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ANALYSIS OF THE HISTORIC TIME-SERIES OBTAINED IN THE FAROE-SHETLAND CHANNEL

by

W R Turrell, E Devonshire, R Payne and G Slesser

SOAFD Marine Laboratory
PO Box 101, Victoria Road
Aberdeen, AB9 8DB
Scotland, UK

SUMMARY

Hydrographic surveys along two, now standard lines crossing the deep-water channel lying between the European continental shelf and the Faroese Plateau (the Faroe-Shetland Channel) commenced in 1893. The first surveys were conducted by Dr H N Dickson for the Fishery Board for Scotland, in support of international multi-disciplinary studies in the northern North Sea and northeast Atlantic, which subsequently resulted in the formation of the International Council for the Exploration of the Sea (ICES). Since the first surveys the two lines have been relatively frequently resurveyed by Scottish, Norwegian, Swedish, Danish and Russian oceanographers. The early salinity data (pre-1960) may be of questionable accuracy owing to indeterminate chemical techniques. This paper presents a comprehensive review of all available hydrographic data obtained across the two survey lines (Nolso-Flugga section and Fair Isle-Munken section), and attempts to calibrate early data using the stationary characteristics of the deep Norwegian Sea Bottom Water. The reconstructed time-series represents one of the longest oceanographic observational records available today, and provide indices of environmental change within the Northeast Atlantic, Norwegian Sea and northern North Sea.

INTRODUCTION

At 1230 GMT on 4 August 1893 Dr H N Dickson (contracted to the Fishery Board for Scotland), on board the fishery protection vessel HMS *Jackal*, performed the first hydrographic station (Station 1) of the now standard Nolso-Flugga Faroe-Shetland Channel section. He went on to perform water bottle casts (using the Scottish designed Mill's self-locking slip water bottle and reversing thermometers mounted on the Scottish pattern frame) at stations 2, 5, 7 and 9 of the present day Nolso-Flugga section and stations 11, 9 and 6 of the Fair Isle-Munken section (Fig. 1).

Dickson went on to survey the same sections in 1896 (fewer stations were performed during this survey although deeper casts were made reaching >1,000 m and hence

sampling Norwegian Sea Bottom water for the first time). The regular sampling at the full set of Nolso-Flugga sections commenced in 1903, and has been performed since then, except for the war years and a five year period in the early 1980s.

By 1990 all hydrographic data collected after 1960 by the Laboratory had been validated and archived on computer. Earlier data was held on paper in various forms. The different hydrographic parameters which had been recorded were of unknown quality, and had arisen from a variety of measurement methods. This was particularly true for salinity.

Prior to 1960 salinity determinations had been performed by a variety of chemical techniques. Salinity data after 1960 were derived from conductivity determinations performed within the Laboratory under controlled conditions and checked using international standards.

Some pre-1960 salinity data had been previously extracted manually from the paper archives to produce long time-series of salinities, which have been published several times before and used for a variety of purposes (Martin, 1976; Walsh and Martin, 1986; Martin, 1993; Martin *et al.*, 1984; Dickson *et al.*, 1984; Dooley and Martin, 1984).

Calibration of the early data had been performed manually and subjectively based upon careful examination of individual sections. As the data was not computerised an objective calibration routine could not be applied to the data, the long time-series could not be reproduced, and new time-series for different parameters or locations could not be calculated.

Hence the goals of the project described here were to collate all available historic data lying along the two standard sections across the Faroe-Shetland Channel, to computerise the data and then to devise an objective calibration routine for the older salinity records. Finally a long time-series of the salinity of North Atlantic water was required in order to compare with previous estimates of this important variable.

PAST MEASUREMENT TECHNIQUES

The hydrographic measurements performed across the Faroe-Shetland Channel include measurements of the following parameters:

1. Geographical position of a station.
2. Sounding on station.
3. Depth of individual observations.
4. Temperature at each depth.
5. Salinity at each depth.

Each measurement has involved varying techniques over the century of observations available. In particular, during the period one major change in the method of measuring temperature has occurred, along with two changes in the measurement of salinity. Each technique is associated with its own accuracies and limitations, which have been extensively examined elsewhere. Briefly, the following techniques have been employed on Scottish surveys during the 100 year period under consideration:

1. **Position:** The original surveys employed astronomical observations and dead reckoning to fix the position of hydrographic stations (Dickson, 1894). Navigation systems employing the Decca system were introduced on Scottish research vessels in the early 1950s. Satellite based systems became available in the 1980s, and the GPS system during the present decade.

2. **Sounding:** Early soundings were determined by lead and line methods, using sounding machines such as the Thomson sounder (1893-1902, Dickson, 1894, 1897) and the Lucas sounding machine (1903, Robertson, 1903). Acoustic techniques only became available on Scottish research vessels after about 1950.

3. **Depth of individual observations:** Early observations relied upon the amount of wire let out from the vessel. This method obviously has many errors associated with it, particularly when large ship drift is present. Since the earlier part of this century unprotected thermometers in conjunction with protected thermometers have been used to determine depth of reversal. More recently *in situ* pressure sensors mounted on conductivity, temperature and depth (CTD) probes have been available.

4. **Temperature:** The first measurements were obtained using Negretti and Zambra reversing thermometers with calibrations from the Kew observatory (1893-1901; Dickson, 1894, 1896). Subsequently Nansen-Richter thermometers were used (Helland-Hansen, 1905). Reversing thermometers were supplemented by temperature measurement of samples returned to the deck of the vessel in insulated bottles (eg Pettersson bottle). Nansen thermometers were used between 1927 and 1939 (Tait, 1957). During the early period single thermometers were used at each depth. After the late 1920s paired thermometers were employed. During the latter part of the observation period (1940-onwards) paired protected reversing thermometers were used, in conjunction with a third unprotected thermometer, mounted on Knudsen reversing water bottles. The majority of thermometers in use now are of either Negretti-Zambra or Gohla manufacture. These previously were calibrated at the National Physical Laboratory (UK) and subsequently by Gohla (Germany). Discrete temperature measurements employing mercury in glass thermometers are now being replaced by continuous profiles obtained from electronic *in situ* measurement of temperature.

5. **Salinity:** Samples of water for the laboratory determination of salinity have been collected using a variety of sampling bottles. The first surveys employed the Mill's self-locking slip water bottle (Dickson, 1894). Subsequently Petterson-Nansen, and Knudsen bottles have been used.

   The first determinations of salinity were performed by density measurements using hydrometers and Sprengel tubes (Dickson, 1894). In addition calibration samples were analysed for chlorinity using titration methods. These chemical analyses were performed at several laboratories including ones at Oxford and University College, Dublin. Between about 1930 and 1960 titrations were performed by the UK Government Chemist. During this period poor accuracies were most probably achieved as the analysts were not specifically marine chemists. Long sample storage times were common. Batches of samples often contained internal inconsistencies, and systematic errors occurred between batches.

Electronic determination of conductivity commenced in 1960 with the acquisition of a Cox salinometer. This was replaced with a CSIRO model in the mid-60s, a Guildline Autosal in the early 80s and a Guildline Portosal in 1992. Samples have been analysed at sea, but owing to short cruise times and higher achieved accuracies, samples are now analysed immediately on return to the laboratory. As with temperature, continuous *in situ* conductivity profiles are now possible using CTDs.

Calibration

Other than noting the possible limitations of accuracy of the measurements of position, sounding, and depth of individual measurements, it may be impossible to improve upon the recorded values. While historic measurements of temperature have been re-calibrated following careful historical research of past methods, particularly for sea surface temperatures, again it would appear that the temperatures obtained at depth within the Faroe-Shetland Channel must be left uncorrected.

The early measurements of salinity, however, are certainly prone to large errors owing to the methods of salinity determination. A method does exist whereby these observations may be adjusted to correspond to modern day measurements, and this is described below.

DATA SOURCES AND COLLATION

A number of data sources have been employed during the collation of historic data from the Faroe-Shetland Channel. These are listed in the Appendix. Data from early cruises were extracted from reports of the Fishery Board for Scotland and from the ICES Bulletin Hydrographique. In addition original station books held by the Marine Laboratory, Aberdeen, along with some loose records, were searched for data obtained in the Faroe-Shetland Channel.

Once data had been manually extracted from the original sources it was entered into standard hydrographic data formats on the Laboratory's computer. Cruise files were constructed containing data obtained during surveys by individual vessels. These were then searched using position criteria to determine which stations lay close to the present day stations worked across the standard lines. Table 1 gives the location of the present day standard section stations. The boxes were used to determine if historic stations were close enough to present day stations to be accepted are shown in Figure 1, and their boundaries are given in Tables 2 and 3. Larger boxes were used for the earlier data to ensure as much data was recovered as possible without a significant reduction in accuracy.

100 Year Data Set

After the search of the historic data set was complete, a database was constructed containing full or part sections across the Fair Isle-Munken and Nolso-Flugga sections. In all 290 Nolso and 108 Munken sections now exist for the period 1893-1993. The availability of data at each of the 12 standard stations along the two survey lines may be seen in Figure 2. Coverage of the Nolso-Flugga line is most complete. Regular surveys across the Fair Isle-Munken section commenced in 1970, with sporadic sampling during the preceding years.

SALINITY CALIBRATION

In order to calibrate the older salinity observations the quasi-stationary characteristics of the Norwegian Sea Bottom Water (called Norwegian Sea Deep Water by Martin, 1993, and referred to here as NSDW) have been employed. Peterson and Rooth (1976) estimate that exchange times of the NSDW are greater than 100 years, the length of the present observations. Hence the salinity of this water is assumed to be stationary over the period of observations. Post 1960 data has been employed to determine the salinity of NSDW, as observed at the two sections. After the removal of notable outliers the mean salinity of NSDW was:

Section	Mean	Standard deviation
Noslo - Flugga	34.921	0.017
Munken - Fair Isle	34.919	0.010

Temperature-salinity diagrams for post-1960 (Figs 3a, 3c) and pre-1960 (Figs 3b, 3d) data demonstrate the large scatter in the earlier salinity data as compared to the later data. This is not only evident in the NSDW water, but also in the salinity of the North Atlantic (NA) and Modified North Atlantic (MNA) waters.

The method of calibrating the older data was to determine all samples which occurred within the NSDW at depths greater than 800 m. For each cruise where this water was sampled a mean value was calculated and compared to the post-1960 mean values shown above. The differences for individual cruises may be seen in Figure 4. The computed differences were used to correct the individual values of salinity at each observation depth, for each cruise.

Once these corrections were applied, the resulting pre-1960 t-S diagrams more closely resemble the post-1960 profiles (Fig. 5). Not only do salinities in the NSDW water lie within acceptable limits as determined by modern data, but the distribution of t-S characteristics for NA and MNA water appears more reasonable.

RESULTS

In order to compare the salinity of NA water as determined by the objective calibration routine described above with the previous subjective manual estimates, a time series of NA salinity was constructed. Data from both standard sections were combined, and the salinity of NA water defined as the maximum recorded in any one year at the four stations lying inshore from the 200 m contour on the Scottish shelf edge. Only pre-1960 data which had been calibrated was used. The results may be seen in Figure 6. It is evident that while time-series used in the past have not been entirely consistent with one another, most major features are reproduced. For example, the low salinity prior to 1910, high salinity between 1935 and 1940, high salinities in 1960 and the early 1970s and the low salinity event in the mid-1970s, followed by recovery in the 1980s.

The time-series generated by the present method also reproduces these main features. The RMS error associated with the different time-series are presented in Table 4. From this it would appear that, at best, the salinity of NA water has been estimated to an

accuracy of about 0.03. It may be seen from Figure 6 that the amplitude of variation over the past century has been of the order of 0.2 hence it has been resolved by the various methods used to measure and determine NA salinity.

DISCUSSION

The time-series of NA salinity generated by this project may be seen in Figure 7. It is to be hoped that this time-series will now be continually extended. The Marine Laboratory Aberdeen presently plans to survey the standard sections at least three times each year. It is to be hoped that other ICES nations working in the Faroe-Shetland channel may also work part or all of these sections and report the data to ICES.

The databases produced by this project are presently being used to extract more information from the recovered data. Time-series of salinity in other water types are being constructed, and used to examine events such as the Great Salinity Anomaly and the more recent 1989-91 high salinity event. Annual cycles within the Faroe-Shetland Channel are being examined.

While the data-sets constructed during this project represent some of the longest directly observed environmental time-series in the world, the period covered is short compared to the time-scales involved with many climatic and biological processes. For example 100 years represents just six circulation periods of the North Atlantic sub-polar gyre (period of 15 years), 13 flushing periods of the Norwegian Sea (period seven years) and possibly just 20 generations of a pelagic fish such as the Atlantic salmon (*Salmo salar*).

The period has included, however, several significant climatic events marked by the high and low salinity anomalies, and studies of the processes which produced these events may well help climate modellers. The period also encompasses the last century of industrial development, and the continuation of the time-series is of global importance if we wish to observe possible effects of the emission of "greenhouse" gases.

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TABLE 1

Hydrographic station positions and typical soundings as currently worked along the two Faroe-Shetland Channel standard sections. Station numbers displayed in Figure 1 are centred on these positions

Nolso-Flugga Section				
Station number	Station name	Latitude	Longitude	Sounding (m)
1	1	60°56.0′N	1°00.0′W	120
2	2	61°04.5′N	1°53.0′W	170
3	3	61°08.0′N	2°10.0′W	500
4	3a	61°11.0′N	2°25.0′W	700
5	4	61°14.0′N	2°40.0′W	900
6	5	61°21.0′N	3°10.0′W	1,100
7	6	61°28.0′N	3°42.0′W	1,100
8	7	61°35.0′N	4°15.0′W	800
9	8	61°42.0′N	4°51.0′W	200
10	9	61°49.0′N	5°21.0′W	150
11	10	61°54.0′N	5°45.0′W	200
12	11	62°00.0′N	6°12.0′W	100

Fair Isle - Munken				
Station No	Station Name	Latitude	Longitude	Sounding (m)
1	1	60°10.0′N	3°44.0′W	100
2	2	60°16.0′N	3°59.0′W	150
3	3	60°20.0′N	4°10.0′W	350
4	4	60°25.0′N	4°19.0′W	600
5	5	60°29.0′N	4°26.0′W	800
6	6	60°35.0′N	4°45.0′W	1,000
7	6a	60°38.0′N	4°54.0′W	900
8	7	60°43.0′N	5°06.0′W	700
9	8	60°47.0′N	5°16.0′W	650
10	9	60°51.0′N	5°29.0′W	500
11	10	61°02.0′N	5°57.0′W	200
12	11	61°12.0′N	6°22.0′W	200

TABLE 2

Limits of boxes used to identify hydrographic stations lying along the two Faroe-Shetland Channel standard sections as applied to pre-1960 data. The boxes defined by these limits may be seen in Figure 1 (dotted lines)

Nolso - Flugga Section			
Station number	Station name	Latitude	Longitude
1	1	60°37′-61°12′N	0°52′-1°20′W
2	2	60°41′-61°17′N	1°21′-1°59′W
3	3	60°48′-61°23′N	2°00′-2°17′W
4	3a	60°51′-61°26′N	2°18′-2°31′W
5	4	60°54′-61°29′N	2°32′-2°53′W
6	5	61°01′-61°36′N	2°54′-3°28′W
7	6	61°08′-61°43′N	3°29′-3°59′W
8	7	61°15′-61°50′N	4°00′-4°33′W
9	8	61°22′-61°57′N	4°34′-5°07′W
10	9	61°29′-62°04′N	5°08′-5°33′W
11	10	61°34′-62°09′N	5°34′-5°59′W
12	11	61°40′-62°15′N	6°00′-6°23′W

Fair Isle - Munken			
Station number	Station name	Latitude	Longitude
1	1	59°55′-60°25′N	3°36′-3°51′W
2	2	60°01′-60°31′N	3°52′-4°05′W
3	3	60°05′-60°35′N	4°06′-4°15′W
4	4	60°10′-60°40′N	4°16′-4°22′W
5	5	60°14′-60°44′N	4°23′-4°36′W
6	6	60°20′-60°50′N	4°37′-4°50′W
7	6a	60°23′-60°53′N	4°51′-4°59′W
8	7	60°28′-60°58′N	5°00′-5°11′W
9	8	60°32′-61°02′N	5°12′-5°23′W
10	9	60°36′-61°06′N	5°24′-5°43′W
11	10	60°47′-61°20′N	5°44′-6°10′W
12	11	60°57′-61°27′N	6°11′-6°34′W

TABLE 3

Limits of boxes used to identify hydrographic stations lying along the two Faroe-Shetland Channel standard sections as applied to post-1960 data. The boxes defined by these limits may be seen in Figure 1 (solid lines)

Noslo - Flugga Section			
Station number	Station name	Latitude	Longitude
1	1	60°52′-61°02′N	0°52′-1°12′W
2	2	60°56′-61°07′N	1°26′-1°59′W
3	3	61°03′-61°13′N	2°00′-2°17′W
4	3a	61°06′-61°16′N	2°18′-2°32′W
5	4	61°09′-61°19′N	2°32′-2°50′W
6	5	61°16′-61°26′N	3°00′-3°20′W
7	6	61°23′-61°33′N	3°34′-3°54′W
8	7	61°30′-61°40′N	4°05′-4°25′W
9	8	61°37′-61°47′N	4°41′-5°01′W
10	9	61°44′-61°54′N	5°11′-5°31′W
11	10	61°49′-61°59′N	5°35′-5°55′W
12	11	61°55′-62°05′N	6°02′-6°19′W

Fair Isle - Munken			
Station number	Station name	Latitude	Longitude
1	1	60°05′-60°15′N	3°36′-3°51′W
2	2	60°11′-60°21′N	3°51′-4°05′W
3	3	60°15′-60°25′N	4°05′-4°15′W
4	4	60°20′-60°30′N	4°15′-4°22′W
5	5	60°24′-60°34′N	4°22′-4°36′W
6	6	60°30′-60°40′N	4°36′-4°50′W
7	6a	60°33′-60°43′N	4°50′-4°59′W
8	7	60°38′-60°48′N	5°00′-5°11′W
9	8	60°42′-60°52′N	5°11′-5°23′W
10	9	60°46′-60°56′N	5°23′-5°43′W
11	10	60°57′-61°10′N	5°43′-6°10′W
12	11	61°07′-61°17′N	6°10′-6°32′W

TABLE 4

RMS errors computed between previously published time-series of the salinity of North Atlantic water, and between these series and the series produced by the present project. The sources of the time-series are:

1. Martin (1976)
2. Walsh and Martin (1986)
3. Martin (1993)
4. Martin, Dooley and Shearer (1984)
   also used in Dickson *et al.* (1984) and Dooley and Martin (1984)
5. This project

RMS errors have been computed between series of salinities obtained by digitising published diagrams:

	2	3	4	5
1	0.015	0.027	0.023	0.041
2		0.032	0.025	0.039
3			0.025	0.025
4				0.033

APPENDIX

Sources of data used in the historic analysis of Faroe-Shetland hydrographic data. The cruise codes relate to the name of individual computer files created containing the extracted data. The first two letters of the cruise code relate to the survey vessel, the next 4 digits is the year of the survey, and the final two digits is the allocated cruise number. Vessel codes are:

Code	Vessel	Country
CN	*Clione*	UK
DA	*Dana*	Denmark
DI	*Discovery*	UK
EH	*Ernest Holt*	UK
EX	*Explorer*	UK
GO	*Goldseeker*	UK
GS	*G O Sars*	Norway
HA	*HMS Heckla*	UK
HH	*Helland Hansen*	Norway
JA	*HMS Jackall*	UK
NO	No name recorded	
RE	*HMS Research*	UK
SB	*Somov*	Russia
SC	*Scotia*	UK
SD	*Sverdrup*	Norway
SP	*Sevastopol*	Russia
VA	*Vartdal*	Norway

Cruise Code	Source
189301	Dickson (1894), pp336-382
RE180601	Dickson (1897), pp280-296
NO190201	Helland-Hansen (1905), pp1-49
NO190202	
NO190203	
NO190301	Robertson (1905), pp51-113
NO190302	
NO190401	Robertson (1907), pp1-140
NO190402	
NO190501	
NO190502	
NO190503	
GO190601	Robertson (1909a), pp1-60
GO190602	
GO190603	
GO190701	Robertson (1909b), pp143-196
GO190702	
GO190801	
to	
GO190806	
GO190901	Robertson (1913), pp337-404
to	
GO190907	
GO191001	
GO191002	
GO191003	
GO191101	ICES Bulletin Hydrographique 1911-1912
GO191201	ICES Bulletin Hydrographique 1911-1912
GO191301	ICES Bulletin Hydrographique 1913-1914
GO191401	ICES Bulletin Hydrographique 1913-1914
GO191402	ICES Bulletin Hydrographique 1913-1914
EX192001	Un-numbered station books
EX192201	Un-numbered station books
EX192301	Un-numbered station books

EX192302	Un-numbered station books
EX192401	Station book EX 1
EX192402	Station book EX 2
EX192403	Station book EX 3
EX192404	Station book EX 3
EX192501	Station book EX 8
EX192502	Station book EX 9
EX192503	Station book EX 10
EX192601	Station book EX 12
EX192602	Station book EX 12
EX192701	Station book EX 15
EX192702	Station book EX 17
EX192801	Station book EX 21
EX192802	Station book EX 24
EX192901	Station book EX 25
EX192902	Station book EX 26
EX192903	Station book EX 27
EX192904	Station book EX 27
EX192905	Station book EX 29
EX193001	Station book EX 30
EX193002	Station book EX 30
EX193101	Station book EX 35
EX193102	Station book EX 37
EX193103	Station book EX 37
EX193104	Station book EX 40
EX193201	Station book EX 41
EX193202	Station book EX 42
EX193301	Station book EX 47
EX193302	Station book EX 48
DA193401	Tait (1957), pp 212-213.
DA193402	Tait (1957), p 214.
DA193403	Tait (1957), pp 215-216.
EX193401	Station book EX 52
EX193402	Station book EX 53
EX193403	Station book EX 53
EX193404	Station book EX 54
EX193501	Station book EX 55
EX193502	Station book EX 57
EX193503	Station book EX 59
EX193601	Station book EX 60
EX193602	Station book EX 61
EX193603	Station book EX 64
EX193701	Station book EX 66
EX193702	Station book EX 67
EX193703	Station book EX 69
DA193801	Tait (1957), pp224-225
EX193801	Station book EX 72
EX193802	Station book EX 74
EX193803	Station book EX 75
DA193901	Tait (1957), p231
EX193901	Station book EX 79
EX193902	Station book EX 81
EX193903	Station book EX 82
DA194601	Tait (1957), pp232-233
EX194601	Station book EX 84
EX194602	Station book EX 84
EX194603	Station book EX 85
DA194701	Tait (1957), pp236-237
EX194701	Station book EX 87
EX194702	Station book EX 88
EX194703	Station book EX 89
EX194704	Station book EX 89
EX194705	Station book EX 91
DA194801	Tait (1957), pp241-242
EX194801	Station book EX 92
EX194802	Station book EX 93
EX194803	Station book EX 95
EX194901	Station book EX 99
EX194902	Station book EX 99
EX194903	Station book EX 99
EX194904	Station book EX 100
EX194905	Station book EX 102
SC194901	Station book SC 1
SC194902	Station book SC 4
SC194903	Station book SC 5
SC194904	Station book SC 6
SC194905	Station book SC 7
VA194901	Loose records
DA195001	Tait (1957), pp265-266
DA195002	Tait (1957), pp273-274
EX195001	Station book EX 104
EX195002	Station book EX 105
EX195003	Station book EX 106
EX195004	Station book EX 107
EX195005	Station book EX 107
EX195006	Station book EX 109
GS195001	Loose records
SC195001	Station book SC 8
SC195002	Station book SC 8
SC195003	Station book SC 9
SC195004	Station book SC 10
SC195005	Station book SC 11
SC195006	Station book SC 15
SC195007	Station book SC 15
DA195101	Tait (1957), pp291-292
EX195101	Station book EX 111
EX195102	Station book EX 114
EX195103	Station book EX 117
GS195101	Loose records
SC195101	Station book SC 16
SC195102	Station book SC 17
SC195103	Station book SC 19
SC195104	Station book SC 21
SC195105	Station book SC 22
DA195101	Tait (1957), pp 299-300.
EX195201	Station book EX 120
EX195202	Station book EX 120
EX195203	Station book EX 121
EX195205	Station book EX 123
SC195201	Station book SC 24
SC195202	Station book SC 25
SC195203	Station book SC 26
SC195204	Station book SC 28
SC195205	Station book SC 28
SC195206	Station book SC 29
SC195207	Station book SC 30
SC195208	Station book SC 34
SC195209	Station book SC 34
DA195301	Loose records
DA195302	Loose records
SC195301	Station book SC 36
SC195302	Station book SC 36
SC195303	Station book SC 38
SC195304	Station book SC 39
SC195305	Station book SC 40
SC195306	Station book SC 41
SC195307	Station book SC 41
SC195308	Station book SC 41
SC195309	Station book SC 45
DA195401	Loose records
EX195401	Station book EX 132
EX195402	Station book EX 134
EX195403	Station book EX 135
SC195401	Station book SC 50

SC195402	Station book SC 51
SC195403	Station book SC 52
SC195404	Station book SC 54
SC195405	Station book SC 58
SC195406	Station book SC 60
SC195494	Station book SC 55
DA195501	Loose records
EX195501	Station book EX 139
EX195502	Station book EX 142
SC195501	Station book SC 60
SC195502	Station book SC 62
SC195503	Station book SC 63
SC195504	Station book SC 64
SC195505	Station book SC 65
SC195506	Station book SC 66
SC195507	Station book SC 66
DA195601	Loose records
DI195601	Loose records
EX195601	Station book EX 148
EX195602	Station book EX 149
EX195603	Station book EX 150
SC195601	Station book SC 68
SC195602	Station book SC 70
SC195603	Station book SC 71
SB195601	Loose records
DA195701	Loose records
EX195701	Station book EX 153
EX195702	Station book EX 155
EX195703	Station book EX 157
EX195704	Station book EX 158
SC195701	Station book SC 72
SC195702	Station book SC 75
SC195703	Station book SC 78
SP195701	Loose records
EX195801	Station book EX 159
EX195802	Station book EX 160
EX195803	Station book EX 163
EX195804	Station book EX 165
GS195801	Loose records
SC195801	Station book SC 83
SC195802	Station book SC 85
SC195803	Station book SC 86
SC195804	Station book SC 90
SP195801	Loose records
EX195901	Station book EX 168
EX195902	Station book EX 168
EX195903	Station book EX 170
SC195901	Station book SC 94
DI196101	Loose records
HH196101	Loose records
HH196102	Loose records
HH196103	Loose records
EH196201	Loose records
CN196301	Loose records
EH196301	Loose records
EH196302	Loose records
HH196301	Loose records
to	
HH196306	Loose records
SD196301	Loose records
SD196302	Loose records
HH196401	Loose records
HA196501	Loose records
HH196501	Loose records
to	
HH196504	Loose records

FIGURE 1 Map showing the location of the two standard Faroe-Shetland Channel sections as currently worked (centred figures), as used to summarise post-1960 data (solid boxes) and as used to summarise pre-1960 data (broken boxes).

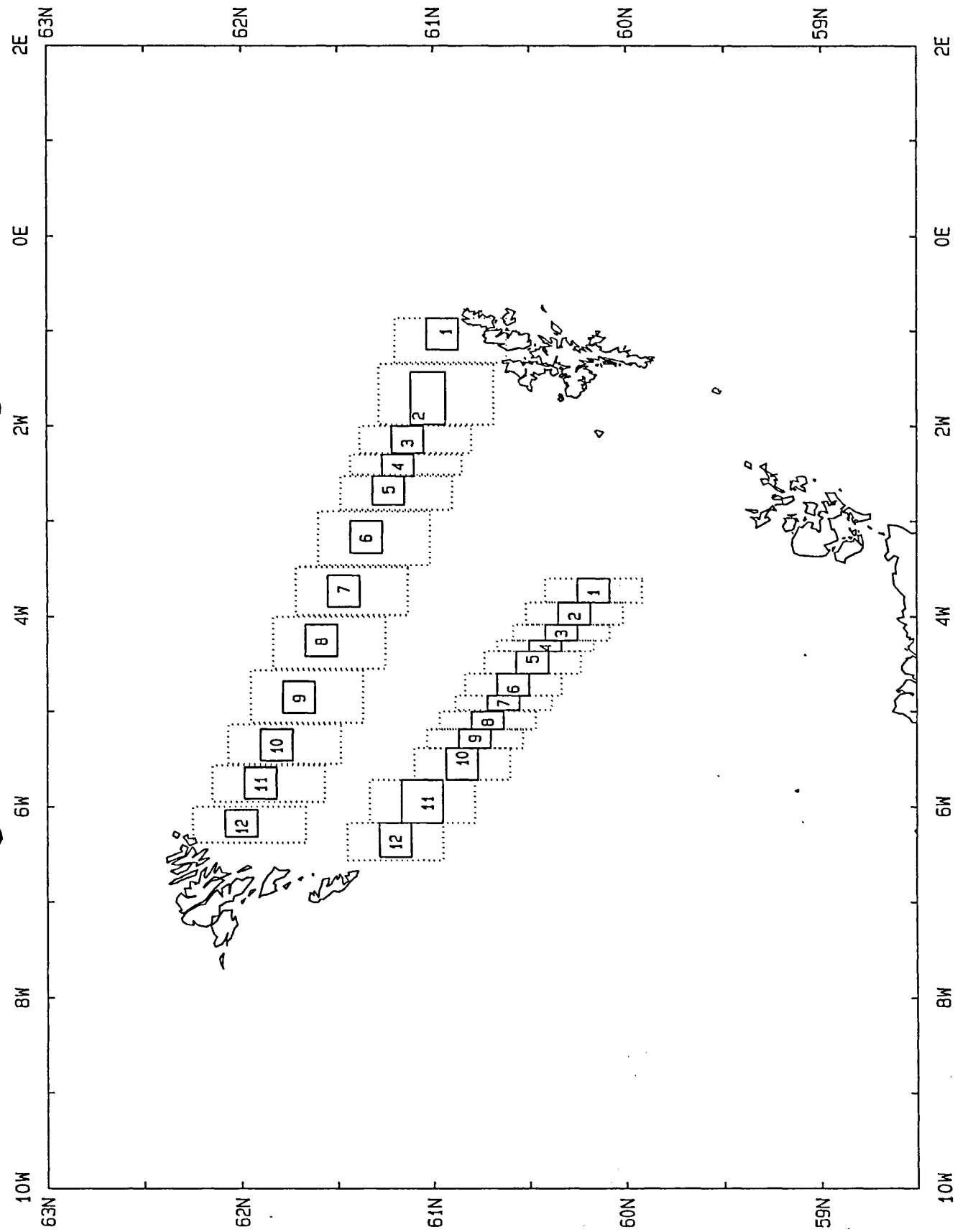
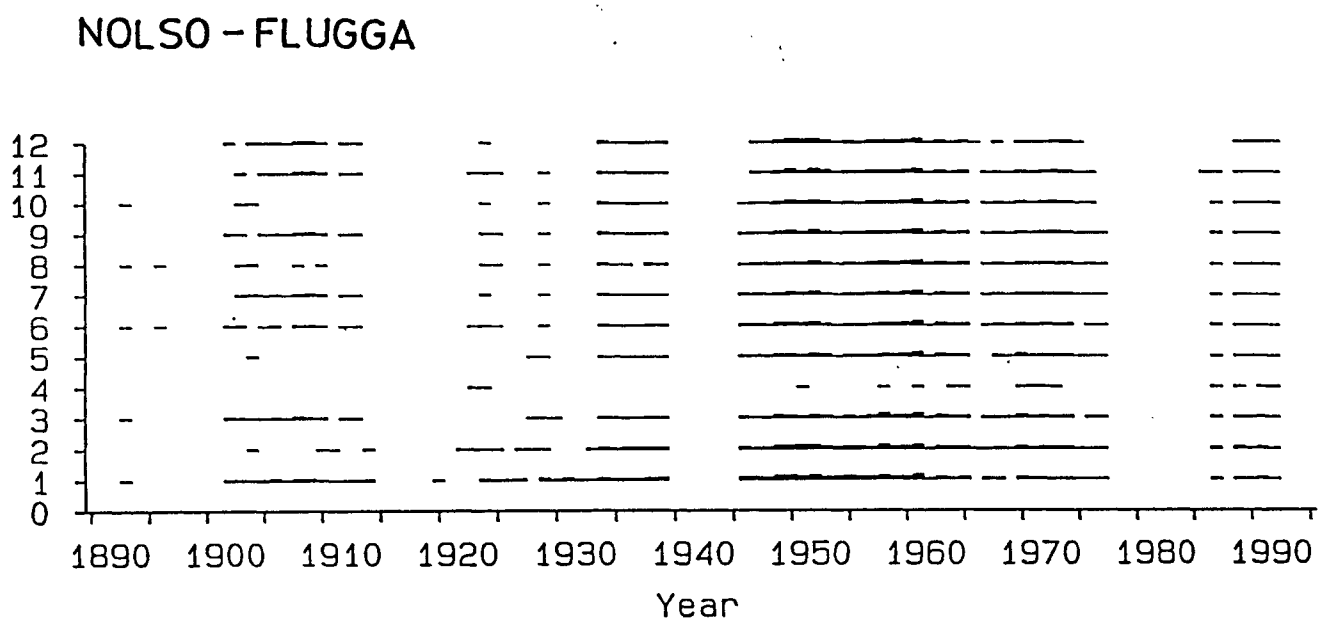


FIGURE 2 Summary of station data availability along the two Faroe-Shetland standard sections following the merging of the two data sets. a) Nolso-Flugga section; b) Fair Isle-Munken section.



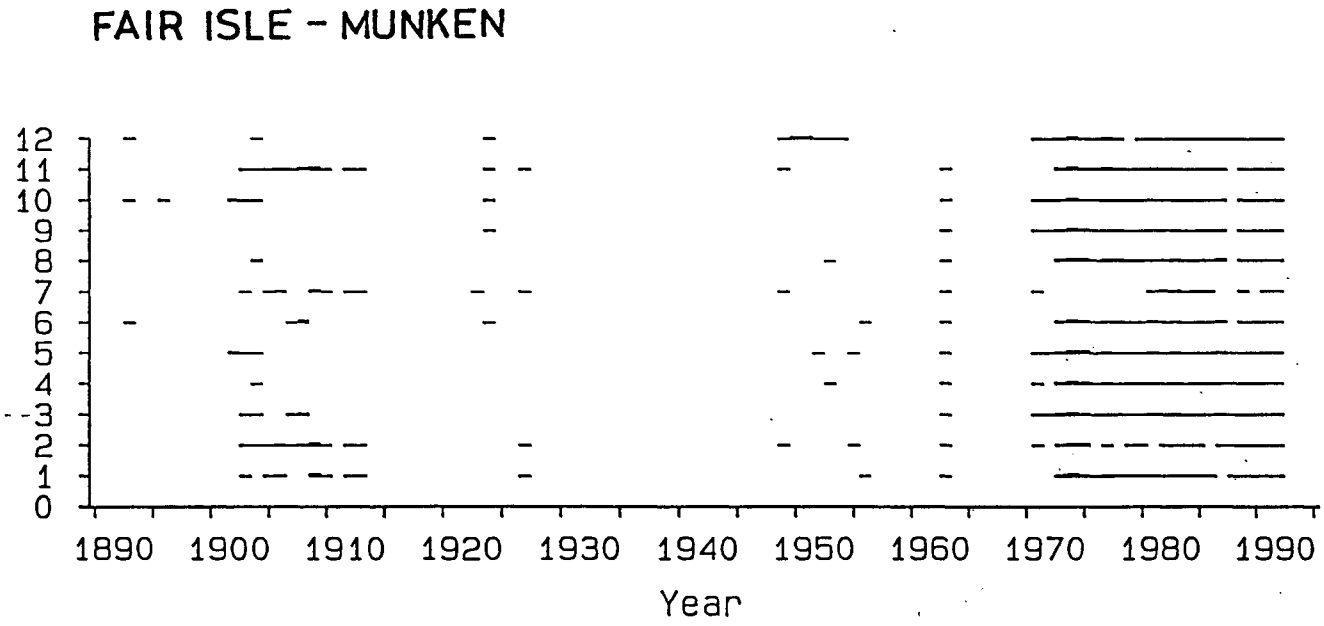


FIGURE 3 Temperature-Salinity diagrams for the four databases prior to correction of the pre-1960 data. a) Nolso-Flugga post-1960 (4,506 data pairs); b) Nolso-Flugga pre-1960 (7,111 data pairs); c) Fair Isle-Munken post-1960 (3,351 data pairs); d) Fair Isle-Munken pre-1960 (937 data pairs).

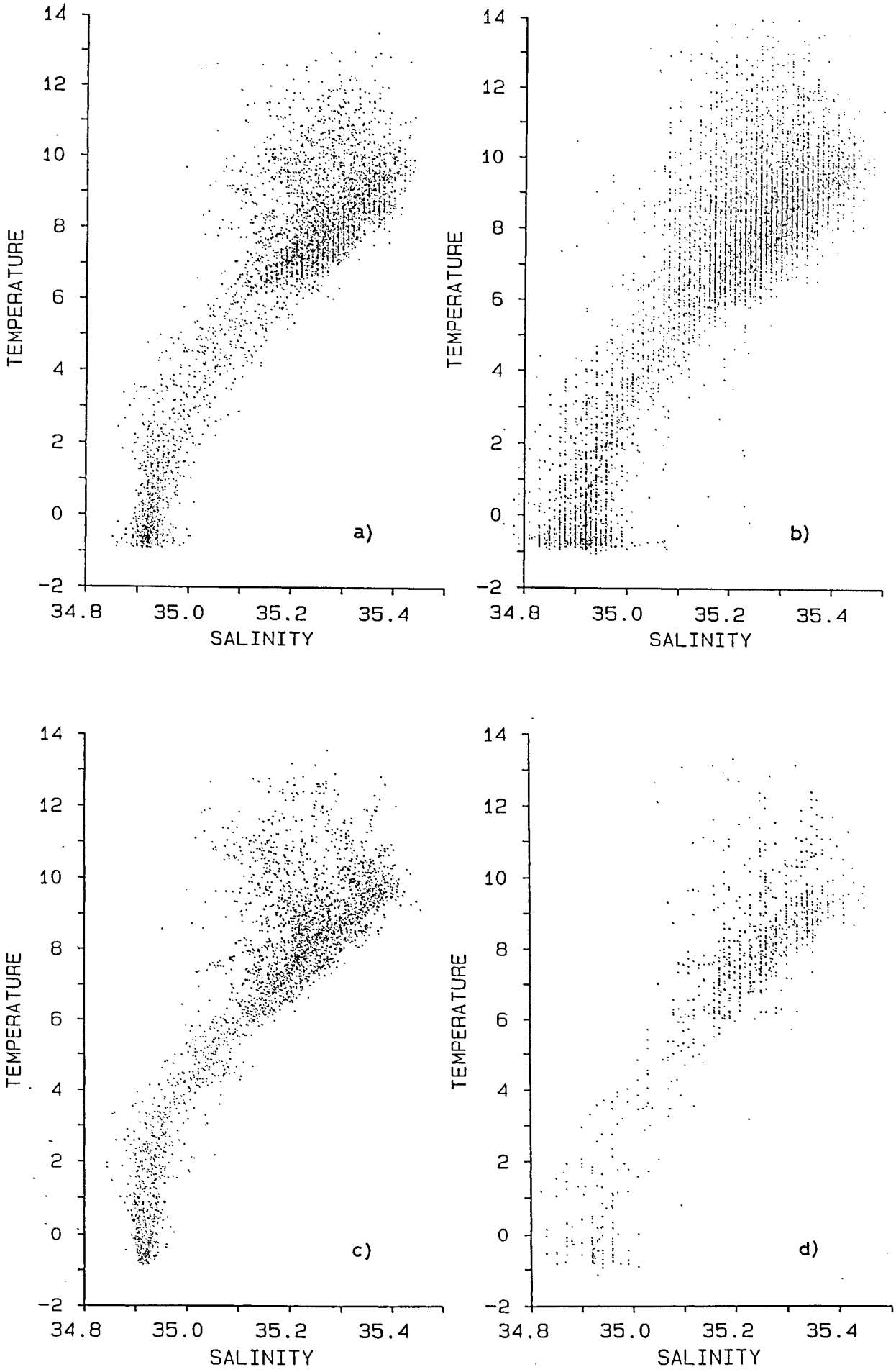


FIGURE 4 Anomalies of the mean salinity of Norwegian Sea Bottom Water salinity computed from pre-1960 data obtained beneath 800 m along the two standard Faroe-Shetland Channel sections. Anomalies are relative to the mean values for the two sections computed from post-1960 data. a) Nolso-Flugga (post-1960 mean 34.921); b) Fair Isle-Munken sections (post-1960 mean 34.919).

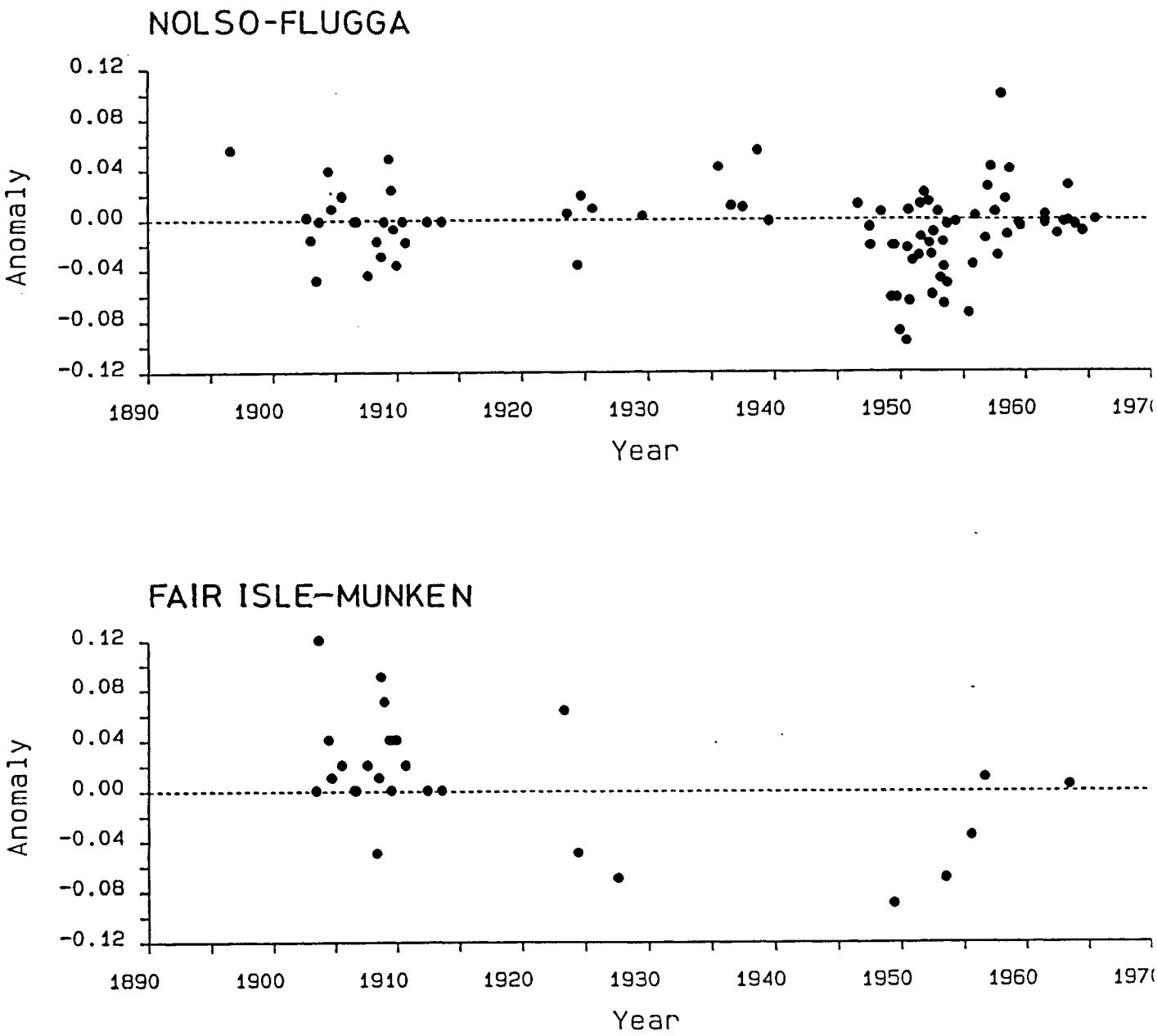


FIGURE 5 Temperature-Salinity diagrams of pre-1960 data before and after corrections have been applied to salinity values. a) Nolso-Flugga pre-1960 uncorrected; b) Nolso-Flugga pre-1960 corrected; c) Fair Isle-Munken pre-1960 uncorrected; d) Fair Isle-Munken pre-1960 corrected.

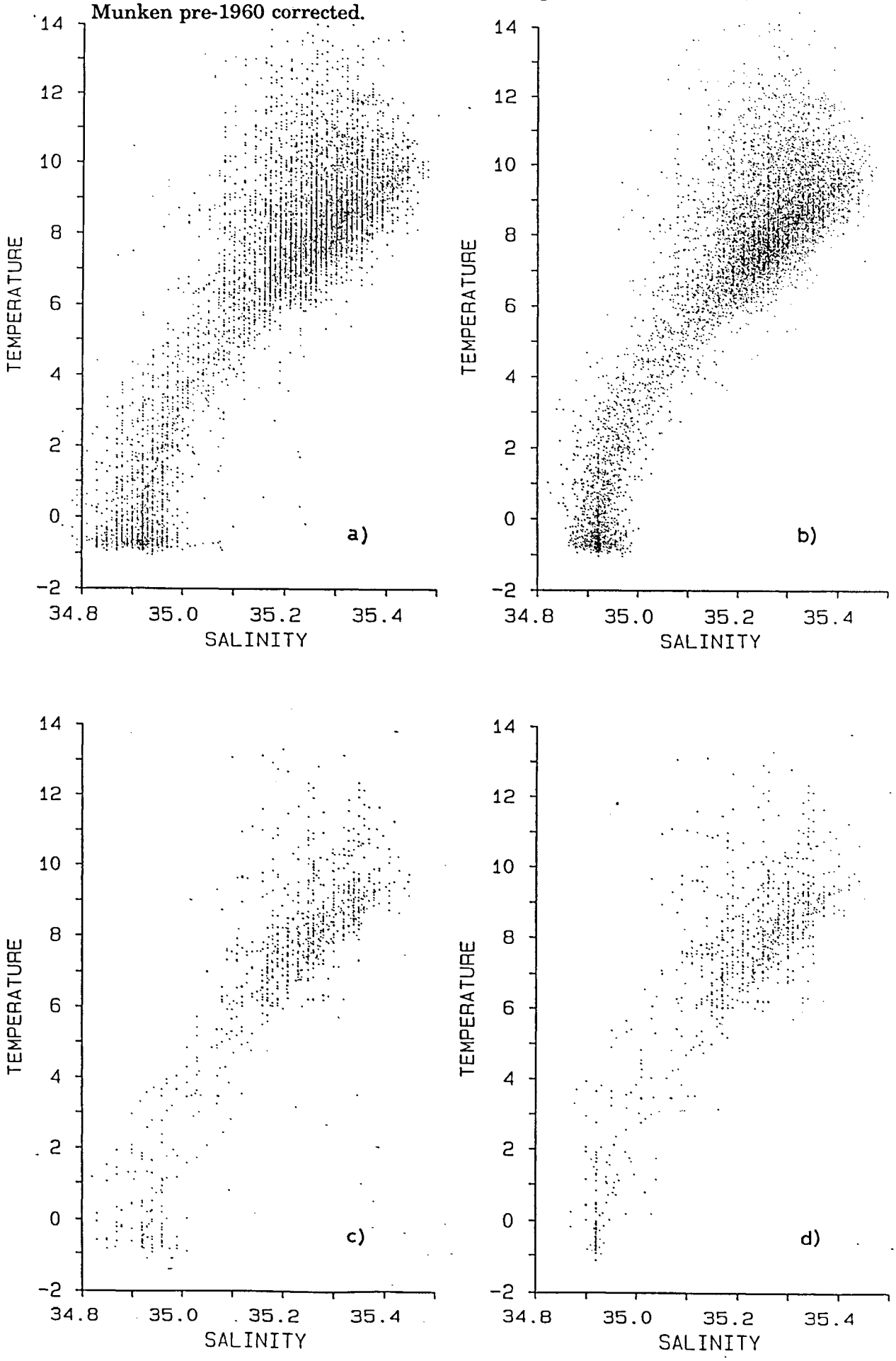


FIGURE 6 Time-series of salinity of North Atlantic water derived from observations made along the two standard Faroe-Shetland Channel sections. Thin multiple lines are derived from literature; Martin (1976), Walsh and Martin (1986), Martin (1993), Dooley and Martin (1984). Heavy solid line derived from this project after corrections applied.

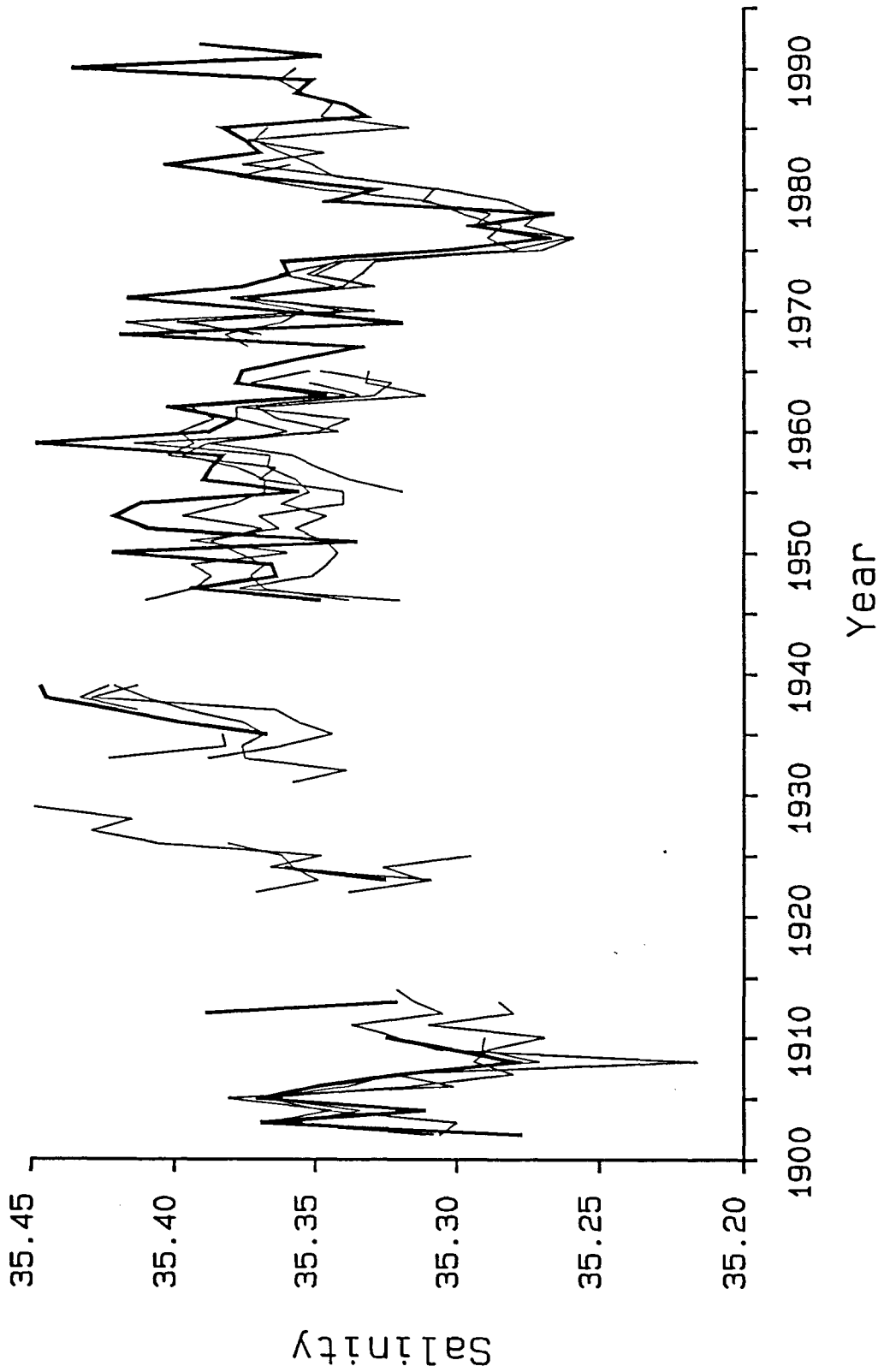


FIGURE 7 Time-series of the salinity of North Atlantic water 1900-1992 derived from corrected values of salinity obtained along the two standard Faroe-Shetland channel sections.