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Major cold air outbreaks affecting coffee and citrus plantations in the eastern and northeastern Mexico

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RESUMEN

Se analizan varios casos de la situación sinóptica asociada con heladas intensas, las cuales han afectado las plantaciones de cítricos y café en el este y noreste de México, mismas que también han dañado cítricos y verduras en Texas, Louisiana y Florida. Este trabajo se remonta al origen y evolución de la circulación anticiclónica asociada a la masa de aire ártico o polar. Ciertos casos se originaron por una situación de bloqueo de los vientos de los oestes en el Pacífico nororiental, zona de confluencia en la vecindad de Alaska, así como una ciclogénesis intensa en el noreste de los Estados Unidos. Los fríos más intensos sobre el este, noreste y mesa central de México se observaron cuando un anticiclón en superficie asociado con la masa de aire polar cubrió el sureste de Estados Unidos, Golfo de México y parte este de México.

ABSTRACT

Several cases of the synoptic situation associated with intense frosts, which has affected the plantations of coffee and citrus in eastern and northeastern Mexico, are analyzed; these events also damaged citrus and vegetables in Texas, Louisiana and Florida. The origin and evolution of the anticyclonic circulations associated with the polar air mass, are traced. These originate during a blocking situation of the westerlies in the Northeastern Pacific with a confluence zone close to Alaska, and an intense cyclogenesis in the northeast of United States. The major cold air outbreak over the east, northeast and Central Mexican Plateau is observed when an anticyclone associated with the polar air covers southeastern United States, Gulf of Mexico and the easthern Mexico.

1. Introduction

Mexico has a great variety of climatic regions, Mosiño and García (1973). The regions of tropical forests are situated along the eastern Sierra Madre Oriental with warm and semiwarm climates (see page 69 of SRH). These regions include parts of the states of Nuevo León, Tamaulipas, San Luis Potosí, Hidalgo, Puebla, Veracruz and mainly the Huasteca regions, which have broad areas of favorable conditions for the cultivation of citrus and coffee.

Coffee was introduced in Mexico at the end of the 18th Century in two regions of Veracruz (Coatepec and Córdoba), where it obtained great importance since the end of the 19th Century. From this time to the begining of the 20th Century the cultivation of coffee has been extended into the states of Oaxaca and Chiapas. The coffee is also produced in the states of Jalisco, Michoacan, Morelos, Sinaloa, Tabasco and Tamaulipas (Fig. 1).

Coffee cultivation has been subjected to very little investigation in Mexico. From 1874-1893 Matías Romero (1887, 1889) developed essays on the cultivation of coffee and its propagation. Another Mexican who was interested in the progress of exploration of the coffee plant and its possibilities was Ramón Fernández y Fernández (1934). He was more concerned with the problems in relationship with the production and interchanging of regional products. In 1985, Nolasco gave a global vision of the mexican coffee cultivation, and more recently Villaseñor (1987) has discussed technical problems in this field.

Fig. 1. Major commercial coffee producing areas of the south and southeast regions of Mexico (dashed zones) and orography (in 500 m contour intervals).

Other countries in Latin America that export coffee are Brazil, Colombia, El Salvador and Guatemala. In addition to the social problems that occurred in Angola and Central America, the plage of 1888 and the 1975 frost problems in Brazil (Parmenter, 1976; Tarifa *et al.*, 1977) stimulated the cultivation and development of coffee in Mexico. However, the major sweeping changes took place after the intense frosts in Brazil during the middle of July 1975, provoked an increment of the international coffee prices in 1976.

Along with coffee plantation, the citrus cultivation, substituting for the sugar cane wás also introduced into this country at the begining of the 20th Century. Citrus fruit is commercially produced from the southeast to northeast regions of Mexico, including parts of Veracruz and southeastern Nuevo León (Fig. 2).

Fig. 2. Major commercial citrus producing areas of the northeast-southeast regions of Mexico (dashed zones) and orography (in 500 m contour intervals).

Both eastern and northeastern Mexico have had unusual cases of intense frosts (Table 1). These intense frosts were registered during the years 1951, 1962, 1979, 1983 and 1989 in the coffee and citrus plantations. The states of Nuevo León (NL), Tamaulipas (TMPS), San Luis Potosí (SLP), Hidalgo (HGO), Puebla (PUE), Queretaro (QRO) and Veracruz (VER) were the most affected.

For frost forecast purposes, the synoptic situation of these cases will be discussed in this paper. It is not attempting to realize a composite climatological analysis of the five frosts episodes, since various causes and mechanisms may be involved in the cases of developing the polar air mass. According to Mecikalski and Tilley (1992), a *cold air outbreak* is present in the entire area east of the Continental Divide which experiences the colder air associated with an anticyclone of polar or arctic origin, a cold surge type NA.

TABLE 1. Selected cold air outbreaks episodes which has affected the northeastern Mexico. Day/Year (Min. Surf. Temp. °C)

Station Lat°N/Long°W	December	January	February	Period
Herreras NL 25.9/99.4	12/66(-6) 17/79(-5) 25-26/83(-12) 15/85(-5)	31/49(-9);11/62(-13) 19/77(-3.5);3/79 (-5.5) 14/82(-4);1/84(-8)	3/51(-8.5) 23-24/76(-3) 2/85(-5)	1942-1985
Linares NL 24.8/99.5	12/66(-4) 21/73(-5) 22/77(-3) 14/81(-3) 25-26/83(-7)	31/49(-5);12/62(-11.5) 29/73(-4); 13/75(-6.5) 9/76(-5); 19/77(-3) 3/79(-4); 5/85(-5)	3/51(-6.5) 9-10/73(-3) 24/75(-3.5) 23-24/76(-3) 3-4/85(-4)	1941-1985
Lampazos NL 27.0/100.5	21/73(-4) 25-26/83(-8) 14-15/85(-3) 22-23/89(-7)	12/62(-8);6-7/71(-2) 12/73(-3);13/75(-5) 10/77(-1);3/79(-4) 14,17/82(-3);5,13/85(-3)	10-11/73(-3) 11-12/81(-2) 7-8/82(-2)	1942-1989
Vallecillo NL 26.6/100.0	24/83(-8) 23-24/89(-8)	12/62(-11.5);13-14/75(-6) 10/77(-3);3/79(-5) 21/84(-4),13;22/85(-4,-6)	1/51(-3) 10/73(-0.5)	1942-1989
N.Laredo TMPS 27.5/99.5	25/83(-10) 14/85(-2) 23/89(-10)	12/62(-7.9);13/66(-5.1) 2/79(-6);13,21/85(-3,-4.5) 11/88(-2.5)	1/49(-4.3) 2/85(-6.5) 5/89(-2.5)	1941-1989
La Piedad TMPS 25.3/97.8	13/66(-4) 25-26/83(-6)	12/62(-9);13/73(-3) 13/75(-6);9/76(-3) 1/79(-1)	3/51(-2) 10/73(-4)	1952-1983
Villagrán TMPS 24.5/99.5	24-25/83(-3) 23-24/89(-6)	12/62(-10);13/84(-4) 5/85(-2);6-8/71(-1) 13-14/75(-3)	3/51(-4) 7-8/89(-1)	1943-1989
Matehuala SLP 23.5/100.6	22/77(-8.5) 21/89(-0.2)	12/62(-10);13,30/73(-4,-6) 9/76(-3);9,14/78(-8,-5.5) 4/79(-4)	13-14/71(-2) 11/73(-2) 24/76(-5.5)	1942-1989
Moctezuma SLP 22.7/102.0	26/83(-3)	12/62(-10);4/79(-4) 24/76(-9)	2/51(-12)	1942-1983
Cedral SLP 23.8/100.7	31/63(-12) 22/77(-7.5) 26/83(-8)	12/62(-11.7),3/79(-4) 20/76(-8.6)	14/60(-11.6) 24/76(-10)	1942-1983
Atzalan VER 19.8/97.2	5/45(-3) 22/77(0) 25,31/83(0) 24/89(-2)	12/62(-4);13,29/73(0) 3/79(0);6/85(0) 23/87(-2)	2/51(-2) 10-11/73(0) 4/80(0) 10/87(-2.5)	1941-1990
Las Minas VER 19.6/97.1	25,30/83(2.5,-2) 24/89(-2)	12/62(-1.5) 3/79(-1.5)	3/51(0.5)	1950-1990

2. Scientifical research related to coffee and citrus freezes and a historical overlook

Large scale patterns associated with major frost episodes over Mexico have been the object of very little investigation. During the Northern Hemispheric winters, Mexico has been invaded by polar air and the premature and tardy frosts cause the worst damage to crops (Pérez, 1990a). The season running from September to the following June, when freeze events occurs, is the time when the growing of the citrus fruit takes place. Frost occurs most during the months of December and January. During these months one of every five years observed freezes of great intensity and duration which caused extensive economical losses to the citrus and coffee industries. For example, a severe frost occurred on February 12, 1899 (Noble and Lebrija, 1954) which caused much damage close to the coast of Veracruz and covered an extensive region of

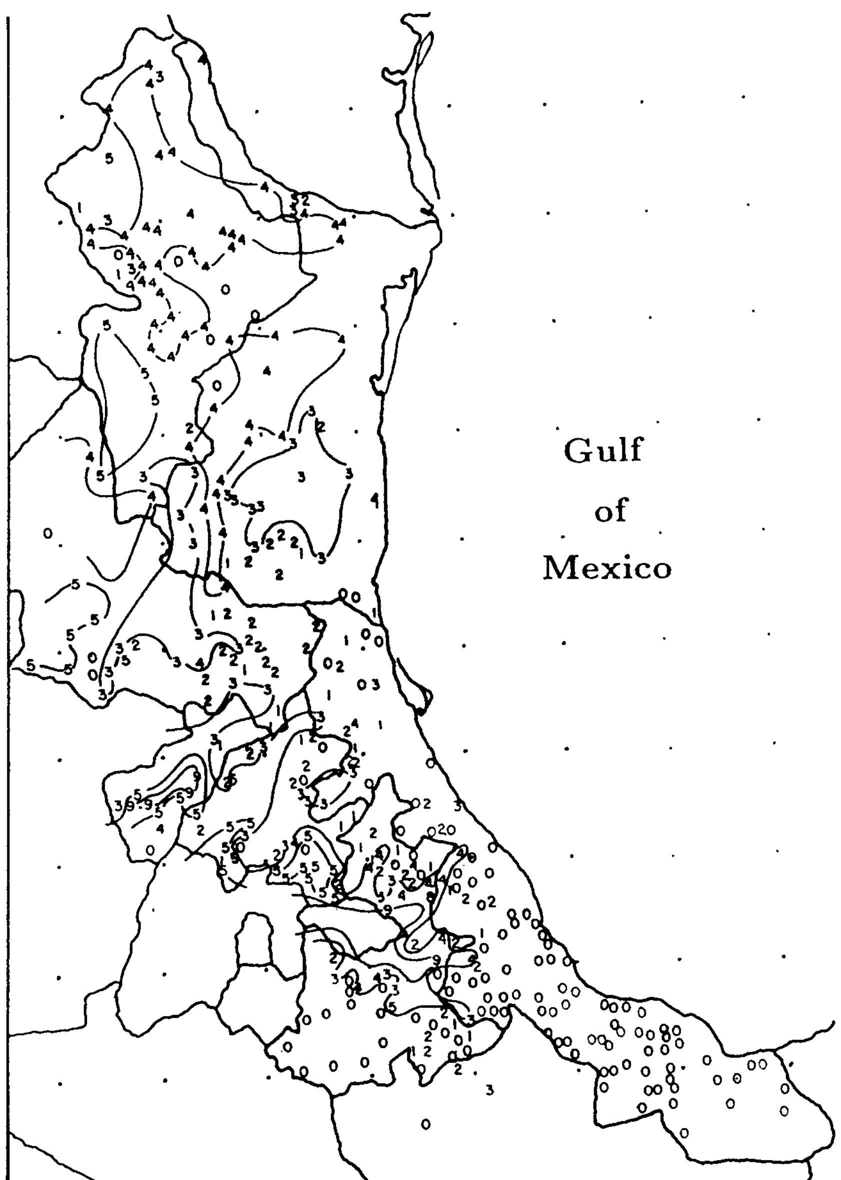

Fig. 3. Number of days with frosts, between 10-18 January, 1962; contour represents zones of pooling cold air.

the Sierra of Puebla. Kocin *et al.* (1988), has documented the unprecedented extreme frost cold that occurred during February 12-14, 1899, called "Blizard of 99", which formed along the leading edge of one of the greatest outbreaks of the Arctic air ever experienced in the central and eastern United States.

In the United States, citrus fruit and vegetables are produced in southern Florida, southeastern Louisiana, southern Texas, southwest Arizona and southern California, where the frost is less severe. Hamilton (1985), Mortimer and Johnson (1986), Brotak (1986) and Rogers and Rohli (1991) have documented major Arctic outbreaks that have affected these regions and they have also indicated that there are recognizable synoptic patterns prior to the occurrence of the severe frost. Observing these dates and comparing them with the severe cases of frost reported from Mexico, it is clear that eastern and northeastern Mexico was also affected by these same severe frosts. In some cases, the reaction of the same frost reported from Mexico was slight for the agricultural regions in the southeastern or southwestern United States.

For the case of January 29-February 3, 1951, frost, Noble and Lebrija (1954) mention that the intense cold wave that occurred on January 31 affected the state of Tamaulipas, causing serious losses to the citrus in its southern region and Nuevo Laredo. This event also affected the coffee regions in Puebla, Veracruz and San Luis Potosí. Miller and Gould (1951) discussed the synoptic condition of the extensive cold air outbreak during the last week of January, 1951, in the USA. They indicated that the week was one of the worst cold waves of the twentieth century. Crops of southern Texas and Louisiana were affected by the frost during the days of January 29 - February 2, 1951.

Another severe frost that affected northern and northeastern Mexico was the one that occurred on January 11-13, 1962. The states of Sonora, Chihuahua, Coahuila, Nuevo León, Tamaulipas and Veracruz were the most affected by this cold air mass (Fig. 3). Orosco and Olivera (1985) mention that in Nuevo León an estimated 400,000 tons of citrus were lost by this frost. This weather also affected the United States and was the worst cold wave since February 1899, that affected the Gulf Coast States (Stark, 1962; Dightman, 1962). It is also interesting to mention the case that took place during the first days of January 1979 in the east and northeast parts of Mexico when a cold air outbreak occurred (Fig. 4).

Miller (1988) gave a summary about the effects of the Florida citrus frost to both private and public sectors. He mentioned that in the United States, the first serious frost after the development of the commercial citrus industry in Florida occurred in December 1962, followed by light frosts in December 1967, January 1971, and January 1977. However, in 1981 the first frost from a set of four severe frosts occurred in a period of five years: January 1981, January 1982, December 1983 and January 1985 (Shapiro *et al.*, 1987). The frosts of January 1981, and January 1982, were considered more damaging than the December 1962 frost. Their impacts, however, were relatively minor compared to the destruction associated with the frost of December 1983 and January 1985.

For the United States as a whole, Quiroz (1984) mentioned that December of 1983 was the coldest of all Decembers in at least 53 years, and the 1983 - 1984 winter was the sixth coldest. Among the social consequencies of the December 20-25, 1983 frost, it can be mentioned that there were extensive vegetable and citrus damages in Texas, Louisiana and Florida. It is estimated that in 1983 and 1985 the frosts in Florida killed approximately one third of the citrus trees (Miller, 1988).

However, in the citrus region of Nuevo León in Mexico, the frost killed 40 percent of the citrus trees on December 24-26, 1983 (Fig. 5). As indicated Orosco and Olivera (1985) this frost is considered to be the major agricultural disaster that occurred in the history of this region.

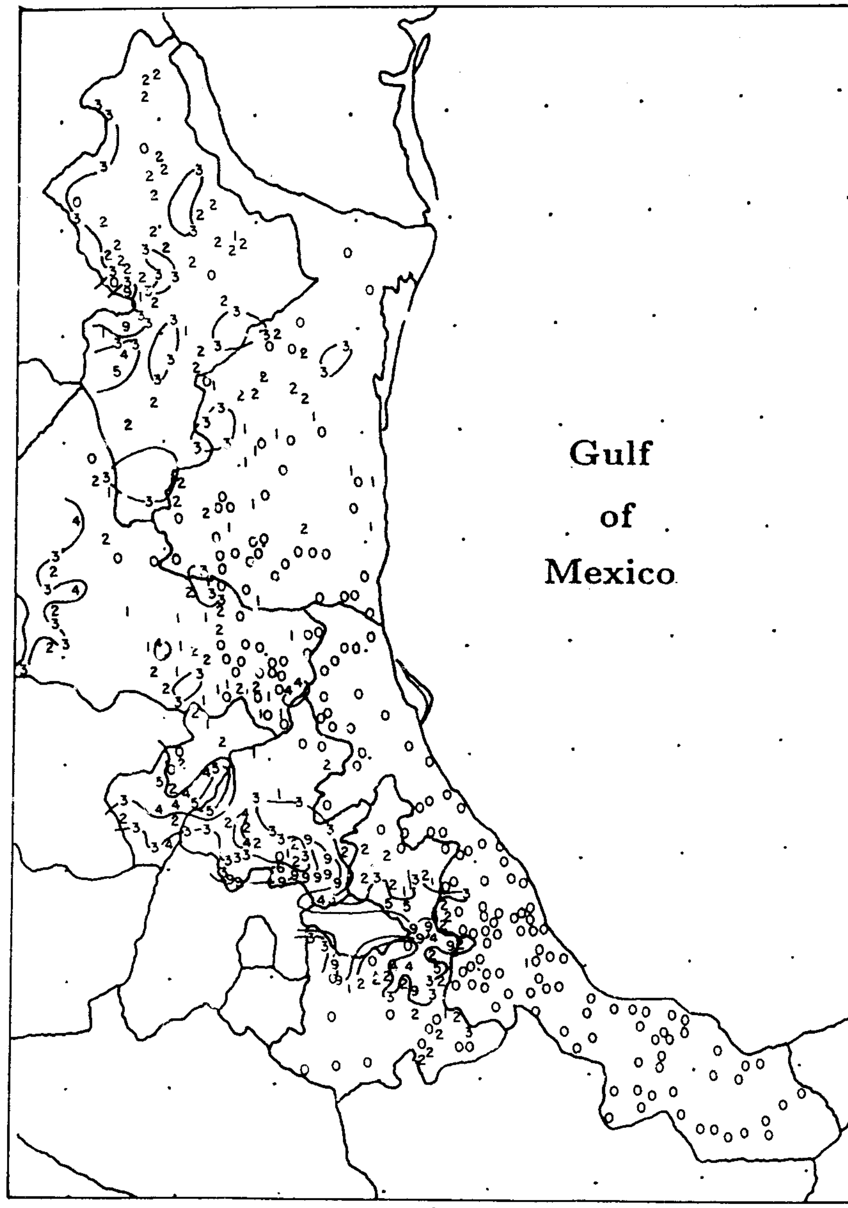

Fig. 4. Same as Figure 3, for 31 December 1978-8 January 1979.

The meteorological phenomenon which recently has acquired more importance by its social and economic impact was the frost that occurred during the days of December 22-24, 1989 (Fig. 6). During those days a strong cold wave, spreading southwards and eastwards, broke daily temperature records, causing severe damage to coffee and citrus groves in the easthern and northeastern Mexico (Pérez, 1990b). Texas, Rio Grande Valley, Louisiana and Georgia also experienced frost damage. During the days of December 24 and 25, 1989, unprecedented cold weather penetrated into central and southern Florida causing damage to the citrus crop, WWC (1989, 1990).

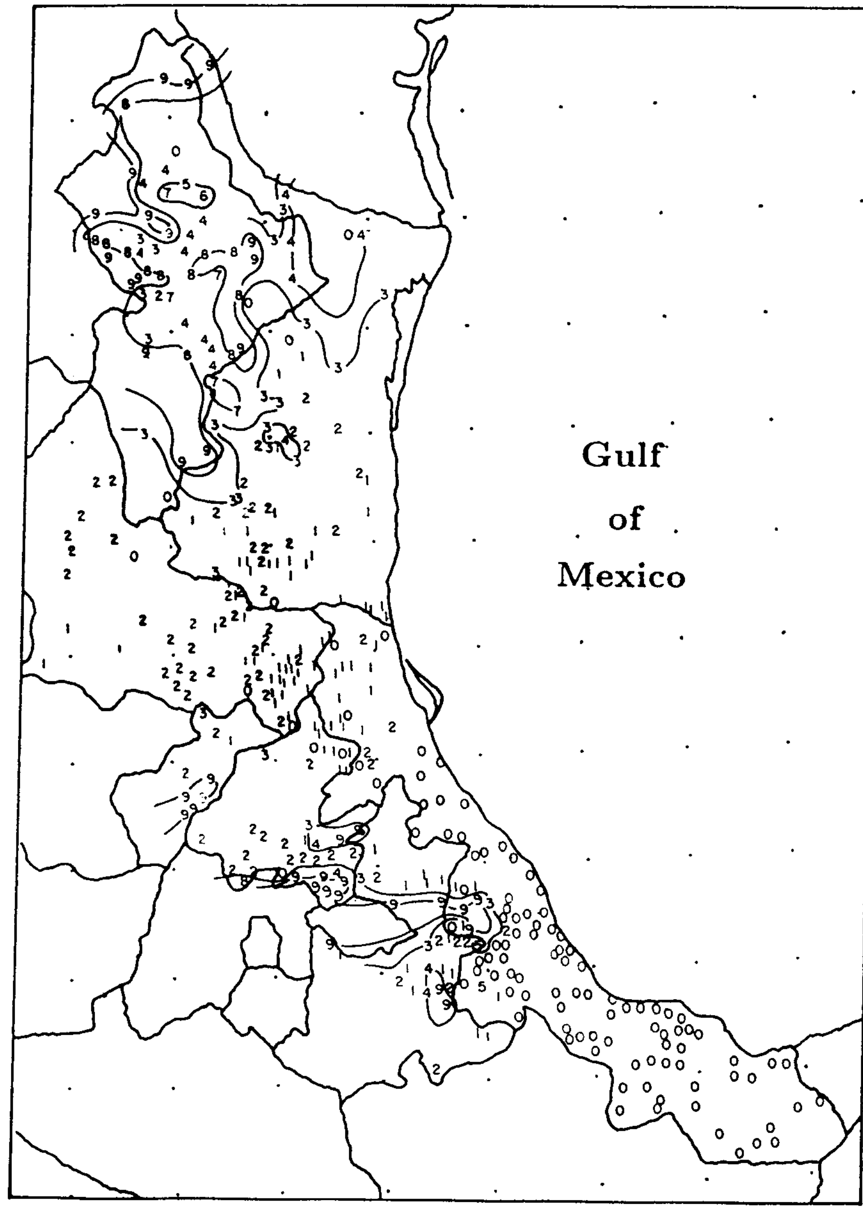

Fig. 5. Same as Figure 3, for 23-31 December 1983.

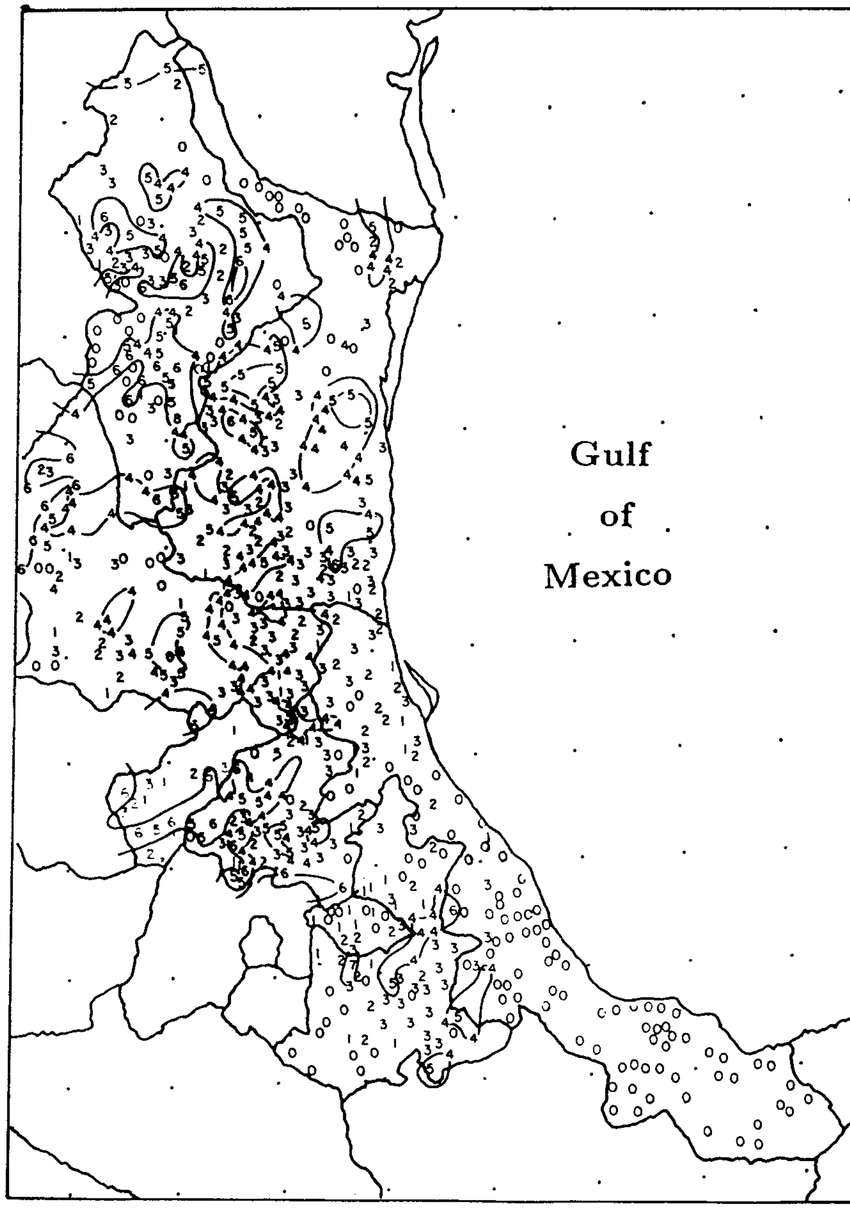

Fig. 6. Same as Figure 3, for 22-27 December 1989.

3. Synoptic conditions preceding the cold weather

January 29–February 3, 1951

During the last days of January and the first days of February, a cold air outbreak occurred in northwest of Canada, United States and Mexico. During February 1-3, 1951, the cold surge entered Northern Mexico. Miller and Gould (1951) discussed this extensive cold air outbreak for the period January 24–31, 1951. In agreement with previous observations of very intense polar anticyclones, Miller and Gould (1951) noted from the 500mb chart that on January 27, in the northwest of Canada a well–developed "warm" ridge was positioned directly above the surface high position at approximately the same time as the maximun intensity. The warm ridge at this level appeared for a 3–day period on January 19-21 at the southwest of the Aleutian Chain (Fig. 7a). For this same period in the pressure surface chart (Fig. 8a) we see three centers of high pressure, one located in the central part of Canada, another at Beaford Sea, and the last one in the Bering Sea. It is noteworthy in Figure 8a to mention an intense cyclone over the Gulf Alaska and another developing over the Kamchatka Peninsula. During January 22-24, 1951, the 500mb warm ridge gradually intensified northward into the Bering Strait (Fig. 7b). In the mean surface analysis, we see that the three high pressure systems, as mentioned above, are now joined on the Yukon territory, forming a more intense high center with central pressure of 1043mb. We denoted this center with H^s (Fig. 8b).

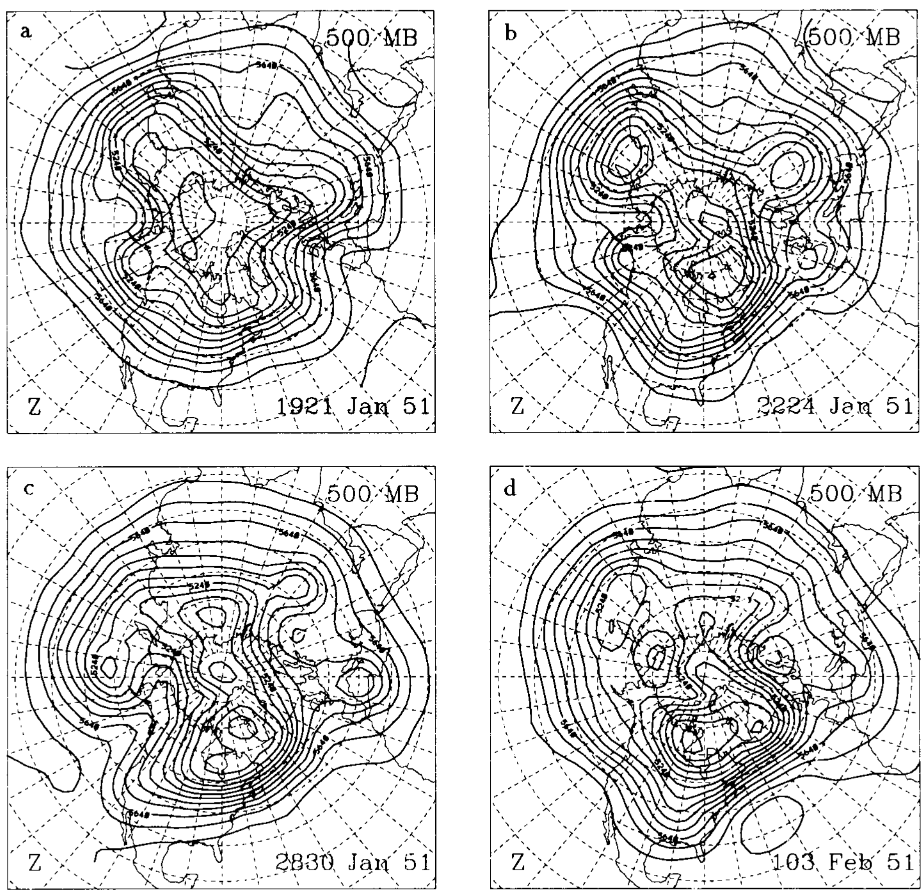

Fig. 7. Mean 500mb height (m) contours at an interval of 80 m, (a) for 19-21 January 1951, the symbol 1921 indicates 19-21, (b) for 22-24 January 1951, (c) for 28-30 January 1951, and (d) for 1-3 February 1951.

From January 25-27, 1951, a 500mb ridge became more intense over eastern Europe, where it separated into an anticyclonic cell. However, the blocking ridge centered over the Bering Strait proceeded eastward over the Beaufort Sea, and then positioned itself southward over the northwest corner of Canada. During these days the high H^s was located in northwest Canada, intensifing and reaching a value of 1051mb.

For the period of January 28-30, 1951, the 500mb blocking ridge over eastern Pacific was extending towards the northwest, and the axis trough over North America changed its orientation southwest–northeast (Fig. 7c). When this occurred, a mass of cold air (cold surge) was separated from the surface anticyclone H^s located in Yukon territory (not shown). By January 30, 1951, another mass of cold air from H^s was displaced southeastward. On January 31, 1951, this mass covered western Canada and northwestern United States.

The comparison of 3 day mean heights at 500mb (Fig. 7c and Fig. 7d), reveals the remarkable change in circulation which occurred from the Central Pacific to the east Coast of North America during these six days. The blocking ridge from eastern Pacific it broke down and provoked a westerly flow that reached west of the United States. The cold air outbreaks into northeastern Mexico and the "northern" over the Mexican Gulf coast associated with the cold air pool H^s were initiated (Fig. 8c).

On February 2, 1951, the center of high pressure H^s, with contours greater than 1035mb, covered Louisiana, Texas and northeastern Mexico. The synoptic situation in the surface that is obtained when the cold air outbreaks over the citrus and coffee regions (Fig. 1 and Fig. 2) is shown in Figure 8d. It is noted that the high pressure H^s in southern United States changed its orientation from NW-SE to NE-SW.

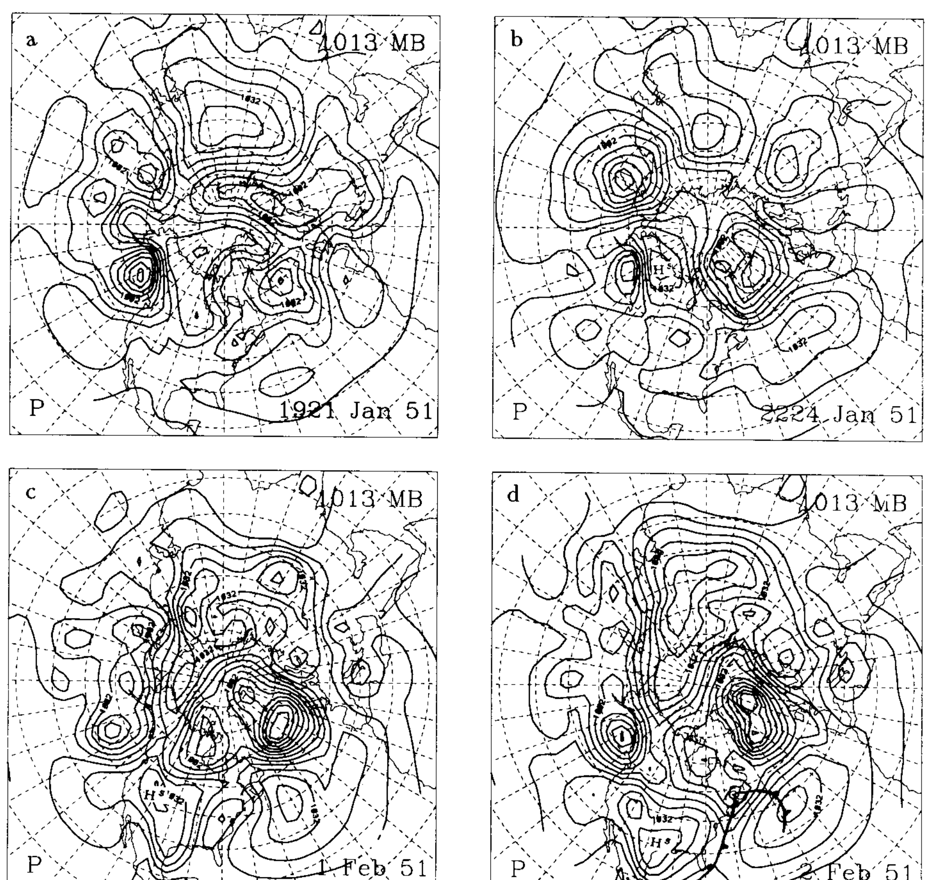

Fig. 8. Mean sea level pressure analysis, the contours are drawn at an interval of 6 mb, (a) for 19-21 January 1951, (b) for 22-24 January 1951, (c) for 1 February 1951 and (d) for 2 February 1951.

January 12–13, 1962

The synoptic condition associated with the January 12-13, 1962, cold air outbreak will now be described along with its previous conditions. On January 3, 1962, the surface map showed a weak anticyclone H_w that moved south from the Bering Sea. By January 4, 1962, we noted that H_w moved northwards and interacted in the west of the Bering Strait with another H_w^1 which was located southwest of the Chukchi Sea. We now have that $H_w^1 \mathrm{U} H_w$ (U meaning union), which gives us another high pressure center called H_s (not shown here). During the next day (Fig. 9a), the anticyclone H_s at surface moved on the Bering Strait, and on January 6, 1962, it was located over easthern Alaska (Fig. 9b). However, on the same day at a 850–700mb layer, a cold core covered the north and northeast areas of the Yukon territory.

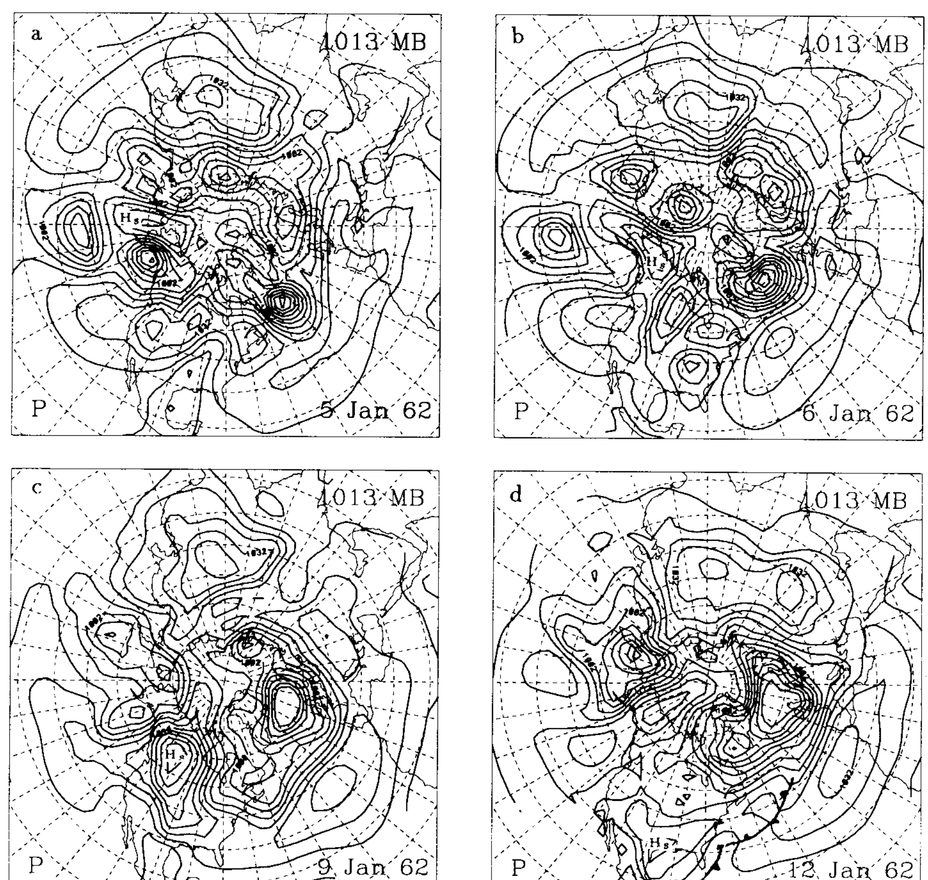

Fig. 9. Sea level pressure analysis 12Z, (a) for 5 January 1962, (b) for 6 January 1962, (c) for 9 January 1962 and (d) for 12 January 1962.

The mean 500mb height contours, corresponding from January 4-6, 1962, are shown in Figure 10b. Generally, the wave number m=4 component in the zonal direction described this height field. From January 7-9, 1962, the ridge that had been over western North America retrograded towards the easthern Pacific, while the ridge over the Bering Sea moved towards the northeast. This situation formed the wave number m = 3 component of the Arctic circulation (Fig. 10c)

However, by January 7, 1962, the anticyclone at surface H_8 (central pressure = 1044mb) was located between Alaska and the Yukon territory, and a cold cell in the 850 to 700mb layer covered the regions between the Yukon territory and Hudson Bay. On January 8, the shallow polar cold H_8 was located in western Canada and the cell at 850 mb (−30°C) that was covering the southwest Hudson Bay deepened at 700mb level with −25°C (not shown).

For January 9, 1962, 12GMT, the strong high pressure cell H_8 in western Canada extended southeastward into the central plains of the United States (Fig. 9c). However, at 850mb, a

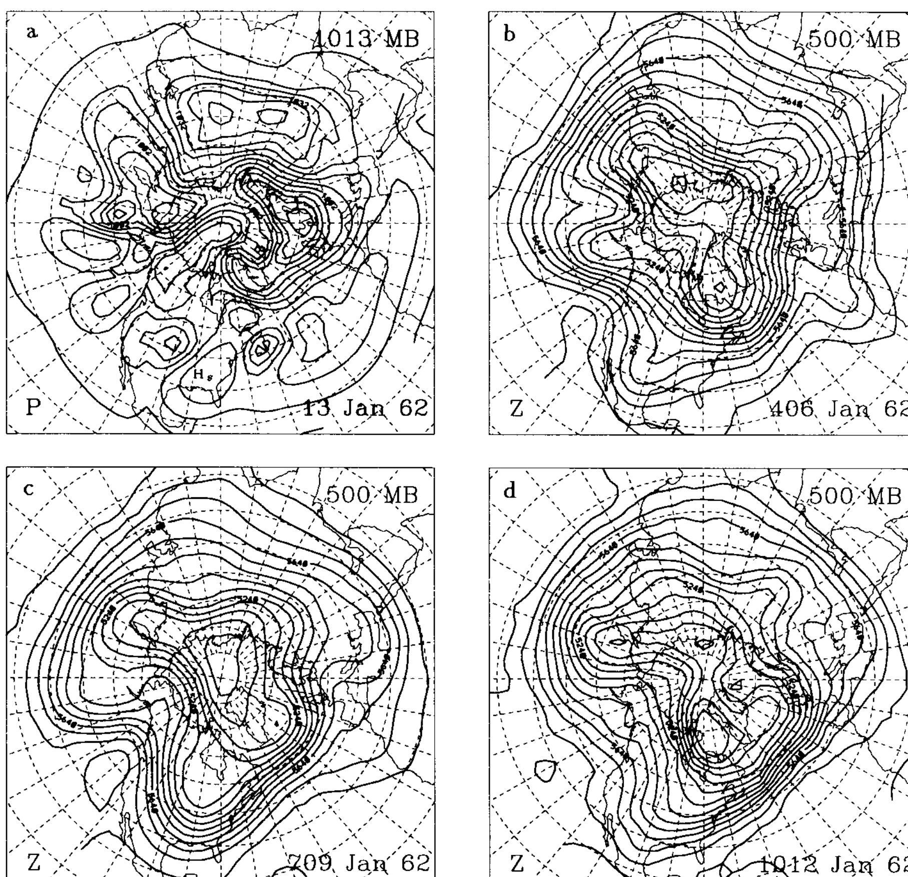

Fig. 10. (a) Sea level pressure analysis 12Z, for 13 January 1962; Mean 500mb height (m) contours, (b) for 4-6 January 1962, (c) for 7-9 January 1962 and (d) for 10-12 January 1962.

cell with a minimum temperature of -30^oC was located between southwest United States and central Canada. On January 10, 1962, the strong high H_8 that had been located over western Canada was transported southeastward, covering the entire United States and extending into northeasthern Mexican territory. By January 11, 1962, due to wide cyclonic circulation at the northeast of North America, the supply of arctic air continued across Canada, and the strong high H_8 was contracted and separated into two cells.

On January 12, 1962, the high pressure cell H_8 penetrated into northern Mexico, the killing frost occurred in localities that were under its influence as well as the Atlantic Polar front extended from Honduras regions towards the east coast of the United States (Fig. 9d). A developing surface cyclone, that had been located northeast of Florida moved over east of Virginia. The mean height field of 500mb from January 10-12, 1962, showed a blocking ridge over Alaska that extended toward the Polar region; similarly a ridge from Europe that was extended over the North prolonged near the North Pole. This circulation formed the wave number m=2 component of Arctic circulation (Fig. 10d). The Polar vortex located northeast of the Hudson Bay developed a source region of arctic air, which was advected southward.

On January 13, 1962 (Fig. 10a), the surface anticyclone H_8 over northeastern Mexico changed its orientation from northeast to southwest and began a shift northeastward. When this occurred the major killing frost appeared in the interior of the Mexican territory. An examination of the 700mb map for this day indicated that the cold air covered northeastern United States. However, when the Polar vortex over Hudson Bay shifted eastward, the southward transport of Arctic air was weakened.

January 3–4, 1979

Let us assume that a chess board is the atmosphere and the pieces are cyclones and anticyclones with the possibility that they have movement. Let us study a case where northeastern Mexico was affected by the movement of chess pieces. In the surface chart of December 18, 1978, 00 GMT (not shown), a developing low pressure center L_1 was located over Maine, and by the 19th, it had migrated beyond the northeast of Maine. In response to this development, a ridge at 500mb was built over the North Atlantic. This ridge was extending toward the Northwest during December 19-20, 1978 (Fig. 11a). Furthermore, for the period of December 21-22, 1978, the strong ridge extended into the Arctic close to the North Pole, and it then transformed into a large scale anticyclonic vortex H_1, covering southeastern Greenland (not shown).

During December 21-27, 1978, 500mb westerlies were observed between 50–60°N over the Gulf of Alaska, and a dominant single blocking over the northern Atlantic formed the wave number m=1 component of the Arctic circulation (Fig. 11b). If the westerlies are zonal by definition, they would not mass transport north-south across the belt of the westerlies. Although, as it was indicated by Wexler (1957), there may be advective transport of a shallow surface layer of polar air southward underneath the westerlies. For the period of December 23-26, 1978, the cyclonic vortex at 500mb that is associated with the low center L_1 at surface moved to the east and to the south of H_1. On December 26, 1978, another cyclonic center at surface L_5 reached southwestern Maine, and by December 27, 1978, a cyclone L_4 at 500mb was developing over the southwestern Bering Sea. In response to this development, the ridge R_2 at 500mb intensified over the Eastern Pacific and extended northward. Also on this day, the anticyclonic vortex H_1 covered Greenland, and a broad cyclonic center L_2 at upper tropospheric levels stagnated over the Kara Sea (not shown).

On December 28, 1978, the cyclone L_4 was located over the Bering Sea and the 500mb blocking ridge R_2 that was located over the Gulf of Alaska was extending northwest, just south of the Chukchi Sea. In response to the strength of the ridge R_2 and the intensification westward of H_1 located over Greenland, the deep trough located over northwestern North America changed into a Polar vortex L_3 (not shown).

The mean field 500mb height for the period from December 28-31, 1978, is shown in Figure 11c. It is noted that the Polar vortex L_3 over central Canada moved between two ridges, R_2 and R_3UH_1 respectively: R_3 located over eastern North America and R_2 generally with its axis, located along 140°W. This situation formed the wave number m=2 component of the high latitudes circulation and allowed the transport of Arctic air toward North America. As noted by Kimoto and Ghil (1993), the hemispheric circulation remained very quiescent from December 31, 1978 - January 9, 1979: This is an example of recurrent flow patterns.

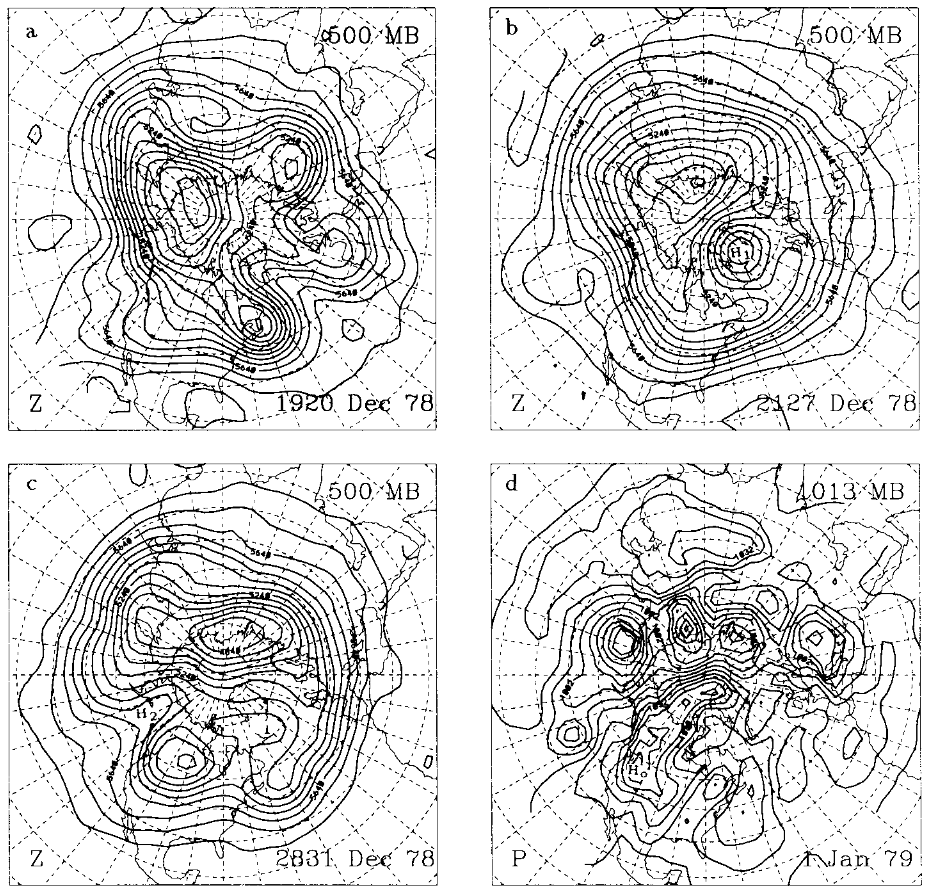

Fig. 11. As in Figure 7 except now, (a) for 19-20 December 1978, (b) for 21-27 December 1978, (c) for 28-31 December 1978, (d) sea level pressure analysis, 12Z, for 1 January 1979.

On January 1, 1979, the 500mb ridge R_3UH_1 over northeastern Canada weakened and the strong ridge R_2 over the eastern Pacific extended towards the Beaufort Sea and broke off into the anticyclonic vortex H_2 (not shown). This period coincided with the establishing of a confluence zone near the North Pole and was provoked by H_2 and the cyclonic center L_2 located on the Kara Sea. The Polar vortex L_3 of a ellipsoidal shape over Central Canada changed its orientation from west–east to southwest– northeast, allowing the Arctic air to surge southwards. A cold core C_c in the layers 850mb (−25°C)–700mb ($-30°C$) - 500mb(−40°C) was located from Montana to Lake Winnipeg. Associated with the cold core C_c was the surface anticyclone H_o that covered westhern North America (Fig. 11d). A piece of this anticyclone propagated towards the southeast during the following 24 hours (Fig. 12a).

By January 3, 1979, the surface anticyclone H_o appeared to change shapes northeastward (Fig. 12b). The frigid cold air outbreak associated with H_o was an important component in the frosts that were recorded over the tropical region of northeastern Mexico.

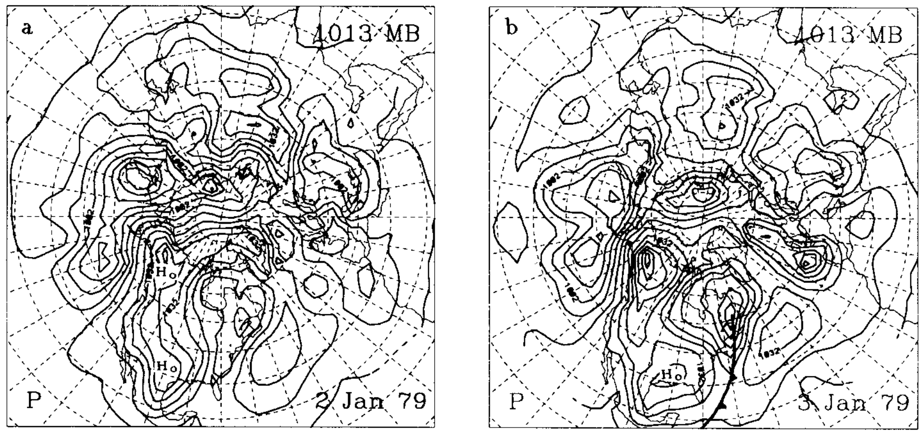

Fig. 12. Sea level pressure analysis 12Z, (a) for 2 January 1979 and (b) for 3 January 1979.

December 25-26, 1983

During December 10-12, 1983, a 500mb anticyclonic vortex V_a was observed over the northern of Bering Strait, which still persisted from December 13-15 (Fig. 13a). By those days we noted that a 500mb blocking ridge R_b was defined near the West Coast of the United States, and an anticyclone at surface H_i rapidly developed over northwest North America (Fig. 14a). From December 16-18, 1983, the ridge R_b moved westward and remained at phase with the "ridge V_a" near 140°W. This situation reinforced H_i (not shown). On December 18, 1983, the first piece of H_i was separated and moved southeastward (Fig. 14b), and on December 19, 1983 covered part of north central United States. By December 20, 1983, this piece covered part of eastern North America and sligtly affected northeastern Mexico. From December 19-21, 1983, the blocking ridge R_b extended across Alaska toward the North, and along with the ridge located between Greenland and Scandinavia, formed the wave number two component of the Northern Hemisphere circulation (Fig. 13b). For the period of December 22-23, 1983, the blocking ridge R_b broke off into an intensive anticyclonic vortex, and a broad cyclonic circulation (Polar vortex) covered the United States and Canada (Fig. 13c). On December 21-22, 1983, the huge Arctic high H_i was again reinforced over the Yukon territory and a small portion of it broke under the influence of the air flow aloft and moved southeastward. However, at 850mb, a piece of cold air extended southwestward from the Hudson Bay.

On December 23, 1983, a cold core at 850mb covered the region between Alberta and South Dakota. Under this situation the whole central region of North America was opened for the frigid arctic air mass that crossed the Western United States–Canadian border. So, on December 24, 1983, the intense surface anticyclone H_i that was located over northwest of Canada was separated and moved southeastward. The huge Arctic high H_i covered nearly all of North America, and the leading edge of this frigid air mass was marked by the Polar front (not shown). For the period from December 24-26, 1983, the configuration in 500mb that was acquired by the blocking ridge R_b on the Eastern Pacific was a tripolar vortex (Fig. 13d), which changed to "modon" (bipolar vortex) on December 27. The severe cold air outbreak in northeastern Mexico occurred from December 25-26, 1983, and the synoptic situation at the surface, that is associated with this event is shown in Figures 14c and 14d; which is similar to other cases of intense frosts.

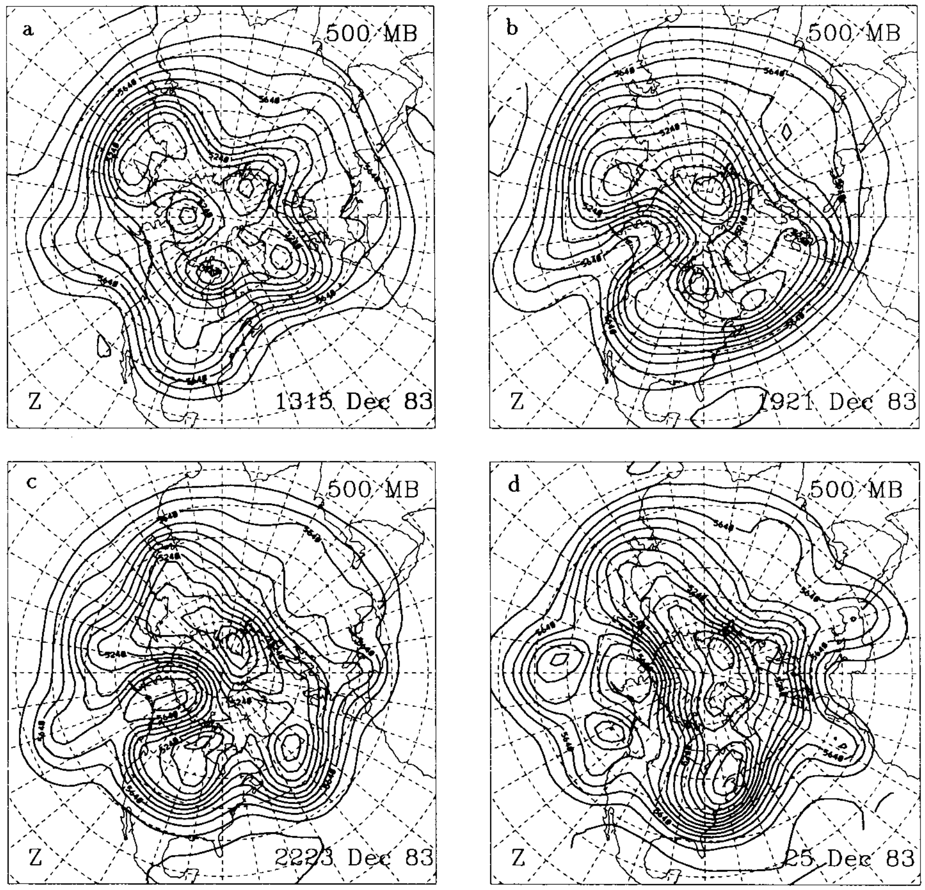

Fig. 13. As in Figure 7 except now, (a) for 13-15 December 1983, (b) for 19-21 December 1983, (c) for 22-23 December 1983 and (d) 500mb height contours, 12Z for 25 December 1983.

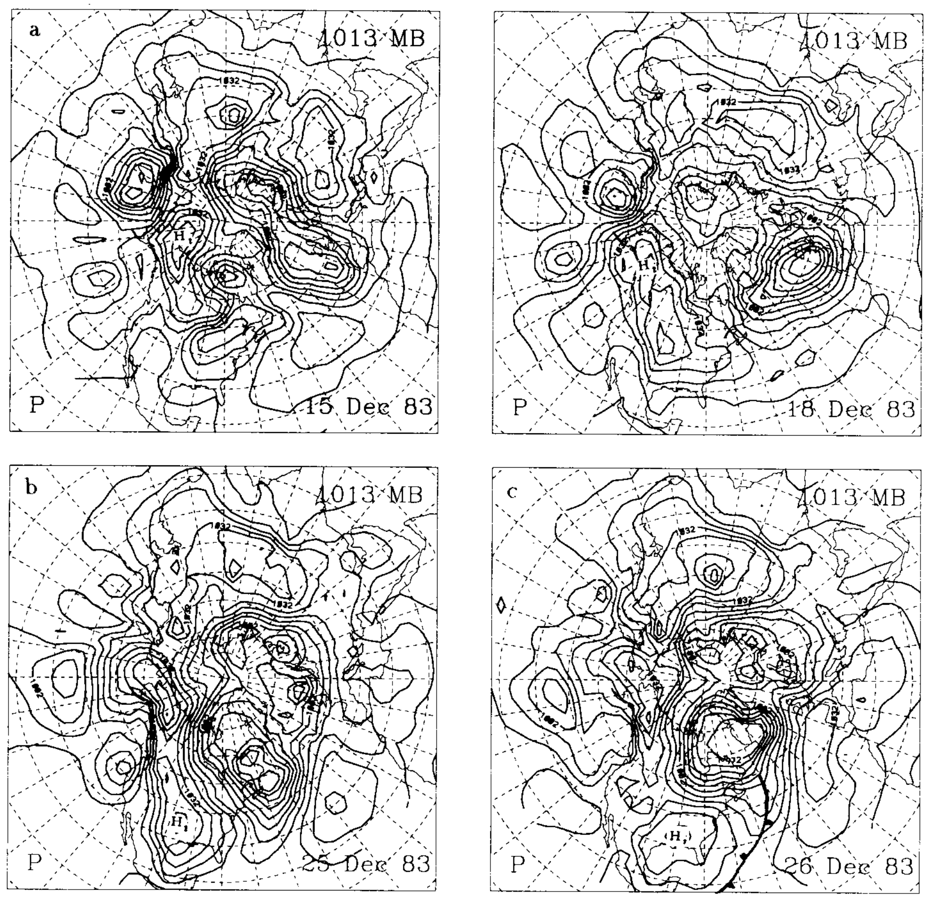

Fig. 14. (a), (b), (c), and (d) sea level pressure analysis 12Z for 15,18 and 25-26 December 1983 respectively.

December 22–24, 1989

During the last days of October, 1989, a blocking ridge R_2 at 500mb developed and stretched across the Scandinavian Peninsula. This ridge moved across the northern part of the Atlantic Ocean during the days of December 2-6, 1989. At the end of November, 1989, a ridge R_1 stretched across the western coast of North America.

During the days of December 1-7, 1989, these ridges extended even more towards the Arctic in such way that from December 12-16, 1989, the north part of each ridge broke into anticyclonic vorteces, H_1 and H_2 (Fig. 15a); where H_2 was located across the Davis Strait and H_1 moving toward the north of the Chukchi Sea. This condition permitted the development of an anticyclonic A_s at surface which appeared over the northwest of Beaufort Sea (Fig. 15c). On the other hand, from December 17-21, 1989, we note that the wave number m=2 component of the Arctic circulation was nearly defined (Fig. 15b). However, in the daily fields of 500mb it can be seen that a blocking ridge associated with H_1 moved toward the West Coast of North America, so that the anticyclonic A_s at surface was obligated to move toward western Canada (Fig. 15d). The maximum central pressure obtained by A_s that occurred during the days of December 21-22, 1989, was aproximately 1055mb. During this period, A_s covered all of North America (Pérez 1990b). Furthermore, a week cyclogenesis was initiated east of Virginia.

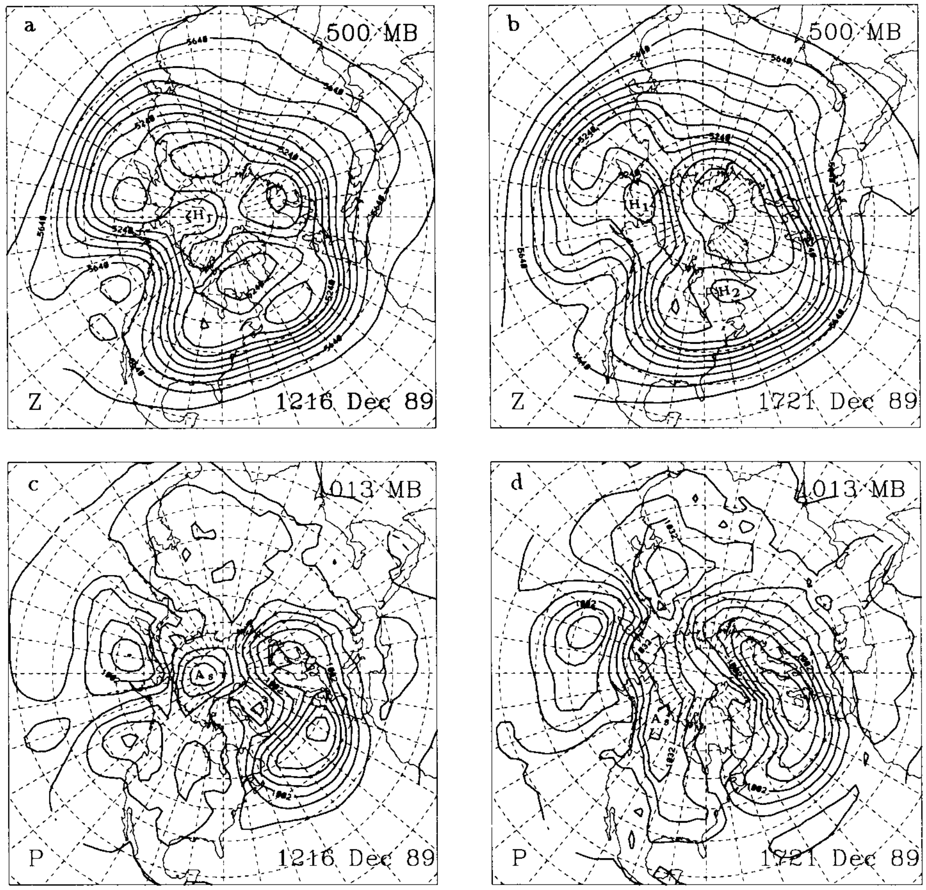

Fig. 15. As in figure 7 except now, (a) for 12-16 December 1989, (b) for 17-21 December 1989; Mean sea level pressure analysis, (c) for 12-16 December 1989 and (d) for 17-21 December 1989.

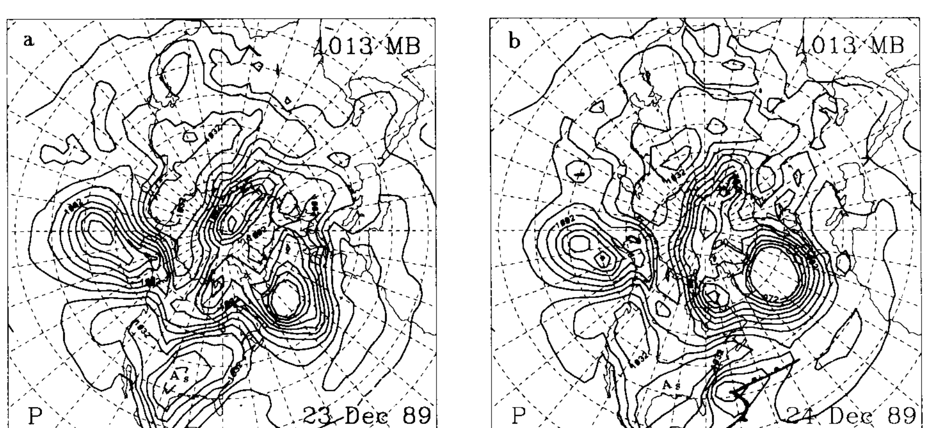

Fig. 16. Sea level pressure analysis 12Z, (a) for 23 December 1989 and (b) for 24 December 1989.

On December 22, 1989, the continental polar air mass associated with H_8 entered Mexico, affecting the states of Chihuahua, Coahuila, Nuevo León and Tamaulipas. In southwestern Nuevo León, snow was observed. On December 23, 1989, at 12GMT, the surface anticyclone A_8 was positioned from central Mexico to the eastern part of the United States and Canada (Fig. 16a).

The lowest temperatures were registered during the first hours of December 24, 1989, over the northern states, the high lands of central Mexico and northeastern Mexico. In these places a very intense frost was observed.

The citrus regions of the state of Nuevo León, Allende and Montemorelos, were damaged. The frost also damaged the coffee and citrus groves in the regions of Huasteca Potosina, Tamaulipeca, Veracruzana, Poblana and Hidalguense. On December 24, 1989, the anticyclone A_8 at surface and the frontal system associated with it were located in a position which has been identified in the cases of premature and tardy frost (Pérez, 1990a), see Figure 16b. During the period December 22-26, 1989, the mean field heights of 500mb indicated that a change would occur during the following days in the atmospheric circulation of North America.

4. Concluding Summary

In this paper the synoptic situation associated with a set of five intense frosts, which affected the coffee and citrus plantation in the east and northeast part of Mexico, has been analyzed. The origin of these synoptic systems are associated with the action of blocking, which occurred over the east Pacific and the North Atlantic and forms the wave number m=2 component of the Arctic circulation, which plays a role in the initiation of cold air outbreak spliting the Polar vortex into two parts. One part migrated toward North America and the other part toward northern Asia. Several authors have indicated that the development and intensification of a ridge is independent of another blocking ridge; but the processes which are generated over the Arctic basin when two ridges interact, in some way affect the transport of polar air toward North America, such as in the events of 1951 and 1962 which were influenced by the amplification of the ridge blocking over Europe. In the case of 1951, the ridge over eastern Pacific transformed into an anticyclone vortex. It generated zonal flow that advanced towards the east and moved the surface anticylcone toward the southeast (Figs. 7d, 8c, and 8d). This same situation occurred from January 7-12, 1962, but in this case, the ridge split over northwestern North America.

Other cases of intense frosts that occurred over northeastern Mexico in the years of 1979, 1983, and 1989, were influenced by a blocking ridge from the north Atlantic that developed between Greenland and Canada. The existence of blocking in the Pacific and Atlantic concurrently during a period constitute a double blocking. The maximum transport of cold air toward central parts of North America occurred when the ridge (meridional Ω- shaped blocking) located over eastern Pacific acquired maximum intensity, especially when the north sector fractionated into an anticyclone vortex.

A common pattern in all cases of intense frosts was an anticyclone at surface that developed over northwestern North America and moved rapidly southeastward, toward the Gulf of Mexico. This happened about 7-10 days after it originated. It then moved eastward or northeastward, dissipating over the western Atlantic. The cold air outbreak over eastern, northeastern, and the high lands of central Mexico was observed when a broad zone of low pressure at surface that was associated with the polar vortex at 500mb over northeastern North America covered the North Atlantic. At the same time the anticyclone at surface over southeast of United States acquired the configuration (showed in Figs. 8d, 9d, 12b, 14d, 16b). These patterns of surface pressure occur at least several times a year. What distinguished hard freeze events from weakes frost?

Anticyclones associated with weakes freeze events originates south of 50°N over North Pacific Ocean, moved into the northwest US and then southeastward to the Gulf of Mexico ("Western class" of Mecikalski and Tilley, 1992). However Anticyclones associated with hard freeze tracked from NW Canada. The major intensity cases were 1962, 1983, 1989, 1951 and 1979, 1962 being the most intense and 1979 the least. The majority of days with frosts occurred over the high lands, and the days with very intense frosts affected the tropical regions (Figs. 1-6). Therefore, the orography effect (of pooling cold air) plays a role in the development of the frosts, this effect was noted mainly for the cases of 1951, 1962, 1979 and 1983 (Figs. 3, 6, 9 and 11 of Pérez, 1990a), where they were probably also influenced by strong radiative cooling. The lack of observations at surface, sparsity of radiosonde and data quality have prevented the knowledge of the dynamic mechanism and complex physics associated with the frosts.

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