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Temperature and salinity fluctuations in the Norwegian Sea in relation to wind

by

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Abstract

Hydrographic observations in the Svinøy section and results from the Princeton Ocean Model are used to investigate the role the wind forcing has on temperature and salinity fluctuations in the Norwegian Sea. In order to investigate the role the wind forcing has on observed fluctuations in the Norwegian Sea the model is driven for two different air pressure regimes. A period from the 1960s with a relatively low NAO index is used for one regime while a period from the 1990s with a relatively high NAO index is used for the other regime. Wind data used in the model are from the Hindcast data base archive from the Norwegian Meteorological Institute. The period with high NAO index caused a freshening and cooling of the upper layers in the central Norwegian Sea relative to the period with low NAO index. This was caused by a reduced transport of Atlantic water over the Iceland-Faeroe Ridge and at the same time the transport through the Faeroe-Shetland increased. In the period with low NAO index the opposite case occured.

Introduction

The Nordic Seas (Greenland, Iceland and Norwegian Seas) current system consists of several persistent currents. The principal currents are the warm Norwegian Atlantic Current which is a northern continuation of the North Atlantic Current, the cold East Greenland Current (EGC) directed southward and the East Icelandic Current (EIC) flowing southeastward northeast of Iceland (Fig. 1).

The inflow to the Nordic Seas occurs mainly between Scotland and Iceland while a smaller part of the inflow occurs west of Iceland. The Atlantic inflow which occurs west of Iceland (i.e. the northern branch of the Irminger Current) mixes with water from the East Icelandic Current. The mixed water mass produced during the winter is referred to as the North Icelandic Winter Water (Stefánsson, 1962). North of Iceland, the mixed water then flows eastward into the Norwegian Sea.

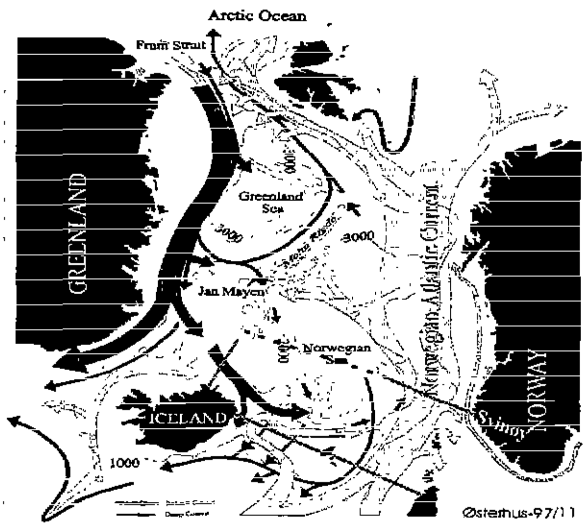

Fig. 1. Schematic view of the circulation pattern in the Nordic Seas. The position of the Svinøy, Iceland, Faereo-Shetland and Iceland sections are marked. Dark grey arrows indicate cold and fresh surface currents, while light gray arrows indicate warm and saline surface currents. Black arrows indicate deep currents. From Østerhus et al. (1996).

In the zone between the warm and cold water masses in the Norwegian Sea is the Arctic Front which is characterized by large horizontal gradients in temperature. At the front, cold and fresh water from the west is subducted and an intermediate layer between the warm Atlantic layer and cold deeper layers develops. Between Iceland and Jan Mayen variation in the volume of the Arctic waters carried by the EIC may result in relatively large displacement of the Arctic Front. Waters coming from the EGC may affect the water mass structure in the Norwegian Sea in two ways. It may occur either by transport of Arctic water, mainly in the EIC, directly into the Norwegian Basin, or more indirectly through the Subpolar Gyre in the North Atlantic. Since the 1960s there has been a decrease in temperature and salinity in the upper layer in the western and central Norwegian Sea. The reason is mainly increased freshwater supply from the EIC (Blindheim et al., 1999). The wind forcing plays an important role for fluctuations in the water mass properties. Blindheim found that the western extent of Atlantic water in the Norwegian Sea fluctuated with the winter "North Atlantic Oscillation" (NAO) index. Also, Mork and Blindheim (1999) showed that in the central Norwegian Sea there are large interannual variations in the depth of the 3°C isotherm and these variations are influenced by the winter NAO index.

With its location, the Svinøy section is well suited for monitoring the temperature and salinity fluctuations. Hydrographic observations from this section are used together with results from an ocean model for the study of the affect which atmospheric forcing has on the water mass properties in the Norwegian Sea.

Material and methods

From 1978 to present hydrographic observations have been made every summer in the Svinøy section. The section runs NW from 62°22´N and 5°12´E at the Norwegian coast to 64°40´N and 0°E in the Norwegian Sea where it transects the Norwegian Atlantic Current (see Fig. 1). The bottom depth at the westerly station in the section is about 2800 m.

Results from an ocean model are also used with different wind forcing. The ocean model is run for two cases; 1) one period with strong westerlies (high NAO index) and 2) one period with low westerlies (low NAO index). The two periods that are chosen are from 1) September 1993 to June 1994 and 2) September 1963 to June 1994. Figure 2 shows the mean air pressure systems for the winter (Dec-Mar) 1964 and the winter (Dec-Mar) 1994.

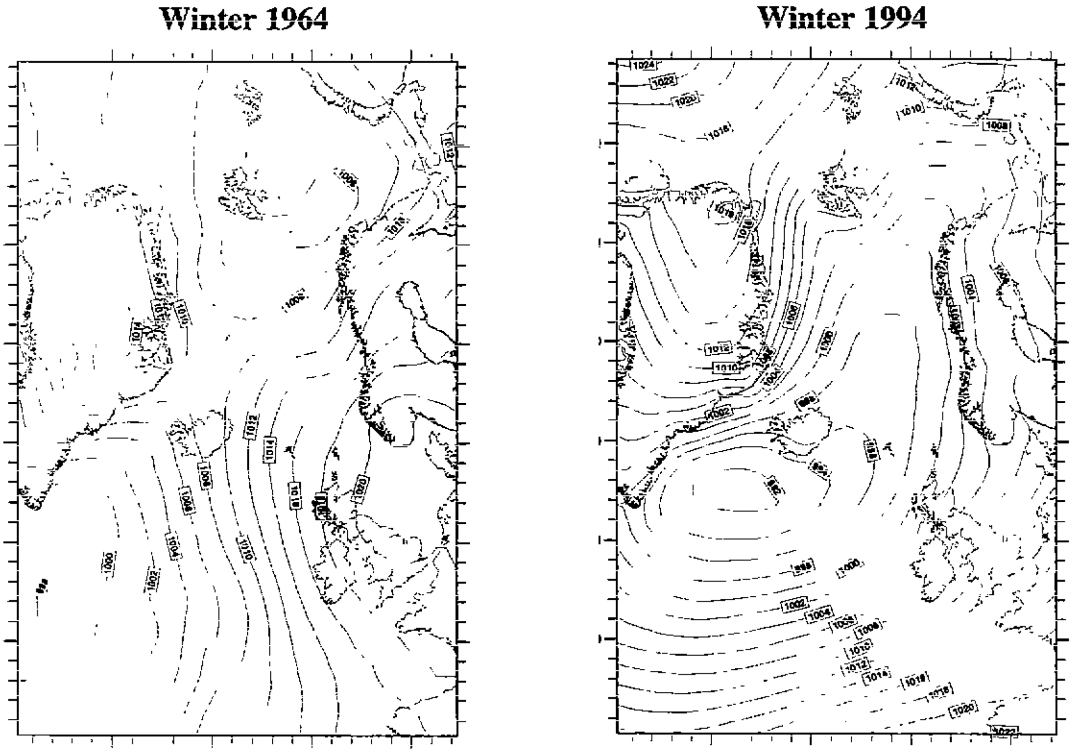

Fig. 2. Winter (Dec-Mar) air pressure at sea level for 1964 (left) and 1994 (right). From DNMI (Eide et al., 1985).

For the wind forcing we will use the hindcast database archive from the Norwegian Meteorological Institute (Eide et al., 1985). As an indication on the strength of south-westerly winds into the Norwegian Sea we will use the North Atlantic Oscillation (NAO) index which is based on the normalized difference between the sea-level pressure at Lisbon, Portugal and Stykkisholmur, Iceland (Hurrell, 1995). Temperature and salinity variations from both observations and numerical results will be compared with the winter NAO index

The used ocean model is the Princeton Ocean Model (POM) developed by Blumberg and Mellor (1987) with modifications done at the The Norwegian Meteorological Institute (DNMI) and Institute of Marine Research in Bergen, Norway (IMR). The model is a three-dimensional baroclinic ocean model, with surface elevation, three components of velocity, salinity, and temperature as the main model variables. The primitive equations are solved numerically using finite differences techniques. In the vertical, σ-coordinates with 15 levels are used. The model domain covers the Nordic Seas, the Barents Seas, the North Sea and parts of the Arctic and the North Atlantic Seas. The horizontal grid resolution is 20 km. The initial values of the model variables are from the DNMI-IMR diagnostic climatology (Engedahl et al., 1998). A more comprehensive description and a model validation is presented in Asplin et al. (1998).

Results

Figure 3 shows time series of the Winter NAO index and temperature and salinity averaged between three vertical intervals: 75-500 m, 500-800 m and 800-1000 m west in the Svinøy section. From about 1982 the temperature in all layers fluctuate in opposite phase with the winter NAO index. Similar is seen for the salinity in the interval 75-500 m but not in the deeper layers. This could be due to the difficulty of resolving salinity differences in deep layers.

From the summer observations in the Svinøy section we calculated the temperature and salinity anomalies. The anomalies are the difference between years with high winter NAO indices (83, 89, 90, 92-95) and years with low indices (79, 85, 87, 96, 97). Figure 4 shows the anomalies. In the upper layers, the water masses are colder and fresher in the period with high NAO indices compared to the period with low NAO indices. This difference can be up to -3^{o}C and -0.2 for respective temperature and salinity. East in the section, at the shelf edge, there are small differences, about 0.5^{o}C and 0.05 for respective temperature and salinity.

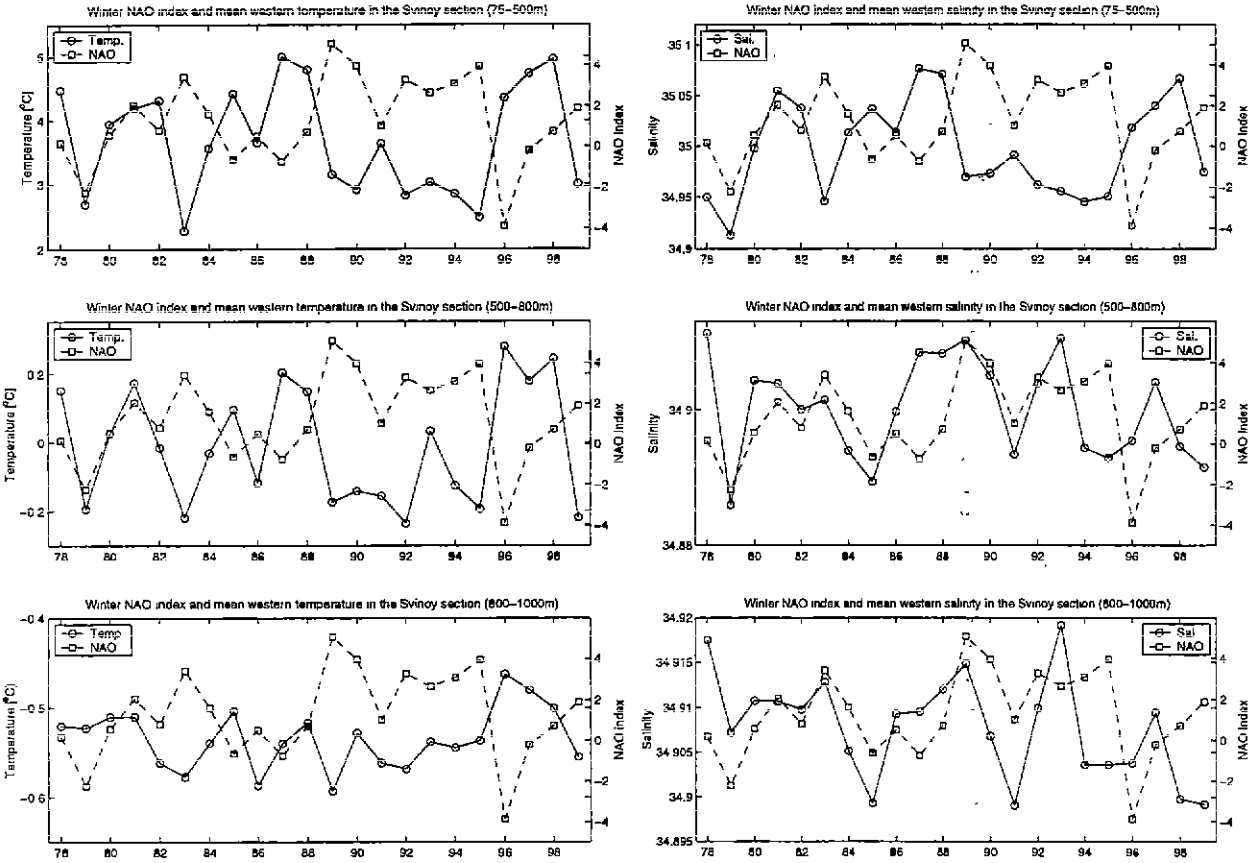

Fig. 3. Timeseries of the mean temperature (left) and salinity (right) west in the Svinøy section for three vertical intervals together with the Winter NAO index. The three intervals are 75-500 m, 500-800 m and 800-1000 m depth.

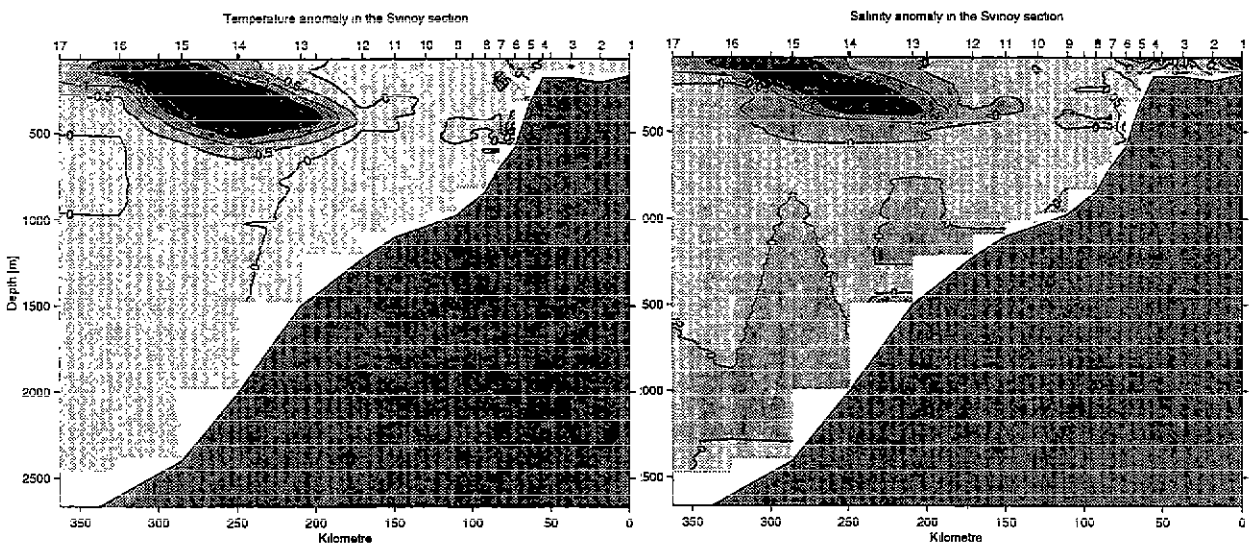

Fig. 4. Temperature and salinity anomaly during summer in the Svinøy section. The anomalies are the difference between years with high winter NAO indices (83, 89, 90, 92-95) and years with low indices (79, 85, 87, 96, 97).

From results of the ocean model runs we have plotted the temperature and salinity anomalies between May 1994 and May 1964 in an extended Svinøy section to about 11°W (Fig. 5). Between 75 and 700 m depth in the central of the Norwegian Sea and eastward there are fresher and colder water masses in May 1994 than in May 1964. The maximum differences in salinity

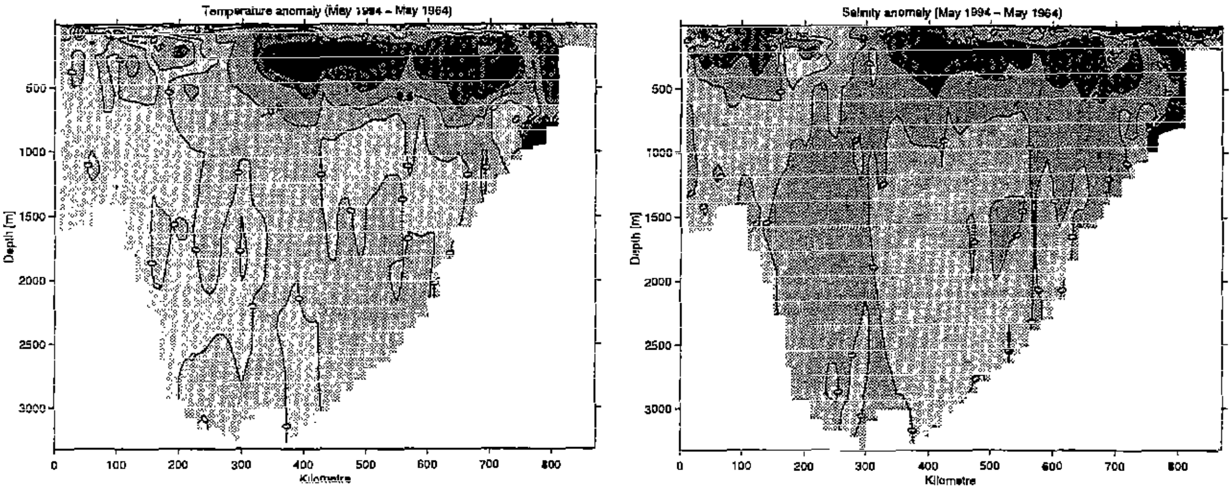

Fig. 5. Temperature (left) and salinity anomalies (right) between May 1994 and May 1964 in a section NW from Svinøy at the Norwegian coast to about 11°W (see Fig. 1. for location).

and temperature are 0.2 and 2.5°C, respectively. In the western Norwegian Sea there is saltier and warmer water from about 75 m to 500 m depth in 1994 compared to 1964.

In figure 6 we have plotted time series of the temperature and volume transport from a section north of Iceland (see Fig. 1. for location) for both 1963-1964 and 1993-1994. The mean temperatures are averaged over the section between the surface and 200 m depth while the volume

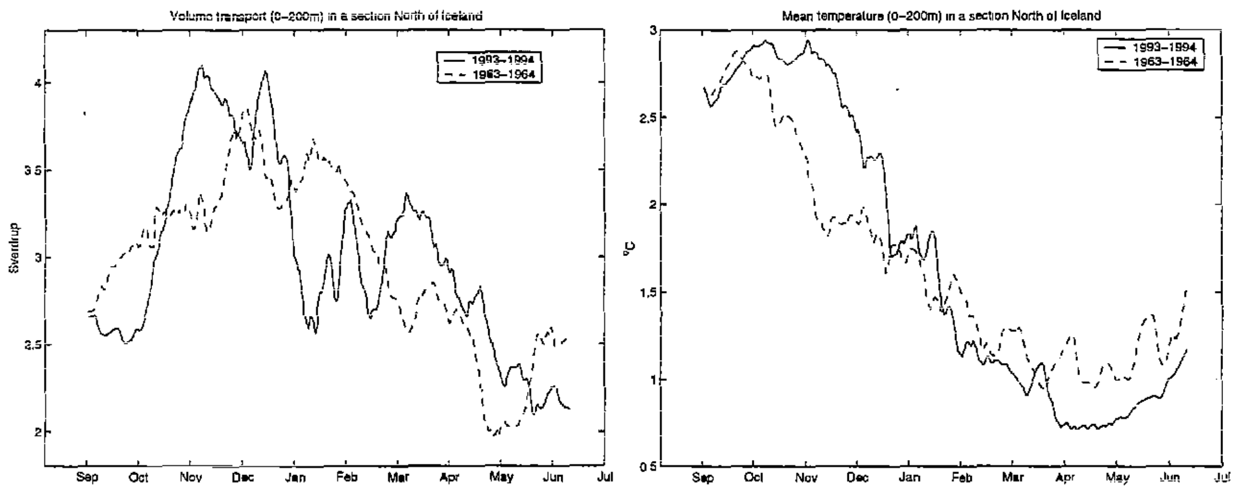

Fig. 6. Volume transport (0-200m) in Sverdrup (1Sv=10^6 m^3/s) and mean temperature (0-200m) for 1963-1964 and 1993-1994 in a section North of Iceland. See Fig. 1. for location of the section.

transport is the net transport in the section from the surface to 200 m depth. There are small differences in temperature and transport between the years 1964 and 1994. Thus there are only small differences in transport of Arctic water masses from the East Greenland Current to the Norwegian Sea through the East Icelandic Current between the two runs.

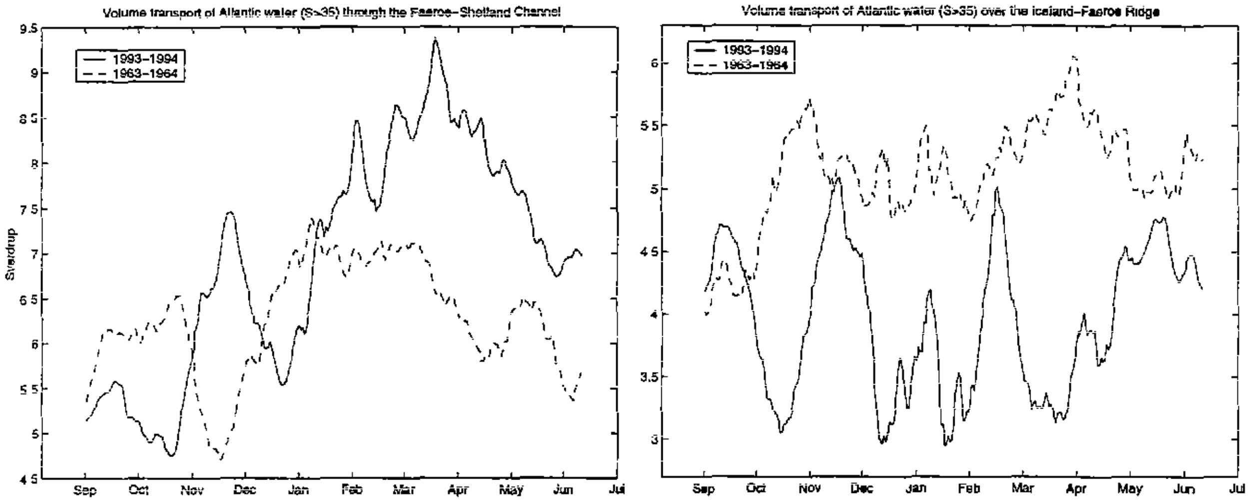

Fig. 7. Volume transport of Atlantic water through the Faeroe-Shetland Channel (left) and over the Iceland-Faeroe Ridge (right) for 1963-1964 and 1993-1994. Water with salinity over 35 is used as Atlantic water.

Figure 7 shows the net volume transport of Atlantic water a) through the Faeroe-Shetland Channel and b) over the Iceland-Faeroe Ridge. In the year 1964 there is a higher transport over the Iceland-Faeroe Ridge than in year 1994, while the volume transport through the Faeroe-Shetland Channel is higher in 1994 than in 1964.

Concluding remarks

Observations show that the strength of south-westerly winds influence the water mass structure in the Norwegian Sea even down to 1000 m depth. Strong south-westerly winds lead to negative temperature and salinity anomalies in the central Norwegian Sea while weak south-westerly winds lead to positive temperature and salinity anomalies. The influence on water masses down to 800-1000 m depth is due to the fact that the upper layers are mixed downwards during winter cooling and convection.

Results from the ocean model show that the strength of south-westerly winds influence the transports of Atlantic water over the Iceland-Scotland Ridge. This causes interannual temperature and salinity variations in the upper layer of the Norwegian Sea. Weak south-westerly winds (low NAO index) results in a reduced transport over the Faeroe-Shetland Channel and an increased transport over the Iceland-Faeroe Ridge. Warmer and saltier waters are then transported further west in the Norwegian Sea compared to the case with high south-westerly winds. This gives interannual temperature and salinity variations without changes in supply of Arctic water from the west through the EIC.

Acknowledgements

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