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LONG-TERM TEMPERATURE TRENDS IN NORWEGIAN COASTAL WATERS

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ABSTRACTS

Time series of sea surface temperature at four meteorological stations on the coast of Norway are compared with observations from three fixed oceanographic stations in Norwegian coastal waters. The longest time series at the meteorological stations cover the period after 1867. Five-year-running means for the January-March and July-September quarters are presented. The fixed oceanographic stations have been operated since 1935, though with gaps in the observations. Fluctuations of duration varying betweeen about 5 and 20 years are observed in all time series, and there is fair agreement between the observations at all stations in summer and winter. The observations suggest that these fluctuations may be of advective nature. A more long-term trend towards warming is observed at the meteorological stations. This warming was more conspicuous in summer than in winter. In summer the trend was clearly observed for nearly 50 years after the turn of the century. In winter there are indications of a weak temperature increase from the beginning of the observational period. It is suggested that this trend is due to direct heat transfer in the region.

INTRODUCTION

The trend towards warming in the north-east Atlantic and European Arctic regions in the first half of this century has been a subject of interest over several decades already (e.g. HESSELBERG and BIRKELAND 1940, 1941, AHLMANN 1949). This trend has been linked with fluctuations observed in the atmospheric circulation (DEFANT 1924, ERIKSSON 1943, HESSELBERG and BIRKELAND 1943), indicating that these two types of fluctuations are components of a more complex climatic system. It has also been observed that the atmospheric fluctuations are linked with environmental fluctuations in the sea. For instance HESSELBERG (1940) and SMED (1947 - 1979) found similar trends in sea surface temperature (SST) as in the atmosphere, and RODEWALD (1972) found good agreement between SST trends at North Atlantic Ocean weather stations and atmospheric circulation. DICKSON, LAMB, MALMBERG and COLEBROOK (1975) link the fluctuations in the East Icelandic Current with the atmospheric pressure distribution.

The need for a better understanding of the role played by the oceans in the climatic system has increased the need for time series of oceanographic observations. The present paper links SST observations at meteorlogical stations, situated at lighthouses on the Norwegian coast with temperature observations at fixed oceanographic stations in the coastal waters.

MATERIALS AND METHODS

The location of the various observation sites is indicated in Fig. 1. Sea surface temperature is observed daily at some coastal meteorological stations. Some of these observation series were initiated by Professor H. Mohn in 1867 and have been operated since then. Monthly means have been published by the Norwegian Meteorological Institute since 1870 (ANON. 1874 - 1979). MOHN (1887) refers to these time series in his report on the Norwegian North Atlantic Expedition 1876-1878. HESSELBERG (1940 and 1948) utilized the data in climate studies and FROGNER (1948) presented a comprehensive analysis of the data series up to 1945. For the present paper, averages have been

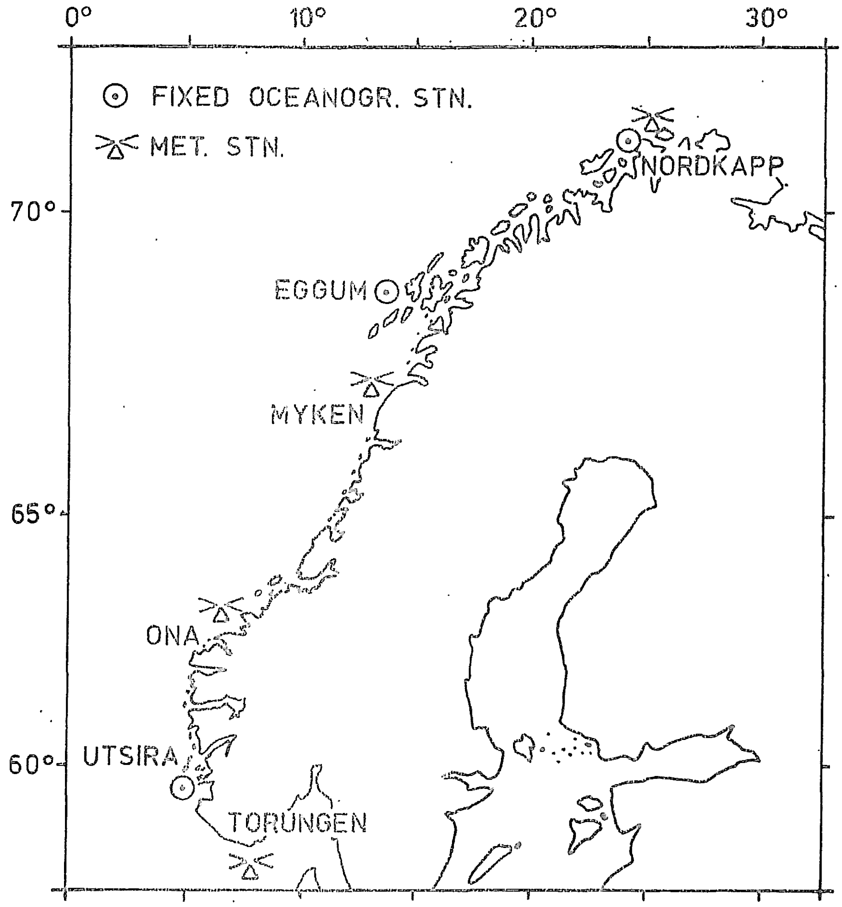

Fig. 1. Position of observation sites.

prepared for the January-March and July-September quarters and five-year-running means of these averages are presented. Time series from four meteorological stations are used, i.e. Torungen on the south coast, Ona on the west coast and Myken and Nordkapp off the northern part of the coast. The position of these stations is shown in Fig. 1. From Torungen and Ona there are continuous time series since 1867 and 1868 respectively. Myken has been operated since 1922. From this station only data collected after 1930 have been used in order to have a continuous time series from the northern part of the coast, overlapping in time with the observation series from the fixed oceanographic stations. The station near Nordkapp was operated at Gjesvær from 1881 to 1925 and from 1922 to 1944 at Ingøy (20 km from Gjesvær). In the period 1945-1973 daily SST observations are lacking in the Nordkapp area. Therefore, sea surface thermograph data from a nearby coastal shipping route (MIDTTUN

1971) are chosen to represent the Nordkapp station after 1945. Observations have generally been made twice weekly at about 4 m depth.

The fixed oceanographic stations, initiated by EGGVIN (1938, 1948), have, in general, been operated since 1935. Time series from stations off Utsira, Eggum and Nordkapp (Ingøy) are used here (Fig. 1). Mean values have been prepared in the depth intervals 0-50, 50-100 and 100-200 m. Temperature averages ($\bar{t}$) for the depth intervals have been calculated from observations at standard depths by:

$$\bar{t} = \frac{1}{Z_N - Z_o} \sum_{n=o}^{N-1} \frac{t_{n+1} + t_n}{2} (Z_{n+1} - Z_n)$$

where t_n is the temperature at the standard depth Z_n, Z_o and Z_N are the upper and lower depths in the layer respectively. From these averages over depth, means have been prepared for the January-March and July-September quarters. In the time series the quarterly averages were smoothed by three-year-running means, where the current year has twice the weight of the year before and the year after:

$$\bar{t}_n = \frac{1}{4} (t_{n-1} + 2t_n + t_{n+1})$$

The observation rate at the fixed oceanographic stations has varied. Utsira and Nordkapp have in general, been operated two or three times monthly, while Eggum has mostly been operated twice, and some times only once a month. It has not been possible to operate these stations regularly since 1935. Utsira was operated in the period 1942-1967 and after 1973. Eggum has been operated in the periods 1935-1954, 1960-1970 and after 1973. As regards the Nordkapp station, observations from the periods 1936-1944 and 1955-1976 have been used.

RESULTS AND DISCUSSION

Fig. 2 shows time series for the January-March quarter from the fixed oceanographic stations. Three-year-running means for the depth interval 0-50 m are plotted for all three stations. Also three-year-running means (1-2-1) of SST from Torungen, Ona and

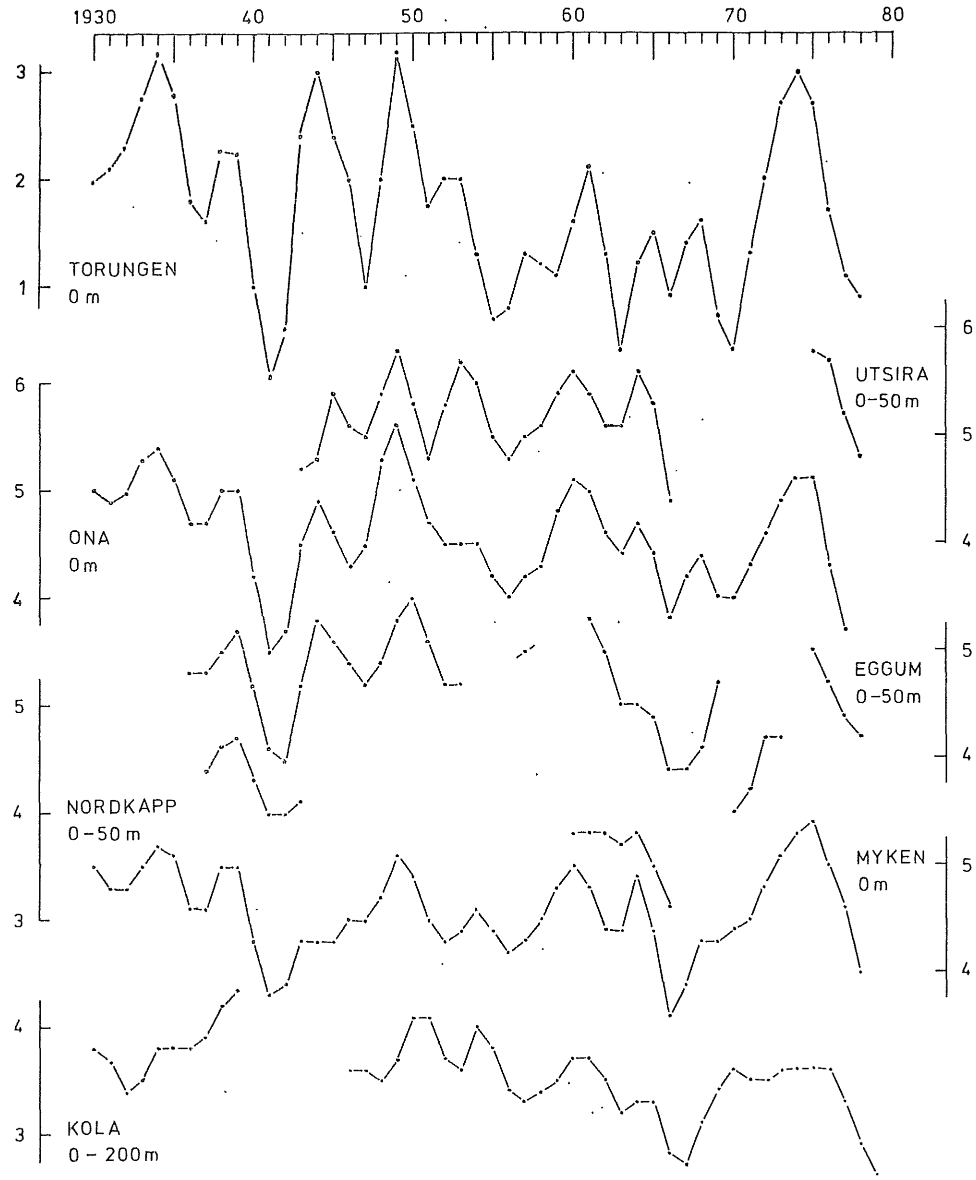

Fig. 2. Three-year-running means (1-2-1) of quarterly means for January-March. Means of sea surface temperature at Torungen, Ona and Myken, of mean temperature in the depth interval 0-50 m at Utsira, Eggum and Nordkapp and the depth interval 0-200 m in the Kola section are entered.

Myken are plotted in the same manner. Further, by courtesy of the Knipowich Polar Research Institute of Marine Fisheries and Oceanography, Murmansk, three-year-running averages for the depth interval 0-200 m in the Kola section are included. Corresponding time series for the July-September quarter are shown in Fig. 3. The figures show good agreement between the three

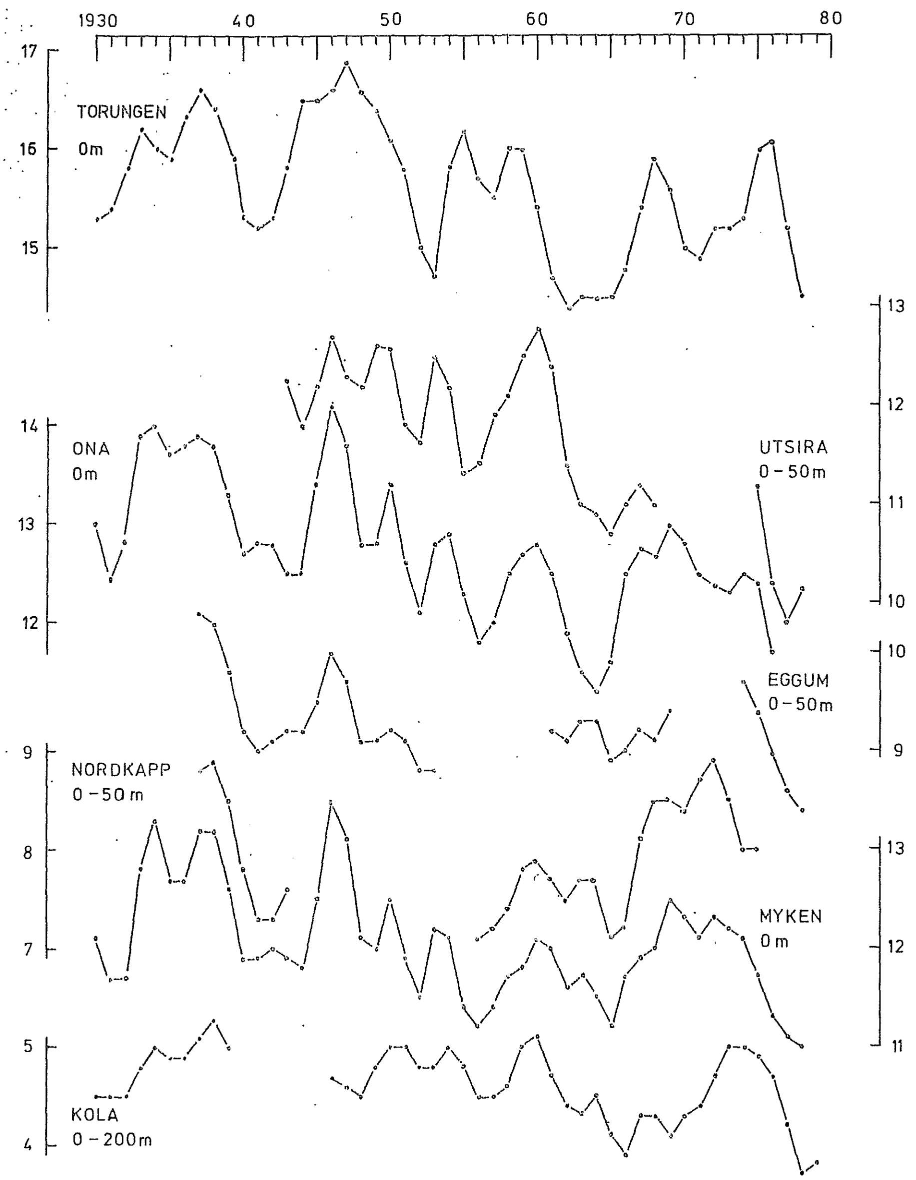

Fig. 3. Three-year-running means (1-2-1) of quarterly means for July-September. Means of sea surface temperature at Torungen, Ona and Myken, of mean temperature in the depth interval 0-50 m at Utsira, Eggum and Nordkapp and in the depth interval 0-200 m in the Kola section are entered.

meteorological stations, indicating similarities between the SST trends in near-shore waters along most of the Norwegian coast.

In spite of the gaps in the time series, the fixed oceanographic stations evidently reveal similar trends as do the meteorological stations. There is also fair interrelationship between the trends from the meteorological stations and those in the upper 200 m of the Kola section.

Fig. 4 shows three-year-running means of temperature averaged over the depth intervals 0-50, 50-100 and 100-200 m at the fixed oceanographic stations. A close correlation between the three depth layers is clear. This indicates that most of the SST fluctuations reflect similar fluctuations in all depth layers of the coastal waters. The agreement with the trends in the Kola section (Fig. 3) suggests that these fluctuations are of oceanic character, and not confined to near-shore and coastal waters. Fluctuations with a duration of approximately 5 to 20 years are to a great extent repeated at all three stations, and there seems to be no systematic difference between summer and winter.

Time series in the Rockall Channel (ELLETT 1978), in the North Sea (LJØEN and SÆTRE 1978), in the Norwegian Atlantic Current (BLINDHEIM and LOENG 1981) and in the Norwegian and Greenland Seas (ALEKSEYEV and PENIN 1973) all show fluctuations of similar character. Though these time series are short, they still indicate good agreement with the trends shown in Figs. 2-4. As regards the relative long-term series at the meteorological stations, the above considerations suggest that they give information on long-term oceanic trends.

At Torungen and Ona the time series (Fig. 5) indicate a trend towards warming lasting for a much longer period. This trend, which is known also in the atmosphere and from other SST series, (e.g. SMED 1947 - 1979), was considerably more conspicuous here in the summer quarter than in the winter. In

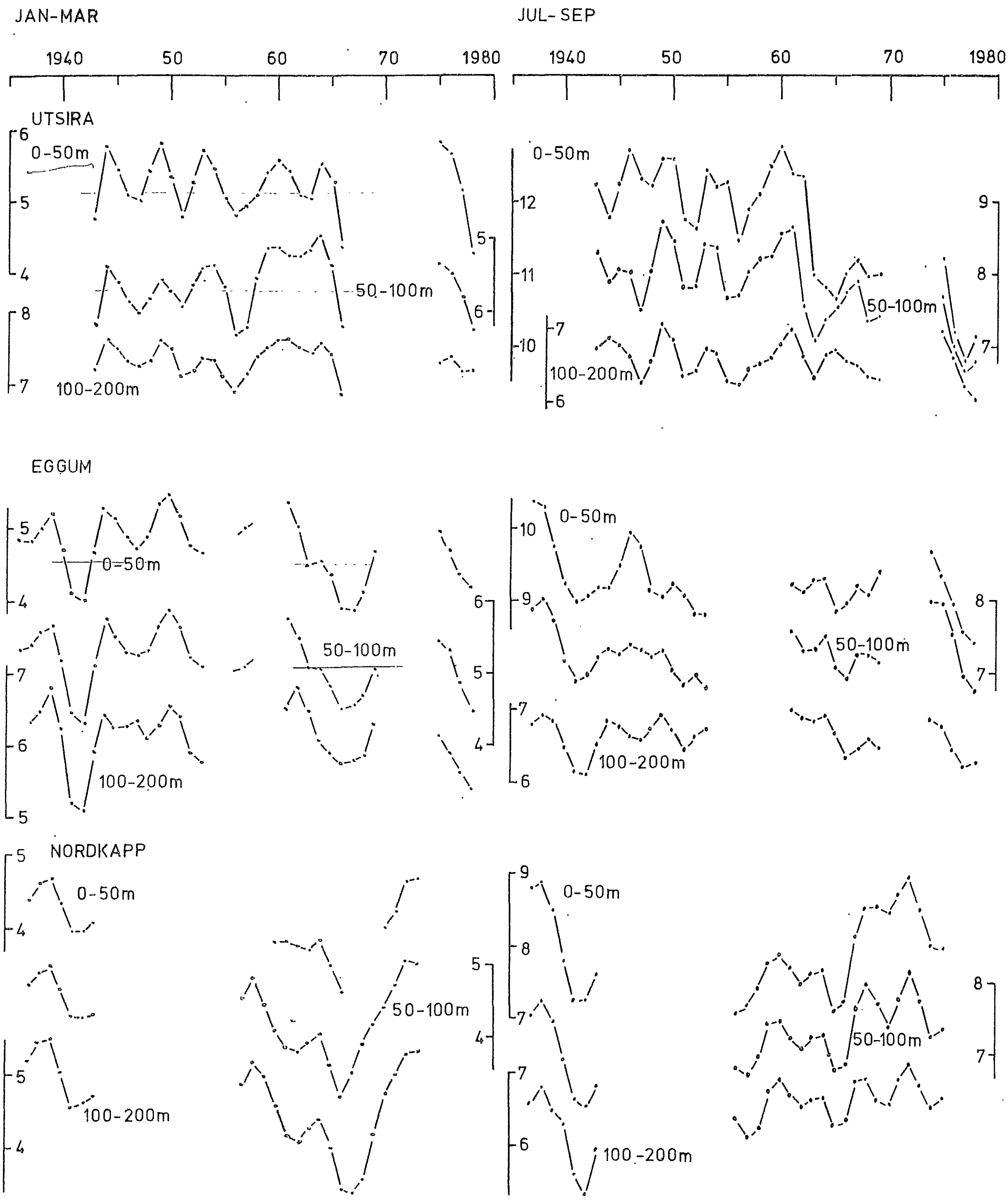

Fig. 4. Three-year-running temperature means (1-2-1) for the January-March and July-September quarters at Utsira, Eggum and Nordkapp. Means of averages over the depth intervals 0-50, 50-100 and 100-200 m are entered.

the summer this trend is clearly indicated for nearly 50 years from about the turn of the century. Fig. 5 suggests a slowly rising trend in winter temperatures going on from the beginning of the observation period, culminating about 1940-1950. The increase in ten-year mean from 1901-1910 to 1931-1940 at Torungen was 1.3 and 0.3°C in summer and winter respectively. At Ona the corresponding temperature rise in the summer quarter was 1.4°C and 0.1°C in the January-March quarter.

The time series at the Nordkapp station gives little information about this trend because of the inhomogenity in the data. Fig. 5 is, however, suggestive of a trend off Nordkapp similar to that at the two other stations.

The difference between temperature trends in summer and winter is in contrast to the temperature trend in the atmosphere over the same period (e.g. AHLMANN 1949, HESSELBERG 1940). The atmospheric climate turned more maritime during the period and the temperature increase occurred in connection with mild winters to a greater extent rather than due to warmer summers.

The seasonal pattern of the temperature trend in the sea may to some extent be due to winter convection. The summer heating being confined to the surface layers during the warm season, is during the winter evened out over a deeper water column by convection. This assumption is supported by the time series in the Kola section where the mean temperature of the 0-200 m layer shows close relationship between summer and winter. The 0-50 m layer shows, however, a steeper temperature increase in summer than in winter, the increase between the five-year periods 1900-1904 and 1936-1940 being close to 1.2°C both for the summer and winter quarters in the 0-200 m layer and for the winter quarter in the 0-50 m layer. The mean for the July-September quarter in the 0-50 m layer increased by 1.9°C.

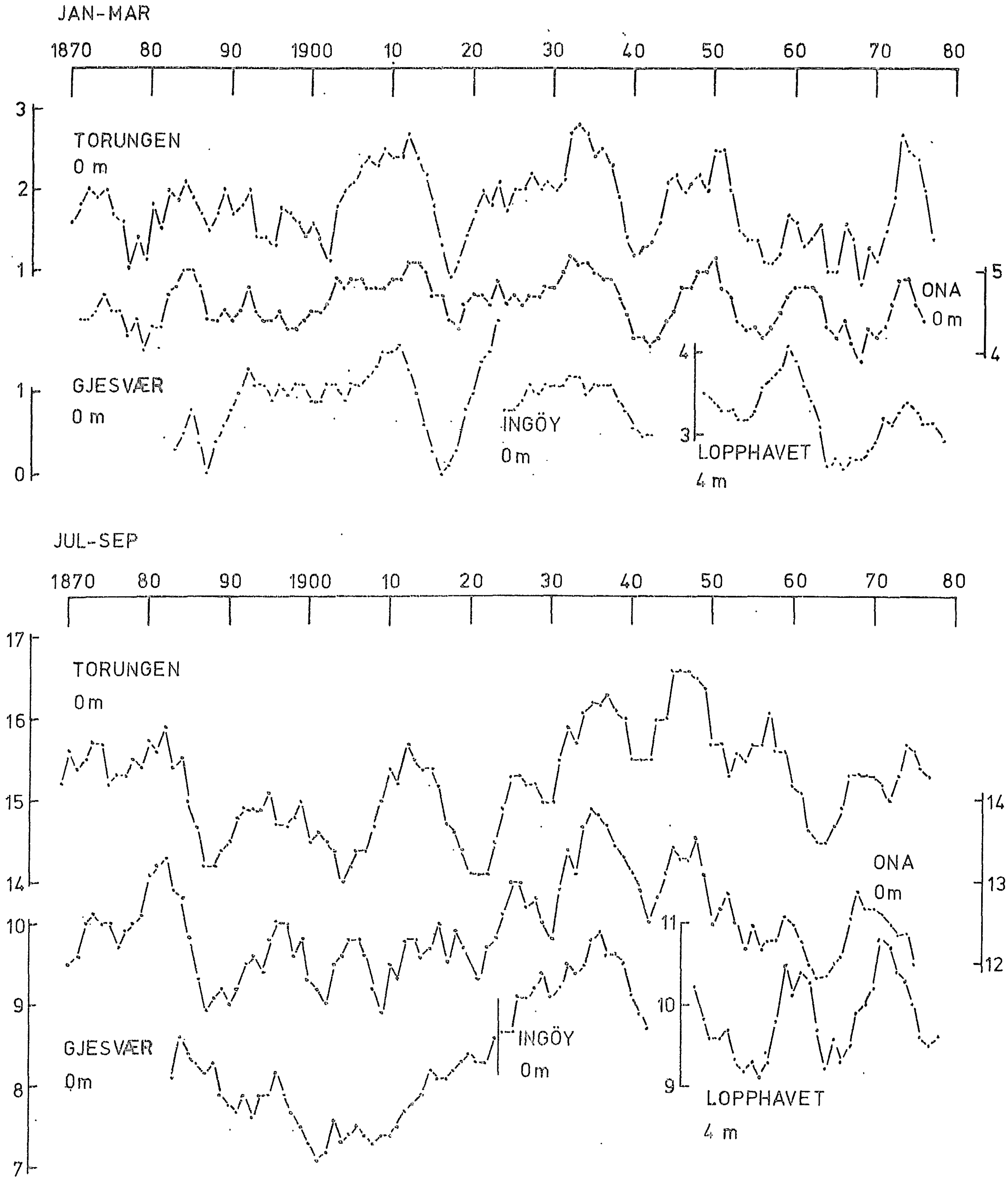

Fig. 5. Five-year-running means of quarterly sea surface temperature means at Torungen, Ona and Nordkapp. Graphs for January-March and July-September are shown.

The time series of the fixed oceanographic stations are too short and have too many gaps for being of definite support in this respect. The variation with depth and season of the temperature decrease from 1935 to 1954 at Eggum may, however, be in support of the role of the convection.

The above considerations suggest that the long-term trend is due to direct heat transfer in the region. The shorter long-term fluctuations, lasting in the order of 5-20 years, show about the same amplitudes in all the three depth layers at the fixed stations, and their trends show small differences between summer and winter. These fluctuations are therefore probably of advective nature.

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