Oceanus®

Volume 30, Number 3, Fall 1987

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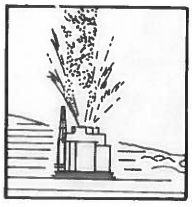
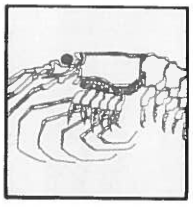
by Philip L. Richardson, and Roger A. Goldsmith

contents





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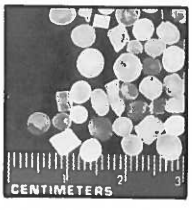

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COVER: Painting of Columbus' ships—the Pinta, Santa María, and Niña—by Richard Schlecht, courtesy of National Geographic Society. Map illustration by E. Kevin King.

 Oceanus (ISSN 0029-8182) is published in March, June, September, and December by the Woods Hole Oceanographic Institution, 93 Water Street, Woods Hole, Massachusetts 02543. Second-class postage paid at Falmouth, Massachusetts; Windsor, Ontario; and additional mailing points. POSTMASTER: Send address changes to Oceanus Subscriber Service Center, P.O. Box 6419, Syracuse, N.Y. 13217.

The first known portrait of Columbus, from the Town Hall, Genoa, Italy. (The Bettmann Archive)

The Columbus Landfall: *Voyage Track Corrected for Winds and Currents*

—Where did Columbus first land in the New World? Two oceanographers from the Woods Hole Oceanographic Institution join the debate. Their calculations point to San Salvador Island.

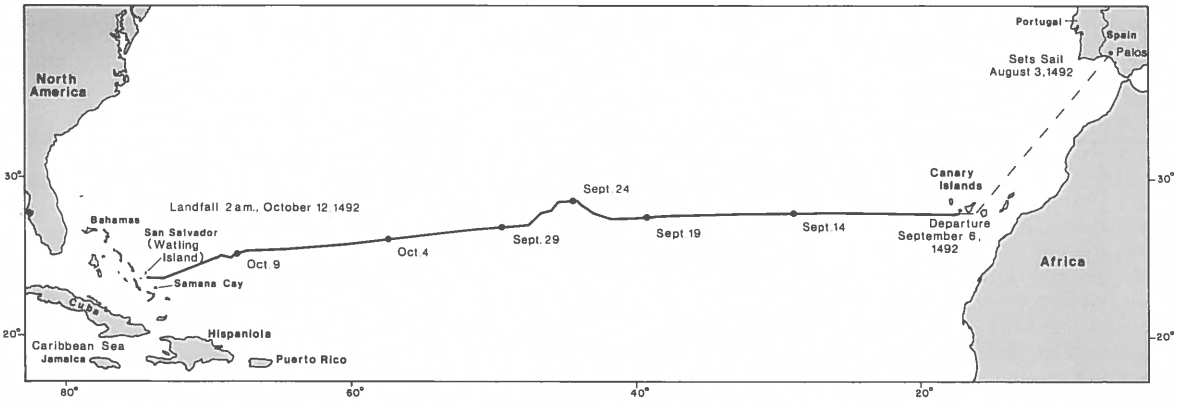
by Philip L. Richardson, and Roger A. Goldsmith

Wednesday, October 10, 1492: The 34th day at sea, sailing westward from the Canaries. The crew is complaining bitterly of the long voyage, urging their captain to head for home. Columbus promises that they will go another 44 leagues, no more.

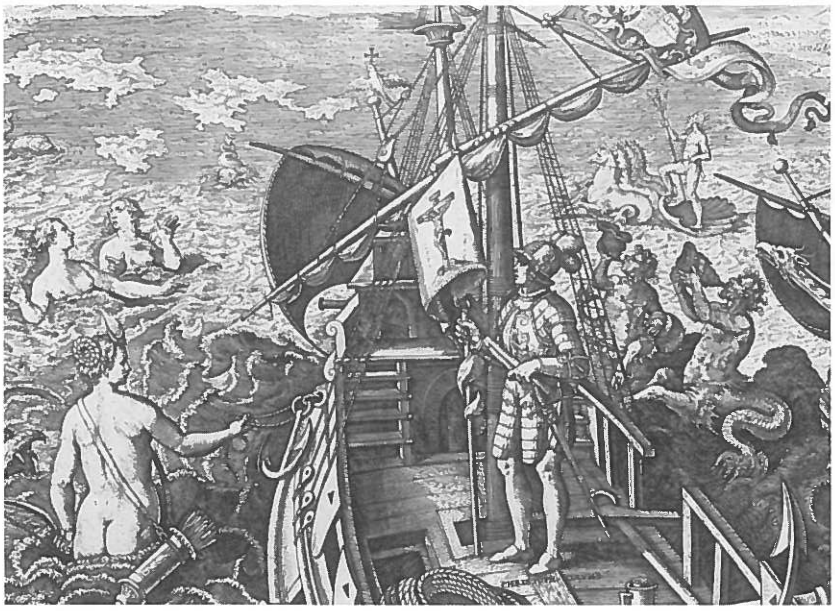
Thursday, October 11: Birds and floating sticks are sighted, hinting that land could be near. The lookouts keep an especially sharp watch that night.

2 A.M., Friday, October 12: A sailor, Rodrigo de Triana, first spies land at 2 leagues distance. The *Santa María*, *Niña*, and *Pinta* lay to waiting for daylight, and for Columbus to step ashore for the first time in the New World.

The island Columbus landed on was called Guanahani by the Indians. But just which island is it? Despite the historical significance of Columbus's first landfall, the identification of Guanahani has remained uncertain for nearly 500 years. The ambiguity of the written description of the island combined with the uncertainties of 15th century navigation has made it difficult to determine on which of the many possible Bahamian Islands Columbus landed.



With corrections for winds and currents, the computer-generated track of the 34-day voyage from the Canary Islands points to a landfall at San Salvador.



Christopher Columbus overcoming the terrors of the ocean. (Engraving by Johannes Stradanus, printed by Adrianus Collart about 1580. The Bettmann Archive)

The most recent addition to the controversy over the identity of Guanahani is a study reported by Luis Marden and Joseph Judge in the November 1986 *National Geographic* magazine. Using three main lines of reasoning, they argue persuasively that Columbus landed first on present-day Samana Cay. They claim that 1) Columbus's transatlantic voyage when corrected for wind and current ends at Samana Cay, 2) Columbus's description matches features of the island, and 3) Columbus's description of his subsequent voyage toward Cuba and among the West Indies matches real islands and sailing passages only when one starts at Samana Cay. However, many earlier geographers, including R. T. Gould, Samuel Eliot Morison, and John W. McElroy concluded that the first landfall was San Salvador (Watling Island). Others have argued that Columbus first landed as far southeast as Grand Turk Island, or as far northwest as Egg Island.

Luis Marden, however, was the first to quantitatively apply corrections for wind and current to Columbus's transatlantic voyage; this shifted the endpoint of the cruise from San Salvador to Samana Cay. There were, it seemed to us, two flaws in Marden's corrections. He applied wind corrections for the first part of the voyage in the Northeast Trades, but not for the latter part in the Southeast Trades. Second, he used speed and direction of currents given in the modern U.S. Pilot Charts. The velocity on these charts is rather schematic, but more importantly, the charted speeds are about three times larger than the appropriate values of average velocity (for explanation, see box on page 8)—the result of the charted speed being calculated using only those observations in the same general direction as the average velocity. These flaws suggested to us that Marden's result could be incorrect.

To test this idea, we assembled the best historical wind and current data available and applied corrections consistently along the whole track of the *Santa María*, Columbus's flag ship. These historical data sets were already in hand, and have been used for several years as part of our ongoing investigations into the currents and circulation of the world's oceans. All that was needed was to extract from previous compilations a detailed subset for the region to be studied.

The most significant finding is that, when winds and currents are accounted for, the end of the voyage falls within 25 kilometers of San Salvador Island. No adjustments were applied to decrease the cruise track length to match a possible first landfall as other investigators have done. The effect of the wind and current is rather small—wind shifts the cruise endpoint only 8 kilometers northwestward; current shifts it 135 kilometers westward.

Columbus's Log

To hit his expected landfall, Cipangu (Japan), and to later chart his cruise track and discoveries, Columbus paid very careful attention to his navigation; he maintained an accurate log of the steered magnetic courses of the *Santa María* and the estimated distance in leagues travelled through the water. Although the original log is lost, an abstract of a copy of it by Bartolomé de Las Casas, who was on the cruise, is extant. The navigation data was published and plotted by John McElroy in 1941, and more recently by Marden in 1986. We used Marden's value for a league, which is equal to 2.819 modern nautical miles, as well as his listed courses and distances. The departure point of the cruise was identified by McElroy as being located near 28 degrees North and 17 degrees West, southeast of the Canary Island of Gomera. For consistency with previous investigations, we used this point (as did Marden).

The landing of Columbus in the New World. (Painting by Vanderlyn, engraving by H. B. Hall. The Bettmann Archive)

Current, Wind, and Magnetic Variation

Even though at least some of the navigational information is on hand, reconstructing the ship's track, and landfall, depends heavily on external factors—the wind, currents, and magnetic variation (Figure 1). We assumed that winds and currents encountered by Columbus in September and October of 1492 did not differ appreciably from historical compilations for September and October taken during the last 50 years. Part of the justification for this is the consistency of the general climatological circulation patterns in this tradewind region of the North Atlantic. We did, however, adjust the dates of the voyage by 9 days to match the modern Gregorian calendar* used in the compilation of the modern wind and current values.

The current field was calculated using historical ship drift data obtained from the Naval Oceanographic Office.** Each ship-drift measurement of surface current velocity consists of the vector difference between the velocity of a ship determined from two position fixes and the average estimated velocity of the ship through the water during the same time interval, usually 12 to 24 hours. Because of their method of derivation, these measurements are especially appropriate for correcting the track of the *Santa María*. Vector averages were calculated from all velocity measurements in each 2-degree latitude by 5-degree longitude quadrat for September and October separately. Average velocity values were then interpolated to a 1-degree by 1-degree grid in order to have a uniform, closely spaced field for correcting the track.

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* The original Julian calendar did not appropriately match the astronomical year. During the course of 1500 years, therefore, the calendar became out of step by about 10 days. The seasons were out of skew with the calendar, affecting, for example, the planting and harvesting of crops. Therefore, in 1582 Pope Gregory XIII decreed that the day following Thursday, October 4, 1582, should be Friday, October 15, 1582—along with other calendar reforms. Since Columbus sailed 90 years before the decree, we advanced the date of the voyage by 9 days, instead of the full 10.

** Under direction of Matthew Fontaine Maury, the U.S. Naval Oceanographic Office began compiling wind and current measurements in the mid 1800s. Maury studied ship's logs and developed charts and sailing directions that were issued as a series of publications—including the first Pilot Charts. He was instrumental in systematically collecting logs from U.S. Naval ships as well as domestic and foreign merchant vessels. Free copies of the charts were given to each vessel furnishing Maury with an abstract log. The pilot charts issued today are based on the entire suite of data collected since the time of Maury.

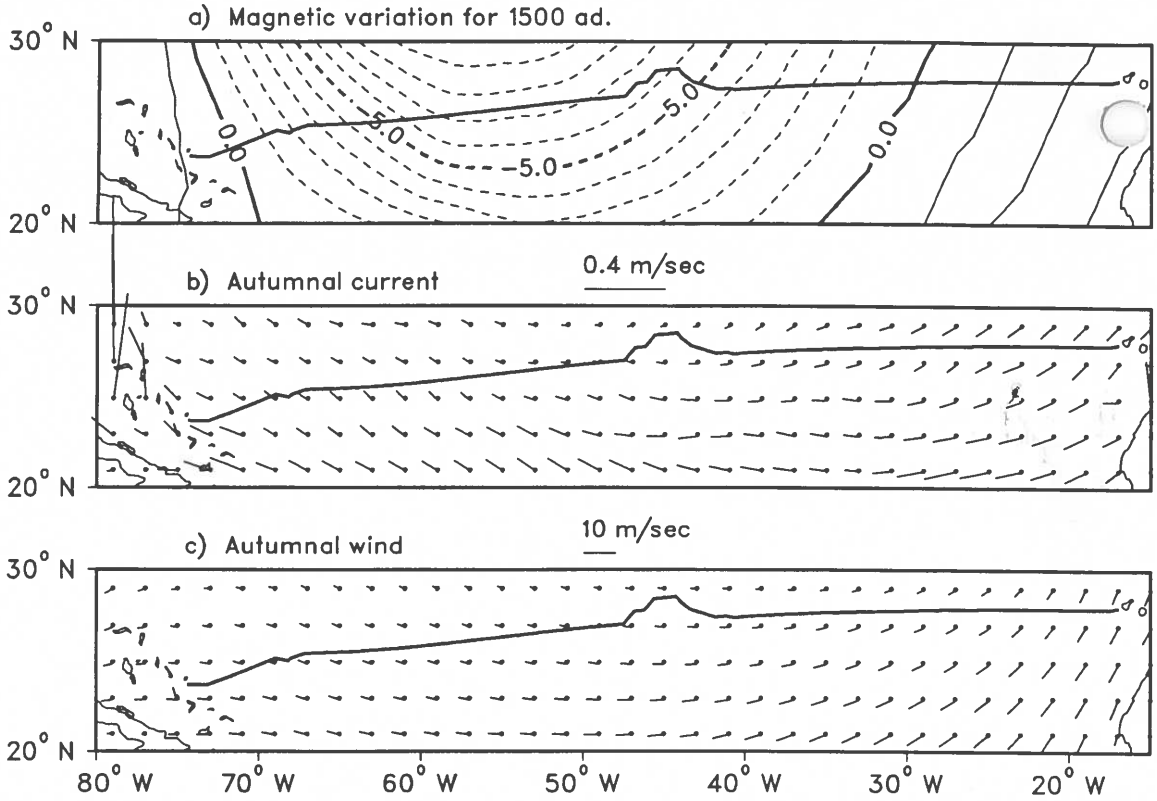


Figure 1. Corrected track of Columbus's flag ship Santa María *superimposed on maps showing a) magnetic variation for the year 1500 as charted by Van Bemmelen in 1899, b) the autumnal current field, and c) the autumnal wind field. Negative values of magnetic variation correspond to westward variations. The historical current and wind fields were vector averaged for the combined months of September and October. Wind and current measurements were obtained from ship's logs.*

Historical winds for the North Atlantic have been compiled at the Woods Hole Oceanographic Institution by Andrew F. Bunker and author Roger Goldsmith. The data were obtained from the National Climatic Center, a branch of the National Oceanic and Atmospheric Administration, which acts as collection agency for the many observations made by ships of opportunity and the merchant marine. The results of that study were further processed by Hans J. Isemer, at the University of Kiel, West Germany, to produce the data set on the 1-degree by 1-degree grid used in this study. The winds were computed using the vector averaging method for each month, September and October, separately.

The effect of the wind blowing on the *Santa María* is leeway, the sideways drift of the hull through the water. The leeway is a complicated function of the wind velocity, sea-surface condition, and the characteristics of the vessel. Today, 495 years after the voyage, the exact leeway is unknown. We therefore estimated leeway by calculating the component of wind at right angles to the steered course and by multiplying this component by an empirical factor of 0.014.* This correction for leeway is similar to Marden's during the first part of the cruise; however, we applied leeway consistently throughout the whole voyage. Even though our exact numerical value of leeway could be in error, the approximate magnitude and direction are correct. Further, subsequent tests, discussed later, show that the cruise endpoint is not very sensitive to the leeway factor. Lastly, the component of wind parallel to the course was ignored since it would vary the speed of the *Santa María*, but not the leeway, and the speed was already included in Columbus's log.

Magnetic variation, the difference between true North and magnetic North, was different in 1492 than it is today. To correct Columbus's logged magnetic courses, we used the magnetic variation for the year 1500 compiled by Van Bemmelen in 1899, and as used by both McElroy and Marden.

*Leeway can be expressed either as a sideways drift velocity or as the angular difference between a steered course and a course through the water. Our leeway factor value of 0.014 for sideways drift was calculated to be equivalent to Marden's 1.5 degree angular course difference in the northeast tradewinds off the Canary Islands.

Track of the *Santa María* and First Landfall

We calculated the track by starting near the Canary Islands at 28 degrees North and 17 degrees West on September 8, 1492 (old calendar), and advanced the *Santa María* in half-hour steps following the logged headings and distances. Every half hour, magnetic variation, wind, and current were interpolated to *Santa María's* position and corrections were applied to the next half hour of the cruise. The small time steps are necessary to reduce errors that could be introduced in interpolating wind, current, and magnetic variation over daily intervals.

At two hours after midnight, on October 12, 1492, land was sighted 2 leagues (about 10 kilometers) ahead. For that time, our best replotted position (point d on Figure 2) places *Santa María* about 24 kilometers southeast of the present island of San Salvador. Another possible island, Rum Cay, has been excluded from consideration because it does not match Columbus's written description; most previous researchers agree that Rum Cay is not the first landfall.

This result is exciting, and merits emphasis—when the *Santa María's* voyage is corrected for wind and current, it ends very close to San Salvador. All earlier attempts to replot the voyage resorted, by necessity, to adjusting *Santa María's* speed to make the end point come out right. Usually the endpoint was much too far (about 500 kilometers) to the west, and the cruise had to be artificially shortened to make the end match a possible landing site. Marden's overrun of 10 percent of the total distance was due primarily to the inflated current speeds that he used. McElroy's overrun was apparently the result of his using an incorrect length of a league. In our reconstruction, the cruise length matches almost perfectly with San Salvador. By perfectly, we mean within several kilometers out of a total cruise length of about 5,500 kilometers. It is difficult to know if this match is the result of chance, or due to Columbus's very accurate log coupled with modern corrections. Considering Columbus's careful attention to navigation, we favor the latter.

The effect of wind and current on the latitude of the endpoint is rather small. This is because the track cuts across the southern half of the North Atlantic gyre, and northward and southward deflections of the *Santa María* by wind and current nearly compensate for each other. Wind and current velocities are directed toward the Southwest during the first part of the voyage, but they swing around through West and are toward Northwest during the second part (Figure 1). Leeway alone shifts the end of the cruise 8 kilometers toward the Northwest (Figure 3). Current alone shifts the end 135 kilometers westward. Overall, the combined wind and current shifts it westward 140 kilometers, but northward only 16 kilometers.

The small deflections as the result of wind and current are in agreement with the conclusions of McElroy, but in disagreement with Marden. Marden found a much larger, 52 kilometer, southward shift. We attribute this to misuse of the pilot charts as a basis for wind and current corrections, and omission of leeway corrections west of 40 degrees West.

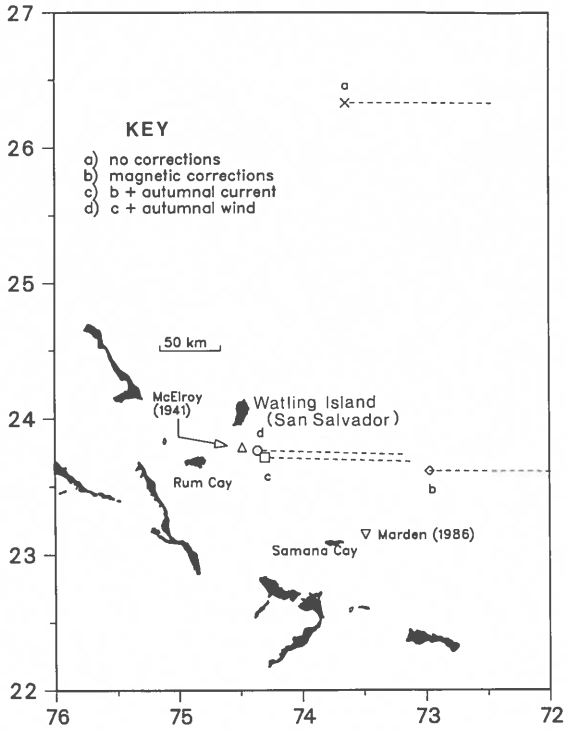


Figure 2. Endpoints of Columbus's transatlantic track showing the effect of successively adding corrections for magnetic variation, current, and leeway. Also shown are endpoints plotted by McElroy, who used no corrections for leeway or current, and Marden, who corrected for current along the whole cruise, but corrected for leeway only for the first portion of the cruise. Both McElroy and Marden resorted to backtracking the endpoint about 500 kilometers to make it match a possible landfall. Vertical axis is latitude in degrees North, horizontal axis is longitude in degrees West.

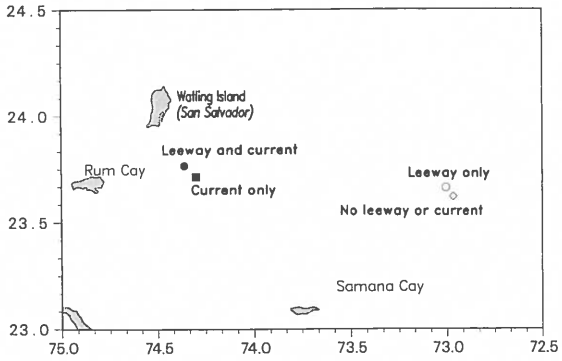


Figure 3. Expanded scale plot of cruise endpoints showing the effects of currents and leeway. Magnetic correction was applied for all cases. Vector average wind and current fields for the combined months of September and October (autumnal) were used to correct the track.

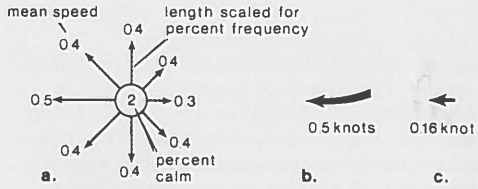
Current Calculations

Two terms—"prevailing current" and "vector average current"—can be used to describe ocean currents. In practice, the numerical values of these are calculated differently. The resulting values can also be very different.

Pilot Charts show prevailing currents, which indicate the most likely direction in which a current will flow, and the average speed of current in that direction. The prevailing current direction is the direction of the largest number of velocity observations in a certain region. The speed of a prevailing current is an average of only those observations lying within a 45-degree sector containing this direction. On the other hand, the average current is a vector average of all velocity observations in a certain region without regard for their direction.

Consider a hypothetical example, which is representative of currents in the mid-Atlantic portion of Columbus's track. In this example, the prevailing current is 0.5 knots westward, several times larger than the vector average velocity, which is 0.16 knots.

To correct a trackline for average conditions, the vector average velocity is the appropriate quantity to use. This is especially true where variations in velocity are large. Variation in velocity is a combination of real ocean fluctuations, or eddies, plus measurement errors. Random errors, which can be large in ship drift measurements, tend to cancel out in vector averages of velocity, but may not cancel in averages of speeds. Thus, part of the difference between the speed of prevailing currents and that of vector averages could be due to measurement errors.



Current depiction: a) "Current rose" representative of the mid-Atlantic portion of Columbus's track. The variability of currents in this region is shown by displaying the percentage of current velocities lying in each of the 8 principal directions, and the average speed in each direction. This information can be summarized in two additional ways: by b) a prevailing current, as shown on the Pilot Charts, which is the direction in which the largest percentage of velocity observations lie and the average speed in this direction—0.5 knots westward in the present example; and c) a vector average velocity of all velocity observations in a certain region—0.16 knots westward in this example.

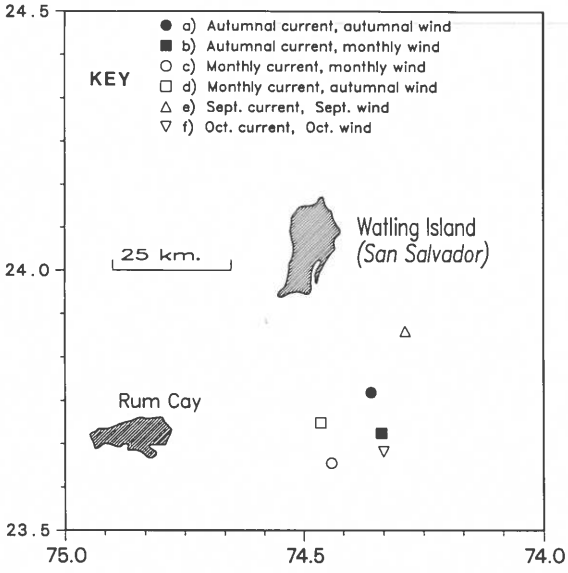


Figure 4. Cruise endpoints determined by using different wind and current fields. Autumnal is used to signify averages over September and October. Monthly means that September fields were used for the September portion of the cruise, October fields for the October portion. A leeway factor of 0.014 was used for all cases.

Examining the Results

With our first computer-generated track in hand, and the tentative conclusion that San Salvador was indeed the landfall, we next sought to critically examine what we had done. In generating our first track, a number of decisions were made about the variables involved, and "best estimates" were made for some of the unknowns. Would different choices change the outcome?

We think that the most representative wind and current fields for the Columbus voyage are given by averages of the combined months of September and October, called autumnal here (Figures 1 and 2). This is because the cruise overlapped both months. To study how the seasonally varying winds and currents would affect the track, we recalculated it using various combinations of different months (Figure 4). All values of the cruise endpoint fall within a circle 16 kilometers in radius, the center of which lies virtually on top of the autumnal endpoint adopted as our best case. A remarkable result is that there really is not much variation in position attributable to different wind and current fields. All tracks favor San Salvador; none of the endpoints lie close to Samana Cay.

The relative importance of the numerical value of the leeway factor was studied by recalculating the track with various values ranging from zero to 0.020 (Figure 5). Increasing the leeway

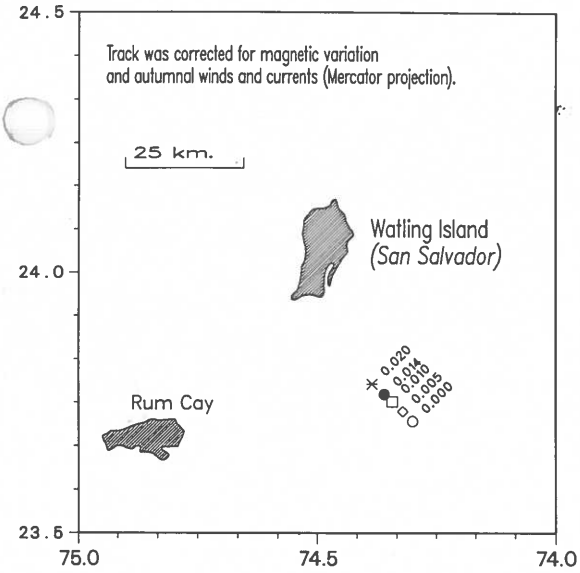


Figure 5. Cruise endpoints showing the effect of varying the leeway factor. The cruise track was corrected for magnetic variation and autumnal (September and October) wind and current.

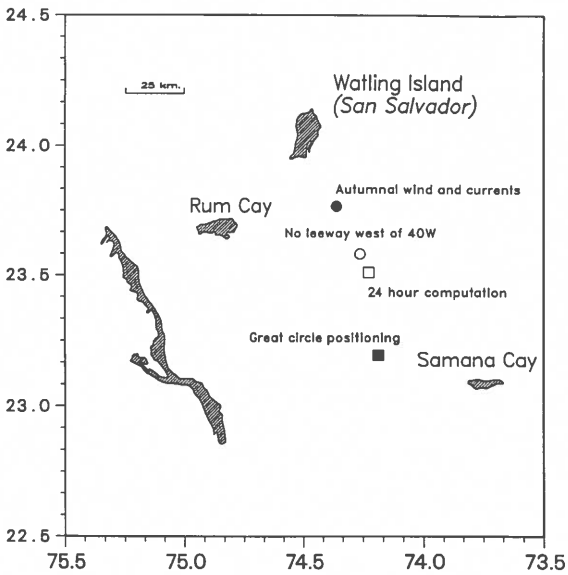


Figure 6. Cruise endpoints showing the effects of Marden's calculations; the progressive effects of removing leeway west of 40 degrees West, using a one day computation interval, and using a great circle positioning. Magnetic corrections and a leeway factor of 0.014 were used in all cases.

factor shifts the endpoint northwestward toward San Salvador, but the shift is rather small, 12 kilometers for the full range considered here. Thus, if we have underestimated the leeway factor, the error is probably small, and would tend to make the endpoint lie even closer to San Salvador. The northwestward shift with increasing leeway factor clearly shows the influence of the Southeast trade winds in the western Atlantic, which would set the *Santa María* northwestward. Thus, one cannot assume, as did Marden, that no leeway occurs west of 40 degrees West.

When we included the leeway correction only east of 40 degrees West to simulate Marden's calculation, the endpoint is shifted about 23 kilometers toward Samana Cay. What then causes the remainder of the distance toward Samana Cay that Marden shows? The difference could be accounted for in part by the daily computation intervals that he used. It is also important that rhumbline positioning* and not great circle positioning be used when computing positions for time intervals of this magnitude. When we recalculated the track using Marden's 1) leeway only east of 40 degrees West, 2) great circle positioning, 3) daily time steps, *but* 4) our vector-averaged currents, the endpoint is shifted southward 65 kilometers (from our endpoint), to lie 39 kilometers west-northwest of Samana Cay (Figure 6). This is almost due west of Marden's endpoint, which he shifted eastward to match a first possible landfall.

While several factors have a rather small role, the cruise track depends heavily on the magnetic variation. For example, when the track is recalculated with a zero magnetic variation, instead of the Van Bemmelen field for 1500 A.D., the cruise ends 300 kilometers northward, implying an eventual landfall on Great Abaco Island (Figure 2). If this had been the real track, presumably the 44 leagues Columbus promised his men would have been exceeded before reaching land, and his mutinous crew would have forced him to turn East toward Spain. Viewed from the Canary Islands the angle between the two islands San Salvador and Samana Cay is only about 1 degree. This means that to accurately pick one of these as the landfall based on the track of the *Santa María*, her average course and the average magnetic variation need to be known to better than ±1 degree. We suspect that neither the course nor magnetic variation for 1492 are that accurate, which implies that there remains a large uncertainty in our conclusion that San Salvador was Columbus's first landfall.

To further demonstrate the key role of magnetic variation, we retracked the cruise with modern values of magnetic variation which are about 15 degrees West. The track is shifted far to the south, and passes between the islands of Antigua and Guadaloupe in the Antilles (Figure 7). In fact, Columbus was aiming for Cipangu (Japan), which he

* Rhumbline positioning approximates the track of a vessel following a constant course on a spherical surface—the ship's track crosses all meridians at the same angle. A vessel sailing due West will remain at the same latitude at which it started. Great circle positioning results in a track along which the course will vary—sailing along the arc of a great circle is often the shorter route. A vessel starting out with a course due West along a great circle track would soon find itself on a course south of West (in the Northern Hemisphere) and south of the latitude at which it started. For small distances, such as those covered in a half-hour sail, the rhumbline and the great circle track are nearly the same. For a 24-hour period, however, the endpoints may be several kilometers different.

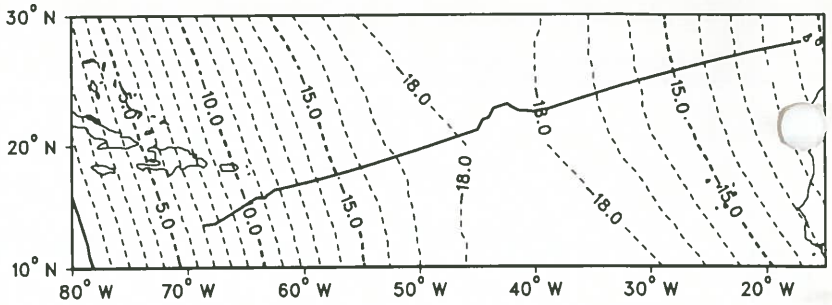


Figure 7. Hypothetical track using 1980 magnetic variation field, demonstrating the key role of magnetic variation in determining the cruise track. Negative values indicate westerly variation. Wind and leeway corrections were not included. The cruise track cuts between Antigua and Guadaloupe in the Antilles, the first possible landfalls.

thought was due West of the Canaries. Had the magnetic variation been as large as today's values, he might have compensated by steering north of magnetic West. Whether or not he tried to compensate for the smaller 3 degree West real variation on his voyage is not entirely clear.

Summary

We think that our corrections to Columbus's first voyage have helped improve our knowledge of his real track and first landfall. Our cruise endpoint matches very closely with San Salvador, suggesting that this island was his first landing in the New World. The differences between our endpoint and Marden's near Samana Cay were explored and explained as being due to Marden's partial leeway corrections, his daily time steps, and his inflated current speeds. We found the track depends critically on magnetic variation, which is rather poorly known for 1492. Further work validating Van Bemmelen's magnetic variation map could lead to a better track. A real improvement in the reconstructed track and a final resolution of the landfall question may have to wait until Columbus's original log is discovered. The original log would help clear up inconsistencies and gaps in the Las Casas version.

The analysis presented here considered only the transoceanic portion of the voyage. Marden and Judge also match Columbus's description of Guanahani with Samana Cay and his subsequent voyage to other Bahama Islands. The complete suite of information needs to be considered before the first landfall can be identified unequivocably.

Philip L. Richardson is an Associate Scientist in the Department of Physical Oceanography, Woods Hole Oceanographic Institution. Roger A. Goldsmith is a Research Specialist in the Department of Ocean Engineering at WHOI.

Acknowledgments

Funding was provided by National Science Foundation Grant OCE85-14885. Contribution 6561 from the Woods Hole Oceanographic Institution. The Judge and Marden provocative articles stimulated our interest in the Columbus voyage. Colleen Hurter helped find early studies of the first landfall, Terry McKee calculated the ship-drift current vectors, and Mary Ann Lucas typed the manuscript.

Selected References

Gould, R. T. 1927. The landfall of Columbus: an old problem restated. *Geographical Journal 69:* 403–429.

Judge, J. 1986. Where Columbus found the New World. *National Geographic 170:* 567–599.

Marden, L. 1986a. The first landfall of Columbus. *National Geographic 170:* 572–577.

Marden, L. 1986b. Navigation data from the Atlantic Passage: entries in the Columbus Log. In: *A Columbus Casebook, A Supplement to "Where Columbus Found the New World,"* pp. 48–50. Washington, D.C.: National Geographic Society.

McElroy, J. W. 1941. The ocean navigation of Columbus on his first voyage. *The American Neptune I:* 209–240.

Morison, S. E. 1942. *Admiral of the Ocean Sea, a Life of Christop Columbus.* 680 pp. Boston: Little, Brown & Co.

Van Bemmelen, W. 1899. Die abweichung der magnetnadel. In, *Supplement to Observations of the Royal Magnetical and Meteorological Observatory at Batavia* 21. Batavia.