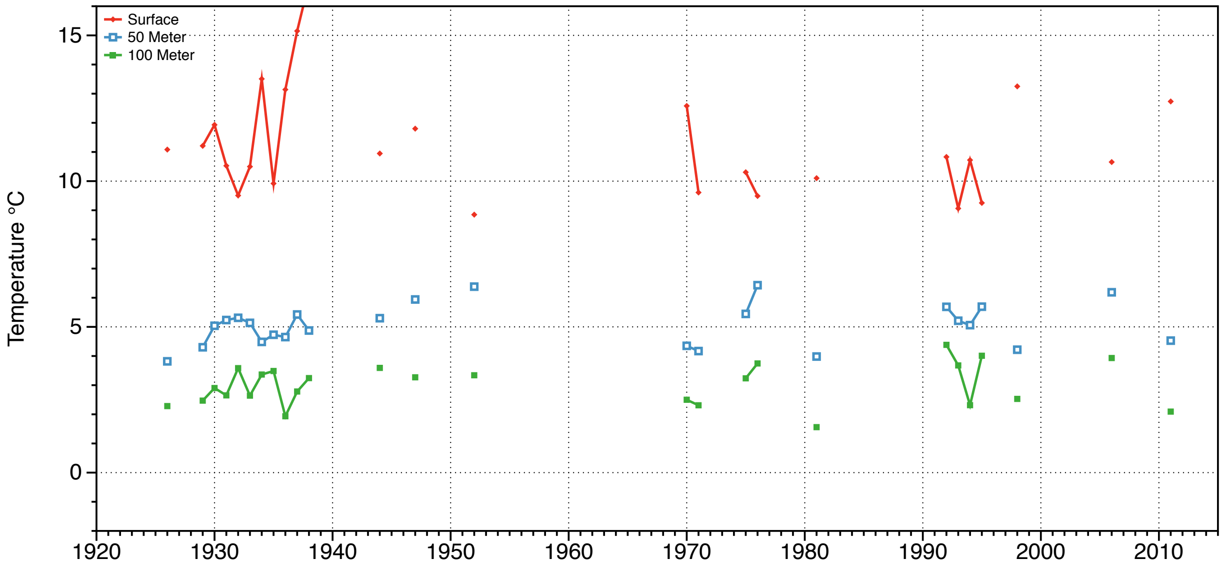


Figure 419: Interannual variability of temperatures (July – August) at station Inner Balsfjorden

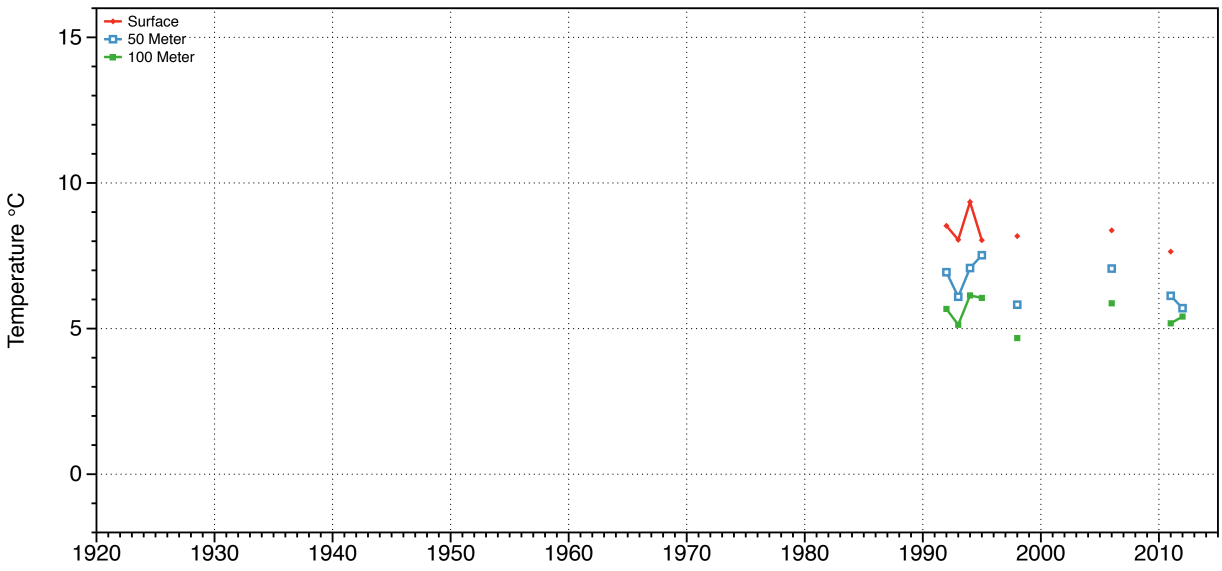


Figure 420: Interannual variability of temperatures (July – August) at station Kvalsund

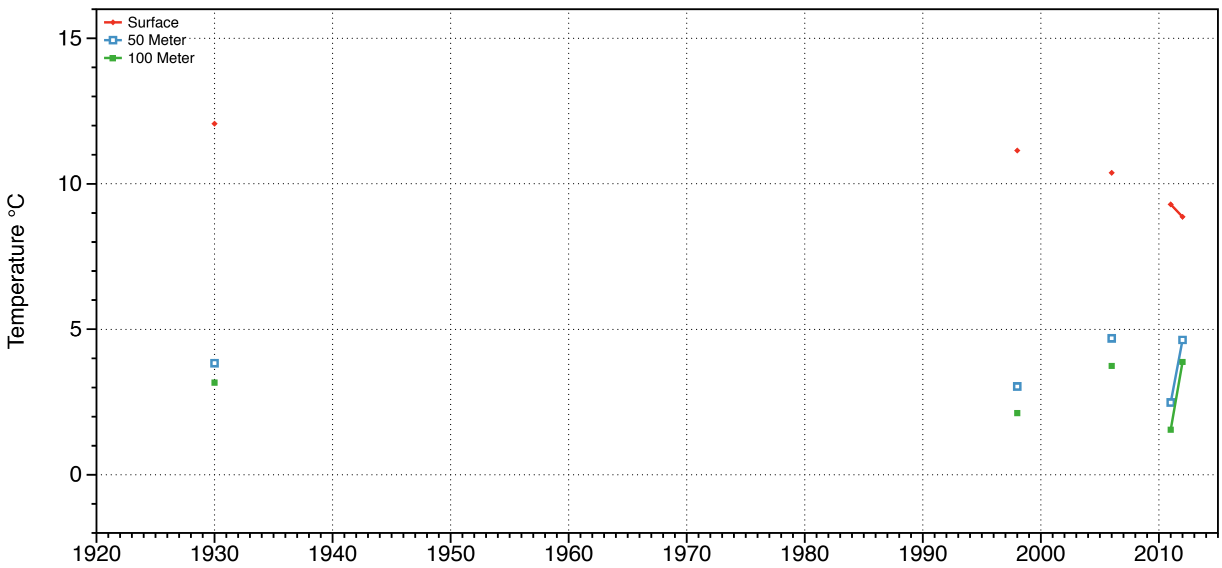


Figure 421: Interannual variability of temperatures (July – August) at station Sørfjord

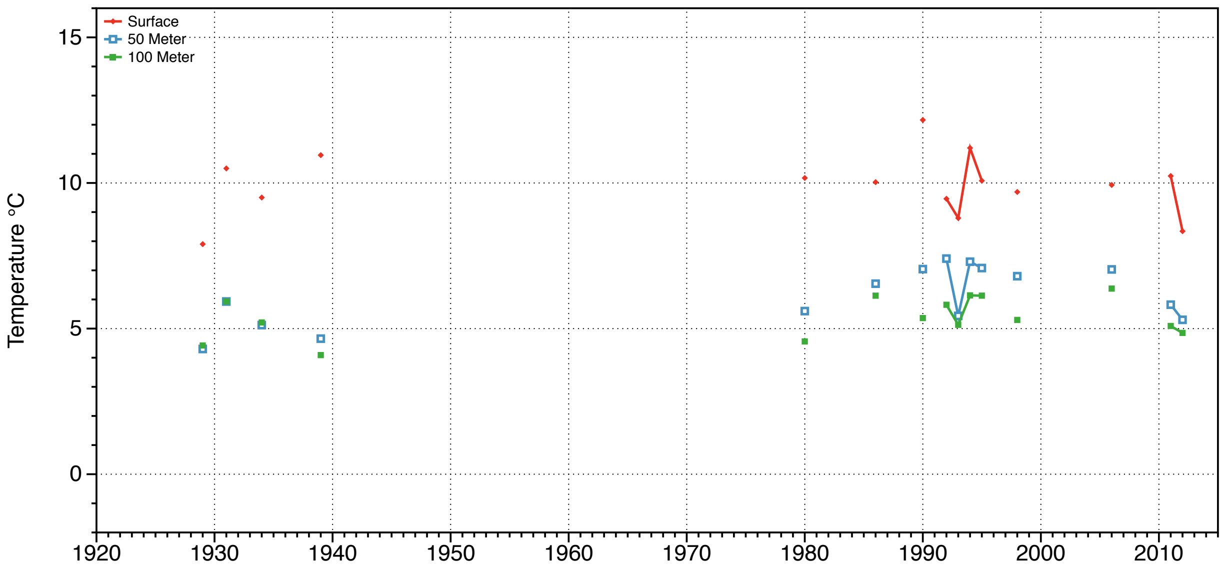


Figure 422: Interannual variability of temperatures (July – August) at station Outer Altafjorden

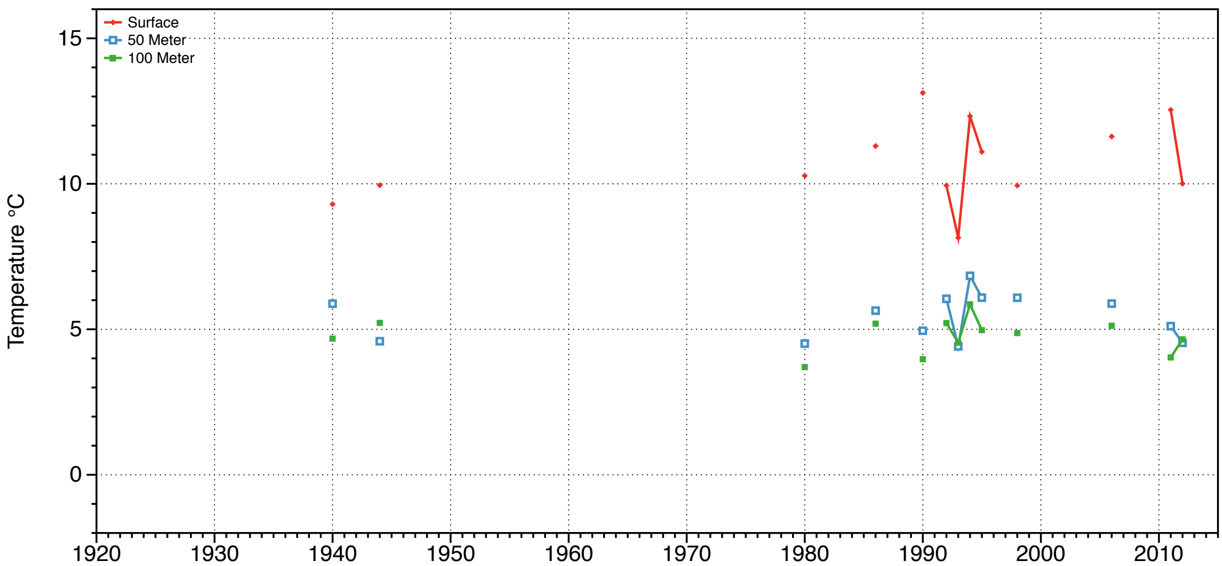


Figure 423: Interannual variability of temperatures (July – August) at station Inner Altafjorden

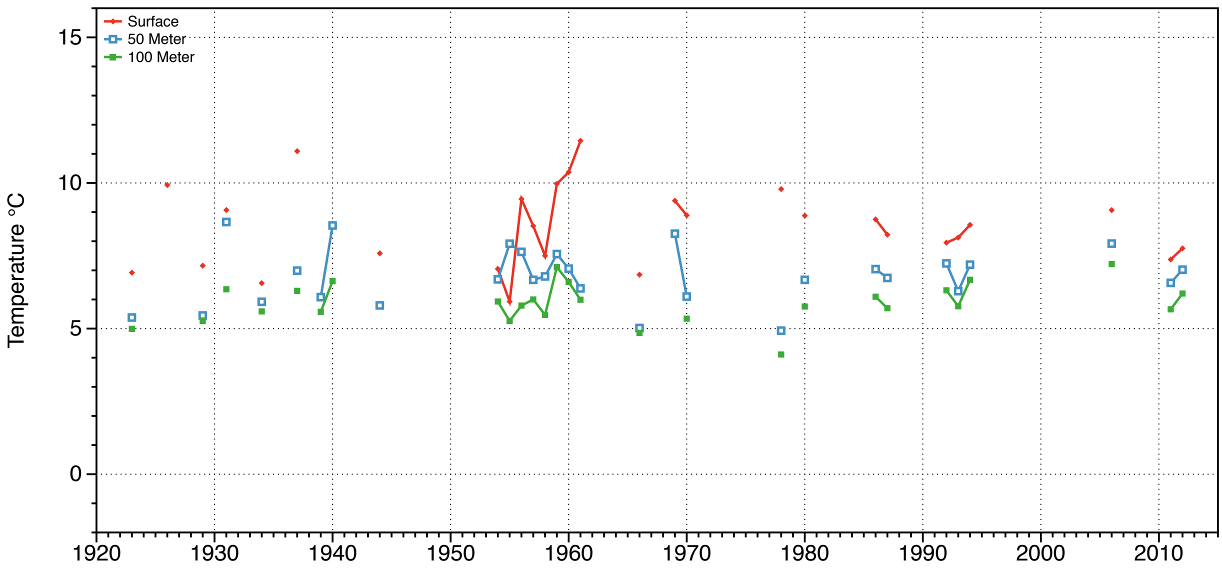


Figure 424: Interannual variability of temperatures (July – August) at station Refsbotn

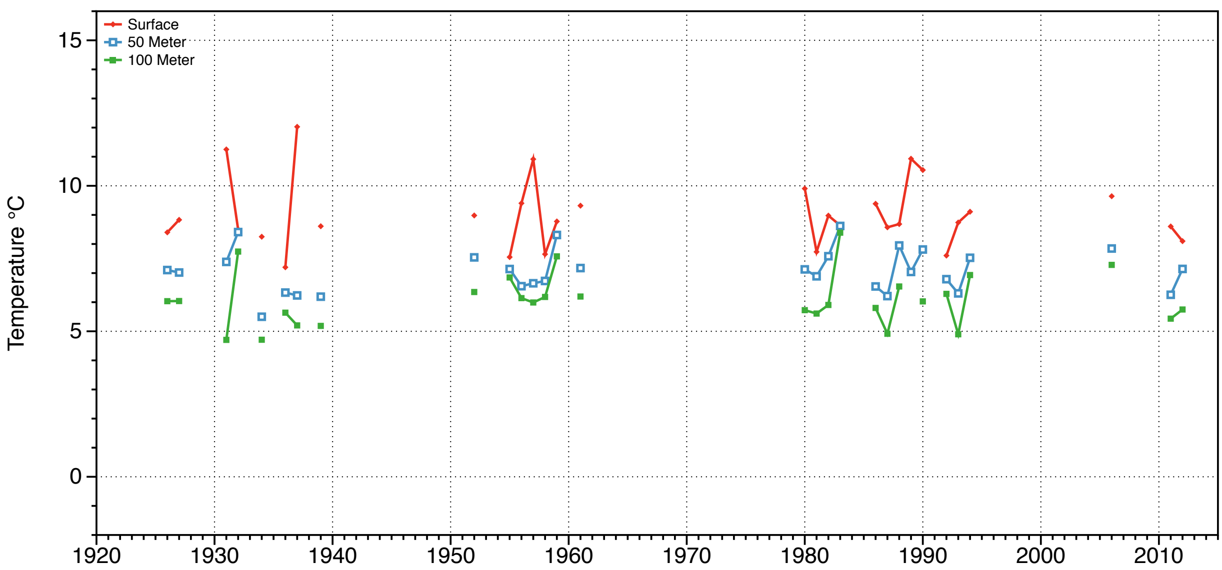


Figure 425: Interannual variability of temperatures (July – August) at station Outer Porsangerfjorden

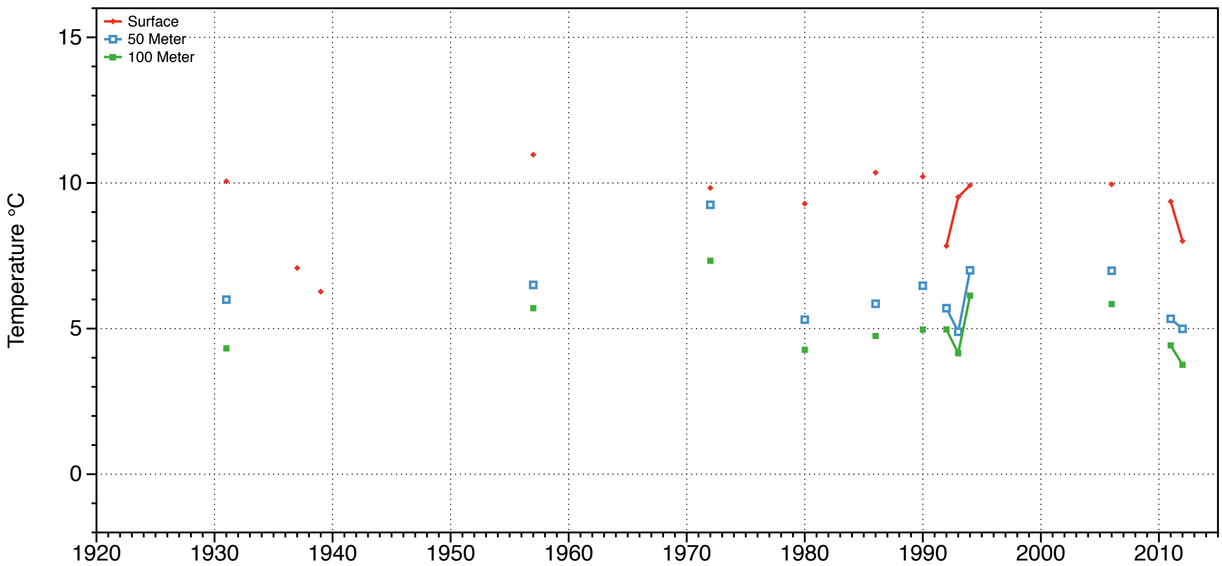


Figure 426: Interannual variability of temperatures (July – August) at station Inner Porsangerfjorden

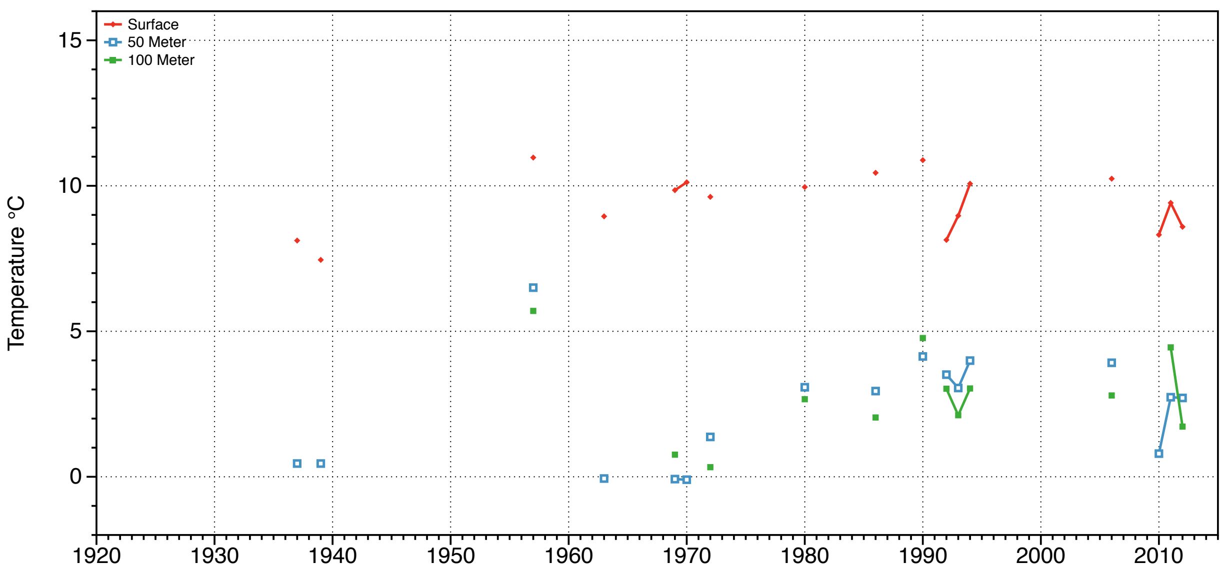


Figure 427: Interannual variability of temperatures (July – August) at station Østerbotn

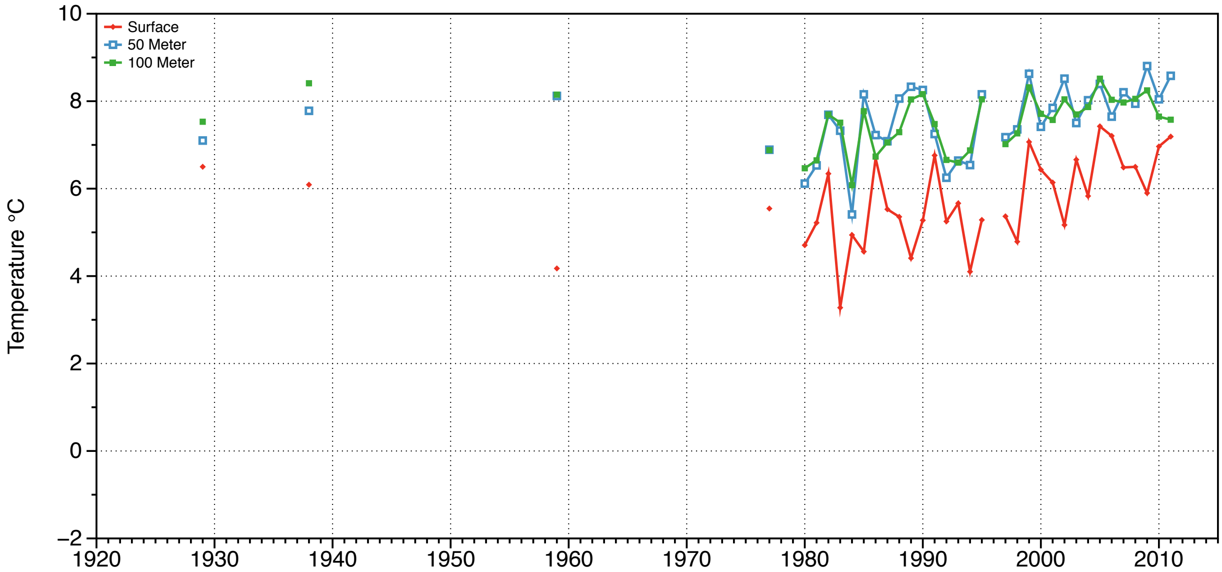


Figure 428: Interannual variability of temperatures (November – December) at station Inner Malangen

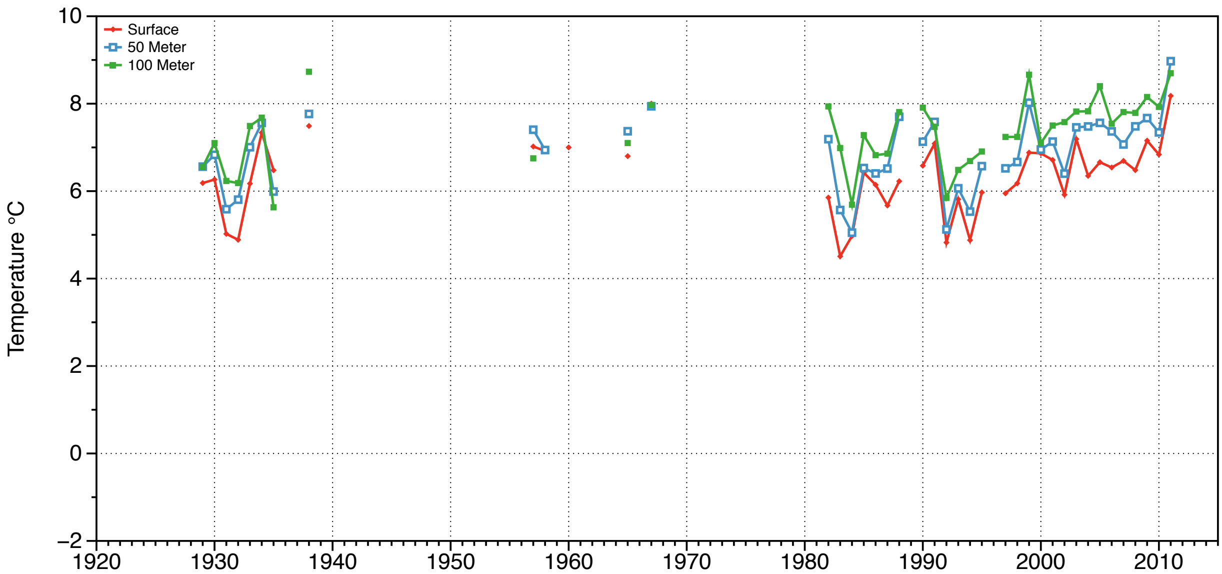


Figure 429: Interannual variability of temperatures (November – December) at station Outer Malangen

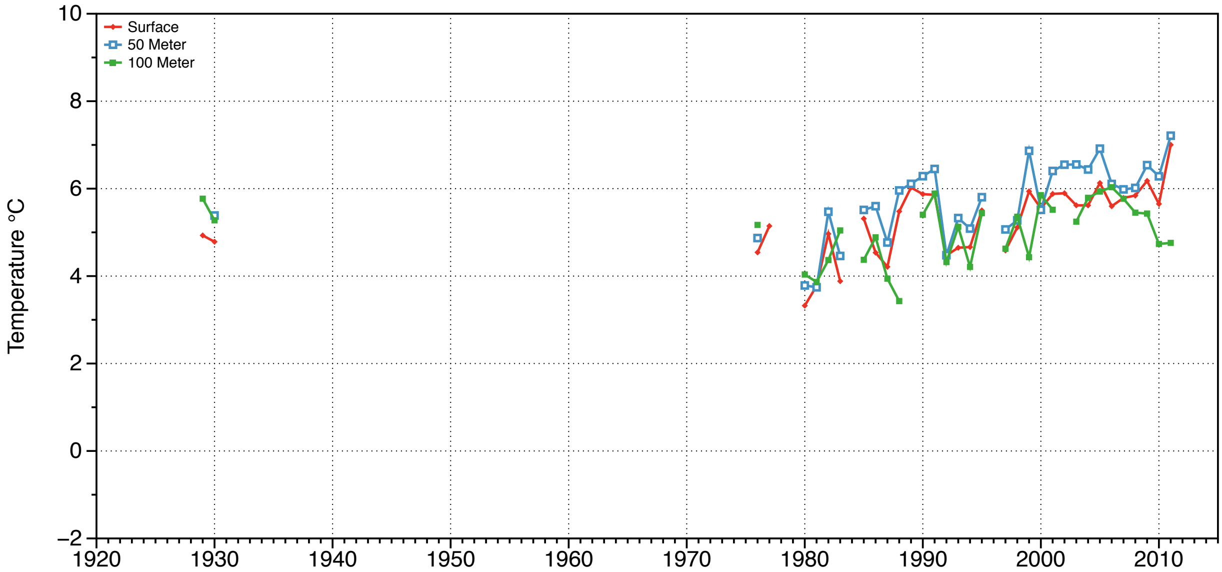


Figure 430: Interannual variability of temperatures (November – December) at station Outer Balsfjorden

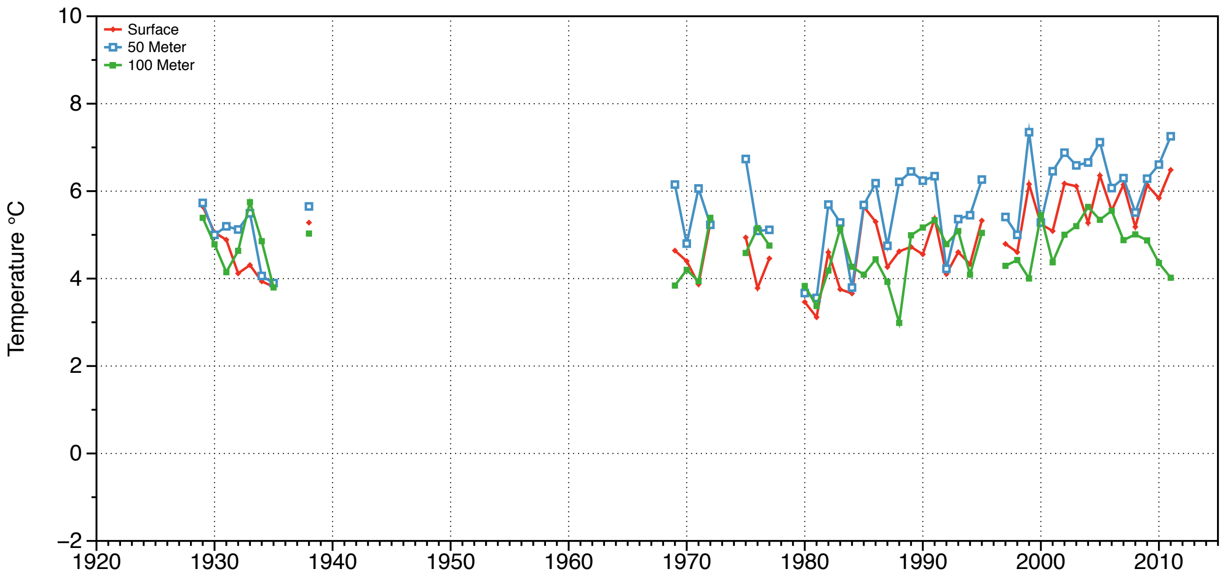


Figure 431: Interannual variability of temperatures (November – December) at station Inner Balsfjorden

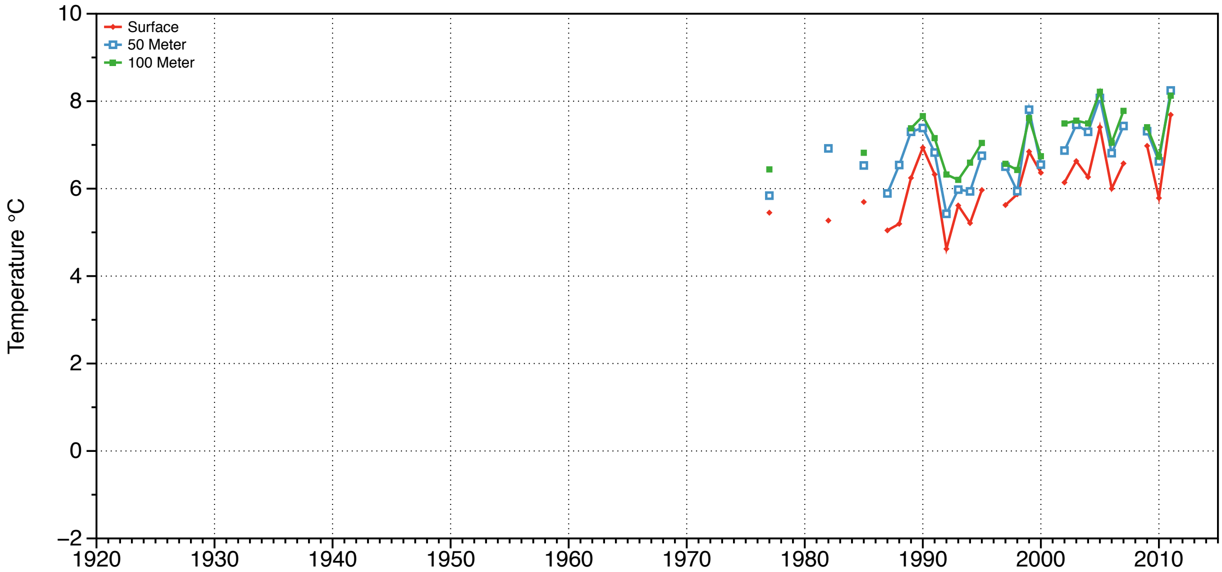


Figure 432: Interannual variability of temperatures (November – December) at station Kvalsund

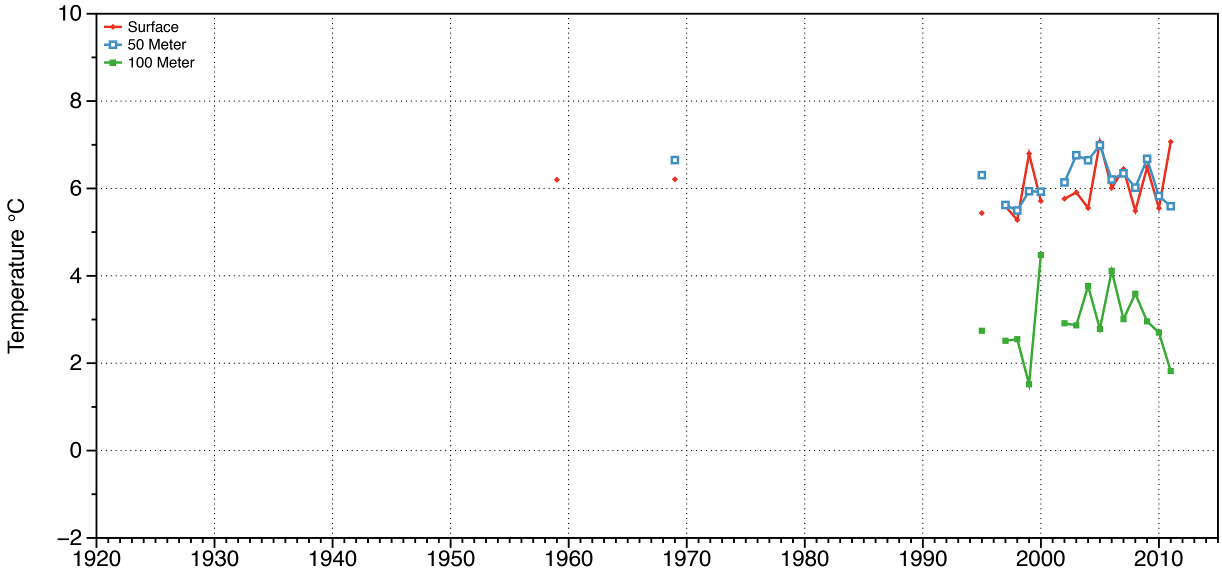


Figure 433: Interannual variability of temperatures (November – December) at station Sørfjord

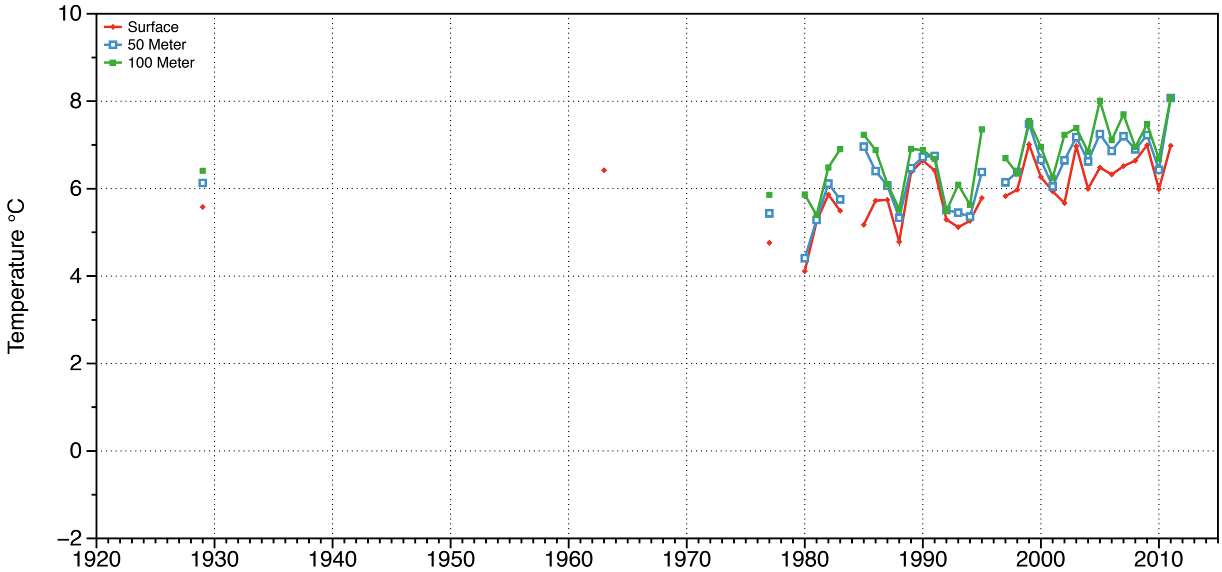


Figure 434: Interannual variability of temperatures (November – December) at station Outer Altafjorden

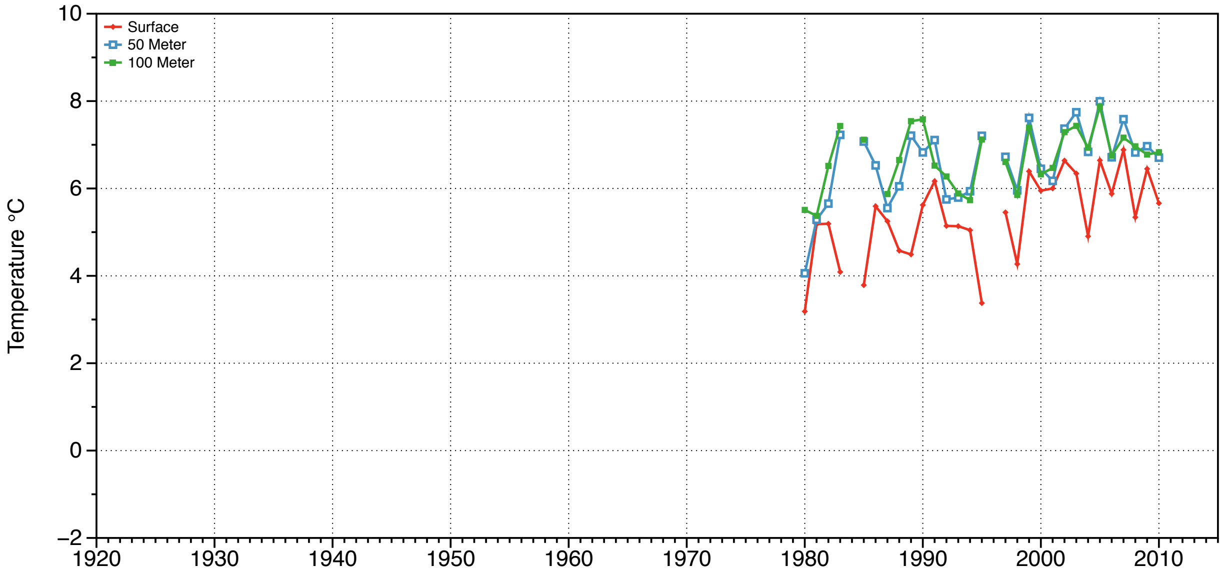


Figure 435: Interannual variability of temperatures (November – December) at station Inner Altafjorden

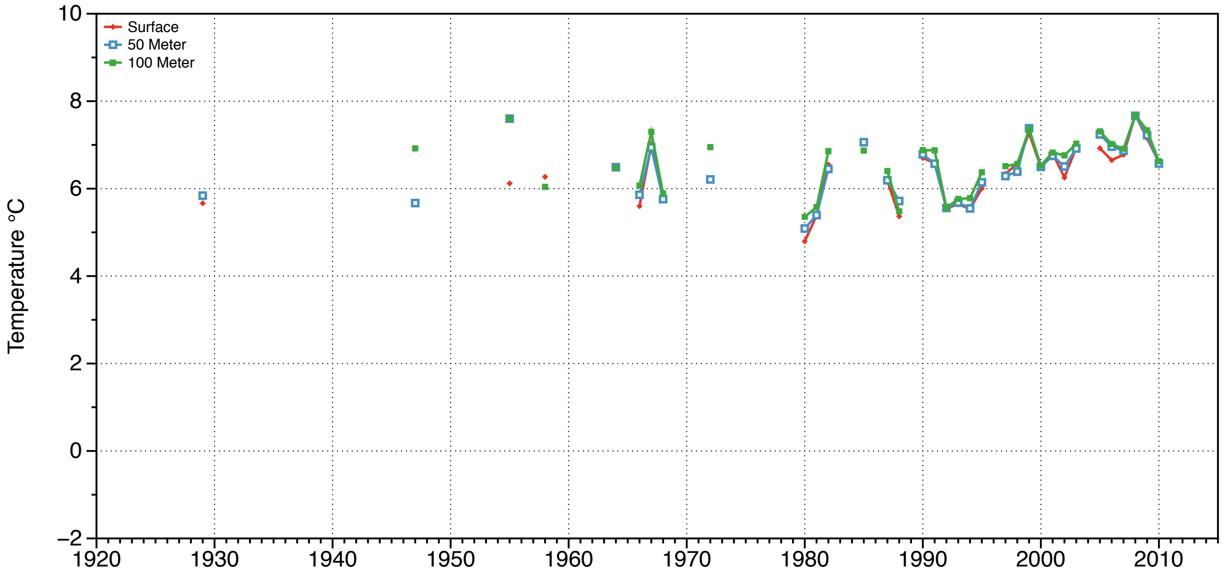


Figure 436: Interannual variability of temperatures (November – December) at station Refsbotn

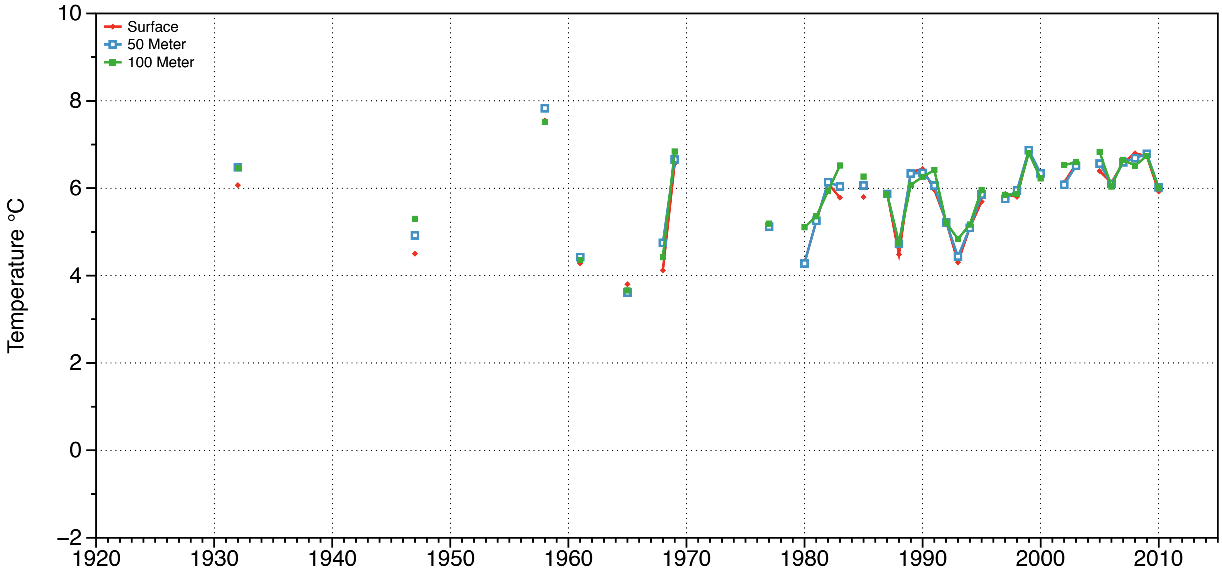


Figure 437: Interannual variability of temperatures (November – December) at station Outer Porsangerfjorden

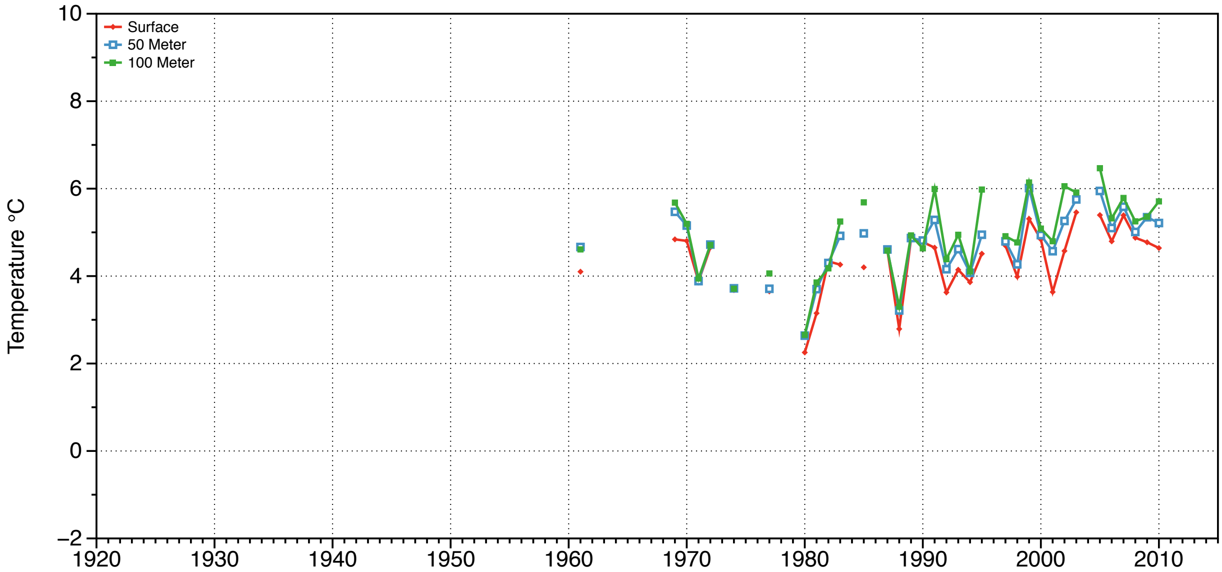


Figure 438: Interannual variability of temperatures (November – December) at station Inner Porsangerfjorden

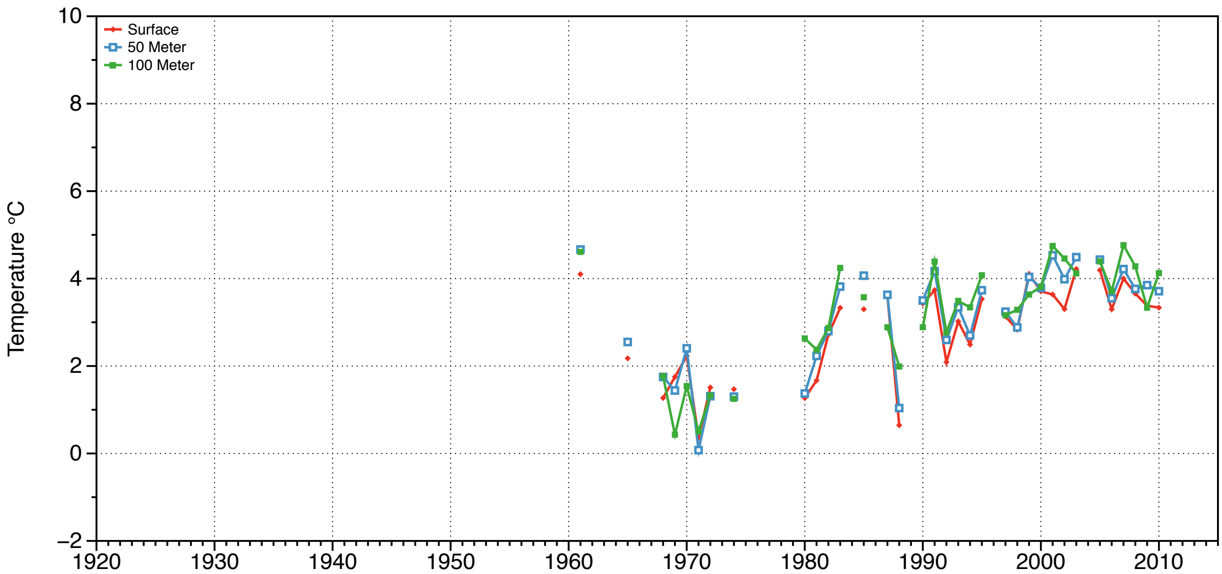


Figure 439: Interannual variability of temperatures (November – December) at station Østerbotn

A.8 INTERANNUAL VARIABILITY IN SALINITY (TWO MONTHS AVERAGE)

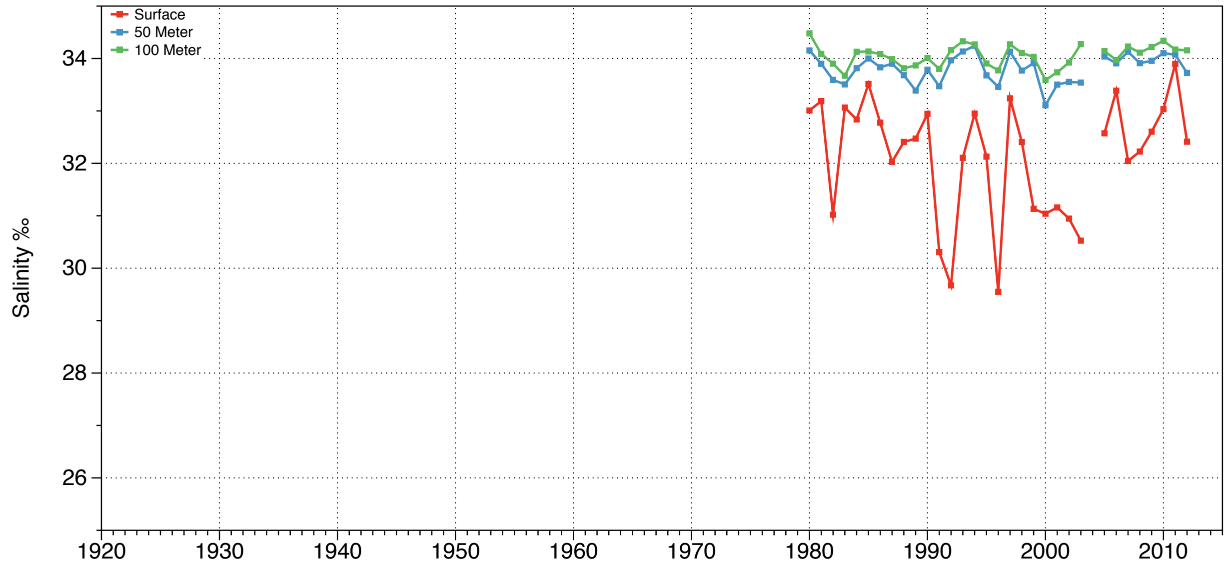


Figure 440: Interannual variability of salinity (January – February) at station Inner Malangen

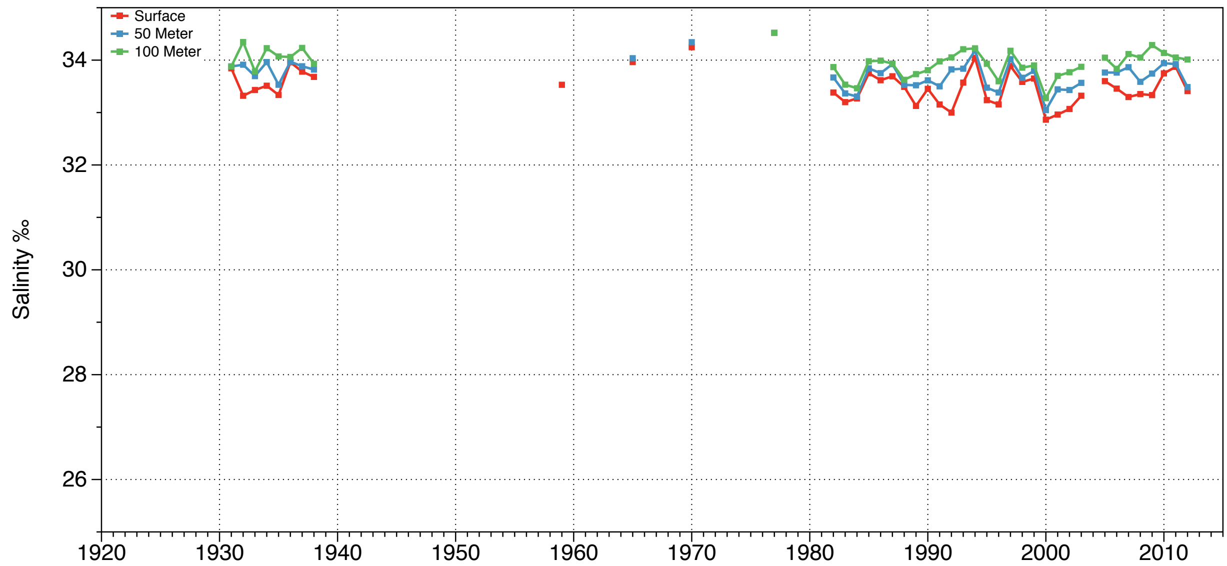


Figure 441: Interannual variability of salinity (January – February) at station Outer Malangen

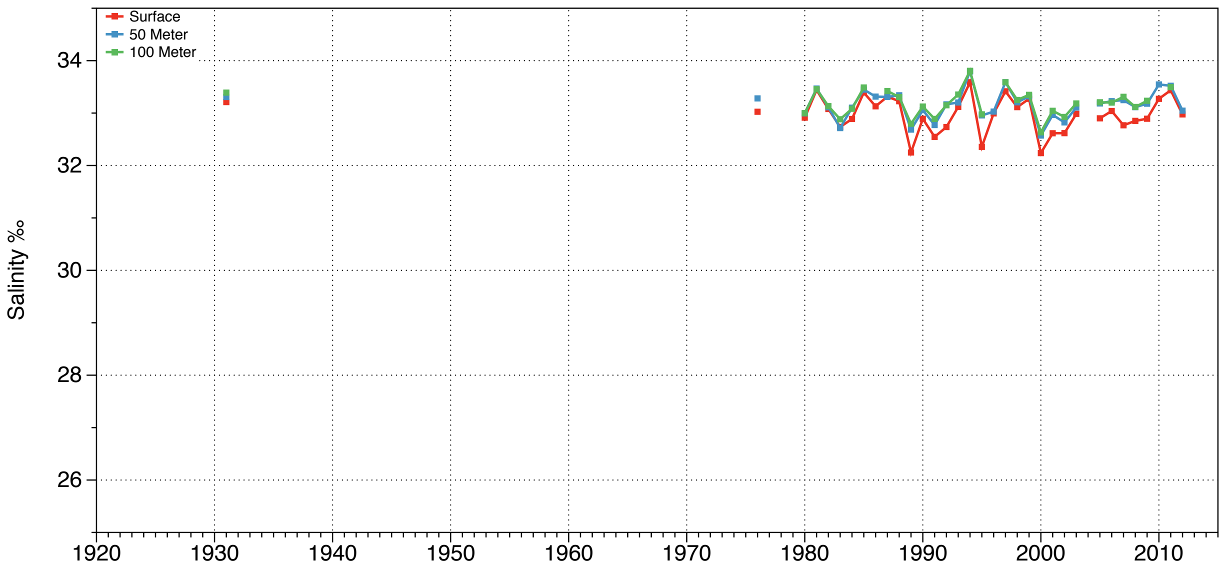


Figure 442: Interannual variability of salinity (January – February) at station Outer Balsfjorden

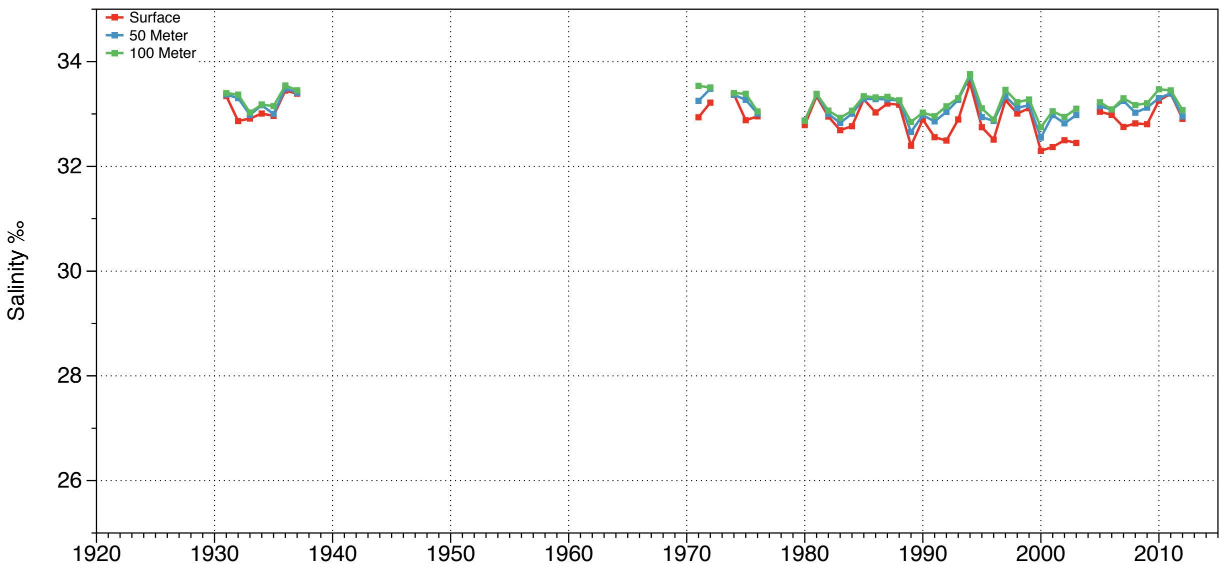


Figure 443: Interannual variability of salinity (January – February) at station Inner Balsfjorden

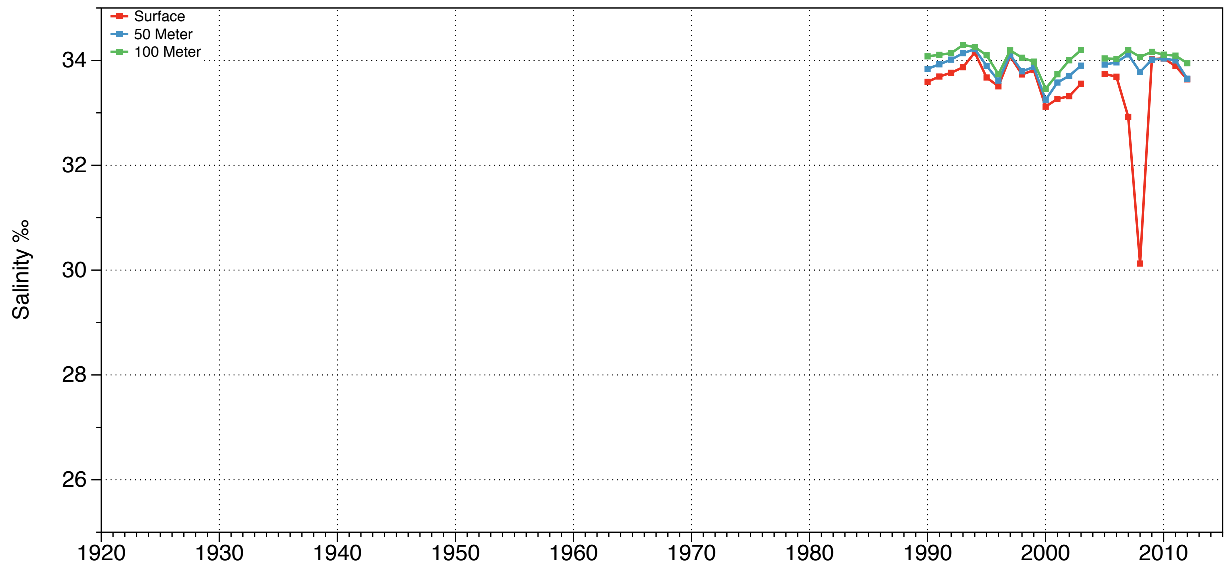


Figure 444: Interannual variability of salinity (January – February) at station Kvalsund

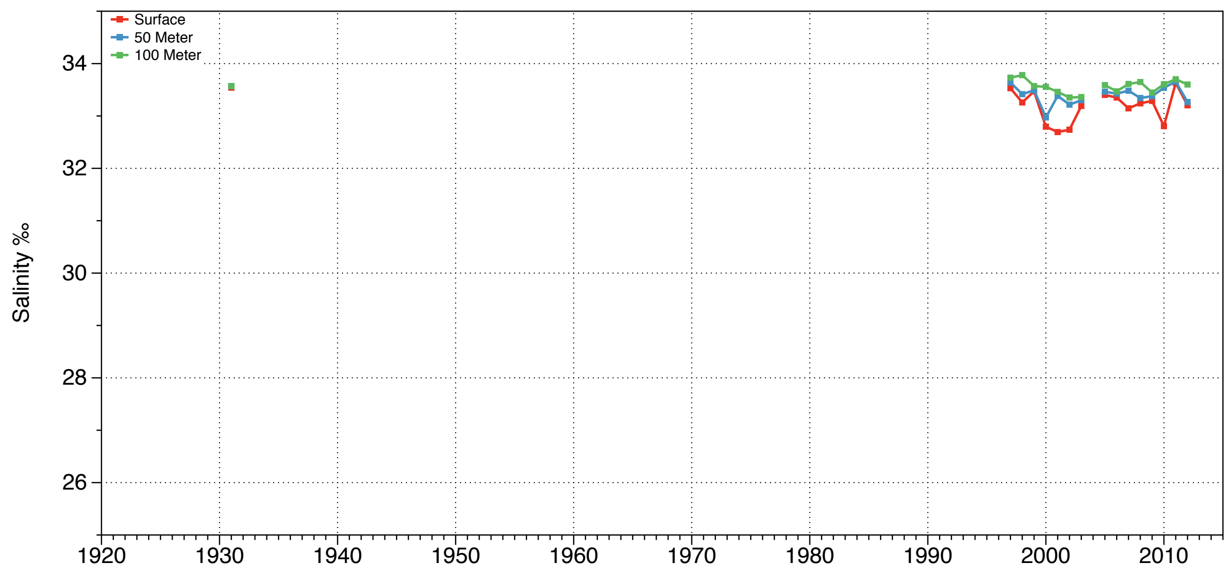


Figure 445: Interannual variability of salinity (January – February) at station Sørfjord

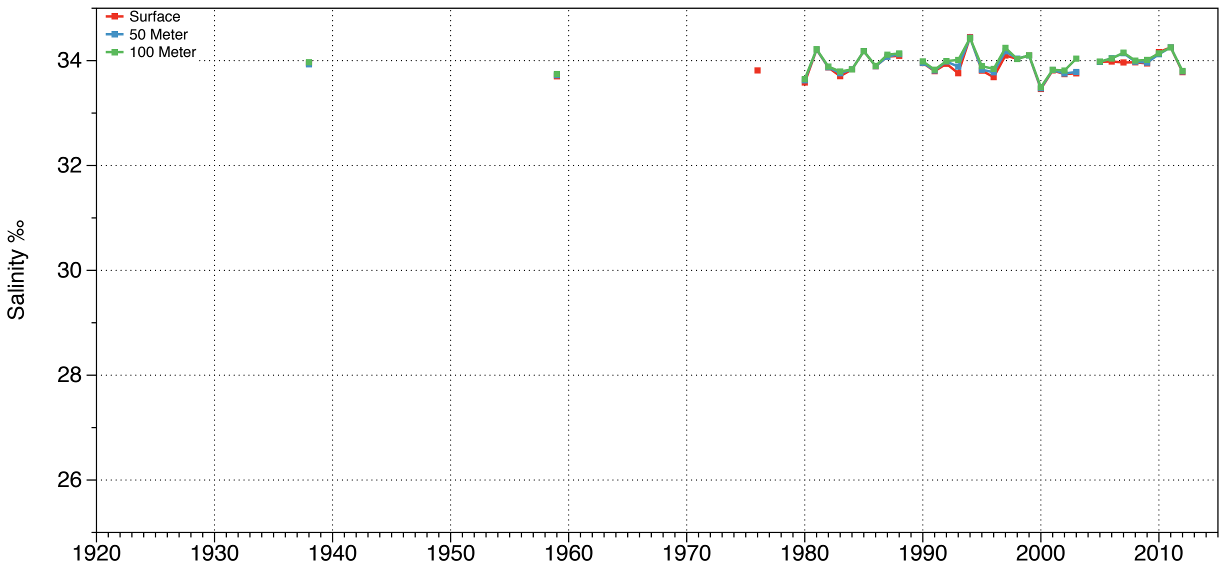


Figure 446: Interannual variability of salinity (January – February) at station Outer Altafjorden

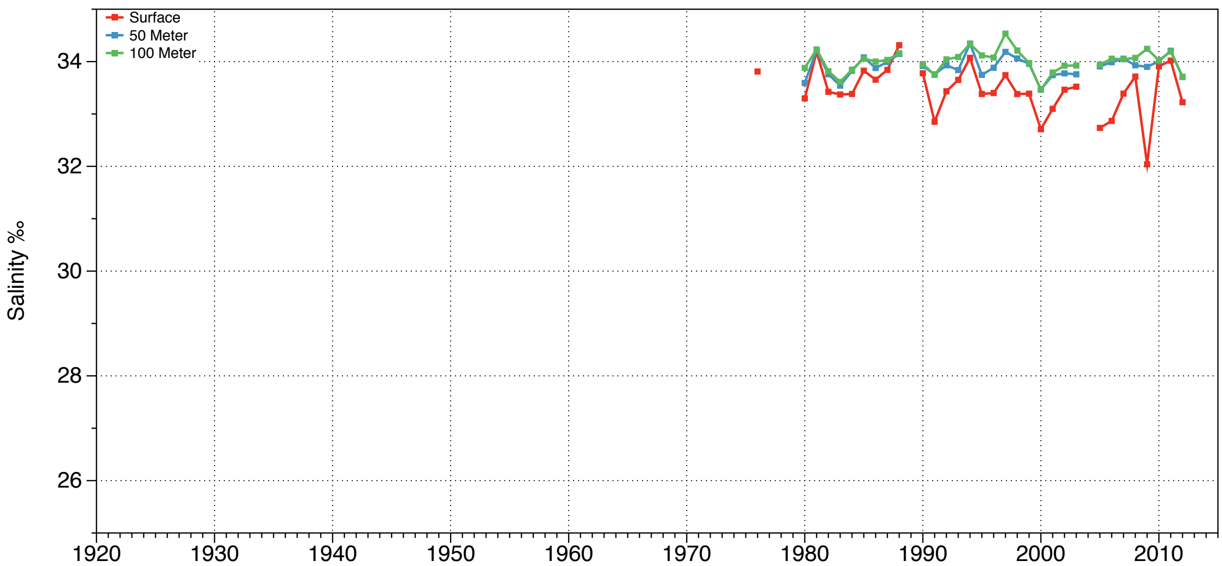


Figure 447: Interannual variability of salinity (January – February) at station Inner Altafjorden

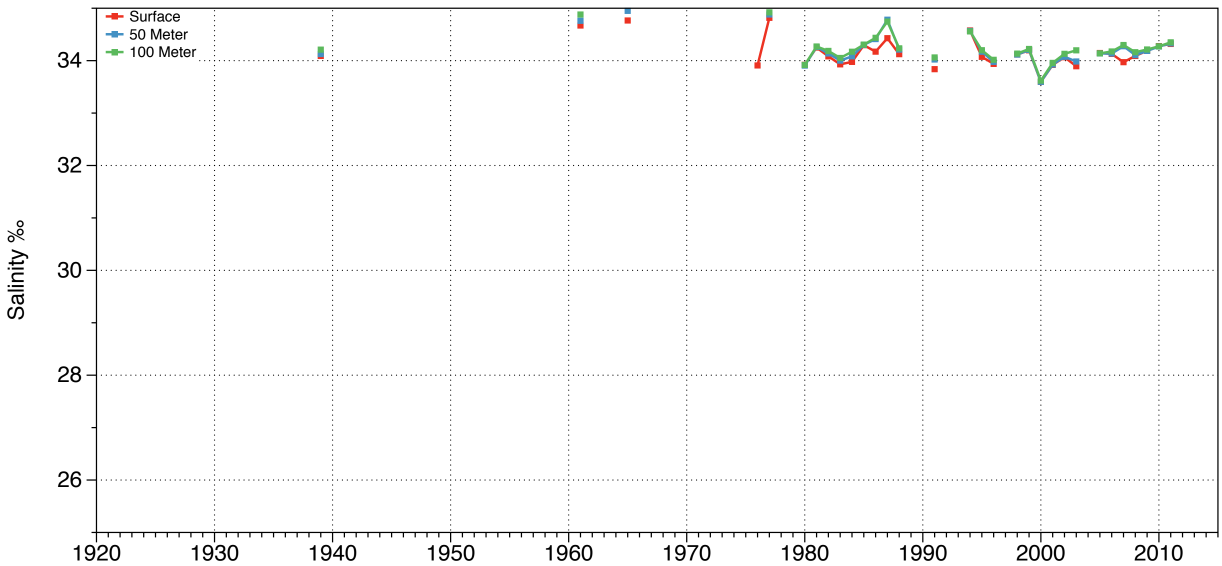


Figure 448: Interannual variability of salinity (January – February) at station Refsbotn

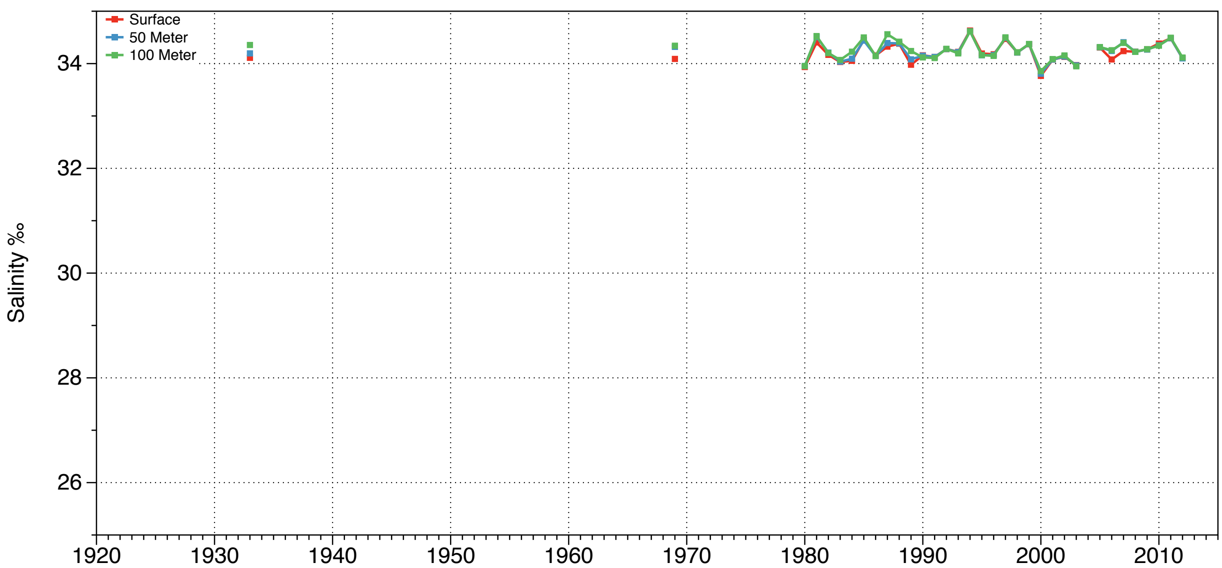


Figure 449: Interannual variability of salinity (January – February) at station Outer Porsangerfjorden

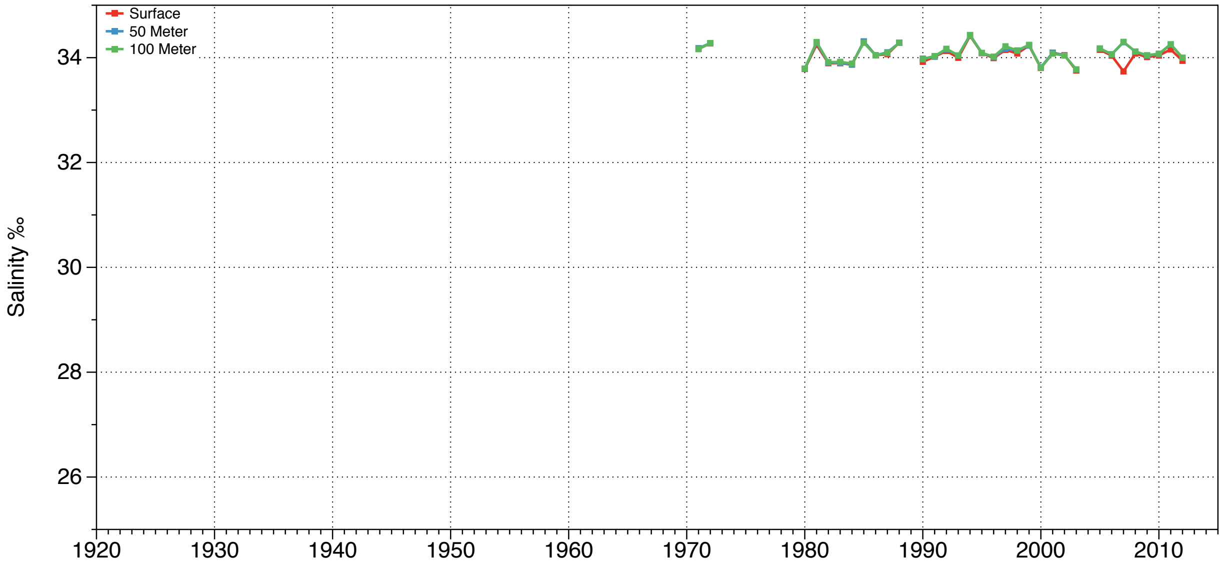


Figure 450: Interannual variability of salinity (January – February) at station Inner Porsangerfjorden

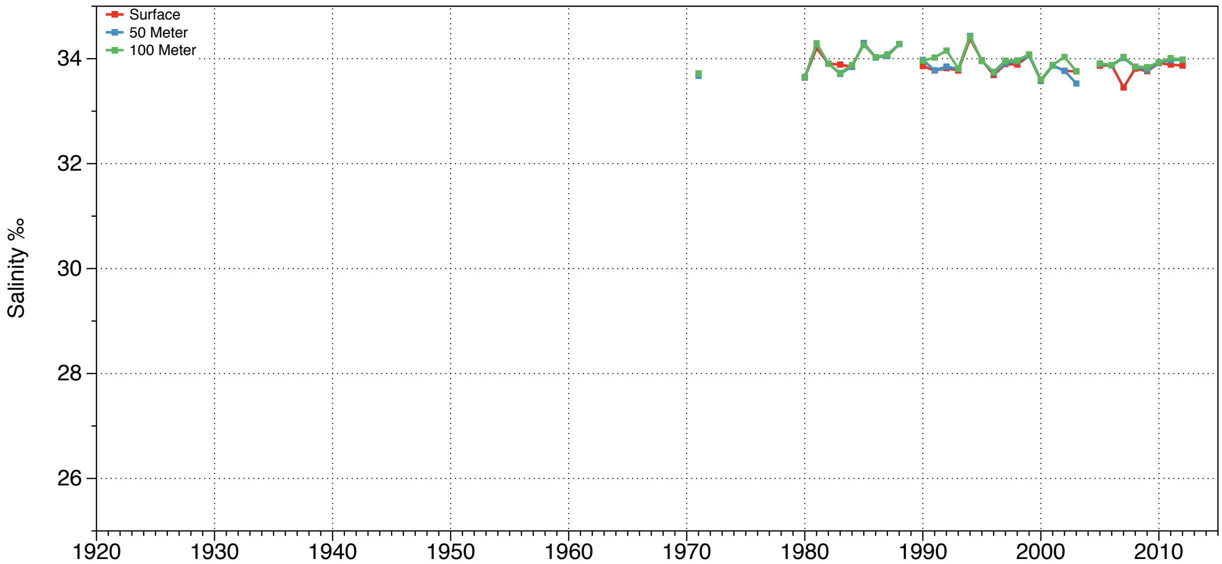


Figure 451: Interannual variability of salinity (January – February) at station Østerbotn

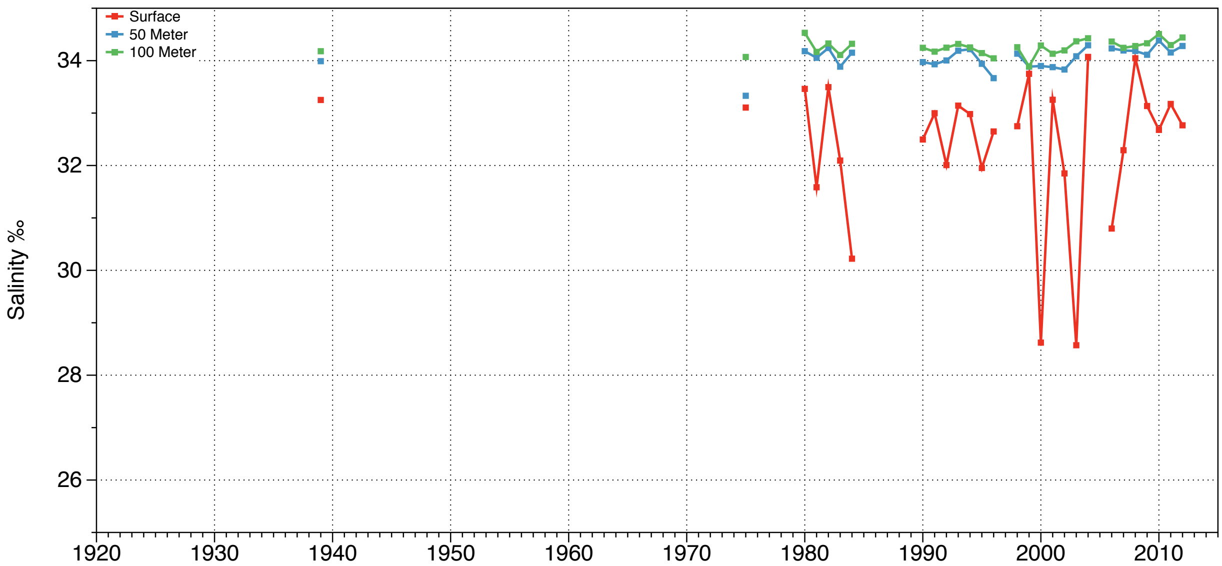


Figure 452: Interannual variability of salinity (March – April) at station Inner Malangen

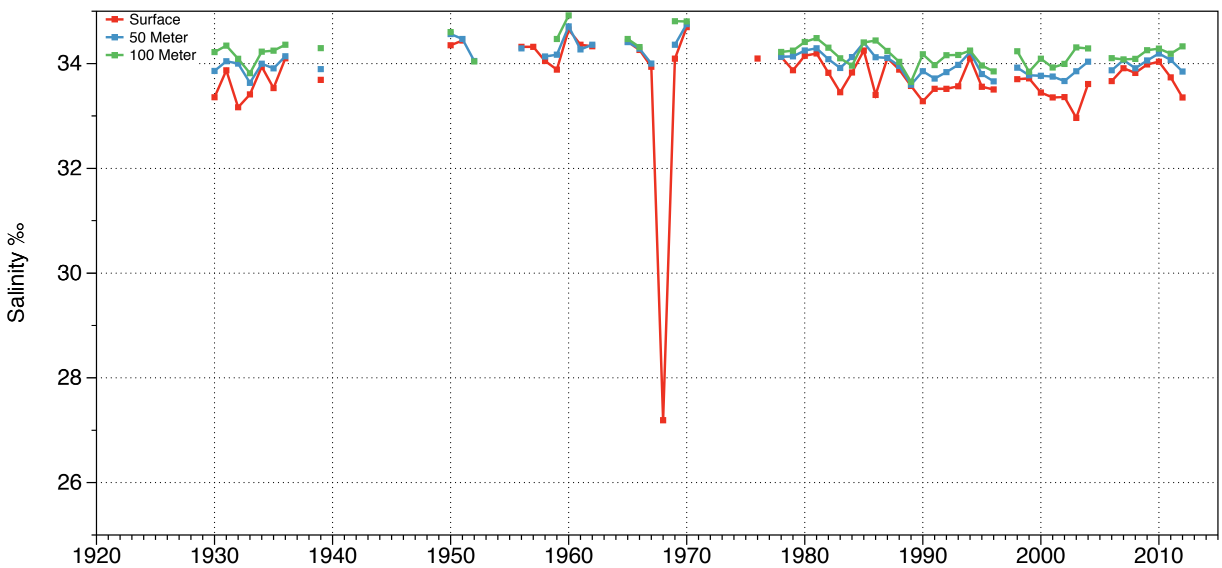


Figure 453: Interannual variability of salinity (March – April) at station Outer Malangen

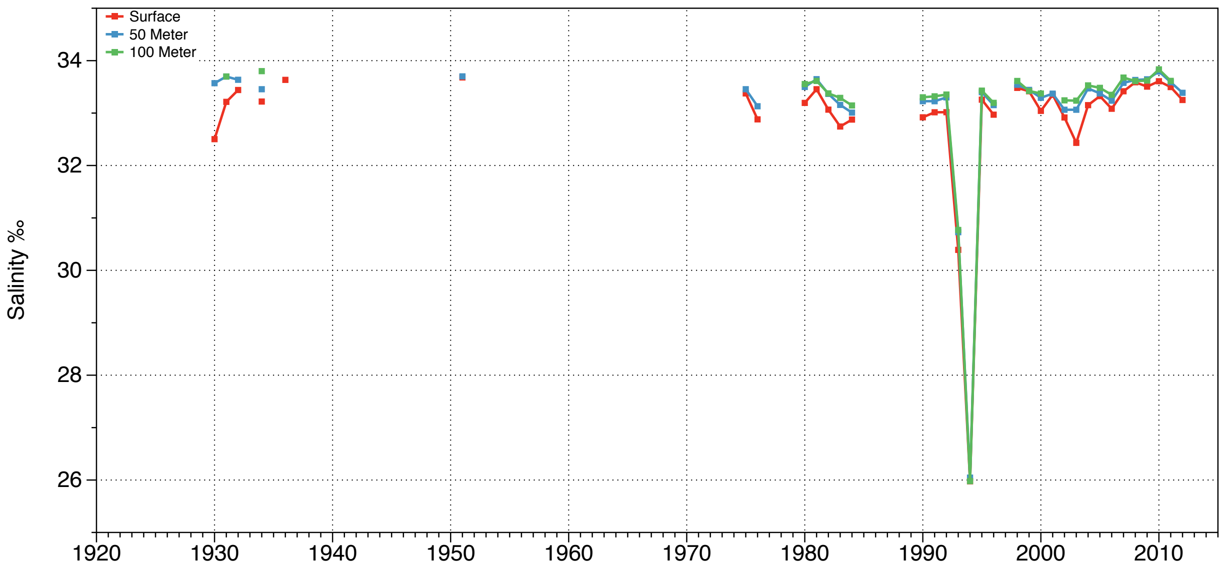


Figure 454: Interannual variability of salinity (March – April) at station Outer Balsfjorden

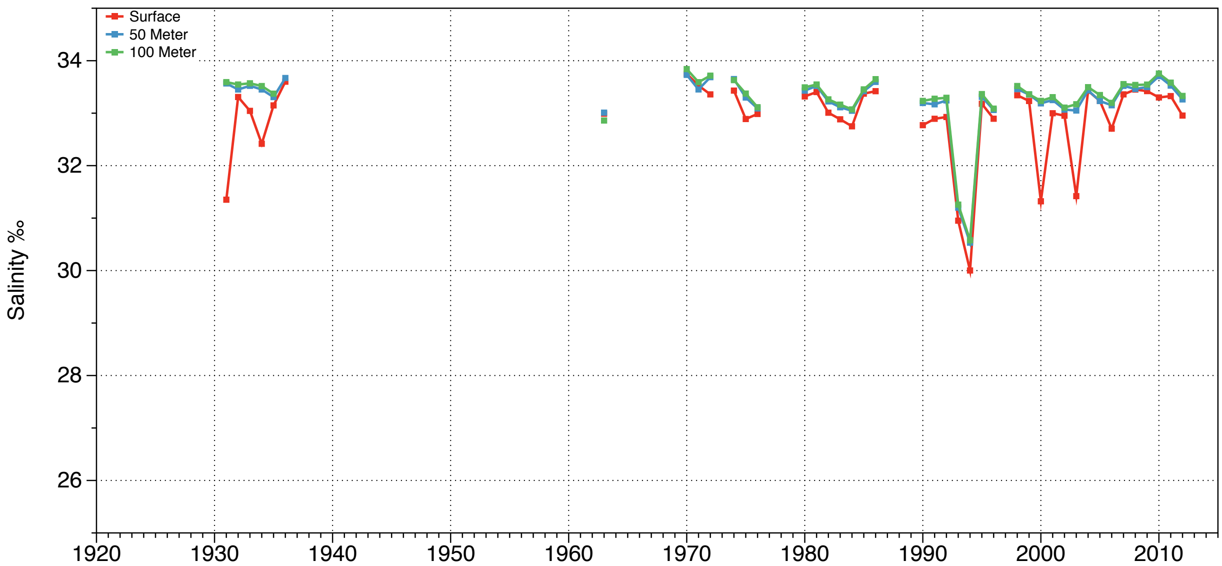


Figure 455: Interannual variability of salinity (March – April) at station Inner Balsfjorden

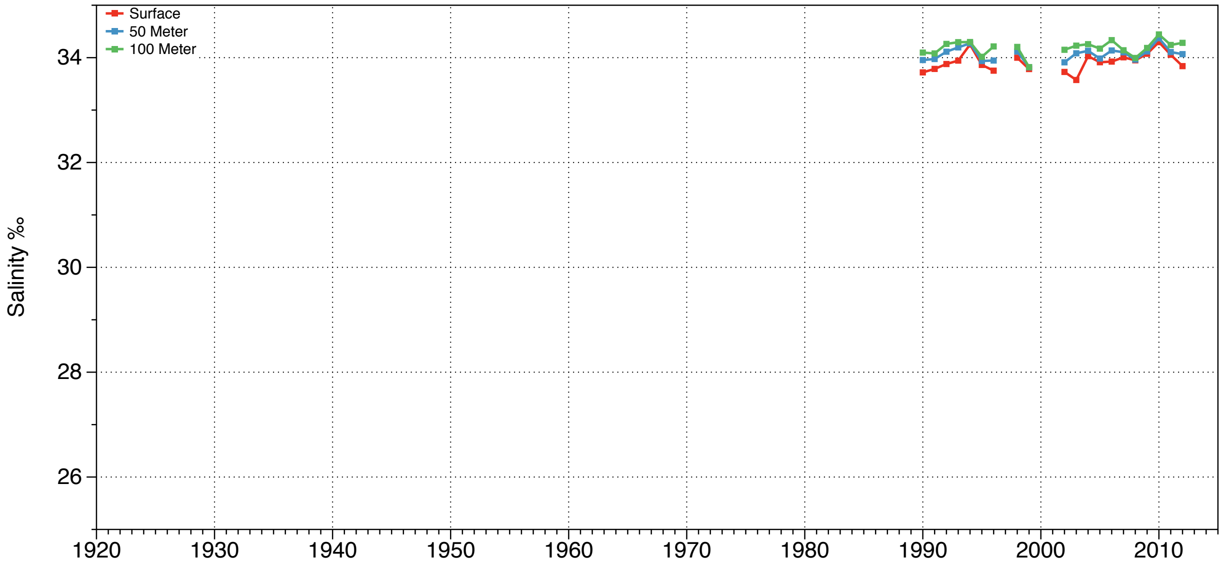


Figure 456: Interannual variability of salinity (March – April) at station Kvalsund

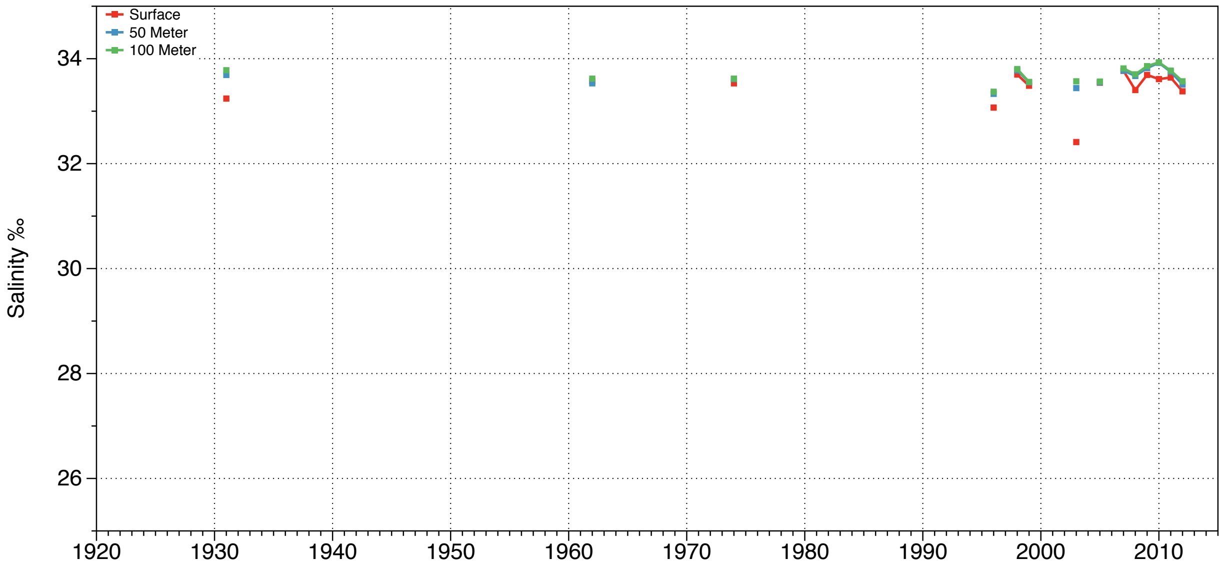


Figure 457: Interannual variability of salinity (March – April) at station Sørfjord

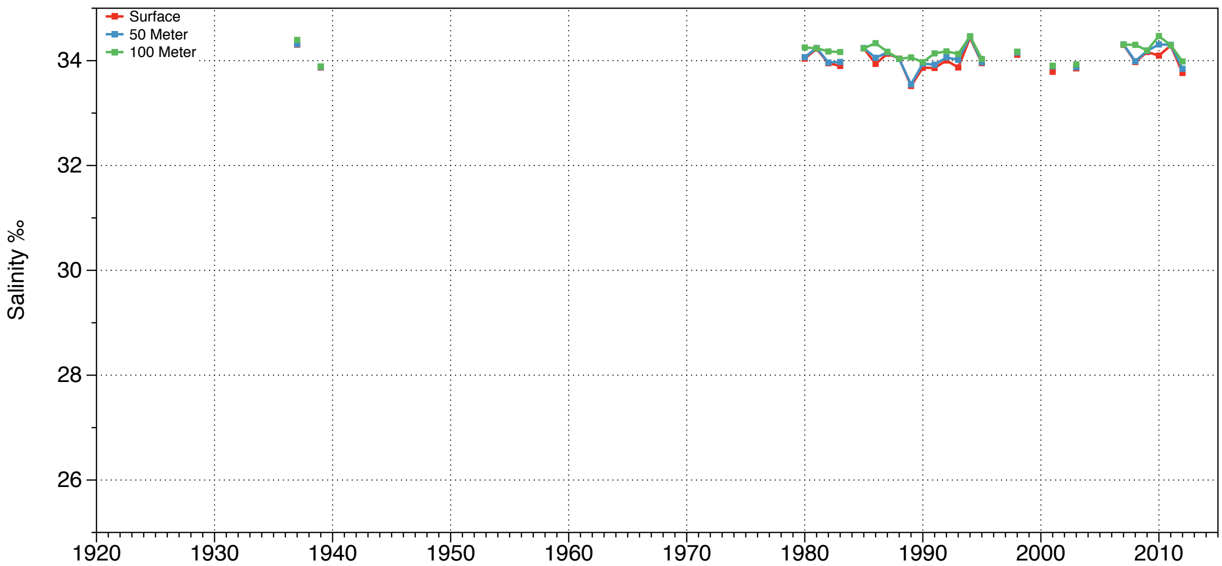


Figure 458: Interannual variability of salinity (March – April) at station Outer Altafjorden

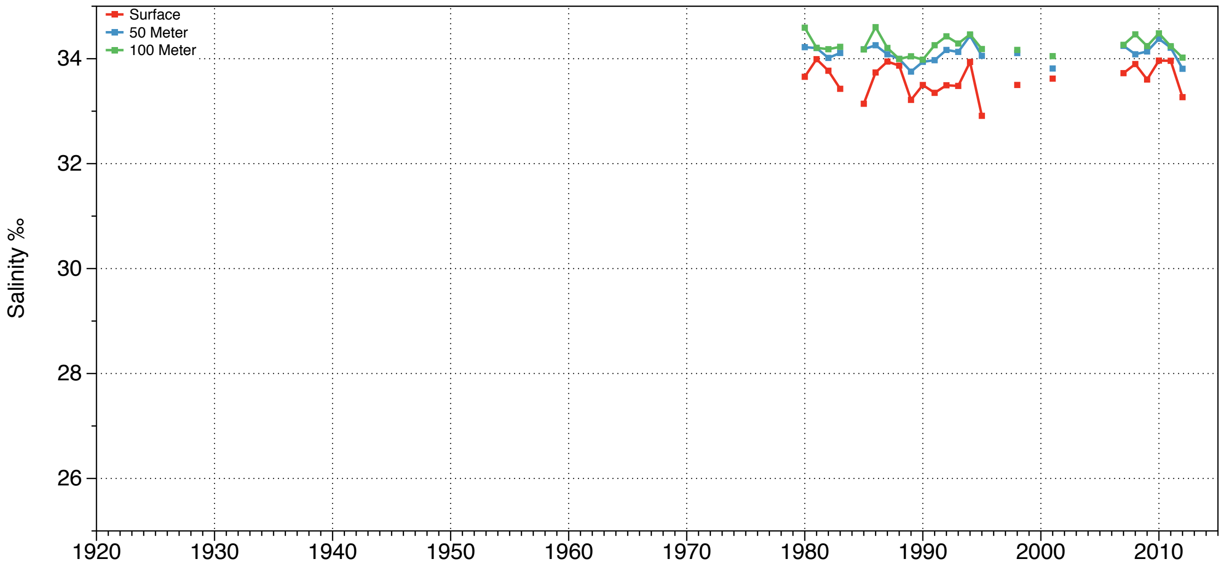


Figure 459: Interannual variability of salinity (March – April) at station Inner Altafjorden

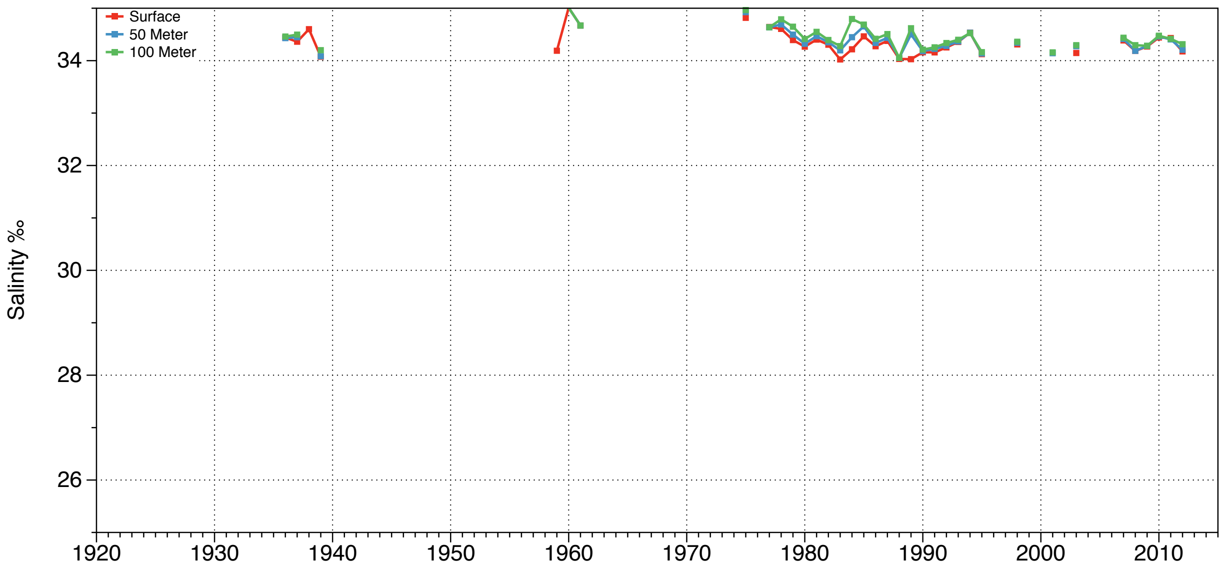


Figure 460: Interannual variability of salinity (March – April) at station Refsbotn

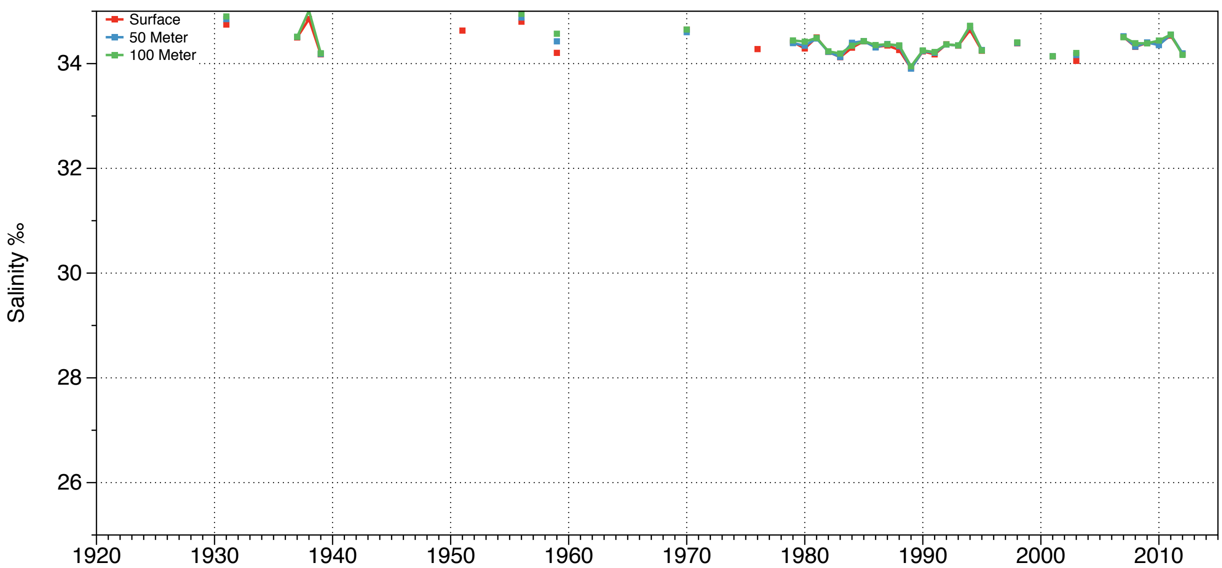


Figure 461: Interannual variability of salinity (March – April) at station Outer Porsangerfjorden

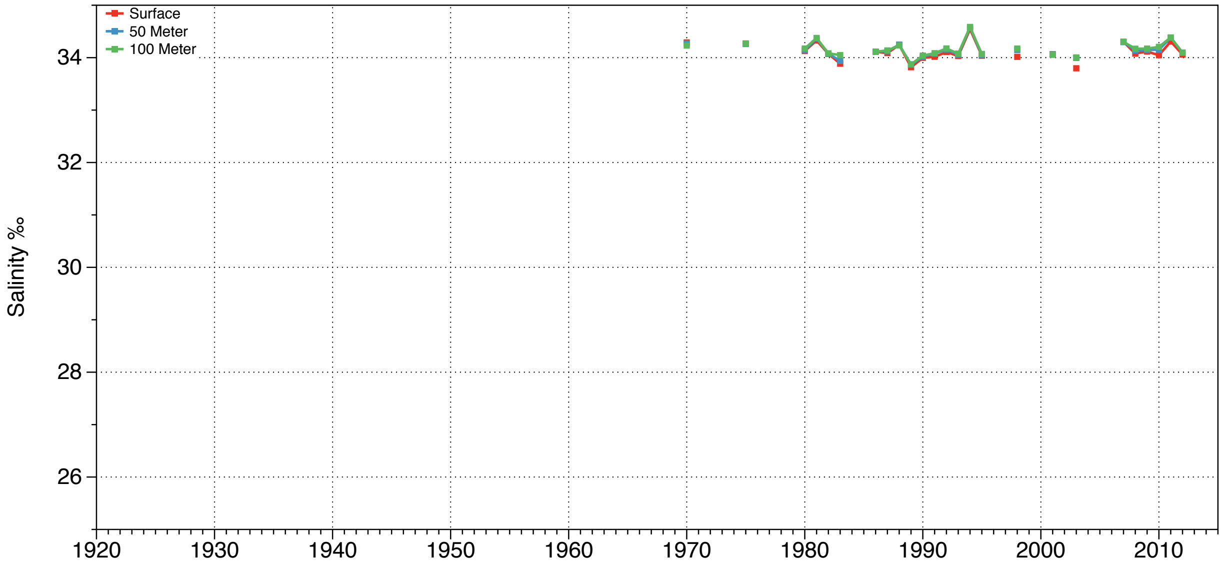


Figure 462: Interannual variability of salinity (March – April) at station Inner Porsangerfjorden

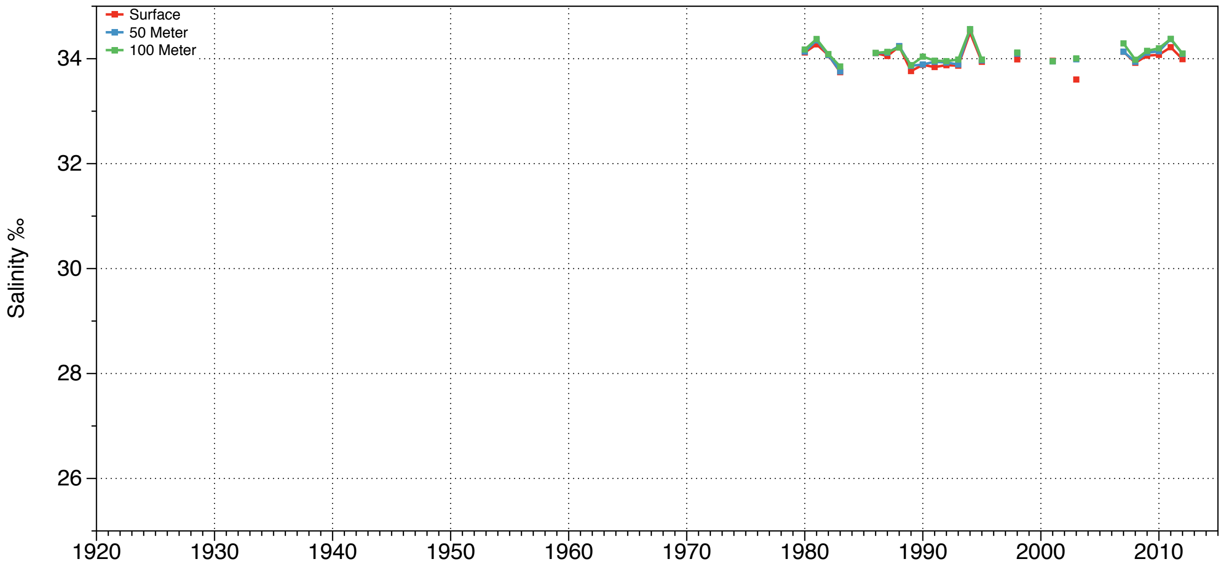


Figure 463: Interannual variability of salinity (March – April) at station Østerbotn

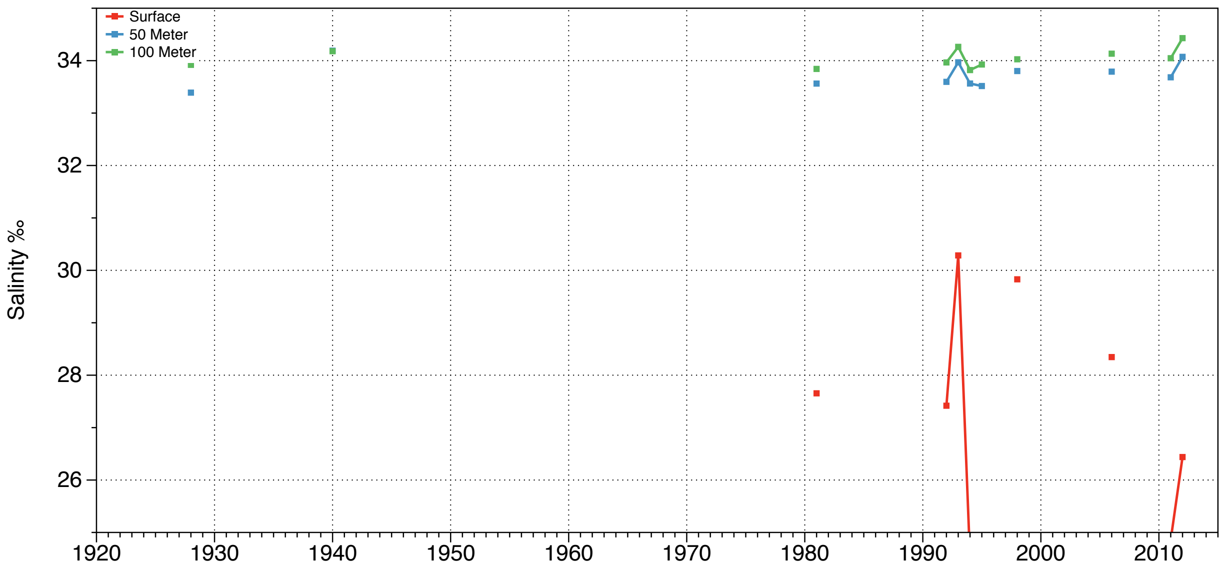


Figure 464: Interannual variability of salinity (July – August) at station Inner Malangen

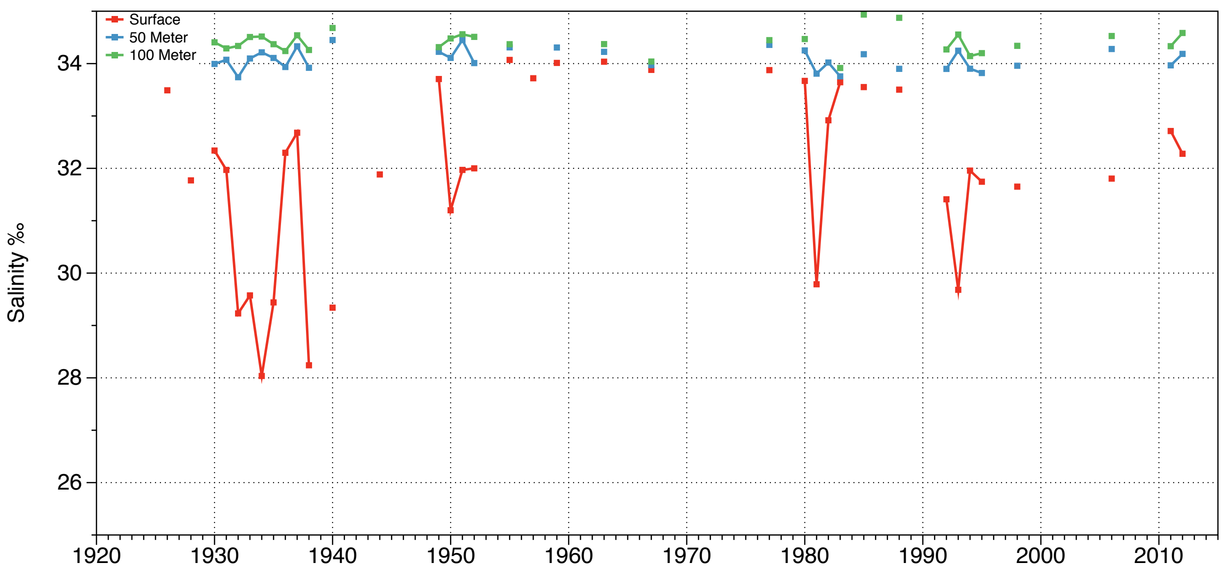


Figure 465: Interannual variability of salinity (July – August) at station Outer Malangen

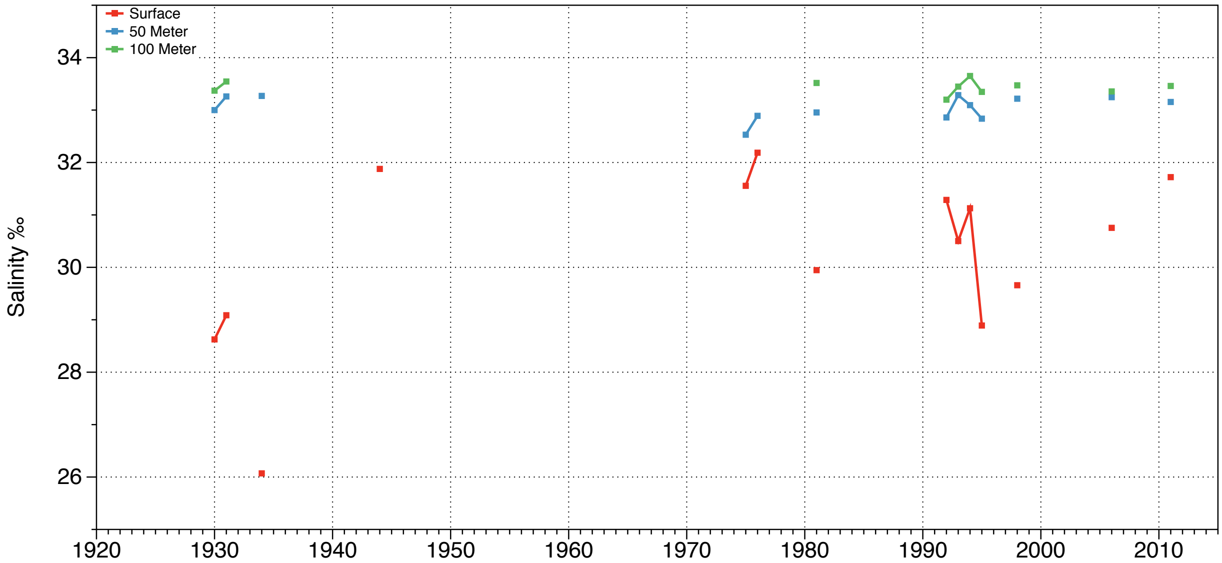


Figure 466: Interannual variability of salinity (July – August) at station Outer Balsfjorden

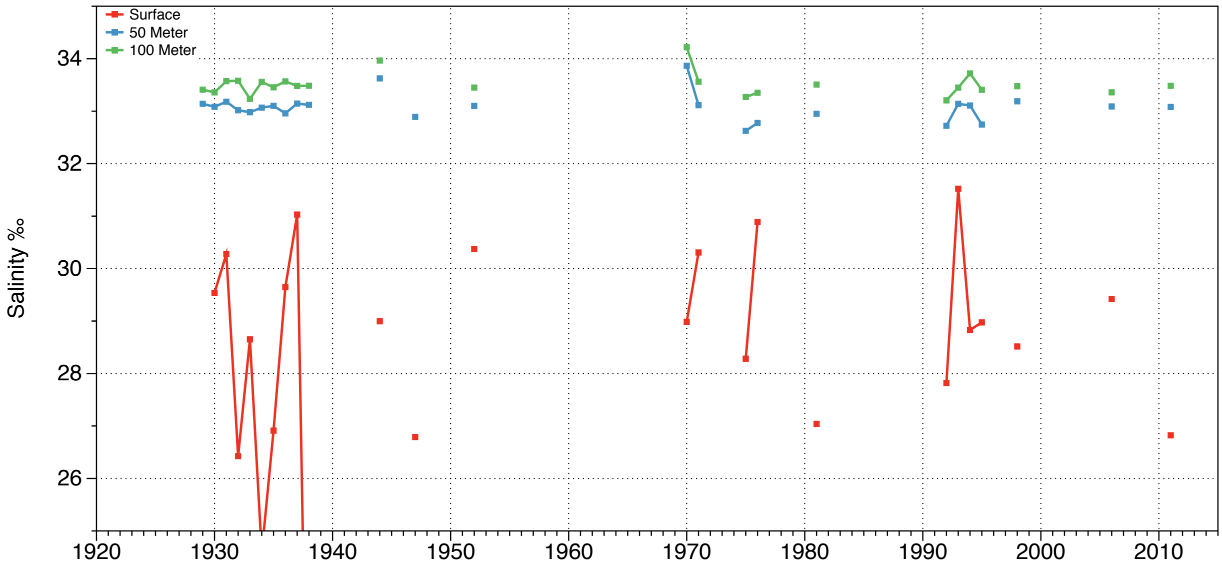


Figure 467: Interannual variability of salinity (July – August) at station Inner Balsfjorden

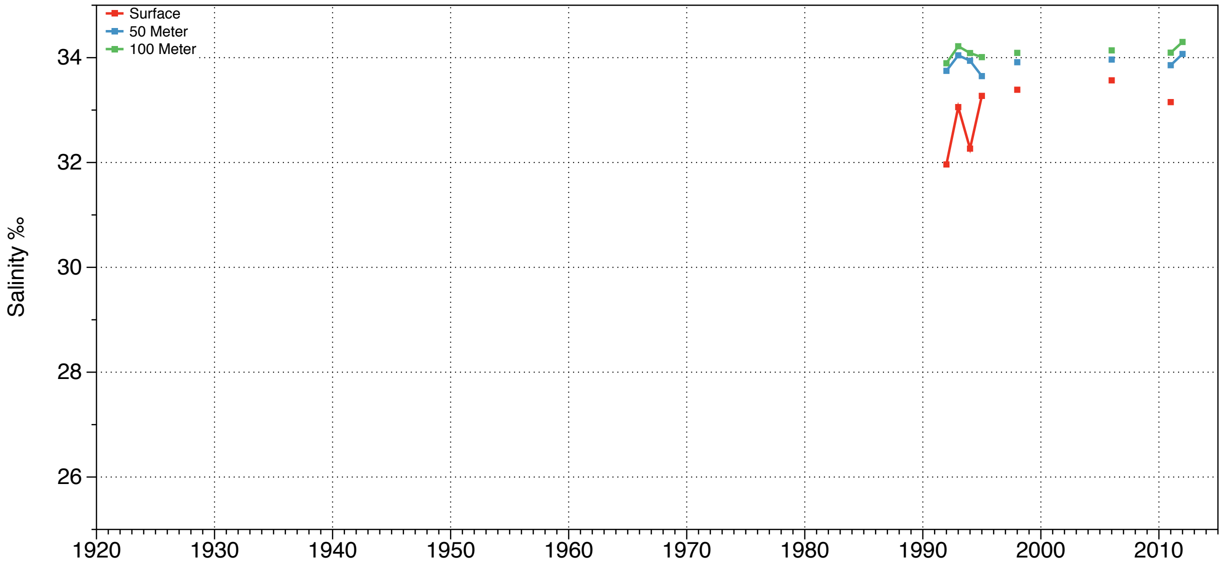


Figure 468: Interannual variability of salinity (July – August) at station Kvalsund

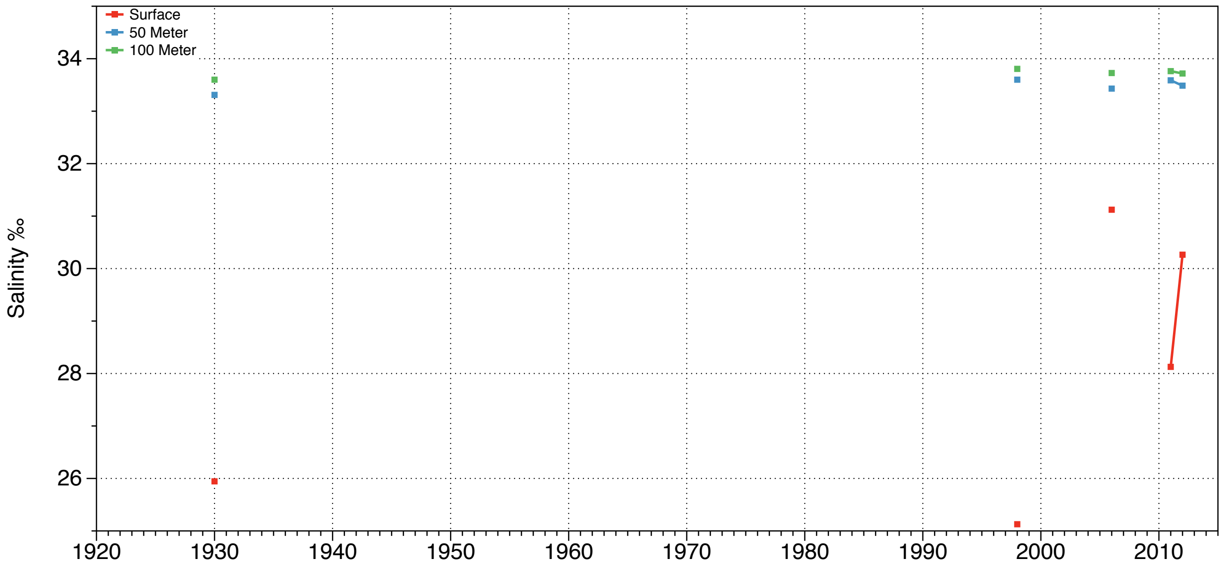


Figure 469: Interannual variability of salinity (July – August) at station Sørfjord

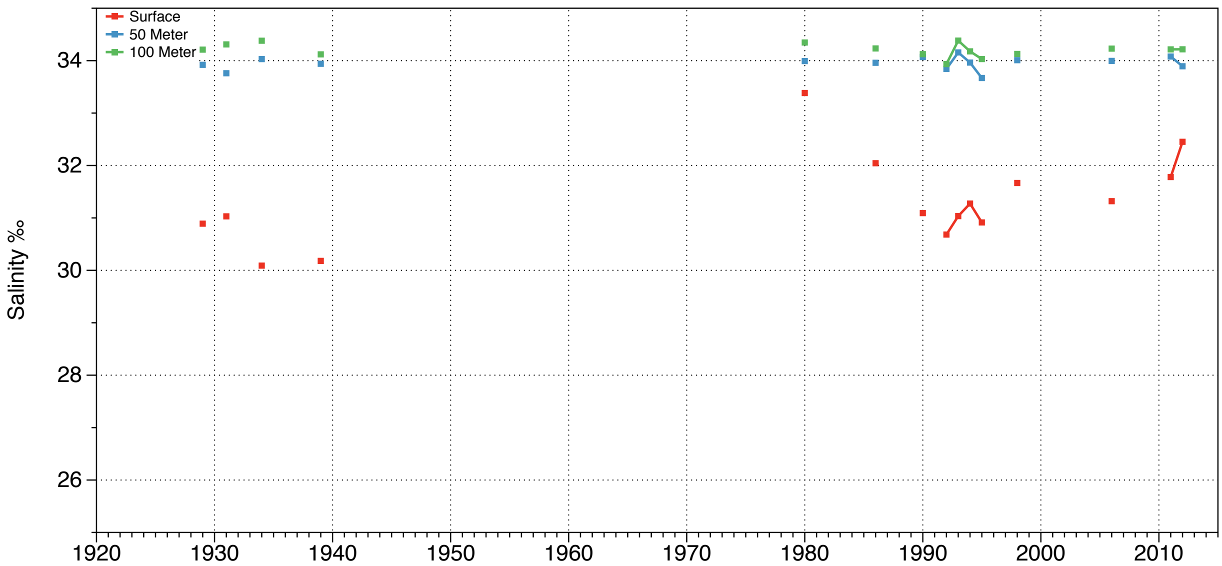


Figure 470: Interannual variability of salinity (July – August) at station Outer Altafjorden

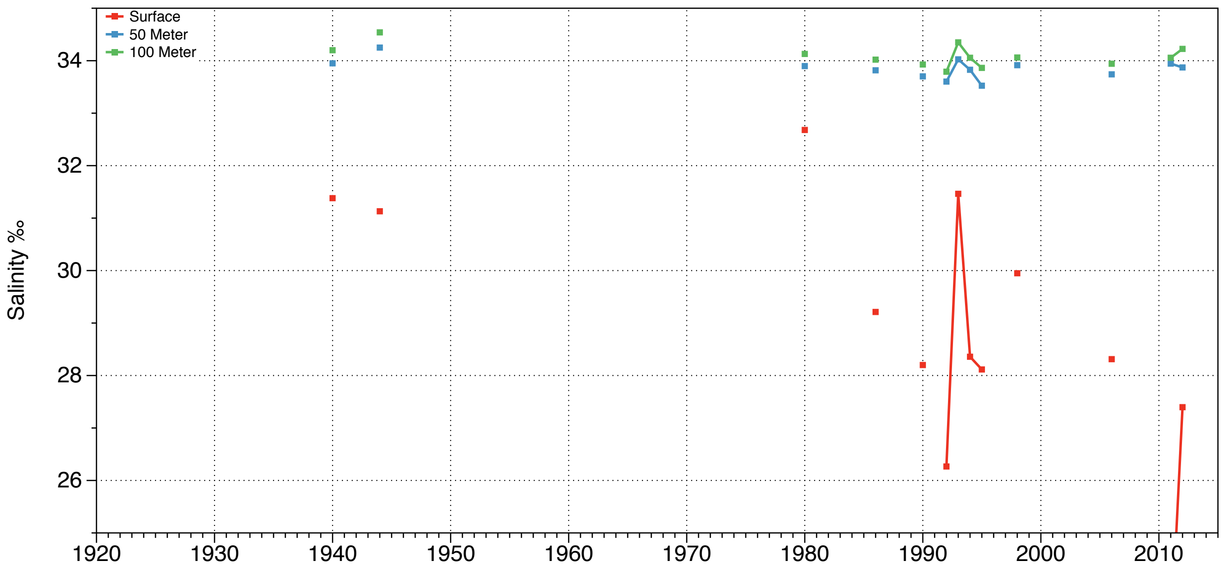


Figure 471: Interannual variability of salinity (July – August) at station Inner Altafjorden

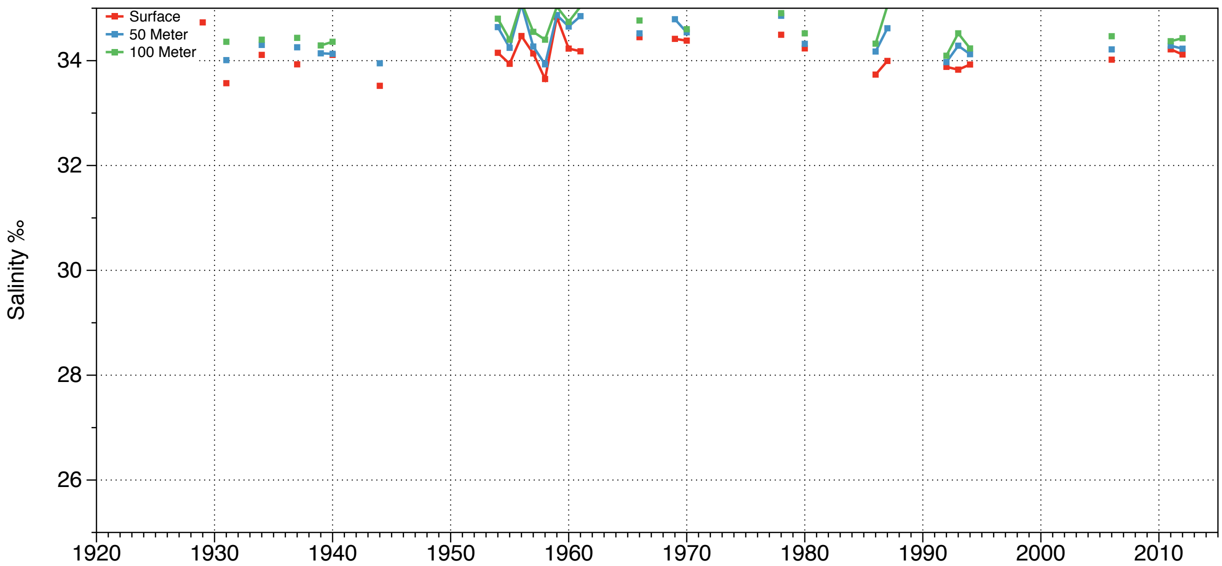


Figure 472: Interannual variability of salinity (July – August) at station Refsbotn

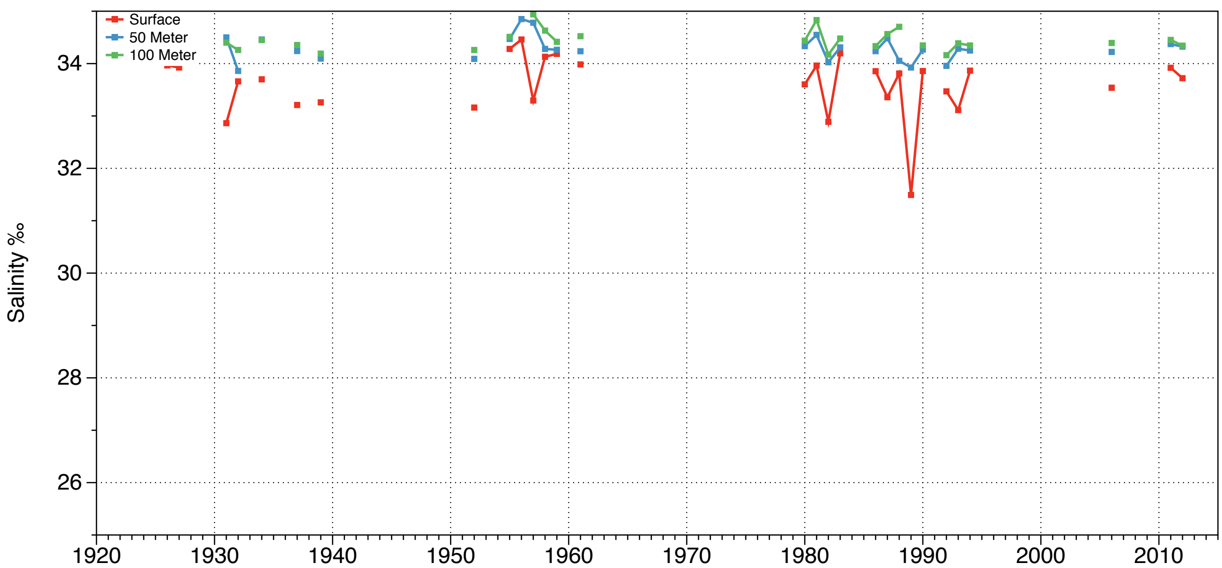


Figure 473: Interannual variability of salinity (July – August) at station Outer Porsangerfjorden

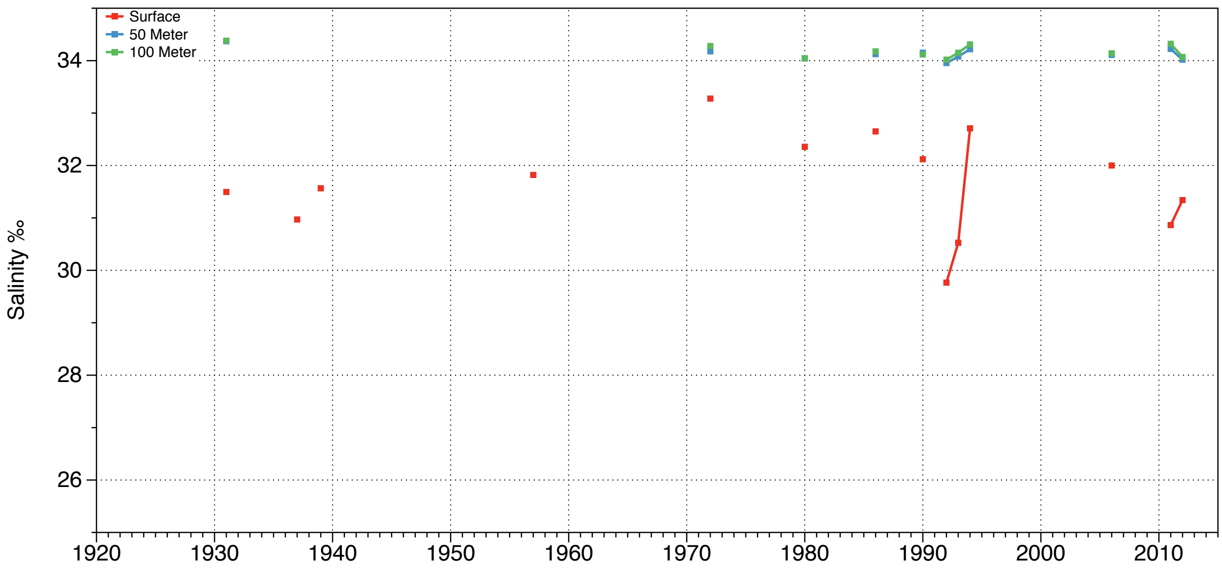


Figure 474: Interannual variability of salinity (July – August) at station Inner Porsangerfjorden

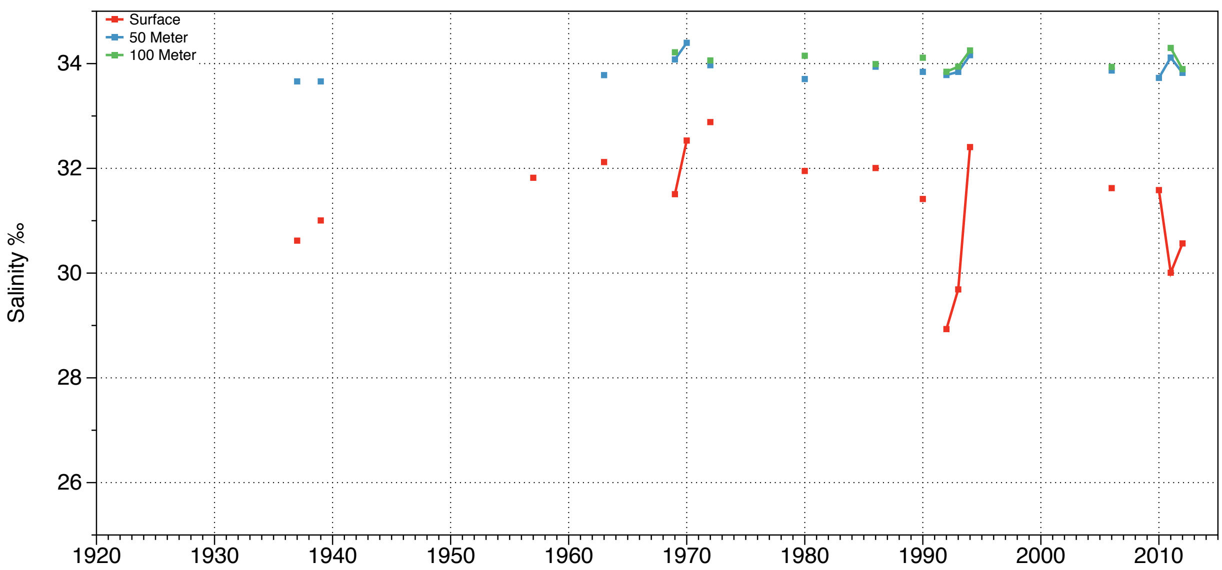


Figure 475: Interannual variability of salinity (July – August) at station Østerbotn

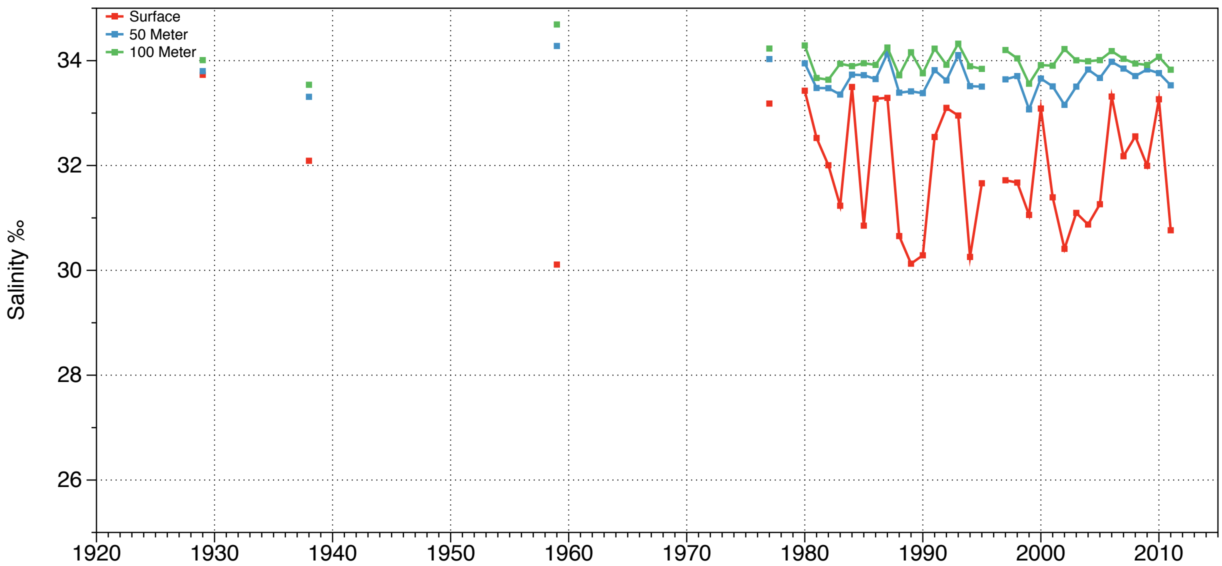


Figure 476: Interannual variability of salinity (November – December) at station Inner Malangen

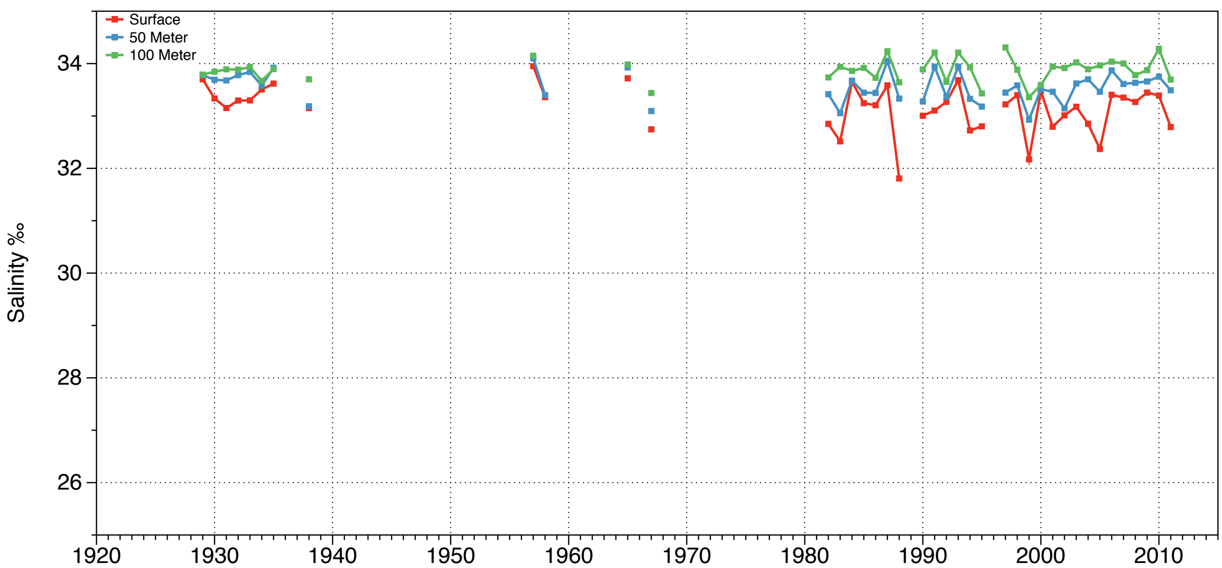


Figure 477: Interannual variability of salinity (November – December) at station Outer Malangen

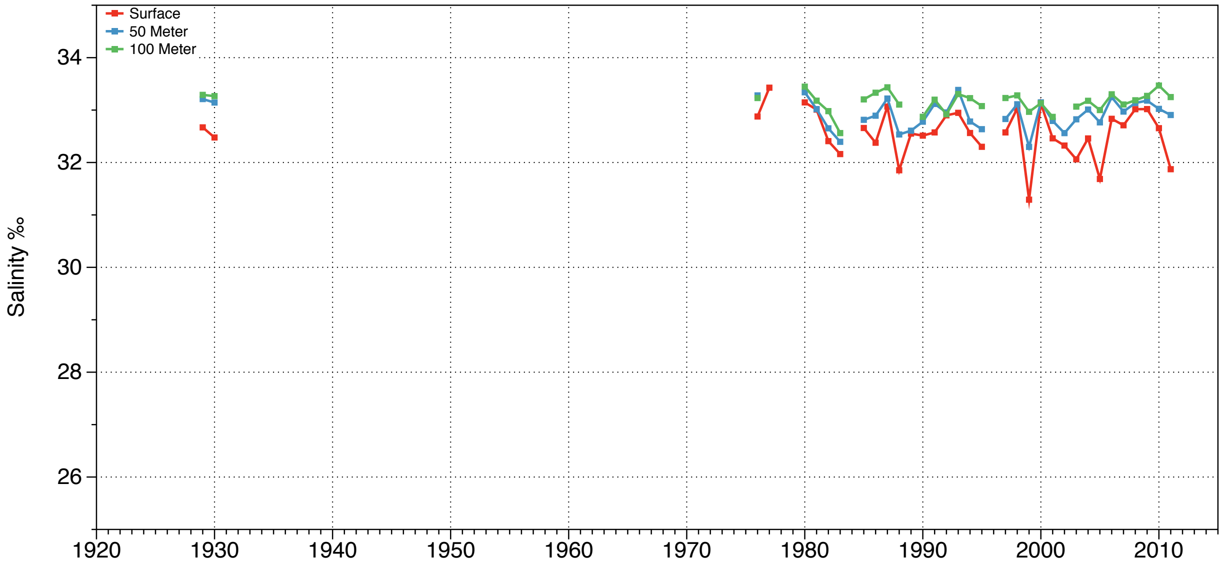


Figure 478: Interannual variability of salinity (November – December) at station Outer Balsfjorden

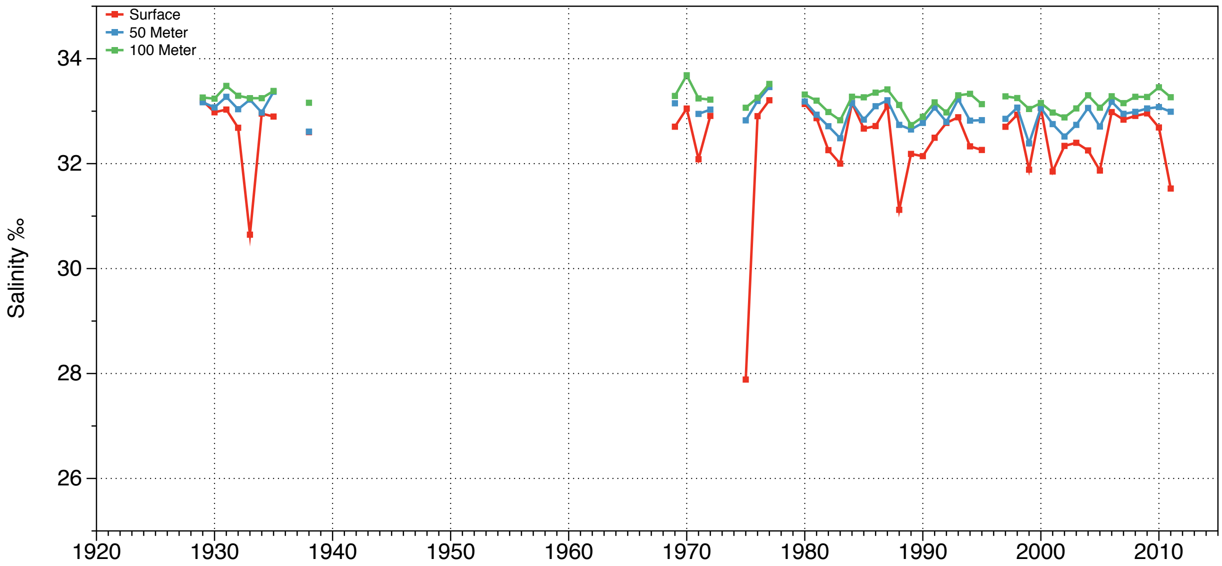


Figure 479: Interannual variability of salinity (November – December) at station Inner Balsfjorden

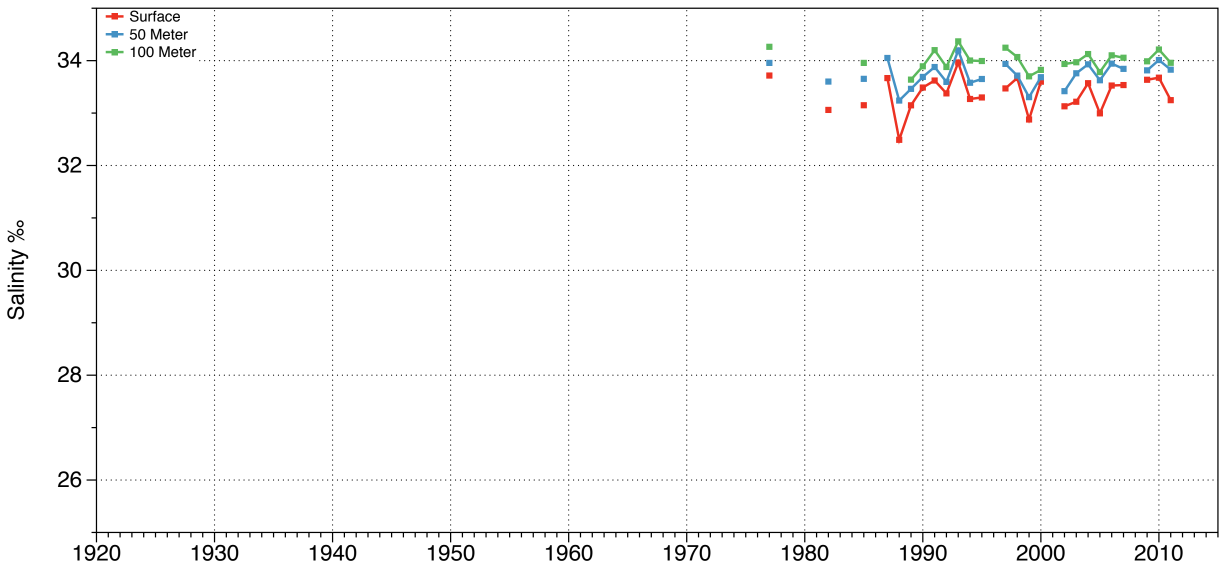


Figure 480: Interannual variability of salinity (November – December) at station Kvalsund

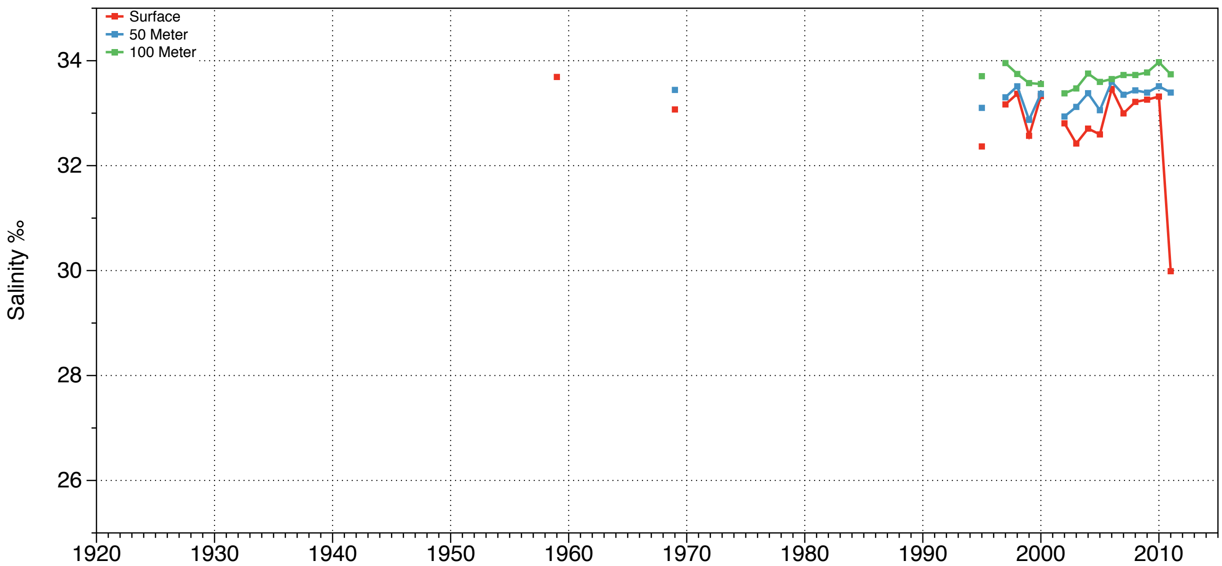


Figure 481: Interannual variability of salinity (November – December) at station Sørfjord

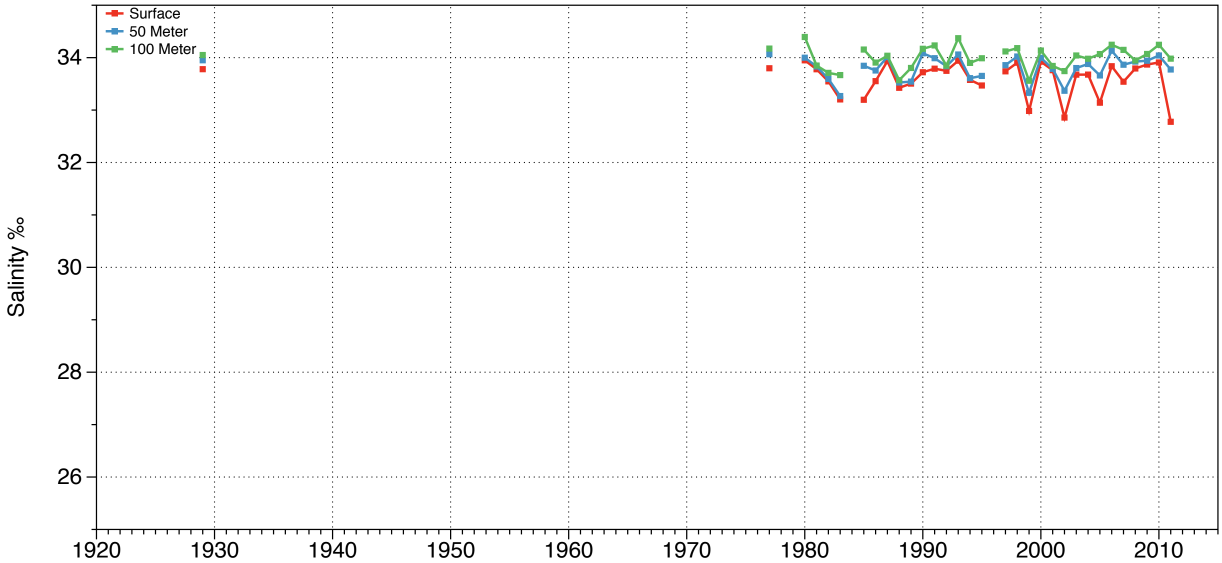


Figure 482: Interannual variability of salinity (November – December) at station Outer Altafjorden

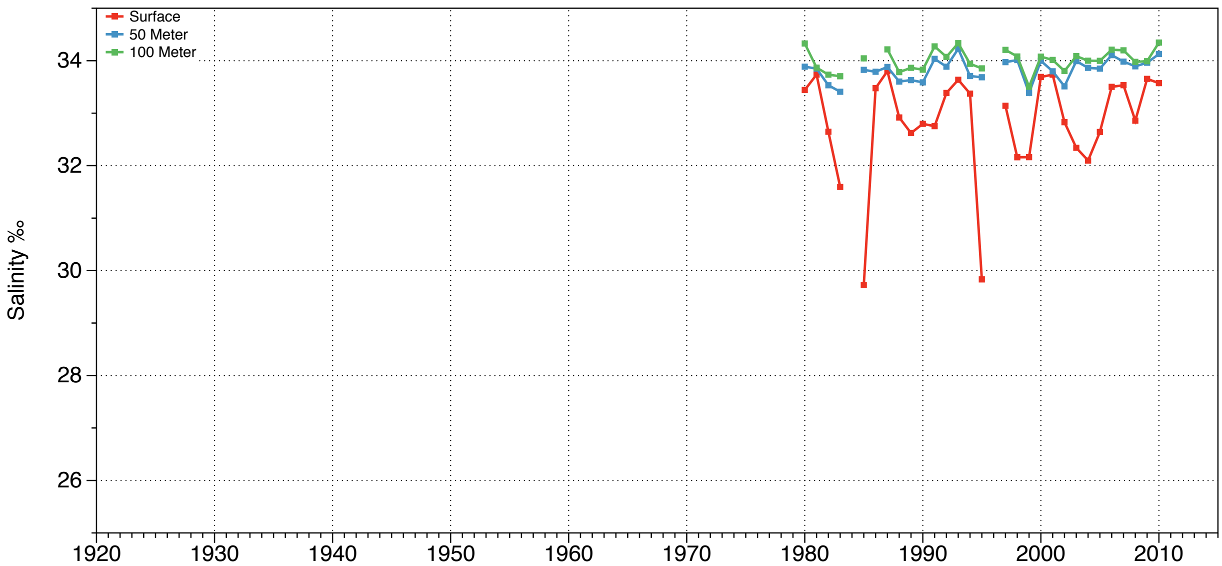


Figure 483: Interannual variability of salinity (November – December) at station Inner Altafjorden

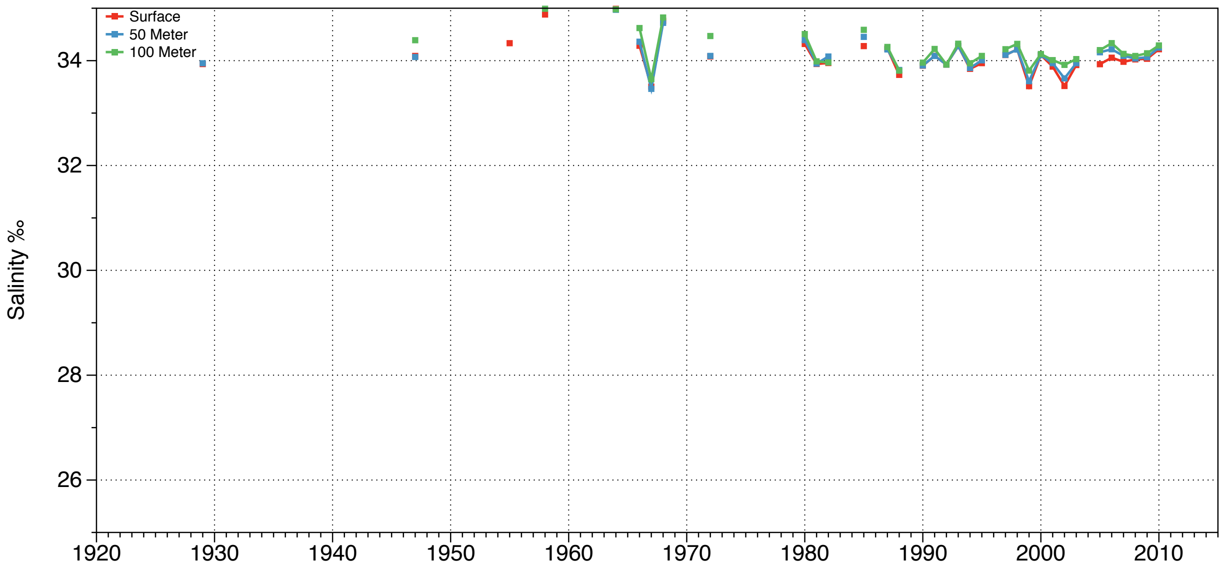


Figure 484: Interannual variability of salinity (November – December) at station Refsbotn

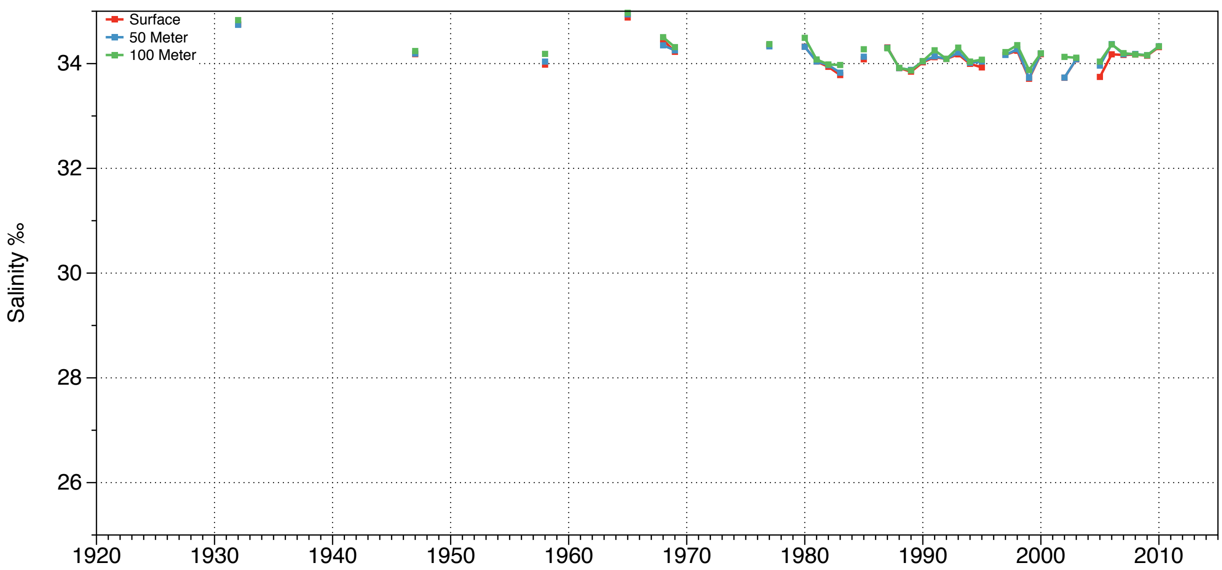


Figure 485: Interannual variability of salinity (November – December) at station Outer Porsangerfjorden

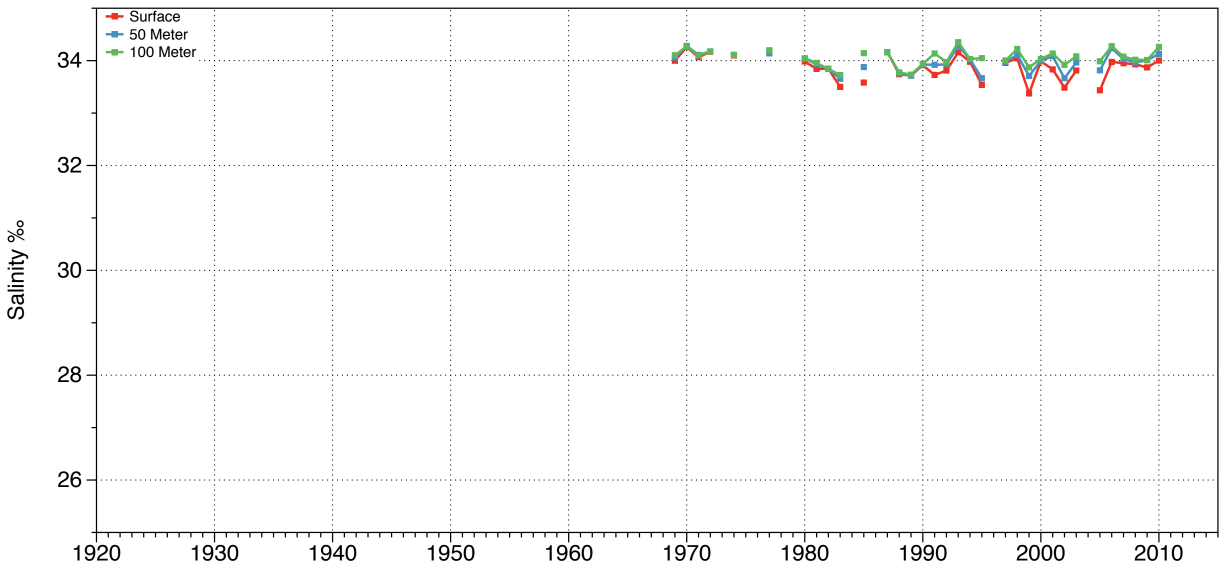


Figure 486: Interannual variability of salinity (November – December) at station Inner Porsangerfjorden

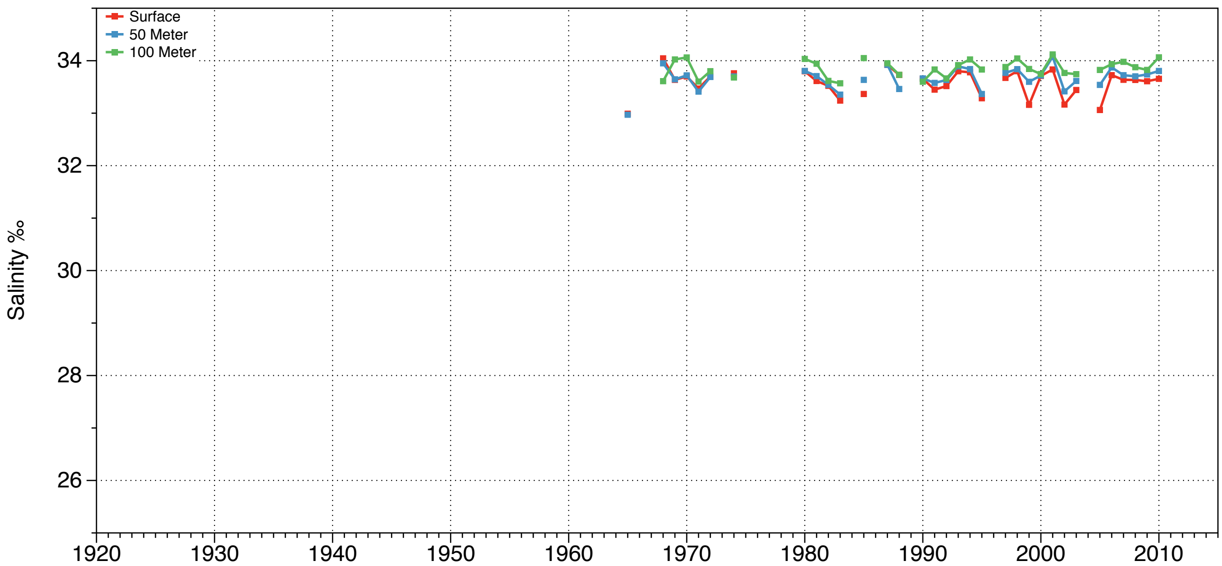


Figure 487: Interannual variability of salinity (November – December) at station Østerbotn

A.9 INTERANNUAL VARIABILITY IN DENSITY (TWO MONTHS AVERAGE)

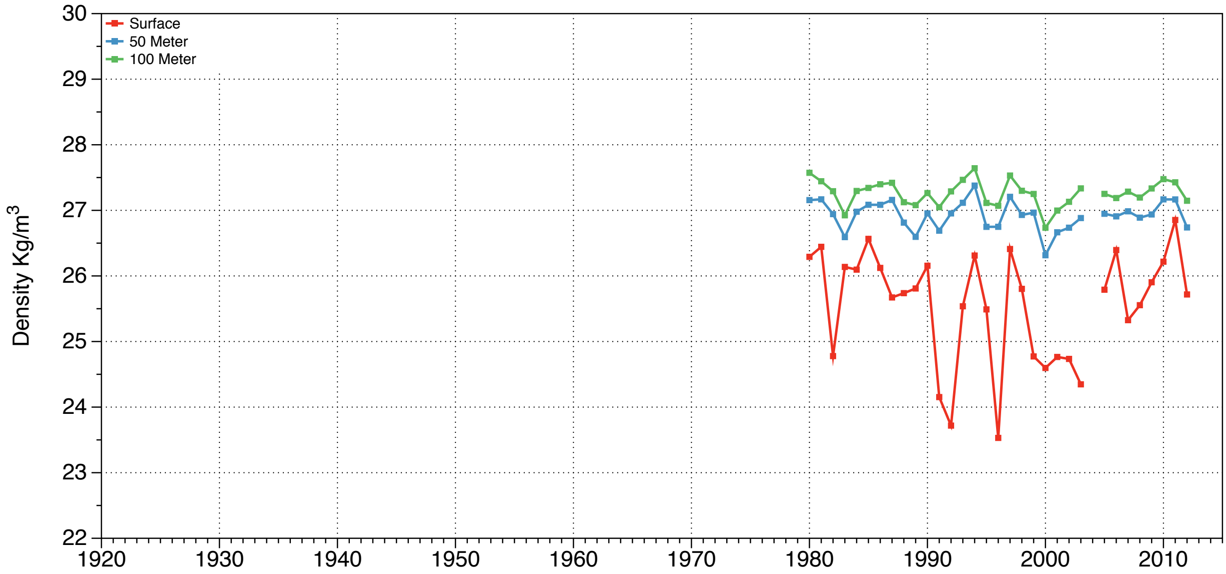


Figure 488: Interannual variability of density (January – February) at station Inner Malangen

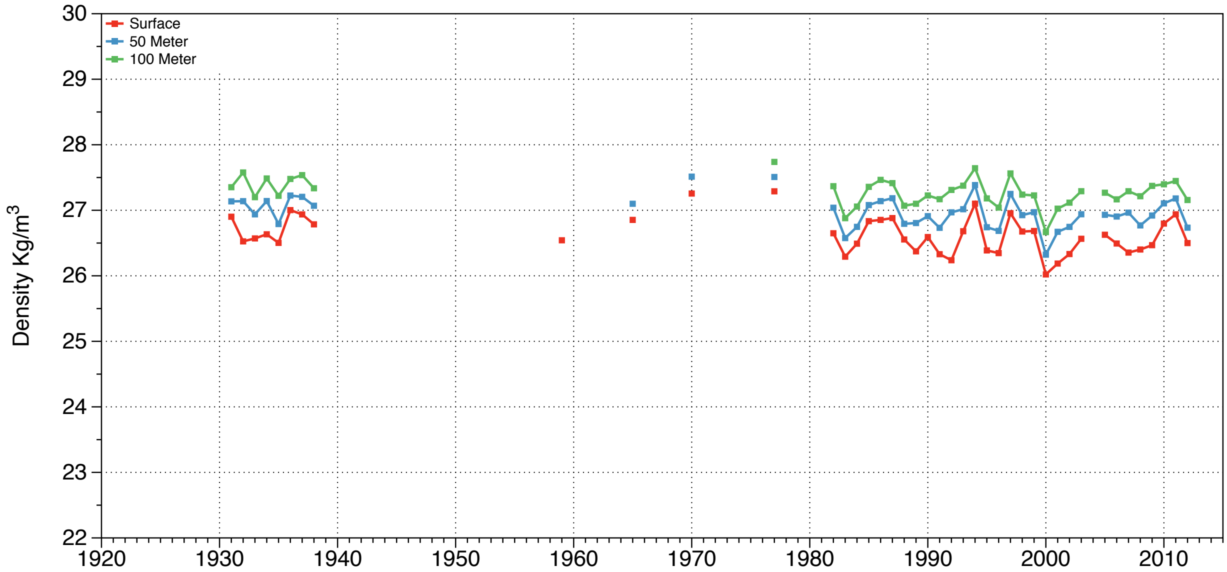


Figure 489: Interannual variability of density (January – February) at station Outer Malangen

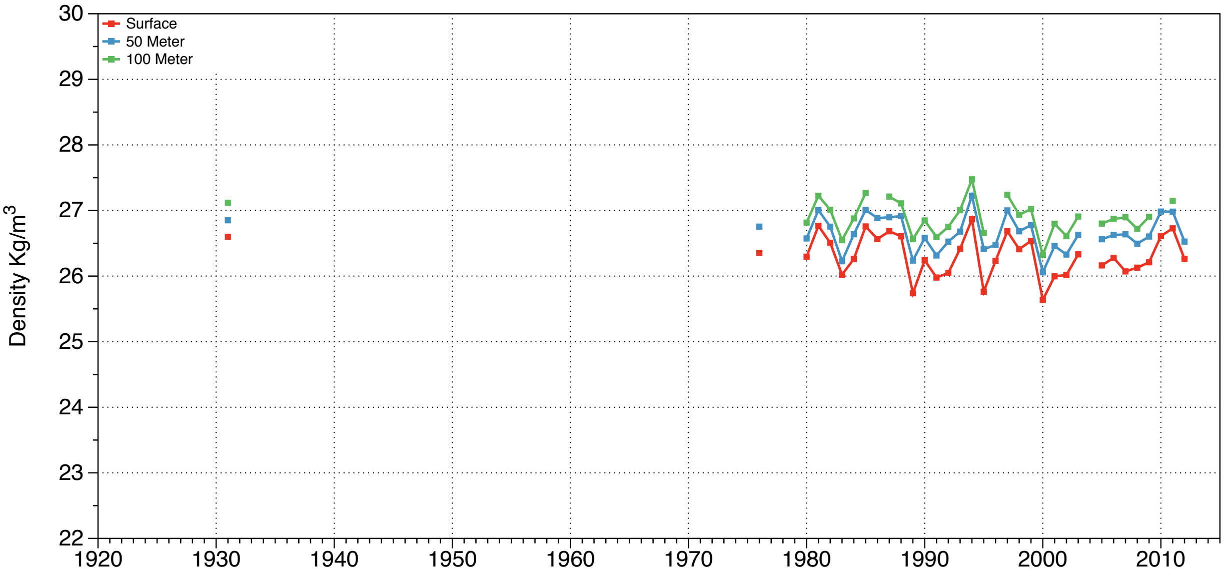


Figure 490: Interannual variability of density (January – February) at station Outer Balsfjorden

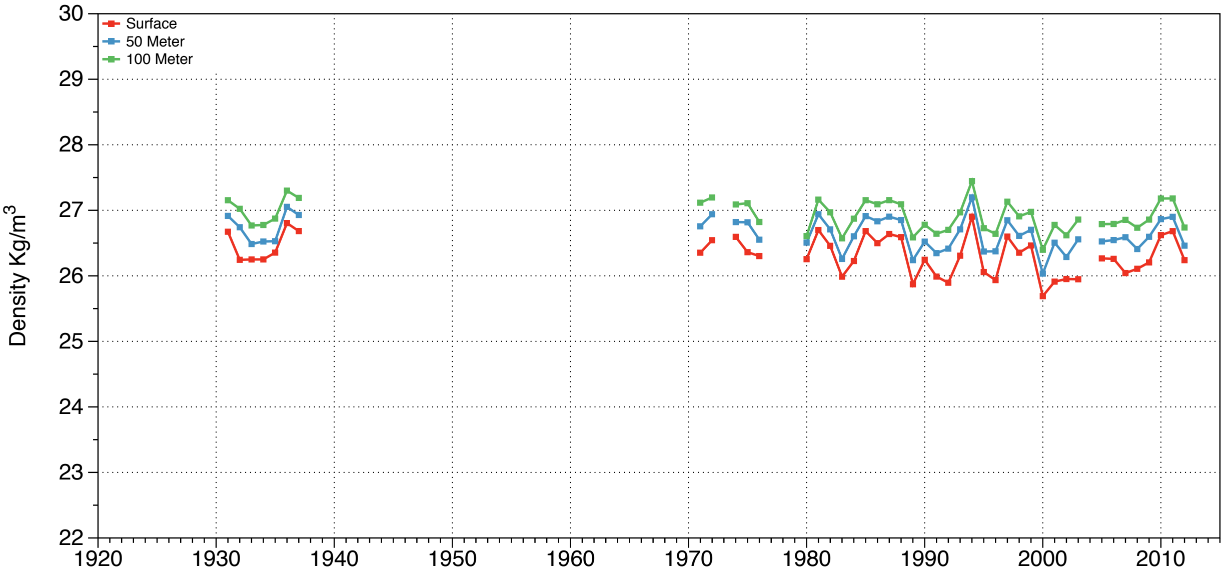


Figure 491: Interannual variability of density (January – February) at station Inner Balsfjorden

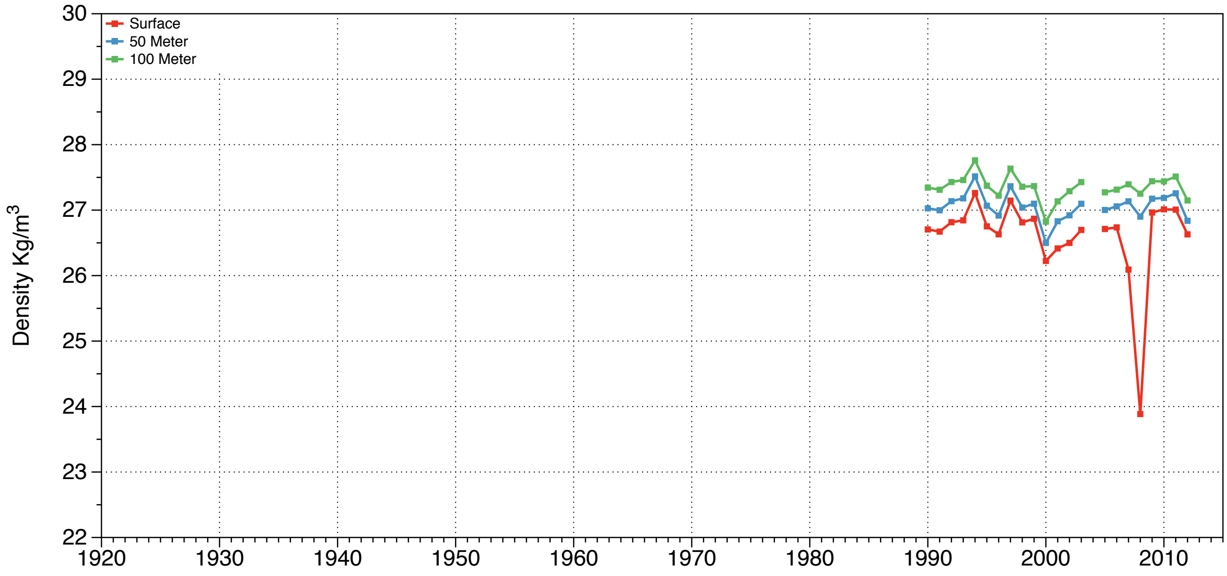


Figure 492: Interannual variability of density (January – February) at station Kvalsund

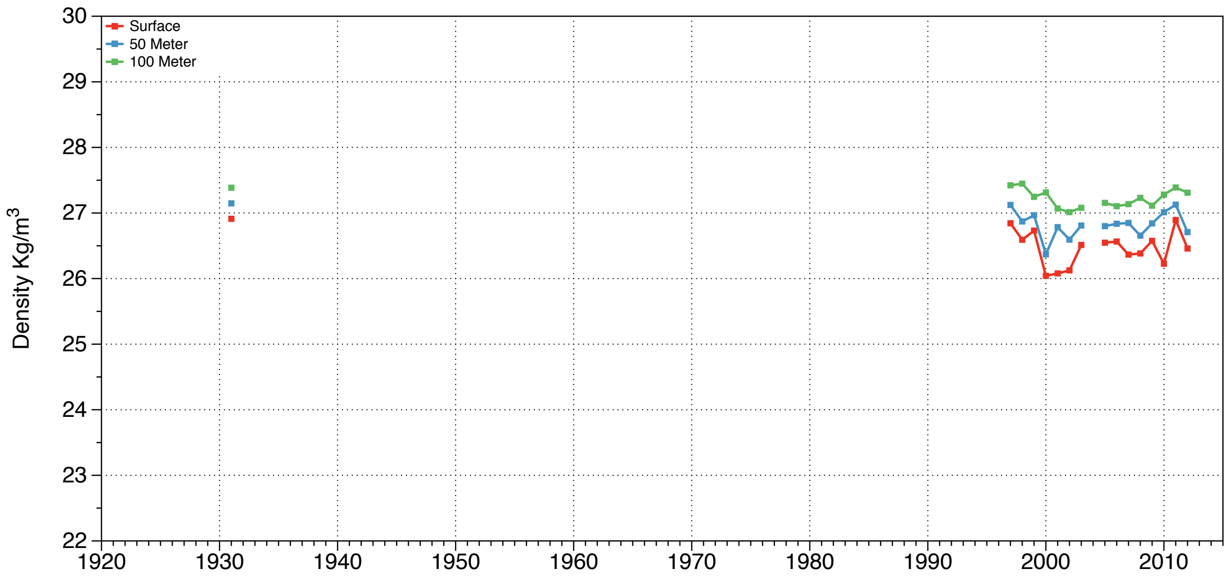


Figure 493: Interannual variability of density (January – February) at station Sørfjord

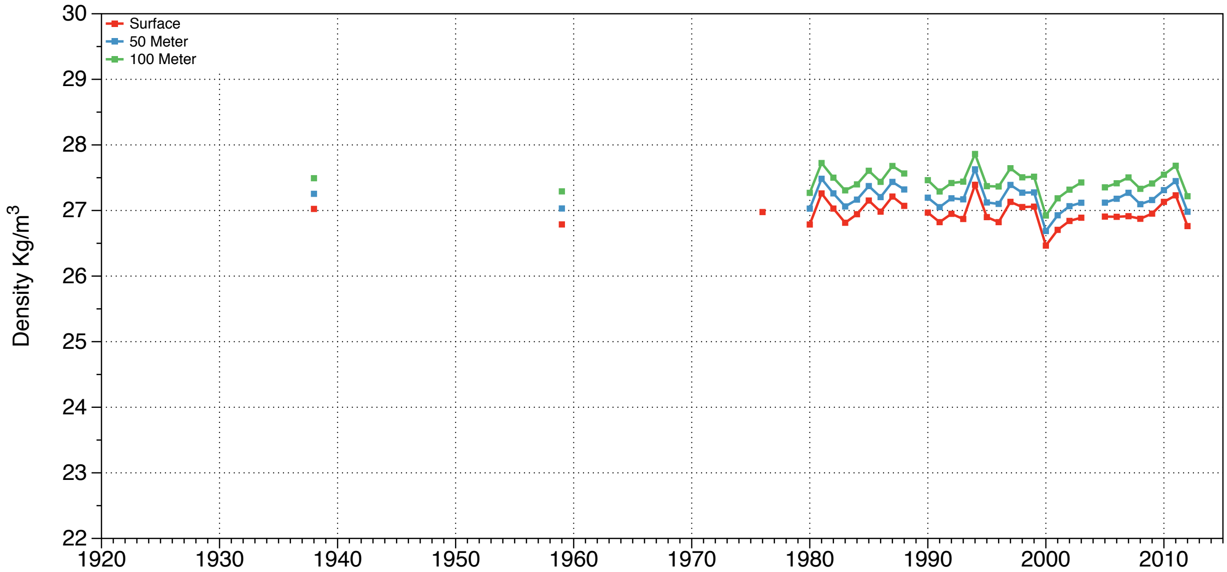


Figure 494: Interannual variability of density (January – February) at station Outer Altafjorden

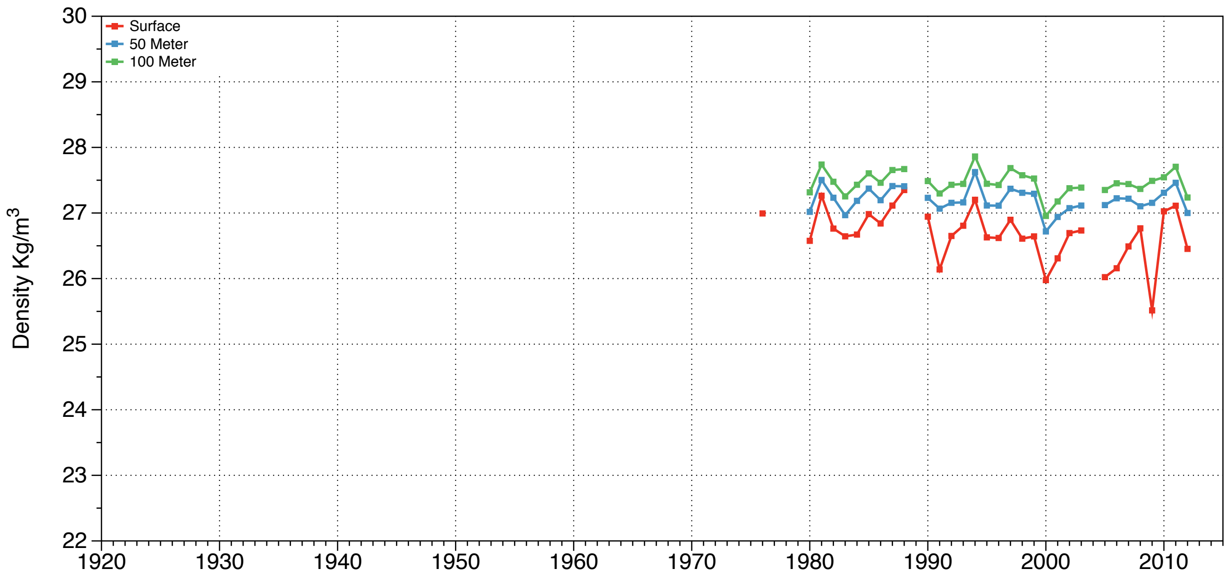


Figure 495: Interannual variability of density (January – February) at station Inner Altafjorden

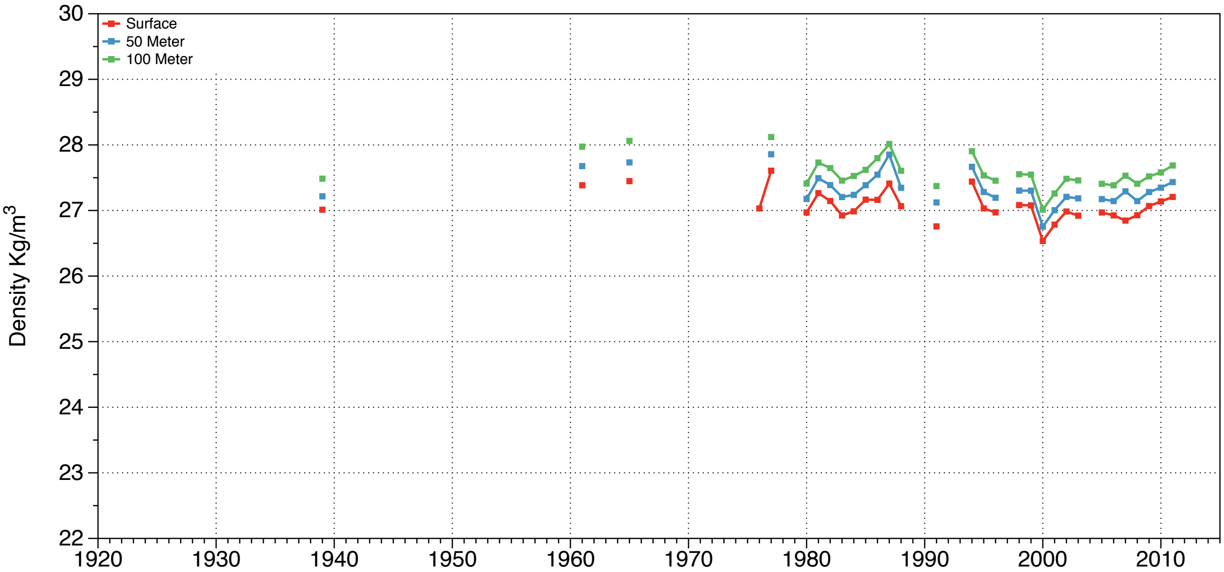


Figure 496: Interannual variability of density (January – February) at station Refsbotn

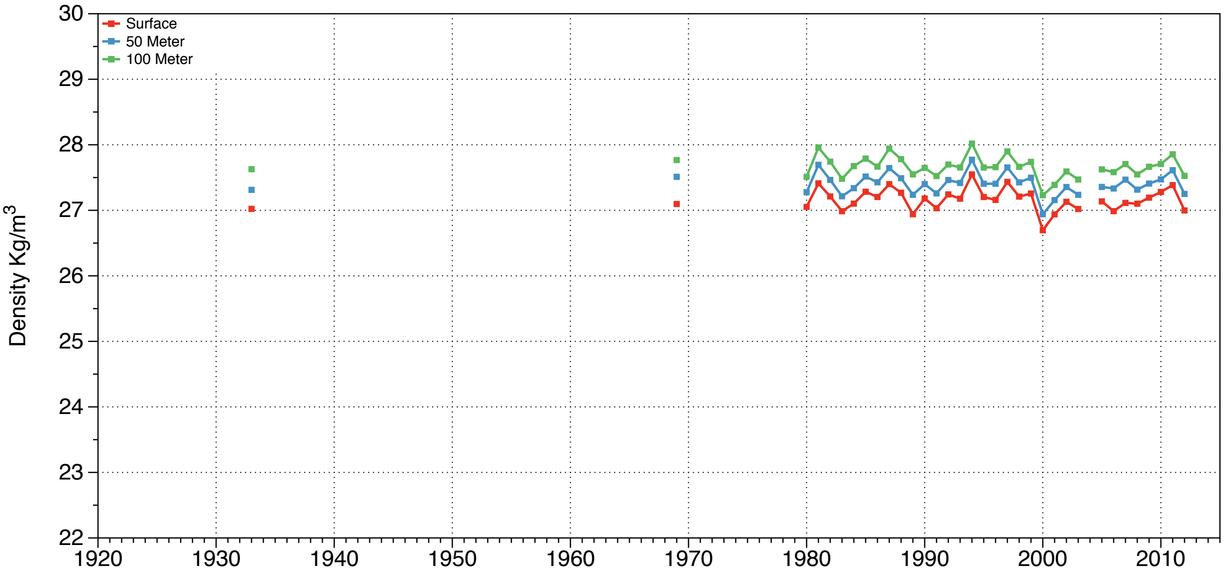


Figure 497: Interannual variability of density (January – February) at station Outer Porsangerfjorden

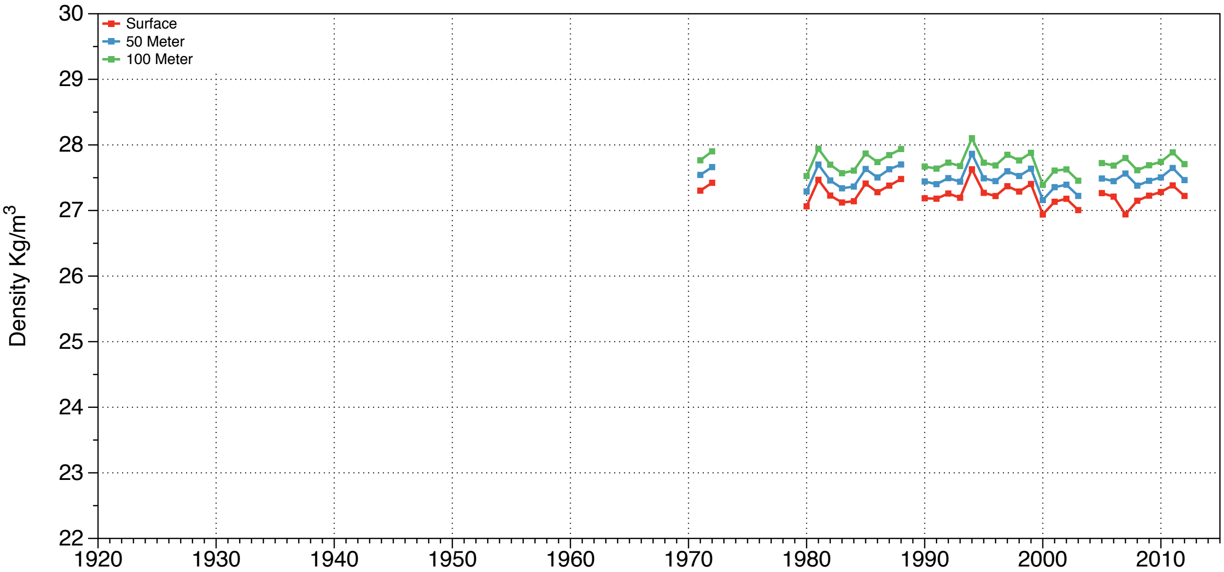


Figure 498: Interannual variability of density (January – February) at station Inner Porsangerfjorden

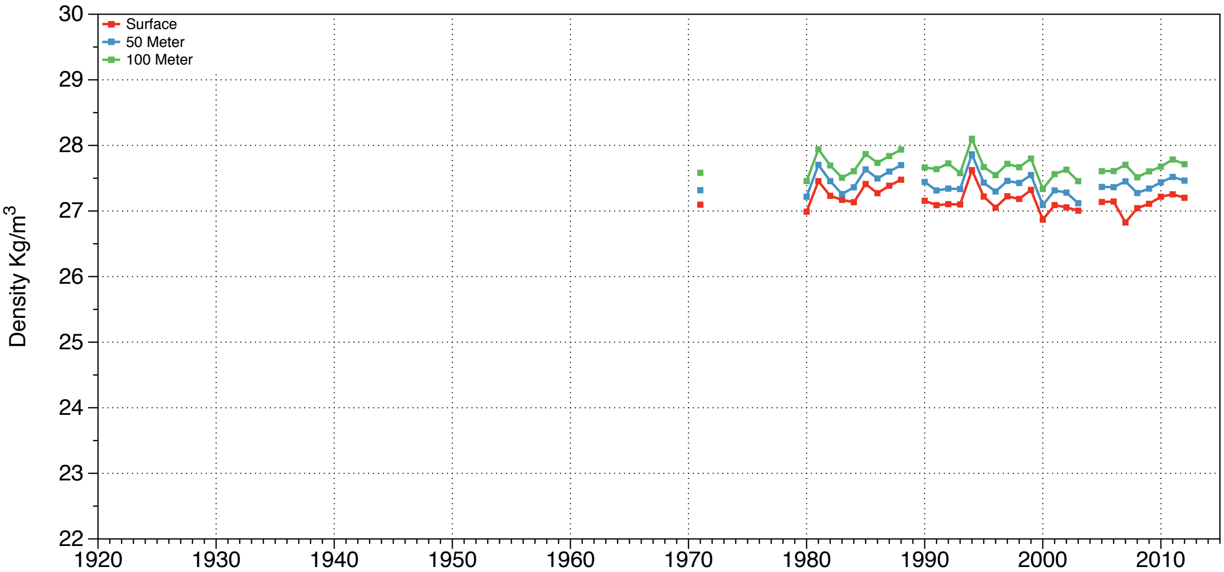


Figure 499: Interannual variability of density (January – February) at station Østerbotn

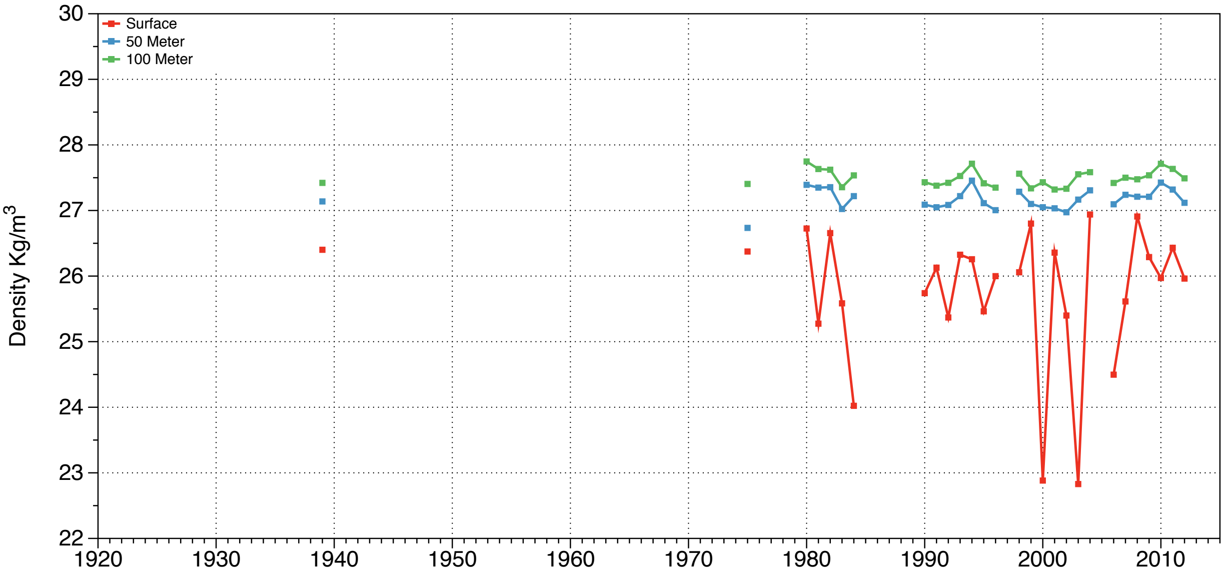


Figure 500: Interannual variability of density (March – April) at station Inner Malangen

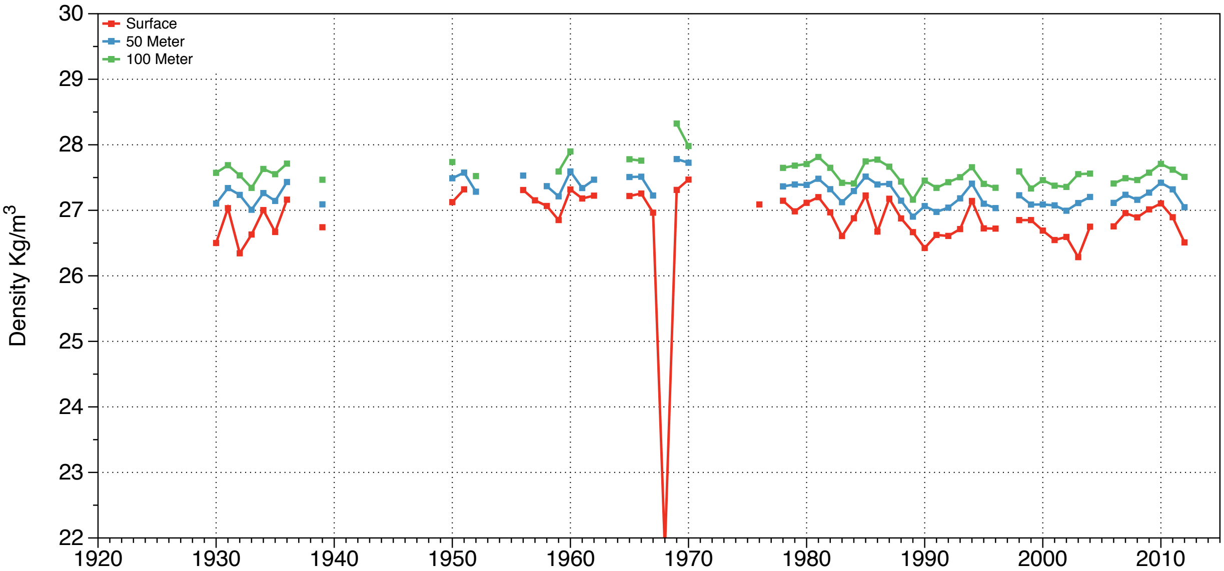


Figure 501: Interannual variability of density (March – April) at station Outer Malangen

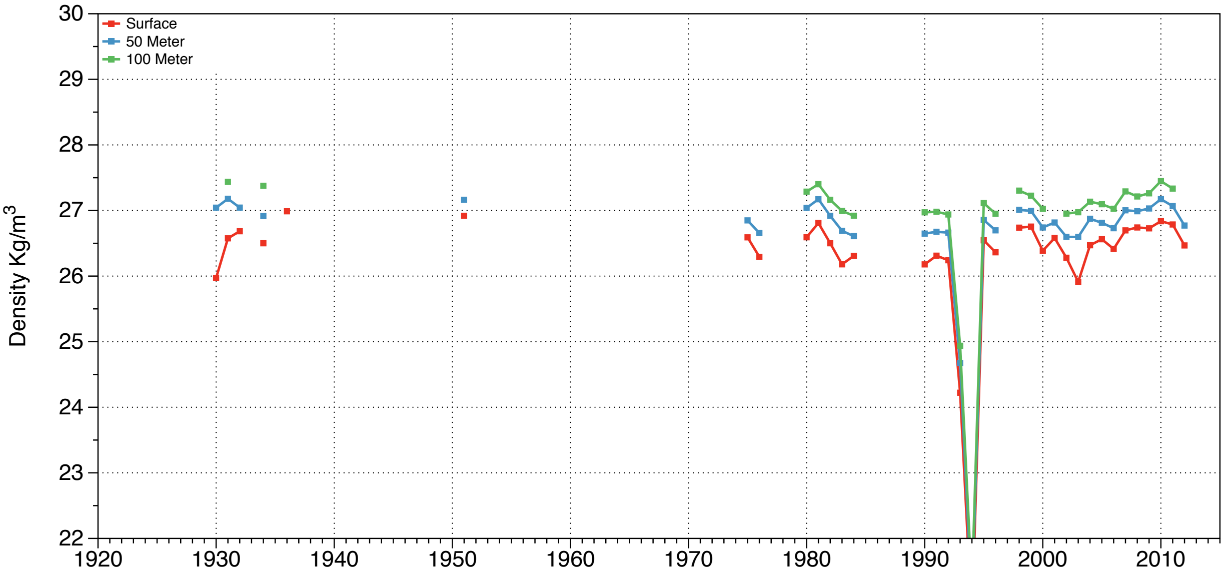


Figure 502: Interannual variability of density (March – April) at station Outer Balsfjorden

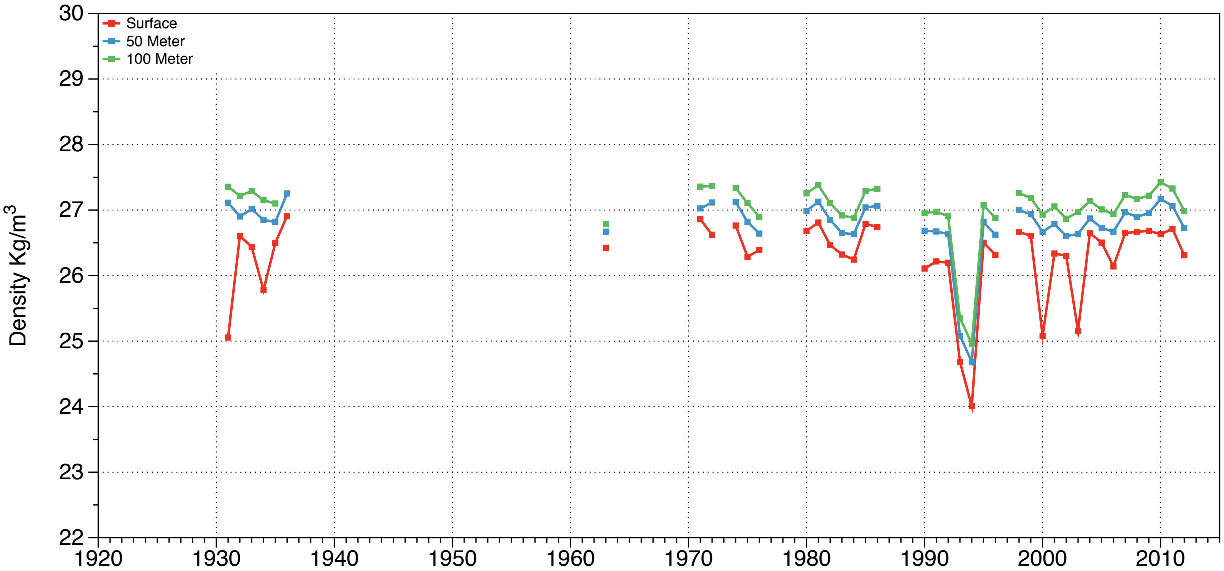


Figure 503: Interannual variability of density (March – April) at station Inner Balsfjorden

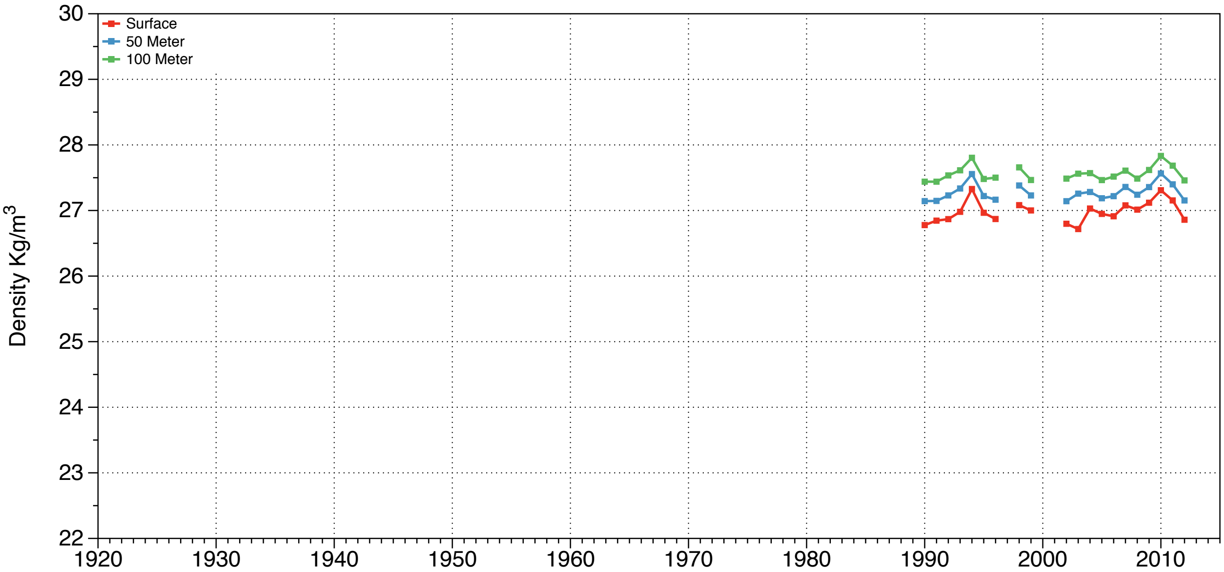


Figure 504: Interannual variability of density (March – April) at station Kvalsund

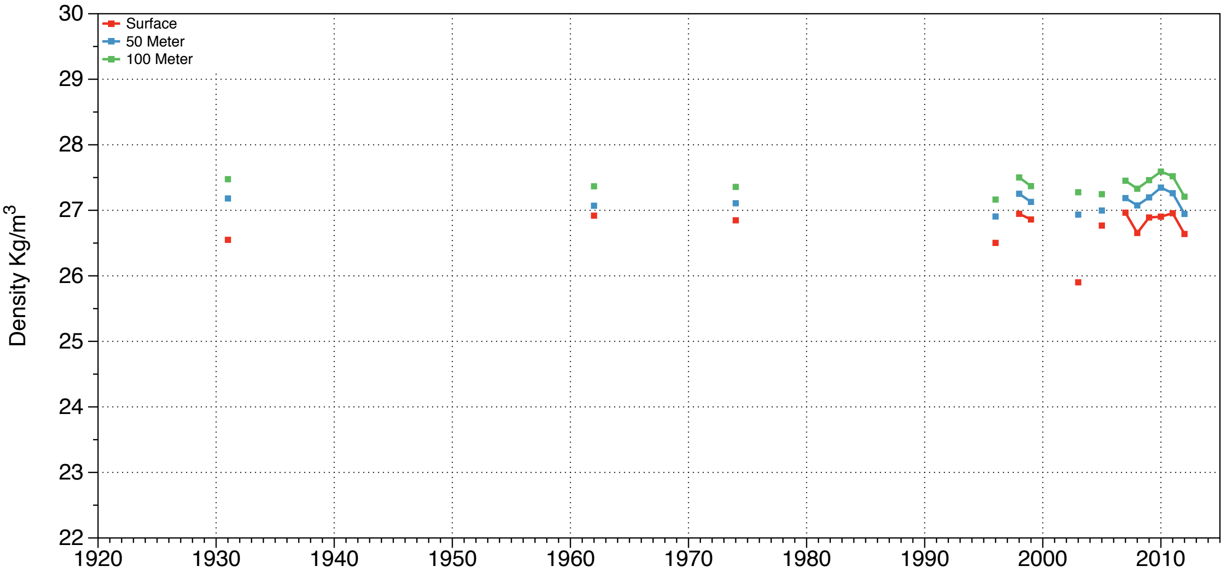


Figure 505: Interannual variability of density (March – April) at station Sørfjord

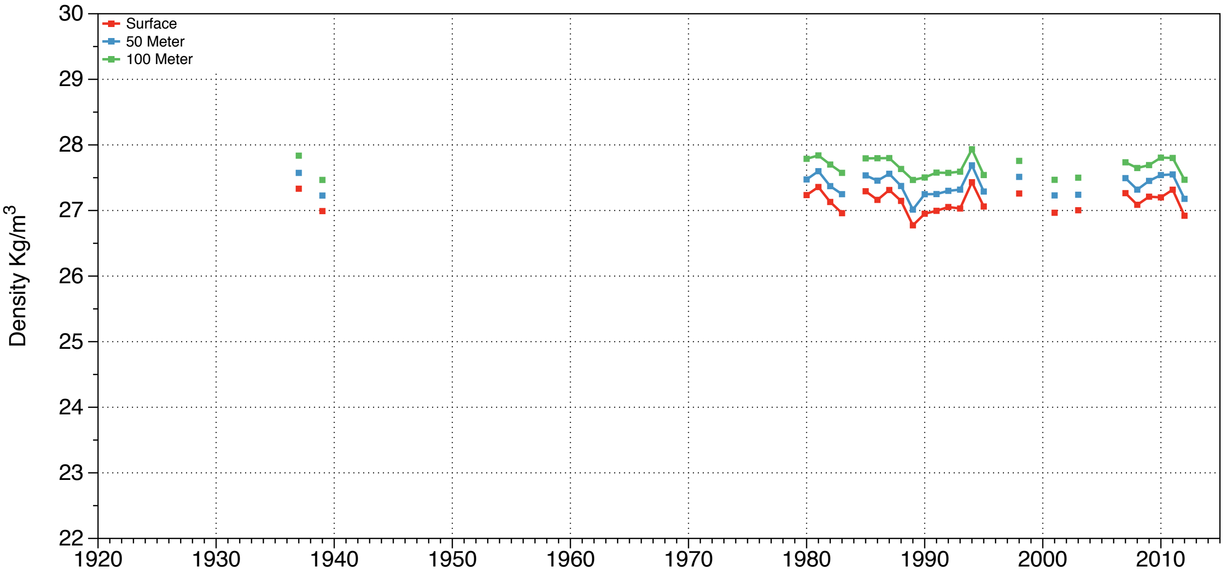


Figure 506: Interannual variability of density (March – April) at station Outer Altafjorden

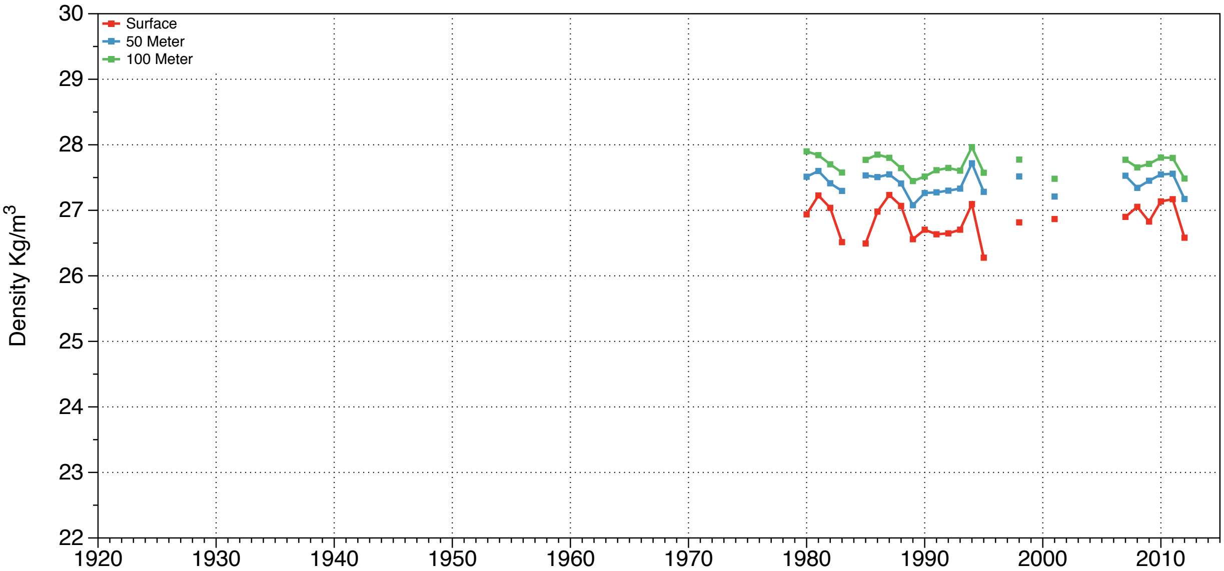


Figure 507: Interannual variability of density (March – April) at station Inner Altafjorden

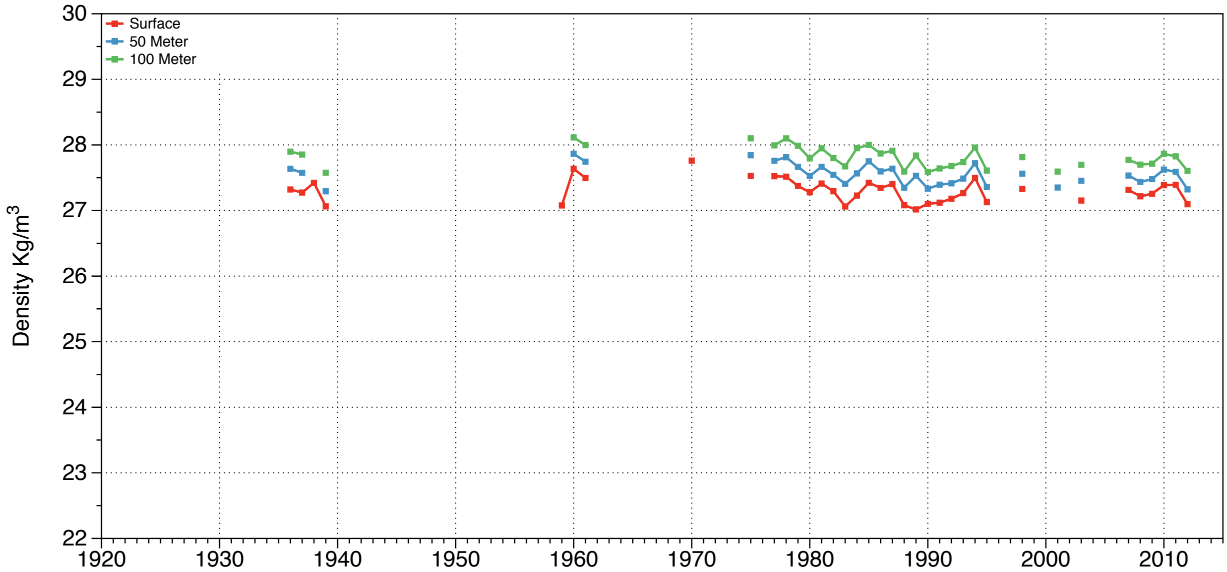


Figure 508: Interannual variability of density (March – April) at station Refsbotn

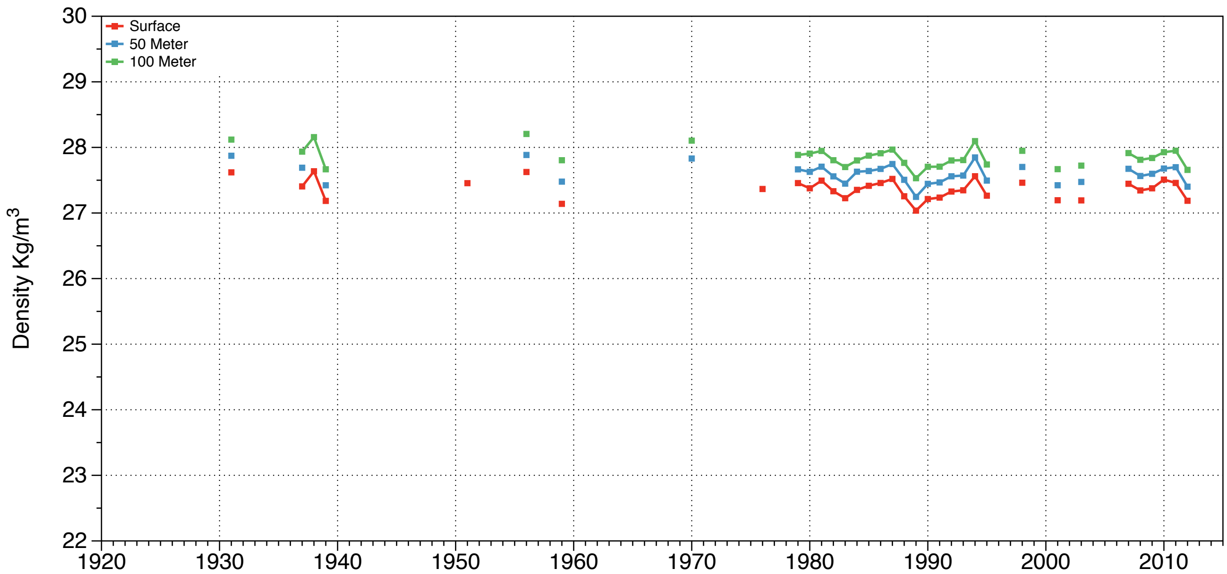


Figure 509: Interannual variability of density (March – April) at station Outer Porsangerfjorden

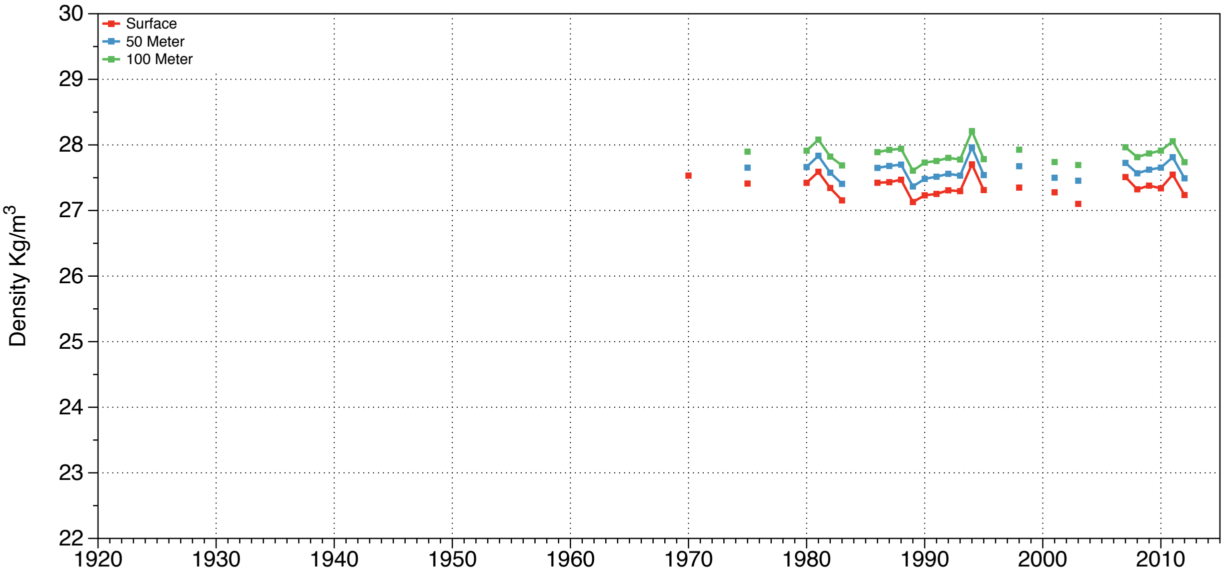


Figure 510: Interannual variability of density (March – April) at station Inner Porsangerfjorden

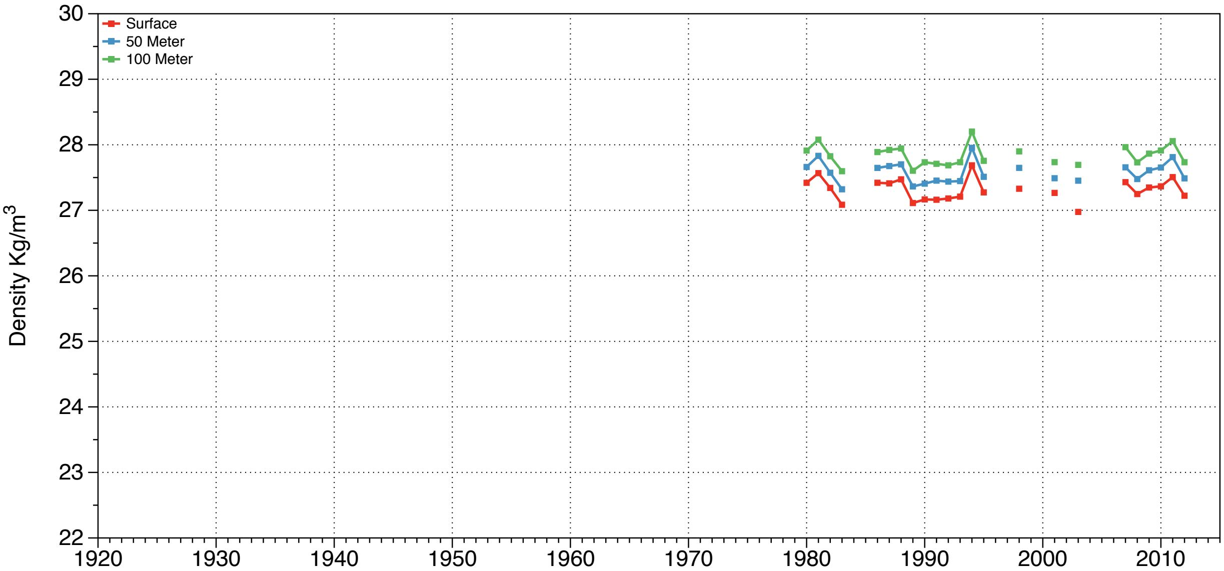


Figure 511: Interannual variability of density (March – April) at station Østerbotn

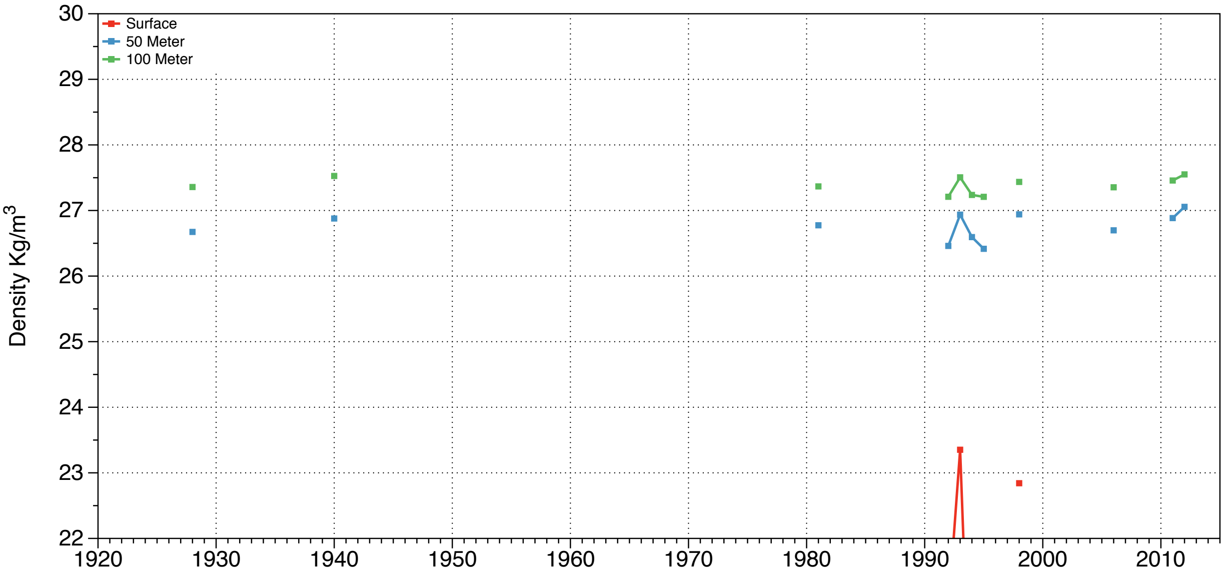


Figure 512: Interannual variability of density (July – August) at station Inner Malangen

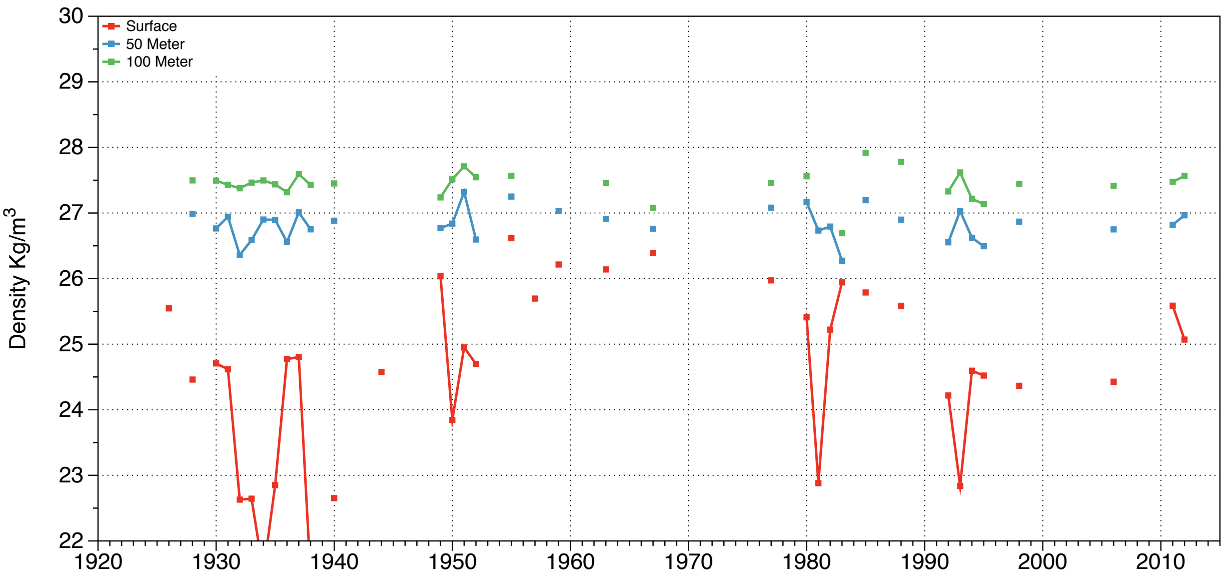


Figure 513: Interannual variability of density (July – August) at station Outer Malangen

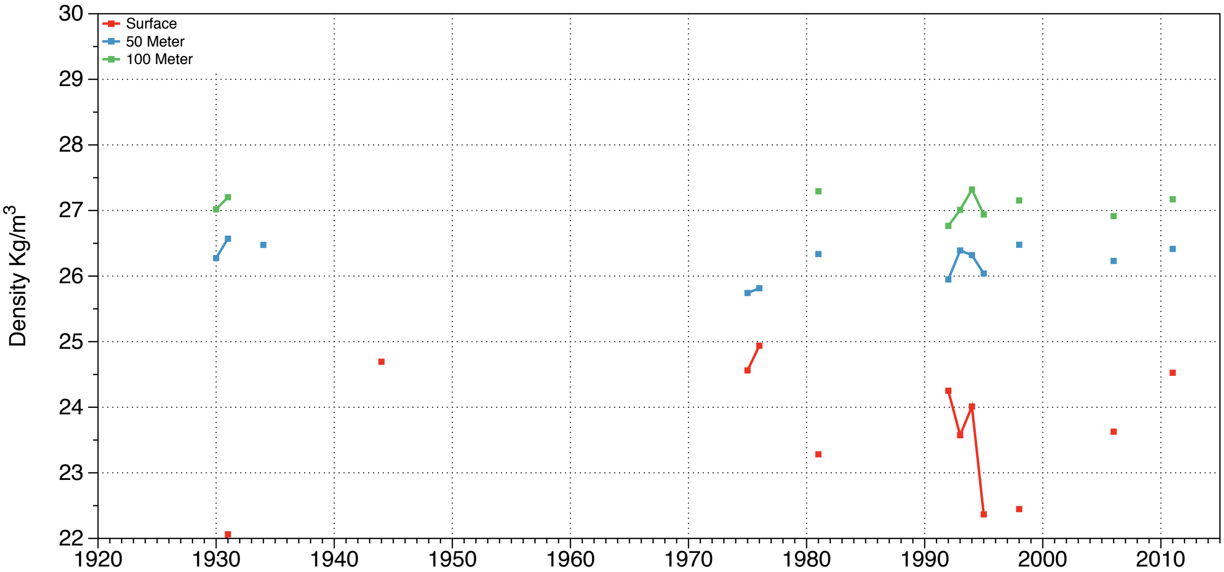


Figure 514: Interannual variability of density (July – August) at station Outer Balsfjorden

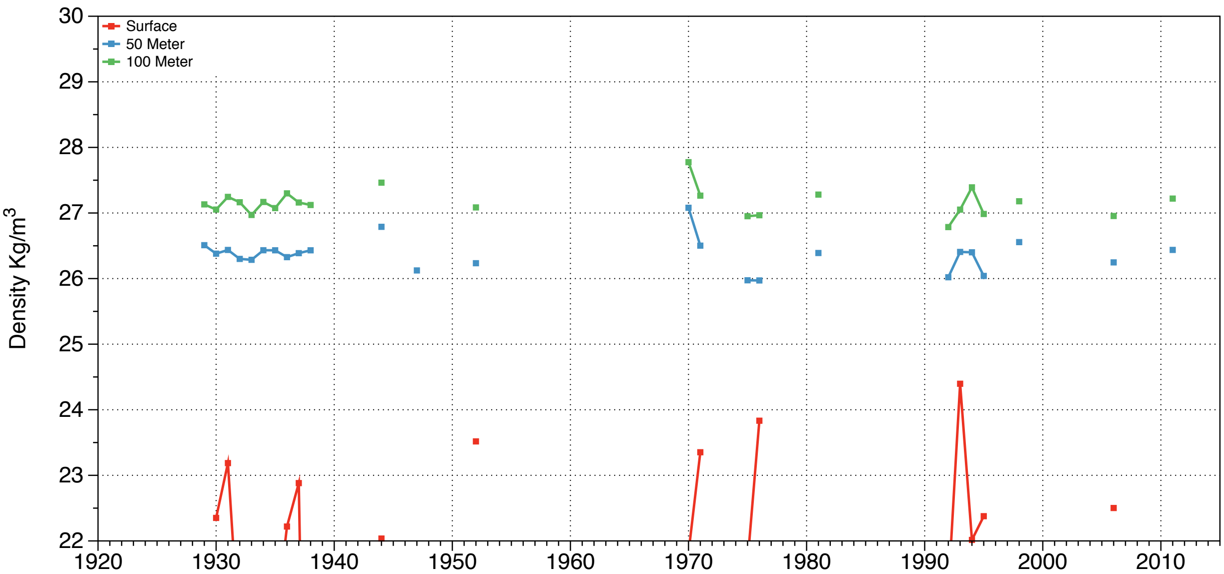


Figure 515: Interannual variability of density (July – August) at station Inner Balsfjorden

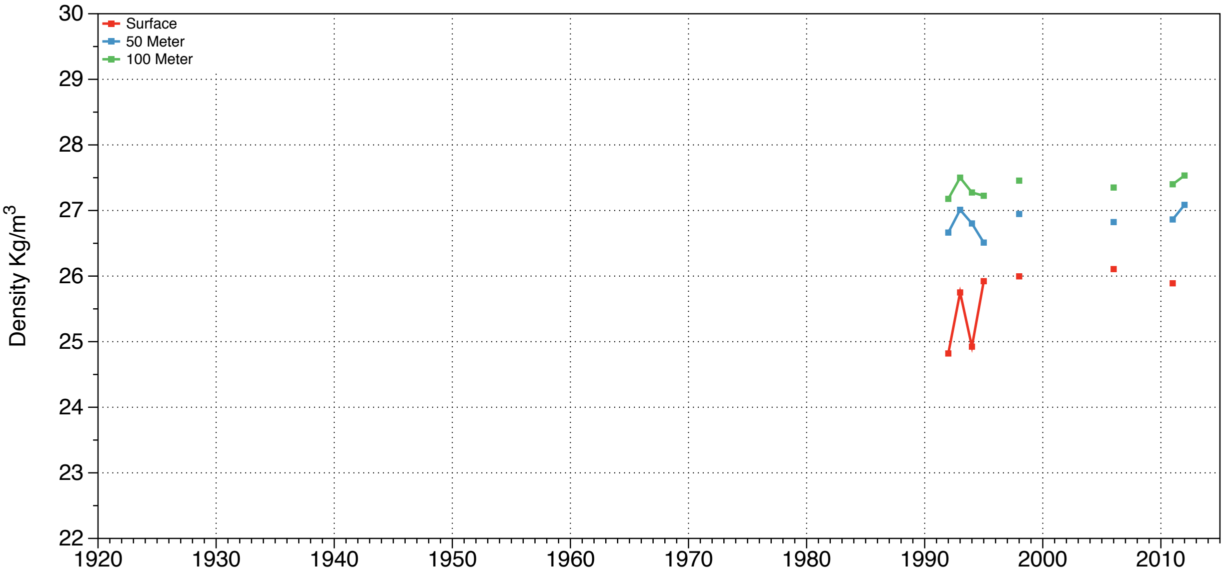


Figure 516: Interannual variability of density (July – August) at station Kvalsund

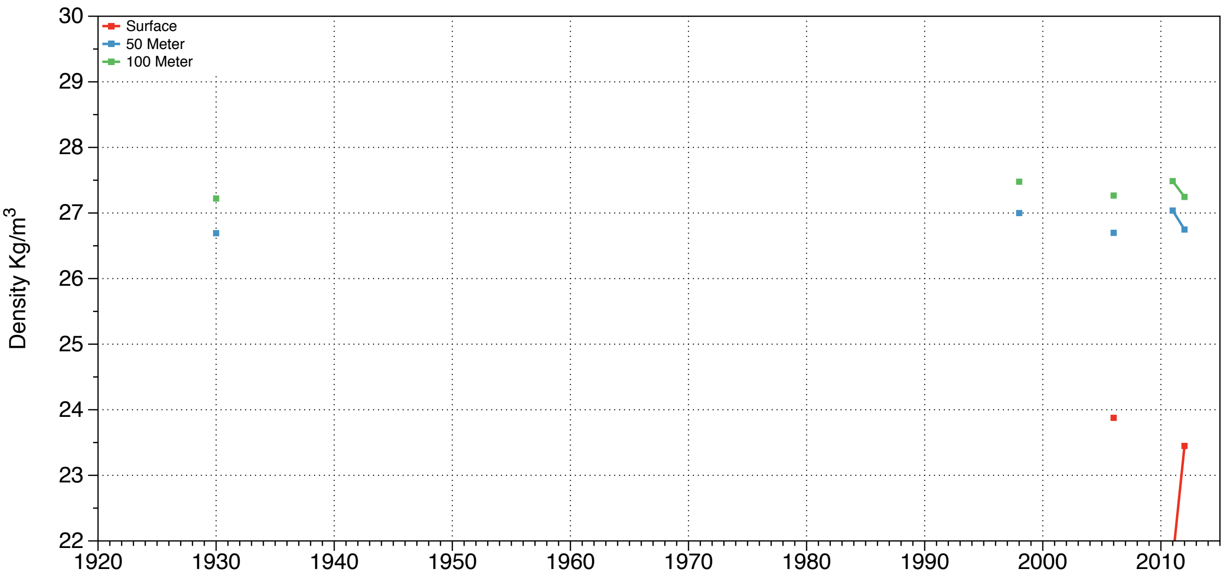


Figure 517: Interannual variability of density (July – August) at station Sørfjord

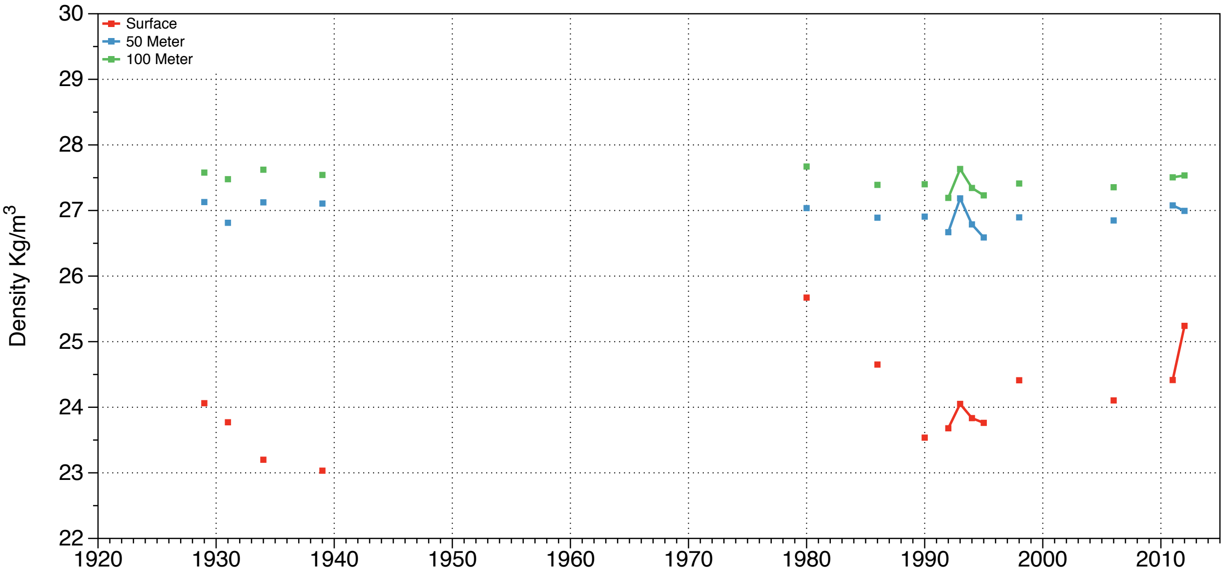


Figure 518: Interannual variability of density (July – August) at station Outer Altafjorden

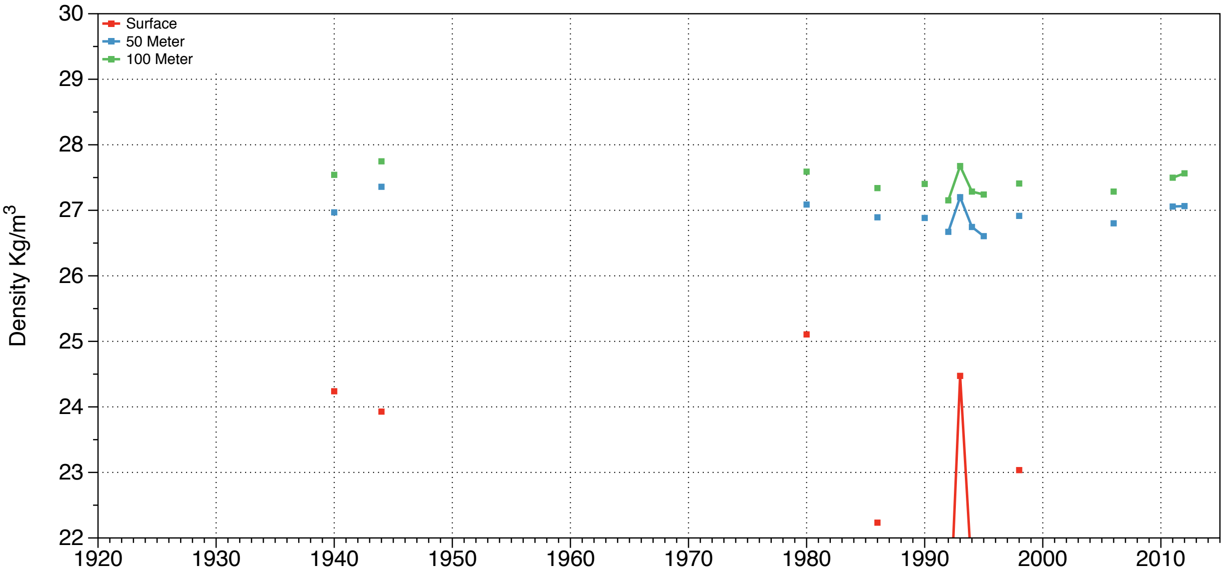


Figure 519: Interannual variability of density (July – August) at station Inner Altafjorden

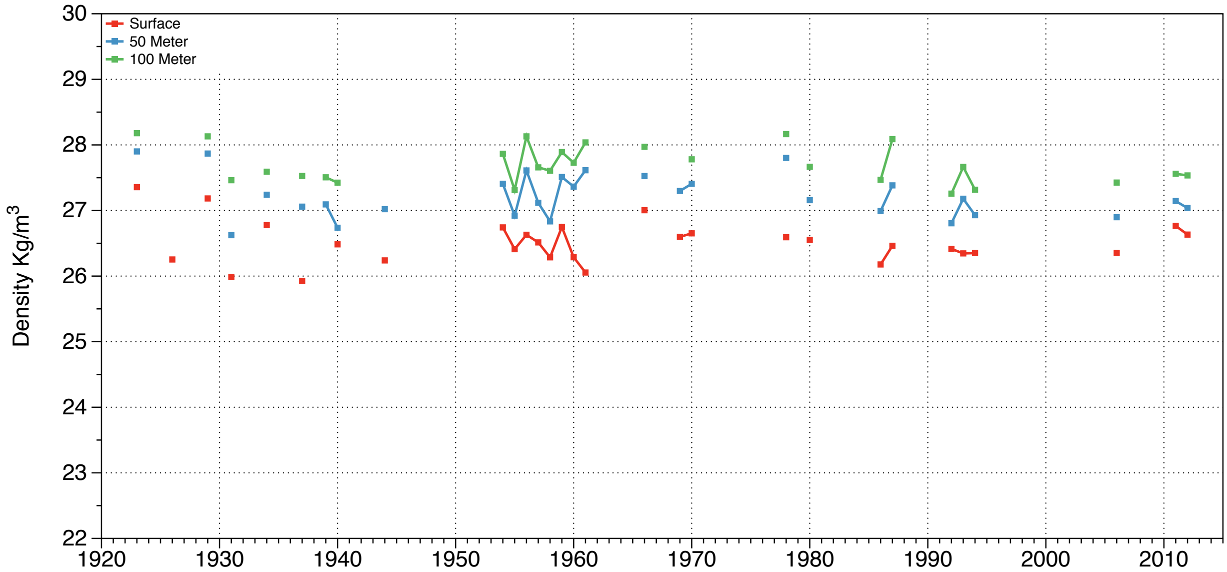


Figure 520: Interannual variability of density (July – August) at station Refsbotn

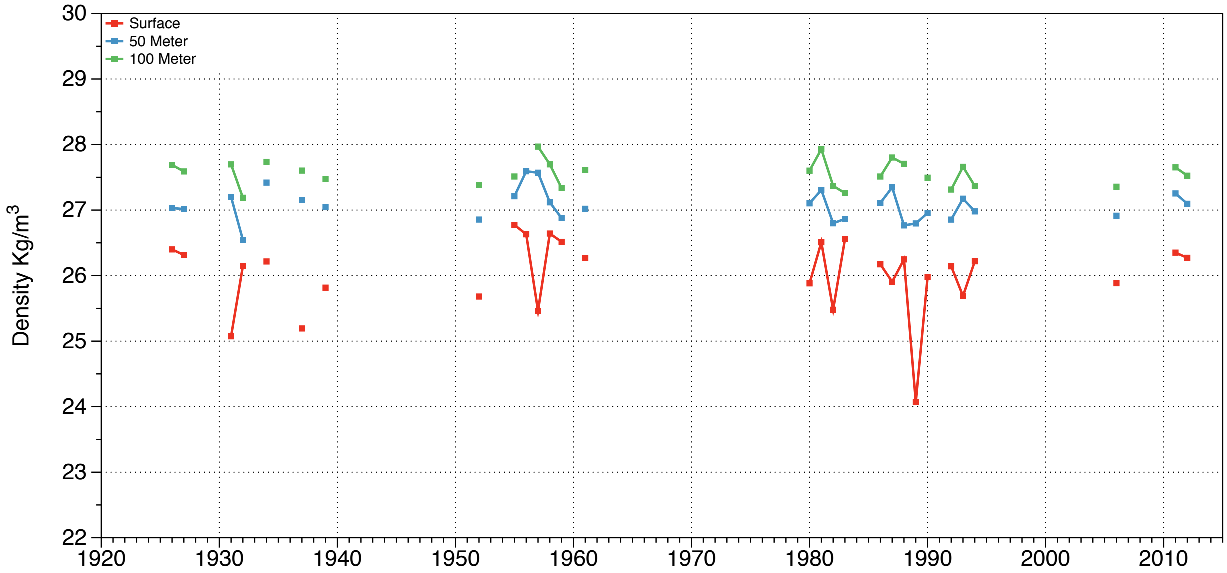


Figure 521: Interannual variability of density (July – August) at station Outer Porsangerfjorden

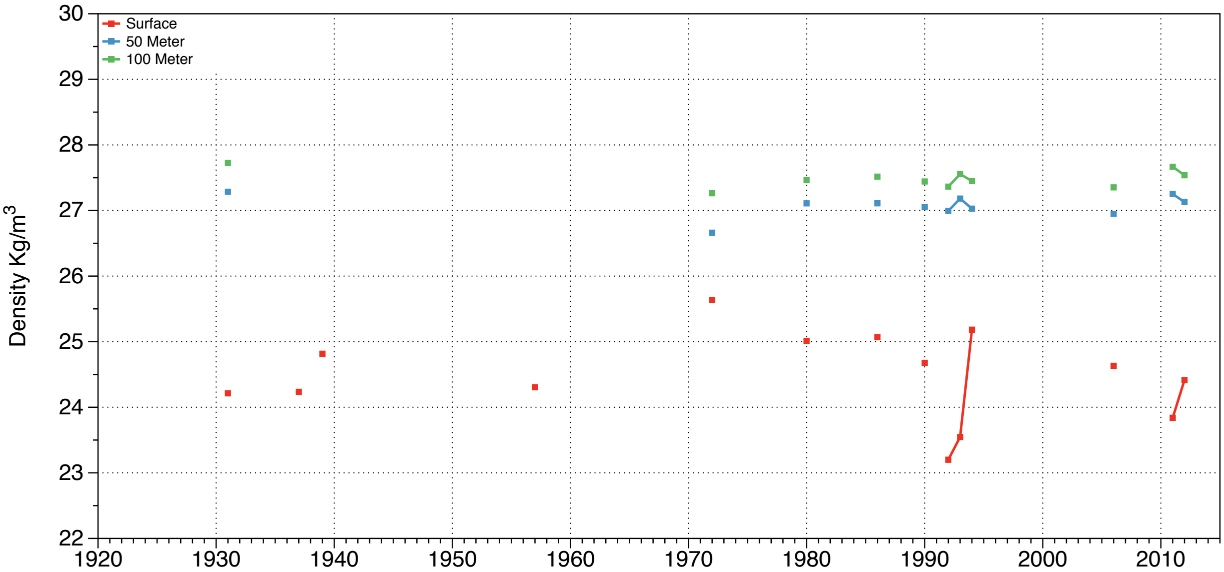


Figure 522: Interannual variability of density (July – August) at station Inner Porsangerfjorden

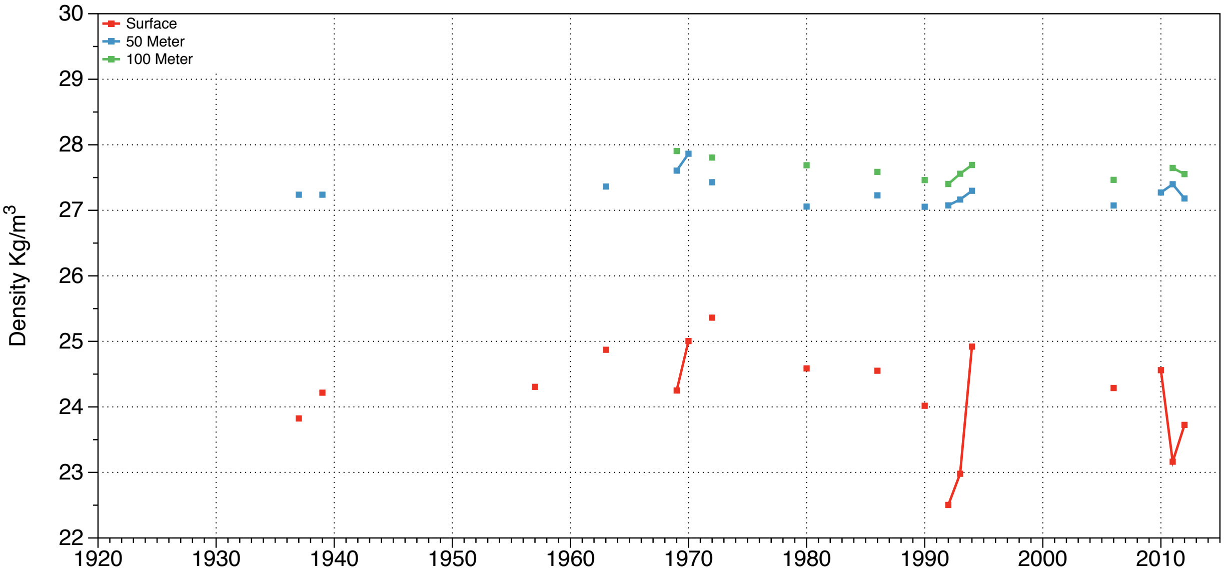


Figure 523: Interannual variability of density (July – August) at station Østerbotn

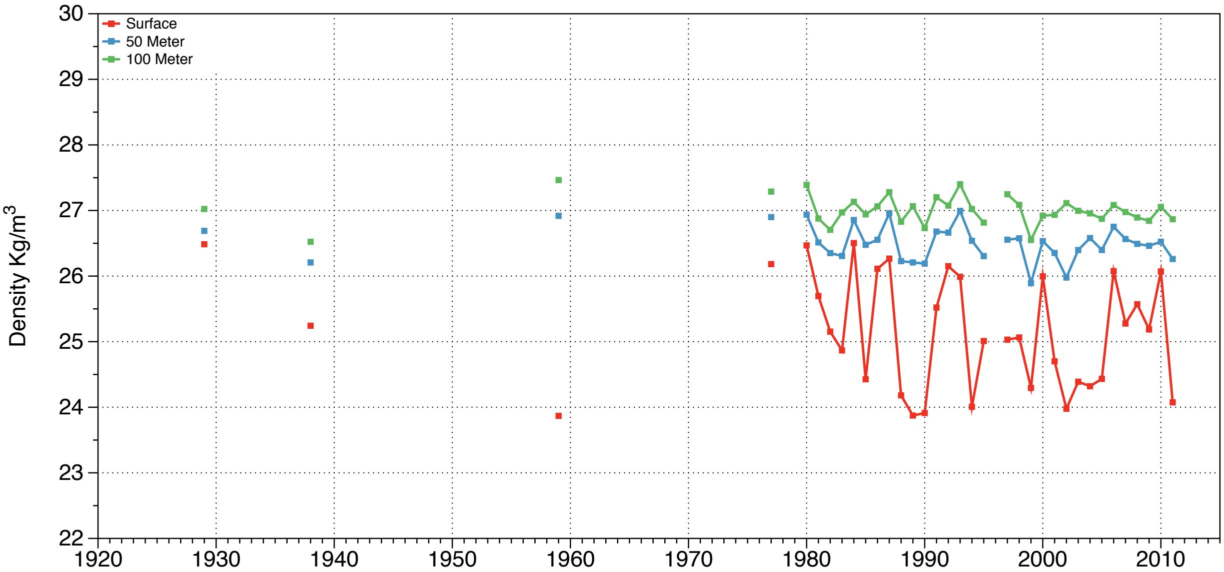


Figure 524: Interannual variability of density (November – December) at station Inner Malangen

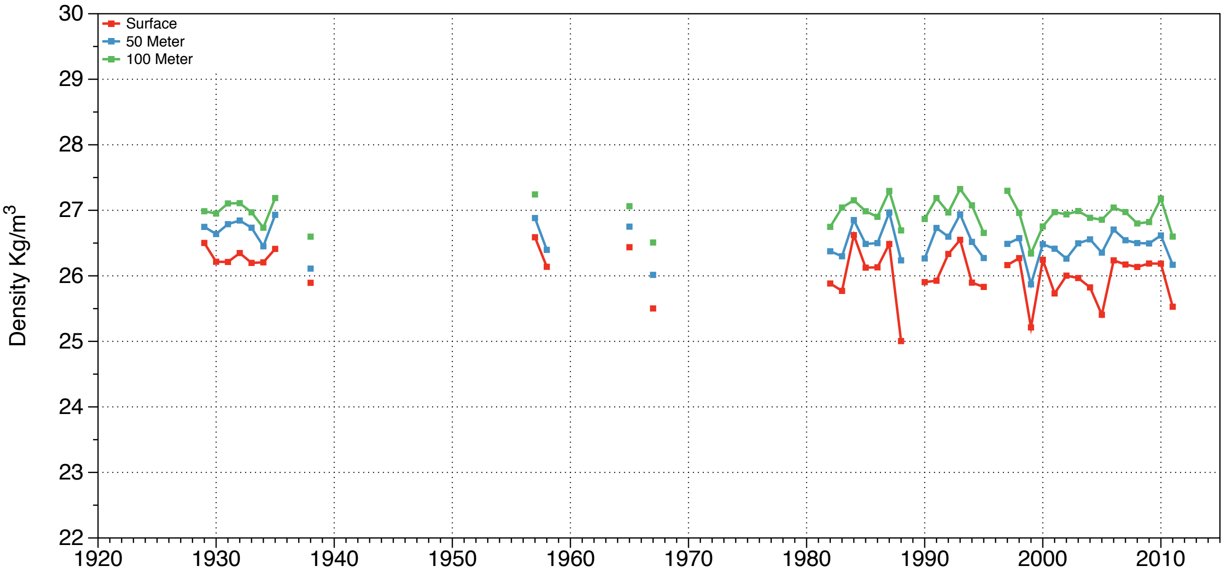


Figure 525: Interannual variability of density (November – December) at station Outer Malangen

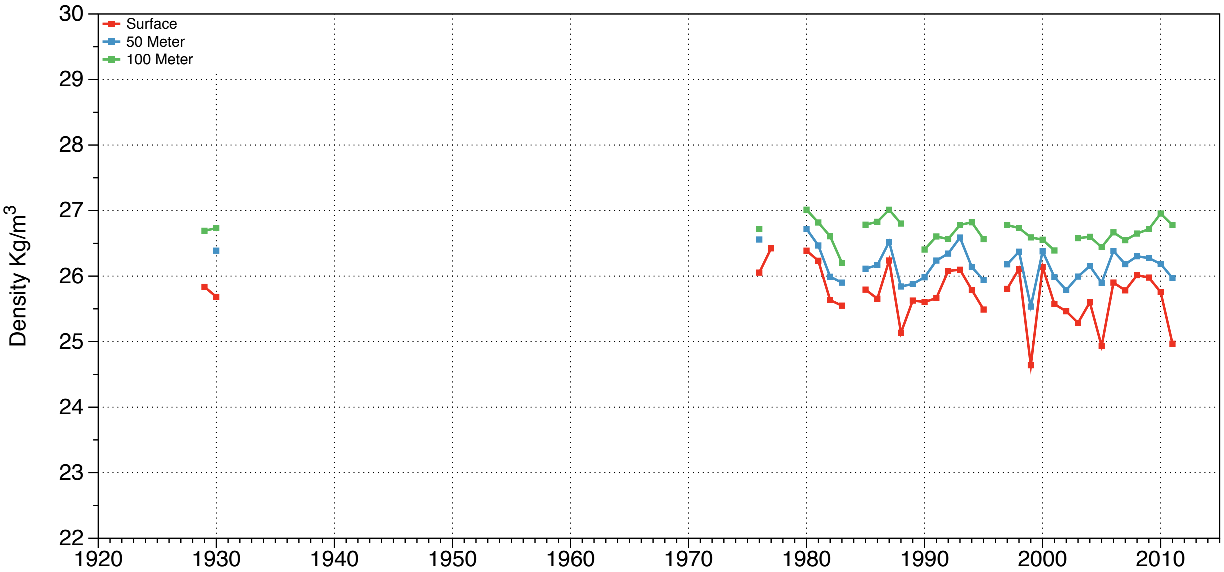


Figure 526: Interannual variability of density (November – December) at station Outer Balsfjorden

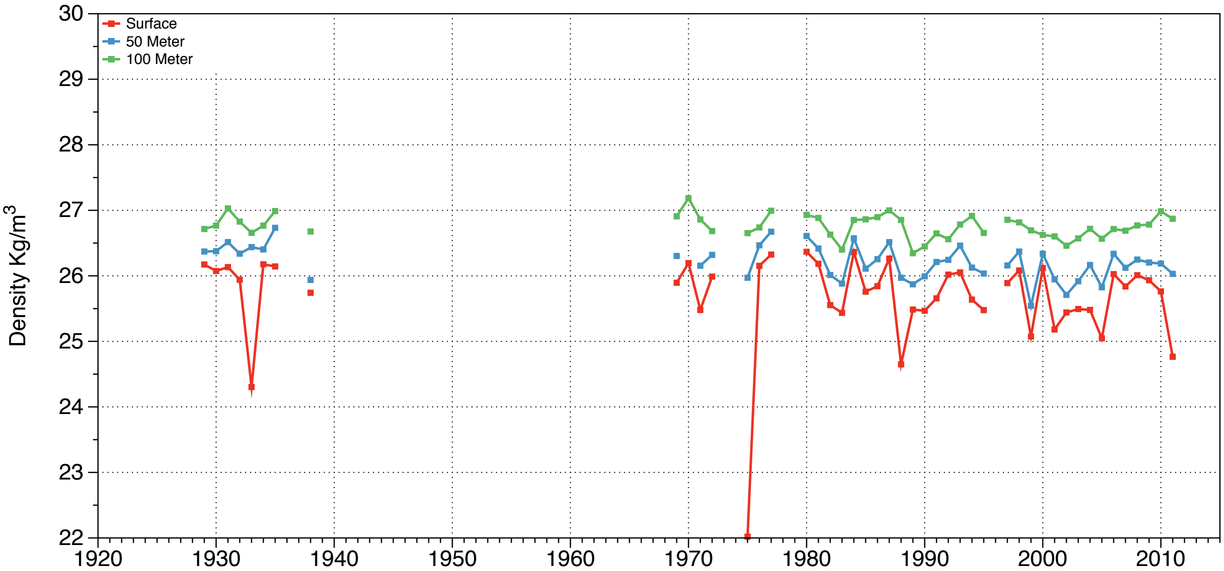


Figure 527: Interannual variability of density (November – December) at station Inner Balsfjorden

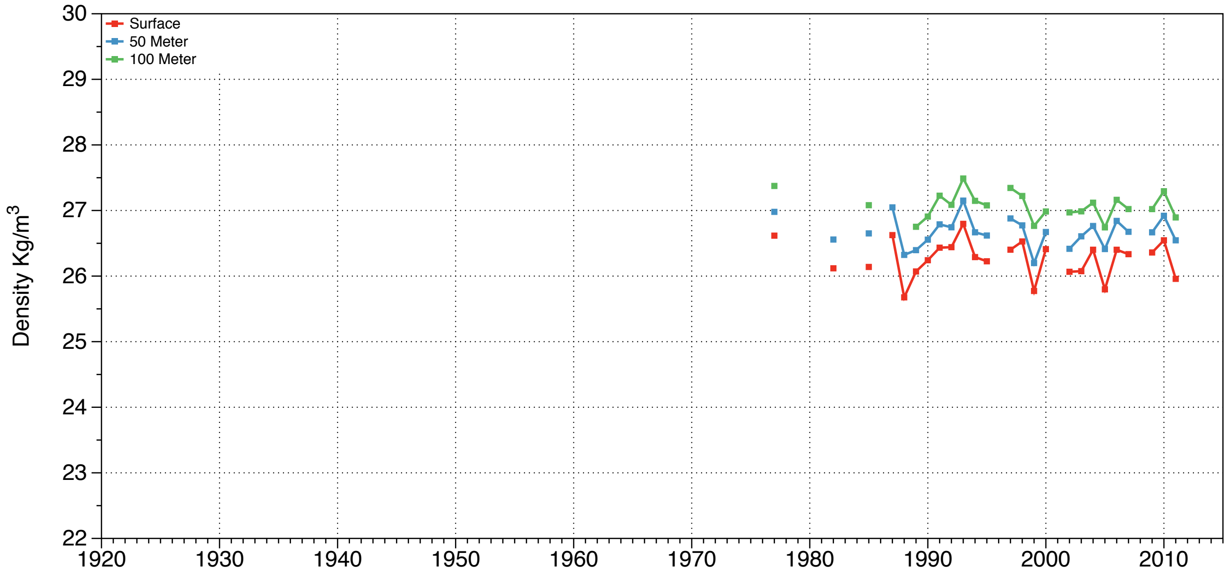


Figure 528: Interannual variability of density (November – December) at station Kvalsund

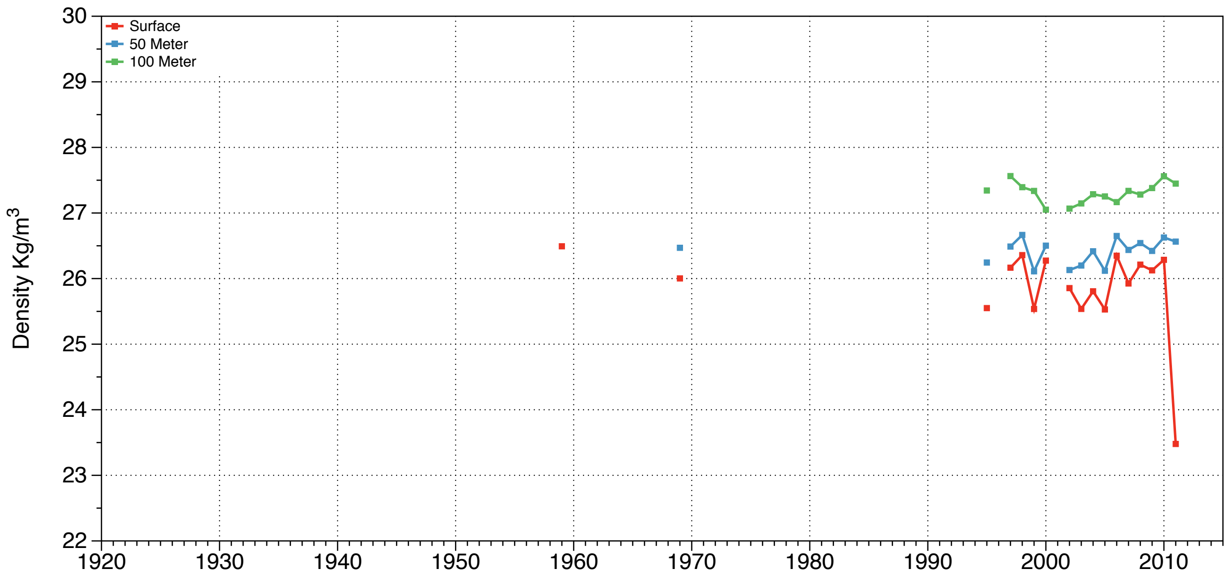


Figure 529: Interannual variability of density (November – December) at station Sørfjord

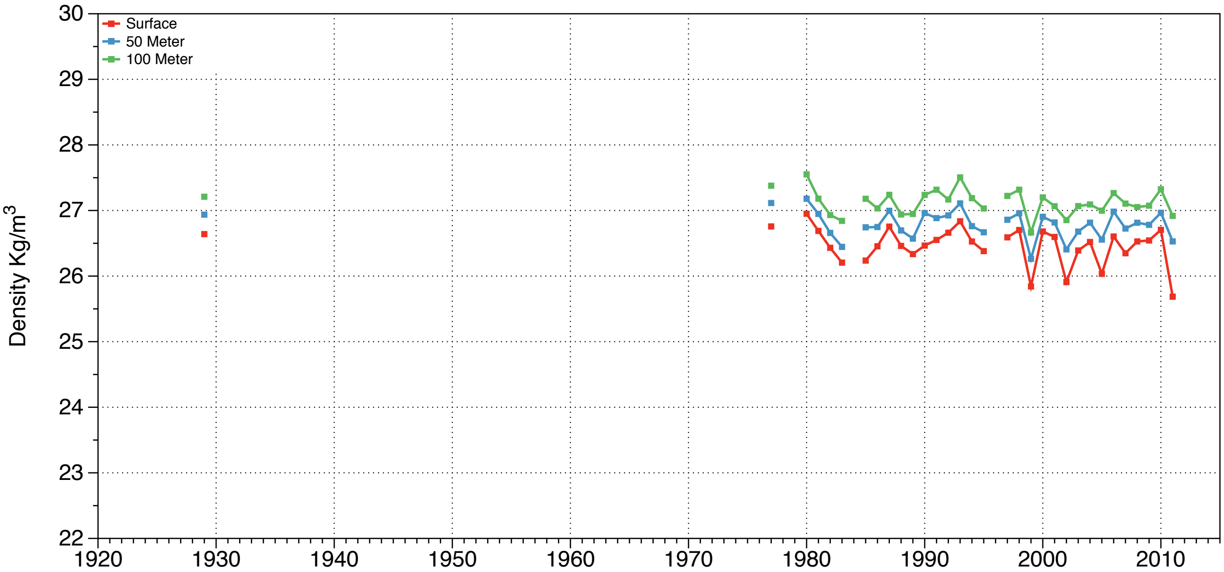


Figure 530: Interannual variability of density (November – December) at station Outer Altafjorden

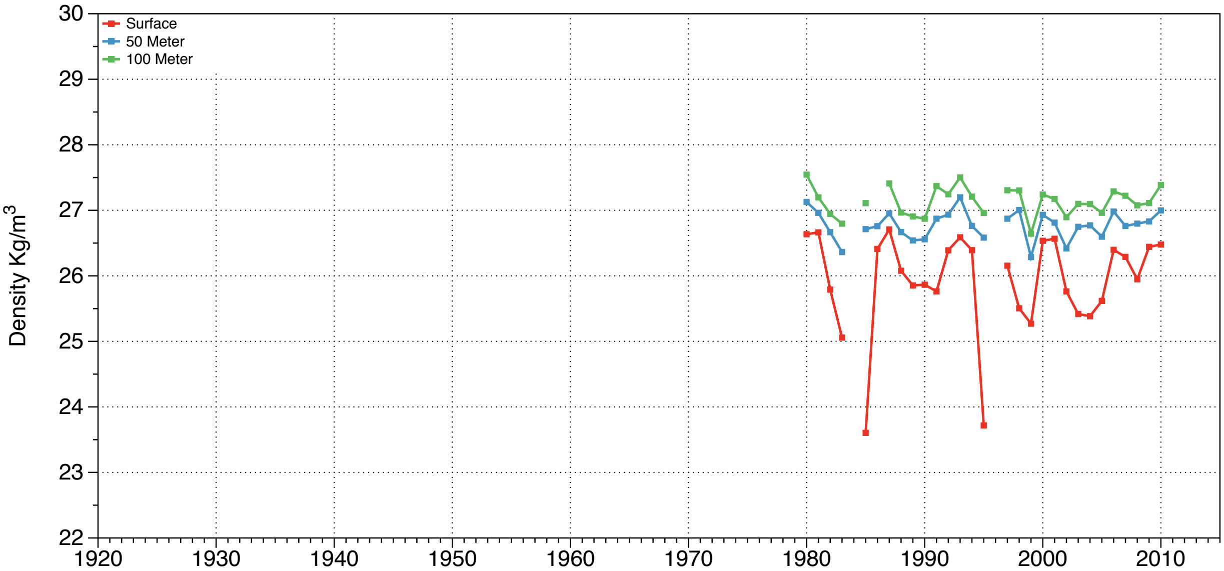


Figure 531: Interannual variability of density (November – December) at station Inner Altafjorden

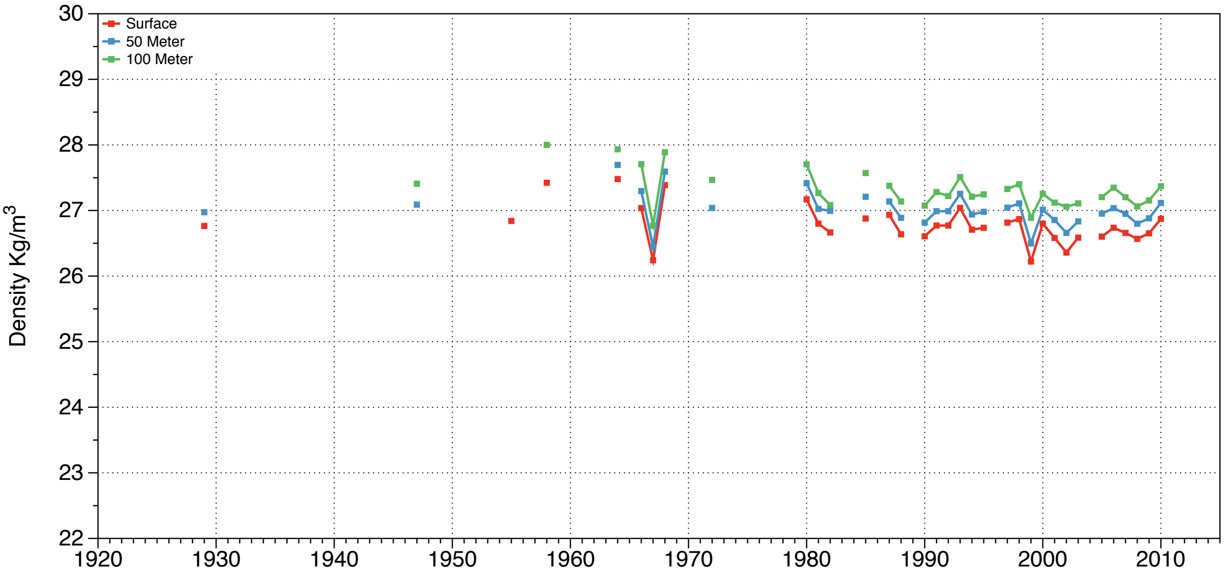


Figure 532: Interannual variability of density (November – December) at station Refsbotn

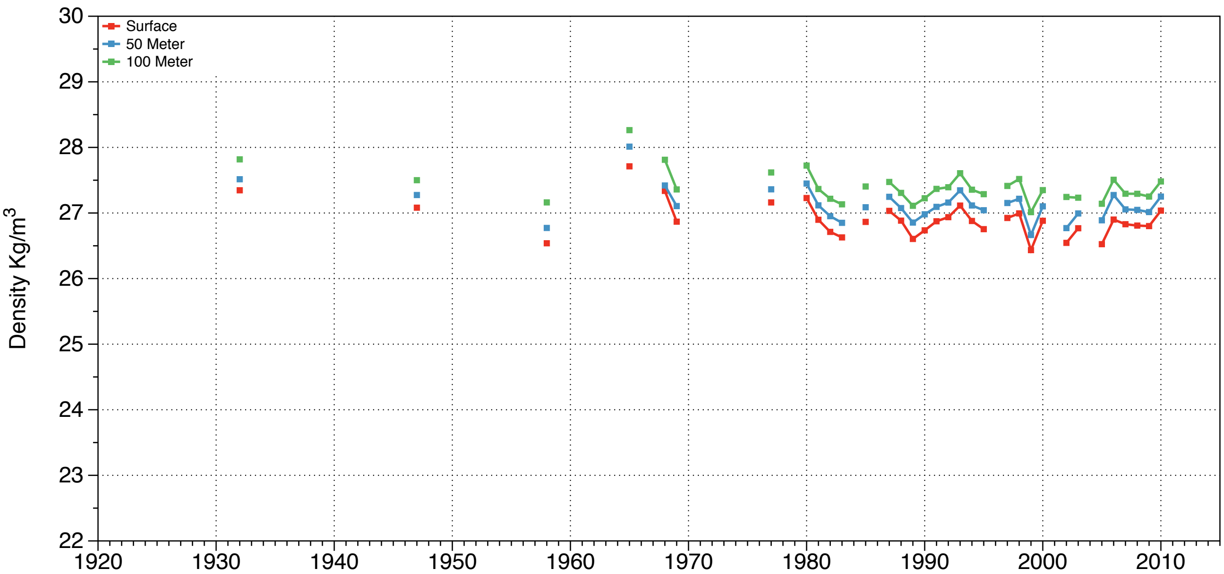


Figure 533: Interannual variability of density (November – December) at station Outer Porsangerfjorden

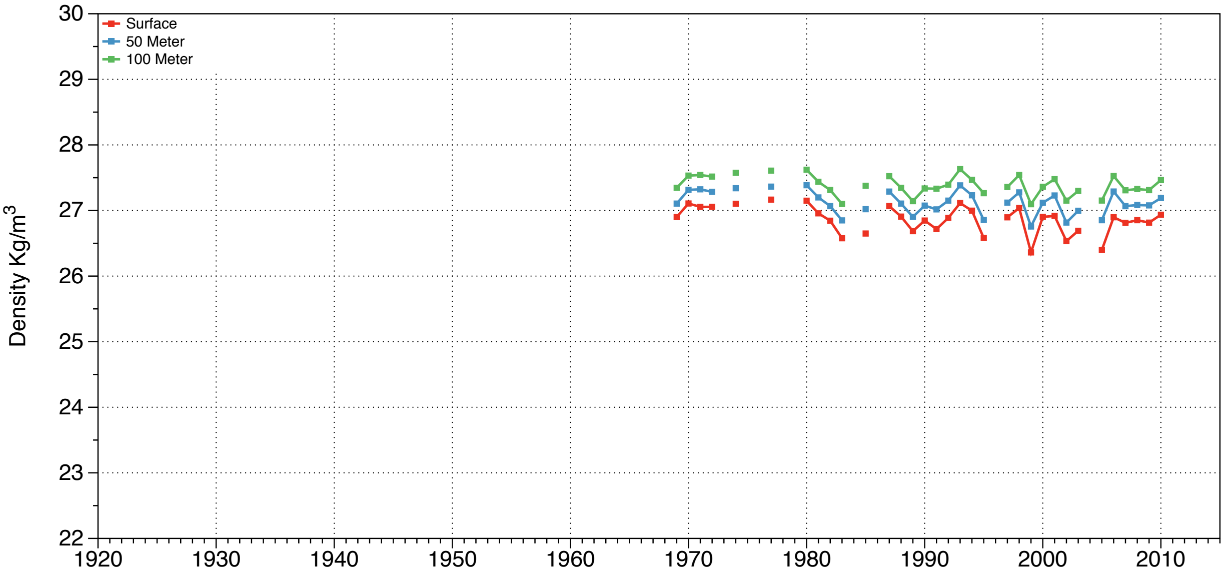


Figure 534: Interannual variability of density (November – December) at station Inner Porsangerfjorden

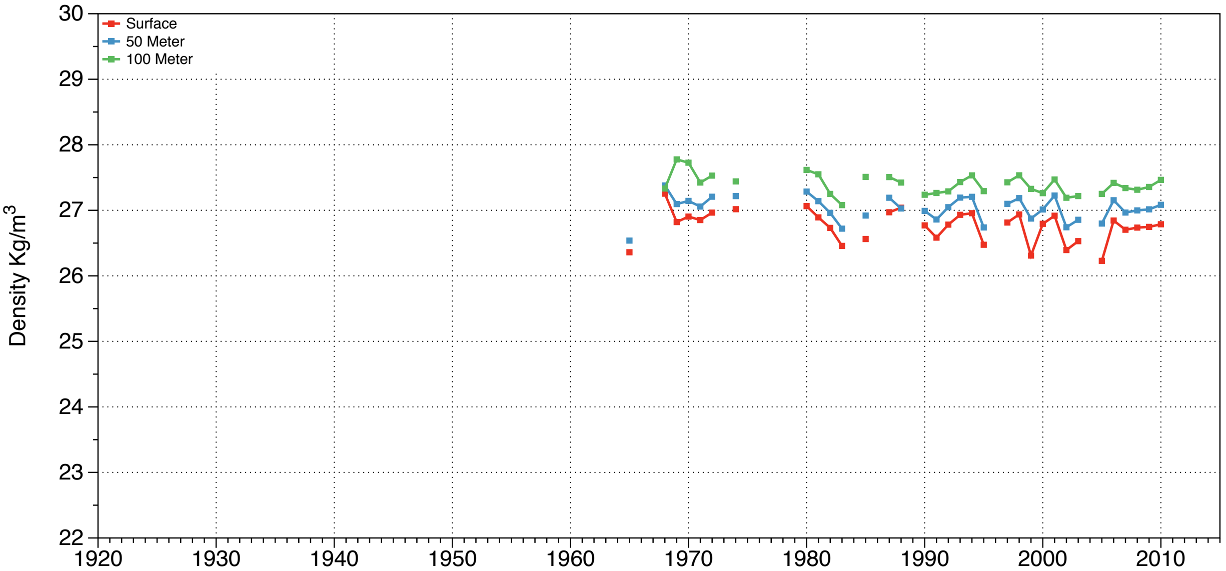


Figure 535: Interannual variability of density (November – December) at station Østerbotn

B

TABLES

B.1 COMPILATION OF HYDORGRAPHIC PROPERTIES (TWO MONTHS AVERAGE)

Table 27: Compilation of temperatures (January – February) at the sampled stations (°C)

Locality	Depth	Mean	Minimum	Coldest Year	Maximum	Warmest Year
Inner Malangen	0 m	3.5	-0.02	1992	6.19	2007
(1003–1004)	100 m	6.01	3.54	1987	7.81	2003
Outer Malangen	0 m	3.8	1.96	1986	5.48	2007
(1006–1007)	100 m	5.15	2.9	1899	7.61	2012
Outer Balsfjorden	0 m	2.55	-0.03	1982	4.43	2008
(2001–2002)	100 m	3.01	0.93	1982	5.01	2008
Inner Balsfjorden	0 m	2.12	-0.55	1988	4.29	2005
(2004–2005)	100 m	3.01	0.48	1987	5.41	2008
Outer Altafjorden	0 m	3.84	1.95	1980	5.54	2008
(7001–7002)	100 m	4.02	2.14	1980	6.09	2003
Inner Altafjorden	0 m	2.89	0.37	2001	4.82	2008
(7005–7006)	100 m	3.92	1.63	1982	6.06	2008
Outer Porsangerfjorden	0 m	3.99	1.29	1980	5.34	2007
(9001–9002)	100 m	3.87	0.97	1982	6.2	1933
Inner Porsangerfjorden	0 m	1.51	-1.61	1994	3.74	2007
(9007–9008)	100 m	1.73	-0.36	1982	3.76	2008
Østerbotn	0 m	-0.57	-1.79	1983	0.8	2008
(9009–9010)	100 m	-0.34	-1.13	2006	1	2007

Table 28: Compilation of temperatures (March – April) at the sampled stations (°C)

Locality	Depth	Mean	Minimum	Coldest Year	Maximum	Warmest Year
Inner Malangen	0 m	3.7	-1.23	1981	5.56	1990
(1003–1004)	100 m	5.42	3.32	1994	7.07	2012
Outer Malangen	0 m	3.42	-0.39	1968	6.12	1932
(1006–1007)	100 m	4.47	0.22	1989	6.63	1939
Outer Balsfjorden	0 m	2.41	0.05	1936	4.82	1990
(2001–2002)	100 m	2.76	0.89	1981	4.23	1992
Inner Balsfjorden	0 m	2.15	-1.01	1983	8.45	1934
(2004–2005)	100 m	2.41	0.33	1981	4.32	1934
Outer Altafjorden	0 m	2.79	1.02	1980	4.01	2007
(7001–7002)	100 m	3.21	1.42	1987	5.41	2010
Inner Altafjorden	0 m	2.28	-0.03	1987	4.51	1983
(7005–7006)	100 m	3.51	1.48	1998	5.95	2010
Outer Porsangerfjorden	0 m	3.05	0.23	1998	4.7	1959
(9001–9002)	100 m	3.15	1.24	1998	4.94	1959
Inner Porsangerfjorden	0 m	0.6	-1.44	1987	3.05	2012
(9007–9008)	100 m	0.8	-0.85	1987	2.24	2012
Østerbotn	0 m	-0.84	-1.77	1995	0.85	1990
(9009–9010)	100 m	-0.89	-1.75	2001	0.21	1992

Table 29: Compilation of temperatures (July – August) at the sampled stations (°C)

Locality	Depth	Mean	Minimum	Coldest Year	Maximum	Warmest Year
Inner Malangen	0 m	10.62	7.42	1981	15.28	1994
(1003–1004)	100 m	5.02	3.25	1981	6.12	1992
Outer Malangen	0 m	9.78	6.43	1935	16.3	1934
(1006–1007)	100 m	6.79	4.42	1940	9.2	1983
Outer Balsfjorden	0 m	9.47	4.34	1995	19	1934
(2001–2002)	100 m	3.27	1.5	1981	4.72	1992
Inner Balsfjorden	0 m	10.76	6.16	1926	19.2	1934
(2004–2005)	100 m	3.08	1.39	1981	4.53	1992
Outer Altafjorden	0 m	10.12	6.54	1993	14.86	1994
(7001–7002)	100 m	5.56	4.09	1939	6.7	1994
Inner Altafjorden	0 m	10.88	6.02	1993	16.25	1994
(7005–7006)	100 m	4.85	3.7	1980	5.99	1994
Outer Porsangerfjorden	0 m	9.1	6.6	1900	12.3	1931
(9001–9002)	100 m	6.11	3.97	1993	8.45	2006
Inner Porsangerfjorden	0 m	9.49	5.46	1939	12.64	1993
(9007–9008)	100 m	5.12	3.18	1993	7.33	1972
Østerbotn	0 m	9.51	5.99	1994	12.11	1994
(9009–9010)	100 m	0.35	-0.59	1986	4.32	1931

Table 30: Compilation of temperatures (November – December) at the sampled stations (°C)

Locality	Depth	Mean	Minimum	Coldest Year	Maximum	Warmest Year
Inner Malangen	0 m	5.86	1.08	2002	8.73	2006
(1003–1004)	100 m	7.62	6.08	1984	9.14	1999
Outer Malangen	0 m	6.32	3.33	1931	8.62	2011
(1006–1007)	100 m	7.46	5.47	1992	9.27	1999
Outer Balsfjorden	0 m	5.31	3.24	1986	7.63	2011
(2001–2002)	100 m	5.01	3.43	1988	6.43	2005
Inner Balsfjorden	0 m	5.07	2.96	1998	7.4	2005
(2004–2005)	100 m	4.65	2.8	1988	6.67	1933
Outer Altafjorden	0 m	6.02	3.99	1980	7.86	1999
(7001–7002)	100 m	6.79	4.89	1988	8.36	2009
Inner Altafjorden	0 m	7.08	2.2	1982	16.25	1994
(7005–7006)	100 m	5.99	3.7	1980	7.79	2005
Outer Porsangerfjorden	0 m	5.95	0.69	1961	7.55	1958
(9001–9002)	100 m	6.01	0.71	1961	8.1	1999
Inner Porsangerfjorden	0 m	4.5	2.01	1980	6.52	2005
(9007–9008)	100 m	5.08	2.63	1980	7.35	1999
Østerbotn	0 m	2.33	-1.74	1988	5.3	1999
(9009–9010)	100 m	1.9	-0.15	1971	3.6	1990

Table 31: Compilation of salinity (January – February) at the sampled stations (‰)

Locality	Depth	Mean	Minimum	Least saline Year	Maximum	Most saline Year
Inner Malangen	0 m	32.08	24.7	2007	34.11	2011
(1003–1004)	100 m	34.07	33.57	2000	34.64	1993
Outer Malangen	0 m	33.44	31.4	2007	34.52	1977
(1006–1007)	100 m	33.95	33.11	2000	34.52	1977
Outer Balsfjorden	0 m	32.99	31.05	2007	33.79	1994
(2001–2002)	100 m	33.23	32.63	2000	33.83	1994
Inner Balsfjorden	0 m	32.92	31.27	2007	33.71	1994
(2004–2005)	100 m	33.21	32.71	2000	33.8	1994
Outer Altafjorden	0 m	33.95	32.48	2007	34.48	1994
(7001–7002)	100 m	34	33.48	2000	34.47	1994
Inner Altafjorden	0 m	33.46	10.79	2009	36.23	1988
(7005–7006)	100 m	34.02	33.46	2000	34.56	2009
Outer Porsangerfjorden	0 m	34.24	31.95	2006	34.75	1995
(9001–9002)	100 m	34.27	33.84	2000	34.95	1981
Inner Porsangerfjorden	0 m	34.06	31.39	2007	34.49	1994
(9007–9008)	100 m	34.1	33.74	1980	34.46	1994
Østerbotn	0 m	33.57	29.87	2007	34.83	2005
(9009–9010)	100 m	33.66	33.34	2003	34.49	1962

Table 32: Compilation of salinity (March – April) at the sampled stations (‰)

Locality	Depth	Mean	Minimum	Least saline Year	Maximum	Most saline Year
Inner Malangen	0 m	32.4	21.38	1981	34.3	2004
(1003–1004)	100 m	34.26	33.79	1996	34.55	1980
Outer Malangen	0 m	33.56	23.5	1968	34.7	1960
(1006–1007)	100 m	34.15	33.58	1933	34.92	1960
Outer Balsfjorden	0 m	32.62	17.96	1994	33.91	2010
(2001–2002)	100 m	32.97	18.1	1994	33.88	2010
Inner Balsfjorden	0 m	32.75	11.38	1931	35.11	1933
(2004–2005)	100 m	33.19	20.89	1994	35.22	1933
Outer Altafjorden	0 m	34.03	33.45	1989	34.52	1994
(7001–7002)	100 m	34.18	33.85	2012	34.72	2010
Inner Altafjorden	0 m	33.58	20.85	1995	34.46	1994
(7005–7006)	100 m	34.25	33.76	2012	34.82	2010
Outer Porsangerfjorden	0 m	34.33	33.35	2003	34.98	1981
(9001–9002)	100 m	34.4	33.94	1989	35.01	1938
Inner Porsangerfjorden	0 m	34.1	33.58	2003	34.6	1994
(9007–9008)	100 m	34.17	33.87	1989	34.65	1994
Østerbotn	0 m	33.71	33.36	1992	34.11	1960
(9009–9010)	100 m	33.78	33.54	1989	34.29	1960

Table 33: Compilation of salinity (July – August) at the sampled stations (‰)

Locality	Depth	Mean	Minimum	Least saline Year	Maximum	Most saline Year
Inner Malangen	0 m	26.47	8.73	1928	32.76	2006
(1003–1004)	100 m	34.02	33.66	1994	34.46	2012
Outer Malangen	0 m	31.54	10.75	1934	34.07	1955
(1006–1007)	100 m	34.39	33.92	1983	34.94	1985
Outer Balsfjorden	0 m	30.51	20.66	2006	33.18	1944
(2001–2002)	100 m	33.44	33.14	1992	33.67	1994
Inner Balsfjorden	0 m	28.59	13.17	1932	32.85	2006
(2004–2005)	100 m	33.48	33.16	1992	34.22	1970
Outer Altafjorden	0 m	31.33	25.82	2006	34.41	1980
(7001–7002)	100 m	34.19	33.88	1992	34.52	1993
Inner Altafjorden	0 m	28.7	9.33	1994	33.45	1980
(7005–7006)	100 m	34.08	33.67	1992	34.54	1944
Outer Porsangerfjorden	0 m	33.61	30.56	1993	34.46	1956
(9001–9002)	100 m	34.42	34.16	1992	34.94	1957
Inner Porsangerfjorden	0 m	31.73	23.82	1993	33.57	1994
(9007–9008)	100 m	34.19	33.99	1980	34.48	1994
Østerbotn	0 m	30.9	25.74	1993	33.24	1994
(9009–9010)	100 m	33.94	33.64	1990	34.33	1980

Table 34: Compilation of salinity (November – December) at the sampled stations (‰)

Locality	Depth	Mean	Minimum	Least saline Year	Maximum	Most saline Year
Inner Malangen	0 m	31.78	21.49	2003	33.92	1987
(1003–1004)	100 m	33.97	33.24	1999	34.69	1959
Outer Malangen	0 m	33.06	27.66	1988	34.23	1957
(1006–1007)	100 m	33.89	33.19	1999	34.67	1997
Outer Balsfjorden	0 m	32.53	27.49	1999	33.43	1977
(2001–2002)	100 m	33.16	32.56	1983	33.47	2010
Inner Balsfjorden	0 m	32.47	23.42	1975	33.33	1931
(2004–2005)	100 m	33.2	32.74	1989	33.68	1970
Outer Altafjorden	0 m	33.61	31.87	2002	34.86	1990
(7001–7002)	100 m	34.02	33.34	1999	35.06	1990
Inner Altafjorden	0 m	32.2	9.33	1994	34.09	2006
(7005–7006)	100 m	33.99	33.41	1999	34.39	2010
Outer Porsangerfjorden	0 m	34.07	32.39	2005	34.88	1965
(9001–9002)	100 m	34.17	33.72	2002	34.97	1965
Inner Porsangerfjorden	0 m	33.83	31.52	2005	34.35	1970
(9007–9008)	100 m	34.05	33.69	1983	34.42	1993
Østerbotn	0 m	33.36	31.41	2005	34.67	1988
(9009–9010)	100 m	33.64	33.27	2002	34.14	1970

Table 35: Compilation of density (January – February) at the sampled stations (Kg/m^3)

Locality	Depth	Mean	Minimum	Least dens Year	Maximum	Most dens Year
Inner Malangen	0 m	25.51	19.54	2007	27.07	1981
(1003–1004)	100 m	27.28	26.73	2000	27.72	1993
Outer Malangen	0 m	26.57	24.88	2007	27.3	1977
(1006–1007)	100 m	27.28	26.59	2000	27.74	1977
Outer Balsfjorden	0 m	26.33	24.74	2007	27	1994
(2001–2002)	100 m	26.93	26.32	2000	27.52	1994
Inner Balsfjorden	0 m	26.3	24.89	2007	26.93	1994
(2004–2005)	100 m	26.92	26.38	2000	27.51	1994
Outer Altafjorden	0 m	26.98	25.76	2007	27.44	1994
(7001–7002)	100 m	27.45	26.91	2000	27.9	1994
Inner Altafjorden	0 m	26.67	8.57	2009	29.08	1988
(7005–7006)	100 m	27.47	26.96	2000	27.89	1994
Outer Porsangerfjorden	0 m	27.19	25.3	2006	27.57	1994
(9001–9002)	100 m	27.68	27.16	2000	28.21	1981
Inner Porsangerfjorden	0 m	27.26	25.12	2007	27.68	1994
(9007–9008)	100 m	27.74	27.39	2000	28.14	1994
Østerbotn	0 m	26.99	23.94	2007	28.03	2005
(9009–9010)	100 m	27.5	27.28	2000	27.72	2007

Table 36: Compilation of density (March – April) at the sampled stations (Kg/m^3)

Locality	Depth	Mean	Minimum	Least dens Year	Maximum	Most dens Year
Inner Malangen	0 m	25.75	17.09	1981	27.1	2004
(1003–1004)	100 m	27.5	27.29	1996	27.77	1980
Outer Malangen	0 m	26.71	18.84	1968	27.47	1970
(1006–1007)	100 m	27.51	27.16	1989	28.32	1969
Outer Balsfjorden	0 m	26.04	14.36	1994	27.02	1936
(2001–2002)	100 m	26.75	14.96	1994	27.55	1994
Inner Balsfjorden	0 m	26.16	9.09	1931	28.04	1933
(2004–2005)	100 m	26.95	17.19	1994	28.61	1933
Outer Altafjorden	0 m	27.14	26.71	1990	27.51	1994
(7001–7002)	100 m	27.67	27.4	2012	27.96	1994
Inner Altafjorden	0 m	26.82	16.66	1995	27.55	1994
(7005–7006)	100 m	27.7	27.4	2012	28	1994
Outer Porsangerfjorden	0 m	27.36	26.65	2003	27.79	1986
(9001–9002)	100 m	27.85	27.51	1989	28.21	1956
Inner Porsangerfjorden	0 m	27.36	26.95	2003	27.79	1994
(9007–9008)	100 m	27.86	27.6	1989	28.26	1994
Østerbotn	0 m	27.11	26.79	1992	27.44	2007
(9009–9010)	100 m	27.64	27.47	1989	28.08	1960

Table 37: Compilation of density (July – August) at the sampled stations (Kg/m^3)

Locality	Depth	Mean	Minimum	Least dens Year	Maximum	Most dens Year
Inner Malangen	0 m	20.21	6.36	1928	25.31	1998
(1003–1004)	100 m	27.36	27.06	1992	27.57	2012
Outer Malangen	0 m	24.29	7.12	1934	26.62	1955
(1006–1007)	100 m	27.42	26.69	1983	27.92	1985
Outer Balsfjorden	0 m	23.53	14.87	1934	26.06	1944
(2001–2002)	100 m	27.07	26.7	1992	27.35	1994
Inner Balsfjorden	0 m	21.83	8.79	1934	25.58	2006
(2004–2005)	100 m	27.13	26.73	1992	27.77	1970
Outer Altafjorden	0 m	24.07	19.45	2006	26.66	1980
(7001–7002)	100 m	27.43	27.08	1992	27.73	1993
Inner Altafjorden	0 m	21.9	6.05	1994	25.87	1980
(7005–7006)	100 m	27.43	26.98	1992	27.77	1993
Outer Porsangerfjorden	0 m	26.01	23.51	1993	26.93	1900
(9001–9002)	100 m	27.54	27.09	1994	27.98	1987
Inner Porsangerfjorden	0 m	24.49	18.19	1993	26.06	1994
(9007–9008)	100 m	27.47	27.22	1994	27.72	1931
Østerbotn	0 m	23.84	19.69	1993	26.18	1994
(9009–9010)	100 m	27.7	27.42	1990	28.02	1994

Table 38: Compilation of density (November – December) at the sampled stations (Kg/m^3)

Locality	Depth	Mean	Minimum	Least dens Year	Maximum	Most dens Year
Inner Malangen	0 m	25.03	17.11	2003	26.73	1987
(1003–1004)	100 m	26.97	26.17	1999	27.46	1959
Outer Malangen	0 m	25.99	21.93	1988	26.81	1957
(1006–1007)	100 m	26.94	26.15	1999	27.55	1997
Outer Balsfjorden	0 m	25.69	21.69	1999	26.44	1977
(2001–2002)	100 m	26.67	26.2	1983	27.01	1980
Inner Balsfjorden	0 m	25.67	18.62	1975	26.48	1931
(2004–2005)	100 m	26.75	26.35	1989	27.18	1970
Outer Altafjorden	0 m	26.46	25.18	1999	27.38	1990
(7001–7002)	100 m	27.13	26.6	1999	27.95	1990
Inner Altafjorden	0 m	25.18	6.05	1994	26.88	1998
(7005–7006)	100 m	27.21	26.63	1999	27.59	1980
Outer Porsangerfjorden	0 m	26.83	25.49	2005	27.71	1965
(9001–9002)	100 m	27.35	26.87	1999	28.26	1965
Inner Porsangerfjorden	0 m	26.81	25	2005	27.25	1970
(9007–9008)	100 m	27.37	26.94	1999	27.67	1998
Østerbotn	0 m	26.63	25.04	2005	27.91	1988
(9009–9010)	100 m	27.35	27.02	1983	27.81	1970

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