7A.2

HAZARDS OF LONG-LIVED, CONVECTIVELY GENERATED HIGH WIND EVENTS IN THE UNITED STATES

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1. INTRODUCTION

Convectively generated windstorms occur over a wide array of temporal and spatial scales (Fujita and Wakimoto 1981); however, the longer-lived, larger-scale, and most intense of these windstorms are termed "derechos" (Hinrichs 1888, Johns and Hirt 1987). Johns and Hirt (1987), Johns (1993), and Wakimoto (2001) have claimed that derechos account for much of the structural damage and casualties resulting from convectively induced non-tornadic winds. Yet, to date, no study has thoroughly examined the hazards (defined as any derecho that results in a human casualty or any amount of reported economic damage) associated with U.S. derechos. In order to illustrate the future risk and potential vulnerability of the U.S. population to these extreme windstorms, the following study reveals the hazards associated with derechos by examining casualty statistics and damage estimates of events that occurred during the 18-yr period 1986-2003.

2. DATA AND METHODOLOGY

2.1 *Derecho Dataset*

The contiguous U.S. derecho dataset utilized in this study was compiled through several sources including two long-term climatological studies. First, a dataset containing 230 derechos identified by Bentley and Mote (1998) and Bentley and Sparks (2003) for the period 1986-2000 was obtained (M. L. Bentley personal communication). Second, a derecho database produced by Michael Coniglio of the Cooperative Institute for Mesoscale Meteorological Studies, consisting of 244 events from 1980-2001, was acquired via the Internet [http://www.nssl.noaa.gov/users/mcon/public_html/derlist.htm] (see Coniglio and Stensrud (2004), Coniglio et al. (2004)). Finally, the authors documented derechos for 2002-2003 by examining the SPC's daily on-line severe storm reports, SPC's severe thunderstorm event database, *Storm Data*, and *SeverePlot* (Hart 1993). In order to be consistent with the derecho identification methodology outlined by Coniglio and Stensrud (2004), all derechos that were previously not identified utilizing radar data (namely, those events identified by Bentley and Sparks (2003)) were verified using available radar resources from NCDC, SPC, and NASA's Global Hydrology Resource Center. All events in the database were scrutinized in order to make sure that multiple swaths of damage were a part of the same MCS as indicated by the radar data. Events that did not verify were removed from the dataset.

All derechos that were identified or compiled for this study met a set of consistent criteria. This set of criteria is analogous to that proposed and utilized by Bentley and Mote (1998), Bentley and Sparks (2003), Evans and Doswell (2001), Coniglio and Stensrud (2004; their "low-end" criteria), and Coniglio et al. (2004). [See P4.4 (this volume) for further details on this dataset]

2.2 *Casualty Data*

Since 1959, *Storm Data* has been the primary source of severe event data utilized by meteorologists and climatologists for locating areas of storm damage and determining the number of casualties produced by significant weather events. Although *Storm Data* contains the best information on storms affecting the U.S., it is *not* all-inclusive owing to the difficulties inherent in the collection of these types of data. Despite inherent problems with *Storm Data* (see Curran et al. 2000, Changnon 1999), it is the only consistent data source for storm-induced casualties for the period of record.

For a particular derecho event, *Storm Data* casualty statistics were coordinated with the derecho wind report data in a GIS to ensure that all casualties were a consequence of the straight-line winds from a corresponding derecho. Fatality data were obtained and tabulated for both hurricanes and tornadoes in an attempt to compare derecho fatalities with those attributable to hurricanes and tornadoes. Only hurricane fatalities produced by a landfalling or "near-miss" (i.e., in which the outer bands of the hurricane made it onto the contiguous U.S. shoreline) hurricanes were included in the hurricane fatality statistics.

2.3 *Damage Estimates*

Initially, *Storm Data* was utilized to estimate damage totals for derechos in this study. However, estimates extracted from *Storm Data* were promptly ruled inadequate because 1) damage estimates produced by NWS offices and compiled within the publication are arbitrary and subjective; 2) in few instances are NWS offices provided with legitimate damage estimates from necessary parties, emergency managers, or insurance companies; 3) reporting inconsistencies and a difference in reporting policies between NWS offices (R. L. Beasley personal communication); and 4) lack of estimates for described damages. Thus, a second, independent, record of estimated losses to the

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insurance industry was employed to provide a potential assessment of the insured losses due to derechos and to illustrate further the major drawbacks when estimating damage totals using *Storm Data*. These data – the Property Claims Service's (PCS) catastrophe database – were obtained from the Insurance Services Office, Inc (ISO; G. Kerney personal communication). The catastrophe database includes estimated industry-wide insurance payments for property lines of insurance covering fixed property, building contents, time-element losses, vehicles, and inland marine diverse goods and properties.

For each qualifying thunderstorm-caused catastrophe, the PCS dataset included the event's date(s), the conditions/perils causing the losses, and the amount of insured losses by state. Unfortunately, the insured losses are estimated for *all* storm perils, making it difficult to separate the cost of each peril (e.g., hail from wind). In effect, then, extracting only derecho wind damage loss from the PCS estimates was not possible except in a single case (20 November 1989) where the only peril associated with the catastrophe was wind. In all other cases, losses from flooding, hail, and/or tornadoes were included in the catastrophe database. In these situations, only insured damage from derechos that lack considerable tornado, hail, and flood events were tallied utilizing the PCS data. In making this subjective judgment, the use of detailed verbal descriptions of damage that often accompany the events in *Storm Data*, the analysis utilities of NCDC's Severe Storm Event database, and the mapping utilities of *SeverePlot* were employed to assure that the damage losses were predominantly due to the straight-line winds associated with a derecho.

3. RESULTS

3.1 *Casualties*

There were 153 fatalities during the 18-yr period of record attributable to damaging straight-line winds from derechos (Table 1). The number of fatalities per year is highly variable – from 21 in 1998 to no fatalities in 1988. Examining the derecho fatalities spatially indicates an interesting distribution that does not necessarily correspond with derecho frequencies across the U.S (Fig. 1). Three northern states, Michigan, New York, and Ohio, contain nearly 37% of all derecho fatalities. This is somewhat counterintuitive as one would expect the highest fatality rates in regions with the greatest likelihood of derecho occurrences (i.e., across the south-central Great Plains or Midwest; see Bentley and Sparks (2003) and Coniglio et al. (2004)). Several possible explanations could account for this unusual distribution, including: 1) the tendency for more outdoor-related activities in state parks and wilderness areas of Michigan and New York; 2) boating activities along the Great Lakes; 3) the increased likelihood of particularly intense, warm-season derechos across the northern-tier of the U.S. (Coniglio and Stensrud 2004); 4) a heightened awareness of severe storms by people in the southern Great Plains states due to the high frequency of extreme thunderstorm-related perils in this region; and 5) the existence of better warning systems in the southern Great Plains. Thus, it is possible that there is some underlying integration of both physical and social vulnerabilities attributable to the observed derecho fatality distribution (Riebsame et al. 1986).

When examining derecho fatalities by type, boating and vehicular deaths accounted for nearly 50% of all fatalities (Fig. 2). In the majority of cases, vehicular fatalities occurred in one of three ways: 1) overturned tractor semi-trailer; 2) felled tree landing on automobile;

	Derechos			Thunderstorm Winds	
Year	**Events**	**Deaths**	**Injuries**	**Deaths**	**Injuries**
1986	10	6	134	-	-
1987	14	8	113	-	-
1988	2	0	3	-	-
1989	15	13	126	-	-
1990	10	7	196	-	-
1991	11	6	157	-	-
1992	12	2	136	-	-
1993	13	2	154	25	461
1994	21	6	93	15	337
1995	31	18	212	38	473
1996	24	11	142	23	335
1997	25	13	72	37	425
1998	42	21	606	41	860
1999	32	14	146	29	325
2000	31	10	87	25	296
2001	26	9	123	17	341
2002	29	6	42	17	287
2003	29	1	63	19*	226*
Sum:	377	153	2605	*286*	*4366*
Mean:	20.9	8.5	144.7	*26*	*396.9*
Max:	42	21	606	*41*	*860*
Min:	2	0	3	*15*	*226*

Table 1. The number of derechos, fatalities, and injuries for the 18-yr period of record. Included are deaths and injuries from thunderstorm winds during years in which tallies were available in *Storm Data*. Asterisks indicate preliminary data.

Figure 1. U.S. derecho fatalities by state 1986-2003. Circles indicate fatality locations.

or 3) an automobile driven into a felled tree. Marine fatalities principally occurred as drownings when either sailing vessels or motorized boats were overturned due to high derecho winds.

On average, 145 injuries per year were attributable to derechos; however, annual values were highly variable with a maximum of 606 injuries occurring in 1998 and a minimum of 3 injuries occurring in 1988 (Table 1). In terms of spatial distribution (not shown), derecho injuries were clustered around several specific regions including 1) Lake Michigan; 2) the Interstate 95 corridor in the Northeast; 3) the Ohio River Valley; 4) the interior of the Southeast; and 4) the south-central Great Plains. Like fatalities, the higher frequency of injuries tends to occur outside of regions of the highest derecho frequency maxima. The states of Kentucky (333 injuries), Michigan (200), and Illinois (187) are highest in terms of derecho injuries.

Unlike fatalities, a considerable number of the injuries reported in *Storm Data* are not accompanied by a description of how the injuries occurred other than that they were caused by thunderstorm-related winds. In fact, nearly 40% of all derecho injuries reported in *Storm Data* have no description of injury type. The remaining 60% of injuries were classified according to how or where the injury occurred revealing a different distribution by type than derecho fatalities. Injuries in mobile homes (23% of classifiable injuries) and vehicles (21% of classifiable injuries) lead all other injury types by a considerable margin. Other high-frequency injury types (accounting for nearly 10% of classifiable injuries each) include camping, flying debris, permanent structures/homes, and temporary structures (i.e., recreational or special-event tents).

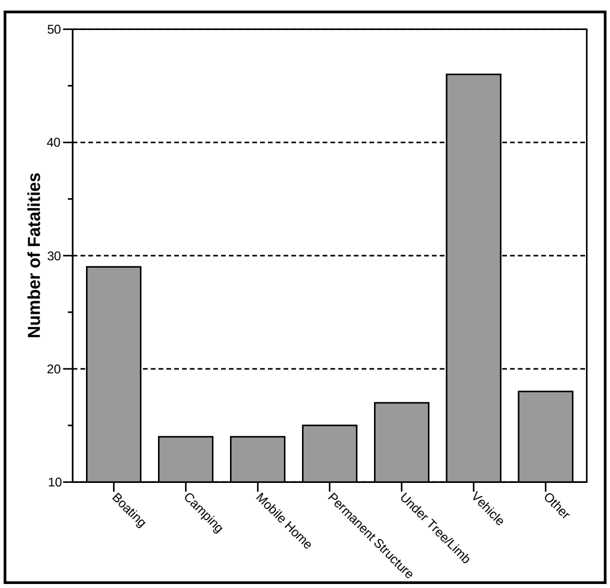

Figure 2. 1986-2003 derecho fatalities as classified by location of occurrence or type of death.

3.2 C*asualty Comparisons*

Comparing derecho casualties to those produced by all thunderstorm winds for the period 1993-2003 indicates that derechos *do not* account for the majority of casualties due to non-hurricane and non-tornadic winds (Table 1). In terms of fatalities (injuries), derechos accounted for 38.8% (39.9%) of all fatalities (injuries) caused by thunderstorm winds during this 11-yr period.

In order to illustrate that derechos can be as hazardous as most hurricanes and tornadoes, a comparison between derecho-induced fatalities and those produced from contiguous U.S. hurricanes and tornadoes was constructed for the derecho dataset period of record (Table 2). Derecho fatalities exceed fatalities from F0 and F1 tornadoes by a wide margin but account for fewer deaths than those produced by F0, F1, and F2 tornadoes combined. If one considers that F0 and F1 tornadoes account for nearly 88% of all U.S. tornadoes from 1986-2003, then derechos exceed the number of fatalities produced by most tornadoes.

Hurricane fatalities surpass those caused by derechos; though, if the anomalously high fatality rates from Floyd (56) and Fran (34) are removed, the fatality statistics are essentially comparable. It is important to consider that hurricane fatality statistics *include* deaths related to hurricane-spawned tornadoes, floods, and rip-tides. For this study, those deaths attributable to tornadoes embedded within or floods attributable to derecho-producing convective systems were not included. Hence, it is possible that fatalities from derechos exceed those fatalities induced solely by hurricane winds.

Year	Derechos	Hurricanes	F0 and F1 Tornadoes	F0, F1, and F2 Tornadoes
1986	6	8	0	10
1987	8	0	2	11
1988	0	4	3	16
1989	13	37	9	21
1990	7	0	2	9
1991	6	15	8	12
1992	2	23	3	5
1993	2	3	6	19
1994	6	8	2	9
1995	18	23	3	12
1996	11	48	3	9
1997	13	2	7	14
1998	21	5	2	17
1999	14	60	6	14
2000	10	1	1	5
2001	9	0	5	19
2002	6	0	6	22
2003	1	17	3	5
Sum	153	254	71	229

Table 2. The number of fatalities due to derechos, hurricanes, F0 and F1 tornadoes, and F0, F1, and F2 tornadoes for the 18-yr period utilized in this study.

3.3 *Damage Estimates*

Previous studies that have documented derechos have very limited descriptions regarding damage summaries or estimates. When estimates are presented for events, they are typically deduced from *Storm Data*. There is only one case in the literature that highlights, in detail, the damaging potential of a derecho. Fujita and Wakimoto (1981) provided extensive documentation of the 16 July 1980 derecho that produced widespread damage across large areas of Michigan, Illinois, Wisconsin, and Minnesota. They indicated that this storm produced approximately $650 million in damage as it traversed the four-state region. Accounting for inflation (to 2003 dollars), this storm produced an estimated $1.3 billion in damage from strictly straight-line winds. This estimate exceeds many damage tallies from U.S. hurricanes and is larger than the inflation-adjusted damage estimates from all major tornadoes that have affected the U.S. from 1890-1999 (Brooks and Doswell 2001). This single event illustrates that derecho damage can exceed the damage from most hurricanes and tornado events affecting the contiguous U.S.

Unfortunately, detailed damage summaries as that provided by Fujita and Wakimoto (1981) are not available for other derechos. Therefore, the PCS catastrophe dataset was employed to estimate the impact derechos have had on the insured built environment. In total, 206 of the 377 derechos in the dataset (54.6%) were associated with 129 separate PCS catastrophe events. All thunderstorm perils (flooding, hail, tornadoes, and wind) associated with these 129 catastrophe events were responsible collectively for nearly $33 billion (2003 dollars) in insured losses. In some cases multiple derechos (i.e., derecho "families" (Bentley and Sparks 2003, Ashley et al. 2004)) were a part of the same PCS defined catastrophe.

A detailed process was utilized to extract PCS damage estimates for derechos. Estimated insured losses due to derechos are provided to illustrate the devastating impact these events can have on the built environment and compare these statistics with analogous data from U.S. hurricanes. A number of extremely intense derechos or families (e.g., 08 July 1993, 15 May 1998 family, 4-7 July 2003 family) were excluded from this analysis because these events were accompanied by considerable damage produced by flooding, hail, or tornadoes and, therefore, could not be accurately assessed for damages solely due to derecho winds. Hence, the "high-end" damage potential of the most intense derechos is likely not illustrated in this analysis.

In all, nine derechos and derecho families producing more than $100 million in insured losses were identified from the methods utilized in this study. The costliest derecho identified was the 31 May 1998 event that affected the Great Lakes region. This event was responsible for $432 million in insured property losses across the states of Minnesota, Wisconsin, and Michigan. Interestingly, this is the only event in which *Storm Data* property damage estimates exceeded values obtained from the insured losses estimated from PCS. In all other derecho cases from 1996-2002, PCS estimates exceed, in some instances, by an order of magnitude, the estimates provided by *Storm Data*. *Storm Data* accounts for only 39.6% of the PCS damage losses from the 27 events in which both *Storm Data* and PCS data were available. This is especially troubling since *Storm Data* estimates account for both insured and non-insured losses while PCS data report only insured losses. This suggests that estimated damage totals from derechos can not be deduced from *Storm Data*.

The PCS catastrophe database includes insured losses from hurricanes and is the primary dataset employed by NOAA's Tropical Prediction Center to estimate damage from hurricanes. The most damaging hurricanes affecting the U.S. from 1986-2003 were compared to the estimated insured damages from derechos obtained from this study (Table 3). Clearly, certain hurricanes (e.g., Andrew, Hugo, etc.,) are in a category unto themselves and result in enormous insured damage estimates. However, individual derechos or families of derechos appear to approach the damage potential of some of the most damaging hurricanes in the 18-yr period of record. For example, the 31 May 1998 case exceeded estimates from Hurricane Erin and Bonnie and approached the insured losses produced by Hurricane Lilly. It is likely that other extreme derechos events have exceeded the 31 May 1998 case (e.g., 16 July 1980) and are comparable to the most damaging hurricanes in U.S. record.

3.4 *Forest Blowdowns*

Not included in either PCS or *Storm Data* estimates is the impact derechos have on both private and public forests throughout the U.S. Several derechos have produced extensive forest blowdowns including the "Independence Day Downbursts" of 04 July 1977 (3440 km^2 of forest affected; see Fujita 1985), the two Minnesota derechos of 13 and 14 July 1995 (810 km^2 destroyed; *Storm Data* 1995), the "Adirondack" derecho of 15 July 1995 (3642 km^2 affected; 505 km^2 sustaining moderate to severe damage; *Storm Data* 1995), and the "Boundary Waters" derecho of 04 July 1999 (2691 km^2 affected; 1934 km^2 destroyed; Parke and Larson 2004, Price and Murphy 2003). The meteorological community often labels these blowdown events as Pakwashs after the Pakwash Provincial Forest in Northwest Ontario, Canada, that was impacted severely by a derecho that occurred on 18 July 1991. Derecho-produced blowdowns have altered forest landscapes and community dynamics by influencing tree mortality rates, reducing tree size and structure, decreasing forest diversity, and modifying species composition by advancing succession status (Peterson 2000).

The financial impact these events have on forests is difficult to approximate. Some assessments have been provided including a monetary estimate of the impact the 15 July 1995 derecho had on the Adirondack Park in New York. The New York Department of Environmental

Year	Storm	Cat.	PCS Estimate (Millions Of $)
1992	Andrew	5	18,985
1989	Hugo	4	3,993
1995	Opal	3	2,411
1999	Floyd	2	2,117
1996	Fran	3	1,803
2003	Isabel	2	1,685
1998	Georges	2	1,264
1991	Bob	4	766
2002	Lili	1	437
1998	31-May	-	432
1995	Erin	1	431
1998	Bonnie	3	394
1998	*7-Sep	-	252
1998	4-Jun/5-Jun/6-Jun	-	191
1989	4-May	-	180
2001	16-Feb	-	176
1999	26-Apr	-	162
1996	Bertha	2	152
2002	*9-Mar	-	137
1999	Irene	1	108

Table 3. The most damaging hurricanes that have directly impacted the contiguous U.S. from 1986-2003 in comparison to the most damaging derechos identified in this study utilizing the procedures outlined in the methodology. Cat. indicates the intensity (using the Saffir-Simpson Hurricane Scale) of each hurricane as it made landfall or approached the coast (for non-landfalling hurricanes). All estimates account for inflation and are adjusted to 2003 dollars. Asterisk indicates events occurred as families.

Conservation indicated that the timber damage due to the derecho was estimated at 1 billion board feet with an estimated value of $234 million (2003 dollars; *Storm Data* 1995). Unfortunately, damage to forests is not the only hazard realized by these events. In some cases, campers and hikers visiting these forests during the height of the tourist season have been killed or seriously injured by derecho-felled trees.

4. CONCLUSION

Assessing the human and economic impacts of derechos has received considerable less attention in comparison to "large-impact" events such as floods, hurricanes, and tornadoes. By consolidating and extending the record of U.S. derechos, this investigation quantitatively and qualitatively revealed the impacts derechos have had on the U.S. from 1986-2003. Results indicate that derecho hazards can be as substantial as hurricanes and tornado hazards.

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