Summary Report

FUJITA-SCALE FORUM

Prepared by

James R. McDonald, Ph.D., P.E.
Kishor C. Mehta, Ph.D., P.E.

Submitted
December 10, 2002

WIND SCIENCE AND ENGINEERING
Texas Tech University
Lubbock, Texas 79409

INTRODUCTION

The Fujita Scale (F-Scale) is a measure of tornado intensity that was invented by Dr. Ted Fujita (Fujita 1971). Because there was a need to distinguish between weak and strong tornadoes and a need to assess tornado risks, the F-Scale was quickly adopted and has been in use to the present time. F-Scale ratings were applied to word descriptions of tornadoes in the historic database. Most tornadoes since 1971 have been rated as they occur by National Weather Service (NWS) personnel. Since its inception, both engineers and meteorologists recognized limitations of the F-Scale. The professionals recognized that the F-Scale

1. Fails to account for variations in the quality of construction,
2. Is difficult to apply consistently,
3. Does not yield accurate assessments when there are no damage indicators, and
4. Is not based on a correlation of damage descriptions and wind speeds.

Recognizing the F-Scale limitations, the Wind Science and Engineering Center at Texas Tech University initiated a program to examine and enhance the F-Scale. The first step was to issue a white paper, which identified problems with the F-Scale and suggested the need for making changes (Appendix A). The next step was to organize a steering committee, charging them to develop strategies for addressing the issues. The Steering Committee, consisting of three meteorologists and three engineers, met in Dallas, Texas on December 4, 2000. The Steering Committee organized a forum to introduce the issues to a broader audience of users and interested parties. Approximately 30 persons were invited to participate in the Forum, which was held March 7-8, 2001 in Grapevine, Texas. Twenty-two persons were in attendance at the one and one-half day forum (see Appendix B for a list of steering committee members and forum participants). Objectives of the forum were:

1. To bring together a representative group of F-Scale users,
2. To identify key issues,
3. To make recommendations for a new or modified F-Scale, and
4. To develop a strategy for reaching a consensus from a broad cross section of users.

The Forum Agenda included:

1. Introduction of Participants
2. Opening Remarks by Jim McDonald
3. Definition of Issues by Forum Participants
4. Focus on Three General Issues
5. Discussion of the Three Issues
6. Recommendations and Follow Up

IDENTIFICATION OF ISSUES

Each participant was given three to five minutes to present thoughts and identify issues. The participant comments generally fell into three categories relating to:

1. The historical tornado database
2. Consistent assignment of F-Scale ratings
3. Correlation of damage and wind speeds

Three breakout sessions were organized to discuss the issues and make recommendations. On the second day of the forum the entire group reconvened. Each breakout group identified key issues and proposed ways to address each. The following were identified as key issues:

1. Database

- Need to preserve and continue the historical database.
- Need to establish a standard frame of reference for wind speed (3 sec gust at 10m in open terrain).
- Need to provide additional information in the database, including average and maximum damage path width.
- Need for more resources to conduct damage surveys.

2. Consistent Assignment of F-Scale Ratings

- Need for additional damage descriptions and photographs.
- Need for more training of NWS personnel who assign the F-Scale ratings.
- Development of an expert system for consistent assignment of F-Scale ratings.
- Need for more funding for damage surveys.
- Need for involvement of engineers in the damage surveys of intense tornadoes.

3. Correlation of Damage and Wind Speeds

- Redefinition of F-Scale wind speed ranges.
- Need for a sliding scale to account for structural variability.
- F-Scale assignment based on maximum or representative damage.
- Interpretation of Doppler measurements of wind speed.

The Storm Prediction Center (SPC) and the National Climatic Data Center (NCDC) together maintain the historical tornado database with input furnished by the NWS. The publication Storm Data provides a hard copy of the tornado data, including damage descriptions. Forum participants agreed that the historical database should be preserved and maintained in the future. Some participants requested that additional information be collected and stored on the electronic form of the database. There was a discussion on including the basis on which the F-Scale rating was made, and how much time was spent conducting the damage surveys.

Achieving more consistency in assigning F-Scale ratings was of concern to everyone, especially the NWS personnel. Additional damage descriptions, more photographic examples and specific instructions on what to look for in the damage are needed. The NWS personnel in attendance urged development of more training and training materials for the persons responsible for assigning F-Scale ratings. It was suggested that a computer-based expert system could be developed that would lead to a more consistent assignment of the F-Scale rating. There is also a need to eliminate political pressure to inflate the ratings in an effort to obtain federal disaster recovery funds.

Several studies suggested that wind speeds associated with F0, F1 and F2 generally match current residential damage descriptions (Minor et al. 1977). Wind speeds in F3, F4 and F5 ranges are not necessary to cause the damage as currently described (Twisdale 1978; Phan and Simiu 1998). Analysis of damage produces lower bound wind speeds, i.e. the minimum wind speeds to produce the observed damage (Mehta et al. 1976; Golden 1976). Several suggestions were made for new wind speed ranges. Others proposed a median wind speed for each F-Scale category and a variable standard deviation. The question of overlapping wind speed ranges was raised and will need to be resolved. Most agreed that a sliding scale similar to the one proposed by Dr. Fujita could account for various levels of structural integrity (Fujita 1992). The same type of damage, e.g. roof removal, to a weak farm building would receive a lower F-Scale rating than a roof removed from a school building that had received considerable engineering attention in its design.

Technology is available and is being improved for direct measurement of wind speeds by Doppler radar. Both fixed-base Doppler and Doppler on Wheels are capable of measuring tornado wind speeds. The measured wind speeds must be adjusted to the standard frame of reference at building height. Standards are needed for interpreting the Doppler full-scale data.

RECOMMENDATIONS

Forum participants recommended the following steps to continue the F-Scale enhancement process:

1. Publish a summary report that defines issues and recommendations from the Forum discussions. (TTU)
2. Submit comments and suggestions to be included in the forum summary report. (Forum Participants)
3. Propose modified wind speed ranges and additional damage descriptions, examples and photos. (TTU)
4. Review TTU proposals before submission of proposals to Forum members for consideration. (Steering Committee)
5. Refine TTU proposals based on comments from Forum members with the goal of reaching a consensus. (TTU)
6. Explore opportunities for workshops or symposia to involve a wider audience than the forum with the goal of obtaining a general consensus.
7. Inform NWS administrators of the actions being taken and obtain their input.

FORUM PARTICIPANT INPUT

Forum participants were invited to submit comments after the forum. These comments are presented in Appendix C.

CONCLUSION

The Forum identified key issues associated with use of the F-Scale. The next step is to propose changes and reach a consensus among Forum participants. Additional meetings in the form of workshops and symposia will be needed to reach consensus among a wider group of users. One participant suggested that the final version of the modified F-Scale be called the Enhanced F-Scale or EF-Scale.

REFERENCES

Fujita, T.T., 1971: *Proposed characterization of tornadoes and hurricanes by area and intensity*, SMRP No. 91, the University of Chicago.

Fujita, T.T., 1992: *Memoirs of an effort to unlock the mystery of severe storms,* Wind Research Laboratory, Department of Geophysical Sciences, the University of Chicago.

Golden, J.H, 1976: "An assessment of wind speeds in tornadoes," *Proceedings*, Symposium on Tornadoes: Assessment of Knowledge and Implications for Man (Lubbock, TX, June 22-24, 1976), Texas Tech University, Lubbock, TX.

Mehta, K.C., Minor, J.E. and McDonald, J.R., 1976: "Wind speed analyses of April 3-4, 1974 tornadoes," *Journal of the Structural Division,* ASCE Vol. 201, No. ST9, Proc. Paper 12429, pp. 1709-1724.

Minor, J.E., J.R. McDonald and K.C. Mehta, 1977: *The tornado: An engineering-oriented perspective*, NOAA Tech. Memo., ERL NSSL-82, National Weather Service, Norman, OK. (reprinted as NOAA Tech. Memo. NWS SR-147 in 1993).

Phan, L.T. and E. Simiu, 1998: *The Fujita tornado intensity scale: A critique based on observations of the Jarrell tornado of May 27, 1997*, NIST Tech. Note 1426, US Dept. of Commerce, Gaithersburg, MD.

Twisdale, L.A., 1978: "Tornado data characterization and wind speed risks," *Journal of the Structural Division*, ASCE, *Vol.*104, No. ST10, Reston, VA.

APPENDIX A

White Paper on

The Need to Refine Wind Speeds Related to Fujita Scale
by James R. McDonald, Ph.D., P.E.

A White Paper on

THE NEED TO REFINE WIND SPEEDS
RELATED TO FUJITA SCALE

By
James R. McDonald, Ph.D., P.E.
Texas Tech University
November 2000

T. Theodore Fujita published the Fujita Scale in 1971. Its purpose was to provide a method for classifying the intensity of tornadoes. Prior to 1971 no such method existed. As a result, much confusion existed at the time regarding the magnitude of wind speeds in tornadoes.

The Fujita Scale is based on appearance of damage within a tornado path. Dr. Fujita connected the Beaufort scale and mach number 1 and divided the resulting wind speed range into 12 categories, F1 to F12. Wind speed ranges were assigned to each category. F0 corresponds to Beaufort 0 (calm) having little or no damage. Only the first six categories, F0 to F5, are appropriate for tornado wind speeds. Dr. Fujita described F6 as “inconceivable.” Table 1 gives the F-Scale wind speed ranges for F0 to F5. Wind speeds are fastest one-quarter mile winds at 10m in open terrain.

The next step was to describe the damage associated with each wind speed category. A set of word descriptions was formulated for each category. In addition, Dr. Fujita selected a set of photographs that were thought to be typical of damage in each category.

A tornado is classified by first identifying what appears to be the worst damage (assumed to be caused by the highest wind speed). The damage is compared with the word descriptions and/or the photographs. An F-Scale rating is then assigned to the storm.

Another objective of the F-Scale was to make possible the assignment of intensity category to historical tornado records on the basis of word descriptions of the damage. Such a method was needed to make the historical tornado database useful for tornado risk assessment.

Primarily because of Dr. Fujita’s reputation as the leading tornado expert in the world in 1971, the F-Scale was accepted by both the meteorological and engineering communities. The scale met the needs that existed at the time. Meteorologists were concerned with tornado climatology and engineers were struggling to assess tornado risks. The nuclear power industry was particularly concerned with tornado risks to nuclear power plant facilities.

The National Weather Service has assigned F-Scale ratings to tornadoes that have occurred since 1971. The National Severe Storms Forecasting Center (NOAA) organized a tornado database and assigned F-Scale ratings to the tornadoes. Damage descriptions from <u>Storm Data</u>, as well as information from newspapers and other publications, were used to assign the ratings. Dr. Fujita also compiled a tornado database at the University of Chicago and assigned F-Scale ratings from the Storm Data damage descriptions. The University of Chicago database has not been maintained since Dr. Fujita retired in 1992.

Shortcomings of the F-Scale were almost immediately apparent. There were no calculations or verifications of the relationships between appearance of damage and the wind speed categories. Dr. Fujita relied on his judgment and intuition. At the time, meteorologist, rather than engineers, conducted damage investigations. Minor et al. (1977) determined that wind speeds estimated from damaged residences were significantly lower than those predicted in the F3, F4 and F5 wind speed categories. The study further concluded that a single residence or structure should not determine the F-Scale classification. The Fujita damage descriptions fail to recognize the quality of construction, weak links in the load paths or the design criteria (building code) at the time of construction. Other investigators have conducted detailed engineering analyses of tornado damaged structures and likewise reported lower wind speed estimates than those which bound the F-Scale categories (Golden 1976; Mehta et al. 1974; Twisdale 1978).

In a study of damage caused by the Jarrell, Texas, tornado of May 27, 1997, Phan and Simiu (1998) concluded, "…the strongest damage caused by the Jarrell tornado can be explained by wind speeds corresponding to an F3 rating. An F4, or F5 rating officially issued by NWS, need not be assumed to explain the observed damage."

Thus, several shortcomings in wind speeds associated with the F-Scale have been identified by various researchers:

- Fujita Scale does not recognize quality of construction, weak links in the load paths, or variation of design criteria with time or geographical locale.
- The damage descriptions do not have specific meanings that can be interpreted by non-engineers, who most often make the storm classifications.

In view of these shortcomings, which were recognized by Dr. Fujita (1992), it is time to consider revisions to the Fujita Scale. A panel consisting of tornado experts and users of the Fujita Scale should be convened to study the problem and make recommendations for change.

The panel should consider but not be limited to the following:

- Calibrate damage with the wind speed categories of the F-Scale.
- Account for different types of construction, i.e. distinguish between the extent of damage to a manufactured home and an engineered building, or between a timber and reinforced concrete building.
- Consider the regional variation of wind design criteria, e.g. structures designed for 90 mph wind will have more damage than one designed for 120 mph wind.
- Factor the tornado translations speed into the classification. A slow moving storm (Jerrell, Texas) will cause more damage than the one that is moving very rapidly.

An expert system could be developed that would account for the various factors that affect the appearance of damage. The factors could be precisely defined so that a non-engineer could recognize them and enter them into the expert system for processing. The expert system would apply weighting factors and produce a recommended Fujita Scale rating that would be consistent with the wind speed that caused the damage.

Each Fujita Scale category should have an expected wind speed with variable confidence bounds rather than specific upper and lower wind speed limits. This approach will discourage the news media from citing the upper bound wind speed limit of the category and giving an unrealistic assessment of the wind speed.

The task of revising the Fujita Scale is not an easy one. Innovation and creative thinking are required. The panel with the assignment will have much work to do. Resources will be needed to complete the job. Nevertheless, the need for revisions is critical and should be undertaken.

Table1. F-Scale and associated wind speed ranges

F-Scale	**Wind Speed Range, mph (m/s)**
F0	40 – 72 (17.8 – 32.6)
F1	73 – 112 (32.7 – 50.3)
F2	113 – 157 (50.4 – 70.3)
F3	158 – 206 (70.4 – 91.9)
F4	207 – 260 (92.0 – 116.6)
F5	261 – 318 (116.7 – 142.5)

REFERENCES

Fujita, T.T., 1971: *Proposed characterization of tornadoes and hurricanes by area and intensity*, SMRP No. 91, the University of Chicago.

Fujita, T.T., 1992: *Memoirs of an effort to unlock the mystery of severe storms*, Wind Research Laboratory, Department of Geophysical Sciences, the University of Chicago.

Golden, J.H, 1976: "An Assessment of Windspeeds in Tornadoes," *Proceedings*, Symposium on Tornadoes: Assessment of Knowledge and Implications for Man (Lubbock, TX, June 22-24, 1976), Texas Tech University, Lubbock, TX.

Mehta, K.C., Minor, J.E. and McDonald, J.R., 1976: "Windspeed Analyses of April 3-4, 1974 Tornadoes," *Journal of the Structural Division*, ASCE Vol. 201, No. ST9, Proc. Paper 12429, pp. 1709-1724.

Minor, J.E., J.R. McDonald and K.C. Mehta, 1977: *The tornado: An engineering-oriented perspective*, NOAA Tech. Memo., ERL NSSL-82, National Weather Service, Norman, OK. (reprinted as NOAA Tech. Memo. NWS SR-147 in 1993).

Phan, L.T. and E. Simiu, 1998: *The Fujita tornado intensity scale: A critique based on observations of the Jarrell tornado of May 27, 1997*, NIST Tech. Note 1426, US Dept. of Commerce, Gaithersburg, MD.

Twisdale, L.A., 1978: Tornado data characterization and wind speed risks, J. Struct. Div., ASCE, 104 (ST10), Reston, VA.

APPENDIX B

Steering Committee and Forum Participants

Fujita Scale Forum

Steering Committee

Don Burgess
NSSL, Assistant Director
Chief, Warning Research & Development Div
National Severe Storms Lab
1313 Halley Circle
Norman, OK 73069
Phone: (405)366-0414
Donald.Burgess@noaa.gov

Jim R. McDonald
Professor and Chairman
Civil Engineering
Texas Tech University
Box 41023
Lubbock, TX 79409-1023
Phone: (806) 742-3476 x323
Fax: (806) 742-3446
jim.mcdonald@coe.ttu.edu

Kishor C. Mehta
Director, Wind Science and Engineering
Research Center
Texas Tech University
Box 41023
Lubbock, TX 79409-1023
Phone: (806) 742-3476 x323
Fax: (806) 742-3446
kishor.mehta@wind.ttu.edu

Joseph T. Schaefer
Director, Storm Prediction Center
Storm Prediction Center
1313 Halley Avenue
Norman, OK 73069
Phone: 405-579-0771
joseph.schaefer@noaa.gov

Emil Simiu
Represented by Michael Riley
National Institute of Standards and Technology
Building 226
100 Bureau Dr., Stop 8611
Gaithersburg, MD 20899-8611
Phone: (301) 975-6065 ES; -6076 MR
Fax: (301) 869-6275
emil.simiu@nist.gov
michael.riley@nist.gov

Brian Smith
National Weather Service
6707 N. 288 St.
P.O. Box 719
Valley, NE 68064
Phone: (402) 359-5166 x726
brian.e.smith@noaa.gov

Additional Participants

Chuck Doswell
CIMMS, University of Oklahoam
Sarkey's Energy Ctr
100 East Boyd Rd., Rm 1110
Norman, OK 73019-1011
Phone: (405)325-6093
CDoswell@hoth.gcn.ou.edu

Gregory S. Forbes
Severe Weather Expert
The Weather Channel
300 Interstate North Parkway
Atlanta, GA 30339
Phone: (770) 226-2045
Fax (770) 226-2951
gforbes@weather.com

Joseph H. Golden
Senior Meteorologist
Forecast Systems Laboratory
325 Broadway, DSRC-2B133
Boulder, CO 80301
Phone: (303) 497-6098
Fax:(303) 497-6821
jgolden@fsl.noaa.gov

Tom Grazulis
Director, The Tornado Project
PO Box 302
St. Johnsbury, VT 05819
Phone: (802) 748-2505
Fax: (802) 748-2543
tom@tornadoproject.com

Rose Geier Grant, AIA
Research Superintendent
Building Technology Research Laboratory
Strategic Resources Dept., Research Division
One State Farm Plaza
Bloomington, IL 61710
Phone: (309) 735-2964
FAX: (309) 735-2968
rose.grant.gsxj@statefarm.com

Quazi Hossain
Project Leader
Hazard Mitigation Center
Lawrence Livermore National Laboratory
L-203, 7000 East Ave.
Livermore, CA 94550-9234
Phone: (925) 423-2289
Fax: (925) 423-2163
hossain1@llnl.gov

Jeffrey Kimball
U. S. Department of Energy
19901 Germantown Rd
Germantown, MD 20874
Phone: (301) 903-6413
Fax: (301) 903-8754
jeffrey.kimball@ns.doe.gov

Timothy Marshall, P.E.
Damage Consultant
Haag Engineering
2455 S. McIver Dr.
Carrollton, TX 75381
Phone: (972) 247-6444
Fax: (972) 484-1821
TimPMarshall@cs.com

Daniel McCarthy
Warning Coordination Meteorologist
Storm Prediction Center
1313 Halley Circle
Norman, OK 73069-8480
Phone: (405) 579-0747
Fax:(405) 579-0700
daniel.mccarthy@noaa.gov

Brian Peters
Warning Coordination Meteorologist
NWS-Birmingham, AL
National Weather Service Forecast Office
465 Weathervane Road
Calera, Alabama 35040
Phone: (205) 664-7954
Fax: (205) 664-7821
brian.peters@noaa.gov

Erik Rasmussen
Research Scientist
Cooperative Institute for Mesoscale
Meteorological Studies
3450 Mitchell Lane, Bldg 3, Room 2034
Boulder, CO 80301
Phone: (303) 665-1244
Fax: (303) 497-6930
rasmussen@nssl.noaa.gov OR rasm@ucar.edu

Tim Reinhold
Associate Professor
Clemson University
Dept of Civil Engineering
110 Lowry Hall, Box 340911
Clemson, SC 29634-0911
Phone: (864) 656-5941
Fax: (864) 656-2670
rtimoth@ces.clemson.edu

Thomas W. Schmidlin
Chairperson, Geography
Department of Geography
P.O. Box 5190
Kent State University
Kent, OH 44242-0001
Phone: (330) 672-3227
Fax: (330) 672-4304
tschmidl@kent.edu

Lawrence Twisdale, P.E.
Applied Research Associates, Inc.
Southeast Division
811 Spring Forest Rd., Suite 100
Raleigh, NC 27609
Phone: (919) 876-0018
Fax: (919) 878-3672
twisdale@sed.ara.com

Larry Vannozzi
NWS-Southern Region HQ
819 Taylor St, Room 10E09
Fort Worth, TX 76102-6171
Phone: (817) 978-1100 x106
Fax:(817) 978-4920
Larry.vannozzi@noaa.gov

Roger Wakimoto
Department of Atmospheric Sciences
405 Hilgard Ave.
UCLA
Los Angeles, CA 90095-1565
(310) 825-1751
Fax: (310) 206-5219
roger@atmos.ucla.edu

Josh Wurman
Associate Professor
School of Meteorology
University of Oklahoma
1945 Vassar Circle
Boulder, CO 80305
Phone: (720) 304-0000
Fax: (720) 304-0900
jwurman@ou.edu

APPENDIX C

Individual Statements by Forum Participants

DON BURGESS
National Severe Storms Laboratory

I enjoyed attending the Fujita Scale Forum. I thought much progress was made when a diverse group of experienced people sat down together, exchanged ideas, and sought meaningful solutions. I thank the Texas Tech folks for bringing us together.

I would like to make inputs in three areas: the radar observations I mentioned during the forum; the collection of times of tornado occurrence, particularly beginning time; and National Weather Service (NWS) activities necessary to better survey damage, estimate F-Scale and incorporate modifications proposed during the forum. A recent area of research is the use of mobile Doppler radars to closely approach tornadoes and measure their wind fields, including measurements down to about 50 m above ground level. As mentioned during the forum, the recent Oklahoma City tornado of 3 May 1999 was scanned by the Doppler on Wheels (DOW). The first measurement (mentioned by Josh Wurman) was 139 m/s (310 mph) at a time when F5 intensity was estimated to vegetation and structures (non-building-code area). When the height of the estimate (50 m) is reduced to the proposed standard height (10 m) and the sampling time is reduced to the proposed 3-second standard, the wind speed would become something closer to the middle of the proposed F-5 range (190-330 mph). The second Oklahoma City tornado measurement (mentioned by me) was 95 m/s (213 mph) when the tornado was in West Moore at a time when F5 intensity was estimated to houses (building-code-area; area discussed by Tim Marshall). When reduced to 10 m and 3-seconds, the West Moore estimate would be somewhere in the lower half of the proposed F-4 range (139-259 mph). I will mention two points. First, the reduction to a standard height (10 m) and standard averaging time (3 sec) certainly improves the comparison of speeds between mobile Dopplers and that inferred/measured from damage. Second, the details of how the Doppler radar wind estimates are reduced to standard height and time have yet to be worked out. Is a power law to be used to reduce to a standard height? If so, what formulation? Reduction to a 3-sec time standard for radar observations is not straight forward. It is unlikely that radar sampling dwell time could easily be changed from the current fraction of a second to three seconds. If time is converted to space, over what distance should measurements be averaged and how should the averaging be done? More work is necessary to determine how radar estimates should be reduced to 10 m and 3 seconds.

In addition to determining tornado intensity, damage surveys document other tornado characteristics such as tornado touchdown time and other times along the path. Times are an important part of the tornado database. Times are used as ground truth in developing radar algorithms to detect tornadoes and are used in many other ways. NSSL has found that at least 30% of the tornado times in the current database (in recent years) are incorrect by at least 5 minutes, and the range of errors is about +/- 30 minutes. The reported time of most tornado beginnings is later than what actually occurred. Obtaining accurate tornado times is challenging, but techniques (which I won't list here) are available. If interaction/training is initiated with NWS (or other) tornado surveyors, improvement in determination of tornado occurrence times needs to be part of the activity.

My last comments pertain to tornado surveys. The NWS is responsible for rating tornado intensity. Although individual offices and individual personnel give great effort in the surveys, not enough resources are currently available to adequately survey all damage that needs surveyed to determine if a tornado has occurred, and, if a tornado occurred, how intense was it. Response is ad hoc, many times not rapid, and often done without surveying all the damage from the air and from the ground. Of course, not all weak tornadoes can be surveyed in a complete manner, but the indicated problems exist with many strong and violent tornadoes, and most tornado outbreaks. When Ted Fujita was involved with surveys, at least for major events/outbreaks, many of these problems did not exist. Since Ted's passing, problems have increased. Organized rapid response teams are needed for major events/ outbreaks. More resources are needed at local NWS offices to deal with the more-isolated strong and violent tornadoes. In addition, training is needed for all those participating in the survey activities. Training will also be important for the changes being discussed/recommended by the forum group. It may be possible for the NWS to organize itself to handle all of the surveying, but I think a better solution would be to include others (research meteorologists, wind engineers, university professors, and other experts) in the survey teams. Proposals to do just that have previously been introduced. I think they should be reconsidered. Having recently worked in the NWS, in the training area, I have several specific suggestions for the training activities, but I will hold those suggestions until closer to the time to work with the NWS to develop the training.

CHUCK DOSWELL
CIMMS University of Oklahoma

I had a number of points that I raised during the discussions.

1. We should modify the existing database to save information about individual tornado events that is already being gathered (and paid for) during the existing survey process. If WCMs gather evidence, it should be reflected in the routine database being created at the SPC by modifications to the format to include more information (as discussed during the Forum), and preserved at the TTU "clearinghouse" for such data. I repeat my long-term concern for the development of *digital* databases (images and text), both to help with storage and to encourage the *use* of the accumulating data.

2. If we are going to relate damage to windspeeds by some "enhancement" to the F-scale (I support Roger's "EF Scale" nomenclature) along the lines that were discussed at the Forum, this will be a big step forward. I want the EF-Scale to reflect our *uncertainties* in an accurate way. The sliding scale and the explicit representation of *overlapping* distributions of windspeeds associated with a given level of damage is the correct way to go, in my opinion.

3. We must collaborate to develop new materials (Webpages, Tech. Memos, formal publications, … whatever) that can guide non-meteorologists to understand the uses and potential for abuse contained in *all* the existing databases … *Storm Data*, the SPC data, the DAPPLE data, Tom Grazulis' data, etc. I have seen and heard some egregious examples and for each one about which I know, there probably are hundreds of abuses about which I know nothing. Our users often make many unwarranted assumptions about the existing data in their analysis.

4. We must develop some consistency in our measurements, such that we can begin to separate the two components of variability: real variability among the events versus what amounts to measurement errors of various origins. I believe we can accomplish this, but it will require more commitment to training the WCMs (who, after all, do most of the work assembling the reports). If we ask the WCMs to *do more* than what they are doing now, we need to accept the fact that someone must provide them with the *resources* to do more. It is futile to propose all sorts of enhancements if we are not willing to work toward the actual accomplishment of those enhancements.

5. I have no problem with changes to our methodology and database, so long as we do not lose information we now have. We can always degrade enhanced information to be compatible with older, less comprehensive data, but information loss is irretrievable. There can be no substitute for lost data.

I have some more points to make, however (surprise!).

1. I like the suggestions we made regarding the standardized meaning of "windspeed" that was proposed at the Forum (i.e., a 3-s wind at 10 m). However, I have acute heartburn about how we might "reduce" our measurements (via radar, mobile mesonets, or whatever) to that standard. Any assumptions must be made very clear, and no information lost. That is, we should always strive to preserve the "raw" data instead of providing only the "reduced" values, and the details of any reduction process must always be made available. Frankly, I'm very skeptical of *any* reduction process!

2. We need to get behind the effort to reestablish a "fast response" team (to replace what Ted Fujita did for us for so many years) that combines meteorologists and engineers on a routine basis and has access to both aerial and ground survey information. We should be able to get a large list of volunteers to participate, provided we can get funding to support the effort. Our endorsement could be an important part of *getting* that funding!

3. Moreover, any proposal that contributes to the acquisition of enhanced information (beyond that of the typical WCM survey) for *more* than a handful of tornadoes every year deserves a long, careful look. In most cases, we continue to deal with "small sample" statistics, especially for strong and violent tornadoes. Anything we can do to get better information about what is happening in as many significant tornadoes as possible should be encouraged.

4. Our understanding of the relationship between damage and windspeed is *always* going to be in a state of flux. We need to consider having some sort of routine process for encouraging meteorologists and engineers to interact on this and related topics. It shouldn't take a special meeting, based on the vision (and funding) of the conveners, to have the opportunity to exchange information. Every time I'm around engineers, I learn new things. I hope they feel the same way about interacting with us meteorologists. From what I have seen, this always has been fruitful when it's aggressively pursued. Why not institutionalize the interaction in some way? Texas Tech. seems like a logical place for such a development.

5. The original F-scale was defined as a windspeed scale. That is, its categories were defined in a very precise way using windspeeds directly. The merits and demerits of the F-scale as a windspeed scale never really came up in our discussions. Rather, the connection between the F-scale and damage was the source of the numerous conflicts that we've been having. The F-scale's *application* has been as a *damage* scale - the opposite of the way it was defined - and the inference of windspeeds from damage justifiably has been the source of much angst in the engineering community. I have very mixed feelings about the details of what I heard during the Forum regarding proposals for the EF-Scale. In spite of my lack of confidence in an egalitarian approach to a solution, perhaps it is only through the involvement of many more people that a workable solution to the situation can be found. Thus, I am not wildly confident that our Forum discussion provided much more than a starting point for a "solution" to the issues we confront. Perhaps *any* "solution" we arrive at can only be viewed as another step along a long road. I think that is the way it should be presented.

GREG FORBES
The Weather Channel

A workshop was held to ponder changes in the Fujita Scale. Motivations included: (1) engineering concerns about wind speeds assigned to damage in the upper F2 through F5 categories, (2) the need to account for variations in strength of construction in assigning F-scales, (3) a lack of uniformity in operational assignment of F-scales, (4) impacts of debris, wind duration, and other factors on F-scale and (5) other issues. To address these concerns, a group of meteorologists, engineers, and other interested parties met for a day and a half and came up with a number of recommendations and an action plan.

The Texas Tech group, in consultation with other structural engineers, is going to prepare a proposed set of revised Fujita Scale damage descriptions and associated wind speeds. This report will be reviewed by the Tornado Rating Forum steering committee (which previously met in Washington, DC) and then circulated to the other workshop participants. The intent is to prepare a final report for distribution by late summer 2001 describing the recommended changes. Workshop attendees have been invited to submit individual statements for inclusion in the report. Operational implementation of some of the recommendations would be contingent upon their approval by the National Weather Service, who would be given the report. The workshop attendees felt that it would be useful to give widespread audience to the proposed changes and their implications at a national symposium, such as at the 2002 Annual Meeting of the American Meteorological Society.

The workshop attendees were in general agreement that the present damage descriptions affiliated with the Fujita Scale should not change substantially. In other words, F0 would still relate to primarily cosmetic damage. F3 would still relate to a well built home that had roof removed and some but not all walls collapsed. F5 would still relate to a well built home that was crushed and completely swept clean of its foundation. Some additional examples would be added upon which to assign the F-scale, and perhaps others deleted. For example, TV antennae were much more common when the F-scale was invented than now. TV antennae might be removed and satellite dish overturning added to the damage description listings. The basic preservation of the F-Scale descriptions will assure that the tornado climatological databases will retain their validity without a need to be completely redone.

A key cause of the concern regarding assessment of winds based upon the Fujita Scale damage descriptions is that they are geared largely to the extent of the destruction of homes. Such residences typically must only meet fairly lenient building codes that are designed to keep the structure intact during the type of winds statistically expected during the lifetime of the building (on the order of 50 years). This results in a design wind speed of roughly 75 mph in most regions of the country, much more frequently occurring at a site from severe thunderstorms than from the rarer tornadoes. Thus, damage is to be expected as wind speeds approach 100 mph in most areas, even if the buildings have been built properly - which many have not.

Structural engineers have found that F4-type damage can occur at wind speeds as low as about 130 mph for a typical residence, and F5 damage at winds of around 200-230 mph or lower. By contrast, the Fujita Scale wind speeds for F4 are 207-260 and for F5, 261-318 mph.

A further complication is that structural engineers point out that there are a number of factors that can lead to variations in the response of different structures to equal winds. Homes inadequately secured to the foundation can be lifted or slid away in some instances when winds were not sufficient to remove the roof. In other instances the roof may be poorly attached to the top plate and/or the top plate to the walls, leading to removal of the roof and progressive failure of the building. Large garage doors facing the strongest tornado winds can fail, taking part of the home away with the garage. The duration and gustiness of the winds, the amount of flying debris, as well as other factors, can contribute to the variation in damage between structures.

In his 1992 "Memoirs" publication, Dr. Fujita himself had begun to advocate the application of different f and F scales to the damage and estimated wind speeds of tornado damage, respectively. For weak structures a downward adjustment factor would be assigned before applying the raw f (damage-based) scale to the F (wind speed) scale. The workshop attendees endorsed the preparation of training materials that the NWS could use to help make such determinations in their storm surveys.

The description of F5 tornado damage includes not only houses crushed and swept away, but also includes "steel-reinforced concrete structures badly damaged." This potentially results in a broadening of the range of wind speeds associated with F5 winds because of the considerable differences in the strengths of these two types of structures. As a consequence, the revised Fujita Scale wind tables are expected to reflect a broader range of wind speeds than at present. Revised-scale F5 winds may range from 200-320 mph, for example. To reflect uncertainties related to strength of structures, the revised wind scales are likely to overlap to some extent.

It can also be argued that broadening the F-scale wind categories will avoid problems associated with a vertical normalization of the tornado wind speed. There are a number of photogrammetric and Doppler radar measurements of wind speeds in the 261-318 mph (F5) range. These have all been measured considerably above the typical roof-top level, however, and may be considerably larger than the winds affecting structures. The workshop attendees preliminarily agreed that the wind speed reference would be a 3-second average wind at the 10-meter level.

Various other issues were addressed at the workshop. Some involved maintenance and use of the historical tornado database. Mean tornado width needs to be reported and tabulated in the database. Information should be added to the report and in the database about how tornado classification was performed (survey, newspaper clippings, etc.) and how much time was spent in a damage survey - as a type of quality indicator. The tornado database (including NCDC's on-line Storm Data) should include a tornado number that would readily enable users to identify which county segments were all part of the same tornado. Provide latitude and longitude for the beginning and ending of the track. Surveyors should attempt to compute the areas of the tornado path affected by the various F-scales in order to expand the DAPPLE database. Somewhat related, a discussion was held (without definite conclusion) concerning whether the F-scale should be assigned on the basis of maximum damage or some more representative extent of damage.

The workshop attendees also expressed a desire for a survey team of engineers and meteorologists to every tornado damage path preliminarily categorized as having F4 or F5 damage. The sentiment was that waterspouts prompting warnings to land or offshore waters should be classified as tornadoes.

JOE GOLDEN

Forecast Systems Laboratory, NOAA

I very much appreciate the efforts taken by Texas Tech and NIST to put together this forum; it was one of the more productive two-days I've had in a while, particularly over such a potentially contentious topic. I agree with much of what Erik, Roger and Chuck have already noted, so here's my spin on a few things that need stronger emphasis and follow-up, in my view.

1. I, too, endorse the sliding-scale, "Enhanced F-scale development, along the lines suggested by Jeff Kimball, with some overlap at the higher EF numbers. We need to reflect current uncertainties and be able to adapt the EF-Scale as new tornado windspeed ESTIMATES are made, preferably by two or more sensor types (portable Doppler and simultaneous digital stero-photogrammetry would be a big step forward here). All data should be normalized to 10m heights and 3-sec gusts. We should all be very careful what we release to the media early on, but I know the intense pressures. I am willing to concede that windspeeds have been estimated by portable Dopplers and photogrammetry at 225+ mph in a few tornadoes at tens or hundreds of meters above the ground (at probably different time-averages), but statements to the news media need to reflect also the much lower failure mode windspeeds found by Tim Marshall and the NIST wind engineers in tornado surface structure damage. (We never like to admit that even after 30 years, there is still APPARENT wide disagreement on probably max windspeeds in the level occupied by structures on the ground!)

2. Goal for SPC and NCDC (need to get NOAA to commit funds and staff-time!) should be a digital database with metadata indicating local staff and time spent doing surveys and the other items we listed (if done at all, by sfc and aerial mapping) and digital damage photos (many WFO's now have digital cameras, originally bought with Mark Powell's (HRD) pushing NWSH to document ASOS site exposures).

3. Education and training for ALL WCM's (and other collaborators) doing ground and aerial damage surveys will be a must, and the work already done in Tech Memo form by Brian Smith and Bill Bunting along with inputs from Roger and all of us is important, along with many more good, well-documented damage photos that can be used to illustrate the EF-Scale (including those with engineering calculations).

4. All this effort so far will be for naught if we cannot convince NWSH (John Ogren and his boss, Greg Mandt) and the Regions that it is needed and can be implemented WITHOUT significant addition of new staff. The damage surveys must be organized with cross-discipline teams expeditiously (24 hr or less), and aerial surveys should be carried out for all outbreak and other questionable, significant tornadoes (criteria need to be developed here). I endorse Erik's shameless plug and the development of a PC and PDA-based "expert system," but we need to convince NWS and OAR that tornado research needs to be higher in the funding priorities (NWS does, after all, pledge to cut its tornado warning FAR by half over the new few years in its Strategic Plan!) I still feel that because of political tinkering by NWSH officials in past "service assessments" that this process should be funded and organized by NOAA (TTU and NIST could approach new NOAA administrator, whoever he/she turns out to be).

5. Next steps must be to reach out to the broader meteorological community (good start to approach Severe Storms Committee, as well as AMS Broadcasters and Education Committee), but also to the Wind Engineering community (AAWE and ASCE) which is plugged into the current Congressional Wind Caucus activities that AMS and NOAA do little to encourage. Two upcoming opportunities are the America's Conference on Wind Engineering at Clemson in early

June and the AMS Broadcaster's Conference also in June, but these may be too early for Jim's target date for a final report?

TOM GRAZULIS
The Tornado Project

1. Overlap the wind speed numbers. That would be the single best way to reflect the true complexity of the problem. Even if all homes were engineered, the terrain and the angle of attack would change the degree of damage for a particular wind speed. "Confusion among the public" should not be a concern. Instead of blind acceptance of a number, questions would be raised. This might provide an opportunity for explanation and learning.

2. Keep the top F5 wind speed at 318 mph. I believe that there are tornadoes that produce winds of that magnitude. The forum lacked an authoritative voice on vortex structure and modeling to speak to that issue. Until we know what the winds are, lowering the number moves us from inaccurate guess to another. We should keep the top value at Josh Wurman's 318 mph "measurement" in 1999, which confirmed Fujita original guess. Lowering the top F5 wind to 250-280 sets up an unfortunate scenario for the future. There will be other high values based on Doppler radar measurement. When there are others above the F5 limit, the press will have free reign to label the tornado as "F6". The top of the F6 range will hit the headlines. The press won't stop at 318. Years of work needed to get the public perception down to a 318 mph top will have gone for naught.

3. The written standards should contain a long list of damage items that are not F5, not F4... and so on. That list should be longer than the list of what damage actually does qualify a tornado to be rated at a particular F-Scale level. The list should be updated annually, by reviewing the *Storm Data* descriptions and finding the mistakes that have been make. For instance, the carrying of the bell tower for a quarter mile (from a small South Carolina rural church) is not valid F4 damage (yes, that's there). The initial list can be constructed by reviewing the many inappropriate ratings during the past 10 years. An annual published list of the 10 worst ratings of the year would be revealing and instructive.

QUAZI A. HOSSAIN
Hazard Mitigation Center, Lawrence Livermore National Laboratory

In order to prepare the context for my viewpoint on what should be done towards improvement of Fujita Scale, let me list the major shortcomings of Fujita Scale:

- Does not recognize the actual strength difference between two structures having the same or similar physical descriptions, but built to two different design and construction criteria. This error can result in either underestimation or overestimation of wind speeds.
- Application yields only lower-bound intensity classifications, because damage descriptor includes only failed structures. This error results in underestimation of wind speeds.
- Intensity can be underestimated because of lack of structures or objects in the tornado path.
- Does not recognize the effects of various parameters that may contribute to failure other than “open terrain” wind pressure: topography, the presence of other structures, rate and duration of loading, distribution of pressure on the structure, etc.

Several different forms of modifications have been used on an ad-hoc basis to account for these shortcomings of the original Fujita Scale, some by Fujita himself. But none of these are based on a systematic approach of actually calculating the strength of the failed structures in terms of wind pressure. Such an approach is not considered practical when thousands of past tornado records are involved. Instead, the uncertainties and errors in establishing a design wind speed based on historically observed tornado damage data can be suitably accounted for by developing an Expert System that would yield a wind speed velocity distribution when the user inputs into it the quantitative and qualitative damage data and opinions. In such an Expert System, the characteristics of the wind speed velocity distribution of a given tornado would be compared to a set of standard distribution characteristics (predetermined based on the consensus of the experts) for nominally categorizing the tornado into five wind intensity categories. For simplifying the development of tornado wind hazard curve, the standard wind speed velocity distribution of the categorized tornado will then be used instead of tornado-specific distribution.

JEFF KIMBALL

U.S. Department of Energy

The workshop was extremely useful in getting the issues and actions identified to start the process of updating the relationship between tornado damage and wind speed.

The one issue I would like to see acknowledged (beyond what was discussed) is the use of any published relationship to better understand tornado hazard in the United States, and review of this hazard to decide if any changes are needed to building codes or other design codes. This could take the form of an effort similar to what the United States Geological Survey does for seismic hazard, and the publication of a national seismic hazard map. I could envision a national tornado hazard map of wind speeds at different return periods. Such a map or analysis could be used by a [FEMA-led] working group to assess and recommend any needed changes to design codes. The outcome of this would be directly working with appropriate code groups to make any needed changes.

This is important because it provides a long goal that improves safety for the public at large in addition to a better understand of the relationship between damage and wind speed.

Thanks for inviting me, it was a great experience.

DAN MCCARTHY

SPC Warning Coordination Meteorologist

The goals set by the forum are excellent. And I agree with Dr. Wakimoto that Dr. Fujita would be proud. In recent research I have performed I found that the trend of Tornado Warned Counties by the local Weather Forecast have a correlation close to 1 with F0 tornadoes. What this displays is that we are confirming many warnings with F0 tornadoes. Thus, the questions asked are: since a warning was issued, was there an actual tornado report or are we assuming F0 damage? Statistics show that a majority of tornadoes are warned by radar first, then second comes those verified by calls to sheriffs or from spotters. But, do we actually confirm these any of these actual storms? Can we? This has already skewed the database some just to verify warnings.

Thus, I have been intrigued by the suggestion or question about F0 tornadoes that was posed in the forum. How do you identify them by damage? Can you?

I agree wholehearted to preserve the database as much as possible and provide an increase in training not only for Warning Coordination Meteorologists, but storm spotters and law enforcement in order to provide some standard of verification for the light damage provided by weaker tornadoes. Finally, I think we should provide an increase in engineering expertise in storm surveys to provide a more consistent evaluation of tornado intensity. It is quite amazing that one violent tornado is estimated to 318 mph by Doppler Radar corresponding to the top end of the Fujita estimation. We must be careful using the proposed scale in our second day in that we do not confuse the message with the media when it comes to explain the adjusted scale. I recommend that those who do surveys start with Fujita's modified scale from his *Mystery of Severe Storms* book.

Thank you for letting me be a part of the forum.

ERIK RASMUSSEN
National Severe Storm Laboratory

Reporting/archiving issues

My primary concern, for a number of years now, has been that the current method of reporting tornado damage and occurrence is inadequate for climatological research. My research needs are broad and general (i.e., did a tornado occur, and, if so, was it significant?), and if *I* find the data inadequate, it is certain that they are not adequate for tornado risk assessment.

At the forum, I presented what I consider to be a classic example for much of the rural United States (the tornado is described in some detail at: http://mrd3.nssl.ucar.edu/~eras/www/SSR/Exp/Expframeset.htm under the "STEPS" experiment). This was a tornado that under normal circumstances would be described as "small and weak". It did not damage any structures because there were none present. Thus, typically, it would receive a "default" damage rating of F0 and default path lengths and widths. A careful damage survey of this tornado revealed that corn was scoured down to bare earth, a damage indicator considered to be F4-F5 by Dr. Fujita. Photogrammetric analysis of a set of very high quality, fixed focal-length photographs revealed that the tornado debris cloud was typically about 350 m in diameter, consistent with the damage envelope, which is a medium-large size tornado. For example, it is about the same size as the Edmond, OK tornado of 3 May 1999. It is my hypothesis that tornado hazard is very poorly estimated in the rural United States, especially the High Plains, because of the mis-assessment of many tornadoes similar to this one.

Although we do not have means available at present to assess the potential damage intensity of rural tornadoes, our forum considered one very significant recommendation for improving the tornado database. It was suggested that a number of pieces of ancillary information be included with the tornado reports. For example, the means through which a damage rating is assigned should be codified.

In my opinion, "guess" or "default" are perfectly acceptable techniques. If we knew that, historically, most rural tornadoes were assessed F0 or F1 ratings through guesses or defaults, we might have an entirely different level of confidence (much smaller) in our estimates of tornado risk in some parts of the United States. And researchers who need to know where and when "weak" tornadoes occur could have some confidence that a tornado truly was weak if a damage survey had been conducted, the tornado did affect structures, and all of the damage was minor.

Thus, I reiterate my viewpoint that these "metadata" about the means through which various items in the tornado report were ascertained are ***absolutely vital*** for inclusion in our future tornado database. The metadata that were recommended at the forum (green items next to red list) are the essential, minimum set.

Personally, I am happy to discard the idea of including a surveyor's name and hours invested as part of the metadata if these are a stumbling block to acceptance of the changes to the reports. I think we can achieve a reasonable reduction of uncertainty just by having the means of assessment codified in the report. I will be happy to volunteer to help develop the metadata standards for tornado reporting.

Calibration issues

I favor the modification of the wind calibration of the F-scale. I like the idea of a sliding technique, with overlap in the wind ranges. I do suggest that we be very explicit about the 10 m, 3 s standard, and that a nominal "well-built frame house" is our primary standard for F-scale assessment. What this means in terms of construction, and why the F-scale slides for non-nominal structures, should be well explained in any publications we produce regarding the new scale. Also, I urge the wind engineering community to establish these windspeeds based on best estimates of minimum failure windspeeds similar to the work Tim Marshall has submitted to the meteorological literature. Put another way, I urge against including gut feeling and guesses of meteorologists in the new scale; that is the technique that was used a few decades ago, and now we find ourselves in a position to make fairly drastic revisions. Finally, I would recommend that we let all users know that the windspeed scale will likely require further revision as our understanding of tornado flow improves through in-situ and close-range remote sensing over the next decade or so.

I also favor leaving the F5 wind range very open at the top unless we wish to retain F6 as a category. This latter option is the most scientifically acceptable route, and it does not in any way imply that we believe that F6 will be observed. But in a statistical sense it is a possibility. So we are faced with the choice of having a probability curve at F5 that is radically different in shape from the other categories (much more skewed toward large windspeeds), or including F6.

I believe that F0 windspeeds should go down to zero; more specifically, they should be identified as being < X. This opinion is based on the practical consideration that we do not know at what windspeed dust starts to swirl below a funnel cloud and the vortex is *de facto* identified as a tornado. Put another way… do we wish to have NWS personnel querying spotters in realtime asking them if they are confident that the dust is moving faster than 45 m.p.h.? I do not think so. And I believe it is useful to know that the dust did indeed swirl.

Name of revised system
I am supportive of the name “Enhanced Fujita Scale” for a revised scale. I believe it will be enhanced through more thorough documentation, training, means for objective application, and better knowledge utilized in the wind estimates.

Shameless plug
I want to be very clear that we are now, or shortly will be, in a position to apply many new technologies to gain tornado knowledge. These include mobile Doppler radar at several wavelengths, Doppler LIDAR, in-situ surface state sensors, mobile mesonets, RPV penetration aircraft, and multi-camera digital image photogrammetry. I am already undertaking work to develop several of these technologies for application to the tornado problem. However, ***I am seeking partners***. In particular, I want the wind engineering and hazard mitigation communities to be aware of the potential of this new knowledge, the feasibility of obtaining it, and then need for multi-disciplinary collaboration in data collection, analysis, and funding of these activities. Further, I need everyone to be aware that funds are very scarce (do they exist?) in the meteorological community for this work. We have the ambition and ability, but the only way this work will get done is through collaboration.

TIM REINHOLD
Clemson University

The Fujita Scale has provided a useful and highly popular method for rating windstorms and particularly tornadoes. However, since its inception, it has also been subjected to critical assessments by researchers, engineers and scientists concerning the validity of the wind speed ranges assigned to the various damage descriptions. The Fujita Scale is a damage scale since numerical values are assigned based on descriptions of typical types of damage and since it has been closely aligned with photographs that depict the assigned levels of damage. Consequently, it suffers from two basic limitations. First, a structure or some sort of vegetation must exist in the path of the storm if a rating is going to be assigned. Second, in the absence of detailed forensic investigations, and frequently even with careful investigation, it is difficult to determine whether the observed damage levels can be attributed to high wind speeds or to weaknesses in the structures and environmental conditions that may affect the performance of vegetation.

While the number of careful engineering analyses of tornado damage are limited, they have consistently indicated that the observed damage could have been caused by wind speeds that were substantially lower than those assigned to the F-scale value recorded for the particular event and location under consideration. Thus, most of the careful examinations of damage support some level of reduction in the assigned wind speeds. In some instances these analyses are only able to determine that the damage could have been caused by lower wind speeds but are unable to establish upper bounds on the speeds. In a few instances, it has been possible to also establish upper bounds. Mobile Doppler radar units are beginning to provide some independent measurements of wind speeds in tornadoes. However, they tend to provide measurements at some distance above ground and adjustments need to be applied to these values in order to estimate speeds at heights appropriate for low-rise buildings. To date, there are no obvious inconsistencies between the engineering-based estimates of wind speeds and those obtained from Doppler radar measurements. Thus, adjustments in the wind speed ranges appear warranted both by the data from anemometer measurements and from engineering assessments.

Dr. Fujita was well aware of the criticisms leveled at the non-overlapping wind speed scales and their correlation with specific damage observations. Before he died, he had worked up an initial cut at a method for adjusting wind speed estimates based on assessments of building strength. This work needs to be continued and used as a basis for a simple, rational system for adjusting wind speed estimates based on damage observations.

I support the work to adjust wind speed estimates as undertaken by the workshop. We need to devise a system that will allow more refined estimates of wind speeds for two primary reasons. First, we need to provide estimates of wind speeds that are as accurate as is practical because the estimated wind speeds play an important role in the design of critical facilities. Second, unrealistically high wind speeds tend to lead the public to discount the importance of building stronger structures since the conclusion is that no building could stand up to the particular event.

While it is true that well-built homes or structures constructed using conventional construction methods would likely be destroyed by a tornado with winds above 200 miles per hour, tornadoes with these magnitude winds are quite rare. Furthermore, the fraction of the area struck by these storms that actually experiences the extreme winds is also quite small. We have a great deal of information that can be used to educate people that stronger well built buildings can provide significant protection from the most severe hurricanes and from strong tornadoes. However, the high wind speed estimates that are assigned to various types of damage, without recognition of construction weaknesses that pervade much of our conventional construction, frequently blunt this message.

We need to provide accurate assessments of wind speeds that recognize the incredible variabilities in tornado events and the fact that tornadoes can and do produce extremely high wind speeds. At the same time, we need to provide estimates that convey the reality that conventional construction can be absolutely destroyed by relatively low wind speed events. We can certainly build buildings that will have a much better chance of surviving most tornadoes, if they are well built and contain clear load paths and good connections.

THOMAS W. SCHMIDLIN
Department of Geography, Kent State University

I was pleased to be invited to the Fujita Scale Forum and applaud Jim McDonald, Kishor Mehta, and others for bringing this group together for the discussion.

A consensus developed to:

- keep the name ‘Fujita’ in the revised version,
- maintain the F0-F5 categories in roughly the same damage classes as Fujita proposed and as exists in the historical data base,
- enhance the data and improve consistency in the collection of data in the tornado data base (as time and money are available to WCMs),
- improve the damage descriptions associated with each F-scale, and
- revise the wind speeds associated with each F-scale.

Regarding the last item, I liked the scheme proposed by Kishor and Tim Reinhold of mid-range wind speeds for each F-scale (with speeds adjusted downward from current winds at F3-F5) and a standard deviation to indicate our uncertainly in the process. If we use 2 times the standard deviation, it effectively puts bounds on the range. The fact that the F-scale is used for hurricanes and downburst wind damage should be considered.

My remaining comments will address the fourth item above, improving the damage descriptions. Motor vehicles are everywhere that people are located in the United States and can be reasonable indicators of wind speed. Private passenger vehicles (called ‘cars’ from here on) have changed a lot in design and safety features since the late 1960s and early 1970s. In addition, we know much more about cars and wind than we did 30 years ago. A selection of our own field and lab work on this topic is cited below.

Our examination of about 300 cars parked outside houses struck by tornadoes showed that at houses with F1 or F2 damage (n=165), only 30% of cars were even moved by the wind and just 4% of cars were tipped over. At houses with F3 damage (n=105), 50% of the cars were moved and 18% were tipped over. Of course, any of the small number of cars that are tipped over make impressive images and are remembered as ‘typical’ of the scene, yet careful inquiry of owners of the damaged homes reveals a different image, as represented in the numbers above.

In addition, our tests of a sedan and minivan in the idealized, but informative, world of the wind tunnel showed that wind speeds of 115 mph to 150 mph at car height (~1 m) were required to lift a wheel and perhaps initiate lifting or a roll-over of the vehicle. These winds correspond roughly to an F3 wind at 10 m height and are consistent with the field work described in the preceding paragraph.

The current Fujita Scale refers to cars in the F1 and F2 categories as “moving autos pushed off the road” and “cars blown off highway,” respectively. These should be discarded as vague and difficult to evaluate. Cars pushed or blown off the road are often gone before a survey is done, it is impossible to know exactly why the car ended up sitting on the shoulder or in the median (wind or driver?), and there are many driver-related factors affecting these descriptors. In addition to our data, there is plenty of anecdotal evidence that winds of 100 mph do not cause general upset or destruction of cars.

The current F3 description states “cars lifted off the ground.” While some cars are lifted off the ground in F3 damage (although it is difficult to determine whether a car was ‘lifted’ if it was not tipped or moved some distance), our field work and wind tunnel data indicate that most cars are not tipped over in F3 residential damage and (current) F3 winds at 10 m are unlikely to flip over most cars.

These are my suggestions for F-scale damage descriptions and 10 m winds related to vehicles. For F0 with wind speeds of about 75 mph, I suggest there be no reference to vehicles in damage descriptions. For **F1** with wind speeds of about 95 mph, **"Semi-trucks and high-profile vehicles may be tipped over; cars, vans and pick-ups are not tipped over."**
For **F2** with wind speeds of about 125 mph, **"Cars, vans, and pick-ups may be moved but fewer than 10% are tipped over."**
For **F3** with wind speeds of about 155 mph, **"Cars, vans, and pick-ups are moved and 10% to 50% are tipped over. Vehicles that are tipped over may be rolled tens of meters."**
For **F4** with wind speeds of about 200 mph, **"More than 50% of cars, vans, and pick-ups are tipped over. Vehicles that are tipped over may be rolled or lifted and thrown hundreds of meters."**
The damage surveyor should avoid assessing only those vehicles remaining on-site, which is biased toward the more heavily damaged vehicles, and ask about all vehicles that were outside when the tornado struck. This will include those vehicles that may have had little damage and are in a glass shop or are still being driven and are parked elsewhere.

The description of damage to manufactured homes is difficult due to dependence on wind angle and strength of the tie-down system. I suggest the F1 (~95 mph) description read, "Manufactured homes without tie-downs or with weak tie-downs are rolled over and destroyed, those with strong tie-downs sustain major damage to roof, windows, awnings, etc." The F2 (~125 mph) description could read, "Manufactured homes are destroyed, even with tie-downs."

To evaluate damage to site-built houses, I agree with the general comments at the Forum that the F-scale descriptions should include sections called "weaknesses to be aware of" (poor grammar but useful and brief). These would highlight simple things that anyone with minimal training could inquire about and detect in damaged houses to evaluate whether there were exceptional weaknesses in the load path that would cause premature failure and result in a downward slide in the F-scale rating.

Descriptions of damage to vegetation are not very useful because trees are highly variable in how they fail and the wind speed required for failure. Stripped bark is a poor indicator of wind speed. However, since much wind damage is simply uprooted or broken trees and some assessment of wind speed may be requested, perhaps we can suggest a lower limit for "widespread toppling of trees" in an F-scale description (at F1, about 100 mph I expect).

Related references on vehicles in wind:

Schmidlin, T.W., P.S. King. 1995. Risk factors for death in the 27 March 1994 Georgia and Alabama tornadoes. *Disasters* 19:170-177.

Schmidlin, T.W., P.S. King. 1996. Cars and tornadoes: Where is the research? *Bull. Amer. Meteorol. Soc*. 77:963-964.

Schmidlin, T.W., P.S. King, B.O. Hammer, Y. Ono. 1998. Tornado effects on motor vehicles. *Preprints, 19th Conference on Severe Local Storms*, p. 428-430, Amer. Meteorol. Soc., Boston.

Schmidlin, T.W., P.S. King, B.O. Hammer, Y. Ono. 1998. Behavior of vehicles during tornado winds. *J. Safety Res*. 29:181-186.

Schmidlin, T.W, B.O. Hammer, Y. Ono, L.S. Miller, G. Thumann, P.S. King. 2000. Wind tunnel tests of the stability of vehicles in severe winds. *Preprints*, *20th Conference on Severe Local Storms*, p. 427-430, Amer. Meteorol. Soc., Boston.

Hammer, B.O., T.W. Schmidlin. 2001. Deaths in motor vehicles caused by tornadoes in the United States, 1900-1998. *Environmental Hazards* (in press).

And… Quick Response Reports 98, 106, and 119 from the Natural Hazards Center, University of Colorado, Boulder.

LARRY VANNOZZI
National Weather Service, Southern Region Headquarters

I commend Texas Tech University's Wind Engineering group for initiating the Fujita Scale Forum in Grapevine, Texas, March 7-8, 2001. It was very interesting to listen to the informative comments from experts from the meteorological, engineeering, research, and insurance communities. Many thoughtful suggestions were offered for how (and why) to improve upon Dr. Fujita's historic work.

Three main issues were developed during this meeting (modified F-Scale, consistent assessment of damage, and data collection/archiving). I accept the modified F-Scale and consistent assessment issues in their entirety and so will not rehash them in this article. However, I have several comments for altering the third (data collection/archiving) issue. In particular, I will address database preservation, *Storm Data*, and time spent on surveys. Following those remarks, I will make additional comments regarding training.

It seemed that much of the discussion regarding data collection/archiving at the forum revolved around maintaining the tornado database and the need for additional data to be collected and added to Storm Data. I believe that, assuming the Fujita scale is revised, this group must also address how the revision applies to the current tornado database, if at all. This is a major item of concern and should be added to the data collection/archiving issue. Should revisions apply to the current database? If so, how will that be accomplished? By whom? It is my recommendation that the revision should not apply to the present database, or at least that the present database should be maintained in its current state while an additional new database could be developed by applying the revised scale to the old database. Either way, this is a significant concern that should be addressed as part of the data collection/archiving issue.

Much time was also spent at the meeting discussing the need for additional information to be collected during surveys and for that information to become part of the database by adding it to *Storm Data*. Based on comments that were made, it is clear that the *Storm Data* database and its users are disconnected. Further, it is evident that this 'disconnect' has existed for a long time. One has to wonder about the viability of a publication that is failing to meet the needs of its users. Although this is a significant issue that should be addressed, I suggest that it be done outside of the future work attempted by the participants in the Fujita Scale forum.

I am concerned with a need that was expressed at this forum. Namely, it was suggested that the number of man-hours that were spent developing the tornado survey be included as part of the data. This recommendation presumably developed from a need to know how much work or effort was put into the survey. I reject this recommendation. I believe that the extent of the survey information will speak for itself; a thorough, detailed report will be the result of a significant effort while a brief and/or skimpy report will be the result of a weaker effort. Further, the number of man-hours will be a false indicator of the effort expended in the survey since that number will depend on (and vary greatly by) the talent of the people that are conducting the survey. Tracking the number of man-hours is an administrative workload that I believe is unnecessary. I strongly believe that the work will speak for itself and that the amount of time spent on the surveys should *not* be tracked.

In my final comment, I merely want to support the notion that extensive training needs to be developed and implemented to all storm surveyors. There is a significant need for this within the National Weather Service (NWS). The NWS has been weak in this area but is presently trying to improve its damage survey efforts. Some innovative tools and training were discussed at the forum. I hope that these ideas can be refined and implemented as we try to improve the practice of damage surveys.

Much work awaits those of us interested in improving the Fujita Scale. Even after we can decide upon a new scale, it must be presented and agreed upon by a wide audience. If we can improve damage survey methods and usefulness of the information, then the work will be worthwhile.

ROGER WAKIMOTO
University of California-Los Angeles

The Fujita (F) Scale was one of many pioneering contributions made by the late T. Theodore Fujita. It provided a subjective means to estimate tornado intensity by assessing surface damage patterns. However, shortcomings using the scale became apparent soon after it gained widespread acceptance within the meteorological and engineering communities. The attached summary report is a result of two days of discussion and constructive debate with representatives from the meteorological, engineering, and insurance communities. It contains well-conceived recommendations and has provided a blueprint for modifying the scale.

Perhaps the most important change is the recommended reduction of the estimate of the miimum windspeed for the F5 category while maintaining the maximum windspeed. This decision is a result of two important findings. First, compelling evidence has been advanced by engineers that F5 damage to well-constructed houses could occur at speeds significantly less than 261 mph. Doppler velocities measured by mobile radars and photogrammetric estimates obtained from videos and movies, however, have suggested that intense tornadoes are associated with maximum windspeeds that approach 300 mph. Since the general public and the scientific community now associate the most intense tornadoes with the F5 category, it would be prudent to maintain the high windspeed limit that was first proposed by Fujita.

The modifications to the F-Scale are not Draconion and I believe Ted would have approved of them. Successfully implementing the proposed changes will require a great deal of work. Modified narratives need to be created and agreed upon. Illustrative examples of the damage from each category that account for the structural integrity of the buildings must be selected. Finally, these changes must be effectively transmitted to the NWS, media and the general public. Training manuals need to be assembled and an effective outreach program must be created.

I have proposed that the modified scale be called the Enhanced Fujita Scale or EF-Scale. If EF is treated as an acronym, the pronunciation would remain the same (indeed, it is how you say the letter "F"). The change is subtle but effective [Enhance means "to make greater (as in value, desirability, or attractiveness)"] and we would still be honoring the creator of the scale.