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Characterization and Analysis of Hailstorms in the Northern Great Plains

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ABSTRACT

Hail is a meteorological occurrence that appears frequently during spring and summer across the Northern Great Plains. This paper first characterizes patterns associated with reported hail events occurring within a five-state region (North Dakota, Minnesota, South Dakota, Iowa, and Nebraska) from 2000-2006 using records taken from the National Climatic Data Center (NCDC) Severe Storms database. Patterns of interest include the seasonality of hail activity for each state and across the region, observational bias in the reporting of hailstone size, and temporal trends in the number of hail reports across the region and in each state. This paper then explores a possible link between the solar cycle and regional hail activity. Daily observations of solar radio flux (at 10.7 cm) and National Weather Service hail reports dating from 1956-2006 were compared. A chi-squared goodness of fit analyses showed possible associations exhibiting weaker significance in Solar Cycles (S.C.) 21 and 22, and higher significance during S.C. 23. The recent appearance of a significant linkage may be due to changes in reporting effort, weather patterns, or both. Further study is required to distinguish observational artifacts from geophysical effects. Because hail activity is common to the Northern Great Plains, a deeper understanding of the effects of the solar cycle on hail and also the spatial and temporal patterns associated with regional hail may prove beneficial for climate prediction, weather forecasting, and underwriting of crop-hail insurance.

INTRODUCTION

Hail is a natural, though unusual, form of precipitation that routinely occurs only in certain regions of the planet. It can have a range of effects on people and property. For the city dwellers, hail may be, with exceptions, no more than a minor annoyance inflicting minimal damage. However, for farmers and ranchers, hail can have severe impacts and even disrupt the local agricultural economy through substantial crop or forage damage and even loss of livestock. Hail damage to crops is complex function contingent on several variables: frequency, intensity, hailstone size, crop phenology, prevailing windspeed and direction during the hailfall, and the growing conditions in the days after the event (Parker et al. 2005).

In this paper, patterns associated with the National Weather Service (NWS) reports of hail recorded from 2000 to 2006 in the Northern Great Plains region (North Dakota, Minnesota, South Dakota, Iowa, and Nebraska) are characterized. The first aim of the paper is to summarize the seasonal pattern of hail reports and illustrate an apparent bias in reporting of hailstone size. The second aim is to investigate possible linkages between the phase of the solar cycle and hail occurrence across the region. Interest in this linkage arose upon reading a recent publication suggesting linkages between solar activity and climate mode effects (Kryjov & Park 2007).

METHODS

Hail reports were accessed through the Severe Storms database maintained by the National Climatic Data Center (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms). The database allows access to NWS storm reports filtered by state, date range, or event type. Only hail events with hailstone size of at least three-quarters of an inch (~19 mm) are recorded in the database. Hail reports recorded within the five-state region during 2000 through 2006 (7 years) were imported to spreadsheets for analysis. Patterns of interest included (a) hail report frequency by month for the region and each state, (b) frequency distribution of hailstone size reports; (c) interannual variability of reports; and (d) temporal trends in hail reports across state and region. Mann-Kendall nonparametric trend analysis (de Beurs & Henebry 2004) was performed using a Visual Basic/Excel implementation (Grimvall & Libiseller 2003).

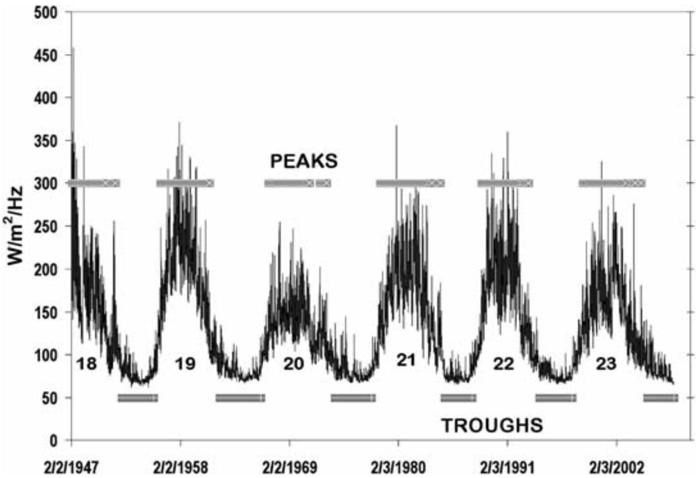

Figure 1. Daily solar flux at 10.7 cm. Periods determined to be high, or greater than 150 Wm²/Hz, and periods determined to be low, or less than 85 Wm²/Hz, are highlighted by the gray symbols above and below the respective time periods. Solar cycle numbers indicated.

Daily observations of solar flux at wavelength 10.7 cm are available through the National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) website, SPIDR (Space Physics Interactive Data Resource; (http://spidr.ngdc.noaa.gov/spidr/). The observations were divided into different phases of the solar cycle by two schemes (Figure 1). Extended periods of flux activity greater than 150 W/m²/Hz were classified as "Peak" periods; extended periods of flux activity lower than 85 W/m²/Hz were classified as "Trough" periods; "Rising Limb" and "Falling Limb" periods were those observations falling after the Trough and Peak periods, respectively (Table 1).

Table 1. Hail reports from 1956 through 2006 allocated to phases of the solar cycle.

	Trough	Rising Limb	Peak	Falling Limb	RL + FL	Total	Reports/day
Total # of observation days	5893	2492	6808	3733	5865	18567	N/A
Total hail reports in region	14153	4433	13606	7837	12270	40029	2.156
Hail reports in NE	4345	1498	3857	2227	3725	11927	0.642
Hail reports in MN	3225	999	2598	1253	2252	8075	0.435
Hail reports in IA	2409	821	2544	1866	2687	7640	0.411
Hail reports in SD	2457	594	2630	1677	2271	7358	0.396
Hail reports in ND	1717	521	1977	814	1335	5029	0.271

In addition to this four-class scheme, counts during each limb period were summed to make a three-class scheme. A Chi-Squared goodness of fit test (Zar 1984) was used to evaluate whether there was a disproportionate number of hail reports occurring during particular phases of the solar cycle. Tests were applied to each state and to the five-state region using both the four-class and three-class schemes for the entire record of observations from 1956 through 2006 (Table 2) as well as by solar cycle (Tables 3, 4).

Table 2. Chi-squared analyses to evaluate disproportionate association of hail reports with particular phases of the solar cycle over the period 1956 through 2006.Region

	χ^2 statistic (four-class)	p-values for *d.f.*=3	χ^2 statistic (three-class)	p-values for *d.f.*=2
Region	3.00	>0.10	0.72	>0.10
Nebraska	1.29	>0.10	1.18	>0.10
Iowa	1.27	>0.10	1.21	>0.10
Minnesota	3.13	>0.10	3.10	>0.10
South Dakota	3.42	>0.10	0.13	>0.10
North Dakota	1.13	>0.10	0.63	>0.10

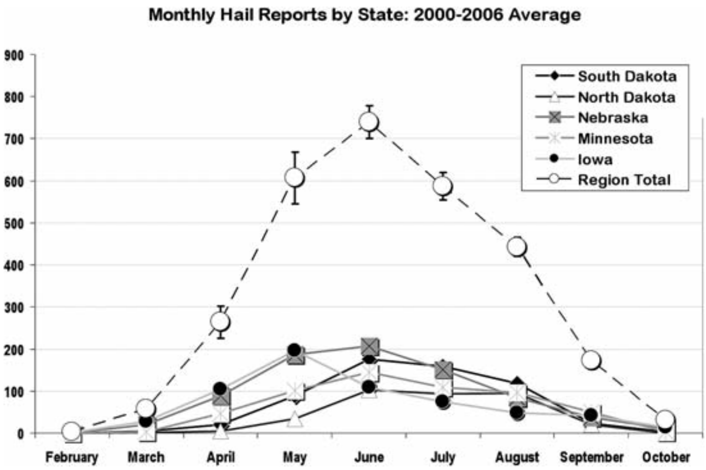

Figure 2. Seasonality of hail reports in the Northern Great Plains. Note the divergence in peak timing across the region and the high interannual variability of reports in May.

RESULTS

Figure 2 illustrates the seasonality of hail report activity for each state and across the region from 2000 through 2006. On average across the region, the highest number of hail reports occurs in the May-June time period. However, in the Dakotas, the average peak period for hail reports occurs later, during June-July time frame. Also, an interesting point is that Iowa's average peak was during May and then drops below the average of the four other states through the rest of the growing season. There is also a distinct pattern of higher interannual variability during May than the rest of the year, as shown by the errors bars in Figure 2. The variability is not symmetrical on either side of the June peak: interannual variability for July is much lower than for May.

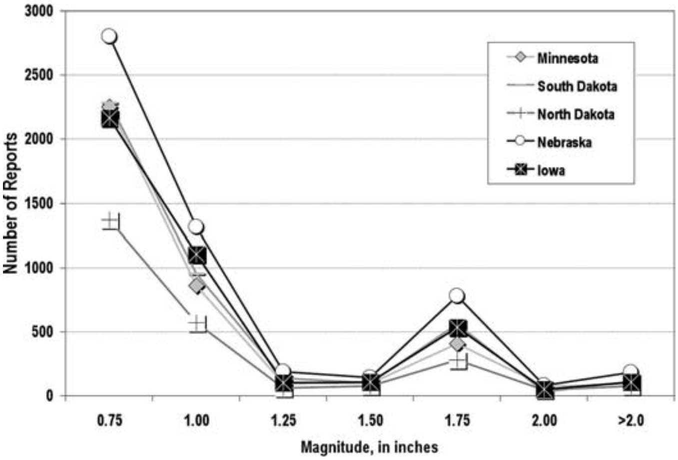

Figure 3. Frequency distribution of hailstone size reports. Note the anomalous spike in reports at 1.75 inches. This appears to be observational bias.

Figure 3 reveals an observational bias in the reporting of hailstone size. The minimum reporting size for hail events is three-quarters of an inch with the most common increment being one-quarter of an inch (6.35 mm). There is a clear spike in the number of reports at 1.75", contrary to expectation.

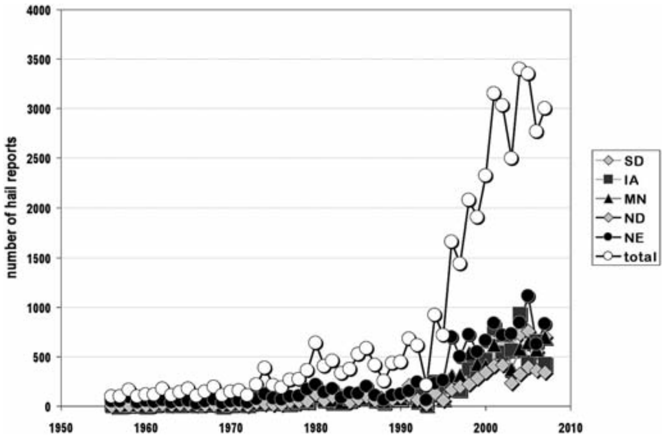

Figure 4. Total amount of hail events recorded in the Northern Great Plains region from 1956-2007, as well as for each state in the region. Note the significant increase in reports in the mid-1990s.

Figure 4 shows strong temporal trends in the number of reports in the region and in each state. There is a remarkable increase in reports in the mid-1990s and this increase is fairly consistent across states. Figure 5 captures the proportional contribution of each state to the regional total. An 11-year retrospective moving average filter was applied to the proportional reports to reduce the possible effects of the solar cycle. It is clear that there has been a decreasing trend of reports in Nebraska (Mann-Kendall test = -4.02, $p<0.001$) and increasing trends in both South Dakota (Mann-Kendall test = 1.70, $p<0.1$) and North Dakota (Mann-Kendall test = 2.95, $p<0.01$). Trends in Iowa and Minnesota were not significant at $p<0.1$.

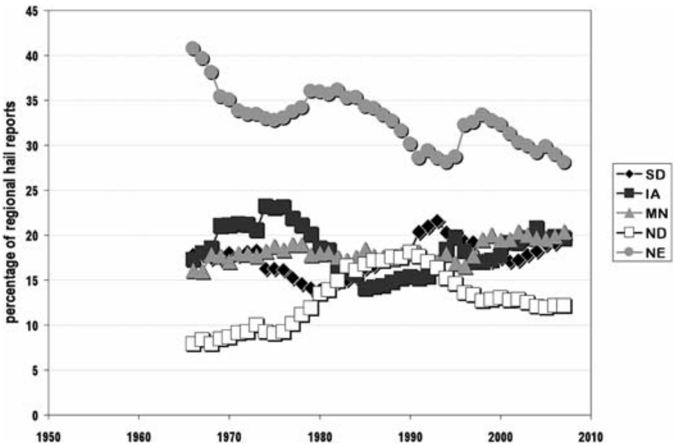

Figure 5. Trends in percentage of total region-wide hail reports by state filtered by an 11-year moving average. Nebraska is significantly decreasing while the Dakotas are significantly increasing.

Average daily rate of hail report occurrence during the entire observational record was just over 2.2 across the region, with rate in Nebraska more than twice that of North Dakota (Table 1). The null hypothesis of no linkage between the solar cycle and hail occurrence makes a prediction of an even distribution of hail reports across the phases of the solar cycle. When viewing along the entire observational record, the occurrence of hail reports across the region and in each state was not significantly disproportionate (Table 2). However, Figures 4 and 5 reveal significant changes in reporting effort during the observational record that could obscure more subtle associations between the solar cycle and hail reports. Table 3 shows the results of the chi-squared analyses for the five-state region applied at the level of solar cycle. (In 2008, we are at the very end of Solar Cycle 23.) There is no association in Solar Cycle (S.C.) 20 and weak association in S.C. 21 and 22; by S.C. 23, the association is highly significant for both the four-class and three-class schemes. Table 4 extends the analysis to each state. Only in Nebraska is there not a highly significant association in S.C. 23. In the Dakotas the association is highly significant starting as early as S.C. 21.

Table 3. Chi-squared analyses to evaluate disproportionate association of hail reports across the five-state region with particular phases of the solar cycle for solar cycles (SC) 20 through 23.

SC	Variable	Trough	Rising Limb (RL)	Peak	Falling Limb (FL)	RL + FL	Total	χ^2 statistic (four-class)	p-values for *d.f.*=3	χ^2 statistic (three-class)	p-values for *d.f.*=2
20	Total Days	1310	1142	632	931	2073	4015				
20	Hail Reports	437	436	243	454	890	1570	2.140	>0.10	1.204	>0.10
20	Reports/Day	0.334	0.382	0.385	0.488	0.429	0.391				
21	Total Days	1476	415	1645	484	899	4020				
21	Hail Reports	1060	288	1830	678	966	3856	6.705	**<0.10**	3.687	>0.10
21	Reports/Day	0.718	0.694	1.112	1.401	1.075	0.959				
22	Total Days	1134	316	1433	663	979	3546				
22	Hail Reports	1547	213	1980	536	749	4276	5.175	>0.10	5.100	**<0.10**
22	Reports/Day	1.364	0.674	1.382	0.808	0.765	1.206				
23	Total Days	1279	619	1327	698	1317	3923				
23	Hail Reports	4632	3496	8987	5895	9391	23010	9.045	***<0.05***	7.142	***<0.05***
23	Reports/Day	3.62	5.648	6.772	8.446	7.131	5.865				

DISCUSSION & CONCLUSION

The quality of the hail report data is suspect in several respects. There is apparent observational bias (Figure 3). The temporal trends in number of reports (Figure 4) and proportional contribution of each state to the regional total (Figure 5) suggest a systematic change in reporting effort in the mid-1990s. There are likely also to be effects arising from changes in population density, observer mobility, weather awareness, and, possibly climate change. Resolution of these effects must be left to another study.

The linkage between solar cycle and hail occurrence appears stronger in the most recent solar cycles than earlier. The recent appearance of a significant linkage may be due to changes in reporting effort or to weather patterns. More data and analyses will be required to distinguish observational artifacts from geophysical effects.

Table 4. Chi-squared analyses to evaluate disproportionate association of state-level hail reports with particular phases of the solar cycle for solar cycles 20 through 23.

	χ^2 statistic (four-class)	p-values for *d.f.*=3	χ^2 statistic (three-class)	p-values for *d.f.*=2
Nebraska				
S.C. 20	1.87	>0.10	0.89	>0.10
S.C. 21	6.62	**<0.10**	5.37	**<0.10**
S.C. 22	3.19	>0.10	2.23	>0.10
S.C. 23	3.85	>0.10	3.55	>0.10
Minnesota				
S.C. 20	6.52	**<0.10**	6.46	***<0.05***
S.C. 21	3.60	>0.10	1.04	>0.10
S.C. 22	10.86	***<0.05***	10.35	***<0.01***
S.C. 23	8.03	***<0.05***	8.00	***<0.05***
Iowa				
S.C. 20	4.42	>0.10	1.18	>0.10
S.C. 21	1.51	>0.10	0.56	>0.10
S.C. 22	3.42	>0.10	2.83	>0.10
S.C. 23	20.31	***<0.01***	13.80	***<0.01***
South Dakota				
S.C. 20	4.42	>0.10	4.42	>0.10
S.C. 21	19.59	***<0.01***	9.44	***<0.01***
S.C. 22	8.06	***<0.05***	7.48	***<0.05***
S.C. 23	19.25	***<0.01***	9.30	***<0.01***
North Dakota				
S.C. 20	6.22	>0.10	0.89	>0.10
S.C. 21	21.90	***<0.01***	15.16	***<0.01***
S.C. 22	11.34	***<0.05***	9.80	***<0.01***
S.C. 23	9.66	***<0.05***	9.15	***<0.05***

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