Sources of the Maelstrom

The Lofoten Maelstrom on the northern coast of Norway has been renowned for centuries for its strength and dangerous whirlpools. We now complete a previous review[1] of the historic literature about the Maelstrom and present results of simulations describing the large-scale dynamics of this remarkable phenomenon.

The Maelstrom is located at 67° 48′ N, 12° 50′ E between Lofoten Point (Lofotodden) and the island Værøy southwest of the main chain of the Lofoten Islands, and takes its name, Moskstraumen, from the small island Mosken in the centre (Figs 1, 2). The current is of tidal origin, although the prevailing northward currents and southwesterly wind may contribute to its strength. It is said to run at a speed of up to 5 or 6 $m\ s^{-1}$, but no current records are available for estimates of these extremes. Eddies and current shear-zones appear on satellite images[2].

The earliest accounts of the Maelstrom survive in old Nordic tales[3]. They tell of a pair of ponderous and magical millstones which sank either near the Pentland Firth north of Scotland or on the northwestern coast of Norway. Their continuous grinding of salt is said to form large eddies in the sea above. The term maelstrom is commonly thought to derive from the Dutch verb *malen* (Nordic *male*) meaning 'to grind'.

The first written account is probably by Olaus Magnus (1490–1558), a Swedish bishop in Rome[4]. On *Charta Marina* (1539) he drew a large eddy west of Lofoten, which he described as stronger than the Sicilian Charybdis, and attributed it to a divine force. Subsequently, fictional descriptions of a huge eddy appeared, were reprinted, and cited in mainstream seventeenth and eighteenth century European geographical literature[1]. Contemporary Norwegian authors gave more factual descriptions[5–8].

Petter Dass (1647–1707), a Norwegian priest, produced a detailed and realistic description of Moskstraumen, as well as other strong tidal currents, in his poem, *The Trumpet of Nordland*[6], written around 1685. He attributed its strength to the phases of the Moon — the current being strongest at full and new moons and weakest at half moons. Unfortunately, Dass was not translated into English. A report by Schelderup[7] (written before 1751), noted the rotation of the current during the tidal cycle and attributed the driving force to differences in sea level across the Lofoten islands.

The celebrated stories by Edgar Allan Poe (*A Descent into the Maelström*, 1841) and Jules Verne (*Vingt Mille Lieues sous la Mer*, 1869), featuring the Lofoten Charybdis, rely heavily on Nordic sources. Poe's detailed knowledge of the landscape and local tales, can be traced back to a fictitious description by Jonas Ramus from about 1715, which includes elements from an older source[5]. Ramus's description was quoted by Pontoppidan[8] and reprinted in the sixth edition of *Encyclopaedia Britannica* (1823). Poe also acquired some information on local fishing practice, probably through the Anglo-American sources mentioned by Mabbott[9].

No substantial modern studies of this strong tidal current have been reported. The Norwegian pilot book[10] provides some information albeit of limited scientific value. We have therefore developed a high-resolution depth-integrated tidal model with a 0.5 km grid size (Fig. 1). This has enabled a study of the transition of the tide from a northwards progressive wave[11] on the outer shelf to standing oscillations in the fjords, and the enhancement of the tidal current particularly around Lofotodden. Input on lateral boundaries (sea level and volume flux) were obtained by interpolation from coarser models[11,12].

The simulated amplitude and phase for the dominant semi-diurnal tidal component M_2 (Fig. 1) agree well with observations. A strong sea-level gradient appears across the island chain with up to 25 cm higher amplitudes in Vestfjorden inside the islands than outside. This drives the current around Lofotodden and through the narrow channels between the islands further east. The sea-level variation, with contour lines converging on Lofotodden (Fig. 1) is due to the change in shelf width from a relatively broad shelf south of Lofoten to a narrow shelf further north, and the scatter-

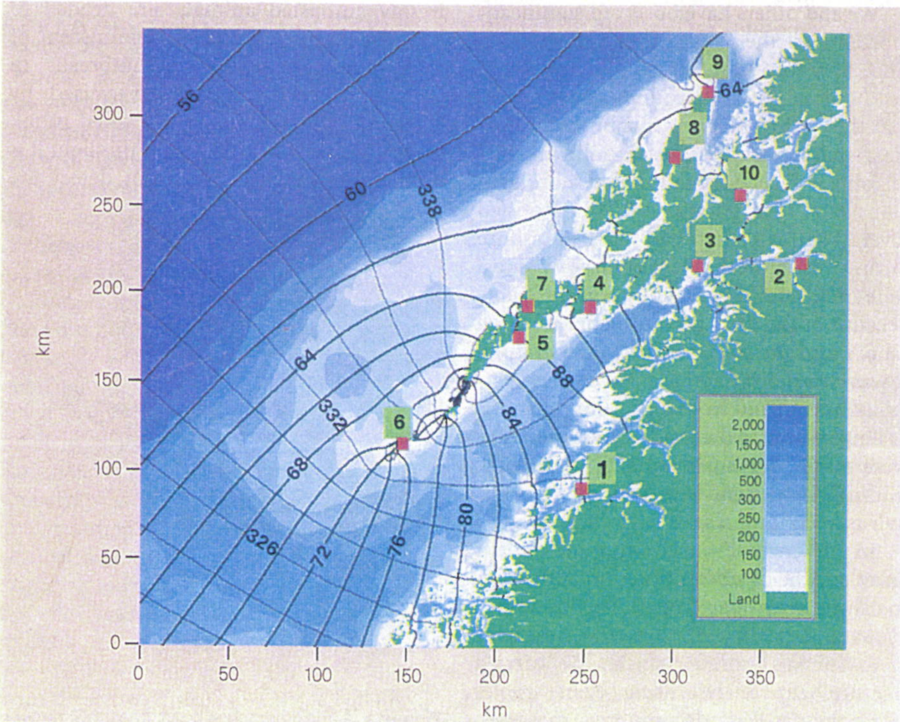

Figure 1 Modelled sea-level amplitude and phase for the dominant semi-diurnal tidal component (M_2). The Lofoten Islands extend northeast from Røst (6), to Lødingen (3). Vestfjorden between Lofoten and Bodø (1), Narvik (2), Andenes (9) and Harstad (10). Colour depth-scale is in metres. Solid contour lines show amplitude (in cm) with 2-cm separation. Dotted contour lines indicate phase (deg, GMT) with 2 deg separation. A decrease of 2 deg in phase corresponds to a time delay of the tide of 4 min. Observed/modelled amplitude (in cm) for the stations 1–10: 87/86, 99/100, 93/96, 93/92, 88/89, 78/76, 62/63, 68/66, 65/63 and 69/66, respectively.

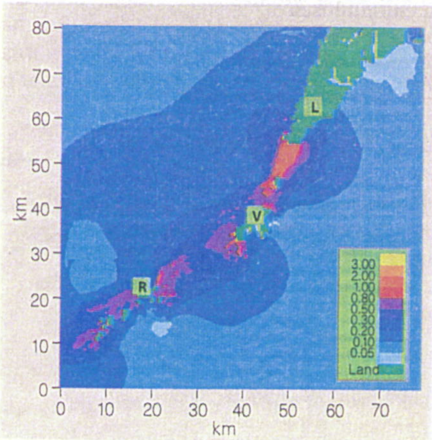

Figure 2 Maximum depth mean current for M_2 in the area southwest of Lofotodden (L) with Værøy (V) and Røst (R). Mosken is midway between L and V. Colour scale is in $m\ s^{-1}$. Volume flux through the sections between L and V and between V and R are $0.35\times10^6\ m^3\ s^{-1}$ and $0.55\times10^6\ m^3\ s^{-1}$, respectively, at the peak of the tide. Volume fluxes at spring tide are 1.8 times larger.

ing of the northbound tidal wave by the islands and shallow bank to the southwest.

The mean currents are predicted to be of the order of 0.1 m s^{-1} in deep water and up to 3.0 m s^{-1} on the narrow ridge (50–100 m deep) between Lofotodden and Røst (Fig. 2). A lack of data from this area hampers validation of the model; however, we have made comparisons with measurements from channels between the islands east of Lofotodden at Napp, Sundklakk and Gimsøy. Current shifts are predicted to occur about 2 h before high water, with a northwards current at high water and a southwards current at low water, in agreement with observations[10].

A weak, roughly 6-km diameter, clockwise eddy appears in the simulations, centred about 5 km southwest of Lofotodden at the time of current shift on a rising sea. A similar sized anticlockwise eddy appears nearer Lofotodden at the time of current shift on falling sea. The current speed in these eddies is roughly 0.1 m s^{-1}, no comparison to the eddy in ancient literature. The eddies owe their existence to sea-floor topography and friction. West and east of Mosken the current vector rotates clockwise in nearly circular ellipses which may have been interpreted as a large eddy by early observers.

The semi-diurnal components, S_2 and N_2, show a similar amplitude pattern to M_2. The diurnal component, K_1, which interacts with shelf wave modes, produces dominant diurnal currents in Sortlandsundet between stations 7 and 8 (Fig. 1), where the M_2 current is weak, matching observations (Norwegian Hydrographic Service, 1994). The generation and advection of small-scale eddies in the strong tidal jet remain a subject for future studies but these local effects are not likely to alter the large-scale patterns of sea-level variations reported here.

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