Norwegian Meteorological Institute

METreport
No. X/2016
ISSN 2387-4201
Oceanography

# Evaluation of the FjordOs-model

July 2016

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# METreport

| Title | Date |
| --- | --- |
| Evaluation of the FjordOs-model | July 20, 2016 |
| **Section** | **Report no.** |
| Type | X/2015 |
| **Author(s)** | **Classification** |
| Karina Hjelmervik, Nils Melsom Kristensen, André Staalstrøm, Lars Petter Røed | ● Free ○ Restricted |
| **Client(s)** | **Client's reference** |
| Client name | |

**Abstract**

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**Keywords**

relevant, keywords, here

Disciplinary signature

Responsible signature

# Abstract

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# Contents

# 1 Introduction - André/Karina

Provided is an evaluation of the FjordOs-model (*Røed et al.*, 2016). This study is a part of the FjordOs project. FjordOs is a cooperation between MET Norway, University College of Southeast Norway (HSN), The Norwegian Institute for Water Research (NIVA), The Norwegian Coastal Administration (Kystverket), Exxonmobil, Norwegian Defence Research Establishment (FFI), Vestfold, Buskerud, and Østfold county, and AGNES AB Miljøkonsulent.

The evaluation is based on existing observations in the area of interst and results from the FjordOs model (*Røed et al.*, 2016). The observations are gathered from different sources and not carried out as a part of the FjordOs project. The observations includes measurements of water level, current measurements, water temperature, and CTD measurements. A short scientific cruise on board the research vessel (R/V) Trygve Braarud in September 2015 provided additional observations of hydrography and trajectories of drifters. These observations are compared with simulated results in *Hjelmervik et al.* (2016).

The aim of this study is to reveal any weaknesses of the FjordOs and clarify the extent to which the model can be be trusted.

## 2 Area of interest - Karina

The area of interest is the Oslofjord including the Drammensfjord (Fig. 1). The Oslofjord is located in Southern Norway with the capital of Norway, Oslo, in the innermost part of the fjord. The fjord is about 100 km long. About halfway the fjord splits into two branches, the Inner Oslofjord and the Drammensfjord. The width varies from about 25 km at the entrance to about 1-2 km at Drøbak Sound in the Inner Oslofjord and 180 meters at Svelvik in the Drammensfjord.

Numerous smaller and larger islands combined with deeper and shallower basins (Fig. 1) contributes to a complex circulation pattern. In addition several river discharge fresh water into the fjord, including two of Norway's largest rivers, namely Glomma (near Fredrikstad) and Drammenselva (near Drammen).

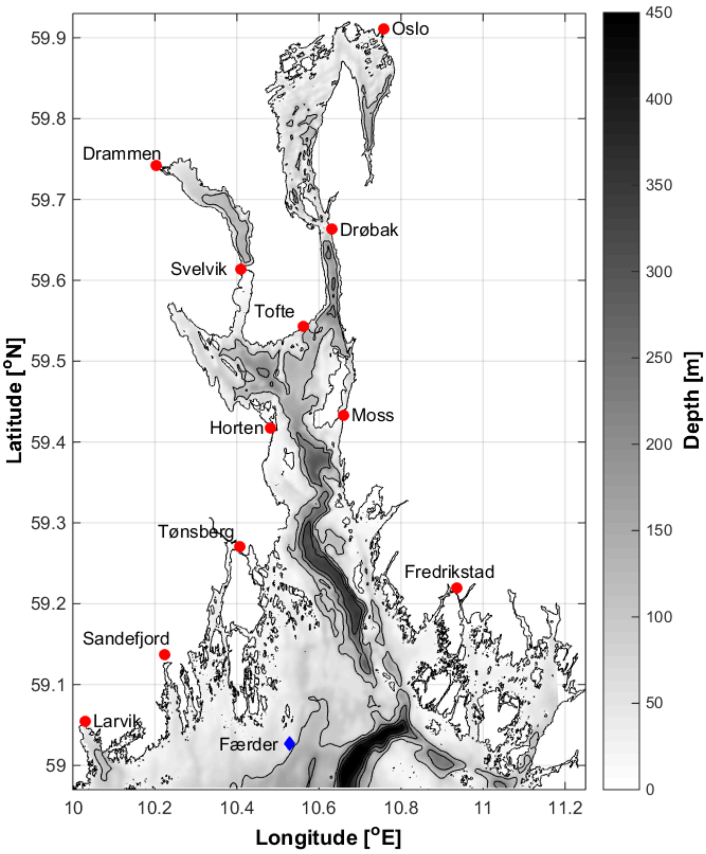


Figure 1: Area of interest.

# 3 Model - Karina

The FjordOs model is a curvilinear, free-surface, and terrain-following model based on the Rutgers Regional Ocean Modeling System (ROMS) (*Haidvogel et al.*, 2008; *Shchepetkin and McWilliams*, 2003, 2005, 2009) adapted to the Oslofjord (*Røed et al.*, 2016).

The model applies several external inputs, such as atmospheric input, river input, tides, and input of sea level, currents and hydrography at the model's open lateral boundaries, in addition to bathymetry (Fig. 2). Mean values of sea level, currents, and hydrography from the NorKyst800 model (*Albretsen et al.*, 2011) is applied on the open boundary towards Skagerak. The necessary atmospheric input is extracted from the AROME-MetCoOp model that runs operationally at MET Norway (*Müller et al.*, 2015). The tidal input is based on the TPXO Atlantic database (*Egbert and Erofeeva*, 2002) and modified using the measurements at Viker close to the southern boundary. The freshwater discharges from the rivers are based on the discharge data from a database constructed by use of the hydrological model HBV (*Beldring et al.*, 2003). For more details on the FjordOs model, see *Røed et al.* (2016).

The FjordOs model covers the area of interest (Fig. 1). The model period in this study is April 2014 to December 2015.

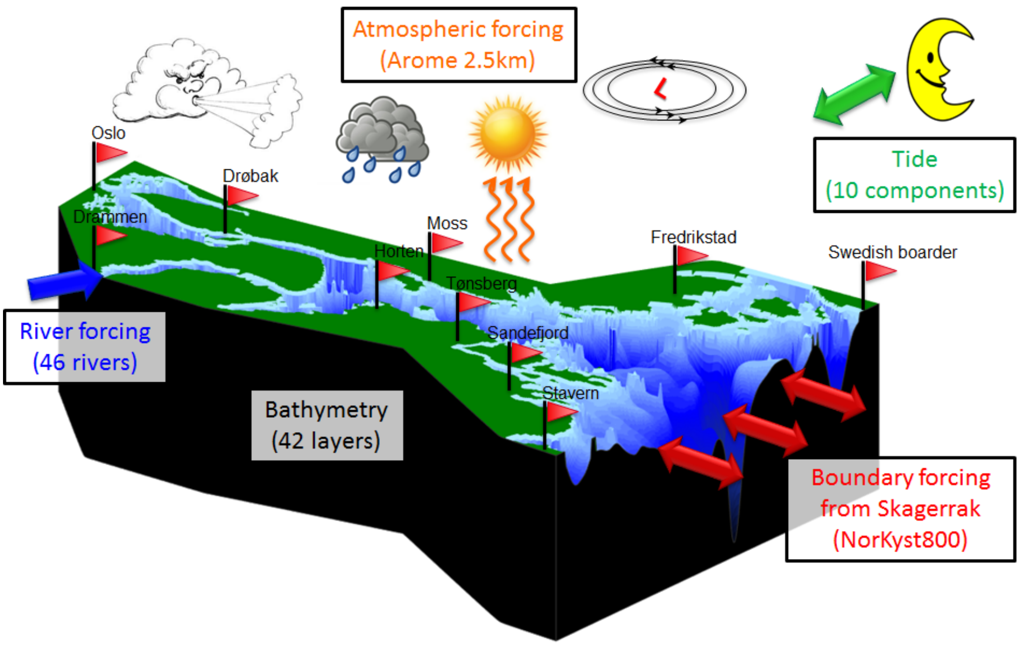


Figure 2: Illustration of external inputs to the FjordOs model.

# 4 Observed data

Figure 3: Area of interest. Positions for observations are marked. (Karina)

The relevant observed data in the area of interest are scattered in both time and space (Fig. 1). Observations over longer time period includes three stations measuring sea level, one bottom-mounted doppler measuring currents in two depths level, and one device measuring sea temperature. In addition more occasional observations includes CTD measurements, current measurements, ferrybox, some drifter experiments, and sea temperature at three beaches during the summer.

## 4.1 Water level - Karina

The Norwegian Mapping Authority has three permanent stations measuring sea level in the area of interest. The station at Viker is placed close to the open boundary of the model area. The station at Oscarsborg is placed halfway in the inner Oslofjord, and the station at Oslo is placed in the innermost part of the fjord.

## 4.2 Currents

### 4.2.1 Currents in two cross sections - André/Karina

Current measurements were performed by Statnett in two cross sections. To be continued ...

### 4.2.2 Currents at Slagentangen - Karina

Using a bottom-mounted doppler Exxonmobil has measured the currents in two depths since 1997. The device is placed 50-80 meters northwest of Turning Dolphin at the Slagen Refinery (Fig. 4).

## 4.3 Hydrography

### 4.3.1 CTD measurements - André

### 4.3.2 Water temperature near Åsgårdstrand - Karina

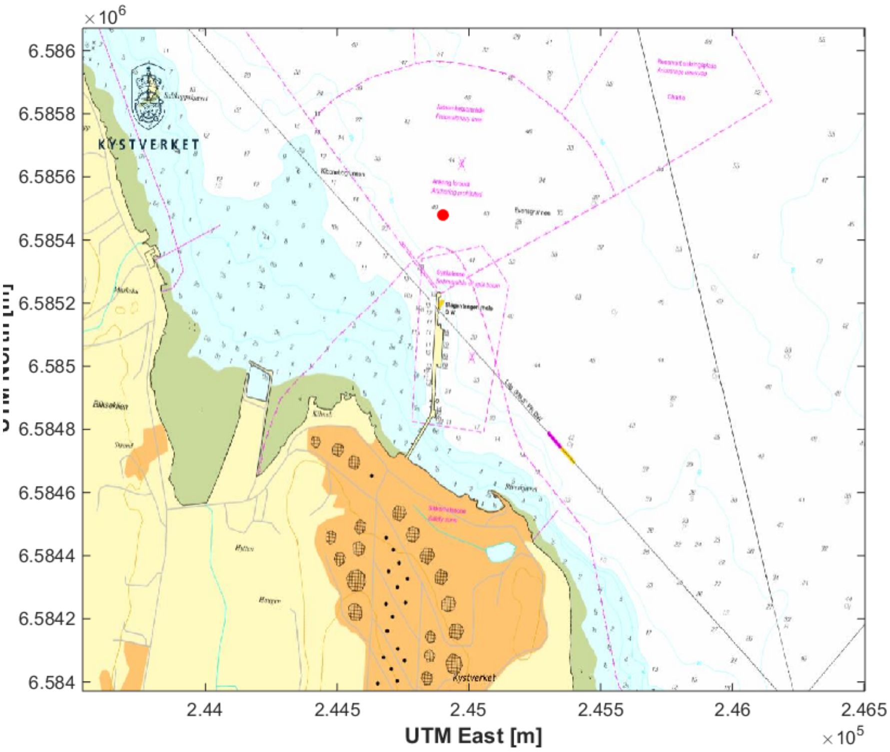


Figure 4: Map of Slagen Refinery. The red dot marks the position corresponding to the extracted simulated data. Souce: the Norwegian Coastal Administration

Hourly temperature measurements at one meter depth for the last 10 years have been measured by Scanmar AS located three kilometres south of Åsgårdstrand. The device has an accuracy of $\pm0.15^{o}$C in the range from -5 to +30$^{o}$C.

### 4.3.3 Water temperature in the inner Oslofjord - Karina

Temperature measurements at three beaches in the inner Oslofjord (Fig. 5) are performed in a cooperation between Asker and Bærum kommune, and Finnerud Elektronikk. The digital thermometers (Maxim Integrated DS18B20) have an accuracy of $\pm0.5^{o}$C and are placed 40 cm beneath the water surface in positions where the water depths are several meters. Temperatures are measured every three hours from 09:00 to 18:00 during the summer months.

The trends of the observed temperatures at the three beaches are similar, but the temperature is generally lower at the southern beach, Sjøstrand, than at the northern beach, Storøyodden (Fig. 6). In 2014 there were two local maximums during July, and the maximum observed temperatures in 2014 were higher than in both 2013 and 2015. The temperature increases 1-3 degrees during the day and decreases during the night.

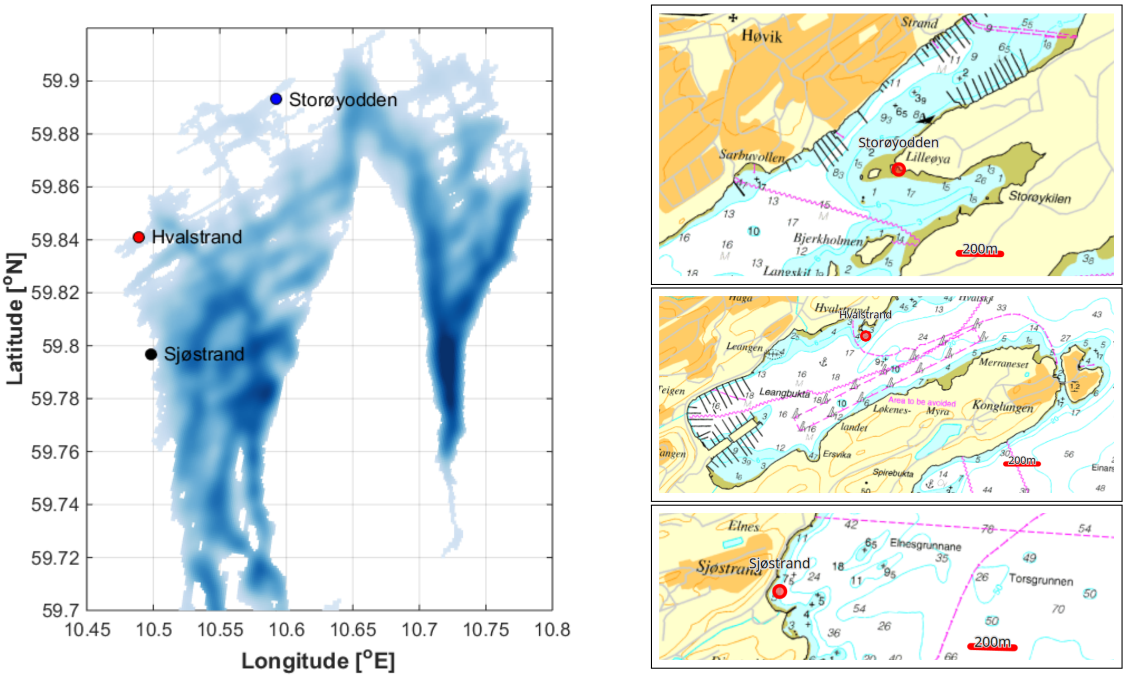


Figure 5: The positions at three beaches in the inner Oslofjord where the temperature measurements are performed

#### 4.3.4 Ferrybox - André

### 4.4 Drifting lanes - Karina

Godafoss ...

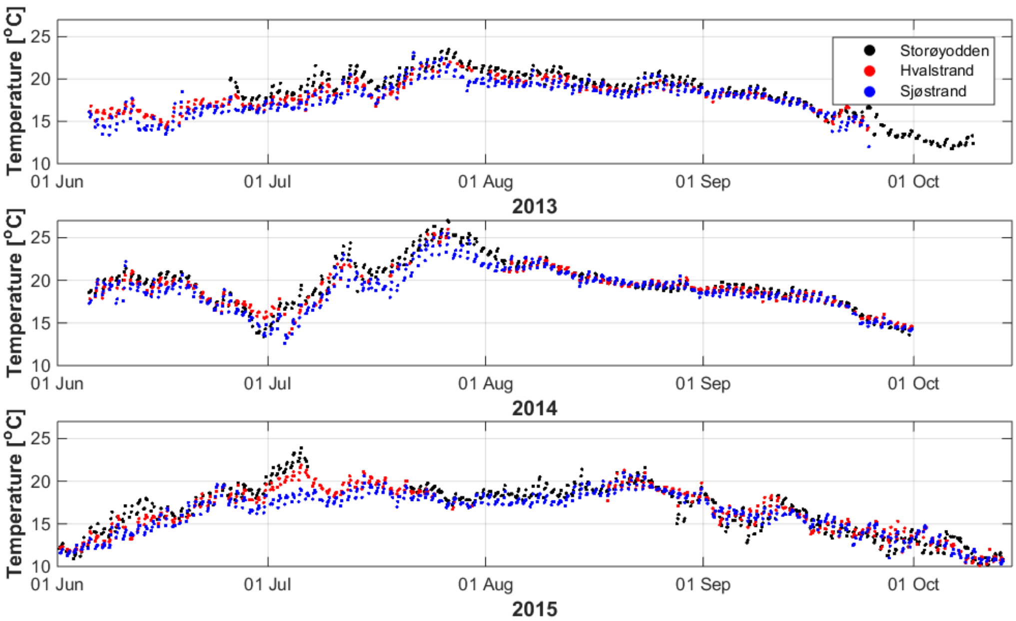


Figure 6: Observed temperature at three beaches in the inner Oslofjord

# 5 Evaluation

## 5.1 Water level and tide - Karina

Time series from the three permanent stations measuring water level have been analysed and compared with simulated time series of water level extracted from locations near the three permanent stations. Time series of water level are analysed using t_tide (*Pawlowicz et al.*, 2002) in order to extract the tidal components. The same period in time are applied for both the simulations and the observations.

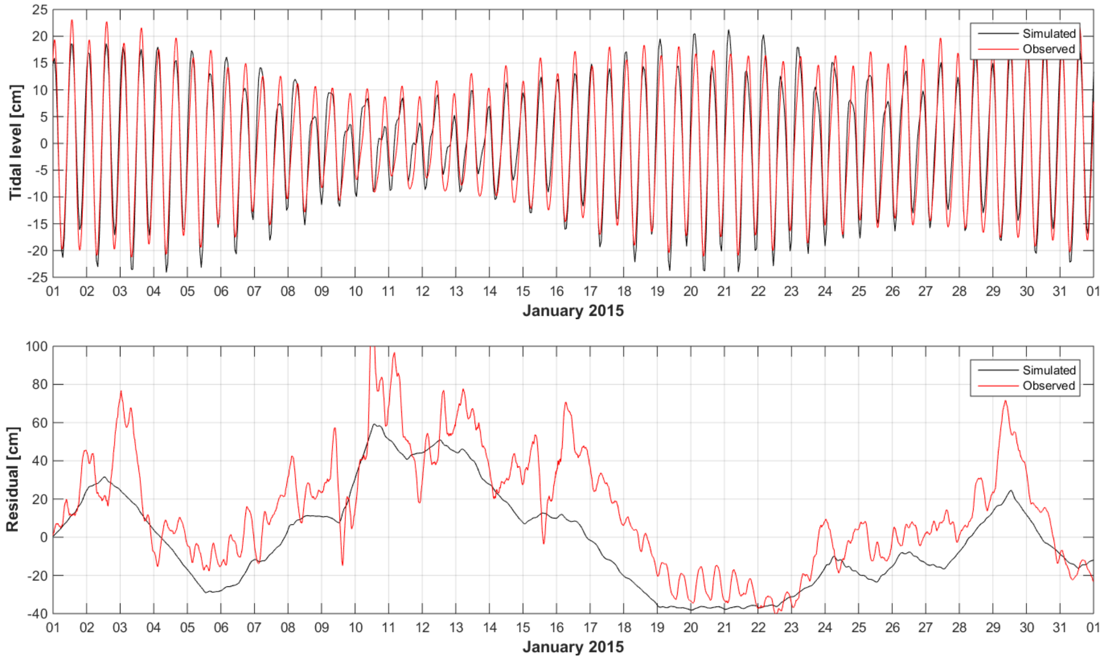


Figure 7: Simulated (black) and observed (red) time series of tides (upper) and residual (lower) at Oscarsborg. The tidal elevation includes only the eleven components included in the tidal forcing. The residual includes the total water level minus the tidal elevation.

Eleven tidal components are included in the model at the southern open boundary using their corresponding amplitudes and phases for both depth integrated currents and water level (*Røed et al.*, 2016). The time series of tidal components included in the tidal forcing are in fairly good agreement (Fig. 7,upper, and Tab.1). In addition to the tidal components included in the tidal forcing, more tidal components are present in the time series (Fig. 8). Tidal components with periods of approximately one year (SA) and half a year (SSA) respectively are present in both the observations and the simulations (Tab.1).

In addition, the observations have more components with shorter periods which are not included in the tidal forcing and thereby not present in the simulations. This is consistent with the frequency series of the Fourier transformed water level (Fig. 9).

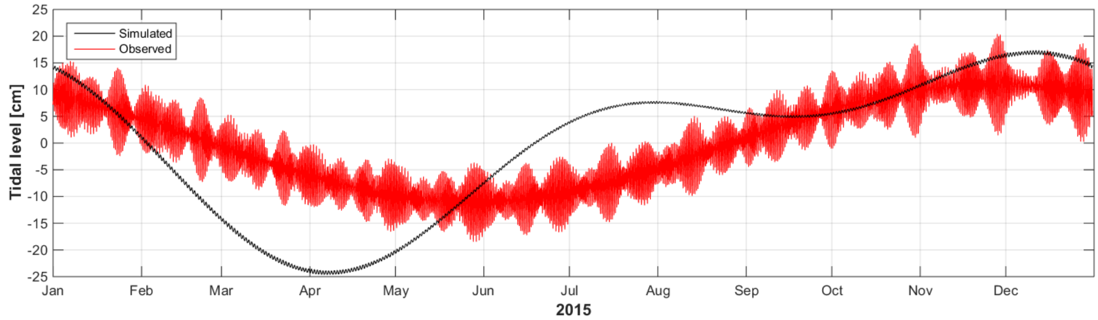


Figure 8: Time series at Oscarsborg of the tidal components not included in the tidal tidal forcing.

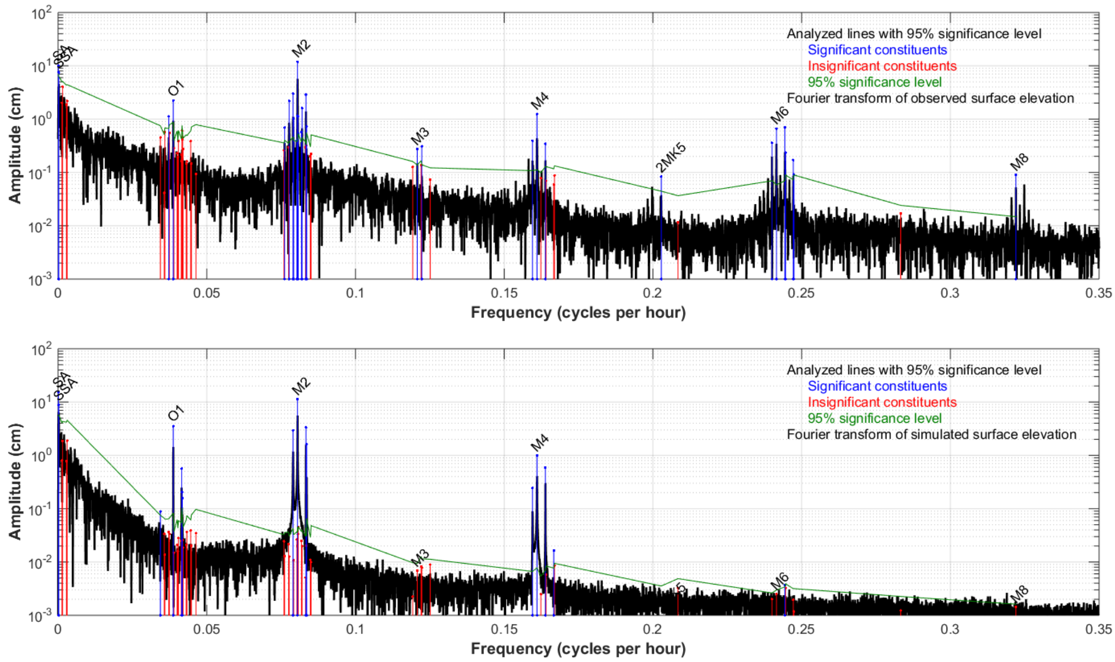


Figure 9: Frequency series of Fourier transformed observed (upper) and simulated (lower) water levels at Oscarsborg

Table 1: Simulated and observed tidal amplitude and phase for selected tidal components.

| **Comp.** | **Period [h]** | **sim/ obs** | **Viker amp. [cm]** | **Viker phase. [deg]** | **Oscarsborg amp. [cm]** | **Oscarsborg phase. [deg]** | **Oslo amp. [cm]** | **Oslo phase. [deg]** | **Included in tidal forcing** |
|---|---|---|---|---|---|---|---|---|---|
| SA | 8764 | sim | 15.6 | 286 | 15.5 | 284 | 15.4 | 286 | no |
| | | obs | 11.0 | 322 | 10.0 | 319 | 11.4 | 324 | |
| SSA | 4382 | sim | 9.2 | 200 | 8.8 | 197 | 9.4 | 200 | no |
| | | obs | 8.0 | 189 | 7.5 | 188 | 8.2 | 190 | |
| K2 | 11.9672 | sim | 2.0 | 13 | 1.6 | 10 | 2.1 | 15 | yes |
| | | obs | 0.8 | 66 | 0.7 | 45 | 0.9 | 66 | |
| S2 | 12.000 | sim | 3.9 | 69 | 3.3 | 64 | 4.2 | 70 | yes |
| | | obs | 3.3 | 65 | 2.9 | 46 | 3.5 | 69 | |
| M2 | 12.4206 | sim | 13.2 | 112 | 11.5 | 105 | 13.9 | 114 | yes |
| | | obs | 13.8 | 121 | 11.9 | 105 | 14.4 | 125 | |
| N2 | 12.6584 | sim | 3.5 | 75 | 3.0 | 69 | 3.7 | 76 | yes |
| | | obs | 3.4 | 76 | 3.0 | 60 | 3.6 | 80 | |
| K1 | 23.9345 | sim | 0.1 | 175 | 0.2 | 187 | 0.2 | 157 | yes |
| | | obs | 0.7 | 130 | 0.4 | 127 | 0.8 | 130 | |
| P1 | 24.0659 | sim | 0.6 | 334 | 0.6 | 322 | 0.7 | 342 | yes |
| | | obs | 0.3 | 102 | 0.2 | 129 | 0.4 | 97 | |
| O1 | 25.8193 | sim | 3.8 | 339 | 3.5 | 337 | 3.8 | 339 | yes |
| | | obs | 2.3 | 281 | 2.2 | 277 | 2.4 | 282 | |
| Q1 | 26.8684 | sim | 0.0 | 216 | 0.0 | 231 | 0.1 | 215 | no |
| | | obs | 1.2 | 198 | 1.1 | 190 | 1.3 | 200 | |
| MN4 | 6.2692 | sim | 0.5 | 32 | 0.2 | 5 | 0.6 | 35 | yes |
| | | obs | 0.6 | 289 | 0.4 | 249 | 0.7 | 297 | |
| M4 | 6.2103 | sim | 1.9 | 18 | 1.0 | 355 | 2.5 | 23 | yes |
| | | obs | 1.8 | 324 | 1.2 | 281 | 2.3 | 332 | |
| MS4 | 6.1033 | sim | 1.2 | 107 | 0.6 | 80 | 1.6 | 111 | yes |
| | | obs | 0.5 | 44 | 0.3 | 360 | 0.7 | 56 | |

## 5.2 Currents

### 5.2.1 Currents in two cross sections - André/Karina

To be continued... André?

### 5.2.2 Current at Slagentangen - Karina

The observed currents at Slagentangen are compared with simulated data from 1st October 2014 until 30th November 2015 at approximately the same location and depth.

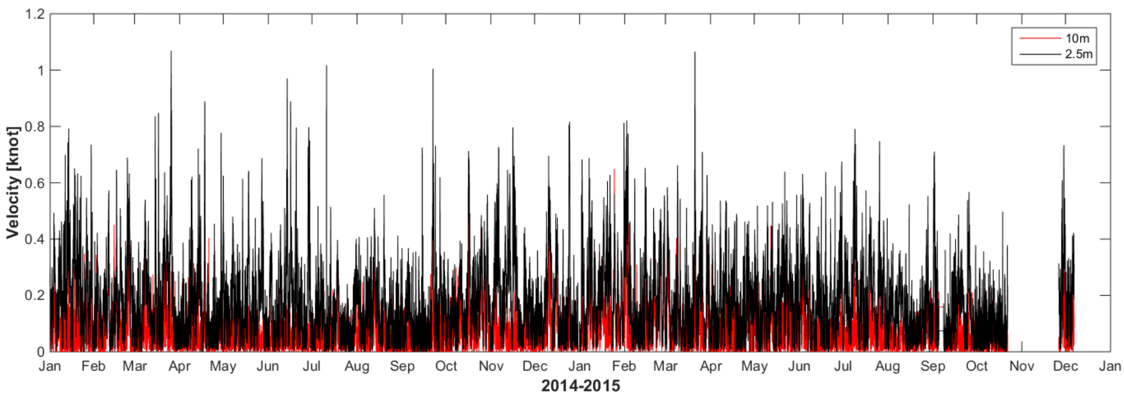


Figure 10: Timeseries of observed velocities at Slagen from 1st of January 2014 to 31st of December 2015.

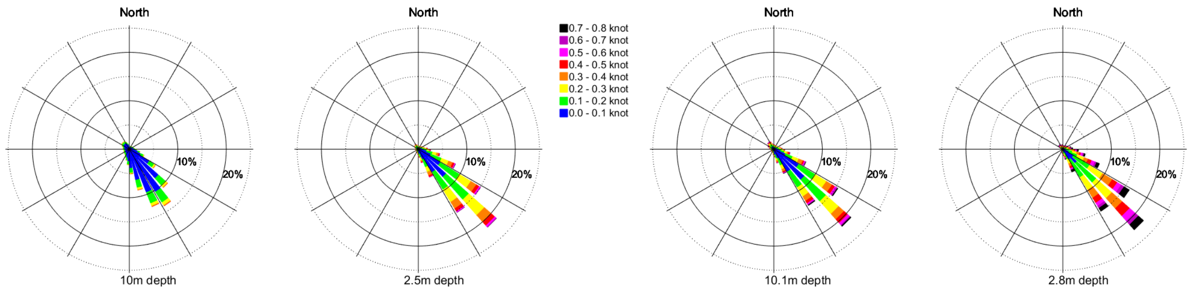


Figure 11: Current roses for observed (left) and simulated (right) velocities at two depths from 1st of October 2014 to 1st of October 2015.

Time series show that the observed velocities varies and follows no striking pattern (Fig. 10). Current roses show that the both the observed and the simulated velocities are stronger in the upper layer (Fig. 11). The simulated velocities are stronger than the observed velocities. This is in accordance with the probability density functions (Fig. 12).

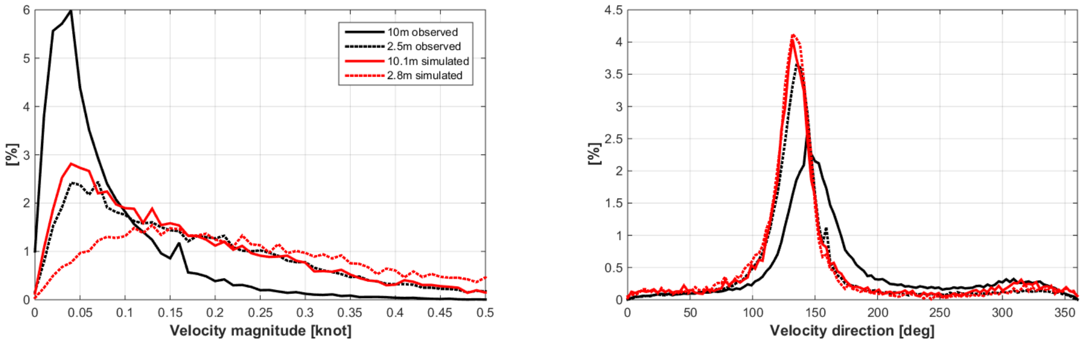


Figure 12: Probability density functions of velocities and directions at Slagen for 1st of October 2014 to 1st of October 2015. The bin width is 0.01 knots for velocity and 3 degrees for direction.

Table 2: Maximum observed velocity at Slagen.

| | **Max. velocity at 10m depth** | | | **Max. velocity at 2.5m depth** | | |
|---|---|---|---|---|---|---|
| **Year** | **Date** | **[knots]** | **[deg]** | **Date** | **[knots]** | **[deg]** |
| 2006 | 21 January | 0.81 | 139 | 31 October | 1.10 | 140 |
| 2007 | 14 January | 0.81 | 172 | 21 August | 2.00 | 359 |
| 2008 | 22 March | 0.70 | 149 | 19 December | 1.10 | 160 |
| 2009 | 17 December | 0.87 | 142 | 24 March | 1.10 | 139 |
| 2010 | 09 November | 0.81 | 138 | 09 November | 1.05 | 138 |
| 2011 | 01 January | 0.76 | 146 | 30 March | 1.21 | 185 |
| 2012 | 05 December | 0.75 | 138 | 29 May | 1.11 | 140 |
| 2013 | 10 October | 0.82 | 143 | 10 October | 0.95 | 144 |
| 2014 | 18 April | 0.85 | 147 | 26 March | 1.07 | 143 |
| 2015 | 24 January | 0.65 | 128 | 21 March | 1.07 | 141 |

The maximum velocities are approximately 0.8 and 1.1 knots at 10 and 2.5 meters depth respectively (Tab. 2). During 2014 and 2015 maximum observed velocity at 2.5 meters depth was 1.07 knots in southeast direction (143$^o$N) the 26th of March 2014. The velocity at 10 meters depth was 0.15 knot at the time of maximum velocity at 2.5 meters depth indicating that the velocities are different in the two layers.

The mean directions are to the south east. At approximately 2.5 meters depth the mean directions are 146$^o$N and 141$^o$N for observed and simulated directions respectively which is in fairly good agreement. At approximately 10 meters depth the observed mean direction shifts to 170$^o$N while the simulated mean direction is 149$^o$N. The probability

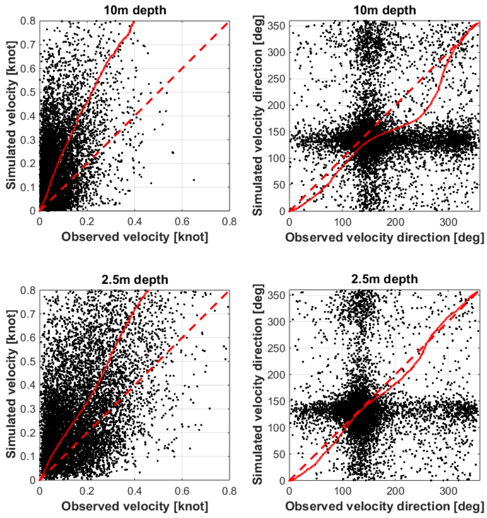


Figure 13: Combined QQ- and scatter plot of observed and simulated current at Slagen from 1st of October 2014 to 1st of October 2015.

density functions reveals that the model captures the distribution of directions in the upper layer, but does not capture the change in direction between the two depths (Fig. 12). The standard deviations at 2.5 and 10 meters are 55 and 66 degrees respectively for the observed directions, and 58 and 65 for the simulated directions.

The scatter plots reveal that the correlation in time is not satisfying (Fig. 13). The model seen to have difficulties with capturing the right phenomena influencing the currents to the right time. This is a well known problem when it comes to forecasting currents. The QQ-plots also confirms that the simulated currents are stronger than the observed currents.

## 5.3 Hydrography

### 5.3.1 CTD-measurements - André

To be continued... André

### 5.3.2 Water temperature near Åsgårdstrand - Karina

The temperature observations from Scanmar AS are compared with simulated data from 1st October 2014 until 30th November 2015 at the same location at 1.15 meters depth.

Time series show that the simulated temperatures are between 2 and 8 degrees lower than the observed temperatures 14. The model captures the variations in temperature fairly good (Fig. 15). Notice for example the variations in January with around three days period, and the local minimum around 1st of August. (Karina: Her bør det nevnes hva som forårsaker disse variasjonene.)

The probability density functions reveals that not only are the simulated temperatures lower than the observed temperatures, but the variation is larger in the observed temperatures (Fig. 16). The mean of the observed and simulated temperatures are 10.1$^o$C and 5.5$^o$C respectively, while the variances are 27.2$^o$C and 16.4$^o$C respectively.

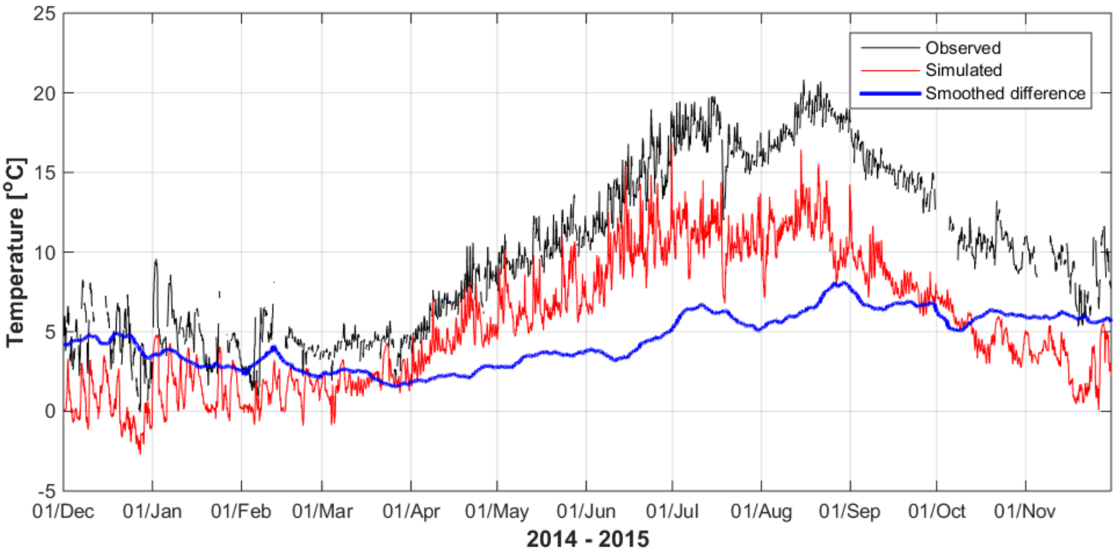


Figure 14: Time series of observed and simulated temperature at Åsgådstrand from 1st of December 2014 to 1st of December 2015. The difference is smoothed over 10 days.

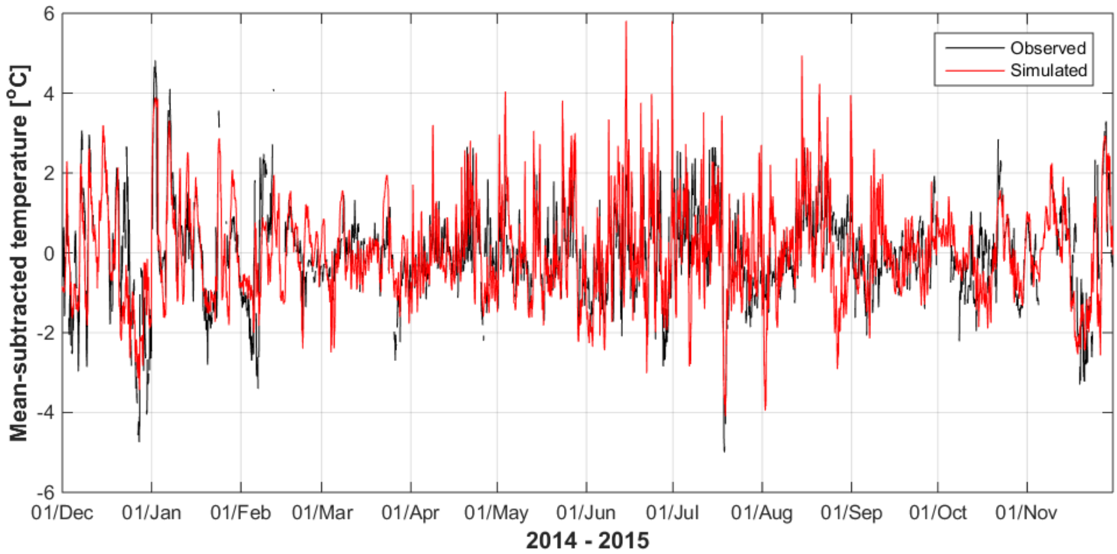


Figure 15: Mean-subtracted time series of observed and simulated temperature using a gliding mean of one month.

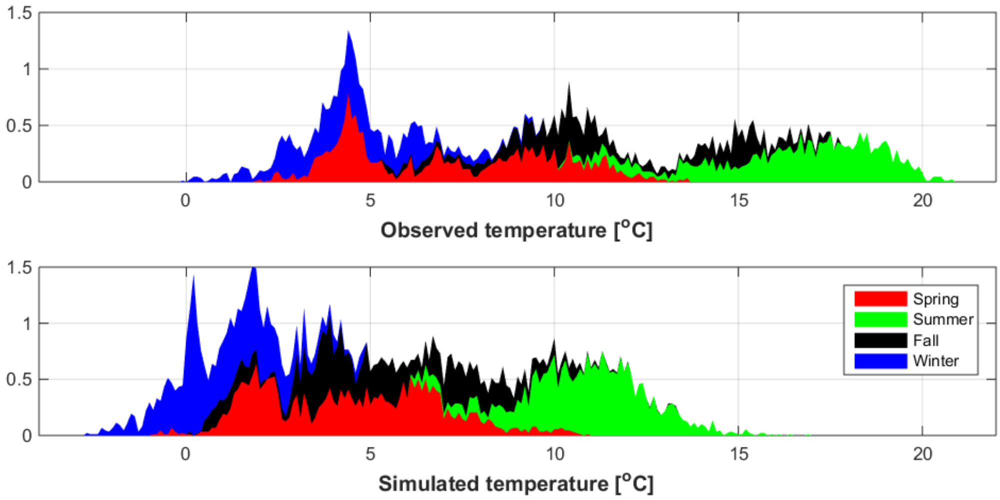


Figure 16: Probability density functions of observed and simulated temperature at Åsgådstrand from 1st of December 2014 to 1st of December 2015.

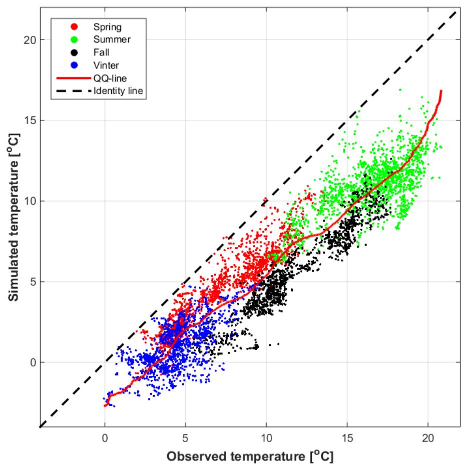


Figure 17: Combined QQ- and scatter plot of observed and simulated temperature at Åsgådstrand from 1st of December 2014 to 1st of December 2015.

### 5.3.3 Water temperature in the inner Oslofjord - Karina

The observed and simulated temperature at three beaches in the inner Oslofjord are in relatively good agreement (Fig. 18 - 19).

Close to the shoreline and only 40 cm under the surface, the temperature is heavily influenced by the weather situation and local circulation patterns.

The temperature differences during the day are larger in the model than in the observations. The observed temperature increases 1-3 degrees from 09:00 to 18:00 and is not measured during the night, while the modelled temperature increases up to six degrees from 06:00 to 23:00. The fact that temperature is not measured during the night, but only from 09:00 to 18:00, might explain differences i temperature rise during the day, but the difference might indicate too much heating in the model.

During the summer 2014 the model predicts higher temperatures at Sjøstrand than was observed. The observations in Hvalstrand have some of the same trends as the modelled temperature with temperatures up to 25 degrees. The air temperatures in 2014 was higher than in 2015 and resulted in higher water temperatures, especially in shallow areas.

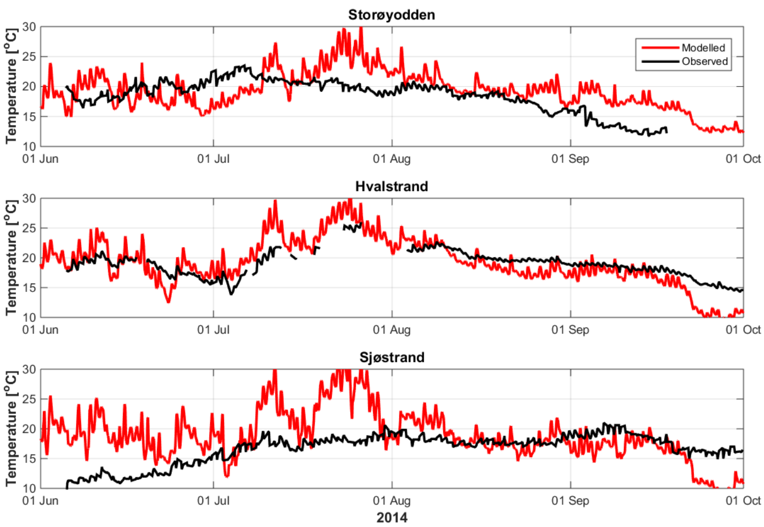


Figure 18: The observed and modelled temperature at three beaches in the inner Oslofjord during the summer 2014

### 5.3.4 Ferrybox - André?

To be continued... André?

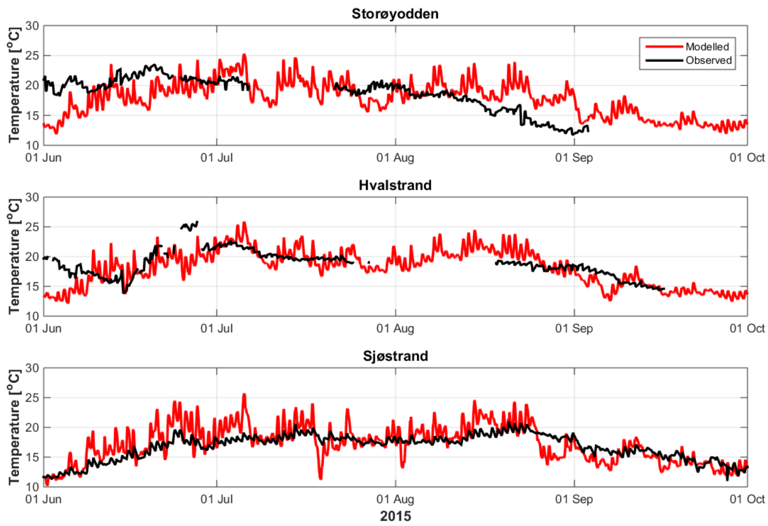


Figure 19: The observed and modelled temperature at three beaches in the inner Oslofjord during the summer 2015

### 5.3.5 Drifting lanes - Karina/Nils

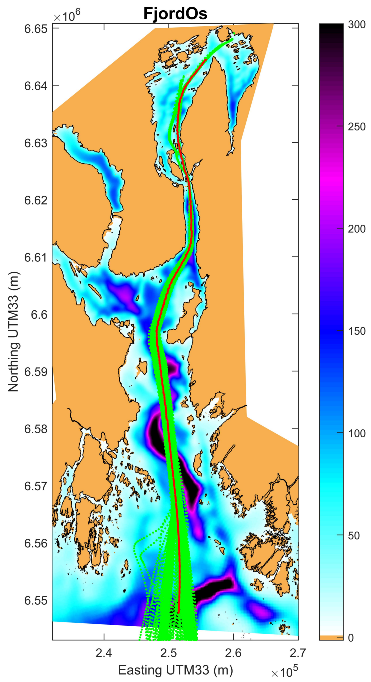


Figure 20: The track of Color Fantasy.

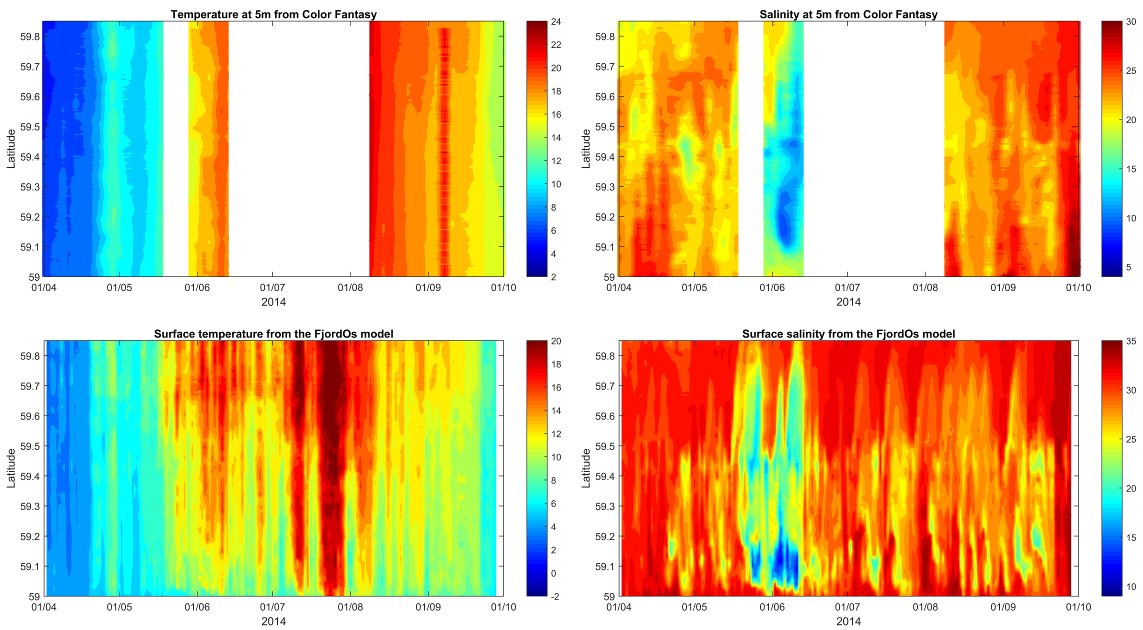


Figure 21: Simulated daily mean compared with observations from ferryboxes for temperature (left) and salinity (right).

### 5.4 Godafoss

Oppsummer værforhold og oljedriften etter Godefoss. Sammenlign med lignende tilfelle i 2014/15, samt alternative drivbaner under andre forhold.

### 5.5 Slagentangen

Utslipp fra Slangentangen havner alltid i Bliksekilen ifølge erfaring (Exxonmobil). Vi skal gjøre noen beregninger om hvor utslipp fra Slagentangen havner ifølge modellen.

## 6 Summary and final remarks

## Acknowledgements

# Appendix

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