PROFILING THE UPPER OCEAN BY MEANS OF THE TOWED VEHICLE "SEASOAR".

by
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Abstract

A brief description of the use of the towed undulator SeaSoar on the R/V "Håkon Mosby" of University of Bergen is given. The effectiveness and shortcomings of this hydrographic mapping technique are pointed at. Methods of data quality monitoring and subsequent corrections and calibrations are presented, with figures showing different real time and post cruise data presentation methods.

1. Introduction.

Since the first test cruise early in 1985, the towed underwater vehicle "SeaSoar" has been regularly used on oceanographic surveys from University of Bergen's R/V "Håkon Mosby".

The SeaSoar as depicted in Fig. 1 is developed and manufactured by the Institute of Oceanographic Sciences, Wormley, England. The SeaSoar, in turn, evolved from the original Batfish, developed at the Bedford Institute of Oceanography (Dessureault, 1976).

The SeaSoar undulates by movable wings, depth control being regulated by a deck unit which monitors a pressure sensor and compares it with a prescribed flight path. The flight characteristics, i.e. extreme depth, diving and ascending rates, are in principle determined by the deck unit settings. However, speed, cable length, cable type (faired/unfaired), sensor weight, ballasting and cable tension affect the flight characteristics.

The Operation of the SeaSoar from "Håkon Mosby" as such is now going smooth, as a result of some minor technical adjustments and the operators gaining experience underway.
The SeaSoar has from R/V "Håkon Mosby" been operated on several cruises in Norwegian fjords and coastal areas, as well as in more remote areas like the Greenland Sea, the Faeroe Banks and in the Gulf Stream. The vehicle has been equipped with a standard Neil Brown CTD unit, with an additional Beckman dissolved oxygen sensor used on some cruises. Also tests have been made with a Copenhagen Q-fluorometer installed.

The present paper is an attempt to sum up the experience with the use of the SeaSoar of the University of Bergen, with emphasis on data quality monitoring, processing and presentation.

2. The SeaSoar as a tool in oceanographic surveying.

For upper ocean physical and biological investigations the SeaSoar and equivalent vehicles are indisputably effective, and they are extensively used by several oceanographic institutions. See e.g. Herman (1985). As compared with traditional lowered CTD stations, it gives more synoptic mappings for investigations to moderate depth. After deployment and relevant settings of the deck unit, the SeaSoar can in principle run undisturbed for hours with the attention from just one or two persons.

The maximum depth of the SeaSoar is essentially a function of ship speed and the length of faired cable being paid out. With 600 metres of cable (as for "Håkon Mosby"), depths close to 400 metres have been reached. However, forcing the SeaSoar to depths beyond 350 metres greatly increases the undulation period, and thus reduces horizontal resolution of the transect being made. There is a "break even" depth of the SeaSoar versus traditional lowered CTD stations, beyond which the latter method gives better horizontal resolution. Assuming that the ship's towing speed is half of full speed, and that regular lowering speed of the CTD is 1 m/s, this "break even" depth is around 350 metres in our case.

Certainly the SeaSoar also has other limitations. There is presently no method by which one can obtain high quality calibration information for the CTD probe (as e.g. rosette samples for regular lowered CTD stations). The ascending or descending speed can during the flight vary significantly. This may create some problems when applying lag corrections on the conductivity.

For investigations in narrow or shallow waters SeaSoar towing can be difficult, and requires great attention from navigators as well as the SeaSoar operators. For investigations in some fjords this may be a serious limitation, as e.g. dynamic and biological fronts often are observed in the (narrow) sill areas.

Contamination of the sensors can be a problem, which in the worst cases may require complete recovery of the SeaSoar for proper cleaning. Usually however, contamination does not stick for too long, and a surface flushing of the SeaSoar helps cleaning.

Near surface observations may be difficult to obtain, as the SeaSoar sometimes has been apt to riding on the surface, long after having received a down signal from the deck unit. This
problem is now small, partly due to the installation of a more suitable, narrow-range pressure sensor in the CTD probe.

3. Data acquisition and data quality monitoring.

The data acquisition for the SeaSoar goes essentially as for regular CTD stations. The ship's main computer facilities consist of a HP1000 system. The CTD-$O_2$ data acquisition programme is a slight modification of the programme due to Power (1978). The data acquisition system is schematically shown in Fig. 2.

Each SeaSoar "station" consists of many undulations, with decreasing and increasing pressure, and may contain continuous data from several hours of steaming. In order to keep track of position underway, records of navigation data are merged at specified intervals (e.g. 2 minutes) between the CTD-$O_2$ data records. The navigation data comes from the ship's separate navigation computer which receives input from many sources. The navigation data records also contain information on ship speed, gyro and system heading, bottom depth etc. which are subsequently used.

The fluorometer data has not yet been merged into the CTD data stream, but are transmitted separately via the sea cable to an Apple II computer, which stores the data on diskettes.

On a digital plotter the path of the SeaSoar (CTD pressure versus time) is monitored. This plotter is controlled by a programme which runs on the HP-1000 parallel with the data acquisition programme (but with a lower priority). This programme (due to J.L. Lillibridge at University of Rhode Island) has also the neat feature of marking specified iso-surface "crossings" of temperature, salinity, oxygen or derived parameters, Fig. 3a. These plots can then easily be contoured (Fig. 3b). The real time vertical sections (in pressure-time space) are very handy and are essential when making detailed frontal mappings.

Only one parameter (like temperature) are contoured in real time. Other parameters can subsequently be contoured on board by replaying the digital tape through the HP-1000.

3.1. Data quality.

Salinity and temperature. Monitoring the data quality is essential when running the SeaSoar. This is usually done by continuously plotting temperature versus salinity in a T-S diagram (Fig. 4) on a second digital plotter. Sudden shifts in e.g. salinity can usually be detected as a change from the characteristic T-S curve. By carefully noting the time of this event, the bad data can later be flagged as "bad" or edited back to "normal".

Underway calibration of the conductivity sensor is done at regular intervals by sampling surface water from the ship's cooling water intake, and phasing the sampling time to match with the next surfacing of the SeaSoar. The water samples are later analysed in a lab salinometer for determination of salinity. This method
definitively has its shortcomings and limited accuracy. But with a sufficient number of samples one gets a fairly good statistic data set for determination of possible medium and long term drift in the conductivity sensor. Very high absolute accuracy of the data, as required for e.g. deep water observations, is seldom required in upper layer studies, where the spatial variation commonly is high.

Oxygen.
Monitoring the oxygen probe data is more difficult. This probe suffers from its slow response time and problems with hysteresis, i.e. significant and systematic differences between up and down casts (Fig. 5). Also turbulence (bubbles) may cause trouble at high towing speed (especially downcasts). The latter problem has crudely been overcome by covering the sensor head with gauze(!).
Vertical profiles of dissolved oxygen obtained from rosette samples on regular stations with the SeaSoar CTD-O2 probe in between SeaSoar tows may give some extra information on accuracy, response time and hysteresis.

4. Post cruise processing and presentation of data.
A significant number of digital tapes containing raw data is the result of most SeaSoar cruises. The first step in the post cruise data processing is editing, calibrating and decimating the (raw) data. This work is done also on a HP-1000 computer. The editing is done to eliminate bad points (contamination etc.). Then a recursive lag correction filter is applied to conductivity and pressure. Then, 1-second values of pressure, temperature and conductivity are calculated by low-pass filtering and decimation. The oxygen data (oxygen current and oxygen temperature) have a real sampling rate of only 1 Hz, and are pipelined through the 1-second reduction process unchanged, and are subsequently "sped up" to reduce hysteresis (Golmen et. al. 1986).

The 1-second values of data are copied back to tape, and stored in a format similar to the format of the raw data tapes. Most of the remaining work on the data is done on a mainframe computer at University og Bergen.

The final plotting and calculating routines for the SeaSoar CTD-O2 data are essentially the same as those used for regular CTD data. However, to run SeaSoar data on the existing software, a "verticalization" of the data is required. The verticalization implies treating each SeaSoar descent and ascent as a separate "station", with unique station number, station time and position. The latter updated from the most recent navigation data record. This verticalization introduces a minor distortion of the isolines in the finally plotted vertical sections, according to the following expression:

$$\cot a = \begin{cases} \cot a' - \cot b & \text{shoaling} \\ \cot a' + \cot b & \text{deepening} \end{cases}$$

Here a is the real angle between the sea surface and the iso-surface, and b is the diving angle of the SeaSoar (Fig. 1). a' then is the perceived angle of the iso-surface, as shown in the
vertical sections. This distortion is for most oceanic and coastal hydrographic features negligibly small (Golmen and Hackett, 1986). An example of a computer contoured section is shown in Fig. 6 (only SeaSoar descents).

The distinction between descents and ascents gives a better opportunity for a systematic correction of hysteresis (especially for oxygen data). The verticalization of the data into regular CTD station format, also makes storing, retrieval and sorting of final, corrected SeaSoar data easy.

Recently the SeaSoar has been used simultaneously with the acoustical doppler current profiler mounted on "Håkon Mosby". The detailed dynamic and hydrographic mappings thus obtained, give the opportunity to do calculations on mixing and diffusion in frontal areas (Rickardson numbers, Cox numbers, stability angle calculations etc.). The next step is to improve oxygen data quality, and to get variosens/fluorometer data into the data stream of the CTD, i.e. through the HP-1000 and on to digital tape directly.
REFERENCES


Fig. 1. Sketch of the SeaSoar towed undulator. Also shown are ship's steaming direction and SeaSoar flight path relative to the slope of isolines.
Fig. 2. Sketch of the real time data acquisition and monitoring system.
Fig. 3. Example of a real time contour plot (3a) and hand drawn contours (3b). Pressure trace (optional) is not plotted. Tick marks identifies each turnover of the SeaSoar.
Fig. 4. Example of T-S monitoring. A sudden shift is seen in the first (upper) T-S cluster. The second (lower) cluster is due to an origo shift of the plotter.
Fig. 5. Plot of uncorrected, raw dissolved oxygen values. Fully drawn lines represent SeaSoar descents, Dashed lines ascents. The effect of slow response time (and hysteresis) can easily be seen.
Fig. 6. Example of a computer contoured section, after verticalization and separation between ascents and descents are done. Only descents, each with a unique "station" number are shown here. Min. and Max. pressures of each descent are marked.