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PROBLEMS INVOLVED IN A LARGE ENVIRONMENTAL TELEMETERING SYSTEM

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CONTENTS

Abstract	ii
Problem Status	ii
Authorization	ii
INTRODUCTION	1
OCEAN-WIDE TELEMETERING NETWORKS	1
CURRENT NETWORK PROBLEMS	2
ACCOMMODATION OF NETWORK PROBLEMS	3
Telemeter Complexity	3
Clock Dependence	4
Telemetering Code	4
Rate of Data Transfer	5
A TELEMETERING SYSTEM COMPOSED OF PRESENT TELEMETERS	6
System Specifications	6
The Present Telemeters	7
The Hybrid Telemeter	8
The Mooring	9
The Central Station	9
Estimated Support	10
AREAS REQUIRING FURTHER DEVELOPMENT	12
SUMMARY	12

ABSTRACT

Extensive laboratory-conducted field tests and semioperational use by military personnel have demonstrated the reliability and utility of various types of automatic weather and oceanographic telemetering equipments. It appears feasible to combine the best design features of the various types into a single equipment because of similarities in the principles of operation employed. All of the equipments would require some modification to adapt them to large network operation; however, most of them could be so modified. Central-station equipment to adapt any of the various codes used to automated data processing is currently available. An analysis has been made of performance requirements of the units composing a large telemetering and data-handling system having a high degree of automation, an estimate of the support that would be required, and the expected system capability. For illustrative purposes, a hypothetical ocean-wide network in the North Pacific Ocean was developed as a model. The model network was composed of 60 buoys of a hybrid design embodying the best features of a number of existing environmental telemetering equipments.

PROBLEM STATUS

This is an interim report; work is continuing on other phases of this problem.

AUTHORIZATION

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INTRODUCTION

Automatic weather and oceanographic telemetering stations have been used, with varying degrees of success, for a number of years. In most cases, these units have been installed, serviced, and monitored by laboratory personnel from the interested activities. The usual employment of automated weather and oceanographic data-gathering equipments has also been characterized by single-station or small-network operation.

The United States Navy has maintained a small network of automatic weather stations in Antarctica for the past three years. The successful use of a small network of automatic weather stations by the Navy in Antarctica during the Deepfreeze '60 operation, on an essentially operational basis, inaugurated a new era in the field.

Even though this was the first successful operation of this sort, there were some surprising results. In spite of the fact that this network has never consisted of more than ten stations, a number of network and system problems have become apparent. Although these problems could be accommodated in the operation of a small network, they would present major obstacles to the operation of a large network. The very fact that these problems became apparent so fast is indicative of their critical nature. Therefore, it seems advisable to study the entire problem of network operation and utilization to find out whether or not there are other less obvious problems that might appear if the present network is expanded by an order of magnitude, and to devise solutions to these problems.

Consider, for example, an ocean-wide network of telemetering buoys located in the North Pacific Ocean. It is conceivable that the telemetering units might combine the best design features of the various environmental telemetering equipments that have evolved in recent years. Also, it is certainly desirable that such an ambitious undertaking should not be planned without a careful study of the support requirements.

OCEAN-WIDE TELEMETERING NETWORKS

The establishment of ocean-wide networks of telemetering weather and oceanographic stations has been envisioned by the United States Navy for a number of years. This represents a logical development based upon the experience gained in small-scale operations of such equipments at various places and times during recent years. It is of interest, therefore, to consider what such an undertaking might involve. In the past, the objective of the various groups engaged in this activity has been the development of a telemetering station that would work reliably for modest periods of time in connection with special Navy operations or research projects. The establishment of an ocean-wide synoptic network of telemetering stations advances the goals to include the successful operation of a fairly large network, spread over an entire ocean and required to operate unattended for periods of the order of twelve months. In such a network, each telemetering unit comprises only a small part of the overall system. Such an undertaking is far more ambitious than has been heretofore attempted.

It appears that an ocean-wide network of telemetering buoys with a buoy for each ten-degree square of latitude and longitude would provide reasonably adequate data coverage.

This arrangement would give the buoys an average spacing of about 500 miles. With such a network, about 60 buoys would be required for the North Pacific Ocean and about 40 buoys for the North Atlantic. Due to the geographical separation of the two areas, it would probably be convenient to have a network in each area with a control center for each. Each control center should be capable of interrogating its network of telemetering stations (if this mode of operation is needed), receiving their transmission, and relaying the network data to appropriate fleet weather centers or environmental computer facilities.

CURRENT NETWORK PROBLEMS

Most of the current problems being encountered in Antarctica result from the fact that the equipment is in the process of making the transition from the "laboratory-prototype" to the "operational-equipment" stage of development. The following problems are considered to be in this category:

1. Lack of interchangeability of component instrument assemblies
2. Lack of trained personnel through normal channels
3. Lack of overhaul and repair services through normal channels
4. Lack of support equipment and spare parts
5. Lack of complement allowance for operating the network
6. High cost of the telemetering units
7. Lack of well-defined, routine operating procedures
8. Uncertainty as to the capabilities and limitations of a network of unmanned weather stations
9. Occasional equipment unreliability.

These problems are encountered by all new equipment and are not peculiar to automatic weather stations. With continued procurement and experience with the equipments, one may expect these difficulties to disappear gradually.

There seem to be four major obstacles to the use of current models of environmental telemetering stations on a large enough scale to consider seriously an ocean-wide network, or a substantially increased network in Antarctica. These are as follows:

1. The complexity of the telemetering units
2. The dependence upon individual station clocks for control of the network
3. The telemetering code, which is not well suited to automated data transfer and processing
4. Long "on-air" time.

It is felt that these obstacles to large network operation can be studied most effectively by considering the complete system, made up of numerous telemetering units linked by radio to a central station that controls and monitors the network. The central station possibly may be connected, by radio or wire, to an environmental computer for data analysis.

ACCOMMODATION OF NETWORK PROBLEMS

Telemeter Complexity

A simple telemetering unit can obviously be made more highly reliable and produced at a lower cost than a more complicated telemetering unit, given the same degree of development, engineering, and tooling. Therefore, a reduction in telemeter complexity is highly desirable.

The complexity of the telemetering units might be reduced by the following means:

1. Telemetering only the most essential data
2. Requiring only the minimum usable telemetering accuracy
3. Employing an analog rather than a digital telemetering code
4. Telemetering all channels simultaneously.

A reduction in telemeter complexity may be expected to reduce the cost and to increase the reliability of the telemetering unit. It could also reduce the training and logistic support.

Limiting the number of variables telemetered might limit the utility of the network, but operational experience with existing weather networks suggests that a reduction of the number of variables measured does not necessarily reduce the utility of the network to any noticeable degree. For example, a network of buoys for tracking hurricanes in the Caribbean would be very useful even if the buoys were equipped to telemeter only wind direction. The addition of wind-speed data would add a little value to the network. The addition of data on barometric pressure, air temperature, and sea temperature (which have little variation throughout the year) would add virtually no value to the network, yet a substantial increase in the complexity of the buoys results from the presence of the additional sensors. Similar situations have been observed in Antarctica, the only difference being in the variables that appear to be most essential to weather forecasting for a particular location.

The present automatic weather stations employed by the United States Navy telemeter some variables with a greater accuracy than can be utilized with present forecasting procedures. Wind direction is the most noticeable of these; however, wind speed and air temperature also seem to be over-accurate. It is surprising, though, that the increased accuracy does not appear to have added as much complication to the existing stations as one would expect. However, the possibility of compromising accuracy in favor of simplicity should not be overlooked in an effort to simplify the telemeters.

Practically all of the Navy environmental telemetering equipments employ some sort of code-selecting device to convert the data from an analog to a digital form. NRL experience indicates that much of the development time and cost, much of the equipment complexity and cost, and much of the personnel training effort required are associated with this portion of the equipment. The National Bureau of Standards hurricane buoy avoids this problem by using a prf (pulse-repetition-frequency) code to telemeter its data in analog fashion. Pulse spacing, a variation of the prf coding, uses similar circuits. It should be mentioned that while these analog coders have proved to be simple and reliable, they seem to require further development to improve their precision and reproducibility.

The use of an analog code to transmit data requires special monitoring equipment to make it practical, but it appears that this may result in an overall simplification of the

system. The reduction in telemeter complexity might well offset the requirement for special monitoring equipment. Although the special equipment is not in current use by the Navy, it is commercially available. Therefore, the use of analog code is a very interesting possibility.

One can eliminate the programmers used in all of the current Navy weather and oceanographic equipments by transmitting the data from all of the various information channels at the same time. This method has been used, in the form of multitone coding, for land-line and for vhf and uhf radio links (line-of-sight propagation); however, the multipath effects due to ionospheric propagation make it unlikely that such an arrangement could be used at hf. Fortunately, most of the currently used programmers have proved to be quite simple and reliable.

Clock Dependence

The most accurate clocks having low enough power requirements to consider using them to control battery-operated telemetering stations have timing errors of the order of two seconds per day. Under many circumstances, these clocks show much greater errors. This forces one to set the station clocks of a network so that the stations will transmit at times separated by 30 minutes to one hour, to keep any two of them from eventually transmitting their information at the same time due to clock drift. This is awkward in several ways. First, it places a severe limitation on the number of telemetering stations operating on the same radio frequency that could otherwise be deployed in a given area. Second, the staggering of transmission times means that the data from the various telemetering units would be taken at widely different times, unless the units are equipped with a memory – a further complication of the telemeters. Third, the gradual change in times of transmissions makes it necessary to monitor the network continuously and denies the use of the assigned frequency for other communication traffic.

There appears to be a possibility of developing a crystal clock having a low power requirement and an accuracy of the order of two seconds per month. A few companies are reported to have built and tested prototypes of such a device, but the extent of their tests seems to be quite limited. It is believed that such a device may be available in the near future, and its importance should be recognized.

Telemetering Code

Most of the present Navy telemetering units convert their information to letter pairs which are transmitted in Morse code at speeds of 5 to 25 words per minute. Morse code has been employed to allow the use of conventional receiving equipment. Letter pairs rather than numbers are used to conserve power consumption in the telemetering unit. A power reduction of about 50 percent can be realized. At the monitoring site the code is copied and decoded manually by means of tables or calibration curves. The data can then be used locally by plotting it manually on weather maps, or it can be converted manually to teletype code for relaying or for inserting into an environmental computer. Equipment for receiving Morse code and automatically converting it to teletype code are available but have not been used because of their high cost. The use of such a device would require the computer to decode the information, to insert the station location, and to rearrange the message in the standard format required by the computer. Any weather maps plotted locally would still require manual decoding.

It appears to be feasible to use a code recorder for the continuous monitoring required by even a modest-sized network, but the recorder cannot work with weak signals as readily as a man. Thus an increase in telemeter transmitter power will be required for reliable

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recorder operation. A similar power increase may also be required if the Morse-to-teletype code converter were employed.

Automatic decoding of the present Navy automatic weather stations could be accomplished by existing environmental forecasting computers with suitable programming. This would be facilitated by designing all stations to have the same letter groups represent the same value of a given variable for all of the telemetering units. This feature is also desirable for manual decoding. A further degree of standardization may also be desirable, since the format of the messages from the automatic weather station should conform to that of the manned station.

The use of more sophisticated telemetering codes has been considered. The various types of binary codes appear to lend themselves to automatic data processing, but they require additional "parity" information to insure communication reliability. This roughly corresponds to the same degree of redundancies observed in Morse-code transmissions. Teletype code requires precise synchronizing between the sending and receiving stations but provides no parity checks. Both binary and teletype codes require code-selection apparatus in the telemeter similar to that now employed by the Navy's present automatic weather stations for sending Morse code. Pulse-repetition frequency, pulse spacing, or pulse duration require some sort of special receiving equipment to make them usable on an operational basis; however, these codes do lend themselves to a certain amount of telemeter and automatic monitoring-station simplification. Pulse spacing or pulse duration also offer possibilities of short "on-air" time, with a resultant power economy.

Some of these more sophisticated coding arrangements offer the promise of increased telemeter simplicity and power economy, but others do not. They all require relatively strong signals and precise frequency control to be effective. They all require rigid standardization of sensors, coding mechanisms (electromechanical or solid state), and decoding apparatus. In short, their requirements are essentially the same as those of the Morse-code telemetering arrangement.

Rate of Data Transfer

The automatic weather stations now used by the Navy transmit in Morse code at speeds of 5 to 25 wpm and have numerous repeats of both the station identifying call and the various information groups. The result of this is to make their "on-air" time as follows:

GMT-1 (Grasshopper)	142 seconds
GMT-4 (Polar Automatic Weather Station)	112 seconds
WMT-1 (Transobuoy)	112 seconds
SMT-1 (Nomad)	300 seconds
Hurricane Buoy	240 seconds
Parachute Buoy	112 seconds

There are two results of the above-mentioned on-air times. The length of on-air time limits the rate of data transfer to a very significant degree, even with perfect clocks or the use of a "demand" interrogation by the central-station means of network control. With perfect timing, or demand operation, it would require one hour to sample 12 SMT-1's, 15 hurricane buoys, 18 GMT-1's, and 23 GMT-4's. The WMT-1 and the parachute buoy have the same transmitting characteristics as the GMT-4. The length of on-air time limits the transmitting power of the telemetering units for a given battery complement and operating time.

It should be mentioned that in the case of most of the above-mentioned telemetering units, one could shorten the on-air time to 25 seconds by eliminating the numerous repetitions of station call and information groups and by sending the message at 50 wpm. Such a move would require the use of a code recorder, but the higher transmitter power that could be used with the shorter on-air time should make it possible to operate the recorder without increasing the battery complement of the telemetering units. The use of short on-air time by the telemetering units also would require the use of crystal-controlled monitoring receivers. With the elimination of repeats and the use of higher-speed transmissions, one could theoretically sample over 100 stations in an hour, given sufficiently accurate clocks or an effective demand mode of network control. The addition of a memory to the telemetering units would insure that the data were all taken at the same time but would have no effect upon the rate of data acquisition.

A TELEMETERING SYSTEM COMPOSED OF PRESENT TELEMETERS

The preceding discussion makes it evident that the main features required in a telemetering unit to adapt it to a large telemetering system are precise network control (either by using very accurate clocks or an effective demand arrangement), a rigid standardization of telemeter calibrations, the use of short high-power transmissions, and a capability for long-time reliable operation without servicing. The particulars of code or hardware may affect cost, reliability, support-equipment requirements, or personnel training problems; however, they do not appear to represent fundamental obstacles to the large-scale employment of the present Navy telemetering units. This can be illustrated by studying a hypothetical telemetering network composed of such units.

System Specifications

The first step in determining the makeup of a network is to specify what the network will be expected to do and the extent of support that will be available. Therefore, the following network specifications will be considered.

1. The network is to provide data coverage over the entire North Pacific Ocean.

2. The network will provide at least five channels of data at approximately six-hour intervals.

3. The accuracy of the telemetered data shall be comparable with that of manned stations.

4. Communication reliability shall be comparable with that usually achieved with ships at sea.

5. Requirements for ship and communication-station services shall be reduced to an extent that the overall cost of operating the network is minimized.

6. Technical support of the network will be furnished through normal channels.

The first requirement determines that the network, to be located in the North Pacific Ocean, will consist of approximately 60 telemeters and a control center. Due to the timing errors inherent in the best available clocks, the size of the network, coupled with the requirement of a six-hour schedule, will make necessary a demand mode of network control. To have all of the data taken at about the same time, say within one hour, it will also be necessary to use short high-power transmissions. The third requirement presents no problem, since all of the present Navy telemeters seem to have adequate telemetering accuracy. Intermittent experience with seven types of Navy automatic weather

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stations over a period of eight years indicates that all of them can meet the fourth requirement, particularly if they are equipped for multifrequency operation. The fifth requirement implies that a relatively long operating time between servicing visits by a buoy tender will be required. In order to eliminate routine tracking of the buoys, which would require a substantial network of direction-finding stations and considerable ship support for relocating them when they drift too far from their desired locations, the telemetering units should be moored. This will also reduce the data-handling problem to some extent, because the locations of the telemeters will be fixed and can be stored in a computer memory for automatic insertion into the telemeter messages as the computer processes the data from the network.

The usual practice of the United States Coast Guard is to replace their buoy moorings every two years and to charge the batteries of light buoys every year. A similar servicing and replacement cycle with the telemetering buoys should be planned.

A 60-buoy network will produce a large amount of communication traffic and require a large amount of data-processing effort, unless every attempt is made to automate the monitoring and data handling. The fact that high-speed transmissions on demand are found to be necessary in order to sample the telemeters within the desired time makes it impractical to employ manual monitoring. Automatic decoding and code conversion at the central station will also be required. This implies that telemeter calibrations be standardized to the required degree of accuracy. It also implies the use of some special (but available) monitoring equipment. The general features of the network are thus defined.

The Present Telemeters

Considering the application of the present Navy telemeters to the problem, it is immediately evident that all of them require some modification to adapt them to large network operation. They all have too much on-air time and too many repeats. The SMT-1 has adequate power, but there is only one radio frequency available, and it has no demand facility. An additional fact should be mentioned; only one laboratory prototype has been operated (by laboratory personnel only), thus calibration standardization, spare-parts provisioning, and personnel training problems have not yet been encountered. The NBS hurricane buoy and the GMT-1 employ individual telemeter calibrations and have low-power outputs, one frequency, and no demand capability. The WMT-1 and GMT-4 require individual calibration for barometric pressure only and have low-power output. The parachute buoy is in the same situation as the SMT-1, except that it lacks the test and evaluation experience that the SMT-1 has had. However, it does have multiple-frequency operation. The GMT-1 and the GMT-4 equipments have had a substantial amount of operational experience in Antarctica. The NBS hurricane buoy and the SMT-1 have had a substantial amount of laboratory-conducted operation at sea. The WMT-1 and the GMT-4 have multifrequency operation and a demand facility available, but the demand operation at long ranges has not been tested.

None of the existing Navy automatic weather stations completely meets all of the requirements of short on-air time, high-power transmission, proven long-time reliability, accurate clocks, or an experimentally demonstrated capability for a demand mode of operation. Therefore, one is led to consider the extent of modification of any of these equipments that would be required to adapt them to the problem of a large network extending over the entire North Pacific Ocean. Because each of these equipments has some desirable design features (although some of them have not been thoroughly tested), and because of their proven reliability, the possibility of combining the best parts of all of these telemetering units into a single equipment is suggested. Any of them would have to be modified to some extent, and this modification would be tantamount to a certain amount of combination.

The Hybrid Telemeter

The fact that all of the telemeters under consideration have numerous design features in common should facilitate the combination of the best of the various instrument assemblies. This circumstance makes the hybrid-telemeter idea rather attractive.

In the foregoing sections, the general features required in an ocean-wide telemetering system were defined, the modifications required to adapt the present Navy telemeters to such a large system were discussed, and the possibility of combining the best design features of several of these telemetering units into one equipment designed for large network operations was suggested. Since these telemeters will be required to have a high degree of reliability, it would appear that the design features of the present Navy telemeter that has had the most extensive operational or semioperational experience should dominate the hybrid telemeter, provided they do not preclude meeting the other basic large-network requirements. The instrumentation of the current GMT-1's, modified by NRL for use by Operation Deepfreeze, appears to meet this requirement. In addition, most of the GMT-1 sensors have been used in the GMT-4 (also extensively used by Deepfreeze), the WMT-1, and the parachute buoy; the coding and programming arrangement is quite similar circuit-wise to that used in the SMT-1. There is also a marked circuit similarity between many of the GMT-1 sensors and those used in the SMT-1 and the hurricane buoy, as well as those of a number of oceanographic telemetering buoys developed by Woods Hole Oceanographic Institute.

The GMT-4 features a demand capability, copied from the WHOI telemetering buoys, where it seems to have been rather extensively used at modest ranges, but until the current winter season in Antarctica, circumstances have discouraged the utilization of this feature on the GMT-4. Recent dispatches from McMurdo Station indicate that the demand feature of the GMT-4 is now being used regularly – however, still at short ranges. The WMT-1 is a buoy equivalent of the GMT-4, but it has not had as much service experience.

It appears that the GMT-1 has had the most extensive operational use, so its instrumentation design should dominate the telemeter. However, a number of design features incorporated in other Navy telemetering units have been extensively tested in laboratory field operations and offer either facilities that the GMT-1 does not possess or the promise of greater simplicity and lower cost. Therefore, it would appear advisable to consider the use of some of the instrumentation in the other telemetering equipments. However, in the case of instrumentation offering only the promise of required features that the GMT-1 does not have, one has little choice. In the case of competitive but proven instrumentation, the choice should be based upon cost, simplicity, and the amount of development needed to adapt them for use in the hybrid telemeter.

Communication-wise, the telemeter should be equipped with at least two transmitters operating on different frequencies to provide for changing ionospheric conditions. These transmitters should have at least 50 watts of radiated power in order to operate automatic monitoring and code-conversion equipment. The telemeter should also be equipped with command receivers operating on different frequencies to make it possible to operate the units of the network on demand.

NRL, in collaboration with NBS, has developed a hybrid telemeter that combines what were felt to be the best design features of a number of weather or oceanographic telemetering equipments developed by a number of laboratories. This telemeter has the following features:

1. A sealed main-instrument package

2. Two command receivers, operating on different frequencies, for a demand mode of network control. (Provisions for clock control of telemeter will be retained.)

3. Two transmitters operating on different frequencies to enhance communication reliability

4. Capability for accommodating five to 100 sensors of varied types with negligible modification

5. Provisions for a radio beacon that would be useful for telemeter recovery and as a navigational aid

6. A sealed external instrument assembly with barometer vented through spray filters only during "on-air" time

7. Provision for a large increase in transmitter power to accommodate future requirements

8. Adapted to external batteries and battery chargers

9. Adapted to air or submarine delivery, either ashore or afloat, when installed in appropriate deployment structures

10. Convenient access for servicing.

The above-mentioned features and instrument designs have been derived from a critical review of many existing equipments. They have been combined into a telemeter instrumentation package that should have a high degree of reliability and versatility.

The Mooring

The structure of the telemeter must be designed to facilitate reliable midocean mooring. However, the large-scale use of buoys moored in midocean has never been successfully accomplished. A large number of offshore buoys are regularly maintained by the United States Coast Guard and corresponding activities in foreign countries. These buoys, not usually moored in water depths of more than 100 fathoms, rarely slip their moorings. It would appear that the type of moorings used to secure offshore navigational buoys might represent a promising approach to the design of midocean moorings. While midocean mooring of buoys has not been done on a large scale, both Woods Hole Oceanographic Institute and Scripps Oceanographic Institution have moored as many as 20 buoys in midocean with about 50-percent reliability on a six-month basis. The National Bureau of Standards has moored the SMT-1 in the Gulf of Mexico for periods as long as three or four months with about the same degree of reliability. The structures of the above-mentioned buoys vary considerably, and the mooring designs have varied almost as much.

It thus appears that while the instrumentation of the telemeter can readily be selected from a group of more-or-less proven telemetering equipments, the structure and mooring arrangement appears to require some further study. The mooring of the telemeter does not affect its system behavior, but it may prove to be the major factor in determing the amount of ship support required by a network.

The Central Station

The central station should have the following features:

1. Centrally located within the network of telemeters

2. A high-power transmitter for interrogating the network and for relaying the data to a computer center

3. Crystal-controlled receivers for monitoring the telemeter transmissions

4. A device for automatically converting from Morse code to teletype code and recording the data on punched tape

5. A computer for automatic decoding of data for local use

6. A teletypewriter for local display of raw data

7. A good-quality communication antenna arrangement

8. A direction-finding antenna for occasional checking of buoy locations and tracking, should they slip their moorings, and to facilitate their recovery.

None of the above-mentioned features will require the development of new equipment or the establishment of new communication stations. The Navy Communication Station at Pearl Harbor or the FCC field station at Keneoe (both in Hawaii) appear to be well located and would already be expected to have all of the necessary equipment except the decoding computer. There are a number of small, commercially available computers which could be programmed to decode the data automatically.

The communication reliability of the network would be enhanced by using more than one central station. If this is done, it might be desirable to split the network so that each central station controls and monitors its own group of telemeters. The use of auxiliary monitoring facilities in addition to the central stations might also improve communication reliability. As envisioned, these auxiliary monitoring facilities would only receive and relay data; they would not need to be equipped for telemeter interrogation or decoding of the messages from the telemeters.

Estimated Support

At the present time the only Navy operational experience in maintaining and utilizing a network of telemeters has been in the Deepfreeze operations in Antarctica. The equipments have been semiexperimental units, procured in small quantities, on short notice, and are land stations rather than buoys. The routine procurement and use of much larger quantities of telemeters having a standardized design may be expected to reduce the procurement costs and the training and maintenance effort on a per-unit basis. The fact that the buoys will have to be moored and occasionally recovered, when their moorings fail, will require ship support, which will probably be greater on a per-unit basis than for the land stations. There will have to be a routine annual buoy-replacement program in addition to occasional special buoy replacements due to telemeter malfunction or mooring failure.

The contemplated telemetering instrumentation is known to have a service life of at least three years. Therefore, an annual procurement of 25 buoys would be indicated to allow for a certain amount of attrition. Assuming an annual procurement of buoys in quantities of 25 (to a firm specification and adequate production drawings), it is estimated that the buoys would cost about $20,000 each. The cost of the mooring hardware for each buoy is estimated to be about $5,000. Assuming that the operating cost of a buoy tender is about $3,000 per day and that the ship would have to travel about two days between buoys, it is estimated that the annual cost of routine ship support per buoy would be about $6,000. Thus the direct cost of each telemeter, installed, would be about $30,000, for a total of $750,000 for the 25 buoys procured annually. If one assumes an overall telemeter reliability of 90 percent, the estimate should be increased by 10 percent to about $825,000.

The interrogation and monitoring of 60 telemeters on a six-hour schedule will require about four hours of communication-station effort each day. The high-powered transmitter for network interrogation will be used four times per day, and, assuming that 15 minutes would be required each time to set it up on the right frequency, about one hour of operation would be required per day. The remaining three hours would be for monitoring, involving only the receiving, code-conversion, and decoding equipment.

The relaying of the data to a computer center will require about three hours of high-power transmitter operation. Thus it would appear that the routine control, monitoring, and relaying of data from the 60-buoy network might be accomplished by one man and would occupy the communication equipment for about seven hours per day. To allow for communication difficulties that may be expected and occasional tracking service that will be needed, this estimate might have to be doubled or, perhaps quadrupled, if more than one central station or auxiliary monitor relay facility is required to maintain the desired communication reliability.

This estimate is presented mainly to illustrate the various problems of supply, training, installation, and maintenance involved. It is intended only as a very rough estimate of operating costs and manpower that would be necessary to maintain an ocean-wide telemetering system in the North Pacific.

The monitoring, data-processing, and data-utilization problems of a small network of telemeters in Antarctica have been accommodated by the Antarctic Support Activity without any significant increase in complement; however, it must be appreciated that the few Navy technicians needed to support the small network of telemeters in Antarctica have been given specialized training in automatic weather station operation at NRL each year for the last five years. NRL has also provided overhaul-and-repair services to support the network. The training and repair services required to maintain a network that is ten times as large as the Antarctic network, on a routine basis, would have to be provided through normal Navy training and service organizations. Adequate personnel allowance of the necessary technical specialties would have to be provided. In addition, meteorological and communications officers would have to be trained to supervise the maintenance and utilization of a large environmental telemetering system.

The telemetering system described above would provide reasonably adequate environmental-data coverage (barometric pressure, wind speed, wind direction, air temperature, water temperature, perhaps sea state, and eventually salinity and other oceanographic data) over the North Pacific Ocean upon demand, usually at six-hour intervals. The accuracy of the telemetered data would equal that of a manned network with communication reliability comparable with that normally achieved with ships at sea. The system would be adapted to the use of numerical environmental forecasting computers and would employ only the present Navy telemeters (or units representing combinations of their best design features), existing Navy equipments and facilities, and commercially available devices. Based upon the experience gained in Antarctica, such a system could be maintained either by Navy personnel or on a contract basis involving other governmental agencies and/or private companies.

It is believed that the environmental telemetering system would provide a means for obtaining more accurate forecasts of synoptic weather and oceanographic variables. The accumulation of environmental data on a day-in, day-out basis over an extended period of time would also provide climatological data on these variables that will never become available through the usual means of occasional oceanographic surveys or isolated weather ships.

AREAS REQUIRING FURTHER DEVELOPMENT

The major unknowns in contemplating the use of a system composed of a large network of hybrid telemeters and a few central stations for monitoring and data relaying seem to be as follows:

1. The effectiveness of the demand arrangement at long ranges

2. The feasibility of operating automatic monitoring equipment with relatively low-powered transmitters, for retransmission at great distances from the monitoring site, on a routine basis

3. The reliability of midocean moorings.

While the present Navy telemetering buoys or equipment embodying some combination of their best design features appears to be capable of telemetering weather variables with adequate reliability and accuracy, sensors for observing the oceanographic aspects of the marine environment are almost completely lacking. Most of these buoys are designed to accommodate additional sensors for oceanographic variables, but the sensors for these variables are not available. Take, for example, wave height. Only one ship in this country is equipped for midocean wave measurement. Since ocean waves represent a very conspicuous feature of the ocean environment, it is surprising that such instrumentation has not been developed to any greater extent. Instrumented appendages, or moorings, to enable the buoys to telemeter temperature-depth, current-depth, or salinity-depth profiles are in a similar state.

There is one other idea that has not been touched upon. The 25-second transmission time that appears to be feasible with some modification of the present telemeters was predicated on the basis of telemetering five variables. This might be adequate for a land network with only the most important information being telemetered; however, a reasonably well-equipped environmental-telemetering buoy should be capable of accommodating over 20 information channels. It would be prudent, therefore, to design any future telemeters to accommodate far more extra channels than the present telemeters provide.

SUMMARY

The foregoing sections of this report have considered the problem of adapting the present Navy telemeters to a large environmental telemetering system designed for a high degree of system automation and to supply data to an environmental forecasting computer. The results of this study may be summarized as follows.

1. None of the present telemeters are suitable for large network operations without some modification.

2. A major obstacle to large-scale use of these equipments is the inaccuracy of their clocks and the fact that the demand mode of operation at long ranges has not been proven out.

3. A second major obstacle to large networks of these equipments is the fact that automatic monitoring (recording, decoding, and relaying) of relatively low-powered transmitters located at great distances from the monitoring site has not been proven out.

4. A third major obstacle is the apparent lack of reliable midocean mooring arrangements.

5. The long "on-air" time of the coding and programming arrangements in the present units seem to represent fairly minor problems.

6. The combination of the best design features of the various equipments into one hybrid telemeter seems to be entirely feasible – in fact, one might say convenient.

7. Sensors for measuring major oceanographic variables are not available, and this lack results in a substantial reduction in the utility of an ocean-wide network of telemetering buoys.