FiskDir. Skr. Ser. HavUnders., *15*: 266–273.

PHYSICAL VARIABILITY IN THE SEA AND THE CONSEQUENCES FOR FISHERIES HYDROGRAPHY

By

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INTRODUCTION

Fisheries hydrography relies on physical, chemical and biological oceanography and as a marine science tries to solve practical problems in fisheries by understanding the behaviour of various organisms in connection with the natural environment. A broader basis of studies was given by the foundation of the International Council for the Exploration of the Sea (ICES) in 1902. General and detailed facts could be established: the stocks of commercial fish are integrants of ecological systems in which interrelated physical and chemical conditions of great complexity operate and fluctuate from year to year. These systems exercise decisive influence on reproduction, growth and mortality of the organisms, and no rational study of fish can be undertaken without exhaustive inquiry on the physical-chemical conditions. Among the factors of the ecological systems are water temperature, salinity, depth, pressure, currents, content of different nutrients, oxygen, light, osmotic pressure, hydrogen-ion concentration, food (DIETRICH, SAHRHAGE and SCHUBERT 1959). Measuring and understanding of the physical and chemical factors have developed enormously during the last ten years. This is not without influence on fisheries hydrography as such factors have to be taken into account in biological oceanography. New important environmental factors could still be discovered.

The great development in physical and chemical oceanography in the last decade became possible by the introduction of modern electronics to measurements and data processing. Stratification and motions were revealed and showed surprising variations, periodic and non-periodic. Physical oceanography was challenged to measure and to ex-

Contribution given in honour of Gunnar Rollefsen at his 70th birthday.

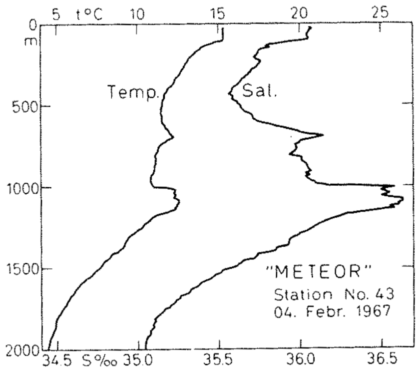

Fig. 1. Vertical profile of temperature and salinity based on a bathysonde record 40 n.m. west of Cap São Vicente ($\varphi = 36°53'N$, $\lambda = 9°50'W$). (After SIEDLER 1968).

plain these phenomena and to give the biological oceanography a base to study the consequences on the behaviour of the species. Under the topic "variability" these processes and their interrelation in space and time became one of the central tasks of present oceanography.

PHYSICAL VARIABILITY IN TIME AND SPACE

What is the meaning of the general term "variability" in the sea? The answer is demonstrated in five examples using the recordings of modern instruments. The first one (Fig. 1) shows the vertical distribution of temperature and salinity with the fine structure of layering. The continuous records were taken during an anchor station of R/V Meteor during the Atlantic seamounts cruises 1967 near Cap São Vincente in the mixing area of Atlantic and Mediterranean water masses. The second example (Fig. 2) shows the variations in time of temperature and current

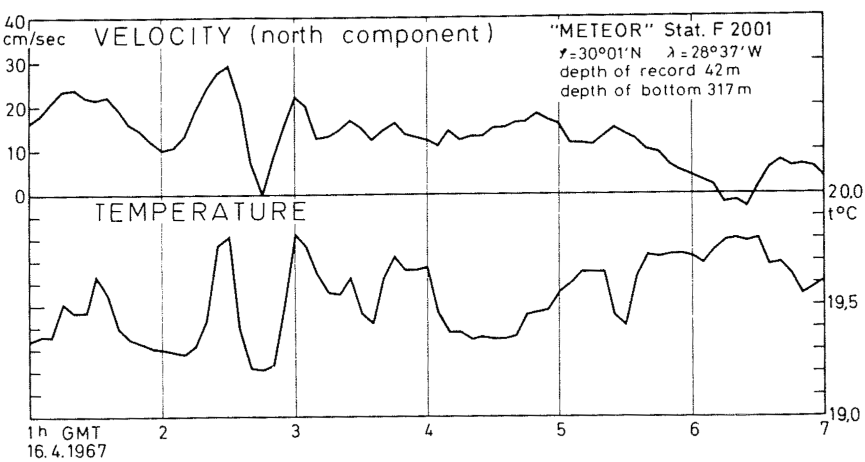

Fig. 2. Time variations in current velocity and temperature on the Great Meteor Seamount over a period of 6 hours. (After MEINCKE 1969).

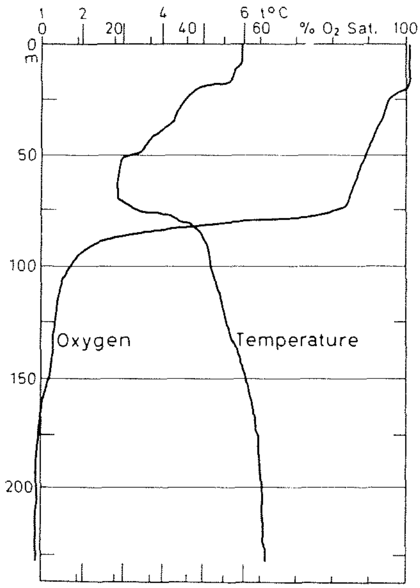

Fig. 3. Vertical profile of temperature and oxygen in % of saturation based on an oxygen-sonde record in the central Baltic 8 May 1968 ($\varphi = 57°03'N$, $\lambda = 19°50'E$). (After GRASSHOFF 1969).

velocity (north component) recorded from a moored instrument system. This example covers six hours and is a small part of a series of long records in the area of the Great Meteor Seamount, showing that even in the open ocean short term changes govern the current and temperature recordings. In a third example (Fig. 3) the vertical distribution of oxygen and temperature in the central Baltic is presented, showing the fine structure of layering. The oxygen changes from 90% to 10% saturation in a thin discontinuity layer at about 80 m depth. In depths more than 150 m the curve is below the zero line, i.e. hydrogen-sulphide appears in the water. In the fourth example (Fig. 4) is demonstrated that a recording

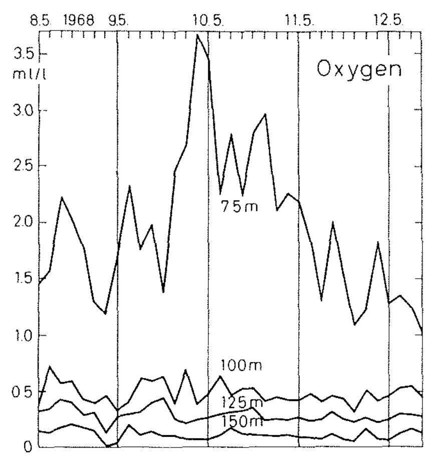

Fig. 4. Time variations of oxygen at different depths during 8–12 May 1968 in the central Baltic ($\varphi = 57°03'N$, $\lambda = 19°50' = E$). (After GIESKES and GRASSHOF 1969).

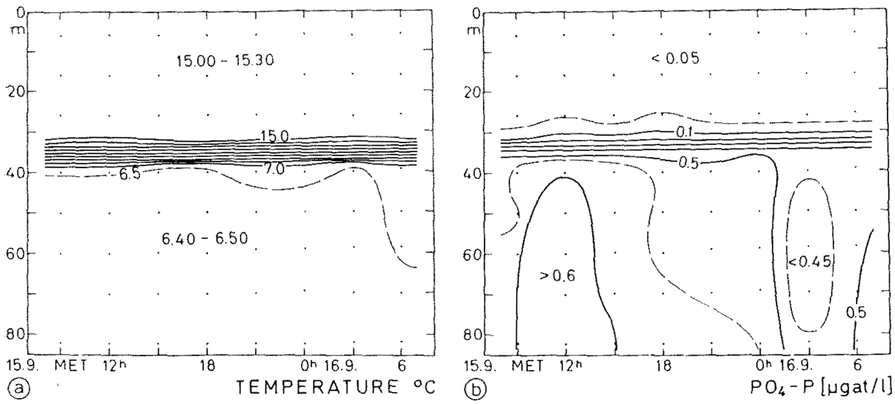

Fig. 5. Time variations during 24 hours, 15–16 Sept. 1968 in the central North Sea represented as isopleths ($\varphi = 56°21'N$, $\lambda = 1°3'E$). (After EHRHARD and SCHOTT 1969).

as in Fig. 3 is not representative, even for some hours. There are time variations in the oxygen content at the same point in the central Baltic. The reasons are vertical movements in internal waves as well as horizontal movements transporting different horizontal water masses which, in the Baltic, are of relatively small dimensions. Such a local inhomogenety of the water can exist in a sea like the Baltic with extremely small tidal currents. But even in the North Sea with strong tidal currents and great mixing short term changes of chemical parameters are pointed out (Fig. 5b) as opposed to the temperature (Fig. 5a). Both figures are based on repeated observations during an anchor station of R/V Alkor. The changes of phosphate content in the deeper layers are about 50% of the absolute value, although the temperature is constant. This means that short term chemical-biological processes exist, which qualify to differentiate between water masses where temperature and also salinity show homogeneous water. Results like these reveal that the sea is much emor complicated in stratification, motion and variations with time than physical and chemical oceanographers had imagined only ten years ago. This, of course, is not without consequences for the fisheries hydrography.

The following facts of common validity may be summarized:

1. The stratification has a rather fine structure, i.e. temperature and salinity may vary strongly in only a few meters of vertical distance. These abrupt changes influence the vertical distribution of currents and chemical parameters and therefore, the environment of the organisms.
2. The fine structure of the stratification changes in time and space.
3. The changes in time consist partly of periodically vertical move-

ments. They are partly unperiodic, and partly they belong to local inhomogeneties in the water.

A single hydrographic station is only representative within a wide range when measuring the fine structure of the vertical distribution of the main physical and chemical components (temperature, salinity, sound velocity, current-shear, oxygen). These measurements must be taken by research ships, since new principles in instrumentation have been developed in the last ten years (bathysonde, sound-velocity meters, current-shear meters, oxygen sonde, etc.).

The observed facts require further special instrumentation to obtain continuous records from moored measuring systems of at least temperature, salinity and current speed and direction. As carriers of instruments different systems are used:

1. Surface buoys damped against surface wave oscillations.
2. Submerged buoys, released from the mooring by an acoustic signal.
3. Masts or posts at the bottom.
4. Underwater winches moving sensors up and down regularly.

The two last systems are usable only in the shelf regions as it was done in the Baltic (Krauss 1960, Siedler and Krause 1967).

By the period analysis of longterm registrations general conclusions can be drawn in spite of the special local characteristics in different areas. Examples from the central Baltic, the central North Sea and the subtropical Atlantic Ocean may illustrate this fact. Figs. 6 and 7 show the amplitude spectra of current velocity components from these records. In Fig. 6 curve a) from the Baltic Sea indicates a significant peak at the

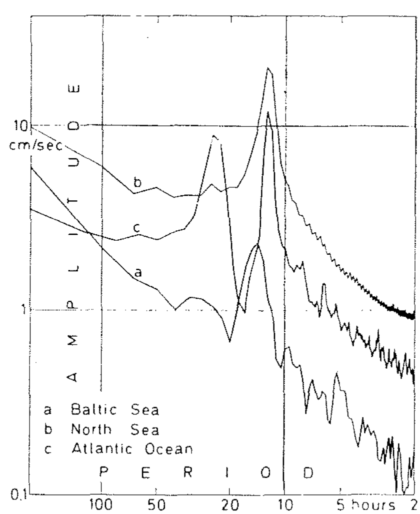

Fig. 6. Amplitude spectra of current velocity, north component, from a) Baltic Sea ($\varphi = 55°3'N$, $\lambda = 13°51'E$), depth of record 39 m, depth of bottom 45 m, 4–25 Aug. 1965. (After Krauss, unpubl. results). b) North Sea ($\varphi = 56°20'N$, $\lambda = 1°0'E$), depth of record 10 m, depth ob bottom 85 m, 14–27 Sept. 1968. (After Schott 1969). c) Atlantic Ocean ($\varphi = 29°60'N$, $\lambda = 28°37'W$) depth of record 50 m, depth of bottom 322 m, 30 April–30 May 1967. (After Meincke 1969).

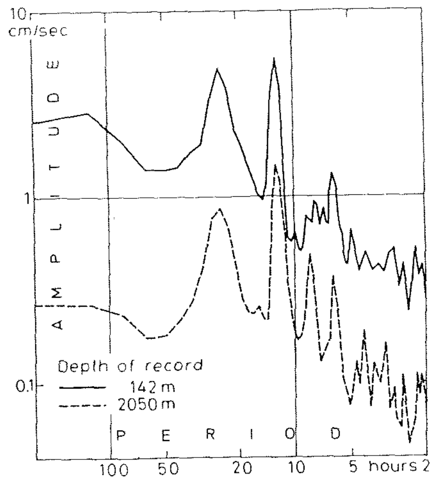

Fig. 7. Amplitude spectra of velocity, north component, from current meters moored by R/V Meteor ($\varphi = 29°05'$N, $\lambda = 29°02'$W, depth of bottom 4630 m, 13–28 April 1967. (After MEINCKE 1969).

inertial period. Curve b) gives the spectrum from a 14 days-record of the homogeneous upper layer in the central North Sea and shows that the half day-tidal component is the only motion of importance. In curve c) the spectrum from a 30 days-record in the Atlantic measured on top of the Great Meteor Seamount, the tidal periods of 12.4 and 24 hours and the inertial period predominate. Two spectra from different depths of a deep sea mooring with water depth 4630 m (Fig. 7) demonstrate that the spectra may differ on different levels even at the same location.

The general features revealed by spectral analysis are:

1. The amplitudes of motion decline towards shorter periods.
2. Records in close vicinity—vertical as well as horizontal—may show low coherence.
3. Only three main types of motion exist in almost all areas of the sea: the tidal currents of half and one-day periods, inertial oscillation with its latitude-dependent period, and the stability oscillation with a period determined by the density stratification.
4. In addition to these narrow bounded sectors of the period spectrum a multitude of periodic and non-periodic motions of almost unknown origin complicates the picture.

Measurement and interpretation of these processes and of the fine structure of stratification are among the main tasks of modern physical oceanography, and this requires further use of moored systems of instruments.

INSTRUMENTS REQUIRED FOR STUDIES OF THE VARIABILITY

The instruments available for mooring are prepared to record up to two months. A longer time interval is not realistic unless sufficient fouling protections for the sensors are developed. The time interval between two single measurements can be between quasi-continuity and one hour, but further changes are not difficult. The measuring depths desired are mainly down to 500 m, in some cases to the bottom in 5000 m.

The accuracy requirements of the measurements depend on the variability in the ocean areas and may, therefore, only be stated for certain ranges. The necessary high accuracies are not fulfilled in all cases as they can be made available only with great technical efforts, e.g. ±0.01‰ in salinity or ±0.01 dbar in pressure:

The standard lower limits of accuracy are:

Temperature	±0.01	to	±0.1 °C
Salinity	±0.01	to	±0.1‰
Current direction	±1	to	±5°
Current speed	±1	to	±10 cm/sec
Pressure (gauge)	±0.01	to	±0.1 dbar
Pressure (depth)	±1	to	±10 dbar.

The attention is focussed on better reliability of the measuring systems under the hard conditions at sea and also on better mooring systems. The methods must be improved, the losses of instruments must be diminished thus increasing the efficiency of the measurements.

CONSEQUENCES FOR FISHERIES HYDROGRAPHY

As demonstrated new sophisticated methods have been developed in physical and chemical oceanography. The progress in fisheries hydrography, however, seems to be inadequate because the correlations between nonbiological and biological factors are not fully understood. Two steps should be made:

1. To study the processes causing the physical and chemical variability.
2. To investigate the biological variability and its relationship to the physical and the chemical variability.

Both can be done in form of experiments in selected areas of the ocean. One of such tests is prepared in the Norwegian Current on the continental slope in autumn 1969 with scandinavian, icelandic and german scientists and with a concentrated effort of research ships and moored recording systems. The results may among other things give criteria, e.g. sampling positions, for moored buoys with data-telemetering systems. Even if no other relationship is known but that between the temperature and the fish distribution such buoys may prove to be as useful as a multinational project of synoptic surveys with research ships as discussed in the ICES and demonstrated by the usefulness of the pilot project in 1966 (EGGVIN 1966).

SUMMARY

Progress in fisheries hydrography depends on progress in the knowledge of physical and chemical variability in the sea. This variability is caused by short term changes in the fine structure of layering in temperature, salinity, current and chemical parameters and revealed by the new ways developed in instrumentation. Some examples of the results, achieved in the North Atlantic, the North Sea and the Baltic, are represented.

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Received 18 June 1969

Printed 10 November 1969