FISKEN OG HAVET

nr. 2/2011

NorKyst-800 Report No. 1
User Manual and technical descriptions

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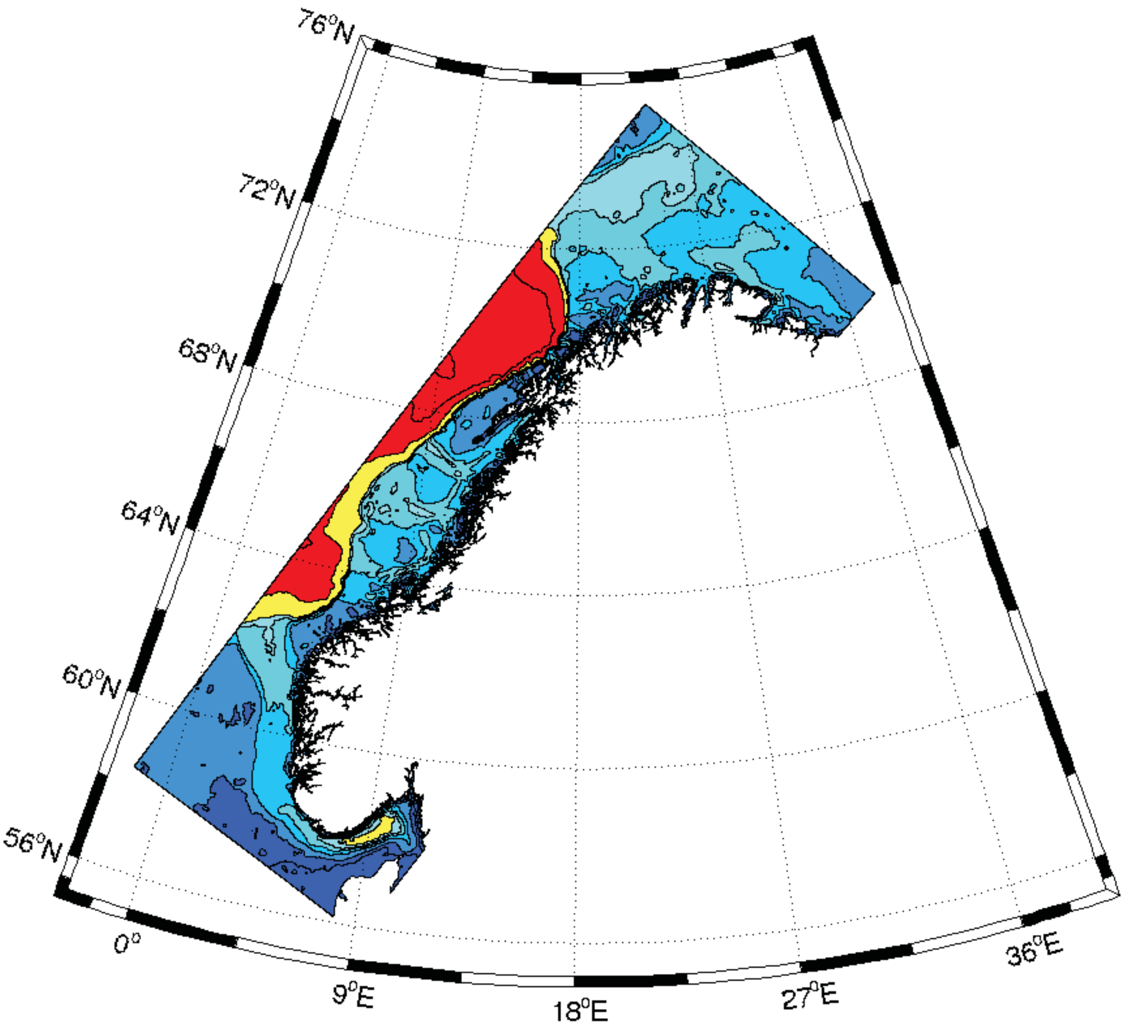

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PROSJEKTRAPPORT

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Flødevigen 4817 HIS

Distribusjon: Åpen

Prosjektnr.: 13191

Oppdragsgiver(e):

Oppdragsgivers referanse:

Rapport:	**Nr. - År**
Fisken og Havet	2-2011

Dato: 15. februar 2011

Program: Klima - fisk

Faggruppe: 432 Oseanografi

Antall sider totalt: 43

Tittel (norsk/engelsk):
NorKyst-800 report no. 1
User manual and technical descriptions
NorKyst-800 Rapport nr. 1
Brukermanual og tekniske beskrivelser

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Sammendrag (norsk):

NorKyst-800 er et komplett, numerisk, høyoppløst havmodelleringsopplegg. NorKyst-800 er lett å implementere og har et svært forenklet brukergrensesnitt. Ved siden av dette har hovedmotivasjon for etableringen av modellsystemet vært muligheten til formidling av fysisk miljøinformasjon for alle norske kystområder som inngangsdata til applikasjoner vedrørende oljedrift, redningsoperasjoner (”man-over-board”), spredning av skadelige alger, lakselus mm. Forbedringen fra typiske dyphavsmodeller med 4km horisontal oppløsning er essensiell for å gjengi fysiske forhold land norskekysten. NorKyst-800 vil også være en viktig komponent for å overføre informasjon til enda finere oppløste havsirkulasjonsmodeller (150-200m). NorKyst-800 er etablert gjennom et samarbeid mellom Havforskningsinstituttet, Meteorologisk institutt og Norsk Institutt for Vannforskning. Denne rapporten er bygd som en veiviser og beskrivelse for brukere av modellsystemet. Rapporten kan også være nyttig som bakgrunnsinformasjon til den neste NorKyst-800-valideringsrapporten.

Summary (English):

NorKyst-800 (Norwegian Coast 800m) is a numerical, high-resolution, ocean modelling system. The main motivation for establishing NorKyst-800, besides the easy-to-implement and easy-and-rapid-to-use facilities, is the potential to provide environmental information for all coastal areas in Norway as input to applications regarding oil spills, drift of floating objects (“man-over-board”), spread of harmful algae and salmon lice etc. The step from previous models with 4km horizontal resolution to NorKyst-800 is essential to be able to reproduce physical conditions along the Norwegian shore. NorKyst-800 will also act as an intermediate model transferring information from the coarse 4km deep ocean models to even finer scale fjord models with 150-200m horizontal resolution. NorKyst-800 is initiated and developed as a co-operation between the Institute of Marine Research, the Norwegian Meteorological Institute and the Norwegian Institute for Water Research. This report is meant to act as a guidance and description for users of the model system. This report may also serve as background information for users of the results along with the next NorKyst-800 validation report.

Emneord (norsk):	Subject heading (English):
1. Havmodellering	1. Ocean modelling
2. Norskekysten	2. The Norwegian coast
3. Brukergrensesnitt	3. User interface

Prosjektleder

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Abstract

NorKyst-800 (Norwegian Coast 800m) is a numerical ocean modelling system suitable for reproduction of physical variables as sea level, temperature, salinity and currents for all coastal areas in Norway and adjacent seas. The full NorKyst-800 bathymetric grid consists of 2600x900 grid cells where each cell have an area of 800mx800m. The time resolution of the results can in principle be as high as the model time step, although one hour resolution will resolve most processes of interest.

The NorKyst-800 model system can easily be defined to simulate an arbitrary part or potentially the entire Norwegian coast. Due to limited computer resources, smaller subareas must be chosen in a model simulation. Even the smallest domains are storage and computational demanding, and High-Performance Computers must be applied for all purposes.

The main motivation for establishing NorKyst-800, besides the easy-to-implement and easy-and-rapid-to-use facilities, is the potential to provide environmental information in coastal regions as input to applications regarding oil spills, drift of floating objects ("man-over-board"), spread of harmful algae and salmon lice etc. The step from previous models with 4km horizontal resolution to NorKyst-800 is essential to be able to reproduce physical conditions along the Norwegian shore. NorKyst-800 will also act as an intermediate model transferring information from the coarse 4 km deep ocean models to even finer scale fjord models with 150-200m horizontal resolution.

NorKyst-800 is initiated and developed as a co-operation between IMR (Institute of Marine Research), met.no (Norwegian Meteorological Institute) and NIVA (Norwegian Institute for Water Research) and has lead to a closer interaction between the institutes.

This report is meant to act as a guidance and description for users of the model system. It gives detailed information on how to use NorKyst-800, details on its external forcing data base and some characteristics of the numerical ocean model. This report may also serve as background information for users of the results along with the subsequent validation report (Report no. 2).

Contents

1 Introduction

NorKyst-800 is a coastal model system that will provide information on the physical environment with relatively high resolution along the Norwegian coast from the Swedish border to Russia. The numerical ocean model ROMS (Regional Ocean Modeling System; http://myroms.org) is implemented with a spatial horizontal resolution of 800m. Applying this resolution, most of the relevant topographical features and dynamical processes should be resolved for the Norwegian coastal areas.

An important intention in the development of NorKyst-800 has been simplification of the process of modelling a specific part of the Norwegian coast for a shorter or longer time period. Until now this work has consisted of laborious collection of external data, as bathymetry, initial conditions, boundary conditions, atmospheric forcing and river runoffs, and several manual programming steps for collection of necessary input to the ocean model. These programming steps and sufficient data for input are now unified in a complete model system. The concept is based on the users needs to simulate sub-areas along the Norwegian coast. The results from NorKyst-800 are also intended to be appealing and easily available.

Related to for instance aquaculture, transportation on the sea or tourism aspects, Norway has an increased need for detailed information on the physical environment in the coastal zones including fjords. If we intend to administrate coastal areas, we need detailed knowledge on natural variability. This will enable us to use these areas in a sustainable way. The NorKyst-800 results will provide important information for coastal- and fjord related issues, as e.g. shipwrecks, oil spills and algae blooms, or simply for understanding of ocean variability. The model intends to be a central part of the national rescue services where both Institute of Marine Research and Norwegian Meteorological Institute are obligated to deliver scientific advices related to accidents. Other useful applications are input to particle tracking models for pollution or growth and dispersion of biological material such as salmon lice or egg and larvae from coastal cod populations. By providing initial fields and boundary conditions, NorKyst-800 is also a necessary step in numerical modelling with even higher resolution for Norwegian fjords. In addition, external forcing established for NorKyst-800 will also be available for higher resolution models.

Several of NorKyst-800's down stream services will need ocean forecast while others focus on incidents back in time (hindcast). We aim at implementing NorKyst-800 to handle both scenarios, and regarding hindcast experiments, we aim at building up an external data archive with coarser resolution ocean fields (4km), atmospheric fields and river runoffs that covers a time period several decades back in time. In addition the NorKyst-800 will be ported for execution on the main high-performance computing facilities in Norway, as hexagon (hexagon.bccs.uib.no), njord (njord.hpc.ntnu.no), stallo (stallo.uit.no), and titan (titan.uio.no), all of them as a part of NOTUR (The Norwegian Metacenter for Computational Science[1]).

[1] http://notur.no

The implementation of NorKyst-800 is a cooperation between Institute of Marine Research (IMR), Norwegian Meteorological Institute (met.no) and Norwegian Institute for Water Research (NIVA). Specific tasks involve adjustment of the model system to met.no's 24/7 operational system and to automate simulation set-up's for hindcast experiments. We also intend to have regular prognosis from NorKyst-800 available from met.no's joint online weather (and ocean) service; http://yr.no. The NorKyst-800 success can be quantified from availability for users and the public. After NorKyst-800 has become operational in met.no's daily forecasting suite, probably in 2011, we plan to form a broad national user group encouraged by continuously improving the model system. This user group will preferably consist of both modelers and users of the model results and/or downstream products since both the model system and results will be open accessible.

Model results validation is a continuous task that is needed in all kinds of ocean modelling to describe strength and weaknesses of your model performance. Specific tasks related to validation in the development of NorKyst-800 are identification of data sources, identification of both subjective and objective validation methods and establishment of on-line validation products. A subsequent report (no. 2) will focus on validation of several experiments that apply the NorKyst-800 set-up for different coastal regions. Several observational platforms applied regularly or sporadically, are presented along with different validation techniques, all of them aiming at demonstrating the quality of the NorKyst-800 model system.

Prior knowledge to ROMS, shell scripting and Fortran90 programming is an advantage for NorKyst-800 users. The model system may be treated as a "black box", but interpretation of model results and validation should be carried out by competent users. The main focuses in this report are the modelling part and the preprocessing steps necessary to perform to be able to run the ocean model. The post processing and model results analysis is explained in report no. 2.

We organize this report by first giving a presentation of the user interface and how users can easily start using the model system (Section 2). Then we describe details regarding the bathymetry and the external forcing included (Section 3), and specific details of the configuration of the ROMS system and local adjustments (Section 4). We end this report with showing results from some test examples of simulations performed initially in the development period (Section 5).

2 User interface

The NorKyst-800 model system is separated into a pre-processing part and a modelling part. The latter consists of the ROMS code that is explained in more details in Section 4. By pre-processing we mean arrangement of forcing fields and ROMS specific input information read as standard input by the numerical code. Efforts are made on reducing number of actions and command statements for each individual model user.

After installation of the NorKyst-800 model system, the only definitions that need to be fed into the system before model execution are the geographical extension of the sub-model area to be used and the simulation period. Every step in the pre-processing phase is collected in the main script, *NorKyst800_main.sh*. This shell-script is controlled by another script, *execute_script.sh*, which is the only shell-script that most users need to treat. The part of *execute_script.sh* that users have to set their definitions, displays as follows:

```
#!/bin/bash
#
# Define min./max. grid points in x- and y-direction where all refer to full grid (i1 > i0 and j1 > j0)
#
i0=2; i1=573; j0=2; j1=703    # Limits for sub-domain [max(i1)=2600, max(j1)=900]
#
# Define start and stop simulation date
#
t0='2009-01-02-00'; t1='2009-08-01-00' # Start and stop date
#
# Set the name of your machine. Available: hexagon, njord, stallo, titan
#
machine=hexagon
#
# Set no. of tiles (both directions) for your parallel execution (you allocate the product of these numbers)
#
NtileI=12
NtileJ=12
#
# Choose parameters for configuration of vertical levels and grid resolution
#
Nvert=35          # No. of vertical levels
theta_s=8.0       # S-coordinate surface control parameter (0 < theta_s < 20)
theta_b=0.1       # S-coordinate bottom control parameter (0 < theta_b < 1)
Tcline=10.        # Width (m) of surface or bottom boundary layer*
#
# Parameters relevant to your job-script execution
#
accountname=imr       # Name of project the job should be accounted on
email_pre=jonal       # First part of your e-mail address (before "@")
email_post=imr.no     # Last part of your e-mail address (after "@")
dti=60                # Internal (baroclinic) time step (s)
dt_times=1            # No. of hours between output of time series (sta.nc-file)
dt_inst=1         # No. of hours between output of instantaneous fields (his.nc-file)
dt_inst_f=24      # No. of hours between creation of new file with instantaneous fields
dt_avg=24         # No. of hours between output of time averaged fields (avg.nc-file)
dt_avg_f=24       # No. of hours between creation of new file with time averaged fields
dt_rst=24             # No. of hours between dumping restart fields
coldstart=1           # Switch used to define if this simulation is a cold start (=1) or a warm-/re-start (=0)
#
# Define data sources for clima/nesting-fields and atmospheric forcing (script exits if data source is inconsistent
with simulation period)
#
# Options available for climasrc:
#   1) METNO4KM       (period archived 2008.01.01 -> )
#   2) ROMS4KM        (period archived 1989.01.01 - 2008.12.31)
#   3) MONCLI4KM      (all years, monthly averages based on ROMS4KM)
#
climasrc=METNO4KM
#
# According to defined climasrc, make sure that path to model fields is correct.
```

```
# Directories on hexagon are made permanent:
#
metnoobcpath=/work/shared/norkyst/NorKyst-800m_Forcing/OBC/
met.no_Nordic4km                 # Path where metno-files from 4km model are located
romshindcastpath=/work/shared/norkyst/NorKyst-800m_Forcing/OBC/
ROMS_hindcast                    # Path where ROMS hindcast fields are located
romsmonclimpath=/work/shared/norkyst/NorKyst-800m_Forcing/OBC/
ROMS_hindcast_monclim      # Path with monthly averaged files from the ROMS run
#
# Options available for atmsrc:
#   1) METNO10KM      (1958.01.01 - 2010.01.01) *
#   2) ERAINT            (2007.01.01 - 2010.05.31)
# * (NB: Restrictions on commercial use, enquiries may be sent to met.no)
#
atmsrc=METNO10KM
#
# According to defined atmsrc, make sure that path to model fields is correct.
# Directories on hexagon are made permanent:
#
atmhindcastdir=/work/shared/norkyst/NorKyst-800m_Forcing/Atmos/
met.no_hindcast  # Path where met.no hindcast atm. fields are located
atmeraintdir=/work/shared/norkyst/NorKyst-800m_Forcing/Atmos/
ERA_Interim      # Path where ERA Interim atm. fields are located
#
```

The limits for the sub-domain are defined as grid points referring to the full NorKyst-800 grid, and the other definitions given here are examples for a test run.

Some subsequent switches (not displayed above) must be defined in *execute_script.sh*, defining which forcing fields that are needed, whether ROMS input files are to be updated and whether a compilation or execution of the ROMS code is requested. These switches are mainly used in a testing or development phase. Under normal circumstances all switches will be turned on for a fully realistic simulation.

Editing and execution of execute_script.sh will then generate forcing fields and send ROMS to the batch queue of the high-performance computer for model execution.

All necessary forcing and input information for the ROMS simulation is generated by *NorKyst800_main.sh*. The switches set in *execute_script.sh* control the number of tasks performed. Each task will generate necessary data input in various files to run NorKyst-800.

The tasks are separated into:

1. gridonly   # Switch to generate grid file (=1) or not (=0) or to make grid file only (=2)
2. makeclima   # Switch to generate clima file (=1) or not (=0)
3. makebry   # Switch to generate bry file (=1) or not (=0)
4. makeini   # Switch to generate ini file (=1) or not (=0)
5. maketidal   # Switch to generate file with TPXO tides interpolated to grid (=1) or not (=0)
6. makeatmos   # Switch to generate atmospheric forcing files (=1) or not (=0)
7. makeriver   # Switch to generate river forcing file (=1) or not (=0)
8. makeinput   # Switch to generate ROMS station and ocean.in-file (=1) or not (=0)
9. compileROMS # Switch to compile ROMS (=1) or not (=0)
10. executeROMS # Switch to generate job-script and send ROMS to batch queue (=1) or not (=0)

Here follows a more detailed explanation of each task. The data input is explained in details in Section 3.

The main shell-script controlling the execution of NorKyst-800 experiments, *NorKyst800_main.sh*, is separated into several tasks arranging forcing data and ROMS input and forcing compilation and execution of ROMS:

1 gridonly: The initial step is to configure the geographical extension of your simulation. This will typically be a subset of the total domain. By putting the switch equal to 2, you can adjust your sub-domain before the rest of the external forcing fields are generated. Your sub-domain is defined as a subset from the full NorKyst-800 grid file *Origfiles/norkyst_800m_grid_full.nc*) by the ncks-operator (netCDF Kitchen Sink). Users should be aware of the internal defined nudging zone in ROMS of 15 grid points from the open boundary that is applied in the nesting condition of momentum and tracers (see Section 4.2.). For instance it is important close to fjord heads to allow a 14 grid point margin to the boundary of the model area to avoid influence from the (extrapolated) nesting fields in the fjord.

Output is *Input/norkyst_800m_grid.nc*.

2 makeclima: The model set up assumes input of de-tided information of hydrography and currents along the open boundaries and as initial state (when cold started). This task takes information from daily averaged fields on z-levels and interpolates them to the full 3D ROMS grid defined by the output in generation of the grid-file. Note that sea ice variables are not read. Definition of simulation period will decide which files that are read, and the conversion is performed by NorKyst-800-developed Fortran90-programs (*Prepro/Clima/metno2clima* or *Prepro/Clima/roms2clima* dependent on which input source is defined, climasrc, or which years the two data archives have forcing available).

Output is stored in *Input/norkyst_800m_clima.nc*.

3 makebry: ROMS needs a separate file with information (boundary conditions) along the open boundaries, and a NorKyst-800-developed Fortran90-program (*Prepro/Clima/bry_from_clim*) reads *Input/norkyst_800m_clima.nc* to perform this action. Dummy sea ice variables (assuming ice free conditions) are also added to the output and applied in ROMS as clamped boundary conditions (see Section 4.1.).

Output is *Input/norkyst_800m_bry.nc*.

4 makeini: The production of a file with initial values is only necessary when a cold start is performed (see switch *coldstart* in *execute_script.sh*). The normal procedure when splitting a long model run into several simulation periods is to write a restart-file at the end of the simulation period followed by reading the same file when continuing the simulation. The first simulation period must, however, start with information from another source, and in this case, the interpolated hydrography and currents from the 4km fields (external models) are used.

The ncea-operator (netCDF Ensemble Averager) is applied to pick out the time step in *Input/norkyst_800m_clima.nc* that is closest to (equal to or larger than) the starting date of the simulation period. Some modifications of the name of the time variable and supplement of sea ice variables (assuming no ice) is performed by ncrename- (netCDF Renamer) and ncap-operators (netCDF Arithmetic Processor), respectively.

Output is *Input/norkyst_800m_ini.nc*.

5 maketidal: The tidal information to be used is stored as amplitude and phase of sea surface elevation and currents (see Section 3.3.2.). A NorKyst-800-developed Fortran90-program (*Prepro/Tpxo/tpxo2grid*) interpolates this information to the chosen domain. Further processing of the output is performed in the NorKyst-800 job-script where the phases of both current and sea surface elevation for all constituents are shifted to the appropriate reference time of the actual model run.

Output is stored in *Input/norkyst_800m_tpxo.nc*.

6 makeatmos: Based on the defined simulation period, necessary fields of atmospheric forcing are picked out and arranged for reading by ROMS. The ECMWF fields are processed and interpolated to the model grid by a NorKyst-800-developed Fortran90-program (*Prepro/Atmos/get_forcing*), while the met.no Hirlam hindcast fields are copied to your local directory. A list of forcing files is written to an ascii text-file (*list_atmforcing.asc*) and must be read in the update of the ROMS input file (step 8), i.e., the generation of *Apps/NorKyst_800m/norkyst_800m.in*. The ROMS varinfo.dat-file listing all input/output variables (located in *ROMS/External*) is generally defined in the input-file, and the correct version is picked out based on the defined source of atmospheric forcing (*atmsrc*).

Output is stored in *Input/norkyst_800m_atmos_NN.nc* where *NN=01,02,...,NTOT* counts no. of atmospheric forcing files necessary to fill entire simulation period with all parameters.

7 makeriver:Two ascii station list files with potential river runoff locations are available, including 147 Norwegian and 2 Swedish rivers. Time series consist of daily mean values of runoff, and a NorKyst-800-developed Fortran90-program (*Prepro/River/MakeRivers*) picks out data corresponding to the defined simulation period and adjusts discharge location consistently with the defined sub-domain. If the simulation period is outside the range of available runoff data, daily climatological values are applied.

Output is stored in *Input/norkyst_800m_river.nc*.

8 meinpuakt: This option will update the input file read by ROMS as standard input and generate the list of stations suitable for the defined sub-domain. A ROMS input file with several keywords is located as *Origfiles/norkyst_800m_keyword.in*.Some keywords are replaced by applying this switch, but those referring to dates are replaced by statements in the job-script (see *NorKyst800.job* after execution of step 10). A list of atmospheric forcing files (see step 6), size of the model grid, vertical spacing parameters and path to your directory is filled in during this step. Regarding list of stations, a list of strategic locations (containing observational position for IMR's regular monitoring programs, the tide gauges drifted by the Norwegian Hydrographic Service, etc.) is pre-defined in *Origfiles/stations_NorKyst_800m_full.in*, and an update here will list valid stations within the model area in the final ROMS station file. If you want to add your own stations, the safest method is to find the positions as grid points in the full NorKyst-800 grid (*Origfiles/norkyst_800m_grid_full.nc*), and then add them in the *Origfiles/stations_NorKyst_800m_full.in* file. Users should note that manual adjustments of the final positioning of the model station may be necessary to have comparable values with observational data. The model land may be slightly displaced due to inconsistencies between model land mask and the GSHHS shoreline (see Section 3.1.). A reasonable adjustment will be to put the model station in a grid point that has comparable bottom depth with the real observational site.

Output is *Apps/NorKyst_800m/norkyst_800m.in* and *Apps/NorKyst_800m/stations_NorKyst_800m.in*.
Note that the ROMS input file read by the ROMS executable is created in the job-script (*NorKyst800.job*) and located as *ocean.in*.

9 compileROMS: This step makes sure that ROMS is compiled with the available fortran compiler before execution. A main makefile, *Origfiles/makefile_NorKyst_800m_<machine>*, containing keywords and made individual for each high-performance computer (hexagon. njord, titan, stallo) is read and written as *makefile* before compilation. The ROMS directory *Compilers* contains several compilation-files suitable for different operating systems and different Fortran compilers, and the main *makefile* calls the appropriate compiler.

Output is the executable ROMS named ***oceanM***

10 executeROMS: This option will first edit a keyword-based job-script located as *Origfiles/ NorKyst800_keyword.job_<machine>*, then substitute the keywords with some of the definitions in *execute_script.sh* and finally send ROMS to the batch queue for execution on the computer (by *NorKyst800.job*). The definitions that are applied in the job-script deal mainly with the internal time step in ROMS and the time interval between writing output files (history, average and station file), all defined by users in *execute_script.sh*. If your model run is a (warm) re-start, you must set the *coldstart*-switch to be *0* and make sure that a restart-file is available from the simulation you want to continue (either as *Output/norkyst_800m_rst.nc* or *Output/norkyst_800m_ini.nc*).

Output files after simulation are *Output/ norkyst_800m_his_NNNN.nc*, *Output/ norkyst_800m_avg_NNNN.nc*, *Output/norkyst_800m_sta.nc* and *Output/norkyst_800m_rst.nc* where *NNNN* counts *dt_inst_f* and *dt_avg_f* long time steps with output of history and average fields, respectively, and where the station file contains all results for time steps of the entire simulation.
Output before model is executed is *NorKyst800.job*.

When you split your model simulation into several parts, you will need to perform a (warm) re-start. This is often convenient when your simulation ranges several years. Only a few actions are then necessary to proceed with your simulation after the previous run has finished, and all of them are related to *execute_script.sh*. First, enter the *Output*-directory to change file names of all output files that you want to keep (otherwise they will be overwritten), but make sure that you don't touch the *norkyst_800m_rst*.nc-file. Then edit the *execute_script.sh* where *t0* is changed according to the *t1*-value from the previous run and the *coldstart*-switch is set equal to *0*. The *makeini*-switch may be set to *0*, but the reading of this file is overridden when *coldstart=0*.

3 Bathymetry and external forcing

Every step in the generation of the forcing fields is either based on pre-installed netCDF operators[2] or on Fortran90 programs written especially for this purpose. ROMS specific configuration statements are defined in the main script (*NorKyst800_main.sh*) controlling the model system. Editing the input data in preprocessing programs should not be necessary except when a complete modification of the set-up is desired or for debugging.

3.1 Bathymetry

The full NorKyst-800 grid was agreed to cover the entire Norwegian coast for potential modelling of the Norwegian Coastal Current, the Skagerrak and the northward circulation of Atlantic Waters (the Norwegian Atlantic Current, NwAC). The northward flow of Atlantic water is mainly steered by bottom topography, and the grid was increased in the westward direction to include most of the NAC off the Vøring Plateau. The model domain with bathymetry is shown in Figure 1.

The bathymetry data were collected from the online data source Norge Digitalt[3] established by the Norwegian Mapping Authority, the Hydrographic service (Statens Kartverk Sjø). The original resolution was 50m. The coverage of Norge Digitalt data is for coastal zones only, and GEBCO_08 data (General Bathymetric Chart of the Oceans[4]) were applied for the open ocean. The resolution of the GEBCO_08 global bathymetric grid is 30 arc-seconds, i.e., approximately 900m. The merged product of Norge Digitalt high resolution data and GEBCO_08 was interpolated bilinearly to the NorKyst-800 grid, and the land-sea mask was manually adjusted according to the high-resolution shoreline data from GSHHS (A Global Self-consistent, Hierarchical, High-resolution Shoreline Database; Wessel and Smith 1996). Modifications of some of the topographical features were needed to fulfill the restriction of the ROMS model to avoid one-point bays. Additionally, effort was made in opening up narrow straits that were less than 800m wide but still important for the local circulation, in particular advection of brackish water originating from rivers. To avoid model instability

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[2] http://nco.sourceforge.net
[3] http://www.norgedigitalt.no
[4] http://www.gebco.net

and/or spurious deep currents the final masked bathymetry is smoothed to fulfill a requirement on the ROMS slope or r_{x1}-factor (Beckmann and Haidvogel 1993), defined as

$$r_{x1} = \frac{|h_{i-1} - h_i|}{|h_{i-1} + h_i|},$$

where *h* is the bottom depth and the index *i* indicates a model grid point. The final bathymetry in NorKyst-800 has a maximum r_{x1} of 0.34.

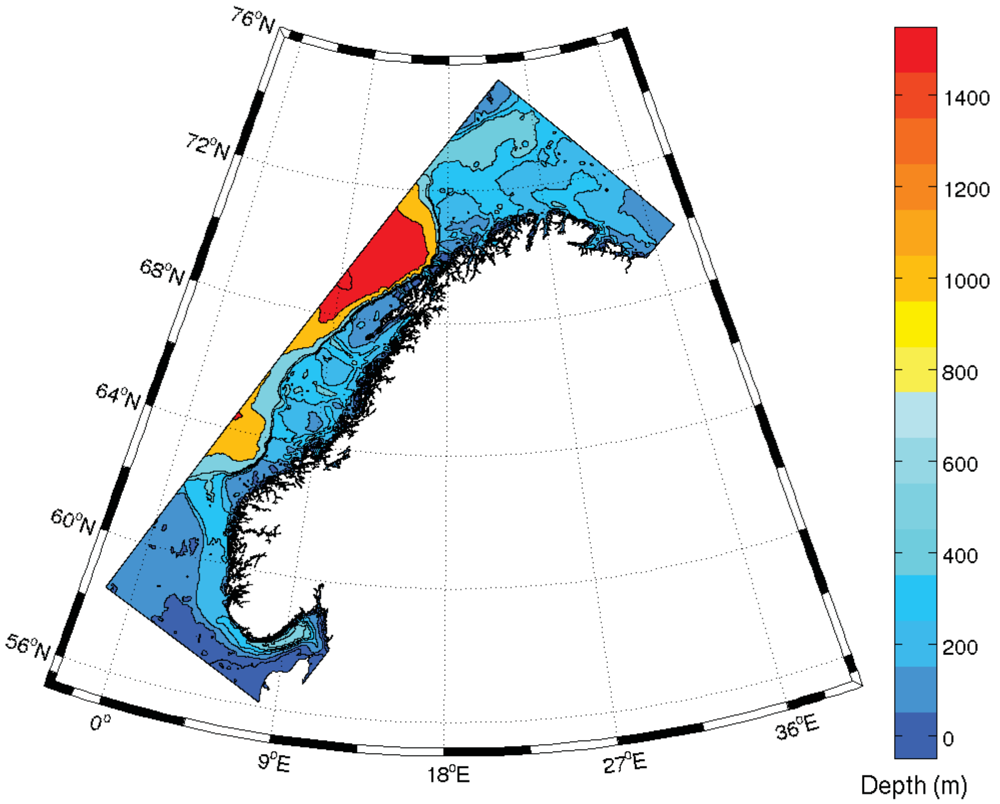

Figure 1. NorKyst-800 domain and bathymetry for the entire grid. Contours are shown for 50, 100, 200, 300, 400, 500, 1000, 2000 and 3000m depth.

In addition, Haney (1991) argues that in order for difference schemes to be hydrostatically consistent, the parameter settings must be defined so that

$$\left|\frac{\sigma}{D}\frac{\partial D}{\partial x}\right| \delta x < \delta\sigma,$$

where σ denotes the value of the sigma-layer (0 at the surface, 1 at the bottom), *D* is the total depth, $\partial D/\partial x$ is the difference in depth over a grid cell, δx is the grid size and $\delta\sigma$ is the vertical distance between sigma-layers. E.g. in a grid cell with total depth (*D*) of 1000m, with neighboring depth of 900 m, with a grid resolution (*dx*) of 800 m, near the seabed between sigma-layer 0.9 and 1.0, the Haney number would be 1. A practically implementation of estimating the Haney number would be to estimate

$$r_{x2} = r_{x1}\left(\frac{Z_w(i,j,k) - Z_w(i-1,j,k) + Z_w(i,j,k-1) - Z_w(i-1,j,k-1)}{Z_w(i,j,k) + Z_w(i-1,j,k) - Z_w(i,j,k-1) - Z_w(i-1,j,k-1)}\right),$$

where Z_w is the depth of the water column at grid coordinates (i,j) and at sigma level k. In the case where the second deepest sigma level of grid cell (i,j) has equal depth to the deepest level in grid cell (i-1,j) the Haney number will be 1. Obeying the criteria ensures that for a certain grid size the vertical grid increment is small enough for the s-layer immediately above (below) remains above (below) within the distance of a one grid interval. There is, however, not really a consensus on how much this criteria can be bended. A rule of thumb is a Haney-number below ~10. However, Kate Hedstrøm allows a Haney number of several tens while Alexander Shchepetkin considers a value below 3 as safe and conservative and values above 8-10 as "insane"[5].

3.2 Atmospheric input

3.2.1 ERA Interim

ERA-Interim is an archive of global atmospheric reanalysis ranging from 1989 to present. Information about the data set can be found at http://www.ecmwf.int/research/era/do/get/era-interim, and a detailed description of the ERA-Interim model and data assimilation system, the observations used, and various performance aspects is in preparation at ECMWF.

For NorKyst-800 purpose we have downloaded 1) daily (00, 06, 12 and 18 UTC) surface analysis of wind, temperature, pressure and cloud cover, 2) daily (00, 06, 12 and 18 UTC) model level analysis of humidity, and 3) surface forecast of accumulated precipitation (12h accumulated fields at 00 and 12 UTC) and radiation (12 and 24h accumulated of long and short wave radiation respectively), as listed in Table 1. All parameters are stored on a 0.7 ^{o} x 0.7^o (N128) global grid. Note that the default NorKyst-800 set up calculates short wave and net long wave radiation terms internally (analytical expressions) and does not apply the radiation fields from ERA-Interim.

Table 1. Parameter list of ERA-Interim forcing parameters. More information about the individual parameters might be found at: http://www.ecmwf.int/services/archive/d/parameters.

Parameter name and ECMWF-number code	Surface/Model level Analysis/Forecast	unit	ROMS input name	Unit
10 m U wind component (165)	Surface Analysis	ms^{-1}	Uwind	ms^{-1}
10 m V wind component (166)	Surface Analysis	ms^{-1}	Vwind	ms^{-1}
2 m temperature (167)	Surface Analysis	K	Tair	^oC
Mean seal level pressure (151)	Surface Analysis	Pa	Pair	hPa
Total cloud cover (164)	Surface Analysis	(0 – 1)	cloud	(0 – 1)
Specific humidity (133)	Model level Analysis	$kg\ kg^{-1}$	Qair	$kg\ kg^{-1}$
Convective precipitation (143)	Surface Forecast	m	rain	$kgm^{-2}s^{-1}$
Stratiform precipitation (142)	Surface Forecast	m	rain	$kgm^{-2}s^{-1}$
Surf. solar rad. downw. (169)	Surface Forecast	$Wm^{-2}\ s$	swrad	Wm^{-2}
Surf. thermal rad. downw. (175)	Surface Forecast	$Wm^{-2}\ s$	lwrad_down	Wm^{-2}

[5] Comments from the ROMS Discussion Forum (https://www.myroms.org/forum/viewtopic.php?f=14&t=612)

3.2.2 Hirlam hindcast database

NORA10 (Norwegian ReAnalysis 10km) is a high resolution hindcast archive covering the Norwegian Sea, Barents Sea and the North Sea, developed by the Norwegian Meteorological Institute (Reistad et al. 2007). The hindcast is based on the ERA40 reanalysis, but the simulation has higher spatial and temporal resolution. The atmospheric model used for the hindcast simulation is a version of the HIRLAM model with 10 km horizontal resolution on a rotated spherical grid (Bjørge et al. 2003). Temperature, wind velocity, specific humidity and liquid cloud water in the boundary zone are relaxed towards ERA40. Some large-scale features from ERA40 are preserved by a digital filter. The hindcast archive covers the period from 1958 to 2009, but may potentially be prolonged.

For NorKyst-800 purposes the daily (00, 06, 12 and 18) surface forecast (6h after analysis) of wind, temperature, mean sea level pressure, cloud cover, specific humidity and accumulated precipitation have been stored on a 10 km resolution polar stereographic grid, slightly smaller than the original grid. An example map of mean sea level pressure and wind is shown in Figure 2. As NORA10 has a temporal resolution of 3h it would be possible to refine the temporal resolution for NorKyst-800 in the future. Note that the hindcast archive primarily is available for research projects, and that hindcast-forced NorKyst-800 applications have some restrictions on commercial use. Enquiries should be sent to the Norwegian Meteorological Institute.

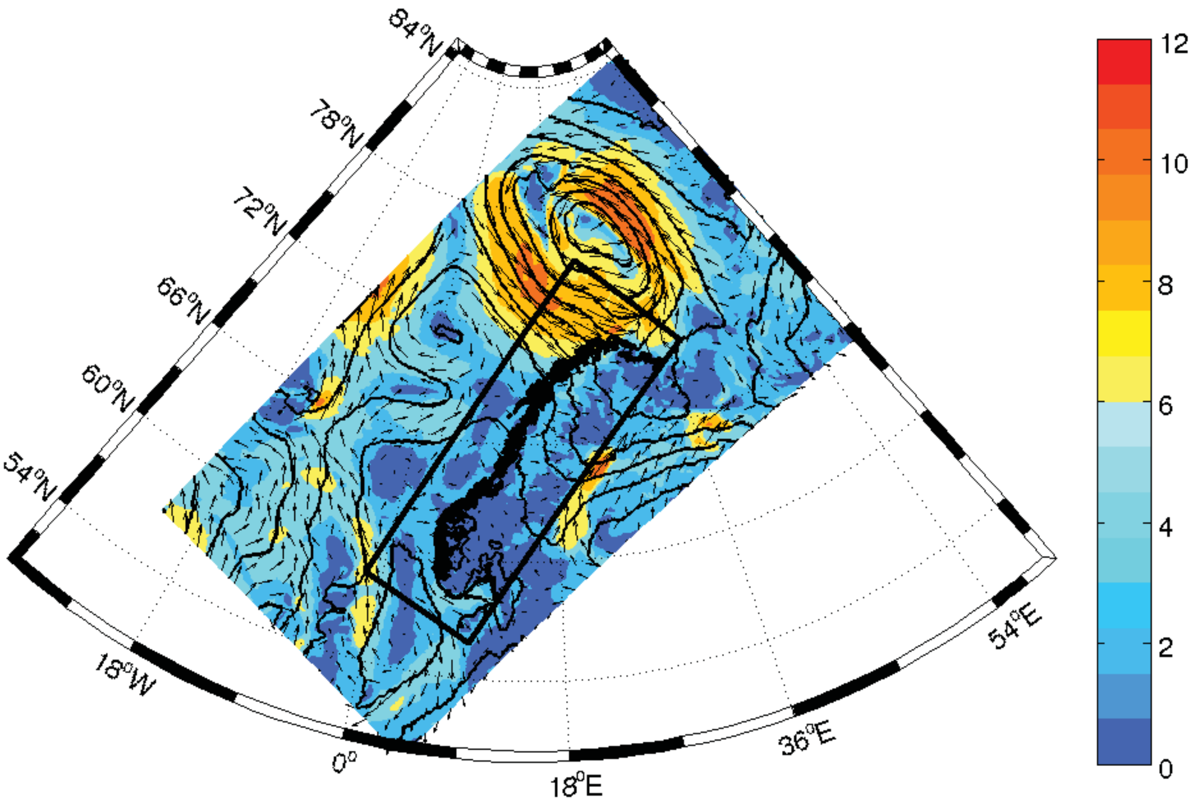

Figure 2. Example map from the Hirlam hindcast database showing mean sea level pressure (black lines), wind speed (colors) and wind vectors. Every 10th wind arrow is shown, i.e., internal spacing between vectors is approximately 100km. The entire NorKyst-800 domain is indicated by the black square.

3.3 Input along open boundaries

3.3.1 De-tided input

3.3.1.1 Operational ocean fields from met.no

The met.no operational model MI-POM (Blumberg and Mellor 1987, Engedahl 1995 and many others) of the Nordic4km domain, which covers the North Sea and the Nordic Seas as well as a portion of the Barents Sea and the Arctic Ocean on a polar stereographic grid with horizontal resolution of 4km, provides boundary conditions (and initial conditions in case of a "cold" start of the model) for NorKyst-800. The archive is updated routinely, and adds back to 2008. The MI-POM Nordic4km application has 17 vertical levels, and applies monthly climatology (Engedahl et. al 1998) as boundary conditions. The sea surface temperature (SST) is nudged towards satellite data of SST, and at depths greater than 500m the model is relaxed towards climatological salinity and temperature values. The atmospheric forcing is supplied by met.no's operational weather forecast model, HIRLAM12km. The MI-POM Nordic4km also includes tides, which means that in order to feed boundary conditions to another model these must either be provided at least hourly to resolve the tidal signal, or de-tided.

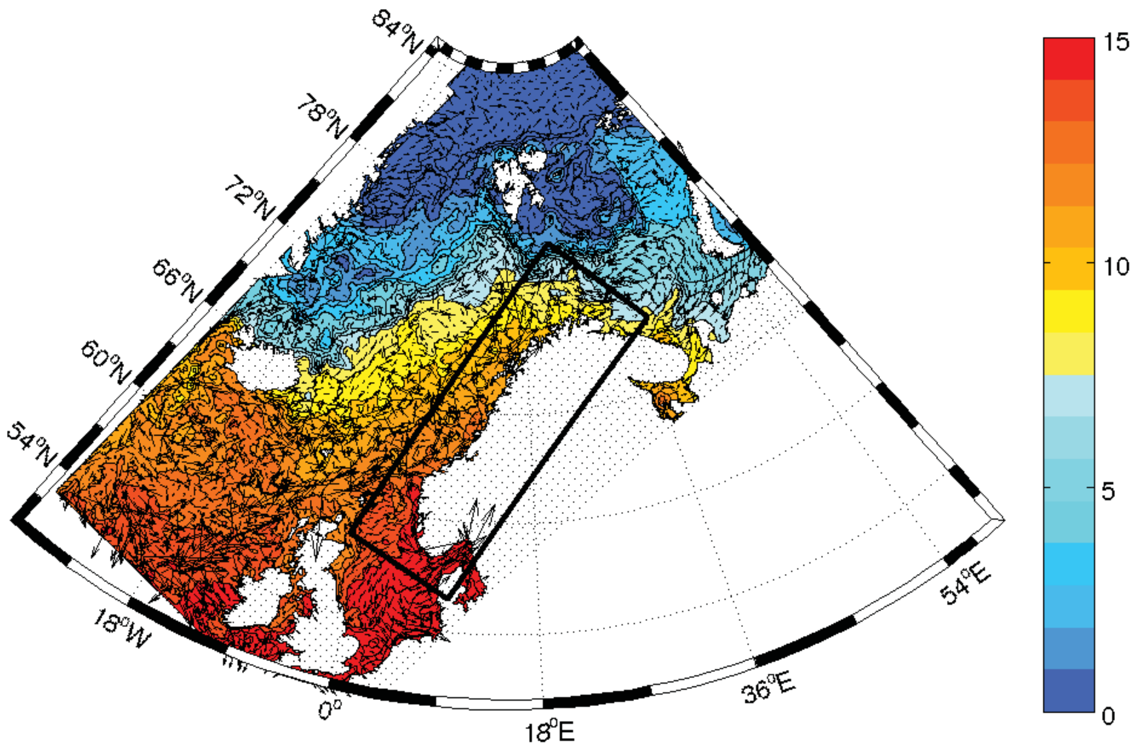

Figure 3. Example map from the operational met.no model of the Nordic-4km domain showing SST (colors) and surface currents. Every 12th current arrow is shown, i.e., internal spacing between vectors is approximately 50km. The entire NorKyst-800 domain is indicated by the black square.

For NorKyst-800 purpose the latter is preferred, and the boundary conditions consist of daily mean current, salinity and temperature at 10 vertical z-levels. An example map of SST and surface current is shown in Figure 3. Users should note that the met.no 4km fields do not contain daily averages of sea surface elevation, thus we miss this information. This means that storm surge effects is not accounted for along the open boundaries and sea level estimates from NorKyst-800 is less reliable close to these boundaries. We will, however, emphasize that storm surge effects are included in the current field provided by the met.no 4 km model.

3.3.1.2 Ocean fields from hindcast ROMS simulation

At the IMR a 4 by 4 km ROMS hindcast simulation is performed on the same grid as the met.no operational simulations, and with an additional extension to include the Kara Sea. The period covered is 1989-2008. Monthly mean lateral boundary conditions were taken from a global version of ROMS, with a resolution of 20 km in the North Atlantic and Arctic, and it comprised three-dimensional velocities, sea-surface height (SSH), temperature, and salinity. In addition, eight tidal constituents from the Oregon State University TOPEX/Poseidon Global Inverse Solution (TPXO 7.0; Egbert and Erofeeva, 2002) were added to the SSH and barotropic flow at the lateral boundaries. Six-hourly atmospheric boundary conditions were taken from ERA-Interim (see Section 3.2.1.), including mean sea level pressure, wind stress and latent, sensible, downward shortwave radiative and net long wave radiative heat flux. Monthly mean climatological fresh water sources were added around the North Sea and the Norwegian Coast. The model setup has 30 vertical s-coordinates, a minimum depth of 50 m and has resulted in a data archive of daily mean 3D velocities, turbulence parameters, sea surface height, salinity and temperature. Modeled circulation and hydrography along the Norwegian Coast seemed to fit well with observations, see Vikebø et al. (2010) for details. An example map of sea surface salinity (SSS) and currents is shown in Figure 4.

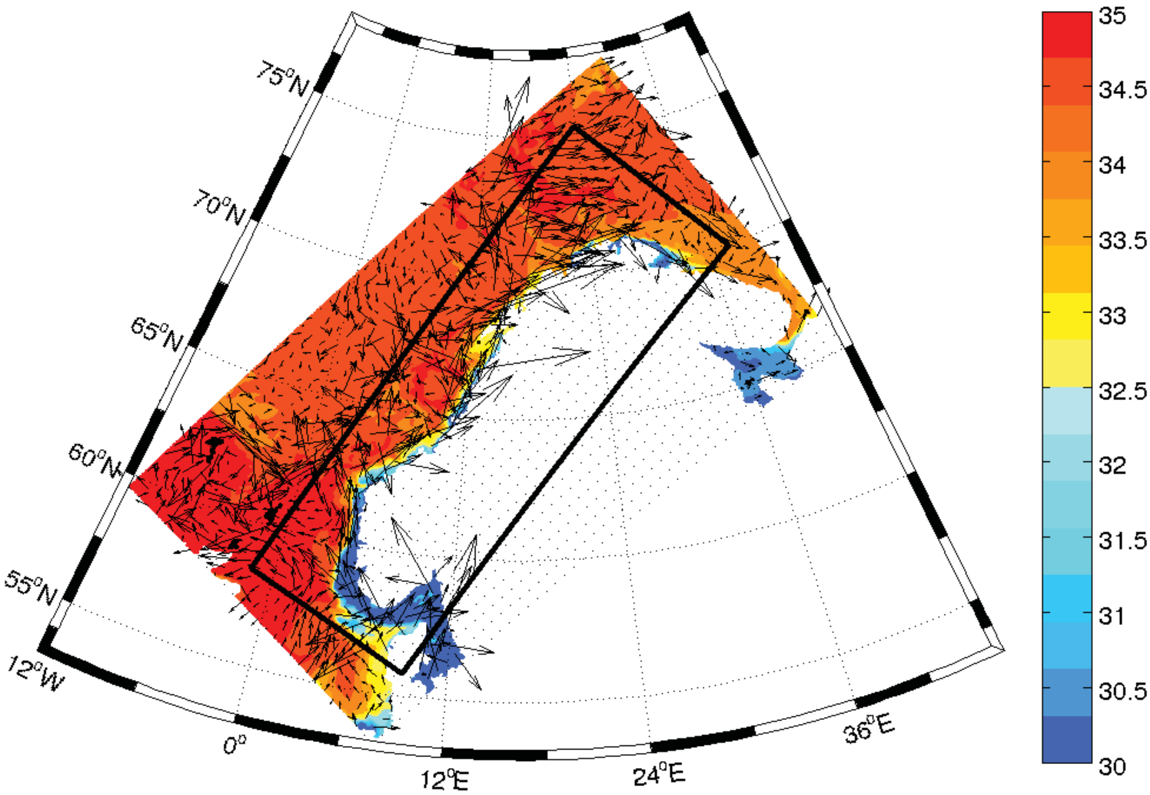

Figure 4. Example map from the ROMS hindcast model of the Nordic-4km domain showing SSS (colors) and surface currents. Every 12th current arrow is shown, i.e., internal spacing between vectors is approximately 50km. The entire NorKyst-800 domain is indicated by the black square.

3.3.2 Tidal forcing

The tidal forcing applied in NorKyst-800 is based on a global inverse barotropic model of ocean tides, TPXO7.2[6] (Egbert et al. 1994, Egbert and Erofeeva 2002). This model has a horizontal resolution of 0.25 degrees and uses inverse modelling techniques to assimilate satellite altimetry data as well as data from tide gauges. TPXO7.2 provides the tides as amplitude and phase for sea surface elevation and currents for eight primary harmonic constituents (M_2, S_2, N_2, K_1, K_2, O_1, P_1, Q_1) of diurnal and semidiurnal frequencies, two long period (Mf, Mm) and three nonlinear (M4, MS4, MN4) constituents.

The tidal data is first interpolated to the chosen domain by a met.no developed Fortran90 program tpxo2grid. An example of the co-tidal range and lines of the M_2 constituent interpolated from TPXO7.2 to the full NorKyst-800 grid is shown in Figure 5. The output of this program is further processed in the Norkyst-800 job-script, where the Fortran90 program tidenc2roms shifts the phases of both current and sea surface elevation according to the appropriate reference time of the current model run, performs nodal corrections due to long period times, and converts the current parameters to tidal ellipse parameters.

Currently, only the eight primary constituents are included in the tidal forcing supplied to ROMS, as this should be sufficient to simulate realistic tides. The additional harmonic constituents provided by TPXO7.2 can however be included with only minor changes to the tidenc2roms program.

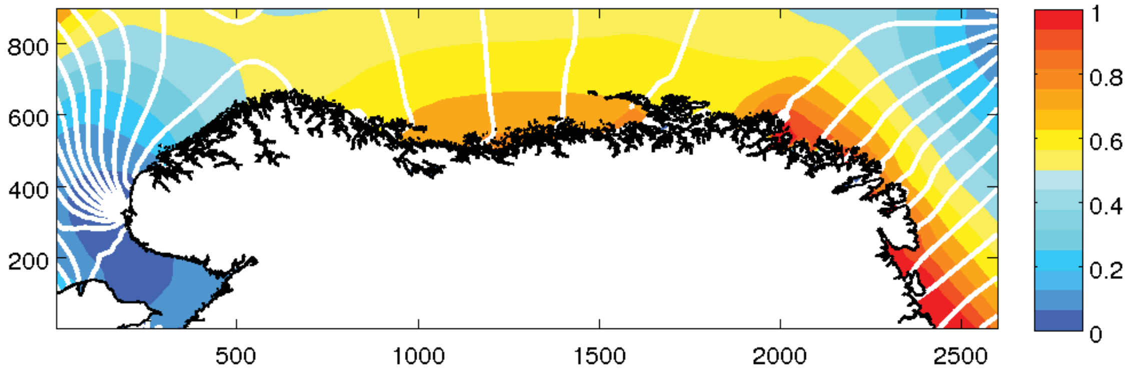

Figure 5. Co-tidal range (colors) and co-tidal lines (white lines) interpolated from the TPXO database to the entire NorKyst-800 grid. The spacing of the co-tidal lines is one hour and the equidistance of the co-tidal range is 0.1m.

3.4 River runoff

The river runoff in NorKyst-800 is based on modelled discharge from the 247 main Norwegian catchment areas that drain to the sea and 2 catchment areas along the Swedish west coast. The geographical distribution of the runoff locations for the entire domain and a zoom of the western part of Norway are shown in Figure 6. The Norwegian river discharges are modelled by NVE (Norwegian Water Resources and Energy Directorate[7]) using a

[6] http://volkov.oce.orst.edu/tides
[7] http://nve.no

distributed version of the HBV-model with 1 km horizontal resolution (Beldring et al. 2003). Note that river discharges are estimated from natural variations in weather climate, and there are no modifications due to regulations by damming. Runoff values will then vary from real discharge at some locations in cases where water is provided or restrained by dams.

Users of these river discharges should acknowledge NVE as their source based on atmospheric input from the Norwegian Meteorological Institute. NVE also state that users are responsible for evaluating the uncertainties and usability of the modelled runoffs.

The river runoffs for the Norwegian and Swedish rivers are stored as daily values in two separate ascii text-files and need to be updated when new data are available. All the available data are used to calculate climatological time series for all rivers with a time resolution of one day. These data are used if NorKyst-800 is running in a time span not covered by the runoff data.

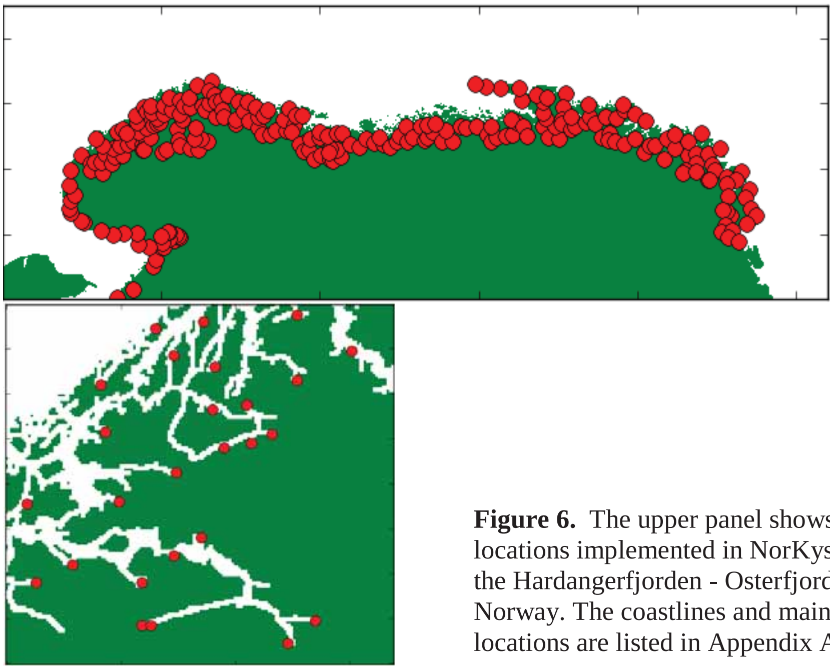

Figure 6. The upper panel shows all 249 freshwater discharge locations implemented in NorKyst-800. The lower panel is a zoom on the Hardangerfjorden - Osterfjorden area along the western coast of Norway. The coastlines and main rivers corresponding to these runoff locations are listed in Appendix A.

The outlets are placed in the model grid at a position inside the catchment area, usually in the point were the main river of that particular catchment area is draining out. The outlet positions are found manually based on the shoreline in the model, and they are listed in

Table 3 in Appendix A jointly with the name of the catchment areas, and for some areas, the name of the main river.

The discharge is distributed linearly from the surface down to a prescribed depth for each river, and this vertical shape of the runoff is kept constant throughout the model simulation. Further details regarding calculation of the freshwater input level depths can be found in Appendix B.

4 ROMS specific

The Regional Ocean Modeling System (ROMS) version 3 (Shchepetkin & McWilliams 2003 and 2005, Haidvogel et al. 2008) used in the NorKyst-800 model system is a 3D free-surface, hydrostatic, primitive equation ocean model using terrain-following s-coordinates in the vertical. The model is mainly developed at Rutgers University and the UCLA Ocean modeling groups and is widely used by the scientific community for a diverse range of applications. The visiting Internet-address is http://myroms.org.

The main repository, https://www.myroms.org/svn/src/trunk, includes the latest version from Hernan Arango. The dynamical kernel of this version is comprised of four separate models including the nonlinear, tangent linear, representer tangent linear and adjoint. The SeaIce-module is, however, not compatible with all these separate models except for the nonlinear. In NorKyst-800 we are not aiming at applying data assimilation, and in addition we need to include SeaIce. This leads us to an alternative ROMS repository, held by Kate Hedström at https://www.myroms.org/svn/omlab/branches/kate/trunk. Her branch is updated subsequently with the main repository updates, and it also includes a usable version of the sea ice model from Budgell (2005).

4.1 ROMS definitions

ROMS consists of several built-in schemes and algorithms, and it uses C-preprocessing to activate the various physical and numerical options. ROMS is a very modern and modular code written in F90/F95. The entire input and output data structure of the model is via NetCDF which facilitates the interchange of data between computers, user community, and other independent analysis software.

Every user must define which advection scheme, which turbulence scheme and so on to apply before compilation. The NorKyst-800 set-up forms a basis that is tested for many applications along the Norwegian coast. A complete list of definitions applied in NorKyst-800 is given in Appendix C, but the main definitions are specified here.

In the horizontal, the primitive equations are evaluated using boundary-fitted, orthogonal curvilinear coordinates. The general formulation of curvilinear coordinates includes both Cartesian (constant metrics) and spherical (variable metrics) coordinates. The transformation of any of these coordinates to ROMS grid is specified in metric terms (***pm***, ***pn***). The model state variables are staggered using an Arakawa C-grid. The free-surface, density, and active/passive tracers are located at the center of the cell whereas the horizontal velocity (u and v) are located at the west/east and south/north edges of the cell, respectively. That is, the density is evaluated between points where the currents are evaluated. The horizontal variable placement on a ROMS grid is shown in Figure 7.

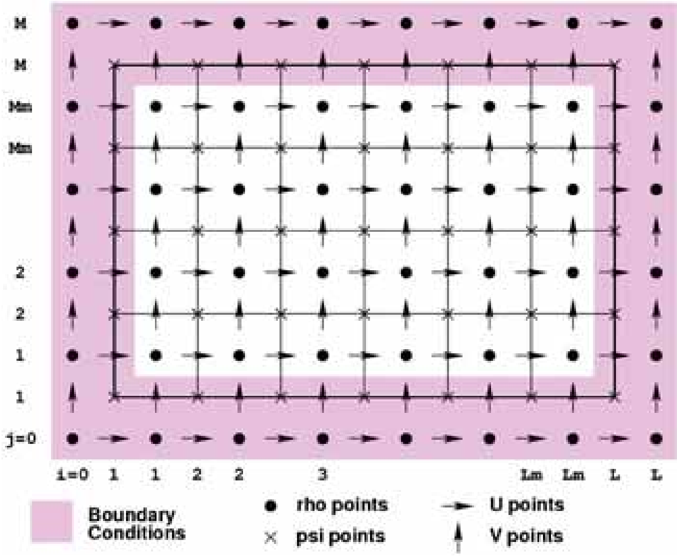

Figure 7. Horizontal variable placement on a ROMS grid showing the additional boundary zone (colored in pink for i=0 and i=L and for j=0 and j=M) along the interior grid points denoted by 1:Lm and 1:Mm. The schematic grid structure is downloaded from the http://myroms.org web site.

The ψ –points are used as slipperiness mask points for calculation of horizontal viscosity where the derivatives of u and v with respect to y- and x-direction, respectively, need special treatment due to masking of all state variables at the end of every time step.

In ROMS all the state arrays are dimensioned the same size to facilitate parallelization, and the computational ranges for all the state variables are shown in Table. Users should note that the size of the model grid is defined in the ROMS input file (*ocean.in*) with interior points only (*Lm* and *Mm*). However, all input forcing files must and output result files do contain fields at the full grid, including the extra one grid point boundary zone.

Table 2. Computational ranges for all state variables. Lm and Mm denote the number of interior grid points in the x- and y-direction, respectively. They are set outside the executable ROMS (in ***ocean.in***). The full computational ranges add a one grid point boundary zone outside the interior domain.

Variable	Interior Range	Full Range
ρ-type	1:Lm, 1:Mm	0:L, 0:M
ψ -type	2:Lm, 2:Mm	1:L, 1:M
u-type	2:Lm, 1:Mm	1:L, 0:M
v-type	1:Lm, 2:Mm	0:L, 1:M

In the vertical, the primitive equations are discretized over variable topography using stretched terrain-following coordinates (Song and Haidvogel 1994). As a result, each grid cell may have different level thickness (*Hz*) and volume. The model state variables are vertically staggered so that horizontal momentum, density, and active/passive tracers are located at the center of the grid cell. The vertical velocity and vertical mixing variables (*Akt, Akv*, etc) are located at the bottom and top faces of cell. The stretched coordinates allow increased resolution in areas of interest, such as thermocline and bottom boundary layers. The default configuration in NorKyst-800 has increased resolution in the surface layer and reduced resolution near the bottom (*THETA_S = 8.0* and *THETA_B = 0.1*). This will lead to fewer problems compared with a configuration with increased resolution of bottom layers due to the steep bathymetry in the coastal zones and within some of the fjords. By having the s-levels more confined to the surface layers, less smoothing is necessary to fulfill the restriction on the r-factors (see Section 3.1.). By applying the default grid configuration for NorKyst-800, we attain a maximum Haney-number, r_{x2} , around 6. Users should note that adjustments of the s-level configuration may lead to different behavior between experiments at different regions. In addition the s-levels will influence the magnitude of the horizontal pressure gradient errors[8]. An example of the vertical distribution of the s-levels by applying the default parameters in NorKyst-800 is seen in Figure 8.

The advection scheme chosen in NorKyst-800 is a third-order upstream, which is the model default. It has a velocity-dependent hyper-diffusion dissipation as the dominant truncation error (Shchepetkin and McWilliams 1998). This scheme is stable for the predictor-corrector methodology of the model. In addition, the option for conservative parabolic spline representation of vertical advection is switched on.

The horizontal mixing of momentum and tracers can be along vertical levels, geopotential (constant depth) surfaces, or isopycnic (constant density) surfaces. In NorKyst-800 momentum is mixed horizontally along vertical levels, while tracers are mixed horizontally along geopotential surfaces. However, the harmonic horizontal mixing coefficient for tracers and momentum are set to zero, and this implies that no explicit horizontal eddy viscosity term is activated in NorKyst-800. Some weak numerical, horizontal momentum diffusion is left due to the application of the third order upstream advection scheme.

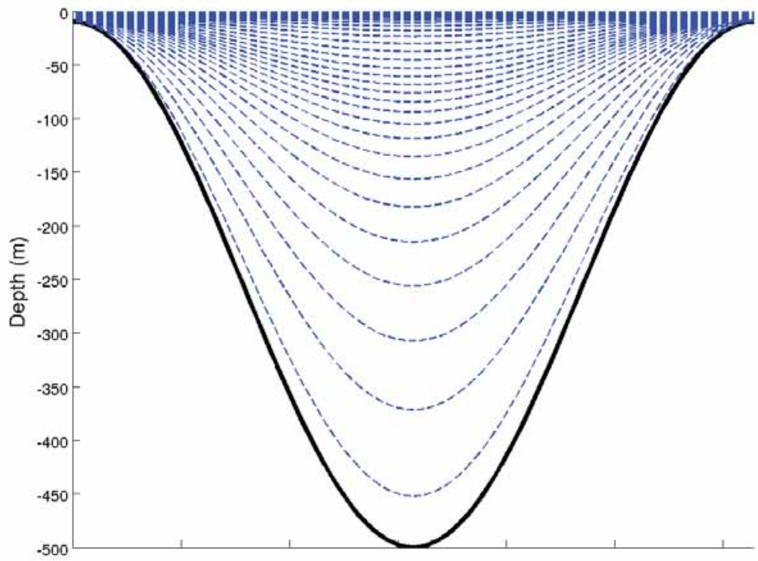

Figure 8. Example of the vertical distribution of the s-levels in ROMS when applying the default values of θ_s (8.0), θ_b (0.1), Tcline (10m) and N (35), where the latter is number of vertical levels. The black line denotes the bottom, and the dashed blue lines denote the s-levels (of rho-surfaces). Depth is given by the vertical axis in m.

There are several sub grid-scale parameterizations in ROMS. The vertical mixing parameterization in ROMS can be either by local (MY2.5 or GLS) or nonlocal (K-profile) closure schemes. The local closure scheme defined in NorKyst-800 is based on the Generic Length Scale (GLS) parameterization (Umlauf and Burchard 2003). The GLS is a two-equation turbulence model that allows a wide range of vertical mixing closures, including the popular k-kl (Mellor-Yamada level 2.5), k-e, and k-w schemes. The GLS turbulence closure parameters applied in NorKyst-800 correspond to the k-kl scheme.

[8] HPG-errors are not explained any further here, but we encourage users to run experiments without any forcing, with closed boundaries and only vertical gradients in hydrography initially, to verify that velocities can be neglected.

ROMS comes with a variety of lateral boundary conditions, including open, closed, and periodic (Marchesiello et al. 2001). The Chapman boundary condition (Chapman 1985) is used for the free-surface boundary condition and the Flather boundary condition (Flather 1976) is applied for the barotropic velocity. As described in Marchesiello et al. (2001) and as applied in NorKyst-800, ROMS has an option for providing radiation conditions on outflow and nudging to a known exterior value on inflow for 3D momentum and tracers. This is implemented as a variation on the radiation condition, requiring two timescales, namely the inflow nudging timescale and the outflow nudging timescale. In NorKyst-800 the nudging on inflow is 120 times larger than on the outflow. Sea ice is allowed to form internally in NorKyst-800, but the external values set along the open boundaries correspond to no sea ice at all. Regarding the boundary condition for sea ice variables, only clamped conditions are used.

The sea-ice component in ROMS is a combination of the elastic-viscous-plastic (EVP) rheology of Hunke and Dukowicz (1997) and simple one-layer ice and snow thermodynamics with a molecular sublayer under the ice (Mellor and Kantha 1989). The sea-ice component also modifies the original air-sea interaction boundary layer, which is based on the bulk parameterization of Fairall et al. (1996), in areas where the thermodynamic fluxes allow sea ice to grow. These bulk flux algorithms were adapted from the COARE (Coupled Ocean-Atmosphere Response Experiment) algorithm for the computation of surface fluxes of momentum, sensible heat, and latent heat. In NorKyst-800 analytical calculations are performed to calculate the albedo and solar radiation combined with cloud cover, net long wave radiation and evaporation. In addition a cool skin correction of the thermodynamic fluxes is applied due to the vertical displacement of the surface temperature grid point and the actual surface (the SST grid point is one half grid length below the surface).

4.2 Local adjustments

To prevent any misinterpretations of external humidity fields from the atmosphere model, a CPP-option named SPECIFIC_HUMIDITY is applied in the calculation of thermodynamic fluxes. Applying this option ensures that atmospheric humidity fields are interpreted as specific humidity with unit kg/kg given that the input is consistent with that unit.

The routine calculating the nudging time scales, *Apps/Functionals/ana_nudgcoef.h* (copied from *ROMS/Functionals*), also includes a definition of the width of the nudging zone for applying open boundary conditions. The default definition in ROMS, when nudging conditions are switched on, is the entire model area, but in NorKyst-800 the width is set to 15 grid points. This width of the nudging zone is set arbitrarily, and should be investigated. The time scales applied for nudging towards tracer and momentum data are both set to 5 days for passive (outflow) open boundary conditions. The nudging of active (inflow) open boundary conditions is defined stronger by a factor of 120 (*OBCFAC*) which gives a time scale of one hour.

5 Results from test examples

Several simulation experiments with NorKyst-800's realistic set-up are performed and explained in a follow-up report focusing on validation. To give a brief presentation of model performance, we have collected results from four different realizations here. The extent of the four model grids is explained in Table 2 and showed in Figure 9, and they cover the Norwegian coast line from Skagerrak/Oslo fjord in the south to Lofoten in the north.

Users of model results should be aware of the potential confusion regarding count of grid points. Some programming languages start from 0 while others start from 1. ROMS has a boundary zone, and *netcdf*-files count from 0 (as shown in see Figure 7). *Python* programming language also starts counting at 0, while other programming languages as *Fortran* and *matlab* starts counting at 1. Note also that the leading dimension may be specified differently (loops run through dimensions in opposite order).

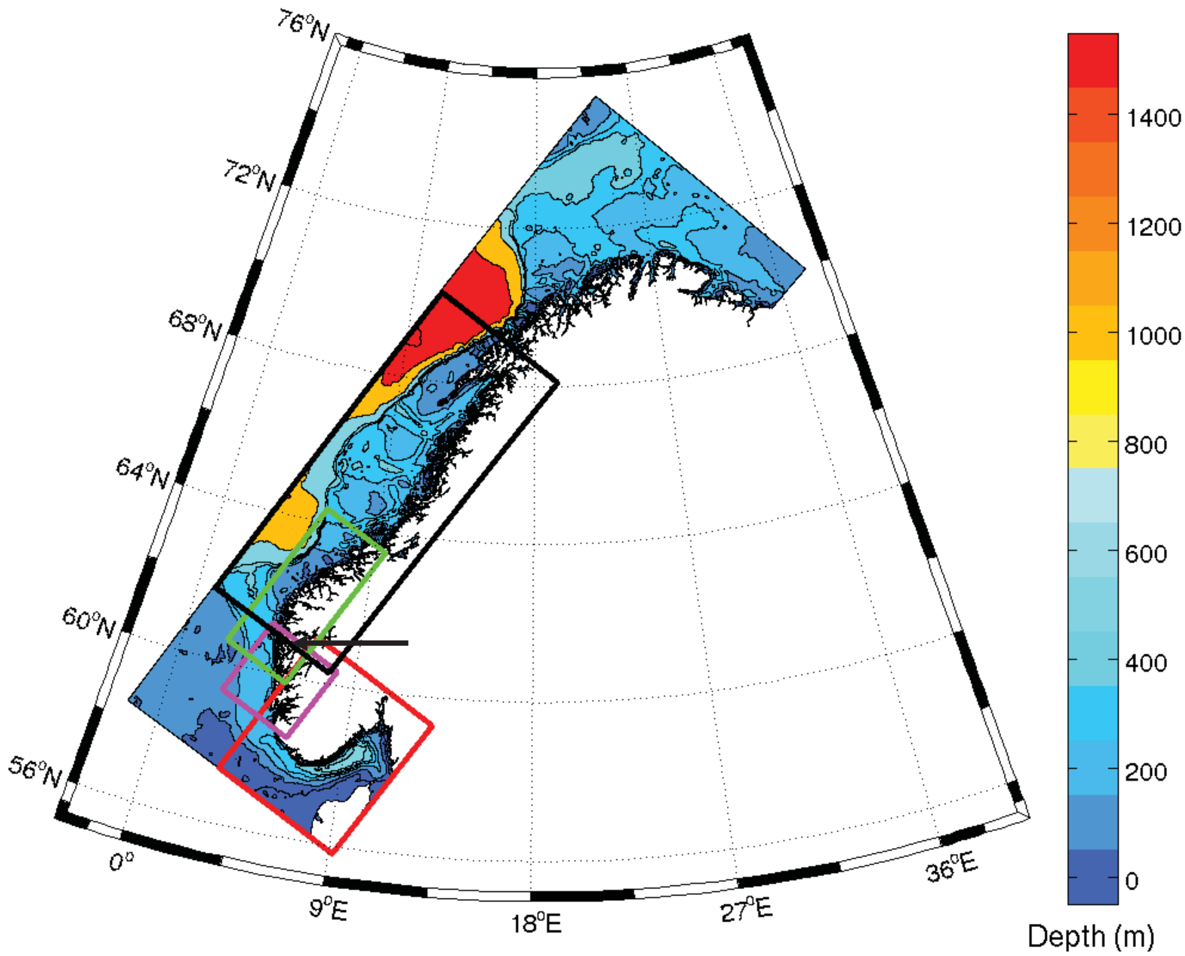

Figure 9. Bathymetric chart of the entire NorKyst-800 grid showing frames from the four simulation experiments presented in this report. The red square denote the Skagerrak-run, the magenta square covers the Hordaland coast, the green square the Sogn and Møre coast and the black square covers the shore from Møre to Lofoten. The arrow indicates the position of the Sognesjøen-location.

Table 2. Details from the model realizations run as test simulations with the NorKyst-800 set up. The sub-grid coordinates refer to the entire NorKyst-800 grid, and the simulation period indicates model time after a spin-up period, typically from 2-12 months.

Name of experiment	Simulation period (t0,t1)	Sub-grid (x) (i0,i1)	Sub-grid (y) (j0,j1)
Skagerrak	March 2009 – July 2009	(2, 573)	(2, 703)
Hordaland	January 2008 – May 2010	(230, 520)	(380, 660)
Sogn and Møre	April 2009	(380, 950)	(500, 750)
Møre to Lofoten	March 2009 – July 2009	(500, 1773)	(400, 893)

5.1 Sea level

Modelled sea level is retrieved from Sognesjøen (location shown in Figure 10) where the Hordaland-simulation provided a 2 ½ year time series (January 1st 2008 to June 1st 2010). The total sea level was unbiased by subtracting the mean sea level for this station found by averaging the entire 2 ½ year period. The sea level anomaly was then detided by harmonic analysis after the ROMS simulation, and the predicted sum of all tidal constituents and the detided (modelled ssh – tide) time series are shown in Figure 11 for an example month period (October 2008). We clearly see that the tidal fluctuations are dominating the sea level fluctuations and that the storm surge signal is characterized with longer periods.

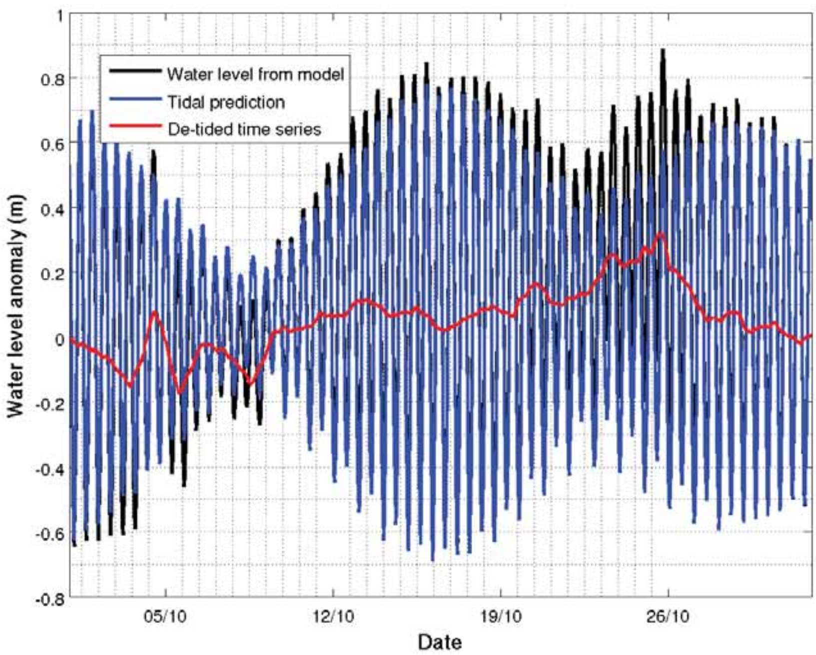

Figure 10. Time series of modelled sea level (black line), and its tidal (blue line) and detided (red line) prediction from October 2008 at the Sognesjøen location from the Hordaland-simulation. The horizontal axis denotes time and the vertical axis denotes sea level height with respect to a mean level.

A fast Fourier transform of the 2 ½ year sea level series is performed to investigate the signal in the frequency domain. The tidal and detided prediction is transformed separately, and their power spectral density (PSD) is shown in Figure 11. We see clearly that the tidal prediction in its frequency domain have peaks in PSD representing the periods according to the daily and semi-daily constituents. As expected, the detided sea level have higher amplitude spectrum for periods exceeding one day.

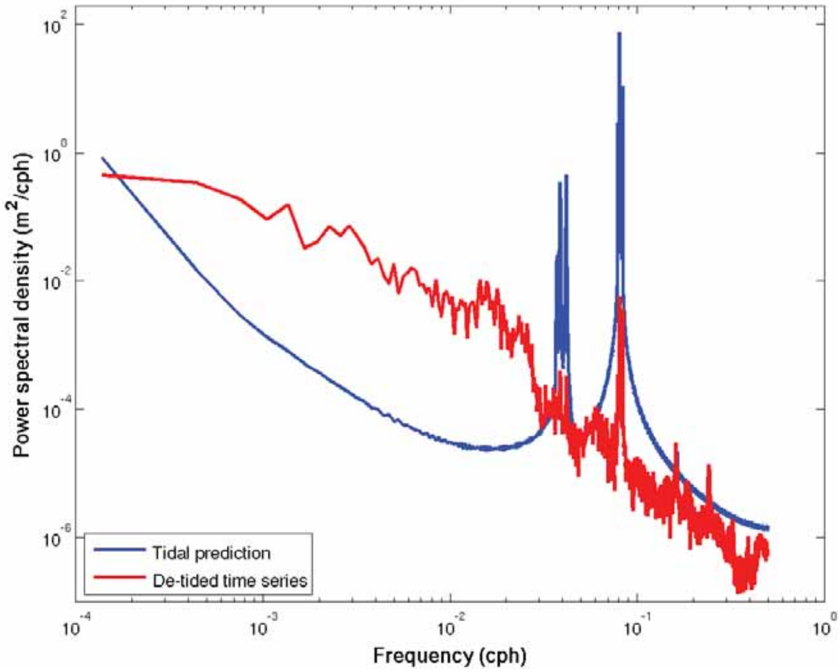

Figure 11. Power spectral densities of the tidal predictions (blue line) and the detided time series (red line) at the Sognesjøen location from the Hordaland-simulation for the period January 2008 to May 2010. The horizontal and vertical axes denote frequency (in cycles per hour) and power spectral (m^2/cph), respectively.

5.2 Currents

Ocean currents are highly valuable in numerous applications, for instance in particle drift modelling and water mass distribution. Also valuable is information of horizontal and vertical distribution of current properties. The reliability of the results varies from location to location and between depths, and extensive validation is important to map how the model reproduces the dominant features between the open ocean, in coastal regions and in fjords. Validation is presented from several simulation experiments in the follow-up report, but some averaged surface current maps are presented in Figure 12-14.

The four model realizations show that the main current features along the Norwegian coast are reproduced. This is important to be able to model the water exchange between offshore and inshore regions. The typical cyclonic circulation is visible in the Skagerrak where water with Atlantic origin meets the Baltic outflow north of Jutland. These water masses along with the Jutland current initiates the Norwegian Coastal Current (NCC). The NCC can be followed in all four realizations close to the coastline. In addition the Norwegian Atlantic Current is visible in the Møre to Lofoten simulation as a north flowing current meandering off the Vøring plateau.

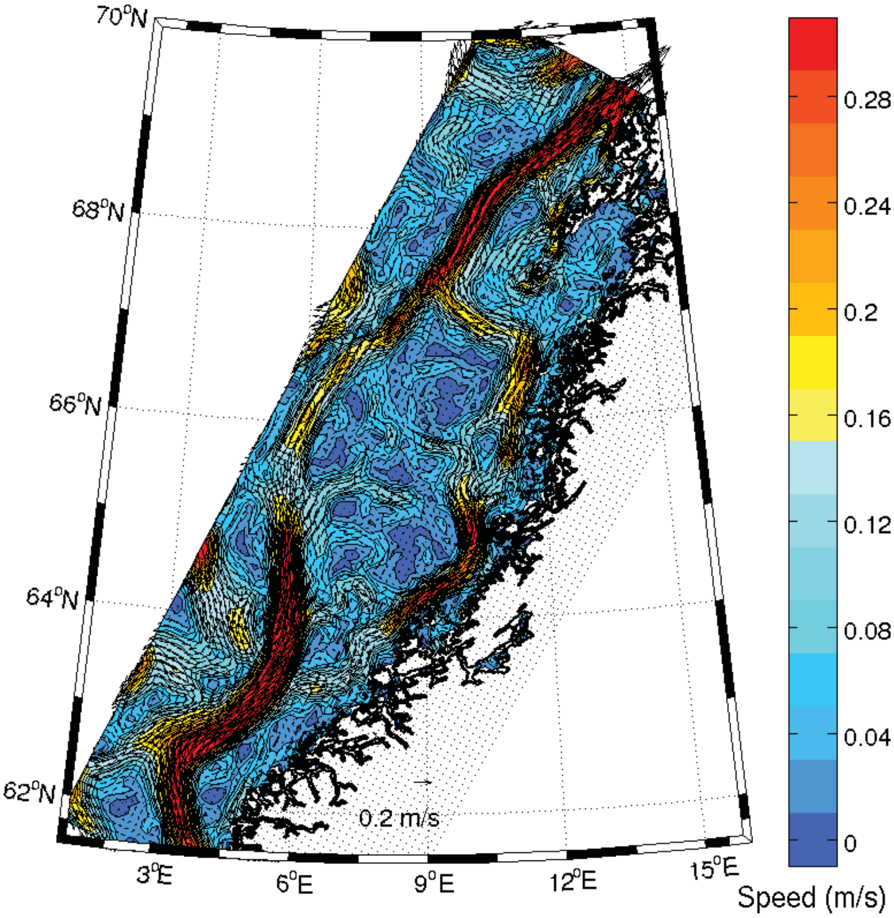

Figure 12. Sea surface currents from the Møre-to-Lofoten model realizations averaged over its simulation period (exclusive spin up), see Table 2 for details. The color scale denotes current speed and line interval is 0.05 m/s. The magnitude of the arrows refers to the arrow at the bottom. Every 10th arrow is shown, i.e., the internal distance is approx. 8 km.

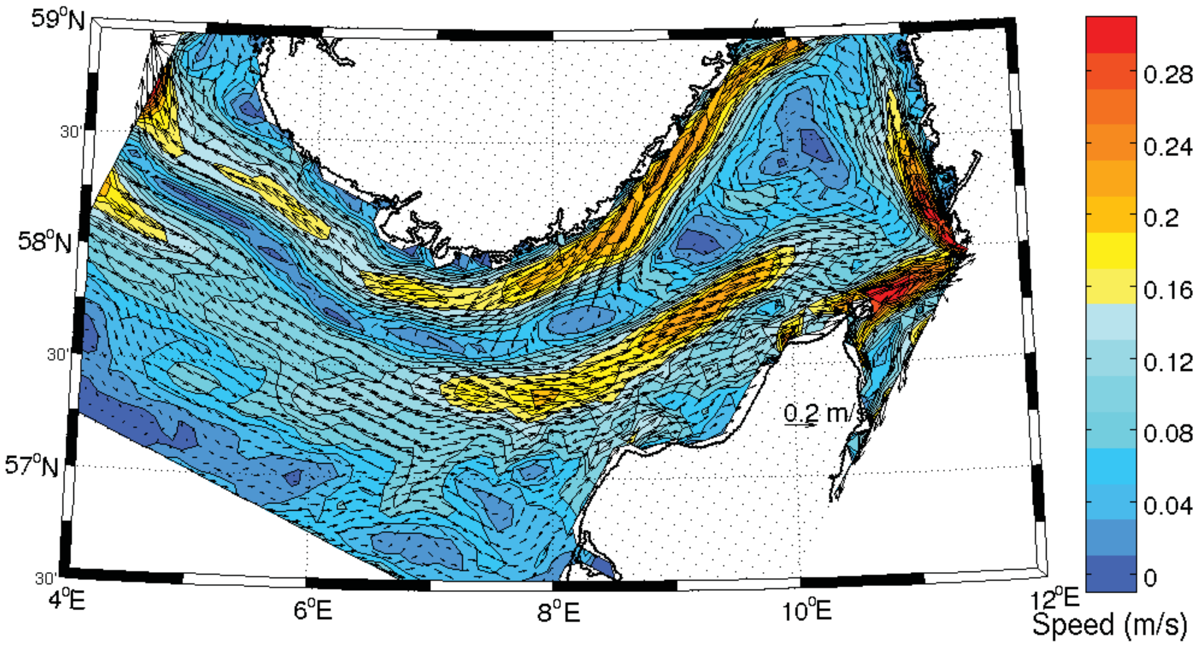

Figure 13. As Figure 12, but surface currents from the Sogn-and-Møre simulation is shown. Every 8th arrow is shown, i.e., the internal distance is approx. 6.4 km.

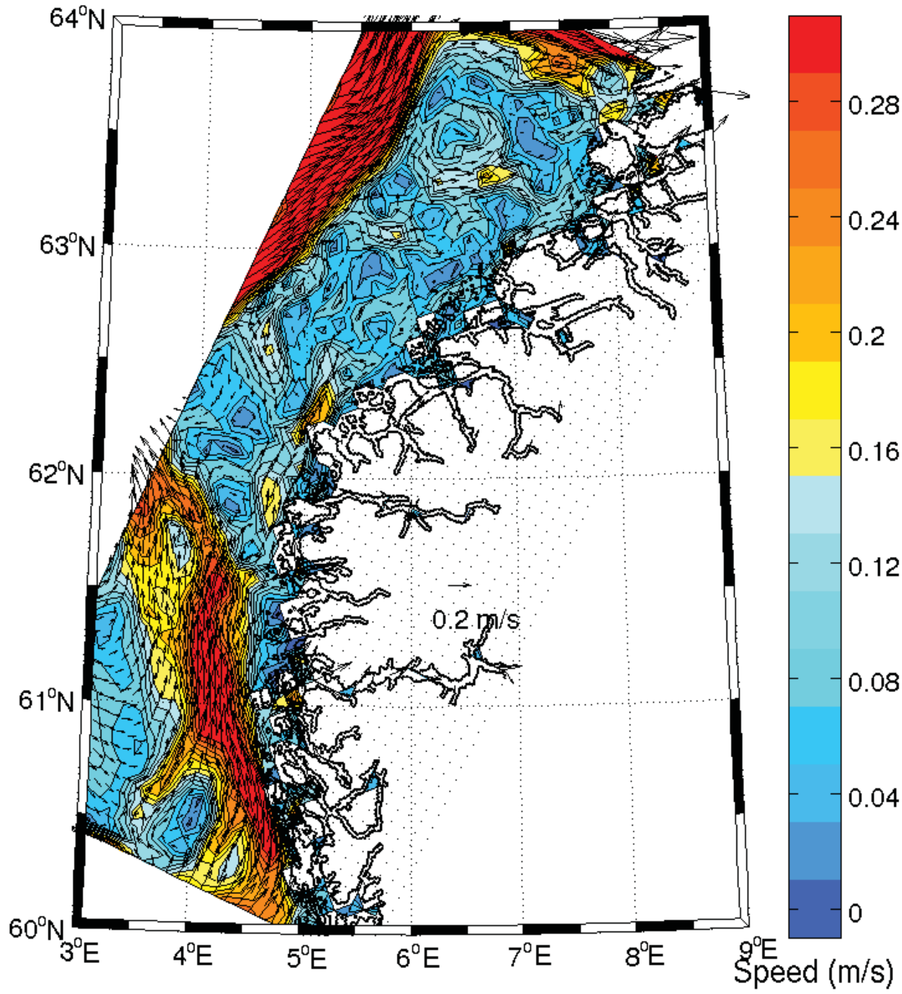

Figure 14. As Figure 13, but surface currents from the Skagerrak simulation is shown.

5.3 Salinity

Time averaged sea surface salinities are displayed in Figure 15 and Figure **16** from all model runs to see how the horizontal gradients are reproduced in the NorKyst-800 model system. We see the Atlantic inflow in Skagerrak as relatively saline waters, and there is a pronounced gradient toward fresher water masses along the shore and within the fjords due to the different freshwater discharges from rivers.

5.4 Temperature

Sea surface temperature (SST) is collected from the Skagerrak and the Møre to Lofoten realizations and averaged over their respective simulation period (March to July 2009 for both areas). The collection of mean SST is displayed in Figure 17 and Figure 18. We see that the averaged SST pattern follows the main currents with fronts in areas with a shear in the horizontal velocity. Regarding both salinity and temperature, there are no pronounced gradients toward the open boundaries. This indicates that the averaged surface hydrography is unbiased between NorKyst-800 and the 4km resolution models covering the Nordic Seas providing boundary conditions.

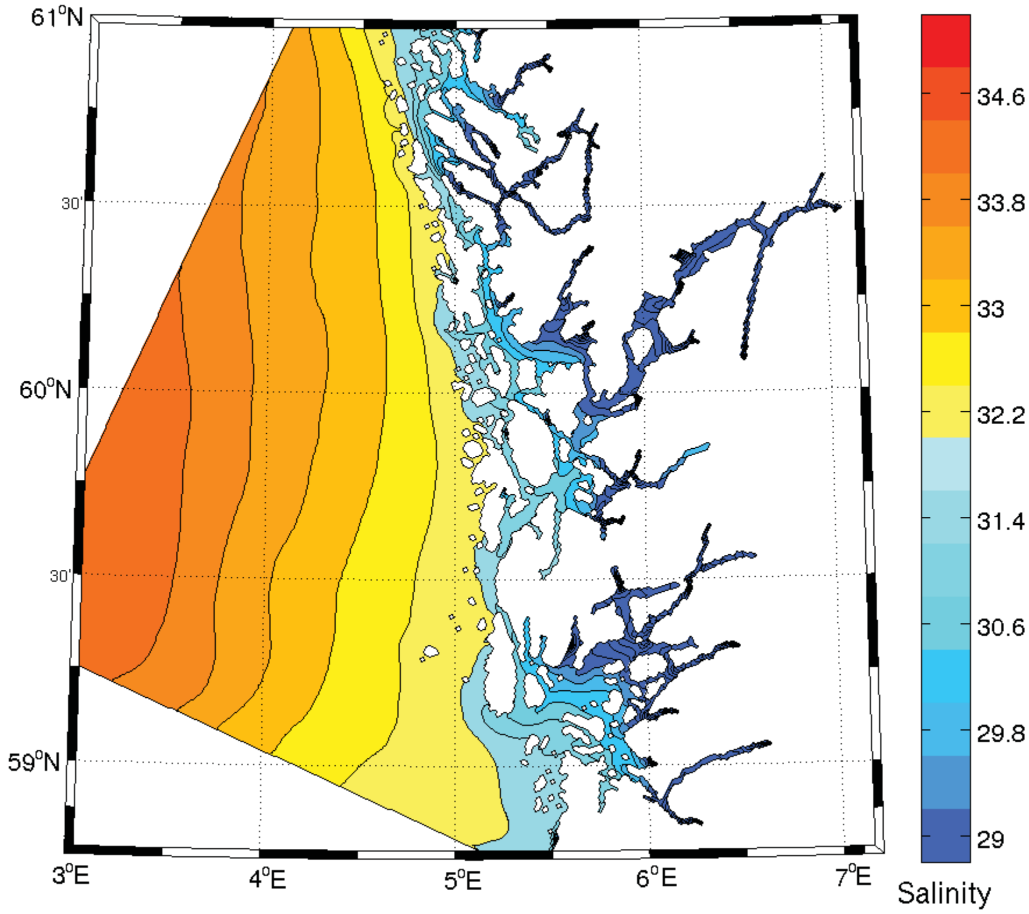

Figure 15. Surface salinity from the Hordaland model realizations averaged over its simulation period (exclusive spin up), see Table 2 for details. The line interval is 0.5.

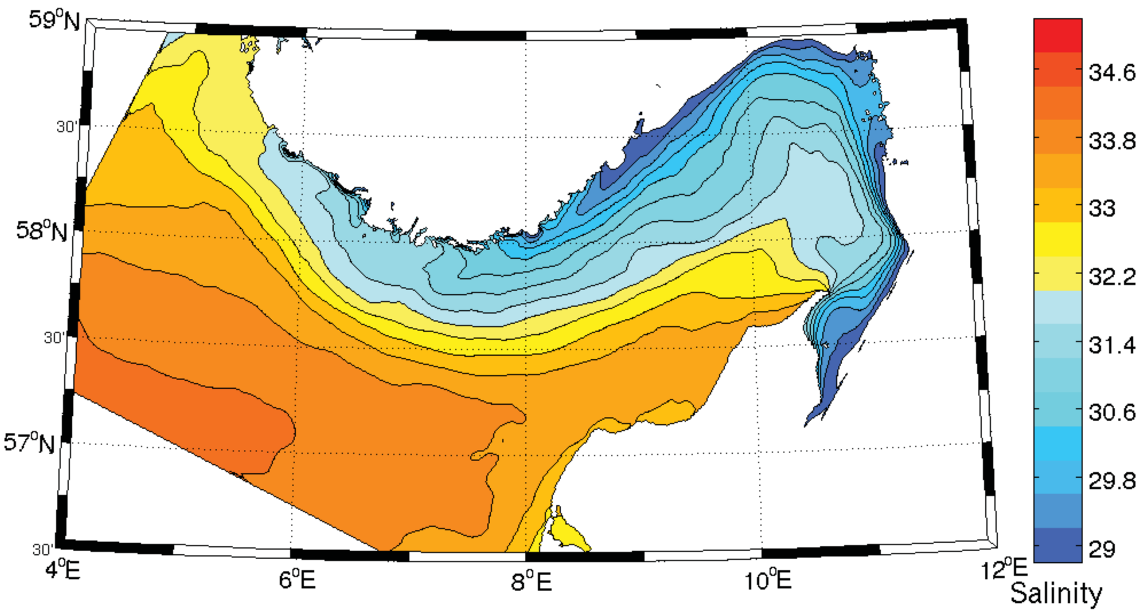

Figure 16. As Figure 15, but surface salinity from the Skagerrak simulation is shown.

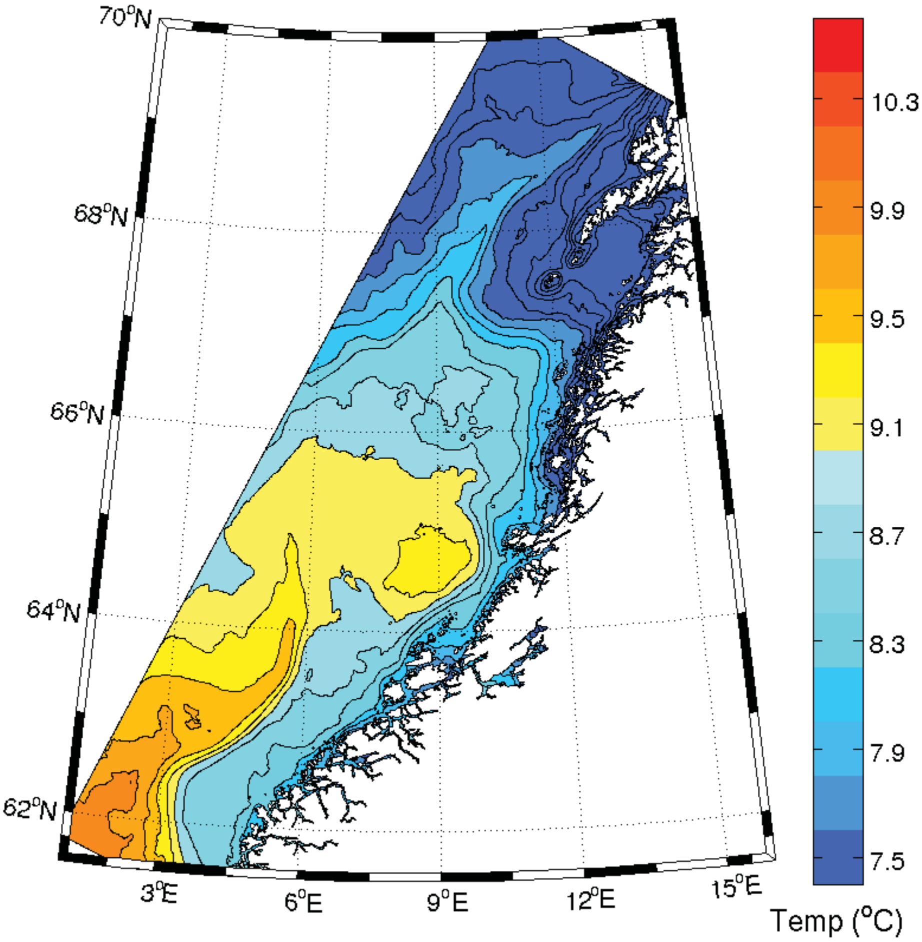

Figure 17. SST from the Møre-to-Lofoten area averaged from March to July 2010. The color scale denotes temperature in °C, and the line interval is 0.1 °C.

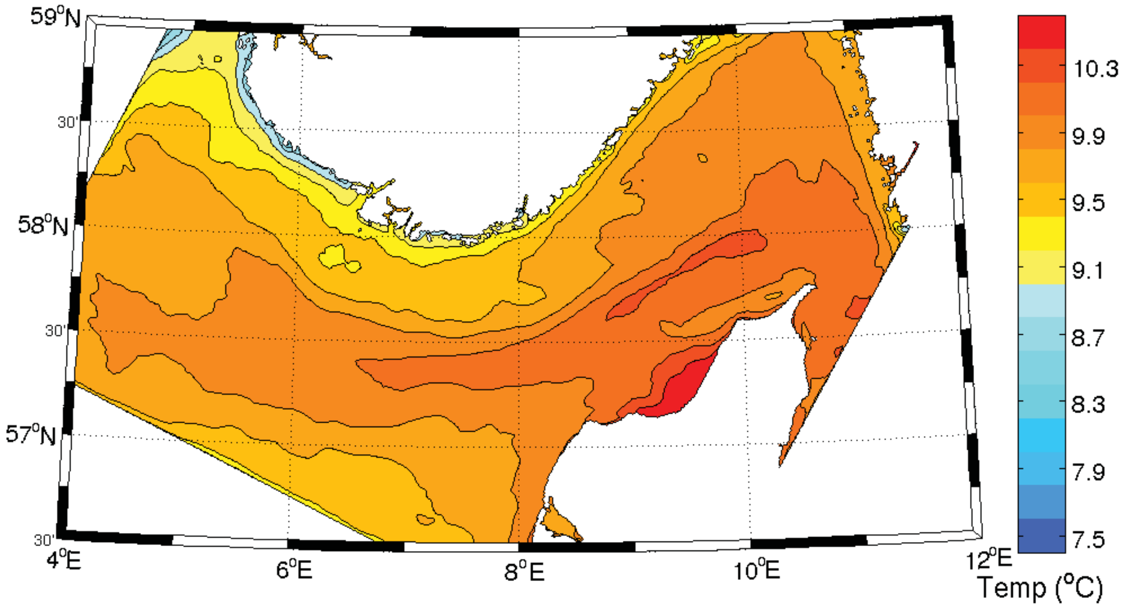

Figure 18. SST from the Skagerak area averaged from March to July 2010. The color scale denotes temperature in °C, and the line interval is 0.1 °C.

6 Final remarks

Documented above is a recently developed numerical ocean modelling system covering the entire Norwegian coast and the adjacent main current systems using a horizontal numerical grid of 800m x 800m. The ocean model applied is the open-source ROMS[9] (Regional Ocean Modeling System). The new artifacts in the model system in addition to the refined resolution are arranged external forcing data (open boundary conditions, atmospheric data, river runoffs and tidal information) suitable for long hindcast runs starting as early as 1958, and newly developed scripts (shell) and pre-processing programs (Fortran). One of the main motivations for developing NorKyst-800 has been simplification of the modelling process with only a minimum of operations to accomplish for standard model simulations.

The developed model system is here verified by performing four simulations with different simulation periods, from half a year to several years. Simultaneously with the development, validation of model runs is performed and will be described in a subsequent report (no. 2).

Acknowledgement:
The development of NorKyst-800 is funded internally by the three cooperating institutes, Institute of Marine Research (IMR), the Norwegian Meteorological Institute (met.no) and the Norwegian Institute for Water Research (NIVA). In addition to the authors of this report, the following members have been involved in the project: Einar Svendsen, Svein Sundby, Bjørn Ådlandsvik and Mari Myksvoll from IMR, Lars Petter Røed, Ana Carrasco, Yvonne Gusdal and Nils Melsom Kristensen from met.no and Dominique Durand and Kjersti Daae from NIVA.

[9] http://myroms.org

7 Bibliography

Beckmann A, Haidvogel DB (1993) Numerical simulation of flow around a tall isolated seamount. Part I: Problem formulation and model accuracy, J. Phys. Oceanogr., 23:1736-1753.

Beldring S, Engeland K, Roald LA, Sælthun NR, Voksø A (2003) Estimation of parameters in a distributed precipitation-runoff model for Norway, Hydrology and earth System Sciences, 7(3): 304-316.

Bjørge D, Haugen JE, Homleid M, Vignes O, Ødegaard V (2003) Updating the HIRLAM numerical weather prediction system at met.no 2000-2002. Norwegian Meteorological Institute, Research Report No. 145.

Blumberg AF, Mellor GL (1987) A description of a three-dimensional coastal ocean circulation model. In: Heap N (ed) Three-dimensional coastal ocean models of Coastal and Estuarine Sciences, vol. 4, American Geophys. Union.

Budgell WP (2005) Numerical simulation of ice-ocean variability in the Barents Sea region, Ocean Dynamics, doi:10.1007/s10236-005-0008-3.

Chapman DC (1985) Numerical treatment of cross-shelf open boundaries in a barotropic coastal ocean model, J. Phys. Oceanogr., 15:1060–1075.

Egbert GD, Bennet AF, Foreman MGG (1994) TOPEX/POSEIDON tides estimated using a global inverse model, J. Geophys. Res., 99, #C12: 24,821-24,852.

Egbert GD, Erofeeva SY (2002) Efficient Inverse Modeling of Barotropic Ocean Tides, J. Atmos. Ocean. Tech., 19: 183-204.

Engedahl H (1995) Implementation of the Princeton Ocean Model (POM/ECOM-3D) at the Norwegian Meteorological Institute (DNMI), Norwegian Meteorological Institute, Research Report No. 5.

Engedahl H, Ådlandsvik B, Martinsen EA (1998) Production of monthly mean climatological archives for the Nordic Seas, J. Mar. Syst. 14: 1-26.

Fairall CW, Bradley EF, Rogers DP, Edson JB, Young GS (1996) Bulk parameterization of air-sea fluxes for tropical ocean-global atmosphere Coupled-Ocean Atmosphere Response Experiment, J. Geophys. Res., 101, 3747-3764.

Flather RA (1976) A tidal model of the northwest european continental shelf. Memoires de la Société Royale de Sciences de Liège, 6:141–164.

Haidvogel DB, Arango HG, Budgell WP, Cornuelle BD, Curchitser E, Di Lorenzo E, Fennel K, Geyer WR, Hermann AJ, Lanerolle L, Levin J, McWilliams JC, Miller AJ, Moore AM, Powell TM, Shchepetkin AF, Sherwood CR, Signell RP, Warner JC, Wilkin J (2008) Ocean forecasting in terrain-following coordinates: Formulation and skill assessment of the Regional Ocean Modeling System. Jour Comp Phys 227(7):3595-3624.

Haney RL (1991) On the pressure gradient force over steep topography in sigma coordinate ocean models. Jour. Phys. Oceanogr. 21: 610–619.

Hunke EC, Dukowicz JC (1997) An elastic-viscous-plastic model for sea ice dynamics, J. Phys. Oceanogr., 27:1849–1868.

Marchesiello P, McWilliams JC, Shchepetkin A (2001) Open boundary conditions for long term integration of regional oceanic models, Ocean Modelling, 3:1–20.

Mellor GL, Kantha L (1989) An ice-ocean coupled model, J. Geophys. Res., 94:10,937–10,954.

Reistad M, Breivik Ø, Haakenstad H (2007) A high-resolution hindcast study for the North Sea, the Norwegian Sea and the Barents Sea. Proceedings of the 10th International Workshop on Wave Hindcast and Forecasting and Coastal Hazard Symposium, p. 13.

Shchepetkin AF, McWilliams JC (1998) Quasi-monotone advection schemes based on explicit locally adaptive dissipation, Monthly Weather Review, 126:1541-1580.

Shchepetkin AF, McWilliams JC (2003) A method for computing horizontal pressure-gradient force in an oceanic model with a nonaligned vertical coordinate, J. Geophys. Res., 108(C3), 3090, doi:10.1029/2001JC001047.

Shchepetkin AF, McWilliams JC (2005) The Regional Ocean Modeling System (ROMS): a split-explicit, free-surface, topography following coordinate oceanic model. Ocean Modeling 9:347-404.

Song Y, Haidvogel DB (1994) A semi-implicit ocean circulation model using a generalized topography-following coordinate system, J. Comp. Phys. 115(1): 228-244.

Umlauf LH, Burchard (2003) A generic length-scale equation for geophysical turbulence models, J. Marine Res. 61:235-265.

Vikebø FB, Husebø Å, Slotte A, Stenevik EK, Lien VS (2010) Effect of hatching date, vertical distribution, and interannual variation in physical forcing on northward displacement and temperature conditions of Norwegian spring spawning herring larvae, ICES Journal of Marine Science 67: 1710–1717.

Warner JC, Sherwood CR, Arango HG, Signell RP (2005) Performance of four turbulence closure models implemented using a generic length scale method. Ocean Modeling 8:81-113.

Wessel P, Smith WHF (1996) A Global Self-consistent, Hierarchical, High-resolution Shoreline Database, J. Geophys. Res., 101, #B4: 8741-8743.

Aas E (1983) Estuarer (compendium), Institute for Geosciences, University of Oslo.

Appendix A – List of river outlets

Table 3. List of river outlets. Isrc and Jsrc denote the grid position of the outlet and refer to the entire NorKyst-800 domain. If Dsrc is 1 the outlet is at a U-point (release in y-direction) and if Dsrc is 0 the outlet is at a V-point (release in x-direction). Sign defines the direction of the river flow.

NO	Isrc	Jsrc	Dsrc	Sign	NAME
1	474	102	1	1	Haldenvassdraget/Iddefjorden
2	481	122	0	-1	Glommavassdraget/Hvaler og Singlefjorden
3	497	159	0	-1	Mossevassdraget/Kyst Onsøy-Son
4	509	163	0	-1	Hølenelva/Drøbaksundet øst
5	542	180	0	1	Nesodden og Bunnefjorden
6	557	190	0	-1	Nordmarkvassdraget/Kyst Gjersjøelva-Bygdøy
7	554	195	1	-1	Lysakerelva
8	547	200	1	-1	Sandvikselva
9	524	189	1	-1	Årosvassdraget/Indre Oslofjorden vest
10	505	175	1	-1	Hurumlandet øst og sør
11	522	205	1	-1	Lierelva/Drammensfjorden øst
12	520	208	1	-1	Drammensvassdraget/Drammensfjorden vest
13	499	195	1	-1	Sandevassdraget/Kyst Berger-Tønsberg
14	461	162	0	-1	Aulivassdraget/Kyst Tønsberg-Sandefjord
15	429	169	0	-1	Numedalslågen og Siljanv./Kyst Sandefjord-Mølen
16	423	201	0	-1	Skiensvassdraget/Langesundsfjorden
17	383	201	0	-1	Kragerøvassdraget/Bamble og Kragerø Kommuner
18	349	200	1	-1	Vegår- og Gjerstadv./Kyst Kragerø-Tromøya
19	310	211	1	-1	Arendalsvassdraget/Kyst Moland-Homborsund
20	255	237	0	-1	Tovdalsvassdraget/Lillesand Kommune
21	246	239	1	-1	Otra/Kristiansand og Flekkerøy
22	212	266	0	-1	Mandalselva/Kyst Flekkerøy-Mandal By
23	208	279	0	-1	Audna/Kyst Mandal By-Lindesnes
24	212	303	1	1	Lygna/Kyst Lindesnes-Lista
25	225	321	0	-1	Kvina/Fedafjorden
26	207	350	0	-1	Sira og Sokna/Kyst Hidra-Sokndal
27	215	395	0	-1	Bjerkreimvassdraget/Kyst Sokndal-ogna
28	247	442	1	1	Figgjo/Jæren
29	275	417	0	1	Stavanger og Sandnes Kommuner
30	275	396	1	1	Frafjordelva/Høgsfjorden og Frafjorden
31	313	386	1	1	Lysevassdraget/Lysefjorden
32	289	421	1	1	Jørpelandsåna/Strand Kommune
33	309	422	1	1	Årdalselva/Årdalsfjorden
34	321	445	1	1	Ryfylkeøyane
35	343	415	0	-1	Ulla og Førreelva/Jøsenfjorden og Erfjorden
36	354	437	1	1	Suldalsvassdraget/Sandsfjorden sør og Hylsfjorden
37	379	441	0	-1	Saudav./Saudafjorden og Sandsfjorden nord
38	346	461	0	-1	Vikedalselva/Vindafjorden
39	315	470	1	-1	Kyst Nedstrand-Haugesund-Tittelsnes
40	295	494	1	1	Karmøy
41	367	471	1	1	Etnevassdraget/Ålfjorden og Etnefjorden
42	393	476	0	-1	Blåelva/Kyst Etnefjorden-Sunde
43	359	515	0	-1	Bømlo
44	377	523	1	1	Stordøya
45	409	484	1	1	Hardangerfjorden øst: Sunde-Ænes

46	439	476	0	-1	Maurangerfjorden og Sildefjorden øst
47	453	488	1	1	Samlafjorden sør og Jondal Kommune
48	439	457	0	1	Opo/Sørfjorden vest
49	443	457	1	1	Tysso/Sørfjorden øst: Tysso-Krossanes
50	503	449	0	1	Eidfjordv., Kinso og Sima/Kyst Krossanes-Osafjorden
51	515	459	0	-1	Osafjorden, Ulvikfjorden og Eidfjorden nord
52	465	496	1	-1	Granvinfjorden og Samlafjorden nord
53	429	512	0	-1	Sævareidelva/Kyst Strandebarm-Strandvik
54	389	511	0	-1	Tysnes og Austevoll Kommuner
55	454	525	0	-1	Samnangervassdraget/Fusafjorden
56	423	543	1	1	Bergen og Omegn
57	421	564	1	1	Sotra
58	445	589	1	1	Øygarden Kommune
59	453	577	1	1	Askøya og Holsnøya
60	470	553	1	1	Osterøya
61	475	536	1	1	Bergsdalsvassdraget/Kyst Salhus-Dale
62	487	538	1	1	Vossovassdraget/Bolstadfjorden
63	496	542	0	-1	Eksingedalsvassdraget/Eidsfjorden
64	485	555	1	-1	Steinslandsvassdraget/Osterfjorden nord
65	471	572	1	1	Lindåshalvøya, Seimsfjorden og Austfjorden
66	466	592	1	1	Fosnøya, Radøya og Fedje
67	507	566	1	1	Masfjorden
68	507	595	1	1	Sognesjøen sør
69	531	579	1	1	Ytre Sognefjorden sør: Rutledal-Varmråk
70	550	523	0	1	Viksvassdraget/Varmråk-Vangsnes
71	553	488	0	1	Nærøyelvi/Fresvikbreen
72	559	470	1	1	Aurlandsvassdraget/Aurlandsfjorden
73	593	465	1	1	Lærdalsvassdraget/Lærdalsfjorden
74	619	459	0	-1	Årdalsvassdraget/Årdalsfjorden
75	645	482	0	-1	Fortunvassdraget/Lusterfjorden øst og nord
76	623	494	1	-1	Jostedøla/Lusterfjorden vest
77	605	493	0	-1	Årøyvassdraget/Kyst Kaupanger-Hella
78	607	524	0	-1	Vetlefjorden og Fjærlandsfjorden
79	566	553	0	-1	Høyangervassdraget/Kyst Dragsvik-Kyrkjebø
80	558	568	0	-1	Ytre Sognefjorden nord: Kyrkjebø-Risnes
81	524	618	0	1	Solund Kommune
82	558	612	1	1	Guddalsvassdraget/Åfjorden og Vilnesfjorden sør
83	571	592	1	1	Gaularvassdraget/Dalsfjorden
84	591	587	1	1	Jølstra/Førdefjorden
85	587	620	1	1	Oselvvassdraget/Flora Kommune
86	627	591	0	1	Gjengedalsv./Frøysjøen og Ytre Nordfjord sør
87	639	582	1	1	Breimsvassdraget/Nordfjord sør: Hyenfjorden-Innvik
88	670	559	0	-1	Strynvassdraget/indre Nordfjord
89	649	602	1	1	Hornindalvassdraget/Nordfjord nord
90	613	657	0	-1	Bremangerlandet
91	657	669	1	1	Sildegapet
92	651	638	1	1	Gusdalelva/Vanylvsfjorden og Syltefjorden
93	665	628	1	1	Rovdefjorden sør og Syvdefjorden
94	672	606	0	1	Stigedalselva/Voldafj., Austefjord og Dalsfjorden
95	689	612	1	1	Ørstavassdraget/Ørstafj. og Vartdalsfjorden sør
96	708	625	0	1	Hareidlandet og Gurskøya
97	692	580	0	1	Storfjorden sør, Hjørundfjorden og Sykkylvsfjorden

98	698	559	0	1	Storfjorden sør, Sunnylvsfjorden og Geirangerfj.
99	732	540	0	1	Tafjordvassdraget/Tafjorden og Norddalsfj. sør
100	735	553	0	-1	Valldøla/Norddalsfjorden nord og Storfjorden øst
101	743	607	1	1	Ålesund og Omegn
102	760	575	0	1	Midtfjorden sør og Romsdalsfjorden vest
103	777	547	1	1	Rauma/Romsdalsfjorden
104	807	528	1	1	Eira/Langfjorden
105	805	560	1	1	Gusjåvassdraget/Moldefjorden og Fannefjorden
106	773	607	0	1	Aukra, Misund og Sandøy Kommuner
107	795	588	1	1	Frænfjorden, Julsundet og Hustadvika
108	822	565	0	1	Kornstadfjorden og Batnfjorden
109	818	505	0	1	Driva/Tingvollfjorden og Sunndalsfjorden
110	833	581	0	1	Averøy, Frei og Kristiandsund Kommuner
111	841	507	1	1	Kyst Tingvollfjorden-Surnadalsfjorden
112	858	519	1	1	Surna/Surnadalsfjorden og Halsafjorden øst
113	895	516	1	1	Fjelna/Korsnesfjord sør og Vinjefjord
114	883	553	0	1	Tustna Kommune og Ertvågøy
115	900	583	0	1	Smøla Kommune
116	918	533	0	1	Røsta/Trondheimsleia: Aure-Stamnes
117	923	565	0	1	Hitra Kommune
118	945	562	0	-1	Frøya Kommune
119	910	515	0	1	Trondheimsleia øst: Stamnes-Agdenes Fyr
120	955	483	0	1	Ytre Trondheimsfjorden: Agdenes Fyr-Geitaneset
121	935	477	0	1	Orkla/Orkdalsfjorden
122	950	456	1	1	Gaula/Kyst Viggjaneset-Flakk
123	965	457	0	1	Nidelvvassdraget/Strindfjorden
124	983	431	1	1	Stjørdalsvassdraget/Stjørdalsfjorden
125	1002	441	0	-1	Åsenfjorden
126	1030	431	0	1	Trondheimsfjorden øst: Frosta-Verdalsøra
127	1041	425	1	1	Verdalsvassdraget/Borgenfjorden
128	1065	440	1	1	Snåsavassdraget/Beitstadfjorden øst
129	1051	458	1	-1	Follavassdraget/Beitstadfjorden vest
130	1031	465	1	-1	Verransundet
131	1029	451	1	-1	Trondheimsfjorden vest
132	970	492	0	-1	Skaudalsv./Ytre Trondheimsfj:Stadsbygd-Brettingnes
133	999	495	0	-1	Stjørnfjorden
134	998	513	1	1	Teksdalselva/Frohavet sør: Garten-Lysøysund
135	1022	502	0	-1	Stordalselva/Åfjorden og Skråfjorden
136	1054	509	1	1	Hofstadelva/Frohavet nord
137	1070	511	1	1	Osen og Flatanger Kommuner
138	1095	474	0	1	Årgårdsvassdraget og Bogna/Namsfjorden sør
139	1124	469	0	-1	Namsen/Namsfjorden øst
140	1144	492	1	1	Salsvatnvassdraget/Kyst Namsos-Foldfjorden
141	1170	479	0	-1	Oppløyvassdraget/Oppløyfjorden og Kvistfjorden
142	1199	477	0	-1	Indre Folda
143	1187	496	1	1	Vikna og Kyst Foldfjorden-Bindalsfjorden
144	1221	469	1	1	Åbjøra/Bindalsfjorden sør og Tosenfjorden
145	1242	483	0	-1	Bindalsfjorden nord
146	1251	500	0	-1	Kyst Røyingen-Velfjorden
147	1271	532	1	-1	Vega Kommune
148	1275	482	0	-1	Lomsdalsvassdraget/Velfjorden og Vevelstadsundet
149	1293	495	1	1	Visten, Halsfjorden og Ytre Vefsnfjorden øst

150	1319	531	1	1	Alsten og Tjøtta
151	1329	489	0	1	Vefsna/Vefsnfjorden sør
152	1337	496	1	1	Fusta og Drevja/Vefsnfjorden nord
153	1353	515	0	-1	Leirfjord Kommune
154	1339	536	1	-1	Dønna og Herøy Kommuner
155	1384	484	0	1	Røssåga/Elsfjord og Sørfjorden
156	1416	483	0	-1	Ranavassdraget/Ranafjorden nord
157	1396	517	0	-1	Kyst Utskarpen-Nesna-Tonnes
158	1363	539	0	-1	Øyer I Nesna, Lurøy og Træna Kommuner
159	1443	531	1	1	Vestre Svartisen og Rødøy Kommune
160	1461	526	1	1	Fykanåga/Glomfjorden, Gåsværfjorden og Sørfj.
161	1493	530	1	1	Beiarelva, Morsdalsfjorden og Nordfjorden
162	1528	507	0	1	Saltfjorden: Nordfjorden-Skjerstad
163	1540	485	0	1	Saltelva/Skjerstadfjorden og Saltdalsfjorden sør
164	1555	495	1	1	Sulitjelmavassdraget/Skjerstadfjorden nord
165	1540	532	0	-1	Kyst Saltstraumen-Bodø-Tårnvikfjellet
166	1585	501	0	-1	Fagerbakkvassdraget og Laksåga/Sørfolda sør
167	1607	506	0	-1	Kobbelvvassdraget/Sørfolda nord
168	1621	543	1	1	Nordfolda
169	1603	551	0	-1	Ytre Del Av Steigen Kommune
170	1642	532	0	1	Sagelvvassdraget/Ytre Del Av Hamarøy Kommune
171	1651	499	1	1	Hellemovassdraget/Tysfjord Kommune
172	1705	530	0	-1	Forsåvassdraget/Efjorden
173	1722	497	1	1	Skjomavassdraget/Ofotfjorden sør
174	1755	492	1	1	Indre Ofotfjorden
175	1742	531	0	-1	Ofotfjorden nord: Tangvik-Bogen-Selnes
176	1710	554	1	-1	Tjeldøya
177	1702	572	0	-1	Østre Hinnøya
178	1704	606	1	1	Vestre Hinnøya
179	1638	611	1	-1	Vågan Kommune
180	1626	646	1	1	Vestvågøy Kommune
181	1571	649	1	-1	Flakstadøya og Moskenesøya
182	1523	651	1	1	Værøy Kommune
183	1489	661	1	-1	Røst Kommune
184	1684	627	0	1	Hadseløya
185	1718	619	0	1	Langøya
186	1776	633	1	1	Andøya
187	1766	591	0	-1	Grytøya, Bjarkøya og Sandsøya
188	1764	552	0	-1	Rolla
189	1761	538	1	1	Skoddebergvassdraget/Skånland Kommune
190	1791	523	1	1	Gratangen og Lavangen
191	1804	531	1	1	Salangselva/Salangen
192	1791	560	1	1	Andørja
193	1838	544	0	1	Skøelvv./Kyst Salangen-Malangen og Dyrøya
194	1849	561	0	1	Lakselva og Lyselvvassdraget/Senja øst
195	1844	597	0	1	Senja vest
196	1866	539	0	1	Målselvvassdraget/Malangen
197	1901	559	0	-1	Kvaløya og Tromsøya
198	1890	497	1	1	Nordkjoselva/Balsfjorden og Straumsfjorden
199	1936	555	1	1	Tromsøy- og Grøtsundet øst, Reinøya og Karlsøya
200	1961	582	1	1	Ringvassøya
201	1957	599	1	1	Rebbenesøya, Grytøya, Nord-Kvaløya og Helgøya

202	1995	568	0	1	Vanna og Nord-Fugløya
203	1915	509	1	1	Lakselva/Ullsfjorden og Sørfjorden
204	1909	487	0	1	Signaldalselva/Lyngen vest
205	1929	486	1	1	Skibotnvassdraget/Lyngen: Skibotn-Kåfjorden
206	1958	475	1	1	Kåfjordv./Lyngen øst, Uløya, Kågen og Skjervøya
207	2027	546	1	1	Arnøya og Laukøya
208	1992	493	0	1	Reisavassdraget/Reisafjorden
209	2023	451	1	1	Kvænangsvassdraget/Kvænangen sør
210	2040	471	0	1	Storelva/Kvænangen nord
211	2058	470	0	1	Loppa Kommune og Langfjorden
212	2087	428	1	1	Altavassdraget/Altafjorden
213	2161	442	1	1	Repparfjordvassdraget/Vargsundet og Sammelsund
214	2093	492	1	1	Stjernøya
215	2119	465	1	-1	Seiland
216	2118	506	1	-1	Sørøya
217	2160	483	1	1	Kvaløya
218	2188	447	1	1	Russelvvassdraget/Revsbotn
219	2202	508	1	1	Ingøya og Rolvsøya
220	2224	446	0	1	Nordre Porsangerhalvøya, Måsøya og Hjelmsøya
221	2261	464	0	1	Magerøya
222	2188	419	0	1	Vestre Porsangen
223	2152	396	1	-1	Stabburselva/Indre Porsangen vest
224	2145	387	0	1	Lakselvvassdraget/Indre Porsangen sør
225	2187	390	0	-1	Børselvvassdraget/Indre Porsangen øst
226	2238	412	1	1	Østre Porsangen
227	2244	397	0	1	Ytre Laksefjorden vest
228	2223	365	0	1	Storelva/Indre Laksefjorden vest
229	2229	365	1	1	Adamselvvassdraget/Indre Laksefjorden øst
230	2283	377	1	1	Ytre Laksefjorden øst
231	2327	392	0	1	Nordkinnhalvøya nord
232	2311	366	1	-1	Hopsfjorden
233	2284	354	0	1	Langfjordvassdraget/Langfjorden
234	2286	318	0	1	Tana/Tanafjorden sør
235	2353	336	0	1	Stordalselvvassdraget/Tanafjorden øst og Trollfj.
236	2343	312	0	1	Kongsfjordvassdraget/Kongsfjorden
237	2356	278	0	1	Vesterelv./Kyst Båtsfjordnæringen-Hamningberg
238	2373	258	0	1	Sandfjordelva/Persfjorden og Bussesundet
239	2347	233	1	-1	Komagelva og Skallelvv./Kyst Kibergneset-Skallnes
240	2295	256	0	-1	Vestre Jakobselva/Ytre Varangerfjord nord
241	2283	272	1	-1	Bergebyelva og Vesterelva/Indre Varangerfjord
242	2271	273	0	1	Reppenelva og Nyelvvassdraget/Varangerfj. sør
243	2279	228	0	1	Klokkerelvvassdraget/Bugøyfjorden
244	2266	205	0	1	Neidenvassdraget/Munkfjorden
245	2299	213	0	1	Skogerøya
246	2288	192	1	1	Pasvikelva/Bøkfjorden
247	2320	178	1	1	Grense Jakobselv/Varangerfjorden øst
248	360	4	0	-1	Göta Älv (Sweden)
249	409	29	1	-1	Örekilsälv (Sweden)

Appendix B – Lowest level for freshwater discharge

The lowest level of entering freshwater is calculated from an internal Froude number consideration (Aas 1983). We assume a typical two layer stationary estuarine circulation and neglect friction forces. The pressure term is assumed to be hydrostatic (mainly advection in the horizontal) and by integrating the momentum equations for the two layers, we get the relationship

$$\frac{Q^2}{g' B^2 H^3} = 2\left(\frac{h}{H}\right)^2 \left(1 - \frac{h}{H}\right).$$

Q is the river runoff, *B* is the width of the river mouth, *h* is the depth of the upper layer in the estuarine, *H* is the depth of the upper layer when zero velocity is assumed, and *g'* is the reduced gravity defined as

$$g' = g\left(1 - \frac{\rho_1}{\rho_2}\right).$$

g is here the constant of gravity and ρ_1 and ρ_2 are the densities in the upper and lower layer, respectively. The critical depth for maximum transport is defined by $h/H = 2/3$, and by defining an inner Froude number, *Fi*, as

$$F_i = \frac{u^2}{g' h} = \frac{Q^2}{g' B^2 H^3}$$

from the relation that $Q = uhB$, the maximum transport corresponds to $Fi = 1$. The depth of the upper layer when $Fi = 1$, named *hmix*, is then

$$hmix = \frac{3}{2}\left(\frac{Q^2}{g' B^2}\right)^{\frac{1}{3}}.$$

Most rivers mouths are narrower than *B* (which is 800m for NorKyst-800), and we compensate this by applying *hmax = 2hmix* as the bottom level of freshwater discharge (corresponds to a river mouth width of about 280m).

Appendix C – ROMS CPP-options

The following statements are copied and pasted from the ROMS CCP-options file (*Apps/NorKyst_800m/norkyst_800m.h*) applied in the default NorKyst-800 simulations.

```
/*
** Options for NORKYST_800M
*/

#define CURVGRID              /* define if using curvilinear coordinate grid          */
#define UV_ADV                /* turn ON or OFF advection terms                       */
#define UV_COR                /* turn ON or OFF Coriolis term                         */
#define UV_VIS2               /* turn ON or OFF Laplacian hor. mix.,NB: coeffs zero!  */
#define UV_SADVECTION         /* turn ON or OFF splines vertical advection            */
#define UV_QDRAG              /* turn ON or OFF quadratic bottom friction             */
#define NONLIN_EOS            /* define if using nonlinear equation of state          */
#define DJ_GRADPS             /* splines density Jacobian (Shchepetkin, 2000)         */
#define TS_DIF2               /* turn ON or OFF Laplacian hor. mix.,NB: coeffs zero!  */
#define TS_U3HADVECTION       /* define if 3rd-order upstream horizontal advection    */
#define TS_SVADVECTION        /* define if splines vertical advection                 */
#define MIX_GEO_TS            /* mixing on geopotential (constant Z) surfaces         */
#define MIX_S_UV              /* mixing along constant S-surfaces                     */
#define SALINITY              /* define if using salinity                             */
#define SOLVE3D               /* define if solving 3D primitive equations             */
#define SPLINES               /* turn ON or OFF parabolic splines reconstruction      */
#define MASKING               /* define if there is land in the domain                */
#define AVERAGES              /* define if writing out time-averaged data             */
#define STATIONS              /* define if writing out station data                   */
#define STATIONS_CGRID        /* define if extracting data at native C-grid           */

#define GLS_MIXING            /* activate Generic Length-Scale mixing                 */
#ifdef GLS_MIXING
# define N2S2_HORAVG          /* activate horizontal smoothing of buoyancy/shear      */
#endif

#undef WESTERN_WALL           /* define if all grid points along western bry are land  */
#undef NORTHERN_WALL          /* define if all grid points along northern bry are land */
#undef SOUTHERN_WALL          /* define if all grid points along southern bry are land */
#undef EASTERN_WALL           /* define if all grid points along eastern bry are land  */

#define EAST_FSCHAPMAN        /* free-surface Chapman condition                       */
#define EAST_M2FLATHER        /* 2D momentum Flather condition                        */
#define EAST_M3NUDGING        /* 3D momentum passive/active nudging term              */
#define EAST_M3RADIATION      /* 3D momentum radiation condition                      */
#define EAST_TNUDGING         /* tracers passive/active nudging term                  */
#define EAST_TRADIATION       /* tracers radiation condition                          */

#define WEST_FSCHAPMAN
#define WEST_M2FLATHER
#define WEST_M3NUDGING
#define WEST_M3RADIATION
#define WEST_TNUDGING
#define WEST_TRADIATION

#define NORTH_FSCHAPMAN
#define NORTH_M2FLATHER
#define NORTH_M3NUDGING
#define NORTH_M3RADIATION
#define NORTH_TNUDGING
```

```
#define NORTH_TRADIATION

#define SOUTH_FSCHAPMAN
#define SOUTH_M2FLATHER
#define SOUTH_M3NUDGING
#define SOUTH_M3RADIATION
#define SOUTH_TNUDGING
#define SOUTH_TRADIATION

#define M2CLIMATOL0GY               /* define 2D momentum climatology                           */
#define M3CLIMATOLOGY               /* define 3D momentum climatology                           */
#define TCLIMATOLOGY                /* define tracers climatology                               */
#define M3CLM_NUDGING               /* nudging 3D momentum climatology                          */
#define TCLM_NUDGING                /* nudging tracers climatology                              */

#define ANA_BSFLUX                  /* analytical bottom salinity flux                          */
#define ANA_BTFLUX                  /* analytical bottom temperature flux                       */
#define ANA_SSFLUX                  /* analytical surface salinity flux                         */
#define ANA_STFLUX                  /* analytical surface temperature flux                      */

#define ICE_MODEL                   /* turn ON or OFF sea ice module                            */

#define BULK_FLUXES                 /* turn ON or OFF bulk fluxes computation                   */
#ifdef BULK_FLUXES
# ifdef ICE_MODEL
#  define ICE_BULK_FLUXES
# endif
# define EMINUSP                    /* turn ON internal calculation of E-P                      */
# define ANA_SRFLUX                 /* analytical surface shortwave radiation flux              */
# define ALBEDO                     /* use albedo equation for shortwave radiation              */
# define LONGWAVE                   /* compute net long wave radiation internally               */
# define COOL_SKIN                  /* turn ON or OFF cool skin correction                      */
#endif

#define ATM_PRESS                   /* use to impose atmospheric pressure onto sea surface      */
#define SOLAR_SOURCE                /* define if solar radiation source term                    */
#define SPECIFIC_HUMIDITY           /* if humidity-input is specific humidity in kg/kg          */

#define SSH_TIDES                   /* turn on computation of tidal elevation                   */
#define UV_TIDES                    /* turn on computation of tidal currents                    */
#define ADD_FSOBC                   /* add tidal elevation to processed OBC data                */
#define ADD_M2OBC                   /* add tidal currents to processed OBC data                 */

#define UV_PSOURCE                  /* turn ON or OFF point Sources/Sinks (rivers)              */
#define TS_PSOURCE                  /* turn ON or OFF point Sources/Sinks (rivers)              */

#ifdef ICE_MODEL
# define ICE_THERMO                 /* use for thermodynamic component                          */
# define ICE_MK                     /* use for Mellor-Kantha thermodyn. (no other choice)       */
# define ICE_MOMENTUM               /* use for momentum component                               */
# define ICE_EVP                    /* use for elastic-viscous-plastic rheology                 */
# define ICE_ADVECT                 /* use for advection of ice tracers                         */
# define ICE_SMOLAR                 /* use for MPDATA or UPWIND advection scheme                */
# define ICE_UPWIND                 /* use for UPWIND advection scheme                          */

# define WEST_AICLAMPED             /* use if clamped boundary condition for ice conc.          */
# define WEST_HICLAMPED             /* use if clamped boundary condition for ice thickness      */
# define WEST_HSNCLAMPED            /* use if clamped boundary cond. for snow thickness         */
# define WEST_TICLAMPED             /* use if clamped boundary cond. for internal ice temp.     */
# define WEST_SFWATCLAMPED/          * use if clamped boundary cond. for surf. melt water       */
```

```
# define WEST_SIG11CLAMPED      /* use if clamped boundary cond. for int. ice stress 11      */
# define WEST_SIG22CLAMPED      /* use if clamped boundary cond. for int. ice stress 22      */
# define WEST_SIG12CLAMPED      /* use if clamped boundary cond. for int. ice stress 12      */
# define WEST_MIGRADIENT        /* use if gradient boundary condition for ice velocities     */

# define NORTH_AICLAMPED
# define NORTH_HICLAMPED
# define NORTH_HSNCLAMPED
# define NORTH_TICLAMPED
# define NORTH_SFWATCLAMPED
# define NORTH_SIG11CLAMPED
# define NORTH_SIG22CLAMPED
# define NORTH_SIG12CLAMPED
# define NORTH_MIGRADIENT

# define EAST_AICLAMPED
# define EAST_HICLAMPED
# define EAST_HSNCLAMPED
# define EAST_TICLAMPED
# define EAST_SFWATCLAMPED
# define EAST_SIG11CLAMPED
# define EAST_SIG22CLAMPED
# define EAST_SIG12CLAMPED
# define EAST_MIGRADIENT

# define SOUTH_AICLAMPED
# define SOUTH_HICLAMPED
# define SOUTH_HSNCLAMPED
# define SOUTH_TICLAMPED
# define SOUTH_SFWATCLAMPED
# define SOUTH_SIG11CLAMPED
# define SOUTH_SIG22CLAMPED
# define SOUTH_SIG12CLAMPED
# define SOUTH_MIGRADIENT
#endif
```

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