

**About the premature and tardy frosts  
that occurred over the central plateau of Mexico  
and were associated with some tropical cyclones**

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RESUMEN

Se presentan las regiones donde han afectado las heladas tempranas y tardías. Principalmente las más severas que ocurrieron en septiembre de los años 1909, 1917, 1974, 1975, 1979 y 1988 y en junio de 1979. Se relaciona la presencia de ciclones tropicales con la manifestación de las heladas. Se encuentra que el fenómeno de la helada temprana o tardía tiene conexión con la presencia de ciclones tropicales, siendo esto una condición necesaria más no suficiente ya que se tienen otros casos con ciclones tropicales en que no se presentan heladas sobre las tierras altas del Altiplano Central.

ABSTRACT

A study of the regions of Mexico that have been affected by the premature and tardy frosts are presented in this paper. The most severe ones have occurred mainly in September of the years 1909, 1917, 1974, 1975, 1979 and 1988 and in June of 1979. The presence of tropical cyclones and the manifestation of the frost are related. It is found that the phenomenon of either the premature or tardy frosts has connection with the presence of tropical cyclones; being this a necessary, but no sufficient condition, since there are other cases with tropical cyclones in which the frost is not present over the high lands of the Central Plateau.

**Introduction**

Among the most important problems that are present in agriculture we have the precipitation forecasts, the drought, the premature and tardy frosts. At least one of these phenomena affect Mexico each year. The actual knowledge of the dynamic mechanism and complex physics, associated with these phenomena, is still unknown, because different space and time scales of atmospheric movements interfere in them. Often the causes of frost have been divided into those due to advection of large masses of cold air and those due to loss of heat by radiation. In the first case the pool of cold air is often associated with the passage of a deep cyclone and a well developed cold front in advance of a strong anticyclone. The frost by radiation often occurs in connection with slow moving anticyclones in which the air is moderately cool and dry (Blanc *et al.*, 1963).

Another form of explaining how the temperature can fall in autumn was given by the meteorologist Lucio, who described the autumn of 1923 in his book published in 1930. He observed that always, when an Atlantic tropical cyclone turns into the oriental part of the Gulf of Mexico, the temperature descends, and a frost period in the Central Mexican Plateau is produced. This fall of temperature and clear skies provoked by the tropical cyclone, can be perceived from a long distance. Lucio called it "Cyclonic Blue".

Bagdonas *et al.* (1978) prepared a review of the techniques of frost predictions and methods of protection from frosts and cold now in use by many nations of the world. Recent studies about frost for local regions of Mexico have been presented by García and Valdez (1988), Camacho *et al.* (1988), Montesino *et al.* (1988), Gómez and Morales (1988), Pereyra and Zitacuaro (1988) and Morales *et al.* (1988). Generally these studies used statistic techniques that calculated the probability of occurrence of the first and last frost.

Following the idea of Lucio (1930) and considering the frost phenomenon as associated with the general circulation of the atmosphere, in this paper, the phenomenon is reexamined. Mainly, the premature and tardy frosts have a strong economical and social impact, just as can be seen from the cases that occurred in September of the years 1909, 1917, 1974, 1975, 1979, 1988 and in June of 1979. The analysis method is to relate the position of tropical cyclones with the frost reported in a large number of stations situated in the Central Plateau of Mexico or in the United States. The synoptic patterns prior to the occurrence of frosts are also identified. These are similar to the patterns in the winter seasons, which are described with the representative case below. For the cases of the frosts of September of 1909 and 1917 the information is taken from the Boletín Mensual del Observatorio Meteorológico y Sismológico Central de México (September, 1909 and 1917) and the Monthly Weather Review (September, 1909 and 1917). The dramatic situation that was observed then, is almost a repetition of the other years already mentioned.

## Cases of Study

### *A representative case of winter*

As a representative example of the surface synoptic condition, it is observed that in winter during some mornings extremely low temperatures are reached in some localities of the Central Mexican Plateau. We have the case illustrated in Figs. 1a-d, which occurred during the days 22nd to 23rd of February of 1989. An anticyclone moved from north Nebraska to Central Missouri extending to the south as far as into the east-northeastern part of Mexico. The killing frost occurred, when the localities were under the influence of this anticyclone, mainly on the 23rd. Also an extensive cold front is shown in Figure 1a-d, extending from the southeast of Mexico and all along the east coast of the United States. This front was associated in 500 mb with a deepening large amplitude trough which on the 21st moved eastward across Central North America. Noteworthy it is also the multiple cold front farther to the northwest of the United States over the Rockies. This surface cyclogenesis appears to be linked with the arrival of polar air, which is propagated downwind from the major mountain mass of North America. Also a weak cyclone located along the frontal system was developing in the east of Virginia (see Figure 1c).

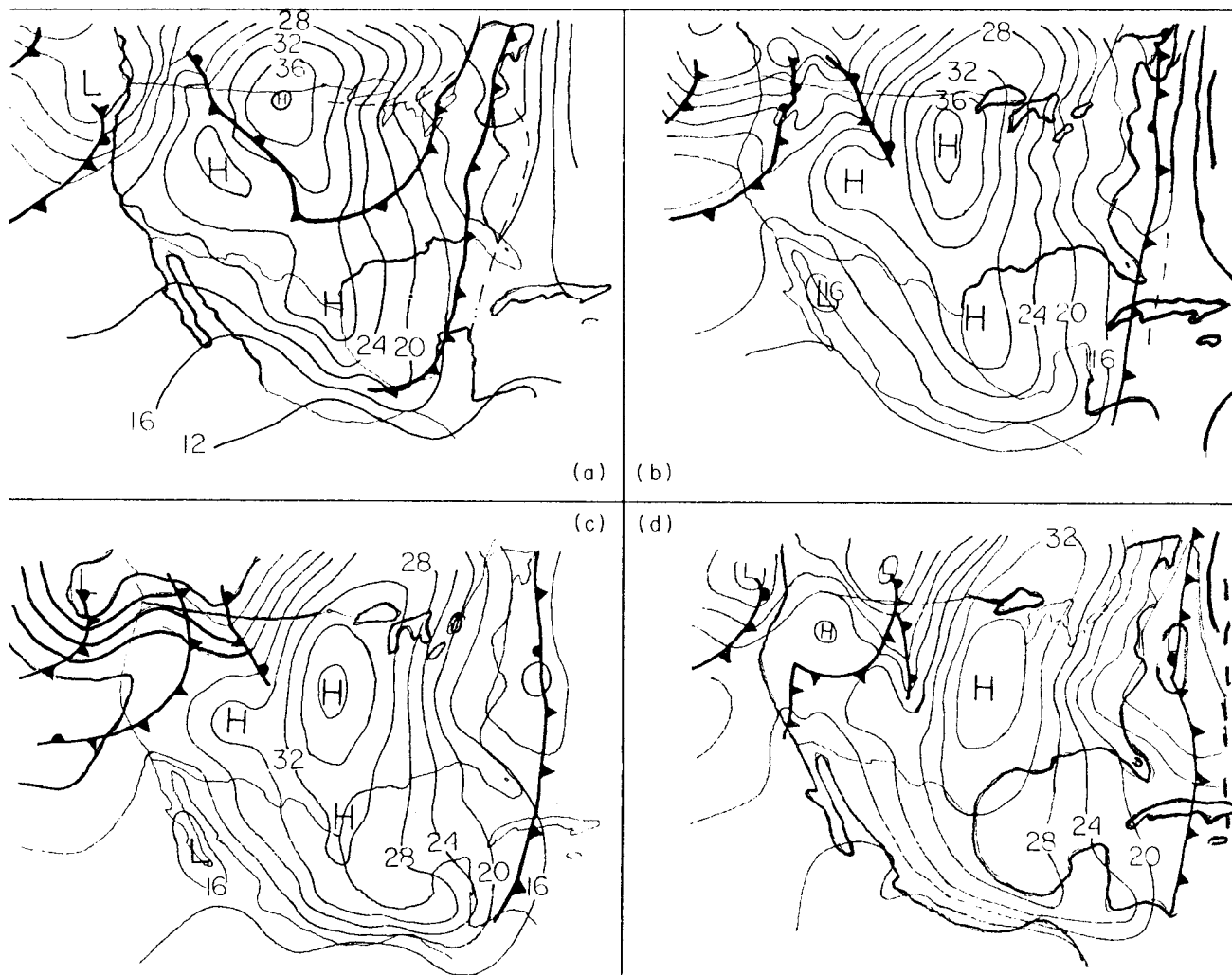


Fig. 1. Analysis of sea level pressure for a) 1200 GMT February 22, 1989, b) 0000 GMT February 23, 1989. c) 0006 GMT February 23, 1989 and d) 1200 GMT February 23, 1989. The contour interval is 4mb.

*Frosts of September, 1909*

The general conditions of frosts in the United States at the end of September, 1909, reported by Mon. Wea. Rev. (September 1909), were: For the North Atlantic States, the temperature was very variable during the first and second decades and frosts occurred generally during several days, mainly at the end of the first decade. The cold weather developed on the 19th with an area of high pressure, which covered these states. Killing frost in the interior of New England, on the more elevated parts of New York, of Pennsylvania, Virginia, West Virginia, and the interior of New Jersey of this memorable morning of the 19th.

On the West Atlantic Ocean two areas of low atmospheric pressure appeared near the southern tip of Florida, too. The first was a hurricane that approached the middle of the Gulf coast that day. On the 20th the vortex had reached the mouth of the Mississippi River, reaching Little

Rock, Ark., on the 21st (see Figure 2(i)). The second was a tropical storm that developed north of Panama on September 18th. This tropical storm was moving towards the north-northeast and continued west of Cuba, on the 25th. During this time it turned towards the northeast. On the

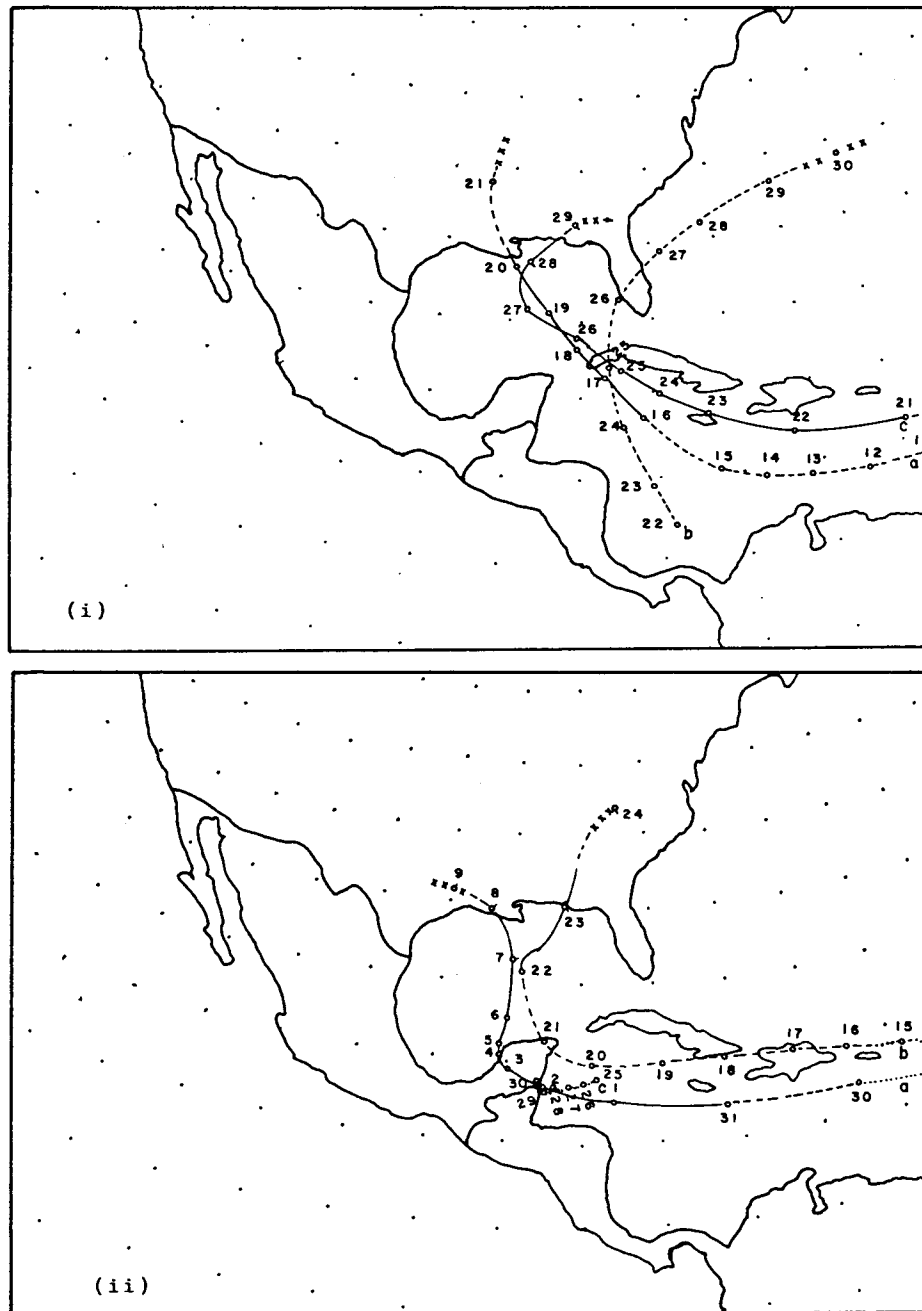


Fig. 2(i). Tracks of hurricanes and tropical storms: a) Sept. 10-21 1909; b) Sept. 21-29 1917. The line — indicates hurricane stage; - - tropical storm stage; xxx depression (dissipation) stage; ... tropical depression (development) stage; o position at 7:00 a. m. E. S. T.;  $\sigma$  position at 7:00 a. m. E. S. T., when frost occurred at a number of stations situated on the Central Mexican Plateau.

(ii). Now for: a) Carmen Aug. 29-Sept. 10 1974; b) Eloisa Sept. 15-24 1975; c) a tropical depression, Sept. 25-30, 1975. Taken from the Historical Climatology Series 6-2, over tropical cyclones of the North Atlantic Ocean, 1871-1986, NOAA, 1987.

26th the tropical storm had reached the central part of Florida and after this the system generally moved northeastwards during the days 27th - 30th (see Fig. 2(i)).

However, during September the temperature for the South Atlantic and East Gulf States of the United States, was below normal in Virginia, North Carolina, and large portions of Georgia and Florida. A pool of cold air spread over this region and on the 26th it was influenced by high atmospheric pressure from the North. The lowest temperatures of the month occurred from the 26th to 30th with general light frosts on both the 28th and 29th. In Florida the light frosts occurred at Wausav on September 29th. In the Ohio Valley, frost occurred during the first week of September in nearly all the Central, Northern and Eastern States. Also during the period of the 27th to the 29th light to killing frosts occurred in practically all the places. Generally the last week's frosts occurred in the Lake Region. Similarly in the Upper Mississippi Valley killing frosts and freezing temperatures were reported generally in eastern and northern North Dakota, northern and middle Minnesota, northern and middle Wisconsin. Less severe frosts occurred in Iowa, southern Minnesota, southern Wisconsin, and very general over Illinois. In the state of North Dakota frosts were reported from various stations on the 23rd and 24th. In Wyoming the killing frosts occurred on the 22nd and 23rd in nearly all sections of the state. In Colorado frosts occurred at most of the higher stations from the 21st to 24th. Killing frosts occurred generally in the northwestern portion of Nebraska on the 23rd and 24th. Light frosts occurred in all parts of Iowa on the 23rd and 27th, and in Kansas on 27th and 28th. In the morning of the 28th in Missouri freezing temperatures occurred at a number of stations in the Ozark region. Light frost occurred on the 27th, 28th and 29th in portions of Oklahoma, Arkansas and Texas areas.

On the Mexican Plateau: In the Chihuahua state killing frosts were reported in Hidalgo del Parral, Ciudad Guerrero and Jimenez, Temosachic and Aldama on September 28th, 29th and 30th. Reports indicate that damage was done to corn and bean crops. In Coahuila state killing frosts occurred at Saltillo and Arteaga on the 28th. In the Nuevo Leon state frosts were reported in Doctor Arroyo and Galeana on the 27th, 28th and 29th. In the Durango state on the mornings of 28th, 29th and 30th freezing temperatures occurred at the Nazas and Santiago Papasquiario regions. Practically in all parts of the State of Zacatecas on the 27th to 29th light to killing frosts occurred. During the last days of the month being 28th, 29th and 30th killing frosts occurred generally at a number of stations in the States of Guanajuato, Mexico, Puebla, Tlaxcala and middle of Veracruz. Light to killing frosts were reported on the 28th to 30th generally in eastern and northeastern parts of Jalisco and Michoacan States, as well as south of the States of Queretaro and Hidalgo. In the southern Mexican Plateau in the State of Oaxaca killing frosts were reported on the 28th to 30th in Coixtlahuaca, Teposcolula, Villa Alta, Ixtlan de Juarez, Zimatlan and Oaxaca city.

### *Frosts of September, 1917*

In the United States during the last days of September, 1917 the synoptic situation showed a moderate high pressure system. However, during the second half of the month prevailing conditions stayed below normal in the Gulf and the South Atlantic States. The temperature was below normal, too, at: East of Mississippi River, Iowa, Minnesota, the northern portions of North Dakota and Montana. During the last days of the month cool weather invaded the northern border states. A light frost occurred on the 26th in the Texas Panhandle, and frost temperatures

in the northwestern parts of Oklahoma. Frost warnings were reported on the 9th, 10th, 12st and 29th for the western Lake Regions, Valleys of the Upper Mississippi and the north of Red River (*Mon. Wea. Rev.*, September, 1917). Franklin (1920) was reporting great loss of cranberry bogs in the Cape Cod region, due to the frost during the nights of September 10th and 11th, 1917. He defines several types of pressure distributions, which seem to have special significance in local forecasting of minimum temperatures of the Cape Cod region. For example one of the dangerous types occurred during September 27th to 30th, 1915. A hurricane was also moving in the Gulf of Mexico as well.

However, a tropical perturbation appeared south and near of Haiti on September 23rd, 1917 (see Figure 2(i)). The next day this vortex reached southern Habana, moving towards the Gulf of Mexico through the Yucatan Canal. The upper clouds of this system always going in the front began to appear in Valladolid, Yucatan. On the 25th the hurricane remained quasi-stationary the pressure falling to 1011 mb. However, the same day near the Mexican Pacific Coast a depression of moderate intensity appeared. This situation permitted the formation of an anticyclone in the Mexican Plateau, thus changing the weather. During the night the temperature fell, the sky cleared and the winds calmed. On the next morning light frosts were reported in Tulancingo, Hidalgo, and Chignahuapan, Puebla, and Puebla city. The hurricane entered the Gulf of Mexico with strongest winds sweeping the extremity of Pinar del Rio, Cuba, and reached the middle of the Gulf coast on September 29th. In the evening on the 29th the vortex passed over the southwestern part of Georgia and continued to the Georgian coast during the following morning of September 30th.

Although with this system no damage was reported in the Yucatan Peninsula. Its presence in the Gulf of Mexico provoked the formation of a "Wedge type", being the origin of the formation of an anticyclone in the Plateau, which later reinforced, contributed to the rapidly falling temperature with killing frost in the higher areas of the Central Mexican Plateau. Most portions of the corn belt of the Southern Plateau were damaged. Generally on the 29th and 30th in the regions of the States of Guanajuato, Michoacan, Mexico, Hidalgo, Puebla and Tlaxcala, killing frost occurred. On the 30th "hoarfrost" was reported in susceptible localities of Hidalgo, which damage corn planting, large bean and barley. In the Toluca region of the State of Mexico, most corn fields did not reach maturity and much damage was done. The last frost of this period occurred on October 5th. The Boletín Mensual del Observatorio Meteorológico y Sismológico Central de México, September, 1917, also wrote that the small-scale farmers, as well as people in general, remained in misery.

#### *Frosts of September, 1974*

By the 2nd of September a surface high was centered north of Wyoming surrounded from the southwest and southeast by a cold front moving southeastwards of the United States. By 1200 GMT on September 3rd, the surface high is centered over Kansas and extended southwards. The southern most portion of the cold front is located now in southeast New Mexico. On the 4th the high was centered over Illinois extending from northeast Mexico to northeast United States. From the 4th to 5th the cold front extended from the Central area of Mexico towards the northeast Atlantic Coast of the United States. Furthermore a weak cyclogenesis was observed east of North Carolina and along the frontal system. On the 5th the high remains centered northeast of Ohio and extending also into Mexico. Noteworthy is a second front further to the northwest into the

United States. By the 6th the interaction between the frontal system and the hurricane Carmen began in the Gulf of Mexico, the frontal system retreating towards the North. However, the surface anticyclone is now nearly situated in northern Pennsylvania extending towards the north of the frontal system.

Taubensee (1974) has indicated that low temperatures had occurred in the United States during this month. From the 2nd to the 8th a northerly mean 700mb flow between a blocking high near Alaska and the Canadian low, helped to drive a pool of cold cP air into the eastern part of the United States. During the first 5 days of the month this unusually cool mass of air brought record early season cold at numerous stations situated from the Great Plains to the Appalachian Mountains, including Omaha, Nebraska, Wichita, Kansas, Amarillo and San Antonio, Texas, Shreveport, Louisiana, Columbia, Montana and Evansville Indiana.

The disturbance which spawned the hurricane Carmen left the African West Coast in August 23rd and reached hurricane intensity on September 1st. By September 3rd Carmen crossed the Yucatan Peninsula and turned northwards towards the Louisiana coast south of New Orleans (see Figure 2(ii)). Thompson and Miller (1976) observed that there is a dramatic increase in the extent of cloudiness from the 1st to the 7th of September mainly, when Carmen moves across the Gulf of Mexico and also that on September 7th, just before landfall at Louisiana, Carmen shows an almost perfectly circular overcast with a large amount of cirrus outflow. Hope (1974), however, observed, that some weakening occurred just before landfall on September 8th and suggested that cooler, dryer air was entering the system. During the days 7th to 8th of September the hurricane Carmen remains just south and along of the cold front (see Figure 5). By the 9th Carmen separates from the cold front and moved into the State of Texas.

Curiously enough, prematurely killing frost appeared in nearly all the South Central Mexican Plateau on the morning of September 7th. Mainly in the States of Guanajuato, Queretaro, Mexico, Hidalgo, Mexico city, Tlaxcala, Puebla and middle Veracruz, as well as northeast of the Jalisco and Michoacan States. The frosts were reported from the 7th to 9th of September and are shown in Figure 3.

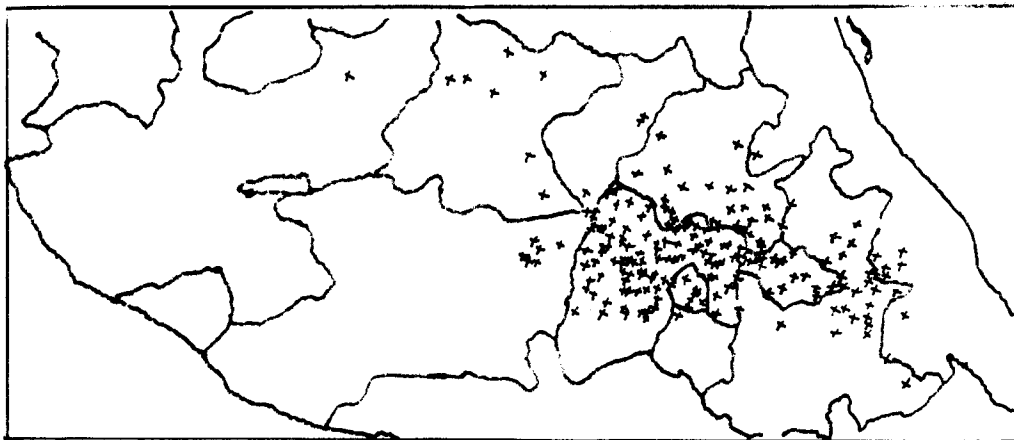


Fig. 3. Stations that reported premature frost, in general from 7-9 Sept. 1974.

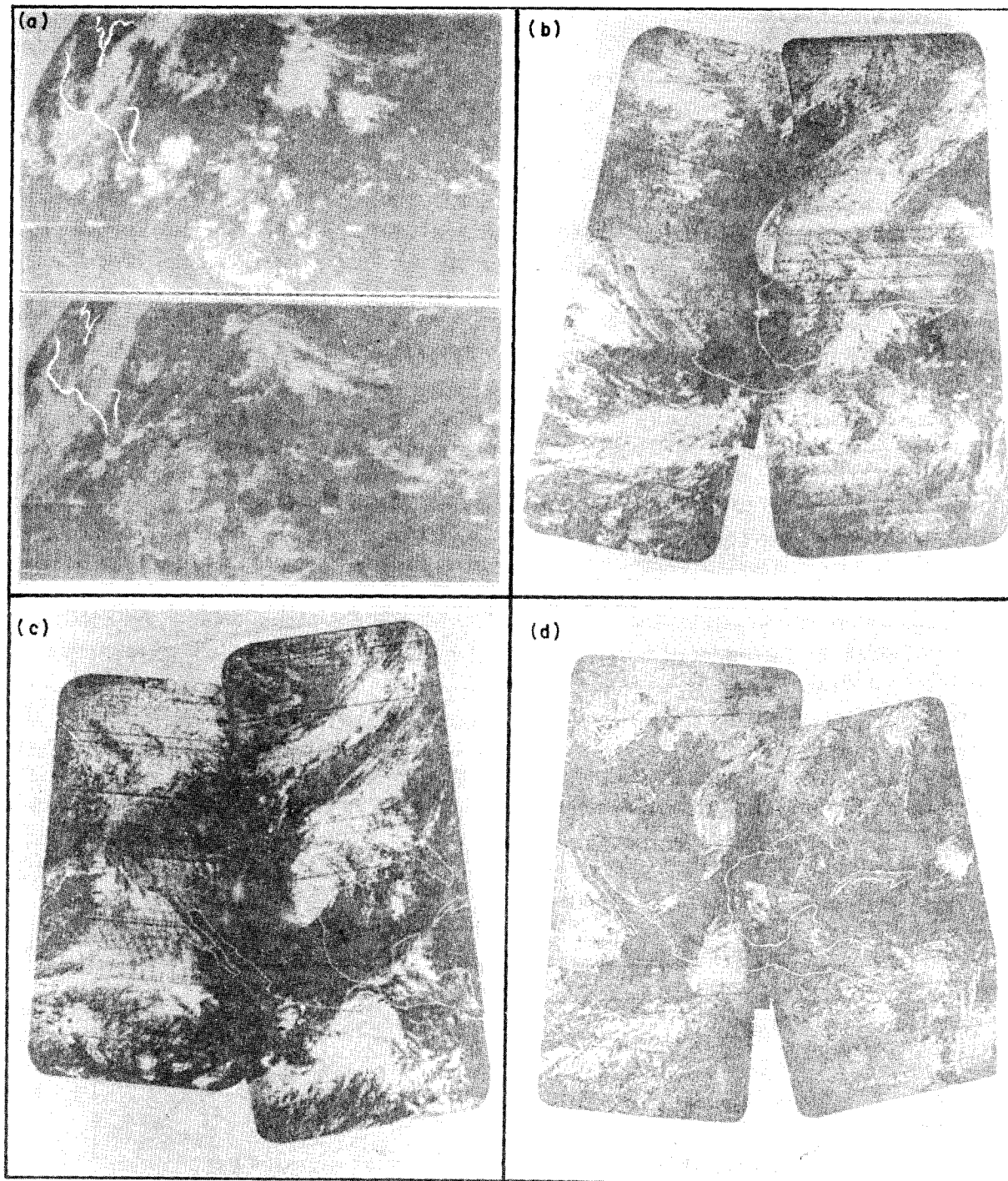


Fig. 4. Infrared satellite photos of hurricane Carmen approaching the Louisiana coast south of New Orleans, (a) on 6 and 7, 1200 GMT, (b) 8, 1547 GMT, (c) 9, 1827 GMT, and (d) 10, 1516 GMT, Sept. 1974.

Figure 4 shows infrared images from the 6th to 10th of September, 1974. On September 7th a dry tongue of air is observed from the western border of hurricane Carmen, extending to the central parts of the Mexican Republic. Surely there was a stream of cold air that came from central parts of the United States.



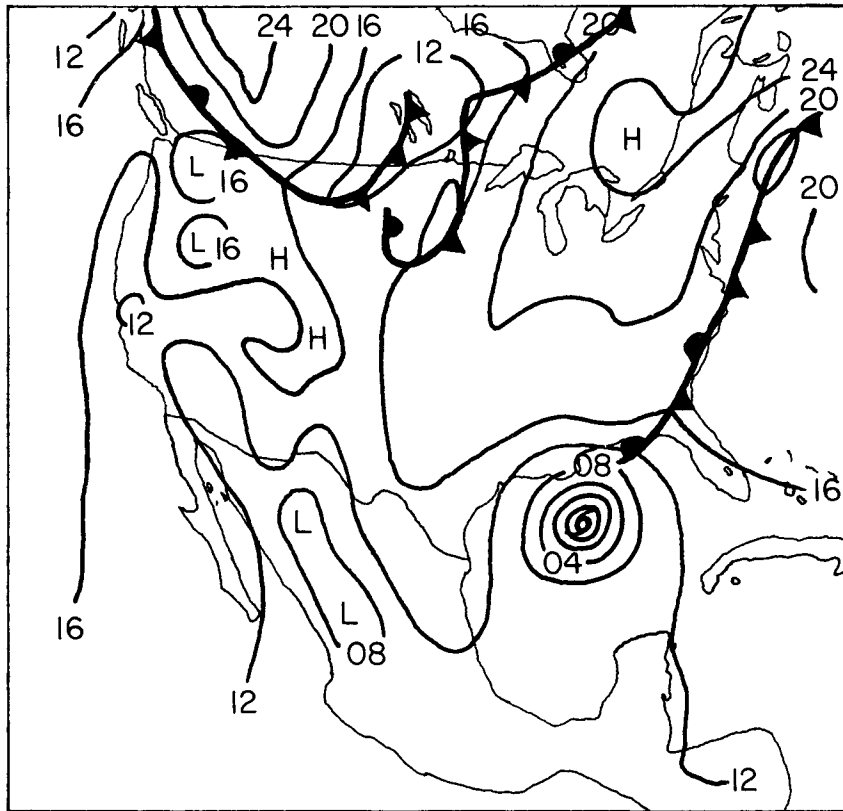


Fig. 5. Surface pressure analysis for 1200 GMT, September 7, 1974.

### *Frosts of September, 1975*

By September 15th, 1975, in response to a deep, cold trough developing in the eastern Pacific or the west coast of North America, a short wave or trough was superimposing and extending into Alaska with a strong zonal flow towards the south. On the 16th the short wave is located over the southeastern part of Yukon Territory. From the 17th to 18th of September the trough is deepening towards the south, extending to west United States and appears unstable by the 18th. Associated with the instability (cutting-of process) or formation of a closed center at the 500 mb level, occlusion of a wave cyclone in the surface level in the northern part of North Dakota occurred.

From the 19th to 21st of September, the intense upper-level trough system propagated eastwards across Central United States, and the strong ridge entered into the northwest North America. The cold front associated with the cyclonic wave moved eastwards across the United States and remained parallel to the coast of the Gulf of Mexico and the Atlantic respectively.

By 1200 GMT on the 21st of September, an anticyclone, surface level over western United States appeared. It traveled towards the east extending south into northern Mexico on the 22nd.

Further discussion of weather and circulations in the United States for September, 1975, has been given by Taubensee (1975). Only a small review is given here. September, 1975, marked a seasonal change for the northwest and northeast, when at the beginning of the month cold air

moved southwards from Canada and was unusually cool around the Great Lakes. In the week of September 22nd to 28th, a large mass of cold air moved over Central United States. Scattered frost damaged corn crops in northern Iowa, Kansas, Minnesota and Nebraska. In Wisconsin frost was felt in most areas and Texas had clear skies, according to Weekly Weather and Crop Bulletin, September, 1975.

However the tropical storm Eloisa appeared on September 16th near Puerto Rico moving towards the west and strengthening. On the 21st it reached the Yucatan Peninsula and turned northwestwards (see Figure 2(ii)). As Eloisa moved across the warm Gulf of Mexico, she gained intensity to hurricane, until reaching landfall on 23rd where it weakened rapidly (Hebert 1976).

On the 23rd the interaction between hurricane Eloisa and the cold front in the northern part of the Gulf of Mexico was initiated. Now the anticyclone centered over Iowa regions and extending well southwestwards. The hurricane Eloisa interacted with a baroclinic wave along the frontal system and then weakened during the following day, the 24th. However, a tropical depression was developing east of the Yucatan Peninsula and remained just south of the cold front. The synoptic situation that arrived (see Fig. 7) is similar to the one in Fig. 1c.

Dramatically in the morning of the 23rd, freezing temperatures occurred at a number of stations situated over the Central Mexican Plateau. Generally, killing frost occurred in most of the same stations in the mornings of the 24th to 30th of September (see Fig. 6).

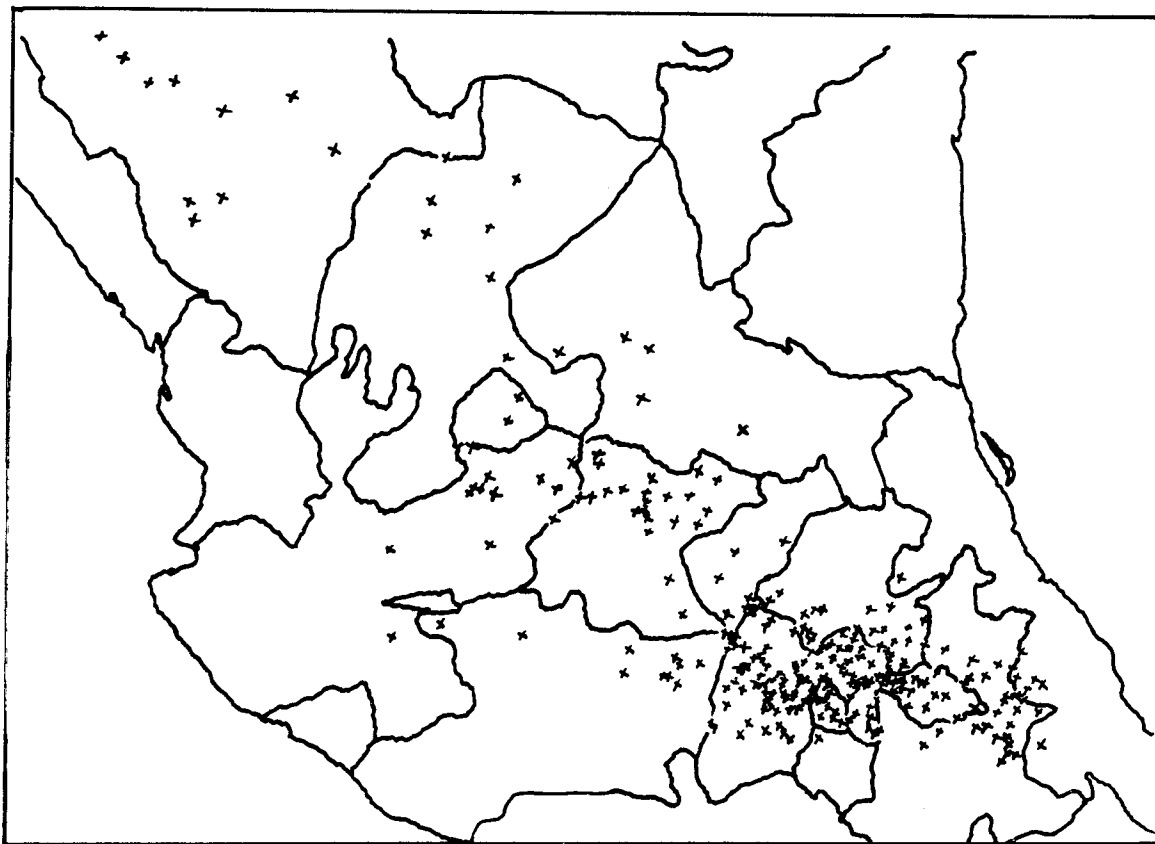


Fig. 6. Stations that reported frost, in general from 24-30 of Sept. 1975.

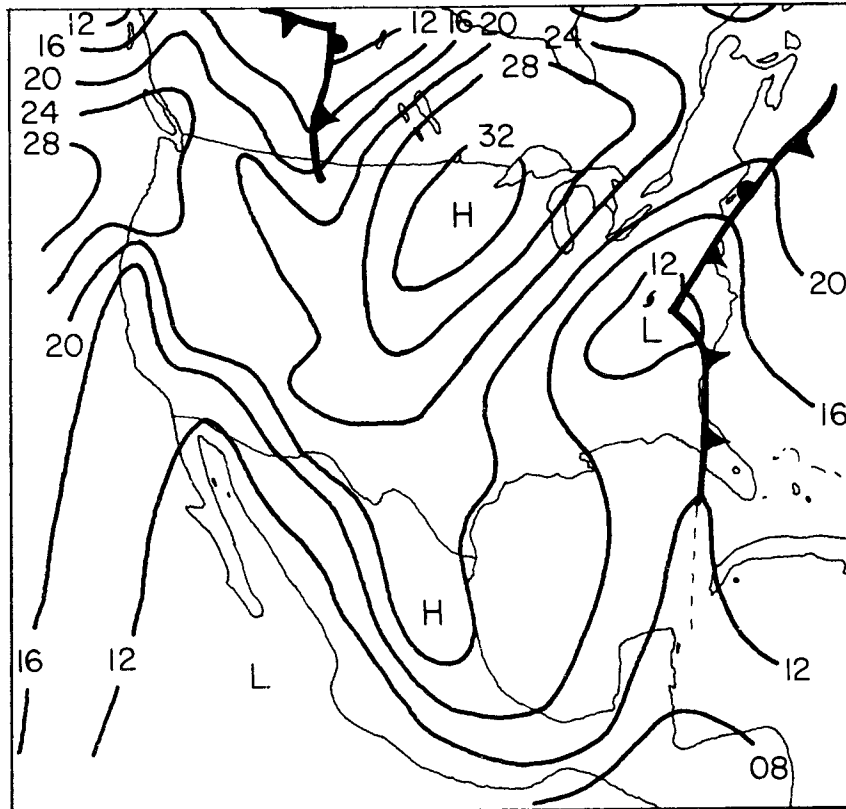


Fig. 7. Surface pressure analysis for 1200 GMT, Sept. 24, 1975.

### *Frost of June, 1979*

In response to a deep trough located south of the Yukon territory and a ridge in northwestern North America, on the 10th of June a deepening 500 mb trough moved slowly eastwards over the Hudson Bay extending southwards into Central United States. During the period 11th to 15th of June an anticyclonic circulation centered in 700 mb developed and covered the near center and northwestern Mexico. A surface baroclinic cyclone, coupled with its sustaining upper-level trough, was centered north of the Great Lakes with a cold front oriented southwestwards, on the 10th. Also a surface anticyclone covered Utah, Wyoming and Colorado regions being bordered to the east by the cold front. Likewise from the 10th to the 14th the surface anticyclone and cold front moved southeastwards of the United States the latter remaining parallel to the Atlantic coast.

One of the three depressions of the tropical system of the Atlantic in 1979, which did not reach the intensity of tropical storm, was a depression formed in the western Caribbean Sea. The forerunner of this system was an easterly wave, which moved off the African coast on May 30th. This wave interacted on June 11th with a trough in the western Caribbean Sea, where the depression was generated, provoking heavy precipitation over Jamaica on the 12th (Frank and Clark, 1980). This tropical depression moved towards the north and crossed middle Cuba on the 13th and reached South Carolina on the 16th (see Fig. 8). However, on the morning of the 13th of June, tardy frost appeared in nearly all the South Central Mexican Plateau. This unusual cold air brought killing frost to numerous stations situated on the South Central Mexican Plateau from

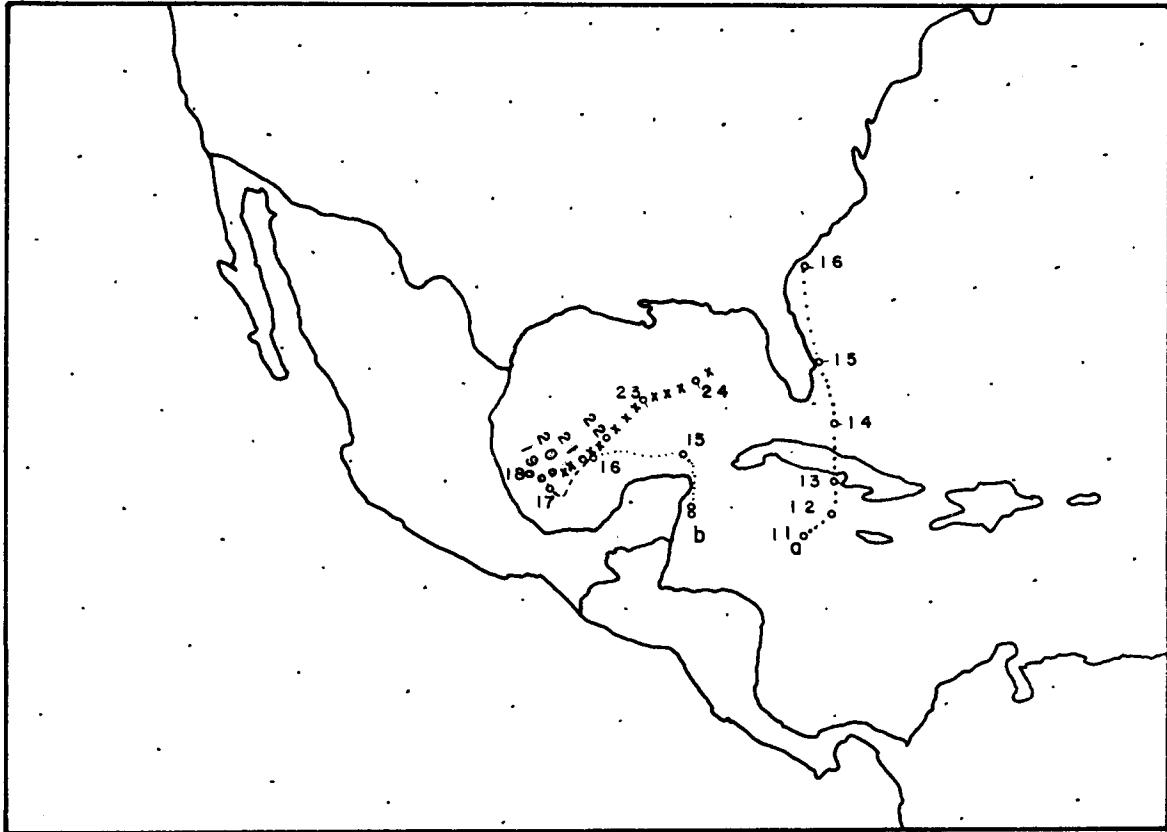


Fig. 8. As in Figure 2 now for: a) tropical depression June 11-16, 1979; b) Henry, Sept. 14-24, 1979.

the 14th to the 16th of June (see Fig. 9). Most portions of the southern corn belt were damaged, mainly the cornfields located near the rivers or low regions. Some farmers decided to sow again and others just to cut the damaged leaves. In particular the author of this paper cut the leaves of the damaged corn. A most sad event. Taubensee (1979) also noted that during the week 11th to the 17th of June the temperature dropped below normal across wide parts east and northeast of the United States.

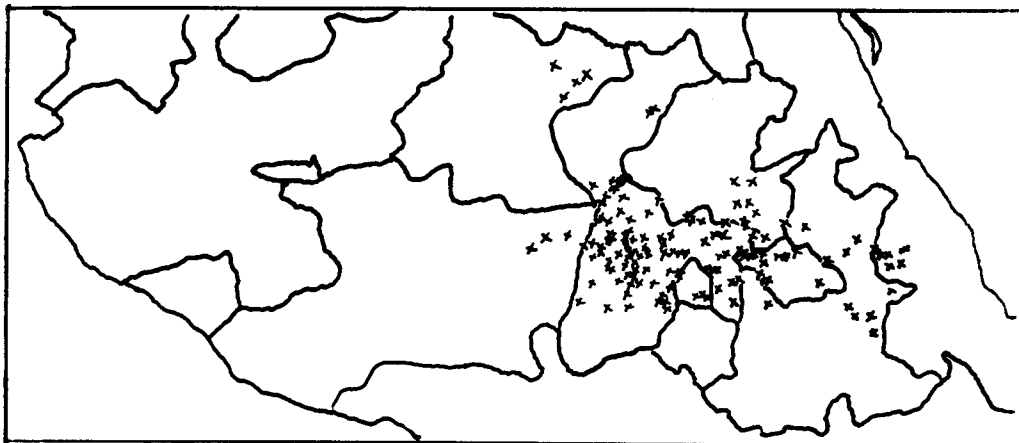


Fig. 9. Stations that reported tardy frosts, in general from 14-16 of June, 1979.

The surface chart for 1200 GMT on June 13th is shown in Figure 10a, with the stationary front running from the Central Gulf of Mexico to the east Atlantic coast of the United States, which later interacted with the tropical depression.

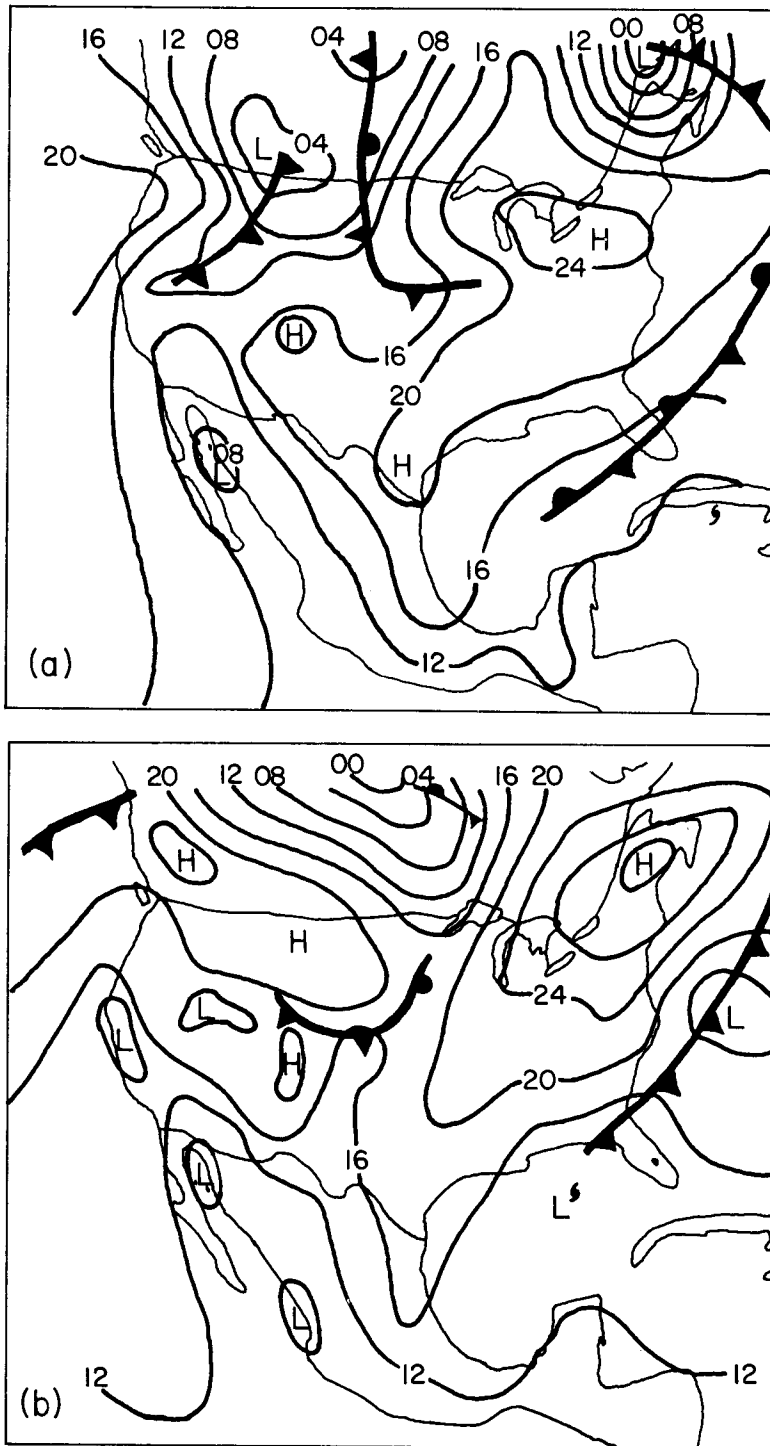


Fig. 10. Sea level isobars at intervals of 4 mb: (a) for 1200 GMT, June 13, 1979 and (b) 1200 GMT, September 24, 1979.

*Frost of September, 1979*

From the 20th to the 23rd of September, 1979, a broad complex, large-scale cyclonic circulation in 500 mb exhibiting multiple centers and multiple troughs tended to move slowly east across the Hudson Bay, with a trough extending southeastwards into the United States. Furthermore, a broad anticyclonic circulation center appeared in 700 mb northwest of Mexico from the 22nd to the 26th. During these days the trough extended as far as the Gulf of Mexico. Also during the period 20th to 24th of September a surface middle latitude anticyclone moved southwards in the lee of the Canadian Rockies and eastwards across the United States. On the 24th this cold anticyclone was situated over New England extending as far as northeast Mexico (see Fig. 10b).

Taubensee (1979) observed that in response to a trough over eastern Canada, in the week of the 17th to 23rd of September, 1979 cold air moved into the northeastern quarter of the United States, where temperature below freezing occurred in Sault St. Marie, MI., on the 19th and in Albany, New York, on the 20th. Also some relatively cold air persisted along the Gulf coast according to a low pressure system located over New Orleans and Louisiana, the week from the 24th to 30th of September.

On the other hand the depression Henry moved near the Veracruz coast, Mexico, on the 18th. Afterwards it moved slowly east and northeastwards (see Fig. 8). It remained just south of the cold front, which had moved into the northern Gulf of Mexico, and finally became part of the frontal low pressure trough in the northern Gulf of Mexico on the 24th (Hebert, 1980, see Fig. 10b). Surprisingly light to killing frosts appeared in nearly all the Central Mexican Plateau

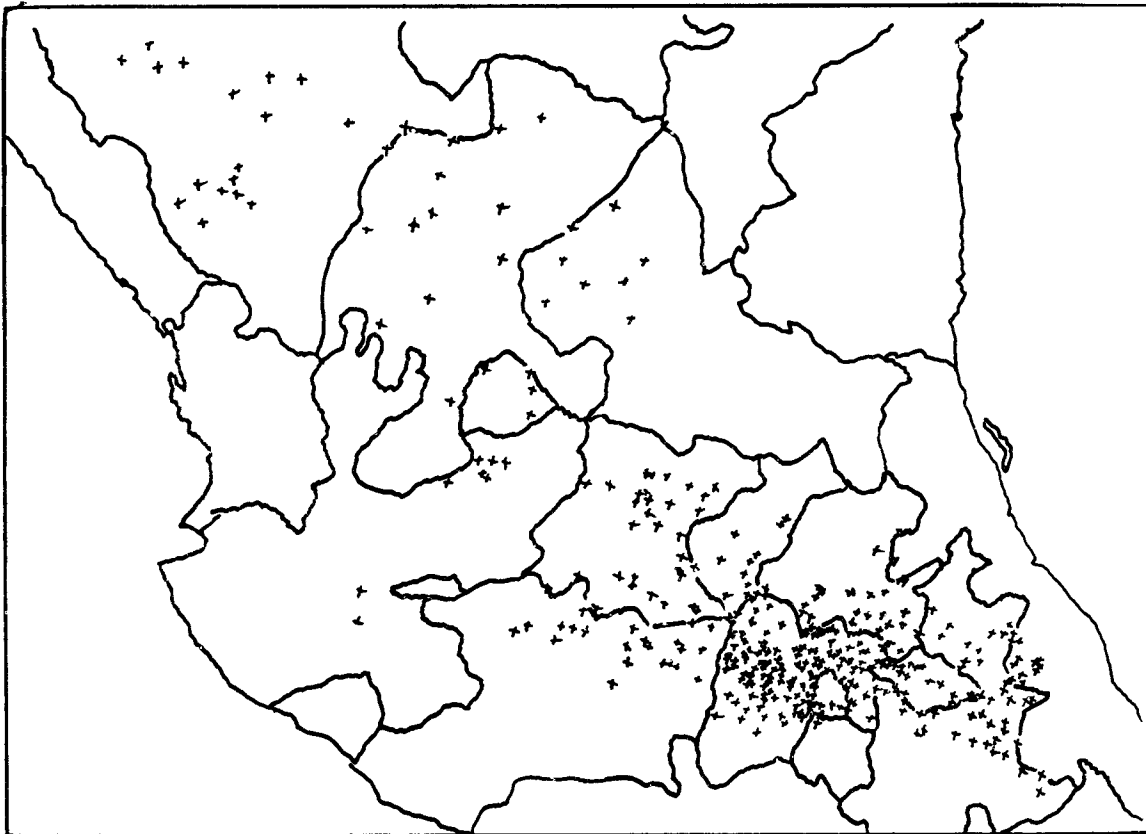


Fig. 11. Stations that reported frost, in general from 24-30 of September, 1979.

in the morning of the 24th of September. This premature frost was reported from the 24th to 30th, and can be seen in Figure 11. As mentioned before in June most portions of the Central Plateau corn belt were damaged by the tardy frost. The cornfields, large bean and barley did not reach maturity, since again it was damaged by the frost that occurred during these last days of September.

#### *Frosts of September, 1988*

At 500 mb, we have observed the following: A low pressure train was situated, on the 4th of September, 1988, from the Istmo of Tehuantepec, Mexico, to regions close to the North Pole, with an anticyclone in the Rockies and a cyclone south of Alaska. The superposition of the low train provoked the formation of a cyclonic circulation in the northeast of the Hudson Bay and one deepening large amplitude trough, extending as far as the northern Gulf of Mexico. Furthermore the ridge associated with the anticyclone in the Rockies extended northwards, on the 5th. By 0000GMT on the 7th of September the ridge was situated in Central North America and the cyclone south of Alaska, is now located east of Yukon Territory. This cyclone moved southeastwards and across south of Canada. On the 10th it was located southeast of the Hudson Bay.

The Weekly Weather and Crop Bulletin (Sept. 4th to 10th, 1988) had reported that a high pressure system over the middle Mississippi Valley was responsible for clear, cool weather from New England to the Great Plains, with record low temperature on the 6th and also that a cold front moved across the northern Plains on the 7th.

On the 8th besides the anticyclonic circulation over Mexico vorticity high appeared north west of the Yucatan Peninsula. The anticyclonic circulation was reinforced and moved north and northwest of Mexico during the 9th to 10th. During the 8th to 10th the stationary cold front linked with the large amplitude trough and was situated east of the Atlantic coast of the United States extending to the center of the Gulf of Mexico and with diurnal oscillation.

The tropical depression Florence appeared northwest of Merida, Yucatan, on the 7th (see Fig. 12). On September 9th due to the position of a trough and the strengthening of the Atlantic ridge, the northward movement of the tropical storm Florence, began, Diagnostic Rep. of the NHC (Aug. and Sept., 1988). Florence intensity was upgraded to hurricane just before landfall, between the 9th and 10th of September, when it formed part of the cold front (see Fig. 13). However, light frost began to appear in some localities (personal communication) of the Central Mexican Plateau on the 9th, being more severe from the morning of 10th. A photo in Figure 14 shows cornfields damage by the frost of the 9th to 10th, taken from St. Maria Citindeje, in the northwest of State of Mexico.

On the 10th a frontal system associated with the cyclone from the Hudson Bay was propagated towards the Atlantic coast of the United States. Furthermore a surface anticyclone is located in the Appalachian Mountains extending southwestwards and a cyclogenesis is observed in the northwest United States at 1200 GMT of the 10th (see Fig. 12).

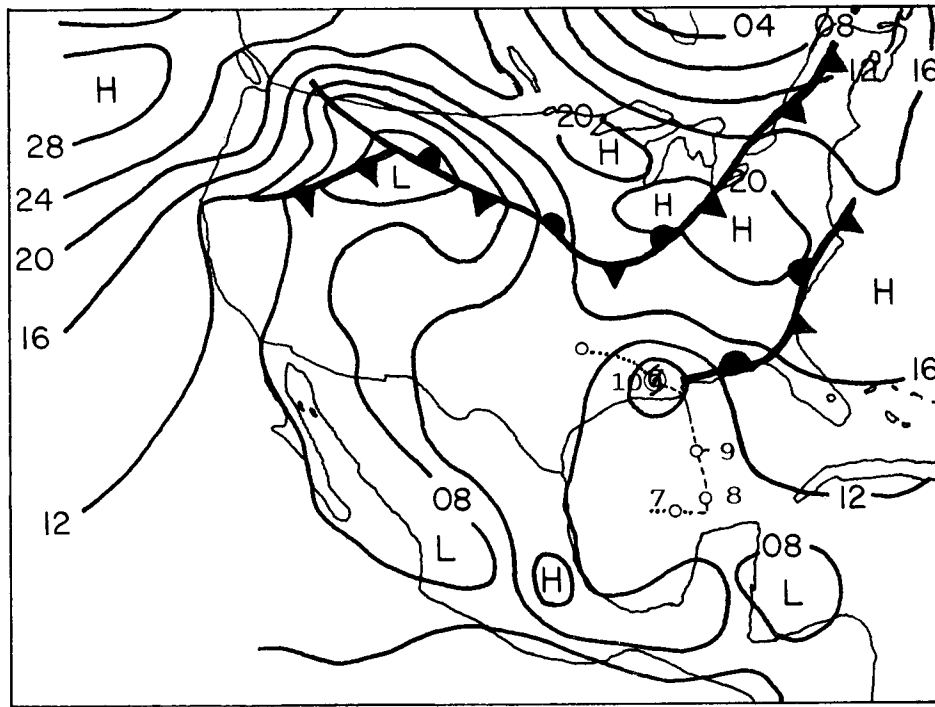


Fig. 12. Surface analysis for 1200 GMT, September, 10, 1988 and the track of hurricane Florence, Sept. 7-10, 1988.

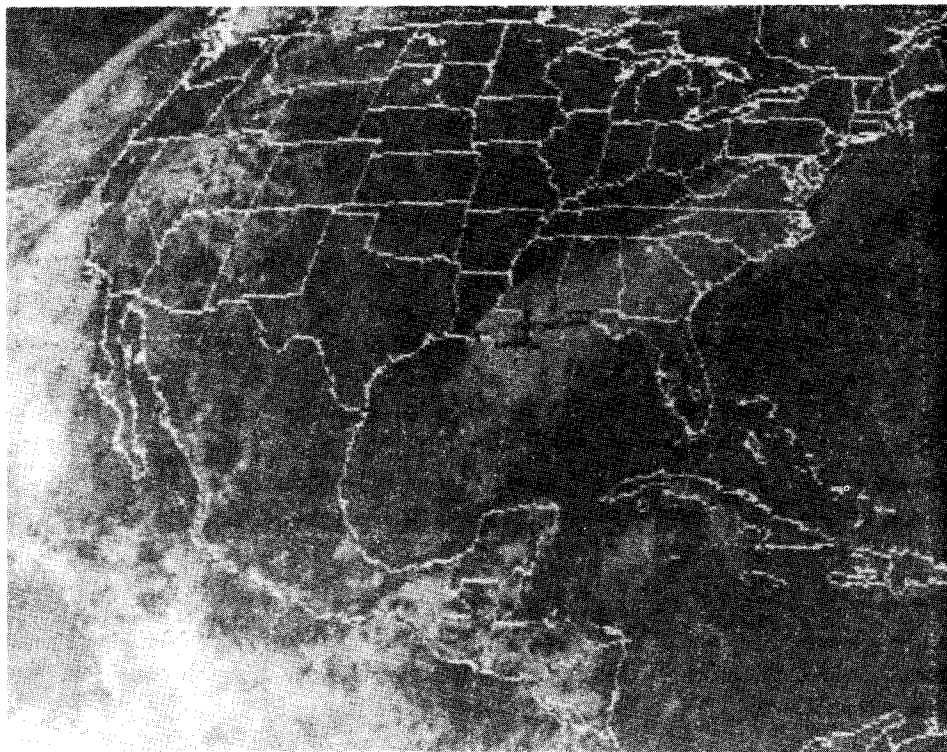


Fig. 13. Visible satellite photo of hurricane Florence approaching the Louisiana coast south of New Orleans 2201 GMT, Sept. 9, 1988.





Fig. 14. A view of cornfields damaged by the frost of Sept. 9-10, 1988 near 19.7°N, 99.8°W, taken in Oct. 2, 1988.

### General remarks and conclusions

In this paper the phenomenon of premature and tardy frosts and the presence of tropical cyclones have been examined. In the cases analysed of frost for Mexico we find that two or three days before, a large mass of cold air moved northwest of Canada and afterwards it moved across Central United States, where it brought record below normal temperatures. When the premature or tardy frost period is initiated in the Central Mexican Plateau, a tropical cyclone turns in the center or northeastern parts of the Gulf of Mexico or west of the Caribbean Sea. Strong frosts occurred in the Central Mexican Plateau, when the tropical cyclones showed maximum intensity, forming part or remaining just south of the cold front, mainly, just before landfall.

Figure 15 shows approximately the initial general period of frost of the South Central Mexican Plateau since the year 1926. To draw these graphs stations were selected (around 100) located in the more elevated parts, except the ones located near snowy mountains. From the years 1926-1950 there are few data. It is noted that in the years 1958 and 1972 the general frost periods were initiated around the 10th of December. This indicates that an anomalous effect had developed globally (warm episodes).

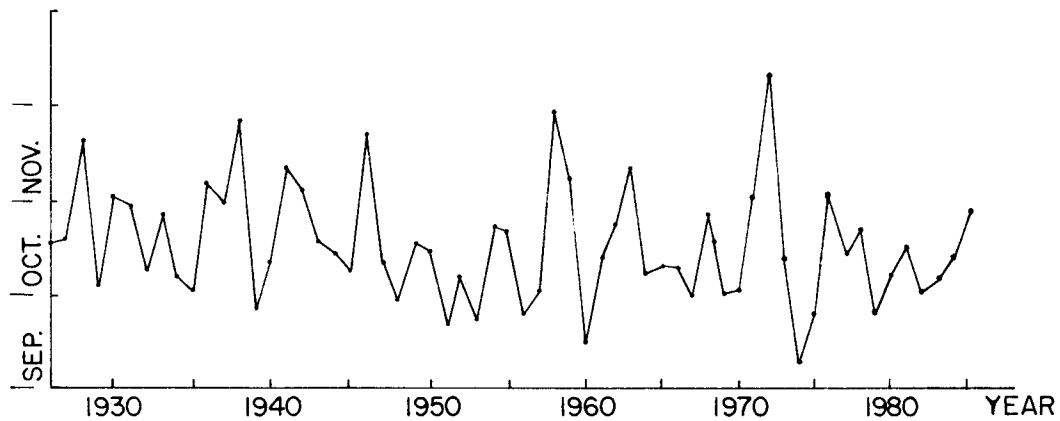


Fig. 15. Initial general period of frost of South Central Mexican Plateau since 1926 on the more elevated parts of the States of Guanajuato, Queretaro, México, Hidalgo, Tlaxcala, Puebla, middle Veracruz, east of Michoacan and Mexico city.

In Figs. 16 to 18 other cases of tropical cyclones are shown that in one way or another during their development or movement frost has occurred in the Central Mexican Plateau. Their tracks located either very much to the east of the Caribbean Sea or the Bahamas had been neglected.

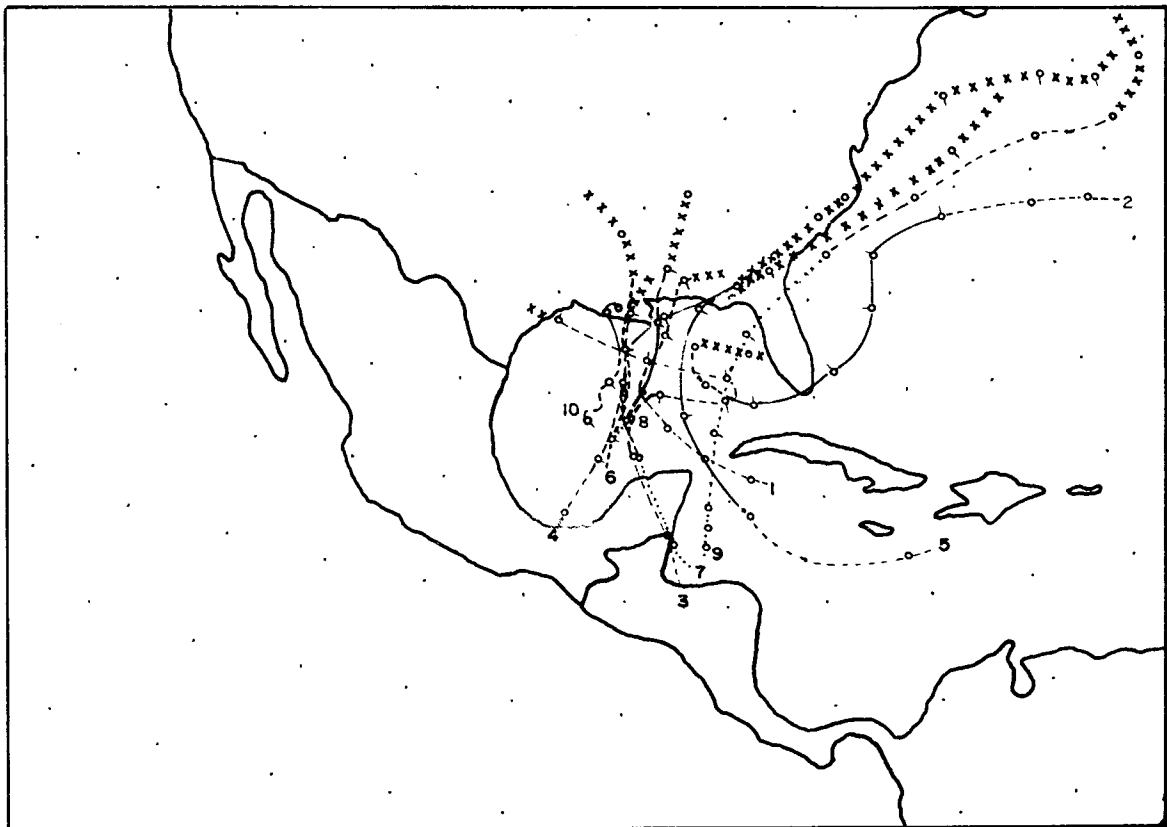


Fig. 16. As in Figure 2 except now for the tracks steered towards the north-oriental part of the Gulf of Mexico

- |                                     |                                    |
|-------------------------------------|------------------------------------|
| 1. Tropical storm Oct. 1-6, 1934    | 6. Tropical storm Jun. 11-14, 1956 |
| 2. Hurricane Oct 30-Nov. 8, 1935    | 7. Eloisa Sept. 21-30, 1956        |
| 3. Tropical Storm Oct. 10-17, 1938  | 8. Ethel Sept. 14-17, 1960         |
| 4. Tropical Storm Sept. 23-26, 1939 | 9. Tropical storm Jun. 2-11, 1964  |
| 5. Florence Sept. 23-28, 1953       | 10. Juan Oct. 25-Nov. 1, 1985      |

We have two areas of influence. The first area is one, where the cyclone just before landfall arrives over the Louisiana coast or its neighbourhood (see Fig. 16); and the second area is in the western Caribbean Sea, where the cyclone tracks are steered towards the Bahamas (see Fig. 17). The majority of the tracks examined in this paper belong to the first area and the case of tardy frost (13th to the 14 of June, 1979) belongs to the second area.

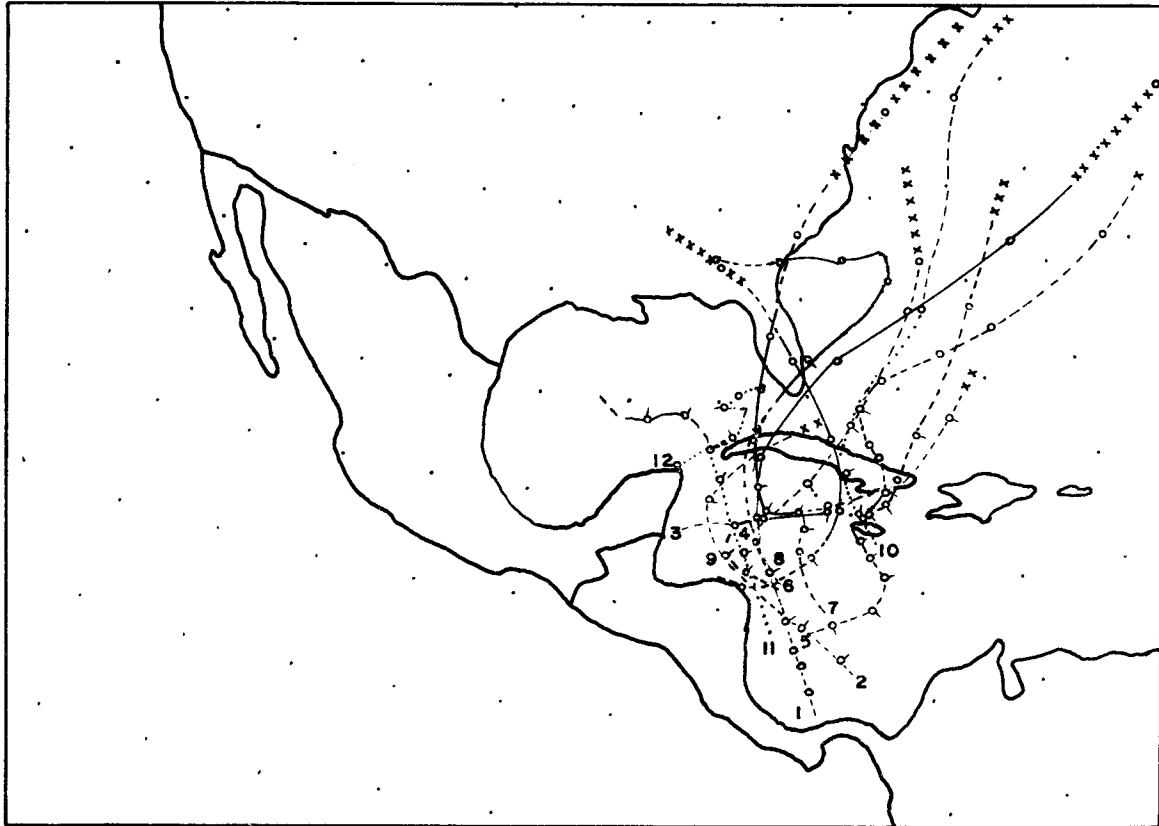


Fig. 17. As in Figure 2 except now for the tracks steered towards the Bahamas:

- |                                       |                               |
|---------------------------------------|-------------------------------|
| 1. Hurricane Oct. 14-24, 1926         | 7. Hurricane Oct. 12-23, 1944 |
| 2. Tropical storm Nov. 13-15, 1926    | 8. Hurricane Oct. 9-16, 1947  |
| 3. Tropical storm Oct. 17-19, 1927    | 9. King Oct. 13-19, 1950      |
| 4. Tropical storm Oct 31-Nov. 3, 1927 | 10. Gerda Oct. 15-22, 1961    |
| 5. Hurricane Oct. 24-Nov. 7, 1933     | 11. Jeanne Nov. 7-16, 1980    |
| 6. Hurricane Oct. 29-Nov. 6, 1939     | 12. Alberto Jun. 2-6, 1982    |

In some of the cases it was observed, that when the frost periods were initiated, it coincided with the formation or development of a tropical cyclone, such as occurred in the years 1940H7, 1946H6, 1951H7, 1951H9, 1956H1, 1964H11, 1966H1, 1967H6, 1969H13, 1971H13, and 1977H6. Part of the tracks of these systems are drawn in Fig. 18. The code 1940H7 meaning the tropical cyclone, number 7 of the year 1940 (presented in the Historical Climatology Series 6-2, over Tropical Cyclones of the North Atlantic Ocean, 1971-1986, NOAA, 1987). Probably, because the development of these perturbations were associated or induced by the passage of deep cyclones and a well developed cold front, which had moved slowly east and northeastwards of the Gulf of Mexico. For example the tropical depression, which was formed west of Cozumel, Yucatan, on the

25th of September of 1975 (Frank, 1975, see Fig. 2(ii)), the frost period was already initiated the day before on the Central Mexican Plateau. It was also observed that when the Atlantic hurricane season ended the frost period was initiated, such as in the years 1955, 1963 and 1968.

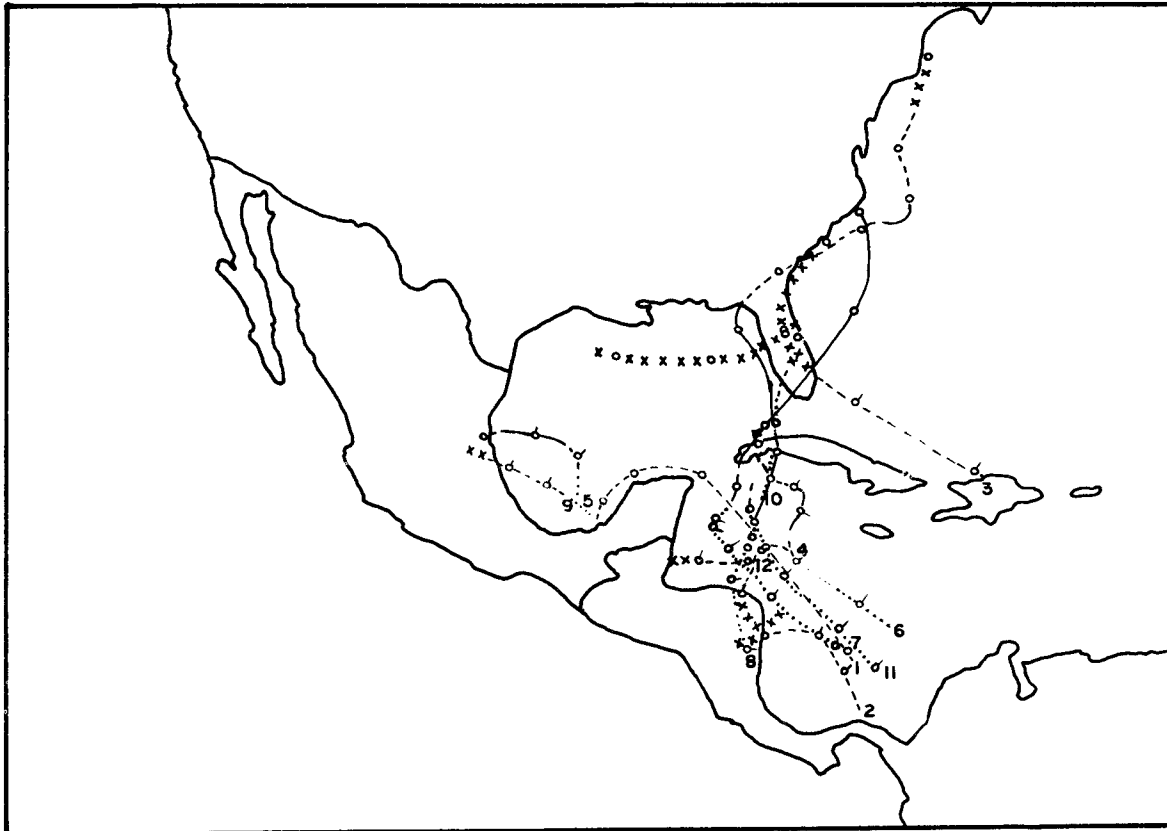


Fig. 18. As in Figure 2 except now for:

- |  |                             |
|--|-----------------------------|
| 1. Tropical storm Nov. 15-16, 1933     | 7. Isabell Oct. 8-16, 1964  |
| 2. Tropical storm Oct. 20-23, 1940     | 8. Alma Jun. 4-14, 1966     |
| 3. Tropical storm Oct. 31-Nov. 3, 1946 | 9. Fern Oct 1-4, 1967       |
| 4. Tropical storm Nov. 3-4, 1949       | 10. Jenny Oct. 1-6, 1969    |
| 5. George Sept. 20-21, 1951            | 11. Laura Nov. 12-21, 1971  |
| 6. Item Oct. 12-17, 1951               | 12. Frieda Oct. 16-18, 1977 |

The synoptic patterns prior to the occurrence of the frosts have been identified for each case and found similar. The frost occurred, when the localities were under the influence of a surface anticyclone, centered north of the Gulf coast states or northeastern parts of the United States with an anticyclonic circulation in 700 mb or 500 mb near the center and northwest Mexico, also when a deep trough was over eastern United States and stationary cold front runs from the central Gulf of Mexico to the east Atlantic Coast of the United States. These synoptic patterns are similar to the ones of the winter season, such as occurred on the 22nd to 23rd of February, 1989 (see Fig. 1a-d).

The unsolved problems that still persists are what provokes the cooling? We think it would be one of the following processes: The advection of polar air, radiative cooling, subsidence of stratospheric air towards the middle and lower troposphere provoked by the interaction of the hurricane with the upper-level frontogenetic process, or a combination of some of these.

The lack of observations at the surface, radiosondes and unavailability of data have prevented the knowledge of the physical processes contributing to the presence of frosts. Associated with the frost phenomena in Mexico there are still a number of unsolved problems and topics that require further research. These include: a) solving the sparsity of radiosonde and surface data, b) investigation of the interaction among the cold front, tropical cyclones, cyclones, anticyclones and their effect on the Mexican Plateau, c) observational documentation of cold front movement throughout Mexico, d) consideration of the effect of pooling cold air, e) to examine the synoptic patterns in terms of isentropic potential vorticity and the theoretical design of models that describe the evolution of cold fronts and baroclinic waves.

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