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fire whirlwind formation over flat terrain

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FIRE WHIRLWIND FORMATION OVER FLAT TERRAIN

Donald A. Haines and Gerald H. Updike

Fire suppression crews face formidable problems when confronted with unusual forms of fire behavior. Such phenomena as firebrand showers or long-distance spotting are often unexpected, and the fire fighter usually is ill-prepared to deal with them. Within this erratic behavior category, one can surely include the fire whirlwind. This phenomenon may display symptoms as mild as a quick swirl on a campfire or it can be incredibly ominous, as described by Pernin (1872) during the 1871 Peshtigo, Wisconsin, conflagration: a "... great black object, like a balloon, whirling with intense rapidity in the air ... (touching) it burst with a loud explosion, like a bomb filled with powder ... (and) streams of fire scatter(ed) off in all directions."

There are only a small number of published field observations of fire whirlwinds, and fewer with photographs. This is surprising, as this fire phenomenon is comparable to the tornado in its potential destructive importance.

Graham (1957) listed some of the physical characteristics of a number of fire whirlwinds and also (1952) described a spectacular event in detail. Pirsko *et al.* (1965) published a well-documented report, including photographs, of a violent fire whirlwind that resulted in four injuries, along with the destruction of two homes, a barn, three automobiles, and an orchard. Countryman (1964, 1969) has done the most extensive work on field characteristics of this type of vortex. He consequently has verified a number of suspected fire whirlwind properties.

Almost all of these published events occurred either in hilly or mountainous country. In mountain areas, the atmospheric lapse rates over the fire area can only be inferred, and consequently lapse rate contribution to formation and maintenance can only be estimated. Also, in mountains or even in low, hilly country, terrain features are often dominant factors in fire-whirlwind formations. Most of the fire whirlwinds observed by Countryman (1969) and Graham (1957) developed on lee slopes. Countryman feels that these vortices resulted from an unstable condition in which thermal wind and the fire blocked incoming cool air. These phenomena tend to develop in areas where wind shear or natural eddies occur.

It would be interesting to know how fire whirlwinds form under less complex field situations, such as in flat terrain with moderate burning conditions and with a known atmospheric lapse rate. Here, among other things, the role of atmospheric stability might be evaluated. Unlike investigations conducted in mountainous terrain, we could easily obtain representative upper-air data and more accurately measure stability. Byram and Nelson (1951) analyzed flat-terrain fire whirlwinds in South Carolina along these guidelines with interesting results. Much of their information complements the observations reported in this paper.

Byram and Martin (1970) state that three conditions appear to be essential for the formation of most fire whirlwinds as well as other types of thermally driven vortices. First, vortex formation requires a generating eddy possessing angular momentum. The heat source will create this eddy in the thermal drive situation. The flow becomes spiral because the horizontal flow toward the base is almost invariably off balance. Second, a fluid sink must be present within this eddy. It is usually produced indirectly by the heat source. The convective column over that source is the fluid sink, and it may be largely controlled by atmospheric stability. And third, some friction or drag must restrict the movement of air so that the inward radial component of air flow does not vanish as the system approaches a steady state. Emmons and Ying (1967) feel that normally the ground slows the rotational motion of the air and therefore the imposed radial pressure gradient pushes the boundary-layer air toward the axis.

Necessary conditions for fire-whirl formation can be easily met in the laboratory using inexpensive equipment. A plastic, cylindrical chamber does the job quite nicely (fig. 1). A number of researchers have investigated laboratory-created fire-whirls in detail and found a number of important features (Emmons and Ying 1967, Blackshear *et al.* 1968, Lee and Garris 1969, and Byram and Martin 1970).

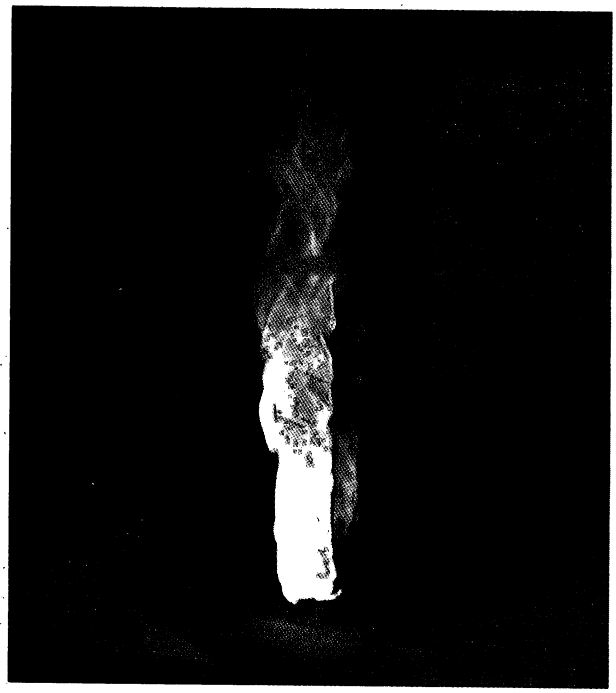


Figure 1.—A laboratory-created fire-whirl in a plastic chamber. The plastic is joined along the seam with nut-bolt bracing that leaves a ½-inch space along the entire length, allowing air to enter. The air becomes a generating eddy as it is forced to spin around the inside of the chamber gaining vorticity. Lighter fluid in the small cup provides the fuel source. Intense heat generated by the whirl has caused the inexpensive plastic cylinder to buckle. The direction of spin can be reversed by inverting the cylinder.

FIELD FIRE-WHIRLWIND OBSERVATIONS

Well-documented field observations are more difficult to find than laboratory descriptions. But information on three recent fire-whirlwind situations in Wisconsin and Minnesota is available (table 1). In this paper we will not be concerned with the relatively small fire-whirls that sometimes appear briefly in a flame front, but rather with the large fire whirlwinds that extend tens or hundreds of feet in height, sometimes move considerable distances, and visually resemble the desert dust devil or tornado.

Necedah

One of the authors observed these conditions at the Necedah National Wildlife Refuge (fig.2) on August 21, 1970. At that time, refuge personnel were conducting a prescribed burn of 408 acres on a flat plain.

The burn began at 10 a.m. c.s.t. on August 20 in an area of oak and jack pine slash. Under backing winds, only a small portion was completed by evening, but burning continued slowly throughout the night. A number of small dust whirls began at 11 a.m. on the 21st, mostly in the burned sectors (fig. 3). Skies were clear at this time, with the temperature in the mid 70's and relative humidity in the 30's. A very light wind (under 5 m.p.h.) was evident from the southwest. In the following 3 hours an estimated 200 dust whirls were seen. These whirls generally moved northwest toward standing timber where they dissipated in the trees. Observers noted that the larger dust whirls (fig 4A) struck the trees with a force comparable to that caused by a wind velocity of about 35 m.p.h. Interestingly, the dust whirls skirted hot spots, following a cooler track. The ground colors were predominantly white (ash) and black (charcoal), which may have helped to determine the path they followed.

Near noon large fire whirlwinds, spinning counterclockwise (fig. 4B), developed in the heavy slash fire region. During the following hour and a half, about 20 of them were seen. These fire whirlwinds often exhibited a concentrated whirling motion throughout their vertical extent when they began (fig. 4C), but in a few minutes (fig. 4D) the upper region developed more turbulent motion. At this time, the fire in the main

Table 1.—Meteorological features during fire whirlwinds

Item	Location			
	Necedah, Wis.	Burnett County, Wis.	Littlefork, Minn.	Virginia, Minn.
Date	August 21, 1970	August 25, 1969	August 11, 1965	July 1, 1970
Time (c.s.t.)	12 p.m.	2 p.m.	2 p.m.	3 p.m.
Temperature (°F.)	75	88	90	86
Relative humidity (Percent)	35	38 and falling	62	22
Surface wind velocity	Under 5 m.p.h.	Very light	Very light	Gusts to 19 m.p.h.
Sky	Clear	Clear	Clear	Clear
General surface synoptic situation	Just west of high pressure center	Just west of high pressure center	Somewhat nondescript, frontalysis occurring in weak system to the north	Behind a cold front
Closest representative upper-air station	(STC) St. Cloud, Minn.	(STC) St. Cloud, Minn.	(INL) International Falls, Minn.	(INL) International Falls, Minn.
Depth and lapse rate of shallow ground layer	340 feet 1.5° F./100 feet	310 feet 1.5° F./100 feet	625 feet 1.7° F./100 feet	360 feet 2.3° F./100 feet
Depth and lapse rate of next higher layer	2,625 feet .66° F./100 feet	5,250 feet .60° F./100 feet	10,105 feet .43° F./100 feet	3,410 feet .52° F./100 feet
Temperature difference between 850-500 millibar surfaces	24.7° C. (44.5° F.)	24.7° C. (44.5° F.)	31.4° C. (56.5° F.)	26.4° C. (47.5° F.)
Area burned or burning (Acres)	408	90	65	30

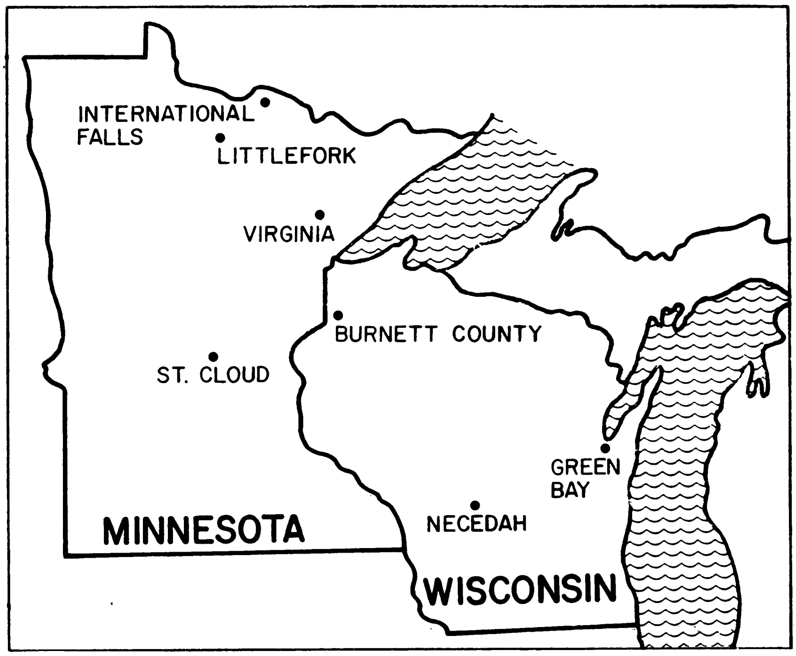


Figure 2.—Location of the fire whirlwind sites. Upper-air weather stations are also shown in the figure.

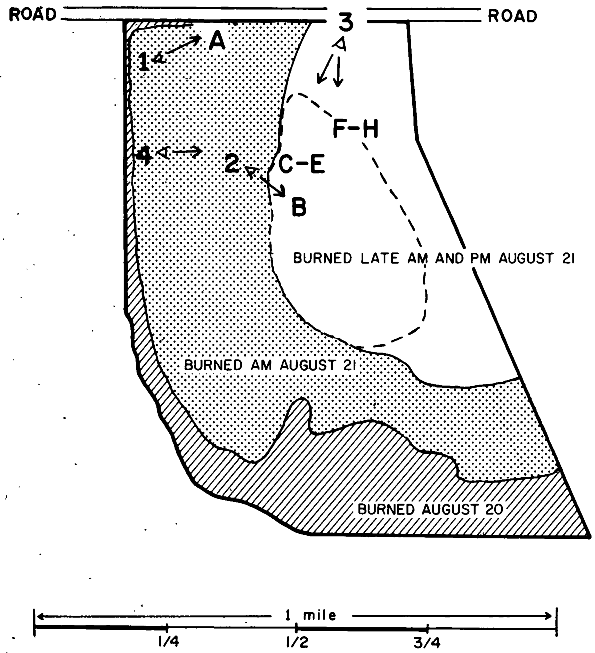


Figure 3.—Area of the Necedah fire whirlwinds. The area enclosed by dashed lines indicates the main portion of the heavy slash burn. Photograph A (fig. 4) was taken from position 1; B from position 2; C, D, E, G, and H from position 3; and F from position 4.

flame region began to roar much like a blast furnace. As the individual fire whirlwinds picked up in intensity, they created a noise like a fast-moving freight train.

At the peak of activity the scene appeared as in figure 4E; seemingly, any burning area was a threatening source for fire-whirlwind genesis. The largest fire whirlwind developed at this time; it was about 40 feet in diameter, with the highest vertical development estimated at 2,500 feet (fig. (4F). The funnel was characterized by a well-developed vortex, looking much like a typical tornado. Closer photographs of it (taken from position 3, fig. 3) show the lower section in or near steady state (fig. 4G) and a thicker, blacker section with more turbulent flow about two-thirds of the way up (fig. 4H).

Burnett County

Another well-documented fire-whirlwind situation occurred in Burnett County, Wisconsin (fig. 2), on August 25, 1969. The Wisconsin Department of Natural Resources was conducting a prescribed burn on a 90-acre tract. Weather conditions included clear skies, temperatures in the high 80's, a relative humidity of 38 percent and falling, and a light, variable wind. By 2 p.m. c.s.t. most of the perimeter had been ignited and an intense burn was in progress.

Small dust whirls began to form over the burned area. One of these dust whirls increased in size until it reached a diameter of 15 feet and a height of 150 feet, becoming a fire whirlwind as it picked up hot ashes and embers. It crossed the south control line, scattering sparks and fire for a distance of 100 yards.

At 2:25 p.m. another large fire whirlwind developed, traveled parallel to the north control line, then suddenly crossed it. A tractor-plow unit and tank truck crew attempted to control it immediately, but there was little they could do. Observers state that the whirlwind seemed to explode, building to an estimated height of 1,000 feet with a wavering tip of flame at the top. Burning snags, 5 inches in diameter and up to 9 feet long, were thrown out of the vortex like flaming arrows at a height of 300 feet. The sound in the column was comparable to a jet aircraft directly over the tree tops. The tanker operator directed a water stream at the whirl base at a distance of 60 feet for about 1 minute, but the water was sucked up into the funnel. The vertical lifting vector of the fire whirlwind was larger than the horizontal velocity vector of the water stream plus gravitation, as no water reached the base of the vortex. The crew used a pumper unit that delivers 100 to 125 p.s.i. of water in a straight stream with a ½-inch nozzle, about 75 gallons per minute.

At a distance of several hundred feet, the wind velocity flowing into the Burnett County fire whirlwind was estimated at 30 m.p.h. Initially, it had the appearances shown in figure 4D. After crossing the control line and assuming smooth funnel characteristics, it became tall and narrow as in figure 4G. After genesis, this fire whirlwind stayed in a turbulent state for about 4 minutes. After crossing the line and changing to steady state, it was able to maintain itself for approximately 10 minutes longer.

According to observers, the path of the fire whirlwind later looked as if a giant vacuum cleaner had swept it. There was nothing but bare mineral soil left, with no trace of the burn visible.

This observation is strikingly similar to that given by the National Oceanic and Atmospheric Administration (NOAA) State Climatologist for Nebraska when he described the effects of one of the 1965 Palm Sunday tornadoes in that State, "The path gave the impression that an enormous vacuum cleaner had swept the ground clean of vegetation, loose soil, all other movable objects" (Fujita *et al.* 1970).

Littlefork

Another fire-whirlwind situation occurred near Littlefork, Minnesota (fig. 2), on August 11, 1965. The Minnesota Department of Natural Resources was conducting a prescribed burn of 65 acres in a cutover black spruce area that had slash concentrated in windrows. Ignition began at 1:30 p.m. c.s.t. with the air temperature near 90°F., clear skies, almost no wind, and a surprisingly high relative humidity (62 percent). The minimum relative humidity during the day was 52 percent.

Beginning at 2 p.m., about 15 fire whirlwinds (probably resembling figure 4D) occurred, interspaced over the next hour. They had an average duration of 5 to 10 minutes. A number of smaller (40 to 50 feet high) ash whirls also began. The largest fire whirlwind was 100 feet in diameter and several hundred feet high. One of these followed a circular path one-eighth mile in diameter within the control perimeter, then came out the northeast corner, setting about 25 spot fires. Observers stressed the fact that winds were light, usually blowing into the fire from around the perimeter. Fire whirlwinds often moved against this light wind, seeming to follow a green vegetation track. The orientation of the windrows probably contributed to this tracking effect as the channels between them were the main formation areas.

Two other large vortices came over the line, and Mr. Otto Eggert, Minnesota Regional Staff Forester, found himself inside one of them. Mr. Eggert[1] states, "There was considerable small debris, mainly ash and charcoal; some of the latter retained glowing embers, not large, but capable of igniting combustible material. I was able to see my way by holding my head down so my face was somewhat shielded by my hard hat . . . the wind, near the (vortex) perimeter, was almost horizontal, with very little vertical lift. Nearer the center, wind velocity seemed to be higher, with a strong vertical lift, and it was also where the larger debris was being picked up." Mr. Eggert did not note an area of downdraft, but this fire whirlwind was erratic. Kaimal and Businger (1970) found in an instrumented study of a similar atmospheric phenomenon, a dust devil, that there was a strong updraft around the vortex and a downdraft within the core. They believe this is a general characteristic of most well-developed, concentrated vortices in the atmosphere. The area of the downdraft, however, is fairly narrow. Evidence for vortex central-core downdraft has also appeared in tornado photographs (Kuehnast and Haines 1971).

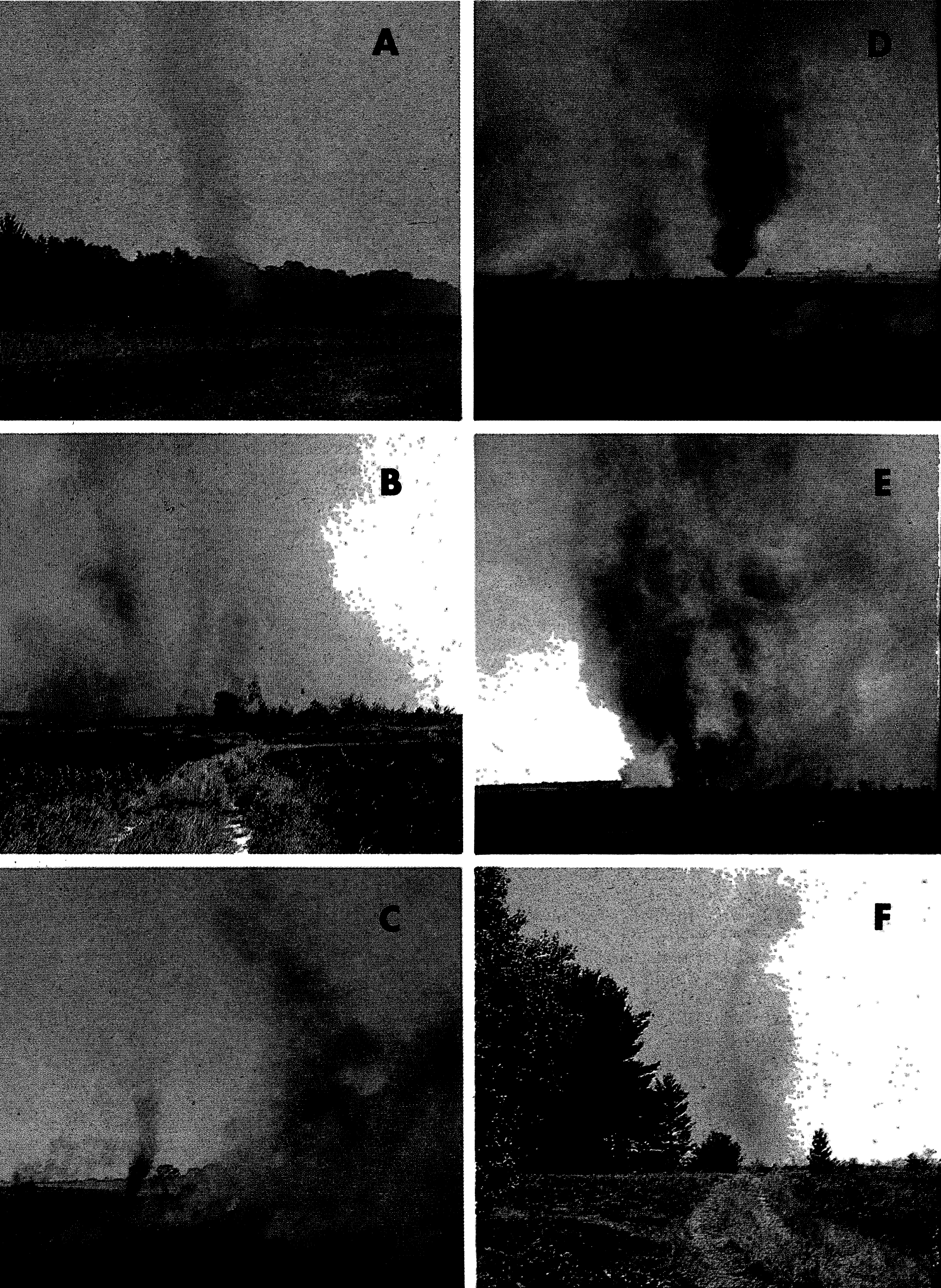
Mr. Eggert was not thrown to the ground or injured, but he did have a number of holes burned in his clothing. This vortex did not achieve the type of steady state shown in figure 4F. Schaefer (1961) and Byram and Martin (1970) believe that the velocities of fully developed fire whirlwinds reach tornado intensities. This appears justified in view of the destruction caused by at least one fire whirlwind (Pirsko *et al.* 1965), as well as the high-frequency sound emitting from the Burnett County vortex.

SUPPLEMENTAL DATA

The Virginia Burn

Meteorological data from an experimental fire conducted on 30 acres of the Virginia District of the Superior National Forest, Minnesota, are included in table 1. Although no fire whirlwinds developed during this burn, the data are useful for comparing conditions under which fire-whirls develop with those under which they do not. The fire was set in heavy slash on July 1, 1970, using nearly simultaneous area-ignition methods, and hence was extremely intense. Skies were mostly clear, temperature 86°, and the relative humidity 22 percent. Windspeed averaged 7 m.p.h. with gusts to 12 m.p.h. at the start, but gustiness increased to as high as 19 m.p.h. 15 minutes after ignition and continued through the burn period. Although no general ground fire-whirlwind development occurred, the main smoke column

[1] *Personal correspondence with Mr. Otto C. Eggert, Minn. Dep. Nat. Resources. 1971.*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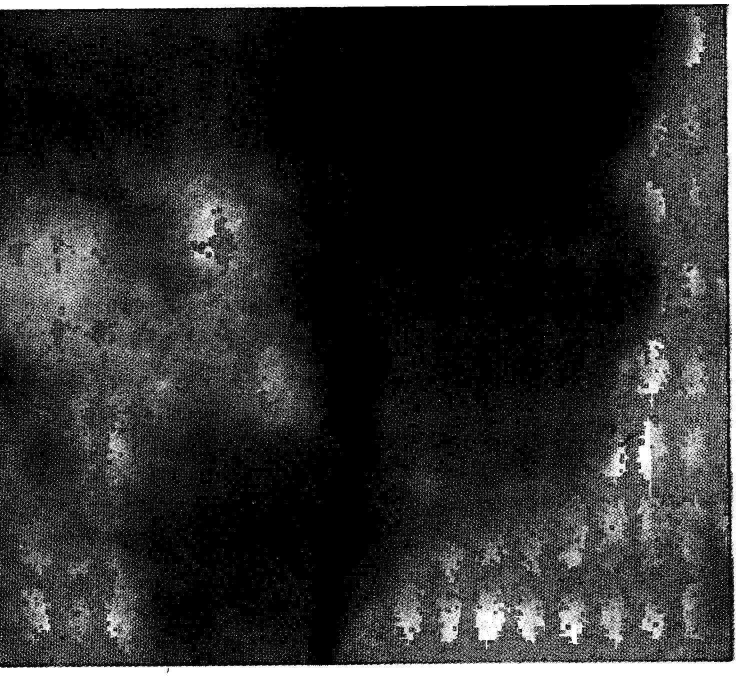

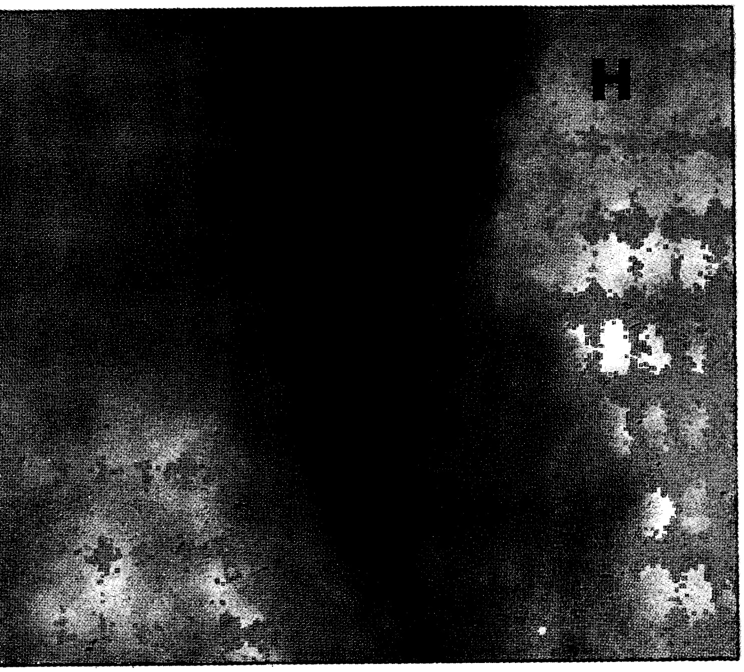

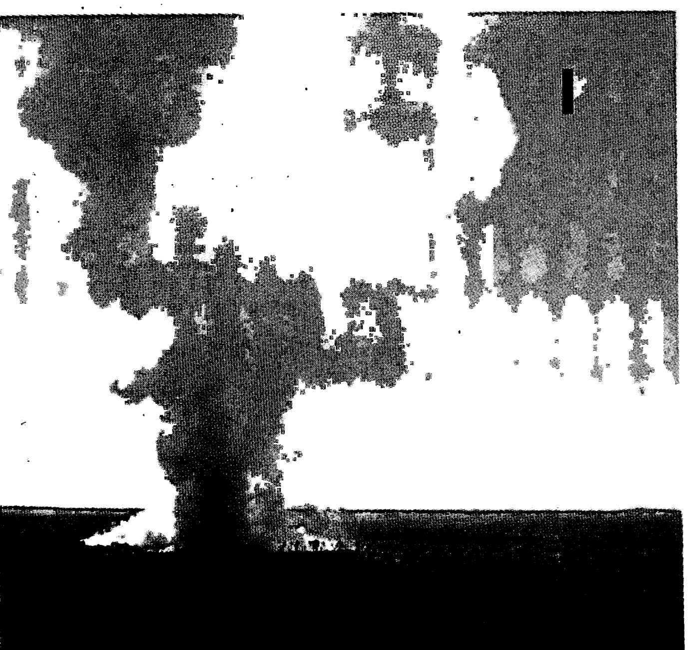

showed brief whirling action during the height of activity (fig. 4I). One of a series of experimental burns conducted on the Virginia District during the 1970 fire season, this fire resulted in the greatest fuel reduction by far. Almost all fuels up to 3.5 inches in diameter were completely consumed, indicating a very hot fire.[2]

The Atmospheric Vortex

Although there is not a large amount of field data available on fire whirlwinds, this is not true for other types of vortices. Most investigators of the fire whirlwind have come to the conclusion that there are strong dynamic and geometric similarities between it and other atmospheric vortex types (waterspouts, dust devils, tornadoes, and even hurricanes). These similarities extend well beyond gross features. Emmons and Ying (1967) feel that the fire whirlwind and the dust devil are especially closely allied in that hot gasses rise and then concentrate vorticity already existing in the air into a small-diameter core: "The air, in the case of a hot desert, brings added buoyancy to the very spot required for added dust-devil violence. In the case of the fire-whirl, the radial component of ground wind not only brings added buoyancy to the core, but more important, it also brings added fuel which continues to add to the buoyancy as it burns while rising in the fire-whirl core."

The dust devil has another environmental feature that makes it similar to the fire whirlwind—extreme instability at low levels. Ryan and Carroll (1970) have examined the atmospheric temperature structure during dust-devil formation and found that it consists of a number of layers.

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[2] *Roussopoulos, P. J. Results of four prescribed burns at Virginia, Minnesota. Paper presented at USDA Forest Service R-9 Fire Control Meeting, Combined Air Officers and Fire Staff, Springfield, Missouri, April 26-30, 1971.*

Figure 4.—A, *Dust whirl at the Necedah, Wisconsin, burn;* B-H, *fire whirlwinds at the Necedah burn;* I, *main smoke column during the Virginia, Minnesota, burn; the photograph was taken from a tower 1 mile north of the site, Height of the smoke column was about 2,500 feet. Strong entrainment into the base was apparent and whirl motion was evident about half way up. (Photos C, D, E, G, and H courtesy of Mr. Harold Carter, USDI Necedah Refuge.)*

The first layer extends from the surface to a height of 0.3 meter or less and is extremely superadiabatic, with lapse rates as much as 9,000 times the dry adiabatic. The second layer, from 0.3 to about 10 meters, is normally 20 to 40 times the dry adiabatic. A ground surface covered with hot ashes or fire will, of course, create the same or even more highly magnified lapse conditions.

Because the two vortex types are closely related, we can use dust-devil observational findings as they apply to the fire whirlwind. A large amount of dust-devil observational information is available in the literature. The most exhaustive study was recently published by Sinclair (1969). He observed over 1,200 dust devils in the Tucson, Arizona, area, and a statistical computation produced the following information:

1. The highest dust-devil frequency occurs with the lowest atmospheric stability and not necessarily with the highest shelter air temperature. Maximum activity peaks between 1 and 2 p.m. local standard time, which is approximately the time of maximum soil surface temperature and convective heat flux. But intense surface heating and superadiabatic lapse rates usually occur together, although the latter is not necessarily dependent on the former. Therefore, it is obviously most important to check vertical lapse rate rather than the air or even the surface soil temperature.

2. Most of the cloud activity in the Tucson area is cumuliform. On days with cumulus cloud cover, dust-devil activity is suppressed or terminated. A change of from 0.2 to 0.4 average cloud cover results in approximately a 20- to 40-percent reduction in the average number of dust devils observed per day.

3. Typical windspeeds occurring with the greatest dust-devil activity are somewhere between 1 and 10 m.p.h. Occurrence was considerably suppressed by increasing windspeeds. Byram and Martin (1970) found that in the open-air thermal method of fire-whirl production, the generating eddy is easily distorted by light winds: "Even when the rate of heat output per unit length of arc is fairly high, a light wind can cause enough distortion either to prevent the formation of the vortex or to cause it to form only intermittently."

DISCUSSION

All the described fire periods occurred during the summer and in the early afternoon (table 1). Air temperatures ranged from 75° to 90° F. and relative humidities from a high of 62 percent at Littlefork to a low of 22 percent at Virginia. Skies were essentially clear in all cases. Stability structure of the lower atmosphere is shown in detail in figure 5. The temperature soundings looked much the same as they did during the 1950 South Carolina fire-whirlwind cases (Byram and Nelson 1951). The atmosphere was characterized by a shallow layer of very unstable air that departed dramatically from the dry adiabatic lapse rate of .54° F./100 feet (table 1, fig. 5). The low layer depth was roughly 350 feet, although it increased significantly in the Littlefork situation to 625 feet. Only at Virginia did the lapse exceed the critical value of the autoconvective lapse rate, 1.87° F./100 feet. Above this value, a spontaneous initiation of convection is possible in the atmospheric layer because overlying air is now more dense than the air nearer the surface.

Except for the Littlefork case, the temperature lapse was near the dry adiabatic through the next higher significant layer, which means that this layer could also have been very unstable. We might caution that it is sometimes risky to extrapolate the structure of layers as shallow as a few hundred feet over relatively long horizontal distances. Consequently, here we are assuming uniform surface conditions.

It did not appear advantageous to examine stability at higher levels. Although some studies of erratic and mass fire situations have tried to involve the positions of high-level jet streams, the general synoptic situation in these cases does not seem to lend itself to that type of analysis. Some western region meteorologists use a 850-500 millibar, "25° stability rule." When the temperature difference (°C.) between 850 and 500 millibars is less than 25° C., there is usually little extreme fire behavior. They have found that violent behavior seems to increase as the temperature difference increases beyond 25° C.[3] However,

[3] *Personal correspondence with Clive M. Countryman, USDA Forest Service, Pacific Southwest Forest and Range Exp. Sta., Riverside, Calif., 1971.*

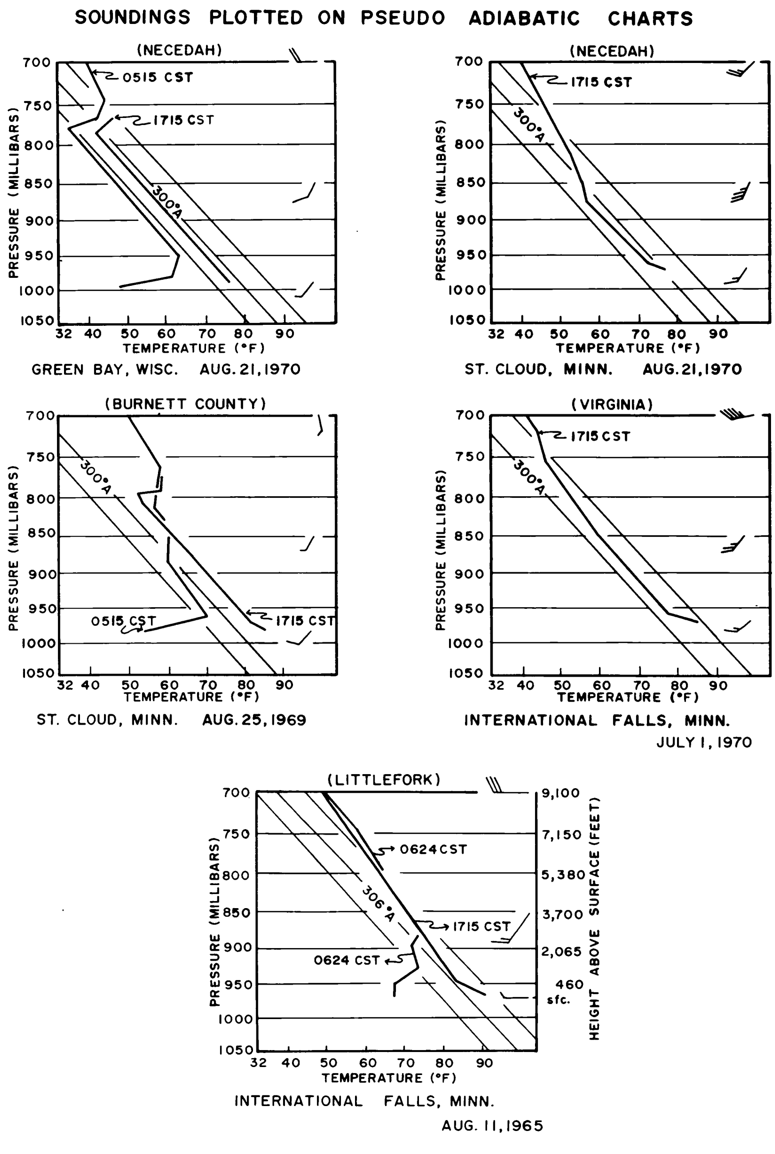

Figure 5.—Upper-air soundings taken near the time of fire whirlwinds. A plot of height is included on the bottom graph (Littlefork) to give some idea of the height of the pressure surfaces. This height does not remain static but varies in time as well as with geography; therefore, it is not the same for all of the included graphs but is roughly so. The straight sloping lines measured in degrees absolute (°A) are the dry adiabates. One can determine the stability of the air by measuring how much the actual temperature sounding departs from these lines. The late-afternoon temperature sounding is plotted on all graphs and the morning sounding (all identified by the Central Standard Time (CST) of release) is included on three of them. Wind velocities at surface, at 850 mb., and at 700 mb. (all measurements at NOAA upper-air station) are also included. The barbed end of the main shaft represents the compass direction from which the wind was blowing, with north at the top of the graph. A half barb represents 5 m.p.h. and a full barb 10 m.p.h.

only in the Littlefork fire-whirlwind situation was there a significant temperature difference between these pressure levels. This forecast rule is probably more applicable at high elevations.

The winds at surface, at 850 mb., and at 700 mb. (fig. 5) reflect the upper-air stations but are not necessarily representative of conditions at the fire-whirlwind site. This is why conditions at two U.S. NOAA stations are shown for Necedah. A high pressure area (fig. 6) was moving rapidly to the east at that time, and the winds over Green Bay were probably more representative of Necedah conditions than those at St. Cloud.

These data do not indicate whether a certain synoptic pattern is most conducive to flatland fire-whirlwind occurrence. There are, of course, a number of synoptic patterns associated with certain types of fire behavior (Schroeder 1969), but there is no clearcut evidence that links them with flatland fire-whirlwind formation.

It may be valuable to try to determine why fire whirlwinds did not develop at the Virginia prescribed burn. Air temperature was high at Virginia and relative humidity was much lower than it was in all other cases, although these do not appear to be important variables. Skies were clear. The lapse rate was autoconvective in the lowest layer, the only instance when this occurred in these case studies. Perhaps if the lapse rate over the region is too steep, it could suppress development. Resultant convective activity with its attendant momentum transfer might, in some cases, inhibit the formation of a generating eddy. However, if we disregard this possibility, there are three remaining features to examine: the intensity and acreage of the burn, and the windspeed. As Countryman (1964) points out, it is not known how much fire area and heat production are necessary to generate vortices. In his field tests of mass fire, however, he produced fire whirlwinds on test plots covering less than 100 square feet. The Virginia burn was intense, yet no whirlwinds formed. Thus, size and intensity do not appear to be controlling factors here. We are apparently left with the probability that gusty surface winds did not allow a generating eddy to form. The heat sink was sufficiently strong, however, to allow brief whirls to appear occasionally in the main fire column.

From case studies examined, it would seem that optimum conditions for development of flat-terrain, fire whirlwinds should include the following:

1. A fire of sufficient acreage and intensity to create the heat source. Methods of burning are also important as they determine total heat production as well as vorticity generation. Interestingly, Countryman (1969) found that too great a fire intensity may prevent fire-whirl formations because of turbulence. Most of the vortices he observed formed in the later stages of a fire.

2. A superadiabatic lapse rate through the lower 300 to 400 feet with a lapse near the dry adiabatic for 2,000 to 5,000 feet above, or just a deeper, lower layer containing a superadiabatic or perhaps even a dry adiabatic lapse rate.

3. Little or no wind; the fire produces enough air movement to start a generating eddy.

4. Clear skies. Although fire whirlwinds have occurred under overcast conditions and even at night, clear skies are optimum.

How often are these conditions met at a given location in the Midwest? To answer this question, late-afternoon, upper-air soundings were examined (from St. Cloud, Minnesota) for each day during the period July 1 to August 31, 1965-1969. All of the information was taken from form WBAN-31A, the adiabatic chart. Minimum criteria were set at:

1. A ground layer, superadiabatic lapse of any depth or strength, or a dry adiabatic lapse rate to at least 860 mb.

2. Winds of 3 meters per second or less (6.7 m.p.h.).

3. Opaque cloudiness less than 4/10.

Of the 310 days involved in the study, 253 days or 81 percent had lapse rates that qualified. A dry adiabatic lapse to at least 860 mb. occurred on only 7 days, so all others had low-level, superadiabatic conditions. The following tabulation gives the percentage of afternoons that a superadiabatic lapse rate exists to various heights above the surface (this height usually represents the top of the strongest superadiabatic layer in the atmosphere):

Height above surface (feet)	*Percent of afternoons*
None	21
240 to 300	20
300 to 400	20
400 to 500	12
500 to 600	8
600 to 1,000	7
Greater than 1,000	12

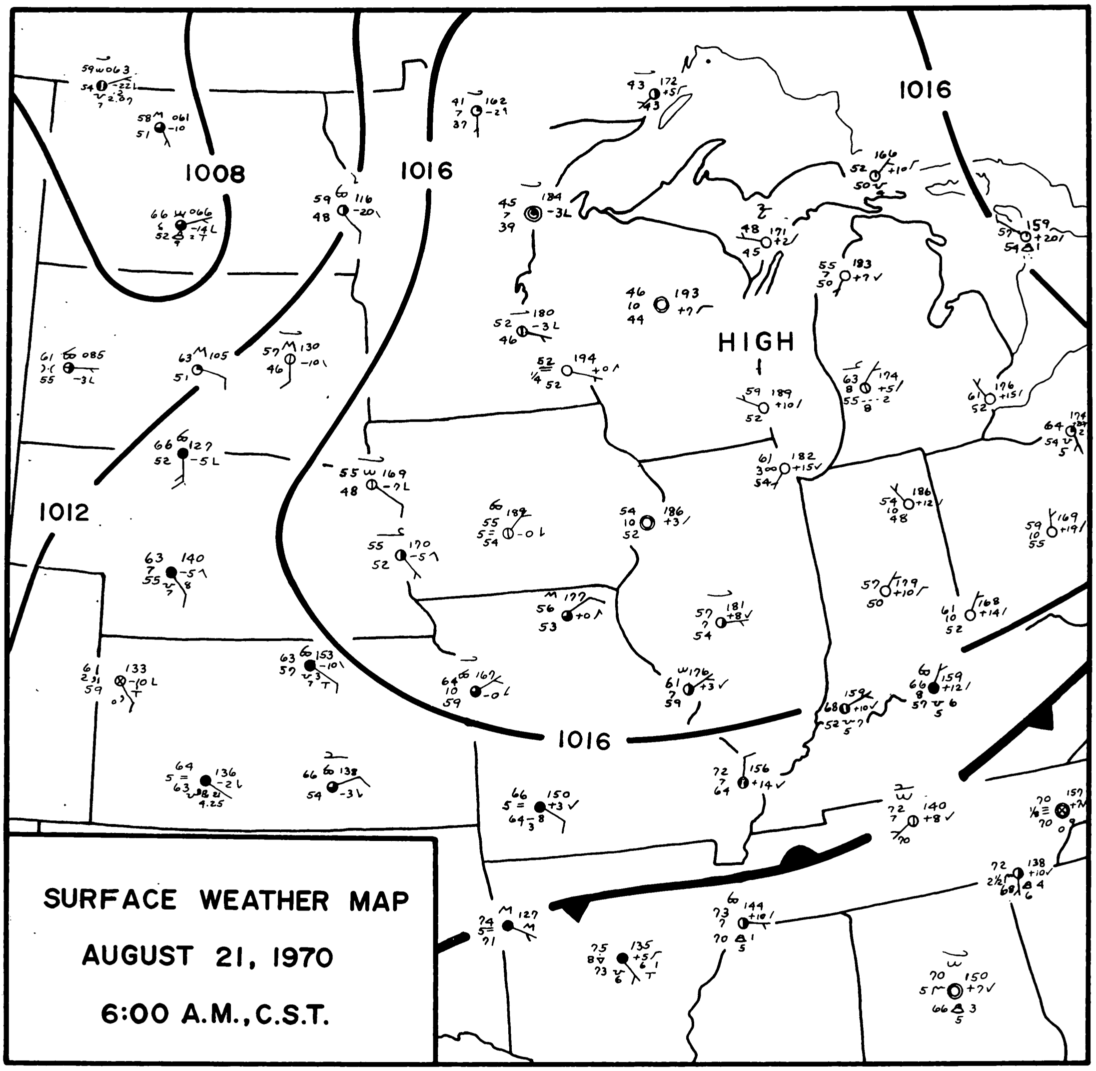

Figure 6.—Morning synoptic features on the day of the Necedah fire whirlwind. Weather symbols and analysis were taken from the Daily Weather Map series of the U.S. Department of Commerce.

Under the opaque cloudiness guidelines, 60 percent of the days were favorable. Interestingly, only 24 percent of the afternoons had favorable windspeeds. The tabulation below shows frequency of occurrence of surface windspeeds during the afternoon upper-air release, July and August 1965-1969.

Windspeed (Meters per second)	*Frequency of occurrence (Percent)*
1	2
2	7
3	15
4	19
5	24
6	10
7	11
8	6
9	2
10	3
11	1

In all, even with generous guidelines, only 32 days or 10 percent of the total had conditions that might favor fire-whirlwind development. This probably is a maximum estimate, because not all of the included lapse rates were sufficiently strong to produce low-level overturning, and winds of 6.7 m.p.h. are probably too high to allow flatland fire-whirlwind development. They were included to this velocity because Simard (1969) has shown that in Canada the average forestry station to airport windspeed ratio varies between 0.26 and 0.66. Also, it is important to remember that vegetative and fuel conditions were not considered in this analysis. If the fuels will not burn, winds, clouds, and temperature lapse rates are of no concern.

SUMMARY

Assuming that fuels are in a receptive state, fire-whirlwind genesis over flat terrain requires (1) a low-layer, superadiabatic lapse rate, (2) little or no wind, and (3) for optimum conditions, clear skies. Weather data from St. Cloud, Minnesota, show only a small percentage of days that fulfill these requirements (less than 10 percent).

In fighting fires on days with fire-whirlwind formation, igniting an additional area or perimeter as a control measure or to widen a fireline may be hazardous. Adding more fire to the danger area increases the possibility of fire-whirlwind occurrence. Vortices have crossed burning firelines with spectacular results, often picking up firebrands and throwing them over wide areas. The possibility of control by using water in the form of a spray or stream is an intriguing idea but requires testing. It would be especially interesting to observe the effects of a plane making a water drop on a fire whirlwind. At this point there is no way to predict the results. Therefore, when confronted with fire whirlwinds, about the only thing one can do is wait for the activity to subside, then move in as quickly as possible to control spot fires.

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