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The Lofoten Vortex of the Nordic Seas

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ABSTRACT

The Lofoten Basin is the largest reservoir of ocean heat in the Nordic Seas. A particular feature of the basin is 'the Lofoten Vortex', a most anomalous mesoscale structure in the Nordic Seas. The vortex resides in one of the major winter convection sites in the Norwegian Sea, and is likely to influence the dense water formation of the region. Here, we document this quasi-permanent anticyclonic vortex using hydrographic and satellite observations. The vortex' uniqueness in the Nordic Seas, its surface characteristics on seasonal, inter-annual, and climatological time-scales, are examined together with the main forcing mechanisms acting on it. The influence of the vortex on the hydrography of the Lofoten Basin is also shown. We show that the Atlantic Water in the Nordic Seas penetrate the deepest inside the Lofoten Vortex, and confirm the persistent existence of the vortex in the deepest part of the Lofoten Basin, its dominant cyclonic drift and reveal seasonality in its eddy intensity with maximum during late winter and minimum during late autumn. Eddy merging processes are studied in detail, and mergers by eddies from the slope current are found to provide anticyclonic vorticity to the Lofoten Vortex.

1. Introduction

The warm and saline Atlantic Water (AW) entering the Norwegian Sea transports heat towards the Arctic, and is thus a key component in maintaining the region's relatively mild climate and ice-free oceans (Rhines et al., 2008). Heat loss to the atmosphere is one of the major processes resulting in water mass transformation in the Nordic Seas, an important component of the Atlantic Meridional overturning circulation (e.g., Eldevik and Nilsen, 2013). The Lofoten Basin of the Norwegian Sea (Fig. 1) is both the largest heat reservoir of the Nordic Seas (Blindheim and Rey, 2004) and a region with strong heat loss to the atmosphere (Bunker, 1976). The Lofoten Basin has earlier been identified as the region of highest eddy activity in the Nordic Seas (Poulain et al., 1996). The residence time of AW in the Lofoten Basin resulting in storage of large quantities of AW, is longer than any other region in the Nordic Seas, due to the deep cyclonic circulation prevailing there (Orvik, 2004; Gascard and Mork, 2008). The long residence time of AW in the Lofoten Basin results in additional cooling of AW before it reaches the Arctic proper. However, the details of circulation and water mass transformation in the Lofoten Basin are still to a large extent unknown.

The Lofoten Basin, bordered by the baroclinic Norwegian Atlantic Front Current (the front current) on the western side and nearly barotropic Norwegian Atlantic Slope Current (the slope current) on the eastern side (Orvik and Niiler, 2002; Mork and Skagseth, 2010), seats a large anticyclonic vortex in its western part. This vortex have been reported in several studies (Ivanov and Korablev, 1995a, 1995b; Köhl, 2007; Rossby et al., 2009; Voet et al., 2010; Andersson et al., 2011; Koszalka et al., 2011; Volkov et al., 2013; Søiland and Rossby, 2013). Ivanov and Korablev (1995a, 1995b) first identified this feature and reported it as a quasi-permanent anticyclonic vortex. They concluded that the main forcing mechanism responsible for the stability of the vortex is winter convection, which via deepening of isopycnals regenerates the lens and reinforces the vortex's circulation. Köhl (2007), using a numerical ocean model studied the generation mechanisms and conditions for stability of the vortex. He proposed that the vortex receives energy primarily from anticyclonic eddies shed from the slope current, propagating south-westward into the central Lofoten Basin. Rossby et al. (2009) supported this argument by showing a link in the isopycnals between the Lofoten Escarpment and deep Lofoten Basin. A recent study of the vortex by Søiland and Rossby (2013)

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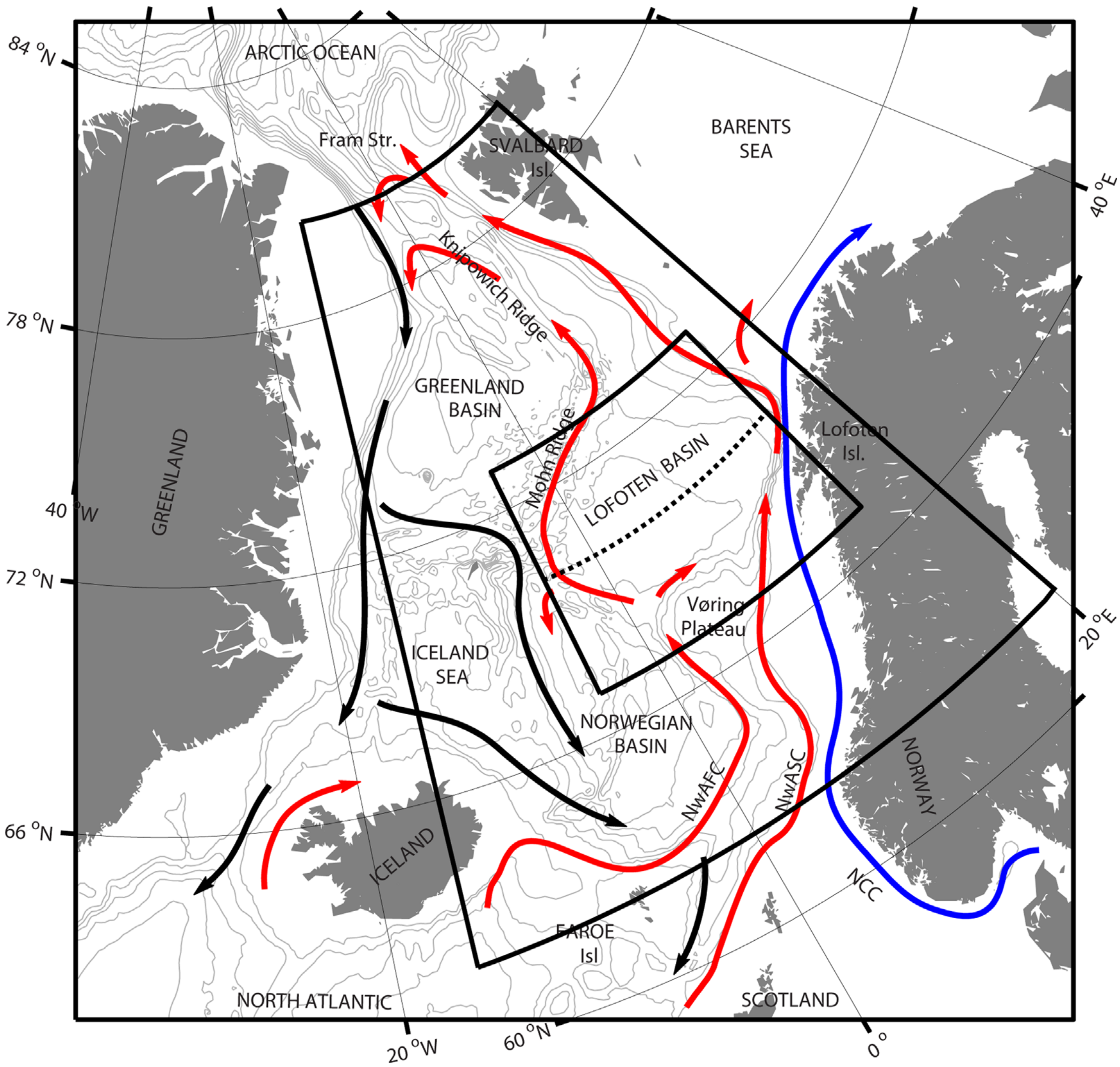

Fig. 1. The Nordic Seas with schematic pathways indicating the overturning circulation from warm inflowing Atlantic Water in the surface (red) to cold and dense overflows to the deep North Atlantic (black). The Norwegian Atlantic slope current (NwASC), here termed as the slope current and Norwegian Atlantic front current (NwAFC) are represented by red arrows. The fresh Norwegian Coastal Current (NCC) is indicated in blue. See Furevik and Nilsen (2005) and Eldevik et al. (2009) for details. Grey isobaths are drawn for every 600 m. The large and small black frames indicate the areas shown in Figs. 3 and 4 and in Figs. 5, 6a and 12, respectively. The dashed line indicates the vertical section shown in Figs. 10 and 11. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

also supported energy transfer via eddy merging mechanism, but also recommended the need to study this in detail.

There are two main disagreements among earlier studies. The first is regarding the drift of the vortex. Ivanov and Korablev (1995b) suggested that the vortex drift is guided by the mean cyclonic circulation that largely follows *f*/*H* contours as described by Nøst and Isachsen (2003). This was later contradicted by Köhl (2007), who modelled the drift of the Lofoten Vortex to be anticyclonic due to the circulation created by cyclones surrounding the vortex. The second disagreement is regarding the size of the vortex. While Ivanov and Korablev (1995a, 1995b), reported the radius of the vortex to be 15 km, Koszalka et al. (2011) retrieved mean velocities and eddy kinetic energy in the Lofoten Basin from surface drifters and found the vortex radius to be 75 km. Recently, Søiland and Rossby (2013) documented the solid body core of the vortex to be of 7–8 km radius. The uniqueness of the vortex in the Nordic Seas has not yet been fully documented.

This study performs a comprehensive observational based quantitative analysis of the vortex, hereafter termed 'the Lofoten Vortex', using a suite of long term hydrographic and satellite observations. The main objectives of this paper are to document the uniqueness of the Lofoten Vortex in the Nordic Seas; to quantify the vortex' surface characteristics on seasonal, interannual, and climatological time-scales; to show its influence on regional hydrography on seasonal and climatological time-scales; and to study eddy merger processes in detail.

2. Data and methods

We use altimeter data to detect the eddies in the Lofoten Basin, in particular the Lofoten Vortex, and to estimate the radii, eddy kinetic energy, as well as drift velocities. Eddies are tracked and mergers with the vortex and the resulting vorticity changes are quantified. Hydrography is used to describe the signature of the Lofoten Vortex.

2.1. Altimeter data

High-resolution sea level anomalies (SLA) during the past 16 years (1995–2010) are used to study the vortex. The SLA fields, corrected for the inverse barometer effect, tides, and tropospheric effects (Le Traon and Ogor, 1998), are based on merged Envisat and ERS-I and II altimetric data (Ducet et al., 2000). The SLA fields obtained from AVISO are provided as weekly means on a 1/3°