HOW ACCURATE ARE WEATHER MODELS IN ASSISTING AVALANCHE FORECASTERS?

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ABSTRACT: Avalanche forecasters and decision makers strongly rely on Numerical Weather Prediction (NWP) models, for example on the forecasted precipitation amount. NWP models are rarely verified for mountainous regions during the winter season, mainly because of large observation errors. We validated two NWP models (GEM-LAM and GEM15) at 95 stations in the Western Canadian and Northwestern US Mountains. We used ultrasonic snow depth sensors to observe 24 hours new precipitation amounts. For the first time, a detailed objective validation scheme was performed highlighting many aspects of forecast quality. Overall, the models underestimated precipitation amounts, although low precipitation categories were overestimated. The finer resolution model GEM-LAM performed better in all analyzed aspects of quality. An analysis of the economic value of the studied precipitation forecasts showed that only mitigation measures with low cost/loss ratios (i.e. measures which can be often performed) will benefit from these NWP models. This means that measures with large associated costs (relative to anticipated losses when the measure is not performed) should not or not primarily depend on forecasted precipitation.

KEYWORDS: Numerical weather prediction models, validation, precipitation

1. INTRODUCTION

Numerical Weather Prediction (NWP) models are widely used by avalanche practitioners. Their decisions, for example to prepare or apply blasting measures to secure roads and ski hills, or to forecast avalanche danger in public bulletins and in helicopter/cat-skiing operations, are partly based on NWP output, as forecasted precipitation, air temperature or wind speed. NWP models were rarely validated in the winter months and in mountainous terrain. Exceptions are short-term studies for example during the Winter Olympic Games in Vancouver 2010 (e.g. Mailhot et al. 2012), a validation of a nowcasting system in the Eastern European Alps (Haiden et al. 2011), or studies focusing on snow water equivalent or snow depth (Carrera et al. 2010, Bernier et al. 2012). None of the mentioned studies presented a detailed validation as presented for example by Belair et al. (2009) for forecasted summer precipitation. The aim of the present study was to provide an in-depth objective validation of forecasted winter precipitation in the Western Canadian and nearby US Mountains. This will help avalanche practitioners to better estimate the value of NWP models with adding this long-term objective validation to their subjective experience with NWP models.

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2. MATERIAL AND METHODS

The Canadian weather models GEM15 (Mailhot et al. 2006) and GEMLAM (Erfani et al. 2005) with spatial resolutions of 15 km and 2.5 km, respectively, were validated against measured precipitation. Modelled data were available for the two winters 2012/13 and 2013/14. A similar approach was used to obtain time series of modelled data as described by Bellaire et al. (2011, 2013). We used 95 stations over 1500 m a.s.l. with ultrasonic snow depth sensors. This resulted in over 25 000 days of validation data. To avoid wrong conclusions based on minor timing differences between models and observations, 24-hours precipitation sums (HN in cm) were analyzed. For forecasted HN the snow cover model SNOWPACK (Lehning et al., 2002) was used to account for settling processes in the snow pack.

To validate the models we calculated the sum of precipitation for predefined categories, which shows general differences between model and observations. Additionally, the models were validated if they were able to forecast precipitation amounts larger than predefined thresholds. To discuss different aspects of quality we used several attributes: the Equitable Threat Score (ETS) describes model's accuracy and the bias describes systematic differences between model and observations. We also discuss the economic value of a forecast. This addresses to the question whether the decision maker benefits or loses from a forecast in relation to decisions based on a climatological frequency only.

3. RESULTS AND DISCUSSION

The following figures highlight the different quality between both models. In Figure 1 the sum of precipitation in total (bars) and in each category (lines) is shown. Both models underestimated the total sum of precipitation. Except for the low precipitation categories (smaller than 5 cm), the model underestimated precipitation amounts. This was more pronounced for GEM15.

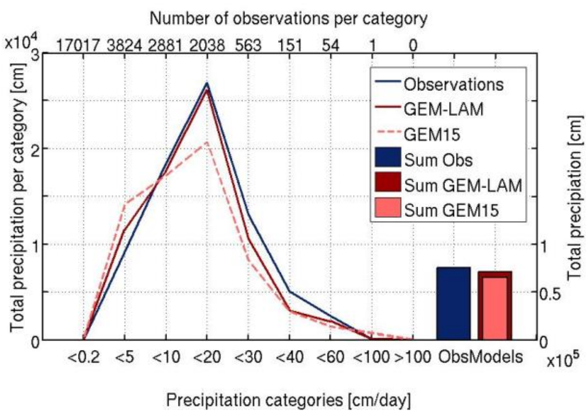

Fig. 1: Sum of precipitation in each category (lines, left axis) and in total (bars, right axis).

While the timing of events did not play a role in Figure 1, correct timing was considered in the following analyses. Also, in the next figures the precipitation categories were not defined as intervals but as precipitation amounts larger then mentioned thresholds. The lowest threshold (>0.2 cm) can be interpreted as “precipitation” vs. “no precipitation”.

Figure 2 shows the bias of GEM15 and GEM-LAM. The bias relates the number of times an event was forecasted with the number of times it was observed. A ratio of 1 indicates an unbiased forecast. Only for the lowest threshold was a positive bias observed, which means the models were forecasting the lowest precipitation category too often. The negative biases in larger precipitation categories indicate that models forecasted higher precipitation categories less often than observed. ‘

The analyses presented in Figure 1 and 2 reveals that decision makers should expect large precipitation amounts to happen more often and in larger amounts than forecasted.

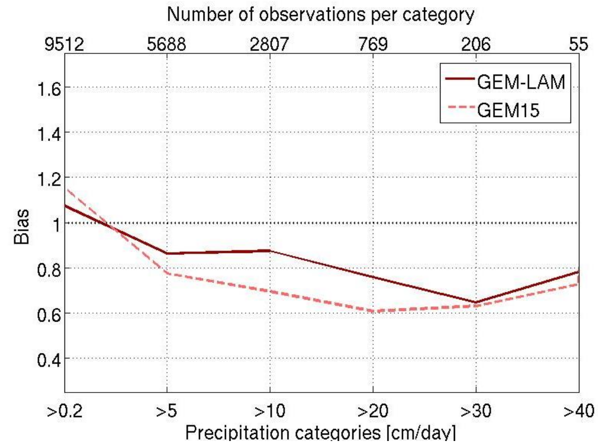

Fig. 2: Bias of each threshold category for GEM-LAM and GEM15.

The accuracy expressed with the ETS is shown in Figure 3. Quality decreased with larger precipitation thresholds, while GEM-LAM revealed better ETS values for all categories than GEM15.

Larger precipitation amounts are probably more important for avalanche practitioners, for which less quality was detected compared to low precipitation categories. However, decision makers may benefit from the higher quality of forecasted low precipitation categories. This implies that decision makers may be quite certain that mitigation measures which are only needed during high precipitation amounts are NOT needed on days with forecasted low precipitation amounts.

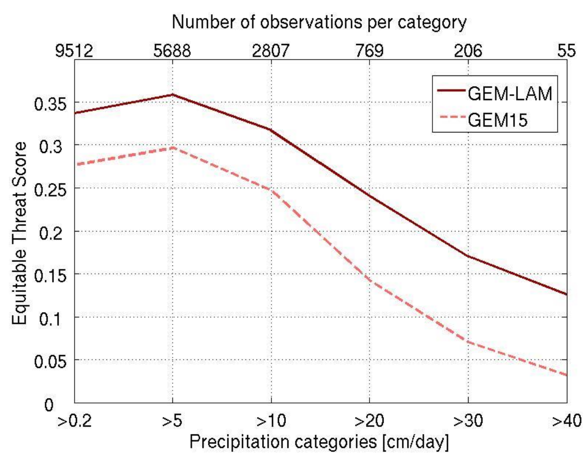

Fig. 3: Equitable Threat Score (ETS) of each threshold category for GEM-LAM and GEM15. Larger values imply better quality.

The economic value for three selected precipitation categories is shown in Figure 4. This value addresses to the question whether the decision maker benefits or loses from a forecast in relation to decisions based on a climatological frequency only. On the x-axis the cost/loss ratio is plotted. Cost refers to the expenses of a decision maker, when he/she applies a measure of mitigation (e.g. blasting, road closure). When the decision maker does not apply a measure, but the event occurs (high precipitation and thus, an avalanche on the road), the anticipated damage is referred to as loss (e.g. the loss of life or damage to infrastructure). Decision makers should define the cost/loss ratios for their specific operation and mitigation measures. In general it can be said that measures with low cost/loss ratios will be applied rather often, since they incur low costs compared to anticipated losses.

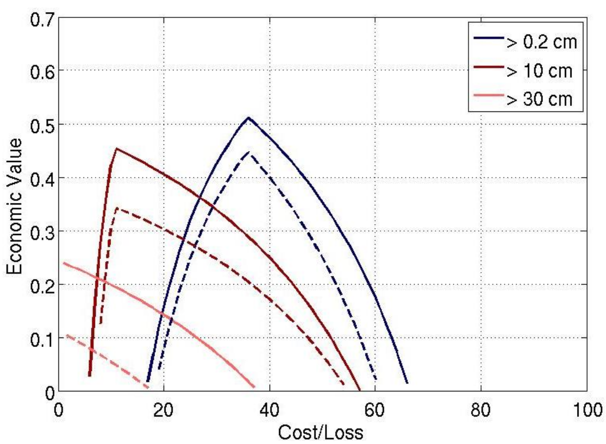

Fig. 4: Economic Value for three selected precipitation categories for GEM-LAM (solid lines) and GEM15 (dashed lines).

The solid blue line shows the economic value of the lowest category for GEM-LAM. Positive economic value can be expected for measures with cost/loss ratios between ~20% and ~70% (solid blue line approaches zero). The highest economic value can be expected for measures of ~35%. For measures with other cost/loss ratios the economic value was negative, which implies the decision maker will lose if he/she relies on the forecast. It would have been economically better to rely on the climatological frequency instead. Decisions based the climatologic frequency will lead to always or never applying a measure. For negative economic values this rather simple strategy is better compared to decisions which are assessed each day and are based solely on forecasted precipitation amounts.

For higher precipitation categories the economic values decreased. For large precipitation categories (>30 cm) a benefit from the forecast can only be expected for measures below a cost/loss ratios of 40%. Especially for these large forecasted precipitation events, avalanche practitioners regularly prepare or apply measures with associated costs. If these measures have large cost/loss ratios, which means they are rather expensive compared to the anticipated loss, this measure should not be relying on a precipitation forecast alone. Note that the point of the maximum economic value is equal with the climatological frequency, which explains the shift towards the left with higher precipitation categories.

Comparing GEM15 (dashed lines) with GEM-LAM indicates that for all precipitation categories the finer resolution model had a larger economic value. For larger precipitation categories GEM15 will add only a small benefit to a decision maker.

4. CONCLUSIONS

In this study a long-term objective validation of winter precipitation forecasted by NWP models in mountainous terrain was presented. The analysis showed that the 2.5 km resolution model performed better than the 15 km resolution model in all analyzed aspects of quality. The analyzed discrepancies between observations and forecasts were similar with both models, but in general greater with the 15 km resolution model: We observed a tendency of overestimating small precipitation amounts while underestimating large amounts. The quality of the models decreased with larger precipitation categories, which are regularly of high importance for avalanche practitioners.

We presented an economic value discussion of the forecasted precipitation amounts. Decision makers who are able to assess their cost/loss ratio of their mitigation measures are able to define for which of their measures the forecast will deliver a benefit compared to decisions based on a climatological frequency. For larger precipitation categories we have shown that decision makers will only benefit from the forecasts if their measures can be applied rather often due to low costs compared to high anticipated losses. For measures with other cost/loss characteristics it is important that decision makers include other information in their decision process, for example snow observations or weather station measurements.

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