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Photogrammetric Circulatory Surveys (PHOCIS)*

Photogrammetric methods combined with conventional current-meter survey techniques provide a highly detailed instantaneous circulatory survey of surface and subsurface currents over a large area.

INTRODUCTION

THE NATIONAL OCEAN SURVEY has been making current surveys since 1844 as part of its service to maritime commerce. Tidal Current Tables are published annually to predict the times of slack water, and the times and velocities of the maximum flood and ebb currents in many locations in the coastal waters. Current charts are issued for the principal harbors and bays, showing the tidal current direction and speed for each hour of the tidal cycle.

ABSTRACT: *Conventional methods for measuring current velocities generally employ current meters suspended from buoys moored at specific locations within the area of interest. Observations of this type are expensive and difficult to obtain, and therefore only a skeletal network of observations usually is made. For this reason, the National Ocean Survey (NOS) has, in selected areas, been combining photogrammetric methods with the conventional current-meter survey techniques to obtain a more highly detailed circulatory survey than would be feasible otherwise. The principal feature and advantage of the* PHOtogrammetric CIrculatory *Survey (PHOCIS) is that it can provide an instantaneous synoptic measurement of surface and subsurface currents over a large area. Efforts are being made to improve the accuracy of the photogrammetric method and to provide the capability for the acquisition of comprehensive offshore measurements.*

Conventional methods for measuring current velocities generally employ current meters suspended from buoys moored at specific locations within the area of study. These observations are expensive and difficult to obtain, and therefore only a skeletal network of observations is usually made. For this reason, the Bureau has, in selected areas, been combining photogrammetric methods with the conventional current-meter survey techniques during the last decade in order to obtain a more highly detailed circulatory survey than would be feasible otherwise. The principal feature and advantage of the PHOtogrammetric CIrculatory Survey (PHOCIS) is that it can provide an instantaneous synoptic measurement of surface and subsurface currents over a large area.

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CURRENTS DEFINED

The tidal current is the horizontal movement of the water and is a part of the same general movement of the sea that is manifested by a vertical rise and fall of the water level known as the tide. Like the tides, tidal currents are periodic and arise from astronomical causes.

Tidal currents are of the reversing type in rivers and harbors where the direction of flow is more or less restricted to certain channels. The water flows alternately in opposing directions, with a period of slack water at each reversal of direction. These cycles of current occur once each day (diurnally) or twice each day (semidiurnally), depending on their location. Reversing tidal currents may be considered as beginning with slack water before flood. The current movement upstream increases in velocity until a maximum flood current velocity is reached. It then decreases until the slack water before ebb. The current flow downstream now begins, increases to a maximum ebb velocity, and then decreases to the next slack which is the slack water before flood. A complete cycle takes about 12½ hours on the Atlantic coast of North America and is an example of the semidiurnal type of reversing current. See Figure 1.

Principles of Photogrammetric Measurement of Currents

In order to apply photogrammetry to circulatory surveys, it is necessary to achieve absolute orientation of stereoscopic models on stereoplotting instruments, as in normal mapping practice, and to have the water surface marked to permit the identification of specific surface points stereoscopically. The number of natural foam markings tends to be proportional to the magnitude of the current speed. Because we are also interested in measuring current velocities of less than 0.5 knots, we cannot depend on the availability of natural foam targets. It is necessary, therefore, to seed the area with suitable floating targets and to record their movement on aerial photography taken throughout the tidal cycle.

Aerial photography for a complete tidal cycle usually cannot be taken on a single day. The area is therefore reseeded with targets, and portions of the tidal cycle are photographed on each of several days until the entire cycle is accounted for.

Office Measurement and Reduction of Data

Stereoscopic pairs of photographs are mounted in the projectors of a stereoscopic plotter. After relative orientation is achieved, the stereomodels are usually scaled and leveled to shoreline on available large-scale nautical charts. The stereoplotter operator sets the floating mark at sea level and then determines the positions of the target as given by the first and second photograph. The more sophisticated instruments possess dials that permit the coordinates of the two target locations to be read directly. The computed distance between the positions represents the target movement in the time interval between exposures, which is determined by reading the camera clock recorded on each picture. This data and the

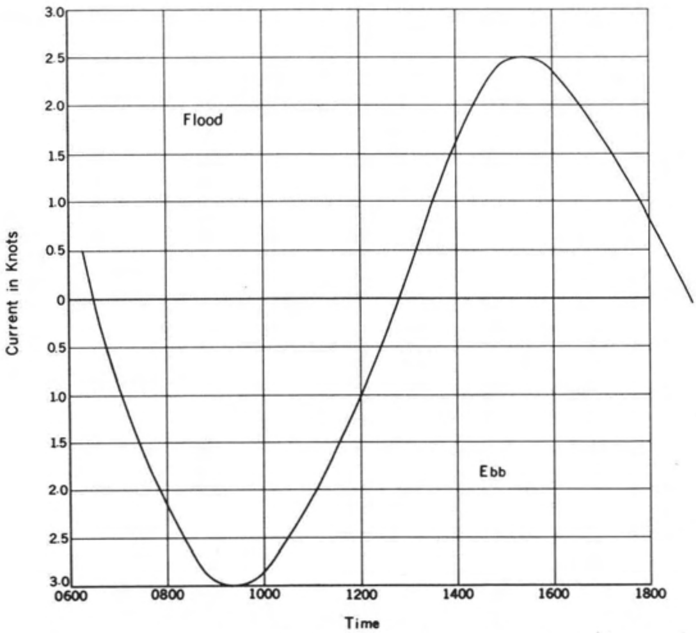

Fig. 1. Current cycle at Charleston Harbor, S.C., reference station on April 2, 1962.

scale of the stereomodel allow the velocity of the target, and therefore the current, to be computed. The less sophisticated plotters do not provide the X and Y coordinates of objects appearing in the model; it is necessary therefore to mark the positions of the target on a map manuscript, as indicated by the earlier and later photographs. The target movement between the photographic exposures is obtained by scaling between the two marked positions on the manuscript.The errors inherent in photogrammetric mensuration include stereoplotter deformation, model orientation, image displacement due primarily to irregular film shrinkage, operator pointing on the targets, and the determination of the time interval between the photographic exposures. These errors produce a cumulative error of about 0.1 knot in the determination of the current velocities.

ADJUSTMENT OF PHOTOGRAMMETRIC CURRENT MEASUREMENTS

Conventional meter stations at strategic locations in the area serve to control the photogrammetric tidal current survey. When the meter operation does not coincide with the photography, predicted current velocities obtained from meter operation at another time can be used as control. For a surface-current survey, the photogrammetric current measurements can be adjusted either to the upper meter alone or to the surface-current value, as extrapolated from a plot of the current speed at each of the suspended meters at the station. For a subsurface-current survey, the photogrammetric currents are adjusted to the current speed given by the meter that is located at the survey depth. The data provided by the long periods of meter observation thus are used to remove any deviations introduced into the instantaneous photogrammetric observations by meteorological or other disturbances.

After considering various geographical factors, the survey area is partitioned into zones containing one or more current-meter stations. A ratio is then computed for each zone by comparing the current velocity furnished by the meter station with the current velocity obtained by photogrammetric measurements on a target in the immediate vicinity of the station. The ratio is applied to all of the photogrammetric current velocities in the zone, thereby adjusting them to agree with the meter station data. The adjusted photogrammetric current velocities are represented on the map manuscript by arrows, with the current speed printed alongside them. In this manner, photogrammetric tidal current charts are constructed for each hour of the tidal current cycle. The photogrammetric data is then incorporated into tidal current charts published for the area.

Photogrammetric Current Surveys to Date

The Bureau's first use of aerial photography specifically for current surveys was the measurement of maximum tidal current at the hazardous entrance to Lituya Bay, Alaska, in 1959. The success of this project gave impetus to plans for making an aerial photogrammetric survey of a complete tidal cycle for an entire harbor area. This was first done in Charleston Harbor, South Carolina, in 1962 in conjunction with a conventional tidal current survey using current meters. See Figure 2.

Since then, PHOCIS operations have been conducted at Ocracoke Inlet, North Carolina; Tampa Bay, Florida; Delaware Bay; Long Island Sound, New York; and Boston Harbor, Massachusetts. A photogrammetric circulatory survey of Oregon Inlet, North Carolina, is now under discussion.

Planning the Phocis Field Operations

FLIGHT PLANNING

Photography normally is scheduled for the period of spring tides when the greater current velocities provide for a more reliable tidal current cycle. A tabulation is made of the hourly mean spring current values for each of the suspended meters at each of the stations in the survey area. Based on this tabulation, photography is scheduled at half-hour intervals over the project site.

It then is necessary to determine the areas of the photograph that will be useless for the identification of target images because of the sun's reflection on the water surface. This requires an hourly trace of the sun's image on the photograph for the calendar day scheduled for photography. Flight-line charts are then drawn so as to preclude the appearance of sun-spot in critical areas of the photograph. See Figure 3. An 80 per cent overlap is used to combat the problem of sun-spot by making it more probable that critical areas will be free of sun-spot on at least one of the pictures.

The present need for land detail to orient the stereoscopic models, together with the desirability of reducing the volume of photography, emphasizes the value of small-scale (high-altitude) photography. When the water area is too large to be spanned, large target floats must be anchored in strategic locations,

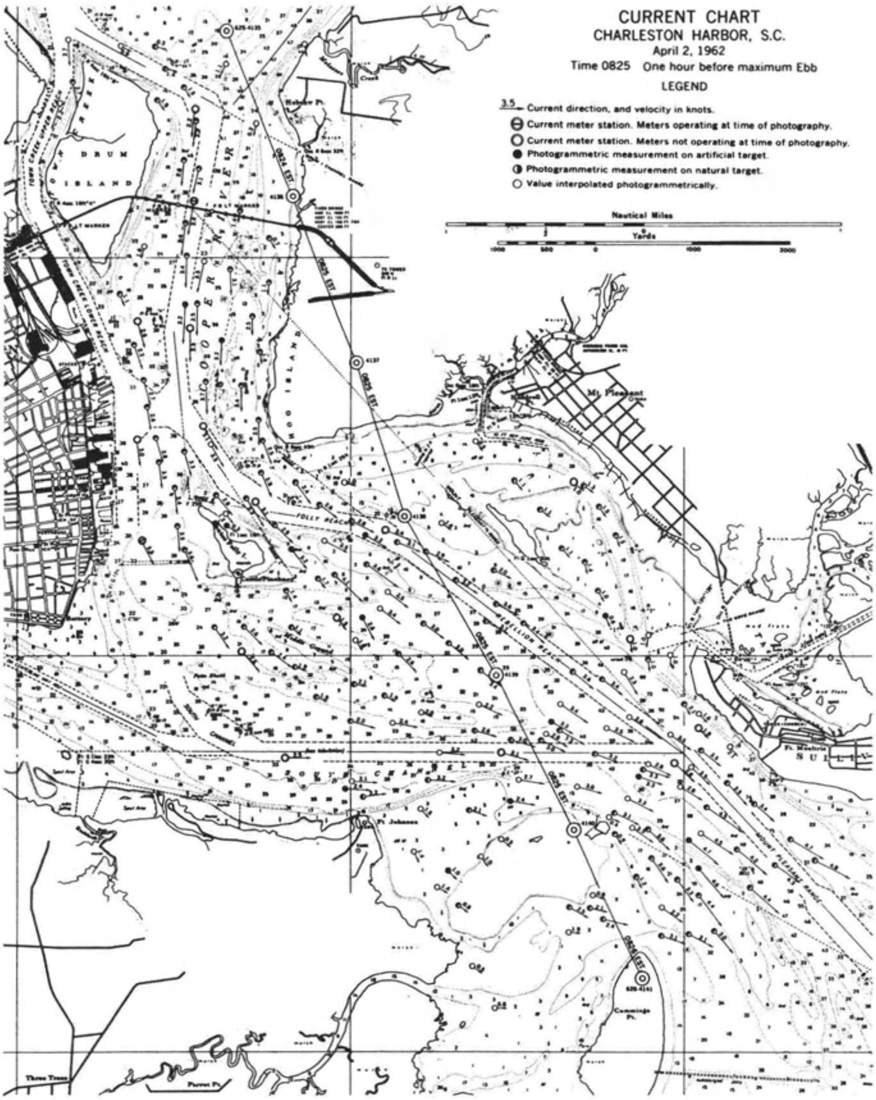

FIG. 2. Current chart for Charleston Harbor, S.C., at one hour before maximum ebb current on April 2, 1962.

prior to photography, to aid in the orientation of the stereo-models.

CAMERA AND FILM EMULSION

Small-scale photography is secured by using a super-wide-angle 3.5-inch focal length aerial camera to span large water bodies. Black-and-white infrared emulsion has the advantage of increased atmospheric haze penetration, reduced sun-spot size, and it yields sharply defined target images and shoreline. However, the black tone of the water surface hinders the identification of any natural markings on the surface. Natural-color emulsion aids in model orientation on the plotters because it can penetrate and record bottom details in shallow waters. The emulsion also permits the color coding of different types of painted targets that may be used in the current survey. However, color emulsion does not record natural surface markings well and gives a larger sun-spot because nearly all of the reflected visible light rays from the water surface are recorded on the emulsion. Black-and-white panchromatic film emulsion is often a satisfactory choice because it yields good overall results in recording both target and water surface details

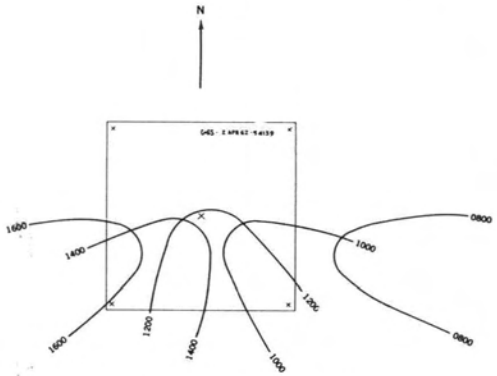

FIG. 3. Sun-spot study for Charleston Harbor showing the trace of the reflected image of the sun on the water surface, as recorded by photographs taken throughout the day during the photogrammetric survey.

on the same emulsion. In addition, the sun-spot-image is intermediate in size between that of infrared and color emulsions.

Recent studies in our office indicate that the best choice of all may be false-color infrared emulsion. False-color infrared provides nearly all of the benefits of the other emulsions with the exception of water penetration, which is limited to about 25 feet. Surface markings show up exceptionally well, the sun-spot image is somewhat reduced in size, and the separable colors that are recorded by the emulsion permit the color coding of surface-marker targets.

TARGET DESIGN AND SEEDING

Drift-type target devices can be classified as surface, transsurface, and subsurface floats. The surface class consists of those which remain essentially at the surface, such as wooden targets, foam, confetti, oil slick, etc. The transsurface group comprises devices that measure the current in the top layers of the water body, such as current poles. The subsurface class includes truly submerged floats, such as a drogue attached to a surface-marker target.

Targets must be designed to present a minimum hazard to health, the environment, and navigation; they must be relatively inexpensive because they may not be recovered; seeding of the targets must be simple; and the target movement must be readily recordable on aerial photography.

SURFACE CURRENT TARGETS

In 1964, after extensive study, aluminum powder was found to give the most effective targets for photogrammetric surface-current surveys. This material, which is commonly used in paints, has a two to four-hour life span in water and its reflective characteristics of silver paint on the water surface make it easily distinguishable on aerial photography. The aluminum powder is not toxic in the form and concentrations we use and, according to results of known research, will not break down into other compounds which constitute a danger to the environment or to an ecosystem. It does not adhere to the hull of a boat and is harmless if passed through an engine intake. The powder breaks up after several hours and is generally completely dispersed in a few days. Thus it is not deposited on the shore in any large amount and certainly is not very distinguishable from the usual shore debris. Any soiled places resulting from contact with aluminum oxide, which forms when the powder is rubbed between two surfaces, are easily removed with common detergents so that no stains remain.

Seeding of the aluminum powder targets is efficient and economical. The powder is packaged in polyvinyl alcohol bags which are water soluble. The bags are dropped into the area from a small aircraft at an altitude of less than a thousand feet. The bags either rupture on contact with the water or dissolve in 15 seconds. A 50-foot-diameter target is produced by using only eight ounces of aluminum powder.

TRANSSURFACE CURRENT TARGETS

Current measurements in the top layers of a water body may be made by using current poles so modified that their movement can be recorded photographically. Although we have not tested it yet, such a device might consist simply of a small target attached to a large-diameter pole, weighted at one end to float upright in the upper water layer. See Figure 4.

SUBSURFACE CURRENT TARGETS

These targets usually consist of a submerged drogue suspended by wire from a floating surface target. See Figure 5. The cross-sectional area of the surface target must be kept small, so that the surface current forces will have a negligible effect as compared to the effect of the subsurface current bearing on the drogue. The drogues used to date on photogrammetric current surveys have consisted primarily of several 5-gallon paint cans, with their tops and bottoms removed before being suspended from painted plywood surface-marker targets. A color coding of the surface-marker target is employed when necessary in order to denote the depth of the suspended drogue.

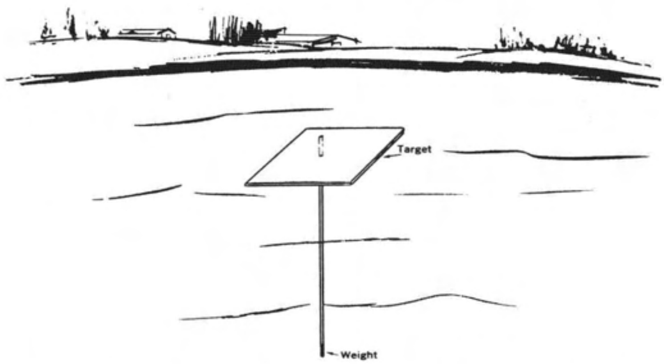

FIG. 4. Target design to furnish an integrated current value over a specified depth.

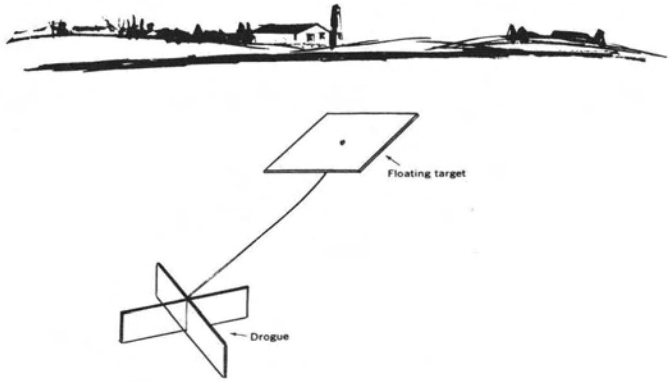

FIG. 5. Drogue type of target.

WEATHER

Difficulties caused by atmospheric haze and sun-spot can be minimized by use of the proper emulsion. By employing a shorter focal-length camera at a lower altitude, problems caused by a cloud cover at higher altitudes may be resolved.

Wind-induced water movement generates nontidal currents, which are not periodic as are tidal currents. Water movement due to strong steady winds and wind gusts often can be recognized by stereoscopic study of the photographs. To date, the stereoscopic effect has not been found on photography taken at wind speeds of less than 10 to 12 knots. Since it is not practicable to delay photography until absolutely no wind-induced water movement is present, photography is secured whenever the wind speeds are of less than 10 knots. For this reason, PHOCIS depends on the long-period observations at the current-meter stations to remove the effects of any wind-induced water movement.

RESEARCH AND DEVELOPMENT ACTIVITIES

Further Research and Development studies are necessary in the following areas:

1. Improved methods for mooring large target floats in strategic locations prior to photography over large water bodies are needed to aid in the orientation of stereoscopic models.
2. Improved target design and seeding methods are required, especially for trans-surface and subsurface current surveys.

It has been suggested that the instantaneous characteristic of photogrammetric current surveys impairs their value, and therefore the photogrammetric survey should be repeated so as to provide statistical strength. This has been done in one instance, and more study is advisable to corroborate this view. It has also been suggested that the photogrammetric survey should precede a conventional current-meter survey in order to improve the choice of location for the current-meter stations.

THERMAL INFRARED MAPPING SYSTEMS

The Coastal Mapping Division has been interested in the potential of airborne infrared radiation-sensing instruments for tracing current flow, identifying a water mass on a tidal wave and tracking its course through the estuary, obtaining water-surface temperature measurements, and for detecting water pollution due primarily to heat sources. The thermal IR data can then be transferred to film in order to provide pictorial thermal infrared imagery.

The Boston Harbor survey included the use of an airborne thermal infrared mapper to obtain a synoptic coverage of the surface water temperatures as a function of the tidal-current cycle from which isotherm charts could be constructed. While most of the IR return was of usable quality, some difficulty with the calibration of the electronic gear reduced the effectiveness of the data. Our experience with thermal infrared mappers has been somewhat frustrating because the complexity of the equipment requires sophisticated handling, calibration, and processing of the data to achieve precise results. It appears that we will continue to face this dilemma until NOS purchases its own complete IR mapper system and is able to effect precise quality controls on all phases of the operation as we now do in our photographic operations.

OFFSHORE CIRCULATORY SURVEYS

The present need for land detail and/or large target floats in strategic locations of the photography, in order to obtain relative and absolute orientation of stereoscopic models, has served to limit photogrammetric current surveys to relatively shallow coastal waters. A photogrammetric system for the acquisition of comprehensive offshore circulatory measurements would require two aircraft equipped to take synchronized photography and an accurate aircraft positioning system.

Simultaneous exposures from two cameras at opposite ends of an aerial base line in effect "freezes" the water surface so that relative orientation of a stereoscopic model can be made by using the images of whitecaps and foam patterns on the sea surface. These naturally occurring images can be augmented by seeding aluminum powder targets in order to provide additional surface images. Absolute orientation can be achieved by scaling and positioning the models to the plotted known aircraft (camera) positions, followed by a leveling to the sea surface datum. The positions of the aluminum powder surface targets, and any other transsurface or subsurface targets seeded in the area and appearing in the models, can then be plotted on the map manuscript.

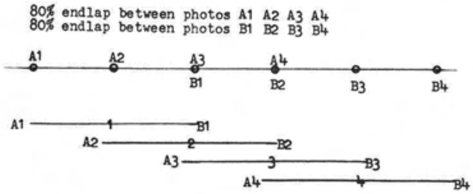

FIG. 6. Time-synchronized photography providing successive independent overlapping stereoscopic models.

Figure 6 shows synchronized photography taken by aircrafts A and B. The first stereoscopic model consists of photographs A1 and B1. The two aircraft then advance and produce the second stereoscopic model consisting of photos A2 and B2. In this manner a strip of successive independent stereoscopic models which overlap each other at 60 per cent can be formed. The change in the positions of the seeded targets during the time interval between successive stereoscopic models can be scaled off the map manuscript to furnish current-velocity values. A preliminary study of the errors inherent in the method indicates a cumulative error of about 0.25 knot in the determination of the offshore current speeds.

The feasibility of securing synchronized photography from dual aircraft was successfully demonstrated by the Naval Oceanographic Office in the 1950's and 1960's. Still needed however, is an aircraft positioning system accurate to about ± 3 meters for aircraft flying some 50 miles offshore.

Successful development of an offshore PHOCIS capability, and the "freezing" of the sea and surf along the coastline, would provide additional benefits to such projects as: chart maintenance; coastal zone wetlands and boundary mapping; photogrammetric bathymetry; terrestrial and marine control densification; and water pollution surveys.

CONCLUSION

On the basis of results obtained, the application of photogrammetry to the field of circulatory surveys is well warranted, especially where detailed information is desired. Consideration of the manpower and equipment requirements, the time and costs of the operations, and the final product that can be produced by exploiting the photogrammetric capability serve to point out the important role that photogrammetry can play in understanding and safeguarding the coastal water ecosystem of the nation.