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PROCEDURES FOR COLLECTING AND PROCESSING OF HYDROGRAPHIC
DATA IN NORWAY

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ABSTRACT

The Institute of Geophysics, University of Bergen, and the Institute of Marine Research, Directorate of Fisheries, are the main collectors of hydrographic data in Norway. During the 1970s the research vessels belonging to these institutes were equipped with CTD systems. The procedures and routines applied for collecting and processing of water bottle and CTD data are outlined. Reversing thermometers and CTD-sensors are regularly calibrated in the laboratory and in situ CTD calibrations are made with reversing water bottles or rosette samplers. Collection and processing of water bottle data have in principle been in line with the ICES punch card system. The presently applied procedures for operation and data processing are described, but since the CTD system are fairly new, the routines for these are still in a developing phase and may be subject to change. During the primary processing the CTD data sets of observed variables are edited and filtered for random errors and low pass filters are applied for smoothing. A delaying recursive filter is applied to the conductivity data to compensate for the longer time constant of the temperature sensor. The final data of pressure (or depth), temperature and salinity are reduced by averaging within selected pressure intervals.

RESUME

L'Institut de géophysique, l'Université de Bergen et l'Institut de Recherches Marines, Directoire des Pêches sont les principaux assembleurs de données hydrographiques en Norvège. Pendant les années '70 les vaisseaux de recherche appartenant à ces deux Instituts furent équipés de systèmes CTD. Les procédés et routines employés pour le recueillement et le traitement des données de bouteilles à prélèvement et de CTD sont esquissés. Thermomètres à renversement et capteurs CTD sont régulièrement calibrés au laboratoire, et des calibrages CTD in situ sont effectués avec bouteilles à renversement et rosette. Le recueillement et le

traitement des données de bouteilles à prélèvement ont en principe été en conformité avec le système CIEM de cartes de données. Les procédés employés actuellement pour l'opération et le traitement des données sont décrit, mais comme les systèmes sont relativement nouveaux, les routines pour ceux-ci sont toujours dans une phase de développement, et peuvent être sujets à des changements. Pendant le traitement primaire, les séries de données CTD des variables observés sont rédigés et épurés d'erreurs fortuits, et des filtres passe-bas sont employés pour le lissage. Un filtre récursif de délai s'utilise pour compenser les données de conductibilité du constant temporel plus long du capteur de température. Les données finales de pression (profondeur), température et salinité sont réduits en trouvant la moyenne de pression des intervalles sélectionnés.

INTRODUCTION

Over several decades there have been standardized routines for collecting hydrographic data with water bottles and reversing thermometers. Details in working procedures may have varied somewhat in the 8 institutes in Norway which collect hydrographic data, but in general collecting and processing of the data have been in accordance with the ICES standards (Anon, 1979).

During the 1970s several vessels were equipped with systems for profiling of hydrographic variables. From 1970 to 1975 one of the vessels belonging to the Institute of Marine Research, Directorate of Fisheries, applied a Bissett Berman STD, but since then only Neil Brown CTD systems have been applied and there are now several systems in use. Most of the organizations mainly work in inshore waters and the data collected are normally not subject to international exchange. The major institutes for oceanographic work in offshore and oceanic waters are the Institute of Geophysics, University of Bergen and the Institute of Marine Research. The present paper aims to describe the procedures at these two institutes.

Standard procedures for collecting and processing of CTD data are not yet established. The systems of the two institutes have therefore some different features, both being under development and may still be subject to change.

THERMOMETER CALIBRATION

Reversing thermometers have in general been calibrated in tank once a year and periodically checks at the triple point of water have also been made. The tank is not equipped with constant temperature regulations, but is isolated to keep temperature change within 0.02°C over a period of 10 minutes when there is a deviation of 25°C between tank temperature and outside temperature. During the last years the CTD-temperature standard has been applied as reference and previously other types of high accuracy thermometers were used.

CTD-MAINTENANCE

The CTD-systems are routinely calibrated in the laboratory two times a year and additional calibrations are made if any component in the underwater unit is exchanged. For this purpose there is a laboratory where a calibration unit is set up. This consists of an NBIS Conductivity and Temperature Calibration Unit, Model CT-2, which is used as a secondary reference. Before calibrations the thermometer of this unit is controlled against the triple points of water and phenoxybenzene at 0.0100°C and 26.8680°C respectively. The conductivity standard is checked against IOS Standard Seawater. After these checks the calibration unit has the following specifications:

	TEMPERATURE	CONDUCTIVITY
Resolution	$.0001^{\circ}\text{C}$	$.0001$ mmhos.
Linearity	$\pm .0003^{\circ}\text{C}$	$\pm .0005$ mmhos.
Stability (3 months)	$\pm .0010^{\circ}\text{C}$	$\pm .0010$ mmhos.

Pressure is calibrated against a precision Pressure Standard to an accuracy of 0.1% of the total pressure.

SALINOMETER CALIBRATION

Salinities of water bottle samples are in general determined with AUTO-LAB salinometers. Whenever in use, the salinometers are standardized with standard seawater. Previously sub-standards were used in addition to Copenhagen or IOS Standard Seawater, but during the latest years only IOS Standard Seawater has been applied.

At intervals sea water samples have been exchanged between the two institutes for intercalibration, and on some occasions samples have been sent to the British Institute of Oceanographic Sciences for control.

DESCRIPTION OF RECORDING FORMAT

When the research vessel arrives at a station, position, depth to bottom, and surface data, i.e. meteorological data, state of sea and ice conditions, are recorded on the bridge and filled into a form. In the ships laboratory these data are filled into the appropriate observation logs. The oceanographic station log is in essentials based on the standard form in the ICES Punch Card System (Anon, 1979). In addition the form includes columns for "wire-out", numbering of water bottles and boxes, readings and corrections of thermometers and salinometer readings.

When the CTD-system is operated on a station, the two institutes apply slightly different recording formats. On the vessels belonging to the Institute of Marine Research the 16-bit parallel output of the CTD deck unit is interfaced to a computer. The total amount of CTD raw data is logged by the computer and stored on 9-track magnetic tape, one file for each station. The data from

each station consists on one header block and the necessary number of data blocks (Tjora, 1984), A back-up is also recorded on audio tape.

The header block contains station identification data, position, depth to bottom and surface data. The identification data consists of vessel and station number and time at the start of the station. Position, in degrees and minutes to the second decimal place, date and time are automatically entered from the navigation system of the vessel, but may optionally be entered manually together with the other data in the header block.

When the CTD is being lowered the computer prints out a provisional listing of selected series, e.g. at 5 DBar intervals. The observed variables are printed together with derived values of salinity, density etc. This listing is based on individual observation series and no error checking or smoothing is made.

At the Institute of Geophysics the output format is somewhat different. Here a data acquisition system, CAQ78, developed at Woods Hole Oceanic Institution is used (Power, 1978). This system is based on a HP-1000 computer and either real time data or data replayed from audio tape may be processed. This system writes all raw data to magnetic tape in CTD-78 format (Millard et al. 1978), plots profiles of selected data and computed variables and lists data and computed variables every minute. The first record of each station is the STATION FILE HEADER, and the last is a FILE TRAILER record. These contain information about station number, date, time, position etc. In this system there is a routine for editing of the data at this level (CTD EDITOR) which is used to correct data items and add data from water samples. These various types of data are placed between the header and trailer for the station, all types identified by a keyword (first word of each record).

STATION PROCEDURES

The procedure at water bottle stations is essentially the same at both institutes. The winchman is given a record of meter wheel wire-out readings for the depths to be sampled. The vessel is manouvered to keep the wire vertical and to enable echo sounder observation of the water bottles. At least during the last two decades unprotected thermometers have not been used, and admittedly, this is a source of error when it is impossible to keep the wire vertical.

The water bottles are always equipped with two protected reversing thermometers, and the temperatures are corrected graphically following a procedure given by Theisen (1947). This method allows the temperature to be quickly corrected as soon as the thermometers are read. If the two corrected temperature readings from any water bottle differ by more than 0.03°C the respective thermometers are read once more. In this way reading errors may be detected before thermometers are reset for the next haul. When a station is completed the water bottles are emptied and reversed to keep the thermometers in a non-broken condition between stations.

Bottles for salinity samples are reused, the former sample normally remaining on the bottle until it is used again. Before a new sample

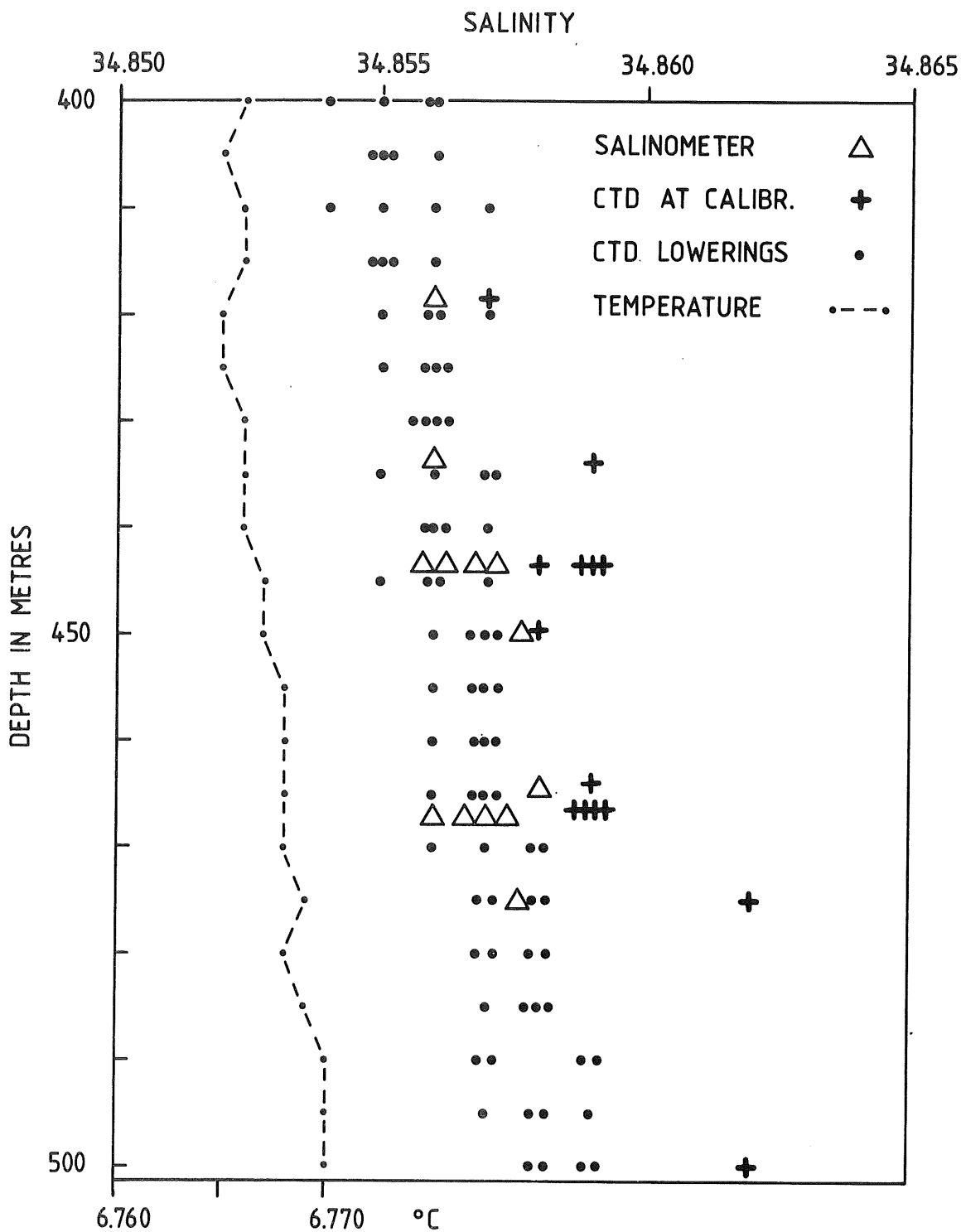
is taken, the bottle is washed twice in seawater drawn from the sample. On some cruises salinities are determined onboard, but generally the salinity samples are brought to the laboratory for analysis.

When oxygen is observed, the Winkler method is applied for analysis and this work is always done onboard. When nutrients are observed, the samples are on some cruises analysed onboard within 2 hours after sampling. In some cases when the analysis can not be done onboard, the samples have to be stored. Three methods for storing have been tried, i.e. freezing and refrigeration with and without preservative added to the samples. The effect of different storage procedures on the analysis of nitrate, phosphate and silicate have been compared (Hagebø and Rey, 1984) and for storage periods longer than 6 days the best results are obtained by adding chloroform, 0.5 to 1% v/v, and keep the samples refrigerated at 1-3°C. The samples are stored on polyethylene flasks.

Before and after each CTD lowering the sensors are washed with freshwater and when the air temperature may be below zero, the underwater unit is kept in a temperate room between stations. Under extreme conditions it may be necessary to wash the sensors with alcohol before lowering to avoid ice formation on the sensors. Various methods have been tried for periodic more thorough cleaning of the conductivity cell which is very sensitive to contamination. In most cases it suffices to wash the cell in a mild detergent solution, but occasionally it is necessary to wash with a 5% hydrochloric acid solution in addition. The detergent used at present is specially made for photographic laboratory work, e.g. Photo-flo.

Calibration of the CTD at sea has mainly been done by means of a reversing water bottle on stations with a homogenous layer, preferably with negligible gradients in both conductivity and temperature. The water bottle is then placed closely above the underwater unit and the layer is selected from the real-time output from the station. A new reading from the CTD is listed when the water bottle is reversed. The reversing water bottle is also equipped with thermometers for temperature checks when wanted. Calibrations have not been made at all stations, but on stations where suitable conditions have been observed. Two vessels have now CTDs with rosette samplers so that conductivity calibrations can be done more conveniently.

It has often been questioned whether the CTD observes correctly when it is not lowered at its recommended speed. To look into this a series of calibrations were made in a fjord basin with a homogenous layer between about 350 and 550 m depth. Four CTD stations were worked within a period of two and a half hour. Just after the two first stations calibration samples were collected with the rosette sampler while the CTD was lowered at 0.5 m/sec and 1.0 m/sec respectively. Just after the two last stations four samples were collected at intervals of 5 minutes while the underwater unit was at a fixed depth (there was no ship motion). On all stations CTD observations were recorded at the release time of each rosette bottle. The results are plotted in Figure 1. The temperature was practically constant between 400 and 500 m, the maximum difference observed was 0.005°C, and no variations was observed over the total time period. The observations from the four CTD lowerings are not



smoothed and it is seen that the random noise did not exceed 0.003 in salinity. The salinities determined in the laboratory from the calibration samples agree well with the CTD lowerings, but the CTD readings recorded when the CTD was idle at a fixed depth, were systematically about 0.002 salinity units higher than the observations from the lowerings. The CTD readings taken before the release of the rosette bottles on the two first stations, fall even more on the high side.

The CTD-winch on the vessels are equipped with a speedometer to monitor the average lowering speed, normally 1 m/sec, but there are no motion compensating facilities to obtain constant lowering speed independent of the motion of the ship.

DATA IDENTIFICATION

At the Institute of Marine Research observations are in general identified by vessel number, station number, position and time of observation. For hydrographic observations consecutive series of station numbers are established for each year and each vessel. When oxygen and nutrients are observed, these observations are given the same station number and identification data as the CTD- or water bottle station simultaneously worked. This is also the case when salinity samples are collected with a rosette sampler on a CTD-station.

Merging of the various data types under a common station number is part of the primary processing in the laboratory. The different data types are given their own blocks in the data file, and markers in the header block of each station indicate the different blocks. For instance fishing stations have separate number series, but otherwise the identification data are identical and can be used for cross reference between different data sets.

The Institute of Geophysics identifies the hydrographic data by cruise number and a new series of station numbers for each cruise. Data files are stored on magnetic tape in cruise order.

PRIMARY DATA PROCESSING AND ANALYSIS

At the Institute of Marine Research the first step in the primary processing of CTD-tapes from the vessel computers is data reduction and packing. The raw data from each observation series are reduced from 5 to 4 16-bit words by the way that the sign bit for temperature is sharing a data word with the synchronizing bits (frame sync). This word also contains a serial index modulo 128. In the same operation the data are also transferred to tapes with higher packing density for storing.

As a second step the actual primary processing is initiated. The series of the three observed variables are edited, i.e. clearly erroneous values are removed and interpolated values are inserted instead. This editing is done by linear regression for selected sections of the data set (e.g. over 10 scans), and observations falling more than 2 standard deviations from the regression line are substituted by the respective ordinate value of the line. When the correlation coefficient is above a chosen value, e.g. 0.7, the same

regression line is applied beyond the data it is based on until a value falling outside 2 standard deviations is encountered. In this procedure pressure is first correlated with the serial index (time) and then smoothed by low pass filtering. Next temperature and conductivity are correlated with pressure.

After this the lowering speed at the various scans is computed from the time derivative of the adjacent pressure data. Scans observed at CTD-velocities less than a chosen value, normally 0.3 m/sec, are discarded. Now the remaining temperature data are smoothed by a low pass filter and a recursive filter (e.g. Perkin and Lewis, 1982) is applied to the conductivity values to generate uniformly lagged responses for conductivity and temperature. Strictly, a similar lag correction should also be implemented on the pressure values, but since pressure effects salinity far less than temperature and conductivity, this is not considered necessary.

In situ calibrations are now applied to the data. Adjustment of conductivity are often necessary while the temperature and pressure sensors have much better time stability. The true conductivity is computed by iteration from the salinity of the calibration sample and the correct values of pressure and temperature. The resulting calibration factor for conductivity is then applied by modifying the cell factor accordingly (e.g. Lewis and Perkin, 1981).

Now salinity is computed, the algorithm for PSS-78 being used, and finally the data set is reduced by averaging of temperature and salinity for selected pressure intervals in the data set. The pressure (or depth) for which temperature and salinity are wanted are in the centre of such intervals. Normally the arithmetic average for intervals of 1 DBar are stored in the final, reduced data file. This is an interactive file with application routines for computation of derived variables and various types of graphical presentations. Data from water bottle observations are written into the file from a keyboard while CTD-data are transferred from magnetic tape after the primary processing. For water bottle data, all standard depths observed are recorded and CTD-data are recorded at 2 m intervals in the upper 30 m and at 5 m intervals at greater depths.

At the Institute of Geophysics the first step in the processing is to produce an edited version of the raw data tapes (Røyset and Bjerke, 1982). The original data are corrected and data from water bottle observations are added. This processing includes a first order difference test to consecutive data values of pressure, temperature and conductivity to substitute erroneous, noisy data with interpolated values. A running mean low pass filter is applied to the pressure data and after this a recursive low pass filter is applied for time lagging of the pressure and conductivity data. In situ calibrations of the conductivity sensor are applied by modifying the cell constant. Salinity is now computed and averages of temperature and salinity are prepared in selected pressure intervals (Røyset and Bjerke, 1982, Østerhus, 1985). The processed data are transferred to an oceanographic data base system (Holm, 1982).

The data file systems of the two institutes are differently structured and different types of computers are used, but in connection with both systems there are routines for selecting

specified data out of the total data mass, the usual types of derived variables can be computed and there are also routines for graphical presentations. For instance the routine for t-s plots can retrieve the relevant data from the data file and present the result on a graphical device. Scaling of the coordinates and limiting values can be selected interactively. The various types of variables can be combined in such plots.

There are also systems for plotting of variables in maps or vertical sections. Here the values of the selected variable can be written in its relevant position, or interpolation routines can be applied to present isolines. Scales of the coordinates and geographical limits can be selected interactively. These routines can also be applied in batch mode (Holm, 1980, Westgård, 1984).

TIMING OF DISSEMINATION OF DATA TO DATA CENTRES

Traditionally water bottle data have been sent to the data centre shortly after analysis and the first quality control have been completed, normally with a delay of about one year. For CTD data there have, however, been much longer delays due to lack of satisfactory routines for the primary processing. As such systems now are developed, efforts are made to catch up with the backlog.

DATA SECURITY

The hydrographic data are submitted to the national datacentre for further dissemination. At present the Norwegian Oceanographic Datacentre submits data to other centres and organizations on request. A condition is that the data shall be used only for the purpose stated in the requisition. The data centre should be informed if the data are used for other purposes or submitted to third parties. If erroneous or questionable data are revealed during their application, the data centre should also be informed. The source of the data should be stated in publications for which they are used and the data centre reserves the right to get a copy of such publications.

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