MONTHLY WEATHER REVIEW

Editor, EDGAR W. WOOLARD

VOL. 64, No. 6
W. B. No. 1185

JUNE 1936

CLOSED AUGUST 3, 1936
ISSUED SEPTEMBER 15, 1936

DUSTSTORMS IN THE SOUTHWESTERN PLAINS AREA

By H. F. CHOUN

[Weather Bureau, Denver, Colo., April 1936]

Numerous articles, and photographs which apparently substantiate them, have in the recent past predicted that either large acreages of land in the dust-bowl area of the southwestern plains must be abandoned, or else continued depression and failure must be faced by those trying to combat the elements. This paper, while it will verify the seriousness and severity of soil erosion due to wind in the area shown in figure 1, will also show that total abandonment of the area is not imminent or necessary.

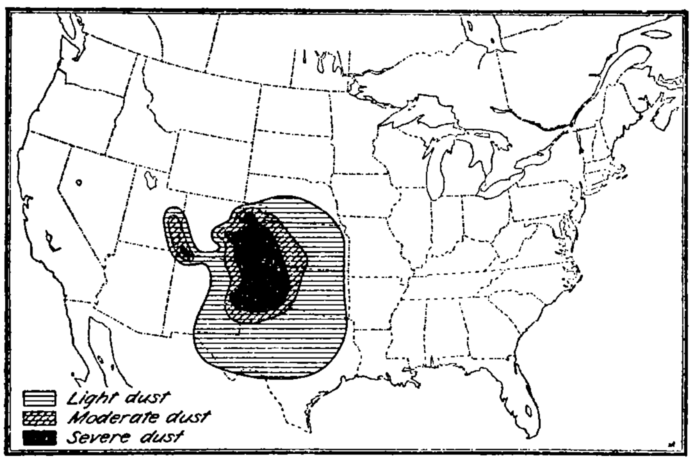

FIGURE 1.—Extent and intensity of duststorms over the southwestern plains during March 1936.

The topographic features of this section of the Great Plains area conform to the underlying rock formations. Valleys and undulating plains have been formed through erosion of the softer, lesser resisting beds. There are many miles of comparatively level country, as well as upland valleys and mesas, which comprise thousands of acres of fertile land that have been reclaimed by irrigation enterprises and improved farming methods.

The climate is very similar throughout the region. The general climatic features are: A low relative humidity; a large amount of sunshine; a light rainfall, confined largely to the warmer half of the year; a moderately high wind movement; and a large daily range in temperature. The wind movement is lowest near the western limits; and over the plains it increases toward the east. At Las Animas, Colo., the average hourly wind movement is 8.5 miles; at Dodge City, Kans., 10.2 miles; at Santa Fe, N. Mex., 7.8 miles, and at Amarillo, Tex., 12 miles. The velocities are greatest in spring, following the driest period of a normal year. The diurnal range in the wind movement is large, the velocities being generally high in the afternoon and dying down at night. Chinook winds prevail to a great extent throughout the area, causing a large daily range in temperature. Occasional dry spells, and periods of abnormally heavy precipitation, persist over periods of 2 or 3 years with resulting serious droughts and great variations in crop yields. The question of whether there has been any progressive or retrogressive change in the amount of precipitation since the Plains area was settled, has been the subject of much discussion. The examination of reliable precipitation records, some of which were begun more than 50 years ago, bears out the view that no appreciable permanent change has taken place that will greatly affect the normal. There has, however, been a gradual increase in temperature and a gradual decrease in precipitation for the past several years. Figure 3 shows the general rainfall trends at two long-record stations, Las Animas, Colo., and Dodge City, Kans., within the so-called dust bowl. This graph is based on the average annual amount of precipitation for these two stations, smoothed by 5-year moving averages. That is, the entry for each year on the graph shows the 5-year average for the two stations, up to and including that year. It will be noted that for the 5 years ending with 1894 the average was almost exactly the same as for the 5 years ending with 1935. In other words, similar droughts occurred at these two times.

The occupation of this Great Plains area for agricultural purposes began about 1885, when there was a migration of land seekers into the region. The settlers made their livelihood by crop farming, at which they succeeded fairly well for 3 or 4 years. Then came 3 "lean years"; 1894 was a year of complete crop failure, due to drought. In some parts of the plains region as many as 90 percent of the settlers left their farms. Following this recession in land settlement, a gradual healing over of the denuded fields by native grama-buffalo sod took place. The settlers who remained learned from experience how to cope more effectively with the unfavorable crop years and with drought. The next impetus to land settlement and crop farming was given by the high prices offered for agricultural products during and immediately following the World War. Promoters launched campaigns to get crop farmers instead of cattle raisers interested in the region, tractors and other labor-saving machinery were introduced, and grain farming was undertaken on a rather large scale. Reckless denuding by cultivation and overgrazing continued on this land, where rainfall at best is light. Experienced cattlemen knew the danger of overgrazing the plains, but the temptation of high prices led them to take the chance.

In the area where there is an urgent need for rain, shown in figure 2, an average of from 60 percent to less than 50 percent of the normal rainfall occurred during the 18-month period from September 1934 to March 1, 1936.

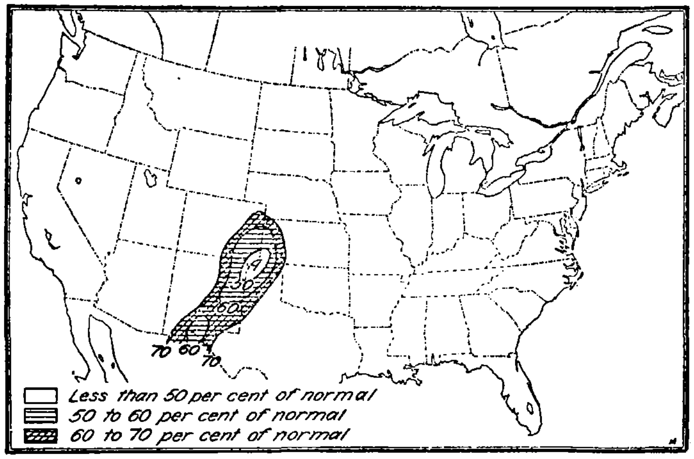

FIGURE 2.—Percentage of normal precipitation during the 18 months from September 1934 to February 1935, inclusive.

Abnormally high temperatures continued from June 1933 to August 1935, with but temporary relief during short periods. This prolonged period of warmth has never been equaled in the recorded climatological history of the area. The digging of wells and installation of pumping plants were resorted to in an effort to save small crops and obtain drinking water. The digging of these wells showed that the subsoil moisture was depleted to a great depth. The prolonged drought made it nearly impossible to secure stands of grain; and where stands were secured, not enough reserve moisture was available to meet the requirements of the plants for survival to maturity. Increased insect activity during this period also played an important part in the destruction of vegetation. A shortage of feed for cattle, and the poor condition of pastures generally, prompted farmers to take advantage of every opportunity to obtain feed; in desperate attempts to obtain forage, Russian thistle and weeds were harvested so closely that no protection was left to hold the soil, and great areas were exposed to the action of the wind.

During the spring months of 1935 loose topsoil from thousands of farms in the drought-stricken area was carried off by winds of high velocity, reducing visibility and causing hazardous driving and flying conditions. In the storms, sufficient static electricity was generated to render automobile ignition systems useless, and scores of motorists were temporarily stranded; when the storms abated, drivers found that their cars again functioned properly. The static electricity, produced by the friction among minute dust particles in the air, was so intense that distinct electrical shocks were received when one came in contact with any metal part of a car. Many resorted to the expedient of dragging chains and wires to ground the static accumulation and prevent short circuits. Cherry orchards in the rich agricultural section between Fort Collins and Loveland, Colo., suffered severely when the freshly plowed soil was swept away, leaving the roots of the trees bare. The topsoil was also blown from fields devoted to winter wheat and alfalfa, so that in many instances reseeding was necessary.

In Colorado the damage was greatest in southeastern counties, e. g., Kiowa, Prowers, Baca, eastern Bent, and Las Animas Counties, where the suffocating dust storms occurred frequently from March 12 to 25, 1935, bringing death to 6 persons and serious illness to more than 100 others. Sickness continued in this section, where lung congestion was reported to have been aggravated by the dust-laden air. In the more seriously affected areas, the dust lay from a few inches to more than 6 feet deep, and considerable livestock perished from starvation and suffocation. The following is quoted from a cooperative observer's report: "The dust has drifted into feed stacks and covered pastures until livestock have suffered greatly; many cattle have perished from eating so much dust. Dead stock lying along the roads is a common sight."

During these "dusters" or "black blizzards", the air was so heavily dust-laden as to make breathing and living conditions generally uncomfortable, and residents of the affected areas hung wet blankets over their doors and windows and covered their faces with wet cloths. Schools were closed temporarily in many localities as a measure of safety, and many ranch homes were deserted by their occupants. Visibility became so limited at times that artificial light was used during midday, while at other times the visibility was reduced to zero. During the height of some of these "blows", it became so dark that business was temporarily forced to be suspended, even when artificial light was used. Aviators reported dust present at altitudes of from 15,000 to 20,000 feet, and brisk winds carried the dust clouds far into the elevated regions east of the Continental Divide.

During the early afternoon of April 14, 1935, the most severe duststorm of the series that started on March 1 began moving across extreme western Kansas and eastern Colorado. The coppery-hued sky cast a brown shadow,

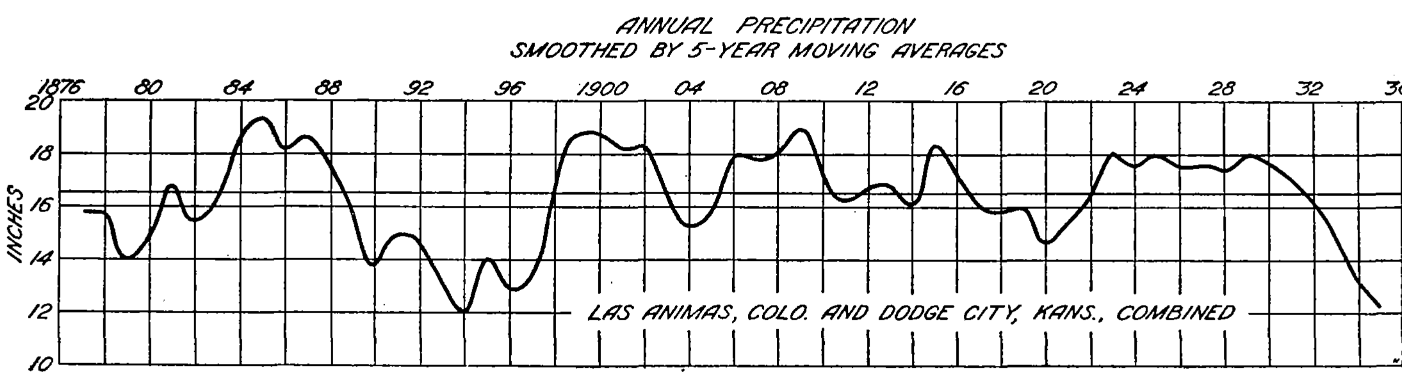

FIGURE 3.—Precipitation trends, Las Animas, Colo., and Dodge City, Kans.

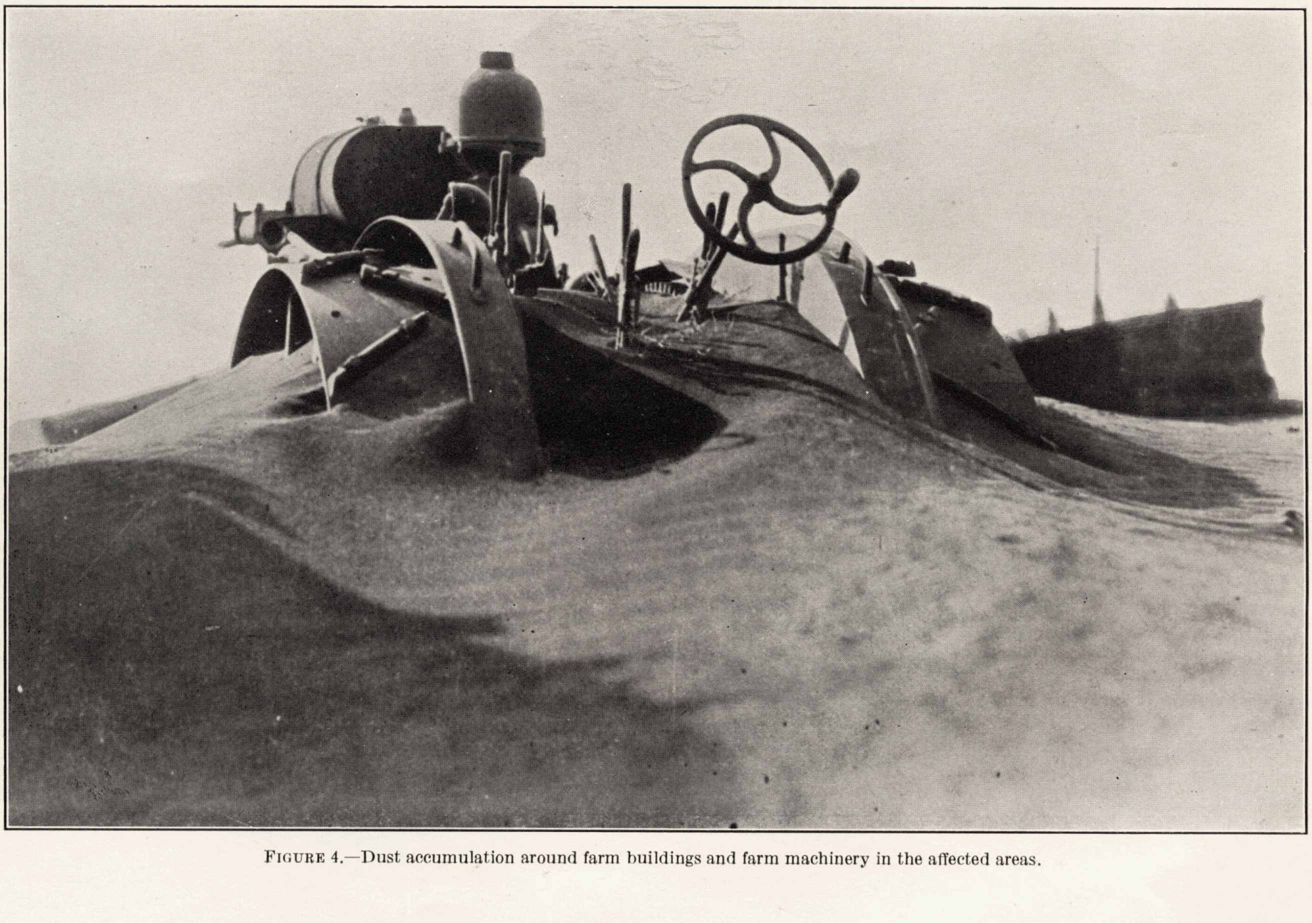

FIGURE 4.—Dust accumulation around farm buildings and farm machinery in the affected areas.

FIGURE 5.—Aerial view of the beginning of a duststorm over the prairie lands east of Denver. This photograph shows the action of northerly winds in removing topsoil. The clouds of dust were raised by southerly convectional air currents to elevations of approximately 16,000 feet as is evidenced in the background, capping the mountain range. Prevailing westerly winds carried some of this dust as far eastward as the Atlantic seaboard.

giving the scene a weird appearance. The storm struck Denver at 2 p. m. and blotted out the sun as it moved southward. Sand drifts were piled up that stopped trains and automobiles, grounded airplanes and enveloped regions little affected by previous storms. Homes and stores were filmed with a thick coating of the powdery dust.

Winds of gale force again were frequent over most of the area during the spring months of 1936. Crops, pastures, and ranges, already suffering from a lack of moisture and the duststorms of February, were further damaged by severe duststorms. On March 1, 1936, light dust began in east-central Colorado, and by the 4th the storm had extended from the Black Forest region in Colorado over the lower Arkansas River Valley into the Panhandles of Oklahoma and Texas. On the 10th moderate to heavy dust occurred in extreme southeastern Colorado and in the Oklahoma and Texas Panhandles, which reduced the visibility considerably in the lower part of the area. On that date, north and northeast winds, with velocities of 30 to 35 m. p. h., bore dust up the South Platte River Valley as far as the South Park region, reducing the visibility to "poor" over much of the area. Southeasterly winds bore clouds of dust which enveloped the entire region east of the 104th meridian in Colorado on the 11th. Dust continued intense on the 13th, and during the following two days practically the entire region east of the mountains was covered by the dust pall, reducing the visibility to from 500 yards to 1 mile in Colorado; to 4 miles in Curry County, New Mexico; and to 25 feet at Kenton, in the Oklahoma Panhandle, where daylight was turned to darkness. In this region, the dust clouds turned from a dark blackish color at the beginning to a yellowish red tinge. A driving wind accentuated the storm. A maximum velocity of 33 m. p. h. was reached at Pueblo on this date, and the air was filled with fine driving silt far into the foothills sections, reducing the visibility to 10 feet at Monument, on the main arterial highway between Denver and Pueblo, and making driving and flying conditions hazardous. The driving sand removed paint from automobiles, and pitted windshields.

Some areas of ungrazed grassland in the foothills were completely covered with the fine dust during the storm, and then uncovered by brisk winds a few hours later. In Baca County, Colo., the visibility was limited to one city block for 9 consecutive hours and to zero for 1 hour. Duststorms continued intense through the remainder of the month in extreme southeastern Colorado, southwestern Kansas, and the twin Panhandles, keeping Baca County in semidarkness for periods of from 3 to 24 hours each day. During the height of some of these blows, highway travel was paralyzed and electric-lighted show windows were not visible from a distance of 40 feet; while at times the raging "dusters" cut the visibility to zero, and pedestrians collided with one another in attempting to get about.

Reports from extreme southeastern Colorado and extreme southwestern Kansas on March 25 and 26 stated that the storm was the most severe and of the longest duration of any ever experienced in that region. On these dates the storm spread from extreme east-central New Mexico, across the Panhandles of Texas and Oklahoma, and covered practically the entire State of Oklahoma, reducing the visibility to 350 yards as far east as Vinita, and to 600 yards in the southeastern portion of that State. The clouds of whirling silt appeared russet, blue, orange, and black in succession.

On the 31st, the storm covered the entire region south of the fortieth parallel east of the mountains, far into the upper reaches of the Arkansas River and westward along the Colorado-New Mexico border to the San Juan and Dolores River valleys, where the heaviest dust in the history of those sections was reported. At Pueblo, the sky was turned to a saffron hue, and when the dust clouds settled, they brought darkness to the city. The clouds of whirling silt made living conditions generally uncomfortable in the affected areas. Veils of the coppery-hued silt were observed over western counties; and snow flurries and rain, mingled with dust, brought mud showers in northeastern localities, in the San Juan Mountain region, and as far north as Columbine, Colorado. A phenomenal accumulation of muddy snow in the form of balls, the diameter of silver dollars, fell over some north-central districts of Colorado.

The data in table 1 were compiled with a view of detecting any progressive or retrogressive changes in duststorms of the area since they have become of proportions sufficiently great to affect human comfort. Data recorded by the Weather Bureau office at Amarillo, Tex., the only first order Weather Bureau station near the center of greatest activity, were chosen as the most reliable and complete for this purpose. Two years ago, the topsoil that blew in these regions was coarsely granular in structure; but due to its having been shifted back and forth, it is now as fine as face powder, and erodes at a lower wind velocity. This condition is especially noticeable in the Clovis, N. Mex., area. It is likewise noticeable that the wind can support and carry the topsoil to greater distances, as was evidenced during March 1936.

Road maintenance problems were not major engineering difficulties; but much trouble was experienced by, and most serious problems confronted, the highway departments during the dust periods. Snow fences running parallel with and about 100 feet north of the east-west highways were, in many areas, completely covered with dust drifts. These wooden picket fences were removed with portable hoists, and the drifts leveled by team or tractor-drawn blades. Drifts frequently filled road ditches and interfered with traffic on the highways. Following an inspection trip by automobile through southeastern Colorado, the writer found nearly a pint of sand and dust had accumulated in the oil-bath air filter of his car. Undoubtedly, automobiles not equipped with some sort of air filter, as a precaution against having dust enter the motor, suffered bearing trouble.

Northerly winds seem to be the most potent in respect to erosion, as they are of slightly greater velocity, colder, heavier, and have greater carrying power near the ground. This is evident from the appearance and size of dust drifts along fences and other obstructions and barriers. Yet southerly winds often are quite strong, with violent gusts; their work of erosion is notable, and they tend to carry the dust to great altitudes. Wind from the south usually reaches its maximum velocity between 2 p. m. and 5 p. m., the period of greatest frequency of soil erosion. Northerly winds appear to develop greatest velocities shortly after setting in and maintain them steadily until near the end of the period. The lapse rate within the air is a major factor in the extent to which dust is carried high aloft and transported long distances.

In response to inquiries sent into the affected areas, came reports of tillage practices which included examples both of effective and of careless forms of farm management. Fields which continued to lose topsoil are those where owners failed to learn the lesson taught during the summers of 1934 and 1935, that bare ground always blows if unprotected. Some farmers put in large acreages of nothing but beans, while others put in protective strips of corn or feed crops, or plowed up ridges crosswise to the prevailing winds. These ridges serve a dual purpose. In addition to the ridges serving to minimize soil blowing, they tend to hold the moisture on the fields where it falls. In recent years, when the grain brought high prices, the majority of farmers in the panhandles of Texas and Oklahoma and in the vicinity of Clovis, N. Mex., raised livestock and row crops of corn, milo, maize, kafir, sorghums, and other fodders.

A few succeeded with wheat; others felt they could do likewise, and cultivated their grassy pastureland, forgot livestock and row crops, and drilled in every available acre to nothing but wheat. The region soon became known as the wheat empire of the Southwest. One farmer northeast of Dalhart, Tex., planted 7,000 acres (nearly 11 square miles) in wheat, while another farm which comprised 10,000 acres was planted with a like crop. Reports as of April 1, 1936, state that several hundred thousand acres of wheat in the twin panhandles and in the wheat districts of New Mexico and southwestern Kansas were either blown out or smothered with dust deposits during March. In extreme southeastern Colorado, 150,000 acres of wheat planted this year has been blown away.

Generally speaking, wind erosion takes place under extremely dry conditions with a wind velocity of 20 m. p. h. on all land which has been in cultivation 3 or more years. A seeder operates to pulverize and level off the top soil, thereby making it more susceptible to blowing and to the action of the full force of the wind. Most of the land that had been in continuous cultivation for several (5 or 6) years lost considerable topsoil. However, some lands that were in cultivation 5 or 6 years ago and then abandoned have been healed over by plant growth and have resisted erosion. Native buffalo sod does not erode from direct action of the wind, although in some places, next to an eroding field, it may yield to attrition. The sod may appear to be "blowing" sometimes, when in reality it is merely captured deposition that is moving off from the impact of the wind in a new direction. Effective forms of farm management would necessarily have to be adopted on a community basis, as an isolated farmer would not benefit if adjoining fields were tilled in a careless manner. The worst offender in allowing fields to become "blow spots" is the owner who lives in town or city and comes out to his farm only long enough to put in crops and harvest them. Seemingly, such owners are more careless; farmers who have to endure the dust if they allow it to rise are more careful and do more planning.

Geological history shows that wind laid the soil in these great grassland areas over centuries of time, and Nature healed the land by providing buffalo sod and other grasses to hold it there. Now that the native grasses have been disturbed, it is natural that the wind claims the soil. In summarizing the possibilities of prevention of soil erosion by the wind, it seems that proper use of the land is the answer. From the evidence that has been presented, it is believed that if we should reach a state of ratiocinative grace, and impartially consider the net results of dry farming west of the one hundredth meridian in the district referred to, where the land is subjected to the full force of the wind, it would be well to retire much of the dry land that now is in cultivation, encourage a return of the native grasses, and confine the use of farming implements to very selective spots. It is also evident that duststorms are not only an attendant of unavoidable drought, but also, in a large degree, a result of destruction of native sods. Careless methods have allowed the topsoil, which contains humus accumulated for centuries, to be blown away, evidence of the fact that restoration of the soil to its predust-era condition will take a considerable number of years. Abandonment of the land is not necessary, as good returns can be obtained by selective tilling of some of the area and by using the remainder for grazing purposes.

The thanks of the author are due to the Weather Bureau offices at Topeka, Oklahoma City, Houston, Amarillo, and Albuquerque for their generous cooperation in furnishing data.

TABLE 1.—*Duststorms at Amarillo, Tex.*

Date	Visibility	Prevailing wind direction during duststorm	Duration of dust storm	Duration of lowest visibility	Highest wind velocity during duststorm
Year, 1933	*Miles*		*Hours*	*Hours*	*M. p. h.*
Jan. 18	¼	W	8	2	45
Jan. 21–22	0	SW	14	1	60
Jan. 25	¼	W	6	1	36
Jan. 26	3	W	5	1	42
Jan. 31	3	NW	4	2	28
Feb. 1	⅓	W	3	1	42
Feb. 5	1	SW	15	3	39
Feb. 6	3	W	7	1	42
Feb. 18	¾	SW	11	4	40
Feb. 21	2	SW	8	2	42
Mar. 4–5	¼	N	14	1	40
Mar. 5–6	¾	N	20	3	30
Mar. 6	3	N	5	3	33
Mar. 8	5	NE	2	2	36
Mar. 12	5	SW	2	1	32
Mar. 13	1	NW	10	3	38
Mar. 17	2	W	8	3	38
Mar. 18	0	NW	6	1	44
Mar. 19	0	N	13	3	48
Mar. 22	1½	NE	9	2	39
Mar. 24–25	1	NE	19	1	42
Mar. 30	1½	N	6	2	26
Mar. 31	6	NW	2	2	13
Apr. 1	½	N	13	6	48
Apr. 2–3	1	NE	34	5	30
Apr. 4	0	N	6	1	44
Apr. 5	2	N	10	3	40
Apr. 7	5	W	2	1	36
Apr. 8	1	W	4	1	34
Apr. 10	1	N	11	3	40
Apr. 12	1	SW	6	2	42
Apr. 13	0	N	18	6	50
Apr. 19	0	SW	11	1	60
Apr. 20	5	W	4	2	30
Apr. 21	1	NE	7	2	30
Apr. 29–30	0	SW	18	5	58
Apr. 30–May 1	1	W	20	5	42
May 1	1½	NE	8	1	26
May 2	6	S	2	2	24
May 3	1	NE	3	1	12
May 6	¾	W	8	1	45
May 8	1	W	11	4	40
May 9	¾	N	5	1	26
May 11	5	SW	3	1	30
May 12	2	SW	7	3	42
May 19	5	SW	2	1	30
May 22	⅛	W	10	3	44
May 28	⅛	NE	14	1	47
June 7	6	SW	5	5	40
June 12	1	NE	10	2	34
Aug. 13	2	E	2	1	32
Sept. 30	1½	N	6	1	32
Nov. 12	4	N	2	1	28
Nov. 23	1	N	6	1	30
Nov. 25	5	NE	5	1	40
Nov. 26	5	SW	12	1	38
Dec. 5	5	N	4	3	45
Dec. 14	1	W	9	4	40
Dec. 31	2	W	2	1	33
Year, 1934					
Jan. 2	1	N	4	1	38
Jan. 6	1	N	8	2	42
Jan. 12	2	N	2	1	30
Jan. 24	5	NE	3	3	51
Jan. 28	6	NE	2	2	30
Jan. 31	2	N	8	1	46
Feb. 1	3	SW	8	3	20
Feb. 3–4	2	E	8	3	36
Feb. 17–18	0	NW	27	2	61
Feb. 24	½		10	2	44
Mar. 7	1	N	4	1	32
Mar. 9	2	NE	9	1	44
Mar. 13	¼	NE	6	4	50
Mar. 14	4	E	3	1	16
Mar. 16	5	S	5	5	40
Mar. 17	0	N	16	1	46
Mar. 31	3	SW	8	4	40
Apr. 1–2	0	N	5	2	38
Apr. 2	¼	SW	12	2	41
Apr. 3	1	NE	15	2	18
Apr. 5	1	NE	2	1	46
Apr. 11	1½	NE	12	1	37

TABLE 1.—*Duststorms at Amarillo, Tex.*—Continued

Date	Visibility	Prevailing wind direction during duststorm	Duration of duststorm	Duration of lowest visibility	Highest wind velocity during duststorm
Year, 1934—Continued	*Miles*		*Hours*	*Hours*	*M. p. h.*
Apr. 12	2	NE	4	2	14
Apr. 13	3	SW	4	2	28
Apr. 14	4	NW	2	1	30
Apr. 22	2	E	6	2	26
Apr. 23	3	SW	11	7	18
Apr. 24	2	E	19	7	24
Apr. 25	5	S	5	3	30
Apr. 26	1	N	6	3	28
Apr. 27	2	NE	5	2	34
May 3	4	SW	2	1	35
May 4	2	NW	4	2	18
May 13	1	N	5	1	40
May 14	5	N	3	1	28
June 15	5	S	1	1	18
June 20	5	NW	5	3	17
June 22	6	SW	4	4	32
July 5	2	SW	8	1	20
Aug. 2	6	S	5	5	16
Sept. 2	½	NE	8	1	60
Sept. 5	5	NE	4	1	40
Sept. 6	6	NE	2	1	49
Sept. 20	3	NE	7	1	48
Sept. 22	¼	S	1	1	42
Sept. 25	6	SW	2	2	40
Oct. 8	5	NE	1	1	17
Oct. 15	2	S	8	3	44
Nov. 2	½	SW	11	1	44
Nov. 4	1	NW	8	2	46
Nov. 27	½	NW	14	2	36
Dec. 1	4	W	4	2	38
Dec. 2	3	NW	7	2	28
Dec. 6	1½	NE	1	1	26
Dec. 31	¾	N	4	4	52
Year, 1935					
Jan. 3	5	NE	7	5	27
Jan. 12	2	W	4	2	41
Jan. 12–13	2	NE	8	2	39
Jan. 16	¼	W	10	1	56
Jan. 17	5	SE	4	1	29
Jan. 19	6	SE	1	1	28
Jan. 20	4	N	2	1	26
Jan. 21	6	NE	1	1	19
Feb. 13	3	SW	6	2	40
Feb. 14	4	NW	1	1	24
Feb. 15	½	N	11	1	30
Feb. 16	6	N	2	2	34
Feb. 17	6	NE	1	1	8
Feb. 18	1½	W	7	3	15
Feb. 21	¾	W	12	2	42
Feb. 21–22	0	NE	11	1	46
Feb. 22	4	SW	3	1	7
Feb. 23–24–25	0	N	56	1	44
Feb. 27	6	SW	1	1	18
Feb. 28	1½	SW	9	2	34
Mar. 3	0	W	4	11	48
Year, 1935—Continued	*Miles*		*Hours*	*Hours*	*M. p. h.*
Mar. 4–5	0	W	18	1	52
Mar. 5	¼	W	8	1	37
Mar. 6	½	N	4	1	44
Mar. 8	4	S	8	2	35
Mar. 13	5	NE	1	1	20
Mar. 15–16–17	0	S–SW–N	55	3	50
Mar. 18	¾	SW	1	1	38
Mar. 19	¼	N–SW	14	4	28
Mar. 20	¼	SW	8	1	44
Mar. 21	2	SW	5	1	30
Mar. 22	3	SW	1	1	28
Mar. 26	3	W	2	1	25
Mar. 27	0	NE	19	8	46
Mar. 28–29–30–31	0	SW to NE	83	6	36
Year, 1936					
Feb. 3	¼	N	10	1	38
Feb. 7–8	0	SW–NW	23	5	40
Feb. 9	1	SW-NW-NE	15	2	40
Feb. 12–13	1	W-N-N-E	21	2	35
Feb. 13–14	⅛	SW–W–NE	22	1	44
Feb. 14	5	SE	5	3	18
Feb. 16	2½	SE	3	2	30
Feb. 17	1	NE	8	2	30
Feb. 23	½	SW	12	2	38
Feb. 24	½	SW	8	3	44
Feb. 25	1	NW	7	1	10
Feb. 25	1½	W	4	1	32
Feb. 26	½	NW	8	1	20
Mar. 1	0	NE	4	1	40
Mar. 3	3	SW	4	1	20
Mar. 4	½	NE	10	1	38
Mar. 5	3	S	4	1	30
Mar. 10	0	NE	13	1	40
Mar. 12	4	SW	16	1	33
Mar. 13–14	0	E–SE–S	12	2	29
Mar. 14–15	¼	NE	7	1	30
Mar. 15–16	0	N	7	4	48
Mar. 16	1½	N	7	1	24
Mar. 17	3	SW	6	1	16
Mar. 17	1	SW	12	2	40
Mar. 19	0	NE	8	1	36
Mar. 21–22	0	S–SW	17	2	42
Mar. 22	0	SW	13	3	52
Mar. 23–24	0	SW–W	19	9	56
Mar. 24	1	SW	4	1	36
Mar. 25	0	SW–W	15	1	42
Mar. 26	¾	E–SE	14	1	28
Mar. 27	1¼	SE–SW	10	2	13
Mar. 28	1½	W	3	1	33
Mar. 29	1	W	6	2	27
Mar. 30	2	W	5	1	28
Mar. 30	0	NE	11	2	40
Mar. 31	1½	SE	8	1	38

WINTER AIR-MASS CONVERGENCE OVER THE NORTH PACIFIC [1]

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[University of California, Berkeley, May 1936]

This paper is the result of a study of storm tracks in their relations to frontal zones and to the distribution of air masses over the North Pacific Ocean. Upon the completion of cyclone frequency maps, the question of the location of the Pacific polar front appeared to be significant; a comparison of the maps with Bjerknes' map of the principal fronts in the Northern Hemisphere [2] reveals discrepancies that can hardly be accounted for by mechanical errors or incomplete data. It is admitted that the frontal zone shifts its latitude with the seasons; the question dealt with here concerns only the mean position of the polar front during the winter.

Figure 1 is based on the map and figure [3] employed by the authors of Physikalische Hydrodynamik, and illustrates the application of their theory in establishing the position of the Pacific polar front in winter from the mean pressure map for February. The underlying principle is that a front is produced by a particular combination of air movements that may graphically be represented by stream lines and is termed a deformation field. A typical frontogenetic deformation field is illustrated in the inset in figure 1. Considering the stream lines to conform to gradient winds in the Northern Hemisphere, the distribution of pressure will be as indicated. If the deformation field is to produce a front, however, it must be superimposed on an appropriate temperature field. The isotherms of such a field are indicated by the broken lines—temperature decreasing toward the top of the diagram. The warm air entering the deformation field from below, and the cold air brought in from above, escape along the axis of extension to the left and to the right. It is only along the front to the right of the intersection of axes, where the direction of the gradient wind produced by the frontal solenoidal field is opposite to that of the wind in the warmer current, that the equilibrium of the atmosphere is disturbed, and wandering cyclones are generated.

If these principles are applied to the map of mean pressure for February, upon which the sea level temperature field for February [4] has been superimposed, it is to

[1] Presented before the Association of Pacific Coast Geographers, Los Angeles, Calif., June 27, 1935.
[2] Bjerknes, V., et al., Physikalische Hydrodynamik, Berlin, 1933, 708, fig. 130.
[3] Op. cit., 703, fig. 127; 708, fig. 130.

[4] Isotherms from Schott, G., Geographie des Indischen und Stillen Ozeans, Hamburg, 1935, plate VI.