Effects of Surface Baroclinicity on Frontal Overrunning along the Central Gulf Coast

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ABSTRACT

Along the United States Gulf coast and over the northern Gulf of Mexico, frontal overrunning occurs frequently. Cyclogenesis over the Gulf is often associated with this type of weather system. Effects of baroclinic fields on frontal overrunning are investigated from synoptic and climatological points of view. It is found that, from October through April, the orientation of the shelf break is a very important baroclinic characteristic because fronts tend to stall there rather than at the physical coastline. To further substantiate this deduction dynamically, the local geostrophic vorticity field over the western Louisiana–upper Texas shelf region is estimated monthly. The correlation coefficient between the vorticity field and the frequency of frontal overrunning along the central Gulf coast was .86. For forecasting applications, a simple formula is provided to estimate this local vorticity from the temperature difference between Lake Charles, Louisiana, and buoy station 42002 in the deep Gulf.

1. Introduction

Frontal overrunning is defined here as occurring when a polar front is nearly stationary along the central Gulf coast or over the northern Gulf of Mexico (see, e.g., Muller 1977). Typically observed overrunning conditions are heavy cloud cover and precipitation. These prevailing conditions may result in operational problems such as disruption of onshore–offshore helicopter flights for offshore oil field workers and supplies due to stronger wind shears and lower visibility than normal.

Kinematically, frontal overrunning along the central Gulf coast has mainly been attributed to the difference in air temperature across the coastal zone (Hsu 1988, pp. 52–55). The purpose of this paper is to further substantiate this deduction from dynamic points of view. Also, most recently, more climatological data are available from the National Data Buoy Center (see NDBC 1986, 1990). In addition, more stations are now operating in and around the Gulf of Mexico. These stations are summarized monthly in the National Oceanic and Atmospheric Administration's (NOAA's) *Mariner's Weather Log.* The results of this study can certainly aid the forecaster's method of estimating the potential for frontal overrunning.

2. Distribution of sea surface temperature

Because frontal overrunning depends in part on the characteristics of the surface boundary layer, some background information related to the distribution of water temperature in the northwestern Gulf of Mexico is provided in Figs. 1 and 2 for summer and winter, respectively. In July, the SST gradient is approximately 1°–2°C between shelf water and deep Gulf, whereas in January the SST gradient is about 7°C between the nearshore area of the Louisiana and Texas borders and the shelf break with a much weaker gradient in the deep Gulf. Note that the shelf break used here follows closely along the 200-m isobath (see Fig. 1). Note also that in fall and winter, shelf water cools rapidly, mainly due to strong evaporation or latent heat flux (see, e.g., Huh et al. 1978).

3. Winter baroclinicity over the Gulf of Mexico

From previous discussions, it is clear that during the winter season the shelf water is colder than the deep Gulf. Therefore, a baroclinic field should exist over these two water masses. If a cold front moves from northwest to southeast, it may bring cold air to the northwestern Gulf of Mexico. On 22 February 1986 a cold front was located over the central Gulf. On this day both dropsondes and rawinsonde observations (RAOBS) were available for analysis, as shown in Figs. 3 and 4. The dropwindsondes were conducted by the air force from 1830 UTC 22 February to 0245 UTC 23 February, whereas RAOBS were obtained at 0000 UTC (or 1200 UTC if 0000 UTC was not available) by the National Weather Service (NWS). The baroclinic or solenoidal field from Key West (EYW), Florida to Del Rio (DRT), Texas, via Victoria (VCT), Texas, and the Gulf of Mexico is based on a cross section shown in Fig. 3 and plotted in Fig. 4. The cool air over the cold shelf water off the coast of southern Texas

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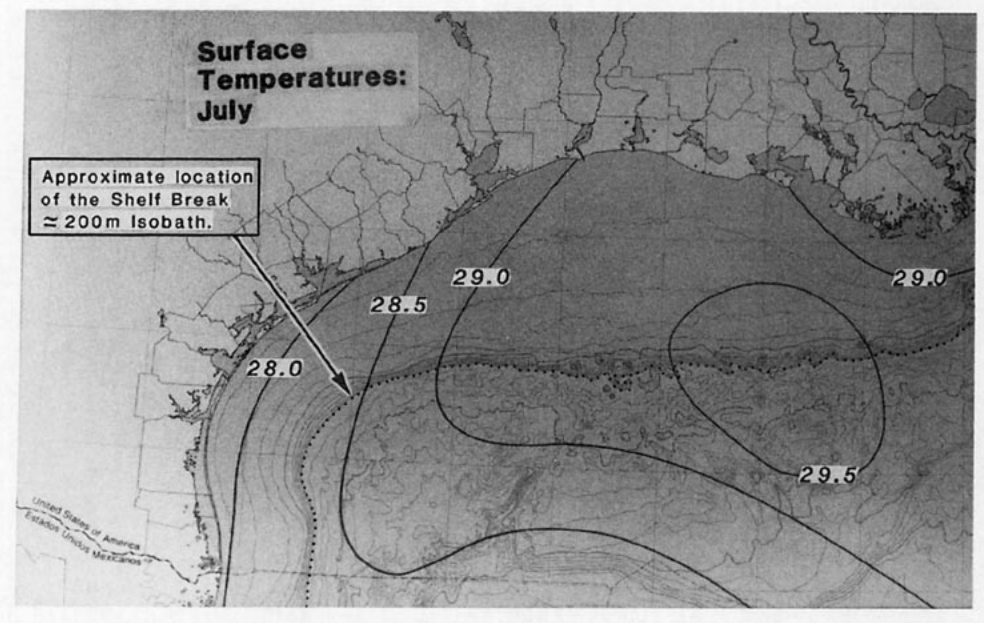

FIG. 1. Distribution of sea surface temperature (SST, °C) in July in the northwest Gulf of Mexico based on National Ocean Service (1985). Note that the shelf break is plotted as the dotted line along the 200-m isobath.

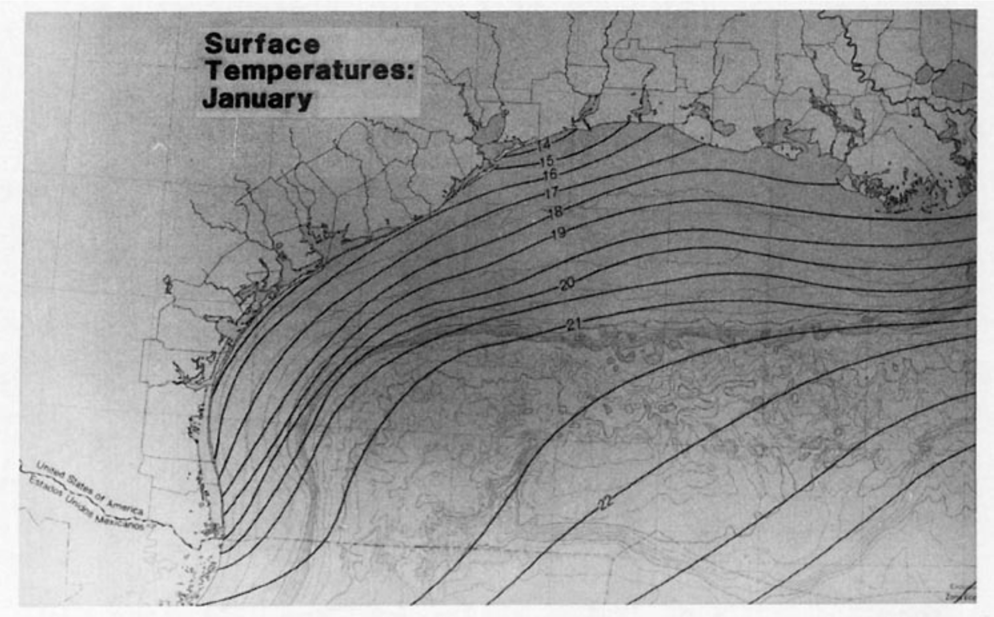

FIG. 2. Distribution of sea surface temperature (°C) in January based on National Ocean Service (1985).

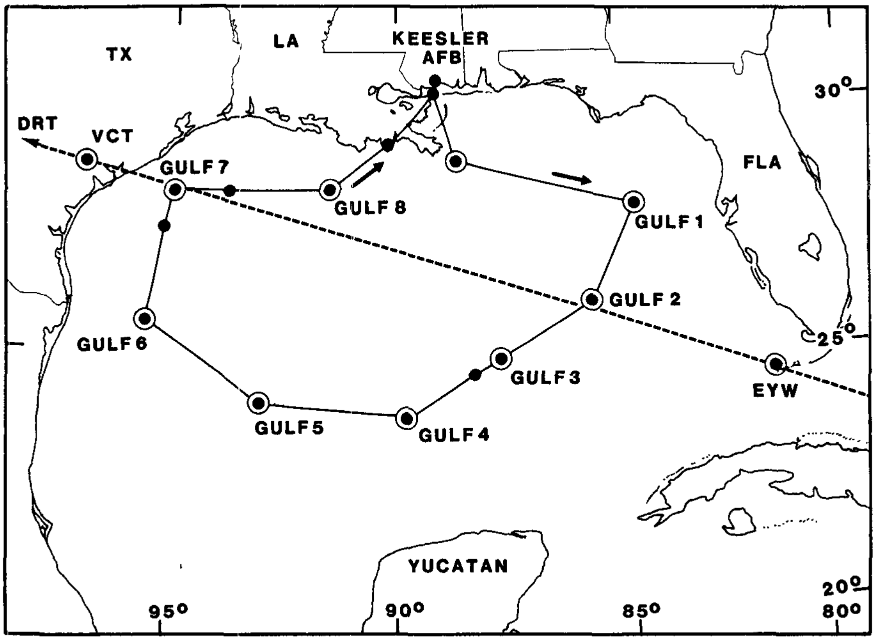

FIG. 3. Upper-air soundings on 22 February 1986 during GALE (see GALE Data Center 1986). The dashed line is the cross section used in Fig. 4. Radiosondes were launched by the NWS at land stations in Key West (EYW), Florida, and Victoria (VCT) and Del Rio (DRT), Texas, whereas dropwindsondes at GULF1–GULF8 over the Gulf of Mexico were conducted by the air force.

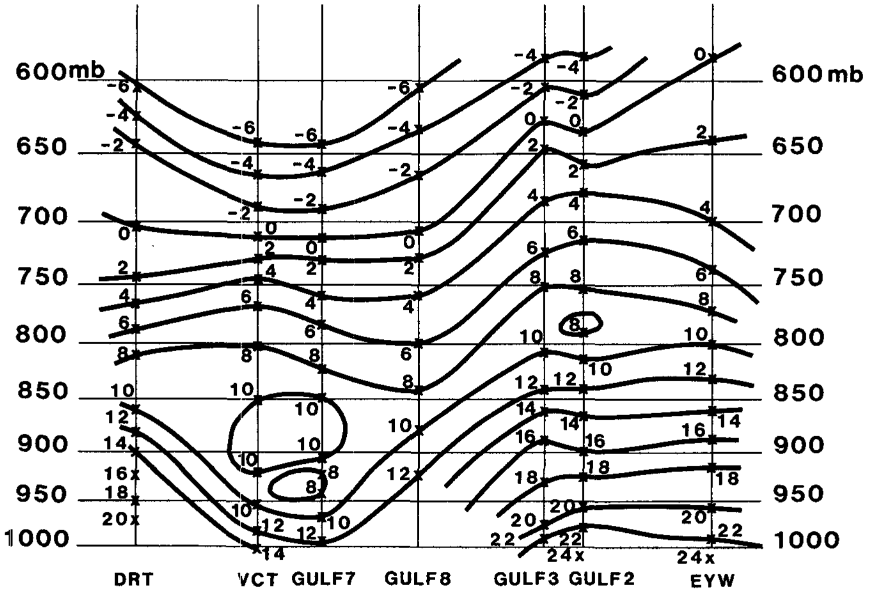

FIG. 4. An example of baroclinic (or solenoidal) field from Key West, Florida, to Del Rio, Texas, via the Gulf of Mexico and Victoria, Texas, on 22 February 1986. The thick curves are isotherms (°C). The unit for the vertical axis is millibars. For station locations, see Fig. 3.

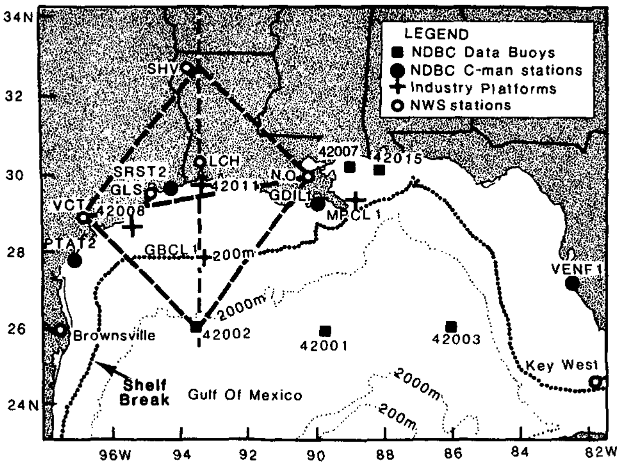

FIG. 5. Station locations for onshore and offshore temperature distribution used in Fig. 6 and subsequent analysis. A five-point stencil (see the rhombus with its center approximately over buoy station 42011) for the computation of the Laplacian of temperature field to obtain the relative or local vorticity.

and VCT region is clearly delineated. These data were obtained during the Genesis of Atlantic Lows Experiment (GALE) 1986 project by air force dropsonde measurements (see GALE Data Center 1986).

Figure 5 incorporates an industrial Coastal-Marine Automated Network (C-MAN) at GBCL1 to form a unique transect from deep Gulf buoy station 42002 through NDBC's C-MAN station SRST2 via Lake Charles (LCH) to Shreveport (SHV), Louisiana. Note that station GBCL1 was located about 15 km south of the shelf break on an underwater bank in 209 m of water and station SRST2 was located about 100 m inland from the shoreline. Monthly variations of air temperature from September 1989 through March 1990 are shown in Fig. 6. This figure also delineates that the largest temperature gradient exists between the shelf break and the nearshore region.

4. Mesoscale differences between shelf water and deep Gulf

Plots are provided to show the comparison of air temperature and SST characteristics over regions east and west of the Mississippi River delta as well as over shallow and deep waters. The station locations are given in Fig. 5. We generally use buoy station 42002 in the deep Gulf as a reference. Figure 7 shows that the difference among New Orleans (MSY), Louisiana, and buoy stations 42007 and 42015 in the eastern shelf is negligible. The deep Gulf is warmer than all other stations, as expected. Since station MPCL1 was located in 55 m of water about 30 km north-northwest of the 200-m isobath, it may be considered as a station on the shelf. Note that December 1989 was unusually cold since the normal monthly mean in December at New Orleans is approximately 12.6°C. Since there were no long-term (at least one year) measurements of air temperature over the shelf break west of the Mississippi River delta, only the shelf stations of 42011 and LCH are compared with the deep Gulf buoy station 42002, as shown in Fig. 8. It can be seen that the difference between LCH and 42011 is negligible, indicating the

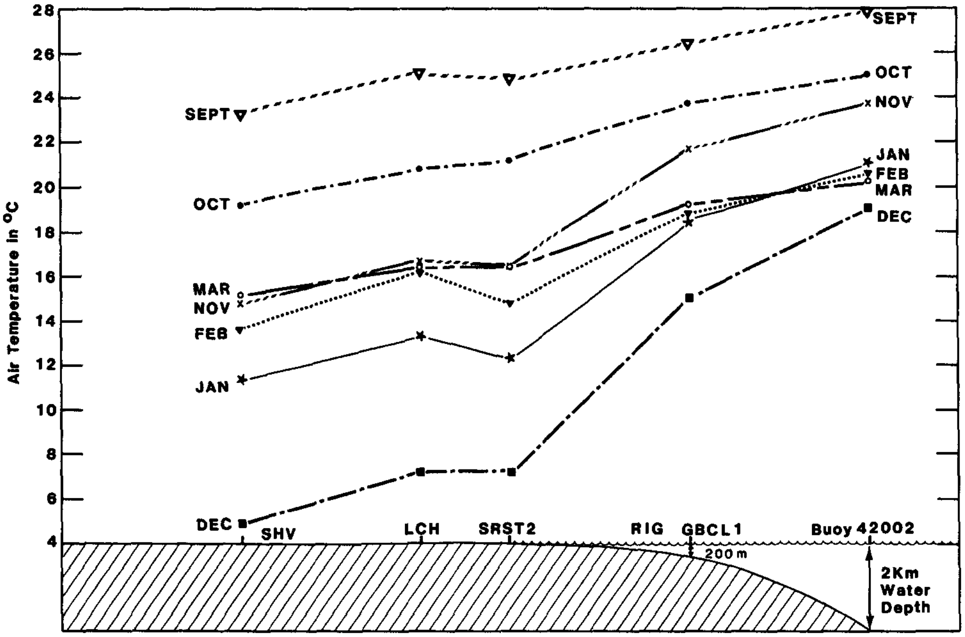

FIG. 6. Monthly variations of air temperature from deep Gulf to Shreveport, Louisiana, via stations near shelf-break and coastal areas from September 1989 through March 1990.

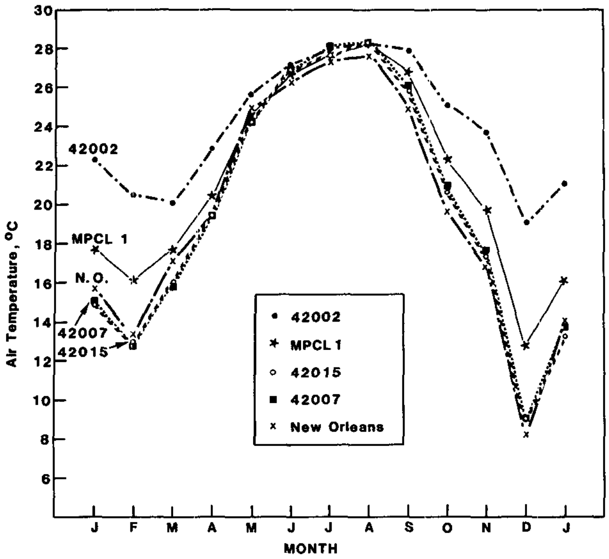

FIG. 7. Monthly variations of air temperature in 1989 and January 1990 over shelf waters east of the Mississippi River delta. For comparison, data from buoy station 42002 in the deep Gulf are also included.

nearshore region may be represented by a nearby station onshore.

Figure 9 shows the variations within similar environments. The difference in air temperature between New Orleans and LCH is within 0.5°C. Over shelf waters east and west of the Mississippi River delta, the difference in air temperature is within 3°C. The same range is found over the entire deep Gulf.

Figure 10 shows that the variations of SST of shelf

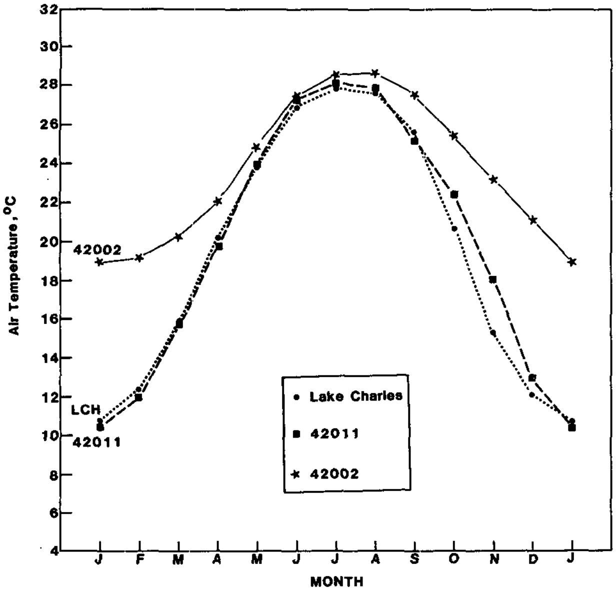

FIG. 8. Monthly variations of air temperature over shelf waters west of the Mississippi River delta.

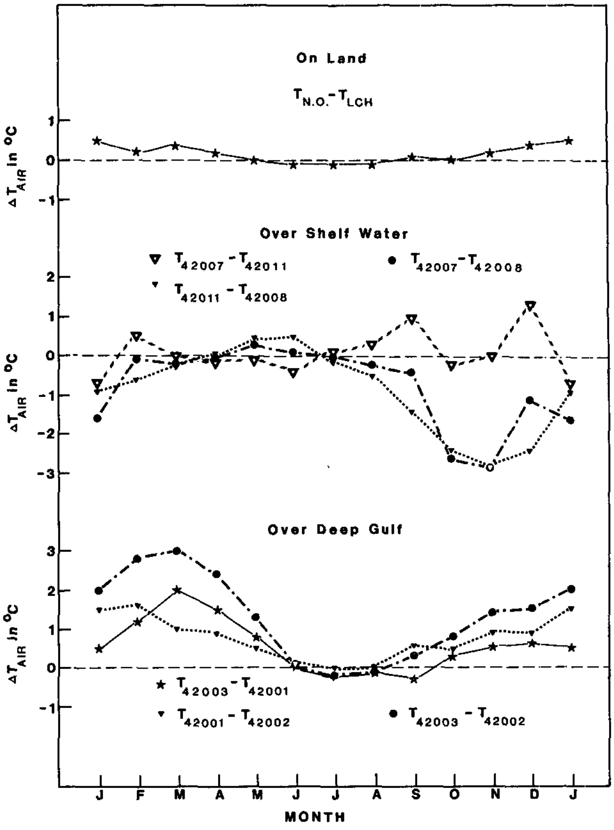

FIG. 9. Variations of difference in air temperature within similar environments on land, over shelf water, and in the deep Gulf.

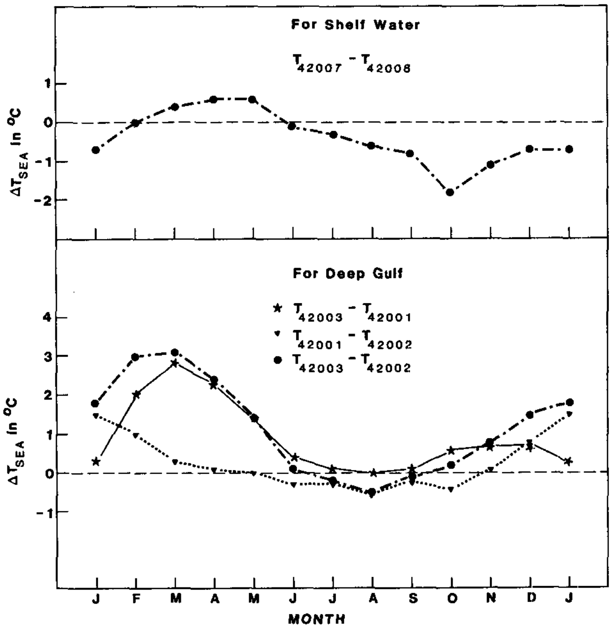

FIG. 10. Comparisons of SST between shelf waters east (42007) and west (42008) of the Mississippi River delta as well as three buoy stations (42001, 42002, and 42003) in the deep Gulf.

waters east and west of the delta are within 2°C, whereas over the entire deep Gulf SST differences are within 3°C. The data period was from 1951 to 1980 for both LCH and New Orleans, from 1975 to 1988 for offshore buoy station 42001; from 1976 to 1988 for both 42002 and 42003; from 1981 to 1988 for 42007; from 1980 to 1984 for 42008; and from 1981 to 1984 for 42011.

5. Relationship among baroclinicity, vorticity, and frontal overrunning

The monthly frequency of frontal overrunning at New Orleans is obtained from the *Louisiana Monthly Climate Review* (published by the Louisiana Office of State Climatology, Department of Geography & Anthropology, Louisiana State University, Baton Rouge) for 29 years from 1960 to 1989. For the methodology to determine the frontal overrunning, see Muller (1977). Figure 11 correlates the frequency of frontal overrunning at New Orleans and the difference in air temperature between buoy station 42001 and New Orleans. If one accepts 3°C difference in air temperature between New Orleans and 42001 as background noise as discussed previously, then 13% in the frequency of frontal overrunning at New Orleans is also noise. Therefore, for operational purposes, a 6-month period from October through March is significant. Figure 11 may be used as a guide to forecasters in that if air temperature difference between New Orleans and buoy station 42001 is greater than 5°C in October or March, there is a tendency for frontal overrunning to occur.

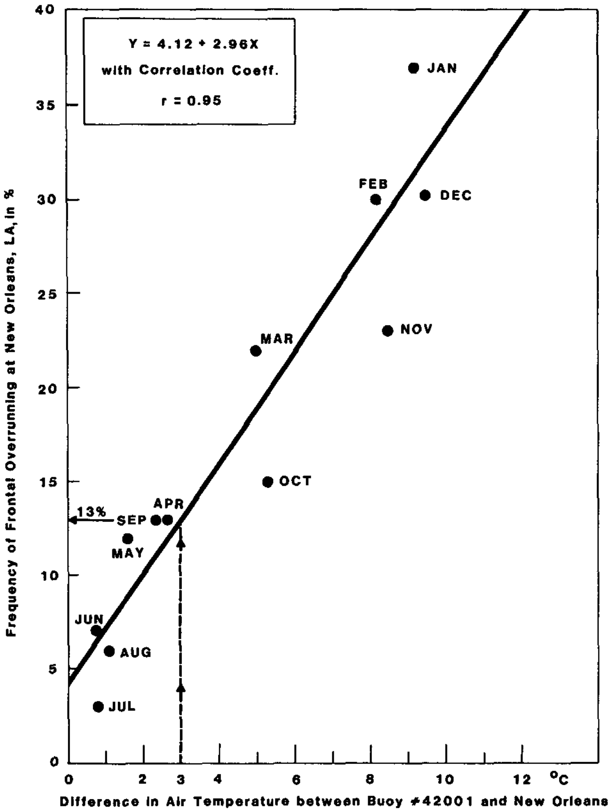

FIG. 11. Linear regression between monthly frequency of frontal overrunning at New Orleans, Louisiana, and the difference in air temperature between buoy station 42001 and New Orleans.

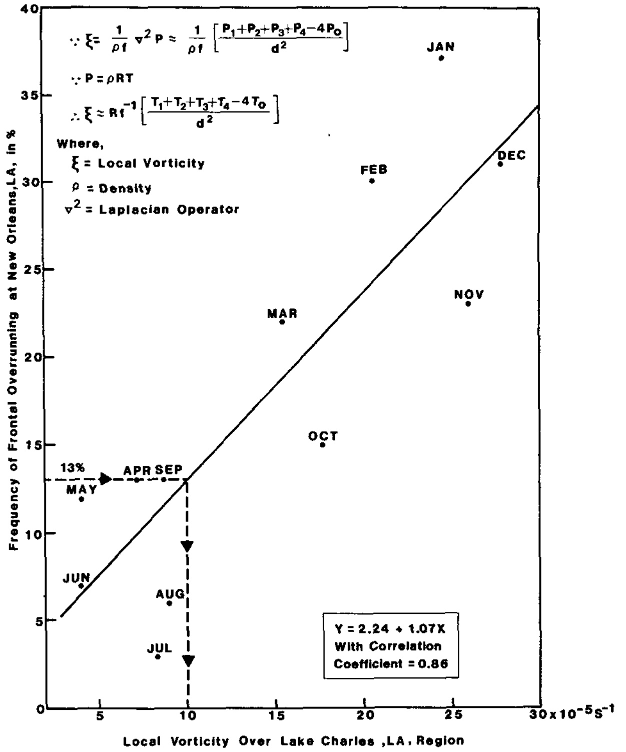

FIG. 12. Linear regression between local vorticity (computed from Fig. 5) over west Louisiana–upper Texas shelf and monthly frequency of frontal overrunning at New Orleans.

In order to explain these frontal overrunning characteristics dynamically, relative or local geostrophic vorticity over the west Louisiana–upper Texas shelf region is presented in Fig. 12. The vorticity is computed from a five-point stencil to obtain the Laplacian in temperature field, as shown in Fig. 5. For the computation, LCH in Fig. 5 has substituted 42011 as the center point due to its long-term record (30-yr normal 1951–1980 versus 4 yr for 42011) and because the temperature differences between the stations has been shown to be negligible. The four end points of this rhombus (see Fig. 5) are buoy station 42002 (data period 1976–1988), MSY (1951–1980), SHV (1951–1980), and VCT (1951–1980). The results are shown in Fig. 12. If one accepts this high correlation coefficient of .86 with 12 points of data (for 12 months), the frontal overrunning can be explained dynamically. Similar to Fig. 11, if the vorticity value is less than 10 $\times 10^{-5}$ s^{-1}, it is not significant. Note that the Laplacian of the temperature field is a measure of the vorticity

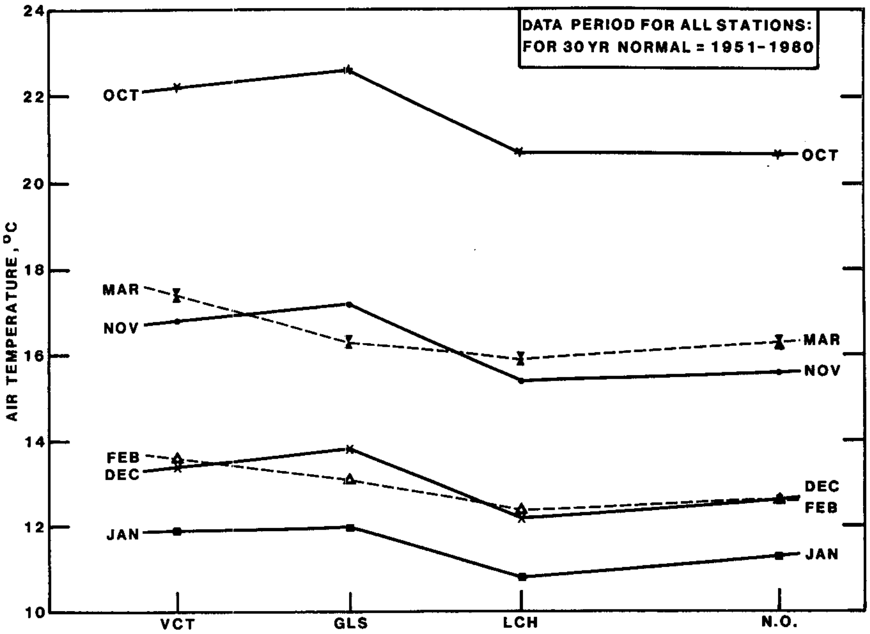

FIG. 13. Monthly variations of air temperature along the east–west orientation of the rhombus shown in Fig. 5, from New Orleans to Victoria via Lake Charles and Galveston.

of the thermal wind. It is used here only as a first approximation to aid forecasters because all of the data needed for this computation are readily available. From the five-point stencil in the computation of the local vorticity over the west Louisiana–upper Texas shelf (Fig. 5), it is found that the alongshore variation in air temperature from New Orleans to VCT [via LCH and Galveston (GLS), Texas], is less than 2°C (Fig. 13), whereas the onshore (e.g., at LCH) and offshore (at buoy station 42002) variation exceeds 8°C (Fig. 14). Therefore, the local geostrophic vorticity can be estimated directly by the temperature difference between LCH and buoy station 42002, as shown in Fig. 15, which may be used as an aid to forecasters.

6. Conclusions

Comparison of air temperature measurements over the deep Gulf, shelf water, and on land such as at Lake Charles (LCH), Louisiana, indicates that in summer from June to August all stations in the Gulf and LCH have similar values. From September through December, LCH is cooler than the shelf water, but the deep water is warmer than both LCH and shelf water all year round. From January through May air temperatures over the shelf are nearly the same as those over land. Therefore, the orientation of the shelf break from January through May is the more important "demarcation" line in baroclinicity than the physical coastline. Yearly intershelf and inter-deep-Gulf variations both in air and sea temperatures are found to be within 3°C. The shelf east and west of the Mississippi River delta

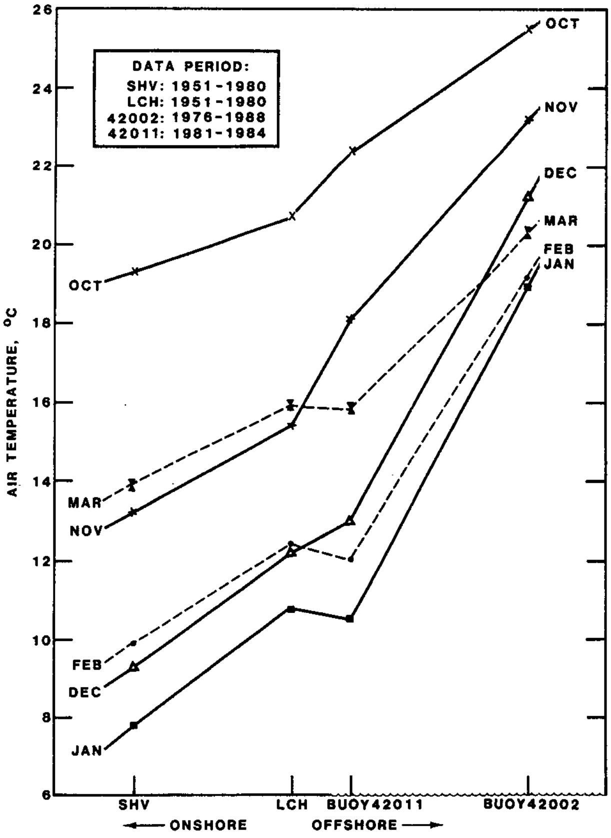

FIG. 14. Monthly variations of air temperature along the north–south orientation of the rhombus shown in Fig. 5, from buoy station 42002 in the deep Gulf to Shreveport (SHV), Louisiana, via buoy station 42011 and LCH.

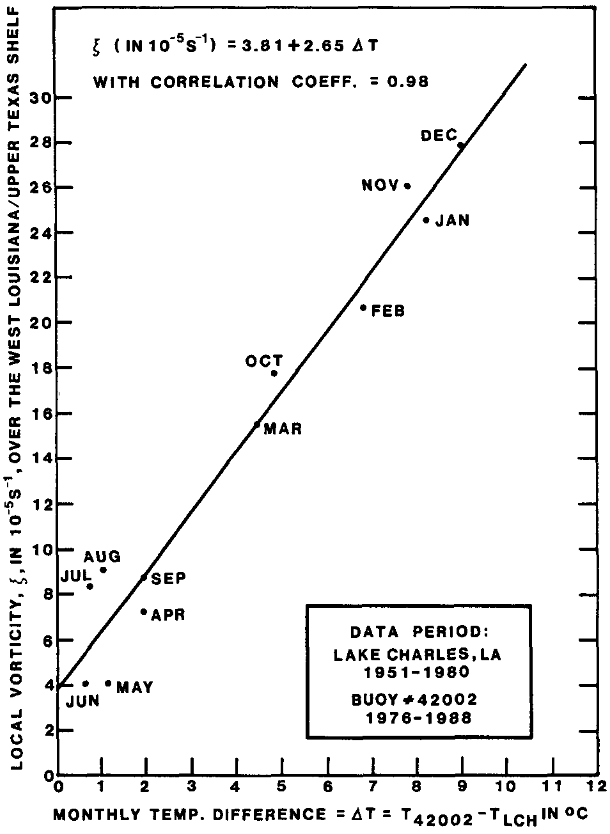

FIG. 15. Linear regression between the local geostrophic vorticity over the west Louisiana–upper Texas shelf and the monthly temperature difference between buoy station 42002 in the deep Gulf and LCH.

can be considered the same from a baroclinicity point of view.

Linear regression between monthly frequency of frontal overrunning at New Orleans and the difference in air temperature between buoy station 42001 in the deep Gulf and New Orleans is highly significant, with a correlation coefficient as high as .95. Dynamic explanation through vorticity computation is also successful. The correlation coefficient of .86 is found between vorticity over the Louisiana–Texas shelf and the frequency of frontal overrunning. For forecasting applications, this local geostrophic vorticity can be estimated directly from the temperature difference between LCH and buoy station 42002, as given by a simple equation shown in Fig. 15.

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