Final Project Results Report

Deliverable ID:	[D1.2]
Dissemination Level:	[PU]
Project Acronym:	[PNOWWA]
Grant:	[699221]
Call:	[H2020-SESAR-2015-1]
Topic:	[Sesar-04-2015]
Consortium Coordinator:	[FMI]
Edition date:	[24th June 2018]
Edition:	[00.04.00]
Template Edition:	02.00.02

Founding Members
EUROPEAN UNION
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Authoring & Approval

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Document History

Edition	Date	Status	Author	Justification
00.01.00	23.3.2018	First published final version	Ari-Matti Harri / FMI Harri Haukka / FMI Elena Saltikoff / FMI	
00.02.00	12.4.2018	Second revision of the Final Report	Ari-Matti Harri / FMI Harri Haukka / FMI Elena Saltikoff / FMI	
00.03.00	5.6.2018	Third revision of the Final Report	Ari-Matti Harri / FMI Harri Haukka / FMI Elena Saltikoff / FMI	
00.04.00	24.6.2018	Fourth revision of the Final Report	Ari-Matti Harri / FMI Harri Haukka / FMI Elena Saltikoff / FMI Heikki Juntti / FMI	

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PNOWWA

PROBABILISTIC NOWCASTING OF WINTER WEATHER FOR AIRPORTS

This document is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No [699221] under European Union's Horizon 2020 research and innovation programme.

Abstract

The SESAR2020 exploratory research project called Probabilistic Nowcasting of Winter Weather for Airports (PNOWWA, grant #699221) developed methods to support the Air Traffic Management (ATM) challenged by winter weather. The project was running for two years from April 2016 until April 2018.

The principal PNOWWA result is the probabilistic radar-based nowcasting of winter weather, which will enable the estimation of winter weather conditions affecting the ground part of air traffic 4D trajectories. When applied to ATM applications and services, our method will enhance timely operations in surface management and ATM decision making. It can decrease the effects of adverse winter weather to airport procedures and by that it will increase airport resilience, shorten delays and will also maintain safety of airport functions during winter weather cases. PNOWWA has developed and demonstrated the benefits of the very short-term (0-3h nowcast) probabilistic winter weather forecasting method, which is based on identification and extrapolation of the movement of weather radar echoes with 15min time resolution. The benefits of the PNOWWA nowcasting method were shown through two research demonstrations that were conducted both offline and online at Operative User Environment (OUE) sites at the airports of Innsbruck and Helsinki, representing the influence of the underlying terrain to forecast accuracy. An extensive user consultation survey among a number of airports and ATM stakeholders was performed to ensure the forthcoming products are suitable to be integrated in various applications on the ATM side. Based on the survey, majority of stakeholders see most potential for probabilistic weather forecasts to help render decisions objectively, and secondly by using them in decision support when cost-loss ratios are known. The achievements gained in PNOWWA contribute to all the SESAR Key Performance Areas except to 'Security'. The ATM Key Feature, which benefits mostly from PNOWWA is 'High-performing airport operations'. Based on the maturity analysis performed for PNOWWA project, it can be concluded that the PNOWWA project belonging to the Enabler METEO-04d has reached the maturity represented by Technology readiness Level 1 (TRL1 INTERMEDIATE). During the PNOWWA development process, needs to update the Enabler METEO-04d were found and update of the METEO-04d were suggested. The PNOWWA project roadmap towards implementation has connection points in future SESAR projects. The PNOWWA methodologies that were developed utilizing probabilistic radar-based nowcasting and tested in actual operational ATM environment

need to be brought up to higher TRL levels (next TRL2) for the benefit of ATM stakeholders and their operational activities.

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1 Executive Summary

The SESAR2020 exploratory research project called Probabilistic Nowcasting of Winter Weather for Airports (PNOWWA, grant #699221) developed methods to support the Air Traffic Management (ATM) challenged by winter weather. The project was running for two years from April 2016 until April 2018.

The principal PNOWWA methodology is based on probabilistic nowcasting of winter weather, which will enable the estimation of winter weather conditions affecting the ground part of air traffic 4D trajectories. This kind of ATM methods and tools are called for, because the uncertainties during flight, departure and arrival at airports create a need to effectively utilize probability forecasts, both in the local operational user environment and en-route.

The major scientific result of PNOWWA is the development of a new method for nowcasting snowfall based on extrapolation of movement analysed in consequent radar images, assessing the uncertainties of snowfall nowcasting related to growth and decay using the scale analysis and ensamble nowcasting technologies. Another major result towards operational implementation consists of two successful research demonstrations, where real-time nowcasts were delivered to a number of stakeholders in the airport environment. Mapping the user needs, the outreach and education of the users is the third cornerstone, building a solid base to be utilized when building more operational products in the future projects.

The PNOWWA research work has focused on the identification and quantification of the uncertainties related to delays in ground operations due to winter weather situations. When applied to ATM applications and services, our methods will enhance timely operations in surface management and ATM decision making, will increase airport resilience, shorten delays and will also maintain safety of airport functions during winter weather cases.

PNOWWA has demonstrated the benefits of very short-term (0-3h nowcast) probabilistic winter weather forecasts, which are based on identification and extrapolation of the movement of weather radar echoes with 15min time resolution. The PNOWWA project has shown the improved predictability of changes in snowfall intensity caused by underlying terrain, such as mountains and lakes or sea. This was performed through two research demonstrations that were conducted both offline and online at Operative User Environment (OUE) sites at the airports of Innsbruck and Helsinki, representing the influence of the underlying terrain to forecast accuracy. These demonstrations represented a major result towards operational implementation through the delivery of real-time precipitation nowcasts to a number of stakeholders in the airport environment.

An extensive user consultation survey was performed to ensure the forthcoming products are suitable to be integrated in various applications on the ATM side. The survey included mapping the user needs of stakeholders in the fields of ANS, ATC tower- approach, ACC, airfield maintenance, flight dispatching, exhibition management, meteorology engineering, aircraft pushback - towing and de-/anti-icing services and technics. It involved countries in the survey were Austria, Denmark, Finland, Germany, Norway and Switzerland. Various airport types were considered, like big hubs, small airports and even alpine airports with weekend traffic peaks due to winter charter flights.

Based on the survey, majority of stakeholders see most potential for probabilistic weather forecasts to help render decisions objectively, and secondly by using them in decision support when cost-loss ratios are known. A general positive and open attitude toward probabilistic forecasting and its benefits by respondents was evident. For most of the stakeholders this survey served as an informational and educational activity. This kind of outreach and educational aspect of PNOWWA serves the ATM community very well, when building a solid base to be utilized when building more operational ATM products in the future projects.

The PNOWWA project has tight links to completed work of the EU SESAR1 program. The initial concept of short-range snowfall forecasts improvement with the usage of weather radar has been validated in that context. The second phase solutions (Step 2: Trajectory-based Operations) will be developed in EU SESAR programs and the methods developed by PNOWWA can be utilized for deducing probability forecasts of winter weather.

The achievements gained in PNOWWA contribute to all the SESAR Key Performance Areas except to 'Security'. The ATM Key Feature, which benefits mostly from PNOWWA is 'High-performing airport operations'. Winter weather is a factor, which can cause non-nominal operating circumstances, and by probabilistic winter weather products, the risk for adverse weather causing disruption is known in beforehand. The achievements of PNOWWA can effectively be used in airport collaborative decision-making (A-CDM), in Operations in low visibility conditions (LVC) procedures and in Airport operations plan procedures. Collaborative airport and remote tower are development areas which in future could benefit from probabilistic winter weather information as well.

Based on the maturity analysis performed for contribution of PNOWWA project to Enabler METEO-04d, it can be concluded that the METEO-04d has reached the maturity represented by Technology readiness Level 1 (TRL1 INTERMEDIATE). During the PNOWWA development process, needs to update the Enabler METEO-04d were found and update of the METEO-04d were suggested.

One major PNOWWA success enabler is the fact that the PNOWWA project team is exceptionally interdisciplinary. The team includes people who are thoroughly experienced in ATM-related activities, as well as scientists with academic merits. This was crucial for the success of the project. A team consisting of scientists only would not have succeeded in getting the needed connection and cooperation with the stakeholders at the ATM field.

The PNOWWA project roadmap towards implementation has connection points in future SESAR projects. The methodologies that were developed utilizing probabilistic radar-based nowcasting and tested in actual operational ATM environment need to be brought up to higher TRL levels. The first next step on this should be an applied research project to bring the PNOWWA methods up to TRL level 2.

2 Project Overview

2.1 Operational/Technical Context

To improve the European aviation system it is recognised that the provision and use of enhanced meteorological capabilities and their integration to ATM planning processes is key, especially in terms of safety and efficiency. As far as disruptive events in winter are concerned, improvements in Total Airport Management (e.g. de-icing) and remote tower activities planning and enhancements in runway throughput (low visibility procedures) and capacity/demand balancing are required. There is a need to investigate the reduction of the vulnerability of ATM operation planning related to winter weather phenomena predictability. Probabilistic nowcasting of winter weather for airports generates such information which can be utilized in ATM planning processes in the time scale of 0-3h. Probabilistic forecasts are also of great interest in the concept of 4D trajectory planning and execution.

To provide better tools for the ATM decision makers, three components are needed:

- knowledge of user needs: parameters (visibility, type of precipitation, intensity or snow depth), thresholds (how heavy is "heavy snowfall") and representation (how to link to visualization);
- probability distributions of different snowfall intensity classes;
- quantified effect of underlying terrain enhancing the approaching snowfall (e.g. mountains, open sea and rivers).

For the needs of different users, the snowfall intensity can be used as basis of forecast of visibility or accumulated snowfall, typically as probability of belonging to some category (moderate or severe snowfall).

Probability distributions of snowfall intensity for 0-3h period, in steps of 15 minutes, are based on extrapolation of movement of weather radar echoes. Echo movement can be determined by different methods.

The probabilistic nowcast approach quantifies the uncertainties of a (deterministic) nowcast. For example, instead of the nowcast “intense snowfall at Heathrow in 30 minutes,” the probabilistic nowcasting process may take into account potential sources of uncertainty and state “70% probability of intense snowfall at Heathrow in 30 minutes.” This type of statement acknowledges that there is always a level of uncertainty in a nowcast. Furthermore, if the applied probabilistic forecasting model is well designed, the produced probability nowcast can be statistically more accurate than a deterministic one, and thus produce better results when integrated in automatic decision making systems.

2.1.1 Background information and co-operation

Steering group of the PNOWWA as a whole played an important role in giving guidance for the project team in terms of radar science and the practical meteorological needs of the airport stakeholders. The head of the steering group, V. Chadrachekar was a key person in providing a state of the art scientific knowledge and enabled the PNOWWA nowcasting system developer, Dr.

Pulkkinen's, one year exchange visit to Colorado State University radar science team. Specifically, Tarja Riihisaari provided a highly useful inside into the operational meteorological systems and tools, by this way assisting the project PNOWWA teams development efforts.

2.1.1.1 Co-operation with other projects

PNOWWA has done co-operation with the following ongoing (at the time of the PNOWWA project) projects:

- European radar project OPERA
  - The objectives of OPERA are:
    - to provide a European platform wherein expertise on operationally-oriented weather radar issues is exchanged;
    - to develop, generate and distribute high-quality pan-European weather radar composite products on an operational basis.
  - FMI is currently acting as a project management organization, Dr. Elena Satikoff (PNOWWA WP and Science Manager) as a project manager.
- EU H2020 ANYWHERE
  - The focus of the EU –funded project ANYWHERE (EnhANcing emergencY management and response to extreme WeatHER and climate Events, 2016-2019) is to develop tools to support real-time coordination of the emergency response operations in extreme weather and climate events. In ANYWHERE a platform with early warning and decision support systems is employed during the project covering regionally the Pan-Europe. The project utilizes already developed products and algorithms by the consortium partners, and in the case of FMI, few of the used products are related to PNOWWA. These products are object-oriented nowcasting tool for severe storms, probabilistic precipitation type and snow load forecasting products. The co-operation of the PNOWWA is constructed upon in the development and testing of these products in a different user environment.
- EU H2020 SMUFF
  - The SMUFF (Seamless probabilistic multi-source forecasting of heavy rainfall hazards for European flood awareness, 2018-2019) is funded by the European civil protection. The objective of this project is to develop improved tools for assessing and forecasting the hazards and risks induced by intense rainfall and severe storms (e.g. flash floods, urban floods, landslides). The idea is to improve a radar- and NWP-based precipitation forecasting methods for now- to short time range (15 minutes-5 days) and transforming the forecasts into flash flood hazard and risk predictions. Although the SMUFF is concentrating on severe convective storms typical for summer weather, the developed nowcasting methods are similar to the PNOWWA. The novelty in SMUFF is the European-scale blending of radar-based nowcasting and NWP models, which can be applied to the possible future projects.
- EU H2020 ERICHA
  - ERICHA (Integrating a European Rainfall-InduCed Hazard Assessment system, 2016-2017) is a continuation to previous projects, HAREN and EDHIT, for building a

platform for precipitation hazard assessment at European scale for severe storm events. The radar mosaics produced by the EUMETNET project OPERA combined with the continental lightning observations is constructed to monitor the precipitation field over Europe. In this context the ERICHA was part of the integration of the developed radar products into the real-time operational platform of the European Flood Awareness System (EFAS), which provides direct support to the European Response Coordination Centre (ERCC) of the DG ECHO, as well as to a large number of European Water Agencies and many national civil protection agencies.

2.1.1.2 Background information projects

The following already ended projects have been utilized as a background for the PNOWWA project:

- EU HAREN and EDHIT projects
  - FMI nowcasting concept has been demonstrated utilizing pan-European OPERA radar composites in European civil protection projects HAREN (Hazard Assessment based on Rainfall European Nowcasts, 2012-2013) and EDHIT (European Demonstration of an enhanced rainfall and lightning induced Hazard Identification nowcasting Tool, 2014-2015).
- WxFUSION
  - DLR has executed a WxFUSION project for Nowcasting winter weather at Munich airport
- MET4LOW
  - Austro Control project with national funding which deals with airport capacity related to weather started in September 2015IPR W (MET Potential for Arrival and Departure Management)
- SESAR 1 Project 11.02.01, SESAR 1 Project 11.02.02 and SESAR WPE project ONBOARD (E02.04)
  - PNOWWA project feeding the probabilistic aviation forecasts
- Snow Experiment of BAECC- campaign 2014
  - BAECC (Biogenic Aerosols–Effects on Clouds and Climate) – campaign took place at University of Helsinki research station, in Hyytiälä Finland. During the campaign the U.S. Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Program deployed their Second ARM Mobile Facility (AMF2) in Hyytiälä for an 8-month intensive measurement campaign from February to September 2014. The snowfall measurement experiment (BAECC SNEX) took place from 1 February to 30 April 2014 and was dedicated on documenting snowfall microphysics through a combination of multi- frequency (C, X, Ka, and W band) radar, microwave radiometer, and lidar measurements supplemented by a comprehensive suite of surface-based precipitation observations. FMI being part of the campaign, is also participating in the research for improving the understanding of the connection between snowfall microphysics with the remote sensing observations. The goal of the studies is to improve the radar-based nowcasting of snowfall with improved

conversions between scattering properties of snow particles and the measured precipitation rate.

- EU FP6 project FLYSAFE 2005-2009
    - Austro Control and DLR were partners in project, which is the baseline for all the later projects aiming to provide ATM the necessary meteorological data to improving safety.
- SESAR1 WP11.2
    - FMI developed STEP 1 (Time Based Operations) winter weather solutions to local Operative User Environment (OUE), especially for the runway conditions.

2.1.1.3 IPR implementation

The project has an Intellectual Property Management Plan [1]. The IPR management of the project follows the guidelines stated in the DESCA (Development of a Simplified Consortium Agreement) specifically designed for Horizon 2020 "Research and Innovation Actions" and "Innovation Actions".

2.1.1.3.1 General intellectual property management approach overview

The general approach to the project IP management is that all

- software tools,
- scientific models and
- generated products

that are developed in the frame of the project will be released under an open source license for other scientific communities to be able contribute and add to the tools after this project as seen fit by the community.

The project consortium encourage the scientific and engineering community, as well as additional small to medium sized companies to take part in further developing the models and other software modules and create more advanced products and services exploiting the data, tools and software made available via this project.

2.1.1.3.2 Intellectual Property Generated as a Result of the Project

If any Intellectual Property protected by patents etc. are generated as a result of the project, the project has an IPR strategy and procedures that will be implemented. Existing, pre-project, organisation or company IPR rights or patents remain as such after the project unless otherwise agreed. All project related IP patent etc. applications shall follow appropriate rules, regulations and laws (international, EU and/or local). The public use and availability of the IPR protected property after the end of the project shall be negotiated between the SJU officer’s and owner(s) case by case basis.

The baseline of the project IPR management is that possible IPR protected project products are to be licenced for any interested operator with reasonable cost after the project. The license/patent owner(s) may grant a permit for private or public educational institutions to use the project Intellectual Property on a royalty-free basis for research and education, but not for commercial purposes, subject to confidentiality requirements.

During the project there were no any new IPR products generated on the top of the background IPR's that should undergo the IPR procedures as described in the project IPR management plan.

2.2 Project Scope and Objectives

2.2.1 PNOWWA project scope

The specific scope of PNOWWA project was to investigate reduction of the vulnerability of ATM operation planning related to winter weather phenomena predictability.

Special interest was focused on mountainous and seaside ATM operation, due to challenges created by underlying terrain to nowcasting. In addition, usage of probability forecasts in several levels of ATM operations management was identified and promoted. Probabilistic weather radar data usage in 4D trajectory planning in network scale was also discussed.

In SESAR programs, solutions to ATM (Trajectory-based Operations) are developed. For this, probability forecasts of winter weather are needed. This was supported by PNOWWA as one the scopes of PNOWWA project was to conduct necessary research needed to be capable to develop the local scale winter weather products to 0-3h timeframe. The applications of that research could be used in SESAR2020 Industrial Development and Validation project.

2.2.2 The specific overall objectives of PNOWWA project

PNOWWA project overall objectives were:

1. to develop a method for probabilistic 0-3h forecasts ("nowcasts") of snowfall and freezing rain at airport, in steps of 15 minutes
2. to improve our understanding, and hence predictability, of changes in snowfall intensity caused by underlying terrain (such as mountains and sea)
3. to identify and promote the potential for use of probability forecasts in variety of airport activities
    a. Total Airport Management (de-icing, Airport demand and Capacity Balancing, AirPort Operations Centre (APOC) runway maintenance)
    b. Enhanced Runway Throughput (low visibility procedures)
    c. Remote tower activities
    d. Capacity balancing of Network (comparing probability of snowfall at all the airports in the network)
4. to make research demonstration of probabilistic winter weather product to show its potential for increasing the resilience of ATM system to winter weather.

2.2.3 Detailed project objectives in work package level

Work package 2 - Probabilistic winter weather prediction

- Calculate motion vectors of precipitating areas and estimate their uncertainty
- Provide real time forecast of probability distribution of precipitation intensity for WP5
- Optimize forecast by verification in winter conditions.
- Provide measure of predictability for WP5 and WP3

Work package 3 - Winter weather forcing

- Improving the nowcasting of snowfall intensity
- Assessing predictability of motion-vector nowcasting
- Increasing understanding of effect of mountains and sea to the snowfall intensity
- Providing conversion formulas for snow measurements by radar

Work package 4 - Assessment of the potential of the ATM tools and roadmap generation

- Identify potential users for probability forecast products of precipitation at airport environment.
  - Map the user needs and study what kind of solutions probability forecast products of precipitation could give to them.
  - Raise awareness of possibilities the probability forecast products of precipitation could give for improving the efficiency of existing and future processes at airport environment.
  - Demonstrate how developed probability forecast products of precipitation could support Total Airport Management.
- Survey via internet
- Individual stakeholder interviews
- Demonstration campaign winter 2017, 2017/2018

Work package 5 - Tools enhancing meteorological support for ATM decision making process

- Develop algorithms and software to generate user-friendly quantities from radar measurements.
- Classify the weather by thresholds for runway maintenance, de-icing and tower.
- Demonstrate product distribution to users.

Work package 6 - Demonstrators and data dissemination

- Test the concepts developed in the other work packages
- Collect feedback from test users and forecasters

Work package 7 - SESAR2020 interaction and outreach

- Raise awareness of SESAR2020 community on PNOWWA work and results
- Get input and feedback from developments in SESAR2020,
  - Especially from Project PJ.18 “4DTM”, Solution 04 “AIM & MET Information Services”
- Provide understandable reports and news reports for the society

2.2.4 Methods for PNOWWA project achieving the objectives

PNOWWA developed very short-term (0-3h, "nowcast") probabilistic winter weather forecasts in 15min 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). Research demonstrations were conducted both offline and online at the Local Operative User Environment (OUE) site representing influence of the underlying terrain to forecast accuracy. An extensive user consultation analyzed needs to ensure products are suitable to be integrated in various applications on the ATM side. The adjustment to user needs covered the most relevant parameters (visibility, intensity and snow depth) and operationally important thresholds of the selected parameters (e.g. heavy snowfall).

The PNOWWA project developed the methods for deducing probability forecasts of winter weather. These results may also contribute to the achievements of the objectives of the SESAR2020 Industrial Projects. PNOWWA project will also deliver a roadmap towards implementation with connection points in future SESAR projects.

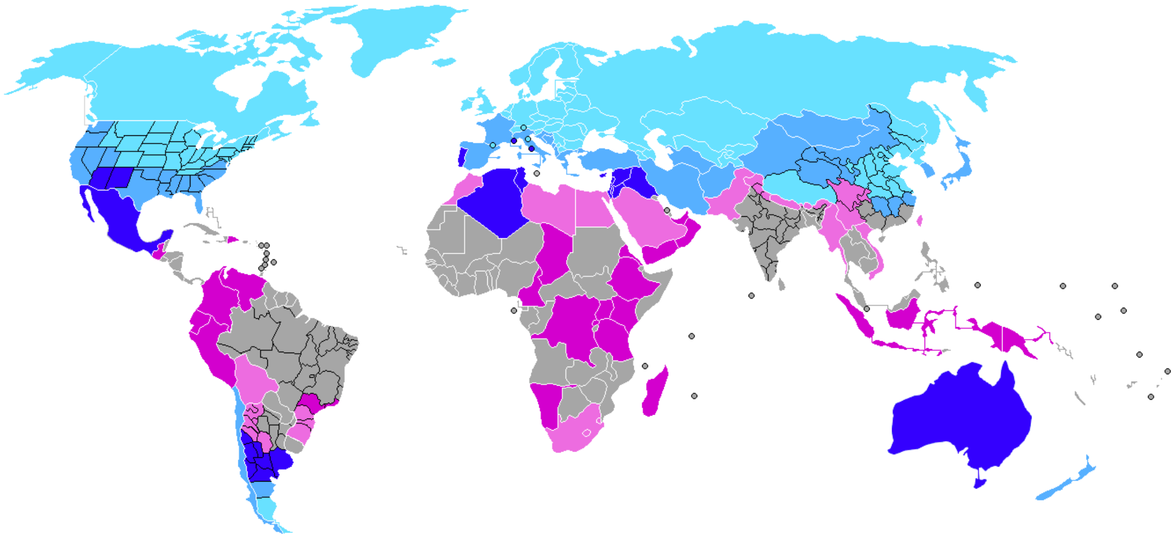

Figure 1: Map of countries receiving snowfall by Fábio Soldá Barbosa Araujo, 2006.

Snow in all of its territory.
Snow below 500m over sea level, but not in all of its territory (esp. in some coastal and/or desert areas)
May snow below 500m over sea level, but rarely.
Snow only above 500m over sea level.
Snow only above 2000m over sea level.
Without snow.

2.3 Work Performed

Work Package 1: Management

WP1 initiated the project office and day-to-day management structures. WP1 assisted the beneficiaries in their management and dissemination issues by providing space for the website server (http://pnowwa.fmi.fi) and setting up the internal communication channels (e.g. intranet for the internal documentation). WP1 assisted in preparation of all deliverables stated for the project. Management WP1 was responsible for the preparation of the Periodic Reports and Final Report [2] of the PNOWWA project. WP1 was also responsible for the communication between the project office/PNOWWA consortium and SJU. As WP8 "Ethics requirements" [31] [32] [33] [34] was part of the management activities of the project, WP1 was responsible for WP related deliverables and work.

In addition, the Management WP1 monitored and managed the following project tasks daily as part of the project work:

- Documentation management (e.g. deliverables)
- Risk management (identifying the possible risks and maintaining the risk matrix)
- Configuration management
- Quality assurance and management (e.g. ethical issues and questions)
- Day-to-day management (e.g. financial issues support, secretarial services, etc.)

Work Package 2: Probabilistic winter weather prediction

In **WP2** a new innovative nowcasting system was developed [3] [4] [7], partially based on the STEPS methodology, but suitable in FMI environment and modified to serve the purposes of wintertime forecasting. Python and R verification libraries were used to assess the quality of the forecasts.

The first version of the system was only able to produce forecasts for one hour with the available computing resources, but optimization and new memory management approaches lead to software able to calculate 3h forecasts.

The reliability of nowcasts was mainly verified by comparing them to actual radar images. Comparison to ground-based measurements was limited to a few case studies.

In the PNOWWA research demonstrations, point forecasts for selected users were the main focus. In the workshop organized after the second research demonstration, the stakeholders expressed need for areal products "to see the bigger image". Some attempts for such products are in Figure below. This is a very promising area for further development.

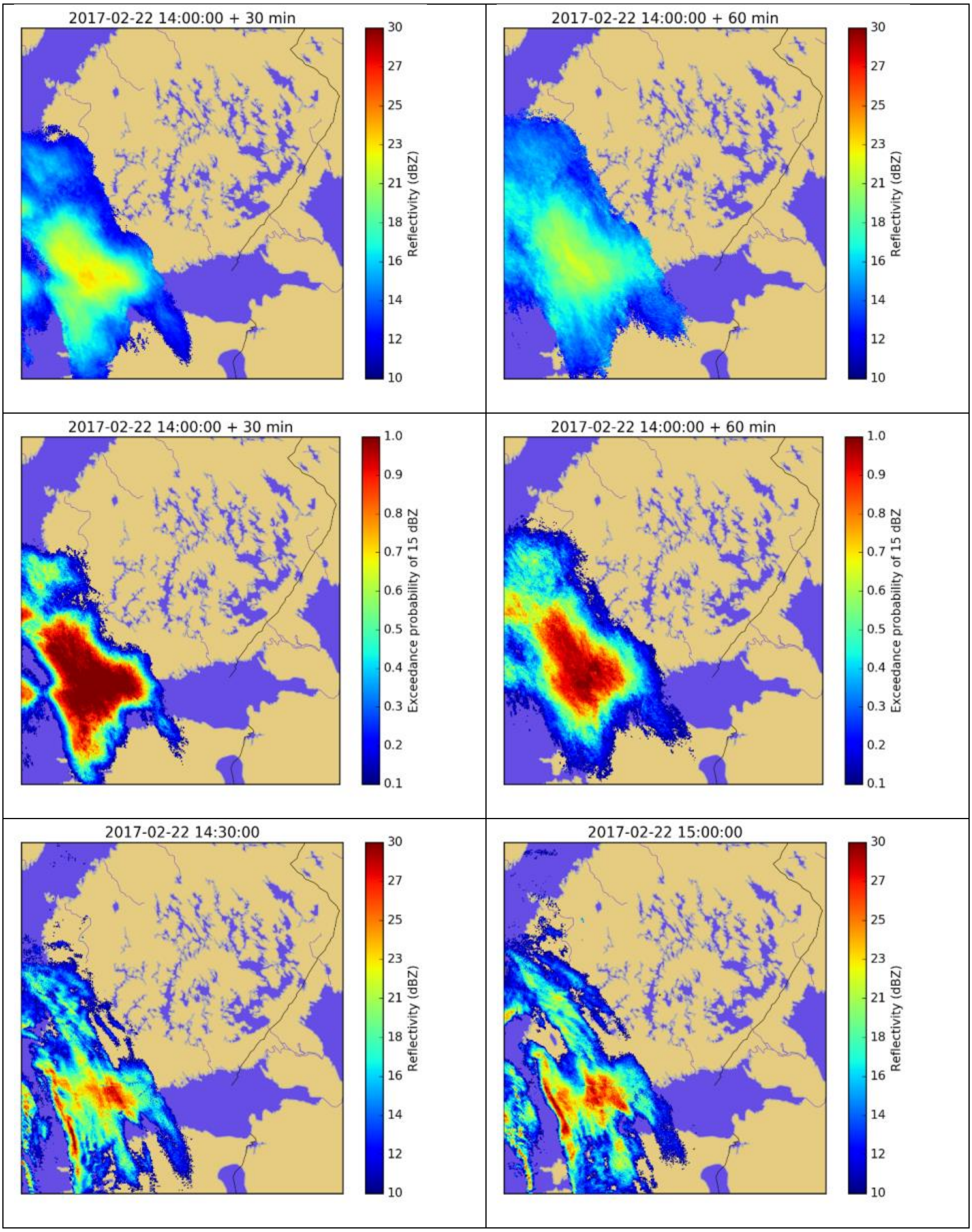

Figure 2: Different forecast visualizations.

In the Figure 2 above are the different forecast visualizations. For 30 min (left) and 60 min (right) lead times with the Stochastic ensamble method. The image on the top tells the most probable precipitation intensity in each point, calculated as an average of the 51 slightly different forecasts contributing to the ensemble. The image on the middle row shows the areas, where the probability of significant snowfall (over 15 dBZ) is most likely. These two visualization approaches can also be used for other weather phenomena, for example thunderstorms. The lowest panel is a verifying radar image.

The image on the top tells the most probable precipitation intensity in each point, calculated as an average of the 51 slightly different forecasts contributing to the ensemble The images in the middle show the areas, where the probability of significant snowfall (over 15 dBZ) is most likely. The image on the bottom row shows actual radar image for verification. These two visualization approaches can also be used for other weather phenomena, for example thunderstorms.

Work Package 3: Winter weather forcing

In **WP3**, effect of orography (mountains, hills and the open sea) to the snowfall was studied mainly as case studies [10] [11] [12]. Andersson method was implemented to German weather radar data to assess the atmospheric conditions favourable for nonlinear movement of the precipitation systems at the Alps. An example for the Andersson method is shown in Figure 3. Due to the proximity of the Alps (app. 80 km south of airport) the linear propagation of the front was slowed down. Also, the intensity of the precipitation rapidly decreased. This did result in an unexpected weakening of precipitation at Munich airport and thus a wrong forecast for times beyond 60 minutes.

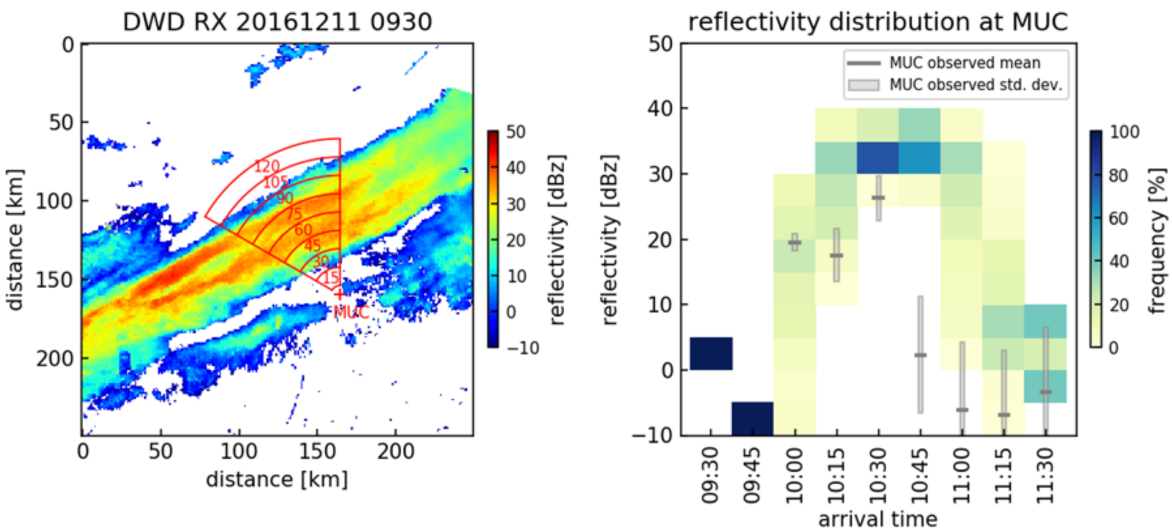

Figure 3: Example of the application of the Andersson method on 11 December 2016 09:30 UTC for Munich airport.

On the figure 3 above, on the left is radar image from DWD showing reflectivity. The sectors indicate the distribution of reflectivity which is assumed to arrive at Munich airport within the indicated times (minutes). On the right is probability forecast of reflectivity for the next 2 hours. Colors indicate frequency of reflectivity estimate; gray bars indicate distribution of observed reflectivity at airport area (25 km2).

22 cases from the winters (December - March) 2013-14, 2014-15, 2015-16, and 2016-17 (April) were investigated where cold fronts did approach the Alps in the Munich/Salzburg region. In about half of the cases the fronts did pass the Alpine Foreland without noticeable delay, whereas the other cases showed considerable delay of the frontal motion leading to long lasting precipitation events. The duration of the events was between 8 and 46 hours. Figure 4 (left) shows the distribution of the events in relation to the approaching direction of the frontal systems. To find relations between flow and behavior the wind profile as measured by the radio sonde München-Oberschleißheim (located in the Alpine foreland about 50 km north of the Alps) was investigated.

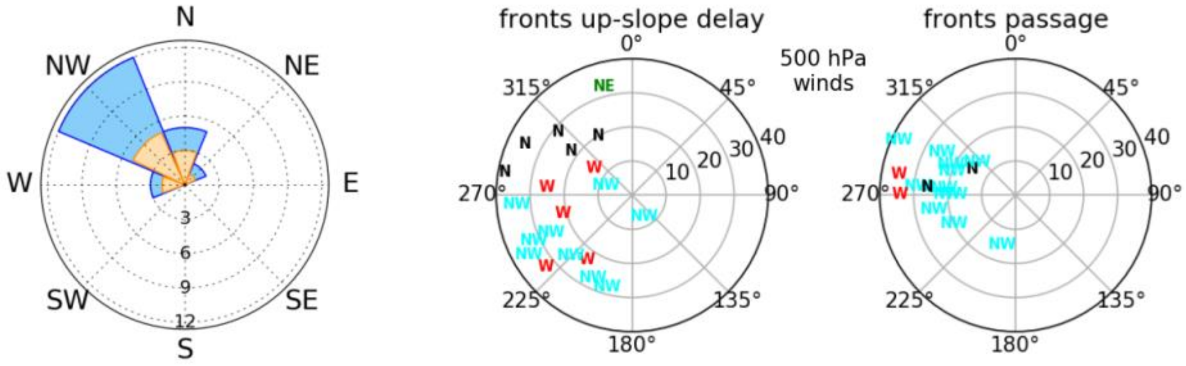

Figure 4: The distribution of the events in relation to the approaching direction of the frontal systems.

On the figure 4 above, on the left is distribution of arrival directions for fronts (blue total number) passing the Alpine Foreland without delay and with up-slope delay (orange). On the center and right are wind direction and speed (markers) as measured by München-Oberschleißheim radio sounding during the events. Letters of markers indicate the arrival direction of the fronts.

Due to the complex interaction between even large scale atmospheric flow and the Alps the predictability of precipitation does not reach the values as were observed in WP2 for airports in flat regions.

Another part of WP3 was development of conversion equations from the reflectivity (measured radar parameter) to liquid water equivalent, snow depth and visibility (the parameters used in different ATM activities) [11]. In addition to first guesses based on the existing literature and statistical analysis, PNOWWA students participated in field campaigns with their universities

Work Package 4: Assessment of the potential of the ATM tools and roadmap generation

In **WP4** the user needs were mapped with an online survey and deep one-to-one interviews after that [12]. Meetings with professional of many different activities at airports of Vienna, Helsinki and Rovaniemi were used to raise awareness of possibilities the probability forecast products of precipitation could give for improving the efficiency of existing and future processes at airport environment.

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 Nowcasting 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.

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 cannot express.

The ATM tower/approach 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. 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.)

An extensive user consultation via web-survey was performed to focus on user needs such as parameters and thresholds (Figure 5) and to ensure products which are suitable to be integrated in various applications on the ATM side.

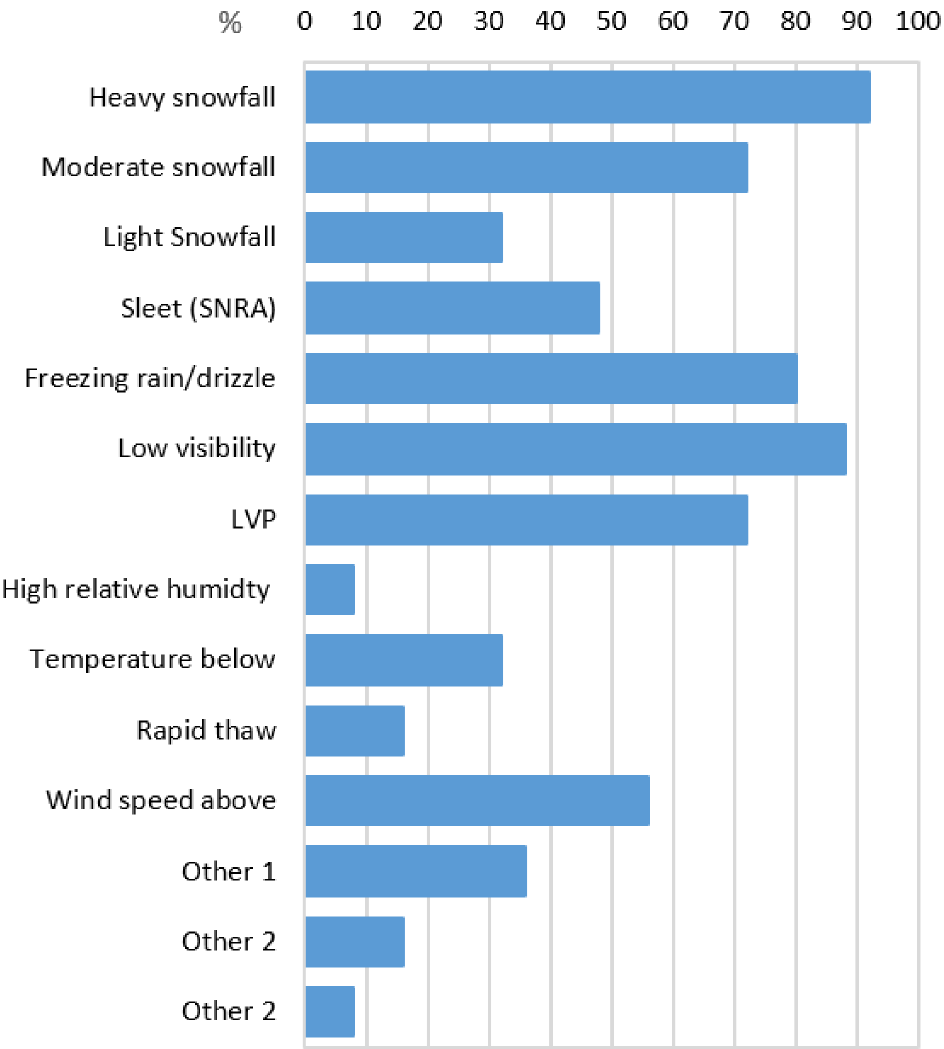

Figure 5: User consultation via web-survey to focus on user needs such as parameters and thresholds.

On figure 5 above is the relative number of responses which show the type of winter weather affecting airport operation, and requires early mitigating actions. Total number of respondents was 25.

Beside the nowcasting lead time of 3 hours (Figure 6, X-axis shows the relative number of responses), 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.

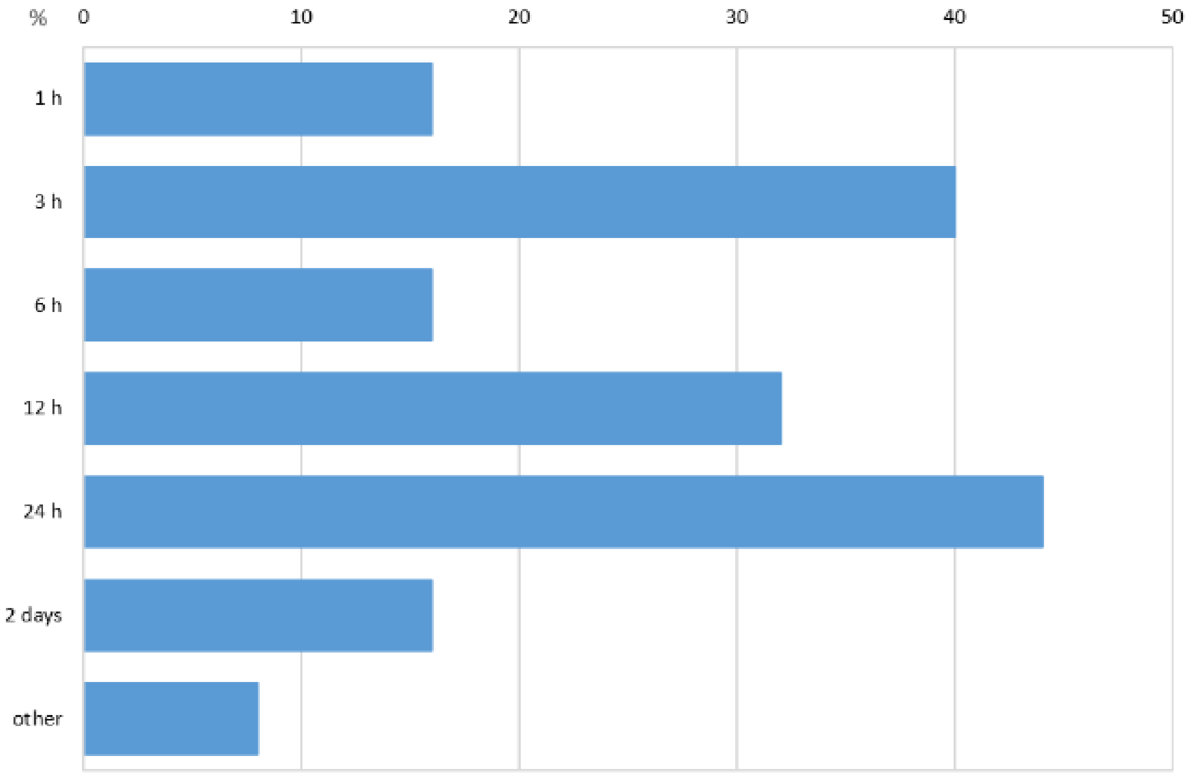

Figure 6: Useful lead time for warning of critical weather.

To define impact mechanisms between winter weather probability product and airport operations, on 4th October 2016 a workshop was held at Vienna airport with stakeholders (ATM, airport operation, airliners).

After presentation of the PNOWWA project and the planed demonstrator product, we discussed and promoted probability forecast information for airport operation during winter. The nowcasting interval of few hours fits well for planning short term actions like ATM APCH/TWR, de-icing or RWY clearance. The stakeholders mentioned the complex system and complex interaction between different departments / companies and different winter weather aspects. Preventive actions, were probabilistic forecast might help, are most important for FZRA [16].

Actual procedures between different companies work well during winter weather events, therefore concerns and resistance were raised during the discussion. But the 2 winter for PNOWWA demonstration gave the opportunity to show concrete and practical examples as well as online products to test during winter conditions at airports

Detailed definition of snow accumulation thresholds and visibility classes were clarified in separate meetings after the workshop with runway operations and ATM for Vienna, Innsbruck, Helsinki and Rovaniemi airports before first demonstration phase started.

The online service with automatic update (15min) delivers tailored products to runway maintenance, de-icing agents and ATM tower/approach as well airliners with pre-defined probabilities of the weather categories. Forecasted parameters were accumulation of dry and wet snow, probability of freezing rain, probability of freezing wet runways, de-icing weather categories and decrease of visibility caused by snow. Detailed accumulation classes can be seen in Figure 7 (provided via web page for different stakeholders at Finnish airports.).

FMI Ilmanet | Finavian testikäyttäjä

Winter weather forecast for airports

EFHK | EFRO

Kaikki SESAR-2020 PNOWWA -projektissa kehitetty tieto ja tuotteet on kehitetty pelkästään tieteelliseen tutkimustarkoitukseen. eikä niitä pidä käyttää missään olosuhteissa operatiiviseen palveluun. Näitä tietoja ei ole validoitu tai hyväksytty sellaiseen käyttöön. Palvelun ja tiedon tuottajat eivät ole missään vastuussa palvelun sopimattomasta tai luvattomasta käytöstä tai niiden aiheuttamista asioista.

All data and products developed by the SESAR-2020 PNOWWA Project are developed purely for research purposes and shall not be used under any circumstances for operational purposes, as they have neither been validated nor designed for such use, and the authors decline any responsibility for inappropriate and unauthorized use.

Alle Daten und Produkte, die im Rahmen des SESAR-2020 Projektes PNOWWA entwickelt wurden und werden sind nur für wissenschaftliche Zwecke gedacht, und dürfen unter keinen Umständen für operationelle Zwecke verwendet werden, da sie weder dafür validiert noch designt wurden, und die Autoren jede Verantwortung für missbräuchliche Verwendung ablehnen.

RUNWAY MAINTENANCE (UPDATED 2017-02-22 16:15:00 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	60	10	0	0	0	0	0	0	0	0	0	0	0
1-5 mm	40	90	100	70	30	40	40	50	40	30	30	30	30
less than 1 mm	0	0	0	30	70	60	60	50	60	70	70	70	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 16:15:00 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	60	10	0	0	0	0	0	0	0	0	0	0	0
2	40	90	100	70	30	40	40	50	40	30	30	30	30
1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	30	70	60	60	50	60	70	70	70	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 16:15:00 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	60	10	0	0	0	0	0	0	0	0	0	0	0
VIS 1500-3000 m	40	90	100	70	30	40	40	50	40	30	30	30	30
VIS over 3000 m	0	0	0	30	70	60	60	50	60	70	70	70	70

Figure 7: Example of the online demonstration.

For LOWW runway clearance an impact based matrix were generated to combine both, likelihood of event with impact in one colour code for easy application (Figure 8).

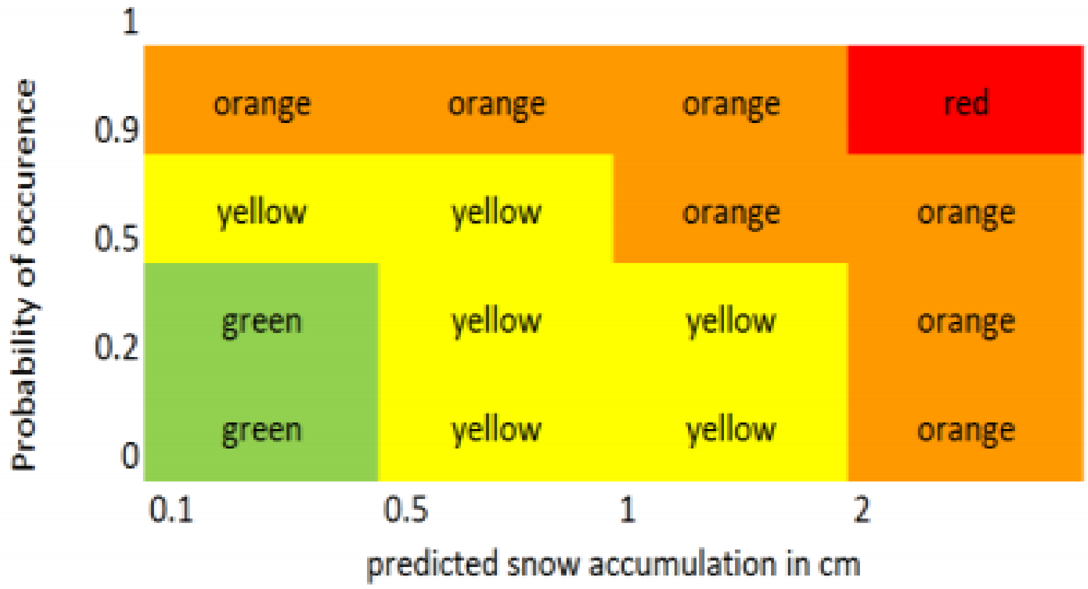

Figure 8: Risk categories for Vienna airport given sets of snow accretion depth and probabilities of airline users.

In the figure 8 above, the X-axis shows the impact to airport runway clearance and y-axis the likelihood of occurrence. (Green colour is assigned to non-adverse winter weather, yellow means be aware, orange be prepared and red stands for take actions)

User opinions were collected during and after the two demonstration campaigns from two Finnish and two Austrian airports for demo1: February-March 2017 and demo2: December 2017 – February 2018.

Additional, a questionnaire survey was used to collect user feedback after demonstration phase 1 in structural way [15].

The PNOWWA demonstration product showed principal applicability and reliability of the short term winter forecast quality during the two demonstration campaigns. Stakeholders saw the potential and benefit of probabilistic weather forecast to help render decision more objective at a glance. But further user training and information is necessary. The definition or calibration of the proper thresholds of probability for each class is essential, when different user preparation depends on event, likelihood, and air traffic. Additional those actions are overlaid by safety priority in aviation and the complex interaction between different airport operations e.g. the use of very low probabilities for low snow fall heights caused high consumption of chemicals for runway maintenance for ordinary snow events. This point out the need for proper adjustment of used probabilistic classes and the gathered feedback of individual colour coding of the product.

A change from most probable class to exceedance of probability was introduced for the second demo, which might be more useful because of the stronger effect of highlighting of adverse winter weather in the PNOWWA product. Most probable class showed the mean of an ensemble, while the exceedance of probability will show the percentage of ensemble for all different classes, even lower probability values for severe events.

Stakeholder requested additional information of cloud ceiling, longer lead time and to include all weather elements such as e.g. fog or drifting snow in an entire decision support system, but those points are beyond the PNOWWA product which is designed for short term nowcasting of winter weather using weather radar data only. Easy graphical layout could increase the applicability of probability products – such e.g. impact based matrix colour code (Figure 8) and mobile app.

Forecast quality worked well in quantity and timing, but for few cases we got feedback about underestimation of visibility reduction (and considering fog and blowing/drifting snow), technical issues of product availability and sensitivity in using proper surface temperature for estimation of freezing wet surfaces and discrimination of wet and dry snow. Especially for mountainous areas forecasted events lasted not long enough.

Additional, we got technical feedbacks, such as reference time and product information has to be included into the web page and auto updating is needed. These issues have been solved for the second demo campaign.

Beside demonstration, presentation and direct contact to stakeholders, a PNOWWA workshop in Vienna (27-28th February 2018) brought together airport stakeholders and scientists of other SESAR projects to discuss and raise awareness of the use of probability in nowcasting of winter weather for airports.

The main objectives have been a) to present PNOWWA concept, methods, feedback and results of the demonstration phases and survey, b) promote probabilistic weather information within aviation community, c) discuss PNOWWA results and collect further feedback for roadmap toward future application for each stakeholder, d) strength cooperation and exchange and e) planning follow-up projects.

Participants of the workshop came from ATM, airport runway maintenance, airport de-icing, airliners flight planning, pilots, weather services and scientists from other SESAR projects.

Potential of probability nowcasts of adverse winter weather are seen for pre-emptive actions on runway maintenance and new procedures of deicing. ATM impacts have to be further investigated by simulations. Higher potential for new application of probability forecasts was seen for tactical planning of airport operation and especially for flight planning.

Conclusion of the workshops and feedback interviews lead to following findings and future possibilities of probabilistic forecasting [17].

The use of seamless probabilistic weather forecasts will increase the resilience of airports. Users will be affected in different manner, focusing on individual aspects. Nevertheless, total airport handling taking into account the complex interactions between different stakeholders, traffic, workload, safety, economic and environmental aspects as well as pre-event conditions.

While ATM procedures for probabilistic forecasts has to be developed (e.g. using simulations), airport operators (runway clearance and de-icing) and airliners can directly use improved probability forecast using proper threshold for different weather elements related to precipitation such as thunderstorm activity or winter weather forecast.

As an outlook, graphical information should be more user friendly and also providing spatial information of probability and beside that for flight planning European wide product should be made available for all airports and additional parameters has to be included such as probabilities of low visibility and ceiling.

The PNOWWA demonstrator was developed within SESAR H2020 fundamental exploratory research program. Further work is needed to reach higher maturity levels and to generate an experimental product for future operational application used by airport stakeholders. The roadmap for future operational application suggest the integration of additional forecast parameter (ceiling, reduced visibility due to fog, …) and the extension of lead time up to 2 days. In close cooperation with air traffic management, de-icing and runway maintenance the impact on airport operation has to be defined with respect to probability classes. From user perspective, in the future also summer weather has to be included, which results in one probabilistic forecast system to predict all weather elements relevant for airport handling.

An overview of the roadmap of probabilistic winter weather forecasts for airports including previous mentioned new applications and modifications is given in Figure 9 (see next page) [18].

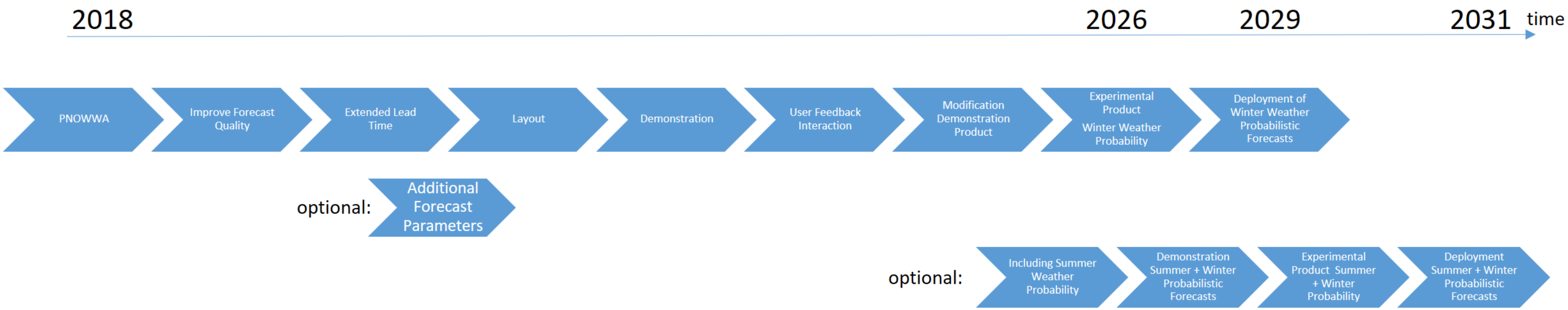

Figure 9: Overview of the roadmap of probabilistic weather forecasts for airports.

Starting from 2018 (end of PNOWWA project) until 2026 for development of the experimental product (up to technical readiness level of 6) and following by deployment phase of probabilistic winter weather until 2031 with optional project phases a) including additional forecast parameters and b) including summer weather probabilistic forecasts for thunderstorms occurrence (technical readiness level 7).

The maturity gates within the roadmap [18] are the demonstration and positive user feedback after extension of the lead time, implementation of additional forecast parameters and change of the layout. Additional the user feedback lead to modification of the experimental product.

Work Package 5: Tools enhancing meteorological support for ATM decision making process

In **WP5** algorithms and software for scientific demonstration was developed [20] [21], and in **WP6** the product was delivered to selected representatives end users [22]. In the demonstration it was demonstrated probabilistic very short range (0-3h) precipitation forecast to airport runway maintenance, de-icing agents and tower.

Possible methods to extrapolate weather radar pictures in near future are described in D5.1 "PNOWWA Detailed methods" [20]. One of them called Anderson method was used in demonstration. Main principle of Andersson method is that it is estimated that 850 hPa wind in atmosphere will move the precipitation areas. Uncertainty to precipitation forecasts rises from the fact that we can't exactly know direction and force of wind and there is also other factors influencing to that movement. Other two methods may give more realistic movement and development of precipitation areas, but there is needed more work in coming research activities before them could be demonstrated.

The different type of snow causes different actions in runway maintenance. That is why in PNOWWA demonstration dry and wet snow accumulations are forecasted separately. A simple method for determining the snow type is used here, see table below.

Table 1: A simple method for determining the snow type.

Type	Temperature	Dewpoint
Dry snow	T<=M0	TD<=M1
Wet snow	M0<T<=3	TD<=0
Rain	T>3	TD>0

The first real-time demonstration campaign organized at four airports: Helsinki-Vantaa, Rovaniemi, Vienna and Innsbruck in February and March 2017 and the second at these four and Munich airport between December 2017 and February 2018.

The forecasts were delivered to pilot users at airports. A web-based user interface was developed to display the forecasts. The campaigns were successful, the components developed in different work packages and the components from existing FMI production chain worked seamlessly together.

Work Package 6: Demonstrators and data dissemination

Technically demonstration worked very well. **WP6** collected user feedback during and after the demonstrations and them will be taken into account in further developing phases of probability winter weather development.

EFHK | EFRO | LOWI | LOWW | EDDM

RUNWAY MAINTENANCE (UPDATED 2018-01-24 08:00:00 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
over 5 mm	0	0	0	0	0	0	0	0	0	0	0	0	0
over 1 mm	100	80	70	80	50	20	20	30	30	20	10	20	20
less than 1 mm	0	30	30	20	50	80	80	70	70	80	90	80	80
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
over 3 mm	0	0	0	0	0	0	0	0	0	0	0	0	0
over 1 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 2018-01-24 08:00:00 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	100	80	70	80	50	20	20	30	30	20	10	20	20
1	0	0	0	0	0	0	0	0	0	0	90	80	80
0	0	30	30	20	50	80	80	70	70	80	0	0	0

Figure 10: Example of user view of runway maintenance and de-icing agent products.

In the figure 10 above is shown the snow accumulation and probability of freezing rain is forecasted. Similar type of product was delivered to Tower. In that the decrease of visibility caused by snow was forecasted, but effects of for and drifting snow was taken into account.

The accumulation rate of snow/15 min time period at 15 min time step was forecasted 3 hours ahead. The rate was forecasted in classes. The thresholds between classes are based on the information got from users and they are defined so that the products helps user to plan their actions. During first demonstration it was forecasted the probability of each class of accumulation, but during second one the exceedance probability was forecasted. That mean it was forecasted the probability that accumulation exceeds the threshold.

For quality control of the delivered product, time series were produced of nowcasts of different lengths (Figure 11) and of different forecasted intensity classes (Figure 12). From these it was clear, that the simple Andersson system is good at forecasting periods when it does not snow. It seems to have a tendency to underestimate the probability of higher intensity classes, but during demonstration periods such cases were so rare, that statistically significant results with sufficient number of independent samples can't be calculated.

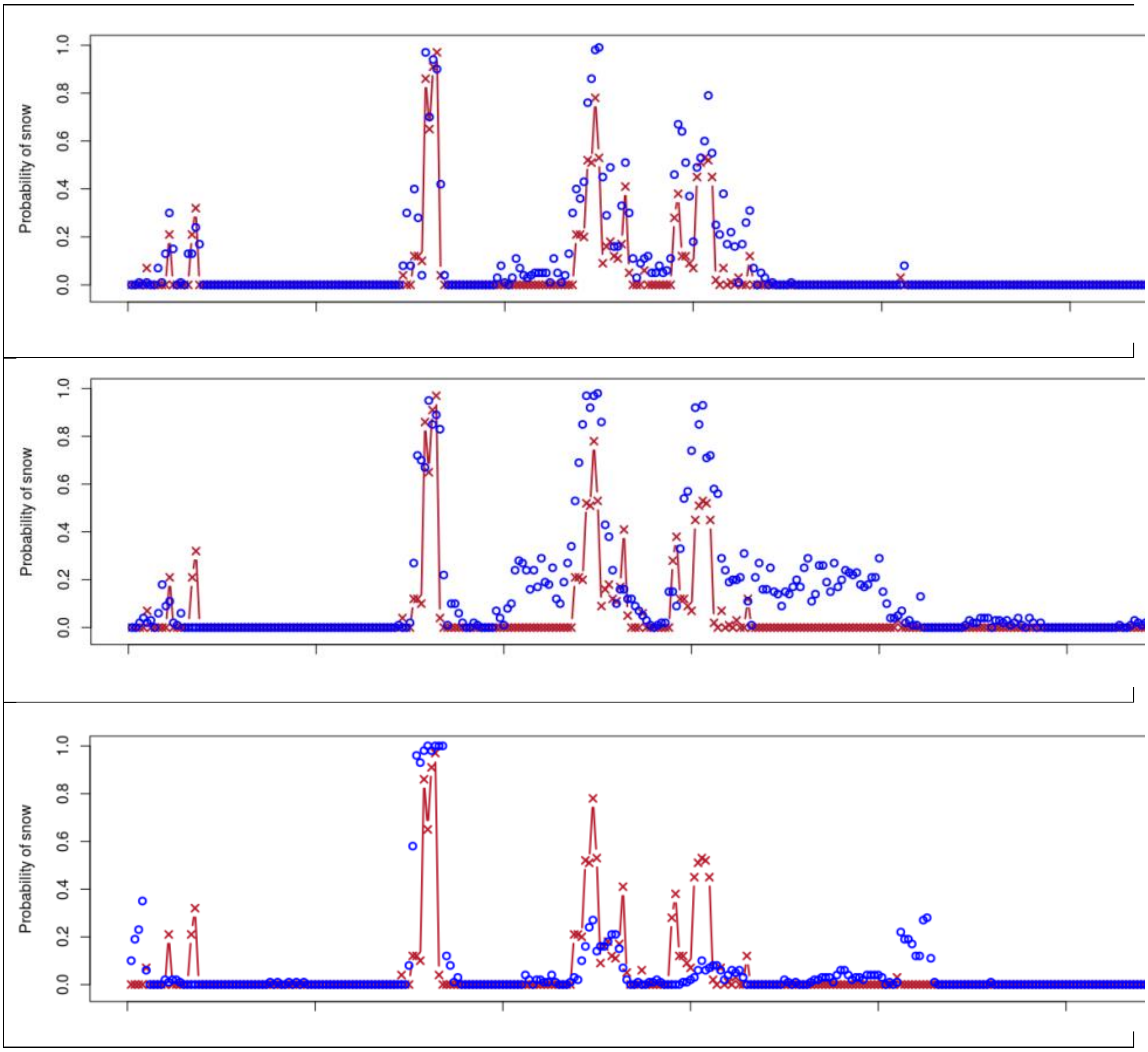

Figure 11: Probability of snowfall exceeding 15 dBZ in Innsbruck 20-22 February 2017.

In the figure 11 above, the red line and crosses represent distribution of the pixels within 15-minute range from the airport, blue circles the nowcast for 30 min (top), 90 min (middle) and 180 min (bottom). Horizontal axis is valid time of the forecasts, from 20 Feb 03:00 to 22 Feb 21:00 UTC.

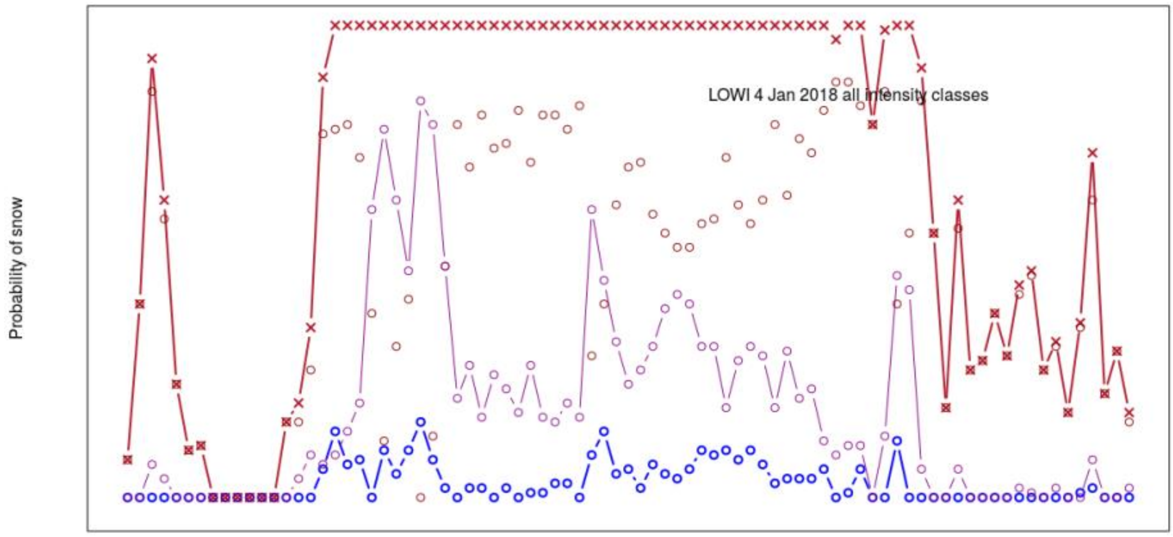

Figure 12: Time series of 30 minutes forecasts for different intensity classes.

In the figure 12 above, the time when the forecast is valid is on the X-axis and the probability of the snowfall over the each intensity threshold as Y-axis. Accumulation of wet snow over 5 mm/15 min (blue), over 3 mm/15 min (purple) and over 1 mm/15 min (red).

For demonstrators and data dissemination in **WP6** suitable partners for testing probabilistic winter precipitation forecast were selected. Based on results of the WP4 survey, three major groups of users were identified. The runway maintenance, which need exact timing of accumulation of snow or freezing rain. The ATM tower/approach need probability of low visibility procedures and de-icing is interested in type and intensity of precipitation and air/surface temperature/humidity, which is combined in the de-icing weather index. Additional we collected feedback from airliners. Selected four airports (Helsinki, Rovaniemi, Innsbruck, Vienna) covers major hubs to smaller regional European airports, characterized by charter traffic and represent different topographic and climatic regions, ranging from Nordic maritime to high Alpine environments.

PNOWWA launched two research campaigns to demonstrate a prototype of probabilistic winter precipitation forecasts [24] [25]. Both demonstration campaigns were carried out online with 15 min updated in winter February-March 2017 and December 2017 – February 2018. Weather radar data from Austria were ingested in the OPERA European composite to produce the PNOWWA demonstration product which is presented in Figure 7 for the three user groups. The layout of the web page consists of 3 parts, the probabilistic winter weather table (color coded probability), a feedback form and a product description showing dependencies between radar reflectivity and de-icing winter weather, visibility or snow accumulation.

Case studies and also interesting cases with user feedback have been collected for demonstration and also cases from feedback.

An example from 14th February 2018 in LOWI of the product during demonstration campaign 2 is shown in Figure 13.

LOWI LOWW

RUNWAY MAINTENANCE (UPDATED 2018-02-15 14:15:00 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	10	10	10	20	20	10	10	0
over 5 mm	0	10	10	10	30	40	40	40	40	40	40	50	30
over 1 mm	100	90	100	100	100	100	100	100	100	100	80	90	100
less than 1 mm	0	10	0	0	-0	0	0	0	0	10	20	10	0
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
over 3 mm	0	0	0	0	0	0	0	0	0	0	0	0	0
over 1 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 2018-02-15 14:15:00 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	10	10	10	30	40	40	40	40	40	40	50	30
2	100	80	90	90	70	60	60	60	70	60	40	40	70
1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	10	0	0	0	0	0	0	0	10	20	10	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

TOWER (UPDATED 2018-02-15 14:15:00 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	10	10	10	20	20	10	10	0
VIS less than 1500 m	0	10	10	10	30	40	40	40	40	40	40	50	30
VIS less than 3000 m	100	90	100	100	100	100	100	100	100	100	80	90	100
VIS over 3000 m	0	10	0	0	-0	0	0	0	0	10	20	10	0

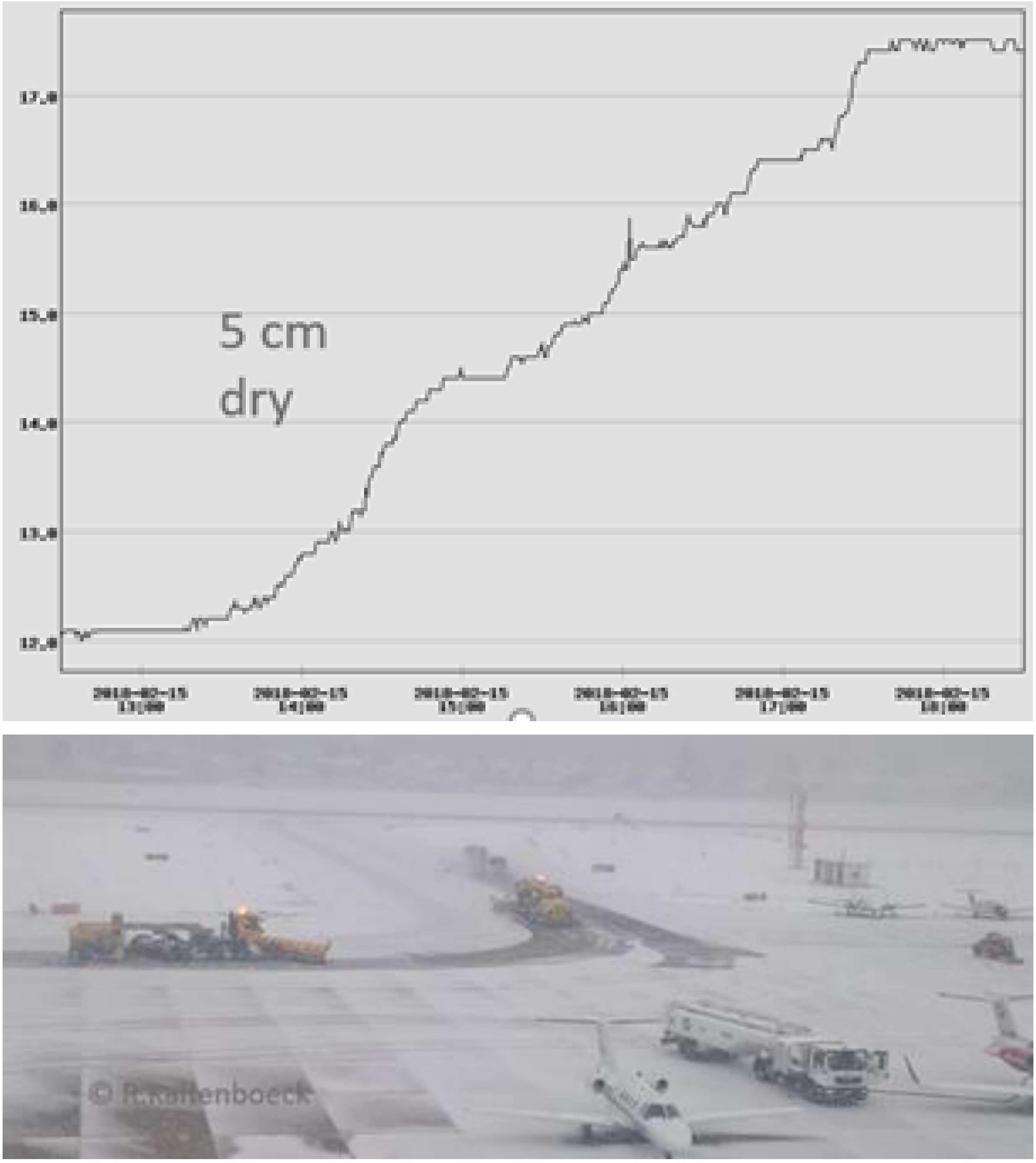

Figure 13: PNOWWA demonstrator for 14th February 2018, 14:15 UTC for LOWI.

In the figure 13 the corresponding snow height measurements and the photo (below) taken at the airport tower in Innsbruck.

Work Package 7: SESAR2020 interaction and outreach

In **WP7** presentations of PNOWWA work and users' feedback were collected, which were given at various workshops, conferences, SESAR Innovation Days, and SESAR Industrial Research Project Solution meetings, either organized by the PNOWWA project or with participation of the PNOWWA team, see project deliverable D7.1 "SESAR2020 Industrial Research Solution workshop presentations" [27].

The PNOWWA stakeholder workshop was held in Vienna from 27 to 28 of February 2018 with 17 participants and 14 presentations. The PNOWWA stakeholder webinar was held on 04.10.2017 by Webex with 21 participants following three presentations. PNOWWA topics have further been presented at two SESAR Innovation Days (SID 2016, 2017). Interactions with two SESAR2020 Industrial Research Project Solutions (Solution PJ.04-02 "Total Airport Management" and PJ.18-04 "ATM improvement by enhanced AIM and MET") have been used to elaborate on the need and requirements for probabilistic winter weather information in Industrial Research. PNOWWA attended (will attend) four stakeholder workshops organized by three other SJU-funded projects. Finally, the PNOWWA work has also been presented at four international conferences.

2.4 Key Project Results

The major scientific result of PNOWWA is the development of a **new method for nowcasting snowfall** based on extrapolation of movement analyzed in consequent radar images, assessing the uncertainties of snowfall nowcasting related to growth and decay using the scale analysis and ensamble nowcasting technologies. Similar approach has been utilized in warmer climate, but winter weather has its unique features.

The major result towards operational implementation consists of two successful **research demonstrations** [24], where realtime nowcasts were delivered to a number of stakeholders in the airport environment.

Mapping the **user needs** [14], the outreach and education of the users is the third cornerstone, building a solid base to be utilized when building more operational products in the future projects

2.5 Technical Deliverables

The detailed technical deliverables descriptions are in Appendix B of this document. This section lists the deliverables that are submitted and approved by the SJU reviewers.

Table 2: PNOWWA project deliverables.

Reference	Title	Delivery Date[1]	Dissemination Level[2]
	Description		
D1.1	Project Management Plan	29/11/2016	CO
D1.2	Technical Project Final Results Report	23/03/2018	PU

[1] Delivery data of latest edition

[2] Public or Confidential

D2.1	Probability distribution time series of predicted precipitation intensity and nowcast predictability to WP5	14/06/2017	CO
D2.2	The same data for WP3 (not real time, research of local conditions affecting precipitation movement)	01/02/2017	CO
D2.3	Manuscript for WP7 (outreach for scientific community)	13/03/2018	PU
D2.4	Description document of the WP2 publications accessible at the web	13/03/2018	PU
D2.5	Definition of data formats and routines to transfer Ensemble forecasts for Tools generation	09/11/2016	PU
D3.1	Manuscript "Predictability of snowfall as function of flow direction at certain airports"	13/03/2018	PU
D3.2	Manuscript "Orographic enhancement of snowfall"	13/03/2018	PU
D3.3	Direction-dependant forcing fields for selected airports for WP 2	15/06/2017	CO
D3.4	Conversion tools for WP 2	03/07/2017	CO
D3.5	Report of method to improve nowcasting with direction-dependent forcing fields	16/10/2017	PU
D3.6	List of scientific publications	13/03/2018	PU
D4.1	Survey of user needs and use of winter precipitation forecast at one selected airport.	10/02/2017	CO
D4.2	Document of user needs for prototype of probabilistic winter precipitation forecast	10/02/2017	PU
D4.3	Survey of user opinions of demonstrated product.	28/11/2017	PU
D4.4	Report of the possible solutions how probability forecast products of precipitation could increase the resilience of airport	14/03/2018	PU
D4.5	Roadmap of future applications	16/03/2018	PU
D4.6	List of scientific publications	13/03/2018	PU
D5.1	Detailed description of the methods	17/07/2017	CO
D5.2	Software packages and documentation	11/05/2017	CO
D5.3	Demonstration of product generation and delivery	03/07/2017	CO
D5.4	List of scientific publications	13/03/2018	PU
D6.1	Report of demonstration campaign	06/06/2017	PU
D6.2	Documented datasets with description and info page	13/03/2018	PU
D6.3	List of scientific publications	13/03/2018	PU
D7.1	SESAR 2020 PNOWWA Solutions Workshop Presentations	12/03/2018	PU
D7.2	PNOWWA website	16/11/2016	PU

D7.3	Contributions in Magazines	13/03/2018	PU
D7.4	Talks in conference and manuscripts for peer-reviewed journals	13/03/2018	PU
D8.1	POPD – Requirement No. 2	07/10/2016	CO
D8.2	H – Requirement No. 1	07/10/2016	CO
D8.3	POPD – Requirement No. 3	11/04/2017	CO
D8.4	H – Requirement No. 4	11/04/2017	CO

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

A Deterministic De-Icing Weather (DIW) prototype was utilised in SESAR 1 V3 validation EXE-06.06.02-VP-513. It was found that the enhanced Winter Weather Information (WWI) supports de-icing management better than conventional ICAO products. Deterministic DIW is planned to be deployed at IP68.

In PNOWWA it was researched the ways to improve the weather radar extrapolation methods used in SESAR1 for snow nowcasts. It was also studied how other users than de-icing managers can use WWI. It was recognized that at least runway maintenance and tower could get benefit from WWI. At time-based separation ATM is using deterministic meteorological information. Trajectory-based ATM and Performance-based ATM automated ATM systems will be developed to the level where information about uncertainties of meteorological conditions will be needed.

The scope of PNOWWA has been to further develop WWI nowcasts and to research possibilities to produce and use probabilistic meteorological information in airport operations.

PNOWWA work contributed EN METEO-04d. During project it was remarked need to update the description of METEO-04d by adding there the probabilistic MET information and nowcasting issues, which are needed in future ATM operations. Bellow is proposal for modifications of METEO-04d. Inserted text is **highlighted by bold text**.

METEO-04d — Generate and provide MET information relevant for Airport and final approach related operations, Step 3

ATM-MET system acquiring, generating, assembling and providing Meteorological (MET) information to the SWIM network and in a SWIM compliant manner to support all actors in Airport and final approach related operations and consistent with information relevant for other operational user environments such as En-route and Network operations.

Dedicated ATM-MET system capabilities will introduce new or improved meteorological observation, nowcast and forecast capabilities to support enhanced decision making. **MET information including the information of uncertainty of forecasts will be delivered to decision making systems of ATM.**

When a high level of consistency and consolidation with MET information for other operational user environments is required, the information will be made available through a system that provides this capability to consolidate and make the MET information consistent.

This includes the ability to acquire, assemble and provide the relevant, ground, aircraft and space-based MET observation information, supported by enablers METEO-3, CTE-S7b and A/C-47.

The ATM-MET system capability for Step 3 focuses on acquiring, generating, assembling and providing meteorological information supporting (automated) ground and aircraft based decision making process or aids involving the relevant MET information, translation processes to derive constraints for weather and converting this information in an ATM impact by ATM systems.

Probabilistic MET information will be tailored to support the processes of each stakeholder at airport.

The system capability mainly targets a 'time to decision' horizon less than 3 minutes. **Time horizons of few hours and 24 hours are also included to the services.**

The ATM-MET system outputs, amongst others, are:

a) MET information for the tactical avoidance of hazardous meteorological conditions

b) MET information to support ATM situational awareness tools including display of MET information

c) MET warnings that give concise information of meteorological conditions that could adversely affect aerodrome operations.

d) Probabilistic MET information for supporting optimisation of airport processes

Maturity of METEO-04d expressed in the table bellow. At the end of PNOWWA it is at TRL1 intermediate level. In PNOWWA it was dealt with winter weather cases, yet there exist other relevant weather cases needing perhaps other solutions to be developed. So further research is needed to achieve full TRL1 concerning all kind of adverse weather conditions.

Code	Name	Project contribution	Maturity at project start	Maturity at project end
METEO-04d	Generate and provide MET information relevant for Airport and final approach related operations, Step 3	PNOWWA solution tailor probabilistic few hours winter weather nowcast to all stakeholders at airports for decreasing the effects of adverse winter weather to airport procedures . It supports predictability of traffic.	TRL0	TRL1 INTERMEDIATE

3.2 Maturity Assessment

The detailed maturity assessment of EN METEO-04d concerning probabilistic winter weather condition nowcasting issues is given in Table 3 (bellow). Above in Chapter 3.1 it is proposed some modifications for METEO-04d for better describing enabler.

Satisfaction explanations (for Table 3):

- **Achieved:** No issues are identified to solve after the exit of the V / TRL-phase – i.e. satisfactorily achieved that V / TRL-phase is completed.

- **Partial - Non Blocking:** Partially achieved, but the remaining aspects do not prevent progress to the next maturity level. They can be address as part of the activities in the next maturity phase.
- **Partial - Blocking:** Partially achieved. There are issues that require further work. These remaining issues prevent progress of the SESAR Solution to the next maturity level until they have been addressed. This may include future exercises planned to complete the validation.
- **Not Achieved:** The criterion has not been satisfied for the SESAR Solution under analysis.
- **Not Applicable:** Related to non-applicable criteria.
- **Not answered:** If the assessor does not provide a response to the criteria, this will be treated the same as "NOT ACHIEVED" in the results tab.

Table 3: ER Fund / AO Research Maturity Assessment

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? Where does the problem lie?	Achieved	The Project members have clearly identified the major need to decrease to effects of adverse winter weather to airport procedures. By probabilistic nowcast it is possible for forecast the risk of adverse winter weather tailored individually to the stakeholders of airport procedures. D4.2 Document of user needs for prototype of probabilistic winter precipitation forecast [15]
TRL-1.2	Has the ATM problem/challenge/need(s) been quantified?	Partially – Non Blocking	The Project members have quantified the major needs to being able to give good winter weather situational awareness as well as good nowcast for the next three (3) hours. The needs have been quantified in details as follows: D4.3 Survey of user opinions of demonstrated product. [16]
TRL-1.3	Are potential weaknesses and constraints identified related to the exploratory topic/solution under research? - The problem/challenge/need under research may be bound by certain constraints, such as time, geographical location, environment, and cost of solutions or others.	Achieved	The weaknesses and constrains have been identified by the project team having long term experience in ATM activities, as well as thru extensive inquiries and survey among the ATM stakeholders, e.g. airport staff, ATM

			subcontractors, airlines, ATM policy makers. D6.1 Report of demonstration campaign [24] (See also Technical lessons learned -chapter of this document)
TRL-1.4	Has the concept/technology under research defined, described, analysed and reported?	Achieved	The PNOWWA winter weather nowcasting concept based on interpolation of radar observations to generate the vector field of movement is well defined, described and analysed in peer-reviewed publications. The real-time analysis of PNOWWA concept was performed by two research demonstrations during the project. D6.1 Report of demonstration campaign [24] D6.2 Documented datasets with description and info page [25] D7.1 SESAR 2020 PNOWWA Solutions Workshop Presentations [27]
TRL-1.5	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	Partially achieved	The Project achievements are expected to support some of the SESAR Key Performance Areas. Especially ATM performance efficiency gains from the PNOWWA methods during winter weather conditions. Especially the automated decision making

			systems will benefit the risk based probabilistic approach of PNOWWA. D4.4 Report of the possible solutions how probability forecast products of precipitation could increase the resilience of airport [17] D4.5 Roadmap of future applications [18] D6.1 Report of demonstration campaign [24]
TRL-1.6	Do the obtained results from the fundamental research activities suggest innovative solutions/concepts/ capabilities? - What are these new capabilities? - Can they be technically implemented?	Partially – Non Blocking	The project results indicate a need for additional innovations, e.g. the uncertainties of snowfall nowcasting related to growth and decay when using the scale analysis and ensemble nowcasting technologies should be addressed and properly investigated. The PNOWWA method has been implemented as research demonstrations, which can be implemented operationally by future research work. D2.3 Manuscript for WP7 (outreach for scientific community) [5] D3.5 Report of method to improve nowcasting with direction-dependent forcing fields [12] D4.4 Report of the possible solutions how probability forecast products of precipitation

			could increase the resilience of airport [17] D4.5 Roadmap of future applications [18]
TRL-1.7	Are physical laws and assumptions used in the innovative concept/technology defined?	Achieved	The PNOWWA methodology is fully based on the physical laws governing the weather and atmospheric flow. D3.1 Manuscript "Predictability of snowfall as function of flow direction at certain airports" [8] D3.2 Manuscript concerning "Orographic enhancement of snowfall" [9] D3.5 Report of method to improve nowcasting with direction-dependent forcing fields [12] D2.4 and D3.6 Peer-reviewed publications of WP2 and WP3 [6] [13]
TRL-1.8	Have the potential strengths and benefits identified? Have the potential limitations and disbenefits identified? - Qualitative assessment on potential benefits/limitations. This will help orientate future validation activities. It may be that quantitative information already exists, in which case it should be used if possible.	Partially – Non Blocking	The strengths and limitations on PNOWWA methodology has been preliminary addressed. Qualitively the strenghts, benefits, limitations and disbenefits are identified, but in qualitevely them are identified only partially. Additional environmental and weather observations in vicinity of the airport would increase the accuracy of the PNOWWA method thru data fusion. Also, existing road models could be modified to fit in the airport environment and

			that way to benefit the PNOWWA results. D4.3 Survey of user opinions of demonstrated product [16] D4.4 Report of the possible solutions how probability forecast products of precipitation could increase the resilience of airport [17] D4.5 Roadmap of future applications [18]
TRL-1.9	Have Initial scientific observations been reported in technical reports (or journals/conference papers)?	Achieved	PNOWWA results have been published in several conference papers, presentations (e.g. in SID, EGU and ATM workshops), peer-reviewed publications and magazines (e.g. in Ilmailu and Geophysica). PNOWWA results are also available in project website as far as the deliverables are public in nature (see http://pnowwa.fmi.fi). D2.4 and D3.6 Peer-reviewed publications of WP2 and WP3 [6] [13] D7.1 SESAR20202 PNOWWA solution workshop presentations [27] D7.2. PNOWWA website [28]
TRL-1.10	Have the research hypothesis been formulated and documented?	Achieved	The PNOWWA research hypothesis was well defined in the PNOWWA project proposal as well as in PNOWWA PMP, in short, the hypothesis reads as follows:

			Accurate winter weather nowcasting (first 0-3 hours) is highly beneficial in increasing the efficiency of ATM operations in winter weather conditions, and such nowcasting methodologies need to be developed.
			
			From original proposal
			
			"The specific objectives of this project are:
			
			• *to develop a method for probabilistic 0-3h forecasts ("nowcasts") of snowfall and freezing rain at airport, in steps of 15 minutes*
			• *to improve our understanding, and hence predictability, of changes in snowfall intensity caused by underlying terrain (such as mountains and sea)*
			• *to identify and promote the potential for use of probability forecasts in variety of airport activities*
			  ○ *Total Airport Management (de-icing, Airport demand and Capacity Balancing, AirPort Operations Centre (APOC) runway maintenance)*
			  ○ *Enhanced Runway Throughput (low visibility procedures)*
			  ○ *Remote tower activities*
			  ○ *Capacity balancing of Network*

			(comparing probability of snowfall at all the airports in the network) • *to make research demonstration of probabilistic winter weather product to show its potential for increasing the resilience of ATM system to winter weather."*
TRL-1.11	Is there further scientific research possible and necessary in the future?	Achieved	There is clear need to develop further the PNOWWA scientific methodologies. Additional environmental and meteorological observations in the vicinity of the airport are needed to supplement the radar observations thru data fusion concepts, to be also combined with runway weather models to be developed from existing road/traffic models This would increase the accuracy and value of the PNOWWA method. To extend the PNOWWA method for the next 24 hours, numerical ensemble prediction system (EPS) seamlessly blended with the radar based nowcast is required. D4.5 Roadmap of future applications [18] D3.2 Manuscript "Orographic enhancement of snowfall" [9] D7.1 SESAR20202 PNOWWA solution workshop presentations [27]

TRL-1.12	Are stakeholder's interested about the technology (customer, funding source, etc.)?	Achieved	The stakeholders have expressed their clear interest and also needs for the scientific methods and technologies developed by the PNOWWA project. Stakeholders have also provided their own ideas for the future development towards operational products and tools utilizing the PNOWWA technologies. D7.1 SESAR-2020 PNOWWA solution workshop presentations [27]

4 Conclusion and Lessons Learned

4.1 Conclusions

The SESAR2020 exploratory research project called Probabilistic Nowcasting of Winter Weather for Airports (PNOWWA, grant #699221) developed methods to support the Air Traffic Management (ATM) challenged by winter weather. The project was running for two years from April 2016 until April 2018.

The principal PNOWWA methodology is based on probabilistic nowcasting of winter weather, which will enable the estimation of winter weather conditions affecting the ground part of air traffic 4D trajectories. This kind of ATM methods and tools are called for, because the uncertainties during flight, departure and arrival at airports create a need to effectively utilize probability forecasts, both in the local operational user environment and en-route.

The major scientific result of PNOWWA is the development of a new method for nowcasting snowfall based on extrapolation of movement analysed in consequent radar images, assessing the uncertainties of snowfall nowcasting related to growth and decay using the scale analysis and ensamble nowcasting technologies. Another major result towards operational implementation consists of two successful research demonstrations [24], where real-time nowcasts were delivered to a number of stakeholders in the airport environment. Mapping the user needs [14], the outreach and education of the users is the third cornerstone, building a solid base to be utilized when building more operational products in the future projects.

The PNOWWA research work has focused on the identification and quantification of the uncertainties related to delays in ground operations due to winter weather situations. When applied to ATM applications and services, our methods will enhance timely operations in surface management and ATM decision making, will increase airport resilience, shorten delays and will also maintain safety of airport functions during winter weather cases. These have been shortly described in Table 3. Airport capacity will increase and delays will be shorten when de-icing activity works efficiently, runway maintenance do their actions proactively, APOC can inform adverse weather to all operators at airport and airlines can plan their actions to all possible weather conditions, which could happen in near future.

The power of probabilistic forecast is that it is possible to forecast not only the most probable weather coming but also the other possible weather. The each stakeholder can optimize their actions. That will also considerably maintain the safety of airport functions when all possible weather scenarios are forecasted.

PNOWWA has demonstrated the benefits of very short-term (0-3h nowcast) probabilistic winter weather forecasts, which are based on identification and extrapolation of the movement of weather radar echoes with 15min time resolution. The PNOWWA project has shown the improved predictability of changes in snowfall intensity caused by underlying terrain, such as mountains and lakes or sea. This was performed through two research demonstrations that were conducted both offline and online at Operative User Environment (OUE) sites at the airports of Innsbruck and Helsinki, representing the influence of the underlying terrain to forecast accuracy. These demonstrations represented a major result towards operational implementation through the delivery of real-time precipitation nowcasts to a number of stakeholders in the airport environment.

An extensive user consultation survey was performed to ensure the forthcoming products are suitable to be integrated in various applications on the ATM side. The survey included mapping the user needs of stakeholders in the fields of ANS, ATC tower- approach, ACC, airfield maintenance, flight dispatching, exhibition management, meteorology engineering, aircraft pushback - towing and de-/anti-icing services and technics. It involved countries in the survey were Austria, Denmark, Finland, Germany, Norway and Switzerland. Various airport types were considered, like big hubs, small airports and even alpine airports with weekend traffic peaks due to winter charter flights.

Based on the survey, majority of stakeholders see most potential for probabilistic weather forecasts to help render decisions objectively, and secondly by using them in decision support when cost-loss ratios are known. A general positive and open attitude toward probabilistic forecasting and its benefits by respondents was evident. For most of the stakeholders this survey served as an informational and educational activity. This kind of outreach and educational aspect of PNOWWA serves the ATM community very well, when building a solid base to be utilized when building more operational ATM products in the future projects.

The achievements gained in PNOWWA contribute to all the SESAR Key Performance Areas except to 'Security'. The ATM Key Feature, which benefits mostly from PNOWWA is 'High-performing airport operations'. Winter weather is a factor, which can cause non-nominal operating circumstances, and by probabilistic winter weather products, the risk for adverse weather causing disruption is known in beforehand. The achievements of PNOWWA can effectively be used in airport collaborative decision-making (A-CDM), in Operations in low visibility conditions (LVC) procedures and in Airport operations plan procedures. Collaborative airport and remote tower are development areas which in future could benefit from probabilistic winter weather information as well.

Based on the maturity analysis performed for PNOWWA project, it can be concluded that the PNOWWA project has reached the maturity represented by Technology readiness Level 1 (TRL1 INTERMEDIATE).

One major PNOWWA success enabler is the fact that the PNOWWA team is exceptionally interdisciplinary, including people who have operational experience as well as scientists with academical merits. This was crucial for the success of the project, as the operational people have not only first-hand experience of the operational challenges, but also they are networked with the right people from the ATM side to find the right people to interview.

As far as SESAR2020 interaction and outreach is concerned, it can be concluded that the results of PNOWWA's research can be applied to all precipitation-dependent solutions at a local (airport) scale, notably for the ATM Key Feature "High-performing airport operations", see D7.1. In the Proposal it was assumed that many of SESAR2020 Industrial Research solutions will organize workshops to clarify their need in using enhanced meteorological services in the area of their responsibility and define respective requirements. The Industrial Research Project Solutions with highest potential to apply the research findings are as follows:

- PJ.02-01 "Enhanced Runway Throughput",
- PJ.04-02 "Total Airport Management",
- PJ.05 "Remote Tower for Multiple Airports", and

- PJ.07 “Optimised Airspace Users Operations”.

Contacts to these IR-Projects were established via Solution PJ.18-04b (MET) by investigations and inquiries on a bilateral level.

The SESAR2020 IR-Project PJ.04-02 “TAM” defines assessment processes for MET impact to provide the Airport Operation Center (APOC) “with a view of how [winter] weather scenarios will affect different airport operational services and the expected increase in their individual demand or decreases in capacity”. Examples are winter weather response processes (snow removal, etc.) and aircraft de-icing processes. It has been noted that the proper use of probabilistic winter weather nowcast as provided by PNOWWA has the potential to

- increase common situational awareness among stakeholders,
- provide time to react to performance issues,
- consume less and more efficiently human and infrastructure resources, and
- improve impact and solution forecast ability.

A list of detailed requirements, and in return specifications and developments, to mitigate winter weather issues on (selected) airports within the TAM consortium should be developed in a future collaboration among PNOWWA and PJ.04-02 partners.

In the enabler project solution PJ.18-04b (MET) the Content Integration and Common Component 3.1 “Airport MET Information and Alert Generation Enhancement” and the Integration Services 1 through 5 in SESAR2020 domains were identified as activity areas where PNOWWA outcome could be used. The PNOWWA team expressed its willingness to fill potential gaps in expertise concerning winter weather issues in Solution 18-04b. It was agreed that when a respective (winter weather) requirement shows up in an Information Exchange Requirement (IER) of (at least) one of the operational SESAR2020 projects, in a first step it will be checked if one of the 18-04 partners is capable and willing to deliver that MET Information Service (IS) and, if not, in a second step it is considered that ECTL contacts a party outside 18-04 (like FMI) to develop and deliver the IS.

The presentations of PNOWWA given at various fora and in different formats raised awareness among applied meteorologists as well as aviation industry partners of the capabilities and chances of probabilistic winter weather nowcast. The PNOWWA team got helpful feedback to steer and adjust its project work, especially in a possible follow-on project where a TRL of 2 with a higher application demand is envisaged. Both, the PNOWWA workshop and the PNOWWA webinar were successful events. The (2 days) workshop attracted mostly representatives of the local aviation industry in Vienna, whereas the (1 hour) webinar was attended by spatially distributed parties. The face-to-face meeting allowed an in-depth discussion on users’ requirements at the Vienna airport for winter weather nowcast and in response on the possibilities PNOWWA could offer to mitigate such events. The short and concise webinar turned out to be a valuable and effective way to inform spatially distributed parties on the user’s side with very limited time and to disseminate PNOWWA findings and approaches to a wider audience. Attending SESAR2020 Project Solution meetings are also a concise mean to interact with parties who work on similar weather-dependent improvements in an aviation sector [27].

4.2 Technical Lessons Learned

4.2.1 Technical procedures

The technical procedures for generating radar based probability winter weather nowcasts to airports are divided in several work packages as follows:

WP2: Probabilistic winter weather prediction

- preprocessing of radar data if needed
- analyzing movement of precipitation from the radar reflectivity imagery
- using the analyzed movement to produce a group of reflectivity nowcasts (ensemble member fields)

WP3: Winter weather forcing

- Andersson method for experimental use for Munich and Salzburg airport for selected case studies

WP5: Tools enhancing meteorological support for ATM decision making process

- post processing the nowcast fields from WP2
- producing probability distribution of precipitation for each airport location
- generating exceedance probability time series for user-defined precipitation intensity/accumulation limits (from WP4 inquiry)
- collecting auxiliary data (surface temperature etc.) for nowcast enhancement
- enhancing the probability time series to fulfill the various needs of different users in each airport (from WP4 inquiry)
- generating end user products for demonstration
- arranging the dissemination of products to users

The WP3 did not produce any software for demonstration purpose use yet, but in the future the winter weather forcing analysis and enhancement system will process the results of WP2 and produce input data to WP5.

From the beginning of the WP5 work the aim was to test the whole production chain. Because of this, we needed as simple as possible method to produce probabilistic nowcasts for WP5 needs. The Andersson method fulfilled this need, and was very straightforward to implement and without noticeable technical challenges, mainly because the NWP model wind was used as the motion field and because of very simple nowcasting algorithm. So it was used for testing all the downstream components in delivery to end users, and to some extent also as a reference to the more advanced systems. So the implementation of the Andersson method it is not included in following inspection.

Following aspects of technical issues concentrates on challenges met during development of several algorithms to working prototype software's especially in WP2, and in WP5.

In WP2 the work was divided in four parts

- Preprocessing the radar data
- Selecting the suitable motion analysis algorithms for testing

- Testing different methods of using motion analysis for extrapolative nowcasting
- Refining the resulting raw ensemble member nowcasts to probability distribution based probabilistic point forecasts

The available run time is crucial limitation when selecting the usable algorithms for the whole nowcasting process. To keep the system in real time, all the three components mentioned above should run within five minutes. Typically the most time consuming process is the motion analysis - slogan could be “the better the slower”, which led to several compromises.

4.2.2 Preprocessing the radar data

Four different radar data sets were available: Finnish composite / raw data, European OPERA composite and Austrian raw data. For selected airports only the Finnish composite data was already preprocessed properly for motion analysis (because it is also used in the FMI's operational nowcasting system). For nowcasting to Austrian airports we had to inject an Austrian composite generated from raw data at FMI to the European ready-made composite. This process appeared to be quite challenging from the motion analysis point of view, and was not solved properly during the testing phase.

4.2.3 Motion analysis

Almost all technical challenges were related to testing and further development of motion analysis. Firstly it was noticed that all methods based on using radar data only were good at interpolating the movement between consecutive radar images. But problems aroused immediately when trying to use the derived motion vectors for extrapolation of the movement more than few image intervals ahead, e.g. about fifteen minutes.

The reason of misbehavior of motion vectors were mainly related to quality of radar measurements and in some extent also to compositing method used to construct a larger area radar composite. The quality of radar measurements varies depending on location of each radar and the disturbance generated by natural phenomena, like sea clutter, or man-made effects, like illegal WLAN transmitters. In FMI there is operational cleaning up process for raw radar measurements, but that wasn't possible to use with European OPERA composites, because the raw data in polar coordinates is not available at the moment.

The radar data quality issues were not in the scope of this project, and removing all residual clutter from radar images is almost impossible without removing also the weaker part of echoes caused by the precipitation. This especially applies to snowfall, because snowfall intensity affecting e.g. visibility at airports causes much weaker echoes than liquid precipitation at same intensity. So it is important to keep as much radar information available as possible.

The only technically reasonable solution for this quality problem was to post-process the motion vector fields themselves. Typically the problems caused during extrapolation were related to few vectors having strong deviation in speed, direction or both compared to the mean of surrounding "good" vectors. So the method to filter out these outliers had to be developed. This was quite time consuming development process, because of four different motion analysis being tested simultaneously.

The solution was to analyze the vector field in overlapping larger areas, typically about one hundred square kilometers. The goal was to extract the physically well behaving vector field without disturbing the movement of small scale precipitation. The evaluation of this goal was done only by visual inspection, because developing an automatic method for the measure of quality of vector field would have been too challenging.

4.2.4 Using the motion analysis for nowcasting

Two different nowcasting systems were examined, RAVAKE and a stochastic ensemble method. Both methods are able to use the same motion analysis, and are comparable in that sense.

The RAVAKE is operational system in FMI, and is based on perturbed trajectories of movement using constant spread pattern, and does not include any precipitation development component. During the implementation test it was noticed that the operational perturbation method to generate ensemble members did not have enough spread to be analogous to the Anderson method output. The system also suffered some instabilities related to the quality problems of motion fields derived from European radar composite.

The stochastic ensemble method adds random perturbations to the motion vectors and also models the growth and decay of precipitation using random field in multiple spatial scales. This system was not tested in real time, and still requires some performance optimization and adjustments to be used in operational environment.

4.2.5 Lessons learned – Summary

PNOWWA software development deals very much with interfacing various kinds of data sources, especially radar data. Even when using similar kind of data sources, the developed software prototypes generated results which were difficult to compare. In the future the output data from test systems should be unified, and contents and formats of output data sets should be decided in advance.

Lots of additional work was done because developers were too confident about the quality of results of the implemented motion analysis algorithms. Part of this problem was related to quality issues of input radar data, which unfortunately was not even inside the scope of the project. In the future the quality of the input data should be ensured beforehand, and time and resources should be allocated to post processing of resulting data from analysis systems.

4.3 Recommendations for future R&D activities (Next steps)

The PNOWWA project has gained ground-breaking exploratory research and development results and it can be considered having been highly successful in its activities, as was clearly proven by the research demonstrations involving ATM stakeholders. Recommendations for future PNOWWA-related research and development activities should be building on the achieved results.

The major scientific result of PNOWWA is the development of a new method for nowcasting snowfall based on extrapolation of movement of precipitation, which is analysed in consequent radar images, as well as assessing the uncertainties of snowfall nowcasting related to growth and decay using the scale analysis and ensamble nowcasting technologies.

Another major PNOWWA achievement towards operational implementation consists of two successful research demonstrations, where real-time nowcasts were delivered to a number of stakeholders in the airport environment. Additionally, the PNOWWA project has been mapping the needs and requirements of ATM stakeholders through an extensive survey.

Currently the PNOWWA methods have been assessed to be on the Technical Readiness Level 1. Further work is needed to reach higher maturity levels and to generate an experimental product for future operational application used by airport stakeholders.

The next PNOWWA-related step should be to elevate the current PNOWWA scientific product to the Technical Readiness Level 2. Through this activity the theoretical and scientific principles of the PNOWWA method will be focused on specific application area and analytical tools are developed for simulation or analysis of the application. This would include continuing the development of the current PNOWWA Nowcast system with known deficiencies such as drifting of precipitation. An excellent means to accomplish that would to utilize SESAR Applied Research programme (preceding industrial research and validation). The PNOWWA stakeholder survey revealed the fact that some stakeholders are not fully aware with the difference between deterministic and much better probabilistic forecasts. Hence communication with ATM stakeholders is of principal importance in the next level of PNOWWA development. **Getting the current PNOWWA method of 0-3 hours winter weather nowcast into TRL2 level is the first major recommendation.** To that end the currently developed PNOWWA winter weather nowcasting method should be exposed to a sensitivity analysis and tests in an operational environment to demonstrate the robustness of the nowcasting method against uncertainties and errors in radar data and airport environmental observations. Based on the sensitivity analysis the PNOWWA nowcasting method will be updated and improved and the resulted method will be validated through two real-time demonstrations in ATM environment.

Scientifically a major step forward would be the extension of lead time up to 48 hours. This could be achieved by including numerical ensemble prediction system (EPS) forecasts in the current PNOWWA nowcast. The numerical EPS would be blended and merged seamlessly with the probabilistic PNOWWA nowcasts. This would create an extended PNOWWA forecast extended up to 48 hours, the most reliable forecast being given for the first three hours given by the current PNOWWA method. This was also requested by airport stakeholders for tactical planning during our survey. **Extending the PNOWWA forecasting system up to 48 hours is the second recommendation.**

The future operational applications suggest the inclusion of additional forecast parameters, e.g. cloud ceiling, reduced visibility due to fog. In close cooperation with air traffic management, de-icing and runway maintenance the impact on airport operation has to be defined with respect to probability classes. From user perspective, in the future also summer weather has to be included, which results in one probabilistic forecast system to predict all weather elements relevant for airport handling. **Adding new parameters through data fusion into the PNOWWA method to improve the forecasting scheme would be the third recommendation.**

Furthermore, more capabilities can be added to the PNOWWA winter weather methods by more thorough characterization of winter weather through, e.g., visualization of selected parameters from TAF and METAR (FG, FZRA, FZDZ), inclusion of a road weather model (for freezing runway), dualpol radar parameters for snow types for better Z/S and Z/VIS and vertical profile of hydrometeors. All of these data would be fused in one probabilistic forecast system to predict all weather elements relevant for airport handling. **Adding information from adjusted road weather models and existing**

TAF, METAR parameter information into the PNOWWA method would be the fourth recommendation.

At the next development step, likely to be the applied research to lift PNOWWA product to TRL2, it would be preferable to include more active stakeholders to provide more in-depth feedback for the development work. This could be done by including some stakeholders (e.g. KLM, Finnair, Austrian, SureWX, Vaisala, Lufthansa) in the consortium to be actively involved in the project starting from the planning phase.

Also, the next development phase should include an improved version of research demonstration with improved product visualization tools, suggested GUI for several data sources as well as explaining the demonstrations through specific workshops for ATM stakeholders.

It is strongly recommended to continue the PNOWWA method development according to the ATM Master Plan by following the product development path of R&D -> solutions -> validations->implementation -> deployment. The Recommendation 1 above (**current PNOWWA method of 0-3 hours winter weather nowcast into TRL2**) is ready to go along the ATM master Plan through first the 'applied research' stage, which would be the next development step for PNOWWA. Thereafter work could be continued into 'industrial development' stage. It would be very useful to include into the applied research phase also Recommendation 2 **(Extending the PNOWWA forecasting system up to 48 hours**), because as a result of our survey, this feature was specifically requested by ATM stakeholders.

Overall, the current PNOWWA project has resulted in excellent results and it would be extremely important to continue the development. The current results were well received by ATM stakeholders and getting those products into operational use is highly useful for the efficiency, and safety during adverse winter weather conditions, of ATM activities.

4.3.1 Outline of a possible PNOWWA-related future research activity

The PNOWWA project generated the methodology for the first winter weather nowcasting system for ATM stakeholders and airports. Building on this work an applied research project should take place. Thereafter an Industrial Research work could be commenced starting the process of generating operational winter weather nowcasting tools for airports. The next step after the PNOWWA project – a possible future research activity scheme to be considered – is outlined below by an overview of research actions.

<u>Specific challenge:</u> Winter weather has major short-term (0 to 3 hours) impacts on the aviation and airport efficiency, and it affects all levels of aviation from airplane landings to the airport (e.g. runways) maintenance. The methodology to predict probabilistically the winter weather conditions during the next few (0-3) hours has been developed, and this allows for the development of decision making tools, processes and precise winter weather nowcasting prediction models. The current methodology calls for an extension to predict probabilistically the winter weather conditions beyond the first few hours, e.g. for the period of the next two days. The whole methodology needs to be tested by a specific real-time research demonstration with product visualization tools for the decision-making systems having tight interaction with ATM stakeholders.

<u>Scope:</u> Research work may investigate the improvement of the short-term nowcast models (0 to 3 hours) by involving additional winter weather related parameters into the probabilistic nowcasting

methodology through data fusion. Also specific local micro-weather models could be utilized by merging the model results with the nowcasts. Extending the prediction to cover the next two days would require to include numerical weather prediction through ensemble prediction system (EPS) and to blend the EPS results seamlessly with the nowcasting results of the first few hours. Research could also suggest improvements for the visualization of the selected TAF and METAR parameters based on use cases and user needs of ATM stakeholders (e.g. airports, airlines and runway maintenance), as well as to conduct an on-line field demonstration campaign to improve and validate the winter weather decision-making methodology paving the way for operational tools and products.

Expected impact: This research will contribute to the development of the winter weather extrapolation system and improve the seamless nowcasting and forecasting of the short-term and long-term winter weather conditions affecting the ATM activities on airports and aviation. This research will enhance the understanding of the specific ATM stakeholder user needs and generate suggestions and prototypes of winter weather services and tools to be developed for the operational use in ATM field.

5 References

5.1 Project Deliverables

[1] D1.1 Project Management Plan, 29 May 2018

[2] D1.2 Technical Project Final Results Report

[3] D2.1 Probability distribution time series of predicted precipitation intensity and nowcast predictability to WP5, 22 June 2017

[4] D2.2 The same data for WP3 (not real time, research of local conditions affecting precipitation movement), 10 February 2017

[5] D2.3 Manuscript for WP7 (outreach for scientific community), 13 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D2.3_Manuscript%20for%20WP7%20outreach%20for%20scientific%20community_RevA_FINAL.pdf

[6] D2.4 Description document of the WP2 publications accessible at the web, 15 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D2.4_Description%20document%20of%20the%20WP2%20publications%20accessible%20at%20the%20web.pdf

[7] D2.5 Definition of data formats and routines to transfer Ensemble forecasts for Tools generation, 17 November 2016, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D2.5_PNOWWA_Definition%20of%20data%20formats%20and%20routines%20to%20transfer%20Ensemble%20forecasts%20for%20Tools%20generation.pdf

[8] D3.1 Manuscript "Predictability of snowfall as function of flow direction at certain airports", 13 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D3.1_Manuscript_PredictabilityLake_Effect.pdf

[9] D3.2 Manuscript "Orographic enhancement of snowfall", 15 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D3.2_Orographic_enhancement.pdf

[10] D3.3 Direction-dependant forcing fields for selected airports for WP 2, 22 June 2017

[11] D3.4 Conversion tools for WP 2, 1 August 2017

[12] D3.5 Report of method to improve nowcasting with direction-dependent forcing fields, 19 October 2017, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D3.5_DirectionDependendForcing_v1.pdf

[13] D3.6 List of scientific publications, 15 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D3.6_WP3%20List%20of%20scientific%20publications.pdf

[14]D4.1 Survey of user needs and use of winter precipitation forecast at one selected airport, 10 February 2017

[15]D4.2 Document of user needs for prototype of probabilistic winter precipitation forecast, 29 May 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D4.2_PNOWWA_User_needs_for%20Demonstration_FINAL_10022017b.pdf

[16]D4.3 Survey of user opinions of demonstrated product, 13 December 2017, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D4.3_PNOWWA_Survey_of_user_opinions_of_demonstrated_product_RevA_Submitted.pdf

[17]D4.4 Report of the possible solutions how probability forecast products of precipitation could increase the resilience of airport, 29 May 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D4.4_V03_PNOWWA_Report%20of%20the%20possible%20solutions%20how%20probability%20forecast%20products%20of%20precipitation%20could%20increase%20the%20resilience%20of%20airport.pdf

[18]D4.5 Roadmap of future applications, 19 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D4.5_PNOWWA_Roadmap%20of%20future%20applications_V0_3_resub.pdf

[19]D4.6 List of scientific publications, 13 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D4.6_WP4%20List%20of%20scientific%20publications.pdf

[20]D5.1 Detailed description of the methods, 4 September 2017

[21]D5.2 Software packages and documentation, 15 May 2017

[22]D5.3 Demonstration of product generation and delivery, 1 August 2017

[23]D5.4 List of scientific publications, 13 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D5.4_WP5%20List%20of%20scientific%20publications.pdf

[24]D6.1 Report of demonstration campaign, 22 June 2017, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D6.1_PNOWWA_Report_of_simulation_campaign_v02_FINAL.pdf

[25]D6.2 Documented datasets with description and info page, 17 November 2017, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D6.2_Documented_datasets_final_RevA.pdf

[26]D6.3 List of scientific publications, 13 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D6.3_WP6%20List%20of%20scientific%20publications.pdf

[27]D7.1 SESAR2020 Industrial Research Solution workshop presentations, 15 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D7.1_PNOWWA_Sesar_presentations_FINAL_SUBMITTED_small.pdf

[28]D7.2 PNOWWA website, 17 November 2017, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D7.1_PNOWWA_Sesar_presentations_FINAL_SUBMITTED_small.pdf

[29]D7.3 Contributions in Magazines, 15 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D7.3_Contributions_in_magazines.pdf

[30]D7.4 Talks in conference and manuscripts for peer-reviewed journals, 13 March 2018, http://fmispace.fmi.fi/fileadmin/PNOWWA/Deliverables/D7.4_Talks%20in%20conference%20and%20manuscripts%20for%20peer-reviewed%20journals.pdf

[31]D8.1 POPD – Requirement No. 2, 14 November 2016

[32]D8.2 H – Requirement No. 1, 14 November 2016

[33]D8.3 POPD – Requirement No. 3, 19 April 2017

[34]D8.4 H – Requirement No. 4, 19 April 2017

See also http://pnowwa.fmi.fi

5.2 Project Publications

5.2.1 Peer-reviewed journal papers

1. von Lerber, A., D. Moisseev, L.F. Bliven, W. Petersen, A. Harri, and V. Chandrasekar, 2017: Microphysical Properties of Snow and Their Link to Ze–S Relations during BAECC 2014. J. Appl. Meteor. Climatol., 56, 1561–1582, https://doi.org/10.1175/JAMC-D-16-0379.1
   - Available: https://journals.ametsoc.org/doi/abs/10.1175/JAMC-D-16-0379.1

2. Moisseev, D., A. von Lerber, and J. Tiira (2017), Quantifying the effect of riming on snowfall using ground-based observations, J. Geophys. Res. Atmos., 122, 4019–4037, doi:10.1002/2016JD026272.
   - Available: http://onlinelibrary.wiley.com/doi/10.1002/2016JD026272/abstract

3. Tiira, J., Moisseev, D. N., von Lerber, A., Ori, D., Tokay, A., Bliven, L. F., and Petersen, W.: Ensemble mean density and its connection to other microphysical properties of falling snow as observed in Southern Finland, Atmos. Meas. Tech., 9, 4825-4841, https://doi.org/10.5194/amt-9-4825-2016, 2016.
   - Available: https://www.atmos-meas-tech.net/9/4825/2016/

4. von Lerber, A., D. Moisseev, D.A. Marks, W. Petersen, A. Harri, and V. Chandrasekar, Early online release: Validation of GMI snowfall observations by using a combination of weather radar and surface measurements. J. Appl. Meteor. Climatol., accepted, https://doi.org/10.1175/JAMC-D-17-0176.1
   - Not available yet.

5.2.2 Magazines

1. "Snow cannons and sea monsters – the lake effect snow", Ilmailu, Elena Saltikoff et. al.

2. "Orographic enhancement of snowfall", Geophysica, by Elena Saltikoff, Martin Hagen, et. al.

   This paper shows that lake effects along the coastlines or flow within the proximity of mountains degrade the forecast quality and the reliable lead time for nowcasts is shorter than for situations which are not affected by heterogeneous terrain.

5.2.3 Thesis

1. von Lerber, Annakaisa, 2018, Challenges in measuring winter precipitation: Advances in combining microwave remote sensing and surface observations. PhD thesis, Finnish Meteorological Institute Contributions 143, ISBN 978-952-336-045-7
   - Available: https://helda.helsinki.fi/handle/10138/231104

2. Knobloch, S., 2017, Zusammenhang der Schneefallintensität zu Sicht- und Radarmessung, (Relation between snowfall intensity and visibility and radar measurements), BSc Thesis, Leopold-Franzens-Universität Innsbruck, Austria, 56 pp.
   - Available: http://acinn.uibk.ac.at/teaching/bachelor-theses

5.2.4 Peer-reviewed conference papers

1. Pulkkinen S., Saltikoff E., von Lerber A. and Hagen M., 2017, Improving Snow Nowcasts for Airports, Seventh SESAR Innovation Days, November, 28-30, Belgrade, Serbia
   - Available: http://www.sesarju.eu/sites/default/files/documents/sid/2017/SIDs_2017_paper_43.pdf

2. Pulkkinen S. and Koistinen J., 2016, Probabilistic Nowcasting of Snowfall for Aviation, the 9th European Conference on Radar in Meteorology and Hydrology (ERAD2016), 10-14 October, Antalya, Turkey.
   - Available: https://erad2016.mgm.gov.tr/abstracts?userId=235 (abstract)

3. Pulkkinen S., Koistinen J. and Harri A.-M., 2016, Consistency-Driven Optical Flow Technique for Nowcasting and Temporal Interpolation, the 9th European Conference on Radar in Meteorology and Hydrology (ERAD2016), 10-14 October, Antalya, Turkey.
   - Available: https://erad2016.mgm.gov.tr/abstracts?userId=89 (abstract)

4. Saltikoff E., Nuottokari J. and Mäkelä A., 2016, Dualpol analysis of graupel as indicator of cool season thunderstorms, the 9th European Conference on Radar in Meteorology and Hydrology (ERAD2016), 10-14 October, Antalya, Turkey.
   - Available: https://erad2016.mgm.gov.tr/abstracts?userId=55 (abstract)

5. von Lerber A., D. Moisseev, L. F. Bliven, W. A. Petersen, A. M. Harri, V. Chandrasekar, 2017, Investigating dependences of Ze-S-relation on microphysical properties of snow, the 38th AMS Radar Conference, 28 August – 1 September 2017 Chicago, USA.

- Available:https://ams.confex.com/ams/38RADAR/meetingapp.cgi/Paper/320773 (abstract)

6. Pulkkinen S. et al., accepted, Stochastic Nowcasting of Winter Precipitation in Finland, European Geosciences Union General Assembly 2018, 8–13 April 2018, Vienna, Austria.
   - Not available at the moment.

7. von Lerber A. et al., 2016, Documenting variability of ice mass-dimensional properties during winter storms in Finland, 17th International Conference on Clouds & Precipitation, 25 - 29 July, Manchester, UK.
   - Available upon request.

8. Hagen M. et al., accepted, On the influence of orography on the predictability of winter weather, European Geosciences Union General Assembly 2018, 8–13 April 2018, Vienna, Austria.

9. Kaltenboeck R. et al., 2017, PNOWWA - Probabilistic Nowcasting of Winter Weather for Airports, the 38th AMS Radar Conference, 28 August – 1 September 2017 Chicago, USA.

10. Kaltenboeck R., et al., 2017, PNOWWA – Probabilistic Nowcasting of Winter Weather for Airports. 2nd European Nowcasting Conference, 3-5. May 2017, Offenbach, Germany

11. Haukka H. et. al, accepted, Probabilistic Nowcasting to increase airport safety and capacity, European Geosciences Union General Assembly 2018, 8–13 April 2018, Vienna, Austria.

12. Kaltenboeck R. et. al., accepted, PNOWWA - Probabilistic Nowcasting of Winter Weather for Airports: Demonstration campaigns and airport stakeholder interactions. European Geosciences Union General Assembly 2018, 8–13 April 2018, Vienna, Austria.

13. Harri, A.-M., 2017, Winter Weather - Probabilistic Nowcasting to Increase Airport Safety and Capacity, Seventh SESAR Innovation Days, November, 28-30, Belgrade, Serbia.

14. Harri, A.-M., 2016, PNOWWA - Probabilistic Nowcasting of Winter Weather for Airports, Sixth SESAR Innovation Days, November, 8-10, Delft, Netherlands.

5.2.5 Conference papers

1. von Lerber A., Moisseev D., Ori D, Tiira J., and Petersen W., 2016, Documenting microphysical processes of winter precipitation and their connection to Ze-S, 8th IPWG and 5th IWSSM Joint Workshop, October 3-7, Bologna, Italy.
   - Available: http://ipwg.isac.cnr.it/meetings/bologna-2016/Bologna2016_Posters/P1-56_vonLerber.pdf

2. Juntti H. et al, 2017, Probabilistic Winter Weather Nowcasting supporting Total Airport Management, WMO Aeronautical Meteorology Scientific Conference, , 6-10 November, Centre International de Conférences, Météo-France, Toulouse, France

5.2.6 Presentations

1. Saltikoff E., Juntti H. and Kaltenboeck, 2017, Snow forecasts for airports, 7th National Pyry-seminar organized together with EU:n COST ES1404/HARMOSNOW, November 1, Helsinki, Finland.

2. Juntti H. et al. 2017, Provision of probabilistic nowcasts (PNOWWA project), International Workshop on Meteorology and Air Traffic Management “Management of Meteorological Uncertainty”, May 24.-25, Sevilla, Spain.

3. Kaltenboeck, R. et al. 2017, Probability of snow nowcasting for airports, Seventh SESAR Innovation Days, November, 28-30, Belgrade, Serbia.

5.2.7 Other dissemination

1. Webinar, October 4, 2017
   - H. Juntti and R. Kaltenböck, Synthesis of user needs for Probabilistc Nowcasting of Snow at the Airports (WP4 and WP5)
   - Prof. M. Laine, Approaches of probability forecasting, guest speaker
   - E. Saltikoff, S. Pulkkinen and M.Hagen, Snow nowcasts with extrapolative methods. Case studies and lessons learned. (WP2 and WP3)

2. Survey of user needs and use of winter precipitation, June 21 – September 22, 2016.

3. PNOWWA stakeholder workshop – Vienna airport, 4th October 2016
   - R. Kaltenboeck and H.Puempel: WP4 - PNOWWA Probabilistic Nowcasting of Winter Weather for Airports

4. Austro Control Forecaster Training, 13th November 2017:
   - R. Kaltenboeck: PNOWWA Probabilistic Nowcasting of Winter Weather for Airports Demonstration campaign 2.

5. PNOWWA project and stakeholder workshop – Vienna, 27-28th February 2018 - scheduled
   - H. Jutti et al., PNOWWA:
     - Results of the demonstration and verification.
     - Summary of what we learned from stakeholders in Finland.
     - Potential for follow-up projects.
   - R. Kaltenboeck et al.,
     - PNOWWA Overview.
     - PNOWWA: Surveys and interviews
   - M. Hagen et al.,
     - Winter Weather Nowcasting – Effects of Sea and Mountains
   - T. Gerz et al.,

- Needs and expectations of winter weather forecasts at Munich airport.
- Nowcast and forecast of Cumulonimbus

5.3 Other

None

Appendix A

Table 4: Glossary

A.1 Glossary of terms

Term	Definition	Source of the definition

A.2 Acronyms and Terminology

Table 5: Acronyms and terminology

Term	Definition
4D	Four dimension
4DTM	4D Trajectory Management
A-CDM	Airport collaborative decision-making
ACC	Air Control Center
AIM	Aeronautical Information Management
AMS	American Meteorological Society
ANS	Air Navigation Services
APCH	Approach
APOC	AirPort Operations Centre
ATC	Air Traffic Control
ATM	Air Traffic Management
AUC	Austro Control
BAECC	Biogenic Aerosols—Effects on Clouds and Climate
BSC	Bachelor of Science
CM	Centimetre
CO	Confidential
COST	Cooperation in science and technology
D	Deliverable
dBZ	Decibel

DFW	Dallas-Fort Worth
DIW	Deicing-weather index
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
DOI	Digital Object Identifier
DWD	Deutscher Wetterdienst
E.G.	Exempli Gratia
ET. AL.	et alii
ECTL	Eurocontrol
EFHK	Helsinki Airport
EFRO	Rovaniemi Airport
EGU	European Geosciences Union General Assembly
EPS	Ensemble prediction system
ER	Exploratory research
ERAD	European Conference on Radar in Meteorology and Hydrology
ETC	Et cetera
EU	European Union
FMI	Finnish Meteorological Institute
FG	Fog
FZDZ	Light freezing drizzle
FZRA	Freezing rain
GMI	GPM Microwave Imager
GPM	Global Precipitation Measurement
GUI	Graphical user interface
H	Hours
hPa	Hehtopascal
IER	Information Exchange Requirement
IPWG	International Precipitation Working Group

IS	Information Service
ISBN	International Standard Book Number
IWSSM	International Workshop on Space-based Snowfall Measurement
KM	Kilometer
KPA	Key Performance Area
LOWI	Innsbruck Airport
LOWW	Vienna Airport
LVC	Low visibility condition
LVP	Low visibility procedures
LSGG	Geneva Airport
LSZH	Zurich Airport
M	Meters
MET	Aviation meteorology
METAR	METeorological Aerodrome Report
MIN	Minutes
MM	Millimeter
MP	Master Plan
MUC	Munich
N	North
NE	North-East
NW	North-West
OI	Operational Improvement
OPERA	Operational Programme for the Exchange of Weather Radar Information
OUE	Operative User Environment
PHD	Doctor of Philosophy
PJ	Project
PMP	Project Management Plan

PNOWWA	Probabilistic Nowcasting of Winter Weather for Airports
PROP	Probability
PU	Public
R&D	Research and development
RAVAKE	Heavy Rainfall Warning Process
RWY	Runway
S	South
SE	South-East
SESAR	Single European Sky ATM Research Programme
SID	SESAR Innovation Days
SJU	SESAR Joint Undertaking (Agency of the European Commission)
STEPS	Short Term Ensemble Prediction System
SW	South-West
T	Temperature
TAF	Terminal aerodrome forecast
TAM	Total Airport Management
TBO	Trajectory Based Operations
TRL	Technology readiness level
TWR	Tower
UTC	Coordinated Universal Time
W	West
WLAN	Wireless local area network
WMO	World Meteorological Organization
WP	Work Package
Z/S	Relationship of reflectivity and accumulated snowdepth
Z/VIS	Relationship of reflectivity and visibility

Appendix B

B.1 Deliverables Descriptions

Here are the PNOWWA project deliverables with short introductions.

FOR WP1

D1.1 "Project Management Plan". PMP – Project Management Plan – describes the management guidelines and the practical management methods of the PNOWWA - Probabilistic Nowcasting of Winter Weather for Airports. PNOWWA Project Management Plan (PMP) follows the management guidelines that are based on the each participating institute own management procedures and regulations. In addition the PMP include procedures introduced in the proposal and agreed in Consortium Agreement and SESAR2020 ER Project Execution Guidelines vs 1.0 dated Feb 2016. PMP was issued and agreed during the Kick-Off Meeting (27 May 2016 by Webex) of the PNOWWA project. Minutes of the meeting are located on the PNOWWA intranet website ("PNOWWA Kick-Off Minutes of the Meeting") and delivered to all participants by email.

PMP document was updated regularly and if new management procedures were required to complete the objectives of the project. The content and format of the PMP follows the structure stated in the "Project Execution Guidelines for SESAR2020 Exploratory Research Projects". All changes to the PMP, such as changes to the planning, a WP leader, etc. were reported to the SJU and agreed by the Project Officer.

D1.2 "Technical Project Final Results Report". This document, please see the executive summary for detailed information.

FOR WP2

D2.1 "Probability distribution time series of predicted precipitation intensity and nowcast predictability to WP5". Deliverable D2.1 is titled Probability distribution time series of predicted precipitation intensity and nowcast predictability to WP5 (and WP3). For clarity, we have included parts of D2.2, to document the full production chain. The documentation covers the main features of the entire productions chain, including the abovementioned data. Radar data is received from four sources: Austria, Germany, Finland and Pan-European Odyssey data hub. Motion vectors are calculated using new methods developed in WP2 and implemented as part of software in WP5. The motion vectors and radar data are then used to produce nowcasts of precipitation intensity and other parameters, selected on basis of on user needs collected by WP4.

D2.2 "The same data for WP3 (not real time, research of local conditions affecting precipitation movement)". Deliverable D2.2 is titled Probability distribution time series of predicted precipitation intensity and nowcast predictability to WP5. The documentation covers the main features of the entire productions chain, including the abovementioned data. Radar data is received from three sources: Austria, Finland and Pan-European Odyssey data hub. Motion vectors are calculated using new methods developed in WP2 and implemented as part of AMV software in WP5. The motion vectors and radar data are then used to produce nowcasts of precipitation intensity and other parameters, selected on basis of on user needs collected by WP4.

D2.3 "Manuscript for WP7 (outreach for scientific community)". This deliverable describes the manuscript "Nowcasting of Precipitation in the High-Resolution Dallas-Fort Worth (DFW) Urban Radar Remote Sensing Network" by Seppo Pulkkinen, V. Chandrasekar and Ari-Matti Harri.

D2.4 "Description document of the WP2 publications accessible at the web". This deliverable gathers together the list of WP2 publications that are accessible at the web. There were 6 peer-reviewed conference papers, 2 magazine articles, 1 conference paper and 1 other dissemination (webinar).

D2.5 "Definition of data formats and routines to transfer Ensemble forecasts for Tools generation". This document describes the required definition of data formats and routines to transfer Ensemble forecasts for generation of tools, which will be used first time during these demonstrations. Data produced for these tools includes parameters which have not yet been defined in widely known information models. This deliverable document the extensions for common data models created for the demonstrations, and the general data structure.

FOR WP3

D3.1 "Manuscript "Predictability of snowfall as function of flow direction at certain airports"". This deliverable includes the manuscript concerning Predictability of snowfall as function of flow direction at certain airports.

D3.2 "Manuscript "Orographic enhancement of snowfall"". This deliverable includes the manuscript (abstract) concerning Manuscript "Orographic enhancement of snowfall".

D3.3 "Direction-dependant forcing fields for selected airports for WP 2". This deliverable describes the quantified effect of mountains and sea to the snowfall observed at airports of Helsinki, Stockholm, Oslo, Rovaniemi and Munchen, based on studies of radar images. Presence of sea and mountains makes the snowfall more difficult to forecast, but for short time scales even the simple the radar-based methods are slightly better other compared methods. Atmospheric dynamics, quantified with Fraude number, explain the behaviour of cold frontal systems when approaching the Alps leading to long-lasting precipitation events.

D3.4 "Conversion tools for WP 2". Deliverable describes the tools used for conversion of parameters measurable with weather radars to the parameters used by end users at the airport. Nowcasting techniques based on the extrapolation of radar observations give an estimation of radar reflectivity at a given location and time. Conversion tools are then necessary to convert reflectivity to parameters which are of interest for airport operation: i.e. snowfall accumulation, visibility. Conversion formulas are taken from literature, measurements at the University of Helsinki testbed, and routine observations at Munich and Salzburg airport.

D3.5 "Report of method to improve nowcasting with direction-dependent forcing fields". Deliverable describes the quantified effect of mountains and sea to the snowfall observed at airports of Helsinki, Stockholm, Oslo, Rovaniemi and München, based on studies of radar images. Proposals how to improve the forecast quality by nowcasting by extrapolation and numerical weather prediction are made. Study consists of three parts: the first two parts consider the quantitative effect of sea and orography on forecasts using a nowcasting system which was developed for SESAR1, and was run on additional periods. The third part of this study aims to estimate the dynamical effect of cold frontal systems approaching the Alps. Finally, improvements for nowcasting are made.

D3.6 "List of scientific publications". This deliverable gathers together the WP3 list of scientific publications. There were 4 peer-reviewed journal papers, 2 thesis, 6 peer-reviewed conference papers, 1 conference paper, 2 magazine articles and 1 other dissemination (webinar).

FOR WP4

D4.1 "Survey of user needs and use of winter precipitation forecast at one selected airport." Winter weather may impact aviation on safety and economic aspects. To identify potential users, their needs and appropriate concepts of operation of winter weather precipitation probability forecasts at airports, three approaches have been selected: a) A survey via internet, b) individual stakeholder interviews and c) a workshop to analyse the potential impact of winter weather probability forecasts on airport operations. We obtained 25 survey responses (2 of the respondents were female) from countries where winter weather is relevant for operations of both smaller and larger airports: Austria, Denmark, Finland, Norway and Switzerland. Most relevant stakeholders came from the domains of ATM, airline operations, de-icing and runway maintenance. 9 individual interviews and one workshop at Vienna international airport complemented the survey in more detail. Results indicate a very heterogeneous approach in the handling of winter weather at European airports, applying local specifications and procedures with different decision thresholds for different stakeholders. Complex interactions between different airport operations and different weather related impacts are evident from the results. High impact winter weather is typically heavy snowfall and freezing rain. Forecasts of freezing wet movement surfaces are additionally mentioned by runway maintenance operators. Low visibility and clouds, often associated with the above-mentioned weather phenomena, are critical for operative planning in ATM, where predominant lead time in short term forecasting time is 3 hours beside long term planning in time range of 24 hours. A majority of stakeholders see most potential for probabilistic weather forecasts to help render decisions more objective but reliability has to be demonstrated.

D4.2 "Document of user needs for prototype of probabilistic winter precipitation forecast". 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

D4.3 "Survey of user opinions of demonstrated product.". After PNOWWA winter 2017 demonstration campaign, user feedback was collected and demonstrates the principal applicability and reliability of probabilistic winter short term forecasting. Deliverable D4.3 contains documentation regarding this PNOWWA survey of user opinions of demonstrated PNOWWA project product. According to the survey The PNOWWA demonstration product showed principal applicability and reliability of the short term winter forecast quality during demonstration campaign 2017. Stakeholders saw the potential and benefit of probabilistic weather forecast to help render decision more objective at a glance. But further user training and information is necessary.

D4.4 "Report of the possible solutions how probability forecast products of precipitation could increase the resilience of airport". Possible solutions are presented how probability forecasts products of precipitation could increase the resilience of airports. In case of non-nominal precipitation weather in winter (snowfall, freezing rain or drizzle) and in summer (flash floods, thunderstorms) probability forecasts consider intrinsic variability of weather, describe the uncertainty and help to render decision objective, depending from individual stakeholder impact factors. Within the PNOWWA project, the potential of probabilistic winter nowcasts are demonstrated. Examples are shown and referred to possible solution. Additional stakeholder PNOWWA demonstration feedback leads to new solution which is suggested.

D4.5 "Roadmap of future applications". The PNOWWA demonstrator was developed within SESAR fundamental exploratory research program. Further work is needed to reach higher maturity levels and to generate an experimental product for future operational application used by airport stakeholders. The roadmap for future operational application suggest the integration of additional forecast parameter (ceiling, reduced visibility due to fog, …) and the extension of lead time up to 2 days. In close cooperation with air traffic management, de-icing and runway maintenance the impact on airport operation has to be defined with respect to probability classes. From user perspective, in the future also summer weather has to be included, which results in one probabilistic forecast system to predict all weather elements relevant for airport handling.

D4.6 "List of scientific publications". This deliverable gathers together the WP4 list of scientific publications. There 4 were peer-reviewed conference papers, 2 presentations and 4 other dissemination activities (e.g. webinar and surveys).

FOR WP5

D5.1 "Detailed description of the methods". In PNOWWA project, different methods of producing probabilistic nowcasts for snow-related phenomena at airports are studied. D5.1 introduces and explains the selected methods for performing required tasks. These studied and selected methods can be grouped into three categories:

Methods to estimate movement of radar echoes. New method developed (based on Proesmans approach), two older methods (Andersson and RAVAKE) used.

Methods to produce probabilistic nowcasts of radar reflectivity based on the estimated movement of radar echoes. New method (based on Stochastic Ensambles) developed, two older methods (Andersson and RAVAKE) used.

Methods to convert radar reflectivity to liquid water equivalent, accumulated snowfall, visibility and De-icing weather index. Much of studies based on earlier work, some own development and assessment of usability of the methods published in other climates.

Based on visual comparison of cases in different weather situations, the Proesmans method was found out to produce the most reliable motion fields. However, the robustness of the method in cases of poor quality of input data (residual clutter) or missing data must be further improved. Verification of results with a statistically representing dataset remains to be made after the improvements have been implemented. The stochastic ensemble method is clearly our preferred solution for producing probabilistic nowcasts, as it is assessing more sources of uncertainty than the simpler methods. Work is needed to improve the computational performance and to define the hardware requirements to calculate the nowcasts for real-time service.

D5.2 "Software packages and documentation". Deliverable describes the data flow, software components and thresholds used for end user products during real time demonstration campaign in the beginning of 2017. First we introduced the structure used in demonstration, including the schematic dataflow. Then we introduced the components and software. In the end there are end-user demo product, delivery and archiving. First test of the software was organized as a real-time demonstration campaign at four airports: Helsinki-Vantaa, Rovaniemi, Vienna and Innsbruck. The details of the campaign are described in PNOWWA deliverable "D6.1 Report of simulation campaign - First research demonstration of prototype of probabilistic winter precipitation forecast".

D5.3 "Demonstration of product generation and delivery". Deliverable describes the generation and delivery of products during real time demonstration campaign (described in deliverable 6.1). Key components of product generation and delivery were tested, and data was provided via a web-based interface to end users at four airports: Helsinki-Vantaa, Rovaniemi, Vienna and Innsbruck in February and March 2017. The developed software combined data from weather radars and numerical weather prediction models to produce short-term forecasts (nowcasts) of precipitation. Together with auxiliary data such as temperature measured at the airports, the forecasted parameters were converted to probability forecasts of different parameters relevant to different user groups at the airports. The campaign was successful, the components developed in different work packages and the components from existing FMI production chain worked seamlessly together. The collected feedback provides valuable input for offline studies and a new campaign next winter.

D5.4 "List of scientific publications". This deliverable gathers together the list of WP5 scientific publications. There were 5 peer-reviewed conference papers, 1 conference paper, 2 presentations and 1 other dissemination activities (webinar).

FOR WP6

D6.1 "Report of demonstration campaign". The demonstration of the product of probabilistic short term forecast for winter weather at airports was successfully tested. The concept showed the applicability for airport stakeholders. User and forecaster feedback was collected to adapt the product and procedure for the second demonstration campaign. Feedback already results in improvement of the nowcast quality by using different motion vectors and topographic forcing will further investigated till next winter. Lessons learned from recent 1st demonstration of the PNOWWA product was, that providing the PNOWWA prototype as online information show applicability and potential for airport operation during adverse winter weather. Users should be informed properly, short before next winter, presenting them well prepared case studies for demonstration. During 2nd demonstration campaign we will individual contact end users during adverse winter weather at the airport, to support and assist stakeholders by using probabilistic nowcasts.

D6.2 "Documented datasets with description and info page". Deliverable describes two datasets of probability forecasts for winter weather at airports. The snow fall events occurred during the first PNOWWA demonstration campaign in winter 2017 in Helsinki and Innsbruck. The datasets made available at the PNOWWA website.

D6.3 "List of scientific publications". This deliverable gathers together the WP6 list of scientific publications. There were 6 peer-reviewed conference papers, 1 conference paper and 2 presentations.

FOR WP7

D7.1 "SESAR2020 Industrial Research Solution workshop presentations". This deliverable gathers together PNOWWA Stakeholders Workshop 2018, PNOWWA Webinar 2017, SESAR Innovation Days, SESAR2020 IR Project Solution Meetings and other related conferences. In the appendixes of this deliverable are all the presentations held in PNOWWA Stakeholders Workshop, PNOWWA webinar and abstract of the TBO-MET Workshop.

D7.2 "PNOWWA website". This deliverable will describe the PNOWWA website format/layout, main content and development plan. The website address is http://pnowwa.fmi.fi . PNOWWA website was updated regularly. For the general public the most visible part of the website that was updated was PNOWWA Twitter feed. Twitter was one of the projects main channels for reaching the general public. For project internal work, the "meeting and workshop documentation" -page was updated when meetings were held. Also the "Dissemination and Publications" and "Deliverables" –pages were updated regularly.

D7.3 "Contributions in Magazines". This deliverable describes the PNOWWA contributions in magazines. There were two magazine articles submitted during the project. The first article was "Snow cannons and sea monsters – the lake effect snow", Ilmailu by Elena Saltikoff et. al. and the second one "Orographic enhancement of snowfall" by Elena Saltikoff, Martin Hagen, et. al.

D7.4 "Talks in conference and manuscripts for peer-reviewed journals". This deliverable gathers together the list of talks in conferences and manuscripts for peer-reviewed journals. There 4 were peer-reviewed journal papers, 14 peer-reviewed conference papers, 2 conference papers, 3 presentations and 1 other dissemination (webinar).

FOR WP8 (Ethics)

D8.1 "POPD – Requirement No. 2". This document will describe the PNOWWA data protection policy and actions that project will implement to ensure proper data protection in frame of the EU/SJU guidelines and national/international legislation. In document chapter 3.1 is described the overall data protection policy and in chapter 3.2 additional PNOWWA project data protection aspects. The accessing the collected data and data storing are introduced in chapters 3.3 and 3.4. Personal data matters of the project are described in chapter 4. PNOWWA survey process has its own chapter (5) where we clarify the survey process and the data we collect as part of it.

D8.2 "H – Requirement No. 1". The PNOWWA project will follow the guidelines stated by the EU and SJU to identify/recruit research participants added by the each project participants own institute guidelines and local/international legislation. This document will describe the PNOWWA project recruitments procedures, recruitments principles and recruitments of young researchers and students.

D8.3 "POPD – Requirement No. 3". This document will describe the PNOWWA project survey and questionnaire procedures that will be implemented. Online survey procedures are presented in the chapter 2.2 and following individual interview questionnaire procedures in the chapter 2.3. The PNOWWA project will follow the guidelines stated by the EU and SJU when collecting personal data by surveys and other means. In PNOWWA we have two types of surveys/questionnaires. First we will have an online survey for ATM experts and second individual interview questionnaire for more interested stakeholders. Ensuring the data protection issues, all survey and questionnaire results of are published as summaries only and individual replies are kept anonymous.

B.2 Publications Short Descriptions

Here are publications short descriptions where available.

B.2.1 Peer-reviewed journal papers

1. von Lerber, A., D. Moisseev, L.F. Bliven, W. Petersen, A. Harri, and V. Chandrasekar, 2017: Microphysical Properties of Snow and Their Link to Ze–S Relations during BAECC 2014. J. Appl. Meteor. Climatol., 56, 1561–1582, https://doi.org/10.1175/JAMC-D-16-0379.1
   - Available: https://journals.ametsoc.org/doi/abs/10.1175/JAMC-D-16-0379.1

   This study utilizes surface observations of snowfall to investigate the connection between microphysical properties of snow and radar observations. The general hydrodynamic theory is applied to video-disdrometer measurements to retrieve masses of falling ice particles. From the derived microphysical properties, event-specific relations between the equivalent radar reflectivity factor Ze and snowfall precipitation rate S (Ze = $a_{zs}S^{b_{zs}}$) are determined. For the studied events, the prefactor of the Ze–S relation varied between 53 and 782 and the exponent was in the range of 1.19–1.61. The dependence of the factors azs and bzs are investigated.

2. Moisseev, D., A. von Lerber, and J. Tiira (2017), Quantifying the effect of riming on snowfall using ground-based observations, J. Geophys. Res. Atmos., 122, 4019–4037, doi:10.1002/2016JD026272.
   - Available: http://onlinelibrary.wiley.com/doi/10.1002/2016JD026272/abstract

   Ground-based observations of ice particle size distribution and ensemble mean density are used to quantify the effect of riming on snowfall. A rime mass fraction is determined in respect to the mass-dimensional relation of unrimed snow. Since dual-polarization radar observations are often used to detect riming, the impact of riming on dual-polarization radar variables is studied for differential reflectivity measurements. It is shown that the relation between rime mass fraction and differential reflectivity is ambiguous, other factors such as change in median volume diameter need also be considered. Given the current interest on sensitivity of precipitation to aerosol pollution, which could inhibit riming, the importance of riming for surface snow accumulation is investigated. It is found that riming is responsible for 5% to 40% of snowfall mass.

3. Tiira, J., Moisseev, D. N., von Lerber, A., Ori, D., Tokay, A., Bliven, L. F., and Petersen, W.: Ensemble mean density and its connection to other microphysical properties of falling snow as observed in Southern Finland, Atmos. Meas. Tech., 9, 4825-4841, https://doi.org/10.5194/amt-9-4825-2016, 2016.
   - Available: https://www.atmos-meas-tech.net/9/4825/2016/

   In this study measurements collected during winters 2013/2014 and 2014/2015 at the University of Helsinki measurement station in Hyytiälä are used to investigate connections between ensemble mean snow density, particle fall velocity and parameters of the particle size distribution (PSD). The density of snow is derived from measurements of particle fall velocity and PSD, provided by a particle video imager, and weighing gauge measurements of precipitation rate. Validity of the retrieved density values is checked against snow depth measurements.

4. von Lerber, A., D. Moisseev, D.A. Marks, W. Petersen, A. Harri, and V. Chandrasekar, Early online release: Validation of GMI snowfall observations by using a combination of weather radar and surface measurements. J. Appl. Meteor. Climatol., accepted, https://doi.org/10.1175/JAMC-D-17-0176.1
   - Not available yet.

Currently, there are several space-borne microwave instruments suitable for detection and quantitative estimation of snowfall. To test and improve retrieval snowfall algorithms, ground validation datasets that combine detailed characterization of snowfall microphysics and spatial precipitation measurements are required. To this endpoint, measurements of snow microphysics are combined with large-scale weather radar observations to generate such a dataset. The feasibility of using this type of data to validate spaceborne snowfall measurements and algorithms is demonstrated with NASA GPM Microwave Imager (GMI) snowfall product.

B.2.2 Magazines

1. "Snow cannons and sea monsters – the lake effect snow", Ilmailu, Elena Saltikoff et. al.

The article was submitted in Ilmailu. The article is published on Ilmailu webpages. First the article is only available for subscribers of the eprinted version on 13th of March, and in printed version in May 2018. After publication the manuscript will released and published in the frame of the PNOWWA project either in PNOWWA webpage or by providing the direct link to the publication.

2. "Orographic enhancement of snowfall", Geophysica, by Elena Saltikoff, Martin Hagen, et. al.

This paper shows that lake effects along the coastlines or flow within the proximity of mountains degrade the forecast quality and the reliable lead time for nowcasts is shorter than for situations which are not affected by heterogeneous terrain.

B.2.3 Thesis

1. von Lerber, Annakaisa, 2018, Challenges in measuring winter precipitation: Advances in combining microwave remote sensing and surface observations. PhD thesis, Finnish Meteorological Institute Contributions 143, ISBN 978-952-336-045-7
   - Available: https://helda.helsinki.fi/handle/10138/231104

In this thesis, the microphysical properties of snowfall are studied with ground-based measurements, and the changes in prevailing snow particle characteristics are linked to remote sensing observations. Detailed ground observations from heavily rimed snow particles to open structured low-density snowflakes are shown to be connected to collocated triple-frequency signatures. As a part of this work, two methods are implemented to retrieve mass estimates for an ensemble of snow particles combining observations of a video-disdrometer and a precipitation gauge. The changes in the retrieved mass-dimensional relations are shown to correspond to microphysical growth processes. The dependence of the C-band weather radar observations on the microphysical properties of snow is investigated and parametrized. The results apply to improve the accuracy of the radar-based snowfall estimation, and the developed methodology also provides uncertainties of the estimates. Furthermore, the created data set is utilized to validate space-borne snowfall measurements. This work demonstrates that the C-band weather radar signal propagating through a low melting layer can significantly be attenuated by the melting snow particles. The expected modeled attenuation is parametrized according to microphysical properties of snow at the top of the melting layer.

B.2.4 Peer-reviewed conference papers

1. Pulkkinen S., Saltikoff E., von Lerber A. and Hagen M., 2017, Improving Snow Nowcasts for Airports, Seventh SESAR Innovation Days, November, 28-30, Belgrade, Serbia
   - Available: http://www.sesarju.eu/sites/default/files/documents/sid/2017/SIDs_2017_paper_43.pdf

   PNOWWA (Probabilistic Nowcasting of Winter Weather for Airports) project has studied methods to forecast snowfall for next few hours by extrapolating movement of radar echoes. Three different methods to create motion vectors (a simple method, a method used operationally and a new method) as well as three methods to produce probability forecasts with help of a motion vector field have been studied.

2. Pulkkinen S. and Koistinen J., 2016, Probabilistic Nowcasting of Snowfall for Aviation, the 9th European Conference on Radar in Meteorology and Hydrology (ERAD2016), 10-14 October, Antalya, Turkey.
   - Available: https://erad2016.mgm.gov.tr/abstracts?userId=235 (abstract)

   Reliable forecasts of heavy snowfall are critical for air traffic; as such events can cause major disruptions and additional costs. Aiming at aviation applications, we have developed a probabilistic radar-based nowcasting method for snowfall and associated phenomena. The presented approach is an extension of the stochastic ensemble prediction system (STEPS) [Seed 2003 and Bowler et al. 2004, 2006]. For estimating the advection field, we utilize an improved multiscale optical flow technique aiming at maximization of consistency between forward and backward flows [Pulkkinen et al. 2016]. We have studied the geographic, flow- and scale-dependency and growth and decay of snowfall and validated the nowcasting method by using the C-band dual-polarization radar located at Vantaa, Finland.

3. Pulkkinen S., Koistinen J. and Harri A.-M., 2016, Consistency-Driven Optical Flow Technique for Nowcasting and Temporal Interpolation, the 9th European Conference on Radar in Meteorology and Hydrology (ERAD2016), 10-14 October, Antalya, Turkey.
   - Available: https://erad2016.mgm.gov.tr/abstracts?userId=89 (abstract)

   Determination of motion vectors from consecutive precipitation fields is a key task in radar meteorology. A novel consistency-driven optical flow technique is proposed for motion estimation. The proposed method aims at minimization of a cost function that penalizes intensity changes.

4. Saltikoff E., Nuottokari J. and Mäkelä A., 2016, Dualpol analysis of graupel as indicator of cool season thunderstorms, the 9th European Conference on Radar in Meteorology and Hydrology (ERAD2016), 10-14 October, Antalya, Turkey.
   - Available: https://erad2016.mgm.gov.tr/abstracts?userId=55 (abstract)

Graupel are soft and white millimeter-sized solid particles formed by riming in convective clouds. Although graupels do not have negative impacts at ground level nor for airplanes, graupels are interesting as an indirect indicator of other phenomena. In aviation meteorology, graupel observations are used as an indicator of icing conditions. The ice crystal–graupel collision charging mechanism is important in thunderstorm electrification process. Modern microphysic schemas of small-scale NWP models include graupel, and modelers are always looking for verifying observations. We have observed the presence of narrow, a few kilometers tall graupel towers in hydrometer classification products in association with thunderstorms outside of the traditional thunderstorm season. Systematic identification of these towers is a challenge to radar measurement geometry. In this study, we compared different approaches to visualize hydrometeor classification data in cold-season thunderstorm cases.

5. von Lerber A., D. Moisseev, L. F. Bliven, W. A. Petersen, A. M. Harri, V. Chandrasekar, 2017, Investigating dependences of Ze-S-relation on microphysical properties of snow, the 38th AMS Radar Conference, 28 August – 1 September 2017 Chicago, USA.
    - Available:https://ams.confex.com/ams/38RADAR/meetingapp.cgi/Paper/320773 (abstract)

   The method to retrieve the mass of falling snow particles utilizing the hydrodynamic theory is presented and the changes of mass-dimensional relation of snowfall is connected to snow growth processes, namely riming and aggregation. These can be linked to changes also in the factors of radar reflectivity factor (Ze) - snowfall rate (S) relation. The uncertainties of the determined Ze – S are shown.

6. von Lerber A. et al., 2016, Documenting variability of ice mass-dimensional properties during winter storms in Finland, 17th International Conference on Clouds & Precipitation, 25 - 29 July, Manchester, UK.
    - Available upon request.

   This study investigates the microphysical properties of snow from the ground observations and links them to weather radar observations. The focus is on understanding microphysical processes and their evolution during winter storms. We have observed that snow microphysics can change within storms, and that the changes can happen on temporal scales of several minutes. To characterize the microphysics of winter precipitation we have implemented a procedure to retrieve mass-dimensional (m-D) properties of ice particles.

B.2.5 Conference papers

1. von Lerber A., Moisseev D., Ori D, Tiira J., and Petersen W., 2016, Documenting microphysical processes of winter precipitation and their connection to Ze-S, 8th IPWG and 5th IWSSM Joint Workshop, October 3-7, Bologna, Italy.
    - Available: http://ipwg.isac.cnr.it/meetings/bologna-2016/Bologna2016_Posters/P1-56_vonLerber.pdf

   The focus of this study is to utilize a combination of microphysical surface measurements and large scale radar observations to validate the space-based snowfall products. The validation is demonstrated with GMI radiometer surface snowfall estimate related to ground-based weather radar estimate of snowfall rate. Clear underestimation of space-estimated snowfall rate is noticed.

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