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THE ILLUSTRATION OF OCEANIC DATA II : VECTORS

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SUMMARY

The vectors most commonly considered in oceanic cartography are ocean currents, which can be represented in a variety of ways, according to the nature of the currents themselves, the manner in which these currents were observed, and the concepts which the illustrator wishes to display. Within the limits of a two-dimensional page there are the requirements of portraying the three-dimensional space in which the vectors were observed, the three-dimensional space of the vectors themselves and the dimension of time. Some solutions to this problem are provided from the literature.

INTRODUCTION

The vectors most commonly considered in the ocean are ocean currents, and although others, such as the oxygen or salinity gradient, do exist, they are a very small fraction of the literature.

A previous article (DUNCAN, 1977) dealt with the illustration of scalars and outlined a simple notation for determining what kind of illustrations could be used to illustrate scalar data taken in a three-dimensional field. Any parameter P was considered to have a range of values in space and time and written as

$$P = P\ (x, y, z, t)$$

This elementary notation can be expanded to include vector fields by considering that a vector is comprised of two quantities, magnitude (M) and direction, and that

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direction can always be uniquely defined by azimuth (θ) and declination (φ). Then we can write for a vector field

$$V = (M, \ \theta, \ \varphi) \ (x, \ y, \ z, \ t)$$

and consider that position vectors are a special case subsumed in the same notation.

Other variants containing the same number of identifiers are possible: magnitude and direction could be defined in terms of Cartesian coordinates while the space in which the vectors are observed could be represented in spherical or cylindrical coordinates and so on, but the above notation, though mixed, is convenient for discussing the illustration of vectors.

The diagrams which follow have been taken from the literature to show the ways in which vector data is commonly represented. The first nine figures have been drawn from the same data set.

Case 1 (M, θ, C) (C, C, C, C)

The simplest case is that of a single position vector such as ship's drift or a single current meter observation, commonly drawn as an arrow with the correct direction referred to a compass rose, and a length equivalent to the speed of the current. To represent direction graphically it is necessary to use two axes, and therefore a third scale for magnitude is included.

Case 2 (M, θ, C) (C, C, C, t)

A time sequence of these vectors, for example the currents measured in one plane by a current meter at a fixed point, can be represented as a succession of such planar graphs but head to tail. They can also be represented by a similar technique in which the length of the plot is proportional to the distance which a particle would travel if it continued in the observed direction for the observed time. This results in a diagram such as Figure 1, which is a progressive vector plot from a current meter in the Gulf of Mexico, with the displacement starting at the origin and moving around clockwise. The time marks on the plot are arbitrary, and for convenience of interpretation only. This Eulerian representation should not be read as though it is the path traced out by a point moving over the surface of the globe (see Figure 12 for a comparison with a Lagrangian illustration) although the appearance on a printed page is similar. The two representations would be the same if the flow past the meter took place in the form of a rigid plate. This type of illustration can be very useful, but is liable to misinterpretation.

For special purposes, the same data can be shown as a progressive vector plot after the mean translational motion has been subtracted and is particularly useful in illustrating currents which have a strong cyclical component. The succession of planar graphs for each vector can also be drawn with their tails all at the origin, instead of head-to-tail, but the diagram very rapidly becomes indecipherable from the overcrowding of lines, and solutions of the current-rose type are sought. The conventional current rose is capable of illustrating vast amounts of information, and for that reason is common to the nautical atlases of all nations. A current rose normally summarises currents observed by a number of ships in a region, rather

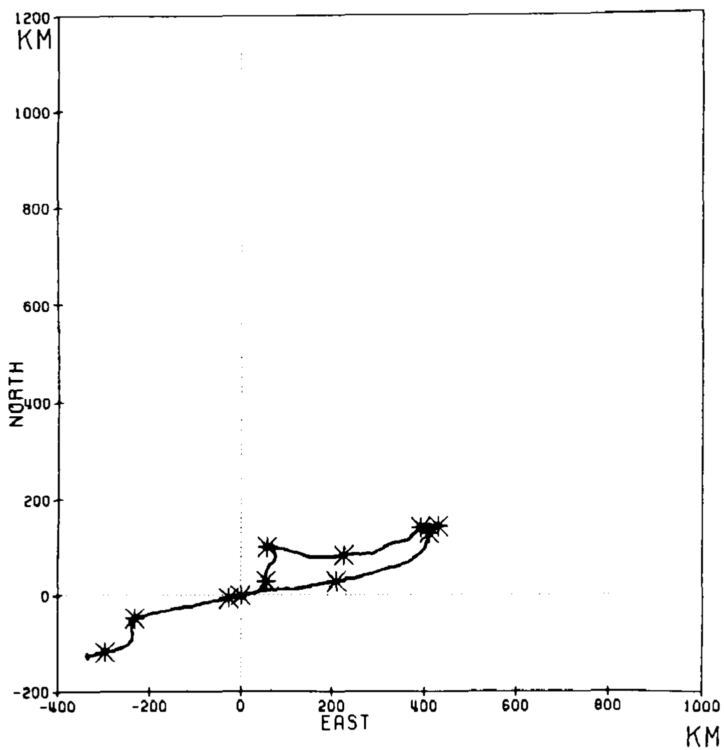

FIG. 1. – Progressive Vector Diagram for data taken at 95 meters depth 29° 11.4′ N, 87° 38.2′ W, 27 February to 16 June 1978. Scales in kilometers. Symbols every 10 days, beginning 27 February 1978, 0009Z.

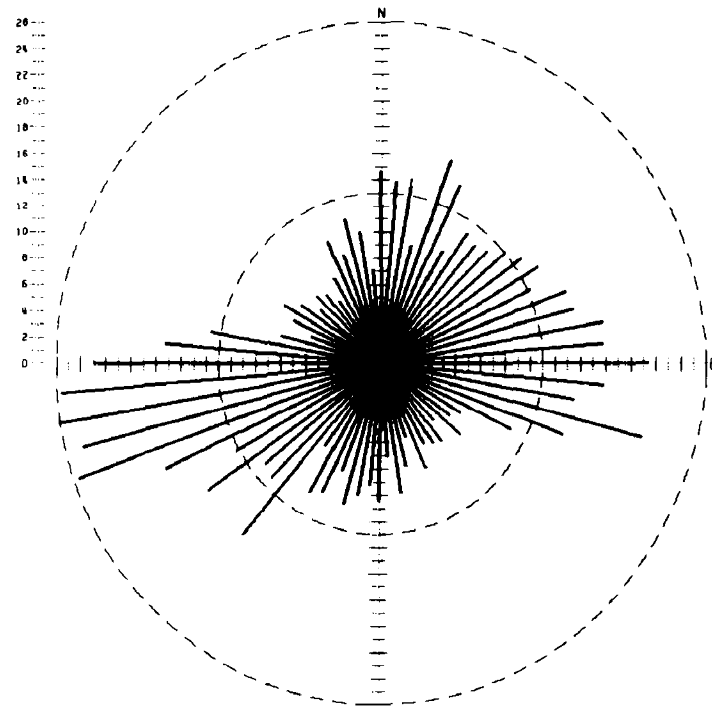

FIG. 2. – Average Speed Diagram for data taken at 95 meters depth 29° 11.4′ N, 87° 38.2′ W, 27 February to 16 June 1978. Scale in centimeters/second. 5° sectors.

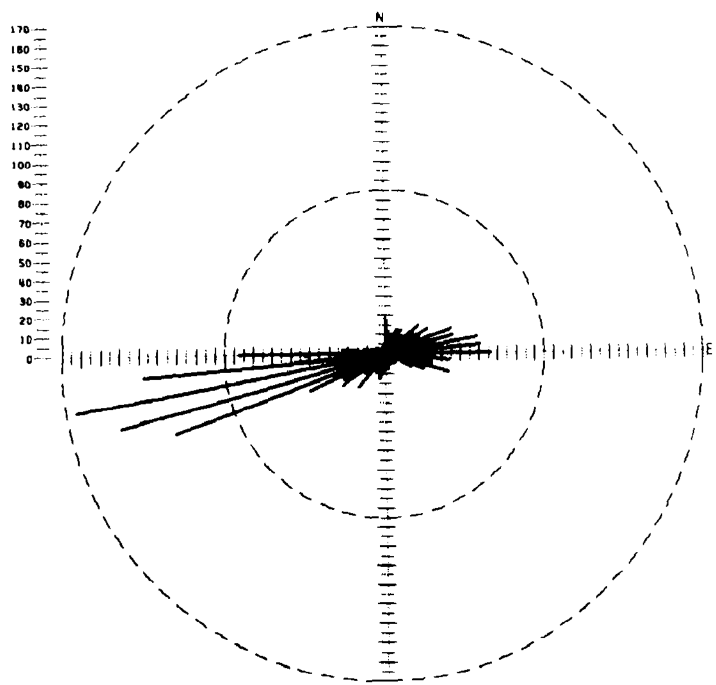

FIG. 3. – Virtual Displacement Diagram for data taken at 95 meters depth 29° 11.4' N, 87° 38.2' W, 27 February to 16 June 1978. Scale in kilometers. 5° sectors.

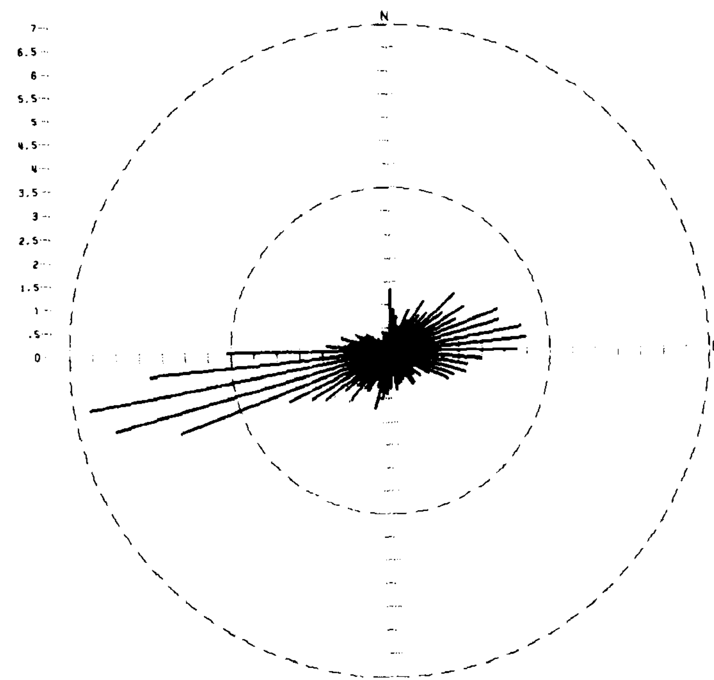

FIG. 4. – Direction Occurrence Diagram for data taken at 95 meters depth 29° 11.4' N, 87° 38.2' W, 27 February to 16 June 1978. Scale in percent occurrence. 5° sectors.

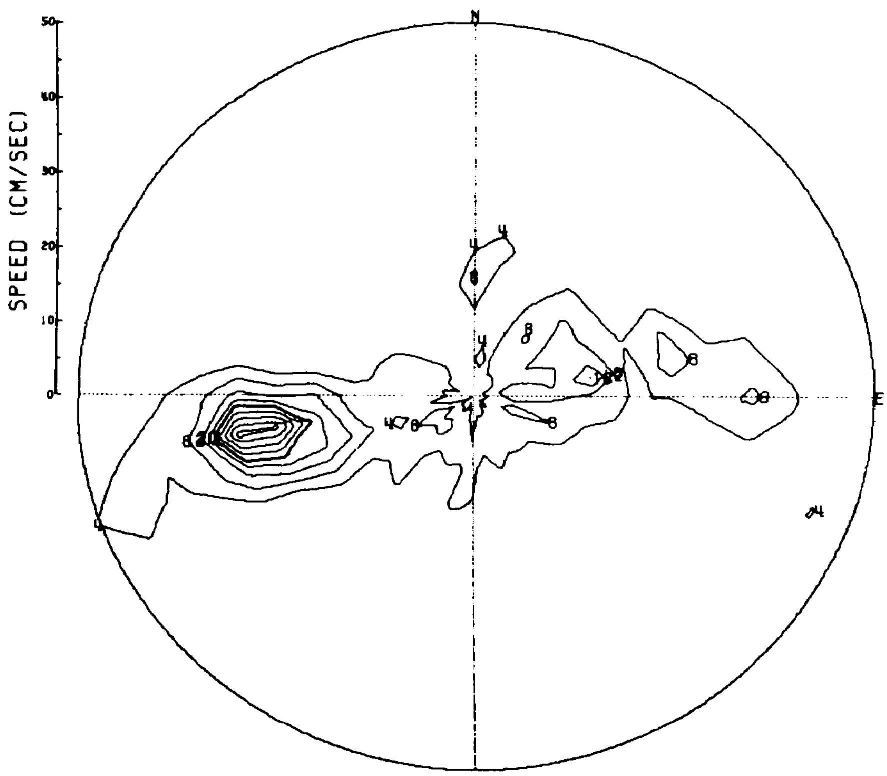

FIG. 5. – Speed and Direction Occurrence Diagram for data taken at 95 meters depth 29° 11.4′ N, 87° 38.2′ W, 27 February to 16 June 1978. Scale in centimeters/second. 4 per mil occurrence contour interval. Sector size : 10°, 5 centimeters/second.

than those recorded by a current meter at a single point, but the principle of illustration is the same. There is an excellent discussion of this aspect by WYRTKI (1960).

Figures 2, 3, 4 and 5 are based on the same general layout as a current rose, but illustrate particular aspects for engineering purposes. Figure 2 shows the average speeds for five degree sectors of a compass rose for the duration of the record, and could be more useful than a conventional current rose for estimating ship's drift, but Figure 3 could be even more useful for that purpose. The illustration of percent time that drift in a particular direction took place is shown in Figure 4. An interpretation of this figure as showing probability of flow in any direction would be justified if the diagram were based on sufficient data. Figure 5 is a very elegant way of portraying both speed and direction in a useful form, once one has become accustomed to the convention which is being used. It could be particularly effective on a two-dimensional page in color or perspective, or even as a three-dimensional representation such as an analglyph or a hologram.

By using time as an axis, the data may be reduced by graphing speed and direction separately as shown in Figure 6. This effectively reduces the problem from the difficult one of illustrating a vector to the simple one of illustrating two (or more)

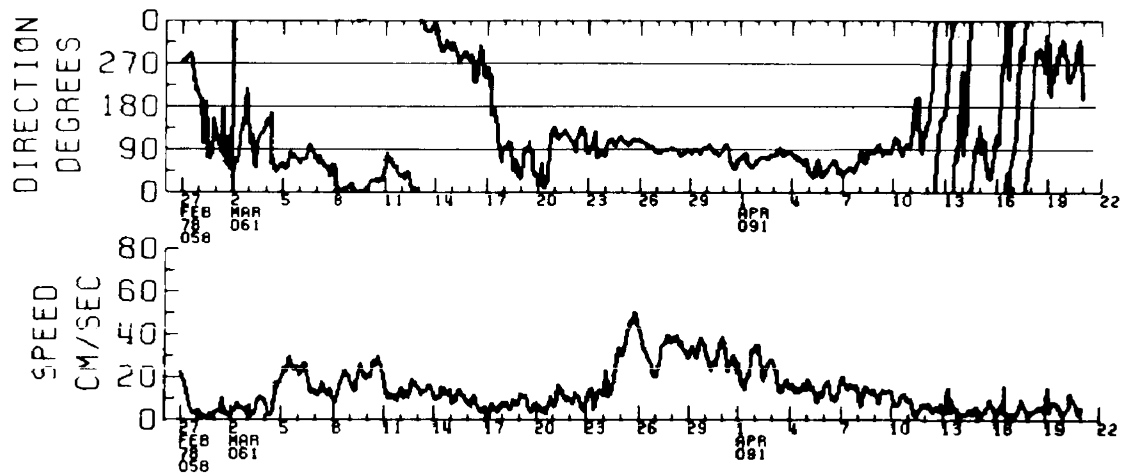

FIG. 6. – Speed and Direction Diagram for data taken at 95 meters depth 29° 11.4′ N, 87° 38.2′ W, 27 February to 16 June 1978. Horizontal scale in days. Vertical scales in degrees and in centimeters/second.

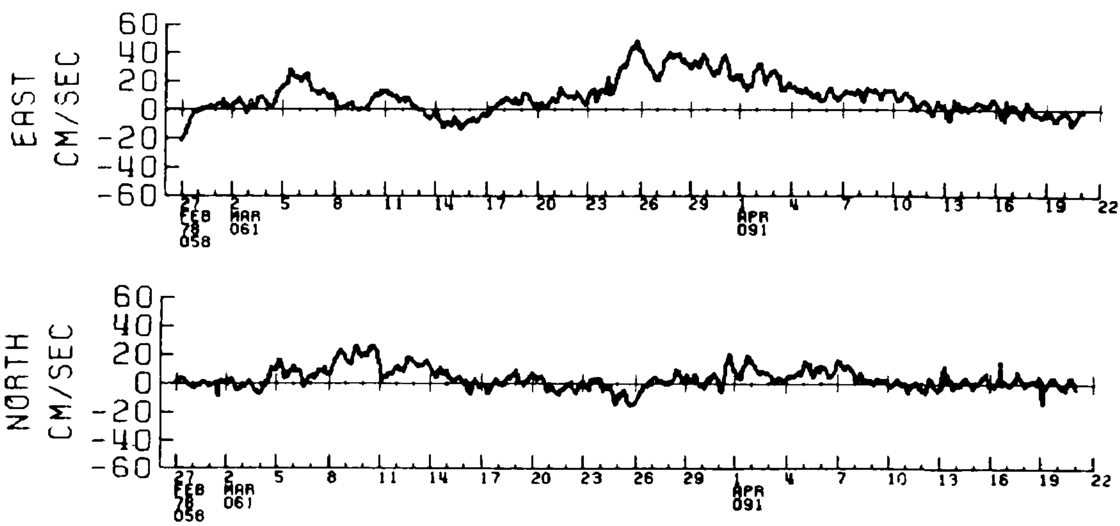

FIG. 7. – Cartesian Component Diagram for data taken at 95 meters depth 29° 11.4′ N, 87° 38.2′ W, 27 February to 16 June 1978. Horizontal scale in days. Vertical scales in centimeters/second East and North.

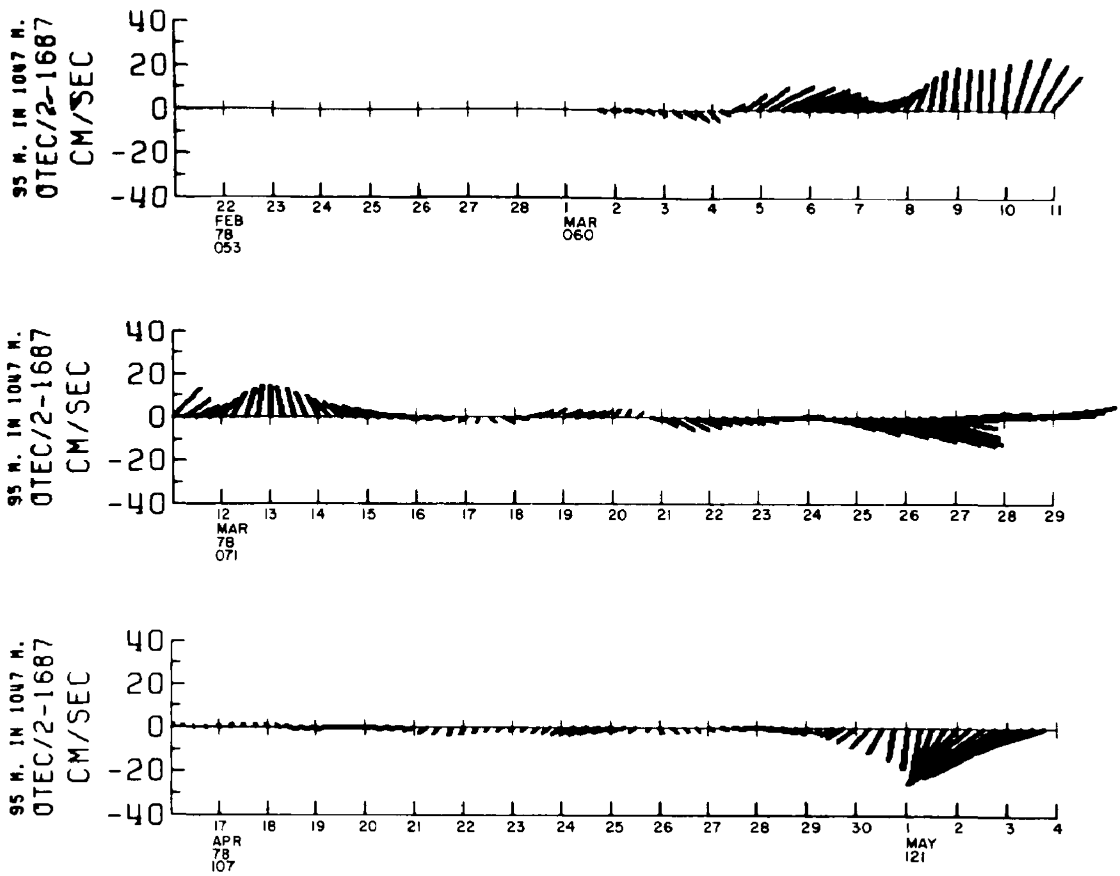

FIG. 8. – Stick Diagrams of a time series of vector components given as speed and direction for data taken at 95 meters depth 29° 11.4′ N, 87° 38.2′ W, 27 February to 16 June 1978. Horizontal scale in days. Stick length in centimeters/second. Stick orientation denotes direction.

scalars, i.e. by reducing (M, θ, C), (C, C, C, t) to (M) (C, C, C, t) and (θ) (C, C, C, t). The comprehension of each trace is simple enough, but even with an equal and parallel time scale for magnitude and direction, the re-combination of these scalars in the mind to form a meaningful vector portrayal requires either a special talent or a lot of training. A similar technique is used in Figure 7, where the velocity vectors have been reduced to speed on Cartesian coordinates, and these speeds have been graphed. Figure 8, a stick plot, represents velocity vectors with their tails stepped along a time axis rather than originating at a common point (hodograph) or head-to-tail (progressive vector).

A utilitarian representation of particular use to engineers who design structures that have to endure in the ocean, such as oil platforms, is given in Figure 9, where the axes are speed and frequency. Clearly, 100% of all currents exceed a speed of zero. This representation can be used, for example, to determine that the frequency of speeds greater than 25 centimetres/second is about 36%, and the structure can be designed accordingly. Admittedly, this representation is rather a form of (M, C, C)

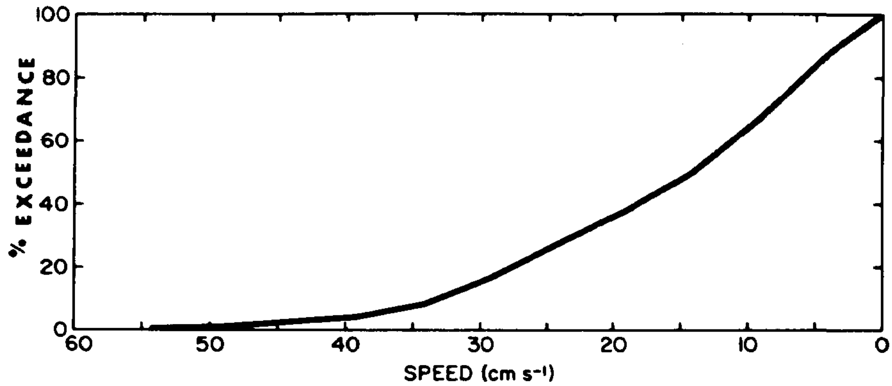

FIG. 9. – Exceedence Diagram for data taken at 95 meters depth 29° 11.4′ N, 87° 38.2′ W, 27 February to 16 June 1978. Horizontal scale in centimeters/second. Vertical scale in percent exceedence.

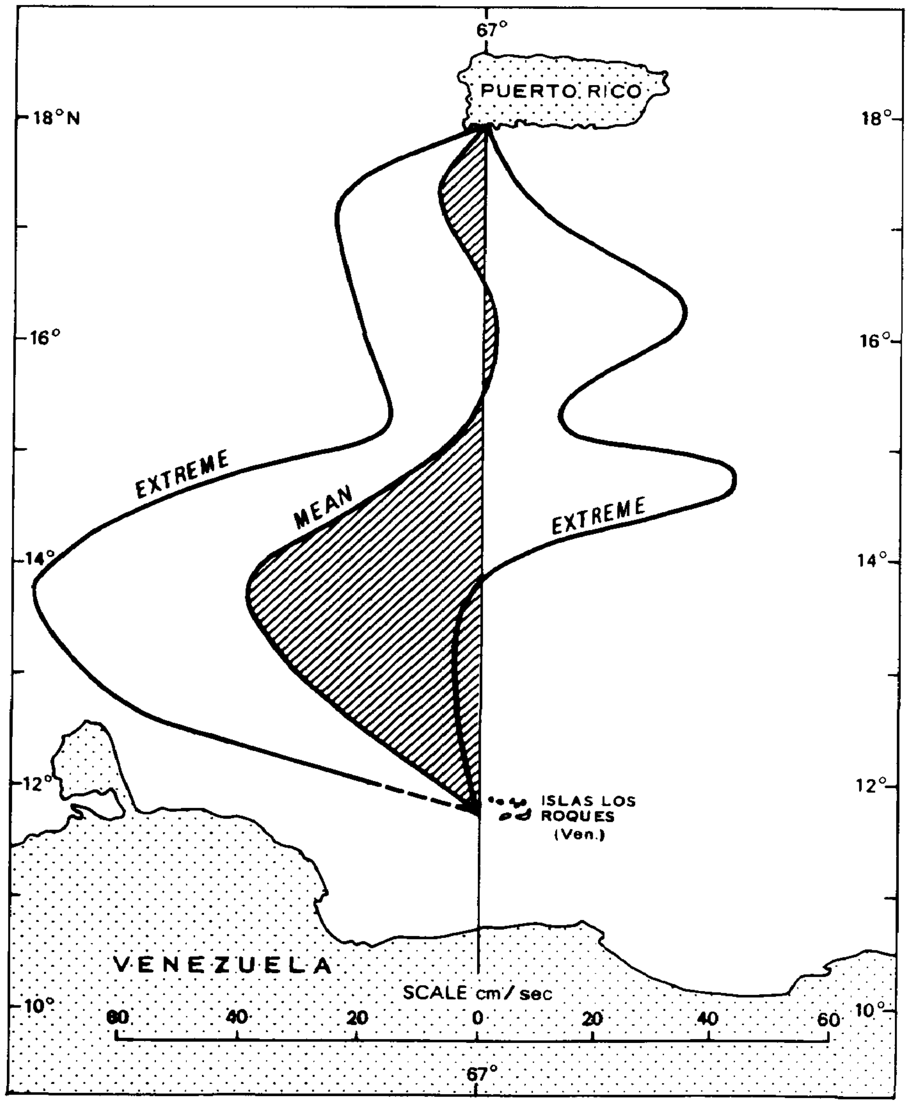

FIG. 10. – Geostrophic surface currents in centimeters/second at 67 °W between Puerto Rico and Venezuela, 1973 to 1975.

(C, C, C, t) in that direction is omitted, and time is given in terms of percent occurence, but it has been included here for completeness.

These diagrams represent common ways of illustrating vector data taken over a period of time at one point and have been drawn from the same data set, so that the reader can form an opinion about the utility of one representation relative to another.

Figure 10 is a close relative of Figure 8, being (M, θ, C) (C, y, C, C) rather than (M, θ, C) (C, C, C, t) and being simplified in that geostrophic currents are inherently perpendicular to their base line – the data set was much more tractable. The artist here has made an ingenious attempt at putting a graph on a map. The axes of the graph are centimetres/second on the abscissa, and degrees of latitude on the ordinate axis, while the map shares the ordinate but has a coastline to suggest location.

Another close relative of both Figures 8 and 10 is that represented by (M, θ, C) (C, C, z, C). In all three cases the vectors are in a single plane and for either a fixed time or a fixed point. Figure 8 is at times difficult to interpret when the vector angles are parallel to the axis or nearly so. When the data set is not as tractable as that used in Figure 10, it is sometimes necessary to use an isometric or perspective drawing to achieve clarity. Figure 11 is such a drawing to illustrate a very simple but awkward set of vectors and is justly famous for its lucid exposition of the Ekman spiral.

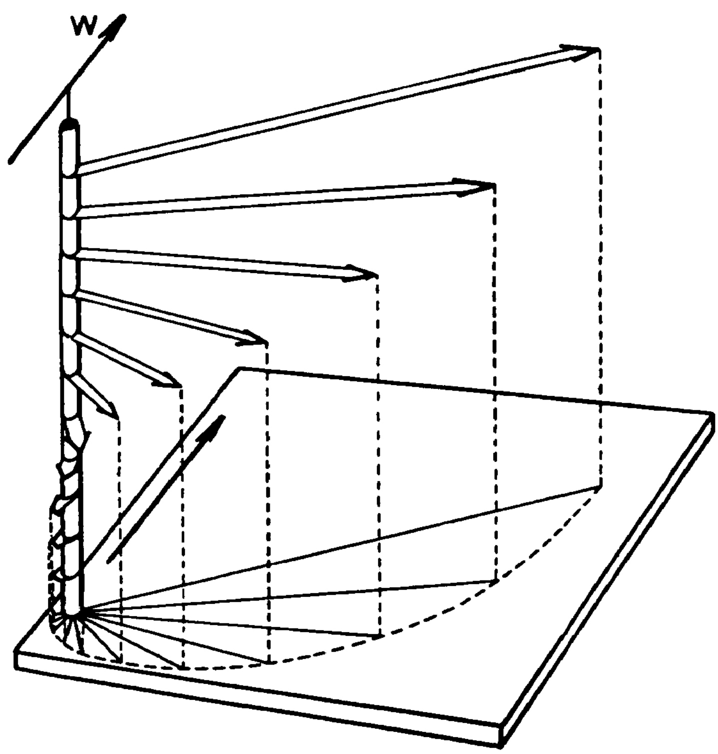

FIG. 11. – Schematic representation of a wind current in the Northern hemisphere in deep water, showing the decrease in speed and change of direction with depth (the Ekman spiral). W indicates wind direction.

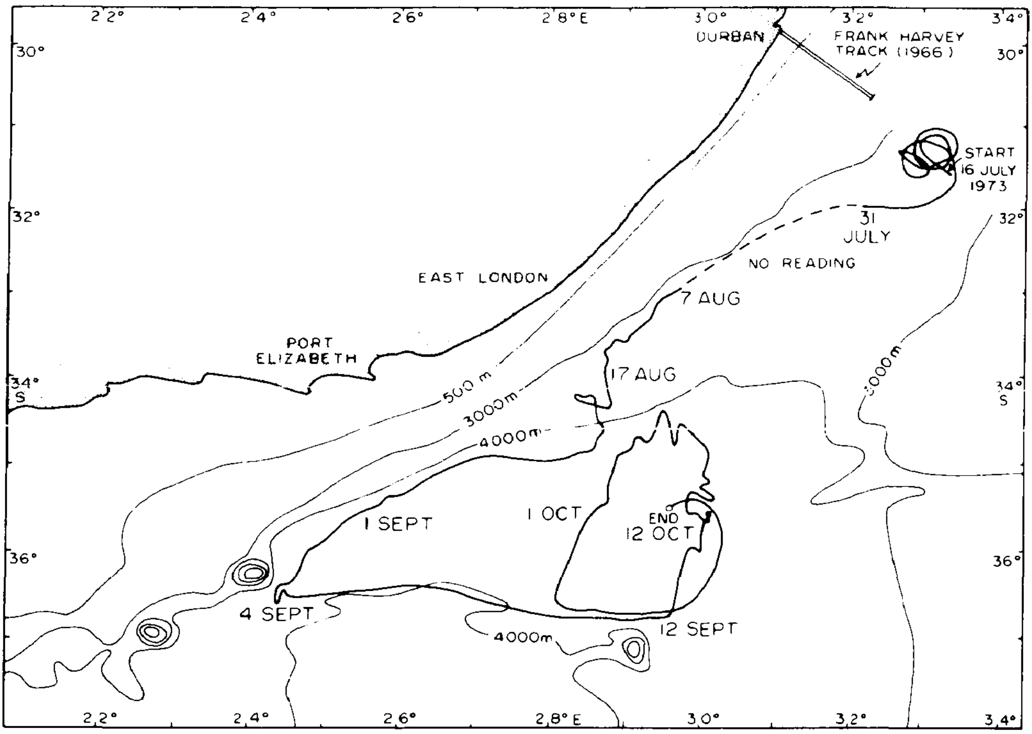

FIG. 12. – Path of a satellite-tracked drogue in the south-western Indian Ocean between 16 July and 12 October, 1973.

Figure 12 shows the track of a buoy in the southwest Indian Ocean between July and October 1973. It is a Lagrangian representation of vector flow, being the path traced out by a point as it travels, rather than a progressive vector diagram constructed from a number of observations at a point, but its graphical similarity to Figure 1 is clear.

Case 3 (M, C, C) (x, C, z, C)

From the notation this is seen to be a vertical section of magnitude only (Fig. 13). Some semblance of directionality is given by the shading, which is used to denote flow parallel to the coast in either direction. As shown, the flow is imagined to be only parallel to the coast, and with no declination. Since horizontal motion in the ocean is commonly held to be an order of magnitude greater than vertical motion, the latter assumption is not unreasonable. Figure 14 is a perspective diagram of the same kind of information as Figure 13, the directionality being limited to that component parallel to the coast.

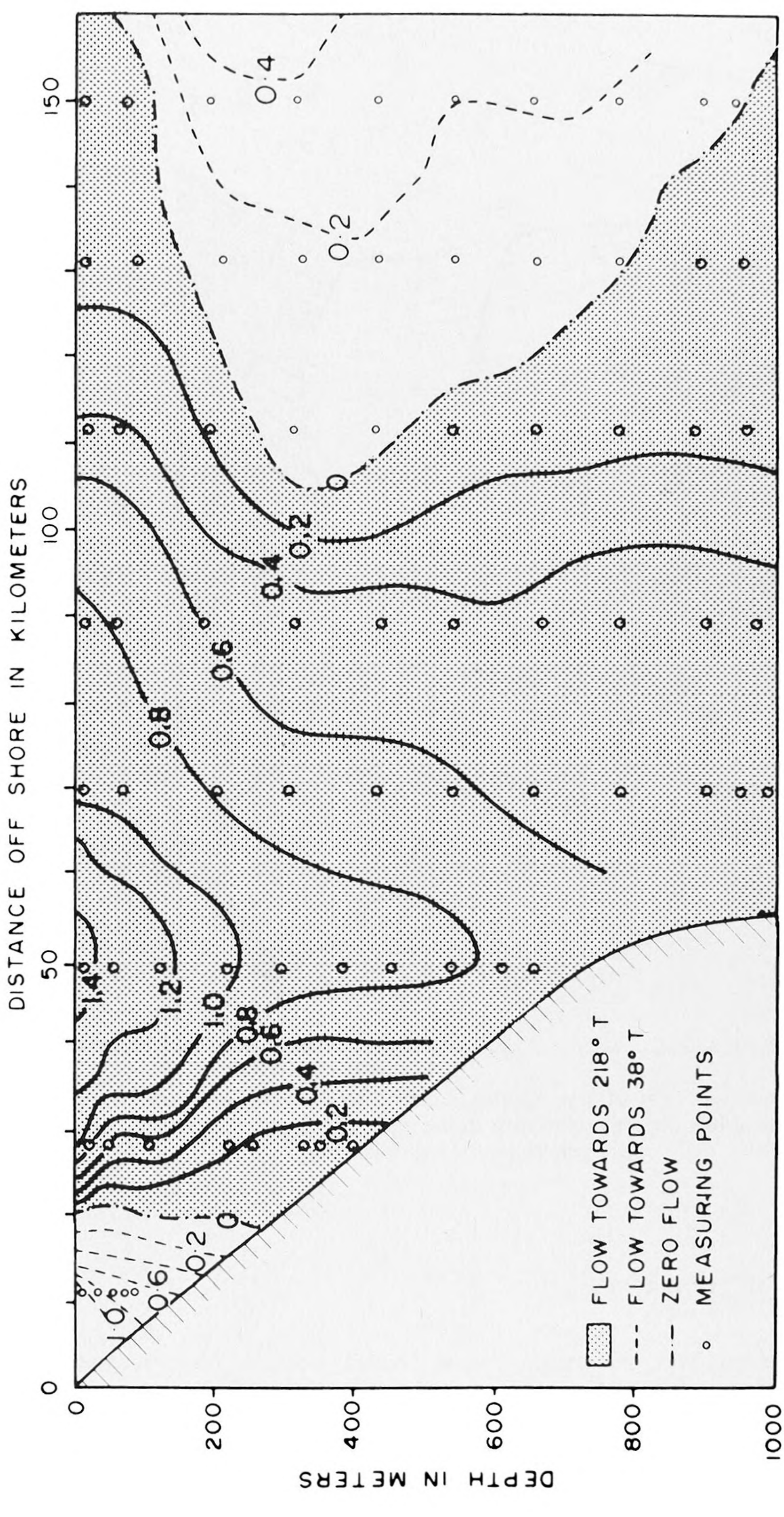

FIG. 13. – Velocity component section through the Agulhas Current along a line bearing 127° True from Durban, South Africa, 17 January 1966. Speeds are in meters per second and the direction of the velocity component perpendicular to the section is shown by shading.

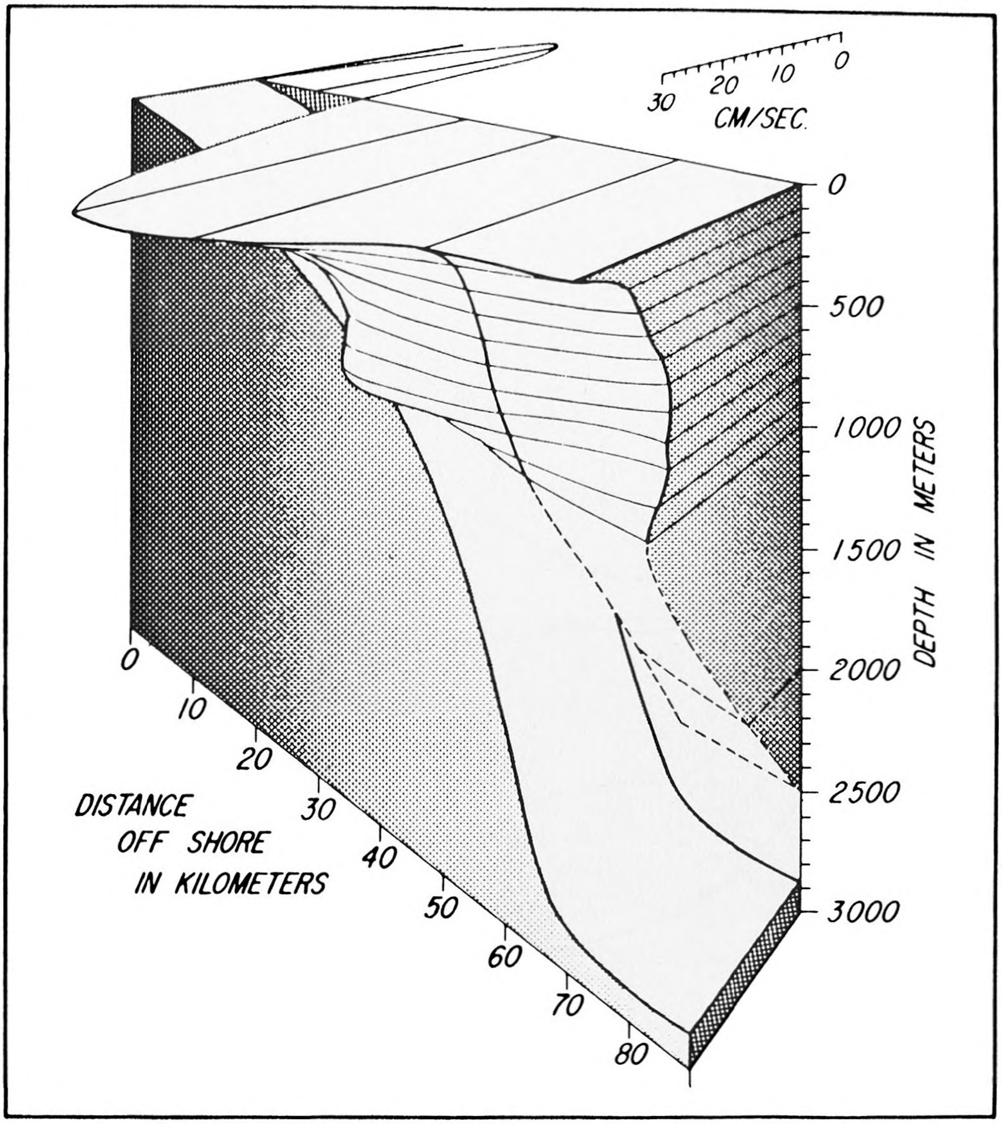

FIG. 14. – Perspective view of the Agulhas Current south-south-east from Durban, South Africa, 22 October 1966. Speeds are relative to the scale given, and direction is assumed to be perpendicular to the track line.

Case 4 (M, θ, C) (x, y, C, C)

One accepted way of making maps which contain both magnitude and direction is shown in Figure 15, where the area has been subdivided into regions for which current roses can be calculated. This approach is possible because the direction of flow is considered to be in the same plane as the map, and is a special case in that it is notationally equivalent to (M, C, φ) (x, y, C, C) and although the latter could be drawn easily enough, it would not be as easy to read.

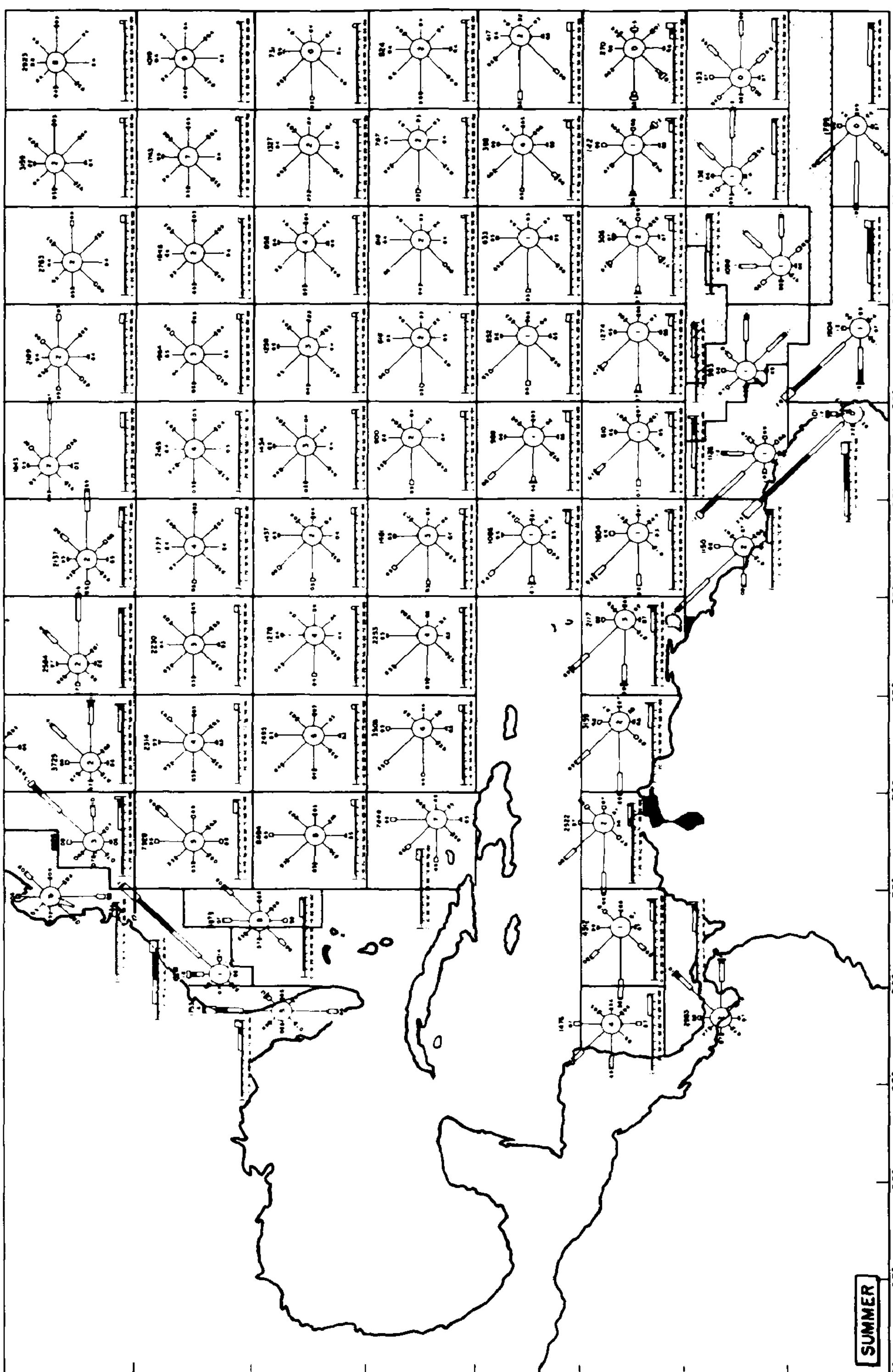

FIG. 15. – Surface current roses for the SE North Atlantic during summer (July, August, September).

An elegant solution to the illustration of speed and direction for a given time is to be found in the U.S. Navy Oceanographic Office Publication Number 700 where the flow patterns of the North Atlantic Ocean are overlaid with isotachs printed in color on a transparency. Figures 16 and 17 are given here as samples of the information contained in these maps, with a recommendation that the originals be referred to.

Case 5 (M, θ, C) (C, C, z, t)

The data from a number of current meters at various depths at one station for a period of time are illustrated in Figure 18, which is a succession of hodographs laid out downwards on a page to represent depth. The vectors have been assumed to be in the horizontal plane.

Figure 19 is an attempt at overcoming the limitations of the essentially scalar vertical section (Figures 13 and 14) by providing a more general directionality than is allowed by considering only flow perpendicular to a transect line. Although in some cases it is difficult to determine whether only horizontal flow is indicated by the vectors, the technique is a valuable one.

Case 6 (M, θ, φ) (x, y, z, C)

The schematic representation of currents put forward in Figure 20 cleverly uses two faces of a perspective drawing to portray the magnitude, azimuth and declination of vectors in a three dimensional field. It is really two separate illustrations of (M, θ, C) (x, y, C, C) and (M, C, φ) (C, y, z, C) with a common edge, but the illusion is more satisfactory to the eye than the equivalent trick used in Figure 6. It should be pointed out that the two figures (6 and 20) are useful for different purposes, in that Figure 20 is intended to convey an instantaneous picture of what is happening, while Figure 6 is basically a data storage technique which is used to find items of interest, such as the complete rotation of current direction between 13 and 20 March, 1978.

CONCLUSIONS

The inherent problem of illustrating a time-variable 3D field which is set in 3D space is beyond the ability of 2D paper to solve. With the added resource of color, more can be achieved, but the most gripping illustrations of time-variable vectors have been time-lapse movies.

Design of the experiment is important if the results are to be well illustrated. It was possible to draw Figure 13 because the observations were made in a plane. If they had not been in a plane, then it would have been necessary to draw something like Figure 19, which is amenable to illustrating data taken in a 3D grid.

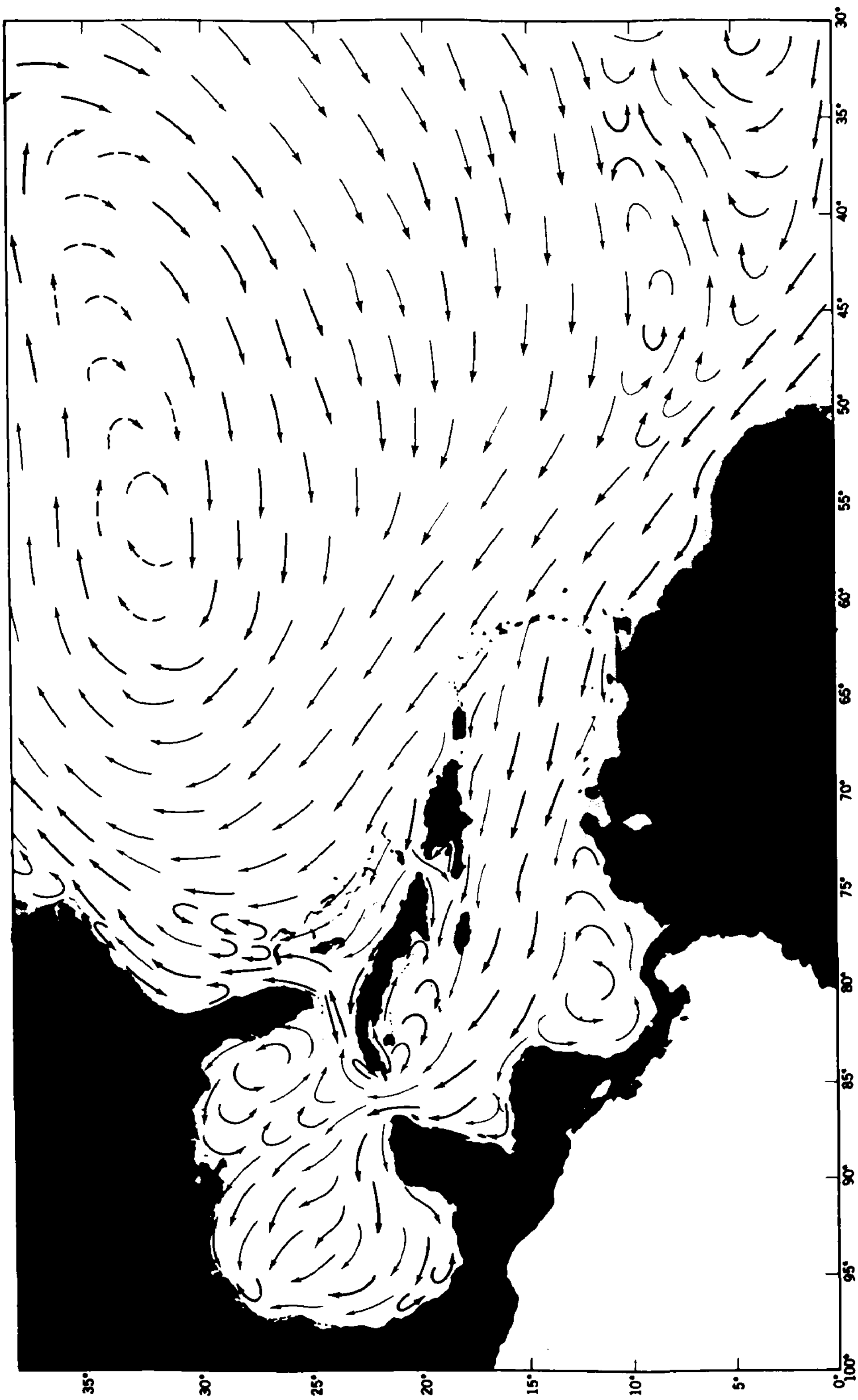

FIG. 16. – Prevailing surface current directions in the SE North Atlantic during summer (July, August, September).

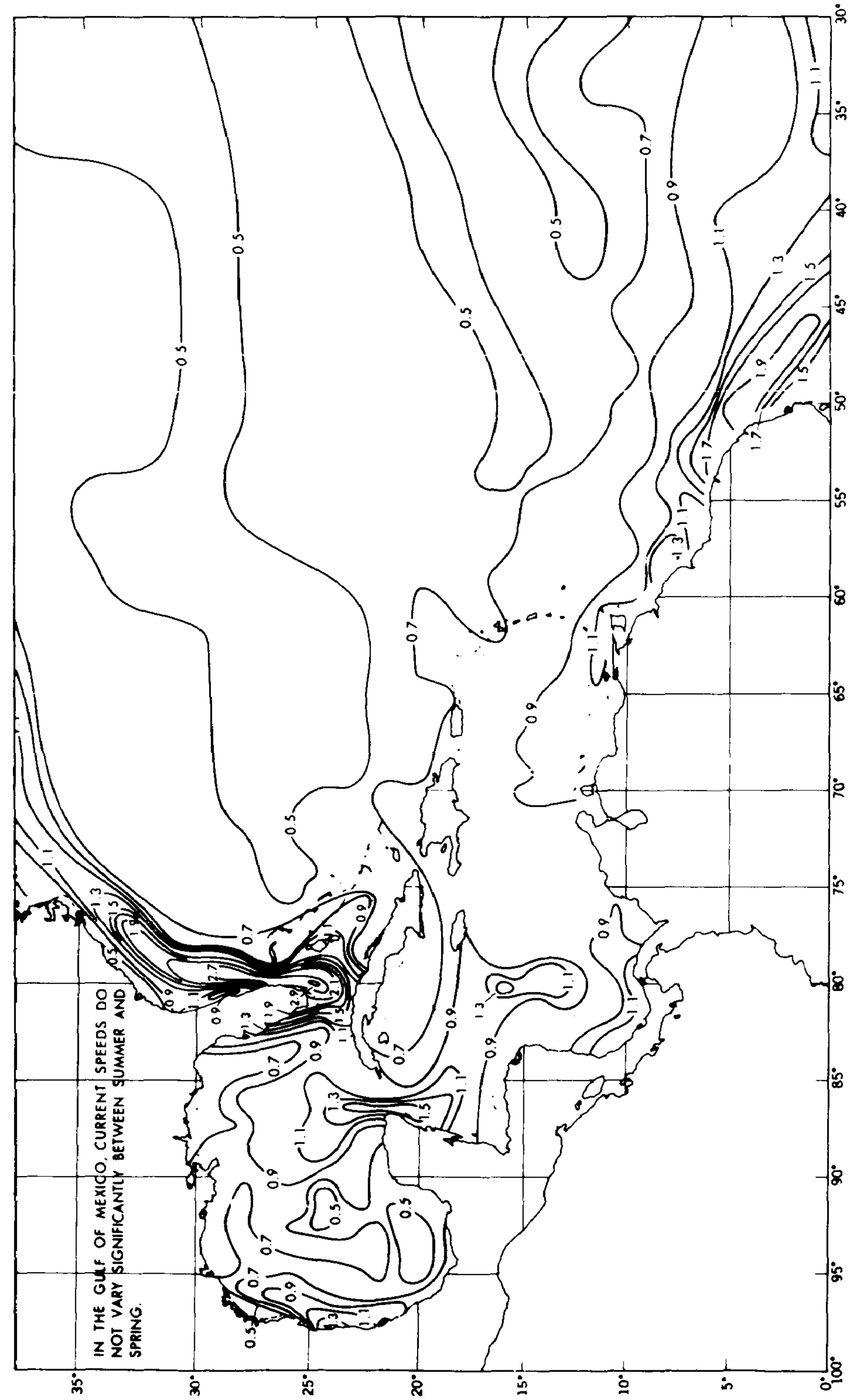

FIG. 17. – Mean surface current speeds in knots for the SE North Atlantic during summer (July, August, September).

It is true that the human mind can be trained to accept conventions which increase our understanding. The introduction of perspective drawing is an example of such a convention, which was introduced during the Renaissance. Perhaps some similar breakthrough will occur in the future?

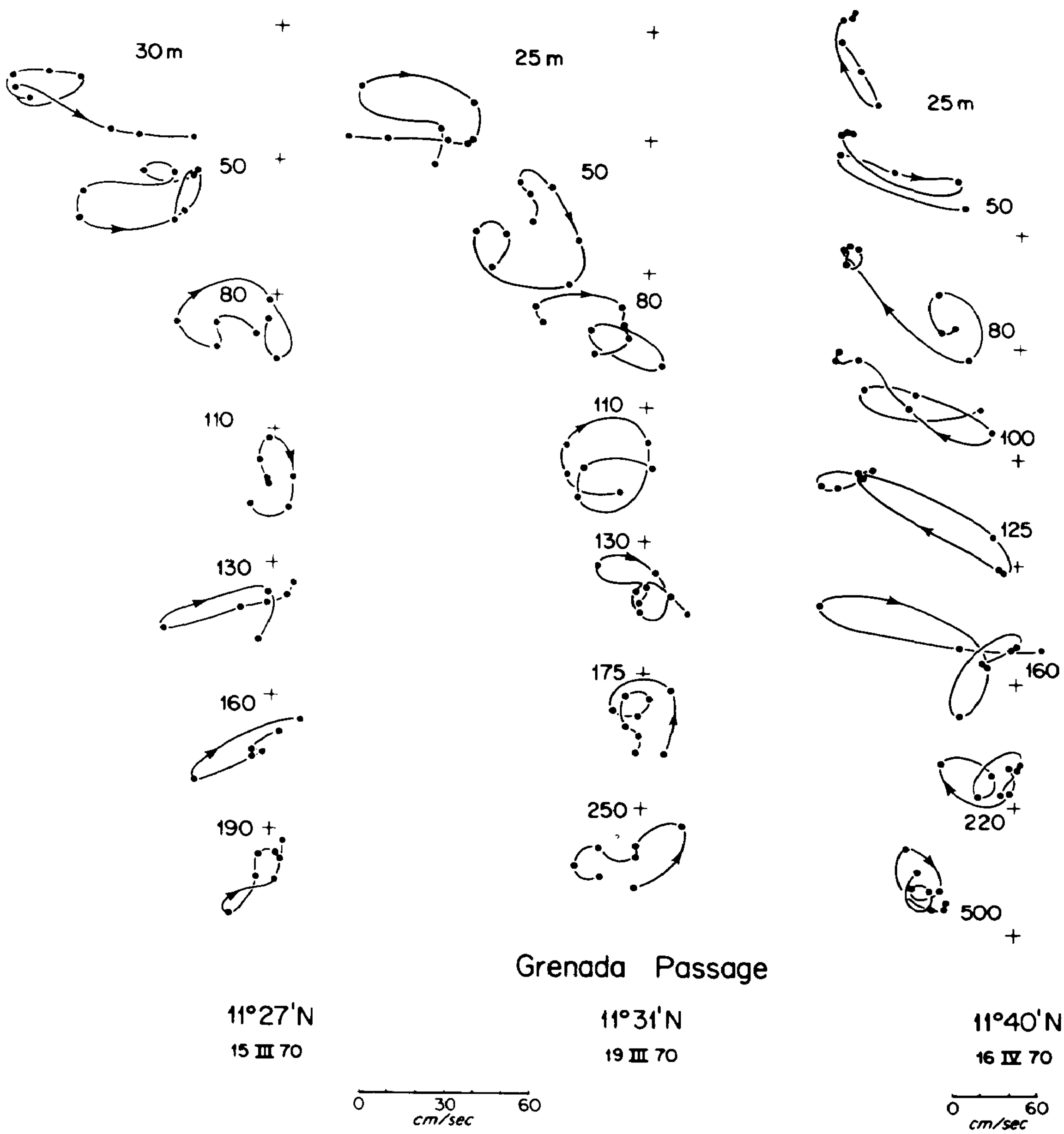

FIG. 18. – Hodographs of tidal currents in the Grenada passage in March 1980. The small circles along the lines indicate the vectors at approximately two-hour intervals; the arrows show direction of rotation; some observations have been deleted for various reasons. (Note that the right-hand column has a contracted scale).

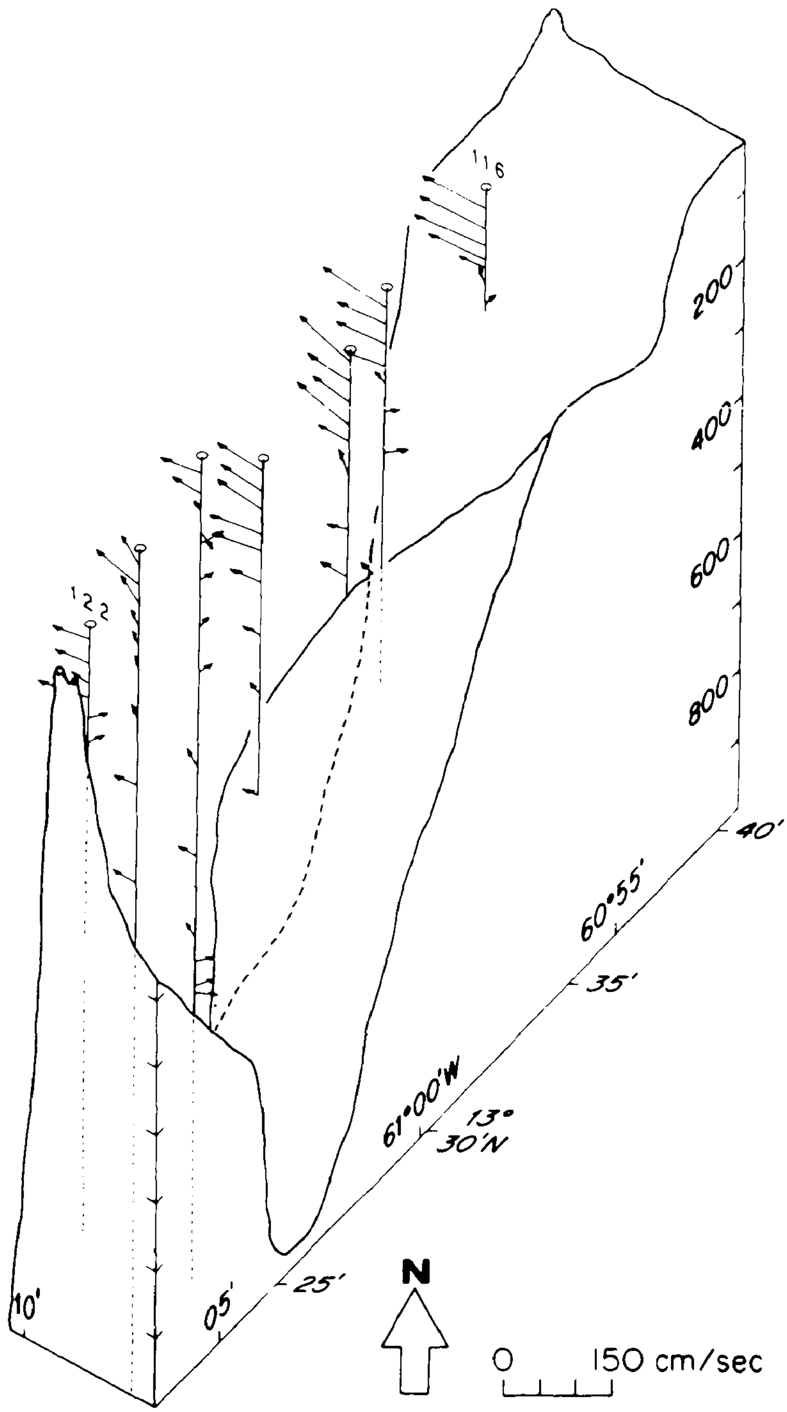

FIG. 19. – Current pattern in the St. Vincent Passage (Lesser Antilles) using data from stations occupied on April 10, 1970.

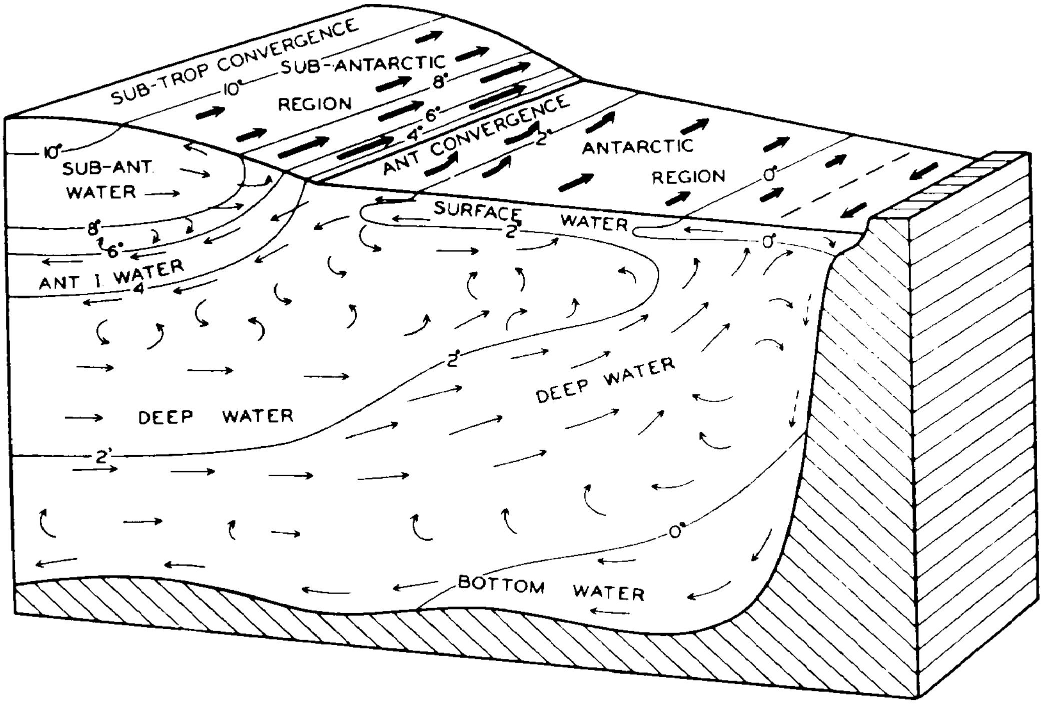

FIG. 20. – Schematic representation of the currents and water masses of the Antarctic regions and of the distribution of temperature.

Acknowledgements

Dr. R.L. MOLINARI of the National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory is thanked for permission to use Figures 1 through 9, which are computer-drawn production plots from a draft report submitted to the U.S. Department of Energy. Figures 11 and 20 are reproduced from "The Oceans" by SVERDRUP, JOHNSON and FLEMING, copyright 1942, renewed 1970, reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, N.J. Messrs. STALCUP and METCALF are thanked for permission to use Figures 18 and 19 of currents in the Grenada passage, which appeared in the *Journal of Geophysical Research*, February 1972. Figures 15, 16 and 17 are taken from U.S. Navy Oceanographic Office Publication Number 700, *Atlas of the North Atlantic*, 1964. The remaining figures have been published by one of the authors (DUNCAN).

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