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Measurement of Lake Currents

Standard photogrammetric procedures were employed to measure lake currents with an accuracy of 2 cm sec^{-1} in speed and 3 degrees in direction.

ABSTRACT: *Measurements of the surface velocity structure off the Keweenaw Peninsula of Lake Superior were obtained using aerial photography to track surface drift cards. Automatic data reduction techniques, employing standard photogrammetric procedures, were developed to process nearly 10,000 velocities. To facilitate data interpretation, interpolation through objective analysis was used to convert from Lagrangian to Eulerian information. Comparisons with direct observations indicate that dense, accurate, synoptic current information can be obtained across an entire Great Lakes coastal region, removed from ground orientation, at intervals of several minutes and to accuracies within 2 cm sec^{-1} in speed and 3 degrees in direction.*

INTRODUCTION

AERIAL PHOTOGRAPHY, with its capability of collecting large amounts of nearly synoptic data, has been used to determine surface currents in nearshore regions by Nakano (1957), Forrester (1960), Keller (1963), Duxbury (1967), Yoshida (1970), Huh (1971), and Wolf and Keating (1973). This method has not seen extended use, however, due most likely to the major problems associated with data reduction and to the fact that the reduced data are relatively difficult to interpret.

In offshore regions, where no land appears in the imagery, the application of aerial photography in current studies is more complicated and thus even more limited. The method employs shipboard navigation techniques in achieving absolute orientation for floating markers. Previous investigations include those of Konovalova and Lagutin (1968), Ramey (1968), and Terrell and Green (1971).

Since 1971 the University of Wisconsin Marine Studies Center has been applying aerial photography in an offshore experiment to examine the fine-scale structure of the Keweenaw Current in Lake Superior (Figure 1). Efficient data reduction techniques have been developed to process the large amounts of photographic data. In addition, to facilitate data interpretation, objective analysis methods have been adopted to convert the Lagrangian information (i.e., velocity vectors of fixed fluid elements) supplied by the photographic method to Eulerian information (velocity vectors at fixed spatial points), which is much more useful to hydrodynamicists. The current data have been analyzed with special interest in time fluctuations, lateral shifts, multiple currents, countercurrents, eddies, horizontal divergences, relative vorticities, eddy viscosities, and surface

FIG. 1. Lake Superior and the Keweenaw Current.

kinetic energy transfers (Yeske, 1973; Yeske and Green, 1974). The work described below is intended to show the methods used in data collection and reduction. The reader is referred to Yeske (1973) for more detail.

DATA COLLECTION

An area 2 km wide and extending 10 km north of Eagle Harbor, Michigan (Figure 2) was selected for study because of the proximity of the current to shore. (The current is rarely more than 20 km from shore in this area.) A network of eleven moored buoys was established within the study area to provide photo control. This was necessary since most of the area to be photographed was too far from shore to include shoreline control in the photographs. Buoy locations are shown in Figure 2; their configuration is given in Figure 3. Masts with red or yellow flags were installed on each buoy to permit visual observations from two shore-based theodolite stations. The buoys were numbered and designated as shown in Figure 3, e.g., red number one (R1), red number two (R2), yellow number one (Y1), etc. To minimize buoy drift motion, lengths of mooring lines were

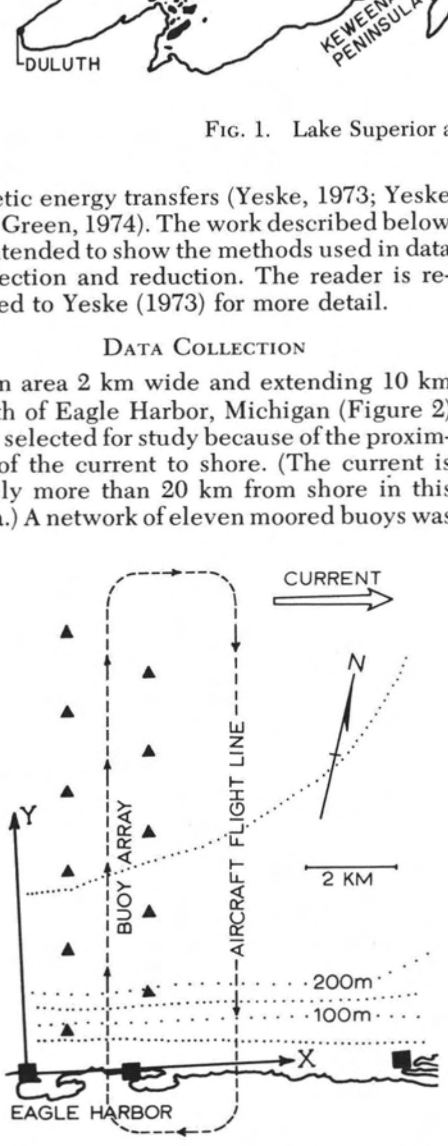

FIG. 2. The study area, showing the location of Buoys (▲) and theodolites■ in 1972. Photographic flight line, bottom contours and the coordinate system are also shown.

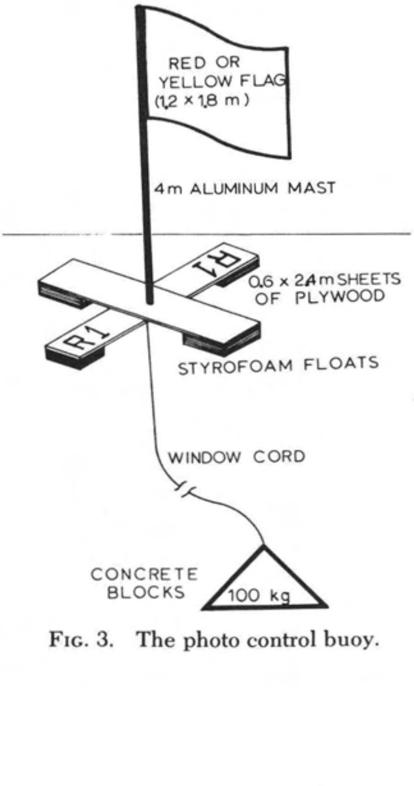

FIG. 3. The photo control buoy.

only about 60 m greater than lake depth (up to 250 m).

The shoreline theodolite stations were about 8.6 km apart. Their horizontal positions and elevations were determined from control surveys tied into U. S. Coast and Geodetic Survey and Lake Survey Center basic horizontal and vertical control monuments near Eagle Harbor, Michigan. A Tellurometer Microdistancer Model MRA-2 and a precision Wild T-3 theodolite were used for the surveys. Additional ground control points were also established, and their positions made photo-identifiable by paneling with white posterboards.

The basic procedure to determine surface currents consisted of distributing 0.7 m by 1.1 m white posterboard floats, from one or two boats, at intervals from 10 to 100 m along a line about 1 km upstream from the buoys (Figure 2). After this distribution had started, repeated time-lapse aerial-photograph flights were made using a calibrated aerial mapping camera (Fairchild F-56). The flight lines were centered over the buoy network and exposures were made while flying in the outbound direction only. The flight height was 3000 m above the lake. From 10 to 25 photographs were taken on each flight line, depending upon the current width, with 60 per cent to 80 per cent overlap. The time interval between successive passes varied from 7 to 12 minutes; experiment durations ranged from one to three hours. Over 1500 floats were used in most experiments. Clock times were synchronized between aircraft, boats, and theodolites before and after each experiment.

Throughout the experiment, buoy positions were monitored continuously by triangulation using two Askania one-second shore-based theodolites. The angle of intersection at the buoys ranged from a minimum of 44 degrees (Buoy R6) to a maximum of 131 degrees (Buoy Y1). For strongest intersection and smallest buoy positioning errors, a 60-to-120 degree angle should be formed at the photo control point.

DATA REDUCTION

To process the large volume of data, a computerized data reduction program called *AERIAL* (Automatic Extrapolation Reduction and Iterative Analysis for Lakes) was developed. This procedure, a combination of photogrammetric techniques, has not to our knowledge been previously applied to any study of water currents.

Initially, all ground reference points, drift cards, and control buoys in photographs taken during a pass are manually identified and labeled. Photo coordinates of each point are then measured using a CEC Corporation DIGI-GRID digitizer interfaced with a card punch. The measurement accuracy of this instrument is 25 micrometers, corresponding to 0.3 m on the lake surface.

The analytical photogrammetric solution for ground coordinates of objects located at varying elevations is correctly based on the *collinearity condition*. This condition states that the exposure station (camera location), the ground object, and its corresponding photographic image point lie on a common straight line. However, for a nearly flat object surface, such as the lake surface in this experiment, and for near vertical photography, three-dimensional conformal coordinate transformation equations can be used to obtain accurate ground coordinates from images on aerial photos. A comprehensive discussion of this technique is given by Wolf (1974).

In the procedure used, the first photograph of a pass chosen for analysis is that which contains all of the ground-surveyed control points and also has the most drift cards visible. The measured photo coordinates of both control points and drift cards are transformed into the basic ground control system, using the three-dimensional conformal coordinate transformation equations. To "best fit" these sets of ground control point coordinates, a least squares approach is used, which minimizes the sum of the squares of the measurement residuals. Thus, ground coordinates are provided for all drift cards appearing on this photograph.

The second photograph of a pass is considered next. Ground control points do not usually appear on this photograph. However, due to the large overlap, 60 to 80 per cent of the cards whose images appear on this photograph already have ground coordinates determined from the solution with the first photo. These can now be treated as "pseudo-ground control" points for another three-dimensional transformation and least squares fit. Having determined the transformation parameters from the pseudo control, uncommon cards in the second photograph are transformed into the ground control system. In this transformation, the scale is held to that of the first photograph. This general procedure alleviates the necessity of having two photo control buoys in each photograph as required in previous studies. In fact, this procedure requires only two offshore control points across the entire coastal region. Although more control is certainly advisable, this is one of the major advantages of our technique.

This method of transforming the new drift cards of a photograph into a coordinate system based upon the coordinates of its drift cards that were transformed in a previous photo is applied to all photographs of the pass. Thus, each photograph transformation extends ground control 500 to 1000 m further offshore. However, these drift cards have been transformed into a ground reference system that is only approximately correct. Because of the successive attachment of each photograph to the preceding one, an accumulation of systematic errors due to drift card motion between exposures, scale variations arising from camera tilt, and inaccuracies in the measurement of photo coordinates occurs (Harris *et al.*, 1962; Moffitt, 1967). The adjustment of these large nonlinear errors is discussed later.

In these transformations, drift card motion between exposures is partially compensated for by the least squares fit in connecting photographs. Because the photo control buoys are essentially stationary and would inhibit this correction, they are not included in these initial transformations.

Drift card identification errors, measurement errors, and tilted photographs are apparent in the printout of residuals of the least squares fit. These residuals (calculated for each drift card being used as a pseudo-ground control point) provide a relative indication of how well each particular card fit in the least squares method. For properly identified and measured vertical photographs these residuals (horizontal and vertical) are usually less than 0.5 m. In cases where a drift card residual is much larger than others, an identification or measurement error has likely occurred. This card is removed from the data but, since it appears in sequential photographs, velocity information is not lost. On severely tilted photographs all of the drift card residuals are large and the entire photograph is eliminated.

From two successive aircraft pass transformations, velocities of common drift cards are determined using *AERIAL*. Then, each drift card velocity is used to compensate for its motion between exposures by correcting its original photo coordinates. No adjustment is required for drift cards appearing on the first photograph of a pass. In the second and all subsequent photographs, drift card photo coordinates are corrected backwards (in the reverse direction of their flow vectors) to the approximate position they would have occupied at the time of the first photograph. This is based upon the above determined velocity vector (scaled to the measured photo system) and the time interval between the first photograph of the pass and the photograph in which the drift card was first transformed. In this way a first-order approximation to the position of each drift card at the beginning of the pass is obtained. Coordinates of drift cards appearing in one pass but not the other (due to a new card line appearing or an old one disappearing) are corrected using the velocity of the drift card closest to it for which a value could be computed.

When all corrections have been made for velocity vectors, all of the corrected drift card photo coordinates are again transformed three-dimensionally into the ground-surveyed system. Because all drift card coordinates in the pass have been adjusted to the time of the first photograph they can be considered synoptic. Thus this second transformation also transforms the measured photo coordinates of each control buoy.

A polynomial strip-adjustment was then performed on the strip using a program adapted from Keller and Tewinkel (1964) as a subroutine in *AERIAL*. A rather comprehensive discussion of this technique has been provided by Harris *et al.* (1962). The polynomial procedure of strip adjustment is based on the assumption that position and elevation errors for the transformed drift card and control buoy coordinates accumulate as a function of their distance from shore. Because buoy positions have been monitored continuously (usually on each pass) and the lake water level enforces vertical control, differences between the transformed and actual ground coordinates for each buoy (on each pass) can be easily obtained. On the first photograph these differences are zero; on the last position errors of 200 m and elevation differences of 10 m frequently occur. Horizontal error curves as a function of distance offshore are usually parabolic (Moffitt, 1967).

The purpose of the strip-adjustment is to correct for these nonlinear solution errors by transforming the calculated, approximate ground coordinates of all photo control points into their actual ground coordinates determined from theodolite observations. Inherent in this technique is a simultaneous correction of all drift card ground coordinates. This adjustment can be linear or it may utilize second or third degree polynomials. The second degree polynomial usually produces the most consistent results.

Obtaining strip-adjusted ground coordinates is normally the last step in most photogrammetric control extension problems.

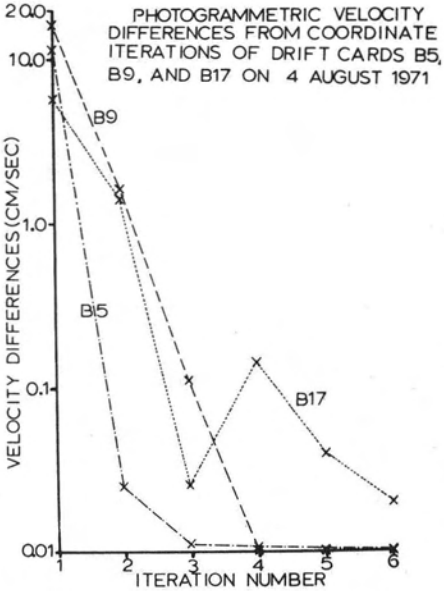

FIG. 4. Typical convergence rates for *AERIAL* computer program (Drift cards B5, B9 and B17 on 4 August 1971).

However, in this problem, the velocities used to correct the original photo coordinates are only approximately correct and cause errors in the strip-adjustment. As a result, the velocity of each drift card between passes is recalculated from the strip-adjusted positions of two successive passes. These new velocities are now used to readjust the original drift card photo coordinates which are again transformed and strip-adjusted to obtain another set of ground coordinates and velocities. This iterative procedure results in convergence of the successive sets of velocities. Rates of convergence between iterations for representative drift cards are depicted in Figure 4. For this study, all drift card velocities converged to within 0.5 cm/sec of the final values after three iterations. The results were then considered complete.

In its present form, *AERIAL* can process any number of consecutive passes with up to 600 drift cards in any one pass.

ERROR ANALYSIS

Inherent in this procedure of determining coastal currents is a complicated interaction of measurement errors caused by tilted photographs, flying height oscillations, varying image coordinates, inaccurate theodolite positioning, and camera misalignments. Inaccurate coordinate measurements, time differences, ground survey measurements, wind and wave-induced motions, and atmospheric refraction must also be considered. Camera tilts and flying height oscillations result in photo scale variations. Because the same drift card appears on at least three consecutive photographs, its location with respect to the photo center changes. This results in varying distortions caused by camera tilt.

Because of the limited photo control, flying height oscillations and camera tilts (the determination of which requires three vertical and two horizontal control points per photograph) cannot be ascertained. To obtain an upper error bound, the most adverse photogrammetric conditions considered realistic for this project were assumed: a 3 degree camera tilt, a flying height variation of ±30 m, and a coordinate measurement error of 0.6 m. With these assumptions the maximum errors can be determined from the equations for a tilted photograph (Moffitt, 1967).

Errors in control buoy positioning are also difficult to evaluate. During all photographic operations, each theodolite was periodically sighted on a known reference point. The *RMS* differences in these zero references, shown in Table 1, are probably representative of the errors in buoy positioning. These results indicate errors less than 17 arc seconds when the Askania one-second theodolites were used. The effect of these errors on buoy positions can easily be evaluated, using the principle of intersection.

TABLE 1. THEODOLITE ZERO REFERENCING ERRORS

	Number of zero references		*RMS* bearing differences (sec)	
Date	Control	Slave	Control	Slave
6 July 72	10	6	17	6
13 July 72	7	9	10	12
19 July 72	4	5	5	13
26 July 72	13	2	4	4
27 July 72 AM	13	2	6	0
27 July 72 PM	3	12	2	10
4 Aug 72	16	4	4	8
10 Aug 72	14	3	5	4

TABLE 2. MAXIMUM PHOTOGRAMMETRIC VELOCITY ERRORS IN A 50 CM/SEC CURRENT. (SPEEDS ARE IN CM/SEC AND DIRECTIONS IN DEGREES.)

Drift card distance from shore (km)	Image distance to center of photograph (mm)	1972 Error	
		Dir	Spd
3.7	25	0.5	0.5
3.7	50	1.1	1.1
3.7	75	2.2	2.0
3.7	100	3.7	3.3
7.4	25	0.5	0.7
7.4	50	1.1	1.2
7.4	75	2.2	2.1
7.4	100	3.7	3.3
11.1	25	0.6	1.0
11.1	50	1.1	1.3
11.1	75	2.3	2.2
11.1	100	3.8	3.4

The other errors mentioned above are considered negligible in relation to those discussed. Drift card motion between exposures has been compensated for by *AERIAL*. Times were synchronized between all stations before and after each experiment. Camera errors, as determined by the U.S. National Bureau of Standards just before the experimental program, were not significant. Since very calm weather prevailed for all analyzed data, wind and wave-induced motions are not a factor. Atmospheric refraction is small and can be neglected (Harris *et al.*, 1962).

Therefore, the maximum velocity errors can be estimated by superimposing theodolite errors on those derived from a tilted photograph. Rotating the photo coordinate axis 45 degrees from the axis of tilt (to examine direction as well as speed errors) yields the values listed in Table 2. Nearly all the photogrammetric operations were conducted within 7 km of shore. Under normal flight conditions, average camera tilts are usually less than one degree and maximum tilts rarely exceed three degrees (Moffitt, 1967). The three-dimensional transformation scheme and the polynomial strip adjustment reduce, through successive photograph averaging, the large single photograph error contribution from camera tilts and flying height variations. As a result, maximum errors less than those given in Table 2 were very likely achieved.

In instances where two control buoys appear in two time-lapsed photographs of the same geographic area, drift card velocities can be determined directly and compared to the *AERIAL* results. Since *AERIAL* compensates for drift card motion between exposures and the comparative observation times are no longer coincident, differences should be expected. The *RMS* speed and direction (azimuth from north) differences for 650 comparisons, presented in Table 3, are about 2 cm sec^{-1} and 3 degrees. The large direction error on July 13 can be attributed to the low velocities (less than 5 cm sec^{-1}) in the offshore region where the direct calculations were performed. Here a 1.5 cm sec^{-1} error, if applied in a cross-stream direction, can easily account for this difference. It should be noted that the *RMS* differences are lower (by up to 1.3 cm sec^{-1} in speed and at least 1 degree in direction) when three control buoys appear on a photograph, thereby permitting a direct three-dimensional transformation.

The same two-control-buoy technique was also used to examine the effects of two and three-dimensional transformation subroutines in *AERIAL*. In a two-dimensional transformation only the horizontal coordinates are scaled, rotated, and translated. *RMS* differences of 4.3 degrees and 2.0 cm sec^{-1}, between direct and *AERIAL* (two-dimensional) calculations, were obtained for 34 observations on 4 August 1971. Differences using three-dimensional *AERIAL* computations were 2.7 degrees and 1.7 cm sec^{-1}. Similar experiments with the strip adjustment indicated greater consistency with the second degree equation.

Although absolute photogrammetric measurement errors are difficult to evaluate, these results do provide a meaningful test for

TABLE 3. VELOCITY DIFFERENCES BETWEEN ITERATIVE PHOTOGRAMMETRIC AND DIRECT TWO-PHOTOGRAPH CALCULATIONS. (SPEEDS ARE IN CENTIMETERS PER SECOND AND DIRECTIONS IN DEGREES.)

Date	Number of comparisons	Two-photograph transformation	*RMS* differences	
			Spd	Dir
3 Aug 71	54	Two dimensional	2.9	2.6
4 Aug 71	272	Three dimensional	2.6	2.4
5 Aug 71	41	Three dimensional	1.8	1.6
13 July 72	163	Two dimensional	1.8	18.6
19 July 72	120	Two dimensional	2.2	3.6

gross errors in *AERIAL*. Comparisons of *AERIAL* velocities with those obtained from direct theodolite tracking of drogues are discussed later.

Objective Analysis

A second obstacle to the application of offshore photogrammetry is that Lagrangian data, such as obtained from *AERIAL*, are relatively difficult for fluid dynamicists to interpret. Objective analysis, a method of transforming data from irregularly spaced points into data at regularly arranged grids through interpolation, is frequently used in weather analysis (Panofsky, 1949; Cressman, 1959; Druyan, 1972; Leary and Thompson, 1973). The data are then in an Eulerian format, thus much more suitable for further processing.

To accomplish this transformation, the Lagrangian data set is scanned to determine the four drift cards nearest each predetermined grid point at which an interpolated

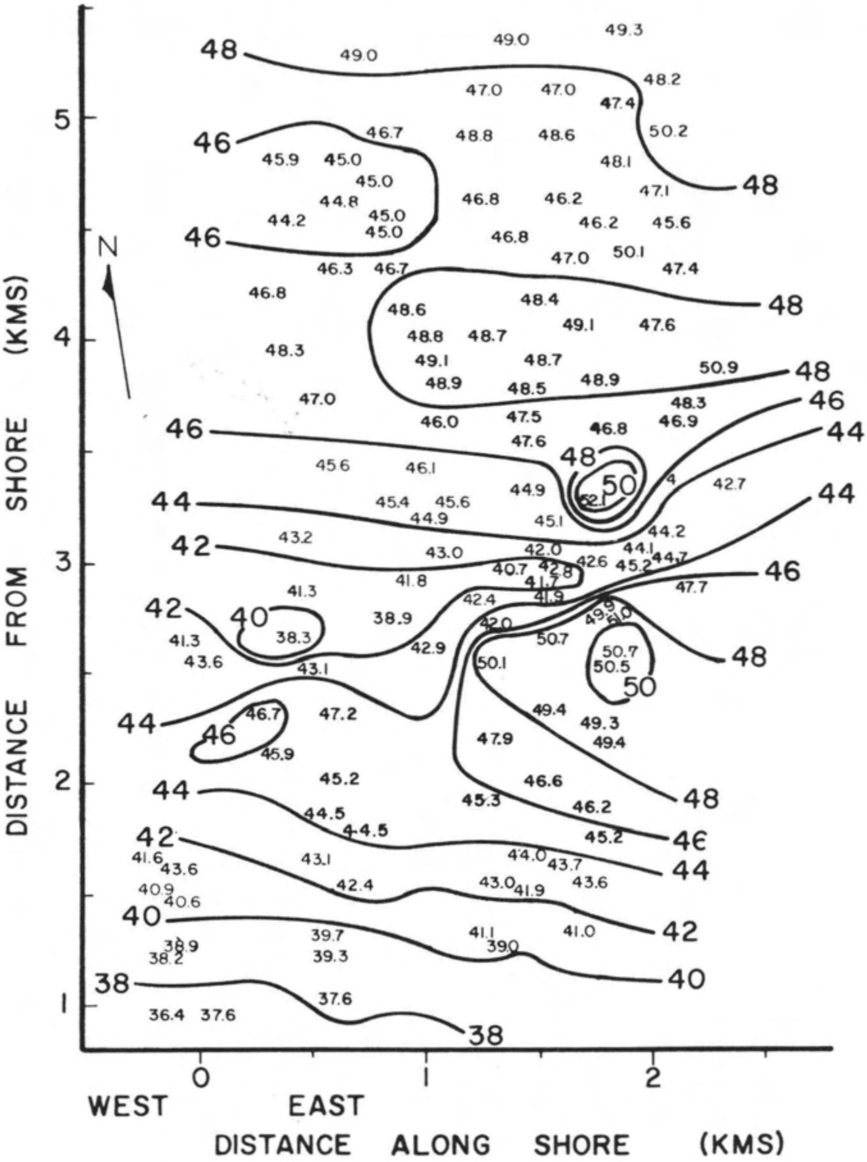

FIG. 5. A comparison between raw and interpolated photogrammetric surface speeds (cm sec^{-1}) on 5 August 1971 at time 1000. Smaller numbers indicate raw values at the location where plotted. Speed contours are based upon the interpolated values (not shown) over a 300 m grid.

velocity is desired (Whittaker, 1974). The velocity of each of these drift cards, weighted by a factor of $(R-D)/(R+D)$ (Cressman, 1959), is then used to determine a value for the grid point. Here, R is the distance from the grid point to a point midway between the third and fourth closest drift cards and D is the distance between the grid point and the particular drift card being weighted. To permit direction resolution, separate analyses were used for the downstream and cross-stream velocity components.

The raw data were interpolated over grid points spaced either 300 m or 100 m apart. These distances approximate the drift-card spacing. Typical results are shown in Figures 5 and 6, which correspond to high and low density Lagrangian data respectively. Contour intervals of 2 cm sec^{-1} were used for the high density information and 5 cm sec^{-1} for

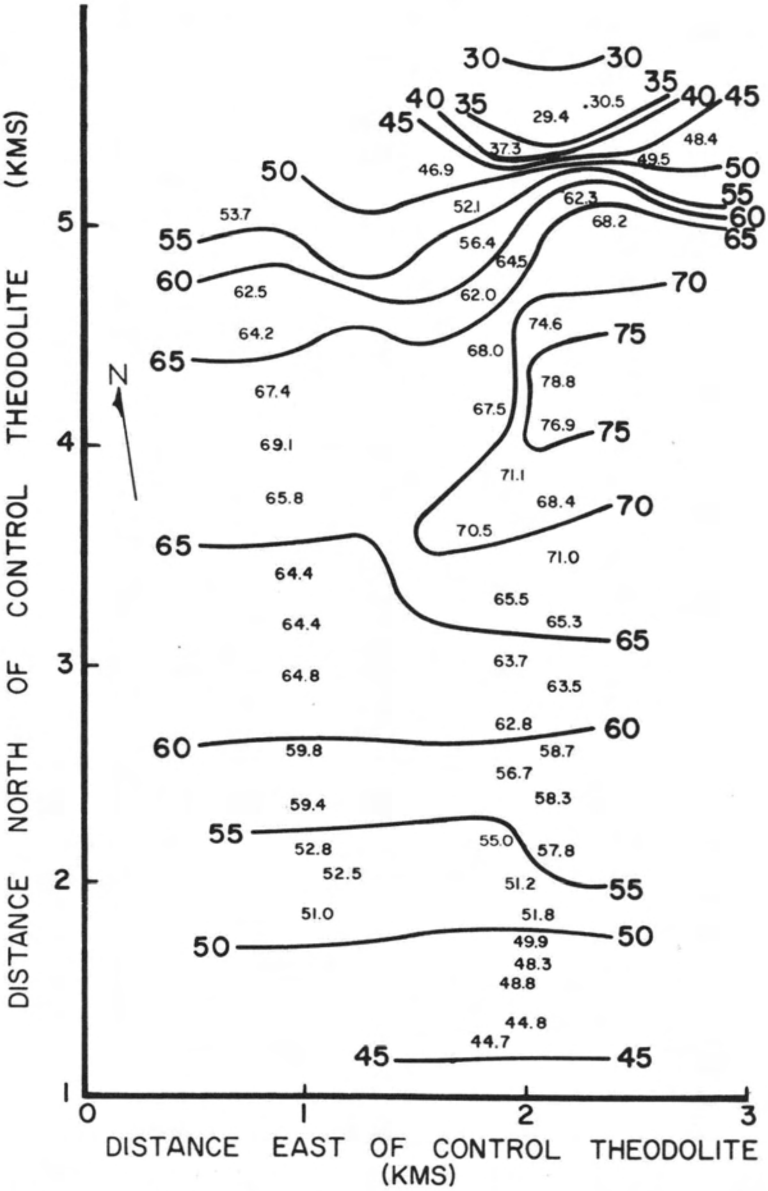

FIG. 6. A comparison between raw and interpolated photogrammetric surface speeds (cm sec^{-1}) on 4 August 1971 at time 1834. Smaller numbers indicate raw values at the location where plotted. Speed contours are based upon the interpolated values (not shown) over a 300 m grid.

the low. In both cases the original current structure is preserved and data smoothing is minimal. To preclude erroneous information, all grid points were manually edited. Those not influenced by a drift card within one grid spacing of the point were rejected. Thus, the number of interpolated velocities is approximately the same as the number of raw velocities.

Because time intervals between aerial passes vary, grid point velocities were also linearly interpolated between passes to provide equal time intervals, retaining as much as possible the times of the first photographs of the passes. As a result, the original Lagrangian data are converted into Eulerian information over hundreds of grid points in numerous synoptically observed surface-current cross-sections.

SUPPORT DATA

A more direct examination of photogrammetric measurement errors can be obtained by tracking drogues with theodolites and comparing these velocities with those derived at corresponding times from *AERIAL*. Several surface drogues, with masts and flags, were seeded along the aircraft flight line in some experiments to permit this evaluation. Because both velocity measurements depend upon theodolites the comparison is not absolute. The theodolite zero referencing results given in Table 1 suggested small errors. This is substantiated in Table 4. Here the track of a control buoy was determined by drawing a least squares fit curve through its theodolite determined positions. *RMS* deviations were then computed between this faired track and the actual observations.

TABLE 4. RMS DEVIATIONS (METERS) FROM FAIRED TRACKS OF THEODOLITE DETERMINED BUOY POSITIONS.

Date	Buoy	N	*RMS* Deviations
3 Aug 71	R3	7	2.2
4 Aug 71	R3	8	0.3
4 Aug 71	Y3	8	0.3
5 Aug 71	R1	5	0.5
7 Sept 71	R1	6	5.4
9 Sept 71	R2	7	1.3
13 July 72	Y2	12	1.5
19 July 72	Y3	4	1.0
27 July 72 AM	Y4	7	1.1
27 July 72 AM	R4	7	1.5
27 July 72 PM	R1	9	1.2

Drogue tracking results from the experiments of July 13 and 27 1972 are given in Table 5. Although the comparisons on July 13 are favorable, some relatively large differences occur 2.9 km from shore. The drogue, in this case, was situated in a pronounced shear zone where time differences between the theodolite observation and the instant of photographic exposure are important. In addition both theodolite operators reported sighting difficulties due to haze. The observations on July 27 are remarkably close except for the 1630 comparison. This discrepancy probably relates to the five minute offset between the theodolite and photographic observation periods.

Camera clock malfunctions precluded comparisons in the other experiments. The drogues were used, however, to determine precise photographic times and thereby salvage the drift card data. Although the time interval between exposures could be deter-

TABLE 5. COMPARISON OF ITERATIVE PHOTOGRAMMETRIC AND THEODOLITE DETERMINED DROGUE VELOCITIES. (SPEEDS ARE IN CENTIMETERS PER SECOND, DIRECTIONS IN DEGREES AND DISTANCES IN KILOMETERS.)

Date	Photogrammetric Time Interval	Theodolite observation	Distance from shore	Photogrammetric		Theodolite	
				Dir	Spd	Dir	Spd
13 July 72	1737-1745	1737	4.0	283	14.1	284	16.2
	1745-1752	1746/1752	4.0	281	14.9	282	14.7
	1752-1800	1752/1758	4.1	283	10.4	263	12.6
	1745-1752	1747	2.9	123	4.7	154	5.0
	1752-1800	1753/1759	2.9	131	20.4	130	14.2
	1800-1807	1759/1806	2.8	076	17.0	104	15.6
27 July 72	1559-1606	1557	1.8	140	34.4	149	34.2
	1606-1613	1608	1.7	134	30.6	137	30.9
	1613-1620	1619	1.6	136	32.4	134	30.6
	1620-1628	1625	1.5	128	30.8	131	31.4
	1628-1635	1630	1.3	126	23.6	129	28.6
	1635-1643	1639	1.3	130	23.3	130	23.9
	1643-1650	1647	1.2	131	26.6	132	27.6
	1650-1658	1655	1.1	120	35.1	123	33.7

mined from the camera intervalometer setting, the interval between successive aerial passes could not. Using the theodolite determined drogue positions a reverse extrapolation was performed to fix the time of the photographs on which the drogue appeared. The time of the first photograph of a pass could then be accurately determined by using the number of intermediate photographs and the intervalometer setting. The degrading effects of this technique on the photogrammetric velocities are not considered significant.

CONCLUSIONS

The results from this investigation indicate that dense, accurate, synoptic current information can be obtained across an entire coastal current, using aerial photography and photogrammetric reduction methods. Although the measurement errors cannot be completely assessed, support data comparisons indicate that such errors are less than 2 cm sec^{-1} in speed and 3 degrees in direction. This is also supported by the statistical analyses given in Yeske (1973).

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REFERENCES

Cressman, G. P., 1959: An operational objective analysis system. *Mon. Wea. Rev.*, 87, 367-374.

Druyan, L. M., 1972: Objective analysis of sea-level winds and pressures derived from simulated observations of a satellite radar-radiometer and actual conventional data. *J. Appl. Meteor.*, 2(3), 413-428.

Duxbury, A. C., 1967: Currents at the mouth of the Columbia River. *Photog. Eng.*, 33, 305-311.

Forrester, W. D., 1960: Plotting of water current patterns by Photogrammetry. *Photog. Eng.*, 26, 726-736.

Harris, W. D., G. C. Tewinkel and C. A. Whitten, 1962: Analytic aerotriangulation. *U. S. Coast and Geodetic Survey*, Bull., 21, 39 pp.

Huh, O. K., 1971: Aerial photographic detection of coastal circulation patterns, South Korea. *Ocean. Inst. Rep.*, 4(5), 2.

Keller, M., 1963: Tidal current surveys by photogrammetric methods. *U. S. Coast and Geodetic Survey Bull.*, 22, 20 pp.

_________and G. C. Tewinkel, 1964: Aerotriangulation strip adjustment. *U. S. Coast and Geodetic Survey Bull.*, 23, 18 pp.

Konovalova, I. Z. and B. L. Lagutin, 1968: Some statistical characteristics of offshore currents according to the results of aerial photo surveys. *Trudy, Gos. Okeanog.* Inst., 95, 72-84.

Leary, C. and R.O.R.Y. Thompson, 1973: Shortcomings of an objective analysis scheme. *J. Appl. Meteor.*, 12, 589-594.

Moffitt, F. H., 1967: *Photogrammetry.* Scranton, Internat. Textbook, 540 pp.

Nakano, M., 1957: On the eddies of Naruto Strait. *Pap. Meteor. Geophys.*, Tokyo, 7, 425-434.

Panofsky, H. A., 1949: Objective weather map analysis. *J. Meteor.*, 6, 386-392.

Ramey, E. H., 1968: Measurement of ocean currents by photogrammetric methods. *U. S. Dept. Comm. Tech. Memo.*, C and GSTM-5, 24 pp.

Terrell, R. E. and T. Green III, 1972: A method for investigating the surface velocity structure of currents and thermal plumes. *Limnol. Oceanog.*, 17, 158-160.

Whittaker, T. M., 1974: A simplified grid interpolation scheme for use in atmospheric budget studies. Ph.D. dissert., Univ. Wisconsin, Madison, Wis. (In preparation).

Wolf, P. R., 1974: *Elements of photogrammetry.* McGraw-Hill, New York.

_________ and T. J. Keating, 1973: Precise velocity measurements using photogrammetric techniques. *Water Res. Bull.*, 9, 312319.

Yeske, L. A., 1973: The structure of the Keweenaw Current by Photogrammetry. Ph.D. dissert., Univ. Wis., Madison, Wis.

_________ and T. Green, 1974: Short-period variations in a Great Lakes coastal current by aerial photogrammetry. *Univ. Wisconsin Mar. Studies Cen. Tech. Rpt.* (In press).

Nomenclature Committee

The ASP Nomenclature Committee is in the process of compiling definitions and symbols of photogrammetric and related terms for publication as a chapter in the forthcoming 4th Edition of the *Manual of Photogrammetry*. Contributions and assistance are being solicited by the Committee. If you have encountered any problems such as inconsistencies, conflicts, or omitted terms with the definitions and symbols as they now exist in the literature, please send your contributions to Professor Paul R. Wolf, Nomenclature Committee, Chairman, Civil and Environmental Engineering Department, The University of Wisconsin, Madison, Wisconsin 53706.