Western Norway University of Applied Sciences

# BACHELOR'S ASSIGNMENT

# Sequences of basin water exchanges in the Outer and Inner Barsnesfjord

**BSc. Environmental Protection/Engineering**

**GE491**

**01.06.2017**

**Number of words 14.166**

**Candidate number 231**

**Kim-Alana Holz**

**Internal supervisor Torbjørn Dale**

**and external supervisor Matthias Paetzel**

Fachbereich 1 - Life Sciences and Engineering

Studiengang Umweltschutz

# Sequences of basin water exchanges in the Outer and Inner Barsnesfjord

Bachelorarbeit

vorgelegt am 01.06.2017

von

**Holz, Kim-Alana**

Matrikel-Nr. 198892

durchgeführt am Western Norway University College

Abgabedatum: 01.06.2017

abgeben bei: Prof. Dr. Elke Hietel

Arbeit angenommen:

Bingen, den ..........................................................

Betreuer (TH): Prof. Dr. Elke Hietel

Betreuer (extern): Associated Prof. Torbjørn Dale, Lars G. Golmen, Associated Prof. Dr. Matthias Paetzel (In alphabetischer Reihenfolge)

Eidesstattliche Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Abschlussarbeit

**„Sequences of basin water exchanges in the Outer and Inner Barsnesfjord"**

selbstständig und ohne fremde Hilfe angefertigt habe. Ich habe dabei nur die in der Arbeit angegebenen Quellen und Hilfsmittel benutzt. Die Arbeit wurde in gleicher oder ähnlicher Form noch keiner anderen Prüfung vorgelegt und auch noch nicht veröffentlicht.

Ort, Datum Unterschrift

## List of Contents

## List of Figures

## List of Tables

## Abstract

Four hydrographical data sets of recent periods (1984-2016) are used to analyze the exchange processes of the basin water of the Inner and Outer Barsnesfjord in Western Norway. The basins are periodically anoxic. The data from the Barsnesfjord will be compared to the data from the Sogndalsfjord, because they are connected, to identify the water that is flowing in and renewing the water in the Barsnesfjord.

This thesis deals with analysis of hydrographical changes in Barsnesfjord and Sogndalsfjord with a prime focus on the parameters oxygen, density, and turbidity. In the Barsnesfjord water bodies, the data from the deeper parts (basin water) are of matter since the aim of this investigation is it to determine the sequence of deep/basin water exchanges.

A gradual or sudden increase in the basin water of the oxygen concentrations as well as an increase in density, salinity values and changes in temperature and/or turbidity are signs for water exchanges. Such exchanges were discernable in three of the four data sets in the Barsnesfjord. Major inflow events to the Barsnesfjord happened in winter time in January/February in the years 1984, 1991 and 2014 but also between late March and late April of 1993. Another basin water exchange happened between October and November in 1984 in the Outer Barsnesfjord. But this was only a partial water exchange since the inflowing water only renewed water at 30 m depth. Major inflow events to the Sogndalsfjord were observed in summer time (June to August) in 1984 and 1991.

It should be mentioned that the focus in this thesis is on the parameter oxygen since it usually shows inflow events with an increase of values. During a basin water exchange in the Outer Barsnesfjord in winter time of 2014, the oxygen concentration in the basin water increased from 1,2 mg/l to 6,51 mg/l due to an inflow of new water from the Sogndalsfjord. During a basin water exchange in the Inner Barsnesfjord in winter time 2014, the oxygen concentration increased from 0,09 mg/l to 5,92 mg/l at the depth of 60 m. In the Outer Barsnesfjord in 2014 however, a second inflow was not revealed by the oxygen concentrations. The density values revealed that there was another inflow or a continuation of a previous inflow.

In addition to the determination of a succession of basin water exchange, it is also investigated how deep the renewing water will sink in the water column. Not always is the whole water column renewed, sometimes there is only a partial renewal of fjord water. The investigation showed that in some cases, water from the Sogndalsfjord only renewed water in the Outer Barsnesfjord at the depth of 30 m. This happened in 1984 as well as in the 2013 to 2014 period.

Important for the basin water exchanges between the Sogndalsfjord and the Barsnesfjord is the sound at Loftesnes (7,5 m depth) because the water has to go over the sill to get into the Barsnesfjord. A new bridge is being built there, which includes rockfills and two new pillars on the sound. It was concluded that if there are changes in the water exchange, they most probably will be positive since the removing of old bridge parts will increase the water exchange.

## Zusammenfassung

Vier hydrographische Datensätze der letzten Perioden (1984-2016) werden verwendet, um die Wasseraustauschprozesse der Becken des Inneren und Äußeren Barsnesfjords in West-Norwegen zu analysieren. Die Becken sind periodisch anoxisch. Die Daten aus dem Barsnesfjord werden mit den Daten des Sogndalsfjords verglichen, weil diese miteinander verbunden sind, um das Wasser, welches in den Barsnesfjord fließt und dieses erneuert, erkennen zu können.

Diese Arbeit beschäftigt sich mit der Analyse der hydrographischen Veränderungen im Barsnesfjord und Sogndalsfjord mit einem Schwerpunkt auf den Parametern Sauerstoff, Dichte und Trübung. Im Barsnesfjord sind die Daten aus den tieferen Schichten (Beckenwasser) von Bedeutung, da das Ziel dieser Untersuchung darin besteht, den Ablauf der Wasseraustausche in den Becken zu bestimmen.

Eine allmähliche oder plötzliche Zunahme der Sauerstoffkonzentrationen im Beckenwasser sowie eine Erhöhung der Dichte, Salzgehalte und Temperatur- und/oder Trübungsänderungen sind Anzeichen für einen Wasseraustausch. Solche Austausche waren in drei der vier Datensätze im Barsnesfjord erkennbar. Im Januar/Februar gab es in den Jahren 1984, 1991 und 2014, aber auch zwischen Ende März und Ende April 1993 einen deutlichen Wasseraustausch im Barsnesfjord. Ein weiter Wasseraustausch im Becken des Äußeren Barsnesfjord fand zwischen Oktober und November 1984 statt. Dieser Wasseraustausch erneuerte allerdings nicht das gesamte Wasser im Becken, sondern nur das Wasser in einer Tiefe von 30 m. Im Sommer 1984 und 1991 (Juni bis August) wurden deutliche Wasserzuflüsse zum Sogndalsfjords beobachtet.

Es sollte erwähnt werden, dass der Schwerpunkt in dieser Arbeit auf dem Parameter Sauerstoff liegt, da er in der Regel Zufluss Ereignisse mit zunehmenden Konzentrationen anzeigt. Während eines Wasseraustausches im Äußeren Barsnesfjord im Winter 2014, stiegen die Sauerstoffkonzentrationen im Becken von 1,2 mg/l auf 6,51 mg/l aufgrund eines Einfließen von neuem Wasser aus dem Sogndalsfjord. Während eines Wasseraustausches im Inneren Barsnesfjord im Winter 2014, stiegen die Sauerstoffkonzentrationen von 0,09 mg/l auf 5,92 mg/l in einer Tiefe von 60 m. Im Äußeren

Barsnesfjord im Jahr 2014 wurde jedoch ein zweiter Zustrom nicht durch die Sauerstoffkonzentration aufgedeckt. Die Dichtewerte hingegen zeigten, dass es einen weiteren Zufluss bzw. eine Fortsetzung eines vorherigen Zuflusses gab.

Neben der Bestimmung einer Abfolge des Beckenwasseraustausches wird auch untersucht, wie tief das erneuernde Wasser in der Wassersäule sinken wird. Nicht immer ist das gesamte Wasser im Becken erneuert, manchmal gibt es nur eine teilweise Erneuerung des Fjordwassers. Die Untersuchung ergab, dass in manchen Fällen das Wasser aus dem Sogndalsfjord nur das Wasser im Äußeren Barsnesfjord in der Tiefe von 30 m erneuert hat. Dies geschah im Jahre 1984 sowie in der Zeit von 2013 bis 2014.

Wichtig für den Wasseraustausch zwischen dem Sogndalsfjord und dem Barsnesfjord ist der Sund bei Loftesnes, denn das Wasser muss über die 7,5 m tiefe Schwelle, um in den Barsnesfjord zu gelangen. An dieser Stelle wird eine neue Brücke gebaut, die Felsaufschüttungen sowie zwei neue Pfeiler auf dem Sund beinhaltet.

Schlussfolgernd lässt sich sagen, dass falls es Veränderungen beim Wasseraustausch durch die neue Brücke geben wird, diese höchst wahrscheinlich positiv sein werden, weil das Entfernen der Pfeiler der alten Brücke den Wasseraustausch verbessern wird.

## Acknowledgement

I want to thank my supervisors Prof. Torbjørn Dale and Prof. Dr. Matthias Paetzel for dedicating a vast amount of time and for supporting me every step of the way. Their willingness to help with every problem no matter how big or small is rare and inspirational to experience. Especially the encouragement, motivation and positive energy of Torbjørn Dale made working on this thesis a pleasant journey. One could not wish for better or more friendly supervisors. Furthermore, I want to thank the Western Norway University of Applied Sciences for giving me the opportunity to write my thesis here. A special thank you to Luuk Lafeber for sacrificing his valuable time for me and helping me with various difficulties with greatest patience. Besides that, I would like to thank Prof. Dr. Elke Hietel for being my supervisor at the University of Applied Sciences in Bingen.

# 1. Introduction

Much is known about the hydrography of the Barsnesfjord (Hovgaard, 1985; Dale & Hovgaard, 1993; Kaufmann, 2014; Reß, 2015) but it lacks information about what happens exactly when water from the Sogndalsfjord spills over the sill and enters the Barsnesfjord. To investigate this topic, the parameters oxygen, density, salinity, temperature and turbidity will be analyzed. They will show when an inflow into the Barsnesfjord happens and how the water distributes in the basin, e.g. if it goes to the very bottom of the basin or just below sill depth, e.g. 30 m deep etc. The provided data is collected during several measurements in the years 1984-1985 (Hovgaard, 1985) and 1990-1993 (Dale & Hovgaard, 1993). The data from 2013-2014 and 2016 are based on previously unpublished results. The amounts and reliability of measurements vary for the different time periods.

A previous bachelor thesis (Kaufmann, 2014) made a hydrographical record of the Barsnesfjord over the years from 1916 to 2013. It investigated oxygen, temperature and salinity data and found out that throughout this period, the concentration in oxygen as well as the salinity value decrease in the whole water column. The temperatures in the water column, except for the 0 m layer, also increased during this period.

An inflow sequence was made which stated that the frequency of an inflow decreased throughout the investigated 97 years. An inflow happened between 1916 and 1956 every year or every second year whereas during the last period between 2002 and 2013 it only occurred every third year.

Located between the Sogndalsfjord and the Outer Barsnesfjord is a bridge, the Loftesnes bridge. In connection with the building of the new Loftesnes bridge that is currently in construction, several reports have been done.

Two reports were published investigating the hydrography in the Barsnesfjord (Golmen et al., 2003; Golmen et al., 2010). They analyzed possible effects on the currents on the Loftesnes sound if a new bridge was constructed. The report from 2003 implied that a reduction in the cross section of the sound at Loftesnes might change the water exchange and the water quality. The 2010 report revealed that the water exchange should not be affected significantly by the new bridge. It even went so far to project an improvement of water exchange since the pillars of the old bridge will be removed.

There was an investigation on the environmental conditions of the Barsnesfjord including the hydrography (Myrseth et al., 2000). It was determined that the deep water in the basins of the Barsnesfjord only contained $H_2S$ and no oxygen and that no living animals were found.

A bachelor thesis investigated the effects of the new Loftesnes bridge on a mudflat in the Outer Barsnesfjord (Venneman, 2014). It also mentioned the increasing narrowness of the inlet, due to the new bridge and its new pillars, which may lead to a decreasing possibility of inflows into the Barsnesfjord (Torbjørn Dale, 2017, *personal communication*).

This thesis will take a closer look to the inflows itself and will analyze when, how and why an inflow into the basins of the Barsnesfjord happens. Depending on the provided data, it will be analyzed not only in what year but also in what month and maybe even week an inflow happens, and if the inflow into a basin happens during the same time in a different period/year. The depth distribution of inflowing water will be investigated and will show that not always the whole water column is replaced with new water. In addition to that, the connection between a variation of inflow events and climate change will be mentioned as well as the effects of said Loftesnes bridge on the inflow events.

# 2. Objectives

The previously mentioned topics conclude to the following main research questions that this thesis will attempt to answer:

1. When does basin water exchange happen in the Outer and Inner Barsnesfjord in the years 1984-1985, 1990-1993, 2013-2014 and 2016?
2. How is the inflow sequence to Outer and Inner Barsnesfjord?
3. The inflow of water into the basin (basin water exchange) of the Barsnesfjord comes from water of the Sogndalsfjord flowing over the sill at Loftesnes. What are the density conditions in the water of the Sogndalsfjord and Barsnesfjord when an inflow happens?
4. Can variations in the water inflow be related to environmental change?
5. How may the new bridge at Loftesnes effect the basin water exchanges?

## 2.1. Objective explanation

### 1. When does basin water exchange happen in the Outer and Inner Barsnesfjord in the years 1984-1985, 1990-1993, 2013-2014 and 2016?

With the provided data sets, an analysis will be made of variations in oxygen concentrations in the basin water of the Barsnesfjord water during the past 30 years. A visualization of the data with graphs and isopleth diagrams will illustrate the basin water exchanges. Since a sudden or gradual increase in oxygen concentrations in the basin water is one sign of a water exchange, this will be used as the prime indicator. But other parameters like density, salinity, temperature and turbidity will be used as well to find out if the oxygen data is supported by these parameters and if they show the same basin water exchange signals, like a sudden increase or decrease.

### 2. How is the inflow sequence to Outer and Inner Barsnesfjord?

This thesis will find out how the inflow into the basins of the Barsnesfjord happens. In addition, it will be investigated if with every inflow, the whole water column is replaced or if there is just a partial replacement.

### 3. The inflow of water into the basins (basin water exchange) of the Barsnesfjord comes from water of the Sogndalsfjord flowing over the sill at Loftesnes. What are the density conditions in the water of the Sogndalsfjord and Barsnesfjord when an inflow happens?

The density values are a distinct indicator for a water exchange because it is high density water from a neighboring fjord that is replacing low density water in the basin of another fjord. Therefore, the density is the driving force that makes an inflow possible and an interesting parameter since it can also detect inflow events.

### 4. Can variations in the water inflow be related to environmental change?

The frequency and intensity of water inflow to the Barsnesfjord might have changed over time. Potential reasons for a change as well as possible effects of wind and upwelling will be discussed.

### 5. How may the new bridge at Loftesnes effect the basin water exchanges?

Since the water that flows into the basin of the Outer Barsnesfjord must pass the sill at Loftesnes, the construction of the new bridge may influence inflow events. A possible landfill and the pillars of the bridge narrow the inflow area which possibly makes it harder for water to spill over and therefore less likely for an inflow to happen.

# 3. Environmental Setting

## 3.1. Fjord morphology

A fjord is a semi-enclosed waterbody (Sætre, 2007) that is formed through glacial movements. A glacier is a frozen body of water (ice) moved by gravitational forces, existing due to an annual net accumulation of snow. Erosional activity of moving glaciers carves U-shaped valleys into former river valleys during a succession of glaciations, eventually over-deepening these valleys below sea-level. How deep the glacier can carve depends mainly on the velocity and dimension of the ice. Thick ice and a high velocity are the optimum conditions for a high erosion of material and therefore a deep valley. The fjords valley is then filled with mainly seawater as it is connected to the sea. The Scandinavian fjord formation started during the Quaternary, ca. 2,57 million years before present (Fjords.com, 2017).

Many fjords have submarine sills (Perillo, 1996) that are located at the mouth of the fjord or within its main arm, or where narrow tributaries meet broader parts of the fjord. Behind the sills there are the basins of the fjord. These sills can be made of moraine deposits, they might be of glacial-marine nature, or they might consist of bedrock (Perillo, 1996). The sill at Loftesnes however consists of silt, sand and gravel (Dale T. , 2015).

## 3.2. Fjord hydrography

### 3.2.1. Surface water/ fresh water/ brackish water

The water masses of a silled fjord are stratified in different layers, defined by their densities. On top is the low-density surface layer that either consist of freshwater, from river and/or precipitation, or is a mixture of freshwater and salt water, called brackish water, depending on the freshwater input (Sætre, 2007). The water masses mix through winds and tides (Stigebrandt, 1981). In winter time the fresh water layer is almost gone due to the low runoff from rivers.

The surface layer is flowing outwards to the coast (Figure 1). That outflow generates an inflowing compensation current. These two current systems are called estuarine circulation (Sætre, 2007).

That water in the surface is characterized with the lowest density and fluctuating but generally high oxygen, temperature and salinity values. The surface layer is strongly influenced by the sun's radiation and by wind.

Another surface water exchange is the locally wind-driven exchange. It does not have a great influence on the exchange of coast and fjord water but it contributes to the mixing of the surface layer of a fjord. When wind blows, it pushes the water in the wind direction and sometimes also a little to the right. That water is blown away and needs to be replaced. Water is coming from greater depth upwards as a replacement. As said, this process only influences the surface layer, therefore at water depths of 10-20 m, there is no signal of wind-driven exchange present (Sætre, 2007).

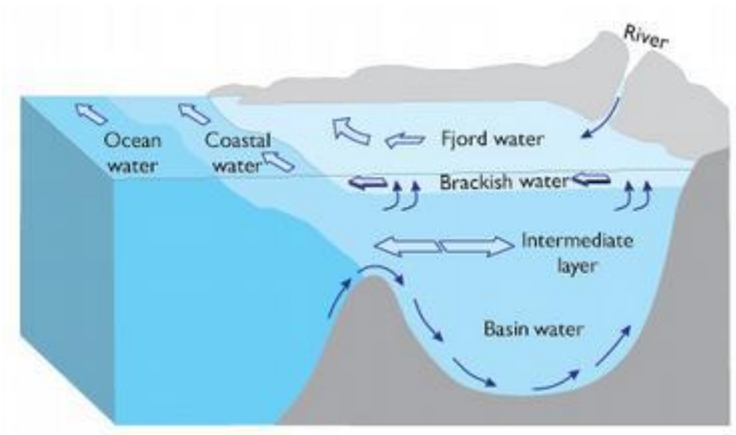



**Figure 1** Layering of water masses in fjords and along the coast (http://www.imr.no/images/bildearkiv/2013/06/figur-9.jpg/en?size=medium)

### 3.2.2. Intermediate water

The water mass that is below the low density surface layer and goes down to the sill depth is called intermediate water layer (Institute of Marine Research, 2017). The top part of the intermediate water layer contributes to the compensation current that compensates the outflowing brackish water layer with inflowing coastal water. It has a fairly high salinity. The horizontal movement of the intermediate water is not restricted by the sill.

The in- or outflow of a fjord can also be driven by pressure differences caused by density changes in coastal water. These density changes may be due to advection of new water masses or due to coastal up- or downwelling caused by wind (Sætre, 2007).

### 3.2.3. Basin water

The water below the sill depth is the deep water, also known as the basin water. It is the densest and most saline water and, depending on the depth of the fjord, is the least influenced by wind and sun's radiation. Parameters like temperature, density, oxygen do not fluctuate the way they do in the uppermost layers and basin water are stagnant due to the restriction of the sill on the water exchange. This might lead to anoxic conditions in the basin water. But this may change when there is water renewal. When new water flows into the fjord or the fjords basin, it changes the parameter values. A sudden increase in the concentrations of oxygen and the density as well as changes in turbidity, temperature and salinity is accompanying as a basin water exchange (Torbjørn Dale, 2017, *personal communication*).

Basin water renewal may happen when the water at sill depth is denser than the water of the basin inside the sill (Syvitski & Burrel, 1987). The heavier renewing water will flow into the basin and may move down to the bottom of that basin as seen in Figure 2. But not every basin water renewal replaces the whole water in a fjord. Sometimes, there is only a partial renewal. There are different mechanisms for that. Firstly, when the inflowing water is not denser than the deepest and most dense water in the basin, the inflowing water will stop sinking at that denser level and will exchange only the water above that level (Perillo, 1996). Secondly, the time of the inflow is too short to replace all of the basin water.

When there are long periods without water renewal or a high oxygen consumption in the basin of a fjord, that basin can become anoxic. Many fish and other organisms will suffocate if oxygen levels sink below 2 mg/l (Rosenberg, 1977).

There are two major mechanisms that create dense surface water involved in basin water exchange. At first the season. During winter time, the atmosphere is colder and there is less fresh water coming into the fjord. The ladder is leading to an increase in salinity and density. That together with the decreasing temperatures also lead to a higher density. Another reason for dense surface water is wind. When wind hits the water, it is blown away and that water needs to be replaced. That replacing water comes from the depth which leads to denser water being transported upwards to the surface. This is called an upwelling. When these two mechanisms occur together, the water can be dense enough to go over a threshold. When a threshold is very shallow, it is more difficult for water to flow over therefore, an inflow may happen less frequent (Torbjørn Dale, 2017, *personal communication*).

Upwelling events outside the Loftesnes sound happen when northerly winds are present. That wind in winter time is often associates with cold weather. Therefore, long periods with northerly wind create favorable conditions for basin water exchange in the Barsnesfjord (Torbjørn Dale, 2017, *personal communication*).

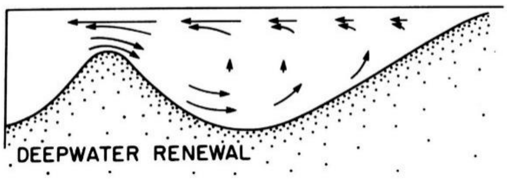



**Figure 2** Scheme of deep water renewal (after Gade and Edwards, 1980; from Perillo, 1996 p.153)

### 3.2.4. Tide

Another influence on water exchange is the tidal variation created by a semidiurnal tide. Tides change in a short time and they create differences in sea level (between high and low tide) of up to 2,7 m on the Norwegian coast. In the Sogndalsfjord the tidal variation is approximately 1 to 1,5 m (Torbjørn Dale, 2017, *personal communication*). The effect of the tidal current on a fjord depends, among other things, on the narrowness of a fjords entrance. When a fjord is very confined, there is only a reduced water exchange possible due to friction or "choking". In addition to that, such a strong rise is rather of occasional presence than a continuous one, an influence, seen over the course of a year, is rather small (Sætre, 2007).

Tidal forces are also important for the renewal of the basin water due to turbulences produced by the sill. The vertical mixing of that water due to bigger tidal amplitudes lead to a higher rate of density reduction in the basin water which then causes a greater possibility of a basin water renewal (Sætre, 2007).

## 3.3. Barsnesfjord and Sogndalsfjord

The Sognefjord is the longest and deepest fjord in Europe and located in Western Norway. The tributaries of the Sogndalsfjord and the Barsnesfjord are tending in a north-east to south-west direction (Figure 3).

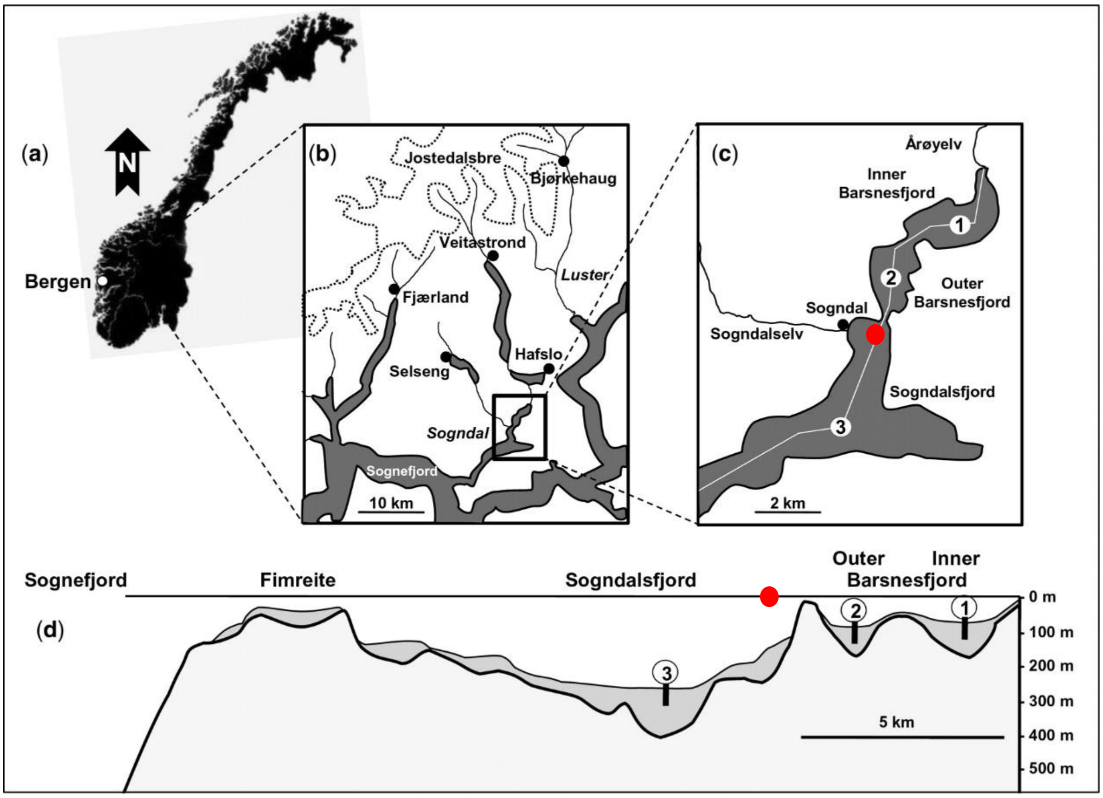



**Figure 3** a) Location of Sognefjord b) Locations of Sogndalsfjord c) Location of Sogndalsfjord & Inner and Outer Barsnesfjord. The red dot is the location Loftesnes d) Profile of fjords in c). 1: Sampling site Inner Barsnesfjord; 2: Sampling site Outer Barsnesfjord; 3: Sampling site Sogndalsfjord; Red dots: Sampling site south of Loftesnes bridge (sampling site name: Loftesnes). The numbers in the figure are referring to sites of sediment core sampling, but the hydrographical samples were taken at the same positions. Modified after: (Paetzel & Dale, 2010)

The Barsnesfjord is divided into the Inner Barsnesfjord basin and the Outer Barsnesfjord basin. These basins are separated by a sill of approximately 29 m depth. The Inner Barsnesfjord basin is ca. 66 m deep whereas the Outer Barsnesfjord basin is approximately 80 m deep. The Sogndalsfjord has a maximum depth of ca. 260 m and a sill of 7,5 m depth separates the Sogndalsfjord from the Outer Barsnesfjord. This is depicted in Figure 4. At the end of the Sogndalsfjord a sill of 25 m separates Sogndalsfjord from the main Sognefjord. That sill creates turbulence in the water which leads to an intermediate water layer that reaches down to approximately 35 m in the Sogndalsfjord.

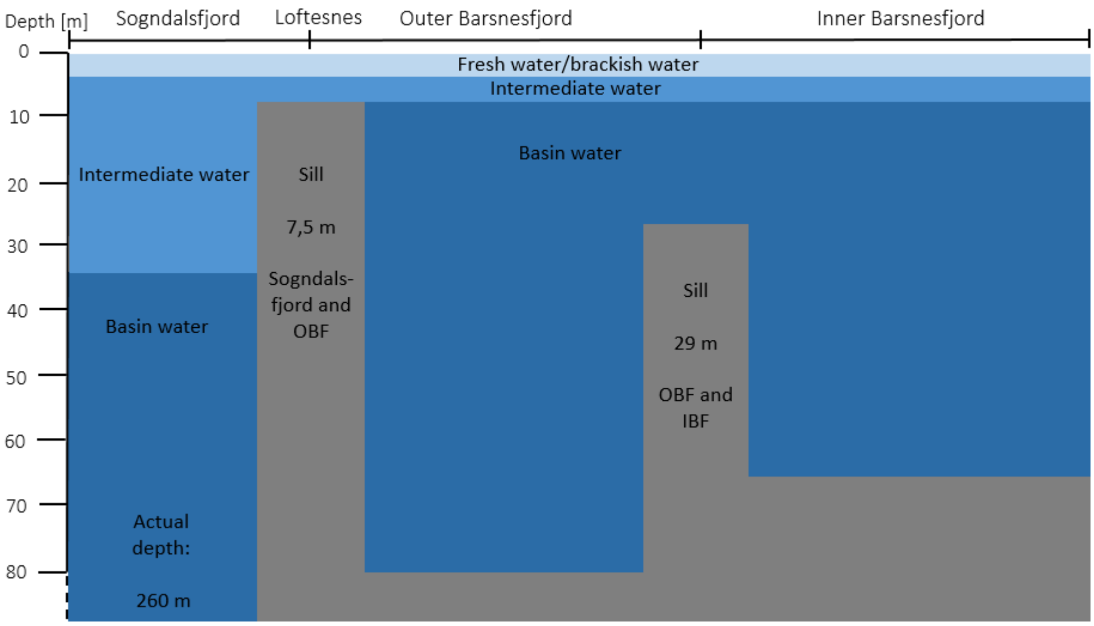



**Figure 4** Drawing of the Sogndalsfjord and the Inner and Outer Barsnesfjord with their sills, depths profiles and water masses.

There is an input of freshwater mainly coming from the river Årøyelv which is connected to the Inner Barsnesfjord. As a consequence of this input, there is a water stratification present in the Barsnesfjord mainly from April to September (Paetzel & Dale, 2010). The fresh water from the Barsnesfjord flows into Sogndalsfjord through the narrow and shallow sound at Loftesnes.

But because the water in the Inner Barsnesfjord gets renewed less and slower than the water in the Outer Barsnesfjord, the oxygen concentration decreases over time and may lead to anoxic periods in the deeper water layer. Due to a more active water circulation in the Outer Barsnesfjord, the oxygen concentration is higher, leading to a mostly oxic deep water layer (Paetzel & Dale, 2010).

The Sogndalsfjord receives most of its freshwater from a river called Sogndalselv (Figure 3) and that also adds to a water stratification. The basin of the Sogndalsfjord is oxic mainly because the threshold in the Sogndalsfjord is 25 m deep.

When the water in the Sogndalsfjord is denser than the water in the Outer Barsnesfjord, it can go over the sill and flow into the basin, depending on the prevailing density conditions.

The water going into the basin of the Inner Barsnesfjord is most likely coming from the Outer Barsnesfjord but might also be coming directly from the Sogndalsfjord.

# 4. Material and methods

The hydrographical measurements in the different periods were taken with different devices as shown in Table 1.

**Table 1** Devices used for hydrographic measuring and sampling of oxygen (mg/l), density (Sigma-t), salinity (‰), temperature (°C) and turbidity (FTU). CTD=Conductivity-Temperature-Depth-Sonde; CTD model used: SAIV-SD204; YSI=Yellow Springs Instrument; OBF=Outer Barsnesfjord; IBF=Inner Barsnesfjord; SF=Sogndalsfjord; LOF=Loftesnes

| Periods | Locations | Device | Oxygen | Density | Salinity | Temperature | Turbidity |
|---|---|---|---|---|---|---|---|
| 1984-1985 | OBF SF | Nansen water sampler | YSI-57 $O_2$-Meter | No data | Salinoterm MC 5 | Salinoterm MC 5 | No data |
| 1990-1993 | OBF SF | Ruttner water sampler | Winkler & YSI | Densimeter | Calculated | Thermometer | No data |
| 2013-2014 | OBF IBF SF LOF | CTD | CTD | CTD | CTD | CTD | CTD |
| 2016 | OBF IBF SF LOF | CTD | CTD | CTD | CTD | CTD | CTD |

## 4.1. Devices

### Nansen water sampler

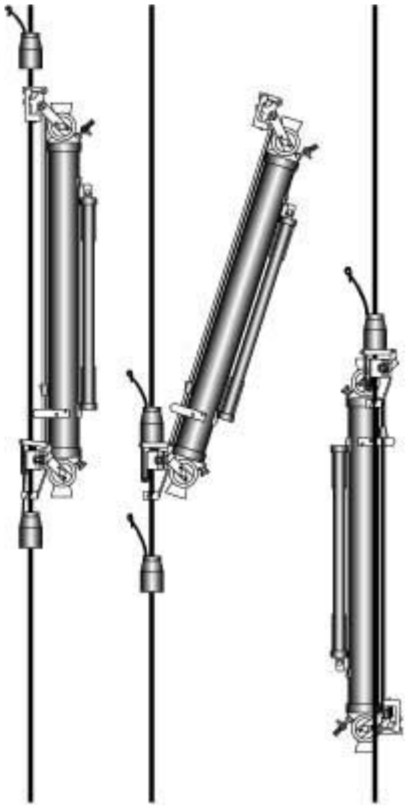


**Figure 5** Nansen water bottle (1. before; 2. during; 3. after reversing) (https://ocean.tamu.edu/images/nansen_bottle_1.jpg)

This device collects water samples of a requested depth. The water bottle (Figure 5) is of metal composition and has a valve on each end. The valves are open when the device is let down into the water attached to a wire until the desired depth is reached. When that depth is reached, a weight, a so called messenger, is sent down along the wire, to start the reversing mechanism. That mechanism separates the upper end from the wire which leads to the bottle being reversed and closed. The water of that specific depth is then trapped in the bottle and can be analyzed when being pulled out of the water (Encyclopedia Britannica, 2017).

### Rutter water sampler

**Figure 6** Ruttner water sampler (https://www.hydrobios.de/wp-content/uploads/2014/08/436132-ruttner-opened-water-sampler-1024x1024.jpg)

The Ruttner water sampler also takes water samples at a requested depth. The left picture of Figure 6 shows the position of the sampler when released into the water to the specified depth. It is open so that the water can flow through it. When the intended depth is reached, a messenger in form of a weight is let down the attached wire to start the closing mechanism. The tube will shut and the water sample can be pulled up (Hydro-Bios, 2017), as indicated on the right picture of Figure 6. Both, the Nansen and the Ruttner water sampler are *ex situ* that means that the water samples are analyzed outside of the water. This might lead to some changes and mistakes in the measured values since for example the atmospheric temperature might be different than the temperature in the water and this may influence the measurements.

### CTD SAIV-SD204 probe

**Figure 7** CTD SAIV-SD204 probe (http://www.oceanografialitoral.com/sites/default/files/saiv_sd204_alquiler.jpg?1362574771)

The CTD probe is an electronic device, depicted in Figure 7, and it can measure as well as calculate and record the conductivity, salinity, temperature, water density, depths (pressure) and the sound velocity of sea water. Three sensors were added to measure dissolved oxygen, fluorescence and turbidity (SAIV / AS, 2017). The CTD probe is the most accurate device used for measurements in this thesis as measurements are taken continuously down the water column.

The data is collected directly in the water, *in situ*, which is a great advantage of this method because taking samples out of the water may change its parameters, especially temperature and oxygen. For the measurement, the CTD probe is lowered into the water connected to a wire or rope. Every two seconds it is set to measure the mentioned parameter. All the collected data are saved on a microchip and can be transferred to a computer software, e.g. Microsoft Excel afterwards.

## 4.2. Years 1984-1985

Hydrographic sampling of the years from 1984 to 1985 (Hovgaard, 1985) is the oldest time period analyzed in this thesis. As seen in Table 1, for the measurements during the 1984-1985 time period, the Nansen water bottle was used. The depth that were sampled are, for the Outer Barsnesfjord 0 to 10 m in one m intervals, 20, 30, 40, 50, 60 m and for the Sogndalsfjord 0 to 10 m in one m intervals, 20, 30, 40, 50, 100, 150, 200, 250 m. After the collection of the water sample, the salinity and temperature was determined using a Salinoterm MC 5.

The oxygen concentration was determined with the YSI Model 57 Dissolved Oxygen Meter (YSI Manual, 2017). This electronic device measures the dissolved oxygen in the water with an accuracy of ± 1% of full scale (YSI Manual, 2017). Compared to Winkler Titration (Torbjørn Dale, 2017, *personal communication*), that will be explained later in this chapter, the accuracy of the YSI-57 oxygen measurements can be rather low depending on calibration, but are more than good enough to detect major changes following basin water exchange.

## 4.3. Years 1990-1993

The data for this period were taken by Dale & Hovgaard (1993). The measurements of the temperature, salinity and oxygen were taken in the Outer Barsnesfjord from 1, 5, 10, 25, 50 and 75 m water depths and in the Sogndalsfjord from 1, 5, 10, 25, 50, 100, 150, 200 and 250 m water depth. The salinity was calculated by means of a nomogram on basis of the measured density and temperature.

The water samples were taken with a Ruttner water sampler (Figure 6). A simple thermometer measured the temperature with an accuracy of ± 0,3°C (Torbjørn Dale, 2017, *personal communication*). The determination of the oxygen content was done with the YSI (Yellow Springs Instrument) as well as the Winkler titration method (Torbjørn Dale, 2016, *personal communication*). During the titration method, chemicals are added to the water. A titration technique is then used to determine the amount of a certain compound. The result is then used to calculate back to the amount of oxygen present in the water. Since the Winkler titration method is more accurate (± 0,1% accuracy) than the YSI determination, the data from the Winkler method was primarily used for analyzation. The salinity values were measured with a densimeter with a salinity accuracy of ± 0,5 ‰ (Torbjørn Dale, 2016, *personal communication*).

## 4.4. Years 2013-2014 and 2016

The measurements of the period 2013-2014 and 2016 were taken by Torbjørn Dale with a CTD probe (Dale T. , 2016). This took place in four different fjord locations down to the following depth: Sogndalsfjord (ca. 0-260 m), South of Loftesnes (ca. 0-50 m depth), Inner Barsnesfjord (ca. 0-66 m depth), and Outer Barsnesfjord (ca. 0-80 m depth). As mentioned before, the CTD probe gathers data of all the parameters every two seconds until the desired depth. As a result, sometimes there were more than one value for the distance of one meter (e.g. one value at 0,2 m depth, another value at 0,35 m depth). A mean value of each meter was calculated so that it could be compared with the older data. That sometimes included only one value for the distance of one meter and sometimes up to e.g. six values. This is because the CTD probe water lowered slowly in the surface water mases where there are rapid changes with depth. In the deeper parts, having more stable values, the lowering of the CTD probe was more rapid.

The CTD measurements during 2013-2014 period were taken on a boat which also had a Simrad Echo sounder. Two observations by the echo sounder will be analyzed.

## 4.5. Data processing

To show a clear structure of the changes of the different parameters, the data are visualized with diagrams made using the Microsoft Office 2016 software Excel, and the R studio Version 0.99.893. The latter program is an integrated environment for the programming language R and was used to make isopleth diagrams.

An isopleth diagram shows lines with the same value of a unit for example mg/l for the oxygen concentration. It visualizes and therefore helps to see changes and variations faster and more clearly (Wetter-gevenich.de, 2017).

The basis of these diagrams are tables with values. The values however need a preparation so that they can be read and used by the program. At first, the dates of the measurements needed to be changed into a different format (e.g. from 05.02.2013 to a value format of 41675. This number is equivalent to the number of days that had passed since 01.01.1900. That date is equivalent to the number one, the 02.01.1900 is therefore number two).

The second step is, to make a table where in the first column are those numbers of days, in the second column, in this case, the depths and in the third column are the values of the parameters that should be illustrated, e.g. oxygen concentrations.

The following steps are made in R studio. It should be mentioned that 'data.TD' is the example file name.

At first an additional package that expands the features of R is installed and then activated in the library.

```
install.packages("vegan")

library(vegan)
```

In the next step, the prepared data (the first two columns, day and depth) are marked and copied before running this commando.

```
data.TD<-read.table("clipboard",header=T,dec = ",")
```

Part of the needed data is now imported. After that, the columns in the data frames are made visible as variables with the following step.

```
attach(data.TD)

names(data.TD)

head(data.TD)
```

The following commandos are the same as used before, but now the third column (oxygen values) is marked and copied. These values are imported and visualized in this step.

```
x.dta<-read.table("clipboard",header=T,dec = ",")

attach(x.dta)

names(x.dta)

head(x.dta)
```

In the next commando, a plot is made and the axis including the labels are made as well as a title of the diagram.

```
plot(Day,Depth, main="Oxygen IBF 2013-14")
```

After running the last commando, the isopleth diagram is finished.

```
ordisurf(data.TD,Oxygen,col=2,add=TRUE)
```

# 5. Results

## 5.1. Years 1984-1985

The dataset from the years 1984 to 1985 provides oxygen measurements in ppm as well as salinity data in ‰ and temperature values in °C. Ppm stands for parts per million and is equivalent to mg/l. Since the oxygen data of the other time periods is provided in mg/l, the data from the 1984 to 1985 time period will also be presented in mg/l. The data is presented in figures made with Excel and Isopleth Figures made with R. Since the Isopleth Figures did not show the inflow events as hoped, they are not depicted in this chapter. But they can be found in the appendix. The Figures constructed with excel all show the date of measuring on the x-axis. On the y-axis, the parameter (oxygen, salinity, temperature) is illustrated. The values of salinity and temperature seem to be so inaccurate that they were excluded from the results but they can be found in the appendix. It should be noted that the y-axes of the salinity figures are reversed. This is due to a better/more realistic illustration since low salinity is on the surface and high salinity is at greater depths of the fjord. In the Figures made with Excel, not all depths are shown since this thesis focuses on the basin water of the fjords.

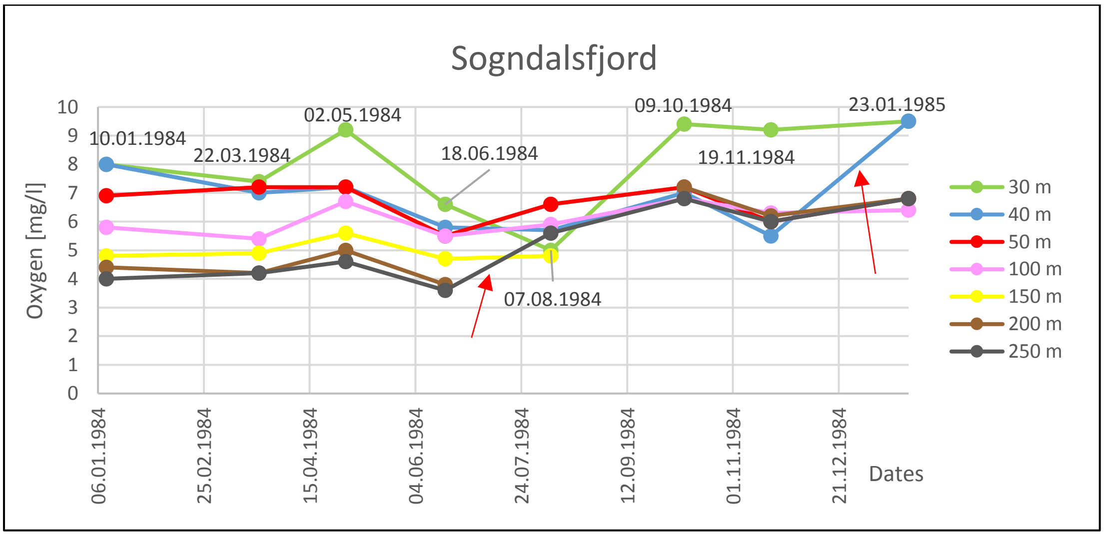



**Figure 8** Sogndalsfjord oxygen data in mg/l for all measured dates in 1984-1985. Data determined with YSI. The red arrow indicate inflow events.

The oxygen values (Figure 8) in the Sogndalsfjord show a rise from 22.03.1984 to 02.05.1984 at all depths followed by a decline at all depths to the 18.06.1984. The 30 m values continue to decline until the 07.08.1984. From that date to the 09.10.1984 an increase is seen at all depths except in 150 and 200 m due to lack of data. At 250 m, the values increased from 3,6 mg/l to 6,8 mg/l. From the 19.11.1984 to the 23.01.1985 another increase, especially in 40 m, is visible at all depths except for 150 m due to lack of data.

The oxygen concentration (Figure 9) in the Outer Barsnesfjord shows a strong increase at the depths from 20 m to 50 m from 06.01.1984 to 21.02.1984. At 50 m depth, the concentration increases from 0,8 mg/l to 8,0 mg/l. The highest value of all depths during this whole period is in 60 m with 9,5 mg/l. A subsequent decrease of the concentration at all depths is interrupted by an increase at the depths of 20 m to 60 m, with an exception of 50 m due to lack of data from the 07.08.1984 to the 09.10.1984. The oxygen concentration in 30 m continues to increase until the 19.11.1984 whereas the concentration in 20 m decreases during the same time.

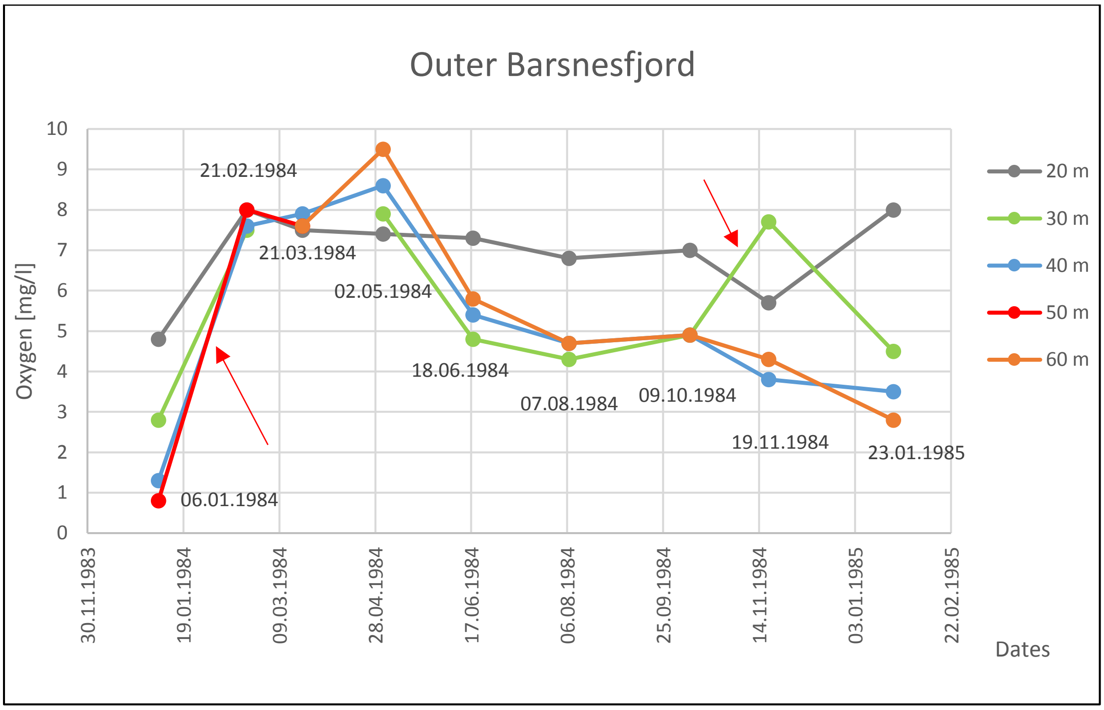



**Figure 9** Outer Barsnesfjord oxygen data in mg/l for all measured dates in 1984-1985. Data determined with YSI. Red arrows indicate inflow event.

The Figures 10 a and 10 b depict the oxygen values in mg/l for both the Outer Barsnesfjord and the Sogndalsfjord. Figure 10 a shows the oxygen concentration for the depth of 30 m. An increase in the Sogndalsfjord occurs from the 18.06.1984 to the 07.08.1984. After that, also the concentration increases in the Outer Barsnesfjord from the 07.08.1984 to the 19.11.1984.

Also, an increase occurs in 40 m in the Sogndalsfjord from the 18.06.1984 to the 07.08.1984 (Figure 10 b). The oxygen concentration rises from under 6 mg/l to 8 mg/l. An even higher increase from ca. 6,5 mg/l to ca. 9,5 mg/l happens during the time from 09.10.1984 to 19.11.1984. Those two events of oxygen increase are a sign of an inflow into the Sogndalsfjord, shown by the red arrows.

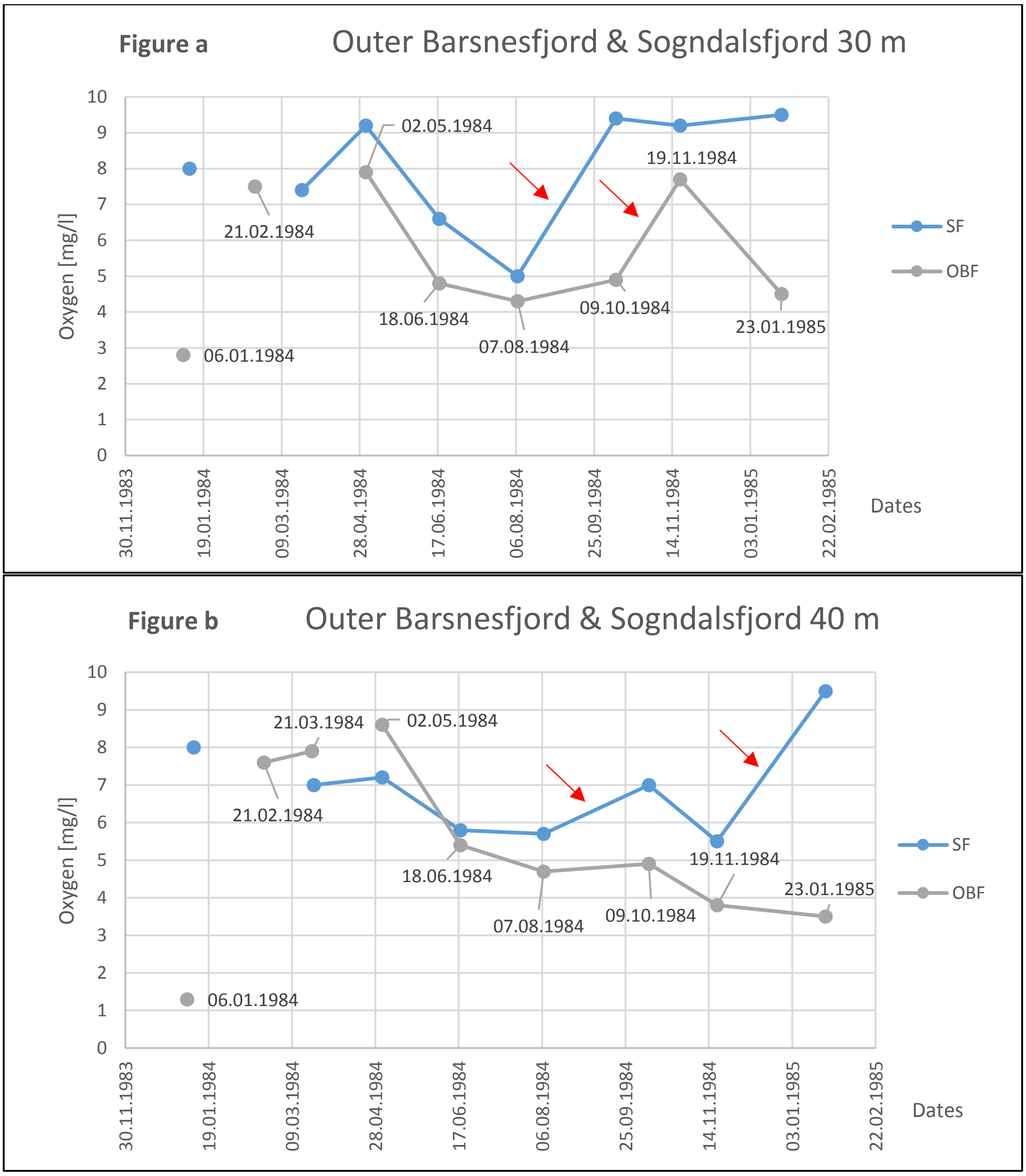



**Figure 10** a: Outer Barsnesfjord and Sogndalsfjord oxygen data in mg/l in 30 m depth. b: Outer Barsnesfjord and Sogndalsfjord oxygen data in mg/l in 40 m depth. Data determined with YSI. Red arrows indicate inflow events.

### Summary Sogndalsfjord

- 18.06.1984 - 07.08.1984: partial inflow to 250 m; a decline at 30 m depth
- 19.11.1984 - 23.01.1984: partial inflow to 40 m

### Summary Outer Barsnesfjord

- 06.01.1984 - 21.02.1984: major inflow
- 07.08. - 09.10. minor inflow at all depths (except for 50 m due to lack of data)
- 09.10.1984 - 19.11.1984: partial inflow at 30 m depth; 20 m decrease (possibly due to uplifting of low oxygen water of 30 m depth

## 5.2. Years 1990-1993

The oxygen values in the period from 1991 to 1993 were determined with the Winkler titration method as well as with the Yellow Springs Instrument. For the analysis of the data, the values derived from the Winkler method were primarily used. For three dates (26.01.1991, 29.01.1991 and 27.02.1991) there were no data collected with the Winkler method available therefore for the three dates, the data collected with the Yellow Springs Instrument is used.

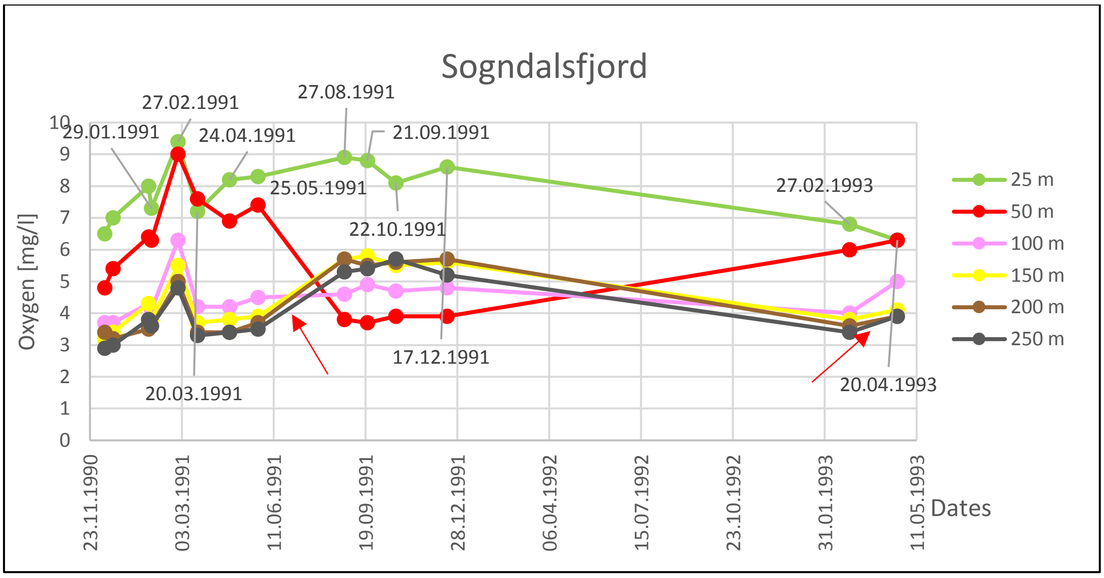



**Figure 11** Sogndalsfjord oxygen data in mg/l in 1991-1993. Data determined with Winkler titration method except for 26.01.1991, 29.01.1991 and 27.02.1991 that were determined with YSI. Red arrows indicate inflow events.

The high values at 27.02.1991 could indicate an inflow event but the peak at that date at all depths followed by a rapid decline to the 20.03.1991 at all depths suggests inaccurate measurements by the Yellow Springs Instrument.

An increase in oxygen in the Sogndalsfjord (Figure 11) is visible at all depths from the 29.01.1991 to the 27.02.1991. At 50 m depth, the oxygen content rises from 6,3 mg/l to 9 mg/l. Until the 24.02.1991 the oxygen content decreases at all depths. Another increase happens from 25.05.1991 to 27.08.1991 at all depths except in 50 m. In that depth, the oxygen decreases rapidly from 7,4 mg/l to 3,8 mg/l.

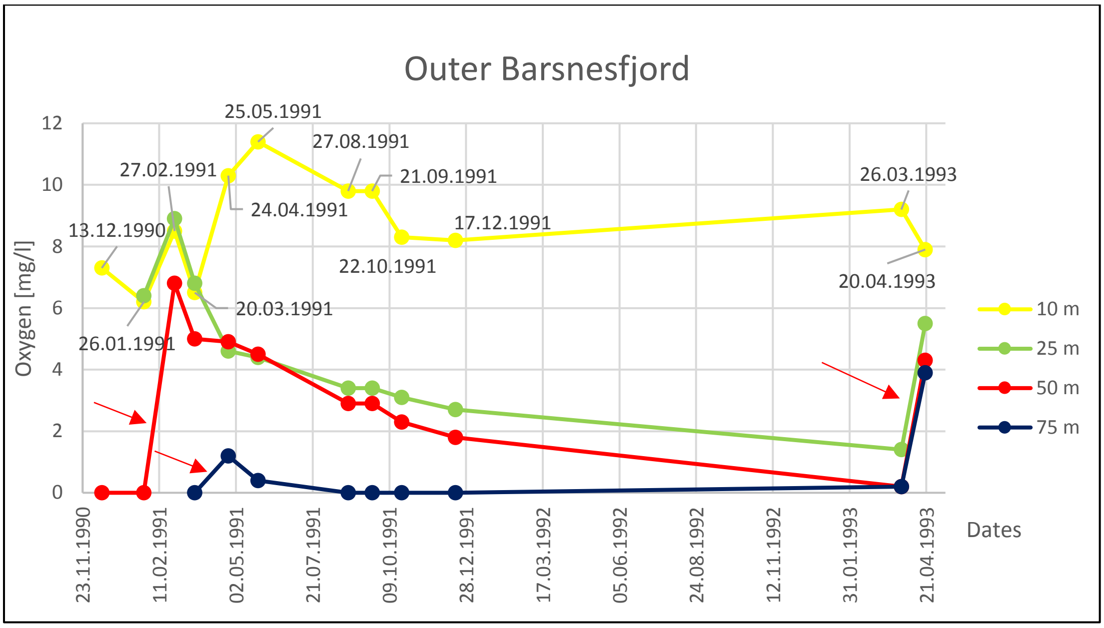



**Figure 12** Outer Barsnesfjord oxygen data in mg/l in 1991-1993. Data determined with Winkler titration method except for 26.01.1991 and 27.02.1991 that were determined with YSI. Red arrows indicate inflow events. Some oxygen values were added since only $H_2S$ was present (at the depth of 50 m: 13.12.1990, 26.01.1991 and at the depth of 75 m: 20.03.1990, 27.08. to 17.12.1991 were added).

In the Outer Barsnesfjord is a strong increase in oxygen (Figure 12) from 26.01.1991 to 27.02.1991 at the depths of 10 to 50 m and from 20.03.1991 to 24.04.1991 in 75 m. The greatest increase is in that period at 50 m depth from 0 mg/l to 6,8 mg/l.

Another increase happened from 26.03.1993 to 20.04.1993 at the depths from 25 to 75 m whereas the oxygen values in 10 m decline in that period. The strong increases in oxygen concentration in these periods are marked with red arrows.

It should be noted that in Figure 12, some oxygen values (at the depth of 50 m: 13.12.1990, 26.01.1991; at the depth of 75 m: 20.03.1990, 27.08. to 17.12.1991) were added since the original data stated that only Hydrogen sulfide ($H_2S$), and not oxygen, was present.

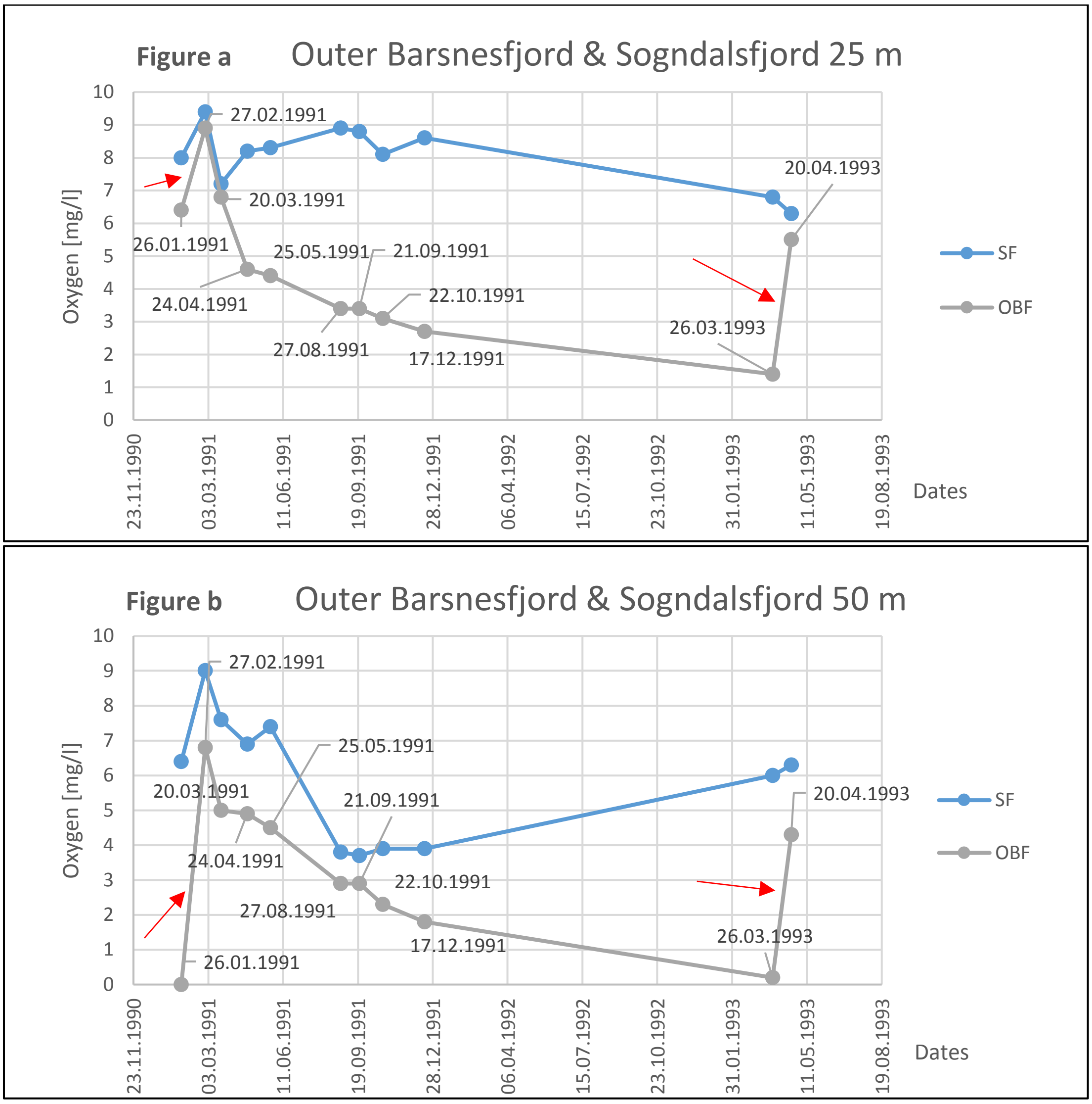



**Figure 13** a: Outer Barsnesfjord and Sogndalsfjord oxygen data in mg/l in 25 m depth. b: Outer Barsnesfjord and Sogndalsfjord oxygen data in mg/l in 50 m depth. Sogndalsfjord data determined with Winkler titration method except for 26.01.1991, 29.01.1991 and 27.02.1991 that were determined with YSI. Outer Barsnesfjord data determined with Winkler titration method except for 26.01.1991 and 27.02.1991 that were determined with YSI.

In Figure 13 a there is a direct comparison of the oxygen values illustrated from the Outer Barsnesfjord and the Sogndalsfjord at 25 m depth. From the 26.01.1991 to the 27.01.1991 there is an increase in oxygen in both fjords at that depth. Another increase occurs in the Outer Barsnesfjord from the 26.03.1993 to the 20.04.1993 from 1,4 mg/l to 5,5 mg/l whereas at the same time the oxygen concentration in the Sogndalsfjord decreases minimally.

The resembling pattern occurs at 50 m depth (Figure 13 b) in the Outer Barsnesfjord and the Sogndalsfjord. A strong increase between the 26.01.1991 and the 27.01.1991 especially in the Outer Barsnesfjord with increasing values from 0 mg/l to 6,8 mg/l.

From the 26.03.1993 and the 20.04.1993 the oxygen concentration increase in both fjords but a greater increase is in the Outer Barsnesfjord with a rise from 0,2 mg/l to 4,3 mg/l.

#### Summary Sogndalsfjord

- 25.05.1991 - 27.08.1991: inflow at 150, 200 and 250 m depth; 100 m almost constant; 50 m decline
- 27.02.1991 - 24.04.1991: inflow 50 to 250 m depth; 25 m decline

#### Summary Outer Barsnesfjord

- 26.01.1991 - 27.02.1991: inflow 10 to 50 m; first at shallower level
- 20.03.1991 - 24.04.1991: inflow now reached all the way down to 75 m
- 26.03.1993 - 20.04.1993: inflow at 25 to 75 m; 10 m values decline due to uplifting of old water

### 5.3. Years 2013-2014

The dataset from the years 2013 to 2014 contributes data from oxygen in mg/l, density in sigma-t, salinity in ‰, temperature in °C, and turbidity in FTU.

The data is presented in figures made with Excel and Isopleth figures made with R. The figures constructed with excel show the date of measuring on the x-axis except for the turbidity graphs. They show the depths on the x-axis. On the y-axis, the parameter (oxygen, density etc.) is illustrated. It should be noted that the y-axes of the density and salinity figures are reversed. This is due to a better/more realistic illustration since low salinity is on the surface and high salinity is at greater depths of the fjord. Since this thesis focuses on the basin water, mostly the values from greater depths are used while the surface water values are not illustrated.

### 5.3.1. Sogndalsfjord

Figure 14 and 15 show the hydrography data of the Sogndalsfjord.

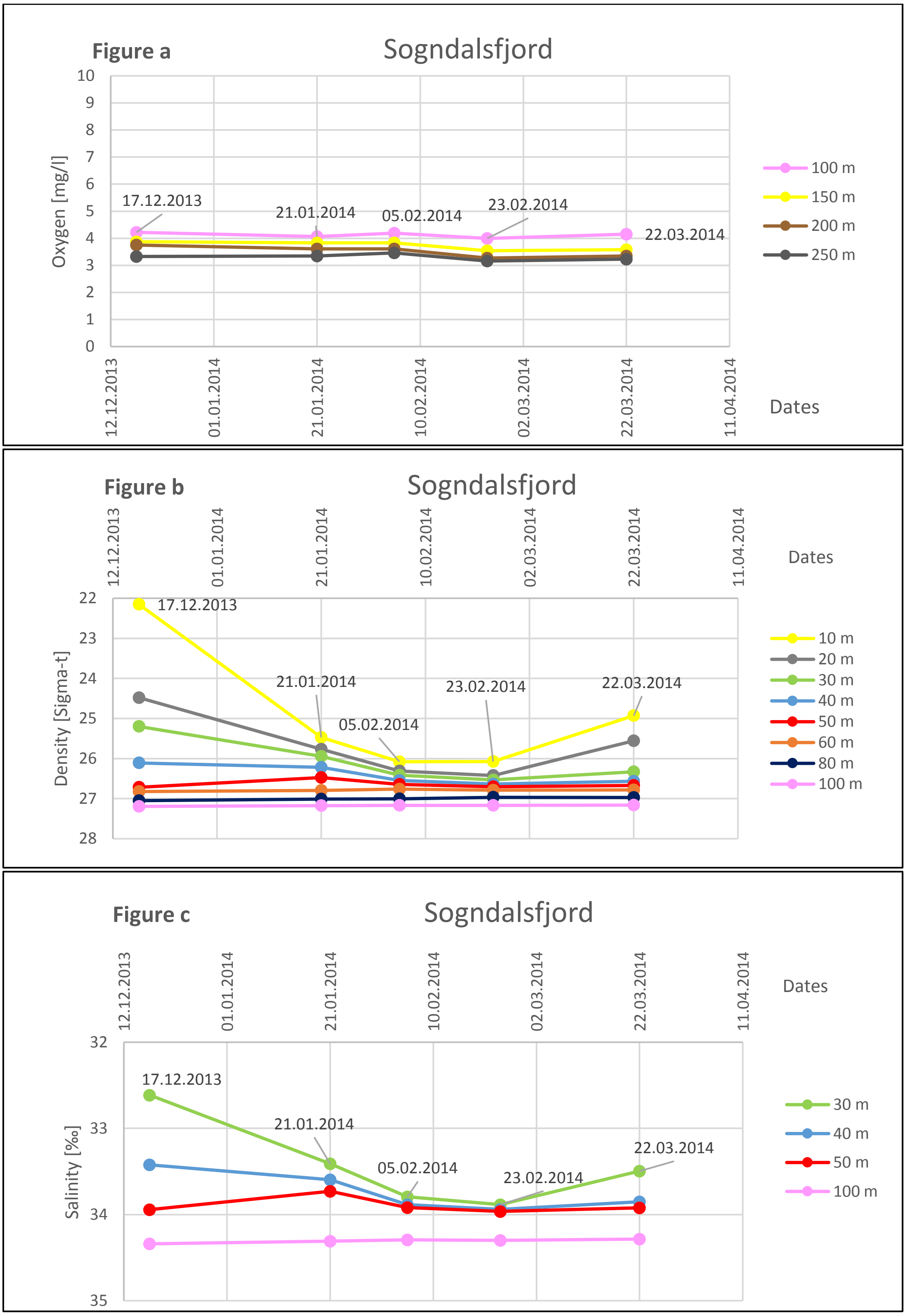



**Figure 14** a: Sogndalsfjord oxygen data in mg/l in 2013-2014. b: Sogndalsfjord density data in sigma-t in 2013-2014. c: Sogndalsfjord salinity data in ‰ in 2013-2014. Data collected with CTD.

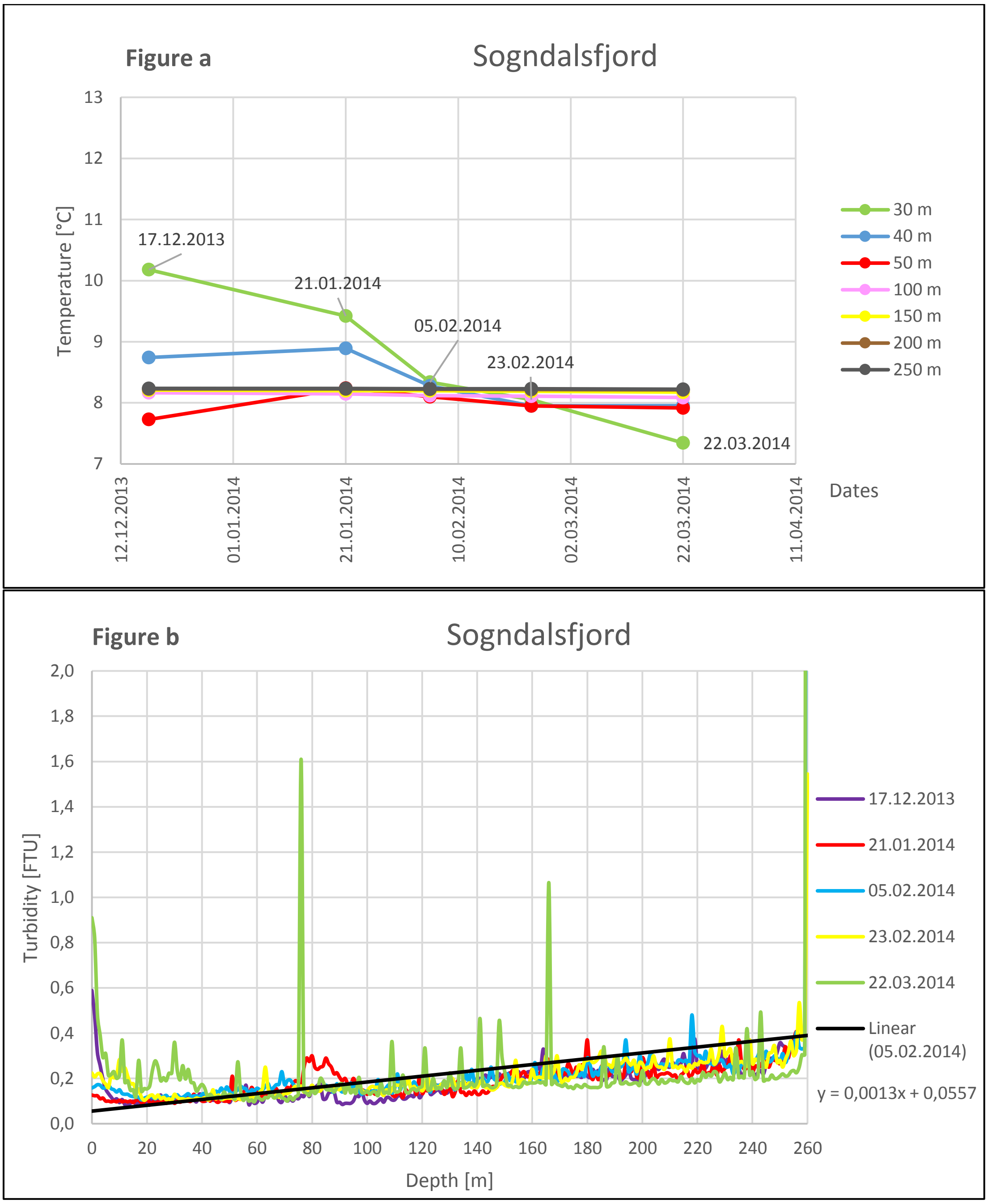



**Figure 15** a: Sogndalsfjord temperature data in °C in 2013-2014. b: Sogndalsfjord turbidity data in FTU in 2013-2014. A trend line from the 05.02.2014 data is shown. Data collected with CTD.

In Figure 14 a, the oxygen values of the Sogndalsfjord are illustrated. They show hardly any variation. At 200 m depth, the oxygen concentration only fluctuates between 3,27 mg/l to 3,61 mg/l.

The densities in the Sogndalsfjord (Figure 14 b), at the different depth roughly show the similar progression as it increases from 17.12.2013 until 05.02.2014 in the upper water body (depths of 10 to 40 m) whereas the deeper parts below that are almost constant. At 30 m depth, the density increases from 25,2 sigma-t on the 17.12.2013 to 26,53 sigma-t on the 23.02.2014.

An increase in salinity (Figure 14 c) is visible from the 21.01.2014 to 23.02.2014 but only in the upper parts of the water body because down in 100 m is almost no change in salinity. In 30 m, it increases from the lowest point with 32,61 ‰ to its maximum of 33,89 ‰.

The temperatures in the upper parts of the Sogndalsfjord (30 and 40 m depth) (Figure 15 a) are changing throughout the four months of measuring. The lower parts, 50 to 250 m, are almost steady and do not change much. This fits with the general pattern of the Sogndalsfjord in this time because at greater depths, the parameters of oxygen, density, salinity and temperature change slowly.

The turbidity data (Figure 15 b) have some high peaks at the depths of ca. 78m, 165 m and 260 m which is not an accurate representation of the turbidity at that depth but probably just a large particle that disturbed the measurement. A general increase of turbidity is visible with increasing depth, illustrated by the trend line.

## 5.3.2. Loftesnes

Figure 16 and 17 show the hydrography data at Loftesnes.

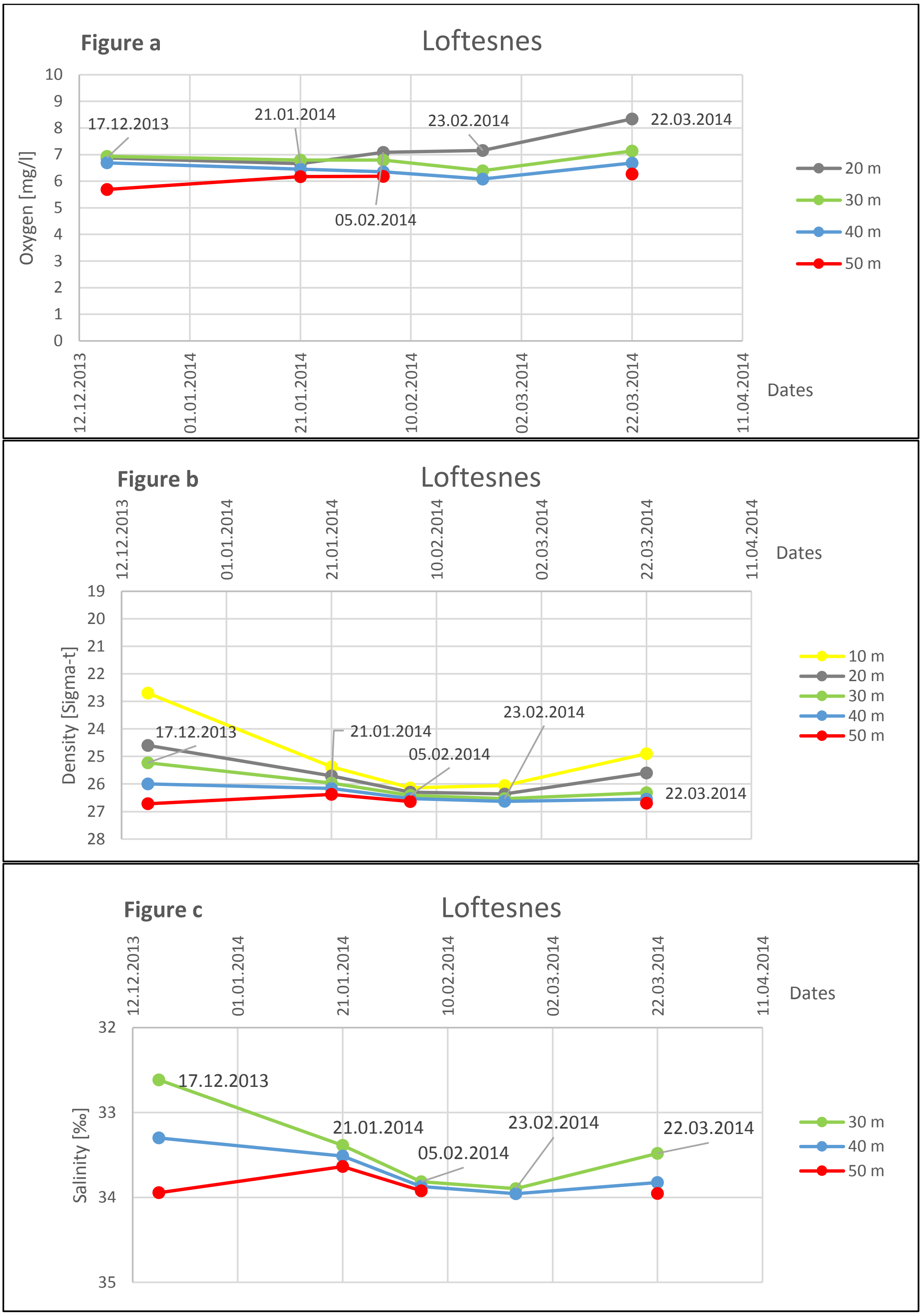



**Figure 16** a: Loftesnes oxygen data in mg/l in 2013-2014. b: Loftesnes density data in sigma-t in 2013-2014. Figure 16 c: Loftesnes salinity data in ‰ in 2013-2014. Data collected with CTD.

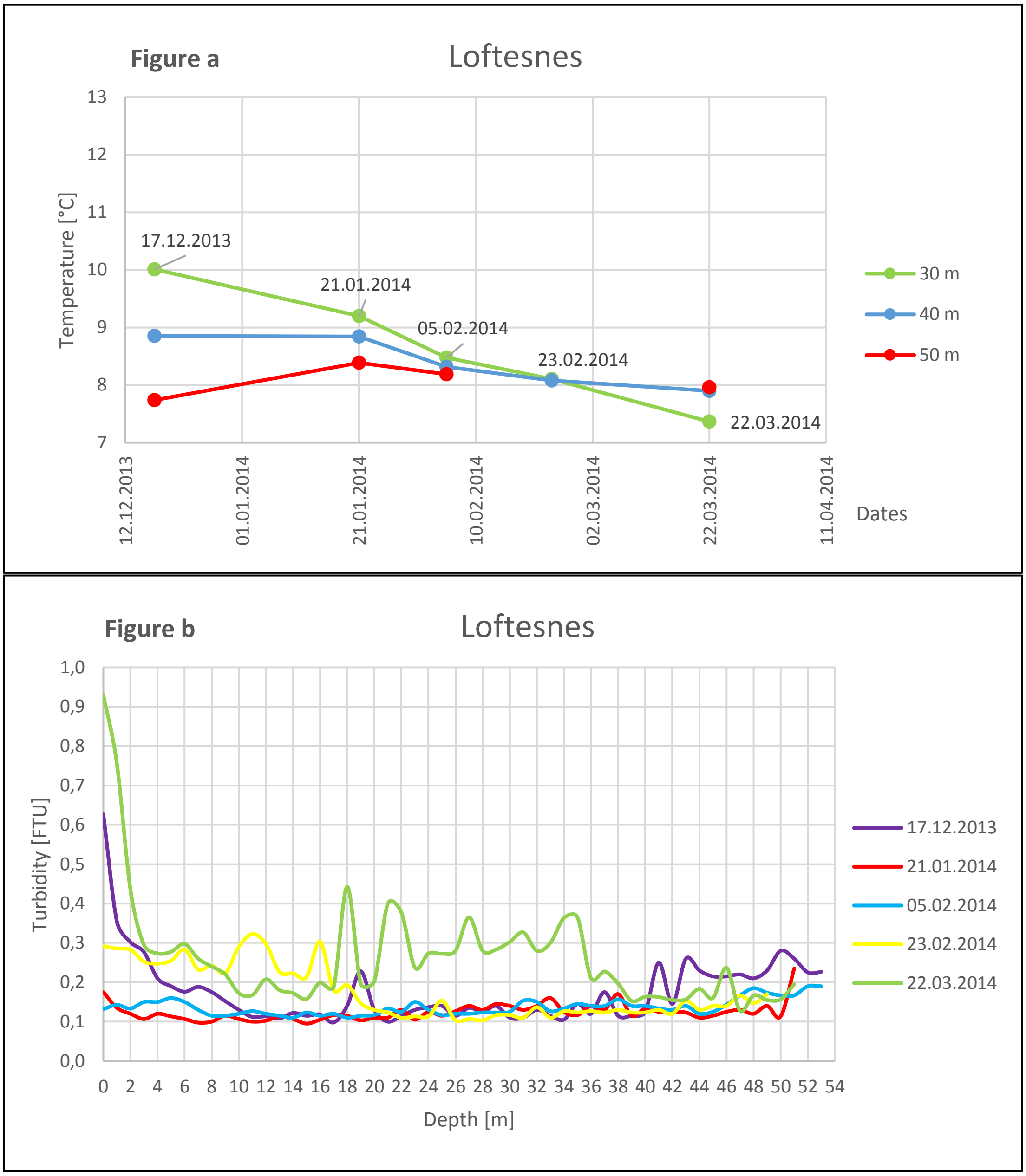



**Figure 17** a: Loftesnes temperature data in °C in 2013-2014. b: Loftesnes turbidity data in FTU in 2013-2014. Data collected with CTD.

There is a small decrease in oxygen concentration at Loftesnes (Figure 16 a) in 20, 30 and 40 m from 17.12.2013 to 21.01.2014 as well as at 20 and 30 m depths from 05.02.2014 to 23.02.2014. This is followed by a small increase at 20, 30 and 40 m depths to the 22.03.2014. In 20 m, the increase in the time between the 23.02.2014 and the 22.03.2014 is from 7,16 mg/l to 8,34 mg/l.

An increase in density (Figure 16 b) at the depths from 10 to 40 m is visible from 17.12.2013 to 21.01.2014 followed by an increase at all depths until the 05.02.2014.

The salinity (Figure 16 c) shows a similar pattern with an increase in 30 and 40 m from 17.12.2013 until 23.02.2014. The temperature (Figure 17 a) shows that the water generally becomes colder at all depths from 17.12.2013 until 22.03.2014 except for the 50 m values from 17.12.2013 to 21.01.2014.

The turbidity values (Figure 17 b), are generally low, but show a lot of fluctuations throughout the depth of the water body, especially the values from 22.03.2014. With high values in the first three meters it is followed by several peaks at the depths between 16 m and 36 m on the same date. Also, the values from 23.02.2014 show several peaks but here from 9 m to 16 m depth.

### 5.3.3. Outer Barsnesfjord

Figure 18 and 19 show the hydrography data from the Outer Barsnesfjord.

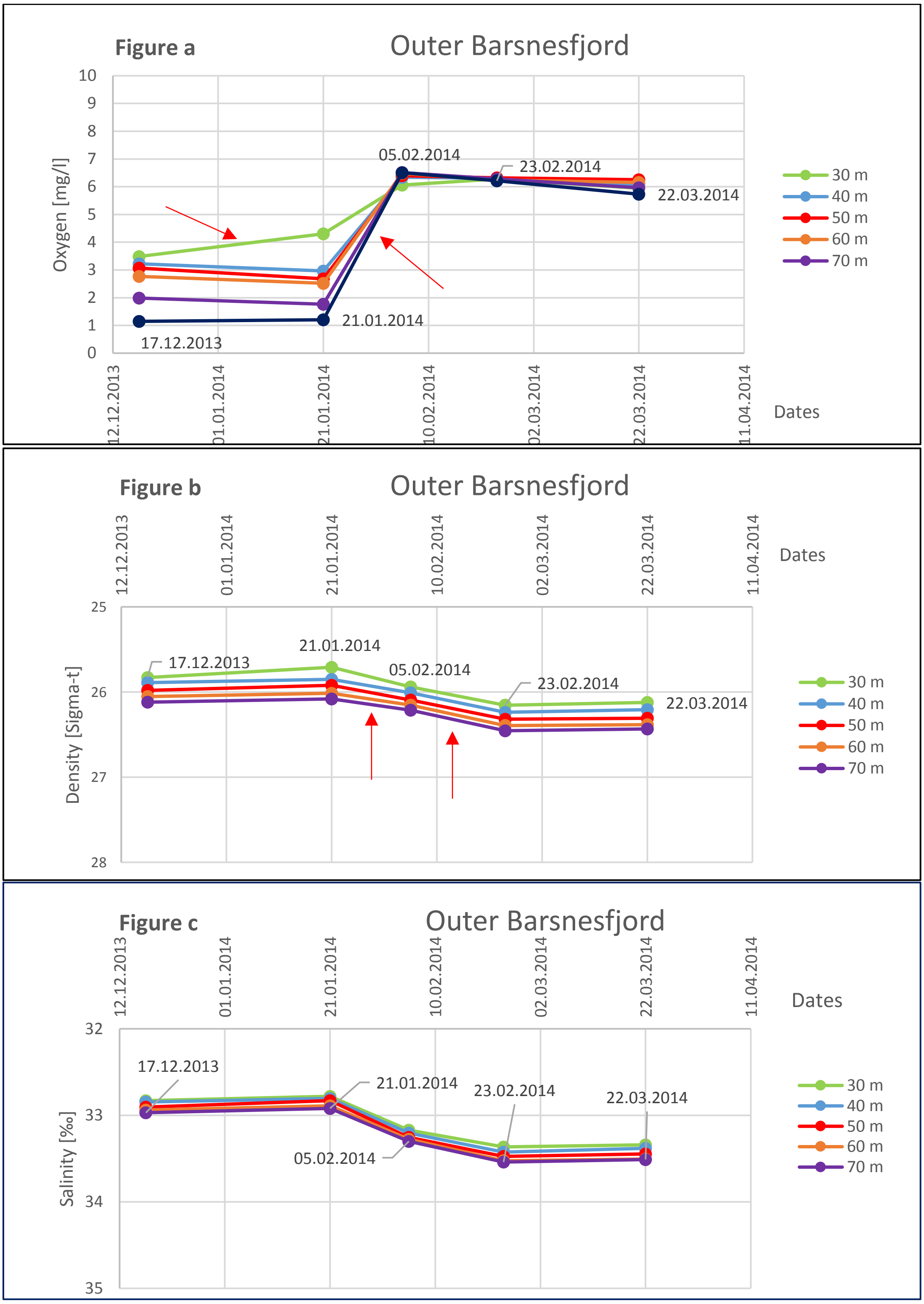



**Figure 18** a: Outer Barsnesfjord oxygen data in mg/l in 2013-2014. b: Outer Barsnesfjord density data in sigma-t in 2013-2014. c: Outer Barsnesfjord salinity data in ‰ in 2013-2014. Data collected with CTD. Red arrows indicate inflow events.

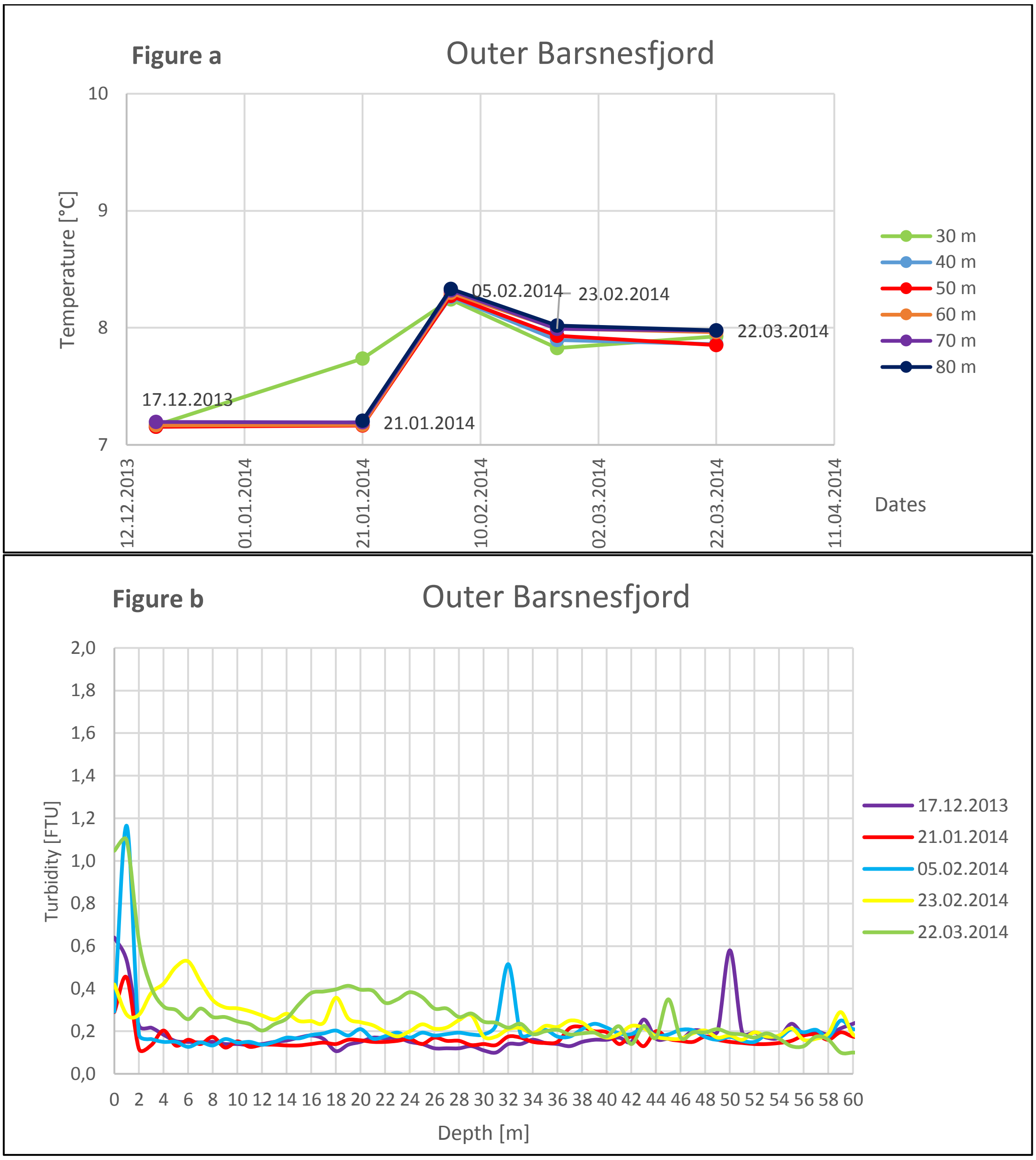



**Figure 19** a: Outer Barsnesfjord temperature data in °C in 2013-2014. b: Outer Barsnesfjord turbidity data in FTU in 2013-2014. Data collected with CTD.

At all depths is a massive increase in oxygen (Figure 18 a) discernable in the Outer Barsnesfjord from 21.01.2014 to 05.02.2014. Within 15 days the oxygen concentration rises in 78 m from 1,2 mg/l to 6,51 mg/l. Whereas in 30 m the oxygen content increases in three steps starting at 17.12.2013 to 21.01.2014 over 05.02.2014 to its maximum on 23.02.2014.

From 21.01.2014 to 05.02.2014 the density (Figure 18 b) increases at all depths which matches the progression of the oxygen concentration. The density continues to increase after that until the 23.02.2014. That is an inflow that is not revealed by the oxygen measurements.

The salinity (Figure 18 c) also shows the same progression as the density with an increase from 21.01.2014 to 23.02.2014 at all depths.

In the winter of 2014 (17.12.2013) the 30 m values begin to increase (Figure 19 a). This partial inflow only renews water at 30 m depth. The density conditions are not sufficient to replace all the water yet. From the 21.01.2014 to the 05.02.2014, the density increases and all the water was replaced by warmer, heavier and oxygen rich water, which can be seen in increasing temperature at all depths during that time.

The changes in turbidity (Figure 19 b) resemble the pattern of the turbidity data at Loftesnes at the same dates. An increase on 23.02.2014 in 5 m to ca. 10 m is visible as well as an increase on 22.03.2014 at the depths of 14 m to 27 m. The values are in the range of ca. 0,1 to almost 1,2 FTU. The turbidity maximum on 22.03.2014 is found at the depths of ca. 15 to 25 m, compared to 18 to 35 m at Loftesnes during the same time.

## 5.3.4. Inner Barsnesfjord

Figure 20 and 21 show the hydrography data from the Inner Barsnesfjord.

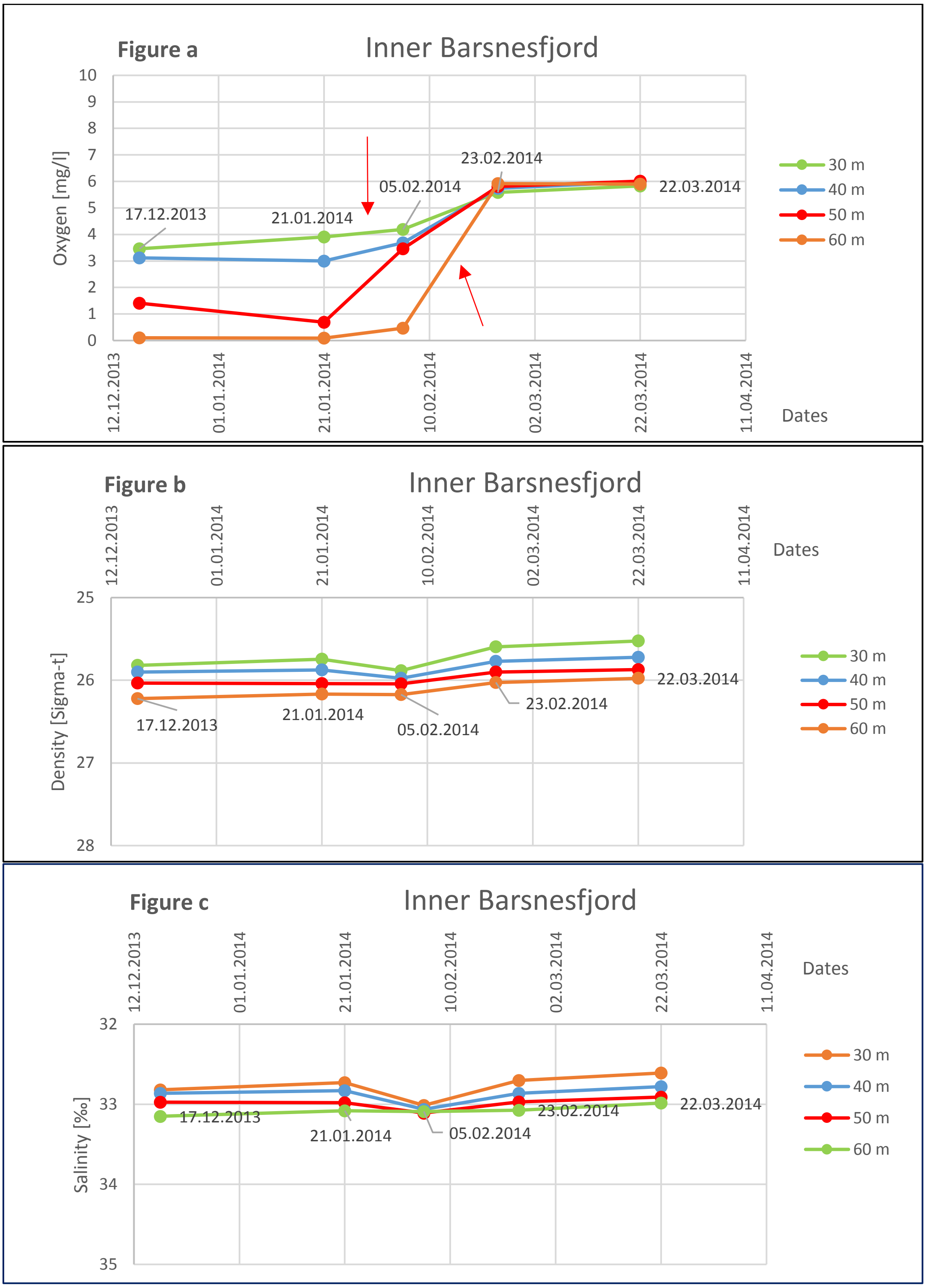



**Figure 20** a: Inner Barsnesfjord oxygen data in mg/l in 2013-2014. b: Inner Barsnesfjord density data in sigma-t in 2013-2014. c: Inner Barsnesfjord salinity data in ‰ in 2013-2014. Data collected with CTD. Red arrows indicate inflow events.

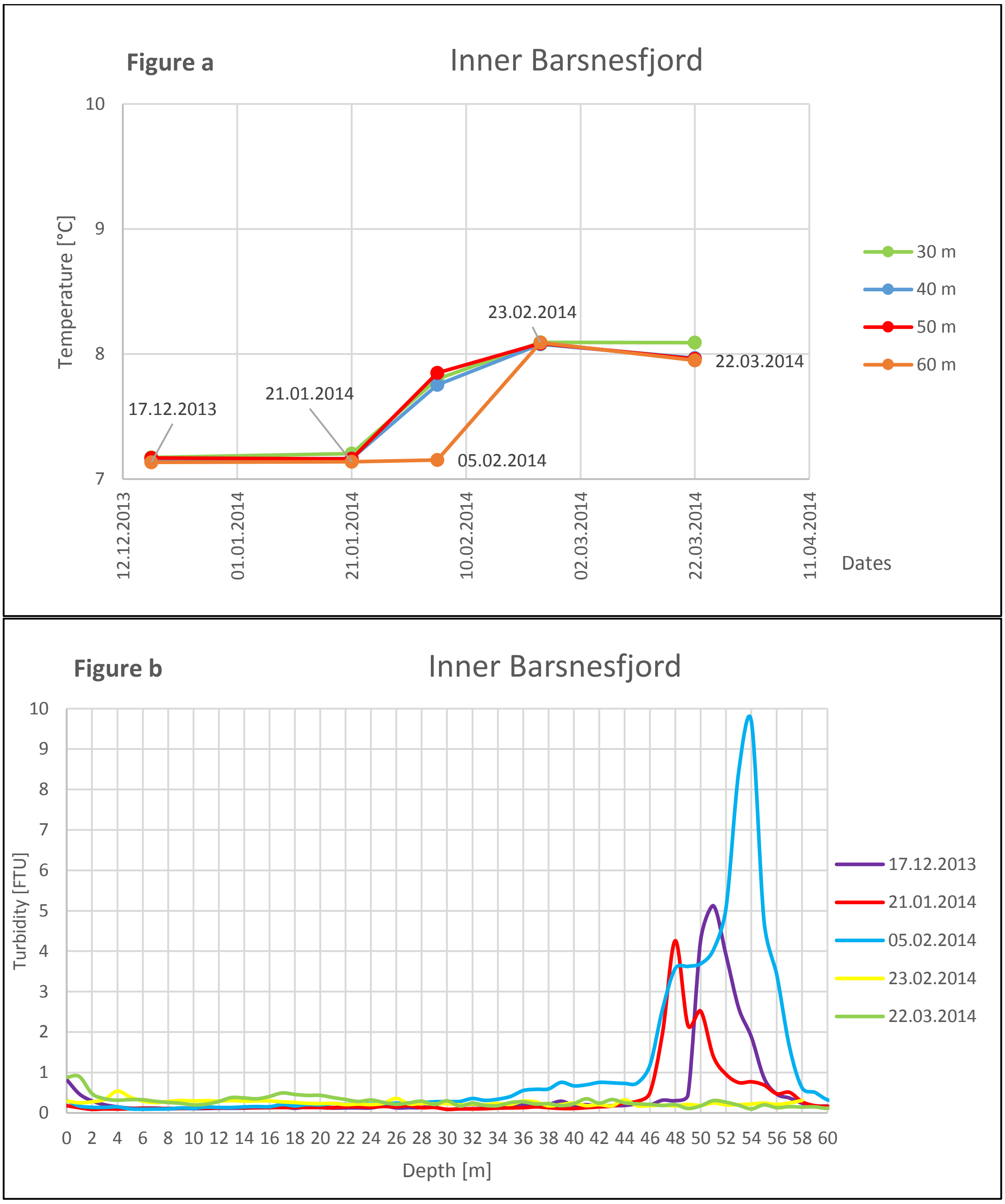



**Figure 21** a: Inner Barsnesfjord temperature data in °C in 2013-2014. b: Inner Barsnesfjord turbidity data in FTU in 2013-2014. Data collected with CTD.

In the Inner Barsnesfjord a pronounced increase in oxygen concentrations was seen at all depths from 21.01.2014 to 23.02.2014 (Figure 20 a). At 60 m, where the increase mainly happened in the following period, the values increased from 0,09 mg/l to 5,92 mg/l.

The density (Figure 20 b) in the Inner Barsnesfjord increases during the period between the 21.01.2014 and the 05.02.2014 but this is followed by an unexpected decrease until the 23.02.2014 at all depths.

The salinity (Figure 20 c) for this period shows the same pattern with an increase followed by a decrease during the same time as the density.

Between the 21.01.2014 and the 23.02.2014, the temperature (Figure 21 a) increases at all depths in the Inner Barsnesfjord. In 60 m, the increase is mainly during the period from 05.02.2014 to 23.02.2014. The temperature values in 60 m rise from 7,15 °C to 8,09 °C. The pattern is the same as for the oxygen.

The turbidity values for the Inner Barsnesfjord in Figure 21 b start increasing at a depth of 46 m but only on the 17.12.2013, 21.01.2014 and the 05.02.2014. The highest point on 05.02.2014 is at about 54 m depth with 9,69 FTU.

The turbidity peaks are probably reflecting the border zone between oxic and anoxic zone with its associated microbial community in the RPD-layer (redox potential discontinuity layer). The peak of turbidity 17.12.2013 is found at approximately 51 m depth compared to 48 m at 21.01.2014. This suggests an elevation speed of 300 cm/35 days. That is equal to 8,6 cm/day. Compared to the elevation speed of the RPD-layer in the Inner Barsnesfjord in 2009 with 4,6 cm/day. (Torbjørn Dale, 2017, *personal communication*).

The Figures 22 and 23 are echo diagrams from the Inner Barsnesfjord. Figure 22 shows a red line at circa 65 m depth according to the scale on the right-hand side and it represents the bottom of the basin in the Inner Barsnesfjord. There are blue dots that lined up to a band at the depths of ca. 52 m, marked with a red arrow. They conform with the turbidity peak in Figure 21 b at the same depth. This shows that the peak in turbidity at that depth, is due to a RPD-layer, which will be explained in the discussion chapter.

Figure 23 depicts the echo diagram from the 23.02.2014. The blue band has now disappeared only some blue dots are left, as marked with a red arrow. Comparing with the turbidity data on that date in Figure 21 b, the values are very low. That means that the pre-existing RPD-layer is no longer present.

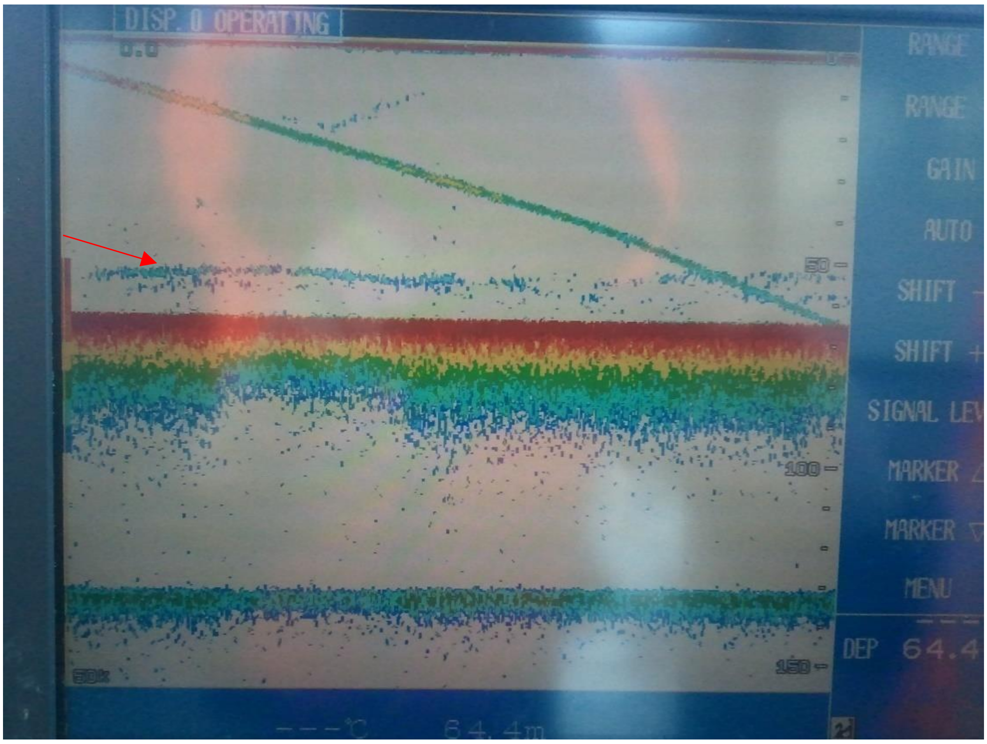



**Figure 22** Echo diagram form the 05.02.2014 in the Inner Barsnesfjord. Picture taken with a cell phone camera. Red arrow points to a layer at ca. 52 m, probably the RPD-layer. The oblique line is the lowering of the CTD probe.

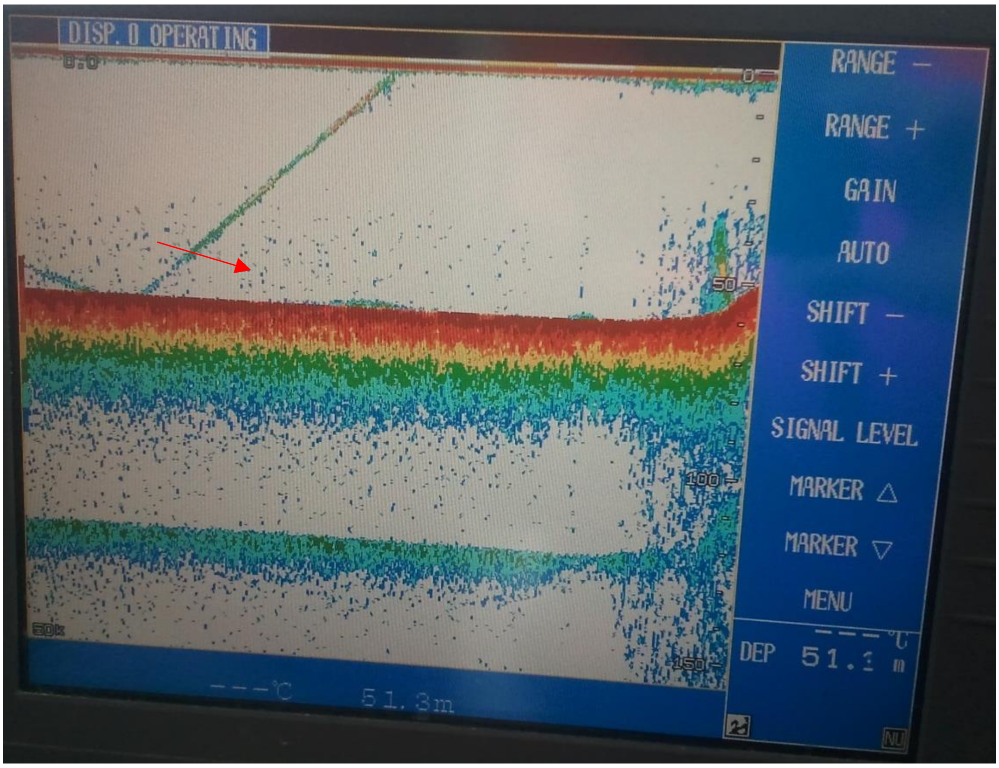



**Figure 23** Echo diagram form the 23.02.2014 in the Inner Barsnesfjord. Picture taken with a cell phone camera. Red arrow indicates the disappeared RPD-layer following the inflow new basin water between 05.02.2014 and 23.02.2014.

## 5.3.5. Comparison of all stations

The Figures 24 to 29 show the already presented data but now they are directly compared to the other three stations.

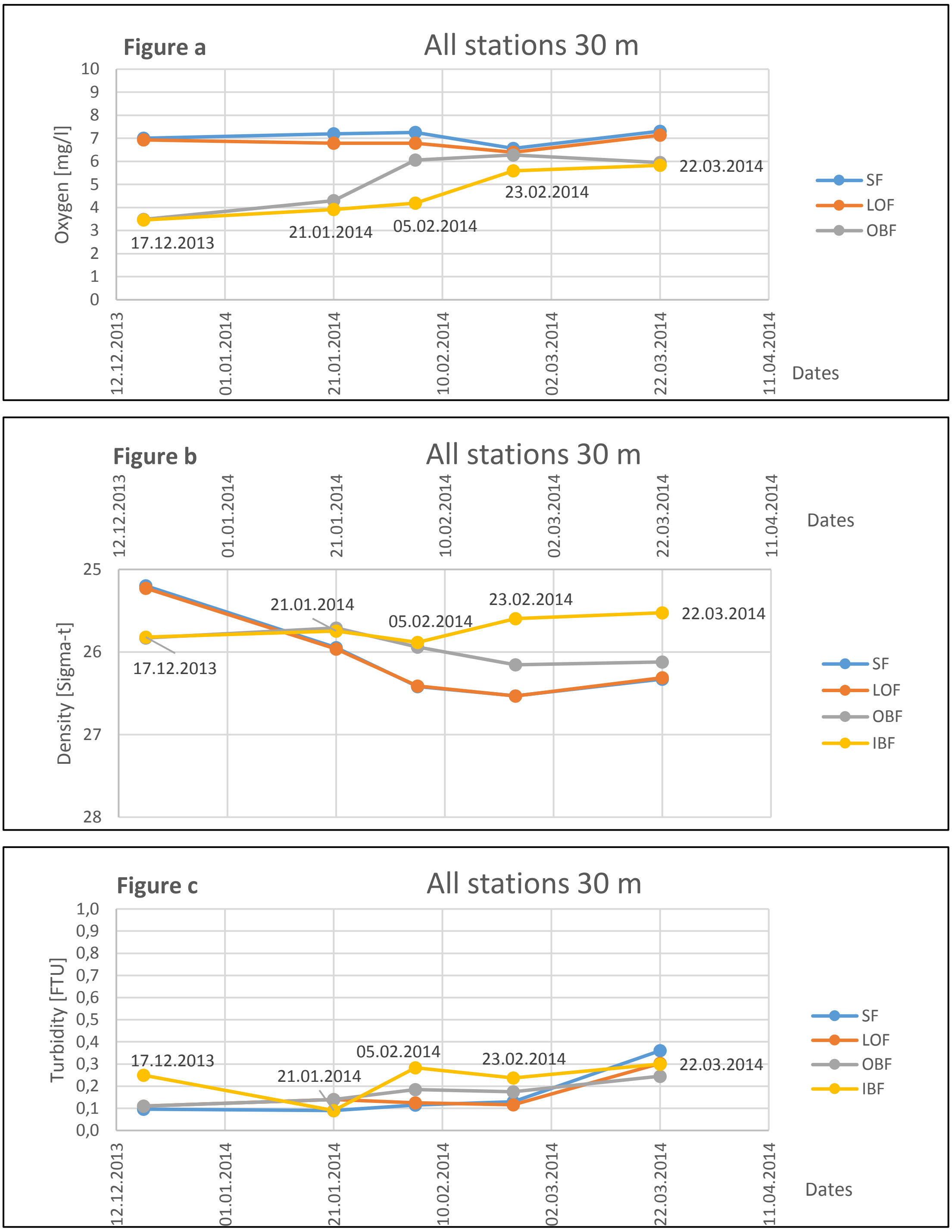



**Figure 24** a: Oxygen data in mg/l of Sogndalsfjord, Loftesnes, Outer and Inner Barsnesfjord in 30 m depth in 2013-2014. b: Density data in sigma-t of Sogndalsfjord, Loftesnes, Outer and Inner Barsnesfjord in 30 m depth in 2013-2014. c: Turbidity data in FTU of Sogndalsfjord, Loftesnes, Inner and Outer Barsnesfjord in 2013-2014. Data collected with CTD.

Figure 24 a shows the oxygen values for all four stations but only the 30 m values. It is visible that there is a pronounced increase in oxygen in the Outer Barsnesfjord from 21.01.2014 to 05.02.2014 followed by a rather small increase until the 23.02.2014. In the Inner Barsnesfjord from 21.01.2014 to 05.02.2014 it starts with a rather small increase and is then followed by a greater increase until the 23.02.2014. In the time from 05. to the 23.02.2014, both the Sogndalsfjord and the Loftesnes oxygen values decrease.

The density (Figure 24 b) in 30 m in the Outer Barsnesfjord increases from the 05.02.2014 until the 23.02.2014 whereas at the same time, the density in the Inner Barsnesfjord decreases. The Sogndalsfjord and Loftesnes values in 30 m are almost the same with the lowest values with 25,2 sigma-t on the 17.12.2013 and the highest values with 26,52 sigma-t in the Sogndalsfjord.

The turbidity (Figure 24 c) in every station increases from 23.02.2014 to 23.03.2014. The Inner Barsnesfjord has higher values in three out of the five measuring dates.

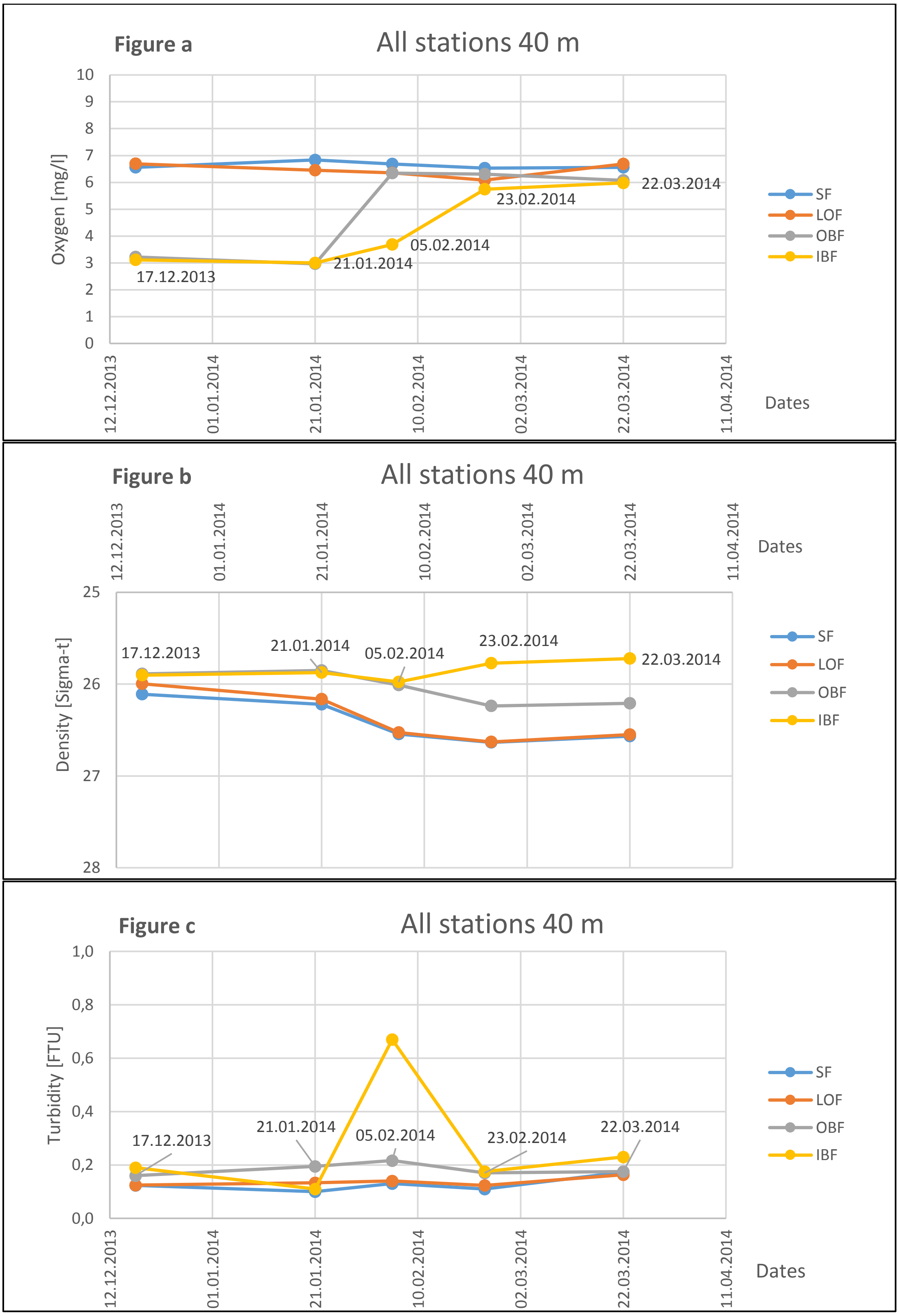



**Figure 25** a: Oxygen data in mg/l of Sogndalsfjord, Loftesnes, Outer and Inner Barsnesfjord in 40 m depth in 2013-2014. b: Density data in sigma-t of Sogndalsfjord, Loftesnes, Outer and Inner Barsnesfjord in 40 m depth in 2013-2014. c: Turbidity data in FTU of Sogndalsfjord, Loftesnes, Outer and Inner Barsnesfjord in 40 m depth in 2013-2014. Data collected with CTD.

There is a noticeable increase in oxygen (Figure 25 a) in the Outer Barsnesfjord at 40 m depth from the 21.01.2014 until the 05.02.2014 from 2,97 mg/l to 6,34 mg/l. At the same time in the Inner Barsnesfjord, the values increase, but less strongly. After that, there is a higher increase in oxygen until the 23.02.2014.

The density (Figure 25 b) data however shows almost the same pattern as the 30 m density data but here, the Sogndalsfjord and Loftesnes have higher values at the beginning (17.12.2013).

At the depth of 40 m the Sogndalsfjord, Loftesnes and Outer Barsnesfjord are rather steady in turbidity (Figure 25 c) whereas the Inner Barsnesfjord has a peak on the 05.02.2014.

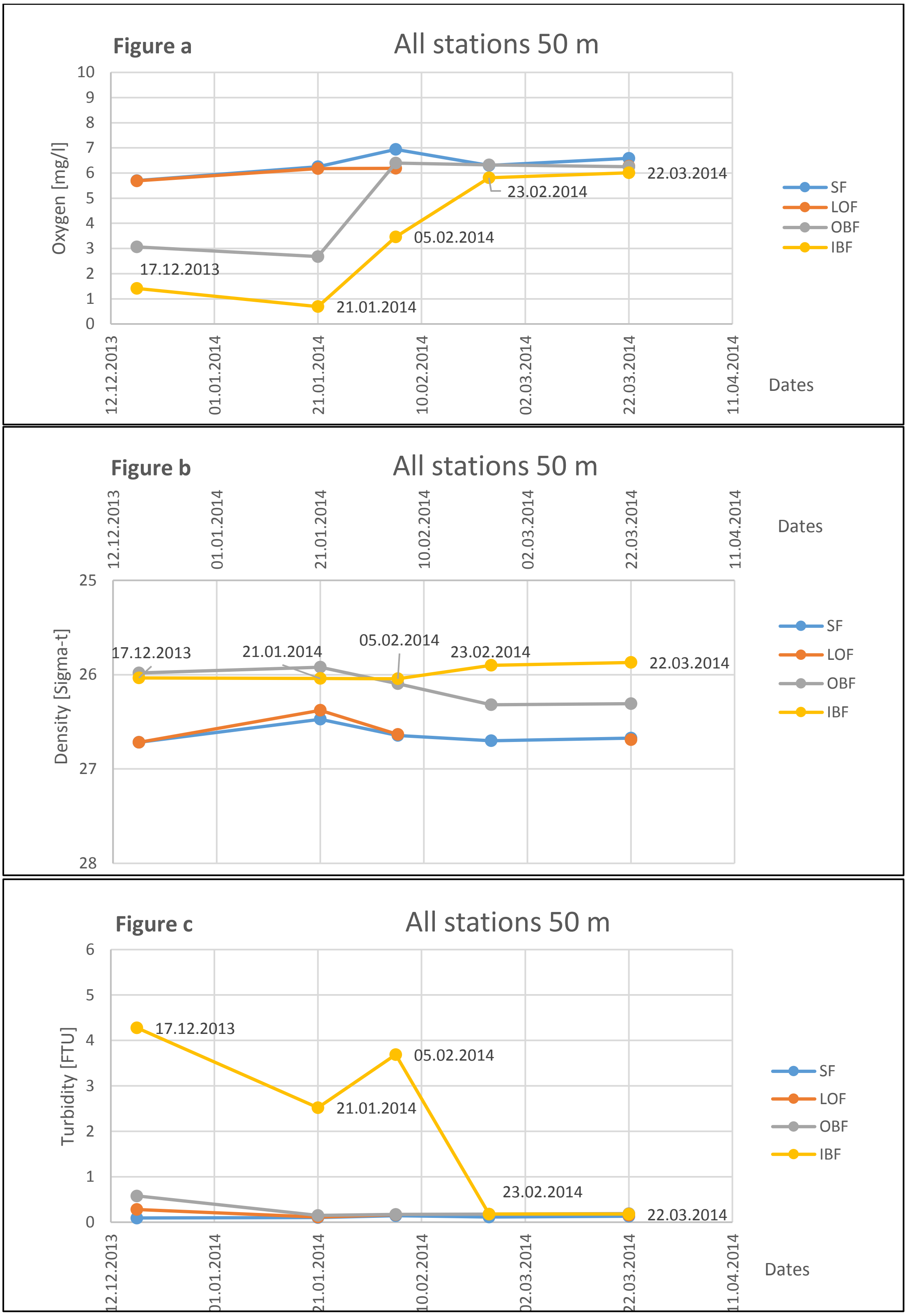



**Figure 26** a: Oxygen data in mg/l of Sogndalsfjord, Loftesnes, Outer and Inner Barsnesfjord in 50 m depth in 2013-2014. b: Density data in sigma-t of Sogndalsfjord, Loftesnes, Outer and Inner Barsnesfjord in 50 m depth in 2013-2014. c: Turbidity data in FTU of Sogndalsfjord, Loftesnes, Outer and Inner Barsnesfjord in 50 m depth in 2013-2014. Data collected with CTD.

The Inner Barsnesfjord, much like in 40 m, has a high increase in oxygen (Figure 26 a) from 21.01.2014 to 23.02.2014 in 50 m depth whereas the Outer Barsnesfjord only has an increase from 21.01.2014 to 05.02.2014. The Sogndalsfjord and Loftesnes only show little variation in oxygen content.

The changes in the density (Figure 26 b) at 50 m depth do not differ much from the upper depths. However, the values in the 17.12.2013 for the Sogndalsfjord and Loftesnes are higher than at the previous depths and with 26,72 sigma-t the highest density in 50 m.

In the Outer Barsnesfjord, Loftesnes and Sogndalsfjord the turbidity (Figure 26 c) only fluctuates a little whereas in the Inner Barsnesfjord it starts on the 17.12.2013 with 4,28 FTU and decreases abruptly between 05.02.2014 and 23.02.2014 to 0,18 FTU.

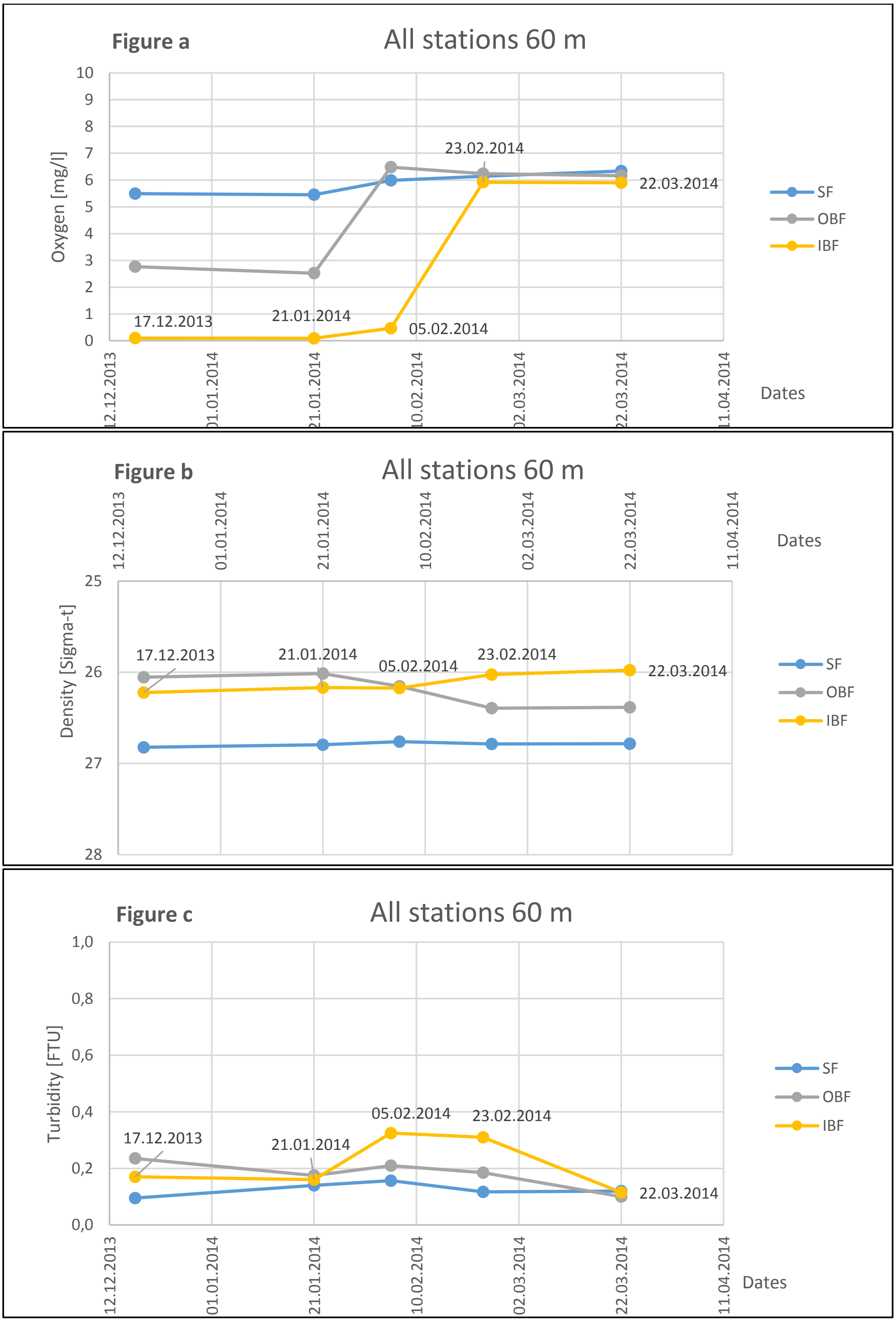



**Figure 27** a: Oxygen data in mg/l of Sogndalsfjord, Outer and Inner Barsnesfjord in 60 m depth in 2013-2014. b: Density data in sigma-t of Sogndalsfjord, Outer and Inner Barsnesfjord in 60 m depth in 2013-2014. c: Turbidity data in FTU of Sogndalsfjord, Outer and Inner Barsnesfjord in 60 m depth in 2013-2014. Data collected with CTD.

At 60 m, there are no data of Loftesnes because the measurement only went down to 53 m depth. An increase in oxygen (Figure 27 a) in the Outer Barsnesfjord from 21.01.2014 to 05.02.2014 is visible. At the same time in the Inner Barsnesfjord, there is a small increase in oxygen, followed by a notable increase until the 23.02.2014 from 0,47 mg/l to 5,92 mg/l.

The density (Figure 27 b) in the Sogndalsfjord is almost stable throughout all dates. The Outer Barsnesfjord values increase from 21.01.2014 until 23.02.2014 whereas the Inner Barsnesfjord values decrease from 05.02.2014 until 22.03.2014.

In all stations, the turbidity (Figure 27 c) increases from 21.01.2014 to 05.02.2014 followed by a decrease in all stations until the next date (23.02.2014).

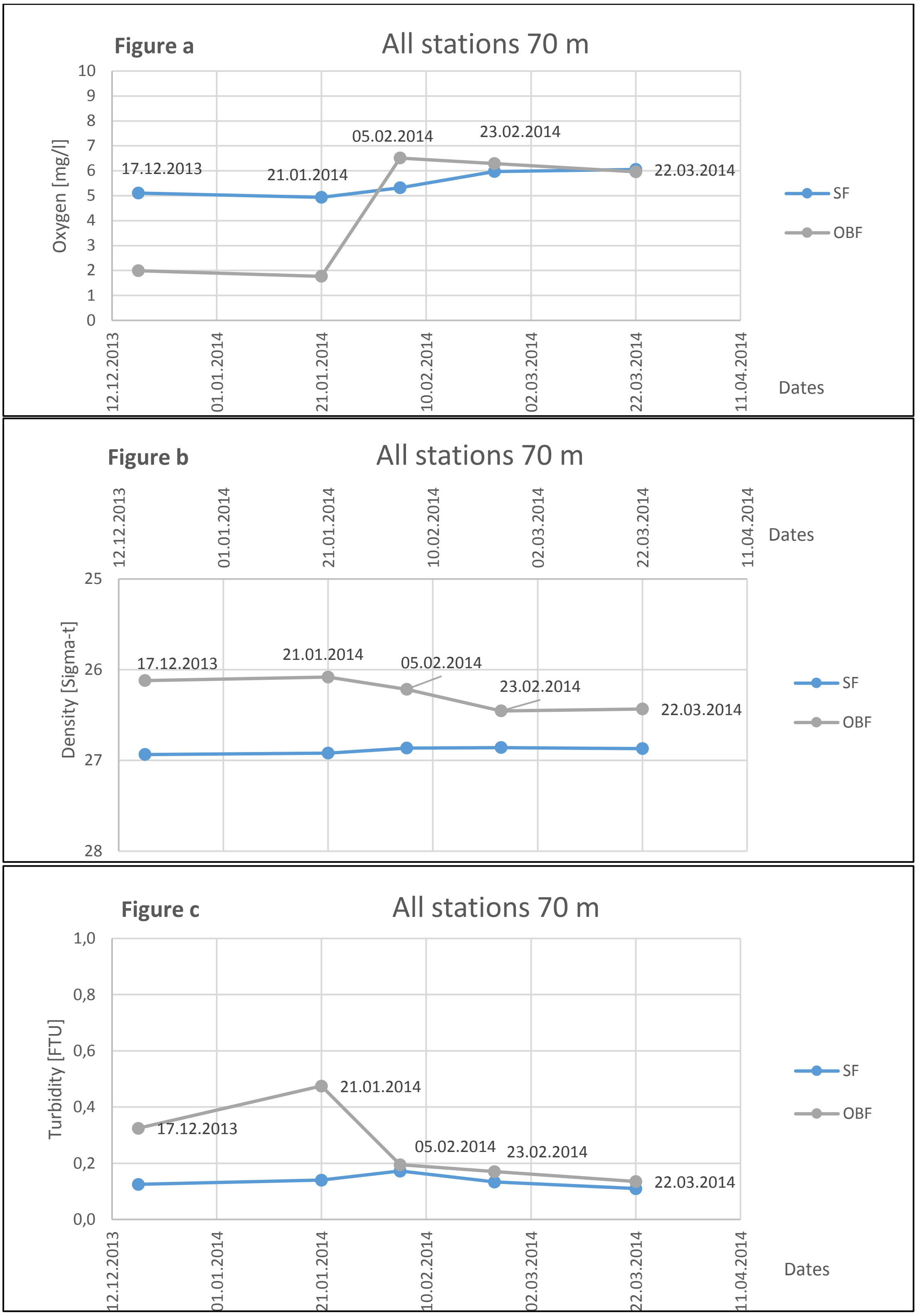



**Figure 28** a: Oxygen data in mg/l of Sogndalsfjord and Outer Barsnesfjord in 70 m depth in 2013-2014. b: Density data in sigma-t of Sogndalsfjord and Outer Barsnesfjord in 70 m depth in 2013-2014. c: Turbidity data in FTU of Sogndalsfjord and Outer Barsnesfjord in 70 m depth in 2013-2014. Data collected with CTD.

In Figure 28 and 29 are only the Sogndalsfjord and Outer Barsnesfjord data illustrated since the measurement of the Inner Barsnesfjord only went down to 64 m. An increase in oxygen (Figure 28 a) in the Sogndalsfjord in 70 m is visible from 21.01.2014 until 22.03.2014 from 4,94 mg/l to 6,05 mg/l. In the Outer Barsnesfjord the oxygen only increases from 21.01.2014 until 05.02.2014 with values from 1,77 mg/l to 6,51 mg/l.

In Figure 28 b the density in the Sogndalsfjord decreases from 21.01.2014 towards the 23.02.2014 whereas the density in the Outer Barsnesfjord increases during the same time.

The turbidity (Figure 28 c) in the Outer Barsnesfjord decreases from 21.01.2014 until 22.03.2014 with the strongest decrease from 21.01.2014 until 05.02.2014 from 0,48 FTU to 0,2 FTU.

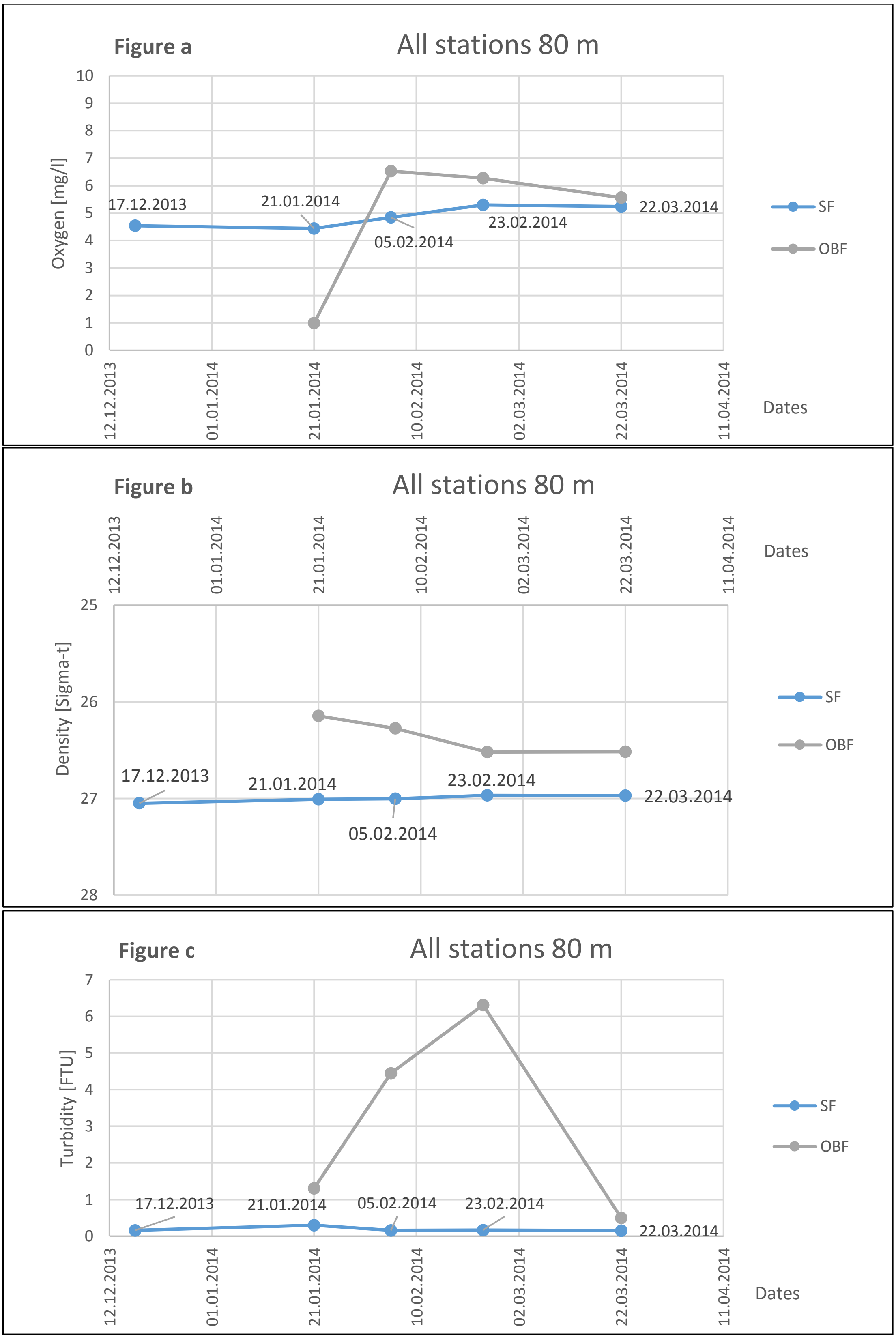



**Figure 29** a: Oxygen data in mg/l of Sogndalsfjord and Outer Barsnesfjord in 80 m depth in 2013-2014. b: Density data in sigma-t of Sogndalsfjord and Outer Barsnesfjord in 80 m depth in 2013-2014. c: Turbidity data in FTU of Sogndalsfjord and Outer Barsnesfjord in 80 m depth in 2013-2014. Data collected with CTD.

The oxygen values (Figure 29 a) show a strong increase in the Outer Barsnesfjord in 80 m depth from 21.01.2014 until 05.02.2014 with 0,99 mg/l increasing to 6,53 mg/l. The Sogndalsfjord values show an increase from 21.01.2014 until 23.02.2014 but only from 4,44 mg/l to 5,3 mg/l.

At the depth of 80 m, the density (Figure 29 b) increases from 21.01.2014 until 23.02.2014 with values from 26,25 sigma-t to 26,52 sigma-t.

The turbidity (Figure 29 c) in the Outer Barsnesfjord shows a strong increase from 21.01.2014 to 23.02.2014 with values from 1,31 FTU to 6,31 FTU followed by a strong decrease until 22.03.2014 down to 0,5 FTU.

### 5.3.6. Isopleth diagrams Loftesnes

Figure 30 shows the density conditions at Loftesnes.

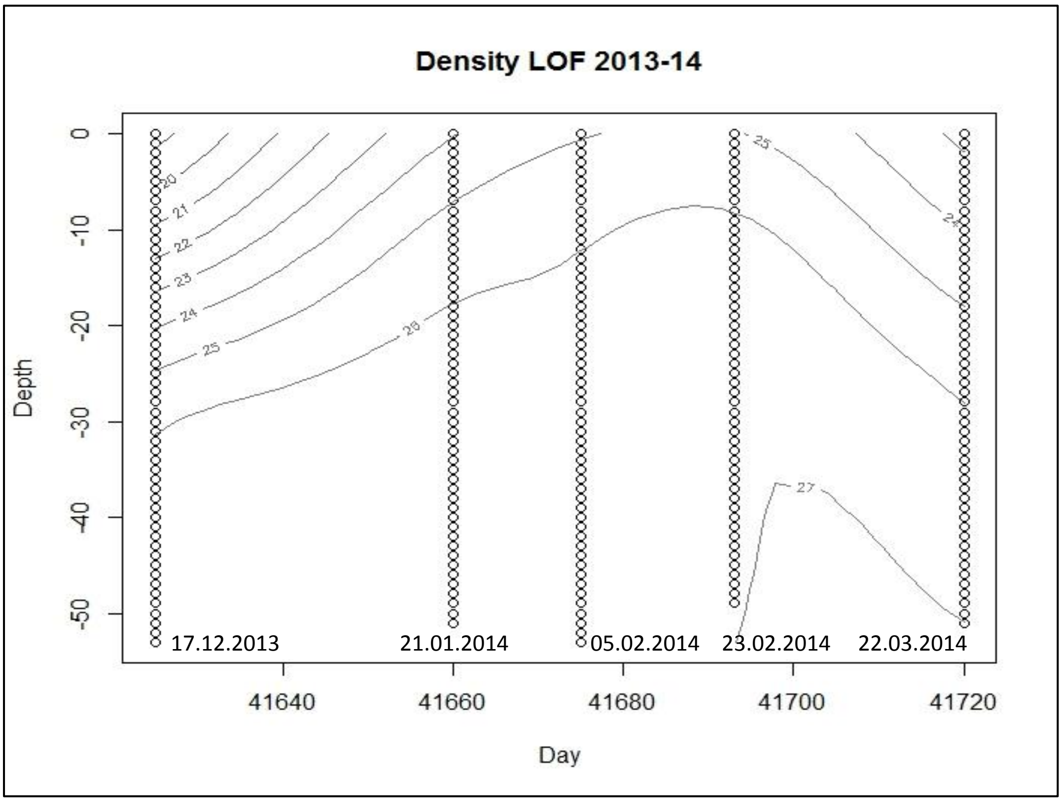



**Figure 30** Isopleth diagram showing Loftesnes density data in sigma-t in 2013-2014. Data collected with CTD.

The Figure 30 shows a strong increase in the densities in the top 20 m from 17.12.2013 until the peak in period between 05.02.2014 and 23.02.2014. Around the day 41.700 (23.02.2014), the density at Loftesnes decreases at all depths. Peak values are found below 38 m depth in the last period.

### 5.3.7. Isopleth diagram Outer Barsnesfjord

Figure 31 shows the salinity values in the Outer Barsnesfjord.

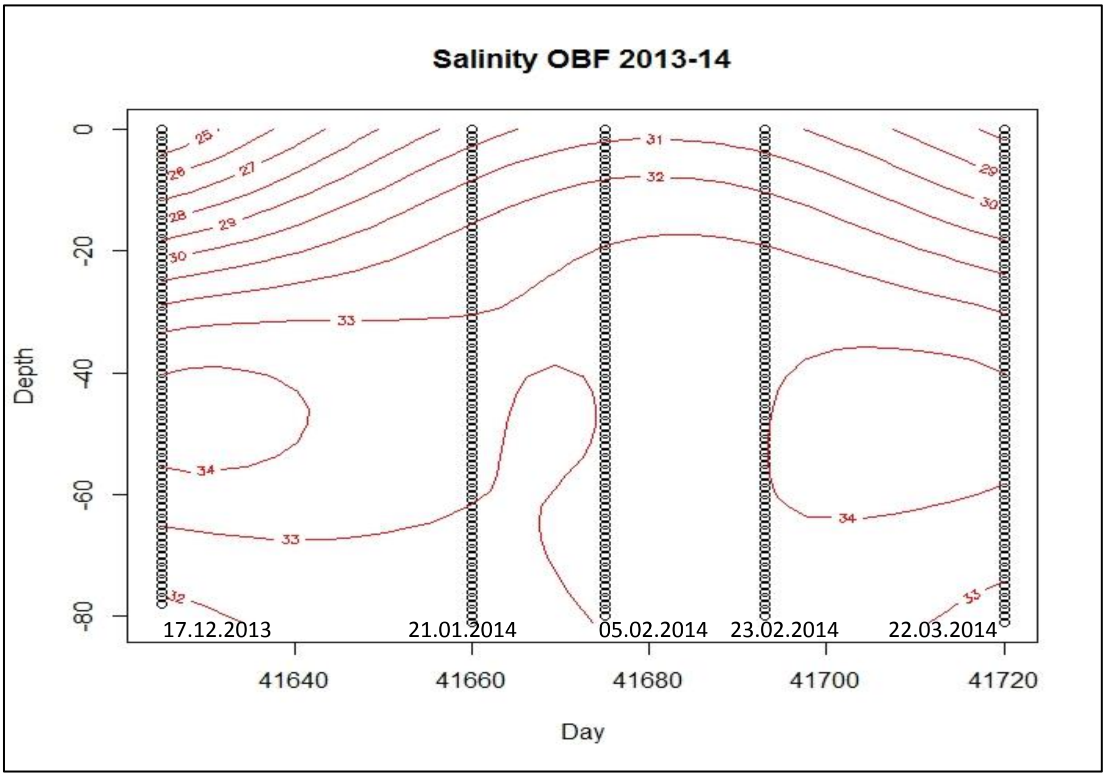



**Figure 31** Isopleth diagram showing Outer Barsnesfjord salinity data in ‰ in 2013-2014. Data collected with CTD.

In Figure 31, there is a salinity reduction from the 23.02.2014 to the 22.03.2014.

### 5.3.8. Isopleth diagrams Inner Barsnesfjord

Figure 32 shows the salinity values in the Inner Barsnesfjord.

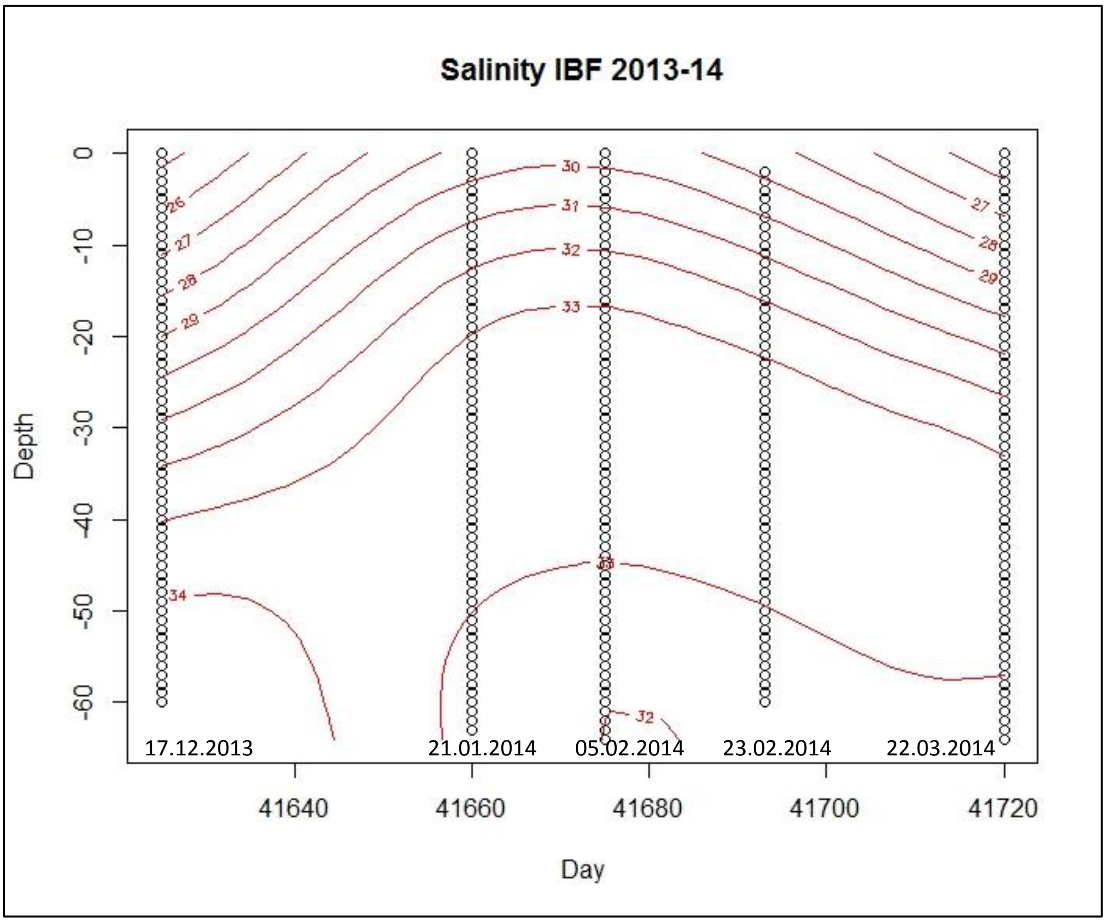



**Figure 32** Isopleth diagram showing Inner Barsnesfjord salinity data in ‰ in 2013-2014. Data collected with CTD.

In Figure 32, a very rapid salinity reduction is shown from the 23.02.2014 to the 22.03.2014. This may be related to the inflow of fresh water from the river. When compared to the isopleth diagram of the Outer Barsnesfjord, the salinity reduction in the last period happens faster in the Inner Barsnesfjord.

### Summary Outer Barsnesfjord

- Oxygen:
  - 17.12.2013 - 21.01.2014: partial inflow at 30 m
  - 21.01.2014 - 05.02.2014: (in 15 days) major inflow at all depths
- Density:
  - 21.01.2014 - 05.02.2014: increase at all depths
- Temperature:
  - 17.12.2013 - 21.01.2014: 30 m values increase; warm water flows in
  - 21.01.2014 - 05.02.2014: values at all depths increases; inflow at all depths
  - 05.02.2014 - 23.02.2014: values at all depths decrease; cold water flow in

  - First part of inflow with warm water (17.12.2013 - 05.02.2014), second part of inflow with cold water (05.02.2014 - 23.02.2014). Probably due to season.

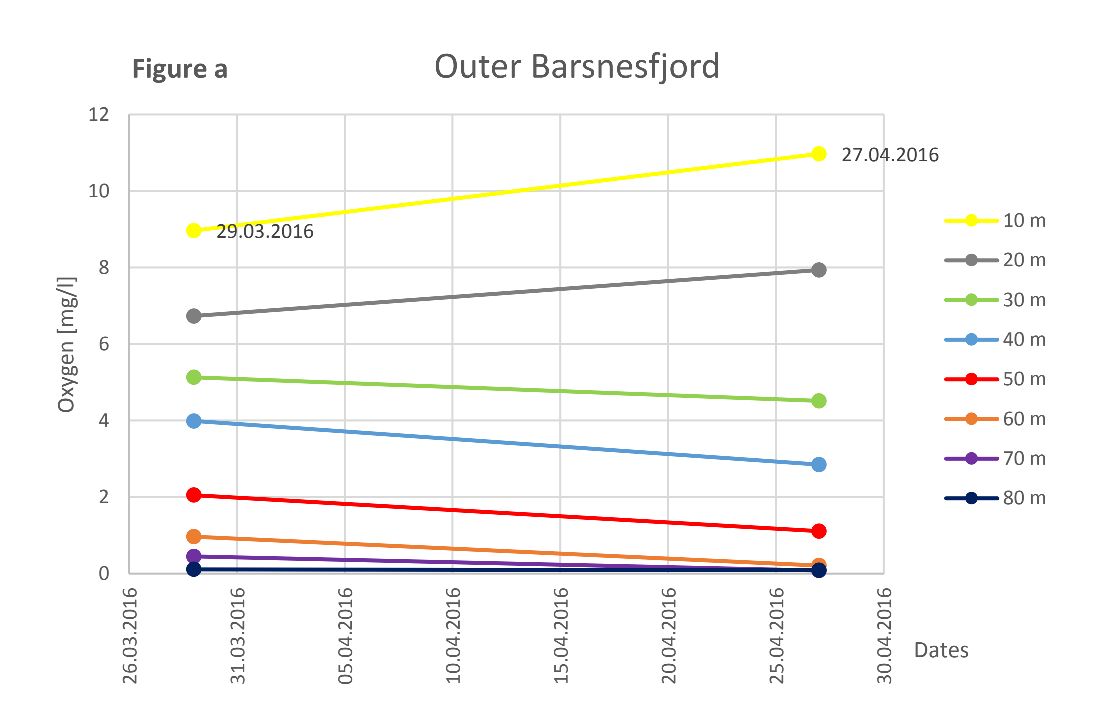
### Summary Inner Barsnesfjord

- Oxygen:
  - 21.01.2014 - 23.02.2014: increase at all depths; 60 m increase mainly from 05.02.2014 - 23.02.2014
- Temperature:
  - 21.01.2014 - 23.02.2014: increase at all depths; 60 m increase mainly from 05.02.2014 - 23.02.2014
- Turbidity:
  - Turbidity peak associated with RPD-layer
  - 17.12.2013: peak at ca. 51 m depth
  - 21.01.2014: peak at ca. 48 m depth; layer went up from 51 to 48 m; because deep water became more anoxic
  - 05.02.2014: peak at ca. 54 m depth; layer went down from 48 to 54 m; due to inflow
  - After that, turbidity values are low because turbid water washed out

## 5.4. Year 2016

The measurement from the year 2016 have only two dates of measurement from the Outer Barsnesfjord, circa one month apart and provided data of oxygen in mg/l and density in sigma-t. The dates of measurement are shown on the x-axis whereas the values of the parameter are shown on the y-axis. The y-axis for the density values is reversed.

In Figure 33 a are the oxygen values for these two dates. At the depths from 10 m to 80 m. At the depths from 30 m to 80 m, the values are decreasing a little. Only the 10 m and 20 m show an increase in oxygen. The density data in Figure 33 b show a minor decrease at all depths.



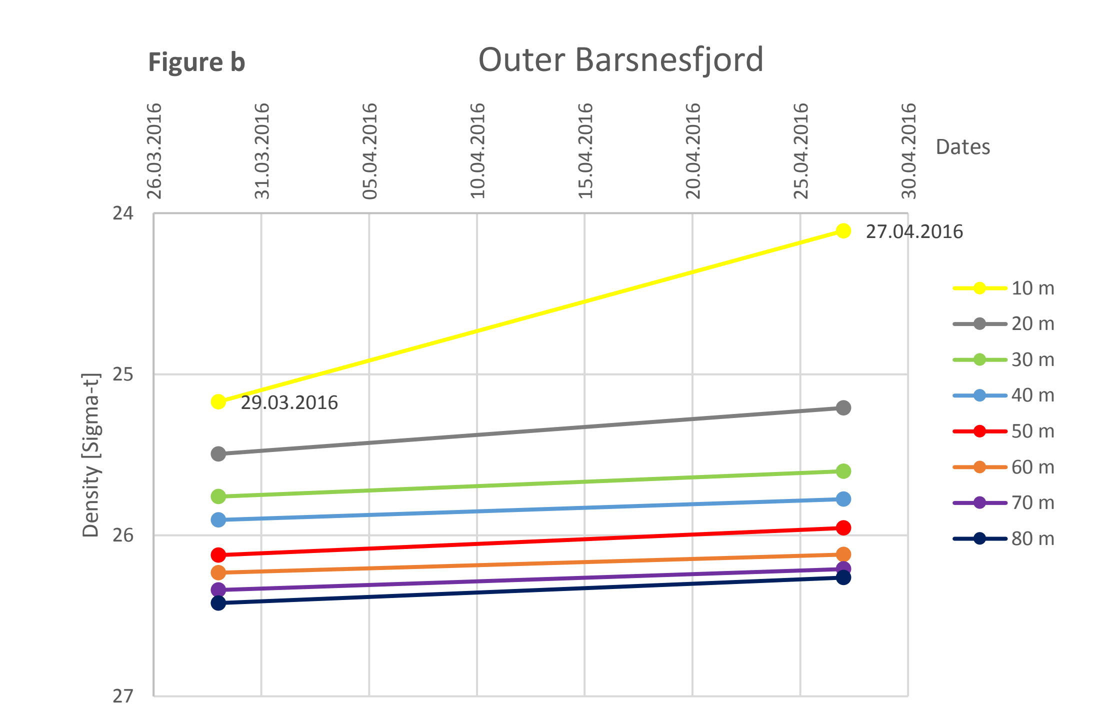




**Figure 33** a: Oxygen data in mg/l of Outer Barsnesfjord in 2016. b: Density data in sigma-t of Outer Barsnesfjord in 2016. Data collected with CTD.

## Summary Outer Barsnesfjord

- Oxygen & density:
  - 29.03.2016 - 27.04.2016: values decrease; no inflow

# 6. Discussion

It should be noted that there might be some inaccuracies due to measuring errors or different methods. All data depicted/visualized in the results are reliable in showing inflow events.

The discussion will be structured as the five objectives.

## 1. When does basin water exchange happen in the Outer and Inner Barsnesfjord in the years 1984-1985, 1990-1993, 2013-2014 and 2016?

An inflow to the Outer Barsnesfjord starts in early winter (December/early January). But the water does not replace the complete basin water, it is only a partial inflow to a shallow depth of 30 m. This kind of partial inflow happened in October/November 1984 and December/January 2014 both at a depth of 30 m. When the water in the Sogndalsfjord becomes denser in late January/February the inflowing water can go deeper down into the basin of the Outer Barsnesfjord.

The inflow to a certain depth, like 30 m, can be revealed by a decrease in oxygen higher in the water, like 20 m. The 20 m in this example decrease because the inflow of new and oxygen rich water caused the older and low oxygen water above to go higher in the water masses.

But an inflow is not always revealed by oxygen values. When new oxygen rich water flows into a basin, it is shown by an increase in oxygen values. But once the highest oxygen saturation is reached, depending on the conditions of the water, new incoming water cannot be detected. There is no further increase since the water already has the highest oxygen level. In the Outer Barsnesfjord (from 05.02. to 23.02.2014) there was an inflow not revealed by oxygen data. The density showed that even after the inflow has seemingly reached its maximum, according to the oxygen data, the inflow continued, according to the density data.

The deepest water in a basin is replaced the latest in the inflow process. This is mostly because several processes must work together to create dense enough water to replace the deepest water of the basin. That is why a complete renewal of the deep basin water happens during winter time. The cold atmosphere and northerly winds together with a low freshwater input create water that is dense enough to replace the deepest parts of the basins.

### 2. How is the inflow sequence to Outer and Inner Barsnesfjord?

During the four periods of data, the years 1984, 1991, 1993 and 2014 showed an inflow to the Barsnesfjord.

The water that is renewing the Outer Barsnesfjord water comes from the Sogndalsfjord. It either replaces the whole water column or, in some cases, just parts of the water column. When the latter is happening, the water from the Sogndalsfjord is not dense enough to go all the way down and replace the complete basin water.

The water renewing the Inner Barsnesfjord water can come either from the Outer Barsnesfjord or directly from the Sogndalsfjord. But it will most likely be the old basin water from the Outer Barsnesfjord that will flow over the sill in the Barsnesfjord (30 m) and replace the fjord water in the Inner Barsnesfjord in a depth depending on its density.

### 3. The inflow of water into the basins (basin water exchange) of the Barsnesfjord comes from water of the Sogndalsfjord flowing over the sill at Loftesnes. What are the density conditions in the water of the Sogndalsfjord and Barsnesfjord when an inflow happens?

Water in the Sogndalsfjord needs a high enough density to replace water from the Barsnesfjord. That dense water then flows into the basin of the Outer Barsnesfjord. The highest density in the Sogndalsfjord as well as in the Outer Barsnesfjord can be observed in late February. What is surprising about this is that the inflow into the basin of the Outer Barsnesfjord in 2014 started before that. It was expected that an inflow happens when the water has reached its highest density but it was revealed that an inflow starts even when the water is not at its densest state.

A high density is found in January/February in the Outer Barsnesfjord in 2014. Since it is wintertime, this period is associated with low precipitation, a cold atmosphere and northerly winds.

### 4. Can variations in the water inflow be related to environmental change?

The frequency and intensity of a water inflow in the Barsnesfjord might have changed over time.

As mentioned earlier, an inflow from the Sogndalsfjord to the Barsnesfjord requires dense enough water to spill over the sill. That dense water is produced by wind and season (colder atmosphere and low freshwater input). When for example the atmospheric temperature, especially during winter time, increases, a decreasing frequency of inflow might be the consequence since this would reduce the density of the water. Warmer water would also result in lower oxygen levels since warm water cannot contain as much free oxygen as cold water. Decreasing oxygen concentration would then lead to anoxic basin water in the fjord.

A decreasing frequency of inflow events may also be due to a change in wind direction. As mentioned before, the creation of dense water is partly due to northerly winds. If these winds change in direction, there will be less upwelling of dense water outside the Loftesnes sound. Less dense water would reduce the frequency of basin water exchanges in the Barsnesfjord which would lead to less oxygen in basin water.

### 5. How may the new bridge at Loftesnes effect the basin water exchanges?

Since the water that flows into the basin of the Outer Barsnesfjord must pass the sill at Loftesnes, the construction of the new bridge may influence inflow events.

The building of the new bridge includes rockfills on the shores on both sides of the sound at Loftesnes as well as the posting of two pillars very close to the shore (Golmen et al., 2010). That will most probably reduce the inflow area in the deepest part of the sill.

If the inflow area will be reduced, the volume of water flowing to the Outer Barsnesfjord will probably decrease. The water will naturally try to compensate the loss of volume by increasing the inflow speed but it will most probably not be sufficient.

The report of 2010 (Golmen et al.) stated that the building of the bridge and the rock-fills as well as the pillars should not significantly affect the water exchange between the Sogndalsfjord and the Barsnesfjord.

It has not been investigated if the depth of the sill will be reduced for the new bridge. Therefore, it can only be speculated that if the depth of the sill will decrease, the frequency of inflow events might reduce even more. Kaufman (2014) found out that during the last 97 years, the frequency of inflow events has already decreased from every year or every second year (during 1916-1965) to every third year (during 2002-2013).

A shallower sill will probably further decrease the frequency since it is more difficult for heavier water to go over the sill. This would lead to less oxygen rich water coming to the Barsnesfjord and then to probably more frequent and longer anoxic periods in the basins of the fjord. The situation would have even worse consequences for the Inner Barsnesfjord. It already has periods with anoxic basin water but then this would increase with probably longer periods and more anoxic water masses.

## 7. Conclusion

The aim of this study was to find out mainly when and how basin water in the Barsnesfjord is exchanged as well as possible changes due to environmental change and the building of the new bridge at Loftesnes.

It can be concluded, that:

1) The major inflow events that exchange basin water in the Barsnesfjord occur in winter time in January/February.
2) Not always is the whole water column replaced. Sometimes there is only a partial renewal of basin water. This is because the water does not have a high enough density to replace all the water including the heaviest water in the basin.
3) Focusing mainly on oxygen values was not sufficient to show all inflow events. The density data was able to reveal another inflow/a continuation of an inflow event.
4) Changing wind direction and increasing temperatures might decrease the frequency and intensity of basin water exchanges even more.
5) The building of the new bridge at Loftesnes will most probably not affect the basin water exchange in the Barsnesfjord negatively.

# References


Dale, T. (2015). *Innsamling av bunnprøver i Loftesnes-sundet for analyser av miljøgifter: En feltrapport fra en pilotinnsamling 25. okt. 2014, og en hovedinnsamling 8. og 12. november 2014.* Sogndal.

Dale, T. (2016). *Overvåking av turbiditeten i vannmassene omkring Loftesnessundet i Sogndal i perioden jan.-april 2016, i forbindelse med dumping av fyllmasser ved bygging av ny bro.* Sogndal: Western Norway University of Applied Sciences.

Dale, T., & Hovgaard, P. (1993). *En undersøkelse av resipientforholdene i Sogndalsfjorden, Barsnesfjorden og Kaupangerbukten i perioden 1991-1993. A study on the recipients Sogndalsfjorden, Barsnesfjorden and Kaupangerbukten in the period 1991-1993.* Sogndal: Sogn og Fjordane Distriktshøgskule.

*Encyclopedia Britannica*. (2017, April 10). Retrieved from Nansen Bottle: https://global.britannica.com/technology/Nansen-bottle

*Encyclopedia Britannica*. (2017, Mai 24). Retrieved from Marine ecosystem: https://www.britannica.com/science/marine-ecosystem#ref588506

*Fjords.com*. (2017, April 05). Retrieved from What Is a Fjord and How Is It Formed: http://www.fjords.com/what-is-a-fjord.shtml

Golmen et al. (2003). *Forprosjekt ny Loftesnesbru, Sogndal.* Sogndal: NIVA.

Golmen et al. (2010). *Ny Loftesnesbru i Sogndal. Vurdering av miljøkonsekvensar i sjøen.* Sogndal: NIVA.

Hovgaard, P. (1985). *Resipientforhold i Sogndal kommune.* Sogndal: Sogn og Fjordane Distriktshøgskule.

Hovgaard, P. (1985). *Resipientundersøkelse i Sogndal kommune. En vurdering.* Sogn og Fjordane Distriktshøgskule.

Howe, J., Austin, W., & Forwick, M. &. (2011). *Fjord Systems and Archives.* London: Geological Society.

*Hydro-Bios*. (2017, April 13). Retrieved from Standard Wasserschöpfer Nach Ruttner 1l Oder 2 l: https://www.hydrobios.de/produkt/standard-wasserschopfer-nach-ruttner-1l-oder-2l/?lang=de

*Institute of Marine Research*. (2017, Februar 13). Retrieved from Fjords - water exchange and currents: http://www.imr.no/temasider/kyst_og_fjord/fjorder_vannutskiftning_og_strom/en

Kaufmann, S. (2014). *A 100 year hydrographical record of the Barsnesfjord, Western Norway and its environmental application.* University of Applied Science Bingen.

Myrseth et al. (2000). *Marinbiologisk miljoundersokelse i Barsnesfjorden, Sogndalsfjorden og Amlabukten, Sogndal kommune.* Sogndal: IFM Rapport Nr. 4 - 2000.

Paetzel, M., & Dale, T. (2010). Climate proxies for recent fjord sediments in the Inner Sognefjord region, western Norway. In J. A. Howe, *Fjord Systems and Archives* (pp. 271-288). London: Geological Society, Special Publications 344.

Perillo, G. M. (1996). *Geomorphology and Sedimentology of Estuaries.* New York: Elsevier Science.

Reß, T. (2015). *Some hydrographical changes in the Sognefjord and its tributaries, the Sogndalsfjord and the Barsnesfjord (Western Norway), the last century.* Western Norway University of Applied Sciences.

Rosenberg, P. &. (1977). *Macrobenthic succession in relation to organic enrichment and pollution of the marine environment.* Scotland: Aberdeen University Press.

Sætre, R. (2007). *The Norwegian Coastal Current: Oceanography and Climate.* Trondheim: Tapir Academic Press.

*SAIV / AS.* (2017, April 14). Retrieved from STD/CTD - model SD204: http://www.saivas.no/upload/SD204%20NY2.pdf

Stigebrandt, A. (1981). *A Mechanism Governing the Estuarine Circulation in Deep, Strongly Stratified Fjords.* Estuarine, Coastal and Shelf Science 13.

Syvitski, J., & Burrel, D. &. (1987). *Fjords: Processes and Products.* New York: Springer.

Venneman, M. (2014). *Effects of a new bridge on an intertidal mudflat in the Outer Barsnesfjord, Western Norway.* Van Hall Larenstein University of Applied Sciences.

*Wetter-gevenich.de*. (2017, April 14). Retrieved from http://www.wetter-gevenich.de/Grafiken_Allgemein/Isoplethen/Isoplethen.html

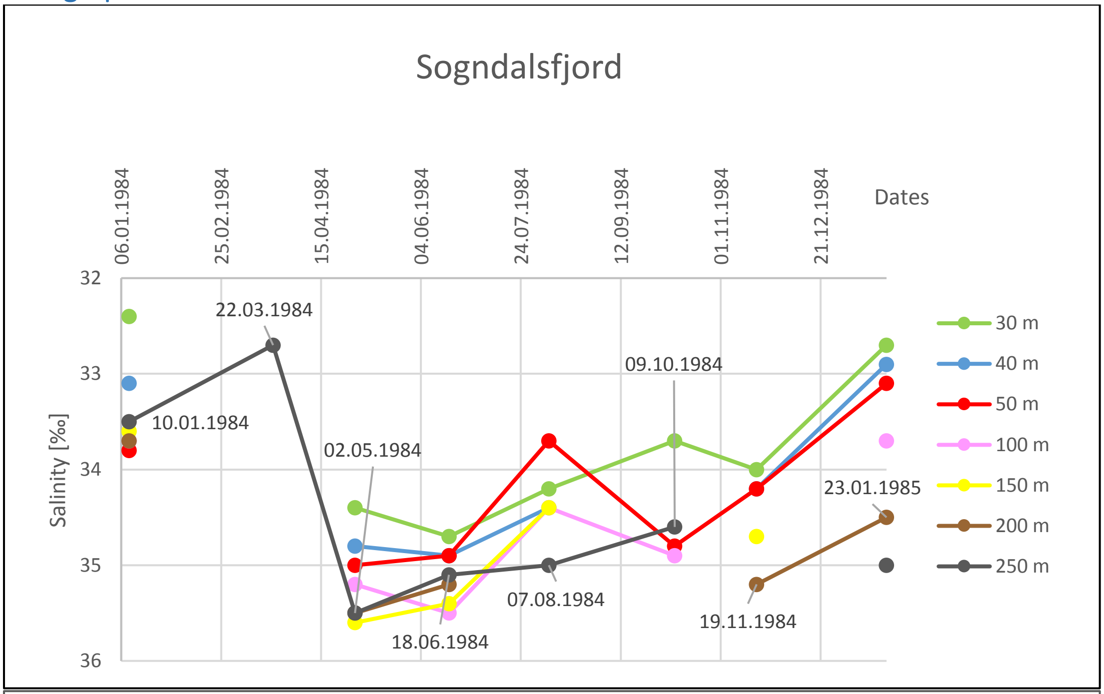
*YSI Manual.* (2017, April 13). Retrieved from YSI Model 57 Dissolved Oxygen Meter Instruction Manual: https://www.ysi.com/File%20Library/Documents/Manuals%20for%20Discontinued%20Products/57-Dissolved-Oxygen-Meter.pdf

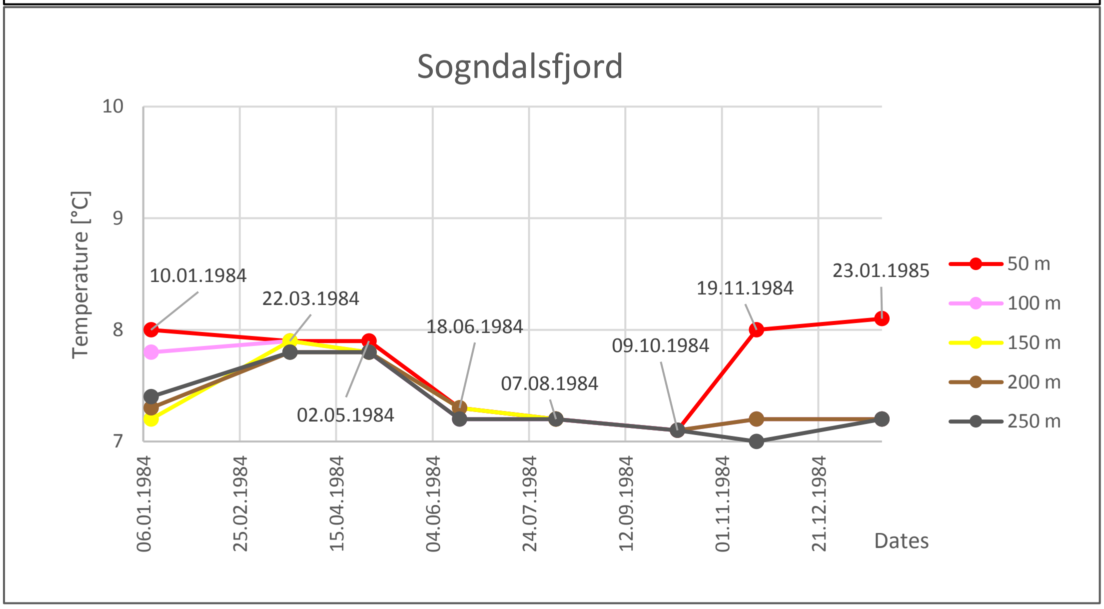
*YSI Model 57 Dissolved Oxygen Meter Instruction Manual.* (2017, April 13). Retrieved from https://www.ysi.com/File%20Library/Documents/Manuals%20for%20Discontinued%20Products/57-Dissolved-Oxygen-Meter.pdf.

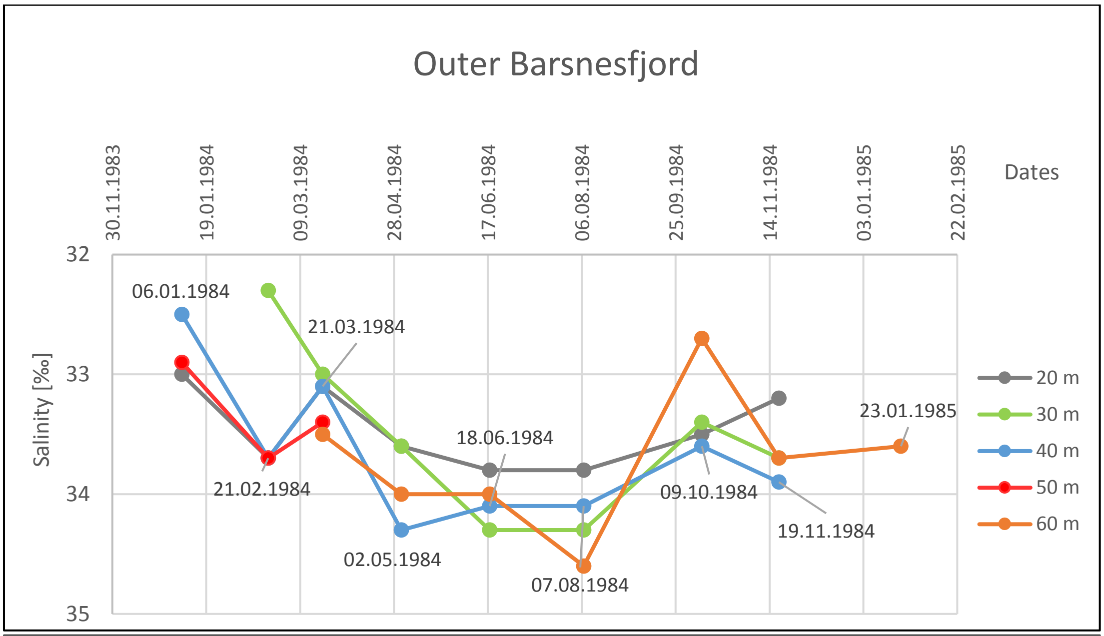
# Appendix

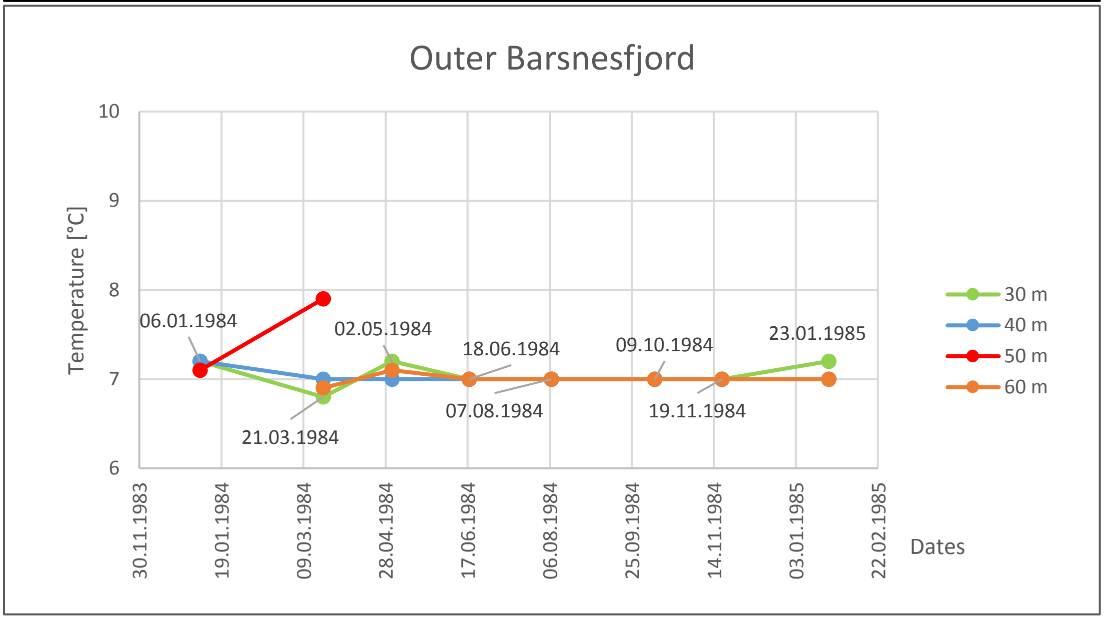
## Appendix I: Additional graphs & diagrams

### Line graphs 1984-1985

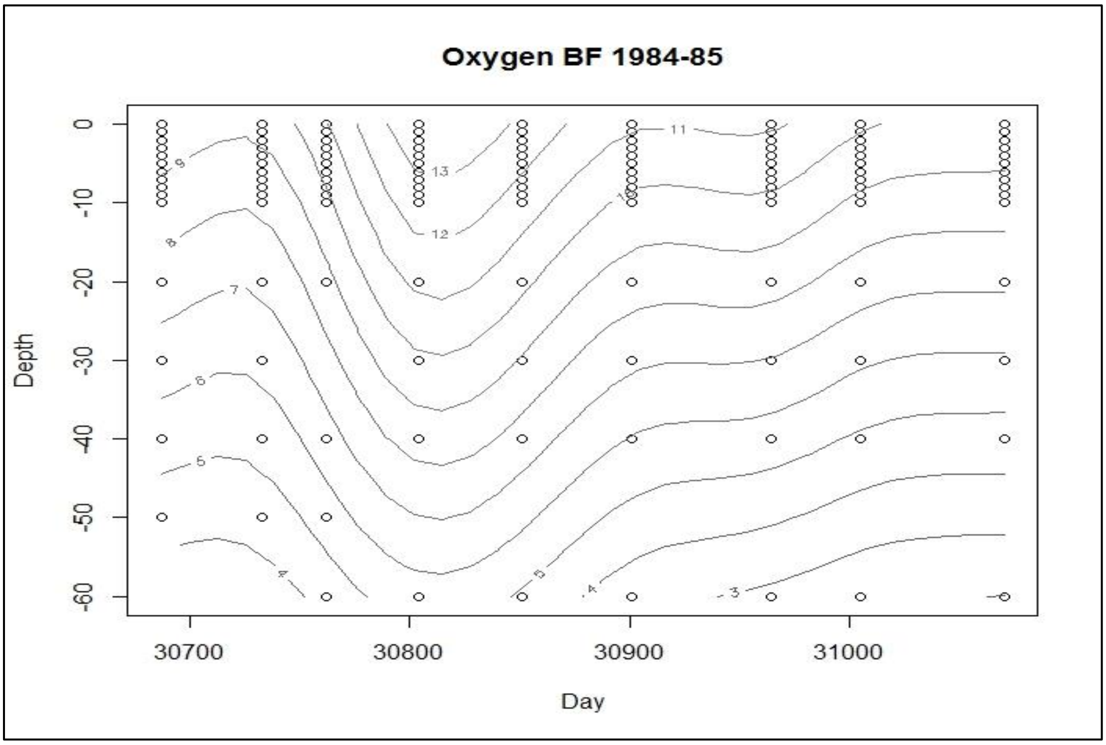


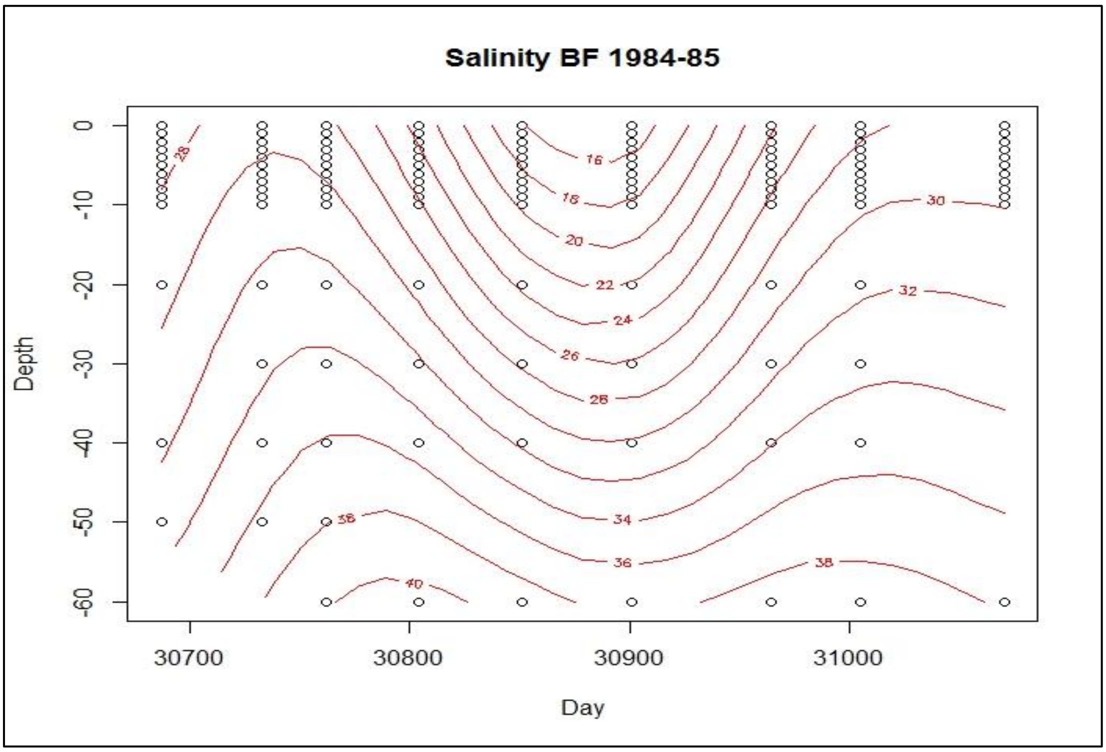




Outer Barsnesfjord
Dates
30.11.1983
19.01.1984
09.03.1984
28.04.1984
17.06.1984
06.08.1984
25.09.1984
14.11.1984
03.01.1985
22.02.1985
Salinity [‰]
32
33
34
35
06.01.1984
21.03.1984
21.02.1984
18.06.1984
02.05.1984
07.08.1984
09.10.1984
19.11.1984
23.01.1985
20 m
30 m
40 m
50 m
60 m

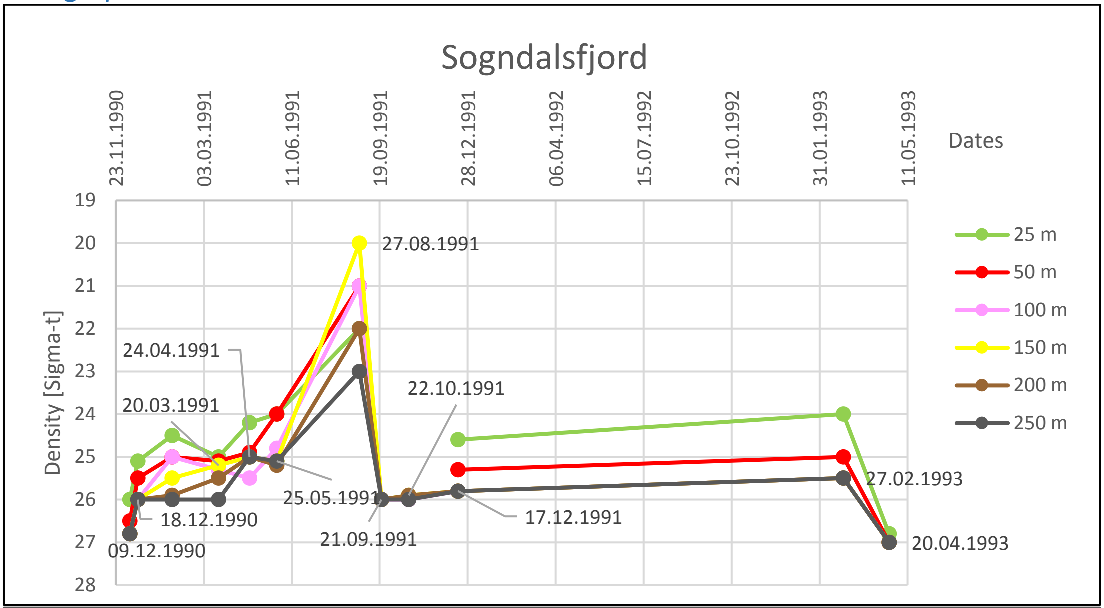

Outer Barsnesfjord
Temperature [°C]
10
9
8
7
6
06.01.1984
02.05.1984
18.06.1984
09.10.1984
23.01.1985
21.03.1984
07.08.1984
19.11.1984
30.11.1983
19.01.1984
09.03.1984
28.04.1984
17.06.1984
06.08.1984
25.09.1984
14.11.1984
03.01.1985
22.02.1985
Dates
30 m
40 m
50 m
60 m

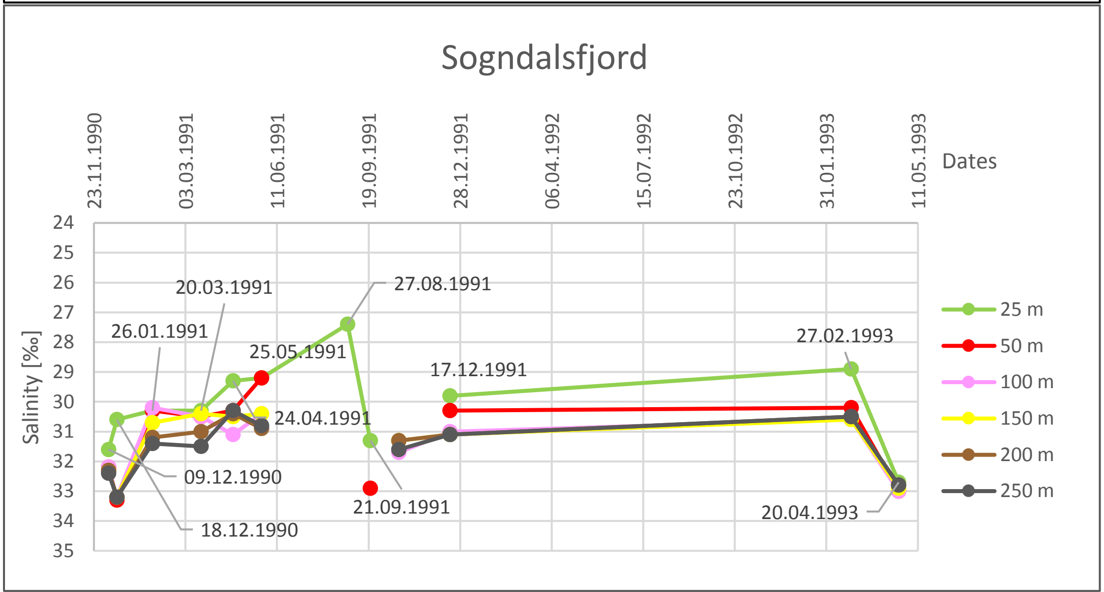
## Isopleth diagrams 1984-1985

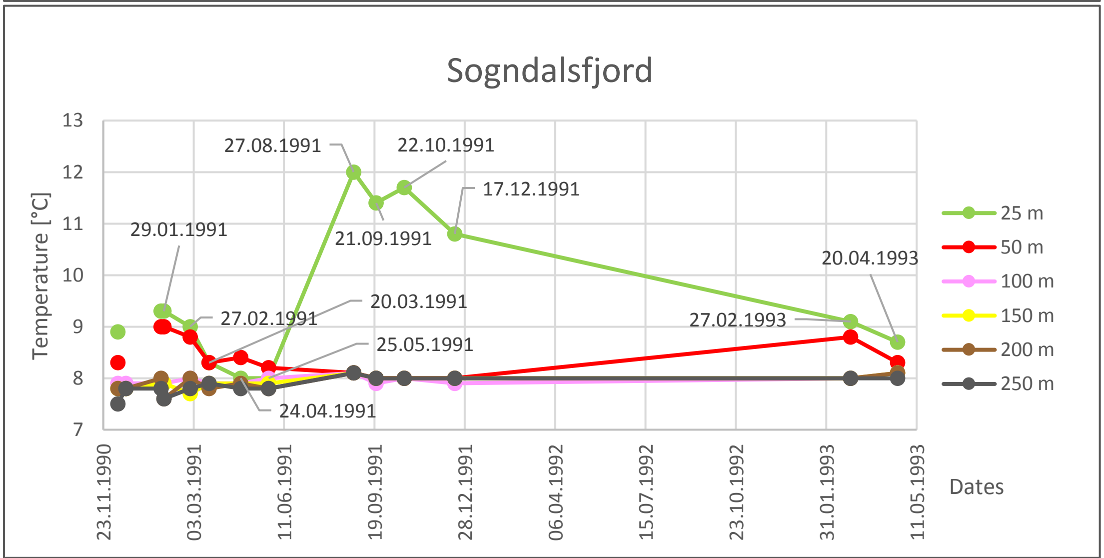


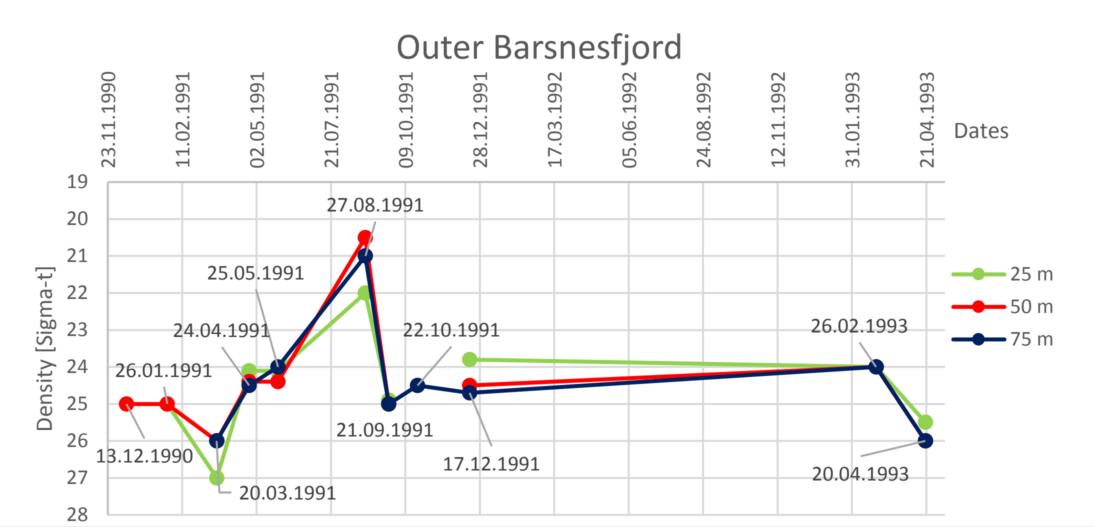



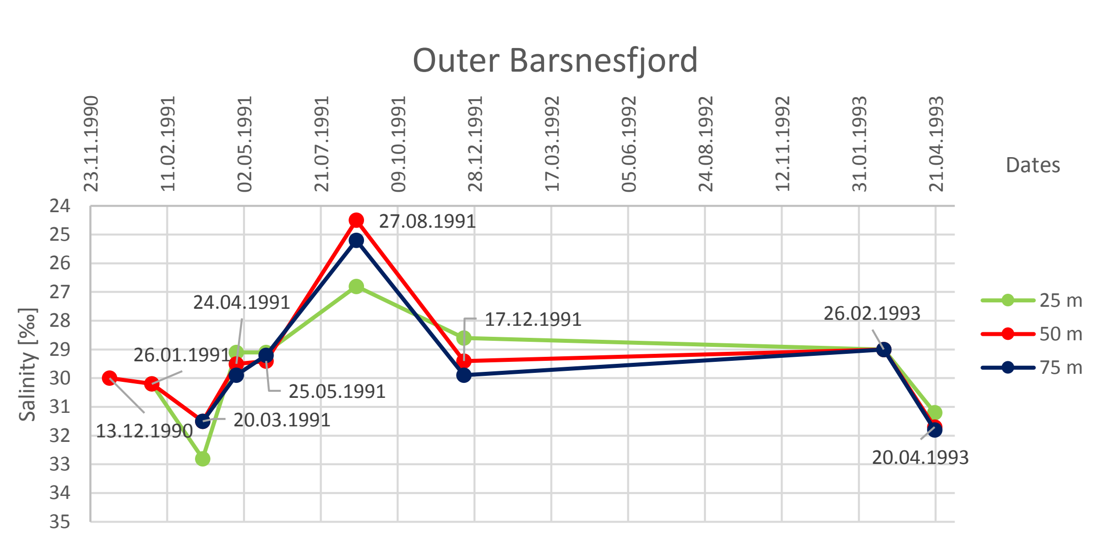
## Line graphs 1990-1993

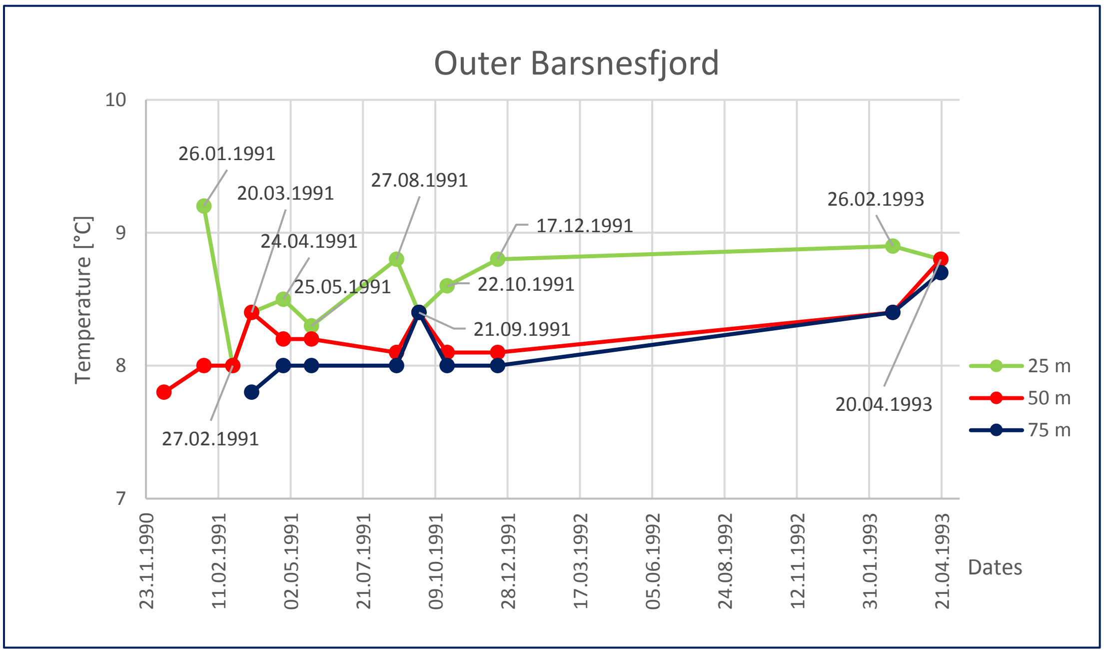


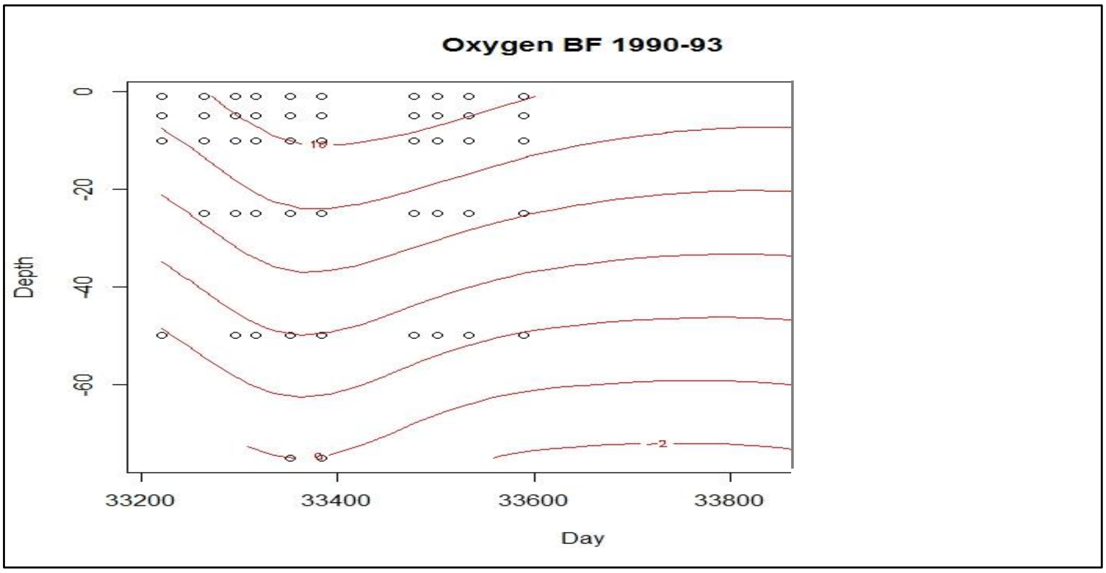



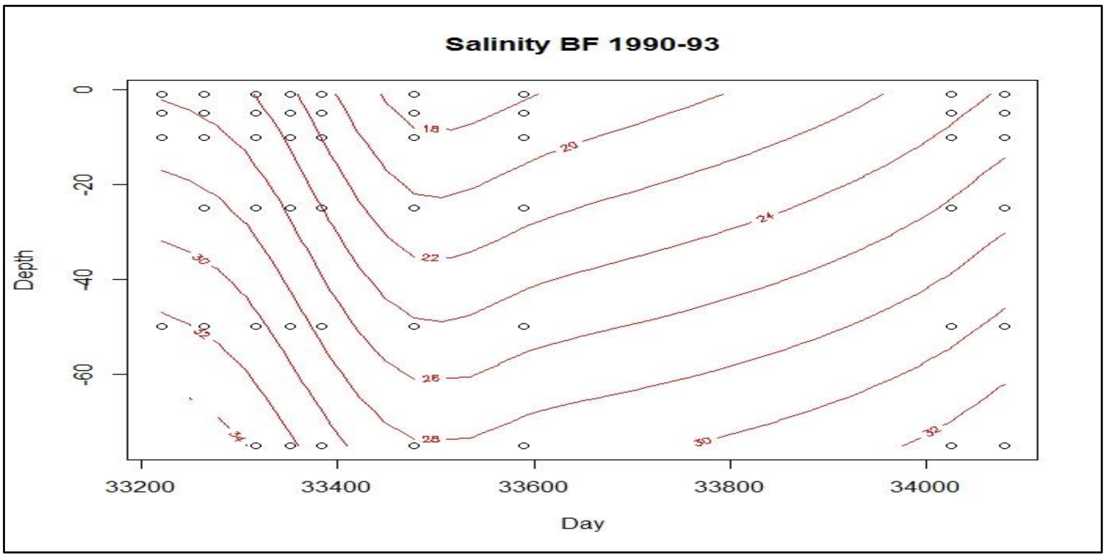

Outer Barsnesfjord
Dates
23.11.1990
11.02.1991
02.05.1991
21.07.1991
09.10.1991
28.12.1991
17.03.1992
05.06.1992
24.08.1992
12.11.1992
31.01.1993
21.04.1993
Density [Sigma-t]
19
20
21
22
23
24
25
26
27
28
27.08.1991
25.05.1991
24.04.1991
22.10.1991
26.02.1993
26.01.1991
21.09.1991
13.12.1990
17.12.1991
20.04.1993
20.03.1991
25 m
50 m
75 m

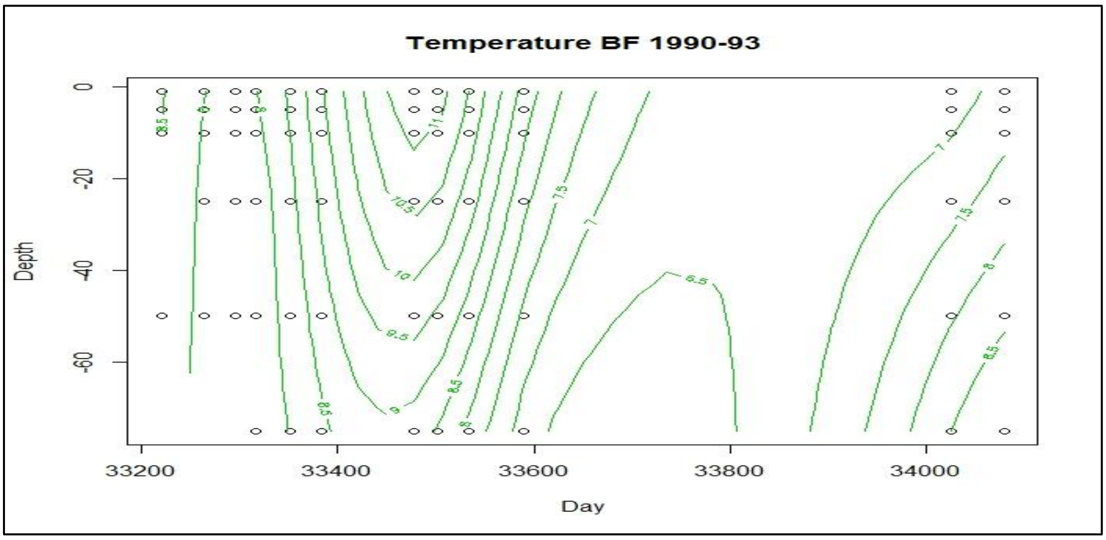

Outer Barsnesfjord
Dates
23.11.1990
11.02.1991
02.05.1991
21.07.1991
09.10.1991
28.12.1991
17.03.1992
05.06.1992
24.08.1992
12.11.1992
31.01.1993
21.04.1993
Salinity [‰]
24
25
26
27
28
29
30
31
32
33
34
35
27.08.1991
24.04.1991
17.12.1991
26.02.1993
26.01.1991
25.05.1991
20.03.1991
13.12.1990
20.04.1993
25 m
50 m
75 m


Outer Barsnesfjord
Temperature [°C]
10
9
8
7
26.01.1991
20.03.1991
27.08.1991
26.02.1993
17.12.1991
24.04.1991
25.05.1991
22.10.1991
21.09.1991
20.04.1993
27.02.1991
23.11.1990
11.02.1991
02.05.1991
21.07.1991
09.10.1991
28.12.1991
17.03.1992
05.06.1992
24.08.1992
12.11.1992
31.01.1993
21.04.1993
Dates
25 m
50 m
75 m

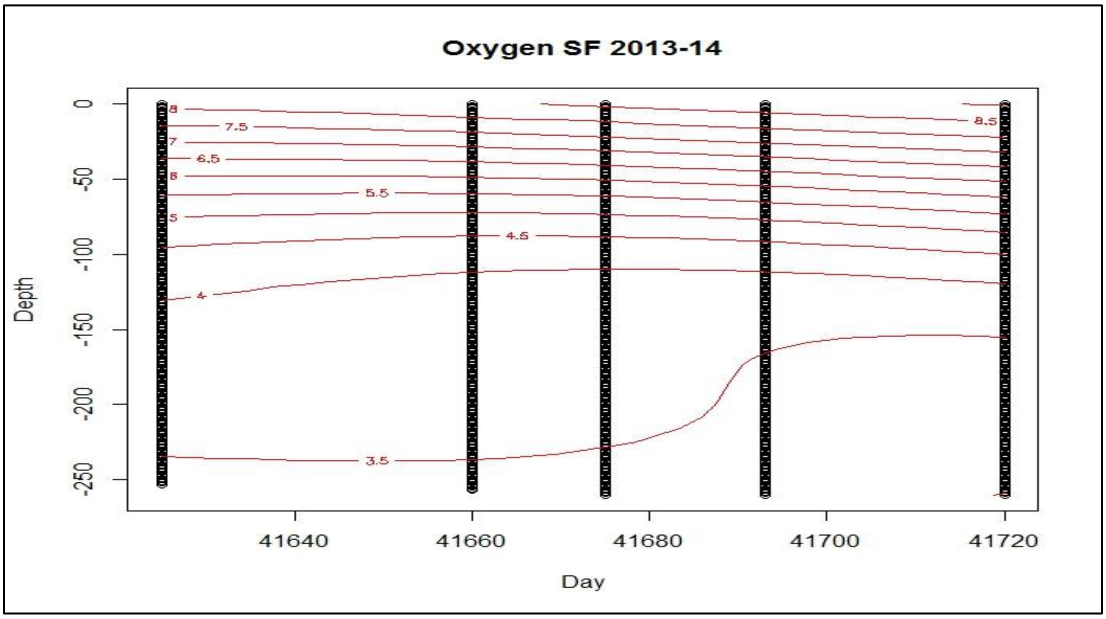
## Isopleth diagrams 1990-1993

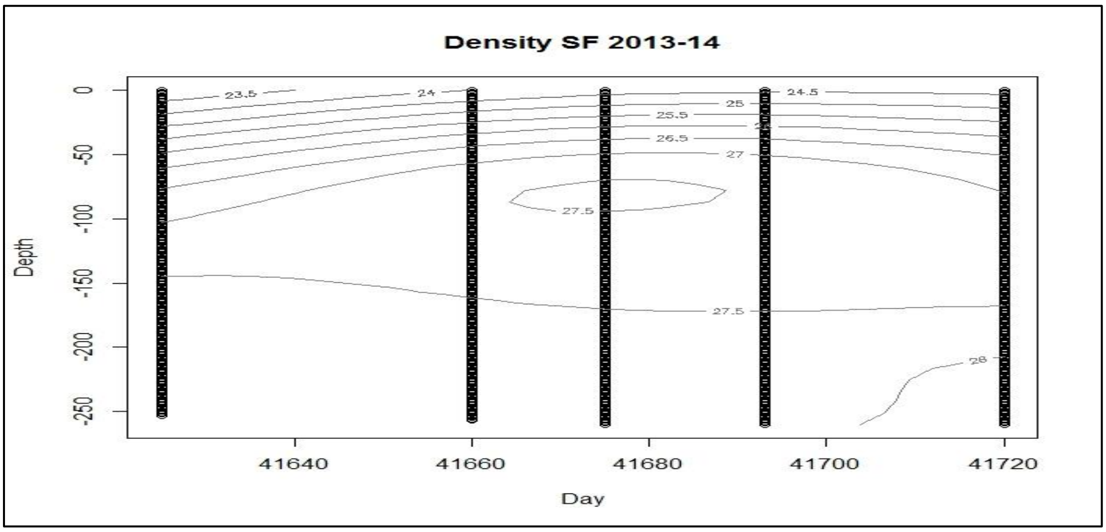


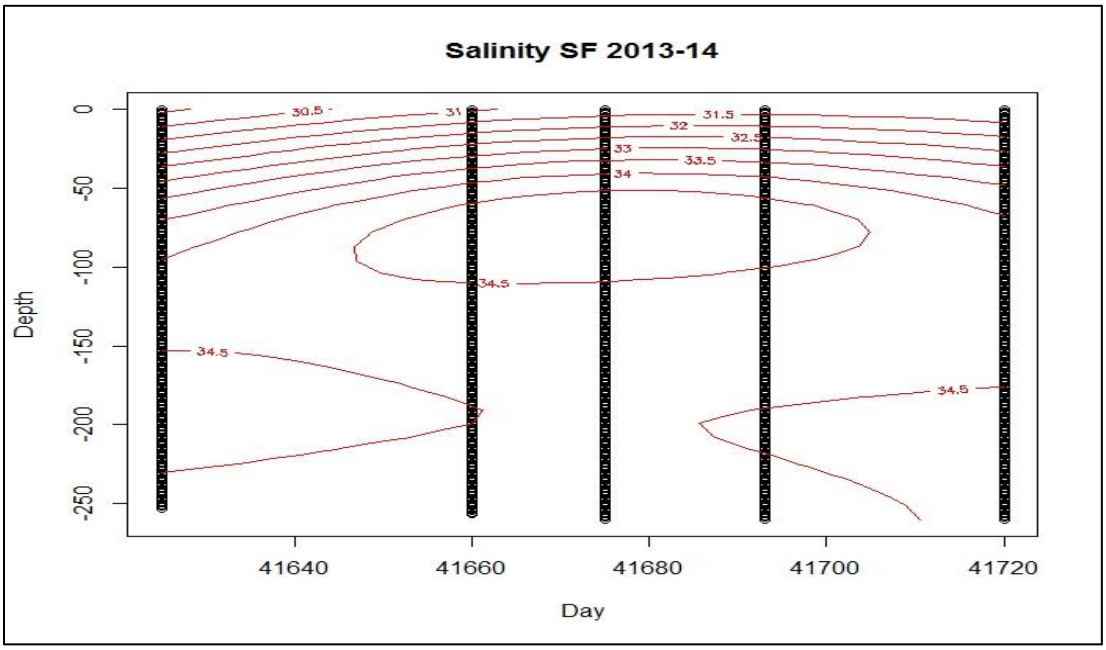



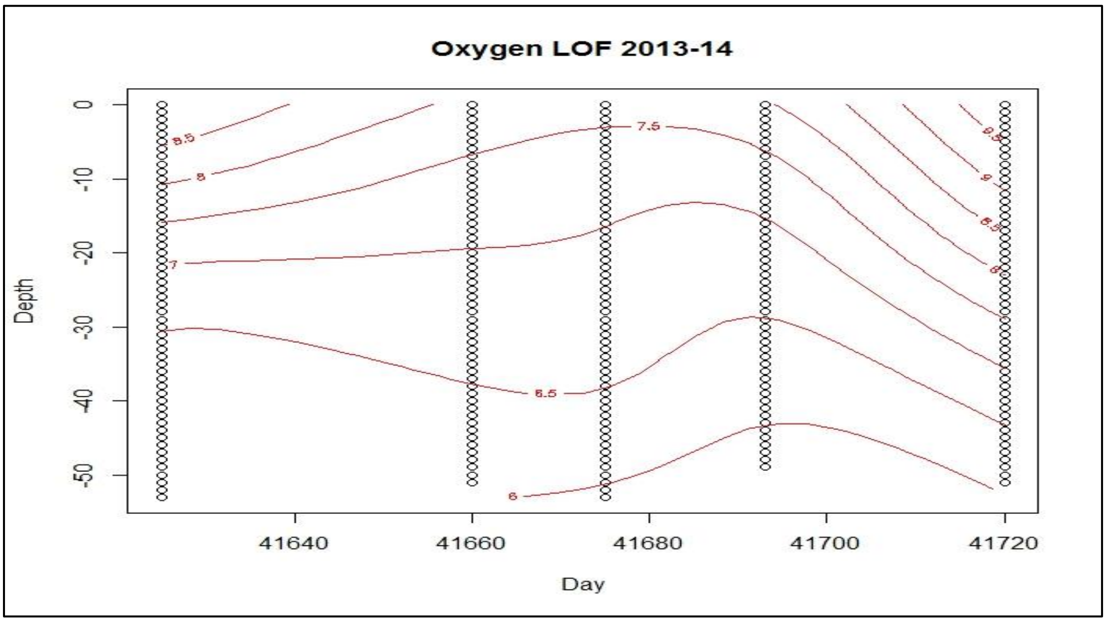



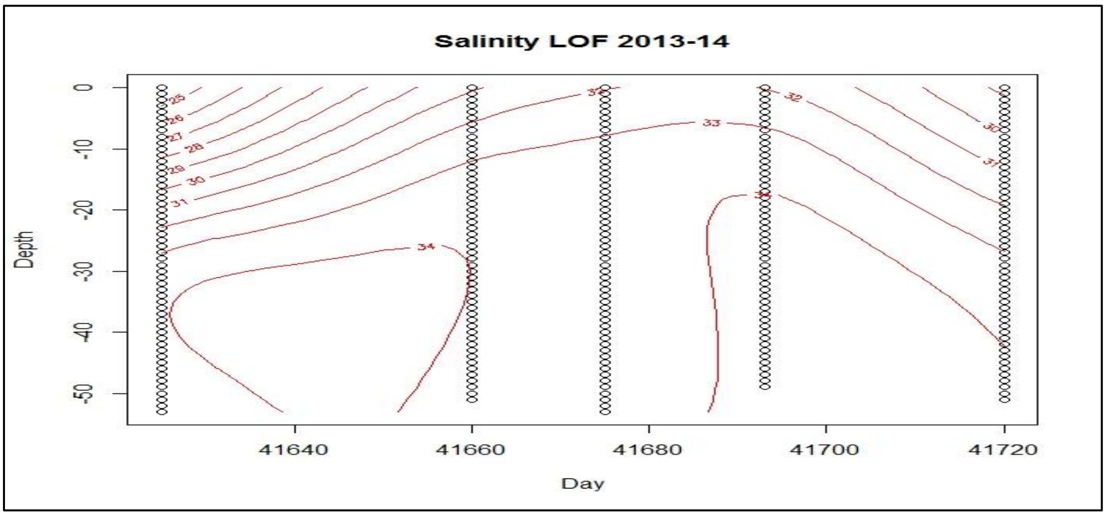
## Isopleth diagrams 2013-2014

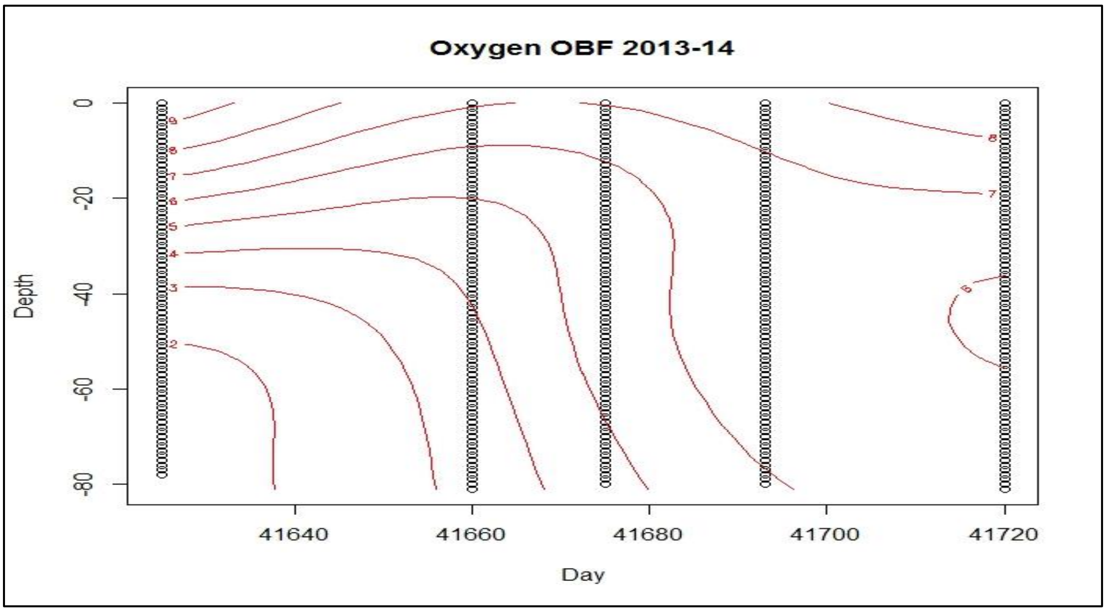


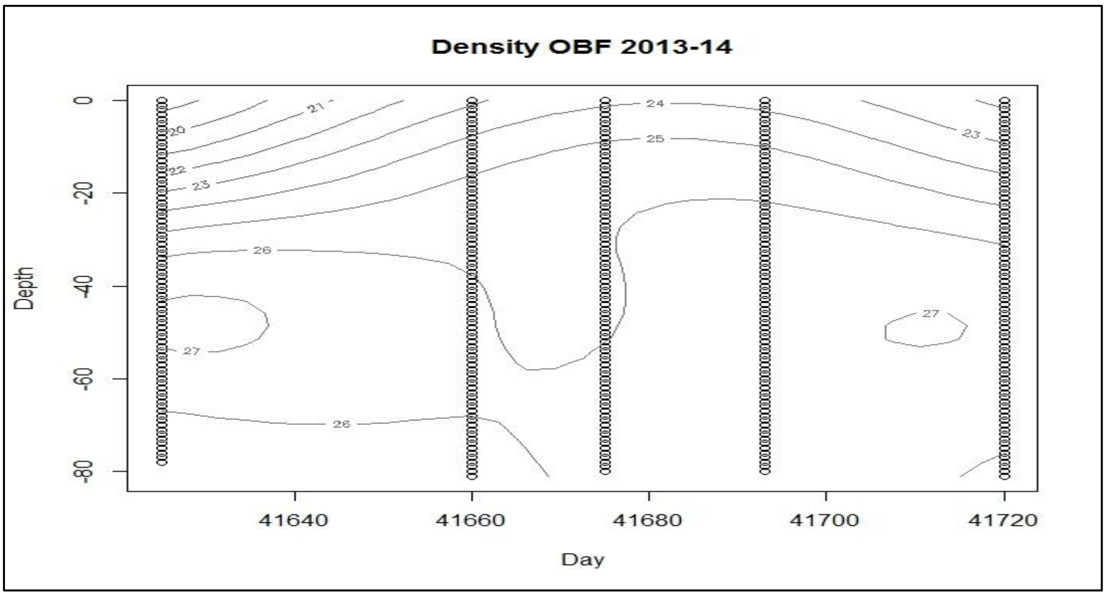



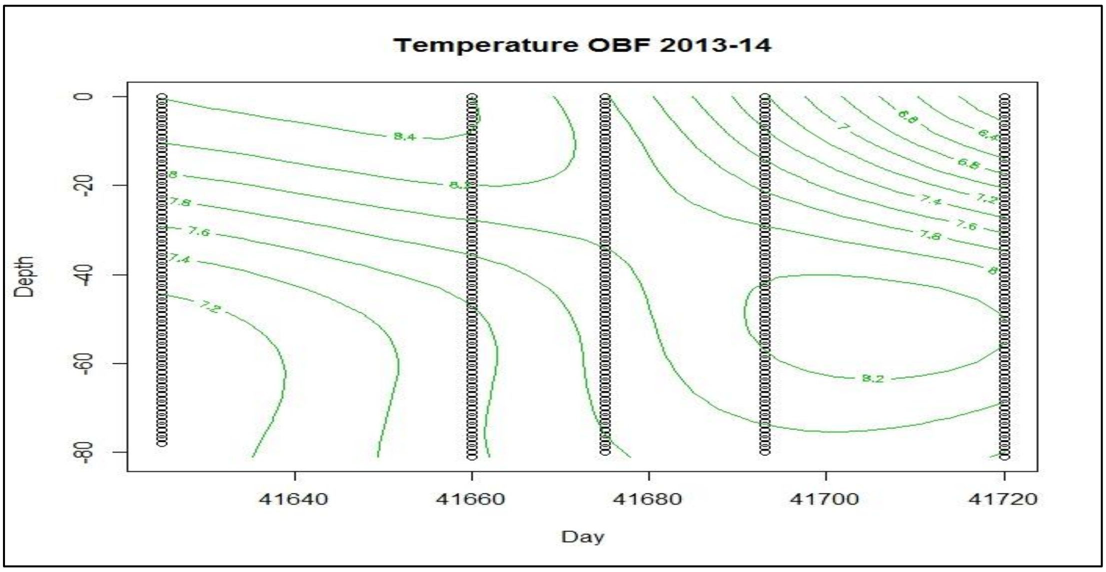



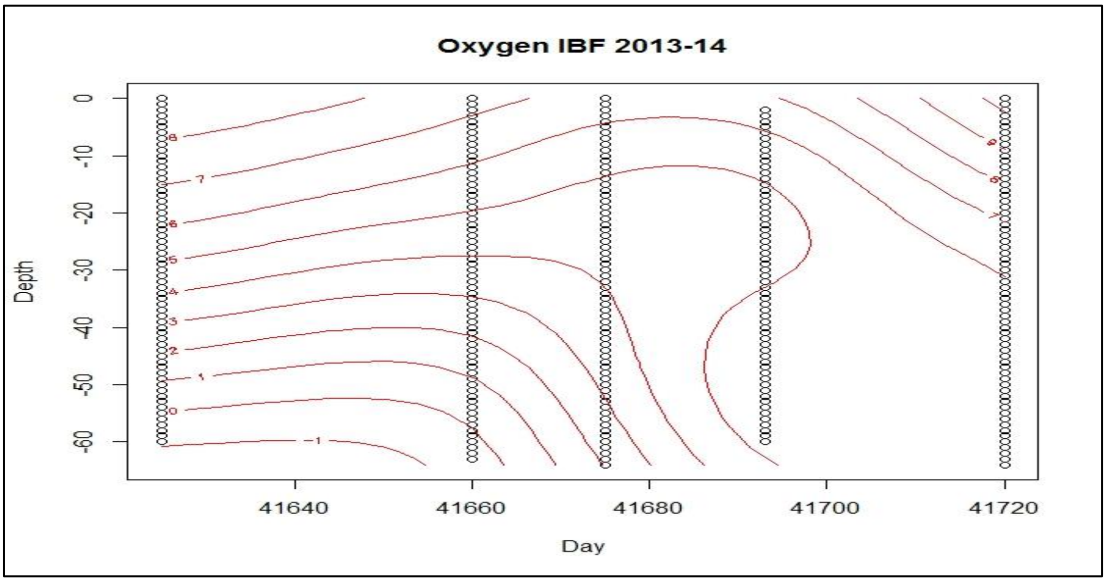

Oxygen LOF 2013-14
Depth
0
-10
-20
-30
-40
-50
Day
41640
41660
41680
41700
41720
8.5
8
7.5
7
6.5
6
9

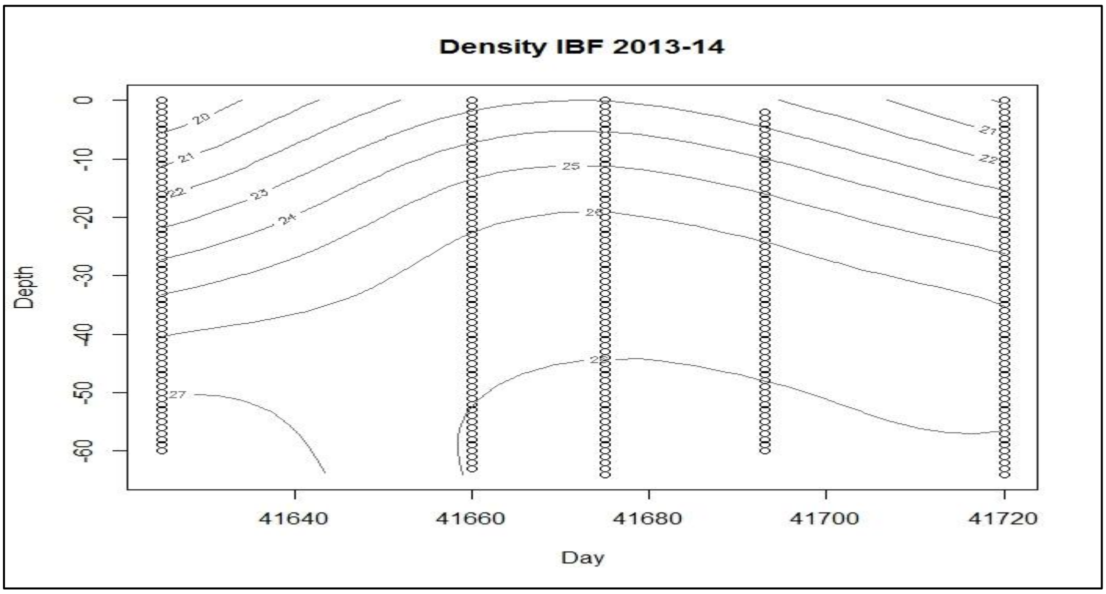


Salinity LOF 2013-14
Depth
0
-10
-20
-30
-40
-50
Day
41640
41660
41680
41700
41720
25
26
27
28
29
30
31
32
33
34

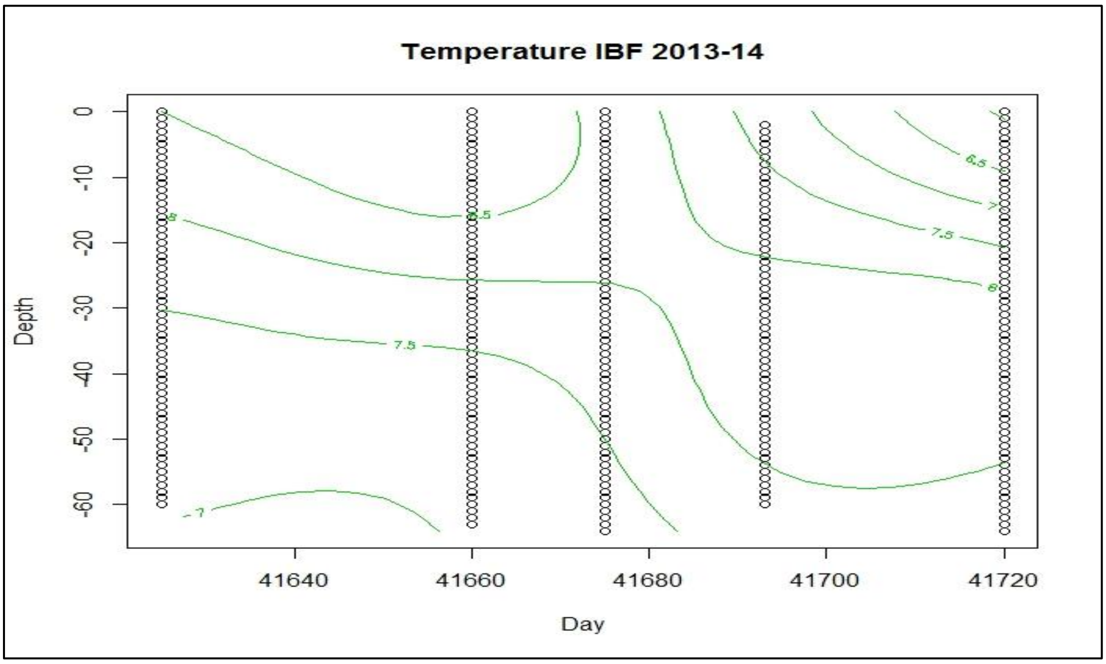


Oxygen OBF 2013-14
Depth
0
-20
-40
-60
-80
Day
41640
41660
41680
41700
41720
9
8
7
6
5
4
3
2


Density OBF 2013-14
Depth
Day
0
-20
-40
-60
-80
41640
41660
41680
41700
41720
20
21
22
23
24
25
26
27


Temperature OBF 2013-14
Depth
Day
0
-20
-40
-60
-80
41640
41660
41680
41700
41720
8.4
8
7.8
7.6
7.4
7.2
8.2
7
6.8
6.6
6.4


Oxygen IBF 2013-14
Depth
Day
0
-10
-20
-30
-40
-50
-60
41640
41660
41680
41700
41720
8
7
6
5
4
3
2
1
0
-1


Density IBF 2013-14
Depth
Day
0
-10
-20
-30
-40
-50
-60
41640
41660
41680
41700
41720
20
21
22
23
24
25
27


Temperature IBF 2013-14
Depth
Day
0
-10
-20
-30
-40
-50
-60
41640
41660
41680
41700
41720
6.5
7
7.5
8

# Appendix II: Data

## 1984-1985: Outer Barsnesfjord

Salinity [‰]

| Depth [m] | Date: | 10.01.1984 | 22.03.1984 | 02.05.1984 | 18.06.1984 | 07.08.1984 | 09.10.1984 | 19.11.1984 | 23.01.1985 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | 26,4 | 32,3 | 8,0 | 2,0 | 2,3 | 17,0 | 29,8 | 32,0 |
| 1 | | 28,4 | 32,6 | 8,9 | 2,0 | 2,3 | | 29,8 | 32,0 |
| 2 | | 29,7 | 32,8 | 25,7 | 2,0 | 2,5 | | 30,4 | 32,0 |
| 3 | | 30,6 | 32,8 | 29,5 | 2,8 | 3,0 | | 30,4 | 32,1 |
| 4 | | 31,0 | 32,7 | 29,5 | 15,0 | 3,4 | | 31,2 | 32,2 |
| 5 | | 31,1 | 32,4 | 31,5 | 17,0 | 10,0 | | 31,6 | 32,3 |
| 6 | | 31,4 | | 31,9 | 18,0 | 25,2 | | 31,7 | 32,3 |
| 7 | | 31,8 | | 32,1 | 22,9 | 30,6 | | 31,8 | 32,5 |
| 8 | | 32,0 | | 32,2 | 25,0 | 32,8 | | 32,0 | 32,5 |
| 9 | | 32,1 | | 32,6 | 31,5 | 33,3 | | 32,0 | 33,0 |
| 10 | | 32,3 | 31,5 | 32,6 | 32,5 | 33,6 | 31,2 | 32,5 | 33,0 |
| 20 | | 33,1 | | 33,9 | 34,7 | 34,3 | | | 33,5 |
| 30 | | 32,4 | | 34,4 | 34,7 | 34,2 | 33,7 | 34,0 | 32,7 |
| 40 | | 33,1 | | 34,8 | 34,9 | 34,4 | | 34,2 | 32,9 |
| 50 | | 33,8 | | 35,0 | 34,9 | 33,7 | 34,8 | 34,2 | 33,1 |
| 100 | | 33,7 | | 35,2 | 35,5 | 34,4 | 34,9 | | 33,7 |
| 150 | | 33,6 | | 35,6 | 35,4 | 34,4 | | 34,7 | |
| 200 | | 33,7 | | 35,5 | 35,2 | | | 35,2 | 34,5 |
| 250 | | 33,5 | 32,7 | 35,5 | 35,1 | 35,0 | 34,6 | | 35,0 |

Temperature [°C]

| Depth [m] | Date: | 10.01.1984 | 22.03.1984 | 02.05.1984 | 18.06.1984 | 07.08.1984 | 09.10.1984 | 19.11.1984 | 23.01.1985 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | 3,0 | 4,6 | 8,2 | 12,4 | 14,6 | 8,0 | 8,0 | 6,2 |
| 1 | | 3,6 | 4,9 | 7,9 | 12,4 | 14,6 | | 8,1 | 6,2 |
| 2 | | 6,0 | 4,9 | 8,8 | 12,4 | 14,7 | | 8,6 | 6,4 |
| 3 | | 6,2 | 4,3 | 8,1 | 13,0 | 14,9 | | 8,6 | 6,4 |
| 4 | | 6,5 | 4,1 | 7,3 | 13,0 | 15,1 | | 9,2 | 6,2 |
| 5 | | 6,4 | 5,3 | 6,8 | 12,8 | 15,1 | | 10,2 | 6,2 |
| 6 | | 6,6 | 5,5 | 6,3 | 12,0 | 12,0 | | 10,2 | 6,5 |
| 7 | | 6,8 | 5,4 | 6,2 | 11,4 | 9,4 | | 10,2 | 6,6 |
| 8 | | 7,0 | 5,6 | 6,1 | 10,2 | 8,3 | | 10,2 | 6,6 |
| 9 | | 7,0 | 5,6 | 6,0 | 8,2 | 8,0 | | 10,2 | 7,4 |
| 10 | | 7,2 | 5,7 | 6,0 | 7,6 | 7,2 | 11,0 | 10,1 | 7,6 |
| 20 | | 8,0 | 10,2 | 6,9 | 7,0 | 7,5 | 11,0 | 10,2 | 8,2 |
| 30 | | 9,4 | 8,1 | 7,2 | 7,0 | 7,2 | 10,5 | | 8,9 |
| 40 | | 9,2 | 8,1 | 8,0 | 7,3 | 7,2 | 8,0 | 8,2 | 8,9 |
| 50 | | 8,0 | 7,9 | 7,9 | 7,3 | 7,2 | 7,1 | 8,0 | 8,1 |
| 100 | | 7,8 | 7,9 | 7,8 | 7,2 | 7,2 | 7,1 | 7,2 | 7,2 |
| 150 | | 7,2 | 7,9 | 7,8 | 7,3 | 7,2 | | | |
| 200 | | 7,3 | 7,8 | 7,8 | 7,3 | | 7,1 | 7,2 | 7,2 |
| 250 | | 7,4 | 7,8 | 7,8 | 7,2 | 7,2 | 7,1 | 7,0 | 7,2 |

Oxygen [ppm]

| Depth [m] | Date: | 10.01.1984 | 22.03.1984 | 02.05.1984 | 18.06.1984 | 07.08.1984 | 09.10.1984 | 19.11.1984 | 23.01.1985 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | 13,5 | 12,5 | 13,1 | 12,0 | 11,4 | 13,2 | 10,4 | 10,6 |
| 1 | | 13,4 | 12,1 | 13,7 | 11,8 | 11,4 | 13,0 | 10,1 | 10,4 |
| 2 | | 12,0 | 12,0 | 16,4 | 11,8 | 11,6 | 13,0 | 10,1 | 10,5 |
| 3 | | 12,1 | 12,0 | 15,9 | 12,5 | 11,5 | 13,0 | 10,0 | 10,5 |
| 4 | | 11,7 | 12,5 | 15,8 | 11,0 | 11,8 | 12,9 | 9,5 | 10,5 |
| 5 | | 11,7 | 12,2 | 14,9 | 10,4 | 11,0 | 12,7 | 9,5 | 10,5 |
| 6 | | 11,7 | 11,9 | 14,4 | 10,8 | 10,8 | 12,5 | 9,3 | 10,6 |
| 7 | | 11,6 | 11,6 | 14,5 | 13,1 | 9,0 | 12,3 | 9,3 | 10,8 |
| 8 | | 11,5 | 11,8 | 13,8 | 13,2 | 8,6 | 12,2 | 9,2 | 10,8 |
| 9 | | 11,3 | 10,6 | 14,2 | 12,0 | 8,2 | 12,0 | 9,2 | 10,8 |
| 10 | | 11,2 | 10,4 | 14,8 | 10,6 | 8,0 | 12,0 | 9,2 | 11,0 |
| 20 | | 10,2 | 9,5 | 11,6 | 7,4 | 4,8 | 9,4 | 9,0 | 10,0 |
| 30 | | 8,0 | 7,4 | 9,2 | 6,6 | 5,0 | 9,4 | 9,2 | 9,5 |
| 40 | | 8,0 | 7,0 | 7,2 | 5,8 | 5,7 | 7,0 | 5,5 | 9,5 |
| 50 | | 6,9 | 7,2 | 7,2 | 5,5 | 6,6 | 7,2 | 6,0 | 6,8 |
| 100 | | 5,8 | 5,4 | 6,7 | 5,5 | 5,9 | 6,8 | 6,3 | 6,4 |
| 150 | | 4,8 | 4,9 | 5,6 | 4,7 | 4,8 | | | |
| 200 | | 4,4 | 4,2 | 5,0 | 3,8 | | 7,2 | 6,2 | 6,8 |
| 250 | | 4,0 | 4,2 | 4,6 | 3,6 | 5,6 | 6,8 | 6,0 | 6,8 |

## 1984-1985: Outer Barsnesfjord

Salinity [‰]

| Depth [m] | Date: | 06.01.1984 | 21.02.1984 | 21.03.1984 | 02.05.1984 | 18.06.1984 | 07.08.1984 | 09.10.1984 | 19.11.1984 | 23.01.1985 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 3,9 | 13 | 9,7 | 2,0 | 0,6 | 0,6 | 3,9 | 26,0 | 5,0 |
| 1 | | 23,1 | 32,3 | 29,5 | 2,0 | 0,6 | 0,6 | 10,4 | 26,0 | 31,7 |
| 2 | | 25,9 | 33,1 | 32,5 | 27,0 | 1,0 | 1,0 | 22,9 | 27,5 | 32,0 |
| 3 | | 27,7 | 33,1 | 32,9 | 30,2 | 1,5 | 1,5 | 24,3 | 30,2 | 32,2 |
| 4 | | 28,4 | 33,3 | 33,3 | 31,2 | 8,5 | 8,5 | 26,5 | 30,6 | 32,2 |
| 5 | | 28,6 | 33,3 | 33,2 | 31,5 | 13,5 | 13,5 | 28,4 | 30,7 | 32,2 |
| 6 | | 29,4 | 33,4 | 33,5 | 31,8 | 15,5 | 15,5 | 29,9 | 31,0 | 32,5 |
| 7 | | 29,6 | 33,4 | 33,3 | 32,5 | 27,5 | 27,5 | 30,3 | 31,3 | 32,4 |
| 8 | | 30,5 | 33,5 | 33,5 | 32,7 | 30,8 | 30,8 | 30,4 | 31,3 | 32,5 |
| 9 | | 31,2 | 33,5 | 33,5 | 33,1 | 32,3 | 32,3 | 30,8 | 31,5 | 32,4 |
| 10 | | 31,4 | 33,5 | 33,5 | 33,2 | 32,5 | 32,5 | 31,5 | 31,8 | 32,5 |
| 20 | | 33,0 | 33,7 | 33,1 | 33,6 | 33,8 | 33,8 | 33,5 | 33,2 | |
| 30 | | | 32,3 | 33,0 | 33,6 | 34,3 | 34,3 | 33,4 | 33,7 | |
| 40 | | 32,5 | 33,7 | 33,1 | 34,3 | 34,1 | 34,1 | 33,6 | 33,9 | |
| 50 | | 32,9 | 33,7 | 33,4 | | | | | | |
| 60 | | | | 33,5 | 34,0 | 34,0 | 34,6 | 32,7 | 33,7 | 33,6 |

Temperature [°C]

| Depth [m] | Date: | 06.01.1984 | 21.03.1984 | 02.05.1984 | 18.06.1984 | 07.08.1984 | 09.10.1984 | 19.11.1984 | 23.01.1985 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | 0,2 | 0,0 | 6,0 | 11,4 | 12,9 | 7,5 | 6,9 | 0,9 |
| 1 | | 3,1 | 4,2 | 6,1 | 11,1 | 12,9 | 9,2 | 7,2 | 7,3 |
| 2 | | 4,,4 | 5,4 | 7,6 | 11,2 | 13,0 | 9,8 | 7,6 | 7,8 |
| 3 | | 5,1 | 5,6 | 7,7 | 11,6 | 13,2 | 10,4 | 9,2 | 8,0 |
| 4 | | 5,4 | 5,7 | 7,1 | 12,2 | 13,7 | 10,6 | 9,8 | 8,0 |
| 5 | | 5,6 | 5,7 | 7,0 | 12,4 | 14,3 | 10,8 | 9,8 | 7,8 |
| 6 | | 5,9 | 6,0 | 6,9 | 12,4 | 10,2 | 10,7 | 9,7 | 8,0 |
| 7 | | 6,2 | 6,0 | 6,7 | 9,6 | 8,4 | 10,6 | 9,8 | 7,7 |
| 8 | | 6,7 | 6,0 | 6,6 | 8,8 | 7,9 | 10,7 | 9,8 | 8,0 |
| 9 | | 7,4 | 6,0 | 6,6 | 7,8 | 7,8 | 10,6 | 9,7 | 8,0 |
| 10 | | 7,5 | 6,0 | 6,6 | 7,4 | 7,6 | 10,2 | 9,7 | 8,0 |
| 20 | | 8,1 | 6,8 | 7,4 | 6,8 | 7,8 | 8,0 | 7,5 | 8,3 |
| 30 | | 7,2 | 6,8 | 7,2 | 7,0 | 7,0 | 7,0 | 7,0 | 7,2 |
| 40 | | 7,2 | 7,0 | 7,0 | 7,0 | 7,0 | 7,0 | 7,0 | 7,0 |
| 50 | | 7,1 | 7,9 | | | | | | |
| 60 | | | 6,9 | 7,1 | 7,0 | 7,0 | 7,0 | 7,0 | 7,0 |

**Oxygen [ppm]**

| Depth [m] | Date: | 06.01.1984 | 21.02.1984 | 21.03.1984 | 02.05.1984 | 18.06.1984 | 07.08.1984 | 09.10.1984 | 19.11.1984 | 23.01.1985 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 13,0 | 14,0 | 11,2 | 14,6 | 12,2 | 12,2 | 11,6 | 10,7 | 13,5 |
| 1 | | 11,0 | 10,1 | 9,2 | 14,7 | 12,2 | 12,0 | 11,4 | 10,4 | 8,9 |
| 2 | | 10,7 | 9,2 | 8,1 | 18,4 | 12,0 | 11,9 | 11,1 | 10,2 | 8,9 |
| 3 | | 10,5 | 8,9 | 7,9 | 17,7 | 11,9 | 11,9 | 11,0 | 9,5 | 8,9 |
| 4 | | 10,2 | 8,7 | 7,8 | 16,3 | 13,2 | 11,8 | 11,0 | 9,0 | 8,5 |
| 5 | | 10,1 | 8,6 | 7,3 | 15,7 | 13,4 | 13,0 | 10,8 | 9,0 | 8,8 |
| 6 | | 10,0 | 8,6 | 7,1 | 15,4 | 12,8 | 12,0 | 10,4 | 9,0 | 8,8 |
| 7 | | 9,4 | 8,4 | 7,3 | 14,6 | 12,4 | 10,0 | 10,3 | 9,0 | 8,6 |
| 8 | | 9,3 | 8,3 | 7,3 | 12,8 | 12,0 | 9,0 | 10,2 | 8,9 | 8,5 |
| 9 | | 9,1 | 8,4 | 7,4 | 12,2 | 11,1 | 8,8 | 9,8 | 9,0 | 8,5 |
| 10 | | 8,0 | 8,4 | 7,6 | 12,0 | 9,6 | 8,2 | 9,8 | 9,0 | 8,5 |
| 20 | | 4,8 | 8,0 | 7,5 | 7,4 | 7,3 | 6,8 | 7,0 | 5,7 | 8,0 |
| 30 | | 2,8 | 7,5 | | 7,9 | 4,8 | 4,3 | 4,9 | 7,7 | 4,5 |
| 40 | | 1,3 | 7,6 | 7,9 | 8,6 | 5,4 | 4,7 | 4,9 | 3,8 | 3,5 |
| 50 | | 0,8 | 8,0 | 7,6 | | | | | | |
| 60 | | | | 7,6 | 9,5 | 5,8 | 4,7 | 4,9 | 4,3 | 2,8 |

## 1990-1993: Sogndalsfjord

Temperature [°C]

| Depth [m] | Date: | 09.12.1990 | 18.12.1990 | 26.01.1991 | 29.01.1991 | 27.02.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 | 27.02.1993 | 20.04.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 5,0 | | 5,9 | | 6,2 | 7,0 | 8,4 | 10,0 | 14,9 | 10,4 | 8,4 | 6,1 | 4,0 | 7,5 |
| 5 | | 7,8 | | 6,8 | | 6,2 | 7,2 | 7,9 | 10,0 | 16,0 | 14,0 | 9,7 | 8,1 | 5,4 | 7,9 |
| 10 | | 7,5 | | 8,5 | 7,5 | 6,8 | 8,5 | 7,7 | 9,2 | 13,0 | 13,5 | 12,0 | 9,0 | 6,5 | 8,8 |
| 25 | | 8,9 | | 9,3 | 9,3 | 9,0 | 8,3 | 8,0 | 8,0 | 12,0 | 11,4 | 11,7 | 10,8 | 9,1 | 8,7 |
| 50 | | 8,3 | | 9,0 | 9,0 | 8,8 | 8,3 | 8,4 | 8,2 | 8,1 | 8,0 | 8,0 | 8,0 | 8,8 | 8,3 |
| 100 | | 7,9 | 7,9 | 7,9 | 7,9 | 8,0 | 7,9 | 7,9 | 8,0 | 8,1 | 7,9 | 8,0 | 7,9 | 8,0 | 8,1 |
| 150 | | 7,8 | 7,8 | 7,9 | 7,9 | 7,7 | 7,9 | 7,9 | 7,9 | 8,1 | 8,0 | 8,0 | 8,0 | 8,0 | 8,1 |
| 200 | | 7,8 | 7,8 | 8,0 | 7,6 | 8,0 | 7,8 | 7,9 | 7,8 | 8,1 | 8,0 | 8,0 | 8,0 | 8,0 | 8,1 |
| 250 | | 7,5 | 7,8 | 7,8 | 7,6 | 7,8 | 7,9 | 7,8 | 7,8 | 8,1 | 8,0 | 8,0 | 8,0 | 8,0 | 8,0 |

Salinity [‰]

| Depth [m] | Date: | 09.12.1990 | 18.12.1990 | 26.01.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 | 27.02.1993 | 20.04.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 24,8 | 28 | 26,2 | 26,4 | 20,2 | 5,2 | 0,0 | 3 | | 19,1 | 19,5 | 26,5 |
| 5 | | 28,2 | 29,2 | 27,3 | 29,0 | 26,1 | 25,0 | 9,3 | 17,1 | | 25,6 | 23,4 | 29,6 |
| 10 | | 28,8 | 30,5 | 29,6 | 30,3 | 27,7 | 26,9 | 25,5 | 23,6 | | 27,5 | 25,5 | 30,2 |
| 25 | | 31,6 | 30,6 | 30,3 | 30,3 | 29,3 | 29,2 | 27,4 | 31,3 | | 29,8 | 28,9 | 32,7 |
| 50 | | 32,2 | 33,3 | 30,3 | 30,5 | 30,3 | 29,2 | | 32,9 | | 30,3 | 30,2 | 33,0 |
| 100 | | 32,2 | 33,2 | 30,2 | 30,5 | 31,1 | 30,4 | | | 31,7 | 31,0 | 30,6 | 33,0 |
| 150 | | 32,3 | 33,2 | 30,7 | 30,4 | 30,5 | 30,4 | | | 31,3 | 31,1 | 30,6 | 32,9 |
| 200 | | 32,3 | 33,2 | 31,2 | 31,0 | 30,4 | 30,9 | | | 31,3 | 31,1 | 30,5 | 32,8 |
| 250 | | 32,4 | 33,2 | 31,4 | 31,5 | 30,3 | 30,8 | | | 31,6 | 31,1 | 30,5 | 32,8 |

**Density [sigma-t]**

| Depth [m] | Date: | 09.12.1990 | 18.12.1990 | 26.01.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 | 27.02.1993 | 20.04.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 21,0 | | | 22,0 | 17,0 | 5,2 | 0,0 | | | 17,1 | 17,0 | 22,0 |
| 5 | | 23,5 | 23,2 | 22,0 | 24,0 | 21,5 | 20,5 | 7,8 | | | 21,5 | 20,0 | 24,5 |
| 10 | | 24,0 | 24,0 | 22,8 | 25,0 | 22,7 | 22,0 | 20,1 | | | 23,0 | 21,5 | 25,0 |
| 25 | | 26,0 | 25,1 | 24,5 | 25,0 | 24,2 | 24,0 | 22,0 | | | 24,6 | 24,0 | 26,8 |
| 50 | | 26,5 | 25,5 | 25,0 | 25,1 | 24,9 | 24,0 | 21,0 | | | 25,3 | 25,0 | 27,0 |
| 100 | | 26,8 | 26,0 | 25,0 | 25,3 | 25,5 | 24,8 | 21,0 | 26,0 | 26,0 | 25,8 | 25,5 | 27,0 |
| 150 | | 26,8 | 26,0 | 25,5 | 25,2 | 25,0 | 25,1 | 20,0 | 26,0 | 25,9 | 25,8 | 25,5 | 27,0 |
| 200 | | 26,8 | 26,0 | 25,9 | 25,5 | 25,0 | 25,2 | 22,0 | 26,0 | 25,9 | 25,8 | 25,5 | 27,0 |
| 250 | | 26,8 | 26,0 | 26,0 | 26,0 | 25,0 | 25,1 | 23,0 | 26,0 | 26,0 | 25,8 | 25,5 | 27,0 |

**Oxygen [mg/l], Winkler**

| Depth [m] | Date: | 09.12.1990 | 18.12.1990 | 01.03.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 | 27.02.1993 | 20.04.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 8,9 | | | 10,9 | 13,3 | 12,8 | 11,5 | 13,0 | 11,6 | 11,8 | 11,7 | 12,1 |
| 5 | | 8,3 | 7,7 | 8,2 | 10,7 | 11,2 | 12,4 | 12,4 | 12,1 | 10,5 | 10,8 | 10,2 | 12,2 |
| 10 | | 8,0 | 7,6 | | 7,4 | 10,6 | 11,0 | 10,5 | 10,7 | 8,6 | 10,0 | 9,0 | 11,9 |
| 25 | | 6,5 | 7,0 | | 7,2 | 8,2 | 8,3 | 8,9 | 8,8 | 8,1 | 8,6 | 6,8 | 6,3 |
| 50 | | 4,8 | 5,4 | | 7,6 | 6,9 | 7,4 | 3,8 | 3,7 | 3,9 | 3,9 | 6,0 | 6,3 |
| 100 | | 3,7 | 3,7 | | 4,2 | 4,2 | 4,5 | 4,6 | 4,9 | 4,7 | 4,8 | 4,0 | 5,0 |
| 150 | | 3,2 | 3,4 | | 3,7 | 3,8 | 3,9 | 5,7 | 5,8 | 5,5 | 5,6 | 3,8 | 4,1 |
| 200 | | 3,4 | 3,2 | | 3,4 | 3,4 | 3,7 | 5,7 | 5,5 | 5,6 | 5,7 | 3,6 | 3,9 |
| 250 | | 2,9 | 3,0 | | 3,3 | 3,4 | 3,5 | 5,3 | 5,4 | 5,7 | 5,2 | 3,4 | 3,9 |

**Oxygen [mg/l], YSI**

| Depth [m] | Date: | 09.12.1990 | 18.12.1990 | 26.01.1991 | 29.01.1991 | 27.02.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | 10,2 | 9,2 | 11,1 | 11,9 | 12,0 | 11,9 | 13,0 | 12,8 | 12,9 | 12,1 |
| 5 | | 9,2 | 9,6 | 9,7 | | 11,9 | 12,0 | 12,1 | 10,4 | 13,5 | 12,1 | 11,7 | 11,1 |
| 10 | | | 9,6 | 8,3 | | 11,5 | 8,8 | 11,2 | 10,7 | 11,9 | 10,8 | 9,9 | 9,5 |
| 25 | | | 8,9 | 8,0 | 7,3 | 9,4 | 8,6 | 9,4 | 7,9 | 9,2 | 9,0 | 8,9 | 8,1 |
| 50 | | 6,1 | 6,9 | 6,4 | 6,3 | 9,0 | 8,9 | 7,7 | 7,2 | 5,6 | 4,7 | 4,9 | 4,7 |
| 100 | | 4,6 | 5,2 | 4,3 | 4,1 | 6,3 | 5,3 | 5,8 | 4,8 | 6,0 | 5,5 | 5,5 | 5,5 |
| 150 | | 4,2 | 3,9 | 4,3 | 3,8 | 5,5 | 5,0 | 5,1 | 4,5 | 7,0 | 6,0 | 6,2 | 6,0 |
| 200 | | 4,3 | 3,7 | 3,5 | 3,6 | 5,0 | 4,9 | 4,4 | 4,2 | 7,2 | 6,4 | 6,5 | 6,0 |
| 250 | | 3,8 | 3,5 | 3,8 | 3,6 | 4,8 | 4,3 | 4,2 | 3,9 | 7,2 | 6,1 | 6,4 | 5,9 |

## 1990-1993: Outer Barsnesfjord

Temperature [°C]

| Depth [m] | Date: | 13.12.1990 | 26.01.1991 | 27.02.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 | 26.02.1993 | 20.04.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 6,9 | 5,0 | 6,5 | 7,0 | 9,0 | 9,1 | 13,9 | 9,7 | 7,5 | 4,3 | 4,0 | 6,7 |
| 5 | | 8,9 | 7,9 | 7,8 | 8,0 | 8,1 | 10,4 | 15,8 | 13,0 | 11,9 | 8,2 | 5,9 | 8,8 |
| 10 | | 9,3 | 9,0 | 8,0 | 8,5 | 8,0 | 9,4 | 12,2 | 13,0 | 12,3 | 10,5 | 6,2 | 8,5 |
| 25 | | | 9,2 | 8,0 | 8,4 | 8,5 | 8,3 | 8,8 | 8,4 | 8,6 | 8,8 | 8,9 | 8,8 |
| 50 | | 7,8 | 8,0 | 8,0 | 8,4 | 8,2 | 8,2 | 8,1 | 8,4 | 8,1 | 8,1 | 8,4 | 8,8 |
| 75 | | | | | 7,8 | 8,0 | 8,0 | 8,0 | 8,4 | 8,0 | 8,0 | 8,4 | 8,7 |

Salinity [‰]

| Depth [m] | Date: | 13.12.1990 | 26.01.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 22.10.1991 | 17.12.1991 | 26.02.1993 | 20.04.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 24,2 | 22,2 | 25,7 | 19,5 | 0,0 | 0,0 | | 0 | 19 | 15,4 |
| 5 | | 27 | 26,3 | 29,5 | 26,7 | 23,0 | 7,5 | | 23,7 | 24,2 | 29,6 |
| 10 | | 28,4 | 29 | 30,3 | 26,7 | 27,0 | 22,0 | | 28,5 | 25,6 | 30,2 |
| 25 | | | 30,2 | 32,8 | 29,1 | 29,1 | 26,8 | | 28,6 | 29,0 | 31,2 |
| 50 | | 30,0 | 30,2 | 31,5 | 29,5 | 29,4 | 24,5 | | 29,4 | 29,0 | 31,7 |
| 75 | | | | 31,5 | 29,9 | 29,2 | 25,2 | 29,4 | 29,9 | 29,0 | 31,8 |

Density [sigma-t]

| Depth [m] | Date: | 13.12.1990 | 26.01.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 | 26.02.1993 | 20.04.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 20,5 | 19,0 | 21,5 | 16,5 | 0,0 | 0,0 | 0,0 | | 0,0 | 16,5 | 13,5 |
| 5 | | 22,5 | 22,0 | 24,5 | 21,9 | 19,1 | 6,5 | 7,1 | | 20,1 | 20,5 | 24,5 |
| 10 | | 23,5 | 24,0 | 25,0 | 22,0 | 22,1 | 18,0 | 21,5 | | 23,5 | 21,5 | 25,0 |
| 25 | | | 25,0 | 27,0 | 24,1 | 24,1 | 22,0 | 24,9 | | 23,8 | 24,0 | 25,5 |
| 50 | | 25,0 | 25,0 | 26,0 | 24,4 | 24,4 | 20,5 | 25,0 | | 24,5 | 24,0 | 26,0 |
| 75 | | | | 26,0 | 24,5 | 24,0 | 21,0 | 25,0 | 24,5 | 24,7 | 24,0 | 26,0 |

Oxygen [mg/l], Winkler

| Depth [m] | Date: | 13.12.1990 | 26.01.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 | 26.02.1993 | 20.04.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 8,7 | | 10,8 | 12,8 | 12,6 | 11,8 | 13,5 | 12,4 | 13,2 | 11,2 | 12,3 |
| 5 | | 7,9 | | 8,8 | 11,0 | 12,8 | 13,3 | 12,6 | 10,2 | 10,2 | 9,8 | 11,0 |
| 10 | | 7,3 | | 6,5 | 10,3 | 11,4 | 9,8 | 9,8 | 8,3 | 8,2 | 9,2 | 7,9 |
| 25 | | | | 6,8 | 4,6 | 4,4 | 3,4 | 3,4 | 3,1 | 2,7 | 1,4 | 5,5 |
| 50 | | H2S 0 | H2S | 5,0 | 4,9 | 4,5 | 2,9 | 2,9 | 2,3 | 1,8 | 0,2 | 4,3 |
| 75 | | | | H2S | 1,2 | 0,4 | H2S | H2S | H2S | H2S | 0,2 | 3,9 |

Oxygen [mg/l], YSI

| Depth [m] | Date: | 13.12.1990 | 26.01.1991 | 27.02.1991 | 20.03.1991 | 24.04.1991 | 25.05.1991 | 27.08.1991 | 21.09.1991 | 22.10.1991 | 17.12.1991 | 26.02.1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 10,8 | 9,5 | 13,5 | 12,2 | 12,5 | 12,2 | 11,9 | 12,6 | 12,3 | 14,2 | 11,6 |
| 5 | | 8,6 | 8,7 | 11,0 | 10,3 | 11,4 | 11,6 | 12,2 | 10,6 | 10,9 | 9,8 | 10,4 |
| 10 | | 7,5 | 6,2 | 8,5 | 8,0 | 10,0 | 10,2 | 10,2 | 9,0 | 8,5 | 8,1 | 9,4 |
| 15 | | 5,4 | 7,0 | | | | | | | | | |
| 20 | | 3,1 | 6,6 | | | | | | | | | |
| 25 | | 0,8 | 6,4 | 8,9 | 8,0 | 5,6 | 4,6 | 5,0 | 4,4 | 3,5 | 3,7 | 5,1 |
| 30 | | | 5,5 | | | | | | | | | |
| 50 | | | H2S | 6,8 | 6,3 | 5,9 | 4,4 | 4,5 | 3,6 | 3,6 | 2,6 | 2,7 |
| 75 | | | | | H2S | 2,6 | 1,4 | H2S | H2S | H2S | H2S | 1,1 |

The 2013-2014 and 2016 dataset is too extensive to be included in the appendix. If someone is interested in the data, Torbjørn Dale (Torbjorn.Dale@hvl.no) can be contacted.

## Appendix III: CD

CD includes:

- Dataset of the four periods used in this thesis (1984-1985, 1990-1993, 2013-2014, 2016)
- Bachelorthesis_Holz.pdf