Winter Intrusions of the Loop Current

Abstract. *Sea-surface temperature data obtained from satellite and subsurface temperature data obtained from ships are used to determine the intrusion of the The Loop Current extended considerably farther to the north during the last three winters than has been observed previously.*

The positions of intense ocean currents have traditionally been of interest to mariners, who must account for such currents in order to navigate effectively. More recently, concern about the dispersal of pollutants dumped into the oceans has created additional interest in accurately locating strong currents. There should be particular concern about this problem with regard to the Gulf of Mexico, which receives the great runoff of the Mississippi River with its load of agricultural and industrial wastes.

The circulation in the eastern Gulf of Mexico is dominated by the so-called Loop Current, which enters the Gulf through the Yucatán Straits and exits through the Straits of Florida. The path in the interior of the Gulf varies considerably with time, sometimes following a nearly direct route between the two straits, while at other times extending far to the north, forming an anticyclonic (clockwise) loop which gives the current its name.

Most of what we know about the position of the Loop is based on the assumption of geostrophic balance. Under the assumption that the vertical current shear is proportional to the horizontal gradient of mass or temperature, one can deduce that the position of strong currents coincides with the strongest depth gradients of temperature surfaces. Figure 1 shows two examples of the structure of the 20°C temperature surface in the eastern Gulf; the core of the Loop Current coincides with the positions of the large gradients observed.

Most of the temperature observations in the eastern Gulf have been made during the spring, summer, and fall. These observations have shown that the Loop Current is farthest north during the summer (*1–3*). The relatively few observations made during the winter show less developed intrusions (*2, 3*). The point of our report is that recent observations made between November 1974 and April 1977 show the northernmost intrusions of the Loop Current during the winter months.

Background. Leipper (*2*) proposed an annual cycle for the intrusion of the Loop Current, based primarily on data collected during 1965 and 1966. He found that the Loop intruded north into the Gulf during the spring. The maximum intrusion in the summer and fall occurred in one of two modes. Either the Loop Current remained continuous from the Yucatán Straits to the northeastern Gulf, or an eddy detached, leaving behind a remnant of the Loop in the southeastern Gulf. The eddy or the extended Loop drifted to the west in the fall. The minimum northward intrusion of the Loop Current was observed in the winter. Maul (*3*) found a similar cycle in 1972–73 (the data displayed in Fig. 1 were used by Maul).

Behringer, Molinari, and Festa (*4*) used the 150-m contour of the 20°C isothermal surface (which is normally found in the high-gradient region of this surface) to represent the position of the Loop Current. Figure 2 gives the maximum northern intrusion of the Loop Current from 1965 to 1977 and includes most of the data available during this time. The data obtained from 1965 through 1973 are consistent with the findings in (*2*) and (*3*),

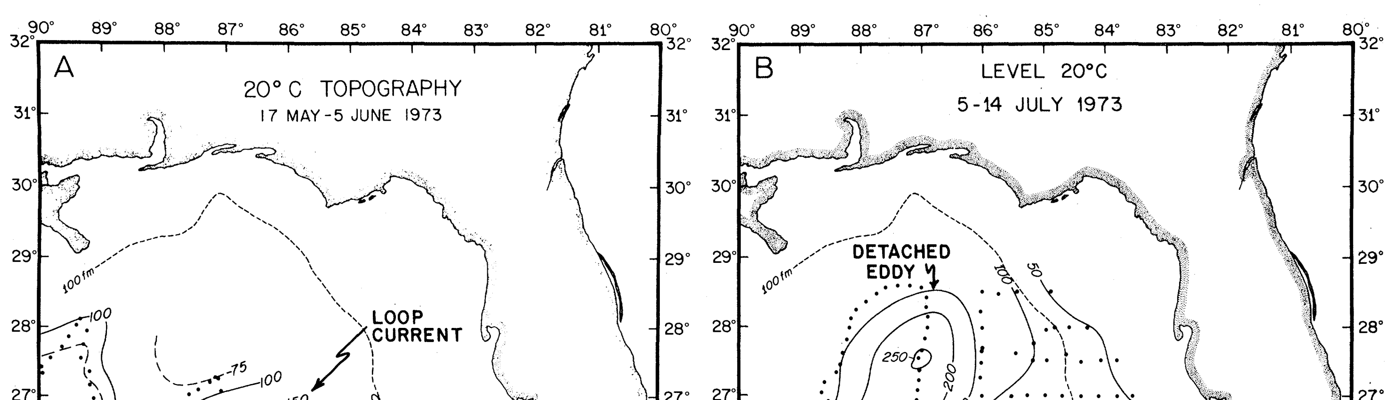

Fig. 1. Depth of the 20°C isothermal surface observed during (A) May and June and (B) July 1973. The intense currents in the eastern Gulf of Mexico are easily identified by their large horizontal temperature gradients. (A) A deep Loop Current intrusion; (B) the temperature structure after an eddy has separated from the Loop.

with the greatest northward intrusions observed from April 1972 through September 1965.

Maul (3) demonstrated that satellite imagery can be used to define the left side (looking downstream) of the Loop Current during the winter. The sea-surface front of the Loop Current was, on the average, 15 km to the left (looking downstream) of the subsurface core as indicated by temperature data.

Legeckis (5) reported on the first winter deep intrusion and eddy separation determined from direct observations during 1974 and 1975. His conclusions were drawn from maps of sea-surface temperature (SST) derived from satellite measurements.

Data sources. The Field Service Station of the National Environmental Satellite Service in Miami, Florida, produced maps of SST gradients. These were used to determine the left side of the Loop and thus define the penetration of the Loop and eddy separations during the winters of 1974–75, 1975–76, and 1976–77.

In addition, in May 1975 we began a series of cruises to study the Loop Current. The most recent survey was completed in April 1977. We have constructed topographic charts of the depth of the 20°C isothermal surface from the temperature data obtained during these cruises. We used the position of the 20°C isotherm at 150 m derived from these maps to determine the northern edge of the Loop Current, as in (4).

Finally, we obtained additional subsurface temperature data from the National Oceanographic Data Center. The timing of some of these observations enabled us to fill in some of the gaps in our data set. In addition, these data were used to construct 20°C isotherm topographies to compare with concurrent SST analyses of the position of the Loop Current.

Results. The few winter observations made before 1974 do not show a Loop Current intrusion north of 26°N (Fig. 2). However, from 1974 through 1977 the winter intrusions were all north of 26°N.

The subsurface temperature data we obtained from the National Oceanographic Data Center for the winter of 1974–75 show Loop Current intrusions during November 1974 and February 1975 which are consistent with the satellite observations in (5). Subsurface data for March 1975 confirm the winter eddy separation during early March but do not extend far enough north to verify the intrusion indicated by the SST data.

The February 1976 subsurface temperature and SST data show a similar maximum intrusion latitude. The late February and March SST data depict a northward progression of the Loop which is consistent with the May 1976 SST and subsurface position of the Loop (Fig. 2).

The SST data suggest no eddy separation before the end of May 1976. Subsurface data from May confirm the SST results in terms of the Loop's intrusion but, like the SST data, are insufficient to determine whether an eddy had detached. The eastern edge of an eddy was observed in August 1976, from which we surmise that an eddy probably separated from the Loop between May and August 1976.

The SST data indicate that the winter intrusions of 1976–77 were again deep and that an eddy detached in mid-March 1977. The circulation pattern derived from a limited ship survey in April 1977 is consistent with the conclusion of an earlier eddy separation event.

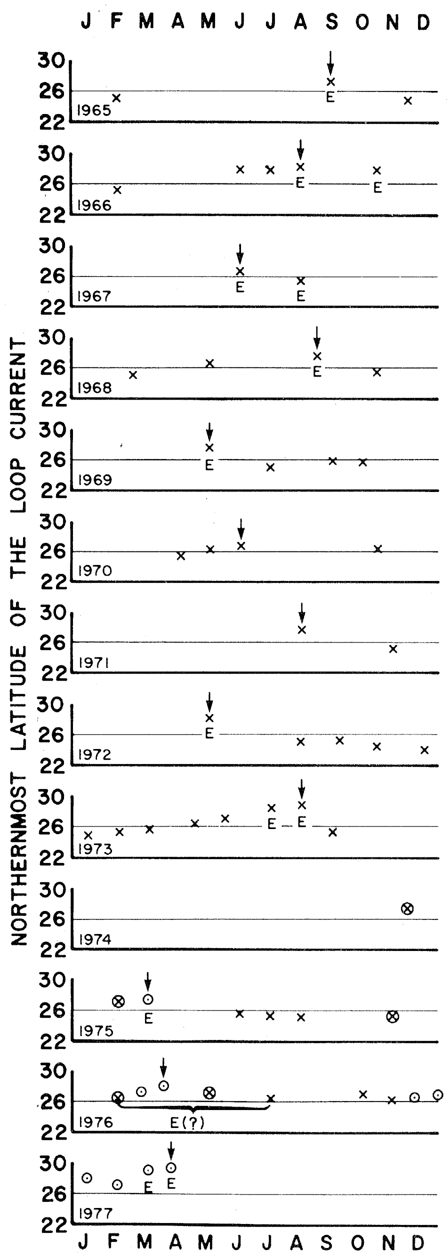

Fig. 2. Intrusion of the Loop Current as indicated by the northernmost position of the 150-m isoline of the 20°C isothermal surface (X), the edge of the current determined from satellite sea-surface temperature maps (⊙), or both (⊗). The arrow denotes the maximum intrusion observed during a particular year and *E* those months when the northern edge of a detached eddy was used to indicate the intrusion. The exact time of the 1976 eddy breakoff and the maximum intrusion during May 1976 could not be determined because of insufficient data.

Discussion. Our present knowledge of the dynamics of the Loop Current is limited. The intrusion of the Loop has been related both to the relative vorticity distribution at the Yucatán Straits (6) and to the volume transport at this passage (3). However, the mechanism which establishes these conditions at the Straits are unknown. Since the Loop Current is part of the North Atlantic gyre, these conditions are probably influenced by events farther upstream in the Caribbean Sea and the Gulf of Mexico. The relation of the Gulf of Mexico to the conditions in these regions has not been established; thus we cannot say with any certainty that the recent winter intrusions are associated with anomalous winter conditions in the Caribbean Sea and the Atlantic Ocean.

In addition, the historical data set is limited, so we do not know whether winter intrusions occurred in the past and were simply not observed. Nevertheless, regardless of the reason, deep winter intrusions of the Loop Current have been heretofore unknown. The evidence presented in this report means that deepwater intrusions must now be recognized by mariners, environmentalists, and all others concerned with the position of the Loop Current.

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Carbon-14: Direct Detection at Natural Concentrations

Abstract. *The ^{14}C atoms naturally present in a piece of 19th-century wood have been detected directly by means of a tandem Van de Graaff accelerator used as a high-energy mass spectrometer. The ^{14}C ions were easily resolved from interfering ions with the use of a ΔE-E detector telescope (this telescope consists of a pair of detectors; one of them measures the specific ionization, ΔE, and the sum of the signals from both detectors gives the total energy for each ion, E_T). The technique offers a number of practical advantages.*

In a recent article (*1*), Muller has discussed the advantages of directly measuring the concentration of ^{14}C atoms in a sample to be radiocarbon-dated, and has proposed a method for using a cyclotron as a high-energy mass spectrometer for such measurements. However, a tandem Van de Graaff accelerator appears to be a better choice for this purpose for a number of technical reasons. First, it has an external ion source easily adapted to quick sample changing. The ion source produces negative ions, and, since no stable or metastable negative nitrogen ions are known (*2*), this accelerator should automatically discriminate heavily against ^{14}N, the ion that would cause most difficulty in this measurement. The use of a ΔE-E energy telescope (*3*) as the ion detector will allow any small amounts of ^{14}N (and any other interfering ions) to be distinguished from the ^{14}C ions. Furthermore, the Van de Graaff accelerator is capable of accelerating all three carbon isotopes (^{12}C, ^{13}C, and ^{14}C) simultaneously. Given an appropriately designed analyzing magnet, these three isotopes may then be detected simultaneously, and the radiocarbon date may be obtained from the $^{14}C/^{12}C$ ratio. A correction for isotopic fractionation could be made based on the value of the $^{13}C/^{12}C$ ratio. Changes in the efficiency of the total system are only likely to take place at the ion source and acceleration stages. As these occur before the ions are magnetically separated, all three carbon isotopes will be affected equally, and the measured isotopic ratios will be independent of the system efficiency. In order to avoid making absolute efficiency measurements, it would be sufficient to compare the measured $^{14}C/^{12}C$ and $^{13}C/^{12}C$ ratios of a sample of unknown age to that of a known radiocarbon standard, such as National Bureau of Standards oxalic acid.

To test the feasibility of this technique we conducted an experiment on the McMaster University model FN tandem Van de Graaff accelerator to determine whether ^{14}C could be measured at naturally occurring concentrations. We found that we could indeed detect the ^{14}C atoms in a piece of white spruce [*Picea glauca* (Moench) Voss] that spanned the decade 1880 to 1890 (*4*).

This wood was reduced to charcoal in a closed steel pipe. About 200 to 300 mg of the charcoal was placed directly in the cesium sputter source of the accelerator. Although carbon beams in excess of 100 μa have been obtained with such ion sources (*2*), only 0.5 μa were obtained from this charcoal sample. The beam was accelerated to the terminal where the negative ions were stripped of electrons by an oxygen gas stripper. At +7 Mv on the terminal the most favored charge state for carbon is 4+; the carbon ions thus emerged from the accelerator with an energy of 35 Mev.

A Faraday cup placed in the beam line a few meters past the analyzing magnet gave a reading of about 150 to 200 na when the beam optics and the field of the analyzing magnet were set appropriately for $^{12}C^{4+}$. When these settings were changed to values calculated for $^{13}C^{4+}$, a beam intensity of roughly 1 to 2 na was found, reflecting the relative natural abundances of ^{12}C and ^{13}C and indicating that accurate settings for a $^{14}C^{4+}$ beam could be calculated.

The normal system for stabilizing the accelerator voltage, measuring the current on the analyzing slits, could not be used for the ^{14}C measurement since there is insufficient beam current when ^{14}C is

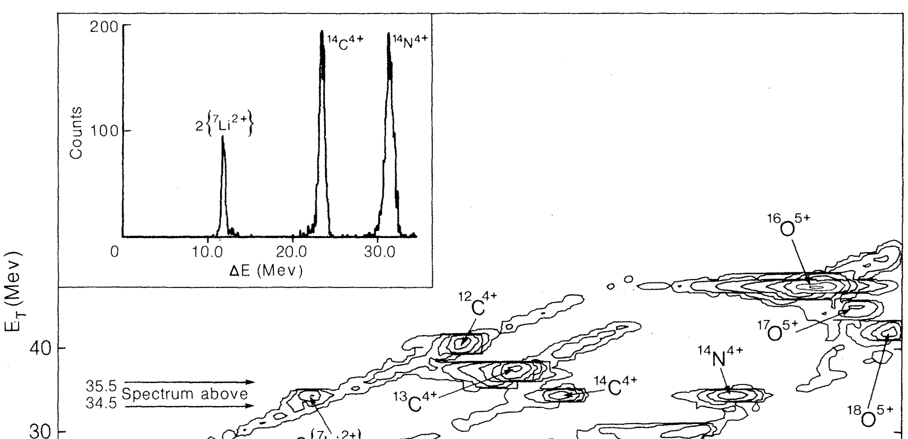

Fig. 1. A display of the number of ions detected in a piece of white spruce (1880 to 1890) (shown as contour lines at intervals 2, 8, 32, 128, 512, 2048, and 8196 counts) plotted versus the total energy (E_T) and the specific ionization signal (ΔE) of the ions. The inset shows the ΔE spectrum obtained from a count of those ions in the region E_T = 34.5 to 35.5 Mev. The isotopic species and charge states are identified. For example, the peaks labeled $^7Li^{2+}$ and $2\{^7Li^{2+}\}$ are due to acceleration of a Li_2^- molecule to the terminal, breakup of the molecule in the stripper, and subsequent detection of one or both of the lithium atoms.