MORE ARS WHAT NOW? ATMOSPHERIC RIVERS AND THE CHANGING REALITY OF AVALANCHE FORECASTING

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ABSTRACT: Historically, avalanche mitigation programs have been focused on snow avalanche forecasting and control. In this paper, we explore the shifting scope of avalanche programs to incorporate heavy rainfall events and the associated landslide, flooding, and infrastructure damage that can ensue, focusing on recent events affecting the inner South Coast of British Columbia. The North Cascades avalanche program comprises avalanche paths along the section of Trans-Canada Highway 1 running along the deep and steep-walled Fraser Canyon, BC Highway 5 known as the Coquihalla connecting Hope to Merritt with a maximum elevation of 1,244 m, and the portion of BC Highway 3 known as the Crowsnest connecting Hope to Princeton with a maximum elevation of 1,342 m. We review the December 2025 Atmospheric Rivers (ARs) that struck the region, present select AR forecasting tools and discuss proactive transportation closure methods in an attempt to better plan and respond to strong AR and rain-on-snow events.

KEYWORDS: Atmospheric River, rain-on-snow, landslide, debris flow.

1. ATMOSPHERIC RIVERS

Atmospheric Rivers (ARs) are narrow moist flows responsible for approximately ninety per cent of the poleward water vapor transport across the midlatitudes (Zhu & Newell, 1994, 1998; Ralph et al. 2004). They are characterized by high water vapor content and strong low-level winds, forming a part of the broader warm conveyor belt of extratropical cyclones. Although the meridional water vapor transport within ARs is critical for water resources, strong ARs can also cause disastrous floods especially when encountering mountainous terrain. They were first labeled as Atmospheric Rivers in the 1990s and have since become a well-studied feature of the midlatitude climate (Gimeno, 2014).

While Atmospheric Rivers can vary greatly in size and strength, the average AR carries an amount of water vapor roughly equivalent to the flux of liquid water into the Gulf of Mexico from 25 Mississippi Rivers, or to the discharge of 2.5 Amazon Rivers (Ralph et al., 2017; Sodemann et al., 2020).

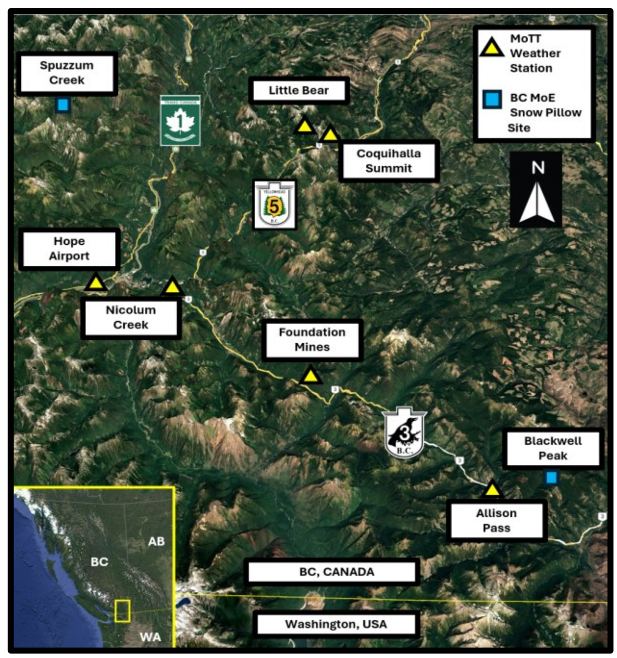

Figure 1 - Map of the BC MoTT's North Cascades Avalanche Program including Highways 1, 3 and 5.

Approximately 30 to 40 ARs hit the British Columbia coast each year, the majority making landfall during storm season spanning October through March (Sharma & Déry, 2020). They have

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been blamed for damaging floods, devastating landslides, and linked to at least one deadly avalanche (Cruickshank, 2019; Mo et al., 2019). Historical Atmospheric River data from the Center for Western Weather and Water Extremes (CW3E) dating back to 1959 suggests both a poleward shift in land-falling ARs as well as an increasing frequency of strong ARs. Research from Pan et al. (2025) support this poleward shift while Shields & Kiehl (2016) modelled the poleward shift of land-falling ARs and forecast an increase in precipitation associated with ARs which are also projected to increase in intensity under global warming (Shields, 2016).

2. THREE NORTH CASCADE ARS DEC 8-18, 2025

Following a wet start to the 2025-26 winter with half of the normal monthly rainfall recorded in just the first week of December (105.6 mm of rain was recorded at the Hope Airport December 1-7, 2026 compared to historical average of 219.0 mm for the entire month of December; Government of Canada, 2026), the first in a series of Atmospheric Rivers struck the South Coast of British Columbia beginning midday on December 8th, 2025. With freezing levels near 1200 m during the onset of the AR, 48.8 mm of rain was recorded at the Hope Airport, elevation 39 m above sea level (ASL) while the Foundation Mines weather station at 1650 m ASL recorded 8 cm of wet snow with a water equivalent of 12 mm by midnight that night. Hourly rainfall rates steadily increased throughout the evening at 2-4 mm per hour while freezing levels rose to 2100 m, some 200 m above avalanche start zones of the North Cascades program. Following a brief 14-hour break in the heavy rainfall, a second AR struck the region on December 10th with even heavier rainfall. Hourly rainfall rates of 3-7 mm were recorded at Fountain Mines for 22 consecutive hours, totalling 69.9 mm while the Hope airport recorded 134.2 mm. Collectively, given the short break between the two ARs, the event was catalogued as a single AR and was classified as a category 4 AR according to the AR scale proposed by Ralph et al. (2019) ranging from 1 or weak for mostly beneficial ARs to 5 for exceptional and primarily hazardous ARs.

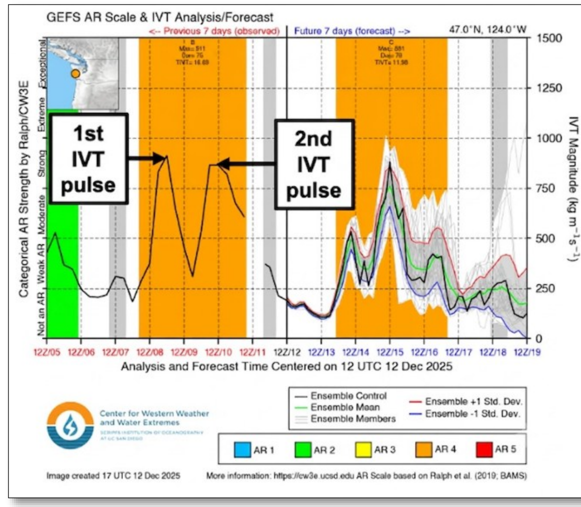


Figure 2 - AR Scale with forecast generated by Global Ensemble Forecast System, including analyzed Integrated Vapour Transport. Source: Center for Western Weather and Water Extremes (CW3E).

The heavy rain tapered off on the evening of December 10th before a third and final AR reached the North Cascades on the morning of December 16th. The third AR delivered 40 to 78 mm of heavy rain bringing the three storm totals to 180 to 230 mm for the North Cascades Area.

Table 1 Precipitation amounts through each of the three Atmospheric Rivers at select BC Ministry of Transportation and Transit and Nav Canada weather stations.

Weather Station (Elevation)	*AR #1 Dec 8 (mm)*	*AR #2 Dec 10-11 (mm)*	*AR #3 Dec 16-17 (mm)*	*Total Snow (cm)*	*Total Rain (mm)*
Hope Airport (39 m)	46.9	138.2	N/A	0	N/A
Nicolum Creek (244 m)	42.7	123.2	51.7	0	217.6
Allison Pass (1340 m)	33.7	105.9	40.1	55	179.7
Coquihalla Summit (1230 m)	54.1	95.3	78.3	200	227.7
Foundation Mines (1650 m)	33.1	99.2	60.8	108	193.1
Little Bear (1660 m)	-	-	-	50	-

To contextualize the 24-hour rainfall amounts, the Short Duration Rainfall Intensity-Duration-Frequency (IDF) curve for the Hope Airport is presented below in Figure 3. The 46.9 mm recorded December 8th, 2025, falls outside the 1 in 100-year return period suggesting this rainfall was relatively rare. The 123.2 mm recorded on December 10th, 2025, falls short of the all-time single day highest rainfall record at the Hope Airport of 174.0 mm which was recorded November 14th, 2021, during the historic category 4, borderline category 5 (CW3E, 2021), AR event that delivered an astonishing two-day total of 277.5 mm on November 14 and 15. Nonetheless, significant impacts included severe highway washouts, culvert failures, and debris flows along the 44 kilometres of Highway 3 between Hope and Manning Park. Damage at 22 separate locations forced an eight-day closure December 16 to 24, 2025 (MoTT, 2025).

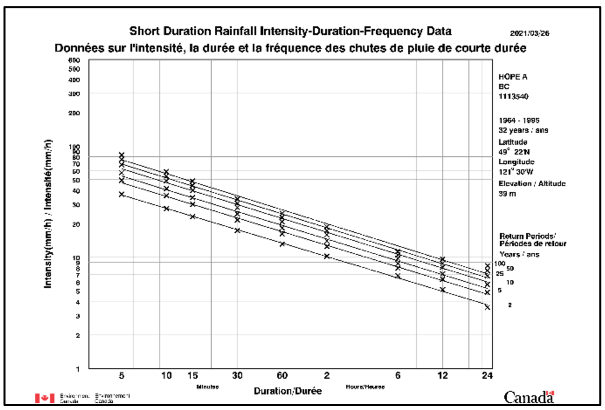


Figure 3 - Short duration rainfall Intensity-Duration-Frequency (IDF) data for the Hope Airport. Source: Environment Canada.

Looking at how precipitation fell in the alpine, it's interesting to compare a treeline site like Spuzzum at 1180 m in Figure 4 with an alpine site like Blackwell Peak at 1940 m in Figure 5. With freezing levels rising to from 1400 m on December 8th to 2500 m by December 15th, lower sites including Spuzzum were quick to transition to rain and have the entirety of their snowpack wash away while higher sites like Blackwell Peak saw the majority of their precipitation fall as wet snow with Snow Water Equivalent measurements steadily climbing from 50 mm to 250 mm during that same period. The contribution of roughly 50 mm of snowmelt inevitably exacerbated the flooding and debris flows.

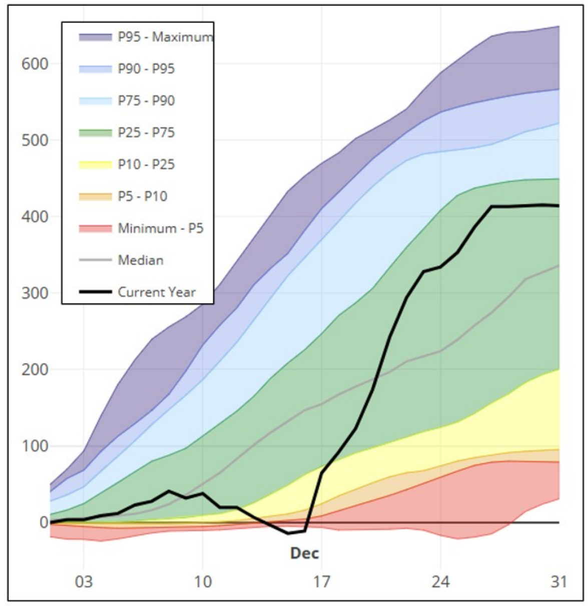


Figure 4 - Spuzzum snow pillow site 1D19P, elevation 1180 m, Snow Water Equivalent (mm) daily change December 2025. Source: BC River Forecast Centre.

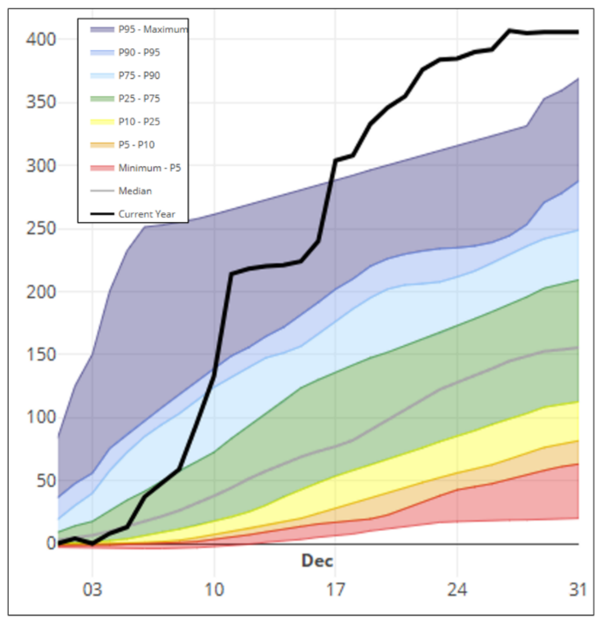
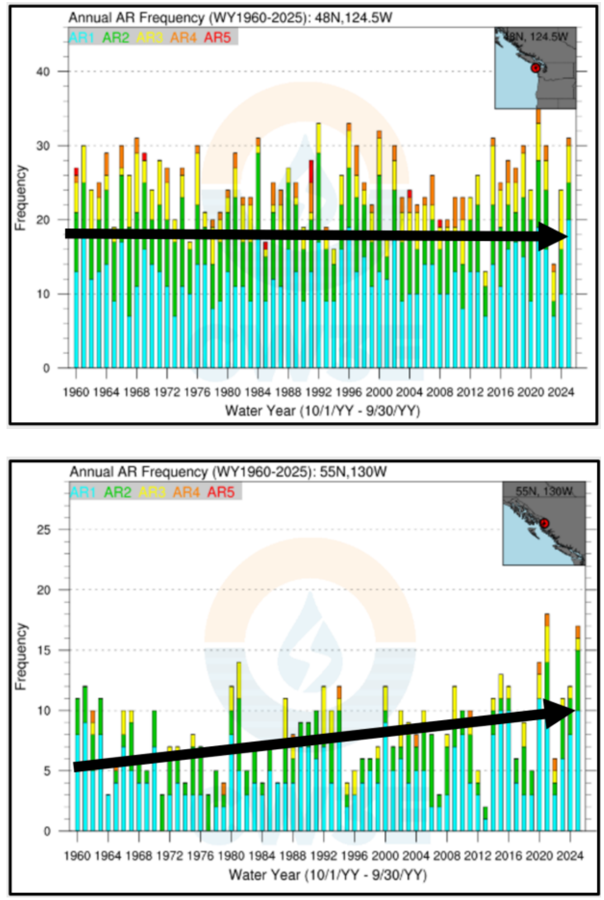


Figure 5 - Blackwell Peak snow pillow site 2G03P elevation 1940 m Snow Water Equivalent (mm) daily change Dec 2025 from BC River Forecast Centre, elevation 1940m.

3. CHANGING CLIMATE AND ARS

As our global climate and weather patterns continue to change, the frequency and intensity of ARs are also forecast to continue changing. Two studies have been published along these lines, one on ARs for California (Dettinger, 2011), and the other for Europe (Lavers et al., 2013). In the Californian study, seven climate models were used, and the results suggest that the risk of flooding (associated with ARs) in a future climate will increase because of increased water vapor transport within ARs, more years with high AR frequency, and an increase in the length of the AR season. All the evidence for California points toward an enhanced flood risk from ARs. In the European study, results from five state-of-the-art global climate models (GCMs) in the fifth Climate Model Intercomparison Project (CMIP5) show a greater number and intensity (increased IVT) in North Atlantic ARs, possibly leading to an increase in the frequency and magnitude of flood events. An extreme result is the doubling of the frequency of ARs for the high emissions scenario (RCP8.5) for 2074–2099 (Gimeno et al., 2014)

Not only is a change in the frequency and intensity of ARs forecast, but recent research has also demonstrated a global poleward shift of ARs. The Centre for Western Water and Weather Extremes (CW3E) from the Scripps Institution of Oceanography at University of California San Diego produced a Landfalling Atmospheric River Catalog which is updated through 2025. The catalog provides a frequency analysis of landfalling ARs for various points up and down the coast of western North America, all shaded according to the AR Scale (Ralph et al., 2019). By comparing the frequency of ARs on the South Coast of British Columbia in Figure 6 with those impacting the North Coast in Figure 7, there is an apparent trend of increasing number of extreme (AR4) and exceptional (AR5) events over the North Coast in comparison to the South Coast, supporting the aforementioned poleward shift in ARs.



Figures 6 & 7 - Annual AR Frequency (Water Year 1960-2025) for 48°N, 124.5°W (top) and 55°N, 130°W (bottom). Source: Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, University of California San Diego.

Furthermore, when examining the historical trend of annual maximum rainfall at the Hope Airport as presented in Figure 8, all time spans from 5 minutes to 24 hours show a clear increasing trend in the frequency of high intensity rainfall events. ARs are inevitably an important contributing synoptic scale meteorological component to this trend. The steady linear increase of heavy rainfall and ARs can only be expected to continue in the future.

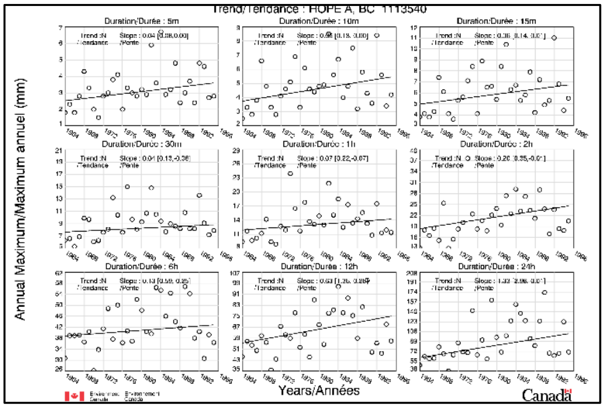


Figure 8 - Historical trend of annual maximum rainfall at the Hope, BC Airport. Source: Environment Canada.

4.THE CHANGING REALITY OF AVALANCHE FORECASTING

Over the past two decades or so, avalanche professionals across western North America have observed and have had to forecast for an increasing number of ARs and associated heavy rain on snow events. Early season heavy rain-on-shallow, or non-existing, snowpack events have forced avalanche forecasters, particularly in the transportation realm, to collaborate with hydrologists, meteorologists, geotechnical engineers and others to anticipate the possible impacts to creeks, rivers, culverts, bridges and other highway infrastructure. While these strong categories 4 and 5 AR events, including the December 2025 storms are not snow avalanche specific hazards, the skill set and familiarity of forecasting snow avalanches and mitigating impacts to transportation corridors by means of avalanche control and highway closure has been applied to these heavy rainfall events, all while remaining in their professional scope of practice.

The shifting and evolving scope of professional avalanche forecasters to help with the forecasting, response, and recovery of strong ARs naturally raises the question of whether a dedicated Atmospheric River and Mountain Hazards Task Force should be established. An AR and Mountain Hazard Task Force could be similar to the Avalanche Task Force announced by British Columbia's Minister of Highways and Public Works, Graham Lea, in 1974 following the fatal avalanche that destroyed the North Route Café near Terrace (Freer & Schaerer, 1980). It could bring together experts from multiple disciplines to improve forecasting, operational response, infrastructure resilience, research priorities and public communication for AR-related hazards. Rather than replacing existing avalanche programs, it would recognize that the risks facing mountain transportation corridors have evolved and now require an integrated, multi-hazard approach.

Figures 9 & 10 - New major culvert site 42km (top) and debris flow onto BC Highway 3 (bottom), both on December 19, 2025. Source: BC MoTT Flickr account.

5. HOW DO WE ADAPT?

As strong category 4 and 5 Atmospheric Rivers become more common under a changing climate, this interdisciplinary approach should become standard practice rather than an exception. This evolution will require expanded training in hydrology, geomorphology, and debris-flow processes, greater integration of weather, snow, and watershed monitoring networks, and stronger collaboration among avalanche forecasters, hydrologists, geotechnical engineers, emergency managers, and transportation agencies.

Ultimately, the avalanche community is well positioned and could contribute to this transition. Its long history of operational forecasting, hazard mitigation, and decision-making under uncertainty provides a strong foundation for adapting to a future in which strong Atmospheric Rivers are expected to become an increasingly dominant driver of mountain hazards along the west coast of North America.

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