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Model validation: Issues regarding comparisons of point measurements and high-resolution modeling results

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ABSTRACT

In this study we compare a high resolution model of waters on the Norwegian Shelf with hydrographic observations obtained during 2009 at Ingøy, a fixed coastal station off northwestern Norway operated by the Institute of Marine Research. The observations comprise snapshots from Ingøy every two weeks, whereas the model represents an average over a certain volume and is continuous in time. We suggest that bias is the best way to compare the modeled and observed times series, while acknowledging the short-term variability (within a day) it is recommended to use the modeled range to estimate an acceptable deviation between single points in the series. Using the suggested method we conclude that an acceptable deviation between the modeled and observed surface temperatures at Ingøy is 0.6 °C. With such an acceptance level the model is correct in 27 out of 33 points for the time series considered.

1. Introduction

Proper model validation Dee (1995) is a necessity before hydrodynamic models can be used for real applications. Models can be confirmed by agreement between observation and prediction, but confirmation is inherently partial Oreskes et al. (1994). Thus model validation should be performed using adequate observations relevant for the purpose of the model simulations in question. All hydrodynamic models in operation have been through model validation to some extent, but no common validation metrics for ocean models presently exist. Without such a set of objective criteria (or benchmarks) to rate the quality of a model, or to evaluate a model when improvements are made, it is difficult to conclude if one model is better than another, even if this has been the main objective of several projects (e.g. Delhez et al., 2004; Proshutinsky et al., 2011) .

While oceanographic observations are accurate but sparse in space and/or time, hydrodynamic models are relatively continuous but with unknown error terms. In addition to the errors coming from the numeric and the finite spatial precision, the model inaccuracy will depend on limitations in available forcing (atmospheric, freshwater, tidal as well as bathymetric resolution). Another common problem with oceanographic models is their spatial error, i.e. the incorrect placement and shape of ocean features, rendering traditional error metrics such as root-mean-square and cross-correlation inadequate as they can lead to large errors, even if the model is accurate except for a small shift in space or time. Such problems are also common in meteorological forecast verification where spatial error metrics are a popular topic, but application of these to oceanographic models has so far been generally lacking Ziegler et al. (2012).

The main objectives of oceanographic monitoring programs have traditionally been to understand and describe the state of the ocean environment and its variability, while there has only been a minor focus on designing observations to validate oceanographic models. Therefore the large efforts spent on *in situ* point measurements, repeated transects and regional coverage, are often of limited use for ocean model validation. One reason for this is that such observations often lack information on short-term variability in either time or space or both. For example while an observational buoy may give almost continuous observations in time, there is no information on how representative these observations are in space. On the other hand observations from satellites provide surface spatial information but no subsurface information.

Consequently, when performing model validation one is often faced with the challenge that the only high quality observations available are lacking information in one or more dimensions in

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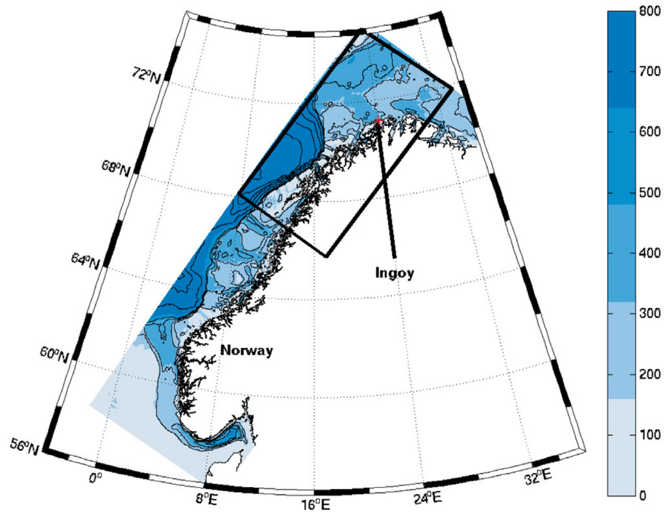

Fig. 1. NorKyst-800 domain and bathymetry (in meters) for the entire grid. The sub domain used in the present set-up is limited by the black lines. The red dot is the Ingøy fixed hydrographic station. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

time or space. For modellers, the question is how to best utilize the observations in a frame that can fit a numerical model. In the present work we use point measurements of temperature from a fixed hydrographic station at Ingøy on the Norwegian Barents Sea coast. With no resolution in the horizontal, and only 1–2 measurements per month, the question is whether a numerical ocean model has any predictive skill compared to the observations. Further, acknowledging the short-term variability at the station and the possible spatial displacement of ocean circulation features in the model, when is it correct to say that there is a match between observations and model?

2. Material and methods

2.1. The NorKyst-800 model

NorKyst-800 (Norwegian Coast 800 m) is a numerical ocean modelling system developed to provide high resolution information about the physical environment along the Norwegian coast Albretsen et al. (2011). The model system is an automation of the numerical ocean model ROMS (Regional Ocean Modeling System; http://myroms.org, Shchepetkin and McWilliams, 2003; 2005), implemented with a spatial horizontal resolution of 800 m, and suitable sources for forcing. It is assumed that 800 m horizontal resolution is sufficient to resolve the main topographical features and dynamical processes in coastal areas. In the vertical 35 generalized σ-coordinate (s) levels, stretched to increase vertical resolution near the surface and bottom, are used. The internal time step is 60 s.

The full NorKyst-800 bathymetry grid consists of 2600 × 900 grid cells covering the entire Norwegian coast (Fig. 1), and is run operationally at met.no to provide ocean forecasts up to +48 h ahead. The NorKyst-800 model system can also easily be used to simulate any chosen part of the coast, and for the present work the model has been run for a sub domain covering the coast from Lofoten (67°N) to the Russian border (see Fig. 1). Atmospheric forcing is taken from NORA10 (Norwegian ReAnalysis 10 km), which 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. (20007), except for the short wave radiation which is computed analytically. Initial fields and lateral boundary conditions are taken from the met.no operational model MI-POM 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 4 km Engedahl (1995); Albretsen and Røed (2010). Tidal forcing is based on a global inverse barotrophic model of ocean tides, TPXO7.2 Egbert et al. (1994); Egbert and Erofeeva (2002). In the present set-up the eight primary constituents (M2, S2, N2, K1, K2, O1, P1 and Q1) are included. River discharge observations are not available for all rivers. Therefore, daily river runoff is based on modeled discharges provided by the Norwegian Water Resources and Energy Directorate (NVE) using a distributed version of the HBV-model with 1 km horizontal resolution Beldring et al. (2003). The model covers the main (247 in whole domain) Norwegian catchment areas that drain to the sea. The runoff data are prescribed as if there was no flow regulation. This is a weakness that might have a great impact in some areas where there is strong seasonal variability owing to river regulation Myksvoll et al. (2011). The simulation started on January 1, 2009, and the model was run until December 31, 2009. As the model was initiated from an operational analysis (4 km × 4 km) beginning on the start date, no further spin-up time was applied. Earlier studies using NorKyst-800 have shown that the model will adjust to the initial analysis in less than 1–2 months. This should be kept in mind when interpreting the results for the first months of the simulation.

2.2. The Ingøy fixed station data series

In the period 1935 to 1947 the Institute of Marine Research (IMR) established 8 fixed hydrographic stations along the Norwegian coast from Skagerrak to the Barents Sea Eggvin (1938); 1948). The main purpose was to monitor the ocean climate in relation to fisheries, but today the time series also have become important indicators of long term climate variability. At all stations temperature and salinity are measured at standard depths (0, 5, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250 and 300 m) from 1 to 2 times per month by local observers. Aure and Østensen (1993) presented both mean values and long term variations from the fixed stations. Data are also available at http://www.imr.no/forskning/forskningsdata/stasjoner/. From the 1990s the measurements were made with mini Conductivity Temperature Depth (CTD) recorders (SAIV SD204 instrument) using an inductive cell for conductivity Brown (1964). The accuracy of the CTDs given by the manufacture of the instrument is ± 0.01° for temperature, ± 0.02 for salinity and ± 0.02% of the range (500 dBar) for the pressure sensor.

Ingøy is the northernmost coastal station (N71°08′, E24°01′). At the station the water masses are a mixture of Atlantic and Coastal waters. Atlantic Water moves around Tromsøflaket and then flows southeastward through Ingøy Deep. There it meets and mixes with Coastal Water flowing northeastwards along the coast Skagseth et al. (2011). The water masses at Ingøy are vertically more mixed than at the other more southerly coastal stations.

3. Results

The modelled current speeds and directions at 10 m depth near Ingøy clearly show the water flowing around Tromsøflaket, entering the area from the northwest, and meeting the coastal jet with maximum mean speeds above 50 cm s^{-1} (Fig. 2). The flow pattern is similar to that based upon trajectories from subsurface drogue drifters as presented by Skagseth et al. (2011) The mean modeled speed at Ingy (39 cm s^{-1} at 10 m depth) is slightly above that reported by Skagseth et al. (2011) from ADCP (34 cm s^{-1} at 28–44 m depth).

The observed surface temperatures for 2009 from Ingøy are given in Fig. 3 (upper left panel). In total there are 33 observations during that year, and except for the period mid-March to