

ENHANCED WINTER PRECIPITATION NEAR FERNIE, BRITISH COLUMBIA

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ABSTRACT: The Lizard Range near Fernie, B.C. often receives high amounts of precipitation in winter months, which can be substantially more than forecast by weather models. In this paper we compare modelled precipitation amounts to measured amounts and analyze atmospheric trends to better understand scenarios that may lead to enhanced precipitation. The primary goal of the study was to better predict precipitation, which should lead to more representative avalanche forecasts for improved public safety.

We obtained weather data between 2017 and 2023 and analyzed three weather models: the High-Resolution Deterministic Prediction System (HRDPS), the Regional Deterministic Prediction System (RDPS), and the Global Deterministic Prediction System. We compared model data primarily to measurements at Fernie Alpine Resort (1615 m) but also to weather data from two neighbouring operations and to expected precipitation amounts recorded by avalanche forecasters.

The most likely weather scenario for enhanced precipitation is having over 40 km/h southwest wind at 2000 to 3000 m elevation, often with a freezing level around 1000 to 1500 m, accompanied by a coastal low pressure system and frontal passage over the Lizard Range. High snow-to-liquid ratios may occur when the minimum air temperature at around 1600 m is -5 °C or colder. Models may properly predict or over-predict QPF when the 2000 m and 3000 m wind are below 40 km/h, particularly for the HRDPS. Forecasters can use these findings to better forecast winter precipitation near Fernie.

KEYWORDS: Enhanced precipitation, Fernie Factor, numerical weather prediction, weather forecasting, avalanche forecasting.

1. INTRODUCTION

Those familiar with forecasting winter precipitation near Fernie, British Columbia acknowledge that accumulated amounts can often seem unpredictable, with measurements sometimes several times higher than modelled amounts. Locals and regional forecasters have termed this the Fernie Factor or Fernie Effect. When Avalanche Canada forecasters prepare bulletins for the Lizard Range near Fernie, they often question whether the quantitative precipitation forecast (QPF) from numerical weather prediction (NWP) models is correct. Previously, an Avalanche Canada forecaster's protocol at reducing uncertainty was to ask weather forecasters at Environment Canada whether enhanced precipitation was likely.

It is well established that the presence of mountains causes orographic lift (e.g. Whiteman, 2000). The Lizard range presents the first major barrier for air coming from the southwest, resulting in rapid orographic lift. In addition, its horse-

shoe shape likely causes air to convergence, further enhancing lift and precipitation amounts. The effect requires a specific atmospheric setup meaning not every storm leads to enhanced precipitation. Avalanche forecasters find it hard to know when NWP models will properly predict QPF and when enhanced precipitation may occur. The uncertainty sometimes leads to publishing avalanche forecasts with decreased confidence.

The purpose of this study is to better understand weather trends near Fernie and identify atmospheric scenarios that may lead to enhanced precipitation. The primary goal is to better predict precipitation, which should lead to more representative avalanche forecasts for improved public safety.

2. METHODS

Data sources used to compare measured precipitation to modelled precipitation included the Information Exchange (CAA, 2020), more commonly called the InfoEx, and NWP models prepared by the Canadian Meteorological Centre (CMC).

The InfoEx contained measured snowfall, snow-water-equivalent (SWE), and rain during the winter seasons between 2017 and 2023. Weather data included observations from manual weather

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plots for three operations in the Lizard-Flathead avalanche bulletin region: Fernie Alpine Resort (1615 m), Island Lake Lodge (1620 m), and Fernie Wilderness Adventures (1830 m).

Fernie Alpine Resort's data were the primary source in this analysis, as they recorded snowfall amount and subsequently weighed the snow to determine the SWE, which better represents what NWP models simulate with QPF. The Fernie Alpine Resort dataset also included rain for days where the freezing level was higher than the weather plot. The 24-hour snowfall accumulation and associated SWE measurements record the precipitation over a 24-hour period at around 7 AM each day. Supplementary data included the maximum and minimum air temperature for the previous day, morning wind speed, and morning wind direction. The analysis also includes a comparison of 24-hour snowfall amounts between the three operations to assess regional spatial distribution.

NWP model data was derived by the High Resolution Deterministic Prediction System (HRDPS) (Milbrandt et al., 2016), the Regional Deterministic Prediction System (RDPS) (Bélair et al., 2000), and the Global Deterministic Prediction System (GDPS) (Côté et al., 1998). All modelled data used the node point over Fernie Alpine Resort (49.45, -115.12). The HRDPS dataset spanned 2017 to 2023 whereas the RDPS dataset only included 2019 to 2020 and 2022 to 2023 and the GDPS dataset only included 2019 to 2020.

HRDPS QPF compared to measured SWE provided manually selected cases of interest between 2017 and 2020. Case included:

- Days where actual SWE was substantially more than modelled QPF (i.e., enhanced precipitation, or Fernie Factor);
- Days where actual SWE was close to modelled QPF; and,
- Days where actual SWE was substantially less than modelled QPF.

Upon identifying the cases, historical meteorograms provided important parameter values for each case. Parameters included modelled 24-hour QPF, 2000 m wind speed and direction, 3000 m wind speed and direction, air temperature, and freezing level. Environment Canada's Mountain Weather Forecast found at www.avalanche.ca/weather provided further weather data, including synoptic-scale atmospheric conditions, locations of pressure systems, and whether frontal passages occurred.

Avalanche Canada's Public Avalanche Forecasters implemented preliminary findings from this analysis circa 2020 and tracked precipitation and snowfall data near Fernie for 146 days between 2020 and 2022. Forecasters recorded the HRDPS and RDPS modelled 24-hour QPF for the Lizard Range, meteorological guidance about potential precipitation enhancements based on the synoptic-scale atmospheric setup, expected 24-hour precipitation and snowfall amounts, and actual 24-hour precipitation and snowfall amounts.

3. RESULTS AND DISCUSSION

3.1 *Modelled QPF and Observed SWE*

QPF simulated by the HRDPS, RDPS, and GDPS compared to observed SWE at Fernie Alpine Resort is shown in Figure 1. The comparison highlights the general tendency for the models to underestimate precipitation. Of the 497 days of precipitation during winter months within the dataset, HRDPS underpredicted precipitation 83 % of the time. Both RDPS and GDPS underpredicted precipitation 69 % of the time for days with precipitation within their datasets.

With a threshold difference of 5 mm between simulated and observed precipitation, HRDPS underpredicted precipitation 21 % of the time, produced false alarms 3 % of the time, and was within 5 mm of measured precipitation 76 % of the time. RDPS produced false alarms 4 % of the time and GDPS

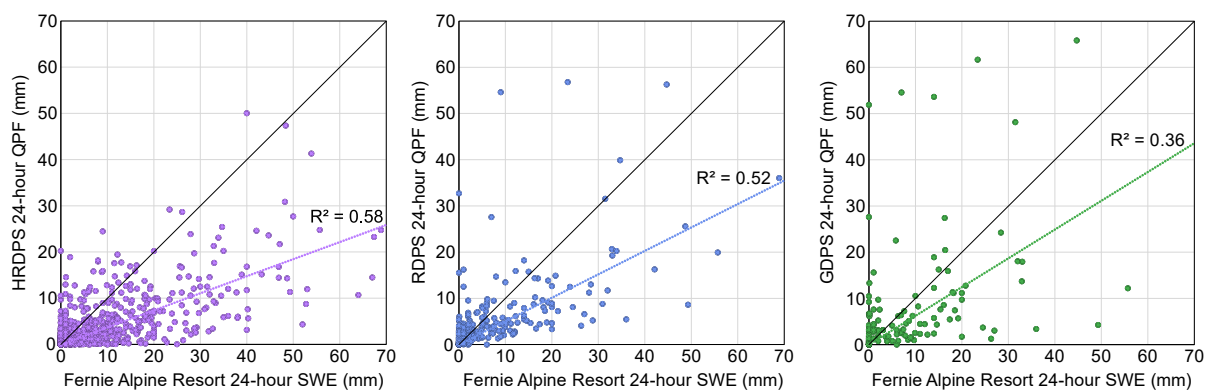


Figure 1. 24-hour QPF simulated by the HRDPS, RDPS, and GDPS compared to 24-hour SWE at Fernie Alpine Resort. Data availability included 2017 to 2023 for HRDPS (n = 1008), 2019 to 2020 and 2022 to 2023 for RDPS (n = 327), and 2019 to 2020 for GDPS (n = 157). The black diagonal line is 1:1.

13 % of the time. RDPS was within 5 mm of measured SWE 77 % of the time and GDPS 64 % of the time.

The results suggest that HRDPS and RDPS are better at predicting QPF than GDPS, although both HRDPS and RDPS still tend to underpredict precipitation substantially more than they overpredict. HRDPS's regression in Figure 1 better fits the data than the other models, suggesting perhaps a better predictive nature using HRDPS than RDPS or GDPS. The HRDPS has a higher horizontal resolution than the other models and should better resolve orographic lift. Regressions were similar to those in Figure 1 when only comparing years where all three models had data.

3.2 Cases

Table 1 provides a summary of average values for the three case types for the three models. Cases are further described below based on various weather parameters followed by an analysis of classifying the cases and preparing predictive scenarios to improve avalanche forecasting near Fernie.

Precipitation

The difference between 24-hour QPF and the observed SWE is what was used to identify days for each of the case types. Table 1 highlights that the RDPS tended to have the highest average QPF for the three case types, followed by the HRDPS, then the GDPS. Anecdotal evidence by Avalanche Canada forecasters suggests that RDPS

QPF was historically lower than HRDPS but model upgrades in July 2019 improved the algorithm (CMC, 2020). Model changes are further described later in the paper.

Wind

The HRDPS wind speed was often stronger than the other two models at 2000 m but all three models had similar average values at 3000 m. Both the 2000 m and 3000 m wind speed distributions were higher for the enhanced precipitation cases compared to the other two cases, particularly for HRDPS (Figure 2). RDPS and GDPS had similar 2000 m elevation wind speed distributions for the enhanced precipitation cases and the cases where the model matched observed amount, suggesting that the 3000 m wind speed may better differentiate between the case types for those models. The distributions suggest that mountain-top wind speed could be a useful metric to assess whether enhanced precipitation may occur.

Wind direction was almost always from the southwest for all three models for the enhanced precipitation cases. There was no trend in which direction was prominent for the other two case types, as the direction either varied or the speed was low, resulting in varying directions. Although Table 1 identified average wind directions for these case types, variability was high.

The wind speed and direction data suggest that the wind likely needs to be strong and from a southwesterly direction for an increased likeli-

Table 1. Comparison of observed SWE and NWP parameter averages from meteograms for the three case types.

Parameter	Data source	Case type 1: underpredicted conditions (enhanced precipitation)	Case type 2: conditions where model matched observed	Case type 3: overpredicted conditions
n	All	33	7	5
Observed 24-hour SWE (mm)	Fernie Alpine Resort	38	15	3
24-hour QPF (mm)	HRDPS	12	12	9
	RDPS	14	23	9
	GDPS	4	11	7
2000 m wind speed (km/h)	HRDPS	53	33	22
	RDPS	34	29	10
	GDPS	32	21	10
3000 m wind speed (km/h)	HRDPS	73	49	36
	RDPS	75	51	34
	GDPS	69	50	32
2000 m wind direction	HRDPS	Southwest	South	West
	RDPS	Southwest	South	Southwest
	GDPS	Southwest	South	South
Freezing level	HRDPS	1300	1000	1500
	RDPS	1200	1100	1600
	GDPS	1300	1100	1500

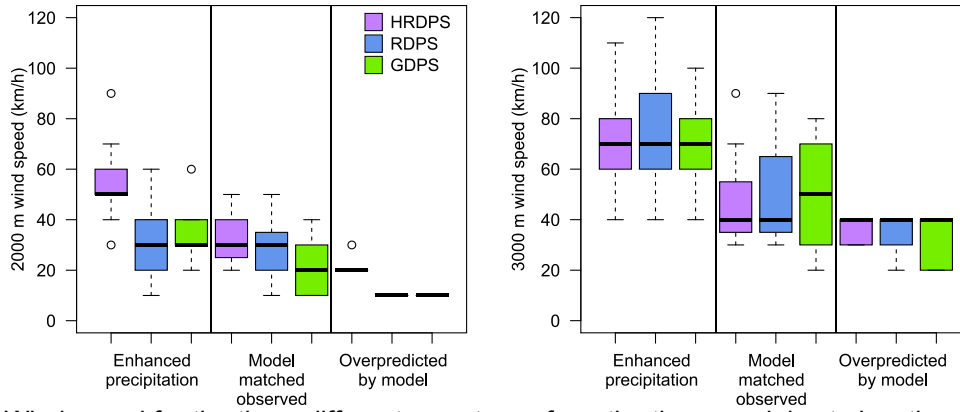


Figure 2. Wind speed for the three different case types from the three models at elevations of 2000 m (left) and 3000 m (right). Black line indicates the median, boxes span the first and third quartiles, and whiskers span the lowest datum and the highest datum within 1.5 times the lower and upper quartiles, respectively. Outliers are displayed as open circles.

hood of enhanced precipitation. This may be because strong storms from the Pacific Ocean tend to have a southwesterly flow associated with them. It could also be due to surrounding topography. There are many mountains between the Pacific Ocean and Fernie to the west and northwest, which often results in western ranges stripping most moisture out of the atmosphere before reaching Fernie. To the southwest lies relatively flat terrain of Washington State. With the lack of orographic lift that can occur during a strong storm originating to the southwest of Fernie, moisture remains within the atmosphere until reaching the high mountains around Fernie. The horseshoe orientation of the Lizard Range can rapidly force orographic lift, promoting enhanced precipitation. This isn't to say that enhanced precipitation won't occur from other directions, but that it is more likely with a southwesterly flow.

Freezing Level

There was no clear differentiation between the case types with respect to freezing level. Many of the days with enhanced precipitation had a freezing level of 1000 m to 1500 m, but so did the days without enhanced precipitation. Freezing level is therefore unlikely to be a good predictor of SWE. However, freezing level, and ultimately the air temperature, may help with predicting snowfall amounts.

The snow-to-liquid ratio is an important factor for avalanche forecasters, as high ratios and hence more snowfall per unit of water tend to mean higher avalanche hazard. High snow-to-liquid ratios often occur with colder air temperature (e.g., Alcott and Steenburgh, 2010), which usually means a lower freezing level. Figure 3 shows the snow-to-liquid ratio for Fernie Alpine Resort's weather plot. The measured snowfall amounts include up to 24 hours of settlement, so the ratios are likely even higher than measured. The lowest

snow-to-liquid ratios tended to occur with a minimum daily air temperature of between 0 and -5 °C whereas higher snow-to-liquid ratios tended to occur with colder minimum air temperatures. This trend suggests that ratios above 10:1 are common with a minimum daily air temperature near 1600 m of -5 °C and colder, which likely corresponds to a freezing level below 1000 m.

Classification

To assess for the strongest predictor, a classification tree (Breiman et al., 1984) split the cases with enhanced precipitation from the other two case types. The tree could split the cases using any parameter defined in Table 1 (i.e., 2000 m wind speed, 3000 m wind speed, 2000 m wind direction, freezing level).

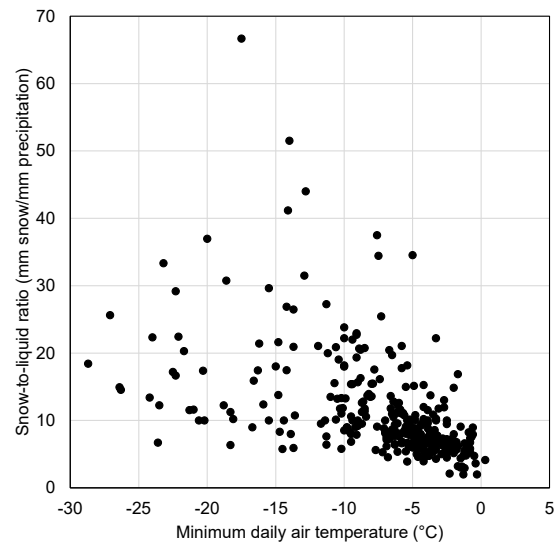


Figure 3. Measured snow-to-liquid ratio for given minimum daily air temperature at Fernie Alpine Resort (1615 m) for winters between 2017 and 2023. Snow-to-liquid ratio was calculated from 24-hour snowfall and associated snow-water-equivalent.

For the HRDPS, the method chose the 2000 m wind speed with a threshold of 35 km/h as the primary split. As seen in Figure 2, this threshold separated all but one of the cases with enhanced precipitation and 10 of the 12 of the other two case groups.

The primary split for the RDPS was the 3000 m wind speed with a threshold of 45 km/h. Given the relatively low 2000 m wind speed observed by the RDPS, the 3000 m wind speed is likely more realistic to use, as suggested by this method.

The GDPS split the cases using the 2000 m wind speed with a threshold of 15 km/h. This threshold is unrealistically low and exemplifies the unrealistic mountain wind speeds simulated by the GDPS for this data point and elevation. Removing the 2000 m wind speed as a potential predictor, the split occurred with a 3000 m wind speed threshold of 45 km/h, similar to the split for the RDPS.

Synoptic-scale flow comparisons were qualitative. In general, days with enhanced precipitation experienced a low-pressure system either off the coast of British Columbia or tracking across the province into Alberta. The systems had associated frontal passages over Fernie, being warm, cold, or occluded. For cases where the modelled QPF matched observed SWE, a low pressure and/or frontal system close to Fernie was present, meaning that the models were already predicting high QPF. For the cases where the model over-predicted QPF, less powerful low-pressure systems or unsettled conditions were present.

Predictive Scenarios

Combining the findings from the cases, the most likely weather scenario that may lead to enhanced precipitation includes strong to extreme (over 40 km/h) 2000 to 3000 m wind from a southwesterly direction, often with a freezing level around 1000 to 1500 m, and with a coastal low-pressure system and frontal passage over the Lizard Range. High snow-to-liquid ratios may occur when the minimum air temperature at around 1600 m is -5 °C or colder. Models may properly predict or over-predict QPF when the 2000 m and 3000 m wind are light to moderate (up to 40 km/h), particularly for HRDPS.

3.3 Regional Spatial Variation

A comparison of 24-hour snowfall amounts near Fernie helps describe spatial variation. Figure 4 compares 24-hour snowfall recorded by Fernie Alpine Resort to the other two operations, Island Lake Lodge and Fernie Wilderness Adventures. In general, snowfall amounts tend to follow the 1:1 line. The operations are within a 15 km radius of Fernie, B.C., suggesting that snowfall is roughly similar at this scale.

It is possible that some variation between the operation's readings are due to two factors. The first is elevation differences, as Fernie Wilderness Adventures' weather plot is about 200 m higher than the other two operation's weather plots, and hence may experience more snowfall than rain when the freezing level hovers around the weather plot elevations. The second factor is time of measurement; Fernie Alpine Resort generally recorded weather between 6 and 7 AM, Island Lake Lodge generally accessed their high elevation weather plot around 9 AM, and Fernie Wilderness Adventures readings generally occurred around 12 PM. The timing could influence the snowfall amounts when storms continued to accumulate snowfall between 6 AM and 12 PM.

3.4 Implementation within a Forecasting Operation

Avalanche forecasters had increased confidence of interpreting when enhanced precipitation may occur for the Lizard Range upon implementing preliminary findings described in this report. Comparing expected precipitation to actual accumulated precipitation, forecasters were within 5 mm 74 % of the time with a false alarm rate of 14 % and an underprediction rate of 12 %. Compared to the RDPS and HRDPS, forecasters had a lower underprediction rate compared to 14 to 16 % for the models, respectively. Forecasters had a higher false alarm rate, compared to 7 to 10 % for the models.

A low underprediction rate is preferred —up to a point— given that an avalanche forecaster's pri-

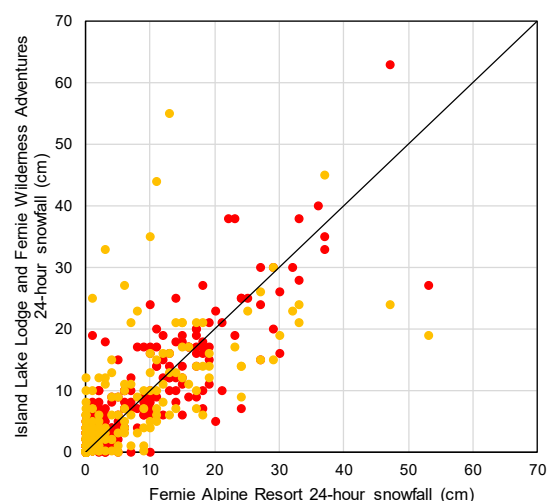


Figure 4. Comparison of 24-hour snowfall between the three operations in the Lizard-Flathead avalanche bulletin region. Island Lake Lodge (orange) and Fernie Wilderness Adventures (red), both on the y-axis, are compared to Fernie Alpine Resort, on the x-axis.

primary duty is to communicate potentially risky scenarios. As long as it doesn't result in loss of confidence by users, a higher false alarm rate can be weathered more easily than missing a significant precipitation event.

3.5 *Model Changes with Time*

NWP model changes occur from time to time as improvements are made to improve predictive accuracy. Both RDPS and GDPS models underwent upgrades in July, 2019 (CMC, 2020), with changes illustrated in Figure 5 for the Fernie area. A substantially higher distribution of 24-hour QPF is observed for RDPS and GDPS but a similar distribution for HRDPS when comparing the datasets pre- and post- model upgrade. Moving forward, upgrades and changes to the models will be important to understand to assess if previous analyses, including this one, remain representative.

4. SUMMARY

The purpose of this analysis was to assess trends that could help predict when enhanced precipitation may occur near Fernie, B.C. The key findings are as follows:

- The 2000 and 3000 m wind and synoptic-scale atmospheric setup are likely the best predictors of potential enhanced precipitation. If a low-pressure system is off the B.C. coast or tracks across the province with an associated frontal passage over Fernie, assess for wind direction. If wind direction is

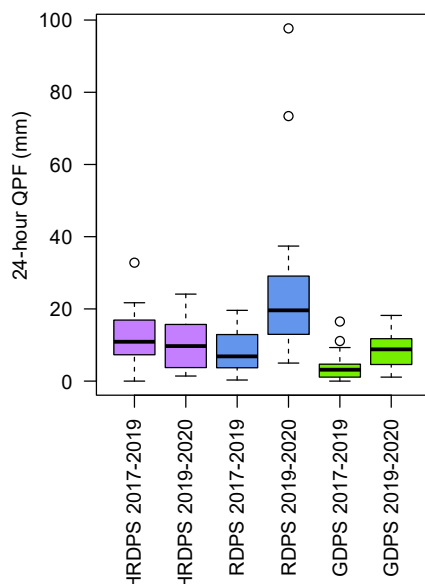


Figure 5. 24-hour QPF for the three models, separated between the 2017-2018 and 2018-2019 winters and the 2019-2020 winter. The 2017-2019 dataset includes 30 cases and the 2019-2020 dataset includes 15 cases. Boxplot format is the same as Figure 2.

southwesterly, assess for wind speed. If HRDPS 2000 m wind speed is over 40 km/h or RDPS or GDPS 3000 m wind speeds are over 40 km/h, enhanced precipitation may result.

- Snow-liquid ratio may exceed 10:1 when the minimum air temperature around 1600 m is -5°C or colder. This temperature generally corresponds to a freezing level below 1000 m.
- Snowfall is similar within approximately a 15 km radius of Fernie, B.C.

Future changes to the models should be reviewed to assess whether the findings in this analysis remain applicable.

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