TORNADO

U.S.
DEPARTMENT
OF
COMMERCE
National
Oceanic and
Atmospheric
Administration

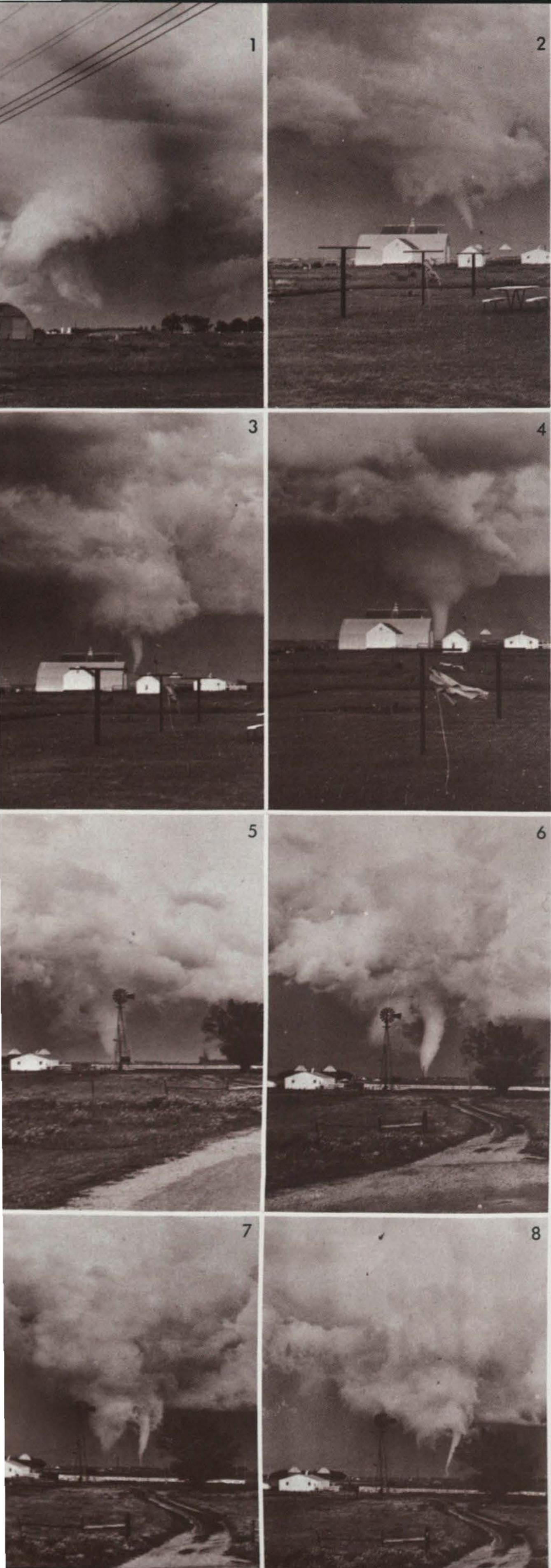
Of all the winds that sweep this planet's surface, tornadoes are the most violent.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

Their time on earth is short, and their destructive paths are rather small. But the march of these shortlived, local storms through populated areas leaves a path of terrible destruction. In seconds, a tornado can transform a thriving street into a ruin, and hope into despair.

It is the business of NOAA, the U. S. Commerce Department's National Oceanic and Atmospheric Administration, to lessen the destructive and demoralizing effects of natural catastrophe. The National Weather Service, a major element of NOAA, provides the Nation's first line of defense against destructive atmospheric phenomena. Through its severe storm and tornado watches and warnings, the National Weather Service gives persons in threatened areas time to find shelter.

This booklet is part of that warning service. It tells what tornadoes are, when and where they occur, how they produce their destructive effects, what they look like, and what to do when threatened by tornadoes.



Life cycle of a tornado. *From a thunderstorm cloud formation (1), a tornado funnel forms (2) and starts toward the surface (3), then lifts and almost disappears before descending to earth (4). The same funnel lifts once more (5), then descends, as a second funnel begins to form (behind windmill, 6); the second funnel becomes better defined (7), then dissipates as the main funnel begins to lengthen (8) and finally disappears.*
(Photographs by Willis Wipf, near Freeman, South Dakota, June 1, 1965)

TORNADOES are local storms of short duration formed of winds rotating at very high speeds, usually in a counter-clockwise direction. These storms are visible as a vortex, a whirlpool structure of winds rotating about a hollow cavity in which centrifugal forces produce a partial vacuum. As condensation occurs around the vortex, a pale cloud appears—the familiar and frightening tornado funnel. Air surrounding the funnel is also part of the tornado vortex; as the storm moves along the ground, this outer ring of rotating winds becomes dark with dust and debris, which may eventually darken the entire funnel.

These small, severe storms form several thousand feet above the earth's surface, usually during warm, humid, unsettled weather, and usually in conjunction with a severe thunderstorm. Sometimes a series of two or more tornadoes is associated with a parent thunderstorm. As the thunderstorm moves, tornadoes may form at intervals along its path, travel for a few miles, and dissipate. The forward speed of tornadoes has been observed to range from almost no motion to 70 miles per hour.

Funnels usually appear as an extension of the dark, heavy cumulonimbus clouds of thunderstorms, and stretch downward toward the ground. Some never reach the surface; others touch and rise again.

On the average, tornado paths are only a quarter of a mile wide and seldom more than 16 miles long. But there have been spectacular instances in which tornadoes have caused heavy destruction along paths more than a mile wide and 300 miles long. A tornado traveled 293 miles across Illinois and Indiana on May 26, 1917, and lasted 7 hours and 20 minutes. Its forward speed was 40 miles an hour, an average figure for tornadoes.

Also see *Spotter's Guide for Identifying and Reporting Severe Local Storms,* for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.

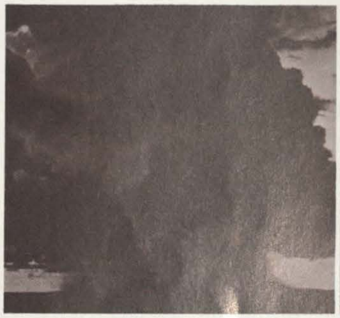
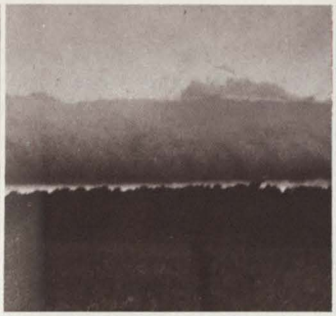
All tornado-like cloud formations are not tornadoes. Recognition of the differences between comparatively harmless meteorological phenomena and tornadoes is an essential part of tornado safety.

Seen at a distance, a rain shower falling from a thunderhead appears as a dark, solid column extending from the cloud base to the ground. From the same distance, a tornado appendage would probably seem narrower, and more distinctly outlined.

An approaching roll-type squall cloud appears to be detached from its parent cloud, and has a slow rolling motion about its horizontal axis. In contrast, a tornado funnel is attached to the parent cloud and rotates about its vertical axis.

As the squall cloud passes overhead, its ragged, windtorn edges are visible from the ground, and detached wisps can be seen moving in arcs to the right or left and up and down. The beginning of a tornado would be seen as a definite, sustained pattern of rotation.

The series of pouches sometimes seen projecting downward from the base of storm clouds consists of individual protuberances of uniform size and shape that have no spinning motion. These cloud forms are seldom seen but are associated with severe squalls and storms.

the look–alikes.... tornadoes and a tornado's many faces



Tornadoes occur over land and water, and may pass from one to the other without much change in appearance. Over water a tornado is called a waterspout (above, left). So-called "fair-weather waterspouts" rise from the water in an upward spiral, do not usually develop into dangerous storms, and diminish rapidly over land. In its early stages, a tornado may appear as a cloud of debris caught up by the tornado vortex (above, center). As more debris is brought into the vortex, the tornado funnel darkens in color. Tornadoes do not always occur singly, as when two are generated within a single thunderstorm cloud system (above, right).

THERMAL

Tornado formation is the result of forces set up by the imbalance created when cool air overrides warm air The imbalance is compensated by rapid upward convection from the lower layers of warm air, which becomes a rotary flow and forms the tornado vortex.

TORNADO FORMATION requires the presence of layers of air with contrasting characteristics of temperature, moisture, density, and wind flow. Complicated energy transformations produce the tornado vortex.

Many theories have been advanced as to the type of energy transformation necessary to generate a tornado, and none has won general acceptance. The two most frequently encountered visualize tornado generation as either the effect of thermally induced rotary circulations, or as the effect of converging rotary winds. Currently, scientists seem to agree that neither process generates tornadoes independently. It is more probable that tornadoes are produced by the combined effects of thermal and mechanical forces, with one or the other force being the stronger generating agent.

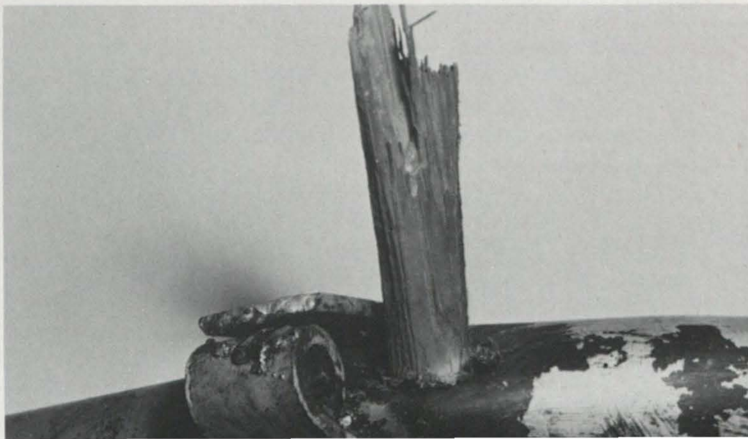
Numerous observations of lightning strokes and a variety of luminous features in and around tornado funnels have led scientists to speculate about the relationship between tornado formation and thunderstorm electrification. This hypothesis explores the alternative possibilities that atmospheric electricity accelerates rotary winds to tornado velocities, or that those high-speed rotary winds generate large electrical charges. Here, as in most attempts to understand complex atmospheric relationships, the reach of theory exceeds the grasp of proof.

MECHANICAL

Slowly rotating air currents are constrained by external forces. As the radius of rotation lessens, the speed of rotation increases, in the same way that an ice skater increases his speed of rotation by drawing in his arms. Ultimately, these converging, accelerating, rotary winds set up the tornado vortex.

Also see *Thunderstorms* and *Lightning,* both for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.

THE WORK OF WIND AND PRESSURE. As tornado-velocity winds rip at the exterior of a house, the air inside the house expands explosively into the near-vacuum of the tornado vortex. The combined effects of wind and vacuum produce the near-total destruction of a tornado's progress through populated areas.



If there is some question as to the causes of tornadoes, there is none on the destructive effects of these violent storms. The dark funnel of a tornado can destroy solid buildings, make a deadly missile of a piece of straw, uproot large trees, and hurl people and animals for hundreds of yards. In 1931, a tornado in Minnesota carried an 83-ton railroad coach and its 117 passengers 80 feet through the air, and dropped them in a ditch.

Tornadoes do their destructive work through the combined action of their strong rotary winds and the partial vacuum in the center of the vortex. As a tornado passes over a building, the winds twist and rip at the outside at the same time that the abrupt pressure reduction in the tornado's "eye" causes explosive overpressures inside the building. Walls collapse or topple outward, windows explode, and the debris of this destruction is driven through the air in a dangerous barrage. Heavy objects like machinery and railroad cars are lifted and carried by the wind for considerable distances.

Where there is such complete destruction there is usually also loss of life. On April 11, 1965, Palm Sunday, 37 tornadoes struck the midwest, killing 271 persons and injuring more than 5,000; property damage was estimated at $300 million. Since the early 1950's, the tornado death toll has averaged about 120 per year.

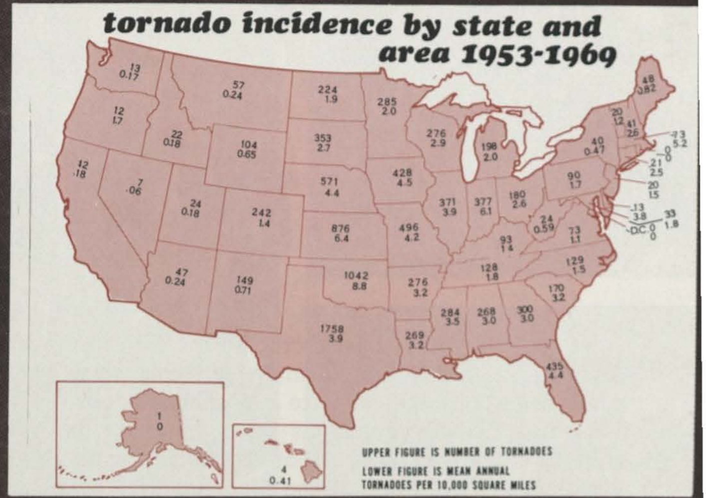
TORNADOES OCCUR in many parts of the world and in all 50 states. But no area is more favorable to their formation than the continental plains of North America, and no season is free of them. Normally, the number of tornadoes is at its lowest in the United States during December and January, and at its peak in May. The months of greatest total frequency are April, May, and June.

In February, when tornado frequency begins to increase, the center of maximum frequency lies over the central Gulf States. Then, during March, this center moves eastward to the southeast Atlantic states, where tornado frequency reaches a peak in April. During May, the center of maximum frequency moves to the southern plains states, and in June, northward to the northern plains and Great Lakes area as far east as western New York state. The reason for this drift is the increasing penetration of warm, moist air while contrasting cool, dry air still surges in from the north and northwest; tornadoes are generated with greatest frequency where these air masses wage their wars. Thus, when the Gulf states are substantially "occupied" by warm air systems after May, there is no cold air intrusion to speak of, and tornado frequency drops. This is the case across the Nation after June. Winter cooling permits fewer and fewer encounters between warm and overriding cold systems, and tornado frequency returns to its lowest level by December.

The mathematical chance that a specific location will be struck by a tornado in any one year is quite small. For example, the probability of a tornado striking a given point in the area most frequently subject to tornadoes is 0.0363, or about once in 250 years. In the far western states, the probability is close to zero.

But tornadoes have provided many unmathematical exceptions. Oklahoma City has been struck by tornadoes 26 times since 1892. Baldwyn, Mississippi, was struck twice by tornadoes during a 25-minute period on March 16, 1942. A third of Irving, Kansas, was left in ruins by two tornadoes which occurred 45 minutes apart on May 30, 1879. Austin, Texas, had two tornadoes in rapid succession on May 4, 1922; and Codell, Kansas, was struck three times in 1916, 1917, and 1918—on May 20.

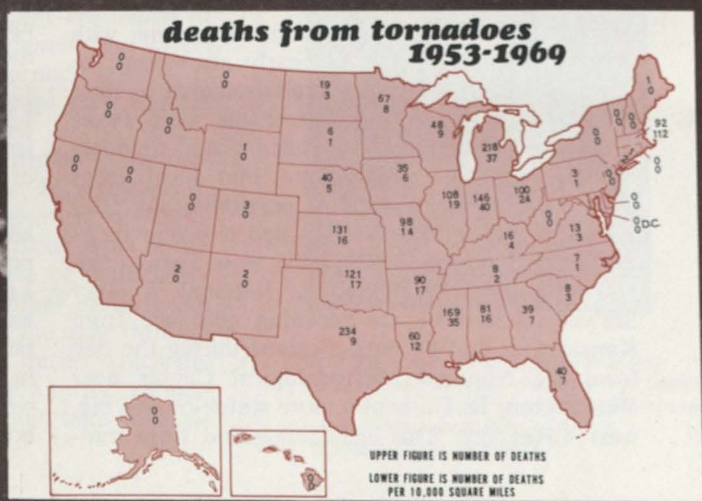
See also *Severe Local Storm Warning Service* (and *Tornado Statistics*, 1953-1969), for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.



During the period 1953-1969, an average of 642 tornadoes per year occurred in the United States, about half of them during three months—April, May, and June. For the same period, the annual average number of tornado days—days on which one or more tornades were reported—was 159. Average annual frequency by states for this period ranges from 103 tornadoes in Texas to less than three in most of the northeastern and far western states.

Tornadoes may occur at any hour of the day or night, but, because of the meteorological combinations which create them, they form most readily during the warmest hours of the day. The greatest number of tornadoes—82 percent of the total—occurs between noon and midnight, and the greatest single concentration—23 percent of total tornado activity—falls between 4 and 6 p.m.

The maps on this page show tornado incidence by state and area (above) and tornado-caused deaths by state and area (below) for the period 1953 through 1969. Figures are based on information from NOAA's Environmental Data Service.



the work of warning

At NOAA's National Severe Storms Forecast Center, Kansas City, Mo., Commerce Department weathermen constantly analyze atmospheric conditions over the 48 contiguous states in order to keep the country as far ahead of destructive events as possible. This work of the National Weather Service goes on around the clock, seven days a week.

It is not possible to predict the exact time of occurrence of tornadoes, or where they will strike; however, it is possible to identify areas approximately 100 miles wide and 250 miles long in which weather conditions suggest a high probability of tornado generation. Then, local offices of the National Weather Service, working with SKYWARN spotter networks, law enforcement agencies and other emergency forces, detect and track severe storms and tornadoes, and issue timely warning.

On May 11, 1970, for example, the combined action of the Kansas City unit and the Lubbock, Texas, office of the National Weather Service provided enough warning to keep a particularly violent tornado from taking as large a toll in life as it did in property. That morning, attention at the Kansas City severe local storms facility focused on atmospheric conditions over the high west Texas plains; at 10 am, CDT, an earlier convective outlook—a forecast of weather-making vertical motion in the lower atmosphere—was amended to include isolated thunderstorms with large hail for that area. By early afternoon, the severe-storms forecasters had advised area weather stations that the air mass over the west Texas high country was unstable, that isolated thunderstorms would be severe, and that local areas should be monitored for this possibility. At 8:40 p.m., the Kansas City unit issued a severe thunderstorm watch bulletin for the west Texas area.

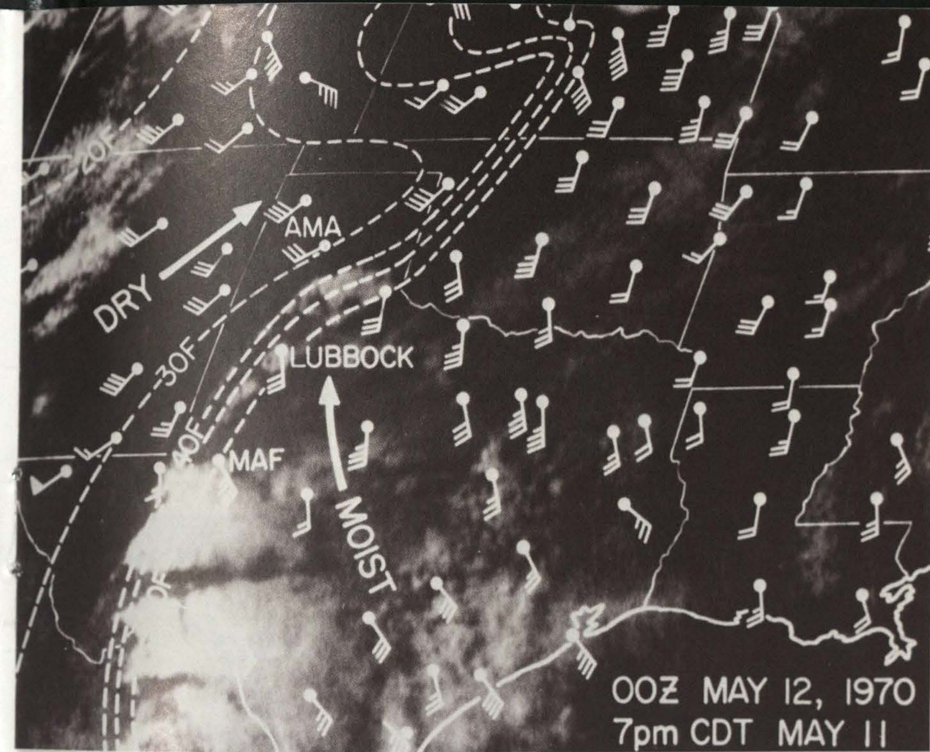
The Lubbock office of the National Weather Service, alerted by the morning guidance from Kansas City and by data received during the day from the National Meteorological Center near Washington, D. C., kept a close watch on the big, west Texas sky. This alert intensified from mid-afternoon onwards, for these are the peak hours for tornado formation. By 6 p.m., towering cumulus clouds in the area indicated increasing atmospheric instability. Not quite an hour later, the local-use radar picked up a moderate thunderstorm five miles south of the city. Continuous monitoring of the radar scope over the following hours, and close coordination with the larger WSR-57 radar at the Amarillo weather station, indicated area thunderstorms were intensifying rapidly.

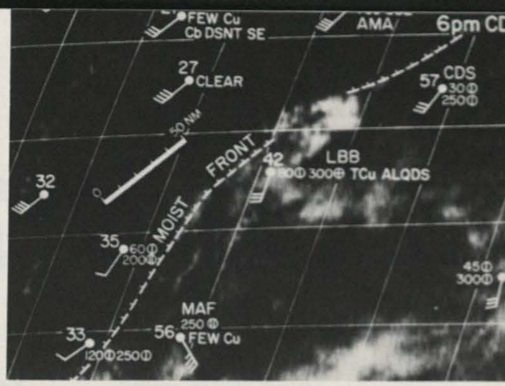
A severe thunderstorm warning was issued at 7:50 p.m. Local radio stations began broadcasting the warning message minutes later. At 8:08 a message was transmitted covering eggsize hail reported south of the city and reaffirming the severe thunderstorm warning. At 8:10, a similar statement advised of grapefruit-size hail five miles south of the city; the warning was repeated. At 8:15 p.m., after Lubbock radar had picked up a hook echo seven miles southeast of the airport, moving northeastward, a tornado warning bulletin was issued.

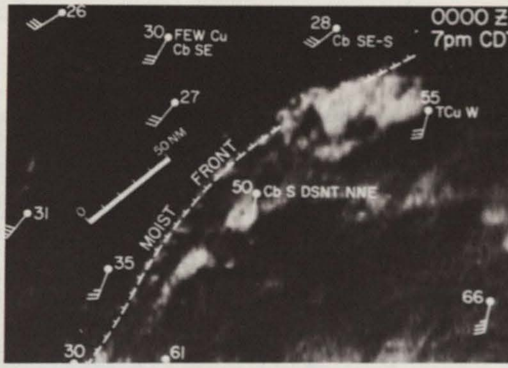
As the thunderstorms moved across the plains, the warnings were extended to cover areas in their path. Then, near 9 p.m., radar picked up another tornado indication, and a report of a funnel cloud came in. Warnings were repeated during the next half hour, even as the tornado touched down in the city at 9:35, and until the approaching funnel made the Lubbock weathermen take cover.

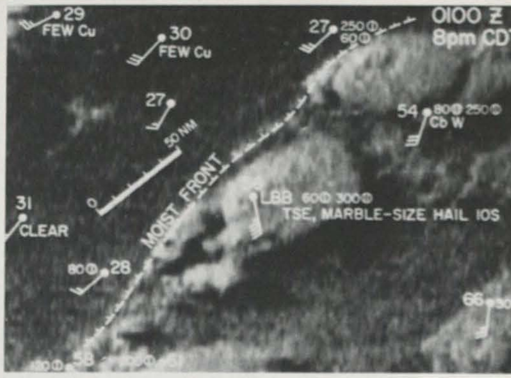
The tornado killed 27 persons and injured 1,500 along its 8½-mile track. It wiped out 1,040 family units and damaged 8,876 more. Estimates of property damage exceeded $125 million.

Lubbock lies in the heart of tornado country, and the violent storms of spring and summer are part of life on the high plains. The wonder of the Lubbock disaster of May 11 was not that the city had been struck by a tornado, or that there had been casualties, but that there had been so few in a city of 150,000. NOAA's work of timely warning, and the tornado-consciousness of Lubbock's citizens, made the difference.







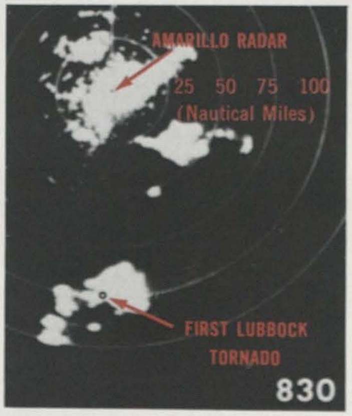


Photos from earth-synchronous ATS-3, marking time 22,300 miles above the equator, provide backdrop for description of atmospheric events which led to Lubbock tornadoes of May 11, 1970. (LBB = Lubbock, AMA = Amarillo; numbers by stations indicate Fahrenheit surface temperatures, arrows indicate wind velocity; Z times are Greenwich).

TORNADO WATCHES are alerting messages between the National Severe Storms Forecast Center and areas potentially threatened by tornadoes. They specify the area covered by the watch, and establish a period of time during which tornado probabilities are expected to be dangerously high. Watches are teletyped directly to local offices of the National Weather Service and disseminated to the general public via radio and television stations in and around endangered areas. Law enforcement officers, emergency forces, volunteer storm reporters, and other cooperating personnel are also alerted by the watches, and they relay the alert to others in the watch area.

Tornado watches are not tornado warnings. They are issued to alert persons to the possibility of tornado development in a specified area, for a specified period of time. Until a tornado warning is issued, persons in watch areas should not interrupt their normal routines except to watch for threatening weather.

TORNADO WARNINGS are issued when a tornado has actually been sighted in the area or indicated by radar. In many cases, warnings are made possible through the cooperation of SKYWARN volunteers and other public-spirited persons who notify the nearest office of the National Weather Service or community warning center when a tornado is sighted. Warnings indicate the location of the tornado at the time of detection, the area through which it is expected to move, and the time period during which the tornado will move through the area warned. When a tornado warning is issued, persons in the path of the storm should take immediate safety precautions.



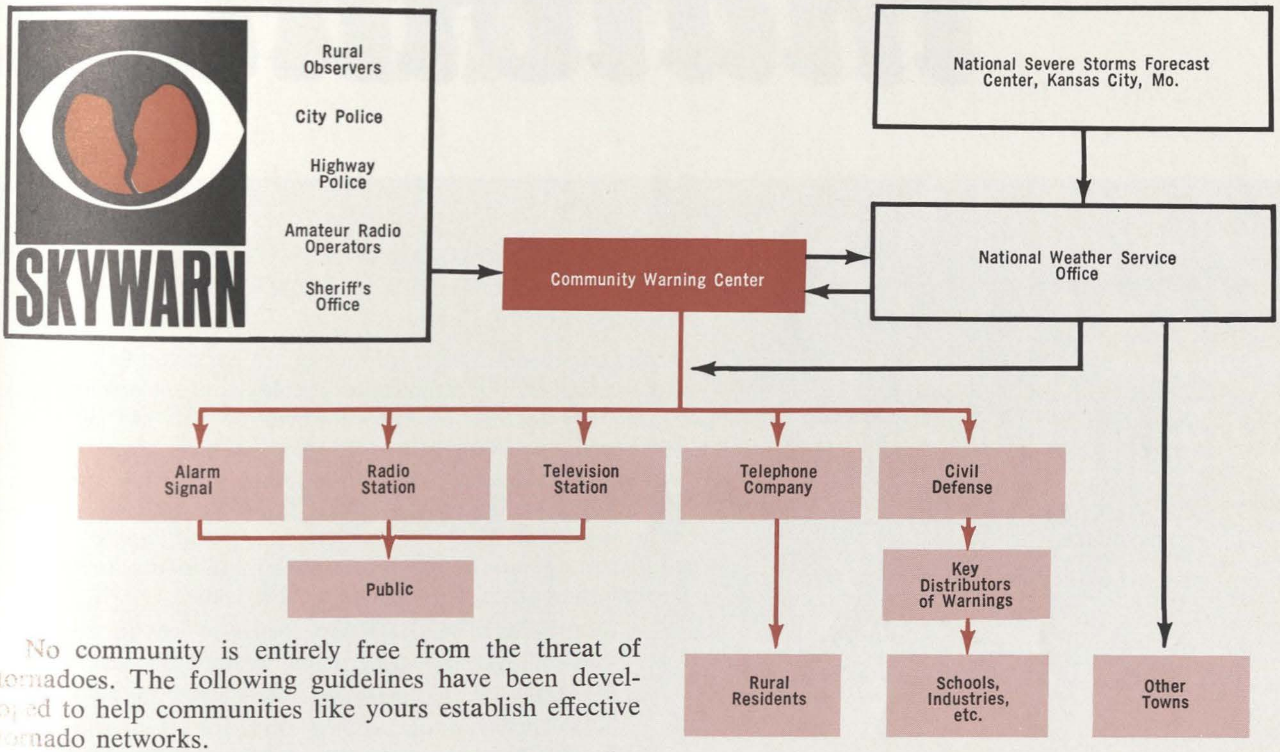
Also see *Severe Local Storms Warning Service (and Tornado Statistics, 1953-1969)*, for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.

community action

Because the destructive effects of a tornado are sually concentrated in a relatively small area, uch of the burden of warning, evacuation, and elter falls to communities and individual citizens. ornado detection requires a dense network of orm reporters and a reporting procedure within ch tornado watch area. The National Weather rvice receives help from nearly 500 local SKY-ARN networks, and could use the help of many ore.

Each network is organized around the needs the area being served. In some locations, adrants of trained observers stationed about o miles apart are established around the popu-ion center to be protected, with the heaviest ncentration of observers to the southwest. In er areas with small populations, everyone is part of the network, and anyone who sees a tornado reports it promptly to the nearest office of the National Weather Service. Nationwide, these networks are made up of thousands of public-spirited citizens and organizations. The only compensation received by SKYWARN volunteers is the certain knowledge that their work saves lives each season. They are the backbone of the tornado warning service.

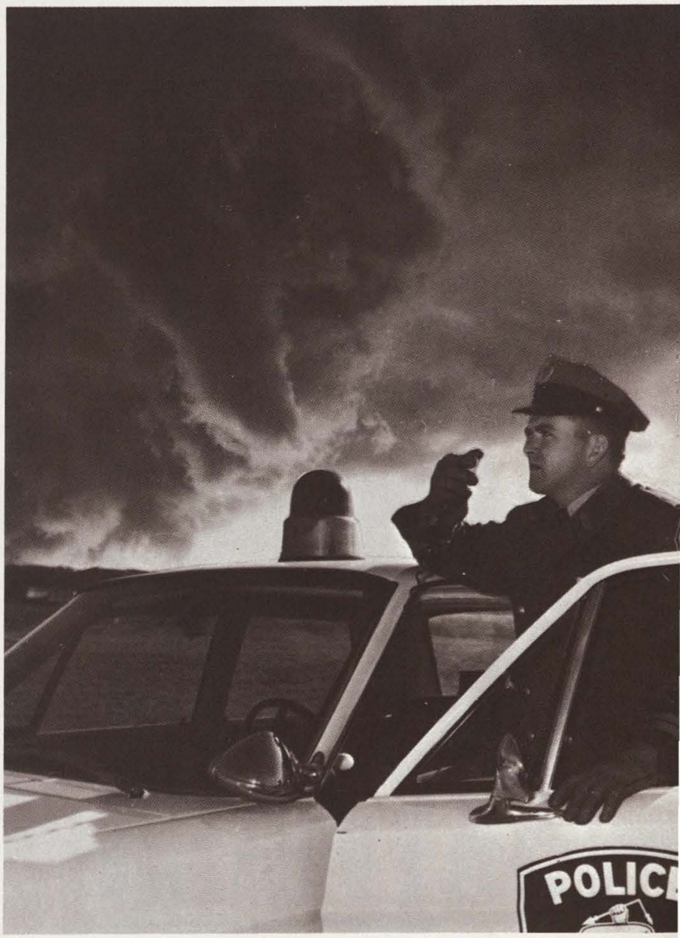
SKYWARN observers and the public are alerted to the possibility of dangerous weather by the watches issued by the National Weather Service. When a watch is in effect, observers are alerted to notify the nearest office of the National Weather Service as soon as a tornado is sighted, describing the type of storm, its location, intensity, and direction of movement.



No community is entirely free from the threat of tornadoes. The following guidelines have been developed to help communities like yours establish effective tornado networks.

1. Set up a community warning center. This is an office that is open at all times—like the police station or telephone exchange—to receive National Weather Service watches and warnings. The community warning center also receives reports of approaching tornadoes from local observers, and issues local warnings. When a tornado is sighted, the warning center notifies nearby towns in the path of the tornado, and telephones the nearest office of the National Weather Service so that other areas can be warned.
2. Set up a SKYWARN observer network. Everyone living within 20 miles of the community warning center should understand that he should promptly report any observed tornado to the community warning center.
3. Set up warning signals. When a tornado is reported locally, a prearranged alarm is sounded. This can be the city fire alarm or Civil Defense siren. Farmers in threatened areas are warned by telephone, and radio and television stations broadcast the alarm.
4. Keep the system functional. Trial runs and public reminders should be made at regular intervals, to ensure a trained, efficient unit.

A community warning network cannot be completely effective, despite all efforts to improve its coverage and response time. There is always the chance that a tornado will not be detected or that a report will not get through to the National Weather Service. Nevertheless, a community warning network will go a long way toward protecting you and your fellow-citizens during tornado emergencies.



individual

tornado safety rules

WHEN A TORNADO APPROACHES, IMMEDIATE ACTION CAN SAVE YOUR LIFE!

A tornado watch means tornadoes are expected to develop. Keep a battery-operated radio or television set nearby, and listen for weather advisories—even if the sky is blue. A tornado warning means a tornado has actually been sighted or indicated by weather radar. Seek inside shelter (in a storm cellar or reinforced building) and stay away from windows. Curl up so that your head and eyes are protected. Keep a battery-operated radio or television nearby, and listen for further advisories.

IN OFFICE BUILDINGS, go to an interior hallway on the lowest floor, or to the designated shelter area.

IN HOMES, the basement offers the greatest safety. Seek shelter under sturdy furniture if possible. In homes without basements, take cover in the center part of the house, on the lowest floor, in a small room such as a closet or bathroom, or under sturdy furniture. Keep some windows open, but stay away from them.

IN SHOPPING CENTERS, go to a designated shelter area (**not** to your parked car).

IN SCHOOLS, follow advance plans to an interior hallway on the lowest floor. If the building is not of reinforced construction, go to a nearby one that is, or take cover outside on low, protected ground. Stay out of auditoriums, gymnasiums, and other structures with wide, free-span roofs.

IN OPEN COUNTRY, move away from the tornado's path at right angles. If there is not time to escape, lie flat in the nearest ditch or ravine.

MOBILE HOMES are particularly vulnerable to overturning during strong winds and should be evacuated when strong winds are forecast. Damage can be minimized by securing trailers with cables anchored in concrete footing. Trailer parks should have a community storm shelter and a warden to monitor broadcasts throughout the severe storm emergency. If there is no shelter nearby, leave the trailer park and take cover on low, protected ground.

TORNADOES ARE ONLY ONE OF A THUNDERSTORM'S KILLERS.

LIGHTNING IS THE WORST KILLER. Stay indoors and away from electrical appliances while the storm is overhead. If you are caught outside, stay away from and lower than high, conductive objects.

THUNDERSTORM RAINS cause flash floods. Be careful where you take shelter.

SKYWARN

action

constructing a cellar

IN parts of the country where tornadoes are comparatively frequent, a form of shelter is vital for protection from tornadoes. The shelter may never be needed; but during a tornado emergency, it can be worth many times the effort and cost of preparing it. One of the safest tornado shelters is an underground excavation, known as a storm cellar.

LOCATION
When possible, the storm cellar should be located outside and near the residence, but not so close that falling walls or debris could block the exit. If there is a rise in the ground, the cellar may be dug into it to make use of the rise for protection. The cellar should not be connected in any way with house drains, cesspools, or sewer and gas pipes.

SIZE
The size of the shelter depends on the number of persons to be accommodated and the storage needs. A structure 8 feet long by 6 feet wide and 7 feet high will protect eight people for a short time and provide limited storage space.

MATERIAL
Reinforced concrete is the best material for a tornado shelter. Other suitable building materials include split logs, 2-inch planks (treated with creosote and covered with tar paper), cinder block, hollow tile, and brick. The roof should be covered with a 3-foot mound of well-pounded dirt, sloped to divert surface water. The entrance door should be of heavy construction, hinged to open inward.

DRAINAGE
The floor should slope to a drainage outlet if the terrain permits. If not, a dry well can be dug. An outside drain is better, because it will aid ventilation.

VENTILATION
A vertical ventilating shaft about 1 foot square can extend from near the floor level through the ceiling. This can be converted into an emergency escape hatch if the opening through the ceiling is made 2 feet square and the 1-foot shaft below is made easily removable. Slat gratings of heavy wood on the floor also will improve air circulation.

EMERGENCY EQUIPMENT
A lantern and tools—crowbar, pick, shovel, hammer, pliers, screwdriver—should be stored in the cellar to ensure escape if cellar exits are blocked by debris. Stored metal tools should be greased to prevent rusting.

U. S. GOVERNMENT PRINTING OFFICE : 1971 O - 412-719

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402—Price 30 cents
NOAA/PI 70007 1970