

ably the one that showed a 200-meter high in the cruise of Figure 6.

The next chart of the sequence, Figure 8, shows the flow for February 1966. The east gulf loop now passes at least 370 km north of the Yucatan Channel before turning. At this position the observations are subject to several different interpretations. The variations along the north-northwesterly line could be taken to show a small separate eddy north of the main loop, or they could be fitted into a twisting of the main loop either to the east or to the west. To aid in deciding which of these descriptions was most plausible, the more broadly representative topography of the 20° isothermal surface was also drawn. This method favored the selection of a twist toward the east and return, which

was then used in analyzing Figure 8. The 20° topography was also useful in indicating the position of 22° surfaces in the west gulf leg.

On the 20° and 22°C patterns for February 1966, as indicated for example by the 100-meter contour, it appears that some of the water transported through the Yucatan Channel into the loop turned westward and moved clockwise around the west gulf before rejoining the loop. Computations of transport show that 12 million m³/sec branched westward.

The current pattern for June 1966 is presented in Figure 9. It is from a cruise directed by Nowlin and Reid and used by *Hubertz* [1967] (as a basis for his thesis under the direction of Nowlin). The eastern gulf loop was oriented at this time in a direction similar to

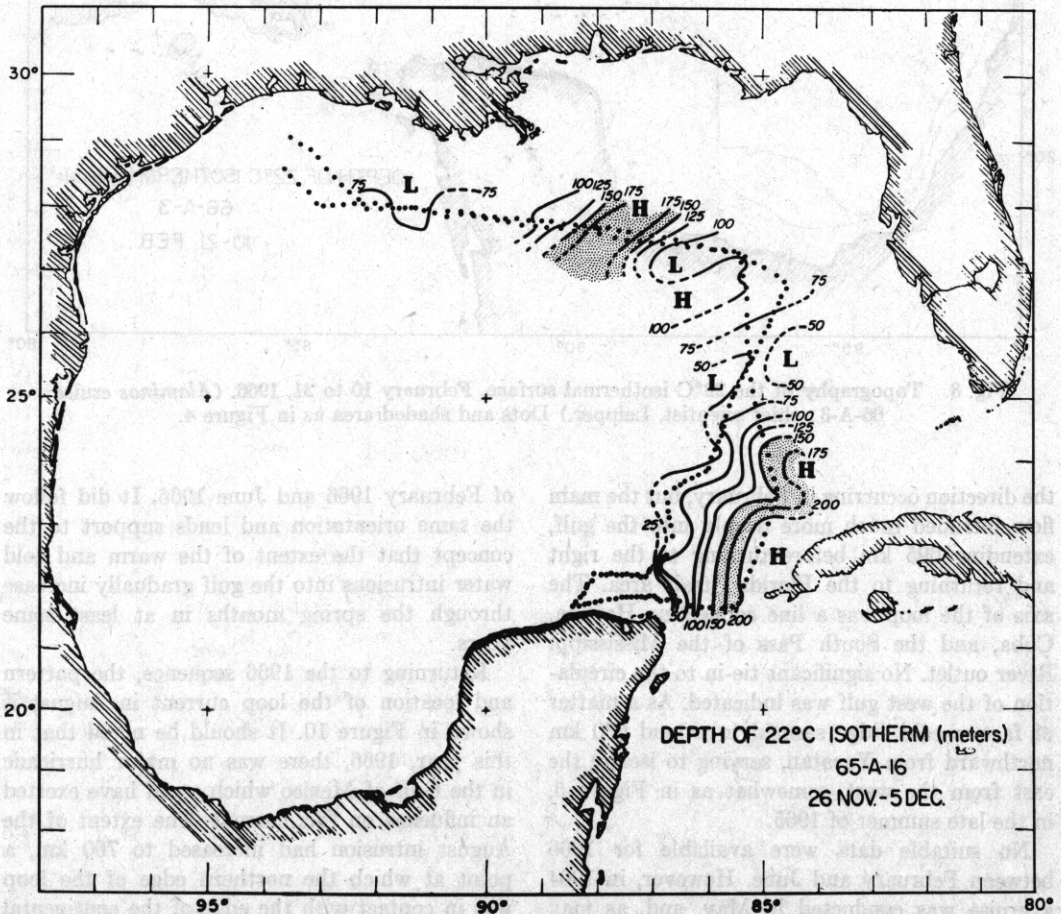


Fig. 7. Topography of the 22°C isothermal surface, November 26 to December 5, 1965. (*Alaminos* cruise 65-A-16; chief scientist, Cochrane.) Dots and shaded area as in Figure 4.

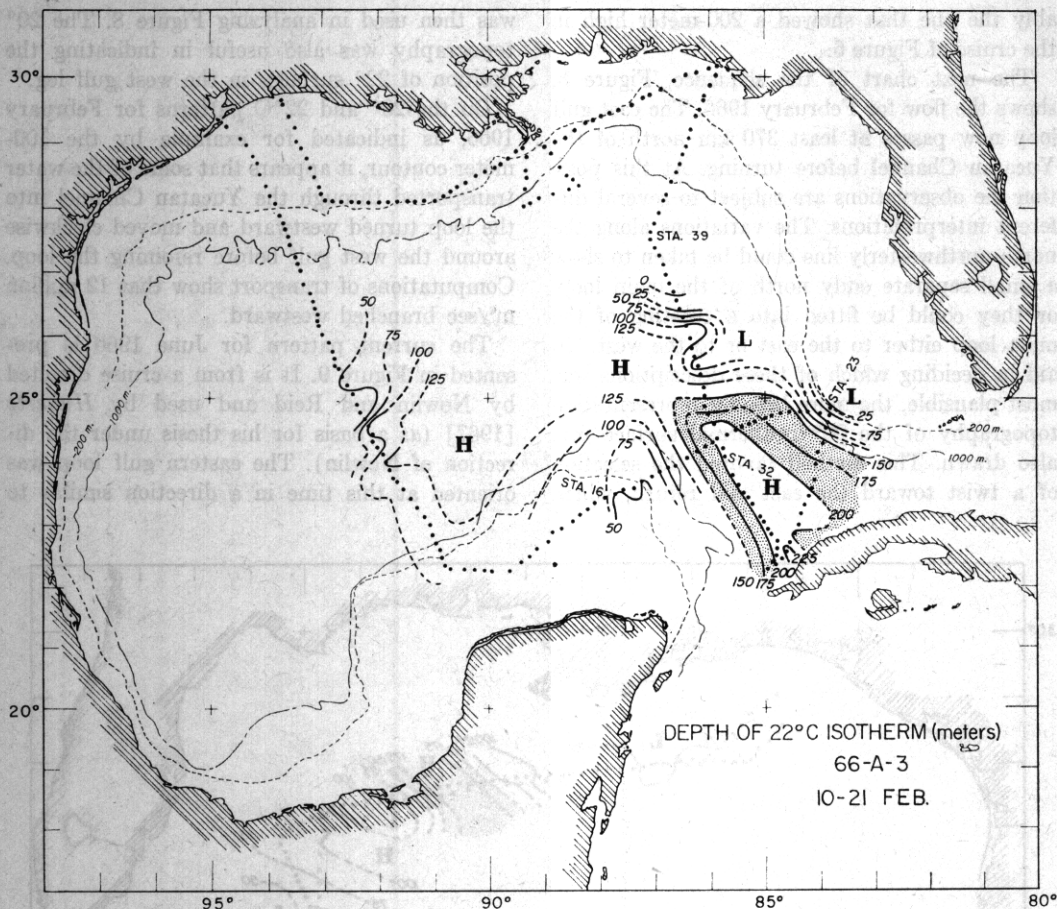


Fig. 8. Topography of the 22°C isothermal surface, February 10 to 21, 1966. (*Alaminos* cruise 66-A-3; chief scientist, Leipper.) Dots and shaded area as in Figure 4.

the direction occurring in February, but the main flow intruded much more deeply into the gulf, extending 695 km before turning to the right and returning to the Florida Strait area. The axis of the loop was a line connecting Havana, Cuba, and the South Pass of the Mississippi River outlet. No significant tie-in to the circulation of the west gulf was indicated. As a matter of fact, a cold ridge seemed to extend 630 km northward from Yucatan, serving to isolate the east from the west, somewhat as in Figure 5, in the late summer of 1965.

No suitable data were available for 1966 between February and June. However, in 1964 a cruise was conducted in May, and, as may be seen in Figure 14, the extent of the intrusion of the loop was intermediate between that

of February 1966 and June 1966. It did follow the same orientation and lends support to the concept that the extent of the warm and cold water intrusions into the gulf gradually increase through the spring months in at least some years.

Returning to the 1966 sequence, the pattern and location of the loop current in August is shown in Figure 10. It should be noted that in this year, 1966, there was no major hurricane in the Gulf of Mexico which could have exerted an influence on this current. The extent of the August intrusion had increased to 760 km, a point at which the northern edge of the loop was in contact with the edge of the continental shelf off the Mississippi River delta. Irregular portions of the isothermal pattern here are

probably due to the effects of bottom topography. The north end of the axis of the loop had now shifted toward the west and an important change had occurred at a latitude of approximately 25°N . A relatively narrow neck had formed at the midsection of the loop. (The cruise plan was altered so that a section could be run through the neck to better define it.) A cold ridge again extended across the gulf from Yucatan north-northwestward. It also tended to the northeast and it appeared off the Florida shelf, but it did not cut completely through the warm basin as it had in August 1965 (Figure 5). It was still an important feature.

The final figure for the 1965-1966 sequence represents a cruise in late October and early November (Figure 11). Several noticeable changes are evident from the August 1966 cur-

rent pattern. The northern end of the axis of the loop has swung more toward the west. The cold water ridge from Yucatan extends less than halfway northward across the mid-gulf, but its northeastward branch is again reflected off the Florida shelf. Although the extent of the warm intrusion has not decreased, the current is somewhat weaker and less well defined in the western branch. Indications are that the two portions of the loop are still connected by a narrow neck, but the observations are not sufficient to guarantee that this was the case. The flow approaching the Florida Strait comes very close to the coast of Cuba before turning, and a portion of this flow in the south end of the lower loop seems to pass toward the west making a closed eddy within this end of the loop.

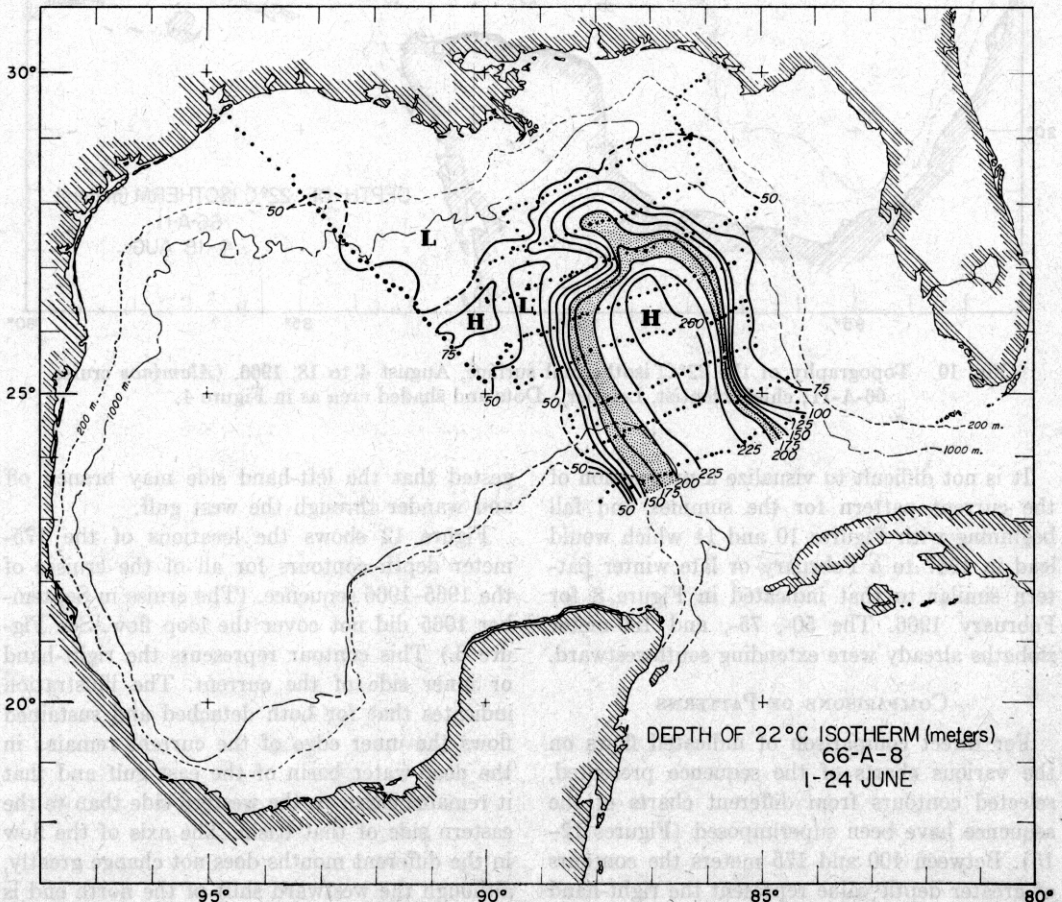


Fig. 9. Topography of the 22°C isothermal surface, June 1 to 24, 1966. (Alaminos cruise 66-A-8; chief scientists, Reid and Nowlin.) Dots and shaded area as in Figure 4.

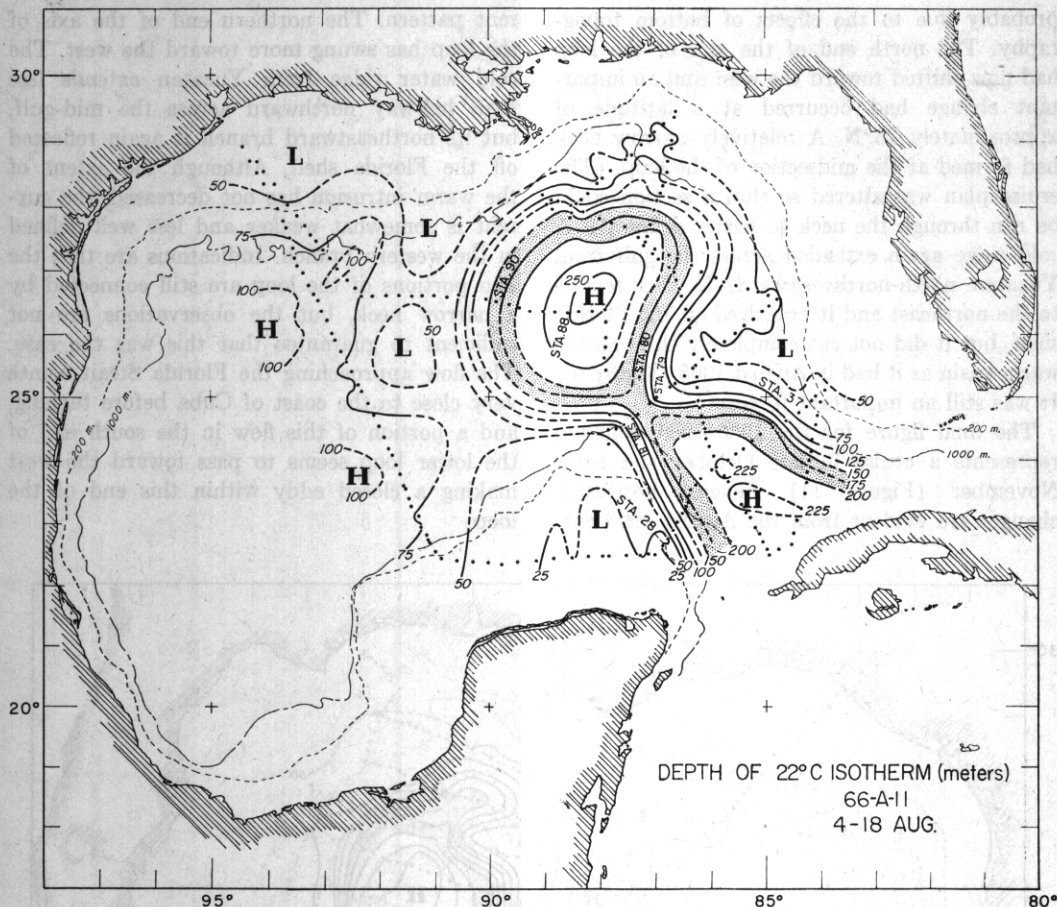


Fig. 10. Topography of the 22°C isothermal surface, August 4 to 18, 1966. (Alaminos cruise 66-A-11; chief scientist, Leipper.) Dots and shaded area as in Figure 4.

It is not difficult to visualize a progression of the current pattern for the summer and fall beginning with Figures 10 and 11 which would lead in 1967 to a February or late winter pattern similar to that indicated in Figure 8 for February 1966. The 50-, 75-, and 100-meter isobaths already were extending southwestward.

COMPARISONS OF PATTERNS

For direct comparison of indicated flows on the various charts of the sequence presented, selected contours from different charts of the sequence have been superimposed (Figures 12-15). Between 100 and 175 meters the contours of greater depth value represent the right-hand side of the current and those of lesser value represent the left-hand side. It has been sug-

gested that the left-hand side may branch off and wander through the west gulf.

Figure 12 shows the locations of the 175-meter depth contours for all of the cruises of the 1965-1966 sequence. (The cruise in September 1965 did not cover the loop flow. See Figure 6.) This contour represents the right-hand or inner side of the current. The illustration indicates that for both detached and sustained flows the inner edge of the current remains in the deep-water basin of the east gulf and that it remains closer to the western side than to the eastern side of that basin. The axis of the flow in the different months does not change greatly, although the westward shift of the north end is apparent for the late 1966 flow.

The cold ridge during the sequence of cruises

was indicated by the appearance of the 22°C isotherm at depths less than 50 meters. This contour might be thought of as the outer edge of the loop flow when it is associated with that flow. Figure 13 is a superpositioning of the 50-meter contours for all cruises of the series. It is apparent that the cold ridge never crossed the center of the deep east gulf basin except the one time that it extended completely across the lower portion of the basin in August 1965. It was very narrow at this time. However, extensions of the ridge toward the basin occur in several places (off the Florida shelf at latitude 26°, off the Louisiana coast south-southwest of the Mississippi delta, and north-northwest of the Yucatan peninsula), and each extension is indicated on several cruises. The extension of

the ridge northward and almost across the gulf is indicated at times.

Reference to the individual cruise charts (Figures 4-11) will show the distributions of observations. These must be kept in mind in interpreting all figures. For example, in Figure 13 no cold ridges are shown in the extreme western gulf, but none of this series entered that area.

In Figure 14 contours have been superimposed from four consecutive cruises beginning in November 1965 and ending in August 1966. This sequence has been called the spring intrusion. The gradual development of the loop can be seen in the figure.

Figure 15 is for the fall-winter period and is based on the 100-meter contours of the 22°C

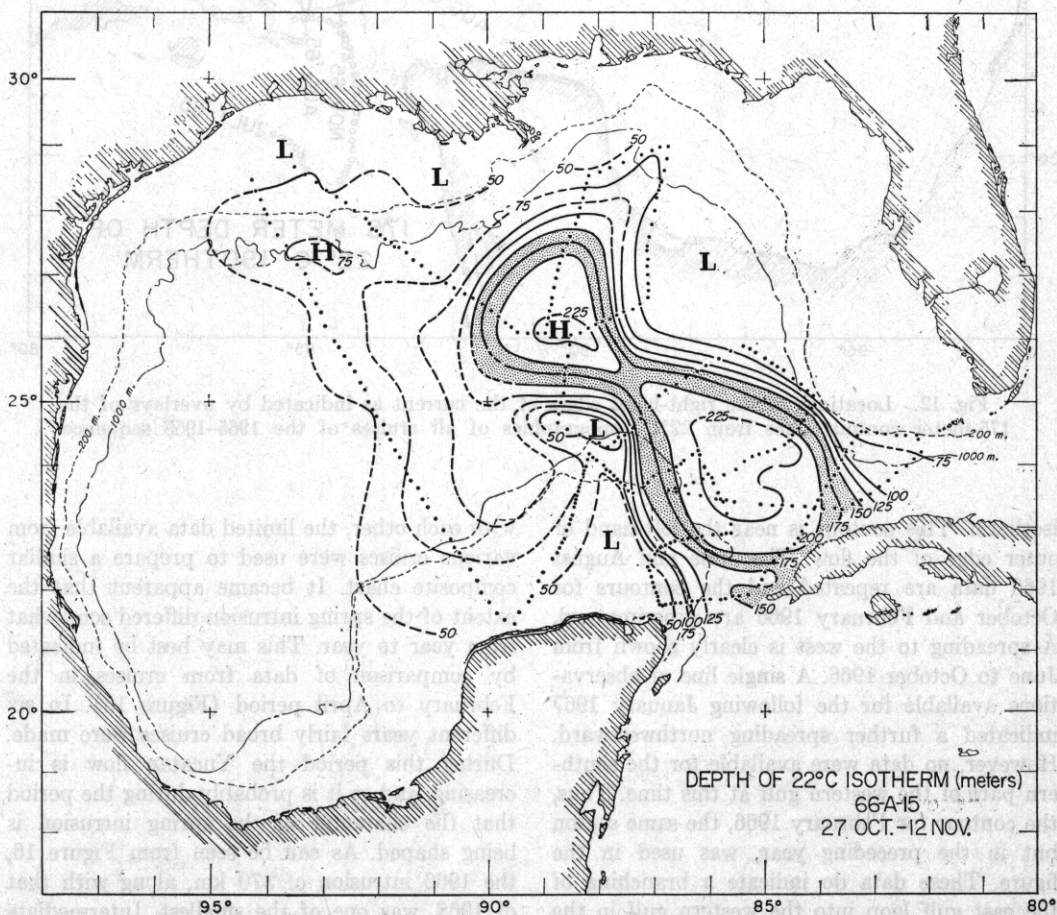


Fig. 11. Topography of the 22°C isothermal surface, October 27 to November 12, 1966. (*Alaminos* cruise 66-A-15; chief scientists, Leipper and Cochrane.) Dots and shaded area as in Figure 4.

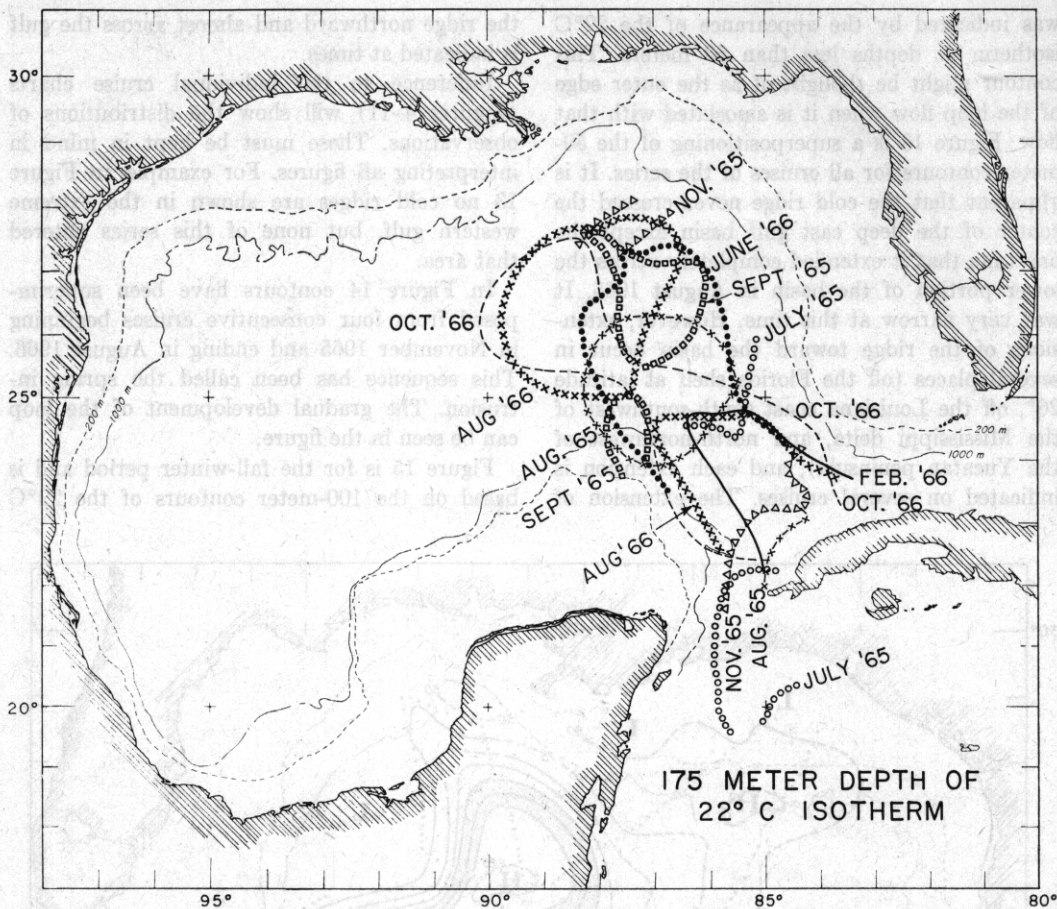


Fig. 12. Locations of the right-hand edges of the current as indicated by overlays of the 175-meter contour lines from 22°C topographies of all cruises of the 1965-1966 sequence.

isotherm. This contour is near the left-hand or outer edge of the flow. The June and August 1966 data are repeated and the contours for October and February 1966 are superimposed. A spreading to the west is clearly shown from June to October 1966. A single line of observations available for the following January 1967 indicated a further spreading northwestward. However, no data were available for the southern part of the western gulf at this time. Thus, the contour for February 1966, the same season but in the preceding year, was used in the figure. These data do indicate a branching of the east gulf loop into the western gulf in the fall.

To investigate how different years compared

with each other, the limited data available from various cruises were used to prepare a similar composite chart. It became apparent that the extent of the spring intrusion differed somewhat from year to year. This may best be indicated by comparison of data from cruises in the February to April period (Figure 16). In six different years fairly broad cruises were made. During this period the Yucatan flow is increasing, and so it is probably during the period that the character of the spring intrusion is being shaped. As can be seen from Figure 16, the 1966 intrusion of 370 km, along with that of 1968, was one of the smallest. Intermediate intrusions (460 km) were observed in 1932 and 1962, and more extensive intrusions (590 km)

appeared in 1935 and 1967. Differences in the months in which observations were made account for some but not all of the variation.

A check of the dates on which stations determining the location of the northern end of the intrusion were made shows that the 1966 and 1968 northern limits were observed about February 14 and 20, respectively. These were the smallest intrusions and the earliest dates. At the other extreme, the 1935 northern limit was observed in late March, or early April, and that of 1967 was observed between March 23 and 31. Thus, the observations in the 2 years having the smallest intrusions were made roughly 6 weeks earlier than those in the 2 years having the deepest intrusions. The deepest intrusions extend approximately 220 km mi fur-

ther into the gulf than those of 1966 and 1968, the smallest intrusions.

The 1932 and 1962 intrusions limits were observed in early April and between February 18 and March 7, respectively. The 1962 intrusion is thus intermediate between the two extremes, as might be expected, but the 1932 position shows less intrusion than the two others (1935 and 1967) observed in late March and early April.

From Figure 14 the over-all rate of intrusion growth from December through August appears to be about 65 km per month. It might be expected to be greatest in the middle of this period when the Yucatan speed of inflow is greatest. The difference between the 1966-1968 and the 1935-1967 intrusions, being about 6

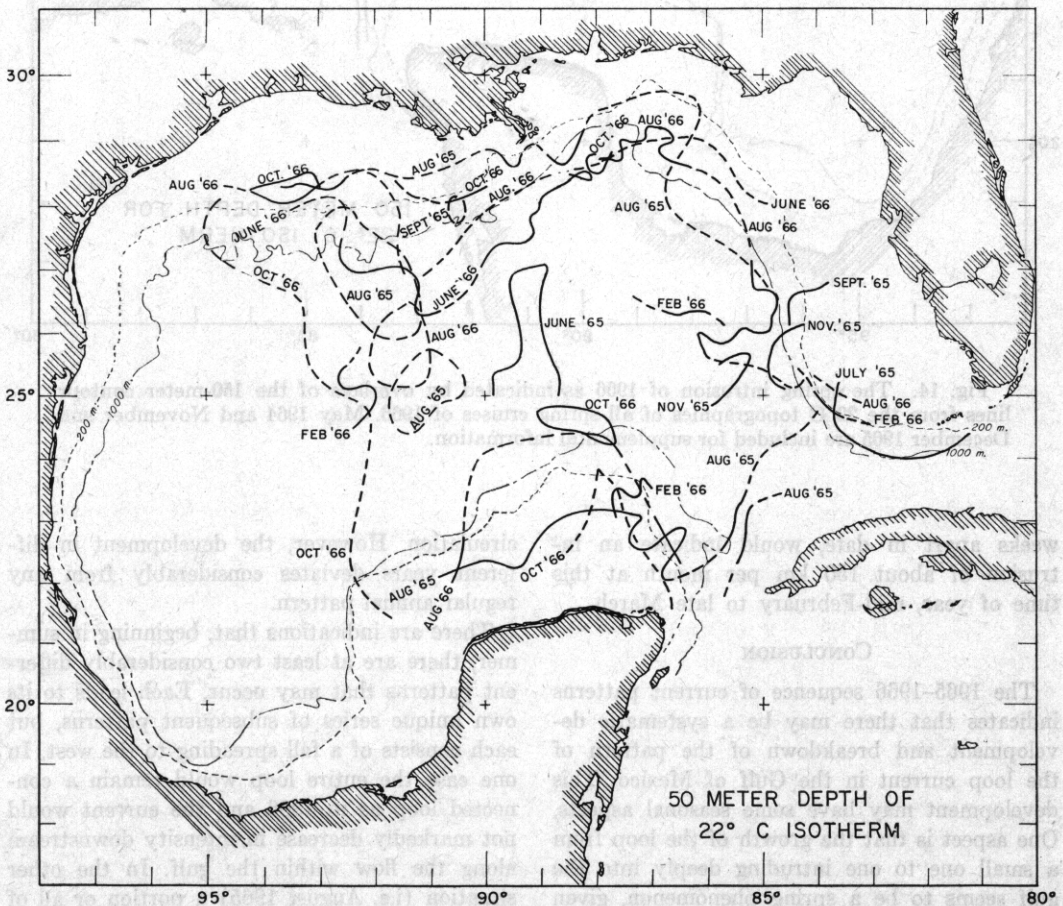


Fig. 13. Location of the 'cold ridge,' as indicated by overlays of the 50-meter contour lines from the 22°C topographies of all cruises of the 1965-1966 sequence.

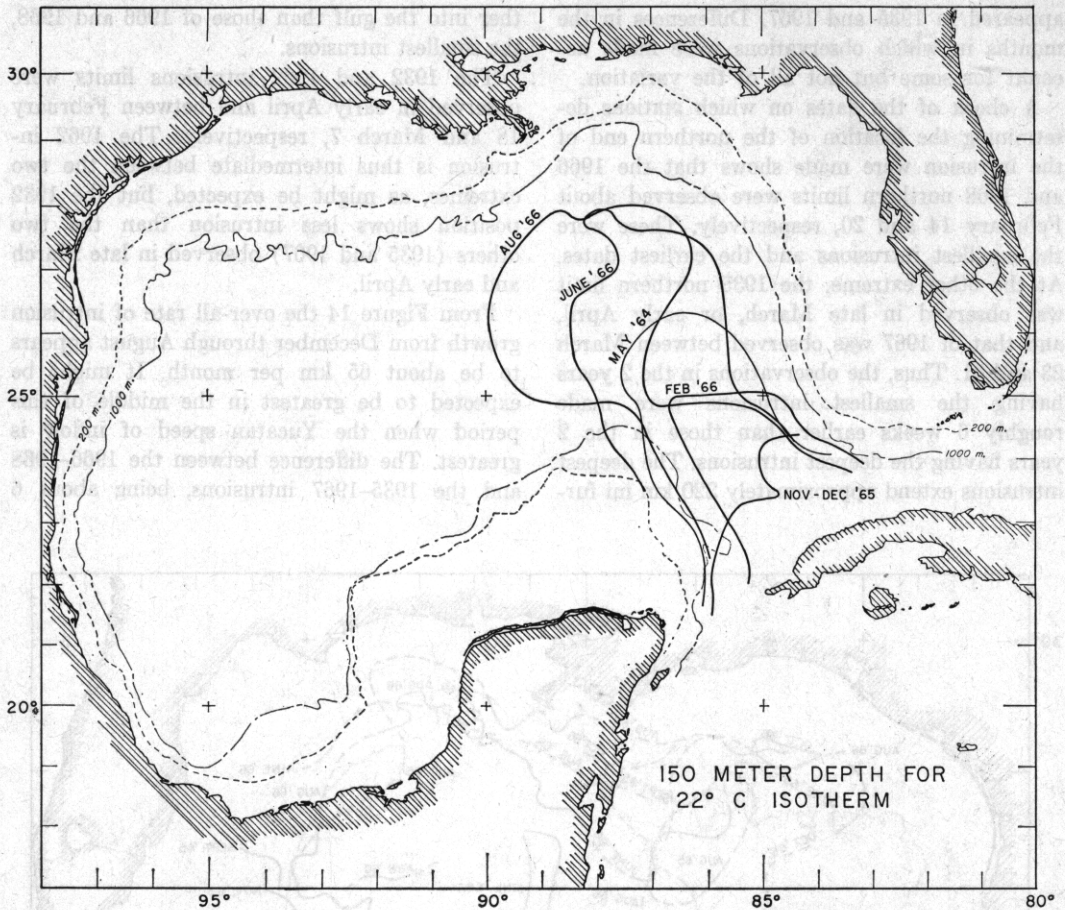


Fig. 14. The spring intrusion of 1966 as indicated by overlays of the 150-meter contour lines from the 22°C topographies of all spring cruises of 1966. May 1964 and November and December 1965 are included for supplemental information.

weeks apart in date, would indicate an intrusion of about 150 km per month at this time of year, mid-February to late March.

CONCLUSION

The 1965-1966 sequence of current patterns indicates that there may be a systematic development and breakdown of the pattern of the loop current in the Gulf of Mexico. This development may have some seasonal aspects. One aspect is that the growth of the loop from a small one to one intruding deeply into the gulf seems to be a spring phenomenon, given the name spring intrusion. Another is that the winter cooling of the northern gulf affects the

circulation. However, the development in different years deviates considerably from any regular annual pattern.

There are indications that, beginning in summer, there are at least two considerably different patterns that may occur. Each leads to its own unique series of subsequent patterns, but each consists of a fall spreading to the west. In one case the entire loop would remain a connected loop as in 1966 and the current would not markedly decrease in intensity downstream along the flow within the gulf. In the other situation (i.e. August 1965) a portion or all of the upper part of the loop may break off from its feeder current. In this case it is likely that

the isolated or partly isolated eddy would decrease in intensity and shift in position, probably toward the west.

It is to be expected that opportunities for the synoptic coverage of the currents in the Gulf of Mexico will increase in the future. At this writing several subsequent cruises have been made which will extend the present series. Detailed cooperative ship surveys and studies are being planned. Anchored buoy networks are becoming practical. Aircraft and spacecraft tracking of currents is being accomplished. Also, as more knowledge is gathered about the nature of the currents and the various means of identifying them, currently available information such as sea temperature data from Bathy messages (radio transmissions of BT

data) and from the merchant vessels as reported on weather teletypes will become more meaningful and useful. Meantime, it is hoped that these preliminary and sketchy results for the deep-water portion of the Gulf of Mexico will be of some value for immediate application and will serve as a basis for better planning of future work.

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It should be mentioned that further detail and additional preliminary discussion on this topic is

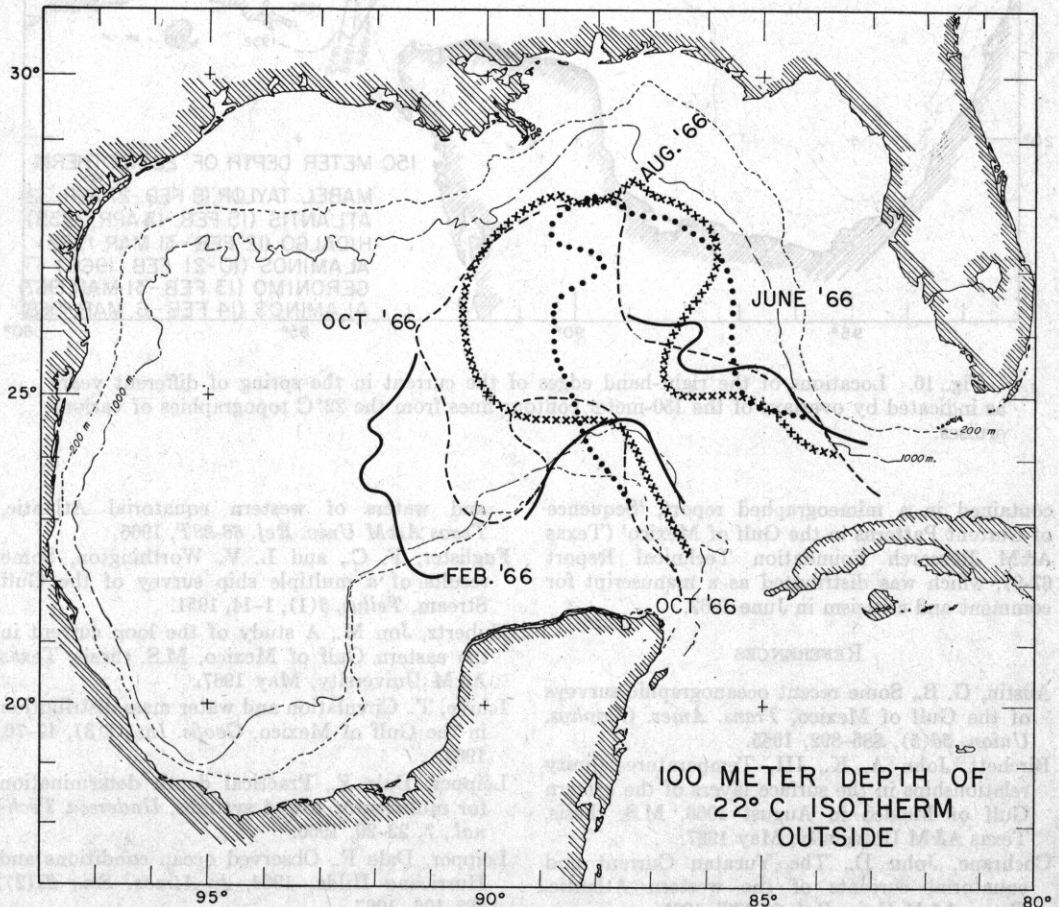


Fig. 15. The fall spreading in 1966 as indicated by overlays of the 100-meter contour lines from the 22°C topographies, with February 1966 added.

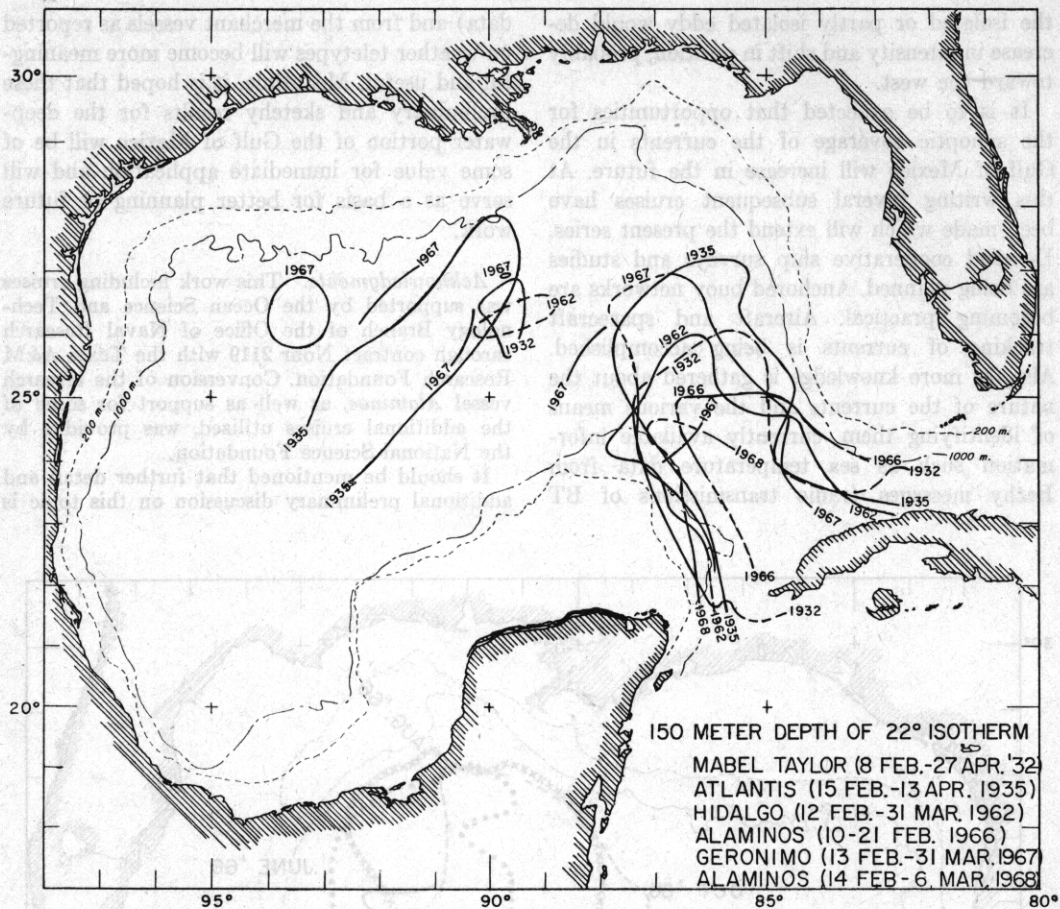


Fig. 16. Locations of the right-hand edges of the current in the spring of different years as indicated by overlays of the 150-meter contour lines from the 22°C topographies of various cruises.

contained in a mimeographed report, 'Sequence of Current Patterns in the Gulf of Mexico' (Texas A&M Research Foundation Technical Report 67-9), which was distributed as a manuscript for comment and criticism in June 1967.

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CURRENT PATTERNS IN GULF OF MEXICO

657

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