NOAA TM ERL AOML-18

PUBLICATION

NOAA Technical Memorandum ERL AOML-18

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

Formulation of Drifting Limited Capability Buoy Placement and Retrieval Concepts

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Oceanographic
and
Meteorological
Laboratories
MIAMI, FLORIDA
April 1973

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This report is submitted in response to the National Data Buoy Center's requirement for a "Formulation of Drifting Limited Capability Buoy Placement and Retrieval Concepts". The search and rescue methodologies of the agencies engaged in finding lost objects at sea are summarized, and a method for predicting the drift of a buoy subject to surface current stresses is suggested. Finally, a test program for the Drifting Limited Capability Buoy is offered.

1. INTRODUCTION

The "Formulation of Drifting Limited Capability Buoy (DLCB) Placement and Retrieval Concepts" as delineated in National Data Buoy Center (NDBC) Statement of Work 0134EC, consists of two tasks. The first task requires a "summary of buoy location prediction models" and the second "recommendations for future NDBC direction". The requirements have short term aspects related to the field testing of the buoys during the R and D phase of the program and long term operational aspects. Primary emphasis in this report is given to drift prediction and buoy retrieval concepts as placement concepts are determined by the experiment being conducted, and will require detailed individual analysis. However, some suggestions concerning deployment during initial DLCB tests will be presented.

The procedures of the United States Coast Guard and the United States Navy's Fleet Numerical Weather Central (FNWC) at Monterey, California, are summarized, as both groups are actively engaged in finding lost objects at sea. The Coast Guard Search and Rescue (SAR) plan, given in Coast Guard Manual CG-308, is operationally oriented and strives for an engineering handbook solution to the problem. Each step of the SAR procedure is presented with accompanying charts and figures to facilitate the computations.

The FNWC has developed a computer program in support of the Coast Guard SAR operations. The program uses sea surface current and wind forecasts generated at the FNWC to determine the probable drift of a SAR object. The Coast Guard is presently instituting an operational SAR computer program which is more sophisticated than the FNWC model.

The problems encountered in balloon location are similar to those found in buoy location. The work of Quinlan and Hoxit (1968) is summarized as an example of the meteorologist's approach to balloon location. Other reports were reviewed which discussed short-term tracking of balloons and rockets (Young 1962, Rachelett and Armendary 1967, for example) but their procedure is too specialized for application to the buoy problem.

Recommendations for future NDBC action are given in a following section. A procedure for predicting drift and retrieving non-functioning buoys, as well as a test program for the DLCB are offered. The specialized nature of the DLCB's and the methods employed by various SAR agencies are considered in these recommendations.

2. SUMMARY OF PREDICTION MODELS

2.1 Coast Guard Search and Rescue Plan CG 308 Procedure

Chapter 6 of CG-308 pertains to the "Determination of Search Areas". Relevant sections of this chapter discuss the means of estimating the probable position of a SAR object, and determining the search area. The position of the lost craft is based on a probable drift from the initial location of the SAR incident.

The object's drift is computed as a function of three variables, the average sea current, the local wind current, and the wind's effect on the object (leeway). All variables are tabulated on maps, charts, or figures. For instance, the average sea current is obtained from one of three sources, which in order of preference are U.S. Naval Oceanographic Office Atlases, Oceanographic Office Atlas of Surface Currents, and Pilot Charts.

Section I of the Oceanographic Atlas of the North Atlantic (Publ. No. 700) is an example of the first publication, and contains tides and currents of the region. Two surface flow charts are presented, one combining data taken in the summer months of July, August, and September and the other for the winter months of January, February, and March. Current directions are given by arrows. The color of the arrow indicates the variability of the flow, with only the prevailing currents to be used in the computations. Isotachs are plotted on overlays to the direction charts, permitting determination of the velocity vector at any point.

The Atlas of Surface Currents, such as Publ. No. 576, are being replaced by Publ. No. 700-type publications, and are used only in areas where these publications do not exist. Monthly current representations are given for the region of the particular atlas. Pilot charts, which also give monthly currents, are mentioned as a last resort and only in regions where no other information is available. Technical reports of NOAA, the Naval Oceanographic Office, and interested research groups are recommended as a source of supplementary data.

The wind induced current is obtained from figure 1, which is taken from James (1966). James considered the effect of wave transport as well as pure wind drift to arrive at the functional dependence of the current on the wind speed, the fetch over which the wind acts, and the duration of the wind. Although James considers the deviation of the drift from the wind to be 20° to the right in the Northern Hemisphere, the Coast Guard tabulates the drift as a function of latitude.

Both wind speed and the "sail" characteristics of the lost object are used to determine leeway. The larger the sail presented to the wind, the greater the drift caused by the wind. Figure 2 is given to aid in leeway determinations, the curves representing the leeway of a liferaft with and without drogue. Small objects other than liferafts are assumed to have leeway curves falling between the two presented. Although most boats will tend to drift off the downwind line, the direction of the leeway vector is considered downwind.

The three terms are combined vectorially to give the drift, and thus probable position, of the SAR object. Computations are continued to arrive at an estimate of the error

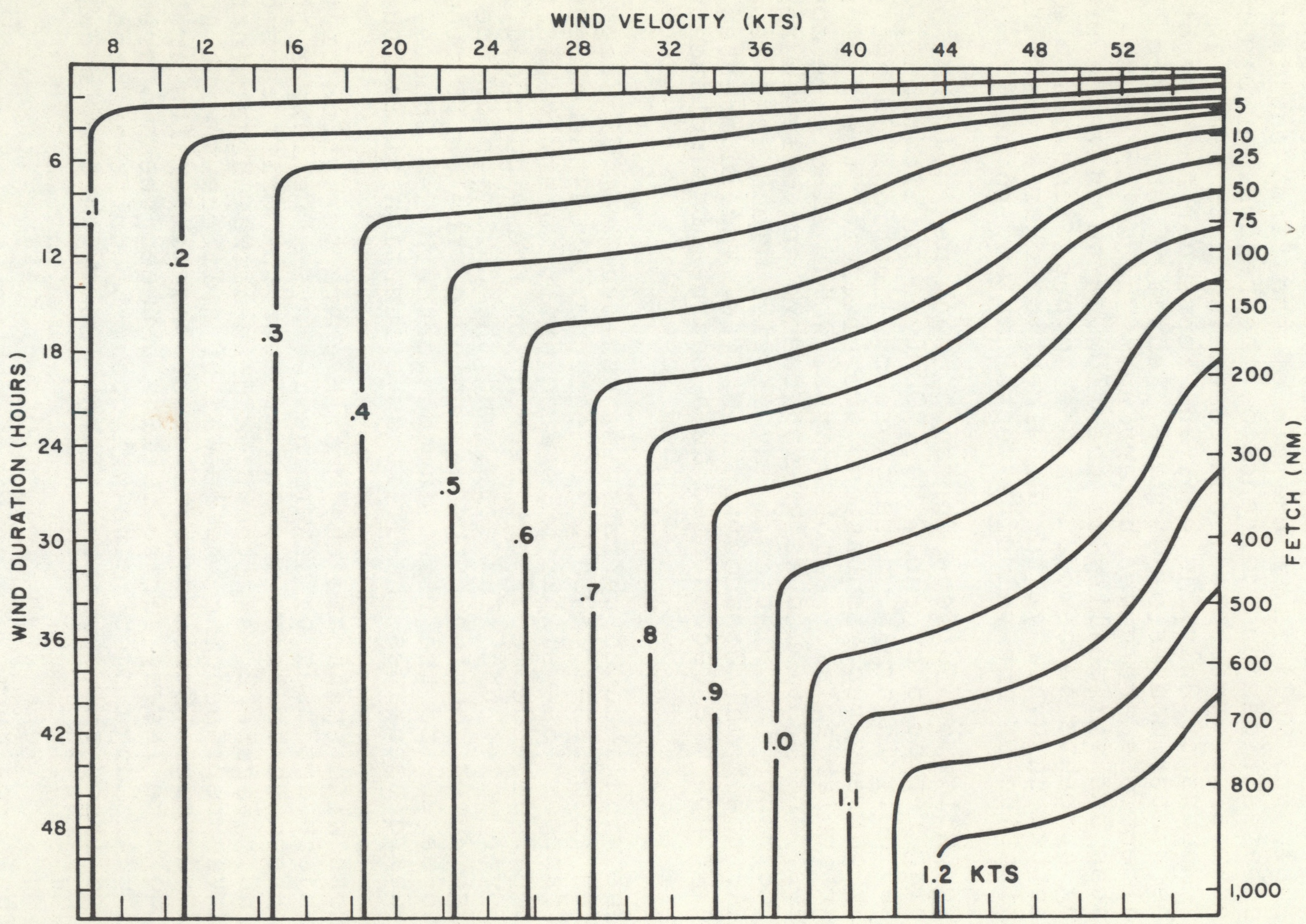

Figure 1. The wind-induced surface current component as deduced by James (1966).

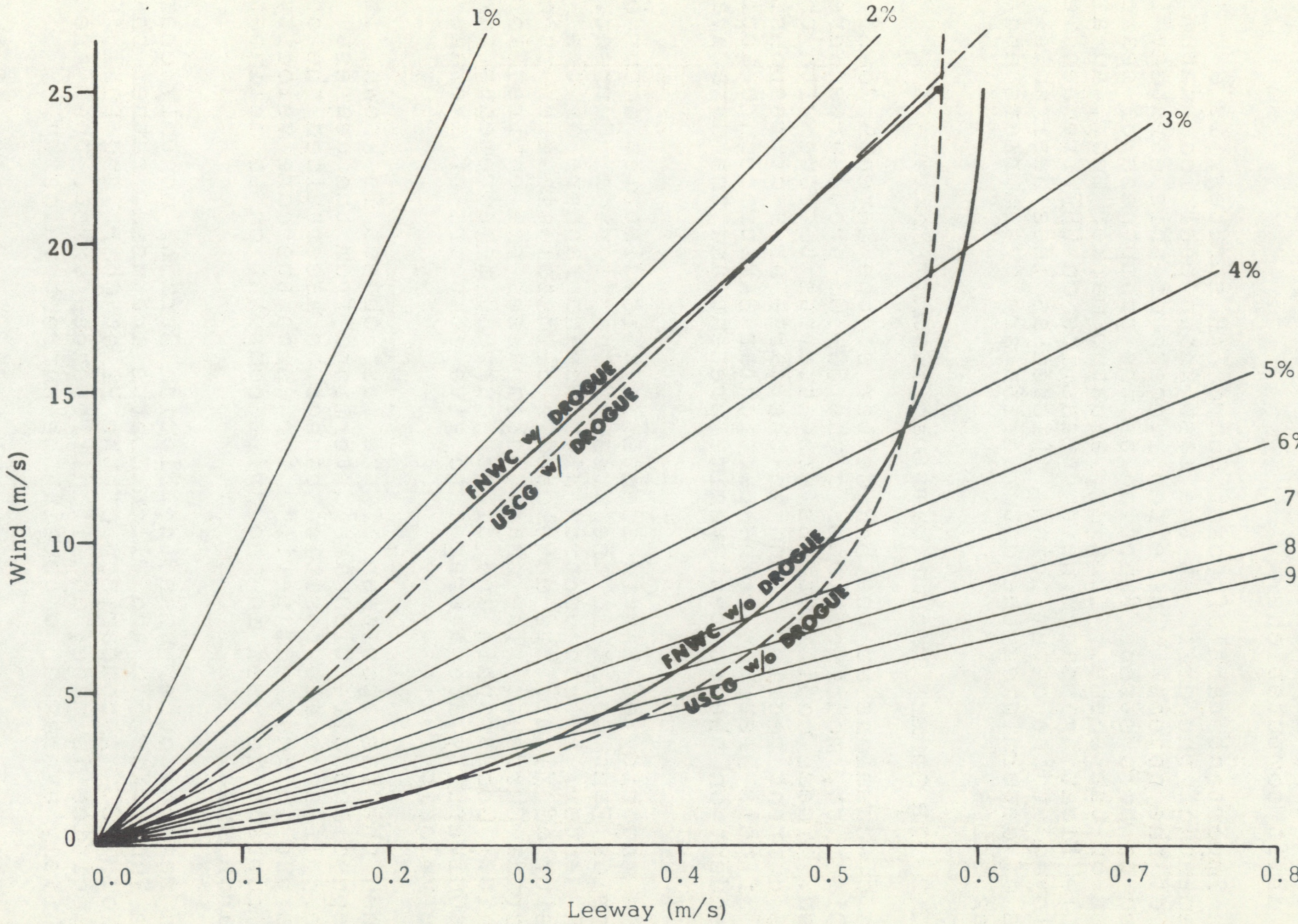

Figure 2. Leeway for liferafts with and without drogue used by the FNWC and USCG. Linear curves for percentage of wind contribution to leeway component are also shown.

in the computations. This quantity is a function of the error in the last known position of the object, the navigational errors of the search vessel and the drift error. This last error is taken as the total drift divided by eight, that is a 12% error is automatically assumed to exist in the drift computations.

An important part of Coast Guard SAR strategy is a measurement of the drift at the last known position (datum point) of the object. The effectiveness of this strategy is expected to be a strong function of the promptness of search vehicles on the scene. Ideally, a datum marker buoy, an air-droppable floating beacon which transmits on UHF frequencies, is deployed at the datum point. Listed as less desirable methods of determining the datum drift are dye markers and/or drifting ships.

2.2 SAR Center, Seventh Coast Guard District Procedure

In discussions at the SAR Center of the Seventh Coast Guard District, modifications to the CG-308 procedures were outlined. These modifications are attempts to cope with the diverse current regimes found in the large area of responsibility of this District. The particular SAR procedure applied is dependent on the current regime present and the data available.

The majority of SAR incidents in this district occur off the Florida East Coast in the area of the Florida Current. The SAR Center, in conjunction with oceanographers of the University of Miami, has developed a climatological chart of the Florida Current. The chart encompasses the entire Florida Strait. Geostrophic and direct current measurements taken by the University are averaged to give contours of average surface velocity.

When the last position of the lost object is known, it's drift speed and direction are determined from the nearest isotach. If an exact position cannot be ascertained the object is put in "maximum peril", for which the core velocity of the current is used in the drift computation to delineate the search area.

In regions other than the Florida Strait, monthly charts such as Publ. No. 576 and Pilot Charts are used, rather than Publ. No. 700. A comparison of the Pilot Chart and Publ. No. 576 velocities is made; and if differences exist, they are subjectively averaged to obtain the current velocity.

The leeway component is tabulated as a function of the lost object. A percentage of the wind speed, dependent on the sail area, is used as the velocity of the leeway. The deviation from downwind direction is also given in a table. For instance, the maximum deviation of a sailboat has been empirically determined as 60°, either to the right or to the left of the wind direction. The search area must be enlarged accordingly to compensate for this unknown drift direction component.

This Center is compiling a store of observational current measurements as datum marker buoys are deployed during most search operations. The use of these buoys follows the procedures set down in CG-308. One difficulty encountered in applying this technique is obtaining accurate positions when the plane cannot sight land.

The Center personnel do not use the Monterey Search and Rescue program operationally. They indicate that the area prescribed by this program is often prohibitively large to launch a successful search because of the poor spatial resolution afforded by this model relative to the SAR problems most frequently encountered at the Center. Occasionally they do use the program to verify their calculations.

2.3 FNWC Search and Rescue Computer Program

Hubert, Hinman, and Mendenhall (1970) describe the computer program developed at the FNWC to predict the position of an object lost at sea. The program uses in-house generated forecasts of surface current and wind to compute the probable drift of a craft. SAR missions are initiated upon request from a suer who must provide the details of the SAR incident.

Larson and Laevastu (1971) describe the procedure for forecasting surface currents from local temperature structure and wind stress. The density field is approximated by the average temperature of the upper 600 feet of the water column in the calculations to determine "the permanent flow component". The average temperature is a weighted mean of the sea-surface temperature and 600-foot temperatures which are both computed twice daily from ship reports. Horizontal temperature gradients are then substituted into the following simplified version of the thermal wind equation to arrive at the velocity,

$$u = (-gz/fT)\,(\partial T/\partial y)$$

$$v = (\ gz/fT)\,(\partial T/\partial x)$$

where,

(x,y) = (east, north) directions
(u,v) = (east, north) components of velocity
g = acceleration of gravity
z = 600 feet
T = average temperature
f = Coriolis parameter.

Witting's formula is used to determine the wind-induced current. Empirically derived in the early 1900's from lightship observations (Defant, 1961), the induced flow is proportional to the wind speed. The deviation of this current, D, from the wind direction, W, is given by

$$D = 40.0 - 8.0W^{\frac{1}{2}} \qquad W \leq 25\text{m/sec}$$

$$D = 0 \qquad W \geq 25\text{m/sec}$$

where the deviation is to the right in the northern hemisphere.

The FNWC approximations to the liferaft leeway curves determined by the Coast Guard are given on figure 2. Options are available for calculating the leeway of craft other than liferafts. A linear percentage of the speed, depending on the sail area of the object, is applied as the leeway component. Figure 2 also contains some percentage drift lines used in the FNWC program.

Drift components are computed on a grid with 200-mile space increments. To obtain the drift at non-grid points, a non-linear interpolation is used. Drift forecasts are made every 12 hours at present, but it is planned to reduce the time interval to 6, then to 3 hours.

2.4 Coast Guard SARP Computer Program

The Operations Analysis Branch of the Coast Guard's Atlantic Area Command has developed a search and rescue computer program called SARP (Operations Analysis Branch, personal communication 1972). This program was initiated in response to the need for an automated SAR program, to the evolution of SAR methodology, and to the problems encountered during the applications of the FNWC model. SARP has been tested at Third Coast Guard District, New York, and due to its success will become operational in the near future. The present model adhers strictly to the SAR methodology of CG-308. Future models will include the newer techniques.

SARP has a surface current file based on the climatological data of Publ. No. 700. Only currents with a steadiness of greater than 55% are on file. Supplementary information, such as the Florida Strait surface current chart constructed for the Miami SAR Center also will be input on the data file.

An updated version of the SARP current file is being developed in conjunction with the Naval Oceanographic Office. Historical data are being recompiled to arrive at new monthly climatological charts. The computations also will result in a determination of the error bounds of the current means. The present method of applying a constant 12% drift error is probably optimistic in regions of poorly known or highly variable currents.

The option to override the Publ. No. 700 current file is available in the SARP program. If the user has knowledge of the current field in the region of the SAR incident, these data can be input to the SARP program.

The local wind drift is determined from the chart of James (fig. 1). The program models the effect of wind shifts by considering the degradation of the previous wind drift as well as the onset of the new current. The technique described by James (1966) is used in these computations.

The leeway component is computed by the CG-308 method. The user option to specify the percentage of wind to apply to the leeway speed also exists.

The 200-nautical mile spacing between grid points of the Monterey program is too large for an operational SAR tool. The Coast Guard program, however, will have a space increment of approximately 30 nautical miles, with a 6-mile space in regions of numerous data such as the Florida Strait. The time increment of SARP is one hour.

The Coast Guard, through a contract to a consulting firm, is developing another SAR computer program to be called CASP. This model will be more statistical in nature producing probability maps of the search area. Environmental data, search plans and other possible factors will be assigned uncertainty values to arrive at these maps. The program will be tested operationally at the Third Coast Guard District, and if successful will become available to all the Coast Guard SAR Centers within two years.

2.5 Balloon Location

Quinlan and Hoxit (1968) describe a technique developed to determine the trajectories of high altitude balloons. A "climatology of balloon positions" for packages launched from Chico, California, to float for up to twenty hours at 90,000 feet was needed to plan recovery operations. The climatologies were computed for seven 2-week periods to arrive at the optimum launch time.

The first step was to compute trajectories from winds aloft data stored at the National Weather Records Center Asheville, North Carolina. Displacement vectors at 5, 10, 15, and 20 hours after launch were computed from three consecutive twelve-hourly observations. Between 30 and 38 randomly selected sets of data were chosen for each two-week period.

Target ellipses (climatologies) were then constructed to outline the probable area of impact. The two-dimensional displacement vectors were assumed to have a bivariate normal distribution with a probability density which falls off exponentially in all directions from a mean value. When the standard deviations of the east and north components are equal, the distribution is circular, otherwise it is elliptical.

The computational procedure involves determining the major and minor axes of the ellipses as well as the angle of orientation. The .90 and .99 probability ellipses are then drawn on a base map for use by the retrieval personnel. Examples of these ellipses for a typical two-week period are given on figure 3. The optimum launch period has the smallest target area.

To facilitate the retrieval operation, the probability that the balloon package will be within a circle of given radius centered at the mean position of the probability ellipse can also be calculated. This computation results in a probability curve such as shown in figure 4. Although conceptually appropriate also for the drifting buoys, this technique is presently inapplicable because insufficient data on ocean current condition exist at present and, in any case, is likely to involve an impractically large search area.

3. RECOMMENDATIONS FOR FUTURE DIRECTION

3.1 Introduction

In contrast to the meteorologist's one-parameter problem, the SAR techniques of the Coast Guard and FNWC emphasize the importance of considering two variables, current and leeway,

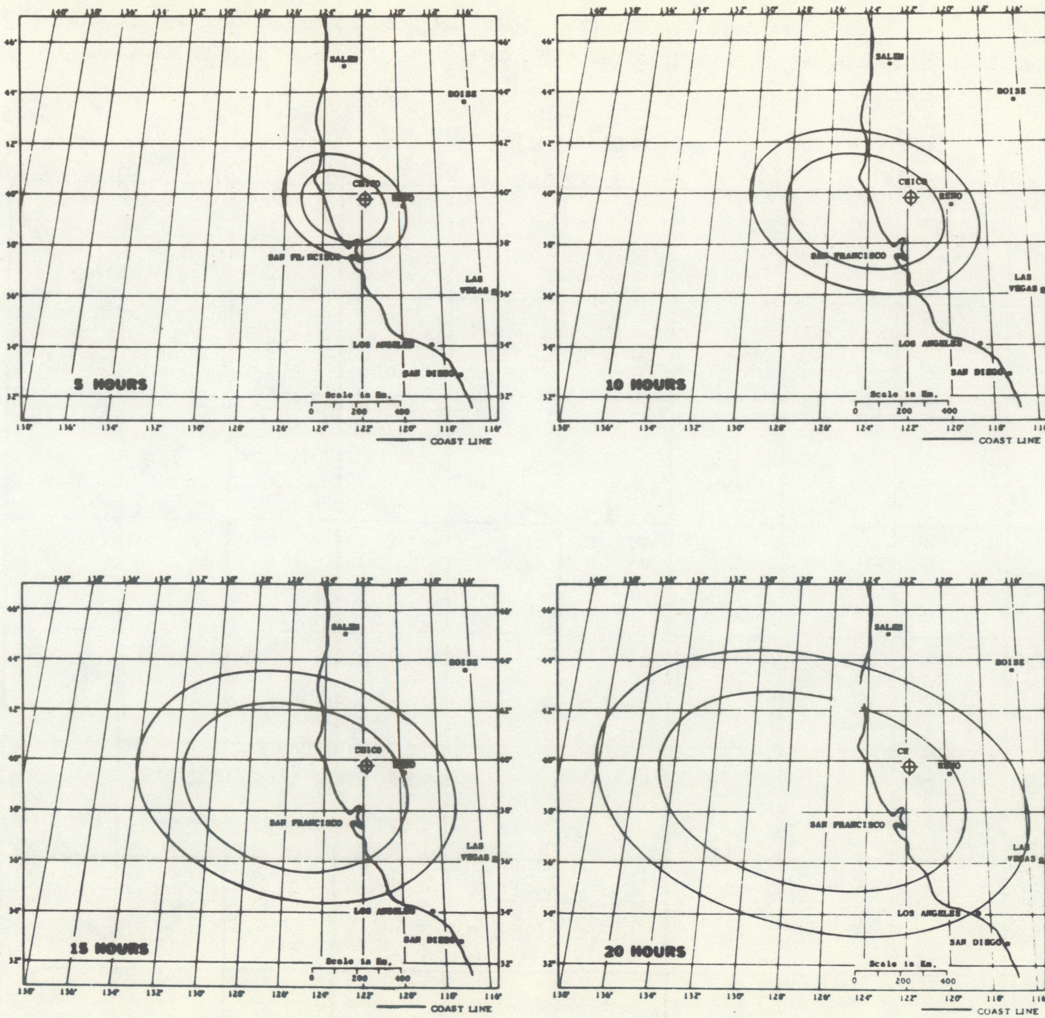

Figure 3. The 0.90 and 0.99 probability ellipses for balloon positions after 5, 10, 15, and 20 hours, at 90,000 feet.

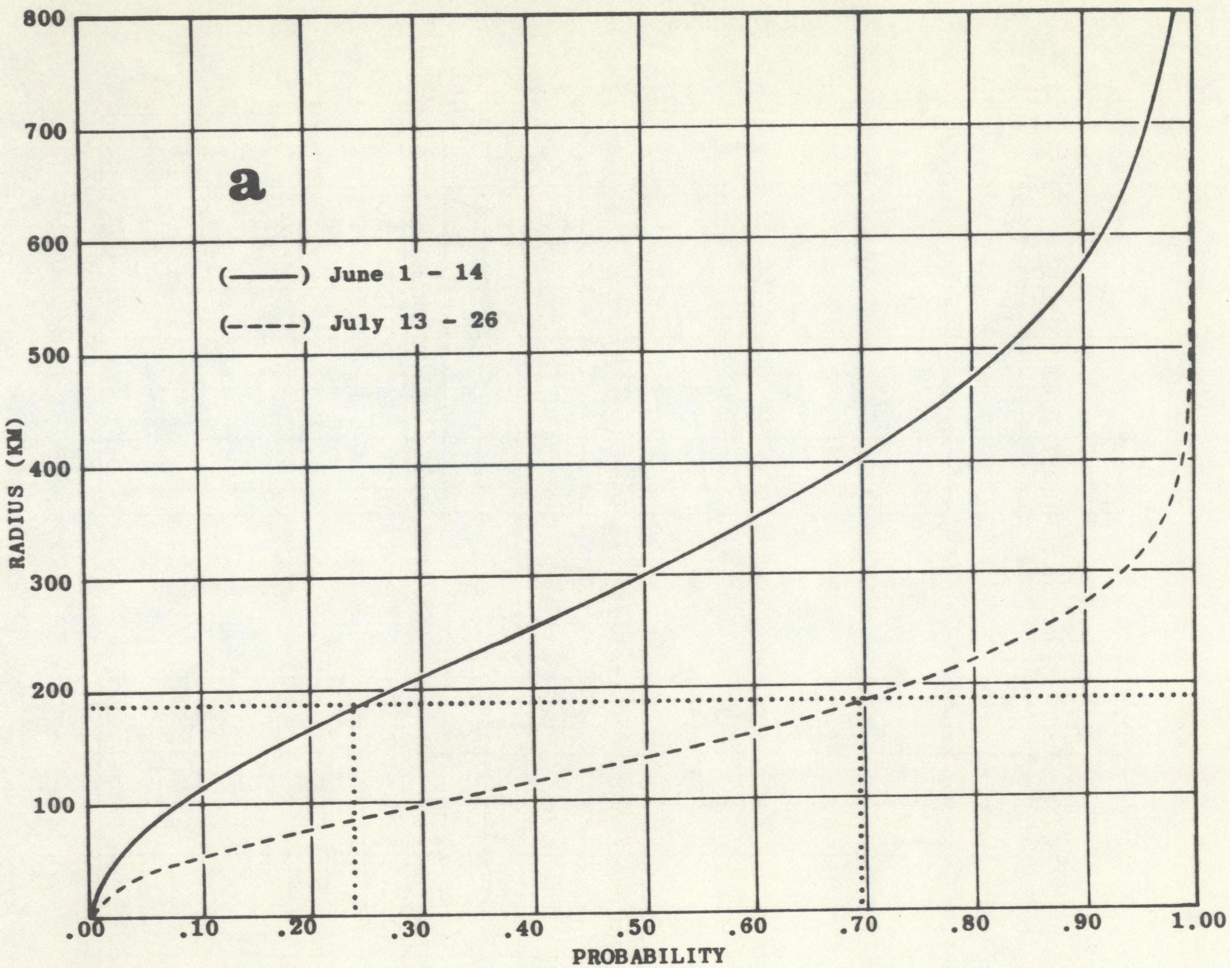

Figure 4. The probability of a balloon being within a circle centered at the mean of the respective distribution for two, two-week periods.

in the drift computations. Intuition dictates that an object will drift at the velocity of the current in which it is floating, but it is not as clear as to how a buoy will sail in the wind. Thus, an example of the magnitude of the sail component under typical oceanic conditions is presented.

Consider a 1 m/sec current flowing to the north and a 10 m/sec wind acting in the same direction. If the duration of this wind is two hours, an insignificant wind induced current will result. Assuming the DLCB approximates a liferaft with drogue, the 10 m/sec wind will produce a leeway of $\frac{1}{2}$ knot. This is a 25% and 10 mile per day increase in the resultant drift.

If this component is not considered in the drift computations, the probability of failing to locate the drifter increases. If included, the additional mileage would shift the center of the search area. Furthermore, the search area would have to be enlarged to compensate for the possibility of non-downwind drift if the sail characteristics of the object are not known.

The sailing characteristics of the DLCB are a function of the shape of the drifter, its height above and below the water, whether it is drogued or not, and other variables. These factors will have to be determined during the DLCB Test Program, and thus the leeway component of the drift cannot be realistically considered in this report. Therefore, the following sections include recommendations for determining only the current components of drift and for conducting a test program for the DLCB. Specific examples, taken from studies conducted by AOML personnel, are used to argue for various procedures.

3.2 Current Determinations

The knowledge of precisely where and when the DLCB failed and what the previous drift was greatly facilitate the task of locating the buoy. This section considers the DLCB drift as a function of only the current and offers a drift prediction plan consisting of pre-launch, launch, drift, and failure procedures. Some of these procedures are more easily applied during the test program than for operations, but may be operationally applicable in the context of large-scale geophysical experiments from which extensive supporting observations are available.

3.2.1 Pre-launch Stage

Knowledge of the initial DLCB deployment area should be used to predict the probable drift of the DLCB, and to develop the recovery plan for a non-functioning buoy. It is recommended that all possible sources of information be considered to satisfy the prediction and recovery requirements. While describing these data sources, the limitations and advantages of various procedures given in Chapter II also are discussed.

The ideal data source for the prediction and recovery operations is a research project taking observations in conjunction with the DLCB experiment. For instance, if a DLCB is to be launched during a MODE or GATE type experiment, all the information necessary to predict the drift of the buoy is being collected. However, if such an experiment does not exist, it is recommended that the NDBC ascertain if any groups are actively engaged in other descriptive studies of the area. Some examples of such data sources follow.

Dr. W. D. Nowlin, (Personal communication) of Texas A&M University, in conjunction with the NDBC and the Environmental Data Service (EDS), is attempting to develop a seven-day analysis program for the Gulf of Mexico. Temperature data collected from the Buoy Center's EEP buoys and from ships operating in the region would be forwarded to Dr. Nowlin from the EDS and NDBC. Computer programs have been developed which will produce contours of the depth of selected isotherms. Since the temperature field closely parallels the density field in the Gulf, the flow pattern is approximated, at least in the region of the major currents.

Continuing projects of the U.S. Naval Oceanographic Office and the Coast Guard produce maps of surface temperature which, although not as valuable as the previous type of study, could be used to predict the surface flow. The Gulf Stream series of the Oceanographic Office presents monthly charts of the Gulf Stream Axis and mean surface temperature in the northwestern Atlantic Ocean. Also included are descriptions of any anomalous circulation features which were recently investigated. The Coast Guard disseminates the results of their monthly aircraft infrared thermometer measurements of the waters off the eastern seaboard. By means of such observations, the changing position of major currents can be detected and a semi-quantitative measure of current speeds can be obtained from figure 5. This figure was compiled by James (1966) from data relating sea surface temperature gradients to current speed.

Less desirable data must be obtained if these types of projects do not exist. The Coast Guard manual recommends the use of Atlases such as Publ. Nos. 576 and 700 to determine

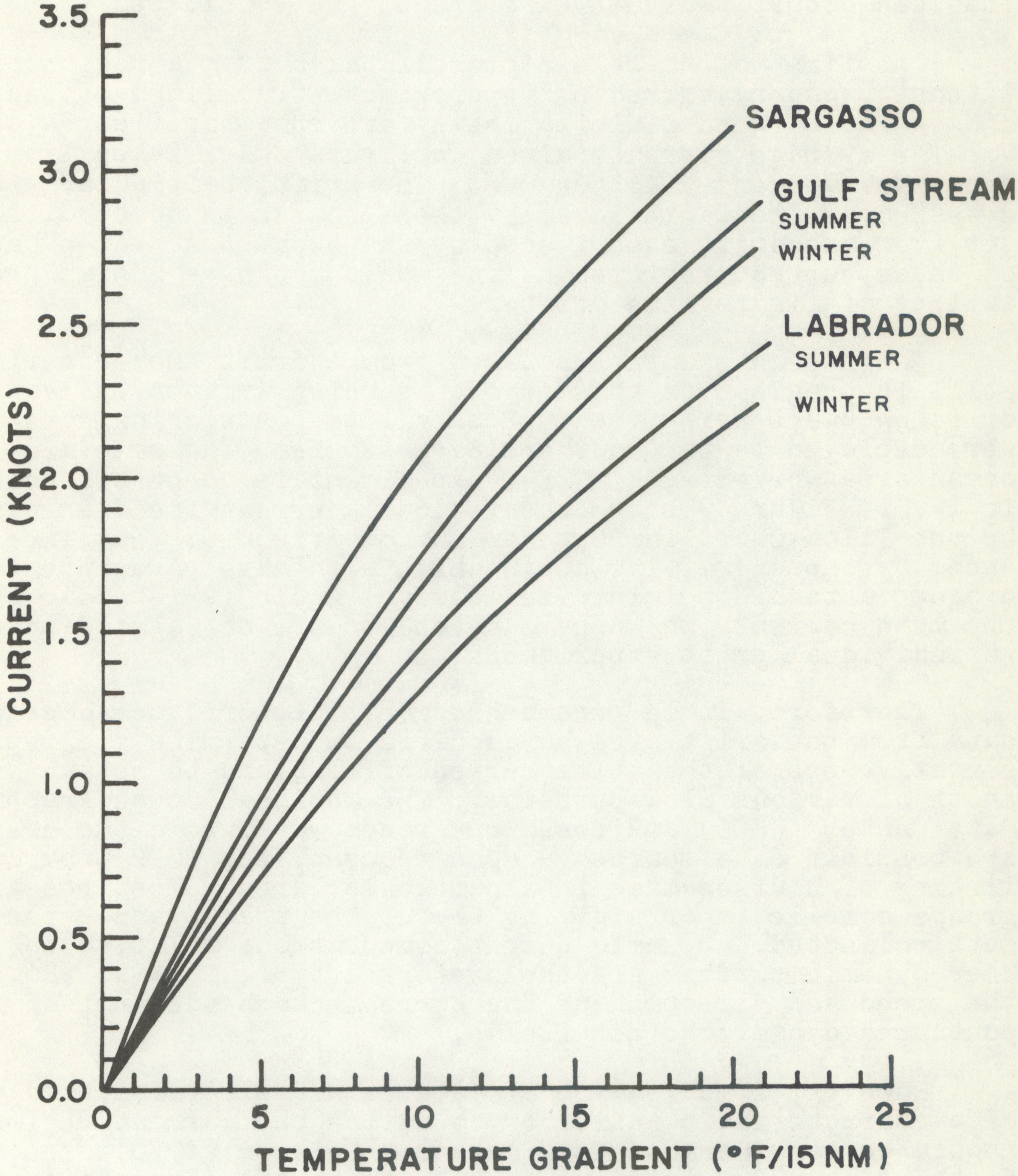

Figure 5. Estimation of geostrophic current from surface temperature gradients as given by James (1966).

the permanent current component. However, this type of data compilation filters out all temporal variations with time scales less than the averaging period. Thus, the atlas picture is seldom duplicated by an instantaneous snapshot of the circulation field. As an example of the type of differences that can occur, two AOML experiments are considered.

The first of these examples is taken from a region of intense boundary currents. Approximate tracklines of buoys drogued at 40 m to minimize leeway are shown as figures 6 and 7. The average currents given on figure 8 are taken from Publ. No. 700 and Pilot Charts. The drift, particularly the speed components, predicted by these charts is quite different from the drift experienced by the buoys. A search based on these current representations would not have a high probability of finding the drifter.

The second example is taken from a drift buoy experiment still in progress as this report is being written. Five drifting buoys using the EOLE satellite positioning system were deployed in the southern Sargasso Sea, the same mid-ocean area wherein the MODE-I experiment is to be conducted in 1973. Figure 9 shows the regional current field as given by the Pilot Chart for October in comparison to that experienced by these drifting buoys which also have parachute drogues attached to minimize leeway. Again it is clear that the mean currents shown by such charts are not a good index to individual drift experiences.

Therefore, it is recommended that historic oceanographic data from the drift area be acquired to determine the representativeness of the atlas current fields and to obtain snapshots of various flow patterns. The National Oceanographic Data Center (NODC) and research groups working in the area are possible data sources. Upon request, the NODC provides a listing of cruises made in a particular area. Most research groups compile reports giving the cruise tracks and types of data collected. Dynamic height computations relative to a deep dynamic surface are the preferred type of data. Both the speed and direction of the current can be determined from contoured dynamic height fields.

However, if this type of data is not plentiful, the use of a characteristic indicator to define the current regime should be considered. For instance, Leipper (1970) uses the depth of the 22°C isotherm to illustrate the circulation pattern in the Gulf of Mexico, while Hansen (1970) uses the 15°C isotherm at 200 m to depict the Gulf Stream axis. In areas other than the North Atlantic, it may also be possible to calibrate the temperature data to obtain current speeds as well as direction.

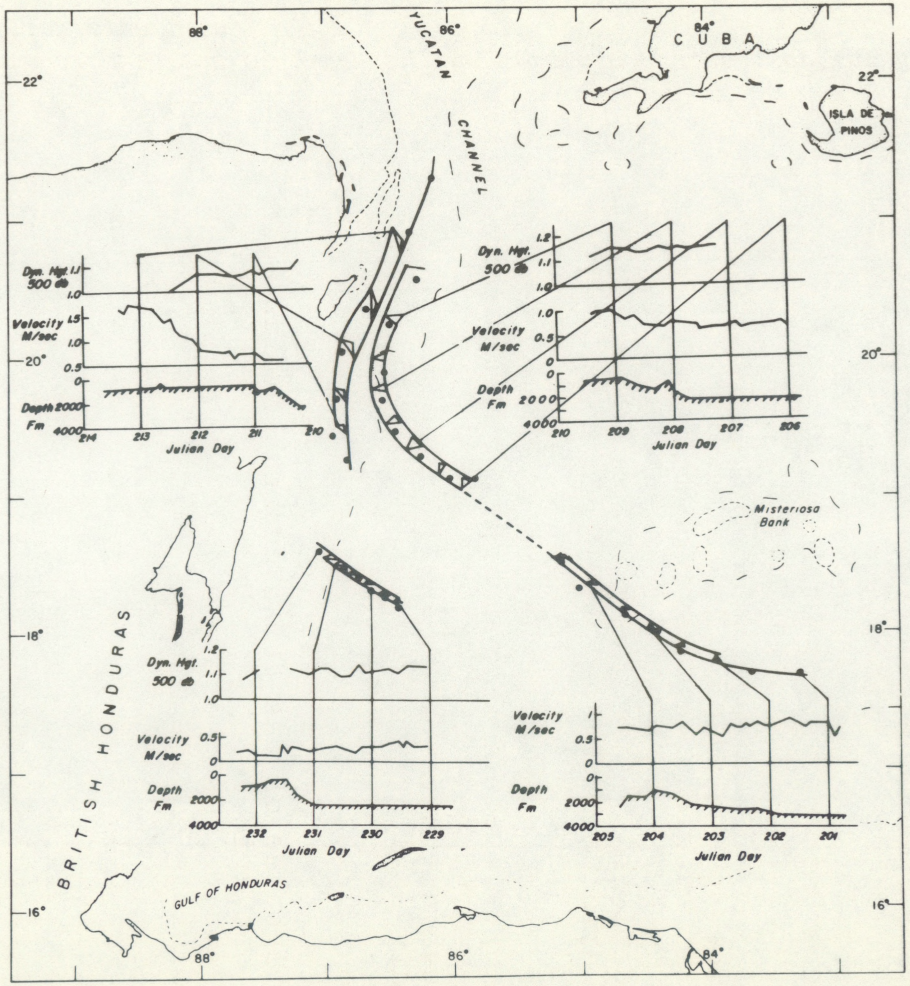

Figure 6. Approximate drogue tracks for the AOML July 1971 Caribbean Sea drifter experiment.

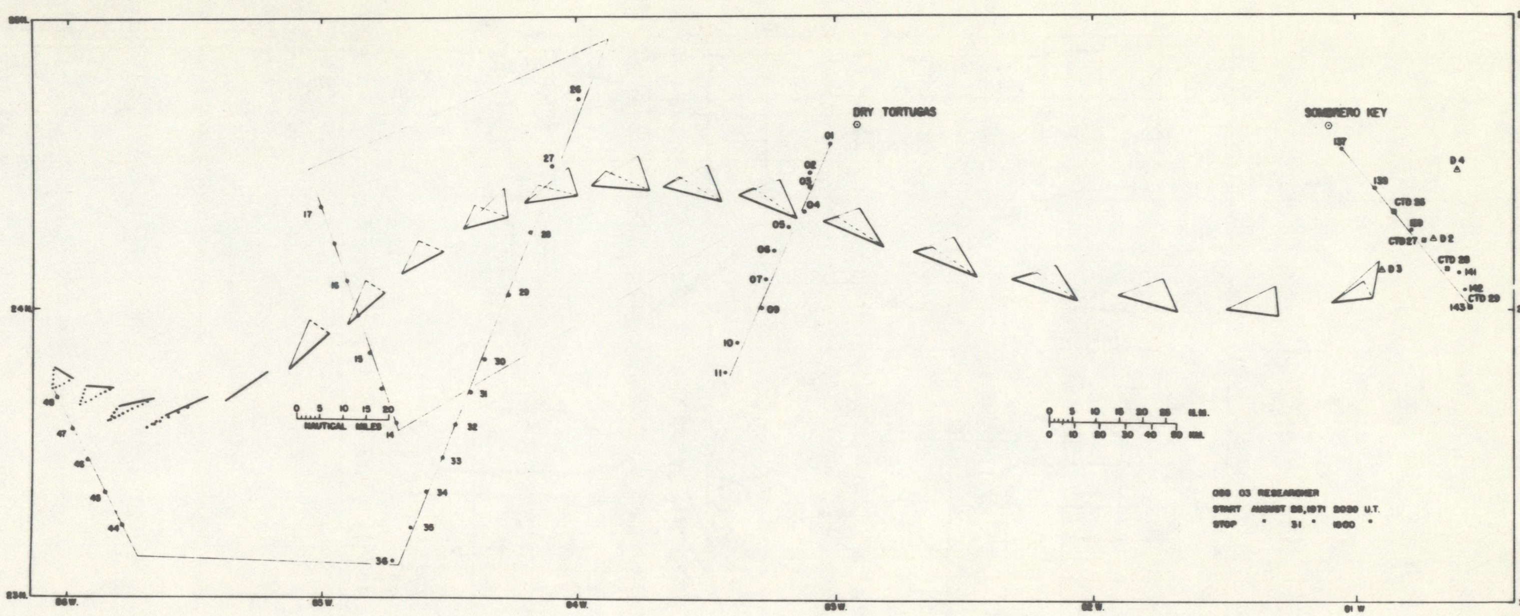

Figure 7. Approximate drogue tracks, given by the triangle apexes, for the AOML August 1971 Gulf of Mexico drifter experiment.

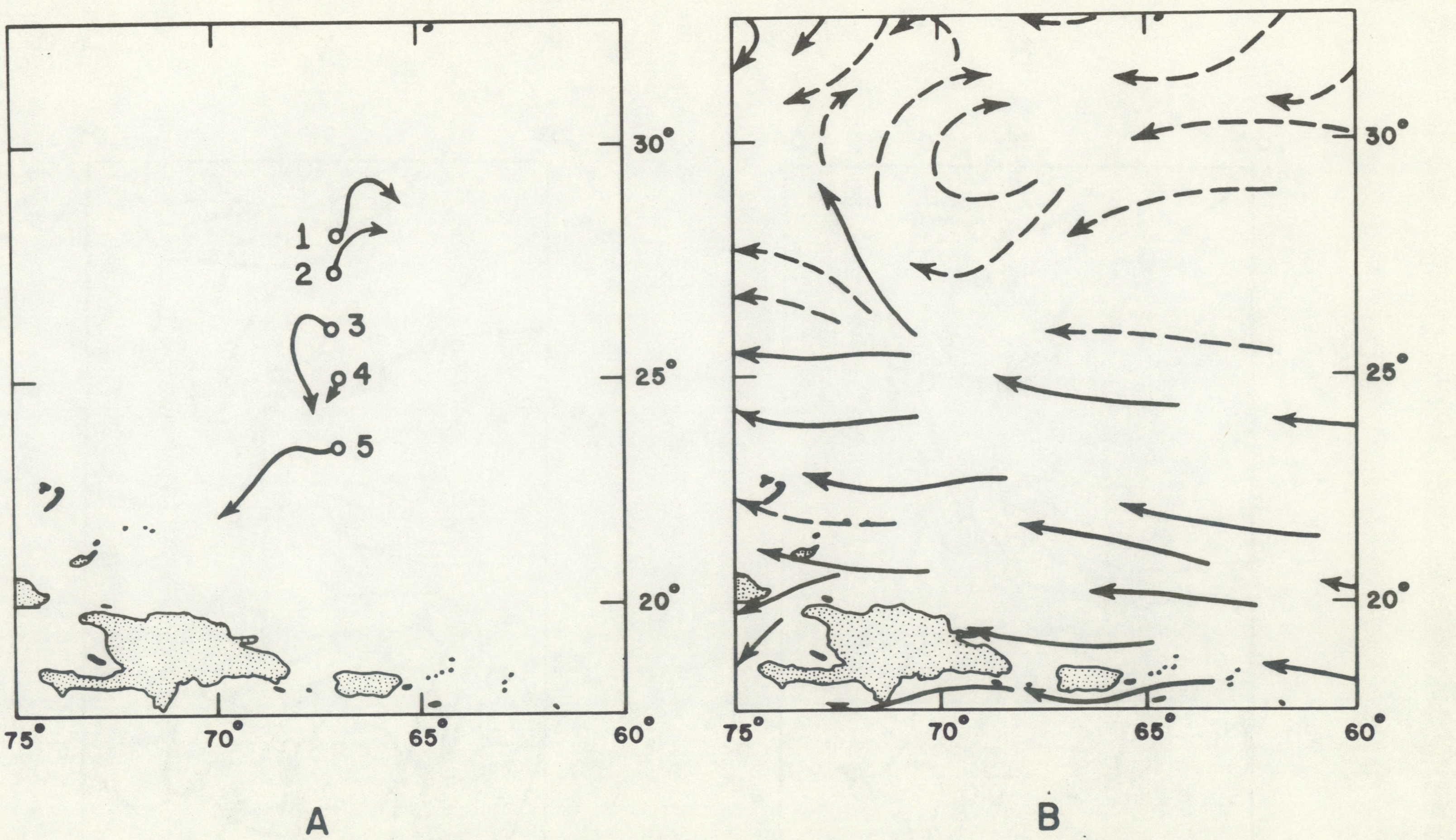

Figure 8. Mean surface currents for the western Caribbean Sea and Gulf of Mexico taken from Publ. No. 700, A (dashed lines represent isotachs in knots), and the August Pilot Chart (current speed in knots).

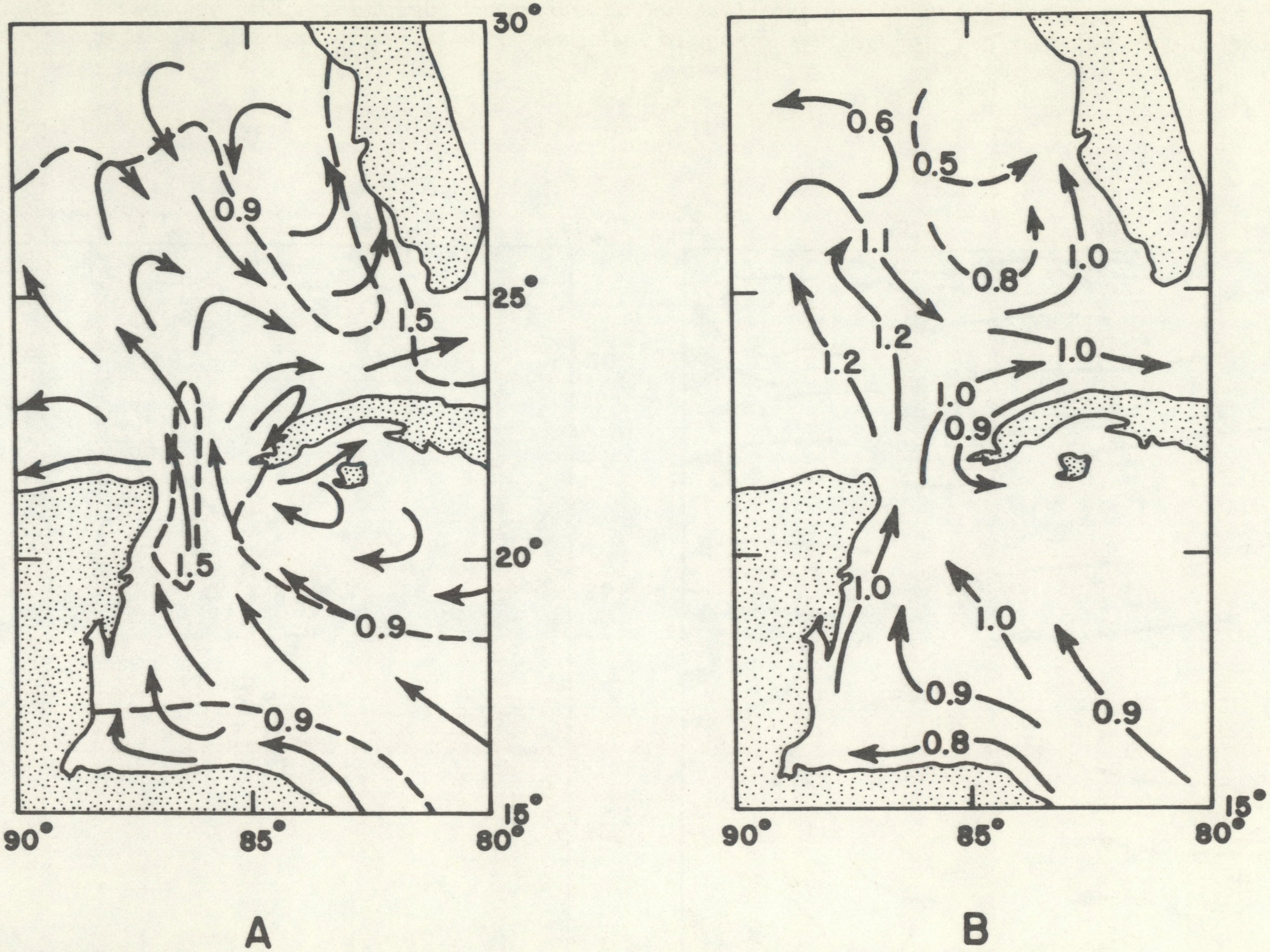

Figure 9. Preliminary drogue tracks of the five buoys deployed in September 1972, A, and the mean surface currents as given by the October Pilot Chart, B.

Since little is known about long-term cycles in the ocean, it is advised that all pertinent data be considered, not just those taken during the month of the launch. The importance of this procedure will be illustrated later.

If little or no data exist in the drift region, it will be necessary to use atlases to predict the probable DLCB drift. Supplementary information can be obtained from the FNWC temperature forecasts. As mentioned, the 200-nautical mile grid spacing of the FNWC program can define only large scale phenomena such as the Gulf Stream of Kuroshio. However, the program does use the latest ship injection and bathythermograph reports to arrive at these features. A more accurate updated representation of the current field could result from a comparison of the two circulation patterns. Over a period of years, records of drift buoy movements can be expected to improve upon the present state of knowledge of the current systems.

3.2.2 Launch Stage

The late August 1971, AOML drifter studies in the Gulf of Mexico included an XBT survey just prior to the launch of the buoys. An early October 1970 cruise and Publ. No. 700 depict a well defined Loop Current, extending deep into the Gulf of Mexico (figs. 8 and 10). Based on these data, it was decided to plant the drogues at the northern boundary of the Loop, at approximately 26°40'N and 87°30'W.

However, midway through the survey it was obvious that the historical and snapshot picture did not exist at that time, but rather that an eddy had detached from the flow and the axis of the Yucatan Current remained at 24°N (fig. 7). This circulation pattern had been observed before (Nowlin, 1972) but at earlier times of the year. A search plan based on either the previous or atlas data would have had little success in recovering a non-functioning buoy. Therefore, it is recommended that a pre-launch survey be conducted to determine the flow pattern in the drift area.

It is recommended that buoys be launched in pairs during the test program. This procedure will be of scientific as well as practical value. Practically, two buoys insure the representativeness of the measurements. For instance, the rapid separation of two drogued buoys probably indicates a parachute failure. Drogue studies (Molinari and Starr, 1972) suggest that in many current regimes the rate of separation of neighboring buoys is not great. In case of buoy failure, the trackline of the other drifter would be a valuable tool

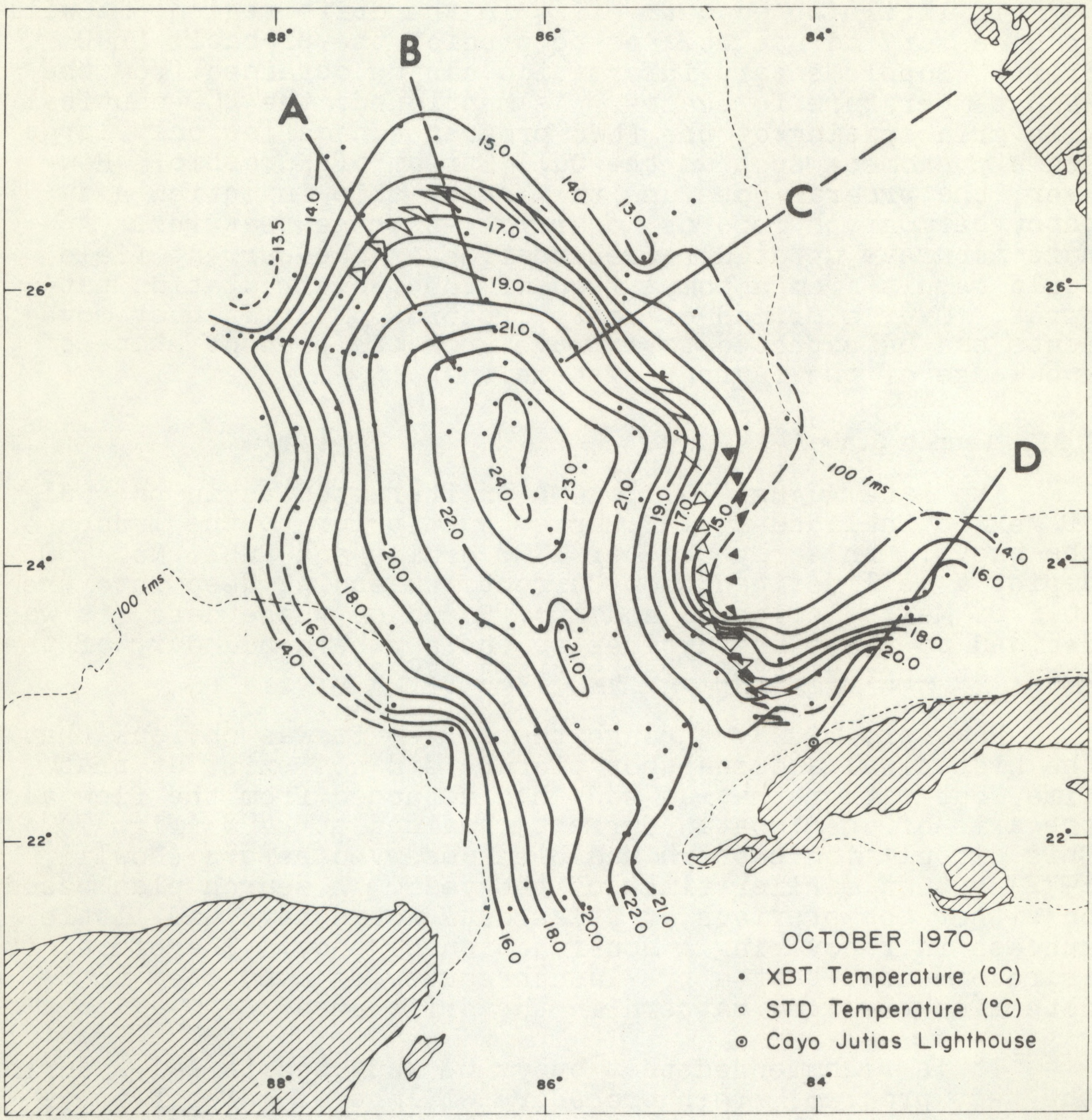

Figure 10. Approximate drogue tracks, given by the triangle apexes and the temperature field at 200 m for the AOML October 1970 Gulf of Mexico drifter experiment.

in the recovery operation. The rate of separation of properly functioning buoys will produce data on diffusive processes in the ocean.

3.2.3 Drift Stage

An attempt to correlate the DLCB drift with the available data should be made. If the correlation is good, the prediction and recovery operations are simplified. If the the correlation is not good, an attempt to explain the discrepancy should be made in order to predict future drift.

The drift data should be input both the the FNWC and to the Coast Guard SAR computer programs. If either or both of these programs are successful in predicting the future drift of the DLCB, the models can be used in case of a buoy transmission failure.

3.2.4 Failure Stage

It is recommended that arrangements be made with the responsible Coast Guard District to consider the transmission failure of a DLCB as a SAR incident. In particular, the immediate deployment of a Coast Guard aircraft would increase the probability of locating the drifter. If a plane is dispatched within a day or two, under most oceanic conditions, a simple extrapolation of the buoy path would suffice to locate the DLCB.

However, if more than three days are required to initiate a search, and a plane cannot be used, other methods to drift determination must be considered. The longer time period would require a study of all the variables considered by the FNWC and Coast Guard. The procedures applied by these agencies during a SAR incident, as well as possible modifications, are considered next.

As described in the pre-launch procedures, the ideal data source for surface current determination is a simultaneously conducted experiment. The resulting data would eliminate any guesswork in determining both the wind-induced and permanent current components. As long as the buoys remained in the experiment area, which can be ascertained by current velocity computations, the time required to launch a recovery mission is not critical.

If the buoys leave the study region, or if no experiment exists, the data compiled during the pre-launch, launch, and drift state must be reviewed to predict the probable trackline.

If correlation is good between the observed drift and the compiled data, an extrapolation based on the compilation would suffice to locate the DLCB. If the correlation is bad, factors that can cause differences must be considered.

For instance, changes in the surface current forcing functions would produce different flow patterns. Large-scale wind shifts can alter the circulation. The exact form of the alteration cannot be predicted with the present knowledge of ocean dynamics. In such cases predictions of the drift would be based on a subjective choice of a theoretical or observational study.

Both the Coast Guard and FNWC deduce the wind-induced current from empirically derived relationships. The Coast Guard method considers wind duration, fetch, and wind velocity, while the FNWC program considers only the wind velocity for the prior 36-hour period. Figure 11 from James (1966) shows the results of some wind drift current formulas indicating the range of results possible. Again, the choice of a relationship is dependent on the biases of the user.

If a drogue is not used, and the sail characteristics of the buoy have not been defined, the leeway effect also has to be determined subjectively. The Coast Guard solution to the problem appears satisfactory.

Many of the choices just mentioned would not have to be made if two buoys were deployed together. If the rate of separation of the buoys were determined during the drift stage, and if no dramatic changes occurred in the drift of the functioning buoy, an extrapolation assuming a constant separation rate could determine the DLCB position. If a significant change occurred in the functioning buoy's drift, the rate of separation probably also changed (Molinari and Starr, 1972).

It most probably is not feasible to use the buoys in pairs operationally. An operational counterpart of the pairing procedure is to infer movement of nonresponding buoys from that of adjacent buoys in an array. Successful use of this idea, however, requires much greater knowledge of the horizontal coherence of ocean currents than is presently a-available outside major currents such as the Gulf Stream. The present EOLE buoy experiment will provide initial data of this sort, and investigators associated with MODE-I are developing new techniques for use of Lagrangian correlation data, but further drift experiments must be conducted in a variety of ocean environments to provide data needed for implementation of such techniques.

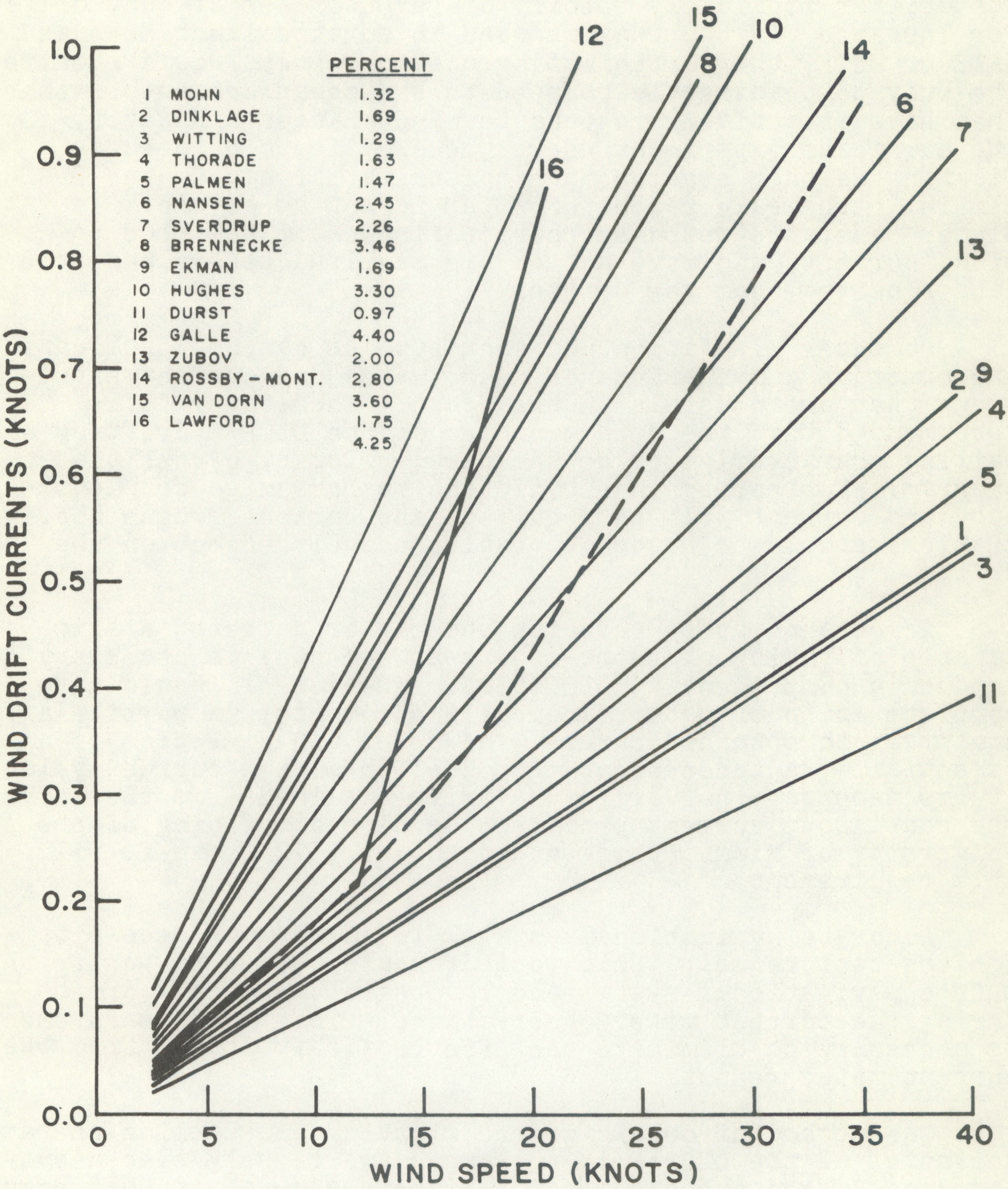

Figure 11. Results of several wind drift studies as presented by James (1966).

3.3 Recommendations for the DLCB Test Program

The five DLCB scenarios describing the possible uses of the drifter implicitly specify different modes of buoy drift. For instance, if the buoy is used in an experiment such as GATE or MODE, the participating oceanographers would require the buoy to be directly coupled to the ocean current, rather than have it actively respond to wind changes. However, in the hurricane experiment where the buoy is to be used as a floating weather station, the constraint of having the DLCB remain in the same parcel of water is not as severe. In either case, the response characteristics of the DLCB to wind, current, and wave action are required to evaluate the data received from the drifter.

Computer simulation and tank studies can not duplicate the numerous combinations of wind, wave, and current situations that are possible in the ocean. Therefore, it is recommended that the determination of the DLCB's drifting and sailing characteristics be the first priority of the test program. Furthermore, an efficient mechanism to couple the buoy and current will be required, and various drogue configurations should be tested to evaluate their effect on the drift.

An oceanographic research vessel, or at least a ship capable of taking over-the-side measurements, is necessary to conduct a comprehensive DLCB test. The vessel should have a complete suite of meteorological instruments; in particular, equipment to obtain accurate wind speed and direction is essential. An independent method of obtaining current velocity is necessary to verify the drift obtained from the buoys. The continuous current profiler, developed by Duing of the University of Miami (Duing and Johnson, 1972), can fulfill this requirement.

Accurate navigational control is an obvious necessity for the test vessel. Ship positions are needed to verify the DLCB's navigational system and to obtain the ship's drift during the current meter observations. This last measurement is necessary to eliminate the effect of ship motion from the current meter results.

One method of obtaining the floating and sailing characteristics of the DLCB's is to launch two closely spaced buoys, one drogued and the other not. Since the depth of the drogue will be determined by the requirements of the particular experiment being conducted, various drogue depths should be used during the test. Simultaneous direct current and wind measurements should be taken regularly along the buoy's tracklines.

The rate of separation of the drogued and non-drogued buoys is a function of the buoy's response to the wind. The greater the sail area, the more rapidly will the DLCB's separate in a wind. The deviation from downwind drift, if any, should be determined at this time.

The response of the drogued buoy to the current can be ascertained by a direct current measurement at the nominal depth of the drogue. Duing (personal communication) has used the continuous current profiler while in the drift mode, and he reports that the current measurements are representative of the flow if the ship's drift is accurately known. The differences between the drogue and current meter velocities are an indication of how the DLCB's react to a current.

The DLCB's response curves to wind and current are probably non-linear necessitating a series of tests in different oceanic and atmospheric situations. The optimum logistical area would be one where various wind and current regimes exist in a small region. The drifter studies of Molinari and Starr (1972) suggest that the western Caribbean Sea and Gulf of Mexico is such a region.

Figure 7 summarizes the preliminary results of a July-August 1971 drifter study in the Caribbean Sea. The current speeds vary from 1.5 knots in the basin to over 3 knots at the Yucatan Strait, and the current directions range from due west to northeast. The current also accelerates dramatically near Cozumel Island.

Testing the drifters in this area would subject them to both constant and accelerating currents, without extensive deploying redeploying of the DLCB's. For instance, the drogued buoy could be left in the water while only the non-drogued buoy was moved. This region has the logistical advantage of currents flowing towards the staging area in Mississippi.

The Gulf of Mexico also contains many dissimilar current regions. These range from the intense but usually slowly varying Loop Current in the Eastern Gulf to the weaker currents in the Western Gulf. If the test is conducted in the winter, the Gulf has the advantage of having a more variable wind pattern than the Caribbean Sea. The occurrences of "northers" and other weather systems cause frequent shifts in the wind pattern over the Gulf of Mexico. This wind variability will permit a more comprehensive study of the sail characteristics of the DLCB's.

The drift prediction procedures outlined previously should be tested during this time to verify their usefulness. A pre-launch survey is essential during the test to assure the most efficient deployment of the DLCB's in the short time available. The validity of the Coast Guard and FNWC drift predictions should be ascertained during the test.

Finally, because the importance of ancillary data on the currents in the vicinity of the buoy test has appeared throughout our investigation of the problem, and present knowledge and predictability of instantaneous currents in most parts of the ocean are still very weak, it is advisable to associate the buoy tests with other ocean observation projects to the greatest extent possible. This will maximize the amount of current data available to those who may have to make estimates of buoy movement.

4. ACKNOWLEDGMENTS

The authors would like to express their appreciation to Lt. Cdr. A. Shirvinski (USCG), Director, Operations Analysis Branch, Atlantic Area Coast Guard, and Lt. P. Hill (USCG), Seventh Coast Guard District, for their time. The Coast Guard's SARP computer program and the Seventh District search and rescue procedures were described to the authors by these officers. This work was funded through the National Data Buoy Center's Statement of Work 0134EC.

5. REFERENCES

Atlas of Pilot Charts, Central American Waters and South Atlantic Ocean, United States Naval Oceanographic Office (1955), HO Publ. No. 576, Supt. of Documents, Washington, D. C. 20402.

Defant, A. (1961), Physical Oceanography, Vol. I, Pergamon Press, 729 pp.

Duing, W. and D. Johnson (1972), High resolution current profiling in the Straits of Florida, *Deep-Sea Res.* 19: 259-274.

Hansen, D. V. (1970), Correlation of movements in the Western North Atlantic, *Deep-Sea Res.* 17: 495-511.

Hubert, W. E. K. G. Hinman, and B. R. Minderhall (1970), The NFWC search and rescue planning program (NSAR), Tech. Note 60: 217 pp., Fleet Numerical Weather Central, Monterey, California.

James, R. W. (1966), Ocean thermal structure forecasting, SP-105: 217 pp., U. S. Naval Oceanographic Office, Washington, D. C.

Larson, S. and F. Laevastu (1971), Numerical analysis of ocean surface currents, Tech. Note No. 71-1: 21 pp., Fleet Numerical Weather Central, Monterey, California.

Leipper, D. F. (1970), A sequence of current patterns in the Gulf of Mexico, *J. Geophys. Res.* 75: 637-657.

Molinari, R. L. and R. B. Starr (1972), Lagrangian current and hydrographic measurements in the Western Caribbean Sea, abstract in: *Trans. Am. Geophys. Union* 53: 392.

National Search and Rescue Plan, United States Coast Guard, CG-308, Supt. of Documents, Washington, D. C. 20402.

Oceanographic Atlas of the North Atlantic Ocean, United States Naval Oceanographic Office (1965), Section I, Tides and Currents, Publ. No. 700, Supt. of Documents, Washington, D. C. 20402.

Quinlan, F. T. and L. R. Hoxit (1968), A technique for determination of a climatology of high altitude balloon trajectories, Tech. Memo EDSTM 6: 18 pp., Environmental Data Service, Silver Spring, Maryland.

Rachelett, J. and M. Armendariz (1967), Surface wind sampling for unguided rocket impact prediction, *J. Appl. Meteorol.* 6: 516-518.

Young, M. J. (1962), Comparison of methods for determining probable impact areas in planning short range instrumented balloon flights, *J. Appl. Meteorol.* 1: 531-536.

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