ANNEX V

REPORT OF SCOR WORKING GROUP 21
ON
CONTINUOUS VELOCITY MEASUREMENTS

Terms of Reference:

To design, and propose means of carrying out, an intercomparison at sea of the principal current measuring systems now employed for the continuous recording of current velocity on moored stations.

Sponsorship:

Jointly by SCOR, UNESCO and IAPO.

Members:

K.A. Chekotillo (USSR)	nominated by	SCOR
N.P Fofonoff (USA)		UNESCO
T. Kvinge (NORWAY)		IAPO
B. Shekhvatov (USSR)		UNESCO
G. Siedler (FRG)		IAPO
J.C. Swallow (UK)		SCOR (Chairman)

Summary of activities:

The Group has met twice this year, but before the first meeting it had been agreed by correspondence that the most effective way of meeting the terms of reference was, first, to attempt a modest intercomparison experiment within the framework of the Woods Hole buoy program. Consequently, the main purpose of the first meeting of the Group, held at the National Institute of Oceanography, Wormley, Godalming, on 18 April 1967, was to plan such a comparison in detail.

The minutes of that meeting (attached as ATTACHMENT I) may be summarized briefly as follows. All members were present, and agreed that for this first attempt at an intercomparison only the following types of current meters should be used: Alekseev (to be provided by Chekotillo and Shekhvatov), Bergen (Kvinge), Geodyne (Fofonoff), Plessey (Swallow) and Teifenstrommesser (Siedler). It was proposed that two Geodyne meters and one of each of the other types should be put closely spaced near 500 m depth in each of three moorings, to be laid a few miles apart near WHOI site "D" (39° 20'N, 70° W), and left in place with the meters running at their maximum sampling rate for 5 days. The moorings could then be laid for a second 5-day period, with the option of some rearrangement of meter positions.

In the second meeting, at the Woods Hole Oceanographic Institution and at sea in the R.V. "Gosnold", during July 1967, this intercomparison experiment was carried out. It is too early for a full report to be written, but an account in the form of a cruise report is attached as ATTACHMENT II, and the main features are outlined here. It was unfortunate that K.A. Chekotillo and B. Shekhvatov were unable to attend, and no Alekseev meters could be included in the intercomparison. The rest of the Group met as arranged at Woods Hole on 6 July, and, after re-calibrations in the towing tank sailed in the "Gosnold" for Station "D". Three moorings were laid on 16-17 July and recovered on 24 July.

On returning to Woods Hole, the records were rapidly processed and it was possible to compare some of the results before the Group dispersed on 2 August.

Conclusions:

The terms of reference have been met in the sense that an intercomparison experiment was designed, and the means proposed (and employed) for carrying it out were adequate to produce some data suitable for further analysis. The aim of the experiment was, of course, to obtain records from a variety of current meters, placed in the sea in a situation where they might be expected to behave similarly, and to see to what extent any differences in the results could be accounted for by the known characteristics of the instruments. Any further variations might then be interpreted either as unexpected differences in response of the meters or as real differences of current. First, though, the moorings have to be laid, the current meters have to work properly, and then they have to be recovered. With some good luck the first and last of these three basic requirements were met, but more than half of the current meters developed faults of varying degrees of seriousness during only a week's run. The first conclusion from our intercomparison experiment is, that more attention should be paid to designing for reliability in routine production of current meters. Fortunately at least one of each kind of instrument gave some useable output, and a rough preliminary comparison showed an encouraging similarity in the results.

Proposals:

More detailed comparison must await further processing of the data, and it seems desirable that the Working Group should meet again when this has been done, in a few month's time.

The Working Group recognizes that this intercomparison was a very limited one, both in duration and in numbers and variety of current meters used. Further comparisons are needed. We should like to hear from anyone who has made similar experiments or is planning to do so in the future.

Acknowledgements:

The Group wishes to express its gratitude to its sponsoring bodies, for providing funds for travelling and subsistence and, to some extent, for transport of equipment. At the same time, we are even more indebted to the Woods Hole Oceanographic Institution and the U.S. Office of Naval Research for their support of the actual intercomparison experiment itself. We wish to acknowledge the indispensable help of Captain H. Seibert and the crew of the R.V. "Gosnold", and of James Gifford and Clayton Collins of the Woods Hole buoy group, who did most of the work of laying and recovering the moorings. We are grateful also to Ferris Webster and John Maltais for their capable handling of data from the current meters and for their continuing contributions to its analysis.

ANNEX V
ATTACHMENT I

Minutes of Meeting of SCOR Working Group 21, on Continuous Velocity Measurements
18 April 1967

SCOR Working Group 21 held its first meeting on 18 April 1967 at the National Institute of Oceanography, Wormley, Godalming, Surrey, U.K. All the members of the Group were able to attend. Informal discussions took place on the preceding and following days.

1. The chairman recapitulated what had already been agreed by correspondence, i.e. that we should in fact try to make an intercomparison experiment, since this appeared to be the most practical way of meeting our terms of reference. It was already agreed that this might best be done within the framework of the Woods Hole buoy program, and Dr. Fofonoff has tentatively assigned two weeks of ship time in the "Gosnold" to this purpose. The main task before the meeting was, to agree on a plan for this experiment, and also to consider in what ways a more ideal intercomparison might be made.

2. It was noted that certain limitations are imposed by choice of area (Station "D", 39° 20'N, 70° W) and choice of ship. For example, the "Gosnold" can carry a maximum of 4 moorings, and cannot handle loads exceeding 2 tons. Choice of area is limited by time available and ship's speed, but Station "D" has the advantage that other moorings are laid there. The choice of depth at which to put the current meters is limited, not only by the nature of the vertical distribution of current, but also by the strength of the pressure cases of the instruments. At shallow depths, where currents are relatively strong, giving a good signal to be measured, the shear may be so large that comparison of even closely spaced current meters could be difficult. Dr. Fofonoff showed an example of differences of current of as much as 50 cm/sec, in 2 meters vertical separation, at a depth of about 100 meters at Station "D". The shear may be expected to be much less at greater depths, but the current itself will be less and may sometimes be below the threshold of the current meters.

3. Bearing in mind the existing plans and limitations outlined above, more detailed plans were discussed and the following conclusions were reached:

4. It was agreed that only the following types of current meter should be used in this summer's experiments:

Alekseev	(Chekotillo, Shekhvatov)
Bergen	(Kvinge)
Geodyne	(Fofonoff)
Plessey	(Swallow)
Tiefenstrommesser	(Siedler)

The group was of the opinion that only well-tried types of instruments, familiar to at least one member of the group, should be used. There is still some doubt about the suitability of the Plessey meter in this respect, but it has some features (propeller instead of Savonius rotor, and bracket mounting) that make it attractive for use as a comparison meter.

5. It was agreed that three meters of each type would be a practical number to use in the comparison experiment, and that three moorings would be needed.

6. The manner in which the current meters should be arranged in the moorings was discussed. In correspondence, it had been proposed that frames should be constructed that would enable three or four meters to be suspended at the same depth in the moorings. Although such arrangements would help to avoid the difficulty due to strong vertical shear, the idea was reluctantly abandoned for the following reasons: such a frame would be difficult to handle from the "Gosnold", it might induce extraneous oscillations not normally present in the mooring, and there could be masking of one current meter by another. It was decided that the only practical

way to arrange the meters would be in closely spaced vertical arrays, putting Geodyne meters (which will be available more plentifully than the other kinds) at the top and bottom of each array.

7. Choice of depth for the vertical arrays of current meters was discussed. A region of small shear is desirable and Dr. Fofonoff undertook to obtain STD profiles at Station "D" to help in this choice. A depth of 500 meters was provisionally suggested, and Drs. Chekotillo and Shekhvatov agreed that it would be desirable to use three of the deep version of the Alekseev meter, despite the extra weight involved. Bearing in mind the possibility of currents being sometimes too weak at 500 meters depth, an alternative arrangement was proposed in which two arrays of four meters each were used in each mooring, one array at 200 meters and one at 500 meters. The final choice of depth was left open, since the mooring wire can be made up suitably at a day's notice.

8. With three of the five types of meter being mounted on brackets instead of in line with the mooring wire, and with the likelihood of long vertical arrays of 6 meters having to be handled, a majority of the group were in favour of laying the moorings anchor-first. The usual practice in the "Gosnold" is to lay moorings anchor-last, but Dr. Fofonoff agreed that the anchor-first method might be practicable and that it should be given further consideration and trial.

9. On the question of using surface or subsurface floats, it was agreed that both types should be tried since both are in common use. It is useful to have at least one surface float as a radar mark for the ship. A spacing of 2 miles between moorings was considered to be the minimum advisable at Station "D" (water depth 2600 meters).

10. The number and duration of moorings was considered, and it was agreed that three moorings should be laid, recovered after 5 days, then laid again for another 5 day period. All meters should be run at their highest sampling rates consistent with a recording duration of 5 days. Mr. Kvinge had doubts about the significance of individual 5-minute readings of speed with the Bergen meter, since a change of 1 bit in the coded rotor count in 5 minutes corresponds to several cm/sec, but he agreed to consider the possibility of using a smaller gear ratio in the rotor gear box, which would help to improve the situation.

11. The group discussed the calibration of the current meters in the two tanks at Woods Hole. It was agreed that members should calibrate their meters beforehand so that only a few steady runs would be necessary on each at Woods Hole for checking calibrations. Dynamic tests should be made on one of each type of speed sensor and compass, perhaps by photographing the sensors with a cine-camera attached to the towing carriage. The group was of the opinion that one week would be needed at Woods Hole, before going to sea, for adjusting and calibrating the current meters.

12. To ensure that the current meters being brought to Woods Hole can be incorporated conveniently into the W.H.O.I. moorings, members agreed to supply Dr. Fofonoff with drawings of the meters showing the methods of attachment provided, and materials used, as well as overall dimensions of current meters. Dr. Fofonoff agreed to have brackets made at WHOI for the Alekseev current meters, on receiving a drawing of a suitable bracket from Dr. Shekhvatov.

It was noted that the breaking strain of the tie rods or brackets of the current meters, which are inserted in the mooring line, should be not less than 7000 lbs. (3300 kg).

13. It was agreed that rapid processing and evaluation of the records obtained was most important, and that the group should plan to spend one week at Woods Hole after the cruise in analysing the results. Dr. Chekotillo and Dr. Shekhvatov estimated that the Alekseev records could be read by eye in two or three dyas. The records from the Bergen and Plessey meters will need to be machine-read, and may have to be sent across the Atlantic. Mr. Kvinge and

Dr. Swallow agreed to supply samples of the data format from these types of records to Dr. Fofonoff. Dr. Siedler thought that it should be possible to develop and read the Tiefenstrommesser records quickly at Woods Hole.

14. The four weeks, 5 July to 2 August, were proposed as a suitable time for the experiment, using the "Gosnold" from 12 to 26 July. These dates are only tentative since the ship's program has to be arranged with other users in mind.

15. Transportation of current meters to Woods Hole presents some problems. The heavy parts will have to be sent by sea but the delicate parts of the recorders must be carried by air. Approximately 800 kg of equipment will have to be shipped across the Atlantic and back. This will cost something like $800 for the sea passage alone. The Alekseev meters will have to be sent first to Bergen or Hamburg for onward shipment to Woods Hole. There will be no time to spare for delays in customs.

16. In order to carry out the planned intercomparison experiment, the Working Group asks for the following support from SCOR, UNESCO and/or IAPO: (a) air travel for Dr. Chekotillo, Mr. Kvinge, Dr. Shekhvatov and Dr. Swallow to Woods Hole and back (Drs. Fofonoff and Siedler will be there already); (b) subsistence for two weeks ashore for the four persons first named above; (c) cost of shipping equipment from Europe to U.S.A. and back (rough estimate only); (d) any help that UNESCO can give in explaining the importing and exporting of these current meters to the U.S. customs.

17. The group agreed that a further meeting will be needed, after the data has been processed and examined, a few months after the Woods Hole meeting.

18. In considering how an intercomparison experiment might be done better, the group agreed that, in the present state of development of the use of moorings, a more extensive program of comparison would seem to be too ambitious, and that the present somewhat modest proposal was within the capability of all concerned and had reasonable hopes of yielding useful results. The members of this group hope that other comparisons between closely spaced current meters, either of the same or different types, will be made independently by any laboratories engaged in moored buoy work.

19. On the question of the form in which raw current meter data should be exchanged, the group were inclined to think that instrument development was proceeding too rapidly at present for any rigid scheme to be laid down, though clearly such voluminous data must be exchanged in a form suitable for automatic processing. With any time series such as current measurements, it is most useful to assign a time to each sample, for identification, even if the time usually has to be interpolated.

For most purposes, however, the data can be distributed in a much condensed form, e.g. power spectra, trajectories, and mean values, as has been done in the compilations made by Webster and Fofonoff (WHOI unpublished reports 65-44 and 66-60), for example.

20. The group did not have any very firm recommendation to make in answer to Professor Munk's inquiry about near-bottom current meters, but were inclined to think that, initially, any of the existing self-recording current meters could be tried in a buoyant mooring above the bottom pressure gauge, rather than undertaking the development of another type of current meter that could use the same data logger as the tide gauge. It is not obvious that the near-bottom currents will be extremely slow, expecially if readings above the boundary layer are needed, and a conventional existing meter may be sufficient in many cases.

K.A. Chekotillo
N.P. Fofonoff
T. Kvinge
B. Shekhvatov
G. Siedler
J.C. Swallow

ANNEX V
ATTACHMENT II

Report on Meeting of SCOR Working Group 21, on Continuous Velocity Measurements
6 July - 1 August 1967

Introduction:

The second meeting of SCOR Working Group 21 took place, partly at the Woods Hole Oceanographic Institution and partly at sea in the R.V. "Gosnold", during the period 6 July - 1 August 1967. The following members were present; N.P. Fofonoff, T. Kvinge, G. Siedler, J.C. Swallow. Unfortunately K.A. Chekotillo and B. Shekhvatov were not able to attend.

Our aim in this second meeting was to make an intercomparison of current meters, by calibrating them in a tow tank and by putting them out in closely spaced moorings, as proposed in the minutes of the first meeting of the Group, and to see to what extent the differences between the various current meter records could be explained in terms of the response characteristics of the instruments themselves.

Three of each of the following types of current meters were available:

Geodyne (tape recording)	(Fofonoff)
Geodyne (film recording)	
Bergen	(Kvinge)
Tiefenstrommesser (TSM)	(Siedler)
Plessey	(Swallow)

Calibration:

The most striking differences between the types of meters available are in the following features:

(a) sampling rate (every 5 sec. for Geodyne, 5 min. for others) and related differences in rate of response of speed and direction sensors.

(b) method of suspension, related to type of speed sensor (bracket mounting for Plessey and TSM, using propellers; in line with mooring for Geodyne and Bergen, using Savonius rotors).

(c) threshold speeds (ranging from 2 cm/sec for Geodyne to 3-5 cm/sec for Plessey) and nonlinearity of the relationship between speed and rate of rotation of speed sensor.

Previous observations with Geodyne meters at the proposed site showed that the energy of horizontal motions with periods shorter than 5 minutes would probably be too small to contribute a serious amount of noise in the records from the meters sampling at 5 minute intervals, even if the extra filtering action of their direction sensors compared to the Geodyne vane was ignored. It seemed likely therefore that item (c) above would be a more important source of differences in the results than (a) and (b), and most of the towing tank trials were aimed at determining the shape of the speed calibration curve and threshold speeds for each type of meter. The Bergen, Plessey and TSM instruments were calibrated, at about a dozen speeds in the range 2-35 cm/sec, though the size of the TSM compared to the cross-section of the tank made the absolute value of its calibration doubtful. Some crude visual measurements were made, with each meter, of the acceleration of the speed sensor when released from rest while being towed at various steady speeds. Calibration runs were made on this occasion on only one Geodyne rotor, since this sensor had already been studied in great detail (Fofonoff and

Ercan 1967). Check calibrations were made on one Bergen and one Plessey meter, after the moorings had been recovered and the instruments had been in the sea for approximately one week.

In converting the recorded rotation of a speed sensor into current, a simple linear relationship (not necessarily through the origin) is usally adopted, characteristic of a particular type of current meter. Departures from linearity occur mainly at speeds below 10 cm/sec, and fortunately speeds in this range were encountered during most of the intercomparison period. Variations of individual meters, from the mean for that type, were of the order of 1 cm/sec. Fuller details of the calibrations will be given in a later report.

Narrative of cruise:

The "Gosnold" left Woods Hole p.m. 13 July and reached site "D" the next day. With two kinds of current meters being bracket-mounted, and with the hope of getting the moorings more closely spaced, it was proposed to lay the moorings anchor-first. This had not been done before with the equipment available, and it was soon evident that the drums of pre-cut mooring wire would have to be re-spooled more tightly before they could be used. This took about 12 hours, and then an attempt was made to lay the first mooring, on 15 July.

The 680 kg. Stimson anchor, having considerable drag when rigged normally, caused excessive fluctuation of tension in the wire while lowering, in only a moderate swell, and before long the wire broke, causing the loss of an acoustic release but fortunately nothing more. Subsequent anchors were rigged with their narrowest side downwards, to minimize drag, and on 16 July the first two moorings were laid successfully. There was no difficulty in handling the various current meters closely spaced in the moorings, in fact the 2 m nylon spacers, put in below the bracket-mounted meters, could have been shortened to only 1 m without inconvenience. The only untoward incident was the breaking of a nylon tag line which could have caused the loss of 5 current meters, but luckily a stopper had been hooked on in time, and it held. The third mooring was laid without incident on 17 July. The positions and general arrangement of moorings and current meters are shown in Figs. 1-3. More gasoline had been used than had been expected, in driving the winch for re-spooling the wire, and the "Gosnold" returned to Woods Hole for more supplies. On returning to site "D" a.m. 20 July, the moorings were found in their expected positions, approximately in a right-angled triangle with short sides 1.5 and 2.2 km. During the next four days, several observations were made with a lowered sensing digitizer (LSD) through the depth range occupied by the current meters. The LSD records temperature, conductivity, pressure and relative current at 2 second intervals in digital form. Water samples were taken during some lowerings. Positions are shown in Fig. 1. Fixes were made on the acoustic beacons, and on beacons belonging to other moorings in the area, and the depths of the three subsurface floats were determined by echo-sounding. From the latter, the actual depths of the current meters in each mooring have been inferred. They are listed in Table I below.

TABLE I
Corrected Depths on SCOR - 21 Moorings

Mooring Number	1	2	3
Geodyne (Tape)	477 m	492	500
Bergen	478	493	501
Plessey	481	496	504
TSM	485	500	508
Geodyne (Film)	488	503	511
Bottom	2589	2594	2591

All three moorings were recovered on 24th July, the first two without incident. The acoustic release of the third one did not fire when triggered, but the timed release worked as planned. There were no difficulties in handling the current meters from the "Gosnold". It was an advantage being so close to the water (about 1 m) with the closely spaced current meters.

None of the instruments showed any obvious external signs of corrosion or fouling. Some corrosion had however occurred on galvanized fittings in the neighborhood of the stainless steel parts of the Bergen and Plessey meters, despite precautions taken to insulate them. Two of the Plessey current meters had leaked slightly, about 5 cm^3 of water in each.

The "Gosnold" arrived back in Woods Hole P.M. 25th July.

Data Processing:

A special effort was made to get the records processed quickly. The tapes and films from the Geodyne meters were read by the Geodyne Company and returned to Woods Hole. The films from the TSM's were developed at Woods Hole and read by eye, cards being punched for each 5-minute reading. The tapes from the Gergen and Plessey meters were sent to Bergen and London respectively for reading, and output lists were returned to Woods Hole by 31 July. Cards were then punched from these lists.

Not all the current meters had worked satisfactorily. A first impression of the quality of the records is tabulated below:

TABLE II

Quality of Records (as of 1st August 1967)

Mooring No:	1	2	3
Geodyne (tape)	Short tape	Good	Stuck Compass?
Bergen	Good	Good	Good
Plessey	No data	Mainly good	Fragmentary data
TSM	Good	No speeds	No speeds
Geodyne (film)	Weak film	Weak film	Weak film

It is expected that useful data may be extracted from some of the imperfect records. The Geodyne film records, which gave excessively scattered results when machine-read, can be read at 5-minute intervals by eye. The TSM's with no speed output have produced useable direction records. The records from the two Plessey meters that had leaked slightly (on moorings 1 and 3) were very weak, and it seems possible that they may have been partially demagnetized by leakage currents through the recording head while the tapes were being rewound, but parts of the record from No. 3 may be useable.

By 1st August it was possible to make rough visual comparisons of some preliminary analyses of the data from at least one of each kind of current meter. Progressive vector diagrams had been plotted showing the cumulative movement of water past the current meters, which were encouragingly similar both in overall displacement and in smaller detail. Histograms were plotted, of the speeds and directions recorded in each 2 hour period by one of each type of current meter, to provide another compact presentation of the data for comparison. Convenient means of making these and other analyses of current meter data have been developed at Woods Hole (e.g. Webster and Fofonoff 1965, 1966).

What needs to be done now is, first, checking and editing of the data. Subsequent analysis to allow intercomparison may include, besides the methods mentioned above, compu-

tation of shear between data from different meters (to locate systematic deviations), comparison of vector average and arithmetical average speeds (to reveal systematic differences due to varying fluctuations of recorded direction), comparison of spectra (may reveal instrumental differences in frequency response).

There is also the possibility of comparing these data with the records from two long-term moorings, at site "D" throughout the intercomparison period. It seems likely that, after this further analysis of the data has been made and circulated to members of the Working Group, a third meeting may be necessary for discussion before a full report can be written.

REFERENCES

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WEBSTER, Ferris and N.P. FOFONOFF 1966 A compilation of moored current meter observations. Volume II. Woods Hole Oceanographic Institution Technical Report, Reference No. 66-60, 91 pp. (Unpublished manuscript).

FOFONOFF, N.P. and Y. ERCAN 1967 Response characteristics of a Savonius rotor current meter. Woods Hole Oceanographic Institution Technical Report, Reference No. 67-33, 4 pp. (Unpublished manuscript).

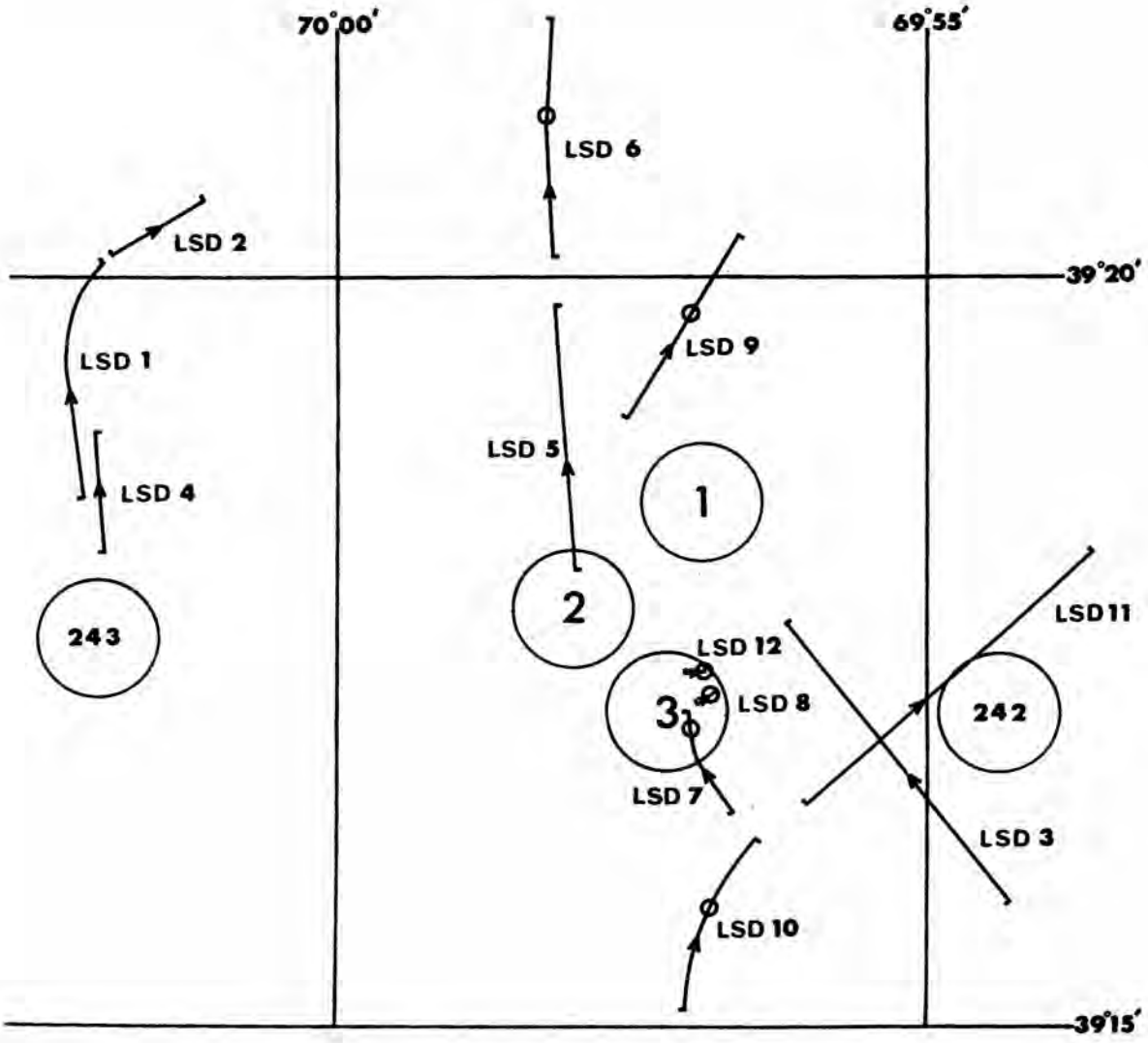

Figure 1. W.H.O.I. Site "D" July 1967

1,2,3: SCOR-21 moorings
242, 243: existing moorings
⟶⊙⟵: LSD lowerings. Arrow shows direction of drift. Circle shows where water samples were taken.

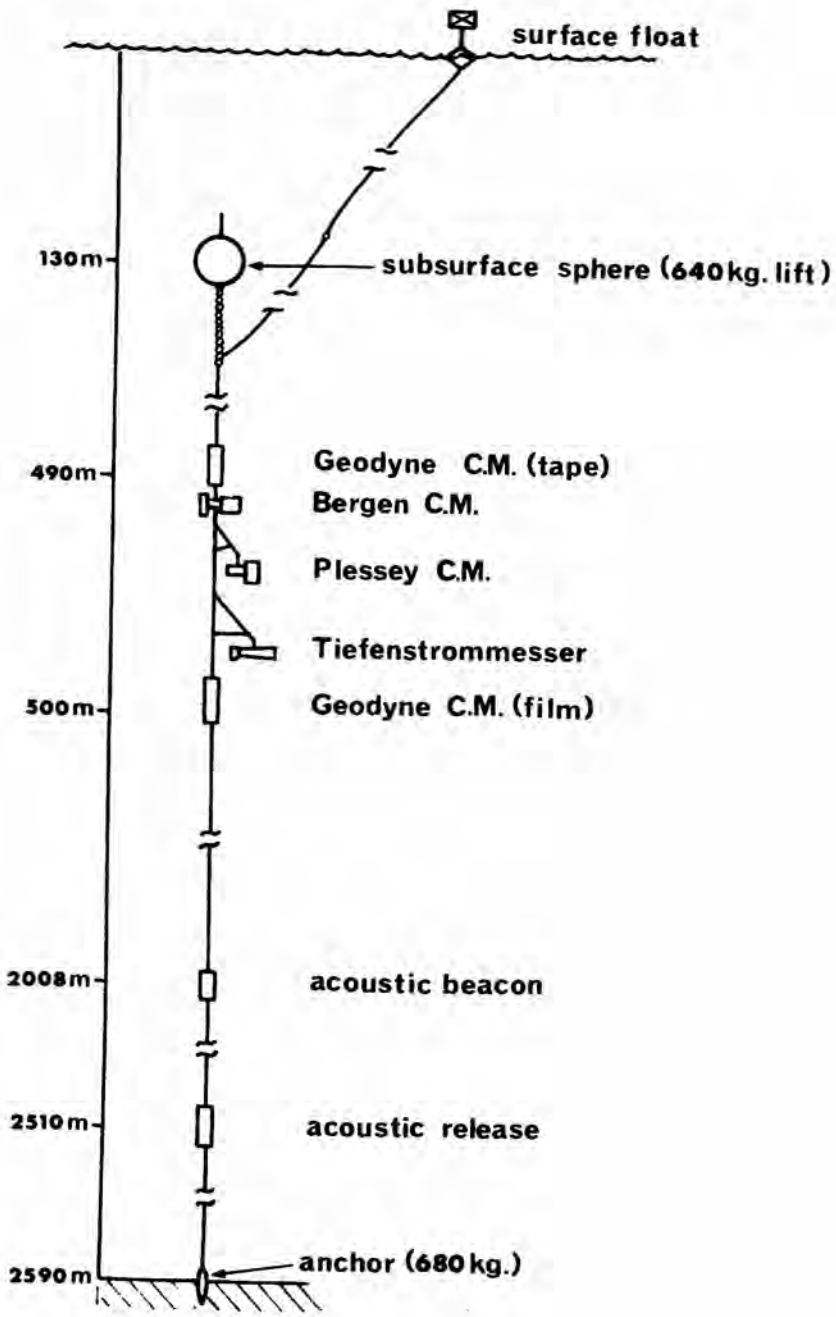

Figure 2 SCOR-21 mooring. (not to scale)

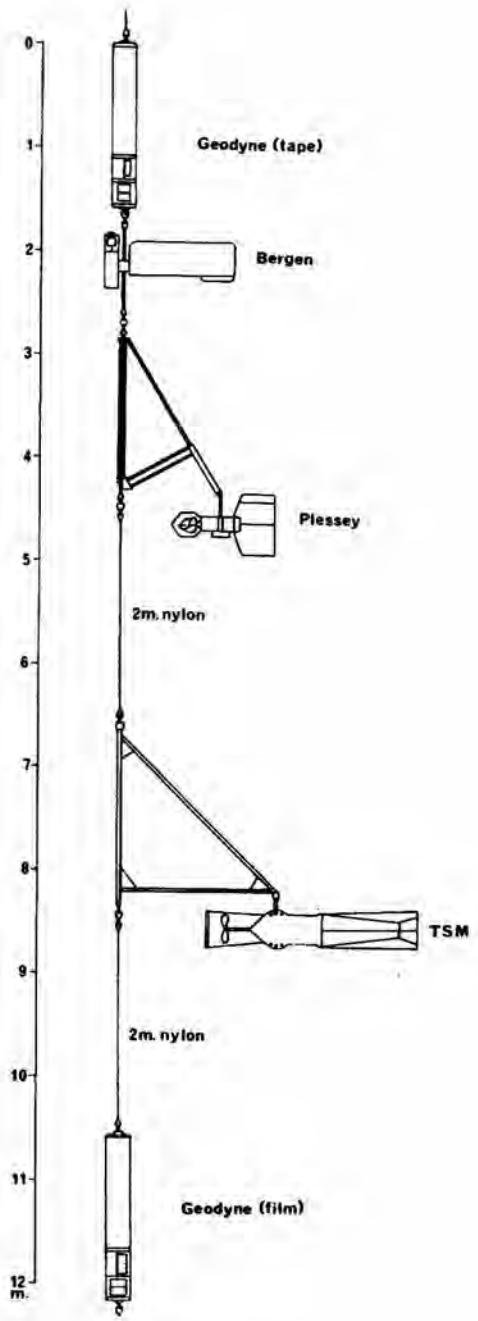

Figure 3 Enlarged diagram of relative positions and sizes of current meters in SCOR-21 moorings