FFI-rapport 2008/02369

Operational METOC models at Norwegian Meteorological Institute (met.no)

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14.12.2008

FFI-rapport 2008/02369

1062

P: ISBN 978-82-464-1561-1
E: ISBN 978-82-464-1562-8

Keywords

meteorologiske modeller

oseanografiske modeller

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English summary

The numerical forecasting models run by the Norwegian Meteorological institute (met.no) are crucial in providing meteorological and oceanographic services to the Norwegian armed forces. In this report our goal is to demonstrate the large spectrum of forecasting parameters available to the Armed forces from these models.

The METOC projects at FFI has been the link between FFI and met.no since 2002. Working closely together with military representatives – in particular the METOC department at KNM Tordenskjold – FFI has been consulted about focus areas and priorities for present models and future developments at met.no.

Why should we do high cost model development in Norway when we have access to high-quality forecast products from our closest allies? Access to services from our allies does not render our national modeling capacity redundant:

- No other forecasting service has the same experience or self-interest in providing high quality forecasting services for Norwegian areas as the Norwegian Meteorological Institute (met.no).
- Met.no has proven that it is capable of implementing and providing services that are dedicated and tailor-made to the needs and requests of the Norwegian Armed forces – and do so at extremely short notice. It is hard to imagine that other national weather services will have the same degree of commitment to the Norwegian needs and wants.
- Met.no is now committed to develop capacity to rapid deploy numerical models for areas anywhere in the world. This capacity is an important part of the Norwegian commitments to the NATO alliance.
- Research and development are integral part of a modern forecasting service. Without ongoing research and development even the best service will soon be obsolete.
- No matter what the Military decides, Met.no will make intensively use of forecasting models to solve its commitment to the civilian community.

Limitations in computing power dictate that the model setup is a choice between resolution and areal coverage. Met.no uses a low resolution atmospheric model to cover the Atlantic Ocean, Europe and the Arctic and several high resolution models to “zoom in” on areas of interest, such as Scandinavia (4km resolution in models UM4, Hirlam4) and smaller regions with several 1 km resolution models (UM1). A similar setup is used for wave and ocean forecasting models.

Looking ahead, we would like to emphasize the ongoing implementation of data assimilation in oceanographic models and infrastructure for METOC data. This report provides a snapshot of available models per December 2008. This snapshot will soon be outdated on certain technical details. However, the overview of different model setup, different model types and the range of available parameters will maintain its merit. We would also like to emphasize that all models have strength and weaknesses, and these should be understood when applying the results.

Sammendrag

Numeriske varslingsmodeller er en svært viktig del av tjenestene til Meteorologisk institutt (met.no), som er Forsvarets leverandør av vær- og oseanografiske tjenester. I denne rapporten ønsker vi å vise frem det store spekter av varslingsparametre som er tilgjengelig for Forsvaret fra disse modellene. Dette danner grunnlaget for utvikling av nye tjenester til beste for Forsvaret.

METOC prosjektene ved FFI har siden 2002 vært bindeleddet mellom met.no og FFI. Sammen med forsvarets representanter – i første rekke METOC avdelingen ved KNM Tordenskjold – har FFI vært rådspurt om hvilke geografiske områder og egenskaper Meteorologisk institutt (met.no) skal prioritere i sitt arbeid med varslingsmodeller.

I blant møter vi spørsmålet om hvorfor det er riktig å prioritere kostbar modellutviking nasjonalt når vi samtidig har tilgang til gode varslingsprodukter fra våre allierte. Selvsagt skal vi benytte gode tilbud fra våre allierte, men det er likevel behov for en nasjonal kapasitet:

- Ingen andre nasjoner har samme erfaring med værvarsling for ”våre” områder som Meteorologisk institutt – eller har samme egeninteresse for å løse denne oppgaven.
- Andre nasjoners tjenester kan ikke gi samme servicegrad som meteorologisk institutt når det gjelder å utvikle nye tjenester spesialtilpasset Forsvarets behov og sette disse i drift på kort varsel.
- Meteorologisk institutt har forpliktet seg til å bygge opp kapasitet til å sette i drift modellkjøringer for hvor som helst i verden på kort varsel. Slik kapasitet er en viktig del av våre forpliktelser i internasjonale operasjoner.
- Forskning og utvikling er en integrert del av en moderne værvarslingstjeneste. Uten kontinuerlig FoU-innsats vil tjenestene raskt bli akterutseilt og utdaterte.
- Uavhengig av Forsvaret så vil Meteorologisk institutt løse sitt oppdrag for det sivile samfunn med intensiv bruk av varslingsmodeller.

Tilgjengelig regnekraft gjør at man i oppsettet for en modell må velge mellom detaljert oppløsning for et lite geografisk område eller større område, men grovere oppløsning. Dermed blir det naturlig å kjøre en grovmasket atmosfæremodell for å dekke Atlanterhavet, Europa og Arktis og finere modeller som dekker mindre områder, for eksempel Skandinavia med 4 km (Hirlam4, UM4) og luftrommet nær Værnes med 1 km oppløsning (UM1). Tilsvarende oppdeling har man i bølge- og havmodellene.

For det videre arbeidet vil vi spesielt trekke frem arbeidet med data assimilasjon i oseanografiske modeller og infrastruktur for METOC data. Videre fremover vil økt regnekraft og generell videreutvikling gjøre at modellene nevnt her erstattes av mer detaljerte og bedre modeller. Rapportens øyeblikksbilde per desember 2008 vil derfor relativt fort bli utdatert på en del tekniske detaljer. Rapporten har likevel relevans fordi den gir en oversikt over spennvidden i modelltyper og hvilke datatyper som tilbys. Vi vil også trekke frem at alle modeller har sine sterke og svake sider. For eksempel burde det være rett frem å lage varsling av sikt basert på fuktighetsvarsel fra modellene – men her er presisjonen ennå ikke god nok.

Contents

1 Introduction

Being the institution with the national responsibility to produce weather and ocean forecasts for the public and the Norwegian Armed Forces, met.no applies several numerical models which describe the atmospheric and oceanic circulation, including ocean waves. The models are run on high performance computers one to four times a day producing forecasts for the atmosphere and the ocean. The forecast models are coupled in the way that the atmospheric models provide parameters like winds and mean sea level pressure which act as forcing fields in the ocean and wave models. At present, there is no coupling back from the oceanic to the atmospheric models.

Regarding atmospheric or weather forecast models, the main types are the HIRLAM (http://www.hirlam.org) and UM (http://www.metoffice.gov.uk/research/nwp/numerical/unified_model) models. HIRLAM (HIgh Resolution Limited Area Model) is the model that has been developed trough more than 20 years of collaboration between Norway and some other European countries, while the UM (Unified Model) has been developed at the UK MetOffice in Great Britain. At met.no there is a continous further development of all the atmospheric models in a close cooperation between all the HIRLAM countries and in cooperation with UK MetOffice.

A special model system for the atmosphere is the NORLAMEPS system. This is an Ensemble prediction system used on a limited area. The basic idea is to introduce perturbations in the initial analyses within the observational accuracy. 20 different such analysis is then used as starting analyses for individual forecasts. The perturations are carefully chosen so that the spread in the resulting 20 forecasts gives a useful estimation of the uncertainty in the forecasts. The locally computed 20 forcasts is then combined with somewhat similar forecasts from ECMWF to produce the best uncertainty estimate.The end product of the system is probability distributions of the forecasted parameters.

Today's main model for operational ocean forecasting at met.no is the model MI-POM. This model is a version of the well-known Princeton Ocean Model (POM), which was developed in the late seventies and early eighties. An early version of POM called the ECOM3D was brought to Norway in 1988. Since then the model has undergone major and significant developments and enhancements (e.g. [1] and [2]). In addition, met.no also runs the TOPAZ ("Towards an Operational Prediction system for the North Atlantic and European coastal Zones") model system in fully operational mode. TOPAZ consist of a numerical ocean-sea ice model of the North Atlantic and Arctic oceans which utilizes an Ensemble Kalman Filter (EnKF) to assimilate ocean and ice observations into the model. TOPAZ has been developed at the Nansen Environmental and Remote Sensing Center (NERSC). Further information about TOPAZ may be found at http://topaz.nersc.no/.

During the last few months met.no has implemented and started operational testruns with the Regional Ocean Modeling System (ROMS). It is planned that ROMS will replace MI-POM as the main operational ocean forecast model. A description of ROMS is given at http://www.myroms.org.

For producing forecasts for ocean waves, the model WAM is applied e.g.[3]. It was developed by the WAM (WAve Modelling) group during the late eighties and early nineties, and has been used at met.no since 1992/1993. In addition to WAM, another wave model named SWAN (Simulating WAves Nearshore) is applied for the near shore or coastal areas. SWAN is developed at Delft University of Technology in the Netherlands, see http://www.fluidmechanics.tudelft.nl/swan/index.htm.

The main models (or model codes) are applied in several types of model set up, i.e., the same model is used to compute operational forecasts on different grids and areas, and with different types of forcing. One of the most frequently applied techniques is nesting, in which model results from rather coarse resolution numerical grids are applied at the open boundaries of a finer computational mesh. Regarding HIRLAM, three applications are used: HIRLAM12, HIRLAM8, and HIRLAM4. Here, the numbers refer to the approximate horizontal grid size in km. For UM eight applications are used: UM4 and 7xUM1. Again the numbers refer to the approximate horizontal grid size. UM1 is applied for seven Norwegian airports. The ocean wave model WAM is used in three applications: WAM.50km,WAM.10km and WAM4km, while for waves in coastal waters SWAN.500m is applied. Regarding the ocean model MI-POM, a total of twelve applications are currently used: Arctic-20km, Nordic-4km (with and without atmospheric forcing), NorthSea-20km, NorthSea-4km, NseaSkag-1.5km, Oslofjord-300m, Westcoast-200m, Trondheimsleia-500m, Barents-1.5km, BodoLoppa-500m, andSS_EPS-20km. For these models the names refer to the area covered by the model together with the approximate grid size. For instance, “Nordic-4km” means a model covering the Nordic Seas with a horizontal mesh size of approximately 4 km.

Details for all the present operational atmospheric-, ocean- and ocean wave model applications are listed in the following tables. Note that this list is indeed dynamical in that the types and numbers of operational models continually change. The attached figures show the exact coverage of the different model domains. The vertical resolution given in the tables is the resolution for the final model output. The models themselves apply several types of terrain or pressure following coordinates (e.g., sigma type or pressure surfaces) during computation. As an example, the output from the ocean models consists of horizontal fields interpolated from the internal model levels to specified depths in meters. For the atmospheric models the output is stored both in model levels and e.g., in pressure surfaces, the latter most often on request. The output from all models can be converted to the GRIB file format.

2 Atmospheric models

Atmospheric Model Products. Name: **HIRLAM12**	
Parameters	Wind, temperature, pressure, humidity, cloud liquid water, precipitation, long and short wave radiation. Other parameters on request.
Area coverage	Scandinavia and most of Europe, Svalbard, Greenland. North Sea, Norwegian Sea, Barents Sea and part of the North East Atlantic. Also see figure 1.1.
Spatial resolution	Approximately 12 km.
Vertical resolution	The model has 60 levels in the vertical. Surface data and data on specified pressure or height levels available on request.
Availability	4 runs a day available in suites 00, 06, 12, 18 UTC. Available approximately at 02:40, 08:30, 14:40 and 20:30 UTC
Time steps	1-hourly from T+0 to T+66

Table 2.1 Atmospheric model HIRLAM 12

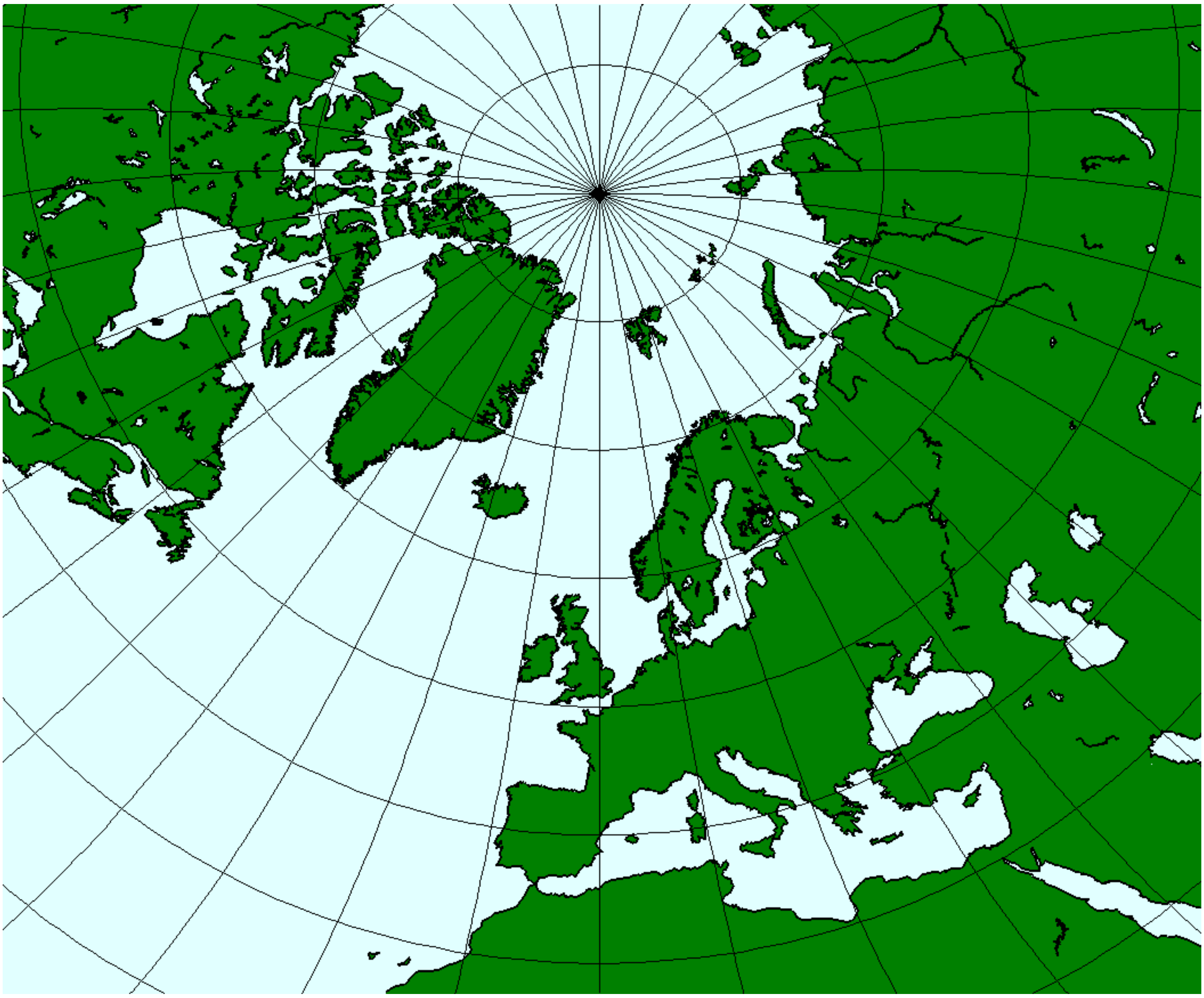

Figure 2.1   Model domain for HIRLAM12

Atmospheric Model Products. Name: **HIRLAM8**	
Parameters	Wind, temperature, pressure, humidity, cloud liquid water, precipitation, long and short wave radiation. Other parameters on request.
Area coverage	Scandinavia, Norwegian Sea, Barents Sea and part of the North East Atlantic. Also see figure 1.2.
Spatial resolution	Approximately 8 km.
Vertical resolution	The model has 60 levels in the vertical. Surface data and data on specified pressure or height levels available on request.
Availability	4 runs a day available in suites 00, 06, 12, 18 UTC. Available approximately at 03:10, 08:30, 15:20 and 20:30 UTC
Time steps	1-hourly from T+0 to T+66

Table 2.2 Atmospheric model HIRLAM 8

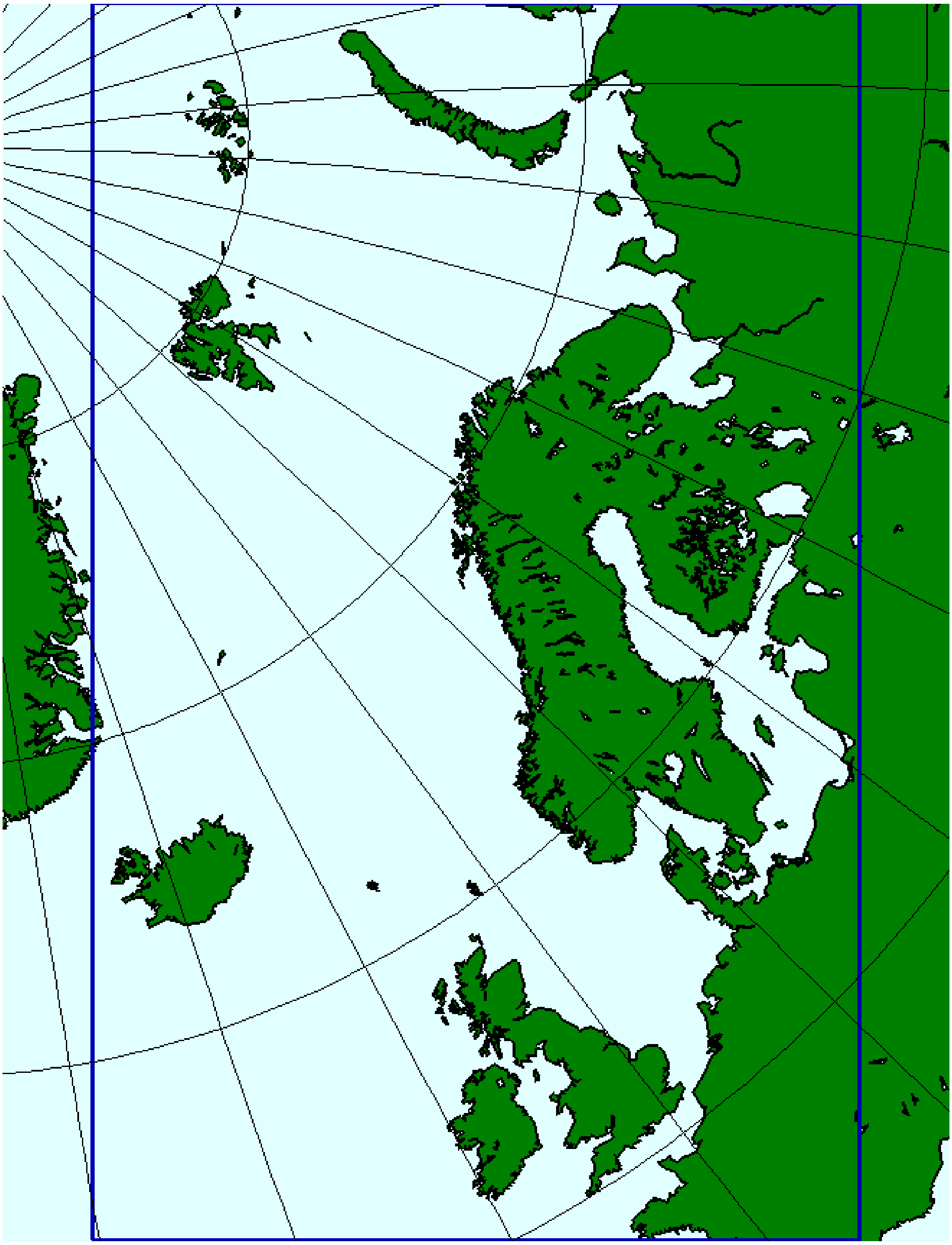

Figure 2.2 Model domain for HIRLAM8 (within blue frame). The same area is used as model domain in the NORLAMEPS system

Atmospheric Model Products. Name: **HIRLAM4**	
Parameters	Wind, temperature, pressure, humidity, cloud liquid water, precipitation, long and short wave radiation. Other parameters on request.
Area coverage	Scandinavia and some adjacent sea areas. Also see figure 1.3.
Spatial resolution	Approximately 4 km.
Vertical resolution	The model has 60 levels in the vertical. Surface data and data on specified pressure or height levels available on request.
Availability	2 runs a day available in suites 00 and 12 UTC. Available approximately at 03:00 and 15:00 UTC
Time steps	1-hourly from T+0 to T+48

Table 2.3 Atmospheric model HIRLAM4

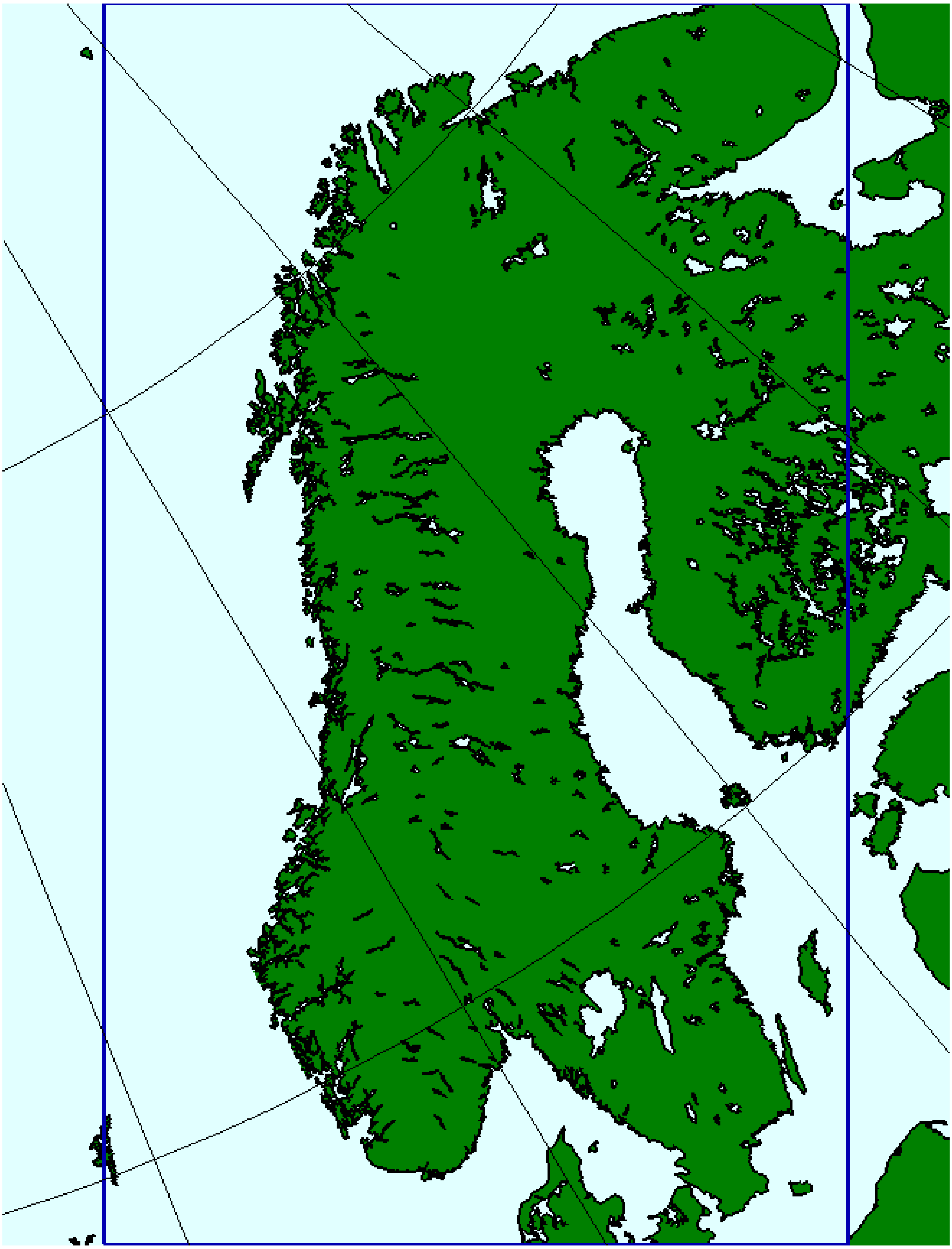

Figure 2.3 Model domain for HIRLAM4 and UM4 (within blue frame)

Atmospheric Model Products. Name: **UM4**	
Parameters	Wind, temperature, pressure, humidity, cloud liquid water, precipitation, long and short wave radiation. Other parameters on request.
Area coverage	Scandinavia and some adjacent sea areas. Also see figure 1.3 (same domain as HIRLAM4).
Spatial resolution	Approximately 4 km.
Vertical resolution	The model has 38 levels in the vertical. Surface data and data on specified pressure or height levels available on request.
Availability	2 runs a day available in suites 00 and 12 UTC. Available approximately at 03:00 and 15:00 UTC
Time steps	1-hourly from T+0 to T+60

Table 2.4 Atmospheric model UM4

Atmospheric Model Products. Name: **UM1** (including 7 separate models)	
Parameters	Wind, temperature, pressure, humidity, cloud liquid water, precipitation, long and short wave radiation. Other parameters on request.
Area coverage	7 models covering large cities and selected airports in Norway. Also see figure 1.4. At present testing of UM1 on two larger areas is ongoing. Those two areas covers most of Northern and Southern Norway respectively. The future choice of UM1 areas and set up is under consideration. The 7 model solution shown in the figure is presently the solution.
Spatial resolution	Approximately 1 km.
Vertical resolution	The model has 38 levels in the vertical. Surface data and data on specified pressure or height levels available on request.
Availability	2 runs a day available in suites 00 and 12 UTC. Available approximately at 03:30 and 15:30 UTC
Time steps	1-hourly from T+0 to T+48 for the cities. 1-hourly from T+6 to T+21 for the airports.

Table 2.5 Atmospheric model UM1

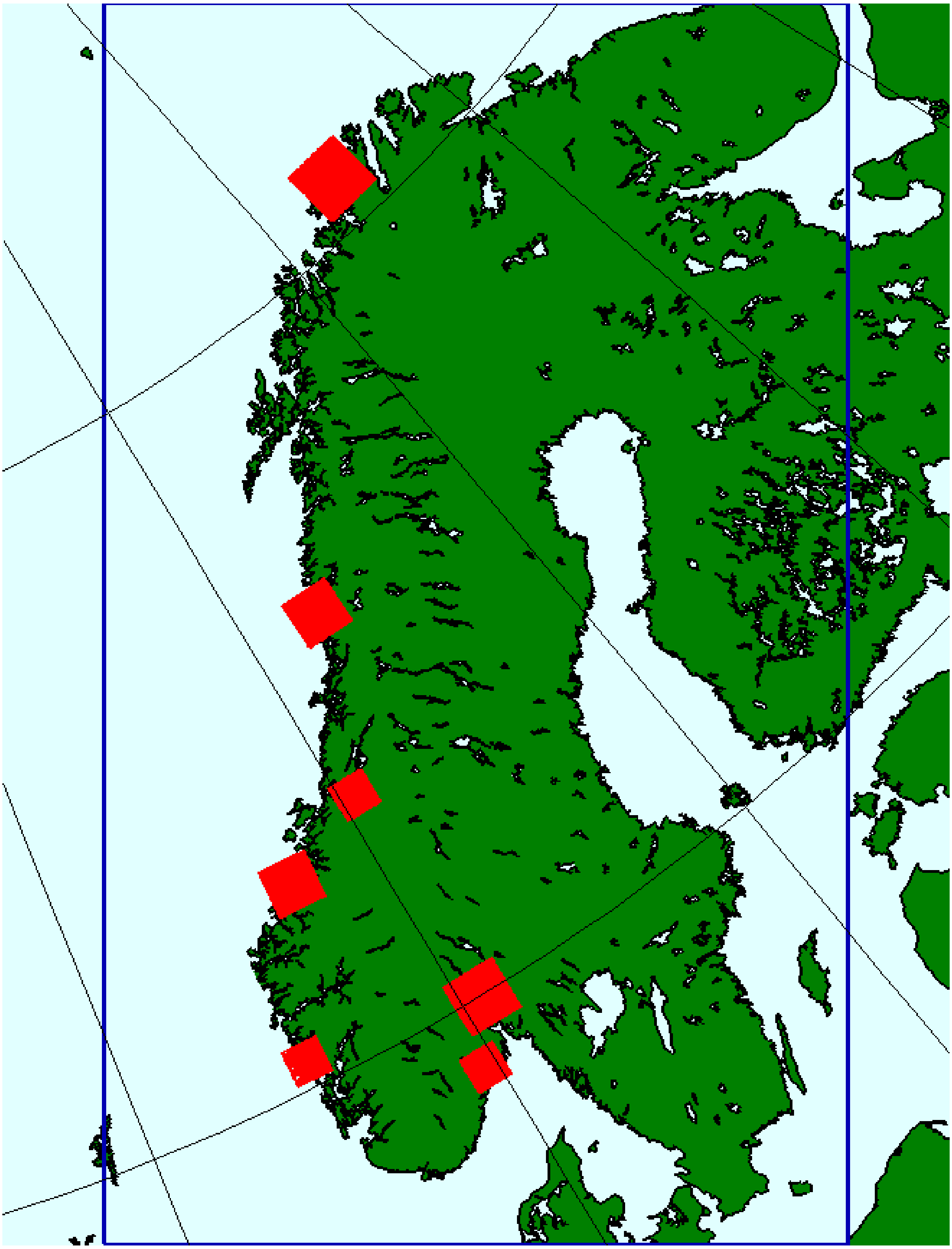

Figure 2.4   Model domains (in red) for the seven UM1 models

Atmospheric Model Products. Name: **NORLAMEPS**	
Parameters	Probality distributions of temperature, precipitation and wind. Probablity of excedence for specified threshold values are also computed together with selected indexes for e.g. wind chill, atmospheric icing and others. Other parameters on request.
Area coverage	Scandinavia, Norwegian Sea, Barents Sea and part of the North East Atlantic. Also see figure 1.2.
Spatial resolution	Approximately 12 km.
Vertical resolution	The model has 60 levels in the vertical. Surface data and data on specified pressure or height levels available on request.
Availability	2 runs a day available in suites 06 and 18 UTC. Available approximately at 09:40, 21:40 UTC
Time steps	1-hourly from T+0 to T+48

Table 2.6 Atmospheric model system NORLAMEPS

3 Ocean Models

Ocean wave Model Products. Name: **WAM.50km**	
Parameters	Total sea: significant wave height, mean period, peak period, peak direction. Wind sea: significant wave height, peak period, peak direction. Swell: significant wave height, peak period, peak direction.
Area coverage	North Sea, Norwegian Sea, Barents Sea, part of the North East Atlantic. Approximate coverage in degrees N, S, W, E: 90, 40, -55, 90.
Spatial resolution	Approximately 50 km.
Vertical resolution	Only sea surface fields.
Surface Forcing	Hirlam 12
Availability	4 runs a day available in 00, 06, 12, 18 UTC. Results available approximately at 03:00, 11:00, 15:00 and 23:00 UTC.
Time steps	1-hourly from T-17 to T+60

Table 3.7 Wave model WAM50

Ocean wave Model Products. Name: **WAM.10km** (nested in WAM.50km)	
Parameters	Total sea: significant wave height, mean period, peak period, peak direction. Wind sea: significant wave height, peak period, peak direction. Swell: significant wave height, peak period, peak direction.
Area coverage	North Sea, Norwegian Sea, Barents Sea. Approximate coverage in degrees N, S, W, E: 84, 54, -25, 65.
Spatial resolution	Approximately 10 km.
Vertical resolution	Only sea surface fields.
Surface forcing	HIRLAM8
Availability	2 runs a day available in 00 and 12 UTC. Results available approximately at 03:00 and 15:00 UTC.
Time steps	1-hourly from T-11 to T+60

Table 3.8 Wave model WAM10

Ocean wave Model Products. Name: **WAM.10km EPS** (nested in WAM.50km)	
Parameters	Total sea: significant wave height, mean period, peak period, peak direction. Wind sea: significant wave height, peak period, peak direction. Swell: significant wave height, peak period, peak direction. Ensemble Forecast, output probability.
Area coverage	North Sea, Norwegian Sea, Barents Sea. Approximate coverage in degrees N, S, W, E: 84, 54, -25, 65. (same as WAM.10km)
Spatial resolution	Approximately 10 km.
Vertical resolution	Only sea surface fields.
Surface forcing	LAMEPS12
Availability	1 run a day available in 18 UTC. Results available approximately at 22:30 UTC.
Time steps	3-hourly from T+3 to T+60

Table 3.9 Wave model WAM10km EPS

Ocean wave Model Products. Name: **WAM.4km** (nested in WAM.10km)	
Parameters	<u>Total sea:</u> significant wave height, mean period, peak period, peak direction. <u>Wind sea:</u> significant wave height, peak period, peak direction. <u>Swell:</u> significant wave height, peak period, peak direction.
Area coverage	“Scandinavian waters”. Approximate coverage in degrees N, S, W, E: 70.00, 57.00, 2.00, 35.00 (same grid as HIRLAM4)
Spatial resolution	Approximately 4 km.
Vertical resolution	Only sea surface fields.
Surface forcing	HIRLAM4
Availability	2 runs a day available in 00 and 12 UTC. Results available approximately at 03:00 and 15:00 UTC.
Time steps	1-hourly from T+5 to T+60

Table 3.10 Wave Model Wam4km

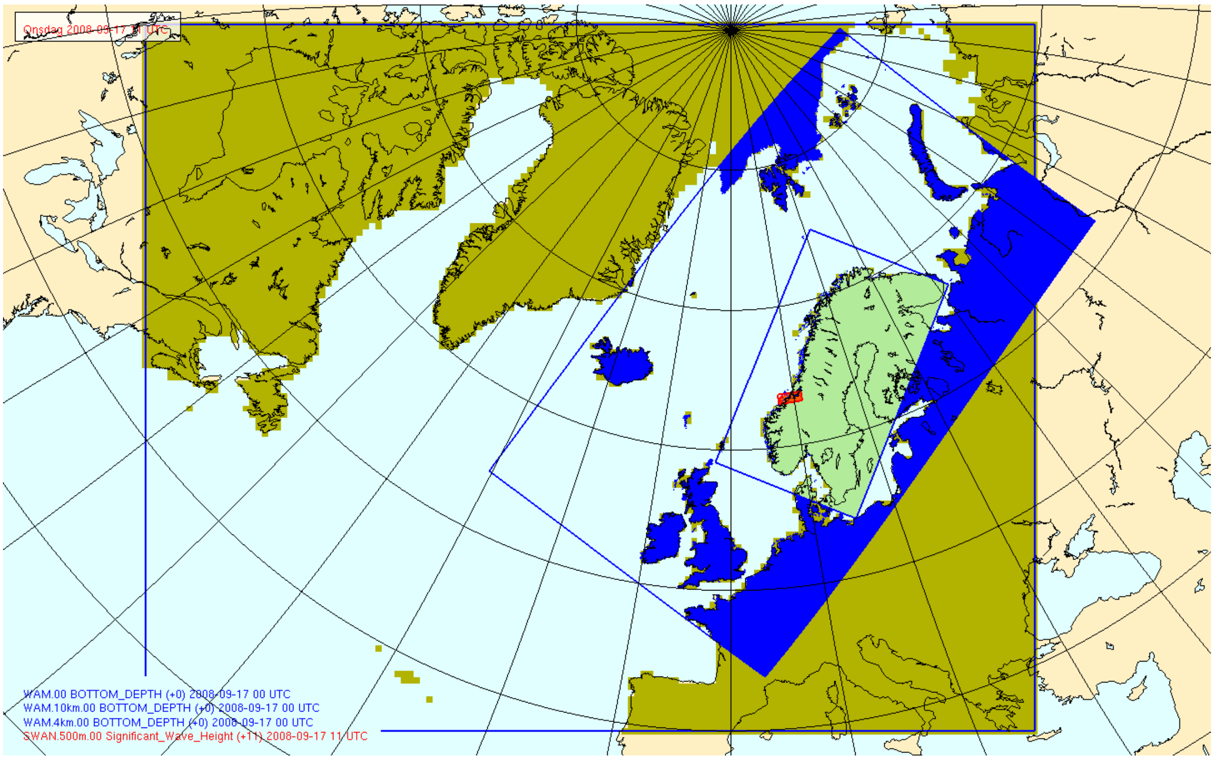

Figure 3.1 Model domains: WAM.50km (green), WAM.10km (blue), WAM.4km (light green), SWAN.500m (red)

Ocean wave Model Products. Name: **SWAN.500m** (nested in WAM.10km)	
Parameters	<u>Total sea:</u> significant wave height, peak period, peak direction.
Area coverage	Norwegian Northwest coast (Møre-Trondheimsfjord). Approximate coverage in degrees N, S, W, E: 63.50, 63.00, 7.50, 11.25.
Spatial resolution	Approximately 500 m.
Vertical resolution	Only sea surface fields.
Surface forcing	UM4 (alternatively HIRLAM4)
Availability	2 runs a day available in 00 and 12 UTC. Results available approximately at 06:00 and 16:00 UTC.
Time steps	1-hourly from T+9 to T+36

Table 3.11 Wave model SWAN500

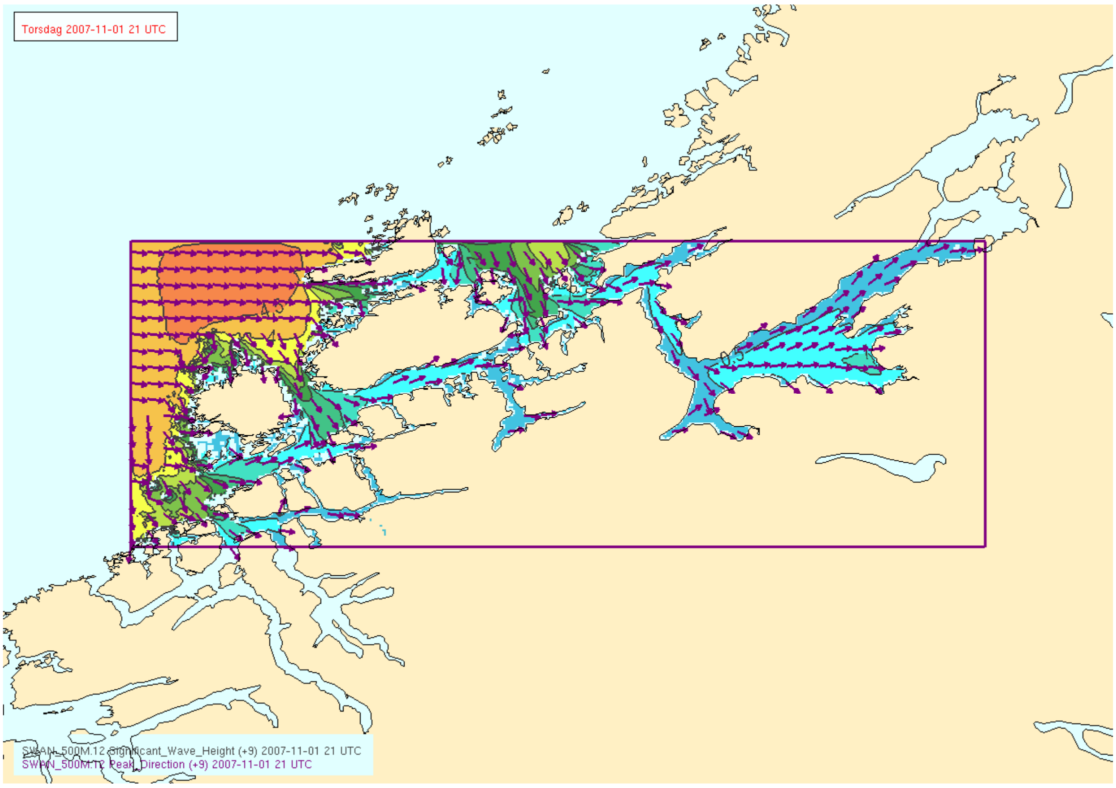

Figure 3.2 Model domain for SWAN.500m, figure shows modeled Significant wave height and peak direction (arrows)

Ocean Model Products. Name: **Stormsurge-20km EPS**	
Parameters	Probability of different levels of sea surface elevation and depth integrated currents. Other parameters possible on request.
Area coverage	North Sea, Norwegian Sea, Barents Sea. Approximate coverage in degrees N, S, W, E: 80, 50, -15, 60.
Spatial resolution	Approximately 20 km.
Vertical resolution	Only sea surface or depth integrated fields.
Surface forcing	LAMEPS12
Availability	1 run with 20 ensemble members once a day available in 00 UTC. Results available approximately at 03:30 UTC.
Time steps	3-hourly from T+0 to T+60

Table 3.12 Stormsurge mode Stormsurge-20

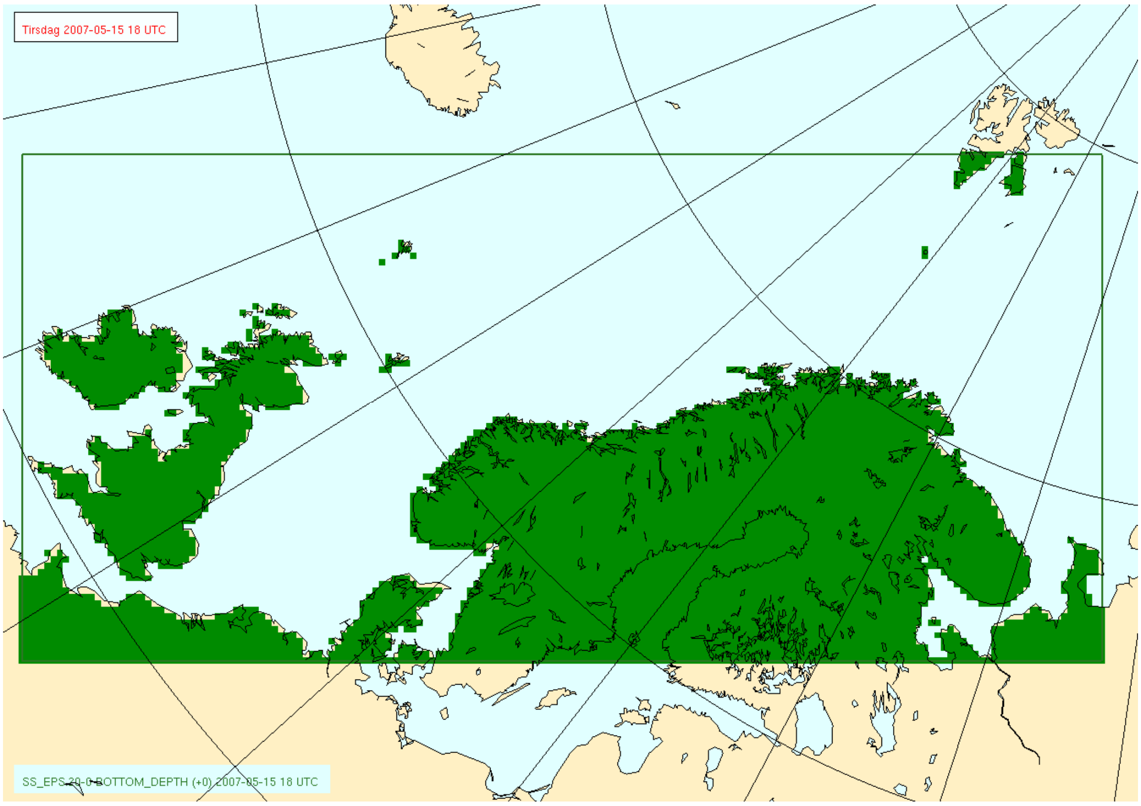

Figure 3.3 Model domain for Stormsurge-20km EPS (green)

Ocean Model Products. Name: **Arctic-20km**	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature, Ice concentration, Ice thickness, Ice velocities. Other parameters possible on request.
Area coverage	Arctic Ocean, Norwegian Sea, Barents Sea, North Sea. Approximate coverage in degrees: Circumpolar north of 50N in the Atlantic.
Spatial resolution	Approximately 20 km.
Vertical resolution	Depths: 0, 3, 10, 25, 50, 75, 100, 500, 1000 m
Surface forcing	ECMWF 0.25 degree (MSLP, winds, cloud cover, T2m, Td2m, total precip.) Analysed SST from OSISAF + ECMWF
Availability	1 run a day available in 00 UTC. Results available approximately at 03:00 UTC.
Time steps	6-hourly from T-30 to T+168

Table 3.13 Ocean model Artic20

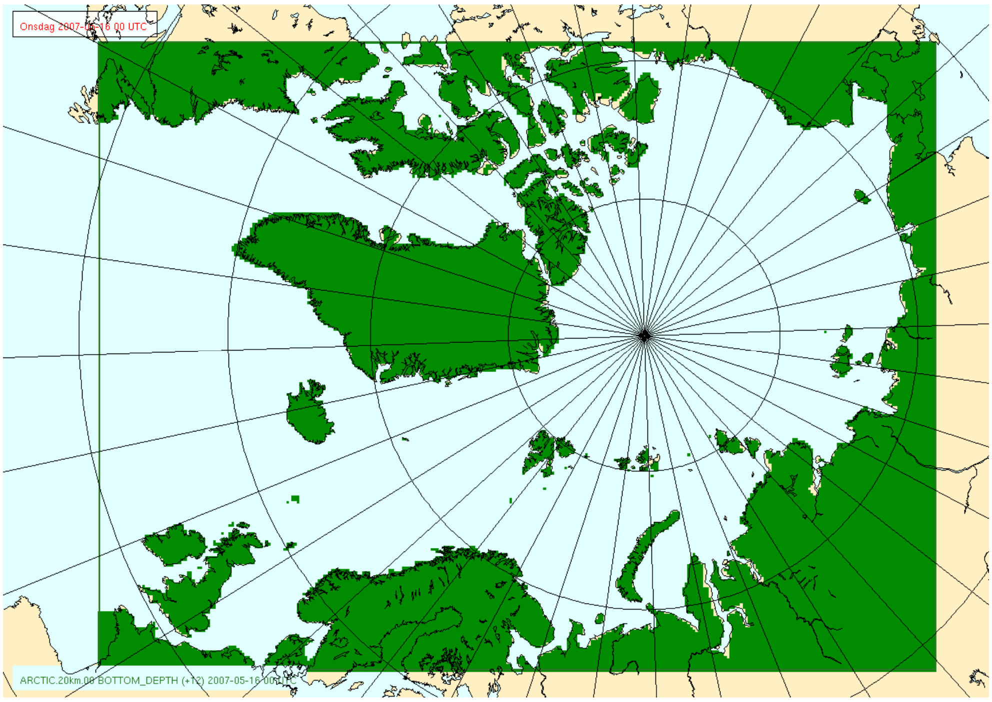

Figure 3.4 Model domain for Arctic-20km (green)

Ocean Model Products. Name: **Nordic-4km/ Nordic-4km_noatm** (nested in climatology)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature. Other parameters possible on request.
Area coverage	Norwegian Sea, Barents Sea, North Sea. Approximate coverage in degrees N, S, W, E: 85, 50, -25, 60.
Spatial resolution	Approximately 4 km.
Vertical resolution	Depths: 0m. Other depths available on request for horizontal subsection of the total domain.
Surface forcing	HIRLAM12 / no atmospheric forcing
Availability	2 runs a day available in 00 and 12 UTC. Results available approximately at 03:00 and 15:00 UTC.
Time steps	1-hourly from T-18 to T+60. 2-hourly for other depths than 0m.

Table 3.4 Ocean model Nordic4

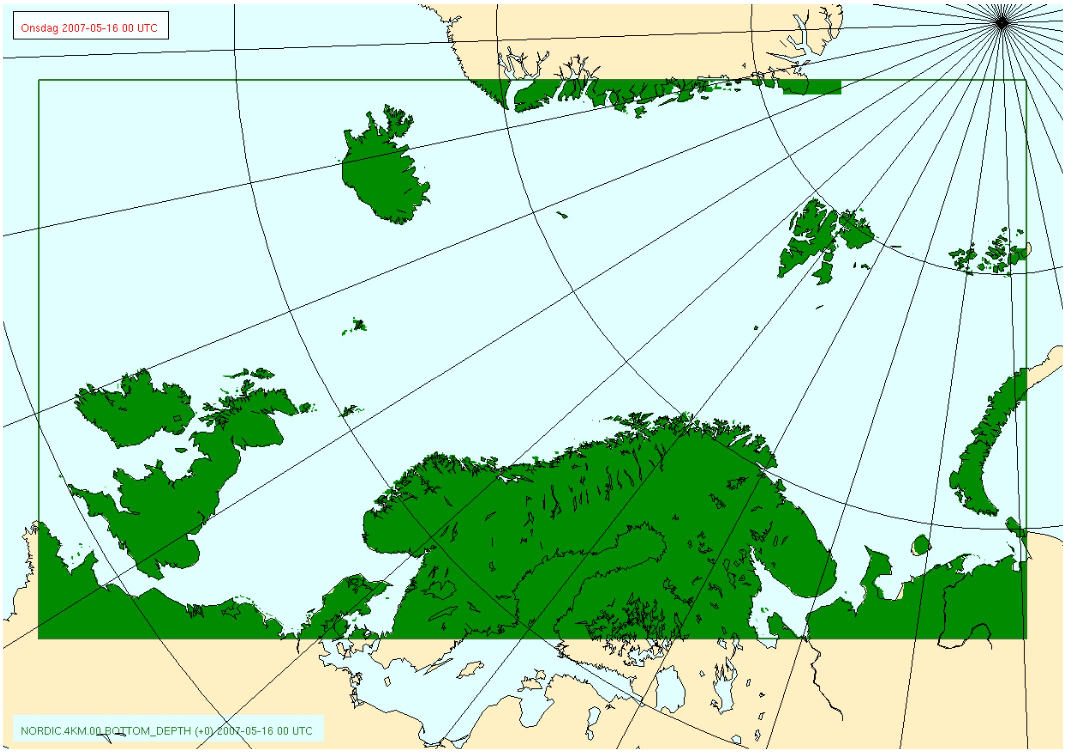

Figure 3.5 Model domain for Nordic-4km (green)

Ocean Model Products. Name: **NorthSea-20km** (nested in UK-ORCA ¼ 1/9 degree model)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature, Nitrogen, Phosphate, Silicate, Detritus, Diatome, Flagellate, Oxygen. Other parameters possible on request.
Area coverage	North Sea. Approximate coverage in degrees N, S, W, E: 65, 50, -10, 15.
Spatial resolution	Approximately 20 km.
Vertical resolution	Depths: 0, 5, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 600 m
Surface forcing	ECMWF 0.25 degree (MSLP, winds, cloud cover, T2m, Td2m, total precip.) Analysed SST from OSISAF + ECMWF
Availability	1 run a day available in 06 UTC. Results available approximately at 11:00 UTC.
Time steps	6-hourly from T-30 to T+240.

Table 3.5 Ocean model NorthSea20

Ocean Model Products. Name: **NorthSea-4km** (nested in NorthSea-20km)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature, Nitrogen, Phosphate, Silicate, Detritus, Diatome, Flagellate, Oxygene. Other parameters possible on request.
Area coverage	Northeast part of North Sea. Approximate coverage in degrees N, S, W, E: 64, 54, -5, 15.
Spatial resolution	Approximately 4 km.
Vertical resolution	Depths: 0, 5, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 600 m
Surface forcing	ECMWF 0.25 degree (MSLP, winds, cloud cover, T2m, Td2m, total precip.) Analysed SST from OSISAF + ECMWF
Availability	1 run a day available in 06 UTC. Results available approximately at 11:00 UTC.
Time steps	6-hourly from T-30 to T+240.

Table 3.6 Ocean Model NorthSea4

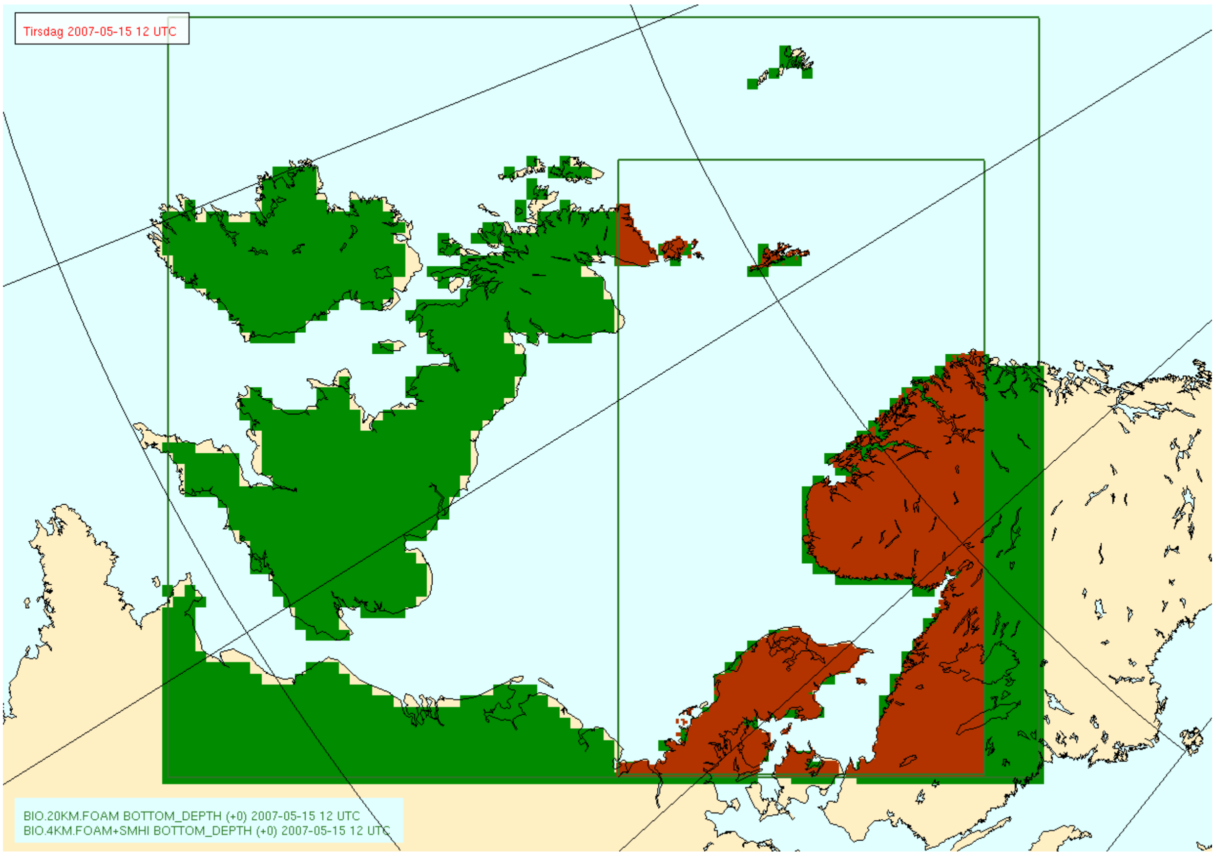

Figure 3.6 Model domains for NorthSea-20km (green) and NorthSea-4km (dark red)

Ocean Model Products. Name: **NseaSkag-1.5km** (nested in Nordic-4km)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature. Other parameters possible on request.
Area coverage	Northeast part of North Sea including Skagerrak. Approximate coverage in degrees N, S, W, E: 64, 54, -5, 15.
Spatial resolution	Approximately 1.5 km.
Vertical resolution	Depths: 0, 3, 10, 30, 50, 75, 100, 150, 200, 300, 400, 500 m.
Surface forcing	HIRLAM12
Availability	1 run a day available in 00 UTC. Results available approximately at 03:30 UTC.
Time steps	6-hourly from T-18 to T+60.

Table 3.7 Ocean model NorthSea1.5

Ocean Model Products. Name: **Oslofjord-300m** (nested in NseaSkag-1.5km)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature. Other parameters possible on request.
Area coverage	The Oslofjord. Approximate coverage in degrees N, S, W, E: 60.00, 58.50, 10.00, 11.00.
Spatial resolution	Approximately 300 m.
Vertical resolution	Depths: 0, 3, 10 m. Also 20 and 30 m available for currents.
Surface forcing	HIRLAM12.
Availability	1 run a day available in 00 UTC. Results available approximately at 03:45 UTC.
Time steps	1-hourly from T-18 to T+60.

Table 3.8 Ocean Model Oslofjord300m

Ocean Model Products. Name: **Westcoast-200m** (nested in NseaSkag-1.5km)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature, Density. Other parameters possible on request.
Area coverage	The Norwegian west coast outside and around Bergen. Approximate coverage in degrees N, S, W, E: 61.00, 59.50, 4.00, 5.75.
Spatial resolution	Approximately 200 m.
Vertical resolution	Depths: 0, 3, 10, 30, 50, 75, 100, 150, 200, 300 m.
Surface forcing	HIRLAM12.
Availability	1 run a day available in 00 UTC. Results available approximately at 04:00 UTC.
Time steps	6-hourly from T+6 to T+36.

Table 3.19   Ocean model WestCoast200m

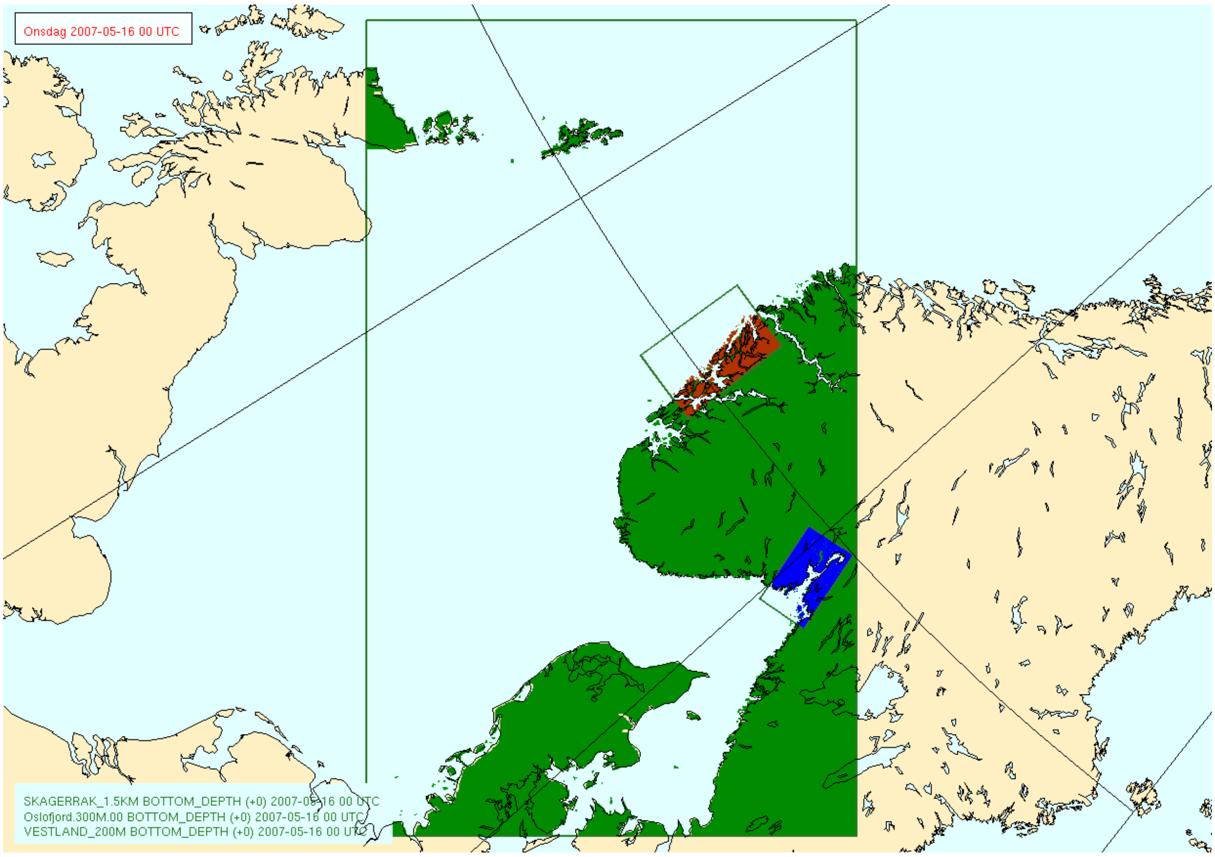

Figure 3.7   Model domains for NseaSkag-1.5km (green), Oslofjord-300m (blue), Westcoast-200m (dark red)

OCEAN Model Products. Name: **Trondheimsleia-500m** (nested in Nordic-4km)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature. Other parameters possible on request.
Area coverage	Norwegian Northwest coast (Møre-Trondheimsfjord). Approximate coverage in degrees N, S, W, E: 63.50, 63.00, 7.50, 11.25. (same domain as wave model SWAN.500m)
Spatial resolution	Approximately 500 m.
Vertical resolutions	Depths: 0, 1, 2, 5, 10, 15, 30, 50, 75 and 100 m.
Surface forcing	UM4 / HIRLAM4
Availability	1 run each day available in 00 UTC. Results available approximately at 03:30 UTC.
Time steps	1-hourly from T-18 to T+60.

Table 3.20 Ocean model Trondheimsleia500m

OCEAN Model Products. Name: **Barents-1.5km** (nested in Nordic-4km)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature, Ice concentration, Ice thickness, Ice velocities. Other parameters possible on request.
Area coverage	Barents Sea and part of Arctic Ocean and Norw. Sea. Approximate coverage in degrees N, S, W, E: 85.00, 65.00, 5.00, 60.00.
Spatial resolution	Approximately 1.5 km.
Vertical resolution	Depths:
Surface forcing	ECMWF 0.25 degree (MSLP, winds, cloud cover, T2m, Td2m, total precip.)
Availability	1 run once a day available in 00 UTC. Results available approximately at 03:45 UTC.
Time steps	6-hourly from T-6 to T+72.

Table 3.21 Ocean model Barents1.5km

OCEAN Model Products. Name: **BodoLoppa-500m** (nested in Barents-1.5km)	
Parameters	Sea surface elevation, Currents, Salinity, (Potential) Temperature. Other parameters possible on request.
Area coverage	Norwegian coastal areas from Bodø to Lopphavet. Approximate coverage in degrees N, S, W, E: 70.00, 67.00, 12.00, 23.00.
Spatial resolution	Approximately 500 m.
Vertical resolution	Depths: 0, 3, 10, 30, 50, 75, 100, 150, 200, 300 m.
Surface forcing	HIRLAM12
Availability	1 run each day available in 00 UTC. Results available approximately at 04:00 UTC.
Time steps for results	6-hourly from T-18 to T+60.

Table 3.22   Ocean model BodøLoppa500m

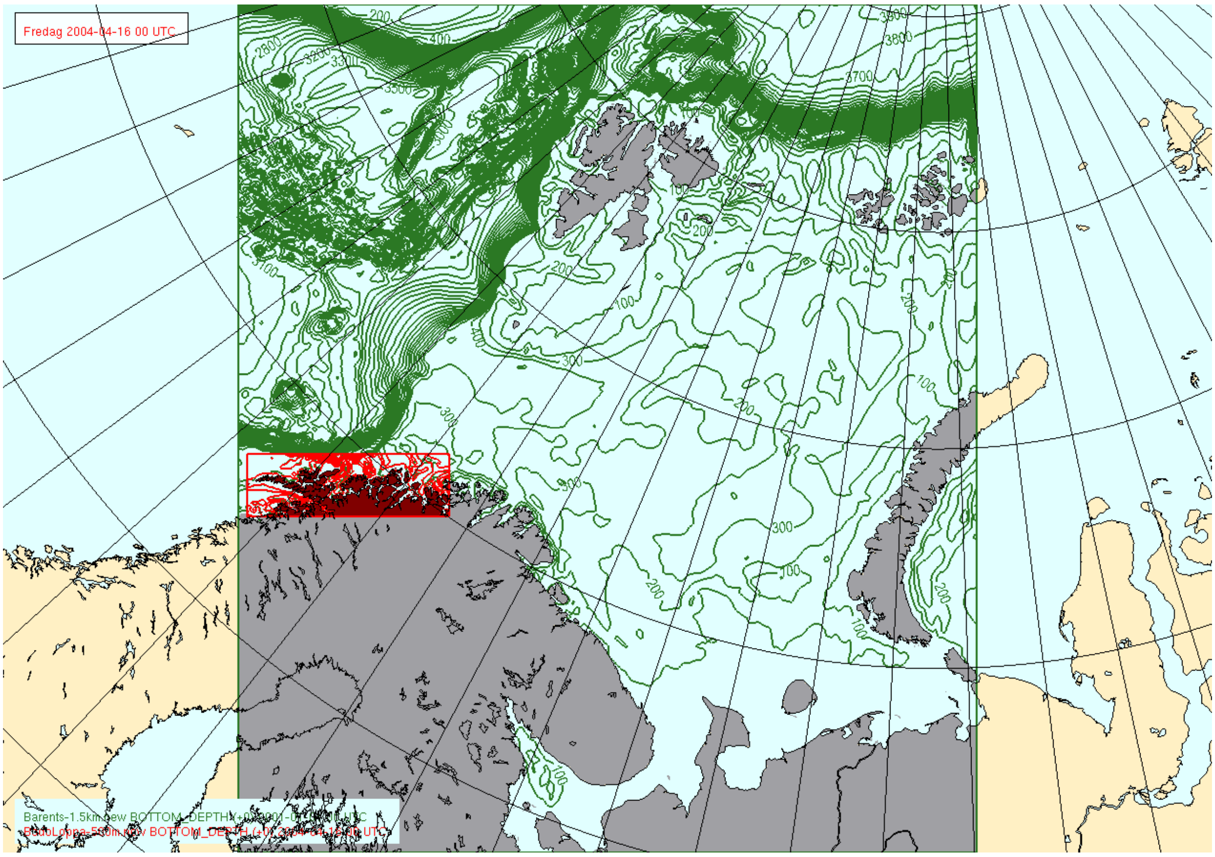

Figure 3.12 Model domains for Barents-1.5km (green/grey) and BodoLoppa-500m (red/dark red)

OCEAN Model Products. Name: **TOPAZ3**	
Parameters	Currents, Salinity, Temperature, Ice concentration, Ice thickness, Ice velocities. Other parameters possible on request.
Area coverage	The Arctic, and Atlantic, including the Gulf of Mexico and the Mediterranean Sea. Approximate coverage in degrees N, S, W, E: Circ., -10.00, -100.00, 35.00.
Spatial resolution	18-35 km (finest in the North)
Vertical resolutions	Interpolated on request from 5 m down to 3000 m
Surface forcing	ECMWF 0.25 degree (MSLP, winds, cloud cover, T2m, etc.) Analysed SST.
Availability	The system is run once a weak from Tuesday evening to Thursday morning. Results available approximately at 03:40 UTC on Thursday.
Time steps for results	Daily mean fields to T+240 hrs

Table 3.23 Ocean model TOPAZ

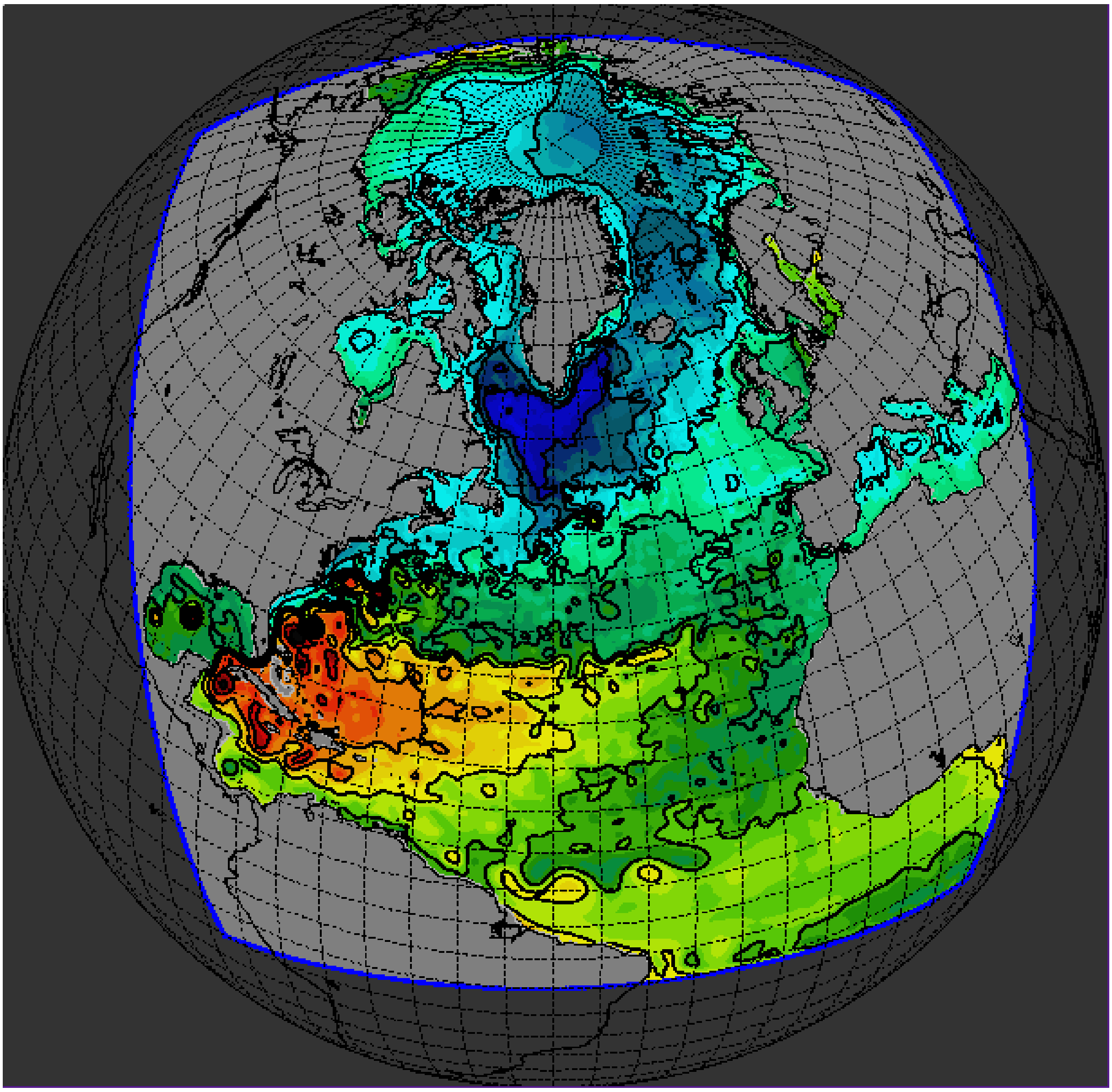

Figure 3.13 Model domain for the TOPAZ3 ocean model system

3.1 Assimilation in Ocean models

The operational ocean forecast system at the Norwegian Meteorological Institute currently uses a simple data assimilation scheme called nudging. An attempt to implement a more sophisticated data assimilation scheme was conducted in 2008 for the model system MI-POM [4]. Experiments with this new model were overall positive in the sense that the assimilation scheme improved the model performance, and for a so called local version it did so to a greater extent than the nudging assimilation scheme. However, the SEIK assimilation implementation also tended to perturb some of the model fields. The new ocean model ROMS has built in assimilation schemas (nudging, optimal interpolation, 3DVAR). The first test with ROMS and data assimilation will be performed for the area currently covered by the Ocean Model Nordic-4km (Table 3.1). In addition, the TOPAZ modell system utilizes EnKF for assimilation of observed data.

4 Infrastructure

The infrastructure for delivering meteorological and oceanographic services to Norwegian forces are web based systems. Presently, the two most important systems are:

- The web service *Kilden* is a simple to use, but fairly sophisticated web GUI that gives the user manual access to a large suite of services and products.

- The *METOC WEB/WMS server* provides overlays that client applications may put on top of their own map GUI, using the *Web Map Services (WMS)* protocol [5] to handle the details of map projection, coordinates and the like. In addition, this service provides sophisticated data distribution through a simple, but non-standard http-based programming interface [6]. This serves as a prototype for the more sophisticated services and protocols discussed in section 5. The server also provides a simple map-based web GUI for manual browsing and data distribution.

The services *Kilden* and *METOC WEB/WMS* are described in more detail in [7] ,[8] and [9]. The *Kilden* and *METOC WEB/WMS* services are partially duplicated on Norwegian classified military network as described in the next section.

We would like to emphasize that the Norwegian Meteorological Institute try to respond as fast as possible to new user requirements. In particular, the institute tries to respond quickly when Norwegian forces are deployed abroad. An example of this is given in section 4.2, where a dedicated service was established to deliver products for naval vessels deployed in the eastern Mediterranean.

Both within the NATO framework and in the civilian World Meteorological Organization (WMO) there is mutual international exchange of a vast amount of meteorological and oceanographic data. The Norwegian Meteorological Institute is therefore able to provide products, services and data from other nations in addition to the national products.

4.1 Services at the classified military network

The services above are duplicated at the national classified network at the classification NATO SECRET (HEMMELIG). Data are transferred automatically from unclassified to classified through a security approved one-way data transfer mechanism, labeled a “diode”

The duplication of services at classified network is only partial. There is some loss in functionality at the *Kilden* service. Due to bandwidth and other practical limitations only a portion of the model data available are transferred to the classified network. Some infrequent used and more exotic services and data types are not duplicated. This infrastructure is described in more detail in [7].

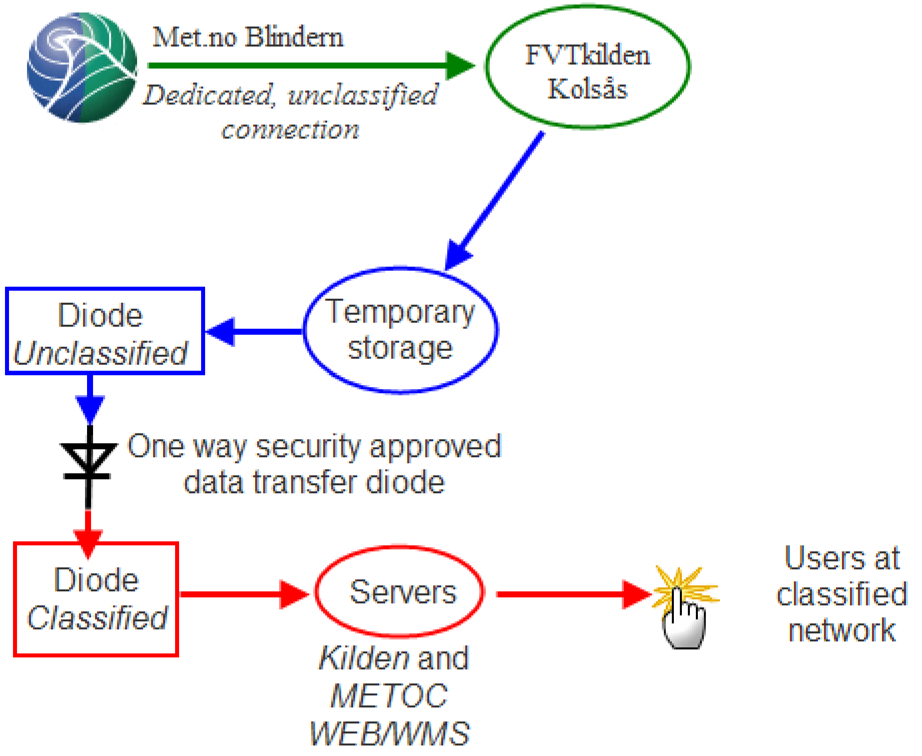

Figure 4.14 Data flow of METOC-information from Meteorogical Institute (met.no) to the classified network through security approved data transfer diode. The services Kilden *and* METOC WEB/WMS *are duplicated on the classified network. Data updates are continuously being made available at the server* FVTKILDEN *by met.no. After the automatic data transfer, updated data are available at the classified network with just a minor delay. This delay depends on file size and the number of files being transferred, and is on the order of seconds to a couple of minutes*

4.2 An example of quick deployment: Forecast for Lebanese waters

In the autumn 2006 the Norwegian Armed Forces deployed four missile torpedo boats and a support ship to patrol the Lebanese waters. Although not a NATO operation, the infrastructure for delivering METOC data to the Norwegian Armed Forces on a secure network was re-established and tested during the start of this mission. FFI in cooperation with the Norwegian Meteorological Institute, the METOC department within the Royal Norwegian Navy and the Norwegian Defence Logistics Organisation (NDLO) introduced a website on the secret network, named the Lebanon source (Figure 4., Figure 4.), which provided relevant METOC information to the forces. The METOC data on this website was fed with fresh METOC data from the Norwegian Meteorological Institute automatically by use of the one-way diode,

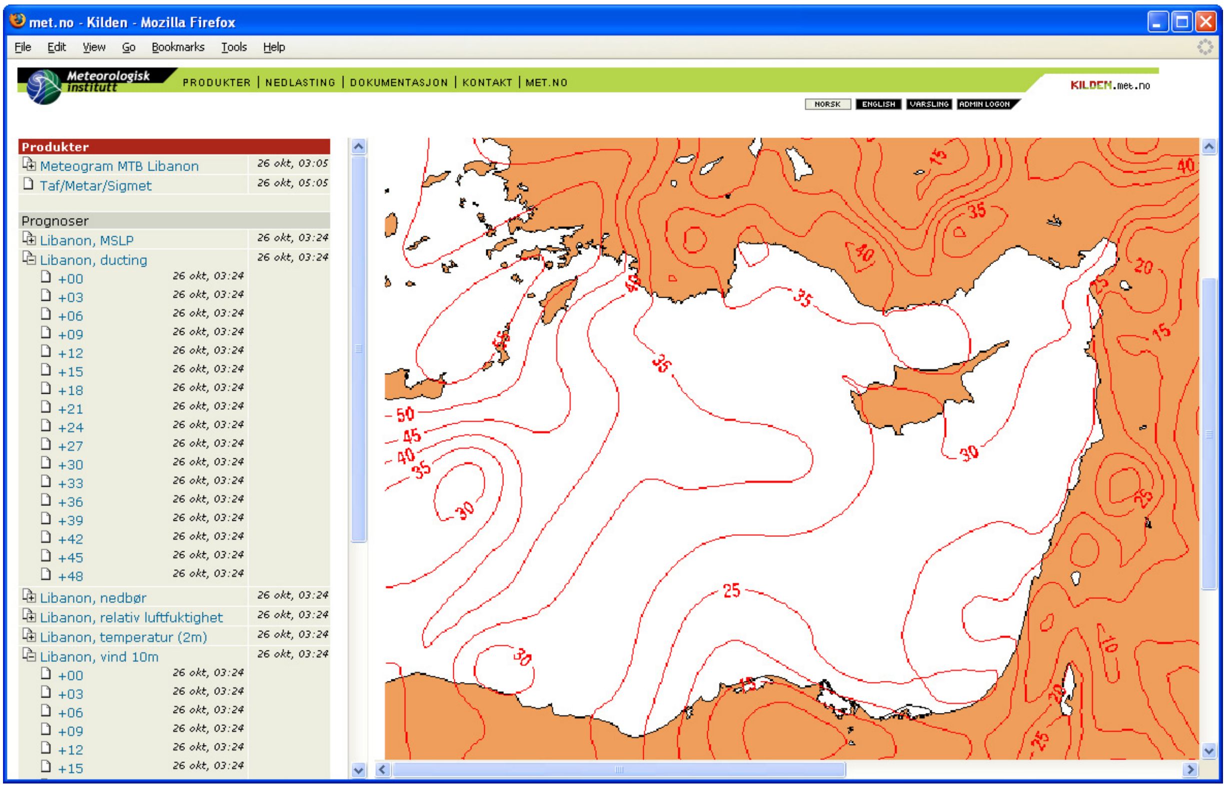

Figure 4.15 The Lebanon source website showing the forecasted ducting conditions in the western part of the Mediterranean

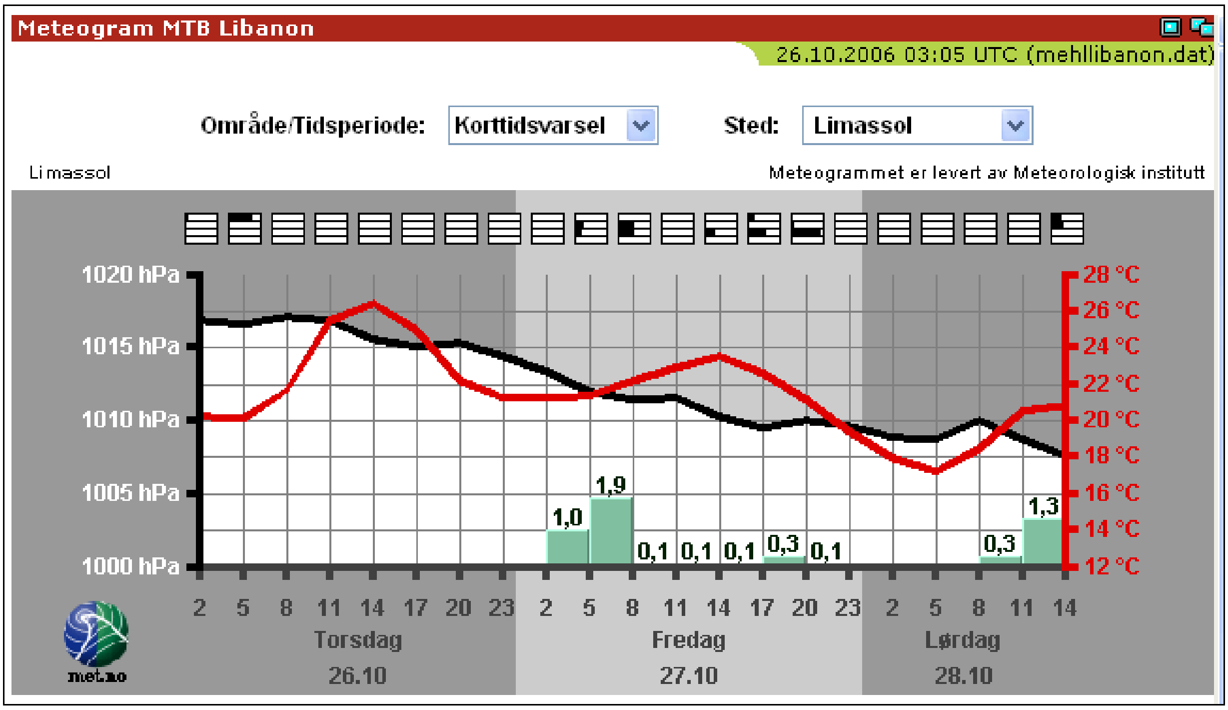

Figure 4.16 Meteogram from the UN base in Limassol on Cypros

5 Future development of infrastructure

For several years, there has been an ever increasing demand for seamless integration of services that are independent of platform and vendor peculiarities. A suite of protocols and standards have emerged to meet this demand. These protocols use simple http requests as building blocks for complex system interaction. The simplest of these is the *WMS (Web Mapping Services)* protocol. Today, we see the development of catalog based services where *WMS* and its more complex siblings – such as *WFS (Web Feature Services*) and *WCS (Web Coverage Services)* run in parallel under the framework of Catalogue Services, providing a large suite of services to a wide range of applications. Description and definition of these standards may be found at the Open Geospatial Consortium (OGC) web server [5].

The future information infrastructure of NATO is still being forged. An important aspect is that NATO requires seamless integration of data and services while at the same time adhering to security restrictions. New infrastructure concepts are emerging and are being revised, refined and put into plans and investments. At present, the outcome of this process is not clear. In our opinion, there is one thing that seems certain: That the free, open standards of Geospatial Consortium [5], such as WMS, WFS, WCS and catalogue based services will be an integral part of the future infrastructure.

Some of the more sophisticated protocols are still under vivid development, with frequent revisions and new services and requirement. Others protocols are stable, but the development of clients and servers is a complex process, and requires time and effort to reach a mature stage.

As a logical consequence, Norwegian Defense Research Establishment (FFI) has research and development activities into these standards. Specifically, we have chosen to develop a prototype for distribution and visualization of meteorological and oceanographical data based on the open source *Mapserver.* This platform was chosen because important partners – in particular the Norwegian Military Geographical Service and Norge Digital (digital Norway [10]) – have chosen this platform in their implementation. In our view, it is not necessarily the prototype itself that is the most valuable outcome of FFI's work. Much more important are the lessons learned that will be transformed into user requirements and technical specifications.

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