Central Region Technical Attachment
Number 16-02
August 2016

Verification of a Blowing Snow Model with Utility for Decision Support Services

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ABSTRACT

Blowing snow is a forecast challenge for meteorologists in parts of the Great Plains during the cold season. Impacts to travel and to commerce can be significant because of visibility reductions related to blowing snow. This study examines the potential use of a blowing snow model (BSM) to aid in forecasting blowing snow and to discern possible impacts from blowing snow events. The BSM was run for significant blowing snow events occurring within the Grand Forks, North Dakota, Weather Forecast Office county warning area between 2006 and 2014. These data then were compared with two parameters related to impacts from blowing snow: coverage and duration. A preliminary analysis suggests that output from the BSM may provide forecasters with greater confidence of the potential impacts from significant blowing snow events, which, in turn, may aid forecasters in providing more effective impact-based decision support services to National Weather Service partners.

1. Introduction

Blowing snow occurs when wind lofts snow to a height of ≥2 m above ground with horizontal visibility reduced to ≤7 statute miles (SM; Glickman 2000). Significant visibility reductions from blowing snow—even in the absence of precipitating snow—can pose a substantial threat to life and property. The onset of visibility reductions from blowing snow can occur rapidly, sometimes in conjunction with very cold or rapidly decreasing temperatures, resulting in significant impacts to transportation and public safety. Therefore, accurately forecasting blowing snow events is critical for the protection of life and property.

Forecasting the severity of blowing snow events ranging from minor visibility restrictions to whiteout conditions often is challenging given a strong sensitivity to factors such as temperature, snow rate, snow age, and especially wind speed. Environment Canada has developed empirical guidance (Baggaley and Hanesiak 2005; hereafter BH05) to help forecasters determine the likelihood that a significant blowing snow event will occur. A large sample of hourly surface observations from across the Canadian prairies and Arctic was used to develop the empirical model. The blowing snow model (BSM) was developed as point-based guidance, and later converted to gridded guidance for the United States by the Weather

Forecast Office (WFO) at Grand Forks (Grafenauer 2016). BSM output is given as the probability that the visibility due to blowing snow will be less than a given threshold.

This paper describes the initial work done at WFO Grand Forks to evaluate the usefulness of the BSM as a tool to help better forecast high-impact blowing snow events and to communicate potential impacts and convey uncertainty to customers. The following section describes the methods and data used for local validation of the model. Preliminary results, a discussion, and a summary are provided in subsequent sections.

2. Data and methods

a. Identification of blowing snow events

Blizzard warnings within the WFO Grand Forks county warning area (CWA) for 2006–2014 were used as an initial blowing snow event dataset for local verification of the BSM. The National Weather Service (NWS) defines a blizzard based upon the occurrence of visibility <0.25 SM due to falling and/or blowing snow, wind speeds or frequent gusts of ≥ 35 mph, and a duration of ≥ 3 h. The intent in developing the dataset for this study was not to relate BSM output to the occurrence of a blizzard, but rather to identify a wide range of blowing snow conditions over an area, from isolated or short-lived blowing snow events to widespread and long-duration events. For this reason, it is believed that this dataset is sufficient for a preliminary evaluation of the BSM. During this period, 27 blowing snow events were documented. However, three events were not included in the analysis because of limited data or excessive missing data. The number of stations analyzed per event ranged from 4 to 30.

In this study, data from automated surface weather stations were used to evaluate key ingredients for identifying blowing snow events, including wind speed and visibility. Observed data obtained from raw station observations were then compared with output from the BSM. For each blowing snow event, all available NWS automated stations within or immediately adjacent to a NWS blizzard warning area were considered. Files containing raw surface observations were obtained from the Iowa Environmental Mesonet (available online at mesonet.agron.iastate.edu/request/download.phtml).

b. Coverage and duration of blowing snow events

In order to estimate the severity of blowing snow events from observed data, two metrics were computed for visibility thresholds of 0.5 SM and 0.25 SM: coverage and duration (Table 1). These thresholds were used for direct comparison with output from the BSM, which computes probabilities for visibility ≤ 0.5 SM due to blowing snow, and NWS blizzard visibility criteria, respectively. Coverage is the percentage of available stations within each blowing snow event with a minimum visibility at or below the visibility threshold value. Duration is the mean time period across all stations that the visibility was reduced to at or below the threshold value. In an attempt to identify periods of reduced visibility due only to the effects of snow and blowing snow, a minimum wind threshold of 20 kt was required. This threshold was chosen to eliminate observations with heavy snow and light winds that could contaminate the visibility dataset.

The coverage and duration of low visibility varied quite significantly from event to event, as indicated in Table 1. This variability would be expected because the blowing snow events ranged from relatively short-lived events with little falling snow to much larger synoptic-scale events with heavy falling snow.

A significant limitation of this method involved using a sparse, non-uniform, point-based observation network to approximate an areal coverage and mean duration of low visibility. For many blowing snow events—especially events without concurrent falling snow—visibility can vary considerably based upon the land surface and the degree of sheltering at a particular location. These visibility differences can occur over very short distances. With many sensors situated in open areas (such as at airports), observed conditions may not be representative of nearby urban or sheltered areas. Over broad sparsely populated regions, available real-time data often are limited, and these data typically cannot capture the variability of conditions over a wide area. However, the observing stations generally were spaced sufficiently throughout the area of interest to provide a reasonable depiction of conditions over a broad area.

c. Blowing snow model output

Output from the BSM was analyzed for each event for all available stations within a blowing snow event. Data used to initialize the BSM include surface temperature and wind speed, snow rate, and snow age. While temperature and wind speed measurements were available from automated sensors, reliable snow rate and snow age were less readily available for individual stations. Because of this, single values of snow age and snow rate were used—based on observed data available from Grand Forks and Fargo, North Dakota.

The version of the BSM used in this analysis generates probabilities for achieving visibility reduced to <0.5 SM for each observation at each station. Two sets of gridded probabilities were computed, one assuming falling snow and one without concurrent falling snow. These results are controlled by setting the snow rate parameter. Both of these results are identical for events occurring without falling snow. The probabilities for reduced visibility increase for higher snow rates.

Four BSM variables were calculated for each blowing snow event (Table 2): (i) the event average maximum probability with concurrent falling snow, (ii) the event average maximum probability without concurrent falling snow, (iii) the average highest hour probability with concurrent falling snow, and (iv) the average highest hour probability without concurrent falling snow. BSM probabilities were created for every available station observation. The event average maximum probabilities were computed by taking the mean of the highest BSM probability for each station for an individual event. The average highest hour probability was computed by calculating the mean BSM probability at each hour across all stations, and selecting the highest hourly value. The event average maximum BSM probability output therefore incorporates the most severe conditions regardless of time for each site for an event (e.g., 1900 UTC for one station versus 2300 UTC at a second station), while the highest hour probabilities attempt to capture the conditions during the most severe hour of the event (e.g., only 1900 UTC for all stations).

Table 1. For each blowing snow event occurring within the WFO Grand Forks CWA between 2006 and 2014, the number of automated stations included in the analysis, the percentage of those stations achieving a minimum visibility of ≤0.5 and ≤0.25 SM (coverage), and the average duration of all stations for the particular event reaching the ≤0.5 and ≤0.25 SM visibility thresholds are given.

Date	Number of Stations	Coverage ≤0.5 SM (%)	Coverage ≤0.25 SM (%)	Duration ≤0.5 SM (h)	Duration ≤0.25 SM (h)
24 January 2006	13	38	31	1.37	0.83
9 February 2008	10	80	80	7.12	4.03
14 December 2008	14	87	87	11.31	7.8
12 January 2009	5	60	40	2.88	2.67
10 March 2009	11	91	91	11.35	8.62
25 December 2009	12	50	50	8.12	2.76
25 January 2010	13	100	83	7.58	6.44
30 December 2010	19	53	37	8.71	9.01
1 January 2011	20	65	45	6.25	4.9
12 January 2013	8	88	38	9.93	11.11
19 January 2013	12	67	33	4.5	4.82
10 February 2013	10	70	60	5.01	3.63
18 February 2013	21	76	52	9.27	7.99
18 March 2013	25	88	72	7.23	5.2
28 December 2013	23	91	74	5.37	4.54
3 January 2014	23	57	26	1.88	1.28
16 January 2014	30	93	77	4.73	3.47
22 January 2014	24	75	29	4.7	3.95
26 January 2014	27	96	96	5.88	4.06
13 February 2014	12	67	58	4.34	2.59
26 February 2014	15	87	80	1.97	1.36
5 March 2014	8	25	13	3.33	1
21 March 2014	4	75	25	2.91	3.23
31 March 2014	20	80	65	8.36	7.94

Table 2. Average maximum BSM probability for visibility reductions due to blowing snow ≤0.5 SM and average maximum hourly BSM probability for visibility reductions due to blowing snow ≤0.5 SM computed with and without concurrent falling snow for blowing snow events occurring within the WFO Grand Forks CWA between 2006 and 2014.

Date	Ave. Max BSM Probability with Falling Snow (%)	Ave. Max BSM Probability without Falling Snow (%)	Ave. Highest Hour Max BSM Probability with Falling Snow (%)	Ave. Highest Hour Max BSM Probability without Falling Snow (%)
24 January 2006	56	2	38	1
9 February 2008	100	92	96	71
14 December 2008	95	82	94	74
12 January 2009	96	75	83	58
10 March 2009	100	87	98	79
25 December 2009	50	12	40	9
25 January 2010	96	73	94	57
30 December 2010	88	62	80	51
1 January 2011	89	58	75	36
12 January 2013	98	74	95	62
19 January 2013	100	84	97	70
10 February 2013	65	16	54	9
18 February 2013	94	78	91	67
18 March 2013	93	60	86	50
28 December 2013	96	76	84	54
3 January 2014	89	48	65	20
16 January 2014	99	82	92	63
22 January 2014	94	76	76	50
26 January 2014	99	96	98	91
13 February 2014	91	66	85	57
26 February 2014	92	56	82	41
5 March 2014	56	13	53	9
31 March 2014	83	57	73	41

3. Results and discussion

In order to determine if the relatively small dataset used in this study compares favorably with the BH05 dataset, the probability of detection (POD), false alarm ratio (FAR), and critical success index (CSI) were calculated following the BH05 methods using a 0.5 SM visibility threshold with mean wind and snow age. Note that BH05 displayed results using a 1-km (0.62 SM) visibility threshold, but for general comparison purposes this difference is insignificant. The events were separated into those that occurred with concurrent falling snow and those that occurred without concurrent falling snow (Table 3). The results between the two datasets are very similar, validating the use of the BSM within the Grand Forks CWA.

Table 3. POD, FAR, and CSI for blowing snow with visibility ≤0.5 SM and concurrent falling snow and without concurrent falling snow using the BH05 dataset and local data from this study.

	0.5 SM with Falling Snow			0.5 SM without Falling Snow		
	POD	**FAR**	**CSI**	**POD**	**FAR**	**CSI**
BH05	95.54	64.54	34.49	95.39	42.82	55.65
Grand Forks CWA Events	100	64.37	35.63	95.41	44.52	54.04

From an operational perspective, the 0.5 SM BSM visibility threshold can be used as a proxy for diagnosing significant blowing snow events. Higher probabilities for visibility restrictions ≤0.5 SM can increase confidence for the potential for a significant blowing snow event. Given the variability in conditions over a larger geographic region, the coverage of high-impact blowing snow conditions may be an important consideration in the forecast decision process. For example, winter weather advisories may be issued for blowing snow events with visibility<0.25 SM, but with limited coverage. A blizzard warning may be issued for blowing snow events with increasing coverage.

During the 2013–2014 winter weather season, there was a logarithmic correlation (Fig. 1) between the BSM output and the coverage of 0.5 SM visibility conditions, although this correlation deteriorated once more cases from previous seasons were introduced (Fig. 2). All but one case from the 2013 to 2014 cold season occurred without concurrent falling snow. Separating the events that occurred with and without concurrent falling snow for the entire dataset, the BSM appears to perform better for events without falling snow (Fig. 3) than events with falling snow (Fig. 4). It is speculated that the added complexity associated with cases with falling snow lowers the predictability. With that said, given the number of variables that impact blowing snow, it is inevitable that some cases will not be handled well by the statistical BSM, but the output still provides value in a qualitative sense to the operational forecaster.

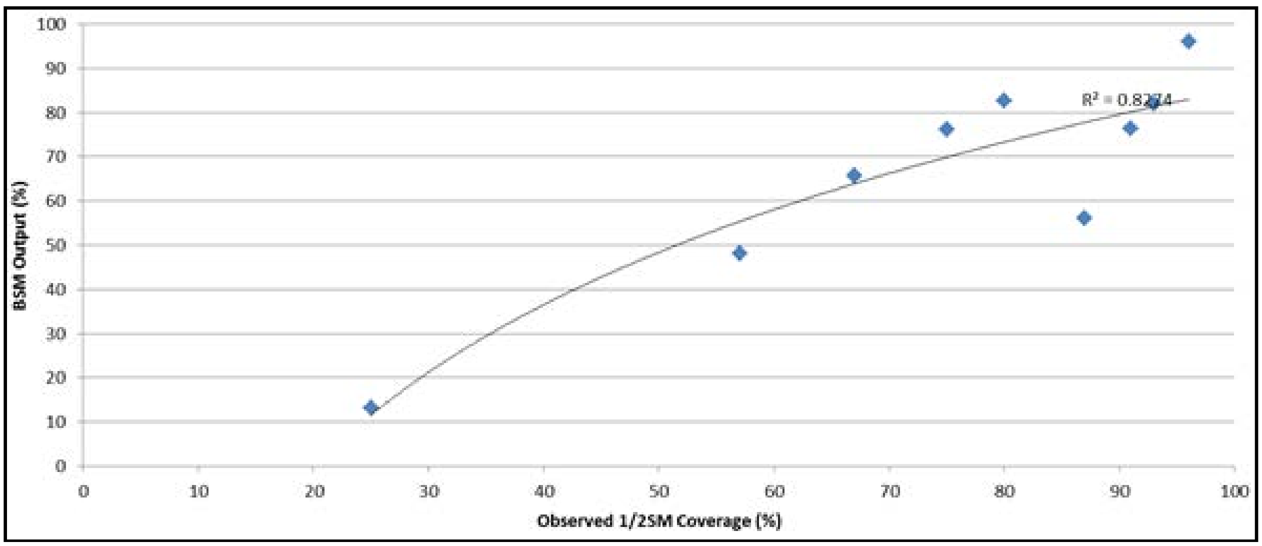

Figure 1. The 2013–2014 winter season scatter plot showing the observed coverage of visibility ≤0.5 SM versus the BSM probability for reductions in visibility ≤0.5 SM ($R^2 = 0.8274$).

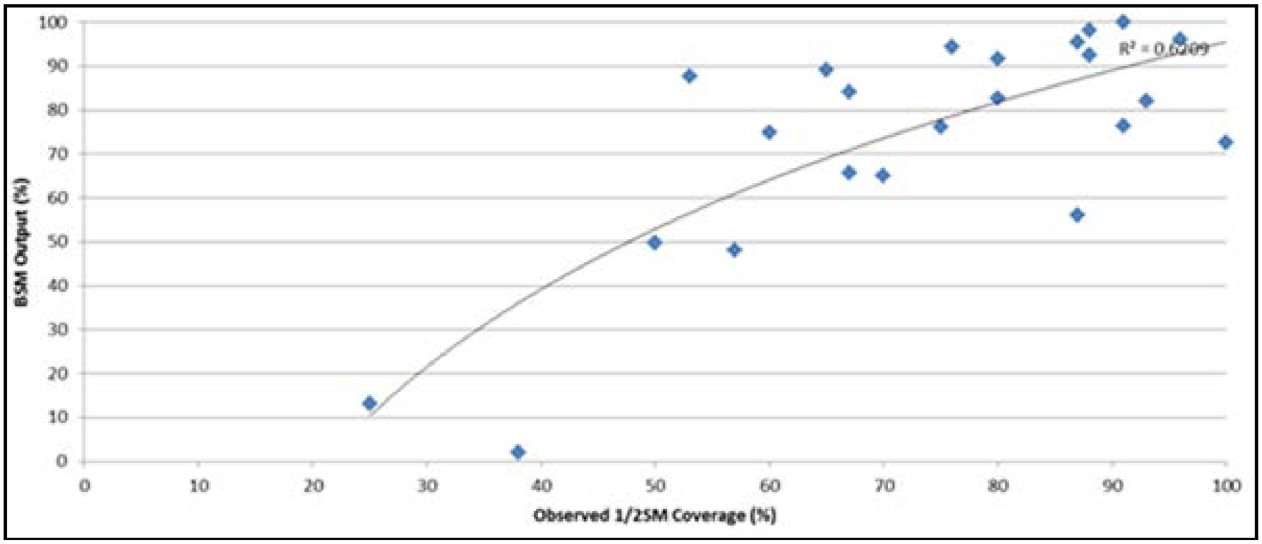

Figure 2. Scatter plot showing the observed coverage of visibility ≤0.5 SM versus the BSM probability for reductions in visibility ≤0.5 SM for all events ($R^2 = 0.6209$).

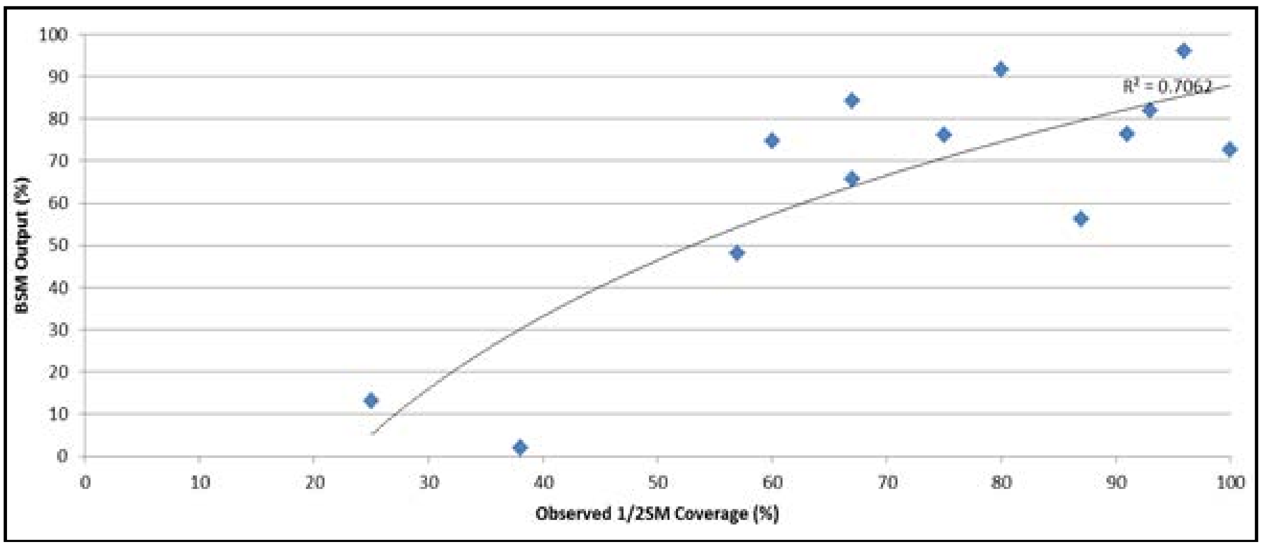

Figure 3. Scatter plot showing the observed coverage of visibility ≤0.5 SM versus the BSM probability for reductions in visibility ≤0.5 SM for events without falling snow ($R^2 = 0.7062$).

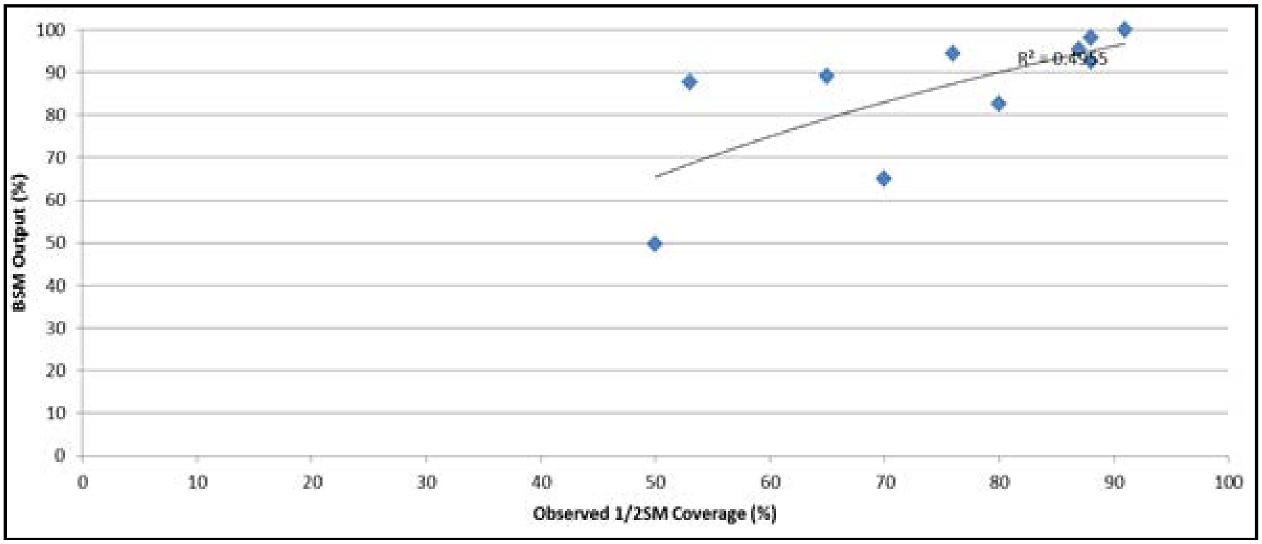

Figure 4. Scatter plot showing the observed coverage of visibility ≤0.5 SM versus the BSM probability for reductions in visibility ≤0.5 SM for events with falling snow (R^2 = 0.4955).

Blowing snow impacts can be difficult to quantify for forecasters tasked with providing decision support services (DSS) to stakeholders. There may be a large range of impacts from event to event, or even during one event from location to location. Lower-impact blowing snow events often are confined to relatively open areas, while higher-impact blowing snow events often experience greater coverage and longer duration. The coverage of reduced visibility due to blowing snow is related to the total area impacted, with increasing impacts as more people are affected. Travel may still be possible for locations within lower-impact blowing snow events because conditions may not be widespread and may be temporary. Longer-duration blowing snow increases the impacts by causing longer disruptions to travel and commerce.

Using the approach that blowing snow impacts are caused mainly because of the coverage and duration of blowing snow, we can develop a blowing snow impact level (BSIL) for each event:

Blowing Snow Impact Level (BSIL) = (0.5-SM Coverage * 0.5-SM Duration)/100

The components of this formula include the coverage (%) and duration (h) of blowing snow with a visibility ≤0.5 SM. A subjective analysis (including school closures, road closures, and public comments) of each event compared favorably with the results of the BSIL.

There was a logarithmic relationship between the BSM output and the BSIL (Fig. 5), with impacts associated with blowing snow events increasing with increasing BSM probabilities. This information may be useful in determining potential impacts from a blowing snow event and providing DSS to stakeholders. In other words, a higher mean BSM probability, such as 90%, may add confidence in forecasting a high-impact blowing snow event, with widespread coverage and/or a long duration of significantly reduced visibility. This is just one possible method to relate output from the BSM to impacts.

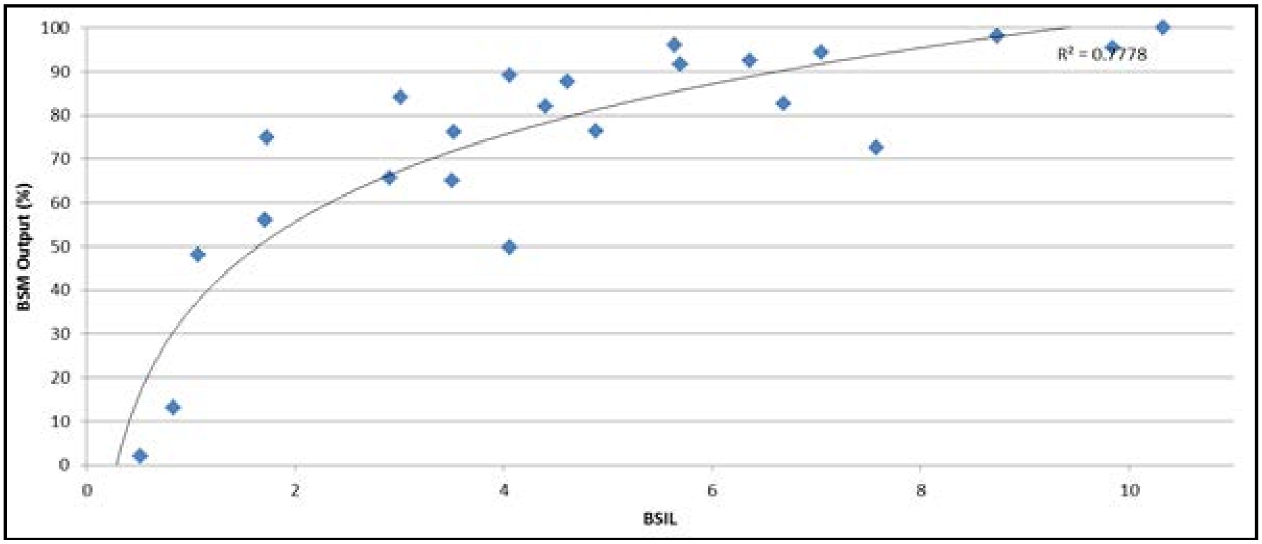

Figure 5. Scatter plot showing the BSIL versus the BSM probability for reductions in visibility ≤0.5 SM for all events ($R^2 = 0.7778$).

As discussed earlier, the events within the dataset were further separated into events with and without concurrent falling snow. The average BSIL for events with falling snow was 6.52 (10 total cases), while the average BSIL of events without falling snow was 3.35 (13 total cases). Comparing the average coverage and duration of these two types of events indicated that the average coverage of falling snow versus no falling snow events is similar, but the average duration nearly doubles for events with falling snow (Table 4). This adds justification to including duration into the verification of the BSM for attempting to discern impacts for an upcoming event.

Table 4. Average coverage (%) and duration (h) of 0.5 SM and 0.25 SM visibilities during blowing snow events.

Visibility Threshold	Average Coverage During Blizzard Events with Falling Snow (%)	Average Coverage During Blizzard Events without Falling Snow (%)	Average Duration of Blizzard Events with Falling Snow (h)	Average Duration of Blizzard Events without Falling Snow (h)
0.5 SM	75	72	8.6	4.3
0.25 SM	60	55	6.9	3.2

4. Summary

This study has highlighted the possible applicability a blowing snow model for use in forecasting high-impact blowing snow events. Preliminary local verification at WFO Grand Forks of a blowing snow model developed at Environment Canada has shown the potential utility for both forecasting blowing snow events and providing guidance for forecasters and key decision makers regarding confidence level and possible impacts.

Whereas forecasters generally are highly skilled with forecasting individual sensible weather elements, high-impact blowing snow events are related to several of these elements—among other factors—making forecasts quite challenging in some cases. A calibrated forecast tool, such as the BSM, may aid the forecaster in quickly diagnosing the potential for high-impact blowing snow events. This additional information, in conjunction with a thorough meteorological diagnosis of the event, can add confidence to the forecast. Moreover, as forecasters gain experience using the BSM, this added confidence may be utilized to help guide DSS geared toward core partners. The BSM has shown potential utility in helping to determine impacts between sheltered and unsheltered areas, as well as discriminating between isolated to scattered significant visibility reductions and widespread significant visibility reductions. The interpretation of this information may be quite valuable to decision makers.

As ensemble modeling systems continue to evolve, incorporating this probabilistic guidance into available tools, such as the BSM, likely will add additional value. The NWS issues forecasts based on the most likely scenario, but decision makers may be better prepared to make decisions by knowing the spectrum of possibilities. This type of information then can be provided to decision makers by displaying the probability for different levels of the BSIL.

Other future work includes adding lower-end blowing snow events and null events to the database in order to increase the number of events toward the lower spectrum of impacts and assess false alarms. Determining the applicability of the BSM outside of open plains would also need more investigation.

References

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