10.2 HIGH IMPACT SUB-ADVISORY SNOW EVENTS: THE NEED TO EFFECTIVELY COMMUNICATE THE THREAT OF SHORT DURATION HIGH INTENSITY SNOWFALL

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1. Introduction

The National Weather Service (NWS) employs a multi-tiered approach to inform its customers of the likelihood, potential severity and impact of impending weather events. When weather conditions are expected to become hazardous, routine forecast products are headlined, complimented with specific, event-driven Watches, Warnings, Advisories or Special Weather Statements (SPSs) that discuss a particular hazard. To fulfill its mission of protecting life and property, the NWS issues event-driven forecast products with as much lead time as possible so that preventative actions may be taken by the general public, local, state and Federal Emergency Management Agencies (EMAs) to mitigate potential impacts.

The NWS' multi-tiered approach provides increased public awareness of impending weather events. NWS Warnings are issued when potentially life-threatening weather conditions are imminent or in progress, and are usually preceded by a Watch. Watches alert users of the *potential* for significant weather conditions to occur which may pose a threat to life and property. Advisories are issued for events which present a significant inconvenience to the public, but not a threat to life or property as long as people are aware of the weather condition.

More specifically, Table 1 shows Advisory and Warning criteria set forth in NWS Directive NWSI 10-513 (October 2002) regarding the issuances of Winter Weather Advisories (WSWs). Snowfall over central Pennsylvania meets advisory criteria when 3 inches of snow accumulates in a 12-hour period. An accumulation "midpoint" value of 3 inches is used to decide if an advisory is issued (Table 1). For example, if the forecast is for 2-4 inches of snow, the midpoint of the forecast range is 3 inches of accumulation, so an advisory is issued. However, if the forecast is for 1-3 inches, the 2 inch midpoint is less than the criteria, and an advisory is not issued. Warning criteria is reached when 6 inches (defined by the midpoint of the forecast range) of snow or more falls within a 12-hour period. In the lee of Lake Erie over northwest Pennsylvania, Lake Effect Snow Advisories are issued when 3 inches of lake effect snow (also midpoint of a forecast range) is expected in a 12-hour period. Lake Effect Snow Warnings are issued when an average of 6 inches of snow or more is expected in a 12-hour period. Herein lies a problem, when snowfall rates are high, yet advisory criteria are not met, an advisory typically is not issued and the public is not aware of the potential impact of the snowfall.

While the NWS forecast tier approach works well in most cases, a number of weather events occur each year when the event (e.g., total snow accumulation) falls short of meeting Advisory and Warning criteria, yet

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still poses a substantial hazard to the public. Many of these occur during the winter season, where a combination of precipitation intensity, duration and type, along with fluctuations in wind and temperature present a multitude of dangers. Events characterized by extremely heavy but short-lived snow bursts or squalls create potentially dangerous conditions including blinding snowfall, rapidly deteriorating road conditions, and increasing driver anxiety and confusion. Therefore, the need is to more effectively communicate when conditions of "high intensity" (e.g., high rates of accumulation on the order of an inch or more per hour) occur for a short period of time (e.g., 1-3 hr), resulting in total snowfall accumulations that are "sub-advisory" (below the Advisory criteria of 3 inches).

This paper examines the consequences and impact of high intensity, sub-advisory snowfall, and the need for the NWS to find better methods to inform the public, media and emergency management communities of these events.

2. The Problem

In areas of the United States which receive substantial measurable snowfall each year, forecasts calling for one to two inches of snow do not typically arouse substantial public concern. For this reason, the NWS does not typically headline its forecasts for such amounts in these areas. However, snow falling at a high rate (in bursts or squalls), such that 1-2 inch amounts occur in a 1-2 hour period, greatly magnifies the potential impact in these same areas.

In one of the first published examinations related to high intensity snowfall, Homan and Uccellini (1987) highlighted forecast problems associated with a pair of light to moderate snow events in the mid Atlantic states in February 1986. Despite similar prevailing upper level patterns and features, the storms' ultimate public impacts were remarkably different. To explain the contrasting magnitudes of observed and perceived public impact (in terms of snow intensity and overall accumulation), a thorough examination of potential forcing mechanisms responsible for the heavier snow bursts was conducted. The authors concluded by stressing the need for higher resolution numerical forecast models to be developed and made operationally available to forecasters, allowing real time examination and identification of forcing mechanisms conducive to heavy snow bursts, and improving overall nowcasting and predictive capabilities in general.

More than fifteen years later, Mass (2003) stated that perhaps the greatest failure of the United States weather forecasting enterprise is its inability to provide detailed information in the short-term (0-6 hours). This remains a critical problem, as over \$3 trillion of the nation's annual economy is directly affected by weather events (Freedman 2003). Energy companies, truck drivers, farmers, construction workers, transportation department snow removal crews, railroad dispatchers, and many other occupations rely upon short-term forecasts to effectively manage their time and resources. While the amount and quality of short-term weather information has increased substantially over the past decade, methods of making short-term forecasts understandable and widely available to the public are still lacking. Short-term forecasts pertaining to high intensity, sub-advisory snowfall are no exception.

On a case by case basis, NWS forecasters can exercise subjective judgment in the issuance of Advisories and Warnings when expected combinations of weather pose a potential threat and the public impact can be justified. Advisories *can* be issued for weather events that do not technically meet specified criteria, as long as there is a compelling reason from an impact standpoint. For example, the first snowfall of the season often catches the public off-guard, therefore the issuance of an advisory, even if the expected snowfall is only 2 inches (below advisory criteria), may be warranted. Similarly, a combination of falling and/or blowing snow and low wind chill values may be sufficient to prompt an advisory issuance, even if none of the individual hazards exceed the specified criteria.

Another method of communicating this type of sub-advisory weather event is the issuance of event-driven, short-term forecasts (NOWCASTs). Although NOWCASTs are available on NWS websites and play on NOAA Weather Radio (NWR) throughout the country, they often receive only limited dissemination over the most popular media outlets as compared to NWS Advisories and Warnings. Furthermore, the NWS Interactive Forecast Preparation System (IFPS) has not yet been optimally configured to effectively communicate sub-advisory information in routine forecast products. The end result is that many users do not receive this critical short-term forecast information, although several modes of communication are currently available.

3. The Frequency and Impact of High Intensity, Sub-Advisory Criteria Snowfall

Across the United States, the frequency of sub-advisory events increases as one moves north, and towards areas downwind of the Great Lakes. Table 2 summarizes information extracted from Cember and Wilks (1993), a climatology of snowfall from 1955 through 1992 throughout the northeast United States. The percentage and number of 1 inch or greater and 4 inch or greater snowfall occurrences near 3 locations in central Pennsylvania: Bradford (BFD), State College (University Park – UNV) and Harrisburg (MDT) are shown, along with the percentage of and number of days with greater than 1 inch but less than 4 inch accumulation.

Closer examination of Table 2 reveals that snowfalls greater than 1 inch but less than 4 inches occur three to four times more often than snowfalls of 4 inches or more. Since these are calendar day totals (e.g., 24 hours), most of these are likely to be of sub-advisory criteria (3 inches in 12 hours). Given the potential impact of high intensity snowfall, it is equally if not more important to diagnose and communicate the expected character (intensity and duration) of snowfall during sub-advisory events than to precisely predict snow accumulation totals.

Short duration, high intensity snowfall ranges from a nuisance at the low end of the spectrum to a serious hazard to the public at the high end. The timing of snowfall intensity and duration in relation to traffic volume (PENNDoT 2001), including time of day and day of week, is critical in determining potential public impact. "Seemingly" minor sub-advisory snowfall events are common occurrences each winter, yet their impacts are greatly magnified during periods of higher traffic volume, especially weekday rush hours and weekend afternoons. Without prior notification, the general public can be too easily caught off guard by sudden increases in rates of snow accumulation, instantaneous reductions in visibility and rapidly deteriorating road conditions. The following examples illustrate severe public impacts encountered as a result of such events.

a. High Impact Sub-Advisory Snowfall on 5 January 2003

On 5 January 2003, a vigorous yet moisture-challenged clipper-type storm system moved across the Ohio Valley and mid-Atlantic regions, producing a generally light snowfall. What distinguished this event from other typically minor snowfalls was its disproportionate impact on the public with respect to total amounts. The York Dispatch (January 6, 2003) carried a front page story the next day, reporting that the "snowfall wreaked havoc out of proportion to its volume." York County EMA Director Pat McFadden added that what made the Sunday snowfall most difficult was that there was enough traffic to melt the snow as it fell, but not enough to prevent it from refreezing as ice on roadways, "which makes the absolute worst conditions."

The snow arrived quickly and fell in locally intense bursts, accumulating at a rate of 1 to 2 inches per hour. While most areas of central Pennsylvania received only 1 to 2 inch accumulation totals, parts of the south central mountains and Lower Susquehanna River Valley region received up to 3 inches of snow in less than 3 hours. Numerous traffic accidents resulted, some involving serious personal injury. The rate at which the snow fell clearly had a major impact on this day.

b. Lake Effect Snow Squalls 28 December 2001

The 28 December 2001 52-vehicle pile-up on Interstate 80 near Loganton, PA (Clinton County) is a tragic example of the hazard posed by high intensity, sub-advisory criteria snowfall. This accident occurred as a heavy snow squall reduced visibility to near zero on a stretch of the busy interstate highway in central Pennsylvania. Seven people died and dozens were seriously hurt in the fiery crash, which occurred between Lock Haven and Milton. Subsequent newspaper headlines proclaimed "Unexpected Snow in Pennsylvania" (The New York Review, 2001) as the reason for the deadly accident. In reality, the snowfall was neither unexpected nor an infrequent seasonal occurrence in that part of the state. Scattered snow showers were forecast well in advance, with more detailed short-term NOWCASTs in effect at the time. Although accumulations were generally less than an inch, people were not prepared for the snow's intensity and localized white-out conditions.

c. Multiple Chain Reaction Crashes in Virginia on 22 February 2001

A serious rash of accidents occurred on 22 February 2001 throughout Virginia, as a band of sub-advisory snowfall affected the region. One particularly serious multi-vehicle crash involved a total of 131 vehicles on Interstate 95 during "whiteout" conditions. A minor storm by NWS verification standards, 2 to 3 inches of snow fell in less than 2 hours. However, its impact was arguably more severe than many medium- to heavy snowfalls because of the snowfall's rate of accumulation.

Two other major pileups involving a total of 80 vehicles occurred on Interstate 95 within a few miles of the 131-vehicle wreck. Others included a 10-vehicle pile-up in Ashland, VA and a fiery 30-car crash near Stafford. VA. Another serious collision involved 20 vehicles (10 cars and 10 tractor trailers) on Interstate 81 in Rockbridge County, Virginia.

4. Predictability of Events

The NWS devotes significant organizational effort and resources to warning the public, media and emergency management agencies of widespread heavy snowfalls due to their widespread financial and societal impacts. Historically, the meteorological community's ability to provide increasingly accurate weather information on smaller scales has always been limited by available computer resources, both in terms of computational power and the feasibility of applying theoretical research into forecast operations. These limitations have been greatly reduced in recent years.

Substantial upgrades in NWS information technology (IT) infrastructure have been realized in the past decade. Increased spatial and temporal resolution of multi-spectral satellite imagery, improved Doppler radar image resolution and data processing algorithms, along with the operational implementation of higher resolution numerical forecast models are all a direct result of the notable advancements in technology. More specifically, the commissioning of the Advanced Weather Interactive Processing System (AWIPS) in the late 1990s, and an infusion of science and applied operational research (e.g. Cooperative Program for Operational Meteorology, Education and Training [COMET]) within the past decade have provided NWS forecasters with new tools to diagnose real time meso- and smaller-scale weather phenomena. Operational application of theoretical research, such as snow microphysics, to diagnose high impact snow events is an excellent example of this progress.

Roebber et al. (2003) and Waldstreicher (2001) have shown how improved snowfall forecasts and better advisory/ warning decisions can be made through the operational application of snow microphysics concepts. Using operationally available Eta forecast model data and the BUFKIT forecast profile, an analysis tool kit (Mahoney and Niziol 1997), forecasters can more accurately predict the timing of heavier snow bursts by keying in on the orientation of the omega field in relation to the dendritic snow growth zone (-12 to -18 ^{o}C). Waldstreicher (2001) showed how greater awareness and application of snow microphysics considerations along with improved understanding of heavy precipitation processes in the cold season, such as those detailed by Wetzel and Martin (2001), can greatly improve forecasters' success in diagnosing the potential for high intensity snow events, as well as helping to distinguish between advisory and warning criteria snowfall.

The application of research to existing forecast methodology will improve forecasters' ability to identify areas conducive to high intensity snowfall. A large number of sub-advisory events are associated with lake effect snow bands in the lee of the Great Lakes. Many others occur as a result of common synoptic scale forcing mechanisms in the presence of low static stability and/or small/negative conditional symmetric stability and frontogenetical forcing such as those described in Sanders and Bosart (1985), Moore and Blakley (1988), DeVoir (1998) and Wiesmueller and Zubrick (1998). Forecaster assessment and identification of these forcing mechanisms/instabilities within the dendritic growth zone in a saturated environment should prompt forecasters to more closely examine the potential for and consider the potential impact of high intensity snowfall.

Future forecaster ability will only continue to increase as advances in computational power and technology are developed and refined, and research, such as Waldstreicher's, are incorporated into operational forecasting. The challenge remains, now and in the future, to devise better ways of disseminating this improved short-term weather information to our customers.

5. Recommendations

The consequences of high intensity, sub-advisory snowfall can be severely disproportionate to observed amounts. Snow removal crews, EMAs and the general public are often ill prepared for the rapid deterioration of local weather and roadway conditions accompanying high rates of snow accumulation. Improvements in the dissemination of short-term forecast information are needed to help mitigate these impacts.

The problems discussed in Section 2 of this paper illustrate the need for NWS forecasters to make better use of current NWS products to alert the public of potentially hazardous weather conditions associated with high intensity snowfall. Given the impact of high intensity, sub-advisory snow events, forecasters need to consistently use the appropriate terminology to distinguish high intensity events from more ordinary "snow shower" occurrences. The general public and DOTs benefit from the judicious use of terms such as snow bursts or squalls and specific mentions of accumulation rates, as it helps improve road crews' responsiveness to quickly changing conditions. Routine forecast products and NOWCASTs worded in this manner are more valuable to all user groups.

Additionally, forecasters should consider subjective WSW issuances more often for the occurrence of intense snow bursts or squalls. High intensity, sub-advisory snowfalls can create a variety of hazardous conditions, but the timing of events is of the essence. Heavy snow bursts have very high public impact when they occur during periods of high traffic volume, such as weekday rush hours or afternoon weekends. However, sub-advisory snow squalls occurring late at night in an isolated, remote area would not have nearly as great of a public impact, and a subjective WSW issuance would not be justified. Also, it may not be worth issuing a WSW for a single county being affected by a small but intense snow band; such instances might be better handled SPSs.

Liberal usage of SPSs leading up to and during potentially significant sub-advisory events is another way to better inform the public, EMA agencies and transportation departments of potentially hazardous conditions. SPSs receive high priority media dissemination, nearly as wide and efficient as watch, warning and advisory statements over local media and cable outlets.

Additionally, since SPSs and WSWs are broadcast on NWR, they can also be broadcast on Highway Advisory Radio Systems (Information Station Specialists, Inc. 2001) to directly alert drivers of weather hazards in specific geographic areas. Highway Advisory Radio Systems can alert drivers of potential hazards by means of flashing lights and a sign (Figure 1) directing them to tune into a local radio station for information concerning the alert. The radio systems can be programmed to broadcast NWR transmissions, but the decision to utilize existing stations in this manner lies with individual county DOT supervisors (this is the case in central PA). Therefore, great opportunities exist for NWS offices to develop partnerships with Departments of Transportation (DOT) and/or public works officials within their County Warning Areas (CWA) to investigate the need and feasibility of installing such radio systems and broadcasting critical weather information.

Subjective Winter Weather Advisory issuances or liberal usage of SPSs to alert of the hazard would provide the most immediate solution to the sub-advisory problem. It is hoped that further capabilities may yet be developed for IFPS, and probabilistic forecasts be generated for high intensity, sub-advisory events. In the meantime, NWS Forecast Offices must work closely with County EMAs and State Transportation Departments to keep them abreast of policy decisions in order to anticipate and make the best use of the short-term forecast information provided in NWS routine and event-driven forecast products.

6. Conclusions

High intensity, sub-advisory criteria snowfall events have been discussed from an operational and public impact standpoint. In each of the cases presented, the impact of "seemingly" minor snowfall events was extremely high due to the rate with which the sub-advisory criteria snow fell. There is a compelling need for the NWS to more clearly articulate the threat regarding these sub-advisory events, especially when the snow falls at critical times (i.e. rush hours, weekend afternoons, etc.).

Subjective Advisory issuances and routine and liberal usage of SPSs may be the most effective solutions, since these products receive wide media distribution and are broadcast on all NWR transmitters. Further strides can be made through the cultivation of partnerships with DOT and public works departments to investigate the feasibility of utilizing or developing Highway Advisory Radio Systems (US DOT, 2003) within their areas of responsibility. Such road-side alert systems can be programmed to provide vital short-term weather information, alerting highway motorists in a timely fashion through their standard in-dash stereo receivers.

Heightened awareness of the high intensity, sub-advisory snowfall threat will lead to focused effort in improving the dissemination of short-term forecast information to NWS customers. Such work will ensure that users are informed of *all* impending weather hazards, and move the NWS closer to its organizational vision of becoming America's "No Surprise" Weather Service.

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NWS Winter Advisories (for Snow)	Advisory Criteria	NWS Winter Warnings (for Snow)	Warning Criteria
Winter Weather Advisory	3 inches or more in 12 hours. *	**Winter Storm Warning**	**6 inches** or more in 12 to 24 hours. *
Lake Effect Snow Advisory (Northwest PA only)	3 inches or more in 12 hours. *	**Lake Effect Snow Warning (Northwest PA only)**	**6 inches** or more in 12 hours *

Table 1. Winter Weather (Snow) Advisory and Warning Criteria for NWS State College, PA. *Accumulation "midpoint" values are used to decide if an advisory or warning should be issued (3 inches for a Snow Advisory or Lake Effect Snow Advisory, and 6 inches for a Winter Storm Warning or Lake Effect Snow Warning). For example, if the forecast is for 2-4 inches of snow, the midpoint of the forecast range is 3 inches and an advisory is issued. However, if the forecast is for 1-3 inches, the 2 inch midpoint is less than the criteria, and an advisory is not issued.

		Avg. % of Days > 1”	Avg. # of Days > 1”	Avg. % of Days > 4”	Avg. # of Days > 4”	Avg. % of Days 1” < x < 4”	Avg. # of Days 1” < x < 4”
NOV 8-15	BFD	10	0.8	~2	0.2	8	.6
	UNV	3	0.2	~1	0.1	2	.2
	MDT	1	0.1	< 1	0.1	< 1	~ 0
DEC 1-15	BFD	24	3.8	6	~1	18	2.9
	UNV	8	1.3	1	0.2	7	1.1
	MDT	4	0.6	< 1	< 0.2	~ 3	< 0.5
JAN 1-31	BFD	25	7.8	5	1.6	20	6.2
	UNV	13	4	2.5	0.8	10.5	3.3
	MDT	9	2.8	1.5	0.5	7.5	2.3
FEB 15-28	BFD	21	2.9	4	0.6	17	2.4
	UNV	10	1.4	2	0.3	8	1.1
	MDT	6	0.8	1.5	0.2	4.5	0.6
MAR 24-31	BFD	10	0.8	~2	0.2	8	0.6
	UNV	5	0.4	1.5	0.1	3	0.2
	MDT	2	0.2	< 1	< 0.1	~ 1	< 0.1

Table 2. Percentage (%) and Number (#) of Days per indicated time period of snowfall occurrences of one inch or greater, four inches or greater, and greater than 1 inch but less than 4 inches (1” < x < 4”, where x is snowfall in inches) for Bradford (BFD), State College (UNV) and Harrisburg (MDT). Data extracted from Cember and Wilks (1993), covering the years 1955-1992.

Figure 1. A Highway Advisory Radio Station along the Pennsylvania Turnpike in the western Philadelphia suburbs. Such roadside signs alert drivers to listen to a radio station to receive urgent travel information. Highway Advisory Radio systems can be programmed to broadcast NWS weather information heard on NOAA Weather Radio (NWR).