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Snow-Related Injuries in Aomori Prefecture, Japan

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Abstract

Snow-related injuries are a recurrent public-safety concern in regions with heavy snowfall, yet the temporal effects of snowfall and their heterogeneity across accident mechanisms remain insufficiently understood. This study examines snow-related accidents in Aomori and Hirosaki, two cities in one of Japan's heaviest-snowfall regions, using detailed accident records for fiscal years 2013–2022 linked to daily weather data. We estimate Poisson distributed-lag models of daily accident counts, allowing snowfall to affect accident incidence contemporaneously and for up to six subsequent days. We further estimate mechanism-specific models and an ordered logit model of injury severity. The results reveal a distinct temporal pattern. Same-day snowfall is associated with a lower incidence of snow-related accidents, whereas snowfall on preceding days is generally associated with higher accident incidence, particularly over the first several days following snowfall. Greater snow depth is also associated with increased accident incidence, while relatively warmer conditions are associated with fewer accidents. These relationships vary across accident mechanisms: high-place falls, same-level slips and falls, and injuries caused by falling snow or ice respond differently to current and lagged snowfall and snow depth. In the severity analysis, greater same-day snowfall is associated with less severe outcomes, while snow depth shows little association with severity. These findings demonstrate that snow-related injury risk depends not only on the amount of snow but also on its timing, accumulation, and the mechanism through which injuries occur. Accounting for these dimensions may improve the timing and targeting of warnings and preventive measures in heavy-snowfall communities.

Keywords: snowfall; snow-related accidents; distributed lag; injury severity; accident mechanisms; Japan

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Previous research has consistently linked snow and icy conditions to elevated risks of accidents and injuries. Snow- and ice-related slips and falls constitute a substantial injury burden (Björnstig et al., 1997; Modji et al., 2025), while studies of traffic safety have shown that snowfall affects daily crash frequency and that these effects may depend on snowfall intensity and recent snowfall history (Seeherman and Liu, 2015; Ayon et al., 2020). Snow-removal activities also involve diverse injury mechanisms, including overexertion, slips and falls, and other snow-related injuries (Watson et al., 2011). Injuries associated with rooftop snow removal have been shown to increase with greater snow accumulation or snow depth and frequently involve serious falls and fractures (Pipas et al., 2002; Bylund et al., 2016; Yamaguchi et al., 2017). Bylund et al., for example, found a strong association between snow depth and injury incidence, with roof and ladder falls constituting the predominant mechanism.

More recent studies have emphasized that snowfall-related risks may unfold over several days. Bobb et al. (2017) found increased risks of fall-related hospitalization in the days following snowfall, and Huynh et al. (2021) similarly documented elevated risks of fall-related emergency department visits for several days after snowfall. Japanese studies have likewise associated snow-related casualties with snowfall, temperature, and accumulated snow (Myojin et al., 2015; Hosokawa et al., 2017; Kikuchi et al., 2022). Hosokawa et al. examined meteorological conditions over multiple preceding days, while Kikuchi et al. emphasized that accumulated snowfall may increase risk not only through physical snow conditions but also by increasing the need for hazardous snow-removal activities. Myojin et al. found a positive association between snowfall and snow-related casualties across a number of heavy-snowfall prefectures, including Aomori. Evidence from Aomori also indicates that heavy-snow winters can produce substantial numbers of injuries, particularly falls from roofs, ladders, and stepladders during snow removal (Koseki, 2022).

Snow-related injury risk also appears to depend on broader demographic and social conditions. Long-term Japanese studies have linked changes in the composition of snow-related accidents to population aging and changes in snow-removal practices, while subsequent research has associated greater vulnerability with aging, depopulation, regional snow conditions, and local snow-removal capacity (Numano, 1993; Inoue and Hattori, 2006; Yamagata et al., 2014; Chiba et al., 2020). Inoue and Hattori (2006), for example, documented a concentration of snow-related deaths in peripheral and depopulating communities, whereas Chiba et al. (2020) identified both snow conditions and population aging as important contributors to snow-related human casualties in Hokkaido.

Despite this evidence, relatively little research has jointly examined the contemporaneous and delayed associations of daily snowfall, snow depth, heterogeneity across accident mechanisms, and injury severity within a single empirical framework. We address this gap by linking detailed snow-related accident records to daily weather conditions in Aomori City and Hirosaki City, Aomori Prefecture in Japan.

1. Aomori, Japan

In July 2026, the number of international visitors to Japan reached a record high for the month of July [1]. Aomori has also attracted growing international attention. Among Japan's prefectures, Aomori has the largest following on China's Weibo [2]. The number of followers exceeds the population of Aomori Prefecture. Aomori is also known for its scenic landscapes, festivals, and food. At the same time, it experiences exceptionally heavy snowfall in winter, and Aomori City is often described as one of the snowiest major cities in the world [3]. Snow-related hazards are therefore an important local concern and, as tourism expands, may affect not only residents but also visitors.Recent episodes of exceptional snowfall further illustrate the severity of winter hazards. In December 2024, Aomori Prefecture experienced heavy snowfall, particularly in the Tsugaru region. Monthly maximum snow depth reached 84 cm in Hirosaki, 85 cm in Ikarigaseki, and 357 cm in Sukayu, setting December records at all three stations [4]. The heavy snow disrupted road traffic and required extensive snow-removal activity, imposing substantial burdens on daily life.

This study uses the Snow-Related Accident Records (FY2013-FY2022) provided by the Disaster Prevention and Firefighting Division of the Aomori Prefectural Government (now the Disaster and Crisis Management Division, Aomori Prefectural Crisis Management Bureau). The records contain the date and time of each incident, municipality, injury severity (minor, serious, or fatal), age, sex, and a brief narrative description of the accident.

Figure 1 presents snow-related accident rates by winter season and city based on the prefectural accident records [5] [6]. Accident rates fluctuate considerably across winters, with particularly high levels in 2020 and 2021. Although the individual-level records used in this study end in FY2022, the exceptional snowfall observed in December 2024 underscores the continued relevance of snow-related injury risk.

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[1] https://www.jnto.go.jp/news/press/20260819_montly.html (accessed August 30, 2026).

[2] https://news.ntv.co.jp/category/international/ra22267a72ee4245d9b029be819f1aa3ae (accessed August 30, 2026).

[3] https://japanupmagazine.com/archives/19280 (accessed August 30, 2026).

[4] https://mutsushimpo.com/news/m90xpa7a/ (accessed September 6, 2026).

[5] The individual-level source data were obtained directly from the Aomori Prefectural Government through a data request and are not publicly available.

[6] Population data source （https://opendata.pref.aomori.lg.jp/dataset/2463/resource/28944/content.html?page=9, accessed September 6, 2026）

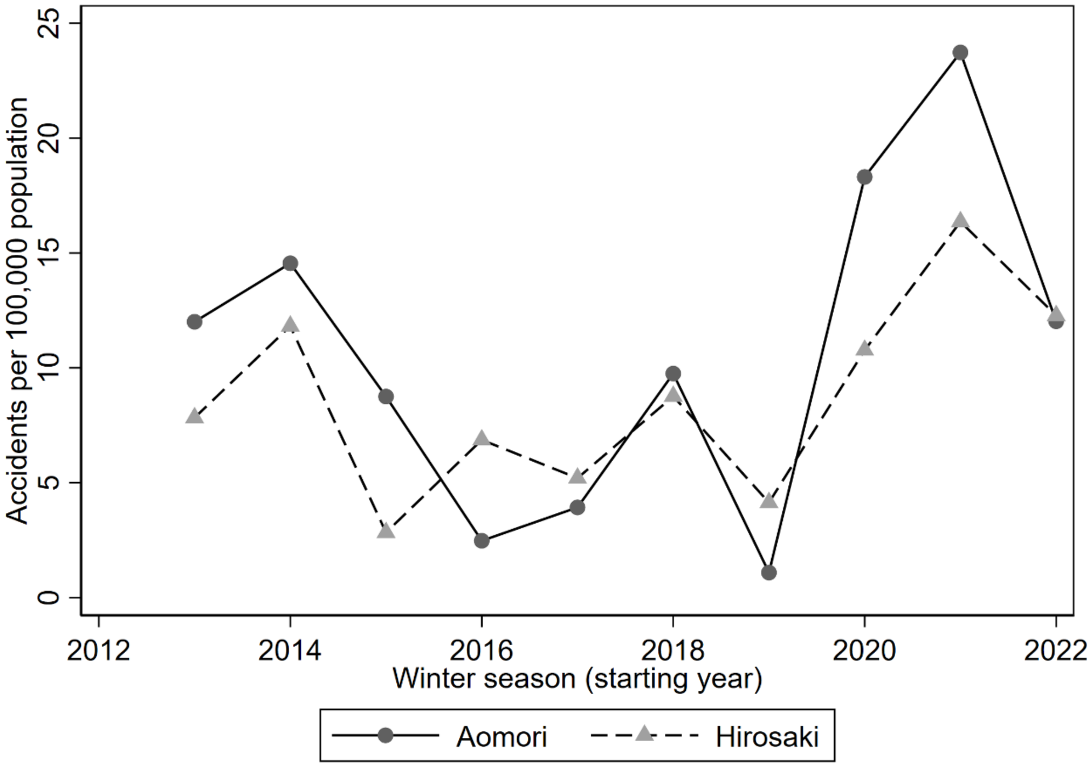

Figure 1. Snow-related accident rates by winter season and city

Figure 2 shows the monthly distribution of snow-related accidents. In the data shown, accidents occur from December through March, with January accounting for the largest number. Figure 3 shows the distribution of accident mechanisms. Based on the narrative descriptions, we classified accidents into five categories with assistance from ChatGPT: high-place falls, same-level slips/falls, falling snow/ice, snow-removal machinery, and other mechanisms. High-place falls are by far the most common mechanism. Figure 4 compares weather conditions on accident and non-accident days [7]. Accident days are descriptively characterized by greater daily snowfall, lower mean temperatures, and deeper snow cover. These are unadjusted comparisons and should not be interpreted as causal effects.

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[7] Meteorological data source（https://www.data.jma.go.jp/stats/etrn/index.php, accessed September 6, 2026）

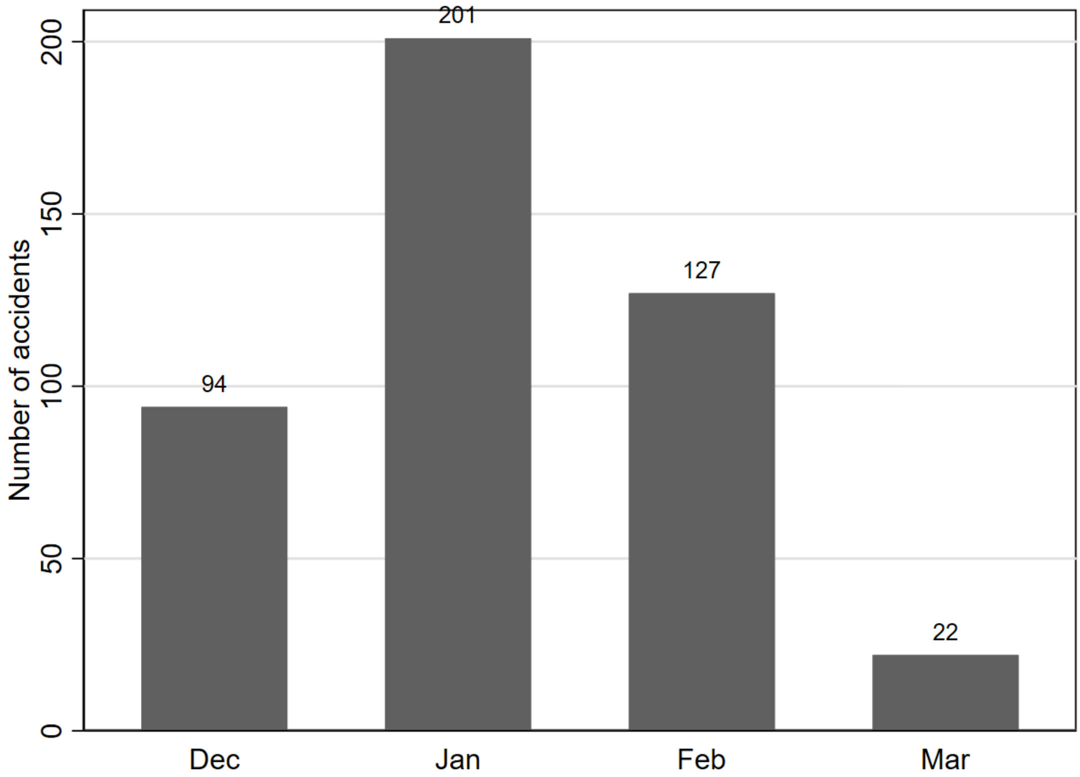

Figure 2. Seasonality of snow-related accidents

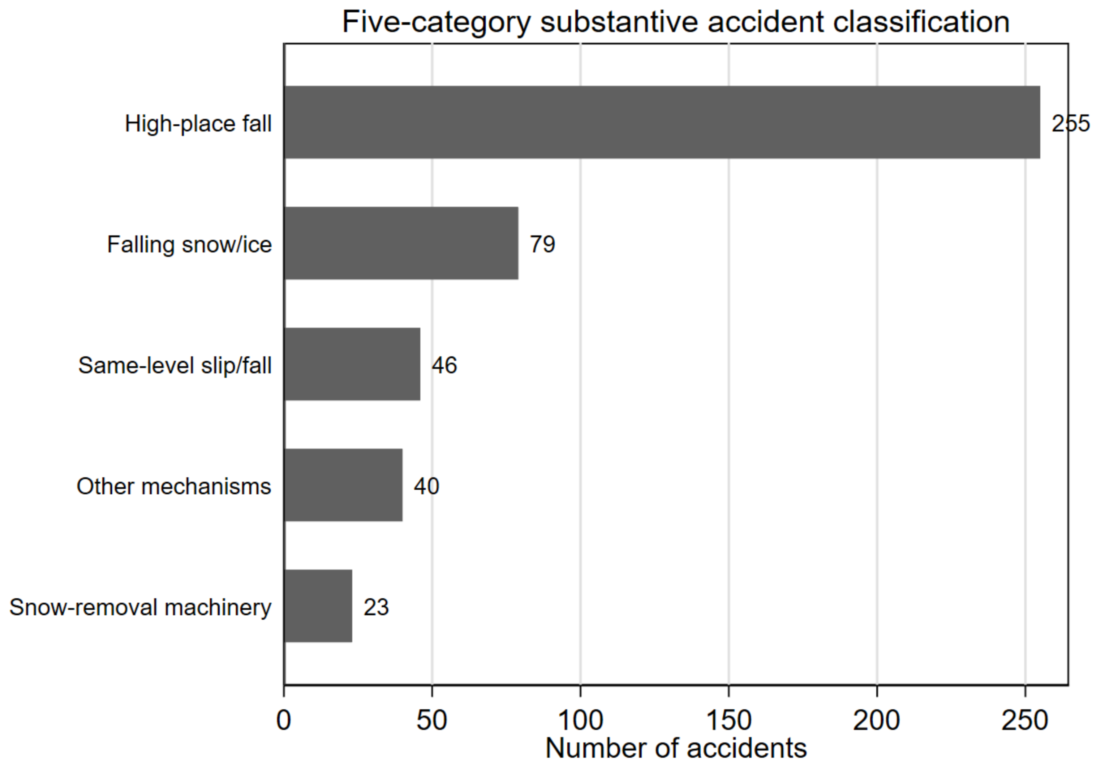

Figure 3. Snow-related accidents by mechanism

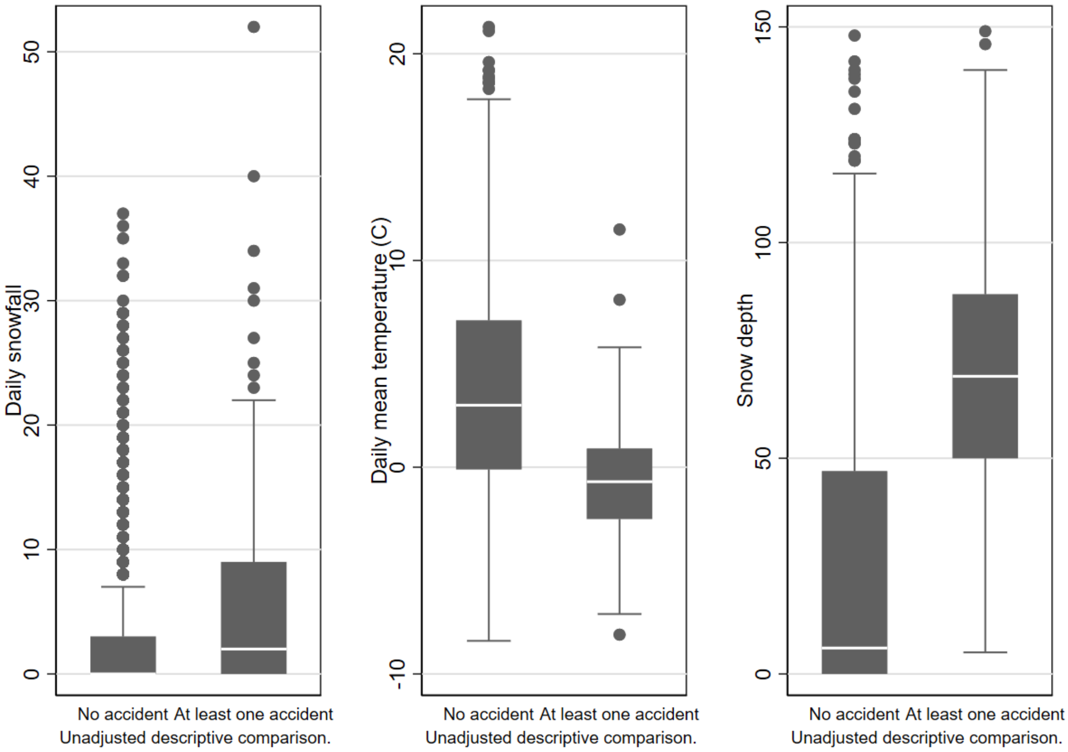

Figure 4. Weather conditions on accident and non-accident days

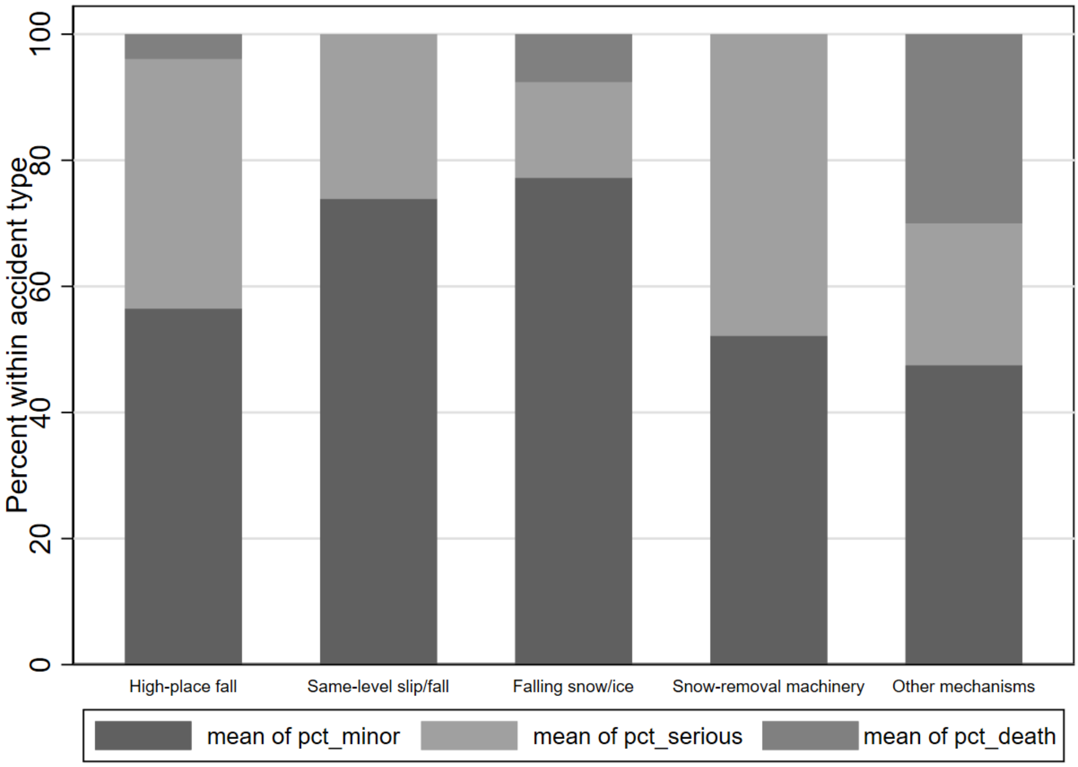

Figure 5. Injury severity by accident mechanism

Figure 5 shows that injury severity varies across accident mechanisms. High-place falls and the other-mechanisms category contain comparatively larger shares of serious or fatal outcomes, whereas same-level slips/falls and falling snow/ice accidents are more concentrated among less severe injuries. We next use regression models to examine these patterns in greater detail.

2. Empirical Analysis

We conduct three sets of empirical analyses using the snow-related accident data. First, we model the daily number of snow-related accidents. Second, we estimate mechanism-specific daily accident counts. Third, we model injury severity among accidents that occurred. The first two analyses use city-day observations and, following Bobb et al. (2017), employ Poisson distributed-lag models with contemporaneous snowfall and six daily lags (lags 0–6). For the total-count analysis, we report a baseline specification without snow depth and an extended specification that additionally controls for snow depth. The mechanism-specific models include snow depth. The logarithm of city population is included as an offset. The third analysis is an accident-level ordered logit model of injury severity. The model structures are summarized below.

Total-count model:

$$\ln(\mu_{it}) = \alpha + \sum_{k=0}^{6} \beta_k \text{ Snowfall}_{i,t-k} + \gamma_1 \text{Warm}_{it} + \gamma_2 \text{Cold}_{it} + \gamma_3 \text{Depth}_{it}$$
$$+\delta_i + \lambda_{m(t)} + \theta_{w(t)} + \phi_{d(t)} + \ln(\text{Population}_{it}).$$

Mechanism-specific count model:

$$\ln(\mu_{it}^c) = \alpha^c + \sum_{k=0}^{6} \beta_k^c \text{ Snowfall}_{i,t-k} + \gamma_1^c \text{Warm}_{it} + \gamma_2^c \text{Cold}_{it} + \gamma_3^c \text{Depth}_{it}$$
$$+\delta_i^c + \lambda_{m(t)}^c + \theta_{w(t)}^c + \phi_{d(t)}^c + \ln(\text{Population}_{it}).$$

Severity model:

$$\ln\left[\frac{\Pr\left(\text{Damage}_j > r\right)}{\Pr\left(\text{Damage}_j \le r\right)}\right] = \beta_1 \text{Snowfall}_j + \beta_2 \text{Warm}_j + \beta_3 \text{Cold}_j + \beta_4 \text{Depth}_j$$
$$+\sum_a \eta_a \text{ Age}_{aj} + \sum_s \xi_s \text{ Sex}_{sj} + \sum_h \psi_h \text{ Time}_{hj} + \sum_c \omega_c \text{ Mechanism}_{cj}$$
$$+\delta_{\text{City}(j)} + \lambda_{\text{Month}(j)} + \rho \text{ WinterTrend}_j - \kappa_r, \quad r \in \{1,2\}.$$

For the count models, i indexes cities, t indexes days, and c indexes the four mechanism groups. The conditional mean denotes the expected daily number of snow-related accidents for a given city-day. Snowfall denotes daily snowfall at lag k (k = 0, …, 6), while Warm and Cold are piecewise-linear temperature terms measuring degrees above and below 0°C, respectively, and Depth denotes snow depth. In the baseline total-count specification, the Depth term shown in the equation is omitted. The fixed-effect terms represent city, month, winter-season, and day-of-week fixed effects. The logarithm of population enters with its coefficient constrained to one as an offset. Age, sex, time of day, and accident mechanism enter as sets of categorical indicators. The severity model includes city and month fixed effects and a linear winter trend; it does not include winter-season or day-of-week fixed effects due to sample size. Standard errors are clustered by date in all models to allow for within-date correlation across observations.

Table 1 reports descriptive statistics for the city-day variables used in the occurrence analyses, while Table 2 reports descriptive statistics for accident-level variables used in the severity analysis. The count-model estimation sample is slightly smaller than the descriptive city-day sample because the distributed-lag specification requires complete lag histories. The severity regression uses 434 accidents because time-of-day information is missing for nine otherwise eligible cases.

Table 1. Descriptive statistics for city-day occurrence variables

Variables	N	Mean	SD	Min	Max
Daily snow-related accidents	3566	0.125	0.460	0.000	5.000
High-place falls	3566	0.072	0.316	0.000	4.000
Same-level slips/falls	3566	0.013	0.120	0.000	2.000
Falling snow/ice accidents	3566	0.022	0.177	0.000	3.000
Other (incl. machinery)	3566	0.018	0.142	0.000	3.000
Daily snowfall (cm)	3563	2.916	5.544	0.000	52.000
Snow depth (cm)	3563	28.860	33.678	0.000	149.000
Degrees above 0°C	3565	3.874	4.144	0.000	21.300
Degrees below 0°C	3565	0.637	1.336	0.000	8.400

Table 2. Descriptive statistics for accident-level severity variables

Variables	N	Mean	SD	Min	Max
Severity (1=minor, 2=serious, 3=death)	443	1.454	0.612	1.000	3.000
Daily snowfall (cm)	443	5.269	6.938	0.000	52.000
Snow depth (cm)	443	74.223	28.876	5.000	149.000
Degrees above 0°C	443	0.623	1.296	0.000	11.500
Degrees below 0°C	443	1.467	1.709	0.000	8.100
Age decade	443	60.790	14.755	10.000	90.000
Male (=1)	443	0.731	0.444	0.000	1.000
Time-of-day category (1–3)	434	—	—	1.000	3.000
Accident mechanism category (1–5)	443	—	—	1.000	5.000

Table 3 reports the Poisson estimates for daily snow-related accident occurrence as incidence-rate ratios (IRRs). Specification (1) excludes snow depth, whereas specification (2) includes it. Contemporaneous snowfall is negatively associated with accident incidence, and the association becomes statistically significant when snow depth is included. One possible interpretation is that very heavy same-day snowfall discourages outdoor activities such as snow removal, although the present data do not directly test this mechanism. In the specification controlling for snow depth, snowfall at lags 1–3 and 6 is positively associated with accident incidence, whereas the estimates at lags 4–5 are not statistically distinguishable from zero. Degrees above 0°C are associated with fewer accidents, while greater snow depth is associated with higher accident incidence.

Table 3. Poisson models of snow-related accident occurrence

	(1)	(2)
Variables	Main	Depth
Daily snowfall	0.9857	0.9718***
	(0.0103)	(0.0101)
L.Daily snowfall	1.0392***	1.0211**
	(0.0085)	(0.0089)
L2.Daily snowfall	1.0465***	1.0313***
	(0.0058)	(0.0063)
L3.Daily snowfall	1.0371***	1.0256***
	(0.0061)	(0.0061)
L4.Daily snowfall	1.0197***	1.0104
	(0.0066)	(0.0067)
L5.Daily snowfall	1.0144**	1.0073
	(0.0072)	(0.0070)
L6.Daily snowfall	1.0391***	1.0344***
	(0.0080)	(0.0069)
Degrees above 0°C	0.8571***	0.8743**
	(0.0459)	(0.0469)
Degrees below 0°C	0.9275*	0.9399
	(0.0368)	(0.0367)
Snow depth		1.0199***
		(0.0035)
N	3539	3539
Log likelihood	-964.6174	-945.6848
City fixed effects	Y	Y
Month fixed effects	Y	Y
Winter-season FE	Y	Y
Day-of-week FE	Y	Y
Population offset	Y	Y

Incidence-rate ratios

Standard errors in parentheses; clustered by date

* p<0.10 ** p<0.05 *** p<0.01

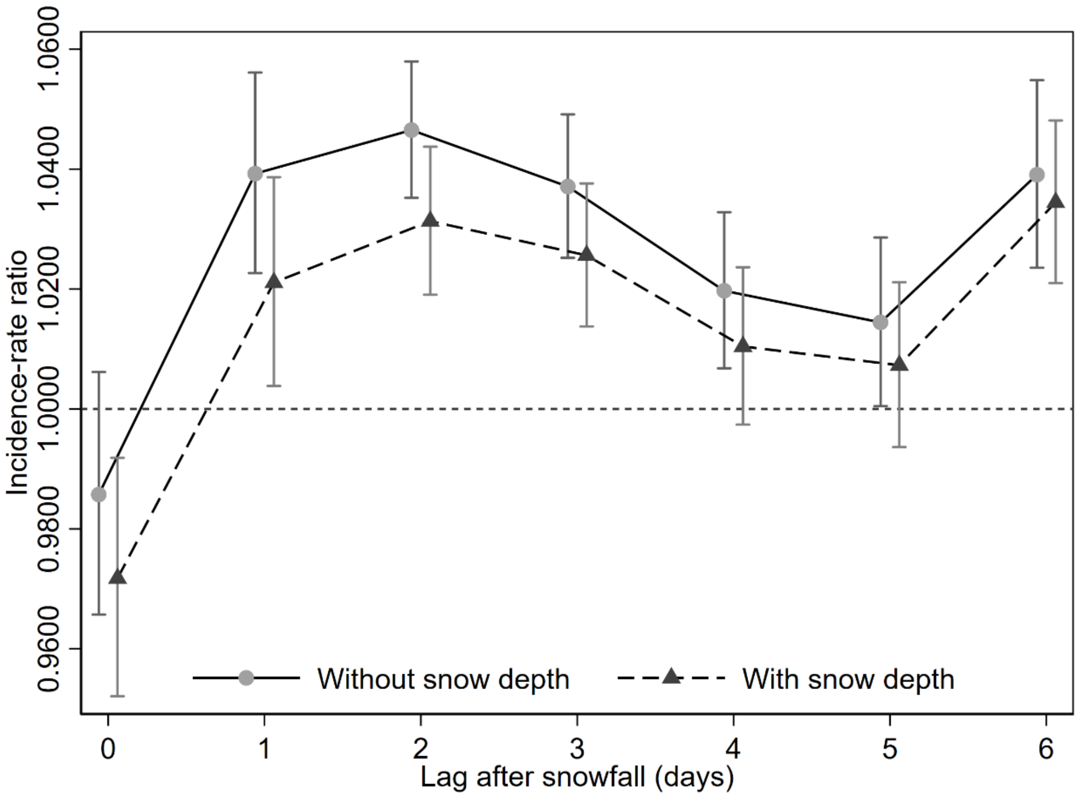

Figure 6. Distributed-lag estimates for snowfall

Figure 6 plots the lag-specific snowfall estimates. Table 4 reports the mechanism-specific Poisson models as incidence-rate ratios (IRRs). Greater same-day snowfall is associated with lower incidence of high-place falls and same-level slips/falls, while no statistically significant contemporaneous association is observed for falling snow/ice or the pooled other-mechanisms category. Lagged snowfall associations vary across mechanisms rather than forming a uniform pattern. Degrees above 0°C are negatively associated with high-place and same-level falls, whereas greater snow depth is positively associated with high-place falls and falling snow/ice accidents.

Table 4. Poisson models of accident occurrence by mechanism

	(1)	(2)	(3)	(4)
Variables	High fall	Same-level fall	Falling snow/ice	Other (incl. machinery)
Daily snowfall	0.9669**	0.9304**	0.9531	1.0243
	(0.0131)	(0.0300)	(0.0340)	(0.0192)
L.Daily snowfall	0.9968	1.0419**	1.0210	1.0775***
	(0.0106)	(0.0186)	(0.0213)	(0.0165)
L2.Daily snowfall	1.0327***	1.0373**	1.0351*	1.0241
	(0.0074)	(0.0157)	(0.0187)	(0.0175)
L3.Daily snowfall	1.0201***	1.0271	1.0448***	1.0226
	(0.0076)	(0.0191)	(0.0156)	(0.0179)
L4.Daily snowfall	1.0112	1.0103	1.0137	0.9991
	(0.0085)	(0.0194)	(0.0166)	(0.0198)
L5.Daily snowfall	1.0065	0.9723	1.0117	1.0235
	(0.0089)	(0.0243)	(0.0156)	(0.0187)
L6.Daily snowfall	1.0394***	1.0259	1.0410***	1.0201
	(0.0087)	(0.0217)	(0.0145)	(0.0160)
Degrees above 0°C	0.8828*	0.5115**	1.0197	0.9352
	(0.0564)	(0.1571)	(0.1232)	(0.1437)
Degrees below 0°C	0.9564	0.9457	0.9961	0.8469
	(0.0529)	(0.0997)	(0.0884)	(0.0913)
Snow depth	1.0240***	1.0060	1.0214**	1.0115
	(0.0043)	(0.0096)	(0.0103)	(0.0076)
N	3539	3539	3539	3539
Log likelihood	-635.1444	-189.9534	-232.4946	-237.0470
City fixed effects	Y	Y	Y	Y
Month fixed effects	Y	Y	Y	Y
Winter-season FE	Y	Y	Y	Y
Day-of-week FE	Y	Y	Y	Y
Population offset	Y	Y	Y	Y

Incidence-rate ratios

Standard errors in parentheses; clustered by date

* p<0.10 ** p<0.05 *** p<0.01

Table 5. Ordered logit model of injury severity

	(1)
Variables	Severity
Daily snowfall	0.9555**
	(0.0204)
Degrees above 0°C	0.9547
	(0.0910)
Degrees below 0°C	0.9099
	(0.0752)
Snow depth	1.0016
	(0.0049)
10s	0.0000***
	(0.0000)
20s	0.7040
	(0.4785)
30s	0.2853*
	(0.1908)
40s	0.9257
	(0.4787)
50s	0.7915
	(0.2713)
60s	0.8469
	(0.2124)
70s	Base
80s	1.1238
	(0.4905)
90s	10.9866
	(24.4932)
Female	Base
Male	1.1187
	(0.3208)
06:00–11:59	Base
12:00–17:59	0.8242
	(0.1795)
18:00–05:59	0.7681
	(0.3904)

High-place fall	Base
Same-level fall	0.4677*
	(0.2014)
Falling snow/ice	0.4452**
	(0.1644)
Snow-removal machinery	1.1710
	(0.4228)
Other mechanisms	2.6124*
	(1.3898)
City fixed effects	Y
Month fixed effects	Y
Winter trend	Y
N	434
Log likelihood	-323.3197

Odds ratios
Standard errors in parentheses
* p<0.10 ** p<0.05 *** p<0.01

Table 5 reports odds ratios from the ordered logit model of injury severity. Greater same-day snowfall is associated with lower odds of a more severe outcome. This pattern may reflect selection in the types of activities undertaken during heavy snowfall, but the model does not identify the underlying mechanism. Snow depth is not significantly associated with severity. Most age categories do not differ significantly from the 70s reference group; the near-zero estimate for the 10s category reflects very sparse information and should not be substantively interpreted, while the 30s category shows lower severity only at the 10% significance level. There are no statistically significant differences by sex or time of day. Relative to high-place falls, same-level slips/falls and falling snow/ice accidents are associated with lower severity, whereas the other-mechanisms category is associated with higher severity at the 10% level. The estimate for the latter category should also be interpreted cautiously because of its relatively small sample size.

3. Discussion

The results indicate that snow-related accident risk in Aomori and Hirosaki is associated differently with contemporaneous and preceding snowfall. Same-day snowfall is negatively associated with overall accident incidence, whereas snowfall on several preceding days is positively associated with accident incidence. This pattern is broadly consistent with previous studies showing that snowfall-related injury risks can persist for several days after snowfall (Bobb et al., 2017; Huynh et al., 2021), as well as Japanese studies emphasizing cumulative meteorological conditions over preceding days (Hosokawa et al., 2017; Kikuchi et al., 2022). One possible interpretation is that active snowfall temporarily reduces outdoor activity, while risks subsequently increase as residents resume outdoor activities or undertake snow removal. However, because individual behavior is not observed, this interpretation remains tentative.

The mechanism-specific results also show that snow-related accidents are heterogeneous. Greater snow depth is positively associated with high-place falls and falling snow/ice accidents, consistent with previous studies linking accumulated snow to hazardous rooftop snow-removal activities (Pipas et al., 2002; Bylund et al., 2016; Yamaguchi et al., 2017). The severity analysis points in the same direction: same-level slips/falls and falling snow/ice accidents are less severe than high-place falls. This accords with clinical evidence that rooftop snow-removal accidents frequently involve fractures and moderate-to-serious injuries. Taken together, these findings suggest that both the timing and the mechanism of snow-related accidents are important for understanding winter injury risk.

These findings may have practical implications for snow-hazard prevention. Warnings based only on current snowfall may overlook risks that emerge in the days after snowfall or as snow accumulates. Attention to recent snowfall history and snow depth may therefore be useful, particularly for hazards related to snow removal and falls from height. Several limitations should nevertheless be noted. The analysis is observational and does not identify causal effects; weather observations may not perfectly represent conditions at each accident location; behavioral exposure such as time spent outdoors or removing snow is not observed; and the study is limited to Aomori City and Hirosaki City. Some mechanism and severity categories also contain relatively few observations.

Conclusion

This study examined the association between weather conditions and snow-related accidents in Aomori City and Hirosaki City. The results show that contemporaneous and lagged snowfall are associated with accident incidence in different ways and that these patterns vary across accident mechanisms. Accumulated snow depth is particularly associated with high-place falls and falling snow/ice accidents, while high-place falls are also associated with greater injury severity. These findings suggest that snow-related accident risk cannot be understood solely from same-day snowfall and that both recent snowfall history and accident mechanism are important. Because the analyses are observational, these associations should not be interpreted as causal effects.

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