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Arizona "Eddy" Tornadoes

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NATIONAL WEATHER SERVICE

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WESTERN REGION
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ARIZONA "EDDY" TORNADOES

The number of tornadoes and funnel clouds reported in Arizona per year has increased dramatically in the past 10 years--from 1 in 1963 to 20 in 1972. This increase is not believed to be related to changing meteorological conditions, but to other factors such as:

1. Increase in population;
2. Increase in public awareness due to disaster publicity;
3. Over-reaction due to the 1971 tornado in Tempe, and
4. The fact that not all localized circular storms are true tornadoes.

In the past 90 years, according to Court [4], tornado incidence in the United States has been mapped more than 40 times, but in so many different ways that few pairs of maps are directly comparable! Nonetheless, a study of these maps shows the chronological progress of settlements westward associated with an increase in tornado incidence! In two of these mappings prepared by the U. S. Army Signal Service in 1888, for example, and both presented by Court, tornadoes west of the Rocky Mountains are indicated respectively as zero and "practically unknown". Yet the earliest reported "tornado" in Arizona occurred in Phoenix on June 12, 1883, when a "whirlwind" struck the Herrick and Luhrs Shop. In the period prior to 1910, there have been other occasional historical references made to "tornadoes", "whirlwinds", and "twisters", so their occurrence in Arizona is not new, especially when the population density (the people available to observe tornadoes) of territorial days is considered. In 1910, the population density was 1.8 persons per square mile; but by 1972 it had risen to 15.6 persons per square mile!

As early as 1856, Blodget wrote that tornadoes "...*occur over every part of the United States where the rainfall is abundant, and at the seasons of its greatest abundance*". Although rainfall is not really abundant in Arizona, the summer season of June, July, August, and September is the wettest of the two precipitation seasons, the other being the winter season of December, January, and February. Over the past 10 years, 75% of the reported tornadoes and funnel clouds have occurred in those summer months.

With the advent of radio news in the 1920s and of television presentations in the 1940s, the public became more and more aware of the destructive ferocity of tornadoes. Little attempt was made, however, to forecast tornadoes until after the end of World War II, when radar assisted the meteorologist greatly in pinpointing the existence and probability of tornadoes; and when increased understanding of the mechanisms of tornadoes resulted in warnings being issued in advance of the development of these storms. Through the public issuances of tornadoe watches and warnings by the Severe Local Storms Forecast Office which was established in 1952 in Kansas City, more people were being made aware of tornadoes and what to do should such a storm be sighted.

However, Arizona because of its low population density still did not report many tornadoes. As late as 1958, Flora [5] said, *"Arizona may be considered to be well out of the tornado area of the country even though it reported sixteen of these storms in 37.5 years. No deaths resulted and property loss amounted to only $2,590"*. Rechecking the records showed that one death actually resulted from a tornado in Glendale on August 19, 1921. But, since 1959 when statistics on severe storms began being kept on a formal basis (STORM DATA [13], Environmental Data Service), the tornado losses in Arizona can be conservatively estimated at over $10 million but only one fatality. Part of this tremendous increase must be attributed,of course, to economic inflation; but at the same time Arizona's population has increased from 749,587 in 1950 to 1,925,000 in 1972 (Arizona Statistical Review [1]). There were more people to report tornadoes and there was more home and industrial development to damage!

Ernie Pyle was supposed to have said that war was that which was five feet on one side of you and five feet on the other (McLuckie [11]). People in Arizona had been rather apathetic about tornado occurrences prior to 1971 because not much damage had really been done and there had been no dramatic loss of life. They had seen and reported funnel clouds and had seen dust devils out over the open desert; but these sightings were looked on as novel and picturesque, rather than something of concern. Even the twenty-seven percent or more of the people moving into Arizona in 1971 (ASR), who came from the "tornado belt" of the Midwest largely ignored Arizona twisters as being "unreal".

Then on August 30, 1971, a tornado struck Tempe, which with accompanying strong winds injured 41 people and caused about $1 million damage. Pyle's "War" that had been five feet to the side had arrived. Tornado reports increased from 5 statewide in 1970 to 20 in 1972. But were they all real, genuine tornadoes?

Court [4] quotes Dr. Gustavus Hinrichs (1888-1889), founder and director of the Iowa Weather Service, who complained:

> *"The climate of Iowa has been most outrageously maligned both by thoughtless or sensational newspaper correspondents and by official and semiofficial publications of the Signal Service in ascribing to Iowa an excessive tornado frequency. Both of these ever-grinding tornado mills for Iowa have furnished abundant material for frightening people from settling in Iowa, and for coaxing residents of Iowa into the thriving tornado insurance institutions of both the East and the West".*

Dr. Hinrichs may well have stated Arizona's problem today as the frequency of public tornado and funnel cloud sightings increases.

During the summer season as moisture of the Summer Monsoon increases over Arizona, thunderstorms do increase in frequency. During July and August, thunderstorms occur in Arizona about 25 days each month, mostly along the Mogollon Rim.

A thunderstorm is a chaotic mass of clouds resulting from violent vertical motions of moist air. Cloud elements in these storms often can be seen to be moving in various horizontal directions, up and down, and even rotating in circles. Sometimes these cloud elements seem to protrude downward from the base of the storm and look like a funnel. Concentrated shafts of heavy rain or hail falling from the cloud often give the appearance of funnel clouds. But rarely in Arizona do rotating funnel clouds dip to the ground out of these clouds to form true tornadoes; i.e., tornadoes generated within or associated with the cumulonimbus cloud itself.

Thunderstorms viewed in slow motion represent an exciting display of changing forms. In their mature stages a cap of feathery ice-crystal cirrus or a broad shelf of thick cirrus develops and extends in the direction of the storm's movement. These thunderstorm tops over Arizona during the summer can reach altitudes in excess of 50,000 feet which is well into the stratosphere and above the levels flown by commercial aircraft. Major Ernest Shuler, Forecaster, Detachment 15, 5th Weather Wing, Luke AFB, has said it is not unusual for Air Force radars at Luke and Davis-Monthan AFBs to detect thunderstorm tops during the summer to 65,000 feet.

It is a rule of thumb that the higher the tops the more severe is the storm (Weather Radar Manual [12]). These severe storms can build to such heights in a matter of minutes. For example, on the morning of June 22, 1972, a small family of thunderstorms approached Phoenix from the southwest. These storms had tops of 43,000 feet reported by the Luke AFB radar at 0620M. At 0650M, 30 minutes later, Luke reported these tops to be above 57,000 feet! This particular storm moved across central sections of the city, dropping upwards of 5 inches of rain and causing extensive localized flooding.

An unpublished study by H. T. May [10] of the Weather Service's Radar Unit in Albuquerque, New Mexico, contains the following Summary of Aircraft Top Reports in July and August 1972 over Arizona and New Mexico:

Altitude Thousands of Feet	Number of Tops Reported	Percent of Total
Below 31	0	0
31-33	18	4
34-36	31	7
34-36	54	13
37-39	118	28
40-42	106	25
43-45	74	18
46-48	7	2
49-51	8	2
Above 51	3	1

Average daily maximum top July 1972 - 46,000 feet.

Average daily maximum top August 1972 - 43,000 feet.

At least 23% of these reported tops were probably in the stratosphere, and 3% reached 50,000 feet or higher.

Thunderstorms whose tops build to 50,000 feet or more during the summer are capable of producing very strong straight-line winds in addition to spawning true tornadoes such as occur in the middle West and South (Weather Radar Manual [12]). The most notable tornado reported in Arizona recently was the Tempe Tornado of August 30, 1971. Two days later, September 1, 1971, another true tornado moved 45 miles down the relatively flat Santa Cruz Valley from near Casa Grande to Mesa. No major damage was done, but this storm had the distinction resulting in the National Weather Service Office in Phoenix issuing its first tornado warning. However, this type of true tornado is believed to be rare in the state as the providential roughness of Arizona's terrain breaks up most tornadoes before they can strike an inhabited area.

To an unexperienced observer of the phenomena, dust devils sometimes have the appearance of tornadoes when their cores reach upward to 1,000 feet or more and are partially immersed in wells of dust (Idso, et al [7]). However, they are usually very localized circulations, caused by extreme instability (when the lapse rate equals or exceeds the autoconvective lapse rate of 3.42°C/100M) of the air close to the earth's surface. This occurs under clear skies due to the intense heating of extremely dry air. Consequently dust devils are rather common during the very hot and very dry pre-monsoon season when skies are mostly clear, as opposed to tornadoes associated with thunderstorms during the monsoon season.

Dust devils can and do cause structural damage and injury. For example, on June 2, 1964, a dust devil destroyed a church under construction in Tucson; and on May 29, 1902, it was reported that a "violent whirlwind" cut a narrow path through Phoenix from the southwest at 3:15 p.m., demolishing a livery stable.

A special type of "dust devil" may be produced in Arizona and in other arid regions associated with thunderstorms that results in them being mistaken for tornadoes. On occasion a small rotating circulation develops in advance of or imbedded in the dust cloud of a thunderstorm downdraft. These circulations have been observed along the leading edge of Arizona's "haboob" duststorms (Idso, et al [7]) that are well in advance of the parent cumulonimbus cloud. These circulations have been dutifully reported as tornadoes by the public; but such "dust devils" are very transient and very localized. They are associated with the extreme turbulence generated by the very sharp temperature discontinuity of the cold outdraft of thunderstorms. In a study of such duststorms passing Phoenix, Ingram [8] found that the average temperature change for these out-draft duststorms was about 13°F, with some as large as 22°F. In effect, these downdrafts form mini-cold fronts which set off dust devils and which have been described by Cooley [3] as whirlwinds.

Most existing municipal building codes have been designed to protect structures against about 75-80 mph winds with about a 10% safety factor to be balanced against the weight of the roof. However, a factor of 50% is generally used against wind overturning a building. Some building codes specifically exempt residences from the design requirements imposed for all other buildings. Herein lies one of our Arizona problems.

During thunderstorms, wind gust velocities in the downdrafts may, in extreme cases, reach 100 mph or more (USDOC: "Aviation Weather" [14]) while the average in Arizona is probably between 30 and 50 mph. A study of over seventy-five thunderstorm-produced duststorms in Phoenix between 1952 and 1971 showed an <u>average</u> wind gust velocity of 42 mph (Ingram [8]). The force of a 100-mile per hour wind on the side of a building according to the American Society of Civil Engineers is itself about 33 lbs/sq. ft. This force, exerted by a straight-line wind, has tremendous destructive potential for structures not built in strict conformance with these building codes. Yet such winds have nothing to do with tornadoes or dust devils. They are caused by strong downdrafts from large thunderstorms. In some cases these downdrafts have been known to fan out for 100 miles from the originating thunderstorm.

Although often referred to as straight-line winds, these winds may occasionally form small-scale circular eddies or vortices when the flow is interrupted by an obstruction. These vortices under certain conditions can appear as tornadoes; however, because they are initiated by mechanical turbulence rather than thermodynamic instability, we would like to hypothesize that they are "eddy tornadoes" and not "true tornadoes". Formation of these sometimes destructive vortices may be likened to the eddies formed downstream from a rock in a fast moving stream of water. In some cases, condensation does form within the vortex or dust is drawn up into the vortex, which extends from the ground to the base of the thunderstorm, giving it all the physical appearance of a tornado funnel. People locally have even referred erroneously to these latter phenomena as "dust devils".

Fujita [6] has divided true tornadoes into five categories ranging from GALE TORNADO (40-72 mph) where some damage is done to chimneys and TV antennae through INCREDIBLE TORNADO (261-318 mph) where whole frame houses are tossed off foundations, automobile-sized missiles are generated and incredible damage can occur. Assuming that the rotational velocities of "eddy tornadoes" can be classified in the lowest Fujita classification of 40 to 72 mph, and the straight-line wind that spawned the eddy is even 50 mph, the combined wind effect could give a total damage effect resembling Fujita's WEAK TORNADO (72-112 mph) classification. Such winds result in surfaces being peeled off roofs, windows being broken, light trailer houses being pushed or overturned, some trees being uprooted or snapped, and automobiles being pushed off the road. Conceivably, with even stronger straight-line winds, damage could simulate Fujita's STRONG TORNADO (113-157 mph) classification where roofs are torn off frame houses leaving only strong upright walls, trailer houses are destroyed, large trees are snapped or uprooted, railroad box cars are pushed over, light objects become missiles and cars are blown off the highways. It should be noted in regard to the Fujita classification that the given structural damages do not take into account design capacities and at the best are descriptive only. Unfortunately, in Arizona, because of residential code exemptions, damage may appear to be in a higher Fujita classification than is perhaps justified.

Nevertheless, limited studies are available on rotational velocities of vortices. R. H. Clarke [2] determined that 50% of the Australian tornadoes studied had velocities of less than 70 mph. Assuming again, an "eddy tornado" of even the lowest Fujita classification with rotational winds of 40 to 72 mph moving in a straight-line wind flow of 50 mph, the tangential velocity would be 90 to 122 mph over the life of the eddy and along the tangential **path!** Damage along such a path would produce rotational debris distribution AND, at the same time, straight-line wind damage caused by velocities of a much greater magnitude than might be expected from an ordinary thunderstorm downdraft.

Many of our Arizona "tornadoes" have created damage patterns that are difficult to explain from either purely the straight-line wind or the tornado concept. However, the combination of the two does explain the superwinds experienced in some areas and at the same time the additional evidence of rotational forces.

These "eddy" tornadoes, like dust devils, could have either clockwise or counter-clockwise circulations (Cooley [3]) depending completely upon the physical orientation of the obstruction and the angle at which it is struck by the straight-line wind. From local investigational experience of these phenomena, the most likely area for their occurrence would be between one half mile and three miles downwind of the obstruction and the destructive tangential path length would probably be one quarter to one mile.

Such combinations are obviously capable of great localized destructive force. The increasing frequency of their reported occurrences and the damage caused are directly proportional to the increasing population of the area and to the increasing urban sprawl.

It is becoming recognized, therefore, that all storms in Arizona that look like tornadoes are not the "true" tornadoes that have caused so much damage and loss of life elsewhere in the nation. The so-called "eddy tornadoes" in combination with straight-line winds are thought to be quite common in the summer monsoon season because of the comparatively great number of summer thunderstorms and the wide variety of streamflow obstructions. This type of storm is therefore possibly responsible for the increasing number of "tornado" reports received in recent years by the National Weather Service in Phoenix.

Notable examples of such "eddy" storms include the "Scottsdale Tornadoes" of June 21, 1972, where at least two vortices were sighted in the area downwind and northeast of Camelback and Mummy Mountains. Three million dollars worth of damage was caused to homes in the area near Shea Boulevard and Scottsdale Road--an area which 10 years before was almost raw desert. In this case, the rotational damage caused by the vortices was evident in aerial photographs of the area, but was masked to a large degree by the widespread structural damage caused by extensive straight-line winds. Damages were estimated by structural engineers to be similar to that caused by 80 to 90 mph winds (Lundgren [9]).

Again, on July 20, 1968, a small vortex triggered by the Papago Buttes, caused damages of about $25,000 near 52nd Street and East Taylor in Phoenix. Similarly, on July 4, 1968, a similar vortex destroyed some buildings and caused two injuries downwind from the Superstition Mountains near Apache Junction.

Paths of many true tornadoes are rather spectacular and are annually well documented in the press and on television. Complete devastation over distinctive paths up to 1/2 mile wide or wider with consequent fatal results are often the rule.

Damage from Arizona's reported wind storms and tornadoes on the other hand is relatively limited compared with "true" tornadoes of the Midwest and South. Deaths associated with Arizona wind storms and tornadoes are rare with only two recorded deaths (Glendale in 1921 and near Tucson in 1964) in 75 years. Homes have been unroofed, carports peeled back, and some houses have even been demolished. But rarely have commercial structures been seriously damaged, despite the $10 million plus damage bill since 1958.

Much of this damage that was attributable completely to tornadoes should perhaps, be credited to the damage caused by a combination of simple straight-line winds and "eddy tornadoes". Straight-line winds often do cut a much broader swath than a tornado; and, whereas an "eddy tornado" may be imbedded in the swath, its damage alone is often difficult to differentiate from that of the violent straight-line wind.

Dr. Harry R. Lundgren PE [9], Associate Professor of Civil Engineering at Arizona State University, has said in referring to the Tempe, Mesa, and Scottsdale "tornadoes" of 1972, *"In no case did we find a properly designed building (which would be designed for 75 to 80 mph winds) that had suffered any damage whatsoever. Again, this lends credence to the fact that we did not have the kind of tornadic activity that we would associate with Midwest tornadoes"*.

When a storm strikes, whether it is a straight-line wind of destructive force or a rotational storm, chaos results. Witnesses are confused. They report hearing a roar like "a thousand locomotives"; but a 100-mph plus wind can wail like a banshee, and hail drumming on a hundred roofs can confuse even the best railroad man. Witnesses report seeing funnel clouds at the height of the storm often with diminishing light and heavy rain. Yet, how can one tell a man who has had his home demolished or badly damaged that it was *not* a true tornado, the most destructive of severe local storms, that had fated him!

In summary, not all tornadoes and funnel clouds reported in Arizona are true tornadoes. Perhaps as high as 75% of them are "eddy tornadoes", dust devils, hail shafts or areas of heavy rain. Perhaps some of the damage attributed to "tornadoes" should be realistically attributed to a combination of straight-line winds and "eddy tornadoes".

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