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Tittel (norsk/engelsk):
HYDROGRAFISK VARIABILITET I TID OG ROM I SKAGERRAK/
TEMPORAL AND SPATIAL HYDROGRAPHIC VARIABILITY
IN THE SKAGERRAK

Forfatter(e):
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Sammendrag:
Rapporten omhandler variabilitet i hydrografien i Skagerrak. Ved hjelp av statistiske metoder analyseres variasjonsmønstre i rom og tid. Metodene brukt omfatter frekvensanalyse og romlig korrelasjonsanalyse. Analysen tar utgangspunkt i det faste hydrografiske snittet som går på tvers av Skagerrak fra Torungen (Arendal) til Hirtshals, nær et år med tidsmessig godt oppløste strømmålinger fra en fast montert automatisk strømmåler plassert utenfor Torungen og modellresultater fra den fysisk-kjemisk-biologiske modellen NORWECOM.

Summary:
This report addresses the temporal and spatial variability in the hydrography of the Skagerrak by means of statistical investigations including frequency analyses and spatial correlations. The analysis is based on the fixed hydrographic section across the Skagerrak between Torungen (Arendal), Norway and Hirtshals, Denmark, close to a full year of temporally highly resolved hydrographic measurements by moored automatic current meters, placed off the coast from Torungen, and modelled output from the coupled physical-chemical-biological model system NORWECOM.

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prosjektleder

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TEMPORAL AND SPATIAL HYDROGRAPHIC VARIABILITY IN THE SKAGERRAK EVALUATED BY OBSERVATIONS AND MODEL RESULTS

By

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1. Summary

The hydrodynamics of the Skagerrak region in Northern Europe are quite complicated due to the combined effect of major water exchanges with the North and Baltic Seas, with large supplies of freshwater. Since about 70% of the water entering the North Sea is assumed to pass through the Skagerrak before leaving the North Sea again, many of the hydrographic events taking place in the North Sea will be reflected here.

This report addresses the temporal and spatial variability in the hydrography of the Skagerrak by means of statistical investigations including frequency analyses and spatial correlations. The analysis is based on the fixed hydrographic section across the Skagerrak between Torungen (Arendal), Norway and Hirtshals, Denmark, close to a full year of temporally highly resolved hydrographic measurements by moored automatic current meters placed off the coast from Torungen, and modelled output from the coupled physical-chemical-biological model system NORWECOM.

The total temporal variability in both salinity and temperature decreases dramatically with depth in the Skagerrak, while the relative importance of variability at interannual and lower frequencies increases strongly. 10 km off Arendal the total variance in salinity was at 20 m depth 13% of the surface value, at 50 m only 2%. The reduction in variance with depth is similar within all period intervals. The percentage of total temperature variability in the upper layers relating to seasonal variation is high

while the interannual component is small close to the coast and somewhat larger in the central basin.

Spatial variability in salinity and normal velocity in the upper layers of the Skagerrak depend on location and direction, but may be pronounced even at relatively small distances. At 5 meters depth along the section Torungen-Hirtshals, variability in modelled salinity explains on average only about half of the variability at locations 20km away.

2. Introduction

The Skagerrak is an extension of the North Sea covering the region between Norway, Denmark and Sweden. From shallow areas in the south the bottom slopes towards the deep basin of the Norwegian trench, extending down to about 700m. The Skagerrak can be viewed as a transition zone between the much larger Baltic and North Seas and is strongly influenced by both (Dahl and Danielssen 1992; Skogen et *al.* 1997a). The basic and deep reaching cyclonic circulation in the area is to a large extent forced by the mixing of the high-saline deep water into the outflowing low-saline surface water of Baltic origin (Fig 1). The time-dependent part of the motion, on the other hand, is probably an effect of wind, both locally and at a more regional scale. In both cases the topography, viz. the existence of the Norwegian Trench, plays a crucial role (Rodhe 1996). Our observations and model results indicate that under certain conditions the prevailing westwardly flowing current along the Norwegian Skagerrak coast may reverse and flow eastwards.

Since about 70% of the water entering the North Sea is assumed to pass through the Skagerrak before leaving the North Sea again, many of the hydrographic events taking place in the North Sea will be reflected in this area (Danielssen et al. 1996). A mean total volume transport from the North Sea to Skagerrak of 0.5-1.0 Sverdrup (Sv., 1 Sv. $=10^6$ m^3s^{-1}) has been suggested (Svansson 1975; Rodhe 1987; Rydberg et al. 1996). From moored current meter measurements in May 1990, during SKAGEX (Danielssen et al. 1991; 1997; Dybern et al. 1994), a water mass exchange in the magnitude of 1 (+/- 0.5) Sv. between the Skagerrak and North Sea was calculated. This is in accordance with modelled transports for the same period (Svendsen et al. 1995; Svendsen et al. 1996; Skogen et al. 1997a; Skogen et al. 1997b). However, a clear seasonal pattern, going from more than 3.0 Sverdrup in November and December to less than 1.5 Sv. in April has been indicated by Skogen et al. (1997a) in addition to a moderate interannual variability. Furthermore, the inflow of different water masses from the North Sea is highly variable on time scales of a few days (Danielssen et al. 1997; Skogen et *al.* 1997a).

The maximum net outflow from The Baltic is about 0.1 Sv. (Andersson and Rydberg, 1993). However, since this is water of very low salinity (about 10), it strongly influences the stratification and baroclinic forces in the Skagerrak. Short time variability in the inflow of low-salinity water from the Baltic to the Kattegat is to a large degree determined by the surface level in the Kattegat (Stigebrandt 1980). However, the outflow from the Kattegat to Skagerrak is regulated by the baroclinic structure, particularly related to the Northern Kattegat front (Stigebrandt 1983; Jakobsen 1997). The distribution of the relatively fresh surface water (typically about 20m thick) is strongly influenced by varying wind conditions (Aure and Sætre, 1981; Sætre et al. 1988; Gustafsson and Stigebrandt, 1996). However, when the wind is weak the surface water will, as a rule, follow the general cyclonic circulation (Danielssen et al. 1997).

Further information on the circulation pattern and water masses in the Skagerrak area can be found in a number of earlier publications (e.g. Svansson 1975; Otto et al. 1990; Danielssen et al. 1991; Rodhe 1992; 1996; 1998; Gustafsson 1997).

Here, we examine the temporal and spatial variability in the hydrography of the Skagerrak by means of observations and model results. The distribution of variance within periodic components is analysed as a function of depth and geographical location. The spatial covariability pattern throughout the region is studied as a function of distance and direction, both for raw and temporally filtered values. The focus is primarily on salinity variability, while also density, temperature and normal velocity are studied. This is because the water masses in the region are mostly characterised by the salinity which, to a large degree, also determines the density. In addition, the very strong seasonal signal tends to obscure other features in the temperature variability.

The analyses are based on salinity and temperature data from selected stations on the fixed hydrographic section across the Skagerrak between Torungen (Arendal) on the southeast coast of Norway and Hirtshals on the Danish northwest coast (Fig 2), salinity measured by moored automatic current meters placed off the coast from Torungen, and salinity and normal velocity calculated by "The NORWegian ECOlogical Model system", NORWECOM, (Skogen 1993) for five sections along the Norwegian coast. The combination of long time series of station data, temporally highly resolved measurements from the current meter and spatially highly resolved modelled values, gives us a unique opportunity for a comprehensive study.

3. Material and methods

3.1 Hydrographical observations

Salinity and temperature have been surveyed along the section Torungen-Hirtshals (Fig 2) at near monthly resolution since 1952. We use time series for the period 1952-1996 with focus on four stations. These stations have been selected to represent different areas and water masses. Station 205 is situated in Norwegian coastal water and 220 in an area in the middle of the trench effected by deep water, while station 235 is influenced by the core of the inflow of Atlantic water along the 200 m isoline, and 241 is affected by water masses with origin in the central and southern North Sea influenced by continental river runoff. The custom of naming the stations with the digit "2" preceding the distance (in nautical miles) from the Norwegian coast is applied (Fig 2). To study the degree of covariability between stations, standard Pearson product-moment correlations are used.

Stigebrandt et al. (1995) measured salinity (and temperature, not used here) outside Torungen (Fig 2, position N 58° 21.98', E 8° 50.83') with a temporal resolution of 10 minutes, by means of moored automatic Aanderaa current meters. They showed that variance in density at periods of less than one hour is negligible at all depths. We therefore use hourly means as our most highly resolved series. Measurements taken at 13, 20, 30 and 75 meters during the period 27.10 1992 - 22.9 1993 are used in this work.

3.2 Output from the NORWECOM numerical model

NORWECOM is a coupled physical-chemical-biological model system (Skogen 1993) which is operational for the North Sea and the Skagerrak. The North Sea model has a horizontal resolution of 20 km and covers the whole North Sea and adjacent areas. Results from runs of this model are used as boundary conditions for the Skagerrak model covering the Kattegat, Skagerrak and the coast of Norway to Stadt with a horizontal resolution of 4km. NORWECOM is forced with realistic winds made available by the Norwegian Meteorological Institute (Eide et al. 1985; Reigstad and Iden, 1995), realistic monthly means of freshwater and nutrient inputs from the mayor European rivers and modelled outflow from the Baltic. In this study, we are only interested in the physical output from NORWECOM.

The complete NORWECOM was run for 1993 and modelled values saved for five sections along the Norwegian coast (Fig 2). Three of the sections cross the Skagerrak from the Norwegian to the Danish coast: Jomfruland-Skagen (JoSk), Torungen-Hirtshals (ToHi) and Oksøy-Hanstholm (OkHa). The two last sections stretch from the coast of Norway into the North Sea, one section along the western boundary of the Skagerrak, Lindesnes-SSW (LiSSW), and one further northwest, Egerøy-SW (EgSW).

Modelled output was averaged over 25 hours and saved once a day for the selected stations. Variability at periods shorter than the Nyquist period of 2 days was thus removed. Modelled values from the sections were interpolated vertically to 5m and horizontally to equidistant "stations" 4 km apart. This results in time series for each station along the sections consisting of 355 daily (24h) means. These daily values are the "raw data" which are the starting point for all further calculations. They were filtered by means of simple running means, giving additional time series accounting for periods shorter than 7 days (high pass 7 day), in the 7-29 days range (band pass 7-29 days) and in the 29-91 days interval (band pass 29-91 days).

At each station the local standard deviation is calculated for both raw data and filtered series. The standard deviations indicate regions of smaller and larger variability; standard deviations of the filtered series also show which time scales dominate the variability. Correlations between the time series from the different stations along a section were calculated. By graphing these as a function of distance between the stations, a picture of how the correlations on average develop with distance is given. Correlations were also computed locally, for a single point, as a function of distance. These correlations for a specific point where expected to depend not only on distance, but also on direction. This was handled by finding the minimum and maximum correlation values. By defining the distance where the correlation falls below a specific threshold as the scale of decorrelation, the two distances will give the maximum and minimum scale of decorrelation. This scale is here chosen to be the distance where the correlation is 0.7, i.e. roughly 50% of the variance being explained by a linear model ($(0.7)^2$).

We analysed how the variance in a time series is distributed in different period intervals. The method used is explained in detail in Stigebrandt (1984) and Stigebrandt et al. (1995). The principle behind is that the total variance in a time series can be approximated by the sum of two subvariances, one pertaining to variability at shorter time scales than a specific period and one to longer periods. This procedure can be used repeatedly to split the total variance into as many period bands as wished. Components of less than 3 months, from 3 to 12 months ("seasonal" variance), and more than 12 months (interannual) are used for the analysis of stations 205, 220, 235, and 241 (see Fig 2 for locations). For the salinity recordings from the current meter intervals of < 1 day, 1-7 days, 7-28 days and > 28 days were chosen, the three latter periods were also applied to the modelled values. Statistical calculations were partly done by means of the SAS system (SAS Institute 1988) partly by FORTRAN programs developed by ourselves.

4. Results and discussion

4.1 Temporal variability

The salinity time series at station 220, in the deepest part of the Skagerrak, shows several periods with less than 34‰ at 30 m depth (e.g. 1977-1981), while the period

1989-1993 is characterised by unusually high salinities throughout the entire year (Fig 3; from Danielssen et al. 1996). Both these anomalies seem to be present also at 200 m depth. The relatively cold and low salinity period of 1977-1981 may be associated with the large-scale "Great Salinity Anomaly" in the North Atlantic (Dickson et al. 1988; Danielssen et al. 1996).

Monthly mean values and standard deviations for temperature and salinity are shown in Fig 4. Maximum values for surface temperature typically occur in August with respectively 1,2, and 4 months delay at 10, 20 and 50 m depth. At larger depths, the mean seasonal variation is weak. Interannual variability, as indicated by the standard deviations, is for the surface layer highest in May, at 10 m in July-August and at 20m in September.

Surface salinity has a clear seasonal pattern with a minimum of about 27 in June increasing to a maximum of around 32.5 in December followed by a decrease throughout the next winter. As expected, the seasonal variation is weaker at 10 m and 20 m, and from 100 m and down it disappears. The year to year variability in the upper layers is largest in March / April, below 100 m it is similarly small for all months. This in agreement with and expands upon the results of Danielssen et al. (1996).

Except for the seasonal cycle, hydrographic variability in the Skagerrak region is not dominated by any single periodicity. On the contrary, changes typically occur as a result of nonperiodic pulses bringing water masses with different characteristics into the system from outside (Aure et al. 1998). Methods developed for detecting single frequencies (e.g. Fourier analysis) are therefore not well suited in this case. By using the method earlier used by Stigebrandt (1984) and Stigebrandt et al. (1995), which decomposes the variance into different period bands or intervals, this problem is avoided. The chosen method is methodically simple and robust.

Fig 5 shows the relative distribution of variance in temperature within period bands by depth. Variability within the 3-12 month band dominates the upper layers. At 50 m 50% (station 220) to 75% (station 241) of the variance is within this interval. The relative importance of variation in the 3-12 months variation declines with depth while the part of the variability in the long period band increases dramatically. Near the bottom of the two deepest stations, at 240 m at station 205 and 600 m at 220, over 90% of the variance in temperature is on the interannual or longer time scale, while variance at a shorter time scale than 3 months is almost totally missing.

Seasonal variability is, as could be expected, not as dominating in the upper layers for salinity (Fig 6) as for temperature. At 50 m 25% to 50% (station 220) of the variance is in this 3-12 month range. As for temperature, but not as pronounced, the relative importance of interannual variability in salinity at the deeper stations grows with depth.

Another noteworthy phenomena is that a larger part of the temperature variance in the upper layers lies in the low frequency band at station 220, in the central part of the trench (30% at 50 m), than at the three other stations, closer to either the Danish or Norwegian coast (10%, (Fig 5). A similar, but less pronounced pattern is also present for salinity (Fig 6). This may be related to the coastal areas being more strongly influenced by processes at shorter time scales, typically related to wind conditions and fresh water runoff.

However, at 150 m depth the longest frequencies still contribute a lot more at station 220 than at 205 and 235. This is in accordance with the results of Danielssen et al. (1996). The large, somewhat warmer, sub-surface volume found in this central part of the trench during winter, also indicates a distinctly higher residence time than closer to both the Norwegian and Danish coast. It has furthermore been noted (Danielssen et al. 1996; Ottersen et al. 1998) that in August the water masses at 150-250 m in this area is fresher and has a smaller standard deviation than along the shelf on both the Norwegian and the Danish side. This results in the so-called "twin peaks" phenomenon (Danielssen et al. 1991) observed by Ljøen and Svansson (1972) in April-May.

The salinity variances themselves (as opposed to the relative values in percent of total variance) at the same depths and stations and distributed among the same three period intervals, are presented in Fig 7 and Table 1. The variance decreases dramatically with depth at all four stations. The variance is, throughout the water column, highest in Norwegian coastal water (stations 201 and 205). The total variance at station 205 is 13% of the surface value at 20 m depth and at 50 m only 2% of the surface value. At the other stations the variance is somewhat smaller, but the reduction with depth even clearer. At station 235 the variance is 8.52 at the surface, 0.42 at 20 m (5% of the surface value) and 0.06 at 50m (0.7%). The reduction in variance with depth is similar for the different period bands.

In order to study hydrographic variability at shorter time scales, analyses similar to that above were performed on the temporally highly resolved hydrographic data recorded by Stigebrandt et al. (1995) by means of moored automatic current meters. Relative distribution of variance in salinity, density and temperature within the period intervals < 1 day, 1-7 days, 7-28 days and > 28 days was analysed. For salinity / density variance at a time scale of more than 28 days accounts for 60% / 53% of the total variance in the series at 13 m, 55% / 73% at 75 m. Variance in density in the 7-28 day range is about 15-20% of the total at all depths, with a slight increase with depth. For salinity, the percentage of the variance in the 7-28 day range has a stronger increase with depth, from 12% at 13 m to 31% at 75 m. For both salinity and density, the relative part of the variance accounted for by frequencies shorter than 7 days decreases rapidly with depth. This is the case in particular for the 1-7 day range which accounts for 20 / 23% of the salinity / density variance at 13m, but only 5% / 0.7% at 75 m. For temperature close to 100% of the variance is located in the frequencies longer than 28 days.

The total variance in both salinity (Table 1) and density decreases rapidly with depth. While the total variance in salinity at 13 m is 4.08, it is reduced to 0.86 (20% of the 13 m value) at 20 m and 0.07 (<2%) at 75 m. The corresponding values for density are 2.37 at 13m, 0.67 (28%) at 20m and 0.09 (4%) at 75m. Temperature variability also decreases with depth, but in a less pronounced manner. Total variance for temperature is 13.70 at 13 m, reduced to 11.88 (87%) at 20 m and 2.16 (16%) at 75 m.

Components of more than 28 days contribute more to the total variability in the density than in the salinity series from the automatic current meter. The reason for this must be the large seasonal variability in temperature having a certain influence on density. This is the case even if density variability in the area otherwise is most strongly related to salinity fluctuations.

The relative distribution of variance at depth within period bands for modelled density values is compared with density measurements from automatic current meter (both located nearby station 205) (Fig 8). The overall impression is that there is good correspondence for the depth interval covered by both sources. The distribution of total variance within period bands for modelled and measured salinity at the same location is given in Fig 9. In both cases, the variance decreases with depth, but the total variance near the surface is higher in the observations than in the modelled values and also decreases more rapidly with depth. Especially the low frequency component of the surface variance seems to be underestimated by the model.

4.2 Spatial variability

The correlations in observed salinity between stations along the Torungen-Hirtshals section (Table 2) decrease with distance at 10 meters depth and, slightly less systematically, at 30 m. High correlations between station 201 and 205 at all levels should be noted and compared to the low levels of covariability between 205 and 215 at 30 m and 50 m. At 30m the correlation between the three stations situated most centrally in the Skagerrak is reasonably high, a tendency which is equally clear at 50 m and 100 m. These stations are, from 30 m and deeper, uncorrelated or weakly negatively correlated with the stations closer to the coast on both the Norwegian and Danish side.

The large spatial salinity correlations between stations 201 and 205 off the Norwegian coast reflect the position of both stations within the Norwegian coastal current. On the other hand, the lack of correlation between these stations and stations 215 and 220 below 10m depth must reflect the latter stations location well outside the coastal water masses. This is in accordance with the similar findings of Ottersen et al. (1998) by means of cluster analysis. They concluded that the former stations are situated in Norwegian coastal water, the latter are more influenced by Atlantic water masses. Our findings furthermore confirm the results of Gustafsson and Stigebrandt (1996) who find the typical width of the Norwegian Coastal Current to be 10-15 km most of the year.

With support in the model validation of Fig. 9, the following results are derived from NORWECOM. The local standard deviation (sd) for salinity at 5 meters depth is graphed as a function of distance from the Norwegian coast in Fig 10. For the three most westerly sections the main characteristic is that of variability being highest near the coast and decreasing with distance. By the coast the variability is highest at Oksøy and decreases as one moves westwards. The sd's are larger along the two easternmost sections. On ToHi the highest sd occurs about 60km from the coast of Norway, on JoSk at around 30 km from Skagen. In this area an eddy, related to downwelling or upwelling processes is often observed. On both sections, the variability decreases again towards the Danish coast. The sd's for the high pass (hp 7 days) and band pass (bp 7-29 days) filtered series are smaller, but the spatial structures are similar, especially in bp 7-29 days). On the other hand, for the longest periods the variability along the Norwegian coast is low. For the 3 westernmost sections it rises to a maximum about 40km from the coast, while for the two sections further east maxima occurs at about the same position as for the raw data. There is a clear tendency at all period bands that the variability decreases when moving westwards from JoSk to EgSW.

The same kind of sd calculation was done for the current normal velocity along the sections (Fig 11). The four sections furthest west cross more or less 90 degrees on the Norwegian Trench, while JoSk is partly parallel to it. All the sections have large variability in the 20 km closest to Norway and minimum values 40-60 km out. The variability in EgSW stays low also when it crosses into the North Sea, while LiSSW has a local maximum 80-100 km from the coast, in the region of inflow of North Sea water. OkHa and ToHi have about the same size of sd's in the Jutland current on the Danish side as in the Norwegian coastal current. The variability in JoSk also has its highest values near the coast of Denmark, but because of the topography, a significant part of the current velocity is along the section so it is difficult to get a proper picture of the variability and width of the current. The sd values are higher for the high frequency band (1-7 days) than for the longer (7-29 days) band. This is the opposite situation to that found for salinity. This is particularly clear on the Danish side of the Skagerrak. This latter result could be related to the eddy north of Skagen noted in the previous paragraph.

Fig 12 shows correlation (r) for salinity at 5 m graphed as a function of distance. The correlation decreases most rapidly on the OkHa section and most slowly on EgSW. Along OkHa r decreases to 0.7 at a distance of somewhat below 20 km, while on EgSW the distance is over 30 km. It should also be noted that on two of the sections crossing the Skagerrak, ToHi and OkHa, r decreases faster than on the two stretching into the North Sea, LiSSW and EgSW. For bp 7-29 the order of the sections according to scale of decorrelation is the same as for the raw data, but in this case the scale lies between 15km and 20km.

Maximum and minimum scales of decorrelation for modelled salinity are in Figs 13 respectively 14 plotted as a function of distance from the coast of Norway. It is important to be aware of the values being dependent on the choice of r, 0.7. A higher value of r would lead to smaller scales of decorrelation. However, tests indicate that the relations between the scales are close to independent of r in this case. The hp 7 variability displayed spatially nearly constant scales of decorrelation (both minimum and maximum) at about 10 km on all sections. For the raw data and the other filtered time series the picture is more complex, but by studying the maximum and minimum scales of decorrelation in unison quite a lot of useful information may be extracted.

On the EgSW section the scale grows with distance from the coast, on the outermost part of the section the scale is more than 60 km. The scale of the bp 7-29 series changes about 70 km from the coast. At this point the maximum scale increases from about 20km to about 30km and the minimum scale from around 15km to 20-25km. The change is also seen in the other curves. On the LiSSW section a jump shows up about 100 km from the coast, for the bp 7-29 series the scale changes from about 20 km to about 30 km. For the raw data, the jump is followed by a V form in the curve for maximum scale.

The unfiltered and the bp 7-29 series from OkHa are characterised by relatively stable scales of decorrelation of around 20 km, only the longest periods show any clear fluctuations. On the ToHi section the unfiltered data and the series of longer periods have zones of about 15 km close to Norway and 30-40 km close to Denmark where the scales of decorrelation are a lot smaller than in central parts of the Skagerrak. The scales of decorrelation for the variability at lower frequencies on the JoSk section reflect that there is a stretch of about 80 km with high intercorrelation. For the more high frequency series, the scales also grow towards the middle of the section, but slowly and never reaching more than 20km.

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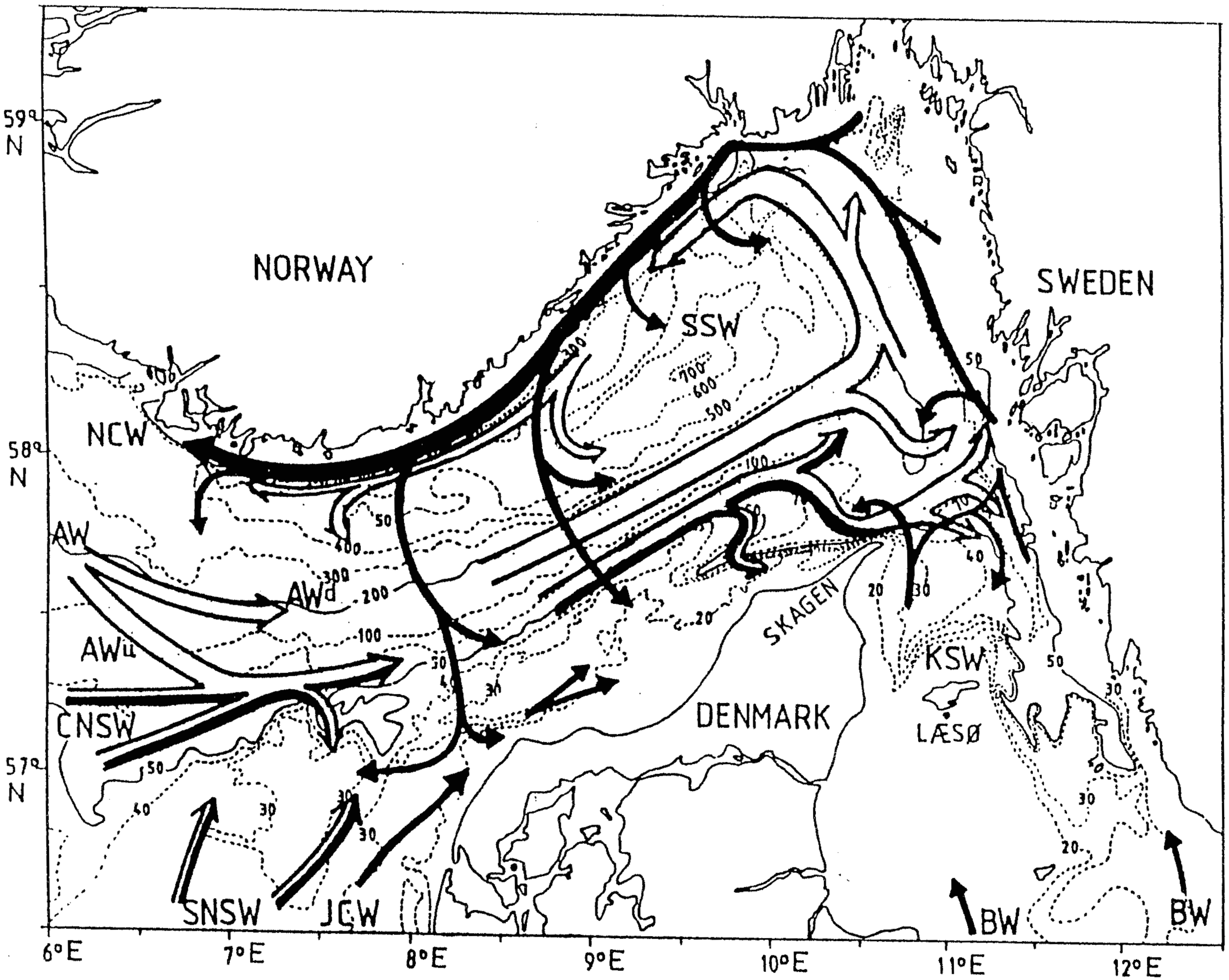


Figure 1. The main features of the general circulation pattern in the Skagerrak and adjacent areas. Filled and open arrows indicate respectively surface and subsurface currents. AW=Atlantic Water, AW^u=Atlantic Water upper, AW^d=Atlantic Water deep, BW=Baltic Water, CNSW=Central North Sea Water, JCW=Jutland Coastal Water, KSW=Kattegat Surface Water, NCW=Norwegian Coastal Water, SNSW=Southern North Sea Water, and SSW=Skagerrak Surface Water (from Danielssen & al. 1997).

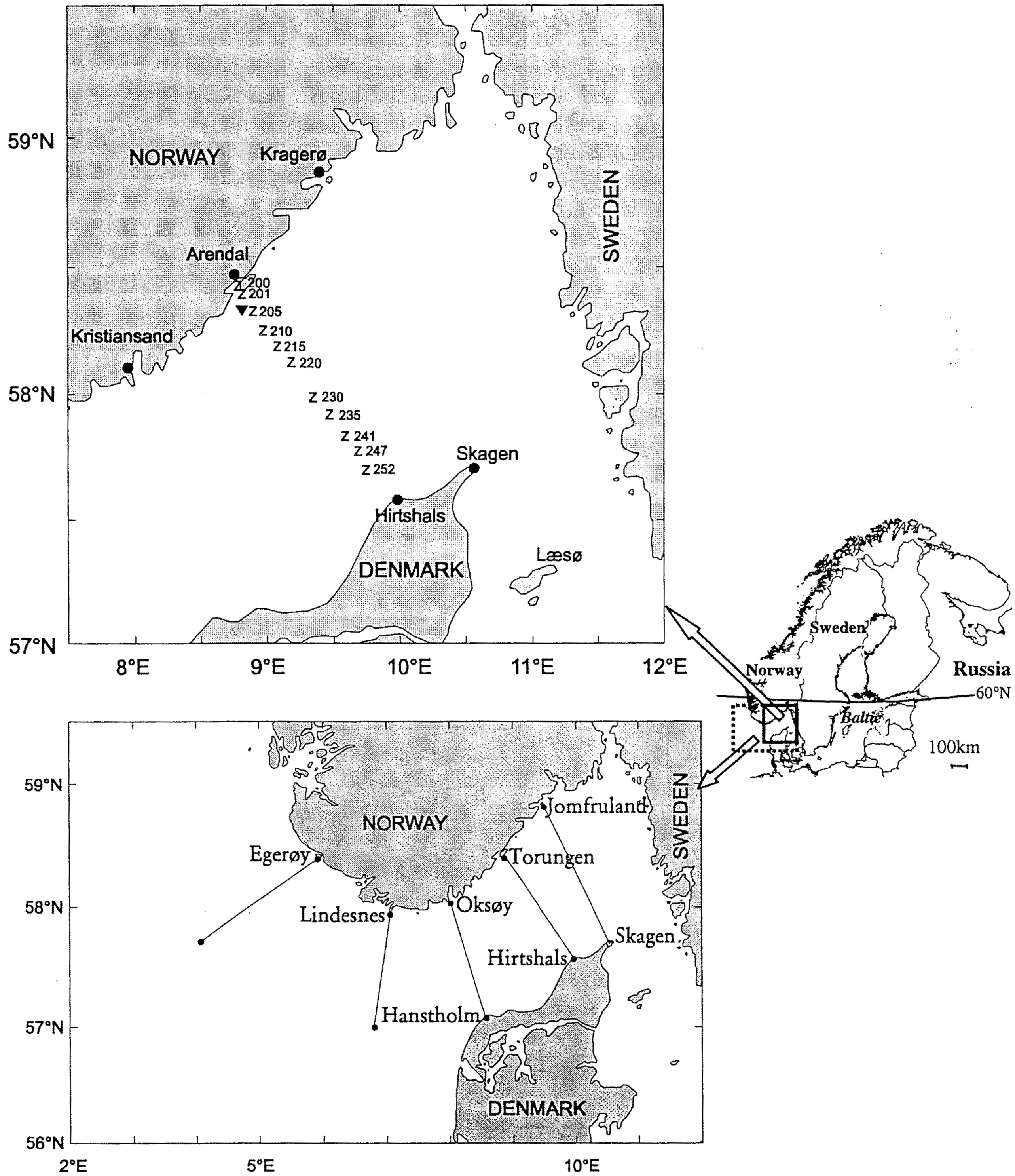


Figure 2. Location of hydrographic stations and sections. Upper panel: The section from Torungen (Arendal) to Hirtshals. The last two digits in the station numbers indicate the distance (in nautical miles) from the Norwegian coast. The position off Torungen of the moored automatic current meter where high-resolution hydrographic measurements were taken is indicated by the filled triangle. Lower panel: Sections were modelled salinity and normal velocity values have been extracted. From west towards east: Egerøy-SW, Lindesnes-SSW, Oksøy-Hanstholm, Torungen-Hirtshals and Jomfruland-Skagen.

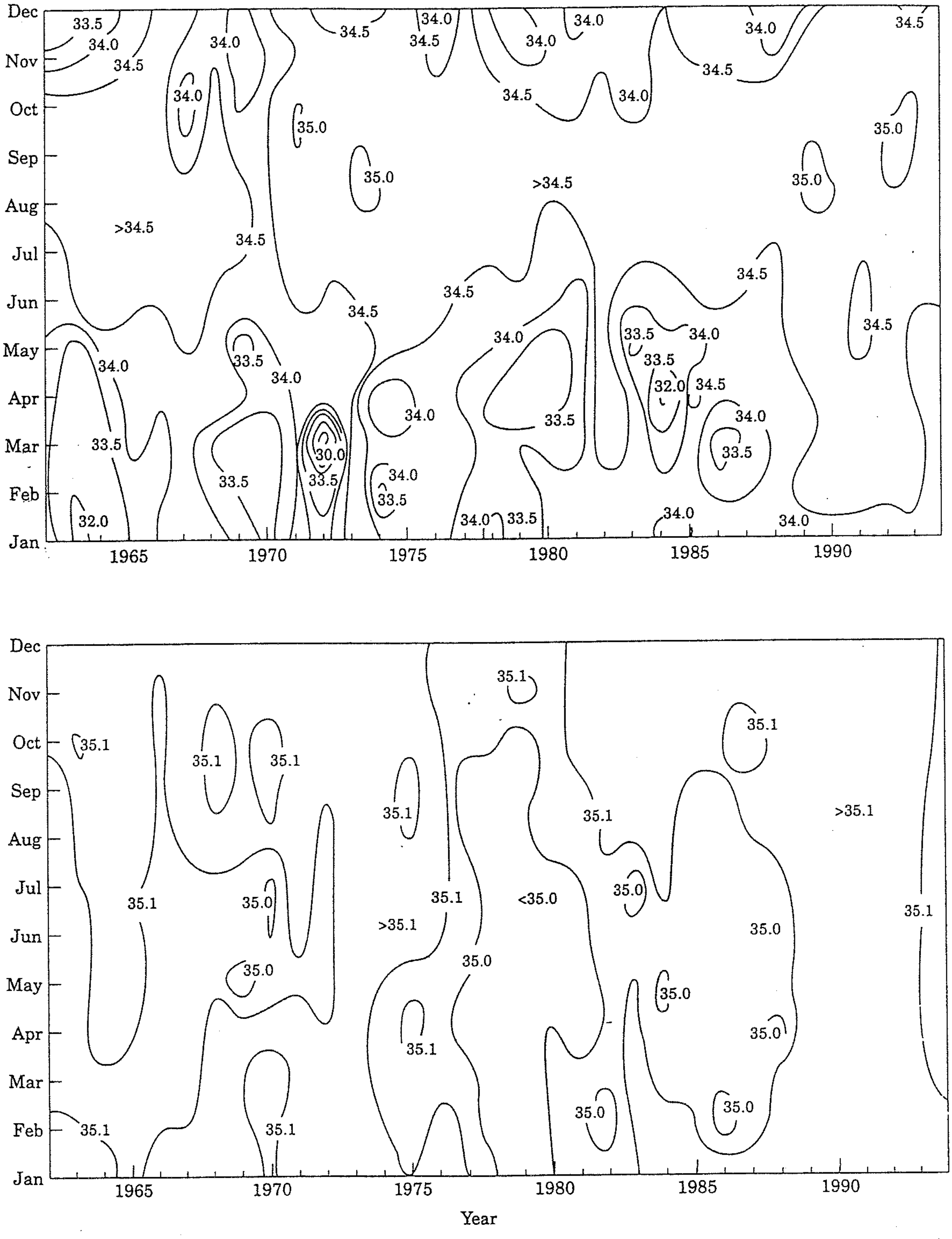


Figure 3. Salinity at station 220 at depths of 30 m (upper panel) and 200 m (lower panel), 1962-1994 (from Danielssen & al. 1996).

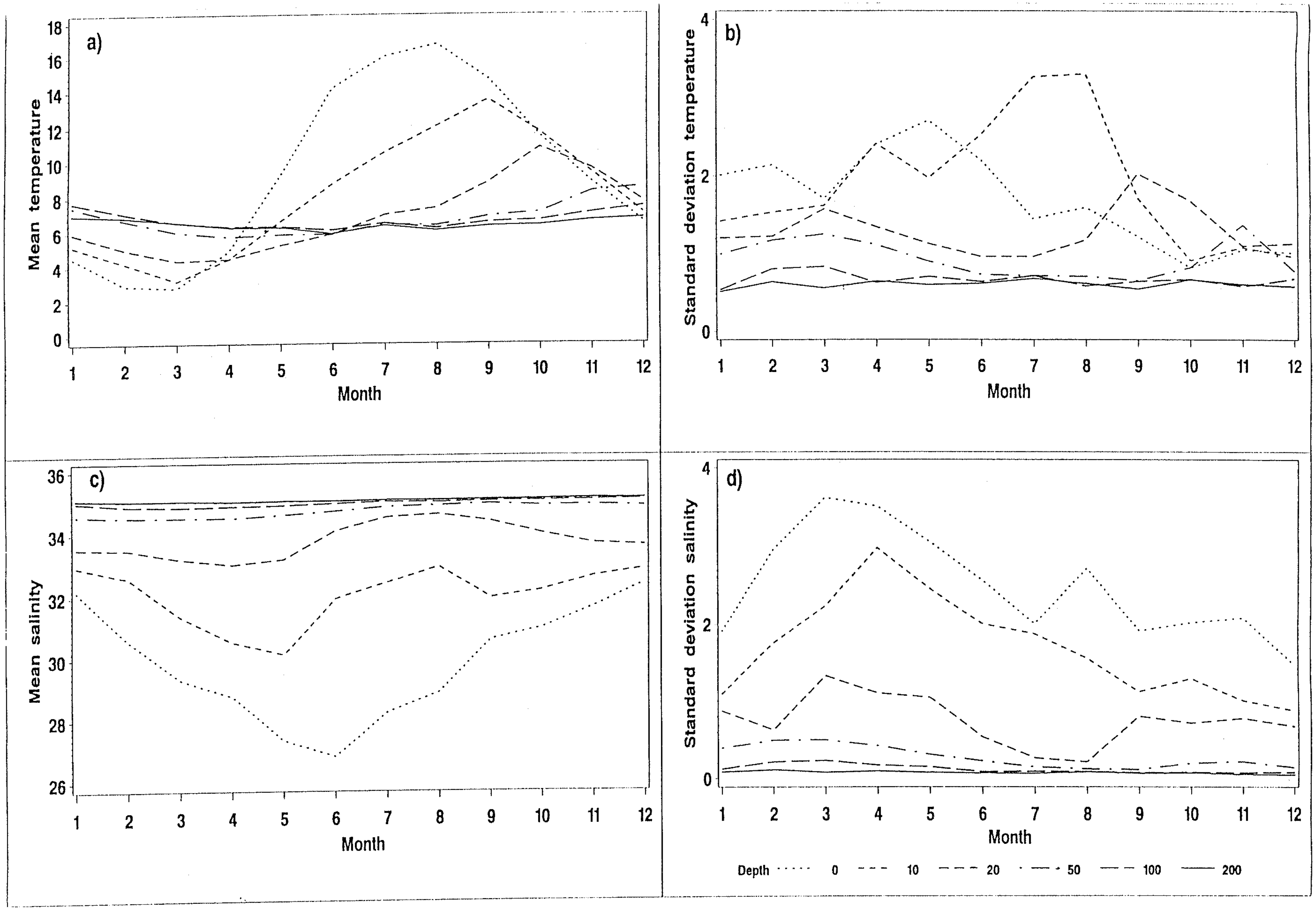


Figure 4. Means and standard deviations of temperature and salinity by month from selected depths at station 220 at the deepest part of the Skagerrak in the middle of the Norwegian trench. a) Temperature means, b) standard deviation of temperature, c) Salinity means, d) standard deviation of salinity.

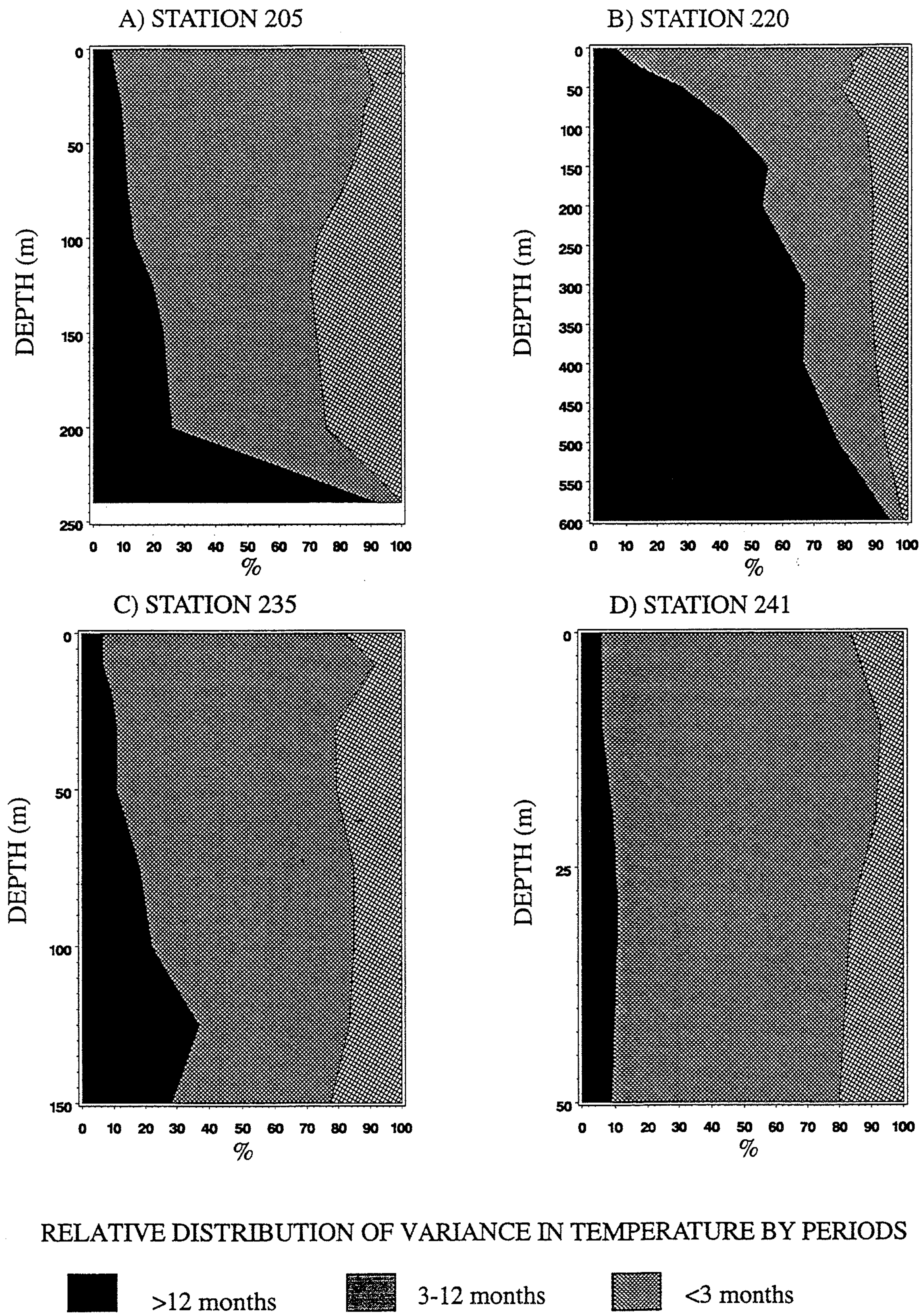


Figure 5. Relative distribution of temperature variance by period band and depth for stations A) 205, B) 220, C) 235, and D) 241 along the section Torungen-Hirtshals. Data from 1952-1996. Note different depth scales. The variance in the original series is put to 100%. The figure shows how much of the total variability that is explained in the different period bands.

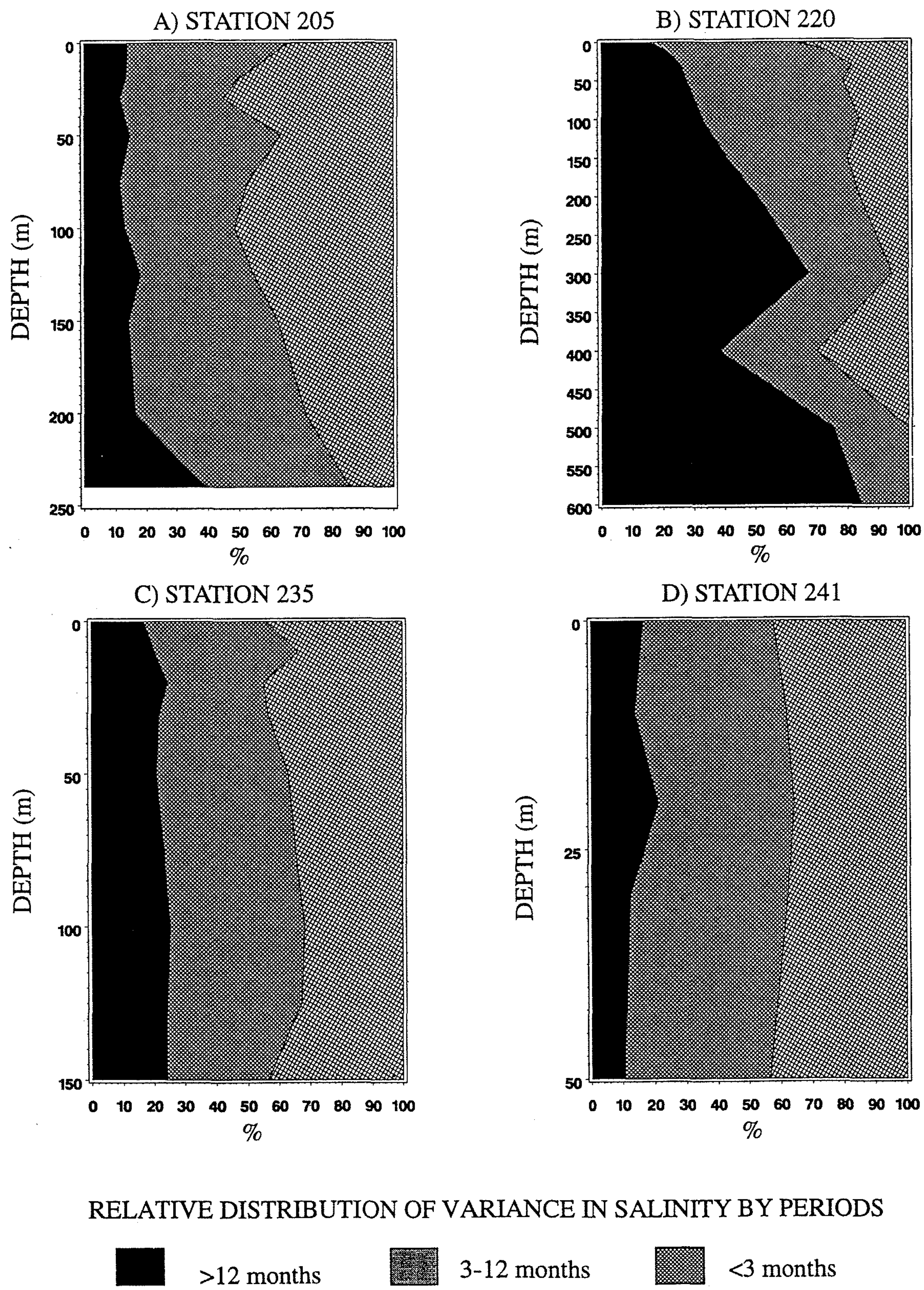


Figure 6. Relative distribution of salinity variance by period band and depth for stations A) 205, B) 220, C) 235, and D) 241 along the section Torungen-Hirtshals. Data from 1952-1996. Note different depth scales. The variance in the original series is put to 100%. The Figure shows how much of the total variability that is explained in the different period bands.

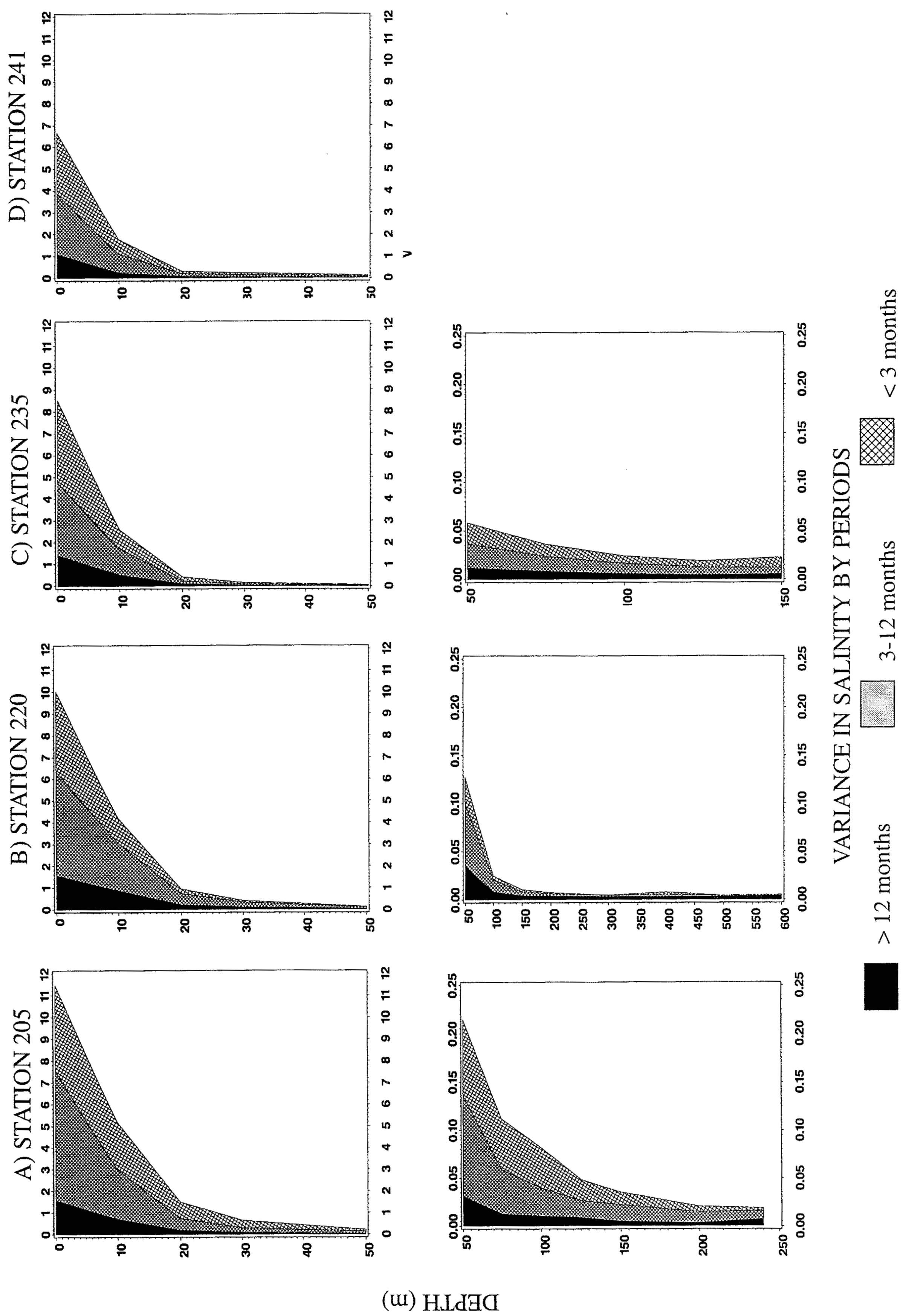


Figure 7. Distribution of salinity variance by period band and depth for stations A) 205, B) 220, C) 235, and D) 241 along the section Torungen-Hirtshals. Data from 1952-1996. Note different depth scales and that due to difference in size of values the intervals 0-50m and 50m- are plotted with different scales.

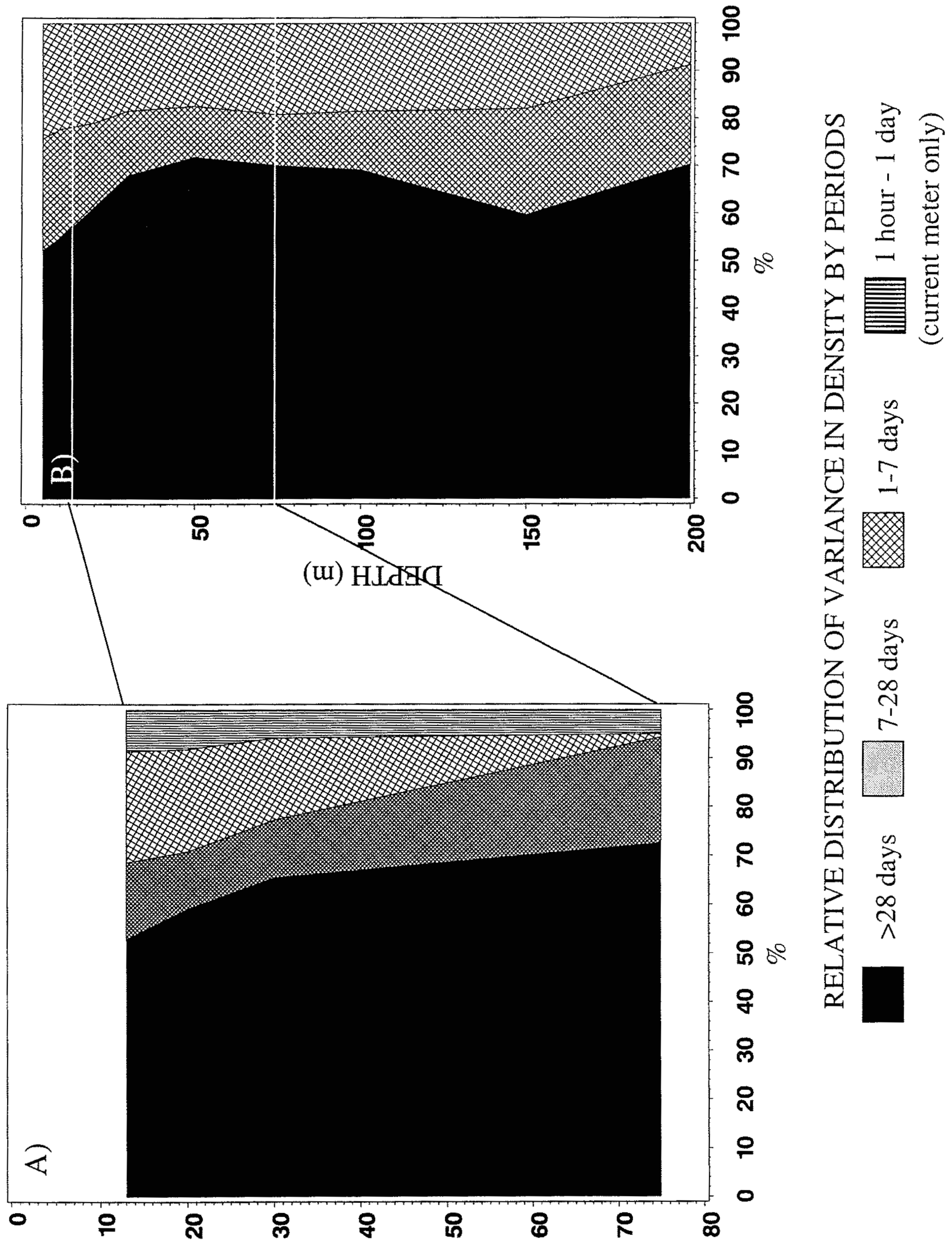


Figure 8. Relative distribution of density variance by period band and depth from highly resolved current meter data (left panel) and modelled values from near station 205 (right panel). Data from 1993. Locations are shown in Fig 2.

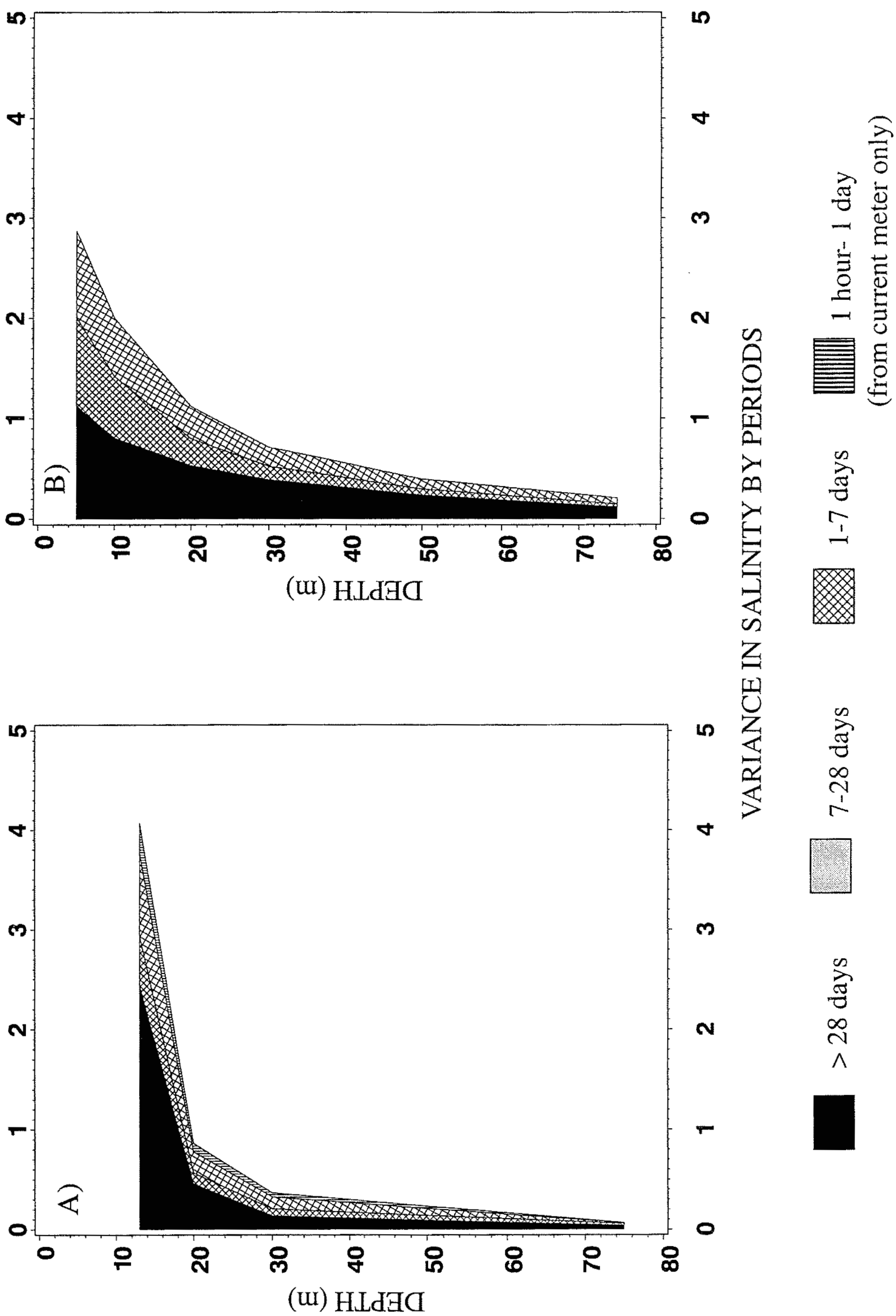


Figure 9. Salinity variance from highly resolved current meter data (left panel) and modelled values from near station 205 (right panel). Data from 1993. Locations are shown in Fig 2.

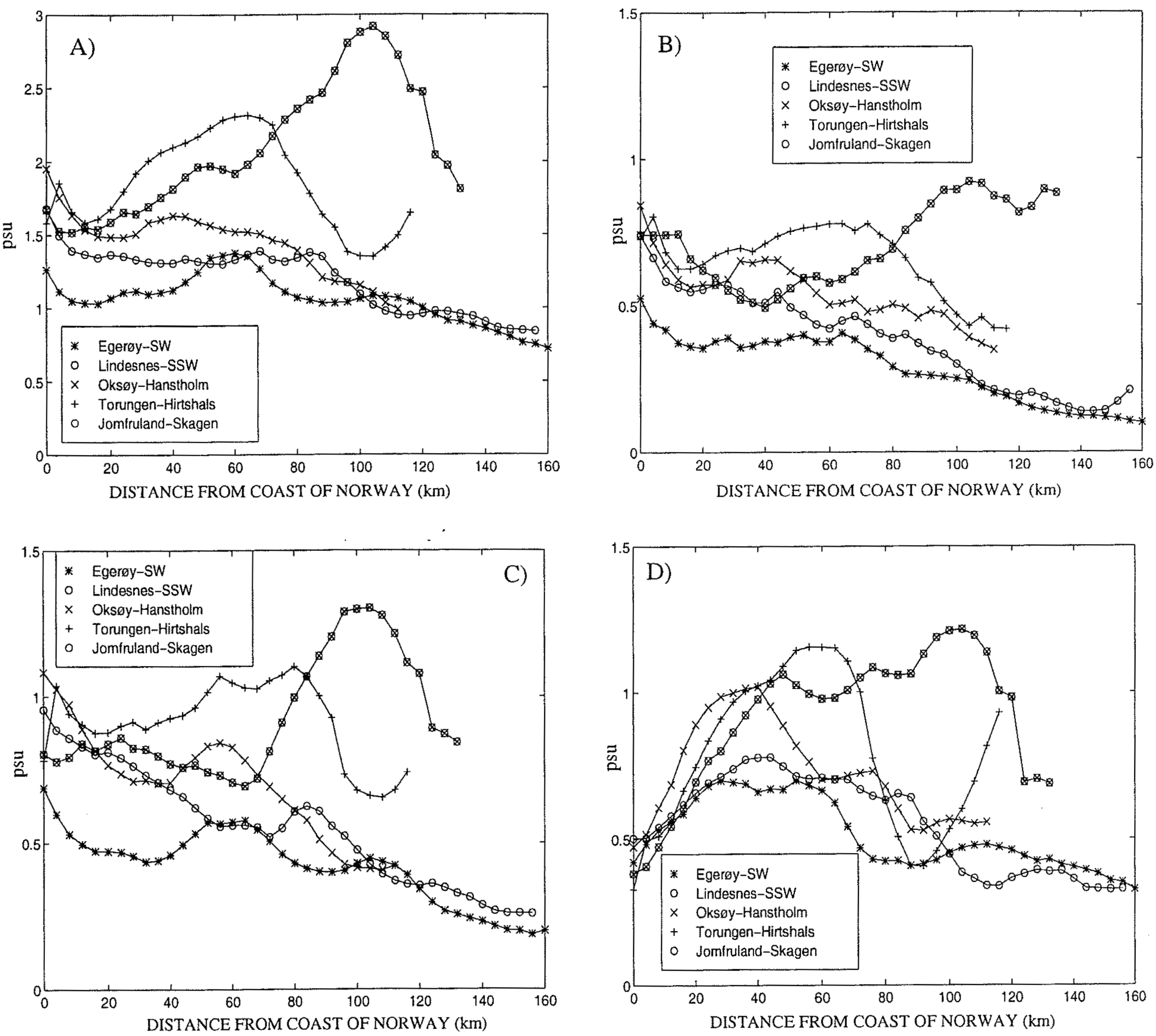


Figure 10. Standard deviations from modelled salinity at 5m depth as a function of distance from the Norwegian coast along the five sections Egerøy-SW, Lindesnes-SSW, Oksøy-Hanstholm, Torungen-Hirtshals and Jomfruland-Skagen. Standard deviations are shown for raw values (A) and 3 filtered time series: B) high pass 7 day, C) band pass 7-29 days and D) band pass 29-91 days. Note that the vertical scale is different for the raw and filtered series.

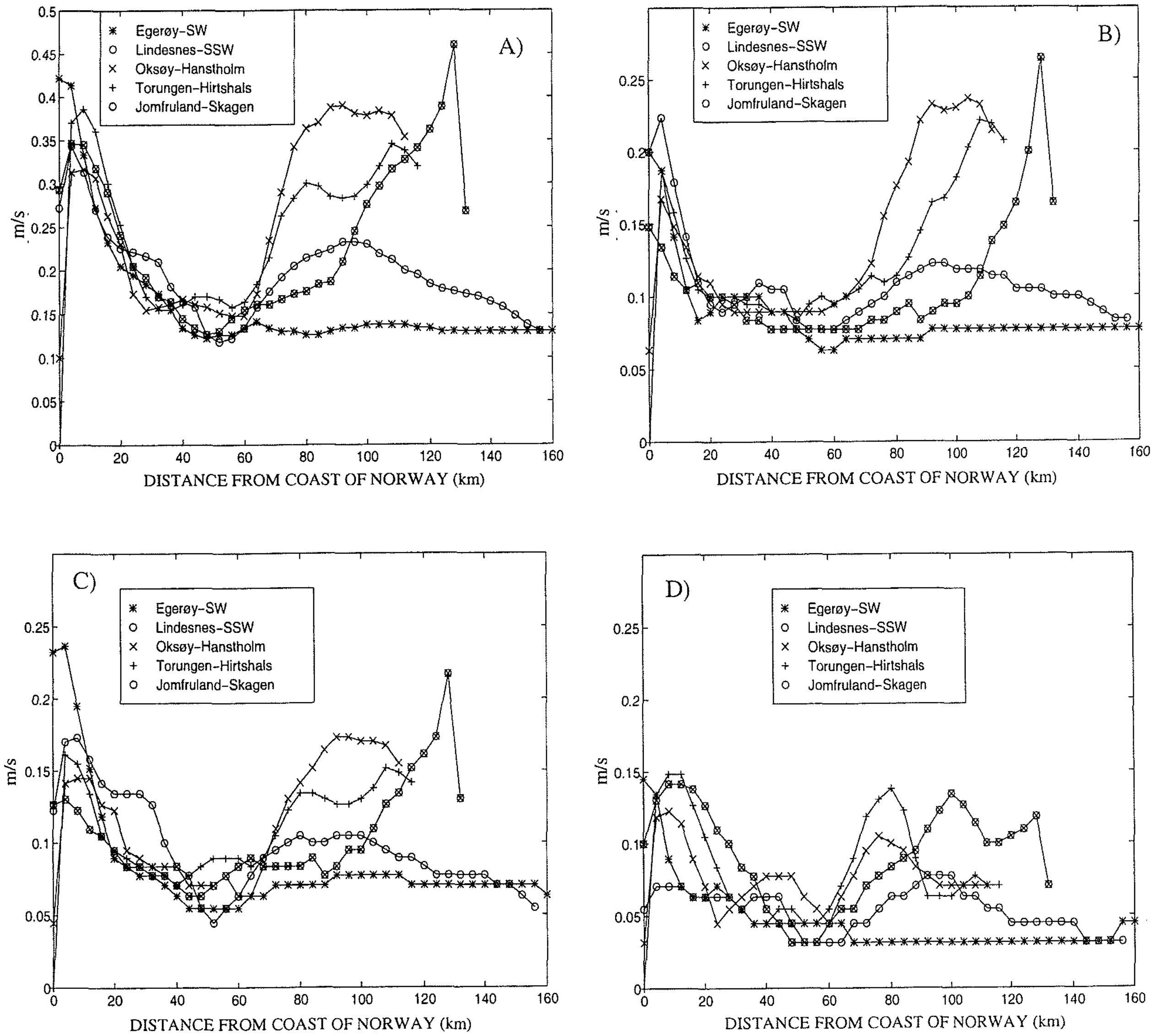
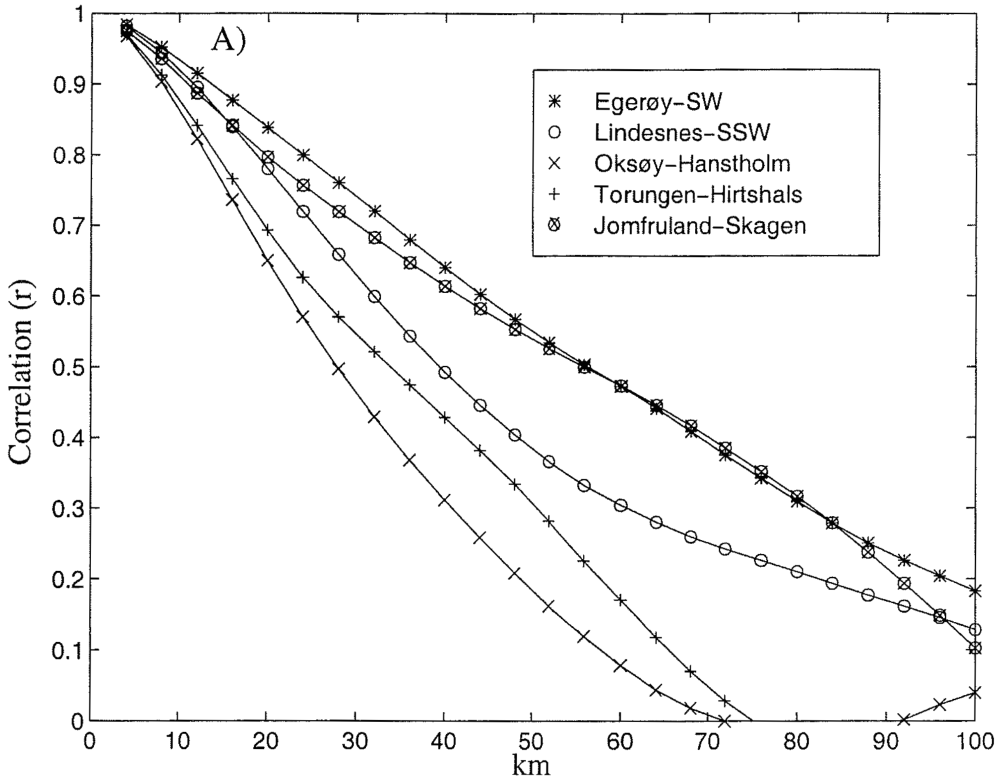


Figure 11. Standard deviations from modelled normal velocity at 5m depth as a function of distance from the Norwegian coast along the five sections Egerøy-SW, Lindesnes-SSW, Oksøy-Hanstholm, Torungen-Hirtshals and Jomfruland-Skagen. Standard deviations are shown for raw values (A) and 3 filtered time series: B) high pass 7 day, C) band pass 7-29 days and D) band pass 29-91 days. Note that the vertical scale is different for the raw and filtered series.



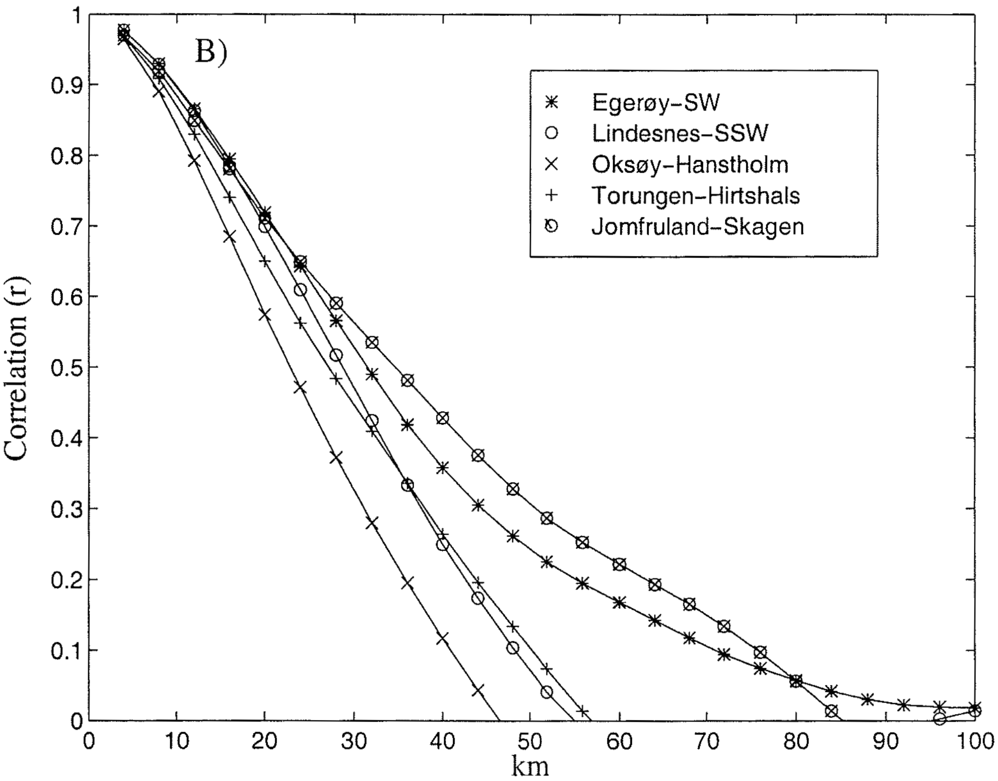


Figure 12. Correlations for modelled salinity at 5m as a function of distance between the stations along the five sections Egerøy-SW, Lindesnes-SSW, Oksøy-Hanstholm, Torungen-Hirtshals and Jomfruland-Skagen. Correlations are given for raw data (upper panel) and the 7-29 days band pass filtered series lower panel) .

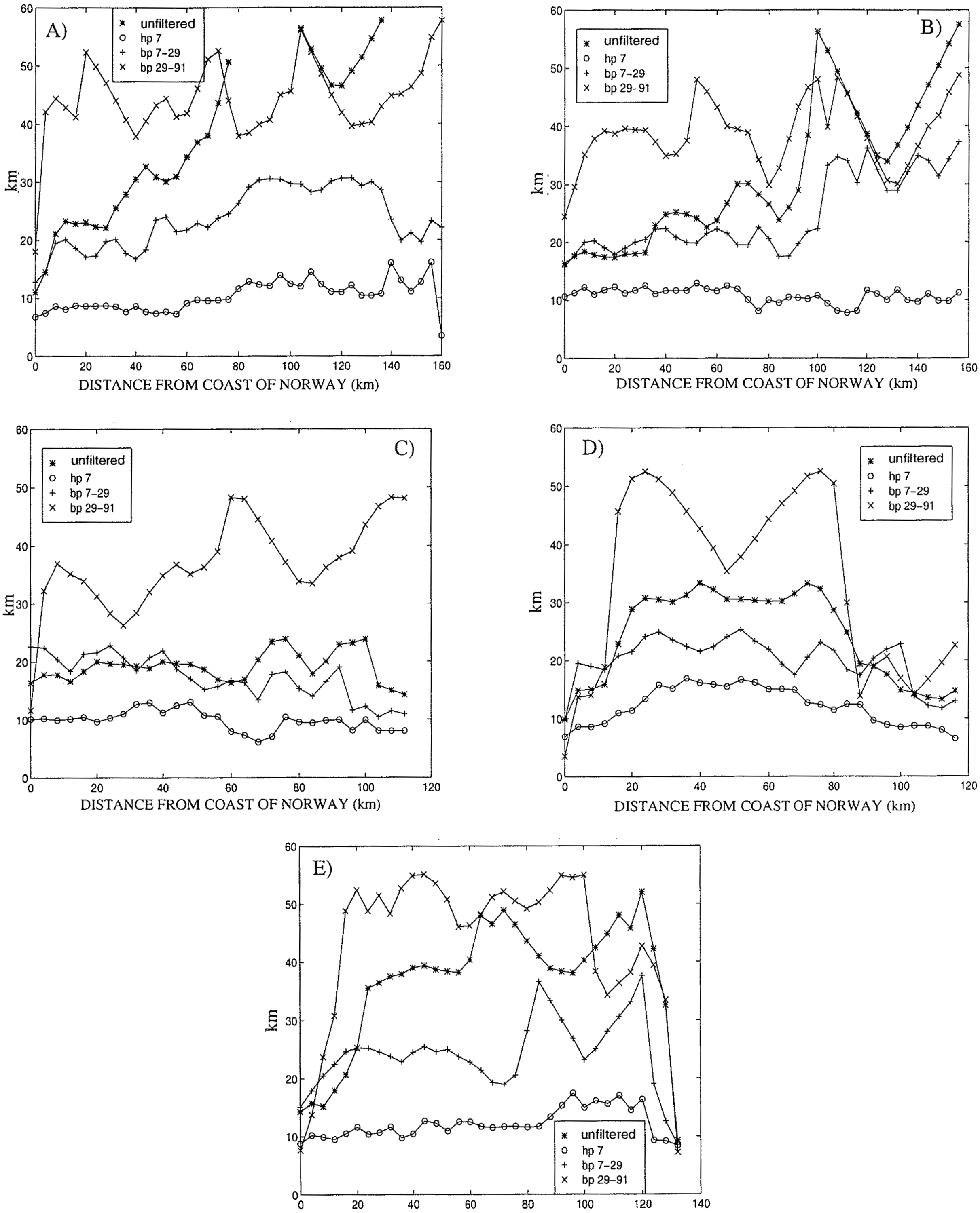


Figure 13. Maximum scale of decorrelation (r=0.7) for modelled salinity at 5m as a function of distance from the Norwegian coast for raw values and 3 filtered time series: High pass 7 day (hp 7), band pass 7-29 days (bp 7-29) and band pass 29-91 days (bp 29-91). Decorrelation scale is shown for the five sections A) Egerøy-SW, B) Lindesnes-SSW, C) Oksøy-Hanstholm, D) Torungen-Hirtshals, and E) Jomfruland-Skagen.

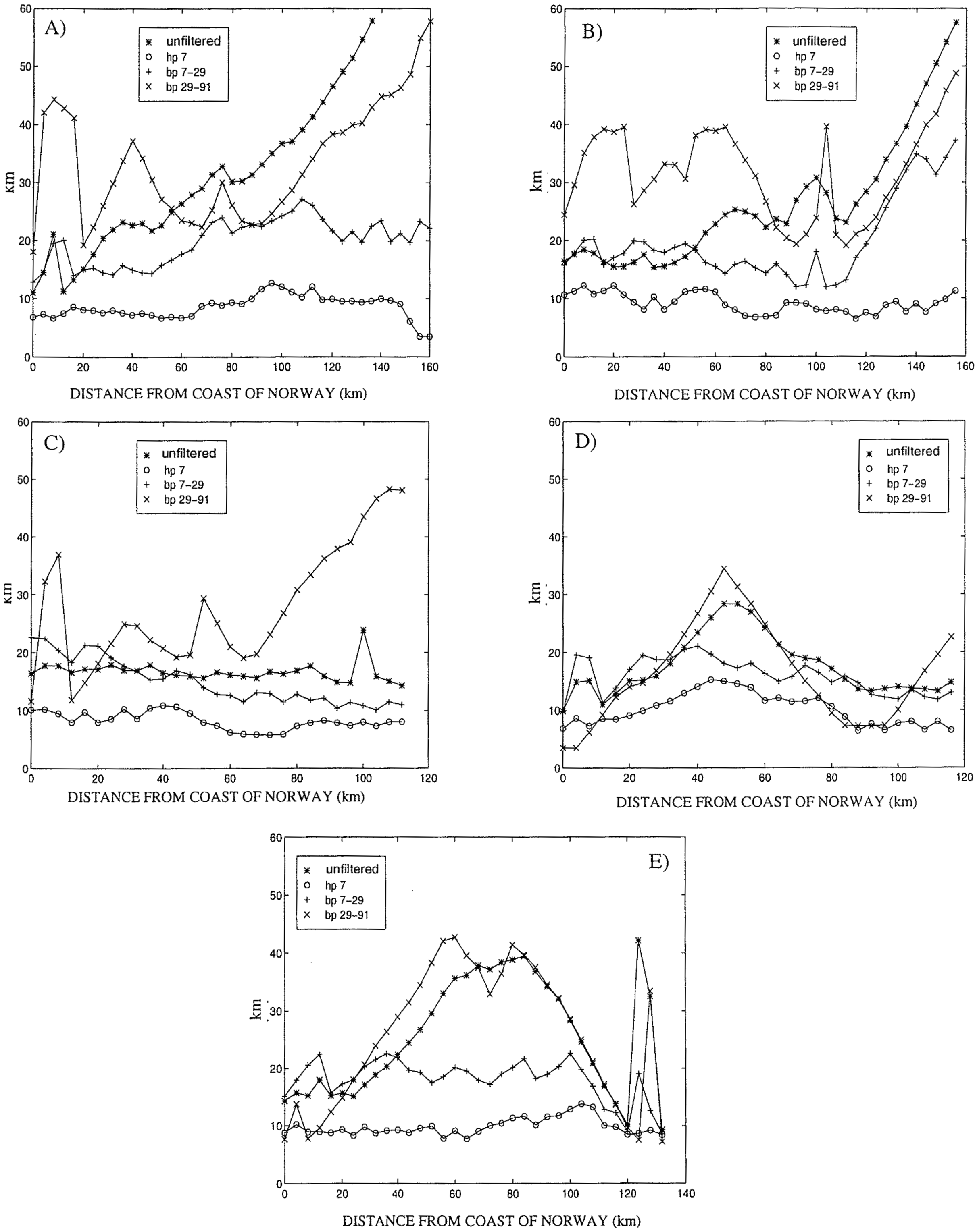


Figure 14. Minimum scale of decorrelation (r=0.7) for modelled salinity at 5m as a function of distance from the Norwegian coast for raw values and 3 filtered time series: High pass 7 day (hp 7), band pass 7-29 days (bp 7-29) and band pass 29-91 days (bp 29-91). Decorrelation scale is shown for the 5 sections A) Egerøy-SW, B) Lindesnes-SSW, C) Oksøy-Hanstholm, D) Torungen-Hirtshals, and E) Jomfruland-Skagen.