Norwegian Meteorological Institute

METreport

No. X/2016
ISSN 2387-4201
Oceanography

Evaluation of the FjordOs-model

July 2016

Karina Hjelmervik[1], André Staalstrøm[2], Nils M. Kristensen[3], Lars P. Røed[3,4]

[1]University College of Southeast Norway, [2]Norwegian Institute for Water Research,
[3]Norwegian Meteorological Institute, [4]Department of Geosciences, University of Oslo

Norwegian
Meteorological
Institute

METreport

Title Evaluation of the FjordOs-model	Date July 8, 2016
Section Type	**Report no.** X/2015
Author(s) Karina Hjelmervik, Nils Melsom Kristensen, André Staalstrøm, Lars Petter Røed	**Classification** ● Free ○ Restricted
Client(s) Client name	**Client's reference**

Abstract

Abstract text...

Keywords

relevant, keywords, here

Disciplinary signature

Responsible signature

Abstract

Abstract text...

Norwegian Meteorological Institute
Org.no 971274042
post@met.no
www.met.no / www.yr.no

Oslo
P.O. Box 43, Blindern
0313 Oslo, Norway
T. +47 22 96 30 00

Bergen
Allégaten 70
5007 Bergen, Norway
T. +47 55 23 66 00

Tromsø
P.O. Box 6314, Langnes
9293 Tromsø, Norway
T. +47 77 62 13 00

Contents

Figure 1: Area of interest. Positions for observations are marked. (Karina)

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.

To be continued...

2 Area of interest - Karina

The area of interest is the Oslofjord including the Drammensfjord (Fig. 1).

3 Model - Karina

The FjordOs model is a curviliniar, 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). For details on the FjordOs model, see *Røed et al.* (2016).

The model period is April 2014 to December 2015.

To be continued...

4 Observed data

The relevant observed data in the area of interest is 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 experiemnts, and sea temperature at three beaches during the summer.

4.1 Water level observations - Karina

The Norwegian Mapping Authority has three permanent stations measureing 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 in the midle of the inner Oslofjord, and the station at Oslo is placed in the innermost part of the fjord.

Water level is a result of both baroclinic and barotropic. The difference between high and low tides are ...

4.2 Observations of 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. 8).

4.3 Observations of hydrography

4.3.1 CTD measurements - André

4.3.2 Water temperature 3km south of Åsgårdstrand - Karina

Hourly temperature measurements at one meter depth for the last 10 years have been measured by Scanmar AS located south of Åsgårdstrand. The device has an acurracy of $\pm 0.15^o$C in the range from -5 to +30^{o}C.

4.3.3 Beach temperature in the inner Oslofjord - Karina

Temperature measurements at three beaches in the inner Oslofjord (Fig. 3) are performed in a cooperation between Asker and Bærum kommune, and Finnerud Elektronikk. The digital thermometers (Maxim Integrated DS18B20) have an acurracy of $\pm 0.5^o$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

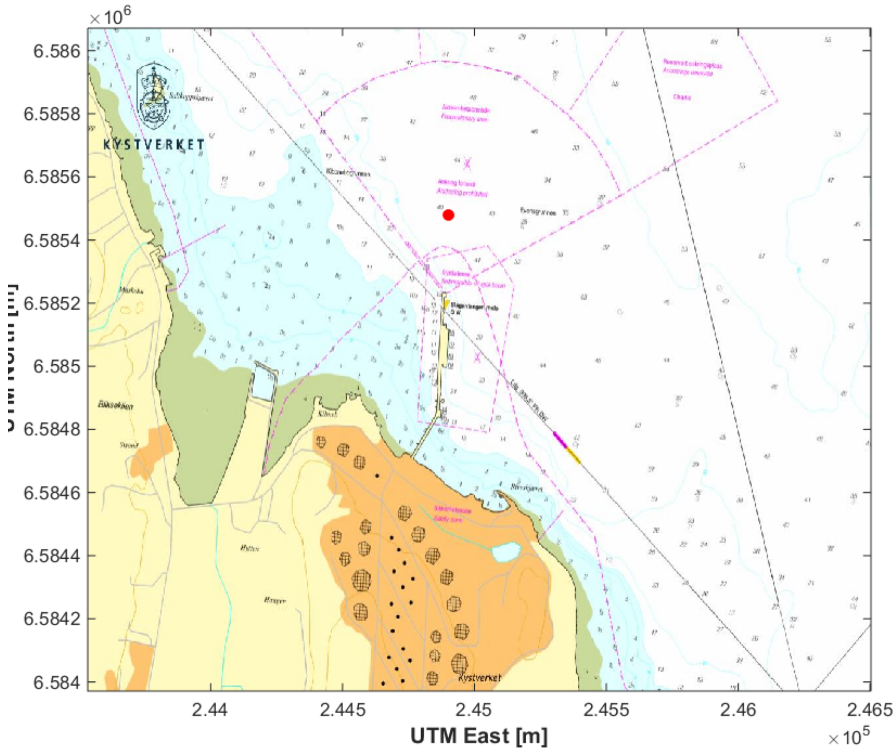

Figure 2: Map of Slagen Refinery. The red dot marks the position corresponding to the extracted simulated data. Souce: the Norwegian Coastal Administration

summer months.

With some exceptions the mean temperature is higher at the southern beach, Sjøstrand, than at the northern beach, Storøyodden during the summer (Tab. 1). The observed temperatures in 2014 were higher than in both 2013 and 2015. The temperature increases up to 2-3 degrees during the day and decreases during the night.

4.3.4 Ferrybox - André

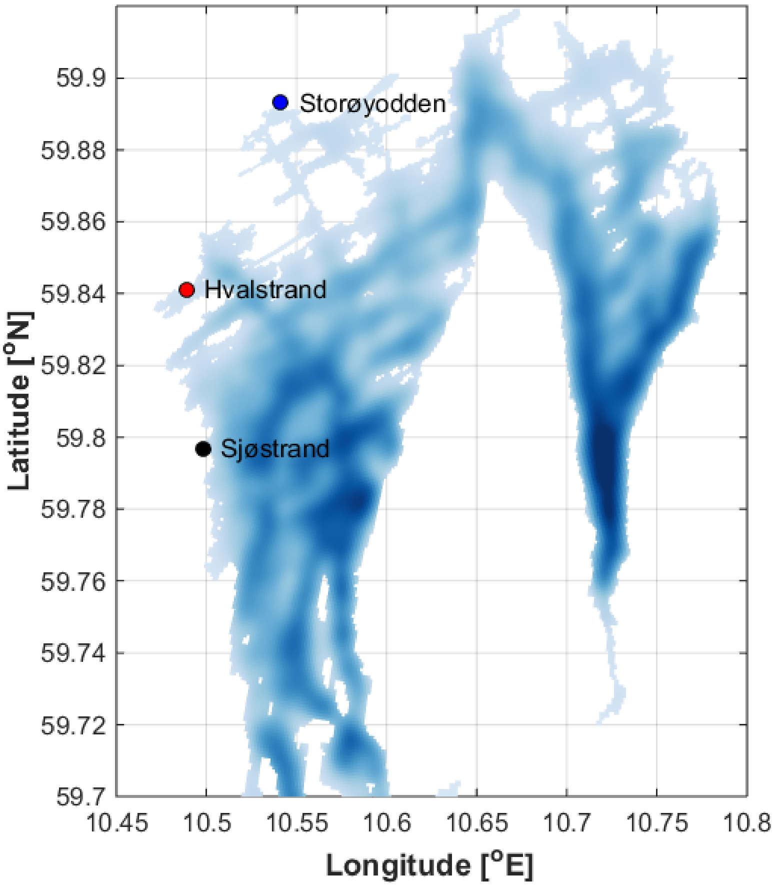

Figure 3: The position of the temperature measurements performed at three beaches in the inner Oslofjord

Table 1: Mean observed temperatures at three beaches in the inner Oslofjord. Only time periods with more than 8 days of observations during the given time period are included.

	Storøyodden			Hvalstrand			Sjøstrand		
Time period	2013	2014	2015	2013	2014	2015	2013	2014	2015
16 - 31 May	13.7	-	11.6	-	-	12.2	-	-	12.8
01 - 15 Jun	15.0	19.0	13.3	15.9	19.4	13.7	-	19.9	14.6
16 - 30 Jun	16.2	17.3	17.1	16.7	17.7	17.5	-	17.9	18.0
01 - 15 Jul	17.8	17.6	18.2	18.3	18.3	19.8	19.4	19.3	-
16 - 31 Jul	20.1	22.2	18.1	19.7	-	18.9	21.2	23.9	18.4
01 - 15 Aug	19.5	21.3	18.0	19.8	21.3	-	20.6	21.7	18.8
16 - 31 Aug	18.9	19.6	19.1	18.9	19.6	19.3	19.5	19.4	19.0
01 - 15 Sep	17.9	18.3	16.1	17.7	18.6	16.5	18.1	18.9	16.2
16 - 30 Sep	-	15.9	14.1	-	16.2	14.1	15.1	16.3	13.7
01 - 15 Oct	-	-	12.0	-	-	11.9	-	-	11.5

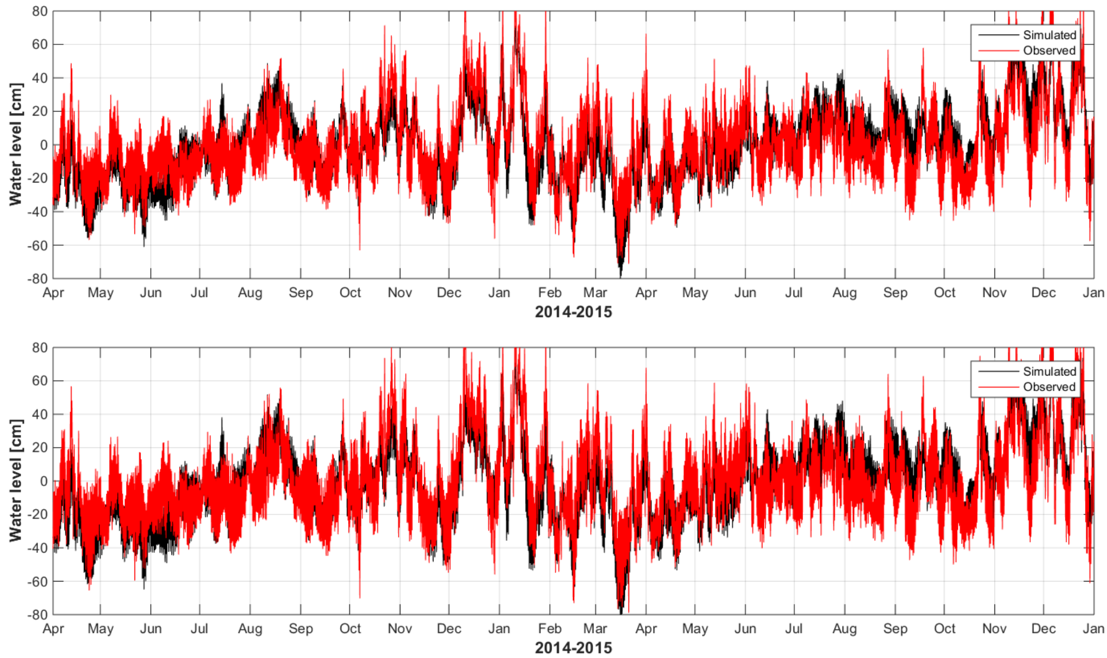

Figure 4: Observed and simulated water level for Viker (upper) and Oscarsborg (lower)

5 Evaluation

5.1 Water level and tide - Karina

Time series from the three permanent stations measuring sea level have been analysed and compared with simulated time series of waterlevel from the same period in time.

Tides are included in the model at the southern open boundary in two ways. The FjordOs model is nested into NorKyst800 through daily mean forced on the boundary. This forcing includes the tidal components with longer periods. In addition 11 components with shorter periods are introduced explicitly using their corresponding amplitudes and phases for both depth integrated currents and water level (ref. tidevannsartikkel?). The timeseries of tides originating from explicit tidal forcing are in fairly good agreement (Fig. 5, upper, and Fig. 6,upper). The main characteristics of the remainding tidal components are present in both the observed and the simulated timeseries (Fig. 5, lower).

To be continued... Karina (Figurer og tabeller er laget og satt inn, men en del tekst mangler fortsatt)

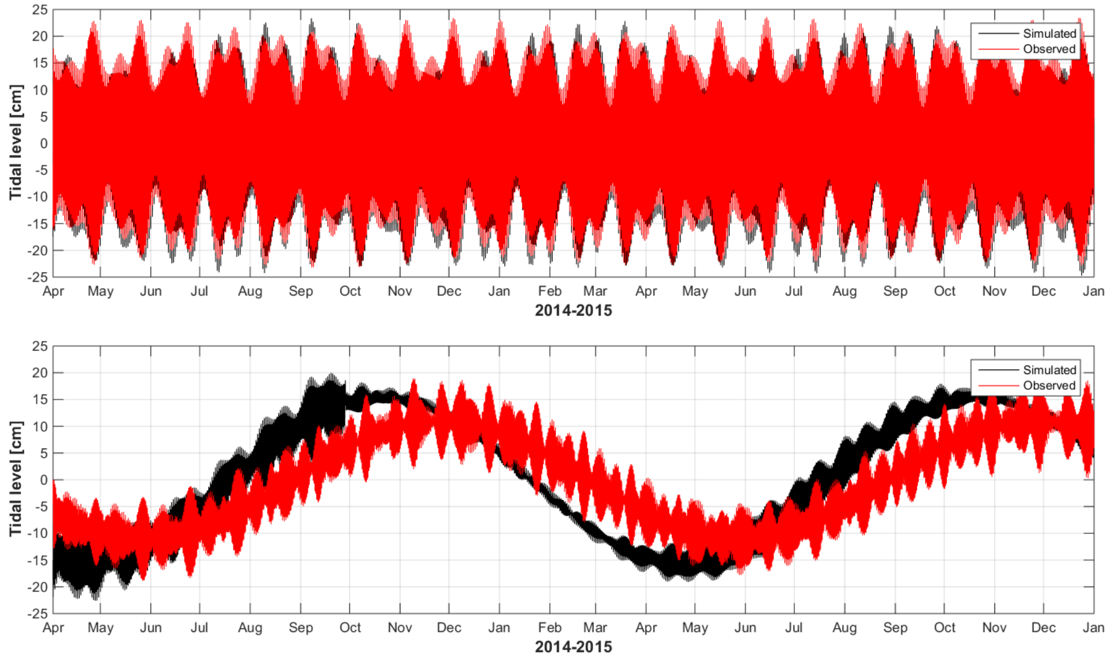

Figure 5: Timeseries at Oscarsborg of the tidal components included (upper) and not included (lower) in the explicit tidal forcing.

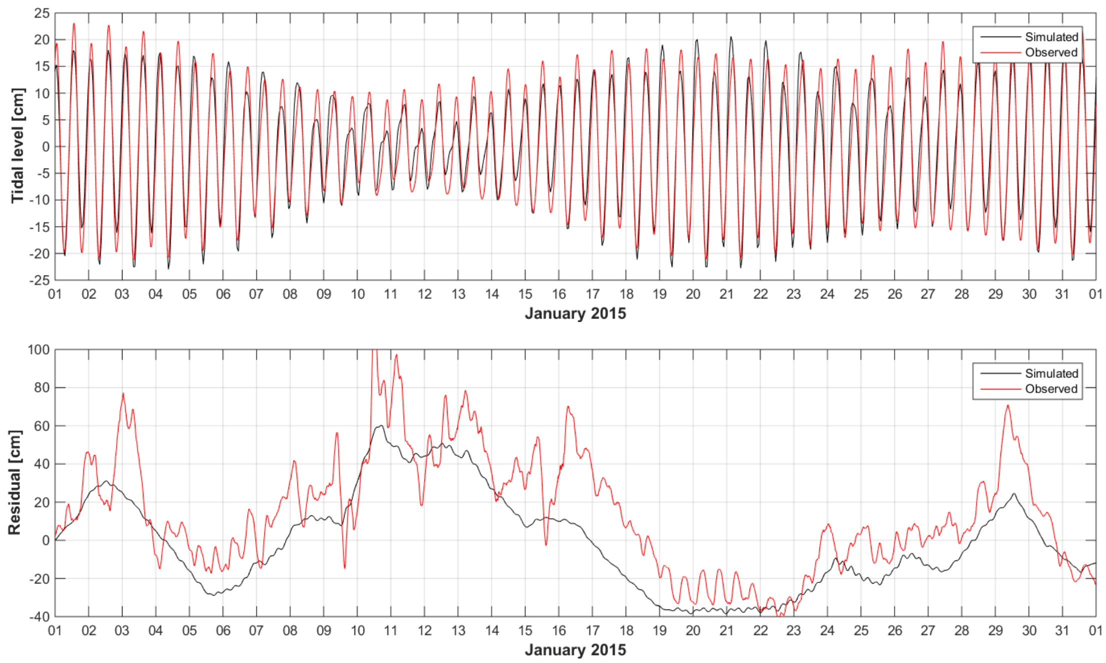

Figure 6: Timeseries of tides originating from explicit tidal forcing (upper) and the residual (lower) at Oscarsborg

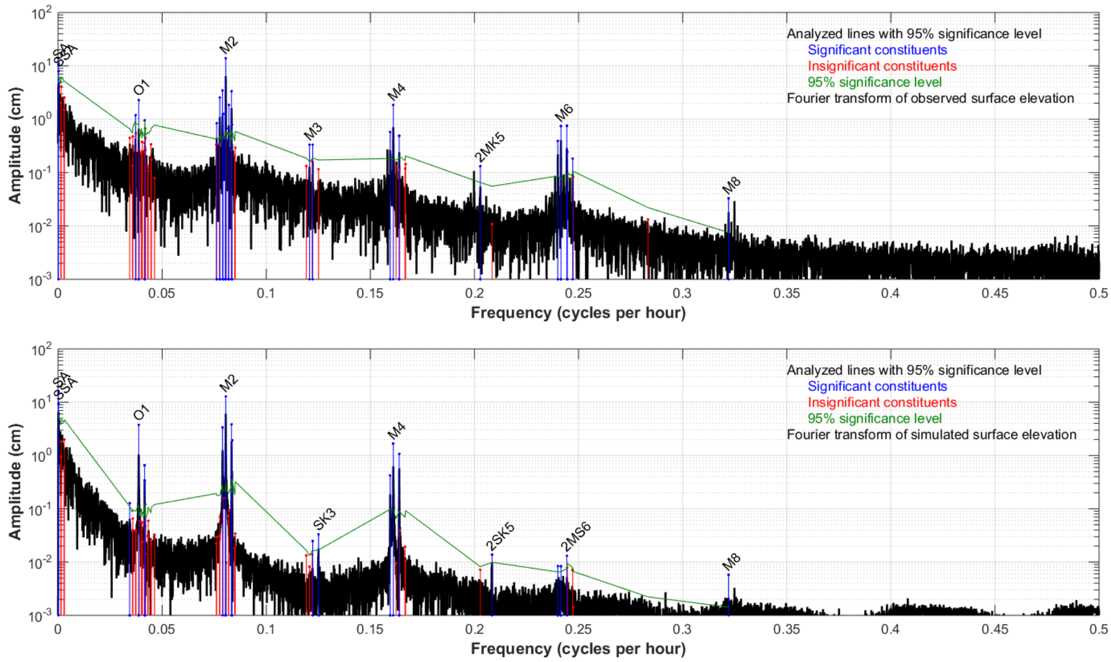

Figure 7: Frequency series of Fourier transformed observed (upper) and simulated (lower) water levels at Oscarsborg

Table 2: 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	365 days	sim	15.5	284	15.5	286	15.2	286	no
		obs	10	319	11	322	11.3	324	
SSA	182 days	sim	8.8	198	9.2	199	9.3	200	no
		obs	7.5	188	7.9	188	8.2	190	
K2	11.9672	sim	1.6	32	1.9	35	2.1	37	yes
		obs	0.7	46	0.8	66	0.9	67	
S2	12.0000	sim	3.3	87	3.8	91	4.1	92	yes
		obs	2.9	46	3.3	65	3.5	69	
M2	12.4206	sim	11.2	127	12.9	134	13.6	135	yes
		obs	11.9	105	13.8	121	14.4	125	
N2	12.6584	sim	2.9	91	3.4	96	3.6	98	yes
		obs	3	60	3.4	76	3.6	80	
K1	23.9345	sim	0.2	194	0.1	185	0.1	165	yes
		obs	0.4	125	0.7	128	0.8	129	
P1	24.0659	sim	0.6	335	0.7	346	0.7	352	yes
		obs	0.2	123	0.4	100	0.4	95	
O1	25.8193	sim	3.5	347	3.8	348	3.8	349	yes
		obs	2.3	276	2.3	281	2.4	282	
Q1	26.8684	sim	0	177	0	188	0.1	201	no
		obs	1.1	189	1.2	197	1.3	199	
MN4	6.2692	sim	0.2	50	0.4	76	0.6	78	yes
		obs	0.4	249	0.6	289	0.7	297	
M4	6.2103	sim	0.9	37	1.7	61	2.2	65	yes
		obs	1.2	281	1.8	324	2.3	332	
MS4	6.1033	sim	0.5	123	1.1	150	1.4	154	yes
		obs	0.3	360	0.5	44	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 aproximately the same location and depth.

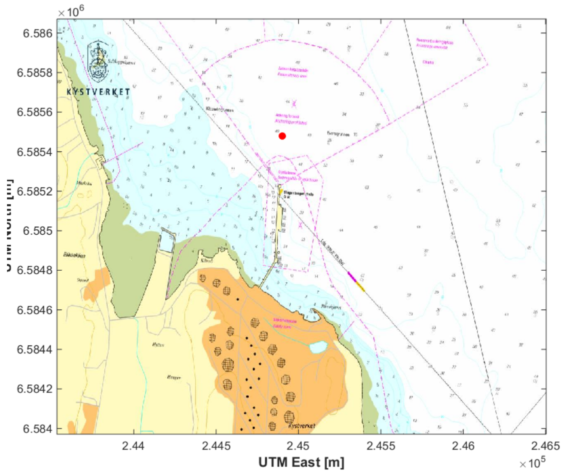

Figure 8: Map retrived from the Norwegian Coastal Administration. The red dot marks the position corresponding to the extracted simulated data.

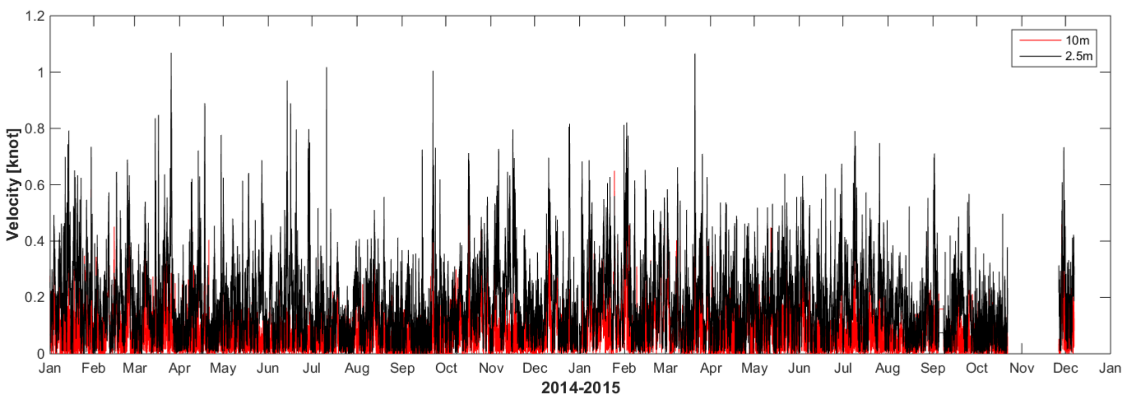

Figure 9: Timeseries of observed velocities at Slagen from 1st of January 2014 to 31st of December 2015.

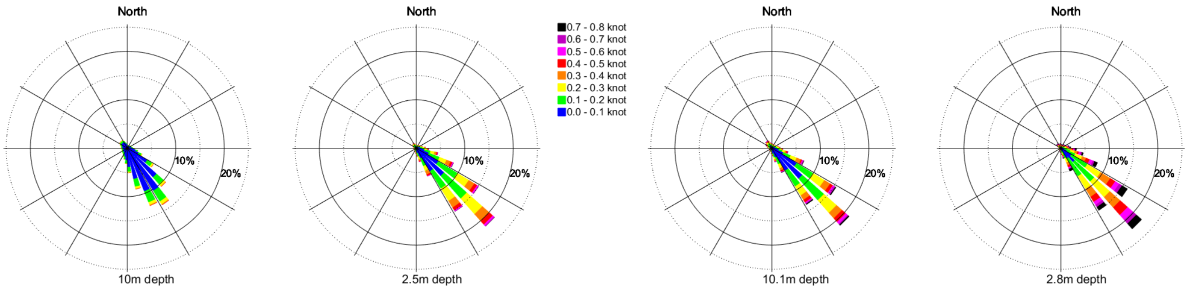

Figure 10: Current roses for observed (left) and simulated (right) velocities at two depths from 1st of October 2014 to 1st of October 2015.

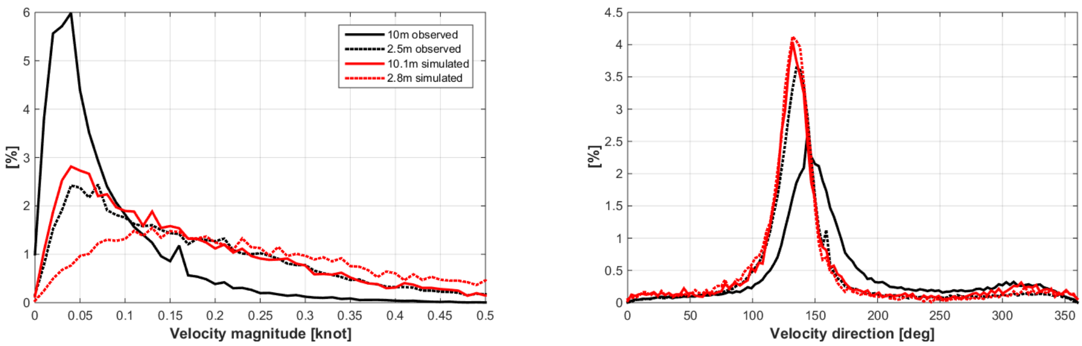

Figure 11: Probability density functions of velocities and directions at Slagen for 1st of October 2014 to 1st of October 2015. The bin width is 0.01 knots for velocity and 3 degrees for direction.

Time series show that the observed velocities varies and follows no striking pattern (Fig. 9). Current roses show that the both the observed and the simulated velocities are stronger in the upper layer (Fig. 10). The simulated velocities are stronger than the observed velocities. This is in accordance with the probability density functions (Fig. 11). The maximum velocities are approximately 0.8 and 1.1 knots at 10 and 2.5 meters depth respectively (Tab. 3). 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 density functions reveals that the model captures the distribution of directions in the upper

Table 3: Maximum oberved velocity at Slagen.

	Max. velocity at 10m depth			**Max. velocdity at 2.5m depth**		
Year	**Date**	**[knots]**	**[deg]**	**Date**	**[knots]**	**[deg]**
2006	21 January	0.81	139	31 Octotber	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 Octotber	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

layer, but does not capture the change in direction between the two depths (Fig. 11). 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. 12). 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 forecating currents. The QQ-plots also confirmes that the simulated currents are stronger than the observed currents.

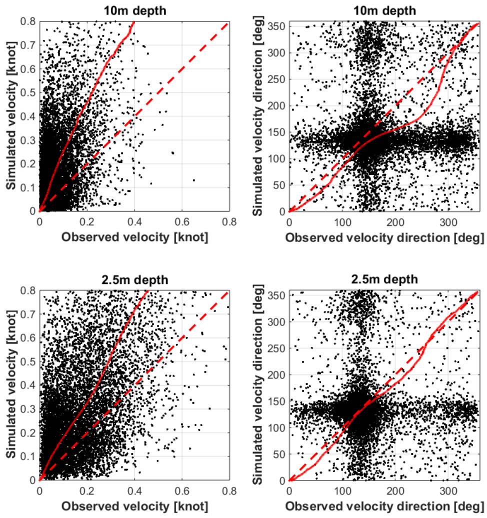

Figure 12: Combined QQ- and scatterplot of observed and simulated current at Slagen from 1st of October 2014 to 1st of October 2015.

5.3 Hydrography

5.3.1 CTD-measurements - André

To be continued... André

5.3.2 Water temperature 3km south of Åsgårdstrand - Karina

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

Timeseries show that the simulated temperatures are between 2 and 8 degrees lower than the observed temperatures 13. The model captures the variations in temperature fairly good (Fig. 14). 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. 15). 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.

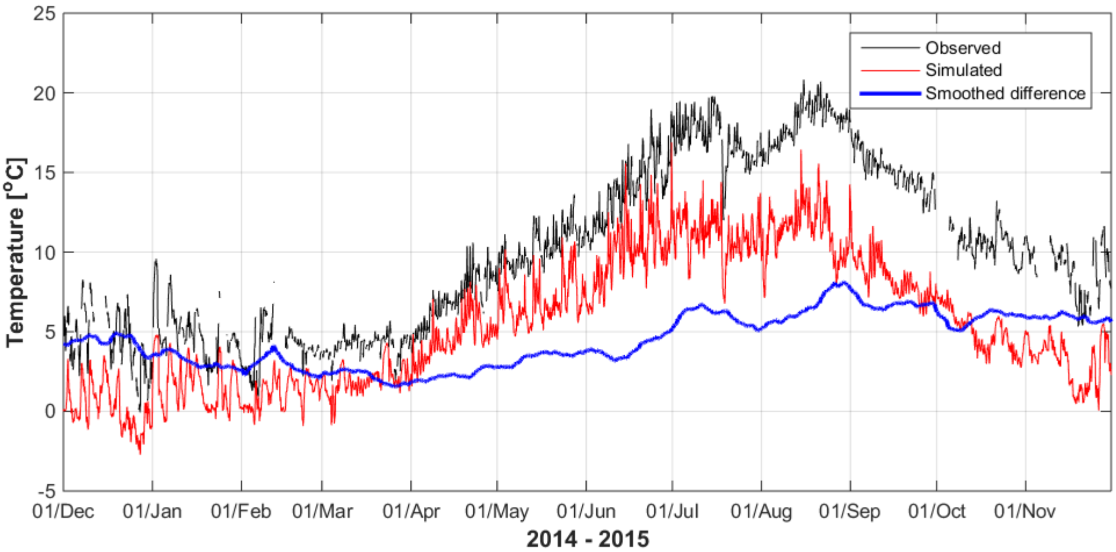

Figure 13: Timeseries of observed and simulated temperature at Åsgådstrand from 1st of December 2014 to 1st of December 2015. The difference is smoothed over 10 days.

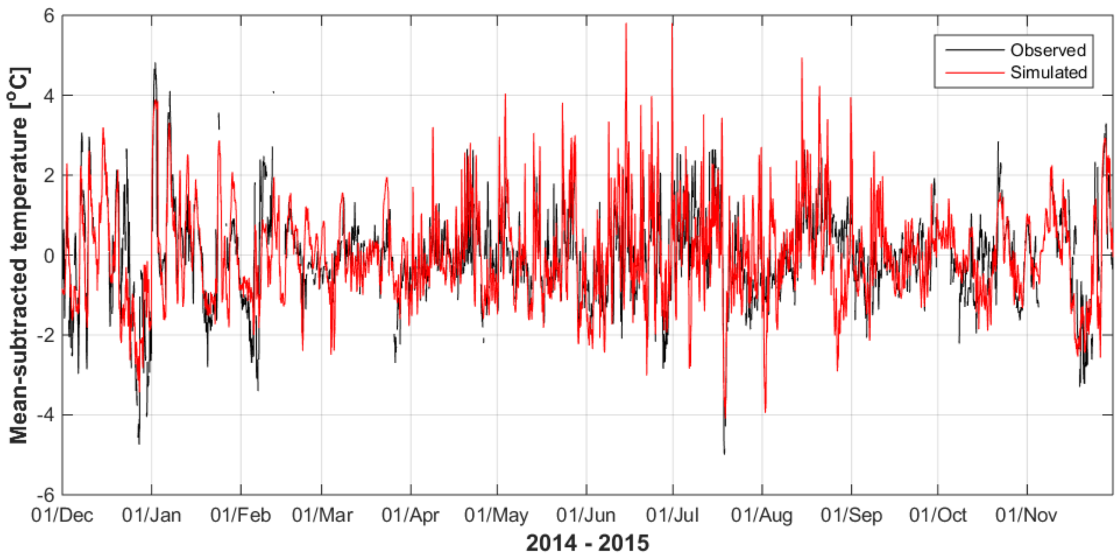

Figure 14: Mean-subtracted timeseries of observed and simulated temperature using a gliding mean of one month.

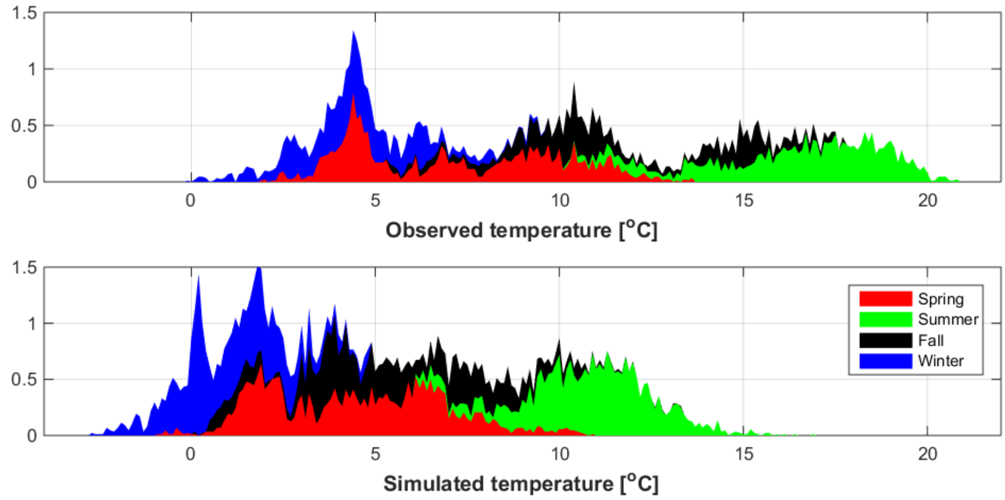

Figure 15: Probability density functions of observed and simulated temperature at Åsgådstrand from 1st of December 2014 to 1st of December 2015.

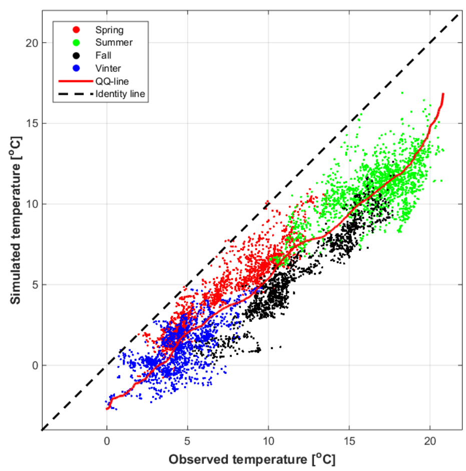

Figure 16: Combined QQ- and scatterplot of observed and simulated temperature at Åsgådstrand from1st of December 2014 to 1st of December 2015.

5.3.3 Beach temperature in the inner Oslofjord - Karina

The observed and modelled temperature at three beaches in the inner Oslofjord are in relativ good agreement (Fig. 17 - 18). Since the temperature is observed close to the shoreline, near river outlets, and only 40 cm under the surface, the observations are heavily influenced by the weather situation and local currents. The model is not expected to capture such detailed effects. Still there are similarities between the modelled and the observed temperatures both in temperature level and in fluctuations. There temeprature differences during the day are larger in the model than in the observations. Since the temperature is not measured during the night, but only from 09:00 to 18:00, this might explain some of the differences.

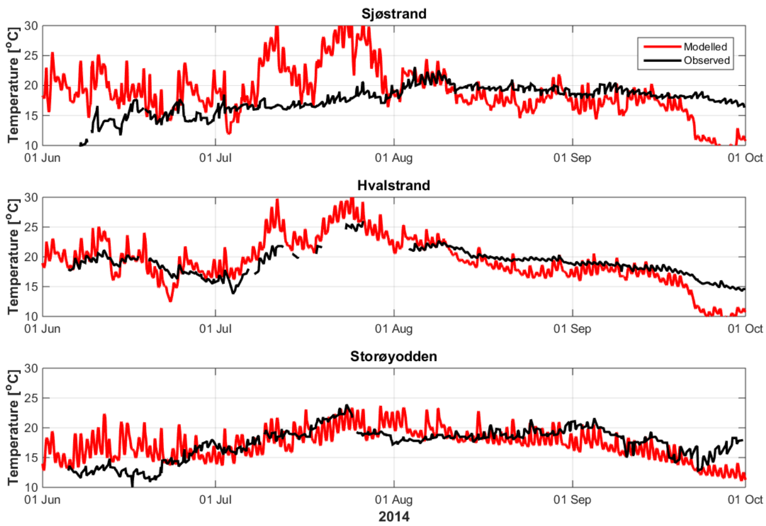

Figure 17: The observed and modelled temperature at three beaches in the inner Oslofjord during the summer 2014

5.3.4 Ferrybox - André?

To be continued... André?

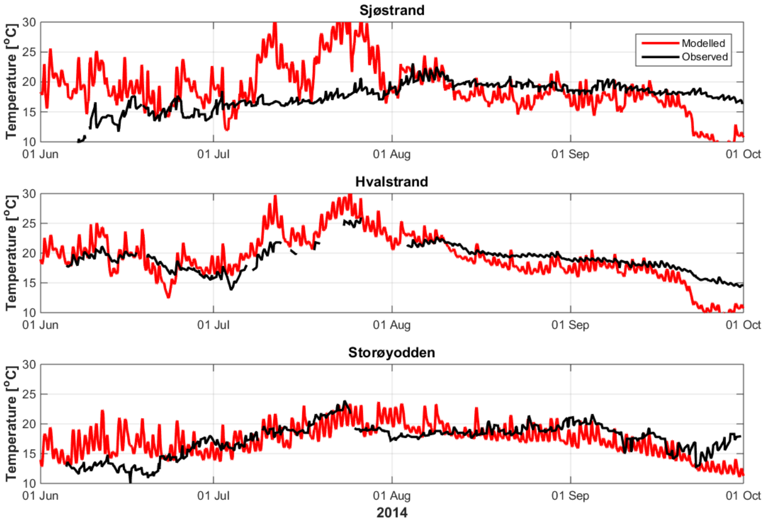

Figure 18: The observed and modelled temperature at three beaches in the inner Oslofjord during the summer 2015

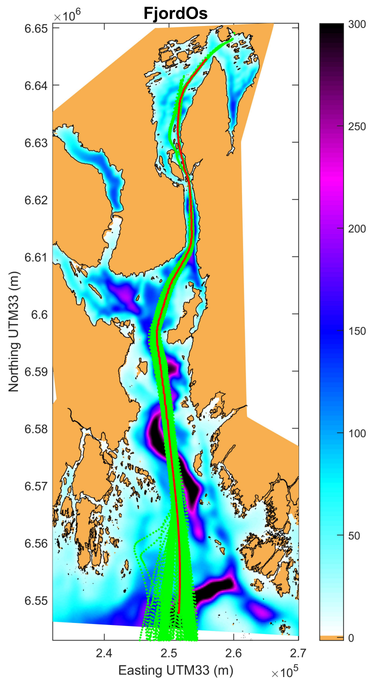

Figure 19: The track of Color Fantasy.

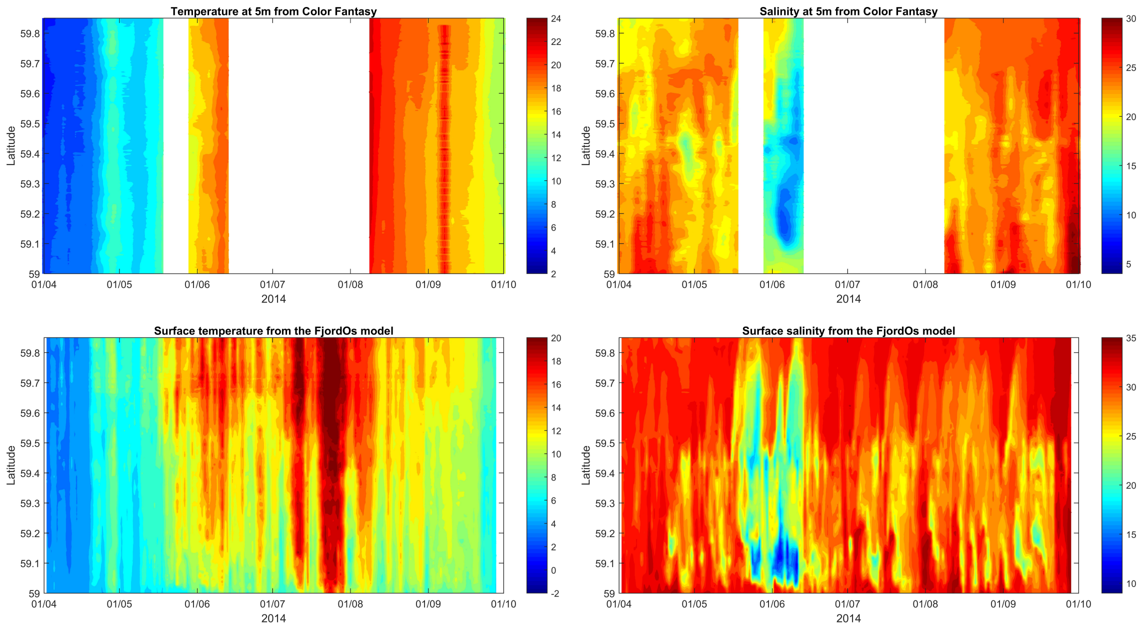

Figure 20: Simulated daily mean compared with observations from ferryboxes for temperature (left) and salinity (right).

6 Summary and final remarks

Acknowledgements

Appendix

References

Haidvogel, D. B., H. Arango, P. W. Budgell, B. D. Cornuelle, E. Curchitser, E. D. Lorenzo, K. Fennel, W. R. Geyer, A. J. Hermann, L. Lanerolle, J. Levin, J. C. McWilliams, A. J. Miller, A. M. Moore, T. M. Powell, A. F. Shchepetkin, C. R. Sherwood, R. P. Signell, J. C. Warner, and J. Wilkin (2008), Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the Regional Ocean Modeling System, *J. Comput. Phys.*, *227*(7), 3595–3624, doi: http://dx.doi.org/10.1016/j.jcp.2007.06.016.

Røed, L. P., N. M. Kristensen, K. B. Hjelmervik, and A. Staalstrøm (2016), A high-resolution, curvilinear roms model for the oslofjord, *Technical Report 4*, Norwegian Meteorological Institute, MET Norway, P.O.Box 43 Blindern, NO-0313 Oslo, Norway.

Shchepetkin, A. F., and J. C. McWilliams (2003), A method for computing horizontal pressure-gradient force in an oceanic model with a nonaligned vertical coordinate, *J. Geophys. Res.*, *108*, 3090, doi:10.1029/2001JC001047.

Shchepetkin, A. F., and J. C. McWilliams (2005), The Regional Ocean Modeling System (ROMS): A split-explicit, free-surface, topography-following coordinate ocean model, *Ocean Modelling*, *9*, 347–404.

Shchepetkin, A. F., and J. C. McWilliams (2009), Correction and commentary for "Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the regional ocean modeling system" by Haidvogel et al., J. Comp. Phys. 227, pp. 3595-3624, *J. Comp. Phys.*, *228*(24), 8985 – 9000, doi:10.1016/j.jcp.2009.09.002.