wisps are formed over the cloud windows, even in the cold stratum above 16,000 feet, indicating that the humidity of the uprising valley air is low, even after it has absorbed the moisture contained in many cubic feet of cloud.

The occurrence of nonmoving windows in the cloud strata of a mountain region should, therefore, immediately suggest the presence of warm, upward-diverted valley winds.

The type location for these cloud windows is the head of Fourth of July Gulch, Boulder County, Colo.; lat. 40°01′ N., long. 105°41′ W.; shown on the U. S. G. S. Rocky Mountain National Park quadrangle. These observations were made during the progress of research assisted by the Penrose Fund of the American Philosophical Society. The writer is indebted to Bruce R. Snow, of the University of Colorado, for check observations.

DUSTSTORMS OF 1938 IN THE UNITED STATES

By ROBT. J. MARTIN

[Weather Bureau, Washington, February 1939]

The duststorms of the year just ended were far less extensive and noteworthy than in several preceding years,[1] but there were some sections of the country, particularly in the Dust Bowl itself and locally to northward, where occasional storms were as severe as any reported during recent years. The most severe storms generally came early in the year, particularly during the winter and early spring months when winter wheat was most susceptible to damage from drifting soil. Reports were all too frequent of tender growth being cut and eroded away by flying grains of sand or of young growth being buried.

While there were a few reports of dust being observed in central and eastern sections of the country, especially during March and May, and locally in several other months, duststorms were not nearly so widespread as in 1934, 1935, and 1936.

January.—Precipitation during January was subnormal in more than half the country with the greatest deficiencies noted in portions of the Plains States, the upper Mississippi Valley, the Southwest, the northern Rocky Mountain region, and the Pacific States. Portions of Kansas and Nebraska had only 3 to 25 percent of the normal January fall. Precipitation was normal or decidedly above in a wide belt reaching from the Rio Grande Valley in Texas eastward and northeastward and several stations in southwestern Texas, southeastern New Mexico, Arkansas, Iowa, and Wisconsin had more than 200 percent of normal precipitation.

Because of dry subsoil and greatly subnormal rain and snow, duststorms were rather numerous and severe during January in portions of the Dust Bowl. Some damage was done by shifting soil in Nebraska and duststorms were especially severe in Kansas on the 13th of the month, resulting in considerable deterioration of winter wheat. Some grain was blown out in western Oklahoma and some in sandy lands of the Northwest. New Mexico had duststorms during the week ending January 18.

During the following week heavy duststorms were noted in western Kansas and on several days in western Oklahoma. There was also some damage by high winds and drifting soil in western portions of New Mexico, Colorado, and Wyoming, and locally in Montana and Nebraska.

During the following week considerable damage resulted from blowing in west-central and northwestern Oklahoma; duststorms in western Kansas, with considerable soil movement, injured winter wheat in several southwestern counties. Less extensive damage was reported in the Northwest, but Wyoming indicated some injury to grains from this cause. Rather severe storms were experienced in eastern New Mexico. Over the northern Great Plains light dust was reported as far north as Montana and in extreme western Minnesota on the 24th. Light dust was noted as far east as Tennessee on the 12th and 18th and was also reported during the latter part of the month in portions of Illinois and Mississippi.

In southern sections of the Great Plains light dust was reported on as many as 9 days, nearly all during the latter half of the month. Brownsville, Tex., had light dust on 3 days. The storms were most severe in the Dust Bowl, that is, portions of western and southwestern Kansas, western Oklahoma, northwestern Texas, northeastern New Mexico, and southeastern Colorado. In western Kansas, particularly in the areas around Sublette, the dust movement was sufficient to cause marked delay in transportation schedules. A train of the Dodge City and Cimarron Valley branch of the Santa Fe was delayed 18 hours by impassable drifts of dust. A combination snow and dust plow was required to clear a pile of dust 3 to 6 feet deep and 1,400 feet long from the tracks. At times during these storms, not only in Kansas, but in other portions of the Dust Bowl, and locally as far north as Wyoming, visibility was reduced to zero, flying schedules were canceled, street lights were necessary and a marked increase in respiratory troubles was reported. Several deaths occurred from automobile accidents during the times of least visibility.

In Colorado a heavy "duster" on the 16th covered practically all southeastern counties and on the 23rd swirling clouds of dust continued for 60 consecutive hours, reducing visibility to zero or one city block throughout Baca and eastern Prowers Counties. The damage with respect to soil erosion was noteworthy during this storm.

The observer at Goodwell, Okla., reported 7 days with heavy dust and several days on which visibility was 75 feet or less. The storms of the 24-25th were the most severe in northwestern Oklahoma and, according to competent authority, were the worst ever experienced in that section.

February.—February brought good rains or snows to most of the Plains States, particularly Texas, Oklahoma, Kansas, and portions of the Dakotas and Nebraska. Much of the precipitation was in the form of snow which aided materially in reducing the number of duststorms. Because of insufficient precipitation in portions of Colorado dust blowing caused considerable damage to wheat in Las Animas County and a large acreage in the western part of the State was abandoned. Generally, the rains of the month were not sufficient to restore deficient subsoil moisture, however, and there was no permanent let up in soil blowing.

The presence of dust in the upper atmosphere was shown by highly colored sunrises and sunsets as far east as Reading, Pa. At Marquette and Sault Ste. Marie, Mich., dust

[1] For accounts of previous duststorms, see the following REVIEWS: 1934, January and May; 1935, February to May, inclusive; 1936, March, May, and December; 1937, April.

mixed with snow fell on the 13th. At Sault Ste. Marie the amount of dust was estimated to exceed 5 tons per square mile.

In New Mexico duststorms were fairly general in Union, Quay, Curry, Harding, Roosevelt, and Lee Counties on the 2d; visibility during the day averaged about ¼ mile. There was considerable wind movement over the northeastern counties of the State during the last 2 weeks of February but very little dust blowing because of the general precipitation in that area near the close of the month. Dense duststorms occurred in Kansas on the 1st and 8th and light storms on several other days during the first half of the month. Light local soil blowing was reported in Nebraska, South Dakota, and Colorado early in February. The storms of the 5th, 7th, and 12th were most severe and widespread in Colorado with durations of 6 to 8 hours and minimum visibilities ranging from zero to 100 yards; at Pueblo the dust cloud was a mile high. Precipitation began over the eastern plains of Colorado on the 15th and dust subsided for the remainder of the month; during the first 15 days dust had followed any wind velocity exceeding 15 miles per hour. As far north as Montana, severe dust blowing was reported, in areas not locally snow-covered, in portions of Cascade, Fergus, and Gallatin Counties.

The observer at Dodge City, Kans., reported that the snow and rain the last of February went down into the soil not more than 5 inches and usually less than that. He also stated that this precipitation did not terminate the dust threat in southwestern Kansas and that indications were for much dust unless heavy rains came very soon.

March.—March brought above-normal precipitation to much of the central and southern Great Plains area and to portions of eastern New Mexico, but a large portion of central New Mexico, the Dakotas, Nebraska, Wyoming, and part of southeastern Montana had subnormal falls. Duststorms were more extensive than in any other month of 1938 and were reported generally from the Rocky Mountain States eastward to the Ohio Valley and Tennessee, and from Texas and Mississippi northward to the Canadian border. At some stations in more eastern sections the presence of dust in the upper atmosphere was shown only by colored sunsets or sunrises and by muddy rains and snows, but in portions of Kentucky and Tennessee, and locally in Wisconsin, Illinois, and Mississippi, the dust was thick enough materially to limit visibility.

In southern Plains sections the frequency was rather evenly distributed throughout the month, although there was a general tendency for the more severe storms to group near the close. Farther north storms were most general and severe during the latter half of March with some reports of grain blown out near the close as far north as Minnesota. At Pueblo, Colo., the storm of the 24th made highway travel extremely dangerous; flying schedules were canceled and business houses and homes were quickly "filled" with fine red silt. In Colorado, although precipitation was generally above normal for March, hardly a day passed without some dust being raised, substantiating the fact that at times heavy dust began blowing from fields within an hour or two following rainfall of half an inch or more. The worst part of the blowing season in Colorado, normally from February 15 to March 31, was marked by some rather severe storms, although the precipitation, especially snow, did well in checking the destructive and irritable storms during that period; a moderate duststorm of 7 hours' duration prevailed in southern Baca County on the 3d. On the 4th visibility was reduced to from ½ mile to 200 feet in portions of both Baca and Prowers Counties for several hours. On the 14th a storm lasted about 10 hours in Baca and 3 hours in eastern Prowers County, visibility ranging from 50 feet to zero at times; other storms were reported on the 2d, 21st, 24th, 26th, and 29th.

In Kansas light dust was reported in Dodge City on 13 days, thick dust on 9 days, and dense dust with visibility of less than ¼ mile on the 2d, 3d, and 14th. A letter from the official in charge at Dodge City, dated April 5, 1938, calls attention to the fact that the day after an inch of rain had fallen on the 27th–28th, dust was observed in all sections of the State. He also added that it was necessary for the Santa Fe Railroad to plow the dust from the track about twice a week between Dodge City and Boise City, Okla.; the dust piled on the track ranged in depth from 6 inches to 5 feet. It was also stated that 12 hours after a rainfall of 0.75 inch, the dust was so dense that visibility was less than ½ mile.

In New Mexico storms were most prevalent on the 3d, 12th, 14th, 16th–17th, 21st–22d, 25th–26th, and 30th. The storm of the 25th–26th spread over the entire State and was accompanied at times by visibilities of less than ¼ mile and wind velocities of 30 to 40 miles an hour. The storm of the 30th was most severe; it began about 10 a. m. in the northeast and under the influence of winds of 30 to 50 miles per hour and the dry effect of the previous duststorms, especially those of 25th–26th, caused blowing sand over the eastern and southern portions of the State; it ended early on the morning of the 31st.

The adverse effect of the duststorms of the month was shown in occasional reports of damage to winter wheat in portions of the Oklahoma Panhandle, southwestern Kansas, parts of New Mexico, and some States to northward, including North Dakota, Minnesota, and Washington.

April.—The Plains States from western Kansas northward through South Dakota, and portions of North Dakota had above-normal precipitation during April; heavy falls were also reported in eastern Colorado and most of Wyoming, but half of Kansas, nearly all of Oklahoma, much of Texas, and practically all of Montana had decidedly subnormal rain.

Because of previously dry subsoil and insufficient surface-soil moisture, duststorms were again widespread and were reported from Texas northward to the Canadian border and from New Mexico and Montana eastward to Illinois. Nearly all of the most severe storms in southern sections occurred before the 15th; extreme southwestern Kansas had severe storms on several days early in the month but only light or thick dust was reported from this State during the latter half. In Arkansas and Illinois dust was most noticeable after the 15th while in portions of Nebraska, the Dakotas, Minnesota, Iowa, and New Mexico the storms were distributed rather uniformly.

Some damage to winter wheat was reported in southwestern Texas the first week of April, in New Mexico during the week ending the 12th, locally in Montana during the first week, and in portions of the southern Great Plains and southern Rocky Mountain region near the close. In Colorado "Black Blizzards" again "squelched" southeastern counties; in points of severity and destructiveness they were unequalled. Even though precipitation had been generally sufficient for growing crops during February and March, wind-whipped dust cut plants into shreds or completely covered them, thus preventing vegetation from gaining a foothold. In extreme eastern counties south of the 89th parallel, duststorms continued with greater severity than in previous months and were much more frequent. Fields were badly blown and dunes as much as 5 feet high resulted from the dust and sand in southern Lincoln County. Windshields on automobiles

were pitted by the flying sand. After the 7th, duststorms, locally of considerable severity, occurred every day, except on the 17th, 20th, and 21st, and reduced visibility daily to a few hundred feet and frequently to zero. Even rains of an inch or more failed to bring surcease for more than 6 hours and lister furrows were completely leveled after a few days of blowing.

May.—May brought above-normal precipitation to all the Plains States, except Texas and New Mexico; in Kansas the monthly total was more than twice the normal and valuable excesses were also recorded in Nebraska, Montana, Colorado, and Oklahoma; in New Mexico precipitation for the month was 55 percent of normal, in Texas 86 percent. During the week ending May 17 there was unusual wind movement in portions of the Great Plains area and duststorms occurred in southwestern Kansas, western Oklahoma, and central and western North Dakota.

Despite the heavy, beneficial rains, dusty conditions were more prevalent east of the Mississippi than for several months past; dust was noted as far east as South Carolina on several dates and from the 15th to the 18th dusty conditions were reported from the eastern Gulf States northward to the Lake Region; a minimum visibility of 100 feet occurred in portions of Indiana on the 16th. In nearly all instances, however, these storms were light in character to eastward of the Mississippi, but in western areas, particularly throughout the Great Plains, they were occasionally Statewide and were rather frequent. The most extensive storms generally occurred during the first half or near the middle of the month in Iowa, Minnesota, and the Dakotas, while in Montana the most severe storms occurred in extreme northeastern counties on the 13th. The storms in western North Dakota on the 1st, 13th, and 15th were the worst ever observed in that area. Further south the number of dense storms was less; visibilities in New Mexico were seldom less than ⅛ mile and in northwestern Texas dense dust occurred on only 3 days.

Low seasonal wind velocities in conjunction with above-normal precipitation for the third consecutive month practically ended destructive duststorms, at least temporarily, in Colorado. Even in southeastern counties vegetation gained a foothold and this further lessened the probability of dust erosion. Excessively strong winds on the 1st, however, raised dust throughout the eastern portion of the State and caused heavy erosion in southeastern counties where the storm continued throughout the 2d–3d. A destructive storm occurred in Baca County on the afternoon of the 13th and another continued throughout the 17th. Other light storms occurred in southeastern counties on the 14th, 15th, 16th, 18th, 25th, 27th, and 28th, but most of these were local in origin and where precipitation was more or less deficient.

At Dodge City, Kans., light dust occurred on May 1, 2, 3, 11, 13, 15, 17, 19, 28, 29, and 30, and thick dust on the 1st with minimum visibility of ⅛ mile; as reported before Kansas had duststorms only a short time after heavy rains.

On the 13th the most severe duststorm of the month in Montana affected all of Sheridan, Daniels, Roosevelt, and Richland Counties, and eastern parts of McCone and Valley Counties; local storms occurred in northern Judith Basin and central Lincoln Counties. Duststorms were general in North Dakota on the 13th–16th and in central and western portions of that State on the 1st–2d; some western stations reported the storms of the 13th–15th the worst ever observed. No damage was caused by the duststorms in Oklahoma, where heavy dust was confined to the Panhandle counties. Visibility was reduced to 100 feet at times at Kenton, Cimarron County, on the 15th; on the 13th, the visibility was 400 feet.

June.—The month of June brought deficient precipitation to large areas from the Texas Panhandle northward; in portions of Nebraska and the Dakotas the deficiency amounted to 15 percent or more of normal. Portions of Texas, Oklahoma, and eastern Kansas had above-normal rains and the heavy rains of the preceding month were also beneficial in reducing both the extent, severity, and frequency of duststorms. None was reported east of the Mississippi. In the northern Great Plains local storms occurred in portions of Daniels and Sheridan Counties, Mont., on two dates, and light dust was general in North Dakota on the 6th. In South Dakota local storms were general in the eastern two-thirds on 4 days early in the month and in the western portion on the 27th. Visibility was reduced to ¼ mile at times at Moorhead, Minn., on the 6th, and light dust was reported at that station on two other dates early in the month. At Rock Springs, Wyo., on June 20, visibility was reduced to zero for half an hour and several storms with zero visibility were reported at Goodwell, Okla. The storm at Springfield, Mo., on the 14th was the worst reported in 2 years.

The following comment from the Colorado report is interesting:

> Duststorms during June have been less extensive and intensive due to large sections being "healed" over with weeds. There are large tracts of land, however, which will not grow weeds or any cover of vegetation and dust of considerable intensity continues in the lee of these fields with the slightest wind movement * * *. Duststorms reducing the visibility to from 100 feet to zero and lasting from 4 to 18 hours occurred in Baca County on the 8th, 12th, 13th, 15th, 18th, 27th, 28th, and 29th.

At Dodge City, Kans., the most severe duststorm of recent years occurred on the 10th. The visibility was reduced to 10 feet or less and windshields of cars driving against the storm were sandblasted to such an extent that new glass was required. At the time of the Dodge City report the center of the dust section was 50 to 60 miles west and south of Dodge City and the railroad was still using plows to enable them to move trains on the branch line from Dodge City to Boise City, Okla. In one of the cuts dust filled in 2 to 7 feet deep for a distance of 2,500 feet despite the fact that Kansas had from 2 to 4 or more inches of rain during the past month.

It is interesting to note that on June 5 a duststorm rivaling those of the United States' Dust Bowl struck the central part of Japan's Hokkaido Island. This storm covered 75,000 acres of valuable farm land with an inch of fine silt and inflicted crop losses estimated at 65 to 80 percent. Six factories and numerous dwellings were damaged heavily, schools had to be closed, and communication lines were put out of service.

July.—During July the extreme northern and extreme southern Great Plains and portions of Nebraska and South Dakota had above-normal rainfall; elsewhere in the Plains area subnormal precipitation occurred. Light dust was reported in central and southern Illinois on the 7th and 10th and local soil-blowing occurred in the eastern two-thirds of South Dakota on the 2d–4th, 11th, 13th, and 18th. No unusual duststorms occurred in Nebraska and the month was the first at Dodge City, Kans., without such storms since January 1937. Light storms were reported in western Kansas on about 5 days during the first half of the month. Light to moderate storms were reported at Waynoka, Okla., on the 13th, at Kenton on the 22d and at Tulsa on the 27th. Light dust was reported at Abilene, Tex., on the 7th.

Portions of Montana, particularly Valley, Chouteau, and Yellowstone Counties, had light storms on 1 or 2 days and a severe storm occurred in Gallatin County, but elsewhere there was little dust blowing or soil movement during the month in that State.

August.—August was similar to July, as only a few storms were reported and these were usually light and local in character, despite the fact that precipitation for the Great Plains as a whole was subnormal, particularly in much of Texas and Oklahoma and large portions of the Dakotas and Nebraska.

Light dust was reported in extreme western Minnesota on the 18th and local soil blowing occurred in all sections of South Dakota on the 1st–5th, 13th–20th, and 24th but with little or no damage. Light storms were reported in portions of McCone, Fergus, and Garfield Counties, Mont., on the 2d, 11th, and 29th and a few light local storms occurred in Nebraska on the 2d, 9th, 13th, 18th, and 19th. Only one was reported from Oklahoma; this was at Waynoka on the 20th and was unimportant. It was dusty on several days in Kansas, but only a few storms of local nature occurred in extreme northwestern and extreme southwestern portions; the soil in this State, particularly in the west, was still very dry at the close of the month.

September.—During September precipitation was much greater than normal over a wide belt extending from Lake Michigan southwestward to Colorado and northern New Mexico with from two to nearly four times the usual amounts for the month. Totals were subnormal in the extreme northern Great Plains and also in southern sections from eastern Kansas and extreme western Oklahoma southward. Despite these heavy rains and even larger percentages of normal in eastern sections, light dust was reported at Hartford, Conn., on several dates; this is the most eastern occurrence of dust during the year.

Light local duststorms occurred on 4 days during the last half of the month in South Dakota, on only 1 day in Nebraska, and there were a few local storms in Kansas, mostly in southwestern counties, on the 12th, 17th, and 28th; one of these storms was especially severe. A few local storms were reported in Oklahoma on the 14th, 17th, 27th, and 29th. The storm at Alva on the 17th reduced visibility to ¼ mile for an hour.

At Rock Springs, Wyo., a storm on the 30th caused occasional zero visibility during the afternoon, and severe duststorms were reported in the vicinity of Helena and Trident, Mont., on the 4th. On September 29 southerly winds of gale force caused considerable dust and soil blowing in the Missoula River and Flathead Valleys during the late afternoon. The storm began about 5 p. m. in central Missoula County and moved northward through Lake and eastern Sanders Counties to the upper end of the Flathead Valley; it lasted nearly an hour during which time traffic was at a standstill because of poor visibility.

October.—October was unusually dry in practically all central portions of the country; Kansas and Oklahoma had 17 percent of normal rainfall, Nebraska 11, South Dakota 12, North Dakota 51, Texas 32, Colorado 72, and New Mexico 91 percent; the total monthly fall for Minnesota was only 26 percent of normal. Despite these low monthly totals there were only a few duststorms and none of these compared in severity or extent with those in earlier months. In southern sections light local dust was reported on three dates in Oklahoma and on one date in Texas. Only light dust was reported in extreme western Minnesota and this only on the 6th, 10th, and 12th. No storms were reported in Kansas and only one light storm occurred in Nebraska; this was on the 8th. There were a few light and widely scattered storms at the beginning and near the end of the month in North Dakota. Local dust blowing was reported on the 1st, 10th–12th, 21st–25th, and 29th–30th in South Dakota; all of these storms were light; the one on the 25th was the most prominently mentioned. Light storms occurred in southern Rosebud County, Mont., on the 13th and in west-central Sheridan County on the 27th.

November.—Percentages of normal precipitation for November were much more favorable in the Plains area than during October. The lowest percentage reported in the northern Plains was 85 for South Dakota and in the southern sections 41 and 70 for New Mexico and Texas, respectively.

Duststorms of November were confined to Montana, Wyoming, South Dakota, Kansas, Oklahoma, and Texas, although there was one report of a heavy dust fall mixed with snow at Sault Ste. Marie, Mich. In Montana a light storm occurred in Judith Basin County on the 18th and dusty conditions prevailed at Rock Springs, Wyo., on the 4th with visibility reduced to zero at times. Light local dust blowing was reported in South Dakota on the 1st, 8th, and 21st, and at Dodge City, Kans., on the 1st, 2d, 9th, and 21st; the storm on the 21st covered three or four counties in the southwestern portion of the State. In Oklahoma dust was reported on the 2d and 21st at Waynoka; the only occurrence of heavy dust in this State was on the 21st when visibility at Alva was reduced to ½ mile. Light dust was reported at Abilene, Tex., on the 17th and 21st.

December.—The final month of 1938 brought above-normal precipitation to much of the Dust Bowl and nearly all the Plains States. The lowest percentage of normal was 88 in South Dakota and Texas. During December there was again a heavy fall of dust mixed with snow at Sault Ste. Marie, Mich., on the 7th and muddy rain fell on December 4 at Madison, Wis. Kansas City, Mo., reported dusty conditions on the 28th with a minimum visibility of 1¾ miles.

Light duststorms were reported in Montana on the 3d, 5th, 10th, 24th, and 25th; the storm of the 25th was severe in portions of central Big Horn County. Local dust blowing was reported in South Dakota on the 17th, 24th, and 26th, and from several stations in the eastern and western thirds of that State on the 25th. Heavy dust occurred at Dodge City, Kans., on the 4th with a visibility of ½ mile and light dust at Wichita on the 26th and 28th; rather severe storms occurred locally in the western third of the State on the 4th, 26th, and 27th. At Goodwell, Okla., the visibility was less than a mile on the 4th and dusty conditions were reported in the Panhandle on the 4th, 15th, 26th, 28th, 30th, and 31st; light dust occurred at Goodwell on about 10 days during December. In Texas only a few storms, mostly light, were reported; Abilene reported dusty conditions on the 4th, 5th, 16th, 26th, and 27th; while at Amarillo visibility was at times reduced to ¾ mile.

Occasional soil blowing was still being reported as the year closed, and until rainfall returns to normal, or a more permanent vegetative cover is secured, duststorms may be expected from time to time throughout the Great Plains area.