CONSIDERATIONS IN THE DESIGN OF AN OFFSHORE DATA COLLECTION PROGRAM

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1. INTRODUCTION

In-situ data collection in the ocean is costly and unpredictable even when the program is relatively well planned and executed. Despite these inherent difficulties, designers of a data collection program will find little guidance in the literature to assist them in the planning and organizational stages. Some papers have been published discussing particular aspects of a program such as instrumentation, and others have described some of the general experiences of various programs. However, there has been no attempt to conceptualize the process of design of an offshore data collection program and this is one of the purposes of the discussion which follows. The various steps involved in design are identified, ordered, and discussed in some detail. Specific examples are drawn from the authors' experiences with several offshore monitoring programs.

The work presented is most applicable to the collection of oceanographic and meteorological (O/M) data since the authors' experience is essentially restricted to this particular type of data collection. However, it is suspected that a significant portion of the aspects considered would apply to offshore programs involving the collection of other types of data such as geotechnical.

Many of the ideas presented originate from experience with two large O/M programs conducted by Instituto Tecnológico Venezolano del Petróleo (INTEVEP). One of the studies extended over the Orinoco Delta region of Venezuela with an area of roughly 150 x 150 kms. The program began in late 1977 and ended in the spring of 1979. O/M data were taken at nine stations in the region. Figure 1 shows the region and the location of the stations involved in the study.

The second INTEVEP program was started in the summer of 1979 and covers the contiguous coastline of Venezuela, approximately 1200 x 100 kms. O/M data are being taken at nine stations during the three year life of the program. Figure 2 shows the coast of Venezuela and the station locations.

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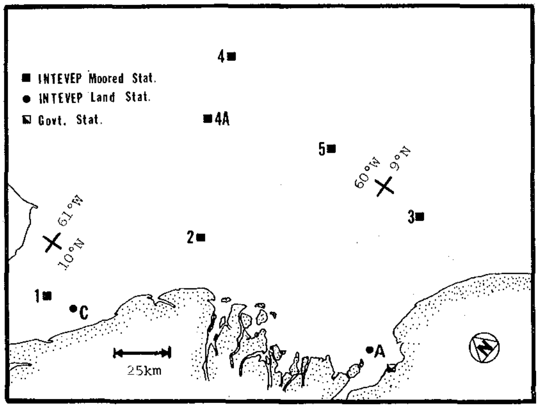


Figure 1: Locations of the oceanographic and meteorological stations in the Orinoco Delta region of Venezuela.

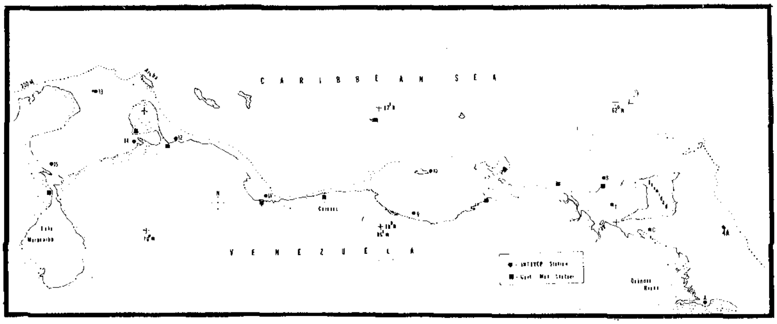


Figure 2: Locations of the oceanographic and meteorologic stations in the Integral Program along the coast of Venezuela.

The primary objective of these studies is to gather the information needed for design and operation of offshore petroleum facilities. The Orinoco program cost approximately $3 million (U.S.) and the Integral Program is expected to cost about $5 million (U.S.). Justification for these expenditures was based on the absence of historical data in the region and the high likelihood of petroleum deposits and subsequent development.

2. MAJOR STEPS IN DESIGN AND IMPLEMENTATION

An offshore data collection program can be conceptualized into six major steps: (1) identification of the objectives of the program; (2) identification of the data which must be obtained; (3) detailed design of the program including selection of the resolution of the monitoring network, instruments, quality control methods, navigation methods, logistics, and program duration; (4) implementation and execution of the program including modifications which become necessary during the life of the program; (5) data processing; and (6) data analysis.

Figure 3 summarizes these steps in the form of a flow chart. The first three fall within the planning stage and the latter three within the execution stage of the program.

The flow chart in Figure 3 implies a downward progression which is somewhat idealized. In fact there is likely to be a good deal of iteration during the first three steps as the designer faces the inevitable tradeoffs imposed by financial and technical constraints.

The discussion which follows will focus primarily on Steps 2 and 3. A fairly thorough discussion will be presented on parts 1 and 2 of Step 3, Program Design. The remaining parts of Step 3 are addressed only briefly primarily because of space limitations. Discussion of Step 1 is not included, but this should not be taken to imply that determination of the objectives of an O/M program is a trivial task. Rather, the usual processes of determining objectives is often influenced by political and financial considerations and is difficult to address in a general sense. It is simply assumed in the discussion which follows that the designers have (1) identified a set of reasonable objectives, (2) identified any financial constraints that may exist, and (3) defined the region or area to be monitored.

3. DATA IDENTIFICATION

There are two major questions which must be resolved at this stage. The first concerns identification of the data needed to satisfy the objectives of the program. The second is to determine what historical data is available for the region.

In programs primarily concerned with ecological impacts, the first question is a bit difficult to address in general terms. However, for programs whose results will be used primarily for design and operation

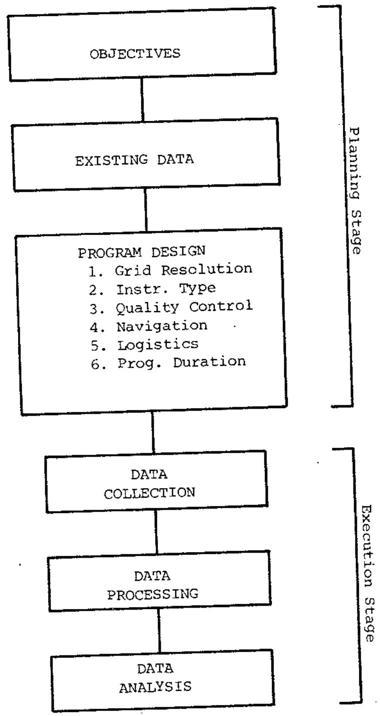


Figure 3: Steps in design & implementation of an O/M data collection program.

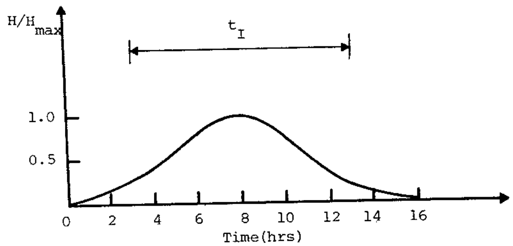
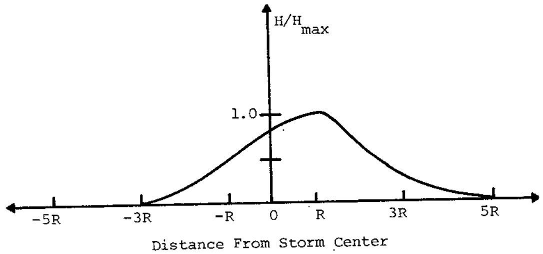


Figure 4: Time history of water level changes during a tropical storm.

Figure 5: Maximum surge profile along the coast during a tropical storm.



of offshore structures, the questions are more easily addressed. The data of primary interest will include: (1) surface waves with 2 to 20 second period; (2) currents with periods of several minutes and longer; (3) winds, both gusts and sustained; and (4) tides, both astronomical and storm-induced. Some other parameters would probably be of secondary interest and these would include water conductivity, water temperature, air temperature and air pressure. The marginal cost of acquiring these secondary parameters for specific sites is relatively small.

The Data Identification stage should also include an assessment of historical data. This is important for several reasons. First, previous studies can give considerable insight into the nature of the processes which dominate in the region of interest. This information is particularly helpful in the selection of grid resolution, instrumentation, etc.. Second, existing data bases can sometimes be used to effectively extend the time span of a monitoring program. This is important since most data collection programs have a duration on the order of a year and calculation of extreme events with long recurrence intervals will be severely limited if other data sources are not available or are not used. Third, the historical data may satisfy some of the objectives of the program, thus making some data collection unnecessary.

4. DETAILED DESIGN

As indicated in Figure 3, Detailed Design involves six topics. An attempt has been made to place these topics in the order in which they should be addressed. However, all six are strongly interrelated, and initial choices limit options for later decisions. For instance, in specifying the resolution of the monitoring network, the designer must select the time increment between samples. If the designer chooses a relatively small interval between samples, this will often affect the instrument servicing interval, which in turn affects servicing vessel logistics, which in turn affect project costs, and project duration. This requires the designer to iterate many times in order to arrive at an optimal detailed design.

4.1 Resolution of the Monitoring Network

4.1.1 Characteristic Length and Time Scales. In designing the monitoring network, there are two main parameters which must be specified: T_I, the time increment between record samples of process I, and X_I, the distance between instruments which monitor process I. The term T_I refers to the time period between individual samples on the recording media. This, of course, implies a digital sampling method. For analog instruments such as the Datawell Waverider with a Warep receiver, the discussion of T_I which follows is not relevant, but comments regarding X_I remain valid.

One of the primary goals governing the choice of T_I and X_I is that both be small enough to adequately describe the process to be monitored. Determining the largest value of T_I and X_I which achieve sufficient resolution is of considerable interest from the standpoint of minimizing program cost. Larger sampling intervals allow the use of fewer instruments which allow increased servicing intervals and reduced boat time. These optimizations can ultimately lead to substantial reductions in program costs.

As an illustration of how the maximum T_I can be estimated, consider the temporal variation of a process I. The process has a finite duration in which most of the energy associated with the process is concentrated. This duration will be referred to as t_I. To take the illustration a step further, assume the process to be the storm surge created by the passage of a hurricane or tropical storm. Figure 4 shows the time history of the normalized storm surge, H/H_{max}, where H is the time history of the storm surge at the site of interest, and H_{max} is the maximum observed surge at the site. Astronomical tides have been removed. The characteristic time scale (t_I) for a storm surge is on the order of 10 hours. Thus it follows that the sampling interval for a hurricane induced storm surge should be less than 10 hours, otherwise a definite risk exists that the event would go completely unrecorded.

In more general terms, the above example implies that the largest T_I which should be used for a monitoring network is slightly less than t_I. If such an interval is chosen, then some form of interpolation will be necessary in order to derive the extreme or peak at the site. On the other hand, if one wishes to eventually extrapolate the collected data to longer intervals, then many points must be taken within the storm period, t_I, so that the peak value (or near it) is recorded. For some processes it is possible to get these additional points with no substantial increase in program cost. Storm surges tend to be one of these processes. However, other processes, such as hurricane generated waves, can be costly to monitor frequently. If wave data is stored internally in a moored wave device, then storage space may become limiting long before the instrument might otherwise need servicing. This requires more frequent and costly retrieval and so the marginal cost of additional data points may be high. For such processes it is often more economical to apply mathematical models or statistical means to extrapolate and interpolate the data. In this mode, the data serves mainly to tune and verify the simulation method.

The determination of a maximum X_I can be approached in a manner similar to that used for determining the maximum T_I. Returning to the previous example of storm surge, it should be fairly evident that the largest X_I for storm surges should be less than the maximum distance x_I affected by the storm. Figure 5 indicates a typical spatial variation of the maximum surge associated with a tropical storm approaching a fairly straight coastline. In this figure, H is the maximum surge which occurred during the passage of the storm at locations along the coast and R is the radius to maximum winds. As indicated in the figure, the characteristic length scale of storm surges (x_I) is on the order of 8R and it follows that the largest X_I which could be used in a monitoring network is somewhat less than 8R.

The characteristic length and time scales (i.e. x_I and t_I) can be identified for other processes besides surge and this is done in Figure 6. This figure is a modification of one appearing in Stolzenbach et al. (1977). Atmospheric disturbances are indicated by the lined regions and two current processes (tidal and geostrophic) are indicated in the clear regions. Other types of currents not shown are generated by local atmospheric disturbances and thus would occupy roughly the same region in the figure as the atmospheric disturbance which is responsible. For example, currents generated during a hurricane would tend to have the same characteristic length and time scales as the winds which create them. Similar observations can be made regarding surge and local wind-generated waves. Examples of processes contained in each region in the figure are: (1) weather system fluctuations - extratropical storms, tradewinds, and tropical storms; (2) mesoscale wind fluctuations - thermal and orographic types of air flow such as land-sea breezes and thunderstorms; (3) atmospheric boundary layer fluctuations - vortex shedding and natural convection near the sea surface; and (4) geostrophic currents - permanent currents such as the Gulf Stream and the gyres and eddies associated with them.

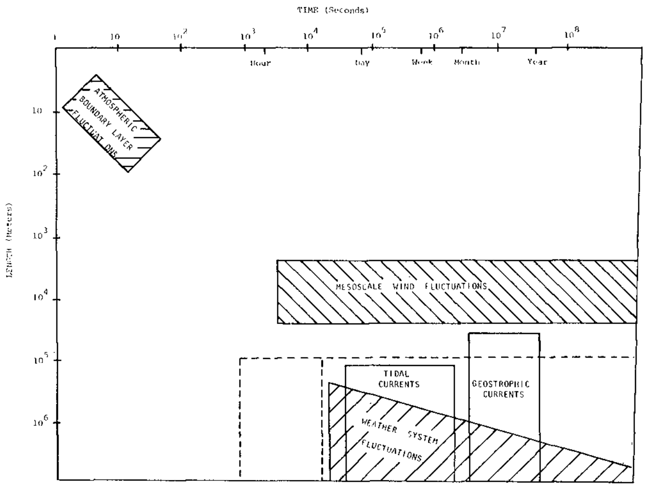


Figure 6: Typical length and time scales associated with winds (& the waves & currents associated with them) & currents in open areas.

It should be pointed out that the length scales shown in the figure apply primarily to open coastal regions. Complex coastlines or bathymetry tend to shorten the length scales of several of the processes such as currents and waves.

With the use of Figure 6, one can estimate the sampling intervals needed to describe various processes. In general, the maximum spatial distance (X_I) and time increment (T_I) needed to monitor a process will be given by the length and time scales associated with the upper left-hand corner of the appropriate region in Figure 6. For example, in order to monitor mesoscale wind fluctuations, the figure indicates that $X_I < 20$ km and $T_I < 1$ hour.

For most programs, one would not be interested in monitoring all the processes included in Figure 6 and this is indeed fortunate because doing so would be expensive, at least for programs covering any significant area. This is true because of the small sampling intervals which would be necessary to describe some of the processes shown in the figure, most notably atmospheric boundary layer fluctuations. Monitoring larger scale processes such as mesoscale wind fluctuations may be desirable from the standpoint of achieving certain objectives in the program. However, the cost of obtaining the data may be prohibitive if the region to be covered is large.

The comments on length scales made thus far have focused on horizontal spatial variations. A figure similar to Figure 6 can be constructed to show the vertical variations as well. This is of particular interest when deciding on the number of current meters to string in a given location.

4.1.2 Auxiliary Stations*. Losses of data and instruments are common and should be considered inevitable. It is interesting to examine data loss rates from a few O/M programs.

In the Orinoco Project, about 30% of potentially recoverable data was lost due to mooring failures, instrument malfunction or loss of instruments. The Integral Program has faired somewhat worse. Approximately 30, 65, 45, and 53% of the potentially recoverable data of waves, currents, tides and winds, respectively, has been lost, primarily due to outside interference.

One of the more extreme and recent cases of high data loss was the NEOCSPO program (EG&G, 1978), a study of the physical oceanography of New England outer continental shelf, including Georges Banks. In one region of the study, current meters were deployed for 8 months and of the 21 system-months of data potentially available, only 2 usable system-months were obtained. This translates to approximately a 10% recovery rate. A major factor in this poor showing was the use of unconventional instrumentation.

It should be evident from the above examples that significant data losses can be expected for O/M Programs. If the monitoring network is

*The term "station" refers to a complete instrument package, e.g. current meter string, a meterological buoy and mooring, etc.

designed such that $X_I \sim x_I$ and/or $T_I \sim t_I$ then loss of data may mean an inadequate description of the process. In the case of an O/M program oriented towards design of offshore structures, some loss of data during normal conditions would probably not meaningfully impair the overall success of the program. However, loss during significant storm events could be crucial.

There are several ways to minimize data losses. One way is to keep the instruments and moorings well maintained. Another is to use only instruments, moorings, and deployment techniques which are well proven in the ocean environment. Even with these precautions, some data losses are inevitable. Therefore, it may be wise to include some auxiliary stations to minimize the impact of those data losses.

A less expensive alternative to providing auxiliary stations would be the addition of more instruments at a station, e.g. the addition of an extra current meter on a string or the addition of extra anemometers to a meteorological buoy. In some situations, the marginal cost of the added instrumentation is relatively small and the method does improve the odds against loss due to instrument malfunction. Furthermore, the extra instrumentation can provide valuable data on the vertical variations of the process being monitored.

If it is decided to include auxiliary stations, the instrument capitalization costs can be minimal in some situations. For instance, if the storm patterns are highly seasonal, as they are on the coast of Venezuela (see Figure 7), then temporary stations can be established during the stormy seasons. In the case of Venezuela, temporary stations could be established during the months of August and September when about 85% of all major storm events occur. Since the temporary stations would only be deployed for 2 months per year, labor and capital expenses could be kept to a minimum. The additional instruments could be provided in a number of ways. Some of the spare instruments normally kept on hand in any large program could be temporarily utilized. Other instruments could be obtained by leasing. The typical rental rate for a two month lease would be about one-third of the retail price of the instrument. A further benefit of leasing is that it would not overburden servicing facilities since most leasing firms provide all servicing.

There are two primary schools of thought in positioning auxiliary stations. One may choose to place auxiliary instruments near primary stations. This was the method used for the BOMP and GAWWMP programs reported by Mcleod (1979) in which the wave instruments were placed in clusters of three. This method has the advantage of minimizing retrieval-deployment time and giving a convenient means of calibration or intercomparison. Clustering of instruments increases the visibility of the station and this is an advantage if the local outsiders are amicable towards the program, since they can more easily identify the station locations and avoid them. Needless to say the approach also offers considerable opportunity to outsiders with mischevious or larcenous intent.

The other school of thought is to place auxiliary stations at some distance between primary stations, possibly equidistant. The advantages include: (1) a decrease of the likelihood of multiple failures when such failures are caused by accidental interference by outsiders or by extreme

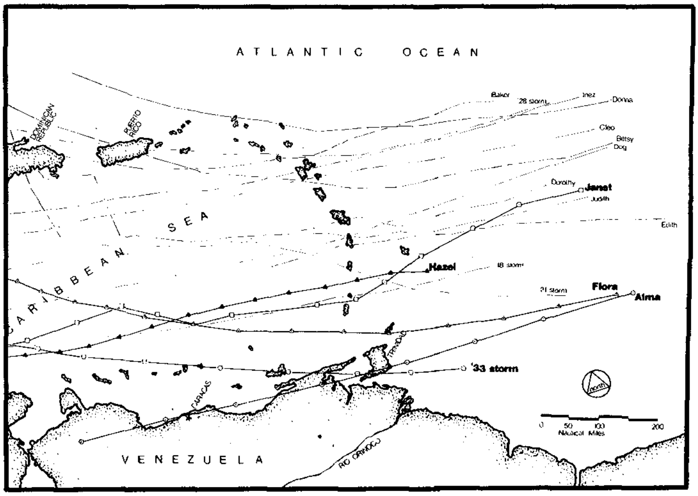


Figure 8: The paths of tropical storms in the southern Caribbean during the past 75 years of record.

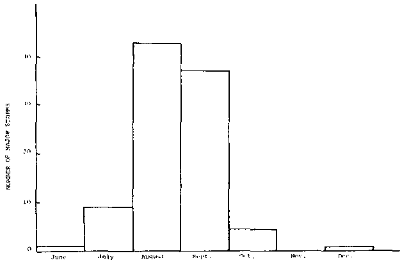


Figure 7: Monthly histogram of storms for the Orinoco Delta (75 yrs of record).

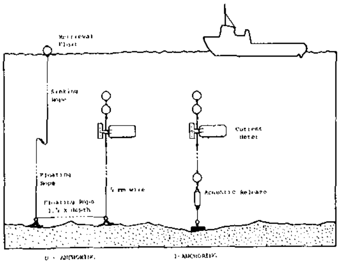


Figure 9: Two mooring configurations (from Aanderaa Brochure).

local environmental conditions, and (2) if failures do not occur, horizontal spatial information can be gained which will lessen the need for interpolation during the data analysis step.

4.1.3 Other Siting Considerations. The two major considerations presented above should ideally be of foremost importance in design. But other factors will clearly influence the final positioning of stations. The more important of these are briefly discussed below.

Interference from people outside the program often claims more instruments than Mother Nature or mistakes by program personnel. Mcleod (1979) attributed roughly 50% of all mooring failures to outside interference. In the ocean, certain neighborhoods, as it were, should be avoided - shipping lanes constituting a prime example. Other areas are also undesirable, such as heavily fished regions, although avoiding these often large areas is not always possible.

A second consideration in siting stations is that deployment in deeper waters may require costly special equipment. This cost may not be justified, particularly if the location is near the continental break and a small shift in position would eliminate the problem.

The navigation method to be used should also be considered. In general, the further one gets from shore the more difficult and costly it is to navigate precisely.

A fourth consideration is the method of data retrieval. For instance, the distance between instrument and shore-based receiving stations for VHF telemetry must be less than 50 km for most standard instrument packages.

Boundary effects should be considered in the placement of stations as well. The method described in Section 4.1.1 applies to open coastal areas and does not include the complicating effects caused by coastlines, such as shear currents and land induced fetch limitations. If information within these areas is desired it may be necessary to decrease the spatial distance between instruments.

Finally, servicing logistics should be taken into account. The servicing interval may vary from a few weeks to many months depending on the instrument and measurement interval. The cost of a large servicing vessel dedicated solely to an O/M program can constitute a significant portion of the budget for a typical O/M program. In the Orinoco Program, roughly 50% of the total budget was spent on the servicing vessel and crew. Thus, significant cost savings can be achieved by establishing stations on or near a coastline, an island, a fixed platform, or a semi-permanent ship, hence minimizing the use of a large vessel. However, data from stations on or near land can be seriously distorted by the land forms to the extent that the data are not representative of the open ocean. Fixed offshore platforms are generally the most favorable sites since they offer: (1) minimum interference with O/M processes; (2) a fixed, relatively dry environment; (3) some protection from outside interference (e.g. fishing); and (4) improved reliability since damaged or missing instruments can often be spotted and replaced more quickly.

4.1.4 Illustration-Integral Program. Figure 2 indicates that the typical distance between stations in the Integral Program is on the order of 100 km. In the case of winds and tides there are also some additional stations maintained by the Venezuelan Government which can be used to augment the stations in the Integral Program.

The time sampling intervals used in the program are 10 minutes for currents and winds and 15 minutes for tides. For waves, 1 sample is recorded each second for 20 minutes. This is repeated every 4 hours. These space and time intervals are indicated on Figure 6 by the three dotted lines and it is apparent that the network should describe weather system fluctuations, tidal currents and most characteristics of geostrophic currents.

Note that no attempt was made to monitor mesoscale wind fluctuations primarily because the cost was prohibitive. But peak winds along the Venezuelan coast are dominated by convective storms (thunderstorms) which fall within the range of mesoscale wind fluctuations. Fortunately, even though thunderstorms control the maximum design winds, they do not govern design waves or currents, the two more important factors in most aspects of design. Furthermore, the wind data collected in the program can be supplemented by comparatively plentiful wind data recorded at government installations.

There are several other aspects of the Integral Network which should be of general interest. For instance currents, winds, tides and waves are all recorded at each station, this despite the fact that each process has a different X_I as discussed previously. Stations were centralized for two main reasons. First, Figure 6 implies that x_I is roughly equivalent for the three processes of primary interest (i.e. tidal currents, weather system fluctuations and geostrophic currents) justifying a constant X_I. Second, servicing logistics and retrieval-deployment are significantly simplified.

The space and time intervals used in the Integral Program are quite close to the x_I and t_I of the respective processes and, hence, there may be an insufficient number of data points to adequately resolve the process using data alone. In these cases, mathematical or statistical modeling will be necessary to extrapolate and interpolate the data. Examples of these processes include tropical storm induced waves, currents and winds. Mathematical modeling of these particular processes has been fairly successful. See, for example, Forristall et al. (1977) and Ross and Cardone (1977).

Essentially no auxiliary stations were included in the program. This was due to financial reasons, but it can also be argued that because of the unique storm patterns along the coast, the network already has some inherent redundancy. Figure 8 shows the paths of tropical storms which passed near the Venezuelan coast in the past 75 years of record. As one can see, the storms tend to parallel the coast. Returning to Figure 2, it can easily be seen that if a station does fail during a tropical storm, it is likely that the storm will pass another station further along the coast.

4.2 Instrument Selection

The data of primary interest in O/M data collection programs would generally include one or more of the following: currents, winds, waves and/or water level. The sections below will focus on the considerations involved in selecting instruments for collecting these four types of data.

Remote sensing via airplane, land based radar and satellites are not presented here. The first two have considerable problems, including accuracy. The last option also is somewhat limited by accuracy and in additon it is not a technique readily available to non-governmental groups. All three techniques, however, deserve considerable attention since they may ultimately become technically competitive and they already offer some significant cost advantages over in-situ monitoring.

4.2.1 Siting Requirements. Some instrument types have inherent deployment limitations. Three helpful publications by NOS (1977, 1978, & 1979) give information concerning these limitations as well as other valuable information.

Wind sensors can be deployed on a buoy, ship, fixed platform, or land. Land stations have the advantage of being easy to service and relatively inexpensive to construct. However, as Hsu (1978) and others note, the effects of land can seriously distort the wind field so that it is not representative of the open ocean. Additional analysis is usually necessary in order to at least partially correct for the influence of land. Buoys avoid this major disadvantage of land stations but usually at a significant cost in terms of increased initial capital expenditure, long term maintenance and increased likelihood of loss. A site on a semi-permanent ship or platform is perhaps the best location for wind measurements. Some of the advantages of these two sites were given in Section 4.1.3.

It is not uncommon to place the instrument recorder in a comparatively dry, fixed site such as a platform and to moor the instrument sensor. The sensor and recorder can be linked via cable or telemetry. Rose et al. (1979) and Howell (1980) report examples of this approach. The major advantages of separating the two are that the recorder can be placed in a location which can be conveniently accessed and the likelihood of total loss of the instrumentation is usually lessened. Servicing of the recording component can be performed regularly and the sensor need only be retrieved when it shows signs of deterioration.

It is interesting to note that in the field of wave measurement, the instrument types capable of measuring wave direction are limited primarily to wave staffs. It is likely that measurement of wave direction will become more important, particularly in light of some recent results reported by Forristall et al. (1978) which indicate that wave direction is an important consideration in wave force calculations. Several manufacturers including Datawell and ENDECO are planning to manufacture buoys which will monitor both wave direction and vertical displacement.

4.2.2 Data Storage Technique. Once the data is measured by the instrument sensor, some preprocessing is usually performed and the data is stored. Existing methods of data storage include: (1) internal recording on magnetic tape or strip charts; (2) telemetry of data to the shore, a platform or a ship where data is received and recorded on magnetic tape or strip chart; and (3) transmitting of data to a land station via satellite.

There have been several successful applications of satellites in transmitting oceanographic data including one by the U.S. Bureau of Land Management (1978). The major limitation as of mid 1978 appeared to be data volume. For instance the American Electronic Lab transmitter in conjunction with the GOES satellite used by the Bureau allows hourly transmissions of 192 bits. Such a rate would not allow actual time series data to be transmitted for most parameters. Data transmission rates for the ARGOS satellite are somewhat higher for some locations on the globe. The status of satellite transmission will no doubt change, and given many of the advantages of telemetry the topic certainly deserves close attention in the future.

Telemetry of data from the instrument sensor to a conveniently located recorder has many advantages. First the method minimizes the costly boat time required to retrieve and deploy internal recording instruments. Second, the recording station can usually be checked frequently at minimal cost and malfunctioning or lost equipment can be quickly identified. Third, once the sensor is in place it is often not necessary to remove it for extended periods of time unless the signal shows deterioration. This is a significant advantage since the deployment-retrieval process is costly and often damages instruments.

There are, however, several problems with existing, non-satellite, methods of telemetry. Most off-the-shelf O/M equipment with telemetry uses very high frequency (VHF) signals and the range is restricted to line of sight, or about 50 km under ideal conditions. Interference from sources such as citizens band radio can also be a problem.

The most popular recording media are magnetic tape (usually cassettes) and paper strip charts. The latter medium is a left-over from older technology, and should be avoided for larger programs. Though the initial cost of the magnetic tape unit is somewhat higher than for a strip chart recorder, the labor saved during data processing usually more than justifies the additional expense in most data collection programs involving more than a few stations. Tapes can be processed quickly and accurately with computers and most manufacturers offer some form of data processing to the user who prefers not to purchase a reader and set up his own break-out facility.

Several recent developments in digital electronics will soon have some significant effects on recording techniques. For instance, it appears likely that solid state recording media such as bubble memory will soon become economically competitive with magnetic tape. This development should significantly enhance instrument reliability, increase storage capacity and lessen overall instrument size and weight.

The other area of significant progress is in the field of microprocessors. Several O/M instruments such as the EG&G current meter, already include internal microprocessors. Microprocessors have not yet been incorporated extensively into other types of instruments. It is likely that this will change in the next few years, particularly for wave measurement devices where microprocessors appear to offer many advantages.

4.2.3 Servicing Frequency. Instruments must be routinely retrieved and serviced for one or more of the following reasons: (1) replacement of the instrument recording media; (2) replacement of the instrument batteries; (3) cleaning of sensors made necessary by fouling; (4) maintenance of mooring systems; and (5) replacement of detiorated components. Not all of these reasons would apply to all types of instruments.

For instruments which record internally, retrieval is usually the only way of determining if the instrument was lost or functioned improperly. Thus there is a strong incentive to service these types of instruments frequently in order to minimize data gaps. This is particularly true if relatively few auxiliary stations have been incorporated into the program, making data gaps more difficult to fill. If an instrument is lost while on station, frequent servicing will probably increase the likelihood of recovery.

The cost of retrieving and deploying moored instruments can be high, since a large, well equipped servicing vessel is often needed. The cost of routine servicing is significantly less for instruments which have the recording unit on land or on a platform or ship. In these cases, servicing of the recording portion of the instrument should probably be done fairly frequently (i.e. on the order of a week) since the cost is small and benefits are substantial. The choice of a servicing interval for moored instruments with internal recorders is not nearly so simple. One must ultimately trade off the cost of servicing against the increased possibility of lost instruments and data.

4.2.4 Maintenance. The cost of maintaining instruments can vary substantially from one model to the next and thus should be considered when choosing instrumentation. Maintenance costs will clearly be affected by: (1) the technical sophistication of the instrumentation, (2) the quality of the components and the design, (3) calibration requirements and (4) availability and cost of replacement parts. Unfortunately, the NOS documents cited earlier give little information regarding these aspects, no doubt due to their subjective nature. Information on maintenance is best gathered from past experience, detailed instrument evaluations by independent sources (see NOS documents) or discussions with frequent users of the instruments being considered.

4.2.5 Reliability. The term is probably best defined as "an instrument's resistance to failure during conditions in which it will normally be used in the program". Some instrument models will experience more failure for a given usage than others. This may occur because of: (1) design, (2) quality of materials and workmanship, or (3) routine servicing which is not up to the manufacturer's specifications. Unfortunately it seems that little independent work has been done in evaluating the dependability of various instruments under similar conditions. Like the situation with maintenance, information on reliability is probably best gained from past experience, detailed instrument evaluations or discussions with others who have extensively used the instrument models being considered.

4.2.6 Cost. Equipment purchases normally constitute a significant portion of the overall program costs: roughly 25% in the case of the Integral and Orinoco Programs. Thus, significant cost savings could conceivably be made by careful shopping. Prices of instruments vary by an order of magnitude within each of the four groups (i.e. waves, currents, etc.). However, in many cases it is unfair to compare the price of one instrument model to another. For instance two instruments may have different capabilities, despite the fact that they both fall within the same group. When comparing purchase prices one should also keep in mind other long term costs associated with the instruments such as servicing. One model may initially cost somewhat more than another but the servicing costs of the less expensive instrument may outweigh the initial advantage.

Another complication to consider is that the life of O/M instruments is often quite short. In the Venezuelan Integral Program twenty instruments from a total of thirty-eight deployments were lost within 6 months. Losses were attributed to outside interference, particularly from fishermen. Since the life expectancy of O/M instruments is usually low, there is a definite incentive to use the least expensive equipment so as to minimize the financial loss of missing equipment.

4.2.7 Accuracy. The error incorporated into the instrument reading can be conveniently conceptualized into two categories: the error registered by the instrument when used under ideal conditions and the error registered under the actual conditions which will prevail in the field. Instrument manufacturers only list the first type of error and these are given in the NOS publications. For most O/M studies the first source of error is negligible when compared to the error from the second source. The Aanderaa RCM4 current meter is a classic example. The manufacturer lists the indicated speed to be accurate to ±2%. However, if the instrument is used in the field in the presence of large wave-induced velocities then the error of the speed measurements is more on the order of 50% (Halpern and Pillsbury, 1976)[1].

Most O/M instruments available on the market are limited and the accuracy listed by the manufacturer will hardly ever be obtainable in the field. When considering an instrument model, the designer should examine all independent evaluations of the model in order to determine the instrument limitations and whether those limitations will be a problem in the study.

4.2.8 Instrument Standardization. A large portion of O/M programs monitor more than one parameter (e.g. waves, currents, etc.). In this case it can be advantageous to have instruments from the same manufacturer. This is no doubt one of the reasons Aanderaa Instruments have been popular. The manufacturer offers current meters, tide gauges, and meteorology stations, all using the same data logger (recorder). The advantages of the standardizing are: servicing personnel can be highly specialized, which probably results in more timely, high quality service; spare parts inventories can be minimized; only one reader for data processing of magnetic tape equipped instruments is needed; and data processing software is

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[1] Aanderaa Instruments now recommends the RCM4 not be used in the wave zone.

simplified. Though the benefits seem significant it is somewhat difficult in practice to standardize instrumentation for several reasons. To begin with, there are only a few manufacturers which produce a line of instruments which measure more than one parameter. In addition, it is not likely that standardization can be achieved without some sacrifice in terms of the other important factors to be considered when selecting instruments (e.g. accuracy, reliability, purchase price, etc.).

4.2.9 Mooring Configuration. If it is not possible to provide a fixed platform at the station site then it will be necessary to moor the instruments. The term mooring is loosely defined here to include anchor, mooring line, connectors, acoustic release (if used) and buoyancy units (if used). Though deceptively simple in concept, moorings allow a multitude of problems. In many studies including the Venezuelan Orinoco Study and GAWWMP Study reported by Mcleod, mooring failures were the primary cause of instrument loss.

In designing a mooring one must consider the following points: (1) deployment and retrieval techniques; (2) environmental loads at the site; (3) deployment and retrieval loads; (4) strength requirements of the connectors and mooring line; (5) buoyancy and anchoring requirements; (6) long term maintenance including considerations of fatique, corrosion and deterioration due to marine life.

Many instrument manufacturers can suggest mooring configurations which have been used successfully in the past. An example is shown in Figure 9. The I-anchoring system shown in the figure incorporates an acoustic release device and this configuration seems to be the most popular. Its popularity arises from the fact that the system is invisible from the surface and hence less susceptible to outside interference. The system is, however, obviously dependent upon the ability of the ship to get within range of the release in order to activate it. Also if the release should fail it may be difficult and time consuming to recover not only the release but the other instrument on the line. Finally, the cost of the release is often significant, varying from \$3,000 to \$10,000. Add to this the cost of the surface activation unit which is on the order of \$10,000.

4.3 Quality Control

The larger the O/M program the more quality control of the data will be a problem. The volume of data which must be processed from a large program can become staggering. Consider the Orinoco program as an example. During that program, approximately 2×10^7 words of data were collected and most were eventually processed. The likelihood for error even with the aid of extensive computerization should be obvious.

Errors can be incorporated into the data in a variety of ways. Calibration errors or instrument malfunctions are of major concern and a routine calibration schedule should be established and rigorously followed. An instrument log should be established and records kept of servicing and calibration for each instrument. Each instrument and station location should have unique numbers assigned to them.

Errors also occur in handling and processing the data. Each tape (or chart) must be properly labeled with essential information such as: instrument type (i.e. currents, waves, etc.), instrument number, station number, time of start-up, time of deployment, time of retrieval and time of shut down. In the case where magnetic tapes are used as the instrument recording medium, the tapes should be quickly processed by computer into a form which expedites rapid scanning by program personnel. The quick break-out of data will assist in identifying problems and rectifying them quickly. This latter point is particularly advantageous if the error originates from an instrument malfunction which might otherwise go undetected.

4.4 Navigation

Whenever moored instruments are used, some form of navigation, however rudimentary, will be necessary. If the stations are within a few kilometers of the coastline then a compass or sextant will suffice. Locations further from the coast will require more sophisticated equipment. In the latter case, issues such as accuracy, cost, availability and reliability of the various alternatives should be thoroughly investigated.

4.5 Logistics

Issues involved here include: procurement of instrumentation and parts; scheduling of the servicing ship(s); and management of personnel.

It should be kept in mind that when procuring instruments, the manufacturer will often require several months delivery time. This means that in most cases spare instruments should be purchased in advance. Extra instruments should also be purchased if moored instruments are used in the program. This is necessary because most instruments can not be adequately serviced on the ship when they are retrieved but should usually be returned to a land-based servicing center. This of course means that replacement instruments must be on board the servicing ship so that at the time the old instruments are retrieved, the replacements can be deployed.

If servicing vessels are used then scheduling of the ships will be necessary. Suitable allowances should be made for contingencies such as poor weather or breakdown of the ship. A centralized servicing center should also be established and should be equipped with appropriate repair facilities and spare parts and staffed with competent personnel.

4.6 Program Duration

Most O/M programs last between 1 and 2 years, perhaps somewhat less in the case of environmental impact studies. In the case of design studies, this relatively short duration can present some problems when one attempts to derive design parameters for long recurrence intervals (i.e. on the order of 50 years). Resio (1975) suggests that the data itself should not be extrapolated in time for periods longer than 5 times the duration of the data. That would imply that data from a 2 year program should not be extrapolated past about 10 years.

The problem can be further aggravated if the recurrence interval of major storm events is large as is the case for Venezuela. Recall from Figure 8, the average recurrence interval for tropical storms along the

Venezuelan coast is about 8 years. Hence the probability of measuring a significant storm during a program of 2 year duration is small. As yet a significant tropical storm has not been recorded in either the Orinoco or Integral Programs.

Because data collection programs are costly it is usually not feasible to maintain the program for the time period needed to derive design information from data. Of course, the results from the program are usually needed long before a program of more desirable duration could be completed. Modeling, therefore, must play an important role in the derivation of design criteria. The data in effect serves primarily to calibrate and check the models, at least as the data pertains to deriving design criteria.

5. SUMMARY

The various steps involved in the planning and execution of an offshore data collection program have been outlined. The aspects that have been presented are most relevant to large programs involving the collection of oceanographic and meteorologic (O/M) data to be used ultimately in the design and operation of offshore oil production facilities. Many examples are taken from two large O/M programs off the coast of Venezuela in which the authors have been deeply involved. Although these are specific examples, the discussion is presented in fairly general terms and should be useful to planners and designers of other types of offshore data collection programs.

The discussion focuses on the steps in program design including selection of the resolution of the monitoring network, instruments, quality control methods, navigation methods, logistics, and program duration. Given the complexity of each topic and the space constraints, it is not feasible to discuss all the topics at a detailed level. A fairly detailed discussion of the monitoring network and instrument selection is given and a brief review of the major points involved in the other topics is presented.

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REFERENCES

EG&G (1978), "Recommendations for the Continuation of the N.E. Outer Continental Shelf Physical Oceanography Program", Waltham, MA.

Forristall, G. Z. et al. (1977), "Continental Shelf Currents in Tropical Storm Delia: Observation and Theory", J.P.O., 1, 532-546.

Forristall, G. Z. et al. (1978), "Storm Wave Kinematics", O.T.C. Paper 3227.

Halpern, D. and R. O. Pillsbury (1976), "Influence of Surface Waves on Sub-surface Current Measurements in Shallow Water", Limnology & Oceanography.

Howell, G. L. (1980), "Florida Coastal Data Network", Proc. 17th Intern. Conf. on Coastal Engr., Sydney, March.

Hsu, S. A. (1980), "On the Correction of Land-Based Wind Measurements for Oceanographic Applications", Proc. 17th Inter. Conf. on Coastal Engr., March, Sydney.

Mcleod, W. R. (1979), "Ocean Wave Measurement Experiences in Hostile Environments", O.T.C., Paper No. 3375.

NOS (1977), "Current Measurement Subsystem Technology Survey" compiled by G. F. Appell and D. R. Crump, Nat. Ocean Survey Test & Evaluation Lab.

NOS (1978), "Wave Sensor Technology Assessment", by R. L. Ribe, Nat. Ocean Survey Test & Evaluation Lab.

NOS (1979), "Water Level Measurement System Technology Survey", by T. N. Mero and Alfred Zulueta, Nat. Ocean Survey Test & Evaluation Lab.

Resio, D. T. (1975), "Extreme Wave Heights for Cleveland Harbor", Proc. from C.E. in the Oceans III, ASCE.

Rose, F. W., et al. (1979), "The U.S. East Rig Instrumentation Program", O.T.C., Paper No. 3373.

Ross, D. and V. J. Cardone (1977), "A Comparison of Parametric and Spectral Hurricane Wave Prediction Products", Poc. of NATO Symp. on Turb. Fluxes Through the Sea Surface, Wave Dynamics & Pred., Marseille, France, Sept.

Stolzenbach, K. D., et al. (1977), "A Review and Evaluation of Basic Techniques for Predicting the Behavior of Oil Slicks", R. M. Parsons Lab, M.I.T., T.R. 222.

U.S. Bureau of Land Management (1978), O.T.C., Paper No. 3178.