7A.3 DEVELOPMENT OF OPERATIONAL REGIONAL SNOWFALL INDICES

Michael F. Squires *, Jay H. Lawrimore, and Richard R. Heim Jr.
NOAA National Climatic Data Center, Asheville, North Carolina

David A. Robinson, Mathieu R. Gerbush, and Thomas W. Estilow
Rutgers University, Piscataway, New Jersey

1. INTRODUCTION

This paper describes a collaborative effort between NOAA's National Climatic Data Center (NCDC) and Rutgers University to develop regional snowfall indices on an operational basis. In 2004, Kocin and Uccellini developed the Northeast Snowfall Impact Scale (NESIS) to characterize snowstorms in the Northeast (Kocin and Uccellini, 2004). The index is based on the spatial extent of the storm, the amount of snowfall, and the juxtaposition of population and snowfall. Including population information ties the index to societal impacts. The NESIS was calculated for approximately 70 historical Northeast snowstorms. In 2005, NCDC began calculating NESIS scores operationally for large snowstorms affecting the Northeast (Squires and Lawrimore, 2006).

The goal of the current project is to develop NESIS-like indices for all regions of the country. The indices are calculated in a similar fashion to NESIS, but our experience has led us to propose a change in the methodology. Different techniques are examined and a final algorithm is presented. The new indices require region-specific parameters and thresholds for the calculations. The paper discusses the process of developing new regional snowfall impact scales.

2. NESIS ALGORITHM

The algorithm for computing the NESIS is

$$NESIS = \sum_n \left[\frac{n}{10} \left(\frac{A_n}{A_{mean}} + \frac{P_n}{P_{mean}} \right) \right] \qquad (1)$$

where:

- n = snowfall threshold {4 for > 4", 10 for > 10", 20 for > 20", 30 > 30"}
- A_n = *area of snowfall greater than or equal to category n* (mi^2)
- P_n = *population affected by snowfall greater than category n (2000 census)*
- A_{mean} = *mean area of >10" snowfall within the 13-state Northeast region (91,000* mi^2*)*
- P_{mean} = *mean population affected by snowfall >10" within the 13-state Northeast region (35.4 million)*

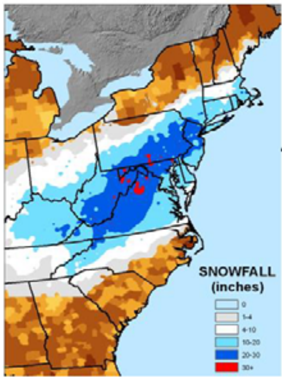
The mean area and population constants are for 30 historical storms from 1956 to 2000 for the 13 Northeastern states. These constants calibrate this index to Northeast snowstorms.

This algorithm typically results in values between 1 and 13 which are then transformed into one of five categories; Notable, Significant, Major, Crippling, and Extreme. Storms that cover a large area, with large snowfall amounts, and affect populated regions have the largest NESIS values. The highest severity case is the March 1993 super storm with a NESIS value of 12.52 placing it in the "Extreme" category. Kocin and Uccellini (K-U) used a combination of hand drawn maps and census data within a GIS to calculate their NESIS values. The process for calculating NESIS operationally at NCDC is shown in Figure 1. Note that snowfall and population outside of the Northeast are used in the calculations.

3. DATA AND STORM SELECTION

In order to develop new regional indices, candidate storms for each region were selected using one degree latitude by one degree longitude snowfall and population data. The gridded snowfall product was generated through efforts at Rutgers' Global Snow Lab and the University of Georgia's Climatology Research Lab using Integrated Near Real-Time (INRT) station data from NCDC and the Spheremap spatial interpolation program, developed at the Center for Climatic Research, University of Delaware. The data were first examined using criteria set forth by D. Robinson (Robinson 1989). Once the quality control and Spheremap interpolation were complete, final 1° x 1° grids were prepared using software developed by T. Mote and J. Dyer at the Department of Geography, University of Georgia (Dyer and Mote 2006).

* *Corresponding author address:* Michael F. Squires, NOAA National Climatic Data Center, 151 Patton Avenue, Asheville, NC 28801; e-mail: Mike.Squires@noaa.gov.



n	Area (SqMi)	Population
0	118,837	15,182,500
1	107,526	16,432,000
4	103,951	19,913,500
10	107,786	29,907,800
20	63,532	30,216,900
30	2,364	340,889

$$NESIS = \sum_{n=4}^{n=30}\left[\frac{n}{10}\left(\frac{A_n}{A_{mean}} + \frac{P_n}{P_{mean}}\right)\right]$$

NESIS = 11.78

NESIS Category 5
Extreme

Figure 1. Diagram of the process by which NESIS values are estimated within a GIS. The earth tone background map is a population density grid. Both the population and snowfall grids are 5x5 km and are aligned. The table represents the values needed for the NESIS algorithm calculated from the GIS map layers.

Average snowfall for each grid cell was multiplied by cell population using 2000 U.S. census data, and then summed within each region to obtain daily regional population-weighted snow values. Running four-day totals of the daily snow values were calculated, with the largest totals used to identify high-impact snow events in each region. Storm event dates were determined by evaluating a combination of the daily population-weighted snow values, daily weather maps (source: http://docs.lib.noaa.gov/rescue/dwm/data_rescue_daily_weather_maps.html), and daily GIS snowfall maps. Once storm event dates were identified, population-weighted snow totals for each event were computed by summing the daily values for the dates within each event period. The seventy-five largest event totals were used to select the candidate storms for which detailed quality control was performed and snow impact scale indices were calculated.

4. REGIONAL SNOWFALL IMPACT SCALE (ReSIS)

NCDC has been calculating NESIS values since the 2004-2005 winter season. Since then there has been a call for snowfall impact indices to be developed for other regions of the country. It is tempting to blindly apply the NESIS algorithm to other regions of the country. However, Equation 1 was developed for the Northeast. For example, the snowfall thresholds of 4", 10", 20", and 30" make sense for the Northeast but are not appropriate for say, the Southeast, where snowfall amounts are not as large. To develop region specific snowfall indices for other parts of the country, several questions need to be answered:

1) How will the new region boundaries be determined?

2) Should snowfall and population outside of a region be included in the calculations?

3) How should the snowfall thresholds for different regions be determined?

4) Should the same NESIS algorithm be used for the new regions?

5) Should all storms be included or should there be a lower cutoff?

4.1 *How Will the New Region Boundaries be Determined?*

For continuity purposes, it was decided to keep the original 13 state Northeast region intact. That decision eliminated the possibility of using the nine NCDC Climate Regions. It was also decided to have the new regions continue to be aligned with state boundaries. This would make it easier to communicate the indices to the public. And in the future it might be possible to correlate the new regional indices with other social and economic indicators that are collected or summarized by state.

After several iterations, it was decided to use the spatial distribution of the 2-day 25-year return period for snowfall to guide the drawing of new boundaries. A map of these values is given in Figure 2. This map provides an objective guide to drawing regional borders aligned with state boundaries. The new regions are shown in Figure 3.

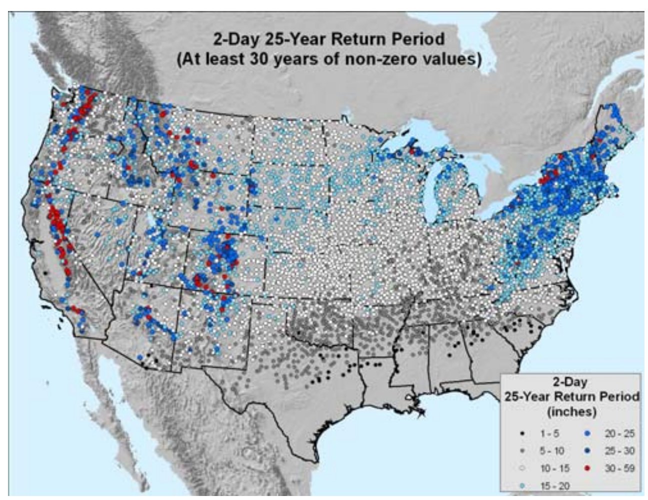


Figure 2. Map of the 2-day 25-year return period.

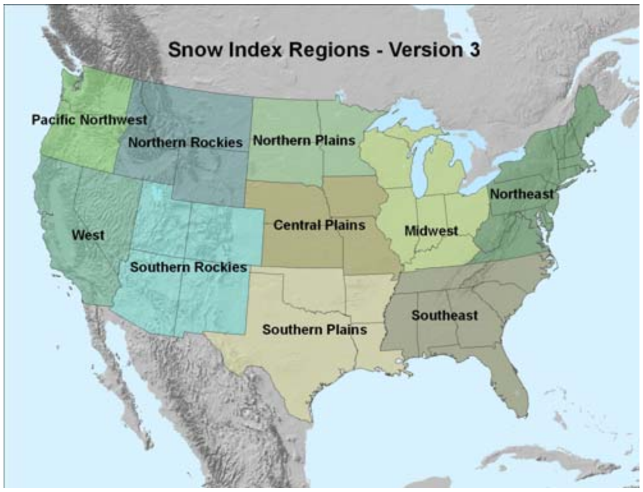


Figure 3. New snowfall regions.

4.2 *Should Snowfall and Population Information from Outside a Region be Included in the Calculations?*

As noted before, the NESIS calculations use snowfall and population information from outside the 13 state Northeast region to calculate an index. The NESIS value is considered calibrated to the Northeast because the snowfall and area terms in the summation of Equation 1 are normalized by the mean snowfall and mean population from 30 "development storms" that produced significant impact in the Northeast. This works well for the Northeast because as storms move through other regions of the country they often reach their maximum intensity in the Northeast. Therefore large NESIS values are usually associated with heavy snow over populated areas. In other words, large NESIS values are associated with significant societal impacts in the Northeast.

However, this would not always be the case in other parts of the country. Figure 4 shows an example of a snowstorm that affected both the Southeast and Northeast regions. The 4-10" of snow over the Southeast would yield a moderate index value for that region. However, if the Northeast were included, a very large and misleading index value would be generated.

Even in cases where an index value is calculated, that is not misleading, it might be ambiguous. That is, it would not be clear if the societal impact is within or outside the region (or both).

For these reasons, the new method diverges from the NESIS convention and only uses snowfall and population information from within a region.

4.3 *How Should Snowfall Thresholds for Different Regions Be Determined?*

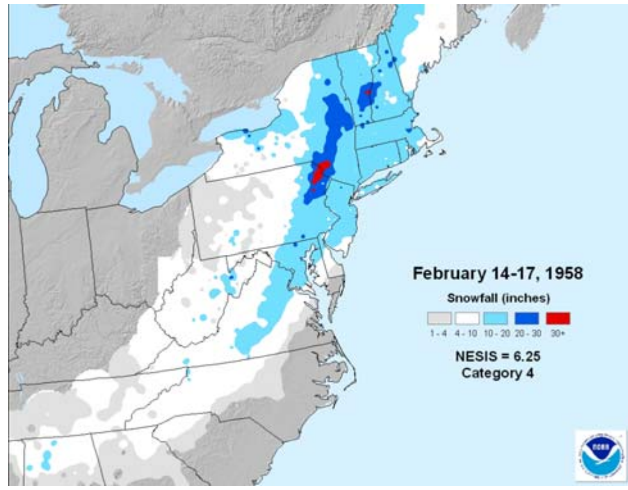


Figure 4. Example of a storm that would have an artificially high index for the Southeast.

The original NESIS algorithm uses snowfall thresholds of 4", 10", 20", and 30". These values were chosen by Kocin and Uccellini based on their expert knowledge of Northeast snowstorms. However, an objective method was needed to identify these thresholds for the other snowfall regions. It was decided again to use return period statistics as a means of providing an objective basis for determining these thresholds.

First, the average 2-day 10-year return period and the average 2-day 25-year return period for snowfall was computed for each region. This was done by simply averaging all the stations within a region. Next a relationship was found between these values and the existing Northeast thresholds. The first threshold (4") is approximately one-quarter of the average 2-day 10-year return period for the Northeast. The second threshold (10") is approximately one-half of the average 2-day 25-year return period for the Northeast. The third and fourth thresholds (20" and 30") are just multiples of the second threshold. This relationship was applied to all the regions' average return period statistics to create regional snowfall thresholds. A fifth threshold was added to give more weight to higher snowfall amounts. Table 1 lists the regional snowfall thresholds for all the regions.

4.4 *Should the Same NESIS Algorithm be Used for the New Regions?*

The NESIS algorithm (Eq. 1) works well for the Northeast, but it might not behave the same way in other parts of the country. The distribution of population and snowfall varies greatly across the country. The original algorithm calibrates the index using mean area and mean population for 30 development storms that were chosen by Kocin and Uccellini who are experts on Northeast snowstorms. This would be difficult to duplicate in an objective fashion in the other snowfall regions. Therefore,

Region	Area	Pop	Thresh 1	Thresh 2	Thresh 3	Thresh 4	Thresh 5
Southern Plains	433,188	31,444,850	1	4	8	12	16
Southern Rockies	424,443	13,484,108	4	8	16	24	32
Northern Rockies	328,391	2,689,930	4	9	18	27	36
Southeast	296,619	35,180,975	1	4	8	12	16
Midwest	288,201	49,196,806	3	7	14	21	28
Central Plains	285,617	12,921,216	2	6	12	18	24
West	268,446	35,869,905	4	10	20	30	40
Northeast	242,557	69,133,382	4	10	20	30	40
Northern Plains	232,527	6,316,523	3	7	14	21	28
Pacific Northwest	164,363	9,315,520	3	8	16	24	32

Table 1. Regional parameters. See text for details.

alternative methods were investigated to calculate the new regional indices. All of the methods proposed to create regional storm indices follow the same general algorithm:

$$SnowIndex = \sum_{i=1}^{5} Coef_i \left(\frac{Area_i}{Norm_A} + \frac{Population_i}{Norm_P} \right) \qquad (2)$$

Therefore there are three parameters that determine the final index; the coefficients ($Coef_i$), the manner in which area and population are accounted for ($Area_i$, $Population_i$), and the method used to normalize area and population ($Norm_A$, $Norm_P$). Table 2 shows how the parameters can be varied and combined to produce alternative methods for producing a regional snow index.

Method	Coefficients	Normalization	Area/Pop
1	Thresh/10	Total A & P	Cumulative
2	Thresh/10	Total A & P	Thresh
3	Thresh/10	Mean of A & P	Cumulative
4	Thresh/10	Mean of A & P	Thresh
5	Thresh	Total A & P	Cumulative
6	Thresh	Total A & P	Thresh
7	Thresh	Mean of A & P	Cumulative
8	Thresh	Mean of A & P	Thresh
9	Index	Total A & P	Cumulative
10	Index	Total A & P	Thresh
11	Index	Mean of A & P	Cumulative
12	Index	Mean of A & P	Thresh

Table 2. Matrix of candidate methods to compute new regional indices.

Coefficients: “Thresh” represents the snowfall threshold. For example in the Northeast the snowfall thresholds are 4”, 10”, 20”, 30”, and 40”. So “Thresh/10” would result in the coefficients of 0.4, 1.0, 2.0, 3.0, and 4.0 for the Northeast. The coefficients for “Thresh” would be 4, 10, 20, 30, and 40. “Index” refers to the summation index “*i*” in Equation 2. The coefficients for “Index” are 1, 2, 3, 4, and 5.

Normalization: The area and population terms inside the summation need to be normalized because the population term is several orders of magnitude larger than the area term. If the terms were not normalized, the population term would completely dominate the calculation. There are two choices for the normalization parameter; “Total A & P” and “Mean of A & P”. The “total” method uses the total area and population of the region. The “mean” method uses the mean area and population of all the storms analyzed.

Area/Pop: This parameter describes the manner in which the area and population terms are computed. “Cumulative” means that the area and population for successive snowfall thresholds are added together. For example, using this method the area for snowfall threshold 1 (4”-10”) would include the area of any snowfall greater than 4”. Likewise, the population would be summed over any area that received more than 4” of snow. The alternative method is “Thresh” which only sums area and population over the locations that received 4”-10” of snowfall.

Each combination of the three parameters for the snow index equation defines a method or technique for calculating the index. There are three alternatives for the coefficients, two for normalization, and two for the area/population methodology. Therefore there are 12 possible methods for calculating the snowfall index. To facilitate analysis and comparison of results from differing techniques, the table defines Method 1 through Method 12. For example, the technique used by Kocin and Uccellini is Method 3 (except we “clip” our results to the region).

Regional snowfall indices using each of the 12 methods were computed for 75 storms in each of the

	index 1	*index 2*	*index 3*	*index 4*	*index 5*	*index 6*	*index 7*	*index 8*	*index 9*	*index10*	*index11*	*index 12*
index1	1.00											
index2	0.99	1.00										
index3	1.00	0.99	1.00									
index4	0.99	1.00	0.99	1.00								
index5	1.00	0.99	1.00	0.99	1.00							
index6	0.99	1.00	0.99	1.00	0.99	1.00						
index7	1.00	0.99	1.00	0.99	1.00	0.99	1.00					
index8	0.99	1.00	0.99	1.00	0.99	1.00	0.99	1.00				
index9	0.99	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00			
index10	0.94	0.98	0.94	0.98	0.94	0.98	0.94	0.98	0.97	1.00		
index11	0.99	1.00	0.99	1.00	0.99	1.00	0.99	1.00	1.00	0.97	1.00	
index12	0.94	0.98	0.94	0.98	0.94	0.98	0.94	0.98	0.97	1.00	0.97	1.00

Table 3. Correlation matrix showing the relationship between index values calculated with different methods for the Northeast.

regions. A correlation matrix for each region was constructed comparing all the methods to each other. Results for the Northeast are given in Table 3. All the correlations were between 0.94 and 1.00 indicating there is little difference between methods. In other words, the different methods only serve to scale the final index to larger or smaller values. The choice of method did little to change the ranking of storms as indicated by the Spearman correlation matrix (not shown).

Therefore the method that made the most physical sense was chosen as the new algorithm. Like Kocin and Uccellini, we chose to sum the area and population in a cumulative fashion. However, we chose to use the total area and population method to normalize the terms in the brackets. This eliminated the need to select a subset of storms upon which to base the mean area and population. Finally we chose to use the index method for the coefficients. This seemed to provide more reasonable results across different regions. Therefore, “Method 9” was chosen as the algorithm to compute the new regional indices. Note that the correlation between this method and the Kocin-Uccellini method is 0.99 (index 9 vs. index 3, respectively).

4.5 *What Is the Minimum Criteria for a Storm to be Ranked?*

It would not be practical or useful to compute a regional index every time it snows. Various criteria were examined to set an objective minimum threshold for an index to be calculated. Since the purpose of this index is to estimate societal impacts, percent of population statistics were examined to find a meaningful minimum threshold. Table 4 compares the number of the storms (from the pool of 75 for each region) *that would not be ranked* based on various criteria. The column headings represent possible criteria for a minimum threshold. For example, the column labeled “40 20 10” means a storm will be ranked only if one of the following conditions is true:

- at least 40% of the region’s population is affected by “threshold 1” snowfall or greater, or
- at least 20% of the region’s population is affected by “threshold 2” snowfall or greater, or
- at least 10% of the region’s population is affected by “threshold 3” snowfall or greater.

Threshold 1, 2, and 3 values are given in Table 1 for each region. There will be occasions when a storm has a significant local effect but little effect on the entire region. The “40% 10% 5%” criteria was chosen as a compromise of including most storms while eliminating smaller storms that did not affect large segments of the region’s population.

5. PRELIMINARY RESULTS

Preliminary rankings for the Northern Plains, Northeast, Southeast, and Midwest are given in Table 5. It is not surprising that the March 1993 super- storm was the number one ranked storm in the Northeast and the Southeast. The index is calculated using Equation 2 with the appropriate regional parameters from Table 1. The calculated indices should only be compared to other values within the same region.

The next step for development is to translate the raw indices into categorical values. The objective is to have five categories. The breakpoints for the categories are still under review. The top category will include only a few storms, perhaps the top 2-5%, while the other

		Number of Rejected Storms by Region and Criteria						
	20 10 5	**20 20 5**	**40 10 5**	**40 20 5**	**50 10 5**	**50 20 5**	**70 10 5**	**70 20 5**
Northeast	0	0	0	4	5	12	9	25
Southeast	0	0	5	17	6	20	10	27
Central Plains	0	0	0	0	0	0	0	2
Northern Plains	0	0	0	1	0	2	0	2
Midwest	0	0	0	1	0	2	2	5

Table 4. Number of storms falling below minimum ranking criteria by region. See text for details

	Northern Plains		**Northeast**		**Southeast**		**Midwest**	
	StormDate	**Index**	**StormDate**	**Index**	**StormDate**	**Index**	**StormDate**	**Index**
1	1985-Mar-02-05	8.77	1993-Mar-13-15	6.63	1993-Mar-12-14	5.94	1999-Jan-01-04	5.44
2	1993-Nov-22-28	6.49	1996-Jan-07-09	6.40	1940-Jan-22-24	5.86	1950-Nov-22-28	4.85
3	1991-Oct-31-03	6.27	2003-Feb-15-19	5.09	1927-Mar-01-03	5.11	1985-Feb-10-15	4.69
4	1966-Mar-02-05	5.91	1978-Feb-06-08	4.36	1988-Jan-06-08	4.72	1978-Jan-25-27	4.43
5	1985-Nov-29-02	5.81	1978-Jan-19-22	4.26	1902-Feb-14-17	4.53	1979-Jan-12-14	3.66
6	1982-Jan-22-23	5.37	1961-Feb-03-05	4.25	1914-Feb-24-26	4.35	1967-Jan-26-28	3.30
7	1940-Mar-11-14	5.21	1983-Feb-11-12	4.20	1979-Feb-18-19	4.23	1931-Mar-05-10	3.14
8	1952-Feb-17-20	4.87	1958-Feb-15-17	4.02	1973-Feb-09-11	3.94	1968-Jan-12-16	2.96
9	1924-Mar-28-30	4.67	1914-Feb-12-15	3.95	1930-Dec-15-18	3.58	1929-Dec-18-20	2.87
10	1969-Dec-05-10	4.45	1960-Mar-03-05	3.92	1960-Feb-13-14	3.58	1978-Dec-28-02	2.87
11	2001-Nov-26-29	4.43	1969-Dec-25-29	3.81	1936-Jan-28-31	3.48	1918-Jan-10-13	2.78
12	1917-Jan-20-22	4.27	1987-Jan-22-24	3.78	1980-Mar-01-03	3.38	1995-Jan-19-24	2.75
13	1989-Mar-02-04	4.21	1964-Jan-12-14	3.76	1963-Dec-31-02	3.34	1927-Jan-12-15	2.74
14	1943-Mar-13-17	4.07	1947-Feb-20-22	3.73	1960-Mar-09-10	3.03	1965-Feb-23-26	2.71
15	1975-Jan-09-12	4.07	1920-Feb-04-07	3.53	1982-Jan-12-15	2.91	1950-Dec-05-09	2.70
16	1983-Nov-26-30	4.03	2003-Dec-05-08	3.51	1901-Feb-22-24	2.73	1973-Dec-18-21	2.70
17	1948-Feb-27-29	3.98	1966-Jan-29-31	3.51	1929-Dec-21-23	2.61	1930-Mar-24-27	2.65
18	1993-Jan-11-14	3.96	1972-Feb-18-20	3.50	1942-Mar-02-04	2.60	1994-Jan-16-18	2.64
19	1975-Mar-26-29	3.93	1941-Mar-07-10	3.48	1987-Jan-21-23	2.57	1974-Nov-30-03	2.59
20	1940-Nov-09-13	3.90	1936-Jan-18-20	3.27	1917-Dec-11-13	2.49	1900-Feb-27-01	2.58
21	1922-Feb-21-24	3.76	1917-Mar-01-06	3.26	1969-Feb-15-17	2.43	1909-Dec-24-26	2.54
22	1943-Nov-05-09	3.70	1935-Jan-22-25	3.19	1936-Feb-06-07	2.43	1944-Dec-10-12	2.52
23	1982-Dec-27-29	3.69	1958-Mar-18-23	3.19	1966-Jan-29-30	2.40	2004-Dec-22-24	2.48
24	1951-Feb-27-01	3.66	1960-Dec-11-13	3.18	1935-Dec-28-30	2.36	1951-Dec-19-22	2.48
25	1996-Mar-22-25	3.61	2005-Jan-22-24	3.02	1965-Jan-15-17	2.29	1977-Dec-08-10	2.38

Table 5. Preliminary ranking for the top 25 storms for the Northern Plains, Northeast, Southeast, and Midwest.

categories will become progressively larger and will also be based on percentiles.

6. SUMMARY AND CONCLUSION

This paper has summarized the ongoing development of regional snowfall impact scale indices. The new indices are an evolution of the Northeast Snowfall Impact Scale (NESIS). Development so far has concentrated on areas east of the Rocky Mountains. The new indices are calculated in a manner similar to NESIS, but there are some important differences. The biggest difference is that only snowfall and population information within a region's boundaries are used to calculate that region's index. This is in sharp contrast to NESIS which uses all snowfall and population information from a storm, no matter how far removed from the 13 state Northeast region. Our decision was based on the fact that many storms that have low to moderate impact in the Southeast would be ranked as significant because snowfall over the densely populated Northeast corridor from the same storm would artificially inflate the index. Other differences between NESIS and the new regional indices include how the population and snowfall terms are normalized and how each of the terms is weighted.

Also, new regions and new snowfall thresholds within those regions were defined. These regions and thresholds were chosen with the help of 10 and 25 year-return period statistics to help ensure objective and consistent choices across regions.

The regional indices are being produced experimentally for the 2007-08 winter season.

7. REFERENCES

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