Impact of increased shrub density on snow accumulation and melt in the Arctic tundra

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Abstract

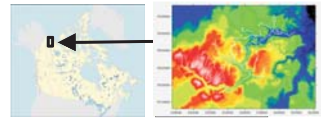
Studies have shown there has been a substantial increase in shrub and low cover vegetation densities within the Arctic Tundra. This trend is forecast to continue and intensify over the coming decades. The increase has the potential to have many profound effects on hydrologic processes in this region, including snow water equivalent at the end of winter, snow melt energy balance, spring runoff, and the soil nutrient balance. Using observed data, including satellite images and air photos, the SnowModel (Liston) snow-evolution modeling system was validated at a tundra site north of Inuvik, NWT in north-western Canada. Multiple model runs were utilized to assess the effects of this shrub and low cover vegetation increase on end of winter SWE and melt.

Although an increase in vegetation has been documented, the hydrological effects, if any, have been largely undetermined. Hypotheses that we consider include changes in snow accumulation (less blowing snow and therefore less sublimation leading to an increased end-of winter snow pack) and changes in snowpack melt rates resulting from the increased shrub canopy density. After SnowModel validation using observed data from the Trail Valley Creek research basin, the model was run with different shrub covers to examine the effect on snow accumulation and melt.

This study is the first step in a series of studies using SnowModel as input for other hydrological models, such as TopoFlow, in an effort to develop an improved coupled model for arctic regions, and as the basis for additional experimental model simulations.

Study Site

The area of interest is the Trail Valley Creek basin, approximately 50km north of Inuvik N.W.T, east of the Mackenzie delta. It is 63 km^2 in area and underlain by continuous permafrost. The land cover of the area is dominated by open tundra (78%) and shrub tundra (20%), with some forest (2%). The area is characterized by a fairly low relief with only some deeper incised river valleys. A high resolution LIDAR-DEM (2m) was acquired for the basin in 2004. This was upscaled to 20m for use with the hydrological model. Meteorological, snow accumulation, snow melt, and other relevant data have been collected since 1992.



SNOWMODEL

An aggregation of four sub models, SnowModel is a spatially-distributed snow evolution numerical model. Applicable to areas conditions favoring snow formation, it can be run in gridded sections varying from 5m to 200m intervals with temporal intervals between 10minutes and 24 hours. SnowModel's aggregates allow for meteorological forcing (MicroMet), surface energy exchange estimation (EnBal), snow depth and snow water equivalent (SnowPack), and snow redistribution due to windy (SnowTran-3D), forest canopy interception, unloading and sublimation, as well as snowpack melt.

Model validation

Our validation runs covered the period between October 1,1998 to June 30, 1999. At the end of winter (April 21, 1999), extended snow surveys were conducted to determine snow water equivalent.

The model results compares very closely with the surveyed snow water equivalent for end of winter snowpack (Figure 1) as well as satellite imagery and air photos collected through out the melt period (Figure 4) indicating that the model captures the spatially distributed snow accumulation and ablation patterns very well. As indicated by Figure 3, north west winds dominated most of the winter storms. Consequently, the model predicts most of the drifts to be on southeast facing slopes, which coincides with the observations.

The model seems to slightly underestimate the amount of drifting over the winter as indicated by the lower modeled drift SWE values compared to snow surveys. This is the likely cause for the model's under prediction of snow covered area late in the melt period figure 5.

Fig. 1 Observed vs Modeled SWE for April 21

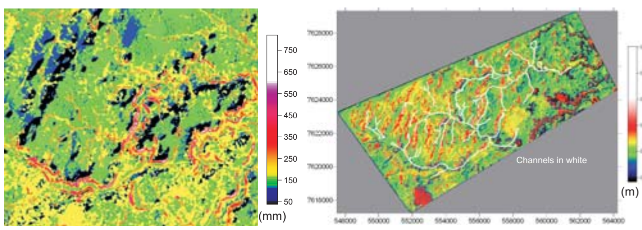


Fig. 2 Simulated SWE for entire model run

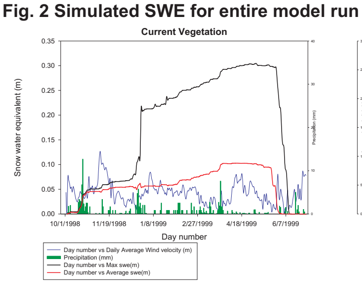


Fig. 3 Hourly wind speed and direction

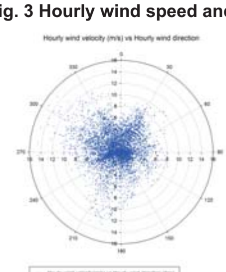
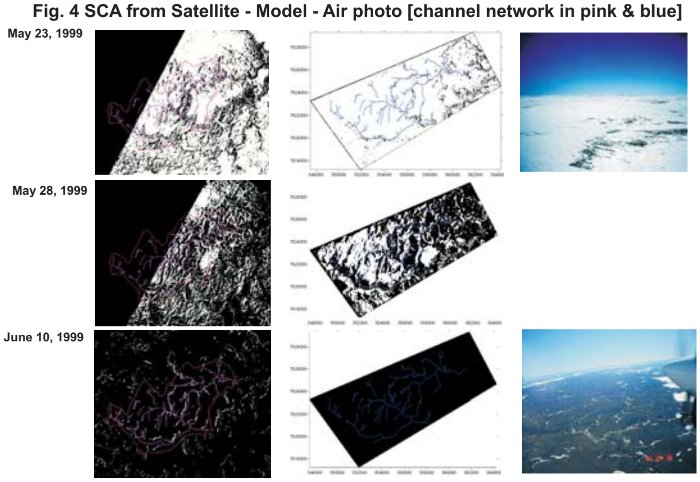
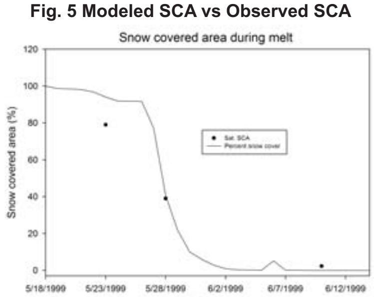


Fig. 4 SCA from Satellite - Model - Air photo [channel network in pink & blue]



The figure to the right showing over prediction of snow covered area during the first half of melt and excellent during the last half of melt.

Fig. 5 Modeled SCA vs Observed SCA



Model Results

Figures 6,7,8 show the effect of vegetation on the snow accumulation.Figure 6 - all tundra run - produces the most drifting, while the average SWE is fairly comparable to current day conditions. An all shrub vegetation cover (figure 7)would drastically reduce the redistribution of snow and lead to a much more uniform, and overall highers end of winter snowpack. This would have considerable impact on a variety of factors such as snowmelt runoff, ground insulation, and animal habitat. Figure 8 shows the average and peak snow water equivalents for current conditions, predicted uniform tundra conditions, and full vegetation coverage conditions.

Fig 6. Modeled SWE for uniform tundra. April 21

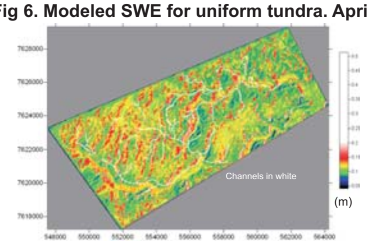


Fig. 7 Modeled SWE for uniform shrub cover. April 21

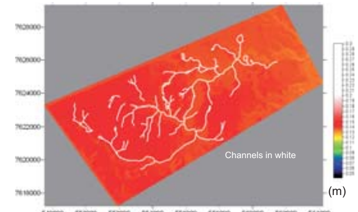
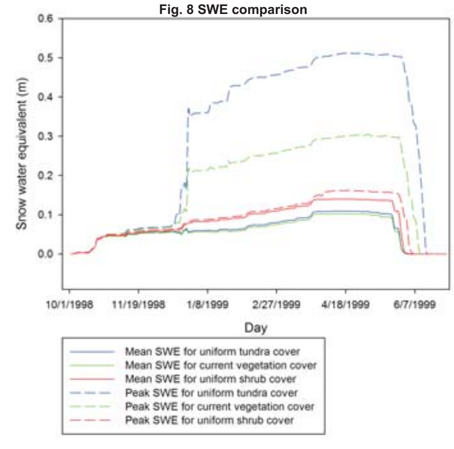


Fig. 8 SWE comparison



Conclusion and Discussion

1. SnowModel predicts the distribution, magnitude and melt of the snowpack under existing conditions with reasonable accuracy.

2. Mean SWE increases (due to decreased sublimation) as vegetation changes from tundra to shrub covered.

3. Maximum SWE in drifts decreases (due to a decline in drifting) as vegetation changes from tundra to shrub covered.

4. This suggests that as shrubs have invaded TVC over during the past decades, snowcover conditions are likely to have also changed. As a result, any studies of past changes in runoff, must consider the effect of shrubs.

5. Previous studies (P.Marsh et.al.) show that shrubs enhance melt in TVC, and Snowmodel does the same. However, future shrub canopies may be denser, and therefore reduce melt rates (Pomeroy et al.). As a result, modeling of future impact of shrubs requires information on future changes in shrub density.

6.Observations at TVC show that in certain years, shrubs are bent over and are fully covered by snow at the end of winter. This complicates modeling shrub landscapes as shrubs behave like tundra for at least part of the winter and during spring melt. These factors are not included in the current simulations.

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