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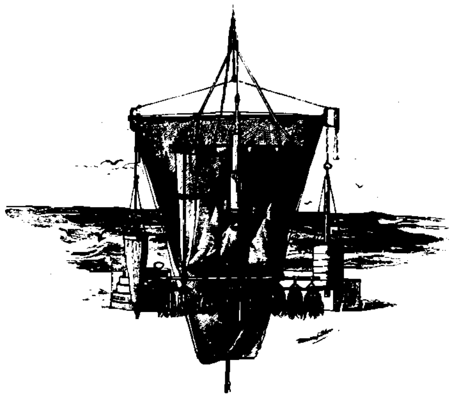
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Drifting Derelict Trajectories in the North Atlantic

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Introduction

In December 1883 the U.S. Navy Hydrographic Office, a branch of the Bureau of Navigation of the Navy Department, began to publish monthly Pilot Charts. Earlier, oceanographer M. F. Maury had produced some summary survey charts showing ocean currents, winds, sailing routes, and the locations of whales. The new charts were unique in that they showed updated positions of derelict vessels and other drifting debris. From this series of positions of identified derelicts the first ocean trajectories were obtained. Much of this information has been forgotten during the last 100 years, and good collections of the Pilot Charts are rare. (The only complete collection that I could find is held by the Defense Mapping Agency.) This article is a recompilation and description of these early trajectories and a reminder of the usefulness of the Pilot Charts. It also provides a glimpse of a little known part of maritime history, the last days of wooden sailing vessels.

The Pilot Chart

The new Pilot Charts were prepared to supply a reliable plotting sheet and a graphic presentation of recent as well as general summary information for mariners [*Hayden*, 1888]. The charts were issued free to navigators in return for their reporting recent navigational and weather information. The success of the Pilot Chart was due to the large number of observers that contributed information for each month's chart and its rapid distribution to ships. In the late 1800's there were nearly 3000 voluntary observers, mariners who crossed the North Atlantic and who patrolled its waters. Reports of marine meteorology and dangers to navigation were collected from these observers at 11 branch offices and forwarded to headquarters in Washington where the latest positions of wrecks and derelicts were plotted on a large blackboard. The Pilot Charts incorporated these data and were published and distributed at the beginning of each month. In November 1893 the office received no less than 400 reports daily from vessels in the North Atlantic alone. In New York during 1886–1887, 6,739 vessels were visited, 3,601 reports were forwarded to Washington, nautical information was furnished to 83,345 masters of vessels and others, and 10,397 Pilot Charts were distributed [*Hayden*, 1888].

Derelicts

A derelict is a vessel abandoned at sea. Derelicts that survived more than a few days at sea were usually wooden sailing vessels, and the longest surviving of these were often lumber schooners. From the point of view of a ship captain, a derelict vessel is a formidable obstruction to navigation. A collision with a derelict at night or in fog could damage or sink a ship. In our age of metal ships it is not generally recognized how many derelicts there were nor how long they remained afloat. The Atlantic was literally strewn with numerous "Mary Celestes" in various stages of disintegration.

The number of reported derelict sightings reached a maximum toward the end of the 19th century [*Hydrographic Office*, 1894]. During 1893, a year of particularly numerous derelicts, there were 732 reports of 418 different derelicts. One hundred six of these derelicts were identified by name. All but two or three of these derelicts were wooden. Over a 7 year period, 1887–1893, a total of 1,628 derelicts were sighted, an average of 232 annually, 19 per month. This suggests that at any one time at least 19 derelicts remained afloat in the North Atlantic. The average length of time a derelict remained afloat is estimated to be 30 days. This time is based on assuming a derelict remained afloat 1 day after its last reported sighting or 3 days for a single sighting. During 1887–1893 there were 1,944 reports of the 482 identified derelicts giving an average of four sightings per derelict. The greatest number of derelicts were first reported in September-November and were caused by severe storms. Most were located in the Gulf Stream off the U.S. coast. The numbers of sightings gradually decreased eastward along the transatlantic steamer routes. Many of the large number of derelicts observed during the fall of 1893 were caused by a series of three hurricanes which occurred in August of that year.

Derelict Trajectories

Numerous derelicts remained afloat over half a year and were reported often enough to give long and interesting ocean trajectories. A listing of derelicts that floated longer than 200 days is given by *Richardson* [1984]. Six of the derelicts drifted longer than a year: (1) schooner *Fannie E. Wolston*, 1100 days; (2) schooner *Wyer G. Sargent*, 615 days; (3) bark *Telemach*, 551 days; (4) bark *Vincenzo Perrotta*, 536 days; (5) schooner *Ethel M. Davis*, 370 days; and (6) schooner *James B. Drury*, 367 days.

The trajectories of three long-lasting and far-drifting derelicts are shown in Figure 1. One of the best known of these was the three-masted lumber schooner *W. L. White*, belonging to A. F. Ames of Rockland, Maine. She was abandoned off Delaware Bay during the great blizzard of March 13, 1888. A telegram dated Stornoway, Hebrides Islands, Scotland, January 23, 1889, marked the termination of the *White*'s 310 day transatlantic drift. She ended stranded upon Haskeir Island in the Hebrides.

The *White* began her drift southward under the influence of the inshore current and northwest gale, with masts and portions of her sails standing. Upon reaching the Gulf Stream she turned and followed a east-northeast course at an average speed of about 32 miles per day. From May to November 1888 she looped and zigzagged east of Newfoundland directly within a major shipping lane. During these 6 months she was reported by 36 vessels, three of which sighted her in a single day. In her cruise of 10 months and 10 days, she traversed a distance of 5,900 miles and was reported 45 times.

Although the detailed paths of the derelicts are very different from each other, there are some similarities which might be described as patterns. Eight of the longest drifting derelicts moved eastward in the Gulf Stream until they reached 50°W where their paths diverged. Three derelicts continued eastward and crossed the Atlantic in an average time of 10 months. The *White* took 310 days, the *Twenty-one Friends* took 255 days, and the *Hunt* took 347 days. Six derelicts drifted southward from the Gulf Stream near 40°W. The *Drury* and the *Hill* both made tight turns and drifted westward just south of the Gulf Stream. The *Wolston* made a complete circuit of the gyre during its 3-year drift. This derelict drifted south to 25°N, westward to the Bahamas, and then northeastward into the Gulf Stream again, crossing its earlier path. The trajectory of the *Telemach*, which was 1.5 years long, is similar to part of the *Wolston*'s. Two derelicts drifted erratically but in a general southwestward direction through the Sargasso Sea and grounded on the Bahama Islands.

Most derelicts looped as they drifted. The *Sargent* and *Wolston* made large, 500 km loops with a characteristic period of 10 months near 30°N, 40°W. Several other derelicts made frequent smaller scale loops: the *Perrotta* and *Francis* in the Sargasso Sea and the *White* east of Newfoundland.

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An example of variability of ocean surface currents is given by the drift of the bow and stern of the *Fred B. Taylor*. On June 22, 1892, the *Trave* collided with the *Taylor* and the latter was cut in two (from Pilot Chart, September 1892). The forward and after parts separated and drifted in entirely different directions (Figure 2). The bow went 340 miles during 93 days and was reported 47 times. The stern went 350 miles during 47 days and was reported 20 times. The different directions could have been partly caused by the different areas of bow and stern presented to the wind and current.

Superimposed Trajectories

A summary diagram was prepared that shows 200 derelict trajectories reported in the Pilot Charts from 1883 to 1902 (see cover). Earlier but less complete charts showing trajectories of derelicts have been given in the supplements of February 1889 and 1893 to the Pilot Charts, by the *Hydrographic Office* [1894], and by *Hautreux* [1897]. Derelict vessels which first appeared near the U.S. Coast south of Long Island and north of Cape Hatteras usually drifted in a southward direction following the inshore current until they reached Hatteras, where they entered the Gulf Stream and drifted eastward.

In general, derelicts entered the Gulf Stream north of 30°N and moved eastward in the Stream. When they reached the area south of the Grand Banks, near 40°N, 50°W, they split into two bands of trajectories. The first band reaches northeastward and then eastward, passing north of the Azores between 40° and 50°N. The second band extends southeastward and then westward near 25°N. Six derelicts moved southward between the Azores Islands and Spain and Portugal. The general pattern indicated by the collected trajectories is of a large clockwise gyre split into two branches, one branch located north of the Azores, the other southwest of the Azores. The splitting of the Gulf Stream near the Grand Banks has been confirmed by more recent measurements [*Mann*, 1967; *Clarke et al.*, 1980], but it is still controversial [*Worthington*, 1976].

Superimposed on the large-scale, long-term general circulation pattern can be seen considerable current variability. The derelicts do not often smoothly follow the large-scale gyre; instead they drift in convoluted trajectories that often cross each other. The convoluted paths give an early Lagrangian measure of mesoscale eddies and longer period current fluctuations. We now know that the ocean is populated by energetic eddies that are usually much stronger than the mean currents [*Schmitz et al.*, 1983; *Robinson*, 1983]. Recently, the importance of these eddies to the general circulation has been recognized, and they have been studied intensively. Because of these eddies, the mean circulation becomes recognizable only by averaging a great quantity of observations in space and time, as can be done by eye on the cover. In the Gulf Stream, the North Atlantic Current, and the North Equatorial Current, one clearly sees the general drift in spite of the eddies. In the Sargasso Sea the trajectories are dominated by mesoscale eddy motion.

One should be cautious about interpreting all the motion indicated by trajectories as being due to water movement. Derelict ships varied in size and weight and in state of damage when abandoned. Some were totally dismasted and filled to the gunwales with water. Along with the 30% of the sightings which were of vessels that had turned bottom up, these probably provided a good indication of the speed and trajectory of near surface water. Derelicts with masts standing and those riding high in the water would no doubt be significantly influenced by the winds blowing directly on the mast and exposed hull.

There are the additional problems of posi-

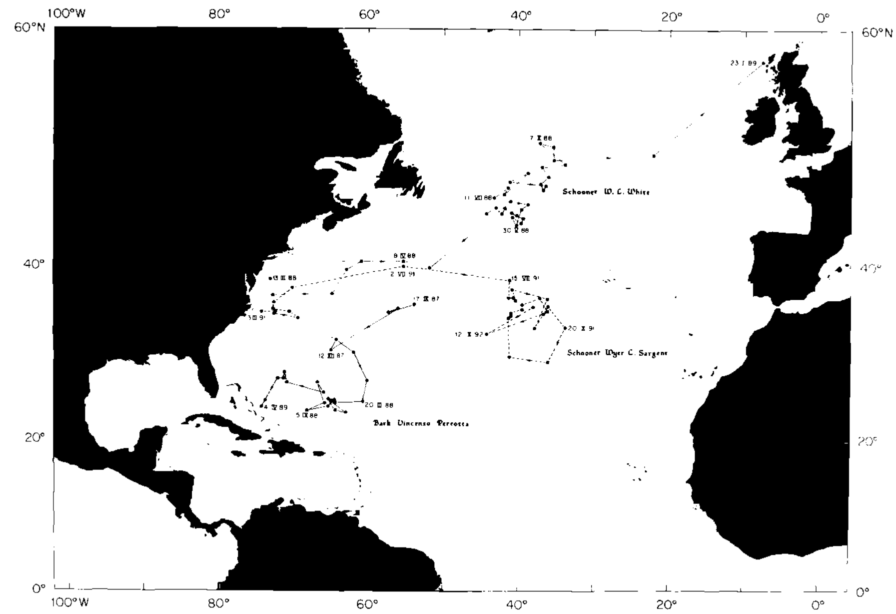

Fig. 1. Trajectories of (1) the schooner *W. L. White* from March 13, 1888, to January 23, 1889, a drift of 5,190 miles and 310 days; (2) the schooner *Wyer C. Sargent* from March 3, 1891, to December 6, 1892, a drift of 5,500 miles and 615 days; and (3) the bark *Vincenzo Perrotta* from September 17, 1887, to April 4, 1889, a drift of 2,950 miles and 536 days.

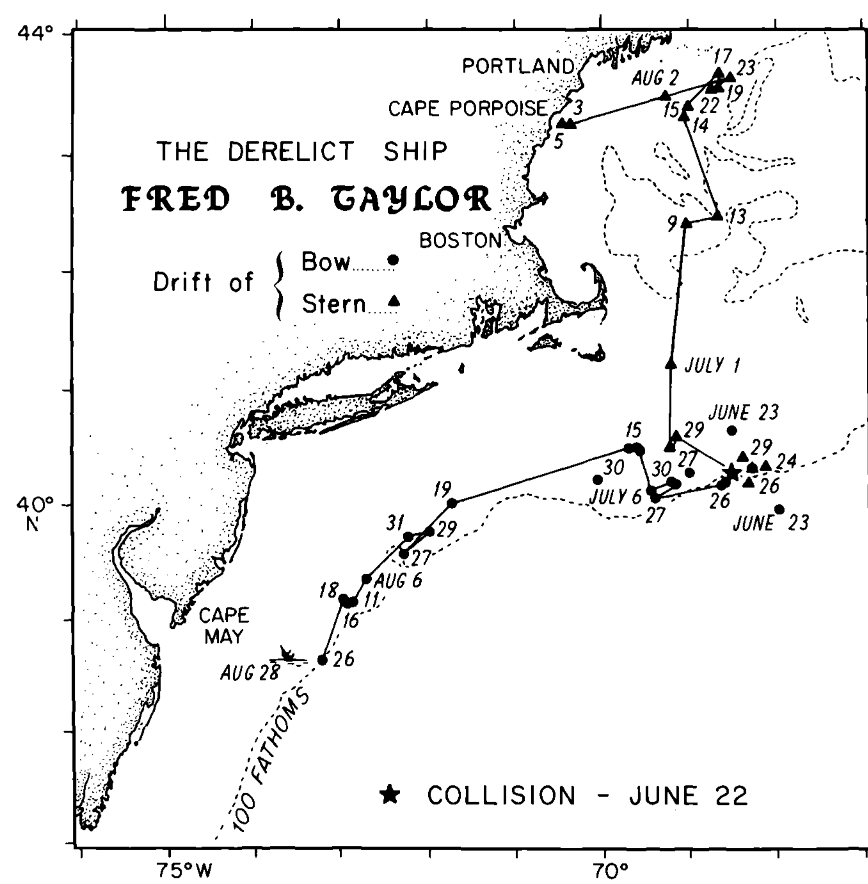

Fig. 2. Drift of the bow and stern of the *Fred B. Taylor*.

tion errors of the reporting ship, misidentification of derelicts, and infrequent sightings. It is difficult to evaluate with the available information how accurate the details of trajectories really are. The average number of days between sightings is about 20, which is sufficiently small that we can see some aspects of mesoscale eddies but not small enough except in a few occasions to resolve individual loops. Despite the lack of frequent and precise positions, the collection of the trajectories represents a realistic view of the general Lagrangian circulation and of current variability.

Within the last decade, freely drifting buoys remotely tracked by satellite have begun to be used in large numbers to measure velocities and trajectories of near-surface currents. The newer measurements have the advantage over earlier derelict trajectories of several fixes per day and a higher positional accuracy. From a collection of these measurements we have been able to obtain a more quantitative picture of aspects of the general circulation and of the geography of ocean variability. A summary figure of the buoy trajectories [*Richardson*, 1983] shows general patterns very similar to those of the derelict trajectories. If these buoys continue to be deployed in the North Atlantic we might expect that the numbers of their trajectories may eventually surpass the numbers of drifting derelict trajectories.

Derelict sightings and trajectories have been viewed here as giving interesting information about ocean currents. We should not forget that this information came with a tragic loss of life and shipping. Toward the end of the 19th century, 12,000 lives and 2,200 vessels were lost at sea each year worldwide (supplement to February 1893 Pilot Chart). Each severe storm that was encountered at sea left new derelicts in its path and added new names to the long list of vessels and men who left port but were never heard of again. The plots of derelict sightings are a sad reminder of lost vessels, suffering, and death.

Summary

Pilot Charts, published monthly during the last two decades of the 19th century, reveal a rare, interesting, and tragic glimpse of maritime history in detailing observations of drifting derelict ships. The large collecton of derelict sightings was made possible by the excellent and fast reporting system established by the Navy Hydrographic Office. Numerous voluntary observers reported dangers to navigation which were quickly incorporated into the next month's chart. By 1900, however, wooden sailing ships, which comprised most of the derelicts, had been superseded by steamers, and derelicts became infrequent.

Drifting derelicts gave some first examples of ocean trajectories. They showed the general pattern of circulation in the North Atlantic Ocean including the bifurcation of the Gulf Stream near the Grand Banks of Newfoundland. The trajectories gave an early indication of current variability. Coupled with set and drift measurements from ships underway, these derelict trajectories provided much of the early knowledge of near-surface ocean currents.

Acknowledgments

A. Green kindly made available the Defense Mapping Agency's collection of Pilot Charts, 1883–1902. Funds were provided by the National Science Foundation under grant OCE81-09145. This is an abbreviated version of a paper that discusses the same information [*Richardson*, 1984].

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Mathematical Models for Zooplankton Swarms: Their Formation and Maintenance

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Introduction

Many aquatic invertebrates are known to form swarms and schools. Thus, zooplankton are usually distributed unevenly both in vertical and in horizontal directions. There are a great number of studies on zooplankton swarms ranging from simple records or observations to more extensive functional and behavioral investigations. Yet, no attempt has been made on mathematically modeling these phenomena, chiefly because of the lack of detailed data on individual movements in swarms.

Swarms are groups of individuals engaging in more or less cohesive movements without parallel orientation. The presence or absence of parallel orientation distinguishes schools from swarms. Individual organisms in a swarm apparently exhibit irregular movements which might be regarded as random. However, random motion alone makes a group of organism spread out to occupy a larger space as time progresses (i.e., diffusion). Therefore, an adequate model for zooplankton swarming must assume certain regularities in the motion of individuals superposed upon its randomness. This deterministic part arises primarily from behavioral interactions between swarming individuals and possesses the nature of an attractive force. A swarm is maintained by the balance between the deterministic and stochastic forces. Modeling for swarm formation involves random search for prey or conspecific individuals followed by accelerated aggregation as a result of mutual communication or biological cue.

In this report we will present both kinematical and dynamical models for the maintenance and formation of swarms.

Kinematic Interpretation of Difference Between Swarming and Diffusion

We consider a simple one-dimensional case (x axis). Swarming implies randomness in motion. Thus both velocity $v(t)$ and displacement $x(t)$ of an individual in a swarm are random variables.

As a statistical measure determining the swarm dimension, the variance of the displacement is calculated by averaging the square of x over the ensemble (e.g., over a sufficiently large number of individuals in a swarm). Without loss of generality we assume that the individual organisms to start at $x = 0$ and the individual movement to be symmetrical with respect to the origin so that the swarm centroid remains at the origin. Thus, the variance of x is obtained by

$$\overline{x^2}\,(t) = \int_0^t \int_0^t \langle v(t')v(t'')\rangle dt'dt''$$

$$= 2\,\overline{v^2}t \int_0^t \tau R_L(\tau)d\tau$$

$$-2\,\overline{v^2} \int_0^t \tau R_L(\tau)d\tau \qquad (1)$$

where

$$R_L(\tau) \equiv \langle v(t')v(t' + \tau)\rangle / v^2 \qquad (2)$$

is the Lagrangian velocity autocorrelation coefficient. We have assumed that the random velocity field is stationary so that the correlation coefficient depends only on the time lag τ.

Equation (1) provides us with kinematic distinction between diffusion and swarming in terms of the velocity autocorrelation. By diffusion we mean that the individual velocity loses its statistical dependence on past velocities as the dispersion continues. In other words, $R_L(\tau)$ approaches zero at large time lags such that the both integrals in (1) converge as $t \rightarrow \infty$. We then find from (1) that as $t \rightarrow \infty$,