Mapping Weather Severity Zones

Meridian Environmental Technology, Inc.

CLEAR ROADS
research for winter highway maintenance

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16. Abstract (Limit: 250 words)

The goals of this project were to develop a methodology to map winter severity from a winter maintenance perspective, and to create electronic maps and associated geospatial data depicting winter weather severity across the country. Work performed under the project examined the advantages and disadvantages of various approaches to mapping winter weather severity. The research team settled on an approach that utilized computer weather prediction model data to define the structure of spatial variations in various aspects of winter weather conditions across the country, and observational data to calibrate these model fields to match actual observed weather conditions. Four significant component measures of winter severity were selected for mapping during the project. These measures included average annual snowfall amounts and average annual duration of each of snowfall, freezing rain, and blowing/drifting snow. The maps were developed following the general approach identified above, although the specific methodologies and datasets used in the development of each map varied. In addition to maps of these component winter severity measures, a composite map illustrating an overall winter severity index was also developed through mathematical combination of the component measure data. Geospatial representations of the data, in the form of ESRI shapefiles, were also developed and provided for each of the component datasets as well as the overall winter severity index.

The states that contributed to the funding of this project include: Colorado, Illinois, Indiana, Iowa, Massachusetts, Maine, Michigan, Minnesota, Missouri, North Dakota, New Hampshire, New York, Ohio, Pennsylvania, Utah, Virginia, Washington, Wisconsin, Wyoming.

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Meridian Environmental Technology Inc.
An Iteris Company

Final Report
MnDOT Contract #98248

Clear Roads Project #10-02: Mapping Weather Severity Zones

Submitted to the

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&
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The weather severity datasets generated under this project were dependent upon several publicly-available weather datasets as explicitly noted throughout this final report. The research team thanks the entities providing these datasets for use of their data.

Further information as to the work performed under this contract can be obtained through Clear Roads, or by contacting the project’s Principal Investigator:

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Project Overview

Overview

State Departments of Transportation are under constant pressure to justify their snow and ice program budgets and to look for new approaches to saving money, such as hiring private contractors and reducing level of service. To effectively defend current budgets and request additional needed funds, winter maintenance professionals need a better understanding of the costs associated with their operations, how these costs compare with other similar states, and opportunities for reducing spending that will not negatively impact level of service. Clear Roads pursued this project to develop a methodology for understanding and mapping weather severity across the snow and ice regions. The resulting maps and data are intended to permit a more meaningful comparison of costs between different states and geographic areas.

Background

A common problem for transportation agencies performing winter maintenance is adequately measuring the effectiveness and efficiency of winter maintenance operations. The combination of temporal and spatial variability in weather, resource constraints, and expected levels of service, and a general lack of quantifiable information on the results of maintenance activities, all conspire to make it exceedingly difficult to objectively measure performance. This lack of quantifiable data hinders an agency's capability to improve the effectiveness and efficiency of winter maintenance operations.

The current practice for many agencies is to measure broad scale efficiency by developing statistical relationships between historical weather conditions and the resources expended when maintaining roads in the presence of those weather conditions. These relationships are often referred to as *winter severity indices*. Once developed, these indices can then be applied in future years to measure whether or not the overall efficiency of maintenance operations has improved relative to historical norms. However, when deviations from historical norms are noted, it is difficult to know whether normalized increases or decreases in resource utilization are the result of changes in efficiency and effectiveness, or limitations of the underlying winter severity index.

There have also been attempts to apply winter severity indices spatially over a given timeframe in order to aid in cross-jurisdictional comparisons of the effectiveness and/or efficiency of winter maintenance operations. However, since the relationship between weather conditions and winter maintenance needs are functions of a given roadway's level of service, traffic patterns, environment, and local maintenance policies and resource constraints, these winter severity indices have historically provided relatively little insight into the justifications for agency-to-agency variability in winter maintenance effectiveness or efficiency over the same period. This fact is illustrated by the relative lack of success stories within the industry when applying winter severity indices developed for one agency to other agencies.

While the sources of difficulty are many, one of the foremost problems is the ability (or lack thereof) of the underlying winter severity indices themselves to capture the important facets of a winter's weather conditions from a maintenance perspective. Most indices seek to use substantially simplified weather data resources, often collected in a diversity of methods by the agencies themselves, to support cross-jurisdictional comparisons. This oversimplification of the problem and the lack of uniformity in the basis data likely serve to undermine the well-intentioned efforts to compare winter maintenance operations across agencies. A primary objective of this project is to address these issues by providing a more reliable basis for isolating the impacts of varying weather conditions in the underlying costs and effectiveness of winter maintenance.

The goals of this research project were to analyze the weather severity in the snow and ice states to develop a methodology for mapping weather severity across the regions and states. The resulting maps and data were intended to depict the weather severity in a manner similar to the plant hardiness zone maps used for agriculture.

Description of Deliverables

The deliverables resulting from this research project included:

1. A kick-off teleconference/webinar to collaborate the start of the project, review the proposed work plan, and solicit and provide guidance on specific work focus.
2. Regular teleconferences to update the Clear Roads TAC on progress.
3. This Final Report of work completed.
4. A color-coded suite of maps of winter severity zones in appropriate electronic print and geospatial data formats.
5. Written Quarterly Reports of progress to the Clear Roads TAC.

Summary of Work Completed

Task 1: Analyze Data to Develop Weather Severity Zones

Subtask 1.1: Kick-off Teleconference

As per item (1) of the project deliverables, Meridian held a kick-off teleconference with the Clear Roads Technical Advisory Committee (TAC) on September 12, 2011. During this meeting, TAC members shared the background and goals of the project, and its relationship to a parallel "True Costs of Winter Maintenance" project. Meridian shared its experiences relating to the difficulties in comparing weather conditions over time and space. The TAC indicated that political boundaries such as regions or states should not serve as the basis for developing the weather severity "zones", but rather that these zones should be based on weather conditions. TAC members volunteered to facilitate the collection of weather data from state agencies, but Meridian also expressed concern about the ability to use state-based weather resources and still establish a consistent picture of weather conditions across state boundaries.

Subtask 1.2: Compiling Meteorological Data Resources

Additional TAC teleconferences held on 10/15/2011 and later dates further defined the direction of the project. Because of the spatial inconsistency that would result from state-provided datasets, it was decided that Meridian would develop the weather severity maps based upon a nationally-consistent data resource. Meridian first acquired and preprocessed hourly "METAR" weather observations for several thousand National Weather Service / Federal Aviation Administration weather stations for the period 2000-2010. Unfortunately, however, these observations do not naturally provide a reliable record of snowfall amounts, often considered a key indicator of winter severity. To address this problem, Meridian had previously developed a suite of algorithms for post-processing the information collected by these sensors in order to estimate of hour-by-hour historical snowfall rates.

The NWS also provides daily snowfall observations that were potentially useful in this project. However, since current methods for measuring snowfall are complex and require manual, *in-situ* observation, official NWS snowfall measurement locations tend to be relatively few and farther between, and did not provide adequate sampling to entirely support the stated project requirement of "three to six weather severity zones per state". Nonetheless, where available, it should be noted that Meridian had previously used these limited measurements to tune the algorithms that it devised for estimating snowfall from the more ubiquitous hourly METAR observations. The hourly-METAR-based technique has been shown to exhibit excellent correlation and very little bias relative to the official, daily NWS measurements at the sampled locations. The NWS also coordinates the collection of daily precipitation and temperature data from a network of (volunteer) cooperative observers across the country. However, since these data are often incomplete, more difficult (and costly) to obtain and process, and more subject to measurement and reporting error than those taken by paid weather observers, Meridian opted against using this data in the generation of the underlying weather severity datasets.

Another important shortcoming of all broadly-available weather records is the lack of reliable information regarding the occurrence of drifting snow. Drifting snow is a major factor in winter maintenance operations across significant swaths of the United States, so it is essential that it be considered when attempting to map winter severity from a maintenance perspective. Here, again, parallel bodies of work in which Meridian had been previously involved provided Meridian with algorithms for post-processing the detailed weather records in order to estimate and track both the depth of blowable snow and its propensity to blow in the presence of varying wind speeds. This permitted Meridian to estimate the frequency of occurrence of blowing/drifting snow in spite of the lacking observational record.

Subtask 1.3: Finalize the Weather Severity Parameters

There are many different potential metrics that can be used to quantify winter severity. The solicitation for this project explicitly mentioned snowfall amounts, number of storms, average storm hours, and temperatures. Snowfall amounts are certainly justifiable as an indicator of winter severity. On the other hand, it had been Meridian's experience that the number of storms is a relatively poor indicator in itself, for several reasons. First and most obviously, any particular storm may present maintenance challenges that are an order of magnitude different from another. Second, but equally important, there is not always a clear separation between storms, so that a location that gets a shorter reprieve between successive periods of snow may end up looking as if it was exposed to just one storm, while a neighboring area with a longer interruption in snowfall may present the appearance of having been exposed to two storms. The number of storms becomes a more powerful indicator when used in concert with a measure of average storm duration. In this case, the product of the two becomes the total storm duration for the period, which is a much more stable indicator of the total period of time that agency forces have had to spend in performance of winter maintenance.

Average temperature, in itself, was deemed by Meridian to be unlikely as a useful statistic for quantifying winter severity. However, given the unique data resources that Meridian opted to use in addressing the problem, it was possible to calculate some potentially more useful measures of the impact of temperature on maintenance operations. One example that was explored was a measure of the average temperature while snow is falling (the thought being that it would help differentiate moderate-temperature situations where snow compacts more readily relative to cold-temperature situations where it may not).

In the end, the final set of weather severity parameters was selected through an iterative process of data compilation and analysis, and subsequent assessment of the usefulness of the resulting weather severity indicator. The final list of weather severity parameters developed under this project consisted of:

- Average annual snowfall accumulation
- Average annual duration of snowfall
- Average annual duration of freezing rain
- Average annual duration of blowing/drifting snow
- A combined measure of overall winter severity based on these parameters

Subtask 1.4: Defining the Weather Severity Zones

The early teleconferences between Meridian and the TAC directed the research toward developing zones that were weather-based as opposed to zones aligned with political boundaries and subdivisions. Because of this, and because of the fact that weather conditions generally vary in a spatially continuous manner, Meridian proposed instead to develop gridded datasets of smoothly-varying indicators of weather conditions that could then be used to generate the required maps. This concept was approved by the TAC. The significance of this approach toward the task of defining weather severity zones was that the need for up-front definition of the weather severity zones was removed, in favor of the development of a smoothly varying, spatially-dense dataset.

Task 2: Develop a Map of Weather Severity Zones

Subtask 2.1: Process and Aggregate Weather Information by Zone

Through the process of conducting this and previous related research, Meridian discovered that biases in weather sensors, even biases that may not be noticeable in day-to-day use, are very common and often present a much stronger signal in the data than the true, underlying variations in weather conditions from one location to the next. This was a major concern for any application of weather data as a metric intended to normalize for spatial differences in winter severity. The sensor bias problem is far more insidious for spatial normalization than it is when comparing historical maintenance records against data from the same weather station over time.

Because of this issue, and because of the importance of developing a spatially-consistent dataset under this project, Meridian revised its initial plan of using weather stations as the primary building block of the winter severity datasets. Instead, Meridian and the TAC opted to pursue an approach that utilized computer-based model data to provide a spatially-coherent baseline which could then be adjusted to (loosely) fit the available observations. These weather analysis and forecasting models provide a far more spatially-consistent and detailed representation of where and when weather conditions vary. While certainly prone to errors in any particular weather event, when data from long periods of time are averaged together, the effects of these individual storm-to-storm errors is likely to be washed out of the data (as its becomes "white noise"). The positive impacts of averaging, and the subsequent adjustment of these gridded datasets to at least loosely fit observational data from weather stations in any given area, was determined to provide the most meteorologically-realistic picture of the true nature of weather conditions across the country.

While this general approach was used in the development of the weather severity datasets and maps generated under this project, the actual weather datasets and approaches by which each weather severity measure was calculated varied substantially. The details of the final approaches used in the development of each weather severity measure are provided in brief in the following subsections.

Subtask 2.1.a: Average Annual Snowfall Accumulation

Annual snowfall was estimated through the combined application of mean annual snowfall data from the National Weather Service's United States Climate Normals, 1971-2000[1,2] and Snow Data Assimilation System (SNODAS, 2004[3,4])

[1] http://cdo.ncdc.noaa.gov/climatenormals/clim20-02/NWS_SNOW_MNFALL_fmt.dat
[2] http://cdo.ncdc.noaa.gov/climatenormals/clim20-02/normalsnwssnow.pdf
[3] National Operational Hydrologic Remote Sensing Center. 2004. Snow Data Assimilation System (SNODAS) Data Products at NSIDC. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.
[4] ftp://sidads.colorado.edu/DATASETS/NOAA/G02158/

gridded snow precipitation data for the 2004-2005 through 2010-2011 winter seasons. The 30-yr climate normals were evaluated against the shorter-duration SNODAS data to develop adjustment factors at each climate normal location. A Barnes objective analysis technique was then used to map these point-based adjustment factors onto the SNODAS grid, permitting the calculation of mean annual snowfall (as opposed to liquid equivalent snow precipitation) on a high-resolution grid. The final dataset is therefore designed to closely match the 30-year NWS climate normals at locations where these data are available, and to use the high-resolution SNODAS data to provide a realistic depiction of how snowfall varies at locations in between them.

Subtask 2.1.b: Average Annual Duration of Snowfall

Annual hours of snowfall were estimated through the combined application of records from METAR observations and precipitation type analyses from the North American Model (NAM) operated by the National Centers for Environmental Prediction and acquired through the National Operational Model Archive & Distribution System (NOMADS[5]). METAR observations for the 2000-2001 through 2009-2010 winter seasons, from Federal Aviation Administration (FAA) and National Weather Service (NWS) weather observing stations across the contiguous United States, were used to develop station-specific counts of the average annual hours with snowfall during the aforementioned 10-year period. Snowfall deemed to be inconsequential based on a lack of any measurable impact on visibility was not counted. These station-specific data were then evaluated against gridded precipitation type distribution data from the NAM model over the course of the 2004-2005 through 2010-2011 winter seasons to develop a calibrated field analysis of the typical annual duration of snowfall. NAM data were only loosely fitted to the station-based duration data due to the fact that weather observing stations can have widely varying sensitivities to light precipitation, such that any accounting of the number of hours of snowfall from those stations can only be considered an approximation.

Subtask 2.1.c: Average Annual Duration of Freezing Rain

Annual hours of freezing rain were also estimated through the combined application of records from METAR observations and precipitation type analyses from the NAM model acquired through NOMADS. METAR observations for the 2000-2001 through 2009-2010 winter seasons were used to develop station-specific counts of the average annual hours with freezing rain during the aforementioned 10-year period. These station-specific data were then evaluated against gridded precipitation type distribution data from the NAM model over the course of the 2004-2005 through 2010-2011 winter seasons to develop a calibrated field analysis of the typical annual duration of freezing rain. NAM data were only loosely fitted to the station-based duration data due to the fact that

[5] http://nomads.ncdc.noaa.gov/data/namanl

weather observing stations can have widely varying sensitivities to light precipitation, such that any accounting of the number of hours of freezing rain from those stations can only be considered an approximation.

Subtask 2.1.d: Average Annual Duration of Blowing/Drifting Snow

Annual hours of blowing/drifting snow were estimated through application of archived data from from the NAM model, again acquired through NOMADS, combined with 1-kilometer AVHRR-based landcover data from the University of Maryland[6,7]. NAM snowfall data over the course of the 2004-2005 through 2010-2011 winter seasons were accumulated and depth-tracked relative to the surface roughness as determined from landcover data. The portion of this snowpack deemed "blowable", as determined by time, temperatures, and precipitation since its original deposition, was also tracked. A simple snowmelt model was used to deplete snowpack based on temperature data.

Wind speed data from the NAM model were subsequently applied to this snowpack data in order to determine whether or not blowing/drifting snow was likely to occur at any given time and location. A determination of blowing/drifting snow required a snowpack depth in excess of the surface roughness depth (below which the wind speed is assumed to approach zero), a non-zero portion of the snowpack considered to be in a "blowable" condition, and a wind speed in excess of a threshold value. The threshold value was varied according to landcover type in a manner consistent with the effects of landcover on the wind profile near the ground, in such a manner that this threshold was approximately 15 mph in landcover types considered “open”, but higher than 15 mph in e.g. densely forested landcovers.

Since there is no reliable national observational record of the frequency of blowing/drifting snow, no calibration to actual observations was able to be performed for this dataset. For this reason, and due to the complexity of the problem, the resulting dataset should be used only to gain an approximate understanding of where blowing and/or drifting snow occurs most frequently, not as a firm representation of the actual duration of blowing/drifting snow at locations across the country.

Subtask 2.1.e: Overall Weather Severity

Overall winter severity was determined based on total average annual snowfall, as well as the annual durations of snowfall, blowing snow, and freezing rain, across the contiguous United States. Winter severity was calculated based upon the formula:

[6] Hansen, M., R. DeFries, J.R.G. Townshend, and R. Sohlberg (1998), UMD Global Land Cover Classification, 1 Kilometer, 1.0, Department of Geography, University of Maryland, College Park, Maryland, 1981-1998.
[7] http://glcf.umiacs.umd.edu/data/landcover/

Winter Severity =

0.50 x (average annual snowfall in inches) +
0.05 x (annual duration of snowfall in hours) +
0.05 x (annual duration of blowing snow in hours) +
0.10 x (annual duration of freezing rain in hours)

Since a typical ratio between the annual snowfall (in inches) and duration of snowfall (in hours) within the U.S. is approximately 10:1, this formula provides an approximately equal weighting between the amount and duration of wintertime precipitation (including blowing snow). Hours of blowing snow were considered exclusive of falling snow, so as not to double-count hours when both snow and blowing snow occur. An hour of freezing rain was given twice as much weight as an hour of snowfall due to the extra caution and proactivity it often requires. Particular index values have no specific interpretation, and are provided only for the sake of relative comparisons of winter severity (from a winter maintenance perspective) between differing locations across the country.

Subtask 2.2: Generate Weather Severity Maps and Data

Meridian generated high-resolution gridded datasets of the selected winter severity parameters following the specific steps described under Subtask 2.1. These gridded datasets were used thereafter to generate high-resolution map images, ESRI shapefiles, and a comma-separated value (CSV) file of average winter severity in 1º x 1º latitude/longitude blocks (for application with the work resulting from Clear Roads' True Costs of Winter Maintenance project).

Subtask 2.2.a: Map Images

The maps resulting from the work performed under this project are provided in Figures 1-5. They have also been provided to Clear Roads as deliverables of the project, in full-resolution, in a Portable Network Graphics (PNG) format.

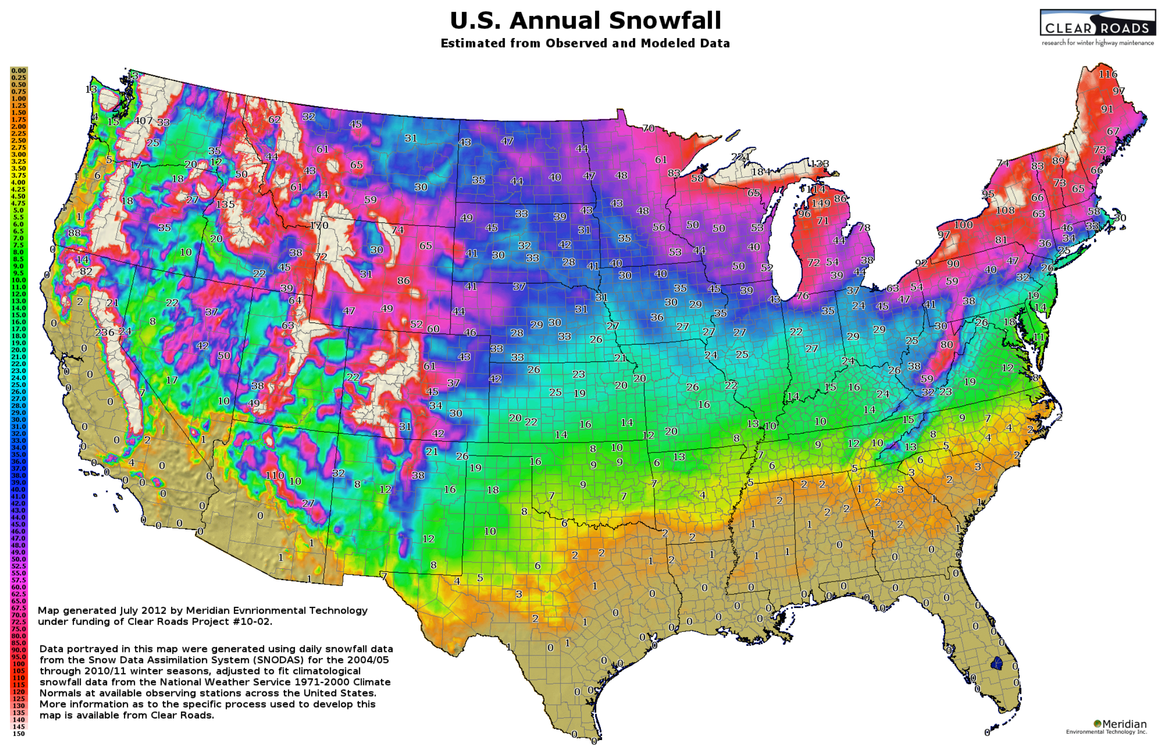

Figure 1: Map of Average Annual Snowfall (in inches) as developed under this project.

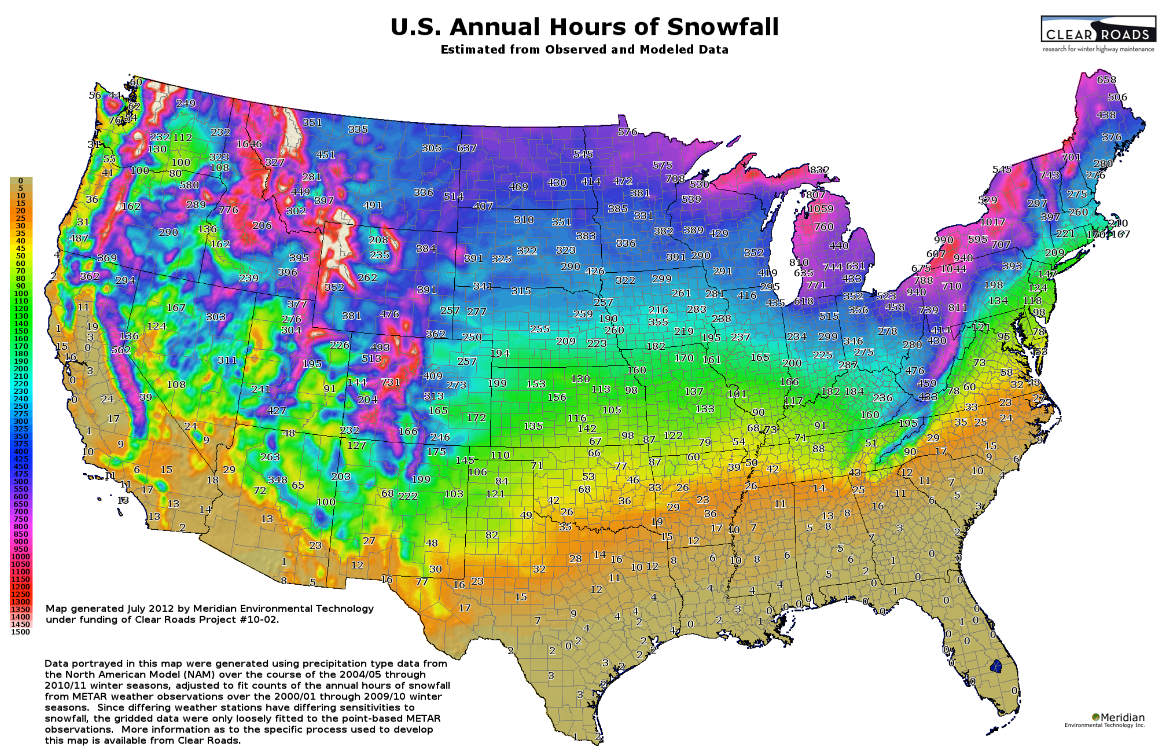

Figure 2: Map of Average Annual Duration of Snowfall (in hours) as developed under this project.

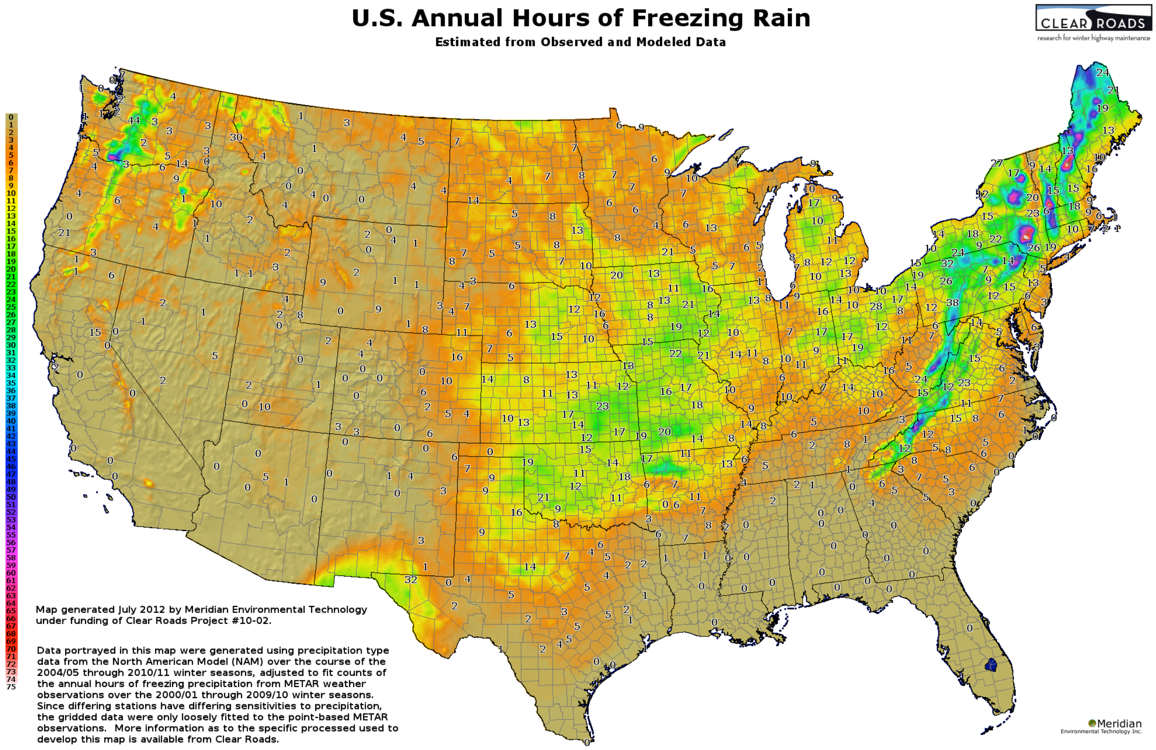

Figure 3: Map of Average Annual Duration of Freezing Rain (in hours) as developed under this project.

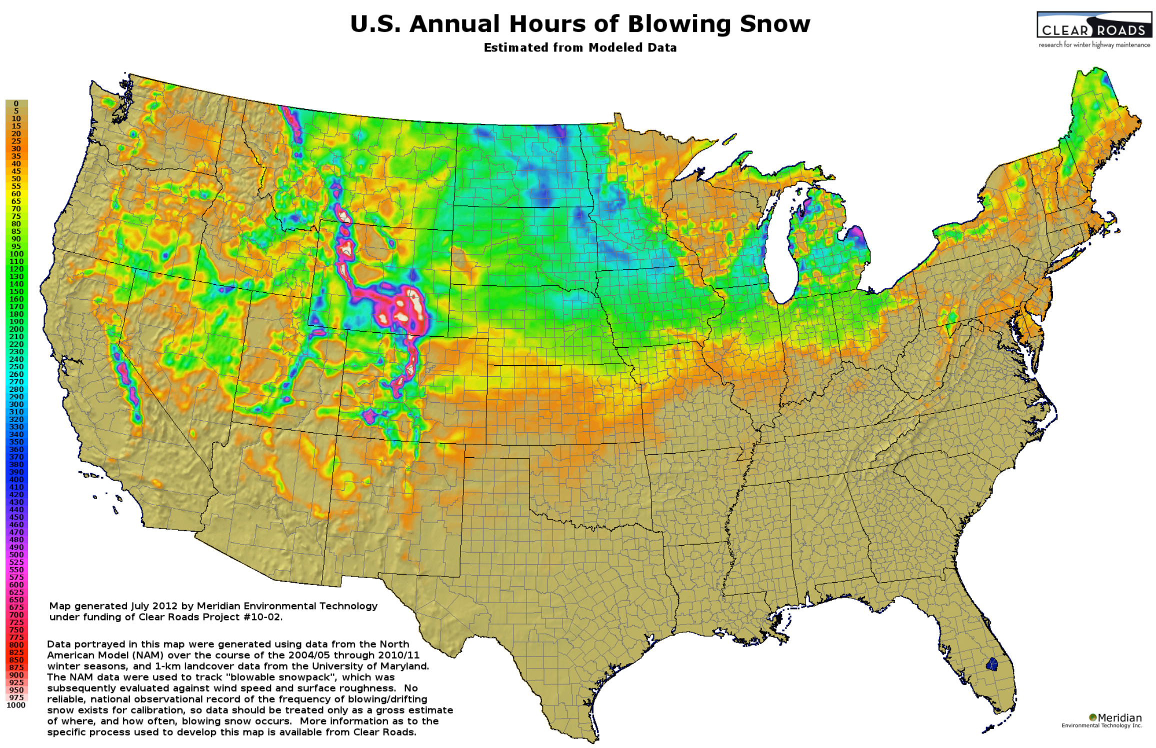

Figure 4: Map of Average Annual Duration of Blowing/Drifting Snow (in hours) as developed under this project.

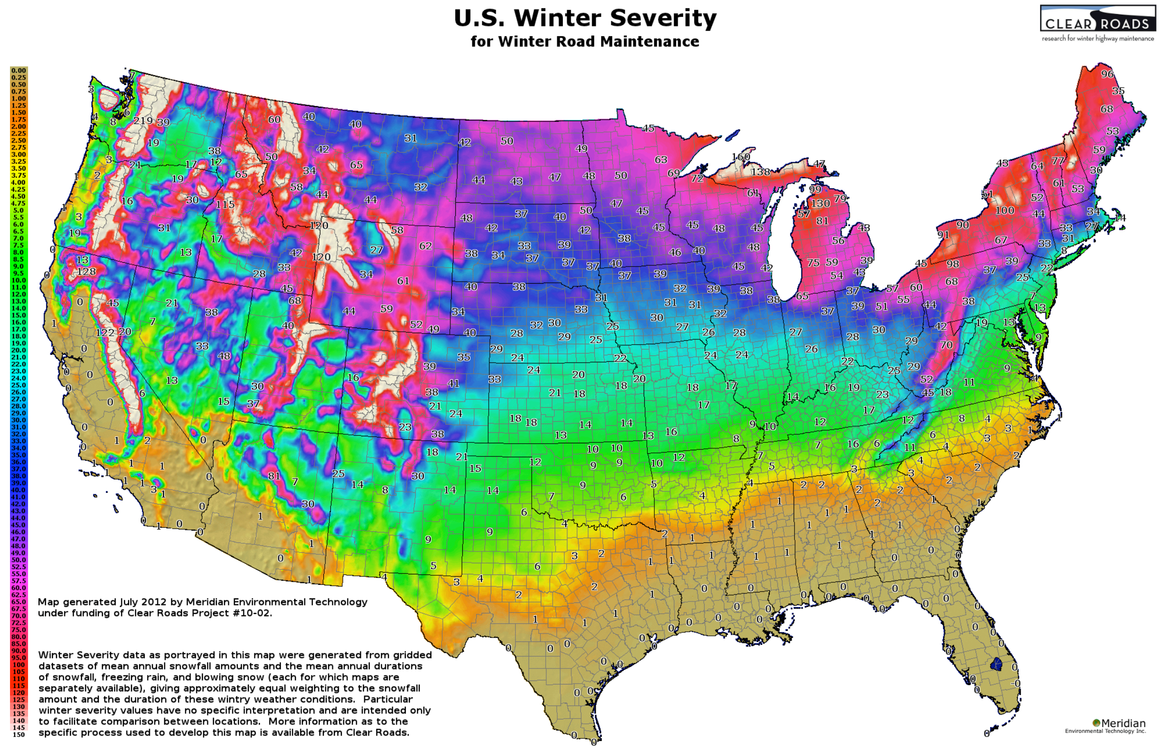

Figure 5: Map of Overall Winter Severity as developed under this project.

Subtask 2.2.b: ESRI Shapefiles

In order to facilitate the visualization of the data resulting from this project alongside other datasets using Geographic Information Systems (GIS), Meridian also developed software to convert the gridded data into ESRI shapefile formats (in a latitude/longitude projection). These shapefiles have been provided to Clear Roads as deliverables of the project. Note that while these shapefiles do contain some data outside the boundaries of the contiguous United States, the data are considered reliable only within the boundaries of the contiguous United States.

Subtask 2.2.c: CSV Files

In order to facilitate the application of this winter severity data in Clear Roads' parallel True Costs of Winter Maintenance project, Meridian has also provided a comma-separated value (CSV) file of average winter severity in 1º x 1º latitude/longitude blocks as a deliverable of the project. Note that while this CSV file contains some data for latitude/longitude blocks falling outside the boundaries of the contiguous United States, the data are considered reliable only within the boundaries of the contiguous United States.

Subtask 2.3: Generate Final Report

At the conclusion of the project, Meridian generated a final report (this document) describing the issues encountered during the project, the final methodologies used to develop the datasets, and the deliverables produced under the project.

research for winter highway maintenance

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