FORECASTERS' FORUM

Buyer Beware: Some Words of Caution on the Use of Severe Wind Reports in Postevent Assessment and Research

ROBERT J. TRAPP AND DUSTAN M. WHEATLEY

Purdue University, West Lafayette, Indiana

NOLAN T. ATKINS

Lyndon State College, Lyndonville, Vermont

RONALD W. PRZYBYLINSKI

NOAA/National Weather Service Forecast Office, St. Louis, Missouri

RAY WOLF

NOAA/National Weather Service Forecast Office, Davenport, Iowa

(Manuscript received 3 August 2005, in final form 16 November 2005)

ABSTRACT

Postevent damage surveys conducted during the Bow Echo and Mesoscale Convective Vortex Experiment demonstrate that the severe thunderstorm wind reports in *Storm Data* served as a poor characterization of the actual scope and magnitude of the surveyed damage. Contrasting examples are presented in which a few reports grossly underrepresented a significant event (in terms of property damage and actual areal coverage of damage), while a large number of reports overrepresented a relatively less significant event. Explanations and further discussion of this problem are provided, as are some of the implications, which may include a skewed understanding of how and when systems of thunderstorms cause damage. A number of recommendations pertaining to severe wind reporting are offered.

1. Introduction

The Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX) is a research study of the life cycles of mesoscale convective systems (Davis et al. 2004). The field phase of BAMEX was conducted from 20 May 2003 through 6 July 2003 over a large portion of the central United States; the base of operations was the MidAmerica Airport in Mascoutah, Illinois (just east of St. Louis, Missouri).

One of the BAMEX goals was to gather an enhanced "ground truth" or verification dataset for proposed and established mechanisms of severe winds in quasi-linear mesoscale convective systems (QLCSs) (e.g., Trapp and Weisman 2003; Weisman 2001; Fujita 1981). Toward this end, aerial and ground surveys of wind damage were conducted (a brief description of each BAMEX event surveyed by our teams, as well as photo documentation of these events, can be found online at http://apollo.lsc.vsc.edu/bamex/index.html) immediately following the occurrence of *presumed significant* QLCSs.

The location and scope of the surveys were guided initially by National Weather Service (NWS) Local Storm Reports (LSRs) and by weather radar [Weather Surveillance Radar-1988 Doppler (WSR-88D) and airborne Doppler] data. Our working assumption throughout the project was that the significance of a given event would be a function of the storm's appear-

Corresponding author address: Robert J. Trapp, Dept. of Earth and Atmospheric Sciences, Purdue University, 550 Stadium Mall Dr., West Lafayette, IN 47907.
E-mail: jtrapp@purdue.edu

ance on radar, as revealed in fields of radar reflectivity and radial velocity, and also of the number of (and wind speed/damage described within) associated severe wind reports; significance was similarly assumed to be function of finalized reports in the National Oceanic and Atmospheric Administration's (NOAA) *Storm Data* publication. As we determined at the conclusion of the project and demonstrate below, these were often poor assumptions during BAMEX, even when considered with otherwise intense-appearing bow echoes, such as ones analyzed by Jorgensen et al. (2005).

A report-based assessment of damaging nontornadic wind events can be derived from the derecho criteria of Johns and Hirt (1987). It is important to note, however, that these criteria (e.g., concentrated area of nonrandomly distributed reports of wind damage and/or gusts >26 m s^{-1}) apply strictly to a *widespread* event, characterized as a "family of downburst clusters," with a corresponding damage length scale (major axis) ≥ 400 km (Fujita and Wakimoto 1981). Other damaging wind patterns associated with QLCSs observed during BAMEX include a "downburst" and "downburst cluster," with 4–40- and 40–400-km major axes of damage, respectively (Fujita and Wakimoto 1981). Illustrations of BAMEX events at these relatively more localized scales are given in sections 2 and 3.

The objective of this paper is to show how the use of severe wind reports in *Storm Data* (and initially in the LSRs) to assess the scope and severity of events at such scales can be problematic. Explanations and further discussion of this problem are provided in section 4, as are some of the implications, which may include a skewed understanding of how and when systems of thunderstorms cause damage. Some recommendations pertaining to severe wind reporting are offered in section 5.

2. Two examples

In the following two examples from BAMEX, we briefly compare our detailed survey analyses with the corresponding *Storm Data* severe wind reports. It is not our intent to criticize the warning and postevent operations of any forecast office or county emergency management office, but rather to illustrate the shortcomings of the reports. Additional details of these events can be found in Wheatley et al. (2006, hereafter WTA); discussions of damage survey procedures and limitations, and also of data analyses techniques, can be found in Atkins et al. (2005) and WTA.

On 10 June 2003, an intense cell bow echo (Lee et al. 1992; Klimowski et al. 2004) in the vicinity of Shelby, Nebraska (east-central Nebraska), caused a 30-km-long swath of *concentrated*[1] wind damage to trees, pivot irrigation systems, and some farm buildings, based on our ground and aerial surveys that were conducted 10–12 June 2003; we have a high degree of confidence that all areas affected by this bow echo were surveyed. As discussed in WTA, the Shelby bow echo was one of three that occurred in this region of the United States on 10 June 2003. We rated most of its damage F0 (Fujita 1981), though an embedded area of F1 damage was also found (Fig. 1).

In the LSRs and *Storm Data*, this event was represented by a mere three reports[2] located near or at the eastern edge of the damage swath (Fig. 1). The LSRs only mentioned "trees down north of Shelby," although these are preliminary and often incomplete reports. Nevertheless, one could easily conclude, incorrectly, that this was a fairly isolated, insignificant event. In fact, only after noting the property damage estimate ($1.0 M) and narrative of one of the *Storm Data* entries (see NCDC 2003a) could one begin to appreciate the scope of the damage:

> Elsewhere, vicious high winds over 70 mph did extensive damage north of Shelby in eastern Polk County. Several farmsteads sustained house, outbuilding, grain bin, and tree damage. In one case, a garage was nearly ripped from the house it was attached to. Twenty four center pivot irrigation systems were severely damaged or destroyed.

A similar case of widespread damage, particularly to crops, with only one or two corresponding *Storm Data* wind (and hail) reports has been shown by Bentley et al. (2002).

In contrast, there were instances during BAMEX in which large numbers of wind reports were listed in *Storm Data* (and initially in the LSRs) for events that we deemed relatively less significant. One such example is shown in Fig. 2, representing an extensive, squall-line bow echo (Klimowski et al. 2004) that moved through Indiana, Ohio, and Kentucky during the afternoon and evening hours of 4 July 2003 (see WTA). A postevent aerial survey—which facilitates the most comprehensive postevent assessment of the damaging surface winds—was not conducted because of the lack of aircraft resources, and so it is conceivable that

[1] In this rural case, "concentrated" equates to some damage in nearly each of the 1 mi × 1 mi sections within the indicated damage swath.

[2] Reports associated with the supercell storm, from which the Shelby bow echo later evolved, were not considered. For other events, including those included in Table 1, we likewise only considered damage that was reported while the convective storms were well organized into a QLCS.

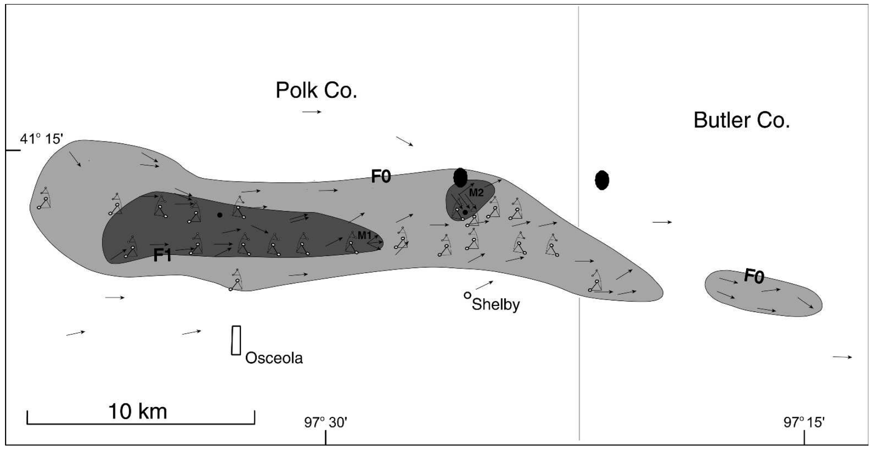


FIG. 1. Survey of damage from the 10 Jun 2003 bow echo observed near Shelby, NE. Areas of F0 damage are lightly shaded in gray, and areas of F1 damage are heavily shaded in gray. (Here, M1 and M2 denote localized areas of damage caused by microbursts.) Arrows represent "damage vectors," and dots represent damage from which wind direction could not be inferred. Triangular symbols represent damaged irrigation systems. Black ovals show locations of *Storm Data* reports. One of the reports from this case falls outside the damage analysis domain.

unreported damage areas were missed. However, all *reported* damage was investigated and formed the basis for the ground surveys. Conducted over roughly the week following the event, this effort revealed only a few scattered areas of concentrated F0 damage (see also Fujita 1981), within which some F1 damage was identified.

Storm Data wind reports associated with this bow echo were numerous (55) and widespread on this day, yet relevant property damage amounted to \$0.3 M (NCDC 2003b). The narratives of many of these reports (NCDC 2003b) were less informative, for example, "Trees were downed."

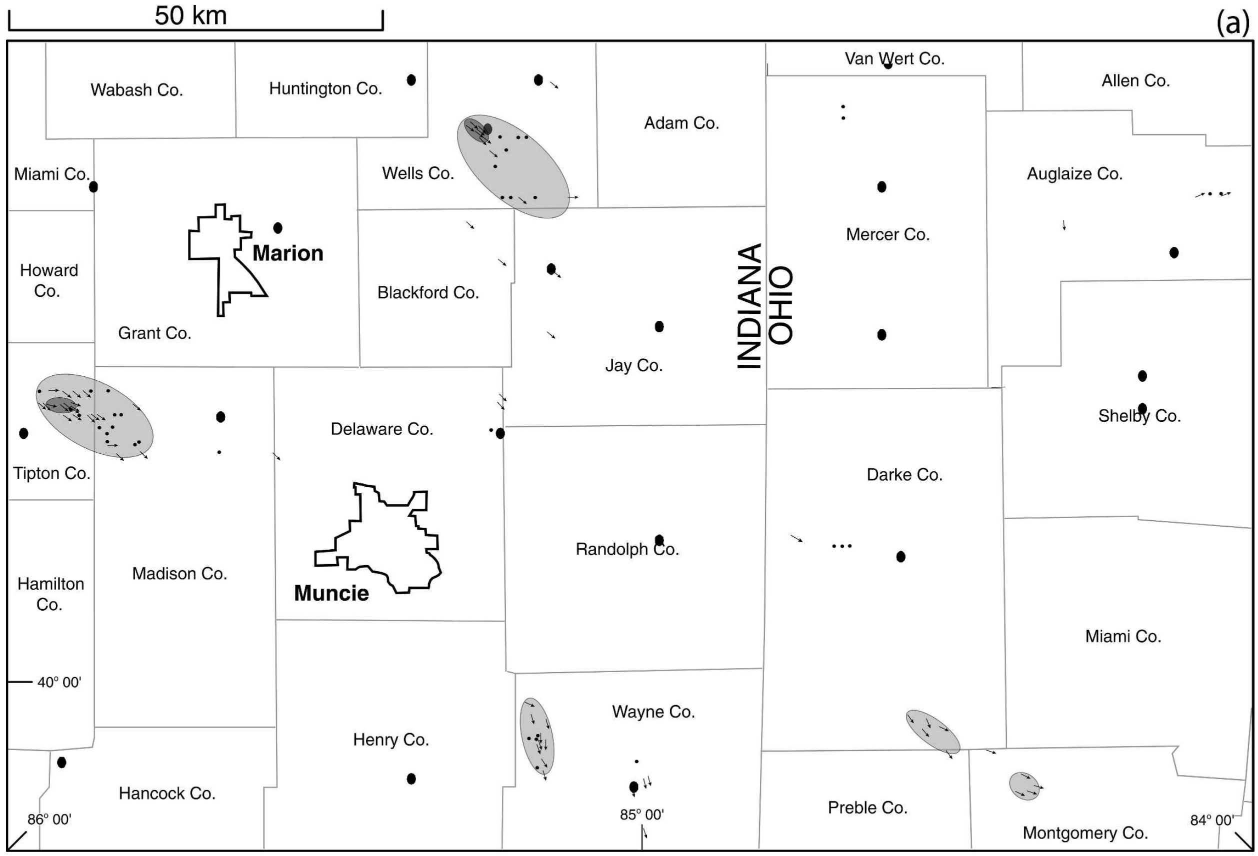
Based on our experience, this could imply a few bent-over samplings, a large grove of snapped hardwood trees with ~0.5 m diameters, or something in between. Reports on this day of severe wind gusts in absence of damage, such as "A trained spotter reported an estimated wind gust to 60 mph," were problematic in terms of assessment (see section 4) and, obviously, could not be verified by the damage surveys.

3. Quantification

To summarize, the severe wind reports for these cases from BAMEX served as a poor characterization of the actual scope and magnitude of the surveyed damage. We have attempted to partially quantify this by comparing the number of *Storm Data* wind reports N_{SD} with the total area of our surveyed F0 damage A_{F0}. For consistency with our surveys, which per the mission of BAMEX focused on damage associated with bow echoes, N_{SD} included only those reports associated with convective storms that were well organized as a QLCS. The value of A_{F0} was estimated graphically after digitizing the F0 contours, which enclosed areas of concentrated damage. The ratio N_{SD}/A_{F0} is 3/118 km^2 = 0.025 km^{-2} for the first case; hence, the report density appears to be low. As could be anticipated using Figs. 1 and 2, the ratio is much larger for the second case: 55/394 km^2 = 0.140 km^{-2}, again, suggesting by virtue of this higher report density a relatively more significant event. An evaluation of other select BAMEX cases is presented in Table 1.

Although it is unclear what the optimal number of reports should be for a given event, we find that in these BAMEX events, the report density tends to misrepresent the scope of the actual damage. This is not too surprising, in light of the NWS requirement for severe thunderstorm warning verification: one severe wind report per every 16.1 km (10 mi) and 15 min encompassed by a severe thunderstorm warning in a given county[3] (e.g., Polger et al. 1994; see also NWS 2005). Hence, for the purpose of verification only, there is little impetus for individual forecast offices to seek additional reports, since only one of possible multiple severe wind reports in the same county and within the 10-mi or 15-min separations can be used to verify a warning. Of course, such multiple reports are still permitted in

[3] To put the N_{SD}/A_{F0} ratio in the context of these criteria, a linear, 1-km-wide damage swath with one report per 16.1-km swath length would have a ratio of 0.062 km^2.



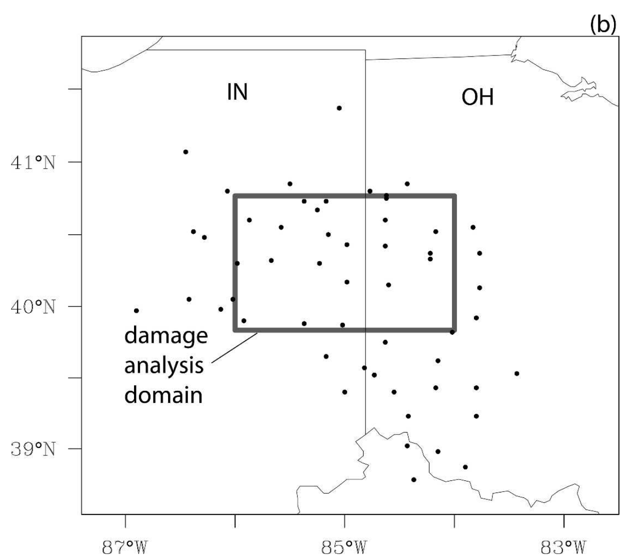


FIG. 2. (a) As in Fig. 1 but for the 4 Jul 2003 bow echo observed in IN, western OH, and northern KY. Note that the length scale in this figure is different from that in Fig. 1. (b) An expanded domain, showing all *Storm Data* wind reports from this case.

Storm Data and, in fact, reports are required for the NWS verification database, and hence will appear in *Storm Data*, in the following circumstances: any event that causes death or injury; any event that causes crop or property damage in excess of $500 000; any report of winds ≥65 kt (33 m s^{-1}; which have caveats of their own; see below); and any hail size report ≥2 in. (5.1 cm; NWS 2005). Nonetheless, for the BAMEX events listed in Table 1, the amount of reporting appears to be related more to time of day of the event (i.e., fewer reports for overnight events) than to property damage.

To help begin to determine how damage intensity is reflected in the *Storm Data* reports, we computed the ratio N_{SD1}/N_{SD}, where N_{SD1} is the number of reports of

TABLE 1. Comparison of estimated areas within F0 and F1 damage contours, with numbers of *Storm Data* severe wind reports and reported property damage (NCDC 2003a,b) for select BAMEX events [see WTA and Atkins et al. (2005) for more information]. Unless otherwise indicated, the time of consideration begins with the initial organization of convection into a quasi-linear system, and ends with the fragmentation/demise of the system, as determined by WSR-88D data. Only the *Storm Data* reports during this time period are included. A reference value for the ratio N_{SD}/A_{F0} can be determined as follows using the NWS severe thunderstorm warning verification requirement of one severe wind report per every 16.1 km (and 15 min) encompassed by a severe thunderstorm warning: a linear, 1-km-wide F0 damage swath with one report per 16.1-km swath length would have a ratio of $N_{SD}/A_{F0} = 0.062\ \text{km}^{-2}$.

Date, time period of consideration, and representative location	Property damage (millions of U.S. dollars)	Area of concentrated F0 damage (km^2; A_{F0})	Area of concentrated F1 damage (km^2; A_{F1})	Tot No. of reports (N_{SD})	Tot No. of reports with gusts ≥ 63 kt (N_{SD1})	N_{SD}/A_{F0} (km^{-2})	N_{SD1}/N_{SD}	A_{F1}/A_{F0}
0300–0400 UTC 31 May 2003, Wingate, IN	0	59	0	3	0	0.05	0	0
0050–0250 UTC 10 Jun 2003, Emerson, NE	0.1	389	0	11	1	0.03	0.09	0
0300–0400 UTC 10 Jun 2003, Shelby, NE	1.0	118	38	3	1	0.03	0.33	0.32
2250–0050 UTC 10 Jun 2003, Mascoutah, IL*	0 (0)	291	0	27 (11)	12 (9)	0.09 (0.04)	0.44 (0.82)	0
4 Jul 2003 2215–0230 UTC, IN, OH, and KY	0.321	394	19	55	1	0.14	0.02	0.05
0510–0700 UTC 5 Jul 2003, Omaha, NE**	2.025	1419	122	17	0	0.01	0	0.09

* The quantities in parentheses are for only those damage reports that relate to the primary damage swath (see Atkins et al. 2005). The time period begins when the leading edge of the bow echo (determined using WSR-88D data) entered the damage analysis domain.
** The time period for this case begins when the leading edge of the bow echo (determined using WSR-88D data) entered the damage analysis domain (see Fig. 8 of WTA).

F1 or greater wind speeds (gusts ≥ 63 kt), and compared it with the ratio A_{F1}/A_{F0}, where A_{F1} is the surveyed F1 damage area. Table 1 suggests a mixed correspondence between the reported gust magnitudes and the intensity of the surveyed damage. This finding is also not too surprising, in light of the NWS-mandated requirement that (severe) wind damage be accompanied by a wind gust in the record. We argue that assignment of a *single*, peak wind speed for damage to trees, nonengineered buildings, etc. is essentially arbitrary and fraught with potential errors. In the absence of damage, reported wind gusts are estimated values, unless otherwise indicated. This is equally problematic since estimation of wind speed by a human observer is inherently difficult, and tends to be overdone (Doswell et al. 2005).

4. Discussion

We are certainly not the first to raise concerns about reports of severe convective winds. Bentley et al. (2002) questioned the usefulness of *Storm Data* "damage estimates obtained after a significant weather event." Johns and Evans (2000) had similar concerns. Weiss and Vescio (1998), and more recently Weiss et al. (2002), have noted that the annual number of severe wind reports has increased substantially over the past 20 yr. Anomalous spikes in the numbers of reported severe wind gusts of 50 kt (26 m s^{-1}), the wind threshold for a severe thunderstorm, have also been noted (Weiss et al. 2002). Besides improved public education/awareness and an increase in population density, explanations for these changes can be attributed to the deployment of the WSR-88D network, enhancement of storm-spotter groups, implementation of a national warning verification program, and of course the NWS policy requiring a wind gust in the severe report (Weiss et al. 2002).

Arguably, the intended purpose of severe wind (and severe hail) reports is to provide a means to verify NWS severe thunderstorm warnings. We will defer the debate of the current verification system [and of suggested future improvements, such as use of polygon warnings instead of county warnings; see Waters et al.

(2005)] to another forum. Our debate here is on the use of wind reports in *Storm Data* as research quality data.

We do not wish to admonish users of these data. For example, in climatological studies of severe convective wind events, and otherwise for models of convective wind hazards, there are few alternatives (see section 5) to the *Storm Data* reports if a reasonable sample size is desired. It should be clear, however, that such studies will be prone to the misrepresentation identified above.

What is the implication of greatest concern to us? Wind report uncertainties and misrepresentation can potentially act to skew the basic understanding of the capacity of QLCS types to produce damage. In the preceding examples, the large bow echo (as viewed by a weather radar) would likely be perceived (incorrectly) as more intense than the small, cell bow echo. A hypothetical collection of equivalent large bow echo events could provide a composite synoptic and mesoscale environment that then would be treated (again, incorrectly) as a higher threat than would the environment of a collection of equivalent small bow echo events; an analogous statement can be made about the respective characteristics of these events as observed by Doppler radar, and the treatment of these characteristics in the context of warning operations. As an important aside, such small bow echoes, and in fact all but perhaps one of the events in Table 1, would be excluded from derecho databases, owing to damage track lengths that fall below the typical 400-km threshold (e.g., Coniglio and Stensrud 2004). It is reiterated here that derechos and severe QLCSs are *not* mutually inclusive.

5. Recommendations

In an ideal world with unlimited resources, we would recommend that a postevent damage survey be conducted for all convective wind events associated with a preliminary report of severe wind damage. This would ensure an accurate assessment of the significance of each event, and in turn ensure accurate historical records, climatologies, hazard models, etc. A case for a similar action for tornadoes, hail, and other damaging weather could be made as well. We of course acknowledge that this as an unrealistic recommendation, knowing all too well the time and personnel required for a detailed survey of an extensive bow echo event.

We do recommend, however, that damage surveys become an integrated part of future field programs of severe and hazardous weather phenomena. The surveys should include NWS personnel whenever possible; proper training of NWS personnel, emergency managers, and field researchers is essential. The data—and in fact current weather—should be shared immediately with relevant NWS and emergency management offices. (In hindsight, we did not do this well during BAMEX, although with only a few dedicated surveyors for the entire BAMEX domain and project duration, we had neither the personnel nor resources to do this efficiently.) Collaborative efforts between universities and forecast offices could aid the collection of damage information outside of special field programs, given proper training of the university personnel. These efforts would stand the highest probability for success if organized as a cooperative project, such as those fostered by the University Corporation for Atmospheric Research's Cooperative Program for Operational Meteorology, Education, and Training.

Research into other damage mapping techniques is also recommended. Satellite remote sensing offers a currently underutilized way to constrain the area potentially affected by thunderstorm winds, and could even complement traditional surveys. One possible application to refine is the use of multispectral satellite data, as employed by Yuan et al. (2002), to map and characterize tornado damage from the 3 May 1999 tornado outbreak, and by Bentley et al. (2002), to determine the areal extent of crop damage due to wind and hail. Images are available from other earth-observing satellites that have pixel widths as low as 1 m, and offer promising damage assessment applications. Striking images of the 28 April 2002 La Plata, Maryland, tornado track provided by the National Aeronautics and Space Administration's Earth Observing-1 Advanced Land Imager (with 10-m panchromatic pixels) support this concept. Issues related to the cost and/or access to these very high-resolution data would need to be addressed, however.

Beyond damage mapping, other steps can be taken to improve the severe wind reports. We echo Weiss and Vescio's (1998) recommendation that it be stated explicitly in *Storm Data* whether a reported wind gust was measured or estimated. Strictly speaking, this is already enabled in the *Storm Data* system[4]: high wind entries must now also include whether the gust (peak 5-s averaged wind speed) was estimated (by damage) or measured (by known calibrated anemometers). Nonetheless, guidance still needs to be offered on how to interpret the rather specific "estimates" that continue to appear in the publication. For example, a brief perusal of the February 2004 (print) issue shows "estimated" gusts ranging between 50, 51, 52, 53, 56, 61, 67, 70, and 97 kt.

Our inclination is to propose that as many reports as

[4] As of this writing, these qualifiers do not appear in National Climatic Data Center's Storm Events online, which is derived from the same relational database as is *Storm Data*.

is feasible be gathered and recorded, regardless of the initially perceived event significance. As one of the reviewers warned, however, this could actually have a deleterious effect on the database, in the form of unforeseen biases. So, we instead support the collection of the highest quality data possible; another reviewer suggested that state climatologists, who in fact were the authors of *Storm Data* during the 1950s and 1960s, might be beneficial to this process. Precise locations should be sought always, and then translated into descriptive wording in the narratives. Good examples of this from past *Storm Data* entries include estimates of tree size (in terms of diameter and height, rather than "large" or "tall"), exact location of damage (e.g., "near the intersection of County Road 100W and County Road 900N," instead of "2 miles north of town," which can be rather vague in rural areas), and an approximate area over which damage occurred (number of city blocks if urban, number of square miles if rural); an integration of geographic information system and global positioning system capabilities into *Storm Data* could help in this regard. Additional descriptors akin to tornado pathlength and path width could be useful, although a path per se is more illusive and difficult to define since some severe wind reports can be associated with distinct cells as well as large convective systems. Moreover, our experience suggests that typical severe convective systems tend not to damage or "blow down" everything they encounter (Fujita 1981).

Finally, we encourage investigators to seek additional sources of information that can be used to assess the severity of convective wind events. These may include utility companies (locations of downed lines and poles), local police departments, state climate centers and agriculture extension offices, the U.S. Department of Agriculture Farm Service Agency, and pivot irrigation system replacement companies, which to varying degrees are already used by some forecast offices and research teams. Another is the insurance industry (e.g., see Changnon and Changnon 1990). A partnership between this group and the NWS would seem mutually beneficial, and result in a higher quality database and subsequent high wind risk assessments.

In summary, it is our hope that this paper has served to further raise the awareness of issues with the *Storm Data* database, and increased the appreciation for the need of producing more representative assessments of damage associated with severe convective wind events. A panel to discuss ways of improving severe wind reporting seems warranted.

Acknowledgments. We appreciate the many useful and thought-provoking comments of the three anonymous reviewers. This work was supported in part by the National Science Foundation under Grants ATM-023344 (RJT and DMW) and ATM-0233178 (NTA). The views expressed are those of the authors and do not necessarily represent those of the National Weather Service.

REFERENCES

Atkins, N. T., C. Bouchard, R. W. Pryzbylinski, R. J. Trapp, and G. K. Schmocker, 2005: Damaging surface wind mechanisms within the 10 June 2003 Saint Louis bow echo event during BAMEX. *Mon. Wea. Rev.,* **133,** 2275–2296.

Bentley, M. L., T. L. Mote, and P. Thebpanya, 2002: Using Landsat to identify thunderstorm damage in agricultural regions. *Bull. Amer. Meteor. Soc.,* **83,** 363–376.

Changnon, S. A., and J. M. Changnon, 1990: Use of climatological data in weather insurance. *J. Climate,* **3,** 568–576.

Coniglio, M. C., and D. J. Stensrud, 2004: Interpreting the climatology of derechos. *Wea. Forecasting,* **19,** 595–605.

Davis, C., and Coauthors, 2004: The Bow Echo and MCV Experiment (BAMEX): Observations and opportunities. *Bull. Amer. Meteor. Soc.,* **85,** 1075–1093.

Doswell, C. A., III, H. E. Brooks, and M. P. Kay, 2005: Climatological estimates of daily local nontornadic severe thunderstorm probability for the United States. *Wea. Forecasting,* **20,** 577–595.

Fujita, T. T., 1981: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.,* **38,** 1511–1534.

——, and R. M. Wakimoto, 1981: Five scales of airflow associated with a series of downbursts on 16 July 1980. *Mon. Wea. Rev.,* **109,** 1438–1456.

Johns, R. H., and W. D. Hirt, 1987: Derechos: Widespread convectively induced windstorms. *Wea. Forecasting,* **2,** 32–49.

——, and J. S. Evans, 2000: Comments on "A climatology of derecho-producing mesoscale convective systems in the central and eastern United States, 1986–95. Part I: Temporal and spatial distribution." *Bull. Amer. Meteor. Soc.,* **81,** 1049–1054.

Jorgensen, D. P., H. V. Murphey, and R. M. Wakimoto, 2005: Rear-inflow structure in severe and non-severe bow-echo observed by airborne Doppler radar during BAMEX. Preprints, *11th Conf. on Mesoscale Processes,* Albuquerque, NM, Amer. Meteor. Soc., CD-ROM, J5J.3.

Klimowski, B. A., M. R. Hjelmfelt, and M. J. Bunkers, 2004: Radar observations of the early evolution of bow echoes. *Wea. Forecasting,* **19,** 727–734.

Lee, W.-C., R. M. Wakimoto, and R. E. Carbone, 1992: The evolution and structure of a "bow-echo-microburst" event. Part II: The bow echo. *Mon. Wea. Rev.,* **120,** 2211–2225.

NCDC, 2003a: *Storm Data.* Vol. 45, No. 6, 190 pp. [Available from National Climatic Data Center, 151 Patton Ave., Asheville, NC 28801-5001.]

——, 2003b: *Storm Data.* Vol. 45, No. 7, 478 pp. [Available from National Climatic Data Center, 151 Patton Ave., Asheville, NC 28801-5001.]

NWS, cited 2005: Verification procedures. National Weather Service Instruction 10-1601. [Available online at http://www.nws.noaa.gov/directives/.]

Polger, P. D., B. S. Goldsmith, R. C. Przywarty, and J. R. Bocchieri, 1994: National Weather Service warning performance based on the WSR-88D. *Bull. Amer. Meteor. Soc.,* **75,** 203–214.

Trapp, R. J., and M. L. Weisman, 2003: Low-level mesovortices within squall lines and bow echoes. Part II: Their genesis and implications. *Mon. Wea. Rev.,* **131,** 2804–2823.

Waters, K. R., and Coauthors, 2005: Polygon weather warnings—A new approach for the National Weather Service. Preprints, *21st Int. Conf. on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology,* San Diego, CA, Amer. Meteor. Soc., CD-ROM, P14.1.

Weisman, M. L., 2001: Bow echoes: A tribute to T.T. Fujita. *Bull. Amer. Meteor. Soc.,* **82,** 97–116.

Weiss, S. J., and M. D. Vescio, 1998: Severe local storm climatology 1955–1996: Analysis of reporting trends and implications for NWS operations. Preprints, *18th Conf. on Severe Local Storms,* Minneapolis, MN, Amer. Meteor. Soc., 536–539.

——, J. A. Hart, and P. R. Janish, 2002: An examination of severe thunderstorm wind report climatology: 1970–1999. Preprints, *21st Conf. on Severe Local Storms,* San Antonio, TX, Amer. Meteor. Soc., 446–449.

Wheatley, D. M., R. J. Trapp, and N. T. Atkins, 2006: Radar and damage analysis of severe bow echoes observed during BAMEX. *Mon. Wea. Rev.,* **134,** 791–806.

Yuan, M., M. Dickens-Micozzi, and M. A. Magsig, 2002: Analysis of tornado damage tracks from the 3 May tornado outbreak using multispectral satellite imagery. *Wea. Forecasting,* **17,** 382–398.