ON THE IMPLEMENTATION OF THE ENHANCED FUJITA SCALE IN THE USA

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I. INTRODUCTION

The National Weather Service (NWS) of the United States has recently implemented the so-called Enhanced Fujita scale for damage-based rating of tornadoes. In contrast, the Fujita scale was originally constituted as a windspeed scale. The advantage of a scale based on velocities is that it doesn't depend on construction practices in one part of the world. It is completely transferable. However, as pointed out in a paper by Doswell and Burgess (1988), this windspeed scale is not useful in practice. We get wind measurements from tornadoes so infrequently as to make an "intensity" scale based on windspeed unworkable. Instead, we have to accept the reality that damage is the best indicator we have on a routine basis, even though the relationship between damage and windspeed is quite far from simple. We are forced to live with this, despite the occasional probing of tornadoes by mobile Doppler radars. The relationship between velocities sensed by these radars and the actual winds near the surface where the damage occurs, remains to be determined. Some recent studies (e.g., Wurman and Alexander 2005) have begun to explore this topic, but it will be some time before we have windspeed estimates from mobile Doppler radars for even a tiny fraction of the lifetimes of another tiny fraction of all tornadoes. We are going to be using the damage-windspeed relationship for some time to come.

In this essay, we discuss some of the changes that have occurred over the years in the practice of rating tornadoes in the US and their impact on the ratings. Some of these changes were intentional, while others were not. The implications for continued applicability of comparisons of ratings across time and space that we have been involved in the past are troubling (e.g., Brooks and Doswell, 2001; Dotzek et al., 2003, 2005; Feuerstein et al., 2005).

II. HISTORY

During the late 1960s, Ted Fujita developed the F-scale, and it was implemented nationally with the strong support of Allan Pearson, then head of the National Severe Storms Forecast Center in Kansas City, MO (predecessor to the current Storm Prediction Center) - part of the NWS. The F-scale became the basis for rating tornadoes in the early 1970s. As part of a study to safeguard the nation's nuclear power generating stations, the Nuclear Regulatory Commission sponsored an effort to develop F-scale ratings for historical tornadoes back to 1950 through 1976. This was done by paying students to review newspaper accounts and come up with an estimate of tornado intensity for every tornado in the record. The result was summarized in a paper by Kelly et al. (1978). Combined with the fact that F-scale ratings were to be determined thereafter for all tornado reports in the official record, *Storm Data* (available from the National Climatic Data Center), this enabled the development of a climatology of tornado "intensities" based on their F-scale ratings. Recently, Verbout et al. (2006) presented evidence to suggest that the retrospective rating process described by Kelly et al. resulted in an overrating of tornadoes compared to the period after 1976.

After some discussions (e.g., Speheger et al., 2002), the NWS created the so-called Quick Response Team (QRT), a group designated as "experts" regarding damage assessments for tornado rating, after the April 2002 La Plata, Maryland tornado was originally rated F5 by the local NWS survey. Subsequent analysis suggested that this was an overrating of this tornado and the QRT was established to assist any local NWS survey team in case that the tornado might be rated F4 or F5. In practice, the QRT was rarely called after its early use following tornadoes in May 2003. Partially as a result of this, the number of F4 or F5 tornadoes in the US dropped precipitously from a mean of 9 per year in the 1990s to 4 per year in 2000-2006. In the NWS's Southern Region, where historically about 40% of F4 and F5 tornadoes have occurred, none were recorded between 8 May 2003 and 1 March 2007, a period almost twice as long as the previous longest gap.

Roughly a decade ago, structural engineers began a discussion with the goal to "enhance" the Fujita scale. It has long been felt that the lack of calibration for the Fujita scale, notably at the high end, was leading to an overestimation of the windspeeds associated with F3-F5 damage. However, any windspeed scale should resolve the full range of physically possible speeds, and Doppler velocities at the high end of the F5 class were indeed observed by radar close to the ground on 3 May 1999.

Still, it is particularly difficult to simulate just what windspeeds are associated with the "high-end" damage produced by tornadoes. Obviously, we have virtually no in situ wind speed sensors capable of withstanding a significant tornado. We are, therefore, forced to use the damage as a proxy indicator. In most cases, tornadoes produce damage to structures that are not even remotely engineered to resist high windspeeds. On rare occasions, engineered structures are found within the tornado damage path, and these can, to some extent, serve to "calibrate" the damage-windspeed relationship: If a structure designed to resist windspeeds of X fails, then the windspeeds must have exceeded X. Unfortunately, such unambiguous indicators are rare, and provide only a greatest lower bound on the windspeeds.

After the Jarrell, TX tornado of 27 May 1997, some engineers disputed its F5 rating, proposing that its relatively slow movement meant that the *duration* of the tornadic windspeeds contributed to the complete destruction of homes in a Jarrell subdivision. According to their analysis, much lower windspeeds than those associated with minimal

F5 rating (117 m/s) could have caused all the observed damage. We do not dispute that finding. However, the windspeed necessary to produce that damage is again only a lower bound to the actual windspeed. As yet, no one has conducted any experiments to determine the relationship between duration of the wind and the damage produced, especially at the upper end of the Fujita scale.

Eventually, the engineers' efforts to produce an enhanced Fujita (EF) scale resulted in its adoption by the NWS, effective 1 February 2007. An important part of the EF scale is the notion of damage indicators (cf, Fujita, 1992). The participants in the process of "enhancing" the Fujita scale were polled to provide what they subjectively felt were "indicators" of the windspeeds in tornadoes, to add new indicators beyond the "well-constructed" frame home that formed the basis for the F-scale. The synthesis of that input was a list of 28 damage indicators to allow the members of a local NWS survey team to estimate the windspeeds associated with an observed level of damage. The indicators and levels of damage can be carried on a PDA by local NWS survey teams. Notably, the windspeeds associated with the high-end indicators, including "well-constructed" US frame homes were revised substantially - downward.

III. DESIRABLE PROPERTIES OF SYSTEMS

There are three fundamentally important properties of damage rating systems, and improving the quality of one of them may degrade the quality of the others. As a result, changes in the systems can have unintended consequences and require careful consideration of the trade-offs.

The first desirable property is that it should resolve all physically possible windspeeds and thus be broadly *applicable*. It would be optimal to have instrumented observations of every tornado, but in practice we have to fall back on damage. Secondly, it should be *accurate*, in order to provide the distribution of winds in all tornadoes, but again, that is not feasible. Clearly, there is a fundamental trade-off between applicability and accuracy. The third property is *consistency*. Ideally, the same process for ratings would be used everywhere through all time. Again, this is not feasible: Differences in construction between countries and even within countries can make evaluation difficult.

The recent changes in the US historical rating system illustrate the trade-offs. Conceptually, at least, the development of the QRT should help with accuracy and consistency. The use of experienced, knowledgeable experts should lead to more accurate estimates done in similar ways for surveyed events. The relatively small group of such experts, however, limits the sample of events that can be surveyed.

Again, conceptually, the EF scale should improve the accuracy and breadth of applicability in the USA. With a larger number of indicators, it is more likely that something will be damaged that can be compared to a database of expert judgment. Assuming that the expert judgments are accurate, then that accuracy could be passed through to the ratings. Yet, one major strength of the F-scale was its simplicity, and it remains to be proven if the complexity of the EF-scale rating is really an improvement.

The EF-scale also raises disconcerting issues about consistency. Only if NWS offices use the portable database appropriately will the ratings be done in similar ways around the US, given the caveat that adequate training is needed. Besides, the QRT procedure for potential violent tornados has contributed to their climatologically implausible near-extinction The temporal consistency of the US tornado record apparently has been compromised. Because there was no period of overlap between the F-scale and the EF-scale, it is impossible to know whether the final ratings are changed because of the new guidance.

IV. IMPLICATIONS FOR EUROPE

Consistency of worldwide ratings is also at stake. The F-scale had just become an international standard, and many countries still lack long-enough records based on F-scale to assess if introduction of an EF-scale specifically adapted to US conditions could bring any improvement.

It is possible that, the assessment of windspeeds for US-damage indicators in the EF-scale has produced more accurate estimates of winds that cause damage there. Certainly, the EF-scale is more complicated to apply and specifically adapted to US construction practice. The effort to produce its decision matrix was huge and it is not yet clear that its benefits justify carrying out a similar effort in Europe that contains sufficient local knowledge of construction practices under the upcoming EU building code. So, it is likely that the F-scale will have to continue to be used.

It may be beneficial to establish communication channels to discuss rating issues. In the US, there is such an online forum for experts and NWS personnel, although it is not clear that it is being used to its full extent. We also recommend that, if large changes are made in rating practice, a parallel period of rating in both systems be used to gauge the effects of the changes. We also urge the continued use of "unknown" as a damage category for those cases in which insufficient evidence exists to assign a rating.

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