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An assessment of the added value from data assimilation on modelled Nordic Seas hydrography and ocean transports

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ABSTRACT

The Nordic Seas is a hotspot both in terms of climate related processes, such as Atlantic–Arctic heat exchange, and natural marine resources. A sustainable management of the marine resources within the Nordic Seas, including the co-existence between fisheries and petroleum industries, requires detailed information on the state of the ocean within an operational framework and beyond what is obtainable from observations only. Numerical ocean models applying data assimilation techniques are utilized to address this need. Subsequently, comprehensive comparisons between model results and observations are required in order to assess the model performance. Here, we apply a set of objective statistics to quantitatively assess the added value of data assimilation in numerical ocean models that are currently used operationally. The results indicate that the inclusion of data assimilation improves the model performance both in terms of hydrographic properties and volume and heat transports. Furthermore, we find that increasing the resolution towards eddy resolving resolution performs similarly to coarser resolution models applying data assimilation in shelf areas.

1. Introduction

The Nordic Seas, which consists of the Norwegian, Greenland and Iceland seas, together with the Barents Sea constitute the link between the Atlantic and Arctic oceans and accounts for the major part of the heat exchange between the two oceans. This is reflected in the warm and saline Atlantic Water (AW) that looses large amounts of heat as it flows northward along the Nordic Seas eastern boundary, and the cold and relatively fresh Polar Water flowing southward along the Nordic Seas western boundary (Blindheim and Østerhus, 2003; Fig. 1). The Nordic Seas is therefore a hotspot in the northern hemisphere climate system, and has deservedly received a lot of attention in terms of climate related research (e.g., Mauritzen et al., 2011; Smedsrud et al., 2013; Eldevik and Nilsen, 2013; Gerber et al., 2014). Adding to that, the Nordic Seas holds vast amounts of natural resources, such as large commercial fish stocks and fossil fuel reserves. Examples include the world's largest commercial cod stock, the Northeast Arctic cod (*Gadus morhua*), and the Norwegian spring-spawning herring (*Clupea harengus*). The variability in the key marine ecosystem components are closely connected to circulation variability; e.g., fish recruitment in the Barents Sea is positively correlated with inflow of AW from the Norwegian Sea with high abundance of the key zooplankton species *Calanus finmarchicus*, (Sundby, 2000; Ottersen et al., 2013), while reduced inflow of AW has been suggested as a prime candidate for the poor fish recruitment in the North Sea in recent years (Beaugrand et al 2009; Payne et al 2009). Offshore installations at the sea surface related to the fossil fuel industry are prone to physical stress from ocean waves and currents, and as the industry moves further north, sea ice becomes an increasing concern. Moreover, the co-existence between offshore industry and fisheries requires robust assessments of potential environmental impacts of, e.g., oil spills (Hauge et al., 2014).

Detailed information on the state of the ocean beyond what is obtainable from observations only, as well as an understanding of the governing physical processes within the Nordic Seas is needed to address the challenges listed above. In order to provide information on the ocean state operationally, which requires assimilation of observational data into numerical ocean models, the MyOcean projects and follow-on Copernicus Marine Environmental

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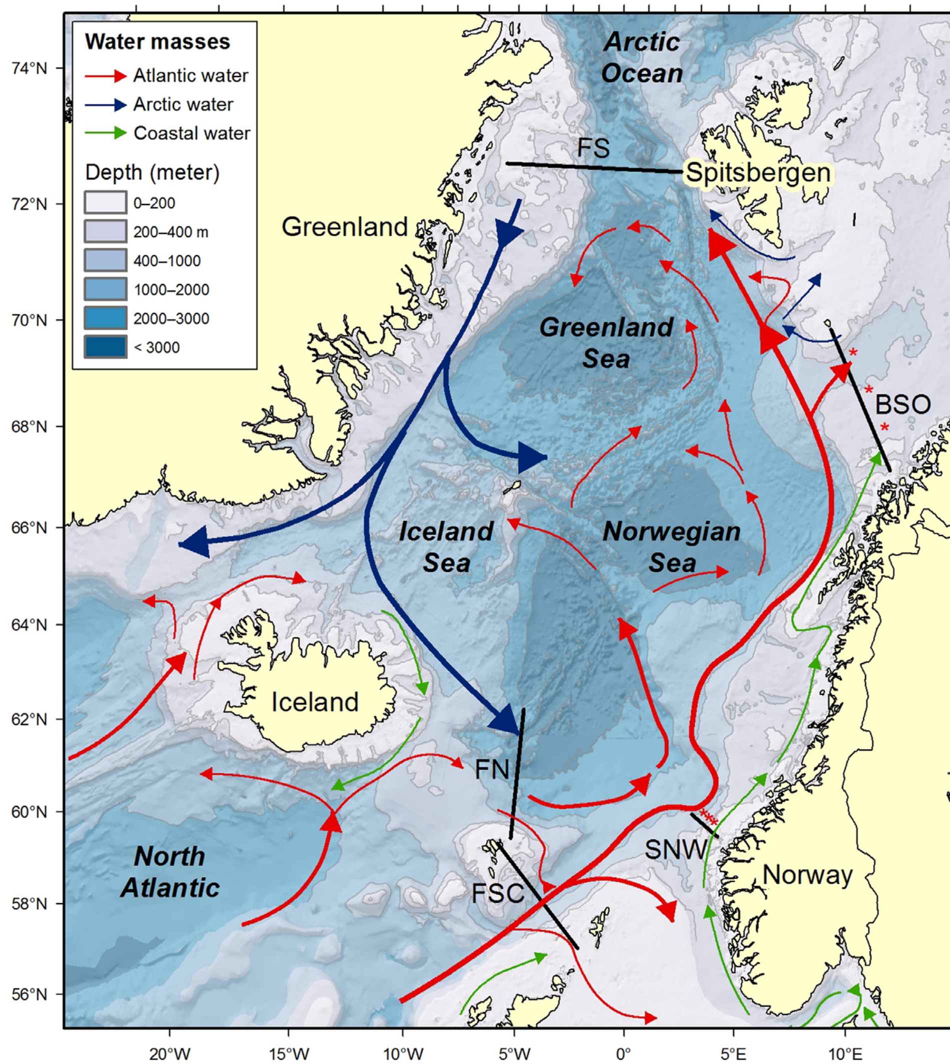

Fig. 1. Bathymetry and general circulation in the study area Blue: Arctic water masses; red: Atlantic water masses; green: coastal water masses. Black lines show the positions of the sections; FN = Færøy North, FSC = Færøy–Shetland Channel, SNW = Svinøy Northwest, BSO = Barents Sea Opening, FS = Fram Strait. Red stars show positions of stations with vertical profiles of temperature and salinity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Monitoring Service (CMEMS; http://marine.copernicus.eu/) operates and delivers a comprehensive Ocean Monitoring and Forecasting system of the Global Monitoring for Environment and Security program Marine Service to users within all marine applications, including maritime safety, marine resources, marine and coastal environment and climate, seasonal and weather forecasting. At present, two models that cover the Nordic Seas and the Arctic Ocean are run in parallel within the CMEMS framework: the Mercator Océan global system, France (NEMO) and the TOPAZ model system, developed at the Nansen Environmental and Remote Sensing Center, Norway, and run operationally at the Meteorological Institute, Norway.

Several challenges arise when modelling the Nordic Seas. First and foremost, the dynamical length scale represented by the Rossby radius of deformation, which is between 1 and 10 km within the Nordic Seas (Nurser and Bacon, 2014), together with strong hydrographic gradients, often in conjunction with steep topography, put strong constraints on the spatial resolution and the choice of sub-gridscale mixing parameterization required to adequately resolve important processes. Adding to that, the area of the Nordic Seas together with the need of adequately including the boundary areas towards the northern North Atlantic and the Arctic Ocean within the model domain, limits the spatial resolution due to the computational demand, especially within an operational framework. Other complicating factors include, among others, large ocean-atmosphere heat exchange associated with vigorous atmosphere dynamics (e.g., Ivanov and Shapiro, 2005; Segtnan et al., 2011), as well as sea–ice–atmosphere interactions (e.g., Smedsrud et al., 2013). In addition, the data assimilation itself adds challenges related to the freshwater balance and dynamical consistency, among other things.

Our analysis includes assimilation and non-assimilation experiments performed by the two CMEMS models, as well as a non-assimilation mode only simulation using the Regional Ocean Modeling System (ROMS). ROMS is currently used operationally at the Norwegian met office and served as a backup system within the MyOcean projects, i.e., the pre-operational phase of the CMEMS, and is also used at the Institute of Marine Research, Norway, for physical oceanography purposes as well as coupled ecosystem models. These three models represent the three main classes of numerical ocean models, namely z-level models, sigma-coordinate models and isopycnic-coordinate models. Moreover, the