VERIFICATION OF HIGH-RESOLUTION NUMERICAL WEATHER MODELS WITH REGARD TO AVALANCHE FORECASTING

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ABSTRACT: Meteorological factors are of major importance in avalanche forecasting. For regional (office-based) avalanche hazard evaluation, high-quality meteorological information is needed. Especially for computer-assisted forecasts (1 - 2 days into the future), highly accurate weather predictions are desired. The objective of this research is to determine whether output from high-resolution numerical weather prediction (NWP) models can be used as input for avalanche forecasting models. Two high-resolution, real-time, numerical weather forecast models that are currently running at UBC are verified. The models use grid spacing of 3.3 km for the Whistler/Blackcomb ski area in the British Columbia Coast Mountains, and 2 km for Kootenay Pass in the Columbia Mountains. Standard statistical methods are used to compare the forecasts with surface observations of manual and automatic weather stations. The results look very promising. For example, for precipitation rate, wind direction and temperature, the MC2 2 km grid gives better results than the 10 km grid because the topography is captured more accurately. At Kootenay Pass, the NMS model produces comparable results for precipitation rate even though the resolution is lower. For temperature, an error reduction as much as 50 % was achieved using the post-processing Kalman-predictor correction method. With such small errors (around 0.7 K), it looks quite promising that the forecast can be used for avalanche forecast models such as at Kootenay Pass where air temperature is a primary variable for wet avalanche prediction.

KEYWORDS: Avalanche forecasting, high-resolution numerical weather prediction, weather forecast verification

1. INTRODUCTION

Forecast verification is a measure of the quality of a forecast as a sub-field of forecast evaluation. Forecast evaluation can be described as "the process and practice of determining the qua-lity and value of forecasts" (Murphy and Daan, 1985). For this project, statistical verification methods are used to determine the quality of weather forecasts and avalanche predictions.

Within this project, the purposes of forecast verification include (a) the determination of the state of the art of weather forecasting at The University of British Columbia (UBC), (b) the comparison of different forecast models as well as dif-ferent grid spacing and (c) the combination of weather forecasts and avalanche predictions to produce longer range (> 1 day) avalanche hazard forecasts.

In Canada, one numerical avalanche forecasting model was developed by McClung and Tweedy (1994). It is used operationally at Kootenay Pass out to 12 – 24 hours into the future with current observations. With more accurate forecast data, it might be possible to predict avalanches out to 24 – 48 hours into the future. Therefore, forecasts from research weather models have been analyzed. At UBC, two numerical weather prediction models are run real-time, making daily forecasts on multiple grids out to 48 hours. The two models are the Mesoscale Com-pressible Community model (MC2), refined by Recherche en Prevision Numerique (RPN) in Canada, and the University of Wisconsin Nonhydrostatic Modeling System (UW-NMS).

This paper is a summary of the first part of the weather forecast verification and its methods used. First results are presented and ideas for future work are mentioned.

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2. DATA

Observation data and forecasts from two different sites were used. The ski area Whistler/ Blackcomb in the Coast Mountains in British Columbia represents a maritime mountain climate. Observation data were from automatic weather stations (hourly or every 15 minutes) as well as manual observations (twice daily) made by ski patrol avalanche forecasters. For Whistler/ Blackcomb, the grid spacing of the MC2 model is 3.3 km and 10 km. From the NMS model, output from the 10 km grid has been used.

The highway operation at Kootenay Pass in the southern Selkirk Mountains represents a transitional climate zone, mid-way between a maritime and a continental climate. Here, observation data is collected automatically at two weather stations from the Ministry of Transportation and Highways (hourly). In addition to this, data from one manual station at the top of the pass (am and pm observations) was used as well. Forecasts from the 2 km and 10 km grid (MC2 model) and the 30 km (NMS model) have been verified here.

3. EVALUATION METHODS

First, standard statistical methods as well as graphical techniques have been used.

Mathematical techniques include information about the variation/spread of the data set, smallest and largest values, and a single representative number for the data set. The correlation coefficient (Pearson product-moment) gives information about a relationship between two data sets. Mean error (ME), the mean absolute error (MAE), the mean square error (MSE) and the root mean square error (RMSE) have been calculated as basic absolute measures for ordinal predictands.

For nominal predictands, measurements of accuracy are represented by contingency tables. With this tool, the hit rate (H), the percentage of forecasts correct (PFC), the threat score (TS), the probability of detection (POD), the false-alarm rate (FAR), and the BIAS can be calculated. The Heidke skill score (HSS) and the true skill score (TSS) are derived by contingency table analysis as well. See Roeger et al. (2000) for definitions and further explanations of these statistics.

4. RESULTS

4.1 *Precipitation rate*

Results from contingency table analysis from Kootenay Pass data are shown in Figure 1. Distinction between precipitation and non-precipitation events was made first. For the three models compared, the hit rate is almost 75 %, which is quite good. It shows that all models underforecast precipitation events, which means that precipitation was observed more often than it was forecasted.

The BIAS (ratio of the number of precipitation events that were forecast to the number observed) of the MC2 2 km grid-point spacing is very good (close to one). The NMS model does slightly better than the MC2 10 km grid. Both models show skill, since the skill scores are greater than zero, but could be improved. HSS and TSS are about 0.4 - 0.5.

It can be seen that the NMS model with the significantly lower resolution produces comparable results to the MC2 model with the higher resolution grids.

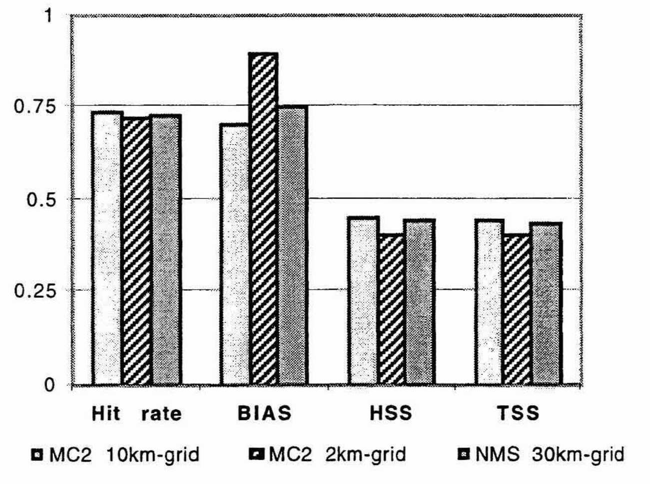

Figure 1: Verification statistics for precipitation rate at Kootenay Pass: Results from contingency table analysis. Perfect forecasts have a value of one.

When precipitation rate was sorted into 5 categories (non-precipitation, 0-1 mm/3hr, 1-2 mm/3hr, 2-3 mm/3hr, >3 mm/3hr), it was seen that the 10 km grid overforecasts non-precipitation events and increasingly underforecasts events with increasing precipitation rate. The 2 km grid overforecasts the category with the highest precipitation rate, but does a better job for non-precipitation events and in the mid-category 1 – 2 mm/3hr. Again, the NMS model demonstrates quite good results even though the resolution is lower. In two categories, its results are better than both MC2 grids.

4.2 Wind speed

For this parameter, an improvement from the lower resolution to the higher resolution can be seen. For Stagleap (second station at Kootenay Pass area), the MC2 2 km grid does better than the 10 km grid-point spacing. The MC2 10 km grid forecasts "Light" winds only whereas the model with the 2 km grid spacing forecasts 61 % "Light", 19 % "Moderate", and 13 % "Strong". This lack of variability from both resolutions is shown in Figure 2. The three left columns present both resolutions from the MC2 model compared to the observations. The two right columns show the observations compared to the NMS model. Similar to the MC2 model, the NMS 30 km grid spacing lacks in variability as well. For all models, there is a bias between the observations and the forecasts. One reason for the different distributions is that the coarser grids have overly smoothed topography.

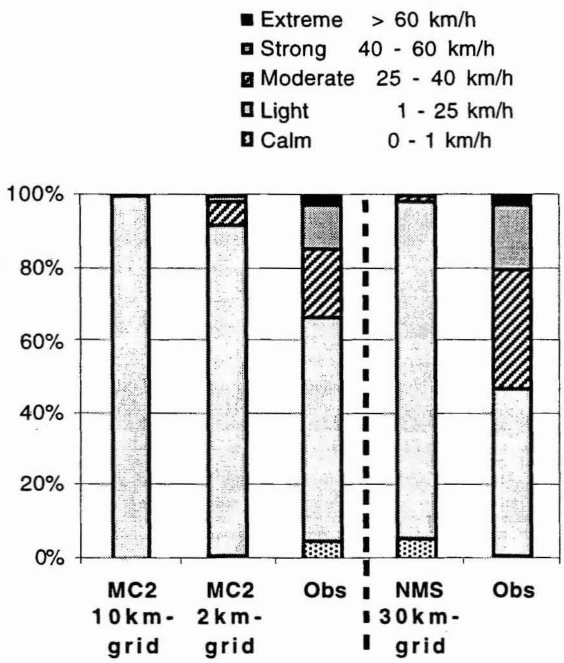

Figure 2: Wind speed distribution (categorical). Stagleap, Nov99 – Jan00

4.3 Wind direction

The BIAS for the wind direction at Stagleap of all 3 different resolutions is shown in Figure 3.

The 30 km grid of the NMS model does quite well. Easterly winds are predicted very well by this grid, but overforecast considerably from the 10 km as well as the 2 km grid of the MC2 model. Comparison of these two shows that the 2 km grid spacing produces better results for almost all aspects.

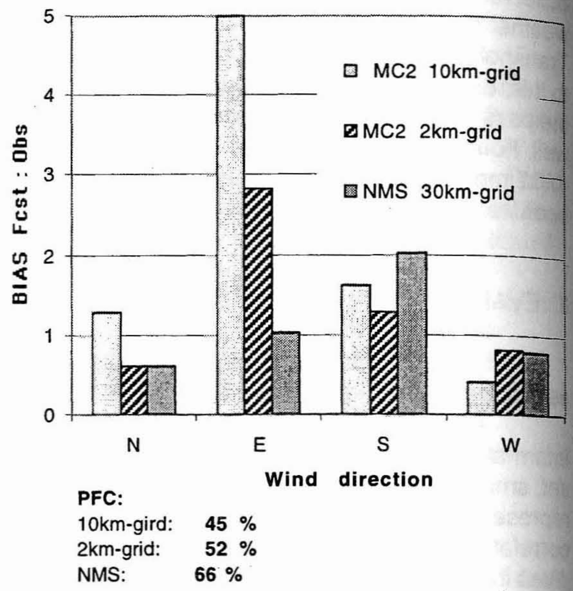

Figure 3: BIAS: Wind direction at Stagleap. 24hr forecast, remote observations, Nov99 – Jan00. A perfect forecast has a bias ratio of one.

4.4 Temperature

For this parameter, results of the comparison between the MC2 original forecasts and forecasts that have been improved by post-processing, using the Kalman-predictor correction method, are shown. The Kalman-predictor correction is a method that uses the observation and the original forecast from the day before to calculate the model error. It then predicts the model error for the next day and corrects the original forecast with it.

Figure 4 shows the mean absolute error (MAE) of the MC2 original forecast versus the Kalman-predictor corrected forecast for temperature at Kootenay Pass (forecast periods 0–24 hr and 24–48 hr).

Again, the 2 km grid gives better results than the 10 km grid for the original forecasts. The Kalman-predictor corrected forecasts have a significantly lower error than the original forecast, in some cases as much as 50 % error reduction is achieved. With this small error around 0.7 K, it looks quite promising that the forecast can be used for avalanche forecast models such as at Kootenay Pass where air temperature is a primary variable for wet avalanche prediction (McClung and Tweedy, 1994).

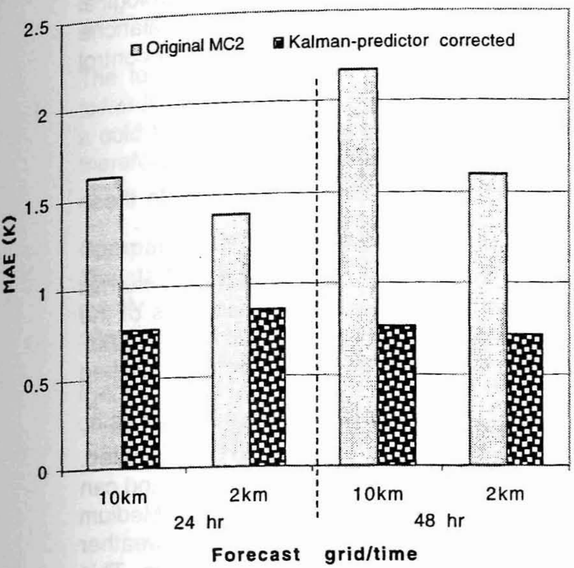

Figure 4: Temperature: MAE. MC2 original forecast vs. Kalman-predictor corrected at Kootenay Pass, Nov99 – Jan00. Perfect forecasts have zero MAE.

5. CONCLUSIONS AND OUTLOOK

The results look very promising so far. It was shown that each model has different strengths and weaknesses. For example, the highest value for PFC for wind direction (Figure 3) from the NMS model indicates, that a single model should not be used for all variables. Considering all parameters, an ensemble forecast that combines several models may do a better job than only one.

The higher resolution of the MC2 model improves the results for wind direction considerably. The main difference between the results of the MC2 model and the NMS model are due to their different approximation of the topography. These results indicate, that a higher resolution does improve the results because the topography is captured more accurately. Boundary effects are also considered to be another reason for the BIAS of the MC2 2 km-grid in wind direction.

The Kalman-predictor correction method is very successful in improving forecast temperatures and should be further developed to use in real-time.

Further verification will include time series analysis to identify phase and amplitude errors.

The output of the numerical weather models will then be directly applied for numerical avalanche forecasting, using the model developed by McClung and Tweedy, 1994.

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