**Technical Memo: Developing data-driven seasonal forecasting models for snow-free time and magnitude**

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# Introduction

## Background

This exercise builds on a previous analysis that looks at the potential of April SWE for predicting peak stage or discharge (collectively referred to as peaks). In this work, a single variable linear regressor was used to predict peaks. The linear model is applied to a series of basins, which are listed in Table 1. A faint linear relationship is observable, with reported R2 values ranging from 0 to 0.4.

A screenshot of a computer

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Figure : Screenshot of preliminary linear regression based analysis, conducted by [?].

Table : Study basins and corresponding gauge codes

|  |  |
| --- | --- |
| Basin | ID |
| Marsh Lake | 09AB004 |
| Teslin Lake | 09AE002 |
| Pelly River | 09BC001 |
| Stewart River | 09DD003 |
| Klondike River (lower Yukon SWE) | 09EA003 |
| Yukon River at Dawson | 09EB001 |
| Porcupine River | 09FD002 |
| Liard River | 10AA001 |

## Objectives

Building on the previous work, which identified a faint linear relationship between April SWE and peaks. In this work, we seek to improve the predictive power of these forecasters through exploiting additional predictor variables and models. Specifically, we establish the the following objectives:

* Evaluate the effects that additional covariates have on prediction accuracy
* Evaluate additional models, including multi-variable linear regression, random forests (RFs), and artificial neural networks (ANNs)

# Methods

# Results

First, we repeat the background experiment, which serves both as a sanity check and baseline with which to compare our results. The linear regression models are illustrated in scatterplots in Figure 2, which note R2 and Nash-Sutcliffe Efficiency (NSE) values.

A graph of different types of water

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Figure : Baseline single variable linear regression models.

A group of graphs showing different types of river

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Figure : Linear models as 1:1 plots.

Next, we seek to evaluate the effect of additional covariates with respect to improving the accuracy of seasonal peak prediction.

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Gridded ERA5 snow water equivalent (SWE) is available at an hourly resolution from 1980 up to a latency of 5 days. This product has the potential to complement SWE measurements obtained from surveys and snow pillow sensors.

The objective of this project is to evaluate the accuracy of ERA5 SWE with respect to the measurements obtained by the Yukon Government (YG). Secondary objectives include generating scripts to download and import ERA5 SWE into AquaCache and Delf FEWS.

**Methods**

Gridded SWE data was obtained from Copernicus for the entire Yukon territory. ERA5 has a spatial resolution of approximately 9km and an hourly resolution, however, only one value per day was downloaded for the following analysis (at 00:00). SWE was downloaded as compressed NetCDF files from the Copernicus Data Store (CDS) using the official CDS Python module.

The YG SWE observations include snow pillow measurements, collected on a continuous basis at seven meteorological stations, as well as snow survey measurements. These measurements should be considered to be more accurate than ERA5, due to ERA5’s high spatial and measurement uncertainties.

An example of a SWE raster is shown in Figure 1 below.

A map of the united states

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Figure : SWE data shown as percent difference from the historical median

**Results**

First, ERA5 is compared to snow pillow measurements at seven sites, including Log Cabin, Wolf Creek Buckbrush Taiga, King Solomon Dome, Tagish, Withers Lake, Hyland North, and Twin Creeks North. ERA5 SWE values are obtained by sampling the cell that overlaps the coordinates of each met station. Reminder that the cells are roughly 31km2, thus SWE within a cell might be highly variable. The timeseries comparison is shown in Figure 2 below from the year 2000 onwards.

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Figure : Timeseries comparison between ERA5 and Snow Pillow SWE at seven meteorological stations.

Both SWE measurements are typically in good agreement with one another. The exceptions are Log Cabin and Hyland North, where ERA5 SWE estimates are considerably higher than the snow pillows. The tendency for SWE values to overestimate SWE compared to the met stations is attributable to highly variable topography near the met stations, combined with the coarse grid size of ERA5, which has the effect of positively skewing the ERA5 SWE estimates when comparing to point-source measurements. This effect is exacerbated by the fact that SWE products such as ERA5 can be very inaccurate in mountainous regions (Mudryk et al., 2025). Interestingly, ERA5 SWE estimates at King Solomon Dome are lower than those of the met station, which might be attributable to the station being at a much higher elevation than the surrounding area that would be included in the ERA5 grid cell. The same results are displayed as 1:1 scatterplots in Figure 3, in which points are colourized by day of year; the red 1:1 line indicates perfect agreement. The day of year colouration illustrates how days of year around 150 (May 30th) tend to produce the largest error (furthest from the red 1:1 line).

A group of graphs showing different colors

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Figure : Scatterplot comparison between ERA5 and Snow Pillow SWE at seven meteorological stations.

Next, we compare ERA5 measurements with snow survey results. Snow survey SWE measurements are collected manually at predefined locations roughly once a month for January through April each year. First, we plot ERA5 against survey measurements in Figure 4 (left) to obtain a rough sense of ERA5 accuracy. Figure 4 (right) shows the error distribution (snow survey measurements are considered the ‘observed’ values). The error histogram is skewed to the left, which again shows ERA5 SWE’s tendency to overpredict. Some comparison points have an error of as much at -1800mm.

A graph with a red line and a dotted line

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Figure : (Left) Scatterplot showing ERA5 versus snow survey SWE measurements; (Right) error histogram.

Lastly, we compare ERA5 SWE with basin-averaged SWE estimates. The YG basin-averaged SWE estimates are obtained using an ad-hoc weighting scheme, in which each basin average is a convex combination of the snow survey locations. In contrast, the ERA5 basin-averaged SWE estimates are obtained my averaging the gridded product over each basin footprint. Results for each basin are illustrated in Figure 5 below. The uncertainty bands show the 10-90th percentile range of ERA5 SWE values within each basin, which provides a sense of SWE spatial variability across each basin. Large uncertainty bands indicate high SWE variability within each basin, according to the ERA5 gridded values. A blue linear trendline between the YG and ERA5 estimates is shown for each location. The 1:1 line is shown again, this time in black, which indicates perfect agreement.

A collage of graphs

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Figure : Comparison of YG and ERA5-based basin averaged SWE.

For the most part, the YG and ERA5-based basin averaged SWE is in good agreement. There are three standout basins, the White, Upper Yukon, and Alsek. In each of these cases, ERA5 significantly overestimates the basin averaged SWE compared to the YG values. This is attributable to a small number of ERA5 cells within these basins having extremely high SWE predictions (some >10,000mm), which biases the mean estimate. This effect can be seen my looking at the median ERA5 SWE values (the median SWE out of all the grid cells in each basin), which is much lower than the mean and much closer to the 1:1 line.

In terms of accuracy, it is difficult to say which of the two basin averaged results is more accurate with respect to real-world conditions. On one hand, the snow surveyed values are not necessarily representative of SWE values across each basin, especially in mountainous regions. On the other hand, ERA5 SWE is known to be inaccurate in mountainous regions (Mudryk et al., 2025). Also, some of the SWE included in the ERA5 basin averages is permanent, thus might not be relevant to a seasonal melt event.

**Conclusion and recommendations**

Overall, ERA5-based SWE tends to be in good agreement with YG’s snow measurements. There are some obvious outliers to this statement, which are caused by the high spatial variability of topographic features, which exist at a spatial resolution smaller than the cell size of the ERA5 grid, meaning that SWE within a cell may be highly variable. This conclusion is based on an ac-hoc evaluation of measurement locations but could be formalized by calculating topographic variability within each ERA5 grid cell. The expected outcome would be a positive relationship between topographic variability and SWE disagreement.

Based on the results above, SWE estimates are reliable enough for applications such as gap-filling historic records, but only in cases where ERA5 estimates can be validated. At stations where the products are not in agreement, a simple bias-correction (such as a linear transformation) is recommended. Caution should be used when using ERA5 SWE at point-source locations without any in-situ measurements with which to compare.

In terms of a basin-averaged SWE value – the ERA5 averages are likely more accurate than the snow survey-based estimates, but only in basins without considerable mountainous regions. If ERA5 basin-averaged SWE is being used going forward, it would be prudent to filter permanent snow, which can be estimated using the mean annual minimums, or some similar statistic.

**References**

Mudryk, Lawrence, et al. "Benchmarking of snow water equivalent (SWE) products based on outcomes of the SnowPEx+ Intercomparison Project." *The Cryosphere* 19.1 (2025): 201-218.