APPLICATION OF SNOW MODELS TO SNOW REMOVAL OPERATIONS ON THE GOING-TO-THE-SUN ROAD, GLACIER NATIONAL PARK

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ABSTRACT: Snow removal, and the attendant avalanche risk for road crews, is a major issue on mountain highways worldwide. The Going-to-the-Sun Road is the only road that crosses Glacier National Park, Montana. This 80-km highway ascends over 1200m along the wall of a glaciated basin and crosses the continental divide. The annual opening of the road is critical to the regional economy and there is public pressure to open the road as early as possible. Despite the 67-year history of snow removal activities, few data on snow conditions at upper elevations were available to guide annual planning for the road opening. We examined statistical relationships between the opening date and nearby SNOTEL data on snow water equivalence (SWE) for 30 years. Early spring SWE (first Monday in April) accounted for only 33% of the variance in road opening dates. Because avalanche spotters, used to warn heavy equipment operators of danger, are ineffective during spring storms or low-visibility conditions, we incorporated the percentage of days with precipitation during plowing as a proxy for visibility. This improved the model's predictive power to 69%. A mountain snow simulator (MTSNOW) was used to calculate the depth and density of snow at various points along the road and field data were collected for comparison. MTSNOW underestimated the observed snow conditions, in part because it does not yet account for wind redistribution of snow. The severe topography of the upper reaches of the road are subjected to extensive wind redistribution of snow as evidenced by the formation of "The Big Drift" on the lee side of Logan Pass.

KEYWORDS: Snow plowing, snow models, Glacier National Park, mountain highways

1. INTRODUCTION

The Going-to-the-Sun Road (GTSR) in Glacier National Park, Montana, was built over the continental divide and opened in 1933, immediately becoming a major tourist attraction. This 80-km road begins in West Glacier on the western border of the park, and follows the Lake McDonald watershed until it ascends to Logan Pass at 2188-m elevation. The GTSR then descends through the St. Mary watershed to the eastern border of the park. The alpine portions of the GTSR were built along a glacially-carved wall along the continental divide and have been recognized as an engineering feat by being designated as a National Civil Engineering Landmark.

The same features that rank the GTSR as one of the most scenic and dramatic drives in the U.S. also expose the road to considerable avalanche damage, making road maintenance more difficult. The annual spring plowing of the GTSR is a significant effort for park personnel and poses considerable risk. Deaths and injuries to plow operators have occurred. However, for every day that the GTSR is not open in the spring, the regional economy loses $1.1 million. Thus, there is public pressure to open the GTSR as soon as possible every spring.

Few consistent records have been kept on snow conditions prior to, and during, snow removal operations with the exception of the "Big Drift" that has been measured as being over 30m high. Individual plow operators with many years of experience can gauge the likely time and effort to plow the GTSR based on general snow conditions in the valleys but they also factor in other issues such as safety and equipment breakdowns when estimating when the GTSR might open to public use. However, the expectation by the public is that the GTSR will open sooner on low snowpack years and later on big snowpack years. Given the economic significance to the region, we felt there was a need to quantify the significance of snowpack year-to-year variation in determining the opening date of the GTSR.

Other than personal experience, the snow plowing crew members had no way to estimate the depth and density of the snowpack they would encounter on upper reaches of the GTSR prior to

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getting there. An effective predictive snow model would aid managers in planning personnel and equipment needs for the annual GTSR opening effort. We applied MTSNOW, a mountain climatology model with snow depth and density algorithms (Ringleb et al. 1994), to calculate snow pack characteristics on the GTSR at various times prior to plowing. MTSNOW is a modified version of the Regional Snow Model (Coughlan and Running 1997) that has been successfully applied to the Glacier Park landscape.

2. STUDY AREA

Our study took place in the Lake McDonald watershed of Glacier National Park, a 4,500km^2 preserve that straddles the continental divide in northwestern Montana, U.S.A. (Figure 1).

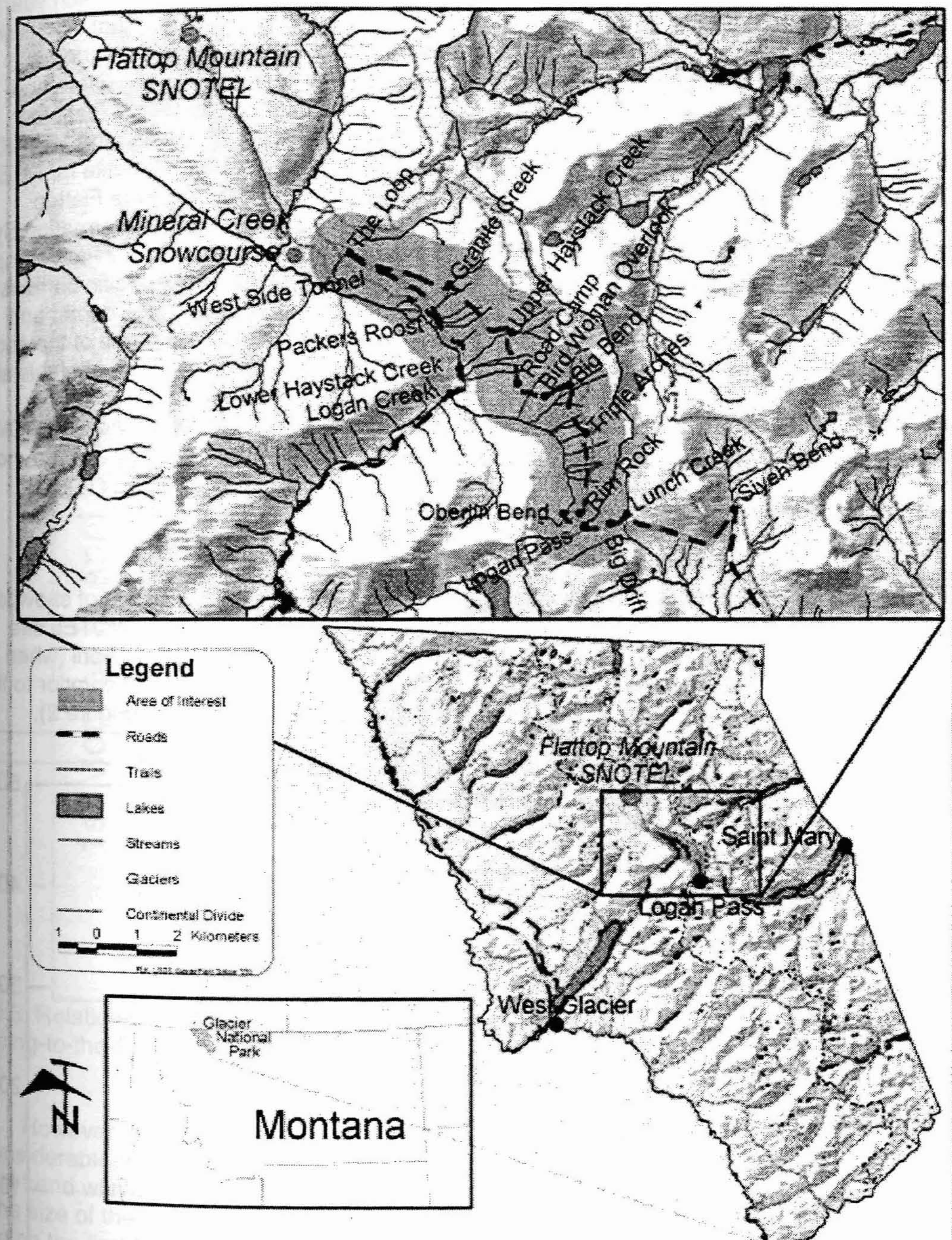

Figure 1: Location of the Going-to-the-Sun Road alpine section (shaded) along continental divide. Flattop SNOTEL site is in upper left corner of upper panel.

Approximately 90% of the park is designated and managed as proposed wilderness. Only the Going-to-the-Sun Road traverses the park. The mountains of Glacier National Park are uplifted beds of sedimentary rock that have been shaped by glaciers into U-shaped valleys, serrated ridges and pyramidal peaks. Approximately 37 small, alpine glaciers remain in the park and snow covers much of the landscape for at least half of each year. Coniferous forests cover about 75% of the park and alpine treeline is between 1900-2300m. The western side of the continental divide is dominated by Pacific maritime climate patterns and the eastern side is influenced more by a continental climate.

3. METHODS

We gathered National Park Service records on the historic opening dates for the GTSR. For this analysis, the opening date means the first day that the public is allowed to drive the entire length of the GTSR over Logan Pass. We also compiled local weather and snow data from various sources to estimate annual snowpacks in Glacier Park during the spring snow removal operations. These records included the Natural Resource Conservation Service's snow courses and National Weather Service's stations in the park. For this analysis, we chose the Flattop Mountain SNOTEL site (15 km from the mid-point of the GTSR) that provided 30 years of detailed records. Flattop Mountain SNOTEL (6128m) is approximately the same elevation as the upper portions of the GTSR but is not located immediately next to the continental divide (Figure 1). Operated by the Natural Resource Conservation Service, this SNOTEL site contains a weight-sensitive snow pillow that provides real-time snow water equivalent (SWE) estimates available over the Internet via satellite uplinks. A statistical model, using 30 years of data, was created to estimate the GTSR opening day based on SWE measurements from the Flattop SNOTEL site on the first Monday in April of each year. The first Monday in April is the date that GTSR snow removal operations are typically started.

We estimated the SWE, depth and density of the snow on the GTSR that plow operators would encounter using the MTSNOW model. The necessary climatic data for MTSNOW estimates were obtained from the Flattop SNOTEL site and Geographic Information System (GIS) layers stored on the Glacier Park computer system. Daily estimates for specific portions of the road were generated. SWE, depth, and density measurements were made of the snow on the GTSR at approximately 100m intervals ahead of the snowplows. These field samples corresponded to the location of the MTSNOW estimates and were compared to validate model accuracy.

4. RESULTS

The 30-year daily average of snowpack accumulation from the Flattop SNOTEL site indicates that the first Monday in April (when plowing operations begin) has been prior to the seasonal snowpack maximum (Figure 2).

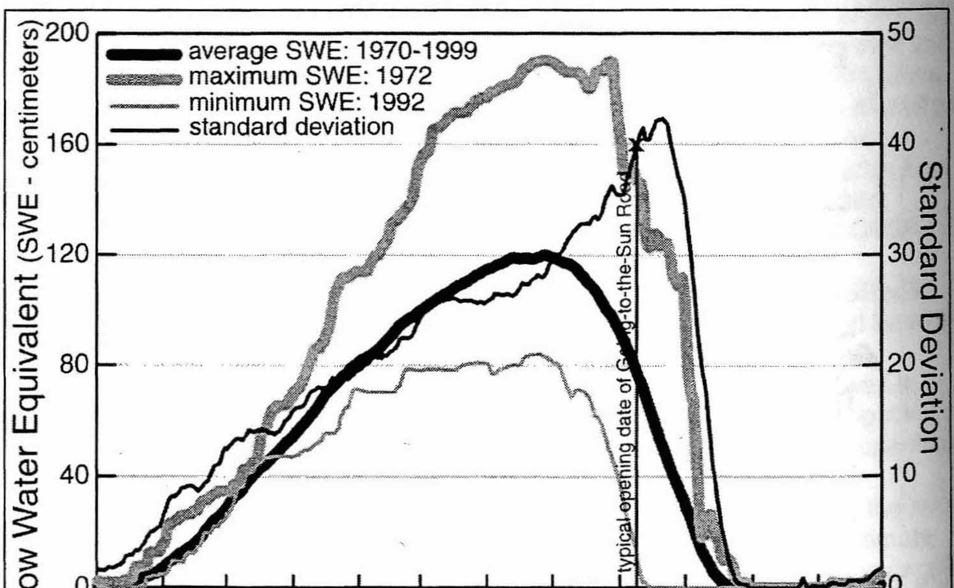

Figure 2: Daily snow water equivalent (SWE) average of snowpack from 1970-2000 at Flattop Mountain SNOTEL (left axis). Maximum snowpack (1972) and minimum snowpack (1992) years also indicated. Standard deviation (right axis) of daily SWE is high during snow plowing operations from April through early June.

During some years, it is nearly a month before maximum accumulation and suggests that Flattop SNOTEL data could be used to plan a later start for years with above average and persistent snowpacks. It also is worth noting that snow removal operations occur near the period of greatest variability in snowpack SWE, making year-to-year planning for snow removal difficult.

There is a positive linear relationship between GTSR opening dates and snowpack size, meaning that larger snowpacks delay the GTSR opening until later in the spring (Figure 3).

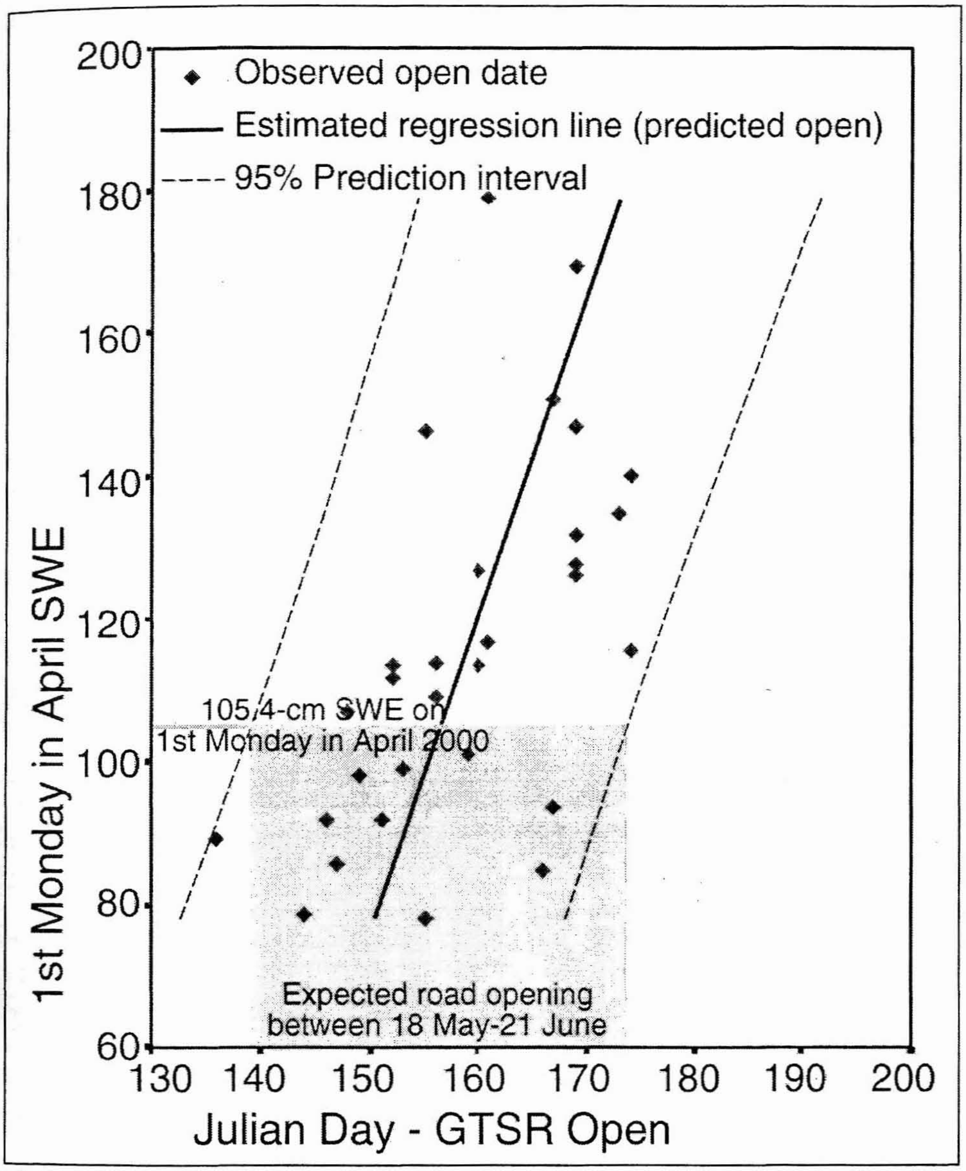

Figure 3: Relationship between snowpack size (measured as snow water equivalent) and opening date of the Going-to-the-Sun Road, Glacier National Park, Montana.

However, the 95% confidence intervals are considerable, indicating that it is only a very general trend with much inherent variation. In fact, the size of the snow pack (i.e. SWE at Flattop on the first Monday in April) explains only 33% of the variation in GTSR opening dates.

The statistical model can be improved so that it explains 69% of the variation in GTSR opening dates by adding another factor, "precipitation during plowing", as a proxy variable for visibility and avalanche danger (Figure 4).

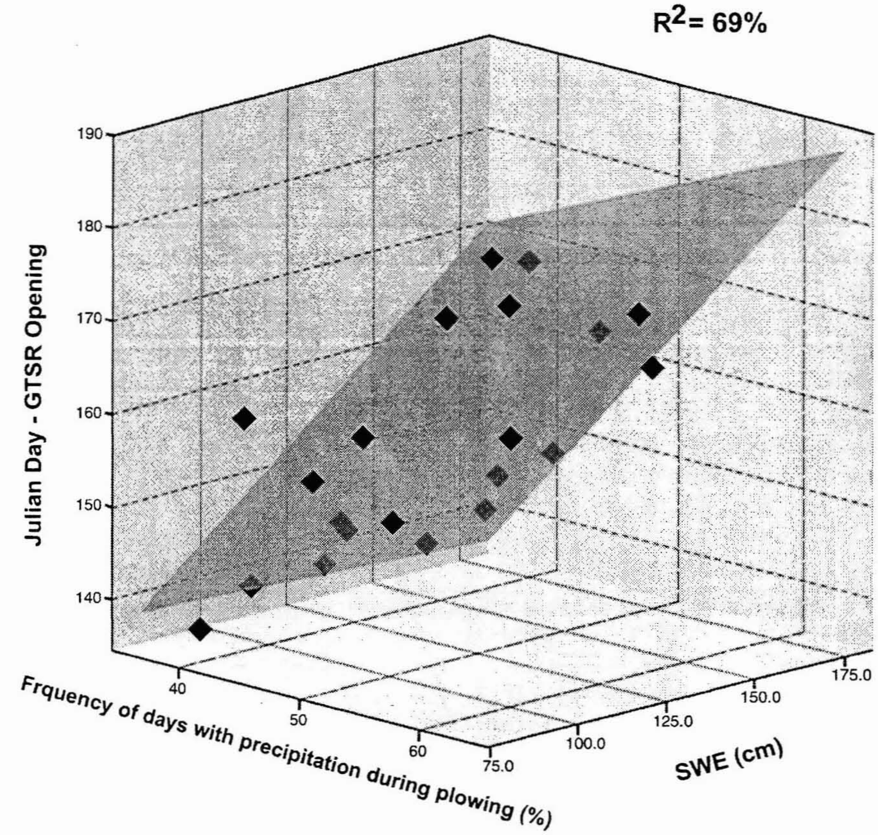

Figure 4: Relationship between the opening date of the Going-to-the-Sun Road and 2 variables – Snow water equivalent on 1st Monday in April at Flattop Mountain SNOTEL and precipitation during period of snow removal operations.

Plowing crews do not work when fog, heavy snow or rain obscure visibility and prevent avalanche spotters from having a clear view into the avalanche start zones. Although this multi-factor model helps us better understand what drives the opening date of the GTSR, it is of limited value in forecasting because daily variation in precipitation and visibility cannot be determined in advance of the plowing period.

The model that relies on only SWE as the major driver has performed well for 3 years despite its inadequacies (Figure 5).

For each year, we used the model on the first Monday in April to predict the GTSR opening date, waited to see when the GTSR opened, and compared the predicted and actual dates. The 1-8 day discrepancies between predicted and actual dates for the 3 years are much less than the calculated confidence intervals of 17-19 days for the 30-year record.

Prediction of Going-to-the-Sun Road Opening Date using Flattop Mountain Snow Water Equivalent on the 1st Monday in April

Year	Method	opening date (± 95% confidence intervals)
2000	Predicted	132.9 + .224*105.4cm = 156.5 ~ 4 June +/- 17 days
	Actual	27 May 2000
1999	Predicted	133.0 + .224*150.6cm = 166.7 ~ 15 June +/- 18 days
	Actual	16 June 1999
1998	Predicted	132.7 + .226*96.77cm = 154.6 ~ 3 June +/- 19 days
	Actual	29 May 1998

Figure 5: Statistical model predictions of the opening date of the Going-to-the-Sun Road compared to actual opening date.

Finally, we compared the MTSNOW-generated SWE estimates for snow on the GTSR with the actual field measurements (Figure 6).

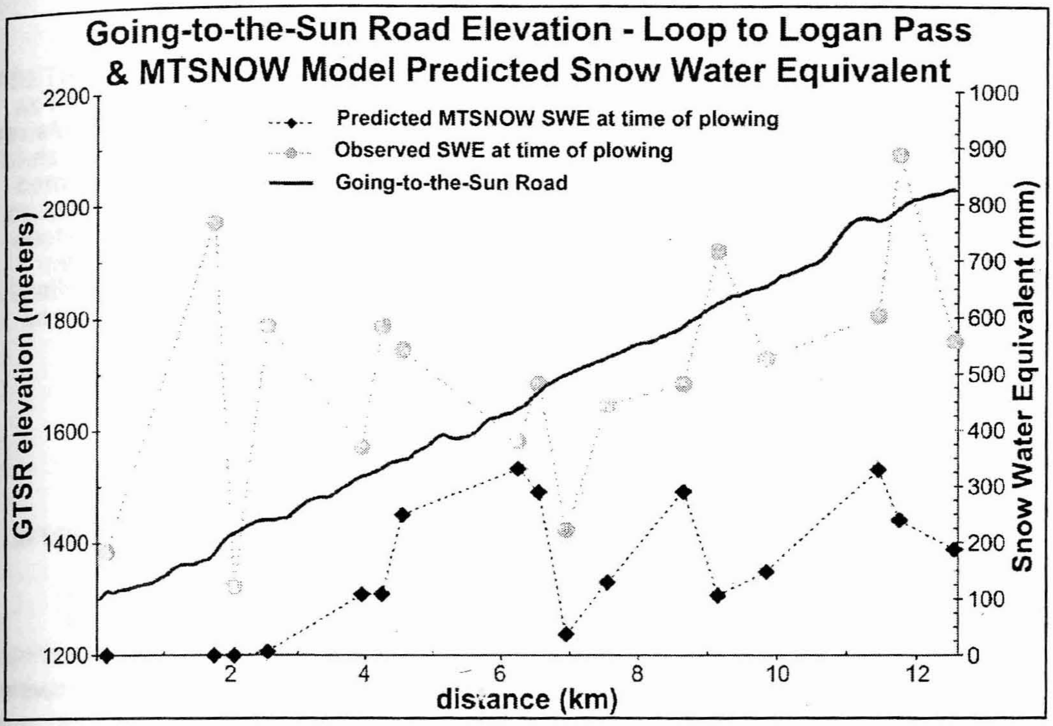

Figure 6: Going-to-the-Sun Road elevation and predicted vs. observed snow water equivalent values. Predicted values are from the MTSNOW model.

Although similar patterns in SWE variability along the GTSR are evident, MTSNOW consistently under-predicted the SWE on the GTSR during snow removal operations.

5. SUMMARY

Using the best available records for the past 30 years, a statistical model could not make accurate predictions of the GTSR opening date from snowpack characteristics alone. This underscores the importance of other factors in snow removal operations besides snow. These include equipment breakdowns, perceived avalanche danger, the number of personnel available, change in policy, improvements in plowing equipment over the 30-year period, turnover in experienced plowing personnel, and changes in safety standards. These results have potential value to park managers by providing a statistical tool to counter the prevailing public expectation that low snowpack years will lead to earlier GTSR opening dates.

The MTSNOW model has worked well in predicting SWE in other mountain environments (Figure 7) (Ringleb et al. 1998) but seriously under-predicted the SWE encountered on the GTSR.

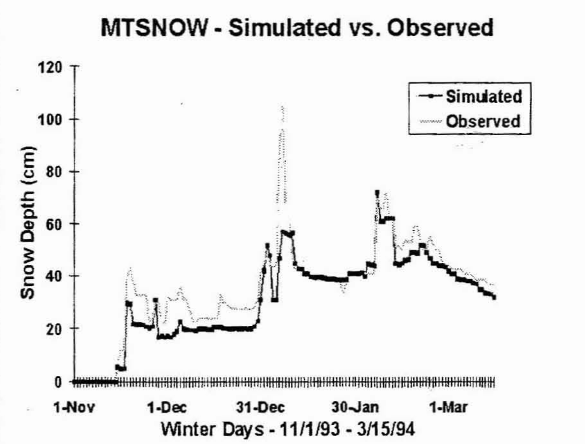

Figure 7: Comparison of snow depths estimated by the model MTSNOW (simulated) vs. depths measured in the field (observed) in the upper Lake McDonald watershed, Glacier National Park, Montana.

One likely factor is the extensive wind redistribution of snow near the continental divide. MTSNOW does not account for wind movement of snow and this section of the GTSR is along the cliffs that form the continental divide in Glacier National Park. Another factor is that snowfall is calculated for the overall slope but the road surface is horizontal and "catches" more than its share. Both of these deficiencies will be corrected in the future.

6. REFERENCES CITED

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