ABSTRACT: The Norwegian Avalanche Warning Service is developing a data analysis and decision support system called Avalanche Problem Solver (APS). The goal is to provide major inputs to the avalanche bulletin automatically, in order to support the avalanche forecasters in their daily work routine. The system collects and filters relevant weather and snow information from various sources. The most relevant sources are the seNorge/xgeo snow models, the numerical weather prediction models AROME-MetCoOp and ECMWF, the observation database regobs.no, and the observational weather database eKlima. The system conducts a statistical analysis of the data within a forecasting region and standard forecast period (normally 24h). APS can weight input data in two different ways: a) by relevance with regard to avalanche terrain, e.g. specific elevation zones or areas with a high density of relevant slope angles or b) weighting of different contributing factors by their relevance to avalanche danger, e.g. precipitation amount is weighted more than humidity. An automatic and customized weather forecast text for the mountainous regions in Norway was implemented and run operationally during the winter 2017/2018. In the future, we would like to develop APS such that it can suggest avalanche problem(s) (distribution/ranking), highlight important weather and snowpack conditions, and suggest a danger level for each region, each day.

Keywords: Avalanche forecasting, decision making, data analysis

1. INTRODUCTION

Avalanche forecasting is an iterative process where continuous re-evaluation is necessary as new data becomes available (LaChapelle, 1980). Regional forecasters often deal with data from various sources and with varying quality and quantity. Each type of data might have its own ambiguity and/or given a subjective weighting depending on the individual forecasters background and experience. A general approach to reduce subjectivity in forecasting is to standardize the forecasters training and the assessment process. With APS, we started to implement such a standard for the Norwegian Avalanche Warning Service (NAWS, Engeset (2013)) into a software that provides guidance through the assessment of typically used data.

Numerical weather prediction models are an invaluable data-source in today’s avalanche forecasting. High-resolution models get often updated several times per day based on new model runs and assimilation of weather observations. The Norwegian Meteorological Institute (MET) updates their 2.5 km resolution model AROME-MetCoOp (Müller et al., 2017) four times a day. With forecasting regions on the order of 4000 km², around 1600 data points need potentially be re-assessed after each model run. Field observations are send via the regObs app (Engeset et al., 2018) directly from the field and are immediately available to the forecaster.

We started the development of APS in 2017 and focused on statistical analysis of the prevailing meteorological conditions in a forecasting region. Products described in section 2 are available to the forecasters since December 2017. In the long run, the goal of the project is to develop a tool that predicts and ranks the relevant avalanche problems within a certain area. The idea is to assign initial score- and decay-functions to relevant parameter with regard to each avalanche problem. E.g. for a new snow problem (or storm slab) the most critical parameter is amount and intensity of new snow. Thus, little new snow will give a low score while a lot of precipitation will give a high score. On the other hand will high temperatures lead to a rapid decay (stabilization) of the new snow problem, while low temperature will result in a slower decay.

Once an initial scoring system for an avalanche problem is in place we will try to refine it using machine learning. For that our software will suggest a score for each forecasting region and day; the forecaster will either approve the suggested score or adjust it; the system will then automatically adjust its
weighting for the different parameters over time depending on the forecasters feedback.

We hope the system will increase the consistency of the bulletins produced by different forecasters and will aid in providing avalanche danger assessment at higher spatial and temporal resolution to the public than is possible today at NAWS.

1.1. SYSTEM SETUP

The APS system runs on a Windows server at the Norwegian Water Resources and Energy Directorate (NVE). It consists of three main components: i) Data collection and processing, ii) data storage, and iii) visualization. Data is collected via application programming interfaces (API) from various sources (see table 1). The data is processed and stored in a Microsoft SQL database after retrieval.

The database itself can be accessed via an API and data can either be downloaded in JSON format or plotted directly in the browser using the JavaScript library Zingcharts (e.g. Figures 1-5).

2. CURRENT OPERATIONAL PRODUCTS

The current operational version of APS uses data from regObs, xGeo, AROME-MetCoOp and ECMWF (Molteni et al., 1996). Forecasters from NAWS had access to a statistical summary of the meteorological conditions for each region and could get a visual overview of most relevant parameters for each forecasting region during winter 2017/2018.

2.1. Regional temperature distribution

The regional air temperature distribution uses modeled temperatures from AROME-MetCoOp for prognosis and gridded observational data (Lussana et al., 2018) for historical values. Both are interpolated on to a 1x1 km grid with temporal resolutions of 1, 3 and 24 hours. Each forecasting region is divided into five elevation bands, which can cover 200 to 500 m of elevation each, depending on the size of the region and the given topography. The second highest elevation band is used as a reference temperature to monitor the daily temperature variation. Figure 1 shows the current visualization of the regional temperature data.

2.2. Regional precipitation

The regional precipitation analysis uses modeled precipitation values from AROME-MetCoOp for prognosis and gridded observational data (Lussana et al., 2018) for historical values. The temporal and spatial resolution match the other gridded datasets (1x1 km and 1, 3, or 24h temporal resolution). 5%, 25%, 50%, 75% and 95% percentiles are calculated for the entire region and the subregion of 20x20 km with the highest 50% percentile. Resulting statistics are presented as a box-plot (see Figure 2).

2.3. Regional wind

Wind data is currently only available from AROME-MetCoOp with a resolution of 2.5 km that is regridded to 1 km to match temperature and precipitation data. The modeled data comes as x- and y-vectors of wind speeds in m/s. We classify all values

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
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<tbody>
<tr>
<td>regObs</td>
<td>regObs is the observational database of NAWS. It is open access. Everybody can submit or view all observations via an API, website or app.</td>
</tr>
<tr>
<td>xGeo</td>
<td>xGeo is a map-centric web portal that provides access to gridded data on weather, soil, water, and snow information over Norway and parts of Sweden (Saileranta (2012), Barfod et al. (2013)). It has an interface to regObs data, data from automatic weather stations, web cams and other relevant sources for geohazard monitoring. The portal is public and provides an open API and Web Mapping Service (WMS).</td>
</tr>
<tr>
<td>AROME-MetCoOp</td>
<td>AROME-MetCoOp is a numerical weather prediction model that is run by a collaboration between the Norwegian, Swedish, and Finnish meteorological services. It provides a prognosis of atmospheric variables over most parts of Scandinavia with a spatial resolution of 2.5 km. Data is publicly available via an API or a thredds-server.</td>
</tr>
<tr>
<td>ECMWF</td>
<td>ECMWF is a global weather prediction model with a 9 km spatial resolution. APS uses ECMWF data for prognosis outside the forecasting range of AROME-MetCoOp which is +66 hours.</td>
</tr>
<tr>
<td>eKlima</td>
<td>eKlima is the weather and climate database at MET. It contains data from all present and past weather stations of MET, as well as data from other institutions (e.g. Norwegian Public Roads Administration). Data is freely available.</td>
</tr>
</tbody>
</table>

Table 1: Overview of data sources currently used by APS.

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within a region into Beaufort classes and eight ordinal wind directions. This classification can then be displayed as a wind-rose, which summarizes both the spatial and temporal distribution of the wind conditions within a region over a 24h period (see Figure 3).

2.4. Terrain filters

Terrain filters are maps with a spatial resolution of 1 km matching the weather data. We created these filters based on a 10 m digital terrain model (DTM). We calculated the percentage of avalanche terrain within each 1 km cell, where we defined avalanche terrain as terrain having a slope angle between 25 and 60 degrees. We calculated the dominant aspects of the avalanche terrain within each cell, which we can use to filter terrain with regard to the dominating wind direction. Thus, all data can now be filtered based on terrain characteristics. E.g. in regions with larger mountain plateaus, we can remove areas with low percentage of avalanche terrain before calculating regional statistics for e.g. wind or precipitation.

2.5. Daily overview

The individual graphs shown in figures 1 to 3 can be combined such that forecasters get an overview over the evolution of the meteorological conditions over several days. Figure 4 shows such an overview for the region of Hardanger in South-West Norway at the end of November 2017. Besides the graphs, information on the latest model runs and how much of the terrain is found in each elevation band is also available. More features will be added to the dashboard as they become available operational.

2.6. Automatic weather forecast

Each of our bulletins contains a short weather forecast that summarizes what the assessment of the avalanche danger is based on. APS automatically generates this text based on the regional meteorological statistics described in sections 2.1 - 2.3. These values are quality controlled by a trained meteorologist and additional parameters such as cloud cover are added manually prior to publication. Table 2 shows an example of the automatically generated weather forecast accompanying the avalanche bulletin for the region of Sunnmøre on December 8th, 2017.

Proceedings, International Snow Science Workshop, Innsbruck, Austria, 2018
Figure 3: Wind-rose showing the wind-speed and -direction in the region Sunnmøre on December 9th, 2017. Yellow or red colors indicate gale force or stronger. The gray arrows at the bottom indicates the wind-direction of the strongest winds during each hour.

Figure 4: The overview panel shows a summary over four days (only three shown here) for the prevailing air temperature, precipitation and wind conditions within a forecasting region. In the example the weather conditions for the region Sunnmøre are shown around December 7th, 2017.

Mountain weather, 08.12.2017

30 mm precipitation, up to 45 mm in the most exposed areas. Fresh breeze from west, change to strong breeze from northwest in the evening. -6 °C to -1 °C at 1400 m a.s.l. Positive degrees up to 600 m a.s.l. Cloudy.

For updated info, please visit yr.no.

Table 2: Automatically generated weather forecast by APS as it appears in the English version of the Norwegian avalanche bulletins. Here we made the text that is manually added by the meteorologists italic for illustration purposes. This example is from Sunnmøre on December 8th, 2017 (see also Figure 4, tomorrow)

2.7. Forecasters dashboard

The dashboard for each region summarizes the issued danger level and avalanche problem(s), the observed persistent weak layers and dominant weather data for a desired period (see Figure 5). It is often useful to get a quick overview, writing reports or providing information to the media. In the future we will also include avalanche activity detected by satellites (Eckerstorfer et al., 2017).

Figure 5: The forecasters dashboard summarizes relevant avalanche data over a given period, e.g. a season within a region. The issued danger level is shown at the top. The second heatmap shows observed persistent weak layers and the third heatmap the relevant avalanche problems at the given date. The combined bar and line chart shows the average precipitation (gray bars), the average precipitation in the most exposed 400 km² (red bars), the average temperature (blue line with dots), and the min/max air temperature (light-blue area). The area graph at the bottom shows the freezing level.

3. CONCLUSION

The Avalanche Problem Solver (APS) is a decision support tool for avalanche forecasters. In its final stage it should provide data and maps on avalanche problems likely to be present within a region. Its first operational products are statistics of meteorological conditions within each forecasting region in Norway. They were applied during the forecasting season 2017/2018 aiding forecasters in the daily work and providing an automatic weather forecast that was published with each bulletin. Day to day evaluation by the meteorologist on duty indicated good agreement for the temperature and precipitation values,
which rarely needed correction. In the beginning of the season too low wind speeds were predicted by APS, which was improved by an adjustment. The next step is to set up an initial score-function for the new snow problem based on these temperature, wind and precipitation data.

REFERENCES


