5.6 **What Are We Doing with (or to) the F-Scale?**

Daniel McCarthy,
Joseph Schaefer and Roger Edwards
NOAA/NWS Storm Prediction Center
Norman, OK

1. Introduction

Dr. T. Theodore Fujita developed the F-Scale, or Fujita Scale, in 1971 to provide a way to compare mesoscale windstorms by estimating the wind speed in hurricanes or tornadoes through an evaluation of the observed damage (Fujita 1971). Fujita grouped wind damage into six categories of increasing devastation (F0 through F5). Then for each damage class, he estimated the wind speed range capable of causing the damage. When deriving the scale, Fujita cunningly bridged the speeds between the Beaufort Scale (Huler 2005) used to estimate wind speeds through hurricane intensity and the Mach scale for near sonic speed winds.

Fujita developed the following equation to estimate the wind speed associated with the damage produced by a tornado:

$$V = 14.1(F+2)^{3/2}$$

where V is the speed in miles per hour, and F is the F-category of the damage. This equation led to the graph devised by Fujita in Figure 1.

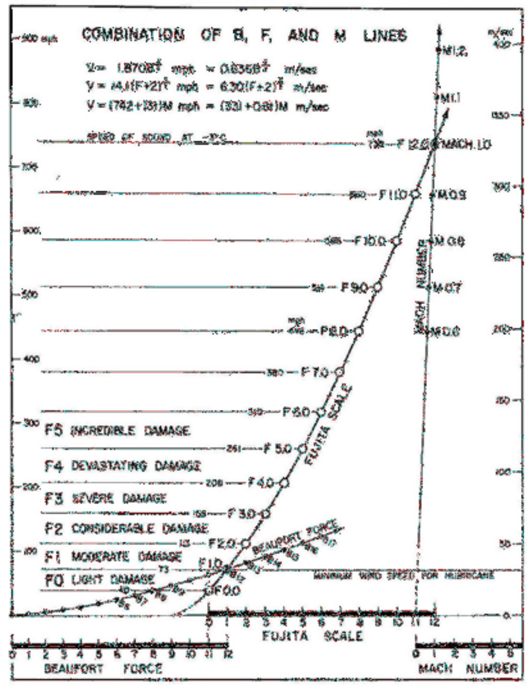

Figure 1: Fujita's plot of how the F-Scale connects with the Beaufort Scale and Mach number. From Fujita's SMRP No. 91, 1971.

Fujita and his staff used this scale to map out and analyze 148 tornadoes in the Super Tornado Outbreak of 3-4 April 1974. According to the Storm Prediction Center (SPC) Tornado Database, there were seven tornadoes with F5 damage, 23 with F4 damage, 33 with F3 damage, 34 with F2 damage, 39 with F1 damage and 12 with F0 damage.

The engineered quality of Fujita's wind estimates could be viewed as amazingly accurate. For example, an evaluation of the damage caused by the tornado that hit parts of Oklahoma City on May 3,1999, resulted in a F5 rating. Amazingly, the University of Oklahoma Doppler-On-Wheels measured up to 318 mph flow some tens of meters above the ground in this tornado (Burgess et. al, 2002).

2. Early Applications

On 11 January 1972, Fujita released Satellite and Mesometeorology Research Project Paper 91 attached to a letter coauthored by Allen D. Pearson, then the Director of the National Severe Storms Forecast Center, to the Meteorologist-in-Charge at all National Weather Service (NWS) Offices. This letter asked local NWS officials to apply the Fujita-Pearson Scale (Fujita and Pearson, 1972) to tornado observations in their area. The Fujita-Pearson Scale consisted of three numbers each of which ranged from a low of 0 to a maximum of 5. The first number was the Fujita intensity rating, while the second and third numbers were related to the tornado's path length and the tornado's mean path width, respectively. For example, a tornado's damage would be rated 5,4,3, indicating that it caused F5 damage with a Pearson Length (P_L) of 4 and a Pearson Width (P_W) of 3. Thus, it was easy to see that this tornado had a fairly long path length, was fairly wide, and caused incredible damage. Similarly if a tornado was rated 4,1,1, it was very narrow and had a short path, but it caused considerable damage.

By the late 1970s, the use of the Fujita Scale to describe the character of a tornado became a routine NWS practice. To apply the Fujita Scale data back in time, the Nuclear Regulatory Commission funded the Technique Development Unit at the National Severe Storms Forecast Center (the predecessor to the Storm Prediction Center) to hire local researchers to update official *Storm Data* reports using historic newspaper articles in order to assign F-Scale values to the existing tornado database back to 1950. As seen in Figures 2a and 2b, there were more tornadoes reported as having F2

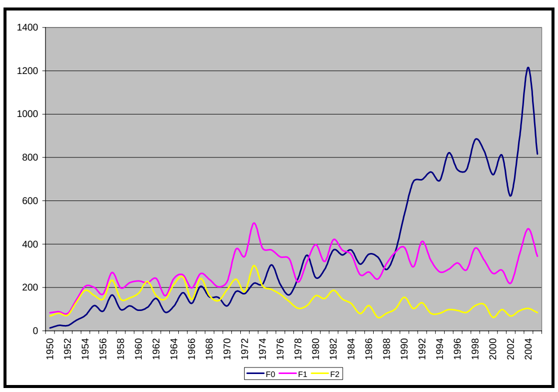

Figure 2a: Plot of damage rated F0, F1 or F2 from 1950-2005.

damage than F0 damage through the early 1970s. This is because a tornado's newsworthiness is strongly related with the damage it causes (Schaefer and Edwards, 1999).

By the 1980s, classifications of tornadoes by F-Scale damage became more common.

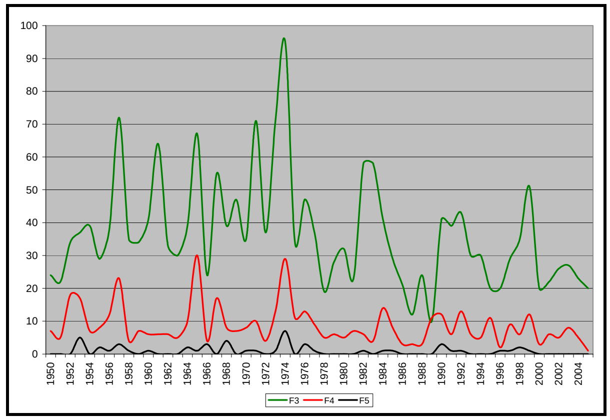

Figure 2b: Plot of damage rated F3, F4 and F5 between 1950-2005.

The proportion of tornadoes causing strong (F2 and F3) damage decreased, with 70% of tornadoes being rated as weak (F0 and F1) and less than 0.1% of them being violent (F4 and F5). The F-Scale had indeed become the standard for comparing tornadoes.

Although, the scale was originally referred to as the Fujita-Pearson Scale (Fujita 1972), the P_L and P_W numbers were found to not be of less value. They were essentially logarithmic categorizations of the observed path length and the mean path width. For instance a tornado with P_L= 0 had a path that ranged between 0.3 and 1 mile long. In contrast, a P_L=5 tornado had a path length between 100 and 315 miles long. There simply was too much resolution in the lower numbers and too little resolution at higher numbers to adequately differentiate the track dimensions of tornadoes. Because of this, the P_L and P_W portions of the scale are seldom used anymore.

3. Changes in the 1990s

Deployment of the WSR-88D Doppler radar and NWS modernization led to several incidental changes that affected and revealed imperfections of the F-Scale. More tornadoes were reported during the decade of the1990s than any other decade in the historical tornado record. Some of this was due to population increases in the Ohio and Tennessee Valleys and some parts of the Plains. Also, changes in communications technology made it easier to report tornadoes in near real time. The NWS modernization itself also brought about increased training of storm spotters to provide ground truth to Doppler observations, and increased efforts at collecting tornado reports in order to verify warnings.

Some storm chasers and professionals in the broadcast field misuse the F-scale as a visual description of a tornado. Frequently, just the image of a tornado leads to the media assuming an F-scale by the size of the tornado without any reference to the damage. Figure 3b shows a general tendency for wider tornadoes to produce more damage. However, the graph also shows considerable overlap between F-scale groups.

The reporting of path width changed in 1994 from the mean path width to the maximum path width. Comparison of Figures 3a and 3b shows how using the maximum path width correlated better with the tornado's size than using mean path width. Thus, it was better to simply record the widest path obtained by the tornado in *Storm Data.*

The F-scale appears to be more a suburban-based scale than an open-field rural scale. For example, the 3 May 1999 Oklahoma City tornado caused massive damage with a maximum width of 3/4 of a

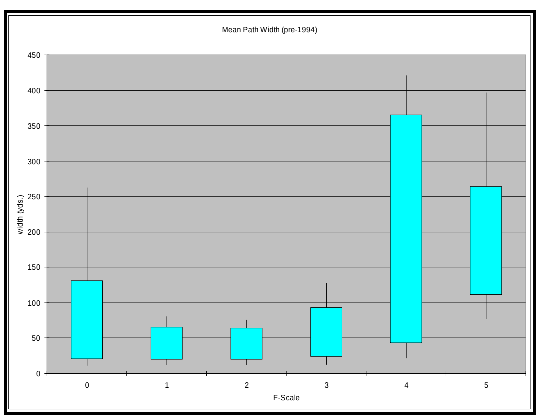

Figure 3a: Box and whisker plots of mean path width and F-Scale damage. Box shows ranges between 25% and 75%, the lines range from 10%-90%.

mile with the damage achieving an F5 rating. In contrast, the 7 April 7 2002 tornado near Throckmorton, TX also had a maximum path width of about 3/4 of a mile, yet the damage was only estimated at F2.

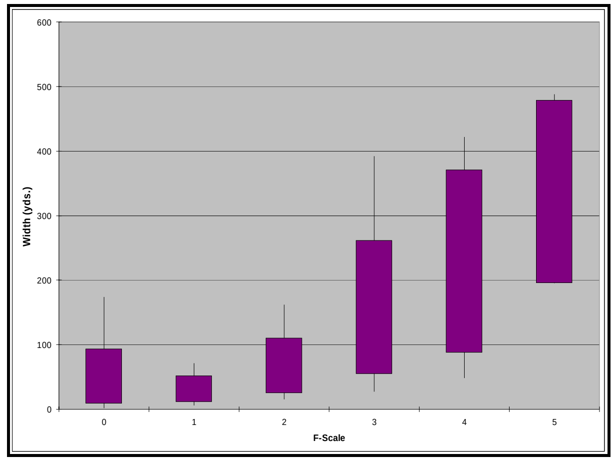

Figure 3b: Box and whisker plot of maximum path width and F-Scale damage. Ranges are the same as in 2a.

While both tornadoes were comparable in size, the 3 May 1999 tornado destroyed homes and businesses, while the 7 April 2002 tornado was over open filed with most of its destruction being downed mesquite trees and fence posts pulled out the ground composed of hard clay.

Another misapplication of the F-Scale that has become more prevalent is its use to describe the variations in tornado intensity along its track. For example:

The tornado continued northeast, spreading debris across F Avenue just north of 125th Street as it maintained F1 intensity. Two additional homes were damaged with outbuildings destroyed as the tornado tracked northeast across G and H Avenues near 105th Avenue. It then intensified to an F2 tornado as it crossed the Boone/Webster county line. Another home was heavily damaged and a large outbuilding destroyed just north of the Boone/Webster county line. The tornado quickly moved northeast, crossing 390th Street and headed toward the Des Moines River, weakening to an F1 tornado.

The question is did the tornado "intensify" because it heavily damaged the home? Does this imply a faster motion or increase in rotational velocity, or give any indication that it had intensified? Hitting an outbuilding with a damage rating of F1 and then causing F2 damage may simply mean that the tornado hit something more structurally sound as it progressed along its track. It is likely that the tornado was in the F2 range the whole time. Notice as the tornado moved toward the river, it described to have weakened back to F1, which is more an indicator that it did not encounter many more structures, rather than evidence of changing intensity.

Contributions in the late 1990s from Marshall (2000) instructed those conducting surveys to assess building quality when estimating the F-Scale. For instance, the engineers/meteorologists that served on the Building Performance Assessment Team (FEMA 1999) noted that there was only weak toe-nailing to the foundation of many of the homes affected by the Oklahoma City tornado.

Fujita (1992) knew that construction quality probably needed to be considered as he discussed *The Fujita Tornado Scale*. This version of the scale took an estimation of the damage and assigned an "f-scale" (little f intended). It then applied the type of building damaged in order to convert the f-scale into the final F-Scale rating (Fig. 4). Thus, if a tornado caused a roof to be removed from several homes, the damage would be rated f3. If then the homes were

Damage f scale		Little Damage	Minor Damage	Roof Gone	Walls Collapse	Blown Down	Blown Away
		f0	f1	f2	f3	f4	f5
Windspeed F scale (17 m/s, 32, 50, 70, 92, 116, 142; 40 mph, 73, 113, 158, 207, 261, 319)		F0	F1	F2	F3	F4	F5
To convert f scale into F scale, add the appropriate number							
Weak Outbuilding	-3	f3	f4	f5	f5	f5	f5
Strong Outbuilding	-2	f2	f3	f4	f5	f5	f5
Weak Framehouse	-1	f1	f2	f3	f4	f5	f5
Strong Framehouse	0	F0	F1	F2	F3	F4	F5
Brick Structure	+1	-	f0	f1	f2	f3	f4
Concrete Building	+2	-	-	f0	f1	f2	f3

Figure 4: The Fujita Damage Scale (from Fujita, 1992).

weak farmhouses there would be a correction of -1 leading to an F-Scale for the tornado to F2.

Since 1999, no tornado has been given a F5 rating. This could be that the damage in Oklahoma City has set an unmatched standard for F5 damage, or that the application of more stringent assessment of structures has led to lower damage ratings. Figure 5a and 5b show the difference in F-Scale ratings between the years 1990-1999 and 2000-2005.

4. Future

Beginning in early 2007, the NWS will implement the Enhanced Fujita Scale, or EF-Scale (MacDonald and Mehta, 2004). The process that led to the development of this scale included a meeting of 30

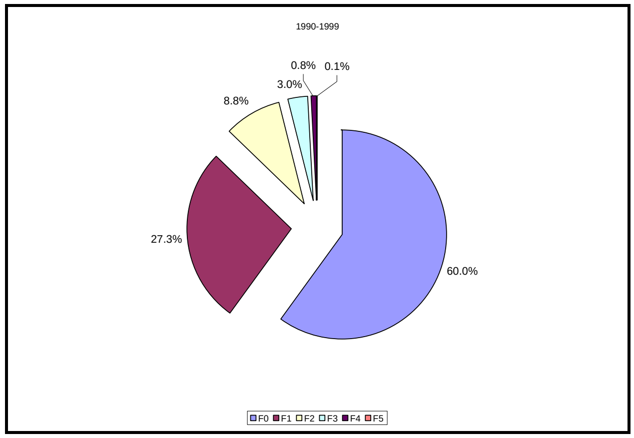

Figure 5a: F-Scale damage 1990-1999.

meteorologists, engineers, statisticians and professionals in the insurance sector that discussed what was needed to improve the scale and to provide consistency to ratings of tornado damage. The group generally followed Fujita's Fujita Tornado Scale referring to it as The Modified Fujita Scale.

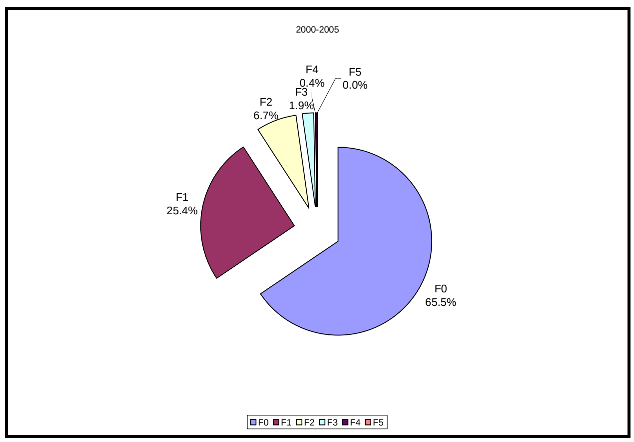

Figure 5b: F-Scale damage 2000-2005.

The EF-Scale uses 28 Damage Indicators each having various Degrees of Damage (DOD). This allows the person performing the damage survey to closely relate their observations to the DOD examples in order to assign an EF-Scale number. However, as before, the scale assigned will be a damage indicator, not a wind speed indicator.

Still needed are more indicators related to vegetation. Fujita (1992) has examples of cornfield damage from the Plainfield, IL tornado on 28 August 1990 that he interpreted to be examples of F0 to F5 damage. By applying more of these types of descriptors to the EF-Scale, there will be less damage-based weighting towards urban tornadoes.

Once the EF rating is established, wind speeds that typically are associated with the damage caused by a tornado are assigned. The maximum wind field associated with the EF-scale was lowered from that of the F-scale since if typical houses are only built to withstand 90-100 mph winds, few houses would be able to withstand a tornado if winds are actually above 200 mph (Fig. 6).

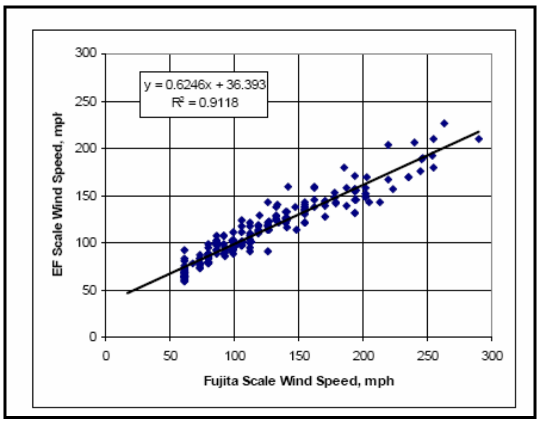

Figure 6: Correlation between EF-Scale and F-Scale. From McDonald and Mehta, 2004.

The existing tornado database that goes back to 1950 will not be affected since for a well constructed frame house the F-scale value is compatible to the EF-Scale. Thus the EF-scale value can simply be substituted for the F-scale value. Only the wind speeds that are associated with a particular category (either EF or F) have been changed. Since the F-rating, not the associated wind speed, make up the historic tornado database, the previous data will remain valid.

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