

Probability of Snow Nowcasting for Airports

PNOWWA (Probabilistic Nowcasting of Winter Weather for Airports)

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Abstract—The PNOWWA project produces methods for the probabilistic short-term forecasting of winter weather and enable the assessment of the uncertainty in the ground part of 4D trajectories. 4D trajectory management is a necessary concept to meet future growth in air traffic. Probabilistic forecasts will be used in air traffic management (ATM) applications to support operational planning in surface management and ATM decision making, thereby increasing airport capacity, shortening delays and promoting safety.

PNOWWA demonstrates very short-term (0-3h, "nowcast") probabilistic winter weather forecasts in 15-minute time resolution based on an extrapolation of movement of weather radar echoes and improve predictability of changes in snowfall intensity caused by underlying terrain (such as mountains and seas). An extensive user consultation was performed to focus on user needs (parameters and thresholds) and to ensure products which are suitable to be integrated in various applications on the ATM side. A research demonstration was conducted at airports in Austria and Finland in winter 2016/2017.

PNOWWA's probabilistic forecast of winter weather for airports have been successfully demonstrated. Data were provided via webpages as "live" data.

User feedback has been collected to improve the PNOWWA product for next year demonstration phase. The PNOWWA project helps to assess impacts on operations at airports during disruptive winter weather and illustrates strong potential for probabilistic nowcasting using weather radar data.

Keywords- ATM, Air Traffic Management, winter weather, nowcasting, probabilities, weather radar

I. INTRODUCTION

Probabilistic forecasting is nowadays used in meteorology to quantify uncertainty. In contrast with deterministic forecasting, the natural intrinsic variability of weather and the uncertainty in the observations and in the forecast process itself are considered. Probabilistic information can be created by generating an ensemble of forecasts or by applying statistical post processing. Then the user must choose proper probability thresholds, which gives them the correct balance of alert and false alarms for specific applications. Hence, an objective

quantity of uncertainty results, which means increasing risk of wrong decision with lower likelihood. These probability forecasts support best the user specific decision-making processes.

While probabilistic forecasting is more common for medium-range (order of days) from numerical weather model output and model output statistics, probabilistic nowcasting methods have been improved during last years, e.g. [1], [2]. Nowcasting (0-3 hour) of precipitation systems is strongly driven by extrapolation of weather radar images, because of the rapid updated high spatial resolution observations, in three dimensions up to ranges of 2-300 km. There, linear translation of a precipitation area is better captured compared with the propagation part. In general, the quality of the forecast decreases with lead time and increasing spatial scale (scale dependent life time of precipitation). As quantitative methods are needed, sectors of increasing catchment areas or decomposition in different scales of snow fall patterns with different behavior are used to create an ensemble of nowcasts from consecutive radar images [2].

The PNOWWA produces methods for the probabilistic short-term forecasting of winter weather and enable the assessment of the uncertainty from the end points (airports) of 4D trajectories. 4D trajectory management, also sometimes called "Gate to Gate concept" is an essential building block of the ICAO and SES concepts (GANP, ATM Master Plan) to meet future growth in air traffic; probabilistic forecasts will be used in ATM applications to support operational planning in surface management and ATM decision making, thereby increasing airport capacity in critical weather situations, shortening delays and promoting safety.

In PNOWWA demonstration campaign very short-term (0-3h, "Now-cast") probabilistic winter weather forecasts at 15min time resolution based on the extrapolation of the movement of weather radar echoes were delivered to a selected group of end users at different airports. Users were consulted to the most relevant parameters and operationally important thresholds of the selected parameters (e.g. how many centimeters is considered "heavy snowfall").

II. MAPPING THE USER NEEDS

A. Selection of representative users

User Needs were sought to be obtained from a wide range of aviation stakeholders mainly at airports, ranging from major hubs to smaller regional European airports. These were selected to represent different (and challenging) topographic regions, ranging from Nordic maritime to high Alpine environments to determine the limits of applicability as well as the capabilities of the proposed Now-casting system. Apart from web-based surveys, direct contact was established to a number of representatives of user groups and their views and operational concepts established and compared, leading to the interesting result that any such Now-casting system will have to be highly flexible, scalable and adaptable to meet genuinely diverse user needs. The relevant thresholds or equivalent decision criteria were discussed in face-to-face meetings with different end users at Vienna (LOWW), Innsbruck (LOWI), Zurich (LSZH), Geneva (LSGG), Rovaniemi (EFRO) and Helsinki Vantaa (EFHK) airports. Written feedback of varying detail was received from Oslo-Gardermoen, Munich, Istanbul, and Salzburg.

B. The different needs as expressed by users

Three major groups of users were identified. The runway maintenance needed accumulation of snow in millimeters during each 15 minute step. Thresholds were expressed separately for dry snow, wet snow and slush. In addition, they wanted a probability for freezing rain – something, what a solely weather radar –based algorithm can not express.

The aviation control tower wanted probability of low visibility procedures, LVP. In winter, LVP is related to clouds, fog or snowfall, and solely weather radar –based algorithm can only express the snowfall-related LVP (visibility reduction without ceiling).

The deicing managers at airports used its own Deicing-weather index (DIW) PNOWWA team had experimented with this already in SESAR1. Basic idea of DIW is that the bigger DIW value is the longer time is needed for de-icing of individual aircraft. Thresholds of frost formation causing need of deicing of planes is based on the experiences of de-icing companies at Helsinki, Oslo and Stockholm airports for conditions when planes will ask for de-icing (interviews during SESAR1 projects 11.02.02. and 06.06.02). The need of individual plane's de-icing is dependent also from the previous phases of flight and conditions it has experienced in past not only meteorological conditions. (That is why the probabilistic approach is more suitable for user purposes than deterministic.)

TABLE I. THE DEPENDENCY BETWEEN WEATHER AND DIW

Weather	Effect on aircraft	DIW
Heavy snow or sleet (visibility < 1500 m)	Snow on plane	3
Freezing rain/drizzle	Ice on plane	3
Light or moderate snow or sleet	Snow on plane	2
Temperature -3...+1C and humidity > 75%	Frost formation on the plane surface.	1
Any other weather	No remarkable contamination on plane	0

An extensive user consultation was performed to focus on user needs such as parameters and thresholds (Figure 1) and to ensure products which are suitable to be integrated in various applications on the ATM side.

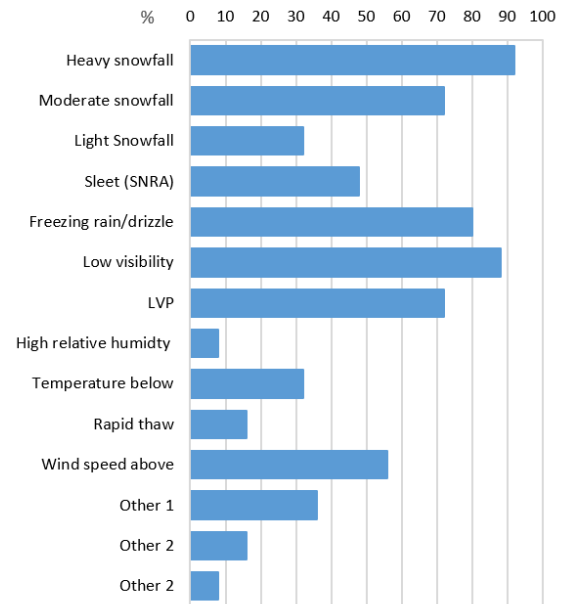


Figure 1: Relative number of responses which show the type of winter weather affecting airport operation, and requires early mitigating actions. Total number of respondents is 25.

Beside the nowcasting lead time of 3 hours (Figure 2), airport operators are interested additionally also in 12 hours, and more dominantly, in 24 hours lead times for tactical planning and pre-emptive actions. In short range forecasting, exact timing is essential, because wrong timing of the adverse weather event might significantly disturb operations planning and subsequently generate substantial delays for air traffic. Respondent from ATM stated that the needed forecast time is also depending on the flight time to another European destination, this means for capacity planning in the time range around 3 hours.

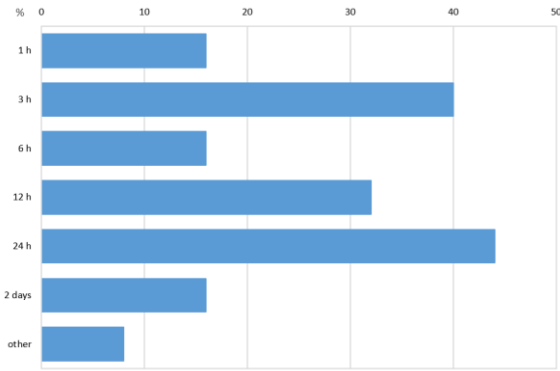


Figure 2: Useful lead time for warning of critical weather. X-axis shows the relative number of responses.

III. NOWCASTING TOOLS FOR DEMONSTRATION

A. General structure of the tools

The structure of PNOWWA “demonstration engine” is modular, to allow the use of different components at their most suitable maturity level independent of progress in the other work packages.

Then conversion equations from literature and PNOWWA studies were used to express the user-defined parameters in radar reflectivity dBZ (summary see in [2]). The results, as used in the first scientific demo, are shown in tables 2-4.

The extrapolation software was used to create class probabilities of these thresholds expressed in radar reflectivity (dBZ). These answer e.g. the question “what is the probability, that radar echoes seen at this airport will be between 24.5 and 29 dBZ 30-45 minutes from now”.

Then using the conversion tables again, the probabilities were converted to “user parameters”. The resulting probabilities answer e.g. the question “what is the probability, that at this airport 5-10 mm cm snow will be accumulated 30-45 minutes from now”.

Then, time-series were created and expressed as tables using a web-based interface.

B. Nowcasting methods

Three nowcasting methods have been tested in PNOWWA [2].

In the method suggested by Andersson and Ivarsson [3], wind at 850 hPa level is used to describe the movement. The wind is taken from HIRLAM (High Resolution Limited Area Model) numerical weather prediction model. The uncertainty of forecast is growing with time, related to the snow field texture. This approach had been tested in SESAR1, so it was known to provide reasonable results. It was used in the first real-time demonstration campaign.

The new nowcasting method developed in PNOWWA uses motion vector analysis schema based on approach of optical flow [4] and the stochastic ensembles for creating probabilistic output [5]. This method was used for case studies and offline demonstrations [2].

The method operationally used and originally developed at FMI, applies modified correlation-based atmospheric motion vector (AMV) system by EUMETSAT [6], [7]. This well tested method was used as a reference for comparisons, when developing the new method.

C. Data sources

Radar data from Finland is part of FMIs operational data flow. Radar data from Austria comes from Austro Control. Radar data from other parts of Europe, needed for calculation of motion vectors, is coming from EUMETNET OPERA [8].

For temperature and dewpoint, METAR observations are used. Other model parameters, needed for parameters not available from radar data, as well as for wind vectors for Andersson method, the HIRLAM numerical weather prediction model is used [9].

D. Conversion tables

Simple conversion tables were used to express the dBZ values in user-defined parameters (“what is the probability, that at this airport more than 10 mm snow will be accumulated 30-45 minutes from now”). Tables 2-5 show thresholds as used in the first scientific demo.

To select the right dBZ thresholds, type of snow had to be determined. ICAO has defined the types of snow as follows [10]

- Dry snow – can be blown if loose or compacted by hand, will fall apart again upon release.
- Wet snow – can be compacted by hand and will stick together and tend to form a snowball.
- Compacted snow – can be compressed into a solid mass that resists further compression and will hold together, or break up into lumps, if picked up.

For this application, the snow type was determined based on temperature and dewpoint, read from the METAR.

TABLE II. TEMPERATURE AND DEWPOINT FOR DISCRIMINATION BETWEEN DRY AND WET SNOW

	dry snow	wet snow
Temperature in °C	≤ -0	$-0\text{ °C} \leq \text{and} \leq +3\text{ °C}$
Dewpoint in °C	≤ -1	≤ 0

RUNWAY MAINTENANCE (UPDATED 2017-02-22 15:15:00 UTC)													
accumulation% dry snow, mm/15min	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	90-105 min	105-120 min	120-135 min	135-150 min	150-165 min	165-180 min	180-195 min
over 10 mm	0	0	0	0	0	0	0	0	0	0	0	0	0
5-10 mm	0	0	0	0	0	0	0	0	0	0	0	0	0
1-5 mm	60	60	70	20	0	0	10	20	30	20	30	40	30
less than 1 mm	40	40	30	80	100	100	90	90	80	80	70	60	70
accumulation% wet snow, mm/15min	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	90-105 min	105-120 min	120-135 min	135-150 min	150-165 min	165-180 min	180-195 min
over 5 mm	0	0	0	0	0	0	0	0	0	0	0	0	0
3-5 mm	0	0	0	0	0	0	0	0	0	0	0	0	0
1-2 mm	0	0	0	0	0	0	0	0	0	0	0	0	0
less than 1 mm	100	100	100	100	100	100	100	100	100	100	100	100	100
prob of freezing rain	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	90-105 min	105-120 min	120-135 min	135-150 min	150-165 min	165-180 min	180-195 min
prob	0	0	0	0	0	0	0	0	0	0	0	0	0
prob of freezing wet runway	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	90-105 min	105-120 min	120-135 min	135-150 min	150-165 min	165-180 min	180-195 min
prob	0	0	0	0	0	0	0	0	0	0	0	0	0

DE-ICING AGENTS (UPDATED 2017-02-22 15:15:00 UTC)													
DIW class %	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	90-105 min	105-120 min	120-135 min	135-150 min	150-165 min	165-180 min	180-195 min
3	0	0	0	0	0	0	0	0	0	0	0	0	0
2	60	60	70	20	0	0	10	20	30	20	30	40	30
1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	40	40	30	80	100	100	90	90	80	80	70	60	70
prob of freezing wet runway	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	90-105 min	105-120 min	120-135 min	135-150 min	150-165 min	165-180 min	180-195 min
prob	0	0	0	0	0	0	0	0	0	0	0	0	0

TOWER (UPDATED 2017-02-22 15:15:00 UTC)													
VIS decreased by snow	0-15 min	15-30 min	30-45 min	45-60 min	60-75 min	75-90 min	90-105 min	105-120 min	120-135 min	135-150 min	150-165 min	165-180 min	180-195 min
VIS less than 600 m	0	0	0	0	0	0	0	0	0	0	0	0	0
VIS 600-1500 m	0	0	0	0	0	0	0	0	0	0	0	0	0
VIS 1500-3000 m	60	60	70	20	0	0	10	20	30	20	30	40	30
VIS over 3000 m	40	40	30	80	100	100	90	90	80	80	70	60	70

Figure 3: Example of end user online web page from 22nd February 2017, issued at 15:15 UTC. Different forecast classes (left in grey) for 3 stakeholder groups are predicted up to 195 min, where likelihoods are color coded (green 0-20 %, yellow 30-50 %, red 60-100 %).

RADAR REFLECTIVITY

Visibility m	dBZ for dry snow	dBZ for wet snow
≤600	>29.0	>29.0
600-1500	24.5-29.0	23.5-29.0
1500-3000	15.5-24.5	19.5-23.5
>3000	<15.5	<19.5

TABLE IV. THE DEPENDENCY BETWEEN LIQUID WATER EQUIVALENT AND RADAR REFLECTIVITY

Liquid water equivalent mm/h	dBZ for dry snow	dBZ for wet snow
≥4	>29.0	>29.0
2-4	24.5-29.0	23.5-29.0
0.4-2	15.5-24.5	19.5-23.5
<0.4	<15.5	<19.5

TABLE V. THE DEPENDENCY BETWEEN SNOW ACCUMULATION AND RADAR REFLECTIVITY

Snow accumulation mm/15 min	dBZ for dry snow	dBZ for wet snow
>10	>29.0	>29.0
5-10	24.5-29.0	23.5-29.0
1-5	15.5-24.5	19.5-23.5
<1	<15.5	<19.5

TABLE VI. THE DEPENDENCY BETWEEN DE-ICING WEATHER INDEX AND RADAR REFLECTIVITY

De-icing	dBZ for dry snow	dBZ for wet snow
3	>24.5	>23.5
2	15.5-24.5	19.5-23.5

IV. END USER DISPLAY

Example of end user display (web page) at one of the participating airports (Figure 3). Blue bars limit sections for different user groups (runway maintenance, de-icing agents, tower). Horizontal axis is time in minutes since the forecast was issued. Vertical axes are severity classes of each phenomena or index, e.g. intensity of dry or wet snowfall, de-icing weather index and visibility. The colourful boxes then depict the probability of each class at each moment, largest probabilities coloured in red and yellow. In layman terms: “it is going to snow for 45 minutes more, then it’s dry for at least half an hour, probably even longer, but after 2 hours the probability of snowfall is increasing again.”

V. EXPERIENCES OF THE FIRST DEMONSTRATION CAMPAIGN

First scientific demonstration of PNOWWA conducted for Austrian and Finland airports during February and March 2017. There were only limited amount of real winter weather cases in Austria and Southern Finland. In Northern Finland

weather was more favorable. In spite of that it was recognized that prototype worked well and it was flexible to tailor it for different users. We were able to collect valuable and positive feedback from users which further helps to assess the applicability of probabilistic nowcasting for disruptive winter weather using weather radar data.

Reference time, automatic update of web page was felt to be necessary character of product. Accumulation of snow expressed as mm/15 min scale as wished by users. Product description and feedback form was included in the webpage, where online feedback form never used by stakeholders. Therefore, individual contact to different stakeholders worked best. Some users felt more comfortable to use traditional material than new product. It would be beneficial to give hands on familiarization to test users during some real winter weather case. That would give us more information about the level of quality of demo product and improvements, that could be done.

Users should also be well informed about the possible limitations of product. In PNOWWA prototype forecasted amount of decrease of visibility caused by snow, only. Mist or fog forecasts were not included. Users were confused with that and in operative service it should be taken into account all type of effects causing reduction of visibility. Also ATM stated the need for ceiling information in nowcasting decision support system. In current PNOWWA demonstrator forecasting of ceiling is not possible from extrapolated weather radar information. It is not enough to develop ways to produce probabilistic weather forecasts, but it is also necessary develop ways how probabilistic weather information could be used efficiently in ATM processes. Cost loss ratios and suitable, impact-related key performance indicators, which combine traffic load, delays, amount of chemicals and workload have further to be developed. At the moment airport operation is always on the safe side. Therefore, stakeholders are concerned about events with low likelihood which leads to no action but results e.g. in snow fall and resulting possible incidents. By the other hand, runway operation stated possible over-interpretation of low probability winter events which might increase the costs. Subsequent, preparation workshops before next demonstration phase will be organized to train users in interpretation of the PNOWWA product.

Feedback from individual discussions and demonstration of high impact “offline” case studies will help to improve the probabilistic application for next winter demonstration campaign.

VI. VERIFICATION OF THE FIRST DEMONSTRATION CAMPAIGN

To demonstrate the reliability and applicability of PNOWWA product in air service provision, we have to validate and verify results and show positive impacts but also limitations.

Hence, for verification we focus on last year winter events during first demonstration phase. Different weather pattern and

different location (Central Europe, Northern Europe, mountains and sea influences as well as flat areas) have been investigated.

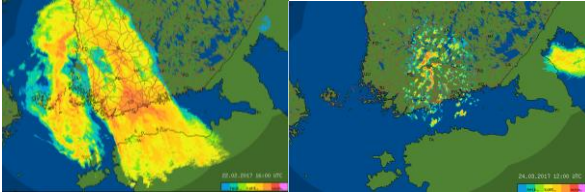


Figure 4: Different types of weather systems: frontal band of snow (left) and snow showers (right) over southern Finland.

Large synoptic systems like frontal band of snow (Figure 4 left) might persist over several hours and therefore, higher probabilities in larger lead times (e.g. 120 minute) occurred in contrast to small scales of snow showers, which have a typical life time of about 60 minutes.

Example of probabilistic forecast performance is given as time series for two different forecast lengths for Innsbruck. In Figure 5 observations are assumed as 15 min forecast, where probability is larger/smaller than 50 % means snow/dry. Note, that in mountainous areas weather radar coverage is reduced due to shielding effects and high situated radar sites at mountain tops accompanied by missing snow below radar horizon (e.g. in valleys).

For short term forecasts in Figure 5 and Figure 6 periods of high probability of snow correlates well with snowfall amount. Dry periods are predicted well on the left half in Figure 5, while at the end in the right half of Figure 5 weak probabilities < 0.2 are present. For large scale precipitation events even longer lead times correlate well with snowfall (accompanied by high probabilities) and dry areas.

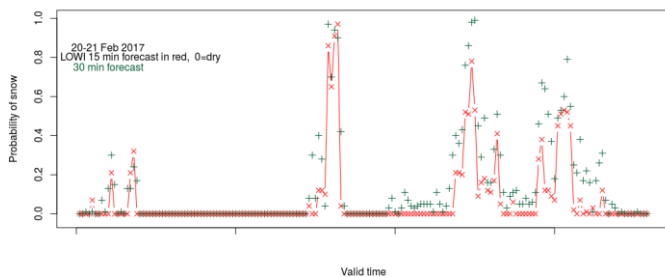


Figure 5: Time series of probability for snowfall gathered from radar extrapolation for lead time of 30 minutes (green +) compared with observations (15 min forecast, red line). X axis length is 48 hours and every data point reflects 15 min time step.

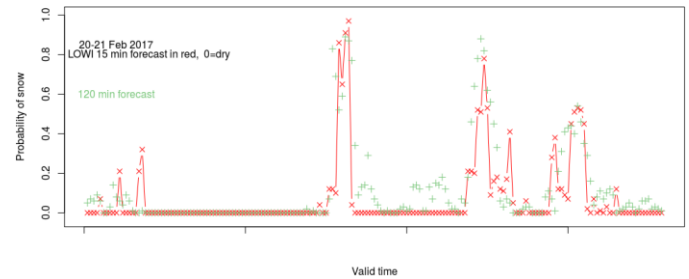


Figure 6: As Figure 5 but for lead time of 120 minutes.

For more quantitative verification results, the reader is referred to paper by Pulkkinen et al. [2].

Investigations of aircraft delay minutes didn't correlate well with snow height accumulation at Vienna airport for winter 2016/2017.

VII. FUTURE WORK

A second real-time demonstration campaign will be organized next winter, making use of the more accurate nowcasting methods developed in PNOWWA and helps for further development of impact based key performance indicators.

Before that, discussions with end users are continued, and change to concept of "exceedance probabilities" instead of "class probabilities" is introduced. At first glance, it would feel natural to forecast, that "is the intensity of snowfall between a and b", and this is what the users asked for. Our experience shows, that forecasting "probability that intensity of snowfall is at least a" is more useful.

Additional winter weather forcing due to topographic influences was investigated. This forcing can strongly affect the weather radar extrapolation technique for nowcasting. Results show, that the forecast quality is lower for precipitation systems arriving from the sea, and north of the Alps frontal delays and upslope enhancement have been observed [2].

In this project, we have focused on radar-based methods due to their outstanding temporal resolution. In the possible follow-up projects, data fusion with other data sources such as numerical weather prediction should be considered, both to extend the valid time and widen the available weather parameters. It should be underlined, that this is S2020 exploratory research, so real-life user applications, such as mobile apps, are not within the scope of this project

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