MONTANA SEVERE WEATHER CLIMATOLOGY USING GEOGRAPHIC INFORMATION SYSTEM AND GOOGLE EARTH

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Abstract

This study develops a historical climatology of severe convective weather (large hail, severe wind, and tornado) reports across Montana from the 1950s through 2006 using Geographic Information System (GIS) files, Google Earth, and the Storm Prediction Center's severe weather database. These tools help us to analyze the spatial and temporal distributions of the severe weather reports. Several patterns become evident in this analysis. For example, higher severe weather report concentrations are found around roadways and population centers, and report frequency changes through time appear to be impacted by the implementation of the WSR-88D radar and changes in the operations of the National Weather Service. The relationship between topographic features and severe weather reports is also made apparent in this study. A major goal of this study is to provide the Montana forecaster with a background of favored areas for severe weather reports, as well as areas where reports seem to be lacking through time. In turn, this should provide additional guidance in the warning process.

INTRODUCTION

Knowledge of the historical geographic distribution of severe weather reports (i.e., wind gusts at least 50 knots, wind damage, hail at least 0.75 inches in diameter, or tornadoes, per standard National Weather Service (NWS) criteria) is critical in severe convective nowcasting and forecasting. Understanding the favored and unfavored locations for these reports is a fundamental tool in maintaining situational awareness for operational meteorologists. This study will detail the distribution of severe weather reports over Montana since the 1950s in both historical and geographical contexts using Geographic Information System (GIS) files and Google Earth. Thus, a major goal of this work is to build a historical framework to contextualize present severe weather events in Montana across the broad climatology of convective weather.

A study such as this one is easily facilitated using GIS and Google Earth, which are increasingly oft-used computer programs that graphically combine geographic information, including information about topography, highways, political boundaries, and towns with many other variables, including demographics and even severe weather reports. Each variable is commonly referred to as a layer in GIS and Google Earth. With so much spatial variability in natural variables, such as severe weather reports, GIS and Google Earth provide convenient ways to comprehend, organize, and analyze the complexity of this spatial variation. GIS and Google Earth are simply processes to support those who regularly use information at any spatial scale, including weather forecasters, emergency managers, politicians, and many others. Using the results of these tools could enhance a Montana forecaster's awareness of local severe weather reports. For example, numerous spatial gaps in severe weather reports are evident from this study, and the forecaster can use his or her knowledge of these gaps to support a warning decision based on remotely sensed data in the absence of visual reports.

The NWS Storm Prediction Center (SPC) routinely collects reports of severe weather. These reports have been compiled by the SPC, with public access from the database called SeverePlot, developed by Hart and Janish (1999). SPC forecaster Bryan Smith has made these reports readily available for analysis using GIS in the database called SVRGIS, documented in Smith (2006). In this program, one can plot severe reports over user-selected areas and times since the 1950s. The author of the present study has converted all the GIS files to files that can be read in Google Earth.

In the present study, tornado reports are studied from 1950 to 2006, while severe hail and wind reports are from 1955 to 2006. By considering topographical features, as well as highways, towns, or roads, we formulate relationships between overall geography and where higher concentrations of reports have occurred, or even which areas are more likely to receive severe wind, severe hail, and tornado reports.

SPATIAL DISTRIBUTION OF SEVERE REPORTS

In Figures 1-5 and 7-9 below, severe weather reports over the state of Montana have been plotted using GIS. Blue boundaries indicate the CWAs of the Montana NWS offices, with the northeastern-most being that of Glasgow, southeastern-most being that of Billings, and the central-most being that of Great Falls, and the westernmost being that of Missoula. Purple shading indicates areas of higher population density.

Severe wind reports are plotted in Figure 1. Reports based solely on damage without reference to a measured or estimated gust are considered 50-knot wind reports throughout this study. The greater concentrations of severe wind reports appear to be over the eastern half of Montana, especially in northeast Montana, with the Glasgow and Billings CWAs standing out as report density maxima. Interestingly, but not surprisingly, these severe wind reports tend to outline the highway system in Montana, along which are also some of the larger population centers, with Interstates (thicker brown lines) appearing to stand out as axes of enhanced severe wind reports throughout central Montana, with a maximum around Great Falls. Across west central Montana, axes of severe wind reports are apparent through several valleys. Reports seem to be most sparse across southwest Montana, with population centers yielding the greater concentrations of severe wind reports. It will be shown in succeeding figures that the alignment of greater report concentrations for hail and tornado events with population centers and the highway system will mirror that for wind events.

Terrain inhomogeneities are greatest over western Montana, capable of producing localized enhancements to the low-level flow. It is possible that the elevation differentials could help explain the distinct severe wind axis in the valley. Future research could also consider the areal proportion of severe wind reports that are extreme wind reports (i.e., at least 65 knots) and determine if these reports are more concentrated around particular terrain features.

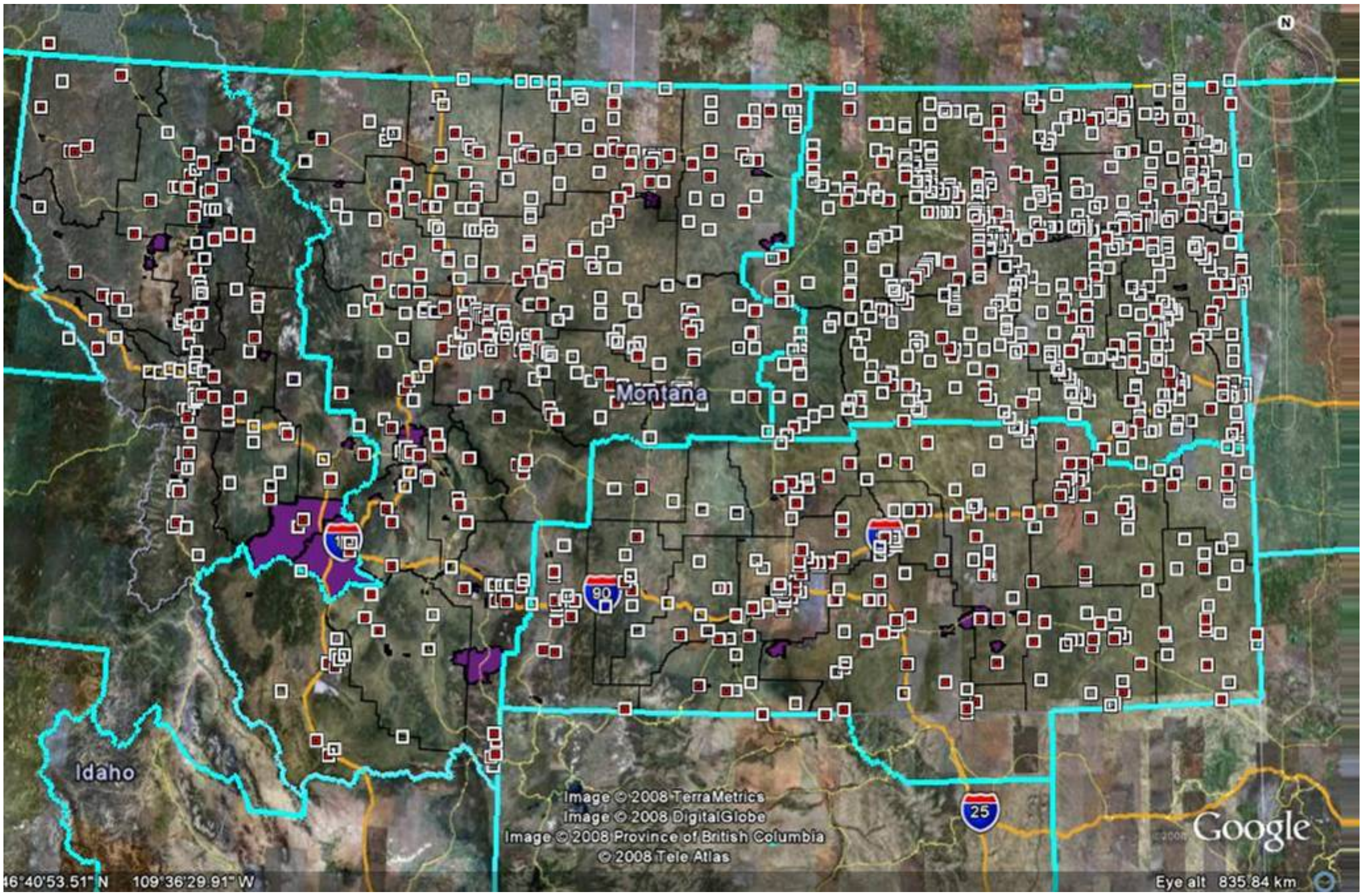

Figure 1: Severe wind reports (white) including 65-knot or more reports (dark red) across Montana from 1955 to 2006.

Figure 2 shows the distribution of severe hail reports through time, with similar concentration axes and maxima to severe wind reports. Sparse reports again appear evident over southwest Montana. What is interesting to note is that there appear to be far more severe hail reports than severe wind reports, especially east of the continental divide. It is possible that these regions more frequently experience richer, deeper, but strongly modified, low-level moisture from the Gulf of Mexico, and thus greater potential instability. It would be expected that this higher-instability air would struggle to cross the continental divide, given the presence steep terrain barriers. The greater number of severe hail reports could possibly be explained by the differences between hail and wind measurements and resulting damage from hail and wind; it is possible that hail is easier to measure than wind, and that more damage could occur from hail than from marginally severe-level winds across Montana.

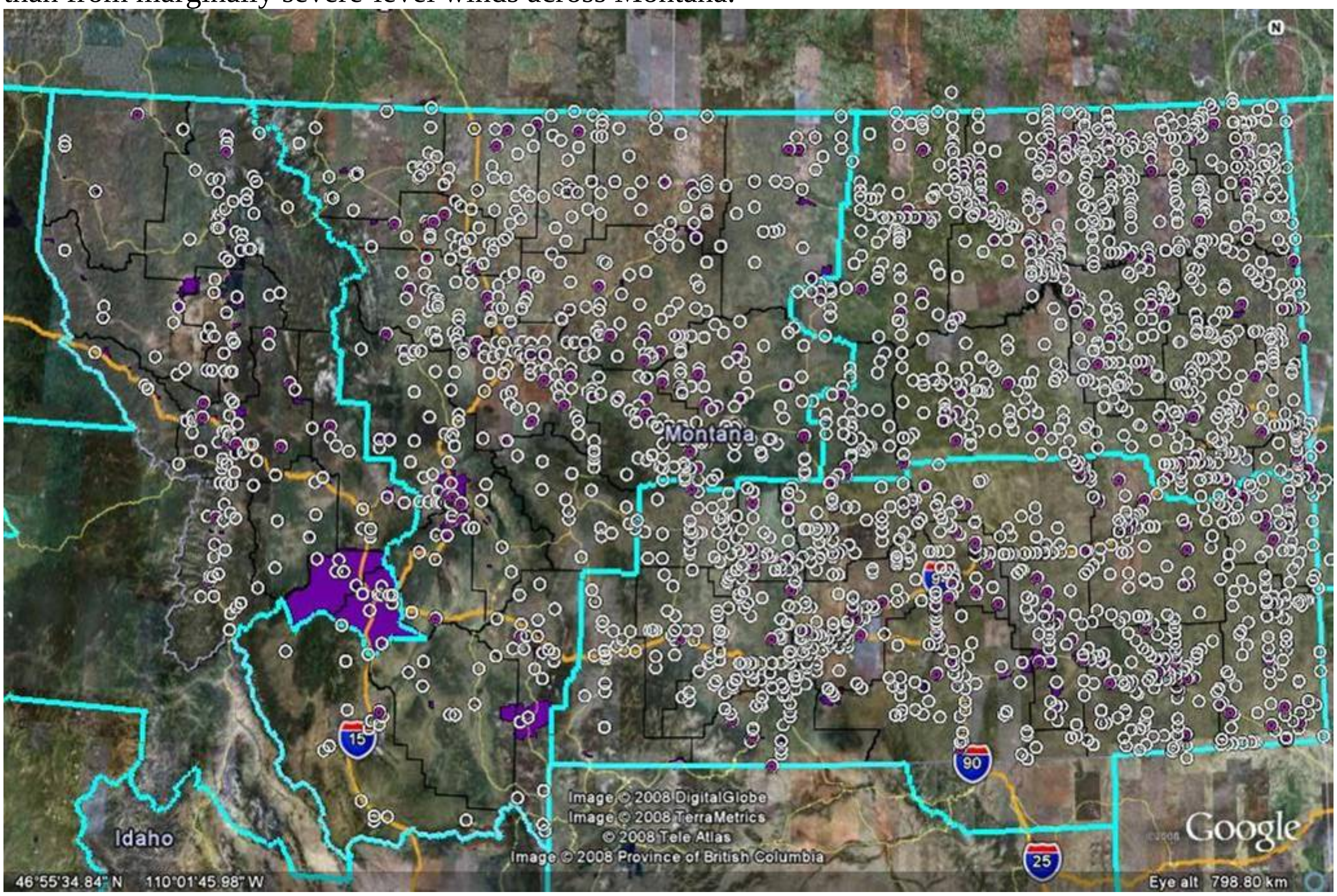

Figure 2: Severe hail reports (white) including 2 inch diameter or greater reports (light purple) across Montana from 1955 to 2006.

Figure 3 shows the distribution of tornado touchdown and lift points, as well as any documented tracks. A deficiency of the database is immediately evident from this figure, as many touchdown and lift points do not appear to be connected by a tornado track. Thus, it is difficult to determine if a touchdown point and a lift point are correlated. Another obvious problem is that some lift points appear isolated from any touchdown point (e.g., far western Montana). Nevertheless, similar to severe hail and wind reports, highways and population centers are highlighted by tornado reports. The highest concentrations of tornado reports exist over the eastern half of Montana, co-incident with the greater concentrations of severe hail reports.

Despite the problems with the tornado database discussed above, what is particularly interesting to note is the maximum in tornado reports over portions of central Montana. These reports appear to coincide with a north-south oriented valley (indicated in a semi-transparent orange rectangle on Figure 3) between two mountain ranges (depicted in darker green shading) – the Little Belt Mountains to the west and the Snowy Mountains to the east. This orientation would support backing of the surface flow for any ambient southerly flow patterns, which are common for severe weather events across central Montana. In turn, low level hodographs would climatologically be enlarged in this region, thus increasing the low level storm-relative helicities, as well as low level mesocyclone and tornado potential. Forecasters have commonly regarded this area as a region of heightened severe weather potential, and this concern is indeed highlighted in this severe climatology. This axis is not as apparent in the severe hail and severe wind report distributions.

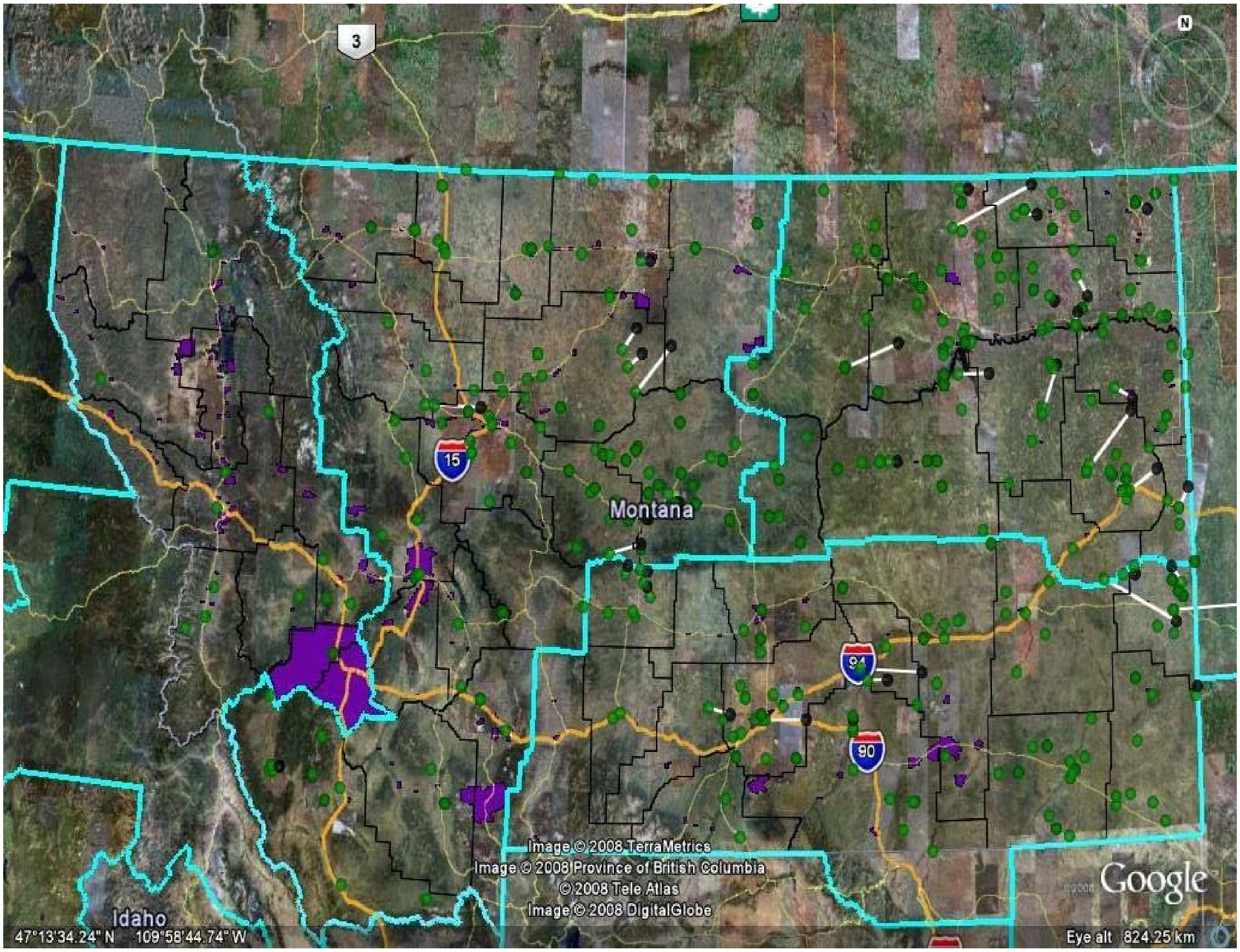

Figure 3: Tornado touchdown points (green), lift points (yellow), and tracks (white) across Montana from 1950 to 2006, with a semi-transparent orange box identifying a critical valley.

Tornado strengths for tornado tracks based on the legacy Fujita scale are plotted in Figure 4. As earlier discussed, not all touchdown and lift points have a documented track associated with them, thus the total number of tracks is less than the either the number of touchdown or lift points. The maxima in eastern Montana are highlighted. The strongest tornadoes are found near the North Dakota border, where those locations (at lower elevations) have the greatest chances of experiencing deeper Gulf of Mexico moisture and stronger instability. Strong tornadoes (i.e., at least F2), though, have been reported as far west as central Montana, where terrain features may be playing a major role in modifying the low-level flow. The set of three F3 tornadoes in central Montana may be an error in the severe weather database, as closer inspection indicates that all three reports are from the same date within 15 minutes of each other.

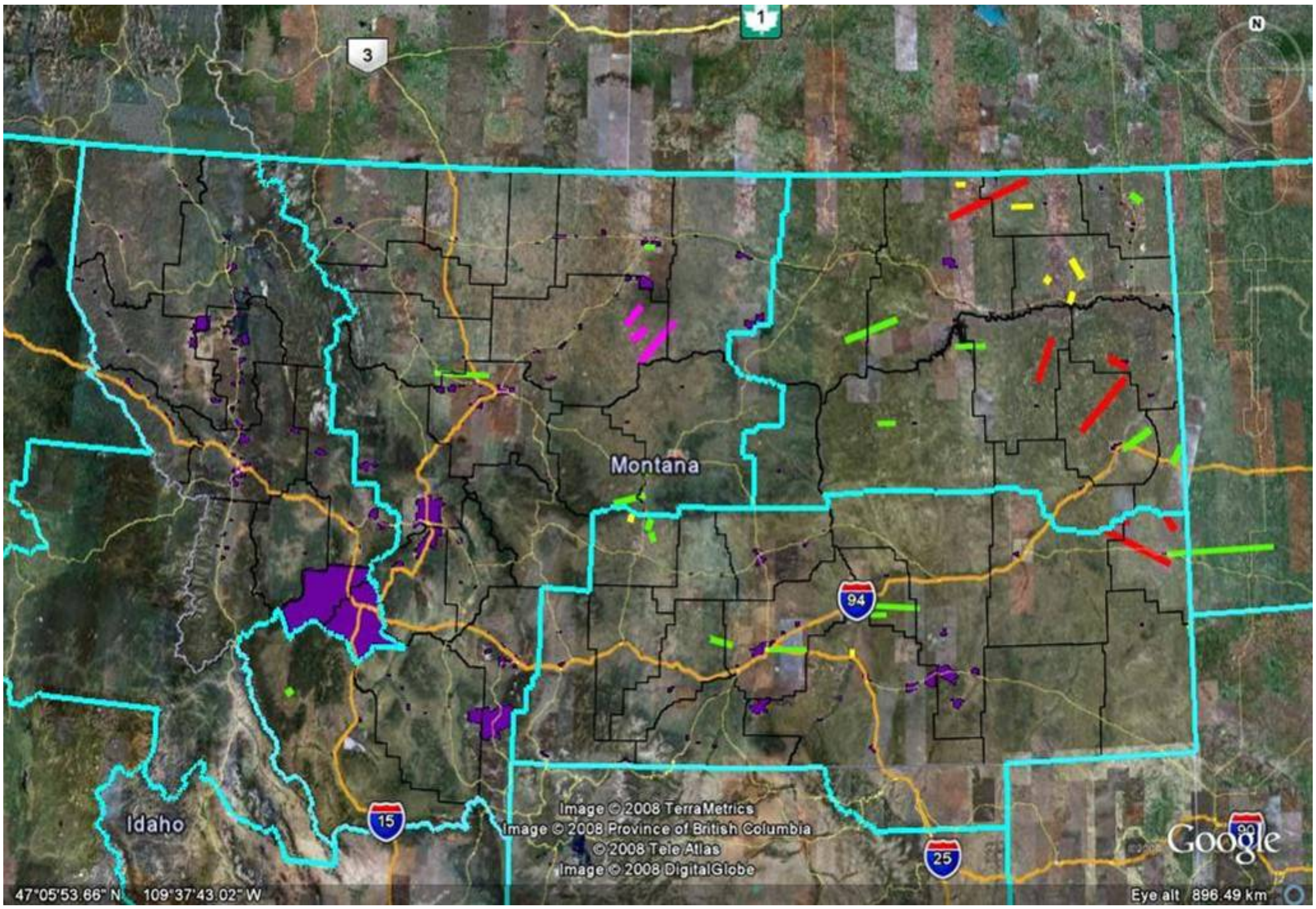

Figure 4: Tornado intensity reports across Montana showing tornado intensity reports – F0 (green), F1 (yellow), F2 (red), and F3 (pink) – from 1950 to 2006.

Figure 5 combines all severe wind, severe hail, and tornado reports across Montana to provide an overall composite of the history of severe weather across Montana. One goal of this figure is to provide the Montana forecaster with guidance regarding climatologically expected locations and climatologically absent locations for severe weather reports. An important message from Figure 5 is that many gaps spatially exist in the severe reports in Montana. One should consider this fact in the verification process; what are the chances that a severe warning for a true severe storm would verify if that area yielded no severe reports for over 50 years? In accordance with Western Region policy, these observational gaps will in no way inhibit the decision to issue a warning for these areas. Likewise, this composite map could provide guidance to local NWS offices in determining which areas are in need of denser spotter networks (i.e., in areas that are spatially lacking severe weather reports over time).

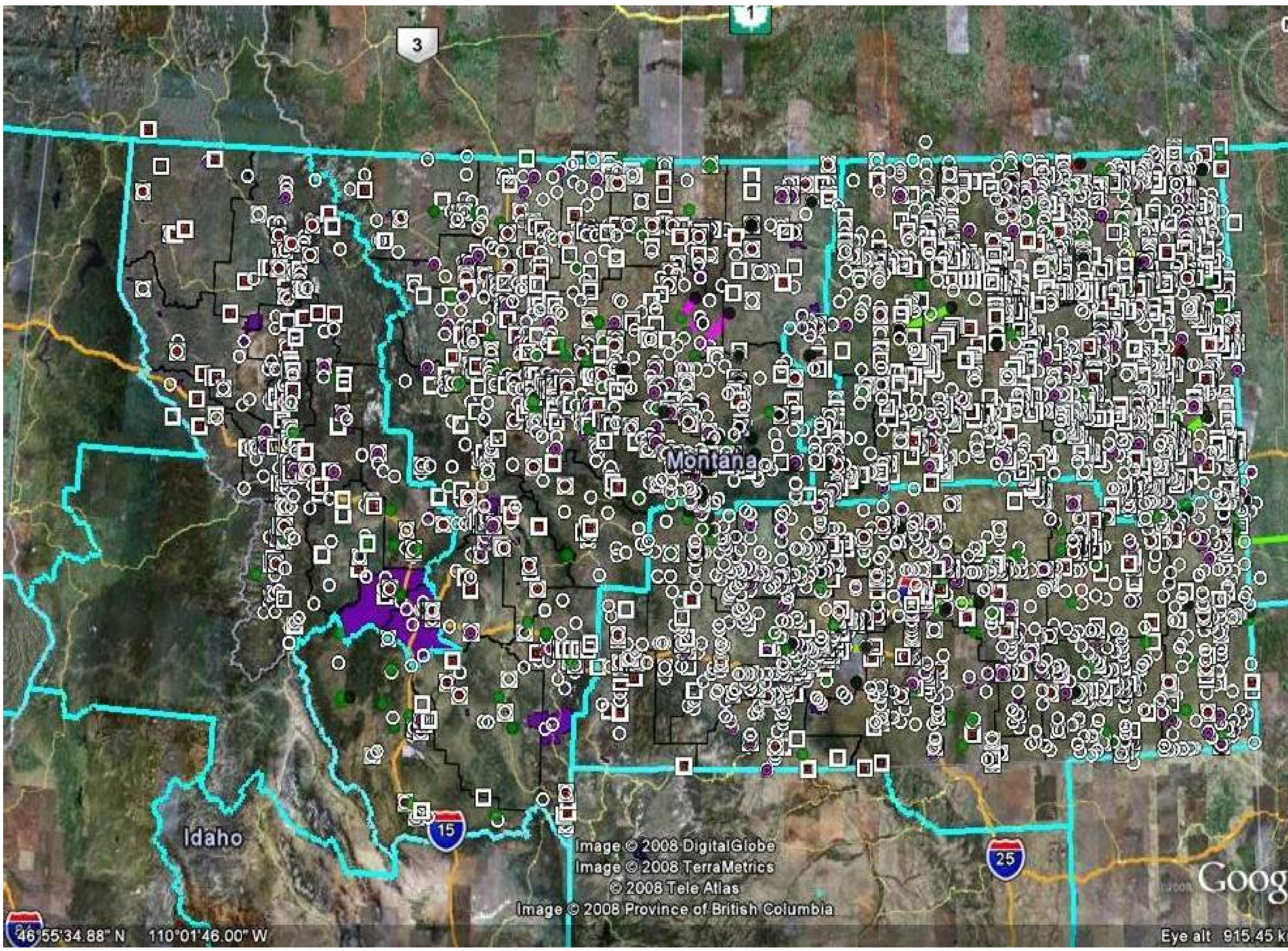

Figure 5: Severe hail, severe wind, and tornado reports in Montana. The color identification scheme is identical to earlier images, except tornado tracks reflect tornado intensities.

HISTORY OF SEVERE REPORTS

Histograms of severe wind, severe hail, and tornado reports over time were generated, and negatively-skewed, mainly unimodal distributions were noted, as would help, with a rapid increase of report frequency after 1989 (i.e., just after the implementation of the WSR-88D) and aggressive expansion of the spotter network. To provide an example of one of these histograms, Figure 6 shows the histogram for severe wind reports.

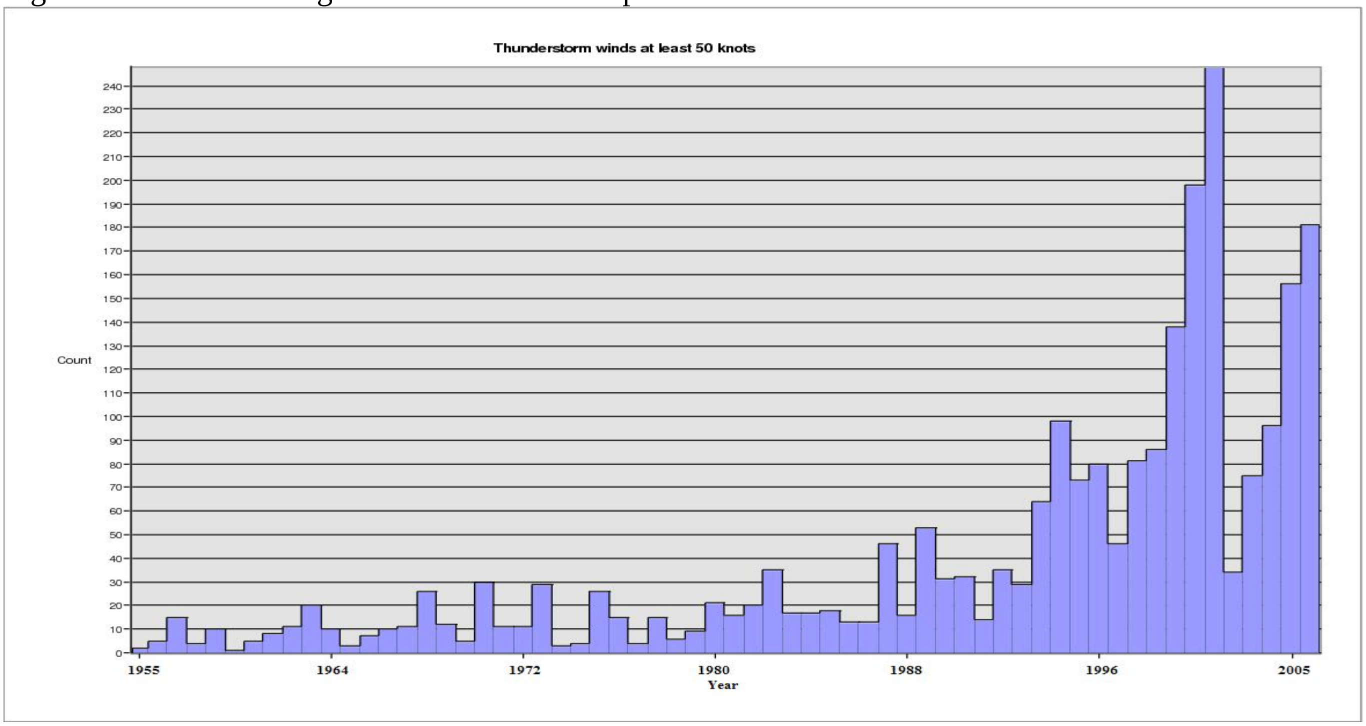

Figure 6: Histogram of severe wind reports from 1955 to 2006 based on year.

In combining spatial and temporal dimensions using GIS, Figures 7, 8, and 9 show the geographic distributions tornado touchdown points and severe wind and severe hail reports, respectively discriminating between during and those after 1990, and those before 1990. A larger proportion of the severe reports over the Glasgow and Billings CWAs appear to have occurred during and after 1990, with a greater proportion of reports in the Great Falls and Missoula CWAs occurring before 1990. The relatively recent increase of reports from the Glasgow and Billings CWAs compared to the Great Falls and Missoula CWAs could be speculated to have occurred as a part of the NWS modernization that occurred in the 1990s; new offices opened the door for expanded spotter networks and more storm verification opportunities. Prior to the middle 1990s, Great Falls housed the main forecast office for the state, before the other Montana offices acquired forecast responsibilities for other parts of Montana. As a result, the history of reports in central and western Montana is larger, as those locations are closer to Great Falls than the current Billings and Glasgow CWAs. Additionally, with only two radars across the state until the mid 1970s (in Billings and Missoula), forecasters at Great Falls relied solely on satellite in severe thunderstorm identification, resulting in numerous missed severe thunderstorms. The implementation of radar was crucial in the identification of potential severe thunderstorms, and thus, the collection of severe weather report. These factors justify the influence of non-meteorological factors as simple as the history of the NWS on our severe report database.

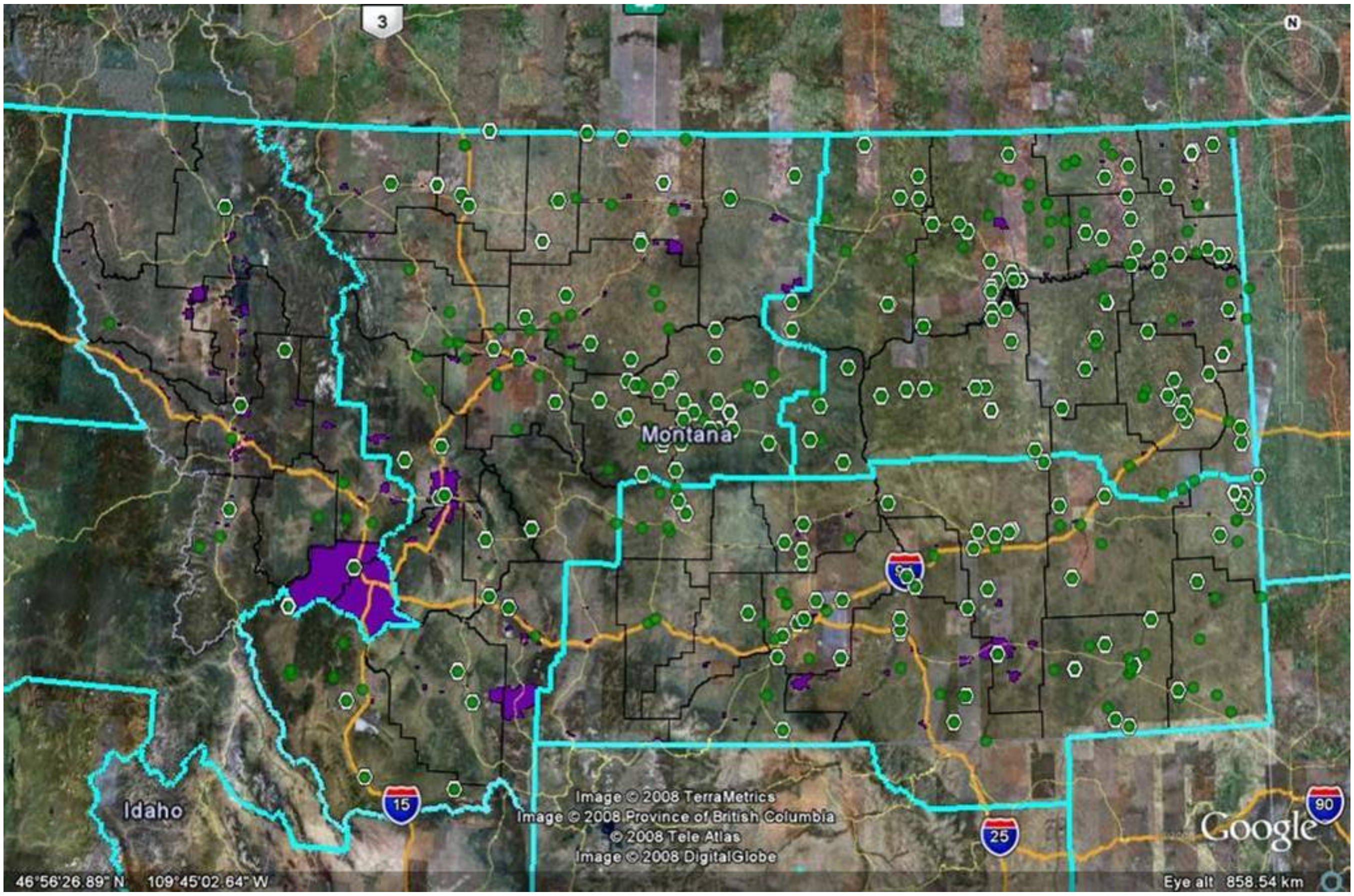

Figure 7: Tornado reports (green), with reports during or after 1990 indicated by a white hexagon.

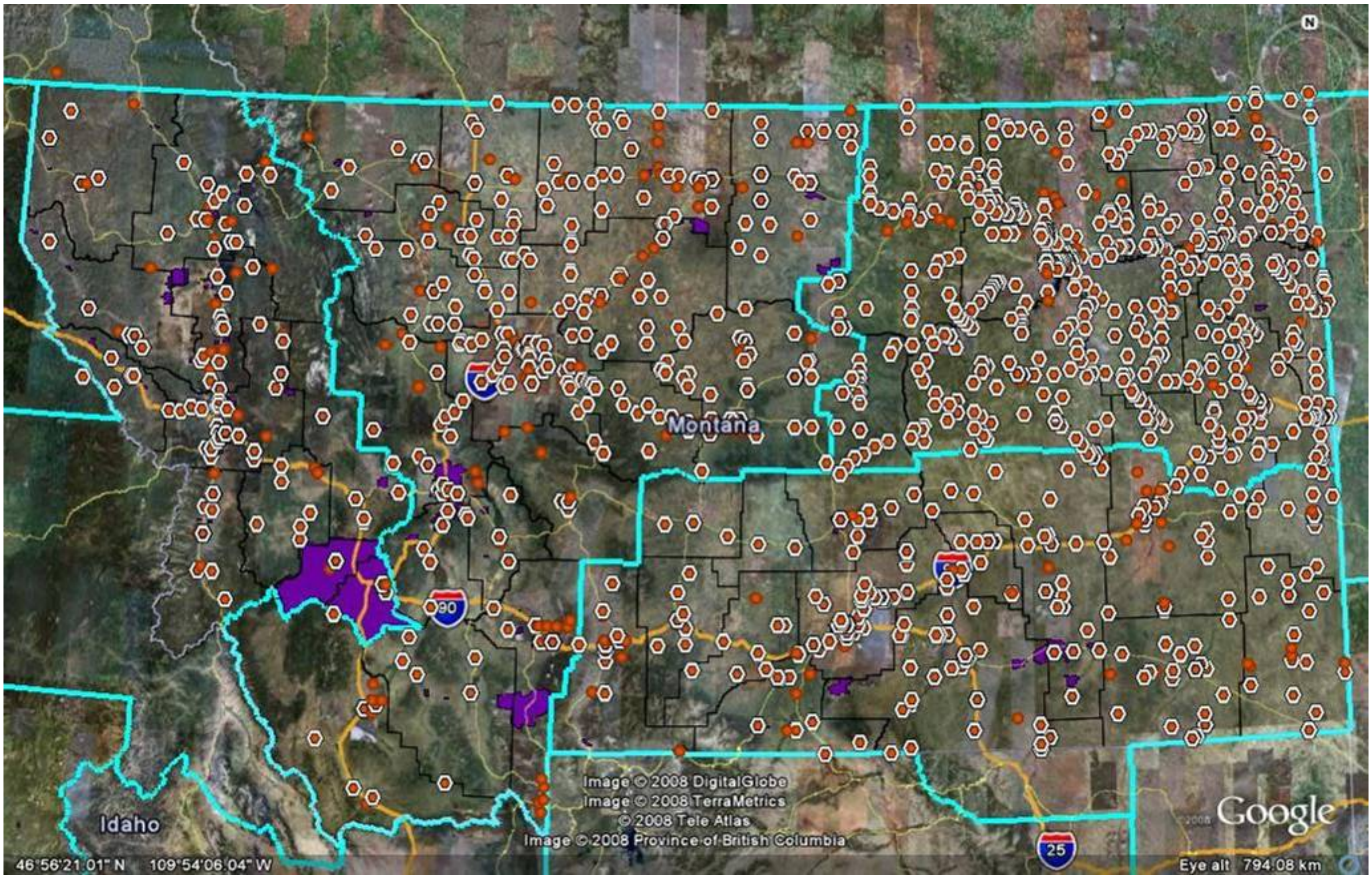

Figure 8: Severe wind reports (orange), with reports during or after 1990 indicated by a white hexagon.

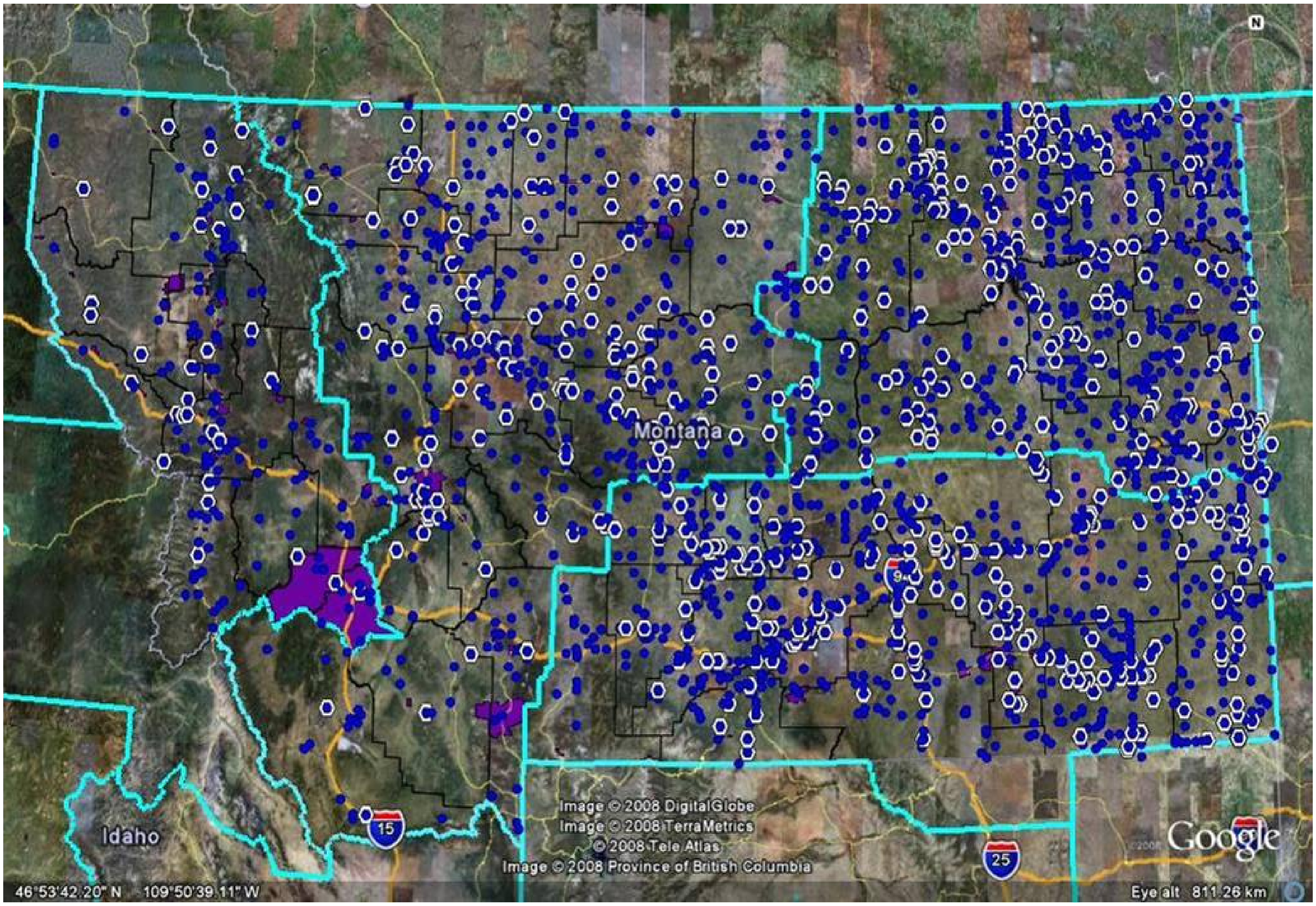

Figure 9: Severe hail reports (blue), with reports during or after 1990 indicated by a white hexagon.

HAIL SIZES

Figure 10 provides a histogram of severe hail sizes over Montana since 1955. This distribution is bimodal and positively skewed, with a peak over the marginal severe hail diameters and a secondary peak near half dollar or golfball size hail. Interestingly, giant hail reports (i.e., at least 2.5 inches in diameter) have occurred over Montana, though have occurred rarely.

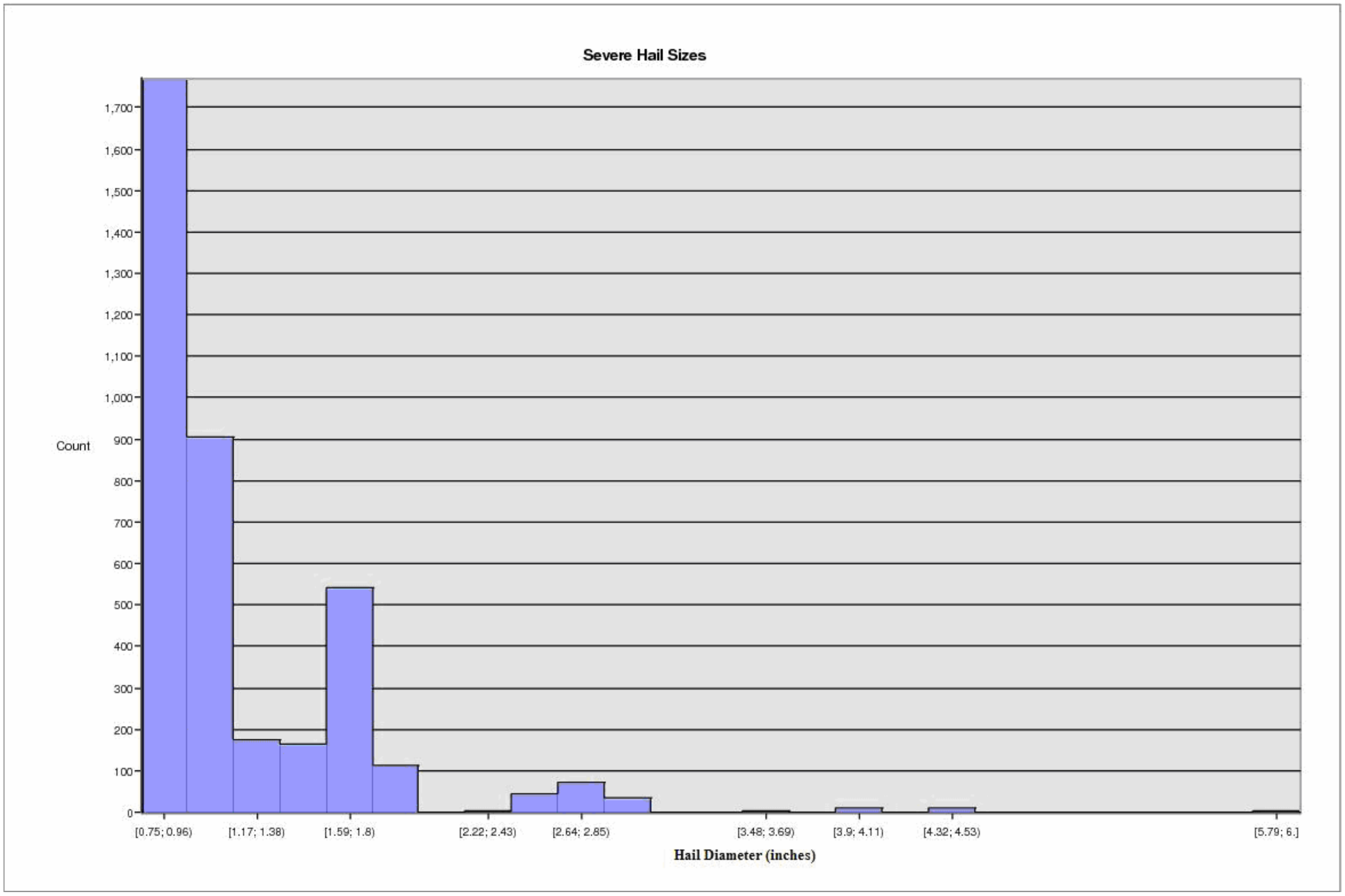

Figure 10: Histogram of severe hail reports from 1955 to 2006 based on hail size.

CONCLUSIONS

In this study, we developed a climatology of severe convective weather reports across Montana from the 1950s to 2006. We used the Geographic Information System (GIS) to generate geospatial distributions of these reports in a historical record. This analysis highlighted areas of Montana that have been historically prone to yielding severe weather reports, potentially providing the nowcaster or forecaster with more confidence in his or her expectations to receive reports from a storm given its location. The analysis also reflected impacts of terrain on enhancements to storm environments and report distributions. The author hopes that the operational forecaster will consider the distributions presented in this study when verifying a storm, especially when no reports have been received from an area usually devoid of severe reports, or one that more commonly yields severe reports than others. While there will always be large tracts of government land, such as national parks, national forests, wilderness areas, and national monuments, where reports are hard to come by, the author also hopes that this study will encourage NWS offices to seek observers in areas of Montana where these reports have been absent over time. This is already being done in southwest Montana around Dillon and Ennis.

ACKNOWLEDGEMENTS
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